The electron spectrometer for the PlasmonX experiment: from the design to the operation

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Outlook

General framework
Design of the spectrometer
Tests and calibration
Data analysis and first experimental results
General framework

Design of the spectrometer

Tests and calibration

Data analysis and first experimental results
Plasma-based accelerators are of great interest because of their ability to sustain extremely large acceleration gradients.

The accelerating gradients in conventional RF Cavity are currently limited to 100MV/m.

Accelerating gradients of the order of 100GV/m have been inferred in plasma based acceleration experiments.

50cm

10µm
The wave breaking

Figure 1 Wakefield acceleration. a, In a plasma excited by a laser pulse, the wake potential rises until it steepens and breaks. Electrons from the plasma are caught in the ‘whitewater’ and surf the wave. b, The load of the electrons deforms the wake, stopping further trapping of electrons from the plasma. c, As the electrons surf to the bottom of the wake potential, they each arrive bearing a similar amount of energy.

\[ n \approx 10^{18} \, cm^{-3} \]

\[ \omega_p \approx 10^{13} \, Hz \]

\[ E = \frac{cm\omega_p}{e} \approx 100 \, GeV/m \]
Near infra-red 800nm
Pulse duration = 30 fs
Pulse energy = 5 J
Peak pulse power = 166 TW
Spot size radius = 9 \( \mu m \)
Maximum Intensity = 5.2 x 10^{19} W/cm^2

Plasma density \( n_e = 3 \times 10^{18} \text{ cm}^{-3} \)
\( \lambda_p \approx 10 \mu m \)

\[ \tau_L \approx \frac{\lambda_p}{2} \]

\( \omega_{p,e} = \left( \frac{n_e e^2}{m_e \varepsilon_0} \right)^{\frac{1}{2}} \approx 900 (n_e [\text{cm}^{-3}])^{\frac{1}{2}} \)
Generic layout

Momentum spectrum

Position measurement

Unfolding

Laser

“e⁻ beam”

plasma

Dipole magnet

Detector screen

P(GeV)

Y(m)

P(GeV)
The PlasmonX Group in Rome has developed a device capable to measure the momentum of electrons over three orders of magnitude (from few MeV to a few GeV) under a not negligible angular divergence.

Unprecedented requirements for high-energy field (huge number of particles), laser-plasma field (few hundreds MeV experiments up to now), and accelerator physics (large emittance to deal with).
General framework

Design of the spectrometer

Tests and calibration

Data analysis and first experimental results
We split the detector in two:
• Low p detector: on the **focal plane**
• High p detector: **as far as possible**

The momentum *resolution* is dominated by the **angular dispersion at low p**: in a given position trajectories from **significantly different momenta** overlay.

Focusing property: all trajectories of a given momentum converge **regardless** of the angle at the origin.
Optimized Detector: fibers

Scintillating fibers Kuraray SCSF-81-SJ

- diameter: $1.0 \pm 0.05 \text{ mm}$
- thickness of cladding: $50 \pm 5 \text{ \mu m}$
- emission wavelength (peak maximum): $437 \text{ nm}$
- material (core): polystyrene
- refractive index (core): 1.59
- material (cladding): ‘fluorinated PMMA’
- refractive index (cladding): 1.42

Active area **80 cm $\rightarrow$ 800 fibers**
(group fibers to reduce electronics channels)
Multi-channel PMT & Maroc2 chips

Hamamatsu H7546B
64 channels multi-anode PMT

To keep the best possible resolution we use to read each single fiber of the high momentum detector and group in three the fibers of the low momentum detector.

Total of 320 electronic channels
(5 PMTs x 64 chs)

The technology based on MAROC2 chips allows to multiplex up to 4096 channels
(LAL-Orsay)

Front end card in collaboration with INFN-BA, GE & ISS-RM1
(A.G. Argentieri et al, NIMA (2009))
The detector, a prototype

Scintillating fibers prototype: 64 Kuraray fibers, 1 fiber/channel (6.4 cm active area)

Multi-channel photo-tubes
Hamamatsu H7545

Fake vacuum flange
General framework

Design of the spectrometer

Tests and calibration

Data analysis and first experimental results
Test Beam @ Frascati BTF

50-500 MeV electrons, 10 ns bunches, up to $10^{10}$ e-/bunch

We measure:
- the beam deflection
- spot size
- charge response

Detectors are in AIR, will be in vacuum
Alignment is very important.

Comparison between prediction and measurement for the beam deflection as a function of the distance of the beam with respect to the magnetic center.

Experimental data at BTF
Focusing property

Spot size measurement: experimental validation of the focusing property
Counts vs Charge

\[ Q_{\text{Measured}} = N_{\text{particle}} \times N_{\text{phe/particle}} \times G_{\text{PMT}} \times G_{\text{el}} \]

High-intensity beam shots
- 0.4% neutral density filter
- Lowest PMT gain (HV=400 V)
- Intermediate electronics gain \( (G_{\text{el}}=8, 0.5x) \)

Increasing the beam intensity \( \rightarrow \) increasing fibers charge

- \( 1 \times 10^9 \text{ e}^- \)
- \( 1.5 \times 10^9 \text{ e}^- \)
- \( 3 \times 10^9 \text{ e}^- \)
We can correlate the total charge in the 64 fibers with the beam charge measured by toroid.

Good linearity up to $2 \times 10^9$ electrons (can be optimized)

- 0.4% ND filter
- HV=400 V
- MAROC gain=8 (0.5x)
General framework
Design of the spectrometer
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Data analysis: Bayesian unfolding

\[ P(C_i \mid E_j) = \frac{P(E_j \mid C_i)P(C_i)}{\sum_{l=1}^{n_c} P(E_j \mid C_l)P(C_l)} \]

If we observe a Q deposition on a given channel j, the probability that it has been due to the momentum i is proportional to the probability of the momentum i times the probability of the momentum i to release Q in channel j.

Box area \sim P(E_j \mid C_i)

Smearing Matrix
Geant4 Simulations

Geant4 includes facilities for handling geometry, tracking and detector response.

Physics List:

- electron
  - multiple scattering
  - electron ionization
  - electron bremsstrahlung
  - synchrotron radiation

- gamma
  - conversion to e+ e- pairs
  - Compton scattering
  - photo-electric effect
Expected resolution

Resolution vs Energy

% Resolution

En(GeV)

Friday, October 14, 2011
Energy reconstruction - Geant4

Full Energy bunch

Energy/4 bunch

True PIC spectrum Unfolded

Up to few MeV good agreement with the true distribution

1 Iter

10 Iter

24
First experimental results

Because of too high electromagnetic, the electronics readout proved to be not screened enough from the pulsed high energy field generated in the laser-plasma interaction, making it impossible to discriminate signal from noise.
Accelerated electrons

The CCD images are analyzed identifying the pixels corresponding to the signal of a single fiber. The obtained position spectra are the input for a Bayesian Unfolding that leads to the momentum spectra.
• A spectrometer for Laser-Plasma acceleration experiments has requirements challenging for high energy physics:
  – Wide range of energies in spectrum
  – Very high charge in a single bunch
  – Large angular dispersion

• Critical aspects and chosen solutions have been discussed, quantified with an existing (preliminary) device. Points to stress:
  – Importance to find ‘focussing’ points
  – Scintillating fibers + PMT + Maroc2 chips
  – Bayesian unfolding
  – Preliminary results showing that the technique does work.