Legnaro National Laboratories
LNL

Founded in 1968, the Legnaro National Laboratories are an international center for research in Nuclear Physics and in Nuclear Technology Applications.

The Laboratories

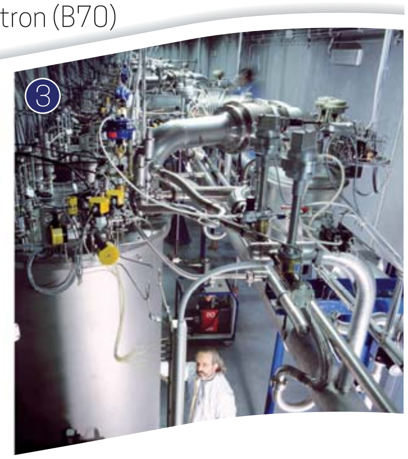
www.lnl.infn.it

The main strengths of the Laboratories are in the development and operation of particle accelerators, gamma-ray detectors as well as particle detectors.
LNL currently employ 250 people among researchers, engineers, technicians and administrative personnel.

The particle accelerators

LNL are equipped with three large scale accelerators:

1. Tandem (XTU)
2. Cyclotron (B70)
3. Linac (PIAVE-ALPI)



Moreover, LNL host two small accelerators (CN and AN2000) mainly used for material science research, health and radiobiology studies and environmental physics.

Detectors for studying nuclear structure and reaction dynamics

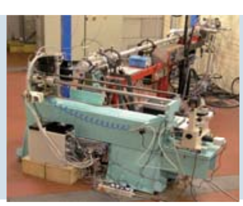
- **GALILEO:** an array of high-resolution gamma-ray detectors to study nuclear structure.

- **PRISMA:** a large acceptance magnetic spectrometer to study nuclear reaction mechanisms.

- **GARFIELD:** a charged particle detector array to study nuclear reaction dynamics

Technological development and applied Nuclear Physics

- **Radiobiology and microdosimetry** for studying the interaction of ionizing radiation with matter and the damage following radiation exposure of living cells or semiconductor devices.



- **Development of new accelerators** and detectors for applied science spanning from nuclear medicine, to the monitoring of environmental radioactivity or cultural heritage study.

LHC

Researchers from LNL contribute to major LHC experiments like CMS and ALICE.

Supercomputing

LNL host a TIER-2 GRID node. GRID is the supercomputing network built to collect, sort and store data produced by LHC experiments at CERN in Geneva.

Nuclear fusion

LNL participate in the greatest international projects for the development of nuclear fusion reactors .

The National Institute for Nuclear Physics

INFN
Istituto Nazionale di Fisica Nucleare

A scientific and economic resource of international prestige.

Who are the physicists?

Physicists are a large community of scientists trying to discover the hidden mechanisms of the Universe, investigating the fundamental principles of Nature.

To achieve their goals they build sophisticated devices and machinery using state of the art technology which contributes to carrying out the most precise measurements known to this date.

Physicists measure the smallest and the largest existing quantities.

Among the various phisicists' inventions, let us mention the World Wide Web, the Nuclear Magnetic Resonance and the largest machine in the world: the 27 km long LHC accelerator in Geneva.

The National Institute of Nuclear Physics promotes, coordinates and performs scientific research in the fields of particle physics, nuclear and astroparticle physics, as well as technological developments relevant to these fields.

INFN overview

- 5000 researchers (2000 internal and 3000 associated University personnel).
- 1300 young scientists (undergraduates, phD students and post-docs).
- An annual budget of about 270 milions euro.
- 2500 yearly scientific publications.
- Qualifying presence in the key global scientific enterprise: INFN scientists manage major important international scientific programs.
- For every 10 € of investment, almost 11 € will be returned in international orders to Italian companies. About 150 Italian companies received orders from CERN during the construction of the LHC accelerator.
- The evaluation of the Institute is accomplished by the International Evaluation Committee composed of internationally renowned experts with scientific and economic expertise.

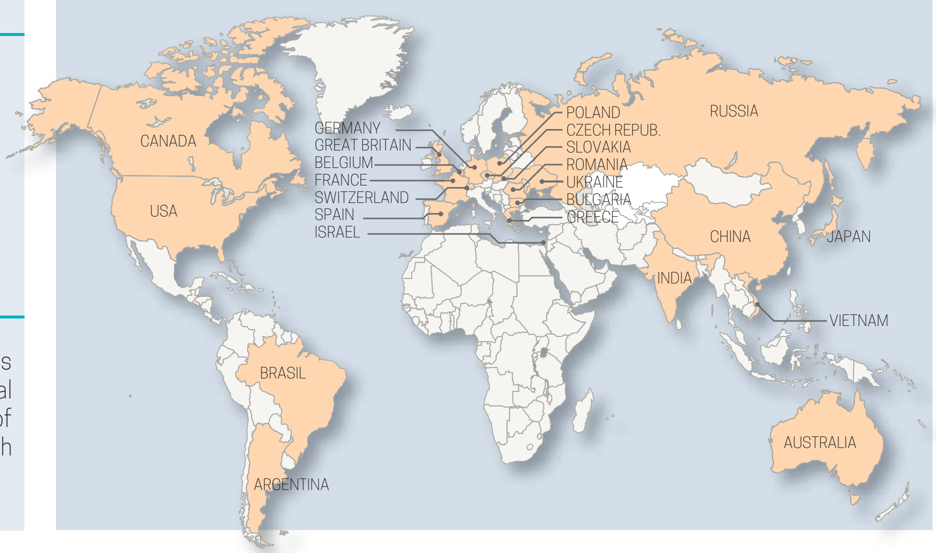
INFN is active in 16 Italian Regions with:

www.infn.it

- 4 large National Laboratories
- 20 departments
- 10 associated groups
- 1 international consotium
- 3 national centers and schools

- For years INFN has performed cancer therapy with protons at LNS laboratory.
- INFN is co-head of CNAO in Pavia, the first center of cancer hadron therapy in Italy.
- INFN is at the forefront of physics applications to cultural heritage and Information Technology.

- Collaboration programmes with 24 countries



Accelerators for new materials and (micro) devices

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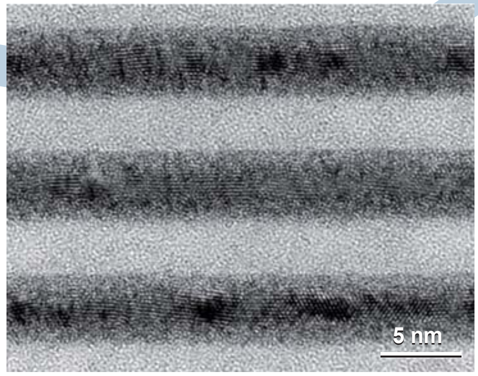
Technologies for particle accelerators - developed at Legnaro National Laboratories for basic research - are applied in the analysis of material composition and in production of innovative micro and nano devices.

Nano-structured materials

By bmbarding materials with heavy ions, it is possible to modify their surface properties, drastically reducing the roughness, thus obtaining smoothed surfaces at atomic level.

Using this advanced technique it is possibile to synthesize thin film coatings with optical and mechanical innovative properties.

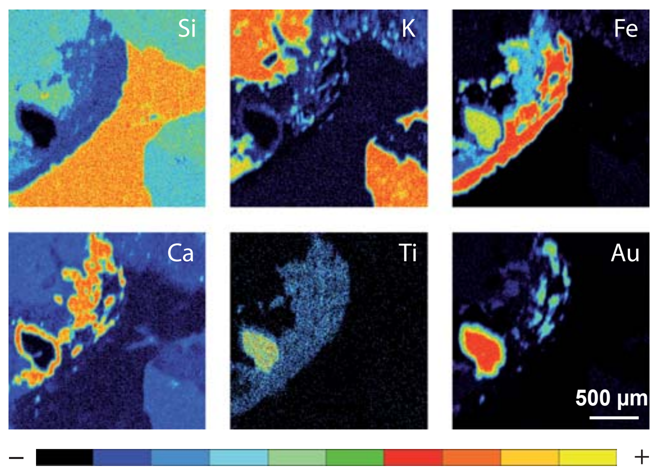


Tens of atoms thick coating is produced in our laboratory and is controlled at atomic scale with the most sophisticated analytical techniques.
The detailed coating picture shows particulars smaller than 5 nm obatined by using electronic transmission microscopy.

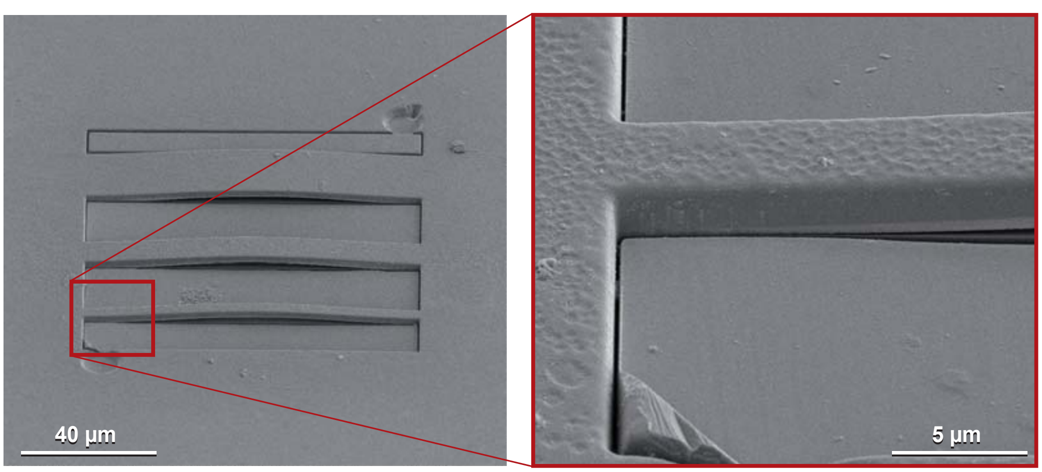
Material analysis

The interaction products between ions and solid matter are analyzed in depth in order to understand the composition of the material surface.

Proton and alpha particle beams with spatial dimension of ~ 1 x 1 μm and with an energy near MeV allow to study the properties of the materials used in nuclear physics research, semiconductor physics, material science, environmental physics, geology, solid state physics and optoelectronics.



Microdevices



Focalized ion beams are used in the preparation of electro-mechanical microdevices on diamond and other materials.

The image shows Diamond microsensor prototypes obtained using the ion beam writing technique.

AGATA
Advanced Gamma Tracking Array

Istituto Nazionale di Fisica Nucleare

A crystal sphere for exotic nuclei.

The AGATA collaboration

The AGATA project is carried on by European collaboration: 43 institutions in 11 different countries share the efforts to build state of the art technological and scientific masterpiece.

The detector is intended to be employed in experimental campaigns at the radioactive and stable beam facilities all across Europe (LNL, GSI, GANIL).

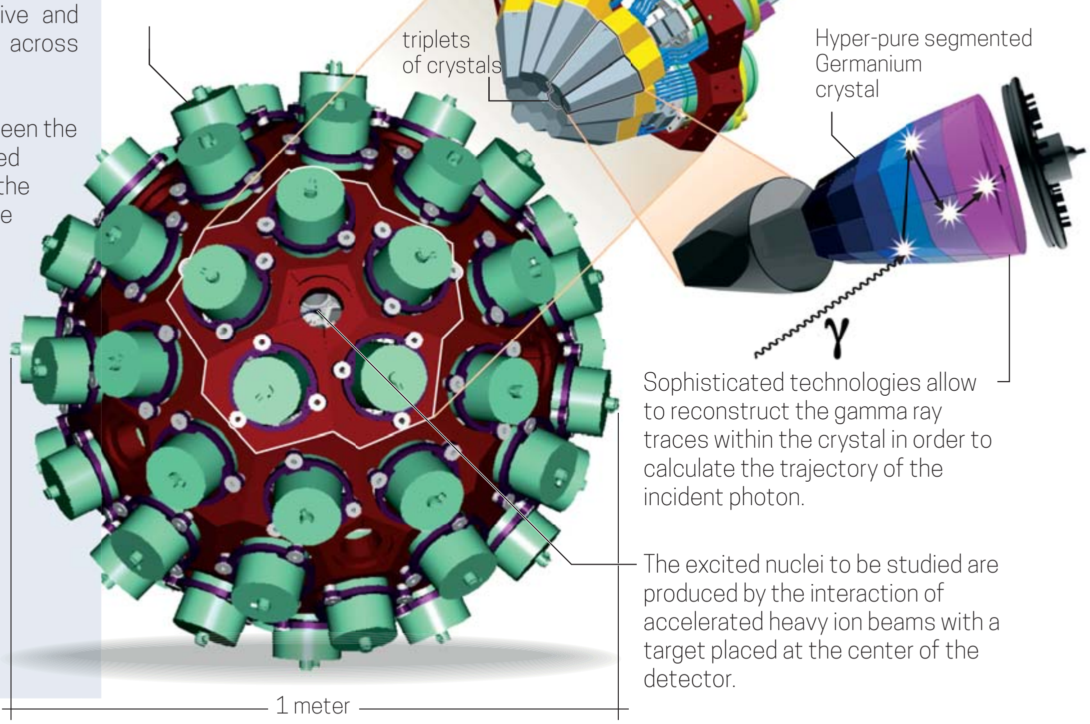
Among the others, LNL has been the first host site for the so-called "demonstrator": a subset of the entire device used to test the project feasibility and its innovative capabilities.

AGATA
ADVANCED GAMMA TRACKING ARRAY

The AGATA Detector

AGATA (Advanced Gamma Tracking Array) is a new generation of gamma ray detector.

It is a hollow sphere composed of 180 hexagonal crystals of hyper-pure Germanium grouped into triplets



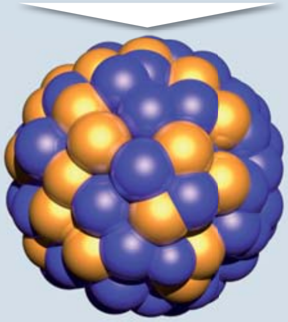
Sophisticated technologies allow to reconstruct the gamma ray traces within the crystal in order to calculate the trajectory of the incident photon.

The excited nuclei to be studied are produced by the interaction of accelerated heavy ion beams with a target placed at the center of the detector.

What is it used for?

Nuclear Physics:

to study the properties of the nuclear force, focussing on the "exotic" features of nuclei far from the valley of beta stability.



Astrophysics:

to investigate what happens in the forge of the stars. To study in the laboratory the processes that rule the Universe.

Future applications

Medical Imaging :

the developed technology will allow diagnostic tests, like PET, to be more accurate and faster, requiring a lower dose of radiopharmaceuticals.

Homeland Security:

it will make the search for radioactive materials more effective, for instance in goods transportation or at the borders.

PRISMA
the heavy-ion spectrometer

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PRISMA is

one of the world largest magnetic spectrometers for heavy ion reaction experiments.
Thanks to its strong magnetic field its is capable of spreading the heavy ions produced in nuclear reactions along its 100 cm wide focal plane.
It is equipped with a particle detection system which allows the reconstruction of the ion trajectories as well as the determination of their charge, mass and energy.

Nuclear Physics with PRISMA

PRISMA studies the nuclei produced in heavy-ion nuclear reactions. During these collisions a certain number of neutrons and protons are exchanged, thus creating other nuclei, both stable and radioactive.

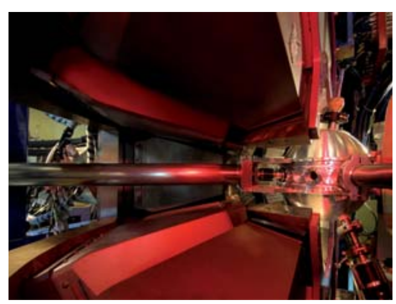
In order to study and understand the features of the physical processes involved, the ions produced are identified by the PRISMA detectors in terms of nuclear charge, mass and kinetic energy.

PRISMA can be also used in combination with high efficiency gamma-ray detector arrays. In these cases it is used to identify the produced nucleus so to study its structure through the spectroscopy of the gamma rays detected simultaneously.

PRISMA highlights

- great momentum acceptance (±10%)
- large solid angle coverage (80 msr)
- excellent mass resolution (1/300)
- excellent energy resolution (up to 1/1000)
- ion track reconstruction capability
- coupling with ancillary detectors like gamma-ray arrays, light or heavy charged particle detectors or neutron detectors
- the spectrometer can rotate around the beam axis allowing to select the sensitive angular range according to the reaction kinematics

further info: www.lnl.infn.it/~prisma



PRISMA can exploit the heavy-ion beams provided by the Tandem-Alpi-Piave accelerators as well as the radioactive beams produced by the SPES facility.

SPES
Selective Production of Exotic Species

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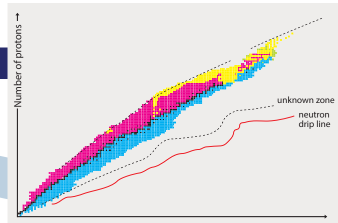
It is the project of an infrastructure for the production of radioactive ion beams at LNL.

Fundamental Physics

Research on exotic nuclei, i.e. nuclei that do not exist naturally on the Earth but are produced in the late stages of star evolution.



■ Stable Nuclei.
Unstable nuclei known. The different colors represent different characteristics of the nuclei, on which depends the way they decay

SPES Project and its four chances

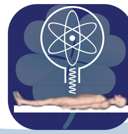
SPES (α)
The core of the project is the high intensity cyclotron with energy up to 70 MeV.

SPES (β)
Will provide re-accelerated radioactive ions for nuclear physics experiments.

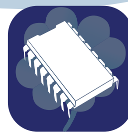
SPES (γ)
Will produce experimental radioisotopes for nuclear medicine.

SPES (δ)
Concerns the realization of an intense neutron source for the development of IV generation nuclear reactors and for medical and material science applications.

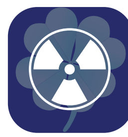
Applications



Biomedicine, for the production of innovative radionuclides to be used in diagnostics and therapy

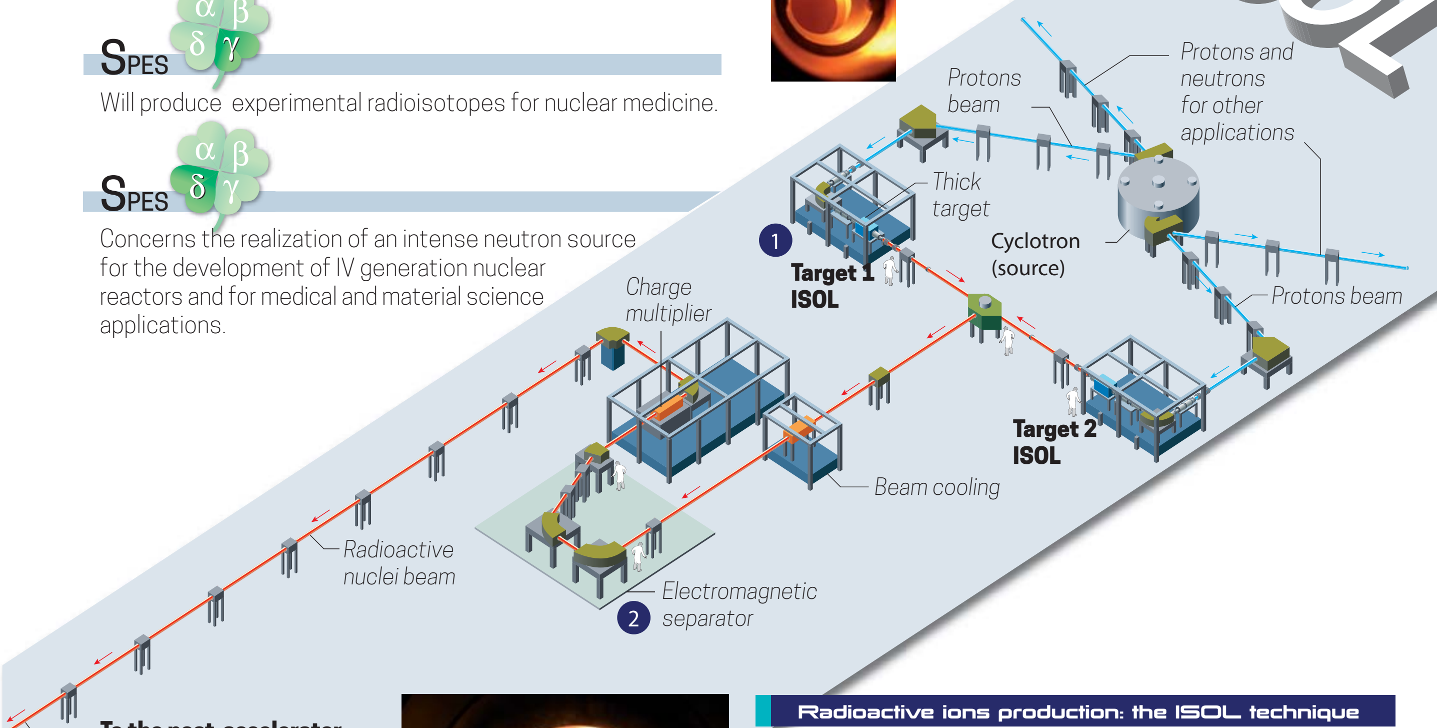


Material sciences, for studying new materials and the effects of neutrons on electronic components with applications in avionics, transport and information technology.



Energy, for the development of fourth generation nuclear reactors.

Isol target at 2000 °C



Surface ionization source.
Terminal part of the Isol target.

Radioactive ions production: the ISOL technique

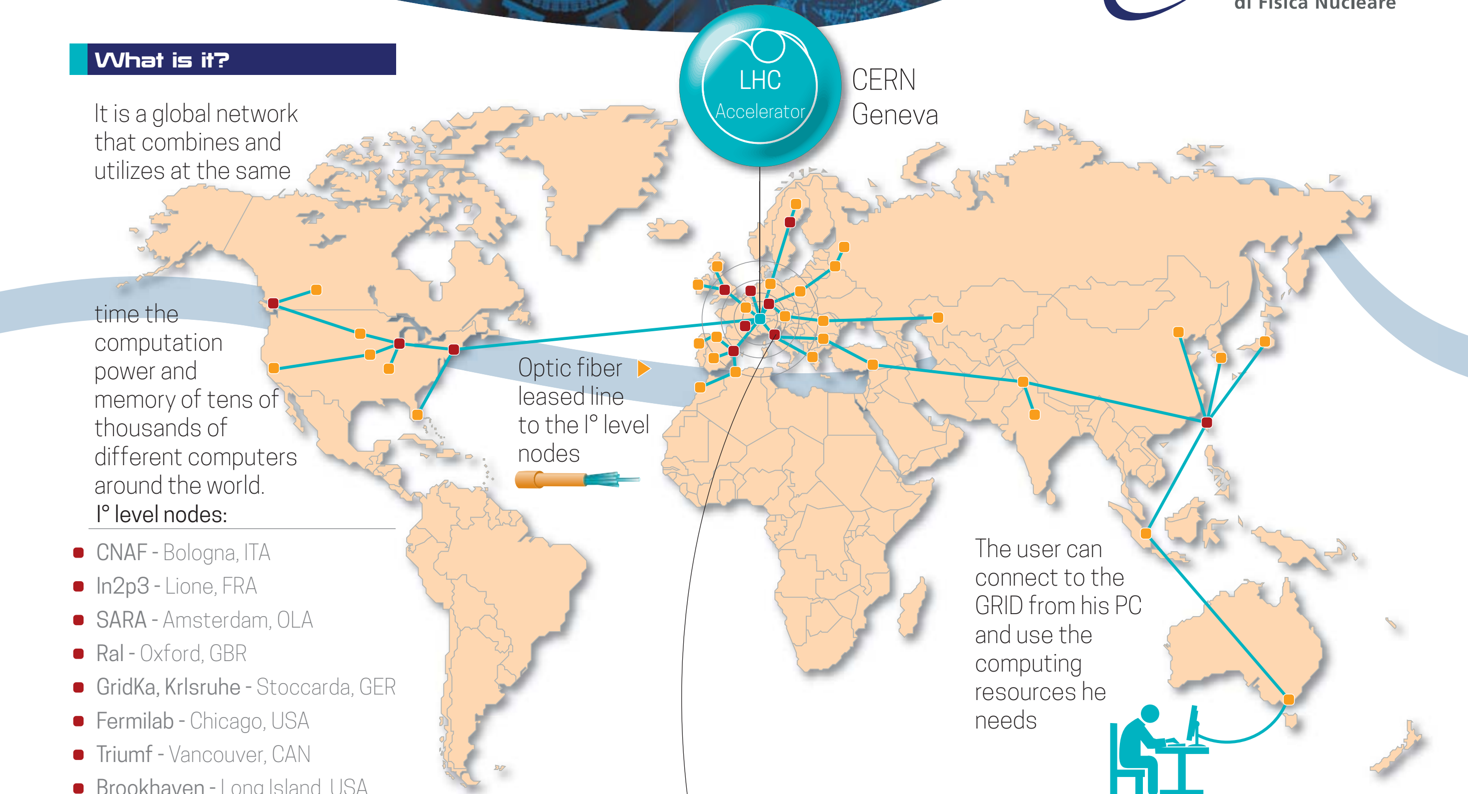
1. The particles are produced in a thick target, from which they are extracted by evaporation at high temperature.
2. The different nuclear species are separated by an electromagnetic device and injected into a post-accelerator which provides the necessary energy for the experiments.

GRID the global network

Istituto Nazionale di Fisica Nucleare

What is it?

It is a global network that combines and utilizes at the same time the computation power and memory of tens of thousands of different computers around the world.



I° level nodes:

- **CNAF** - Bologna, ITA
- **In2p3** - Lione, FRA
- **SARA** - Amsterdam, OLA
- **Ral** - Oxford, GBR
- **GridKa, Krlsruhe** - Stoccarda, GER
- **Fermilab** - Chicago, USA
- **Triumf** - Vancouver, CAN
- **Brookhaven** - Long Island, USA
- **Nordic** - SVE-FIN-NOR
- **Pic** - Barcellona, SPA
- **Assc** - Taiwan, CIN

140 computing center in 33 countries

More than 10.000 users using the GRID

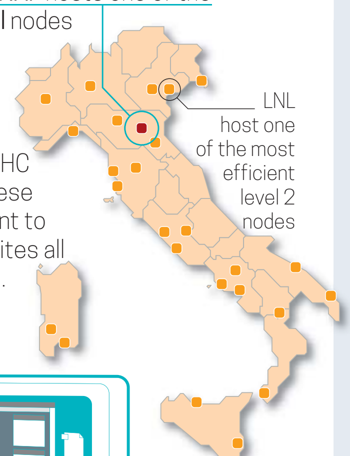
Computing power is similar to 100.000 computers

What is GRID for?

It allows scientists to tackle very complex problems; how to understand the evolution of the Universe after the Big Bang, the global warming effect, the search for drugs against serious diseases such as malaria or cancer.

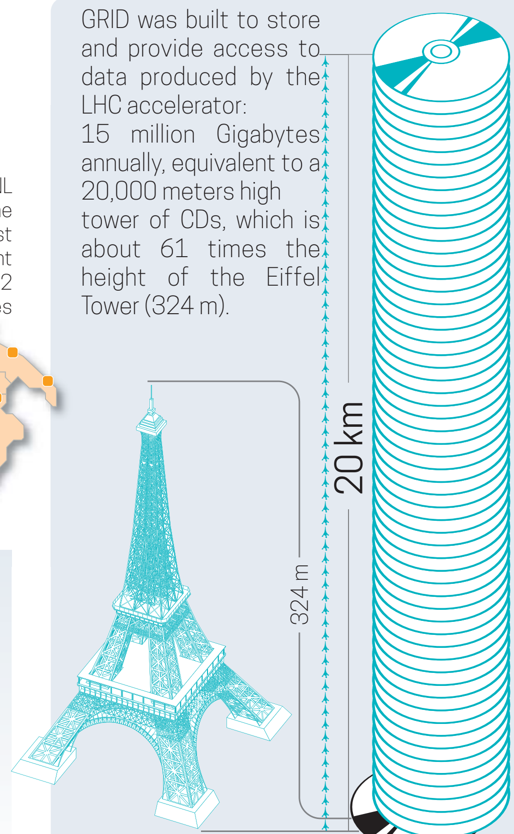
The Italian role

The Institute for Nuclear Physics is one of the main promoters of the project . In Bologna the CNAF hosts one of the eleven first-level nodes of the GRID. These nodes receive directly data produced at CERN by the LHC experiments. These data are then sent to different other sites all around the world.



Storage capabilities

GRID was built to store and provide access to data produced by the LHC accelerator: 15 million Gigabytes annually, equivalent to a 20,000 meters high tower of CDs, which is about 61 times the height of the Eiffel Tower (324 m).



INFN and Nuclear fusion: IFMIF

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The materials used for the construction of nuclear fusion reactors will be exposed to a massive flow of high energy neutrons, this will cause much higher radiation damage in comparison with what happens today in fission reactors.

The purpose of the project

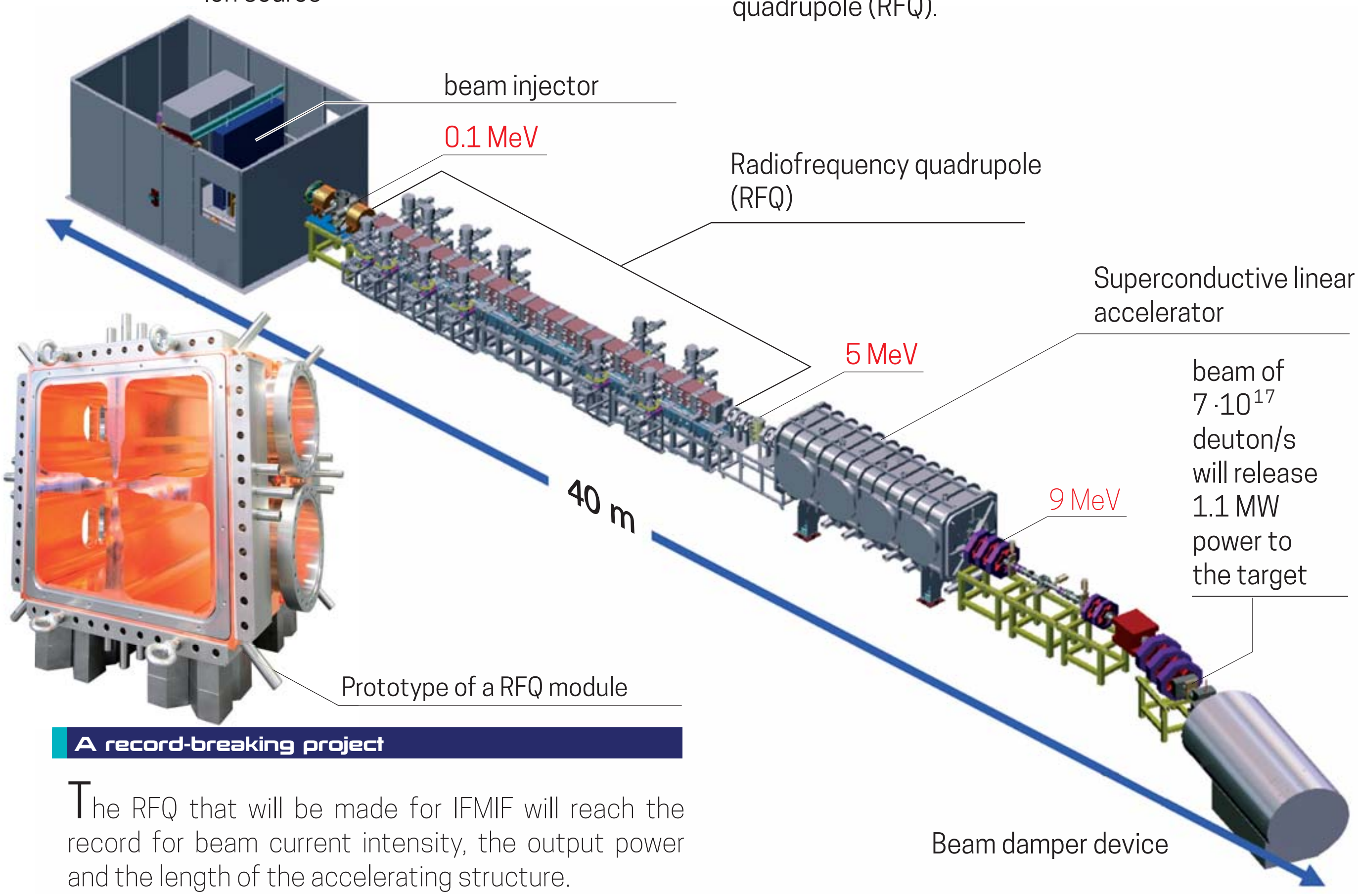
It is necessary to test the material properties under these extreme conditions in order to predict their behavior inside the future fusion reactors. With this purpose in mind, the international project IFMIF (International Fusion Materials Irradiation Facility) was established. A high intensity charged particle beam (up to 10^{17} deuterons/s) will be used to generate an intense neutron beam that will irradiate the materials under study.

The international collaboration

The preliminary phase of IFMIF derives from a collaboration between Europe and Japan, where Japan provides the infrastructure in Rokkasho, while Europe builds the accelerator and the high-tech equipments.

INFN role

INFN is responsible for carrying out the main accelerating structure - the radio frequency quadrupole (RFQ).



A record-breaking project

The RFQ that will be made for IFMIF will reach the record for beam current intensity, the output power and the length of the accelerating structure.

The Italian collaboration

The Italian collaboration is composed by: LNL, with their twenty years experience in RFQ field and INFN Padova, Torino and Bologna departments with their sophisticated mechanical equipment and engineering skills. Some italian companies are also involved.

Physics for Health

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Medicine advances thanks to the research developments in basic physics.

Diagnosis

The main techniques for diagnostic imaging are:

- **Positron Emission Tomography (PET)**, in which a slightly radioactive liquid is injected into the patient and absorbed by the cells with increased metabolic activity, such as cancer cells. This liquid emits positrons which annihilate with electrons of the human body producing two gamma rays. These gamma rays are detected allowing to localize the areas with the highest metabolism.
- **Nuclear Magnetic Resonance (NMR)**
  it utilizes the interaction of a magnetic field with the nuclei within the atoms of the human body.
- **Computed Tomography (CT)**
  it uses X-rays to obtain three-dimensional images of the investigated area.

Among the INFN projects

- The MID interferometer for non-invasive measurement of iron accumulation in liver of patients affected by serious forms of anemia
- Magic 5 is devoted to the development of software that helps the specialist in the diagnosis of pathologies such as Alzheimer and lung or mammary cancers.
- Ecorad is an integrated echo-scintigraphic system to obtain morphological and functional images of the human body.

Cancer theraphy

Particle accelerators developed for research in fundamental physics proved to be useful tools for the treatment of tumors by using radiotherapy and hadroteraphy.

CATANA is the first and only Italian center for proton therapy of ocular melanoma. It has been active since 2002 at INFN LNS in Catania. Since then, over 300 patients were treated with a totl amount of 95% illness remission.

CNAO in Pavia is the National Center of Oncology Hadrontherapy (CNAO). It has been active since November 2011. The CNAO synchrotron, which produces and accelerates particles useful in the treatment of cancer cells, has been designed and realized by INFN.
CNAO is one of the four centers in the world where Carbon ions are used for therapy. The energy of the particle beams is enough to enable the treatment of tumor cells located deep inside the human body. Up until now, few hundred of patients were treated with protons or Carbon ions.

BNCT. At Legnaro National Laboratories (LNL) a feasibility study for the production of a neutron beam for radiobiological studies and the treatment of some cancer pathologies is currently underway.

Physics for
Cultural Heritage and Environment

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Physics meets art and explores its secrets with techniques revealing the chemical composition of an art piece, dating it back to almost fifty thousand years ago.
Ion beams accelerator techology, developed for basic research, now find applications in the framework of cultural heritage and environment.

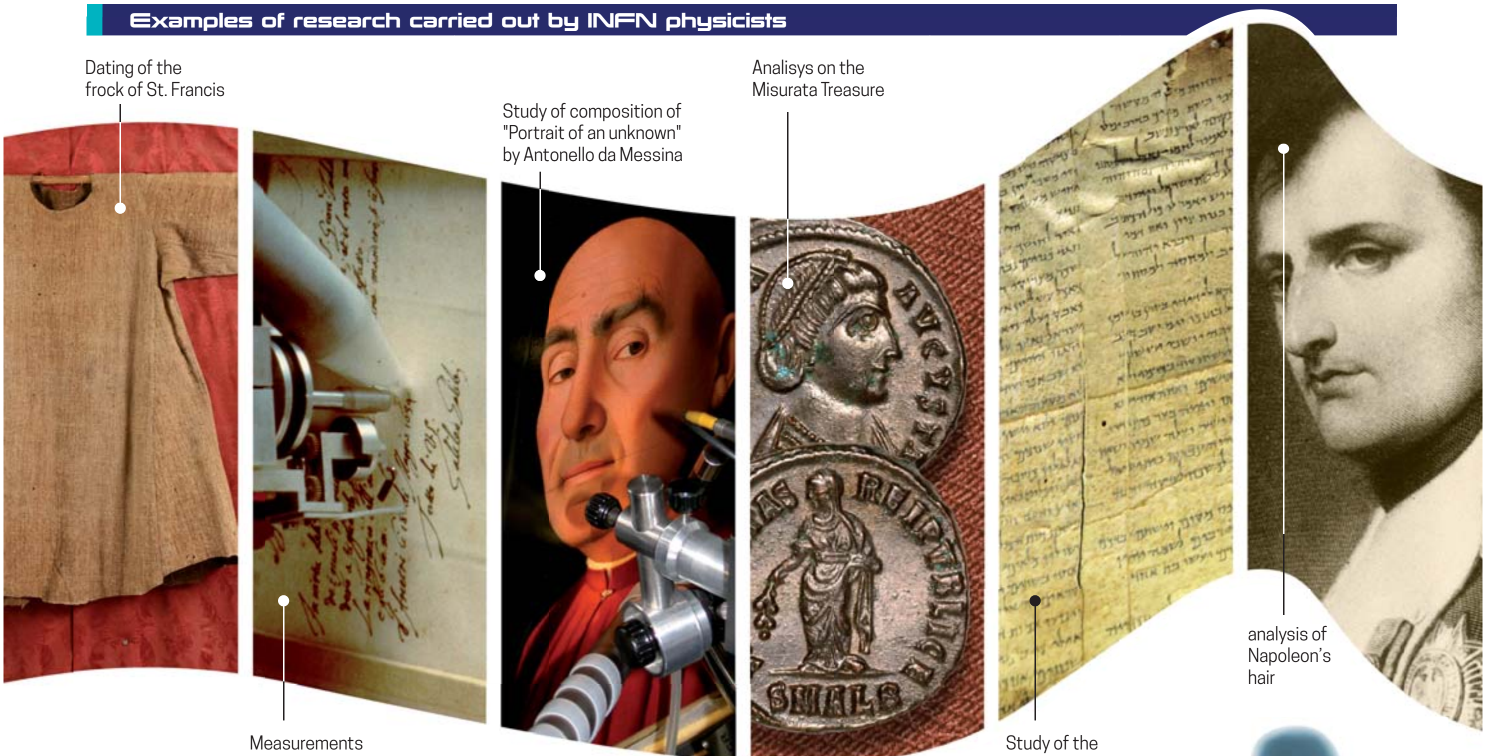
INFN facilities

LABEC Cultural heritage Laboratory in Florence

LANDIS Non destructive Analysis Laboratory at the South National Laboratories in Catania

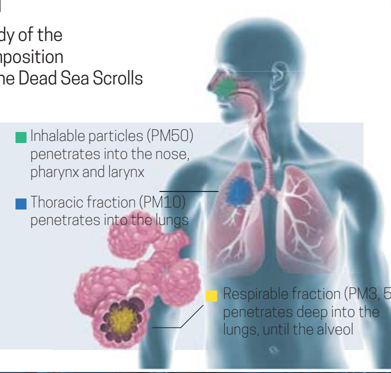
AN2000 The micro-beam line hosted by the AN2000 accelerator at LNL is dedicated to **Particle Induced X-ray Emission** measurements for determining samples elemental composition.

Examples of research carried out by INFN physicists



In the environmental field, nuclear technologies are employed to analyze the atmospheric particles (fine particles) or the presence of radioactivity in the materials.

The particulate matter (PM) is classified according to the size of the aerosol. For instance, PM 10 indicates the particulate with a less than 10 microns diameter.



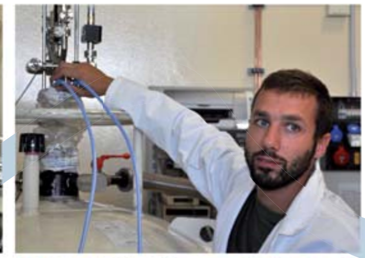
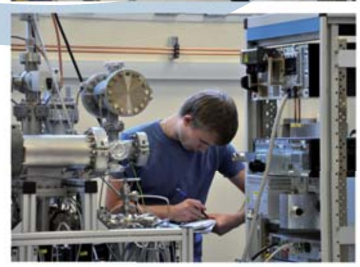
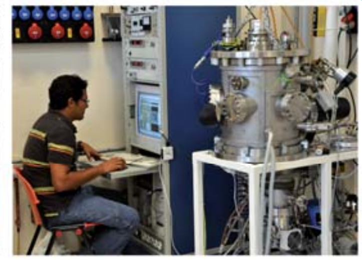
High Level Training @ LNL

INFN
Istituto Nazionale di Fisica Nucleare

Studying, working and conducting research at Legnaro National Laboratories

The aim of the training

Studying and conducting research at the National Laboratories of Legnaro means:
- working on major projects in nuclear, subnuclear and astroparticle physics;
- developing nuclear technology for energy, health and the environment;
- collaborating with Italian and international universities and research centers;
- availability of laboratories, instrumentation and cutting-edge technologies such as particle accelerators, radiation detectors, instruments for material analysis, physical, chemical and computing laboratories, mechanical and electronic workshops.




Training paths

The opportunities to carry out studies and research activities at LNL are manifold:
- Scholarships for graduates with technical education.
- Bachelor and Master thesis (with the possibility to benefit of scholarships).
- PhD thesis.
- Second level master.
- Postgraduate scholarship in scientific and technical disciplines, and also in administrative management.

The laboratories also provide training courses for students in High Schools and Universities:
- Training courses for students of high school (2nd degree).
- Training courses for University students (3rd year degree and master degree courses).

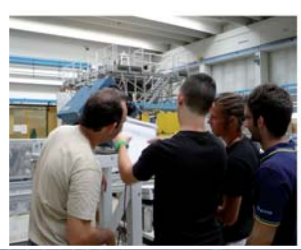
In figures

LNL host about 50 high school students in ten different research teams every year.

Researchers involved in LNL activities advise every year an average of 30 students coming from diferent Univerisites for their thesis.

Young people are deeply involved in the experiments and are the hope of LNL for the coming future.






MASTER @ LNL in

Surface Treatments for Industrial Applications

INFN Istituto Nazionale di Fisica Nucleare

The master was created for transferring the technologies developed at LNL in the research activities with particle accelerators to the industry.

The Master in Surface Treatments for Industrial Applications, active since the 2002-2003 academic year, is a Master of University of Padua, in cooperation with LNL.

Topics

The aim is to train specialists that, upon completion of the master, can apply the most advanced technologies of Plasma Engineering, chemistry and electrochemistry, metallurgy and diagnostics of surfaces, to different market sectors.

High-vacuum and Ultra-high-vacuum.

Vacuum technology is pivotal in a large number of processes of thin film deposition and ultra-cleaning of the surfaces.

DPVD and CVD Deposition Techniques

The physical vapor depositions (PVD) and chemical vapor depositions (CVD) allow to deposit thin films to improve the properties of the original material like wear and corrosion resistance .

Functional and decorative protective coatings.

The thin films deposited by CVD and PVD techniques can have endless applications such as making the material more resistant to corrosion or wear, varying the electrical conductivity or modifying the ability to bind the cells (as in biomaterials).

Tools for surface analysis

X-ray diffractometer, electron microscopy, EDAX spectroscopy, UV-visible spectrophotometer are only some of the analysis tools allowing to study the microstructure of the materials, the knowledge of which is necessary to improve the material properties.

Automation and CAD 3D design

The master trains specialists with expertise for designing and implementing cutting-edge machinery.

Surface treatments have great applicability: from tribological applications to corrosion protection of metals; from applications for the packaging industry to coatings against liquid metal embrittlement for high intensity targets for the production of radiopharmaceuticals.

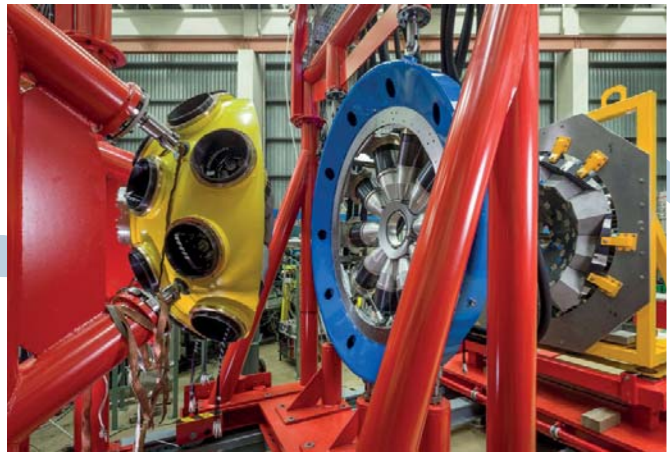
GALILEO

An apparatus for gamma spectroscopy at high resolution and high efficiency.

GALILEO

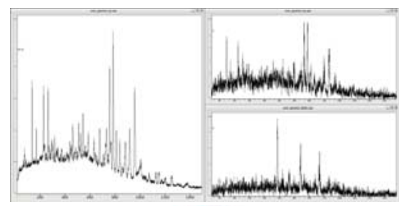
Galileo is a 4π high-resolution gamma-ray spectrometer.

The decay of excited nuclei produced in nuclear reactions is characterized by the emission of specific gamma-rays whose energy, direction and multiplicity can be related to the structure of the emitting nucleus. GALILEO is used to measure those gamma-rays with very high precision and efficiency in order to provide precise spectroscopic information.
The system can be complemented with different ancillary detectors like EUCLIDES for measuring light-charged particles or Neutron Wall for fast neutrons.



GALILEO and its ancillary detectors

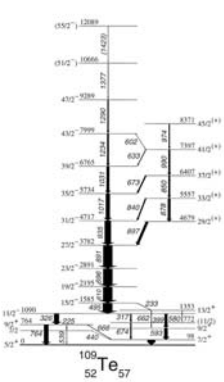
In its final configuration GALILEO will use: thirty Germanium (Ge) tapered detectors together with their anti-Compton shields and ten triple clusters of High-Purity Germanium (HPGe) detectors. GALILEO is built using existing detectors from GASP and EUROBALL arrays and exploits state of the art electronics developed for the AGATA project.



The EUCLIDES detector is a 4π silicon ball, composed of 40 silicon telescopes which are assembled in a compact sphere of 8 cm radius. It is installed inside the reaction chamber at a vacuum of 10^{-5} mb. EUCLIDES detects and identifies light-charge particles emitted in fusion evaporation reactions and is used to select reaction channel.

Neutron Wall is a 1π solid angle apparatus composed of 50 detectors which are assembled in a compact sphere of 510 cm radius. These 50 detectors are liquid scintillators with the capability of discriminating between neutron and gamma-ray induced signals. Neutron Wall detects and identifies neutrons emitted in fusion evaporation reactions with energies that span from 100 keV to 10 MeV and is used to select the reaction channels of interest.

Gamma-ray spectroscopy with GALILEO



The goal of GALILEO is to address hot topics in Nuclear Structure through high resolution gamma-ray spectroscopy. This is done using stable beams at LNL and radioactive ion beams from SPES. The development of efficient gamma-ray arrays is important for the extension of the nuclear structure studies towards the most "exotic" nuclei that are produced with small cross-sections.

- Study of the features of the Nuclear Force
- Study of nuclei at the limits of spin and isospin
- Study of the evolution of magic shells
- Study of neutron-proton pairing in nuclear matter
- Probing collective and single particle features of Nuclear matter