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Spectrometer for laser-plasma accelerated electrons at PlasmonX at the Frascati National Laboratory

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Summary. — This paper describes the characteristics of the magnetic spectrometer realized for the laser-plasma acceleration experiment PlasmonX at the Frascati National Laboratory. The laser-plasma interaction produces bunches of about 10^{10} e^- with energies spreading over three orders of magnitude from a few MeV to the GeV region.

PACS `52.38.Kd` – Laser-plasma acceleration of electrons and ions.
PACS `29.40.Mc` – Scintillation detectors.
PACS `07.81.+a` – Electron and ion spectrometers.

1. – Introduction

Laser-plasma interaction is a new technique for charged particle acceleration. The idea of using focused laser beams to excite a longitudinal plasma wave able to accelerate particle was first proposed by Tajima and Dawson [1] in 1979.

Due to its ponderomotive force, a laser pulse crossing a plasma generates an electron wake wave. The intense electric fields associated to this plasma wave can be employed to accelerate high energy particle [2]. Energy and characteristics of the produced accelerated bunch strongly depend on the laser parameter and the plasma density.

At the Frascati National Laboratory (LNF) the last-generation laser FLAME (Frascati Laser for Acceleration and Multidisciplinary Experiments) has been realized in order to provide ultra-short laser pulses, with length of 20 fs, pick-power till 300 TW and intensity of 10^{18} W/cm^2 with a repetition rate of 10 Hz. The first step of PlasmonX project is a Self Injection Test Experiment (SITE) [3]: The laser FLAME is focused on a 4 mm gas-jet with the goal of producing sub-GeV-class electron bunches from laser-plasma interaction.

A 3D PIC simulation has been performed with plausible laser and plasma parameters [4]. Figure 1 on the left shows the expected energy for the accelerated electron bunch: the whole spectrum is spread over three orders of magnitudes, from a few MeV

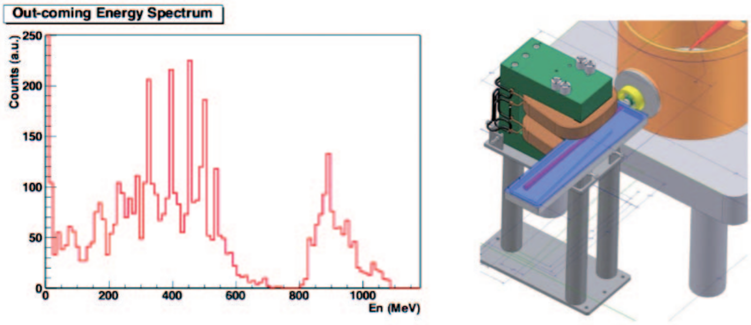

Fig. 1. – On the left, energy spectrum for the electron bunch as expected from a 3D PIC simulation. On the right, technical drawing of the spectrometer: the vacuum chamber, inserted between the magnet's poles, encloses the scintillating fiber detector.

to slidely less than 1 GeV. The electron charge of the high energy pick is of the order of 10^9 particles.

2. – Electrons spectrometer

The magnetic spectrometer realized for the detection of this bunch represents a challenge because the requirements are unprecedented in the high energy field: it must measure the energy spectrum of tens of millions of particles arriving simultaneously spread over three orders of magnitudes in momentum, coming from a point-like source about a meter upstream, with a divergence of some mrad.

The spectrometer is composed by an electro-magnet and a scintillating fiber detector inside a vacuum chamber [5], the technical drawing is shown in fig. 1 on the right. The dipole we are using for the first step of the PlasmonX project can generate a magnetic field of 0.5 T. The accelerated electrons passing through the region where the magnetic field is present will have a momentum-dependent trajectory. The measurement of the position of such particles on appropriately shaped detectors allows the measurement of momentum.

The resolution is dominated by the angular divergence. Due to the angular dispersion, trajectories from signifcantly different momenta could be overlaid in a given position on the detector. This component of the error can be shrunk if there are focii of the trajectories. Operating in the fringe area of the magnetic field, electrons are affected by a different field depending on their angular divergence and trajectories of a given momentum converge in the same point regardless of the angle at the origin. This property has been tested at Beam Test Facility (BTF) at LNF.

With the designed detector we can obtain a focus for particles with momentum up to about 200 MeV: as illustrated in fig. 2 on the left the position monitoring detectors are placed on the focal plane for the low momentum particles, while the high momentum detector ($E > 200$ MeV) is simply placed in the forward direction, orthogonally to the laser beam propagation direction, in order to maximize the spread for different energies. This provides an energy resolution $< 1\%$ till 200 MeV and $< 5\%$ till almost 1 GeV. To achieve a better resolution for energies higher than 1 GeV, the spectrometer will be upgraded.

The detector has an array of Kuraray SCSF-81 single cladding scintillating fibers with 1.00 ± 0.05 mm as diameter. The fibers allow the propagation of the photons generated by

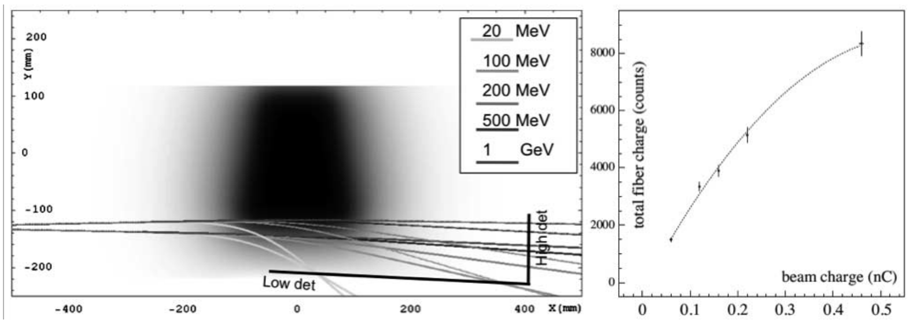

Fig. 2. – On the left, top view of the spectrometer set-up: the dark part is the density plot of the magnetic field; the two black lines indicate the detectors; trajectories for different energies are evaluated. On the right, experimental data from the BTF test: detector response *versus* beam charge.

the electrons through scintillating process inside the fiber core to the entrance of the 8×8 multi-anode Hamamatsu photomultiplier H7546B (R7600-00). There is a total number of 320 electronics channels (5 PMTs) read simultaneously by Multi anode ReadOut Chip Maroc2 chips which allow to multiplex up to 4096 channels.

3. – Tests with a prototype

A prototype of 64 scintillating fibers read by a single PMT has been realized to test the whole chain. Tests are performed with the electrons beam of the BTF in order to calibrate the detector and find the optimal working point.

The calibration in charge of the detector has been performed varying the intensity of the electrons bunches provided by the BTF from the pC up to the nC range. The scintillating fibers of the prototype are placed perpendicularly to the electron beam.The beam charge is measured by an Integrating Current Transformer toroid and compared with the detector response. The calibration curve obtained fitting the progress of the detector signal as a function of the beam intensity is shown in fig. 2 on the right.

The measured charge can be written as: $Q_{\mathrm{measured}} \propto N_e \times N_{\gamma/e} \times G_{\mathrm{PMT}} \times G_{\mathrm{electr}}$ where N_e is the number of electrons impacting the fibers and $N_{\gamma/e}$ the number of the generated photo-electrons. The PMT and electronic gains, respectively G_{PMT} and G_{electr}, can be tuned in order to avoid saturation effects. Optimal values of these parameters have been found. Additionally, if the number of electrons keeps increasing, a calibrated neutral density filter can be placed at the entrance of the photo-cathode.

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