

SINGLE SHOT LONGITUDINAL BUNCH PROFILE MEASUREMENTS AT FLASH USING ELECTRO-OPTIC TECHNIQUES

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Abstract

For the high-gain operation of a SASE FEL, extremely short electron bunches are essential to generate sufficiently high peak currents. At the superconducting linac of FLASH at DESY, we have installed an electro-optic experiment with temporal decoding and spectral decoding to probe the time structure of the electric field of single sub-200 fs electron bunches. In this technique, the field-induced birefringence in an electro-optic crystal is encoded on a chirped ps laser pulse. The longitudinal electric field profile of the electron bunch is then obtained from the encoded optical pulse by a single-shot cross correlation with a 30 fs laser pulse using a second-harmonic crystal (temporal decoding) or by a single-shot measurement of its spectrum (spectral decoding). In the temporal decoding measurements an electro-optic signal of 110 fs FWHM was observed, which is limited by the material properties of the particular electro-optic crystal used. Bunch profile and time jitter measurements were obtained simultaneously with SASE operation.

INTRODUCTION

Precise measurements of the longitudinal temporal profile of extremely short electron bunches are essential for a detailed understanding of the lasing and operating principles of a SASE FEL. At FLASH, the VUV-FEL at DESY, three monitors for the longitudinal profile of the compressed bunch are located within a few meters of each other: the LOLA transverse deflecting RF structure [1], the broadband single shot spectrometer which measures the THz transition or diffraction radiation [2, 3, 4], and the single-shot electro-optic detection monitor measuring the Coulomb field of the bunches which is described in this paper.

EXPERIMENT

Two methods for single shot electro optic detection of the electric field profile of single electron bunches are schematically depicted in Fig. 1. The time structure of the electric field of the bunch is electro-optically encoded onto a chirped laser pulse. The longitudinal electric field

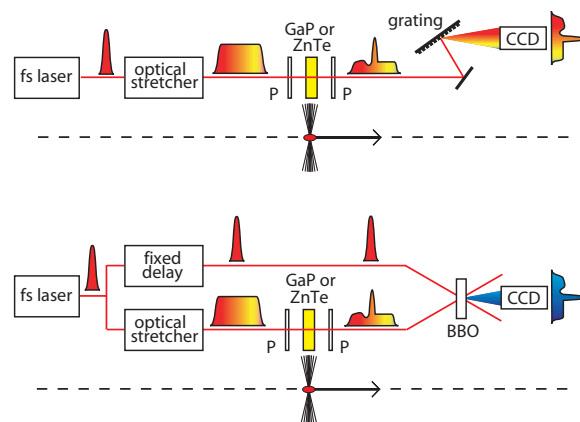


Figure 1: Single-shot techniques for measuring the longitudinal electric field profile of single electron bunches using electro-optic encoding with spectral decoding (top) and temporal decoding (bottom).

profile of the electron bunch is then obtained from the encoded optical pulse by a single-shot cross correlation with an ultra-short laser pulse using a second-harmonic BBO crystal (temporal decoding) [5] or by a single-shot measurement of its spectrum (spectral decoding) [6, 7].

The femtosecond laser consists of a Ti:Sa oscillator, which is synchronised to the rf of the accelerator [8], and a Ti:Sa amplifier, which delivers pulses of 30 fs duration at a central wavelength of 792 nm with an energy of 1 mJ. The laser system is mounted on optical table outside the accelerator tunnel, and the pulses are transferred to the linac tunnel by a 20 m long optical beam line. Inside the linac tunnel two optical tables are installed on top of each other. The lower table holds the beam pipe and the optics to inject the laser pulse into the beam pipe, guide it through the electro-optic crystal (GaP or ZnTe), and couple it out of the beam pipe. The upper optical table contains optical components for temporal decoding (see below). Three experiments can be (and have been) performed:

1. Spectral decoding with the Ti:Sa oscillator. The pulses from the oscillator alone (with nJ energy) are chirped with a SF11 optical stretcher [7], transferred to

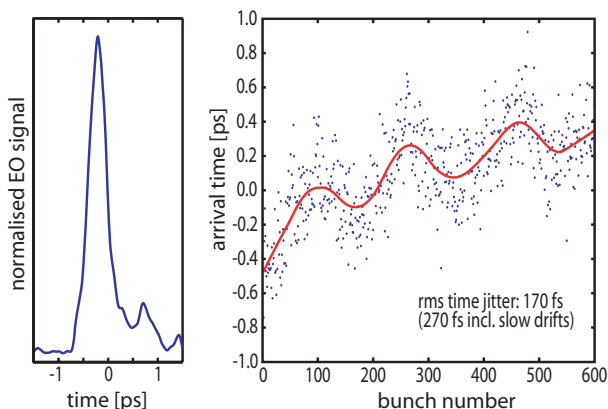


Figure 2: Single shot spectral decoding measurement of an electron bunch under SASE conditions (left) and arrival time distribution between electron bunch and laser pulse at the electro-optic crystal (right).

the lower optical table in the linac tunnel and guided through the electro-optic crystal. Since the optical pulse is linearly chirped, different wavelength components experience different electric field induced birefringence. After exiting the beam pipe, this birefringence is converted into an intensity modulation by a polarizer (see also Fig. 1). The intensity modulated probe pulse is coupled into a fiber, which is connected to spectrometer outside the linac tunnel. The image of the spectrum is recorded with a gated intensified camera.

- Temporal decoding with the Ti:Sa amplifier. The laser beam is guided to the upper optical table and split into two beams: the probe beam and the gate beam. The probe beam passes through an optical grating stretcher providing 20 ps long pulses, and goes to the lower optical table where it passes through the electro-optic crystal in the beam pipe. After exiting the beam pipe, the probe beam is directed to the upper table where it passes through the polarizer. The electro-optically induced intensity modulations of the probe pulse are measured, with a resolution better than 70 fs, by a single shot cross-correlation with the 30 fs gate pulse in a BBO crystal [5]. The position dependent emission of the second harmonic light from the BBO crystal is imaged onto an intensified CCD camera. A fixed delay line for the gate pulse compensates the travel of the probe pulse through the stretcher and beam pipe. Stretcher, delay line, cross-correlator, and camera are all mounted on the upper optical table.
- Spectral decoding with the Ti:Sa amplifier. In the temporal decoding experiment (2), the intensity modulated probe pulse can be coupled into a fiber just before the cross correlator using a remote controlled flip mirror. Connecting this fiber to the spectrometer described in experiment (1) allows spectral decoding

measurements. Alternatively, the uncompressed beam from the Ti:Sa amplifier (4 ps pulses) can be transferred directly to the linac beam pipe for spectral decoding measurements as described in (1).

Besides the direct electro-optic measurement of the Coulomb field of electron bunches, it is also possible to measure the electric field of coherent transition radiation which is transferred from the linac tunnel to the laser laboratory (see also Ref. [4]).

RESULTS AND DISCUSSION

The left panel of Fig. 2 shows a typical single shot electro-optic measurement using spectral decoding as detection technique. Spectral decoding is a single shot electro-optic technique that is rather easy to set up and provides a fast way for online monitoring the arrival time of the electron bunch as is shown in the right panel of Fig. 2. The arrival time difference between the electron bunch and laser probe pulse at the electro-optic crystal is plotted. For the measurements shown here, the rms time jitter without slow drift is 170 fs, which is a result from both the jitter in arrival time of the electron bunches and noise of the laser synchronization (with respect to the linac master frequency). The FWHM of the spectral decoding measurement shown in Fig. 2 is 400 fs. The temporal resolution in this measurement is limited by the electro-optic crystal, which was a 300 μm thick ZnTe crystal, and the detection technique.

Better temporal resolution is obtained using a 100 μm GaP crystal for the encoding step, and temporal decoding as detection step. A typical result obtained while the FEL produced VUV-pulses, is shown in Fig. 3. The top panel shows an image from the camera which detects the position dependent second harmonic (wavelength ≈ 400 nm) light. The time window in which the bunch could be observed was 15 ps. The leading edge of the pulse is on the left. The camera image, which is in false color representation, clearly shows a long tail. The lower panel shows the

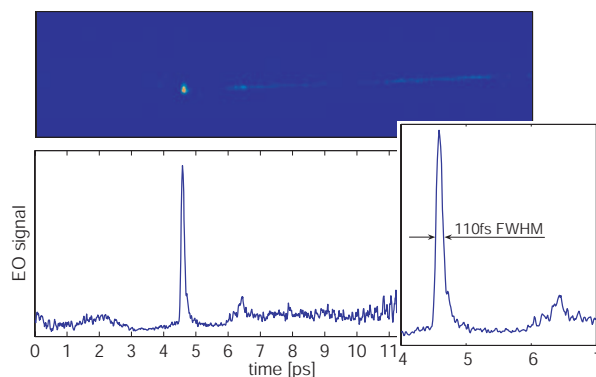


Figure 3: Single shot temporal decoding measurement of an electron bunch under SASE conditions. See text for details.

electro-optic signal obtained after proper binning the image and after background subtraction and normalisation. The inset shows an enlargement. The FWHM of the electro-optic signal is 110 fs. The small peak 2 ps after the main peak is due to a reflection of the Coulomb field within the electro-optic crystal. Work is in progress to extract the true bunch shape from these measurements.

CONCLUSION

This paper provides an overview of the experimental possibilities for the electro-optic experiment at FLASH. Non-destructive single shot measurements of the longitudinal electric field of single electron bunches have been obtained. These measurements are non-intrusive; no change in the SASE process has been observed as result of performing these measurements. Electro-optic signals with a FWHM of 110 fs have been observed.

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