WEPWA045

Development of a Spectrometer for Proton Driven Plasma Wakefield Accelerated Electrons at AWAKE

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THE AWAKE EXPERIMENT

Proton bunches are the most promising drivers of wakefields to accelerate electrons to the TeV energy scale in a single stage. An experimental program at CERN — the AWAKE experiment — has been launched to study in detail the important physical processes and to demonstrate the power of proton-driven plasma wakefield acceleration. AWAKE will be the first proton-driven plasma wakefield experiment world-wide and will be installed in the CERN Neutrinos to Gran Sasso facility. An electron witness beam will be injected into the plasma to observe the effects of the proton-driven plasma wakefield. Simulations indicate electrons will be accelerated to GeV energies. In order to measure the energy spectrum of the witness electrons, a magnetic spectrometer will be installed downstream of the exit of the plasma cell.

ELECTRON SPECTROMETER

In order to measure the energy spectrum of the witness electrons, a magnetic spectrometer will be installed downstream of the exit of the plasma cell. As a change to the previous design, smaller, lighter and more efficient c-shaped magnet (HB4) was considered as an alternative to the window-shaped dipole (MBPS). The energy measurement uncertainties were also compared. HB4 will be installed instead of MBPS since HB4 has sufficient field strength and field width and gives a similar resolution to MBPS.

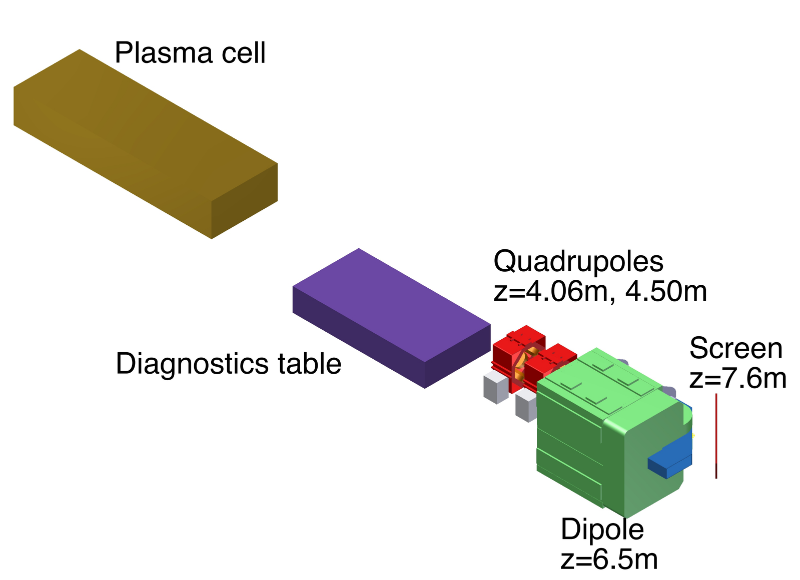
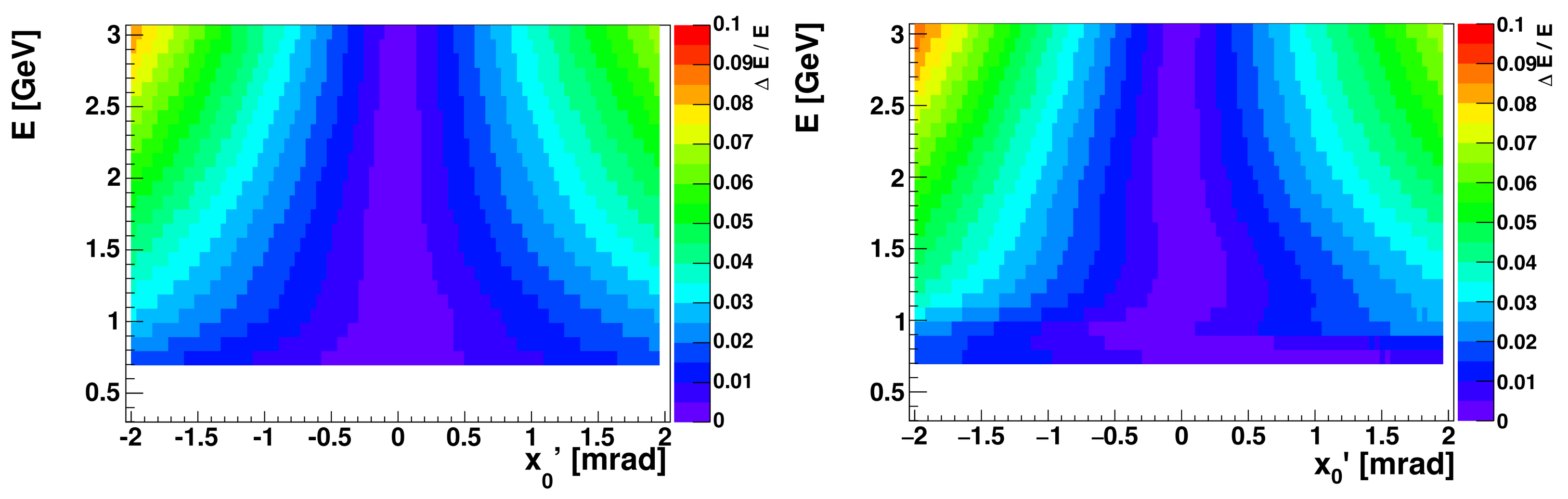


Figure 1. Layout of the spectrometer system.

RESOLUTION



(a) Window shaped dipole MBPS. Field map I scaled so that the integrated field is the same as that of HB4.

(b) C-shaped dipole HB4. B = 1.43 T.

Figure 2. Uncertainty of energy measurement as a function of energy and angle.

Any deviation from the electron reference trajectory will cause a shift in the measured energy, ΔE. The initial electron beam position, horizontal angular spread and mean angular trajectory of the beam are unknown but are limited by the beam pipe aperture and the transverse size of the accelerating plasma column. The maximum position and angular offsets of the beam are estimated to be 1 mm and ~2 mrad at the exit of the plasma cell. Figures 2(a) and (b) compare the resolution of HB4 and MBPS as a function of angle and energy. We define a "positive" and "negative" beam as a pencil beam with the maximum positive or negative angle and position offset (1 mm, 2 mrad). The resulting maximum energy uncertainties are plotted for a range of dipole field maps in figure 3 (quadrupoles are switched off).

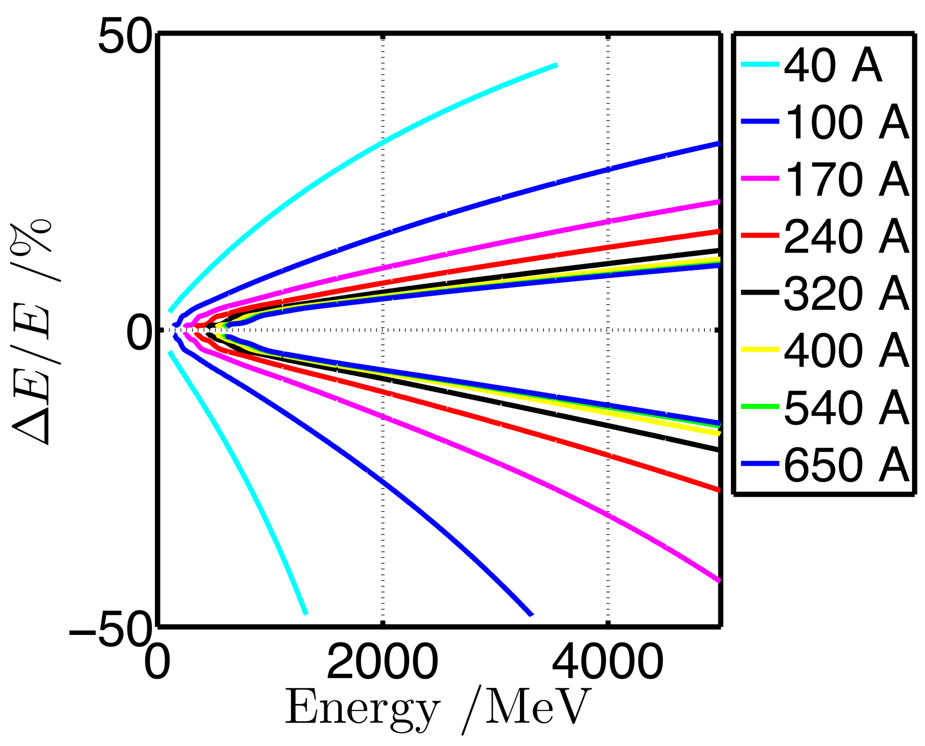


Figure 3. ΔE/E *vs.* energy for dipole HB4 at various current settings.

BEAM FOCUSING

A quadrupole doublet is placed upstream of the dipole as shown in figure 1. This will focus the beam as shown in figure 4. This will reduce the energy measurement uncertainty and increase the flux density at the scintillator screen. The proposed quadrupoles have a maximum field gradient of 18.1 T/m which will provide optimal focusing at ~1 GeV. A plot showing energy measurement uncertainty vs. energy and quadrupole strength for the "negative" offset beam is shown in figure 5. This shows that the energy resolution can be greatly improved with the quadrupoles for the few hundred MeV around the optimum focusing energy, over, low energy beams can be over-focused and lost. Plots such as figure 5 have been produced for a range of dipole field strengths.

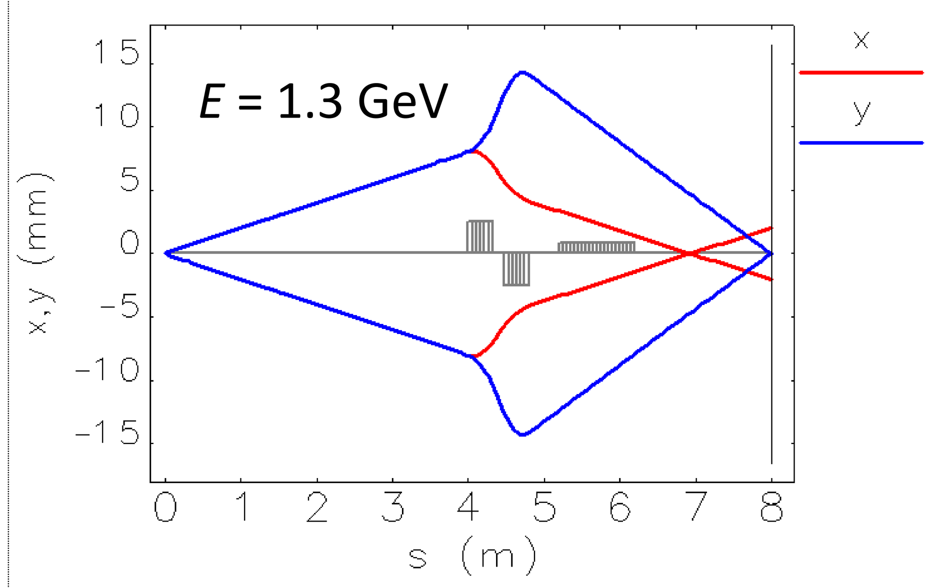


Figure 4. ELEGANT simulation results showing the trajectories of electrons with initial angles of +/- 2 mrad. The quadrupoles have K_1=+/-4.07m^{-2}

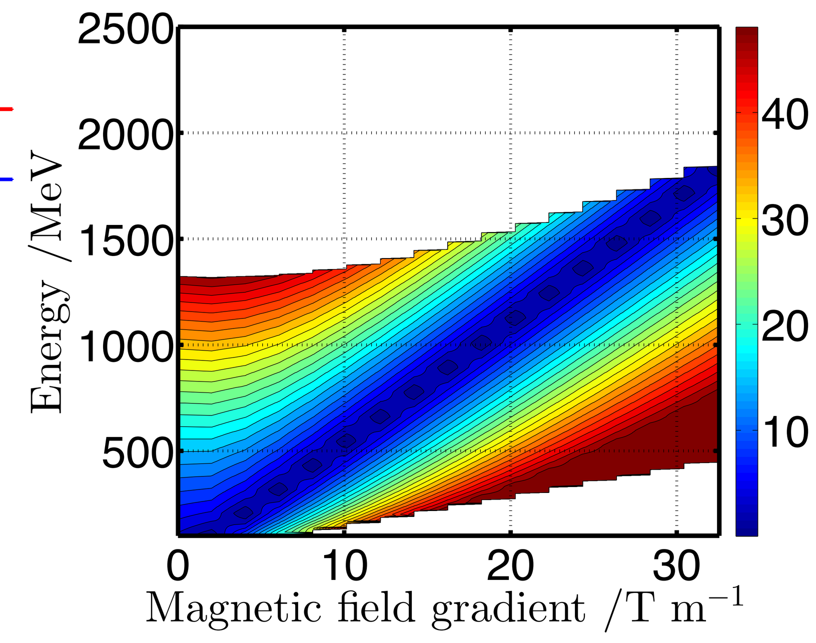


Figure 5. ΔE/E as a function of energy and quadrupole strength with the HB4 dipole current at 40A for the "negative" beam.

SIGNAL TO BACKGROUND RATIO

A FLUKA simulation was carried out to calculate the background particles at the plasma cell exit across the whole width of the tunnel (thanks P. Ortega, CERN). 15 million protons from the CERN Synchrotron Proton Source (SPS) were tracked. A 0.2 mm thick aluminum window included in the simulation will be required to separate the AWAKE vacuum from the SPS. The particles were then tracked through the BDSIM spectrometer simulation. The resulting optical photon numbers emitted from the scintillator screen as a function of horizontal position are plotted in a histogram in figure 6. The plot shows a peak signal to background ratio of ~1000.

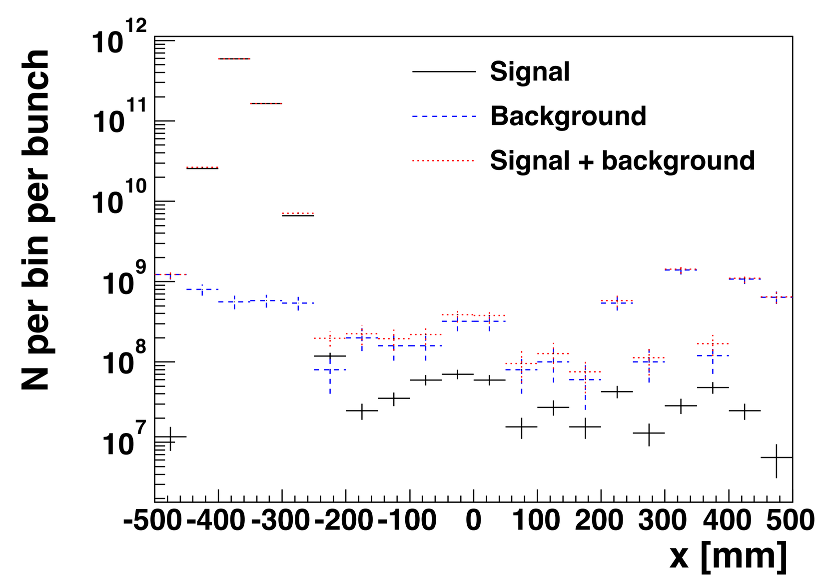


Figure 6. Optical photons emitted from the screen due to signal (witness electrons) and background in the screen.

CONCLUSIONS

Studies have been carried out regarding energy measurement uncertainties for a range of spectrometer settings and an alternative dipole magnet. The energy measurement uncertainty can be greatly improved with the appropriate settings depending on the energy profile of the witness electron beam. The HB4 dipole was selected to replace MBPS. Peak signal to background ratio in terms of flux density of optical photons emitted from the screen was calculated as ~1000, given a 0.2 mm aluminum vacuum window separating the AWAKE beamline from the SPS. Due to the radiation environment in the AWAKE experimental area, the CCD camera will have to be moved ~20 m away to the adjacent tunnel. Work is ongoing to design an optical line to transport light from the screen to the camera.

ACKNOWLEDGEMENTS

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