R. Nania/P. Giubellino
INFN acceleratori 4-5 Aprile 2024
Thanks to
G. Bisogni, G. Volpe, M. La Cognata, S. Piantelli, S. Zavatarelli, S. Pisano, D. Mengoni, J. Valiente Dobon , M. C. Morone

CSN3 and Accelerators

Focus Point on Middle Term Plan of Italian Laboratories in Nuclear Physics:

- Nuclear physics midterm plan in Italy: introduction to the series
- Nuclear physics midterm plan at LNL
- Nuclear physics midterm plan at LNS
- Nuclear Physics Mid Term Plan at LNGS

https://web.infn.it/nucphys-plan-italy/

INFN CSN3

CSN3 Fisica Nucleare

CSN3 Research Lines 2023/24 Following NUPECC indications

1

QUARKS AND HADRON DYNAMICS

KAONNIS (LNF) , JLAB12 (JLAB),), EIC_NET (BNL) MAMBO (Mainz-Bonn), ULYSSES (JPARC

2

PHASE TRANSITION IN HADRONIC MATTER

ALICE (CERN) , NA60_PLUS(CERN)

3

NUCLEAR STRUCTURE AND REACTION MECHANISM

FORTE, GAMMA, CHIRONE, NUCL-EX, NUMEN_GR3, PRISMA_FIDES (LNS, LNL, GANIL, ISOLDE, GSI, RIKEN,....)

4

NUCLEAR ASTROPHYSICS

ASFIN, ERNA, LUNA , n_TOF, PANDORA (LNS, LNL, LNGS, CIRCE , CERN...)

5

FUNDAMENTAL INTERACTIONS

LEA (CERN), JEDI (Jülich),VIP (LNGS), FAMU (RAL)

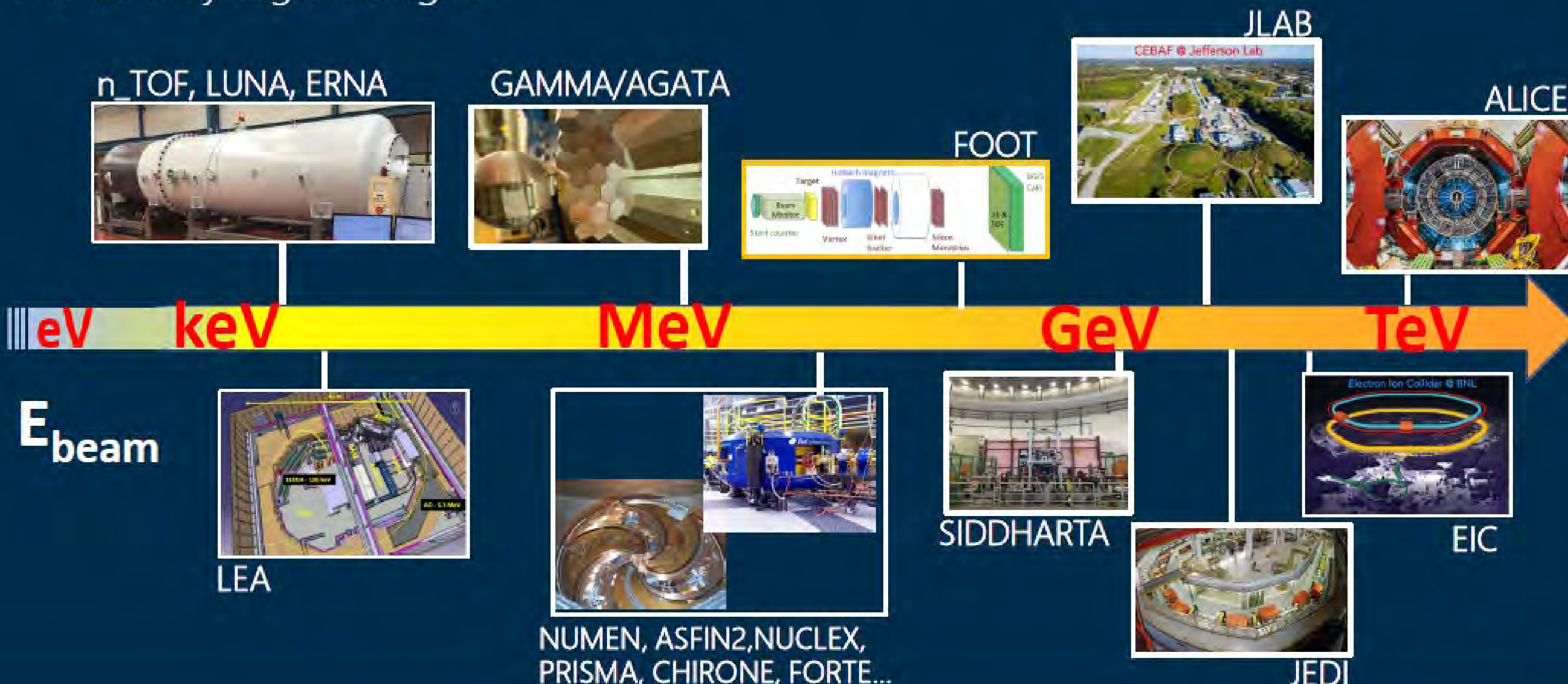
6

APPLICATIONS AND SOCIETAL BENEFITS

FOOT (GSI,CNAO,TIFPA, HIT)

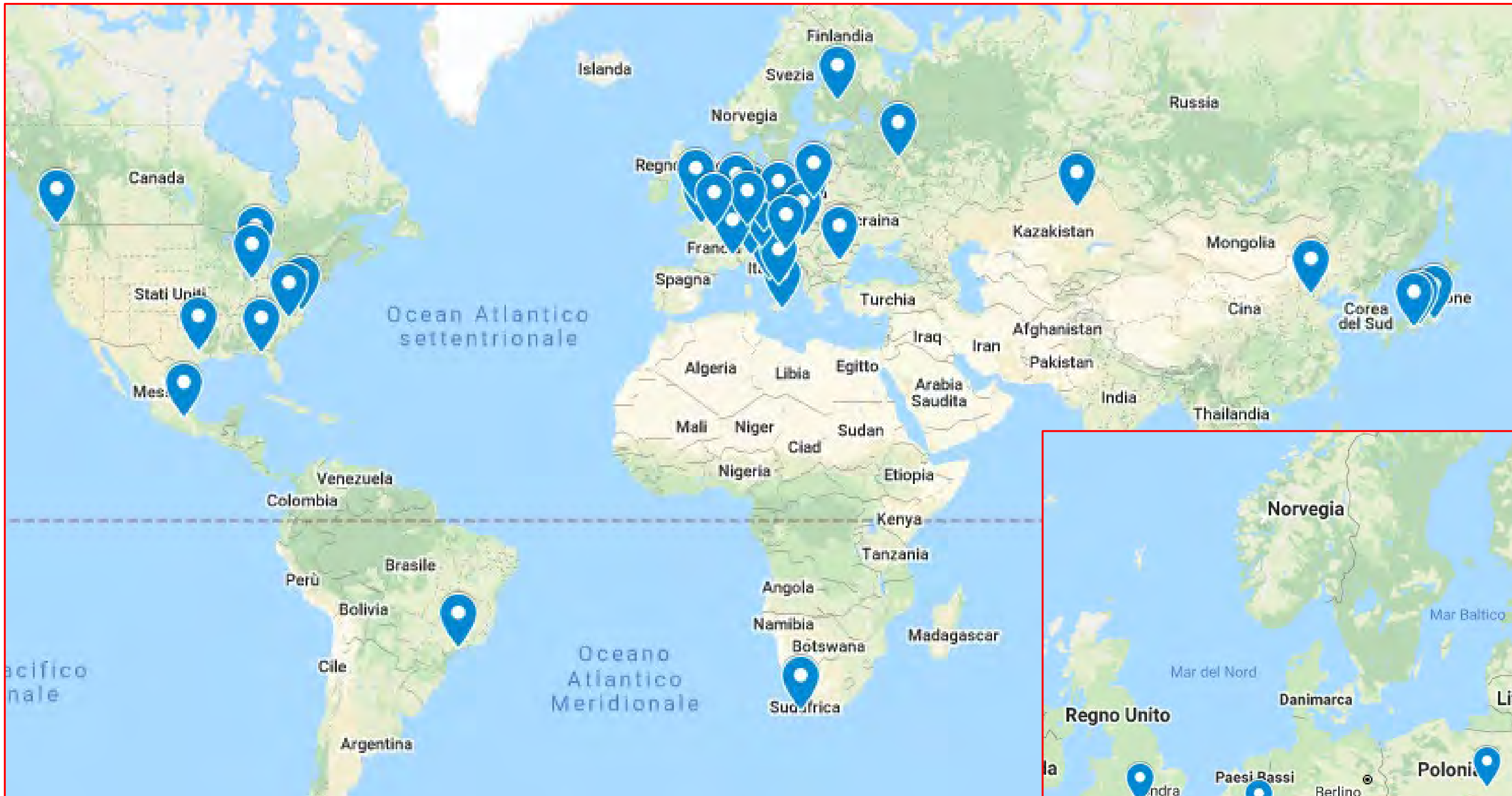
The CSN3 experiments

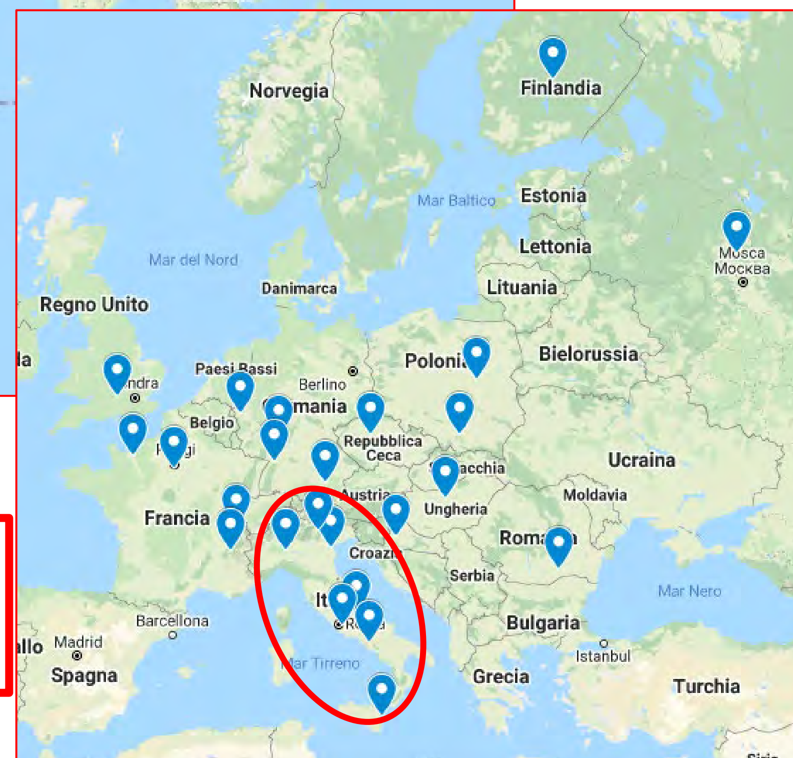
CSN3 experiments use different types of beams (stable or radioactive), from low to very high energies



Modified from R. Arnaldi

National and International Laboratories for CSN3 experiments



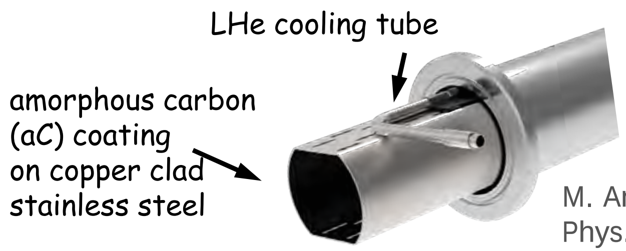


In Italy
LNL, LNS, LNF, LNGS,
TIFPA, CIRCE, CNAO

BNL – INFN collaboration for EIC

slide by R. Cimino

To avoid high resistive-wall (RW) heating and electron cloud, a beam screen (BS) will be installed in the beampipe of the RHIC superconducting magnets.
Project approved within Long Lead Procurements (LLP) items



M. Angelucci, et al.
Phys. Rev. Research **2**, 032030(R)

1) SoW (2023-26) to perform, at LNF, surface studies for qualifying the BS prototypes of the hadron ring vacuum chamber of EIC.

The **mitigation of collective effects** (e-cloud, etc.) and impedance driven instabilities in circular accelerators are also based on the definition of new constructive materials and on their Secondary Electron Yield (SEY) characterization.

LNF-INFN will perform the necessary studies to validate prototype materials and coatings to define the best practices for final production.

2) Collaboration to develop a complete, turn-key SEY measurement system to be delivered to EIC to 'in-house' qualify the BS mass production.

The **qualification of materials during their mass-production** is a necessary end step of the manufactory chain. The possibility to have a measurement mock-up system to qualify materials "in situ", is therefore essential to avoid expensive and time-consuming materials' validation from external laboratories.

LNF-INFN will design, set-up, test and deliver a full-working turn-key SEY measurement system to be available in-house, for BS large scale production validation.

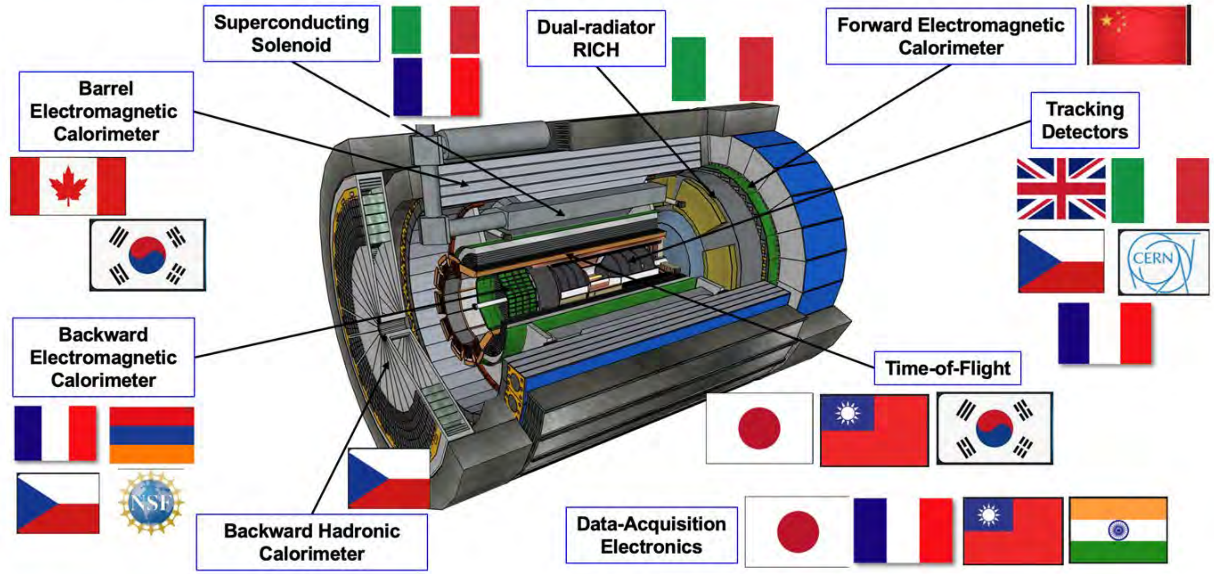
- LNF - INFN can significantly contribute to define and validate the best coating procedure.
- LNF - INFN (in agreement with our top management) will provide the needed measurement system to be delivered to BNL for "in situ" characterization of the industrial production of the **4 km BS.**

INFN
CSN3

ePIC @ BNL Electron Ion Collider (EIC)

Slide by P. Antonioli

Central Detector Non-DOE Interest & In-Kind

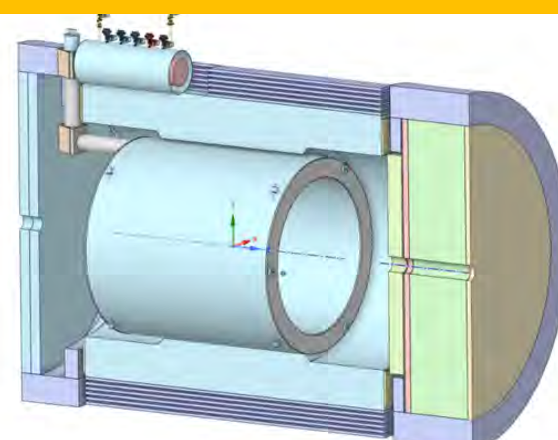


Detector Solenoide MARCO (also part of LLP)

- JLab-CEA-INFN project
- CEA and INFN indicated magnet as in-kind contribution
- GE (D. Bettoni) is negotiating International Cooperation Agreement with DoE, expected to be signed by INFN in 2024

Superconducting Detector Solenoid

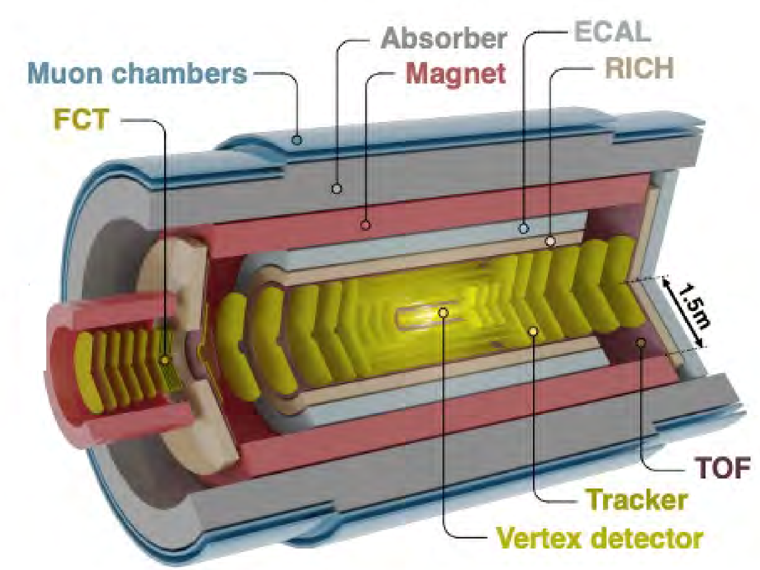
- 3.5 m long coil, 2.84 m room temperature bore diameter
- 2 T on-axis field
- Operating Temperature 4.5 K
- Conductor: Copper Cladded, Rutherford Cable made with NbTi superconducting strands



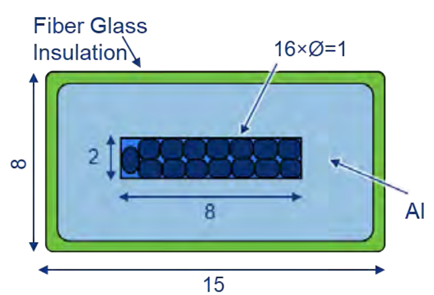
Progettazione/studio del nuovo magnete per ALICE 3

Slide by F. Antinori R. Musenich

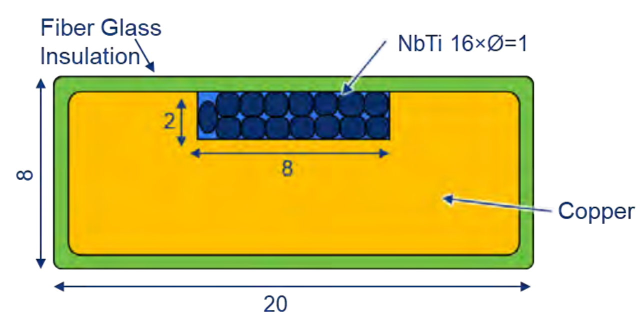
- **Superconducting magnet**
  - ➢ B = 2 T, L = 7.5 m, R_{free} = 1.25 –1.6 m
- **under study in the INFN-Genoa magnet group**
  - ➢ Choice of conductor technology
    - ❖ aluminium-stabilised NbTi
    - ❖ cable-in-channel NbTi (à la EPIC-MARCO)
    - ❖ cable-in-channel MgB_2
- **Conceptual design**
  - ➢ timeline: CDR Q2/2025, TDR Q4/2026



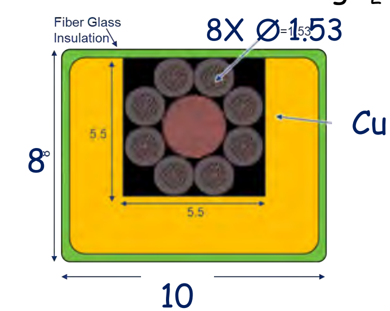
Al-stabilised NbTi



cable-in-channel NbTi



cable-in-channel MgB_2



INFN CSN3

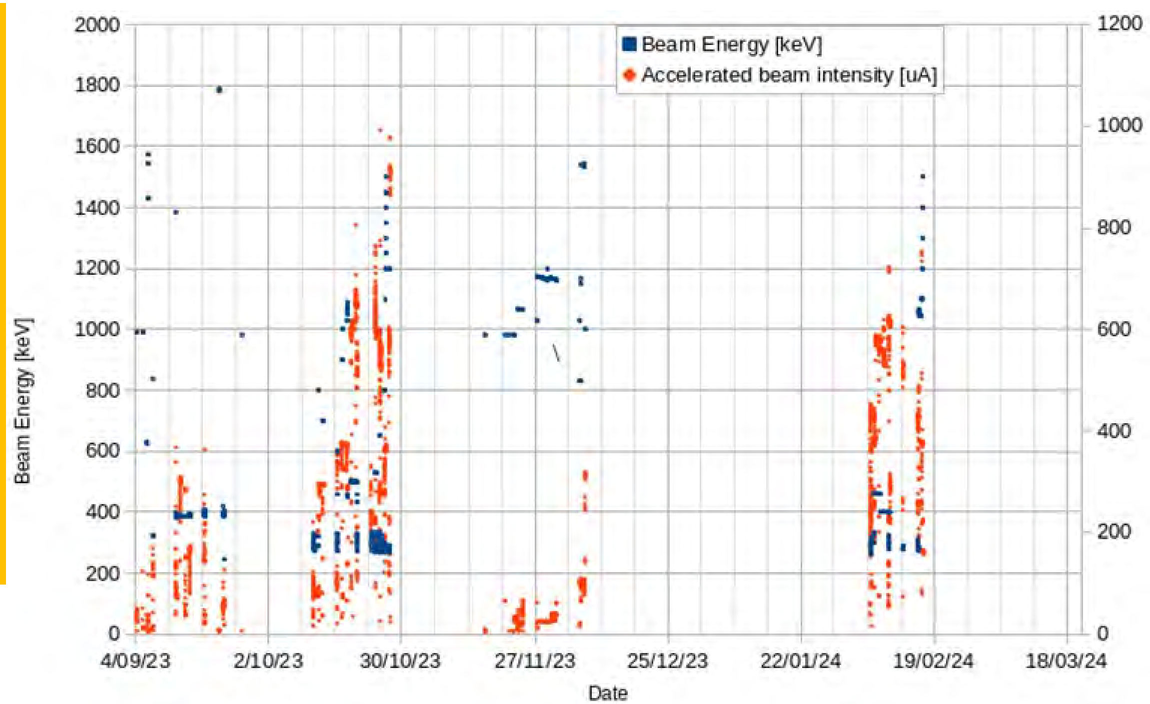
Bellotti Ion Beam Facility

The 3.5 MV Accelerator Singletron "LUNA-MV" can provide Proton, Alpha and Carbon beams

Slides by M. Junker e F. Ferraro

INFN LNGS

- Delivered beam on target: 840h
- Two lines in operations: presently with p and alpha and ^{12}C in July
- Maximum beam energy delivered: 1.8 MeV /alpha beams
- Maximum beam intensity delivered: 1 mA (not on target but on Faraday cup)
- Beam energy spread lower than 100 eV
- First tests for 24/24, 5/7 operations by May 2024

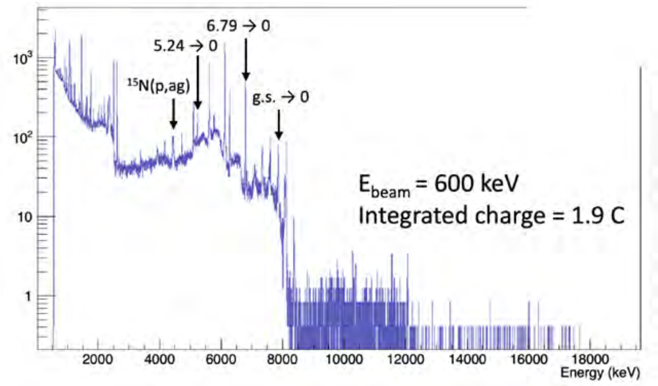


Scientific program at the Bellotti IBF

program approved by the PAC (from June 2023 to November 2024)

$^{14}N(p,\gamma)^{15}O$ bottleneck of the CNO cycle with uncertain weak transitions

- First experiment at the Bellotti IBF. Aimed at measuring weak transitions and angular distributions.
- Helped defining working procedures at the accelerator and its commissioning.
- The experimental setup was also used to perform the energy calibration of the machine.
- Most of the data have been already collected. Additional beamtime is scheduled in June.

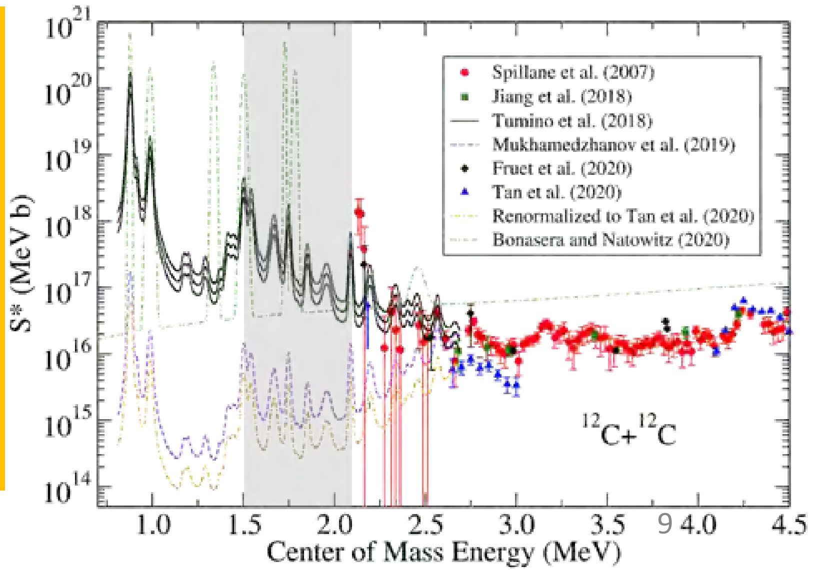


$^{22}Ne(\alpha,n)^{25}Mg$ neutron source for s-process, very uncertain in the Gamow window

- Installation and test of the experimental setup completed.
- Characterization of the gas target ongoing.
- Beamtime request for 2024 will allow measurements at energies of astrophysical interest with adequate statistics.

$^{12}C+^{12}C$ trigger of C burning in massive stars, closely related to SN explosions

- The approved proposal includes the study of the $^{12}C+^{12}C$ process via detection of photons.
- The current setup includes a thick graphite target and a HPGe detector inside a copper box, surrounded by a 25 cm thick, 12-ton lead shielding.
- This setup allows measurements down to energies of about 2 MeV.
- A future upgrade including a large solid angle, segmented NaI detector will allow measurements below 2 MeV, where no direct measurements exist.



CSN3 @ CIRCE-DMF

ERNA
European Recoil separator for Nuclear Astrophysics

AS BeST
A 7-Beryllium electron capture STudy for nuclear and solid state physics

- **Nuclear Astrophysics**
  - Recoil Mass Separator ERNA (European Recoil for Nuclear Astrophysics)
  - Recent and/or ongoing measurements $^{12}C(a,g)16°$, $^{7}Be(p,g)8B$, $^{15}N(a,g)^{19}F$
  - Charged particle spectroscopy – GASTLY detectors array.
  - Recent and/or ongoing measurements $^{12}C+^{12}C$, $^{12}C+^{16}O$
  - Conventional and accelerator mass spectrometry (AMS) for the search for nucleosynthesis signatures in fossil archives and meteoritic materials.
  - Target production – Thermal evaporation and sputtering source.
- **Production of a high-intensity (~109 pps) ^{7}Be radioactive beam for fundamental research and applications**
  - PRIN ASBeST (Univ.Campania (CE), IMM-CNR Bologna, INFN-LNGS, Univ. Salerno)
  - Collaboration with CIRA (Italian Aerospace Research Center) on materials for aerospace.
- **Several possibilities for short-term developments (see Midterm plan LNGS)**

Università degli Studi della Campania *Luigi Vanvitelli*

Dipartimento di Matematica e Fisica

Slide by A. Di Leva , R Buompane



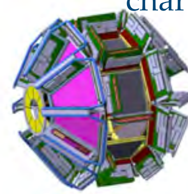

Future SPES
(begin operations 2024-2025)

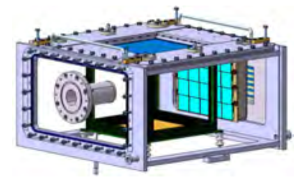
- Astrophysics, reaction dynamics and nuclear structure

- Programs at LNL with the complex TANDEM+ALPI+PIAVE → 90% beam time dedicated to the AGATA spectrometer.
- Development of ^{238}U **beams**.

PRISMA
heavy ions

GRIT
charged particles

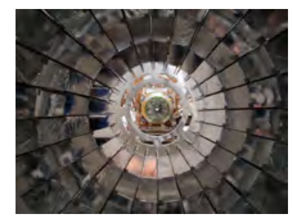




ACTIVE TARGETS
Trasfer reactions

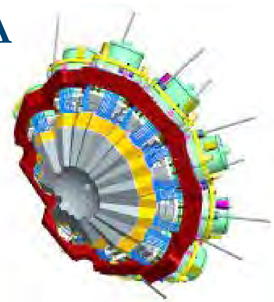
β-decay
station

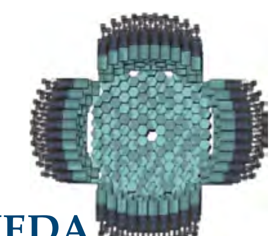
Forefront contemporary nuclear structure needs ground-breaking integrated systems



GARFIELD
Particle decay

AGATA
γ-rays



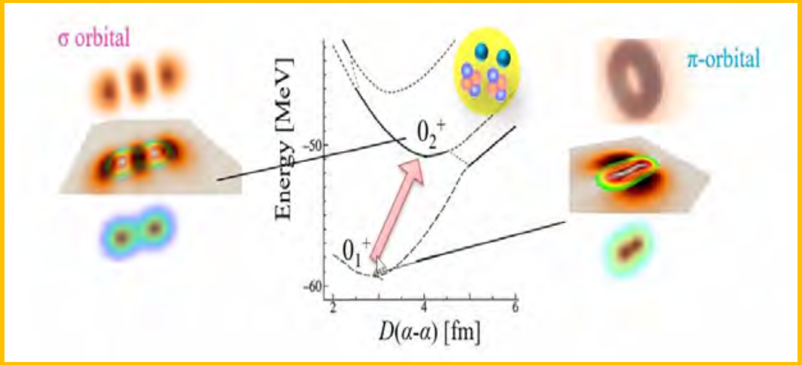


NEDA
neutrons

CTADIR
cryogenic
target

Study of light and medium mass exotic nuclei

- Onset of collectivitazion, clusterization and impact on astrophysics
- Nuclear correlations and nuclear forces (3N forces)
- Structure on neutron-rich medium mass nuclei, proton excitation

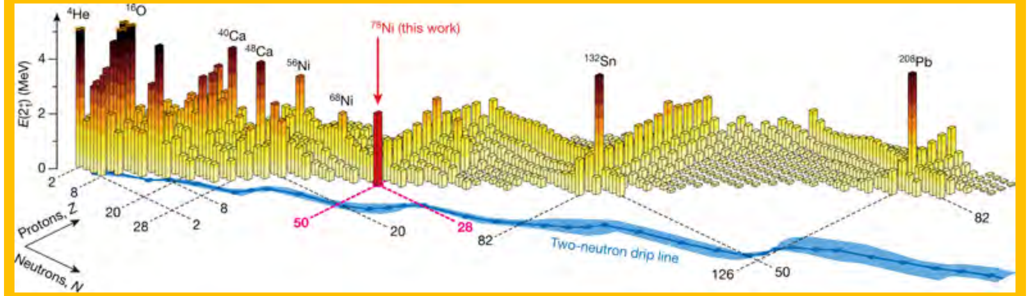


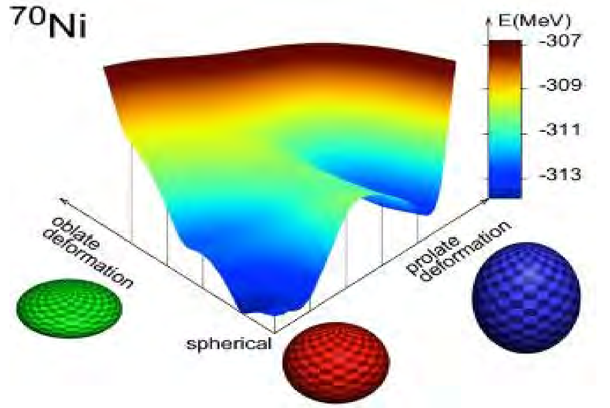
Study of N~Z nuclei and isospin symmetry

- Quadrupole correlations: shapes and symmetries
- Pairing: the role of T=0 pn
- Isospin symmetry (breaking)
- Fundamental interactions

Study of Shell evolution

- N=50 (^{78}Ni): intruder states, medium-spin states, single-particle nature
- Shape coexistence
- N=82 (^{132}Sn): single particle nature, n-p multiplets





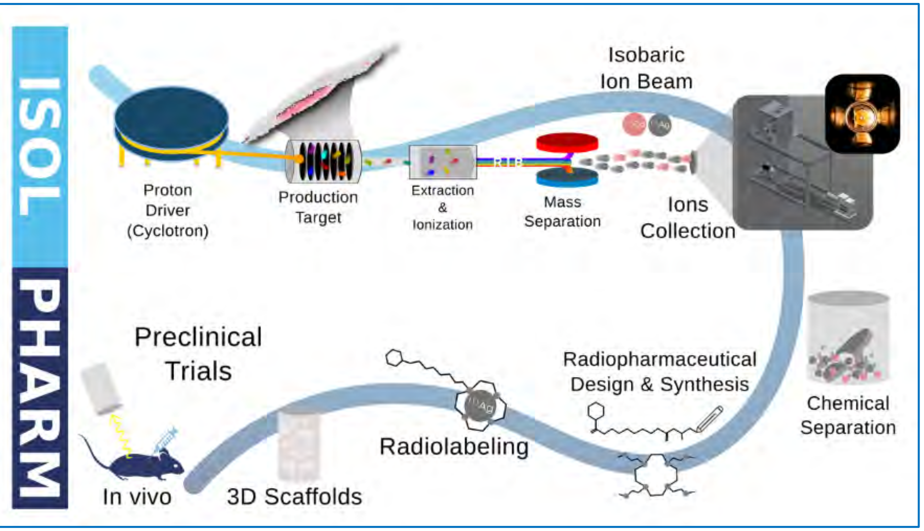
Study of deformation and collective modes

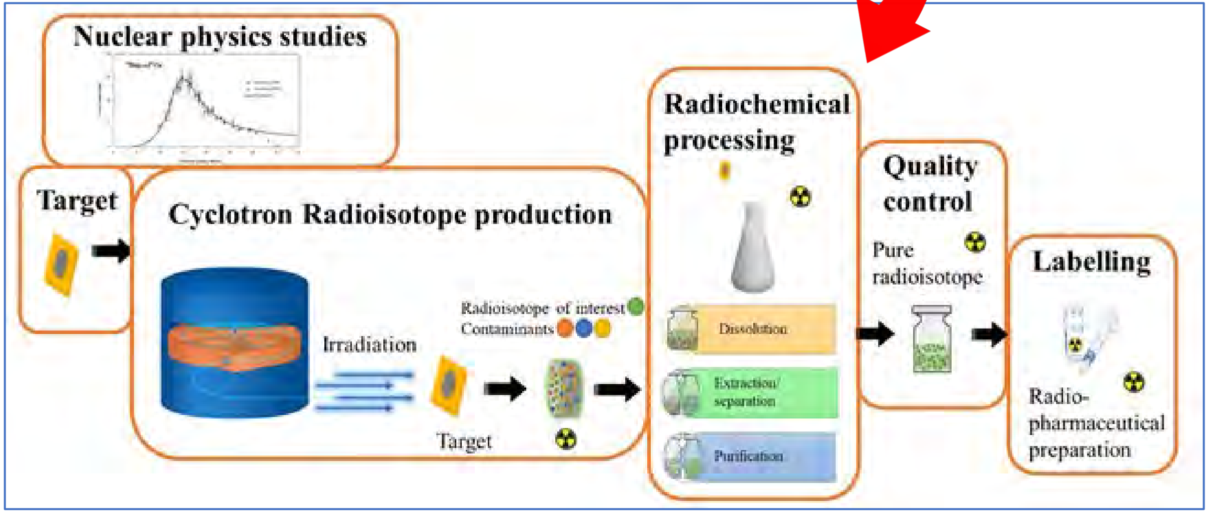
- Pygmy dipole and quadrupole resonances (PDR,PQR)
- Giant dipole and quadrupole resonances(GDR,GQR)
- Isospin mixing, hot PDR
- Jacoby shapes

Medical radionuclides production @ LNL

SPES-γ

https://www.prismap.eu/





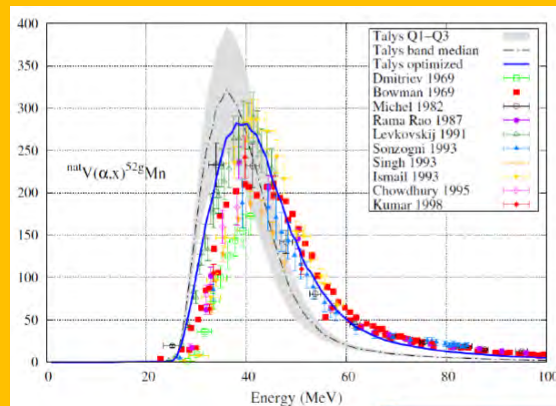
In this **multi-disciplinary** research activity **nuclear physics** plays a key role in the optimization of medical radionuclides production, exploiting innovative routes

Strong collaboration also with LNS

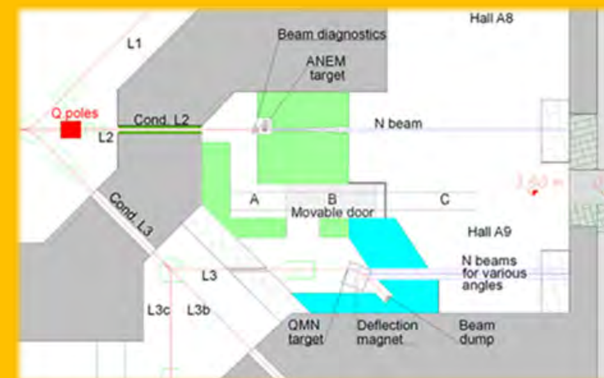
In CSN3 new project **SPES-MED** for studies on production cross-section

Nuclear cross section measurements and modelling for direct radionuclide production and neutron beam lines at SPES.

- **Development of emerging RNs in Nuclear Medicine** (^{67}Cu, ^{47}Sc, ^{xx}Tb and future RNs: ^{117m}Sn, ^{119}Sb, $^{133,135}La$..)
- **Modeling of nuclear cross-sections**

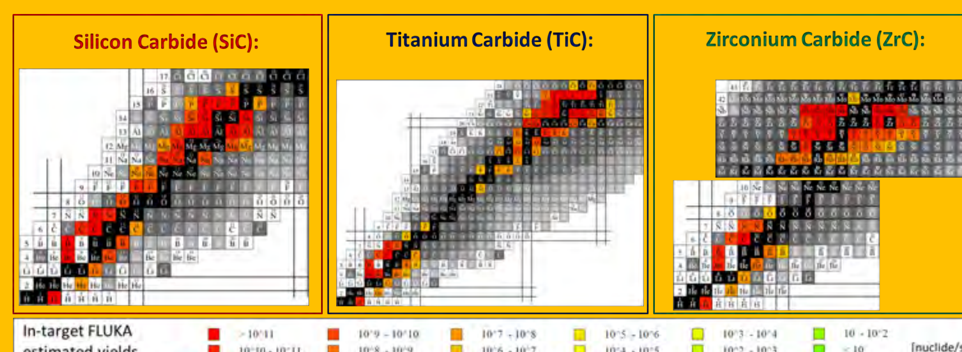


- **Neutron facility @ SPES**



ISOL and laser applications at the SPES

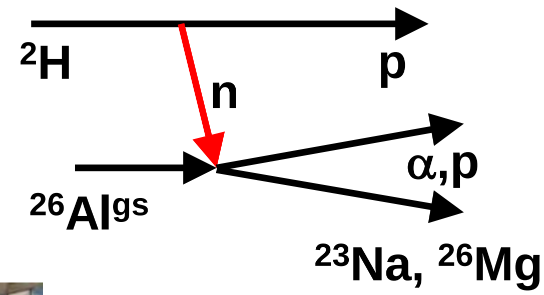
- ***Laser spectroscopy*** and applications
- ***Nuclide production with ISOL*** for medicine and nuclear physics
- ***Decay spectroscopy*** of nuclides of medical interest



Research activities at LNS Tandem , in preparation to Pot-LNS

Upgrading LNS to the future of Nuclear Astrophysics: ASFIN group

- Radioactive ion source for long lived isotopes via Trojan Horse Method
- Noble gas source for the Tandem (^{20}Ne beams);
- $^{12}C+^{16}O$ plays a role near the end of the C-burning phase and in pre-ignition processes of type Ia Supernova.



Nuclear structure and dynamics & novel detectors: Chirone group

Study of γ-decay of Hoyle and excited ^{12}C states : crucial role in the production of 12C in astrophysical environments

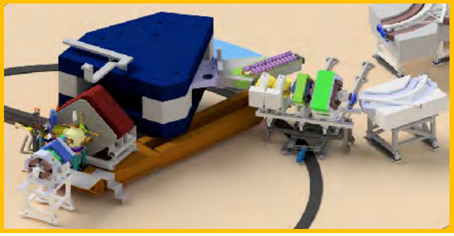
Study of the nuclei structure effects on fusion excitation functions

Important contribution from the FARCOS telescopes.

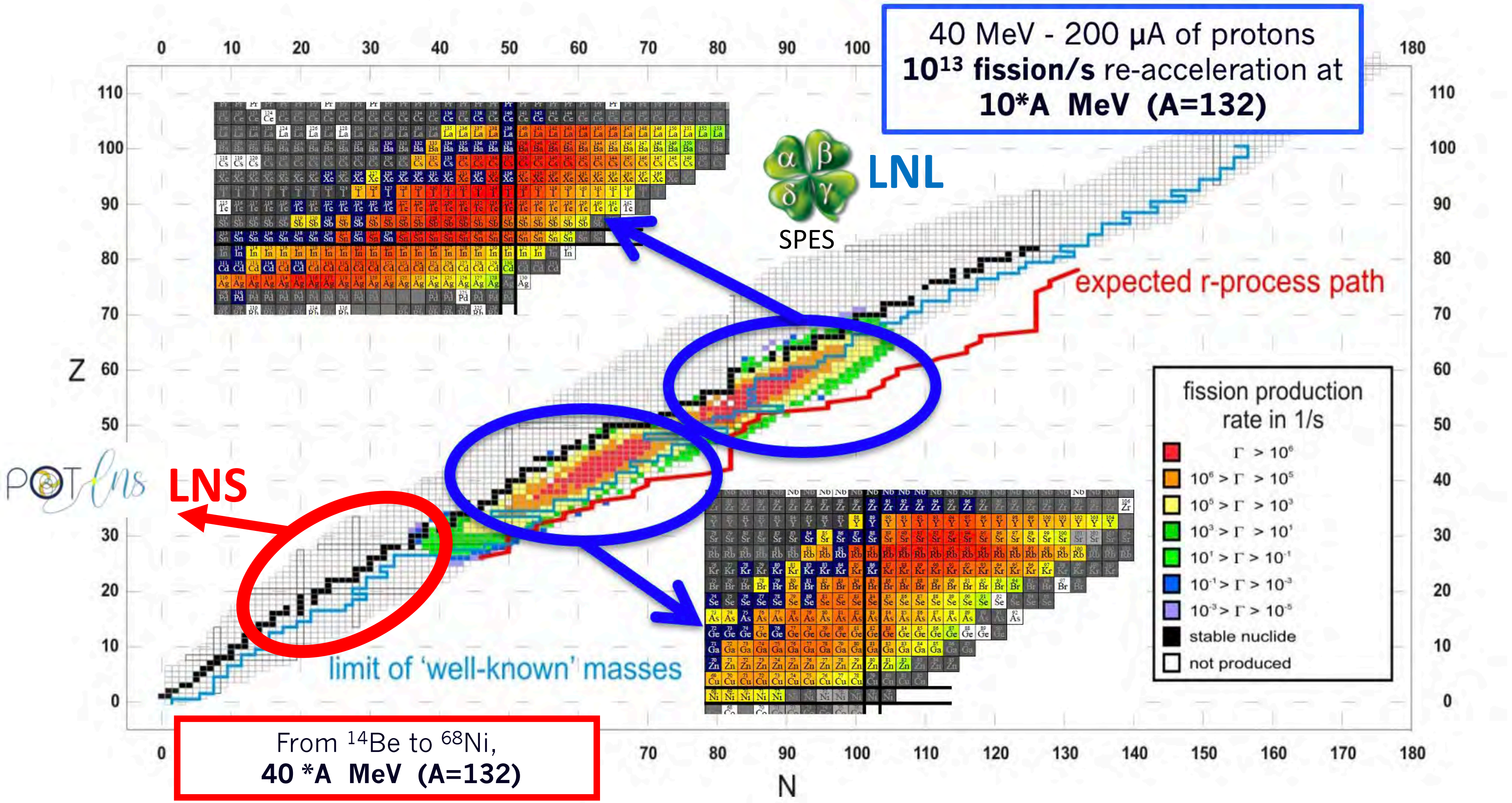
Beyond the standard model: NUMEN group

Measurement of nuclear matrix in Neutrinoless double-beta decay (0νββ)
Commissioning with ^{12}C e ^{18}O beams

MAGNEX @ POT lns



LNL-LNS complementarity

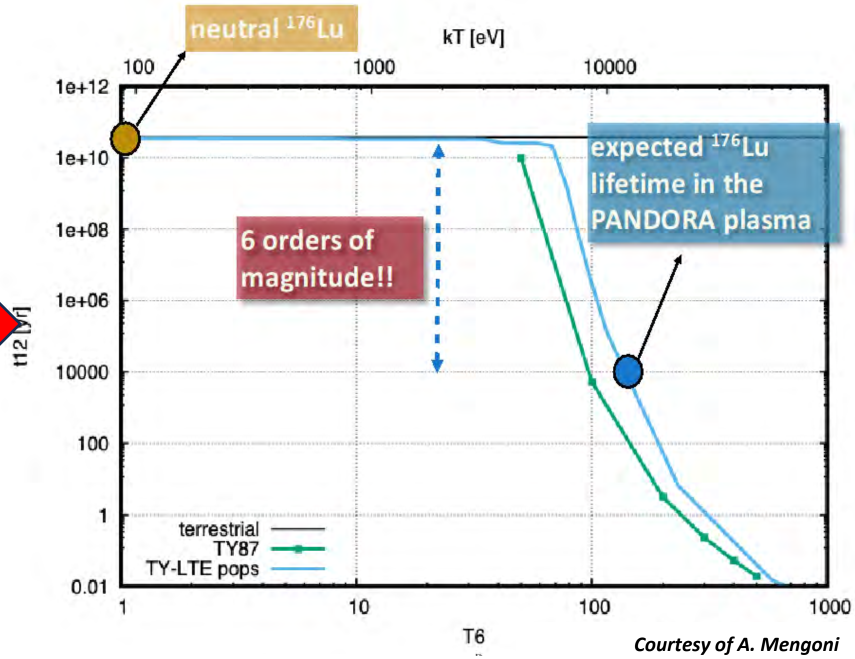


CSN3

…. However !
Stars are made of matter in plasma state where nuclei behaviour could be different

In future, nuclear astrophysics studies will require measurements in extreme conditions different from earth laboratories.

^{176}Lu: lifetime vs. T – theoretical predictions



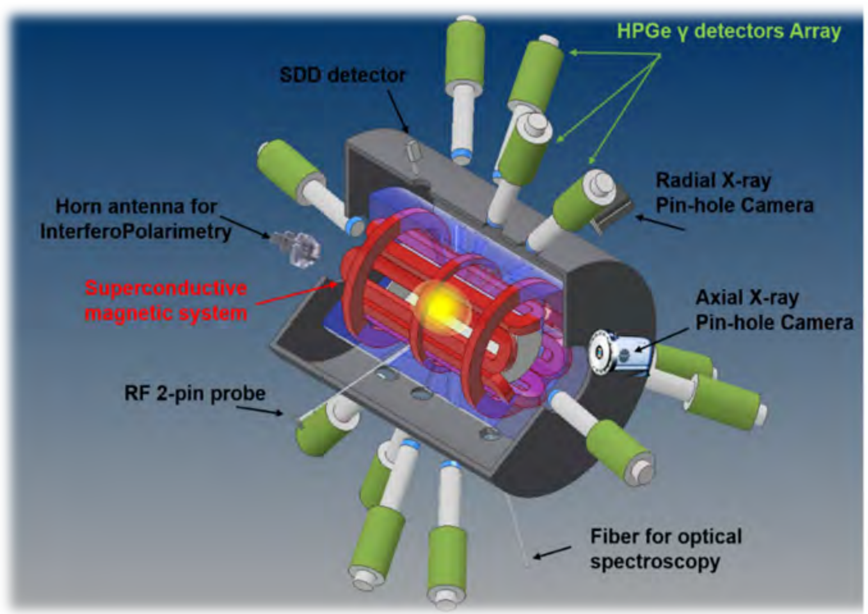
Courtesy of A. Mengoni

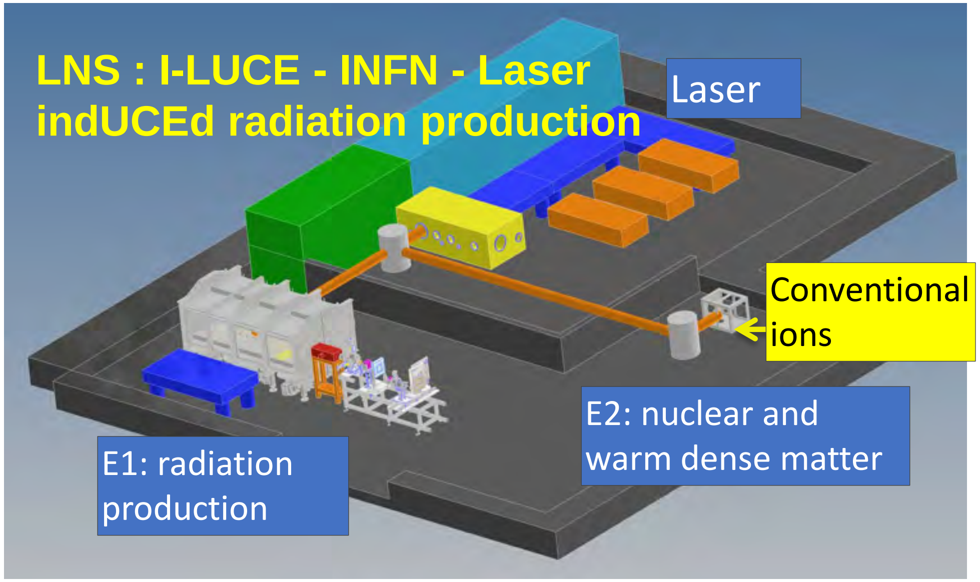
Takahashi et al. 1987, Phys Rev C 36, 1522

The PANDORA experiment (2025)

Build a plasma trap where ion species are confined in a magnetic field and a plasma is created with:

- Electron density: $10^{12} \div 10^{14}\ cm^{-3}$
- Electron temperature: 0.1 ÷ 100 keV
- Ion density: $10^{11}\ cm^{-3}$ → relies on the radiactive isotope concentration in plasma
- Ion temperature: ~ 1 eV → Ions are cold: no access to the excited states





Possible physics topics

- Stopping power in plasma
- Radioisotope production
- Hydrogen generation
- Positron, proton, electrons generation
- Nuclear reaction scheme

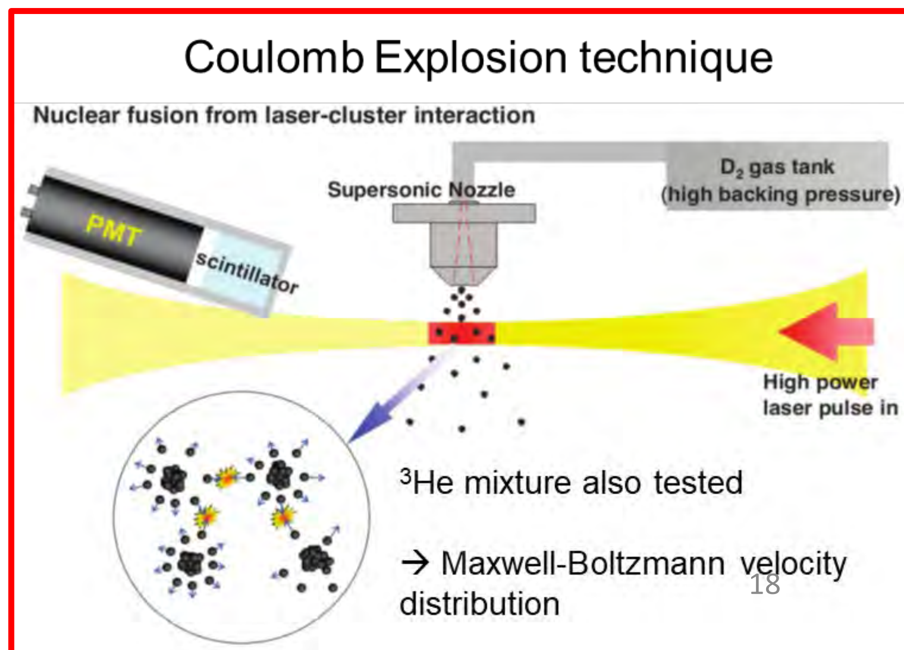
https://link.springer.com/article/10.1140/epjp/s13360-023-04358-7

Workshops on
Nuclear Physics mid term plan in Italy

Laser/plasma and ions: world almost unique environment

An high-power (up to 0.5 PW), ultra-short (down to 23 fs) Ti:Sa laser will provide two laser outputs

To be directed towards two different experimental areas E1 and E2



Laser induced plasma physics at LNF

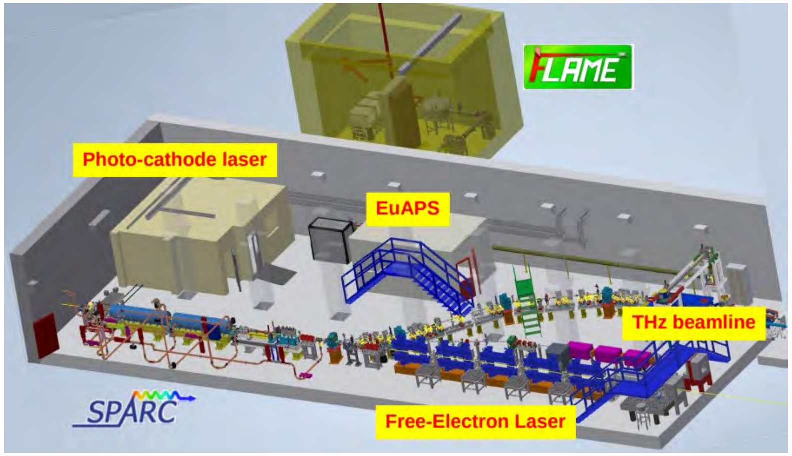
INFN CSN3

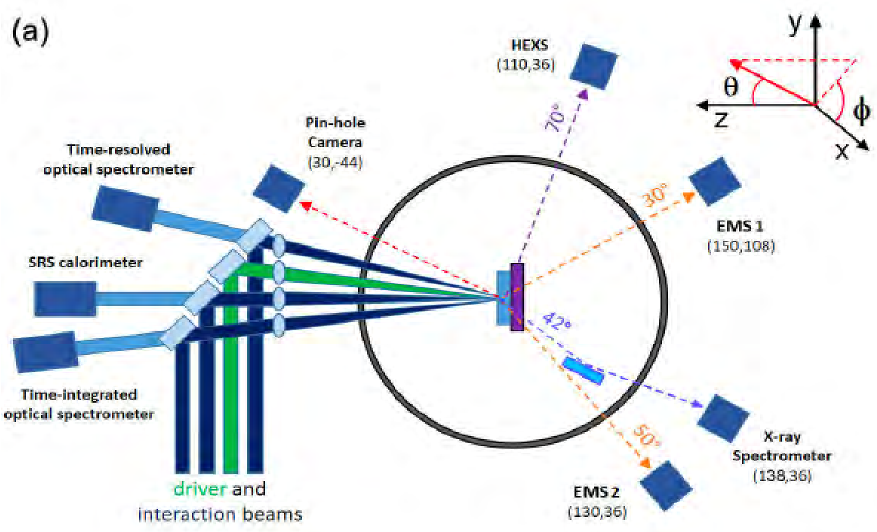
SPARC_LAB – FLAME

Interest to have deuterium fusion induced experiment in next years (2024 ?). Studies are starting on the nozzle specification (design in collaboration with LNS).

EUPRAXIA

The higher laser power (PW) will allow local thermodynamical equilibrium (LTE) conditions with the possibility to study beta-decay of isotopes





INFN CSN3

A comparison between magnetic and laser induced physics with plasma

Magnetic confinement

PRO:

- **Long-living plasma** (order of weeks)
- Steady state dynamical equilibrium for density and temperature (by compensating ion losses)
- Hence, over days/weeks constant values for charge state distribution of in-plasma ions
- Online monitoring of plasma density, temperature, volume, at any energy domain in nLTE conditions

CONS:

- Low density/high temperature plasma: non local termal equilibrium (**nLTE conditions**)
- Difficult "plasmization" of solid/metallic isotopes
- **No access to nuclear excited state studies** (too low T)

Laser-induced plasma

PRO:

- **High density plasma, reaching LTE**
- Fully thermodynamical equilibrium allows, in principle, to **estimate the population of nuclear excited states**

CONS:

- **Difficult to implement diagnostics** following on-time the fast time-variation of plasma parameters
- **Short living plasma**, with duration much shorter than typical lifetimes of isotopes involved in stellar nucleosynthesis

Workshop in preparation by the end of the year

CSN3

Final considerations

- CSN3 experiments cover research programs with very large energy interval (from keV to TeV), with different particle/nuclei types and intensities.
- In the high energy domain (LHC, EIC…) , it requires strong help for high technological developments of large solenoids or accelerator components
- In the low energy domains exploitation of the LNL, LNS facilities , both the available and the new ones (SPES and POT_LNS), will allow many more beams to better understand the nuclei structure. We eagerly wait for the beginning of the experimental programs.
- Facilities like LNGS-Bellotti Lab or CIRCE gives an important contribution toward low energy nuclear astrophysics
- Nuclear processes measurements of interest for medical applications are strongly supported (FOOT , SPES_MED) and represents a natural continuation of CSN5 exploratory projects.
- Measurements of reactions in Plasma with magnetic traps or Laser induced reactions will open a very reach scenario for measurements in nuclear astrophysics (and other applied fields). CSN3 is following with attention such developments and support this accelerator studies in this direction.
- The *Nuclear Physics Middle Term Plan in Italy* defined the main reasearch lines till the end of the decade… **and some ideas are already becoming reality** ! It was a joint effort with CSN4 and CSN5, with many young scientists involved. The final reports (EPJ Focus) are available with many more details

Focus Point on Middle Term Plan of Italian Laboratories in Nuclear Physics