EUROPEAN UNION

GOVERNMENT OF ROMANIA

Structural Instruments 2007-2013

Sectoral Operational Programme
„Increase of Economic Competitiveness"
"Investments for Your Future"

Extreme Light Infrastructure – Nuclear Physics (ELI-NP)

Project co-financed by the European Regional Development Fund

Nuclear Physics Studies at ELI-NP

Dimiter L. Balabanski

Nuclear Astrophysics Town Meeting, GSI
Feb. 16th-17th, 2016

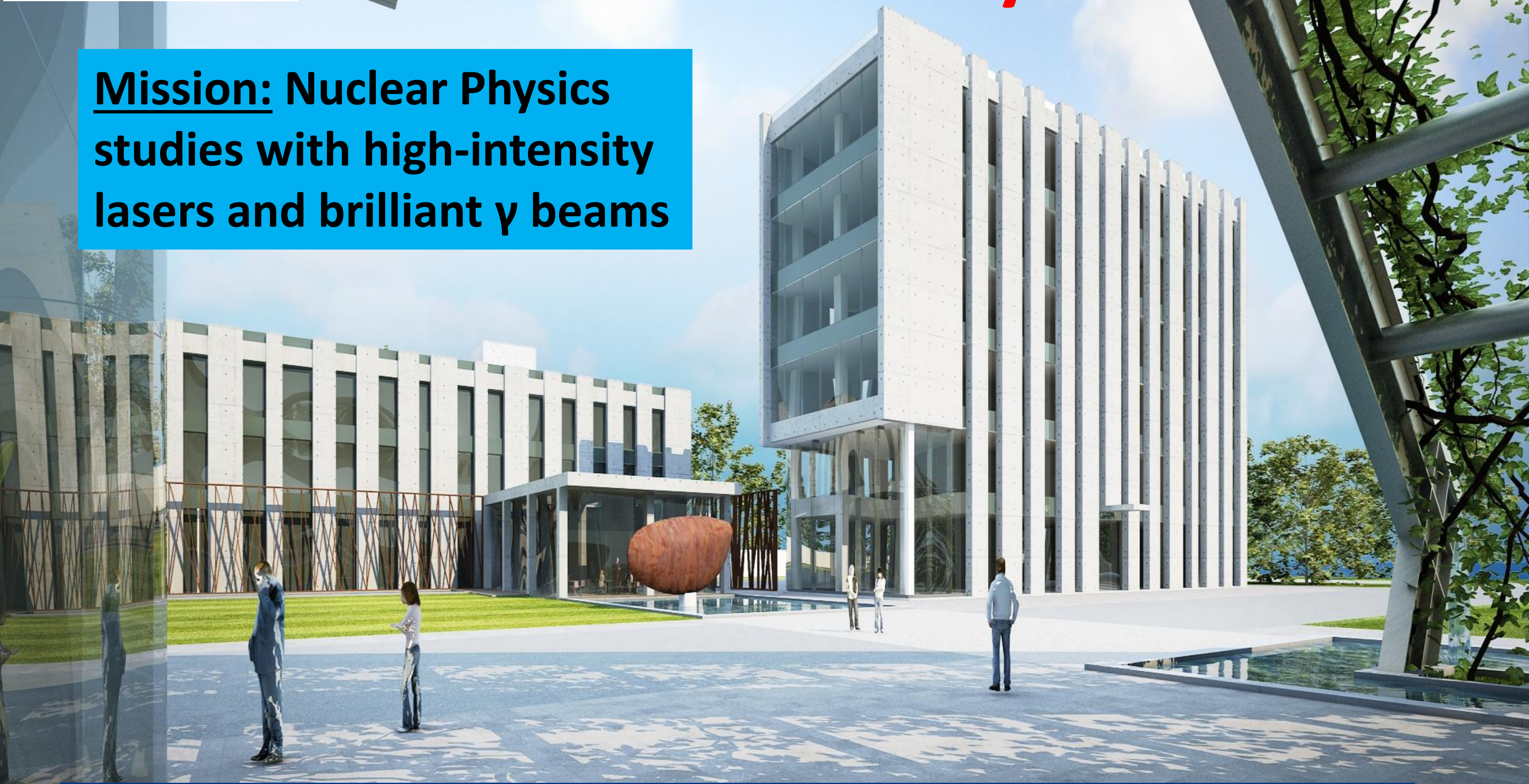
eli Nuclear Physics

IFIN-HH

eli Nuclear Physics

Extreme Light Infrastructure – Nuclear Physics

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



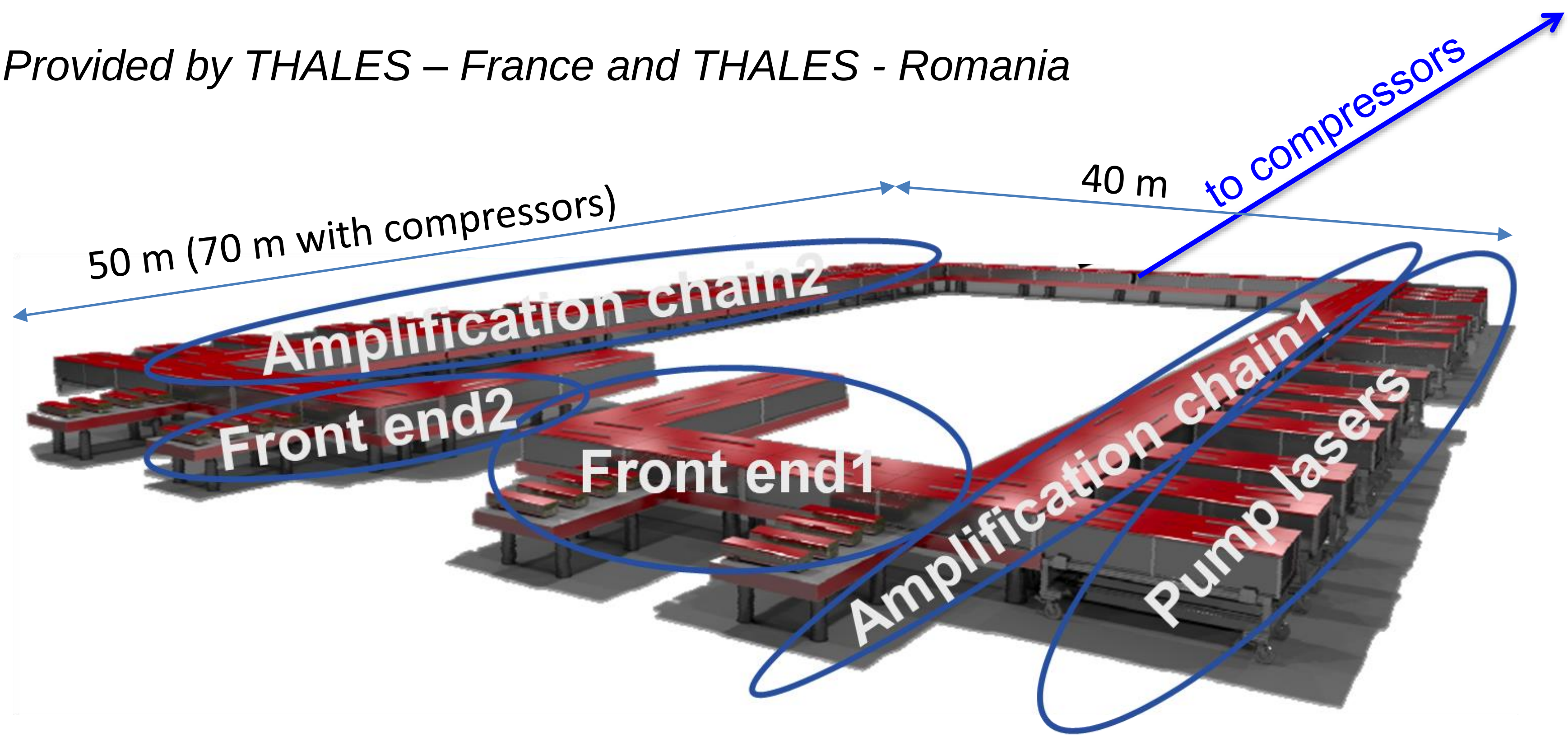
ELI–NP HPLS

2 HPLS up to 10 PW – 6 output lines

2 x 0.1 PW 10 Hz
2 x 1 PW 1 Hz
2 x 10 PW 0.1 Hz

at present the most powerful lasers are 1 PW, *e.g.* CETAL at Magurele (commissioned in 2015)

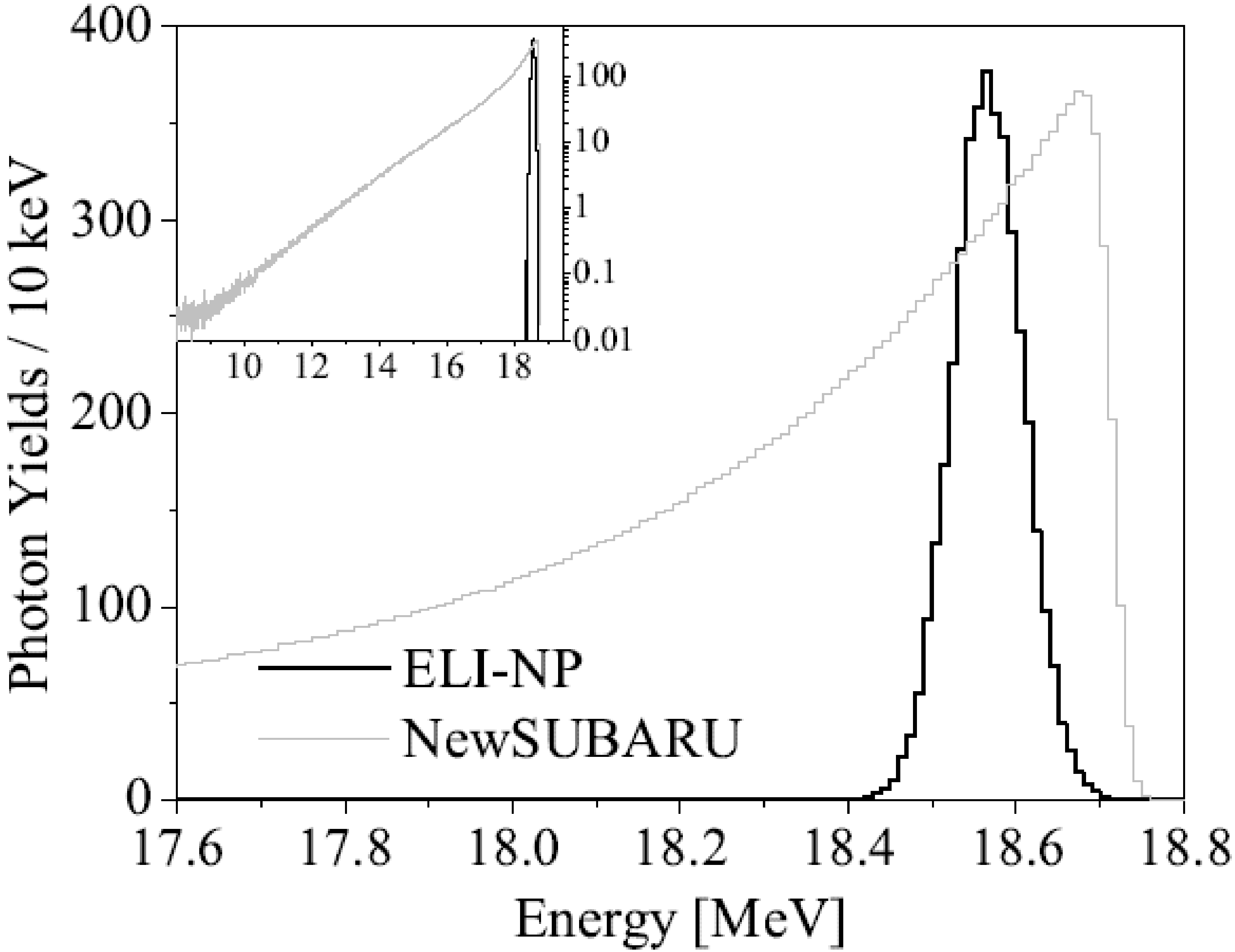
Provided by THALES – France and THALES - Romania



ELI-NP Gamma Beam System (GBS)

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

E_e



Narrow

NA @ ELI-NP

contribution of:

Catalin Matei
Danilo Gambacurta
Yi Xu
Ovidiu Tesileanu
Catalin Balan
Florin Negoita

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]

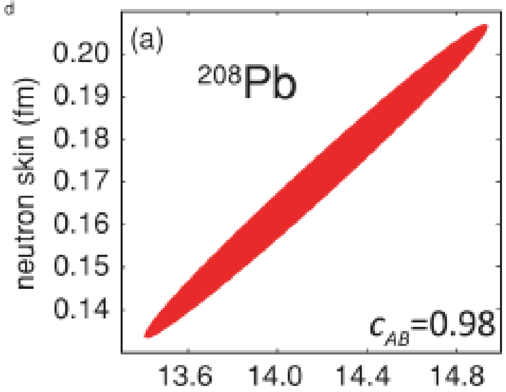


FIG. 1.

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

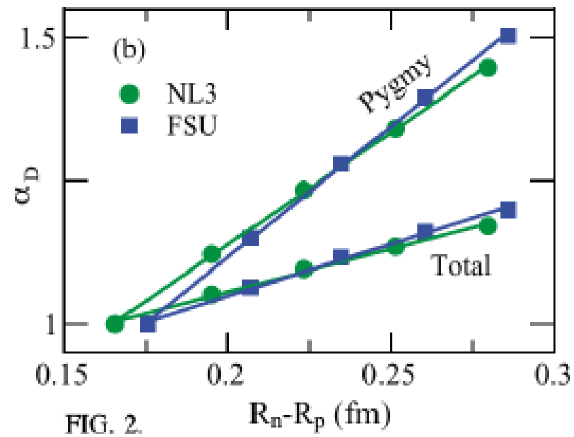


FIG. 2.

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

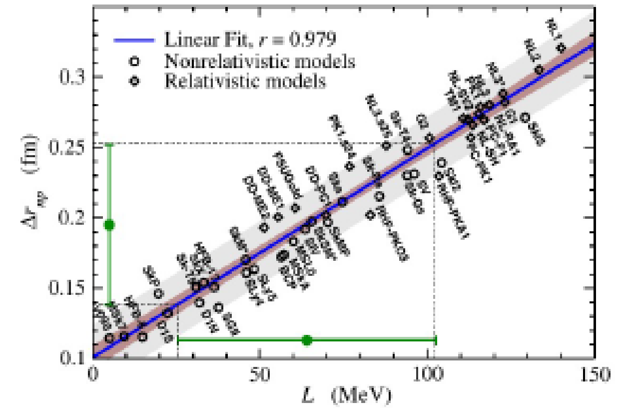


FIG. 3 (color online). Neutron skin of ^{208}Pb against slope of the symmetry energy. The linear fit is $\Delta r_{np} = 0.101 + 0.00147L$.

PRL **106**, 252501 (2011)

Nuclear Physics

ELI-NP: experimental photo-nuclear reaction facility

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

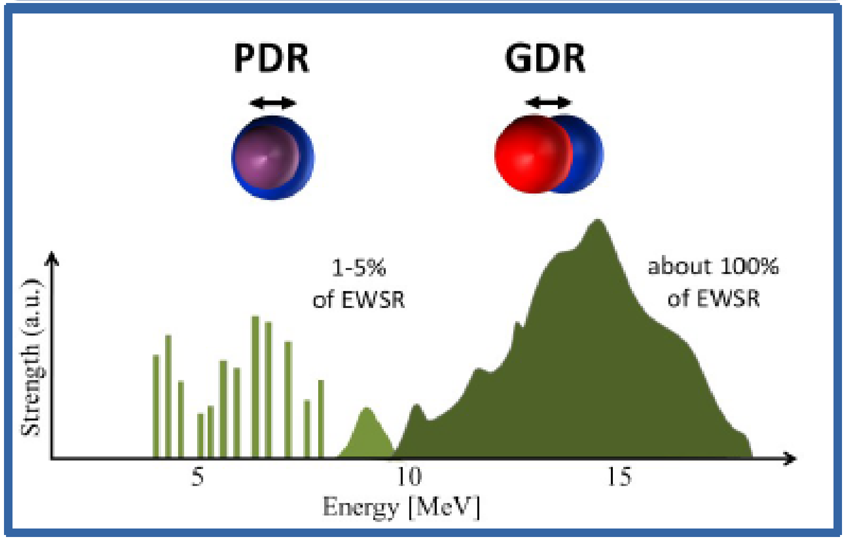
$$\alpha_D = \frac{\hbar c}{2\pi^2}\int_0^\infty \frac{\sigma_{abs}}{\omega}\,d\omega = \frac{8\pi}{9}\int_0^\infty \frac{dB(E1)}{\omega}$$

-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

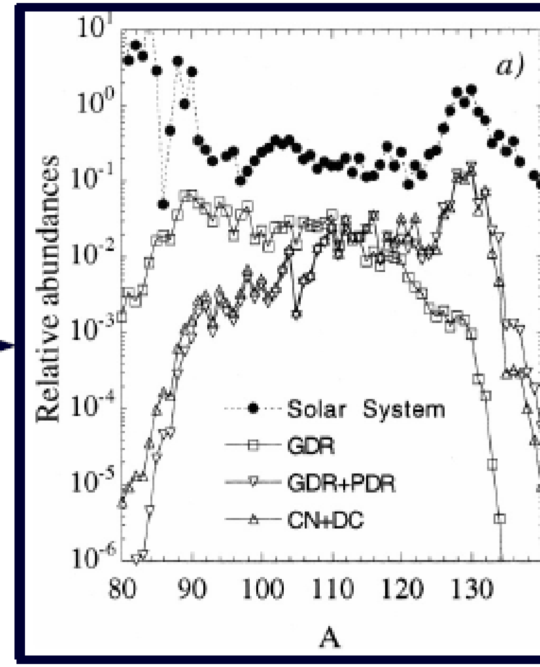
[1]P.-G. Reinhard and W. Nazarewicz, Phys. Rev. C81, 051303® (2010) [2] J. Piekarewicz, Phys. Rev. C83, 034319 (2011) [3] X. Roca-Maza et al., Phys. Rev. Lett.106,252501 (2011)

Investigation of the Pygmy Dipole Resonance @ ELI-NP

Pygmy Dipole Resonance (PDR): low-lying E1 strength located around the particle threshold exhausting few percents of the EWSR [1].



Astrophysical implication:
it can significantly enhance the:
- neutron-capture rates in the r-process nucleosynthesis (**abundance distribution**) [2,3,4,5]
-supernovae explosion [6]



Physics Letters B 436 (1998) 10–18

Nuclear Physics

ELI-NP: high-intensity, mono-chromatic and linear-polarized gamma ray beam facility:
-**Separate measure of E1 and M1**: no need of model-dependent, indirect, determination of M1 strength
-**Wide variety of physics cases**: spherical and deformed nuclei, neutron-rich, far from stability (drip-lines)
-**Complementary studies**: strength below (NRF) and above (ELI-GANT) the neutron threshold
-**Model independent results:** pure electromagnetic excitation process

[1] D. Savran et. al. Prog. Part. Nucl. Phys. 70 (2013) 210
[2] S. Goriely, Phys. Lett. B 436 (1998) 10
[3] S. Goriely et al.,.Nucl. Phys. A 739 (2004) 331
[4] E. Litvinova, et al., Nucl. Phys. A 823 (2009) 26
[5] I. Daoutidis et al. Phys. Rev. C 86 (2012) 034328
[6] J. Piekarewicz Phys. Rev. C73 (2006) 044325

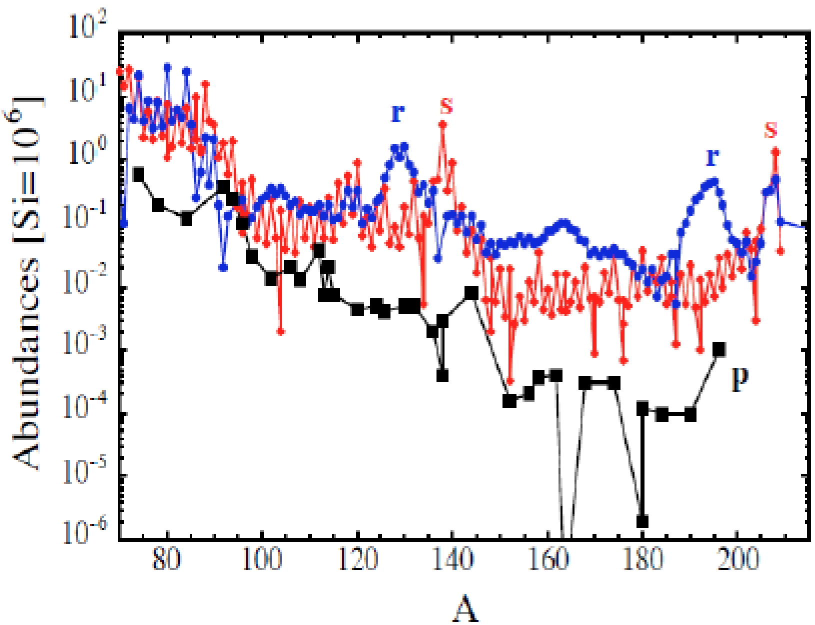
Measurements of key reactions in p-process based on ELI-NP

The p-process contains capture and photodisintegration reactions for about 2000 proto-rich and stable nuclei beyond Fe. For most of them, experimental data are not available.

(1) In solar system abundance, Mo and Ru are produced only by p-process. It is very important to exactly determine the reaction rates around Mo and Ru from experimental measurements.

(2) ^{146}Sm would be a p-process chronometer. The improved reaction rates of (γ,n) and (γ,α) for p-nuclei of Gd and Sm are necessary to confirm the production ratio of ^{146}Sm/^{144}Sm.

Final decompostion of the solar system abundance curve

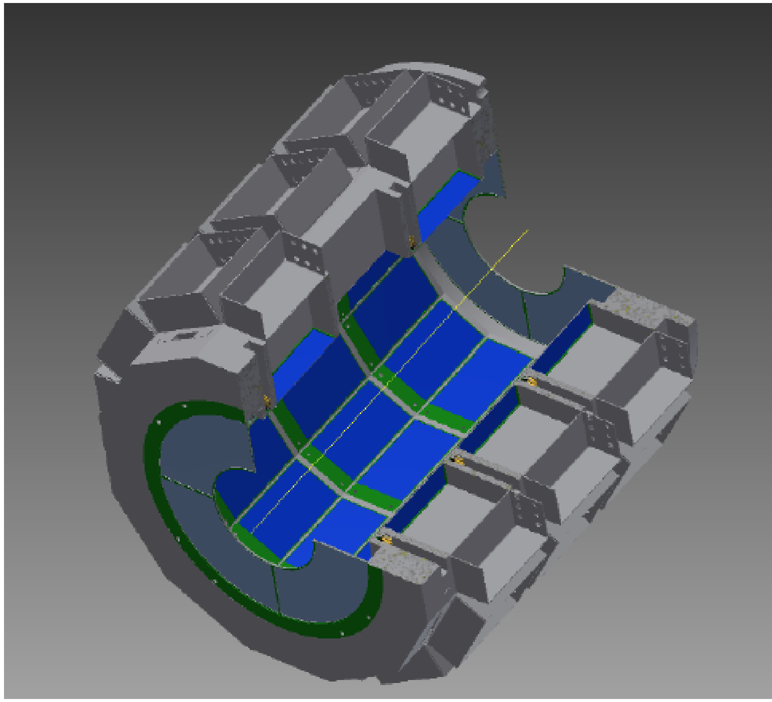


Based on the γ-beam produced by ELI-NP and the scheduled Silicon Strip Detector array, measurements of ^{92}Mo(γ,p)^{91}Nb, ^{96}Ru(γ,p)^{95}Tc, ^{96}Ru (γ,α)^{92}Mo, ^{98}Ru(γ,p)^{97}Tc, ^{144}Sm(γ,p)^{143}Pm, ^{146}Sm(γ,α)^{142}Sm, and ^{148}Gd(γ,α)^{144}Sm are proposed.

nuclear astrophysics with ELISSA

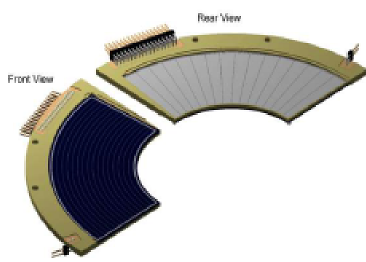
ELISSA:

- 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



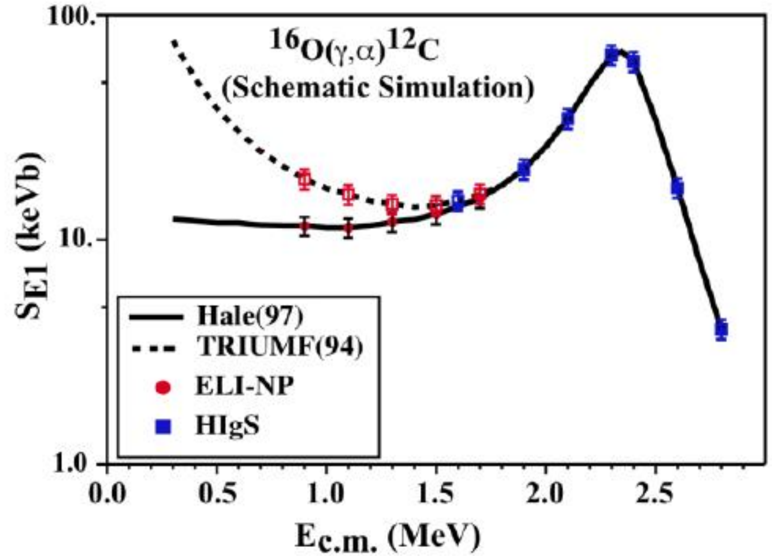
^{7}Li(γ,t)α

- 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

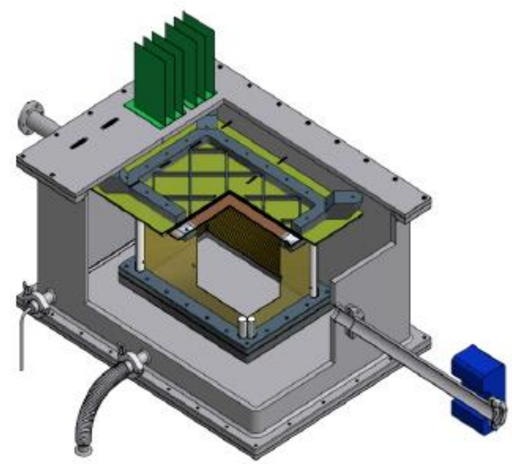


$^{16}O(\gamma,\alpha)^{12}C$ – lower & higher energies

- goal: E1/E2 angular distributions and S-factors below E_{cm}= 2.5 MeV
- the complete angular distributions measured with the e-TPC gas detector will allow to measure S_{E1} and S_{E2} separately and accurately



- goal: E1/E2 angular distributions and S-factors between E_{cm}= 3 - 6.5 MeV
- higher energy data will allow more states to be included in the model and reduce the importance of the background pole which is used in the R-matrix

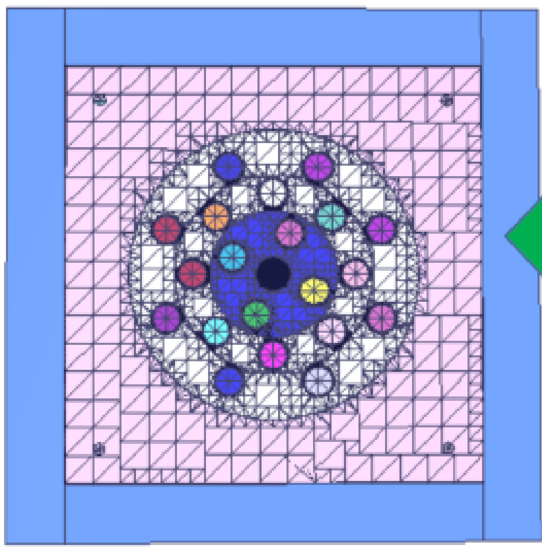


P-PROCESS NUCLEOSYNTHESIS FOR ^{180}Ta AND MEASUREMENTS OF THE PHOTO-NEUTRON CROSS SECTION

^{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.

Nuclear Physics

Laser-driven nuclear astrophysics at ELI-NP

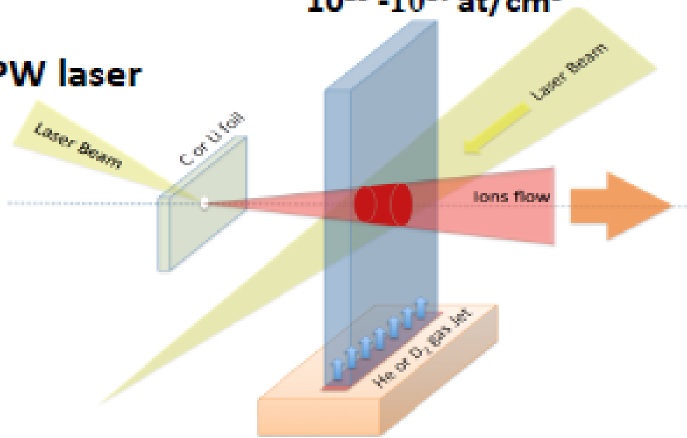
Reactions cross section and screening effect study in laser plasma for nuclear astrophysics

$^{13}C(^{4}He,n)^{16}O$

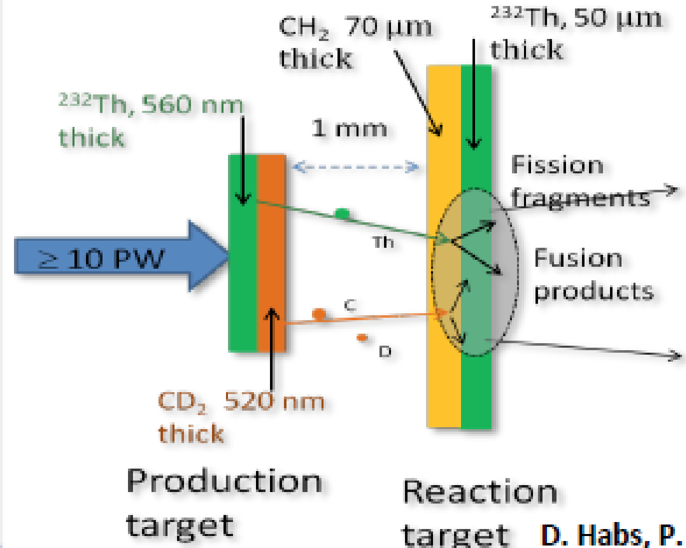
$^{7}Li(d,n)^{4}He$-^{4}He

10^{18} -10^{20} at/cm^3

PW laser



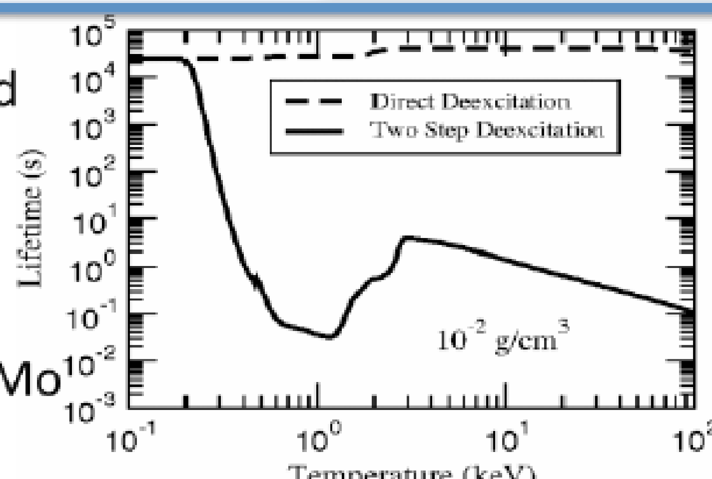
Production of N~126 waiting point nuclei in laser driven fission-fusion reactions

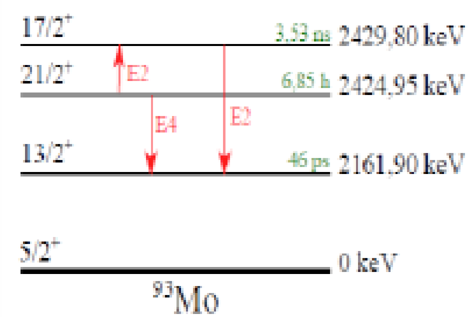


D. Habs, P. Thirolf et al., Appl. Phys. B 103 (2011) 471

Changes in decay modes and half-life of unstable nuclei in hot and dense plasma produced by lasers

First cases: ^{26gs}Al, ^{84m}Rb, ^{93m}Mo

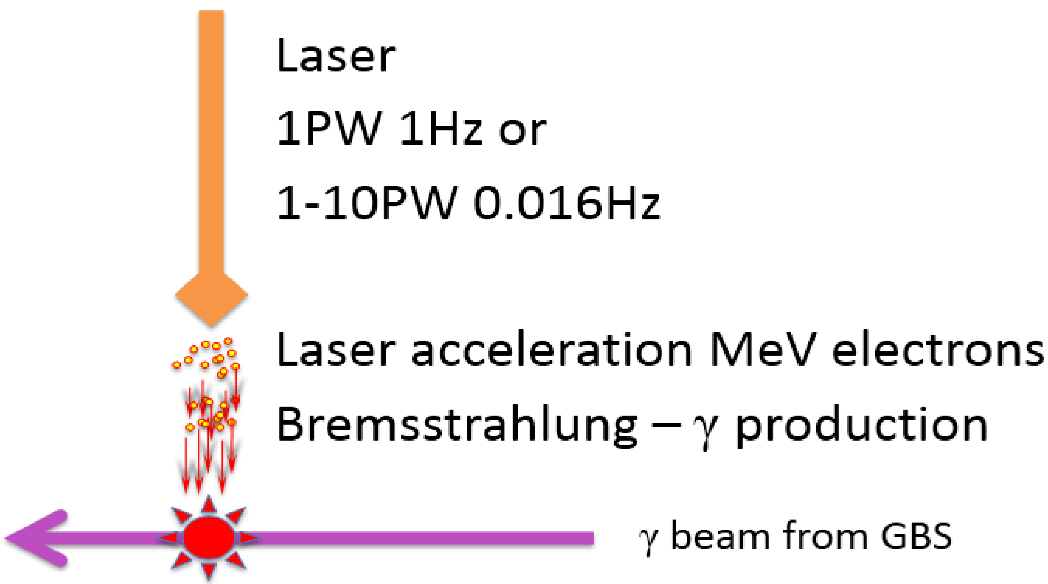


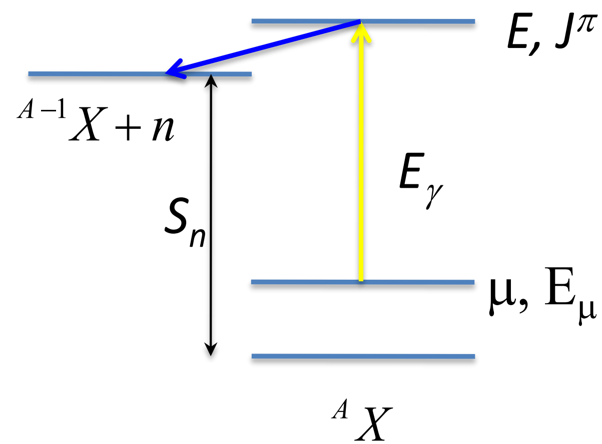


Gosselin, Meot, Morel, PRC 76 (2007) 044611

Production and photoexcitation of isomers

Important for stellar conditions – photon baths with temperatures ranging from 10^8 K (He intershell) to 2-3*10^9K (deep O-Ne layers of massive stars exploding as SNeII)





^{155}Gd: 11/2$^-$, 121 keV, 31.97ms

Concept of production and photoexcitation of an isomer ^{155}Gd with the half-life of 31.97 ms by synchronized irradiations of laser and gamma ray beams at E7

isomers	J^p	E_x	Half-life
$^{189}Os^m$	$9/2^-$	30.8 keV	5.81 h
$^{180}Ta^m$	9^-	75.3 keV	> 1.2 x 10^{15} y
$^{176}Lu^m$	1^-	123 keV	3.66 h
$^{155}Gd^m$	11/2 -	121 keV	31.97 ms
$^{152}Eu^m$	0-	45.6 keV	9.27 y
$^{115}In^m$	$1/2^-$	336 keV	4.49 h
$^{113}Cd^m$	11/2 -	226 keV	14.1 y
$^{85}Kr^m$	$1/2^-$	305 keV	4.48 h

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Thank you!