Nuclear Physics Mid Term Plan in Italy

LNS – Session

Catania, April 4th-5th 2022

Nuclear Physics
Mid Term Plan in Italy

Forthcoming Facilities at LNS

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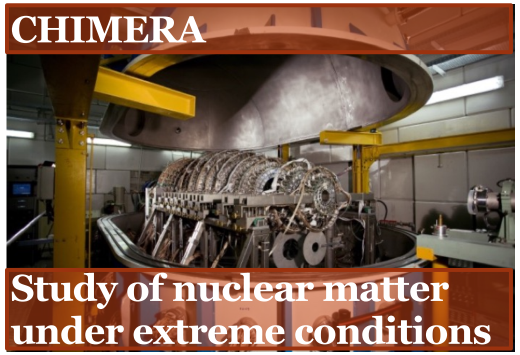
Outline

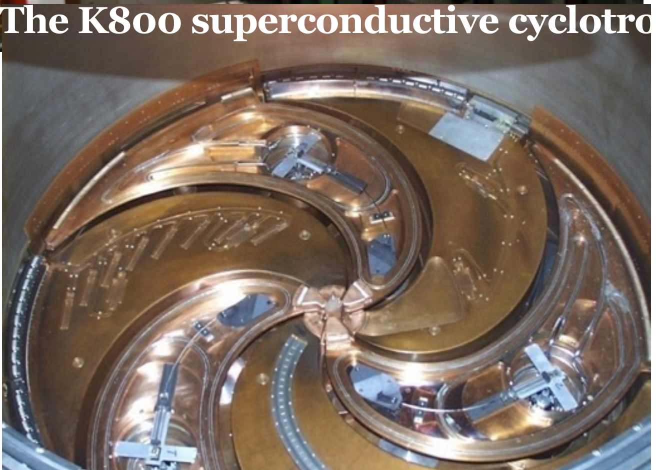
- ✓ General introduction on LNS research facilities
- ✓ Nuclear physics facilities: past and future
- ✓ Perspectives on new beam lines

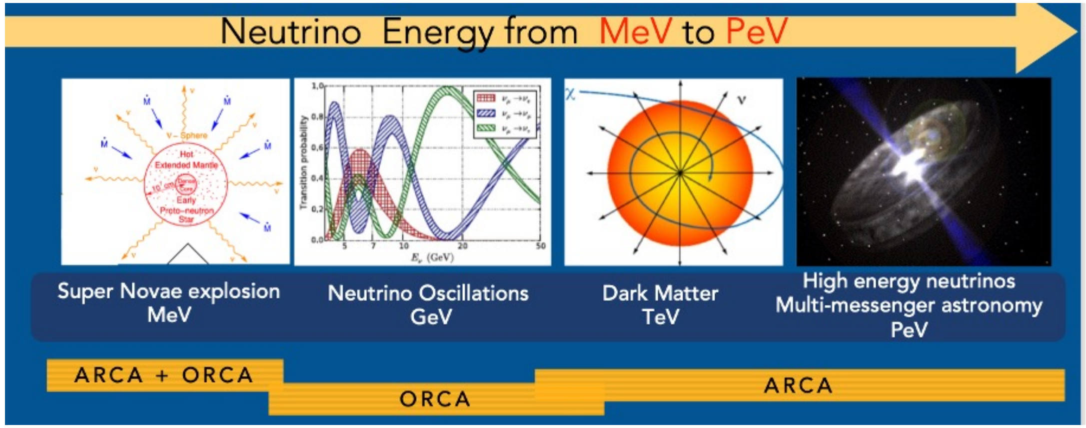
LNS past/present facilities

Thanks to the broad range of available beams and beam energies, LNS research spans a correspondingly broad range of physical problems

- Nuclear structure and dynamics
- Nuclear astrophysics
- Plasma physics
- Medical physics and biophysics
- Astro-particle physics
- Environmental physics
- Applications to cultural heritage







KM3NeT second phase is a research infrastructure housing the next generation neutrino telescopes. KM3NeT will open a new window on our Universe, but also contribute to the research of the properties of the elusive neutrino particles.

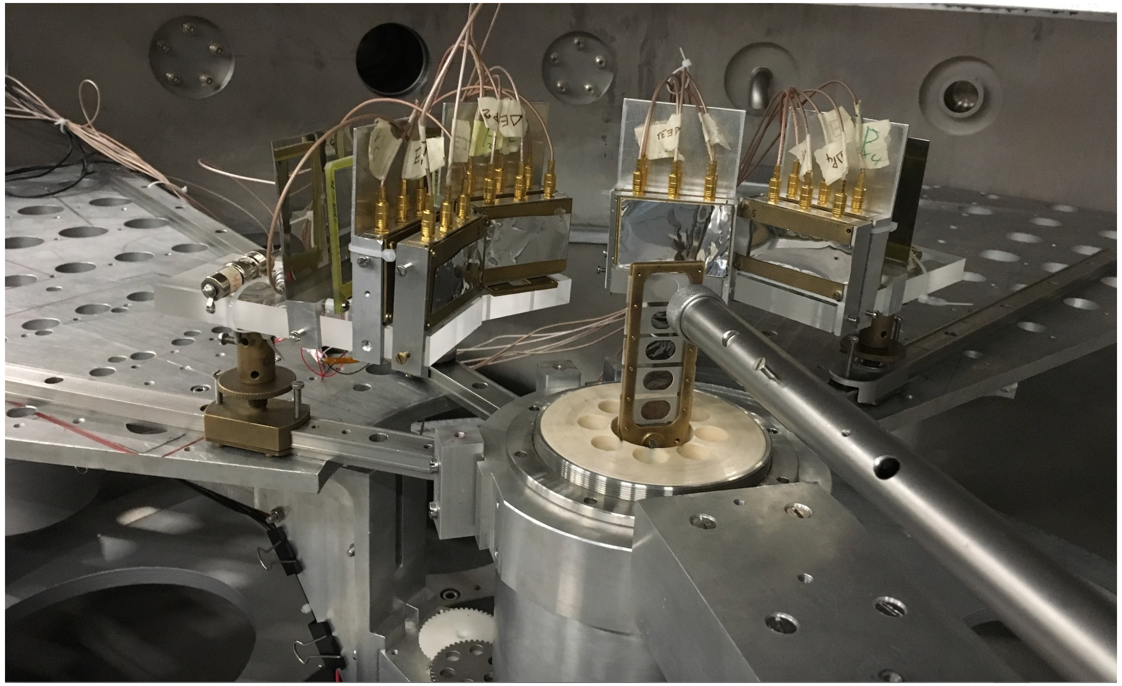
✓ Nuclear physics facilities: past and future

- Multi purpose scattering chambers
- CHIMERA
- MAGNEX
- PANDORA
- BCT, I-LUCE

Other facilities
- in-air irradiation line
- X-ray tube

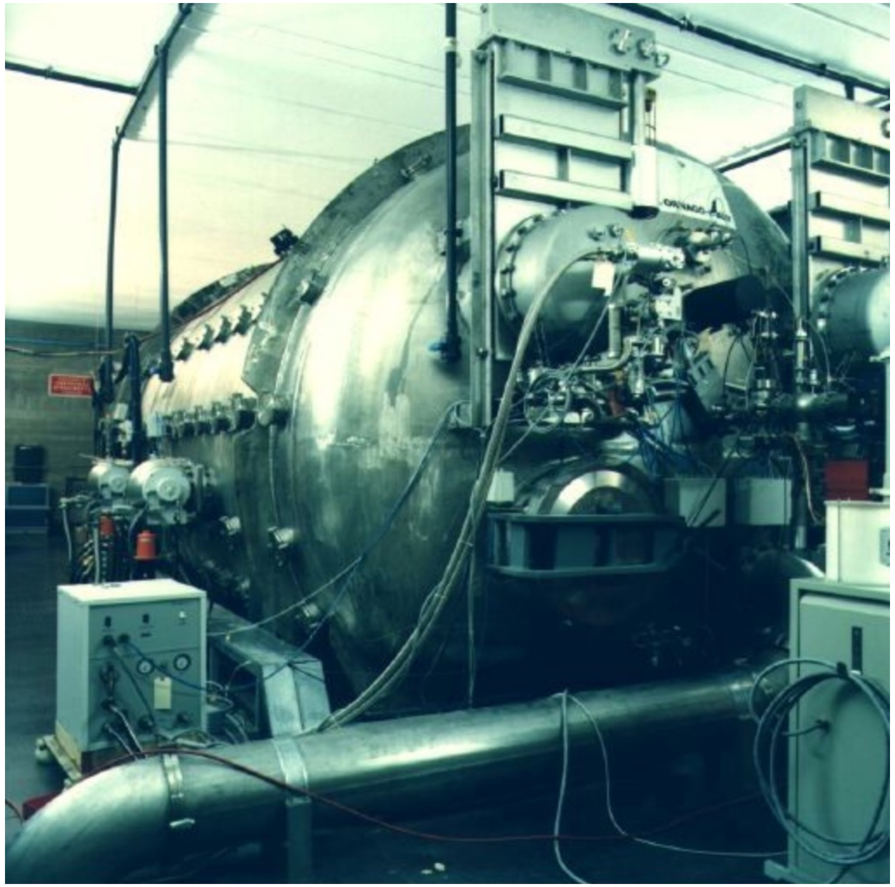
CT 2000 scattering chamber

A diameter of 2 meters, is equipped with 2 independently rotating arms to host the detectors and a collimation system with a goniometer that allows to measure precise angular distributions. Many flanges with vacuum feedthroughs of various standards are available, allowing to run experiments that generate from few to hundreds of signals.

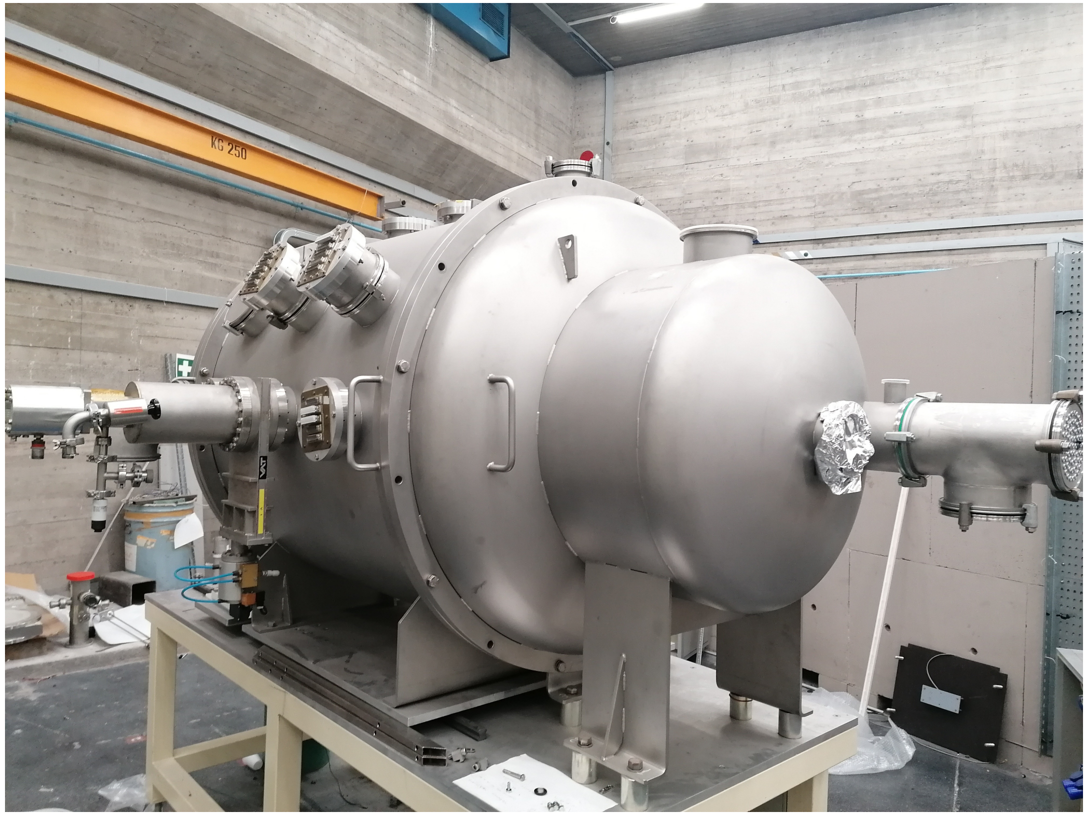


From CICLOPE to GIRA

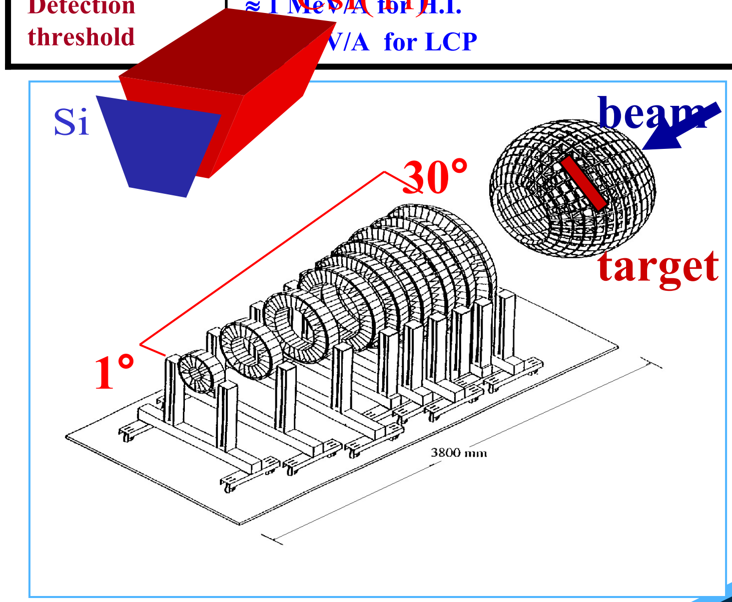
Cylindrical chamber, with a diameter of 2 meters and a length of 4 meters



Cylindrical chamber, with a diameter of 1,2 meters and a length of 2,1 meters



Granularity	1192 telescopes Si (300μm) +CsI(Tl)
Geometry	RINGS: 688 telescopes 100-350 cm SPHERE: 504 telescopes 40 cm
Angular range	RINGS: 1°< θ < 30° SPHERE: 30°< θ < 176° 94% of 4π
Identification method	ΔE-E E-TOF PSD in CsI(Tl) PSD in Si (upgrade 2008)
Experimental observables and performances	TOF dt ≤ 1 ns dE/E LCP (Light Charge Particles) ≈ 2% dE/E HI (Heavy Ions) ≤ 1% Energy, Velocity, A, Z, angular distributions
Detection threshold	≈ 1 MeV/A for H.I. V/A for LCP



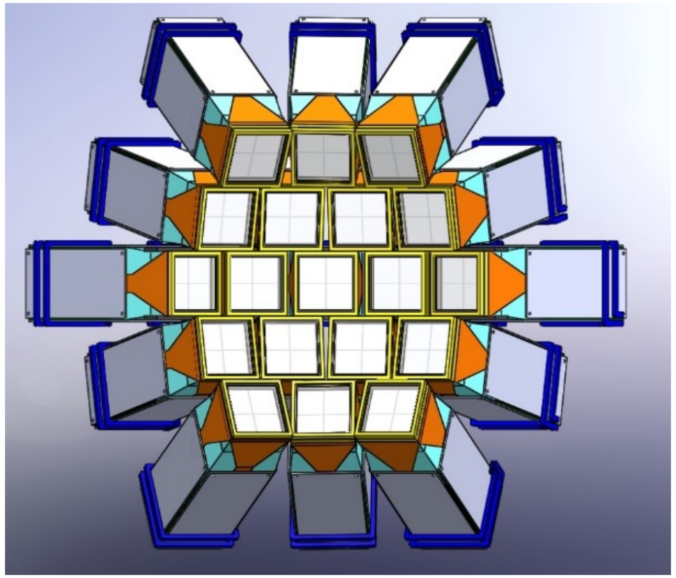
Dynamical range : from fusion, fusion-fission to multifragmentation reactions

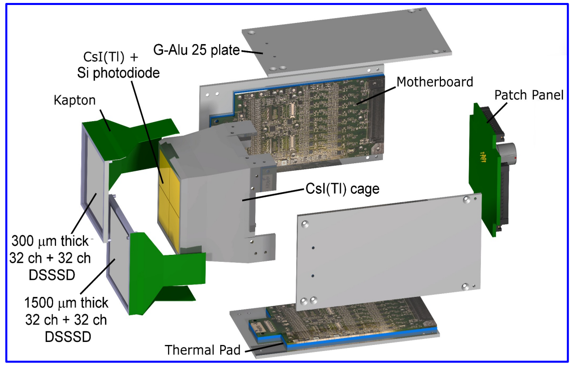
(TANDEM & CYCLOTRON Beams)

Upgrade activities in progress

- Development of a new tagging system for RIBS based on SIC technology
- New cabling in CHIMERA implementing differential signal transmission

FARCOS - Femtoscope Array for COrrelations and Spectroscopy

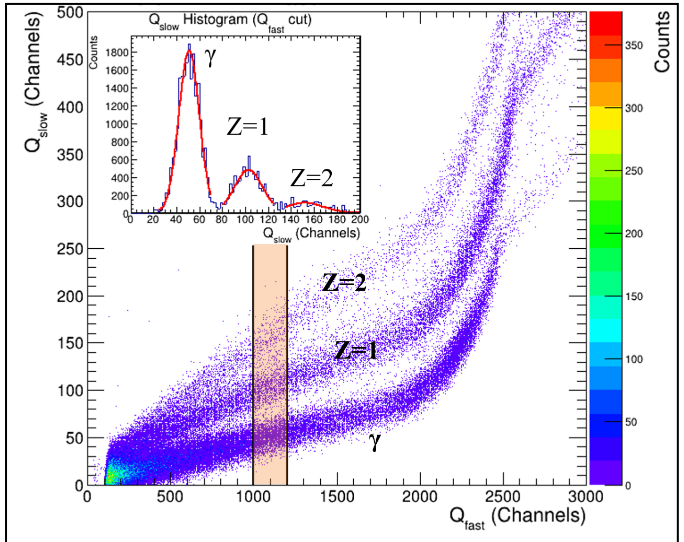




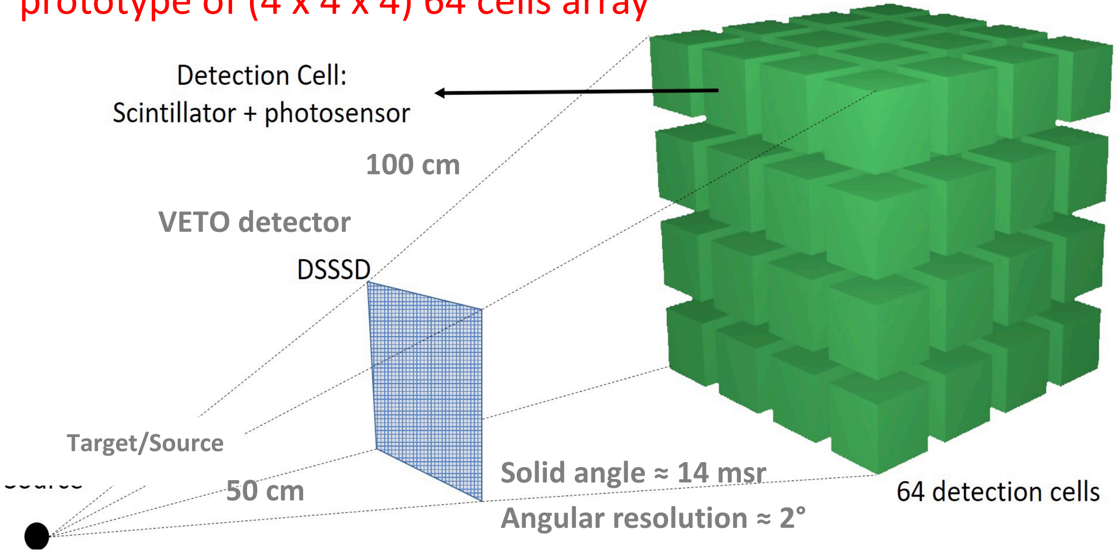
- High energy and angular resolution (δθ, δφ<0.1°)
- Low thresholds (<1 MeV/A)
- Pulse-shape on first Si layer
- High counting rate (1KHz)
- Large Dynamic range (20MeV to 2GeV)
- Flexibility, Modularity, Trasportability: coupling to 4π detectors or spectrometers
- Integrated electronics (GET)
- DAQ, new digital acquisition system
- 20 clusters

Feasibility studies for a new hodoscope for n, gamma and Charged Particles: EJ276(G) read by SiPM

EJ-276G + SiPM

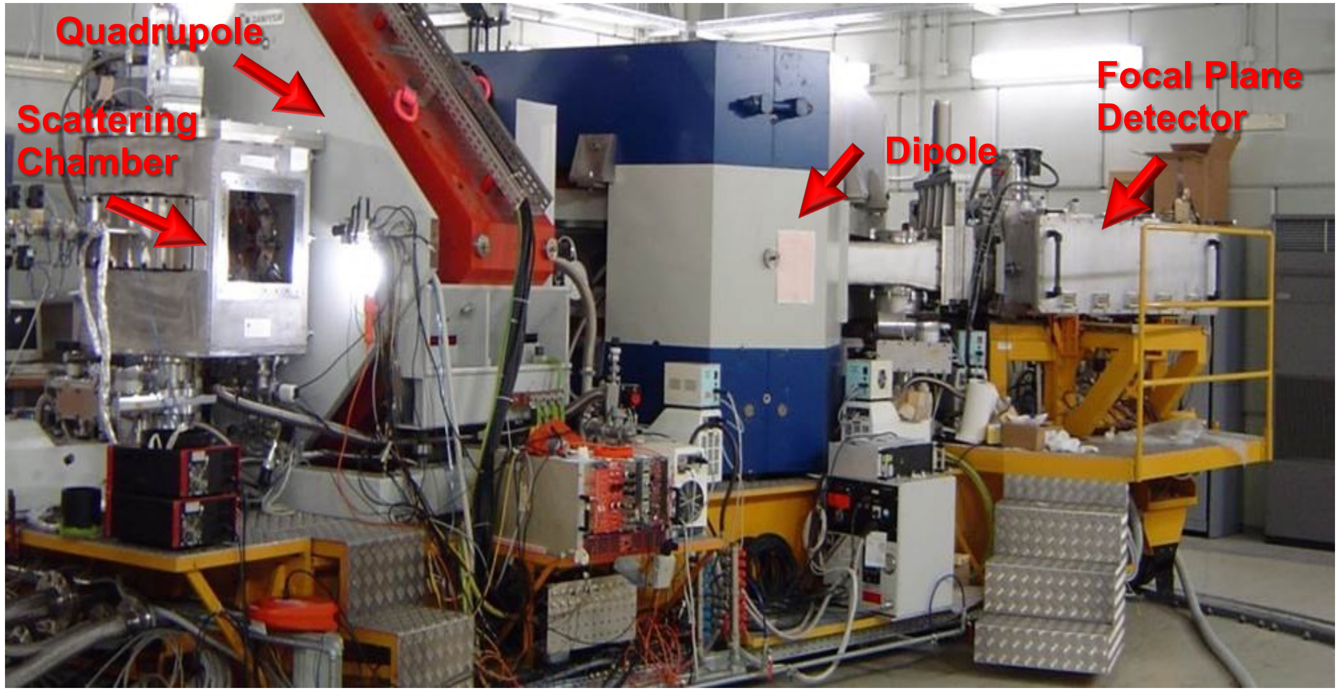


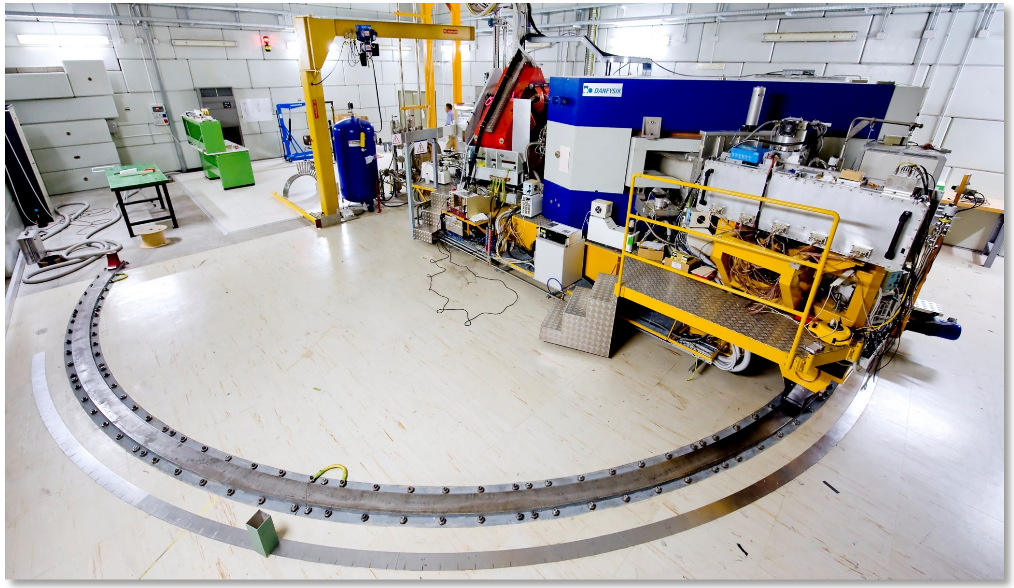
prototype of (4 x 4 x 4) 64 cells array



- 2010 Physics campaigns started

Current MAGNEX configuration



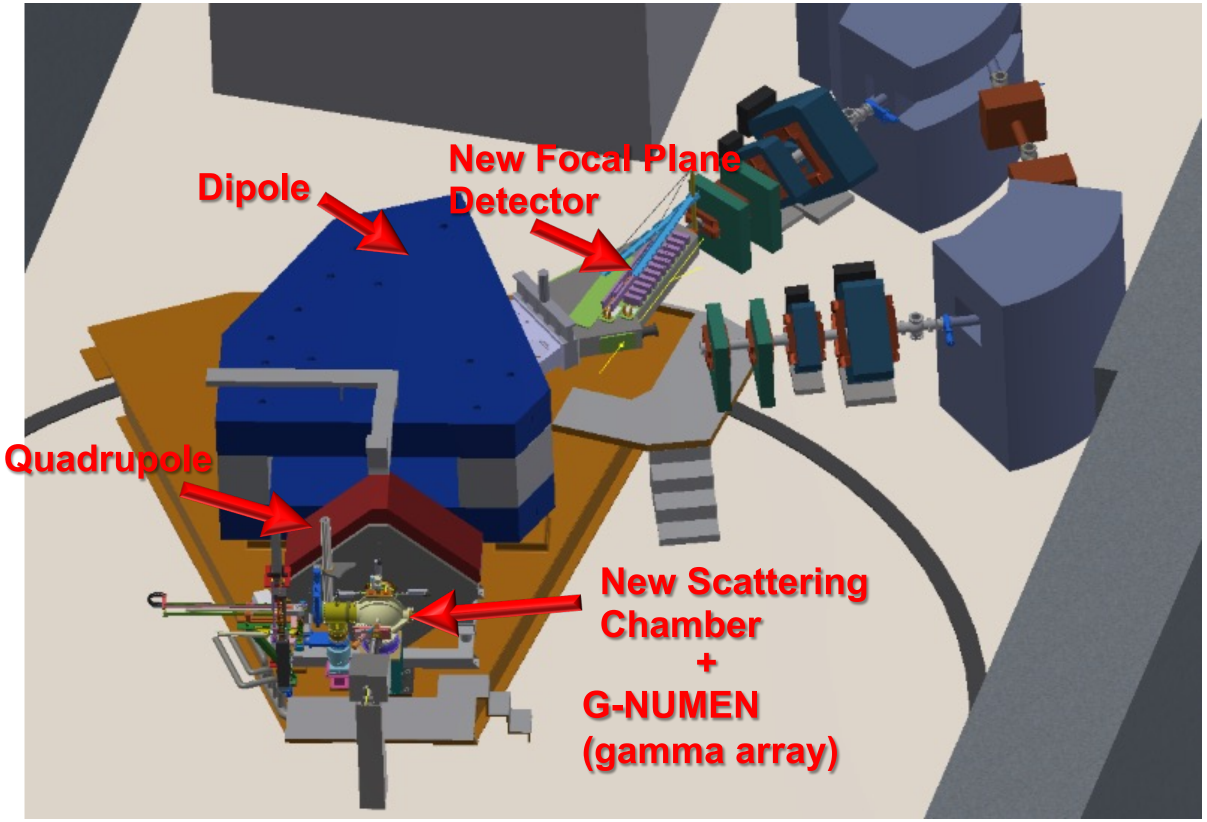


Optical characteristics	Measured values
Maximum magnetic rigidity	1.8 T m
Solid angle	**50 msr**
Momentum acceptance	**-14.3%, +10.3%**
Momentum dispersion for k= - 0.104 (cm/%)	3.68

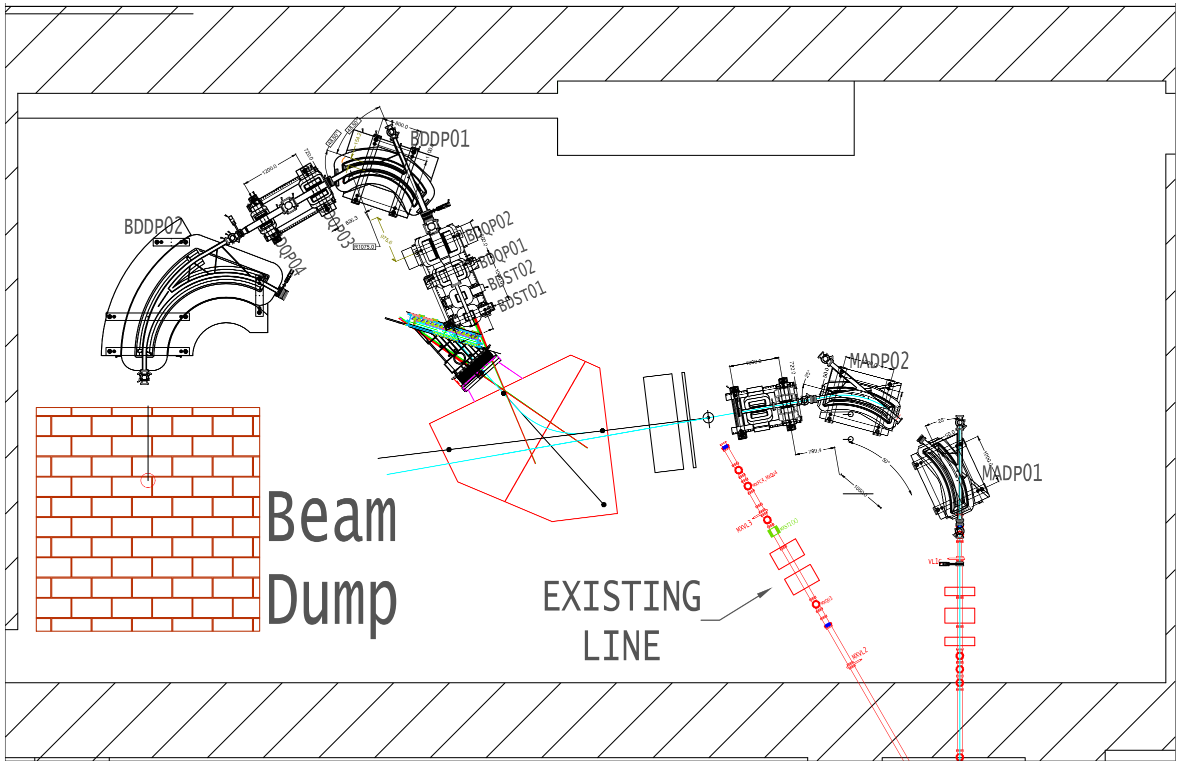
Achieved resolution
Energy $\Delta E/E \sim 1/1000$
Angle $\Delta\theta \sim 0.2°$
Mass $\Delta m/m \sim 1/160$

POTLNS project: triggered by the NUMEN physics case

Future MAGNEX configuration



Future MAGNEX hall

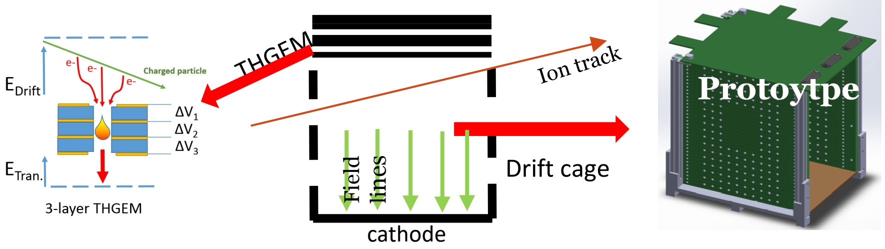


- New MAGNEX power supply to increase the maximum magnetic rigidity acceptance from 1.8 Tm to 2.2 Tm, in order to increase the energy range
- New beam dump in the MAGNEX hall to stop the high power beams

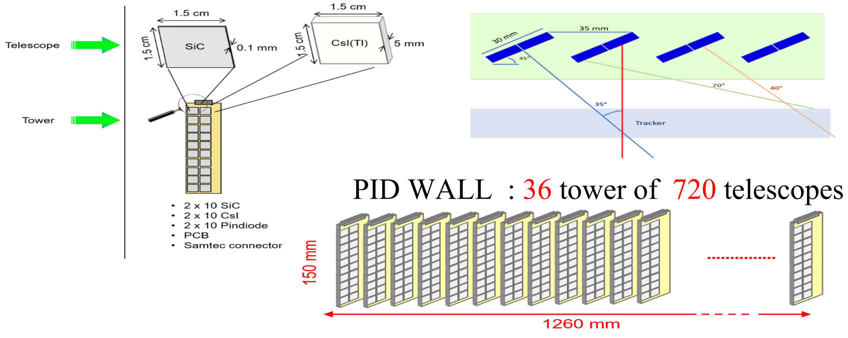
The main MAGNEX upgrade goal is **sustaining high rates**, while maintaining the current MAGNEX **resolution and sensitivity**

MAGNEX upgrade

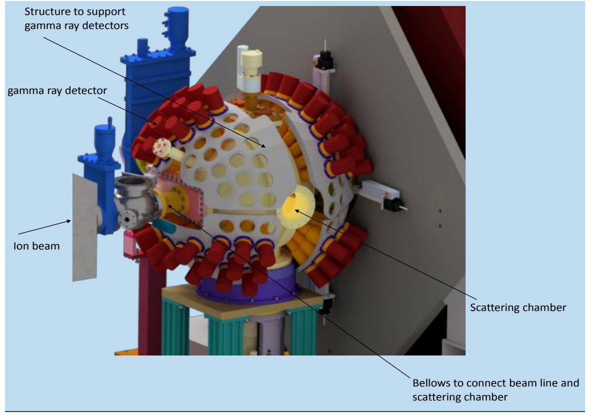
- The construction of a New **Focal Plane Detector:**
  - **- New Gas- Tracker,** based on M-THGEM technology**;**



  - **- New Wall of telescopes** of SiC-CsI detectors for ion identification (PID-wall) ;



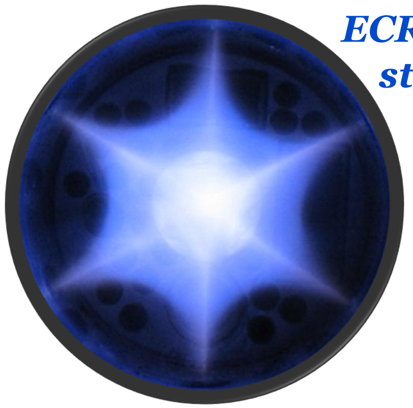
- The introduction of a **gamma - array Calorimeter of LaBr$_3$**(G-NUMEN);



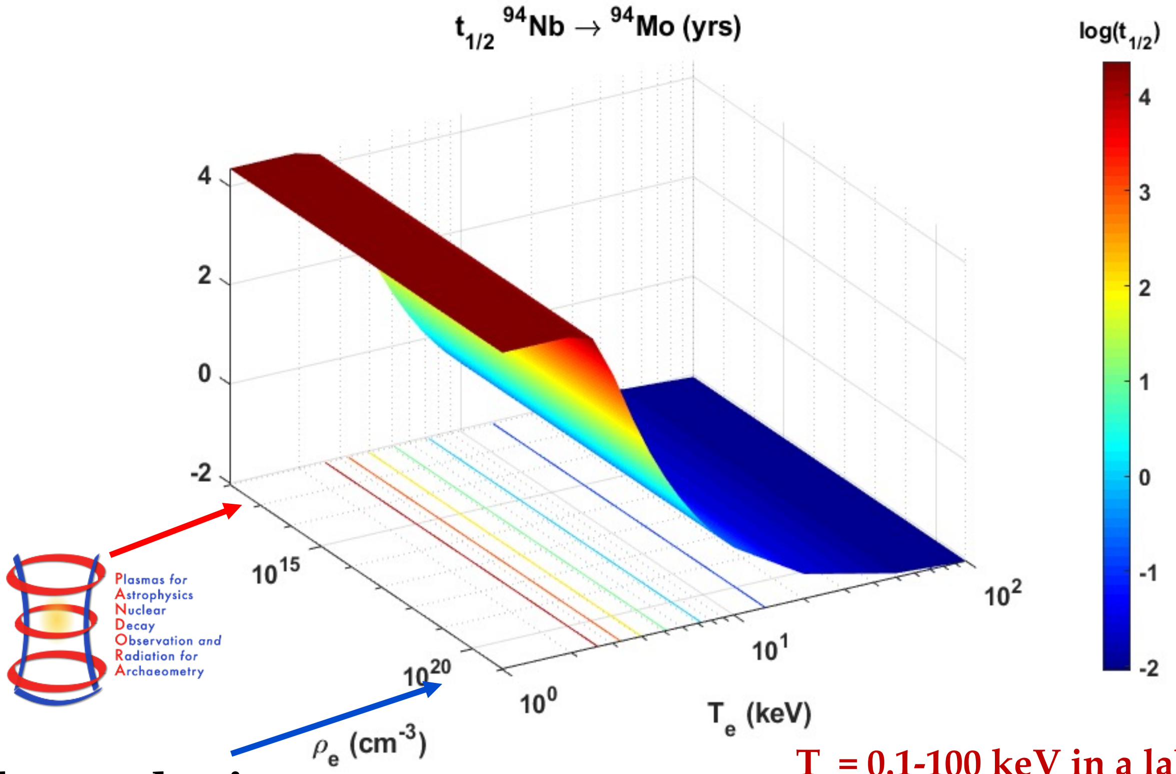
- Refurbishing of the **Dipole** and replacement of the **surface coils**: 420 K€, LNS funding

- The development of suitable **front-end and read-out electronics**, for a fast read-out of the detector signals, a high signal to noise ratio and adequate hardness to radiation;
- The implementation of a **suitable architecture** for **data acquisition, storage and data handling**;
- The development of the **technology for suitable nuclear targets** to be used in the experiments

- Main GOAL: Investigating β-radioactivity in a «stellar» environment



From a laboratory ECR "Plasma star" to…

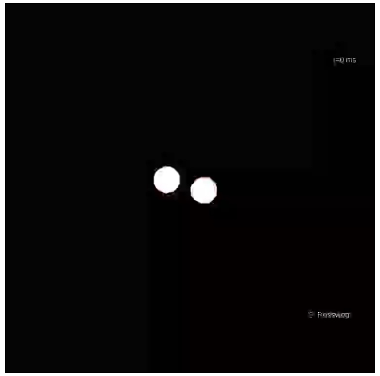


Nucleosynthesis in stars

T_e = 0.1-100 keV in a lab. Magnetoplasma

Additional Goal

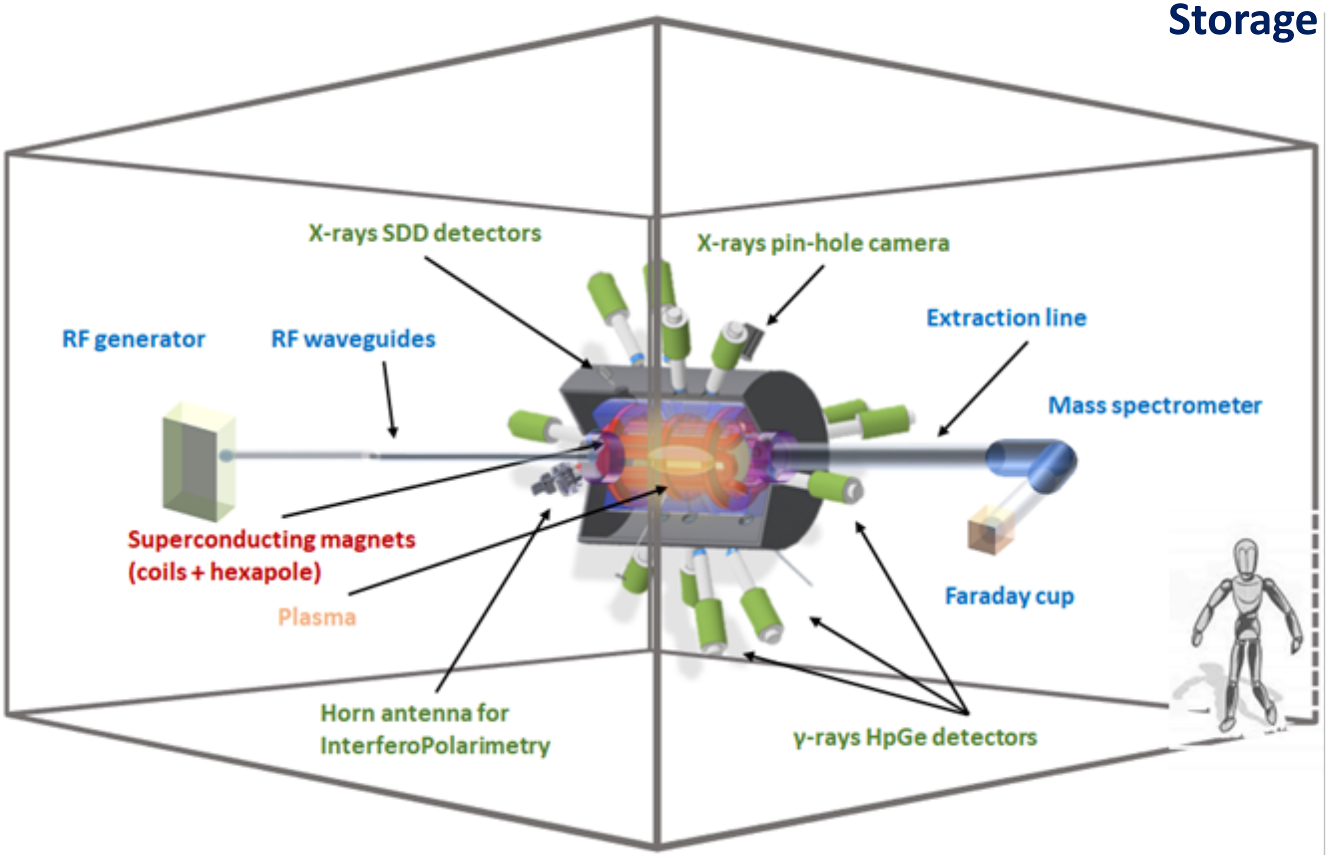
- Measuring plasma opacity relevant for compact binary ejecta (Kilonovae)



Variation with T_e stronger than with ρ so "stellar effect" can be modelled in ECR plasmas

1) **Superconducting Magnetic Plasma Trap:** it contains a plasma made of multiply charged radioisotopes
2) **HpGe Array**: it consists of 14 detectors to measure the γ rays emitted after β-decays
3) **Plasma Diagnostics System:** it consists of RF, optical and X ray spectrometers allowing direct correlation of β-decay rate to plasma density and temperature

This will make it possible is to measure nuclear β-decays in an Electron Cyclotron Resonance Ion Trap and check results obtained in Storage Rings: 187 Re lifetime reduction by 9 orders of magnitude!



Physics cases to investigate:

Isotope	$T_{1/2}$ (yr)	Eγ (keV)
^{176}Lu	3.78×10^{10}	88-400
^{134}Cs	2.06	>600
^{94}Nb	2.03×10^{4}	>700

COSMO-CHRONOMETER

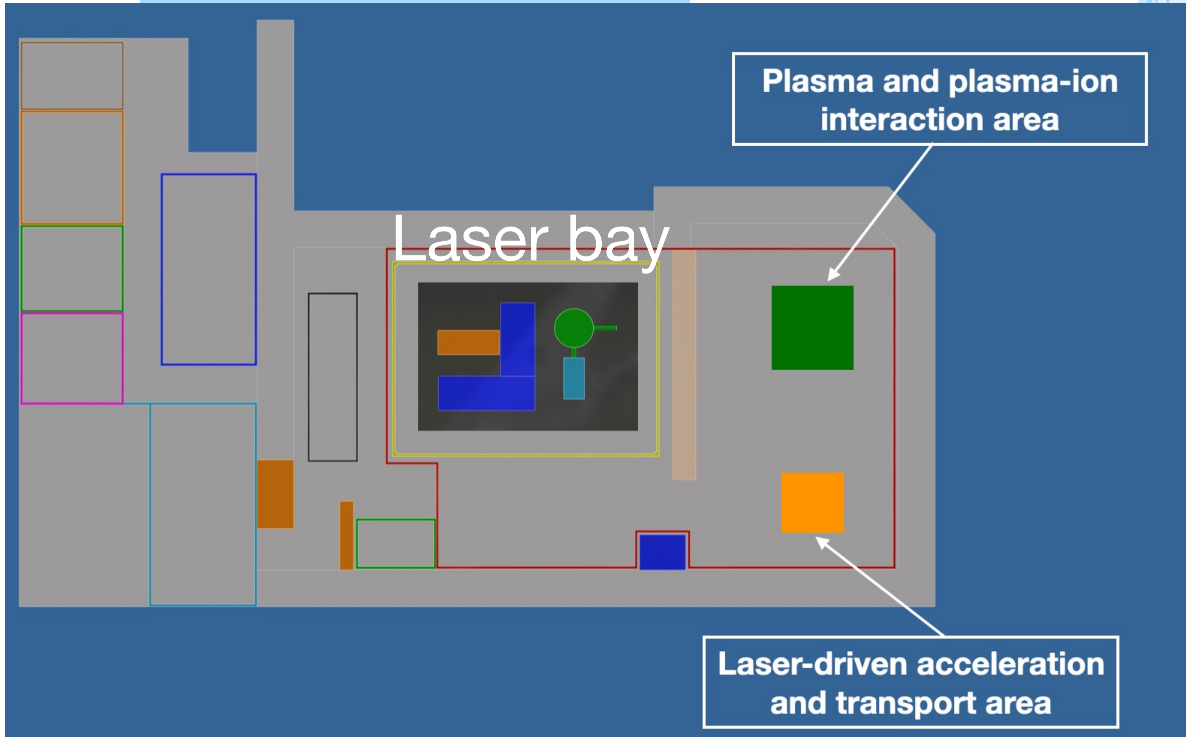
reproduction of the two s-only isotopes ^{134}Ba, ^{136}Ba in suitable proportions

Solving the puzzle about the the exact contribution of s-processing to ^{94}Mo: β-decay or binary stars

BCT: Breast Cancer Therapy (expected by June 2024)

Regional funded project within an agreement between INFN, University of Catania and Cannizzaro hospital

Main purpose: Radiotherapy, drugs development, new treatment modalities of breast carcinoma



I-LUCE: INFN Laser IndUced particle acCeleration

Part of the BCT program

The laser system will provide e- and p acceleration to obtain «FLASH» regime biological irradiation and study of medical applications

First BCT phase:
Laser power: 45 TW - 50 TW
Energy per pulse ≥ 1 J
Pulse duration: <25fs
Repetition rate: 1-5 Hz

→ Proton beams: max energy 5 MeV; fluence: 10^9 cm^{-2} @ 1 MeV
Electron beams up to 200 MeV
X-rays, neutrons

Second BCT phase:
Laser power: 250 TW

→ Proton beams: max energy 30 MeV; fluence: 10^9 cm^{-2} @ 15 MeV
Electron beams up to 500 MeV
X-rays, neutrons

System designed to be upgradable up to 1 PW

What can we do after BCT?

- ✓ **Cultural Heritage:**
  PIXE studies with laser-driven protons
- ✓ **Space applications:**
  laser-driven beams could easily reproduce the space radiation quality
- ✓ **Radioisotopes production:**
  laser-driven beams could easily produce high intensity charged particles beams
- ✓ Imaging at the molecular level with ultrafast X-Rays (ex radiation chemistry of the radiolysis)
- ✓ Neutron sources
- ✓ Free Electron Laser radiation

- ✓ Stopping powers in plasma
- ✓ Studies on **Nuclear Reaction**
- ✓ Materials studies
- ✓ **…………** Many other physics cases

To highlight! Ion beams from the accelerators-plasma interaction: as **UNIQUE CAPABILITY OF INFN-LNS**

In-air irradiation with ion beams

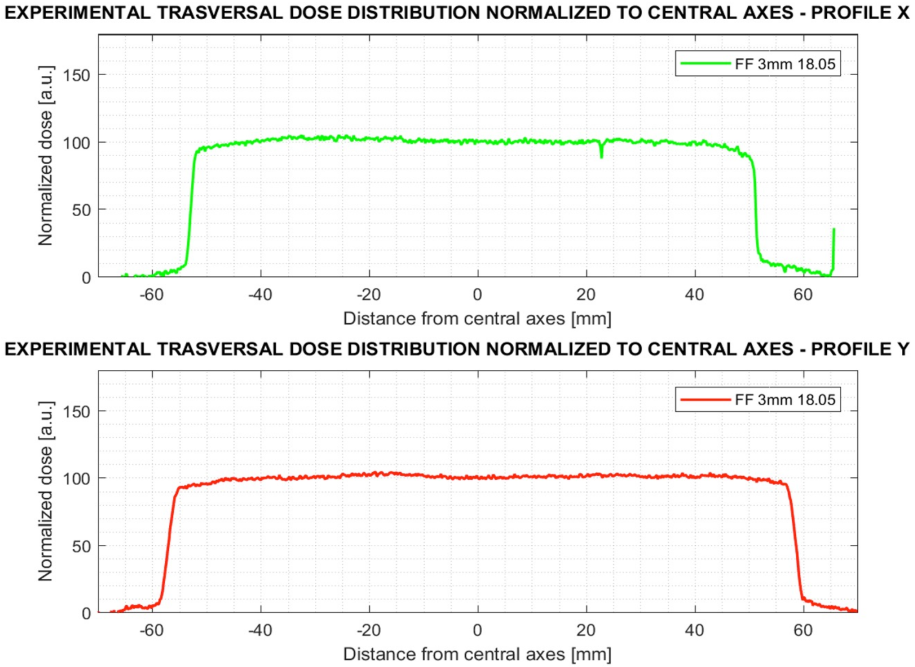
LNS is equipped with a multidisciplinary beamline where several international groups perform innovative experiments for different kinds of application, from radiation damage study to irradiation of biological sample and of electronics devices.

The new intensities as well as the new RIBs will open new perspectives for irradiation of samples under extreme conditions: high dose-rate measurements and for mimicking of laser-driven accelerated beams or high-power pulsed beam from modern accelerators.

the X-ray tube will represent an irradiation facility, fully available for internal and external users with potential applications in the field of irradiation of in-vitro and in-vivo samples for radiobiological purposes, 2D imaging, cultural heritage, irradiation of detectors for X-ray beam calibration, radiation hardness studies, detectors characterization, etc.

- **Removable brass flattening filter (thickness 3 mm)**
- **Homogeneity < 10% along both X and Y directions**
- **Collimation system (attenuation factor 1000) based on 1.5 mm lead slits**
- **Pneumatic ON/OFF light field system for sample positioning**

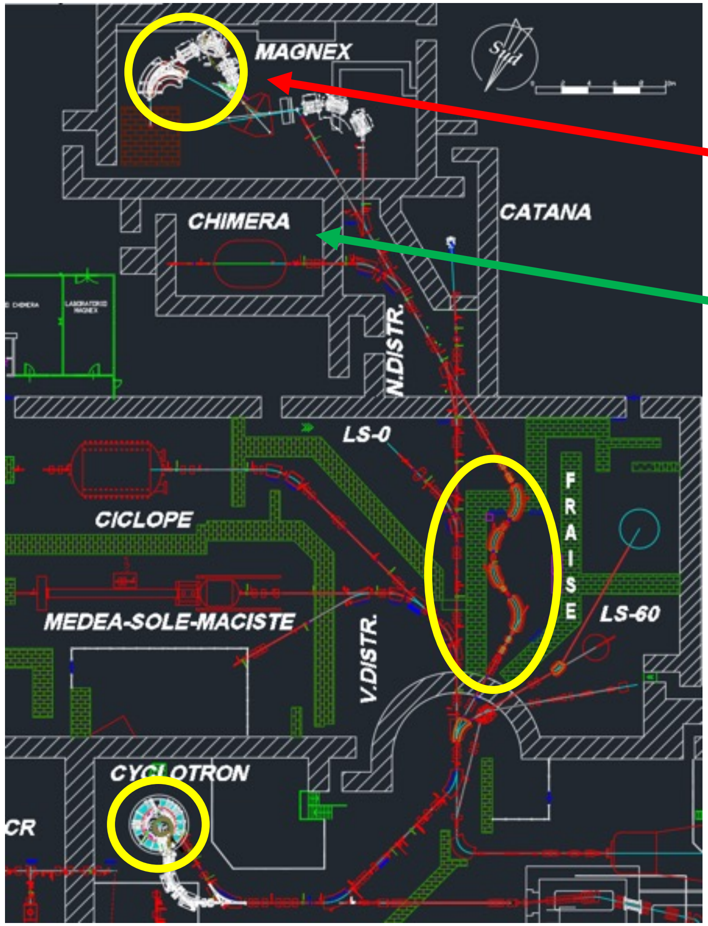
System designed @LNS



Maximum peak voltage: 320 kV
Focal spot: 0.4/1.0 mm

POTLNS - Beam line goals

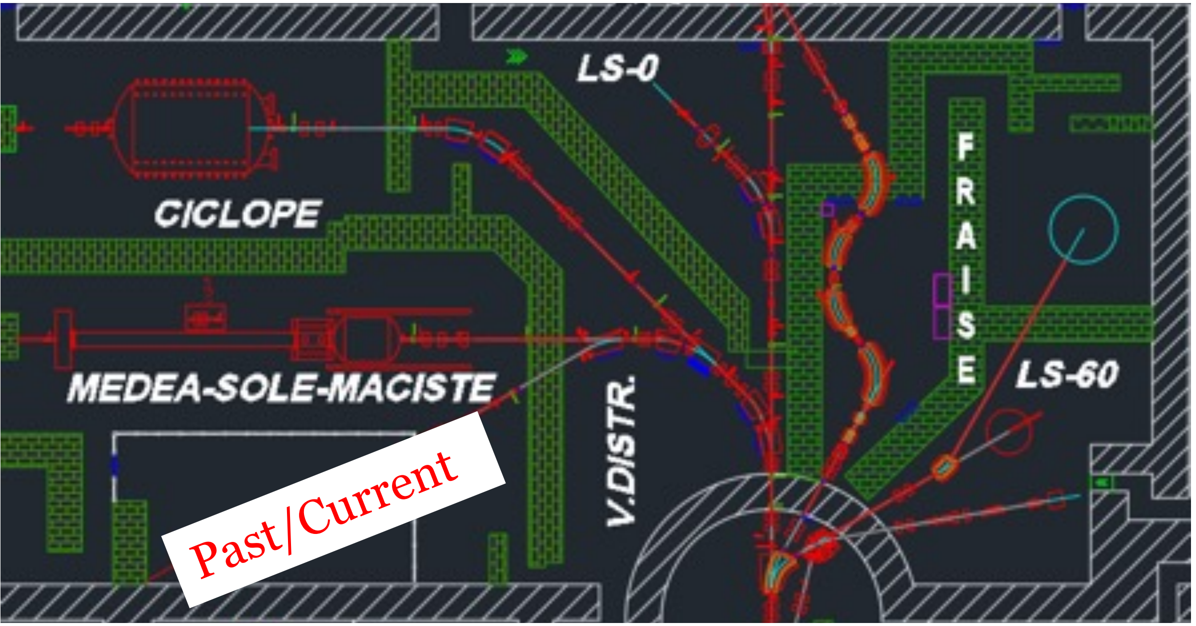
Currently, the POTLNS project plans to install new beam lines suitable to transport the beam extracted from the new exit channel of the K800 to the beam-dump.

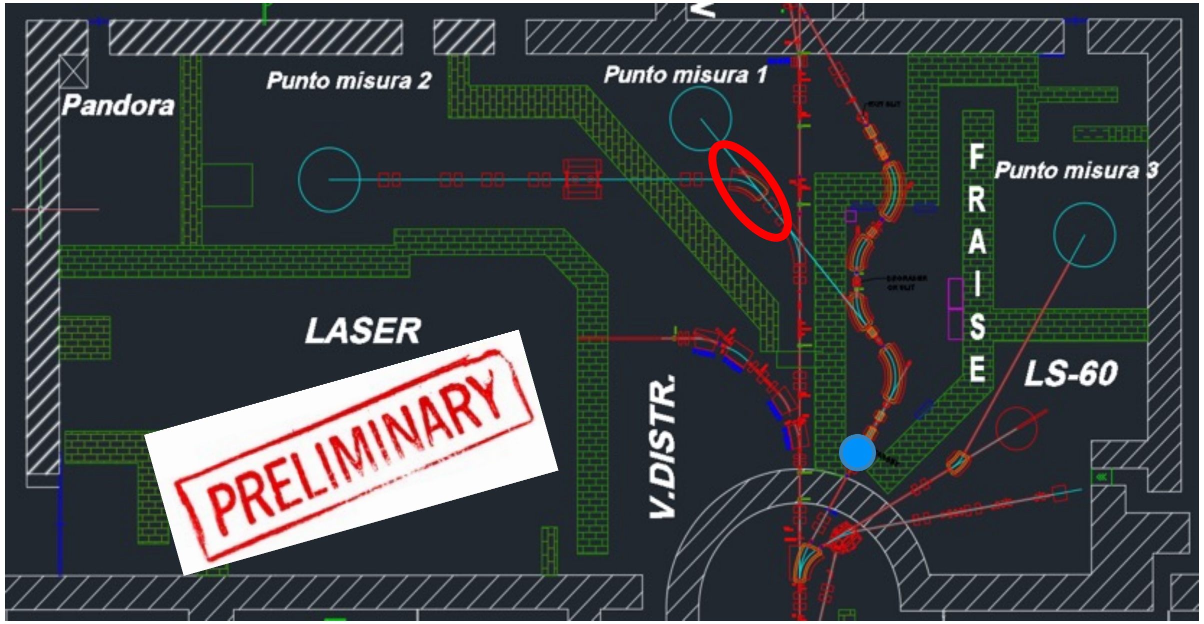


Experimental hall served by beam extracted using the stripping method:

- MAGNEX
  Study of cross sections for double charge exchange nuclear reactions
- CHIMERA
  Study of exotic species produced and selected by FRAISE line;

Need to exploit the new beam features and lines for the users →





With the decommissioning of the Ciclope chamber it is possible to obtain enough space to host a new experimental point and the Pandora setup

A zero degree exit of the second dipole of FRAISE line allows to connect the FRAISE line to new experimental halls.

Both K800 beam extracted by stripping method and the fragment ions produced using the in-flight technique will reach the new measurement point.

This layout opens new scenarios and opportunities for the users, avoiding any interference with CHIMERA and MAGNEX setup.

Summarizing

PAST	FUTURE
CT2000 @ 60° beam line	CT2000 @ 60° beam line
	New chamber @ 40° beam line
CICLOPE	GIRA
CHIMERA	CHIMERA plus CORRELATORS
MAGNEX	MAGNEX upgraded
MEDEA	
	PANDORA
	BCT + I-LUCE

… and a lot of new beams with a broad range of intensities and species.

Many activities currently underway and many to come in the near future …

Thank you for your attention!