A LASER-WIRE SYSTEM AT THE ATF EXTRACTION LINE*

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Abstract

A new laser-wire (LW) system has been installed at the ATF extraction line at KEK, Tsukuba. The system aims at a micron-scale laser spot size and employs a mode-locked laser system. The purpose-built interaction chamber, light delivery optics, and lens systems are described, and the first results are presented.

INTRODUCTION

The International Linear Collider (ILC) will require a large number of non-invasive beam size measurements to extract the phase space of the electron and positron beams before focusing at the collision point. The large charge and energy densities ~1×10^{10} electrons per bunch at 250 GeV and ~ 1μm vertical beam size of the ILC beams preclude the use of traditional beam size diagnostics, such as wire scanners and screens. These problems are solved by using a high power focused laser beam, the LW, instead of a conventional solid wire.

Different technologies may be used in different sub-systems of the ILC. In the ATF damping rings, a system based on a precise optical cavity has been used to good effect [1] and an alternative approach based on a high-power pulsed laser is being pursued at PETRA [2]. For the ILC beam delivery system, the single-shot nature of the electron beam requires the use of high-power pulsed lasers, which is the approach adopted here; the first such device was commissioned at the SLC [3].

In the LW, the laser photons are Compton scattered with electrons from the beam, the total rate of Compton scatters is proportional to the spatial overlap between the laser photon density and electron beam density and given by [4]

$$N_\gamma = N_b \frac{P_L \sigma_C \lambda}{c^2 h} \frac{1}{\sqrt{2\pi\sigma_s}} \exp\left(-\frac{\Delta y^2}{2\sigma_s^2}\right) \qquad (1)$$

where N_b is the electron bunch population, P_L is the peak laser power, λ is the laser wavelength Δy is the vertical offset between the centres of the laser and electron beams and $\sigma_s^2 = \sigma_l^2 + \sigma_e^2$ is the quadratic sum of electron and laser Gaussian widths. By measuring the Compton rate (N_γ) as a function of relative displacement Δy, σ_s can be determined. Provided the laser beam size is known precisely, the electron beam size can, in principle, be extracted. In practice, however, additional machine-related errors may dominate [5]; one of the purposes of a LW experiment at ATF/ATF2 [6] is to quantify and control all the various sources of error that will contribute to an emittance measurement at the ILC.

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EXPERIMENTAL CONDITIONS

Accelerator Test Facility

The Accelerator test facility (ATF) is a test accelerator primarily for damping ring development, but also development of new beam diagnostic devices intended for the ILC. The main important parameters of the ATF are given in Table 1.

Beam energy (GeV)	1.28
Num e- per bunch	1×10^{10}
Bunch frequency (Hz)	1.56
Bunch length (ps)	30
Vertical emittance ε_y (m rad)	5×10^{-11}
Horizontal emittance ε_x (m rad)	1.6×10^{-9}

Table 1: ATF Parameters

The main components of the ATF are a RF photocathode gun, S-band linac, damping ring and extraction line to a dump. The experimental set up described here has been installed after the damping ring extraction system, in the extraction line. A specific electron beam optics has been developed to provide a small vertical beam size at the LW interaction point (IP), with zero vertical and horizontal dispersion. The calculated beam sizes are σ_y = 1μm and σ_x = 20.3 μm. The measured beam size using a wire scanner at the focus location was σ_x = (19.31± 0.72) μm and σ_y = (2.6± 0.3) μm (the vertical size is consistent with a 1μm electron beam interacting with a 10μm tungsten filament).

Laser and Optical System

The laser consists of four main components; a passive mode-locked seed laser (using SESAM technology), Pockels cell pulse picker, regenerative amplifier (RGA), single pass amplifier and finally second harmonic generation. The Nd:VO_4 seed laser produces a pulse train of 20ps long infra red (1064 nm) pulses at a frequency of 357 MHz, which are phase locked to the ATF RF system. Individual pulses from the seed were selected at the ATF bunch frequency by two Pockels cells and then amplified to 20 mJ and stretched with an intra-cavity etalon to 200 ps in the Nd:YAG RGA. Finally, the pulses passed through a vacuum spatial filter before amplification by a pair of birefringence compensated, quad-flashlamp pumped, Nd:YAG rods to a maximum pulse energy of 1J. Green light was produced using a KD*P crystal. The main output parameters of the laser system are shown in Table 2.

Wavelength (nm)	532
Max. Pulse energy (mJ)	400
Pulse length (ps)	150

Table 2: LW laser parameters

The laser pulses were initially attenuated by 75% using beam splitters before transportation to the ATF extraction line IP.

ATF Interaction Region

A schematic overview of the LW IP region is shown in Figure 1, and a photograph of the chamber, together with the associated optics, is shown in Figure 2.

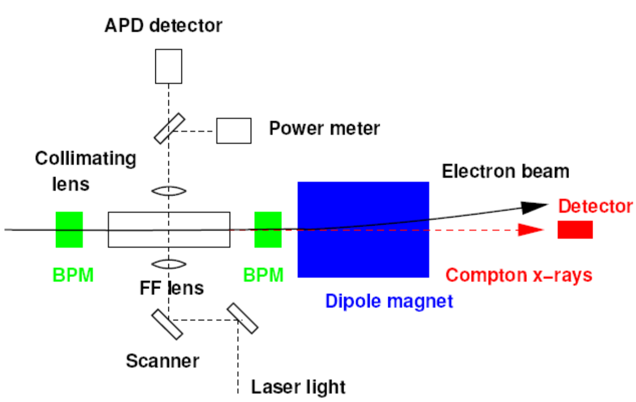

Figure 1: Schematic of the LW IP region.

The laser beam was steered onto a scanning mirror in a normal optical mount with remotely-controlled tilt adjustment about two axes. Then the beam was focused by a plano-convex singlet lens (nominal focal length, 150mm) before passing through a 6.35mm thick fused silica optical flat, which formed the vacuum window, to the IP. After the IP the diverging laser beam was re-collimated with another plano-convex lens (nominal focal length, 100mm) and its power measured. A small fraction of the laser pulse was transmitted through an anti-reflection coated mirror for measurement by an avalanche photodiode detector (APD), which was used to measure the laser light arrival time (see below).

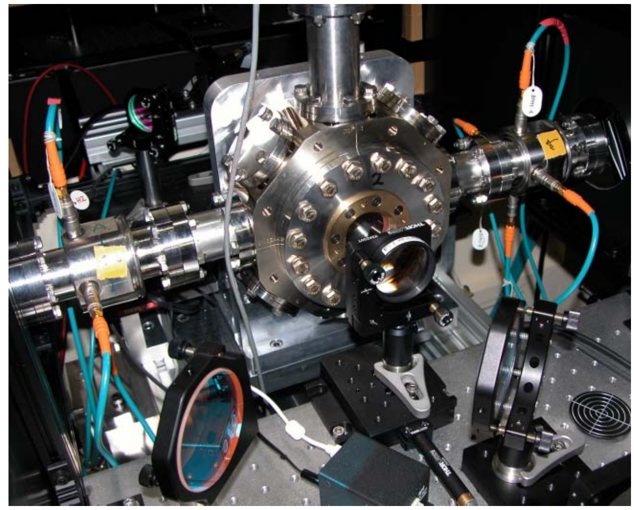

Figure 2: Photograph of the LW vacuum chamber in-situ. Note the two strip-line BPMs, the insertion device for the knife edge (top) and the re-collimation optics.

The electron beam also passed through the chamber. The electron beam position was measured by two strip-line BPMs either side of the LW chamber. One of the horizontal BPM pickups was used to provide a timing signal for the electron beam arrival. Once the laser and electron beams were spatially and temporally overlapped, Compton photons were produced and traveled in the direction of the electron beam. The charged beam was bent into the rest of the extraction line by a dipole and the neutral (photon) signal detected downstream in a gamma-ray detector.

Given the laser and electron parameters above, the maximum Compton scattered photon energy was 28.6 MeV. For a laser beam size of 15 μm, the expected number of Compton photons (from Eq.1) is 51.4×10^3.

Timing and Spatial Alignment

Given the small electron and laser beam sizes and the short bunch lengths, a dedicated system was essential to obtain vertical and temporal overlap between the two transversely colliding beams. A gold-coated silicon knife edge, mounted on a vertical vacuum actuator, was inserted into the chamber at 45° to both the electron and laser beams. The knife-edge was moved so that radiation from the screen (which consists of reflected synchrotron radiation, optical transition, or diffraction radiation) was produced and measured with the APD. The attenuated laser was then scanned so as to pass just below the knife-edge, so that the electron and laser beam arrival times were measured on the same detector, and hence with common systematic errors. The timing of the mode locked seed laser was then adjusted by altering the phase of the local 357 MHz reference clock. This procedure guaranteed good temporal and vertical overlap of the two beams.

Compton Detector

The high-energy photons generated from the LW Compton events exited the beam pipe via a 1mm thick aluminium window. Approximately 15% of the photons were converted to electron positron pairs in a 4mm thick lead plate on the front of an aerogel Cherenkov detector, placed 10 m downstream of the IP. The aerogel was 5cm thick with a refractive index of 1.015, giving a Cherenkov threshold of 2.983 MeV. The Cherenkov photons were detected with a photomultiplier tube and the signal pulse digitized by a gated integrating ADC.

RESULTS AND ANALYSIS

After establishing collisions between the electron beam and laser beam, the signal was maximised by adjusting the laser waist position vertically (y) and horizontally (x) and the timing of the laser system. In order to make a beam size measurement the laser was scanned vertically across electron beam. An example of a vertical waist scan is shown in Figure 3.

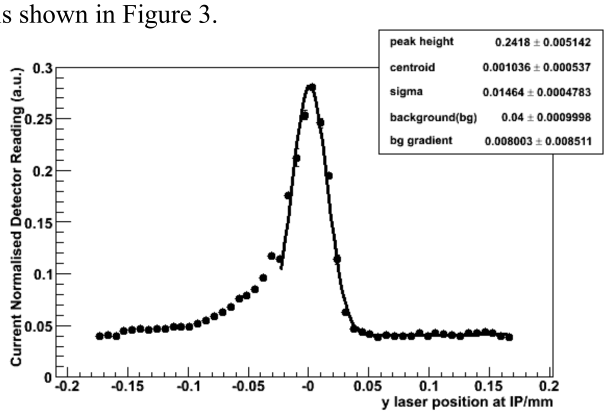

Figure 3: Example of a vertical scan with the ATF extraction line LW system.

The laser was moved vertically in steps of several microns and the Compton signal was recorded for 20 machine cycles at each step and averaged. The average beam charge was also measured and used to normalise the Compton signal to remove variation due to bunch charge variation from the ATF. The signal as a function of laser position at the IP is approximately Gaussian with a width of (15.2 ± 0.1) µm. There is a clear asymmetry in the signal, which can be attributed either to the transverse profile of the laser pulse or to possible aberrations in the lens such as coma. The current (interim) lens is not expected to provide a laser focus sufficiently small to measure the electron beam size as described above. The width of the measured signal was expected to be dominated by a combination of spherical aberrations from the lens and the M^2 of the (imperfect) laser beam.

The laser beam waist was moved to several different positions by moving the lens along the laser axis, and a vertical laser scan performed at each location. The width (σ) of the extracted Gaussian is plotted as a function of the lens position in Figure 4, from which both M^2 and waist size can be extracted. The measured M^2 of the focused laser is 11.6 and σ at the waist is 15.4µm.

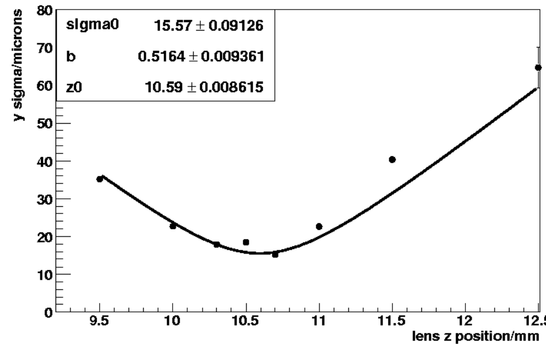

Figure 4: Scan of the laser-waist position by stepping the final focus lens along the laser-beam direction.

CONCLUSIONS AND OUTLOOK

The ATF extraction-line LW has seen first collisions between the 30ps ATF beam pulses of 1.28GeV electrons and 150ps, 532nm laser pulses. The results are consistent with a fine electron beam being scanned by a larger laser beam; this situation will reverse once the technology has developed, as discussed below.

The quadrature beam size, σ_s, measured at the laser beam waist was 15.3µm.

The aim of the ATF system is to verify that beam size measurements of ~1µm electron beams can be performed in the ILC BDS. The first step in this programme has been achieved; the next step is to improve the resolution of the system by improving the transverse mode quality of the laser and upgrading from the commercial lens to a custom-built system with f/2 optics. Longer term, an f/1 system will be designed and it may also be necessary to investigate the use of shorter wavelength light.

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REFERENCES

[1] Y.Honda *et al.*Nucl.Instrum.Meth.**A538:**100-115,2005.
[2] M. Price *et al.*, these proceedings: TUPCH050.
[3] R. Alley et al. Nucl.Instrum.Meth.**A379**:363-365,1996
[4] P. Tenenbaum and T. Shintake, Ann. Rev .Nucl. Part. Sci. 49:125-162,1999.
[5] G.A. Blair *et al.*, these proceedings: TUPCH048.
[6] ATF2 Proposal KEK Report 2005-2.