ELECTRO-OPTIC BUNCH DIAGNOSTICS ON ALICE

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Abstract

An electro-optic longitudinal bunch profile monitor has been implemented on ALICE (Accelerators and Lasers in Combined Experiments) at the Daresbury Laboratories and will be used both to characterise the electron bunch and to provide a testbed for electro-optic techniques. The electro-optic station is located immediately after the bunch compressor, within the FEL cavity; its location allows nearby OTR, beam profile monitors and Coherent Synchrontron Radiation (CSR) diagnostics to be used for calibration and benchmarking. We discuss the implementation and the planned studies on electro-optic diagnostics using this diagnostic station.

INTRODUCTION

ALICE is a test facility accelerator to explore many of the physics issues relating to energy recovery and novel physics experiments using accelerators and lasers. ALICE is a 35 MeV electron accelerator with a bunch length of approximately 0.4 ps and a bunch charge of 80 pC. A tunable mid-infrared free electron laser will be incorporated. We have inserted an electro-optic (EO) diagnostic just before the Wiggler of the free electron laser. A THz beam line is also present before the Wiggler, transporting THz CSR to a separate laboratory for experiments on biological samples. The THz line will also provide a further indirect experiment for the measurement of the electron beam.

Detailed knowledge of the longitudinal electron bunch profile is important in the design and operation of next generation light sources such as XFEL at DESY, New Light Source (NLS), the currently proposed International Linear Collider (ILC) and Compact Linear Collider (CLIC) proposed at CERN. The optimisation of the electron bunches at subpicosecond timescales in NLS will require non-invasive measurement techniques that are also single-shot to avoid problems associated with timing jitter in the arrival times of electron bunches. The electro-optic technique has already been used successfully as non-invasive, single-shot method of measuring bright intense relativistic electron bunches with lengths of the order of 120 fs [1].

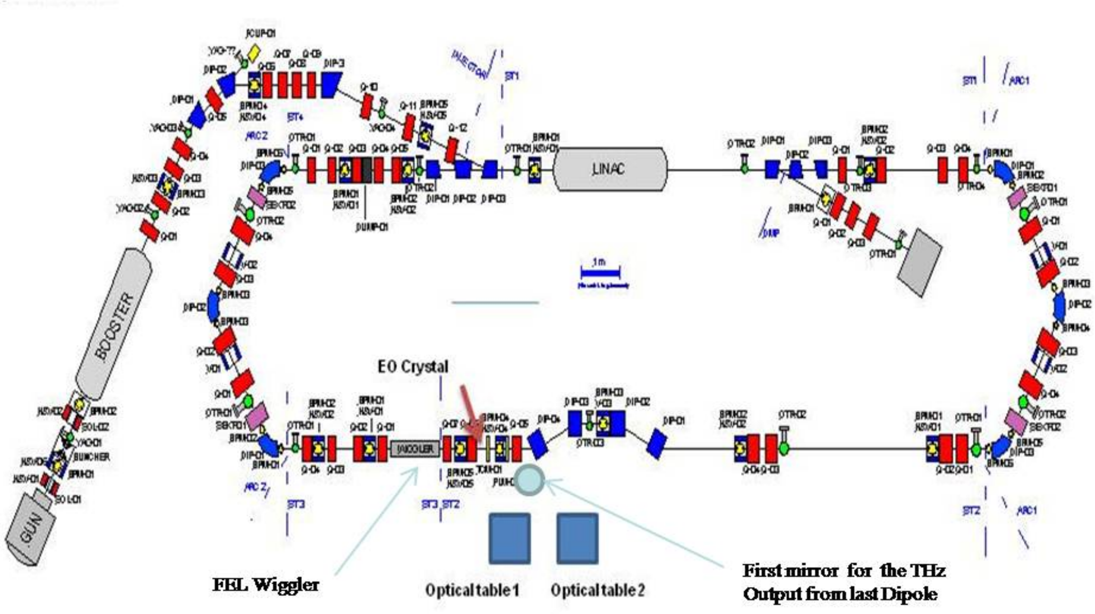

Figure 1: The EO experiment is located on the optical tables shown. The probe beam is injected through the bend in the last dipole magnet and then goes through the EO crystal and then arrives at the optical table 1 for decoding. The Coherent Synchrotron Radiation (CSR) THz output port is located near optical table 2 so that implementing the measurement is achieved with the same setup. This also shows the position of the Wiggler for the FEL.

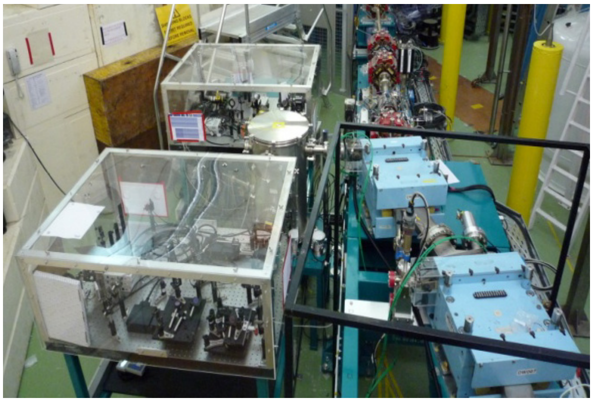

Figure 2: Image showing the optics layout with the two optical tables and the two end dipoles of the electron compressor.

EXPERIMENT

The electro-optic detection method using a femtosecond laser to probe the birefringence induced in a ZnTe crystal is now well known [2]. For the measurements proposed here, the probe laser is an amplified Ti:sapphire laser (pulse length 30 fs, wavelength 800 nm, pulse energy 2.5 mJ, repetition rate 1 kHz) that is actively synchronised to the accelerator rf clock.

The timing resolution of the electron bunch detection is determined both by the EO encoding process occurring within the non-linear crystal, and by the spectral decoding (SD) [2] or single-shot temporal decoding (TD) [2] of the optical pulse, see figure 3. In these measurements the encoding time resolution is limited by the low Lorentz factor of the electrons, and by the response bandwidth of the non-linear crystal. A temporal resolution is defined by $\delta t = \frac{2R}{\gamma c}$ [2], where R is the radial distance between the electron beam and the optical pulse in the EO crystal. For ALICE the maximum energy is 35 MeV (with an energy range of 20-35 MeV) and the distance R is 2 mm, leading to a temporal resolution of 200 fs. The electron bunch length can be varied from 5 ps to 300 fs. The limitations arising from the EO crystal response are best viewed as a frequency cut-off, rather then directly as a temporal resolution. For a 0.2 mm ZnTe crystal, electric field Fourier components with a frequency lower then 2.8 THz are detected with minimal distortion, while higher frequency Fourier components are detected with reduced efficiencies [3]. For a 0.2 mm GaP crystal, electric field Fourier components with a frequency lower then 7 THz are detected with minimal distortion, while higher frequencies are detected with reduced efficiencies [4].

For SD, the optical beam from an ultrafast oscillator, is synchronised to the electron bunches. A linear chirp is introduced to stretch the pulse to a duration which encompasses the measured time window. This beam is then focussed onto the EO crystal which encodes the associated coulomb field onto the optical beam with different positions in the bunch modifying different frequencies in the chirped pulse. An analysing polariser is then used before a spectrometer which resolves the time to frequency mapping of the encoding and a CCD records the data, therefore retrieving the temporal intensity variation of the stretched pulse.

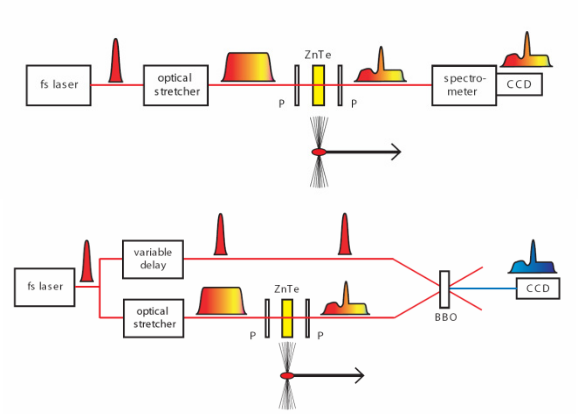

Figure 3: General experiment layout for Spectral Decoding (top) and Temporal Decoding (bottom). Only the ZnTe is in the beamline. P is a half-wave plate and polarizer.

In TD, the optical beam is split into two beams, a probe and a gate. The probe is passed through a grating pair to stretch the pulse to 20 ps, a length that is longer then the electron bunch duration. This samples the birefringence in the electro-optic crystal. The gate beam serves as a short-pulse reference in the cross correlation. The stretched pulse passes through a half-wave plate and a linear polarizer and is focussed onto a ZnTe (GaP) electro-optic crystal. This 0.2 mm thick <110> ZnTe (GaP) crystal is placed inside the accelerator beam pipe at the exit of the Wiggler. The phase retardation induced in the crystal by the bunch field is translated into an intensity modulation on the stretched pulse by passing through an arrangement of polarisers. This encoded intensity is then cross-correlated with the short pulse in a β-Barium Borate (BBO) crystal. The non-collinear nature of the cross correlation geometry provides a mapping of time onto spatial position in the BBO crystal and the CCD [2].

In order to determine the optimal techniques for the measurement of the NLS electron bunches at various phases of their evolution, we will in future investigate the use of both SD and TD techniques with the Ti: Sapphire laser. Initially we will investigate both ZnTe and GaP crystals with the possibility of other materials to be considered at a later date. This will also allow us to make a comparison with measurements using GaP and ZnTe on the FLASH, VUV FEL at DESY.

Single-shot TD has, potentially, a better resolution and has been used to measure electron bunches less then 150 fs at FLASH [5] (γ of 900), but necessitates the use of an amplified ultrafast laser. On the other hand, single-shot SD requires only an ultrafast laser oscillator, but suffers an intrinsic limitation that can, in certain circumstances, causes severe measurement artefacts in the measured bunch profile [6]. It may also be possible to perform SD measurements using a commercial 1550 nm fibre laser or a custom built 1050 nm fibre laser. The 1550 nm fibre laser would also provide a better integration into a large facility such as NLS where it is likely that such lasers will in any case be used for timing stabilisation [7]. This would reduce costs as fibre is less expensive then the current coax cables required for timing signal stabilisation.

Electron bunch profile measurements are to be taken over the full range of bunch compression settings, so that the bunch-length profile and behaviour is completely characterised by these settings. Compression is achieved by a combination of a 4-dipole compressor and the upstream of the arc of ALICE. The output power of the mid-infrared free electron laser will be measured as a function of compressor settings. It is not possible to measure the electron bunch profile directly during the lasing of the free electron laser, as the input mirror for the electro-optic measurement blocks the free-electron laser beam path.

The jitter in the arrival time of electron bunches at the free electron laser gives rise to a corresponding jitter between the accelerator timing signals and the emitted radiation, which is important in user experiments especially pump-probe. The single-shot capability of our EO diagnostic will allow us to investigate the effect of various accelerator parameters on this jitter. Furthermore, by cross correlating the photoinjector laser with the Ti: Sapphire laser used for EO measurements, we will be able to estimate the overall jitter of the system. This can be achieved with a high degree of accuracy as both the photoinjector laser and the Ti: Sapphire laser are located within the same room.

The EO crystal is mounted on a translation stage allowing it to be moved in a direction perpendicular to the beam. Using the adjacent beam position monitor we will be able to investigate the variation in EO signal and resolution as a function of distance from the beam.

We also intend to calibrate the Coulomb field electro-optic measurements with coherent synchrotron radiation (CSR) at the exit of the transfer line from the beam pipe on ALICE. We will be using both the SD and TD techniques at Daresbury. An important distinction between CSR and Coulomb fields is that the CSR will contain both field polarities. The arrangement of optical polarisers can be chosen to produce an EO signal linearly proportional to the CSR fields. This differs from that used in the Coulomb field measurements where the signal is proportional to the square of the field. This will provide data that can be compared with the electron bunch temporal characteristics.

CONCLUSION

We have installed an electro-optic electron bunch length monitor on the ALICE that will allow us to determine the longitudinal bunch profile using Temporal Decoding and Spectral Decoding. This will further allow us to characterise the electron bunch as a function of accelerator parameters and provide information about the jitter in bunch arrival time that will allow this to be minimised. In addition, a minor modification of our EO setup will allow us to use CSR to get a further, independent measurement of the bunch profile.

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