Fast Neutrons Produced by the 5 TW MPQ ATLAS Ti-Sapphire Laser ◇

S. Karsch, D. Habs, U. Schramm, P. G. Thirolf, G. Pretzler [a], and K. J. Witte [a]
[a] Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany

The development of chirped pulse amplification (CPA) lasers has led to focal intensities above 10^{18} W/cm^2 ($\hat{=}$E=3×10^{12}V/m) [1]. When focused onto matter, the electric field ionizes light atoms within one light period and accelerates the quivering electrons up to relativistic energies [2]. Due to the relativistic mass increase the refractive index of the plasma is reduced in regions of high light intensities, resulting in a collapse of the laser beam into a filament with a diameter of several μm and a length of several 100 μm [2]. From this filament electrons are expelled predominantly in forward direction by plasma effects such as wakefield acceleration, forming a narrow jet. Electron energies up to tens of MeVs and currents of several 10 kA as well as megagauss magnetic fields were predicted by 3D PIC simulations [2].

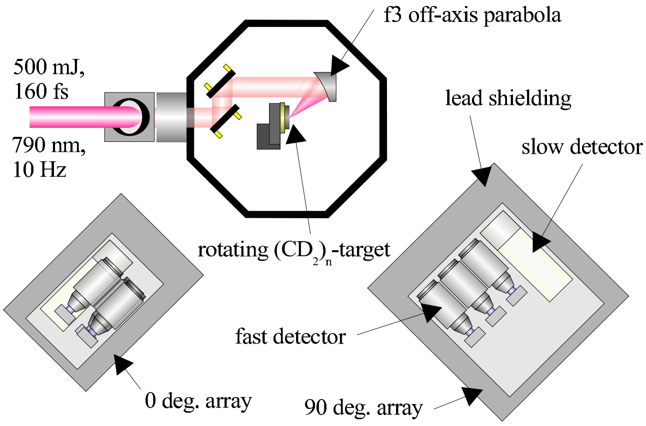

Fig. 1: Detector setup at the MPQ Atlas laser. The two TOF arrays are lead shielded against the strong γ-background. Lead thickness is 15 cm front, 10 cm side and 5 cm top, bottom and back. Target distance is 1.5 m

After the expulsion of the electrons from the channel, strong space charges lead to an acceleration of the plasma ions to energies of up to several MeV's (for d$^+$ ions). In first experiments it was shown that these ions trigger the reaction d(d,^{3}He)n in a deuteron plasma. 130 neutrons/shot were generated from a $(CD_2)_n$ target by a 160 fs, 200 mJ, 10 Hz Ti-Sapphire laser (MPQ ATLAS) [3,4]. Since in the rest frame the energy of the emitted neutrons is 2.45 MeV, any deviation from this energy is due to kinematics and therefore reflects the ion velocity distribution. For investigating this distribution, in a new set of experiments six new neutron detectors have been added to the previous setup (see [4]), consisting of 4 1/2" by 2 cm NE 110 plastic scintillators coupled to fast 4 1/2" photomultipliers (Valvo XP 1041), yielding an overall timing resolution of 1.5 ns, i.e. 2.5% of TOF. Two detector arrays (under 0° and 90° to the laser axis) were set up with 15 cm lead shielding against γ-rays. The ATLAS laser is now capable of delivering 160 fs, 600 mJ pulses at 10 Hz. The focal intensity was $\sim 3 \times 10^{18}$ W/cm^2, and a prepulse of 20 mJ 360 ps prior to the main pulse could be added for preplasma generation. In fig. 2 measured neutron spectra (without prepulse) are shown for the 0° and 90° arrays. 9300 neutrons/shot were observed in this run, but due to multiple hits in the detectors the real neutron number might be larger. A peak occurs at 2.1 MeV under 90° and at 2.4 MeV under 0°.

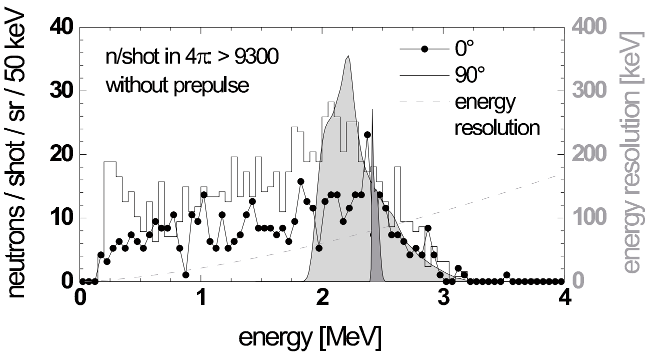

Fig. 2: Neutron energy spectra in 0° and 90° without prepulse, showing an integral 9300 n/shot. Calculated neutron spectra are shown for 0° (dark grey) and 90° (light grey). The observed low energy tail is due to scattering in the lead shielding.

PIC simulations predict that most ions are expelled from the channel in a radial direction, leading to a neutron distribution centered around 2.45 MeV with a width of two times the transverse ion energy under 90° and a sharp peak around 2.45 MeV under 0° in an homogeneous plasma. For a laser hitting a gradient plasma under oblique incidence, the maximum of the transverse spectrum is shifted to lower energies, because ions that are expelled away from the 90° detector hit a denser plasma and therefore yield more neutrons, as shown in fig.2 (shaded curves). Multiple scattering in lead accounts for the unexpected low energy tail of the spectra, and scattering in the target holder is responsible for the large anisotropy between forward and sideways direction. This has been confirmed by Monte Carlo neutron transport calculations. Without prepulse, the γ-background almost totally disappeared because of the absence of a preplasma where the channel formation can take place. Surprisingly, the neutron yield was enhanced in this case, which needs further investigation.

Our experiments showed that a factor of three increase in laser power results in a factor of 20 increase in neutron yield as predicted by theory. A larger target distance is planned for the next campaign in order to avoid multiple hits and achieve a better timing resolution. In addition the lead shielding will be reduced to 5 cm, which is also facilitated by the lack of γ-rays in shots without prepulse. Since laser optimization is done in parallel, we are optimistic to reach the 10^6 n/shot level soon.

References

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