Laser based electron acceleration

To accelerate electrons to TeV energy, one needs very large size accelerators, which in turn requires huge money and human resources. The necessity to have large size system mainly arises because the accelerating electric field has to be kept below ~ 50 MV/m to avoid electrical breakdown in the accelerating structures. On the other hand, laser based electron accelerators can give extremely high electric fields ~100GV/m. As a result, the size of the accelerator can be reduced quite drastically, and in principle, it is possible to reach TeV energy within few meters. Laser Plasma Division has recently carried out initial experiments on laser wake-field electron acceleration, in collaboration with scientists from KEK, Japan, and observed acceleration of electrons to energy of 70 MeV and higher.

The experiments were carried out using the 10 TW Ti:sapphire laser facility at RRCAT. This provides laser pulses of maximum energy of about 300 mJ in 45 fs pulses. The laser beam was focussed on a helium gas jet using an f/6.6 off-axis parabolic mirror. Fig.L.1.1 shows a schematic of the experimental setup. The gas jet was produced by a shock wave-free slit type (10 mm x 1.2mm) supersonic Laval nozzle. Helium gas was puffed using a fast solenoid valve and its density was varied by changing the backing pressure of the gas. The Ti:sapphire laser beam was focused at the entrance edge of the gas jet, about 1mm above the nozzle entrance. The focal spot diameter of the beam was 18μm (FWHM) and the corresponding peak laser intensity was 2.4×10^{18} W/cm^2.

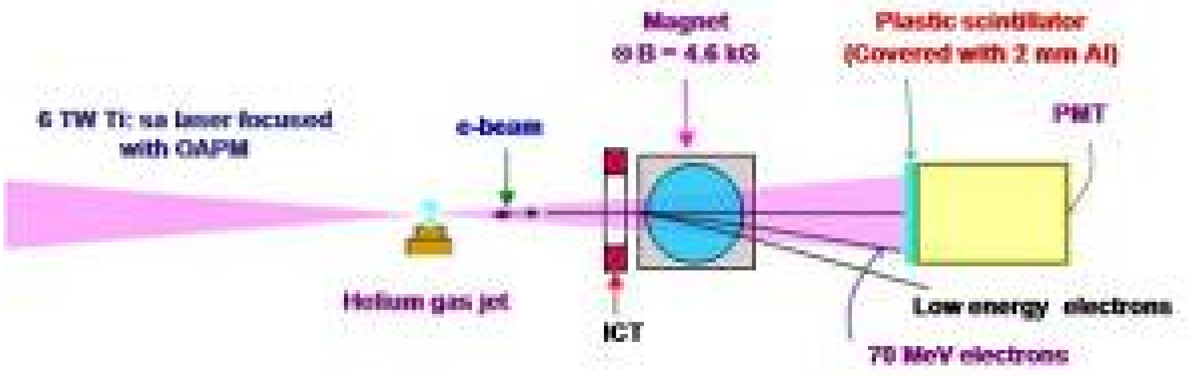

Fig.1 : Set-up of the electron acceleration experiment

A calibrated integrating current transformer (ICT) was used to measure electron beam charge. The ICT generates output pulse whose time integrated area is proportional to the input beam charge. The ICT had a sensitivity of 2.51 V-s/C. A permanent magnet pair providing a field of 4.6 kG was placed at a distance of 10 cm from the gas jet along the direction of the transmitted laser beam. A scintillator (NE102) - photomultiplier combination with the scintillator covered with a 2mm thick aluminium disc was placed along the axis to serve as a detector for the accelerated electron beam

The experiments were performed at different laser intensities and backing pressures of the gas jet. The electron density was estimated from interferometric measurements and was found to be ~ 10^{20} cm^{-3} at a backing pressure of 67 bar of the gas jet. At the maximum laser intensity of 2.4×10^{18} W/cm^2, the electric field gradient due to excitation of the wakefield is calculated to be ~3 GV/cm or 300 GV/m.

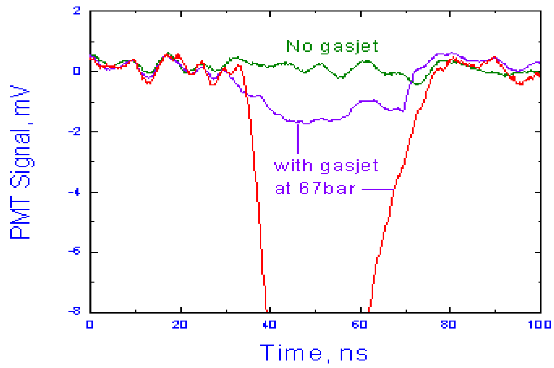

Fig.2 : Scintillator-PMT signals showing presence of electrons accelerated to energy exceeding 70 MeV.

Figure 2 shows the PMT signals corresponding to the accelerated electrons impinging on the detector. Although detailed energy measurements were not performed, a gross estimate of the electron energies can be obtained from the deflection angle of the electrons. Taking into account the magnified field, the size of the detector and its distance from the magnet, the energy of the electrons striking the detector should be ≥ 70 MeV. In absence of the gas jet, there was no PMT signal. The signal amplitude varied in different laser shots. In few shots, a very large amplitude of the PMT signal was observed indicating occurrence of appropriate matching of various laser and gas jet parameters for efficient excitation of the laser wake-field in the plasma. A maximum charge of 2.7 nC was observed from the ICT signals at a backing pressure of 67 bar, which corresponds to ~1.7×10^{10} electrons. Detailed energy measurements are planned using an ICCD based electron spectrograph in experiments using shaped ultrashort laser pulses.

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