Direct Ion Spectroscopy in Relativistic Laser Plasmas ◊

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In recent years great progress has been made in the understanding of relativistic laser plasma channels formed when especially an underdense plasma is irradiated with laser intensities exceeding 10^{18} W/cm^2. Detailed spectra of the intense energetic electron beam emitted in the direction of the laser pulse were recorded, e.g., at the ATLAS TW-Laser (MPQ Garching) and perfectly described by dedicated 3D-PIC simulations [1]. As a direct consequence of the electron depletion in the corresponding plasma channel, ions were observed to be emitted radially from the elongated interaction region [3] reaching energies up to several MeV as predicted earlier [2]. Regarding exemplary a CD_2 plasma, fusion neutrons are released via d(d,n)^{3}He for deuterium ion energies exceeding 100 keV [4]. Their energy strongly depends on the initial ion distribution, which can thus be indirectly studied via fusion neutron spectroscopy [5]. On the other hand, groups from RAL (VULCAN) and LLNL (PETAWATT) recently reported the unexpected emission of brilliant beams of highly charged ions with energies of many MeV mainly perpendicular to the surface of solid targets.

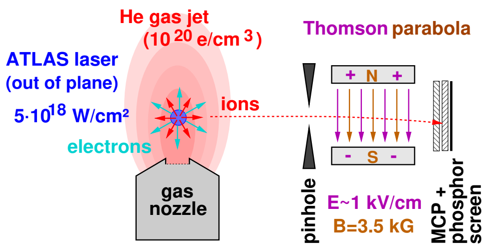

Fig. 1: Experimental setup for the direct spectroscopy of plasma ions. Ions emitted by any relativistic laser plasma are charge state selected and energy analyzed in parallel electric (5 kV/43 mm) and magnetic (3.5 kG) fields (Thomson parabola) from 100 keV up to 10 MeV. The ion traces are recorded either on CR-39 film or employing an image intensified CCD Camera.

We therefore realized a simple but efficient ion spectrometer analyzing the deflection of different charge-over-mass states in parallel electric and magnetic fields, sketched in fig. 1. Each q/m state generates a parabolic trace in the plane normal to the direction of the incident beam (Thomson parabola) where the ion energy decreases with the distance from the apex of each parabolic trace.

A first test of the spectrometer was performed focusing the ATLAS laser onto the surface of various bulk targets simply using a CR-39 film for the detection of the ion traces. A highly directional ion beam (opening angle $\approx 10°$) was observed perpendicular to the target surface and independent from the laser direction. In the case of deuterated polyethylene $(CD_2)_n$ traces of charge states ranging from C^+ to C^{6+} with a maximum yield around C^{3+} were recorded, as depicted in fig. 2. A detailed analysis of the energy distribution still has to be performed. Investigating a glass target, a variety of different charge states of carbon, oxygen and silicon ions showed up, the highest resolved charge state being Si^{11+}. Again the omnipresent hydrogen trace extending to a maximum energy of about 0.5 MeV was used for calibration. Repeated experiments with aluminum bulk targets showed no sign of any comparable ion acceleration suggesting that the conductivity of the target material and thus the possible formation of large quasi-static fields (near the surfaces) plays a major role in the ion acceleration mechanism. Here, further experiments with dedicated (layered) targets are presently prepared to elucidate the described phenomena recently observed by several groups.

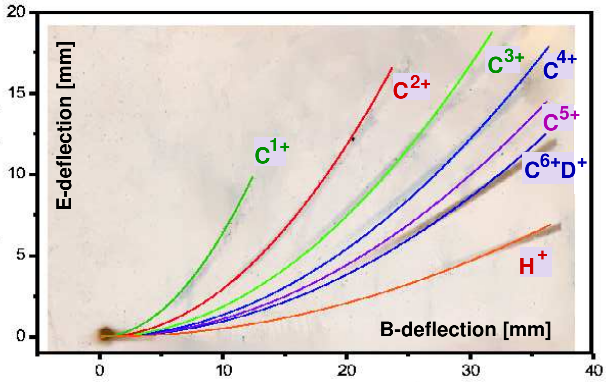

Fig. 2: Preliminary record of ion traces on CR-39 film. The ATLAS pulse was focused to an intensity of $\approx 5\cdot10^{18}$ W/cm^2 at the surface of a bulk target of deuterated polyethylene $(CD_2)_n$. Ion emission was recorded perpendicular to the surface. The fitted lines correspond to the different charge states, revealing the existence of charge states ranging from C^+ to C^{6+} with a maximum yield around C^{3+} as well as D^+. The H^+ signal stemming from surface contaminations is used for calibration.

To establish fast pulse-by-pulse readout of the ion spectrometer, necessary for systematic studies of the ion acceleration mechanism under various plasma conditions, we plan to replace the CR-39 film by a micro-sphere-plate enhanced phosphor screen in combination with a fast CCD camera. In case of, e.g., channel formation in an underdense plasma the analysis of the charge state dependent ion energy distribution will provide new insight into the field distribution as well as the ionization and acceleration mechanisms inside the channel. Furthermore, in contrast to previous measurements [3], systematic online diagnostics at well defined gas jet targets could be established to improve channel formation and calibrate ion spectra. The latter could then be exploited as an ion source for, e.g., the analysis of the electric fields inside the plasma channel.

References

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