ELECTRO-OPTICAL BUNCH PROFILE MEASUREMENT AT CTF3

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Abstract

A new electro-optic bunch profile monitor has recently been installed in CLIC Test Facility 3 at CERN. The monitor is based on an electro-optic spectral decoding scheme which reconstructs the longitudinal profile of the electron bunch by measuring its Coulomb field. The system uses a 780 nm fibre laser system, transported over a 20m long distance to the interaction chamber, where a ZnTe crystal is positioned close to the beam. The assembly also contains a traditional OTR screen, which is coupled to a second optical line and used to adjust the temporal overlap between the laser and the electron pulse. This paper presents the detection system in detail, as well as reporting on the first measurements performed with beam.

INTRODUCTION

A 3 TeV e^+e^- Compact Linear Collider (CLIC) is currently being studied at CERN [1]. To reach high luminosity the machine relies on colliding beams with nanometre transverse sizes. The bunch length must also be kept short to avoid any luminosity dilution [2]. It is to be compressed down to 150 fs rms just before the CLIC main linac, and the longitudinal profile must be measured with a resolution of 20 fs. Only very few instruments can provide longitudinal profile measurement with femtosecond time resolution[3]. A non-intercepting solution can be based on the Electro-Optic (EO) technique [4], such as EO Spectral Decoding (EOSD) [5].

At CERN, some of the key feasibility issues of CLIC are currently being studied at CLIC Test Facility 3 (CTF3) [6]. The CTF3 probe beam, named CALIFES [7], is designed to run with bunches of 1 ps or below. Typical bunches have a charge ranging from 85 to 600 pC depending on the laser pulse energy and the quantum efficiency of the photocathode [8]. The machine can provide either single bunch or bunch trains with a maximum of 226 bunches over 150 ns. The beam energy typically reaches up to 200 MeV at the end of the linac.

This paper presents the commissioning results of the electro-optical longitudinal profile monitor installed on the CTF 3 probe beam line.

PRINCIPLE OF EO SPECTRAL DECODING

The principle of operation of an electro-optical spectral decoding monitor is shown in FIG.1. It is based on the use of a birefringent crystal, which encodes the longitudinal beam profile onto a linearly chirped laser pulse. As the laser passes through the crystal, its polarisation rotates proportionally to the amplitude of the bunch Coulomb field. Two crossed polarizers, installed on both sides of the crystal, transfers this change in polarisation into a laser intensity variation. The bunch profile is thus encoded into the laser pulse both in time and frequency domain. The deconding is then performed using a spectrometer, which converts the spectral information into a transverse profile.

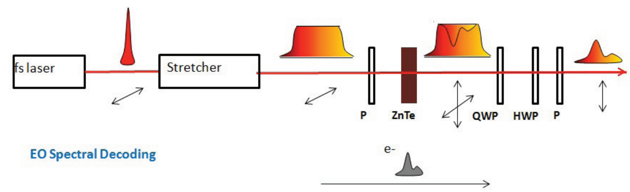

Figure 1: Principle of electro-optical spectral decoding.

Highly relativistic particles, the temporal profile of the Coulomb field becomes an almost perfect replica of the bunch temporal profile [9].

Fig.2 shows the broadening of the Coulomb field with a bunch of 1.4 ps FWHM as a function of the beam energy and the distance between the beam and the crystal. The difference between the duration of Coulomb field and of e-bunch temporal profile is becoming small for high energy beams as shown on Fig.2(a). There is only 1% broadening for a 200MeV beam and a crystal positioned at 5 mm from the beam. The beam is assumed to be entirely on-axis, with no radial extent. The time resolution of the monitor will improve as the crystal is moved closer to the beam. Fig.2(b) shows the amplitude of the Coulomb field for different distances of the crystal from the e-bunch. The optimum distance would depend on a compromise between the expected time resolution, the signal to noise ratio of the monitor and the risk of damaging the crystal if the beam directly impinges on it. In the case of CALIFES, a distance between 5-10 mm seems to be a reasonable choice.

ELECTRO-OPTIC BUNCH PROFILE MONITOR

The present CALIFES EOSD design [10] is based on the use of 1 mm thick ZnTe crystal and 780 nm laser system bought from TOPTICA Photonics AG company. The laser delivers pulses with 110 fs pulse duration at 780 nm. A pulse picker, selecting every second laser pulses, has been added between the oscillator and the amplifier to enhance the output pulse energy in order to provide a better signal noise ratio. After the amplifier, the laser pulse energy can reach up to 2.7 nJ.

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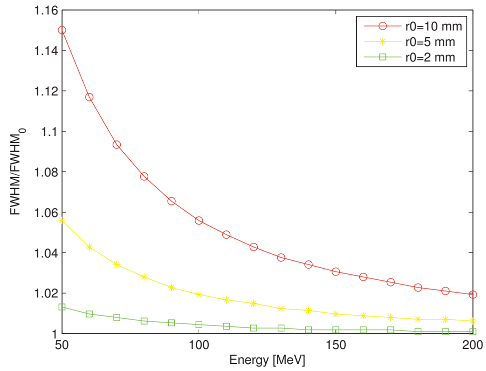
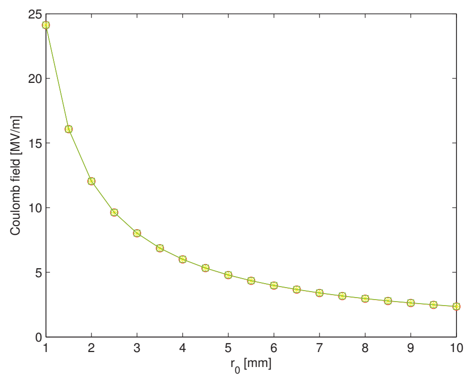
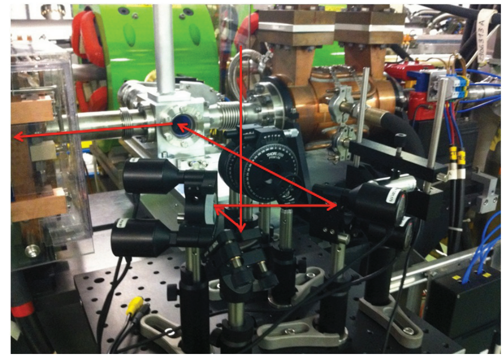


(a)

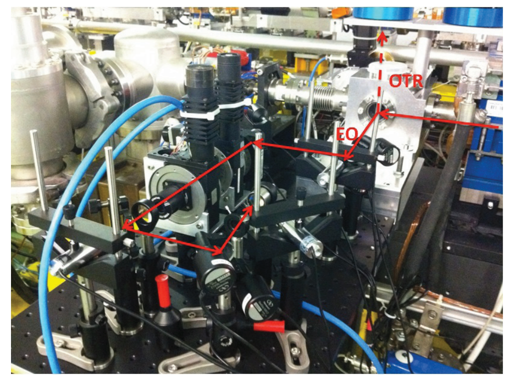


(b)

Figure 2: (a) Broadening of the electron bunch coulomb field as a function of the beam energy calculated at 3 different radial distances away from the particle (b) Evolution of the Coulomb field amplitude as a function of the radial offset, calculated for an electron bunch of 0.6nC.



(a)



(b)

Figure 3: Picture of bunch profile monitor.

Two pictures of the CALIFES EO system are shown in Fig.3. The laser is located in an optical room, not exposed to radiation. The laser line is equipped with an optical delay line providing an adjustable delay over 1ns with a few femtoseconds step resolution. The laser pulse are chirped to 2 ps by a section of SF11 glass, and sent towards the CALIFES beam line through a 20m long optical line composed of 9 mirrors and coupled of lenses. As shown on Fig.3(a), the laser, coming from the ceiling, is then injected into the beam line using a first vacuum chamber equipped with a silver mirror mounted on a movable arm. A waveplate and a polarizer, located right before the vacuum chamber viewport, adjust the polarization of the incoming laser photons to be horizontal. As shown on Fig.3(b), the laser photons are then steered to a second vacuum chamber which holds the crystal and the extraction mirror, both mounted the same movable arm. As the laser comes out of the second chamber, it passes then through the analyser. the latter is composed of waveplates and a cross polarizer, that selects the beam encoded laser photons, which are then optically coupled into a multimode fibre back to the optical room. The detection is finally done using a spectrometer composed of a grating and a gated and intensified CCD camera (PCO dicam pro). In total, ten actuators installed on five mirrors and six finger cameras have been installed around the insertion and extraction vacuum chambers in order to steer and monitor the laser remotely from the control room.

The second vacuum chamber is also equipped with an Optical Transition Radiation (OTR) [11] screen made out of a 200um thick aluminium coated silicon wafer. It is foreseen to adjust and check the time overlap between the beam and the laser using a streak camera. As the electrons pass through the screen, they emit OTR photons which are then sent via a second optical line to the optical room, where the streak camera sits [12]. At the same time, the laser photons reflected by the OTR screen followed the same path as the OTR photons so that they can both be measured simultenaously by the streak camera. The delay between the electrons and the laser can be controlled both by a phase shifter installed on the RF signal locking the laser oscillator and by the optical delay line mentioned above providing a fine scannning range over 1ns.

PRELIMINARY BEAM MEASUREMENTS

The timing overlap between the photons and the electrons have been studied in detail.

Fig.4 shows an example of the longitudinal profile of

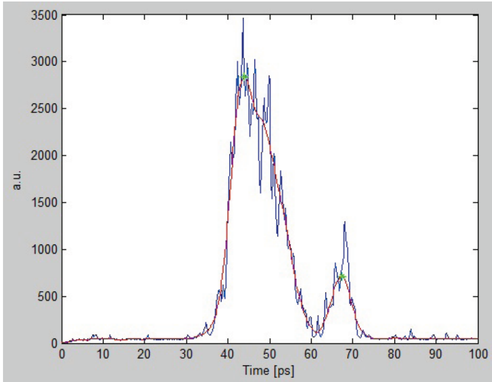


Figure 4: Timing overlap E-bunch and laser pulse measured by the streak camera

both the electron bunch (left peak) and the laser pulse (right peak), measured by streak camera (Hamamatsu femtosecond streak camera C6138). Such images have been recorded with different setting of the optical delay line in order to adjust the overlap between the electrons and the laser photons. On Fig.4 this timing is measured to be 23.4 ps. For the same setting, we acquired a serie of images to measure the pulse/pulse jitter between the two beams. The maximum peak to peak jitter observed over ten consecutive images is 1.2 ps.

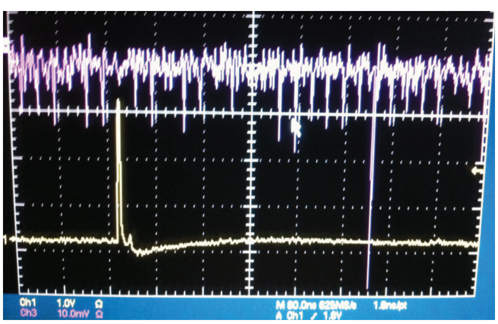


Figure 5: First EO signal measures by a photomultiplier

Although CALIFES has been designed for nominal bunch length of 1 ps, the current configuration of the RF distribution network cannot provide at the moment an adequate bunch compression. The minimum bunch length measured with the streak camera was never shorter than 7 ps FWHM. Designed to measure bunch length shorter than 3ps, the current EOSD monitor cannot provide single-shot measurements. However, with the present beam conditions, the electron bunch length can still be retrieved via a scanning method. A high sensitivity photo multiplier tube was thus installed in front of the spectrometer and has already seen beam induced EO polarisation change as shown in Fig.5. In this figure, the oscilloscope was triggered by a low (2ps) jitter timing signal derived from the RF of the accelerator (bottom trace). The laser pulses are visible on the top curve, which shows one laser pulse, 420ns after the trigger signal, with a larger intensity. In the present situation with 0.2nC bunch charge and 7.4ps bunch length, the EO signal is expected to be around 0.3%, resulting in a signal 3 times larger than the background of our set-up.

SUMMARY

A longitudinal profile monitor for the CALIFES beam has been proposed and is currently under commissioning. It is based on spectral decoding technique and is aimed at providing measurements with a time resolution better than 1ps. The synchronization of e-bunch with laser pulse has been measured using a streak camera, with a peak to peak jitter better than 1.2ps. The first electro-optical signal has been observed, but with the current CALIFES beam parameters, providing too long and too weak bunches, single-shot EOSD measurements have not been performed yet. This will be addressed during the summer shutdown by improving the bunch compression scheme or increasing the crystal length in order to provide a suitable signal to measure longer bunches.

ACKNOWLEDGMENT

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