AN ELECTRON SPECTROMETER FOR PROTON DRIVEN PLASMA ACCELERATED ELECTRONS AT AWAKE: ENERGY AND EMITTANCE MEASUREMENTS - A SUMMARY FOR AN ABSTRACT SUBMITTED TO IEEE NSS 2016

Lawrence Charles Deacon, Simon Jolly, Fearghus Keeble (UCL, London)
Aurélie Goldblatt, Stefano Mazzoni, Alexey Petrenko (CERN, Geneva)
Bartolomej Biskup (CERN, Geneva; Czech Technical University, Prague 6)
Matthew Wing (UCL, London; DESY, Hamburg; University of Hamburg, Hamburg)

Abstract

The Advanced Wakefield Experiment (AWAKE), to be constructed at CERN, will be the first experiment to demonstrate proton-driven plasma wakefield acceleration. The 400 GeV proton beam from the CERN SPS will excite a wakefield in a plasma cell several meters in length. To probe the plasma wakefield, electrons of 10–20 MeV will be injected into the wakefield following the head of the proton beam. Simulations indicate that electrons will be accelerated to GeV energies by the plasma wakefield. The AWAKE spectrometer is intended to measure both the peak energy and energy spread of these accelerated electrons. Under certain conditions it is also possible to use the spectrometer to measure the transverse beam emittance. The expected resolution of these measurements is investigated for various beam distributions, taking into account an optimised vacuum chamber and scintillator screen design and results of beam and optical tests.

SPECTROMETER DESIGN

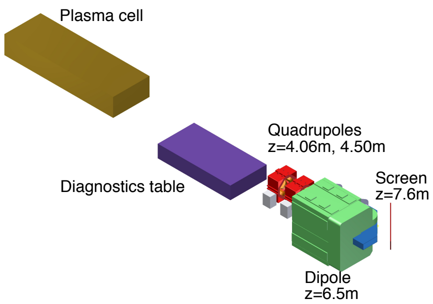

Figure 1: A 3D CAD image of the spectrometer system annotated with distances along the z direction from the exit of the plasma cell to the magnetic centers of magnets, and the center of the scintillator screen.

RESOLUTION

Optical system

he witness electrons accelerated inside the plasma cell will be deflected by a dipole magnet onto a large scintillator screen. Images of the electron distribution will be taken with an intensified CCD camera. The resolution of the energy spectrometer will ultimately depend on the resolution of the optical system imaging the screen. Due to the radiation environment, the intensified CCD camera (Andor iStar 340T) will need to be located 17 m away in an adjacent tunnel. The light will be reflected to the camera using a series of mirrors. In order to collect as much light as possible whilst maintaining good spatial resolution, a large diameter, 400 mm focal length, f#/2.8 lens has been selected (Nikon 400 mm f/2.8 FL ED VR). This lens was tested by imaging various targets back-lit with green with various line widths, and the smallest resolvable bar width was 1 mm.

Screen

Studies are currently ongoing to optimize the vacuum chamber window thickness. The point spread function of the screen will depend on the finally chosen window/screen thickness. The vacuum chamber window thickness is optimised, taking into account disruption to the electron beam, light output and the background shielding effect of the window. The point spread function of the beam is included in the calculation of the resolution of the energy spectrum and emittance measurements.

Emittance

The resolution of the spectrometer will depend on the beam size of the accelerated electrons at the screen which in turn will depend on the beam parameters and the magnetic beam line components which will be used to focus the beam.

Beam parameters The accelerated electron beam has been simulated in plasma simulations using LCODE [1, 2]. The phase space distribution of the accelerating beam is non-Gaussian with long tails. It also appears to be composed of a number of distinct phase space ellipses with different orientations. In this study we approximate the overall phase ellipse using the overall RMS position and angular distributions. The resulting beam parameters at the exit of the plasma cell are give in table 1. The parameters were calculated by assuming twiss parameter $\alpha = 0$, corresponding to an unrotated phase ellipse, which is true for the central part of the phase space (figure 2). Emittance was estimated from the RMS area of the phase ellipse i.e. $\epsilon = \sigma_x \sigma_{x'}$.

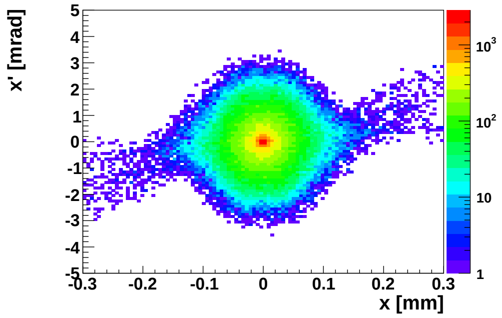

Figure 2: Central region of a sample of the simulated phase space distribution of the witness electron beam.

Table 1: Predicted beam parameters for the accelerated electron beam at the plasma cell exit calculated from the simulated phase space distribution (figure 2)

σ_x [μm]	327.1 ± 0.6
$\sigma_{x'}$ [mrad]	1.048 ± 0.002
ϵ [μm]	0.34280±0.0009

Beam line The beam line down stream of the plasma cell will consist of the components listed in table 2. The 7% offset between the strengths of the two quadrupoles causes the horizontal and vertical foci to coincide at the screen.

Table 2: Beam line components downstream of plasma cell. **l** is magnetic length. **k** is the magnet focusing strength.

Name	**Type**	**l** [m]	**k** [m^{-1}]
qf0	quad.	0.31	-4.2900
d1	drift	0.185	
qd0	quad.	0.31	3.9897
d0	drift	~3 m (energy dependent)	

Based on the above parameters, a transfer matrix was calculated analytically using the thick quadrupole transfer matrices [3] to transfer the beam from the upstream face of qd0 to the screen. As the quadrupole strengths and the length of d0 vary as a function of energy, these were left as functions of energy in the transfer matrix. $l_{d0}(E)$ was determined from a tracking simulation using BDSIM [4–7]. The quad focusing strengths are simply scaled linearly with energy. As the position on the screen is a function of energy, it was possible to derive a function (*beam size function*) describing beam size (and therefore energy resolution) as a function of position (and therefore energy) using the energy dependent transfer matrix and the estimated beam parameters.

Overall resolution

The resolution due to the emittance, when combined with the resolution of the optical system of 1.0 mm by adding the beam size due to emittance and the optical resolution in quadrature, is caluclated for a range of emittances, including the contibution to the resolution of the point spread function of the window and screen.

EMITTANCE MEASUREMENT

A method is described to measure the emittance in a single shot. The procedure is to plot the vertical beam size, which is provided in the vertical beam axis, as a function of horizontal position (or energy), which is given in the horizontal axis of the image. 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 vertical beam matrix upstream, from which the emittance can be derived. The emittance measurement method described requires a large energy spread of the beam to effectively probe the phase space distribution of the beam. The energy spread vs. emittance measurement resolution is calculated, demonstating the range of emittance spread under which an effective emittance measurement can be made.

At the edges of the energy distribution the beam loses intensity, and eventually falls below the noise threshold. Therefore there is a minimum beam intensity required to carry out an emittance method using this method. This minimum intensity is determined using simulated beam data.

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