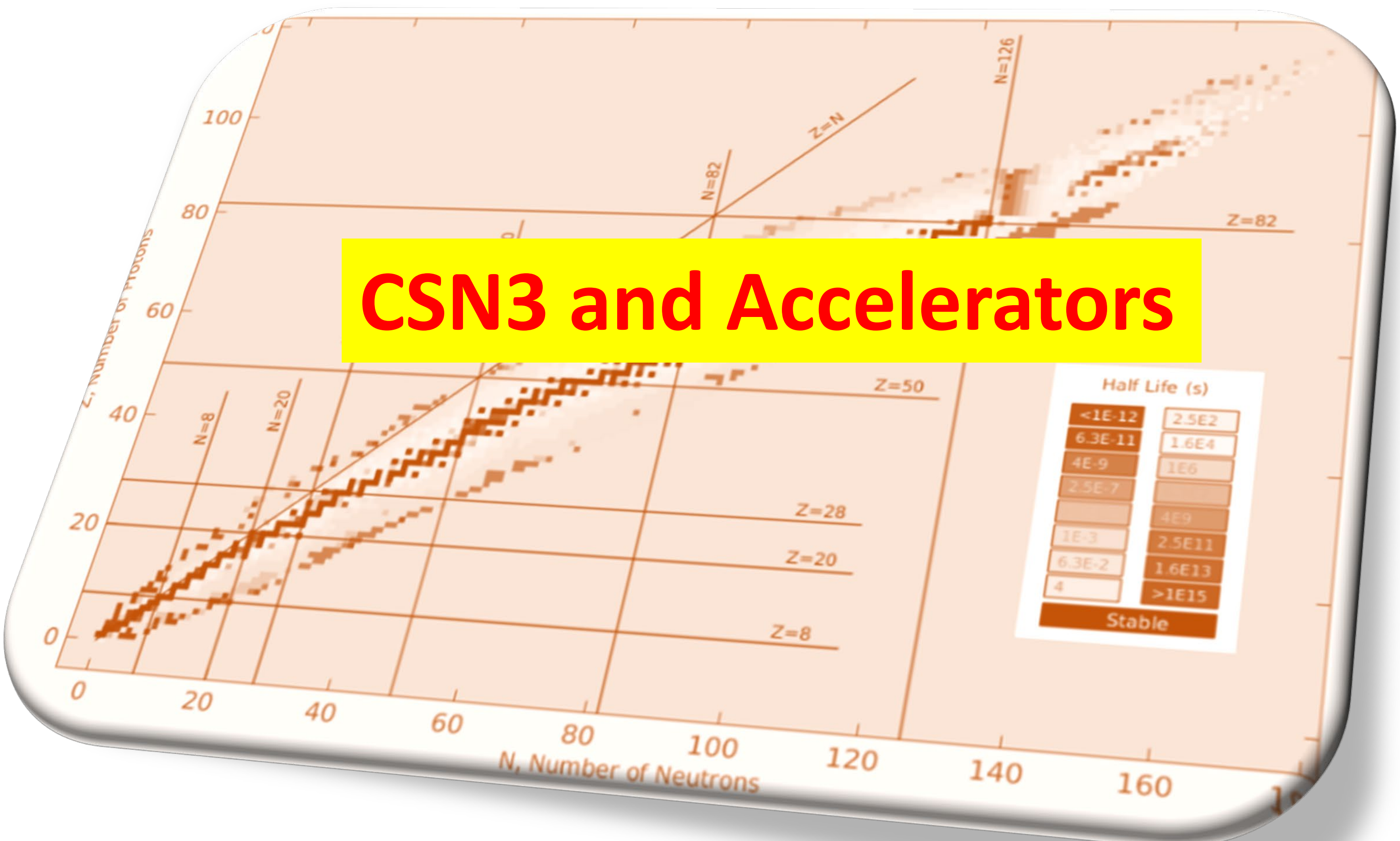
R. Nania
INFN acceleratori – 2 Marzo 2023
Thanks to
G. Bisogni, P. Camerini, M. La Cognata, S. Piantelli, S. Palmerini , S. Pisano, G. Boca, D. Mengoni, J. Valiente Dobon
+ M. Junker, A. Gallo, R. Cimino, P. Antonioli

CSN3 and Accelerators



INFN CSN3

CSN3 Fisica Nucleare

CSN3 Research Lines 2023 Following NUPECC indications

1 QUARKS AND HADRON DYNAMICS

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

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

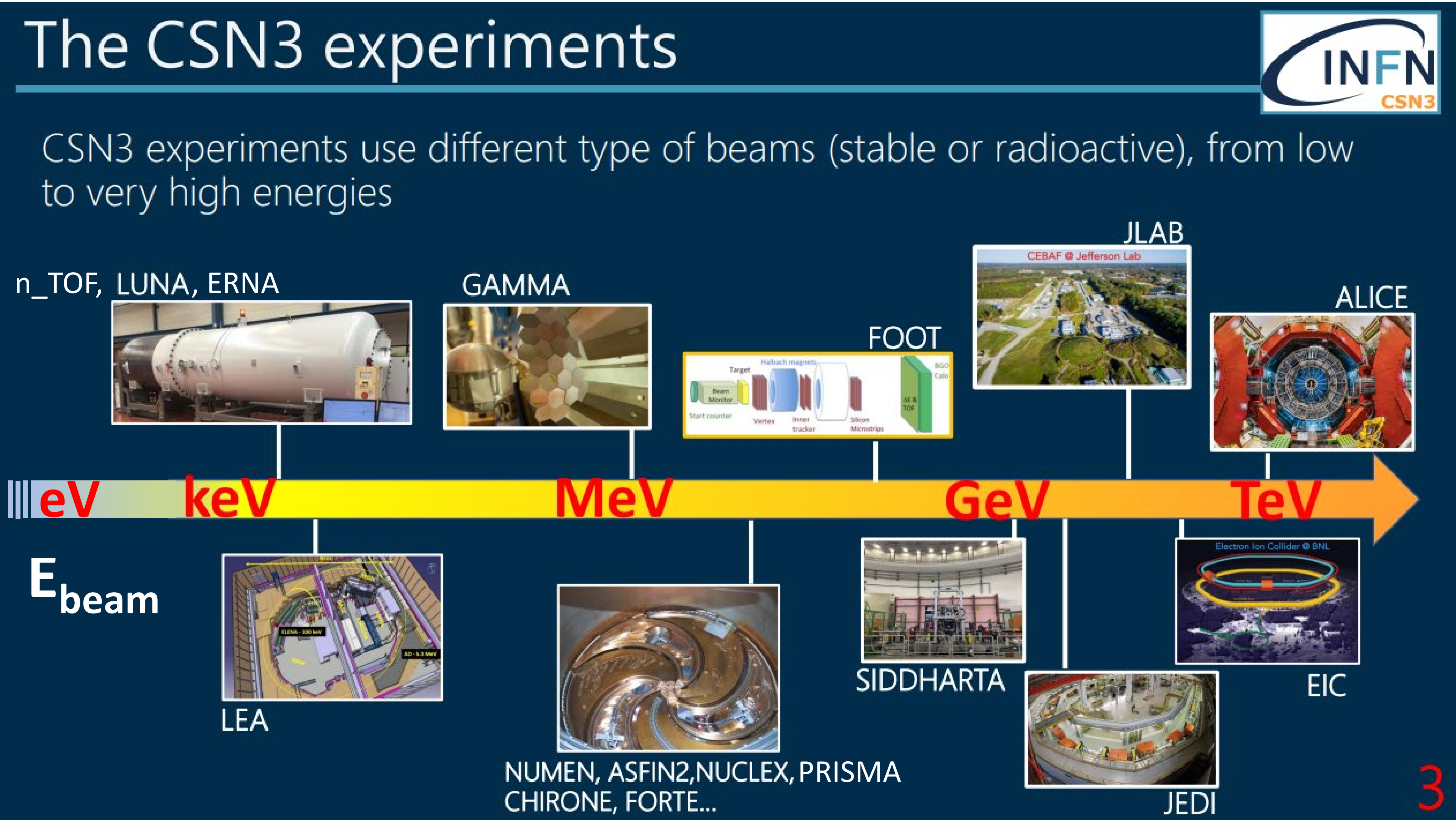
ASFIN, ERNA, LUNA , n_TOF, PANDORA (LNS, LNL, LNGS, CIRCE , CERN…)

5 FUNDAMENTAL INTERACTIONS

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

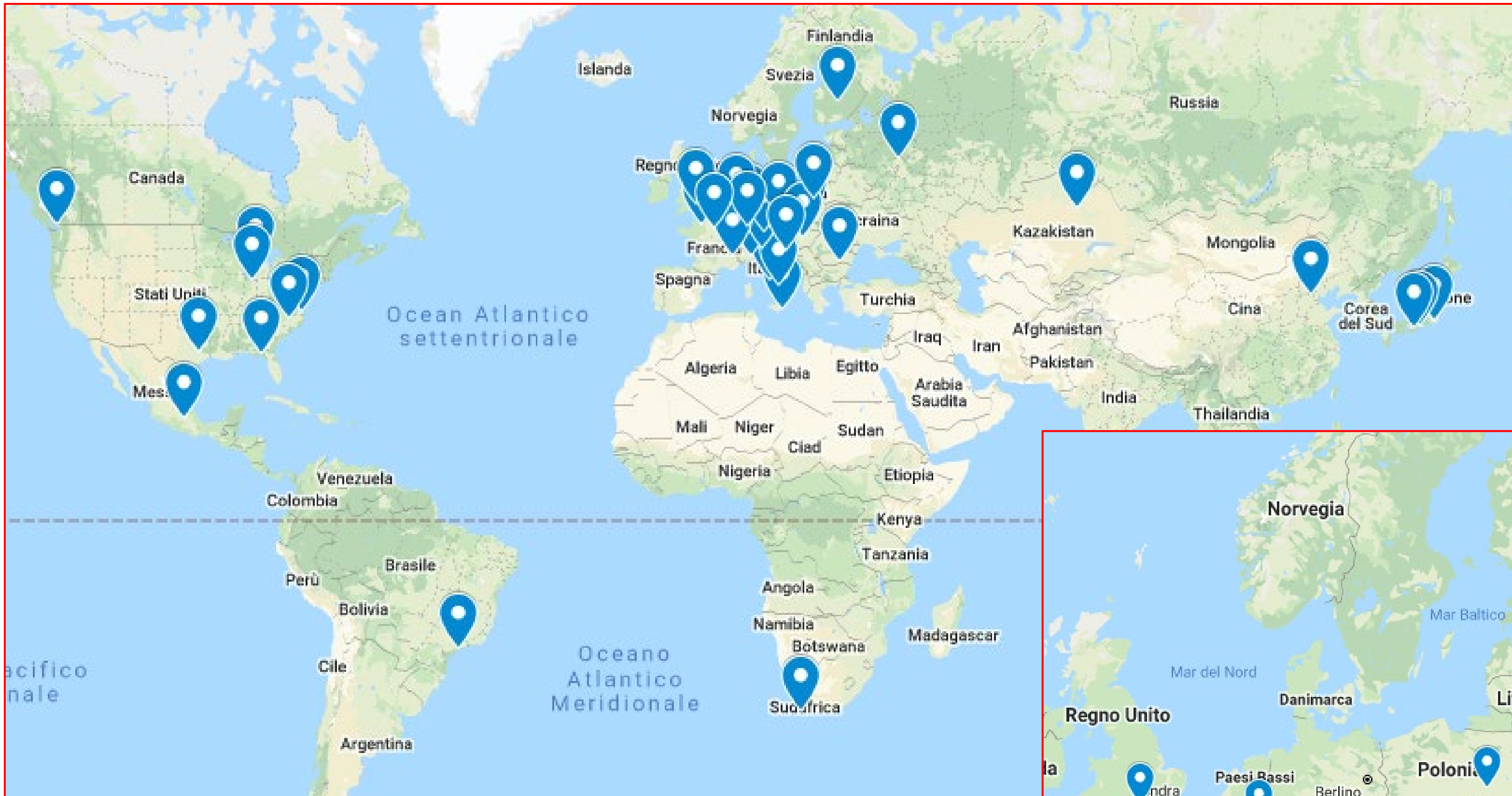
6 APPLICATIONS AND SOCIETAL BENEFITS

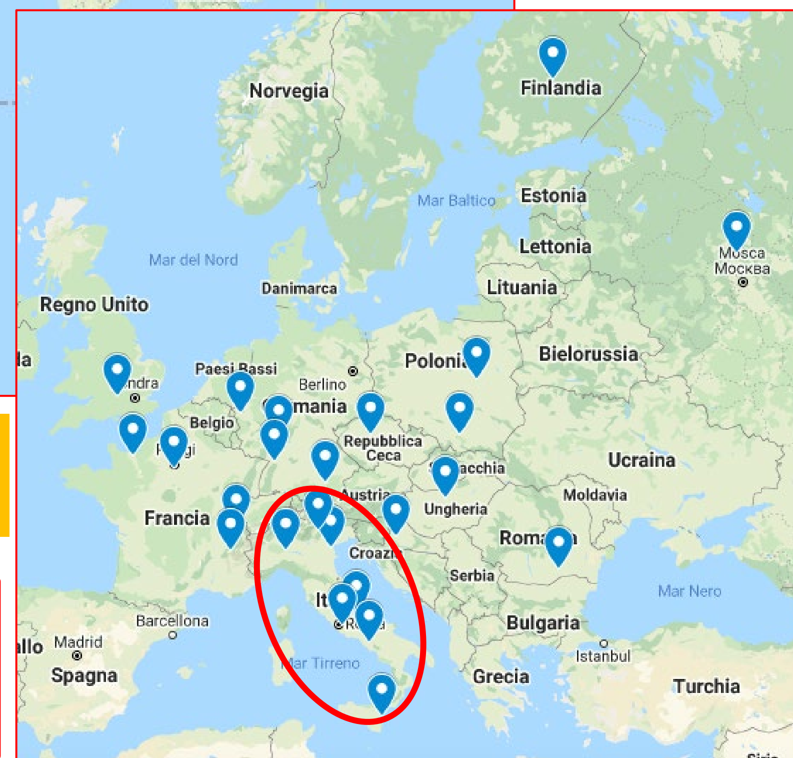
FOOT (GSI,CNAO,TIFPA, HIT)


The CSN3 experiments
CSN3 experiments use different type of beams (stable or radioactive), from low to very high energies
n_TOF, LUNA, ERNA
GAMMA
FOOT
Target
Halbach magnets
Beam Monitor
Start counter
Vertex
Inner tracker
Silicon Microstrips
BGO Calo
ΔE & TOF
JLAB
CEBAF @ Jefferson Lab
ALICE
eV
keV
MeV
GeV
TeV
E_{beam}
LEA
NUMEN, ASFIN2,NUCLEX, PRISMA
CHIRONE, FORTE...
SIDDHARTA
JEDI
Electron Ion Collider @ BNL
EIC
3

R. Arnaldi

National and International Laboratories for CSN3 experiments



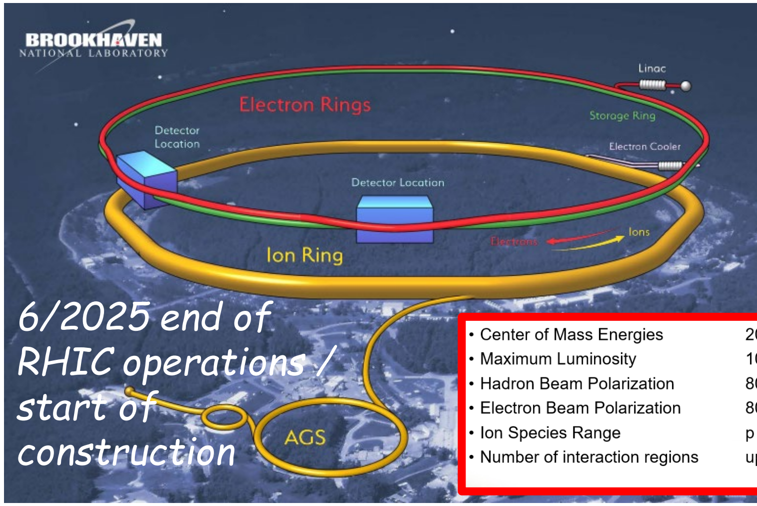


Outside Italy
CERN (LHC, ISOLDE, ELENA), GSI, GANIL, JLAB…

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

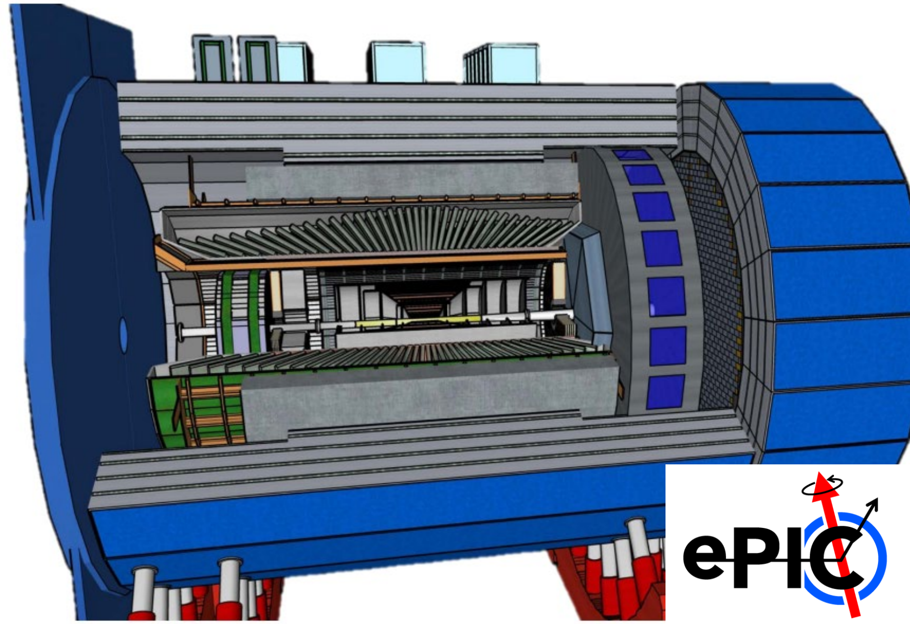
Electron Ion Collider at BNL

EIC Project considerably boosted during 2022.
INFN & DOE in close contact



6/2025 end of RHIC operations / start of construction

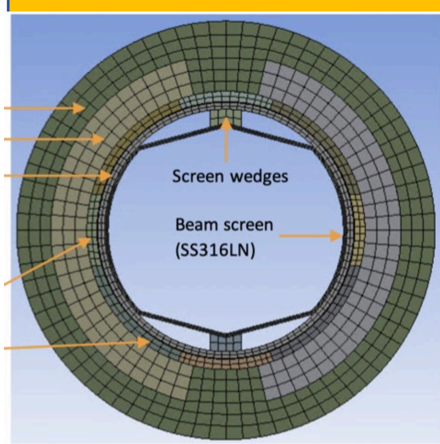
• Center of Mass Energies	20 GeV – 141 GeV
• Maximum Luminosity	10^{34} cm^{-2}s^{-1}
• Hadron Beam Polarization	80%
• Electron Beam Polarization	80%
• Ion Species Range	p to Uranium
• Number of interaction regions	up to two



ePIC

To avoid high RW heating and electron cloud, a beam screen (BS) will be installed in the beampipe RHIC superconducting magnets.

MoU EIC-INFN in preparation



1) Perform, at LNF, surface studies for qualifying BS prototypes of the hadron ring vacuum chamber of EIC.
2) Provide a complete, turn-key SEY measurement system to be delivered to EIC to 'in-house' qualify the BS mass production.

See talk M.R. Masullo

Main Time schedule:
10/2023 draft TDR internal to collaboration
10/2024 ePIC TDR submission to DoE
1/2025 approval of preliminary design
4/2025 approval final design, start construction

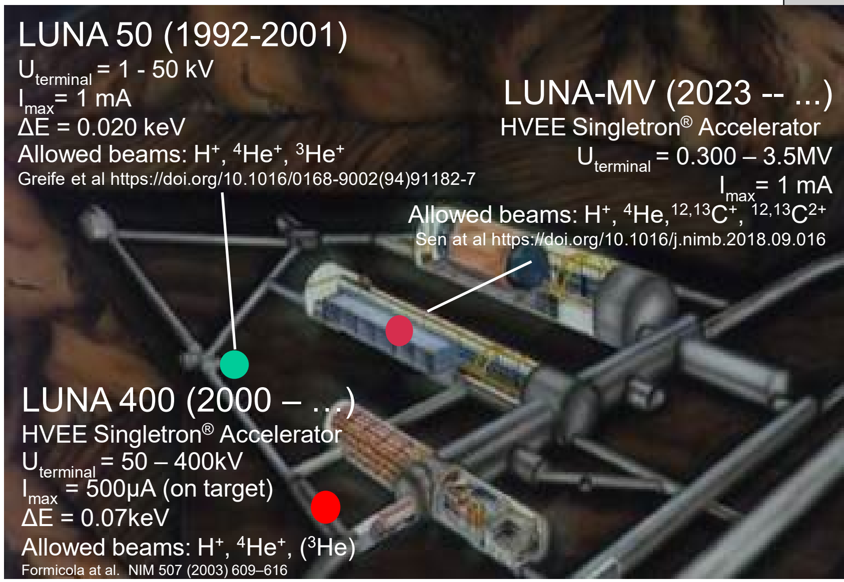
- Strong involvement of CSN3, but also CSN4
- INFN interest in Tracking and PID-doubleRICH
- Strong Sinergy with ALICE3 project R&D
- Possible INFN interest in the new magnet

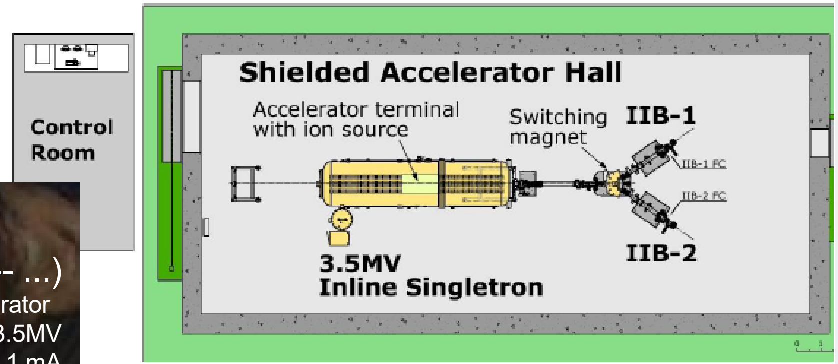
https://web.infn.it/nucphys-plan-italy/

- 14 months of working groups
- 4x2 days workshop with > 800 participants
- 5 contributions to EPJ Focus

INFN CSN3

Bellotti Ion Beam Facility @LNGS





Maximum beam intensity on target at different terminal voltage

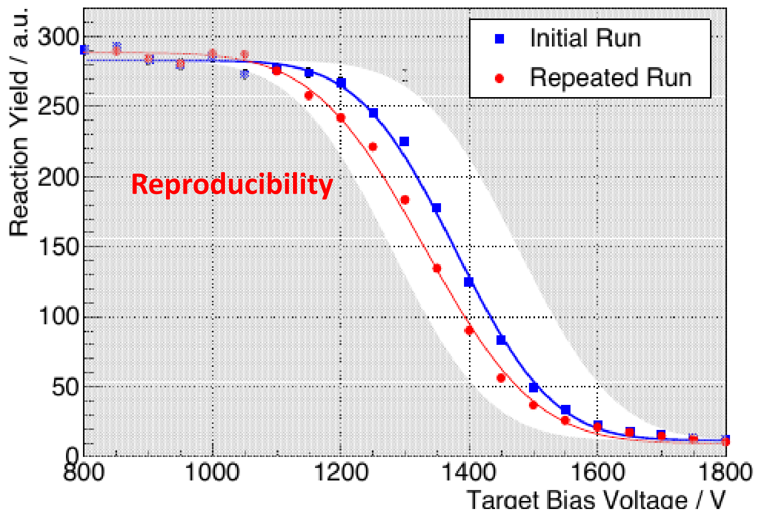
Ion specie	Terminal Voltage 0.3 MV – 0.5 MV	0.5 MV - 3.5 MV
$^1H^+$	500 μA	1000 μA
$^4He^+$	300 μA	500 μA
$^{12}C^+$	100 μA	150 μA
$^{12}C^{+2}$	60 μA	100 μA

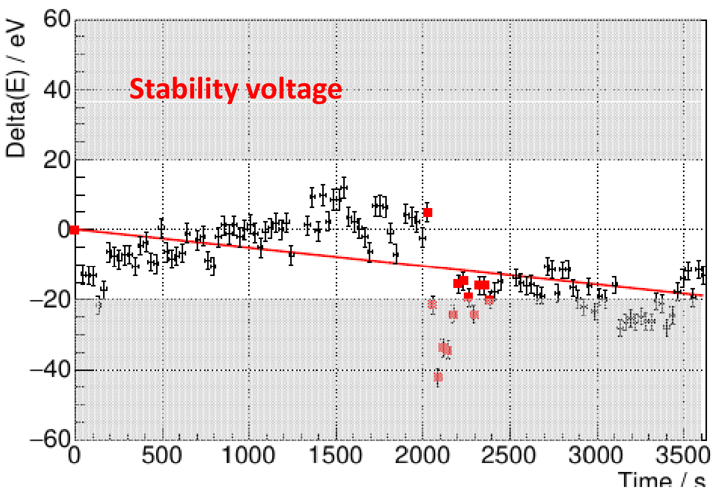
Condition for Accelerator Operation at LNGS:
→ No alteration of low neutron background underground
→ Limit to beam induced neutrons inside accelerator room: max 2000 s^{-1}

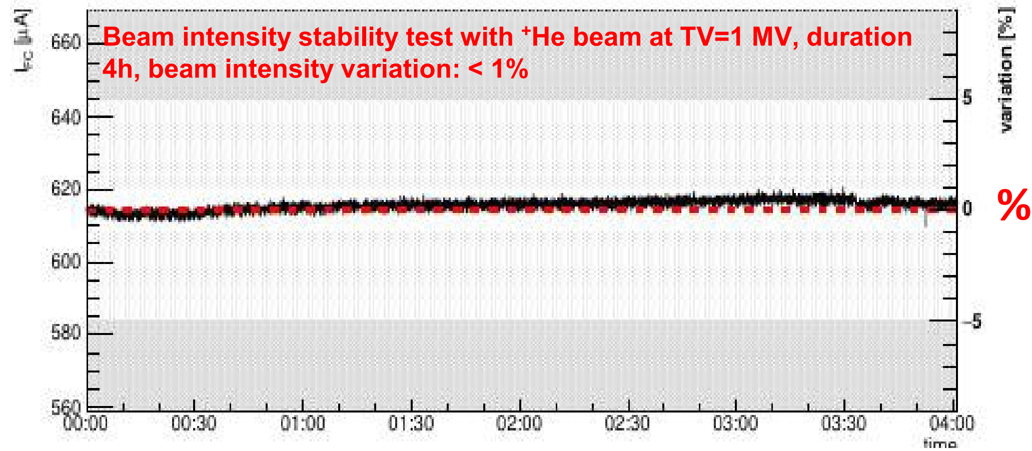
Main program based on nuclear astrophysics cross sect. at low energies

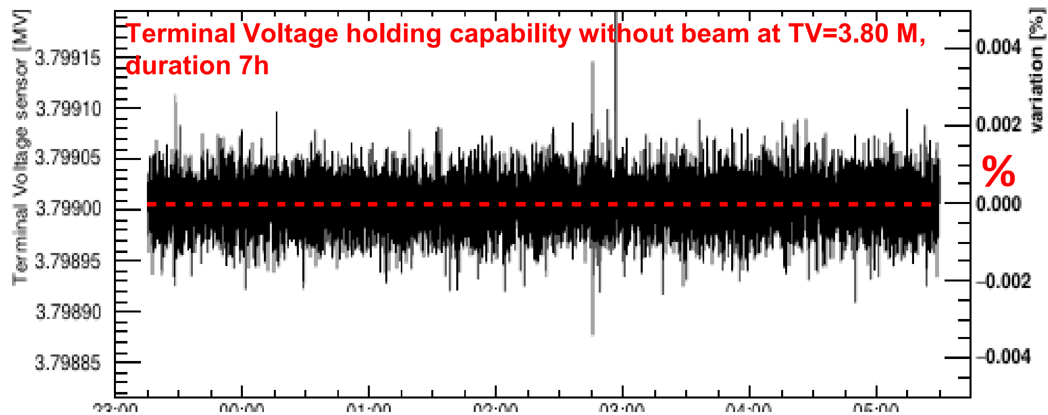
- **PAC @ LNGS** already active (G. Cuttone et al)
- First experiments approved

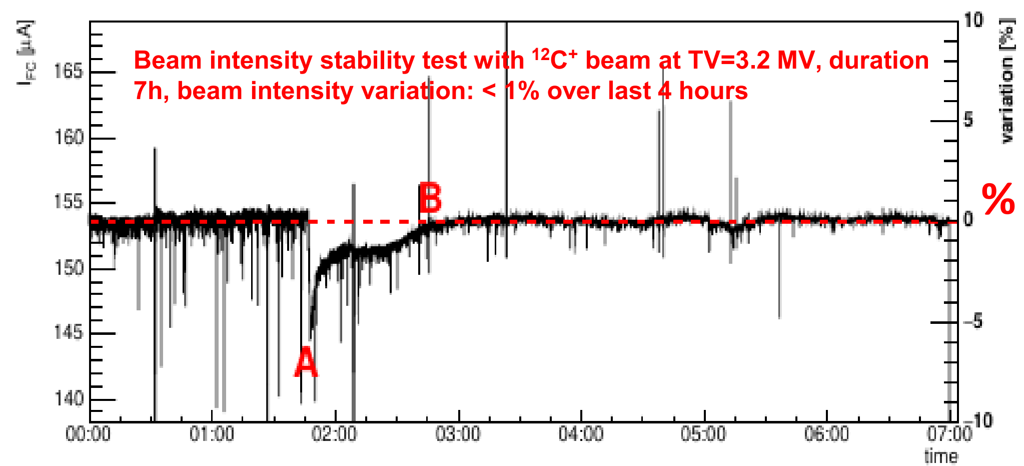
Bellotti Ion Beam Facility
On Situ Acceptance Test (OSAT)







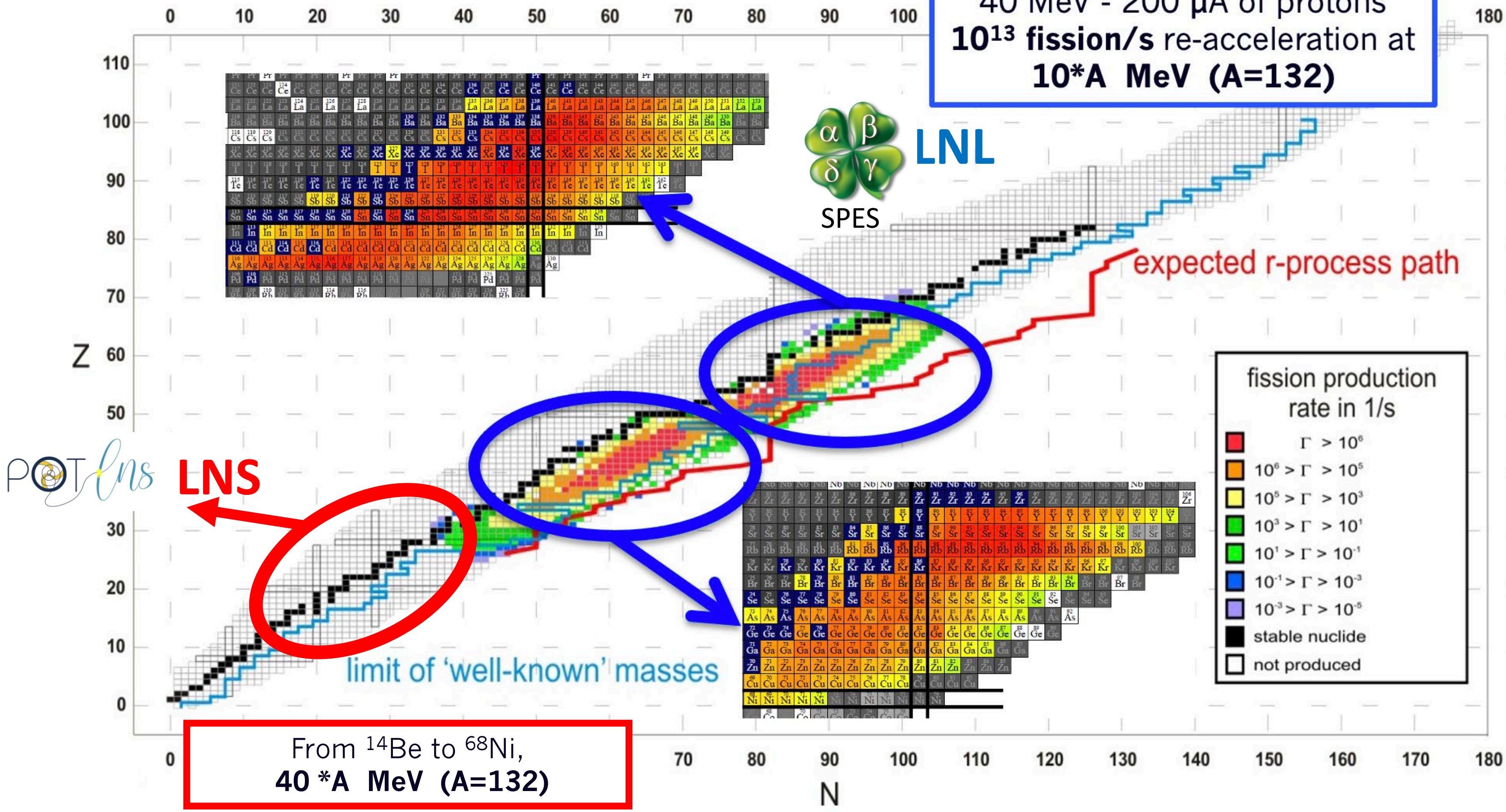




Extremely stable machine

LNL-LNS complementarity

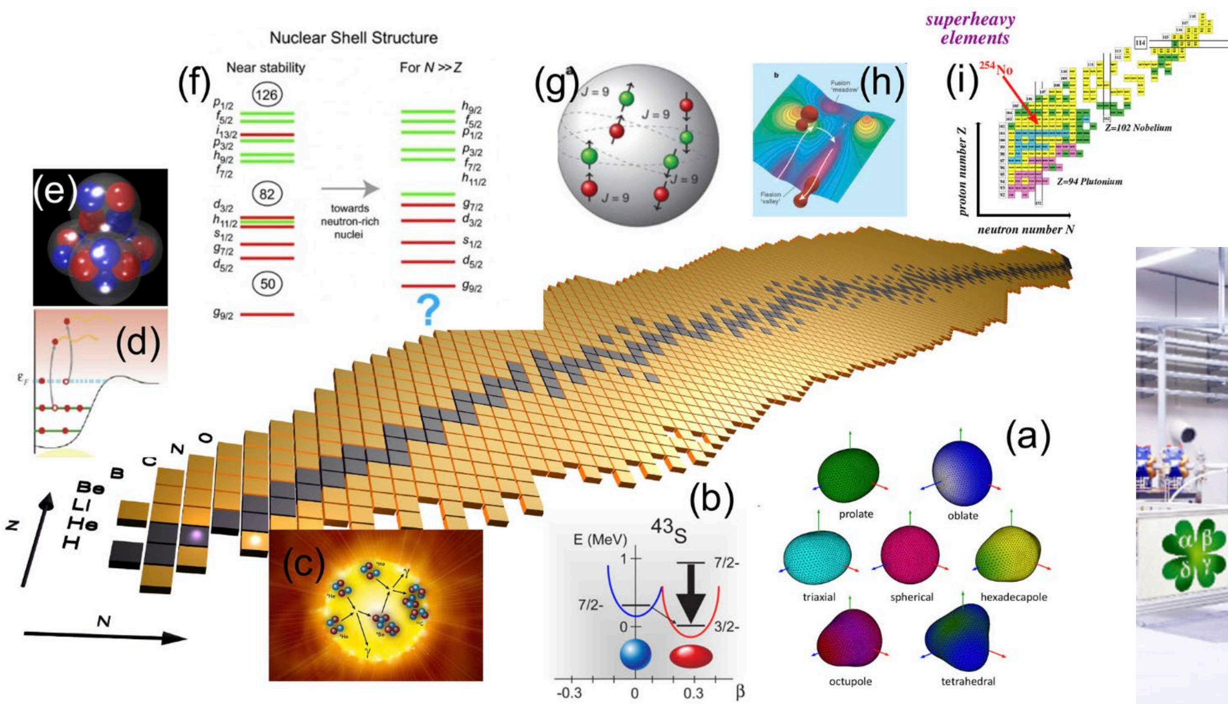
40 MeV - 200 μA of protons
10^{13} fission/s re-acceleration at
10*A MeV (A=132)



From ^{14}Be to ^{68}Ni,
40 *A MeV (A=132)

LNL: Current physics campaign with TANDEM+ALPI+PIAVE

- **Astrophysics**, **reaction dynamics** and **nuclear structure** programs at LNL with the complex TANDEM+ALPI+PIAVE → MTP.
- Currently, large program with the **AGATA+PRISMA spectrometers**.
- Development of **^{238}U beams**.



Future SPES

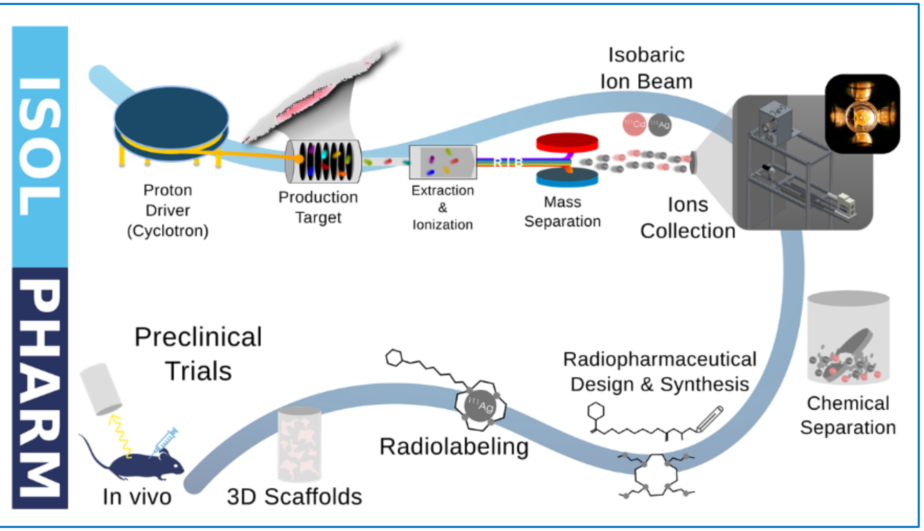
W. Korten et al. , Eur. Phys. J. A (2020) 56:137
https://doi.org/10.1140/epja/s10050-020-00132-w

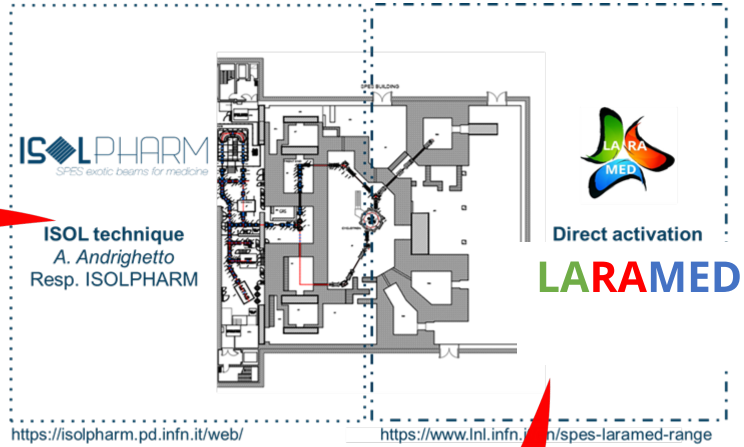
Medical radionuclides production @ LNL

INFN CSN3

SPES-γ

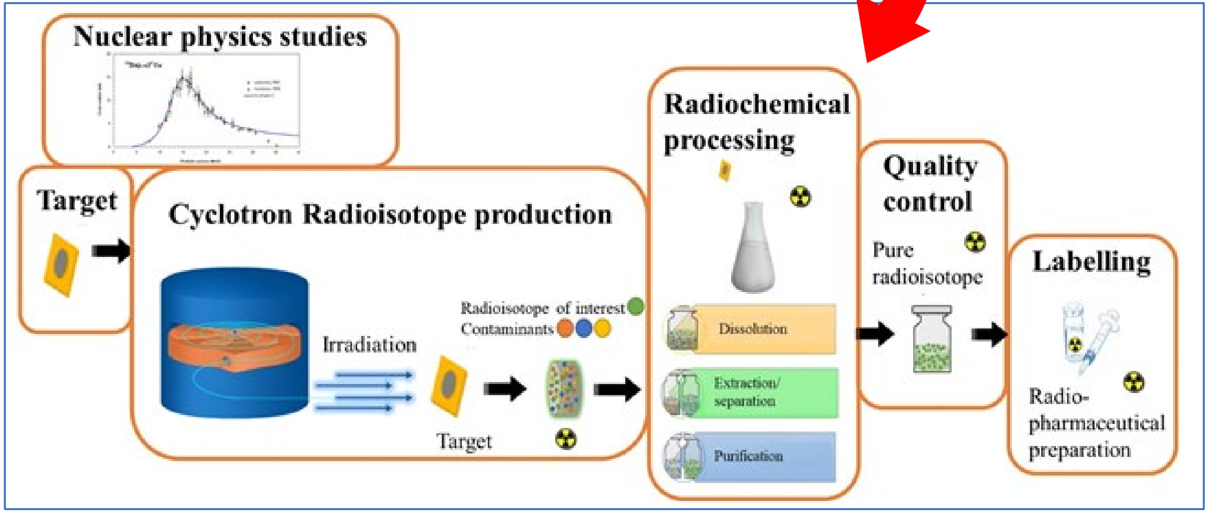
PRISMAP Medical Radionuclides
https://www.prismap.eu/





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

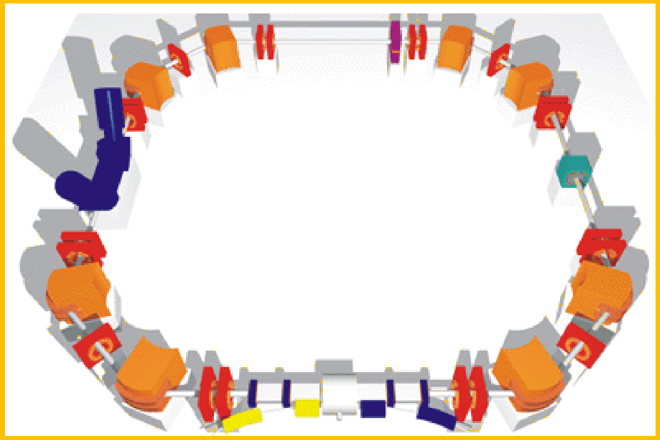


CSN3 support experiments on detailed measurements of processes for medical applications (see FOOT) and follows activities of INFN 4LS

LNL Long Term

Storage Rings

- cooling of the beam, significantly improving position, time and energy resolution, and allowing the use of internal gas targets and the achievement of luminosities higher than with solid targets
- acceleration to higher energies;
- direct measurement of nuclear and ionic properties (mass, lifetime, magnetic moment, …);
- fast extraction of high-intensity pulsed beams for studying interactions with very low cross sections;



Microbeams facility

With the right building infrastructure (temperature - dust free) and instrumentation (such as nuclear nano-probe and improved micro-probe) a new accelerator will feed advanced research for > 3000 hours/year in field such as: **nanotechnology, quantum devices, new detectors, micro-fabrication, nuclear target characterization and development, nuclear astrophysics solid state and surface physics certified micro-analysis and irradiation advanced microscopy and modification of materials, radiation biology and micro-dosimetry**

…..at a top level in Europe, complementary to LUNA-MV (possible higher energies and intensities)

INFN CSN3

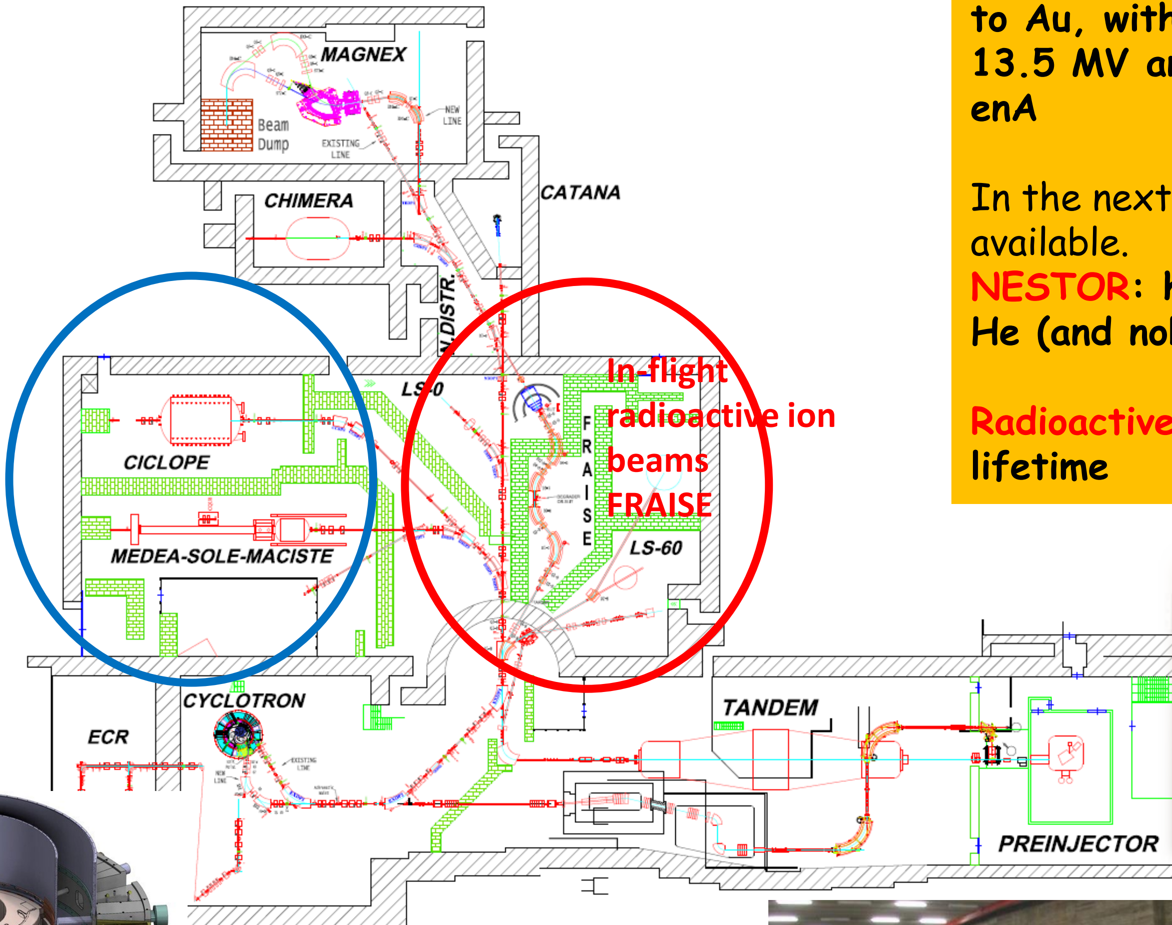
LNS : POTLNS

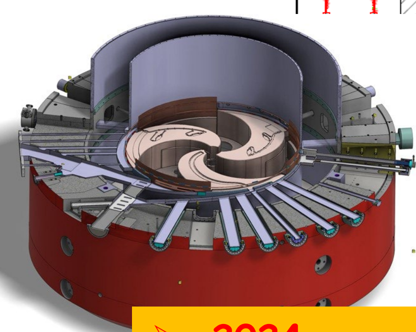
From 2023 the Tandem will deliver the beam so far available, from H to Au, with terminal voltage up to 13.5 MV and intensities of ~100 enA

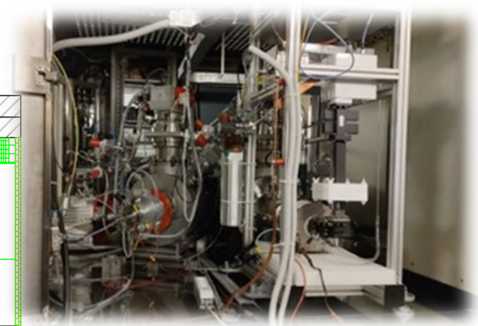
In the next future, new beams will be available.

NESTOR: high-intensity source for He (and noble gases)

Radioactive beams with long lifetime







- 2024
- New extraction line by stripping,

E_{MAX} ~ 80 AMeV for lighter ions

E_{MAX} ~ 25 AMeV for heavier ions (i.e. Au^{36+})

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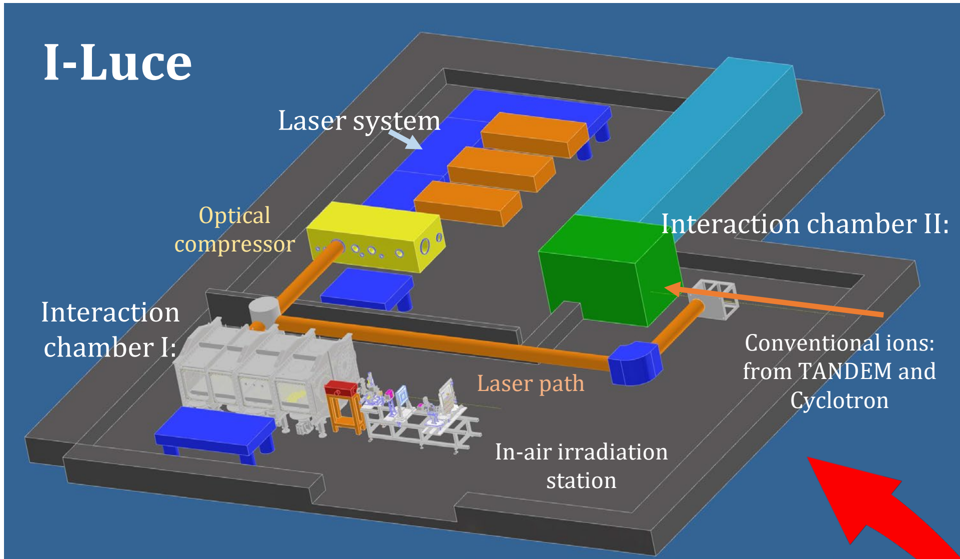
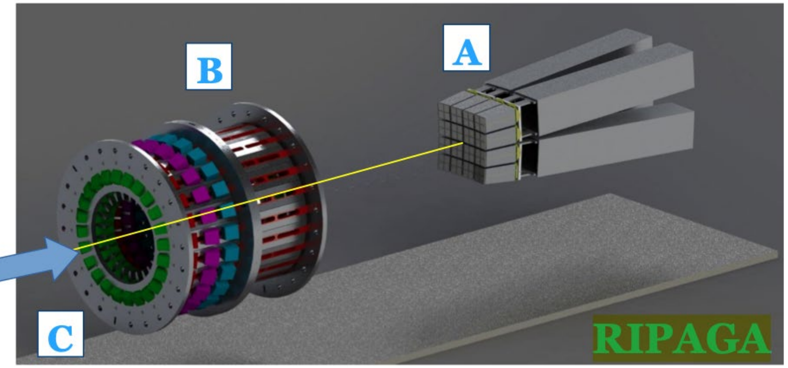
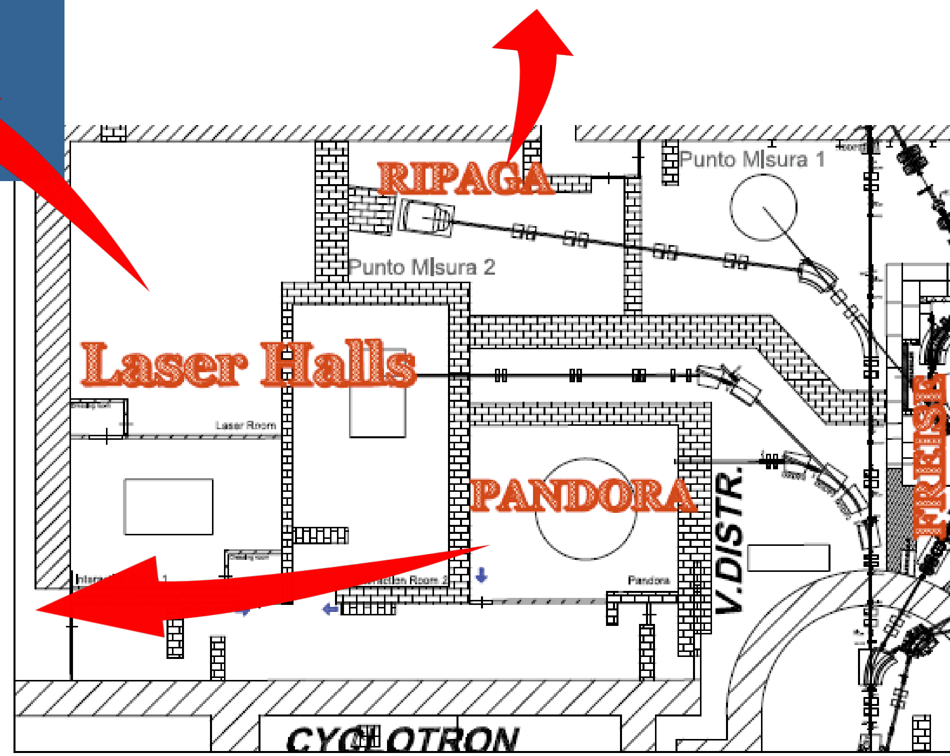
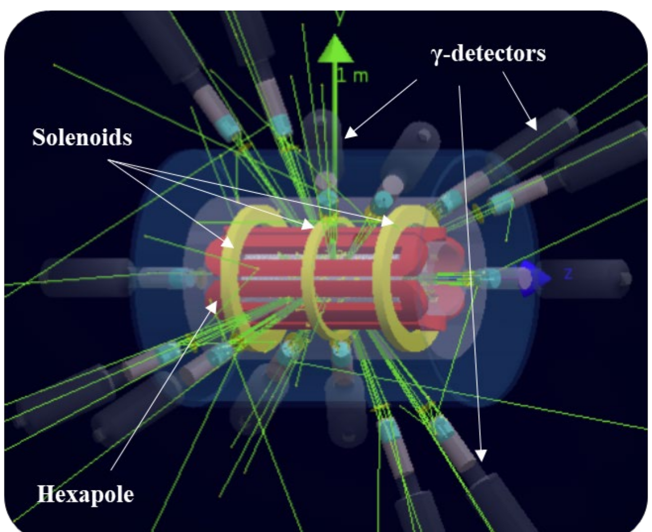
LNS : Beyond POTLNS





A Charged particles: based on FAZIA
B Light charged particles: based on Garfield
C Hard gamma rays: based on MEDEA
D New large scattering scamber

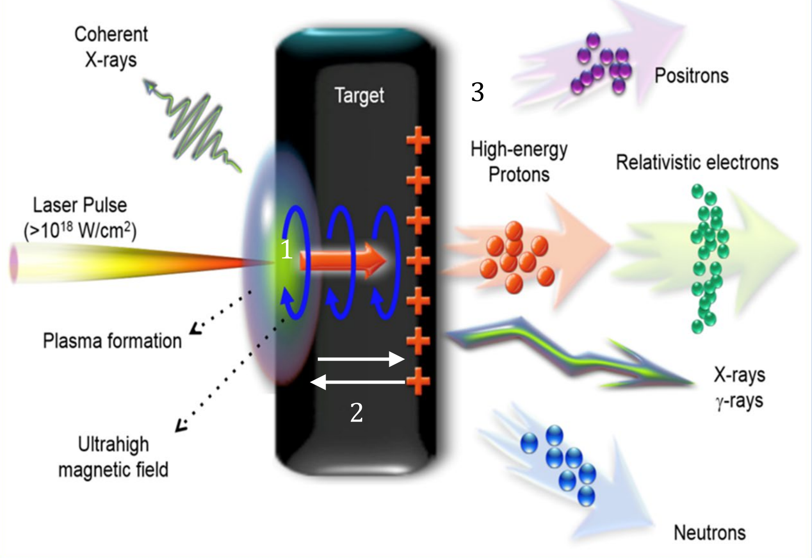




Magnetic Trap 70 cm x 28 cm

Nuclear physics with TW÷PW lasers

- Laser applications open up the possibility to study nuclear reactions in a plasma environment, that mimicks selected stellar-like conditions.
- Different ranges in T and ρ – *i.e.* the relevant parameters for the description of stellar environments - can be explored by varying laser intensities.



Physics cases with hundreds of TW lasers (I-LUCE@LNS, FLAME@LNF):

- Fusion reactions, Electron screening measurements, stopping powers
- Space , cultural heritage, radioisotopes…

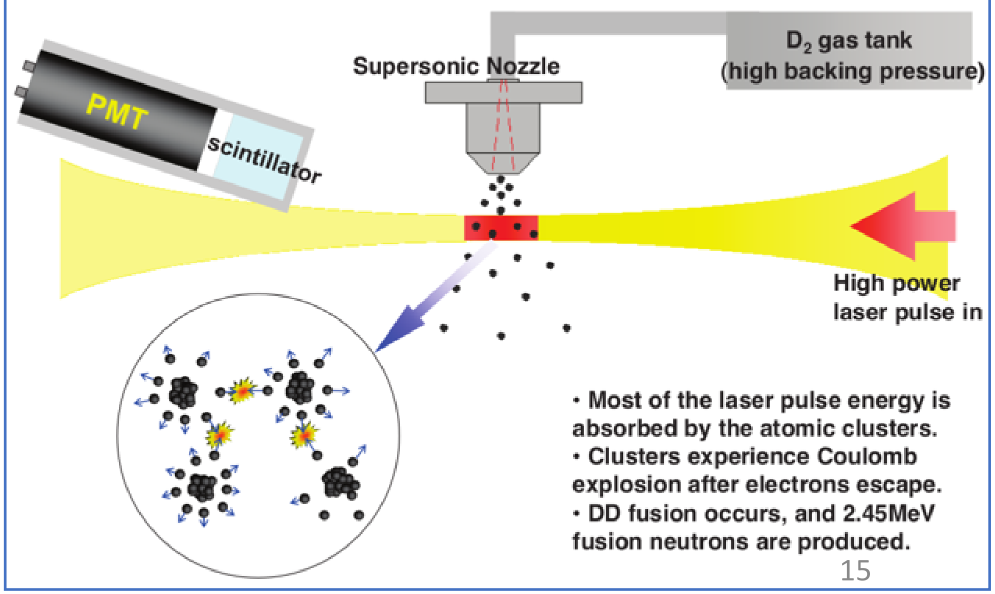
Coulomb explosion of cryoclusters

$$d + d \rightarrow {}^3He(0.82 MeV) + n(2.45 MeV)$$

- Deuteron ions with MB energy distribution
- T = 1-100KeV and density = 1.E18 cm^{-3}
- Fusion yield: 1.E5-1.E7 neutrons/shot

See talks L. Celona e G. Cirrone

Nuclear fusion from laser-cluster interaction



- Most of the laser pulse energy is absorbed by the atomic clusters.
- Clusters experience Coulomb explosion after electrons escape.
- DD fusion occurs, and 2.45MeV fusion neutrons are produced.

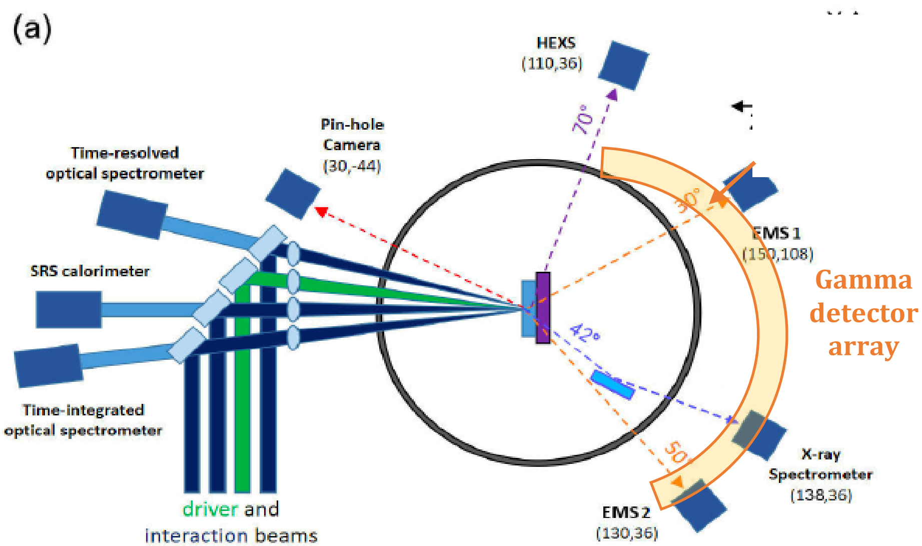
Lattuada D. et al, *s*, Phys. Rev. C 93, 045808 (2016).

Nuclear physics with TW÷PW lasers

Plasmas for Astrophysics Nuclear Decay Observation and Radiation for Archaeometry

Physics cases that can be addressed with PW lasers (EuAPS@LNF):

- Since T ∝ $\sqrt[3]{I_{laser}}$, with an increased laser intensity new scenarios open up where nuclear decays from excited states can be investigated.
- With laser pulses at Δt>1 ps, plasmas in local thermodynamical equilibrium (LTE) can be produced at temperatures up to 100 keV, with nuclear states populated in thermodynamic equilibrium.
- The higher energy density allows to obtain plasma conditions closer to the stellar ones.
- The onset of a LTE allows a direct comparison with stellar model predictions, that normally assume LTE conditions.
- This could be a complementary approach to the PANDORA one, where β-decay studies can be performed in an environment where only *non-local LTE* conditions are attainable.
- The higher temperatures could allow to study the β-decay in plasma also of excited nuclear states.



Cristoforetti, et al, (2023). doi:10.1017/hpl.2023.13

Possible experimental setup for β-decay

1. A PW laser pulse is sent to a solid target containing the radio-isotope under investigation.
2. The plasma is created and a forward emission of the thermalized excited nuclei takes place.
3. The nuclei travel and eventually decay in flight, populating daughter nuclei in excited states.
4. The flight path, and then the distance between the target and a suitable stopper, must be optimized in order define the half-life range that can be explored.

See talk M. Ferrario

INFN CSN3

Final considerations

- CSN3 experiments are heavily active with measurements in many national and international accelerators , with different energies, particle/nuclei types and intensities.

- During 2022, the *Nuclear Physics Middle Term Plan in Italy* defined the main reasearch lines till the end of the decade. It was a joint effort with CSN4 and CSN5, with many young scientists involved. The final reports (EPJ Focus) will soon be available

- Increasing interest from CSN3 to support nuclear processes measurements of interest for medical applications and experimentations at new accelerator facilities devoted to this task. Similarly to the case of the FOOT experiment, CSN3 should take the baton from CSN5 when extensive campaigns of measurements are required.

- Laser induced reactions could open a very reach scenario for measurements in nuclear astrophysics (and other applied fields) , complementary to the present facilities. CSN3 is following with attention such developments and is ready to support this activity.