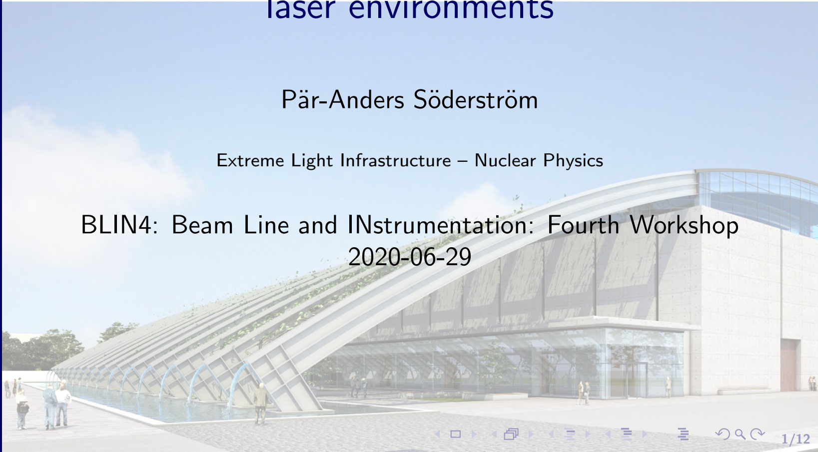
Neutron detection techniques and possible applications for diagnostics in high-power laser environments

Pär-Anders Söderström

Extreme Light Infrastructure – Nuclear Physics

BLIN4: Beam Line and INstrumentation: Fourth Workshop
2020-06-29



Charged particles vs. Neutrons

Charged particles

- Electromagnetic and nuclear interaction
- Stopping depth in thin passive material
- Charge generation in thin active material
- Control and measure with magnetic spectrometers

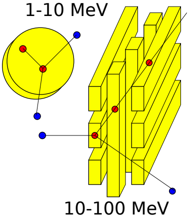
Neutrons

- Only nuclear interaction, no electromagnetic sensitivity
- Generally pass through everything
- No direct charge generation, need lots of material
- Can not be steered with electromagnetic fields

Two types of neutron detection

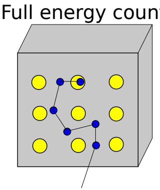
Elastic scattering

- Elastic scattering of protons in, typically, organic detector material
- Two-body kinematics can reconstruct neutron properties
- Actually detecting: recoil protons
- Fast time scales, energy from time-of-flight



Nuclear reactions

- Nuclear capture of low-energy neutrons on a high cross-section material
- Typically: $^{3}\mathrm{He}(n,{}^{3}\mathrm{H}p)$, $^{7}\mathrm{Li}(n,{}^{3}\mathrm{H}\alpha)$, $^{10}\mathrm{B}(n,{}^{7}\mathrm{Li}\alpha)$
- Actually detecting: reaction products
- Large time scales, no energy information



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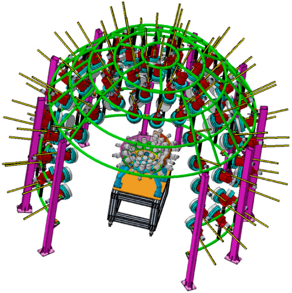
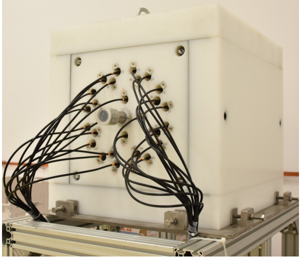
ELIGANT - ELI Gamma Above Neutron Threshold

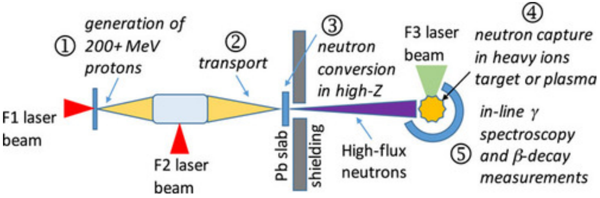


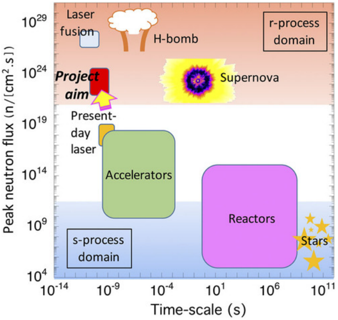


- $CeBr_3$ and $LaBr_3$ for γ-rays, liquid scintillators and Li-glass detectors for neutrons
- Neutron energy from time-of-flight
- Nuclear structure physics, Giant Dipole Resonances, and similar

- ^{3}He tubes contained in a polyethylene moderator for neutron counting
- High-efficiency neutron counting
- High-precision cross section measurements for industry, medicine, astrophysics

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)

Neutron detection challenges in HPLS

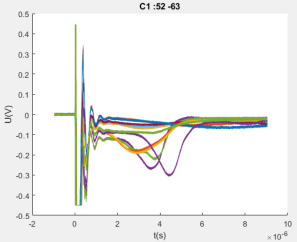
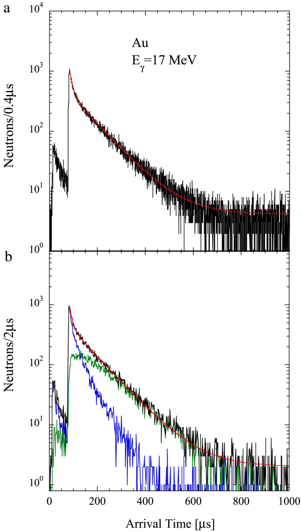


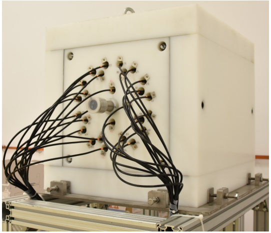
Figure from V. Lelasseux

- Neutron detector prototype in the ARCTURUS laser
- Plastic scintillator, PMT readout
- 30 fs pulse, 10^{20} W/cm^2

- Electromagnetic environment makes sensitive electronics difficult
- For example: ^{3}He counters with thin anode wire sensitive to gas discharge. Preamplifiers close to the board. Signal electronics with a bias of 1500 V.
- Possibly very high intensity neutron flux
- Time structure in the detection necessary to not overload the system
- Ideally small sensitivity to high γ background, or methods to reject

Neutron counting systems





- Nuclear reaction based
- High-efficiency detection (37% for ELIGANT-TN)
- (Almost) no energy information
- Long time between emission and detection
- Zero threshold, can measure down to thermal neutrons

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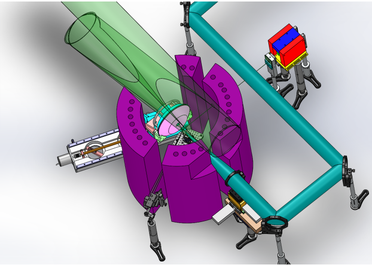
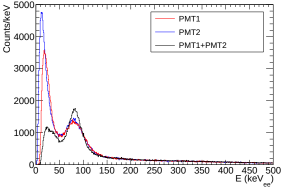
First version of a HPLS neutron counter



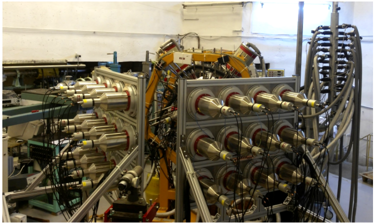
Developed within J. Fuchs ERC Grant

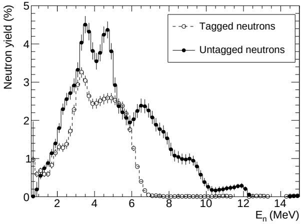
- Based on the ELIGANT-TN concept
- Boron-loaded plastic rods instead of gas tubes
- Large polyethylene volume for neutron moderation
- First experiment scheduled this summer



- Dual photomultiplier readout for noise reduction
- Large number of channels, readout by chain of CAEN V1730 digitizers
- Very clean neutron signal, collected by ^{239}Pu-Be source
- Data aquisition and analysis tools from the nuclear physics community

Energy spectra with liquid scintillator detectors



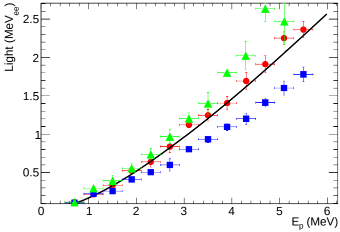


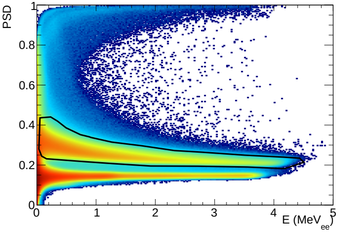
P.-A. Söderström, et al. Appl. Radiat. Isot., submitted

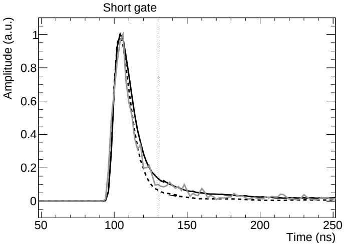
- The ELIGANT Neutron Wall, coupled with the ROSPHERE array
- Here, 24 liquid scintillator cells
- Can not operate in too large neutron fluxes, need low efficiency and large distance to target

- High detail neutron energy spectrum from time-of-flight
- Clean selection of neutrons from pulse-shape analysis
- Examlpe: Neutron energy spectrum from ^{239}Pu-Be source, resonances in ^{13}C clearly visible

Pulse-shape analysis in liquid scintillators







- Non-linear output gives lower neutron energy limit ~ 1 MeV
- Detection time-scale ~ 100 ns
- Pulse-shape analysis gives clean neutron selection

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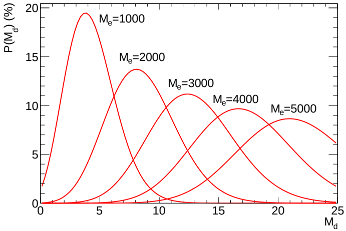
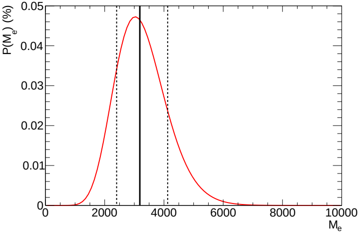
Neutron multiplicity from liquid scintillators





- Example: 24 detectors 2.5 m from interaction point
- 3000 neutrons emitted isotropically - will trigger $\sim$ 13 detectors
- Pulse-shape analysis gives clean neutron selection

- Bayes theorem:

$$P(M_e|M_d) = \frac{P(M_d|M_e)P(M_e)}{P(M_d)}. \quad (1)$$

- 13 detectors triggered - 3200 $\binom{+900}{-800}$ neutrons emitted isotropically

- For (average) energy spectrum statistics, high repetition rate needed

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