Electro-Optic Measurements of Electron Bunch Longitudinal Profile

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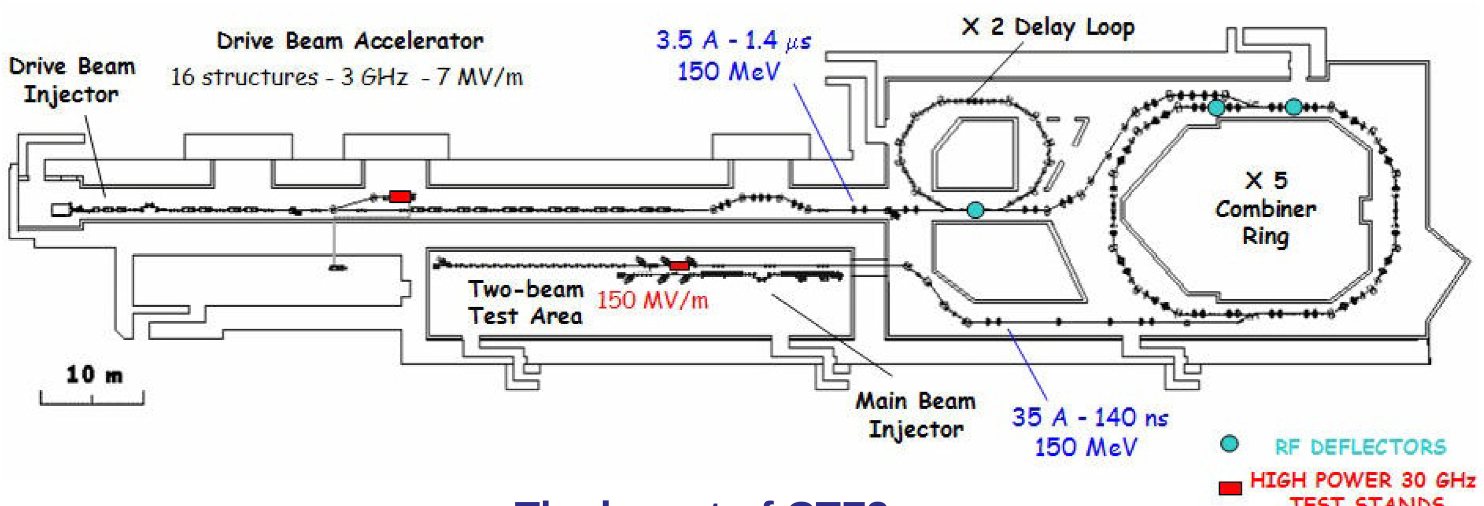
Electro-optic diagnostics of e-bunch longitudinal profile now have a proven time resolution capability of ~140fs FWHM / 60fs rms [1]. Here we examine the potential capabilities of various versions of the electro-optic concept, and discuss the options available in choosing a particular implementation.

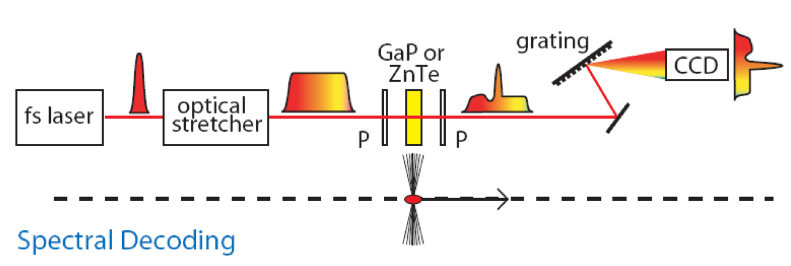
CLIC Test Facility 3 (CTF3)

CTF3 will be used to test CLIC critical components and in particular will provide the 30 GHz RF power needed to test the main beam accelerating structures at gradient 150 MV/m and pulse length 70 ns.



The layout of CTF3

Spectral measurements

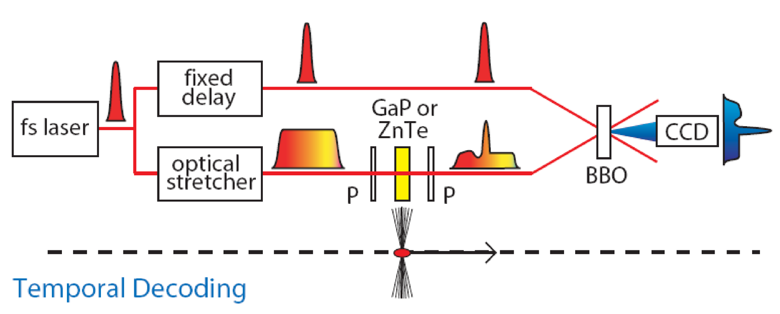


- Limited to characterisation of slowly (~1ps) varying profiles
- Simplest implementation of all techniques

Spectral Decoding (EOSD): Bunch Coulomb field profile encoded onto a time-wavelength correlated optical probe. Temporal profile read-out through spectrum of probe.

Temporal measurements

There are many approaches available for EO measurements that avoid the time-wavelength intermingling of EOSD, two of which have been demonstrated in accelerator diagnostics [2].

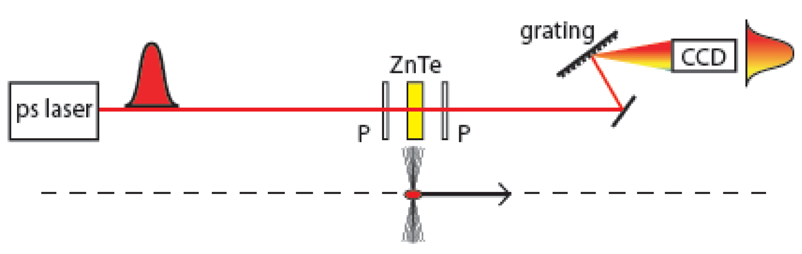


- Highest demonstrated time resolution [1]
- Samples Coulomb field at single point (applicable to low energy beams)
- Currently requires complexity of an amplified laser system

Temporal Decoding (EOTD): Bunch Coulomb field temporal profile encoded onto temporal profile of a several ps long optical pulse, and readout though time-space mapping in optical cross-correlator.

Spectral Upconversion measurements

Here we aim to directly measure the bunch Fourier spectrum



- accepting loss of phase information & explicit temporal information
- gaining potential for determining information on even shorter structure
- gaining measurement simplicity

using long pulse, narrow band, probe laser

References

[1] G. Berden, W. A. Gillespie, S. P. Jamison, E. A. Knabbe, A. M. MacLeod, A. F. G. van der Meer, P. J. Phillips, H. Schlarb, B. Schmidt, P. Schmüser, B. Steffen. *Benchmarking of electro-optic monitors for femtosecond electron bunches.* Phys. Rev. Lett. 99, 164801 (2007)

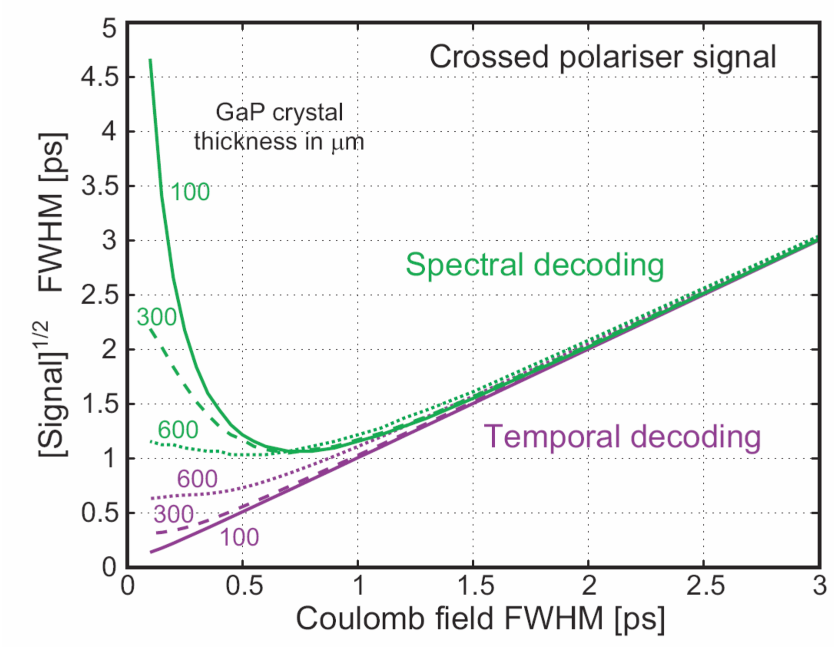
[2] S. P. Jamison, G. Berden, A. M. MacLeod, B. Steffen, P. J. Phillips, W. A. Gillespie. Femtosecond resolution bunch profile measurements. EPAC. 915 (2006)

[3] S. P. Jamison, G. Berden, W. A. Gillespie, P. J. Phillips, A. M. MacLeod. *Limitations of electro-optic measurements of electron bunch longitudinal profile*. EPAC. 1149 (2008)

[4] S. P. Jamison, G. Berden, P. J. Phillips, W. A. Gillespie. A. M. MacLeod. *Upconversion of a relativistic Coulomb field terahertz pulse to the near infrared*. App. Phys. Lett. 96, 231114 (2010)

Material Effects

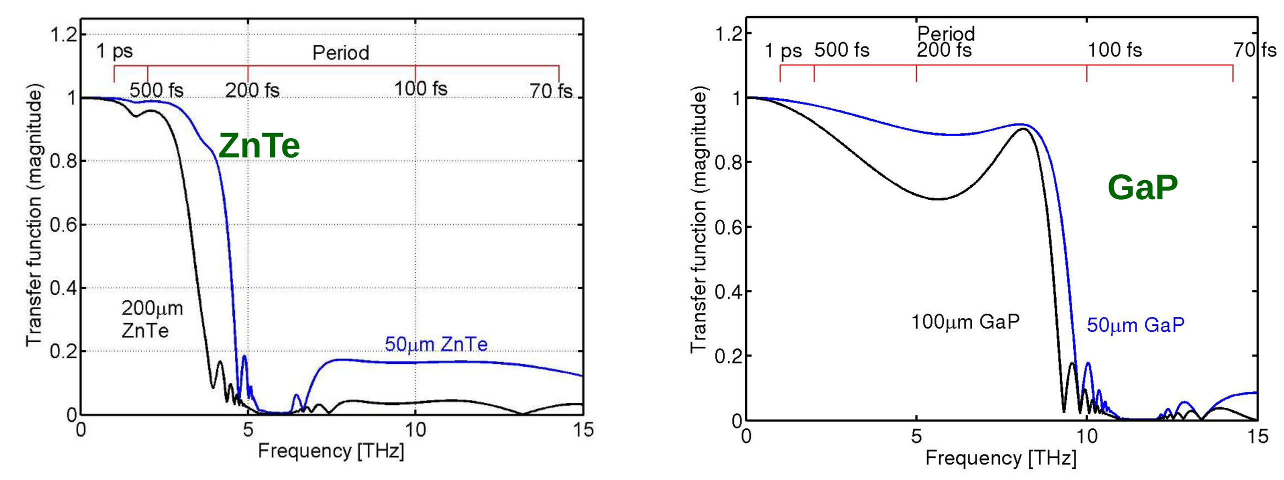
The "temporal" techniques are currently limited by EO material effects. Some, but not all, limitations can be mitigated by using a thin detection crystal, at the cost of lower signal [3].



Physics of EO encoding

Encoding Time Resolution ⇒ material frequency response, R(ω)

- velocity mismatch of Coulomb field and probe laser
- frequency mixing efficiency



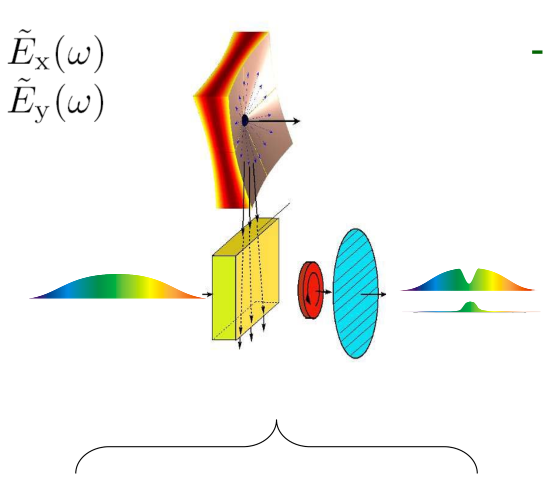
Push towards shorter bunch lengths requires materials with broader frequency response, leading to:

- organic and poled polymeric materials
- multi-crystal approaches
- artificially-produced "metamaterials", including metal-dielectric nano-composites

Spectral Upconversion diagnostic

- shifting Coulomb spectrum to optical region
- creating an optical "replica" of Coulomb field [4]

$$E_x(t) \rightarrow \tilde{E}_x(\omega)$$
$$E_y(t) \quad\;\; \tilde{E}_y(\omega)$$



$$I(t) \propto E_{\mathrm{Coul}}(t)$$
$$[\ \mathrm{or} \ \ \propto E^2_{\mathrm{Coul}}(t)\ ]$$

$$\tilde{E}^{\mathrm{opt}}_{\mathrm{out}}(\omega) = \tilde{E}^{\mathrm{opt}}_{\mathrm{in}}(\omega) + i\omega a \tilde{E}^{\mathrm{opt}}_{\mathrm{in}}(\omega) * \left[\tilde{E}^{\mathrm{Coul}}(\omega)\tilde{R}(\omega)\right]$$

Coulomb spectrum shifted to optical region

$$E^{\mathrm{opt}}_{\mathrm{out}}(t) = E^{\mathrm{opt}}_{\mathrm{in}}(t) + a\left[E^{\mathrm{Coul}}(t) * R(t)\right]\frac{\mathrm{d}}{\mathrm{d}t}E^{\mathrm{opt}}_{\mathrm{in}}(t)$$

Coulomb pulse replicated in optical pulse

envelope — optical field

Technique measures non-propagating long-wavelength spectral components which are not accessible to radiative techniques (CSR/CTR/CDR/SP)