



Figure 1. Single-shot measurements of the electric field of individual electron bunches performed at the FELIX facility.⁵ (a) Raw data, single-shot chirped laser pulse spectra S and S' . Spectrum S (thin solid line) is detected when the electron bunch and the chirped laser pulse overlap in time, while spectrum S' (bold solid line) indicates the spectrum that is measured when the laser pulse is 50 ps earlier than the electron bunch. (b) Electron bunch length and shape obtained from the spectra as displayed in (a). The electron bunch width is (1.72 ± 0.05) ps (FWHM). The shaded areas indicate the regions of increased noise introduced by the correction for the wavelength-dependent variations in intensity of the spectrum. (c) Experimental setup for electron-bunch length measurements by electro-optic sampling with chirped optical pulses. The electron bunch length is measured by using a ZnTe crystal placed inside the vacuum pipe at the entrance of the undulator.

Time-Domain Terahertz Science Improves Relativistic Electron-Beam Diagnostics

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Linear accelerators used as drivers for new femtosecond x-ray free-electron lasers (FELs), or employed in new teraelectron-volt (TeV) linear electron-positron colliders for high energy physics, require dense, relativistic electron bunches with bunch lengths shorter than a picosecond. Precise measurements of the electron bunch length and its longitudinal charge distribution are important to monitor the preservation of the beam quality while the electron bunch train travels through the beam pipe, as well as to tune and to operate a linear collider or a FEL.

The electro-optic detection of the local nonradiative electric field that travels with the electron bunch has recently emerged as a powerful new technique for subpicosecond electron bunch length measurements.¹ The method makes use of the fact that the local electric field of a highly relativistic electron bunch that moves in a straight line is almost entirely concentrated perpendicular to its direction of motion. Conse-

quently, the Pockels effect induced by the electric field of the passing electron bunch can be used to produce birefringence in an electro-optic crystal placed in the vicinity of the beam. In those experiments, the measured bunch length was the average of all electron bunches within a macropulse. Here, for the first time to our knowledge, we present the measurement of the length of an individual electron bunch² by using an upgrade of our previous technique. In our experiment, we probed the birefringence induced by a single electron bunch by monitoring the change of polarization of the wavelength components of a chirped, synchronized Ti:sapphire laser pulse, which is similar to the detection scheme of the freely propa-

gating terahertz radiation pulses of Zhang and co-workers.^{3,4} When the electric field of an electron bunch and the chirped optical pulse copropagate in the electro-optic crystal, the polarizations of the various wavelength components of the chirped pulse that passes through the crystal are rotated by different amounts that correspond to different portions of the local electric field. The direction and degree of rotation are proportional to the amplitude and the phase of the electric field. Thus, the time profile of the local electric field of the electron bunch is linearly encoded to the wavelength spectrum of the optical probe beam. An analyzer converts the modulation of the polarization of the chirped optical pulse into an amplitude modulation of its spectrum. The time profile of the electric field of the electron bunch is measured as the difference of the spectrum with and without a copropagating electron bunch. The width of the temporal profile corresponds directly to the electron bunch length, and the shape of the temporal profile is proportional to the longitudinal electron distribution within the electron bunch (Fig. 1). We achieved determination of the length and the shape of individual electron bunches by measuring the spectra of single chirped laser pulses with an optical multichannel analyzer equipped with a nanosecond shutter. The method allows direct, *in situ* electron bunch diagnostics with a high signal-to-noise ratio and subpicosecond time resolution.

References

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