EUROPEAN UNION

Structural Instruments 2014-2020

Nuclear Physics

Extreme Light Infrastructure-Nuclear Physics (ELI-NP) - Phase II

IFIN-HH

The ELI-NP nuclear photonics program: A new source for nuclear structure data

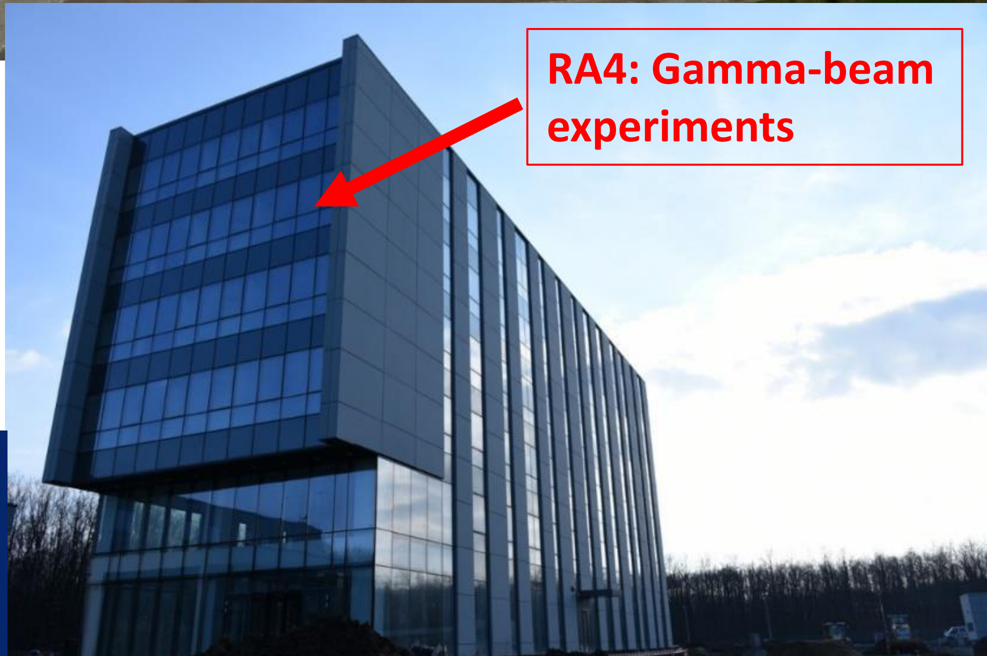
Dimiter L. Balabanski

22nd Technical Meeting of the Nuclear Structure and Decay Data Network, Berkeley, May 22nd-26th, 2017

Project co-financed by the European Regional Development Fund through the Competitiveness Operational Programme
"Investing in Sustainable Development"

June 7th, 2013

Extreme Light Infrastructure – Nuclear Physics (ELI-NP)



<u>Mission:</u> Nuclear Physics studies with high-intensity lasers and brilliant γ beams

"The content of this document does not necessarily represent the official position of the European Union or of the Government of Romania"

For detailed information regarding the other programmes co-financed by the European Union please visit *www.fonduri-ue.ro, www.ancs.ro, http://amposcce.minind.ro*

- **Nuclear Physics experiments to characterize laser – target interaction**

- **Photonuclear Physics**

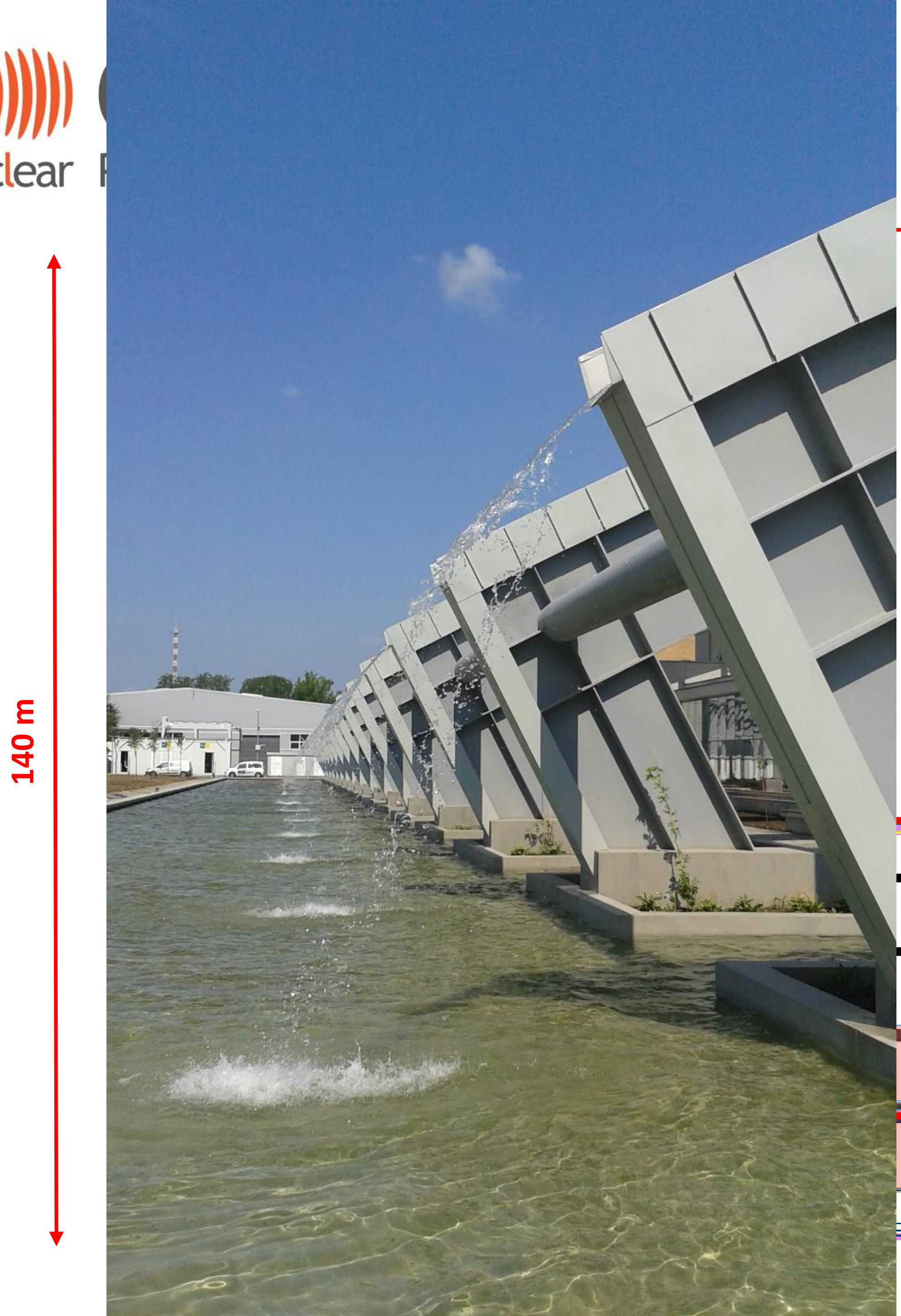
- **Exotic Nuclear Physics and astrophysics**

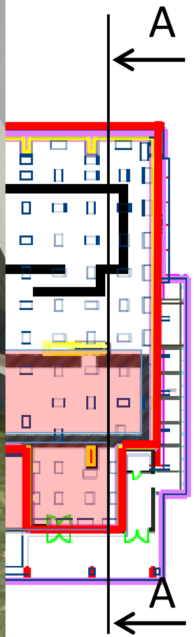
  complementary to other ESFRI Large Scale Physics Facilities (FAIR- Germany, SPIRAL2- France)

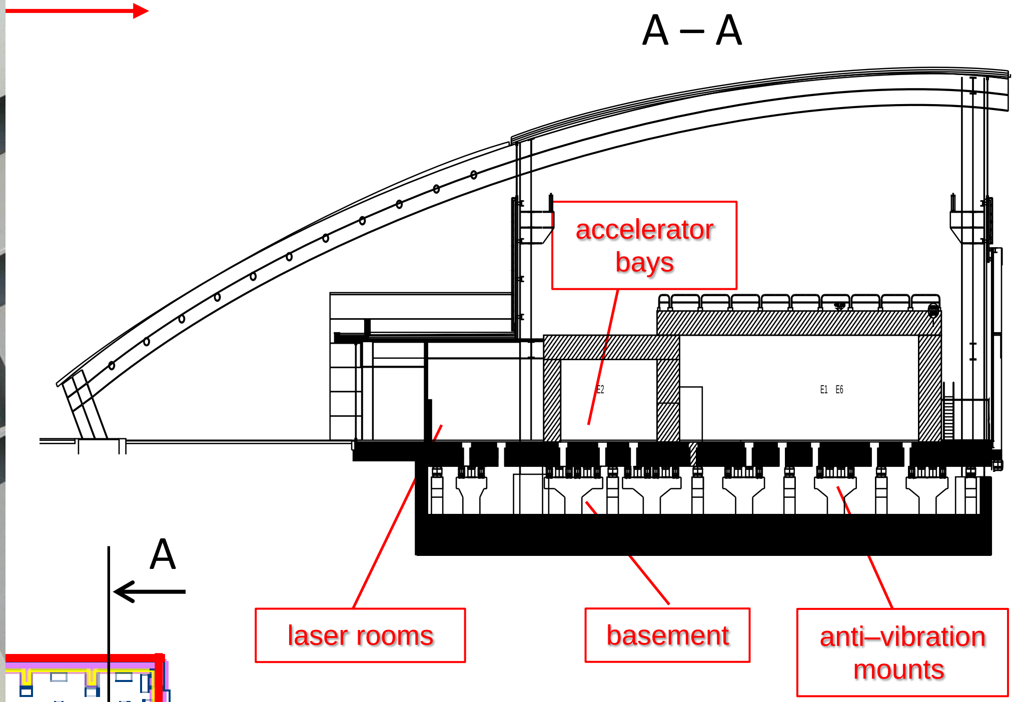
- **Applications based on high intensity laser and very brilliant γ beams**

ELI-NP in ‘**Nuclear Physics Long Range Plan in Europe**’ as a major facility

NP laboratory building







civil construction was commissioned in September 2016

Platform supported on dampers

Anti–vibration platform
±1 μm @ < 10 Hz

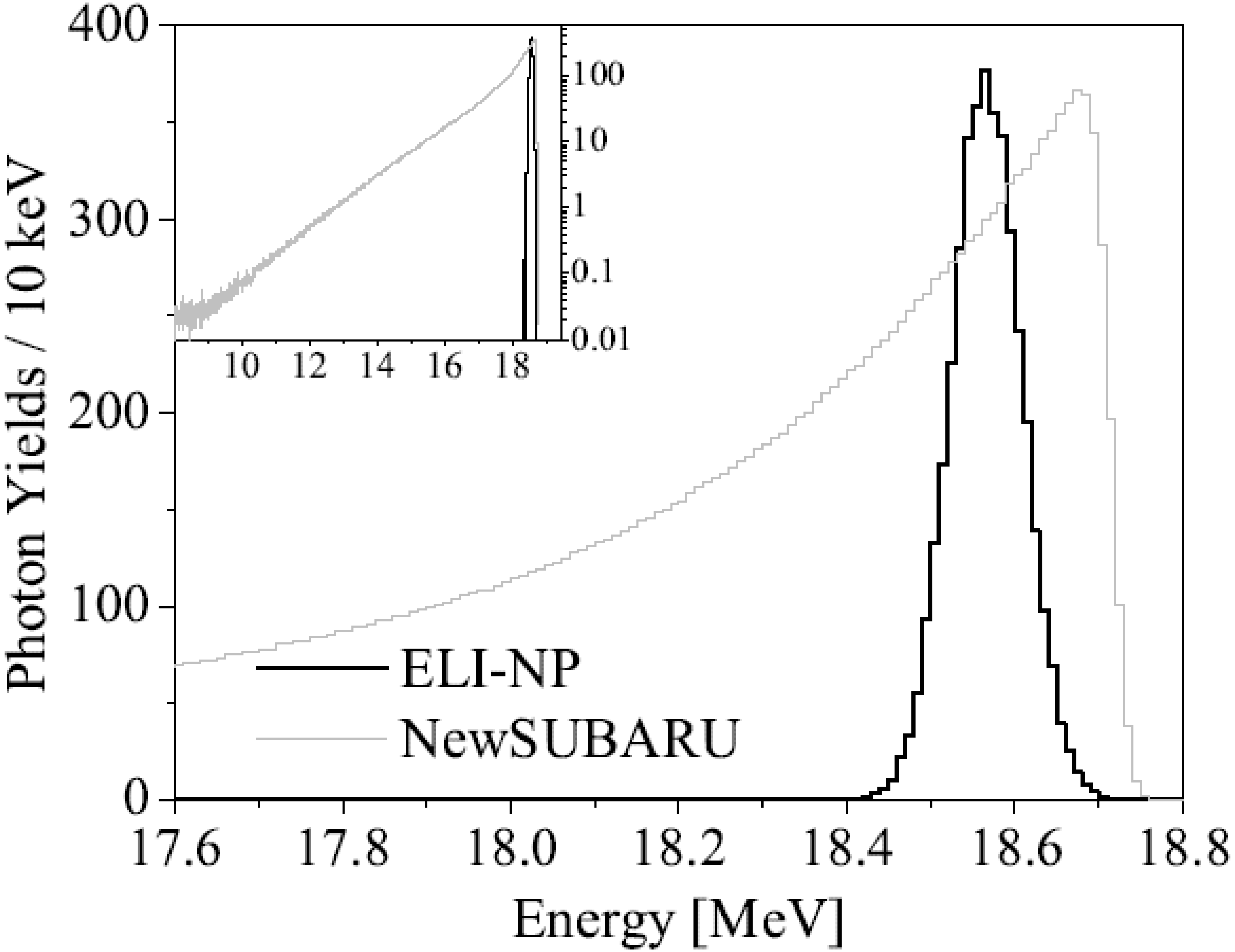
Thermalized building
$22^0 \pm 0.2^0$

Clean rooms

ELI-NP Gamma Beam System (GBS)

$E_\gamma = 2\gamma_e^2 \cdot \frac{}{1+(\gamma_e}$

E$_e$ e

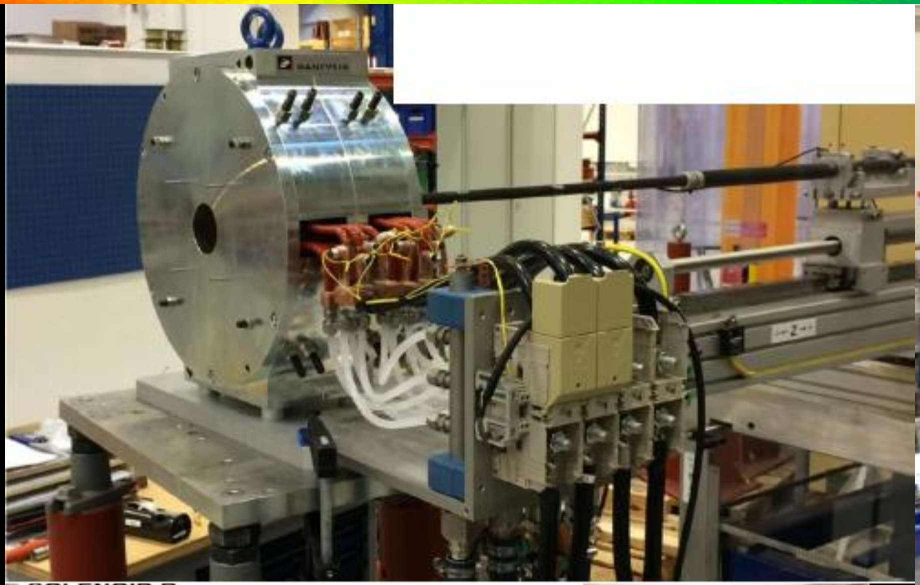


Narrow ba

Gamma Beam System

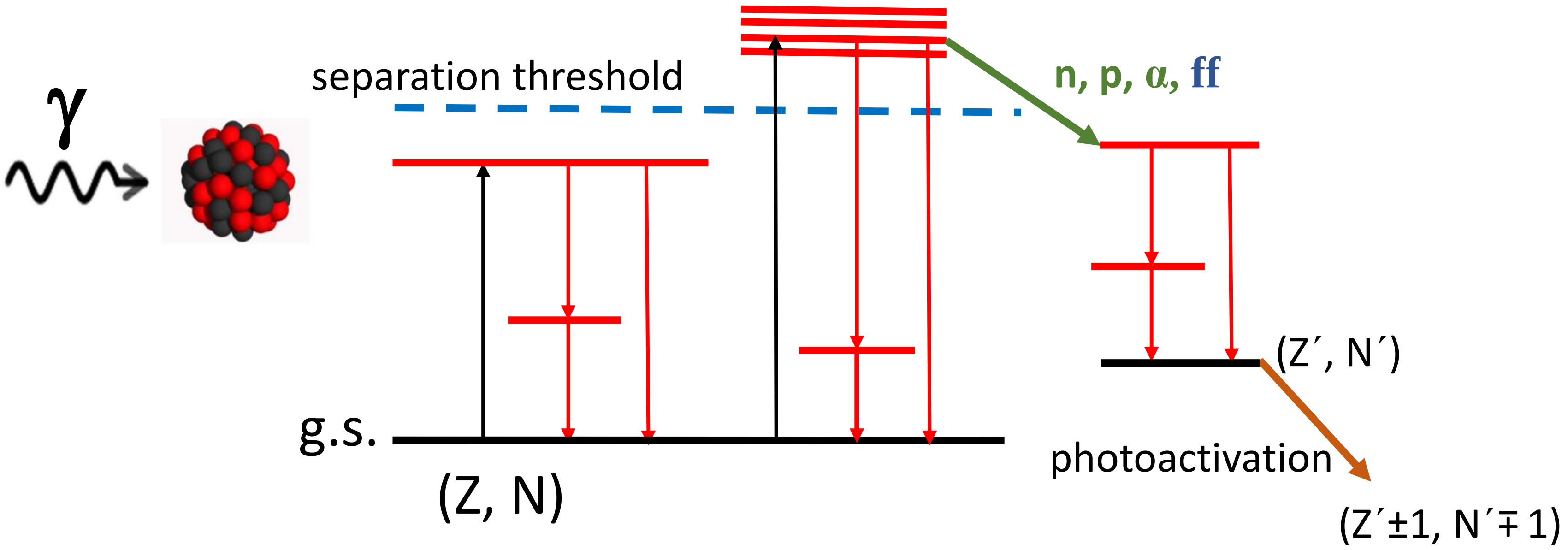
low-energy accelerator section:
0.2-3.5 MeV
factory acceptance in Dec. 2015

high-energy accelerator section:
3.0-19.5 MeV



Experiments with high-brilliance gamma beams at ELI-NP

S. Gales et al., Phys. Scr. 91, 093004 (2016)



Nuclear Resonance Fluorescence (NRF) – **Rom. Rep. Phys. 68, S483 (2016)**

Giant/Pigmy Resonances (GANT) – **Rom. Rep. Phys. 68, S539 (2016)**

Photodisintegration (γ,n), (γ,p), (γ,α) – **Rom. Rep. Phys. 68, S699 (2016)**

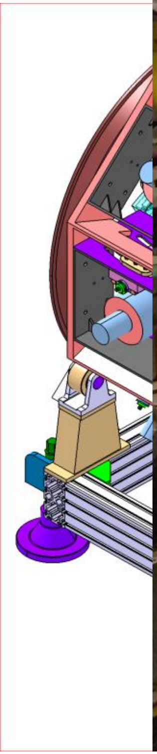
Photofission (γ,ff) – **Rom. Rep. Phys. 68, S621 (2016)**

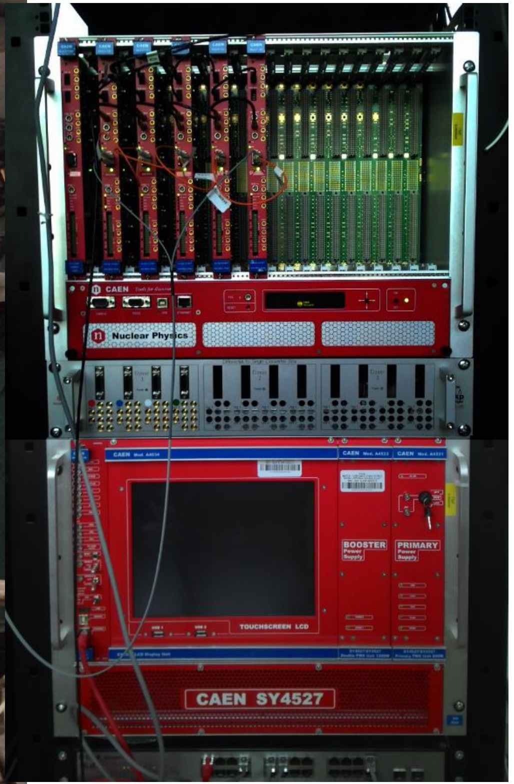
Applications – **Rom. Rep. Phys. 68, S735 (2016), *ibid* 68, S799 (2016), *ibid* 68, S847 (2016)**

Nuclear

ep. Phys. 68, S483 (2016)

g
tage
under discussion





Dec. 12-18, 2016

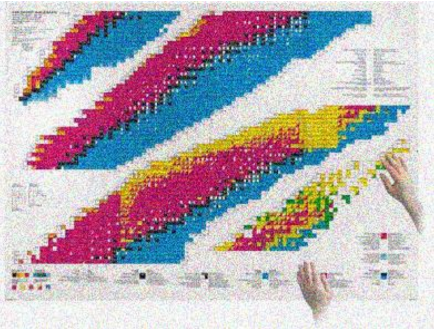
Rom. Rep. Phys. 68, S483 (2016)

ELI-NP NRF physics cases

- Self-absorption measurements (Γ_0/Γ_i)
- Low-energy dipole response (e.g. Actinides)
- Dipole response and parity measurements for weakly-bound nuclei
- Investigation of the Pigmy Dipole Resonance
- Rotational 2^+ states of the scissor mode
- Constraints on the 0νββ-decay matrix elements of the scissors mode decay channel: ^{150}Sm

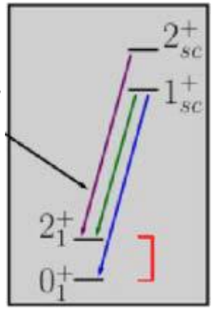
Availability frontier

p-nuclei and actinides



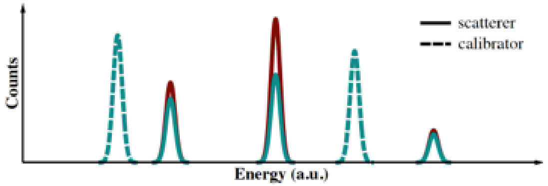
Sensitivity frontier

week channels



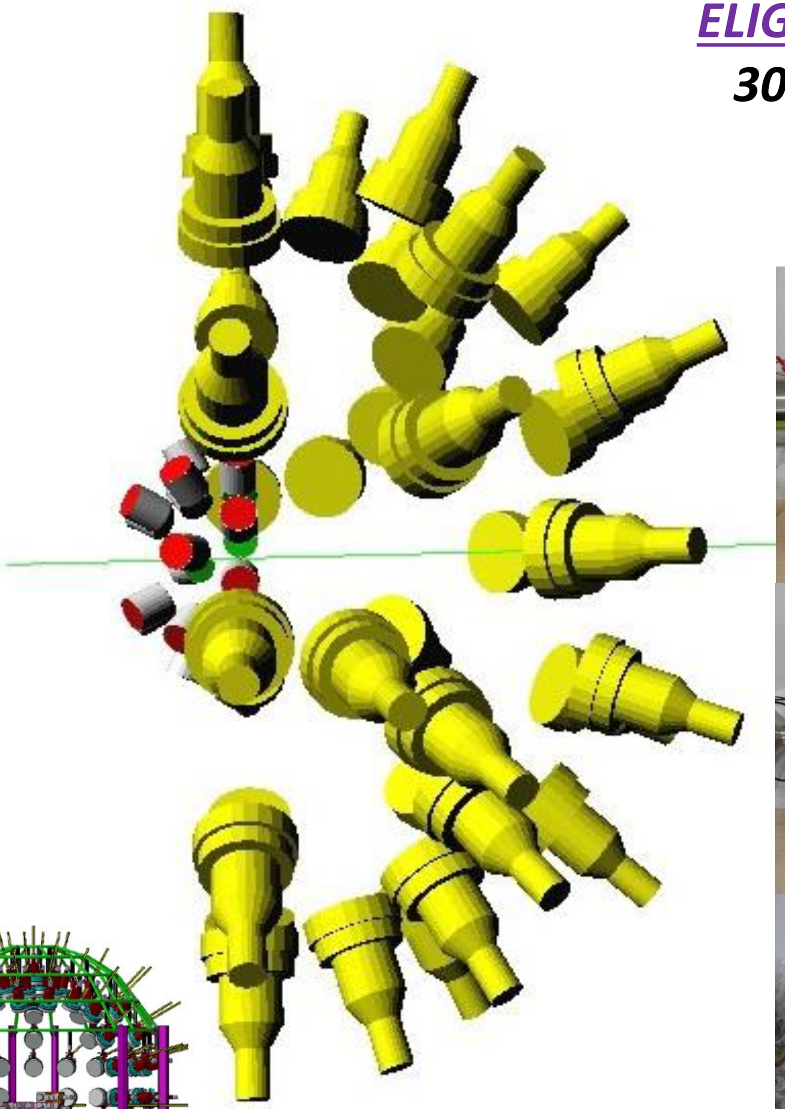
Precision frontier

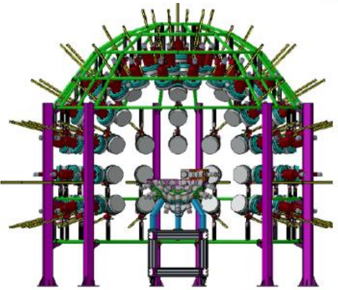
high statistics



Rom. Rep. Phys. 68, S539 (2016)

GANT experiment at ELI-NP





ELIGANT-GN array

30 $LaBr_3$ or $CeBr_3$

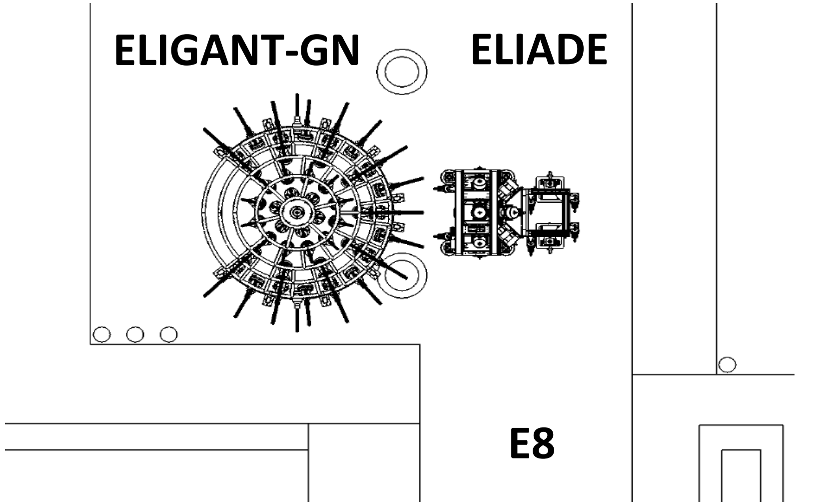
20 ^{7}Li glasses

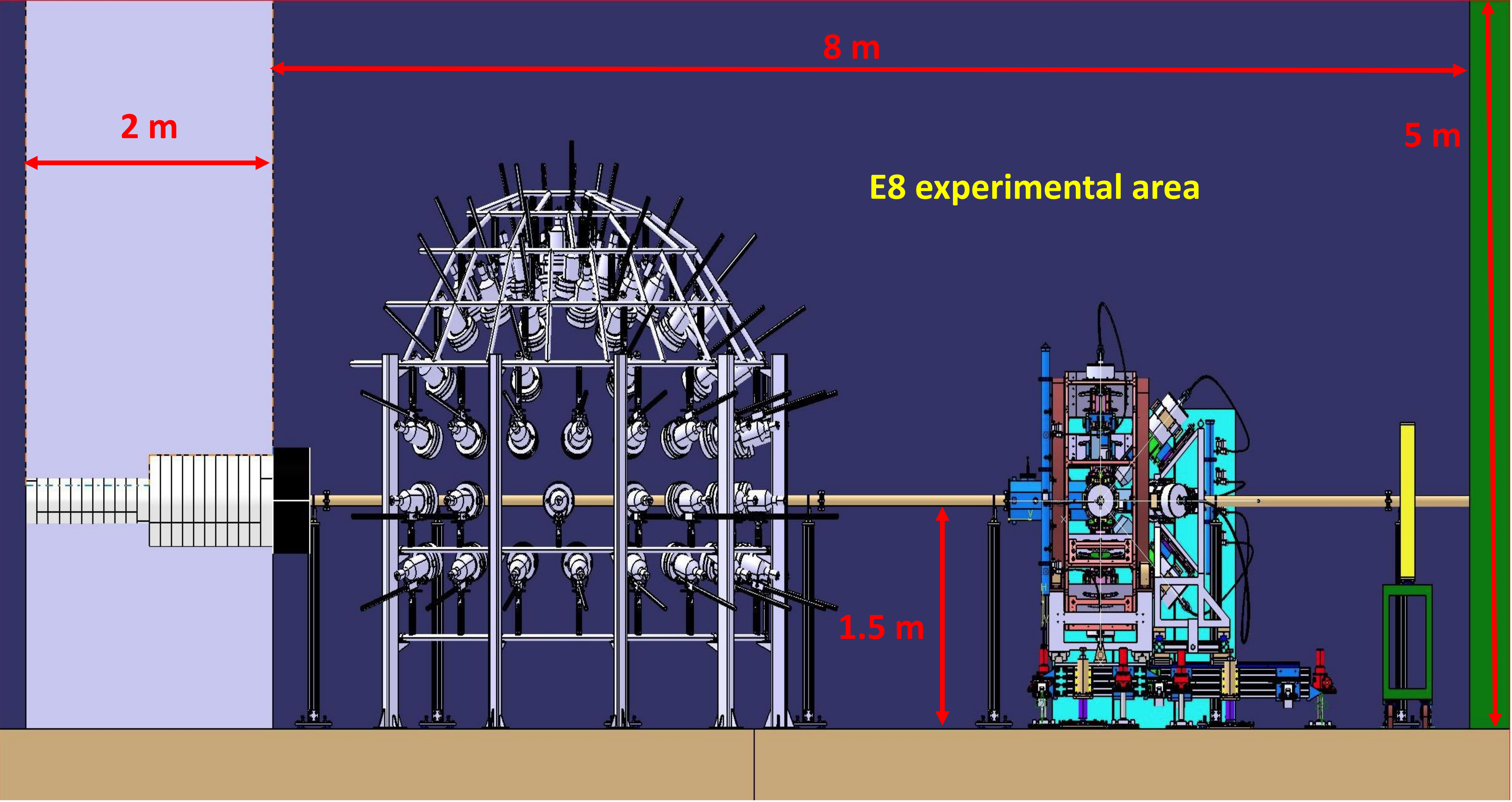
30 Lq. Scint.

Day ONE:

studies of GDR and PDR decay (^{90}Zr, ^{208}Pb)

- combine with information from (γ,n) experiments
- combine with information from (γ,γ’) experiments (*e.g.* polarization)
- γ-decay to gs and excited states as a function of excitation energy




8 m
2 m
5 m
E8 experimental area
1.5 m

Neutron stars, equation of state and dipole polarizability @ELI-NP

-Neutron stars (NS) properties depend sensitively on the equation of state (EOS) of nuclear matter
-EOS can affect many NS properties: mass-radius relationship, moment of inertia, cooling rates, Urca process, …
-It has been suggested that the slope (L) of the symmetry energy term of the EOS is closely related to the dipole polarizability α_D through the neutron skin thickness [1,2,3]

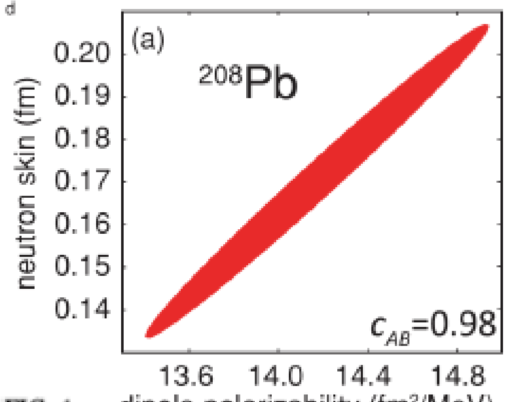


FIG. 1.

PHYSICAL REVIEW C **81**, 051303(R) (2010)

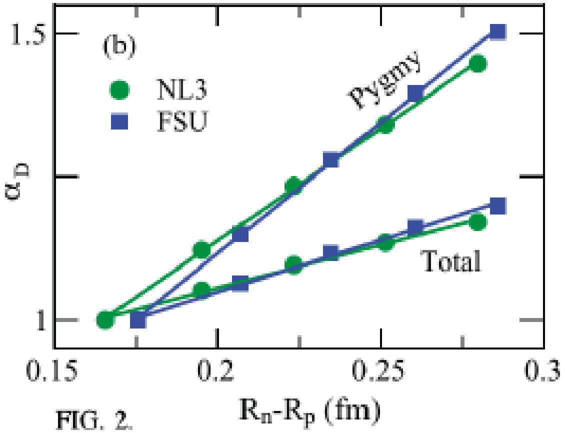


FIG. 2.

PHYSICAL REVIEW C **83**, 034319 (2011)

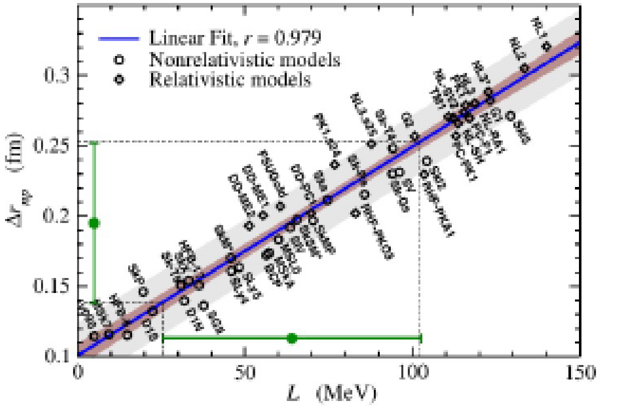


FIG. 3 (color online). Neutron skin of ^{208}Pb against slope of the symmetry energy. The linear fit is $\Delta r_{np} = 0.101 + 0.00147L$.

PRL **106**, 252501 (2011)

ELI-NP: experimental photo-nuclear reaction facility

- The dipole polarizability is obtained from the photo-absorption cross section

$$\alpha_D = \frac{\hbar c}{2\pi^2}\int_0^\infty \frac{\sigma_{abs}}{\omega}\,d\omega = \frac{8\pi}{9}\int_0^\infty \frac{dB(E1)}{\omega}$$

-Strongly dependent on the low-energy strength, e.g. Pygmy resonance (see also FIG. 2)
-ELI-NP will provide (accurate and unambiguous) measures of E1 strength below and above the neutron-threshold
-Model independent results: pure electromagnetic excitation process

[1]P.-G. Reinhard and W. Nazarewicz, Phys. Rev. C81, 051303® (2010) [2] J. Piekarewicz, Phys. Rev. C83, 034319 (2011) [3] X. Roca-Maza et al., Phys. Rev. Lett.106,252501 (2011)

RCNP Osaka vs. ELI-NP experiments

RCNP

High-resolution (p,p') measurement at 0^o and forward angles

A. Tamii, NIM A605, 326 (2009)

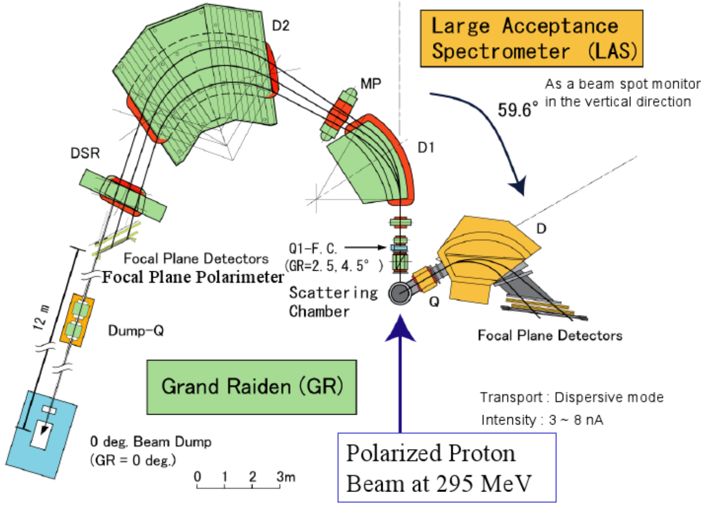
ELI-NP

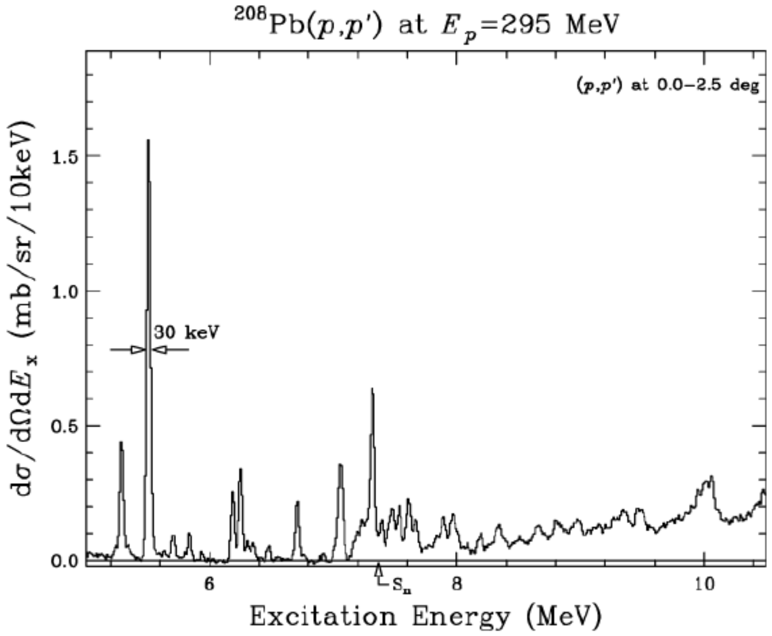
High-resolution (γ,γ') + (γ,n) measurement

experiment: polarized (>99%) γ beam

simultaneous (γ,γ') + (γ,n) measurement

Spectrometers in the 0-deg. experiment setup

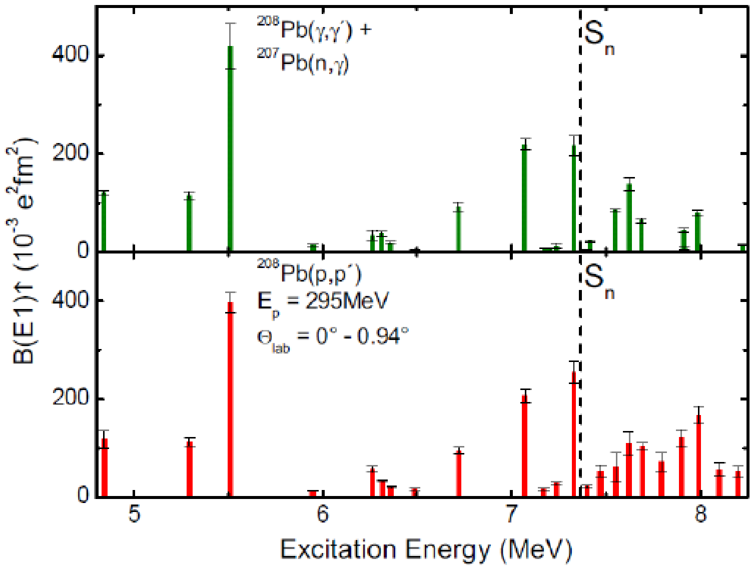




$$\alpha_D \equiv \frac{\sigma_{-2}}{2\pi^2} \cdot \frac{\hbar c}{e^2} = \sum \frac{\sigma_{abs}(E_x)}{E_x^2} \cdot \frac{\hbar c}{2\pi^2 e^2} = 20.1 \pm 0.6 \text{ fm}^3/\text{e}^2$$

A. Tamii, PRL 107, 062502 (2011)

B(E1) of discrete states



B(E1) strength distribution in ^{208}Pb below the GDR region

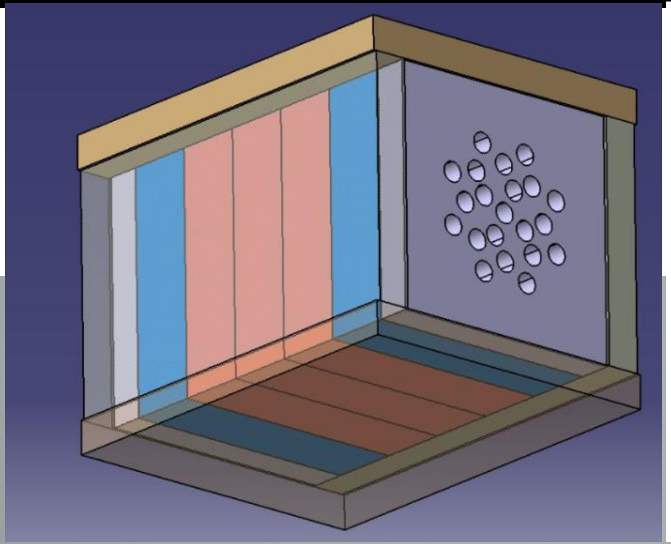
Rom. Rep. Phys. 68, S539 (2016)

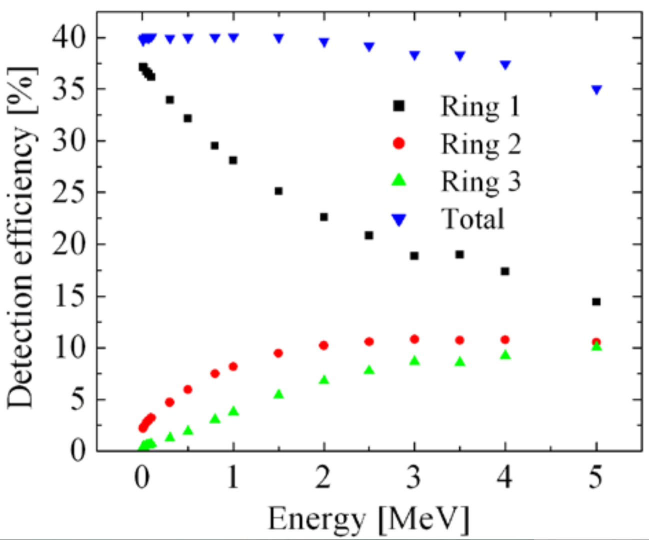
(γ,n) cross-section experiment at ELI-NP

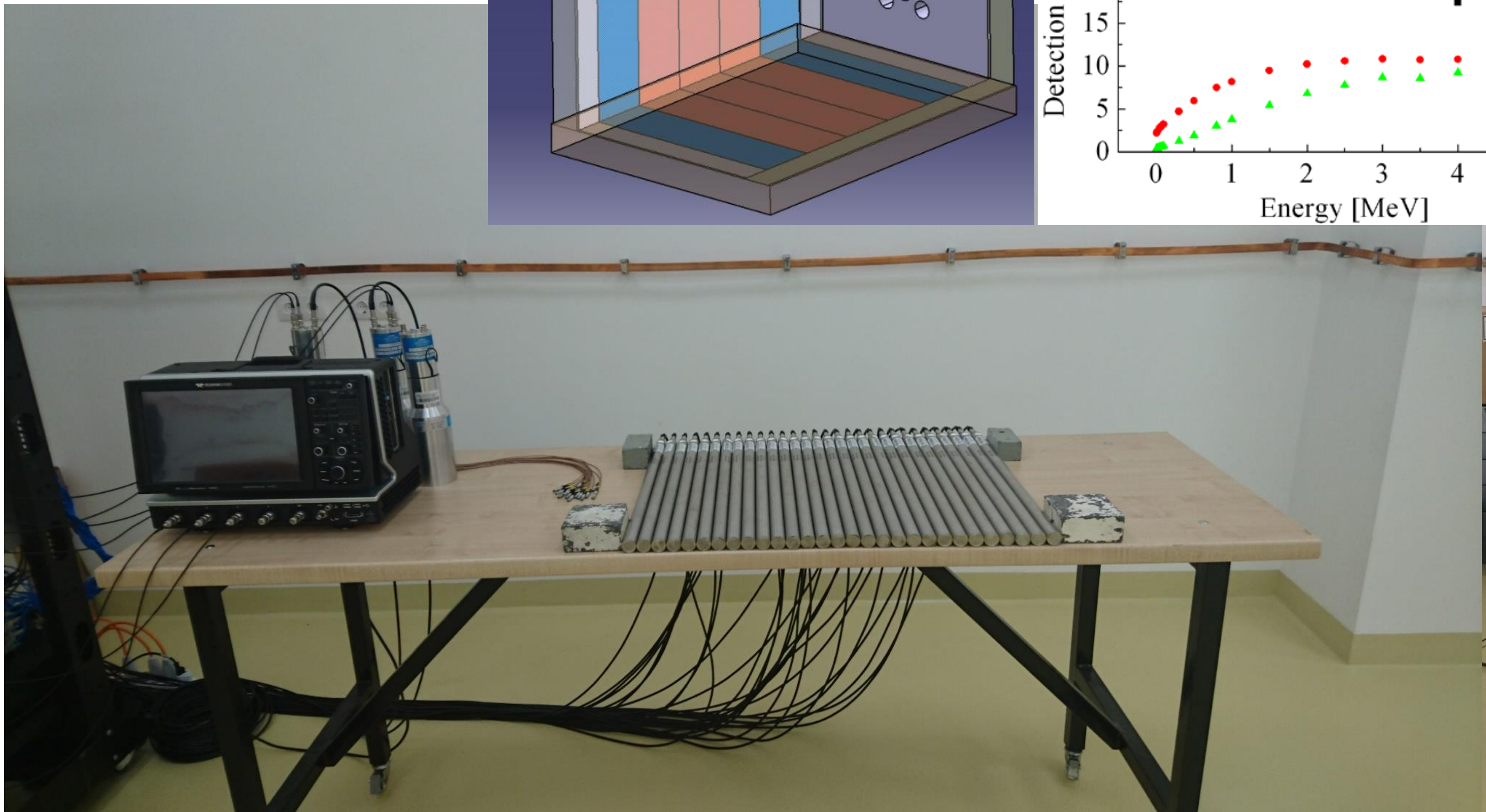
ELIGANT-THN array

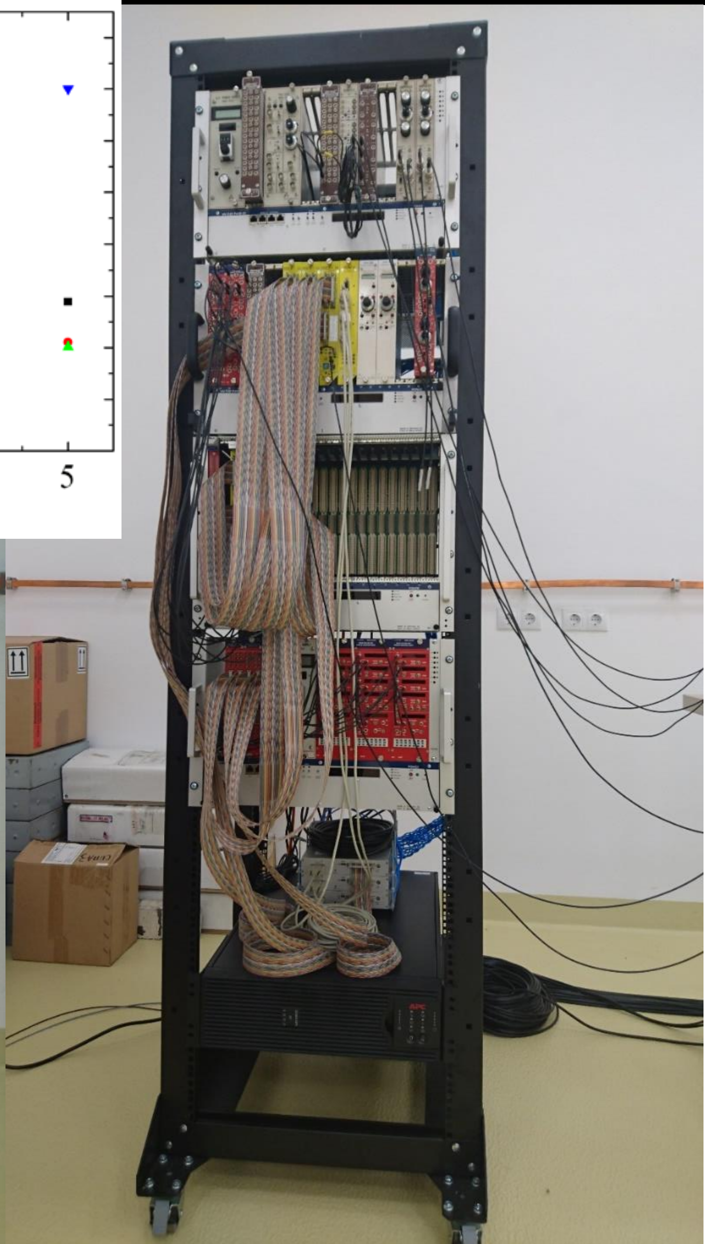
30 ^{3}He counters

40% detector efficiency







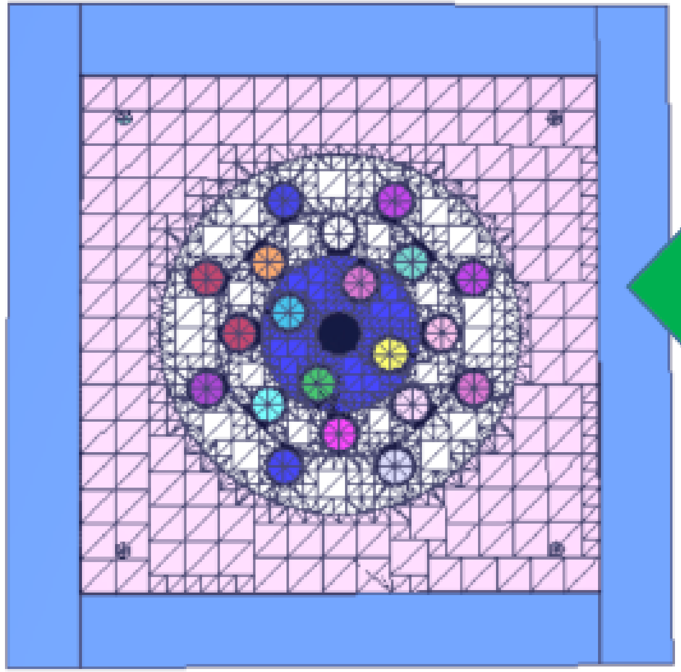


P-PROCESS NUCLEOSYNTHESIS FOR ^{180}Ta AND MEASUREMENTS OF THE PHOTO-NEUTRON CROSS SECTION

^{180}Ta characteristics

- Lowest natural abundancy (0.012%)
- Short-lived ($T_{1/2}$ = 8.15h) $J^{\pi} = 1^{+}$ ground state ($^{180}Ta^{g}$)
- Very long-lived ($T^{1/2} > 10^{15}$ yr) $J^{\pi} = 9^{-}$ isomeric state ($^{180}Ta^{m}$)
- ^{181}Ta(γ,n)^{180}Ta and ^{180}Ta(γ,n)^{179}Ta photo-disintegration reactions

- Correct prediction of the $^{180}Ta^{m}$ yield highly requires both ^{181}Ta(γ,n)^{180}Ta and ^{180}Ta(γ,n)^{179}Ta cross section measurements.
- The measurements for the (γ,n) cross sections related to the p-nuclides destruction requires gamma ray beam three orders of magnitude higher than the existing ones.
- Measurements of the ^{180}Ta(γ,n)^{179}Ta reaction are foreseen in the Day 1 experiment at ELI-NP facility by using the maximum available gamma ray energy of 19 MeV.



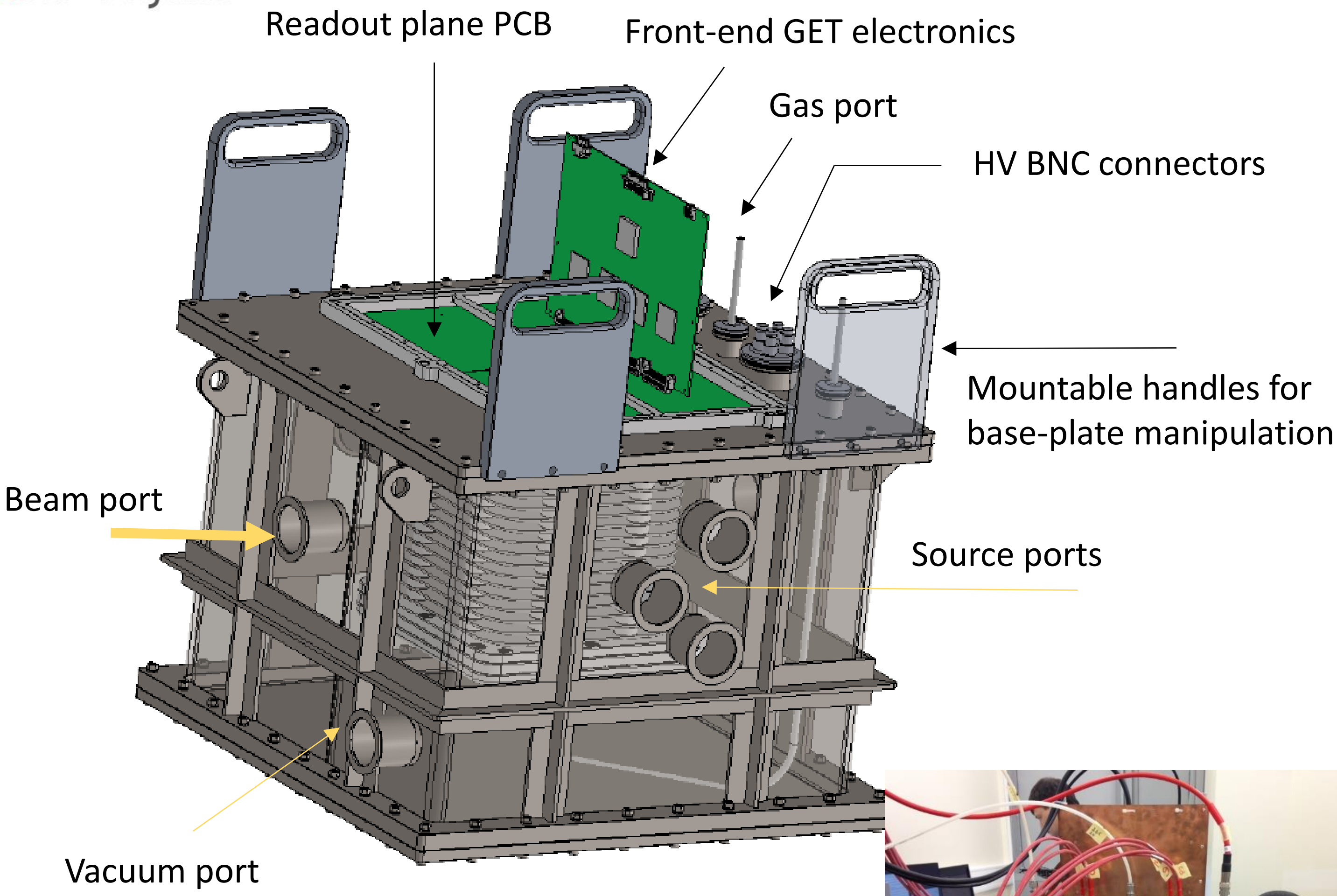
Transversal section of the ELIGANT - TNH High Efficiency 4π Thermal Neutron Detector

- ✓ 20 cylindrical ^{3}He proportional counters
- ✓ 60% detection efficiency
- ✓ low amount of ^{180}Ta target (1mg/cm^{2}) to be used.

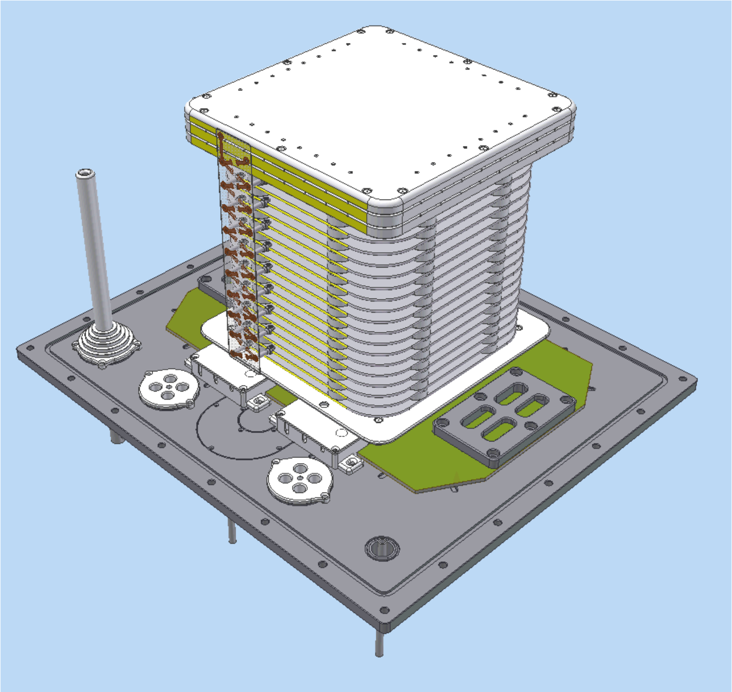
NuPECC LOng Range Plan 2016-2020 – Astrophysics

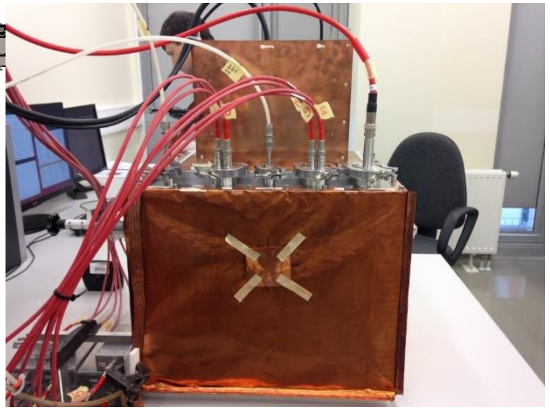
ELITPC

flagship experiment: $^{16}O(\gamma,\alpha)^{12}C$



Detector upside-down view





The mini-eTPC detector with 256-channel readout was built and successfully tested in-beam at the IFIN Tandem in 2016

U. Warsaw, ELI-NP, U. Connecticut

nuclear astrophysics with ELISSA

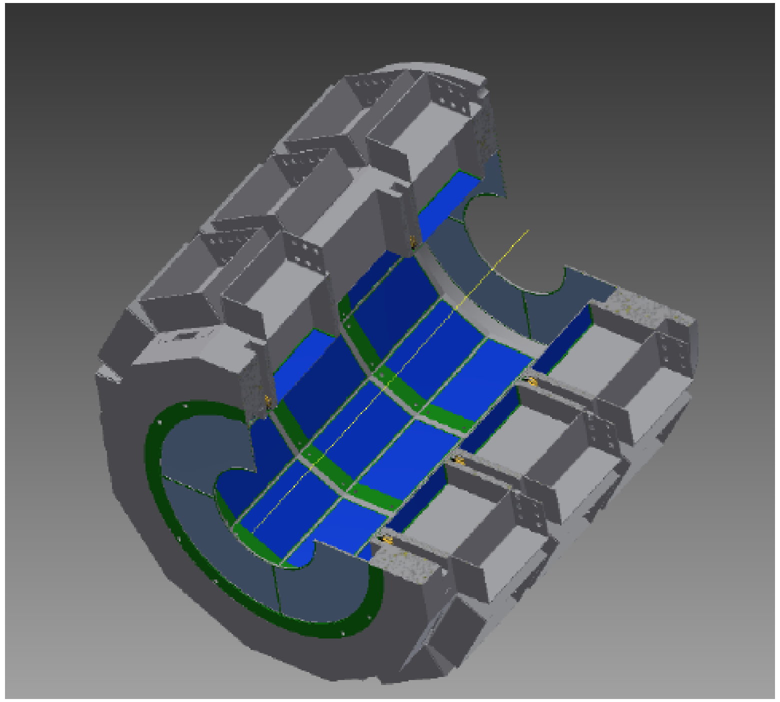
ELISSA:

- 3 rings of 12 position sensitive X3 silicon-strip detectors by Micron
- 2 end cap detectors from 4 QQQ3 segmented detectors by Micron
- 320 channels readout with GET electronics

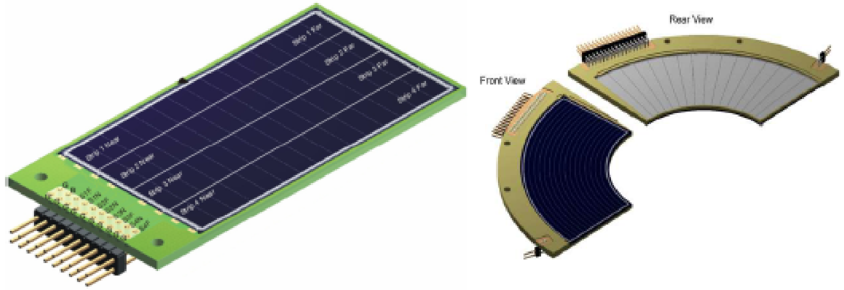
^{7}Li(γ,t)α

- reaction could still be a game changer in resolving the “Li problem”
- experimental measurements below 1.5 MeV are 30 yrs. old and disagree with theoretical predications
- higher energy measurements can restrict the extrapolation to astrophysically important energies

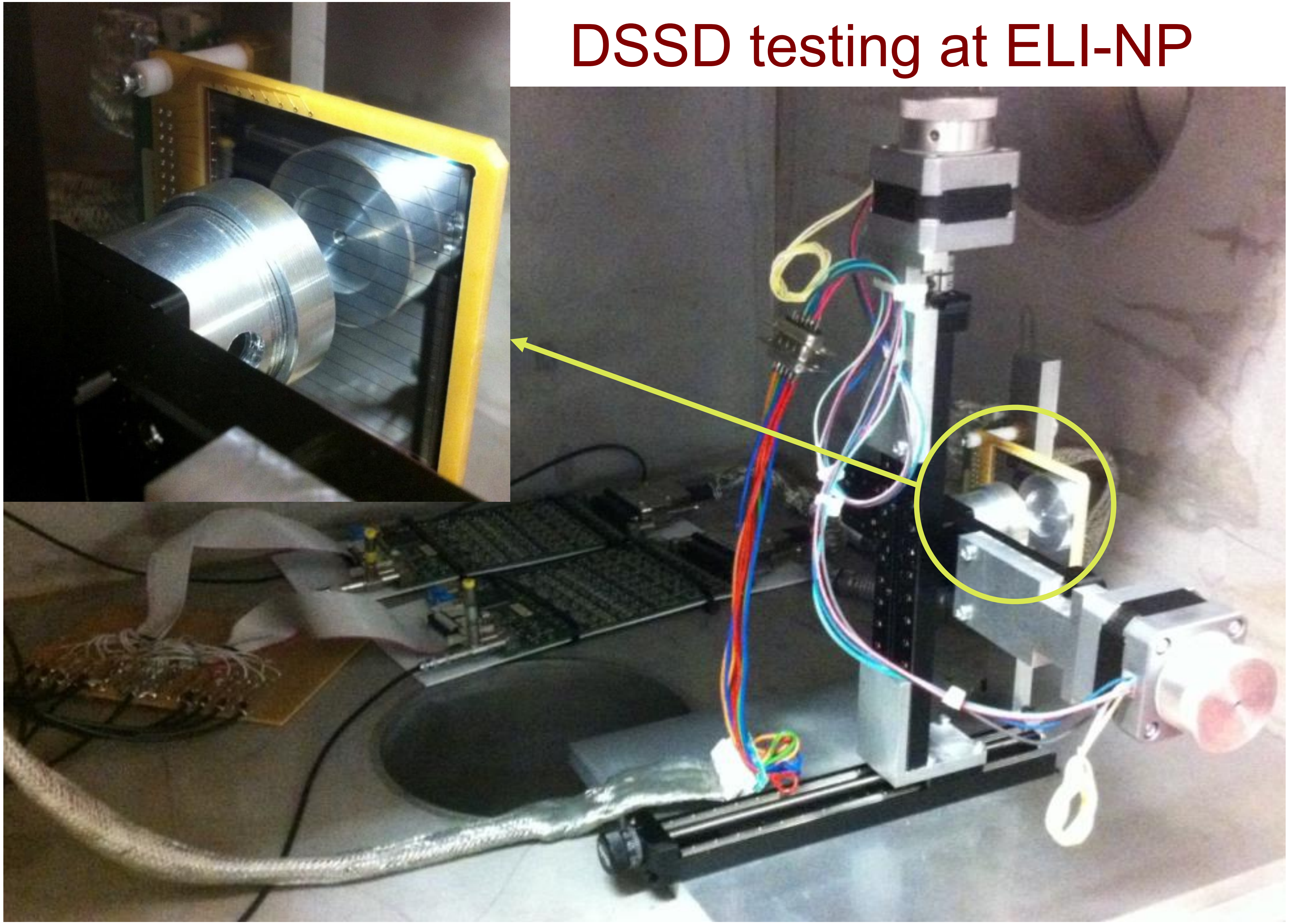
C. Matei et al., exp. at HIγS in March 2017



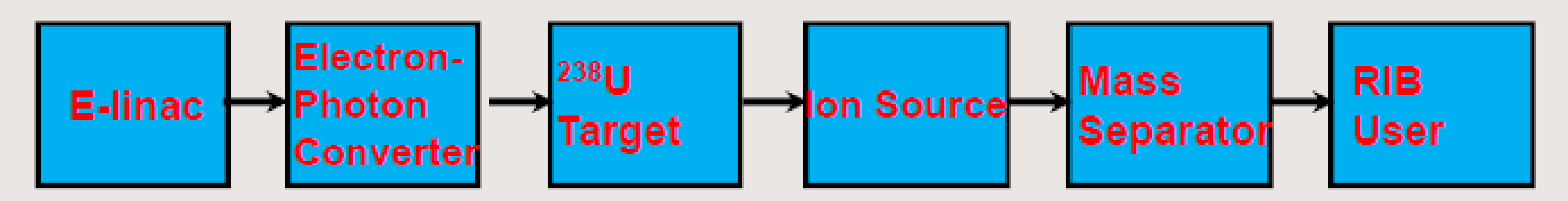
in collaboration with LNS Catania



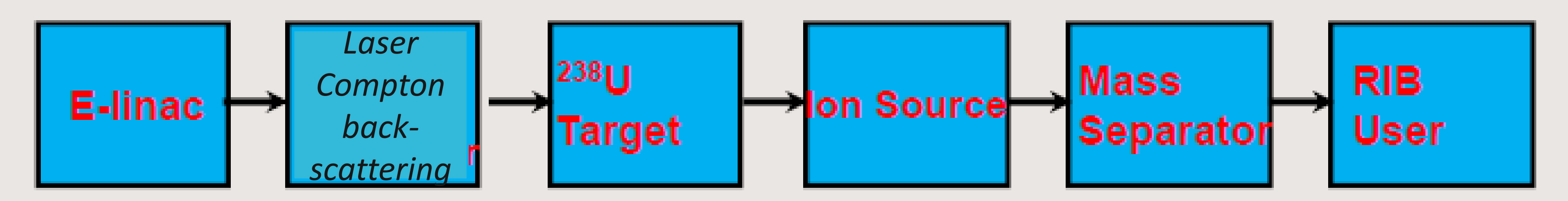
DSSD testing at ELI-NP

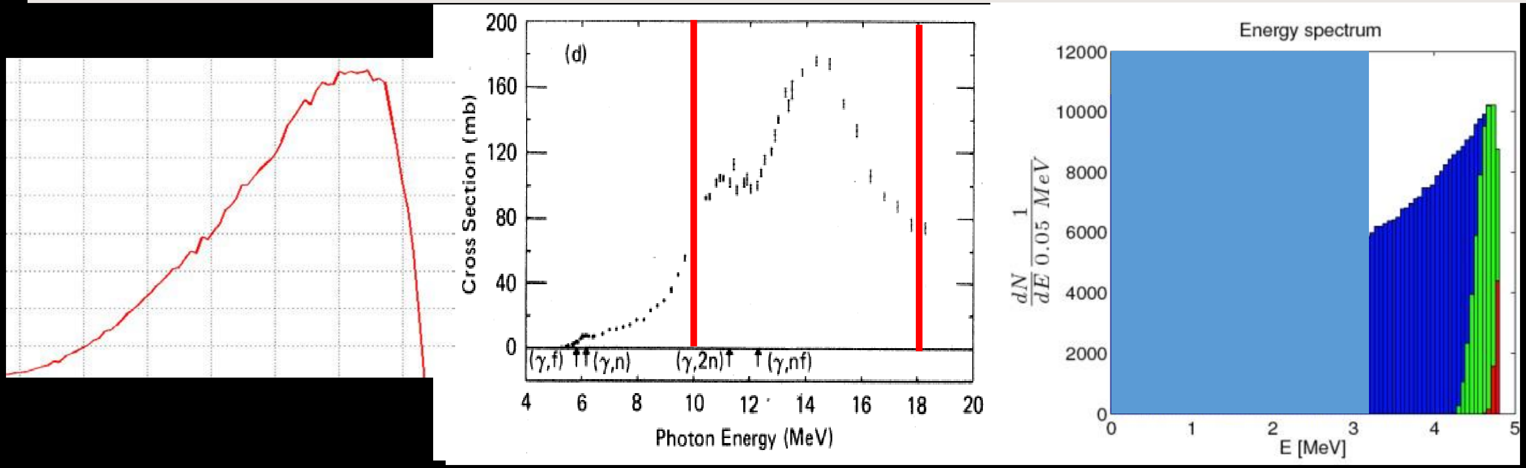


ALTO, ARIEL, etc

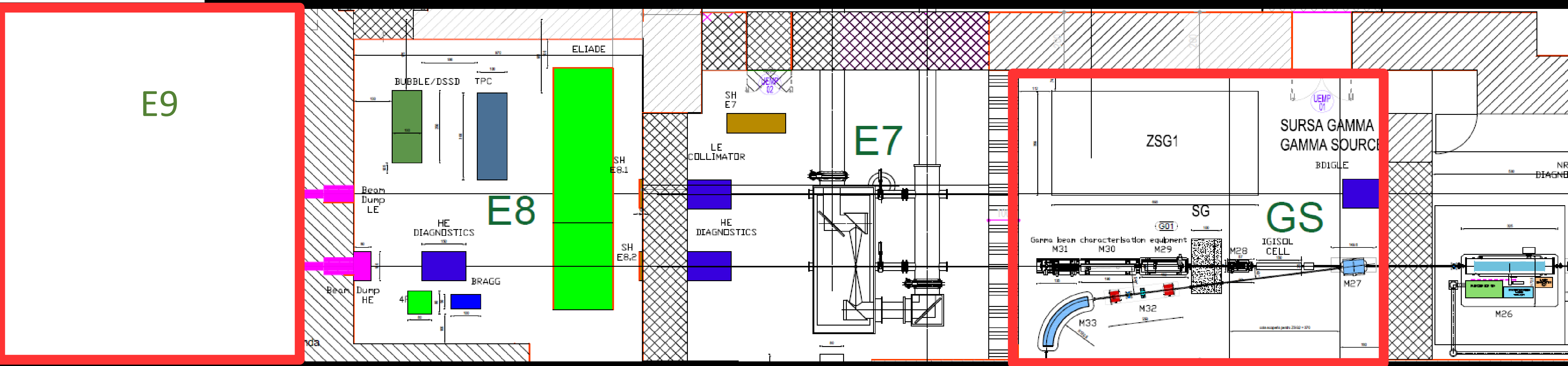


ELI-NP



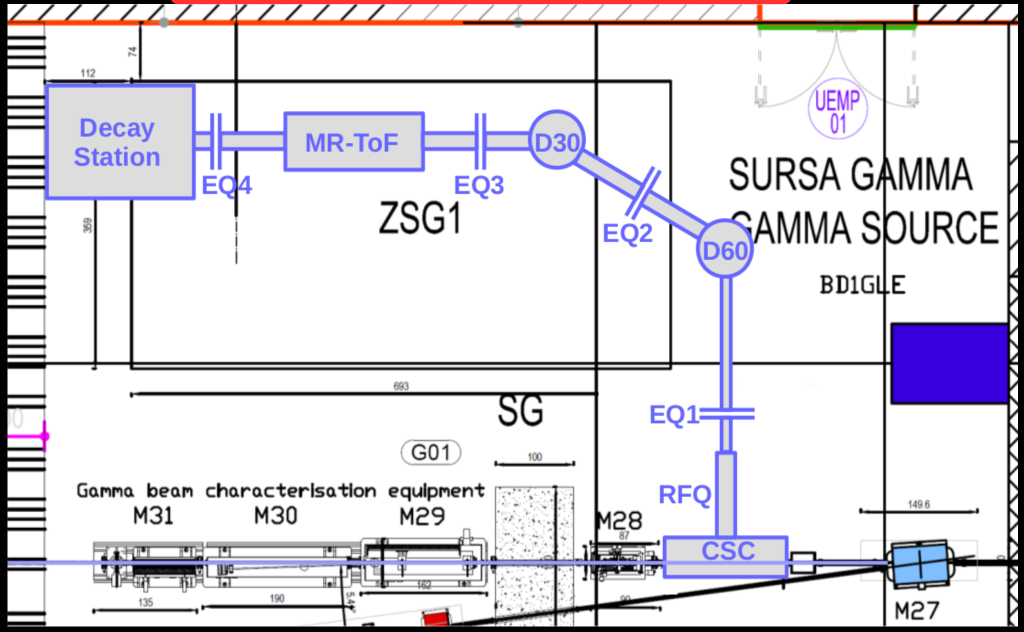


IGISOL beamline: Location



Location 1:
- CSC at 7m from IP →A ≈ 0.7cm
- maximum CSC length 1.5m
- crowded exp hall!

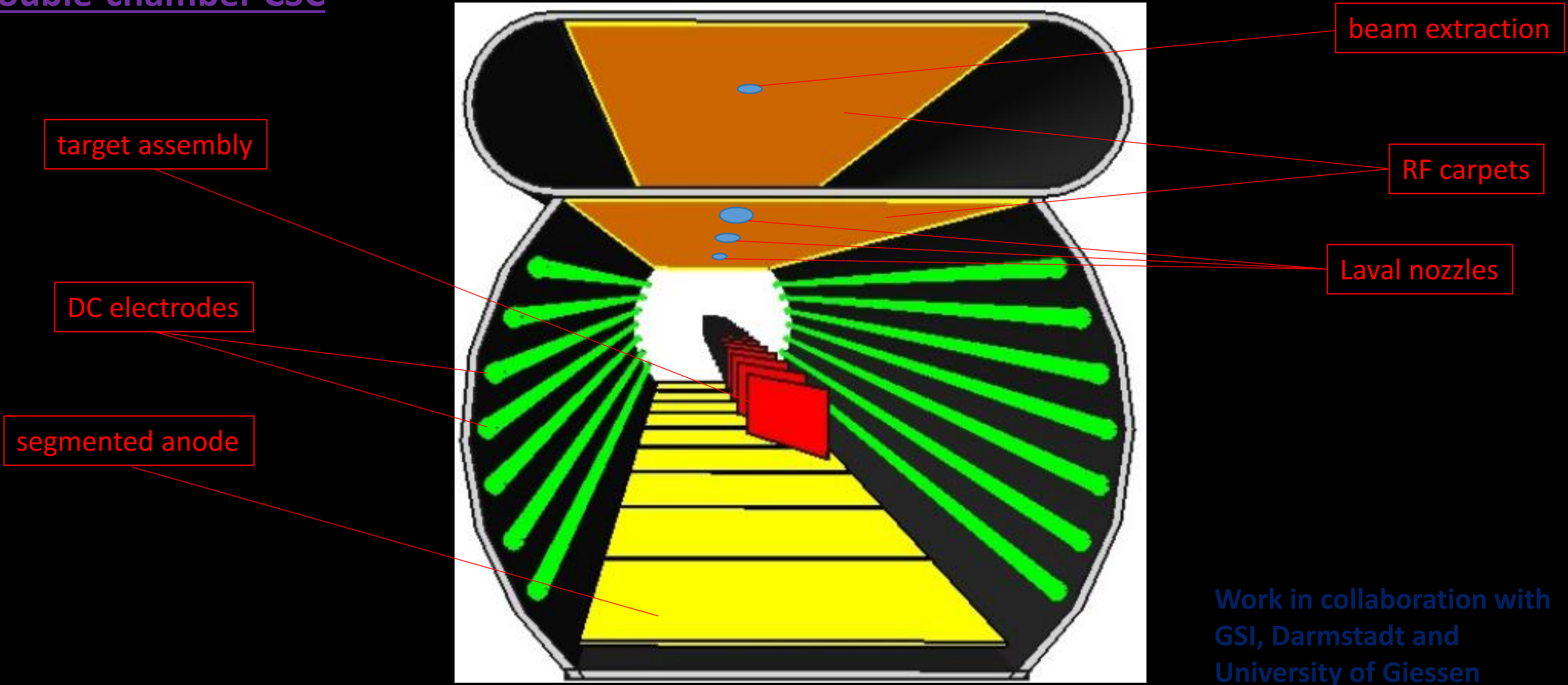
Location 2:
- CSC at 40m from IP → A ≈ 4cm
- plenty of space!



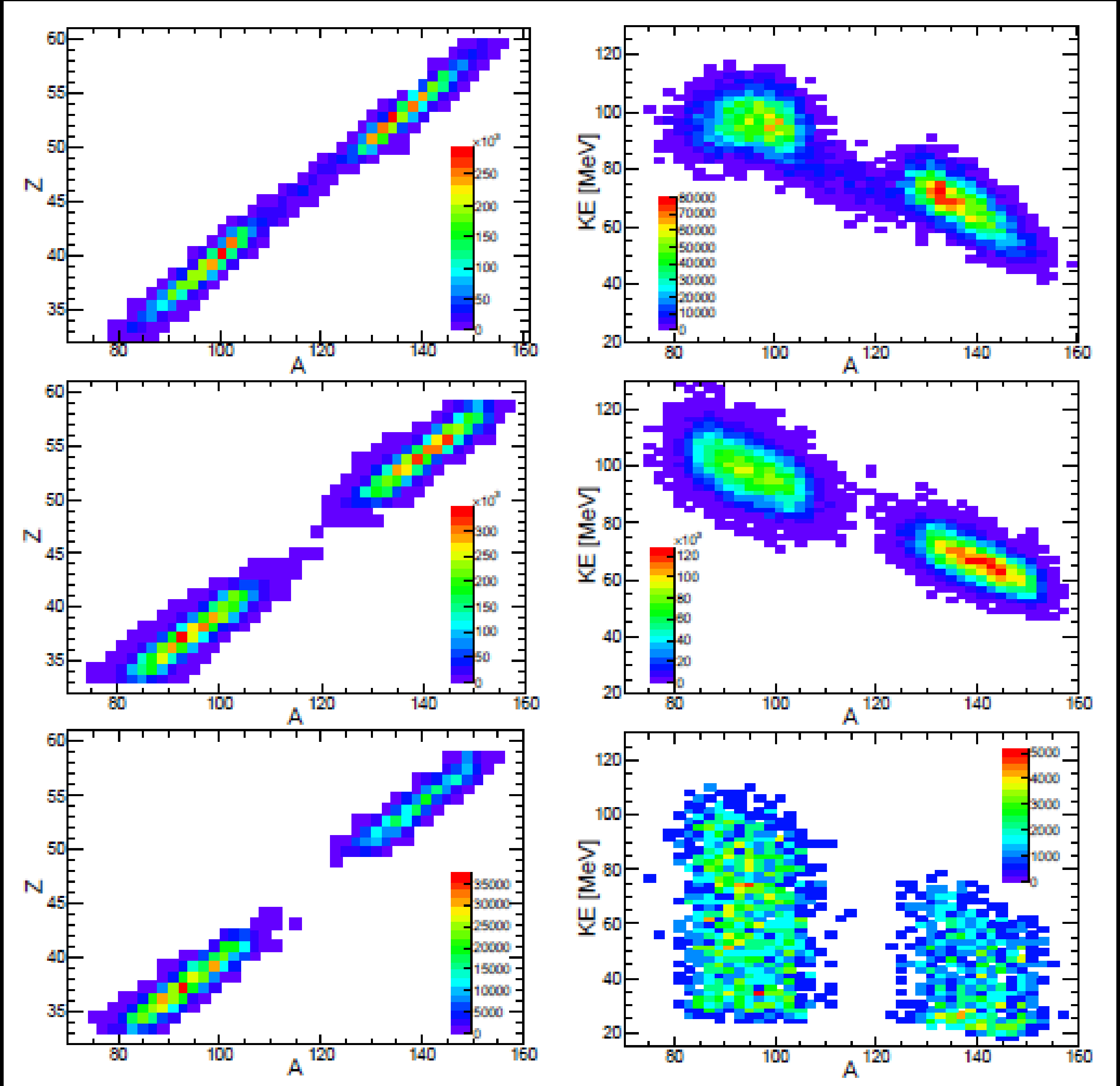
Rom. Rep. Phys. 68, S621 (2016)

IGISOL facility at ELI-NP

double-chamber CSC



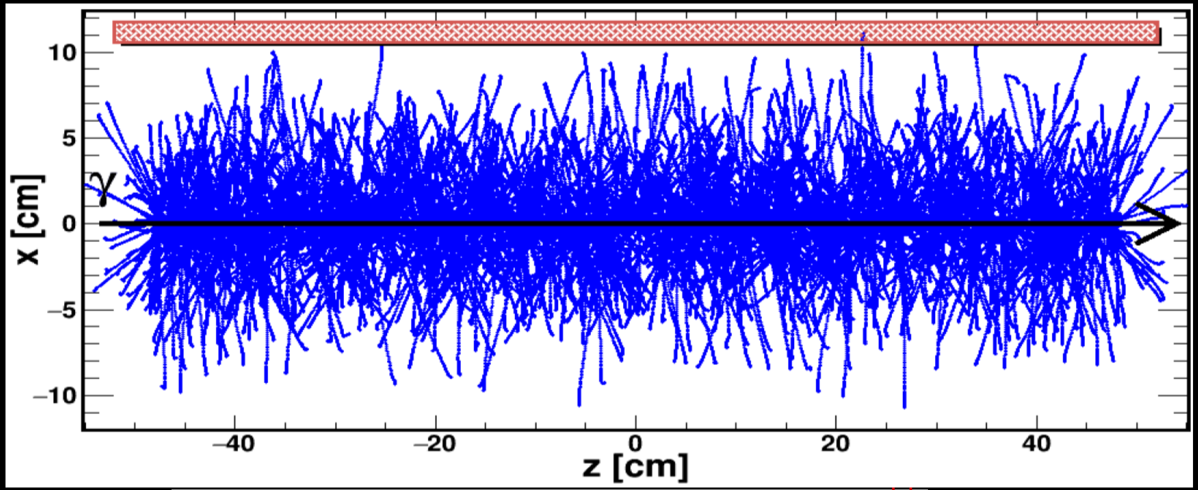
Work in collaboration with GSI, Darmstadt and University of Giessen

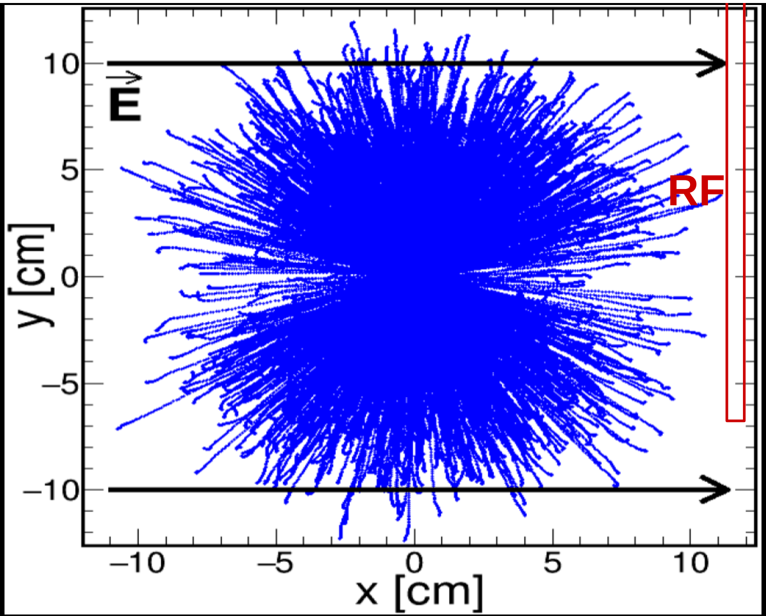


P. Constantin et al, NIM B 378, 78 (2016), ibid (2016) submitted

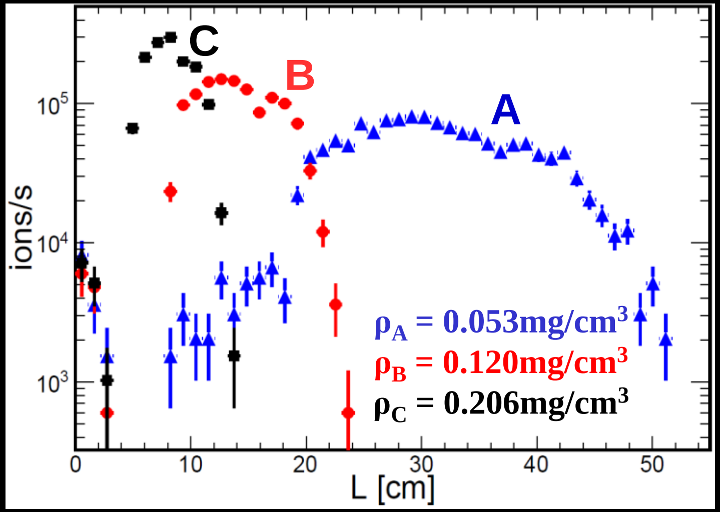
CSC Simulations:
Fragment Slowing Down in the Gas Cell

Geant4: He, T=70K, p=300mbar (ρ=0.206mg/cm³) → >95% of fragments stop in





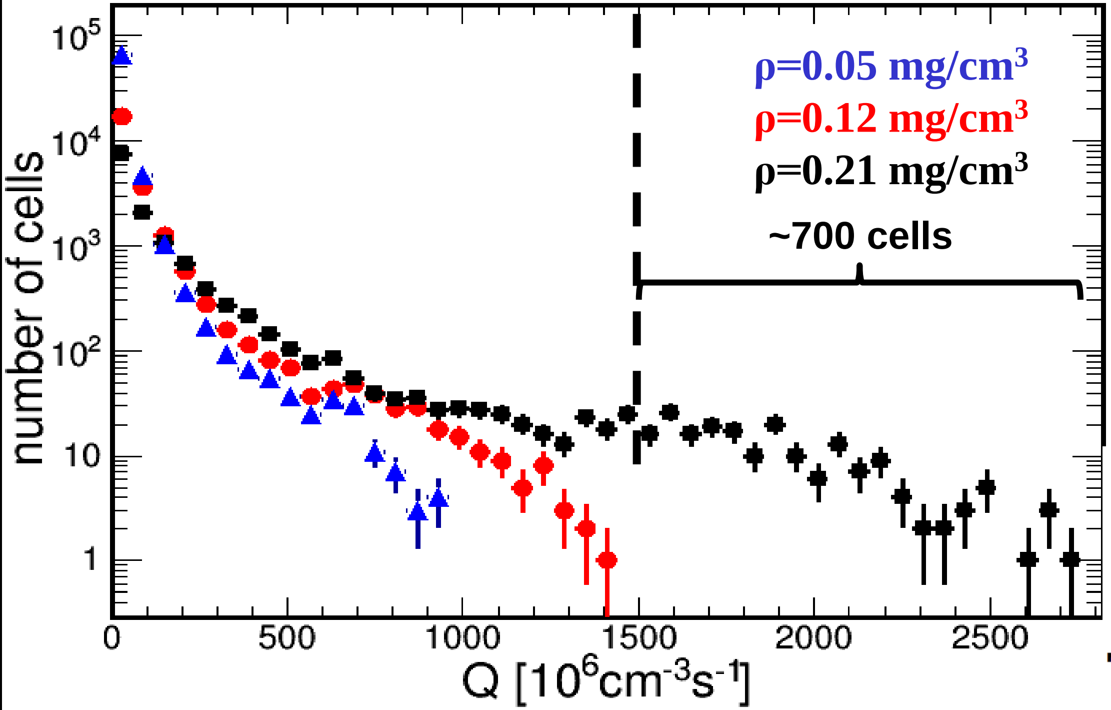
	A	B	C
ρ [mg/cm^3]	0.053	0.120	0.206
p [mbar]	100	200	300
T [K]	90	80	70
L_{max} [cm]	43.7	19.4	11.3
CSC width [cm]:	90	40	24

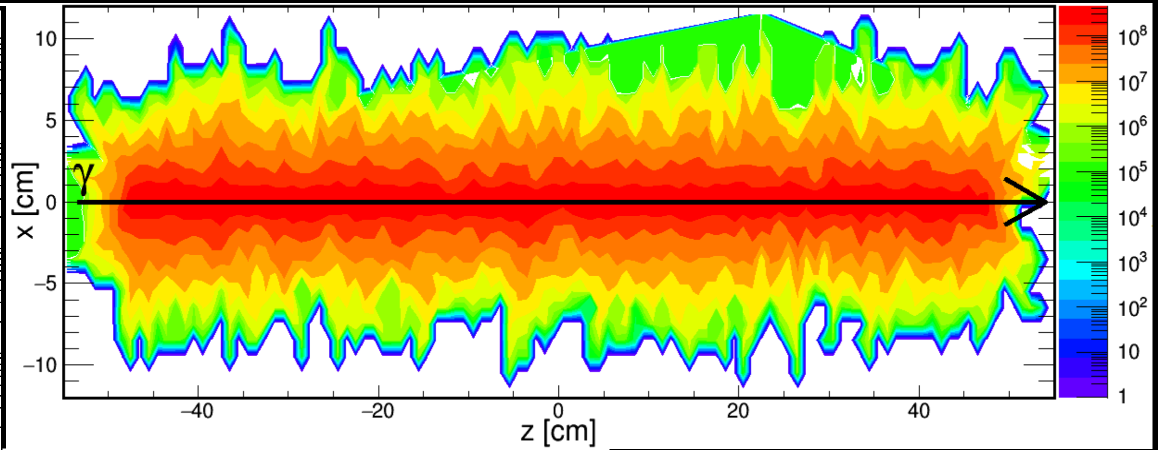


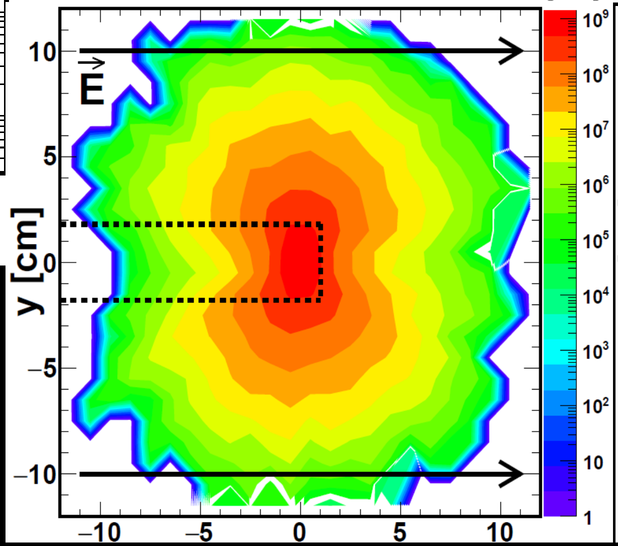
$$\rho \cdot L_{max} = 2.33\ mg/cm^2$$

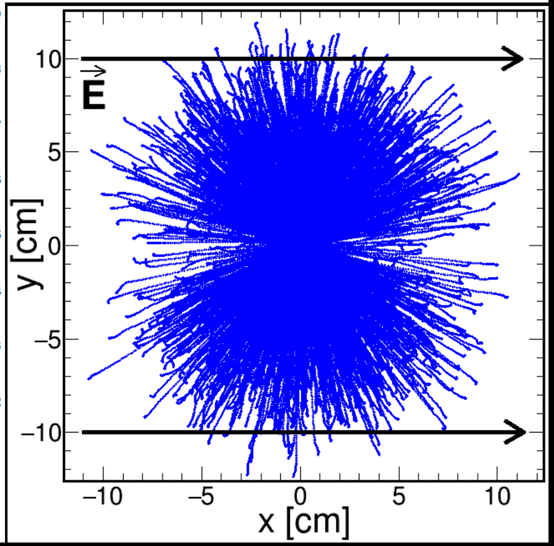
CSC Simulations: Space Charge (I)

Divide CSC in 1x1x1 cm^3 cells: 24x24x100 for ρ=0.21 mg/cm^3, 40x40x100 for ρ=0.12 mg/cm^3, 90x90x100 for ρ=0.05 mg/cm^3;
Cummulate dE/dx deposited in 1s of beam and divide by W_i=41 eV.









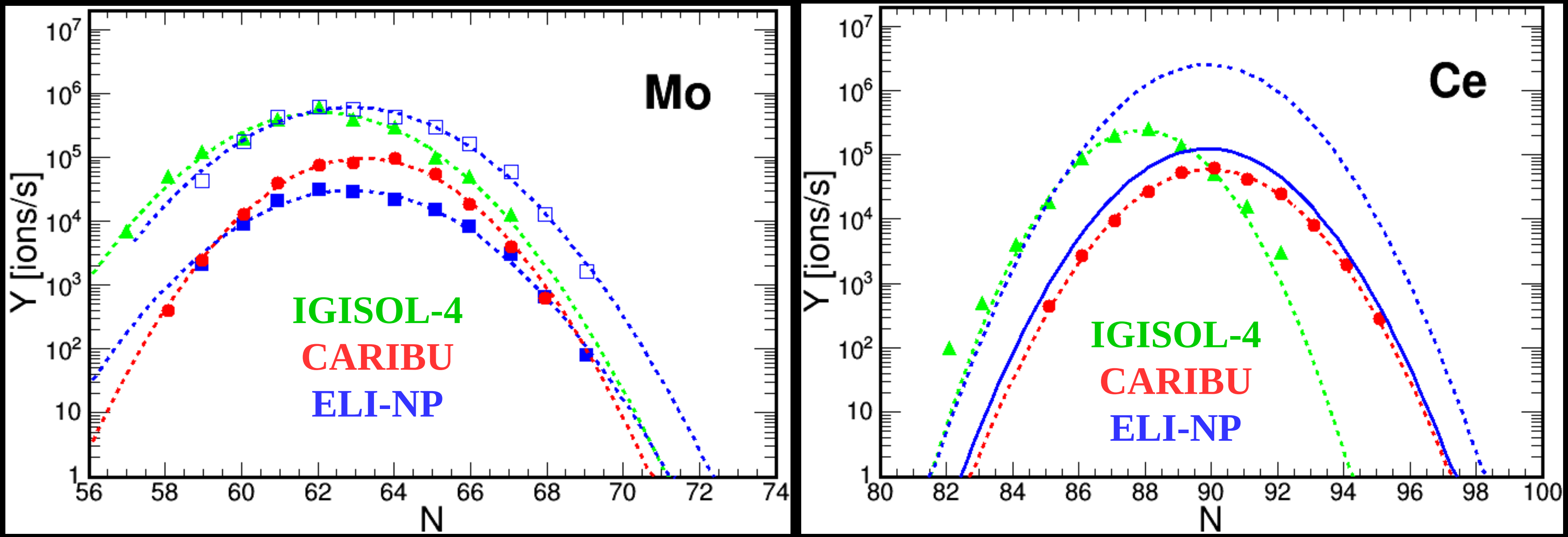
~2% stop in saturated region
~10% stop in "dead region"
~5% ions not stopped
extraction efficiency < 85%

Expected Rates

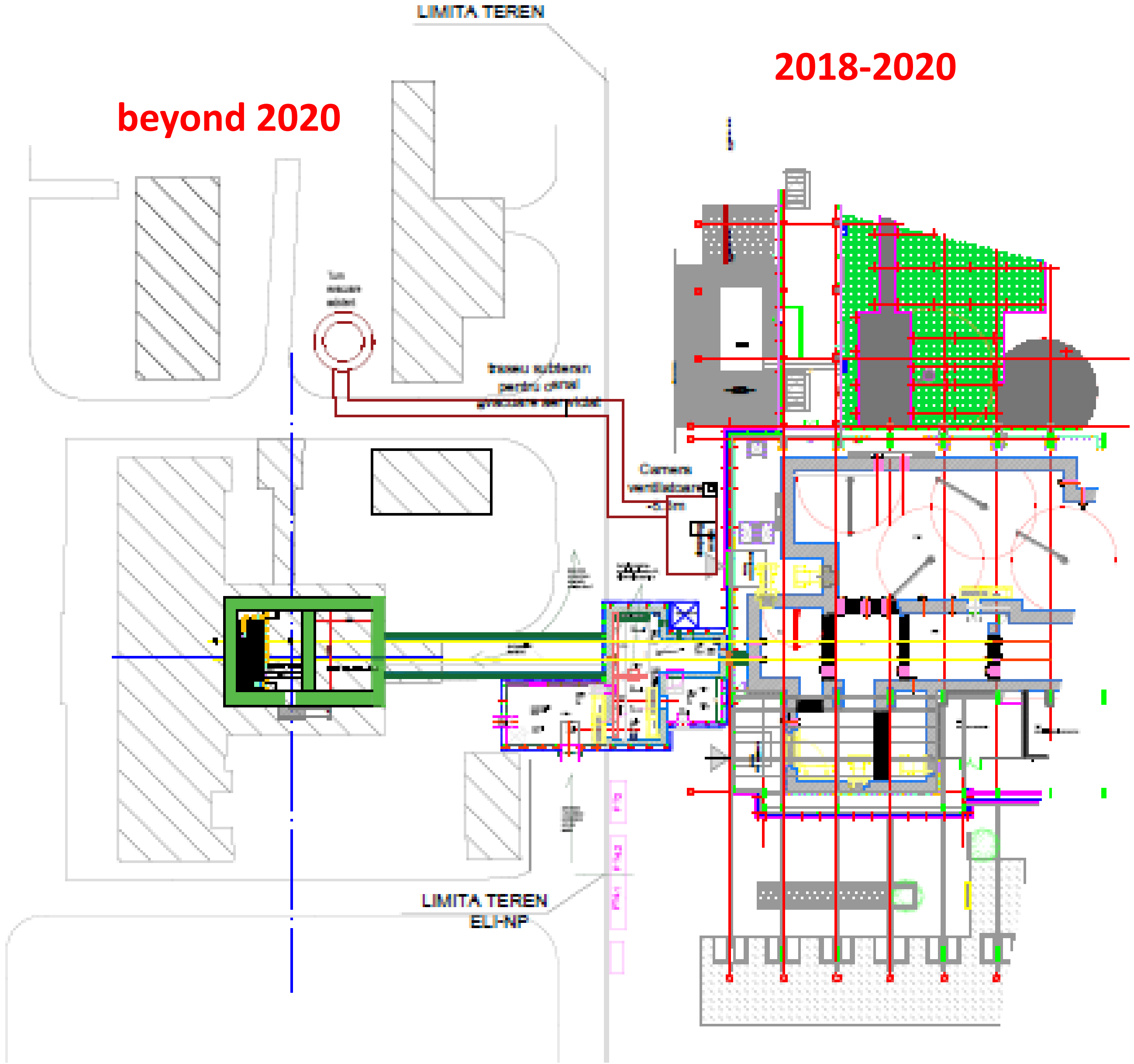
Rom. Rep. Phys. 68, S699 (2016)

Conservative “day-one”: beam $5 \cdot 10^{10}$ γ/s, target release eff. 25% , CSC extraction eff. 50%
→ ~10^7 photofissions/s and ~ $(0.8\text{-}2) \cdot 10^6$ extracted ions/s

Optimal estimate: beam 10^{12} γ/s, twice CSC extraction eff.
→ expect ~2 orders of magnitude more!



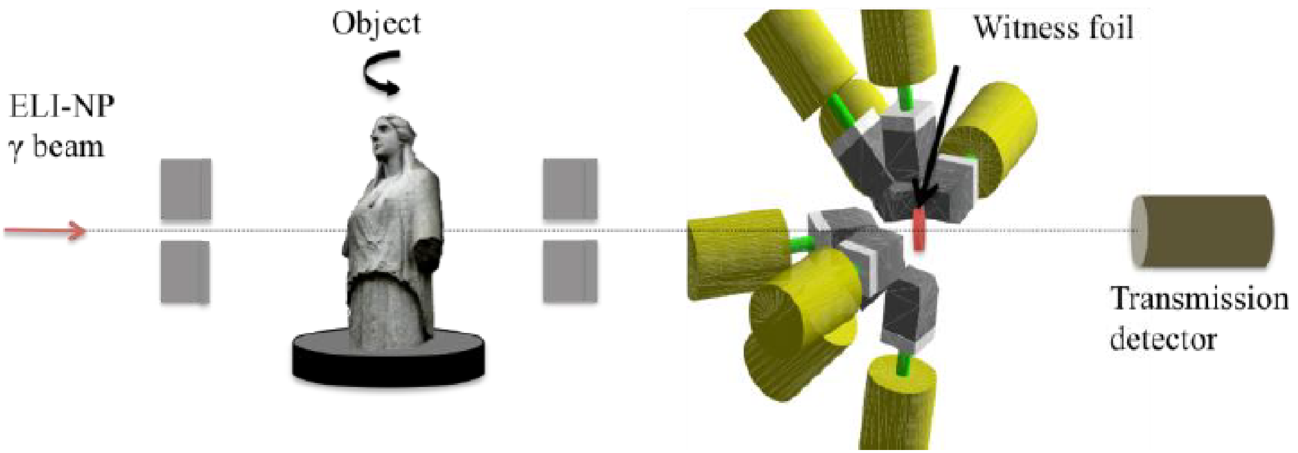
Next phases of ELI-NP



EPS Topical Paper on Cultural Heritage

NUCLEAR PHYSICS FOR CULTURAL HERITAGE

- The European initiative for Extreme Light Infrastructure laboratories in Romania (ELI-NP), will shortly provide tunable energy γ-rays from inverse Compton scattering of laser light on a high-energy electron beam. This will allow Nuclear Resonance Fluorescence studies of isotope-specific trace element distributions to be performed with unprecedented sensitivity. It is planned to use this powerful tool for cultural heritage object studies.

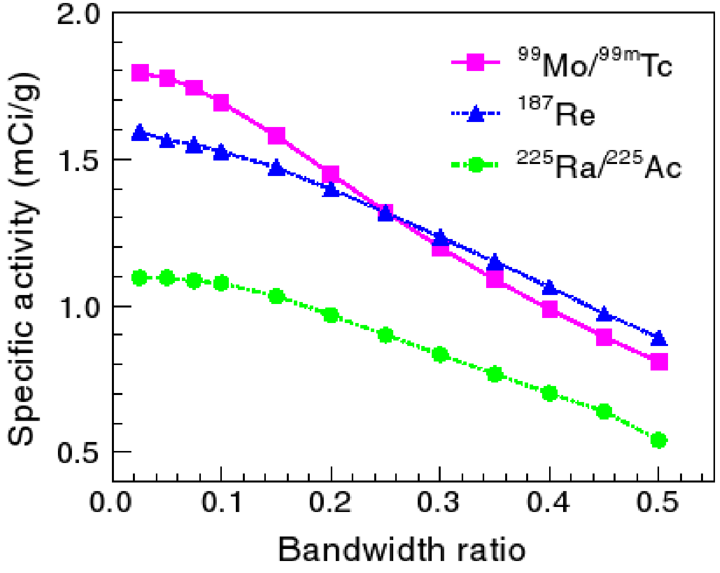


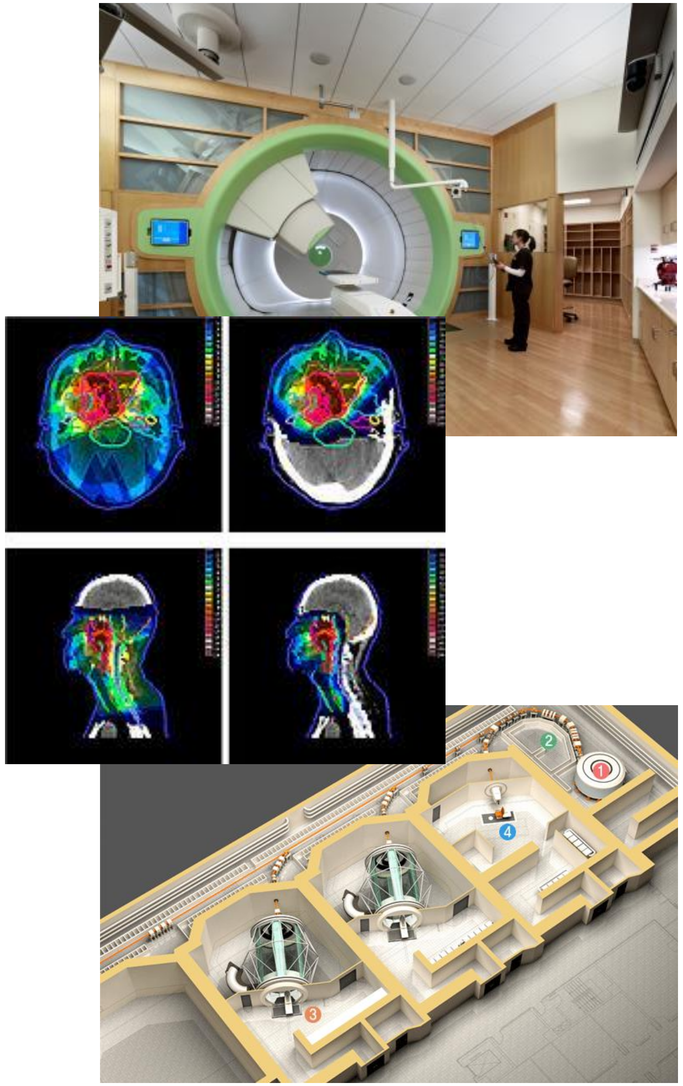
Rom. Rep. Phys. 68, S849 (2016)

Medical radioisotopes at ELI-NP

test case

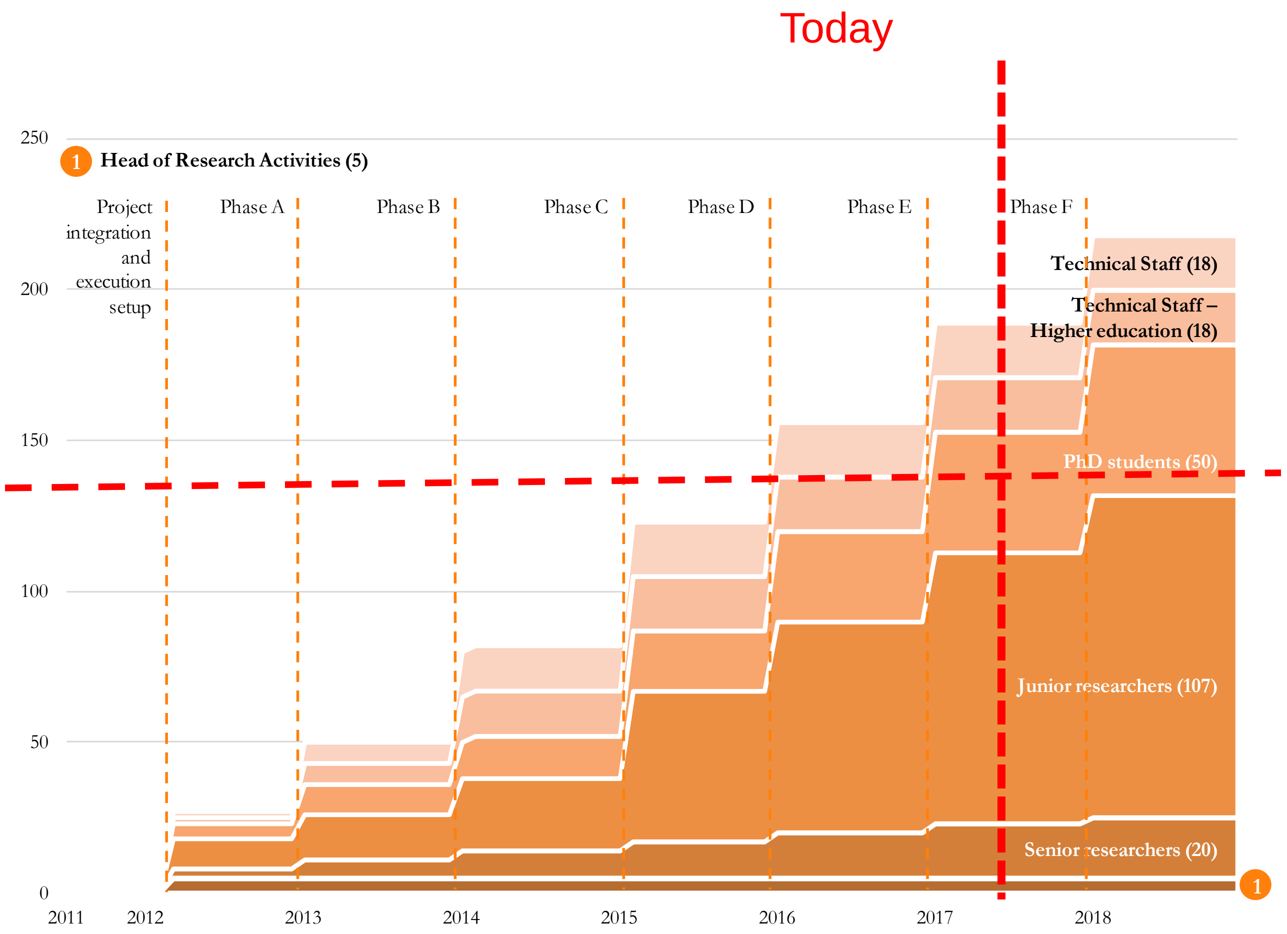
• ^{195m}**Pt**: In chemotherapy of tumors it can be used to exclude ”non responding” patients from unnecessary chemotherapy and optimizing the dose of all chemotherapy





<u>feasibility study:</u> **Wen Luo et al., Appl. Phys. B 122, 8 (2016)**

Human Resources



http://www.eli-np.ro/jobs.php

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Extreme Light Infrastructure – Nuclear Physics (ELI-NP) – Phase II

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Project co-financed by the European Regional Development Fund

Thank you!