PETRA and ATF Laser-Wire Results and Plans

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The Laser-wire will be an essential diagnostic tool at the International Linear Collider. It uses a finely focused laser beam to measure the transverse profile of electron bunches by detecting the Compton-scattered photons (or degraded electrons) downstream of where the laser beam intersects the electron beam. Such a system has been installed at the PETRA storage ring at DESY, which uses a piezo-driven mirror to scan the laser-light across the electron beam. Latest results of experimental data taking are presented and compared to detailed simulations using the Geant4 based program BDSIM. Plans to install a micron-scale laser-wire in the ATF extraction line are also presented.

1. INTRODUCTION

The International Linear Collider (ILC) will be a TeV-scale lepton collider that will require non-invasive beam size monitors with micron and sub-micron resolution for beam phase space optimisation [1]. Laser-wire monitors operate by focusing a laser to a small spot size that can be scanned across the electron beam, producing Compton-scattered photons (and degraded electrons) as shown in Fig 1.

These photons can then be detected further downstream using the total energy observed as a function of the laser spot position to infer the transverse profile of the electron bunch. The laser-wire system installed in the PETRA ring [2] and a micron-scale system currently being planned for installation at the ATF extraction line are part of an ongoing effort [3] in the R&D of producing a reliable non-invasive beam size diagnostic tool.

2. PETRA LASER-WIRE

Laser-wire tests are being run at PETRA using a 7 GeV positron beam with a single bunch of charge typically 7.7 nC. The average beam size is $x = 268$ μm for the horizontal and $y = 68$ μm for the vertical dimension. An exit window for the Compton-scattered photons was designed and installed at DESY in late 2004 to allow these photons to reach the detector with minimum deterioration. Before installation of this window, most of the photon energy was absorbed in the beam-pipe.

The laser pulses are created in a Q-switched Nd:YAG laser operating at 532 nm. The pulses are transported over a distance of 20 m and then reflected off a piezo-driven scanning mirror before reaching a focusing lens with a 117 mm back-focal length. The scanner has a maximum scan range of ± 2.5 mrad. At the interaction point (IP) the peak laser power was measured to be 1.46 MW. The longitudinal profile was measured using a streak camera with 5 ps time resolution, which revealed a pulse length of 12.5 ns FWHM with a sub-structure of roughly 70 ps peak-to-peak and 70 ps peak width at full contrast due to mode-beating. This causes the Compton signal amplitude to vary between zero and full signal for different laser shots. In order to reduce the data taking time the current laser will be replaced in 2005 with an injection seeded system.

*On behalf of the LBBD collaboration [3]

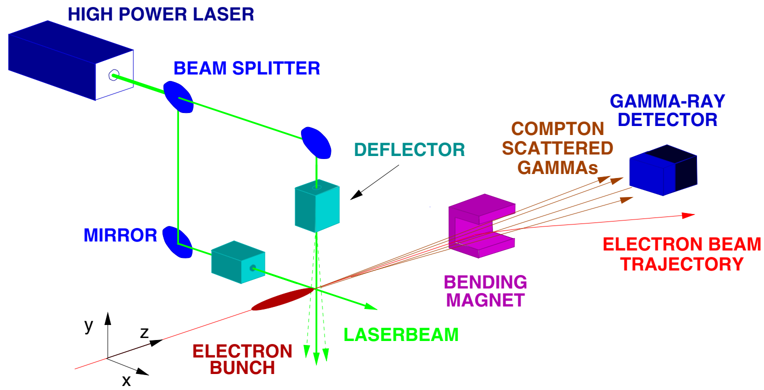

Figure 1: Principle of laser-wire operation.

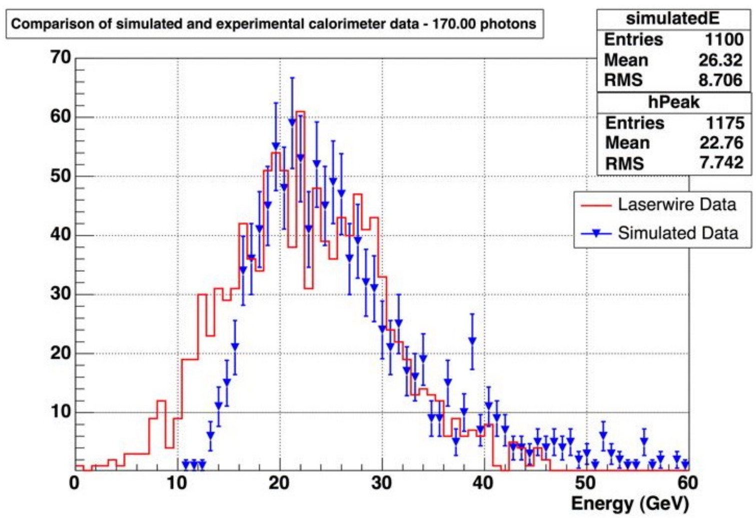

Figure 2: Data and simulation for the PETRA laser-wire.

3. PETRA LASER-WIRE RESULTS

3.1. Compton Detector

The Compton photons are detected in a calorimeter composed of 9 lead tungstate crystals, each with dimensions of $18 \times 18 \times 150$ mm and arranged in a 3×3 matrix. The scintillation light is detected using a photomultiplier. The complete detector set up was tested in a DESYII test-beam using electrons from 450 MeV to 6 GeV. Energy resolution was shown to be better than 6% for individual crystals and 10% for the overall set up. Simulations show that for the 3×3 matrix, 95% of the total energy deposit is collected for an incoming Compton-scattered photon with 300 MeV energy [4]. The detector and PETRA beam-line were simulated using a GEANT4 based tool [5] and the results are shown in Fig. 2. The experimental data show an energy resolution of 34%, which is dominated by the longitudinal fluctuations in the laser power as described above. From a comparison of the shape of the measured spectrum with that expected from theory, it can be inferred that number of Compton photons per shot is 175 ± 25, which agrees with the theoretically expected value for the laser and electron-bunch parameters for that data-taking run.

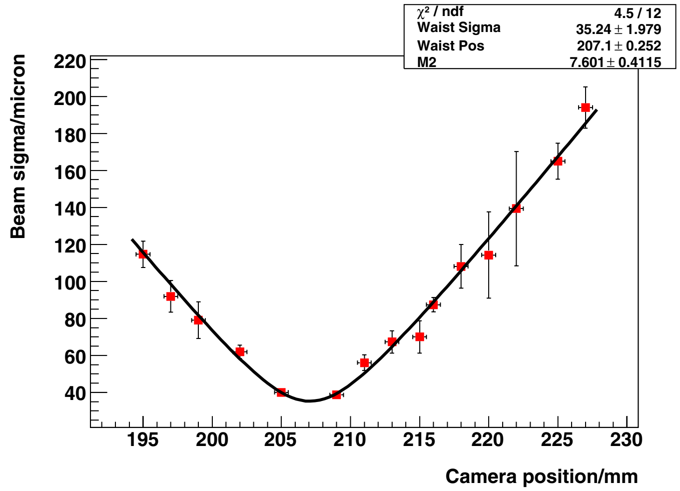

Figure 3: Fit to the laser beam profile at the laser waist.

3.2. Laser Spot-size

In order to determine the transverse size of the electron beam, it is necessary to know the properties of the laser well. Particular attention is paid to the spot size at the laser waist, σ_0, and the Rayleigh range, z_R, (the distance z from the waist at which the beam size $\sigma = 2\sigma_0$). These properties are related by Eq. 1

$$\sigma = \sigma_0 \sqrt{1 + \left(\frac{z}{z_R}\right)^2} \tag{1}$$

where the $z_R = \frac{4\pi\sigma_0^2}{M^2\lambda}$; M^2 is a quality factor for the laser and σ_0 is the spot-size at the laser waist. Values of σ were measured with a CCD camera for various values of z and the results are shown in Fig. 3, giving $M^2 = 7.6 \pm 0.4$ and $\sigma_0 = 35 \pm 2\mu$m.

3.3. Laser-wire scans

The laser is scanned across the electron beam by tilting a mirror on a piezo-electric stack to produce a deflection of ± 2.5 mrad. Focusing through the lens produces a transverse travel range for the focal spot at the IP of 585μm. The scanner voltage was applied in a stepped sinusoidal pattern (other patterns, such as a triangular waveform, are currently being tested); 10 triggers were taken at each of 100 voltages over a whole 2π. The trigger signal is taken from the laser trigger card running at 30 Hz, so a full scan takes approximately 33 s. The result of such a scan is shown in Fig. 4. The electron bunch spot size σ_e can be extracted from the Compton signal profile σ_m by $\sigma_e = \sqrt{\sigma_m^2 - \sigma_0^2}$. Typical results for recent laser-wire runs [2] give $\sigma_e \simeq 72 \pm 4\mu$m, which agrees with what is expected for the PETRA bunch size at the laser-wire location.

4. ATF LASER-WIRE PLANS

An emittance measurement at the ILC will require the measurement of micron-scale spot sizes at several points in the beam delivery system, after (or close to) the exit of the main linac. The length of beam-line required to make such a measurement will be proportional to the machine β-function at that location, which in turn is proportional to $\sqrt{\sigma}$, where σ is the electron spot-size at the same location. In order to keep the required length of beam-line as small as possible, it is essential to be able to measure small values of $\sigma \simeq 1\mu$m.

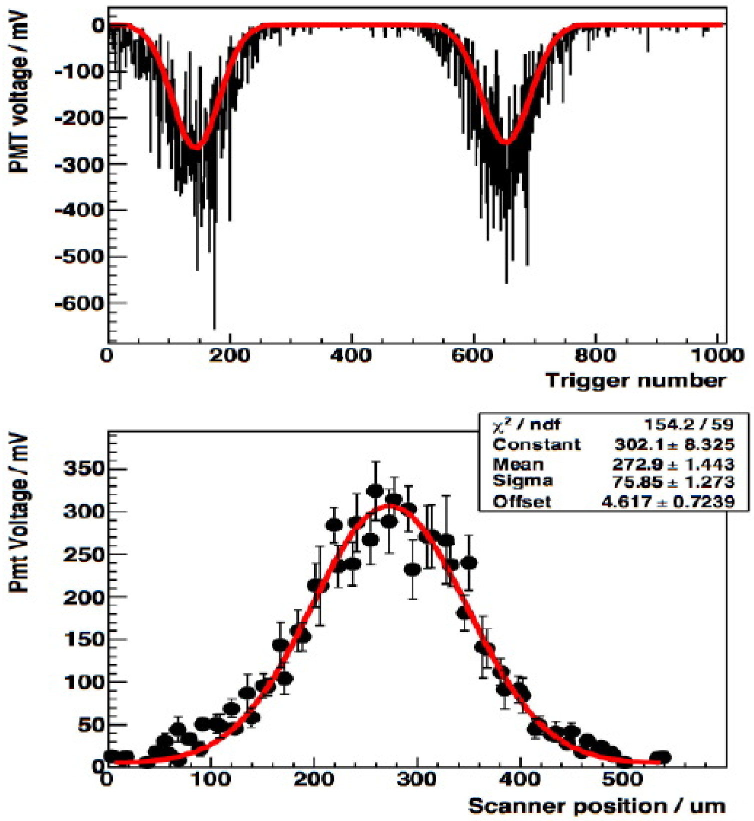

Figure 4: Fit to the electron beam profile from a laser-wire scan. Top: raw signal during the scan of the laser forward and backward across the electron beam. Bottom: fit to the binned histogram from the scan. This scan took approximately 30 s.

With this in mind, a new R&D project is underway at the ATF extraction line in KEK. Advanced laser optics are being developed both for focusing the laser beam down to micron-scales and for ultra-fast scanning, based on electro-optic techniques. The focusing lens, vacuum vessel and laser delivery system will be installed in the autumn of 2005 and first Compton collisions are planned for shortly thereafter.

Acknowledgments

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References

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