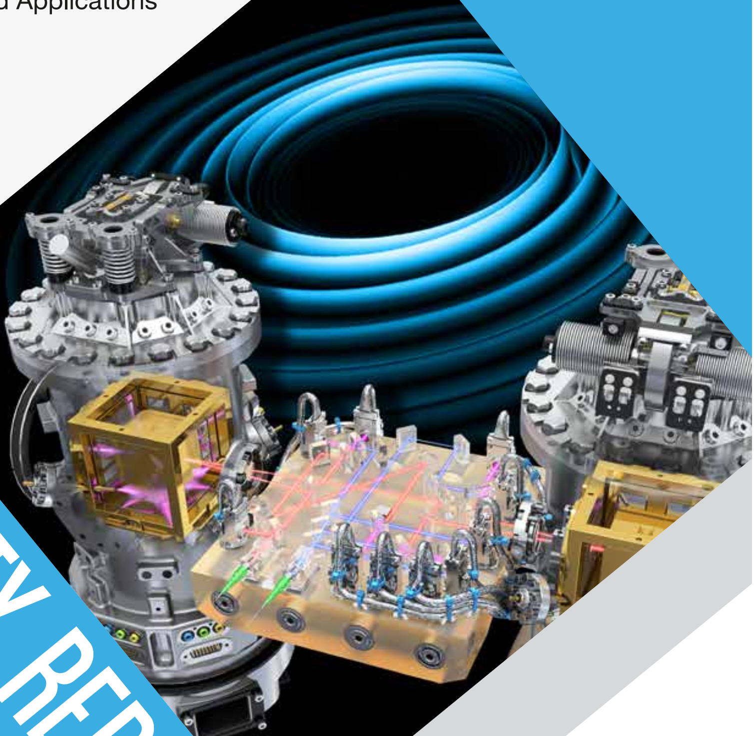
Trento Institute for Fundamental Physics and Applications



ACTIVITY REPORT 2015|16

FONDAZIONE BRUNO KESSLER

Azienda Provinciale per i Servizi Sanitari
Provincia Autonoma di Trento

INFN

A collaborative centre for translational physics research

TIFPA
Activity Report 2015-16

Trento Institute for Fundamental Physics and Applications

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Cover image: foreground — LISA Technology Package, the technological core of LISA Pathfinder mission (see p. 38 for details); background — representation of a gravitational waveform produced by a compact object binary coalescing into a black hole.

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Foreword

Marco Durante

Direttore,
TIFPA

E' per me un grande piacere presentarvi questo primo rapporto di attività del Trento Institute for Fundamental Physics and Applications (TIFPA), un centro nazionale dell'Istituto Nazionale di Fisica Nucleare (INFN). Ho avuto l'onore di dirigere il TIFPA dal 1 Aprile 2015, e questa è la prima occasione per presentare l'attività scientifica del centro. E' quindi un momento importante, il primo biglietto da visita di quello che si può considerare un esperimento molto innovativo, sia per l'Italia che per l'Europa.

Il TIFPA non è infatti una nuova sezione INFN, che si aggiungerebbe alle 20 già presenti sul territorio. Il TIFPA ha infatti un obiettivo diverso ed un mandato preciso, che è quello di essere un *centro di fisica nucleare applicata*, un polo per la *ricerca traslazionale* ed il *trasferimento tecnologico*, soprattutto verso tre settori: lo *spazio*, la *medicina* ed i *sensori*. D'altra parte, il TIFPA non è neanche un Laboratorio Nazionale INFN, che si aggiungerebbe ai 4 in attività (Frascati, Gran Sasso, Legnaro e Catania). Infatti, esso si fonda sulla *cooperazione* con tre partner trentini: l'Università di Trento (UNITN), la Fondazione Bruno Kessler (FBK) e l'Agenzia Provinciale per I Servizi Sanitari (APSS). Le principali infrastrutture scientifico-tecnologiche che rendono possibile la ricerca del TIFPA non appartengono a INFN ma al centro di protonterapia di APSS (con la sala sperimentale per ricerca in radiobiologia, fisica dei protoni e simulazione della radiazione cosmica) ed al Centro Materiali e Microsistemi (CMM) di FBK (le camera pulite per la produzione e test di rivelatori). Gli accordi attuativi del MoU con UNITN non

With great pleasure, I wish to introduce you the first activity report of the Trento Institute for Fundamental Physics and Applications (TIFPA), a National research center of the National Institute for Nuclear Physics (INFN). I had the privilege to serve as TIFPA Director since April 2015, and this is the first chance to present the scientific activity of the center. It is therefore an important milestone, the first business card for a very innovative experiment, both in Italy and Europe.

TIFPA is not a new INFN section division, in addition to the 20 already distributed on the territory. TIFPA has indeed a different goal and a precise mandate, which is to be the Italian applied nuclear physics center, an institute for translational research and technological transfer, especially toward three sectors: space, medicine, and sensors. On the other hand, TIFPA is not a National Laboratory either, such as the other 4 that INFN has in Italy (Frascati, Gran Sasso, Legnaro and Catania). In fact, TIFPA is based on cooperation with three institutes in the Trentino Region: Trento University (UNITN), Bruno Kessler Foundation, and the Healthcare Agency (APSS). The main scientific infrastructures used by TIFPA do not belong to INFN, but to the protontherapy center of APSS (the experimental room for research in radiobiology, proton physics, and cosmic radiation simulation) and the Center for Materials and Microsystems (CMM) of FBK (clean rooms for production and test of detectors). Implementing agreements of the MoU with UNITN are not limited to the Department of Physics, as typical in other INFN divisions, but are exriguardano solo il Dipartimento di Fisica, come tipico per le altre sezioni INFN, ma si estendono ai Dipartimenti di Ingegneria Industriale (DII) e di Biologia (CIBIO).

Il TIFPA è quindi “altro”, un *esperimento di federazione di enti di ricerca, formazione e cura* unico in Europa. Il mandato è quello di lavorare sulle applicazioni, e di coprire il percorso dalla ricerca fondamentale fino al trasferimento tecnologico sul territorio. Nel leggere questo rapporto di attività, scoprirete l’ampiezza della ricerca e la portata dei risultati del centro. Oltre agli esperimenti INFN, che sono stati approvati in tutte e 5 le commissioni nazionali INFN, il TIFPA ha tre *laboratori virtuali* (spazio, fisica medica e rivelatori), che corrispondono ai tre principali filoni applicativi. In questi articoli troverete alcuni dei risultati più importanti raggiunti con il contributo di TIFPA nel suo primo anno, come la missione Lisa Pathfinder e la costruzione della sala sperimentale per i fasci di protoni.

La lista delle persone che devo ringraziare per questo successo è molto lunga, ed a molti di loro ho chiesto di lasciare un saluto introduttivo che testimoni il loro ruolo ed il loro supporto al TIFPA. Vorrei aggiungere alla lista il Dott. Eugenio Nappi, che ha svolto un ruolo fondamentale nel convincermi a lasciare il mio laboratorio Helmholtz in Germania, che avevo diretto per 10 anni, per tentare questa sfida in Italia; e tutto il coordinamento di direzione che ha lavorato duramente per fare di TIFPA un successo: Marta Perucci, Giuliana Pellizzari (distaccata dalla Provincia Autonoma di Trento), Christian Manea, la giovanissima Laura Chilovi, e Piero Spinnato, che ha anche preparato questo documento con il prezioso aiuto di Francesca Cuicchio dell’Ufficio Comunicazione INFN. Auguro a tutti buona lettura, ed un futuro di successi al TIFPA.

tended to the Departments of Industrial Engineering (DII) and Biology (CIBIO).

TIFPA is therefore one of a kind, an experiment for a federation of research, academy and medical institutions unique in Europe. The task is to concentrate on applied sciences, and to cover the full path from fundamental research to knowledge transfer on the territory. In reading this report, you will appreciate the extent of the research and of the scientific results of the center. In addition to the INFN experiments, which have been approved in all 5 National INFN committees, TIFPA has 3 virtual laboratories (space, medical physics, and detectors) which correspond to the 3 main application lines. In the papers you will find the most exciting results achieved with TFPA collaboration in its first year, such as the Lisa Pathfinder mission and the construction of the experimental room for proton beams.

I do have a very long list deserving an acknowledgment for their contribution to the birth of TIFPA. Many of them kindly wrote an introductory paragraph to the report. I would like to add Dr. Eugenio Nappi, who was instrumental in persuading me to leave my laboratory in the Helmholtz center in Germany, whom I had directed for 10 years, to accept this challenge in Italy. I also wish to extend heartfelt thanks to my inner circle, who has worked so hard to make TIFPA successful: Marta Perucci, Giuliana Pellizzari (seconded from the Trento Province), Christian Manea, the young Laura Chilovi, and Piero Spinnato, who also prepared this document with the precious support of Francesca Cuicchio from INFN press office.

I hope you will enjoy reading the report, and I wish TIFPA a future filled of success.

Institutional Addresses

Ugo Rossi

Presidente,
Provincia Autonoma di Trento

Accolgo con piacere la pubblicazione di questo 1° rapporto delle attività del Centro TIFPA, un'eccellenza nel panorama della ricerca di base e applicata a livello nazionale e internazionale e, possiamo dire con orgoglio, anche un importante tassello di quel prezioso lavoro che il governo provinciale porta avanti da anni nella consapevolezza che ricerca, formazione ed innovazione rappresentano un volano fondamentale per lo sviluppo economico e la coesione sociale del territorio.

Il Sistema Trentino della Ricerca e Sviluppo è infatti uno degli assi strategici su cui si è maggiormente sviluppato l'esercizio dell'autonomia provinciale, attraverso un processo di attenzione alla ricerca di alto livello, uno sforzo costante di coordinamento e intermediazione tra i suoi promotori e utilizzatori, un iter legislativo in più tappe accompagnato da cospicui investimenti.

L'elevata qualificazione del nostro sistema territoriale in diverse discipline è ormai riconosciuta anche a livello internazionale. Un esempio è dato anche dal successo riscosso a livello partecipazione dei bandi europei, come quelli a valere su Orizzonte 2020.

TIPFA rappresenta un polo di eccellenza internazionale che è stato in grado di attrarre le menti migliori e attivare progetti di ampio respiro e strategici per lo sviluppo della conoscenza scientifica: una struttura di ricerca altamente innovativa, dove si coniugano attività di ricerca fondamentale con piattaforme scientifico-tecnologiche coprendo un ampio spettro di ambiti.

L'attività del TIFPA, e i suoi straordinari ri-

With great pleasure, I welcome the publication of the 1st activity report of TIFPA, an excellence in scientific research at the National and International level. We can also proudly maintain that TIFPA is an important tile of that precious work that the Province Government is carrying out in the certainty that research, education, and innovation represent an essential driving force for economic development and social engagement of the territory.

The Trentino R&D system is a strategic line for the development of the autonomy of the Province. The system is characterized by a high level of attention to research, a constant effort of coordination and arbitration among promoters and users, and a legislative activity in several steps leading to substantial investments.

The high qualification of our system in different fields is recognized at the International level. An example is the high success rate in EU grants on Horizon 2020.

TIFPA is an excellence center able to attract the best brains and to activate long term projects for the development of the scientific knowledge: it is a highly innovative research structure, where fundamental research is linked to applications in a wide spectrum of fields.

TIFPA activity and its extraordinary results, including the collaboration in the discovery of gravitational waves, Lisa Pathfinder and the APSS protontherapy center, which is successfully treating adult and pediatric cancer patients, confirm the success of the investment in human resources and infrastructures done in the past years by the Provence. They give a measure of the efficacy of the political decisultati, tra i quali la collaborazione alla scoperta delle onde gravitazionali, ma anche e non solo, la missione di Lisa Pathfinder e l'acceleratore per protonterapia oncologica gestito da A.P. S.S., che si sta distinguendo per i successi nel trattamento di pazienti, adulti e in età pediatrica, sono una conferma ulteriore della correttezza degli investimenti in risorse umane e infrastrutture che in questi anni sono stati fatti a livello provinciale, una misura dei risultati concreti e dell'efficacia delle politiche attivate.

Il territorio trentino è molto cresciuto infatti in questi ultimi tempi, anche grazie ad una politica territoriale, basata su un approccio flessibile di integrazione funzionale e di concorso pro-attivo dei diversi attori. Ha raggiunto una massa critica, una caratura nazionale ma anche europea la cui solidità ci rassicura; tuttavia ci sono ancora importanti sfide da affrontare per restare al passo e affinché il sistema continui a rafforzarsi verso la comunità internazionale ma anche in integrazione con il territorio.

Per questo motivo il Governo provinciale conferma, in linea con il Piano pluriennale della Ricerca della XV^ Legislatura, il suo impegno nell'attuazione di politiche capaci di stimolare la ricerca e l'innovazione, valorizzando il patrimonio di conoscenze del territorio e promuovendo forme virtuose di interazione e di coordinamento tra i diversi attori della ricerca, innovazione e sistema produttivo.

Nella convinzione che questo approccio possa essere vincente solo se condiviso da tutti gli attori dei territorio sono certo che questo primo Activity Report rappresenti non solo un bilancio di quanto svolto finora ma uno stimolo verso nuovo traguardi.

sions.

Trentino Region recently grew thanks to the territorial politics based on functional integration and synergy of different actors. It has reached a critical mass and national and International reputation whose solidity is encouraging. Nevertheless, we still have many challenges to keep our system cutting edge and stronger in the International community.

For this reason, the Province Government confirms, in the frame of the long-term research plan of the XV legislation, its commitment in the application of politics to support R&D and to promote interaction and coordination of the research system with the economic and industrial system.

This activity report represents not only a summary of the previous work but a stirring toward new goals, considering that is approach can be successful only with the full support of all the actors in the territory.

Sara Ferrari

Assessore all'università e ricerca,
Provincia Autonoma di Trento

La provincia autonoma di Trento persegue da anni azioni di promozione dell'eccellenza e della competitività territoriale. Politiche queste che affondano le radici in una scelta di investimento nella produzione e diffusione della conoscenza, accolta e vissuta non solo come un'opportunità, ma anche quasi come la migliore risposta alle sfide della nostra epoca.

Si è infatti realizzato un progetto di governo d'avanguardia - sia con riferimento allo scenario nazionale che anche quello internazionale - per contenuti, metodo e quantità di risorse, nella consapevolezza che un sistema integrato di formazione, ricerca e innovazione capace di coinvolgere i diversi attori del territorio sia uno strumento strategico imprescindibile per il sviluppo sociale, industriale e competitivo del nostro territorio, della nostra società e della nostra comunità.

Questa esperienza ha trasformato il Trentino in un vero e proprio "polo della ricerca e del sapere". Un ecosistema che ha riconfigurato l'identità territoriale accreditando il sistema dell'alta formazione e ricerca provinciale nel panorama scientifico globale.

E' quindi per me un estremo piacere poter offrire un breve contributo a questa pubblicazione che presenta gli importanti risultati scientifici ottenuti a Trento dal centro TIFPA. Frutto della collaborazione tra l'Istituto Nazionale di Fisica Nucleare (INFN), l'Università di Trento, la Fondazione Bruno Kessler e l'Agenzia provinciale di Trento per la Protonterapia (ATreP), TIFPA concretizza quel ponte tra la ricerca fondamentale e quella delle applicazioni avanzate e il mondo delle imprese: un approccio vincente che non è solo condiviso ma quotidiana-

Trentino Province Government pursues since many years actions for promoting excellence and competitiveness. These politics reflect a basic choice to invest in knowledge, meant not only as an opportunity but also as an answer to the challenges of our age.

Trentino built an advanced government system for the integration of education, research, and innovation, capable of involving different actors for the social and economic development.

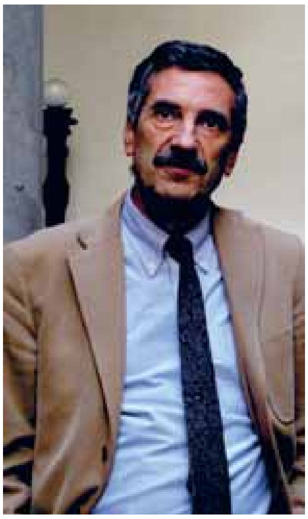
This experience transformed Trentino into a focus of research and knowledge. This ecosystem was able to rearrange the regional system to enter the global scientific and education network.

It is therefore for me a great pleasure to express my greetings for this publication summarizing the scientific achievements of TIFPA. TIFPA, a combined effort of INFN, UNITN, FBK, and APSS, represents a bridge between fundamental research and advanced application in the industrial world. A winning approach, which is daily reinforced by the Province Government.

For this reason, I wish TIFPA to continue its activities with the same enthusiasm and skills that were displayed in its first phase.

mente ribadito e rafforzato da questo governo provinciale.

Per questo motivo auguro a TIFPA di proseguire nelle sue attività con l'entusiasmo e la professionalità che ha caratterizzato questa prima fase.



Fernando Ferroni

Presidente,
Istituto Nazionale di Fisica Nucleare

Trento ha sempre avuto rapporti con l'INFN: per i fisici dell'Università che hanno collaborato alle nostre ricerche, per l'esistenza dell'IRST (poi FBK), col quale abbiamo sviluppato tecnologia insieme e, infine, per il centro di adroterapia i cui lavori di costruzione sono stati diretti dal nostro collaboratore Renzo Leonardi. E' mancata però a lungo una visione organica dei rapporti tra le realtà scientifiche territoriali esistenti.

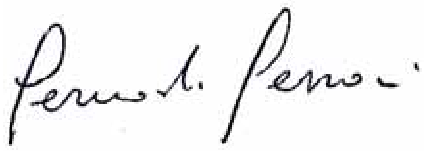
Una attenta analisi condotta dall'INFN con l'Università ha portato alla nascita di una realtà nuova per l'INFN, in cui tutti i protagonisti hanno un ruolo e alla quale la Provincia Autonoma ha prestato grande attenzione. Il Centro, che tale si definisce nel linguaggio INFN, è cresciuto in questo breve tempo in modo importante. I rapporti si sono consolidati, altre realtà sono state coinvolte ed è in pieno svolgimento una attività di eccellenza con punte alte come il successo straordinario del progetto Lisa Pathfinder, co-diretto da Stefano Vitale.

L'INFN è fiero dei successi scientifici del Centro e rivendica la intuizione di aver creduto in un modello innovativo che tenesse conto della grande attenzione che il territorio ha per la ricerca.

Trento traditionally had connections to INFN: physicists in the University worked in research activities supported by INFN, IRST (later FBK) developed essential technologies for INFN and, finally, the hadrontherapy center, whose construction was promoted by the INFN associate Prof. Renzo Leonardi. However, these activities lacked a long-term vision of the collaboration of the different research entities on the territory.

A careful study of INFN and University led to a new entity, where all partners play a role and the Trentino Province accorded great support. The Center (as so it is defined in the INFN structure), grew quickly in such a short time. Links were reinforced, other entities have been involved, and outstanding research activities are ongoing with highlights such as Lisa Pathfinder, co-directed by Prof. Stefano Vitale.

INFN is proud of the scientific success of the Center and claims the intuition of proposing an innovative model to exploit the great support of the local territory to scientific research.



Paolo Collini

Rettore,
Università degli Studi di Trento

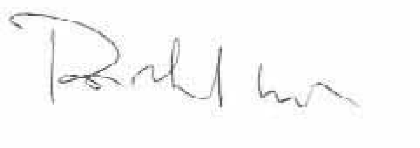
Trento è un'università europea che si distingue per la qualità della ricerca, riconosciuta ad alto livello da vari ranking indipendenti su scala internazionale. Un risultato possibile grazie alla qualità e all'impegno delle persone che vi lavorano ma anche al supporto, non solo economico, che riceve dalla comunità e dal territorio in cui si trova. In questo senso il TIFPA è un buon frutto del sistema della ricerca trentino e della sua capacità di mettersi "in rete" con le migliori istituzioni nazionali e internazionali. Un sistema che ha successo perché si basa sulla cooperazione tra Università, fondazioni e un partner di rilievo come l'INFN. Un sistema, che può contare sul sostegno convinto della Provincia autonoma di Trento. Finanziamenti consistenti oltre a infrastrutture all'avanguardia che sono, assieme all'impegno di ricercatori di grande qualità, le condizioni per realizzare obiettivi scientifici di rilievo internazionale. L'Ateneo è impegnato in molti fronti con risultati di grande livello e proprio nella Fisica, che rappresenta l'area maggiormente coinvolta nel TIFPA, vede uno degli ambiti disciplinari di ricerca più promettenti.

Molti sono i progetti avviati nell'ambito di questa iniziativa congiunta: il programma Lisa Pathfinder, ad esempio, che costituisce il primo fondamentale passo per la costruzione dell'Osservatorio spaziale delle onde gravitazionali; o il progetto del satellite cinese CSES per studiare la variabilità dell'ambiente elettromagnetico attorno alla Terra e sviluppare nuovi metodi per il monitoraggio di fenomeni geofisici su grande scala, come ad esempio i terremoti. Un progetto premiale dell'Agenzia spaziale italiana, che

Trento has a European University highly recognized in the International ranking. These results are made possible by human factor and the support of the local environment, which extends beyond funding. TIFPA is an example of the efficiency of the Trentino research system, and of its strong networking ability with National and International Institutions. The center is successful because it is based on the cooperation of the University with different entities and the solid support of the Trento Province. High level funding and infrastructures are the conditions to achieve scientific results at the International level. The Trento University fostered several activities in physics, the research area with highest involvement of TIFPA.

Several projects have been carried out as a result of the agreement between INFN and the University. Lisa Pathfinder is, for example, the first fundamental step toward a space observatory for gravitational waves. The CSES Chinese satellite will instead study the variability of the electromagnetic environment around the Earth and develop new methods for the monitoring of large-scale geophysical effects, such as earthquakes. This is a special project of the Italian Space Agency, which has been funded by the Italian research Ministry and is under way in strict collaboration among our Physics Department, TIFPA, and the Bruno Kessler Foundation, for the construction of qualified prototypes and flight instrumentations. In this endeavor it is clear the competitive R&D advantage when there is a common work.

ha ricevuto un importante finanziamento dal MIUR e che ha visto una stretta collaborazione tra il TIFPA, il nostro Dipartimento di Fisica e la Fondazione Bruno Kessler, nella realizzazione di prototipi qualificati e della strumentazione di volo. Un progetto in cui è tangibile il vantaggio competitivo che nella ricerca scientifica e nell'avanzamento tecnologico si ha nel fare le cose bene e insieme.



Francesco Profumo

Presidente,
Fondazione Bruno Kessler

Il 15 gennaio 2013 sono venuto a Trento in veste di ministro della Ricerca a suggellare l'impegno tra l'Istituto Nazionale di Fisica Nucleare, la Fondazione Bruno Kessler, l'Università degli Studi di Trento e l'Azienda Provinciale per i Servizi Sanitari per la nascita del TIFPA. In quell'occasione espressi tutto il mio favore all'avvio di una iniziativa che impegnava l'INFN da una parte e rilevanti istituzioni del territorio trentino dall'altra ad avviare una collaborazione che avesse tra gli impegni prioritari anche l'azione innovatrice sostenuta dal trasferimento tecnologico. Azione che si trova rappresentata anche nella sigla stessa del TIFPA: con la lettera A che sta per Applications. Il presidente dell'Istituto Nazionale di Fisica Nucleare, il prof. Ferroni, in particolare sottolineò che, in seguito alla collaborazione pluriennale con la Fondazione Bruno Kessler nella ricerca e sviluppo di microdispositivi, con questa nuovo centro posizionato a Trento l'INFN puntava ad avvalersi di tale esperienza acquisita e a porre particolare attenzione alle applicazioni.

Quattro anni dopo nella veste di presidente della Fondazione Bruno Kessler vengo a salutare questo primo e già molto ricco rapporto delle attività TIFPA, mentre sono in via di perfezionamento nuovi accordi che vedono FBK tra gli attori principali finalizzati all'ulteriore crescita del TIFPA e del territorio che lo ospita. Accanto ai risultati scientifici di rilievo si stanno ponendo le basi per altri sviluppi strutturali che vedono la Fondazione Bruno Kessler partecipare proattivamente. Mi riferisco sia al programma di allestimento della sala sperimentale della protonterapia sia all'accordo in corso

On January 15, 2013, I was in Trento as Research Minister to seal the agreement among INFN, FBK, UNITN, and APSS, which marked the birth of TIFPA. In that occasion, I expressed my support to the initiative promoted by INFN on one side and relevant institutions from the Trentino region on the other to start a collaborative action having as main goal the technological transfer. The mission is clearly visible in the name TIFPA: A is indeed for "Applications". The INFN President, Prof. Ferroni, maintained that, following a long-time collaboration with FBK in R&D of microsystems, INFN was going to use exploit to capitalize on this experience and shift the balance toward applications.

Four years later, as FBK President, I welcome this first, and yet already very rich, activity report of TIFPA. New collaboration agreements are under way to consolidate the relationships with FBK. Beyond the scientific results, we are now fostering new developments where FBK plays a key role, from the construction of the experimental hall in the protontherapy center to the new INFN-FBK collaborative agreement for R&D in new devices for cutting-edge INFN experiments.

TIFPA is in very good health, and so is the collaboration among the different partners upon which the center is built. This report demonstrates that the good wishes dating back January 2013 turned into solid structural elements that guide toward the complete fulfillment of the goals set at that time.

di perfezionamento tra INFN e FBK, finalizzato ad assicurare il prosieguo delle attività di ricerca e sviluppo di dispositivi per esperimenti d'avanguardia INFN.

Tutto questo sottolinea l'ottimo stato di salute del TIFPA e quindi della collaborazione tra i partner che lo sostengono. Allo stesso tempo la sintesi qui raccolta dimostra che i buoni auspici siglati il 15 gennaio 2013 sono oggi solidi elementi strutturali che guidano verso il completo raggiungimento dell'obiettivo allora posto in avvio.

Paolo Bordon

Direttore Generale,
Azienda Provinciale per i Servizi Sanitari

E' con piacere ed orgoglio che l'Azienda Provinciale per i Servizi Sanitari (APSS) di Trento può sottolineare il positivo avvio della esperienza del TIFPA cui l'APSS partecipa attivamente quale socio fondatore e convinto sostenitore. L'idea iniziale di creare un consorzio di enti pubblici votati alle attività di ricerca, scommessa che ha pochi eguali in Italia, possiamo dire che oggi dimostra la sua preveggenza e, anche se molto resta ancora da fare, la sua giustezza. Tale impresa, grazie soprattutto al determinante sostegno dell'INFN, vede impegnate strutture con missioni diverse che possono, grazie alla loro organizzazione e buona volontà, contribuire al successo di idee moderne e positive. Anche l'APSS che fornisce alla comunità un servizio che ha come primo intento risultati di salute ed assistenza contribuisce e contribuirà ai successi di TIFPA convinta che là dove si fa ricerca si può curare meglio. Ciò è ancora più vero dove si sperimentano terapie innovative come quelle che utilizzano particelle (protoni) in campo oncologico. APSS è infatti attenta non solo alle problematiche della salute pubblica ma anche a contribuire alle problematiche di ricerca e sviluppo che le moderne tecnologie sanitarie impongono.

APSS intende proseguire il sostegno a TIFPA con impegno e convinzione per dare ai temi fondativi dell'Istituto concreta applicazione e favorire i successi in campo biologico, fisico e sanitario che le prime ricerche svolte e quelle in fase di progettazione legittimamente fanno presagire.

It is with great pleasure and pride that APSS, the Trento Agency for the public healthcare, which is one of the TIFPA founders and strong supporters, announces the successful start of this experiment. The original and unique idea of creating a consortium of public research bodies proves to have been longsighted, although there is still much to be done. This challenge is especially endorsed by INFN and involves other structures with different missions, whose mutual collaboration and commitment is leading to important achievements. More in detail APSS, whose main task is caring for the public health, is convinced that supporting research will lead to a great improvement in its performances and, consequently, in the public well-being. This is particularly true if we talk about innovative therapies such as those employing particles (protons) in oncology treatments. As a matter of fact, even if APSS main interest is public health, it is well aware of the need for research and development requested by the modern sanitary technologies.

APSS will keep supporting TIFPA with conviction and enthusiasm, and help in applying the results of its research in the biological, physical and health domains. The first two years of its successful activity make us think that there will be big news in future.

Lorenzo Pavesi

Direttore,
Dipartimento di Fisica,
Università degli Studi di Trento

Ce l'abbiamo fatta. Il TIFPA è ora un centro significativo nell'ambito della ricerca in fisica fondamentale e sulle sue applicazioni. Con soddisfazione possiamo guardare indietro da dove siamo partiti per poi andare avanti a progettare le attività future.

Mi piace sottolineare come questo risultato lo dobbiamo allo sforzo congiunto di molte persone che hanno creduto nella proposta che l'INFN ha fatto al territorio trentino: sperimentare una forma nuova di centro di ricerca che sapesse essere un momento aggregante di quanto già la comunità dei fisici trentini faceva e, al contempo, un'iniziativa nuova che promuovesse nuova scienza e nuova tecnologia partendo dall'eccellenze espresse dal sistema della ricerca trentina. In Ateneo questa sfida è stata raccolta con entusiasmo dal Dipartimento di Fisica. Il Dipartimento si è fatto promotore di quest'idea innovativa con il Senato accademico che l'ha fatta propria grazie alla rettrice De Pretis, prima, e al rettore Collini, ora. L'ateneo trentino ha sostenuto il TIFPA sia con finanziamenti per posizioni congiunte di ricercatori che mettendo a disposizione spazi per la realizzazione del centro. Mi piace anche sottolineare che, oggi, TIFPA non vede solo la partecipazione del Dipartimento di Fisica, ma anche di altri Dipartimenti della collina - in particolare il Dipartimento di Matematica, quello di Ingegneria Industriale e il Centro di Biologia integrata. A dimostrazione dell'effetto volano alla ricerca trentina svolto dal TIFPA e della partecipazione convinta e sostanziale dell'Università di Trento al centro stesso.

Credo che ora siamo usciti dalla prima fa-

We have done it. TIFPA is now an important centre in the framework of research on fundamental physics and of its applications. We can look back with satisfaction at the work done and are ready to plan new activities in the next future.

I'd like to point out that we owe this result to the common effort of all people who have believed in the proposal made by INFN to the Trentino research network: to give life to a new conception of a research centre, able to put together all the already existing activities in the field of Physics and to make them bloom towards new scientific goals and innovative technologies. On behalf of the University of Trento, this challenge has been enthusiastically welcomed by the Department of Physics, which was able to gain support from the Academic Senate thanks to the personal involvement of two rectors, earlier prof. Daria de Pretis, and now prof. Paolo Collini.

The University of Trento has supported TIFPA both by cofunding some positions for researcher and making available a portion of its premises for the physical realization of the Centre. The operation was incredibly successful if, within less than two years from its start, TIFPA has widened its partnership to the Departments of Mathematics, Industrial Engineering and to CIBIO, the University Centre for Integrative Biology. This proves how strongly TIFPA has already influenced the Trentino environment of research and how convinced is the participation of the University of Trento to its life.

I now believe that we have come out from the first pioneering phase, and that we can pass se pionieristica, e possiamo passare alla seconda fase del radicamento del TIFPA nella realtà trentina, nazionale ed internazionale. Assieme all'INFN, alla Fondazione Bruno Kessler e all'Azienda provinciale per i Servizi Sanitari, possiamo non solo concentrarci su quelle linee di ricerca nate con il centro (la fisica dei raggi cosmici, i rivelatori per esperimenti nello spazio, le applicazioni sperimentali del fascio di protoni) ma anche promuovere ulteriormente gli altri esperimenti scientifici a cui partecipano i ricercatori afferenti al TIFPA. Questo lo potremo fare seguendo l'intuizione che ha permesso di costruire il centro: la partecipazione, la collaborazione e l'impegno di tutti gli attori della ricerca con una logica inclusiva e valorizzante delle singole specificità.

Su questa strada, noi ci siamo!

to a second step, where TIFPA will become embedded into the research network at a local, national and international level. Together with INFN, Foundation Bruno Kessler and APSS (the local Agency for public healthcare) we will focus not only on traditional research areas such as cosmic rays physics, detectors for experiments in space, proton beams experimental applications, but will also boost other important scientific projects in which take part the TIFPA researchers. This will be done by sticking to the original intuition that led to the realization of the Centre: creating a connection among people and bodies involved in the local research network with the aim of enhancing all and every single peculiarity.

On this path, we will be there!

Dario Petri

Direttore,
Dipartimento di Ingegneria Industriale,
Università degli Studi di Trento

Il Dipartimento di Ingegneria Industriale dell'Università di Trento (DII) è stato costituito nel 2012 allo scopo di raccogliere competenze dell'area industriale relative alla tecnologia dei materiali, all'elettronica, alla meccanica e all'ingegneria gestionale. Queste competenze sono rappresentate da personale docente e ricercatore di diverse discipline, sia ingegneristiche che di base, in grado di coprire una vasta area di settori di ricerca nei settori elencati.

Proprio per la sua composizione e struttura, il DII trova molti punti di contatto con le attività che sono interesse proprio del TIFPA. Nell'ambito dei rivelatori di radiazioni a semiconduttore, con particolare riferimento al settore dell'elettronica, esistono già attività di collaborazione fra il TIFPA e personale del DII associato alla struttura e presente in vari esperimenti INFN, inerenti soprattutto la Commissione Scientifica Nazionale 5 (CSN5), quali APIX2, PIXFEL, SEED, ma anche la CSN1, quali ATLAS e RD_FASE2.

Nel settore della tecnologia dei materiali esistono collaborazioni in atto in esperimenti INFN sui materiali per rivelatori e dosimetri per la radioterapia, quali NADIR e AXIAL, e ulteriori tematiche di ricerca di sicuro interesse in grado di attivare nuove collaborazioni. In particolare, diversi gruppi del DII hanno competenze utili a sviluppare progetti su materiali innovativi per rivelatori o per la protezione da radiazione in missioni spaziali.

Dal punto di vista della meccanica e meccatronica il personale del DII ha già contribuito alla realizzazione e qualificazione di meccanismi per applicazioni spaziali, ad esempio nel-

The Department for Industrial Engineering of Trento University (Dipartimento di Ingegneria Industriale, DII) started in 2012 in order to collect various competences in the fields of Materials Engineering, Electronics, Mechanics and of Management Engineering. This expertise is represented by professors and researchers who belong to a wide range of disciplines, both applied and fundamental, so that a correspondently wide range of research fields is covered in the topics mentioned above.

Due to its specific composition and structure, the DII shares many interests with the activities carried out in TIFPA. A collaboration in the field of semiconductor radiation detectors, especially in the area of electronics, has already been established between TIFPA and DII through the researchers formally associated to INFN, who work on several projects, mainly belonging to the 5th Scientific National Commission (CSN 5) research area, such as APIX2, PIXFEL, SEED, but also belonging to the 1st Scientific National Commission (CSN 1) research area, such as ATLAS and RD_FASE2.

In the field of Materials Engineering there are also collaborations in INFN experiments on materials for detectors and dosimeters for radiotherapy, such as NADIR and AXIAL; there are also other interesting research topics potentially leading to future collaborations. As a matter of fact, some research groups in DII are ready to develop projects on innovative materials for detectors or for radiation protection in space missions.

In the area of Mechanics and Mechatronics, the Department for Industrial Engineering has l'esperimento di CSN2 LISA Pathfinder, ed è in grado di fornire un contributo di alto livello nel progetto e nello sviluppo di sistemi o infrastrutture per acceleratori di ioni, con particolare riferimento all'area di ricerca presso il Centro di Protonterapia.

Infine, va ricordato che presso il DII sono presenti anche attività di ricerca di aree interdisciplinari come le biotecnologie e le analisi per i beni culturali, che sono rappresentate nella CSN5 dell'INFN e che possono stimolare collaborazioni con il TIFPA per ulteriori esperimenti INFN in questi campi. Grazie ai punti di contatto elencati, alle collaborazioni in atto e a quelle possibili, il DII ha accolto con grande favore la convenzione di collaborazione con il TIFPA che potrà dare nuovo impulso alla realizzazione di altre interessanti attività di ricerca.

already given great help in building and certifying machineries for spatial applications, for example in the framework of the CSN2 project LISA Pathfinder, and will be able to give a high level contribution in designing and developing systems and infrastructures for ion accelerators, in particular in the new experimental laboratory of the Trento Protontherapy Centre.

Last but not least, DII also deals with multidisciplinary research activities such as biotechnologies and analysis applied on the study of cultural heritage, which are within the scope of INFN CSN 5, and could inspire new collaborations with TIFPA. Thanks to the many interests in common, to the collaborations already established and to the ones which will be likely in future, DII has welcomed with great favour the extension of the TIFPA original agreement which has formally included DII into this important research network, and has the potential to give momentum for the implementation of further interesting research activities.

Alessandro Quattrone

Direttore,
Centre for Integrative Biology,
Università degli Studi di Trento

In questi anni di recessione, e in un paese che non ha mai considerato il sostegno alla ricerca scientifica come una priorità, il Trentino ha coraggiosamente promosso e concretamente favorito un suo sistema della ricerca, di cui TIFPA è ultimo arrivo ma già componente solidamente strutturale. Le sue prime mosse, descritte in dettaglio in questo report, sono chiaro disegno programmatico di una istituzione destinata a competere con efficacia nell'agone internazionale, e a portare indietro un importante ritorno di visibilità. Il sistema trentino ha saputo rendere una sua debolezza, la piccola dimensione, la difficoltà a raggiungere numeri di ricercatori e istituzioni di ricerca indicati altrove come necessaria massa critica, un vero punto di forza. Ha saputo costruire un mosaico dove la connessione transdisciplinare è vissuta come attività quotidiana, dove la consuetudine delle persone diventa naturalmente collaborazione, accentuando i contenuti innovativi e la significatività del suo prodotto di ricerca.

Nella politica del suo direttore fin dal primo giorno il TIFPA, che nasce peraltro da una collaborazione a quattro enti e vive già nel suo atto fondativo un forte desiderio di convergenza, ha saputo brillantemente inserirsi nel mosaico, aggiungendo fondamentali tasselli che già sono giustapposti a quelli di FBK ed Università. L'ambito che mi compete, quello delle biotecnologie per la salute umana, vede già una collaborazione attiva ed entusiasta, condotta da giovani ricercatori che sullo studio degli effetti delle radiazioni in cellule e tessuti viventi stanno fondando la loro futura carriera.

Alla vigilia di questo primo anno di attività

In the current years of recession, and in a Country which has never considered support to scientific research as a priority, Trentino has bravely promoted and effectively favoured a research system of its own. TIFPA is the latest entry in such system, and is already one of its substantial components. TIFPA first moves, detailed in this report, are a clear programatic blueprint of an institution bound to compete effectively in the international context, and bring back a high visibility return. The Trentino system was able to turn a weakness, i.e., its small geographical size, and its difficulty in attaining the number of researchers and research institutions which are elsewhere considered as preconditional critical mass, into a strength. Trentino has been able to build a mosaic where trans-disciplinary interconnection is experienced as a daily activity, and people familiarity naturally becomes collaboration, emphasizing innovatory contents and meaningfulness of its research product.

TIFPA, which was born from a four-partner collaboration and expresses already in its founding agreement a strong commitment for convergence, since its very beginning has been able to brilliantly place itself within such mosaic thanks to the steering of its director, and has added fundamental tiles to those placed by FBK and Trento University. In my area of competence, biotechnologies for human health, we see already an active and enthusiastic collaboration, carried out by young researchers who are building the basis of their future career on the study of the effects of radiation in cells and living tissues.

il mio augurio è quindi di una rapida crescita e di un altrettanto rapido consolidamento, che corrisponderanno alla ulteriore affermazione di un sistema della ricerca trentino il quale, in totale controtendenza con i tempi e nonostante le colpevoli sordità dell'Italia, continua a credere fermamente che l'unica possibile società progressiva è, oggi, quella fondata sul sostegno strutturale alla ricerca scientifica.

Alessandro Quattrone

Therefore, on the eve of its first anniversary of activity, I wish TIFPA a swift growth and an equally swift consolidation, to be paralleled to the continued pre-eminence of the Trentino research system which, in fully bucking the current trend, and in spite of the guilty unresponsiveness of Italy, keeps on firmly believing that the only progressive society nowadays is that founded on the systemic support of scientific research.

Gianluigi Casse

Direttore,
Centro Materiali e Microsistemi,
Fondazione Bruno Kessler

Il Centro di Materiali e Microsistemi della Fondazione Bruno Kessler di Trento è uno storico collaboratore dell'INFN con cui ha partecipato allo sviluppo di un numero considerevole di progetti e piattaforme tecnologiche specialmente nello sviluppo di sensoristica e strumentazione. Dalla creazione di TIFPA, la proficua collaborazione si è intensificata e i campi di applicazione di comune interesse si sono persino ampliati. Sempre sulla base dello sviluppo di strumentazione avanzata come punto principale di convergenza delle attività scientifiche, collaboriamo su tutti i laboratori virtuali di TIFPA: spazio, sensori e fisica medica.

Personalmente, essendo un fisico delle particelle come estrazione accademica, valuto queste collaborazioni come un grande valore, in termini di prestigio e qualità dell'attività scientifica, e ne saluto con piacere il rafforzamento. In particolare ripongo ottime aspettative nella collaborazione nel settore, ad ora meno esplorato nelle nostre precedenti collaborazioni con INFN, della fisica medica, dove sono certo che le nostre rispettive competenze daranno una forte spinta allo sviluppo di questa importante ricerca, viste le ricadute sociali. Appare specialmente promettente la ricerca sulla protonterapia dei tumori, dove la grande esperienza comune in strumentazioni avanzate per fisica (delle alte energie o dello spazio) può fornire strumenti unici e d'avanguardia.

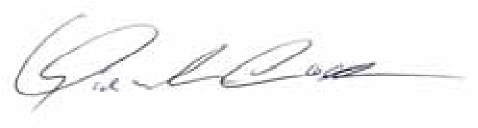
Accolgo con estremo piacere questo rapporto sulle attività di TIFPA che ne sottolinea le scelte e le operazioni di eccellenza e vedo la continuazione di una collaborazione fra i nostri istituti che mette il Trentino in posizione

The CMM Center of FBK is a long-term partner of INFN, having participated together in a large number of projects and technology platforms, mainly for the development of sensors and instrumentation. Since the establishment of TIFPA, such effective partnership has grown and the application fields have even widened. Still converging towards the development of advanced instrumentation, we collaborate in all TIFPA virtual labs: Space Research, Sensors and Medical Technologies.

Personally, having graduated in Particle Physics, I give a great value to such collaborations, in terms of reputation and scientific quality, and hope they will strengthen. Specifically, I have great expectations for collaborations in Medical Physics, an area not much explored in our previous collaborations. I do believe that our respective competences will foster development in such important area, with large social impact. Especially promising is research in protontherapy for cancer treatment, where our large common experience in advanced instrumentation for both high energy Physics and space Physics can provide unique, state-of-the-art tools.

I am extremely pleased to welcome this TIFPA activity report, which highlights the excellence in its choices and activities. Furthermore I foresee the continued collaboration between our institutes, which places Trentino in a position of great scientific visibility and is providing relevant results for the local community.

di grande visibilità scientifica e che sta dando risultati importanti per il territorio.



Maurizio Amichetti

Direttore,
Unità Operativa Protonterapia,
Azienda Provinciale per i Servizi Sanitari

E' motivo di orgoglio poter accogliere presso la struttura del Centro di Protonterapia di Trento il laboratorio di TIFPA, la struttura di ricerca che ha tra i soci fondatori l'Azienda Provinciale per i Servizi Sanitari (APSS) cui il Centro appartiene.

La presenza del laboratorio e l'inizio della sua attività di ricerca ha dato completezza alla struttura di un centro che ha da poco iniziato la sua attività clinica e che solo contemperando attività di assistenza sanitaria in campo oncologico e ricerca clinica potrà trovare risposta completa alla sua missione.

La grande novità caratterizzata dall'entrata in funzione di una terapia radiante innovativa e a grande impatto tecnologico come la protonterapia nell'armamentario della comunità oncologica nazionale, richiede infatti una parallela e complementare azione di ricerca e sviluppo per sviluppare a pieno titolo le enormi potenzialità dell'uso delle particelle in medicina. TIFPA può rappresentare una risposta a tale necessità grazie all'impegno dei suoi ricercatori ed alle idee innovative del suo management.

La collaborazione tra parte clinica e parte sperimentale che andrà sviluppata anche grazie a norme attuative che ne permettano una sempre maggiore integrazione sarà fondamentale per il successo del progetto protonterapia costituendo un esempio di virtuosa collaborazione tra accademia, ricerca e assistenza.

It is a reason of pride for us to host, within the Protontherapy Centre of Trento, the experimental laboratory of TIFPA, the research organisation one of whose founding members is APSS (Azienda Provinciale per i Servizi Sanitari) to whom the Centre belongs.

The presence of the TIFPA experimental lab and the start of the research activity has given completeness to a centre where only in the recent times the medical activity has begun and which needs to put together oncology healthcare and clinical research in order to accomplish its mission.

The big news of the activation of an innovative radiation therapy with a big technological impact such as prototherapy, in the framework of the traditional facilities available to the national oncological community, requires a parallel and complementary activity of research and development in order to take best advantage of the huge potentialities of the application of particles onto the wide field of medicine. TIFPA can represent the answer to this need, thanks to the extraordinary effort of his researchers and to the innovative vision of its management.

The growing integration between medical and experimental expertise should be supported through new rules, thus allowing the success of the Protontherapy project. This will be a sparkling example of good collaboration between academy, research and public healthcare.

Roberto Battiston

Presidente,
Agenzia Spaziale Italiana

Il TIFPA a Trento: una scommessa riuscita

La scienza e le frontiere della ricerca si evolvono e si sviluppano continuamente. E analogamente si devono sviluppare e modificare gli strumenti e le strategie che affrontano i nuovi temi scientifici. Talvolta questo porta alla nascita di centri o istituti di eccellenza dedicati a nuovi settori scientifici, per meglio affrontare le nuove sfide. Se questo è normale in altri paesi, in Italia oggigiorno è raro assistere alla nascita di un nuovo istituto di ricerca.

Il TIFPA, Trento Institute for Fundamental Physics and Applications, rappresenta un'eccezione, nata dalla felice intuizione che ho condiviso con il Presidente dell'INFN Nando Ferroni ed i colleghi del Dipartimento di Fisica di Trento, relativamente al fatto che a Trento si poteva raggiungere la massa critica in un nuovo settore di ricerca, quello della fisica astroparticellare nello spazio, aggiungendo alle competenze spaziali esistenti nel settore gravitazionale e del remote sensing, quelle della fisica dei raggi cosmici che sarebbero potute svilupparsi a seguito del mio trasferimento.

Il nuovo Istituto avrebbe beneficiato dell'esistenza di una importante serie di infrastrutture di ricerca sviluppate dalla Provincia di Trento nel corso degli anni, in particolare la Fondazione Bruno Kessler (FBK) con il suo Centro per i Microsistemi, il Centro di Prototerapia con l'annesso fascio di protoni da 220 MeV e il Centro di Fisica Teorica ECT* oltre, naturalmente, ai docenti e ricercatori del Dipartimento di Fisica afferenti al gruppo Collegato dell'INFN a

TIFPA at Trento: a successful bet

Frontiers of scientific research evolve and develop continuously. Similarly, tools and strategies to address new scientific issues must evolve. Sometimes this leads to the foundations of dedicated centers of excellence to better match the new scientific challenges. If this is normal in other countries, in Italy nowadays is rare to witness the birth of a new research institute.

The TIFPA, Trento Institute for Fundamental Physics and Applications, is an exception, born from the intuition that I shared with the President of INFN Nando Ferroni and the colleagues of the Trento Physics Department, considering the opportunity to create in Trento a critical mass for the new area of research, that of astroparticle physics in space, adding to the existing skills in the field of gravitation and remote sensing, the study of cosmic radiation from space that could be started as a result of my transfer there.

The new Institute would also benefit from the existence of an impressive series of research infrastructure developed by the Province of Trento through the years, especially the Bruno Kessler Foundation (FBK) with its Center for Microsystems, the Proton Therapy Center with its 220 MeV proton beam and the Center for Theoretical Physics ECT* in addition, of course, to the research teams at the Department of Physics members of the INFN Trento "gruppo collegato".

If the intuition was right, its execution was

Trento.

Se l'intuizione era giusta, la sua esecuzione è stata impegnativa: tra il 2012 ed il 2014, con l'aiuto di Graziano Fortuna cui sono straordinariamente grato per il generoso contributo, sono state gettate le fondamenta del TIFPA, primo Centro Nazionale dell'INFN dedicato alla ricerca fondamentale e alle tecnologie collegate alla fisica astroparticellare nello spazio, la medicina nucleare e le tecnologie per i rivelatori di particelle. Con l'arrivo di Marco Durante, primo Direttore del Centro, è iniziata la fase operativa che vede oggi visibilmente crescere l'attività di ricerca sia in intensità che in qualità realizzando concretamente quella presenza dell'INFN a Trento da molti e da molto tempo auspicata.

Anche se ci vorrà ancora del tempo affinché il TIFPA possa raggiungere la piena operatività e l'atteso ritorno scientifico, i risultati già ottenuti mi permettono di affermare che si tratta di una scommessa riuscita per cui ringrazio tutti coloro che stanno contribuendo a questo successo.

challenging: between 2012 and 2014, with the help of Graziano Fortuna to whom I am extraordinarily grateful for his generous contribution, the foundations of TIFPA were layed out as the first INFN National Center dedicated to fundamental research and technologies related to astroparticle physics in space, nuclear medicine and technology for particle detectors. With the joining of Marco Durante as first Director of the Centre, the operational phase began, and we see today visibly growing research activites both in intensity and in quality, eventualy realizing the presence of INFN at Trento for a long time advocated by many.

Although it will take some time for TIFPA to become fully operational and to provide the expected scientific return, the results already obtained do allow me to say that it was a successful bet for which I thank all those who are contributing to this success.

Jochen Wambach

Direttore,
ECT*

The European Centre for Theoretical Studies in Nuclear Physics and Related Areas (ECT*) started operating in 1993 as a “bottom up” initiative of the European nuclear physics community and has since developed into a highly visible and successful research center for nuclear physics in a broad sense. ECT* assumes a coordinating function in the European and international scientific community by:

- conducting in-depth research on topical problems at the forefront of contemporary developments in theoretical nuclear physics
- fostering interdisciplinary contacts between nuclear physics and neighboring fields such as particle physics, astrophysics, condensed matter physics, statistical and computational physics and the quantum physics of small systems
- encouraging talented young physicists by arranging for them to participate in the activities of the ECT*, by organizing training programs and establishing networks of active young researchers
- strengthening the interaction between theoretical and experimental physicists.

These goals are reached through international workshops and collaboration meetings, advanced doctoral training programs and schools, and research carried out by postdoctoral fellows and senior research associates as well as long term visitors. There are presently cooperative agreements with other scientific institutions, in particular the ICTP in Trieste, the Extreme Matter Institute (EMMI) in Darmstadt, the Helmholtz International Center for FAIR, the JINR in Dubna, the research Center

L’ECT* (European Centre for Theoretical Studies in Nuclear Physics and Related Areas) è nato nel 1993 come iniziativa “*bottom up*” della comunità europea della Fisica nucleare, e da allora si è evoluto in un centro di ricerca di grande successo e visibilità per la Fisica nucleare in senso largo. ECT* svolge una funzione di coordinamento all’interno della comunità scientifica europea e internazionale:

- svolgendo ricerche approfondite su problemi cruciali di avanguardia rispetto agli sviluppi contemporanei della Fisica teorica nucleare;
- promuovendo contatti interdisciplinari tra Fisica Nucleare e ambiti di ricerca adiacenti come la Fisica delle particelle, l’Astrofisica, la Fisica della materia condensata, la Fisica statistica e computazionale e la Fisica quantistica dei piccoli sistemi;
- sostenendo e facilitando la partecipazione di giovani fisici di talento alle attività del centro, con l’organizzazione di programmi di training e permettendo di fare rete tra giovani ricercatori;
- rafforzando l’interazione tra fisici teorici e sperimentali.

Questi obiettivi sono raggiunti attraverso l’organizzazione di workshops e collaborazioni internazionali, di programmi e scuole di dottorato avanzate, di ricerche affidate a borsisti postdoc e a ricercatori senior così come a visitatori di lungo termine. Al momento sussistono accordi di collaborazione con altre istituzioni scientifiche fra cui in particolare l’ICTP di Trieste, l’EMMI (ExtreMe Matter Institute) di Darmstadt, l’Helmholtz International Center for

RIKEN, the National Astronomical Observatory of Japan, the ITP of the Chinese Academy of Science and the Asia Pacific Center for Theoretical Physics in Korea. Locally cooperations exist with the Physics Department and the Center for Bose-Einstein Condensation (BEC) at the University of Trento and with the Trento Institute of Fundamental Physics and Applications (TIFPA). The latter sponsors a two-year junior postdoctoral researcher position that is currently held by Dr. Chen Ji. Dr. Ji works in the area of low-energy nuclear physics with emphasis on few-nucleon systems.

FAIR, il JINR di Dubna, il centro di ricerca RIKEN, l'osservatorio astronomico nazionale del Giappone, l'Institute of Theoretical Physics dell'Accademia Cinese delle Scienze e l'Asia Pacific Center for Theoretical Physics in Corea. A livello locale, esiste una collaborazione con il Dipartimento di Fisica e il Centro BEC (Bose-Einstein Condensation) dell'Università di Trento e con il TIFPA (Trento Institute of Fundamental Physics and Applications) dell'INFN. Quest'ultimo sta attualmente finanziando una borsa di studio post-doc a favore del Dr. Chen Ji, che lavora nel campo della fisica nucleare delle basse energie con particolare attenzione ai sistemi a pochi nucleoni.

Graziano Fortuna

Direttore emerito,
TIFPA

La nascita del TIFPA, un sogno che dura da un paio di decenni

L'acronimo TIFPA sta per "Trento Institute for Fundamental Physics and Applications", nome che descrive perfettamente la vocazione del territorio trentino di agire da catalizzatore fra Società e Scienza. Un caso emblematico di tale fertile interazione è l'incredibile crescita di competitività guadagnata dai prodotti della agricoltura trentina nel mercato globale. Il successo di tale politica è direttamente connesso con la capacità di mobilitare e selezionare appropriati temi di ricerca interdisciplinari atti a stimolare e valorizzare le dinamiche sociali indotte dal mondo industriale e dei servizi oltre che dall'accademia.

La più eclatante iniziativa portata avanti dall'INFN assieme a Università di Trento (UNI-TN), Centro Materiali e Microsistemi della Fondazione Bruno Kessler (CMM-FBK), l'Azienda Provinciale per i Servizi Sanitari (APSS), è la fondazione del Centro Tecnologico-Scientifico,TIFPA. Il Centro diretto dall'INFN, rappresenta una organizzazione unica nel panorama dell'Istituto. Nato per coprire l'intera filiera della conoscenza nel contesto della Fisica delle Particelle e della Fisica Nucleare, accanto alle tradizionali attività che si riferiscono alle cinque Commissioni Scientifiche Nazionali, il Centro ospita fino ad un massimo di cinque Settori Tecnologici (ST). Essi assumono la caratteristica di laboratori virtuali dove concentrare finanziamenti e risorse umane atti ad affrontare, facendo uso di concetti e strumenti avanzati, problemi alla frontiera della conoscenza. Tre ST sono già stati identificati e sono: Fisi-

The birth of TIFPA, a dream lasting since a couple of decades

TIFPA stands for "Trento Institute for Fundamental Physics and Applications", a name which perfectly describes the vocation of Trento territory to act as a catalyst between Science and Society. An interesting test case of this fertile interaction is the incredible growing of competitiveness gained by Trentino Agriculture products in the context of the global market. The success of such policy is directly linked to the capability of mobilizing and selecting appropriated, interdisciplinary research topics directed to stimulate and valorize social dynamics induced by industry and academia.

The most striking initiative carried out by INFN together with Partners sited in Trento Autonomous Province (PAT) namely: UNiversity of Trento (UNI-TN), Bruno Kessler Foundation-Center for Materials and MicroSystems (FBK-CMM), Provincial Agency for Health Services (APSS) is the foundation of the scientific-technological Center TIFPA. The Center, ruled by INFN, represents a rather unique organization structure in the INFN context. Born to cover the so-called full chain of knowledge in the context of Nuclear and Particle Physics research area, besides the traditional activities which refer to the National Scientific Committees (NSC), the Center hosts up to five Technological Sectors (ST).They act as virtual laboratories where to concentrate financial and human resources to attack problems at the frontier of knowledge by using advanced concepts and tools. Three STs, covering subjects like Medical Physics and protontherapy, Physics in space, ca Medica e protonterapia, Fisica nello spazio, Sensori e sistemi di rivelazione complessi.

L'eredità, in termini di risultati competitivi a livello internazionale degli ultimi 10 anni, è notevole e riguarda esperimenti, studi e progetti di CSN2 (AMS2, LISA-Pathfinder, Virgo), CSN3 (Fisica Nucleare) e CSN4 (Fisica Nucleare Teorica). Fra i risultati tecnologici, di maggior rilievo vanno menzionati i SiPM e loro applicazioni, ottenuti nel contesto di un accordo pluriennale di ricerca a cofinanziamento fra INFN e FBK, con il supporto della PAT nel ruolo di facilitatore.

E' semplicemente sorprendente e abbastanza unico che un territorio di medio-piccole dimensioni, diversamente da ciò che avviene nella maggior parte delle altre regioni italiane, sia in grado di darsi una politica attiva della scienza e dell'innovazione attraverso lo strumento dei piani triennali. Ancora una volta, scienza applicata e temi alla frontiera della conoscenza pavimentano la stessa via. E' merito di tale politica lungimirante la preservazione della fertilità interdisciplinare delle idee in contrasto alla frammentazione delle stesse.

Un profilo di spesa certo e la disponibilità di infrastrutture di ricerca d'avanguardia sono gli ingredienti che attraggono nel sistema trentino della Scienza e della Tecnologia, scienziati di fama mondiale e giovani brillanti. TIFPA rappresenta un esempio illuminante di ricerca interdisciplinare a forte impatto sociale. Partendo dal nulla, sotto la guida del prof. Marco Durante, Scienziato di fama mondiale, il Centro sta crescendo rapidamente acquisendo, giorno dopo giorno, una reputazione internazionale. Il fascio di protoni accelerato dal ciclotrone, già in operazione in un edificio dell'area ospedaliera di Trento ha consentito di concentrare la logistica e la strumentazione in uno spazio adeguato non solo per un uso clinico di avanguardia ma anche in applicazioni di interesse per settori industriali e progetti di ricerca rilevanti per lo spazio e la microelettronica.

Ringraziamenti: sono immensamente grato a Piero Spinnato che, nel ruolo di coordinatore tecnico del TIFPA fin dai primi giorni, ha assunto la responsabilità riguardo ai lavori edili, impiantistici e di strumentazione connessi alla

Sensors and detection systems have been identified sofar.

The heritage, in terms of successful, world-wide, competitive results of the past decade, is remarkable and spans a wide range of experiments in the domain of CSN2 (AMS2, LISA-PATHFINDER, VIRGO) and CSN3 (Nuclear Physics) and CSN4 (Theory). Among the technological achievements the most sounding result regards the SiPM devices based on Silicon micromachining. The SiPM results and applications have been obtained in the context of a co-funded research agreement between INFN and FBK, with the support of PAT acting as facilitator of the initiative.

It is simply surprising and rather unique that a small size local Government like PAT, differently from other Italian Regions, implements a Science policy, organizing three years Planning of research activities which includes, besides applied Science, important themes paving the frontier of knowledge. The merit of such Policy is the preservation of the fertility of ideas otherwise lost because of the knowledge fragmentation.

Secure funding profile and up-to-date research infrastructures are the necessary ingredients which attract in Trento world-wide renowned Scientists and high skill pupils. TIFPA represents a clear example of real interdisciplinary research Center with strong impact on the territory. Starting from green field, under the guide of Prof. Marco Durante, TIFPA is fast growing. We expect that TIFPA, in a couple of years, will gain international reputation in medical Physics and protontherapy..The available proton beam accelerated by the cyclotron in operation in a hospital site in Trento favours the contacts of Physicists, Biologists and Medical Doctors with a great benefit for patients.

Acknowledgements: I am immensely grateful to Piero Spinnato who, acting as Technical Coordinator of TIFPA in the early days, took the responsibility of all civil works, plants an machinery connected with the birth of the Center.

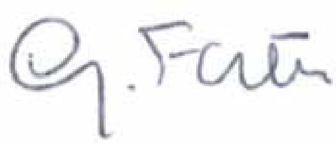
Many thanks to Marta Perrucci e Giuliana Pellizzari who have organized from scratch the administrative activity at the Center.

Rita Dolesi, Stefano Vitale, Roberto Batnascita del Centro.

Sentiti ringraziamenti a Marta Perucci e Giuliana Pellizzari, che hanno organizzato dal nulla l'attività amministrativa del Centro.

Rita Dolesi, Stefano Vitale, Roberto Battiston, Francesco Pederiva sono sentitamente ringraziati come membri del gruppo di lavoro che ha redatto tutta la documentazione necessaria per la realizzazione del Centro.

tiston, Francesco Pederiva are strongly acknowledged as members of the Working Group which prepared all the paper work necessary for the Center Foundation.



Virtual Labs

Space Research

Virtual Labs

The AMS-02 experiment on the International Space Station

Space Research

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with contributions by
William Jerome Burger,[3,2] Roberto Iuppa,[1,2] Chiara La Tessa[1,2]

Space science research represents a unique opportunity for excellence in Trento, coming from the synergy between the diverse areas of expertise and different institutions that come together to form TIFPA. On one side, TIFPA enjoys a position of scientific leadership in different fundamental space science challenges, including the observation of the universe with gravitational waves and astroparticles, and the interaction of high energy particles with biological material. On the other side, TIFPA offers technological expertise, including hardware design, fabrication, and testing for various key technologies that enable space science. Such expertise includes sensor and magnet hardware for high energy particle detection and spectroscopy, inertial sensing and small force measurement for gravitational physics, and testing for radiation shielding and hardware radiation hardness. These activities represent a natural convergence of the Department of Physics, INFN, APSS, and FBK – with APSS and FBK allowing access to top class facilities for, respectively, material fabrication and characterization, and a proton beamline – in addition to a stimulating starting point for future collaboration.

The prominent role of TIFPA researchers in ESA and ASI space missions including LISA Pathfinder / LISA, AMS, ROSSINI, and LIMADOU is testament to the growing impact of the center in space research. New initiatives, including New Reflections, represent the possibility for innovative collaboration in the future. This brief report presents TIFPA's contribution in developing technology for space research in the 2015-2016 timeframe, divided into the main missions that benefit from this research.

LISA Pathfinder: demonstrating the technology of free-fall for the LISA orbiting gravitational wave observatory

The successful in-orbit demonstration of sub-femto-g free-fall achieved by LISA Pathfinder (LPF) (Armano et al. 2016b)[†] represents validation of the key measurement technology needed for measuring mHz gravitational waves from space: the interferometric measurement of the tidal acceleration between free-falling test masses(TM), with sensitivity approaching the 3 $\mathrm{fm/s^2/Hz^{1/2}}$ goal for LISA. The most critical hardware under test in LPF are the geodesic reference test masses themselves and the electrostatic sensing and actuation hardware that defines the environment around the test masses – known collectively as the "Gravitational Reference Sensor". The LPF GRS is a contribution from ASI, developed by Carlo Gavazzi Space (Milano) with the scientific supervision of the Laboratory of Experimental Gravitation of the Università di Trento and TIFPA: in addition to serving as PI group for the mission, the Trento group has had a leadership role in all aspects of

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[†]References cited within Virtual Labs contributions are listed at the end of the Virtual Labs part, p. 55.

the GRS. This activity, supported by ASI and the INFN, has ranged from the conceptual design and initial prototyping of GRS hardware, to torsion pendulum small force testing, “shadow engineering” of the industrial development, and finally to the design and implementation of key GRS verification experiments on the flight hardware on ground and in space.

The LPF GRS is designed for use in LISA and thus represents true space heritage for the hardware that will guarantee precise free-fall references in the space gravitational wave detector.

Figure 1: Key LPF hardware, including the Gravitational Reference Sensor (GRS): 2 kg Au-Pt test masses inside the electrode housings (gold); UV discharge illumination (purple); (surrounding) vacuum chamber and TM caging hardware.

The key technology performances include:

– *Position sensing* The GRS demonstrated capacitive position sensing at the 2 nm/Hz$^{1/2}$ level, which allows the required levels of “drag-free” control of the satellite around the test masses. The in-flight performance confirmed the results of our ground test measurements, in noise and in the critical, sub-mrad, alignment and calibration parameters.
– *pico-Newton electrostatic actuators* LPF has demonstrated the application of GRS electrostatic forces of order tens of pico-Newton (5×10^{-11} N) while introducing force noise below 10 fN/Hz$^{1/2}$ (10^{-14} N/Hz$^{1/2}$), confirming tests by the Trento group with our colleagues, in charge of the GRS electronics development, at ETH Zurich.
– *UV photoelectric discharge and electorstmitigation of electrostatic forces* The LPF GRS successfully demonstrated bipolar photoelectric discharging with UV light, a challenge for the preparation of the Au-coated GRS electrode and TM surfaces, with tests performed in the Trento torsion pendulums. Additionally, LPF has demonstrated the measurement and compensation, at the sub-mV level, of stray electrostatic potentials on the GRS surfaces, with a technique developed and tested in Trento.
– *Vacuum* The GRS vacuum chamber cleanliness and vent-to-space pumping strategy allowed reaching residual pressures below 5 μPa – and still falling at the time of writing – which limits the Brownian motion of the TM from molecular impacts to a level compatible with LISA.
– *Gravitational balancing* of the spacecraft mass distribution (Armano et al. 2016a) is critical to measurement sensitivity, as the applied forces needed to compensate residual gravitational forces and torques introduces noise. LPF demonstrated that the residual gravitational difference at the positions of the two TM could be balanced to within several pico-g, beating the required levels by more than an order of magnitude.

As the LPF measurement campaign comes to a close in the first half of 2017, the Trento group is shifting focus to applying the measurement science of LPF, and particularly the GRS technology, to the LISA observatory. The techniques developed for measuring small forces between TM 40 cm apart will have to be extended to a more complicated interferometry configuration in which the a TM acceleration is measured relative to a reference TM is several million km away. The GRS design will be reanalyzed, maximizing the heritage from LPF while evaluating possible ways to build the margin and robustness of performance in the LISA configuration. The UV photoelectric discharge, the electrode configuration, and the vacuum techniques are among the issues to be studied, and the Trento group will contribute, both with analysis and with an experimental support to the LISA and GRS design tradeoffs. This activity will be particularly intense in the next several years, with participation in the ESA Phase A mission study and work towards adoption of the mission, along with definition of requirements for the Italian GRS contribution, in the early 2020s.

AMS-02

HTS magnets The science of AMS-02 is based on matter/antimatter separation, requiring powerful magnets for spectrometers sensitive to rigidities above 100 GV. Upgrading the current 1 TV limit of AMS-02 (0.13 T dipole field) to 10 TV or more will require fields of several Tesla, requiring superconducting magnets. As AMS-02 itself taught, cryogenics is a key aspect of a superconducting magnet, impacting the expected mission duration and power budget. As a reference, AMS-02 was designed to be operated with a traditional NbTi superconducting magnet giving 0.8 T at 4.2K.

High T_c superconducting (HTS) magnets, featuring peak fields in excess of 10 T at temperatures up to tens of K, are natural candidates for next-generation MRI instruments and table-top-size tokamaks. NASA and ESA have endorsed development of HTS magnets for radiation shielding in long manned missions. All proposals of AMS-02 successors are based on HTS magnets.

Design of prototype YBCO coils is underway, providing fields up to 40 T at temperature up to 70 K, in synergy between ASI and CERN, who are currently developing magnets for the High Luminosity LHC (Rossi et al. 2013). TIFPA has prepared various possible magnetic configurations and is entering the construction phase, focusing on the space qualification of materials and technologies. As an example, a special racetrack configuration is reported in Fig. 2.

The coils will be assembled in various configurations at CERN, and the magnet will be characterized from 4 to 80 K. Support hardware, including mechanical supports, cryocooling, power supply, current leads, will also be constructed, with direct involvement of our Department and ASI. The coils will be tested with 70-230 MeV protons at the Trento APSS center, testing several aspects: the active shield performance, secondary production due to proton-coil interaction, and trapping effects on low energy particles in high-field zones.

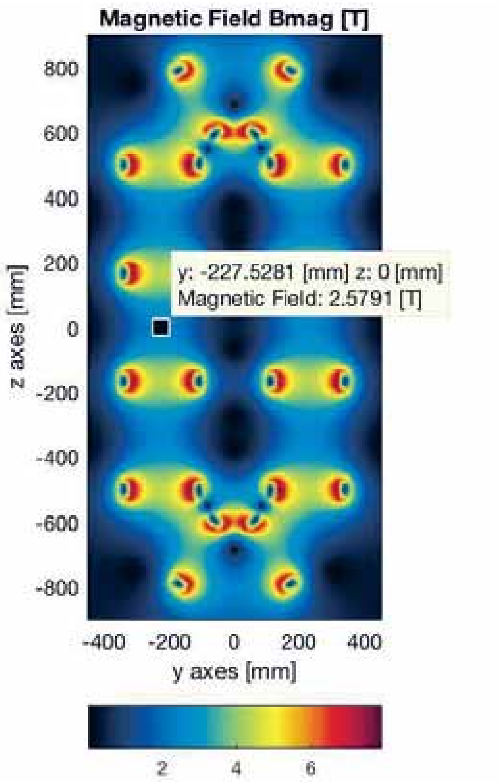


Figure 2: Design of a special 12-coils racetrack magnet developed by our TIFPA group. The color code represents the magnetic field intensity. The region between coils is thought to host silicon trackers, while the inner field-free zone contains other instrumentation.

Silicon detectors for particle tracking. Tracking capability is the other key-ingredient for high-performance magnetic spectrometry. In fact, the momentum resolution of the spectrometer is determined by the sagitta resolution, which in turn depends on the tracking accuracy of the detector. As a reference, AMS-02 uses 27.5 μm pitch silicon strips (readout 110 μm) to achieve single point resolution down to 10 μm for Z=1. To increase the maximum detectable rigidity by 10-30 times, at the same field, sagitta resolutions 10-30 times lower are needed. Standard micro-strip detectors cannot achieve single-point resolution of 1 μm, which appears to be an unsurpassable barrier because of intrinsic limits in strip bonding to front end electronics.

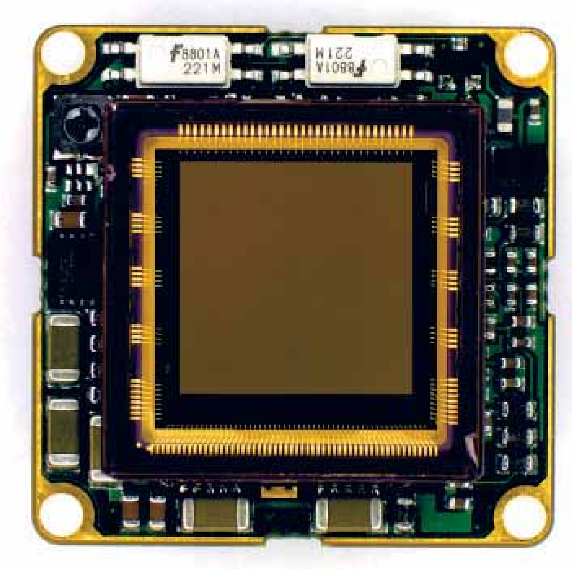


Figure 3: MQ042MG-CM-BRD Ximea sensor, in use at TIFPA as building block of a particle tracker. 5.5 μm pixel size, 10 bit ADC, 90 fps acquisition rate.

In the last decade Monolithic Active Pixel Sensors (MAPS) have been proposed as an efficient alternative to "traditional" silicon-based detectors for charged particles. As with image sensors, they are fabricated with CMOS technology, with most readout electronics embedded on chip, allowing simpler and cheaper assembly. Low noise (2 e), low power consumption (sub-nW) and intrinsic micron resolution have attracted the attention of the scientific community. Many research groups are now designing and fabricating sensor prototypes: a number of proposed solutions have been proven to effectively deal with most important drawbacks, namely readout complexity, charge collection low and long, and low radiation hardness. Nonetheless, as CMOS integration processes are expensive, prototypes are rarely produced with the most modern production lines. To fully exploit benefits of consumer electronics, the AMS team at TIFPA is trying to adopt an alternative approach: using commercial off-the-shelf image sensors to detect charged radiation. A small telescope of three intermediate level consumer cameras has been designed and is under construction. Fig. 3 reports a picture of the CMOS pixel array.

Tests aim at assessing the the effective adaptation of these devices for science purposes. Demonstrating them to be suitable for particle detection, with little or no change with respect to vast commercial productions, may increase the interest of big foundries in high-impact scientific projects, to be viewed as noble spin-offs rather than wasteful enterprises. To our knowledge, single particle detection (and identification at low energy) has been attempted and realized (Paolucci et al. 2011), but as yet tracking has not been demonstrated with these devices.

ROSSINI and ROSSINI 2

Projects overview Future human exploration into interplanetary space will place astronaut crews at increased risk of radiation exposure compared to current Low-Earth Orbit (LEO) destinations, such as the International Space Station (ISS), because of the journey length and the radiation environment. A mission to Mars is estimated to last at least 1.5 years, well beyond the current average mission duration. Furthermore, outside the protective Terrestrial magnetic field, astronauts will be exposed to the full spectrum of Galactic Cosmic Rays (GCR) and Solar Particle Events (SPE), and without proper shielding they would quickly exceed accepted radiation doses limits. A key factor in minimizing risk is thus a shield against GCRs and SPEs.

Since 2011 ESA has supported study of innovative shielding materials for space radioprotection in different missions scenarios. The projects ROSSINI (completed in 2013 with published results in SCI-TASI-PRO-0026 and (Durante 2014)) and ROSSINI 2 (ongoing) address the following issues:

- Trade-off of potential materials identified, including high hydrogen content materials. The selection takes into account only candidates which fulfilled pre-screening criteria for their use in space application, regarding safety, cost, weight, and strength, and includes also

layered shielding structures.
- Simulation of the radiation transport and secondary particle generation through the selected materials, using different Monte Carlo radiation transport codes, including Geant4/GRAS,[1] PHITS[2] and FLUKA.[3]
- Design and manufacturing of radiation shielding test samples.
- Testing of the selected materials with high energy ions.
- Simulation of a realistic habitat and/or vehicle for human exploration beyond ISS.
- Evaluation of radiation doses absorbed in human tissue, given the particle species and energy spectra observed behind the shields considered.

Selection of candidate shielding materials Candidate shielding materials are evaluated on physics considerations. The particle composition and energy distribution of primary radiation is modified upon interaction with spacecraft structures and the human body, by electromagnetic and nuclear processes that depend on the number of atoms per unit mass of the shielding material. The ratio of electronic stopping power to nuclear interaction transmission is proportional to Z $A^{-2/3}$ ρ^{-1}, where Z, A and ρ are the charge, atomic mass number and density of the material, respectively. For liquid hydrogen, this ratio is around 14, whereas for aluminium it is only 0.5, and for lead 0.2. This explains the large interest in hydrogen rich materials.

The ROSSINI campaign focused mostly on testing simulants of in-situ materials (Moon and Mars regoliths) and some types of lightweight hydrides. Rossini 2 will target multilayer barriers for inflatable space modules, epoxy resins, lightweight hydrides, shielding doped with nanomagnetic particles, moon regolith and moon concrete, with polyethylene (PE) and aluminum studied as references. Multilayer configurations have been tested for simulating the spacecraft hull or a permanent habitat, if combined with in-situ materials. All materials have been exposed to beams that simulate space radiation, including protons, ^{4}He, ^{12}C and ^{12}Fe ions at several energies up to 2.5 GeV/u with experiments performed various international facilities including the Proton Therapy Center in Trento. Dose reduction and, when possible, the full Bragg curve, have been measured. Based on those results, a subset of the most promising samples was selected to further characterize the radiation field produced by the interaction with the beams. This study included microdosimetric spectra and detection of the yield and kinetic energy spectra of secondary neutrons.

ROSSINI and ROSSINI 2 combine scientific outputs with technological advances. The experimental results are of interest for characterizing nuclear interactions in new systems and for benchmarking Monte Carlo transport codes. Furthermore, the development of new materials might find applications beyond space radioprotection.

New Reflections

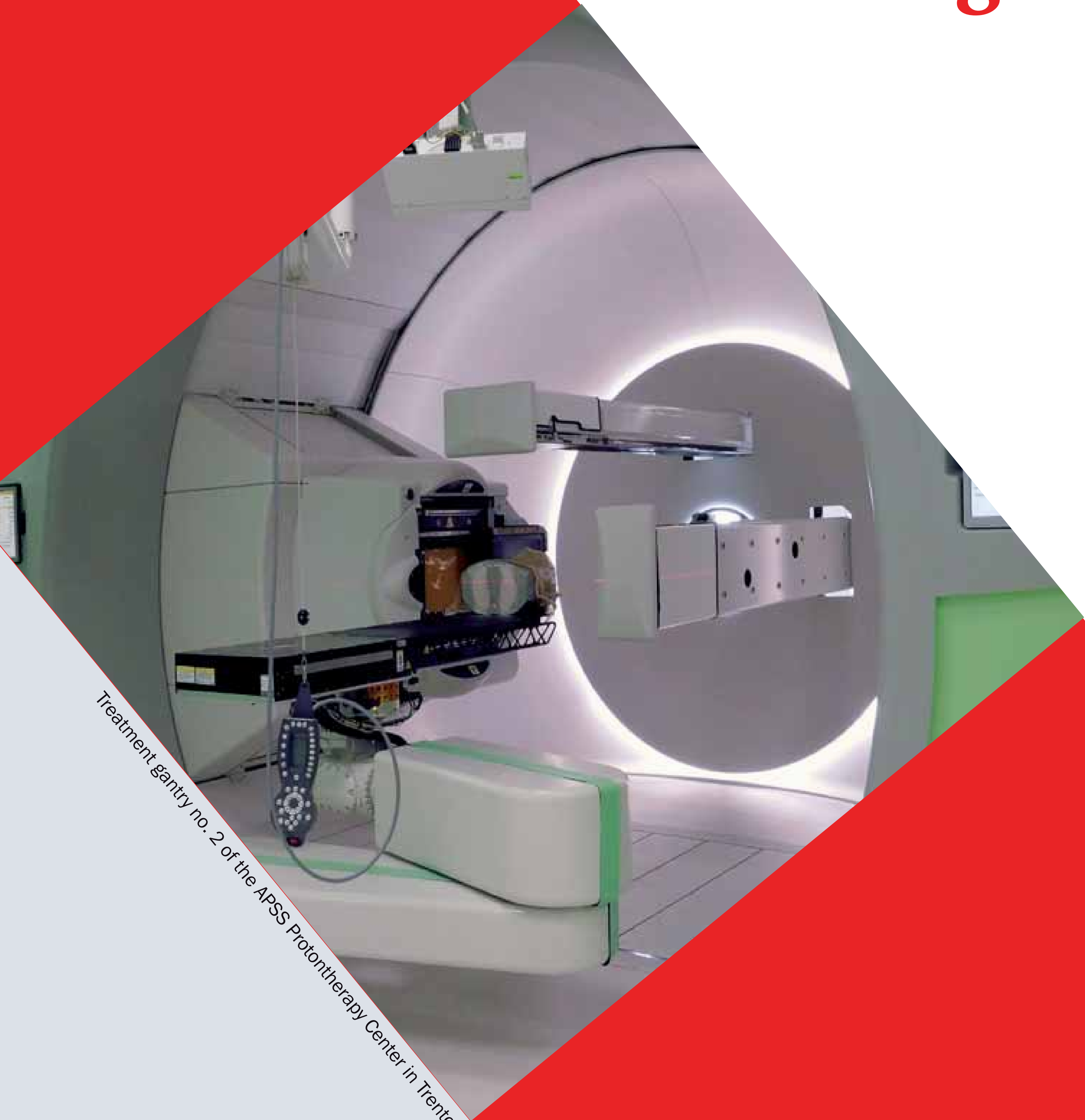
The New Reflection activity at the TIFPA in 2016 was centered on simulation and modeling to quantify the required laser characteristics for debris mitigation, e.g. ground and space systems, debris mass and size. On the technological side, a future participation in a test facility to measure the impulse delivered to different materials is under consideration.

The coupling coefficient C_m for the conversion of incident laser pulse power into force has been measured for aluminium, $\sim 2 \cdot 10^{-5}$ N/W, for the power density range between 0.5 and 0.8 GW/cm^2, at $\lambda = 1.06\mu$m (Wnuk et al. n.d.). The vaporization threshold P_o for aluminum is $\sim$ 0.2 GW/cm^2. The value, measured in vacuum, is relevant for debris mitigation where aluminum is omnipresent. The interest of a test facility is for laser propulsion, where the characteristics of the propellant, material composition and shape, are still in a preliminary phase of definition.

[1] http://space-env.esa.int/index.php/geant4-radiation-analysis-forspace.html
[2] http://phits.jaea.go.jp/
[3] http://www.fluka.org/fluka.php

Virtual Labs

Medical Technologies



Treatment gantry no. 2 of the APSS Protontherapy Center in Trento

Medical Technologies

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Since mid 2014, the protontherapy facility in Trento is technically ready to both treat patients and perform research activities. The facility is hosted in a standalone building and mainly consists in a cyclotron able to produce 226MeV protons, an energy selection system to decrease the beam energy in continuous decrements down to 70MeV, a beam transport line feeding two treatment rooms and one experimental area (see schematic layout in Fig. 1). In the two treatment room the proton beam can be pointed from different directions, thanks to the combination of a 360-degree isocentric gantry and a six degrees of freedom patient positioning system. The beam is delivered in a so called 'pencil beam scanning' mode, where the desired dose distribution is created by combining a large number of quasi monoenergetic gaussian 'pencils' of small dimensions (from 3 to 6mm σ in air at isocentre).

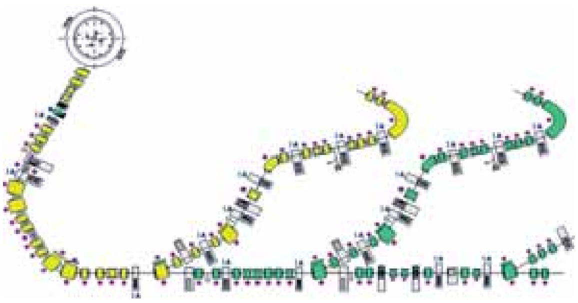

Figure 1: Schematic layout of the protontherapy center in Trento. Picture courtesy of IBA

Pencil beam scanning is the best technology available at the moment for beam delivery in protontherapy, as it allows to achieve the maximum degree of freedom in shaping a dose distribution.

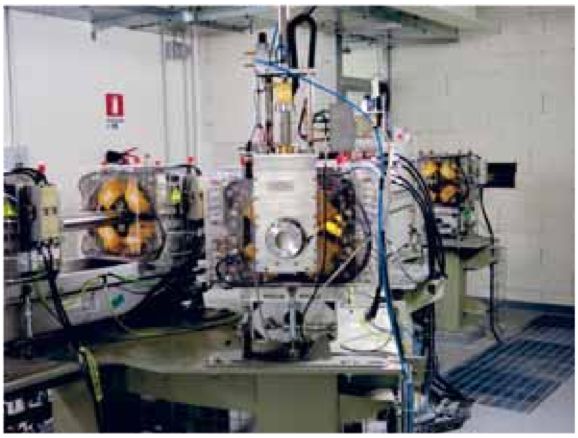

Figure 2: A detail of the 30° beam line exit window. The vacuum in the beam pipe is maintained by a 70 μm thickness titanium layer. A beam profile monitor is also present just before the exit window.

At the beginning of 2016, TIFPA completed the construction of the experimental room and support laboratory. The experimental area is dedicated to a large spectrum of research activities, including medical physics, detector testing, radiation hardness and radiobiology. In the experimental area the beam line is split into two exit lines (at 0° and 30°).

Experiments in physics of high-energy proton beams can take place at the 30° beam line (a detail of the beam line exit window is shown in Fig. 2), where a single pencil beam is avail-

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able. At the same time, work is ongoing, aimed at the design and realization of a passive scattering system, which will make possible to perform large field irradiation in the 0° line. This will strongly expand the range of target experiments, including in vitro and in vivo radiobiology.

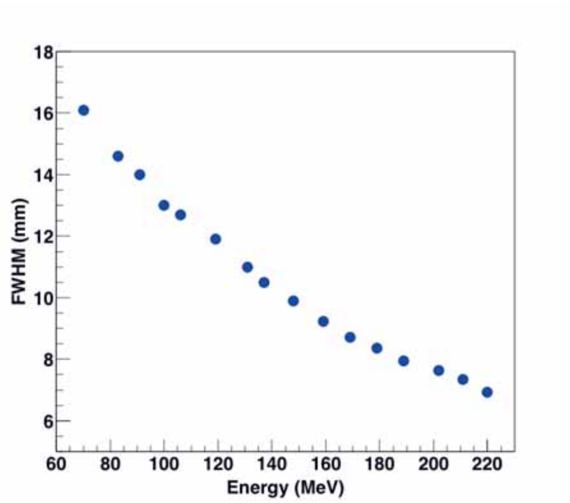


Figure 3: Beam spot in air at the isocenter (1.25 m from beam exit window) as a function of the proton beam energy.

Activity on the experimental beamline

The workgroup on the experimental beamline is composed of Francesco Tommasino, Marta Rovituso, Silvia Fabiano, Christian Manea, Stefano Piffer, Stefano Lorentini and William Burger.

An extensive experimental campaign has been carried out by TIFPA during 2016, in order to achieve the characterization of the physical properties of the spot beam available at the 30° beam line. The measurements investigated the beam properties in the energy range from 70 to 228 MeV. The experimental activities have been performed in collaboration with the Medical Physics division of the Proton Therapy Center, providing access to a series of commercial detectors. A short summary of the most significant beam parameters will be now presented. Starting point is the description of the beam spot profile as a function of the beam energy. Beam profile measurements have been performed with Lynx detector (IBA Dosimetry), consisting in a scintillation screen coupled with CCD cameras.

The results are shown in Fig. 3, where the variation of the beam FWHM (Gaussian profile) with energy is shown. The data shown refer to the beam profile as measured at Isocenter position (i.e. the beam focusing point, distance of about 1.25 m from the beam exit window; alignment lasers are available at Isocenter position for accurate target positioning). A FWHM ($\simeq$2.35 σ) of approximately 16 mm is obtained at the lowest energy of 70 MeV, which decreases down to about 7 mm at the highest energy of 228 MeV.

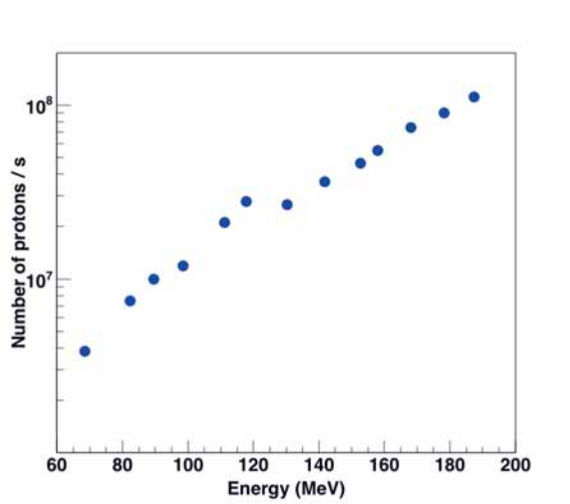


Figure 4: Proton flux in air at the isocenter as a function of the energy, corresponding to a beam extraction current of 1 nA before the energy selection system. Beam extraction current can be increased by a factor of 100 up to 300 nA.

A remarkable feature of the TIFPA irradiation facility is the possibility to provide a very large beam intensity range. In the standard operation mode, a beam current at cyclotron extraction in a range between 1 and 320 nA can be requested. These currents correspond to different fluxes as a function of beam energy, as a consequence of the transport efficiency being gradually reduced when lowering the energy. In order to give an indication, 1 nA corresponds to about 10^6 protons/s at 70 MeV, and to about 10^8 protons/s at 228 MeV, distributed over the spot area. In addition to the standard operation mode, the possibility was tested to significantly reduce the beam intensity. The solution adopted by IBA consists in adopting different settings for the source (i.e. high-voltage power supply and filament current). By means of scintillation detectors, it was possible to measure a reduction of the flux down to values on the order of 10^2 protons/s. This represents a valuable result, making feasible to perform a large spectrum of experiments for which a low beam rate is needed.

A more detailed description of the experiments carried out on this beam line are provided in the Proton Beam-based R&D Part of this Report (pp. 135-150).

In the future, access to the facility will be open to both scientific and industrial partners, after the proposal is accepted by an evaluation committe organized by TIFPA. The committee will evaluate both the scientific relevance and the technical feasibility of the proposed experimental activities. Dedicated TIFPA staff will assist and support external users during experimental activities. Additional upgrades of the experimental area are scheduled for 2017, including the installation of monitor chambers for on-line monitoring of proton flux and the installation of a passive scattering target station for radiobiology experiments.

Medical physics activities on the gantries

The medical physics group is composed of Marco Schwarz, Carlo Algranati, Paolo Farace, Francesco Fracchiolla, Stefano Lorentini, Roberto Righetto, Lamberto Widesott, Nicola Bizzocchi and Francesco Fellin.

Having completed most of acceptance testing and commissioning procedures (Schwarz et al. 2015)[†] and having started the first patient treatments in October 2014, the years 2015 and 2016 represented the 'start up' phase of the protontherapy center, from the point of view of increasing the number of treated patients, the number of indications and the development of new treatment techniques. As of November 2016, slightly more than 200 patients completed their treatment. About 170 adult patients were treated, the most common disease sites being brain (79 pts) and the head and neck region (46 pts). Starting from June 2015, also pediatric patients were admitted at our Institution, when necessary under anesthesia, and so far about 30 completed their treatment. In addition to carry out the routine activity needed to support clinical practice (mainly treatment planning, treatment verification and quality assurance of the protontherapy equipment), the medical physics group was active in the following activities:

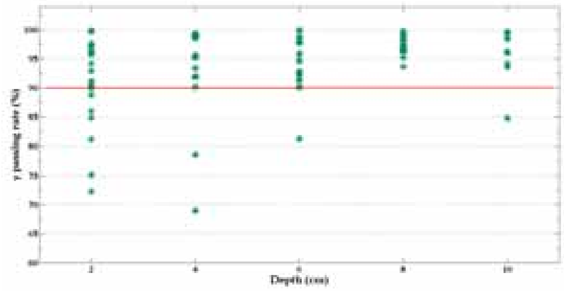


Figure 5: Gamma analysis passing rate of patient specific QA for our clinical dose calculation algorithm as a function of depth. At shallow depths the results are worse due to the presence of a preabsorber.

Independent dose calculation. Dose calculation in pencil beam scanning is not an entirely solved problem. An indirect indication of it is that whenever a preabsorber is needed (e.g. to irradiate shallow targets), the agreement between measurement and calculation is often suboptimal (see Fig. 5).

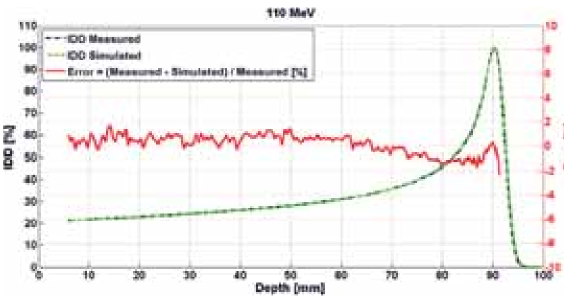


Figure 6: Comparison between measured and simulated integral depth dose after 'tuning' the energy spectrum for 110 MeV (see (Fracchiolla et al. 2015)).

As a consequence, 'patient specific QA' is still needed even after two years of clinical operations, but at the same time the procedure should be made effective enough to be able to treat a sufficiently large number of patients.

[†]References cited within Virtual Labs contributions are listed at the end of the Virtual Labs part, p. 55.

Such need was one of the reasons that triggered the development of a in-house Monte Carlo code. Such code, based on Geant4–TOPAS, has been configured and tested to describe the properties of our beam and extensively validated in both homogeneous and heterogeneous media.

The code is soon going to be introduced in clinical practice to facilitate patient QA, as it performs well against measurements (see Fig. 7).

Planning technique for craniospinal irradiation(CSI). CSI is a technique needed to irradiated several pediatric indications and it involves a number of technical complexities (e.g. the large volume to be irradiated, the need of 'patching fields', etc.) that needs to be addressed during planning. We therefore developed our own technique, that does allow to treat the patient in supine position and that allows to achieve satisfactory dose distributions via three specific features. First, thanks to an 'ancillary beam technique' we could obtain very homogenenous and robust dose distributions along the cranio caudal direction. The main idea behind the ancillay beam is to provide a starting dose distribution for the optimization of the thoracic posterior beam that will allow to obtain the desired shallow cranial and caudal gradients (see Fig. 8).

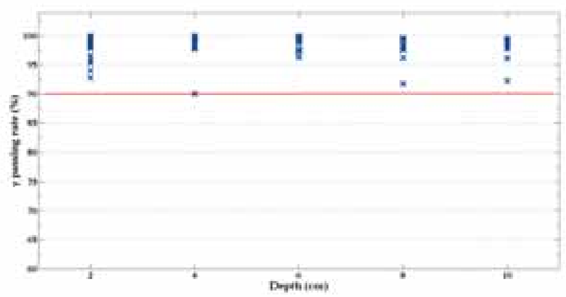


Figure 7: Gamma analysis passing rate of patient specific QA for our Monte Carlo code. Same fields as in Fig. 5.

Alternative methods have been proposed in the literature to achieve such goal. The advantage of our approach is that it does not require extensive and tedious contouring on the CT dataset to outline 'help structures'.

Second, irradiating the most cranial part of the target with three beams with the most appropriate couch orientations, we could achieve at the same time satisfactory target coverage, in particular of the cribiform plate, and at the same time lens sparing (Bizzocchi et al. 2015). Third, using the preabsorber only for the energy layers where it is strictly needed and moving it for every field as close as possible to the treatment couch, we could achieve a better sparing of the kidneys.

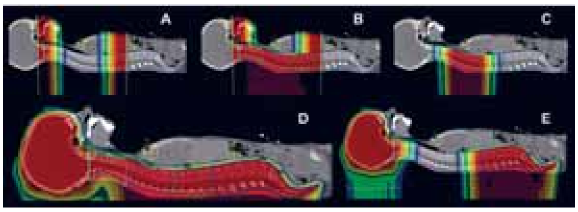


Figure 8: Planning technique to achieve homogeneous and robust dose distribution in CSI (Farace et al. 2015).

Plan robustness evaluation in the clinic. The issue of plan robustness, i.e. of how to ensure that the planned dose distribution is as close as possible to the delivered one even in presence of the inherent uncertainties of the treatment process, is of crucial importance in protontherapy. In fact, proton dose distributions may vary, sometimes significantly, as a function of errors in the conversion from computed tomography (CT) data to proton stopping power, of patient positioning errors, and of changes in patient anatomy. The finite range of protons, which is the main advantage with respect to photons, is a blessing and a curse, as small geometrical errors (e.g. in the order of 3-5 mm) can in some cases translate in large dose errors. The solution for such problems probably lies in the use of the so called 'robust optimization', a way to design dose distributions where the uncertainties are explicitly part of the optimization problem that produces the final dose distribution. However, since this is a relatively new method, at least for the clinical practice, it is far from obvious to decide what are acceptable levels of robustness or, in other terms, what is a reasonable price to pay in dose distribution quality in order to achieve robustness.

As a consequence, we developed and we are going soon to test in clinical practice a tool that explicitly simulates a number of perturbations to the dose distributions, in order to show the clinicians a 'dose with an error bar' instead of the usual dose distribution (see Fig. 9).

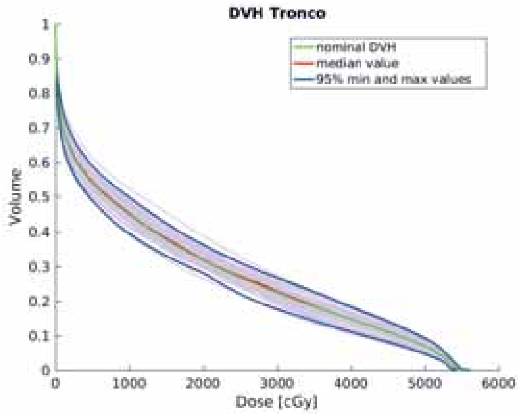


Figure 9: Example of a 'dose volume histogram band', to show the possible variation in dose associated to range and setup errors. The blue band encompasses the probability range from 5% to 95%.

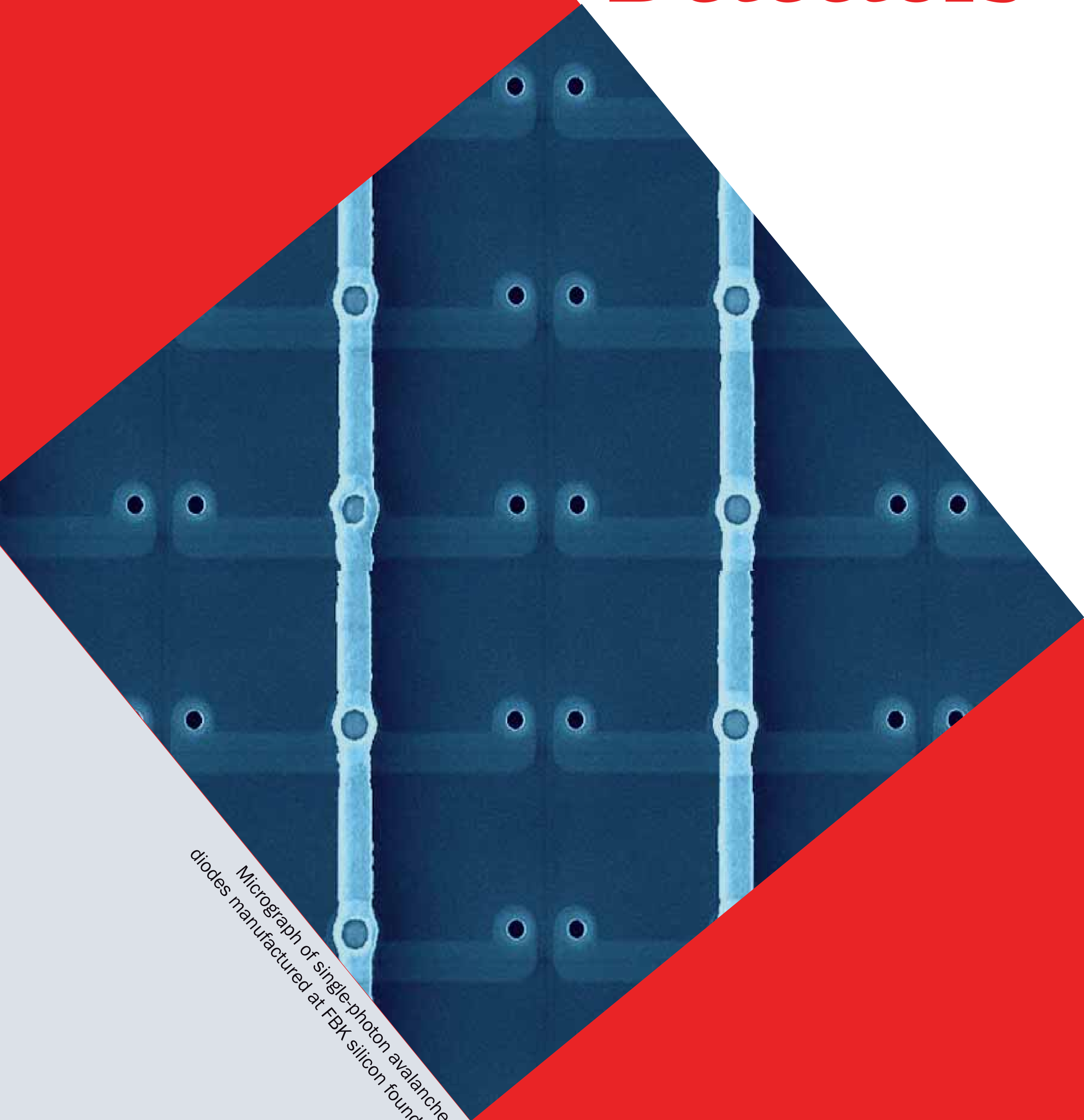
In-room volumetric imaging and treatment adaptation. Protontherapy is in the midst of a significant change in terms of clinical indications. While this technique did develop mostly to treat intracranial lesions firmly attached to the bony anatomy, such as chordomas and chondrosarcomas of the skull base, the developments of photon-based radiotherapy techniques over the past years are such that protontherapy is likely to be superior to conventional techniques in disease sites such as the lung or the liver. This means that patient positioning should be based on volumetric soft tissue imaging, as opposed to bony anatomy imaging, and that frequent patient rescans are needed in order to see whether the patient anatomy changed to an extent to require a new treatment plan. In analogy to the technological evolution of photon radiotherapy, also in protontherapy there is now interest for the so called cone beam CT imaging (CBCT), that allows to image the patient in treatment position at the expense of a reduced image quality. A peculiarity of the protontherapy facility in Trento is the availability of a in-room diagnostic quality CT (see Fig. 10).

This CT is now routinely used for the period rescanning of patients were treatment adaptation may be needed. Given the image quality, both the clinician and the physicist can work directly on the dataset acquired just prior (or after) treatment. This is different from the CBCT, that does require some kind of image processing in order to be usable in protontherapy. The availability of a diagnostic quality CT opens up a number of opportunities, that go from the dose evaluation just prior to treatment to the 'online' treatment adaptation, that in principle will allow to quickly generate a new plan that is tailored to the patient anatomy of the day.

Figure 10: The 'on-rail' CT available in one of the treatment rooms in Trento.

Virtual Labs

Sensors and Detectors



Micrograph of single-photon avalanche diodes manufactured at FBK silicon foundry

Sensors and Detectors

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The TIFPA Center, with its Virtual Lab on Sensors and Detectors, has unique competencies and infrastructures for the development and production of radiation detectors based on Silicon.

Semiconductor radiation detectors are used in a large variety of fields in science and technology, including nuclear physics, elementary particle physics, optical and x-ray astronomy, medicine, and material analysis. Among the semiconductors, silicon is by far the most used mainly because of the material availability and the highly advanced process techniques. These two features allow the production of high-quality, reliable and low-cost sensors.

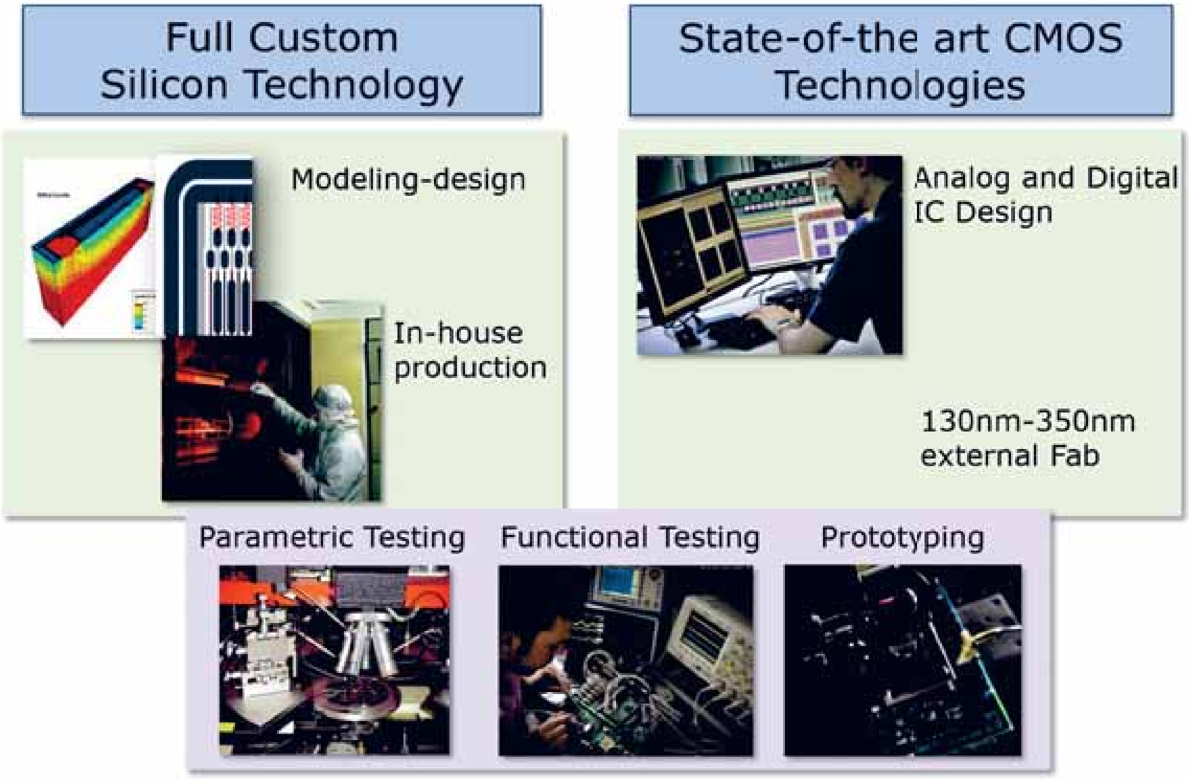


Figure 1: Scheme of the main competencies

[1]FBK, Trento, Italy
[2]INFN TIFPA, Trento, Italy

The main contributions to the Virtual Lab Sensors and Detectors are given by the Center for Materials and Microsystems (CMM) of FBK, the Department of Industrial Engineering of the University of Trento and TIFPA. These groups provide to the Virtual Lab more than 20 years experience in the development of radiation sensors exploiting the microelectronics technology.

Thanks to the presence of an internal silicon foundry combined to the use of external state-of-the-art CMOS foundries, the Lab has the capability to simulate, design, produce and test semiconductor sensors. Furthermore, the Virtual Lab is embedded into the applications providing a unique environment in Italy and one of the very few worldwide.

Competencies

The main competencies of the Virtual Lab are represented in the scheme of Fig. 1. They are related to the development of semiconductor sensors based on micro-electronics technology. In case of full-custom technology, we start from physics-based TCAD simulation of the device. It is possible to evaluate numerically both the electrical parameters inside the device and the measurable quantities at the electrodes. The device can also be stimulated with light or ionizing particles to model the induced electrical signal. Furthermore, to emulate as close as possible a real device, we simulate also the fabrication technology. The tools used are commercial ones (SILVACO or SENTAURUS). These softwares can be used both to predict the functioning of a device as well as to understand anomalous behavior or failures of existing ones.

The output of the simulations are used to design the geometry of all the sensor components (layers) with the proper CAD software and to define the technology process flow. Geometry and process sequence are used to build the device(s) on the silicon wafers in the internal foundry. A description of the manufacturing infrastructure is given later. It involves several processes which are realized with equipment used for micro-electronic fabrication. The requirements given by the sensors are peculiar, for example in terms of low-level contaminants, so we built a specific know-how on the wafer treatment during the years.

In case of the standard CMOS approach, usually there is limited access to fabrication technology. So our competencies are mainly on circuit simulations and Integrated Circuit (IC) design. We have dedicated software tools to this purpose: CADENCE and MENTOR GRAPHICS. We design both analog and digital architectures. Quite important in this case is the capability of firmware design based on FPGA to control and read the ASIC.

Finally, there is a transversal know-how on device characterization. This includes a variety of competencies:

- parametric testing which is usually done at the wafer level contacting it with probes. It is mostly used to evaluate the functionality of the device measuring current and impedance.
- electro-optical testing. It includes measurement of sensor efficiency/noise in controlled environment and of time-of-flight with fast lasers.
- test with radioactive sources. It includes coupling the photosensor with scintillators to measure energy and timing resolution in case of X-ray/Gamma radiation.

All the acquisition systems are automated to have a fast and reproducible feed-back. This is done with an extensive use of LabView programs developed on purpose.

Figure 2: Lithography area

Infrastructures

The main facilities are: the silicon foundry, the material characterization lab, the packaging lab and testing labs.

The silicon foundry is composed by two clean rooms (CRs):

- CR Detectors, 500 m^2, ISO 3-4 class
- CR MEMS, 100 m^2, ISO 4-5 class.

Figure 3: Wet etching area

Pictures of the lithography and wet etching areas are shown in Fig. 2 and Fig. 3. The CR detectors allows full processing of 150mm wafers with a minimum line width of 500 nm. Main equipments are: 8 furnaces, stepper and mask aligner for lithography, dry and wet etching, deep-reactive ion etching, ion implanter, sputtering and in-line SEM. Strategic in the sensor field is the capability to perform double side processing.

An important lab which allows monitoring the quality of the processes is the Material characterization Lab. Main equipments are: scanning electron microscope with EDX, secondary ion mass spectroscopy for dopant profiling, X-ray photoelectron spectroscopy and atomic force microscopy.

The packaging lab has been recently upgraded to a clean environment. It is dedicated to the development of prototype packages for mounting the silicon devices. It is equipped with ball and wedge wire bonders, die bonder, stencil screen printer and tools necessary for encapsulation in resins and hermetic packaging. These laboratories are certified ISO 9001-2008.

Figure 4: Material characterization Lab.

The testing labs are divided in: wafer-level parametric testing and functional characterization. The first consists of 2 manual and 4 automatic probe-stations. The automatic ones allow a full wafer characterization to identify functional devices and to monitor the uniformity of electrical parameters. Two of those feature also a temperature-controlled chuck that allows to set the wafer temperature from -40 to 100 °C.

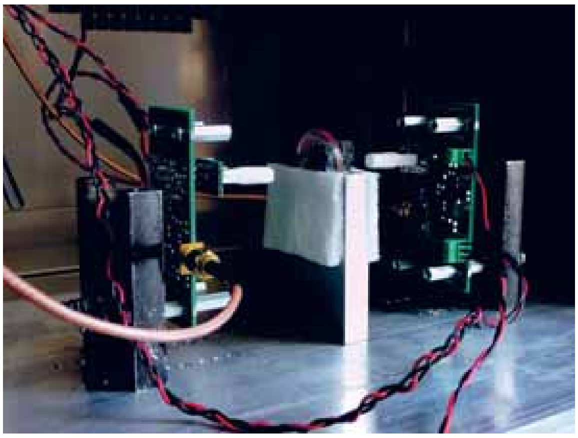


Figure 5: Set up for coincidence timing measurements of 511 keV gamma rays emitted by a ^{22}Na *source.*

The functional testing laboratories are equipped with state-of-the-art instrumentation for a variety of characterizations. Main instruments are:

- multi-channel semiconductor analyzers;
- high-speed, four-channel digitizing oscilloscopes (600 MHz - 2.5 GHz; up to 40 GS/s);
- 3 PC-controlled thermostatic chambers;

- cooled CCD cameras for emission microscopy;
- fast lasers for time-of-flight measurements;
- integrating sphere and optical bench;
- pyroelectric detector;
- THz kit with drive synthesizer;
- radioactive sources of different energies;
- digital pattern generator;
- logic and network analyzer;
- NI acquisition boards.

Main technologies

The main technology platforms available from the Virtual Lab are:

- Single-photon light sensors;
- High-energy radiation detectors.

The first platform is the most important due to the variety of applications requiring the detection of faint light. It is based on the Geiger-mode operation of photodiodes biased above the breakdown voltage. These devices are commonly known as SPADs (single-photon avalanche diodes). A densely packed array of SPADs is referred to as Silicon Photomultiplier (SiPM). This solid-state technology is able to compete for the first time with the classical photomultiplier tube.

We follow two approaches for this sensor development, (see Fig. 6): custom and standard CMOS technology. In the first case, the detector is fully developed in house with optimized microelectronic processes (see (Piemonte et al. 2016)).†

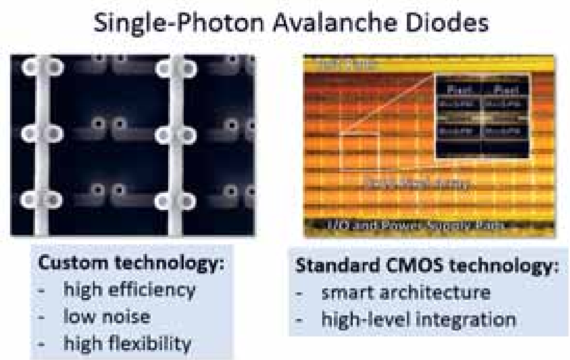


Figure 6: SPAD technologies.

This allows to optimize the device performance such as efficiency and noise and to customize it to a specific application. In such solution, the detector provides an analog signal that has to be processed by an external electronics. In the second case, the standard CMOS technology allows for the sensor and electronics to be integrated (Perenzoni et al. 2016). This means that maximum compactness and integrated intelligence can be achieved. Clearly, the SPADs realized with this approach have suboptimal performance since the technology is not accessible. Depending on the application, one or the other may be preferred. As an example, in the field of gamma-ray detection with scintillators (both in high-energy physics and medical equipment) the custom solution is preferred because of the better performance and the relatively relaxed requirements on the compactness. The main activities on custom devices, within INFN, are for the projects: CTA (Committee for Astroparticle Physics, CSN2), DarkSide (CSN2), Spider (Committee for Technological Research, CSN5), GammaRad (*progetto fondazione Caritro*), which is extensively reported at p. 53. For the CMOS approach the main projects in which we are involved are: APiX2 (CSN5) and MONDO (CSN5).

The second technology platform is on high-energy radiation detectors exploiting direct ionization of the particle in silicon. These sensors are produced in the internal foundry on high-purity high-resistivity silicon material. According to the electrode geometry they are classified in pixel (SPD), strip (SSD) or drift detectors (SDD). The first two are more stable technologies with high TRL. They are mostly used for particle tracking. The SDD has several R&D activities ongoing and its main use is for X-ray spectroscopy or scintillation light detection. The main (ongoing or recently closed) activities within INFN are for the projects: RedSox (CSN5), Ardesia (CSN5), Siddartha upgrade (Committee for Nuclear Physics, CSN3) and CSES-LIMADOU (*progetto premiale*).

Other particular detectors of this technology platform are the 3D/active-edge and LGAD detectors. The 3D are characterized by elec-

†References cited within Virtual Labs contributions are listed at the end of the Virtual Labs part, p. 55.

trodes (columns) that penetrate inside the silicon bulk. In this configuration, the distance between the p and n electrodes can be made small (order of 50 μm) while having a wafer thickness sufficient to get the desired S/N ratio. Such feature is useful to maintain a high carrier collection efficiency in heavily irradiated detectors. With a similar 3D approach, it is also possible to minimize the dead border region around the silicon detector to have a better tiling in the experiment (Active Edge). The relevant projects in this context are: RD-FASE2 (Committee for Particle Physics, CSN1) and PixFEL (CSN5).

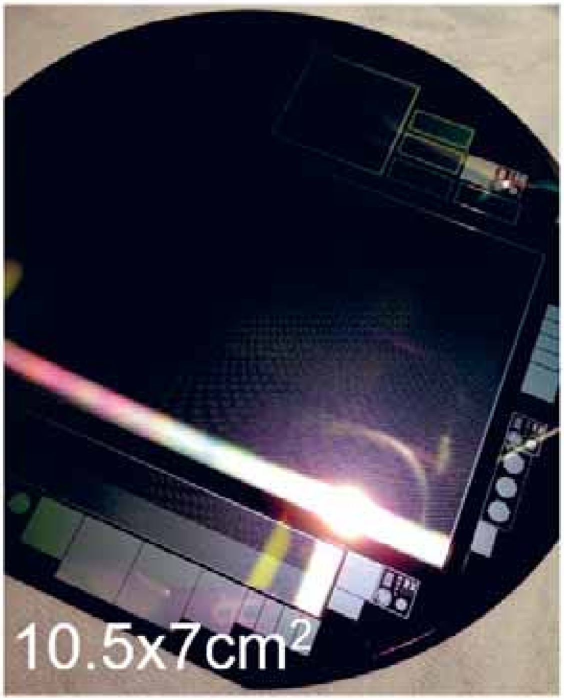


Figure 7: Picture of a wafer with a large-area double-sided silicon strip detector.

The LGAD sensor is a pixel detector with internal multiplication by impact ionization. The goal is to have a very fast detector of ionizing charged particles by reducing the depleted thickness to few tens of microns and to compensate the lower carrier creation with a small internal amplification. First prototypes have been successfully produced. The reference project is UFSD (CSN5). Finally, there is a new activity started on a different semiconductor material: Silicon Carbide. The goal is to produce a radiation detector with much larger radiation hardness (5 times higher than silicon). The reference project is Sicilia (CSN5).

GammaRad

The GammaRad project is developed by Fondazione Bruno Kessler (FBK) (coordinator), INFN, Politecnico di Milano (PoliMI) and APSS. People involved at TIFPA are Alberto Gola, Claudio Piemonte,Veronica Regazzoni (FBK), Christian Manea and Enrico Verroi (INFN). The aim of the four units is the development of a novel, position sensitive molecular/medical gamma ray detection module (GDM hereafter) based on silicon photomultiplier detectors, produced by FBK, with the main purpose of being used as a prompt gamma imager (PGI) for proton therapy applications. Beyond the primary application as PGI, the GDM is also conceived to be versatile enough for the use in other nuclear medicine applications as Positron Emission Tomography (PET) or Single Photon Emission Computed Tomography (SPECT) or, eventually, for wider fields applications such as environmental monitoring. Moving back to the PGI use, its operating principle is briefly summarized ad follow: after interactions with a proton of the beam, the excited nuclei in the target return to their ground state and emit gamma rays on a time scale of nanoseconds (prompt gammas). This almost instantaneous emission can be observed and used for real time imaging of the interaction region, with the goals of achieving a better accuracy in Bragg peak position, leading to safer treatments and more efficient medical cares.

GDM architecture The SiPMs choice for the GammaRad photodetector array was driven by the requirements related to the three main uses of the GDM (PGI, PET and SPECT). After the evaluation of several SiPM technologies produced at FBK, with microcell sizes ranging from 7.5 μm up to 25 μm, the RGB-HD technology with 15 μm cell size was selected as the best option for the PGI application. These SiPMs offer the best compromise between energy resolution and non-linearity in high-energy gamma-ray spectroscopy, between 2 MeV and 15 MeV, which is the energy range of interest in PGI. The first prototype was an 8×8 array of SiPMs, each one with an active area of 4×4 mm^2 and cell size of 15 μm and a high packaging fill factor of 86%. In order to convert the gamma rays incoming from the target into visible photons detectable by the SiPM, a scintillator is placed on top of the array. Rather than a monolithic scintillator, a pixelated one was chosen, in which each pixel is 1:1 coupled to one photodetector array channel. With this choice, the detectors can work in parallel at a higher event rate, particularly in PGI mode, can be handled.

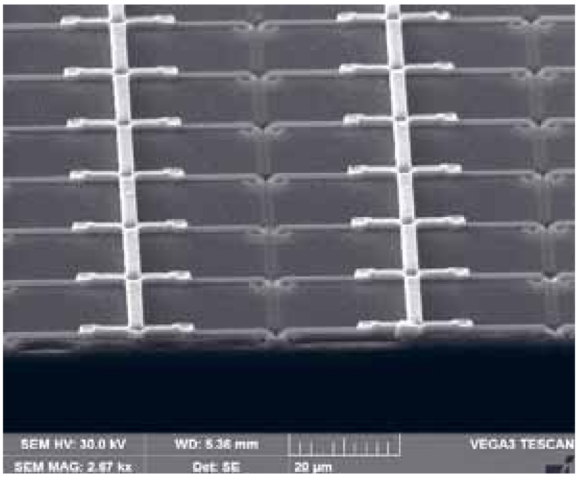


Figure 8: 15μm cells on a SiPM.

The SiPM tile is then connected to one or more (depending on the tile dimension) application specific integrated circuit boards (ASIC) called ANGUS. The ASIC is an integrated circuit specifically designed to readout the SiPM detector in a particular application. The SiPMs provides signals to the chip, then the outcoming data from the ASIC board are managed by an FPGA board for the A/D conversion for the DAQ and storage system. A schematic depiction of the Gamma Detection Module is shown in the figure below.

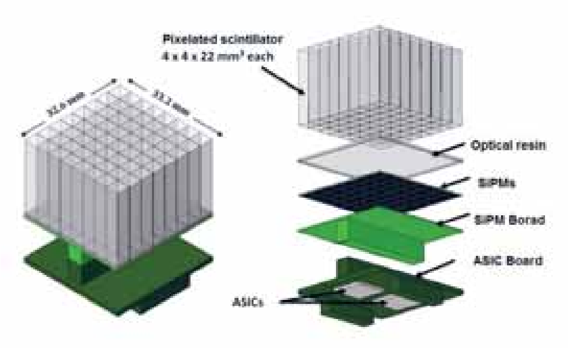


Figure 9: A 8 × 8 pixels GDM schematic representation. Two 32-channels ASICs are in use in order to manage the 64 signals incoming from the SiPMs.

As part of training and education activities, the part of the project developed at the TIFPA involved three 3-years-degree students in electronic engineering for their thesis work, Gloria Travaglia, Maurizio Franceschi and Fabio Bertini; they have been suitably introduced to topics not directly related to their field of study, such as nuclear physics and cellular biology, through some lectures given at the TIFPA. Their works concerned the readout chip ANGUS programming, the realization of communication and control system and simulation of analog front-end. A dedicated LabVIEW interface has been developed to simplify debugging.

Virtual Labs References

Space Research

Armano, M. et al. (2016a). “Constraints on LISA Pathfinder’s self-gravity: design requirements, estimates and testing procedures”. In: *Classical and Quantum Gravity* 33, p. 235015.

— the eLISA Collaboration (2016b). “Sub-Femto-*g* Free Fall for Space-Based Gravitational Wave Observatories: LISA Pathfinder Results”. In: *Phys. Rev. Lett.* 116 (23).

Durante, M. (2014). “Space radiation protection: Destination Mars”. In: *Life Sci. Space Res.* 1, pp. 2–9.

Paolucci, M. et al. (2011). “A real time active pixel dosimeter for interventional radiology”. In: *Radiation Measurements* 46.11. International Workshop on Optimization of Radiation Protection of Medical Staff, {ORAMED} 2011, pp. 1271–1276.

Rossi, L. and Bottura, L. (2013). “Superconducting Magnets for Particle Accelerators”. In: *Rev. Accel. Sci. Technol* 5.CERN-ATS-2013-019, 51–89. 40 p.

Wnuk, E., Golebiewska, J., Jacquelard, C., and Haag, H. “Changes of Space Debris Orbits after LDR Operation”. In: *CLEANSPACE project of EC Seventh Framework Programme (FP7-SPACE: project id 263044)*. URL: `http://www.amostech.com/TechnicalPapers/2013/Orbital_Debris/WNUK.pdf`.

Medical Technologies

Bizzocchi, N. et al. (2015). “A planning approach for lens sparing proton craniospinal irradiation in pediatric patients”. In: *Radiotherapy and Oncology* 119. Supplement 1, S789.

Farace, P. et al. (2015). “Planning field-junction in proton cranio-spinal irradiation - the ancillary-beam technique”. In: *Acta Oncologica* 54, pp. 1075–1078.

Fracchiolla, F., Lorentini, S., Widesott, L., and Schwarz, M. (2015). “Characterization and validation of a Monte Carlo code for independent dose calculation in proton therapy treatments with pencil beam scanning”. In: *Physics in Medicine and Biology* 60.21, pp. 8601–8619.

Schwarz, M. et al. (2015). “Clinical Pencil Beam Scanning: Present and Future Practices”. In: *Particle Radiotherapy - Emerging Technology for Treatment of Cancer*. Ed. by A. K. Rath and N. Sahoo. New Delhi: Springer India. Chap. 7, pp. 95–110.

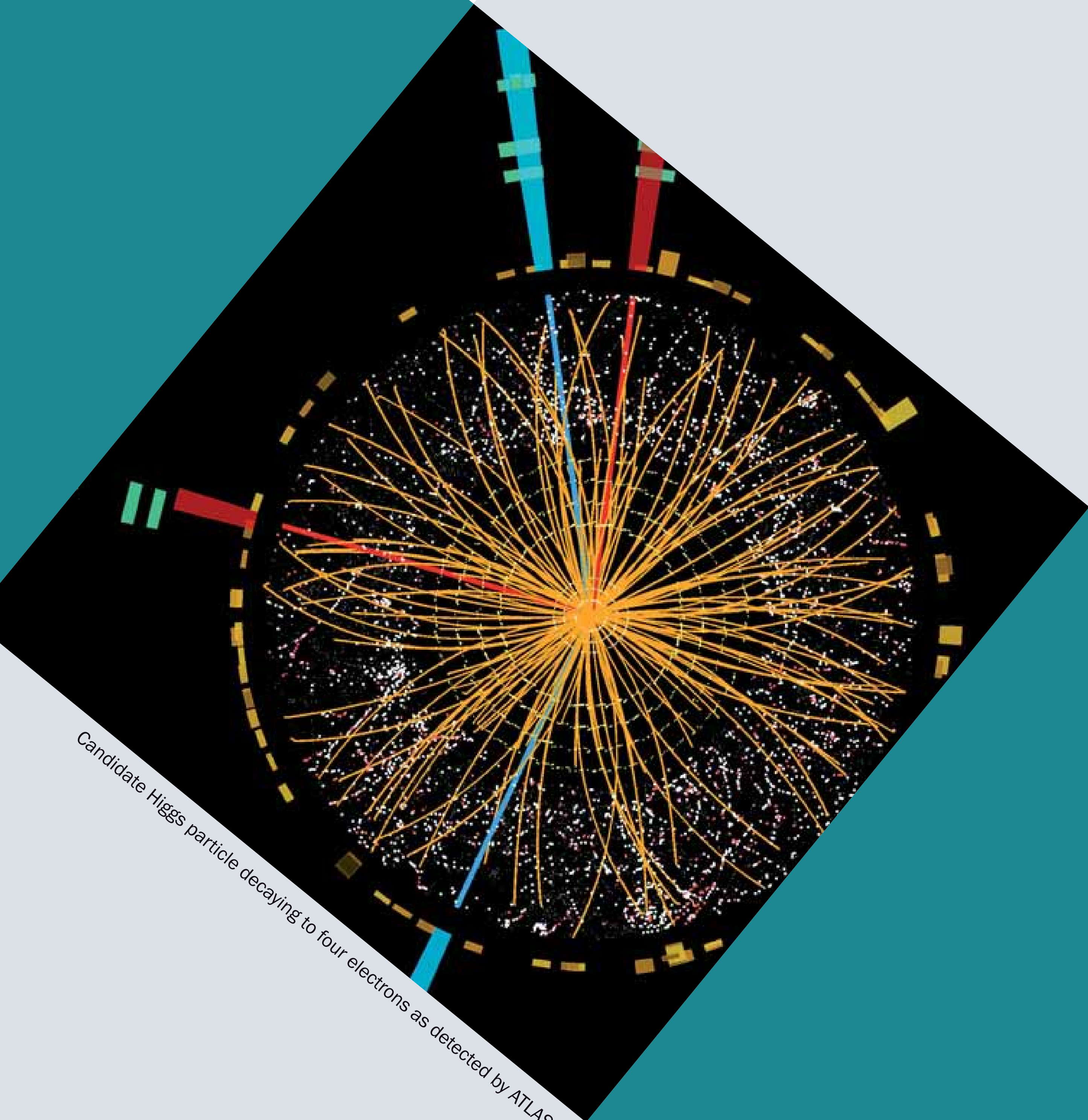
Sensors and detectors

Perenzoni, M., Massari, N., Perenzoni, D., Gasparini, L., and Stoppa, D. (2016). “A 160 × 120 Pixel Analog-Counting Single-Photon Imager With Time-Gating and Self-Referenced Column-Parallel A/D Conversion for Fluorescence Lifetime Imaging”. In: *IEEE Journal of Solid-State Circuits* 51, pp. 155–167.

Piemonte, C., Acerbi, F., Ferri, A., Gola, A., Paternoster, G., Regazzoni, V., Zappalà, G., and Zorzi, N. (2016). “Performance of NUV-HD silicon photomultiplier technology.” In: *IEEE Transaction on Electron Devices* 63, pp. 1111–1116.

INFN

INFN Experiments



Candidate Higgs particle decaying to four electrons as detected by ATLAS

Particle Physics

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Coordinator,
TIFPA Particle Physics Activities

The research activities of the INFN National Scientific Committee 1 (CSN1) deal with fundamental interactions of matter in experiments using particle accelerators, of which the Large Hadron Collider (LHC) is currently the largest and most powerful in the world. The LHC was built at CERN between 1998 and 2008 and its primary objectives are the discovery of the Higgs boson and other particles predicted by supersymmetric theories. The accelerator is a two-ring superconducting proton-proton collider placed inside a 27 km long, 3.8 meters wide underground tunnel, formerly used by the Large Electron-Positron collider (LEP). The machine is built at a depth between 50 and 175 meters beneath the Franco-Swiss border near Geneva, Switzerland. The LHC is designed for proton-proton collisions delivering an unprecedented luminosity of 10^{34} cm^{-2}s^{-1} and a maximum energy of 14 TeV in the center of mass. The particle beams are not continuous but in bunches with a repetition rate never shorter than 25 ns.

ATLAS (A Toroidal LHC ApparatuS) and CMS (Compact Muon Solenoid) are the two general-purpose particle detectors built at the LHC. These experiments take advantage of the unprecedented high energy and luminosity of the LHC to search for new particles and new physics theories. ATLAS has many objectives, spacing between the discovery of new particles, the confirmation of current theories and the discovery of new physics models. The most famous of these objectives is, of course, the discovery of the Higgs Boson, which was announced, jointly with CMS, in July 2012. In order to increase the probability of generating very rare events like the Higgs Boson, the luminosity must be very high, hence, the High Luminosity LHC (HL-LHC) is planned for 2022 and is referred to as Phase-2 upgrade. Many hardware upgrades will be required in order to reach the target luminosity 5×10^{34} cm^{-2}s^{-1} while maintaining the same energy in the center of mass. In particular, for the ATLAS experiment, the Inner Detector will be completely replaced with a new and more modern one.

The Trento group has collaborated with ATLAS since 2007, first within the CERN ATLAS 3D Collaboration and later, since 2011, also within INFN ATLAS Italy. The involvement has regarded the development of 3D pixel sensors for the ATLAS Insertable B-Layer (IBL), the fourth layer of pixel sensors which was installed within the inner tracker. Following this successful contribution, the Trento group was invited by ATLAS Italy to officially join the project, and since June 2015 the University of Trento / TIFPA Group has been an ATLAS institute.

The main commitment of the Trento group has so far been on the engineering side: in particular, within the INFN "RD_FASE2" project, TIFPA has leaded the italian effort, in collaboration with FBK, towards a new generation of 3D pixel sensors for the Inner Tracker (ITk) of the ATLAS detector "Phase 2" upgrade. More recently, since 2016, the group started to be involved also with the physics program. The most significant outcomes of the research activities in 2015 and 2016 are summarized in the ATLAS and RD_FASE2 reports.

ATLAS

Gian-Franco Dalla Betta, Roberto Iuppa,[†] D. M. S. Sultan

$X \to ZV \to \nu\nu qq$ **search** Although the Higgs boson h, with mass 125 GeV, discovered in 2012 (Aaboud et al. 2012), exhibits properties consistent with predictions from the Standard Model, data did not rule out yet most models predicting extended Higgs or extended gauge sectors.

This contribution reports on a search conducted on data recorded in 2015 and 2016 by ATLAS (13.2/fb), looking for exotic particles X decaying to VZ pairs, namely ZZ or WZ, where the V boson decays hadronically and the Z decays to a neutrino pair: $X \to V(qq)Z(\nu\bar{\nu})$ (Aaboud et al. 2016v).

The trigger was based on the Missing Transvere Energy (MET), which experimentally signals the presence of the neutrino pair: $E^{T}_{miss} >$ 250 GeV. Events containing leptons were also vetoed.

Pre-selection cuts were applied to reduce the multijet background to negligible level.

Because of the high mass value of the searched X boson, the $V \to qq$ decay is boosted in the laboratory frame. Trying to reconstruct q-jets as resolved from each other turns out to be suboptimal, as they partially overlap in such a merged regime. The V decay is better reconstructed as a single large-R Jet[1].

The V-Jet mass is required to have a mass consistent with the W or Z boson mass. Events are then splitted in two catergories: high purity ones, i.e. those for which the Jet analysis confirms it coming from a two-prong structure and low purity, the rest. The low purity sample allows to partially recover the efficiency loss in such a boosted regime.

The invariant mass of the VZ system cannot be fully reconstructed, because of the lack of information on the longitudinal momentum of neutrinos in the final state. Another discriminant is used, the "transverse mass", defined as:

$$m_T = \sqrt{(E_{T,J} + E_T^{miss})^2 - (\vec{p}_{T,J} + \vec{E}_T^{miss})^2},$$

where $E_{T,J} = \sqrt{m_J^2 + p_{T,J}^2}$. The transverse mass is expected to peak at the mass of the new particle and to smoothly behave for all background processes. Typical resolutions on m_T are 25-30%, depending on the model under consideration.

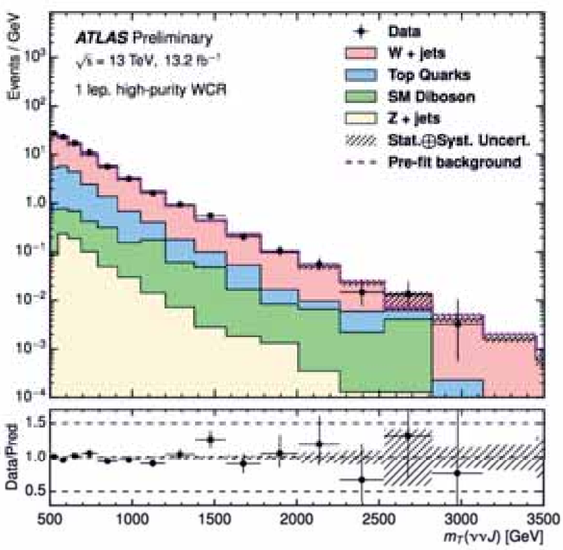

Figure 1: Transverse mass distribution for the W high purity control region. Most events come from W+jets processes (pink), as expected. The bottom panel shows the ratio of the observed data to the predicted background.

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[1]R represents the Jet tranverse size.

After pre-selection, main backgrounds remain due to events where V+jets, $t\bar{t}$ pairs and and diboson pairs are produced. Diboson events account for less than 10% (3%) of background in the high (low) purity selection. To estimate the other backgrounds, simulated samples were used, whose modelling accuracy was estimated in dedicated control regions.

The Z+jets background was studied by selecting events with dimuon decays of Z bosons. The W+jets and $t\bar{t}$ backgrounds were studied in events containing exactly one muon candidate and one large-R jet. b-jet tagging was used to populate the $t\bar{t}$ control region. An example of control region distributions is represented in Fig. 1.

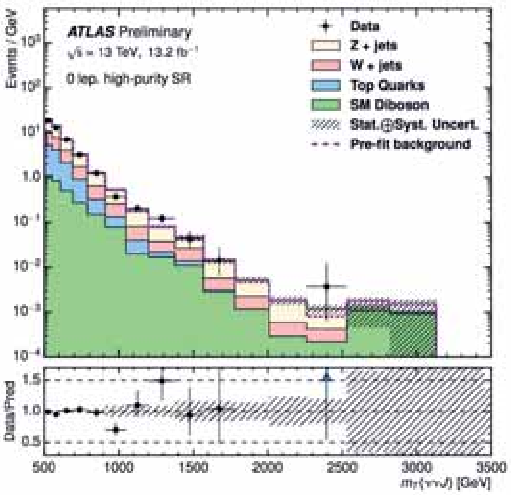

Figure 2: Transverse mass distribution of the $\nu\nu J$ system in the high purity signal region. The pre-fit background (red-dashed line) slightly differs from the background stack compared with data in the bottom panel.

All m_T distributions in control regions were considered in the final fit, together with the signal region.

To measure the compatibility of the background-only hypothesis with data and to test the hypothesis of a heavy resonance, a profile-likelihood-ratio test statistic was used. For positive hypotheses, the estimator was assumed to be the production cross section of the heavy resonance times the branching ratio to VZ, $\sigma \times BR$. The maximum likelihood fit was made on the transverse mass as final discriminant and all systematic uncertainties with their correlations were incorporated in the fit as nuisance parameters. The m_T expected and observed distributions are represented in Fig. 2 for the high purity region.

Models predicting heavy scalars, heavy W-bosons and heavy spin-2 gravitons G were considered and mass values were assumed each time as test hypothesis. No positive result was obtained and 95% CL upper limits could be set on $\sigma \times BR$ for all models. The result for the HVT model is reported in Fig. 3, showing the exclusion of W' masses in the interval 500-2400 GeV at 95% confidence level.

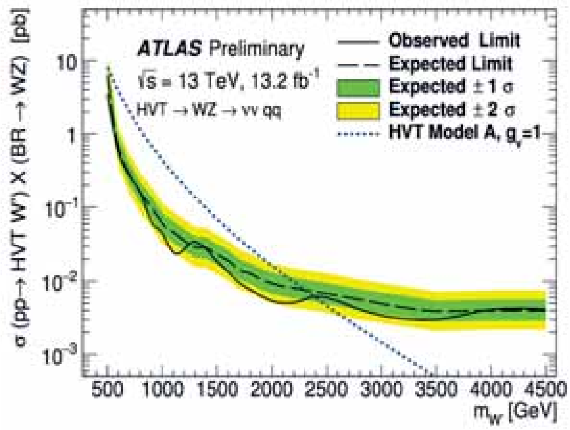

Figure 3: Observed and expected 95% CL upper limits on $\sigma \times BR$ for $ggF \rightarrow W' \rightarrow WZ$.

References

Aaboud, M. et al., The ATLAS Collaboration (2012). "Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC". In: *Physics Letters B* 716.1, pp. 1–29.

— The ATLAS collaboration (2016v). "Searches for heavy ZZ and ZW resonances in the llqq and vvqq final states in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector". In: *ATLAS-CONF-2016-082*.

RD-FASE2

Gian-Franco Dalla Betta,† Maurizio Boscardin, Mostafa El Khatib, Roberto Iuppa, David Macii, Roberto Mendicino, D M S Sultan, Giovanni Verzellesi

Since 2014, the *RD*-FASE2 project within CSN1 has addressed the technological developments for the ATLAS and CMS detector upgrades at the High Luminosity LHC. The role of TIFPA has been concerned with the development of new 3D sensors aimed at the innermost tracking layers. This application requires very high hit-rate capabilities, increased pixel granularity, extreme radiation hardness, and reduced material budget. As a result, in comparison to existing 3D sensors, the new ones will be downscaled by about a factor of two, calling for the development of a new fabrication process.

A sketch of the device is shown in Fig. 1: sensors are made on 6-inch diameter, p-type Silicon-Silicon Direct Wafer Bonded (SiSi DWB) substrates, consisting of a Float Zone high-resistivity layer of the desired thickness directly bonded to a low-resistivity handle wafer. The latter is thick enough to allow for mechanical robustness; it can eventually be partially removed and a metal layer can be deposited to allow for sensor bias from the back-side. To this purpose, the p^+ (ohmic) columns are etched deep enough to reach the highly doped handle wafer. On the contrary, the etching of the n^+ (read-out) columns is stopped a short distance ($\sim$ 20 μm) from the handle wafer in order to prevent from early breakdown (Dalla Betta et al. 2015).

The two considered pixel layouts are shown in Fig. 2. The 50×50 μm^2 pixel features one n^+ column (1E) at the center of a cell, with an inter-electrode spacing L≃36 μm. For better radiation hardness, the 25×100 μm^2 pixel is designed with two n^+ columns (2E), with L≃28 μm. The latter layout is pretty dense and the bump-bonding pad is very near the electrodes, that could be critical in case of lithographical misalignment.

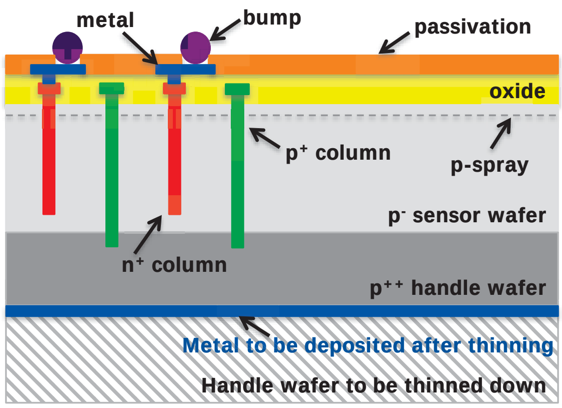

Figure 1: Schematic cross-section of 3D sensors made with a single-sided process on SiSi DWB substrates.

An extensive TCAD simulation activity has been carried out as an aid to the device design. Iit was predicted that a capacitance of ∼50 fF per read-out column and a breakdown voltage higher than 150 V could be achieved before irradiation, good enough for the intended application. As far as the signal efficiency after irradiation is concerned, both pixel layouts yield very high average values, in the range from 60 to 70% after the largest possible irradiation fluence of 2×10^{16} n_{eq}/cm^2, thus confirming the excellent radiation tolerance of these devices (Dalla Betta et al. 2015).

In parallel with the design/simulation activ-

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ity, SiSi DWB substrates of two different active thicknesses (100 and 130 μm) have been qualified by fabricating a batch of planar sensors and test structures. It was proved that the leakage current is low enough ($\sim$ a few nA/cm^2), evidence of a good substrate quality in terms of carrier lifetimes. Moreover, a significant diffusion ($\sim$10 μm deep) of Boron from the highly doped handle wafer into the active layer was also observed, that should be carefully considered to calibrate the read-out column etching depth in order to avoid early breakdown (Dalla Betta et al. 2016f).

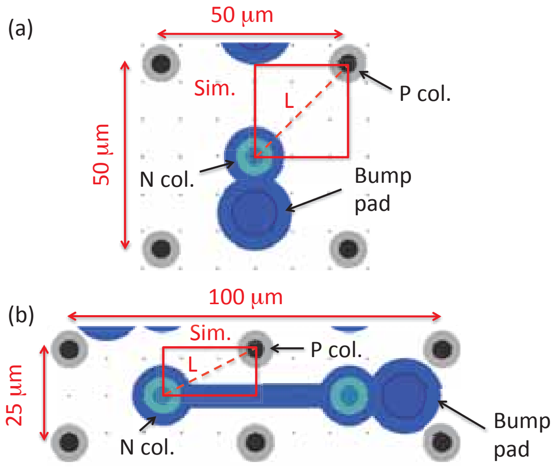

Figure 2: Layouts of 50×50 (top) and 25×100 μm^2 (bottom) pixels. Simulation domains are indicated by the red square/rectangle.

After proving the feasibility of the most critical process steps (e.g., the column etching by DRIE and their partial filling with poly-Si) (Dalla Betta et al. 2015), the first batch of these new 3D sensors was fabricated at FBK with a wafer layout accommodating a large variety of pixel sensors and test structures. Ten wafers were completed. From the electrical characterization of 3D diodes, the following observations were made: (i) the depletion voltage is very small, of the order of 2 - 3 V depending on the layout; (ii) the capacitance is of the order of 50 fF per column; (iii) the leakage current is very small, of the order of 1 pA per column; (iv) the intrinsic breakdown voltage is higher than 150 V, with only a small fraction of devices showing lower values due to defects. All these results are very encouraging and in good agreement with TCAD simulations. All pixel sensors were electrically tested on an automatic probe station, making use of a temporary metal. The best wafers were chosen for bump bonding to be performed at Selex (Rome) and IZM (Berlin). The first prototype modules were characterized using 120 GeV pions at CERN SPS H6A beam line in August 2016, data analysis is under way.

In parallel, the characterization of test structures has been carried out, and irradiation of several samples with X-rays, neutrons, and protons was performed. The most significant results so far achieved are: (i) sensors show a very high detection efficiency at low voltage, in good agreement with the depletion voltage values; (ii) the slim edge termination is effective and allows for a very small dead area at the periphery (a few tens of μm); (iii) after X-ray irradiation to two different doses (5 and 50 Mrad(Si)), the leakage current increases due to surface generation, but the breakdown voltage is only marginally affected; (iv) after neutron irradiation to a fluence of 5×10^{15} n_{eq}/cm^2, besides the leakage current increase, with the expected damage constant $\sim4\times10^{-17}$ A/cm, the breakdown voltage increases, and is much larger than the depletion voltage estimated from C-V curves. Both the previous observations about the breakdown voltage trends in irradiated devices support the assumption that breakdown occurs at read-out column tips.

Functional characterization of irradiated 3D diodes is under way. Moreover, strip sensors of different geometries were irradiated and are currently being tested with a beta source and a position resolved laser system in collaboration with the University of Freiburg.

References

Dalla Betta, G.-F., Boscardin, M., Bomben, M., Brianzi, M., Calderini, G., Darbo, G., Mendicino, R., Meschini, M., Messineo, A. R., Ronchin, S., Sultan, D., and Zorzi, N. (2016f). “The INFN-FBK “Phase-2” R&D program”. In: *Nucl. Instrum. Methods A* 824, pp. 388–391.

Dalla Betta, G.-F., Boscardin, M., Mendicino, R., Ronchin, S., Sultan, D., and Zorzi, N. (2015). "Development of New 3D Pixel Sensors for Phase 2 Upgrades at LHC". In: *IEEE NSS-MIC Conference Record*. Ed. by C. Ilgner. Piscataway, NJ, USA: IEEE.

Launch of LISA Pathfinder on 3 December 2015
from Europe's Spaceport, French Guiana

Astroparticle Physics

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TIFPA Astroparticle Physics Activities

Astroparticle physics is an interdisciplinary field at the intersection of particle physics, astrophysics, cosmology and fundamental physics.

Within INFN, this field is competence of the *Commissione Scientifica Nazionale II*, that deals in fact with a wide spectrum of experimental investigations. They range from studies of the neutrino properties to experiments probing the dark Universe, from studies of radiation and gravitational waves from the Universe to experiments addressing the foundation of general and quantum physics. These activities differ for the topics, for the employed technologies and involve researchers working in various fields. Therefore they greatly benefit from the synergy between INFN and other research institutes, as happens at the TIFPA where INFN, Università di Trento, CNR, FBK and Trento Protontherapy Center can work efficiently in joint projects. Lively and productive is obviously also the collaboration with ASI for the space based experiments.

At the TIFPA, the activities related to astroparticle physics currently involve about 40 researchers in 7 experiments briefly presented in this section, together with their recent highlights. It is noteworthy the high quality of the contribution of the TIFPA members in these projects: their remarkable ability to simulate, to design and then to fabricate cutting-edge devices and to realize challenging novel experimental apparatuses allow for pushing the experimental performance to their limits and therefore to enhance the overall scientific return.

VIRGO and LISA Pathfinder are the leading INFN experiments in the detection of gravitational waves, which recently registered two crucial events: the extraordinary first direct detection of the gravitational sound of two coalescing stellar blacks holes, and the launch and successful operation of LISA Pathfinder, the precursor mission to the space-based gravitational wave observatory.

On the International Space Station (ISS), AMS-02 is a state-of-the-art particle physics detector successfully performing precision measurements of cosmic ray composition and flux , and investigating the Universe and its origin by searching for antimatter and dark matter.

The direct detection of a possible dark matter candidate is the goal of DARKSIDE, while LIMADOU is a particle detector designed to study the correlation observed between seismic phenomena and changes in the trapped particle populations of the inner Van Allen radiation belt. In the domain of quantum simulations operates FISH, modelling interactions and mechanisms at the basis of high energy systems by means of quantum gases of ultra-cold atoms. HUMOR focuses on probing the granularity of space-time at the Planck scale expected by theory trying to unify General Relativity with Quantum Physics.

AMS-02

Laurent Basara, Roberto Battiston, William Jerome Burger, Francesco Dimiccoli, Roberto Iuppa, Konstantin Kanishev, Ignazio Lazzizzera†

AMS-02 is a state-of-the-art particle physics detector designed to operate as an external module on the International Space Station (ISS). It is studying the universe and its origin by searching for antimatter and dark matter, while performing precision measurements of cosmic ray composition and flux.
The high statistics of the measurements, along with the high precision of the experiment, allow to study the detailed variations with rigidity of the flux spectral indices, important in understanding the origin, acceleration and propagation of cosmic rays in our galaxy (Aguilar et al. 2015a),(Aguilar et al. 2016).

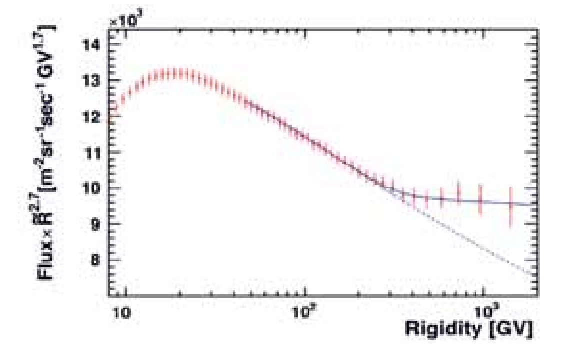

Figure 1: Proton flux with AMS-02

Proton and helium fluxes show a surprisingly similar behaviour: the spectral index of both progressively hardens at rigidities larger than 100 GV. The rigidity dependence of the helium flux spectral index is similar to that of the proton, though the magnitudes are different. The flux above 45 GV is well described by a single power law, given as $\Phi = CR^{\gamma}$, where γ is the spectral index, R the rigidity and C a normalization constant. The more general fitting law for both proton and helium is

$$\Phi = C\left(\frac{R}{45\,GV}\right)^{\gamma}\left[1+\left(\frac{R}{R_0}\right)^{\Delta\gamma/s}\right]^{s}$$

where s quantifies the smoothness of the transition of the spectral index from γ for rigidities below the characteristic transition rigidity R_0 to $\gamma+\Delta\gamma$ for rigidities above R_0. In Fig. 1 the solid line is a fit to the data; the dashed line is the proton flux expected; as seen, it does not agree with the data.

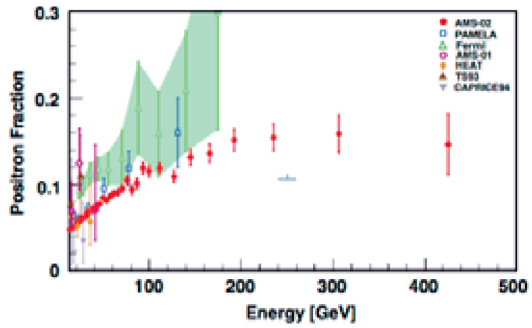

Figure 2: Positron fraction with AMS-02

Of the whole amount of data AMS has analyzed, 10 million particles have been identified as e^- and e^+. AMS has measured the positron fraction (ratio of the number of e^+ to the combined number of e^+ and e^-) in the energy range 0.5 to 500 GeV. It has been observed that this fraction starts to quickly increase at 8 GeV, indicating the existence of a new source of e^+. In particular, between 20 and 200 GeV, the rate of change of the e^+ flux is higher than the rate for e^-. This indicates that the increase seen in the positron fraction is due to a relative excess of high energy e^+ (as would typically be expected from dark matter interaction or decay, or a nearby

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pulsar), and not the loss of high energy e^-.
The TIFPA group is leading the particular measurement of the flux of Deuterons and Anti-Deuterons. They are created from spallation reaction between Cosmic Ray (CR) primaries (mostly protons, antiprotons, and helium) with the protons and helium of the interstellar medium. In the Anti-Deuteron case this secondary contribution could be accompanied by an important input due to Dark Matter (DM) annihilation. The magnitude of this primary contribution is largely dependent on the DM mass and cross sections. The main advantage of Anti-Deuterons, compared to the predictions for the anti-p, is that the primary Anti-Deuteron flux should be up to three orders of magnitude higher with respect to the secondary one in a wide range of possible annihilating DM masses.

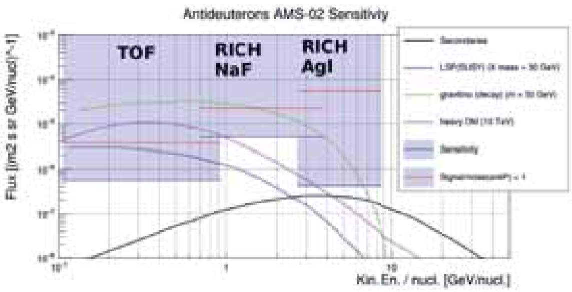

Figure 3: Expected sensitivity on anti-deuteron

Fig. 3 shows AMS sensitivity expected on antideuteron fluxes along with secondary backgrounds according to different theoretical models.
The measurement of the Deuteron flux is a first step in preparation for the study of the cosmic Anti-Deuteron flux, allowing us to understand better the performance of the detector and to optimize the selection strategy. Moreover, the deuteron flux measure is itself very important, because the flux ratio between exclusively secondary and primary produced CR particles gives important constraints to the propagation models of CR in the Galaxy.
We developed a multivariate approach for the distinction of deuterons from the overwhelming proton background, based on the concept of Euclidian distance in 5-dimensional space of the variables used for p/d distinction (momentum, beta, energy deposits), obtaining a very high purity of the Deuteron signal. Fig. 4 shows a preliminary result of the measurement of the Deuteron flux.

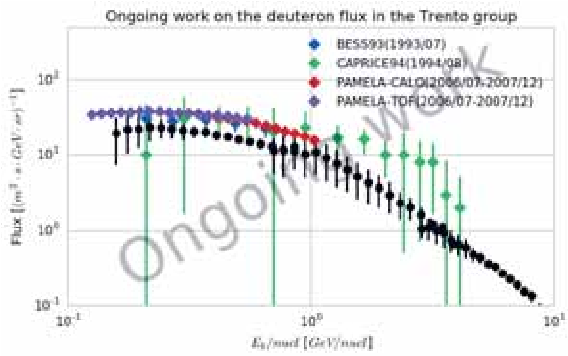

Figure 4: Preliminary Deuteron flux with AMS-02

The TIFPA group also aims to harness the power of modern, robust and powerful classification tools in data analysis, like the gradient boosted decision trees models. The tried and tested supervised machine learning methods have to rely on existing labeled datasets, with their inherent conceptual limits. To remedy those limits, the TIFPA group believes that the pixel structure of the Electromagnetic Calorimeter of AMS-02 makes an ideal candidate to implement a more exploratory and prospective procedure of unsupervised machine learning through convoluted neural networks, aiming at discriminating between different particle species with an ever higher rejection power and energies unreachable with the current supervised methods.

References

Aguilar, M. et al., the AMS-02 Collaboration (2015a). “Precision Measurement of the Helium Flux in Primary Cosmic Rays of Rigidities 1.9 GV to 3 TV with the Alpha Magnetic Spectrometer on the International Space Station.” In: *Phys. Rev Lett.* 115.

— the AMS-02 Collaboration (2016). “Antiproton Flux, Antiproton-to-Proton Flux Ratio, and Properties of Elementary Particle Fluxes in Primary Cosmic Rays Measured with the Alpha Magnetic Spectrometer on the International Space Station.” In: *Phys. Rev Lett.* 117.

DarkSide

Fabio Acerbi, Alberto Gola,† Marco Marcante, Giovanni Paternoster, Claudio Piemonte, Veronica Regazzoni

The existence of dark matter in the Universe is commonly accepted as the explanation of many phenomena, ranging from internal motions of galaxies to the large scale inhomogeneities in the cosmic microwave background radiation and the dynamics of colliding galaxy clusters.

A favored hypothesis that explains these observations is that dark matter is made of weakly interacting massive particles (WIMPs). However, no such particles exist in the Standard Model and none has been observed directly at particle accelerators or elsewhere. Hence the nature of the dark matter remains unknown.

DarkSide 20k experiment (DS-20k) is a direct detection experiment based on a shielded underground detector with 20 tons of liquid argon target mass. It will be based on a two-phase Time projection Chamber (TPC) filled with low-background, depleted Argon (DAr) and will be deployed in in the underground Hall C at National Laboratory Gran Sasso, LNGS, inside a newly constructed Liquid Scintillator Veto, LSV, and Water Cherenkov Veto, WCV, see Fig.1. DS-20k constitutes an expanded version of the DS50 experiment, currently running at LNGS.

DS20k Time Projection Chamber

In the TPC, events in the Liquid Argon result in electron or nuclear recoils that deposit energy in the argon, resulting in excitation and ionization. The direct excitation, and that due to recombining ions, results in a prompt scintillation signal, called S1. LAr scintillation has a wavelength of 128 nm, in the far UV, thus a wavelength shifter (TPC) will cover all surfaces that the UV light hits. Ionization electrons escaping recombination are drifted by an applied electric field to the top of the LAr, where a stronger applied field extracts the electrons into the argon gas above the liquid. Here the strong field accelerates the electrons enough for them to excite (but not ionize) the argon gas, producing a secondary scintillation signal, S2, that is proportional to the initial ionization. Photosensors at the top and bottom of the TPC read out both scintillation signals in each event.

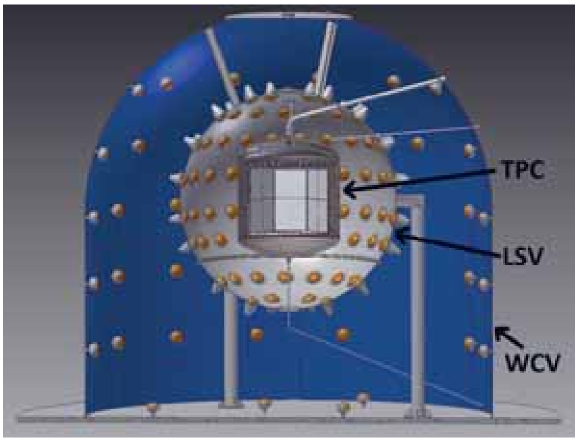

Figure 1: Cross sectional view of the DS20k experiment through its center plane, showing the water tank and the WCV detector, the stainless steel sphere and LSV detector, and the DarkSide-20k cryostat and LAr TPC.

S1 is used for energy determination and pulse-shape discrimination. S2 is used for en-

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ergy and 3D position measurement of the event, obtaining the vertical coordinate from the drift time between S1 and S2, and the horizontal coordinates from the pattern of light in the top photosensors.

Silicon Photo Multipliers

The use of Silicon Photomultipliers (SiPMs) instead of Photo Multiplier Tubes as photodetectors is one of the main technological challenges of the experiment, the other being the production of ultra-low-background DAr. There are several advantages in using these detectors in DS-20k, among them: low bias voltage (20-35 V), efficient integration into tiles to cover large areas, customizable size and performance, excellent photon counting capabilities and high Photon Dection Efficiency (PDE). The most importnat one, however, is that SiPMs are virtually radioactive-free (silicon is very radiopure material). The SiPMs will be grouped in tiles and integrated in several photo-detection modules, to cover a total area of approximately 10 square meters, as shown in Fig.2.

DS-20k Activity at TIFPA

The use of SiPMs at cryogenic temperatures is innovative and very few studies have been carried out on their characterization and optimization at cryogenic temperatures. Furthermore, the readout of such large active areas poses several challenges in the design and optimization of both SiPMs and front-end electornics, developed at LNGS, and in packaging techniques. In this context, TIFPA started the DS-20k activity in 2016, collaborating mainly with Fondazione Bruno Kessler (FBK), LNGS and Naples INFN section. The activity was focused on the cryogenic characterization of different SiPMs technologies developed by FBK to: (i) verify and characterize their functionality at cryogenic temperatures and, in particular, at 87 K; (ii) select the most suitable one for DS-20k; (iii) provide information to optimize the SiPM parameters and layout for the best possible performance in DS-20k. To this aim, TIFPA commissioned a NUV-HD SiPM production to FBK, with several technological splits to be tested at low temperatures. TIFPA also worked on the verification of the FBK SiPM reliability during cryogenic thermal cycling. One of the most important results is the exceptionally low Dark Count Rate (DCR) of NUV-HD-LF (low electric field variant) at 87 K, which is at the state of the art with a value of a few mHz/mm^2. In this conditions, a 100 cm^2 SiPM tile has a DCR of 100 Hz only. This value is very important to demonstrate that SiPMs are a valid and high performance alternative to PMTs for the readout of the large photosensitive areas required by DS-20k.

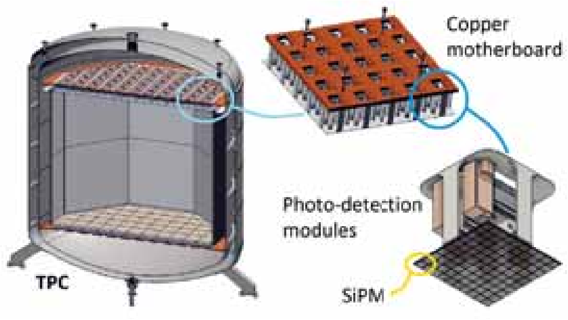

Figure 2: 3D rendering of the DS-20k TPC, motherboard and photo-detection module.

FISH

Giacomo Colzi, Carmelo Mordini, Franco Dalfovo, Sandro Stringari, Giacomo Lamporesi, Gabriele Ferrari†

FIS$\hbar$, Fundamental Interaction Simulations with quantum gases, focuses on the dynamics of quantum gases of ultracold atoms with the aim to model interactions and mechanisms at the basis of high energy physics. This research field belongs to the domain of quantum simulation, where physical systems, difficult to address experimentally, are studied through analogies with simpler systems.

The objective of the project is engineering the interactions in ultra cold atomic gases to reproduce and study in laboratory features typical of gauge theories, such as quantum chromodynamics, which are connected to color symmetries and quark confinement. The strength of this type of approach is twofold: on the one hand the exquisite experimental control available with ultracold atomic samples allows for the fine-tuning of the coupling constants and the parameters of the model under test. On the other hand the diagnostics tools available in atomic physics, together with the lengths and energy scales, are much simpler to access experimentally. This allows for the direct detection of particles as well as various measurements of their properties (imaging, dynamics, correlation functions, excitation spectrum).

The experiments are brought forward at TIFPA and at the INFN section in Florence. In Trento FIS$\hbar$ focuses on the study of vortices in a system made of two coupled Bose-Einstein condensates to simulate quark confinement. Coupled Bose-Einstein condensates, whose wavefunction has a spin term, play a crucial role within the community of ultracold/quantum gases. Since the early demonstration of Bose-Einstein condensation, these systems were studied mainly in the absence of stationary driving among the internal states, focusing on mean-field effects as, for instance, the stability of polarization, the miscibility, and the many-body dynamics of the superfluids under the action of external parameters such as the symmetry of the interactions, the confining potential, or the energy splitting of the internal states. The case of Hamiltonians containing a coupling term among the spin states has been fairly unexplored so far, at least experimentally, because of technical constraints imposed by the stability of the magnetic fields. On the other hand, binary condensates under the action of a resonant coupling among internal states have attracted a substantial theoretical interest since it was recognized that in such systems the additional degrees of freedom (i.e., the relative phase) give access to new kinds of topological excitations, such as domain walls and vortex molecules (Son et al. 2002).

Domain walls are planar structures in 3-dimensions. In 2-dimensions and in the finite-size case, which is readily accessible in laboratory conditions, they give rise to bound states (molecules) of vortex pairs in the two components, whose energy linearly increases with the pair size (Son et al. 2002). Similar to such bound vortex pairs in the coupled binary mixture, also quarks and antiquarks cannot exist as individual objects, but only as composite ob-

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jects, i.e., hadrons. Furthermore, as in the case of vortex molecules, also in mesons the attraction force among quarks does not decay while increasing their distance, but rather remains about constant. The analogies between the two systems, mesons on the one hand and vortex molecules in coupled BECs on the other, offer a real possibility to perform the quantum simulation of some specific features of quark confinement using ultracold quantum gases.

In Trento we plan to realize and bound states of vortices in binary condensates under the action of a resonant coupling. The interaction among the constituents of the vortex molecule will be studied as a function of the accessible experimental parameters, such as the intensity of the coupling, the intra- and inter-species mean-field interactions, or the confining external potential. Quantum simulation of quark confinement will be performed by introducing terms which may result in the breaking of the vortex-molecules, such as time-dependent perturbations of the external potential or high temperature of the sample, and observing how additional molecules are generated after individual processes of molecule-breaking.

Currently we are setting up a novel experimental apparatus specifically designed to produce binary BECs in conditions of very high magnetic field stability (at the microGauss level). This constraint prevents the use of the commonly adopted methods for cooling samples in the quantum-degenerate regime and hence new approaches need to be explored. With this regard we recently demonstrated a novel laser cooling method for sodium gases, the so called gray molasses cooling, which being effective also at high spatial densities will allow the production of BECs in the conditions required by FIS$\hbar$ (Colzi et al. 2016). At the same time we are doing preliminary studies to determine the mean-field stability conditions for two-component sodium binary condensates. Along this line we did the first measurement of the polarizability, and observed the spin-dipole oscillations in two-component superfluids (Bienaimé et al. 2016).

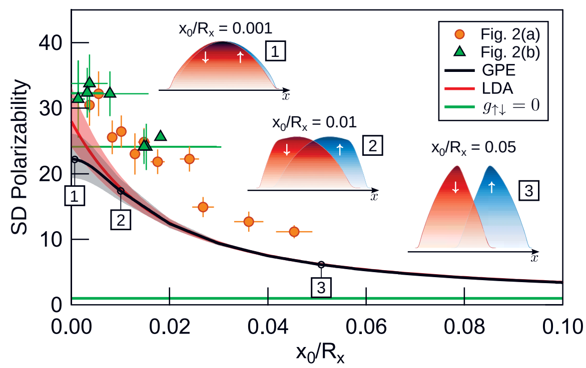

Figure 1: Spin dipole polarizability of 2-component sodium condensates. The black (red) solid line is the prediction computed using the Gross-Pitaevskii equation (local density approximation). The shaded regions give the uncertainties taking into account error bars on the value of the coupling constants. The green solid line corresponds to the situation of no intercomponent interaction $\mathscr{P} = 1$. *We also provide the density profiles* $n_{\uparrow,\downarrow}(x,0,0)$ *from the GPE for* $x_0/R_x = 0.001, 0.01, 0.05$. *The experimental points overestimate the actual value of* $\mathscr{P}$ *due to the approximation of the TF fit and the interaction effect during the expansion (Bienaimé et al. 2016).*

References

Bienaimé, T., Fava, E., Colzi, G., Mordini, C., Serafini, S., Qu, C., Stringari, S., Lamporesi, G., and Ferrari, G. (2016). "Spin-Dipole Oscillation and Polarizability of a Binary Bose-Einstein Condensate near the Miscible-Immiscible Phase Transition". In: *arXiv:1607.04574*.

Colzi, G., Durastante, G., Fava, E., Serafini, S., Lamporesi, G., and Ferrari, G. (2016). "Sub-Doppler cooling of sodium atoms in gray molasses". In: *Phys. Rev. A* 93 (2), p. 023421.

Son, D. T. and Stephanov, M. A. (2002). "Domain walls of relative phase in two-component Bose-Einstein condensates". In: *Phys. Rev. A* 65 (6), p. 063621.

HUMOR

Michele Bonaldi,[†] Antonio Borrielli, Enrico Serra, Giovanni Andrea Prodi

One of the open questions in physics is to reconcile the two most successful theories of physics, Einstein's general relativity and quantum physics. Currently, there are many theories that aspire to achieve this unification, but none of them is convincing and it is not clear how they can be verified experimentally. A common feature of these theories is that the space-time changes nature, become "granular" at a very small length, called "Planck scale" ($L_P = \sqrt{\hbar G/c^3} = 10^{-35}\,\mathrm{m}$). The HUMOR (Heisenberg Uncertainty Measured with Optomechanical Resonators) experiment uses a new method for probing the space-time: the microscopic vibrations of oscillators of different sizes and masses, from a few nanogram up to a few milligrams, are measured with great accuracy, using lasers and/or electromagnetic sensors. The presence of a granularity of space-time at the Planck scale should be reflected in a nonlinear behavior of the oscillators, up to the dimensional scale currently measurable in the laboratory. In fact, in the framework of quantum mechanics, the measurement accuracy is at the heart of the Heisenberg relations, that, however, do not imply an absolute minimum uncertainty in the position. An arbitrarily precise measurement of the position of a particle is indeed possible at the cost of our knowledge about its momentum. This consideration motivated the introduction of generalized uncertainty principles (GUPs), such as

$$\Delta q \Delta p \geq \frac{\hbar}{2}\left(1 + \beta_0 \left(\frac{L_\mathrm{P}\Delta p}{\hbar}\right)^2\right), \qquad (1)$$

that implies indeed a nonzero minimal uncertainty $\Delta q_{min} = \sqrt{\beta_0} L_\mathrm{P}$. The dimensionless parameter β_0 is assumed to be around unity, in which case the corrections are negligible unless lengths are close to the Planck length. Any experimental upper limit for $\beta_0 > 1$ would constrain new physics below the length scale $\sqrt{\beta_0} L_\mathrm{P}$. This GUP implies two relevant effects with respect to a harmonic oscillator: the appearance of the third harmonic and a dependence of the oscillation frequency on the amplitude. Therefore, to set a limit on the value of β_0, we can measure the frequency of highly isolated oscillators at different oscillation amplitudes.

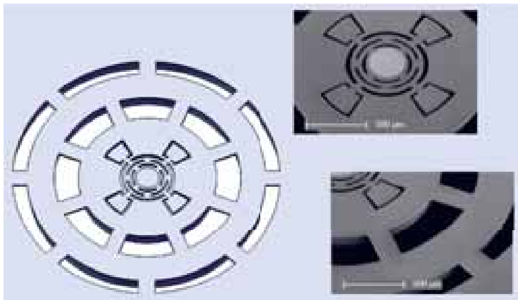

Figure 1: CAD drawings and SEM details of an optomechanical oscillators. The mirror is deposited over the central disk.

The micro-mechanical oscillators are built with micro-lithography on silicon wafers (Borrielli et al. 2015). In Fig. 1 we show for instance a device with a typical mass of 100 μg, with a shape designed to best isolate it from the external environment. The oscillators are then cooled down to a few degrees above absolute zero, to limit heat induced vibrations. The

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movement is measured with laser beams and low noise electrostatic sensors, with sensitivity to the displacement comparable to the size of the atomic nucleus. The setup can measure changes in the oscillation frequency of some part in a billion during the free decay of the oscillation after a resonant drive. In Fig. 2 we report the results obtained with oscillators of different dimensions and shapes, as shown in the insets near the experimental points (Bawaj et al. 2015).

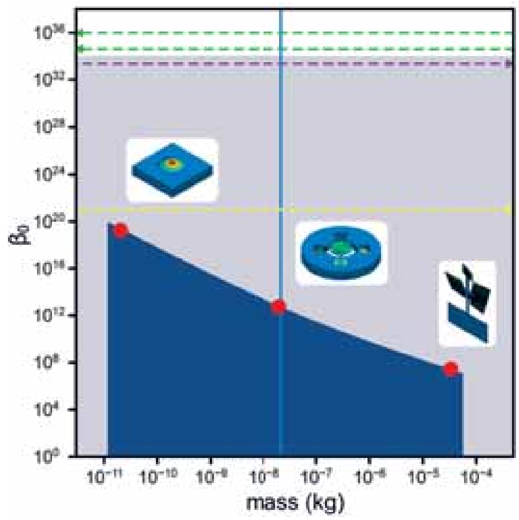

Figure 2: Red dots: upper limits to the parameter β_0. Gray shows the area below the electroweak scale, dark blue the area that remains unexplored. Dashed lines reports some previously estimated upper limits, obtained in mass ranges outside this graph (as indicated by the arrows). The vertical line corresponds to the Planck mass (22 µg).

These results improve the previous upper limits to quantum gravity effects by many orders of magnitude. The next challenge is to further cool an oscillator using laser light. At ultracryogenic temperature the behavior of the oscillator should be markedly quantum-like and it will thus be possible to highlight in the most direct manner any anomalies due to effects of quantum gravity. For this experiment we have designed and produced a membrane resonator, equipped with a specific on-chip structure working as a "loss shield" (Fig. 3), that achieves a mechanical quality factor of 10^7 (Borrielli et al. 2016).

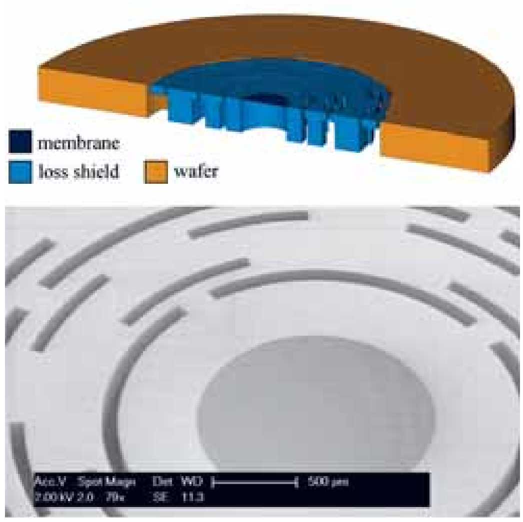

Figure 3: Schematic sectional drawing and SEM image of the membrane resonator equipped a "loss shield" structure.

References

Bawaj, M., Biancofiore, C., Bonaldi, M., Bonfigli, F., Borrielli, A., Di Giuseppe, G., Marconi, L., Marino, F., Natali, R., Pontin, A., Prodi, G. A., Serra, E., Vitali, D., and Marin, F. (2015). "Probing deformed commutators with macroscopic harmonic oscillators". In: *Nature Communications* 6.

Borrielli, A., Marconi, L., Marin, F., Marino, F., Morana, B., Pandraud, G., Pontin, A., Prodi, G. A., Sarro, P. M., Serra, E., and Bonaldi, M. (2016). "Control of recoil losses in nanomechanical SiN membrane resonators". In: *Physical Review B* 94.12.

Borrielli, A., Pontin, A., Cataliotti, F. S., Marconi, L., Marin, F., Marino, F., Pandraud, G., Prodi, G. A., Serra, E., and Bonaldi, M. (2015). "Low-Loss Optomechanical Oscillator for Quantum-Optics Experiments". In: *Physical Review Applied* 3.5.

LIMADOU

William Jerome Burger,† Roberto Battiston, Roberto Iuppa, Ignazio Lazzizzera, Christian Manea

Limadou is the High Energy Particle Detector (HEPD) of the Chinese Seismo-Electromagnetic Satellite (CSES). The HEPD will study a phenomena reported by instruments on different satellites, which indicates a time correlation between the main earthquake shock, and an increase in the electron flux in the inner radiaton belt (Aleksandrin et al. 2003). The time correlation is observed $\sim$ 4 h prior to the main shock for electrons in the energy range 5-50 MeV.

The trapped particle populations in the Van Allen radiation belts are characterized by three adiabatic invariants which describe their motion in the Earth's dipole magnetic field: the conservation of the magnetic moment during the gyration orbit around the field line, the invariance of the field integral between the mirror points, and the flux invariance of the longitudinal drift shell. The particles may be classified according to their drift shell defined by two parameters: the height of the field line at the equator L, and the equatorial pitch angle α_{eq}.

The HEPD is designed to measure with good resolution the pitch angle and energy of electrons and protons. The detector includes a silicon tracker, a scintillator-LYSO calorimeter, and 5 scintillator veto planes which surround the calorimeter volume. The two tracker planes, composed of 12, $109.65 \times 72.60 \times 0.300\,\text{mm}^3$ double-sided silicon microstrip sensors, are located at the top of the detector in order to minimize the influence of multiple Coulomb scattering on the pitch angle measurement (Fig. 1).

The calorimeter consists of a segmented plane (T1) composed of 6, $3.0 \times 24.2 \times 0.5\,\text{cm}^3$, plastic scintillators, followed by 16, $17.7 \times 17.7 \times 1.0\,\text{cm}^3$ scintillator planes, and a 3×3 array of $4.8 \times 4.8 \times 4.0\,\text{cm}^3$ LYSO crystals.

The CSES will be placed in a sun-synchronous, circular orbit at 600 km with a 98° inclination. The HEPD is positioned on the satellite to point toward the local zenith. The pitch angle defined by the line-of-sight of the detector varies between 90° at the equator and $\sim$ 0° near the poles. The dimensions of the HEPD were chosen to maintain a wide angular acceptance throughout the orbit.

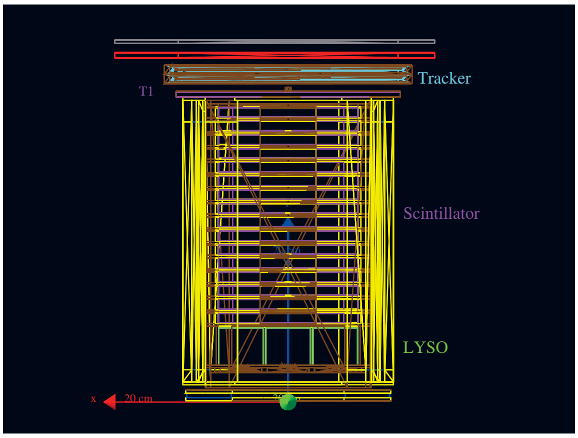

Figure 1: The HEPD in the Geant4 simulation used to study the detector performance.

The electron and proton acceptances are shown in Fig. 2. The corresponding angular resolution for electron energies of 2.5, 5, 10, 15 and 25 MeV are respectively 13°, 8.4°, 4.8°, 3.3° and 1.9°. The proton angular resolution ($\leq 1.5°$) is dominated by tracker position resolution ($\leq 50\,\mu$m). The electron energy resolution varies between 8 and 30% over the energy range 2.5 to 100 MeV. The proton energy

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resolution varies between 4% at 30 MeV to 20% at 200 MeV.

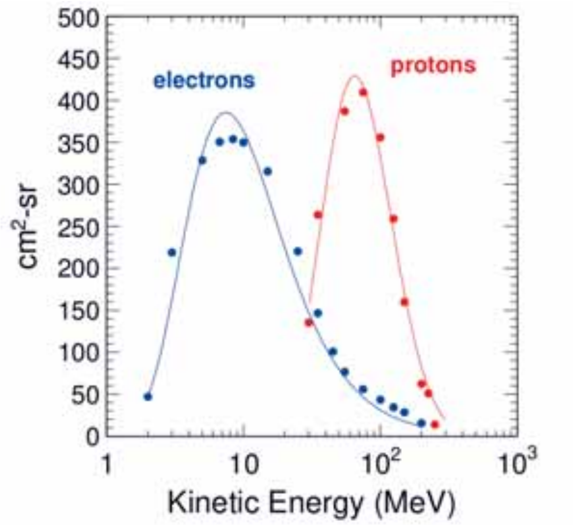

Figure 2: The electron and proton acceptances.

A fundamental issue for the remote detection in near-Earth orbit of seismic phenomena is the spatial correlation between the location of observed particle flux change, the particle burst (PB), and the earthquake epicenter. The program SEPS (Ambroglini et al. 2014), which incorporates the appropriate atmospheric and magnetic field models, has been developed to back-trace the detected electrons of reported time-correlated PB-earthquake observations (Battiston et al. 2003) to verify the spatial correlation.

The back-trace method uses the invariance of the Lorentz equation under an inversion of the momentum direction and sign change of the particle charge. The drift shell of the back-traced positron from the PB site of a time-correlated event observed by a NOAA, Polar-orbiting Operational Satellite is shown in Fig. 3.

The PB observation was made near the Pacific coast of Central America. The back-traced positron passes over the epicenter located off the coast of Southeast Asia. In this case, the event is spatially correlated. The forward-traced electron and back-traced positron interact in the atmosphere near the South Atlantic Anomaly (SAA).

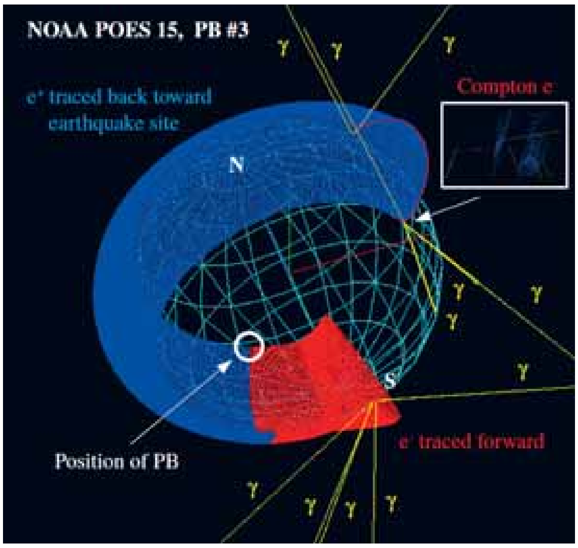

Figure 3: The trajectories of the electron (red) and back-traced positron (blue) of a time correlated earthquake-particle-burst event observed in the data of a NOAA POES satellite.

The TIFPA Limadou group, responsible for the physics simulation in the detector design and the back-trace analysis, contributed to the tracker readout electronics, and participated in the different detector validation tests. Other TIFPA members contributed to the proton test beam at the Trento Proton Therapy Center in November, 2016 (activity reported at p. 141). The CSES launch is programmed in 2017.

References

Aleksandrin, S., Galper, A., Grishantzeva, L., Koldashov, S., Maslennikov, L., Murashov, A., Picozza, P., Sgrigna, V., and Voronov, S. (2003). "High-energy charged particle bursts in the near-Earth space as earthquake precursors". In: *Annales Geophysicae* 21, pp. 597–602.

Ambroglini, F., Burger, W., Battiston, R., Vitale, V., and Zhang, Y. (2014). "Space Earthquake Perturbation Simulation (SEPS)". In: *EGU General Assembly Conference Abstracts*. Vol. 16. EGU General Assembly Conference Abstracts, p. 15024.

Battiston, R. and Vitale, V. (2003). "First evidence for correlations between electron fluxes measured by NOAA-POES satellites and large seismic events". In: vol. 243, pp. 249–257.

LISA Pathfinder

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Our current image of the Universe is essentially based on the observation of electromagnetic waves in a broad frequency spectrum. Much of the Universe, however, does not emit electromagnetic radiation, while everything interacts gravitationally. Despite being the weakest of the fundamental interactions, it is gravity that dominates the Universe on a large scale and regulates its expansion since the Big-Bang. As predicted by Einstein's General Relativity, gravity has its messenger: gravitational waves produced by massive accelerating bodies, such as coalescing black holes binaries or violent phenomena like stellar core collapse. Gravitational waves propagate at the speed of light, essentially undisturbed, bringing often not otherwise accessible information about events across all cosmic ages, from Cosmic Dawn to the present. The observation of gravitational waves promises to open new extraordinary perspectives for investigation of crucial issues like the nature of gravity in weak and in strong field regime, the nature of black holes, the formation and evolution of stellar binary systems, the formation and evolution of cosmic structures since the earliest stages of the Universe.

In 2015-2016, two crucial events marked the beginning of the era of gravitational wave exploration of the Universe: the extraordinary first direct detection of gravitational waves, the gravitational sound of two coalescing stellar blacks holes observed by the two ground-based LIGO detectors in USA, and the launch and successful operation of LISA Pathfinder (see Fig. 1), the precursor mission to the space-based gravitational wave observatory.

The role of the Laboratory of Experimental Gravitation of the Università di Trento and TIFPA in the former is described at p. 81, while here we report on LISA PF, a mission that was designed, implemented and operated under the leadership of the group of Trento, the team of the Principal Investigator prof. Stefano Vitale.

Figure 1: LISA Pathfinder satellite being encapsulated within the half-shells of the Vega rocket fairing.

Einstein's theory describes gravity in terms of the curvature of space-time that is deformed by the passing of gravitational waves. These effect can be detected in space by measuring with great precision the relative acceleration of masses in free fall, i.e., reference masses subject to gravity field but well-isolated from other types of disturbing forces. We consider here the configuration of LISA studied for many years, three identical satellites in a triangular constellation, with arms of several million km, orbiting around the Sun, shown in Fig. 2 with its strain sensitivity. It should allow for the observation

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of thousands of gravitational wave sources with high signal-to-noise, and in many cases very well characterized in terms of frequency, position in the sky, and luminosity distance. It targets massive sources emitting in the 0.1 mHz to 1 Hz band not accessible from ground due to the gravitationally noise Terrestrial environment, ranging from stellar mass binaries in our own Galaxy to the merger of two galactic-core black holes, from 10^5 to 10^7 solar masses, from the recent Universe back to the epoch of the first galaxies. The sensitivity is limited below 5 mHz, where most of the interesting signals are expected, by the residual acceleration noise of the reference masses nominally in free-fall in space, i.e., in geodesic motion.

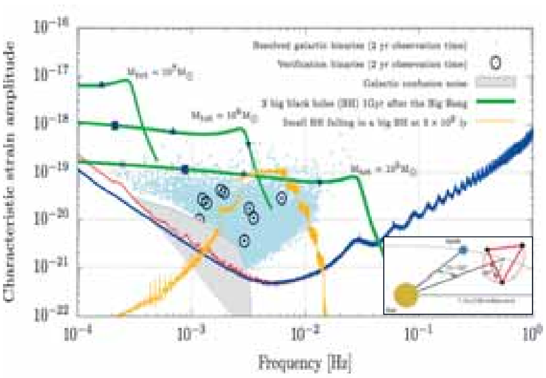

Figure 2: LISA's sensitivity curve plotted with the signal levels for several GW sources. The red curve is the projected sensitivity considering the test mass acceleration noise levels measured with LISA PF. In the inset a schematic of the LISA-concept.

The main goal of LISA Pathfinder is precisely to test the feasibility of measuring geodesic motion to within an order of magnitude of the LISA requirements of $3\frac{fm}{s^2\sqrt{Hz}}$ for a single TM across the mHz frequency band, that corresponds to an improvement of several orders of magnitude relative to what had been attained before.

To achieve its goals, LISA Pathfinder measures the relative acceleration of two 2 kg test masses in near-perfect geodesic motion, 38 cm apart in a single spacecraft (see p. 37 for more details). Its outstanding result is shown in Fig. 3 and would allow for an observatory performance very near the original LISA mission goals. The small noise excess with respect to the LISA requirement at the lowest frequencies is under study in the remaining months of the LPF measurement campaign (ending May 2017).

The Trento Group has contributed in a leadership role in all phases of the mission, including hardware design and prototyping, laboratory torsion pendulum testing, scientific guidance of the industrial aerospace contractors, and finally to the design and operation of the flight measurement campaign.

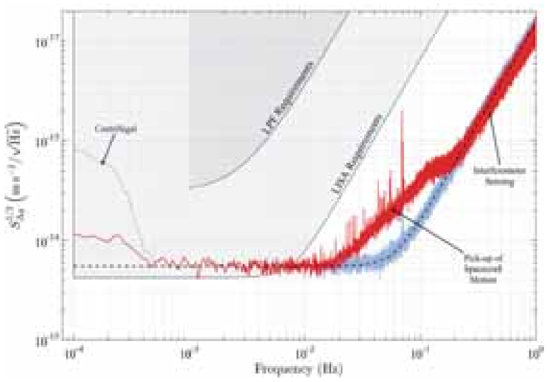

Figure 3: Spectrum of differential acceleration noise measured by LISA Pathfinder shown together with the LISA Pathfinder and the LISA requirement (Armano et al. 2016b).

As internationally recognized leader in development and realization systems of free-falling geodesic reference test masses for space based gravitational wave detector, the Trento group was among the proposing authors for the 2013 -Gravitational Universe- science theme proposal, which has been selected for third large mission (L3) of the Cosmic Vision ESA program, and is currently contributing to the proposal in response to the ESA call for the gravitational wave observatory mission with the perspective of final approval in 2020-2021.

References

Armano, M. et al., the eLISA Collaboration (2016b). "Sub-Femto-*g* Free Fall for Space-Based Gravitational Wave Observatories: LISA Pathfinder Results". In: *Phys. Rev. Lett.* 116 (23).

Virgo

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The observations of Gravitational Waves (GWs) achieved in 2015 by the LIGO Scientific Collaboration and the Virgo Collaboration initiated the new field of gravitational astronomy and opened a new human perception towards the Universe and the nature of space and time (B. P. Abbott et al. 2016m; B. P. Abbott et al. 2016j).

These discoveries are multiple breakthroughs at the same time: the first detections of propagating GWs; the first direct observations of Black Holes (BHs), in particular of BH binary systems tight enough to collide; the first verifications of General Relativity under highly relativistic motion and strongest gravitational field, since the BHs accelerated close to light speed while their event horizons were getting to merge together. In addition, these observations showed unexpected features of the mass distribution and abundance of stellar mass BHs and are posing challenging questions on their astrophysical implications. But nevertheless, the even more relevant perspective is that these achievements set the dawn for unprecedented explorations of our Universe. In fact, GWs carry unique and complementary information with respect to the other messengers from the heavens that have been previously exploited in astronomy, i.e. electromagnetic waves, neutrinos and more generally cosmic rays.

This success comes after one century of theoretical research and half a century of dedicated experimental progresses, both bringing necessary contributions to the final outcome. On the experimental side, the advancements on detector performances allowed to measure the tiny deformations produced by the GWs in the twin LIGO detectors located in the U.S.A. The transits of the waves shook the end mirrors of these interferometers by an infinitesimal 10^{-18} m over the 4 km length of their arms.

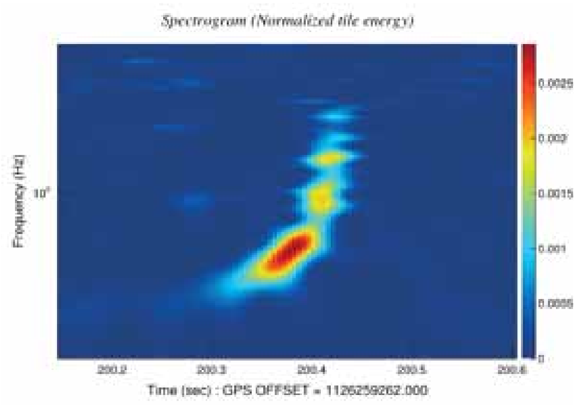

Figure 1: The first syllable from a gravitational wave, captured on Sept. 14, 2015. The time-frequency diagram shows a short signal with increasing pitch, denoting that it was emitted by the last orbits of a pair of Black Holes, accelerating close to light speed and colliding together. A mass of 3 times our sun was transformed in gravitational waves in this process.

To be able to capture this motion, a thousand times smaller than the dimensions of the smallest atomic nuclei, the noise level of the detectors has been reduced by a factor between 3 and 10 times with respect to the previous generation detectors, in the audio frequency band. At the same time, the progresses made to extract the signals from the data streams allowed a prompt capture of the GWs and un-

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veiled their features, see Fig. 1. The theoretical understanding inspired all these progresses and gave us the know-how to decipher these first GW messages.

The LIGO-Virgo community directly involved in these discoveries is an example of successful worldwide collaboration, involving about one thousand scientists from more than twenty countries, who have been awarded the Special Breakthrough Prize in Fundamental Physics 2016. Trento group played a direct role in the detection of the first gravitational wave syllable: in fact, the software pipeline which alerted the collaboration within 3 minutes and first identified the nature of the source has been developed in collaboration by Padova, Trento, Florida and Hannover members (Klimenko et al. 2016).

Following this prompt alert, the collaboration decided to maintain stable operating conditions of the LIGO detectors for one month, to make possible a careful characterization of their performances. In this framework, our pipeline also assessed the high degree of confidence that was required to establish the discovery. The collaboration then performed a few months of close scrutinies of the results prior to their presentation to the public.

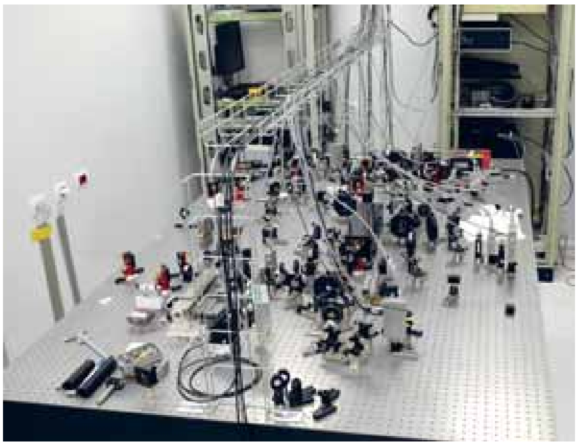

Figure 2: Squeezed states of light are used to beat quantum noise in gravitational wave detectors. Picture of the squeezed light source under development at Advanced Virgo, European Gravitational Observatory, Pisa.

Advanced Virgo, the 3 km-scale interferometric detector of GWs located close to Pisa, is expected to join by early 2017 the second observation run of the LIGO detectors. The addition of a third detector will ensure a much better localization of the source in the sky, therefore boosting the capabilities to identify any counterpart in the electromagnetic or neutrino windows. Moreover, it will open the opportunity to measure both polarization components of the GW, improving the impact of detections on both astrophysics and fundamental physics. The mid term plan of development for all these detectors is aiming at further improving their sensitivity by more than a factor 3, i.e. at increasing the volume of Universe under observation by a factor 30 with respect to 2015.

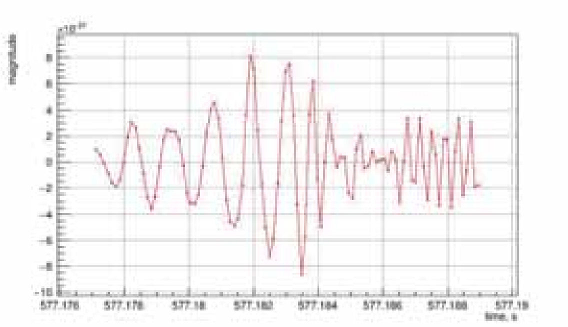

Figure 3: Hunting for the fingerprints of Neutron Star physics in gravitational waves. The plotted waveform refers to a simulated observation of the last orbits of a pair of Neutron Stars merging into one: the tail of this signal carries unique information on the dynamics of Neutron Stars.

Trento group is contributing to this ambitious plan by developing techniques to lower the quantum noise which limit the sensitivity of detectors in a wide band of frequencies. This noise arise from the quantum nature of light and can be mitigated by implementing more advanced measurement schemes. In particular Trento is contributing to the realization and optimization of the light source in a squeezed vacuum state for Advanced Virgo, see Fig. 2.

With an improved network of detectors and a longer observation time, more classes of gravitational wave sources will soon be detected. We are continuing to improve our pipeline to hunt for transient gravitational waves with a eyes-wide-open approach, i.e. targeting at the broadest possible diversity of signal morphologies. This is essential to enable unexpected discoveries for yet unknown or poorly understood sources. In addition to that, we are improving our performance to two specific targets: GW emission from Neutron Stars, see Fig. 3, and from highly eccentric binary systems of Black Holes or of a Neutron Star plus a Black Hole.

References

Abbott, B. P. et al., Virgo, LIGO Scientific (2016j). "GW151226: Observation of Gravitational Waves from a 22-Solar-Mass Binary Black Hole Coalescence". In: *Phys. Rev. Lett.* 116.24, p. 241103.

— Virgo, LIGO Scientific (2016m). "Observation of Gravitational Waves from a Binary Black Hole Merger". In: *Phys. Rev. Lett.* 116.6, p. 061102.

Klimenko, S. et al. (2016). "Method for detection and reconstruction of gravitational wave transients with networks of advanced detectors". In: *Phys. Rev.* D93.4, p. 042004.

Antiproton annihilation: towards the measurement of antihydrogen free fall

Nuclear Physics

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Up to now, TIFPA activities in Nuclear Physics have been carried out by the positron group of Trento. Doing physics research with antimatter is the group's main task. There is a growing interest in fundamental and applied research with antiparticles and antiatoms at CERN and in labs all over the world. For each particle, composing ordinary matter, exists an anti-particle which has the same mass but opposite charge. If a particle and its antiparticle collide, they annihilate giving rise to gamma rays, neutrinos and other couples of particle-antiparticles with lighter mass. Positron, the anti-electron, is the only antiparticle that can be found naturally on the Earth, as product of radioactive decay of some nuclides. Annihilation of positron and electron at rest yields two gamma rays each of energy $E = mc^2$ (m the mass of electron). Other antiparticles can be produced in collisions between particles and matter using accelerators.

Antimatter is one of the great mysteries in physics! At the origin of the Universe we expect by symmetry that the same amount of matter and antimatter would have been produced. But if antimatter annihilates with matter, why only matter survived giving rise to the existing world? Could it be due to some asymmetry between matter and antimatter?

To try to answer this last question, various experiments were set up at the antiproton facility at CERN, the only place in the World where antiprotons are produced. AEgIS (Antimatter Experiment: gravity, Interferometry, Spectroscopy) is one among these experiments. As explained in the detailed description in the following chapter, its main goal is to produce a beam of anti-hydrogen (the antimatter of an hydrogen atom, formed by a positron and an antiproton) and to study if antimatter falls with the same acceleration as the ordinary matter in the Earth gravitational field.

Antiproton bunches are delivered by CERN, while the AEgIS group of Trento is in charge of producing positron bunches moderating fast positrons, storing and dumping them. Although at present the number of antiparticles that can be produced or obtained by natural sources is small, in laboratory the Trento positron group manipulates antimatter not only for facing fundamental questions but also to study matter. In its laboratory at the Department of Physics, a positron beam has been designed and set up in which slow energy positrons, produced from a sodium radioactive source coupled to a moderator, are electrostatically guided and accelerated at an energy between few eV to some tens of keV towards a target in a sample chamber. This beam is used for fundamental R&D research for producing cooled positronium, the lightest atom in nature composed by an electron and a positron and an ingredient to form antihydrogen in the AEgIS experiment, and for applied studies of technological advanced materials in the field of energetic, semiconductor, soft matter and metal alloys. Positron annihilation techniques are unique for in-depth profiling of defects in matter such as vacancy sites and open nanovoids, and in following their evolution under chemical-physical changes.

AEgIS

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The AEgIS (Antimatter Experiment: Gravity, Interferometry, Spectroscopy) experiment has the objective to test the weak equivalence principle (WEP) by studying the free fall of antihydrogen ($\bar{H}$) in the Earth's gravitational field. The measurement of the gravitational acceleration $\bar{g}$ on $\bar{H}$ will be performed by measuring the time of flight and the vertical displacement of each $\bar{H}$ after its passage through a moiré deflectometer. The AEgIS method and set up to produce a pulsed $\bar{H}$ beam is illustrated in Fig. 1. Antiprotons ($\bar{p}$) of 5.3 MeV delivered by AD are slowed down to a few keV passing through a degrader and then caught in a Penning-Malmberg trap in the 5 T magnet where they reach few Kelvin degrees by sympathetic cooling with electrons. Cooled ($\bar{p}$) are transferred into a second Penning-Malmberg trap in the 1 T magnet where ($\bar{H}^*$) is to be formed. Positrons (e^+) are cooled in a two-stage Surko buffer trap and stored in a Penning-Malmberg accumulator delivering e^+ bunches that are transferred in the 5 T and then in the 1 T magnet where they are injected in a e^+ - *Ps* (positronium) porous silica converter. The fraction of formed *Ps* that is cooled by collisions in silica and emitted into vacuum is laser excited in long living Rydberg states. Rydberg *Ps* fly into the antiproton trap, where can be formed in an excited state by the charge exchange reaction: $Ps^* + \bar{p} \rightarrow \bar{H}^* + e^-$. Excited $\bar{H}^*$ is Stark accelerated and decays to ground state along its path towards the moiré deflectometer. An extra chamber to perform R&D experiments on *Ps* is connected to the e^+ accumulator.

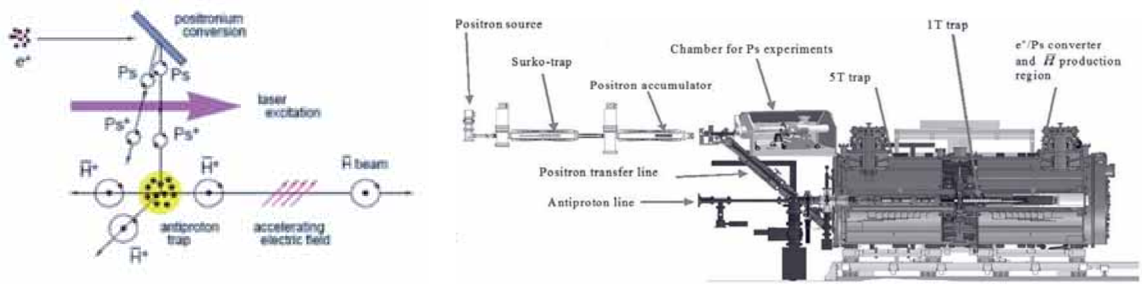

Figure 1: the AEgIS method and the AEgIS experimental set-up for the production of a pulsed cold $\bar{H}$ beam.

Status of the experiment

The feasibility of the free fall measurement of $\bar{H}$ by a moiré deflectometer was proved by measuring the deflection of an antiproton beam with a small scale moiré deflectometer and an emulsion detector with 2 μm resolution mounted at the end of the two main magnets. It was shown that shift of ten microns, as expected in a free fall experiment with $\bar{H}$ can be effectively measured (Aghion et al. 2014). A

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reproducible procedure for trapping e^+ and $\bar{p}$ in the Penning-Malmberg trap in the 5 T region was devised during the 2015-2016 AD run. On the average $3.6 \cdot 10^5$ $\bar{p}$ were captured for each shot of $3.0 \cdot 10^7$ $\bar{p}$ delivered by AD and a cooling efficiency of 90% was achieved in about 60 s with an optimum overlap of the e^- - $\bar{p}$ clouds. Up to $2.2 \cdot 10^8$ e^+ are routinely stored delivering shots of $1.8 \cdot 10^7$ e^+ from the accumulator (Fig. 2). e^+ are stored for tens of minutes without significant losses.

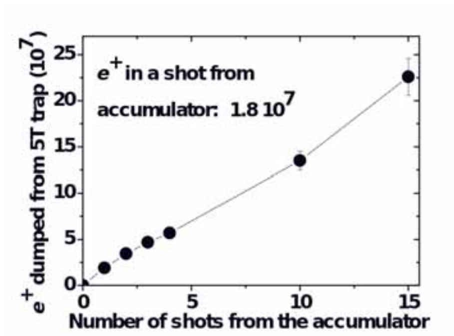

Figure 2: Trapped e^+ in the 5 T *region as a function of number of shots from the accumulator.*

The chamber for *Ps* experiment was successfully tested (Aghion et al. 2015). Pulses of e^+ with 10 ns duration were injected in a Si target with oriented oxidized nanochannels and high yield of *Ps* in vacuum was observed. Then *Ps* excitation was proved by performing a two-step *Ps* excitation $1^3S \rightarrow 3^3P \rightarrow Rydberg$ (Aghion et al. 2016). A UV laser pulse (205 nm) was used to excite *Ps* from ground to $n = 3$ state and simultaneously an IR laser ($\lambda = 1064$ nm) was shot to ionize the excited *Ps*. An IR laser (tuneable wavelength in the $\approx 1650 - 1720$ nm range) was pulsed at the same time with the UV laser to excite *Ps* from $n = 3$ to Rydberg levels. *Ps* excitation was measured by the SSPALS (Single Shot Positron Annihilation Lifetime Spectroscopy). In Fig. 3 a SSPAL measurement is shown and in the inset the *Ps* $n = 3$ excitation line.

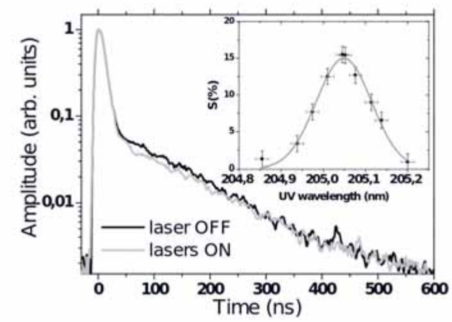

Figure 3: SSPALS spectra. Inset: scan of the UV wavelength, showing the Ps $n = 3$ excitation line.

References

Aghion, S. et al., the AEgIS Collaboration (2014). “A moiré deflectometer for antimatter”. In: *Nat. Commun.* 5, p. 453.

— the AEgIS Collaboration (2015). “Positron bunching and electrostatic transport system for the production and emission of dense positronium clouds into vacuum”. In: *Nucl. Instrum. Methods Phys. Res. B* 362, pp. 86–92.

— the AEgIS Collaboration (2016). “Laser excitation of n=3 level of Ps for antihydrogen production”. In: *Phys. Rev. A* 94.

Activities starting in 2017

FOOT

Research outline The main goal of the FOOT experiment is to improve the accuracy of proton therapy cancer treatments, by studying the inelastic nuclear interactions taking place between the primary beam and the patient tissues. Target fragments that originate from such interactions can have high charge (i.e. high biological effectiveness) and low residual range. This means that they will deposit all their energy close to their generation point. Consequently, a biological effect might be associated to target fragments, especially in terms on normal tissue damage in the entrance channel before reaching the tumour. Currently, these interactions are not accurately considered by treatment planning softwares, due to the lack of cross section data to describe target fragments production. FOOT will measure such cross section with high precision (less than 5% uncertainty), by adopting an inverse-kinematics approach. To this purpose, a complex experimental setup is currently under design and partially already in realization.

involved external institutions GSI, Darmstadt (Germany); Nagoya University (Japan)

INFN groups Napoli, Roma1, Roma2, Frascati, Perugia, Milano, Pisa, Torino, Bologna, TIFPA

Principal Investigator Vincenzo Patera, INFN-Roma 1

TIFPA team Francesco Tommasino (coordinator), Marco Durante, Sebastian Hild, Emanuele Scifoni, Piero Spinnato

A blackboard target irradiated by a theoretical physicist emitted chalk beam

Theoretical Physics

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TIFPA Theoretical Physics Activities

The theory group of TIFPA has a long standing tradition. Its history has always been closely connected with that of the Physics Department of the University of Trento, and, in the last two decades, with that of ECT*. The connection with INFN was guaranteed by the presence of the "*Gruppo Collegato*" of the Padova Section. The advent of TIFPA helped to bring the Trento theory group on the spot within the INFN community, and fostered the possibility of having a more vital interaction with the Institute.

Due to the specific characterization of the Physics Department, the TIFPA theory group does not follow the standard composition found elsewhere in Italy. At present we have activated seven different groups referring to the national projects ("*Iniziative Specifiche*") approved and financed by the national scientific committee for theoretical physics.

One of the main research lines is based on the theory of fundamental interactions. In particular there is a group carrying on modern views and perspectives in gravitation and cosmology (FLAG), and one working on the numerical solution of General Relativity equations related to the investigation of gravitational waves emission (TEONGRAV).

Nuclear physics has always played an important role in Trento. The structure and dynamics of nuclei, and the connections of nuclear theory to stellar physics and the more fundamental quantum chromodynamics theory are investigated with modern few-body (FBS) and many-body (MANY-BODY) numerical techniques. Research in hadron physics was also present until the end of this year, carried out within the NINPHA project.

An interesting development occurred after the establishment of TIFPA was the creation of a research team within the Mathematics Department working on fundamental aspects of quantum theory and extensions of quantum field theory in curved spaces (BELL).

A strong identification mark of the TIFPA group is the presence of interdisciplinary activities, which are of great importance in the context of the Center. In particular, there is a well established activity in theoretical biophysics, looking for innovative tools in the description of the kinetics of complex molecules (BIOPHYS). Very important has always been the fundamental research and the application to condensed matter problems which will be made more visible through the opening of a new project focussed on solid state physics (NEMESYS). In this field it is also active the ECT*-LISC group, mainly focussed on computational materials science and physics of transport phenomena.

The TIFPA theory group has always been connected to the INFN experimental activity in Italy and abroad, and is open to the new developments and new challenges brought by the Center. Presently it counts 42 researchers. About half of them are University of Trento, FBK, INFN and other institutions staff members, and rest are M.Sc. and Ph.D. students, and post-docs.

BELL

Valter Moretti,[†] Romeo Brunetti, Riccardo Ghiloni, Sonia Mazzucchi, Alessandro Perotti, Davide Pastorello, Marco Oppio, Alberto Melati

BELL research group at TIFPA studies various foundational, axiomatic and mathematical topics of Quantum Theories, also in relation with quantum field theory and quantum gravity. Mathematical advanced technologies are exploited to solve difficult problems of theoretical physics or to construct physically significant, non-trivial, mathematical models, completely solvables which can be used as starting points for physical applications. During 2015-2016 we published something like 10 research papers on international research journals or as chapters of research monographies. Just to have a (not exhaustive) look of our intensive production we focus attention on three relevant works about three corresponding topics of mathematical methods for physics.

Quantum Field Theory in Curved Spacetime

The first paper (Khavkine et al. 2016), by Igor Khavkine and Valter Moretti, concerns some technical issues related to the renormalization procedure in Quantum Field Theory on Curved Spacetime. Renormalisation, roughly speaking, is a mathematical technology used to remove infinities and to achieve physically meaningful quantities in interacting Quantum Field Theory. The picture is here even more complicated because the studied quantum fields interact also with the geometrical background of the spacetime and the theory must be formulated into a completely covariant framework as requested by General Relativity. A general locally covariant renormalization approach was constructed starting from R. Brunetti and K. Fredenhagen's work of the end of nineties. (Brunetti is a member of BELL group and he is still producing important research on these topics especially focusing on Quantum Gravity.) A general prescription to renormalize the so called Wick-polynomials was proposed by S. Hollands and R.M. Wald in 2001. That procedure was based on a list of meaningful physical axioms. One of them, however, concerned the analytic dependency of the physical quantities on every metric we may take in the background spacetime. This axiom did not seem very natural and its use turned out to be quite cumbersome. (Khavkine et al. 2016) establishes that this axiom can actually be dropped and replaced with a weaker and more natural requirement, preserving the final classification of finite renormalization counterterms. The key tool to achieve this relavent theoretical result is due to an advanced theorem on differential geometry known as Peetre-Slovák's theorem on the characterization of non-linear differential operators by their locality and regularity properties.

Feynman Functional Methods for Quantum Theoreies

Another result achieved by Sergio Albeverio and Sonia Mazzucchi (Albeverio et al. 2016) regards the so called Feynman integral technology. This elegant and definitely powerful mathematical approach to the formulation of quantum theories was invented by R. Feynmann

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in 1948 and since then it has been fruitfully applied to Quantum Mechanics and Quantum Field Theory. Essentially, the crucial idea is to replace the classical notion of a single, unique temporal evolution for a system with a sum, or functional integral, over an infinity of possible evolutions to compute a quantum amplitude. In spite of the powerfulness of this approach, its rigorous mathematical formulation has always been very challenging due to the well-known deep differences between the path-integral machinery, exploited in quantum physics, and the standard probability measure theory on infinite dimensional spaces. (Albeverio et al. 2016) goes towards the opposite direction as it presents results common to the two technologies. As a matter of fact, an approach to infinite-dimensional integration which unifies the case of oscillatory Feynman integrals and the case of probabilistic type integrals is established in (Albeverio et al. 2016). It provides a truly infinite-dimensional construction of integrals as linear functionals, as much as possible independent of the underlying topological and measure theoretical structure. Various applications are discussed in the paper, including, next to Feynman path integrals, Schrödinger and diffusion equations, as well as higher order hyperbolic and parabolic equations.

Quantum Cryptography

Last but not least, Davide Pastorello's paper (Pastorello 2016b) concerns quantum cryptography. Again the rigorous mathematical approach (POVMs and Quantum Operations theory) plays a crucial rôle here. One of the most prominent practical applications of quantum information theory is quantum cryptography, in particular the so-called Quantum Key Distribution (QKD) where a transmission of quantum information is used to create a shared key between two clients. Pastorello's paper discusses a general open-loop scheme to control a single qubit pointing out some problems about effective eavesdropping attacks. A scheme with two control functions is therefore proposed to define an improved quantum cryptographic protocol where controlled dynamics of qubit (or a string of qubits) gives rise to an encryption procedure and the values of controls are transmitted in a classical communication. The control law is encoded in a bit-string that contains a redundant information. Decryption can be implemented by the receiver once known both the control sequence and the time at which he must perform a measurement on the received qubit. Unconditional security is guaranteed by the fact that the unique way to intercept information is implementing a controlled time evolution of the qubit for decryption causing a detectable delay in transmission.

Figure 1: John Stewart Bell (1928 - 1990), a truly deep and serious thinker, was one of the leading experts on the foundations of quantum mechanics.

References

Albeverio, S. and Mazzucchi, S. (2016). “A unified approach to infinite-dimensional integration”. In: *Reviews in Mathematical Physics* 28, p. 1650005.

Khavkine, I. and Moretti, V. (2016). “Analytic Dependence is an Unnecessary Requirement in Renormalization of Locally Covariant QFT”. In: *Communications in Mathematical Physics* 344, pp. 581–620.

Pastorello, D. (2016b). “Open-loop quantum control as a resource for secure communications”. In: *International Journal of Quantum Information* 14, p. 1650010.

BIOPHYS

Giovanni Garberoglio, Pietro Faccioli,† Simone Orioli, Elia Schneider

The goal of the BIOPHYS Scientific Initiative is to model and analyse the dynamics of complex biological systems by exploiting advanced theoretical physics methodologies and related computational techniques. In particular, the network focuses on problems which lie at the interface between Molecular Biology and Physics. By its own nature, this kind of research addresses problems which are at the crossroad between fundamental and applied science (see Fig. 1).

Within this framework, the main focus on the TIFPA unit is the investigation of the classical and quantum non-equilibrium processes in biomolecules at the atomistic level of detail. In particular, our group operates within the LISC laboratory (see p. 101) and develops and applies theoretical and computational approaches based on path integrals, quantum field theory and renormalisation group (RG) methods to study both the structural dynamics and the electronic dynamics of proteins and other organic or biological polymers.

Starting from a path integral representation of these systems' density matrix and applying the classical approximation for the motion of the atomic nuclei, one can recover the Langevin path integral formulation of the Langevin dynamics, which can be used as a starting point to apply an arsenal of powerful approximations.

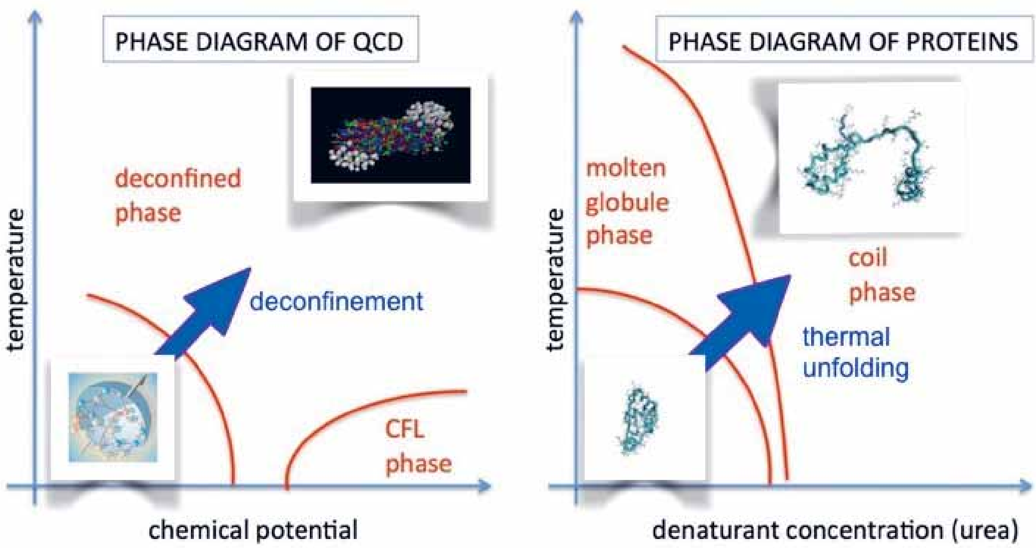

Figure 1: Phase diagrams of hadronic matter and of a typical globular protein. Both diagrams exhibit a low-temperature low-entropy phase and a high-temperature high-entropy phase. This analogy illustrates the usefulness of interdisciplinary approaches and in particular the use of theoretical physics methods developed in the context of subnuclear physics to investigate biomolecules.

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These approximations enabled us to significantly lower the computational cost of performing microscopic simulations and paved the door to investigate a number of processes of biological interest, which occur at time scales which are inaccessible to plain molecular dynamics simulations. In particular, the group developed a variational approximation to the stochastic path integral representing the Langevin dynamics (a Beccara et al. 2015) which was then used to simulate protein folding reactions and to predict the effect of single point mutations of the misfolding propensity of serpins, a family of proteins whose misfolding correlates with severe human lung and liver deficiencies (the latter results are being submitted for publication in Science).

In collaboration with the theoretical chemistry group led by prof. Mennucci at the University of Pisa, the unit has also carried out a project based on interfacing our structural dynamics calculations with advanced electronic structure calculation to obtain directly a prediction for circular dichroism experiments. This represents one of the few attempts to bridge the gap between atomistic calculations for protein folding dynamics and direct experimental data. The unit ha also developed an application of the renormalisation group theory to perform dimensional reduction of stochastic models for complex macromolecular dynamics (Markov State Models) (Orioli et al. 2016). Unlike other existing heuristic approaches, this rigorous method has the advantage to preserve by construction the correct relaxation timescales.

A significant part of the activity of the TIFPA unit has been devoted to investigating the dissipative relaxation dynamics of electronic excitations of biomolecules, using a scheme based on combining stochastic path integrals with quantum field theory formalism. In particular, this scheme can be applied to microscopically study the origin of long-lived quantum coherences observed in photosynthetic antennas. Previous studies focused on the dynamics in the asymptotic short- and long- time regimes, were important simplifications occur which make this theory solvable. In 2015 the TIFPA unit was able to develop a fully non-perturbative numerical scheme which enables us to solve for the real-time open quantum dynamics also in the intermediate time regime, and microscopically compute observables which are directly measured by experiments (e.g. 2D echo maps) (Schneider et al. 2016).

Additional research activity of the unit has been devoted to computational modeling various properties of carbon-based materials, with particular emphasis on graphene-based nanoporous materials, including simulations of adsorption properties of graphene-oxide pillared networks and the mechanical properties of graphene nanofoams. Part of this work was done in collaboration with experimental groups, modeling the processes leading to graphene formation after supersonic molecular-beam epitaxy of fullerenes and the reflection energy-loss spectra.

Finally the quantum field theory techniques developed by the TIFPA unit to study non-equilibrium quantum dynamics of electronic excitations in biomolecules have been adapted and exported to perform simulations of the dissociation and recombination of charmonia states in relativistic heavy ion collisions, starting from an abelian gauge theory mimicking QCD in the deconfined phase.

References

a Beccara, S., Fant, L., and Faccioli, P. (2015). “Variational Scheme to Compute Protein Reaction Pathways Using Atomistic Force Fields with Explicit Solvent”. In: *Phys. Rev. Lett.* 114, p. 098103.

Orioli, S. and Faccioli, P. (2016). “Dimensional Reduction of Markov State Models from Renormalization Group Theory”. In: *J. Chem. Phys.* 145, p. 124120.

Schneider, E., a Beccara, S., Mascherpa, F., and Faccioli, P. (2016). “Quantum propagation of electronic excitations in macromolecules: A computationally efficient multiscale approach”. In: *Phys. Rev. B* 94, p. 014306.

FBS

Winfried Leidemann, Giuseppina Orlandini,[†] Fabrizio Ferrari Ruffino, Paolo Andreatta

The main goal of this research activity is the theoretical investigation of the **structure and dynamics of nuclear few-body systems**. This investigation includes structure properties of light nuclei and hypernuclei, as well as reactions involving continuum states. The motivation for this research is twofold. First, to connect the properties of such nuclear/hypernuclear systems to the microscopic interactions among the constituents. Therefore, part of the activity is devoted to provide a better understanding of the nuclear interaction, in particular its three-body component, by comparing the results of *ab initio* approaches and experimental observables. Second, to develop new methods adapted to solve the quantum mechanical many-body problem for increasing mass number.

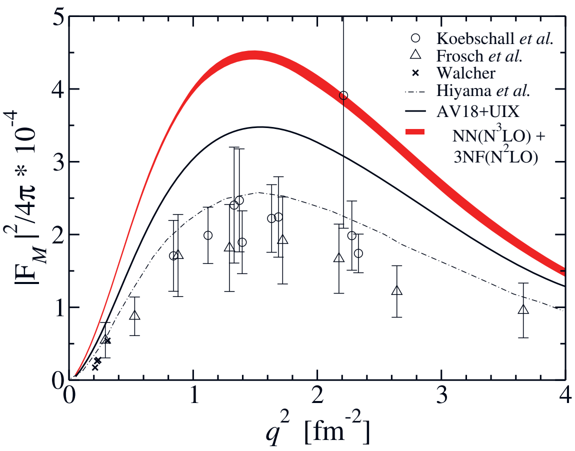

Figure 1: Monopole transition form factor calculated with various potential models.

What characterizes the Trento activity (and which makes it a recognized leader group in the field of Few-Body Physics) is the development and application of an original integral transform approach, which is known as the **LIT method** (LIT=Lorentz Integral Transform) to study reactions involving states in the continuum.

In the following recent selected results, obtained by applying such a method are presented:

(i) An *ab initio* calculation for the ^{4}He inelastic isoscalar monopole response function to an external probe has been carried out (Bacca et al. 2015; Leidemann 2015), using the LIT method in combination with an EIHH (Effective Interaction Hyperspherical Harmonics) expansion. The isoscalar monopole spectrum has been calculated up to 100 MeV for various momentum transfers. In particular we have been able to separate background and resonance strength (see Fig. 1). The results of these calculations have shown two very interesting features: on the one hand the monopole transition form factor has turned out to be one of the very few observables that shows a large potential model dependence (see Fig. 2), and on the other hand various criteria are surprising fulfilled for a classification of the ^{4}He isoscalar monopole resonance as a "collective breathing mode", in spite of the small number of constituents. In fact, using modern realistic nuclear forces (phenomenological AV18 nucleon-nucleon potential and UIX three-nucleon force as well as chiral two- and three-nucleon forces) it has been found that there is a strong exhaustion of the total monopole strength at low mo-

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mentum transfer. Another reason that hints to a breathing mode is the fact that the calculated transition density changes sign close to the ^{4}He radius. Finally the approach has succeeded in giving an accurate and realistic estimate of the incompressibility of ^{4}He. Such a nucleus results to be a very "compressible" system.

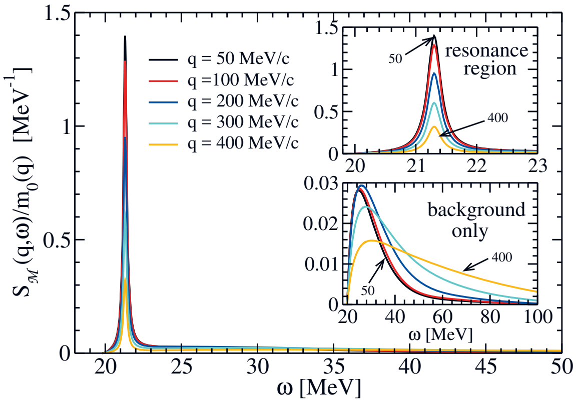

Figure 2: Isoscalar Monopole spectrum of ^{4}He at various fixed momentum transfers. In the insets the strength in the resonance region and the background contribution.

(ii) The ability of the LIT method to resolve narrow resonances has been investigated (Leidemann 2015). It has been shown that the success of the method in such cases is connected to a proper choice of the basis used to represent the Hamiltonian operator. A great improvement has been obtained by using a basis consisting in the (A-1)-body hyperspherical harmonics and additional functions for the part that describes the relative motion of the A-th nucleon with respect to the center of mass of the other A-1 nucleons. For the actual calculation of the very narrow ^{4}He isoscalar monopole resonance a width of 180(70) keV has been obtained, which compares quite well to the experimental value of 270(50) keV, in spite of the central only potential used in the calculation.

(iii) In the attempt to extend to increasing mass number the applicability of the methods born in the few-body sector the LIT method has been implemented within the "Coupled Cluster" (CC) approach. Very important results have been achieved within a large and intensive collaboration, to study a medium mass nucleus, which is at present the object of a widespread experimental interest, namely ^{48}Ca. In (Hagen et al. 2016) the LIT approach has allowed the prediction of its electric dipole polarizability and the observation of correlations among various observables. In Fig. 3 we report the figure from (Hagen et al. 2016) illustrating the correlation of neutron skin, r.m.s. point-neutron radius and electric dipole polarizability versus the r.m.s. point-proton radius when calculated with different potential models.

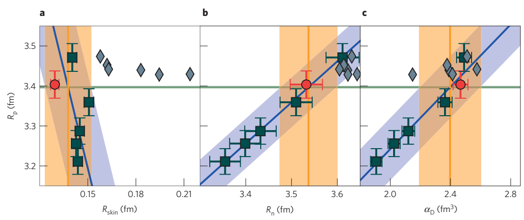

Figure 3: Correlation between the neutron skin, r.m.s. point-neutron radius and electric dipole polarizability of ^{48}Ca versus the r.m.s. point-proton radius. [From (Hagen et al. 2016)]

References

Bacca, S., Barnea, N., Leidemann, W., and Orlandini, G. (2015). "Examination of the first excited state of ^{4}He as a potential breathing mode". In: *Phys. Rev. C* 91.

Hagen, G., Ekström, A., Forssén, C., Jansen, G. R., Nazarewicz, W., Papenbrock, T., Wendt, K. A., Bacca, S., Barnea, N., Carlsson, B., Drischler, C., Hebeler, K., Hjorth-Jensen, M., Miorelli, M., Orlandini, G., Schwenk, A., and Simonis, J. (2016). "Neutron and weak-charge distributions of the ^{48}Ca nucleus". In: *Nature Physics* 12, pp. 186–190.

Leidemann, W. (2015). "Energy resolution with the Lorentz integral transform". In: *Phys. Rev. C* 91.

FLAG

Luciano Vanzo,† Sergio Zerbini, Guido Cognola, Massimiliano Rinaldi, Stefano Chinaglia, Aimeric Colleaux, Ylenia Rabochaya

Most of the research activity 2015/2016 focussed on four/five main research areas:

- (i) scale invariant models of inflation,
- (ii) Black holes in modified theories of gravity,
- (iii) Horndeski theories, mimetic gravity and applications,
- (iv) the nature of dark energy (and possibly of dark matter),
- (v) The Euclid project

(i) In the theory of inflation, we analyzed several attractor mechanism for generating primordial density fluctuations with the spectrum compatible with the data collected by the Planck satellite. The leitmotiv was to emphasize the role of the quasi-scale invariance of the underlying theory, non canonical kinetic terms and non analytic inflationary potentials. We found very good agreement with the data, potentially enlarging the class of viable models (while from other viewpoints we should perhaps try to restrict them). For a paper characteristic of this line of research, see (Rinaldi et al. 2016b).

(ii) Black holes and neutron stars in modified theories of gravity was our second most important activity. We mention a complete study of the thermodynamic properties of black hole in scale invariant quadratic theory of gravity, the discovery and analysis of black holes in Horndeski gravity (see below), and the study of regular black holes (with no singularity at the center). These researches involved collaborations with external partners from Chile Austral University and Belgium institutions. For a characteristic paper, see (Cognola et al. 2015c). These studies help to improve recent claims that signatures of modified gravity could be found by gravitational waves detections such as LIGO.

(iii) Horndeski like theories and mimetic gravity have recently been reconsidered because they have complicated dynamical *second order equations of motions*, despite the presence in the Lagrangian of higher derivatives terms. A bunch of results have been obtained by considering black holes as well as cosmological solutions. Most important was the study of the role of scalar fields in forming neutron stars, where some new solution has been found. For papers see (Cognola et al. 2015b).

(iv) The fundamental and difficult problem of tracing out the origin of the dark energy component responsible for the current accelerated expansion of the world, is always at the center of the interest of members of the FLAG initiative, here in TIFPA as well elsewhere. Some tentative results have been obtained within classical Yang-Mills theories admitting spontaneous symmetry breaking and the Higgs field. And apart from modified classical gravity models, a line of research has been open on the role of quantum effects due to conformal scalars, which is work in progress.

(v) *The Euclid project* M. Rinaldi is a founder

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member of the Euclid Theory Working Group, namely an international group of more than 50 theoreticians engaged to give a theoretical support to the ESA Euclid mission to be launched in 2021. The main activity is to systematically study models of dark matter and dark energy and to produce the related forecasts to be confronted with data. The results of this collaborations are continuously reported an updated in Living Review of Relativity (for the last version see (Amendola et al. 2016) in the general bibliography section at the end of the Activity Report).

Seminar and Events

During June 6-8/2016 we held in Trento the second FLAG meeting "The Quantum and Gravity". With the participation of such outstanding physicists as A. Starobinsky and G. Dvali, A. Burinskii, D. Galt'sov, S. Matarrese, A. Kamenshchik and others, and around fifty participants from FLAG nodes and elsewhere. With more than 30 talks on the subject topics, the meeting was our most intense and worthy activity (contributions are saved in pdf form on the TIFPA web site[1] and are available for public reach).

M. Rinaldi has delivered a number of talks at international conferences, reported in the general seminar list at the end of this Volume.

References

Cognola, G., Rinaldi, M., and Vanzo, L. (2015b). "Scale-invariant rotating black holes in quadratic gravity". In: *Entropy* 17, pp. 5145–5156.

Cognola, G., Rinaldi, M., Vanzo, L., and Zerbini, S. (2015c). "Thermodynamics of topological black holes in R^2 gravity". In: *Phys. Rev.* D91, p. 104004.

Rinaldi, M., Vanzo, L., Zerbini, S., and Venturi, G. (2016b). "Inflationary quasi scale-invariant attractors". In: *Phys. Rev.* D93, p. 024040.

[1] See `http://www.tifpa.infn.it/projects/flag/flag-meeting/`

LISC

Maurizio Dapor,[†] Simone Taioli, Giovanni Garberoglio

The research activity in the period 2015 to 2016 was focused on 4 areas. First, we developed a unified framework based on the scattering theory formalism, which is capable of describing a variety of physical processes ranging from core-electron spectroscopies of solids to the description of the universal properties in ultra-cold Fermi gases, to the investigation of β-decay and e-capture in astrophysical scenarios to unravelling the folding paths of proteins. This method relies on a generalisation of Fano's approach to discrete-continuum interaction (Taioli et al. 2015b) and, in particular, on the calculation of the multichannel T-matrix for determining accurately the continuum wave functions of particles emitted/captured from/in system's excited states, including the main correlation effects.

A second line of research concerned the first-principles simulation of the out-of-equilibrium chemical-physical processes leading to crystal growth by supersonic molecular beam epitaxy (SuMBE) (Tatti et al. 2016b). In particular, we demonstrated that high-kinetic energy fullerene beams impinging on semiconductor (silicon) or metallic (copper) targets can synthesise both 3D structures, such as silicon carbide nanocrystals, and prototype 2D materials, such as graphene, obtaining a significative reduction of the processing temperature with respect to existing growth techniques.

Third, we combined theoretical approaches based on non-euclidean group theory with numerical simulations to obtain the first energetically stable graphene-based molecular structure, which is a manifestation of a specific non-Euclidean crystallographic group. We showed that this group is related to the negative-curvature counterpart of a Platonic solid, and identified this structure as a Beltrami pseudosphere. While this method points to a general procedure to generate all such surfaces, we used graphene hexagonal topology to design the Beltrami pseudosphere. The choice of graphene was dictated by a correspondence between the physics of low-energy electrons in graphene arranged in these geometries, and quantum field theory in the presence of non-trivial curved spacetimes, e.g., 2+1-dimensional black holes. Therefore, from this latter perspective, our work is a solid first step towards a laboratory realization of condensed-matter structures corresponding to discrete spacetimes, whose "Planck length" is the carbon-to-carbon bond-length of graphene. This work has far and wide implications ranging from non-Euclidean geometry, to certain black-hole scenarios, to the solution of the generalized Thomson problem, and to material science. Finally, due to its unique electronic and mechanical properties, graphene demonstrated its potential in a plethora of applications in condensed matter physics and materials science. In this respect, we proposed a number of novel developments of graphene's use by simulating: i) gas adsorption, energy storage and sieving properties in realistic models of organic-pillared reduced-graphene-oxide sheets in comparison to metal organic frame-works; ii) mechanical properties of graphene foams and of bio-inspired materials; iii) a multiscale investi-

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gation of memristive behavior in TiO_2 crystals as alternative to graphene's photo-controllable and photoswitchable characteristics.

The last area is devoted to the transport of electrons in solid targets. In particular we investigated, using the Monte Carlo method, the radial distribution of the energy deposited in polymethylmethacrylate (PMMA) by the secondary electrons generated by proton impact (Dapor et al. 2015a). The initial energy and angular distributions of the emitted electrons by proton impact, as well as the electronic cross sections for the secondary electrons, were obtained by a semiempirical model based on the dielectric formalism, and where a realistic electronic excitation spectrum of PMMA is accounted for. The Monte Carlo simulations consider all the cascade of secondary electrons generated in PMMA and take into account the main interactions that take place: elastic (multiple Coulomb scattering) and inelastic (electronic excitation, ionization, electron-phonon interaction and polaronic effects). We analyzed the influence of a realistic energy and angular distributions of secondary electrons on the resulting radial doses of the deposited energy. Finally, the evolution of the radial dose with the initial proton energy was investigated.

References

Dapor, M., Abril, I., Vera, P. de, and Garcia-Molina, R. (2015a). "Simulation of the secondary electrons energy deposition produced by proton beams in PMMA: influence of the target electronic excitation description". In: *The European Physical Journal D* 69.6, pp. 1–10.

Taioli, S. and Simonucci, S. (2015b). "Chapter Five - A Computational Perspective on Multichannel Scattering Theory with Applications to Physical and Nuclear Chemistry". In: *Annual Reports in Computational Chemistry* 11, pp. 191–310.

Tatti, R., Aversa, L., Verucchi, R., Cavaliere, E., Garberoglio, G., Pugno, N. M., Speranza, G., and Taioli, S. (2016b). "Synthesis of single layer graphene on Cu(111) by $C_6$0 supersonic molecular beam epitaxy". In: *RSC Advances* 6.44, pp. 37982–37993.

MANYBODY

Francesco Pederiva,† Maurizio Dapor, Simone Taioli, Chen Ji, Lorenzo Contessi, Lorenzo Andreoli

The TIFPA unit of the MANYBODY collaboration pursues development and applications of quantum many-body techniques to both systems of interest for nuclear physics and nuclear astrophysics (Pederiva, Ji, Contessi, Andreoli), and applications to condensed matter physics (Dapor, Taioli, Pederiva). The methods toolbox is quite diverse, ranging from Quantum Monte Carlo and transport Monte Carlo to density functional theory and direct diagonalization of the Hamiltonian.

In the last two years the activity of the group was targeted to two main categories of problems: the study of static and dynamical properties of dense matter, in the context of the physics of Neutron Stars and supernovae, and the analysis of the recent lattice quantum-chromodynamics calculations of few-baryon systems in order to derive and understand general aspects of the nucleon-nucleon interaction.

Matter in the interior of a neutron star is believed to undergo several phase transitions. In particular, the *inner core*, the region where density becomes larger than twice the saturation density might see the onset of hyperons, nucleons in which one of the quarks is substituted by a strange quark. Whenever this occurs, the compressibility of the system increases, leading to what is called a “soft” EoS.

The specific density at which this transition occurs and the details of the evolution of the pressure depend very strongly on the model used to describe the microscopic interactions between nucleons and hyperons. The discovery in 2010 of neutron stars with mass $\sim 2M_\odot$ pointed out a severe contradiction between the predictions of such models and the observative results. In Trento we started a long term project that aims to develop an accurate phenomenological hyperon-nucleon interaction only based on existing experimental results. In terrestrial experiments it is quite hard to produce isolated hyperons, ad there is a very limited set of experimental $p-\Lambda$ scattering data that can be used to fit a two-body interaction. All the remaining information comes from experiments measuring the binding energy of Λ-hypernuclei. Almost no data are currently available on the isospin triplet family of hyperons (the $\Sigma^{-,0,+}$ particles), or hyperons with strangeness -2 (the $\Xi^{-,0}$) particles.

Our Quantum Monte Carlo calculations show that the use of a simple two-body Λ-nucleon force fitted on the scattering data fails to reproduce the binding energy of hypernuclei, and in particular does not reproduce saturation. The inclusion of a repulsive Λ-nucleon-nucleon three-body force, instead, produces a remarkable agreement over a very wide range of masses (up to $A = 91$). The use of this force to compute the EoS of Λ-neutron matter shows that such repulsion is sufficient to push the onset of hyperons to larger densities (see Fig. 1), eventually providing an EoS sufficiently stiff to stabilize neutron stars of the observed mass (Lonardoni et al. 2015). This work has been carried out in collaboration with D. Lonardoni

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and S. Gandolfi (LANL), and A. Lovato (ANL). It recently lead to the approval of a proposal of an electron-scattering experiment to measure medium mass hypernuclei by the hypernuclear collaboration at J-Lab, in which INFN is involved.

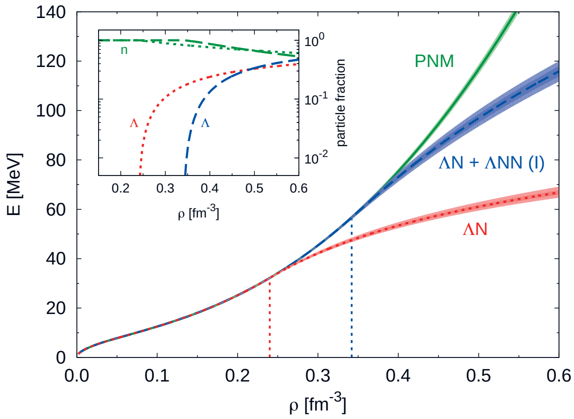

Figure 1: Equation of state of Λ-neutron matter computed with Quantum Monte Carlo methods with a phenomenological Hamiltonian. In the inset the computed fraction of Λ hyperons present in dense matter as a function of number density.

Other important aspects of the EoS were investigated, such us the low-density properties, using non local chiral interactions, and the isospin-density response function, relevant for the understanding of neutrino scattering in neutron star medium, studied within the mean-field linear response theory (in the Time Dependent Local Isospin Density Approximation), based on functionals derived once more from Quantum Monte Carlo calculations (Lipparini et al. 2016).

We also work on Lattice QCD calculations for directly deriving nuclear interactions. At present LQCD can estimate binding energy of multi-baryon systems, but only for artificially large quark masses, leading to pion masses in a range 400 - 800 MeV, and an extrapolation would be needed to describe the physical case. In this context it is interesting to understand how the nuclear systematics evolves as a function of the pion mass. In particular one would like to understand as properties like saturation, or the binding of heavier nuclei evolve, and if extrapolation is at all possible. Together with N. Barnea and D. Gazit of the Hebrew University in Jerusalem, and U. van Kolck from Orsay, we developed a pion-less effective field theory leading to a description of interactions between lattice nucleons, and performed calculations on a few lattice nuclei, showing that the potential developed in this scheme is indeed predictive and consistent with lattice results (Barnea et al. 2015). These calculations have been extended to larger masses, and in particular to ^{16}O, showing that binding might become problematic in these (unphysical) regimes.

As previously mentioned, the activity of the MANYBODY group, also encompass applications to other fields. Particularly important is the research in condensed matter theory. A substantial part of this work is developed within the ECT*-LISC unit, whose activities are described at page 101. However, the group also deals with the development of novel Quantum Monte Carlo techniques, such as the recently introduced Configuration Interaction Monte Carlo (CIMC), or general algorithms to deal with spin-dependent Hamiltonians. In this context, the first natural applications are on Coulombic systems, and therefore part of our scientific production did and will concern applications to many-electron systems such as the electron gas or atoms and molecules.

References

Barnea, N., Contessi, L., Gazit, D., Pederiva, F., and Kolck, U. van (2015). “Effective Field Theory for Lattice Nuclei”. In: *Physical Review Letters* 114.5.

Lipparini, E. and Pederiva, F. (2016). “Transverse isospin response function of asymmetric nuclear matter from a local isospin density functional”. In: *Physical Review C* 94.2.

Lonardoni, D., Lovato, A., Gandolfi, S., and Pederiva, F. (2015). “Hyperon Puzzle: Hints from Quantum Monte Carlo Calculations”. In: *Physical Review Letters* 114.9.

NINPHA

Marco Claudio Traini, Pietro Faccioli†

The goal of the NINPHA Scientific Initiative it to improve the understanding of the internal structure of hadrons (in particular the nucleon), in momentum and in configuration space. A related fundamental question is how the nucleon spin arises by composing the angular momenta of its quark and gluon constituents (partons). To this goal, scientists in the NINPHA projects focus on the analysis of a number of more informative observables such as Transverse Momentum Distributions (TMDs), Generalized Parton Distributions (GPDs), Double-Parton Distributions (dPDF).

The calculation of these quantities involves QCD matrix elements at variable momentum scales, which can be obtained by solving perturbative evolution equations starting from non-perturbative low-energy matrix elements. The TIFPA group has developed and applied different low-energy effective hadronic models, based on constituent quark and mesonic degrees of freedom (Rinaldi et al. 2016d; Rinaldi et al. 2016c). or derived from holografic approaches which exploit the AdS/CFT correspondence (Traini et al. 2016).

In particular, in the period 2015-2016 the team has focused on the possibility of observing parton-parton correlation effects in proton-proton scattering at LHC (see Fig. 1), mainly for two reasons: i) the knowledge of dPDFa represents a step forward in the comprehension of the proton structure at high energy; ii) disentangling multi-parton interaction effects is a crucial ingredient in the search for new physics. In particular, the main interest of the TIFPA group is in disentangling perturbative effects (which are better known) from non-perturbative contributions (less understood).

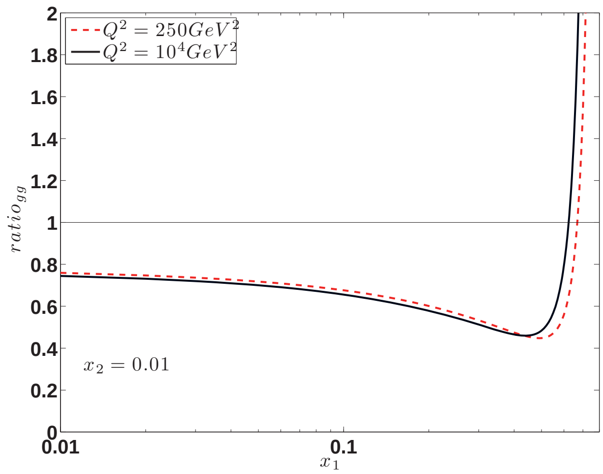

Figure 1: Two gluons of different momentum fraction ($x_2 = 0.01$) and $0.01 \leq x_1 \leq 0.8$ are involved in a proton-proton scattering at two different momentum transfers: $Q^2 = 250$ GeV^2 and $Q^2 = 10^4$ GeV^2. The presence of gluon-gluon correlations shifts the values of the ratio of double-parton distributions to products of single parton distributions from the standard value $ratio_{gg} = 1$. The effects of correlations shows up also at low-x, in region where LHC experiments can reveal their contributions (20% effect at $x_1 = x_2 = 0.01$)

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References

Rinaldi, M., Scopetta, S., Traini, M. C., and Vento, V. (2016c). “Correlations in Double Parton Distributions: Perturbative and Non-Perturbative effects”. In: *JHEP*, in press.

Rinaldi, M., Scopetta, S., Traini, M. C., and Vicente, V. (2016d). “Double parton scattering and 3D proton structure: A Light-Front analysis”. In: *Few Body Syst.* 57, pp. 431–435.

Traini, M. C., Scopetta, S., Rinaldi, M., and Vicente, V. (2016). “The effective cross section for double parton scattering within a holographic AdS/QCD approach”. In: *preprint* arxiv:1609.07242.

TEONGRAV

Bruno Giacomazzo,† Riccardo Ciolfi, Wolfgang Kastaun, Andrea Endrizzi, Takumu Kawamura, Eloisa Bentivegna

Neutron stars are the remnants of supernova explosions (the spectacular deaths of massive stars) and the densest objects in the universe besides black holes. A typical neutron star concentrates more than the mass of the Sun within a radius of only around 10 km. Because of their extreme gravity a proper description of neutron stars requires Einstein's theory of General Relativity. Investigating neutron star properties can shed light on the behavior of matter at very high densities, which is not yet understood well by nuclear physics. Two neutron stars can also bind together in a binary system, and orbit around each other for millions of years with a smaller and smaller separation. Eventually, the two merge together in an instant (just a few milliseconds) resulting either in a black hole or in a rapidly rotating neutron star, which can still collapse to a black hole later on. Binary neutron star mergers are among the most violent astrophysical events, which give rise to powerful gravitational wave signals that could be measured by the gravitational wave detectors LIGO and Virgo. They may also produce bright electromagnetic emission and be responsible for short gamma-ray bursts.

The TEONGRAV group in Trento studied the dynamics of different binary neutron star systems, considering neutron stars with different masses, different mass ratios, different equations of state (describing the internal composition of neutron stars), and different magnetic field configurations (Kawamura et al. 2016). The aim was to compute the gravitational wave signals and electromagnetic emission that these systems can emit.

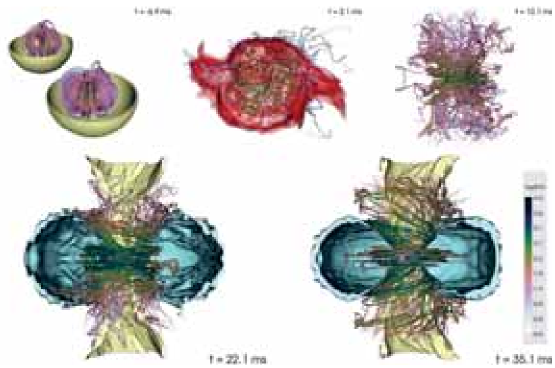

Figure 1: Simulation of a binary neutron star merger. The different panels show different stages of the evolution highlighting in particular the magnetic field structure. The last two panels show the final stages of the simulation where a black hole surrounded by an accretion disk is formed. In this case a magnetized low density funnel is also formed, which could launch a relativistic jet and possibly produce a short gamma-ray burst at a later time. The color of the field lines gives a rough indication of the field strength. Source: (Kawamura et al. 2016).

Fig. 1 shows the typical evolution of a binary neutron star system that forms a black hole soon after merger (Kawamura et al. 2016). The TEONGRAV group in Trento has in particular shown that, in those cases where a black hole is formed, an ordered magnetic field structure, with a low density funnel aligned with the spin axis of the black hole, is typically formed at the end of binary neutron star mergers, independently of equation of state and mass ratio. This has strong implications for the central engine

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of short gamma-ray bursts since such magnetic field structure may launch relativistic jets and power gamma-ray emission.

No jet was formed at the end of these simulations, but this is probably due to the lack of sufficiently high resolution to resolve properly the turbulent dynamics that takes place at merger. Simulations performed by the Trento group have indeed shown that during merger the magnetic field can be amplified of several orders of magnitude if the effect of turbulence is properly taken into account (Giacomazzo et al. 2015). While these simulations focused only on the amplification at merger, future studies will investigate the effects of such large magnetic field on the long-term dynamics of the post-merger remnants.

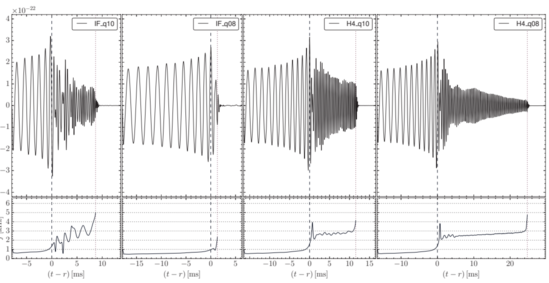


Figure 2: Gravitational wave signals emitted by four binary neutron star systems studied in this project. The top panels show the amplitude of the signals, while the bottom panels show the characteristic frequency as a function of time (time is set to be equal to zero at merger). Note how the signals differ after the merger (vertical dashed line). Detecting these differences could help to distinguish binary neutron stars with different properties. Source: (Kawamura et al. 2016).

Fig. 2 shows the gravitational wave signals emitted by some of the models studied by the Trento group. The strain amplitude is large enough to observe the signal with both the Virgo and LIGO detectors at distances of more than 100 Mpc. The differences between the signals are related to different equations of state and mass ratio and are very evident in the post-merger phase.

For some models where the outcome of the merger is a neutron star, its structure was investigated in unprecedented detail, including thermal evolution and fluid flow in relation to the deformation, with special attention on the phase shortly after merger which is most important for gravitational wave astronomy (Kastaun et al. 2016).

All the simulations used the WhiskyMHD code and were run on supercomputers, such as SuperMUC at LRZ (Germany) and Fermi at CINECA (Italy). More than 100 terabyte of data were generated and analyzed. Some of the data, including the gravitational wave signals, were also made publicly available. Data of this kind can be compared with future detections of gravitational waves in order to distinguish between different neutron star physical models.

The TEONGRAV group in Trento is currently working on several improvements, such as better calculation of initial data, and better description of finite temperature effects and inclusion of neutrinos. All of these improvements will increase the accuracy of the models and the corresponding gravitational wave estimates.

References

Giacomazzo, B., Zrake, J., Duffell, P. C., MacFadyen, A. I., and Perna, R. (2015). “Producing Magnetar Magnetic Fields in the Merger of Binary Neutron Stars”. In: *The Astrophysical Journal* 809, 39, p. 39.

Kastaun, W., Ciolfi, R., and Giacomazzo, B. (2016). “Structure of stable binary neutron star merger remnants: A case study”. In: *Physical Review D* 94.4, 044060, p. 044060.

Kawamura, T., Giacomazzo, B., Kastaun, W., Ciolfi, R., Endrizzi, A., Baiotti, L., and Perna, R. (2016). “Binary neutron star mergers and short gamma-ray bursts: Effects of magnetic field orientation, equation of state, and mass ratio”. In: *Physical Review D* 94.6, 064012, p. 064012.

Activities starting in 2017

NEMESYS

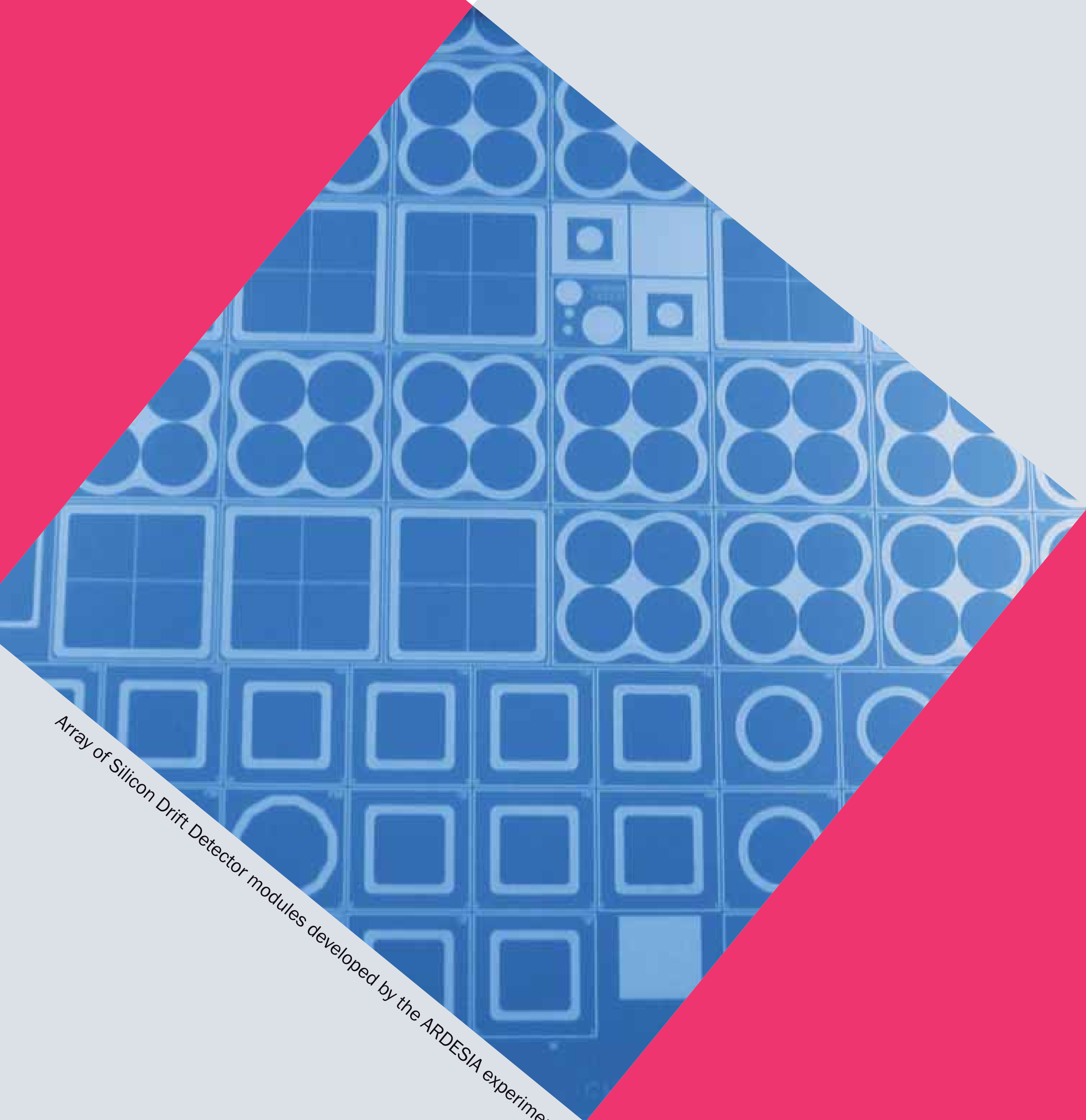
Research outline NEMESYS (Non Equilibrium dynamics Models and Excited state properties of low-dimensional SYStems) is a multidisciplinary and convergence research project in statistical physics and many body Green's function theory. Central to its overall theme is an investigation of the striking out-of-equilibrium properties and excited-state features of many fermions and bosons in low-dimensions. The project aims at developing new methods and computational strategies to unravel the fundamental excitations and corresponding relaxation dynamics of novel low-dimensional materials, which are also of strategic interest for nanoelectronics and quantum computing technologies. The NEMESYS program will involve running massive simulations of spectral features, dielectric screening, conductivity response and electro-mechanical properties of graphene-related and beyond-graphene materials, including their interfaces and contacts with supporting substrates.

involved external institutions 47 institutions from 17 countries

INFN groups Cosenza, LNF, Roma Tor Vergata, TIFPA

Principal Investigator Antonio Sindona, INFN GC Cosenza

TIFPA team Simone Taioli (coordinator), Maurizio Dapor, Giovanni Garberoglio



Array of Silicon Drift Detector modules developed by the ARDESIA experiment

Technological Research

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Coordinator,
TIFPA Technological Research Activities

Research projects of technological and interdisciplinary relevance which are of interest for the National Institute of Nuclear Physics (INFN) are supported by the so called 5th Committee (CSN5). The TIFPA CSN5 group was officially born in July 2015, and so far it has collected research activities mainly related to the development of new radiation detectors and to the study of radiobiological effects of ion beams. Today there are more than 40 persons associated to CSN5 research projects, coming from FBK (Fondazione Bruno Kessler) and from 3 Departments of Trento University: the Department of Physics, the Department of Industrial Engineering and the Centre for Integrative BIOlogy (CIBIO). All the research projects take advantage not only of the know-how and of technical and scientific facilities available at FBK and in the cited Departments, but also of the proton cyclotron facility available at the Trento Center for Protontherapy, giving proton beams of energies ranging from 70 to 250 MeV.

At present 12 projects are active, some funded this year and some which will be active next year; among them, two, MoVe-IT (whose Principal Investigator is from TIFPA) and SICILIA, are large projects named "calls" in CSN5 terminology, and are the only CSN5 projects where funding for grants is provided. In particular MoVe-IT, which will be funded next year, collects an international network for the realization of therapy treatment plans with ion beams, while SICILIA, started this year, is devoted to the production of silicon carbide based particle detectors for the detection of high fluxes of ions in nuclear physics experiments. In the field of detectors, some projects aim to assembly and develop X-ray detectors for spectroscopy, imaging and for space missions (ARDESIA, PiXFEL and REDSOX2, respectively), while other projects, like APIX2 and SEED, are more focused on the development of detectors for ion particles. Some projects aim also at studying and developing new materials for radiation detectors, like GBTD, which studies the use of graphene for the production of new thermal detectors of electromagnetic radiation, and NADIR, where the possibility to exploit the optical properties of quantum dots for the realization of portable nanodosimeters is explored. Finally, TIFPA participates in the project NEW REFLECTIONS focused on evaluation of the capability of laser technology for debris removal in Low Earth Orbit. Next year two new projects will be supported: AXIAL, which is an experiment for the study of the deflection on intermediate energy proton beams by coherent channeling through silicon membranes and HIBRAD, which is an interdisciplinary experiment on the effects of hibernation on the radio-resistance of living animals.

This overview evidences the wide range of research interests in the CSN5 community and the peculiar interdisciplinary character of the Committee. The increasing interplay between scientists from different laboratories suggest a further development of new intriguing projects in the next future.

APiX2

Lucio Pancheri,[†] Andrea Ficorella, Moustafa Khatib, Gian-Franco Dalla Betta

Goal of the APiX2 project is the development of an innovative position-sensitive pixelated sensor for the detection of ionizing particles. The APiX sensor is based on Geiger-mode avalanche pixels operated in fully digital mode with on-chip embedded electronics. In the Geiger-mode operation, a single electron-hole pair can trigger an avalanche event and thus there is no possibility to distinguish a particle-triggered event from a dark count. The proposed device is formed by two vertically-aligned pixelated detectors and exploits the coincidence between two simultaneous avalanche events to discriminate between particle-triggered events and dark counts (Fig. 1) .

This approach offers several advantages in applications requiring low material budget and fine detector segmentation as, for instance, for tracking and vertex reconstruction in particle physics experiments and charged particle imaging in medicine and biology. A sensor based on this concept can have low noise, low power consumption and a good tolerance to electromagnetic interference. In addition, a timing resolution in the order of tens of picoseconds can be achieved thanks to the fast onset of avalanche multiplication in Geiger-mode regime. The APiX device provides on-chip digital information on the position of the coordinate of the impinging charged particle and can be seen as the building block of a modular system of pixelated arrays, implementing a sparsified readout. The technological challenge of the vertical integration of the device, under CMOS processes and integration of on-chip electronics is performed in steps along a 3 years period, starting with a proof-of-concept approach.

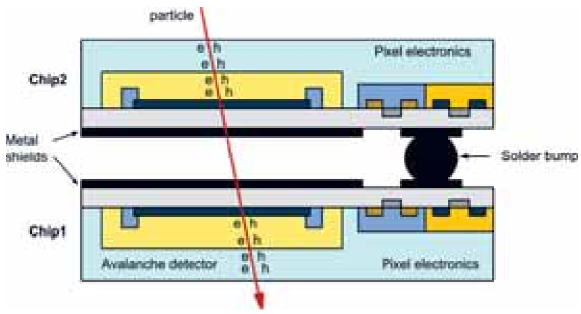

Figure 1: Concept view of a two-tier avalanche pixel

The first demonstrator, a two-tier sensor assembly, was designed and fabricated in a commercial 0.15μm CMOS process (Pancheri et al. 2016). The sensor consists of a 48x16 pixel array, and includes avalanche diodes of different sizes to evaluate the detection efficiency for different fill factors. Each pixel, having a 50μm x 75μm area, includes detectors and electronics on both layers, with the top-layer signal transmitted to the bottom layer using a vertical interconnection per pixel. In the pixel, the detectors are passively quenched and their output signals are digitized by means of a low-threshold comparator. The resulting pulses are shortened by a programmable-length monostable circuit, providing a minimum pulse width in the nanosecond range. The pixels can be independently enabled or disabled with an arbitrary pattern, defined by a configuration register. The output of the monostable in the top half-pixel feeds a coincidence detector located in the bottom layer, and the coincidence output is stored in a 1-bit memory. Data can be transferred in parallel to

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an output register for readout. In this way, signal detection and data readout can be run in parallel, thereby avoiding any dead time in the data acquisition process.

A few samples of top and bottom chips were wire-bonded for testing before proceeding to vertical integration. A micrograph of the bottom chip is shown in Fig. 2. Electrical tests showed the correct functionality of both avalanche detectors and electronics in the two chips. Preliminary DCR statistics were acquired, demonstrating an average DCR per unit area in the range of MHz/mm^2 (Fig. 3). A complete characterization of Dark Count Rate and pixel optical cross-talk has been carried out on single layers (Ficorella et al. 2016).

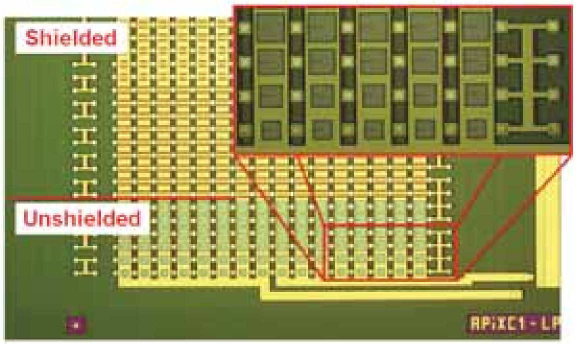

Figure 2: Micrograph of the bottom chip.

Several samples have been processed for vertical integration using bump bonding technique, which was chosen due to the accessibility of the process and good yield obtainable with small sample numbers. The detectors were covered with a metal shield to avoid inter-layer optical cross-talk. The correct functionality and high yield of the vertically integrated sensors has been demonstrated. In particular, the operation of the coincidence circuits has been validated with an experimental assessment of dark count rate. The dark count rate per unit area has been substantially reduced from the range of MHz/mm^2 of the single layers to few 10s or 100s Hz/mm^2 at room temperature of the vertically integrated sensors, depending on the operation parameters. The variation of DCR on coincidence time, temperature and overvoltage was assessed experimentally. A preliminary characterization with beta particles from a 90-Sr source demonstrates the correct sensor functionality. A test beam at CERN has been conducted to calculate the efficiency of the sensor. Results from this test beam are currently under analysis.

On the basis of these results, a new prototype is currently being designed, to inspect the limits of the proposed approach in terms of efficiency, power consumption, timing resolution and scalability.

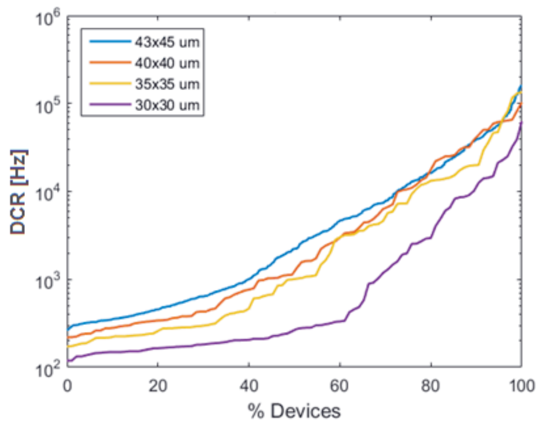

Figure 3: Dark count rate distribution of the avalanche detectors with 4 different sizes, obtained with 3V overvoltage, at 20°C.

References

Ficorella, A., Pancheri, L., Dalla Betta, G.-F., Brogi, P., Collazuol, G., Marrocchesi, P. S., Morsani, F., Ratti, L., and Savoy-Navarro, A. (2016). "Crosstalk mapping in CMOS SPAD arrays". In: *2016 46th European Solid-State Device Research Conference (ESSDERC)*, pp. 101–104.

Pancheri, L., Brogi, P., Collazuol, G., Dalla Betta, G.-F., Ficorella, A., Marrocchesi, P., Morsani, F., Ratti, L., and Savoy-Navarro, A. (2016). "First prototypes of two-tier avalanche pixel sensors for particle detection". In: *Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*. In press.

ARDESIA

Nicola Zorzi,[†] Claudio Piemonte, Francesco Ficorella, Antonino Picciotto, Maurizio Boscardin, Giacomo Borghi

ARDESIA is an experimental project aiming at the realization of a versatile and high-performance X-ray Spectroscopy detection system for synchrotron experiments in the energy range between 0.2keV and 25keV. The target energy resolution at -20 °C and 5.9keV is 123eV at low count rate ($\sim$10kcps) and lower than 150eV at high count rate (>1Mcps) (Quaglia et al. 2015a). The development of the basic detection module is built around a 2×2 monolithic array of Silicon Drift Detectors (SDDs) realized by the technology available at FBK (Trento). The readout chain is based on the CMOS preamplifier CUBE (Quaglia et al. 2015b), developed by Politecnico di Milano: a monolithic version with four channels has been designed and produced to fit the ARDESIA module. Both analog and digital processing systems are considered to assure compatibility with several filtering and data acquisition interfaces available in different synchrotron facilities.

A key concept of ARDESIA detection system is modularity. The single 4-channels ARDESIA module features an area of 16×16mm^2, with minimal dead area in addition to the dimensions of the SDD chip (12×12mm^2). The single basic module can be used when a small detector size is required. Thanks to the minimized dead border, it is possible to assemble many modules together when a bigger detector size or higher count rates are needed.

The role of INFN-TIFPA in the project concerns the design, the development of the fabrication technology, the production and the preliminary characterization of the SDD array detectors in close collaboration with the FBK microfabrication laboratory. The other INFN units involved in the project and their corresponding roles and tasks are as follows:

- INFN-Milan: overall project coordination, supervision of detector design, detection module development, integrated electronics and DAQ, spectroscopic measurements, support to experimentation in final applications;
- INFN-LNF Frascati: detector module development, DAQ, installation of the detection modules in the synchrotron facilities (LNF and ESREF), X ray characterization measurements.

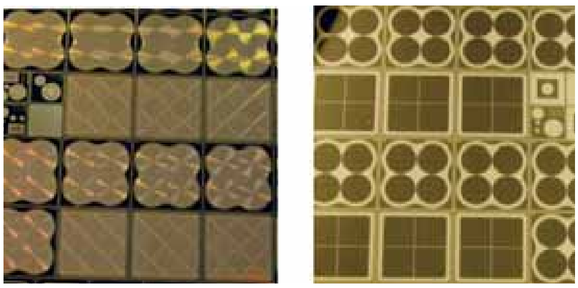

Figure 1: Picture of the SDD arrays on wafer. Left: anode and drift side. Right: entrance window side

The monolithic SDD arrays for ARDESIA were designed in two different versions with the aim to study the better compromise between minimization of drift time and dead area, thus implementing two different single-element

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shapes: circular (5mm-diameter) and square ($5\times5\text{mm}^2$) respectively (see Fig. 1). The SDD detectors were produced in the FBK microfabrication laboratory using floating zone, n-type, 6-inches, 450μm-thick silicon wafers with a resistivity of about 6kΩ cm. A specially tailored double-side, thin entrance window technology was adopted, which is also able to assure low leakage current values well below 500pA/cm^2 at room temperature. The fabricated arrays were tested at wafer level by using an automatic system, thus allowing identification of good/defective devices and their classification based on characteristic parameters (e.g. leakage current).

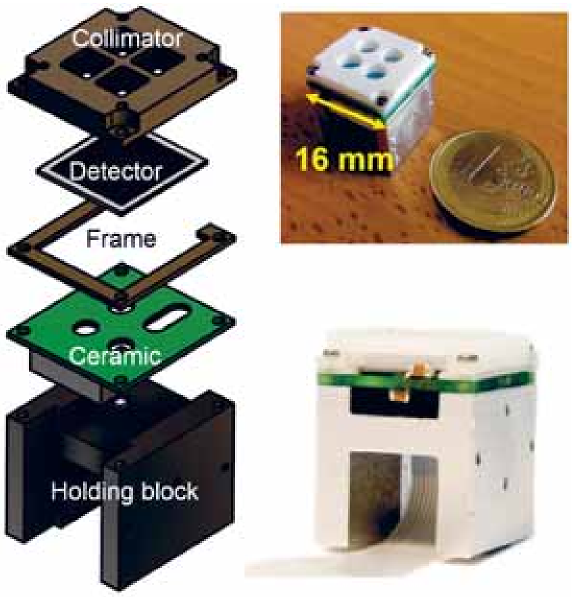

Figure 2: Schematic view and pictures of the prototype ARDESIA detection module

Selected array detectors were mounted at INFN Milan in prototype detection modules consisting of a holding block suitable for modular assembly and Peltier cooling, a ceramic board hosting a 4-channel CUBE preamplifier wire bonded to the 4 anodes of the SDD array and an X-ray collimator as sketched in Fig. 2. X ray spectroscopic tests are currently on going using a ^{55}Fe source at the 5.9keV Mn-Kα line, evaluating both digital and analog signal processing. An example of preliminary spectra obtained from the 4 channels of a detector cooled down at -27°C is reported in Fig. 3 for the case of the 16-channels analog pulse processor SFERA (Schembari et al. 2015). These experimental results look very promising in view of the construction of an X-ray spectrometer to be used for synchrotron beam-line tests.

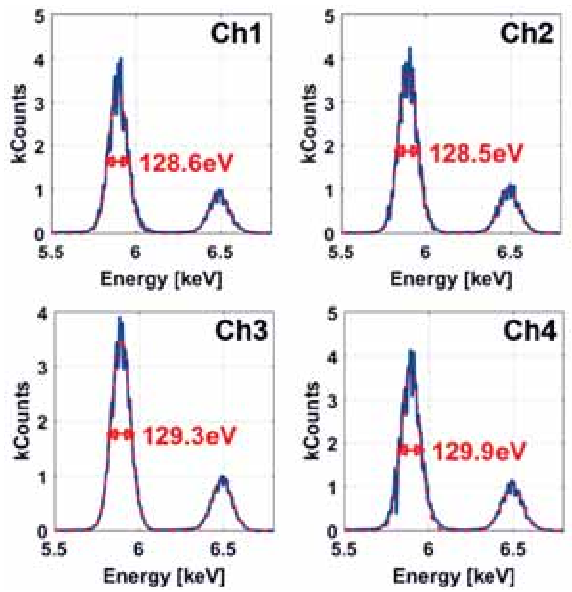

Figure 3: X-ray spectra obtained at T = -27°C and 3μs peaking time with the analog shaper.

References

Quaglia, R., Bellotti, G., Butt, A. D., Fiorini, C., Ripamonti, G., Schembari, F., Bombelli, L., Giacomini, G., Picciotto, A., Piemonte, C., and Zorzi, N. (2015a). "New Silicon Drift Detectors and CMOS Readout Electronics for X-ray Spectroscopy from Room Temperature to Cryogenic Operations". In: *Proceedings of the 2015 NSS-MIC conference, San Diego USA, 31/10-7/11*. IEEE.

Quaglia, R., Bombelli, L., Busca, P., Fiorini, C., Occhipinti, M., Giacomini, G., Ficorella, F., Picciotto, A., and Piemonte, C. (2015b). "Silicon Drift Detectors and CUBE Preamplifiers for High-Resolution X-ray Spectroscopy". In: *IEEE Transaction on Nuclear Science* 62, pp. 221–227.

Schembari, F., Quaglia, R., Bellotti, G., and Fiorini, C. (2015). "SFERA: a General Purpose Readout IC for X and γ-ray Detectors". In: *Proceedings of the 2015 NSS-MIC conference, San Diego USA, 31/10-7/11*. IEEE.

GBTD

Paolo Falferi,[†] Benno Margesin, Renato Mezzena, Nicola Pugno, Giorgio Speranza, Andrea Vinante

The GBTD (Graphene-Based Thermal Detector) project concerns the development of a thermal detector of electromagnetic radiation based on graphene, a two-dimensional material made of a single atomic layer of carbon atoms placed onto a hexagonal lattice. The first target of the project is evaluating the fabrication difficulties and the limits to the performance of this detector also considering possible schemes for the improvement quantum efficiency and scalability. The long-term target is the development of a device for the detection of weak visible light in ultracryogenic experiments of interest to INFN like Double Beta Decay or Dark Matter. The project is based on close cooperation between INFN, University of Trento, and Fondazione Bruno Kessler (FBK) and benefits from the recently started collaboration in the framework of the important European initiative "Graphene Flagship" in which FBK is involved with two research activity.

In a thermal detector, the energy of the absorbed radiation E is estimated by the temperature change of the absorber. The smaller is the heat capacity C of the absorber (plus that of the thermometer), the bigger is the temperature increase E/C. The fundamental limit to the thermal detector sensitivity is represented by the Thermodynamic Fluctuation Noise. This noise is minimized by using absorbers with low heat capacity and by operating at low temperatures. Another important parameter for the thermal detectors is the coupling between the absorber and the thermal bath, which has to be kept as low as possible. Due to its dimensionality and the characteristics of its electron gas, graphene is, in principle, an almost ideal material for the construction of the absorber of a thermal detector, in particular when it is operated at ultracryogenic temperatures ($T < 1K$): very low heat capacity (electronic specific heat scales with T), very fast thermalization, wavelength-independent absorption (2.3%) for normal incident light with photon energy $< 3eV$, very weak electron-phonon coupling , weak coupling to some substrates (SiO_2, SiC, hexagonal BN) so that these graphene layers retain the two dimensional electronic band structure of isolated graphene. It is not convenient to attach a thermometer to the absorber (composite bolometer) constituted by the graphene electron gas because the first one would have a heat capacity much higher than that of the second one. Thus, the only possibility is to use graphene as absorber and thermometer at the same time (monolithic detector). Unfortunately, because of the weak dependence of the graphene resistance on temperature, the simple method to evaluate the temperature from the electrical resistance (as in the case of Transition Edge Sensors) does not permit to achieve the ultimate sensitivity determined by the thermodynamic fluctuation noise. To overcome this problem, we aim to evaluate the temperature of the graphene electron gas by measuring its thermal (Johnson) noise by performing basically a noise thermometry measurement down to a few tens of milliKelvin. A graphene flake, consid-

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ered as a resistance R, generates a voltage noise V_{Th} with power spectral density $4k_BTR$ (k_B is the Boltzmann constant) that scales with the temperature T of the electron gas. The measure of this noise can be performed with low noise cryogenic amplifiers like for example SQUID (Superconducting QUantum Interference Device) or HEMT (High-Electron-Mobility Transistor) provided that the resistance temperature is higher than the noise temperature of the amplifier that operates as a thermometer. In particular, the measurement scheme with SQUID in its simpler configuration is shown in Fig. 1.

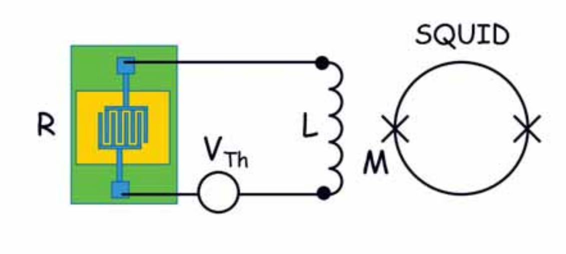

Figure 1: Scheme of the SQUID measurement of the thermal Johnson noise produced by a graphene flake. Graphene is represented in yellow, the substrate (SiO_2) in green, and the interdigitated superconducting electrodes in blue.

The dc SQUID, a superconducting ring containing two Josephson junctions, is a very sensitive detector of magnetic flux able to detect very small fractions ($\sim 10^{-6}$) of the flux quantum ($\Phi_0 = h/2e \simeq 2 \times 10^{-15}$ Wb). By means of the coupling M the SQUID can detect the current flowing in the input coil L due to the thermal Johnson noise produced by the graphene resistance. The noise measured by the SQUID is of the low-pass type with cutoff frequency given by R/L where R is the resistance of the graphene between the interdigitated electrodes and L the inductance of the SQUID input coil. The noise level below the cutoff frequency scales with the temperature of the resistance R that is with the temperature of the graphene electron gas. The graphene, produced by Chemical Vapor Deposition and transferred onto the SiO_2 substrate, is defined by photolithographic processes as well as the superconducting electrodes deposited on it.The graphene electron gas is expected to lose heat through three thermal-conductance channels: coupling to the electrical leads through electron diffusion (in principle negligible with superconducting contacts), coupling to the lattice phonons, and coupling to the used amplifier by radiation (that scales with the bandwidth of the amplifier). Through a careful design of the sample geometry and the coupling to the amplifier, it is possible to make the electron-phonon channel the dominant one and minimize the total conductance. The main issue that, in our trials, has so far prevented the fabrication of a noise thermometer based on graphene is the persistence of a contact resistance between the superconducting electrodes and graphene that is much higher than the resistance of graphene between the electrodes. After many attempts in which different superconducting materials and order of deposition of the layers have been tested, to get round the problem we are trying to realize a suitable capacitive coupling by interposing a layer of Al_2O_3 or SiO_2 between the superconducting electrodes and graphene.

NADIR

Alberto Quaranta,† Gian-Franco Dalla Betta, Lucio Pancheri, Andrea Ficorella, Matteo Dalla Palma, Enrico Zanazzi, Valeria Conte

In ion beam treatment of cancer the track structure of impinging ions plays a critical role in the damage of biological cells. The track structure consists in scattered high energy secondary electrons giving rise to ionizations in the chemical environment surrounding the track. The number and the energy of such secondary electrons depends on the ion mass and energy. From the treatment point of view, the number of ionizations occurring within nanometric volumes, corresponding to short DNA segments, is one of the most important parameters determining the biological effectiveness of the radiation.

So far, the track structure of several ions has been analysed by counting either the number of electrons or the number of ions produced within small volumes of rarefied gas, equivalent to nanometric solid volumes. Such sophisticated apparatuses allowed a deep comprehension of the track structure of different ions at different energies, and the correlation with the number of ionizations with the biological effectiveness of the radiation is still under study.

In radiobiological tests, fast analyses of the released nanodose may be necessary, while specific set-ups for a detailed counting of the number of ionizations are typically complex, time consuming and voluminous, requiring high vacuum systems and dedicated beam lines. So, the realization of portable systems, which are suitable for a significant evaluation of the released dose in real time during the irradiation, is more and more important as the use of ion beams in radiotherapy treatments increases with the time.

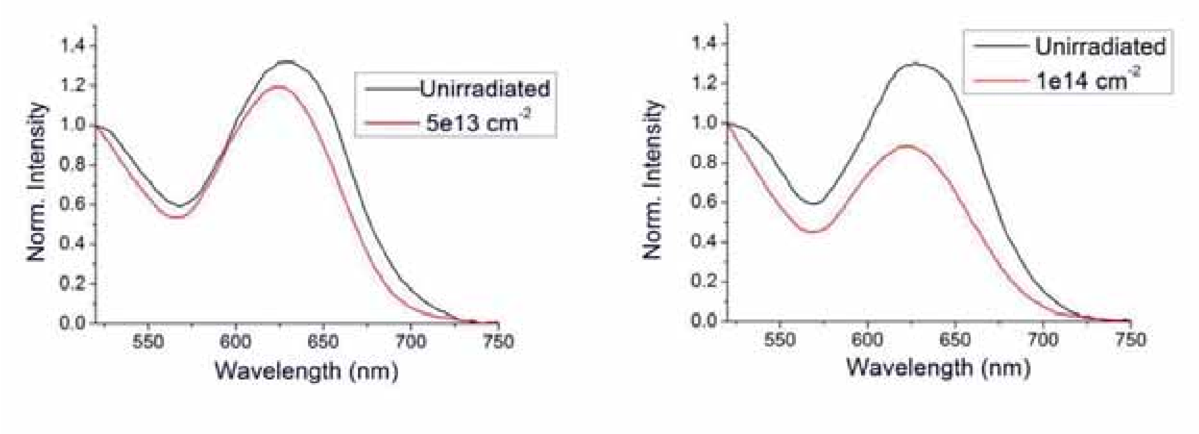

Figure 1: Photoluminescence spectra of unirradiated and irradiated samples (5×10^{13} and 10^{14} ions/cm^2). The spectra were collected with the excitation wavelength of 470 nm.

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The aim of the experiment NADIR (biologically relevant NAnoDosimetry of Ionizing Radiation) is to study, at the proof of concept level, systems based on luminescent quantum dots for measuring the dose released within nanometric volumes. Semiconductor or organic quantum dots (QDs) are nanometric crystals whose luminescence properties (intensity, wavelength and lifetime of the emission spectra) depend on the size and the composition of the particle. Point defects produced in the nanoparticles along the ion track can change their luminescence parameters of a quantity which can be used for evaluating the dose at a nanometric level. So far, a detailed study about the correlation between the ion dose and the point defects in QDs is still lacking, even if some studies demonstrated the possibility of using QDs for the measurement of irradiation doses.

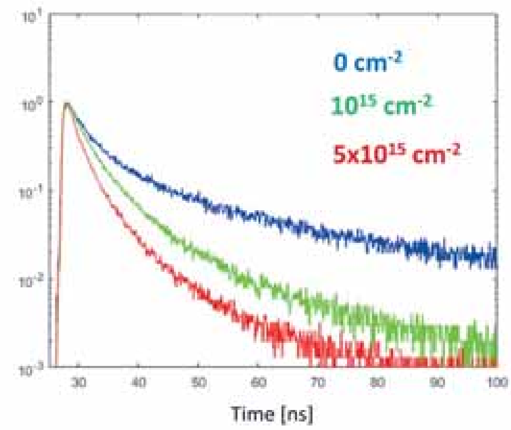

Figure 2: Decay luminescence curves of the unirradiated sample and of samples irradiated at 10^{15} and $5{\times}10^{15}$ ions/cm^2. The excitation wavelength is 405 nm.

As a first test, InGaP/ZnS core shell QDs have been dispersed in polysiloxane thin films and irradiated with 2 MeV H^+ ions at different fluences. Thin films of Silgard^{TM} around 4 mm thick were produced by mixing InGaP/ZnS core shell QDs (4 nm diameter, Evident Technologies) at a concentration of about 10^{17} QD/cm^3. The impinging protons cross the whole film thickness by releasing a nearly constant amount of energy, evaluated as 15 eV/nm with SRIM2010.

The films were irradiated with different fluences, namely 5×10^{13}, 10^{14}, 10^{15} and 5×10^{15} ions/cm^2. The luminescence spectra before and after the irradiation were measured with a spectrofluorimeter Jasco FP6300 and the lifetimes were measured with a 470 nm pulsed diode laser with pulse width of 30 ps and frequency 2.5 MHz. In Fig. 1 are shown the photoluminescence spectra of unirradiated and irradiated samples, for 5×10^{13} and 10^{14} ions/cm^2. As can be observed, the luminescence intensity decreases with the fluence owing to the formation of quenching defects in the nanoparticles. In Fig. 2 is shown the luminescence intensity as a function of the time for unirradiated QDs and of samples irradiated at 10^{15} and 5×10^{15} ions/cm^2. In this case, the formation of quenching centres produced by the ion beam gives rise to a decrease of the excited state lifetime. Further studies are needed in order to correlate the observed changes of the optical properties with the dose and structural analyses are necessary for identifying the point defects which are responsible of the observed trends. The connection with the number of ionizations suitable for the DNA damage will be obtained with the help Monte Carlo simulations of the ionization process of the impinging ions through the QD dispersion.

New Reflections

William Jerome Burger,[†] Roberto Battiston, Andrea Cafagna and Christian Manea

The TIFPA participates in a study of laser ablation for space applications, propulsion and debris mitigation, in the context of New Reflections in the Solar System, an interdisciplinary experiment (2016-2018) in the INFN technological research group (CSN5). The activity at the TIFPA has focused on a performance evaluation of the laser technology for debris removal in Low Earth Orbit (LEO) (Battiston et al. 2016).

The likelihood to create a debris belt around the Earth due to the increase in the number of objects launched in space was first evoked in 1979 (Kessler et al. 1979). The *Kessler Syndrome*, the cascade in the number of collisions between the orbiting objects would render the exploitation of space unfeasible for future generations.

A modified version of the Geant4 application PLANETOCOSMICS was used to quantify the effect of the direction of the applied impulse on the debris orbit. The program propagates elementary particles in the Earth's magnetic field and atmosphere. For the present application, the gravitational field was added, and the effect of the atmosphere on the debris orbit was introduced, a continuous energy loss process of the frictional force acting in the direction opposite to the orbital velocity.

Fig. 1 shows the effect of a radial impulse of $2.5 \cdot 10^5$ Ns directed along the line drawn from the Earth's center to a point mass of 500 kg in a circular orbit at an altitude of 600 km.

The 500 kg mass falls to the Earth in 30 d. A Hohmann transfer, applied in the direction opposite to the orbital velocity, would produce the same result with a factor ~ 5 smaller impulse. A $\sim 10\%$ smaller impulse would be required for an impulse directed radially towards the Earth.

The Hohmann transfer is kinematically the optimal configuration. In practice, the impulse of a ground-based laser will always have a component directed away from the Earth. A space-based laser may engage debris targets at relatively lower and higher altitudes. The radial direction transfers represent the operational limit for the laser system.

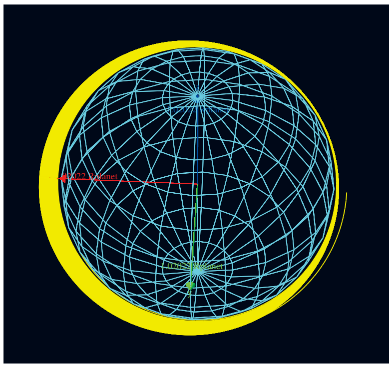

Figure 1: The trajectory of a 500 kg mass in a circular orbit at 600 km after an outward radial impulse of $2.5 \cdot 10^5$Ns *is applied (starting point on the right).*

Four laser deployment scenarios are evaluated in a simulation developed in Matlab© : a dedicated satellite (SAT), a laser system installed on the International Space Station (ISS), and two ground-based systems located in the equatorial (GEQ) and polar (GPO) regions. The relative performance is evaluated for the same debris mass (10 kg) and orbit. The debris and satellite orbital elements, semi-major axis a, inclination i, right ascension Ω and perigee ω, are listed in Table 1. The inclination and altitude (800 km) is representative of the major part of the debris population in LEO.

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	a	i	Ω	ω
mass	7170 km	100°	0°	180°
SAT	6885 km	80°	180°	90°
ISS	6780 km	52°	128°	99°

Table 1: The starting point orbital elements.

The laser beam delivers a 1 N thrust acting along the line-of-sight between the laser and debris positions. The laser is switched on when the debris approaches the ISS or SAT, and the line-of-sight between the space platform and debris is not obscured by the Earth. For the ground-based systems, the laser is turned on when the object approaches the laser position, and the angle of elevation is less than 65° (atmospheric transmission > 65%).

The results for the four laser deployment scenarios are presented in Table 2. Fig. 2 shows the altitude change produced by the equatorial site laser. The simulation time was limited to 60 d; at 200 km the mass enters the upper atmosphere.

	t_{tot}	t_{laser}	Impulse	Alt. Final
	d	h	Ns	km
SAT	0.43	0.83	$3.0 \cdot 10^3$	200
ISS	1.16	1.32	$4.8 \cdot 10^3$	200
GEQ	60.0	1.51	$5.4 \cdot 10^3$	409
GPO	4.15	1.00	$3.5 \cdot 10^3$	200

Table 2: Total time t_{tot}*, time laser on* t_{laser}*, total impulse and debris altitude at* t_{tot}*.*

The impulse delivered to the debris mass is given by the expression (Esmiller et al. 2015),

$$m\Delta v = \left(\frac{E_o T_{tel} T_{atm}}{\pi \phi^2(R)} \right) S C_m \qquad (2)$$

where E_o is the energy per pulse, $\phi^2(R)$ is the size of the beam at the range R. S is the target surface area. T_{tel} and T_{atm} are the transmission efficiency of the laser telescope and the atmosphere. C_m is the coupling coefficient for the conversion of the incident laser pulse power to force, $\sim 2 \cdot 10^{-5}$ N/W for Al for the power density range between 0.5 and 0.8 GW/cm^2, with $\lambda = 1.06 \mu$m (Esmiller et al. 2015).

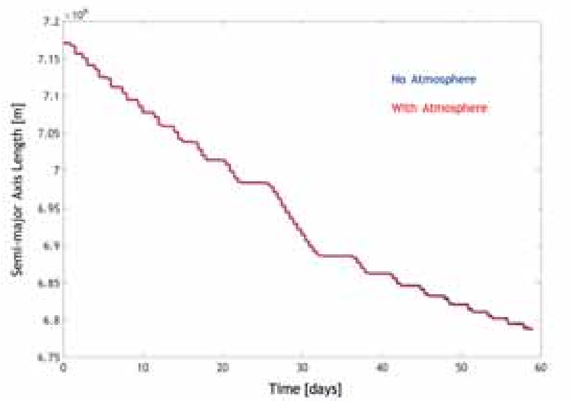

Figure 2: Evolution of the semi-major axis length of the 10 kg mass produced by the equatorial site laser.

With $m\Delta v = 1$ Ns, $T_{atm} = 1$ for the space-based lasers, $T_{tel} = 0.8$, a 0.5 m diameter spot on a 1m^2 surface of the 10 kg debris mass, and a 30% reduction of the impulse value in Table 2, which increases t_{tot} to ~ 25 and ~ 95 d for the two satellites, E_o is 10.5 kJ, the average power 10.5 kW. The parameters of a pulsed 10.5 kW laser, corresponding to the simulated performance, are listed in Table 3.

P_{avg}	E_{pulse}	P_{peak}	width	rate	$P_{density}$
kW	kJ	TW	ns	Hz	$\frac{GW}{cm^2}$
10.5	1	0.2	5	10	1.0

*Table 3: 10.5 kW space-based, pulsed laser for small debris objects (*10 kg/m^2*).*

References

Battiston, R., Burger, W., Cafagna, A., Manea, C., and Spataro, B. (2016). “A Systematic Study of Laser Ablation for Space Debris Mitigation”. In: *Proceedings of the* 8th *IAASS Conference, Melbourne, Florida, 18-20 May, 2016*, pp. 69–78.

Esmiller, B., Jacquelard, C., Eckel, H.-A., Wnuk, E., and Gouy, Y. (2015). “Space debris removal by ground based laser: Main conclusions of the European project CLEANSPACE”. In: *Proceedings of the* 7th *IAASS Conference, Friedrichshafen, Germany, 20-22 October, 2014*, pp. 13–22.

Kessler, D. and Cour-Palais, B. (1979). “Collision Frequency of Artificial Satellites: The Creation of a Debris Belt”. In: *Journal of Geophysics Research* 83.A6, pp. 2637–2646.

PixFEL

Lucio Pancheri,[†] Roberto Mendicino, David Macii, Gian-Franco Dalla Betta, Giovanni Verzellesi, Hesong Xu

The PixFEL project is conceived as the first stage of a long term research program aiming at the development of advanced X-ray imaging instrumentation for applications at the free electron laser (FEL) facilities (Ratti et al. 2015a). The project aims at substantially advance the state-of-the-art in the field of 2D X-ray imaging by furthering the understanding of FEL experiments requirements and exploration of cutting-edge solutions for fabrication technologies and detector readout architecture design. For this purpose, the collaboration is developing the fundamental microelectronic building blocks for the front-end chip of an X-ray detector and is investigating the enabling technologies for the assembly of a multilayer four side buttable module, in particular active edge pixel sensors and low density, peripheral through silicon bias (TSV). The design of the building blocks and of the readout architecture is carried out in a 65 nm CMOS technology. As a final demonstrator, the project will produce a single tier 32x32 channel front-end chip interconnected to a fully depleted pixel sensor.

Within PixFEL project, TIFPA is in charge of the design and characterization of the sensors, that are produced at the FBK microfabrication facility. In FEL applications, relatively thick sensors are necessary to obtain high detection efficiency (>90%) at the maximum X-ray energies of interest, which can exceed 10 keV. For this application it is mandatory to take into account the impact of plasma effects in case a high number of photons hit one pixel at a time, resulting in high charge carrier densities. This effect strongly affects the linearity, point spread function and response time of the detector, unless a high bias voltage is applied.

To minimize the radiation-induced increase of positive oxide charge density sensors were designed with a p-on-n configuration and a <100> crystal orientation was used. The high-resistivity (n^-) substrate is 450 μm thick to obtain a good efficiency at 12 keV. The n^{++} support wafer is directly bonded to the n^- active substrate, so the substrate bias can be applied from the back-side. The support wafer will be eventually back thinned and a metal layer deposited. To improve the high voltage behaviour, metal field-plates are used on all pixels.

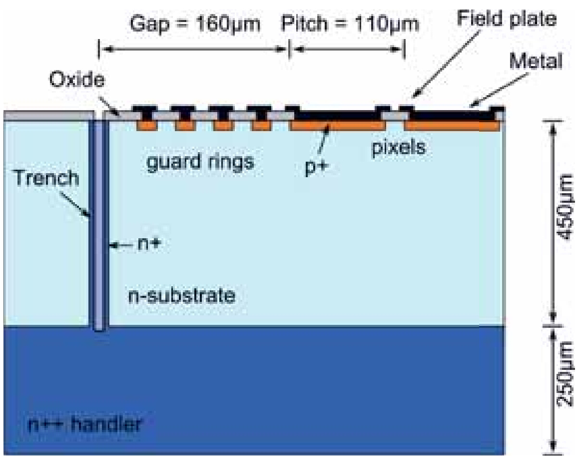

Figure 1: Active edge sensor cross section.

In the sensor design, TCAD analysis has been extensively used to simulate both the charge collection properties and the breakdown voltage characteristics, aiming at the best trade-

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offs between the minimization of the edge region size and the sensor breakdown voltage. Device simulations indicate that operating the sensor at a bias voltage of 300 V could be sufficient to obtain collection times lower than 20 ns and collection distances lower than 90 μm from the generation point (Dalla Betta et al. 2016b).

An edge termination able to withstand at least 300 V bias in all conditions (low and high oxide charge density) while minimizing the edge size was designed. The optimized termination includes four FGRs and has 160 μm total gap between the active edge and the first pixel (Fig. 1). With the proposed edge termination, the breakdown voltage is higher than 400 V regardless of the oxide charge density value within the considered interval, spanning from very low concentrations typical of the pre-irradiation case to the saturation value of 3x10^{12} cm^{-2}, typical of the post-irradiations case to extreme X-ray doses (Dalla Betta et al. 2016a).

Slim-edge structures with segmented and columnar borders were also included in the first submission to experimentally verify the feasibility of the approach. Simulations confirmed that the breakdown voltage obtained with the active edge structures will be maintained with the slim-edge devices. In addition, the simulations showed that the designed structures should be able to confine the depletion region, avoiding the collection of leakage current generated at the border of the dies.

The wafer layout of the first PixFEL sensor batch includes active edge pads, strips and pixel arrays with different termination structures, both active and slim edge, as well as standard test structures for technology characterization (Fig .2).

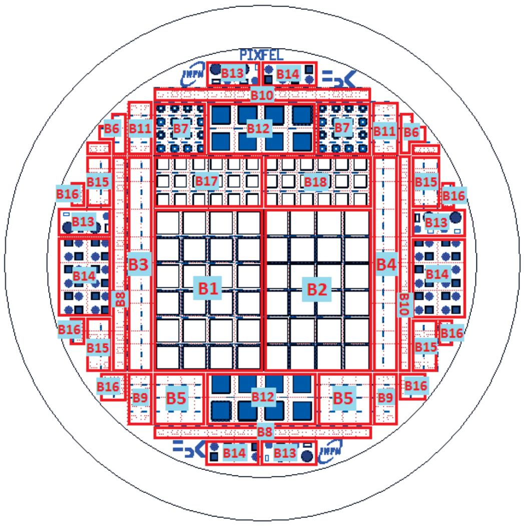

Figure 2: PixFEL wafer layout.

A characterization of the wafers produced in the first fabrication lot has been carried out, and a good agreement was found between the breakdown voltages predicted with simulations and the ones effectively measured on good samples, both on active and slim-edge sensors. Active-edge devices, having continuous trenches, however, have a limited yield due to the presence of of lithography defects of the borders. On the contrary, slim-edge diodes show a much better yield at the price of a slightly larger dead area, in the order of 50 μm. A characterization of radiation tolerance with X-rays is currently on going.

References

Dalla Betta, G.-F. et al. (2016a). “Design and TCAD simulation of planar p-on-n active-edge pixel sensors for the next generation of FELs”. In: *Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 824, pp. 384–385.

— (2016b). “Design and TCAD simulations of planar active-edge pixel sensors for future XFEL applications”. In: *2014 IEEE Nuclear Science Symposium and Medical Imaging Conference, NSS/MIC 2014*.

Ratti, L. et al. (2015a). “PixFEL: developing a fine pitch, fast 2D X-ray imager for the next generation X-FELs”. In: *Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 796, pp. 2–7.

Redsox2

Irina Rashevskaya,† Piero Spinnato, Pierluigi Bellutti, Giacomo Borghi, Francesco Ficorella, Antonino Picciotto, Claudio Piemonte, Nicola Zorzi

In 2015-2016 the collaboration of the REDSOX project worked on several avenues pertaining to the development of silicon drift detectors (SDDs) and the associated frontend and read out electronics:

- realization of noise simulation and digital filter synthesis software for detector system design optimizations
- realization of improved detector setups for the TwinMic and XAFS beam lines at Elettra Sincrotrone Trieste
- experimental characterization of trapezoidal arrays of SDD cells with IR laser and radioactive sources
- electrical characterization of detectors and test structures to provide feedback to FBK for the optimization of the production process (TIFPA)
- realization of a software-driven detector library layout generator
- study and design of a novel detector concept (the sub-millimeter drift pixel detector)
- design and characterization of a 10-bit ADC for the VEGA ASIC
- production and test of a single-cell, 9 mm2 SDD integrated with SIRIO, as PixDD breadboard
- X-ray tests of the noise improvement achieved with a novel anode design on a linear SDD
- design and test of large-area space missions (LOFT, eXTP and LOFT-P)
- performance studies of scintillating crystals coupled with SDDs for Compton cameras
- development of a Compton Camera
- design, realization and test of new SIRIO ASIC versions
- experimental characterization of ultra-low noise SDD-SIRIO systems
- support to other INFN projects employing SDDs

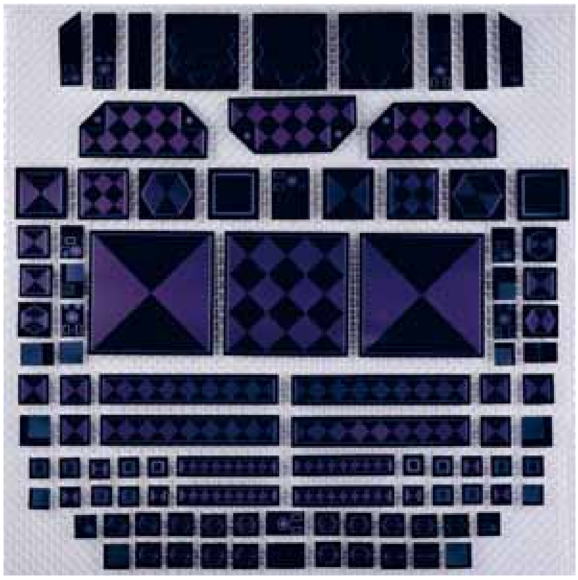

Figure 1: Cut wafer fabricated at FBK for Redsox experiment in 2016.

The design and production of a detector is an iterative cyclic process of device simulations, layout, prototype realization at the foundry, sample characterization at a probe station followed by the sensor installation in a detection setup and test in an environment similar to that of its application, and finally the feedback to the manufacturer that has to evaluate the production process design in order to satisfy the requirements provided by the user. See Fig. 1.

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Based on SIRIO and Milano expertise, the multi-cell array detectors designed in Trieste and produced by FBK, and the collaboration with the Elettra Sincrotrone Trieste colleagues, two new detector prototype systems were realized for the TwinMic (Gianoncelli et al. 2016) and XAFS (Fabiani et al. 2016) beam lines. The data analysis of 55Fe measurements of the detector system shows a very good noise performance on the pedestal, which predicts an energy resolution of about 127 eV FWHM at 5.9 keV and 0 C. The The XAFS prototypes were installed and tested on the beam lines in different beam tests. This work is still in progress within the REDSOX2 project and is instrumental for the realization of the SESAME detectors that INFN will realize for the Jordanian synchrotron facility, which will be the first major international research center in the Middle East.

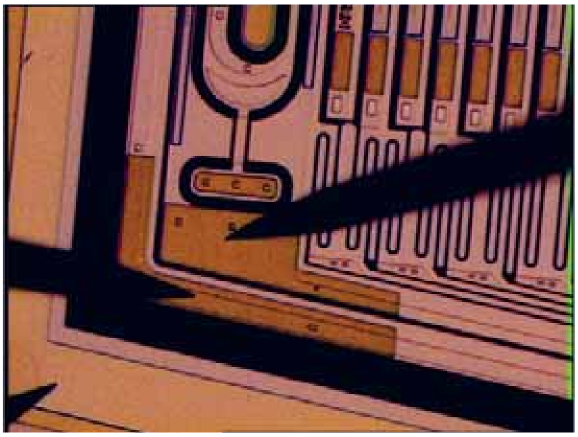

Figure 2: Details of LOFT detectors under test.

The very close collaboration between the REDSOX project and FBK that jointly develop the SDD sensors has produced remarkable achievements in the design of very-large area, low leakage current, spectroscopy detectors for low X-ray measurements. The batch LOFT2016 produced in FBK in august of 2016 has 94% yield of detectors with active area of 76 cm^2. This resulted in a conspicuous number of experiment proposals at national and international financing agencies. See Fig 2.

The PixDD, a novel development in REDSOX, is the result of the interest created by the REDSOX and LOFT work on the Chinese research groups developing the X-ray Timing and Polarization (XTP) and Einstein Probe missions. The PixDD is designed to address low-energy X-ray imaging applications where fast read out is as important as the spectroscopy performance. Two devices having pixel sides of 500 and 300 μm were produced in 2016. See Fig. 3.

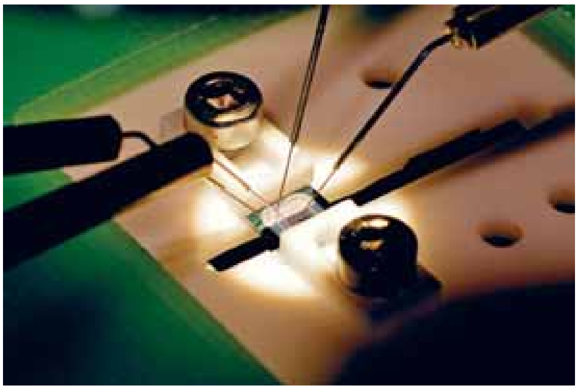

Figure 3: PixDD array of 4x4 under test.

The SIRIO front-end ASIC has been intensively characterized without and with a SDD connected. SIRIO showed minimum intrinsic equivalent noise charges as low as 1.18 and 0.89 electrons r.m.s. at +20 C and -30 C, respectively, corresponding to line width of less than 10 eV FWHM for Silicon Detectors. (Bertuccio et al. 2016)

References

Bertuccio, G. et al. (2016). "X-Ray Silicon Drift Detector—CMOS Front-End System with High Energy Resolution at Room Temperature". In: *IEEE Transactions on Nuclear Science* 63, pp. 400–406.

Fabiani, S. et al. (2016). "Development and tests of a new prototype detector for the XAFS beamline at Elettra Synchrotron in Trieste". In: *J.Phys.Conf.Ser.* 10, PO1002.

Gianoncelli, A. et al. (2016). "A new Detector System for Low Energy X-ray Fluorescence coupled with Soft X-ray Microscopy: first Tests and Characterization". In: *Nuclear Instruments and Methods in Physics Research Section A* 816, pp. 113–118.

SEED

Lucio Pancheri,[†] Matteo Perenzoni, Fabio Acerbi, Alessandro Ferri, Damiano Martorelli

The SEED project targets the development of a state-of-the-art technology for the realization of monolithic fully-depleted radiation sensors. A commercial CMOS process, provided by the industrial partner, will be customized with the help of the foundry process engineers, thus enabling the realization of a fast and efficient pixelated sensor with integrated electronics.

SEED has a two-fold objective: to develop an innovative technology for monolithic sensors in CMOS technology and, at the same time, to demonstrate the possibility of a technology transfer between INFN and industry in the field of microelectronics. From the technology point of view, the goal of the project is the development of a monolithic fully-depleted sensor suitable for a wide range of energies, embedding different dedicated IP blocks. This achievement will demonstrate how monolithic CMOS can meet different requirements in radiation detection applications with a performance that goes beyond the current state of the art. At the same time, the active participation of an industrial partner (LFoundry) providing support on process technology, offers the unique opportunity to create a synergy between microelectronic designers and a silicon foundry, which has been sought for a long time by the national scientific community.

The first phase of the project has been devoted to the tailoring of the CMOS fabrication technology to include the particle sensors. The optimal substrate doping and process parameters have been identified by means of an extensive TCAD device simulation campaign, which was carried out at TIFPA, in tight collaboration with the foundry process engineers.

In parallel, a first test chip including pixels with different geometry parameters has been designed at INFN Torino. This chip will be a first test bench for the proposed technology, suitable for an experimental characterization with particles as well as with optical sources. A first MPW run has been submitted and the first test batch is currently in production. The test procedures have been defined and necessary test boards have been produced at INFN Padova.

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SICILIA

Maurizio Boscardin,† Pierluigi Bellutti, Sabina Ronchin

The scientific goal of this apparatus is to detect high fluxes (about 10^7 pps/m^2) and fluences (about 10^{14}) of heavy-ions in order to determine the cross sections of very rare nuclear phenomena, such as double charge exchange reactions, of impact for determining nuclear matrix elements entering in the expression of the neutrino-less double beta decay half-life. The main issues for these experiments are the high energy (DE/E $\sim$ 1/1000), mass (Dm/m $\sim$ 1/200) and angular resolution (D(θ) $\sim$ 0.1°) required in order to unambiguously select the reaction channels of interest and extract the relevant information from energy spectra and absolute cross section angular distributions. Due to the very low cross sections, these features must be guaranteed at fluences which exceed by far those tolerated in state of the art solid state detectors, typically used in present experiment of this kind.

The Silicon Carbide technology offers today an ideal response to such challenges, since it gives the opportunity to cope the excellent properties of silicon detectors (resolution, efficiency, linearity, compactness) with a much larger radiation hardness (up to five orders of magnitudes for heavy ions), thermal stability and insensitivity to visible light. However, no commercial detector exists and a significant upgrade of present devices is required in terms of thickness of the active region and detection area.

The role of INFN - TIPFA in the project concern the design, the development of the fabrication technology, the production and a preliminary characterization of a detectors based on a schottky diode realized on silicon carbide substrate. In detail, the fabrication process has been defined in partnership with INFN Catania and CNR IMM and the process flow has been optimized in order to adapt the technologies developed at CNR to the FBK capability.

The main process step involved:

i. the deposition of Au or Pt as metal for the rectifier barrier;

ii. the use of a boron implantation in order to define a guard ring structure all around the diode.

A schematic section of the SiC schottky diode is shown in Fig. 1.

Figure 1: Schematic section of the SiC schottky diode.

Furthermore we have defined a first layout that is oriented to the process set up (test structures are present in the layout in order to have a good control of the main process steps) and also to investigate some geometrical option, in particular: the geometry of implanted guard ring and of the field plate. On wafers will be present

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diodes with various active area from 0.25×0.25 cm up to 1×1 cm.

The first batch of sensors that is planned to start before the end of 2016 will be realized on 4-inch SiC material with a an epitaxial of 10μm so due to the thin epi layer the device realized on the first batch could be used as for the process assessment but also as detectors for low energy particles.

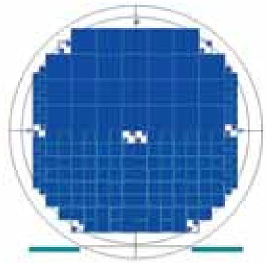

Figure 2: Wafer layout drawing.

Activities starting in 2017

AXIAL

Research outline The use of coherent interactions of charged particles in bent crystals is considered a frontier technology within the accelerator physics community. In recent years there has been a large interest of the international community in understanding how the interactions of charged particles with crystals can be used in accelerator physics. International laboratories of excellence such as CERN in Europe and SLAC in the United States are interested in this topic. AXIAL experiment plans to investigate axial and quasi-axial coherent interactions of charged particle beams with crystals at the edges of the available Lorentz factor, at $\gamma = 1.07$ of 70 MeV protons (TRENTO) and at $\gamma = 3 \times 10^5$ of 150 Gev/c e^+/e^- (CERN). The outcomes of AXIAL experiment would increase the scientific knowledge in this field and open up new opportunities for future applications in several field, from the beam manipulation in particle accelerators at low- and high-energy till the realization of innovative gamma and positron source for future colliders.

INFN groups Ferrara, Lab. Naz. di Legnaro, TIFPA, Milano Bicocca

Principal Investigator Vincenzo Guidi, INFN Ferrara

TIFPA team Alberto Quaranta (coordinator), Lorenza Ferrario, Viviana Mulloni, Claudio Piemonte

CHNET_IMAGING

Research outline The CHNET_imaging activity is devoted to the development of analytical methodologies based on charged particles and X-Rays for the elemental imaging of materials related to the archaeological and cultural heritage fields. The TIFPA group proposes the development of prototypes and methodologies based on X-Ray fluorescence analysis and X-Ray Diffraction using multiple Silicon Drift Detectors to acquire the radiation.

involved external institutions CNR-IBAM

INFN groups TIFPA, Firenze, Lab. Naz. del Sud, Ferrara, Torino

Principal Investigator Francesco Paolo Romano , INFN - LNS

TIFPA team Giancarlo Pepponi (coordinator), Pierluigi Bellutti, Damiano Martorelli

HIBRAD

Research outline Hibernation is a state of reduced metabolic activity used by some animals to survive in harsh environmental conditions. The idea of exploiting hibernation for space exploration and medical purpose has been proposed many years ago, but in recent years it is becoming more realistic, thanks to the introduction of specific methods to induce hibernation-like conditions (synthetic torpor) in non-hibernating animals. In addition to the expected advantages in long-term exploratory-class missions in terms of resource consumptions, aging, and psychology, hibernation may provide protection from cosmic radiation damage to the crew and an increased radioprotection of the healthy tissue during cancer radio/particle therapy. Data from over half a century ago in animal models suggest indeed that radiation effects are reduced during hibernation. In our project, HIBRAD (Hibernation-Induced Radioprotection), we will study molecular mechanisms underlying the putatively increased radioresistance in animals.

involved external institutions CIBIO, University of Trento; University of Bologna

INFN groups Bologna, TIFPA

Principal Investigator Matteo Negrini, INFN Bologna

TIFPA team Walter Tinganelli (coordinator), Marco Durante, Emanuele Scifoni, Francesco Tommasino

MoVe-IT

Research outline The MoVe IT project is aimed at developing at the same time innovative modeling for biologically optimized treatment planning with ion beams and dedicated verification devices allowing its validation accounting for a high complexity of biological effects. The main effects which will be explored and implemented are biological impact of target nuclei fragmentation, relative biological effectiveness (RBE) and intratumor heterogeneity. The radiobiological implementation in research treatment planning system (TPS) will be coupled with design of patented tools for *in vitro* and *in vivo* irradiation, the development and update of the 3 complementary Italian facilities for experiments on therapeutical ion beams, and advanced models for related risk estimation (NTCP) and tumor control assessment (TCP).

involved external institutions GSI, Darmstadt (Germany); UT SouthWestern, Dallas (USA); APSS, Trento; Trento University (Biotech, CIBIO); CNAO, Pavia; CNR-IBB/Università Parthenope, Napoli; CNR-IBFM, Cefalù

INFN groups TIFPA, Laboratori Nazionali del Sud, Torino, Milano, Napoli

Principal Investigator Emanuele Scifoni, INFN - TIFPA

TIFPA team Emanuele Scifoni (coordinator), Marco Durante, Alessandro Ferri, Sebastian Hild, Giovanni Paternoster, Marco Schwarz, Piero Spinnato, Walter Tinganelli, Francesco Tommasino, Enrico Verroi

A quadrupole magnet of the 0-degree experimental beamline at the APSS Protontherapy Center in Trento

Proton Beam-based R&D

Francesco Tommasino
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Coordinator,
TIFPA Protontherapy Experimental Room Activities

The activities in the Experimental Room of the Trento Proton Therapy Centre (PTC) started in early 2016, after completion of an infrastructure upgrade phase. Two derivations of the main beam line are available for experiments in the Experimental Room, one dedicated to the Physics experiments, the other to Radiobiology ones.

The TIFPA research team, supported by the PTC medical physics staff, has initiated an experimental campaign, aiming at the characterization of the beam spot in air in terms of spot size, beam divergence, range-energy tables and beam intensity. This allowed the setup of a library of beam parameters, which is essential for the setup of additional and more sophisticated experiments. Work is currently going on for the setup of a target station for radiobiology experiments, requiring large irradiation field.

Based on the results of the proton beam characterization, it was possible to host already in 2016 several external groups, involved in both national and international collaborations. The activities performed by the guest groups spanned from radiation hardness (ALICE), to space detectors and shielding applications (Altea, Limadou, Rossini2), and detector testing (PRIMA-RDH, QBeRT). At the same time, preliminary studies started dedicated to the irradiation of biological samples (SHIELD). This demonstrates the large spectrum of research lines that might benefit from accessing the Experimental Room. These activities will continue in the next years, and will be extended to collaboration with industrial partners.

Irradiation campaigns for ALICE TOF

Pietro Antonioli,[1†] Casimiro Baldanza,[1] Davide Falchieri,[1] Christian Manea,[2] Marta Rovituso,[2] Francesco Tommasino[3,2]

As part of the upgrade programme foreseen for the ALICE experiment at the LHC, the readout system of the Time Of Flight (TOF) detector will be renewed: in the existing custom VME crates housing TDC cards, the DRM (Data Readout Module) VME master card will be replaced by a new version DRM2, housing new data links to DAQ and trigger systems: an intermediate test board (GBTx test board) with all the newer features has been developed.

The DRM2 is going to work in a moderately hostile environment, with a total dose of 0.13 krads in 10 years and a flux of 0.26 kHz/cm^2 of hadrons with energy above 20 MeV. Given the radioactivity foreseen the damages for TID are here less relevant: we wanted to estimate SEU (Single Event Upset) rates and potential SEL (Single Event Latchups). The components under test are listed in Table 1. We used TIFPA facility at Trento *Centro di Protonterapia* (proton therapy centre) to test several COTS components candidates to be used in the DRM2 during two irradiation campaigns in July and October 2016. The GBTx test board, shown in Fig. 1 was used for these campaigns. The card is a 14-layer PCB with a total thickness of 2.15 mm. The board purpose is to allow the test of the new components planned for the DRM2 The main components are the Microsemi Igloo2 FPGA, the CERN GBTx ASIC, an optical transceiver VTRx and a commercial SFP+. The GBTx and VTRx were designed to be working in a much harsher radiation environment (they can cope with the Mrad dose range). As FPGA we chose a Microsemi Igloo2. Being Flash memory based, it is inherently immune to SEUs in the configuration memory. Igloo2 devices have already been qualified for working in environments with a few krads total dose without major concerns (latch-up effects seen in the first silicon version release have been now fixed).

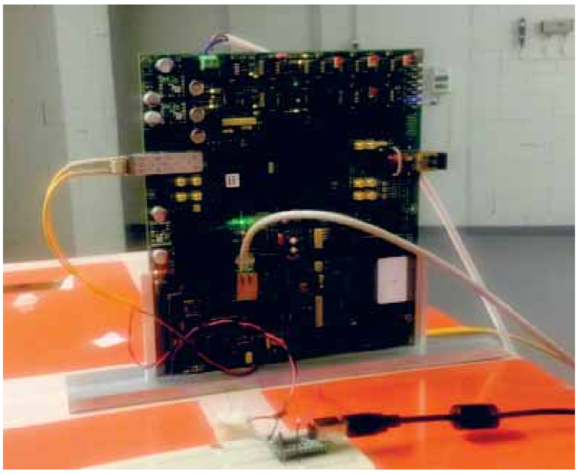

Figure 1: The GBTx Test Board

To monitor SEL and protect against them a LabView interface to DC power supplies was implemented. To monitor SEU we used both data transmission via the SFP+ commercial link: fixed memory patterns were written in SRAM memory cells in external chips under test or within the FPGA available RAM resources and continuously tested. In an addtional card (DRM Radio board) we concentrated some components, not present on GBTx test board and now

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foreseen on DRM2: they are the level translators, the low drop regulator from Linear Technologies and the serial-USB adapter.

During July irradiation the beam intensity delivered in the TIFPA experimental cave was monitored via a Faraday cup and its shape further checked with a Gafchromic EBT2 film. The measurements were repeated at the beginning of each session. During October irradiation the beam intensity was measured with a a detector consisting of a stack of coupled strip and integral IC. The dimensions of the beam spot, fitted with Gaussian approximation, were estimated at σ_x=4.0 mm and σ_y=3.7 mm. In both campaigns we used the proton beam at 200 MeV energy. Table 1 summarizes the devices tested, the radiation dose and the flux intensity used.

DUT	Type	# chip	I (p/cm^{2}s)	TID (krad)
FXL4TD245BQX	level transl.	4	4.1 10^8	13
LT1963AEQ#PBF	low drop reg.	1	4.1 10^8	13
FTDICIFT232R	serial-USB	2	1.2 10^9	13
ECX-L27BM-125	diff. clock	1	4.3 10^7	1
FLTL8524P28BNL	SFP+	2	4.3 10^7	3.8
FLTL8524P28BNV	SFP+	2	4.3 10^7	3.8
CY7C1460KV33-167AXC	SRAM	2	4.3 10^7	3.8
M2GL090T-1FG676I	FPGA	1	4.3 10^7	1.3
AFBR-57R5APZ	SFP+	1	6.2 10^7	4.5
AFBR-57R5AEZ	SFP+	1	6.2 10^7	3.7

Table 1: Devices under test (DUT) during the July and October irradiation campaigns. The proton beam intensities I refer to the highest used irradiating a given device.

The results obtained in July are: 1) no SEL were observed on the SRAM, a SEU cross section was estimated $\sigma_{SEU} \approx 1.2{\cdot}10^{-15}$ cm^2/bit; 2) no SEL and TID damages on buffers and low drop regulators as well as no glitches on the output levels, no SEL and instabilities of the clock. No damages 3) we observed no damages due to TID for FTDI chip up to 0.6 krad, but after TID=13 krad the device was no longer working; 4) after 1.3 krad TID the FPGA device was correctly reprogrammed (this was an issue of concern reported by some groups); 5) we observed SEL in the optical transceiver from Finisar, with an increase of current absorption up to 180 mA. No data transmission was lost after a SEL. But we observed also SEU that produced lost data transmission. If the device is immediately powercycled after SEL, it recovers. If left to operate at this higher power consumption it fails after few minutes.

We decided therefore to have an additional investigation of the SEL observed in the Finisar SFP+ device and, at the same time, test another COTS SFP+ (see Avago SFP+ in 1). We confirmed in October the very weak radiation tolerance of the Finisar SFP+, while for the Avago we didn't observe SEL and just two SEUs in the PZ model. Interestingly in the EZ model we didn't observe SEU and SEL but the internal registers (read via I^{2}C interface) seemed corrupted at the end of the irradiation. After a powercycle and without beam, the SFP+ was no longer working, like some configuration values were damaged by the irradiation.

All together these results allowed to qualify (or to exclude) several electronic components for use in the DRM2 ALICE TOF card. A comprehensive analysis of the results is under preparation. To fully qualify the candidate optical transceiver (from Avago) a new irradiation campaign is foreseen during first months of 2017 with a larger amount of samples.

ACKNOWLEDGMENTS: three authors (P.A, C.B, D.F) gratefully acknowledge the continuous support received by TIFPA personnel during the irradiation campaigns and thank the TIFPA Director for its encouraging support when we first approached TIFPA.

ALTEA: Anomalous Long Term Effects on Astronauts

Alessandro Rizzo,[1,2] William Burger,[3,4] Cinzia De Donato,[2] Silvia Fabiano,[4,1,2] Luca di Fino,[1] Marco Durante,[4] Christian Manea,[4] Livio Narici,[1,2†] Marta Rovituso,[4] Bruno Spataro,[3] Francesco Tommasino[8,4]

The tests carried out on the TIFPA proton beam line at the Trento Proton-therapy Center on the ALTEA detector have followed the ALTEA re-entry on ground after 9 years onboard the International Space Station (ISS). The goal is to check the detector performances under a particle beam in view of the next experimental upgrade LIDAL (Light Ion Detector for ALTEA).

The ALTEA detector

The ALTEA detector system is made of six identical Silicon Detector Units (SDUs) read by a Data Acquisition unit (DAU) which provides also to the power. The system includes a visual stimulator and an electroencephalographer unit (not used for the tests under the proton beam). Each ALTEA SDU is a particle telescope with six silicon planes which can determine the energy loss and the trajectory of a passing-through particle. Each silicon plane (380 μm thick) presents two squared active-areas of $8 \times 8 cm^2$, spaced by 5 mm: each square is segmented in 32 strips with 2.5 mm pitch. Two consecutive planes inside an SDU are orthogonally segmented to reconstruct the x-y coordinate of the track (the position of the paired planes inside the SDU gives the z coordinate). The interplanar space between a pair of silicon planes is 3.75 mm, while the distance between two pairs is 37.5 mm.

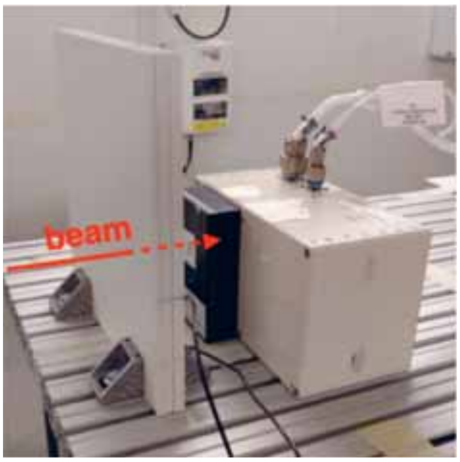

Figure 1: Single SDU test configuration: the first element in line is the plastic degrader (2.5 cm thick), followed by the scintillation counter (black box) and the SDU.

ALTEA tests on the proton beam line

The six Silicon Detector Units (SDUs) of the ALTEA detector system have been tested at the TIFPA proton beam line of the IBA accelerator at the Trento Proton-therapy center (APSS). The SDUs have shown performances that match the

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nominal ones, with exception of SDU 3, which showed a partial failure (25%) of the silicon planes.

As well as such assessment, the use of a proton beam also allows the study of the ALTEA acceptance energy window for the protons on the ground, setting a baseline for the future upgrade aimed to improve the ALTEA sensitivity to hydrogen and helium ions, the LIDAL apparatus.

Two main key issues have been optimized for the ALTEA SDUs tests at IBA accelerator: the beam repetition-rate and the beam energy. The rate capability of the ALTEA Data AcQuisition system (DAQ) is about 700 Hz shared among a maximum of 6 SDUs connected. To perform measurements of a such apparatus in a conservative condition a maximum beam repetition rate has been fixed to 200 Hz. Concerning the beam energy, the ALTEA acceptance energy window for the protons lies below the 70 MeV of the IBA cyclotron, so plastic degraders (*solid water*) of different thickness have been chosen using simulations performed by W. Burger. In order to monitor and to control these two parameters a small scintillation counter has been used as first element in line after the degrader for the single-SDU measurements. The reference proton energy for this set of measures has been set to 37 MeV after the degrader (2.5 cm thick). The configuration used for the single-SDU measurements is shown in Fig. 1.

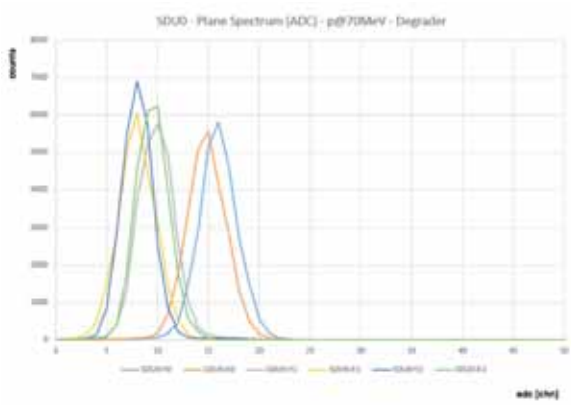

Figure 2: The ADC spectra (in channels) for the six silicon planes of SDU 0. The higher energy is released on the two last planes of the SDU with respect to the direction of the incident beam, in agreement with the Brag theory

All the SDUs have been tested and only the SDU 3 has shown a partial failure of about the 25% of the active area, maybe due to a DAQ readout problem. In Fig. 2 is shown a typical spectrum obtained on the six silicon planes of an ALTEA SDU. The tracking capability of the ALTEA detector has been used also to characterize the beam spot of the proton beam line at the isocenter. In Fig. 3 is shown the proton beam spot as seen by SDU 5.

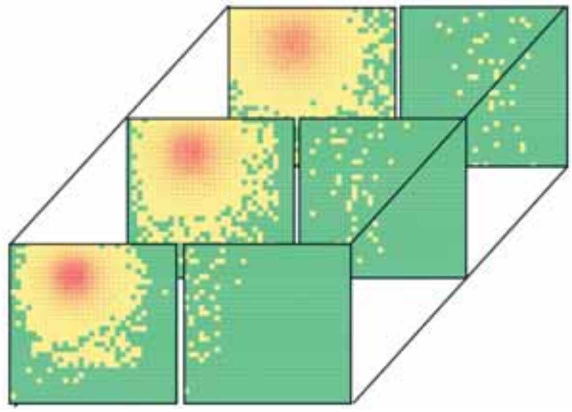

Figure 3: The beam spot profile as seen by ALTEA SDU 5. Each square in the picture represents a x,y paired silicon planes which give the Cartesian coordinate of the event.

As it is possible to see in Fig. 3, the beam spot appears almost round at the isocenter, with a particle leakage on the left part (right square in the picture) probably due a slight mismatch of the emittances in the beam insertion between the main transport line and the TIFPA one. The presence of such particle leakage has been confirmed also by the other SDU during the tests. The ALTEA energy acceptance for protons has been experimentally investigated using a “telescope” configurations with all the six SDU modules in line placed on the beam line. From preliminary evaluation the energy range seems to be wider than the one evaluated by previous simulations which lies between 25 and 45 MeV, but this study is still ongoing. The tests at the IBA cyclotron at TIFPA proton line have allowed to certify that ALTEA detector, after 9 year onboard the ISS, works properly with performances that match the nominal ones. The measurements performed at the proton beam will also allow to study the proton energy acceptance of the ALTEA, setting a baseline for the future ALTEA upgrade with the LIDAL apparatus.

Limadou Silicon Detector and Beam Test

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Production of AC-coupled double-sided silicon microstrip sensors, designed to equip the two layers of the HEPD detector in the Limadou-CSES project has been recently completed at FBK.

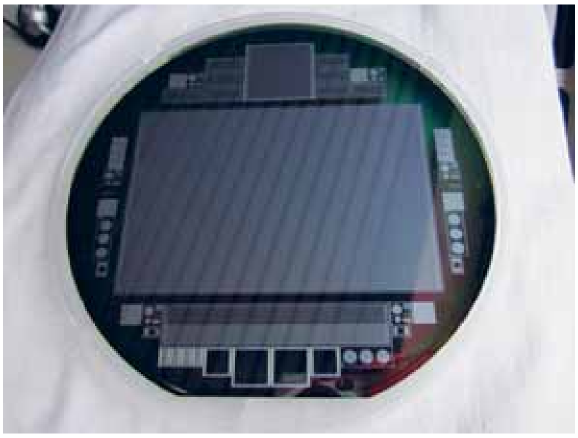

Figure 1: 150 mm silicon wafer

The sensors, fabricated on 150 mm silicon wafers (See Fig. 1), have sequent parameters and characteristics:

- Double-sided strip detector
- AC-coupled strips
- Punch-Through biasing on both sides
- Overall size: 11.0 cm 7.8 cm = 85.05 cm^2
- 300 μm thickness
- P side: 767 strips (384 Readout + 383 NonReadout) 182 μm Readout pitch
- N side: 1151 strips (576 Readout + 575 NonReadout) 182μm Readout pitch
- DC pads contacting the implanted strips at each end
- AC pads contacting the metal strips close to each end

A preliminary test on-wafer of the detector p-side was performed with an automatic system to provide a first classification of the sensors. Selected detectors were then diced and a complete sensor testing and quality control have been performed at INFN Trieste and TIFPA. A castom jig for interfacing the double-sided sensors with the small probe has been designed and fabricated. LabView programs were written for the test and analysis of the results. The complete standard test was done using 50 needles probacard with 182 μm pitch (Fig. 2). The test consists of characterisation of all AC and DC strips on both sides of the sensors.

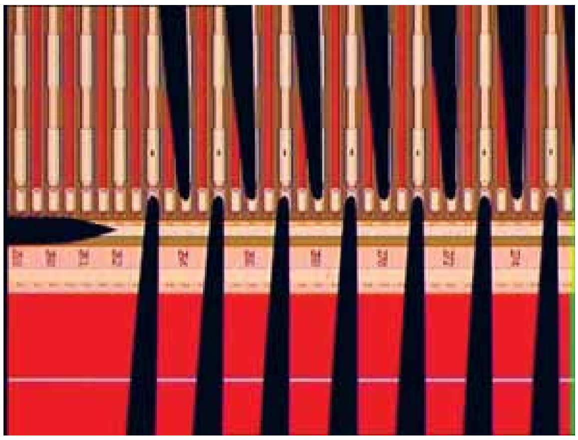

Figure 2: Test DC pad.

The n-side of the sensor is tested first, since it is important to determine the n-side strip insulation voltage as early as possible in the test

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sequence.
The complete test sequence on the n-side is the following:
1) *AC Strip Scan.* Only the AC pads and the substrate (backside bias ring) are contacted. Every strip capacitor is measured sequentially, with a 20V bias applied across it. Capacitance, dissipation factor and leakage current are measured simultaneously, by making use of a custom-designed bias adapter. Capacitance is measured at 1 kHz frequency; the sensor is illuminated in order to shunt the equilibrium depletion capacitance of the junction, which is in series with the oxide capacitance. This test, besides giving the capacitance value of every strip, allows detecting all defect types affecting the AC strips:
- Broken capacitors.
- Leaky capacitors.
- Metal shorts between adjacent strips.
- Metal opens (interruptions of the metal strip).

2) *$I-V$ Measurement.* The probe card is positioned on the CD pads, and the bias ring is contacted with a manipulator. An $I-V$ measurement is performed, with the bias voltage ranging from 1 to 100V. The currents of bias and guard rings on p-side (backside) are measured, together with the current of the n-side bias ring and one n-side strip. The strip $I-V$ characteristics allow a quick and effective estimate of the insulation bias voltage, since parasitic currents due to instrument offset voltages dominate the measured strip current until good strip insulation is reached.
3) *DC Strip Scan.* The contacts are already positioned for the start of the strip scan on DC pads. The bias voltage to be applied on the backside is chosen using as an input the insulation voltage determined in 2) for one strip. During the scan, the following parameters are measured:
- Leakage current of every strip.
- Insulation resistance of every strip (a 0.2V offset voltage is applied to the strip under test, and the resulting current change is measured).
- Bias ring current and backside current once for every probe card position (24 values).
- Strip insulation voltage of one strip for every probe card position. This is performed by starting from a low value of the bias voltage, and increasing it in 2V steps until the measured insulation resistance exceeds 100 MΩ.

The measurement 1) *AC Strip Scan.* and 3) *DC Strip Scan.* are repeated on p-side (except no strip insulation voltage is measured during DC scan on p-side).

In addition to the acceptance test, the investigation of particular problem of characteristic defects were done. As a result of this study, a modification of the fabrication process has been proposed, leading to an increased yield.

The CSES-HEPD Silicon detector consists of 12 Silicon sensors. Totally 71 Sensors were completely tested. 50 Sensors were accepted: 22 sensors for Qualification module (QM) and 28 sensors for Fly module (FM).

The readout electronics of the detector system was developed by HEPD collaboration. The definition of the architecture of the DAQ for reading of silicon detectors and control of adcs data stream were done at TIFPA. A series of spatial qualification test and functional calibration for study of performance of Limadou were performed. The proton test beam and energy calibration of the flight model (FM) was performed at the Trento Proton Therapy Center in November, 2016. It was necessary to characterise the behaviour of the detector with energy protons between 37 and 225 MeV to cover the range accepted by the instrument. The values below 70 MeV were obtained with a beam energy degrader. The test were done by selecting a positions matrix for test of all sensors of flight model. A new automatic table was used to move the detector on the beam line with a range of 2 m and a precision about 100 μm. The analysis of test beam data is in progress.

Figure 3: Proton Therapy Center Experimental Room.

Prima-RDH

Mara Bruzzi,[1,2] Carlo Civinini,[2†] Nunzio Randazzo,[3] Marta Rovituso,[4] Monica Scaringella,[2] Valeria Sipala,[5,6] Francesco Tommasino,[7,4]

Proton Computed Tomography (pCT) is a medical imaging method aimed at improving the accuracy of treatment planning in hadron therapy through a direct measurement of tissues´ stopping power (SP) distribution. This latter is presently extracted from X-rays attenuation coefficients: this introduces inaccuracies in the treatment planning with expected errors typically of a few millimeters. It was shown in the past that pCT has the potential to significantly reduce this source of errors by a direct evaluation of the SP maps. A pCT image can be obtained, with a single event approach, by directly measuring each proton position and direction upstream and downstream the volume under study and, at the same time, evaluating the particle residual energy. The Prima-RDH pCT apparatus is based on a calorimeter, made of YaG:Ce scintillating crystals, and a tracker which is composed of four silicon microstrip planes to measure the proton coordinates and reconstruct the better estimation of the particle trajectory inside the object to be studied. To be competitive with the X-rays CT based SP measurements the pCT maps should have space resolution better than one millimetre and electron density resolution better than 1%.
Fig. 1 shows the assembled Prima-RDH pCT prototype mounted on a beam test. This pCT prototype has a field of view of 5 × 5 cm^2 and has been built as a proof-of-principle apparatus; recent measurements has demonstrate its capability in reconstructing objects with a position and density resolution matching the above mentioned requests (Bruzzi et al. 2016).

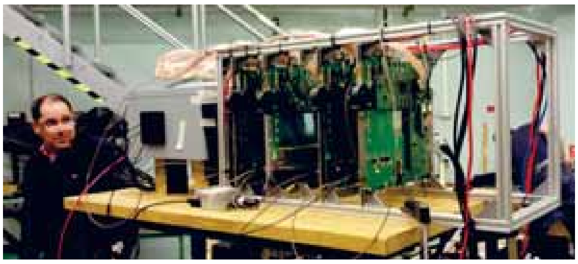

Figure 1: pCT apparatus at The Svedberg Laboratory (Uppsala, Sweden) beam line : tracker (green boards) and calorimeter(gray box).

An extended field of view pCT system, suitable to be used in pre-clinical studies, is currently in an advanced construction phase by the INFN Prima-RDH collaboration. The apparatus employs the same detector technologies of the small area system having a field of view of 5×20 cm^2 and a data acquisition rate capability of the order of one MHz (Civinini et al. 2013). One tracker plane has been tested at the 'Centro Protonterapia', Trento, Italy in May 2016 using a 200 MeV proton beam. A picture of the two dimensions beam profile taken with the tracker plane is shown in Fig. 2. During this test the experimental area of the 'Centro Protonterapia' has been used for the first time and the beam has been commissioned for low intensity. Proton rates in the 2x10^2-10^6 Hz range has been reproducibly achieved with the help of TIFPA

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and IBA personnel.

A second test at 'Centro Protonterapia' has been done in October 2016 with the aim to evaluate the performances of the extended pCT apparatus in an intermediate construction stage.

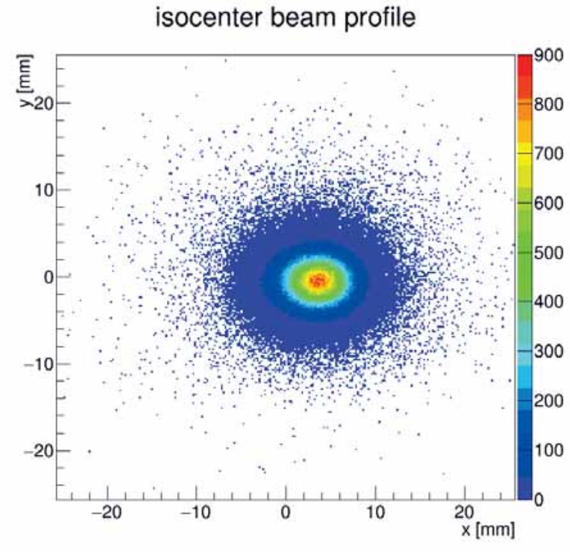

Figure 2: 200 MeV proton beam profile of 'Centro Protonterapia' (Trento, Italy) taken with the extended view Prima-RDH pCT tracker.

Two silicon microstrip tracker planes and the YaG:Ce calorimeter have been mounted on the experimental beam line. Using this setup a set of radiographies of an anthropomorphic phantom (human head) have been acquired and reconstructed. The tracker planes have been installed between the phantom and the calorimeter and used to extrapolate the proton tracks to the crystals, for better energy determination, and back to the phantom median plane for the image reconstruction. Fig. 3 shows one of the radiographies where each 1.5x1.5 mm^2 pixel contains the integral of the inverse of the water stopping power taken between the measured proton energy and the beam nominal energy (181 MeV).

This measurement is an important milestone to the final tomography. The INFN Prima-RDH pCT apparatus will be ready in its final configuration (four tracker planes and the calorimeter) at the beginning of 2017; the 'Centro Protonterapia' experimental beam line will be the ideal place where to take data for a preclinical tomographic image.

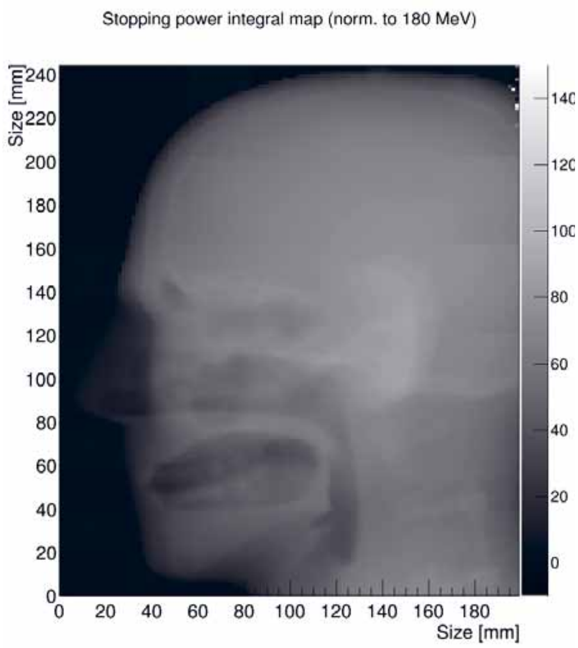

Figure 3: Anthropomorphic phantom radiography taken with the Prima-RDH pCT apparatus at 'Centro Protonterapia'.

References

Bruzzi, M. et al. (2016). "Proton computed tomography images with algebraic reconstruction". In: *Nuclear Instruments and Methods in Physics Research A* in press. URL: `http://dx.doi.org/10.1016/j.nima.2016.05.056`.

Civinini, C. et al. (2013). "Recent results on the development of a proton computed tomography system". In: *Nuclear Instruments and Methods in Physics Research A* 732, pp. 573–576.

QBeRT

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QBeRT (Qualification of particle Beam in Real-Time) is an innovative beam diagnostic and monitoring system composed of a position sensitive detector (PSD) and a residual range detector (RRD), based on scintillating optical fiber and on an innovative read-out strategy and reconstruction algorithm. The PSD consists of four layers of pre-aligned and juxtaposed scintillating fibres (SciFi) arranged to form two identical overlying and orthogonal planes. The RRD is a stack of sixty parallel layers of the same fibres used in the PSD, each of which is optically coupled to a channel of Silicon Photomultiplier (SiPM) array by wavelength shifting fibres. The sensitive area of the two detectors is 9×9 cm^2. The design of both detectors is based on SciFi BCF-12 with 500 μm nominal square section, manufactured by Saint-Gobain Crystals. In the PSD, each fiber is coated with white extra mural absorber (EMA) to remove the cross-talk between individual fibres and the fibres are optically coupled to two SiPM arrays using a channel reduction system patented by the Istituto Nazionale di Fisica Nucleare (Lo Presti 2013) which permits to reduce from 640 optical channels to only 112 channels required to read the signal. Both detectors use an electronic DAQ chain articulated in two main levels. The first level consists of the front-end boards which acquire the electric signal from the light sensor and operate the analogue-to-digital conversion. Each front-end board is equipped with a 64 channels SiPM array manufactured by Hamamatsu Photonics, mod.S13361-3050AE-08, with 3×3 mm^2 effective photosensitive area per channel. The signal from the front-end is sent to a read-out board with a National Instrument System on Module (SoM) for pre-analysis and filtering. The unique feature of this system is that both detectors, PSD and RRD, can be used in imaging conditions, with particle rate up to 10^6 particles per second, and in therapy conditions (up to 10^9 particle sec^{-1}). The PSD and the RRD have a measured spatial resolution of about 150 μm and 170 μm, respectively. The maximum measurable range was about 36 mm in polystyrene/PVC and this was enough to stop protons with 67 MeV input energy, but this value can be easily extended up to higher energies by placing a stack of calibrated water-equivalent range shifters between the beam exit and the RRD entry window, as verified at TIFPA with protons to 228 MeV.

In therapy conditions, up to 10^9 particles per second, the PSD works as a profilometer measuring the size and the position of the beam spot. Because of the read-out channel reduction system, the beam profile can be reconstructed only when the beam spot size is lower or equal to the width of a ribbon (about 2 cm).

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A measure of the beam profile was performed at TIFPA. Here, the beam optics produces a reduction of the beam spot size with increasing energy of the particles. Therefore, the PSD works properly at high energies, as it is possible to see in Fig. 1: a beam with 202 MeV shows a FWHM smaller than 2 cm and by means of a calibration with a Gaussian fit it is possible to reconstruct the beam profile. At lower energies, when the beam size exceeds the PSD specification, the profile and the position of the beam can't be reconstructed as well as before.

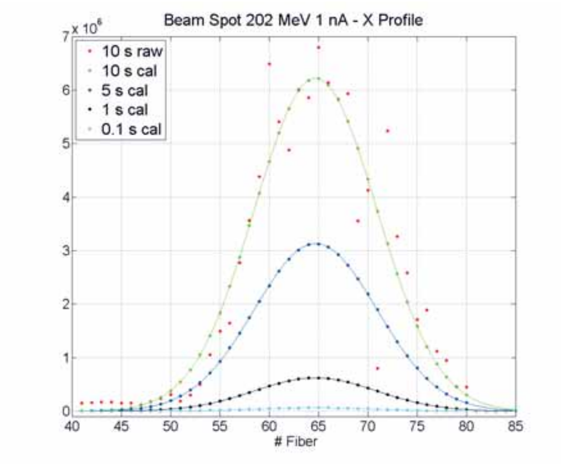

Figure 1: Examples of profiles at 202 MeV.

The variation of the beam spot size as a function of the energy at TIFPA is shown in Fig. 2. Here the measured beam spot size as the sigma of the Gaussian fit is reported as a function of the energy. It is clearly visible that for energies higher than about 160 MeV the values measured by the PSD are very close to those measured with Lynx dosimeter by IBA-Dosimetry, Schwarzenbruck, Germany. In this energy range, the beam spot is contained into a ribbon and the PSD can reconstruct correctly the beam profile. Because the position of the beam spot is obtained as the centroid of a Gaussian fit, also this measure can be carried out properly in the same energy range.

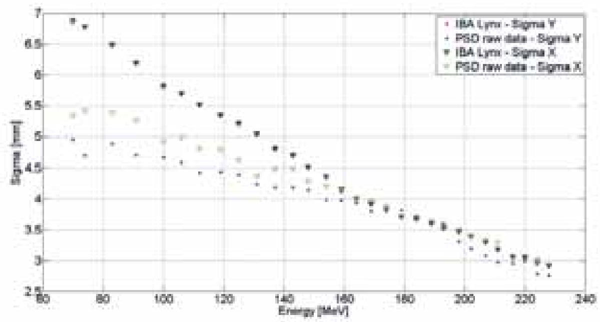

Figure 2: Comparison of measured beam spot size with the PSD and with Lynx by IBA as the sigma of the Gaussian fit of the beam profile.

The combined use of the information coming from the PSD and from the RRD, permits to verify on-line the treatment plan. In imaging condition, the system could be used to realize a particle radiography which permits a real-time monitoring of the patient position in treatment room, see (Lo Presti et al. 2016).

References

Lo Presti, D. (2013). *Detector based on scintillating optical fibers for charged particles tracking with application in the realization of a residual range detector employing a read-out channels reduction and compression method*.

Lo Presti, D., Bonanno, D. L., Longhitano, F., Bongiovanni, D. G., Russo, G. V., Leonora, E., Randazzo, N., Reito, S., Sipala, V., and Gallo, G. (2016). "Design and characterisation of a real time proton and carbon ion radiography system based on scintillating optical fibres". In: *Physica Medica: European Journal of Medical Physics* 32.9, pp. 1124–1134.

ROSSINI 2

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Future human exploration into interplanetary space will place astronaut crews at increased risk of exposure compared to the current Low-Earth Orbit (LEO) missions like at the International Space Station (ISS). Two main factors are the cause of this hazard: the journey length and the composition of the radiation environment. At the moment, a mission to Mars is estimated to last at least one and half year, i.e. well above the average permanence in space experienced so far. Furthermore, outside the protective Earth's geomagnetic field, astronauts will be exposed to the full spectrum of Galactic Cosmic Rays (GCR) and Solar Particle Events (SPE), and with an insufficiently shielded spacecraft they would easily exceed the currently accepted radiation doses limits. One of the key factors for minimizing the associated risks is the selection of an appropriate shield able to offer protection against the magnitude and dynamics of the GCRs and SPEs.

The identification of innovative shielding materials for space radioprotection was the aim of an ESA-funded investigation called ROSSINI (ESA/ESTEC Contract Nr. 4000105061), whose results have been published (Result note reference SCI-TASI-PRO-0026 and (Durante 2014)). ROSSINI 2 is the continuation of this activity and addresses the following issues.

- Trade-off analysis of potential innovative shielding materials both identified in the previous study or from the latest developments in the field (as materials with high hydrogen content). The selection takes into account only candidates which fulfilled pre-screening criteria for their use in space application (e.g. safety, low cost, lightweight, strength etc.) and includes also layered shielding structures.
- Simulation of the radiation transport and secondary particle generation through the selected materials, using different Monte Carlo radiation transport codes, including Geant4/GRAS (http://geant4.cern.ch/, http://geant4.esa.int and http://space-env.esa.int/index.php/geant4-radiation-analysis-forspace.html) , PHITS (http://phits.jaea.go.jp/) and FLUKA (http://www.fluka.org/fluka.php).
- Design and manufacturing of radiation shielding test samples.
- Testing of the selected materials with high energy ions. Dose reduction and, when enough material is available, the full Bragg curve, are measured for all candidates. Based on those results, a subset of the most promising samples is selected to study their shielding effectiveness more accurately. The quality of the radiation field behind the materials is characterized through two types of measurements: microdosimetric spectra and detection of yield and kinetic energy spectra of secondary neutrons.
- Simulation of a realistic habitat and/or vehicle for human exploration beyond ISS.

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- Evaluation of radiation doses absorbed in human tissue, given the particle species and energy spectra observed behind the shields considered.

Based on the recommendations delivered by the ROSSINI project and on basics principles of nuclear physics, the following materials have been selected for ROSSINI 2: multilayer barriers for inflatable space modules, epoxy resins, lightweight hydrides, shielding doped with nanomagnetic particles, moon regolith and moon concrete. Measurements with polyethylene (PE) and aluminum are also acquired as reference. Multilayers configurations are also tested for simulating the spacecraft hull or a permanent habitat, if combined with in-situ materials (e.g. moon regolith). Beams of protons, ^{4}He, ^{12}C and ^{12}Fe ions at several energies up to 2.5 GeV/u were selected as representative to SPEs and GCRs.

Figure 1: Experimental setup for measuring the dose reduction after a multilayer configuration with a proportional EGG counter.

The experiments have been performed at GSI, Darmstadt, Germany (heavy ions), HIT, Heidelberg, Germany (carbon ions), NSRL-BNL, Upton NY, US (protons and heavy ions) and the Proton Therapy Center, Trento, Italy (protons). Examples of the setups for measuring dose attenuation and secondary neutron characterization are shown in Figs. 1 and 2.

Figure 2: Experimental setup for measuring secondary neutron yield after a lithium hydride sample. A set of three telescope composed of a thin plastic scintillator and a liquid scintillator are placed at several angles with the respect to the primary beam direction at a distance of 3 m from the target. Energy deposition and time-of-flight (TOF) of secondary neutrons emerging from the target are acquired to obtain their yield and kinetic energy spectra.

References

Durante, M. (2014). "Space radiation protection: Destination Mars". In: *Life Sci. Space Res.* 1, pp. 2–9.

SHIELD

Walter Tinganelli,[1†] Walter Sanseverino,[2] Riccardo Aiese Cigliano,[2] Luis Matias Hernandez,[2] Silvia Fabiano,[1,3,4] Marta Rovituso,[1] Emanuele Scifoni,[1] Francesco Tommasino[5,1]

The realization of long-term human exploratory-class space missions is based on the *in situ* regeneration of resources (e.g. air, water and food) needed by the crew that can be achieved by plant-based Closed Ecological Life Support Systems (CELSS).

One of the main constraints for the establishment of extra-terrestrial outposts is the presence of high levels of ionizing radiation that affect organisms' growth, including plants.

According to the Health Physics Society, low dose of radiation may result in positive effects on plant growth. Since plants are more resistant than animals, it could be that plants might have benefit from radiation doses that are considered harmful for animals, like the dose resulting from extraterrestrial cosmic and solar radiation.

New plant species are usually created by genetic engineering, cross-separated species, and through mutation breeding with mutagenics like chemicals and radiation.

Mutation breeding is in fact the process of exposing seeds to mutagenic sources, in order to generate phenotypes that are isolated and subsequently breeded. Exposing plants to mutagenics has generated more than 3200 varieties since 1930. The most common radiation type used as mutagen is photon radiation; particles such as protons have barely been used. Particles, owing to their physical features are able to induce a higher mutagenesis in the targeted plant compared to x-rays.

Our project is then divided in two parts:

1. A first part that aims at achieving a systematic understanding of the threshold doses of ionizing radiation discriminating between negative, null and even positive outcomes in crops to define, in case, the shielding requirements throughout the plant cultivation cycle and to select new species of edible plants;
2. A second part using proton beam as mutagenic, aiming to find new plant varieties with interesting phenotypes like parasite resistance, radiation resistance, an increased harvest that could be used both on earth and for future human space exploration.

For the first part, the main biological aim is analyzing plants' sensitivity to acute and chronic doses of ionizing radiation in crops such as tomato, through experiments exposing plants at different life stages (e.g.: seed, seedling, adult plant in vegetative/reproductive phases). Molecular, morpho-anatomical, ecophysiological and biochemical aspects will be analyzed to detect plants' reaction to radiation and to generate dose-response curves.

Techniques for local soil adjustment and amendment will be also tested to cultivate the plants in an artificial alien soil, lunar and martian regolith simulant.

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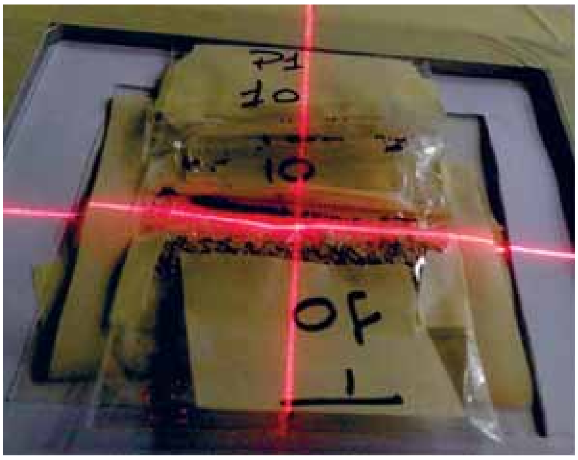

Figure 1: Tomato and petunia seeds aligned and prepared for proton beam irradiation at the APSS center for proton-therapy in Trento.

Furthermore, the technological task aims at setting-up possible designs for shielding depending on the target mission. The shielding properties of materials available *in situ* (e.g. Lunar or Martian regolith) will be analyzed through specific irradiation tests with the same irradiation protocols used for experiments on plants. Characterization and proton beam tests will be performed to measure structural properties and to compare the shielding effects, respectively.

For the second part, irradiation will be performed to create new genotypes. In this part tomatoes and petunia (flower model) will be used (see Fig. 1) . We will use petunia because its genotype is widely known, it can tolerate relatively harsh conditions and, since it grows relatively quickly, effects of irradiations are observable in a short time.

This project is a collaboration between public and private institutions from Italy and Spain. More in detail, in Italy, the TIFPA in Trento, the center for integrative biology (CIBIO) of the University of Trento, the University of Naples Federico II, department of Agricultural Sciences, department of Biology and Telespazio will be involved. For Spain, the Sequentia Biotech SL[1] in Barcelona is involved.

In November 2016, at the APSS protontherapy center in Trento, we performed a first exploratory tomato and petunia proton beam irradiation. More than 100 seeds of tomato and petunia were irradiated and then shipped to Sequentia Biotech for seeding and growing (see Fig. 2).

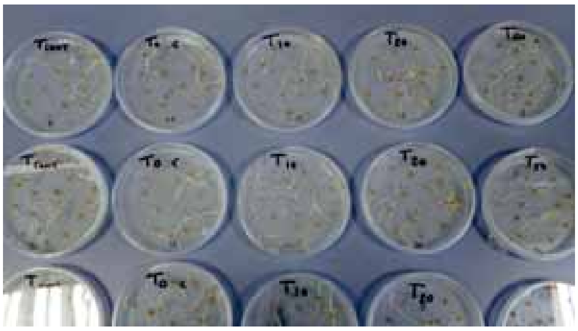

Figure 2: Sprouting irradiated tomato seeds.

[1] http://www.sequentiabiotech.com

TIFPA group photograph 2015

TIFPA group photograph 2016

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Administration

Marta Perucci

TIFPA started being operational in January 2014. Before this date, the official denomination of the group was *Gruppo collegato di Padova*. The administrative activities were managed by the INFN section of Padua, with the support of the Physics Department of the University of Trento.

The TIFPA general budget for the first three years of operation is detailed in the table below. The used funds are also shown in Fig. 1, together with the amount of administrative procedures.

year	allocated funds [k€]	used funds [k€]
2014	745	510
2015	1292	1169
2016	1600	1454

Table 1: TIFPA budget evolution.

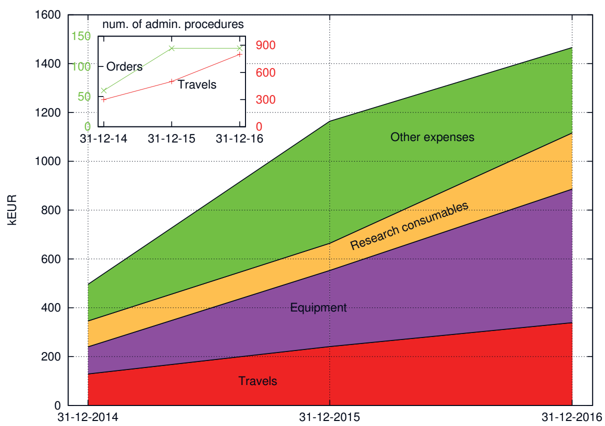

Figure 1: TIFPA budget evolution. Data shown are for funds actually used for purchases in the corresponding year. The inset shows the amount of administrative procedures executed to support purchases and travels.

On October 30, 2015 the *Servizio Integrato di Gestione e Amministrazione* (SIGEA) was created; its diverse activities include the day-to-day support of the different research groups of the institute , the organisation of events and conferences, assistance of the employees and associated personnel, new employment requests and selections, purchases and travel requests, accountability, and assets.

The conferences and meetings organized by the TIFPA were: "La Radiobiologia in INFN" held on may 2016, "Convegno Nazionale SIRR - Società Italiana per la Ricerca sulle Radiazioni" held on september 2016; moreover, SIGEA supported the organisation of Kick-Off meetings for various experiments, the meetings of National Scientific Commissions and also events organized by specific experiments.

The number of administrative procedures of this service is outlined in the table below (data also shown in the inset of Fig. 1):

year	travels	orders
2014	300	60
2015	500	130
2016	800	130

Table 2: TIFPA administrative procedures.

At the beginning of 2014, TIFPA had 1 employee, coming from LNGS. As of December 31, 2016 TIFPA has 10 employees (2 permanent and 8 temporary staff), 1 employee detached from *Provincia Autonoma di Trento*, 9 positions held by research fellows and postdocs, and 3 students in each course of the Doctoral School. TIFPA personnel evolution is shown in Fig. 2, which also includes the research associates (142 as of December 31, 2016).

At the end of 2016, the service has 3 staff members (one detached from the *Provincia Autonoma di Trento*, one employee with a temporary contract, one with a fellowship).

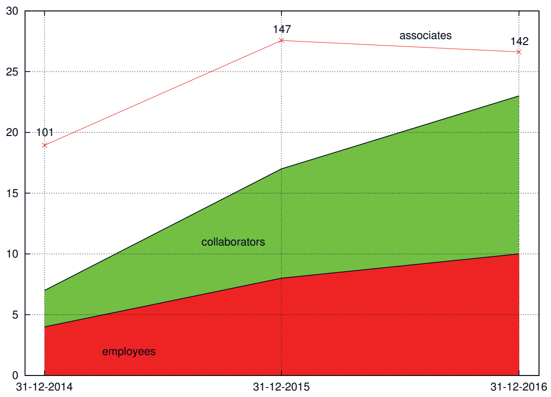

Figure 2: TIFPA personnel evolution. Data shown are both for staff and research associates (the latter are offset with respect to the y-axis scale).

Technical Services

Piero Spinnato, Christian Manea

Prior to TIFPA creation in December 2012, the scientific activities of the INFN associates in Trento had been carried out within the *Gruppo Collegato* associated with the INFN Section of Padua. There was no INFN staff in Trento, and technical support was provided by UniTN personnel, covering basic network and computing services. When we arrived at TIFPA, respectively in December 2013 (P. Spinnato) and, permanently, in April 2015 (C. Manea), the main task of our service (which at the end of 2015 was formalized as *servizio Supporto Tecnologico alle Attività di Ricerca*, STAR) was to lay the foundations for the Centre technological infrastructure. We had to approach this duty moving inside a context quite the opposite to what is typically experienced in INFN sections. The forefront research that is carried out at INFN needs state-of-the-art technologies, and it is normal for INFN technical staff to implement services that have not yet been adopted in the Academic environment where INFN sections are hosted. In fact, it is not unusual for INFN technical services to also provide support for the hosting University Departments. Conversely, in Trento we found a very advanced technological substrate, and grafting our services onto it was quite a natural choice for us. Very high-level IT network services, a brand-new University data centre to host our servers, and an experimental hall at the new Protontherapy Centre (which, by the way, was one of the main impulses for the creation of TIFPA), put at our disposal to be provisioned for proton beam-related R&D are just a few examples of the fertile soil provided to TIFPA by the Trentino research environment.

Concerning the IT infrastructure, we took advantage as much as possible of the services that the UniTN IT Division, which we warmly acknowledge, could provide to us. They include network connectivity and related services (namely DNS, DHCP, VPN, Firewalling and geographic connectivity, wireless network management), IP telephony, hosting of TIFPA servers in the University data center. Servers that are owned and managed by us provide services spanning from electronic mailing to sync and share, storage, wireless authentication, the Centre website, and basic scientific computing.

As no INFN staff was based in Trento when TIFPA started its activities, there were no pre-existing office spaces available for TIFPA staff when we arrived. In fact, a substantial fraction of our time in the first months of activity was devoted to design our office spaces in the area that UniTN allocated for our offices within the Physics Dept. The area at our disposal amounted to about 500 m^2, but its space distribution posed non trivial problems for an optimal office and laboratory subdivision (see Fig. 1a).

Apart from offices for direction, administration, technology and research staff, our requirements included a clean room laboratory, a control room for the upcoming LISA pathfinder space mission, laboratory space, and meeting rooms for seminars and scientific activities. Reaching a satisfactory result for space distribution required a considerable amount of iterations, also including a deal with the canteen service of UniTN for a room swap (see Fig. 1b). Indeed , after a major reconstruction job, since October 2015 the TIFPA staff has been fully operational in its new premises, which were inaugurated during the 2015 meeting of the INFN International Evaluation Committee, held in Trento specifically to underline the TIFPA phase transition to full operativeness.

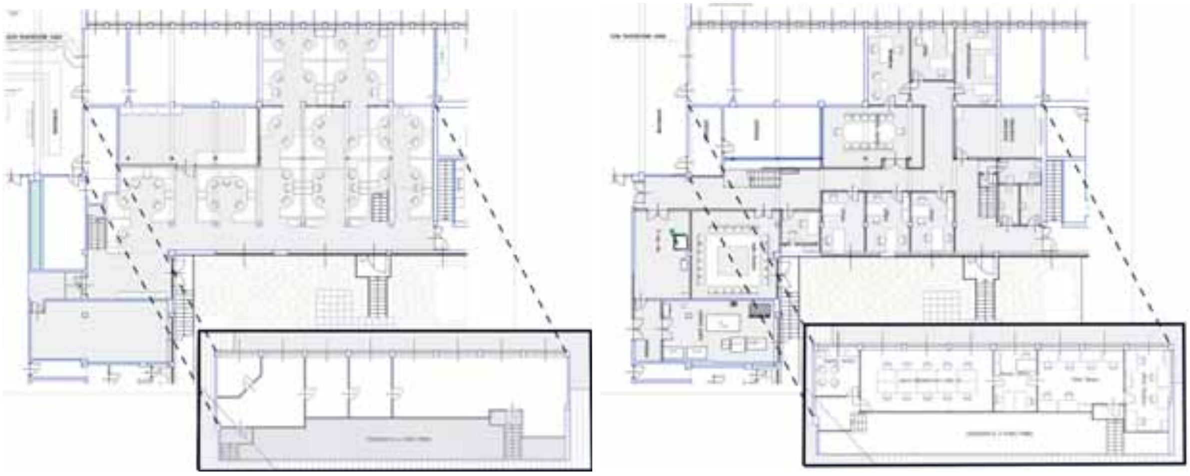

Figure 1: Original space allocation and final arrangement of TIFPA premises. The inset shows the mezzanine area.

During 2016 we have been involved in providing our laboratories with the necessary instrumentation. The electronics lab was equipped with instrumentation such as an oscilloscope, power supply, a generator, and a microscope with a welding station. The clean room laboratory was equipped with instrumentation for the analysis of irradiated biological samples. Namely, we acquired equipment such as a reverse optical microscope, laminar flow hood, precision balance, centrifuge, incubator, refrigerator as well as work benches and consumable material for cell cultures.

The culmination of such instrument provisioning activity was the installation of a fully shielded X-ray radiogenic machine equipped with a generator able to operate up to 200kV and 30mA. The machine was installed in December 2016 (see Fig. 2) and will be operational from January 2017. Such last operation involved a very careful planning and substantial preliminary works, as the machine features a vastly abnormal weight, exceeding 1000 kg, due to its incorporated lead shielding (and another 250 kg must be accounted for the power generator). A custom-made spreading plate was built to make the floor of the hosting lab able to support such weight, and the transportation itself of the machine within the UniTN building to its final location involved a number of complex operations to reinforce the floor and spread the weight along the path on the floor of the underlying level . The UniTN technical staff, namely engs. Mirella Ponte and Roberto Graziola, played a major role in all the above activities, and we take this opportunity to gratefully acknowledge their cooperation and availability.

Figure 2: The X-ray irradiator installed at TIFPA in December 2016, with the power generator on its side and the water cooling system on the background.

Besides the above activities in the Povo headquarters, we have been involved in equipping the experimental hall of the APSS protontherapy center with the basic instrumentation to perform scientific activities within. We first designed and realized the basic structures such as racks for 19" instruments, dedicated point to point ethernet connections between experimental room and control room, as well as other cables for low voltage and high voltage and other connections suitable for slow control signals with standard connectors like nim shv and db25. A further step was to insert two groups of laser lines used to identify the isocenters associated with the two beamlines. Such works were completed in December 2015. This allowed to perform at the beginning of 2016 the characterization measurements of the experimental beamlines with a well-defined position reference.

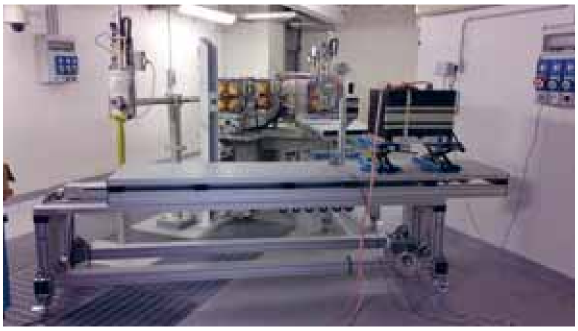

Figure 3: The experimental hall at the APSS protontherapy center with the two positioning tables. The 275 cm × 60 cm table is visible in foreground. The 100 cm × 60 cm table is in the background, below the terminal point of the 30° beamline. The 0° beamline is also clearly visible on the left hand side of the picture.

In the course of 2016 we provided the experimental hall with two crates with power supply and a minimum set of electronic boards such counters, generators, preamps and other glue logic modules, which made it possible to arrange simple measurement setups. Three positioning tables were designed by us, and built with standard aluminium profiles by the mechanics workshop of the Physics Department in Povo, in order to provide a simple and flexible alignment system for devices under test. Currently, two tables are available in the hall (see Fig. 3). A table of 100 cm × 60 cm, manually adjustable in height between 80 cm and 120 cm, and a much bigger table, whose size is 275 cm × 60 cm, which was conceived to allow horizontal movement of heavy objects up to 150 kg to be exposed to the beamline with a precision better than 100 μm and with a stroke of 2 m. This latter table is motorized, and controlled by a remote PC. It was designed mainly having in mind medical physics applications where the number of samples to be irradiated is large and the exposure time is limited. An intermediate size table, of 120 cm × 60 cm has been built but is currently under modification in order to add motorized, remotely PC-controlled height movement.

An illuminating example of the effective collaboration among TIFPA partners is the management of the research data network at the Protontherapy Center, which is structured as an extension of the TIFPA headquarters LAN, through a metropolitan point-to-point interconnect. The aggregation switch at the Protontherapy Center is owned by INFN, the network cabling by APSS, and the network is managed by UniTN servers. All the above layers could not be harmonically intertwined in a seamless infrastructure without the excellent level of interaction between us and our colleagues at UniTN and at the Protontherapy Center, who are gratefully acknowledged for their availability.

Another example of such effective collaboration is the activity of A. Franzoi, who, as INFN employee, works full-time with the clean room staff of the FBK Center for Materials and Microsystems in the technological development and actual realization of radiation detectors. Specifically, Alberto is involved in the lithography, etching and deposition operations of chip manufacturing.

The activity of E. Verroi, the forth component of the STAR service, is carried out within the scope of the Sensors & Detectors Virtual Lab, and is reported at p. 53.

Another activity that exacted a notably large amount of time from us was the support for the various research groups and the administration in procurement procedures and tenders. More than half of the purchasing procedures carried out at TIFPA were supported by the STAR service.

Chronologically last, and definitely not least in relevance was the task of producing the book which you are right now reading, and which, hopefully, you are appreciating as much as we enjoyed editing.

TIFPA Publications

Medical Technologies

Abdollahi, E., Taucher-Scholz, G., Durante, M., and Jakob, B. (2015). "Upgrading the GSI beamline microscope with a confocal fluorescence lifetime scanner to monitor charged particle induced chromatin decondensation in living cells". In: *Nucl. Instr. Meth.* B365, pp. 626–630.

Allen, C. P., Tinganelli, W., Sharma, N., Nie, J., Sicard, C., Natale, F., King 3rd, M., Keysar, S. B., Jimeno, A., Furusawa, Y., Okayasu, R., Fujimori, A., Durante, M., and Nickoloff, J. A. (2015). "DNA damage response proteins and oxygen modulate prostaglandin E2 growth factor release in response to low and high LET ionizing radiation". In: *Front. Oncol.* 5, p. 260.

Anderle, K., Stroom, J., Pimentel, N., Greco, C., Durante, M., and Graeff, C. (2016). "In silico comparison of photon vs. carbon ions in single fraction therapy of lung cancer". In: *Phys. Med.* 32, pp. 1118–1123.

Averbeck, N., Topsch, J., Scholz, M., Kraft-Weyrather, W., Durante, M., and Taucher-Scholz, G. (2016). "Efficient rejoining of DNA double-strand breaks despite increased cell-killing effectiveness following Spread-Out Bragg Peak carbon-ion irradiation". In: *Front. Oncol.* 6, p. 28.

Battistoni, G., Bellini, F., Bini, F., Collamati, F., Collini, F., De Lucia, E., Durante, M., Faccini, R., Ferroni, F., Frallicciardi, P. M., La Tessa, C., Marafini, M., Mattei, I., Miraglia, F., Morganti, S., Ortega, P. G., Patera, V., Piersanti, L., Pinci, D., Russomando, A., Sarti, A., Schuy, C., Sciubba, A., Senzacqua, M., Solfaroli Camillocci, E., Vanstalle, M., and Voena, C. (2015). "Measurement of charged particle yields from therapeutic beams in view of the design of an innovative hadrontherapy dose monitor". In: *J. Instr* 10.

Boscolo, D., Scifoni, E., Carlino, A., La Tessa, C., Berger, T., Durante, M., Rosso, V., and Krämer, M. (2015). "TLD efficiency calculations for heavy ions: an analytical approach". In: *Eur. Phys. J.* D69, pp. 1–6.

Brevet, R., Richter, D., Graeff, C., Durante, M., and Bert, C. (2015). "Treatment parameters optimization to compensate for interfractional anatomy variability and intrafractional tumor motion". In: *Front. Oncol.* 5, p. 291.

Cella, L., Tommasino, F., D'Avino, V., Palma, G., Pastore, F., Conson, M., Schwarz, M., Liuzzi, R., Pacelli, R., and Durante, M. (2016). "OC-0552: Skin-NTCP driven optimization for breast proton treatment plans". In: *Radiotherapy and Oncology* (119), S264ÐS265.

Cerri, M., Tinganelli, W., Negrini, M., Helm, A., Tommasino, F., Scifoni, E., Sioli, M., Zoccoli, A., and Durante, M. (2016). "Hibernation in space travel: implications for radioprotection". In: *Life Sci. Space Res.* 11, pp. 1–9.

Constantinescu, A., Lehmann, H. I., Packer, D. L., Bert, C., Durante, M., and Graeff, C. (2016). "Treatment planning studies in patient data with scanned carbon ion beams for catheter-free ablation of atrial fibrillation". In: *J. Cardiovasc. Electrophysiol.* 27, pp. 335–344.

Durante, M. (2015). "Charged particles for liver cancer". In: *Ann. Transl. Med.* 3, pp. 363–366.

Durante, M. and Paganetti, H. (2016). "Nuclear physics in particle therapy: a review". In: *Rep. Prog. Phys.* 79.

Durante, M., Tommasino, F., and Yamada, S. (2015). "Modelling combined chemotherapy and particle therapy for locally advanced pancreatic cancer". In: *Front. Oncol.* 5, p. 145.

Eley, J. G., Friedrich, T., Homann, K. L., Howell, R. M., Scholz, M., Durante, M., and Newhauser, W. D. (2016). "Comparative risk predictions of second cancers after carbon-ion therapy versus proton therapy". In: *Int. J. Radiat. Oncol. Biol. Phys.* 95, pp. 279–286.

Eley, J., Newhauser, W., Homann, K., Howell, R., Schneider, C., Durante, M., and Bert, C. (2015). "Implementation of an analytical model for leakage neutron equivalent dose in a proton radiotherapy planning system". In: *Cancers* 7, pp. 427–438.

Friedrich, T., Durante, M., and Scholz, M. (2015). "Simulation of DSB yield for high LET radiation". In: *Radiat. Prot. Dosim.* 166, pp. 61–65.

Grün, R., Friedrich, T., Krämer, M., Zink, K., Durante, M., Engenhart-Cabillic, R., and Scholz, M. (2015). "Assessment of potential advantages of relevant ions for particle therapy: a model based study". In: *Med. Phys.* 42, p. 1037.

Helm, A., Arrizabalaga, O., Pignalosa, D., Schroeder, I. S., Durante, M., and Ritter, S. (2015). "Ionizing radiation impacts on cardiac differentiation of mouse embryonic stem cells". In: *Stem Cells Dev.* 25, pp. 178–188.

Helm, A., Lee, R., Durante, M., and Ritter, S. (2016). "The influence of C-ions and X-rays on human umbilical vein endothelial cells". In: *Front. Oncol.* 6, p. 5.

Herr, L., Friedrich, T., Durante, M., and Scholz, M. (2015a). "A comparison of kinetic photon cell survival models". In: *Radiat. Res.* 184, pp. 494–508.

— (2015b). "Sensitivity of the giant loop binary lesion (GLOBLE) cell survival model on parameters characterising dose rate effects". In: *Radiat. Prot. Dosim.* 166, pp. 56–60.

Herr, L., Shuryak, I., Friedrich, T., Scholz, M., Durante, M., and Brenner, D. J. (2015c). "New insights into quantitative modeling of DNA double-strand break rejoining". In: *Radiat. Res.* 184, pp. 280–295.

Hild, S., Graeff, C., Rucinski, A., Zink, K., Durante, M., Herfarth, K., and Bert, C. (2015). "Scanned ion beam therapy for prostate carcinoma: Comparison of single plan treatment and daily plan-adapted treatment". In: *Strahlenther. Onkol.* 192, pp. 118–126.

Hufnagl, A., Herr, L., Friedrich, T., Durante, M., Taucher-Scholz, G., and Scholz, M. (2015). "The link between cell-cycle dependent radiosensitivity and repair pathways: a model based on the local, sister-chromatid conformation dependent switch between NHEJ and HR". In: *The link between cell-cycle dependent radiosensitivity and repair pathways: a model based on the local, sister-chromatid conformation dependent switch between NHEJ and HR* 27C, pp. 28–39.

Iancu, G., Weber, U., Zink, K., Durante, M., and Krämer, M. (2015). "Implementation of fast Monte Carlo algorithm in TRiP: physical dose calculation". In: *Int. J. Particle Ther.* 2, pp. 415–425.

Kamada, T., Tsujii, H., Blakely, E., Debus, J., De Neve, W., Durante, M., Jäkel, O., Mayer, R., Orecchia, R., Pötter, R., Vatnitsky, R., and Chu, W. (2015). "Twenty-years of carbon-ion radiotherapy in Japan: a re-evaluation of the clinical experience". In: *Lancet Oncol.* 16, e93–e100.

Kraft, D., Ritter, S., Durante, M., Seifried, E., Fournier, C., and Tonn, T. (2015). "Transmission of clonal chromosomal abnormalities in human hematopoietic stem and progenitor cells surviving radiation exposure". In: *Mutat. Res.* 777, pp. 43–51.

Krämer, M., Scifoni, E., Schuy, C., Rovituso, M., Tinganelli, W., Maier, A., Kaderka, R., Kraft-Weyrather, W., Brons, S., Tessonier, T., Parodi, K., and Durante, M. (2016). "Helium ions for radiotherapy? Physical and biological verification of a new treatment modality". In: *Med. Phys.* 43, p. 1995.

Lehmann, H. I., Richter, D., Prokesch, H., Graeff, C., Prall, M., Simoniello, P., Fournier, C., Bauer, J., Kaderka, R., Weymann, A., Schmack, B., Szabó, G., Sonnenberg, K., Constantinescu, A., Johnson, S. B., Brons, S., Naumann, J., Jäckel, O., Haberer, T., Debus, J., Durante, M., Bert, C., and Packer, D. L. (2015). "AV node ablation in Langendorff-perfused porcine hearts using carbon ion particle therapy: methods and an in vivo feasibility investigation for catheter-free ablation of cardiac arrhythmias”. In: *Circ. Arrhythm. Electrophysiol.* 8, pp. 429–438.

Maier, A., Beek, P. van, Hellmund, J., Durante, M., Schardt, D., Kraft, G., and Fournier, C. (2015). “Experimental setup for radon exposure and first diffusion studies using gamma spectroscopy”. In: *Nucl. Instr. Meth.* B362, pp. 187–193.

Mattei, I. et al. (2015). “Prompt-γ production of 220 MeV/u ^{12}C ions interacting with a PMMA target”. In: *J. Instr.* 10.

Mirsch, J., Tommasino, F., Frohns, A., Conrad, S., Durante, M., Scholz, M., Friedrich, T., and Löbrich, M. (2015). “Direct measurement of the 3-dimensional DNA lesion distribution induced by energetic charged particles in a mouse model tissue”. In: *Proc. Natl. Acad. Sci. USA* 112, pp. 12396–12341.

Norbury, J. W. et al. (2016). “Galactic cosmic ray simulation at the NASA Space Radiation Laboratory”. In: *Life Sci. Space Res.* 8, pp. 38–51.

Pompos, A., Story, M. D., Durante, M., and Choy, H. “Heavy ions in cancer therapy”. In: *JAMA Oncol.* in press.

Prall, M., Bauer, J., Constantinescu, A., Debus, J., Grae?, C., Haberer, T., Hauswald, H., Kaderka, R., Korkmaz, S., Lehmann, H. I., Packer, D. L., Prokesch, H., Richter, D., Sonnenberg, K., Szabó, G., Weymann, A., Durante, M., and Bert, C. (2015). “Treatment of arrythmias by external charged particle beams: a Langendorff feasibility study”. In: *Biomed. Tech.* 60, pp. 147–156.

Prall, M., Durante, M., Berger, T., Graeff, C., Lang, P. M., La Tessa, C., Mariam, F., Merrill, F., Shestov, L., Simoniello, P., and Varentsov, D. (2016). “High-energy proton imaging for biomedical applications”. In: *Sci. Rep.* 6.

Simoniello, P., Wiedemann, J., Zink, J., Thonnes, E., Stange, M., Layer, P. G., Kovacs, M., Podda, M., Durante, M., and Fournier, C. (2015). “Exposure to carbon ions triggers pro-inflammatory signals, changes in homeostasis and epidermal tissue organization to a similar extent as photons”. In: *Front. Oncol.* 5, p. 294.

Sørensen, B. S., Horsman, M. R., Alsner, J., Overgaard, J., Durante, M., Scholz, M., Friedrich, T., and Bassler, N. (2015). “Relative biological effectiveness of carbon ions for tumor control, acute skin damage and late radiation-induced fibrosis in a mouse model”. In: *Acta Oncol.* 54, pp. 1623–1630.

Steinsträter, O., Scholz, U., Friedrich, T., Krämer, M., Grün, R., Durante, M., and Scholz, M. (2015). “Integration of a model-independent interface for RBE predictions in a treatment planning system for active particle beam scanning”. In: *Phys. Med. Biol.* 60, pp. 6811–6831.

Stöhlker, T., Bagnoud, V., Blaum, K., Blazevic, A., Bräuning-Demian, A., Durante, M., Herfurth, F., Lestinsky, M., Litvinov, Y., Neff, S., Pleskac, R., Schuch, R., Schippers, S., Severin, D., Tauschwitz, A., Trautmann, C., Varentsov, D., and Widmann, E. (2015). “APPA at FAIR: From fundamental to applied research”. In: *Nucl. Instr. Meth.* B365, pp. 680–685.

Tinganelli, W., Durante, M., Hirayama, R., Krämer, M., Maier, A., Kraft-Weyrather, W., Furusawa, Y., Friedrich, T., and Scifoni, E. (2015). “Kill-painting of hypoxic tumours in charged particle therapy”. In: *Sci. Rep.* 5.

Tommasino, F. (2016). “Experimental and modelling studies for the validation of the mechanistic basis of the Local Effect Model”. In: *Il Nuovo Cimento C* (2).

Tommasino, F. and Durante, M. (2015a). “Proton radiobiology”. In: *Cancers* 7, pp. 353–381.

Tommasino, F., Friedrich, T., Jakob, B., Meyer, B., Durante, M., and Scholz, M. (2015b). “Induction and processing of the radiation-induced gamma-H2AX signal and its link to the underlying pattern of DSB: a combined experimental and modelling study”. In: *PloS One* 10.

Tommasino, F., Friedrich, T., Scholz, U., Taucher-Scholz, G., Durante, M., and Scholz, M. (2015c). “Application of the Local Effect Model to predict DNA double-strand break rejoining after photon and high-LET irradiation”. In: *Radiat. Prot. Dosim.* 166, pp. 66–70.

Tommasino, F., Scifoni, E., and Durante, M. (2016). “New ions for therapy”. In: *Int. J. Particle Ther.* 2, pp. 428–438.

Toppi, M., Abou-Haidar, Z., Agodi, C., Alvarez, M. A. G., Aumann, T., Balestra, F., Battistoni, G., Bocci, A., Böhlen, T. T., Brunetti, A., Carpinelli, M., Cirrone, G. A. P., Cortes-Giraldo, M. A., Cuttone, G., De Napoli, M., Durante, M., Fernandez-Garcia, J. P., Finck, C., Golosio, B., Iarocci, E., Iazzi, F., Ickert, G., Introzzi, R., Juliani, D., Krimmer, J., Kummali, A. H., Kurz, N., Labalme, M., Leifels, Y., Le Fevre, A., Leray, S., Marchetto, F., Monaco, V., Morone, M. C., Nicolosi, D., Oliva, P., Paoloni, A., Piersanti, L., Pleskac, R., Randazzo, N., Rescigno, R., Romano, F., Rossi, D., Rosso, V., Rousseau, M., Sacchi, R., Sala, P., Salvador, S., Sarti, A., Scheidenberger, C., Schuy, C., Sciubba, A., Sfienti, C., Simon, H., Sipala, V., Spiriti, E., Tropea, S., Vanstalle, M., Younis, H., and Patera, V. (2016a). “Measurements of ^{12}C ions fragmentation cross sections on thin targets with the FIRST apparatus”. In: *Phys. Rev. C* 93.

Toppi, M., Battistoni, G., Bellini, F., Collamati, F., De Lucia, E., Durante, M., Faccini, R., Frallicciardi, P. M., Marafini, M., Mattei, I., Morganti, S., Muraro, S., Paramatti, R., Patera, V., Pinci, D., Piersanti, L., Rucinski, A., Russomando, A., Sarti, A., Sciubba, A., Senzacqua, M., Solfaroli Camillocci, E., Traini, G., and Voena, C. (2016b). “Measurements of secondary particle production induced by particle therapy ion beams impinging on a PMMA target”. In: *Eur. Phys. J.* 117.

Wölfelschneider, J., Friedrich, T., Lüchtenborg, R., Zink, K., Scholz, M., Dong, L., Durante, M., and Bert, C. (2016). “Quantification of motion compensation by intra-fractionally moving tumors with scanned carbon ions”. In: *Radiother. Oncol.* 118, pp. 498–503.

Yu, Z., Hartel, C., Pignalosa, D., Kraft-Weyrather, W., Jiang, G., Diaz-Carballo, D., and Durante, M. (2016). “The effect of X-ray and heavy ions radiations on chemotherapy refractory tumor cells”. In: *Front. Oncol.* 6, p. 64.

Ahmad, R., Royle, G., Lourenco, A., Schwarz, M., Fracchiolla, F., and Ricketts, K. (2016). “Investigation into the effects of high-Z nano materials in proton therapy.” In: *Physics in medicine and biology* 61.12, pp. 4537–4550.

Bizzocchi, N. et al. (2015). “A planning approach for lens sparing proton craniospinal irradiation in pediatric patients”. In: *Radiotherapy and Oncology* 119. Supplement 1, S789.

Farace, P. et al. (2015). “Planning field-junction in proton cranio-spinal irradiation - the ancillary-beam technique”. In: *Acta Oncologica* 54, pp. 1075–1078.

Fracchiolla, F., Lorentini, S., Widesott, L., and Schwarz, M. (2015). “Characterization and validation of a Monte Carlo code for independent dose calculation in proton therapy treatments with pencil beam scanning”. In: *Physics in Medicine and Biology* 60.21, pp. 8601–8619.

Ruggieri, R., Dionisi, F., Mazzola, R., Fellin, F., Fiorentino, A., Schwarz, M., Ricchetti, F., Amichetti, M., and Alongi, F. (2016). “Nasal cavity reirradiation: a challenging case for comparison between proton therapy and volumetric modulated arc therapy.” eng. In: *Tumori* 102.Suppl. 2.

Scalco, E., Schwarz, M., Sutto, M., Ravanelli, D., Fellin, F., Cattaneo, G. M., and Rizzo, G. (2016). “Evaluation of different CT lung anatomies for proton therapy with pencil beam scanning delivery, using a validated non-rigid image registration method.” eng. In: *Acta oncologica (Stockholm, Sweden)* 55.5, pp. 647–651.

Schwarz, M. et al. (2015). “Clinical Pencil Beam Scanning: Present and Future Practices”. In: *Particle Radiotherapy - Emerging Technology for Treatment of Cancer*. Ed. by A. K. Rath and N. Sahoo. New Delhi: Springer India. Chap. 7, pp. 95–110.

Sensors and detectors

Adamczyk, K. et al., Belle-IISVD (2016a). “Belle II SVD ladder assembly procedure and electrical qualification”. In: *Nucl. Instrum. Meth.* A824, pp. 381–383.

— (2016b). “Belle-II VXD radiation monitoring and beam abort with sCVD diamond sensors”. In: *Nucl. Instrum. Meth.* A824, pp. 480–482.
— Belle-IISVD (2016c). “The silicon vertex detector of the Belle II experiment”. In: *Nucl. Instrum. Meth.* A824, pp. 406–410.
Giacomini, G., Bosisio, L., and Rashevskaya, I. (2016). “Insulation Issues in Punch-Through Biased Silicon Microstrip Sensors”. In: *IEEE Trans. Nucl. Sci.* 63.1, pp. 422–426.

Particle Physics

ATLAS

Aaboud, M. et al., The ATLAS Collaboration (2016a). “A measurement of material in the ATLAS tracker using secondary hadronic interactions in 7 TeV pp collisions”. In: *arXiv:1609.04305 [hep-ex]*.
— The ATLAS Collaboration (2016b). “A measurement of the calorimeter response to single hadrons and determination of the jet energy scale uncertainty using LHC Run-1 pp-collision data with the ATLAS detector”. In: *arXiv:1607.08842 [hep-ex]*.
— The ATLAS Collaboration (2016c). “Dark matter interpretations of ATLAS searches for the electroweak production of supersymmetric particles in $\sqrt{s} = 8$ TeV proton-proton collisions”. In: *JHEP* 1609, p. 175.
— The ATLAS Collaboration (2016d). “Luminosity determination in pp collisions at $\sqrt{s} = 8$ TeV using the ATLAS detector at the LHC”. In: *arXiv:1608.03953 [hep-ex]*.
— The ATLAS Collaboration (2016e). “Measurement of jet activity produced in top-quark events with an electron, a muon and two b-tagged jets in the final state in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector”. In: *arXiv:1610.09978 [hep-ex]*.
— The ATLAS Collaboration (2016f). “Measurement of the $b\overline{b}$ dijet cross section in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector”. In: *arXiv:1607.08430 [hep-ex]*.
— The ATLAS Collaboration (2016g). “Measurement of the inclusive cross-sections of single top-quark and top-antiquark t-channel production in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector”. In: *arXiv:1609.03920 [hep-ex]*.
— The ATLAS Collaboration (2016h). “Measurement of the $t\bar{t}Z$ and $t\bar{t}W$ production cross sections in multilepton final states using 3.2 fb^{-1} of pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector”. In: *arXiv:1609.01599 [hep-ex]*.
— The ATLAS Collaboration (2016i). “Measurement of the ZZ production cross section in pp collisions at $\sqrt{s} = 8$ TeV using the $ZZ \to \ell^-\ell^+\ell'^-\ell'^+$ and $ZZ \to \ell^-\ell^+\nu\bar{\nu}$ channels with the ATLAS detector”. In: *arXiv:1610.07585 [hep-ex]*.
— The ATLAS Collaboration (2016j). “Measurement of W boson angular distributions in events with high transverse momentum jets at $\sqrt{s} = 8$ TeV using the ATLAS detector”. In: *arXiv:1609.07045 [hep-ex]*.
— The ATLAS Collaboration (2016k). “Measurement of W^+W^- production in association with one jet in proton–proton collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector”. In: *Phys. Lett. B* 763, p. 114.
— The ATLAS Collaboration (2016l). “Measurement of $W^\pm W^\pm$ vector-boson scattering and limits on anomalous quartic gauge couplings with the ATLAS detector”. In: *arXiv:1611.02428 [hep-ex]*.
— The ATLAS Collaboration (2016m). “Measurements of $\psi(2S)$ and $X(3872) \to J/\psi\pi^+\pi^-$ production in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector”. In: *arXiv:1610.09303 [hep-ex]*.
— The ATLAS Collaboration (2016n). “Measurements of charge and CP asymmetries in b-hadron decays using top-quark events collected by the ATLAS detector in pp collisions at $\sqrt{s} = 8$ TeV”. In: *arXiv:1610.07869 [hep-ex]*.

Aaboud, M. et al., The ATLAS Collaboration (2016o). "Measurements of long-range azimuthal anisotropies and associated Fourier coefficients for pp collisions at $\sqrt{s} = 5.02$ and 13 TeV and p+Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV with the ATLAS detector". In: *arXiv:1609.06213 [nucl-ex]*.

— The ATLAS Collaboration (2016p). "Search for anomalous electroweak production of WW/WZ in association with a high-mass dijet system in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector". In: *arXiv:1609.05122 [hep-ex]*.

— The ATLAS Collaboration (2016q). "Search for dark matter in association with a Higgs boson decaying to b-quarks in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector". In: *arXiv:1609.04572 [hep-ex]*.

— The ATLAS Collaboration (2016r). "Search for dark matter produced in association with a hadronically decaying vector boson in pp collisions at $\sqrt{(s)}$=13 TeV with the ATLAS detector". In: *Phys. Lett. B* 763, p. 251.

— The ATLAS Collaboration (2016s). "Search for Minimal Supersymmetric Standard Model Higgs bosons H/A and for a Z' boson in the $\tau\tau$ final state produced in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS Detector". In: *Eur. Phys. J. C* 76 (11), p. 585.

— The ATLAS Collaboration (2016t). "Search for new phenomena in different-flavour high-mass dilepton final states in pp collisions at $\sqrt{s} = 13$ Tev with the ATLAS detector". In: *Eur. Phys. J. C* 76 (10), p. 541.

— The ATLAS Collaboration (2016u). "Search for triboson $W^{\pm}W^{\pm}W^{\mp}$ production in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector". In: *arXiv:1610.05088 [hep-ex]*.

— The ATLAS collaboration (2016v). "Searches for heavy ZZ and ZW resonances in the llqq and vvqq final states in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector". In: *ATLAS-CONF-2016-082*.

— The ATLAS Collaboration (2016w). "Study of hard double-parton scattering in four-jet events in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS experiment". In: *arXiv:1608.01857 [hep-ex]*.

Aad, G. et al., The ATLAS Collaboration (2016). "Performance of algorithms that reconstruct missing transverse momentum in $\sqrt{s} = 8$ TeV proton-proton collisions in the ATLAS detector". In: *arXiv:-1609.09324 [hep-ex]*.

RD-FASE2

Da Via, C., Dalla Betta, G.-F., Haughton, I., Hasi, J., Kenney, C., Povoli, M., and Mendicino, R. (2015). "3D silicon sensors with variable electrode depth for radiation hard high resolution particle tracking". In: *Journal Instrum.* 10, p. C04020.

Dalla Betta, G.-F. (2015). "Why and how pixels are becoming more and more intelligent". In: *Journal Instrum.* 10, p. C07010.

Dalla Betta, G.-F., Ayllon, N., Boscardin, M., Hoeferkamp, M., Mattiazzo, S., McDuff, H., Mendicino, R., Povoli, M., Seidel, S., Sultan, D., and Zorzi, N. (2016c). "Investigation of leakage current and breakdown voltage in irradiated double-sided 3D silicon sensors". In: *Journal Instrum.* 11, P09006.

Dalla Betta, G.-F., Boscardin, M., Bomben, M., Brianzi, M., Calderini, G., Darbo, G., Mendicino, R., Meschini, M., Messineo, A. R., Ronchin, S., Sultan, D., and Zorzi, N. (2016f). "The INFN-FBK "Phase-2" R&D program". In: *Nucl. Instrum. Methods A* 824, pp. 388–391.

Dalla Betta, G.-F., Boscardin, M., Darbo, G., Mendicino, R., Meschini, M., Messineo, A. R., Ronchin, S., Sultan, D., and Zorzi, N. (2016g). "Development of a new generation of 3D pixel sensors for HL-LHC". In: *Nucl. Instrum. Methods A* 824, pp. 386–387.

Dalla Betta, G.-F., Boscardin, M., Mendicino, R., Ronchin, S., Sultan, D., and Zorzi, N. (2015). "Development of New 3D Pixel Sensors for Phase 2 Upgrades at LHC". In: *IEEE NSS-MIC Conference Record*. Ed. by C. Ilgner. Piscataway, NJ, USA: IEEE.

Meschini, M., Dalla Betta, G.-F., Boscardin, M., Darbo, G., Giacomini, G., Messineo, A., and Ronchin, S. (2016). “The INFN-FBK pixel R&D program for HL-LHC”. In: *Nucl. Instrum. Methods A* 831, pp. 116–121.

Moscatelli, F., Passeri, D., Bilei, G. M., Morozzi, A., Dalla Betta, G.-F., and Mendicino, R. (2016). “Combined Bulk and Surface Radiation Damage Effects at Very High Fluences in Silicon Detectors: Measurements and TCAD Simulations”. In: *IEEE Trans. Nucl. Sci.* 63 (5), pp. 2716–2723.

Sultan, D., Mendicino, R., Boscardin, M., Ronchin, S., Zorzi, N., and Dalla Betta, G.-F. (2015). “Characterization of the first double-sided 3D radiation sensors fabricated at FBK on 6-inch silicon wafers”. In: *Journal Instrum.* 10, p. C12029.

Astroparticle Physics

AMS-02

Aguilar, M. et al., the AMS-02 Collaboration (2015a). “Precision Measurement of the Helium Flux in Primary Cosmic Rays of Rigidities 1.9 GV to 3 TV with the Alpha Magnetic Spectrometer on the International Space Station.” In: *Phys. Rev Lett.* 115.

— the AMS-02 Collaboration (2015b). “Precision Measurement of the Proton Flux in Primary Cosmic Rays from Rigidity 1 GV to 1.8 TV with the Alpha Magnetic Spec- trometer on the International Space Station.” In: *Phys. Rev Lett.* 114.

— the AMS-02 Collaboration (2016). “Antiproton Flux, Antiproton-to-Proton Flux Ratio, and Properties of Elementary Particle Fluxes in Primary Cosmic Rays Measured with the Alpha Magnetic Spectrometer on the International Space Station.” In: *Phys. Rev Lett.* 117.

Battiston, R. (2016). “What next in fundamental physics in space.” In: *Annalen der Physik* 528, pp. 55–61.

FISH

Bienaimé, T., Fava, E., Colzi, G., Mordini, C., Serafini, S., Qu, C., Stringari, S., Lamporesi, G., and Ferrari, G. (2016). “Spin-Dipole Oscillation and Polarizability of a Binary Bose-Einstein Condensate near the Miscible-Immiscible Phase Transition”. In: *arXiv:1607.04574*.

Colzi, G., Durastante, G., Fava, E., Serafini, S., Lamporesi, G., and Ferrari, G. (2016). “Sub-Doppler cooling of sodium atoms in gray molasses”. In: *Phys. Rev. A* 93 (2), p. 023421.

HUMOR

Bawaj, M., Biancofiore, C., Bonaldi, M., Bonfigli, F., Borrielli, A., Di Giuseppe, G., Marconi, L., Marino, F., Natali, R., Pontin, A., Prodi, G. A., Serra, E., Vitali, D., and Marin, F. (2015). “Probing deformed commutators with macroscopic harmonic oscillators”. In: *Nature Communications* 6.

Borrielli, A., Marconi, L., Marin, F., Marino, F., Morana, B., Pandraud, G., Pontin, A., Prodi, G. A., Sarro, P. M., Serra, E., and Bonaldi, M. (2016). “Control of recoil losses in nanomechanical SiN membrane resonators”. In: *Physical Review B* 94.12.

Borrielli, A., Pontin, A., Cataliotti, F. S., Marconi, L., Marin, F., Marino, F., Pandraud, G., Prodi, G. A., Serra, E., and Bonaldi, M. (2015). “Low loss optomechanical cavities based on silicon oscillator”. In: *Smart Sensors, Actuators and MEMS VII; and Cyber Physical Systems*. Ed. by SanchezRojas, JL and Brama, R. Vol. 9517. Proceedings of SPIE. SPIE.

— (2015). “Low-Loss Optomechanical Oscillator for Quantum-Optics Experiments”. In: *Physical Review Applied* 3.5.

Pontin, A., Bonaldi, M., Borrielli, A., Marconi, L., Marino, F., Pandraud, G., Prodi, G. A., Sarro, P. M., Serra, E., and Marin, F. (2016). “Dynamical Two-Mode Squeezing of Thermal Fluctuations in a Cavity Optomechanical System”. In: *Physical Review Letters* 116.10.

Pontin, A., Bonaldi, M., Borrielli, A., Marino, F., Marconi, L., Bagolini, A., Pandraud, G., Serra, E., Prodi, G. A., and Marin, F. (2015). “Dynamical back-action effects in low loss optomechanical oscillators”. In: *Annalen der Physik* 527.1-2, SI, 89–99.

Serra, E., Bawaj, M., Borrielli, A., Di Giuseppe, G., Forte, S., Kralj, N., Malossi, N., Marconi, L., Marin, F., Marino, F., Morana, B., Natali, R., Pandraud, G., Pontin, A., Prodi, G. A., Rossi, M., Sarro, P. M., Vitali, D., and Bonaldi, M. (2016). “Microfabrication of large-area circular high-stress silicon nitride membranes for optomechanical applications”. In: *AIP Advances* 6.6.

Serra, E., Bonaldi, M., Borrielli, A., Conti, L., Pandraud, G., and Sarro, P. M. (2015[a]). “Low loss single-crystal silicon mechanical resonators for the investigation of thermal noise statistical properties”. In: *Sensors and Actuators A-Physical* 227, 48–54.

Serra, E., Bonaldi, M., Borrielli, A., Mann, F., Marconi, L., Marino, F., Pandraud, G., Pontin, A., Prodi, G. A., and Sarro, P. M. (2015[b]). “Fabrication and characterization of low loss MOMS resonators for cavity opto-mechanics”. In: *Microelectronic Engineering* 145, 138–142.

LIMADOU

Ambroglini, F., Burger, W., Battiston, R., Vitale, V., and Zhang, Y. (2014). “Space Earthquake Perturbation Simulation (SEPS)”. In: *EGU General Assembly Conference Abstracts*. Vol. 16. EGU General Assembly Conference Abstracts, p. 15024.

LISA Pathfinder

Armano, M. et al., the eLISA Collaboration (2015a). “A noise simulator for eLISA: Migrating LISA Pathfinder knowledge to the eLISA mission”. In: *Journal of Physics: Conference Series* 610.1, p. 012036.

— the eLISA Collaboration (2015b). “A Strategy to Characterize the LISA-Pathfinder Cold Gas Thruster System”. In: *Journal of Physics: Conference Series* 610.1, p. 012026.

— the eLISA Collaboration (2015c). “Bayesian statistics for the calibration of the LISA Pathfinder experiment”. In: *Journal of Physics: Conference Series* 610.1, p. 012027.

— the eLISA Collaboration (2015d). “Disentangling the magnetic force noise contribution in LISA Pathfinder”. In: *Journal of Physics: Conference Series* 610.1, p. 012024.

— the eLISA Collaboration (2015e). “Free-flight experiments in LISA Pathfinder”. In: *Journal of Physics: Conference Series* 610.1, p. 012006.

— the eLISA Collaboration (2015f). “In-flight thermal experiments for LISA Pathfinder: Simulating temperature noise at the Inertial Sensors”. In: *Journal of Physics: Conference Series* 610.1, p. 012023.

— the eLISA Collaboration (2015g). “The LISA Pathfinder Mission”. In: *Journal of Physics: Conference Series* 610.1, p. 012005.

— (2016a). “Constraints on LISA Pathfinder’s self-gravity: design requirements, estimates and testing procedures”. In: *Classical and Quantum Gravity* 33, p. 235015.

— the eLISA Collaboration (2016b). “Sub-Femto-g Free Fall for Space-Based Gravitational Wave Observatories: LISA Pathfinder Results”. In: *Phys. Rev. Lett.* 116 (23).

Bassan, M., Cavalleri, A., De Laurentis, M., De Marchi, F., De Rosa, R., Di Fiore, L., Dolesi, R., Finetti, N., Garufi, F., Grado, A., Hueller, M., Marconi, L., Milano, L., Pucacco, G., Stanga, R., Visco, M., Vitale, S., and Weber, W. J. (2016). “Approaching Free Fall on Two Degrees of Freedom: Simultaneous Measurement of Residual Force and Torque on a Double Torsion Pendulum”. In: *Phys. Rev. Lett.* 116 (5), p. 051104.

Ferraioli, L., Armano, M., Audley, H., Congedo, G., Diepholz, I., Gibert, F., Hewitson, M., Hueller, M., Karnesis, N., Korsakova, N., Nofrarias, M., Plagnol, E., and Vitale, S. (2015). "Kolmogorov-Smirnov like test for time-frequency Fourier spectrogram analysis in LISA Pathfinder". In: *Experimental Astronomy* 39.1, pp. 1–10.

Nofrarias, M., Karnesis, N., Gibert, F., Armano, M., Audley, H., Danzmann, K., Diepholz, I., Dolesi, R., Ferraioli, L., Ferroni, V., Hewitson, M., Hueller, M., Inchauspe, H., Jennrich, O., Korsakova, N., McNamara, P. W., Plagnol, E., Thorpe, J. I., Vetrugno, D., Vitale, S., Wass, P., and Weber, W. J. (2016). "Optimal design of calibration signals in space-borne gravitational wave detectors". In: *Phys. Rev. D* 93 (10), p. 102004.

VIRGO

Aasi, J. et al., VIRGO, LIGO Scientific (2016a). "First low frequency all-sky search for continuous gravitational wave signals". In: *Phys. Rev.* D93.4, p. 042007.

— VIRGO, LIGO (2016b). "Search of the Orion spur for continuous gravitational waves using a loosely coherent algorithm on data from LIGO interferometers". In: *Phys. Rev.* D93.4, p. 042006.

Abbott, B. P. et al., VIRGO, LIGO Scientific (2016a). "All-sky search for long-duration gravitational wave transients with initial LIGO". In: *Phys. Rev.* D93.4, p. 042005.

— Virgo, LIGO Scientific (2016b). "Astrophysical Implications of the Binary Black-Hole Merger GW150914". In: *Astrophys. J.* 818.2, p. L22.

— Virgo, LIGO Scientific (2016c). "Binary Black Hole Mergers in the first Advanced LIGO Observing Run". In: *Phys. Rev.* X6.4, p. 041015.

— Virgo, LIGO Scientific (2016d). "Characterization of transient noise in Advanced LIGO relevant to gravitational wave signal GW150914". In: *Class. Quant. Grav.* 33.13, p. 134001.

— Virgo, LIGO Scientific (2016e). "Comprehensive all-sky search for periodic gravitational waves in the sixth science run LIGO data". In: *Phys. Rev.* D94.4, p. 042002.

— Virgo, LIGO Scientific (2016f). "Directly comparing GW150914 with numerical solutions of Einstein's equations for binary black hole coalescence". In: *Phys. Rev.* D94, p. 064035.

— Virgo, LIGO Scientific (2016g). "GW150914: First results from the search for binary black hole coalescence with Advanced LIGO". In: *Phys. Rev.* D93.12, p. 122003.

— Virgo, LIGO Scientific (2016h). "GW150914: Implications for the stochastic gravitational wave background from binary black holes". In: *Phys. Rev. Lett.* 116.13, p. 131102.

— Virgo, LIGO Scientific (2016i). "GW150914: The Advanced LIGO Detectors in the Era of First Discoveries". In: *Phys. Rev. Lett.* 116.13, p. 131103.

— Virgo, LIGO Scientific (2016j). "GW151226: Observation of Gravitational Waves from a 22-Solar-Mass Binary Black Hole Coalescence". In: *Phys. Rev. Lett.* 116.24, p. 241103.

— InterPlanetary Network, DES, INTEGRAL, La Silla-QUEST Survey, MWA, Fermi-LAT, J-GEM, DEC, Zadko, GRAWITA, Pi of the Sky, MASTER, Swift, iPTF, VISTA, ASKAP, SkyMapper, PESSTO, TOROS, Pan-STARRS, Virgo, Algerian National Observatory, Liverpool Telescope, BOOTES, LIGO Scientific, LOFAR, TAROT, C2PU, MAXI, Fermi-GBM (2016k). " Localization and broadband follow-up of the gravitational-wave transient GW150914". In: *Astrophys. J. Suppl.* 225.1, p. 8.

— InterPlanetary Network, DES, INTEGRAL, La Silla-QUEST Survey, MWA, Fermi-LAT, J-GEM, DEC, GRAWITA, Pi of the Sky, Fermi GBM, MASTER, Swift, iPTF, VISTA, ASKAP, SkyMapper, PESSTO, TOROS, Pan-STARRS, Virgo, Liverpool Telescope, BOOTES, LIGO Scientific, LOFAR, C2PU, MAXI (2016l). "Localization and broadband follow-up of the gravitational-wave transient GW150914". In: *Astrophys. J.* 826.1, p. L13.

— Virgo, LIGO Scientific (2016m). "Observation of Gravitational Waves from a Binary Black Hole Merger". In: *Phys. Rev. Lett.* 116.6, p. 061102.

Abbott, B. P. et al., Virgo, LIGO Scientific (2016n). "Observing gravitational-wave transient GW150914 with minimal assumptions". In: *Phys. Rev.* D93.12. [Addendum: Phys. Rev.D94,no.6,069903(2016)], p. 122004.

— Virgo, LIGO Scientific (2016o). "Properties of the Binary Black Hole Merger GW150914". In: *Phys. Rev. Lett.* 116.24, p. 241102.

— Virgo, LIGO Scientific (2016p). "Search for transient gravitational waves in coincidence with short-duration radio transients during 2007?2013". In: *Phys. Rev.* D93.12, p. 122008.

— Virgo, LIGO Scientific (2016q). "Tests of general relativity with GW150914". In: *Phys. Rev. Lett.* 116.22, p. 221101.

Abbott, B. P. et al., Virgo, LIGO Scientific (2016r). "The basic physics of the binary black hole merger GW150914". In: *Annalen Phys.*

Abbott, B. et al., Virgo, LIGO Scientific (2016). "Improved analysis of GW150914 using a fully spin-precessing waveform Model". In: *Phys. Rev.* X6.4, p. 041014.

Accadia, T. et al. (2015). "Advanced Virgo Interferometer: a Second Generation Detector for Gravitational Waves Observation". In: *Proceedings, 16th Lomonosov Conference on Elementary Particle Physics: Particle Physics at the Year of Centenary of Bruno Pontecorvo: Moscow, Russia, August 22-28, 2013*, pp. 261–270.

Adrian-Martinez, S. et al., Virgo, IceCube, ANTARES, LIGO Scientific (2016). "High-energy Neutrino follow-up search of Gravitational Wave Event GW150914 with ANTARES and IceCube". In: *Phys. Rev.* D93.12, p. 122010.

Astone, P. et al. (2015). "Gravitational waves: search results, data analysis and parameter estimation". In: *Gen. Rel. Grav.* 47.2, p. 11.

Klimenko, S. et al. (2016). "Method for detection and reconstruction of gravitational wave transients with networks of advanced detectors". In: *Phys. Rev.* D93.4, p. 042004.

Tiwari, V. et al. (2016). "Proposed search for the detection of gravitational waves from eccentric binary black holes". In: *Phys. Rev.* D93.4, p. 043007.

Tiwari, V. et al. (2015). "Regression of Environmental Noise in LIGO Data". In: *Class. Quant. Grav.* 32.16, p. 165014.

Nuclear Physics

AEgIS

Aghion, S. et al., the AEgIS Collaboration (2014). "A moiré deflectometer for antimatter". In: *Nat. Commun.* 5, p. 453.

— the AEgIS Collaboration (2015). "Positron bunching and electrostatic transport system for the production and emission of dense positronium clouds into vacuum". In: *Nucl. Instrum. Methods Phys. Res. B* 362, pp. 86–92.

— the AEgIS Collaboration (2016). "Laser excitation of n=3 level of Ps for antihydrogen production". In: *Phys. Rev. A* 94.

Caravita, R. et al., the AEgIS Collaboration (2016). "Towards a gravity measurement on cold antimatter atoms". In: *Il Nuovo Cimento C* 39.

Consolati, G. et al., the AEgIS Collaboration (2015). "Experiments with low-energy antimatter". In: *EPJ Web of Conferences* 96.

Kimura, M. et al., the AEgIS Collaboration (2015). "Testing the Weak Equivalence Principle with an antimatter beam at CERN". In: *Journal of Physics: Conference Series* 631.

Mariazzi, S., Di Noto, L., Nebbia, G., and Brusa, R. S. (2015). "Collisional cooled Ps emitted into vacuum from silica-based porous materials: experiment to measure the Ps cooling time". In: *Journal of Physics: Conference Series* 618.

Pistillo, C. et al., the AEgIS Collaboration (2015). “Emulsion detectors for the antihydrogen detection in AEgIS”. In: *Hyperfine Interact.* 233, pp. 29–34.
Ravelli, L., Macchi, C., Mariazzi, S., Mazzoldi, P., Egger, W., Hugenschmidt, C., Somoza, A., and Brusa, R. S. (2015). “Interstitial oxygen related defects and nanovoids in Au implanted a-SiO2 glass depth profiled by positron annihilation spectroscopy”. In: *J. Phys. D: Appl. Phys.* 48.
Storey, J. et al., the AEgIS Collaboration (2015). “Particle tracking at cryogenic temperatures: the Fast Annihilation Cryogenic Tracking (FACT) detector for the AEgIS antimatter gravity experiment”. In: *JINST* 10.

Theoretical Physics

BELL

Albeverio, S. and Mazzucchi, S. (2015a). “An Introduction to Infinite-dimensional Oscillatory and Probabilistic Integrals”. In: *Stochastic Analysis: A Series of Lectures: Centre Interfacultaire Bernoulli, January–June 2012, Ecole Polytechnique Fédérale de Lausanne, Switzerland*. Ed. by R. C. Dalang, M. Dozzi, F. Flandoli, and F. Russo. Basel: Springer Basel, pp. 1–54.
— (2015b). “Infinite dimensional oscillatory integrals as projective systems of functionals”. In: *Journal of the Mathematical Society of Japan* 67.4, pp. 1295–1316.
— (2016). “A unified approach to infinite-dimensional integration”. In: *Reviews in Mathematical Physics* 28, p. 1650005.
Brunetti, R., C. Dappiaggi, K. Fredenhagen, and J. Yngvason, eds. (2015). *Advances in algebraic quantum field theory*. Mathematical Physics Studies. Springer.
Brunetti, R., Fredenhagen, K., Hack, T.-P., Pinamonti, N., and Rejzner, K. (2016a). “Cosmological perturbation theory and quantum gravity”. In: *JHEP* 08, p. 032.
Brunetti, R., Fredenhagen, K., and Rejzner, K. (2016b). “Quantum gravity from the point of view of locally covariant quantum field theory”. In: *Commun. Math. Phys.* 345.3, pp. 741–779.
Khavkine, I. and Moretti, V. (2014). “Algebraic QFT in Curved Spacetime and quasifree Hadamard states: an introduction”. In: *Advances in algebraic quantum field theory*. Ed. by R. Brunetti, C. Dappiaggi, K. Fredenhagen, and J. Yngvason, pp. 191–251.
— (2016). “Analytic Dependence is an Unnecessary Requirement in Renormalization of Locally Covariant QFT”. In: *Communications in Mathematical Physics* 344, pp. 581–620.
Mazzucchi, S. (2015a). “Feynman path integrals for quantum open systems (Introductory Workshop on Path Integrals and Pseudo-Differential Operators)”. In: *RIMS Kokyuroku* 1958, pp. 96–116.
— (2015b). “Generalized Feynman-Kac formulae for the solution of high order heat-type equations (Introductory Workshop on Path Integrals and Pseudo-Differential Operators)”. In: *RIMS Kokyuroku* 1958, pp. 143–159.
Moretti, V. (2016). “Mathematical Foundations of Quantum Mechanics: An Advanced Short Course”. In: *Int. J. Geom. Meth. Mod. Phys.* 13.Supp. 1, p. 1630011.
Moretti, V. and Pastorello, D. (2015). “Frame functions in finite-dimensional Quantum Mechanics and its Hamiltonian formulation on complex projective spaces”. In: *Int. J. Geom. Meth. Mod. Phys.* 13.02, p. 1650013.
Pastorello, D. (2015a). “A geometric Hamiltonian description of composite quantum systems and quantum entanglement”. In: *International Journal of Geometric Methods in Modern Physics* 12.07, p. 1550069.
— (2015b). “Geometric Hamiltonian formulation of quantum mechanics in complex projective spaces”. In: *International Journal of Geometric Methods in Modern Physics* 12.08, p. 1560015.
— (2016a). “Geometric Hamiltonian quantum mechanics and applications”. In: *International Journal of Geometric Methods in Modern Physics* 13.Supp. 1, p. 1630017.

Pastorello, D. (2016b). “Open-loop quantum control as a resource for secure communications”. In: *International Journal of Quantum Information* 14, p. 1650010.

BIOPHYS

a Beccara, S., Fant, L., and Faccioli, P. (2015). “Variational Scheme to Compute Protein Reaction Pathways Using Atomistic Force Fields with Explicit Solvent”. In: *Phys. Rev. Lett.* 114, p. 098103.

Blaizot, J.-P., De Boni, D., Faccioli, P., and Garberoglio, G. (2016). “Heavy quark bound states in a quarkÐgluon plasma: Dissociation and recombination”. In: *Nucl. Phys. A* 946, pp. 49–88.

Calliari, L., Dapor, M., Garberoglio, G., and Fanchenko, S. (2015). “Reflection electron energy loss spectra beyond the optical limit.” In: *Nuclear Instruments and Methods in Physics Research Section B* 352, p. 171.

Garberoglio, G., Pugno, N., and Taioli, S. (2015b). “Gas adsorption and separation in realistic and idealized frameworks of organic pillared graphene: a comparative study.” In: *J. Phys. Chem C* 119, p. 1980.

Orioli, S. and Faccioli, P. (2016). “Dimensional Reduction of Markov State Models from Renormalization Group Theory”. In: *J. Chem. Phys.* 145, p. 124120.

Pedrielli, A., Taioli, S., Garberoglio, G., and Pugno, N. (2017). “Designing graphene based nanofoams with nonlinear auxetic and anisotropic mechanical properties under tension or compression.” In: *Carbon* 111, p. 796.

Schneider, E., a Beccara, S., Mascherpa, F., and Faccioli, P. (2016). “Quantum propagation of electronic excitations in macromolecules: A computationally efficient multiscale approach”. In: *Phys. Rev. B* 94, p. 014306.

Tatti, R., Aversa, L., Verrucchi, R., Cavaliere, E., Garberoglio, G., Pugno, N., Speranza, G., and Taioli, S. (2016a). “Synthesis of single layer graphene on Cu(111) by C60 supersonic molecular beam epitaxy.” In: *RSC Adv.* 6, pp. 37982–37993.

Wang Fang Cazzolli Giorgia, W. P. and Pietro, F. (2016). “Folding Mechanism of Proteins Im7 and Im9: Insight from All-Atom Simulations in Implicit and Explicit Solvent”. In: *J. Phys. Chem. B* 120, pp. 9296–9307.

FBS

Bacca, S., Barnea, N., Leidemann, W., and Orlandini, G. (2015). “Examination of the first excited state of ^{4}He as a potential breathing mode”. In: *Phys. Rev. C* 91.

Ferrari Ruffino, F., Barnea, N., S., D., Leidemann, W., and Orlandini, G. (2016). “Non-Symmetrized Hyperspherical Harmonics Method Applied to Light Hypernuclei”. In: *EPJ Web of Conferences* 113, p. 08005.

Hagen, G., Ekström, A., Forssén, C., Jansen, G. R., Nazarewicz, W., Papenbrock, T., Wendt, K. A., Bacca, S., Barnea, N., Carlsson, B., Drischler, C., Hebeler, K., Hjorth-Jensen, M., Miorelli, M., Orlandini, G., Schwenk, A., and Simonis, J. (2016). “Neutron and weak-charge distributions of the ^{48}Ca nucleus”. In: *Nature Physics* 12, pp. 186–190.

Leidemann, W. (2016). “Resolution of resonances with the Lorentz integral transform”. In: *EPJ Web of Conferences* 113, p. 04014.

Leidemann, W. (2015). “Energy resolution with the Lorentz integral transform”. In: *Phys. Rev. C* 91.

Miorelli, M., Bacca, S., Barnea, N., Hagen, G., Orlandini, G., and Papenbrock, T. (2016a). “Electric dipole polarizability: from few- to many-body systems”. In: *EPJ Web of Conferences* 113, p. 04007.

— (2016b). “Electric dipole polarizability from first principles calculations”. In: *Phys. Rev. C* 94, p. 034317.

Orlandini, G., Bacca, S., Barnea, N., and Leidemann, W. (2016). “Is the isoscalar monopole resonance of the α-particle a collective mode?” In: *EPJ Web of Conferences* 113, p. 06016.

S., D., Efros, V. D., and Leidemann, W. (2016). “Low-energy calculations for nuclear photodisintegration”. In: *EPJ Web of Conferences* 113, p. 08003.

FLAG

Amendola, L. et al. (2016). “Cosmology and Fundamental Physics with the Euclid Satellite”. In: *arXiv:1606.00180 [astro-ph.CO]*.
Cisterna, A., Delsate, T., Ducobu, L., and Rinaldi, M. (2016). “Slowly rotating neutron stars in the nonminimal derivative coupling sector of Horndeski gravity”. In: *Phys. Rev.* D93.8, p. 084046.
Cisterna, A., Delsate, T., and Rinaldi, M. (2015). “Neutron stars in general second order scalar-tensor theory: The case of nonminimal derivative coupling”. In: *Phys. Rev.* D92.4, p. 044050.
Cognola, G., Elizalde, E., and Zerbini, S. (2015a). “Functional Determinant of the Massive Laplace Operator and the Multiplicative Anomaly”. In: *J. Phys.* A48.4, p. 045203.
Cognola, G., Myrzakulov, R., Sebastiani, L., Vagnozzi, S., and Zerbini, S. (2016). “Covariant Horava-like and mimetic Horndeski gravity: cosmological solutions and perturbations”. In: *Class. Quant. Grav.* 33.22, p. 225014.
Cognola, G., Rinaldi, M., and Vanzo, L. (2015b). “Scale-invariant rotating black holes in quadratic gravity”. In: *Entropy* 17, pp. 5145–5156.
Cognola, G., Rinaldi, M., Vanzo, L., and Zerbini, S. (2015c). “Thermodynamics of topological black holes in R^2 gravity”. In: *Phys. Rev.* D91, p. 104004.
Colléaux, A. and Zerbini, s. (2015). “Modified Gravity Models Admitting Second Order Equations of Motion”. In: *Entropy* 17, p. 6643.
Myrzakulov, R., Sebastiani, L., Vagnozzi, S., and Zerbini, S. (2016). “Static spherically symmetric solutions in mimetic gravity: rotation curves and wormholes”. In: *Class. Quant. Grav.* 33.12, p. 125005.
Myrzakulov, R., Sebastiani, L., and Zerbini, S. (2015). “Reconstruction of Inflation Models”. In: *Eur. Phys. J.* C75.5, p. 215.
Rabochaya, Y. and Zerbini, S. (2016a). “A note on a mimetic scalar-tensor cosmological model”. In: *Eur. Phys. J.* C76.2, p. 85.
— (2016b). “Quantum detectors in generic non flat FLRW space-times”. In: *Int. J. Theor. Phys.* 55.5, pp. 2682–2696.
Rinaldi, M. (2015a). “Dark energy as a fixed point of the Einstein Yang-Mills Higgs Equations”. In: *JCAP* 1510.10, p. 023.
— (2015b). “Higgs Dark Energy”. In: *Class. Quant. Grav.* 32, p. 045002.
Rinaldi, M., Cognola, G., Vanzo, L., and Zerbini, S. (2015a). “Inflation in scale-invariant theories of gravity”. In: *Phys. Rev.* D91.12, p. 123527.
Rinaldi, M. and Vanzo, L. (2016a). “Inflation and reheating in theories with spontaneous scale invariance symmetry breaking”. In: *Phys. Rev.* D94.2, p. 024009.
Rinaldi, M., Vanzo, L., Zerbini, S., and Venturi, G. (2016b). “Inflationary quasi scale-invariant attractors”. In: *Phys. Rev.* D93, p. 024040.

LISC

Aversa, L., Taioli, S., Nardi, M. V., Tatti, R.-e., Verucchi, R., and Iannotta, S. (2015). “The interaction of C_{60} on Si(111) 7 × 7 studied by supersonic molecular beams: interplay between precursor kinetic energy and substrate temperature in surface activated processes”. In: *Frontiers in Materials* 2, p. 46.
Dapor, M. (2015a). “Energy loss of fast electrons impinging upon polymethylmethacrylate”. In: *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms* 352, pp. 190–194.

Dapor, M. (2015b). “Mermin differential inverse inelastic mean free path of electrons in polymethylmethacrylate”. In: *Frontiers in Materials* 2, p. 27.

— (2017). “Role of the tail of high-energy secondary electrons in the Monte Carlo evaluation of the fraction of electrons backscattered from polymethylmethacrylate”. In: *Applied Surface Science* 391, pp. 3–11.

Dapor, M., Abril, I., Vera, P. de, and Garcia-Molina, R. (2015a). “Simulation of the secondary electrons energy deposition produced by proton beams in PMMA: influence of the target electronic excitation description”. In: *The European Physical Journal D* 69.6, pp. 1–10.

— (2016). “Energy Deposited by Secondary Electrons Generated by Swift Proton Beams through Polymethylmethacrylate”. In: *Institute for Fundamental Physics and Applications (INFN-TIFPA)* 1, p. 38123.

Dapor, M., Garberoglio, G., and Calliari, L. (2015b). “Energy loss of electrons impinging upon glassy carbon, amorphous carbon, and diamond: comparison between two different dispersion laws”. In: *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms* 352, pp. 181–185.

Garberoglio, G. (2015). “Modeling Quantum Effects on Adsorption and Diffusion of Hydrogen in Metal–Organic Frameworks”. In: *Metal-Organic Frameworks: Materials Modeling towards Engineering Applications*, p. 251.

Garberoglio, G., Pugno, N. M., and Taioli, S. (2015a). “Gas Adsorption and Separation in Realistic and Idealized Frameworks of Organic Pillared Graphene: A Comparative Study”. In: *The Journal of Physical Chemistry C* 119.4, pp. 1980–1987.

Lepore, E., Bonaccorso, F., Bruna, M., Bosia, F., Taioli, S., Garberoglio, G., Ferrari, A., Pugno, N. M., et al. (2015). “Silk reinforced with graphene or carbon nanotubes spun by spiders”. In: *arXiv preprint arXiv:1504.06751*.

Masters, R., Wan, Q., Zhou, Y., Sandu, A., Dapor, M., Zhang, H., Lidzey, D., and Rodenburg, C. (2015). “Application of low-voltage backscattered electron imaging to the mapping of organic photo-voltaic blend morphologies”. In: *Journal of Physics: Conference Series*. Vol. 644. 1. IOP Publishing, p. 012017.

Masters, R. C., Pearson, A. J., Glen, T. S., Sasam, F.-C., Li, L., Dapor, M., Donald, A. M., Lidzey, D. G., and Rodenburg, C. (2015). “Sub-nanometre resolution imaging of polymer-fullerene photovoltaic blends using energy-filtered scanning electron microscopy”. In: *Nature communications* 6.

Masters, R. C., Wan, Q., Zhang, Y., Dapor, M., Sandu, A. M., Jiao, C., Zhou, Y., Zhang, H., Lidzey, D. G., and Rodenburg, C. (2017). “Novel organic photovoltaic polymer blends: A rapid, 3-dimensional morphology analysis using backscattered electron imaging in the scanning electron microscope”. In: *Solar Energy Materials and Solar Cells* 160, pp. 182–192.

Palmerini, S., Busso, M., Simonucci, S., and Taioli, S. (2016). “Lithium abundances in AGB stars and a new estimate for the ^{7}Be life-time”. In: *Journal of Physics: Conference Series*. Vol. 665. 1. IOP Publishing, p. 012014.

Paris, A. and Taioli, S. (2016). “Multiscale Investigation of Oxygen Vacancies in TiO_2 Anatase and Their Role in Memristor’s Behavior”. In: *The Journal of Physical Chemistry C* 120.38, pp. 22045–22053.

Taioli, S. (2015). “A bird’s eye view on the concept of multichannel scattering with applications to materials science, condensed matter, and nuclear astrophysics”. In: *Frontiers in Materials* 2, p. 33.

Taioli, S., Dapor, M., and Pugno, N. M. (2015a). “Editorial: New Frontiers in Multiscale Modelling of Advanced Materials”. In: *Frontiers in Materials* 2, p. 71.

Taioli, S., Gabbrielli, R., Simonucci, S., Pugno, N. M., and Iorio, A. (2016a). "Lobachevsky crystallography made real through carbon pseudospheres". In: *Journal of Physics: Condensed Matter* 28.13, 13LT01.

Taioli, S., Paris, A., and Calliari, L. (2016b). "Characterization of Pristine and Functionalized Graphene on Metal Surfaces by Electron Spectroscopy". In: *Graphene Science Handbook: Size-Dependent Properties*. Vol. 5. CRC Press 2016, Taylor & Francis Group, pp. 269–285.

Taioli, S. and Simonucci, S. (2015b). "Chapter Five - A Computational Perspective on Multichannel Scattering Theory with Applications to Physical and Nuclear Chemistry". In: *Annual Reports in Computational Chemistry* 11, pp. 191–310.

Taioli, S., Simonucci, S., a Beccara, S., and Garavelli, M. (2015c). "Tetrapeptide unfolding dynamics followed by core-level spectroscopy: a first-principles approach". In: *Physical Chemistry Chemical Physics* 17, pp. 11269–11276.

Tatti, R., Aversa, L., Verucchi, R., Cavaliere, E., Garberoglio, G., Pugno, N. M., Speranza, G., and Taioli, S. (2016b). "Synthesis of single layer graphene on Cu(111) by $C_6$0 supersonic molecular beam epitaxy". In: *RSC Advances* 6.44, pp. 37982–37993.

Wan, Q., Masters, R. C., Lidzey, D., Abrams, K. J., Dapor, M., Plenderleith, R. A., Rimmer, S., Claeyssens, F., and Rodenburg, C. (2016). "Angle selective backscattered electron contrast in the low-voltage scanning electron micro-scope: Simulation and experiment for polymers". In: *Ultramicroscopy* 171, pp. 126–138.

Wan, Q., Plenderleith, R., Dapor, M., Rimmer, S., Claeyssens, F., and Rodenburg, C. (2015). "Separating topographical and chemical analysis of nanostructure of polymer composite in low voltage SEM". In: *Journal of Physics: Conference Series*. Vol. 644. 1. IOP Publishing, p. 012018.

Zhou, Y., Fox, D. S., Maguire, P., O'Connell, R., Masters, R., Rodenburg, C., Wu, H., Dapor, M., Chen, Y., and Zhang, H. (2016). "Quantitative secondary electron imaging for work function extraction at atomic level and layer identification of graphene". In: *Scientific reports* 6.

MANYBODY

Ambrosetti, A., Silvestrelli, P. L., Pederiva, F., Mitas, L., and Toigo, F. (2015). "Repulsive atomic Fermi gas with Rashba spin-orbit coupling: A quantum Monte Carlo study". In: *Physical Review A* 91.5.

Barnea, N., Contessi, L., Gazit, D., Pederiva, F., and Kolck, U. van (2015). "Effective Field Theory for Lattice Nuclei". In: *Physical Review Letters* 114.5.

Carlson, J., Gandolfi, S., Pederiva, F., Pieper, S. C., Schiavilla, R., Schmidt, K. E., and Wiringa, R. B. (2015). "Quantum Monte Carlo methods for nuclear physics". In: *Reviews of Modern Physics* 87.3, 1067–1118.

Kirscher, J., Barnea, N., Gazit, D., Pederiva, F., and Kolck, U. van (2015). "Spectra and scattering of light lattice nuclei from effective field theory". In: *Physical Review C* 92.5.

Lipparini, E. and Pederiva, F. (2016). "Transverse isospin response function of asymmetric nuclear matter from a local isospin density functional". In: *Physical Review C* 94.2.

Lonardoni, D., Lovato, A., Gandolfi, S., and Pederiva, F. (2015). "Hyperon Puzzle: Hints from Quantum Monte Carlo Calculations". In: *Physical Review Letters* 114.9.

Melton, C. A., Zhu, M., Guo, S., Ambrosetti, A., Pederiva, F., and Mitas, L. (2016). "Spin-orbit interactions in electronic structure quantum Monte Carlo methods". In: *Physical Review A* 93.4.

Roggero, A., Mukherjee, A., and Pederiva, F. (2015). "Constraining the Skyrme energy density functional with quantum Monte Carlo calculations". In: *Physical Review C* 92.5.

NINPHA

Rinaldi, M., Scopetta, S., Traini, M. C., and Vento, V. (2015b). "Double parton correlations in Light-Front constituent quark models". In: *EPJ Web Conf.* 90, p. 02002.

Rinaldi, M., Scopetta, S., Traini, M. C., and Vento, V. (2016c). “Correlations in Double Parton Distributions: Perturbative and Non-Perturbative effects”. In: *JHEP*, in press.

Rinaldi, M., Scopetta, S., Traini, M. C., and Vicente, V. (2015c). “Double parton distributions in Light-Front constituent quark models”. In: *Few Body Syst.* 56, pp. 515–521.

— (2016d). “Double parton scattering and 3D proton structure: A Light-Front analysis”. In: *Few Body Syst.* 57, pp. 431–435.

Traini, M. C. (2016). “AdS/QCD and Deep Inelastic Scattering on nucleon: Generalized Parton Distributions and the role of the confining potential”. In: *preprint* arxiv:1608.08410.

Traini, M. C., Scopetta, S., Rinaldi, M., and Vicente, V. (2016). “The effective cross section for double parton scattering within a holographic AdS/QCD approach”. In: *preprint* arxiv:1609.07242.

TEONGRAV

Bentivegna, E. (2016). “An automatically generated code for relativistic inhomogeneous cosmologies”. In: *ArXiv e-prints*.

Bentivegna, E. and Bruni, M. (2016). “Effects of Nonlinear Inhomogeneity on the Cosmic Expansion with Numerical Relativity”. In: *Physical Review Letters* 116.25, 251302, p. 251302.

Bull, P., Akrami, Y., Adamek, J., Baker, T., Bellini, E., Beltrán Jiménez, J., Bentivegna, E., Camera, S., Clesse, S., Davis, J. H., Di Dio, E., Enander, J., Heavens, A., Heisenberg, L., Hu, B., Llinares, C., Maartens, R., Mörtsell, E., Nadathur, S., Noller, J., Pasechnik, R., Pawlowski, M. S., Pereira, T. S., Quartin, M., Ricciardone, A., Riemer-Sørensen, S., Rinaldi, M., Sakstein, J., Saltas, I. D., Salzano, V., Sawicki, I., Solomon, A. R., Spolyar, D., Starkman, G. D., Steer, D., Tereno, I., Verde, L., Villaescusa-Navarro, F., von Strauss, M., and Winther, H. A. (2016). “Beyond Λ CDM: Problems, solutions, and the road ahead”. In: *Physics of the Dark Universe* 12, pp. 56–99.

Ciolfi, R. (2016). “X-ray Flashes Powered by the Spindown of Long-lived Neutron Stars”. In: *The Astrophysical Journal* 829, 72, p. 72.

Ciolfi, R. and Siegel, D. M. (2015). “Short gamma-ray bursts from binary neutron star mergers: the time-reversal scenario”. In: *Proceedings of Science* (SWIFT 10), p. 108.

Dall’Osso, S., Giacomazzo, B., Perna, R., and Stella, L. (2015). “Gravitational Waves from Massive Magnetars Formed in Binary Neutron Star Mergers”. In: *The Astrophysical Journal* 798, 25, p. 25.

Endrizzi, A., Ciolfi, R., Giacomazzo, B., Kastaun, W., and Kawamura, T. (2016). “General relativistic magnetohydrodynamic simulations of binary neutron star mergers with the APR4 equation of state”. In: *Classical and Quantum Gravity* 33.16, 164001, p. 164001.

Ghirlanda, G., Salafia, O. S., Pescalli, A., Ghisellini, G., Salvaterra, R., Chassande-Mottin, E., Colpi, M., Nappo, F., D’Avanzo, P., Melandri, A., Bernardini, M. G., Branchesi, M., Campana, S., Ciolfi, R., Covino, S., Götz, D., Vergani, S. D., Zennaro, M., and Tagliaferri, G. (2016). “Short gamma-ray bursts at the dawn of the gravitational wave era”. In: *Astronomy & Astrophysics* 594, A84, A84.

Giacomazzo, B., Zrake, J., Duffell, P. C., MacFadyen, A. I., and Perna, R. (2015). “Producing Magnetar Magnetic Fields in the Merger of Binary Neutron Stars”. In: *The Astrophysical Journal* 809, 39, p. 39.

Kastaun, W., Ciolfi, R., and Giacomazzo, B. (2016). “Structure of stable binary neutron star merger remnants: A case study”. In: *Physical Review D* 94.4, 044060, p. 044060.

Kawamura, T., Giacomazzo, B., Kastaun, W., Ciolfi, R., Endrizzi, A., Baiotti, L., and Perna, R. (2016). “Binary neutron star mergers and short gamma-ray bursts: Effects of magnetic field orientation, equation of state, and mass ratio”. In: *Physical Review D* 94.6, 064012, p. 064012.

Korzyński, M., Hinder, I., and Bentivegna, E. (2015). “On the vacuum Einstein equations along curves with a discrete local rotation and reflection symmetry”. In: *Journal of Cosmology and Astroparticle Physics* 8, 025, p. 025.

Perna, R., Lazzati, D., and Giacomazzo, B. (2016). "Short Gamma-Ray Bursts from the Merger of Two Black Holes". In: *The Astrophysical Journal Letters* 821, L18, p. L18.

Siegel, D. M. and Ciolfi, R. (2015). "Magnetically-induced outflows from binary neutron star merger remnants". In: *Proceedings of Science* (SWIFT 10), p. 169.

— (2016a). "Electromagnetic Emission from Long-lived Binary Neutron Star Merger Remnants. I. Formulation of the Problem". In: *The Astrophysical Journal* 819, 14, p. 14.

— (2016b). "Electromagnetic Emission from Long-lived Binary Neutron Star Merger Remnants. II. Lightcurves and Spectra". In: *The Astrophysical Journal* 819, 15, p. 15.

Technological and Interdisciplinary Physics

APiX2

Ficorella, A., Pancheri, L., Dalla Betta, G.-F., Brogi, P., Collazuol, G., Marrocchesi, P. S., Morsani, F., Ratti, L., and Savoy-Navarro, A. (2016). "Crosstalk mapping in CMOS SPAD arrays". In: *2016 46th European Solid-State Device Research Conference (ESSDERC)*, pp. 101–104.

Pancheri, L., Brogi, P., Collazuol, G., Dalla Betta, G.-F., Ficorella, A., Marrocchesi, P., Morsani, F., Ratti, L., and Savoy-Navarro, A. (2016). "First prototypes of two-tier avalanche pixel sensors for particle detection". In: *Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*. In press.

ARDESIA

Quaglia, R., Bellotti, G., Butt, A. D., Fiorini, C., Ripamonti, G., Schembari, F., Bombelli, L., Giacomini, G., Picciotto, A., Piemonte, C., and Zorzi, N. (2015a). "New Silicon Drift Detectors and CMOS Readout Electronics for X-ray Spectroscopy from Room Temperature to Cryogenic Operations". In: *Proceedings of the 2015 NSS-MIC conference, San Diego USA, 31/10-7/11*. IEEE.

Quaglia, R., Bombelli, L., Busca, P., Fiorini, C., Occhipinti, M., Giacomini, G., Ficorella, F., Picciotto, A., and Piemonte, C. (2015b). "Silicon Drift Detectors and CUBE Preamplifiers for High-Resolution X-ray Spectroscopy". In: *IEEE Transaction on Nuclear Science* 62, pp. 221–227.

Quaglia, R., Fiorini, C., Bombelli, L., Butt, A. D., Giacomini, G., Ficorella, F., Picciotto, A., and Piemonte, C. (2015). "Monolithic arrays of SDDs and low noise CMOS readout for X-ray spectroscopy measurements in nuclear physics experiments". In: *Journal of Instrumentation* 10.

Schembari, F., Bellotti, G., and Fiorini, C. (2016). "A 12-bit SAR ADC integrated on a multichannel silicon drift detector readout IC". In: *Nuclear Instruments & Methods in Physics Research - section A* 824, 353–355.

Schembari, F., Quaglia, R., Bellotti, G., and Fiorini, C. (2015). "SFERA: a General Purpose Readout IC for X and γ-ray Detectors". In: *Proceedings of the 2015 NSS-MIC conference, San Diego USA, 31/10-7/11*. IEEE.

NEWREFLECTIONS

Battiston, R., Burger, W., Cafagna, A., Manea, C., and Spataro, B. (2016). "A Systematic Study of Laser Ablation for Space Debris Mitigation". In: *Proceedings of the* 8$^{\text{th}}$ *IAASS Conference, Melbourne, Florida, 18-20 May, 2016*, pp. 69–78.

PixFEL

Comotti, D., Fabris, L., Grassi, M., Lodola, L., Malcovati, P., Manghisoni, M., Ratti, L., Re, V., Traversi, G., Vacchi, C., Batignani, G., Bettarini, S., Casarosa, G., Forti, F., Morsani, F., Paladino, A., Paoloni, E., Rizzo, G., Benckechkache, M., Dalla Betta, G., Mendicino, R., Pancheri, L., Verzellesi, G., and Xu, H. (2016). “Low-noise readout channel with a novel dynamic signal compression for future X-FEL applications”. In: *2014 IEEE Nuclear Science Symposium and Medical Imaging Conference, NSS/MIC 2014*.

Dalla Betta, G.-F., Batignani, G., Benkechkache, M., Bettarini, S., Casarosa, G., Comotti, D., Fabris, L., Forti, F., Grassi, M., Latreche, S., Lodola, L., Malcovati, P., Manghisoni, M., Mendicino, R., Morsani, F., Paladino, A., Pancheri, L., Paoloni, E., Ratti, L., Re, V., Rizzo, G., Traversi, G., Vacchi, C., Verzellesi, G., and Xu, H. (2016d). “Design and TCAD simulation of planar p-on-n active-edge pixel sensors for the next generation of FELs”. In: *Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 824, pp. 384–385.

Dalla Betta, G.-F., Batignani, G., Benkechkache, M., Bettarini, S., Casarosa, G., Comotti, D., Fabris, L., Forti, F., Grassi, M., Latreche-Lassoued, S., Lodola, L., Malcovati, P., Manghisoni, M., Mendicino, R., Morsani, F., Paladino, A., Pancheri, L., Paoloni, E., Ratti, L., Re, V., Rizzo, G., Traversi, G., Vacchi, C., Verzellesi, G., and Xu, H. (2016e). “Design and TCAD simulations of planar active-edge pixel sensors for future XFEL applications”. In: *2014 IEEE Nuclear Science Symposium and Medical Imaging Conference, NSS/MIC 2014*.

Lodola, L., Batignani, G., Benkechkache, M., Bettarini, S., Casarosa, G., Comotti, D., Dalla Betta, G., Fabris, L., Forti, F., Grassi, M., Latreche, S., Malcovati, P., Manghisoni, M., Mendicino, R., Morsani, F., Paladino, A., Pancheri, L., Paoloni, E., Ratti, L., Re, V., Rizzo, G., Traversi, G., Vacchi, C., Verzellesi, G., and Xu, H. (2016). “In-pixel conversion with a 10 bit SAR ADC for next generation X-ray FELs”. In: *Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 824, pp. 313–315.

Ratti, L., Comotti, D., Fabris, L., Grassi, M., Lodola, L., Malcovati, P., Manghisoni, M., Re, V., Traversi, G., Vacchi, C., Batignani, G., Bettarini, S., Casarosa, G., Forti, F., Morsani, F., Paladino, A., Paoloni, E., Rizzo, G., Benkechkache, M., Dalla Betta, G.-F., Mendicino, R., Pancheri, L., Verzellesi, G., and Xu, H. (2016a). “PixFEL: Enabling technologies, building blocks and architectures for advanced X-ray pixel cameras at the next generation FELs”. In: *2014 IEEE Nuclear Science Symposium and Medical Imaging Conference, NSS/MIC 2014*.

Ratti, L., Comotti, D., Fabris, L., Grassi, M., Lodola, L., Malcovati, P., Manghisoni, M., Re, V., Traversi, G., Vacchi, C., Bettarini, S., Casarosa, G., Forti, F., Morsani, F., Paladino, A., Paoloni, E., Rizzo, G., Benkechkache, M., Dalla Betta, G.-F., Mendicino, R., Pancheri, L., Verzellesi, G., and Xu, H. (2015b). “PixFEL: developing a fine pitch, fast 2D X-ray imager for the next generation X-FELs”. In: *Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 796, pp. 2–7.

Ratti, L., Comotti, D., Fabris, L., Grassi, M., Lodola, L., Malcovati, P., Manghisoni, M., Re, V., Traversi, G., Vacchi, C., Rizzo, G., Batignani, G., Bettarini, S., Casarosa, G., Forti, F., Giorgi, M., Morsani, F., Paladino, A., Paoloni, E., Pancheri, L., Dalla Betta, G.-F., Mendicino, R., Verzellesi, G., Xu, H., and Benkechkache, M. (2016b). “A 2D imager for X-ray FELs with a 65-nm CMOS readout based on per-pixel signal compression and 10-bit A/D conversion”. In: *Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 831, pp. 301–308.

Rizzo, G., Batignani, G., Benkechkache, M., Bettarini, S., Casarosa, G., Comotti, D., Dalla Betta, G.-F., Fabris, L., Forti, F., Grassi, M., Lodola, L., Malcovati, P., Manghisoni, M., Mendicino, R., Morsani, F., Paladino, A., Pancheri, L., Paoloni, E., Ratti, L., Re, V., Traversi, G., Vacchi, C., Verzellesi, G., and Xu, H. (2016). “The PixFEL project: Progress towards a fine pitch X-ray imaging camera for next generation FEL facilities". In: *Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 824, pp. 131–134.

Rizzo, G., Comotti, D., Fabris, L., Grassi, M., Lodola, L., Malcovati, P., Manghisoni, M., Ratti, L., Re, V., Traversi, G., Vacchi, C., Batignani, G., Bettarini, S., Casarosa, G., Forti, F., Morsani, F., Paladino, A., Paoloni, E., Dalla Betta, G.-F., Pancheri, L., Verzellesi, G., Xu, H., Mendicino, R., and Benkechkache, M. (2015). "The PixFEL project: Development of advanced X-ray pixel detectors for application at future FEL facilities". In: *Journal of Instrumentation* 10.2.

Redsox2

Bertuccio, G. et al. (2016). "X-Ray Silicon Drift Detector—CMOS Front-End System with High Energy Resolution at Room Temperature". In: *IEEE Transactions on Nuclear Science* 63, pp. 400–406.

Fabiani, S. et al. (2016). "Development and tests of a new prototype detector for the XAFS beamline at Elettra Synchrotron in Trieste". In: *J.Phys.Conf.Ser.* 10, PO1002.

Gianoncelli, A. et al. (2016). "A new Detector System for Low Energy X-ray Fluorescence coupled with Soft X-ray Microscopy: first Tests and Characterization". In: *Nuclear Instruments and Methods in Physics Research Section A* 816, pp. 113–118.

Seminars

TIFPA Guest Seminars

Paik Ho Jung, Department of Physics, University of Maryland, USA, “Improved Determination of Gravitational Constant G Using a Laboratory Planetary System", January 15, 2015.

Mariafelicia De Laurentis, Tomsk pedagogical University, Russia, “Cosmological and astrophysical applications of f(R,G)-gravity", February 3, 2015.

Daniel Martin Siegel, Albert Einstein Institute, Potsdam, Germany, “Short gamma-ray bursts in the "time-reversal" scenario”, February 19, 2015.

Marco Drago, Albert Einstein Institute, MPG Hannover, Germany, “Low-latency searches for transient gravitational waves: progresses on source location performances”, March 31, 2015.

Berend Ensing, University of Amsterdam, The Netherlands, “Multiscale modelling of bio-molecular transitions”, April 16, 2015.

Alessandro Drago, Dipartimento di Fisica, Università di Ferrara, Italy, “High density matter in compact stars”, April 17, 2015.

Sunny Vagnozzi, Stockholm University, Sweden, “Seeing the invisible: the mystery of Dark Matter”, June 9, 2015.

Elena Litvinova, Western Michigan University, USA, “Nuclear field theory in a relativistic framework: high-order correlations and pion dynamics”, July 13, 2015.

Maria Grazia Bernardini, INAF - Osservatorio di Brera, Italy, “Gamma-ray bursts and magnetars: observational signatures and predictions”, July 13, 2015.

Emilio Elizalde Rius, CSIC - Barcelona, Spain, “Primordial gravitational waves: B2KP new results”, July 23, 2015.

Burke Etienne Zachariah, West Virginia University, USA, “General ralativistic Magnetohydrodynamic Modeling of the most luminous Outbursts in the Universe”, August 4, 2015.

Roberto Pacelli, Department of Advanced Biomedical Sciences, Federico II University School of Medicine, Naples, Italy, “Normal tissue complication probability models: can we trust them for future treatment plan evaluation and optimization?”, November 5, 2015.

Laura Cella, Institute of Biostructures and Bioimaging, National Council of Research (CNR), Naples, Italy, “Normal tissue complication probability models: can we trust them for future treatment plan evaluation and optimization?”, November 5, 2015.

Marco Maria Caldarelli, Mathematical Sciences and STAG Research Centre, University of Southampton, UK, “A new path to holography for asymptotically flat spacetimes”, December 14, 2015.

Cristiano Germani, Institut de Ciències del Cosmos, Universitat de Barcelona, Spain, “Electroweak vacuum stability and inflation via non-minimal derivative couplings to gravity”, December 15, 2015.

Dietmar Klemm, Università degli Studi di Milano, Italy, “New results on ads black holes”, December 18, 2015.

Garcia Yeinzon Rodriguez, Universidad Antonio Nariño, Bogodà, Colombia, “From Scalar Galileons to Generalized and Covariantized (non-Abelian) Vector Galileons”, March 21, 2016.

Albino Perego, Technische Universität Darmstadt, Germany, "Neutrinos in the aftermath of binary neutron star mergers", March 31, 2016.

Adolfo Rene Cisterna Roa, Instituto de Ciencias Fisicas y Matematicas, Universidad Austral de Chile, "Compact objects in the nonminimal kinetic sector of Horndeski gravity", March 31, 2016.

Francesco Pannarale Greco, Cardiff University, UK, "Observation of Gravitational Waves from a Binary Black Hole Merger", April 6, 2016.

Davide De Boni, University of Swansea, UK, "Heavy quark bound states in a quark-gluon plasma: dissociation and recombination", April 12, 2016.

Daniel Martin Siegel, Columbia University, USA, "Electromagnetic counterparts to the gravitational-wave signal of compact binary mergers", June 22, 2016.

Hayley Jessica Macpherson, Monash University, Australia, "Inhomogeneous cosmology with the Einstein Toolkit", June 29, 2016.

Konstantin Kanishchev, CERN, "Trento-AMS group analysis", June 28, 2016.

David Guy Kirsch, School of Medicine, Duke University, USA, "Using Genetically Engineered Mice to Study Radiation Biology", July 5, 2016.

Alan Effraim Nahum, Department of Physics, University of Liverpool, UK, "Using normal-tissue complication probability (NTCP) modelling to improve radiotherapy outcomes", July 11, 2016.

Emilio Elizalde Rius, ICE-CSIC and IEEC, Barcelona, Spain, "The Universe had (probably) an origin: on the theorem of Borde-Guth-Vilenkin", July 26, 2016.

Cecilia Chirenti, Federal University of ABC, Brazil, "Effect of magnetic fields on neutron star non-radial oscillation modes", September 16, 2016.

Alessandro Roggero, Institute for Nuclear Theory, University of Washington, USA, "Thermal relaxation in accerting neutron stars: Unravelling the nuclear physics and plasma physics", October 16, 2016.

Antonio Racioppi, National Institute of Chemical Physics and Biophysics, Estonia, "Quasi-scale invariance and inflation", November 16, 2016.

Medical Technologies

Marco Durante, "Ultraterrorism: risk analysis and mitigation", TIFPA, Trento, Italy, December 17, 2015.

Marco Durante, "Ioni pesanti: dalla terapia del cancro alla missione su Marte", at "I Venerdì dell'Universo", Ferrara, Italy, February 12, 2016.

Marco Durante, Lectio Magistralis "Ioni pesanti: dalla terapia del cancro alla missione su Marte", 2nd University of Naples, Caserta, Italy, October 12, 2016.

Marco Schwarz, "How can protons contribute to radiation oncology", European Cancer Conference (ECCO), Vienna, Austria, September 2015

Marco Schwarz, "How can protons improve radiation oncology", KFMC Conference on Physics and Engineering in Medicine, Ryadh, UAE, October 2015

Marco Schwarz, "Clinical implementation of a pencil beam scanning system", KFMC Conference on Physics and Engineering in Medicine, Ryadh, UAE, October 2015

Marco Schwarz, physics keynote talk "Medical physics challenges in the next few years", IBA user meeting, Trento, Italy, March 2016

Marco Schwarz,"The need for adaptive therapy in protons compared to photons", European Society for Radiation Oncology (ESTRO) Congress, Torino, Italy, May 2016

Marco Schwarz, "Towards adaptive treatments in particle therapy", I European Congress of Medical Physics, - Athens, Greece, September 2016

Marco Schwarz, "How can protons improve radiation therapy?", Central European Symposium on Radiation Oncology, - Ustron, Poland, October 2016

Particle Physics

ATLAS

Roberto Iuppa, "New Physics in di-boson resonances and long-lived particles with ATLAS and CMS: latest Run 1 and early Run 2 results", IFAE 2016, Genova, Italy, March 2016.

RD-FASE2

Maurizio Boscardin, "Preliminary results from the first batch of Si 3D sensors fabricated at FBK on 6 inch wafers", 10th Anniversary Trento Workshop on Advanced Silicon Radiation Detectors, Trento, Italy, February 17 - 19, 2015.

Maurizio Boscardin, "Initial results from a new generation of 3D Sensors for HL-LHC", 11th Trento Workshop on Advanced Silicon Radiation Detectors, Paris, France, February 22 - 24, 2016.

Gian-Franco Dalla Betta, "Development of new 3D pixel sensors for Phase 2 upgrades at LHC", IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS - MIC'15), San Diego, USA, October 31 - November 7, 2015.

Gian-Franco Dalla Betta, invited talk "3D sensors developments", TALENT ITN Final Conference, CERN, Geneve, Switzerland, November 23 - 26, 2015.

Gian-Franco Dalla Betta, invited talk "New Sensors", IFD2015, INFN Workshop on Future Detectors, Torino, Italy, December 16 - 18, 2015.

Gian-Franco Dalla Betta, invited talk "Small pitch 3D", VERTEX 2016, La Biodola, Isola d'Elba, Italy, September 26 - 30, 2016.

Gian-Franco Dalla Betta, "New Thin 3D Pixel Sensors for HL-LHC: first results", IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS - MIC'16), Strasbourg, France, October 30 - November 6, 2016.

Roberto Mendicino, "Design and TCAD simulation of a new generation of 3D Sensors for HL-LHC within the INFN (ATLAS-CMS) R&D program in collaboration with FBK", 10th Anniversary Trento Workshop on Advanced Silicon Radiation Detectors, Trento, Italy, February 17 - 19, 2015.

DMS Sultan, "Investigation of the Electrical Characteristics of Double-Sided 3D Sensors after Proton and Neutron Irradiation up to HL-LHC Fluencies", 10th Anniversary Trento Workshop on Advanced Silicon Radiation Detectors, Trento, Italy, February 17 - 19, 2015.

DMS Sultan, "Radiation Hardness Study on Double Sided 3D Sensors after Proton and Neutron Irradiation up to HL-LHC Fluencies", RADFAC, Legnaro, Italy, March 26, 2015.

DMS Sultan, "Characterization of the First Double-Sided 3D Radiation Sensors Fabricated at FBK on 6-inch Silicon Wafers", poster presentation at IWORID 2015, Hamburg, Germany, June 28 - July 2, 2015.

DMS Sultan, "Initial results from new thin 3D Sensors for HL-LHC", poster presentation at IWORID 2016, Barcelona, Spain, July 3 - 7, 2016.

Astroparticle Physics

Roberto Iuppa, invited talk "ARGO-YBJ results", VII Workshop on Air Shower Detection at High Altitude, Torino, Italy, November 2016.

DARKSIDE

Alberto Gola, "Functional characterization of RGB-HD and NUV-HD FBK Silicon Photomultipliers from 300 K to 60 K", NSS/MIC 2015 - IEEE Nuclear Science Symposium and Medical Imaging Conference, 2015

Giovanni Paternoster, “The DarkSide Photodetection Program”, NSS/MIC 2016 - IEEE Nuclear Science Symposium and Medical Imaging Conference, 2016

FISH

Gabriele Ferrari, “Many-body dynamics and magnetic polarizability in spinor Bose-Einstein condensates”, ECT* workshop on “Equations of state in quantum many-body systems,” Trento, Italy, 30 May - 1 June 2016.

HUMOR

Giovanni A. Prodi, “Silicon nitride membranes for inclusion in optomechanical devices”, EOS Conference on Optomechanical Engineering (EOSOME 2015), Munich, Germany, June 24 - 25, 2015.

Giovanni A. Prodi, “Experimental upper limits to generalized Heisenberg uncertainty relations using harmonic oscillators”, 21st International Conference on General Relativity and Gravitation, Columbia University, New York, USA, July 10 - 15, 2016.

Enrico Serra, “Towards the inclusion of large area high-stress silicon nitride membranes in optomechanical devices”, MNE 2015 - XLI international conference on micro- and nanofabrication , The Hague, The Netherlands, September 21 - 24, 2015.

Enrico Serra, “Filtering acoustic radiation loss in stressed silicon nitride (SiN) nano-mechanical resonators for Quantum Optomechanics”, MNE 2016 - XLII Micro- and NanoEngineering conference, Vienna, Austria, September 19 - 23, 2016

LIMADOU

William Burger, invited talk “A Study of the Spatial Correlation Between Satellite Observations and Earthquakes”, Limadou Physics Open Workshop, ASI, Rome (Italy), March 23, 2016

William Burger, invited talk “Seismic Activity and Particle Detection in Space”, SAFE Project Final Open Study Conference, INGV, Rome (Italy), October 19 - 20, 2016

LISA Pathfinder

Daniele Bortoluzzi, “Injection of a Body into a Geodetic: Lessons Learnt from theLISA Pathfinder Case”, Aerospace Mechanism Symposium 2016 , Santa Clara, USA, May, 4 - 6, 2016.

Daniele Bortoluzzi, “microscale analysis of adhesive contact between rough ductile metals”, XLII Leeds Lyon Symposium on Tribology, Lyon, France, September 6 - 9, 2016.

Daniele Bortoluzzi, “Testing the LISA Pathfinder test mass uncaging and injection into a geodesic”, ESA ECSSMET Conference 2016 , Tulouse, France, September, 27 - 30, 2016.

Rita Dolesi, “LISA pathfinder Mission”, 50 Rencontres de Moriond, La Thuile, Italy, March 18 - 25, 2015.

Rita Dolesi, invited talk “LISA Pathfinder highlights”, Cosmic Ray International Seminar 2016 (CRIS2016), Ischia, Italy, July 4 - 8, 2016.

Rita Dolesi, “The contribution of Brownian noise from viscous gas damping to the differential acceleration noise measured in LISA Pathfinder between two nominally free falling test masses”, XI International LISA Symposium, University of Zurich, Switzerland, September 5 - 9, 2016.

Gibert Ferran, “Thermal experiments on LISA Pathfinder’s Inertial Sensors”, XI International LISA Symposium, University of Zurich, Switzerland, September 5 - 9, 2016.

Gibert Ferran, “Thermal experiments on LISA Pathfinder’s Inertial Sensors”, XXX European Space Thermal Analysis Workshop, ESTEC, Noordwijk, The Netherlands, October 5, 2016.

Roberta Giusteri, “The free-fall mode experiment on LISA Pathfinder: first results”, XI International LISA Symposium, University of Zurich, Switzerland, September 5 - 9, 2016.

Daniele Vetrugno, “Fitting in unknown noise and applications to LISA Pathfinder”, XIV Marcel Grossmann Conference, Rome, Italy, July 17, 2015.

Daniele Vetrugno, “LISA Pathfinder results: towards a space-based gravitational wave observatory”, V Italian-Pakistani Workshop on Relativistic Astrophysics, University of Salento, Italy, July 22 - 24, 2016.

Daniele Vetrugno, “The Δg workflow: from measured displacements to the differential external acceleration”, XI International LISA Symposium, University of Zurich, Switzerland, September 5 - 10, 2016.

Stefano Vitale, Keynote Lecture “Spaceborne GW astronomy, (e)LISA, and LISA Pathfinder”, The Next Detectors for Gravitational Wave Astronomy Conference KITPC, Beijing, April 9, 2015.

Stefano Vitale, “LISA Pathfinder and ESA’s Gravitational Wave Observatory”, XIV Marcel Grossman Conference, Rome, Italy, July 2015.

William Joseph Weber, “LISA Pathfinder and eLISA: measuring differential acceleration for gravitational wave astrophysics”, Iberian Gravitational Wave Meeting, Barcelona, Spain, May 12, 2015.

William Joseph Weber, invited talk, XIV Marcel Grossmann Meeting on General Relativity on Recent Developments in Theoretical and Experimental General Relativity, Astrophysics, and Relativistic Field Theories, Rome, Italy, July 12 -18, 2015.

William Joseph Weber, “The LISA Pathfinder mission: demonstrating a sub-femto-g differential acceleration measurement for gravitational wave observation in space”, Gravitational-wave Astronomy Meeting in Paris (GRAMPA), Paris, France, August 29, 2016.

William Joseph Weber, “Physical model of the LISA Pathfinder differential acceleration measurement and its application to LISA”, XI International LISA Symposium, University of Zurich, Switzerland, September 5 - 10, 2016.

William Joseph Weber, “The LISA Pathfinder mission: first results and implications for an orbiting gravitational wave observatory”, Caltech Physics Research Conference, Pasadena (California), USA, September 27, 2016.

VIRGO

Giovanni Andrea Prodi, “Overview of Gravitational Wave Observations by LIGO and Virgo”, Vulcano Workshop 2016 “Frontier Objects in Astrophysics and Particle Physics”, Vulcano, Italy, May 23, 2016.

Giovanni Andrea Prodi, “Chasing Gravitational Radiation Carrying Footprints of Neutron Stars”, EoS in Quantum Many Body Systems, ECT*, Trento, Italy, June 1 and October 3, 2016.

Giovanni Andrea Prodi, “Overview of observations of Gravitational Waves by LIGO and Virgo”, Flag meeting “The Quantum and Gravity”, Trento, Italy, June 6, 2016.

Giovanni Andrea Prodi, “Long baseline interferometers for gravitational wave astronomy”, Physics Department, Bologna, Italy, June 17, 2016.

Giovanni Andrea Prodi, “The Gravitational Wave Observatory and Its First Discoveries”, New Trends in High-Energy Physics, Budva, Montenegro, October 3, 2016 .

Giovanni Andrea Prodi, “The Gravitational Wave Observatory and Its First Discoveries”, Int. CAE Conference, Parma, Italy, October 17, 2016.

Shubhanshu Tiwari, “Whispers of gravity”, University of Trento PhD Workshop, November 25, 2015.

Shubhanshu Tiwari, “Gravitational waves transients : Sources and Searches”, SciNeGHE 2016, Pisa, Italy, October 20, 2016.

Shubhanshu Tiwari, “Gravitational waves transient sky”, GSSI PhD Workshop, l’Aquila, Italy, November 9, 2016.

Nuclear Physics

AEgIS

Roberto S. Brusa,, invited talk “Positronium cooling and positronium excitation for the AEgIS experiment at CERN”, SLOPOS14 - XIV International Workshop on Slow Positron Beam Techniques & Applications, Matsue, Japan, May 22 - 27, 2016.

Sebastiano Mariazzi, , invited talk “Positronium cloud production and its laser excitation for Antihydrogen formation in AEgIS experiment”, ICPA 17 - XVII International Conference on Positron Annihilation, Wuhan, China, September 20 - 25, 2015.

Sebastiano Mariazzi, , invited talk “Recent advancements in the AEgIS Experiment”, CII Congresso nazionale SIF, Padova, Italy, September 26 - 30, 2016.

Theoretical Physics

BELL

Sonia Mazzucchi, invited talk “Feynman Path Integrals as Infinite Dimensional Oscillatory Integrals”, workshop “Path Integral and Pseudo- Differential Operators”, RIMS, Kyoto University, Japan, October 7 - 10, 2014.

Sonia Mazzucchi, Lecturer of the Doctorate Course “Mathematical theory of Feynman path-integrals” Doctoral School in Mathematical Sciences, University of Milan, Italy, April 2015.

Sonia Mazzucchi, invited talk “A probabilistic representation for the solution of high-order heat-type equations”, workshop “Classic and Stochastic Geometric Mechanics”, École polytechnique fédérale de Lausanne, Switzerland, June 8 - 11, 2015.

Sonia Mazzucchi, invited talk “Generalized Feynman-Kac formulae”, Conference“ Stochastic Partial Differential Equations and Applications - X”, Levico Terme, Italy, May 30 - June 4, 2016.

Valter Moretti, Invited talk “Frame functions in finite-dimensional Quantum Mechanics and its Hamiltonian formulation on complex projective spaces”, SISSA, Trieste, Italy, February 10, 2015.

Valter Moretti, Invited talk “Tunnelling black-hole radiation with ϕ^3 self-interaction: one-loop computation for Rindler Killing horizons”, XIV Marcel Grossmann Meeting - MG14 section QFT in curved spacetime, University of Rome “La Sapienza”, Rome, Italy, July 12 - 18, 2015.

Valter Moretti, Participation in the ESI Program “Modern Theory of Wave Equations”, E. Schroedinger Institute, Vienna, Austria, July - September 2015.

Valter Moretti, Invited Course on the mathematical Foudations of Quantum Theories, XXIV International Fall Workshop on Geometry and Physics, Saragoza, September 2015.

Davide Pastorello, invited seminar “Geometric description of Quantum Systems in a classical-like Hamiltonian picture and applications” XXIV International Fall Workshop on Geometry and Physics, Saragoza, Spain, September 3, 2015.

Davide Pastorello, “Geometric description of finite-dimensional quantum systems in complex projective spaces and applications”, School & Workshop “Mathematical Challenges in Quantum Mechanics” (MCQM2016), February 9, 2016.

Davide Pastorello, invited seminar “Geometric description of quantum systems in complex projective spaces”, University of Munich (TUM), Germany, June 30, 2016.

BIOPHYS

Pietro Faccioli, invited talk at Workshop on “Quantum Phononics”, Heraklyon, Crete, Greece, June 2015.

Pietro Faccioli, invited talk “From Trajectories to Reaction Coordinates: Making Sense of Molecular Simulation Data”, CECAM Conference, Vienna, Austria, September 2015.

Pietro Faccioli, invited talk at VI Visegrad Simposium on Structural Systems Bology, Warsaw, Poland, June 2016.

Pietro Faccioli, invited talk “Reaction Coordinates from Molecular Trajectories”, Lorentz-CECAM Workshop, Leiden, the Netherlands, September 2016.

Pietro Faccioli, invited talk “Molecular Quantum Field Theory”, INFN BIOPHYS meeting, Bari, Italy, September 2016.

Pietro Faccioli, invited talk “Instantons, path integrals and topology: from QCD to proteins”, ECT* workshop on “Gauge topology: from lattice to colliders”, Trento, Italy, November 2016.

FBS

Fabrizio Ferrari-Ruffino, invited talk “Benchmark Results for Few-body Hypernuclei”, XXIII European Conference on Few-Body Problems in Physics, Aarhus, Denmark, August 8 - 12, 2016.

Winfried Leidemann, invited talk “Resolution of Resonances with the Lorentz integral transform”, XXI International Conference on Few-Body Problems in Physics, Chicago, USA, May 18 - 22, 2015.

Winfried Leidemann, invited talk “New Horizons in Nuclear Theory”, Physics Day 2015 del Dipartimento di Fisica dell’Università di Trento, Museo dell’Aeronautica G. Caproni, Trento, Italy, June 6, 2015,.

Winfried Leidemann, invited talk “Ab initio calculations for strange and non strange few-baryon systems”, Program of the Institute for Nuclear Theory INT-16-1 “Nuclear Physics from Lattice QCD”, INT, Seattle, USA, March 21 - 27, 2016.

Winfried Leidemann, invited talk “Ab initio calculations for non-strange and strange few-baryon systems”, TNPI2016 - XV Conference on Theoretical Nuclear Physics in Italy, Pisa, Italy, April 20 - 22, 2016.

Winfried Leidemann, invited talk “Calculation of the S-factor S_{12} with the Lorentz integral transform method”, XXIII European Conference on Few-Body Problems in Physics, Aarhus, Denmark, August 8 - 12, 2016.

Giuseppina Orlandini, invited talk “Resonances/Giant Resonances with EFT Potentials”, FUSTIPEN 2015 @ GANIL, Caen, France, March 16 - 20, 2015.

Giuseppina Orlandini, invited talk “Integral Transform Approaches”, Series of Lectures, ECT* Doctoral Program on “Computational Nuclear Physics - Hadrons, Nuclei and Dense Matter”, ECT* Trento, Italy, 5 - 14 May 2015.

Giuseppina Orlandini, invited talk “Is the 0+ Resonance of the Alpha-particle a Breathing mode?”, XXI International Conference on Few-Body Problems in Physics, Chicago, USA, May 18 - 22, 2015.

Giuseppina Orlandini, invited talk “Testing a Chiral Effective Field Theory Potential on Giant Dipole Resonances”, VI International Symposium on Symmetries in Subatomic Physics, Victoria, Canada, June 8 - 12, 2015.

Giuseppina Orlandini, invited talk “Physics of Electro-weak Interactions with Nuclei”, Series of Lectures at the T.A.L.E.N.T. School “Few-body Methods and Nuclear Reactions”, ECT* Trento, Italy, July 20 - August 7, 2015.

Giuseppina Orlandini, invited talk “Resonances and Giant Resonances with ab Initio Approaches”, Symposium on occasion of 60th Birthday of Giampaolo Co’, Lecce, Italy, November 6, 2015.

Giuseppina Orlandini, invited talk “Nuclear Physics at the UniTN”, Mini-Workshop of the Nuclear Physics European Collaboration Committee (NuPECC), ECT* Trento, Italy, March 11, 2016.

Giuseppina Orlandini, invited talk “Integral Transform Approaches to Continuum Observables and Recent Results”, ECT* Workshop on “Advances in Transport and Response Properties of Strongly Interacting Systems”, ECT* Trento, Italy, May 2 - 6, 2016.

Giuseppina Orlandini, colloquium “Nuclear Physics with Ab initio Few-Body methods”, Università di Torino, Italy, June 10, 2016.

Giuseppina Orlandini, invited talk “Integral Transform Method: a Critical Review of Kernels for Different Kinds of Observables”, XXIII European Conference on Few-Body Problems in Physics, Aarhus, Denmark, August 8 - 12, 2016.

Giuseppina Orlandini, invited talk “Nuclear Physics with Ab initio Few/Many-Body Methods”, KITP Program on “Frontiers in Nuclear Physics”, Kavli Institute UCSB, Santa Barbara-Ca, USA, August 31, 2016.

Giuseppina Orlandini, invited talk “Integral Transform Approaches to Continuum”, ECT* Workshop on “Three-body Systems in Reactions with Rare Isotopes”, ECT* Trento, Italy, October 3 - 7, 2016.

FLAG

Massimiliano Rinaldi, “Higgs dark energy”, Euclid Theory and Simulations Working Group Meeting, Oslo, Norway, January 12 - 13, 2015.

Massimiliano Rinaldi, invited lecture “Higgs dark energy”, University of Lund, Sweden, May 21, 2015.

Massimiliano Rinaldi, “Quasi Scale-Invariant Inflationary Attractors”, XIV Marcel Grossmann Meeting, Rome, Italy, July 12 - 18, 2015.

Massimiliano Rinaldi, “Dark energy as a fixed point of the Einstein Yang-Mills Higgs equations”, XXVIII Texas Symposium on Relativistic Astrophysics, Geneva, Switzerland, December 13 - 18, 2015.

LISC

Maurizio Dapor, “Application of the Monte Carlo Method to Electron Scattering Problems”, University of Sheffield, UK, January 12, 2015.

Maurizio Dapor, “Modeling Electron Materials Interactions by Monte Carlo Method”, Universidad de Alicante, Spain, May 5, 2016.

Maurizio Dapor, “Energy distributions of the secondary and backscattered electrons from polymethylmethacrylate irradiated by an electron beam. A Monte Carlo simulation”, ECOSS-31 - XXXI European Conference on Surface Science, Barcelona, Spain, August 31, 2015.

Maurizio Dapor, “Spectra of electrons from PMMA irradiated by an electron beam”, N&N 2015 - XVI International School and Workshop on Nanoscience and Nanotechnology 2015, INFN-Frascati National Laboratories, Italy, September 29, 2015.

Maurizio Dapor, “The Monte Carlo Method. An Introduction.”, University of Sheffield, UK, November 26, 2015.

Simone Taioli, Invited lecture “Theoretical estimates of stellar e-captures from first-principles simulations”, XII Russbach School on Nuclear Astrophysics, , Rußbach am Paß Gschütt, Austria, March 8 - 14, 2015.

Simone Taioli, “The growth of carbon-based materials by supersonic beam epitaxy: experiments, theory and calculations , Graphene - the Bridge between Low- and High-Energy Physics, Prague, Czech Republic, September 14 - 18, 2015.

Simone Taioli, Invited plenary talk “From materials science to astrophysics with multichannel scattering theory”, Nanoscience & Nanotechnology 2015 conference, Frascati, Italy, September 28 - October 2, 2015.

Simone Taioli, “Theoretical estimates of e^- captures and beta-decay from first-principles simulations”, XXVIII Indian-Summer School on Ab Initio Methods in Nuclear Physics, Prague, Czech Republic, Aug 29 - Sep 2, 2016.

Simone Taioli, “Graphene trumpets, foams, pillared networks, carbon materials growth, and all that from first-principles”, EMN Meeting on Computation and Theory 2016, Las Vegas, USA, October 12, 2016.

TEONGRAV

Eloisa Bentivegna, “Inhomogeneous cosmologies with the Einstein Toolkit”, Spanish Relativity Meeting, Palma de Mallorca, Spain, September 9, 2015

Eloisa Bentivegna, “Numerical relativity for cosmology: prospects and challenges”, AEI seminar, Geneva, Switzerland, December 9, 2015

Eloisa Bentivegna, “Modelling inhomogeneous cosmologies with numerical relativity”, XXVIII TEXAS Symposium, Geneva, Switzerland, December 14, 2015

Eloisa Bentivegna, “Elementi di radiazione gravitazionale”, Appunti di Fisica Teorica, INFN Messina, May 26, 2016.

Eloisa Bentivegna, “Cosmological modelling with numerical relativity”, XXI General Relativity Conference, New York, USA, July 14, 2016.

Eloisa Bentivegna, “Cosmology with the Einstein Toolkit”, UIUC seminar, July 19, 2016.

Eloisa Bentivegna, “Cosmology with the Einstein Toolkit”, CWRU seminar, July 26, 2016.

Eloisa Bentivegna, “Numerical Relativity: a gravitational lab for your desktop”, Max Planck Institute for Dynamics and Self-Organization seminar, August 31, 2016.

Eloisa Bentivegna, “Cosmological Numerical Relativity: a status report”, XXII SIGRAV conference, Cefalù, Italy, September 13, 2016.

Eloisa Bentivegna, at Settimana Scientifica 2016, Dipartimento di Fisica e Astronomia di Catania, October 2016.

Riccardo Ciolfi, invited seminar “Short gamma-ray bursts in the "time-reversal" scenario”, INAF-OAF Arcetri (Florence), Italy, Jan 2015.

Riccardo Ciolfi, invited seminar “X-ray afterglows of short gamma-ray bursts and the "time-reversal" scenario”, INAF-OAR, Monte Porzio Catone (Rome), Italy, Jun 2015.

Riccardo Ciolfi, invited seminar “X-ray afterglows of short gamma-ray bursts and the "time-reversal" scenario”, INAF-OAB, Merate (Milan), Italy, Jul 2015.

Riccardo Ciolfi, invited seminar “Electromagnetic counterparts to BNS mergers: the case of long-lived NS remnants”, Technische Universität Darmstadt, Germany, Feb 2016.

Riccardo Ciolfi, invited seminar “Electromagnetic emission from long-lived BNS merger remnants”, University of Urbino, Italy, Feb 2016.

Riccardo Ciolfi, invited seminar “Binary neutron star mergers and electromagnetic counterparts”, Stony Brook University, New York, USA, Jul 2016.

Riccardo Ciolfi, invited seminar “High-energy electromagnetic counterparts from binary neutron star mergers”, Columbia University, New York, USA, Jul 2016.

Riccardo Ciolfi, invited seminar “Binary neutron star mergers with long-lived remnants and their electromagnetic counterparts”, INAF-OAP, Padova, Italy, Sep 2016.

Bruno Giacomazzo, “Magnetar formation from the merger of binary neutron stars”, workshop on binary neutron star mergers, Thessaloniki, Greece, May 27 - 29, 2015.

Bruno Giacomazzo, invited seminar "General Relativistic Simulations of Binary Neutron Star Mergers", CENTRA (Instituto Superior Tecnico), Lisbon, Portugal, June 4, 2015.

Bruno Giacomazzo, "Magnetar formation from the merger of binary neutron stars" Annual NewCompStar Conference 2015, Budapest, Hungary, June 15 -19, 2015.

Bruno Giacomazzo, "GRMHD simulations of binary neutron star mergers and the central engine of short gamma-ray bursts", XIV Marcel Grossmann Meeting, Rome, Italy, July 13 - 18, 2015.

Bruno Giacomazzo, "Magnetar formation from the merger of binary neutron stars", meeting of the Italian Physical Society (SIF), Rome, Italy, September 21 - 25, 2015.

Bruno Giacomazzo, talk on "Magnetar formation from the merger of binary neutron stars", XXVIII Texas Symposium on Relativistic Astrophysics, Geneva, Switzerland, December 13 - 18, 2015.

Bruno Giacomazzo, "High-Mass Magnetized Binary Neutron Star Mergers and Short Gamma-Ray Bursts", April Meeting of the American Physical Society, Salt Lake City, USA, April 16 - 19, 2016.

Bruno Giacomazzo, invited review talk "General Relativistic Simulations of Neutron Star Binaries and Short Gamma-Ray Bursts", international workshop "SHORT GAMMA-RAY BURSTS: From observation to numerical simulations", Trento, Italy, September 9 2016.

Bruno Giacomazzo, "Structure of Stable Binary Neutron Star Merger Remnants: A Case Study", Workshop "NewCompStar meeting on oscillations and instabilities in neutron stars", Southampton, UK, September 13 - 14, 2016.

Bruno Giacomazzo, "High-Mass Magnetized Binary Neutron Star Mergers And Short Gamma-Ray Bursts", Meeting of the Italian Physical Society (SIF), Padova, Italy, September 26 - 30, 2016.

Bruno Giacomazzo, invited review talk "General Relativistic Simulations of Gamma-Ray Burst Engines", IV National Congress on GRBs, Bergamo, Italy, November 8 - 11, 2016.

Technological Physics

APiX2

Andrea Ficorella, "Crosstalk mapping in CMOS SPAD arrays", ESSDERC 2016 - IEEE European Solid-State Device Conference, Lausanne, Switzerland, September 12 - 15, 2016.

Lucio Pancheri, "First prototypes of two-tiers avalanche pixel sensors for particle detection", VCI2016 - Vienna Conference on Instrumentation, Vienna, Austria, February 15 - 19, 2016.

Lucio Pancheri, "Vertically-integrated CMOS Geiger-mode avalanche pixel sensors", IPRD16 - XIV Topical Seminar on Innovative Particle and Radiation Detectors, Siena, Italy, October 3 - 6, 2016.

Lucio Pancheri, invited lecture "The status and the perspectives of the silicon 3D and 4D pixel detectors", SNRI2016 - V Seminario Nazionale Sensori Innovativi, Padova, Italy, October 24 - 28, 2016.

Lucio Pancheri, "Two-tier pixelated avalanche sensor for particle detection in 150nm CMOS", NSS2016 - IEEE Nuclear Science Symposium 2016, Strasbourg, France, October 29 - November 5, 2016.

ARDESIA

Giovanni Bellotti, "The detection module of ARDESIA: a new versatile array of SDDs for X-ray spectroscopy synchrotron applications", IEEE-NSS 2016, Strasbourg, France, October 29 - November 6, 2016.

Carlo Fiorini, invited seminar "ARDESIA: an X-ray spectroscopy detection system based on arrays of Silicon Drift Detectors for synchrotron experiments", ESRF "Spectroscopy meeting" series, June 2015.

Carlo Fiorini, invited talk “New trends in ASICs development for Photon Science”, IWORID conference 2015, Hamburg, Germany, June 2015.

Carlo Fiorini, invited talk “New trends and challenges for detectors and electronics for XAFS”, XAFS16 conference, Karlsruhe, Germany, August 2015.

Carlo Fiorini, invited talk “New development of silicon drift detectors and readout electronics for high-resolution and high-count rate X-ray spectroscopy”, IXCOM conference 2015, Brookhaven National Laboratory, USA, September 2015.

Carlo Fiorini, “Detector for Synchrotron XRF and XAFS Applications”, ATTRACT Symposium on Detection and Imaging Technologies, Barcelona, Spain, June 30 - July 1, 2016.

NEWREFLECTIONS

William Burger, invited talk, “A Systematic Study of Laser Ablation for Space Debris Mitigation”, 8th IAASS Conference “Safety First Safety for All”, Melbourne, Florida (USA), 18 - 20 May, 2016

PixFEL

Gian-Franco Dalla Betta, “Initial results from the electrical characterisation of planar p-on-n sensors with active/slim-edge for the next generation of FELs”, XI Trento Workshop on Advanced Silicon Radiation Detectors, LPNHE, Paris, France, February 22 - 24 , 2016.

Lucio Pancheri, “PixFEL project: hybrid High Dynamic Range X-ray image sensor for application at future FEL facilities”, IISW 2015 - International Image Sensor Workshop 2015 , Vaals, Netherlands, June 8 - 11, 2015.

Lucio Pancheri, “First experimental results on active-edge silicon sensors for XFEL”, IWORID 2016 - The Internation Workshop on Radiation Imaging Detectors 2016, Barcelona, Spain, July 3 - 7, 2016.

SICILIA

Maurizio Boscardin, “Overview on sensors design and prototyping at FBK”, workshop “From Silicon to SiC detector”, INFN-LNS, Catania, Italy, April, 7 - 8, 2016.

Events

General TIFPA events

TIFPA new headquarters inauguration, TIFPA, Trento, Italy, October 20, 2015.

INFN International Evaluation Committee meeting, TIFPA, Trento, Italy, October 19 - 21, 2015.

NuPECC meeting, ECT*, Trento, Italy, March 11 - 12, 2016.

Meeting of Commissione Calcolo e Reti INFN, TIFPA, Trento, Italy, March 16, 2016.

Miniworkshop of Commissione Calcolo e Reti INFN, "Il Calcolo INFN in Fisica medica", APSS Protontherapy Center, Trento, Italy, March 17 - 18, 2016.
`https://agenda.infn.it/conferenceDisplay.py?confId=10741`

Meeting of Commissione Scientifica Nazionale INFN per la Fisica Nucleare (CSN3), TIFPA, Trento, Italy, April 18 - 19, 2016.
`https://agenda.infn.it/conferenceDisplay.py?confId=10422`

"La Radiobiologia in INFN", FBK headquarters, Trento, Italy, May 12 - 13, 2016.
`https://agenda.infn.it/conferenceDisplay.py?confId=11411`

XVII Convegno Nazionale SIRR, FBK headquarters, Trento, Italy, September 25 - 27, 2016.
`https://agenda.infn.it/conferenceDisplay.py?confId=11411`

Particle Physics

RD-FASE2

"10th Anniversary Trento Workshop on Advanced Silicon Radiation Detectors", Trento, Italy, February 17 - 19, 2015.

"11th Trento Workshop on Advanced Silicon Radiation Detectors", Paris, France, February 22 - 24, 2016.

Astroparticle Physics

LIMADOU

Irina Rashevskaya, poster contribution "Double-sided strip sensors for the Limadou-CSES project", Vertex2016, Isola d'Elba, Italy, September 25 - 30, 2016.

LISA Pathfinder

Live streaming of LISA Pathfinder launch, TIFPA & Physics Department, University of Trento, Italy, December 2 - 3, 2015.

VIRGO

Giovanni Andrea Prodi, "L'onda di Einstein", University of Trento, Italy, February 12, 2016.

Giovanni Andrea Prodi , TEDx talk "Gravitational Waves Revealed: a Revolutionary Perception of Our Universe", Verona, Italy, April 24, 2016.
`https://www.youtube.com/watch?v=I6A3uIQsfN0`

Giovanni Andrea Prodi, "In ascolto dell'Universo", Trieste Next, Trieste, Italy, September 23, 2016.

Giovanni Andrea Prodi, "Catturare onde gravitazionali: un nuovo organo di senso dell'umanità per scrutare l'universo", Università Cattolica, Brescia, Italy, October 12, 2016.

Giovanni Andrea Prodi, "Unveiling new features of our universe through gravitational waves", opening lecture, I Symposium Forum Accademico Italiano, Italian General Consulate of Cologne, Germany, November 28, 2016.

Nuclear Physics

First FOOT meeting, ECT*, Trento, Italy, July 29, 2015.

Theoretical Physics

FLAG

II Flag Meeting "The Quantum and Gravity", Trento, Italy, June 6 - 8, 2016.
`https://agenda.infn.it/conferenceDisplay.py?confId=10849`

LISC

"New Frontiers in Multiscale Modelling of Advanced Materials", ECT*, Trento, Italy, June 17 - 20, 2014.
`http://www.ectstar.eu/node/783`

TEONGRAV

"Einstein Toolkit Workshop 2015", Stockholm, Sweden, August 11 - 14, 2015.
`http://agenda.albanova.se/conferenceDisplay.py?confId=4936`

"Phosforescienza", Centro Siciliano per la Fisica Nucleare e la Struttura della Materia, Catania, Italy, November 21 - 29, 2015.
`http://csfnsm.ct.infn.it/Phosforescienza/`

Eloisa Bentivegna, at Open Day 2016, Dipartimento di Fisica e Astronomia di Catania, February 2016.

Eloisa Bentivegna, High-School lectures in Italian on Gravitational Waves at Liceo Archimede of Acireale, February 2016 and Liceo Galilei of Catania, March 2016.

Eloisa Bentivegna, Public Seminar "Gravità e spaziotempo" at Biblioteca Civica di Lentini, April 2016.

"Einstein Toolkit EU School and Workshop 2016", Trento, Italy, June 13 - 17, 2016.
`http://events.unitn.it/en/et-eu2016`

"Short Gamma-ray Bursts: from observation to numerical simulations", Trento, Italy, September 8 - 9, 2016.
`http://webmagazine.unitn.it/evento/dphys/10447/short-gamma-ray-bursts`

Technological Research

MoVe-IT Kick-off Meeting, TIFPA, Trento, Italy, December 15 - 16, 2016.
`https://agenda.infn.it/conferenceDisplay.py?confId=12330`

Trento Institute for
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