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LASER WIRE SCANNER DEVELOPMENT ON CTF II

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Abstract

A laser wire scanner is under development at CERN in the framework of the Compact Linear Collider study (CLIC). A first test has been carried out at the CLIC Test Facility II (CTF II) with the aim of developing a beam profile monitor for a low energy, high charge electron beam. In our set-up a 2.5 mJ, 1047 nm, 4 ps laser pulse interacts with a 50 MeV, 1 nC, 4 ps electron bunch. A scintillator detects up to 600 X-ray photons, with an average energy of 17 keV. In the present status of the experiment Thomson photons have been observed, but the signal to noise ratio is however still too low for an accurate profile measurement.

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1 INTRODUCTION

A Laser Wire Scanner (LWS) is considered as the most promising option for beam profile measurements at CLIC [1]. Interceptive beam profile monitors, such as Optical Transition Radiation (OTR) screens or solid wire scanners cannot stand high beam current densities without being damaged [2]. Therefore non-degradable diagnostics, like LWS, must be foreseen for both the CLIC Main Beam and Drive Beam. LWS can be very accurate since the resolution is limited by the laser spot size and can be reduced to a few wavelengths. The few microns of transverse size of the CLIC Main Beam can be measured using a UV laser.

LWS are based on the well-known Thomson-Compton scattering [3], where the photons of a laser beam are scattered by incoming electrons. By counting the number of scattered photons as a function of the laser position, the bunch profile can be reconstructed. In a 90° collision the scattered photons spectrum has a maximum at the energy $h\nu_{sc}$, which is given by:

$$h\nu_{sc} = 2\gamma^2 h\nu_0 \qquad (1)$$

where $h\nu_0$ is the laser photon energy and γ the relativistic factor of the electrons. Below 1 GeV, the energy of the scattered photons remains small compared to the initial electron energy (Thomson regime). Above this limit, the electron recoil is no longer negligible (Compton regime) and at very high energies the scattered photons take most of the energy of the incident electrons. With the Thomson cross-section, σ_t, equal to 6.65 10^{-29} m^2, very powerful lasers are required to scatter enough photons to allow an accurate detection.

Signal background comes mainly from bremsstrahlung photons created by beam losses. The detection of scattered photons is therefore much more difficult in the Thomson regime where the scattered photons have energies significantly lower than those of the bremsstrahlung photons.

Only few LWS have been successfully operated around the world so far. At SLAC, on a 50 Ge*V* electron beam, bunch sizes of a few microns have been measured [4]. At Berkeley [5], Thomson photons have been detected using the 50 MeV electron beam and a terawatt Titanium: Sapphire laser. Emittance measurements have been done at the Amsterdam pulse stretcher ring on a 900 MeV electron beam [6]. Recently, at KEK, a laser wire scanner has been developed in order to measure the very small emittances of the 1.28 GeV damping ring [7]. The following sections will describe the LWS tests carried out at CTF II [8] so far.

2 EXPERIMENTAL SET-UP

Figure 1 shows a schematic of the experimental layout. A single laser pulse (1047 nm, 4 ps) from a mode locked Nd: YLF laser [8], is split in two parts. One part with 5% of the initial infrared energy is converted into UV by two consecutive doubling crystals. The UV pulse is then directed onto the photo-cathode and produces the electron bunch. The remaining part of the IR beam (95%) is used in the LWS (2.5 mJ). The CTF II photo-injector laser has been especially rearranged (no Drive beam) in this way in order to deliver the maximum laser energy to the LWS. In this set-up, both the electron and the laser pulses are in synchronism and the relative timing between the two can be adjusted using an optical delay line. At the gun exit, the electrons enter a 3 GHz-accelerating cavity, which increases their energy up to 50 MeV. They are then focused, using a quadrupole triplet, in the interaction chamber, where the collisions with the laser photons occur. The IR laser beam is focused using a 150 mm focal length lens. The electrons are then deflected by 90° using a dipole magnet. The scattered photons propagate in the forward direction, pass through a 100 μm thick, aluminium window, and are detected using a lead loaded plastic scintillator coupled to a photo-multiplier tube (figure 1b). A considerable amount of lead shielding is placed all around the detector in order to eliminate background coming from the nearby beam dump. The detector was calibrated at the ESRF on the SNBL X-ray line (10-40 keV) [9]. The electron beam current and position are monitored using a pick-up located just before the interaction zone. A bunch charge of typically 1 nC was measured during the tests.

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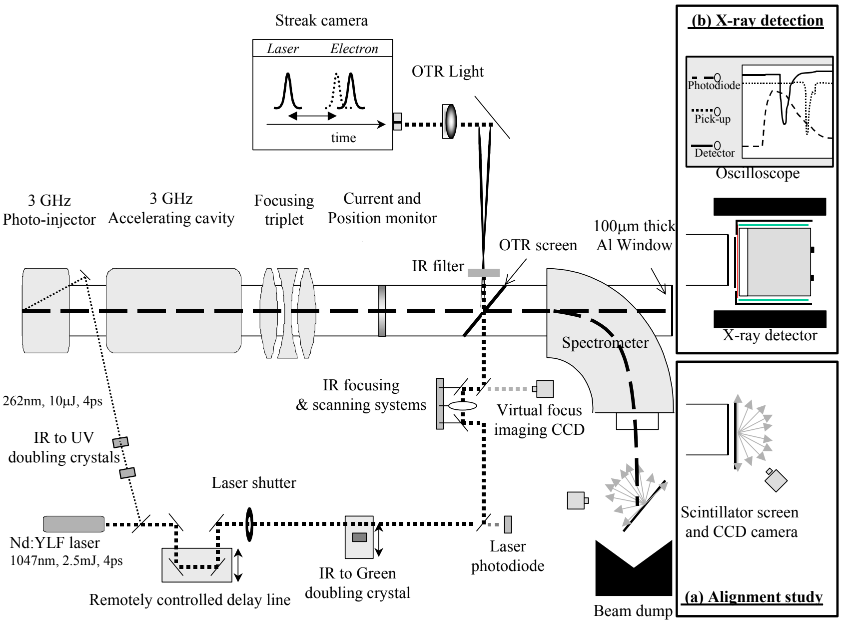

Figure 1: Laser Wire Scanner experimental layout on CTF2

The interaction chamber is also equipped with an aluminium OTR radiator. This is used to measure the electron beam profile ($\sigma_{x,y}$ = 160 µm) and bunch length (σ_z =4 ps) by using a streak camera in either focus or sweep mode. The laser energy is monitored using a photodiode detecting the photons leaking through a mirror. The position and the size of the laser spot is also continuously monitored using a CCD camera looking at the virtual focus behind the last mirror. The laser focusing system produces a 30 µm r.m.s spot size with a 5 mm Rayleigh range. It is mounted on a remotely controlled translation stage allowing vertical scanning with steps as small as one micron.

The scattered photons are emitted in a small cone centred in the direction of propagation of the electrons. The detection angle is 26 mrad and according to simulations small angular misalignments, of the order of 5 mrad, can be tolerated. At the beginning of the test (figure 1a), a scintillating screen and a CCD camera were installed in place of the X-ray detector in order to optimise the beam transport to ensure a good alignment.

3 OVERLAP TECHNIQUE

Before starting the measurements, the positioning of the laser beam with respect to the electron beam must be adjusted. The streak camera is used to verify the spatial and temporal overlap. For this purpose, the IR pulse is converted into green light and a hole (1 mm diameter) drilled in the centre of the OTR screen allowing the laser light to pass through. In this way both beams can be observed on the same streak camera image. The temporal overlap is achieved by adjusting the LWS laser path using a mirror based delay line, installed on a remotely controlled translation stage. Figure 2a shows a picture obtained with the streak camera in focus mode (2D) and Figure 2b the corresponding image obtained with a sweep speed of 10 ps/mm. The time interval between the two beams is adjusted to 45 ps, corresponding to the delay introduced by the doubling crystal. We estimate an accuracy of ±3 ps for the time overlap and ±300 µm for the spatial overlap.

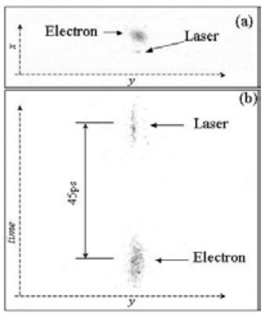

Figure 2: Streak camera images showing the temporal overlap

The doubling crystal is mounted on a remotely controlled translation stage, which allows the overlap of the two beams to be checked without accessing the machine. Small variations in the UV laser position on the photo-cathode or small drifts in the Klystron RF phase have been observed, both leading to changes in the electron timing of a few picoseconds.

4 DATA ANALYSIS AND RESULTS

Assuming perfect alignment and the overlap of the two beams, simulations show that 600 photons per machine pulse with an average energy of 17 keV hit the detector. Using the calibration coefficients of our detector we estimate a signal of 3.8 mV. Scans over ±18ps in time or/and ±500 µm vertically, have been performed using steps of 3 ps and 5 µm respectively. For each point of the scan the peak-to-peak values of the X-ray detector, the bunch charge and the laser power are stored.

4.1 Background studies

Due to the large background signal observed, data are acquired consecutively with the laser on (30 seconds) and the laser off (10 seconds) for each position of the scan. Laser - off values are used for the background subtraction technique. Figure 3 shows the detector voltage versus bunch charge for three different scans. The slope of the fit line indicates the background level. Using the expected value for the Thomson photons signal (3.8 mV), the signal to noise ratio can be calculated. Large variations from 1/8 to 1/30 have been observed. Above 1 nC, beam losses in the accelerating cavity increase rapidly with direct consequences on the background (dot curve).

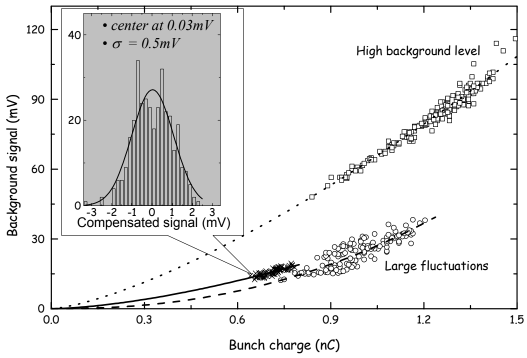

Figure 3: Background signal as a function of bunch charge

In the same figure the histogram of the residuals of the fit is shown. Typical values for the r.m.s of these histograms are between 0.5 and 3.5mV. The background is very sensitive to the position of the beam in the accelerating cavity. Small changes in the position can lead to significant variations in the signal, with no visible effects on the bunch charge.

4.2 Results

In Figure 4 the detector signal is plotted as function of time along the scan.

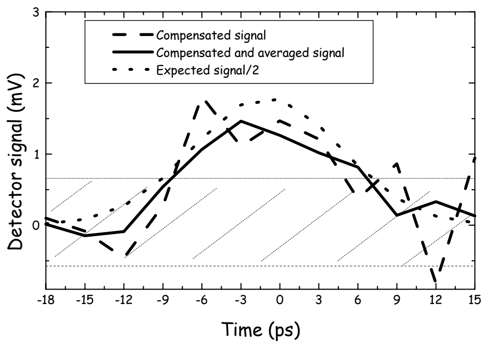

Figure 4: Comparison between measured, smoothed and expected signals for a ±18ps scan

Dash line curve represents the compensated signal and solid line curves the smoothed compensated signal. The two horizontal lines represent the r.m.s amplitude of the random fluctuations of the background signal. The expected signal (dot line) is calculated from the measured parameters. Small offsets in time and position are also introduced in the calculation to fit the measured signal. Maximum values of 2 ps and 175 μm offsets have been observed, which is in good accordance with the precision of our alignment technique. As one can see the X-ray signal is considerably smaller than the expected 3.8 mV mentioned before. The reason for this is not yet clear.

5 CONCLUSIONS

A signal correlated with the Thomson photons has been observed. The signal to noise ratio is however still too small to measure a beam profile with sufficient accuracy.

Increasing the measurement time, in order to reduce the statistical error, is unfortunately hindered by the unavoidable fluctuations of the machine parameters.

Background levels are a very important aspect for the design of a LWS. Collimation and background suppression must be carefully investigated, especially for low energy beams. Laser powers higher than 1GW, would be required to obtain a sufficient signal to noise ratio.

6 ACKNOWLEDGMENT

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[9] Find more details on the Swiss Norwegian Beam Line at http://www.esrf.fr/exp_facilities/BM1B/index.htm