IL NUOVO CIMENTO Vol. 33 C, N. 6 Novembre-Dicembre 2010
DOI 10.1393/ncc/i2011-10771-7

Colloquia: IFAE 2010

Laser-plasma interaction experiments: The design of a multi-GeV spectrometer

N. Drenska

Dipartimento di Fisica, Università di Roma "La Sapienza" and INFN, Sezione di Roma
Piazzale A. Moro 2, I-00185 Rome, Italy

(ricevuto l' 8 Ottobre 2010; pubblicato online il 2 Febbraio 2011)

Summary. — This paper describes the design of a spectrometer developed for experiments of laser-plasma acceleration. Because of the atypical properties of the accelerated electron bunches, the designed device is unconventional both for laser-plasma and for high-energy physics: it needs to detect simultaneously more than 10^9 electrons with energies spread over three orders of magnitude (from few MeV to few GeV).

PACS `29.30.Aj` – Charged-particle spectrometers: electric and magnetic .
PACS `29.40.Mc` – Scintillation detectors.
PACS `52.38.-r` – Laser-plasma interactions.

Plasma-based accelerators are of great interest because of their ability to sustain extremely large acceleration gradients. It has been demonstrated, both theoretically [1] and experimentally [2, 3] that the accelerating gradients in the conventional radio frequency cavity, currently limited to 100 MV/m, can be increased by three orders of magnitude reaching values high as 100 GV/m thanks to the plasma medium.

As described in [1] by Tajima and Dawson an intense electromagnetic pulse can create a wake of plasma oscillations through the action of the non linear ponderomotive force [4].

FLAME is a 300 TW, 30 fs pulse duration laser realized for the PlasmonX project [5] at LNF which first step is a Test Experiment of Self-Injection SITE [6] where the laser FLAME is focused on a 4 cm gas-jet with the goal of producing sub-GeV–class electron bunches from laser-plasma interactions.

The expected electron bunches properties, angular divergence and energy spectrum, are summarized in fig. 1. Results of the 3D PIC simulation show that: the whole spectrum is expected to cover three order of energy range from few MeV to few GeV; only the high energy electrons are collimated in few mrad while instead the low energy tail suffers of a big angular spread; the electron charge of the high energy pick is given by few 10^9 particles.

To match this characteristics, unprecedented both in the high-energy field, because of the huge number of particle to simultaneously detect and for the laser-plasma field, that operates in the MeV region, we have designed a magnetic spectrometer composed by

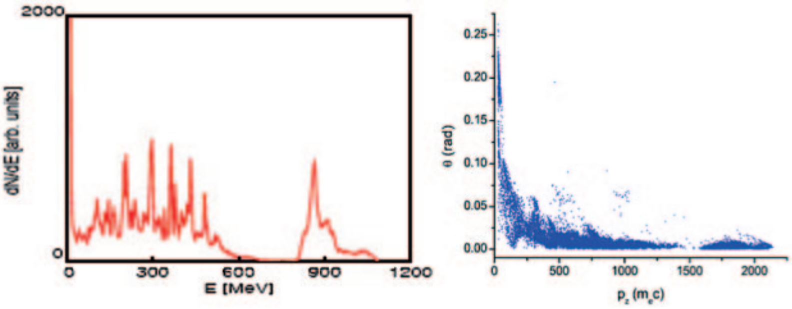

Fig. 1. – Energy spectrum and angular divergence as expected from 3D PIC simulation.

an electromagnet that deflects the charged particle, a vacuum chamber with the position monitor detectors inside it and the readout system [7].

Taking into account the magnetic-field dispersion, the angular divergence, the misalignment and crosstalk effects we can simulate the detector response for different initial electron energies. In order to reconstruct the energy distribution we perform a Bayesian unfolding [8] on the simulated. The expected energy resolution is shown in fig. 2.

The dipole we are using for the first step of the PlasmonX project can generate a magnetic field up to 0.5 T. The pole gap of 6 cm allows to insert the vacuum chamber for the detectors inside it. In order to focalize as much as possible the electrons with the same energy but different initial unknown angular divergence we chose to use the fringe area of the magnet. With the dipole we have in use we can focalize energies up to 200 MeV: the position monitoring detectors are placed on the focal plane for the low momentum particles, while the high-momentum detector is simply placed in the forward direction, orthogonally to the laser beam propagation direction, in order to maximize the spread for different energies. The whole detector length is ∼ 80 cm.

Both the length and the magnetic field need to be upgraded to achieve the goal of a reasonable resolution at 1 GeV.

The optimized detectors are an array of about 800 Kuraray scintillating fibers with 1.00 ± 0.05 mm as diameter with the emission wavelength in the blue region at 437 nm. The fibers allow the propagation of the photons generated by scintillating process inside the fiber core to the entrance of the 64 channels Hamamatsu multi-anode photomultiplier

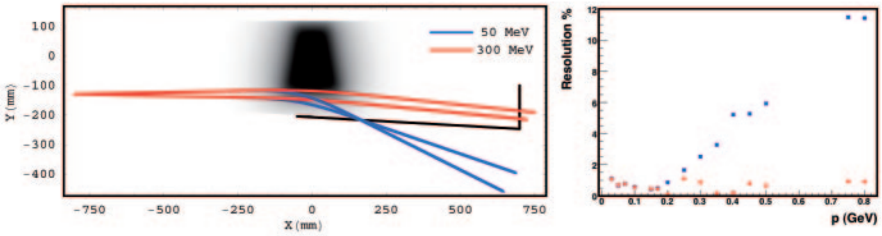

Fig. 2. – (Colour on-line) Left: top view of the spectrometer set-up: in dark is the density plot of the magnetic field, detectors are indicated through lines and trajectories for two different energies are evaluated. Right: expected resolutions: in red the only detector resolution is taken into account, in blue the angular divergence is also considered.

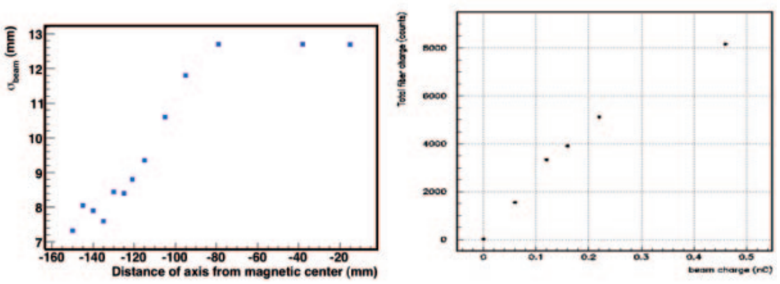

Fig. 3. – Experimental data from the BTF test. On the left is the decrease of the beam spot when moving away from the center of the magnet; on the right the charge calibration.

H7545 (R7600-00). In order to reduce the number of electronic channels we use to group 3 fibers for a single PMT channel in the low momentum region, while to keep the best possible resolution we need to read all the 128 fibers in the high-momentum region. We have a total number of 320 electronics channels (5 PMTs) read simultaneously by Maroc2 chips [9] which allow to multiplex up to 4092 channels.

A prototype of 64 scintillating fibers read by a single PMT is realized in order to test the whole chain. Two sets of test are performed at the Beam Test Facility of LNF in order to calibrate the detector response both in position and in charge.

In the first set of tests we used electron beam with characteristics close to the expected one in the PlasmonX experiment. We have good agreement with the predicted and measured deflection even when we are working on the fringe area and the focusing property is demonstrated experimentally (see fig. 3).

In the second set of tests at the BTF we used an electron beam of 500 MeV and charges in the nC range. The charge measured by the detector is proportional to the number of particles impacting the fibers times the number of photo-electrons generated times the gain of the PMT times the gain of the electronics. The last three terms can be tuned in order to avoid saturation effects (using a calibrated neutral density filter, lowering the high voltage of the PMT and lowering the signal amplifier of the electronics). Using a neutral density filter with attenuation factor 0.4%, applying 400 V to the PMT and setting the gain of the electrons to an intermediate value we observe a linear response of the detector with respect to the beam charge measured by a toroid.

REFERENCES

[1] Tajima T. and Dawson J. M., *Phys. Rev. Lett.*, **43** (1979) 267.
[2] Leemans W. P. *et al.*, *Phys. Rev. Lett.*, **89** (2002) 174802.
[3] Malka V. *et al.*, *Science*, **298** (2002) 1596.
[4] Leemans W. and Esarey E., *Phys. Today*, **62N3** (2009) 44.
[5] Gizzi L. A. *et al.*, *Eur. Phys. J. - ST*, **175** (2009) 3.
[6] Gizzi L. A. *et al.*, *Nuovo Cimento C*, **32** (2009) 433.
[7] Faccini R. *et al.*, arXiv:1002.3497 [physics.ins-det].
[8] D'Agostini G., *Nucl. Instrum. Methods A*, **362** (1995) 487.
[9] Argentieri G. A. *et al.*, *Nucl. Instrum. Methods A*, **617** (2009) 348.