BEAM PROFILE MEASUREMENTS AT PETRA WITH THE LASERWIRE COMPTON SCATTERING MONITOR

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Abstract

The vertical beam profile at the PETRA positron storage ring has been measured using a laserwire scanner. A laserwire monitor is a device which can measure high brilliance beam profiles by scanning a finely focused laser beam non-invasively across the charged particle beam. Evaluation of the Compton scattered photon flux as a function of the laser beam position yields the transverse beam profile. The aim of the experiment at PETRA is to obtain the profile of the positron beam at several GeV energy and several nC bunch charge. Key elements of laserwire systems are currently being studied and are described in this paper such as laser beam optics, a fast scanning system and a photon calorimeter. Results are presented from positron beam profile scans using orbit bumps and a fast scanning scheme.

INTRODUCTION

Future high performance TeV-scale lepton collider as well as high brilliance linac based light sources require on-line, non-invasive beam size monitors with micron and sub-micron resolution for beam phase space optimization [1]. A laserwire monitor is a device where a finely focused, high power laser beam is scanned transversely over the lepton beam. The resulting Compton-scattered photons are detected downstream and the measurement of the total energy of these photons as a function of laser spot position yields the lepton bunch transverse dimensions [2]. Laserwire beam profile monitors have been tested at the SLC at SLAC [3] and ATF at KEK [4]. The aim of the experiment at PETRA is to elevate these designs and to investigate key issues for a laserwire device in order to develop a standard diagnostic tool for low-disruption, high-resolution beam profile measurements.

EXPERIMENTAL SETUP

The laserwire experiment is installed at the storage ring PETRA at DESY. The PETRA ring operates as pre-accelerator for positrons and protons and serves the collider HERA. In the context of an upgrade to a 3rd generation synchrotron light source some beam time is allocated to machine development. PETRA was chosen for experiments with the laserwire because of the availability of a long straight section for hardware installation, an existing access pipe, sufficient energy and because of its bunch pattern, which is similar to high energy linear collider. Beam tests with the laserwire were carried out at 7 GeV with average bunch currents of 7.1 mA and 40.5 mA. The laser pulses were triggered to interact with the first bunch of the bunch train carrying bunch charges of 3.9 nC and 22.3 nC. From the optics lattice the average beam size in the ring is $\sigma_x = 268$ μm for the horizontal and $\sigma_y = 68$ μm for the vertical dimension.

The experimental setup is sketched in Fig. 1. The setup is mainly divided in two areas, the PETRA accelerator tunnel and the laser hut. The trigger signals for synchronization of the laser and positron beams are derived from the PETRA accelerator bunch clock and brought to the laser hut from the access hall. These are then fed into VME-based trigger electronics, which exchanges trigger and status signals with the laser. The laser timing is measured relative to a BPM signal at the IP using two fast photodiodes; one in the laser hut and the other close to the IP. The Compton-scattered photons are boosted along the incoming positron beam direction and exit through the beampipe wall within a downstream dipole magnet. Most of the photons interact with the wall material producing an electromagnetic

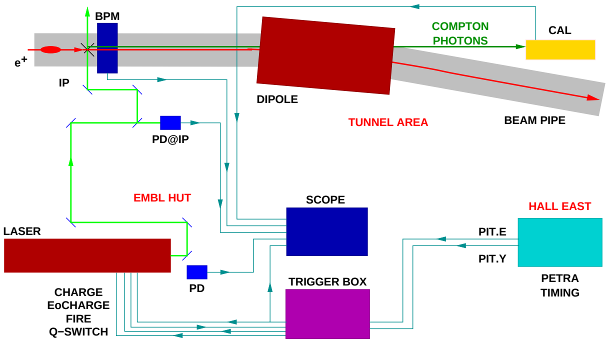

Figure 1: Positron beam, laser and trigger path for the laserwire experimental setup.

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shower. The tail end of the shower is measured by a lead-tungstate calorimeter read out by a fast ADC.

Laser Beam

The laser pulses are created in a Q-switched Nd:YAG laser amplifier with second harmonic generator. The average power is 8 W in the IR at a wavelength of 1064 nm and 2.1 W in the green at 532 nm. Green light was chosen for this experiment because its shorter wavelength enables both smaller spot-sizes to be achieved and greater energy deposits in the calorimeter. The longitudinal profile was measured using a streak camera with 5 ps time resolution. The data revealed a pulse length of $\Delta t = 12.5$ ns FWHH with a sub-structure of roughly 70 ps peak-to-peak and 70 ps peak width at full contrast. This sub-structure is due to mode-beating of different longitudinal modes lasing and causes the Compton signal amplitude to vary between zero and full signal for different laser shots. The transverse profile of the laser beam was measured in the near and far-field with knife edge and sliding slot techniques. For the far-field measurement the beam was focused using a $f = 125$ mm doublet focusing lens of the same type as used for the IP focusing. A viewport window was also included in the setup. The mode quality parameter was measured to be $M_y^2 = 8.5 \pm 0.6$ for the vertical and $M_x^2 = 5.6 \pm 0.4$ for the horizontal dimension. The measured laser waist radius (at $1/e^2$ intensity) is $w_y = 77 \pm 5$ μm and $w_x = 69 \pm 6$ μm.

The laser pulses are transported via a matched Gaussian relay made up of two $f = 5$ m lenses over a distance of 20 m from the laser hut via an access pipe into the tunnel housing the accelerator. The laser beam passes then the scanning mirror before it reaches a focusing lens with $f = 125$ mm back-focal length. The scanner is a piezo-driven platform with an attached 25 mm high-reflectivity mirror. The maximum loaded frequency of the platform is 1 kHz with a scan range of ± 2.5 mrad. The optical elements before the laser-positron IP are shown in Fig. 2. After the interaction the main part of the beam intensity is divided and guided into an appropriate dump. The remaining intensity is used for diagnostics and relayed on a CCD camera for online monitoring of the laser spot size and position at the IP.

Compton Calorimeter

The Compton photon calorimeter is composed of lead-tungstate (PbWO4) crystals fixed with optical grease to a matching square face photomultiplier. The individual crystals have dimensions of $18 \times 18 \times 150$ mm and are arranged in a 3 by 3 matrix (see [5] for more details). From calibration measurements with a testbeam from the DESY II accelerator, the complete detector setup including ADC readout was tested with electrons from 450 MeV to 6 GeV. The energy resolution was found to be better than 6% for individual crystals and 10% for the overall setup. Simulations show that with the 3 by 3 matrix 95% of the total energy deposit is collected for an incoming Compton-scattered photon with 300 MeV energy.

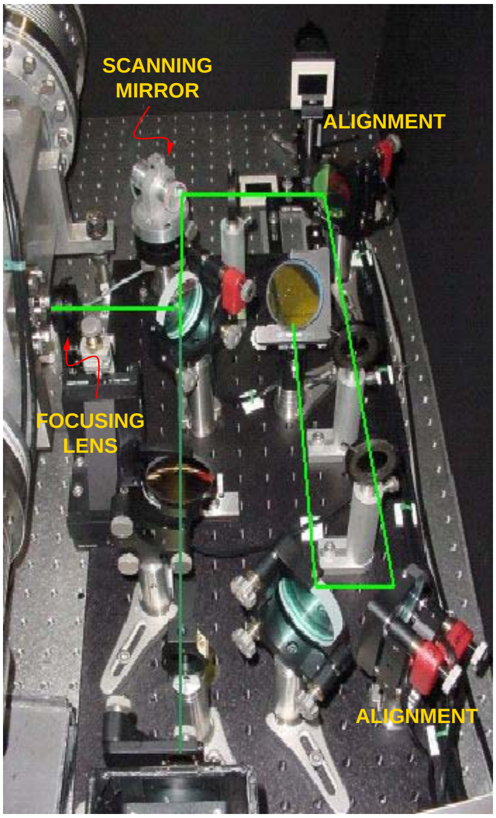

Figure 2: Optical elements and laser pathway before the interaction point with the positron beam.

DATA TAKING

To establish initial overlap between positron and laser beam first the timing was fixed by fine-adjusting the laser pulse timing with a delay box relative to the BPM signal. Then a local orbit bump was driven to bring both beams to transverse overlap. This procedure usually takes less than 5 min. After that the laser beam was scanned using the piezo-driven platform over the positron beam. At each scan point 5000 events were recorded before the beam was moved again. In Fig. 3 a typical background and signal spectra are displayed. The low energy pedestal in both spectra corresponds to the electronics base. With a laser repetition rate of 30 Hz one scan point is handled in 3 min resulting in 30 min to complete a full scan. During the scan the orbit stability is observed with the BPM at the interaction point. The orbit was found to be stable within 40 μm.

DATA ANALYSIS

After applying a background cut eliminating the synchrotron radiation pedestal the individual spectra at the different scan points were integrated. In Fig. 4 the resulting total energy deposit versus laser beam position is plot-

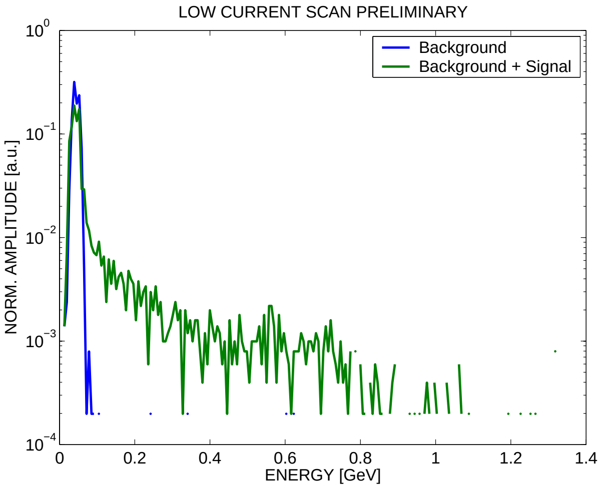

Figure 3: Preliminary data for background and signal events from the low current scan.

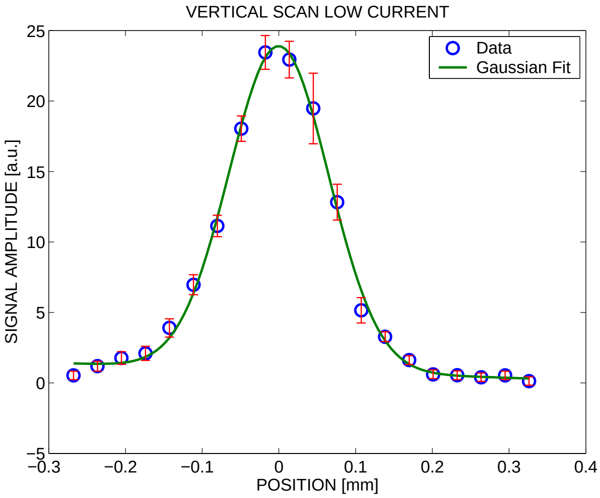

Figure 4: Spotsize measurement data and fit for the low current scan.

ted for the low current scan. For the high current scan a similar results was achieved. This distribution can be approximated with a Gaussian function with a linear gradient term. The linear term in the model compensates for the decreasing beam current over the 30 min measurement time. The measured beam size for the low current scan is $\sigma_m = 68 \pm 3_{stat} \pm 14_{sys}$ μm and for the high current scan $\sigma_m = 80 \pm 6_{stat} \pm 16_{sys}$ μm. The systematic error is dominated by the uncertainty of the set-voltage to angle scanner calibration and will be investigated with dedicated measurements.

COMPARISON WITH SIMULATIONS

The propagation of the Compton photons was simulated using the Geant4 [6] simulation package including background sources like synchrotron radiation and bremsstrahlung. The accelerator environment is modeled including beampipe, magnets, and cooling water channel. From an analytical description of the Compton process [7] the number of Compton photons can be estimated for the relevant laser and positron beam parameters. For the low current case with 3.9 nC in total 98 photons are released and the Compton edge is at 1.17 GeV resulting in 57 GeV total energy deposit, for the high current case with 22.3 nC in total 561 photons are released resulting in 328 GeV energy deposit. Most of the energy is lost in the beampipe material as the Compton photons hit the chamber under a shallow angle inside the dipole magnet with an effective length of roughly 100 cm. In the next step the measured longitudinal profile of the laser beam will be included in the simulations.

CONCLUSION AND OUTLOOK

A laserwire monitor system has been setup and run at the PETRA accelerator. The vertical beam size of the positron beam was measured using a scanning platform, results agree well with expectations from lattice calculations. The laser has been upgraded with a longitudinal mode filtering etalon. For the Compton photons pathway planning and construction is under way to replace the dipole vacuum chamber with a chamber with a thin exit window, to enhance the observed signal.

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