L.1: High quality relativistic electron beam from laser wake-field acceleration

RRCAT had started a programme on laser based electron acceleration in Nov. 2006. In the initial experiments done in collaboration with KEK, Japan, at RRCAT, the Laser Plasma Division of RRCAT had demonstrated laser acceleration of electrons *[RRCAT Newsletter 20 (1), p.10, 2007]* and also recorded the spatial profile of the electron beam using a phosphor screen *[RRCAT Newsletter 21(1) p.15, 2008]*. The recent experimental investigations carried out at RRCAT have shown that ultrashort (< 45 fs), mono-energetic ($\Delta E/E < \pm 8$ %), and low divergence (< 7 mrad) electron beam can be produced using laser, with a peak energy up to ~ 20 MeV over an acceleration length of < 70μm.

Laser wake-field acceleration of electrons is a promising method to reduce the size of the present day RF-cavity based TeV energy accelerators from kilometres to few meters. Such a significant reduction in size can make construction of table-top size electron accelerators feasible and affordable by smaller laboratories in near future. In the laser wake-field acceleration scheme, an intense, ultra-short laser pulse propagating in an under-dense plasma excites plasma waves co-propagating behind the laser pulse (wake-field). For sufficiently large amplitude plasma waves, the electrons in the background plasma can be trapped by the plasma wave and get accelerated to very high energies (~ 100 MeV) over very short distances (~ mm).

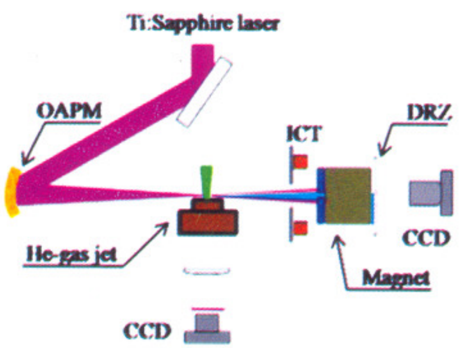

Fig. L.1.1: Schematic of the experimental setup

The experiment was performed using the table-top 10 TW titanium-sapphire laser system at RRCAT, providing laser pulses of 45 fs duration at peak wavelength $\lambda_0 = 790$ nm. A schematic of the experimental setup is shown in Fig.L.1.1. The laser beam was focussed to intensity of ~1.8 x 10^{18} W/cm^2, with an f/10 gold-coated off-axis parabolic mirror, at the entrance edge of a pulsed supersonic helium gas jet. The plasma density in the interaction region was controlled by changing the backing pressure of the gas jet. A single shot electron energy spectrograph, consisting of a permanent magnet (B = 0.46 T) and a DRZ-phosphor screen coupled with CCD imaging, was set up for energy dispersion and recording the energy spectrum of the electron beam. The mono-energetic electron beam charge was estimated from the calibration of the DRZ-phosphor screen against the integrating current transformer (ICT) signal.

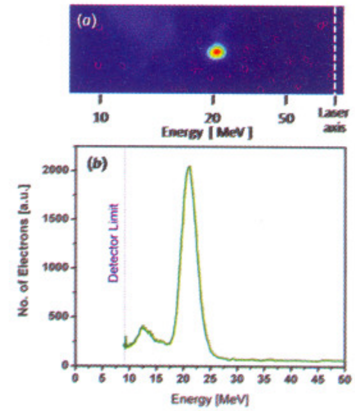

Fig. L.1.2: (a) Image of the electron energy spectrum showing highly collimated, mono-energetic electron beam; (b) Intensity distribution of the energy spectrum. The energy spread of the beam is limited by the resolution of the spectrograph.

By precisely controlling the laser and plasma interaction parameters, high quality relativistic electron beam was produced at a measured plasma density of ~ 8.5×10^{19} cm^{-3}. A typical image of the energy dispersed electron beam is shown in Fig.L.1.2a. The mono-energetic electron beam was produced with minimum geometric emittance, $\varepsilon_x \sim 0.02\pi$ mm-mrad and maximum charge $Q_{mono} \sim 60$ pC. Simulations and experimental studies by other groups indicate that the bunch length is a fraction of the laser pulse duration (45 fs). The presence of plasma wave was confirmed by observing the Stokes Raman satellite in the transmitted laser spectrum. The electron beam shown in Fig.L.1.2b was accelerated by the wake-field over a distance less than the dephasing length (~ 70 μm). This suggests that the wake-field was excited with accelerating gradient > 300 GV/m, which is 1000 times higher than that achieved in conventional accelerators. Such huge accelerating gradients in wake-fields would be exploited to produce 100s of MeV electrons by increasing the acceleration length in future experiments.

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