TOF Spectroscopy of Fusion Neutrons in Relativistic Laser Plasmas ◇

S. Karsch, M. Hegelich, D. Habs, J. Meyer-ter-Vehn [a], G. Pretzler [a], A. Pukhov [a], U. Schramm, P. G. Thirolf, and K. J. Witte [a]

[a] MPI für Quantenoptik, 85748 Garching, Germany

The ongoing development of CPA lasers exceeding focal intensities of 10^{20} W/cm^2 combined with the rapidly improving understanding of relativistic laser plasmas has dramatically increased the energy range of the corresponding plasma electrons and ions (see also [1]). In the special case of channel formation in an underdense plasma energies of the copropagating intense electron beam well into the region of 100 MeV have been reported [2]. Thus, besides direct spectroscopy, the photo-excitation of nuclear reactions [3] has developed into a sophisticated diagnostics tool [2,4]. Regarding, on the other hand, a deuterium plasma, plasma ions were observed to reach energies well beyond the threshold for $d(d,n)^3He$ fusion [5,6]. The energy distribution of these fusion neutrons directly depends on the initial ion energy and, in a more complex way (as illustrated in fig. 2), also on the angular ion distribution characteristic for the acceleration mechanism and on anisotropies in the density of the surrounding deuterium-ion plasma.

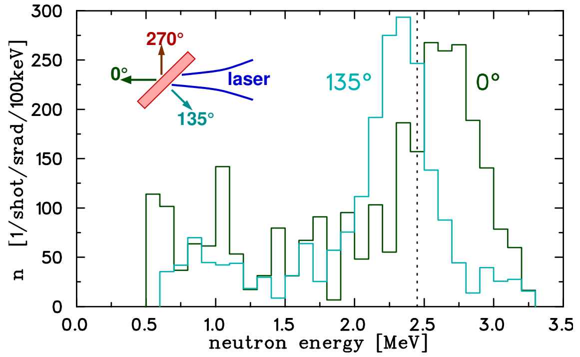

Fig. 1: Energy distribution of fusion neutrons observed under 0° and 135° relative to the direction of the incident laser. The spectra are deduced from time-of-flight measurements taking into account neutron scattering in the lead shielding. The total neutron yield amounts to 30.000/shot ($I = 5 \cdot 10^{18}$ W/cm^2).

We therefore systematically examined the energy distribution of fusion neutrons for different observation angles relative to the direction of the incident laser, the setup being introduced in ref. [7]. Fig. 1 shows two typical neutron energy spectra, deduced from a time-of-flight (TOF) measurement triggered by the laser pulse. The spectra are corrected for neutron scattering in the solid target and the lead shielding of the detectors, which still accounts for the remaining low energy tail in the spectra.

In a first analysis, the variation of the detection angle revealed peak energies of the spectra depicted in fig. 1 of 2.6 MeV (0°), 2.3 MeV (135°) and 2.5 MeV (270°). The unexpected appearance of the highest neutron energies at 0° indicates a significant ion acceleration towards the target, possibly due to a point explosion or ponderomotive forces. To clearly distinguish this signature from the one expected for the radially exploding plasma channel, we prepare similar measurements at an accurately characterized pulsed deuterium gas target (ATLAS) reducing ambiguities due to unknown density gradients. Furthermore, neutron scattering unavoidable in the solid target experiments should be strongly diminished.

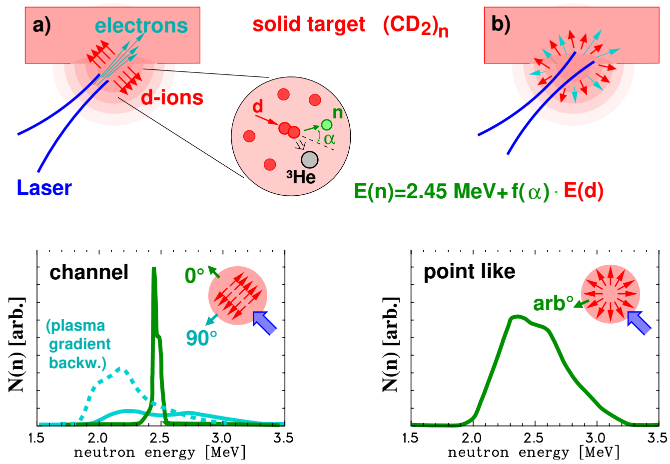

Fig. 2: Expected dependence of the energy distribution of fusion neutrons on the initial laser plasma conditions for different observation angles. In the case of a Coulomb-exploding laser plasma channel (a.) ions are accelerated predominantly in radial direction. In forward direction (0°) the neutron signal is concentrated around 2.45 MeV and mainly determined by the initial ion distribution, whereas under 90° various relative angles α between the incoming deuteron and the fusion neutron have to be considered and the spectra are broadened due to the kinematics of the reaction. Furthermore, the spectra become more sensitive to anisotropies in the plasma density (lower left figure). Assuming a point-like ion source (b.) results in a comparably broad neutron distribution, which, for clarity neglecting plasma gradients, shows no dependence on the observation angle (lower right figure).

On the other hand, this novel process deserves attention due to the high yield of about 4×10^4 neutrons per shot at a moderate laser energy of 500 mJ (130 fs). With an improved yield, presently investigated at the 200 mJ (30 fs) FALCON laser of LLNL (Livermore) and for modified target geometries, applications like the transmission analysis of small samples could come into reach.

References

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