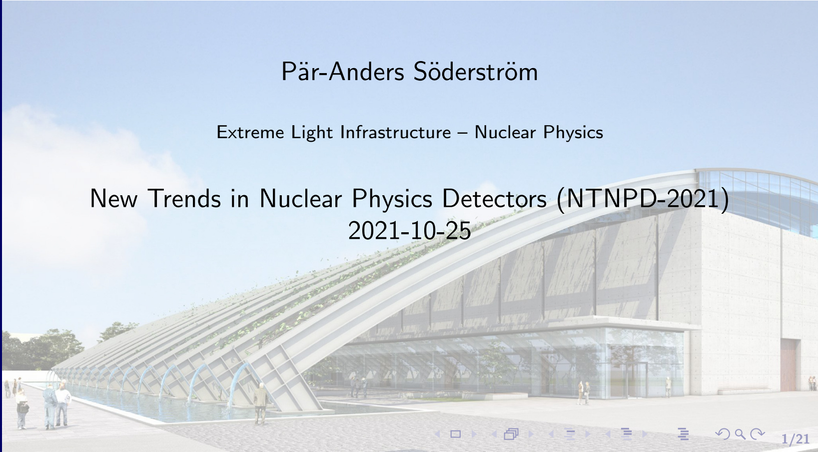
Neutron detectors for spectroscopy and cross-section measurements at ELI-NP

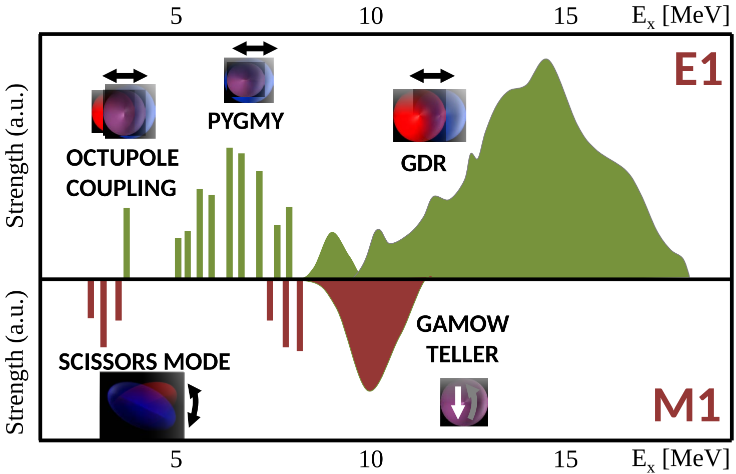
Pär-Anders Söderström

Extreme Light Infrastructure – Nuclear Physics

New Trends in Nuclear Physics Detectors (NTNPD-2021)
2021-10-25



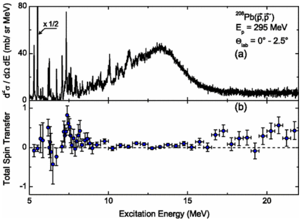
ELIGANT physics scope



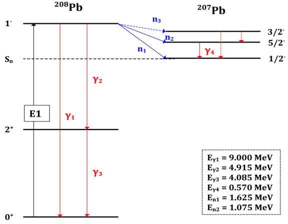
A. Zilges: Nuclear Photonics, June 24 - 28, 2018, Brasov, Romania

Scan of the giant resonance in ^{208}Pb

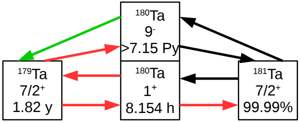
- Excitation cross section measured with polarized protons at RCNP – Good case for commissioning
- No information on the GDR decay to ground or high lying states through gamma or neutron emission – Good case for day-1
- Clean measurement of the absolute value of GDR ground state γ-decay
- Measure the energy dependence of the GDR $B(\mathrm{E1})$
- Simultaneous $\sigma(\gamma, \gamma)$ and $\sigma(\gamma, n)$ to exctract details of the wave function
- Finer structure from higher-order (3p-3h,...) coupling?
- What is the nature of the PDR?



A. Tamii, et al.: Phys. Rev. C 107, 062502 (2011)



Astrophysics with ELIGANT-TN



^{180m}Ta

- The rarest isotope in nature
- Large nuclear physics uncertainties for the stellar yields
- In particular construction and destruction of by (γ,n)
- ^{179}Ta not stable (n,γ) equivalent not possible

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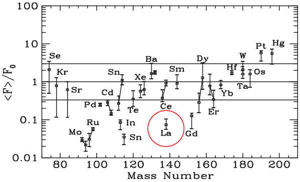
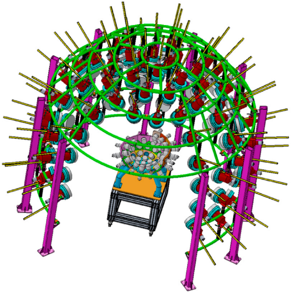
^{138}La

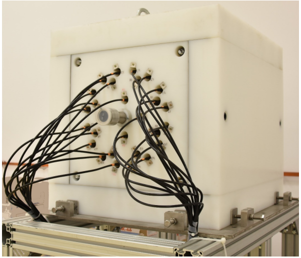


- Very rare with only 0.09% abundance
- Yield predictions rely entirely on theoretical nuclear reaction rates
- Notoriously underproduced in all p-process calculations so far

M. Arnould, S. Goriely.: Phys. Rep. 384, 1 (2003)

ELIGANT - ELI Gamma Above Neutron Threshold

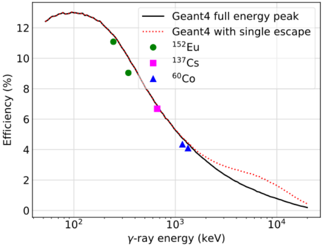


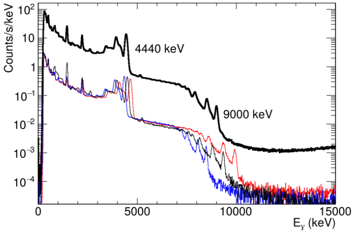


- An array of CeBr and LaBr for γ-rays, liquid scintillators and Li-glass detectors for neutrons
- All the ELIGANT-GN detectors are at ELI-NP
- Mid of June the ELIGANT mechanical structure will be delivered to ELI-NP

- ^{3}He tube array contained in a paraffin moderator for neutron counting
- All the ELIGANT-TN detectors are at ELI-NP
- Tested in-beam (T. Renstrøm, D. Filipescu, I. Gheorghe, et al., IFIN proposal)

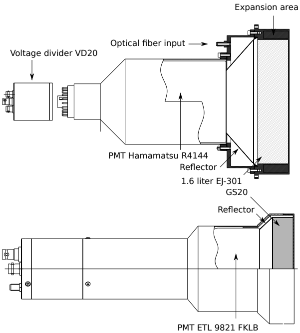
ELIGANT-GN gamma detector performance





- 34 large-volume $LaBr_3$:Ce detectors for γ-rays
- Efficiency of the gamma-detector array simulated and confirmed with standard sources
- Around 8% at 500 keV, 1% at 10 MeV
- High-energy performance and linearity evaluated up to 9 MeV with PuBeNi source

ELIGANT neutron detectors



- Two types of neutron detectors
- EJ-201 liquid scintillators for neutrons $>$ 500 keV
- GS-20 lithium glass scintillators for neutrons $<$ 500 keV

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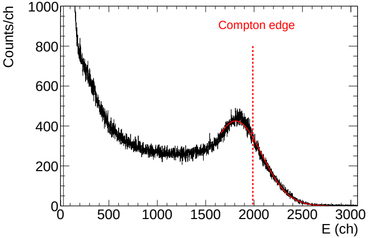
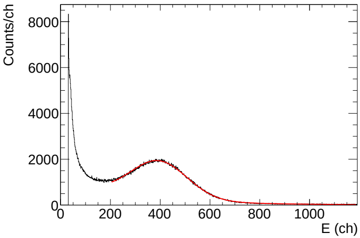
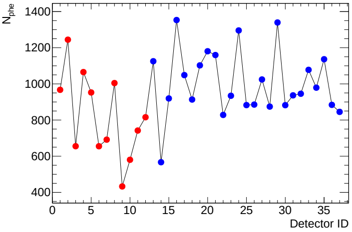
EJ-301 photoelectrons



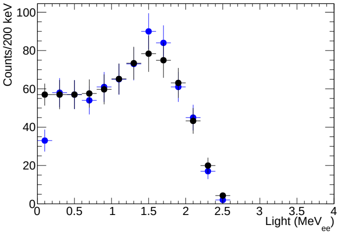


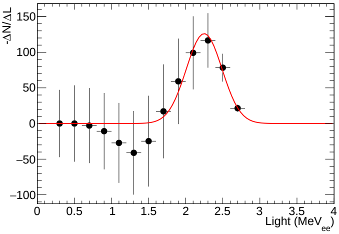


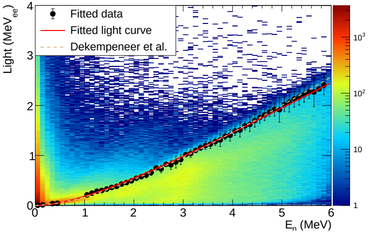
- Photoelectrons per deposited MeV of energy one key quality parameter
- Compare the (amplified) single photoelectron peak to the ^{137}Cs Compton edge

$$N_{\mathrm{phe}} = \frac{P_{\mathrm{ce}} - P_{\mathrm{zo}}}{P_{\mathrm{spe}} - P_{\mathrm{zo}}} \frac{G}{E_{\mathrm{ce}}} \quad (1)$$

EJ-301 light curves

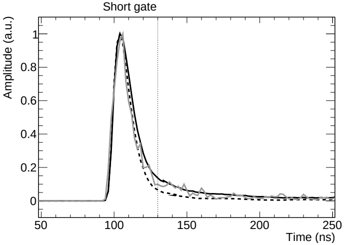


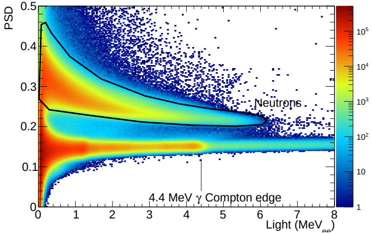


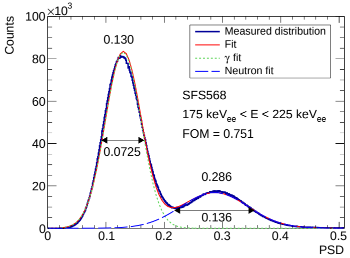


- Liquid scintillators known to have non-linear response
- Correlate the neutron energy from ToF with light output
- Plot the derivative of the histogram and get the maximum edge
- Varies between detectors, nonlinearity correlates with number of photoelectrons

EJ-301 pulse-shape discrimination

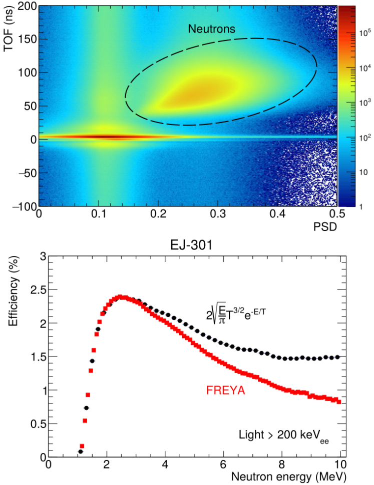






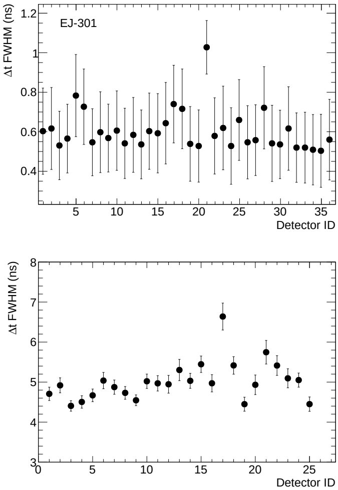
- Different pulse shape for neutrons and γ rays
- Pulse shape discriminate between the two
- Figure of Merit at low-energies sensitive to detector quality
- Correlates with number of photoelectrons and nonlinearity

ELIGANT-GN liquid scintillator performance



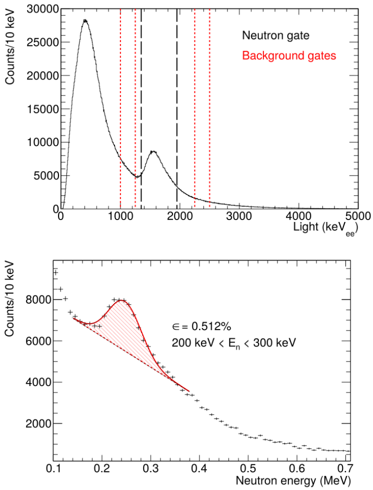
- 36 liquid scintillators for high-energy neutrons
- High-energy neutrons from ^{252}Cf spontaneous fission measured in the EJ-301 liquid scintillators
- Clean neutron identification well separated from gammas
- Efficiency consistent with simulations

Time resolution of the neutron detectors



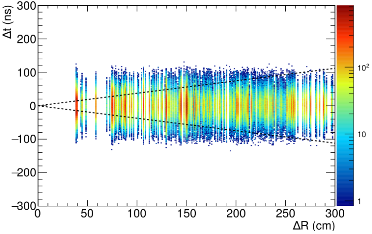
- Same method as for the γ-ray detectors implemented for the neutron detectors
- Mean time resolution of 600 ps for ^{60}Co, with a standard deviation of 100 ps between the liquid detectors
- Mean time resolution of 5 ns for ^{60}Co, with a standard deviation of 500 ps between the lithium glass detectors

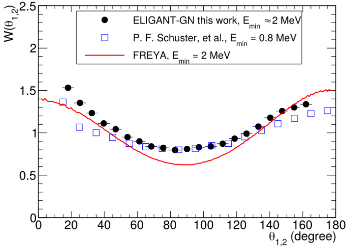
ELIGANT-GN lithium-glass performance



- 25 lithium glass scintillators for low-energy neutrons
- Low-energy neutrons from ^{252}Cf spontaneous fission measured in the GS-20 lithium-glass scintillators
- Resonance peak around 250 keV in ^{6}Li
- Efficiency consistent with simulations

ELIGANT-GN ^{252}Cf array performance





- Neutron detectors characterised for cross-talk using PuBe and ^{252}Cf sources
- Multiplicity based fission trigger, neutron identification, detector alignment and coincidences, all working together
- Neutron angular correlations reproduced
- In principle, ELIGANT-GN ready to take beam

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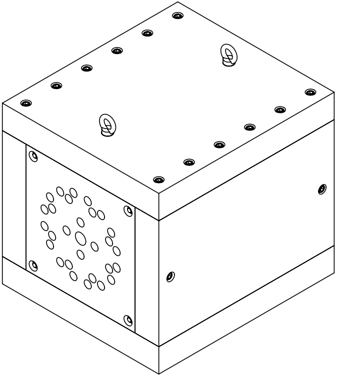
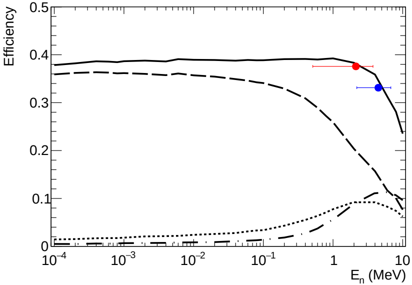
GEANT4 simulations of ELIGANT-TN





- Recent GEANT4 simulations confirm the flat efficiency picture up to 3 MeV
- Neutron efficiency for realistic $^{252}\mathrm{Cf}$ and PuBe sources well reproduced
- In principle ready to recieve γ-ray beam

ELIGANT at IFIN

Preparatory Gamma Above Neutron Threshold experiment

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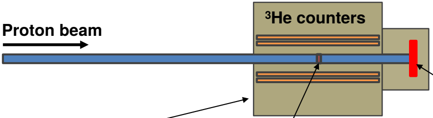
„Test and calibration of the ELIGANT-TN flat efficiency neutron detection system", IFIN-HH

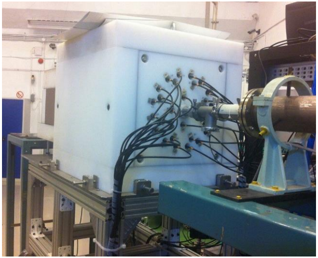


Current
1. Beam line
2. Target
3. Collimator
4. Faraday cup

ELIGANT-TN

Target placed in the center of the detection system: ^{nat}**Cu**, ^{nat}**Al**

Faraday cup



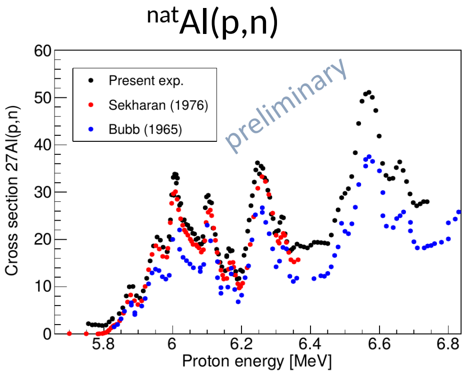
28 ^{3}He counters mounted on 3 rings:
Inner ring: 4 counters
Middle ring: 8 counters
Outer ring: 16 counters
Polyethylene moderator

Cd and polyethylene **shielding**

ELIGANT at IFIN

Results – ^{nat}Al(p,n) cross sections

Nuclear Physics



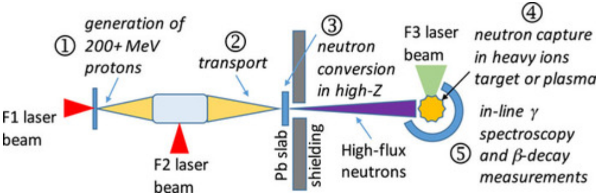
Black dots: Present results considering constant 37% efficiency

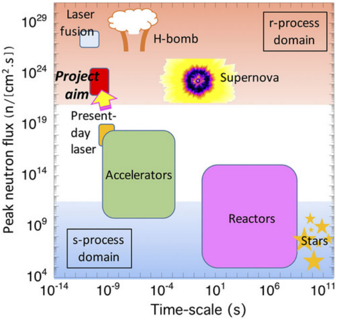
No background subtraction performed yet

Continuous proton beams used for target irradiation

M. Krzysiek: Nuclear Photonics, June 24 - 28, 2018, Brasov, Romania

Neutron interest for high-power lasers

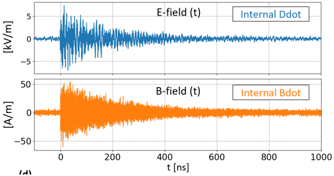


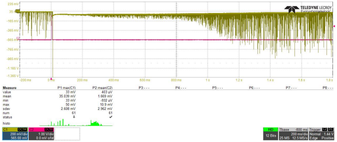


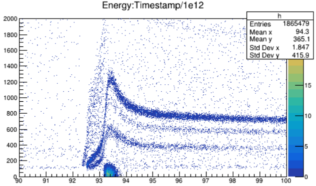
- Generation of very high-intensity, very short neutron pulses
- Secondary reaction diagnostics in plasmas (γ, n), (p, n), (α, n)
- Radioprotection monitoring? Independent diagnostics for intensity?

S. N. Chen, et al. Matter Radiat. Extremes 4, 054402 (2019)

Measurements in a difficult environment



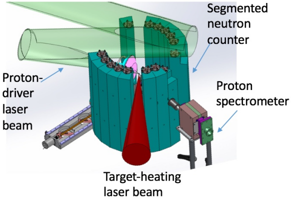




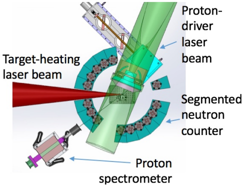
- Very intense electromagnetic pulse (EMP), up to hundreds of kV/m for $\sim$ 100 J
- At ELI-NP, 10 PW beamline will generate $\sim$ 250 J
- Pre-amplifiers, readout electronics, comuters, all at risk
- Photomultiplier tubes robust, but still affected
- Very intense γ-ray/particle flux - all events happen within few ps
- Passive detectors, isomers, “artificial” delay (neutron moderation)

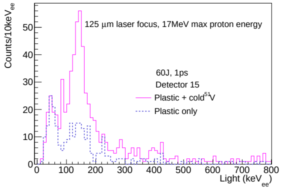
Neutron detection strategy for high-power lasers

(a) 3D view



(b) Top-view





- Thermalizing neutron counter developed for high-power laser experiments
- Gas counters, preamplifiers not possible. High-risk equipment and slow response.
- Neutron-capture concept with borated plastic scintillator rods
- Few ns pulse shapes, high thermal neutron captire cross-section
- Dual PMT concept with one PMT on each end, coincidence removes large amount of laser-induced noise on each PMT
- Neutron moderation in polyethylene ensure that neutrons arrive with a time distribution over ms instead of ps

nuclear physics

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Acknowledgements

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Structural Instruments 2007-2013

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