L.5: Betatron resonance electron acceleration using 200 fs Ti:Sapphire laser pulses

Laser driven plasma based electron acceleration is seen as a potential candidate for development of future compact accelerators. In this regard, laser wake-field acceleration (LWFA) technique is widely studied in which a short laser pulse (few tens of fs) drives electron plasma wave (wake-field) in the underdense plasma and huge electric field (GV/cm) associated with it accelerates electrons to very high energies in a small distance (few mm to few cm). Among other possible laser acceleration mechanisms in plasma direct laser acceleration mechanisms of betatron resonance acceleration, where resonant transfer of energy from the laser field to the oscillating electrons in laser channel occurs, is also of interest. For this a comparatively longer laser pulse is used.

A schematic of the experimental set up is shown in Figure L.5.1. The experiment was performed using 150 TW, Ti: sapphire laser system. For this experiment laser pulse duration used was ~200 fs (power ~15 TW). Laser pulse was focused using an f/5 off-axis parabolic mirror to a focal spot size of ~25x12 μm^2, half width at $1/e^2$ of the maximum, (peak intensity ~2.1×10^{18} W/cm^2, normalized laser vector potential a_0~1). A supersonic He gas-jet target was used (slit nozzle: 1.2 mm x10 mm). DRZ phosphor screen was used as an electron detector and a magnetic spectrograph (diameter: 50 mm, pole gap: 9 mm, peak magnetic field: 0.45 T) with a resolution of ~10% at 10 MeV and ~20% at 20 MeV (for a beam divergence of 10 mrad) was used to measure electron energy. A 6 mm thick aluminium plate placed before the phosphor screen blocked the laser and also electrons with energy below ~2.7 MeV. To study the laser propagation 90^0 side scattering images of the laser plasma interaction region was recorded using a lens and a 14 bit CCD camera of 6.45 x 6.45 μm^2 pixel size with 5X magnification. This corresponds to an overall spatial resolution of few microns.

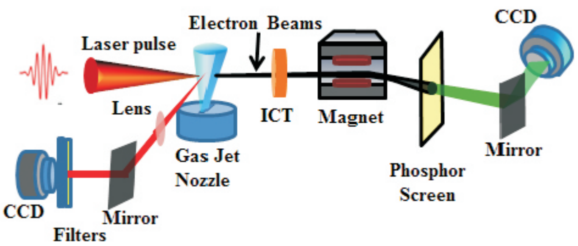

Fig. L.5.1: Schematic of the experimental setup.

Generation of relativistic electron beams was studied by varying plasma density in the range of ~3.6×10^{19} cm^{-3}-1.1×10^{20} cm^{-3}. Collimated electron beams in the forward direction were observed above a threshold plasma density of ~3.6-4×10^{19} cm^{-3}. For density of up to ~7×10^{19} cm^{-3}, similar electron beams with full angle divergence of ~40 mrad (FWHM) were observed. At higher density of 9×10^{19} cm^{-3}, the overall beam divergence increased (~120 mrad), however an intense central spot was still seen.

Laser propagation inside plasma was studied by 90° Thomson side scattering imaging. Relativistic self-focusing and guiding of the laser pulse was observed. For the range of plasma density used maximum propagation length was in the range of ~450-550 µm (~2.5-3 Z_R). Two stages of laser focusing and channeling were observed: after initial propagation the laser pulse slightly defocuses in the middle (bulging of the channel) for a small distance, followed by a further self-focusing in the later stage of propagation.

Generation of prominently two groups of electron beams was observed with peak energy in the range of 8-10 MeV and 15-25 MeV, (divergence ~10-20 mrad), with overall quasi-thermal electron spectrum. The two groups of accelerated electrons could be associated with the observed two stages of laser self-focusing and channeling. Interestingly, generation of single QM electron beams (peak energy ~17-22 MeV, energy spread ~20%) was also observed. A typical spectrum of quasi-monoenergetic electron beam recorded is shown in Figure L.5.2.

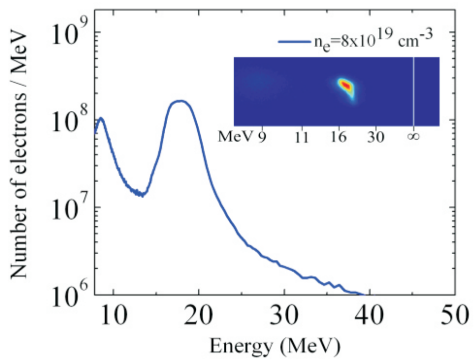

Fig. L.5.2: Energy spectrum of the quasi-monoenergetic electron beam. Inset: Image of energy dispersed electron beam recorded on the phosphor screen.

Studies on betatron resonance electron acceleration in laser plasma interaction is of interest for betatron radiation generation (laser synchrotron x-ray source) associated with this particular regime of electron acceleration. Further, characterization of electron beams generated is also imporatnt, as it may be pointed out here that generation of quasi-monoenergetic electron beams using such long (200 fs) laser pulses in underdense gas-jet plasma where dominant acceleration mechanism could be betatron resonance acceleration has not been reported earlier.

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