# SYNCHRONIZATION SCHEME OF A BUNCH PROFILE MONITOR BASED ON ELECTRO-OPTIC SPECTRAL DECODING

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## *Abstract*

A longitudinal profile monitor based on electro-optic spectral decoding (EOSD) is being developed for the probe beam of the CLIC Test Facility 3 at CERN. Using such technique the longitudinal profile of an electron bunch is encoded into a chirped laser pulse and decoded with a spectrometer. The system, expected to provide time resolution of 1 ps, will be installed and tested in 2012. An accurate synchronization scheme between the laser pulse and electron bunch is mandatory for the reliable operation of this device. This paper will present the design of the monitor and describe the synchronization and timing systems foreseen.

## INTRODUCTION

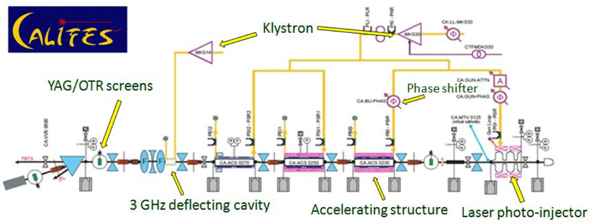

Figure 1: Layout of CALIFES.

The Compact LInear Collider (CLIC) study at CERN [1, 2] aims at developing a high luminosity 3 TeV $e^+$ $e^-$ collider. To achieve such performance, the CLIC beams are made of a succession of short electron (or positron) bunches with a typical bunch length of 150 fs. This puts a very high demand on the performance of longitudinal profile monitors which shall achieve time resolution better than 20 fs. Moreover for ultra relativistic beams, the measurement must be performed in a non-intercepting way. Electro-optic and related techniques [3] have shown themselves to be extremely promising for the measurement of electron beam longitudinal profiles where ultra-short electron bunches have structure in the range of picoseconds down to tens of fs. The principle of electro-optic longitudinal diagnostics is to accurately measure the temporal profile of the Coulomb field of the relativistic particle beam through optical non-linearity induced in an electro-optic crystal. The crystal is placed adjacent to the electron beam, but the beam does not traverse the crystal, making this a completely non-intercepting technique. The Coulomb field sweeping through the appropriately chosen crystal renders the material birefringence during the field transit. This birefringence is probed by a chirped (or sometimes ultra short) optical probe laser pulse which passes through the crystal parallel to the electron beam axis, and in synchronism with the electron bunch. After the probe laser beam has interacted with the Coulomb field of the electron (or positron) bunch, it is then extracted from the beamline and the resulting time-varying rotation of the polarization of the optical pulse can then be sensitively detected using all-optical techniques to yield a temporal (or longitudinal) evaluation of the Coulomb field, which itself is a measure of the charge density longitudinal profile within the bunch. There are a number of different ways of implementing this general principal, i.e. Spectral Decoding (EOSD) [4], Temporal Decoding (EOTD)[5], Spectral Upconversion [6] or other techniques[7, 8], each with their own particular merits. EOSD uses a chirped laser pulse and measures single shot laser profile through a frequency to position correlation in a spectrometer. This is the simplest, and most widely, implemented technique. However it is fundamentally limited in its time resolution to hundreds of fs.

The CLIC Test Facility 3 (CTF3) [9] has been built to study some of key feasibility issues of CLIC. Most of them are related to the concept of two-beam acceleration and CTF3 is composed of two distinct electron accelerators: a drive beam and a probe beam. The layout of the CTF3 probe beam, named CALIFES [10], is shown in Fig. 1. CALIFES is based on a laser photo-injector, followed by three 3 GHz travelling-wave accelerating structures and one beam diagnostic line. The latter provides an emittance meter equipped with YAG and OTR screens, a spectrometer line and a RF deflector for energy and bunch length measurements respectively. At the end of the linac, the beam energy can reach up to 200 MeV. Typical bunches in CALIFES can have a charge up to 0.6 nC and a bunch length of 1.4 ps r.m.s [11, 12]. However the bunch length can be adjusted down to 700 fs. Even if the RF deflector was installed on the beam line, the klystron providing the necessary RF power is only available on request and for short time period. For this reason, as a best compromise between performance, simplicity and cost, a new bunch profile monitor based on EO spectral decoding technique has been proposed and in currently being developed. The monitor will be installed on CTF3 in 2012. This paper describes the implementation of the monitor in the CTF3 machine and presents the design of the technique foreseen to synchronize the laser and the electron bunches.

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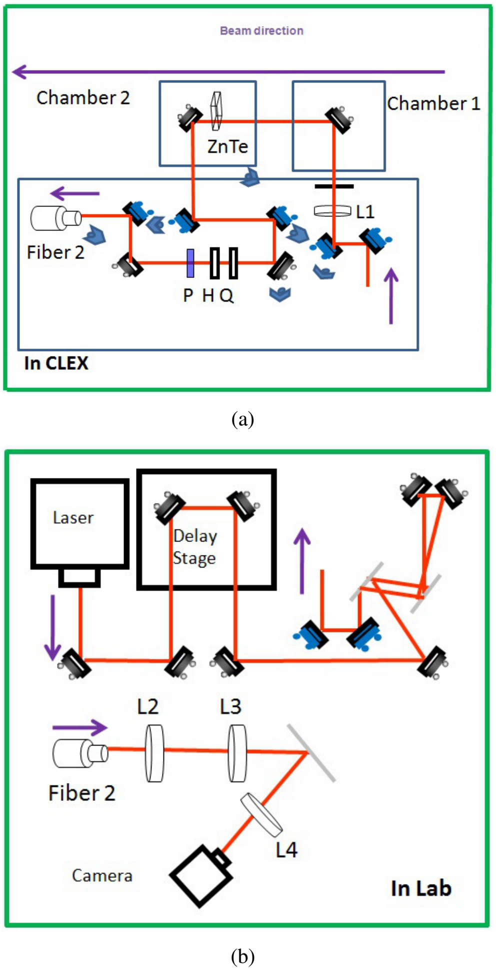
## DESIGN OF THE EO MONITOR

The present CALIFES EOSD design [13] 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 100 fs pulse duration at 780 nm. In the design of the laser, a pulse picker, selecting every second pulses, has been added between the oscillator and the amplifier to enhance the output pulse energy. The pulse picker is triggered by a low jitter (∼few ps) signal also derived from the CTF3 RF system. After the amplifier, the laser pulse energy can reach up to 2.7 nJ. The detection is done using a spectrometer composed of a grating and a gated and intensified camera (PCO dicam pro). The layout of the CALIFES electro-optic profile monitor is shown in Fig. 2.



(a)

(b)

Figure 2: Layout of bunch profile monitor.

The system has been split in two parts, with the laser source and the detector installed in a laboratory located 20 m away from the accelerator, providing a safe environment not exposed to radiations. The laser passes through an optical delay stage and is linearly chirped to around 3 ps by a pair of gratings. An optical line, as depicted in Fig. 3 has been designed to transport the laser photons to the vacuum chamber housing the EO crystal. The optical line is composed of four lenses ($f_1 = f_4 = 515.3mm$, $f_2 = f_3 = 5153mm$, $\phi = 50.8mm$) with 780 nm AR coatings and six high quality mirrors. The vaccum vessel installed on the beam line is composed of two chambers, one to steer the laser into the beam tube and a second one housing the crystal and coupling the photons out. The two chambers are equipped with an insertion mirror and an assembly composed of a 1 mm ZnTe crystal and an extraction mirror, respectively. They are both mounted on a movable arm so that their transverse positions are remotely and precisely adjustable. The distance between the edge of the crystal and the e-beam shall vary between 5 to 10 mm. After the second chamber, the laser pulse goes through a quarter wave plate (QWP), a half wave plate (HWP) and a polarizer selecting the polarization perpendicular to the initial laser polarization. Finally, the laser pulse is coupled into a fibre and sent back to the optical laboratory where a holographic grating used as a spectrometer and a gated ICCD camera sit. The initial diameter of the laser is 1.2 mm and has a divergence of around 1 mrad. Half of the mirrors are equipped by a pair of actuators to be remotely controlled and an observation system composed of six CCD cameras is left in the accelerator to carefully control the steering of the laser throughout the whole optical system.

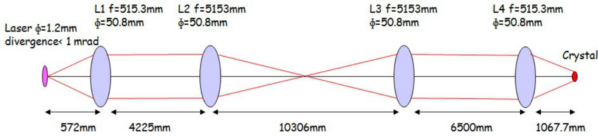


Figure 3: Laser transfer line.

An estimation of the expected time resolution [14] is given below.

- 10 fs contributed by the 5 mm distance between the crystal and the e-beam for the Coulomb field broadening comparing to the original e-bunch profile assuming a beam energy of 200 MeV.
- 330 fs contributed by the frequency response of the 1 mm thick ZnTe crystal.
- 550 fs contributed by the EOSD limitation for a 100 fs laser pulse chirped to 3 ps. The reason is time-wavelength mapping of the chirped laser is distorted by the fast modulation induced by the short e-bunch in the crystal. This limitation can be described by $\tau_{lim} \approx \sqrt{\tau_0^{FWHM} \tau_c^{FWHM}}$, where $\tau_0$ is the duration of original laser pulse and $\tau_c$ is the duration of chirped laser pulse [15].
- 3 fs contributed by the spectrometer and the gated ICCD camera spatial resolution.

As designed, the monitor shall be capable to measure bunch lengths from sub-picosecond to several picoseconds.

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## LASER-ELECTRON SYNCHRONIZATION

In EO based detector, the laser pulse shall pass through the crystal simultaneously to the e-bunch. The synchronization between the laser and the electron pulses shall be handled with a very good precision, of the order of the bunch length. The layout of the timing and synchronization system developed for EOSD is presented in Fig. 4.

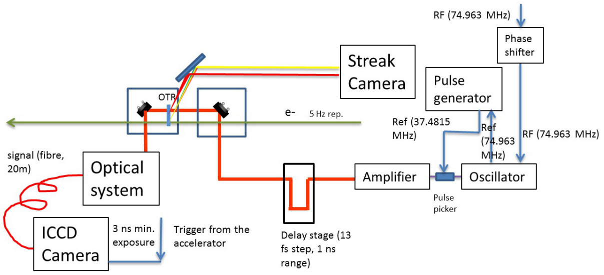

Figure 4: Timing and synchronization scheme.

A 74.963 MHz RF signal, derived from the main 3 GHz (40th subharmonic) RF system driving the accelerating cavities, is provided to lock the frequency of the laser oscillator. A rough ($\sim$100 ps) synchronization is provided by shifting the phase of this RF signal. The precise timing overlap between the e-beam and the laser pulse is then performed using an optical delay line with an ability of 13 fs step increment and 1 ns scanning range. A low jitter ($<$ 1 ns) signal will trigger the ICCD camera, which can be gated with a 3 ns minimum exposure time.

CALIFES is running with 5 Hz repetition rate, in either a single bunch mode or a multi-bunch mode with a pulse train composed of up to 226 bunches. A high reflectivity Optical Transition Radiation (OTR) screen has been introduced in the design of the crystal vacuum chamber. OTR photons induced by the particles and laser photons reflected by the screen will be sent to a streak camera via 20 m long optical line. The details of this line, composed by two lens ($f_1 = 1000mm$, $f_2 = 75mm$, $\phi = 50.8mm$) are shown in Fig. 5. Streak camera measurements will monitor the arrival times of both laser and beam induced OTR photons within few ps accuracy.

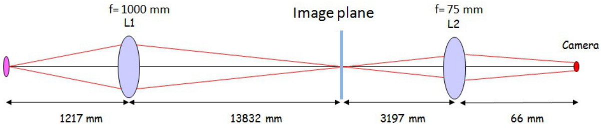

Figure 5: OTR and laser optical line.

## SUMMARY

A new bunch profile monitor based on EOSD has been designed for the CTF3 probe beam at CERN. It is based on a commercial laser system and a 1 mm thick ZnTe crystal. This device is expected to provide subpicosecond time resolution. The implementation of the monitor has been now finalized and it includes an OTR screen coupled to streak camera in order to carefully check the synchronization between the electron and laser within a few picoseconds. The monitor is expected to be installed on the beam line by the end of 2012.

## ACKNOWLEDGMENT

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