

# BEAM PROFILE MEASUREMENTS WITH THE 2-D LASER-WIRE <sup>\*</sup>

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## Abstract

The laser-wire will be an essential diagnostic tool at the International Linear Collider (ILC). It uses a finely focused laser beam to measure the transverse profile of electron bunches by detecting the Compton-scattered photons downstream of the interaction point (IP), 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. This paper reports recent upgrades to the PETRA system, including the implementation of a new laser.

## INTRODUCTION

The ILC will be a TeV-scale electron-positron collider that will require non-invasive beam size monitors with micron and sub-micron resolution for beam phase space optimization [1]. Laser-wire monitors operate by focussing a laser to a small spot size that can be scanned across the electron beam, producing Compton-scattered photons (and degraded electrons). The photons can then be detected further downstream using a photon calorimeter (which measures their energy). The total energy observed as a function of the laser spot position is used to infer the transverse profile of the electron bunch. The Laser-wire system installed in the PETRA ring is part of an ongoing effort in the R&D of producing a feasible non-invasive beam-size diagnostic tool.

## EXPERIMENTAL SETUP

PETRA Laser-wire experiments use a 7.2 GeV positron (or electron) beam with a single-bunch with a charge of 7.7 nC. Optics lattice studies suggest that the average beam size is  $\sigma_x = 268 \mu\text{m}$  for the horizontal and  $\sigma_y = 68 \mu\text{m}$ .

The laser-wire experiment must coordinate the arrival of high-energy laser pulses with the arrival of a targeted electron bunch at the IP, and record the resulting calorimeter measurements from the Compton photons resulting from scattering at the IP. This is all achieved using the laser-wire data acquisition system (DAQ). Figure 1 shows a schematic representation of the laser-wire experiment and its signal coordination.

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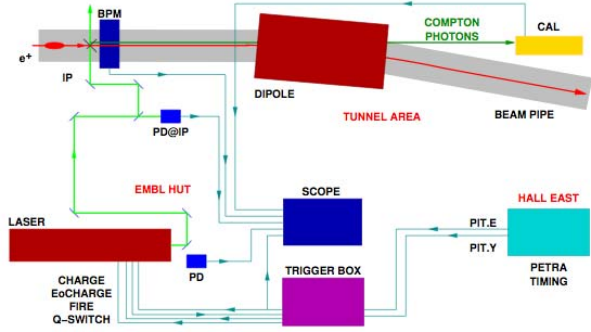


Figure 1: A schematic representation of the electron/positron beam, laser light path and signal coordination for the laser-wire experiment.

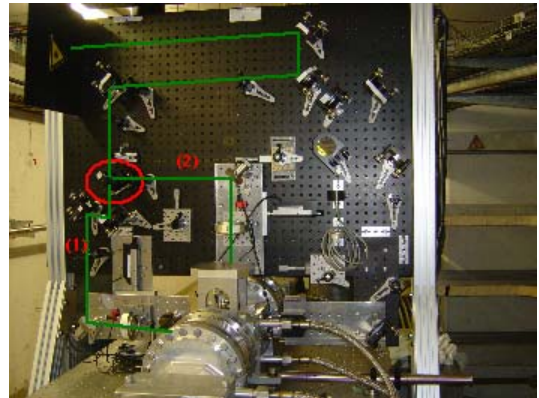


Figure 2: The vertical breadboard arrangement of the Laser-wire experiment: capable of scanning the vertical (path 1) and horizontal (path 2) profiles of the electron beam, at any one time. The pre-IP laser beam path is drawn in green. The mirror flipper, which selects the axis of the electron beam to scan, is circled in red.

An upgrade to the previous 1-dimensional PETRA laser-wire system [3] is reported here. The 2-D scanning *vertical breadboard* (see figure 2) was installed at PETRA in December 2005. Laser pulses arrive at a mirror flipper, which is pre-set to send the pulses along path (1) or (2), scanning the electron's vertical or horizontal profile, respectively. After the mirror flipper the pulses are reflected off a piezo-crystal driven mirror onto a LAP250 lens <sup>1</sup>, where they are

<sup>1</sup>A two-inch diameter compound lens of 250mm focal length

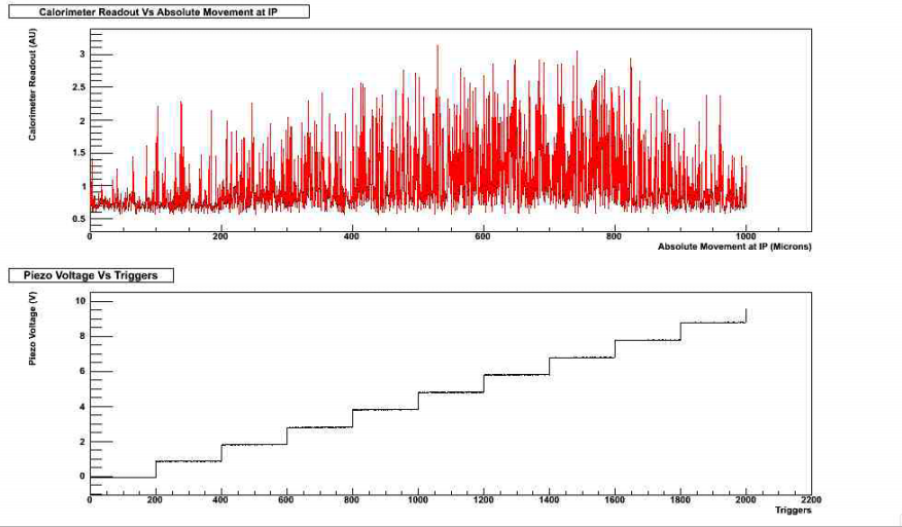


Figure 3: Data taken with the injection seeder turned off. The top plot shows the calorimeter output (arbitrary units) versus the laser spot position at the IP (in microns). The bottom plot is the corresponding piezo scanner voltage (Volts) versus the trigger number (laser shot number).

then focused onto the electron bunch. Changing the voltage across the piezo-crystals changes the angle at which the laser pulses are reflected through the LAP250 lens, thereby controlling the position at which the laser pulses cross the electron bunch. By such means, laser pulses are swept across the electron bunch.

The non-interacting photons continue onto the post IP section of the breadboard. Here the remaining laser pulse energy is measured using an energy meter, and the cross-sectional profile of the laser pulse is measured using a CCD camera. This information is used to monitor laser quality.

### Laser

Laser pulses of  $\lambda = 532 \text{ nm}$  are generated by a newly acquisitioned injection-seeded, Q-Switched Nd:YAG laser firing into a second harmonic separating box<sup>2</sup>. The injection seeding is desired to eliminate mode-beating effects from the laser pulses, producing a more uniform photon intensity in the pulse. A summary of the laser characteristics are shown in table (1).

Initial testing showed the laser exhibited poor modal quality, directional instability, and significant pulse-to-pulse time jitter and power fluctuation. These effects have since been attributed to a damaged Brewster plate and spurious reflections off its internal (single mode) pinhole. Further testing is currently underway to correct and permanently fix the problems.

### Compton Photon Detector

The Compton photon detector is composed of a 3 x 3 matrix of lead tungstate ( $PbWO_4$ ) crystals, fixed to a matching face photomultiplier. Each crystal has dimensions of

<sup>2</sup>Surelite Separation Package (SSP).

Summary of laser Measurements

Laser pulse freq.	20 Hz
$M^2$	1.4
Pulse duration	5 ns
Pulse jitter (trig. Sync_out)	2-6 ns
Pulse jitter (trig. PIT)	2-6 ns
Energy (532nm, pulse-to-pulse)	$3.5 \text{ mJ} \pm 0.875 \text{ mJ}$
<i>Equiv. Power (pulse-to-pulse)</i>	$0.18 \text{ W} \pm 0.044 \text{ W}$

Table 1: The table summarizes the results of initial testing on the new laser.

18 x 18 x 150 mm and an energy resolution of approximately 5.4% measuring electrons at 6 GeV [2]. Measuring the same electrons, the total system had an energy resolution of approximately 10%. Simulations show that Compton-scattered photons (300 MeV) deposit their energy with 95% efficiency on the 3 x 3 crystal matrix.

## DATA-TAKING

The laser spot was scanned across the electron bunch in 11 steps<sup>3</sup>, there were 2048 laser shots, and hence, 2048 triggers or data points per step. Each step corresponded to approximately 46 microns at the IP.

Large time jitters would cause the laser pulses to miss the electron bunch entirely and therefore result in no Compton photons. However a small enough time jitter could result in some overlap between the electron bunch and laser pulse, and hence Compton photons. Such fluctuations can be observed in figures 3 & 4.

<sup>3</sup>Each step corresponds to 1V of the piezo scanner, which has a full scale deflection range of 0-10V.

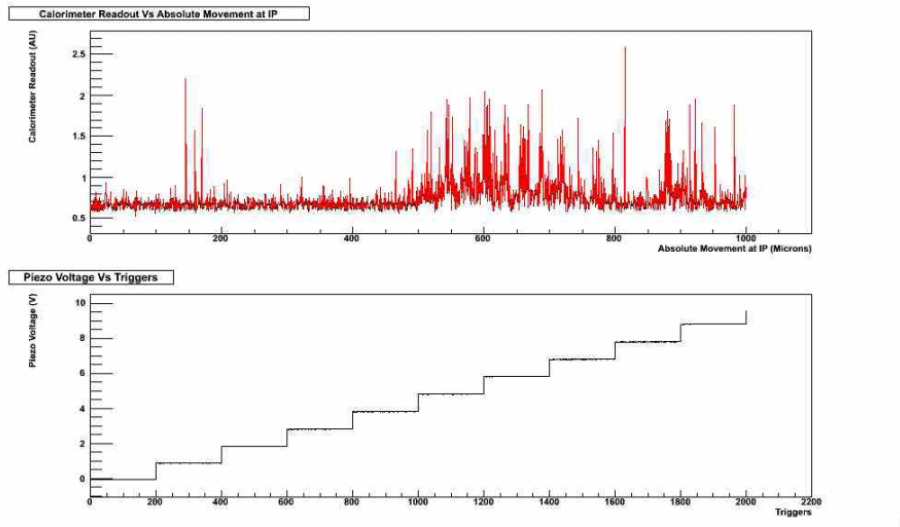


Figure 4: Data taken with injection seeding turned-on. The top plot shows the calorimeter output (arbitrary units) versus the laser spot position at the IP (in microns). The bottom plot shows the corresponding piezo scanner voltage (Volts) versus the trigger number (laser shot number).

## DATA ANALYSIS

Figures 5 & 6 show the data analysis for the unseeded and seeded experiments, respectively. The plots are fit with a compound function consisting of: *a Gaussian<sup>4</sup> and a polynomial function of order 1 (straight line with a gradient and y-intercept)<sup>5</sup>*

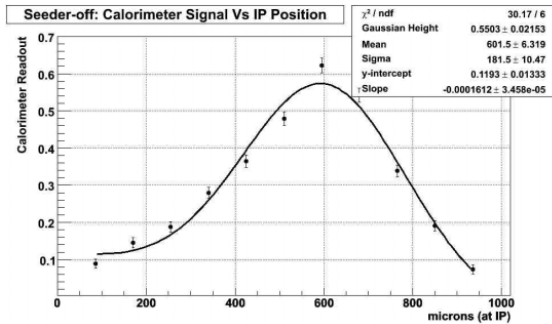


Figure 5: Data analysis of the experiment with no injection seeding. The plot shows 11 points, where each point is the averaged calorimeter readout per piezo voltage, versus the movement at the IP (in microns).

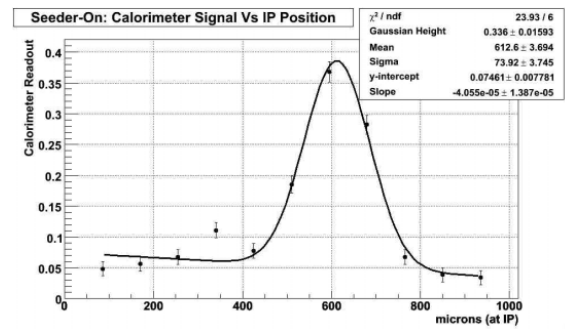


Figure 6: Data analysis of the experiment with injection seeded turned-on. The plot shows 11 points, where each point is the averaged calorimeter readout per piezo voltage, versus the movement at the IP (in microns).

at the IP. Further steps are being taken to reduce the time jitter of the laser to allow a greater scanning efficiency. Studies benchmarking the laser-wire against standard (invasive) carbon wire-scans are currently underway. Research is also being carried out on fast scanning techniques using crystals whose refractive index varies with electric field [5].

## CONCLUSION & OUTLOOK

Compton interactions have been produced using the 2-D laser-wire breadboard in conjunction with the new Nd:YAG laser. The results with the new system agree closely with those expected for the predicted electron bunch dimensions

<sup>4</sup>Due to the convolution of a Gaussian laser pulse with a Gaussian electron bunch [4]

<sup>5</sup>A short-time approximation to the exponential decay of the electron beam with time.

## REFERENCES

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