Gamma-ray measurements in relativistic interactions with underdense plasmas

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Introduction

Fast electrons generated in laser-plasma interactions at relativistic intensities can be studied directly by using electron spectrometers, or indirectly by detecting the gamma-ray bremmsstrahlung radiation generated by the interaction of these electrons with matter[1)]. The gamma-ray detection technique is particularly suitable when the energy of these electrons is very high (>>10 MeV) and traditional spectroscopy would require dedicated, large scale equipment. Here we report on a recent investigation in which this technique was employed to study the effect of a precursor channelling pulse on the electron generation during the interaction of a relativistic laser pulse with an underdense plasma.

Experimental set-up

The 75 J, 1 ps Chirped Pulse Amplified (CPA) Vulcan laser pulse was focused with an f/3.5 optics in a preformed plasma. The preformed plasma was generated by laser explosion of a thin CH foil irradiated at intensities exceeding 10^{14} W/cm^2. Fourth harmonic, picosecond Nomarski interferometry was used to characterise the temporal evolution of the electron density along the axis perpendicular to main CPA pulse. (See elsewhere in this Annual Report [2)] for a detailed description of interferometry measurements). We report on gamma-ray measurements performed using gamma-ray detectors based on NaI(Tl) scintillator coupled to photomultipliers[3)]. A set of detectors with the thickness of the scintillating crystal ranging from 12.5 to 50.1 mm was placed along the direction of the incident CPA pulse. Other detectors were placed at 45º and 90º. All scintillators were shielded from scattered radiation by a 50 mm lead case.

Experimental results and discussion

A preliminary survey of the data indicates that a large number of very high energy electrons are generated, mostly in the forward direction. Numerical simulations were performed using the code GEANT4[4)]. Assuming a given direction of the primary electrons (i.e. the direction of CPA), the comparison of simulation with the experimental data obtained from the scintillators allows a correlation to be established between the number of electrons and their energy. This calculation, combined with the condition set by the energy conservation principle indicates that the minimum electron energy must be around 10 MeV. In this case up to 10^{13} electrons are accelerated. On the other hand our data are also compatible with a flux of 10^7 electrons. Further analysis is in progress to clarify this point.

The gamma-ray emission yield was measured in different preformed channel conditions. Figure 1 shows the dependence of the gamma-ray yield as a function of the delay between the channel forming pulse and the main CPA pulse for three different values of the thickness of the scintillating crystal. In this plot the "zero" delay corresponds to the interaction of the main CPA pulse with the unperturbed preformed plasma (no channel-forming pulse). According to this plot the signal has a minimum around 20 ps and then increases over the entire range of delays explored.

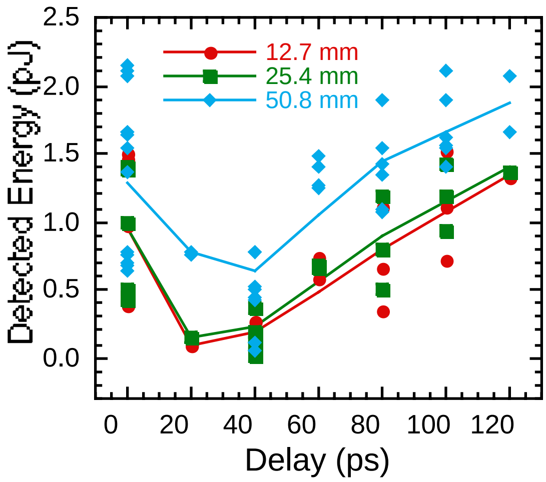

Figure 1. Energy released by the gamma-ray photons in the detector scintillating crystal as a function of the delay between the channel forming pulse and the main CPA pulse. Results are shown for three different thicknesses of the crystal.

Interferometric measurements show that when the main CPA pulse interacts with the unperturbed preformed plasma, it breaks into many filaments. In this case a substantial fraction of electrons can be accelerated in the filaments where the effective laser intensity may be higher than the incident one. This effect may explain the relatively high gamma-ray yield found in this condition as already observed [5)]. The interaction changes completely when the channel preforming pulse is present. For small delays the gamma-ray signal drops rapidly and increases again for delays larger than 20 ps. Simultaneous interfermometric measurements confirm that the presence of a channelling pulse, regardless of its timing, prevents filamentation of the main pulse. On the other hand, for delays greater than 20 ps a long channel develops and the main pulse propagates in this channel. Moreover, the radius of this channel saturates at approximately 100 µm for delays greater than 40 ps.

Although the analysis is still in progress, this preliminary survey shows that the dynamics of plasma channels plays a fundamental role in electron acceleration processes and may be the key to achieving efficient production of energetic electrons from laser-plasmas.

References

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