High Temporal Resolution, Single-Shot Electron Bunch Length Measurements

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Electro-optic detection of Coulomb field

Operating principle:

• Coulomb field concentrated perpendicular to velocity with angle $\approx 1 / \gamma$
• Electric field induces birefringence in electro-optic crystals
• Birefringence results in polarization-dependent phase retardation of probe beam
Analyzer configurations:

Zero background setup

Balanced detection setup

Signal ~ $E^2(\omega, t)$

Signal ~ $E(\omega, t)$
Spectral decoding method

Intrinsic problem: artifacts may arise due to spectral smearing!

I. Wilke et al., PRL 88(2002) 124801

FEL2004, Trieste, Aug 2004
Lab-bench test-bed for EO techniques

able to produce mimic of Coulomb field with unipolar THz pulse from GaAs emitter

Repetitive, scanning delay  Single-shot, spectral decoding
\[ \Delta \tau = (12 \pi \alpha)^{1/2} \]
\[ \approx 2.6 (t_o t_c)^{1/2} \]

(\( \alpha = \) chirp parameter)

(for Gaussian pulses)
Temporal decoding at FELIX

Chirped probe focussed on ZnTe in beamline

~100µJ
30 fs

~1µJ
21 ps

Second harmonic

Probe expanded and collimated for cross-correlator

FEL2004, Trieste, Aug 2004
Second-harmonic generation (single shot) cross-correlation

**Time window, \( \tau \):**

- Beam diameter, \( D \)
- Angle of incidence \( \Phi \)

\[
\tau = \frac{2 \ D \ \sin(\Phi)}{c}
\]

\( \tau \approx 9 \text{ps} \text{ for } D = 5 \text{mm, } \Phi \sim 15^\circ \)

Phase matching in BBO achievable for incident angles \( \Phi < 33^\circ \)

Adjustable time window from fs \( \rightarrow \) 30ps for 1cm beam
Test of EO-setup with 130 µm FEL radiation
Electron beam measurements at FELIX
Early temporal decoding measurements
(July 2003)

Berden et al., Proceedings of FEL2003

FEL2004, Trieste, Aug 2004
Temporal decoding measurements at FELIX
December 2003

Synchronization jitter

![Graphs showing synchronization jitter](image)
Determining Coulomb field from EO signal

Zero background configuration
⇒ EO signal \( \sim \) [Coulomb Field]\(^2\)

\[ E_{\text{coulomb}} = \left[\text{EO signal}\right]^{1/2} \]

Quadratic dependence of EO signal on field confirmed by varying bunch charge ( EO signal \( \sim \) \( Q^2 \) )
Real time monitoring of bunch profile shaping.

Bunch profile modified by changing the buncher and accelerator phase.

≈ 450 fs FWHM Coulomb field on sub peak.
CONCLUSIONS

• Non-destructive longitudinal profile measurement of 650fs FWHM bunches demonstrated

• $\approx 450$fs FWHM substructure observed

• Real-time bunch shape monitoring and adjustment

• Estimated time resolution $\approx 200$fs, due to ZnTe response and low $\gamma$ of bunch