MICRON-SCALE LASER-WIRE AT THE ATF-II AT KEK COMMISSIONING AND RESULTS*

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Abstract

We present the first results from the commissioning of the upgraded laser-wire experiment at the Accelerator Test Facility 2 (ATF-II) at KEK. A new laser transport line and beam diagnostics were used to collide 150 mJ, 167 ps long laser pulses with 1.28 GeV, 30 ps long electron bunches to measure the vertical transverse size. Additionally, a new detector was installed with a reduced area for lower background. Initial scans showing a convoluted beam size of $18.4 \pm 0.4\ \mu$m were used to tune the electron beam optics and reduce this down to $8.0 \pm 0.3\ \mu$m. Laser pulse energy and charge dependency were investigated showing a linear relationship in both with a minimum laser energy of 20 mJ required for adequate signal to make a laser-wire scan.

INTRODUCTION

A laser-wire (LW) is a non-invasive method of measuring the transverse profile of a particle beam by scanning a focussed high power laser beam across the particle beam. Inverse-Compton scattered photons are detected further along the accelerator and are proportional to the overlap of the laser and the particle beam [1]. A LW is capable of micrometre-level profile measurements with a high resolution. Such a diagnostic will be key for future high energy and high intensity particle accelerators where conventional profiling technologies such as wire-scanners and screens will no longer be suitable [2]. The LW demonstrated at the ATF before its upgrade measured a minimum RMS electron beam size of $4.8 \pm 0.3\ \mu$m [3]. The previous measurements were limited by both the electron beam optics and the laser optics used. This paper describes the continued study of the recommissioned LW system at ATF-II using a dedicated set of electron beam optics that created a small vertical focus at our location and rematched to the nominal ATF-II optics afterwards.

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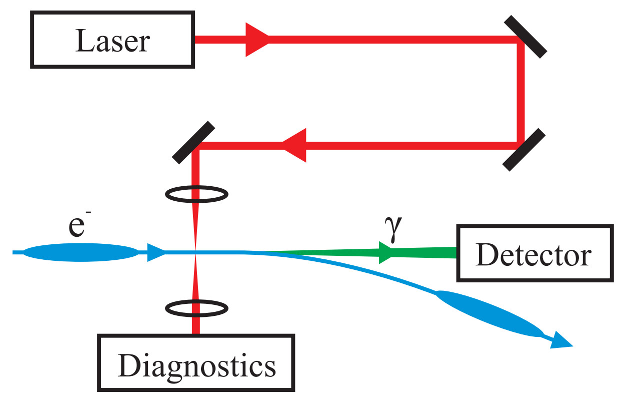

Figure 1: Schematic layout of the laser-wire.

SETUP

The laser-wire installed previously at the ATF extraction line was recently recommissioned after the completion of ATF-II. During this process the interaction chamber was moved to a location in the extraction and emittance diagnostic section of the ATF-II, the detector was moved and upgraded. Additionally, the laser system was moved to a new location with upgraded diagnostics and a new laser transport line was built [4]. Figure 1 shows a schematic layout of the laser-wire where the laser system is placed outside the accelerator and directed through a laser transport line to the interaction point (IP) where the laser beam is focussed to create a $\sigma \sim 2\ \mu$m focus.

The laser system produces 167 ps long pulses of 150 mJ at the repetition rate of the ATF-II, 1.56 Hz. The laser beam is focussed using a custom designed fused-silica lens at the IP. Here, the laser pulses collide with the 1.28 GeV electron bunches producing inverse-Compton scattered photons. The lens is fixed to the vacuum chamber at the IP which is on a two dimensional mover system. By moving the vacuum chamber and hence the lens, the laser focus can be scanned across the electron beam.

Assuming Gaussian spatial density distributions for both the photons and the electrons as well as that the laser pulse dimensions do not vary across the electron beam, the number of scattered photons is given by

$$\langle N_\gamma \rangle = N_e P_L C \exp\left(-\frac{(y_L - y_e)^2}{2\sigma_c^2}\right) \quad (1)$$

where N is the number of the particles, e and L represent the electron and laser beam respectively, P_L is the power of the laser pulse, y is the vertical position of the beam and C is a collective normalisation constant. σc is the sum in quadrature of the electron and laser distribution widths ($\sigma_c^2 = \sigma_L^2 + \sigma_e^2$).

The scattered photons exit the vacuum beam pipe through an aluminium window further along the accelerator before which the electrons are deflected by a dipole. The detector placed immediately behind the window consists of a 6 mm thick layer of lead on top of a 40 mm $\times$ 40 mm $\times$ 40 mm piece of Aerogel. The scattered photons with maximum energy of $\sim$ 28 MeV create electron-positron pairs in the lead. These pairs then generate Cherenkov radiation in the Aerogel which is guided by an aluminium-coated-Mylar lined pipe to a photomultiplier tube (PMT). The PMT is placed near the ground and shielded to reduce background. The front face of the detector is 22.3 $\pm$ 0.1 m from the IP.

An aluminium coated 300 μm thick sheet of silicon is mounted on a 2 axis manipulator arm above the interaction point which is used to generate optical transition radiation (OTR) light for timing and alignment purposes.

RESULTS

In order to obtain collisions, the cavity BPM system [5] and combinations of correcting dipole magnets were used to steer the electron beam to direct the near-parallel scattered photons towards the detector. Only after this were collisions detected. The chamber (and therefore the laser focus) was scanned both vertically and horizontally to maximise the detector signal.

The charge of the electron beam and the energy of the laser pulses were varied independently to verify the linearity of the system as predicted theoretically [2]. Figure 2 shows the dependence of the detected Cherenkov signal on the charge of the electron bunches. Here the charge is represented by the digitally down-converted amplitude of a reference cavity BPM present $\sim$ 4 m before the IP, which is linear with charge.

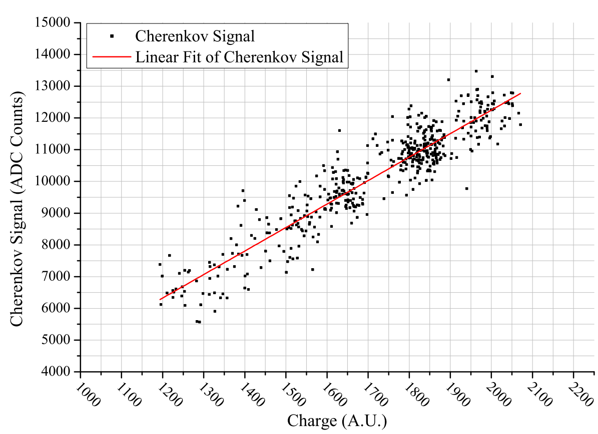

Figure 2: Charge dependence of Cherenkov signal.

The detected Cherenkov signal was found to be linear with charge within the measured range with the gradient found to be 7.4 $\pm$ 0.2. The vertical variation of the data is largely due to the known fluctuation of the laser pulse energy. With the charge of the electron bunches nominally fixed, the laser pulse energy was varied as shown in Fig. 3. The detected Cherenkov signal was also found to be linear with laser pulse energy within the measured range as expected with the gradient found to be 38.8 $\pm$ 0.8 mJ^{-1}.

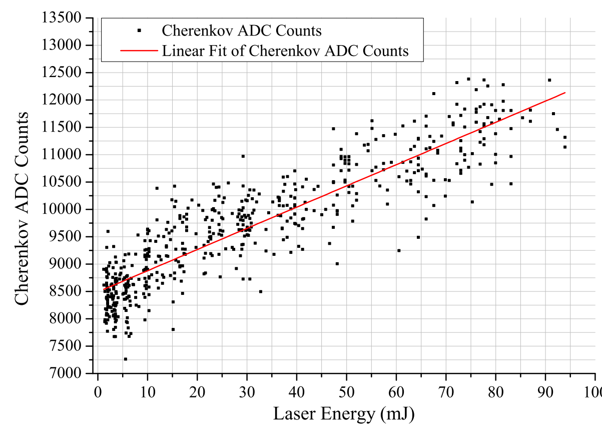

Figure 3: Laser energy dependence of Cherenkov signal.

Figure 4 shows an initial vertical scan made using the laser-wire. At this point, the OTR monitor was not commissioned and so only the convoluted profile of the electron and laser beams is shown in this paper.

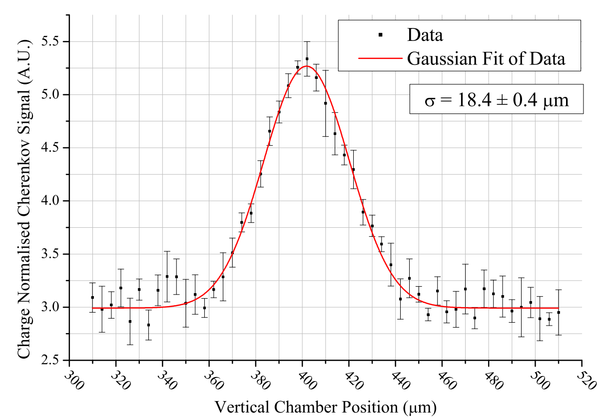

Figure 4: Intial vertical scan.

The initial scan shows a convoluted σ_c of 18.4 $\pm$ 0.4 μm. The laser-wire was used in conjunction with the ATF-II tuning team [6] to firstly correct for the dispersion and then for the x-y coupling. This reduced the measured σ_c considerably. Figure 5 shows the minimum measured convoluted σ_c of 8.0 $\pm$ 0.3 μm.

In Fig. 5, the increased jitter in the laser-wire signal is due to the jitter of the laser pulse energy and work is ongoing to improve this.

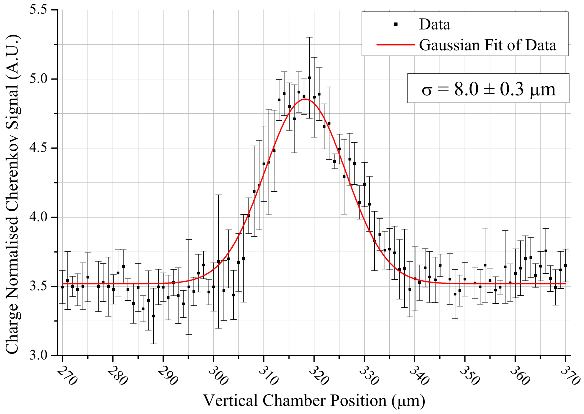

Figure 5: Vertical scan of tuned electron beam.

FUTURE WORK

The use of dedicated ATF-II LW optics necessary to achieve the required small vertical beam sizes created a significant number of operational problems. During the Summer of 2011 the LW IP was moved to a vertical electron beam focus located approximately 15 m downstream from the old location. This location has a vertical electron beam focus of below 1 μm in the normal ATF-II optics configuration and is $\sim$ 7.3 m from the detector. Apart from the reduced beam size, the new location and optics will allow near parasitic LW measurements whilst the ATF-II is being used and the LW will provide an independent beam size measurement to aid ATF-II tuning. The observed background under nominal ATF-II optics is almost negligible and the ATF-II tuning procedures directly improve the beam size at the LW IP. The horizontal beam size at this new location is between 200 and 400 μm which is significantly larger than the laser focus Rayleigh range. This large aspect ratio beam is quite similar to that required for CLIC [7] and studies relevant for this machine can be performed. In order to accurately measure the vertical beam size an independent measure of the horizontal beam size is required [2, 3] and the LW will also need to be rolled to match the electron beam.

The new LW location is instrumented with a laser interferometer system that monitors the LW interaction chamber vertical position with respect to three other BPMs [8]. Preliminary measurements of the vibration of the LW chamber indicate an RMS vertical position variation over a minute of 125 nm, which is comparable with the expected beam jitter at this location. The new location is surrounded by high resolution cavity BPMs (one upstream by 580 mm and another downstream 122 mm) with sub 100 nm resolution [5].

In future, the transverse electron beam size will be measured using an OTR monitor specially developed to cross calibrate the LW [9]. This will allow the electron beam to be quickly tuned to the required vertical size and provide a horizontal electron beam size measurement. The laser optics can then be adjusted to minimise the laser focus spot.

LW measurements at the new location will commence in October 2011 with the aim of achieving a 1 μm beam size measurement, with beam position jitter and mechanical vibration removal. Although charge normalised, the signal is not yet laser pulse energy normalised but soon will be with on-going upgrades. Furthermore, the full overlap integral will be used instead of Eq. 1 to take account of the varying laser spot size through the focus, large horizontal beam size and possible roll effects, providing a more accurate fit of the data given the large horizontal beam size.

CONCLUSION

We have successfully commissioned and demonstrated the upgraded laser-wire system at the ATF-II. Further work remains to fully optimise this system and achieve the goal of measuring an electron beam with $\sigma \approx 1$ μm. However, the laser-wire has already been used as a diagnostic to tune the electron beam towards the goal of the ATF-II of creating a vertical focus of the electron beam of 37 nm. Recent completion of the relocation of the LW at the ATF-II will allow more rapid development of the LW and for it to be used towards ATF-II optimisation and studies for a CLIC LW monitor.

ACKNOWLEDGMENTS

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