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 energy of the electrons will reach about 4-5 MeV. The setup 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 used in order to measure the bunch length with good time resolution. As radiators silica aerogel with low refractive index as well as a fused silica plate will be used. The time dependent behavior 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. Preliminary results of the momentum spread taken with a YAG screen are shown.

1 INTRODUCTION

A photo injector test facility at DESY Zeuthen (PITZ) for the development and operation of optimized photo injector for future free electron lasers and linear colliders has started operation. The components of PITZ are described in [1].

Successful optimization and improvement of the performance of PITZ requires good beam diagnostics, able to investigate the properties of the electron bunch. This contribution is focused on longitudinal emittance measurements.

The bunch length can be measured with a radiation process, when the photon bunch is produced with the same time properties as the electron bunch has. The longitudinal beam shape is seen by a streak camera. At the electron energy at PITZ (4-5 MeV) a large amount of photons can be produced in the Cherenkov radiation process. Therefore, Cherenkov radiation in aerogel (SiO_2) and optionally in fused quartz is discussed as possible options for photon production mechanism. Since the aerogel will be held in vacuum, the behavior of its refractive index at different pressures is studied.

A YAG screen is used for standard measurement of the momentum and momentum spread. For the measurement of the full longitudinal phase space of the electron bunch a dipole, a Cherenkov radiator and a streak camera will be used. The produced photon bunch provides the information of the time properties and the momentum spread of the electron bunch. The simultaneous measurement of the bunch length and momentum spread allows one to investigate the correlation between these characteristics.

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2 THE MEASUREMENT OF THE BUNCH LENGTH

Photon bunch length will be measured using a Cherenkov radiator and a streak camera system. A large amount of Cherenkov photons is required and high time resolution of the system is necessary. In order to obtain adequate photon yields [2] aerogel and fused quartz will be used. The influence of the presence of the aerogel on the vacuum system is described in [3].

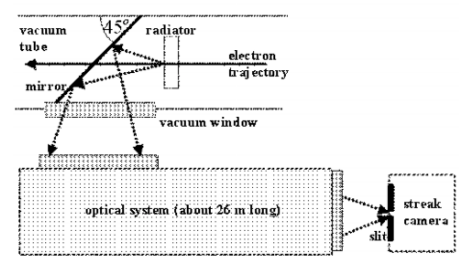

Figure 1: Setup for the bunch length measurement.

The setup used for the bunch length measurement is shown in Figure 1. The Cherenkov photons are reflected off the vacuum tube by a mirror and transported through an optical system (about 26 m long) [4] to the streak camera.

3 BEHAVIOR OF THE AEROGEL REFRACTIVE INDEX IN VACUUM

The radiator has to be located inside of the vacuum tube. Therefore, the behavior of aerogel at low pressure was investigated. The setup used for this purpose is shown in Figure 2. The light from the source passes through a grid, enters the vacuum chamber, and is detected after refraction in the aerogel by a CCD element. The refraction in the aerogel causes the shift of the grid pattern. This shift, denoted by x, depends on the tilting angle α, thickness of the aerogel sample d and the refractive index n:

$$x = d \cdot \frac{\sin(\alpha - \beta)}{\cos \beta} \tag{1}$$

with

$$\sin \beta = \frac{\sin \alpha}{n}. \tag{2}$$

Measuring the pattern shift at different pressures inside the vacuum chamber the refractive index of the aerogel can be obtained.

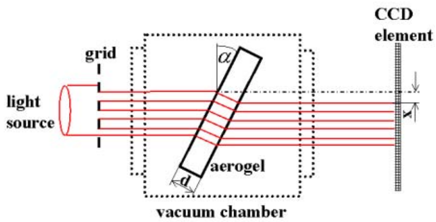

Figure 2: Setup for the refractive index measurement.

An aerogel sample with the same properties as that used in the Ring Imaging Cherenkov detector at the HERMES experiment at DESY was investigated [5]. Figure 3 shows

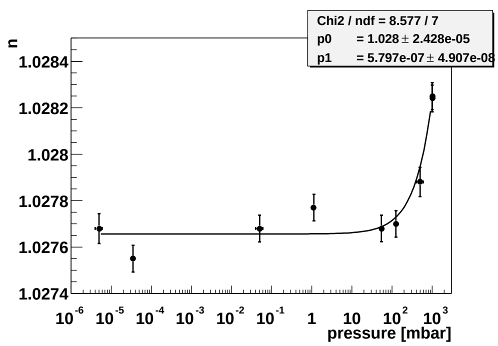

Figure 3: The dependence of the aerogel refractive index on the pressure. The data are fitted with a line.

the refractive index as a function of the pressure. The refractive index is constant up to the pressure of 1 mbar, above which it increases linearly.

4 MEASUREMENT OF THE LONGITUDINAL PHASE SPACE

4.1 Experimental setup

The schematic view of the experimental setup planned to be used for the measurement of the longitudinal phase space is shown in Figure 4. Measuring the electron positions at different y 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 light cone is too big for the optical transport system, and hence only a fraction of the cone can be used.

4.2 Radiators

Two different Cherenkov radiators will be used: aerogel and fused quartz. The advantage of quartz is its vacuum

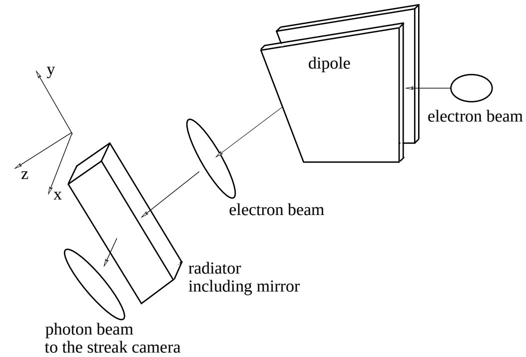

Figure 4: Setup for the measurement of the longitudinal phase space.

stability, but due to the larger refractive index the total reflection has to be considered. To avoid the total reflection effect the quartz plate will be tilted with α' = 10^o as shown in Figure 5.

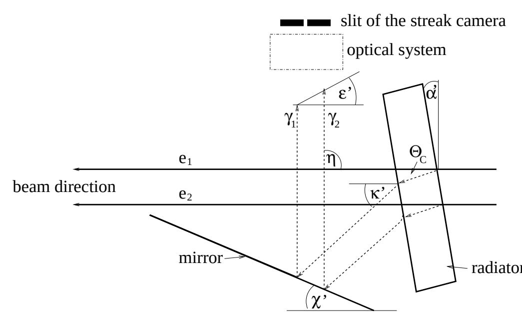

Figure 5: The scheme of the quartz setup in (x,z)-plane. The e_i represent the borders of an electron bunch. The photons are reflected by the mirror on their way out of the beam tube.

The photons leave the vacuum tube at an angle η with respect to the beam direction as shown in Figure 5. The best choice of η would be the right angle. The corresponding tilt angle χ' of the mirror has to be

$$\chi' = \frac{1}{2}\left(90^o - \kappa'\right) \tag{3}$$

with $\kappa' = \arcsin\left(n \cdot \sin\left(\Theta_C - \alpha'\right)\right) + \alpha'$. Here n denotes the refractive index of the radiator and Θ_C is the Cherenkov angle. The electrons of the bunch which enter the radiator at the same z-position, cross it simultaneously, while produced photons get a time difference at the vacuum window due to the difference in their x-coordinate. This time difference is represented by the angle ϵ' and can be calculated as follows:

$$\tan\epsilon' = \frac{\sin\alpha' + \sin\left(\kappa' - \alpha'\right)}{\cos\left(\kappa' - \alpha'\right)}. \tag{4}$$

The calculated angles χ' and ϵ' for both radiators are summarized in table 1.

Name	n	d / mm	χ' / ^{o}	ϵ' / ^{o}
aerogel	1.01	20.0	43.24	3.49
	1.03	2.0	38.91	12.19
	1.05	1.0	36.46	17.07
quartz	1.46	0.1	10.16	64.04

Table 1: Calculated angles χ' and ϵ' for 4 MeV/c for different radiators and refractive indices. The thickness d is chosen to provide the same amount of emitted photons.

4.3 Time resolution

The time difference represented by the angle ϵ' introduces a large contribution to the time resolution. To correct for this three options are considered:
The first option is to use a special shaped reflecting lattice. The photons from the electrons at the same z-position in the bunch reach the lattice at the same time and will be reflected perpendicular to its plane as shown in Figure 6. Using the lattice with a step size of 50 μm would provide a good time resolution Δt_L (see table 2) [6].

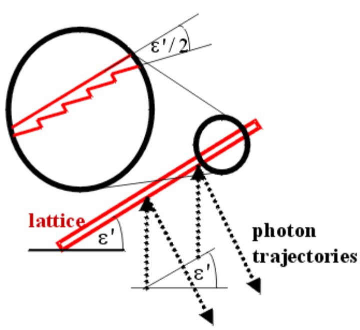

Figure 6: Sketch of the reflecting lattice and its orientation respectively to the photon beam.

The second option would imply the turning of the streak camera under the angle ϵ' with respect to the beam direction. This angle, however, has to be smaller than 5^o in order to provide photons reaching the cathode of the streak camera.
The third option is the transverse cut of the photon bunch with the slit of the streak camera. In this approach the amount of photons is much reduced and one can expect the signal obtained with the streak camera to be weak. The contribution to the time resolution in this case (denoted by Δt_S) for a slit width of 100 μm is presented in table 2.

The time difference of the photons and the electron inside the radiator Δ_{pl}, the angle distribution of the electron bunch behind the dipole $\Delta_{\alpha''}$ and multiple scattering of the electrons in the radiator Δ_{MS} contribute to the time resolution, as well. These contributions are listed in table 2. The detailed description of the calculation can be found in [6] and references therein.

The best time resolution is obtained using aerogel with the refractive index of 1.05. Quartz will be used as well because of its vacuum stability.

	time resolution / ps				
n	Δ_{pl}	$\Delta_{\alpha''}$	Δ_{MS}	Δt_L	Δt_S
1.01	0.25	0.26	3.98	0.01	0.02
1.03	0.30	0.30	0.43	0.04	0.07
1.05	0.29	0.29	0.35	0.05	0.10
1.46	0.37	0.37	0.41	0.15	0.69

Table 2: Different contributions to the total time resolution for electrons with 4 MeV/c.

4.4 Momentum and momentum spread

The momentum and momentum spread have been measured at PITZ using a YAG screen. The momentum distribution is shown in Figure 7 for the charge of about 30 pC. The phase between the laser pulse and radio frequency of the electron gun was optimized to obtain the highest electron momentum of about 4 MeV/c. The measured rms momentum spread of about 13 keV/c represents the resolution limit of the sprectromenter due to an optical mismatch which will disappear at higher charges.

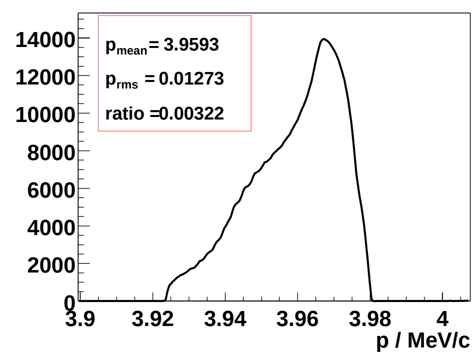

Figure 7: Measured momentum distribution.

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