WEPMY024

A Spectrometer for Proton Driven Plasma Wakefield Accelerated Electrons at AWAKE – Recent Developments

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INTRODUCTION

Proton bunches are the most promising drivers of wake- fields 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 proton-driven plasma wakefield acceleration. AWAKE will be the first proton-driven plasma wakefield experiment world-wide and is currently being installed at CERN, with data taking with the proton beam phase scheduled to take place summer 2016. 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. An quadrupole doublet focuses the beam to improve resolution and brightness.

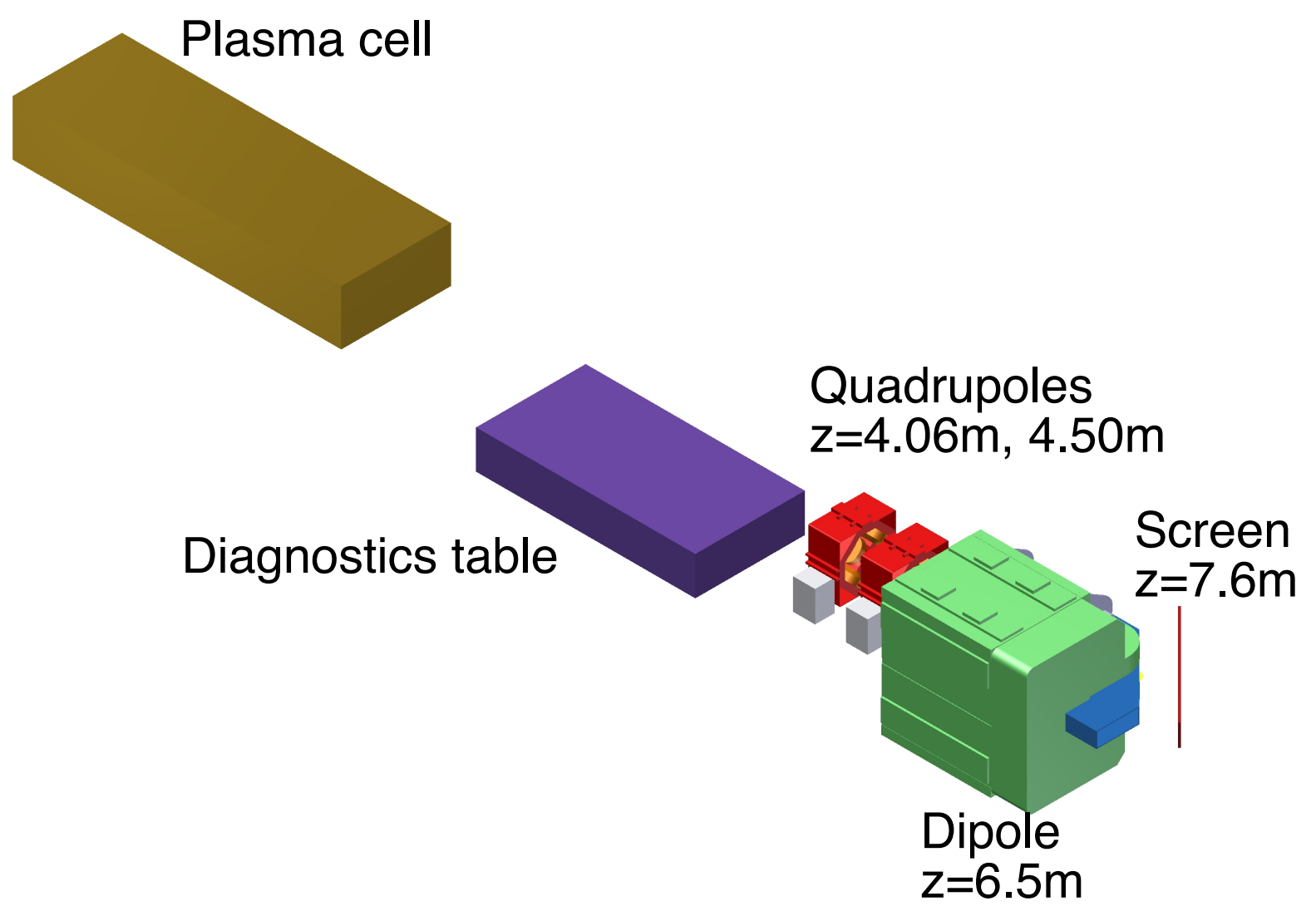

Figure 1. Layout of the spectrometer system.

RESOLUTION

Optical System

Due to the radiation environment, the intensified CCD camera (Andor iStar 340T) will need to be located 17 m away in an adjacent tunnel. A 400 mm focal length, f#/2.8 lens has been selected. The optical system was tested by imaging various targets back-lit with green with various line widths, and the modulation transfer function was calculated. The indicated resolution of the optical system is ~1.0 mm. The resolution of the system finally installed at AWAKE will depend on the optical transfer line finally installed and tests are planned during commissioning.

Emittance

The accelerated electron beam has been simulated in plasma simulations using LCODE (figure 2). 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 given in table 1.

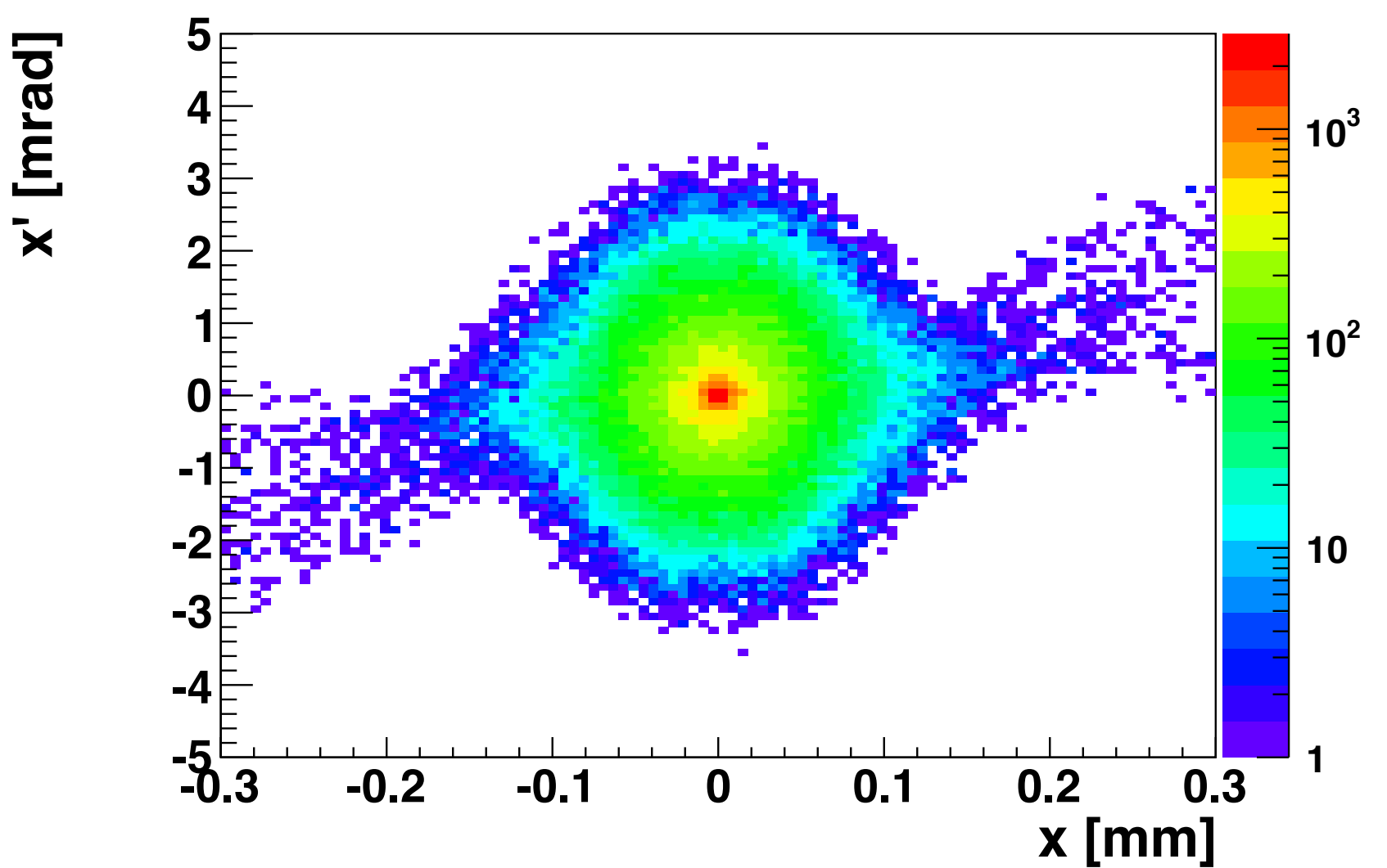

Figure 2. A sample of the simulated phase space distribution of the witness electron beam.

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

A transfer matrix was calculated analytically 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. The final drift length, which also depends on energy, was determined from a tracking simulation using BDSIM. 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.

Screen

Studies are ongoing to optimize the vacuum chamber window thickness. The point spread function of the screen will depend on the finally chosen window/screen thickness. For the purposes of this study we assume the line spread function of the screen will be negligible compared to that of the optical system.

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 plotted in figure 3. The result for the nominal emittance in plotted, together with emittances 10 and 100 times smaller/larger. The resolution in the experiment could be estimated by measuring the vertical beam size on the screen and assuming a circular beam.

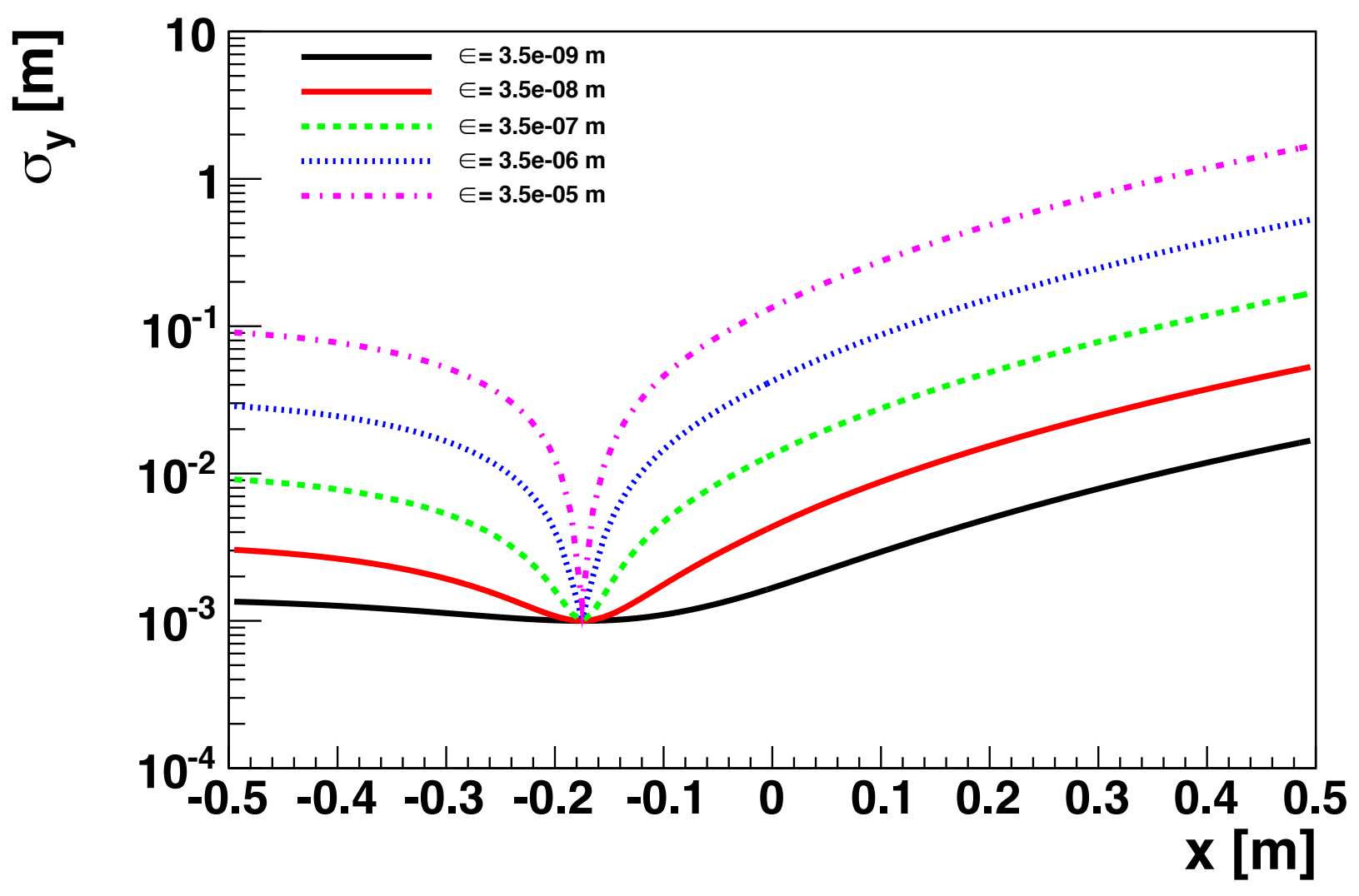

Figure 3: Fractional energy resolution as a function of energy for various beam emittances.

MINIMUM DETECTABLE CHARGE DENSITY

Beam line tests were carried out to determine the minimum detectable charge density of the system. A 5.5 MeV electron beam was used from the PHIN beam line. A 850 µm thick terbium-doped gadolinium oxysulphide scintillator screen was placed after a 0.2 mm aluminum window at the end of the beam line. The electrons passed through the back of the screen, causing photons to be emitted from the front. From the measured screen output as a function of bunch charge, the results in table 2 were derived. From these results we estimate the peak signal to noise ratio for the AWAKE witness beam will be at least 5000 without quadrupole focusing.

Table 2: Results relating to minimum visible charge density of the system, using a 50 mm diameter lens. Minimum visible charge is estimated as response/(2×dark noise)

Dark noise [ADC counts]	6.91±0.02
Response [counts/nC]	$1.11{\pm}0.04{\times}10^9$
Min. vis. charge [nC]	$1.25{\pm}0.05{\times}10^{-8}$
CCD pixel area at screen [mm^2]	5.9±0.6
Min. vis. charge dens [nC/mm^2]	2.1 ± 0.2
Min. vis. charge dens [electrons/mm^2]	130 ± 20

EMITTANCE MEASUREMENT

Under certain conditions a single bunch emittance measurement would be possible using the spectrometer system. The procedure is to 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. An example fit to a simulated beam, assuming an ideal optical system, is shown in figure 4. The input to the simulation and the results of the fit are given in table 3. The fit results show good agreement with the input. Further study is required to determine the limitations of the method.

Table 3: Input and fit result for the emittance measurement simulation.

	Input	Result
bin width [camera pixels]	10	
N_{electons}	$1{\times}10^5$	
σ_y^2 [mm^2]	1.004±0.005	0.92±0.02
$\sigma_{y'}^2$ [10−6]	1.247±0.006	1.271±0.009
ϵ [μm]	1.004±0.005	1.016±0.018

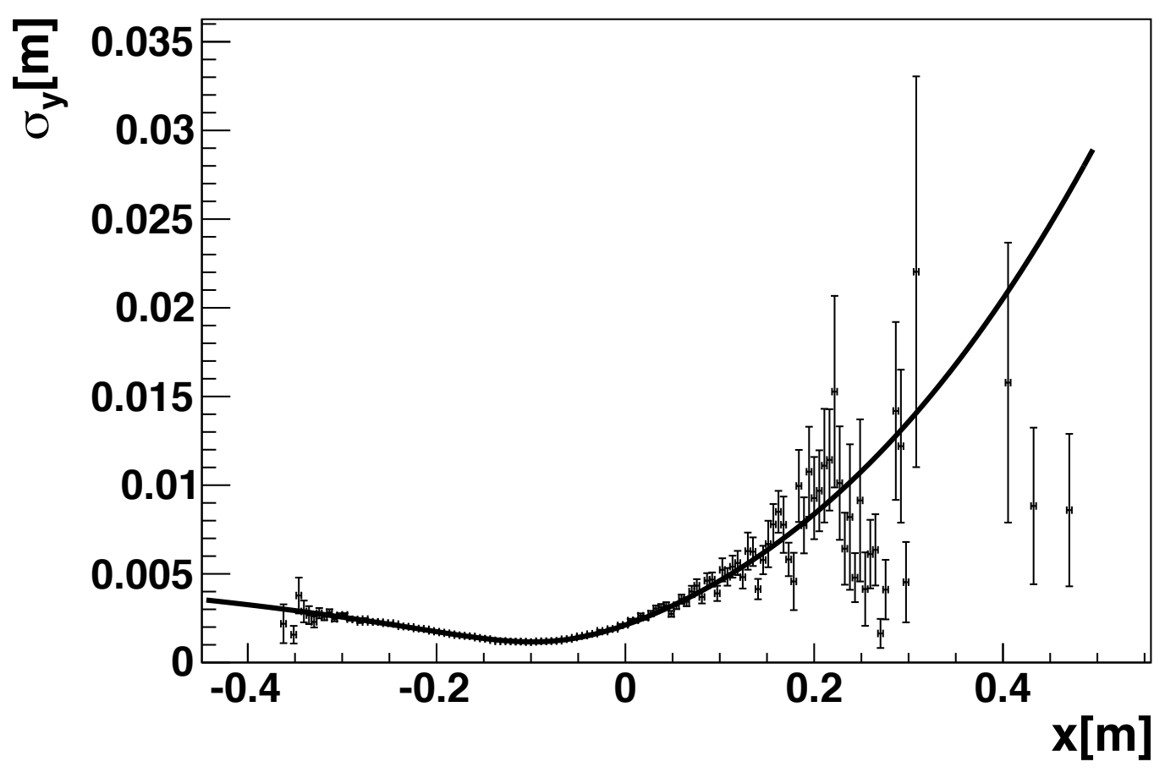

Figure 4: Fit of a simulated electron beam to the beam size function.

ACKNOWLEDGMENTS

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