WE LOOK VERY CLOSELY AT VERY LITTLE THINGS...

....ALLOWING DISCOVERIES WHICH BENEFIT EVERYDAY LIFE.

ENSAR EFINION
nuclear ion beams & tools for society

Showcasing multi-disciplinary applications-oriented research in ENSAR.

EDITORIAL

Showcasing the benefits of nuclear physics research for society

The impact of nuclear physics research goes far beyond the purely scientific and reaches out to applications of great benefit to society and other disciplines. New and better ways of treating cancer, new tools for understanding biochemistry and assuring the reliability of satellite electronics are some of these important applications. These areas have benefitted from the transfer of knowledge originally gained through research in nuclear physics.

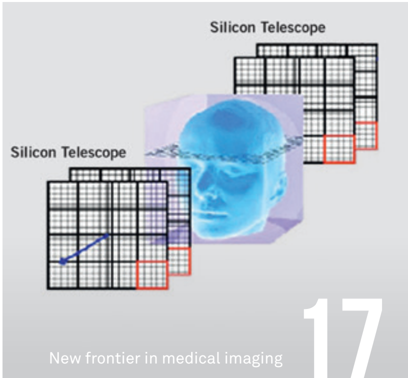
EFINION – the European Forum for INnovative applications of Nuclear ION beams and tools – is a showcase for the multidisciplinary research and benefits to society which arise from nuclear physics research in Europe. Divided into four principal activities: cancer treatment, space electronics, materials science and biophysics propelled by technology transfer, we present a glance in this brochure at the main domains in which knowledge and expertise gained in the pursuit of pure scientific research can have an impact far beyond its original purpose.

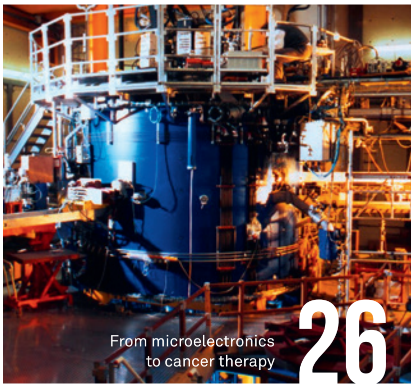
The successful transfer of knowledge from physics to health is a particular case in point. Ever since the discovery of X-rays, developments in modern physics have allowed for improvements in health care, and this continues today in not only diagnosis and imaging but also in therapy. Cancer will affect 30% of the adult population at some stage in their lives and effective treatment still relies on techniques which have emerged from physics. The ability of ion and proton beams for a more precise and better way of deposition of their energy promises a new era in killing tumours with minimal effect to healthy tissue. Developments in machines utilising accelerators for this task are a direct consequence of supporting pure physics research. Novel techniques such as harnessing innovative isotopes for treating tumours are also a direct link to advances in nuclear physics research.

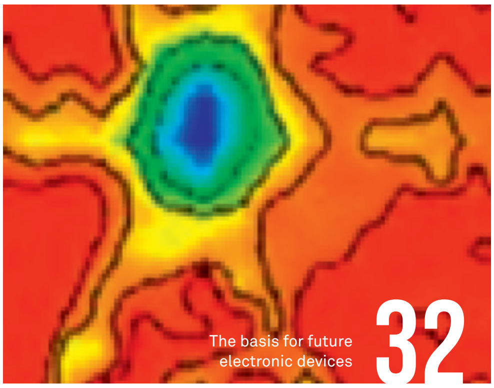
The success of the transnational access programme, supporting access to particle accelerators for European scientists, in bringing together scientists from different domains and fields cannot be underestimated. A considerable number of the developments and innovations presented in this brochure have their origins in the synergetic combination of scientists coming from a variety of scientific disciplines, e.g., nuclear physics, life sciences and medicine. Without such support, it is likely that many fewer innovations would have transferred beyond the confines of the nuclear physics laboratory.

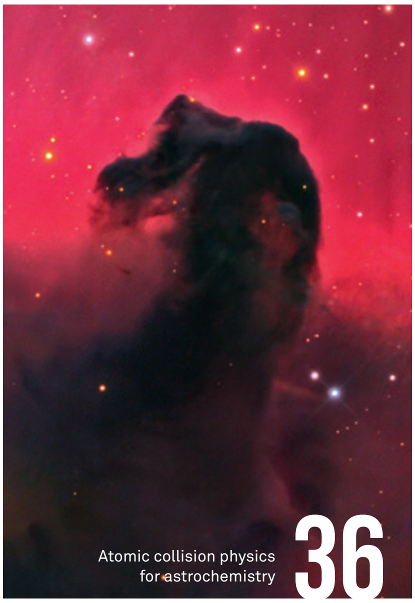
Europe stands at the forefront not only of nuclear physics research, but also in applying this knowledge to many other fields. We hope that this brochure allows the reader to gain an overview of the many various activities which have benefitted from this research. The next generation of large-scale facilities is now under construction. This will provide new opportunities for research in basic science but also in applications to other areas. By maintaining the links which exist between nuclear science and other fields, one thing is certain: it will be society as a whole who benefits.

TABLE OF CONTENT









About ENSAR 4

Areas of Application 6

GSI (Germany) 8

GANIL (France) 12

Joint LNL – LNS (Italy) 16

JYFL (Finland) 22

KVI – CART (Netherlands) 25

CERN – ISOLDE (Switzerland)..... 28

ALTO (France) 34

TNA User Testimony................. 38

JRAs & NAs 39

After ENSAR............................. 40

ABOUT ENSAR

The European Research Network on Nuclear Physics

The European ENSAR is divided in 20 sub-projects, also called work packages:

7 TNAs
Transnational Access Activities

7 JRAs
Joint Research Activities

6 NAs
Networking Activities

Nuclear Physics is the study of the properties and behaviour of nuclei and particles, ranging from tiny quarks to giant explosions deep in space. Nuclear physics is important in a vast variety of situations, from understanding how the Sun provides the energy for life on this planet, to nuclear power plants and radiation therapy. Without nuclei, we simply would not exist, and it is important to understand why!

In order to carry out research at the forefront of fundamental nuclear science, our community of nuclear scientists profits from the diverse range of large research infrastructures existing in Europe. These infrastructures are particle accelerators that can supply different species of ion beams and energies. In this way we can learn how the nuclear forces arising from the interaction between the building blocks of neutrons and protons manifest themselves in the rich structure of atomic nuclei, and how different isotopes of elements are synthesised in primeval stellar processes. Our community also has a long tradition of applying state-of-the-art developments in nuclear instrumentation to other research fields (e.g. archaeology) and to benefit humanity (e.g. medical imaging).

The large nuclear research infrastructures that exist in Europe are complementary in their provision of beams and address different aspects of nuclear structure. These European nuclear physics facilities are world-class and excel in comparison with facilities elsewhere in the world. Furthermore, the vibrant European nuclear physics community has made great efforts in the past to make the most efficient use of these facilities by developing the most advanced and novel equipment needed to pursue the excellent scientific programmes proposed at them. This has been done under the auspices of NuPECC (Nuclear Physics European Collaboration Committee) and drawing support from previous framework programmes of the European Commission.

This community strives to do the same in the future and has delineated the steps needed to pursue coherent research programmes at these facilities. This was done within the framework of the recent Long-Range Plan (LRP) of NuPECC "Perspectives for Nuclear Physics Research in Europe in the Coming Decade and Beyond" which has been published in 2004. In this LRP, NuPECC addressed future perspectives in six major subfields of research in nuclear physics and re-emphasised the role of the European Network of complementary large-scale facilities where past achievements and future perspectives for research in nuclear physics are excellent. In this LRP are also recommendations for future Pan-European facilities.

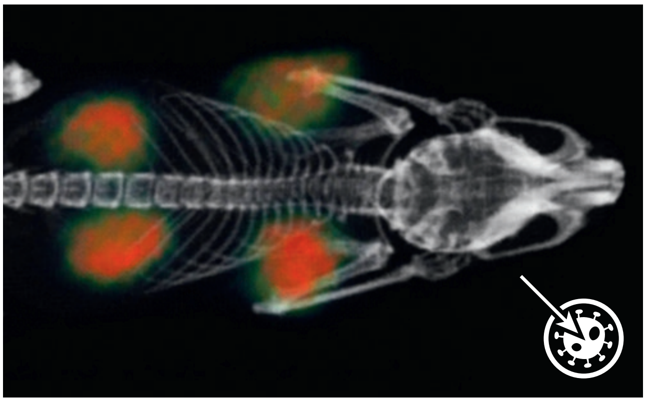
ENSAR is the scientific project for European nuclear scientists who are performing research in three of these major subfields: Nuclear Structure, Nuclear Astrophysics and Applications of Nuclear Science.

Its core aim is to provide access to seven of the complementary world-class large-scale facilities: GSI (Germany), GANIL (France), joint LNL-LNS (Italy), JYFL (Finland), KVI (Netherlands), CERN-ISOLDE (Switzerland) and ALTO (France). These facilities provide ion beams of excellent qualities ranging in a large range of energies.

These facilities are offering access to a very large, wide and diverse user community. The size of this community of physicists in nuclear structure, nuclear astrophysics, and applications of nuclear science in addition to the staff that is involved in accelerator and detector development and in running the facilities ranges between 2700-3000 scientists and highly qualified engineers according to a recent survey by NuPECC. The facilities will provide an increased amount of beam time for applications of nuclear techniques.

NUCLEAR RESEARCH IS USEFUL AND SUCCESSFUL

Innovations arising from European Nuclear Research benefit our daily lives.



HEALTH AND MEDICINE

CANCER TREATEMENT

The transfer of expertise from nuclear physics to medicine has a long tradition. The birth of modern physics was the discovery of X-rays by Rontgen and the first application of this was to medical imaging. This tradition continues to today with medical applications of nuclear physics gathering pace by the year. Nuclear medicine encompasses all aspects of cancer diagnosis and therapy. Europe is a leader in the provision of therapy using ion beams and a vigorous programme exploring exotic isotopes for diagnosis and therapy is currently underway.

Examples:

Cancer therapy: Pioneering ion beam radiotherapy ....GSI **9**

Graphics in four dimensions: Sophisticated algorithms for medical diagnosis..............................GSI **11**

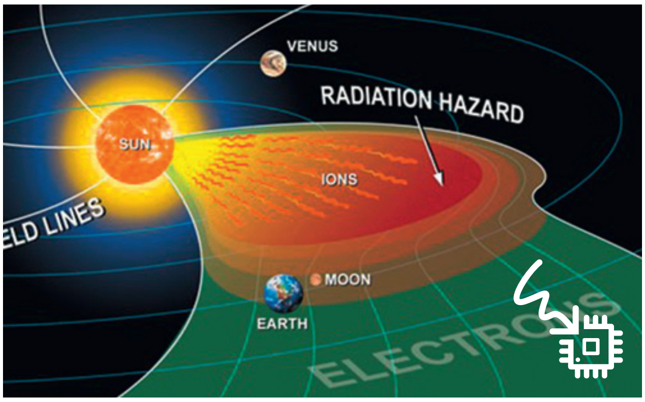
Health treatment in Normandy: Nuclear physics opens innovation ....GANIL **14**

Proton Computed Tomography (pCT): New frontier in medical imaging.......................INFN – LNS **17**

Eye Melanoma: Italy's first proton therapy centre ....INFN – LNS **18**

The Agorfirm Facility: From microelectronics to cancer therapy ....KVI – CART **26**

Tb isotopes in medicine: Innovative ways of detecting and treating cancer ....CERN – ISOLDE **31**



ELECTRONICS FOR SPACE INDUSTRY

RELIABILITY OF SATELLITES

The environment in which satellites orbiting the earth is extraordinarily hostile to the sensitive electronics which are contained on-board. Yet these satellites are increasingly an element of our day-to-day lives be it for GPS systems or communications. Ensuring complete reliability is a considerable task and due to the immense cost of producing satellites needs to be assured of well in advance of launch. Europe has developed a network of facilities benefitting from progress in nuclear physics of re-producing this environment: a direct product of work producing radioactive ion beams at its principal nuclear physics facilities.

Examples:

Electronic components for spatial industry...............GANIL **13**

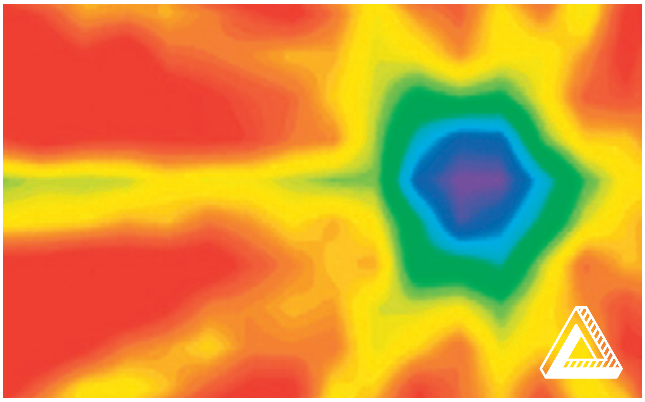
Space radiation simulation: Ensuring excellence before lift-off............................JYFL **23**

The Agorfirm Facility: From microelectronics to cancer therapy ....KVI – CART **26**

Space radiation simulation: Rescuing the Planck Mission .... ALTO **35**

Atomic collision physics for astrochemistry................ ALTO **36**

AREAS OF APPLICATION



MATERIALS SCIENCE AND BIOPHYSICS

MATERIALS FOR THE FUTURE

The use of radioactivity in materials science has almost as long a tradition as in medicine. The attractions are obvious: by utilising a radioactive isotope one obtains sensitive and unique information about the local environment in a material or can chemically label processes which may otherwise remain unknown. Nowadays research in this area encompasses all facets of materials science and is increasingly finding innovative applications to unravelling previously hidden mechanisms in biophysics and biochemistry.

Examples:

Advanced materials for gamma and neutron detection.................................INFN – LNL **20**

Particle beams manipulation and steering by channeling in bent crystals.........................INFN – LNL **20**

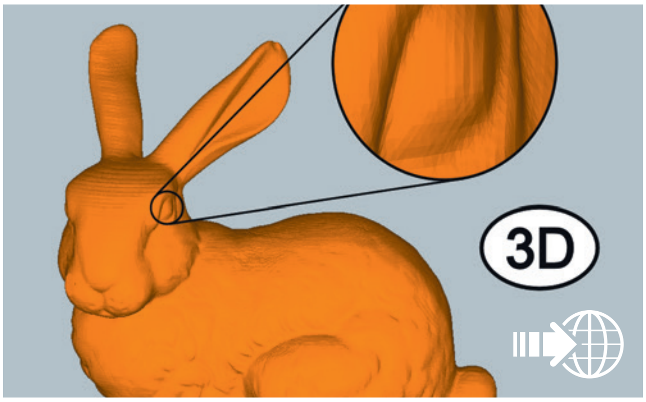
Ion beam writing of diamond biosensors ....INFN – LNL **21**

Pelletron: Monolayer material modification.................JYFL **24**

The Agorfirm Facility: From microelectronics to cancer therapy ....KVI – CART **26**

Unmasking metals' biological role ....CERN – ISOLDE **29**

Location of Mg impurities in semiconductors: The basis for future electronic devices..........CERN – ISOLDE **32**



TECHNOLOGY TRANSFER

INVENTIONS FOR INDUSTRY

Technology transfer is an increasingly important facet of today's research environment. The successful transfer of knowledge beyond the research laboratory can lay the foundation for opportunities not only for future industries but also in raising up entire economic areas. Capitalising on research in this way is still in its relative infancy, but success in transferring results from nuclear physics has been considerable with especial success in the medical industry.

Examples:

Mine detection with gamma rays...............................GSI **10**

Mass spectrometry in everyday life............................GSI **10**

Ion sources: Collaborative research agreement..........GANIL **13**

Microporous membranes...................................GANIL **13**

GSI

Helmhotzzentrum fur Schwerlonenforschung

The goal of the scientific research conducted at GSI Helmholtzzentrum für Schwerionenforschung is to reach a better understanding of the structure and behavior of the world that surrounds us. GSI operates a unique large scale accelerator for heavy ions.

More than 1,000 researchers from around the world and 200 master and doctoral candidates use this facility each year for experiments that help them make fascinating discoveries in basic research.

In addition, they continually develop new and impressive applications. Probably the best-known results are the discovery of six new chemical elements and the development of a new type of tumor therapy using ion beams. In the coming years, a new international accelerator center called FAIR (Facility for Antiproton and Ion Research) – one of the largest research projects in Europe – will be built adjacent to GSI. The GSI accelerators will serve as an injector for FAIR.

FACTS & FIGURES

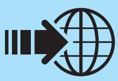
LOCATION

FACILITIES

- 120 metres long linear accelerator UNILAC
- Ring accelerator SIS18 with a circumference of 216 metres
- Experimental storage ring ESR
- Fragment separator FRS

APPLICATIONS


Health & Medicine


Technology Transfer

CANCER THERAPY

PIONEERING ION BEAM RADIOTHERAPY

Together with physicians, scientists of GSI developed a revolutionary new form of cancer treatment with carbon ions. This development was the result of many years of research in conjunction with GSI's large ion beam accelerator system.

Ion beam radiotherapy at GSI has been used to treat more than 440 patients for tumors in the head or neck region. The advantage of this new treatment modality is that the ion beam selectively damages tumor tissues while sparing the surrounding healthy tissues. The therapy with ion beams is precise, highly effective and very gentle for the patients. Subsequent monitoring of these patients over a five year period revealed that the growth of the irradiated tumors was stopped in 75 to 90 percent of the patients, depending on the type of tumor. Side effects requiring treatment occurred only in very few cases.

Since 2009, this type of cancer therapy is in routine clinical use at the Heidelberg Ion Beam Therapy Center (HIT). There, up to 1,000 patients can be treated annually. The accelerator facility and the technique for irradiation at HIT was developed and built by scientists and technicians of GSI.

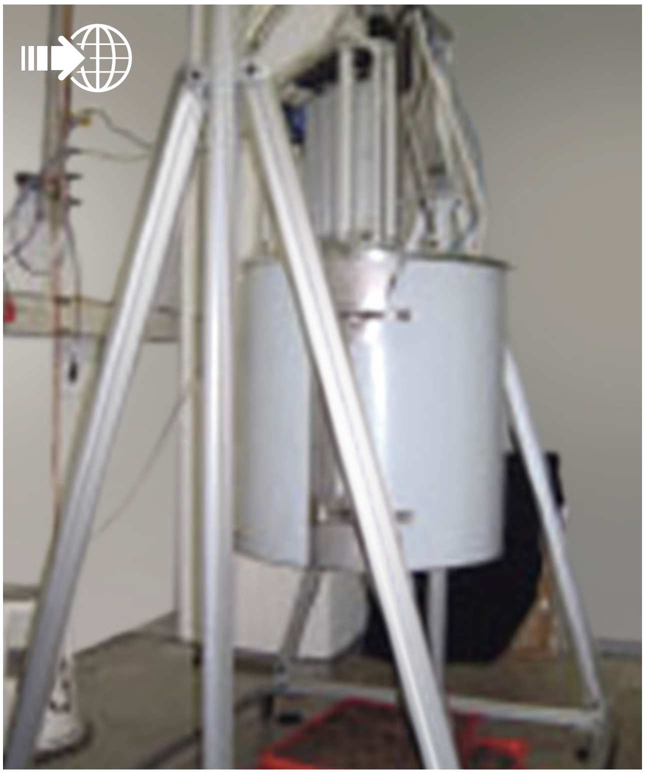
The therapy with ion beams is precise, highly effective and very gentle for the patients.

Further developments aim to treat tumors which change their position constantly due to body movements, like breathing. Experiments show that it is possible to follow a movement of the tumor inside the body by adapting the ion beams stopping position in three dimensions. The implementation could expand the treatment to inner organs like the lung or the liver. The method is continuously improved by GSI scientists and their cooperation partners. Up to today 359 patents connected with this novel therapy technique have been issued.

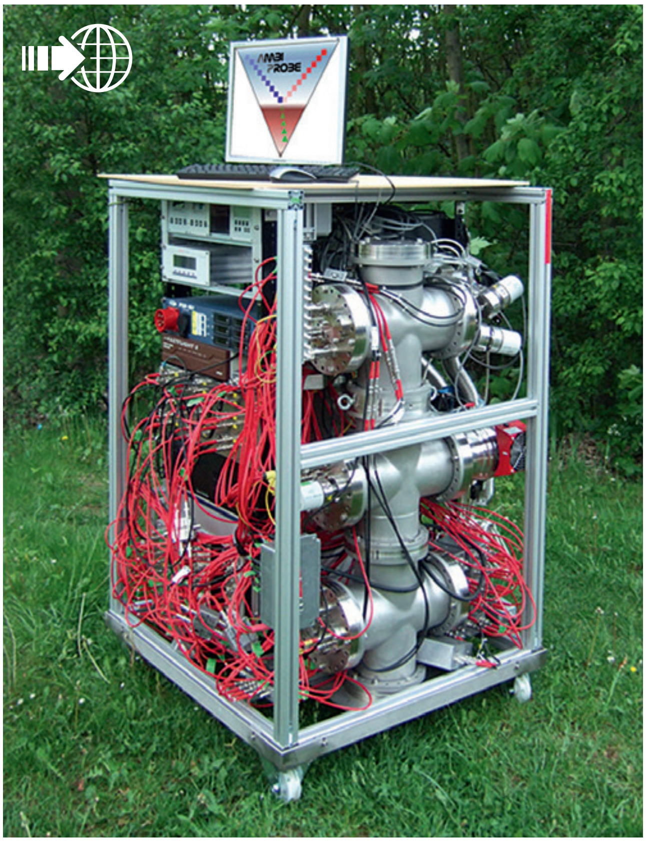
MINE DETECTION WITH GAMMA RAYS

Land mines kill thousands of people every year and pose a threat especially to civilians and children. To find and to remove them is a delicate and very dangerous task to the workers. Common metal detectors used so far can't distinguish between a land mine and a metallic piece of junk, leading to a very slow advance in clearing a land mine area.

With the aid of gamma spectroscopy it is possible to reliably find and identify land mines with a handheld device that weighs no more than a few kilograms. It allows clearing an area of up to 50 square meters in only one day. The device was developed from gamma detection arrays used in nuclear physics for collision experiments with heavy ions, like the AGATA setup currently in use at GSI.



Prototype for land mine detection with gamma rays.



A prototype of newly developed high-performance mass spectrometer, which has its roots in nuclear physics research; being a compact device, it provides ultra-high mass resolving power for in-situ applications in environment, life-sciences and medicine.

MASS SPECTROMETRY IN EVERYDAY LIFE

Mass spectrometry is a technique developed more than hundred years ago. In 1913 it allowed the seminal discovery of isotopes. Besides its wide use and further developments in nuclear physics, mass spectrometry found its application as an analytical tool in many directions of science, e.g. in chemistry, biology, geology, space science and many other fields.

Besides these natural sciences there are a lot of applications like environment, climate research, health, nutrition or security. In the future, mass spectrometers could have down-to-earth applications, such as testing fruits and vegetables for dangerous bacterial contaminants or virus infections.

"In a few years, mass spectrometers may be in routine use in every household"

says **Graham Cooks** from Purdue University, who is one of the pioneers of modern applications of analytical mass spectrometry.

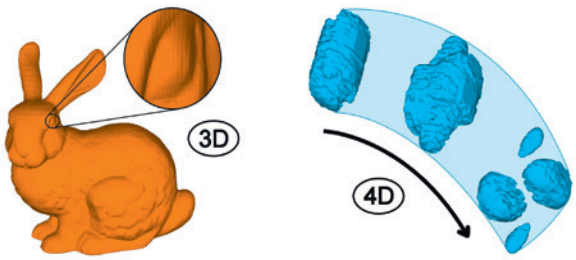
GRAPHICS IN FOUR DIMENSIONS

SOPHISTICATED ALGORITHMS FOR MEDICAL DIAGNOSIS

Since Einstein's relativity theory we know that the world doesn't only exist in our three spatial dimensions, but in a four-dimensional space-time. Yet to calculate four-dimensional tasks quickly is a challenge even for modern computer equipment and sophisticated algorithms are needed.

We present such an algorithm which is able to process four-dimensional problems for medical diagnosis, mathematical and physical simulations or technical applications. It is able to generate a closed hypersurface in four dimensions from a set of elementary starting points. A positive outcome is that it also calculates three-dimensional tasks much faster than common algorithms.

Possible uses could be in MRT and CAT scanners, the calculations of relativistic fluid model simulations or even graphics in computer games.



Examples of three-dimensional (left picture) and four-dimensional (right picture) calculations made with the novel algorithm.

GANIL

Grand Accélérateur National d'Ions Lourds

GANIL is located in Caen, in Basse-Normandie, in France. GANIL is today one of the largest laboratories in the world for research using beams of ions, to study the physics of the atom and its nucleus, and to address questions from condensed matter to astrophysics.

The construction of the new SPIRAL2 accelerator, adjacent to GANIL, constitutes a real technical and scientific advance for both France and Europe. To develop and run GANIL-SPIRAL2 facilities, a very large field of technologies are used at GANIL, most of them at the forefront of progress. Place is also reserved for industrial applications of the beams delivered by the facility. Very low-, low-, medium- or high energy beams are available for various industrial users.

Fully involved in the socioeconomic environment of the Basse-Normandie, GANIL is a founding member of a start-up incubator, and is working together with other research centres and technology transfer structures.

FACTS & FIGURES

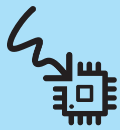
LOCATION

FACILITIES

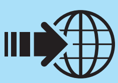
- CSS1 & CCS2: Cyclotrons (medium to high energy ion beams)
- SPIRAL1: Low energy radioactive beams
- IRRSUD: Low energy ion beams
- ARIBE: Very low energy ion beams
- Caves D1 and G4: Medium or high energy ion beams

APPLICATIONS

Health & Medicine



Electronics for Space Industry



Technology Transfer

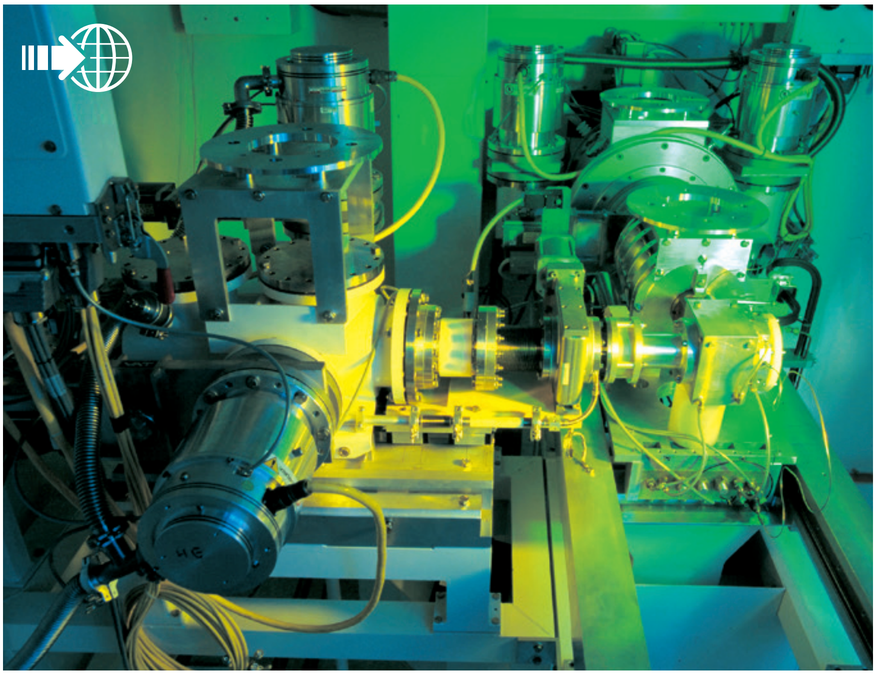
ION SOURCES

COLLABORATIVE RESEARCH AGREEMENT

An ion source is an electro-magnetic device that is used to create charged particles for accelerators. The GANIL ion source staff have strong expertise in this technological domain: the first patent was taken out (CEA & CNRS) in 1991.

The Pantechnik Company was created in the same year to exploit and develop these technologies. A collaborative research agreement has been signed between GANIL and Pantechnik with the aim of common developments in multi-charged ion sources.

Nowadays, Pantechnik know-how is used in various areas:
- Research in Nuclear Physics, Atomic Physics, Nanosciences, ...
- Medical applications: Cancer treatment, production of radionucleides, ...
- Industrial applications: Implantation for microelectronics, development of new materials, ...



Example of a target and ion source used at GANIL.

ELECTRONIC COMPONENTS FOR SPATIAL INDUSTRY

Since the first “Sputnik” launched by the USSR in 1957, numerous satellites are now routinely sent into long or very long space missions. Application areas are diverse, both civilian and military. Whether for the satellites themselves or their equipment, electronics are everywhere. In space however, the electronic components and systems are subject to energetic radiation which can greatly disrupt them.

Particle accelerators are called on to perform tests of various electronic systems, simulating the effects of space particles.

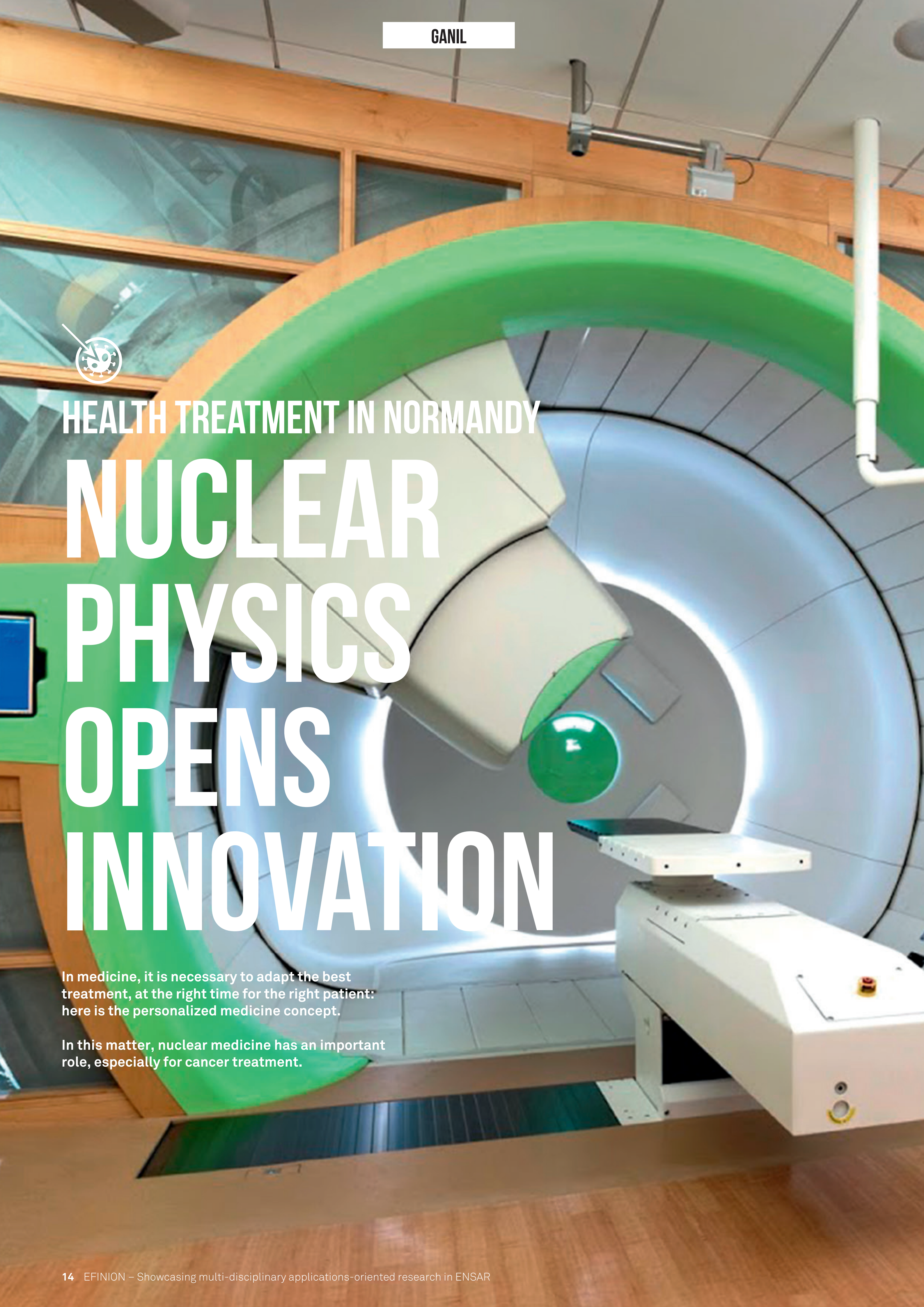
GANIL has been a pioneer in this field in the late 80’s. Today, GANIL has a specific platform dedicated to these tests. GANIL works now on these tests with many national or international institutions and companies.

MICROPOROUS MEMBRANES

Microporous membranes (with pore diameters lower than 2 nm) are used by nanotechnology industries in order to create configurations with microholes or microstructures. These membranes can be used, for instance, for microfiltration in biology studies or as gas sensors.

At GANIL, microporous membranes are made from a polymer film. A heavy ion beam hits this film and drills microscopic holes. The maximum intensity of the beam depends on the pore density desired by the manufacturer. The film is on a roll that is installed as close as possible from the accelerator tube so that the accelerated ions fly a minimum distance in the air (about 22 mm).

Presently, companies from Belgium, Sweden and Germany have taken advantage of GANIL heavy ion beams for this application.



HEALTH TREATMENT IN NORMANDY

NUCLEAR PHYSICS OPENS INNOVATION

In medicine, it is necessary to adapt the best treatment, at the right time for the right patient: here is the personalized medicine concept.

In this matter, nuclear medicine has an important role, especially for cancer treatment.

Nuclear medicine uses radioisotopes that are produced in reactors and accelerators. This is possible thanks to developments in nuclear physics. Therefore, nuclear physics and medicine are two expertise areas, different but complementary and linked.

The city of Caen has got a unique scientific, technological and medical environment in nuclear physics for health. Thus, these skills are considered as one of the principal priorities for Basse-Normandie region.

A dynamic ecosystem

First of all, the hospitals “Centre de Lutte contre le Cancer François Baclesse” (CLCCFB) and “Centre Hospitalier Universitaire” of Caen (CHU) treat cancer patients; they are also involved in research and education. The CLCCFB is one of the most efficient radiotherapy centres in France.

For fundamental research, Caen hosts various research institutions in nuclear physics with medical application activities. The LPC group (Laboratoire de Physique Corpusculaire) called “Applications industrielles et médicales” is an expert in beam control, simulation and dose calculations for radiotherapy. GANIL is one of the biggest laboratories in the world for research with ion beams and is now commencing research in medical applications. Within the framework of the FRANCE HADRON network (part of French “Investments for the Future” programme), GANIL adapted a beam line to specific needs in hadrontherapy and reserved it for use by associated researchers, starting in 2013. SPIRAL2, the new GANIL accelerator, is now under construction. This facility which will provide unique beams will also be used for R&D studies on radioisotope production. In collaboration with ARRONAX (based in Nantes) a programme to produce Astatine-211 has been initiated.

In the Caen region, there are other laboratories and companies which are participating at the frontier between physics and health. CYCERON, IMOGERE or CERMN are biomedical research centers. CYCERON studies are essentially devoted to cancer studies and neurosciences. This research institution has a medical imaging platform (including a cyclotron). All of these facilities are involved in researches about radioisotopes, drug design, medical imaging.

Industry plays also an important role in nuclear and health. Cyclopharma laboratories, Pantechnik, IBA, Adcis are important players in this area. Cyclopharma produces radioisotopes (FDG-F18) for medicine and research.

NUCLEOPOLIS: a nuclear cluster for health, energy and risk management

In the heart of this ecosystem, there is NUCLEOPOLIS. Its members are international industrial and research leaders such as AREVA, CEA, CNRS, EDF, GANIL and successful and innovative SMEs. NUCLEOPOLIS federates the available know-how in Normandy. The aim is to improve territorial cohesion for players, make the attractive aspects of Normandy in that field more legible and strengthen its position at both national and international levels, act as a projects crossroad and facilitate the development of joint cooperation with a strong ambition to break new ground and create new jobs.

NUCLEOPOLIS is the initiator of several collaborations between research and industry.

INFN – LNL

Laboratori Nazionali di Legnaro

INFN – LNS

Laboratori Nazionali del Sud

The INFN's main mission is the study of the fundamental constituents of the matter, conducting theoretical and experimental research in the field of subnuclear, nuclear and astroparticle Physics.

INFN has a key role in the European framework for particle accelerator and detector developments. Moreover, it is strongly involved in the application of already exisiting technology to several fields, such as medicine, superconductivity, cultural heritage and computing science. All these activities are carried out in collaboration with academia.

Research activities at INFN are carried out within two complementary types of facilities: Divisions, located at University Physics Departments, and the four National Laboratories, which host the major facilities. In particular, at the Laboratori Nazionali del Sud (LNS) in Catania two accelerators are in operation and several facilities are available to the national and international scientific community.

FACTS & FIGURES

LOCATION

FACILITIES

Laboratori Nazionali di Legnaro:
- Micro-beam AN2000 accelerator
- TANDEM, 7MV CN, ALPI and PIAVE accelerators

Laboratori Nazionali del Sud:
- 62 MeV Superconducting Cyclotron (SC)

APPLICATIONS

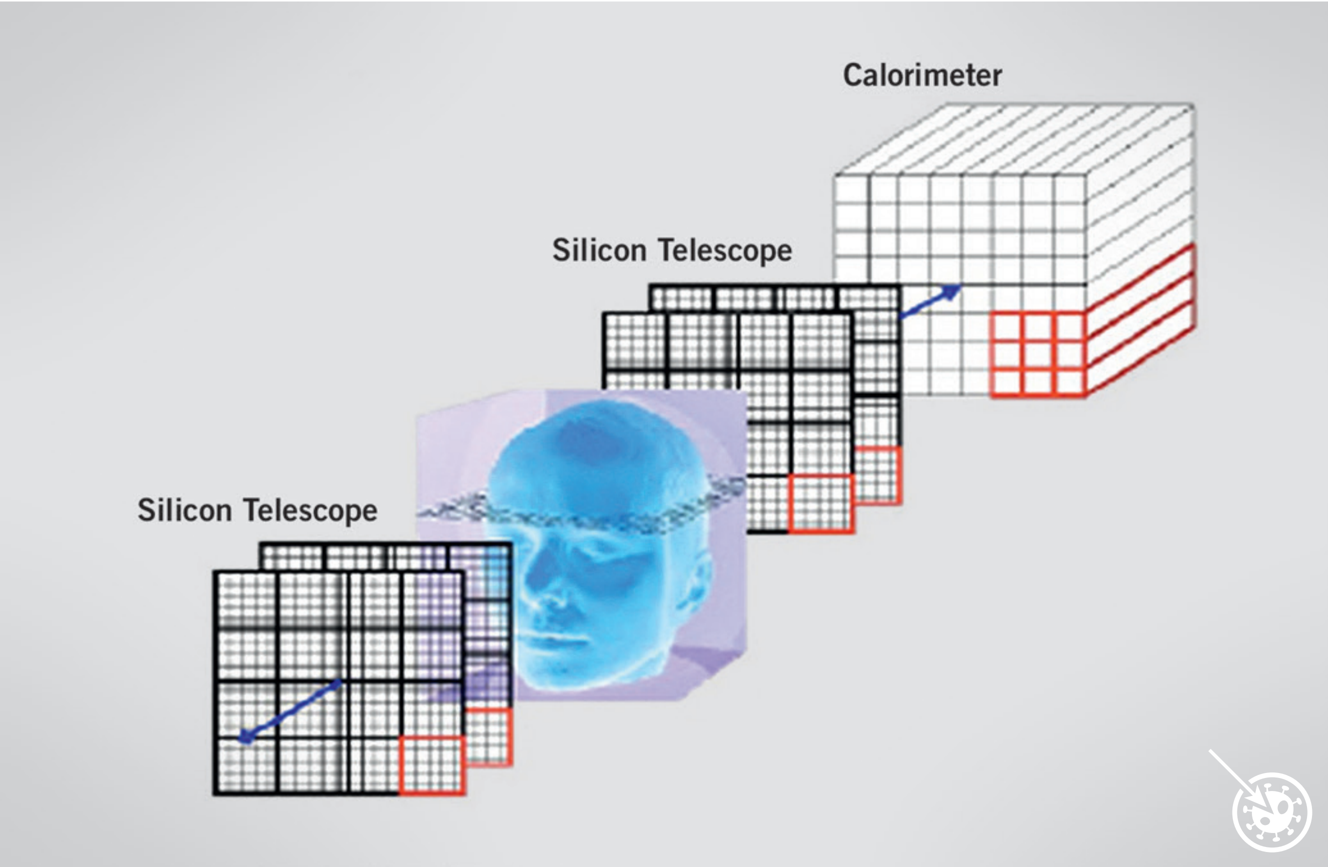
Health & Medicine

Materials Science & Biophysics

Technology Transfer

PROTON COMPUTED TOMOGRAPHY (PCT)

NEW FRONTIER IN MEDICAL IMAGING



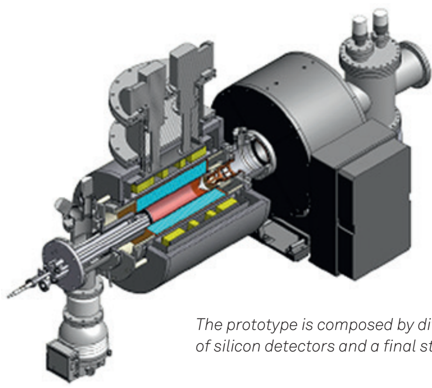
Schematic showing the configuration required for Proton Computed Tomography.

Medical imaging for diagnostics and quality assurance in radiation therapy have been completely renewed in recent years and the improvements are ongoing.

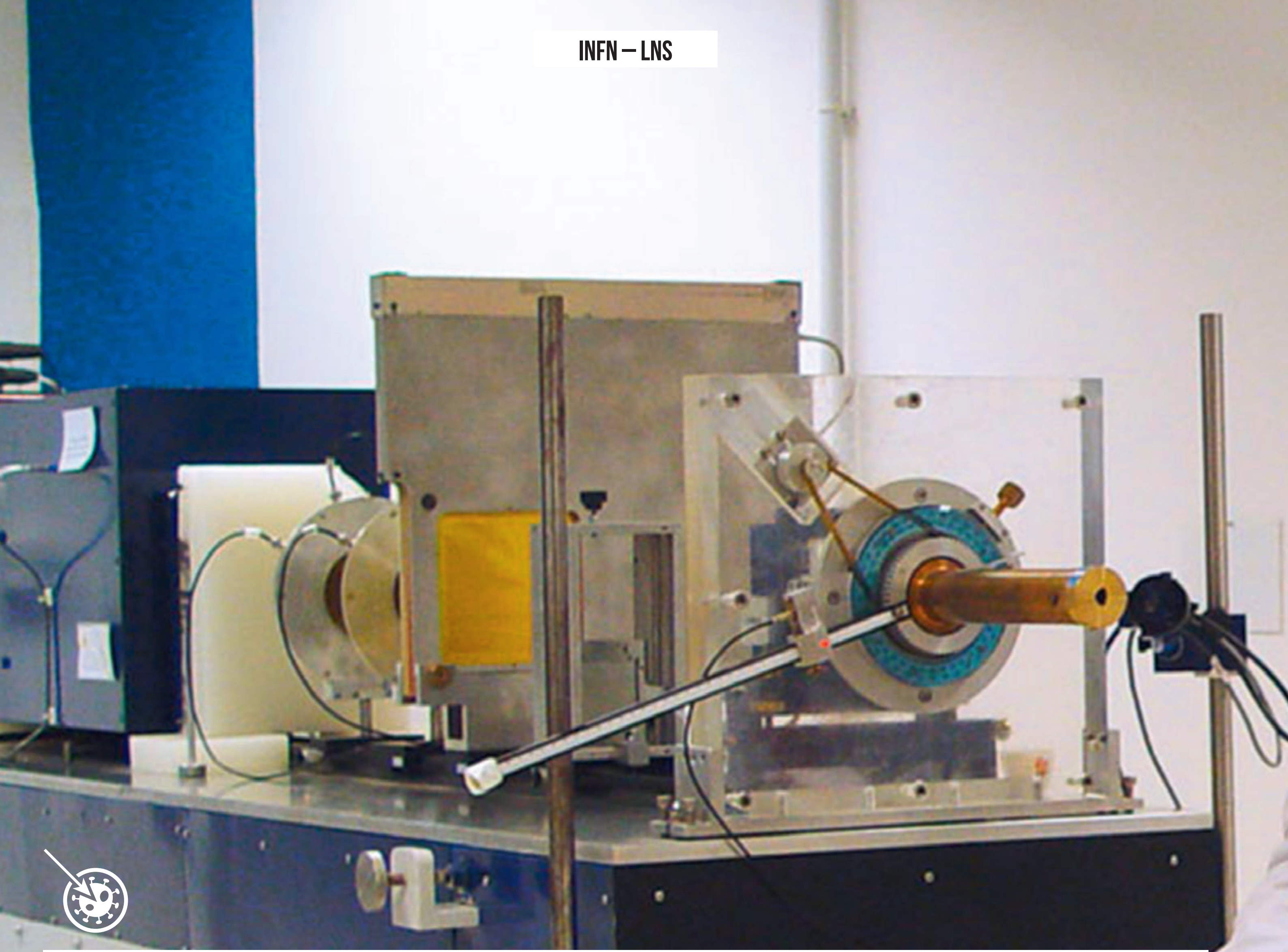
Concerning proton treatments, new techniques for computed tomography and on-line monitoring of the dose have to be developed to allow proton therapy to maintain a competitive role with respect to the new modalities of conventional radiotherapy.

An innovative prototype for pCT has been realized and tested with proton beams. In future it may replace conventional computed tomography (CT) that, for proton treatments, does not guarantee the same level of accuracy for the tissue inhomogeneity computation.

The prototype has already given promising results.



The prototype is composed by different planes of silicon detectors and a final stage of scintillator.



EYE MELANOMA

ITALY'S FIRST PROTON THERAPY CENTRE

Since 2002, advanced capability in irradiating tumours with protons has been present at INFN-LNS. Here, a group of researchers is using proton beams accelerated to 62 MeV to fight one of the most aggressive cancers: eye melanoma. Thanks to advanced techniques, a proton beam which would be typically used for fundamental nuclear physics experiments is 'converted' to a clinical beam for treatment.

Why proton beams?
Proton beams are quite distinct to the photon beams typically used in conventional radiotherapy. Protons are characterized by a high selectivity and an enhanced biological effect on cells. This allows the energy of the proton beam to be deposited directly on the tumour target: killing the neoplastic cells yet sparing the surrounding healthy tissues.

More than 350 patients have been treated so far at the CATANA (Centro di Adroterapia e Applicazioni Nucleari Avanzate) facility in Catania, with a local control of the tumour in 95% of the cases. Moreover, 30% of patients maintain visual acuity, if not already damaged.

With this technique the removal of the eye is avoided, considerably enhancing the quality of life for the patients.

The CATANA facility is the first hadron therapy centre in Italy, and its realization has allowed the development of challenging studies and innovative techniques for radiobiology, dosimetry and medical imaging.

In particular, for radiobiology, activity performed in the framework of ENSAR has allowed the realisation of novel irradiation devices for cell sample irradiations and to study new techniques for the analysis of biological effects, all within a fully equipped biological lab. For dosimetry, innovative procedures have been explored and some prototypes have been realized and tested with different beams of interest for medical applications.

This work has allowed INFN to secure a key role in the European framework for medical physics applications.

An advanced ion source for hadrontherapy centres

The experimental activities carried out at INFN-LNS for ENSAR have created a solid base for the design of AISHa (Advanced Ion Source for Hadrontherapy), a new series of Ion Sources adapted to the requirements of hadron therapy centres.

The availability of high current – high brightness multiply-charged ion beams, good stability and reproducibility, fast maintenance and long lasting operations are key points for the installation in a hospital-like environment. In particular, the AISHa source is deemed to produce ion species with Z<10 and currents between 0.5 and 5 mA in continuous wave or pulsed mode, with a beam ripple lower than 5% and with low emittance.

ADVANCED MATERIALS FOR GAMMA AND NEUTRON DETECTION

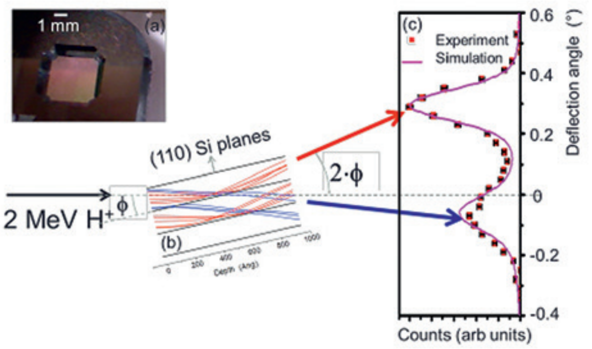
Transparent polisiloxane based scintillators are analyzed by TOF methods at the LNL-CN. A 4 MeV proton pulsed beam (3 MHz, 2 ns) impinges on a thin LiF target to obtain nearly mono-energetic 2.3 MeV neutrons.

The sensitivity to fast and thermal neutrons and the scintillation pulse shape for the n-gamma discrimination capability is analyzed.

Doping with boron for the detection of thermal neutrons preserved the scintillator transparency, while with suitable dye concentrations a good pulse shape discrimination has been obtained.

The CN Accelerator at LNL.

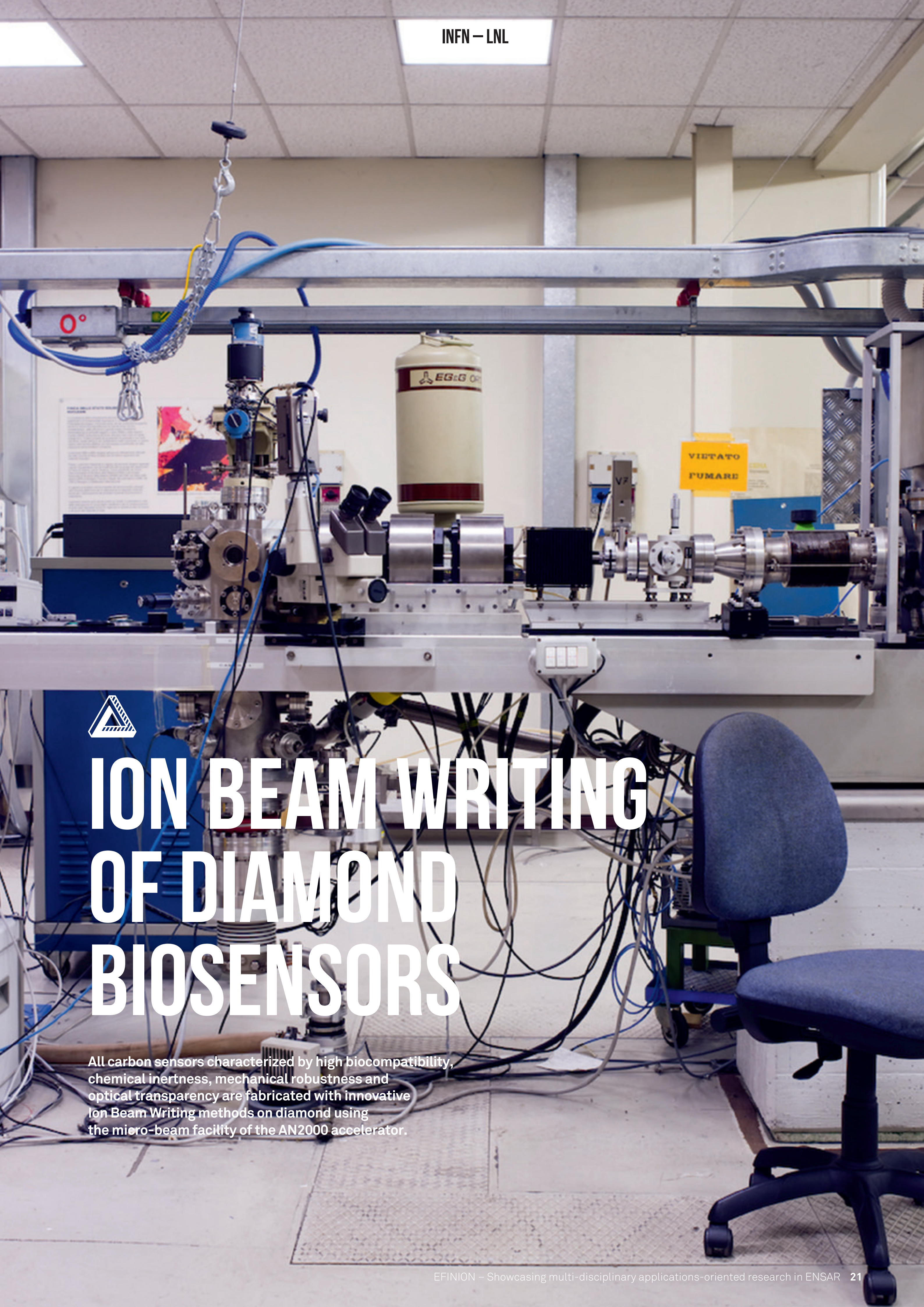
PARTICLE BEAMS MANIPULATION AND STEERING BY CHANNELING IN BENT CRYSTALS



Channeling of MeV charged particles has found wide application as a powerful tool for ion-beam analysis. In recent years, channeling in bent crystals opened up new schemes for beam manipulation and steering of GeV particle beams.

At the LNL-AN2000 accelerator, it has been recently demonstrated that beam-trajectory manipulation can also be performed at MeV energy by means of beam interaction with a flat nano-crystal. A 92 nm thick silicon membrane was realized by micromachining. A 2.0 MeV proton beam interacts with the (110) planes along the membrane thickness with an incident angle $\phi = 0.15°$. The channeled particles make on average half an oscillation into the 92 nm crystal, therefore they are reflected by the lattice planes at the membrane exit (red trajectories).

Over-barrier particles are slightly deflected in the opposite direction (blu trajectories). Angular deflection distribution of the particles has been measured and perfectly agrees with Monte-Carlo model.



ION BEAM WRITING OF DIAMOND BIOSENSORS

All carbon sensors characterized by high biocompatibility, chemical inertness, mechanical robustness and optical transparency are fabricated with innovative Ion Beam Writing methods on diamond using the micro-beam facility of the AN2000 accelerator.

JYFL

University of Jyväskylä

The accelerator laboratory at the University of Jyväskylä, Finland (JYFL) houses the RADEF facility and also a Pelletron accelerator for the modification and characterisation of materials.

Since 2005 RADEF has grown to be the leading test facility in Europe for high penetration ions. Its specialty is to serve the European Space Agency (ESA), and European satellite industry. In addition, NASA and JAXA (Japan Aerospace Exploration Agency) are also regular users of RADEF.

FACTS & FIGURES

LOCATION

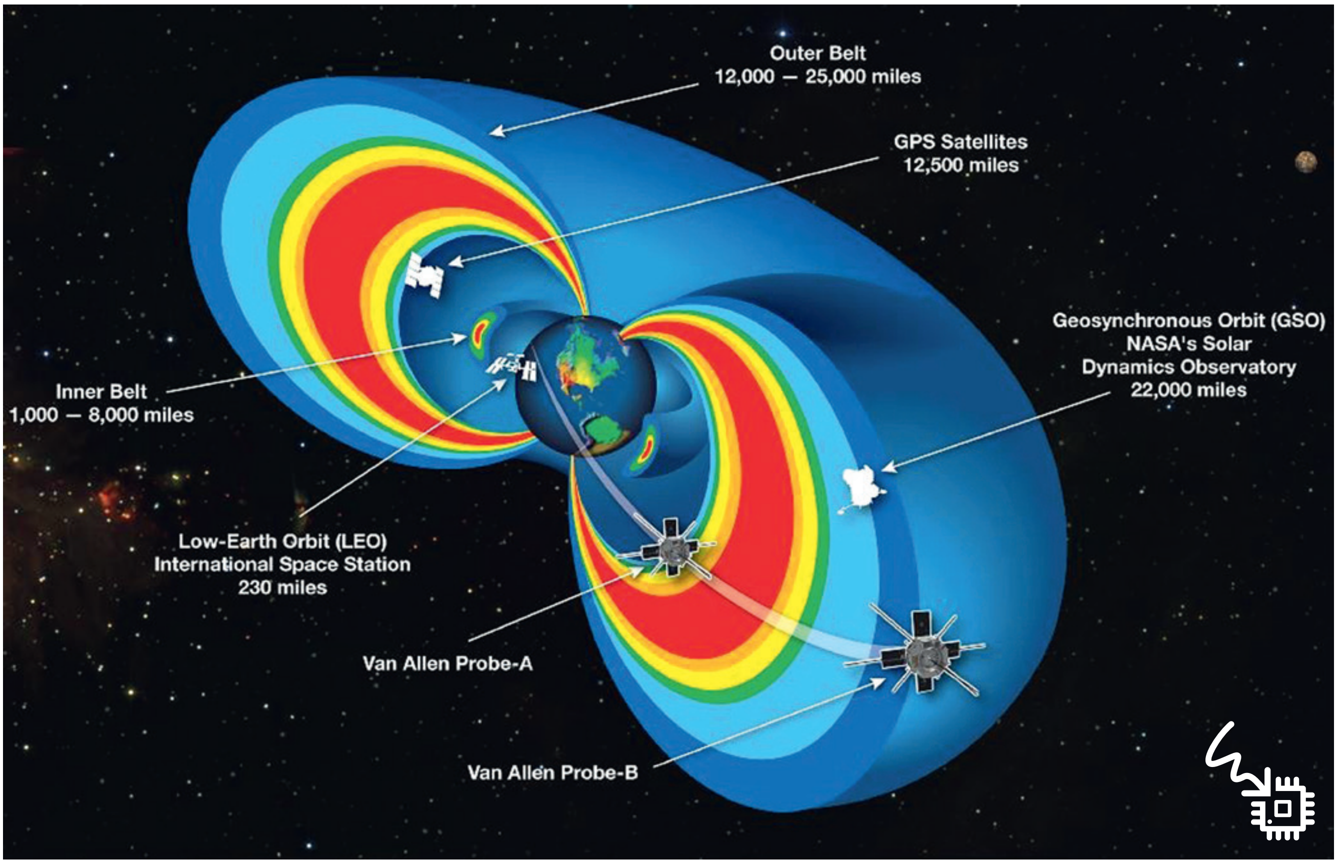
FACILITIES

- RADEF (Radiation Effects Facility) and Pelletron accelerator
- K130 cyclotron
- Multiple ion sources: from proton beams to cocktail beams of ions
- Pelletron (1.7 MV)

APPLICATIONS

Electronics for Space Industry

Materials Science & Biophysics



The Van Allen Radiation Belt Model.

SPACE RADIATION SIMULATION

ENSURING EXCELLENCE BEFORE LIFT-OFF

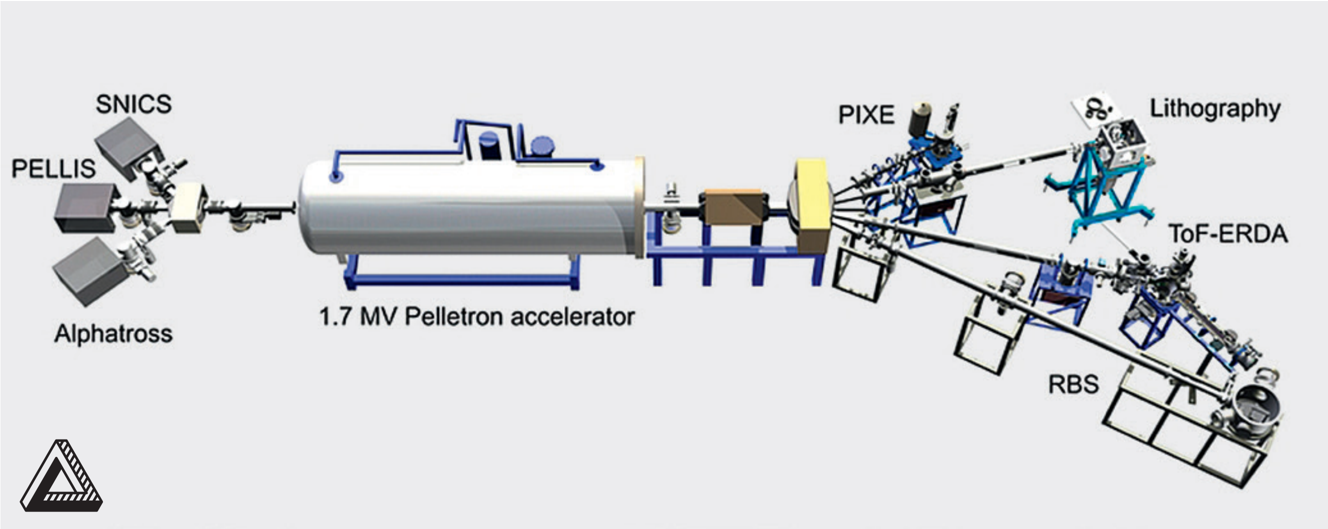
The only way to simulate space radiation environment on a terrestrial level and hence to test the radiation hardness of satellite electronics cost-effectively is to employ a facility such as RADEF. RADEF is the only place in Europe where heavy ion tests with a sufficiently high energy can be performed. The combination of the ECR (Electron cyclotron resonance) ion source and the cyclotron accelerator allows for so-called "cocktail beams" to be produced.

The cyclotron accelerator at RADEF.

In 2011 the JYFL-application program won the first prize in an academic entrepreneurship competition, which is organized every year for Finnish universities. The organizers are the Finland Chamber of Commerce, Confederation of Finnish Industries and Federation of Finnish Enterprises. In the evaluation the jury gave special recognition to RADEF's strong innovation and yearly commercial productivity.

RADEF is unique in Europe and is the main testing facility for ESA.

Strong links with NASA have also been formed. RADEF also has more than 50 annual visitors from satellite companies and institutes from all around the world.



Schematic showing the configuration of the Pelletron accelerator.

PELLETRON

MONOLAYER MATERIAL MODIFICATION

The JYFL pelletron allows for the modification and characterisation of surfaces. Three research stations allow for a variety of surface properties to be probed. Lithography and PIXE (Particle-induced X-ray Emission) are relatively common with considerable applications for cultural heritage and chemistry, but the time of flight Elastic recoil detection analysis (ToF-ERDA) beamline can perform at a very high level of sensitivity: a direct consequence of applying nuclear physics expertise to an “applied” problem.

The principle of ERDA is that heavy incident ions are directed towards a sample. Both recoiled sample atoms and scattered incident ions are detected at the forward direction.

The coincident measurement of velocity and energy from scattered particles makes it possible to identify their masses and therefore elemental depth profiling of all elements including hydrogen. The accessible depth is up to several hundred nanometers, and by different measurement geometries a depth resolution of about 1 nm can be reached.

The ability of ERDA to characterise very thin films – even to a monolayer depth – has considerable potential to be applied to materials and systems constituting the next generation of electronic devices where decreasing component size and widths requires such precise characterisation.

KVI – CART

Center for Advanced Radiation Technology

Based at Groningen, Netherlands, KVI has been carrying out research in Nuclear physics since the early 1970s. Initially focused on fundamental nuclear physics, the programme was expanded in the early 1980s to include a more applied focus.

Since 1997, a new cyclotron (AGOR – *Accélérateur Groningen ORsay*) has been installed. This has allowed for a dedicated irradiation facility – called AGORFIRM – which uses a dedicated beamline of the AGOR cyclotron for irradiations with protons, alpha particles and heavy ions in air.

FACTS & FIGURES

LOCATION

FACILITIES

- AGOR cyclotron
- AGORFIRM: protons, ions and alpha particle irradiations

APPLICATIONS

Health & Medicine

Electronics for Space Industry

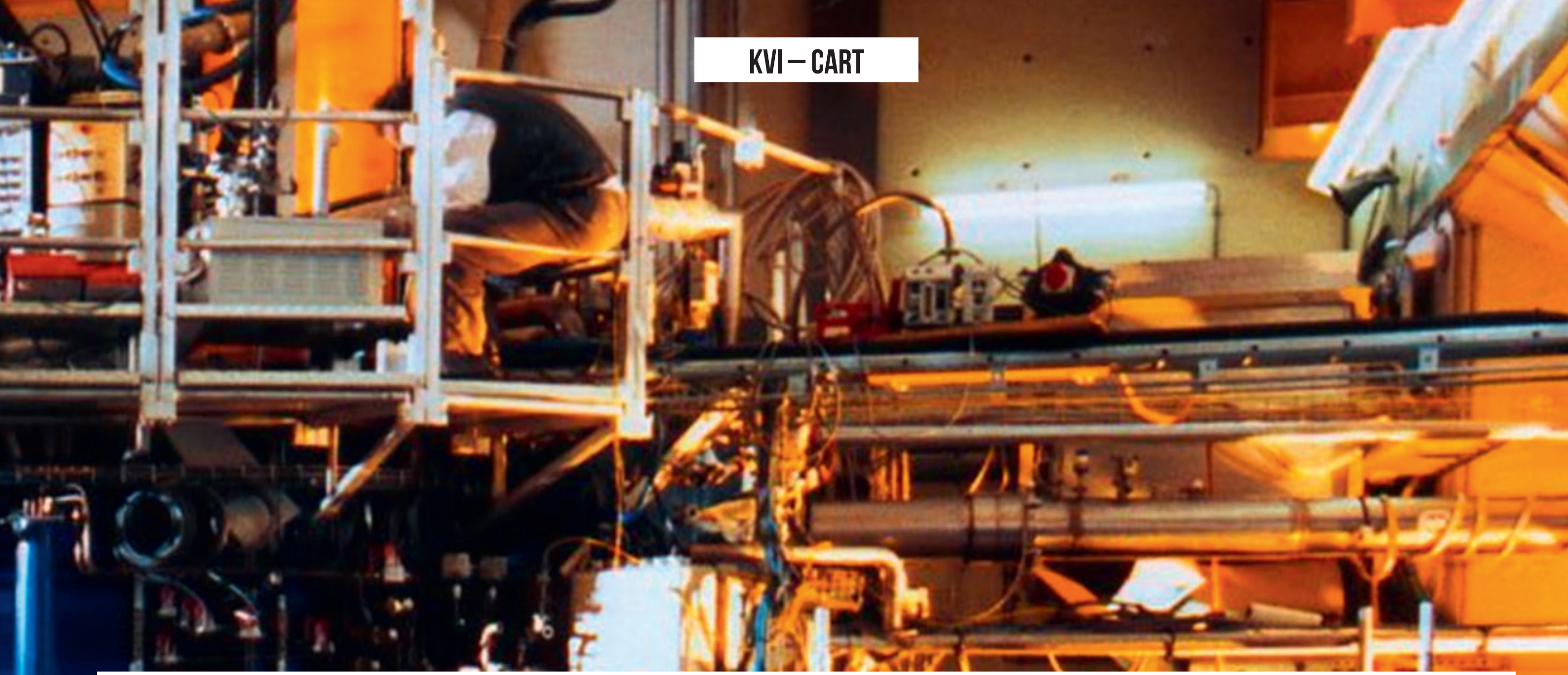
Materials Science & Biophysics

THE AGORFIRM FACILITY

FROM MICROELECTRONICS TO CANCER THERAPY

Uniqueness of AGORFIRM

AGORFIRM is unique in the combination of high energy heavy ion beams, of up to 30 MeV/u xenon beams and 90 MeV/u carbon for heavy ion irradiation in air, with high energy proton beams, enabling realistic simulations of solar flares and also clinical energies for proton therapy related experiments. Moreover, the close collaboration of KVI-CART and the University Medical Centre Groningen establishes a fruitful combination of expertise from which users of the facility will benefit. Furthermore, KVI-CART as a Center of Advanced Radiation Technology maintains electrical en mechanical workshops that can provide last minute trouble shooting during experiments.



Irradiation of materials with charged particles results in material damage. Such damage is often unwanted, harmful and costly, e.g. exposure to solar flare protons of Mars-going astronauts or irradiation of electronic components by cosmic radiation leading to functional failure of satellites and aircraft.

On the other hand, radiation damage can also be applied in a controlled way and have positive effects e.g. in the manufacturing of nanopore polymer membranes using heavy ion irradiation in combination with track-etching to produce nano-sized pores or the intentional irradiation of cancerous tissue with protons or carbon ions to reduce or stop tumor growth. The latter application, particle therapy, is currently rapidly implemented worldwide in hospitals and dedicated centers.

Particle radiotherapy yields, in comparison with the conventional X-ray radiotherapy, a lower radiation dose to the healthy tissues in the vicinity of the tumor, which should result in less and less severe long term complications than currently achieved. Furthermore it is expected to reduce the chance that a secondary tumor is induced, which makes it a better option for young patients.

Microelectronics

Optimal design of radiation hard electronics is largely based on data of radiation tests of components. As electric components become smaller and smaller, the component density on computer chips increases, enlarging the target area for cosmic particles. Cosmic rays mainly consist of protons, but smaller amounts of heavier particles, which cause much more damage to the components, are also present. Moreover, due to their smaller size, the components also become more sensitive to impacts of charged particles. A consequence of this ongoing miniaturization is that the probability of cosmic-radiation induced damage of computer chips is no longer negligible at the earth surface, where radiation levels are lower because of shielding by the atmosphere.

Radiation hardness then also becomes an issue for e.g. computer chips used in the automotive industry and in domestic appliances. The radiation hardness testing should not only be performed with protons, the main component of solar flares, but also heavier ions, both of which are available at the AGORFIRM facility at KVI-CART.

Ion beam therapy

Particle therapy with proton and carbon ions has an intrinsic advantage that the beam is stopped in the tumor, reducing the radiation dose in the surrounding normal tissues, which should lead to less complications. Stopping the beam in the tumor, however, causes the quality of the dose delivery to become very sensitive to uncertainties in tissue properties used for treatment planning and anatomical changes during the treatment course. This sensitivity can cause the dose to be delivered outside the clinical target volume, which compromise treatment outcome in terms of both tumor control and normal tissue complications.

This implies that improvements are needed in the translation of imaging information into the tissue properties required for high accuracy treatment planning in order to and exploit the full potential of particle therapy. In addition, in-vivo techniques to determine the actually delivered dose should be developed to provide the information needed to mitigate the effects of remaining uncertainties and errors on treatment quality using planning and re-planning tools.

The future

Both developments, miniaturization of electric components on computer chips and the worldwide implementation of particle therapy, will lead to an increased demand of beam time at ion beam test facilities. With its background in both radiation hardness testing; more than 15 year expertise in particle therapy related irradiation experiments and availability of heavy ion beams, AGORFIRM is ideally positioned to meet this increased demand.

CERN – ISOLDE

Isotope Separation Online DEvice

ISOLDE is a nuclear physics facility which is capable of producing 1,000 radioisotopes from 70 elements: the largest selection available worldwide. Although the core scientific programme at ISOLDE is nuclear physics, the shear variety of isotopes allows for an active programme in other fields, including astrophysics, solid state physics, medicine and biology.

Solid state physics at ISOLDE brings together materials scientists from all over the world who wish to avail of the unique experiments that are possible using radioactive ions. In particular, local information on the atomic scale is possible which allows for insights unavailable elsewhere.

Biochemistry on the role of heavy metals in proteins is also pursued along with an innovative approach to understanding the function of metals such as Cu and Zn in biological systems.

Research in producing innovative isotopes for medicine is also pursued and will increase from 2016 with the inauguration of a dedicated facility for medical isotopes: MEDICIS.

FACTS & FIGURES

LOCATION

FACILITIES

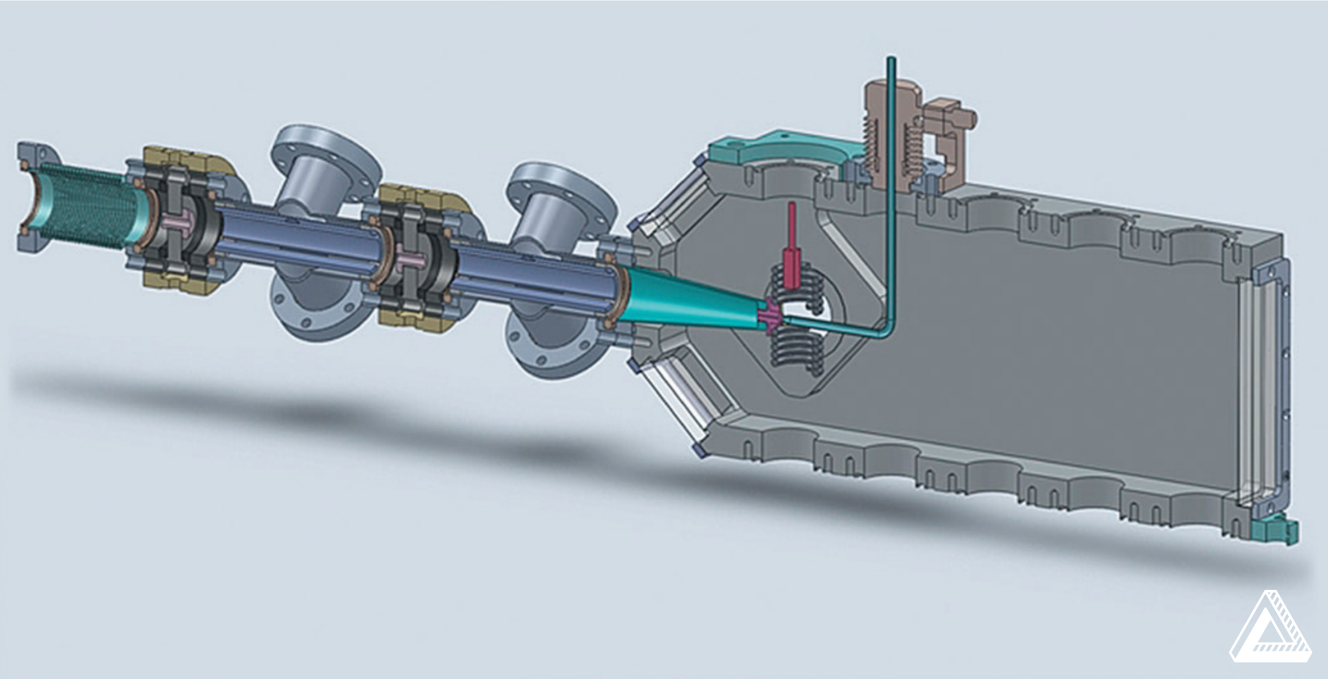
- General and high resolution mass separators
- Low energy and post accelerated beams
- Production of 1,100 isotopic beams from 71 elements.
- Dedicated offline laboratories for solid state and life science

APPLICATIONS

Health & Medicine

Materials Science & Biophysics

Technology Transfer



Schematic of the new experimental chamber capable which will permit the metal-containing proteins at ISOLDE.

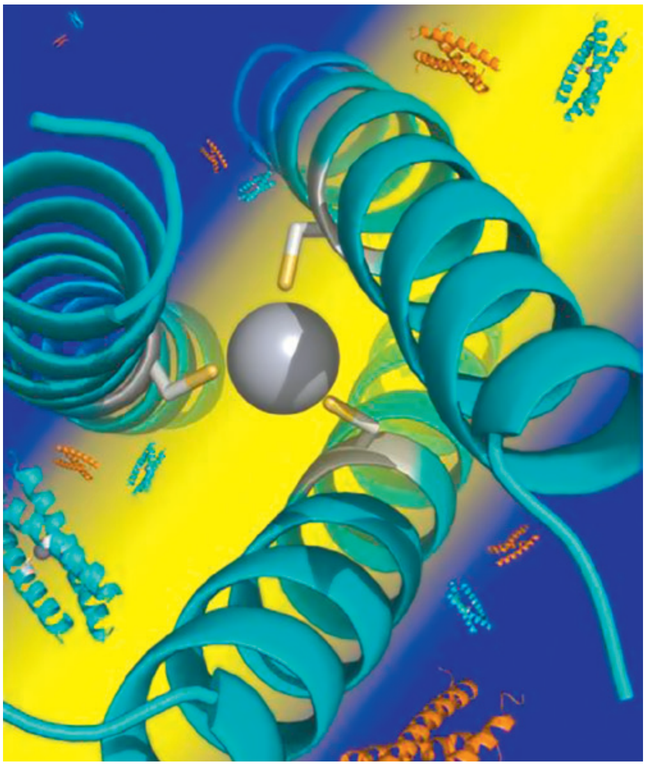
UNMASKING METALS' BIOLOGICAL ROLE

Metals play a role in up to 30% of all biological systems such as proteins etc. However, in spite of this relative ubiquity, the precise role of metals such as Cu, Zn and Mg remains unclear. This is because such metals are often chemically blind to "standard" biophysical techniques.

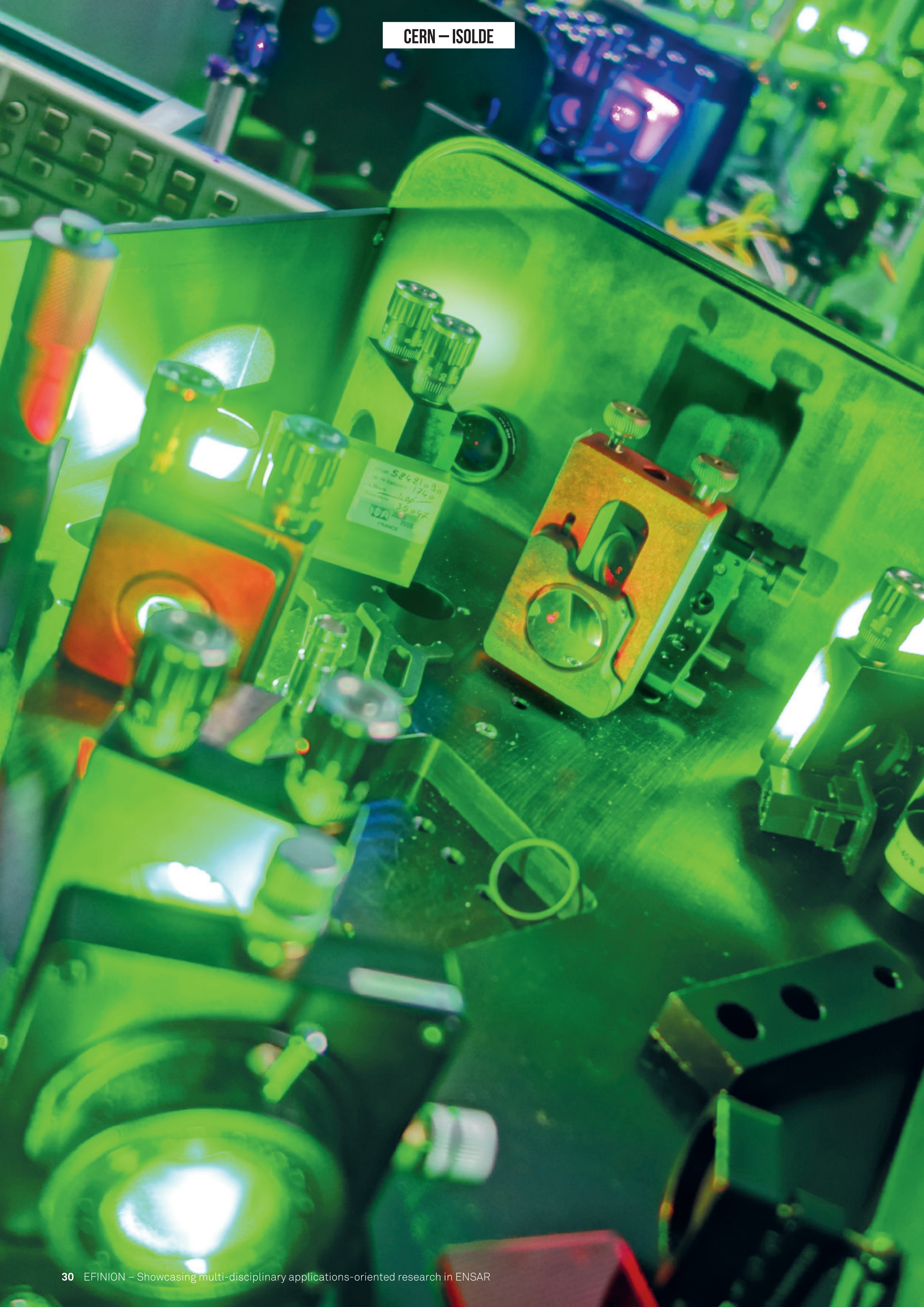
A new approach has now been developed at ISOLDE which promises to revolutionize studies in metallic biochemistry.

A spectrometer capable of hosting liquid samples within a high vacuum will utilise the decay properties of polarised beams of metal ions to reveal the inner workings of metals in biology.

This work has necessitated the development of a unique chamber which allows liquid solutions to be studied within a high vacuum. In addition to the potential scientific output from this new spectrometer, the possibility of developing a new device with wide-ranging applications has attracted investment and support from CERN's technology transfer office.



A metal bound within a protein.



TB ISOTOPES IN MEDICINE

INNOVATIVE WAYS OF DETECTING AND TREATING CANCER

Researchers at ISOLDE are using its unique ability to produce radioactive ions to search for new and innovative ways of detecting and treating cancer. Because of the variety of isotopes it can produce, ISOLDE is able to go beyond the facilities that hospitals presently offer, and explore isotopes which may – in the future – be considerably more efficient in the treatment and detection of cancer, such as Terbium (Tb).

What is so great about terbium?

Terbium (Tb) is the only element in Mendeleev's table offering not only a matched pair but even four clinically interesting radioisotopes with complementary nuclear decay characteristics covering all nuclear medicine modalities: terbium-152 for PET, terbium-155 for SPECT, terbium-149 for α-particle therapy and terbium-161 for therapy with electrons ($\beta-$, conversion and Auger electrons).

Thus, terbium can serve as the "Swiss Army knife of Nuclear Medicine", for fundamental studies of new radiopharmaceuticals and for detailed comparisons of targeted therapy options.

So-called "matched pairs" of a diagnostic and a therapeutic isotope of the same chemical element are particularly valuable since their identical chemical properties assure identical in vivo behaviour, enabling a precise determination and optimization of the radiation dose given to the tumour prior and during treatment. This opens the way for "theranostics", where patients are first given a diagnostic isotope, then, based on the measured patient-specific uptake of the radiopharmaceutical, the optimum therapy option is selected and applied. This type of personalized medicine assures best possible efficacy and minimum side effects since the therapy is tailored to the patient's needs.

Terbium can serve as the "Swiss Army knife of Nuclear Medicine"

LOCATION OF MG IMPURITIES IN SEMICONDUCTORS

THE BASIS FOR FUTURE ELECTRONIC DEVICES

Pure semiconductors are of little practical use: they require small concentrations of impurities to become useable. Knowledge of the *location* of these impurities within the semiconductor crystal allows researchers to predict and explore properties of semiconductors which will be the basis for future electronic devices.

Researchers have recently been able to explore the role of Mg in GaN; a very important semiconductor which is now extensively used for solid state lighting – and the basis for the Nobel Prize in 2014. By better understanding this material and its impurities more efficient devices can be produced, leading to considerable reduction in energy consumption. Understanding impurities in GaN is quite complex.

The unique "picture" given from experiments at ISOLDE allows us to see at an atomic resolution where important impurities reside in the lattice.

ALTO

Accélérateur Linéaire auprès du Tandem d'Orsay

ALTO is located at the Institute of physics, Paris-sud, Orsay. IPN-Orsay has one of the longest traditions in running accelerators for nuclear physics in Europe, surpassing even CERN's first accelerator. Today this tradition continues, with the Linear Accelerator and Tandem at Orsay transnational access facility.

A wide-ranging physics programme is pursued at ALTO in many areas of nuclear physics. However, unique facilities for the study of space electronics in the Van Allen belt and a unique nanoparticle accelerator allow studies in materials science, biochemistry and cultural heritage to be pursued.

The community of scientists working at ALTO numbers about 300 from more than 30 countries.

FACTS & FIGURES

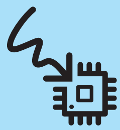
LOCATION

FACILITIES

- 15 MV MP-TAndem
- 50 MeV linear accelerator for production of radioactive ion beams
- ANDROMEDE: Nanoparticle beams
- LINE 320: Irradiation of electronics for space

APPLICATIONS

Health & Medicine

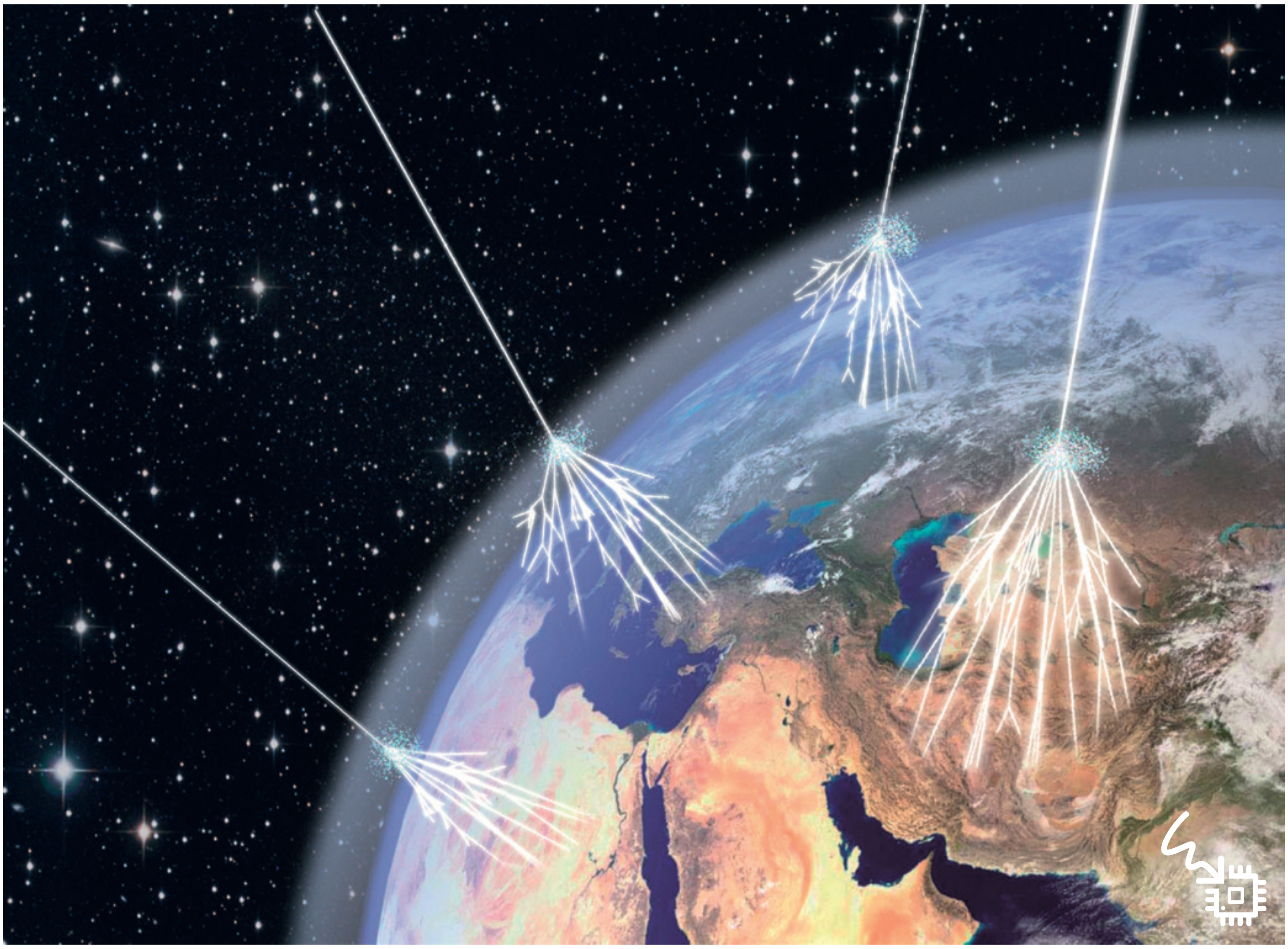


Electronics for Space Industry

Materials Science & Biophysics

SPACE RADIATION SIMULATION

RESCUING THE PLANCK MISSION



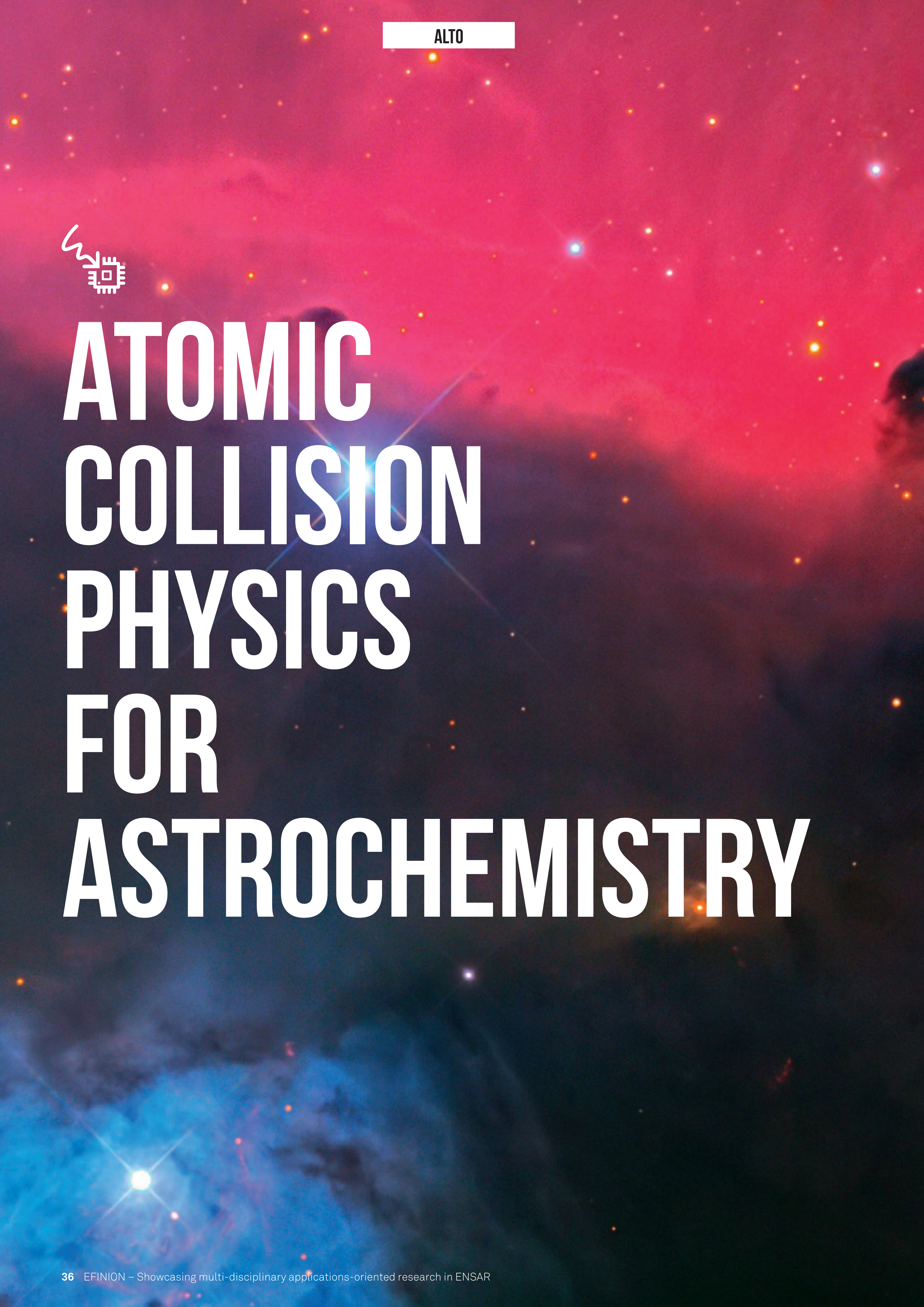
The Van Allen belts are found around any magnetized planet, of which Earth is one, and are caused by the Earth's magnetic field. They extend from about 1,000 to 60,000 km above the Earth's surface and within these belts are found a cocktail of charged particles ranging from electrons, protons to particles such as alpha particles and charged nuclei. They pose a particular threat to satellites which are found in these regions and which need to be shielded against this radiation.

One effective way of combatting this radiation is to use particle accelerators such as ALTO to deliver similar beams such as those found in space in order to improve satellite technology.

At ALTO, a dedicated beamline (320) performs studies in this area using a variety of beams and particles, ranging from protons to heavy ions and with energies from 1 – 100s of MeV.

One significant success story from this beamline was in the characterisation of glitches which beset the PLANCK satellite which was searching for evidence of early light in the universe; by better understanding the effect of proton impacts on the satellite at ALTO, the data from Planck could be corrected and cleaned up to a satisfactory level.

ATOMIC COLLISION PHYSICS FOR ASTROCHEMISTRY



Space contains a multitude of molecules. How are these molecules formed? And what is the underlying chemistry? In order to better understand this, one needs to accumulate a significant data base constituting properties related to nuclear astrochemical processes.

Among these processes, the branching ratio for chemical reactions is paramount. At ALTO, using a molecular beam which is unique in the world, these quantities are measured.

The fragmentation of small molecules which collide with a rest atom is measured. Using inverse kinematics and considerable statistical tools, the branching ratios for chemical reactions which are of astrochemical interest are derived.

TNA USER TESTIMONY

The “Emission Channelling” collaboration

The “Emission channelling” collaboration (see pages 32-33) which performs experiments at ISOLDE is composed of scientists from Belgium, Portugal and South Africa. Since 2010, the Emission channeling collaboration has been awarded 67 days of transnational access to perform their experiments at CERN. Here is just some of the output arising from this access:
- Support for 7 (young and experienced) researchers
- Support for 6 PhD projects (of which two have been completed in this time)

Awards


Dr Lino Pereira presenting his research at the ISOLDE facility, CERN to the King of Belgium and 2013 Nobel Laureate Francois Englert.

Dr Lino Pereira (Tenure track research professor at KU Leuven, Belgium)
- Best student presentation award, 56th Annual Conference on Magnetism and Magnetic Materials (MMM), Scottsdale, Arizona, 30.10.– 3.11.2011, title of contribution: “Lattice location of transition metals in dilute magnetic semiconductors”.
- Runner up in the “Young Researcher for Best Manuscript Competition” (sponsored by Elsevier BV) at the 21st International Conference on Ion Beam Analysis (IBA-21), Seattle, Washington, 23.– 28.6.2013, title of contribution: “Emission channeling studies on a challenging case of impurity lattice location: cation versus anion substitution in transition-metal doped GaN and ZnO”.
- 2014 IBMM prize for early career stage researcher, 19th International Conference on Ion Beam Modification of Materials (IBMM), Leuven, 14.– 19.9.2014, award lecture on the topic “Structure and magnetism of transition-metal implanted dilute magnetic semiconductors”.


Daniel Silva taking data at the ISOLDE facility, CERN.

Daniel Silva
- J.W. Corbett prize at the 27th International Conference on Defects in Semiconductors (ICDS-27), in Bologna, Italy, 21.– 26.7.2013, title of contribution: “Influence of the doping on the lattice sites of Fe in Si”.

Ligia Amorim
- Award for Best Student Oral Presentation at the 17th International Conference on Radiation Effects in Insulators (REI-17), in Helsinki, Finland, 30.6.– 5.7.2013, title of contribution: “Lattice sites of implanted Mg in the group-III nitrides”.


Ligia Amorim exchanging a sample during an experiment.

Currently supported students

Eric Bosne
Since January 2014: PhD student at Instituto Superior Técnico, Universidade de Lisboa (Portugal), topic: “Emission channeling lattice location studies in semiconductors using highly pixellated Timepix detectors”.

Tiago Lima
Since November 2014: PhD student at IKS/KULeuven.

Arnaud De Coster
Since October 2014: Masters student at IKS/KULeuven.

JRAs & NAs

Each work package has a nickname, as FISCO or ARES, and corresponds to a specific activity enhancing the nuclear physics development in Europe.

Joint Research Activities (JRAs) are meant to be innovative and explore new fundamental technologies or techniques underpinning the efficient and joint use of the participating research infrastructures.

JRAs are in general relevant to more than one facility and rely on strong participation of the European university groups.

These activities involve all facets of operation of an accelerator facility starting with the improvement of ion sources to increase the intensity and the energy of stable and radioactive ion beams for experiments (ARES). This goes hand in hand with target technology, which aims at increasing the intensity and reliability of the delivered exotic radioactive ion beams for the operating European facilities (ActILab). These two activities are supplemented by an activity to improve the low-energy beam preparation and manipulation and to go beyond the state-of-the-art in spectroscopic tools used in studies with radioactive beams (PREMAS).

Experimenting at such facilities requires development of new detection materials and detection systems (INDESYS), general platforms for both simulations of current and future detector set-ups (SiNuRSE) and the development of modern theoretical tools for describing and interpreting experimental results as well as pointing the way ahead for experimental projects (THEXO). In addition, a key activity aims at integrating the laboratories in Central and South-Eastern European countries with those elsewhere in Europe, by developing novel technologies and methodologies of universal benefit that could be used both at these laboratories and elsewhere (EWIRA).

These developments will give a strong impetus to these emerging laboratories and their communities and enhance their external use. Particular importance is attributed to all work, which might lead to multidisciplinary or industrial applications.

Networking Activities (NAs) foster a culture of co-operation between the participants in the project, the scientific communities benefiting from the research infrastructures, industries and other stakeholders, and to help developing a more efficient and attractive European Research Area.

ENSAR NAs have been set-up with specific actions to strengthen the communities' coherence around certain research topics (nuclear astrophysics - ATHENA), to pool resources and to provide instruction courses to users (EGAN - Gamma and Ancillary detectors Network).

They foster future cooperation towards achieving high-intensity stable beams (ECOS) and radioactive ion beams (EURISOL NET). They promote foresight studies for new instrumentation and methods and stimulate complementarities. They ensure a broad dissemination of results and stimulate multidisciplinary and application-oriented research at the Research Infrastructures (EFINION).

In addition to these five specific networks, the managing network FISCO ensures a smooth running of the integrating activity as a whole in all aspects of technical, scientific, financial, administrative, contractual and legal activities. It is also stimulating dissemination of knowledge and outreach activities.

AFTER ENSAR

After ENSAR there will be ENSAR2, hopefully!

Our community of nuclear scientists is eager to continue the European venture. Nuclear Physics is European by nature, even International since the very beginning of its existence, at the dawn of XXth century. Europe is the ideal environment for its development.

The European Commission started in 2014 a new framework programme, meaning a new funding campaign for scientific projects. This programme is called HORIZON2020 and will last until 2020. This programme is punctuated by project calls at certain dates every year. The scientific community answers to these calls proposing new collaborative or individual projects, selected on their excellence.

The nuclear physics community is planning to propose a new ambitious HORIZON2020 project to the European Commission in 2014, with a possible financial support from 2015 to 2019.

This new project is called ENSAR2. It will present new activities in comparison to ENSAR. In particular, there will be a work package dedicated to innovation, partnerships with industry and transfer of knowledge.

IMPRESSUM

Publisher: EFINION (European Forum for Innovative applications of Nuclear ION beams and tools), http://www.ensarfp7.eu/projects/efinion
Project director: Sotirios V. Harissopulos – Coordinator: Karl Johnston
Contributors: GSI: Tobias Engert, Christophe Scheidenberger – GANIL: Marek Lewitowicz, Ketel Kurzo – INFN: Dr. Valentino Rigato – JYFL: Ari Virtanen, Timo Sajavaara – KVI: M.A. Hofstee – ISOLDE: Karl Johnston, Bruce Marsh – ALTO: Fadi Ibrahim, Marin Chabot
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