N23-8
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14:00, room Etoile

An Electron Spectrometer for Proton Driven Plasma Accelerated Electrons at AWAKE: Predicted Resolution of Energy and Emittance Measurements

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INTRODUCTION

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 for the first time proton-driven plasma wakefield acceleration. Commissioning of the proton beam phase of the experiment is underway. In the next phase, an electron witness beam will be injected into the plasma to observe the effects of the proton-driven plasma wakefield: plasma

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 (figure 1). A 1 m, ~1.6 T dipole deflects the beam to a 1 m wide scintillator screen. An intensified CCD camera takes an image of the screen and the energy distribution is inferred from the position distribution in the image. A quadrupole doublet focuses the beam to improve resolution and brightness.

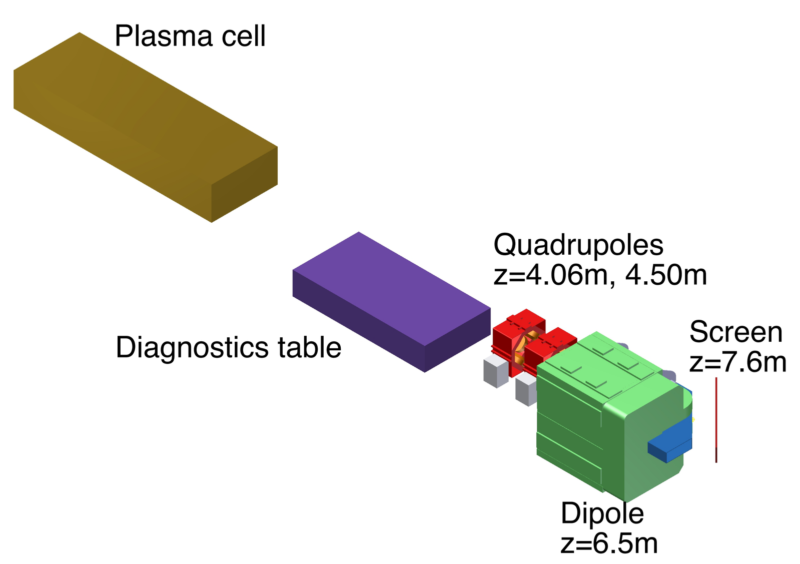

Figure 1. Layout of the spectrometer system.

EMITTANCE MEASUREMENT

Emittance measurement method

In addition to the energy measurement, the electron spectrometer could also be used to measure the vertical beam emittance. A transfer matrix was calculated using the thick quadrupole transfer matrices to transfer the beam from the upstream face of the first quadrupole, qd0, to the screen. The quadrupole strengths were allowed to vary as functions of energy in the transfer matrix. As the position on the screen is a function of energy, a function was derived (beam size function) giving beam size (and therefore energy resolution) as a function of energy using the energy dependent transfer matrix and the estimated beam parameters. With a large enough energy spread, a single bunch emittance measurement could be possible using the spectrometer system. The procedure is as follows: plot the vertical beam size as a function of energy. The *beam size function* is then fit to the data. This energy-dependent function yields an effective "quadrupole scan", and the parameters of the fit give the upstream beam parameters, including ϵ.

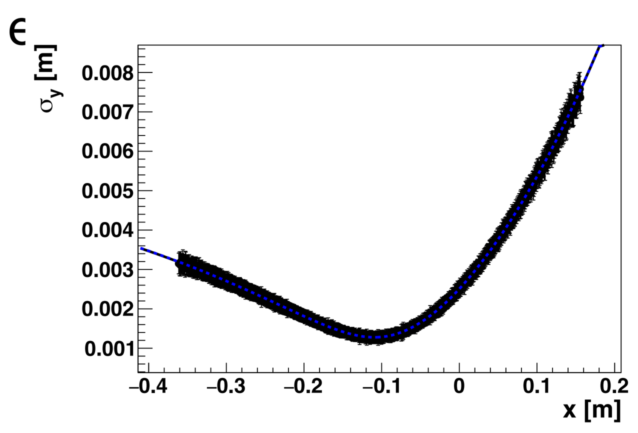

Figure 2: Fit of simulated spectrometer output to the beam size function. The black line is the input function. The dashed blue line is the fit.

Simulation

To determine the resolution of the emittance measurement, simulated spectrometer camera outputs were randomly generated. The simulation assumes a Gaussian beam profile with the parameters approximately equal to those expected for the AWAKE witness beam. An algorithm was written to take account of sources of noise and provide an estimate of the the uncertainty of the emittance measurement. Realistic camera noise parameters were used. The screen output was estimated based on previous measurements using MeV electrons, simulations and the known properties of the scintillator. The background was estimated based on simulations of proton interaction with an upstream aperture. The point spread function of the imaging system was estimated based on modulation transfer function measurements carried out using the lens.

Algorithm

The following steps are carried out, with errors calculated at each step:

1. An energy distribution is generated representing the accelerated electron energies.
2. The corresponding position histogram is filled, with positions convoluted with the point spread function of the system.
3. Electrons are randomly converted to photons taking account of screen efficiency and imaging system acceptance.
4. A uniform background and camera noise is added to the distribution. This distribution simulates the spectrometer raw data.
5. Background is subtracted.
6. Beam size (standard deviation of position) and error calculated for each vertical strip of pixels.
7. The resulting graph is fit to the beam size function by minimising Chi2. The error of the emittance fit gives the error on the emittance measurement (figure 2).

RESULTS

Baseline parameters

The fit with the baseline parameters is shown in figure 2. This gives an uncertainty on the emittance measurement of **~0.8%**. This assumes a 1.3 GeV beam with 0.4 GeV energy spread and 1 um emittance.

Reduced energy spread

A beam with a narrower energy spread increases the uncertainty of the measurement because the fit is less well constrained. Emittance measurement uncertainty vs. energy spread is plotted in figure 3. The uncertainty rapidly increases to **over ~10% for relative energy spreads less than ~5%**

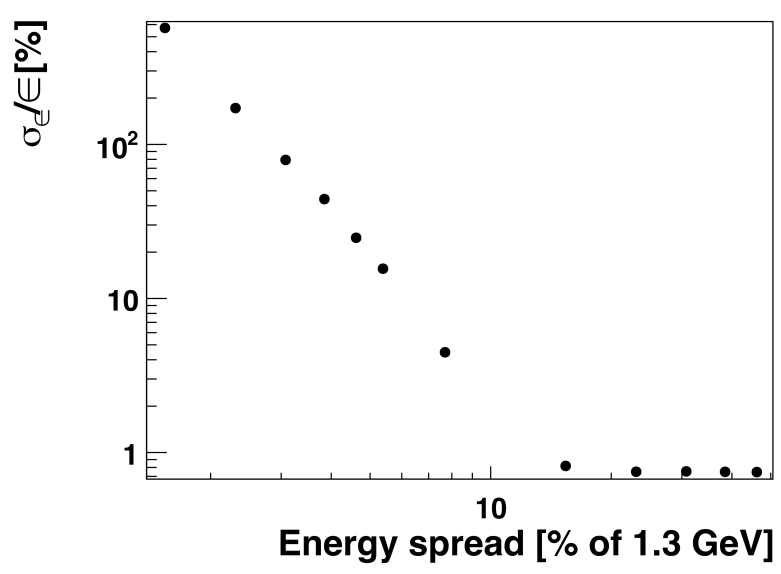

Figure 3: Uncertainty of the simulated emittance measurement vs. energy spread.

CONCLUSIONS AND FUTURE PLANS

An estimate of the energy measurement resolution was given in a paper by the authors presented at IPAC 2016, together with an outline of a possible method for measuring the emittance using a single bunch. Some constraints on the use of this method have now been estimated; with the baseline parameters the uncertainty on the measurement will be ~0.8%. The measurement requires a relatively wide energy spread, and the uncertainty increases to over 10% for energy spreads less than 5%.

The simulation framework described here will be used to determine the dependence of the emittance measurement uncertainty on various parameters such as:

- Radiation background (uniform and non-uniform)
- Camera thermal nose (dependent on temperature)
- Emittance
- Quadrupole field
- Coupled and/or non-Gaussian beam distribution
- Bunch charge

This will provide more information on the limitations of the method.

ACKNOWLEDGMENTS

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