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Summary of Laser-wire Mini Workshop

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Abstract

A summary is presented of the laser-wire mini workshop held as part of Nanobeam 2005. Topics that were covered include machine optics studies of the ILC diagnostics section, simulation of laser-wires in the ILC beam delivery system, the development of pulsed laser stacking plus applications, a laser interferometer in an optical cavity, fast laser-wire scanning with electro-optics, and status reports on the ATF and PETRA laser-wire systems.

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1 Introduction

The latest in a series of laser-wire (LW) mini workshops [1] was held during Nanobeam 2005. Talks were on:

- optics studies of the ILC diagnostics section (D. Angal-Kalinin),
- simulation of the LW in the ILC beam delivery system (BDS) and systematic errors (G. Blair),
- the development of pulsed laser stacking plus applications (N. Sasao),
- a laser interferometer with an optical cavity and cavity beam position monitors (BPMs) (J. Urakawa),
- fast laser-wire scanning with electro-optics (A. Bosco) [2]
- status report on the ATF laser-wire (N. Delerue) [3]
- status report on the PETRA laser-wire system (M. Price) [4].

2 Summary of Presentations

2.1 Laser-wires in the Emittance Measurement Section of the ILC

The current proposal for the ILC emittance measurement section in the BDS has β_y ~34 m, giving σ_y ~ 0.8 μm at 500 GeV centre of mass energy, assuming the extracted emittance from the damping ring, or σ_y ~ 1.1 μm for the budgeted emittance. A LW system would thus need to be able to make an accurate measurement of ~1 μm electron spot-sizes, which is the central goal of an ongoing R&D project at the ATF extraction line [3]. However, as discussed below, the systematic errors involved in extracting the electron bunch size from the LW scan mean that larger electron sizes of order 3 μm are preferred (assuming green light), if measurement accuracies of order a few percent are needed. This would require increasing the 60m diagnostics section, shown in Figure 1, to about 480m for the damping ring emittance (i.e. ideal low-emittance transport) or about 200m for the budgeted emittance. The trade-off of diagnostics system length against the accuracy of the emittance measurement is a topic currently under study for the ILC Reference Design Report (RDR). In addition to providing a sufficiently large electron spot size, the machine optics must also enable the LW signal (Compton scattered photons and/or electrons) to be extracted cleanly. Two designs are currently being investigated, one based on a chicane [5] and another based on a dog-leg [6].

- The chicane contains many dipoles and the beam comes back on axis. The total length is 111m and the emittance growth at 500 GeV CMS is ~1% . The chromatic aberrations are negligible

- The dog-leg solution contains a few dipoles and quadrupoles. The beam is offset at the exit and the length is 122m. The emittance growth at 500 GeV CMS is ~0.16%. There are some small chromatic aberrations.

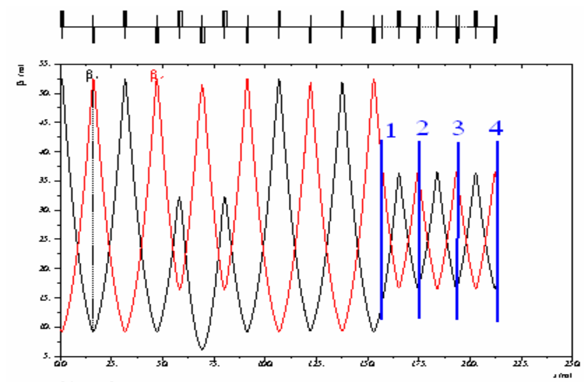

Figure 1. Proposed optics for the ILC emittance measurement section.

The chicane or dog-leg solution could be incorporated as part of a fast-extraction system for machine protection, where any significant energy offset of the beam at the exit of the linac, as measured in the chicane, could trigger a fast extraction kicker.

2.2 Laser-wire Systematic Errors and Simulation

A raw LW profile measurement, σ_m, is a convolution of the electron bunch size σ_e and the laser spot-size σ_ℓ. In the approximation of neglecting the Rayleigh range effects of the laser waist $\sigma_m^2 = \sigma_\ell^2 + \sigma_e^2$. The systematic error from the laser beam profile can then be estimated [7]: define $r \equiv \sigma_\ell / \sigma_e$ and $\delta \equiv \delta\sigma/\sigma$ with the subscripts e, m, ℓ referring to the electron bunch, the measured raw profile, and the laser spot respectively. The electron bunch error is then $\delta_e = \sqrt{\delta_m^2 (1+r^2)^2 + \delta_\ell^2 r^4}$ so $r = \sqrt{\delta_e / \delta_\ell}\left[1 + O\left((\delta_m/\delta_e)^2\right)\right]$. If δ_e <~2.5% (for a 5% emittance measurement) and $\delta_\ell \approx 0.1$, then there results the requirement that $\sigma_e >\sim 2-3\sigma_\ell$. Achieving small laser spot-sizes is therefore essential because the necessary length of the BDS diagnostics section is proportional to the β-function, which in turn is proportional to σ_e^2.

Simulations of the LW in the ILC BDS are ongoing; Figure 2 (left) shows the electron and photon distributions downstream from the LW, whose detection is needed to perform the profile scan. The photons can be extracted cleanly at a single point. Other considerations include the synchrotron radiation (SR) from the chicane and the resulting SR photon energy distribution is shown in Figure 2 (right); for a bunch of 10^{10} electrons, this would result in 1.8

$\times 10^7$ GeV of SR energy per bunch, to compare with about 10^5 GeV from the LW Compton photons. This SR radiation consists of low energy photons compared to the high energy LW Compton photons; however the large amount of total SR power means that appropriate shielding in front of the LW detector will be necessary.

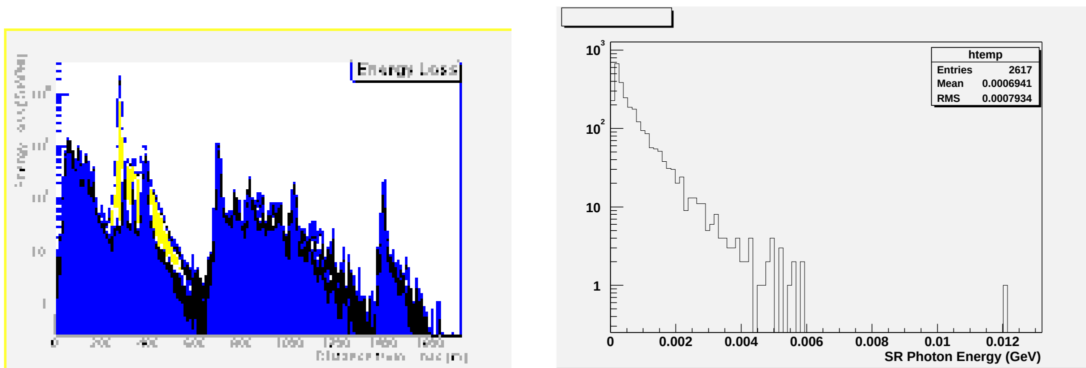

Figure 2. Left: energy escaping the beam-line downstream of the LW from the Compton scattered electrons (blue/dark grey) and photons (yellow/light grey). Right: SR radiation from the chicane; this energy will also enter the LW detector, unless appropriate shielding is included.

2.3 ATF Damping Ring Laser-wire

The LW at the ATF damping ring has been in operation for several years [8]. The system uses a CW laser amplified by an optical cavity at the LW interaction point. Two such cavities exist, one for the vertical scan and one for the horizontal. Results of these scans are shown in fig.3 (left and centre).

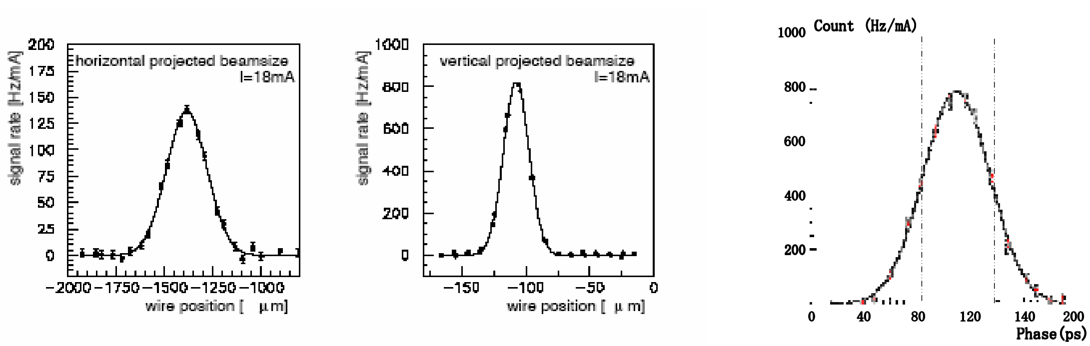

Figure 3. Left and centre: transverse LW scans at the ATF damping ring. Right: Longitudinal phase-scan.

A more recent development [9] is the measurement of the longitudinal bunch profile using a pulsed laser and accurate timing. The laser pulse width is 7 ps, which is very much less than the electron bunch length of ~28 ps. Two methods are employed:

- phase-scan method, where the laser frequency is synchronized with the e^- beam so that the relative timing (phase) is fixed. The signal is measured against the overall timing, which is varied with a trombone. Results of such a scan are shown in Figure 3 (right).
- Phase-sense method, where the laser is run freely run and, for each event, the laser-and-RF relative phase are measured.

The current laser beam waist size (w_0=10 μm) is close to the vertical e^- beam size at the ATF, so the spatial resolution must be improved. One method employed at the ATF is to use higher transverse modes of the laser as shown in Figure 4 (left and centre). A result of the scan is shown in Figure 4 (right); using this method, with the size of the central dark region of the TM01 laser waist tailored to match the beam size, the resolution was improved by a factor of about 3.

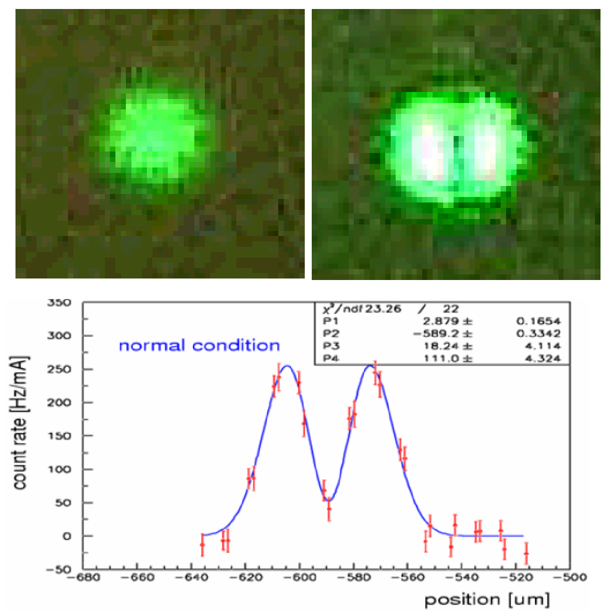

Figure 4. Left: theTEM00 used in the scans shown in Figure 3. Centre: the laser TEM01 mode. Right: profile scan using the TEM01 mode.

A new proposal [10] is to create an interferometer in an optical cavity, which could be a backup system for the Shintake monitor. In this scheme, a short laser pulse is generated by many longitudinal waves that are completely mode-locked; a 7ps pulse width requires 200 longitudinal modes in the case of a 714 MHz repetition rate. The length of the LW optical cavity has now been changed from 84cm to 42cm to match the 741 MHz mode-locked laser. The specification of the laser is 800mW, 7 ps pulse width (FWHM) and 0.4 ps (rms) timing jitter. The first step will be to confirm that interference is taking place, the second step will be to move the interference pattern by a phase shift by using a mover-table. Once these goals have been achieved, the system will be installed in the ATF damping ring. Future plans are to design the chamber, which includes the vertical 42cm optical cavity and is attached with an upstream and a downstream cavity BPM. The two BPMs can measure the beam orbit with an accuracy of a few nano-meters. The laser wavelength will be changed from 1064 nm to 532 nm (Green).

2.4 ATF Extraction Line Laser-wire

As discussed in Sec. 2.2, a key challenge for the LW is to measure electron bunch sizes of ~1 μm. This issue is being addressed head-on at the ATF extraction line where a high-power pulsed green laser light will be focused down to measure an electron bunch with $\sigma_y \sim 1$ μm. This has required the development of low f-number optics; a final focus preliminary system has been designed to be f/1.3 and a future upgrade to f/1 is planned. More details are given in [3].

2.5 PETRA Laser-wire

A high-power pulsed LW system has been in operation at the PETRA accelerator [11] and a screen-shot from a representative LW scan is shown in Fig.5 (left). The laser used is a ~5 MW Q-switched system and each entry in the plot in Fig.5 (left) is the Compton signal from a single laser shot. The scans are performed by moving the laser spot using a mirror on a piezo-driven mount. The signal fluctuations are believed to be due to the multiple longitudinal modes of the laser; an upgrade is planned to an injection-seeded Q-switched laser system which should reduce these fluctuations considerably. In addition, a vertical breadboard plus optics mounted on stepping-motor drives have been installed in the PETRA tunnel to enable both vertical and horizontal scans using the same laser system as shown in Figire 5 (right). More details of this system can be found in [4].


Figure 5. Left: LW scan of the vertical beam dimension at PETRA using original (horizontal) system. Right: New vertical system installed at PETRA that will allow both vertical and horizontal LW scans.

3 Conclusion

Laser-wire R&D is ongoing at several test facilities world wide. Dedicated projects at exist at PETRA at DESY, and two projects at the ATF at KEK. LW techniques give rise to a variety of applications. The use of a LW as a beam size monitor has already been established as shown above, however there is still R&D required to produce faster monitors with better spatial resolution. An example of such R&D was presented [2] where an ultra-fast scanning system based on electro-optic crystals is being explored. Additional LW applications include X-ray sources (and many proposals exist) and also tertiary beam sources such as of positrons or neutrons. The technologies are challenging and R&D efforts have only just started.

Acknowledgement

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