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

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Within the field of laser driven nuclear physics, there is a recent interest for creating and measuring neutrons of various energy ranges. These neutrons can either be generated in dedicated high-energy and high-intensity neutron beamlines for a variety of applications [1], or they can be produced as secondary products in experiments with other types of primary beams and be used as a diagnostics tool for interactions within a laser-induced plasma. As neutrons are uncharged particles that does not directly interact through the electromagnetic force they can not be observed or controlled in the same way as electromagnetic radiation or charged particles with regular diagnostics. Instead, there are two indirect approaches for neutron detection that are complementary both in type and in terms of information obtained: neutron detection via nuclear capture, or neutron detection via the recoil of charged particles.

For the first approach, the neutrons are generally moderated to thermal equilibrium with the ambient atmosphere. This is a process that takes a few hundreds of microseconds, which means that the information of each individual reaction will be lost. However, it allows for a very high efficiency counting of total neutron yield without issues of energy thresholds, and the extraction of gross properties like the average neutron energy and neutron yield in the reaction. In addition, the long moderation time makes this approach suitable for high-EMP environments as the detectors can be placed close to the interaction and given ample time to recover before the neutrons are registered.

The second approach for neutron detection is to use a hydrogen-rich material as an active detector, typically liquid or plastic scintillators, where the neutrons scatter off the protons in the material and the recoil proton is detected and measured. This very fast process can provide high-precision timing information, providing a high-resolution measurement of the true energy spectrum of the emitted neutrons from the time difference of the laser pulse and the time of the detected neutron. Due to the rather non-interacting property of neutrons this type of detectors can be placed far from the interaction point providing excellent reconstructed energy resolution and while remaining at a safe distance from the electromagnetic environment.

In this contribution I will discuss these approaches, based on and with examples from the neutron-detection programme at ELI-NP currently within the gamma beam facility [2], and the possible application of these techniques and instruments for high-power laser diagnostics. I will also briefly mention possible approaches for high-energy neutrons where, for example, diagnostics based on the tracking of the very high energy recoil-proton through a hodoscope [3] could be developed, reaching sensitivities up to hundreds of MeV.

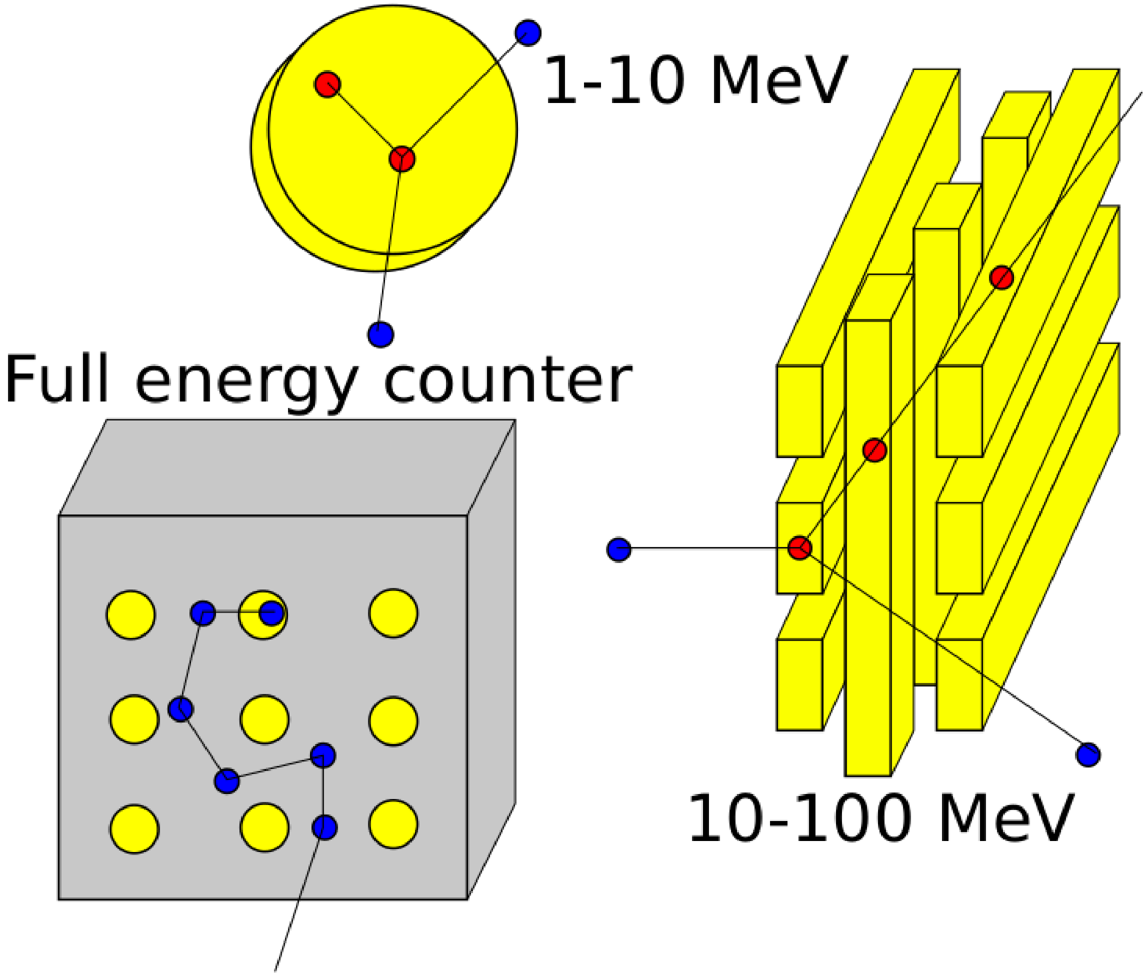

Figure 1: Illustration of different neutron detetection methods for different energy ranges and types of applications. (Top left) Detector cell for single proton-recoil detection, sensitive to about 1-10 MeV energies (Right) Hodoscope for proton recoil tracking from high-energy neutrons, sensitive to energies up to and beyond 100 MeV. (Bottom left) Thermal neutron counter for high-efficiency yield measurements over the full possible neutron energy range.

[1] S.N. Chen, *et al.*, Extreme brightness laser-based neutron pulses as a pathway for investigating nucleosynthesis in the laboratory, Matter Radiat. Extremes, **4**, (2019), 054402.

[2] F. Camera, *et al.*, Gamma above the neutron threshold experiments at ELI-NP, Rom. Rep. Phys., **68**, (2016), S539.

[2] Y. Kondo, *et al.*, NEBULA (Neutron Detection System for Breakup of Unstable Nuclei with Large Acceptance), RIKEN Acc. Prog. Rep., **44**, (2011), 150.