INFN-LNS: an European Research Infrastructure for nuclear physics, nuclear astrophysics and applications

Stefano Romano

INFN – Laboratori Nazionali del Sud, Catania, Italy

PID

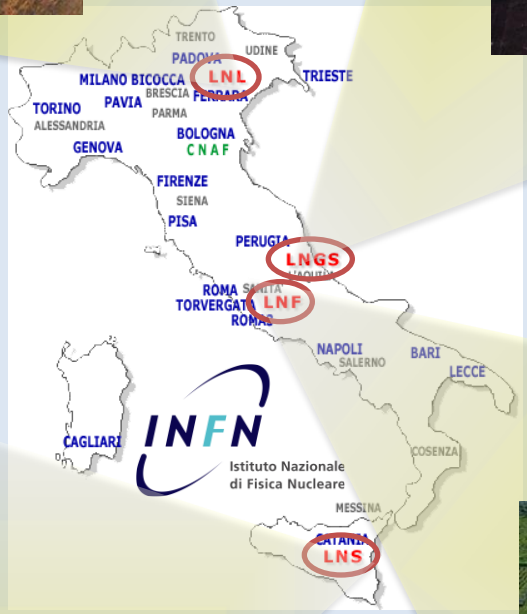
Programma Infn per Docenti

LNS – 18-22 febbraio 2019

INFN – Istituto Nazionale di Fisica Nucleare

Laboratori Nazionali di Legnaro

Laboratori Nazionali del Gran Sasso



Laboratori Nazionali del Sud

Laboratori Nazionali di Frascati

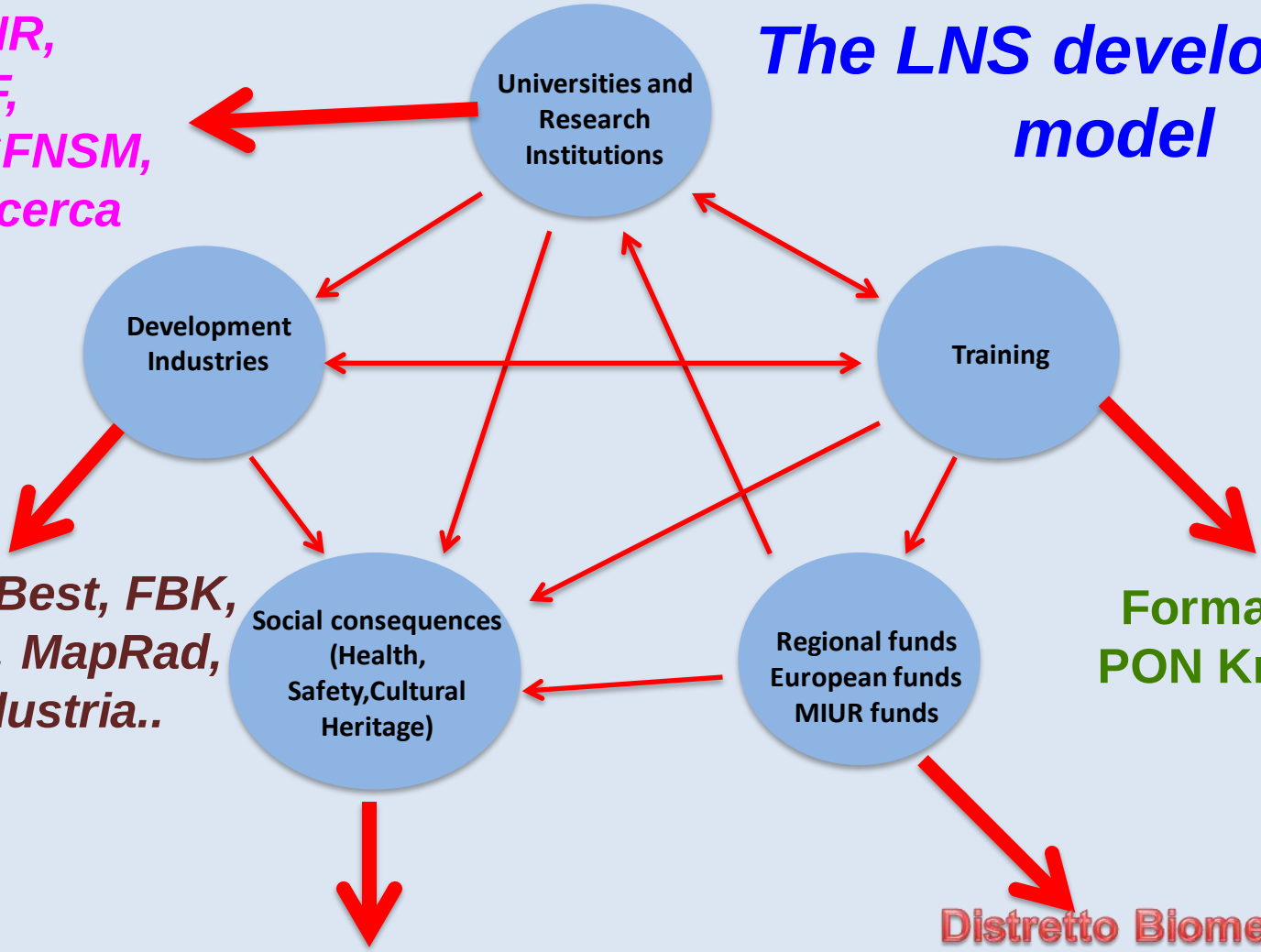
Laboratori Nazionali del Sud dell'INFN

Laboratori Nazionali del Sud (LNS) is the most southern laboratory of INFN and with the wider spectrum of research acitivies. Founded in 1976, nowdays are constituted by 250 people (120 permanent staff) including researches, technicians, doc and post-doc, undergraduate, etc. LNS are an advanced technological and research pole in Italy. Budget 11 M€ per year (exc. Salaries)

The research and development activities find applications in medicine, biophysics, photonics and cultural heritage. About 400 external users per year.

The LNS development model

Uni CT, CNR, INGV, INAF, ISPRA, CSFNSM, Catania Ricerca



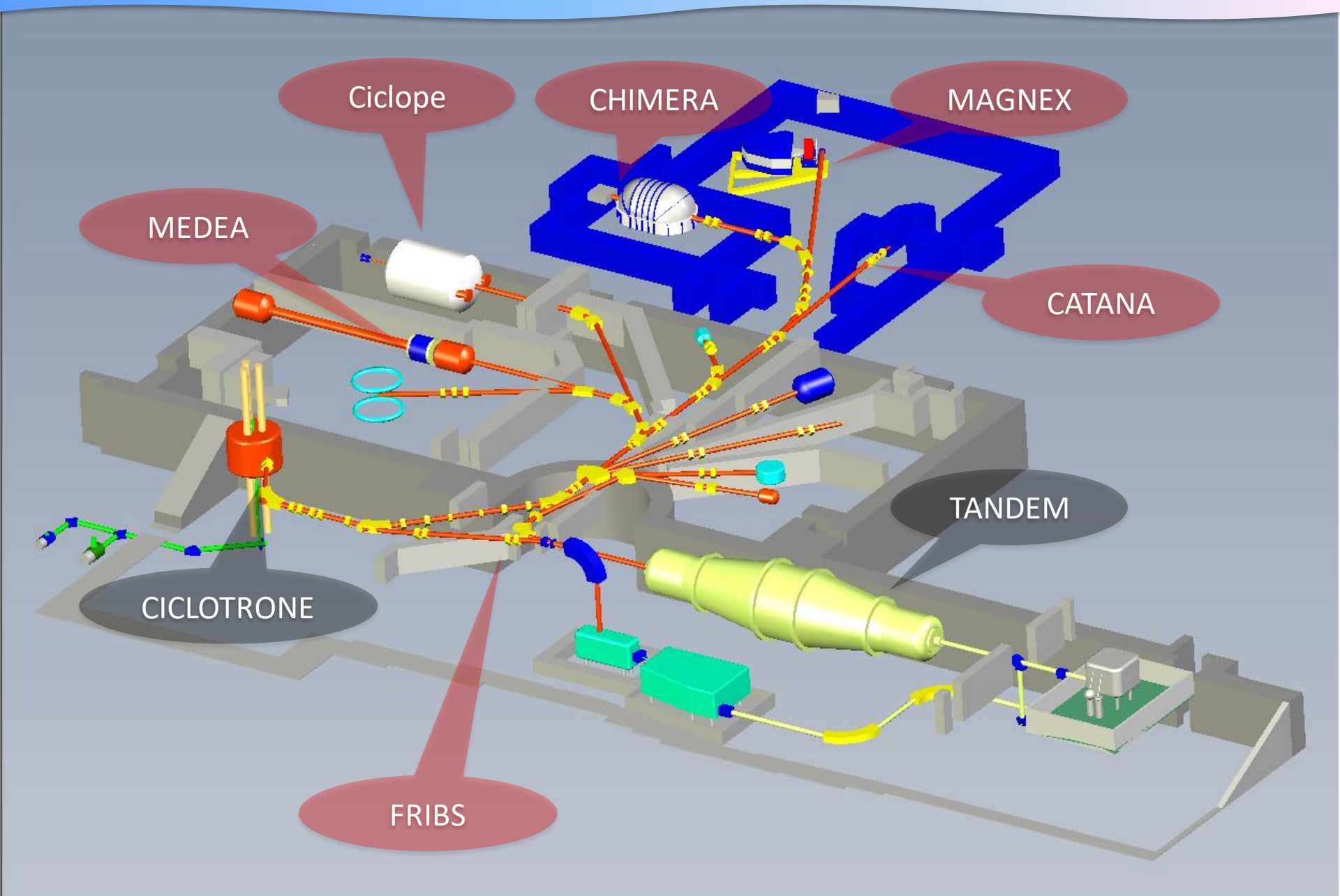
STM, IBA, Best, FBK, Caen, IMT, MapRad, Confindustria..

Formazione
PON Km3NeT

- CATANA: 500 patients, 95% success
- LANDIS: Coll. with CNR-IBAM (Misurata Coins, Dead Sea Scrolls…)
- Radioactive Waste Management: Sogin
- Enviromental Radioactivity Lab
- Radiobiology Lab

Distretto Biomedico
Dstretto del Mare
Distretto Beni Culturali
PON-POR Projects
FIRB/SIR-Prin
H2020

The Laboratori Nazionali del Sud



Accelerator equipment for ion beam production

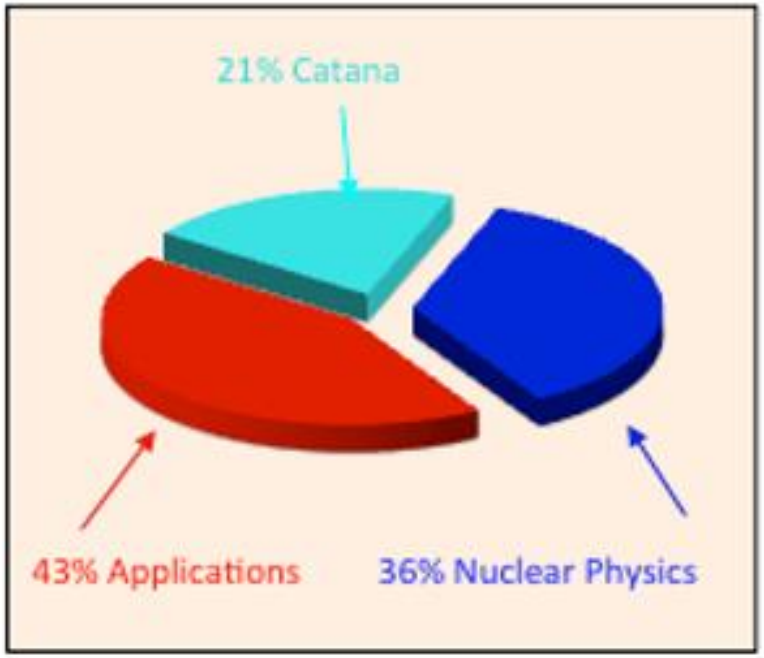
450 KV injector
2 sputtering sources

Normal conducting ECR source CAESAR

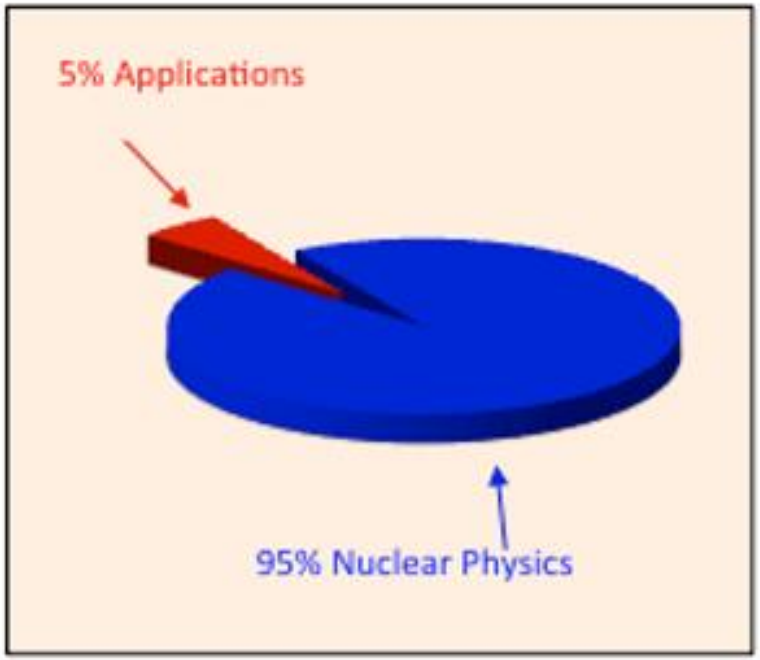
Superconducting ECR source SERSE

Average use of Cyclotron and Tandem

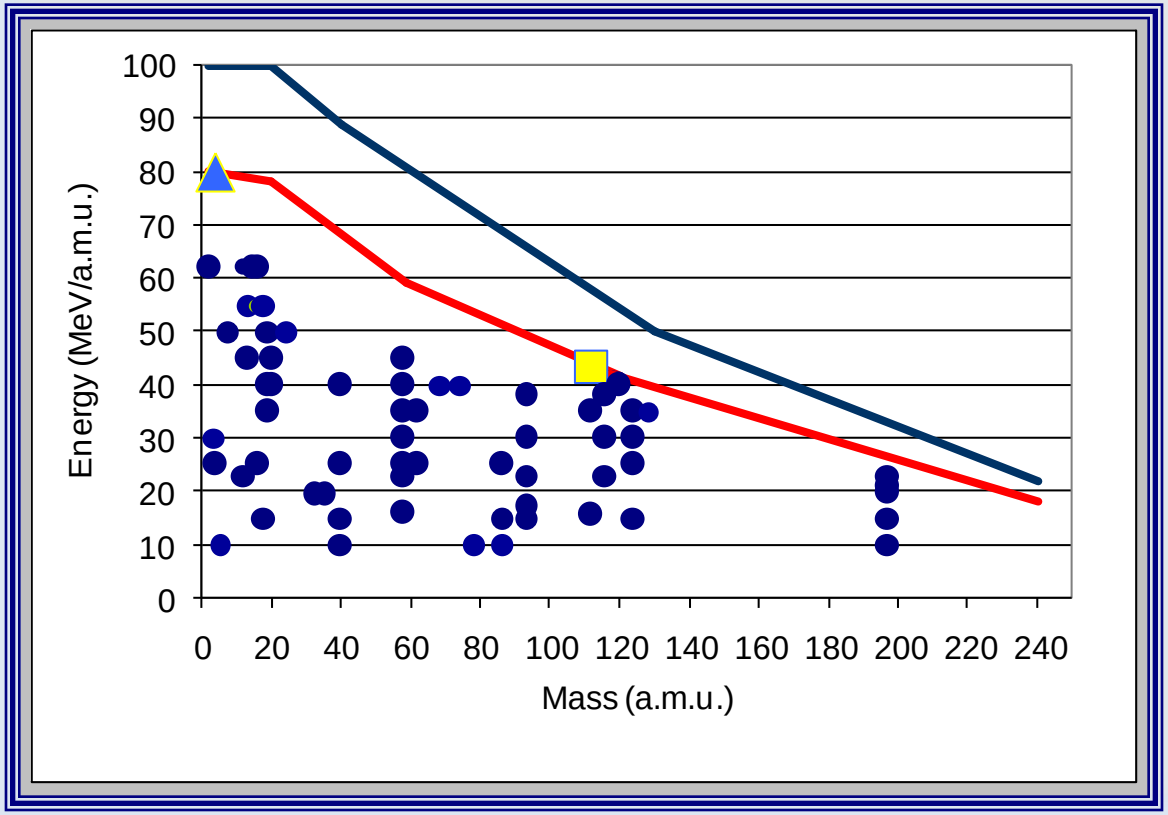
Cyclotron 2600-2800 hours/year



Tandem 1800 - 1900 hours/year



Superconducting Cyclotron developed beams



^{4}He 80 AMeV

^{112}Sn 43.5 AMeV

In red beams with intensity 10^{12} pps

^{A}X	E (AMeV)
H_2^+	62,80
H_3^+	30,35,45
$^{2}D^+$	35,62,80
^{4}He	25,62,80
He-H	10, 21
^{9}Be	45
^{11}B	55
^{12}C	23,62,80
^{13}C	45,55
^{14}N	62,80
^{16}O	21,25,55,62,80
^{18}O	15,55
^{19}F	35,40,50
^{20}Ne	20,40,45,62
^{24}Mg	50
^{27}Al	40
^{36}Ar	16,38
^{40}Ar	15,20,40
^{40}Ca	10,25,40,45
^{42,48}Ca	10,45
^{58}Ni	16,23,25,30,35,40,45
^{62,64}Ni	25,35
^{68,70}Zn	40
^{74}Ge	40
^{78,86}Kr	10
^{84}Kr	10,15,20,25
^{93}Nb	15,17,23,30,38
^{107}Ag	40
^{112}Sn	15.5,35,43.5
^{116}Sn	23,30,38
^{124}Sn	15,25,30,35
^{129}Xe	20,21,23,35
^{197}Au	10,15,20,21,23
^{208}Pb	10

The Laboratori Nazionali del Sud

Chimera

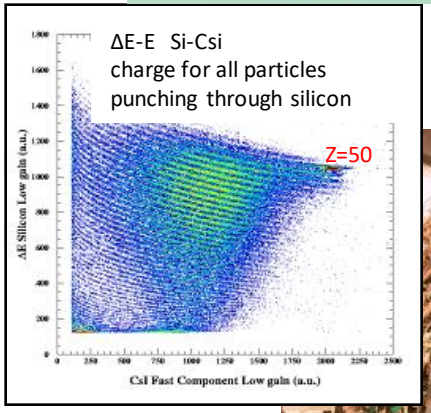
CHIMERA (CHarged Ion Mass and Energy Resolving Array)

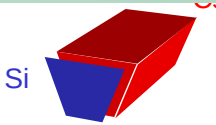
is a 4pi detector for charged particles devoted to the study of nuclear reaction at intermediate energies and operating at *Laboratori Nazionali del Sud* in Catania

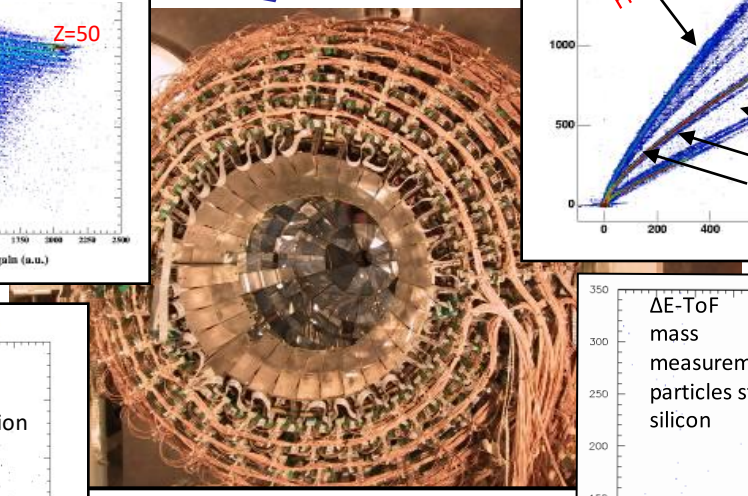
CHIMERA

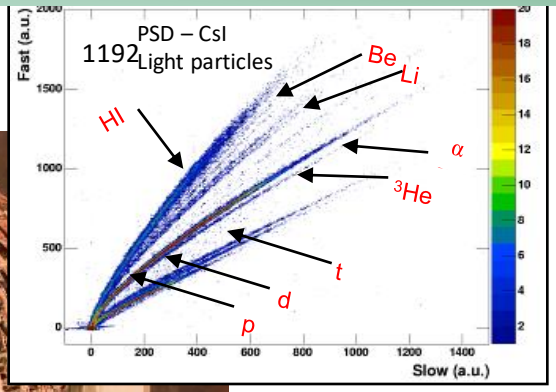
- Equation of State of Asymmetric nuclear matter
- isospin dependence of the symmetry energy
- Time scale of particles and cluster emission
- Isospin dependence of compound nucleus formation and decay (ISODEC)
- Use of the FRIBS beam lines: coupling CHIMERA with the FARCOS prototype (CLIR [^{16}C] and PIGMY [^{68}Ni] experiments (2015)

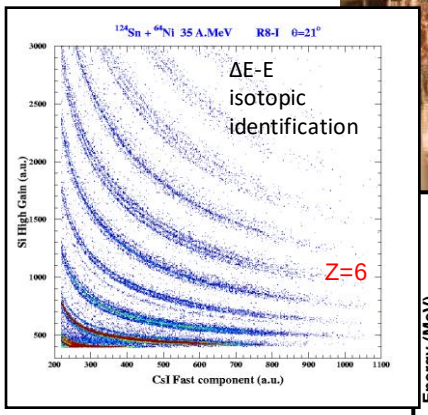
CHIMERA Detector: Identification methods

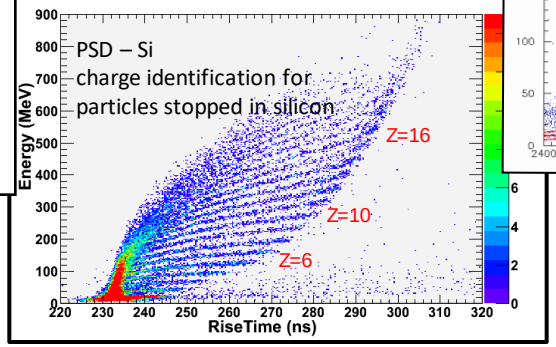


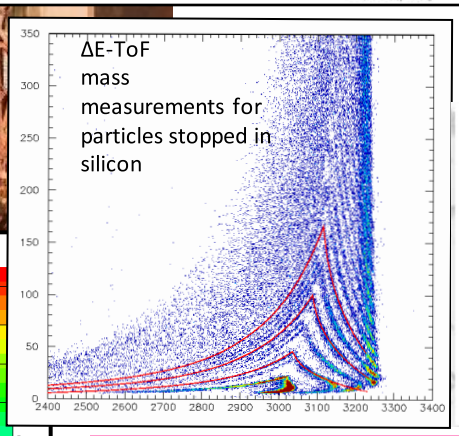


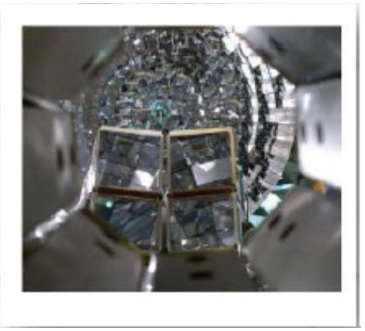








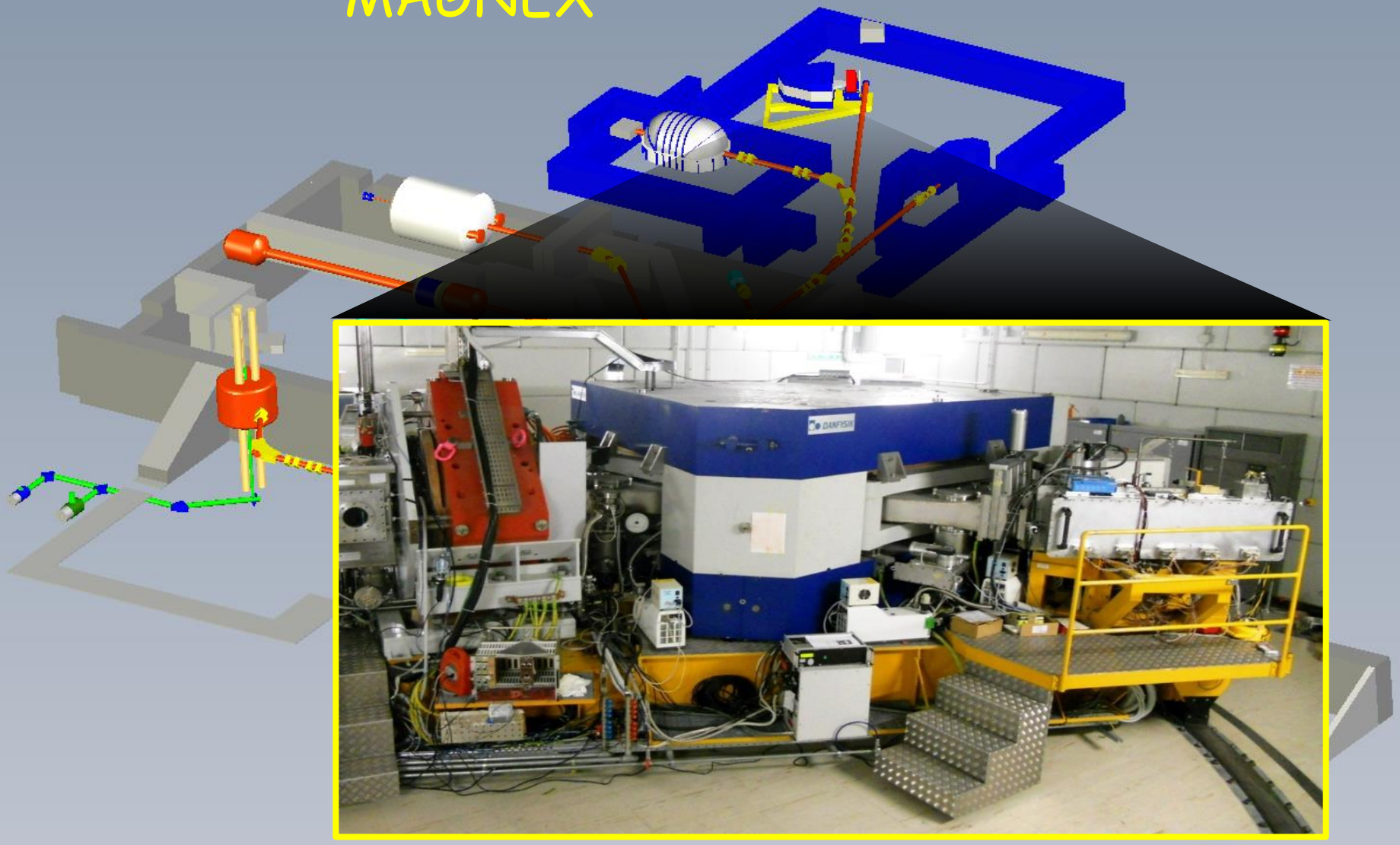




Recently improved by an array of triple telescopes DSSSD-CsI FARCOS

The Laboratori Nazionali del Sud

MAGNEX

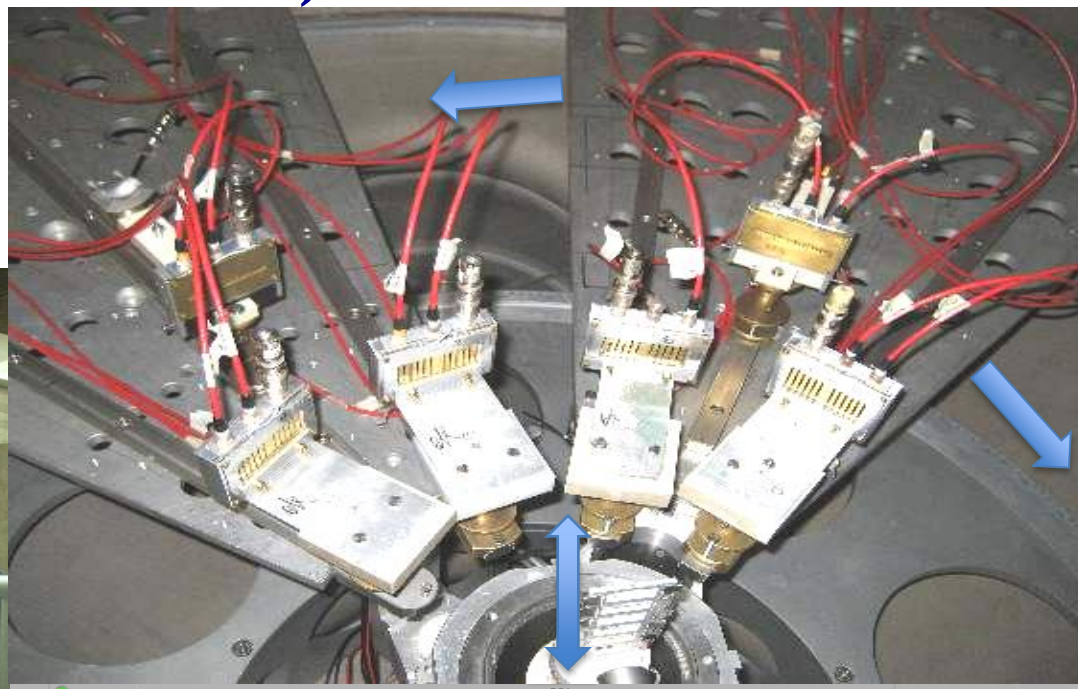


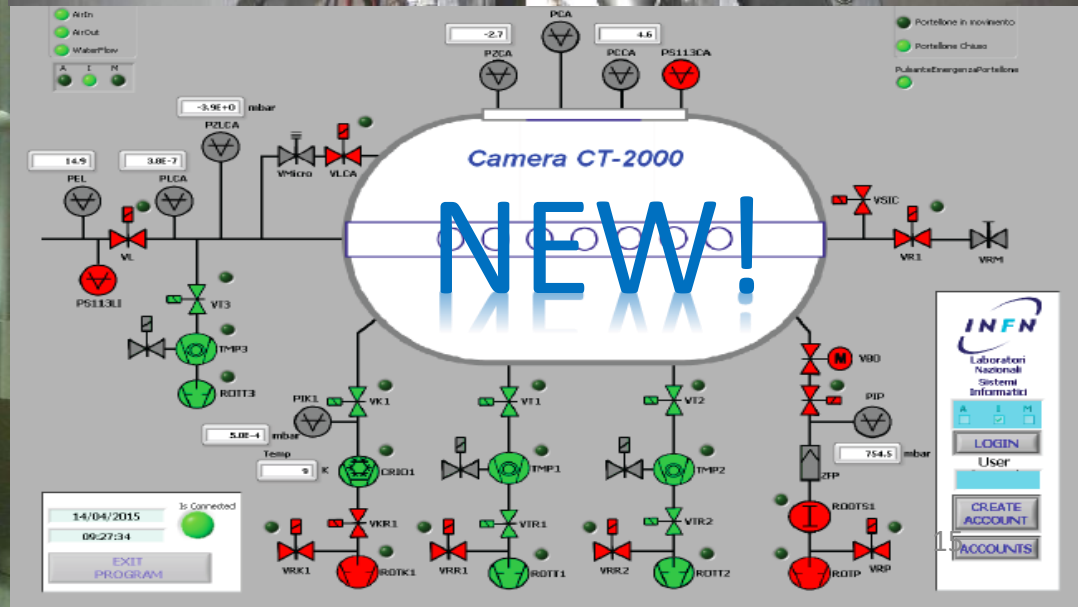
MAGNEX*EDEN

- Light nuclei structure
- Nuclear astrophysics
- Spectroscopy
- Structure effects on reaction mechanism
- Exotic nuclei
- Isgm
- DCE

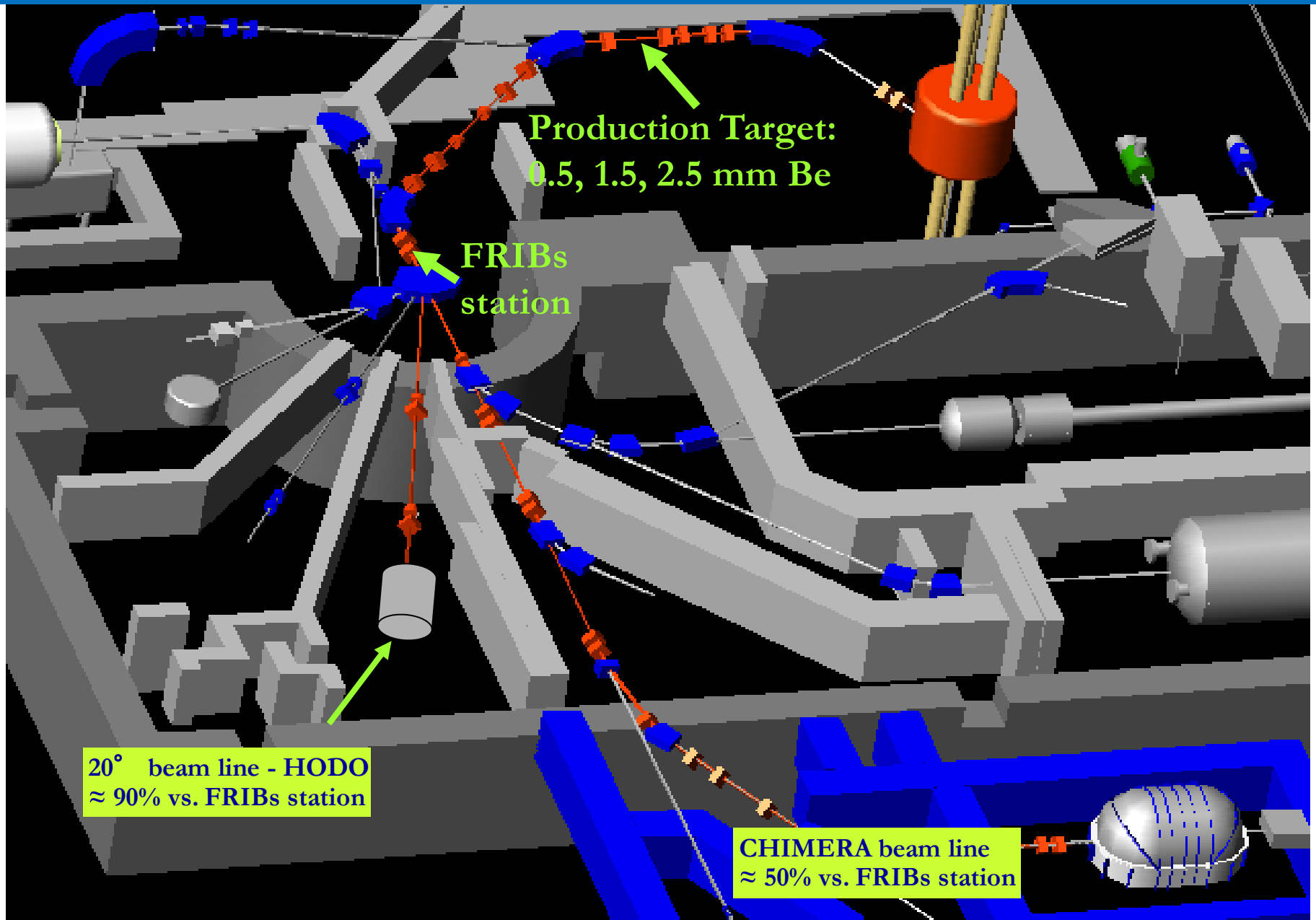
The 2000 Scattering Chamber (2 m diameter)

- Nuclear Physics
- Nuclear Astrophysics
- Applications





FRIBS@LNS: in Flight Radioactive Ion Beams



Beams developed at FRIBS@LNS

primary beam	beam	intensity (kHz/100W)
18O 55 AMeV	16C	120
setting 11Be	17C	12
	13B	80
	11Be	20
	10Be	60
	8Li	20
18O 55 AMeV	14B	3
setting 12Be	12Be	5
	9Li	6
	6He	12
13C 55 AMeV	11Be	50
setting 11Be	12B	100
36Ar 42 AMeV	37K	100
setting 34Ar	35Ar	70
	36Ar	100
	37Ar	25
	33Cl	10
	34Cl	50
	35Cl	50
20Ne 35 AMeV	18Ne	50
setting ne18	17F	20
	21Na	100
70Zn 40 AMeV		
setting 68Ni	68Ni	20

Beams to be delivered to approved experiments

^{16}C (CHIMERA)

^{68}Ni (CHIMERA)

^{8}He (CHIMERA) new

^{14}Be (test experiment) new

^{38}S (MAGNEX) new

Unique facility in Europe

The NUMEN project at INFN-LNS

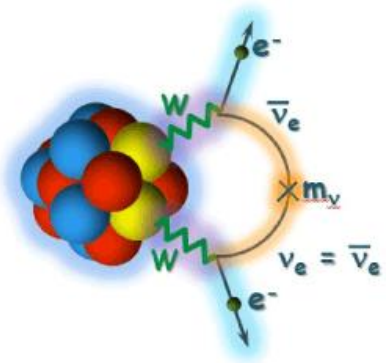
77 Researchers
19 Institutions
12 countries

Spokespersons: F. Cappuzzello (cappuzzello@lns.infn.it) and C. Agodi (agodi@lns.infn.it)

The NURE grant of ERC

Principal Investigator: M. Cavallaro (manuela.cavallaro@lns.infn.it)

Neutrinoless double beta decay



1. **Beyond standard model**
2. **Access to effective neutrino mass**
3. **Violation of lepton number conservation**
4. **CP violation in lepton sector**
5. **A way to leptogenesis and GUT**

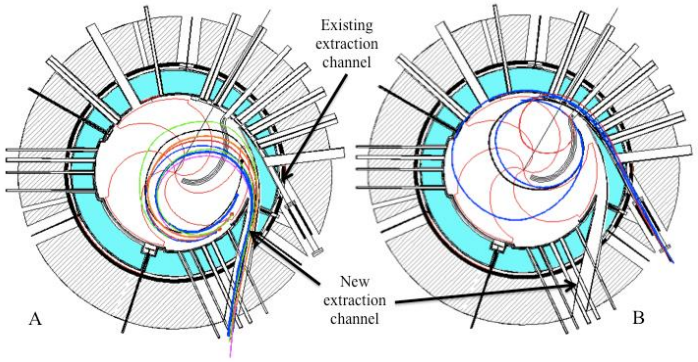
- Italy
- Greece
- Germany
- Israel
- France
- Brazil
- Mexico
- Turkey
- Romania
- US

$$1/T_{1/2}^{0\nu}(0^+ \rightarrow 0^+) = G_{01}\left|M^{\beta\beta\,0\nu}\right|^2\left|\frac{\langle m_\nu \rangle}{m_e}\right|^2$$

Major upgrade of LNS facilities: The CS accelerator

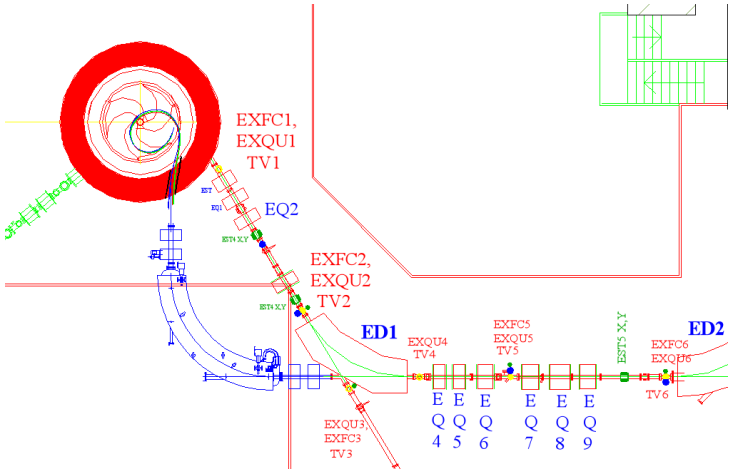
- The CS accelerator current (from 100 W to 5-10 kW);

Cost: 10.5 M€



Extraction by stripping

- The beam transport line transmission efficiency to nearly 100% (*Cost including FRIBs and Magnex beam line Upgrading 5.5 M€*)



Upgrade of the Research Infrastructures selected among the ones having priority in Italy according to the PNIR – Piano Nazionale delle Infrastrutture di Ricerca, located in regions under developed or in transition

18 Candidate Institutions selected by MIUR (for INFN:DHCTS, Km3NeT, LNS and LNGS)

NUCLEAR PHYSICS @ LNS

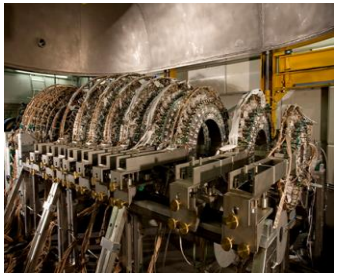
Among the scientific activities at LNS …

- Studies of the EOS of nuclear matter with stable beams
- Studies of the EOS of nuclear matter with radioactive beams (FRIBs)
- Studies of nuclear structures with stable beams
- Studies of nuclear structures with radioactive beams (FRIBs)
- Studies of nuclear reaction for astrophysics with stable beams
- Applications

CS – UPGRADE → NEW FRONTIERS

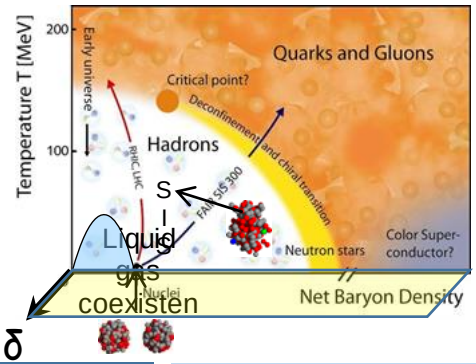
HIGHER INTENSITIES: STABLE BEAMS – RADIOACTIVE BEAMS

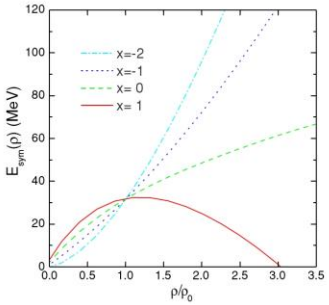
CHIMERA – stable beams



The nuclear EOS describes the relation among energy, pressure, density, temperature and isospin asymmetry of nuclear matter. It is a fundamental ingredient in nuclear physics and astrophysics.

Nuclear matter phase diagram (schematic)

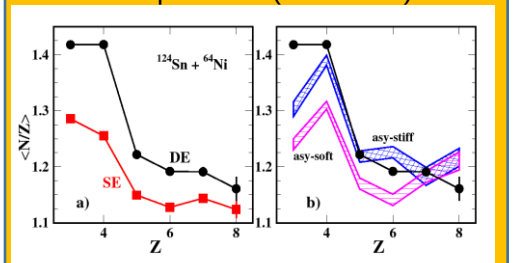




Z. Xiao et al., PRL102, 062502 (2009

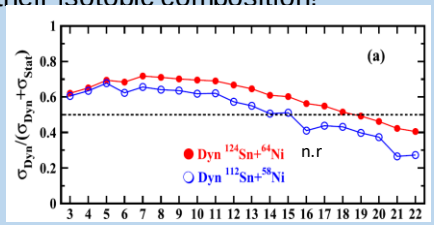
Density $\rho <\approx \rho_0$ (sub- and around saturation density, ρ_0=0.17 fm^{-3}): Isospin Transport properties in HI collisions at Fermi Energies, (diffusion, fractionation, migration), flows, n/p emission….

The "neck" emission : light IMFs (Z<≈9) produced at midrapidity due to the 'neck' rupture.
FAST process (<100 fm/c)

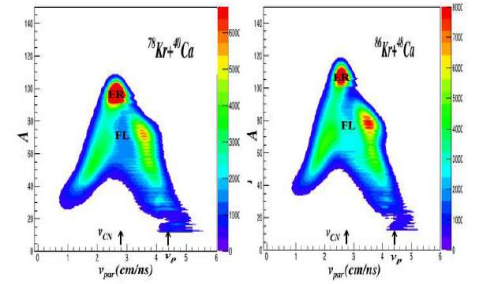


E. De Filippo et al., PRC86, 014610 2012)

Symmetry Energy and Isospin contents affect IMFs production and their isotopic composition!

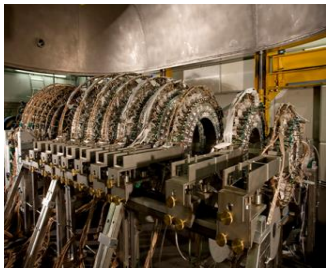


The use of exotic neutron rich beams will be a step forward in this field! By G.Cardella and S.Pirrone



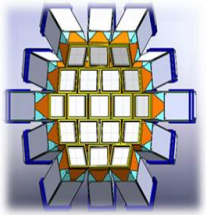
Influence of the system isospin on CN formation and decay in reactions ^{78}Kr+^{40}Ca and ^{86}Kr+^{48}Ca at 10 AMeV

CHIMERA – radioactive beams (FRIBS)

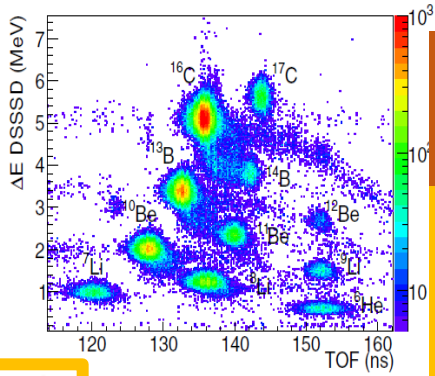


Search for isoscalar excitation of the PIGMY resonance in ^{68}Ni

Farcos

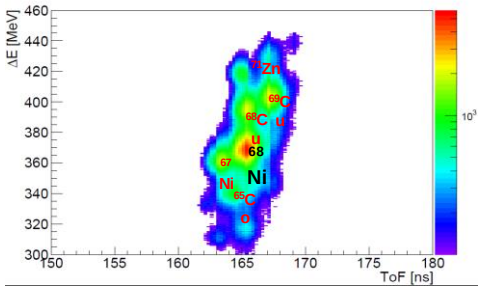


Study of clustering phenomena in exotic nuclei:



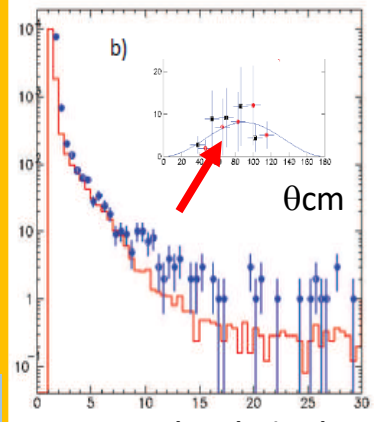
Study of the ^{10}Be and ^{16}C structure using intermediate energy sequential break-up

Beam intensities:
^{10}Be (4x10^4 pps)
^{16}C (10^5 pps)
from 55A MeV ^{18}O primary beam



About 20 kHZ of ^{68}Ni for 100 W beam

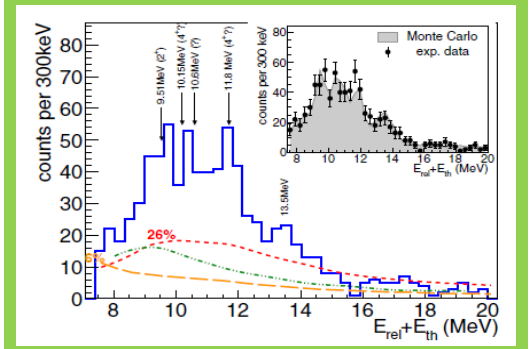
Gamma-ray spectrum measured in coincidence with ^{68}Ni.
Red line represents the background evaluated in concidences with ^{66,67}Ni



To be submitted on PLB

First measurement of the ^{68}Ni γ-decay of the Pygmy res. excited by isoscalar mode

First observation of a new level of the ^{10}Be with cluster structure α-^{6}He



First observation of a new ^{10}Be level with cluster structure α-^{6}He
PRC 93(2016)0246111

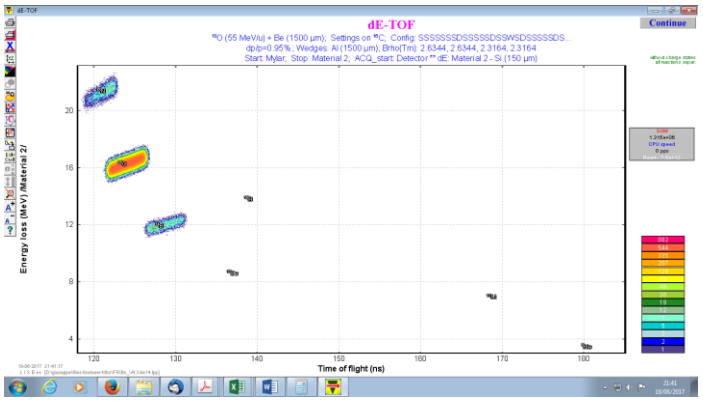
By G.Cardella and S.Pirrone

CHIMERA – FRIBS upgraded

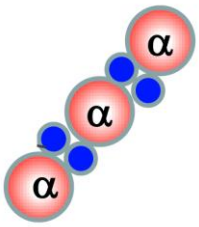
Most of the themes studied up to now will be further developed using radioactive beams

Very important for NEWCHIM experiment, the possibility to improve intensity for light-medium fragmentation beams in order to study exotic clustering

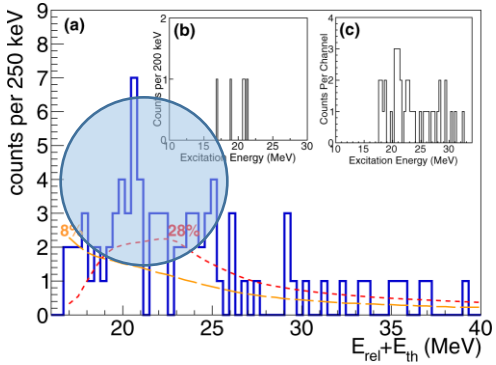
On the same topic of the exotic clustering phenomena explored
in ^{10}Be, primary beams with higher intensities can be used to produce ^{16,18}C using FRIBS searching for channel ^{6}He + ^{10}Be



Predicted intensity ^{16}C @ 34*A* MeV: 2x10^{6} pps
Contaminant: 2%



linear chain
^{10}Be,$^{13\text{-}14}$C,^{16}C(?),…



Indication of the presence such kind of resonances in ^{16}C was already observed but higher statistics is needed

Nuclear astrophysics

Explosive phenomena in the Cosmos

→ short time scales

→ **unstable nuclei are burnt before decay**

Examples: Supernovae, novae, X-ray bursts

Typical temperatures are of the order of 10^9 K

Since the Boltzmann constant is k= 8.6 10^{-8} keV/K, even at this high temperatures energies of astrophysical interest are smaller than about 1 MeV in the centre-of-mass system → very difficult to reach at present-day RIB facilities.

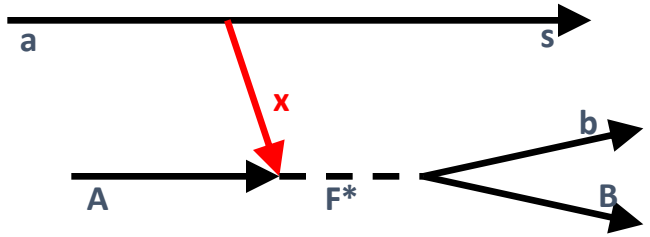
Moreover: low production at these low energies, low cross sections owing to the Coulomb barrier, poor energy and angular resolution.

→ **The Trojan Horse method (THM) may help:**

→ Higher beam energies necessary

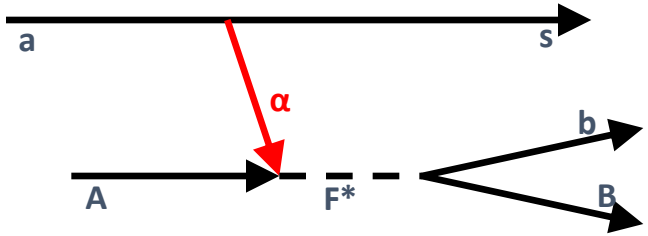
→ Larger cross sections

→ Yet astrophysical energies can be accessed



THM: A(x,b)B from A(a,bB)s under QF conditions → see e.g. **Rep. Progr. Phys. 77 (2014) 106901**

Nuclear astrophysics @ FRIBS upgraded



Using **^{6}Li** or **^{20}Ne** we can transfer a α particle and induce the reaction of astrophysical importance at the relevant energies

^{14}O(α,p)^{17}F → **breakout from the hot CNO cycle**: in explosive hydrogen burning, this reaction determined the permanent loss of catalysts leading to the production of heavy (A>100) proton-rich nuclei

^{13}N(α,p)^{16}O → In **asymptotic giant branch (AGB) stars**, the ^{13}C(α,n)^{16}O reaction is the n-source for heavy element production. However, the ^{13}C supply might be reduced if ^{13}N is burnt to ^{16}O before it decays → **influence on the s-process** in massive AGB stars

^{34}Ar(α,p)^{37}K → ^{34}Ar is a waiting point in **x-ray bursts**: if the (α,p) reaction rate is weak OR if the temperature is too low to overcome the Coulomb barrier, nuclear flow must await β decay before continuing on → **influence on nucleosynthesis and luminosity**

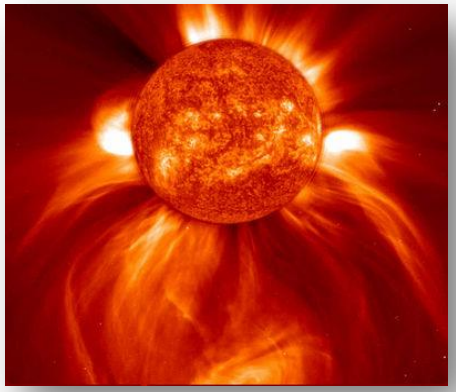
^{18}Ne(α,p)^{21}Na → it influences X-ray burst light curves as well as nucleosynthesis, in particular the abundance of ^{15}N, ^{18}F, ^{21}Ne and ^{33}S in the ashes of the thermonuclear runaway

Complementary to SPES

https://web.infn.it/spes/images/NEW_SITE/PDF/SPES_Beam_Tables/4_beam_spes_all.pdf

Most of the visible Universe is in the state of plasma

- Solar nucleosynthesis occurs *in-plasma*
- Primordial nucleosyntesis occurs *in-plasma*
- *s*-process nucleosynthesis occurs *in-plasma*
- Visible to X-ray radiation is generated *in-plasma*
- Magnetized plasma in stars is extremely peculiar



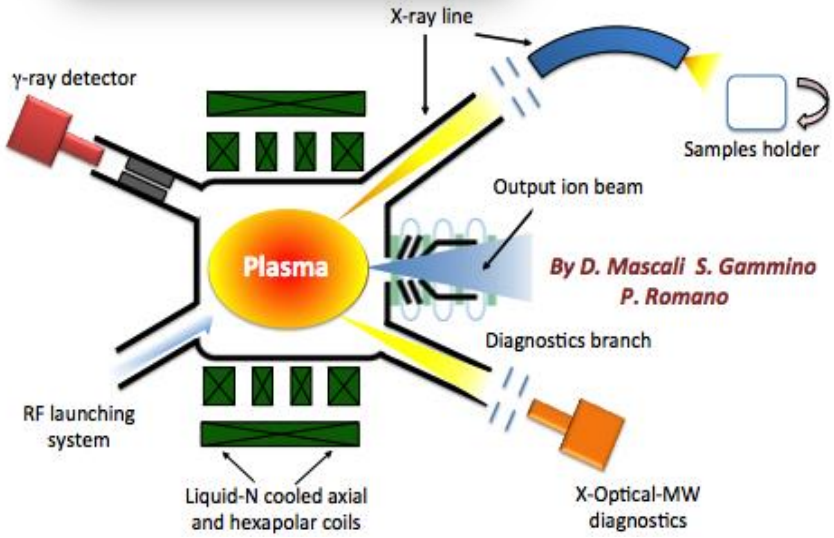
But on *Earth* (or underground at LNGS) we perform nuclear reactions and decay rate measurements by using solid-gas-liquid samples

To be investigated

^{7}Be half-life has ***never*** been measured in-plasma (important for solar neutrino physics and Cosmological Lythium Puzzle)

Decay from nuclear low-lying excited states;

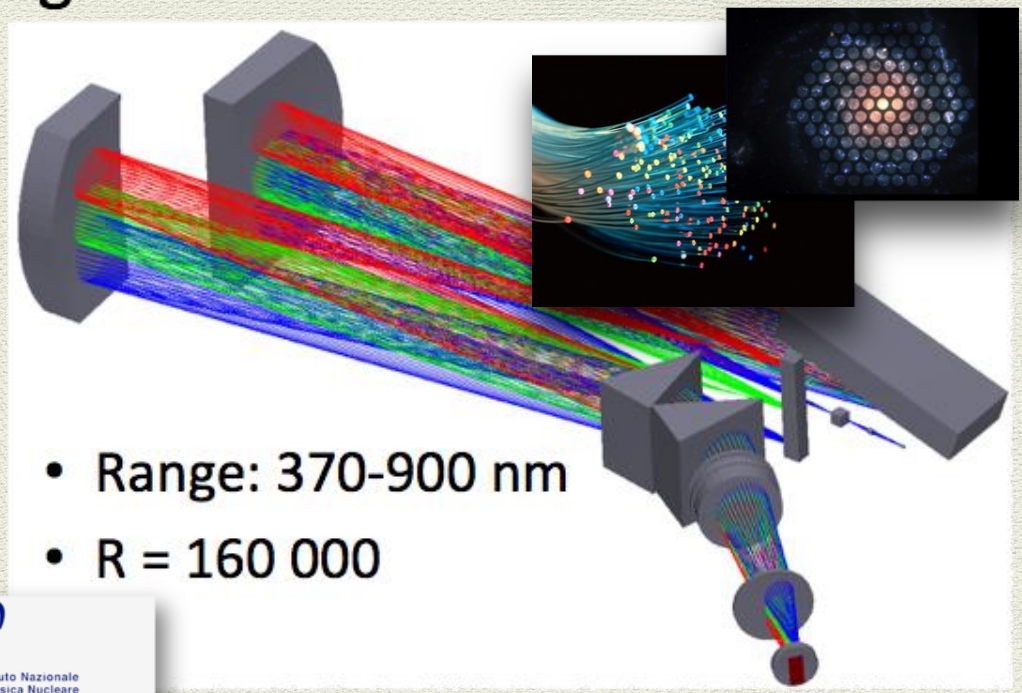
Bound-electron beta decay activation in ionized species;



1. On-Line Measurements of n, T, CSD of the plasma
+
2. 7Be handling and injection into the plasma trap

PANDORA feasibility study

Spettrografo Alta Risoluzione Galileo

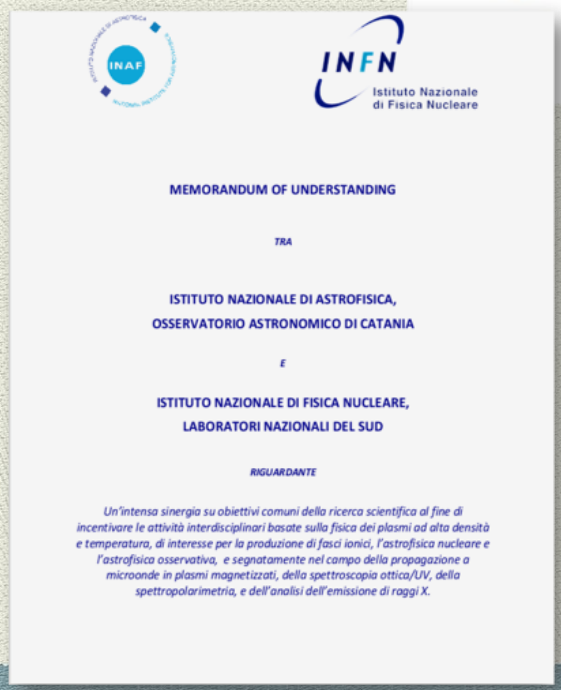


PANDORA@Work

INFN-INAF *MoU*
in progress

the first *MoU* to
be signed by the two institutions

CSN III and V



INAF

INFN
Istituto Nazionale
di Fisica Nucleare

MEMORANDUM OF UNDERSTANDING

TRA

ISTITUTO NAZIONALE DI ASTROFISICA,
OSSERVATORIO ASTRONOMICO DI CATANIA

E

ISTITUTO NAZIONALE DI FISICA NUCLEARE,
LABORATORI NAZIONALI DEL SUD

RIGUARDANTE

Un'intensa sinergia su obiettivi comuni della ricerca scientifica al fine di incentivare le attività interdisciplinari basate sulla fisica dei plasmi ad alta densità e temperatura, di interesse per la produzione di fasci ionici, l'astrofisica nucleare e l'astrofisica osservativa, e segnatamente nel campo della propagazione a microonde in plasmi magnetizzati, della spettroscopia ottica/UV, della spettropolarimetria, e dell'analisi dell'emissione di raggi X.

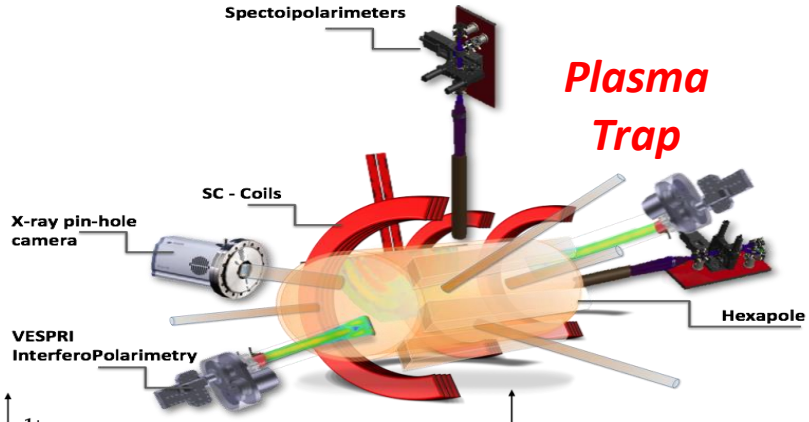
Starting a new synergy with Astronomy/Astrophysics!!!

SARG came to LNS from T.N.G. in La Palma, Canary Islands

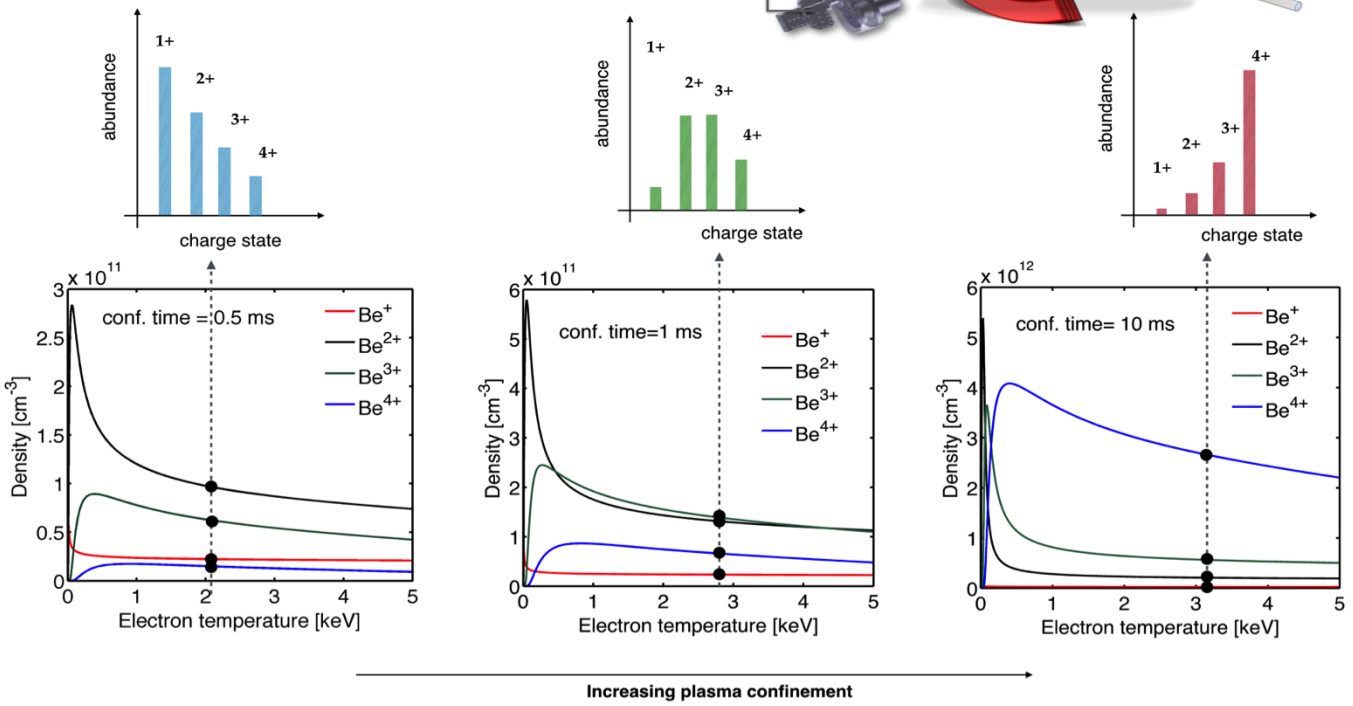
The PANDORA goal:

PANDORA's white book accepted for pubblication on EPJ-A

Trap radionuclides in magnetoplasmas and study their decay times as a function of ionization states



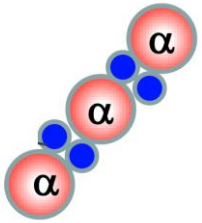
E.g. → ^{7}Be charge states distribution as a function of plasma density and temperature



Synergy with INAF observative measurements

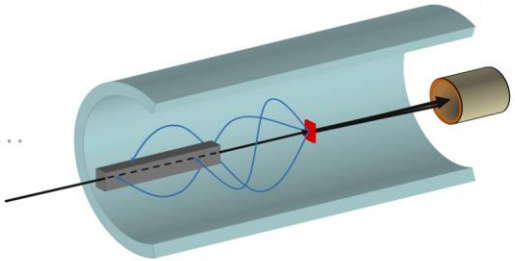
Outlook

NUMEN

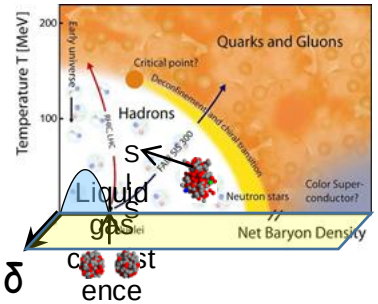


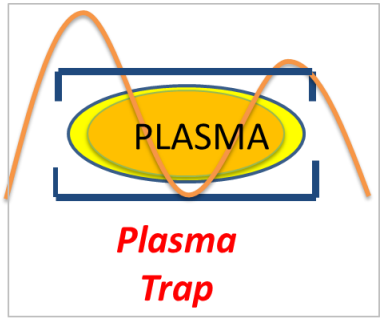
linear chain

^{10}Be, $^{13\text{-}14}$C, ^{16}C(?),…

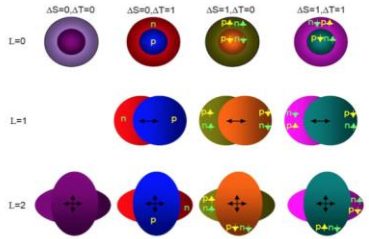


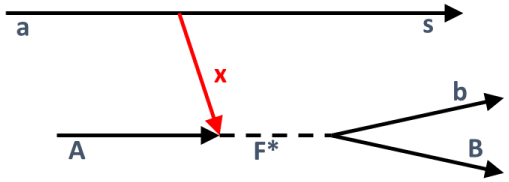
Nuclear matter phase diagram (schematic)



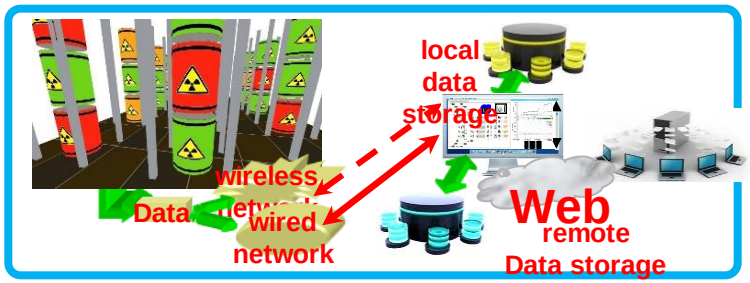


Plasma Trap





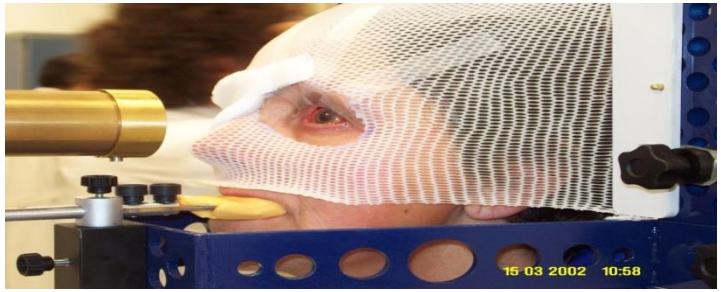
Nuclear physics applications @ LNS



Development of systems and detectors for real-time monitoring of radioactive waste.

Environmental radioactivity monitoring and development of system for the treatment and monitoring of soil and water contaminated by radionuclides

Non-destructive study of finds of art and archaeological interest using X-rays or particle accelerators.

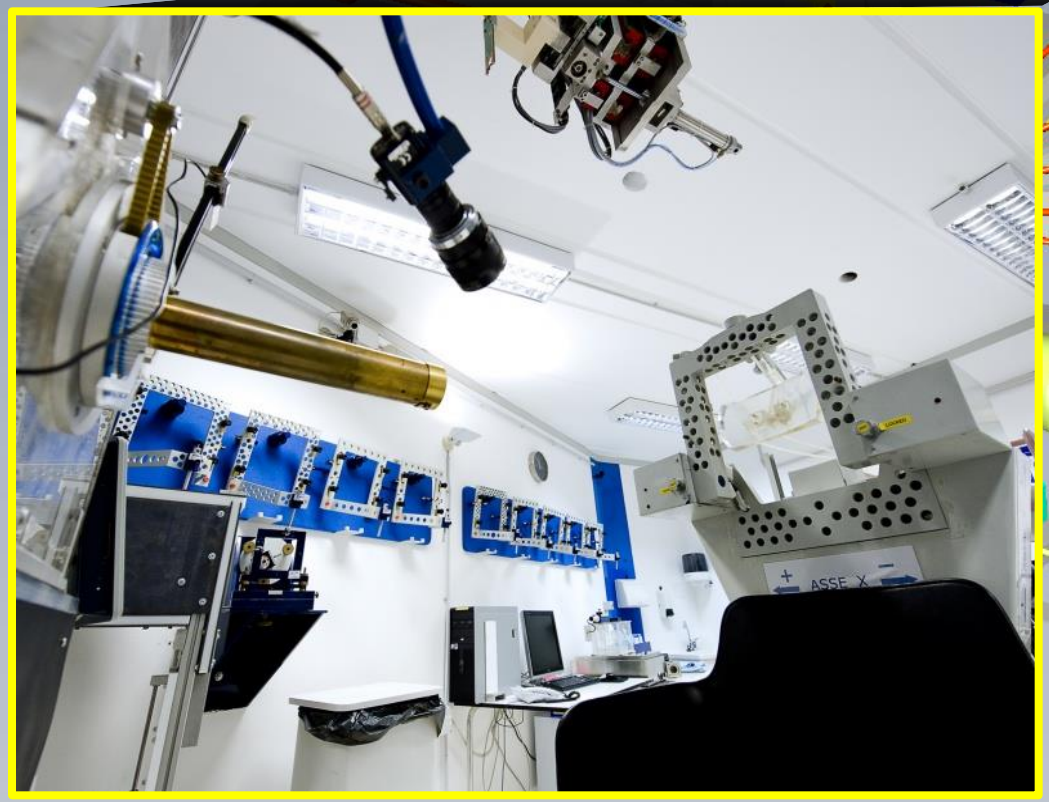


Radiation therapy with protons beams.

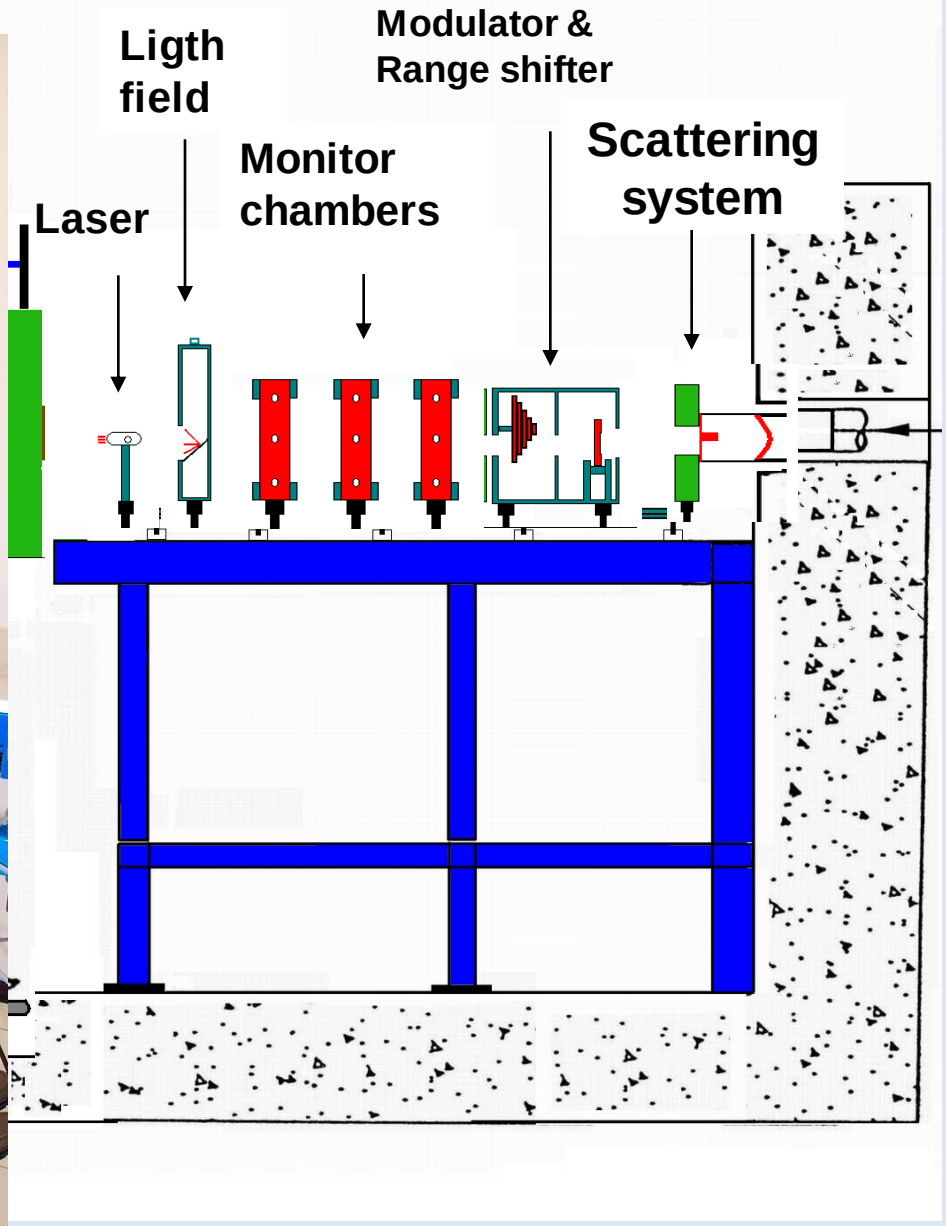
Radiobiology research by irradiating carcinogenic cells to evaluate their survival, damage, and genetic mutations.

The Laboratori Nazionali del Sud

CATANA



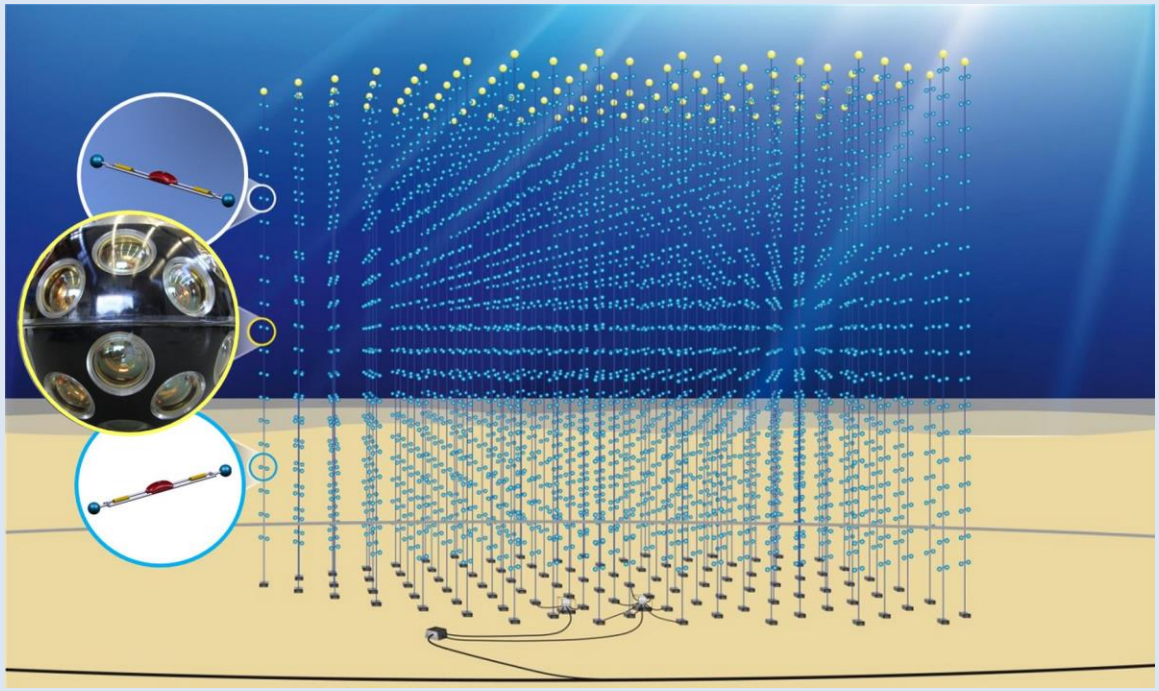
CATANA proton therapy beam line



Total Number of patients	> 500	
Deaths	6	
	Metastatis	5
	Other	1
Eye retention rate	95 %	
Surviving	98 %	
LOCAL CONTROL	95 %	

The giant-scale detector KM3NeT

Faintness of neutrino fluxes and small interaction probabilities oblige to use large natural target such as sea-water: a volume of 5 km^3 of seawater will be instrumented with optical detectors.



5 building blocks
120 Detection Units (DU)
750 m DU height
180m DU distance
5 km^3 volume
Budget 210 M€

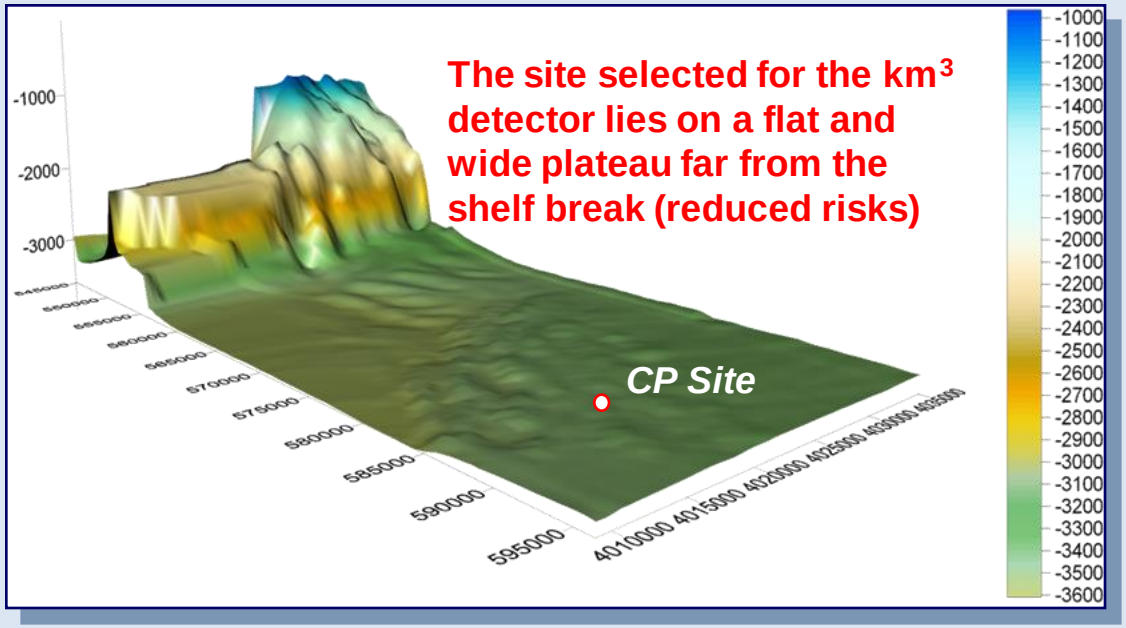
KM3NeT-It is funded by INFN since 1999 (NEMO)
In 2012 the project was awarded with a
PON grant of 21 M€

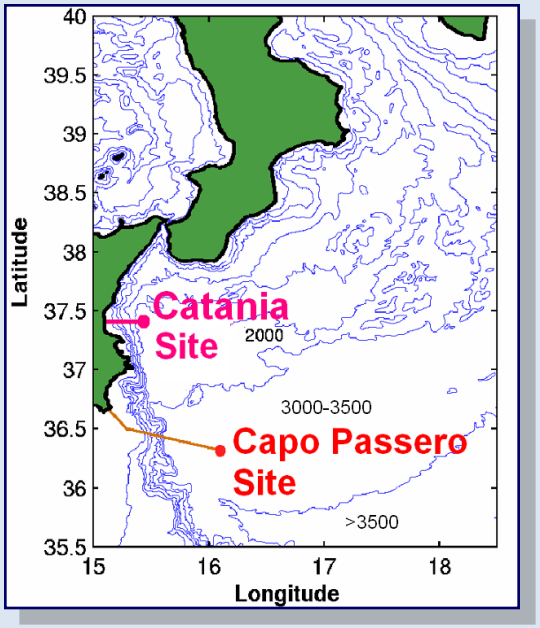
KM3NeT is a EU funded ESFRI Infrastructure since 2006.
INFN leaded the Prparatory Phase

The Capo Passero Site

More than 30 naval campaigns seeking deep sea sites in the Mediterranean Sea. Capo Passero is an optimal site.

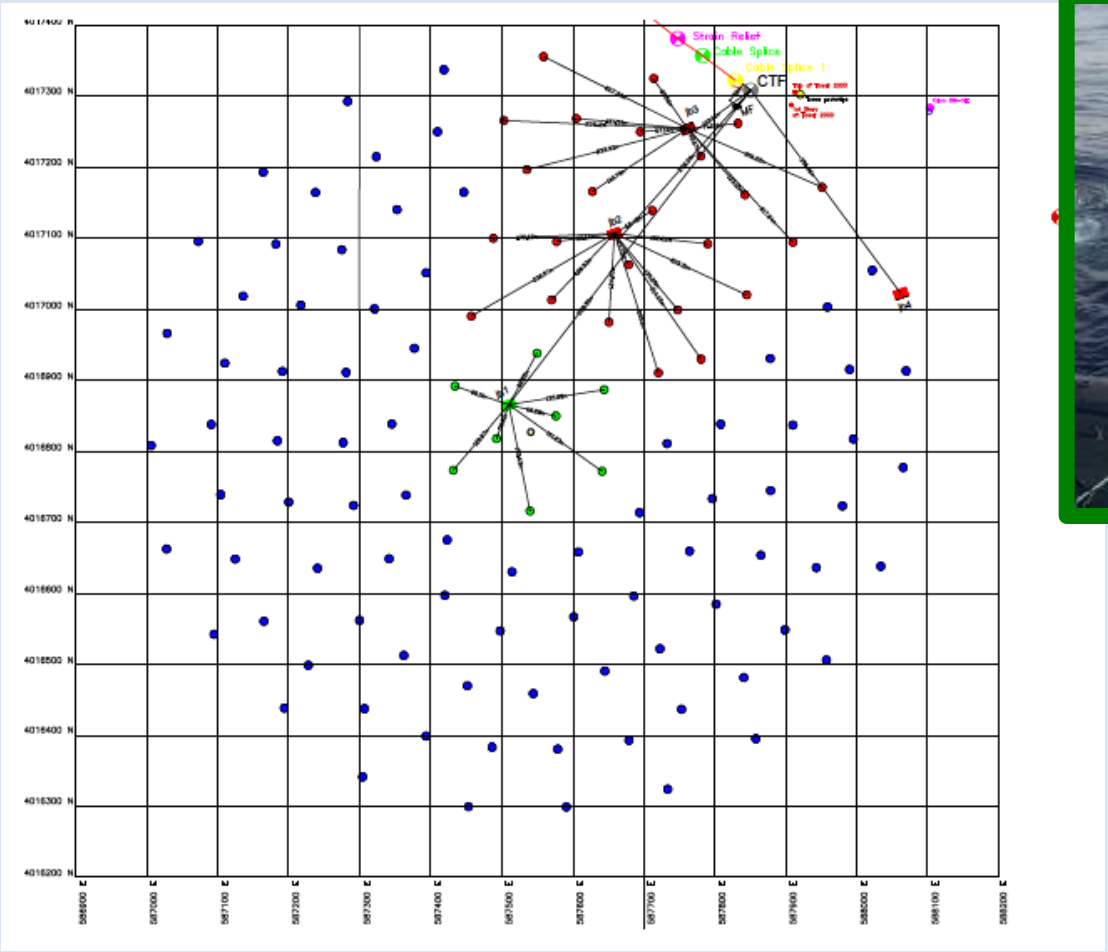
- ***Depth >3500 m, 90 km distance from the shore***
- ***Excellent water optical properties ($L_a \approx 70$ m @$\lambda = 440$ nm)***
- ***Optical background from bioluminescence extremely low***
- ***Deep sea water currents are low and stable (3 cm/s avg, 10 cm/s max)***
- ***Wide abyssal plain: large extension of the detector***

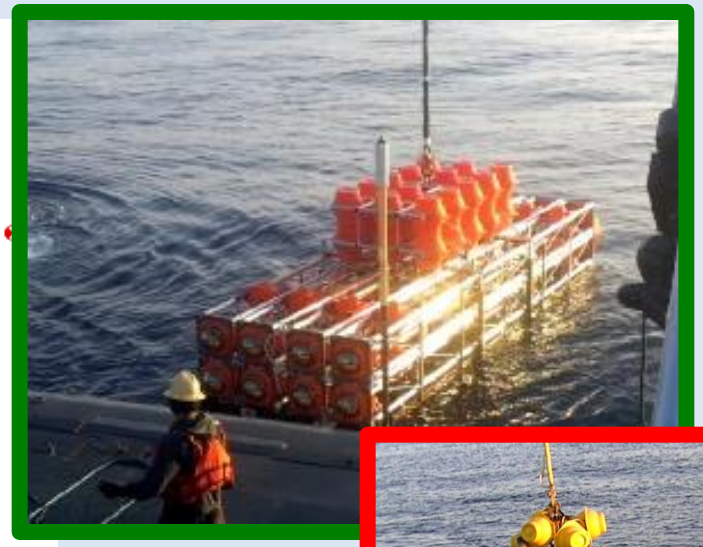




KM3NeT Installation Plan

→ Site full Survey (05/2014) Area Clearance (11/2014) 1 DU (11/2014)
→ 8 **Detection Units 2016** 26 Detection Units in 2017
A full Building Block before 2020



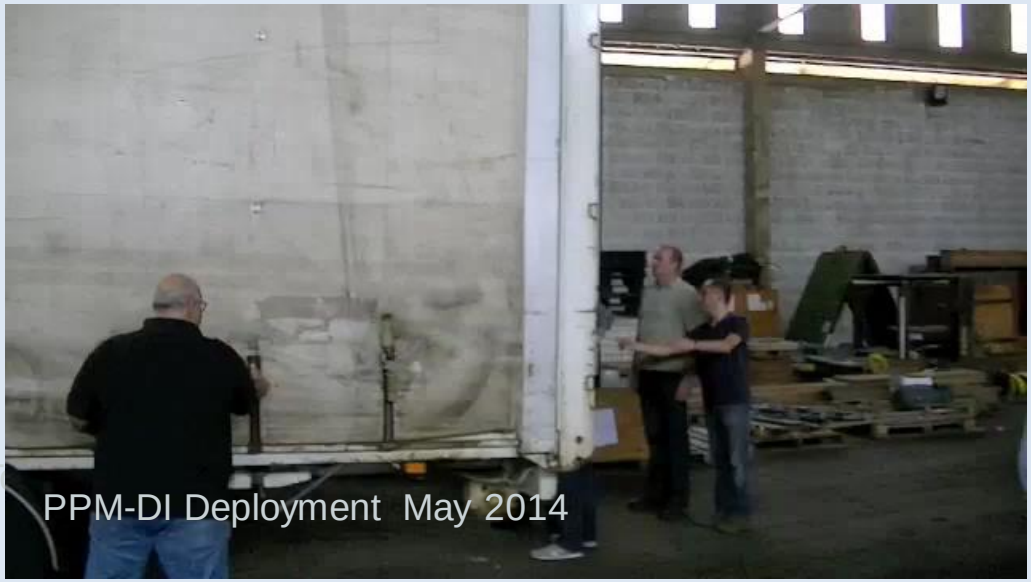


Sea Operation: deployment and connection

The DSV Nautical Tide


The ROV

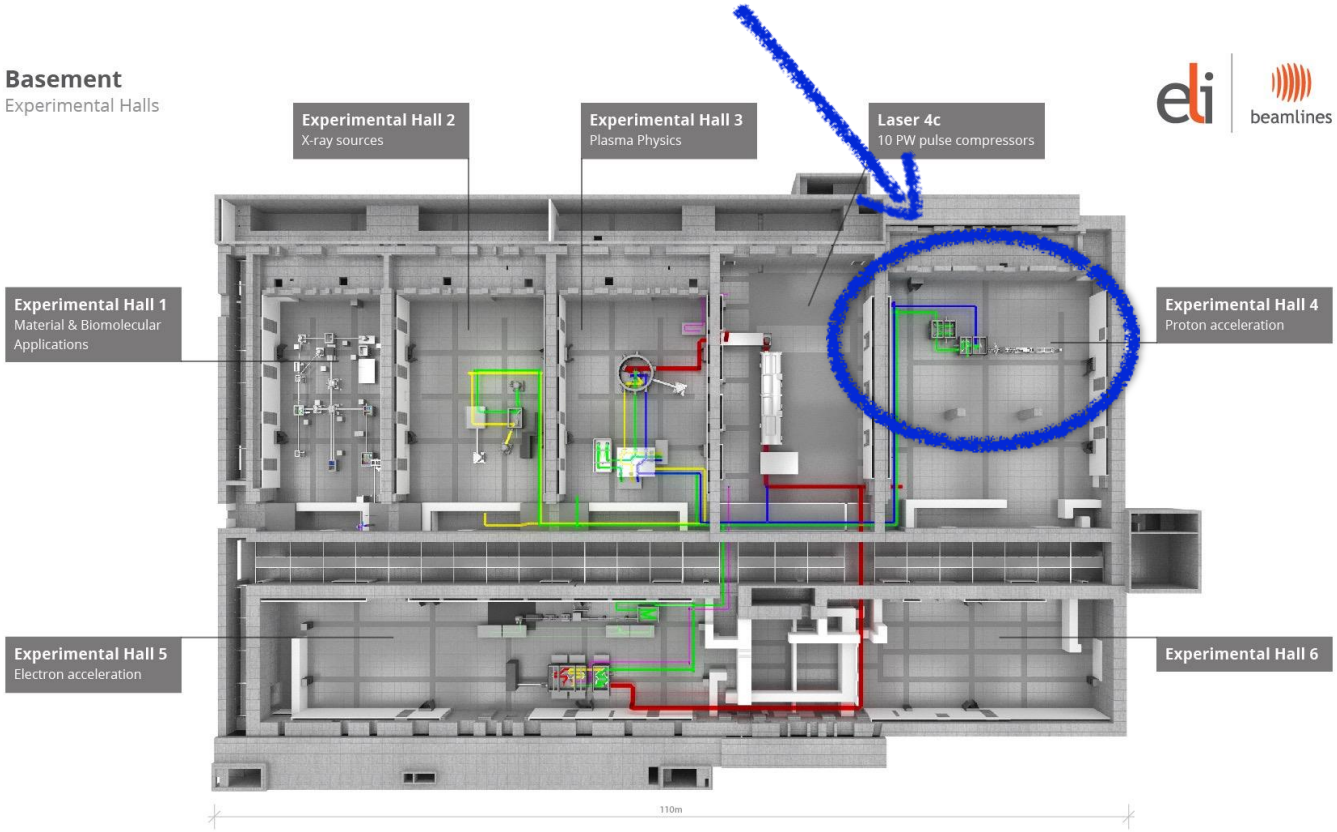
Tower Deployment April 2013


PPM-DI Deployment May 2014

ELIMED:
ELI-Beamlines MEDical and multidisciplinary applications

- Design and development of a transport beamline for the next generation of laser-driven beams
- Design and development of diagnostic and dosimetric devices to measure the absolute and relative dose and the characteristics of laser-driven beams
- The final beamline has been successfully installed at the ELI-Beamlines facility (Prague, CZ) in July2018. Perfectly on time with the contract.

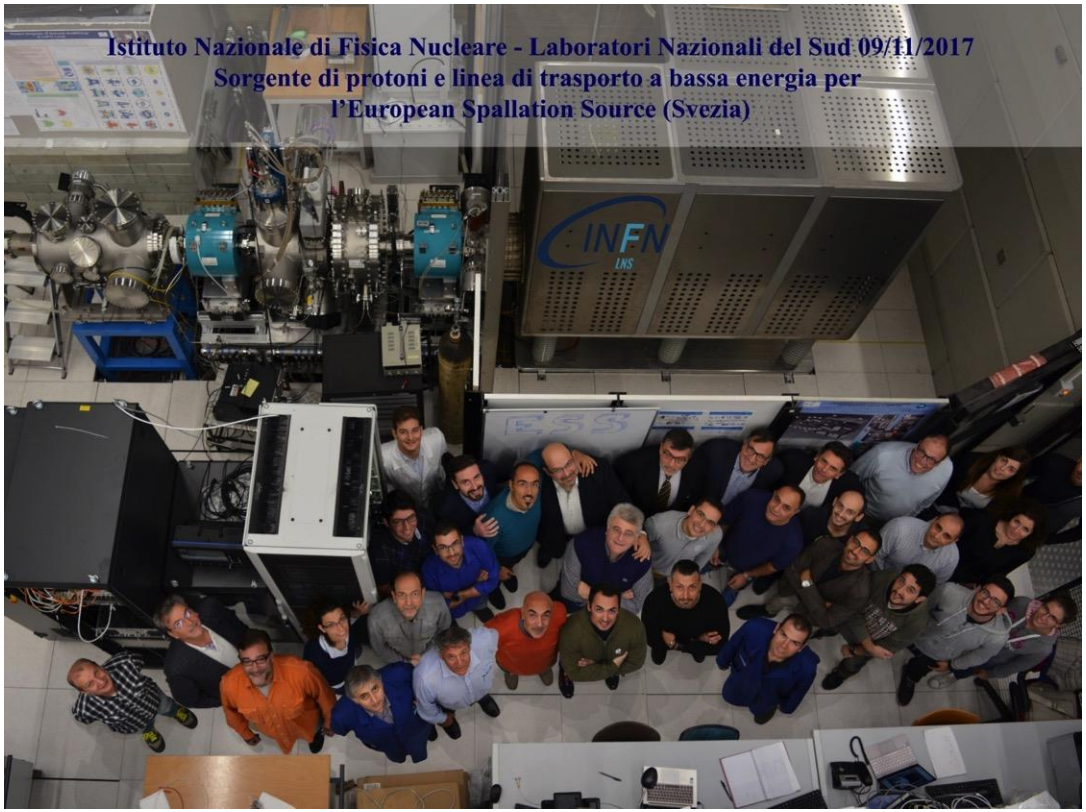
ELIMED beamline at the ELI facility



ELIMED Inauguration on Nov 27th

Sorgente di protoni e linea di trasporto per la European Spallation Source (Svezia)

2017-11-09 Source fully commissioned at INFN-LNS



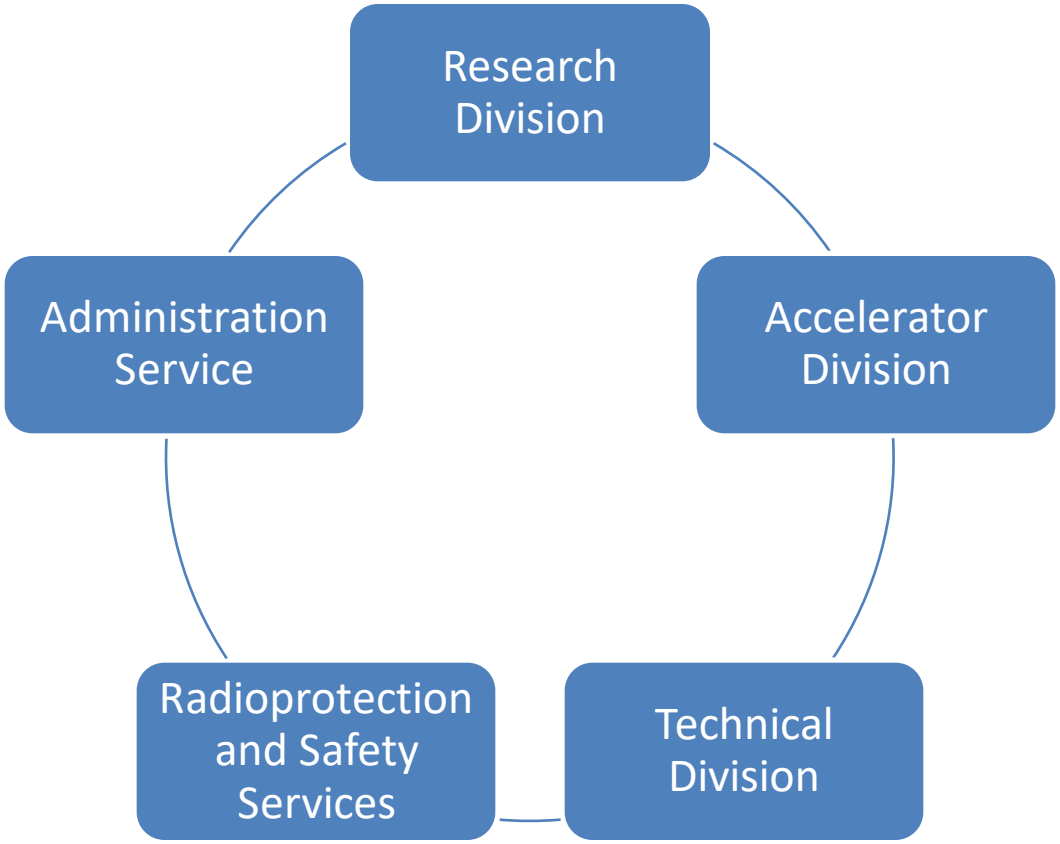
Milestones 3/3

2018-08-03 Source ready for commissioning in Lund

ESS Inauguration on Nov 15th


BUILDING THE FUTURE TOGETHER

LNS towards users



European Nuclear Science and Application Research 2

ENSAR2 – Grant Agreement n. 654002

- Starting date March 1st , 2016
- Duration 48 months

ENSAR2 is the integrating activity for European nuclear scientists who are performing research in three of the major subfields defined by **NuPECC**: Nuclear Structure and Dynamics, Nuclear Astrophysics and Nuclear Physics Tools and Applications.

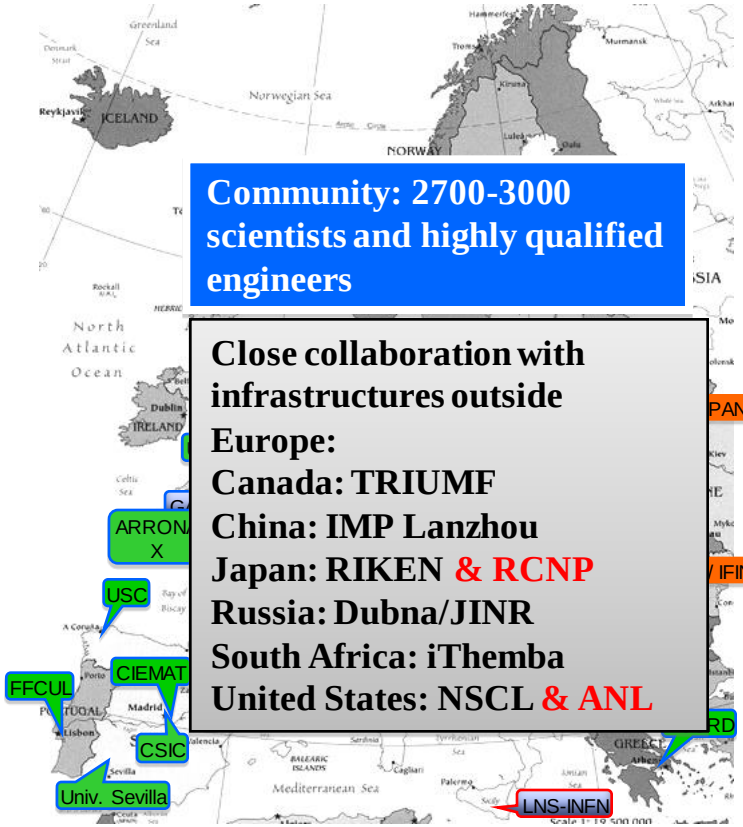
Grant Agreement between

… on the one part the **European Unione**

… and on the other part

GANIL, as coordinator and other 29 beneficiaries (15 countries)

Activities: **25 WP:** **8** Networking Activities **(NAs)**
7 Joint Research Activities **(JRAs)**
10 Transnational Access **(TAs)**



TAs

- **GANIL-SPIRAL2 (France)**
- **LNL-LNS (INFN, Italy)**
- **ISOLDE (CERN, Switzerland)**
- **JYFL (Finland)**
- **ALTO (CNRS, France)**
- **GSI (Germany)**
- **KVI-CART (The Netherlands)**
- **NLC (HIL/IFJ PAN, Poland)**
- **IFIN-HH/ELI-NP (Romania)**
- **ECT* (Italy)**

NEW
NEW
NEW

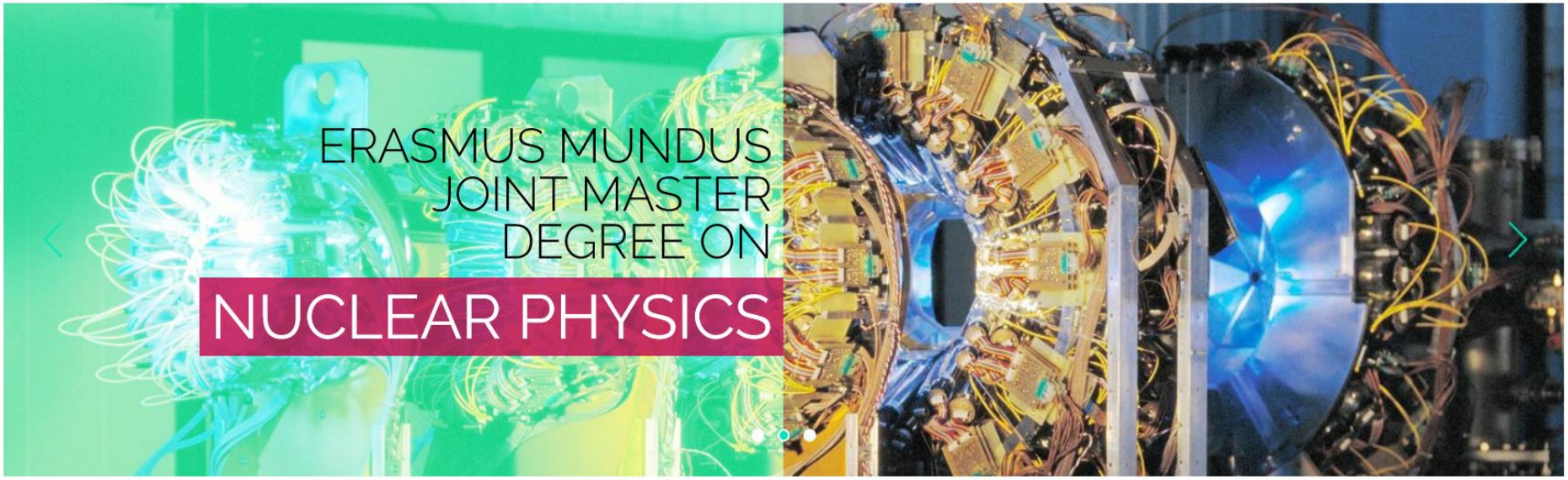
UNIVERSITÀ degli STUDI di CATANIA

Erasmus Mundus JMD on Nuclear Physics

Education and Culture DG

ERASMUS MUNDUS

Co-funded by the Erasmus+ Programme of the European Union



Consortium

French part of the consortium

UNIVERSITÉ
CAEN NORMANDIE

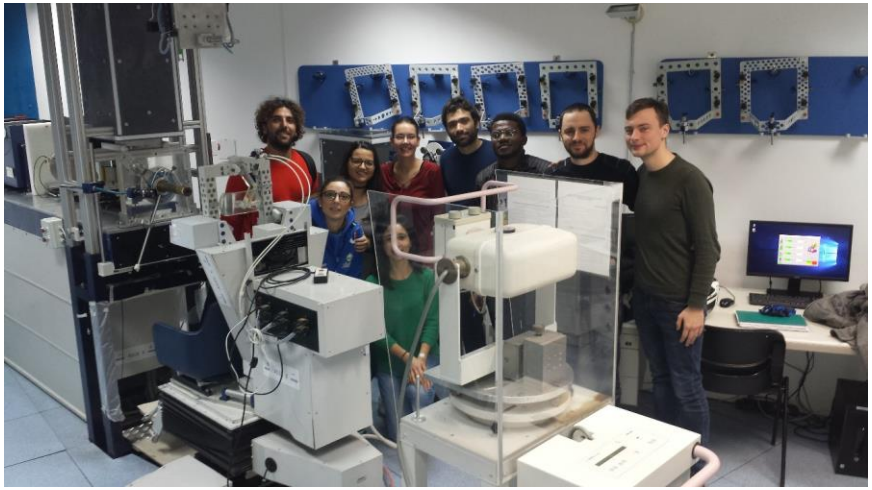
Italian part of the consortium

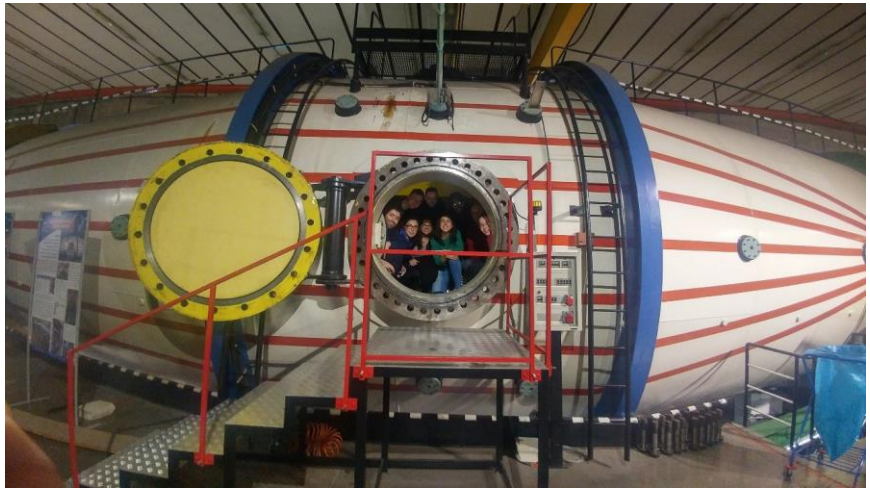
University of Catania is one of the first Universities in Italy, founded in 1433. It is closely related to the INFN unit in Catania and to the Laboratori Nazionali del Sud (LNS). LNS is one of the four national laboratories of INFN. Founded in 1976 it currently employs about 130 people (researcher and technicians) and associates about 130 people among professors, researcher, PhD and Diploma students from the University. It is an advanced development centre for technology and instrumentation. The research activity is mainly devoted to the study of structure and reaction of atomic nuclei by means of both a Tandem and a Supeconducting Cyclotron, in collaboration with more than 700 hundreds researchers coming from Italy as well as several european and non-european countries. A Tandem accelerator allows an intense activity in Nuclear Astrophysics measuring the cross section of interest for fusion nuclear energy and stellar nucleosynthesis (ASFIN2 project). Among the new projects in fundamental research it is also worth mentioning a submarine laboratory installed at 2000m depth offshore from Catania, to be used for R&D related inside the KM3NET project (http://www.lns.infn.it/). UniCT and INFN at CT and LNS, beyond the experiments at the frontier of the Nuclear Physics, are strongly active in several aspects of Applied Nuclear Physics such as accelerators technology, cultural heritage and Achaeometry with non –destructive techniques (LANDIS and PH3DRA labs), monitoring of Nuclear Waste, Laser Physics for Nuclear Fusion plasma and above all in Nuclear Medicine with a centre for eye-melanoma therapy and the projects CATANA, ELIMED, SCENT (see Form A.1.4). The students of EMJMD will be allowed to profit also from an on-going agreement between LNS and Azienda Ospedaliero Universitaria Policlinico di Catania to have a direct experience of applied nuclear medicine.

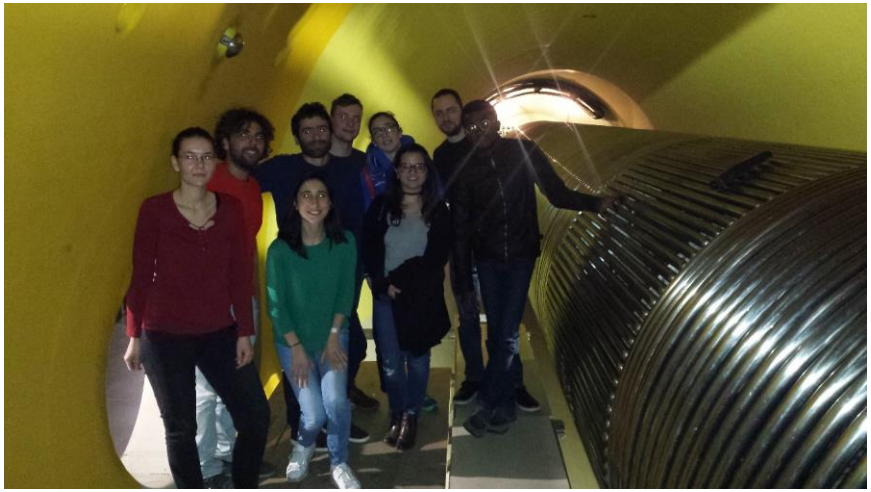
Erasmus Mundus JMD on Nuclear Physics

PATH 3: Applications and small accelerators (1/4 of the students)

Catania S1	Advanced Quantum Mechanics (6)	Advanced Statistical Mechanics (6)	Nuclear & Subnuclear Physics Lab. (6)	Nuclear and Subnuclear Physics (6) or / Nuclear Structure (6)	Advanced Nuclear Techniques Applied to Medicine/ Environmental Radiactivity (6)
Catania S2	Nuclear Reaction Theory (6)	Theory of the Strong Interaction (6)	Nuclear Astrophysics (6)	Experimental Nuclear Physics / Environmental Physics Lab. (6)	Archeometry / Accelerator Physics and Applications (6)
France; S3	Research Internship + Thesis Project (12)	Common Advanced course (6)	Choice between		
			Metrology and data analysis (6) + exp.nucl.phys.+accelerators (6)		
			Applications for therapy (12)		
Spain S4	Master thesis on applications and small accelerators (30)				



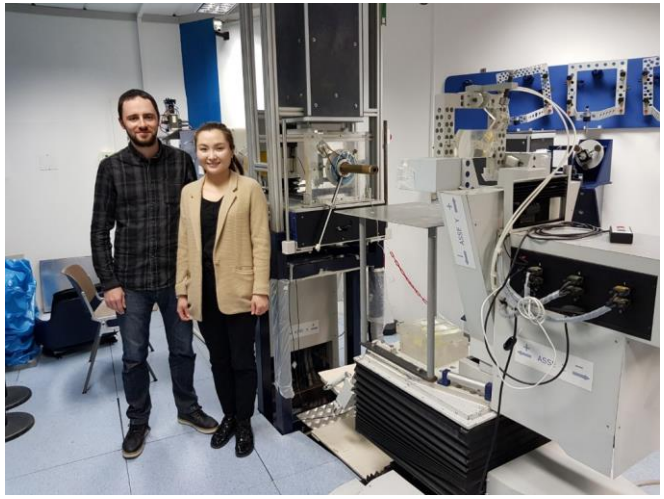


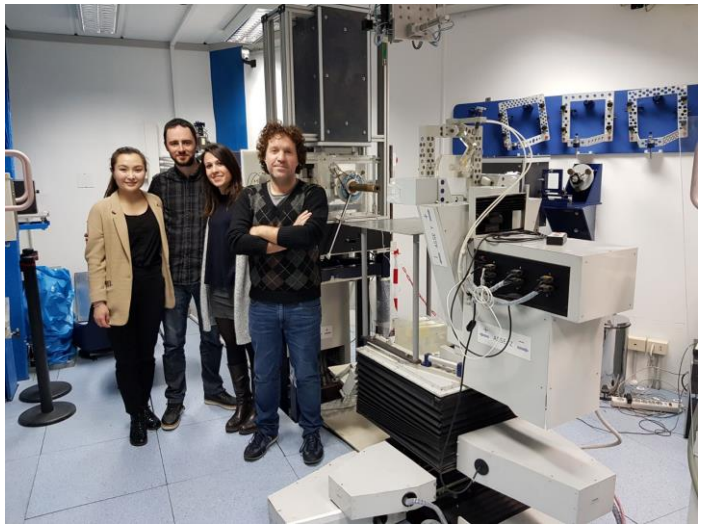


Activities

#NucphysCatania students have been involved in a session of CATANA (Centro di AdroTerapia e Applicazioni Nucleari Avanzate) activity, at the Laboratori Nazionali del Sud.
CATANA was the first Italian center where protontherapy for tumors treatment was applied and still is the unique Italian center where is possible to treat ocular melanoma with proton beams.
Students had the opportunity to observe the different phases of clinical treatments: beam preparation, beam monitoring, dose monitoring and patient irradiation.
In addition, two of them were directly involved in a new INFN project called "ELECTRODE".
The ELECTRODE project is aimed in to the development of a completely new in-vivo, non-invasive, bias-free dosimetric system for the on-line dose monitoring of patients undergoing to radiotherapy treatment.
Two external experts have supervised the activities, Dr. G.A.P. Cirrone (INFN-LNS) responsible of the CATANA beam line and Dr. L. Raffaele (Azienda Ospedaliera Universitaria) responsible of the dose monitoring for CATANA treatments.

External experts





Conclusions

- LNS has a scientific program well defined based on 3 pillars: Nuclear Physics + Nuclear Astrophysics and Accelerators, Km3NeT and Applied Physics.
- LNS has a management system growing up in a well structured context applying modern concepts of scientific management
- LNS has a leading role for Nuclear astrophysics (with FRIBs beams and Trojan Horse Method)
- LNS is an international Research Infrastructure for neutrino astrophysics and deep see applications (The site for KM3Net)
- LNS plays an important role in the educational processes of students from many countries

Thank you for your attention