Measurement of the longitudinal phase space at the Photo Injector Test Facility at DESY Zeuthen

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Abstract

A setup for the measurement of the longitudinal phase space at the photo injector test facility at DESY Zeuthen is described. The measurements of the momentum distribution, the length of an electron bunch and of their correlation are discussed. The results of the momentum distribution measurement are shown, a maximum mean momentum of 4.7 MeV/c and a RMS momentum spread of 14 keV/c is observed. The setup for the measurement of the bunch length includes a Cherenkov radiator which is used to convert the electron beam into a photon beam with a wavelength in the visible range. The Cherenkov radiation mechanism is chosen in order to measure the bunch length with good time resolution. A silica aerogel radiator with low refractive index will be used. Geant 4 simulations show that a resolution of 0.12 ps can be reached. The time dependent behaviour and the position of the photon bunch will be measured by a streak camera system. A simultaneous measurement of the bunch length and the momentum spread will provide the full information about the longitudinal phase space. The design considerations of the radiators and their properties are discussed.

INTRODUCTION

The photo injector test facility at DESY Zeuthen (PITZ) has been developed with the aim to deliver low emittance electron beams and study their characteristics for future applications at free electron lasers and linear accelerators. The energy of the electron beam varies in the range between 4 and 5 MeV. A description of PITZ can be found in [1].

Successful optimisation and improvement of the PITZ performance requires good beam diagnostics for investigating the electron bunch properties. This paper is focused on longitudinal emittance measurements.

A spectrometer dipole and a YAG screen are used for the measurement of the momentum distribution of the electron bunch. The bunch length can be measured by using a radiation process, where a photon bunch is produced with the same time properties as the electron bunch has. The photon bunch is transported by an optical transmission line [2] to a streak camera, where the bunch length will be measured. At the electron energies available at PITZ a large amount of photons can be produced in the Cherenkov radiation process. To be able to transport the photon bunch to the streak camera small output angles from the radiator are requested. Therefore, Cherenkov radiation in silica aerogel (SiO_2) is suggested for the photon production mechanism.

For the measurement of the full longitudinal phase space of the electron bunch a dipole, a Cherenkov radiator in the dispersive arm and a streak camera will be used. The produced photon bunch provides the information about the time properties and the momentum spread of the electron bunch. The simultaneous measurement of the bunch length and momentum spread allows to investigate the correlation between these characteristics.

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MOMENTUM DISTRIBUTION

The mean momentum of the electron bunch as a function of the set point phase compared to a simulation with ASTRA [3] is shown in Fig. 1. In a large phase range the mean momentum is consistent with the simulation, where an appropriate phase shift is chosen. Up to now, the highest measured mean momentum at PITZ is 4.7 MeV/c, which corresponds to a gun gradient of 41.5 MV/m and a RF power of 3.15 MW.

Fig. 2 compares a measured momentum distribution with the simulation. The experimental data are obtained by using the projected image from the YAG screen in the dispersive arm, the space coordinates are recalculated into values of momentum. The simulation was done from the gun cathode to the middle of the dipole, it was not tracked through the full dipole, while the data are taken on the

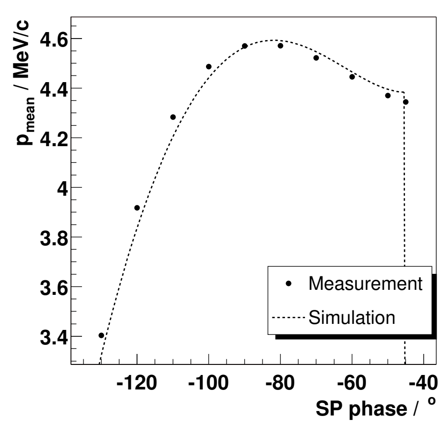

Figure 1: Mean momentum of the electron bunch as a function of set point phase for a gradient of 40.5 MV/m compared to the simulation. The errors of the measurements are of the order of 50 keV/c.

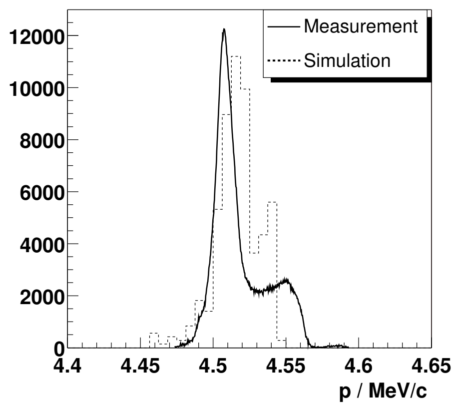

Figure 2: Momentum distribution compared to the simulation at a set point (SP) phase of -70^o, gradient 40.5 MV/m and electron bunch charge 1.1 nC.

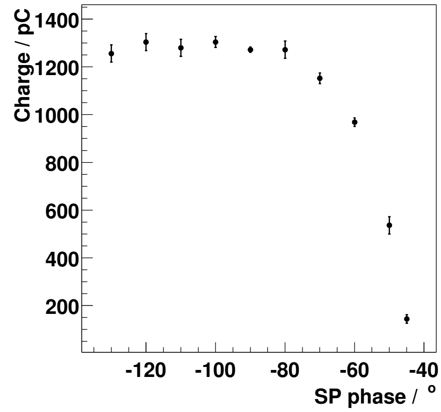

Figure 4: Measured electron bunch charge as a function of set point phase.

screen of the dispersive arm. This explains the disagreement between the measurement and the simulation. The resolution limit due to the finite beam size and the divergence of the spectrometer system is about 5 keV/c. A higher intensity for lower momenta and lower intensity for higher momenta are observed which results from strong longitudinal space charge of a short bunch due to a short laser pulse of 7 ps FWHM at the first half cell of the gun.

The RMS momentum spread as a function of the set point phase is compared with the simulation as shown in Fig. 3, the same phase shift as in Fig. 1 is used in the simulation. A smallest momentum spread of 15 keV/c for 1 nC is measured at a set point phase of about -60^o. The measurement of the momentum spread and the simulation are consistent. For each phase a different electron bunch charge is measured (see Fig. 4) because of the short laser pulse and apertures in the system. Therefore the set point phase with highest mean momentum (see Fig. 1) is not equally to the phase with smallest RMS momentum spread (see Fig. 3).

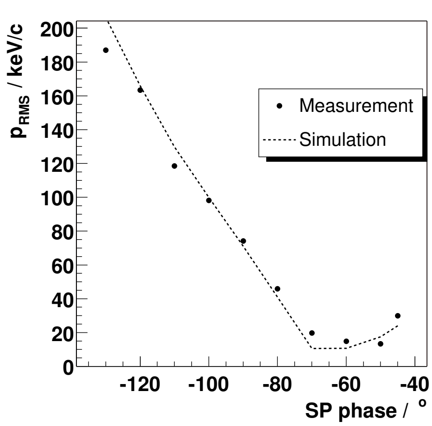

Figure 3: RMS momentum spread of the electron bunch as a function of set point phase for a gradient of 40.5 MV/m compared to the simulation. At small RMS momentum spread the errors are of the order of 5 keV/c.

BUNCH LENGTH

The photon bunch length will be measured using a Cherenkov radiator, an optical transmission line [2] and a streak camera. A large amount of Cherenkov photons is required in conjunction with a small output angle with respect to the optical axis of the transmission line. A time resolution of the whole system smaller than 1 ps is necessary. In order to obtain the adequate photon yields [4] silica aerogel will be used.

For the calculation of the time resolution for different aerogels Geant 4 simulation with a point-like electron source as input have been performed. The acceptance of the optical transmission line is estimated with an acceptance angle of 20^o and a maximum object size of 5 mm. In the Geant 4 simulation the Cherenkov effect, Rayleigh scattering, ionization and multiple scattering are considered. In addition an Aluminium window of a thickness of 20 μm is placed in front of the aerogel to prevent the gun cathode from outgasing molecules into the vacuum chamber. The simulated time resolution of the differnt radiators is presented in table 1. Aerogel with a refractive index of 1.03 will be used instead of 1.05 because of the large Cherenkov

n	thickness / mm	σ_t / ps
1.01	20	0.51
1.03	2	0.12
1.05	1	0.11

Table 1: Time resolution of the different aerogels and Aluminium window; the thickness of the aerogel is chosen to obtain the same number of photons for all samples.

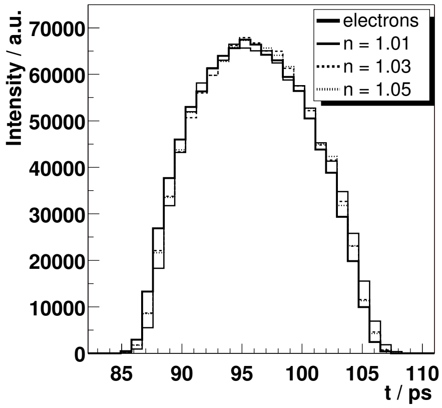

Figure 5: Simulated distributions of an electron bunch and Cherenkov photon bunches, produced in aerogel of different refractive indices and thicknesses (see table 1). The distributions are normalized to their area.

angle of 16.6^o of the latter which does not match to the acceptance angle of about 14^o of the realized optical system.

For a consistency check a typical electron bunch distribution simulated with ASTRA [3] is used as an input for the Geant 4 simulation. Fig. 5 shows the time structure of the electron bunch and the Cherenkov photon bunch for the considered aerogels. As expected, the photon distribution repeats that of the electron bunch. The time resolution of the transmission line is estimated to be of the order of 0.3 ps, whereas the streak camera has a time resolution of 0.2 ps.

LONGITUDINAL PHASE SPACE

A schematic view of the experimental setup planned to be used for the measurement of the longitudinal phase space is shown in Fig. 6. Measurements of the electron positions at different y-coordinates provides the information about their momenta, while the length in z corresponds to the bunch length.

The photon bunch, produced in the Cherenkov radiator, is transported to the streak camera, where its length and y-position can be measured simultaneously.

The opening angle of the Cherenkov light cone is too big for the optical transmission line, and hence only a fraction of the Cherenkov cone can be used. By using a fraction of the cone fused quartz can be used as radiator, too. The time resolutions for the different radiators are given in table 2. The best resolution is obtained for aerogel with the refractive index of 1.05, but fused quartz will be used as well because of its vacuum stability.

OUTLOOK

Momentum distribution measurements will be extended for different gun parameters (charge, gradient, focusing solenoid, gun phase) and compared to the simulation including the aperture of the beam line.

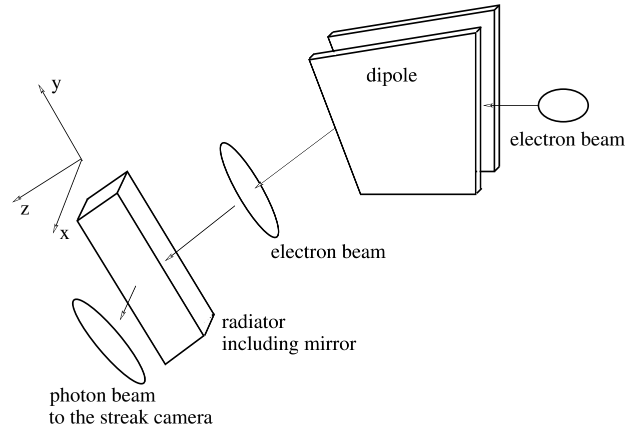

Figure 6: Setup for the measurement of the longitudinal phase space.

n	thickness / mm	σ_t / ps
1.01	20	3.98
1.03	2	0.43
1.05	1	0.35
1.46	0.1	0.41

Table 2: Time resolution of different radiator candidates, the thickness is chosen to obtain the same number of the photons.

The commissioning of the bunch length measurement setup is scheduled for end of May 2003. First measurements will start in June 2003. The parts of the setup for the measurement of the whole longitudinal phase space are in the production phase, the expected date of its integration in the facility is fall 2003.

In 2004 the photo injector will be extended by a booster cavity. The energy of the electrons after the booster will go up to about 30 MeV. At this energy optical transition radiation can be used in order to transform the electron bunch into a photon bunch, which provides an even better time resolution than the Cherenkov radiation mechanism.

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