EO single-shot temporal measurements of electron bunches

and of terahertz CSR and FEL pulses.

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- **Capabilities of EO detection**

- **FELIX longitudinal profile measurements**

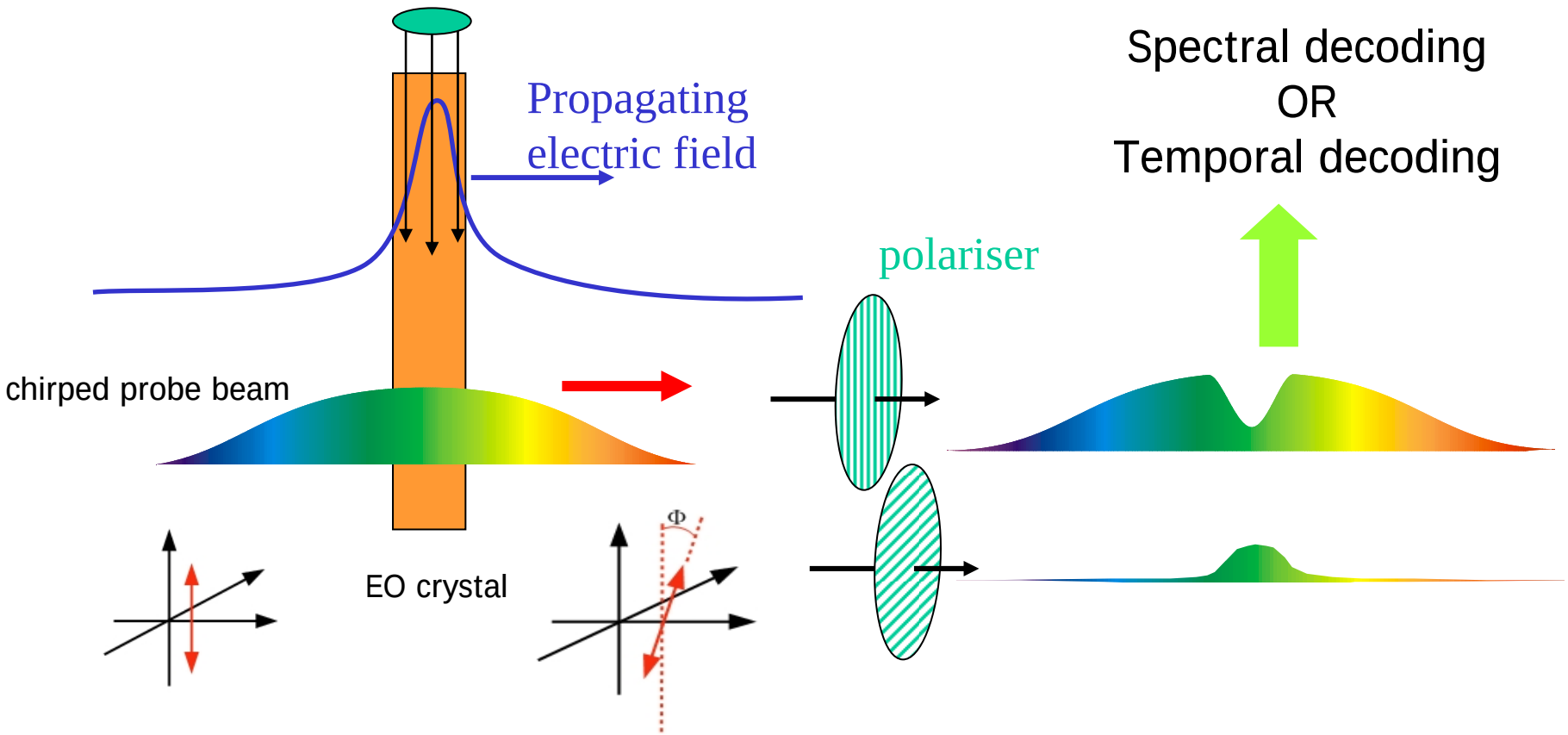
  real time bunch profile adjustment
  bunch timing jitter
  charge dependence

- **FELIX CSR measurements (edge radiation)**

  non-invasive synchronization measurements ?

- **Fast feedback bunch length monitor ?**

Single-shot EO measurement of Coulomb field

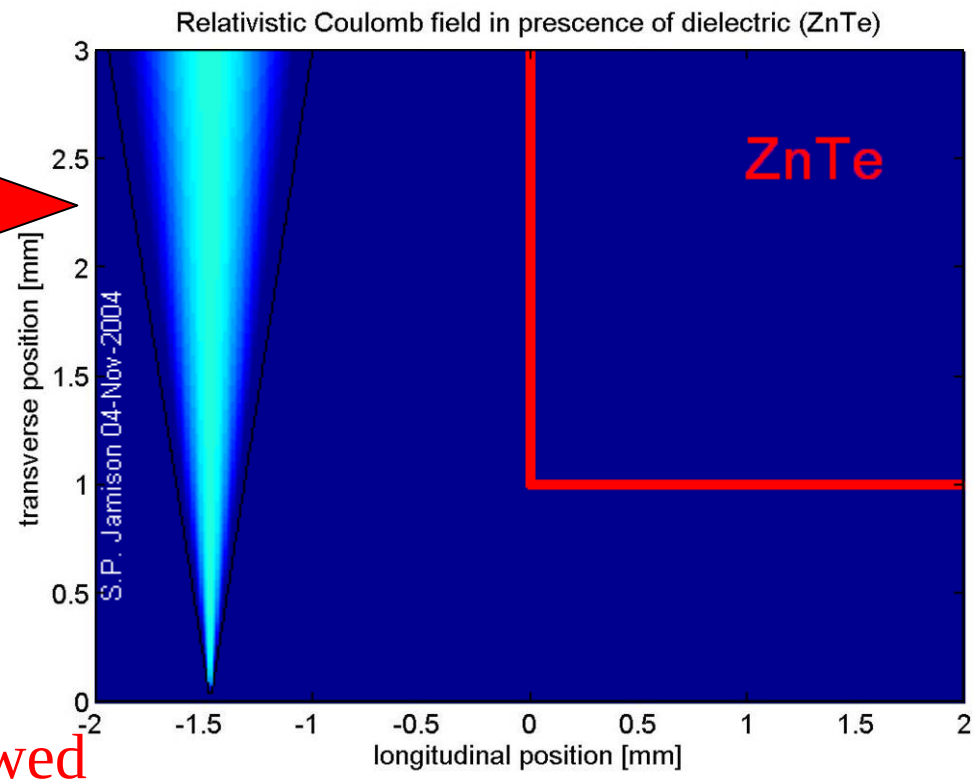


Effective polarisation rotation proportional to coulomb field

Coulomb field intercepting dielectric…

probe laser

Co-propagates with Coulomb field



Measure "slowed down" Coulomb field

the probe pulse velocity is reduced by a very similar factor

Calculation only applied to region inside the crystal.

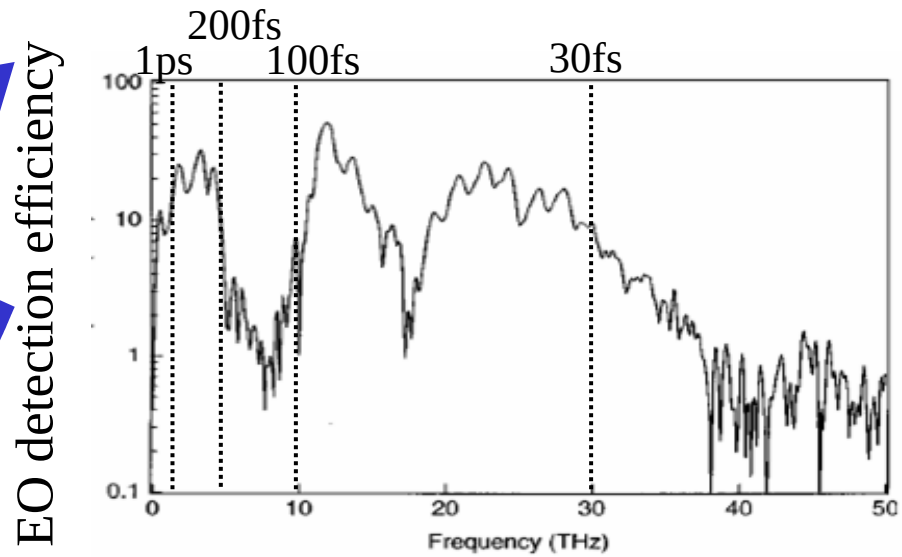
time-resolution capability….

300 fs

Calibration of material properties….

- phase matching, crystal absorption
- $\chi^{(2)}(\omega)$ coefficient frequency dependence

Limits ability to recover true electric field.



- Alternative materials (GaP, GeSe,…)
- Interpolation of data through missing region

30 fs

Bench marking of diagnostic..

Calibration of EO crystals..

- EO coefficient frequency dependence , $\chi^{(2)}(\omega)$

  Requires known source of ultrafast THz…

  …no such source available for <100fs pulses

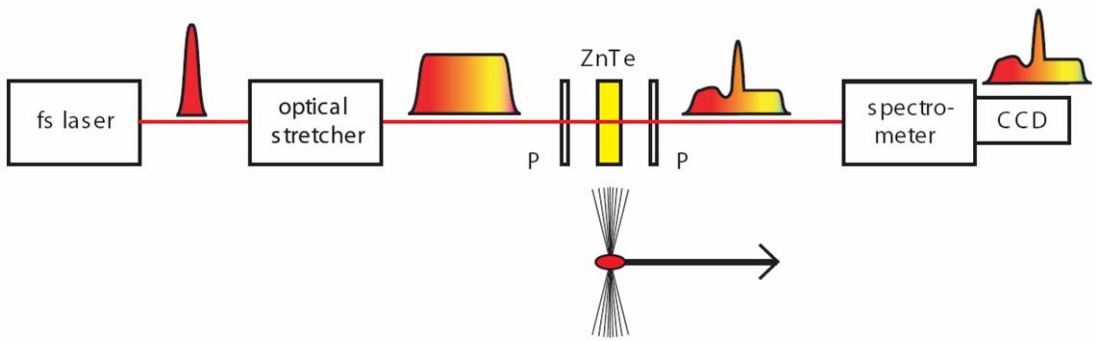
Calibration through CSR spectrum? (not unique)

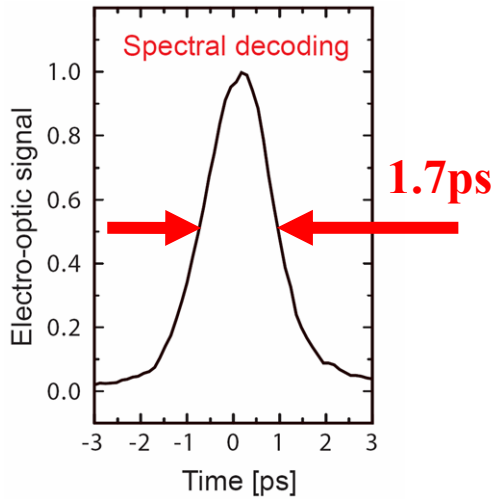
Calibration with transverse deflecting cavity?

- In situ initial calibration
- calibration can reliably be extrapolated to shorter time scales

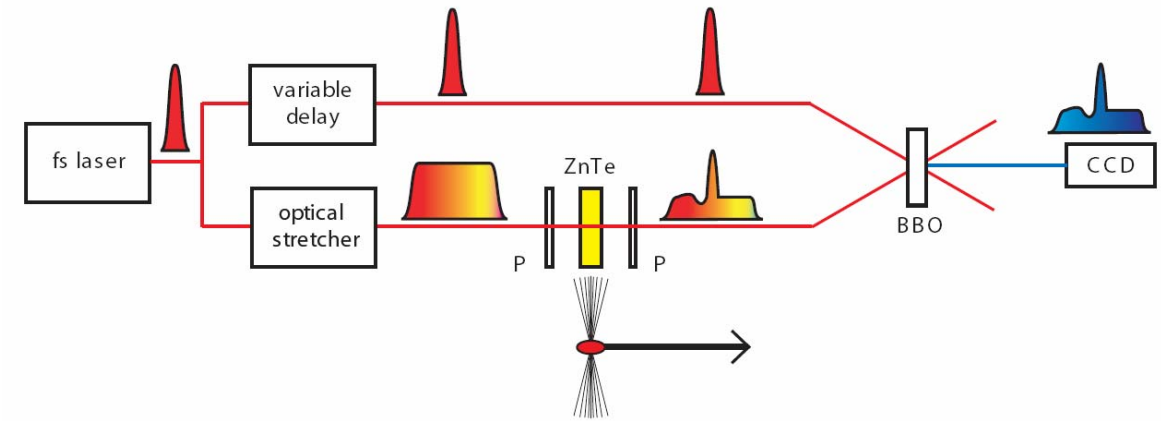
Electro-optic detection of Coulomb field

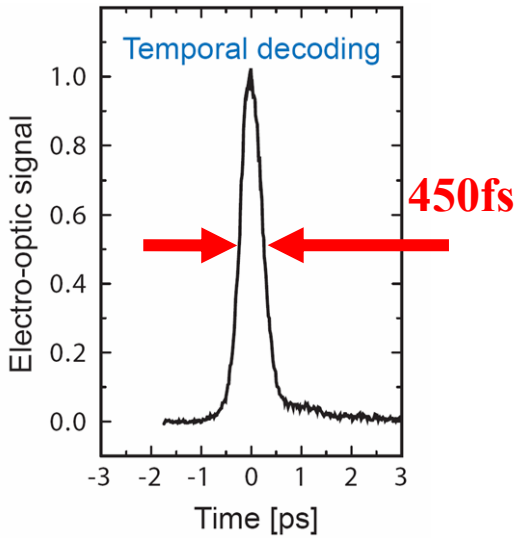
Spectral decoding method





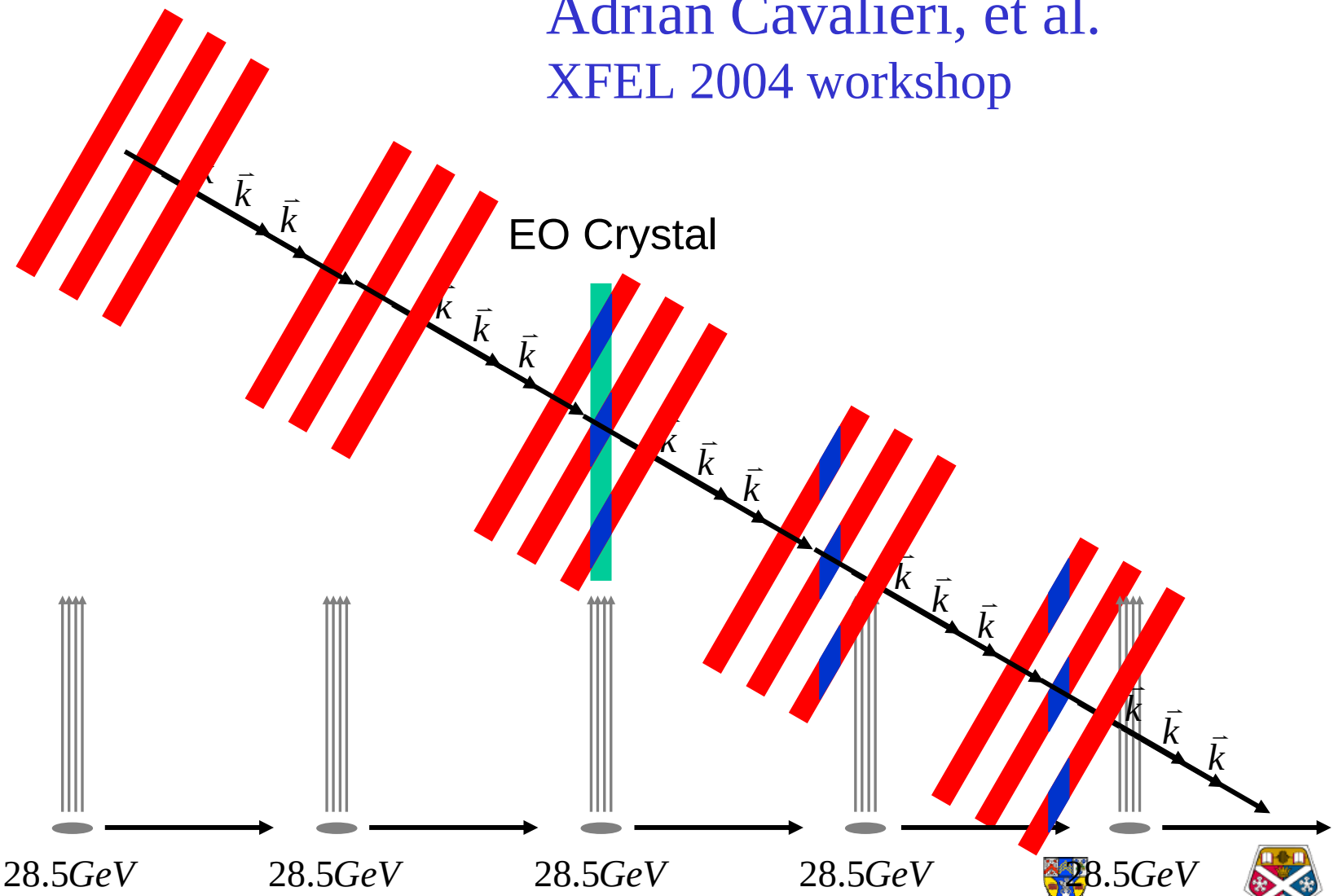
Temporal decoding method





Spatially Resolved Electro-Optic Sampling

Adrian Cavalieri, et al.
XFEL 2004 workshop



Spectral decoding

- Temporal **limit** on bunch length (~1ps)
- Temporal resolution ~ [time window]$^{1/2}$

- High repetition rates
  ~100MHz laser oscillator
  detection with photodiode arrays (?)

Temporal decoding

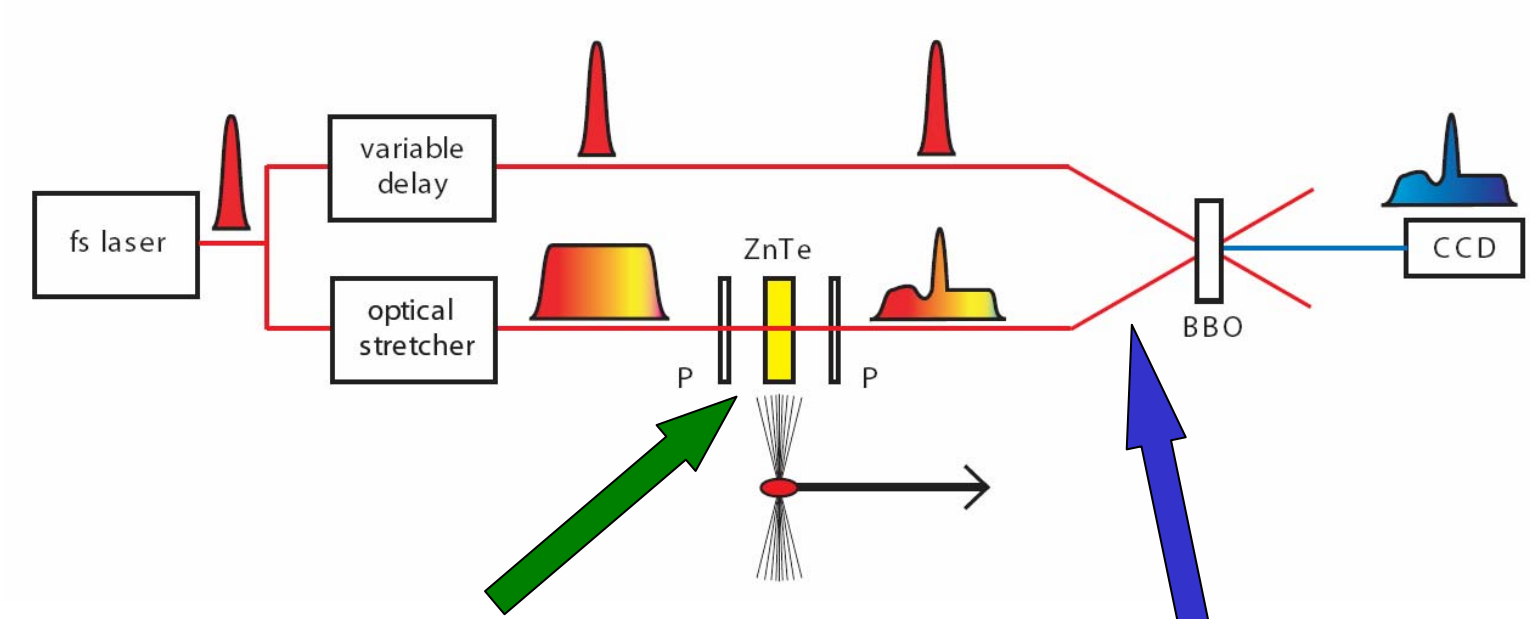
- High temporal resolution
- Large time window

- Low repetition rates
  kHz amplified laser
  amplified CCD camera

Time-Space encoding
(SLAC/DESY method)

- High temporal resolution
- moderate time window
- high repetition rates (?)

Temporal decoding…

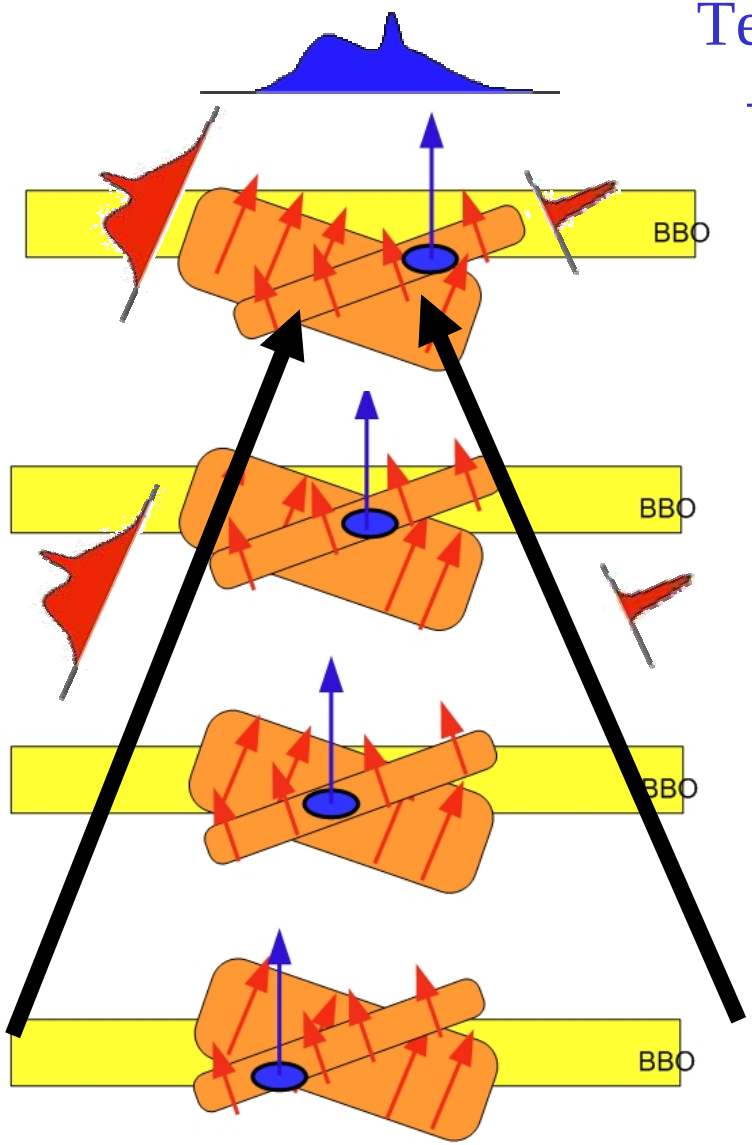


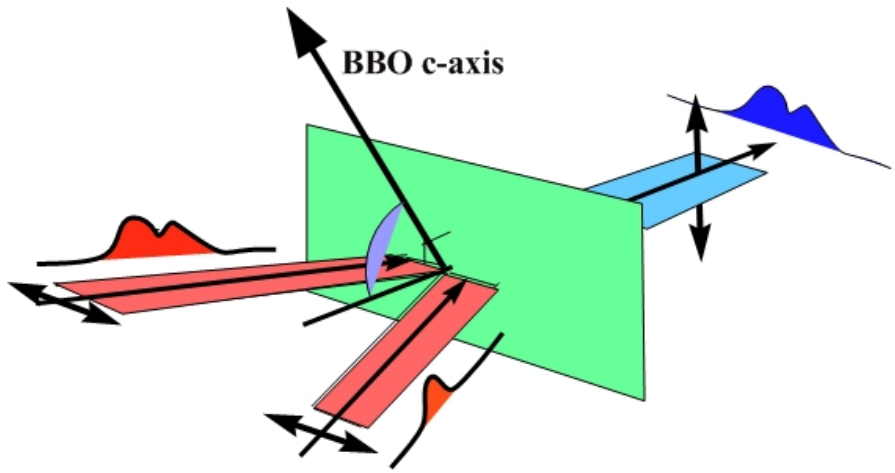
Chirped probe focussed on ZnTe in beamline (sampling field at single point)

Probe expanded and collimated for cross-correlator (for temporal-spatial mapping)

Single-shot “temporal decoding” of optical probe

Temporal profile of probe pulse
→ Spatial image of SHG





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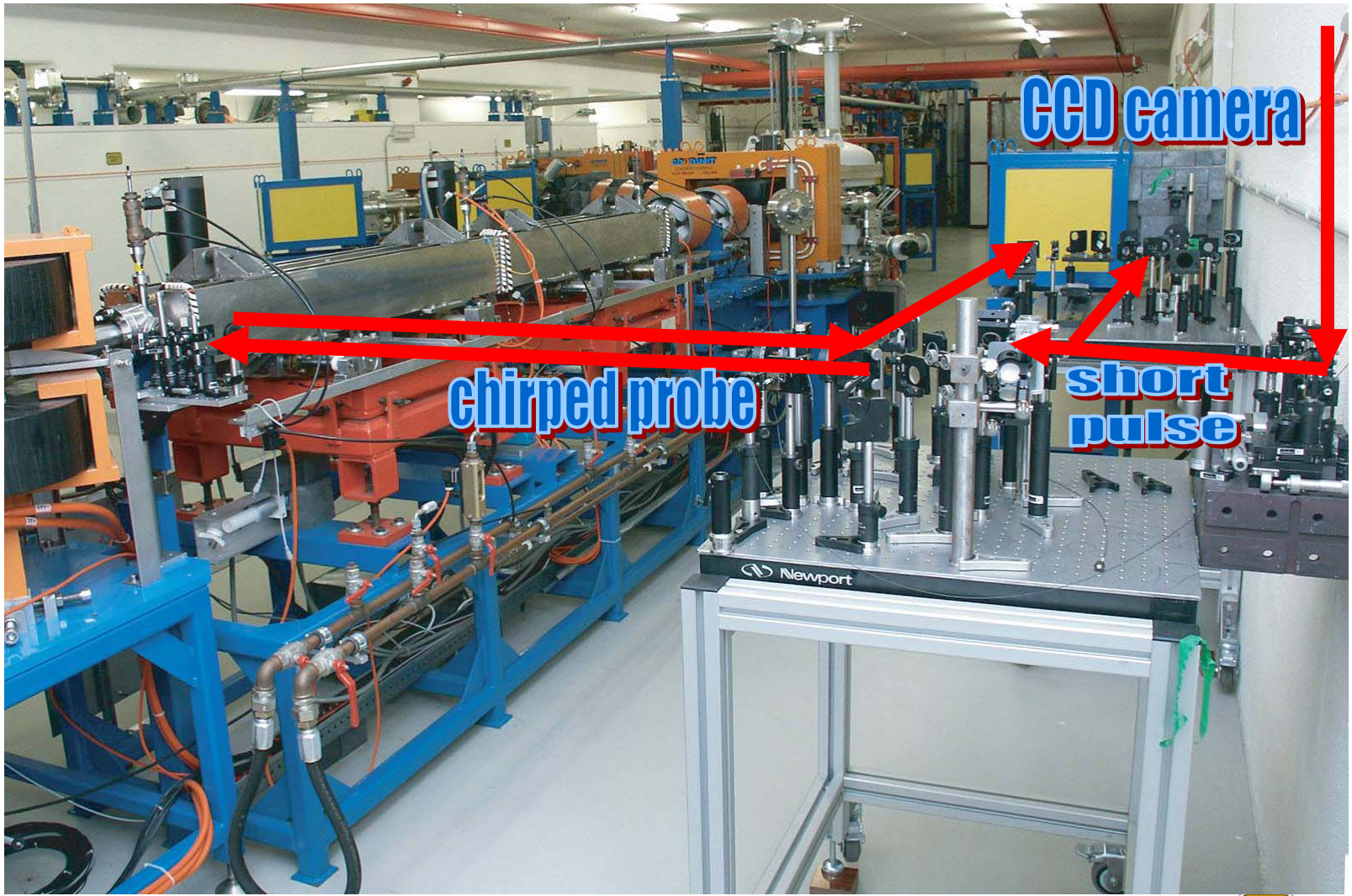
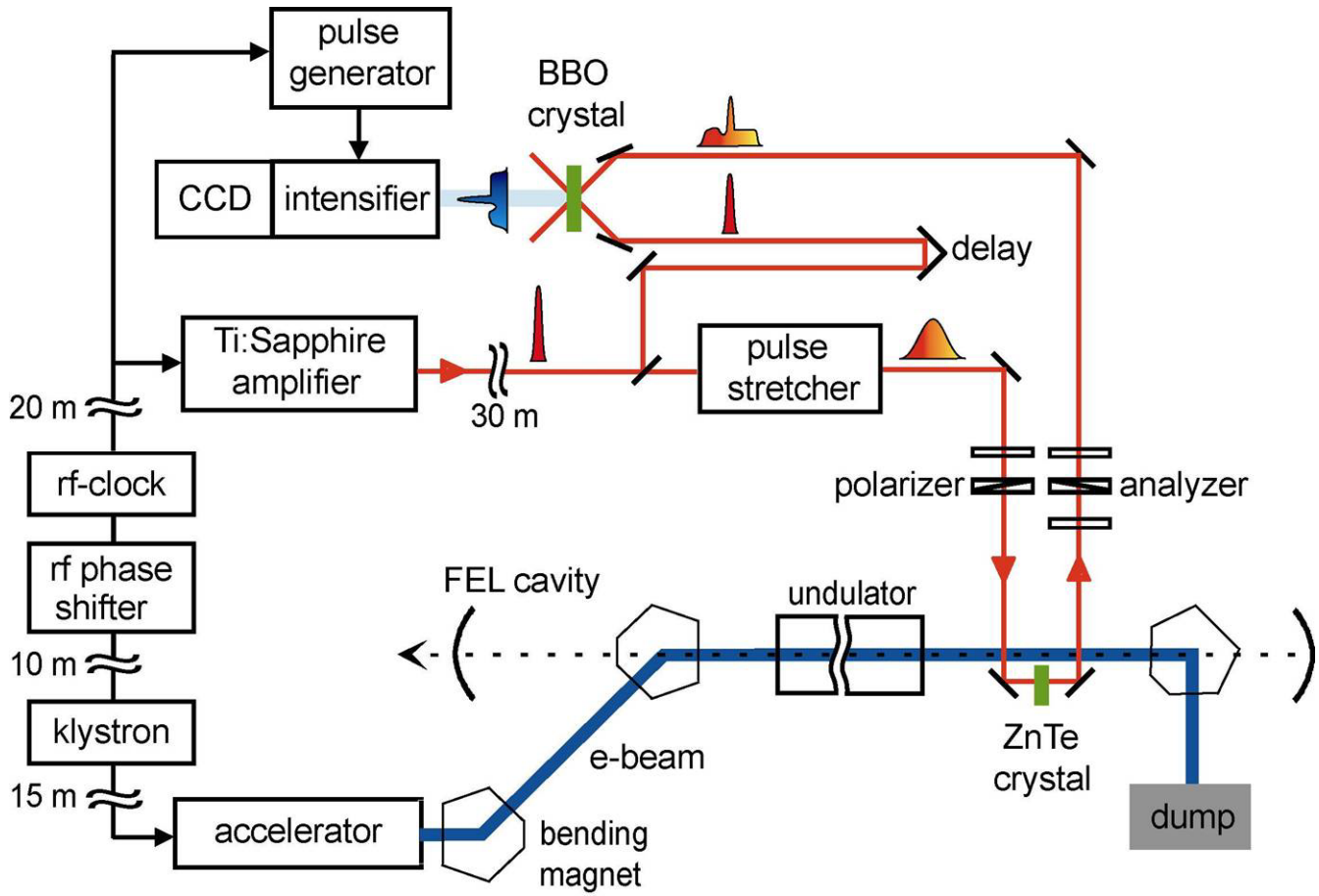
50MeV electron beam measurements

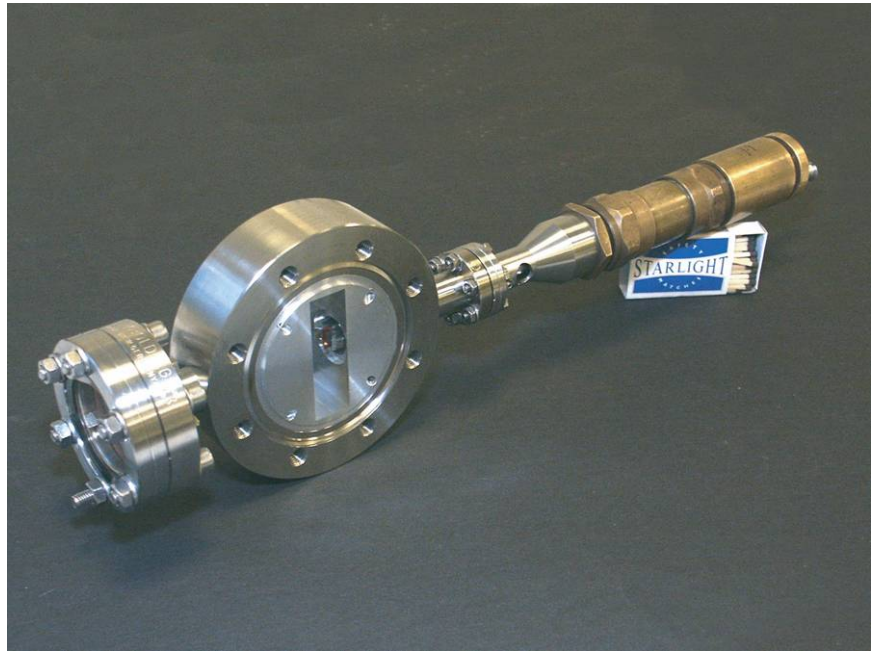
FELIX FEL facility, Rijnhuizen, Netherlands

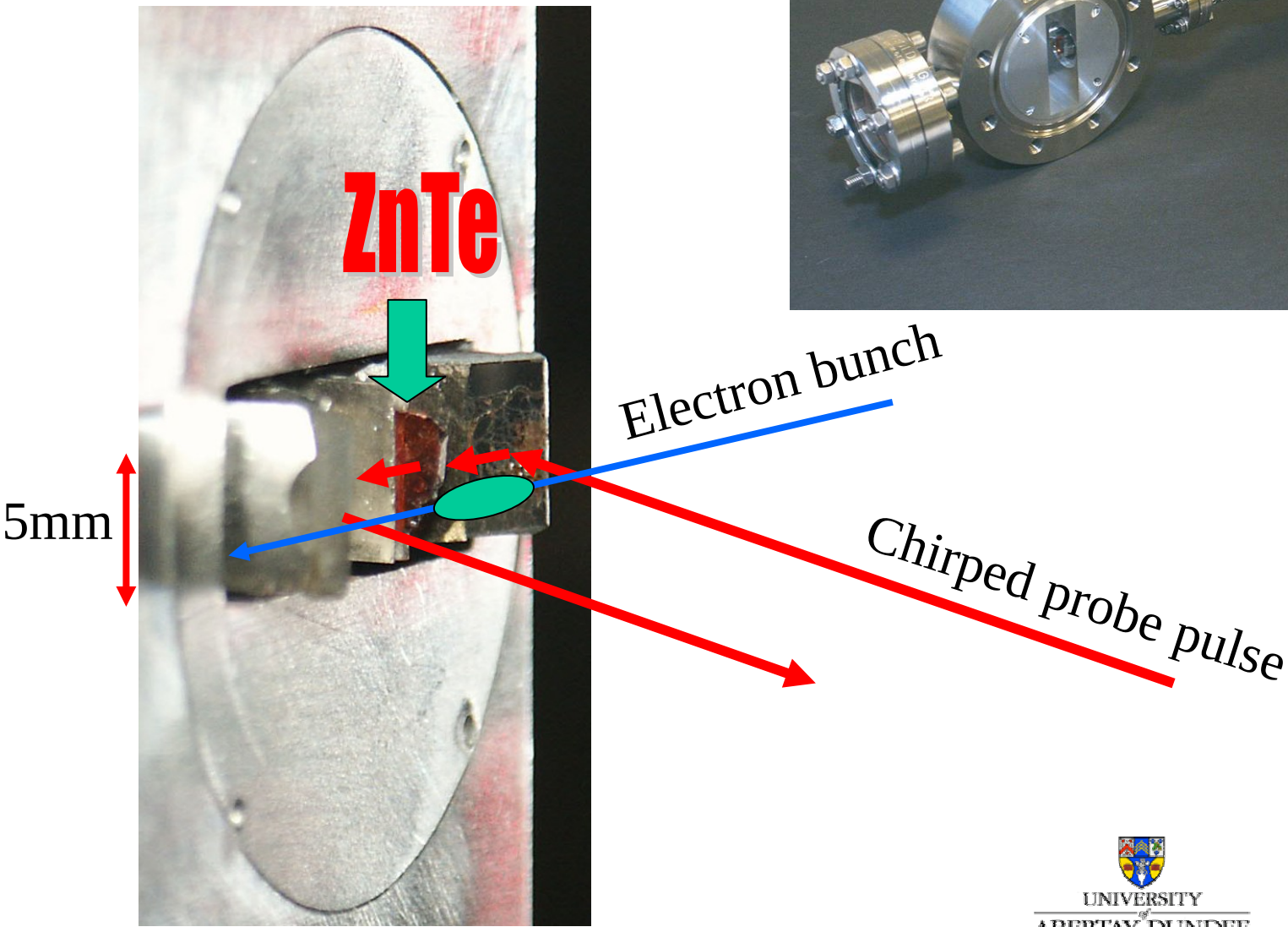


30-50MeV electron beam measurements

FELIX FEL facility, Rijnhuizen, Netherlands







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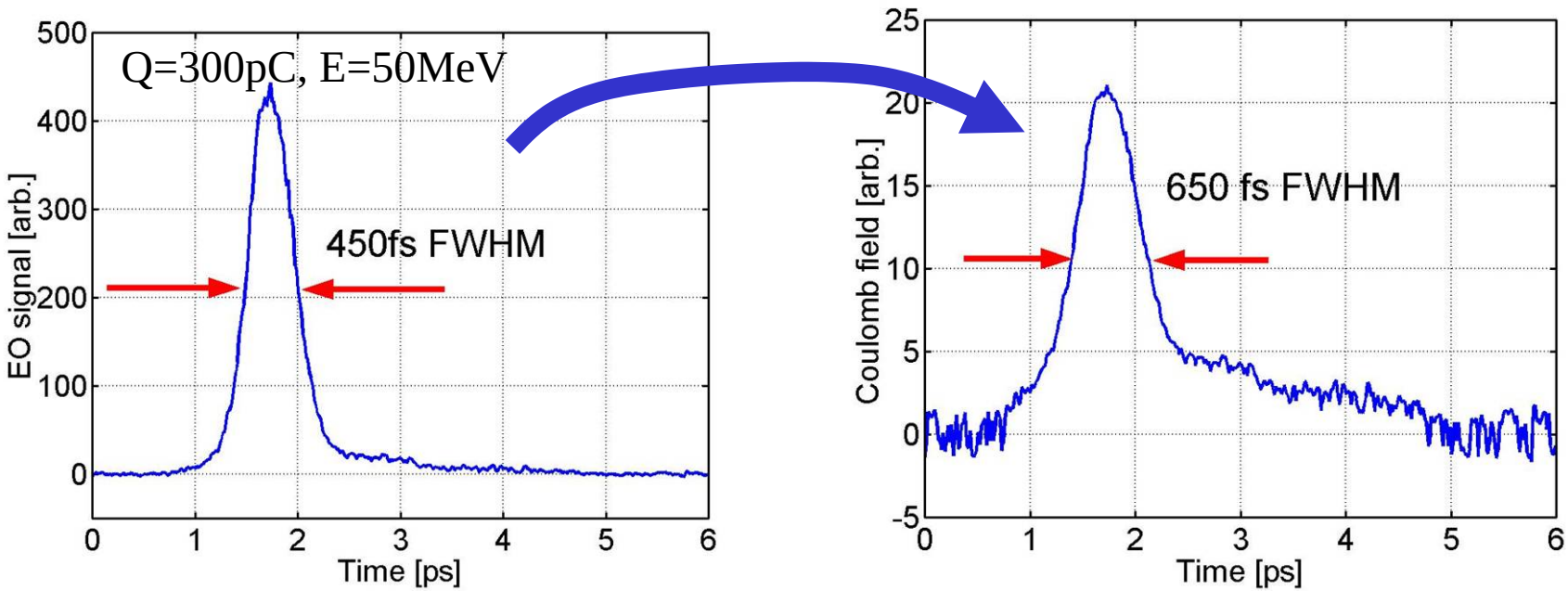
Electro-optic Signal vs Coulomb Field

"crossed-polariser" configuration

$\Rightarrow$ EO signal α [Coulomb Field]^2

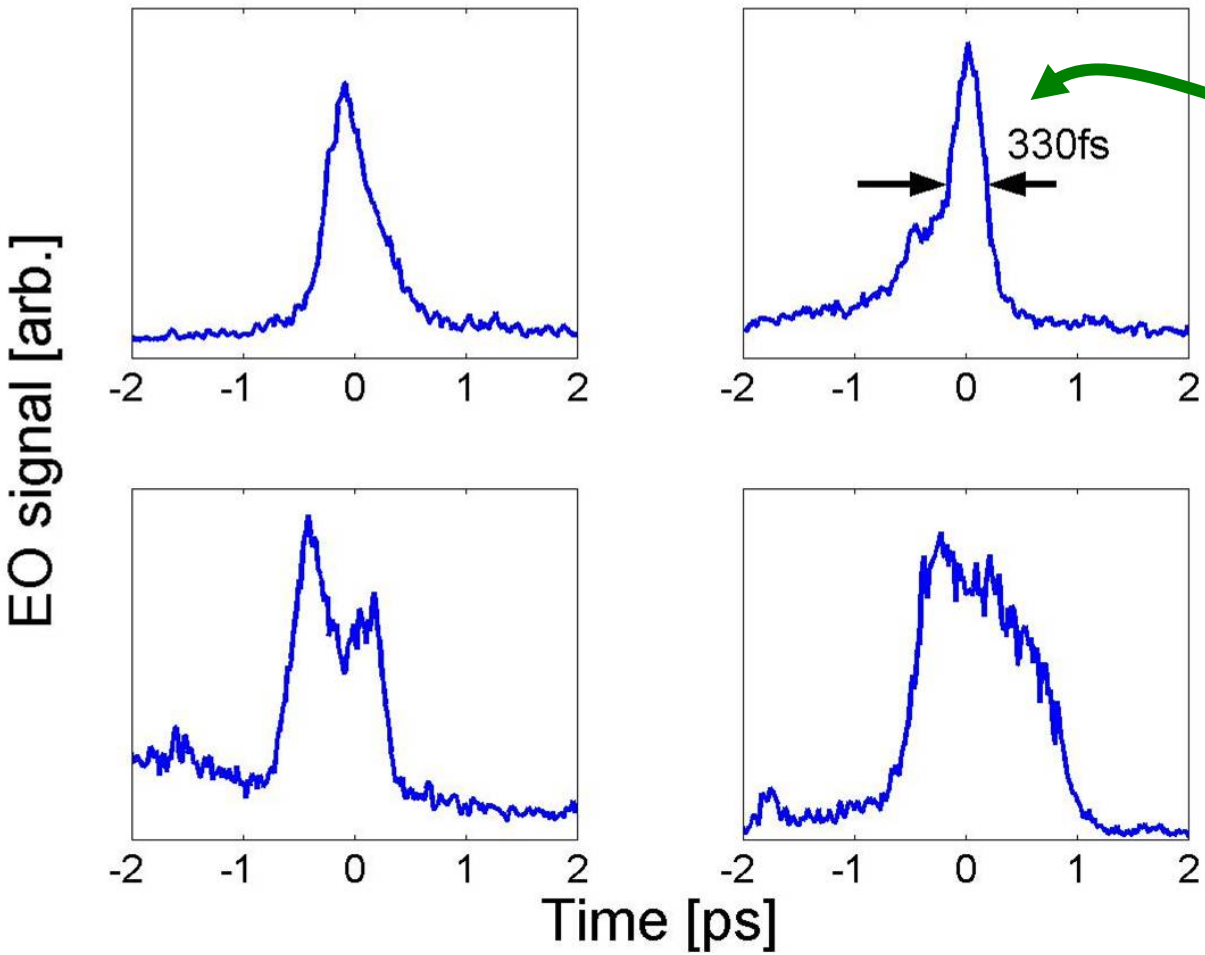


Berden, Jamison, et al., Phys. Rev. Lett. **93** 114802 (2004)

measurements have been made with

150pC < Q < 300 pC

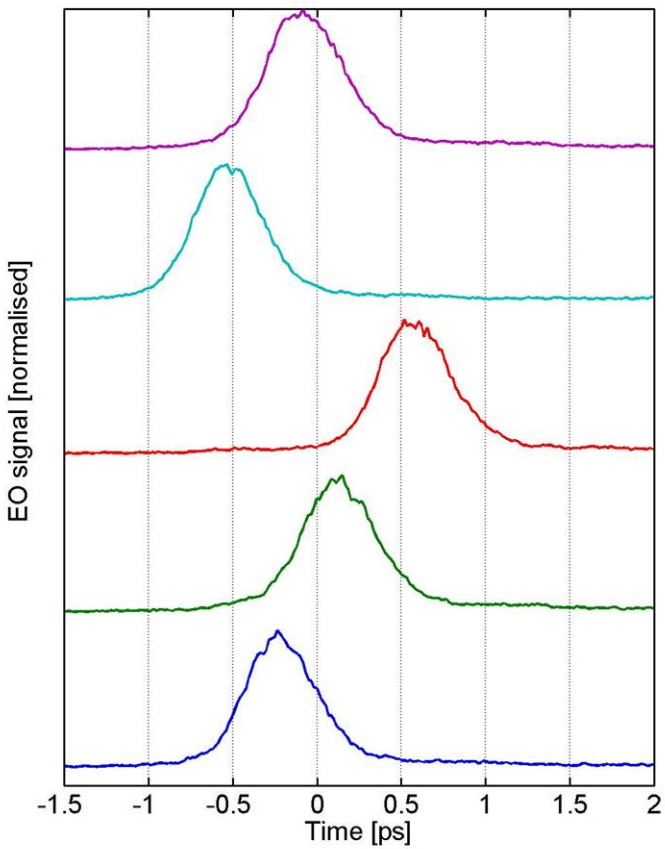
Real time monitoring and bunch profile modification…

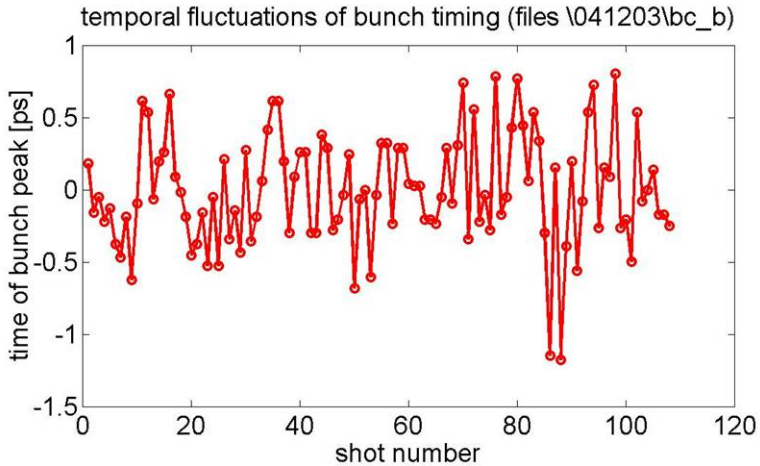


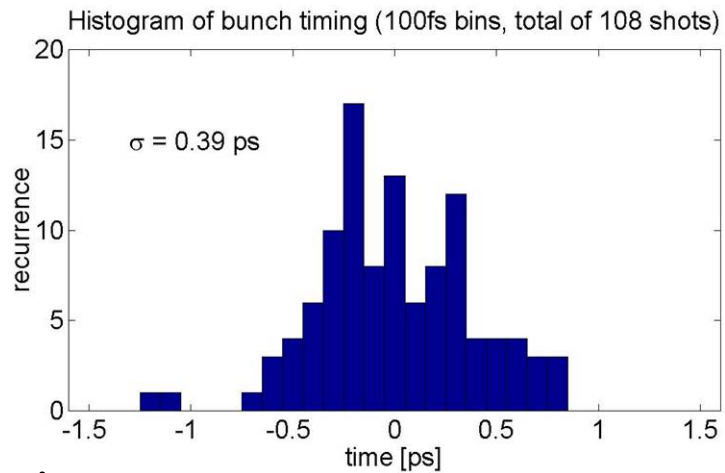
. ≅ 450 fs FWHM Coulomb field on sub peak

Bunch profile modified by changing the buncher and accelerator phase.

EO measurement of bunch timing jitter





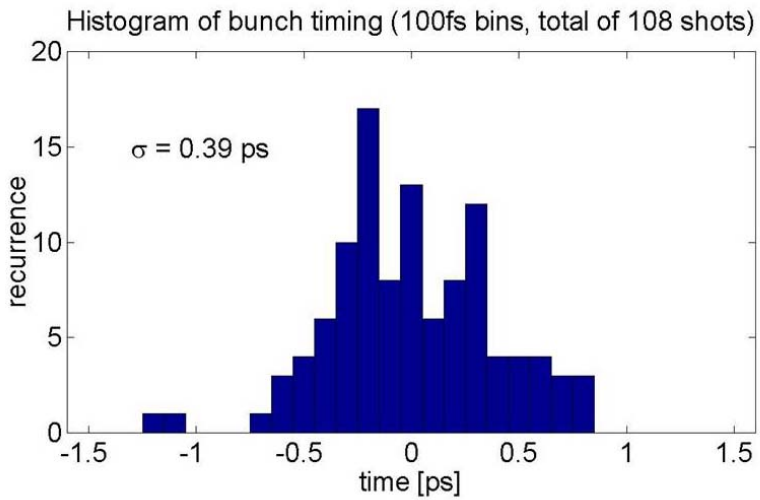


Bunch timing jitter ~ bunch duration

Synchronisation and bunch timing jitter

Probe laser synchronised to RF

- ~100fs laser-RF synchronisation
- Jitter measurement also subject to laser beamline path length changes
  (active stabilisation?)

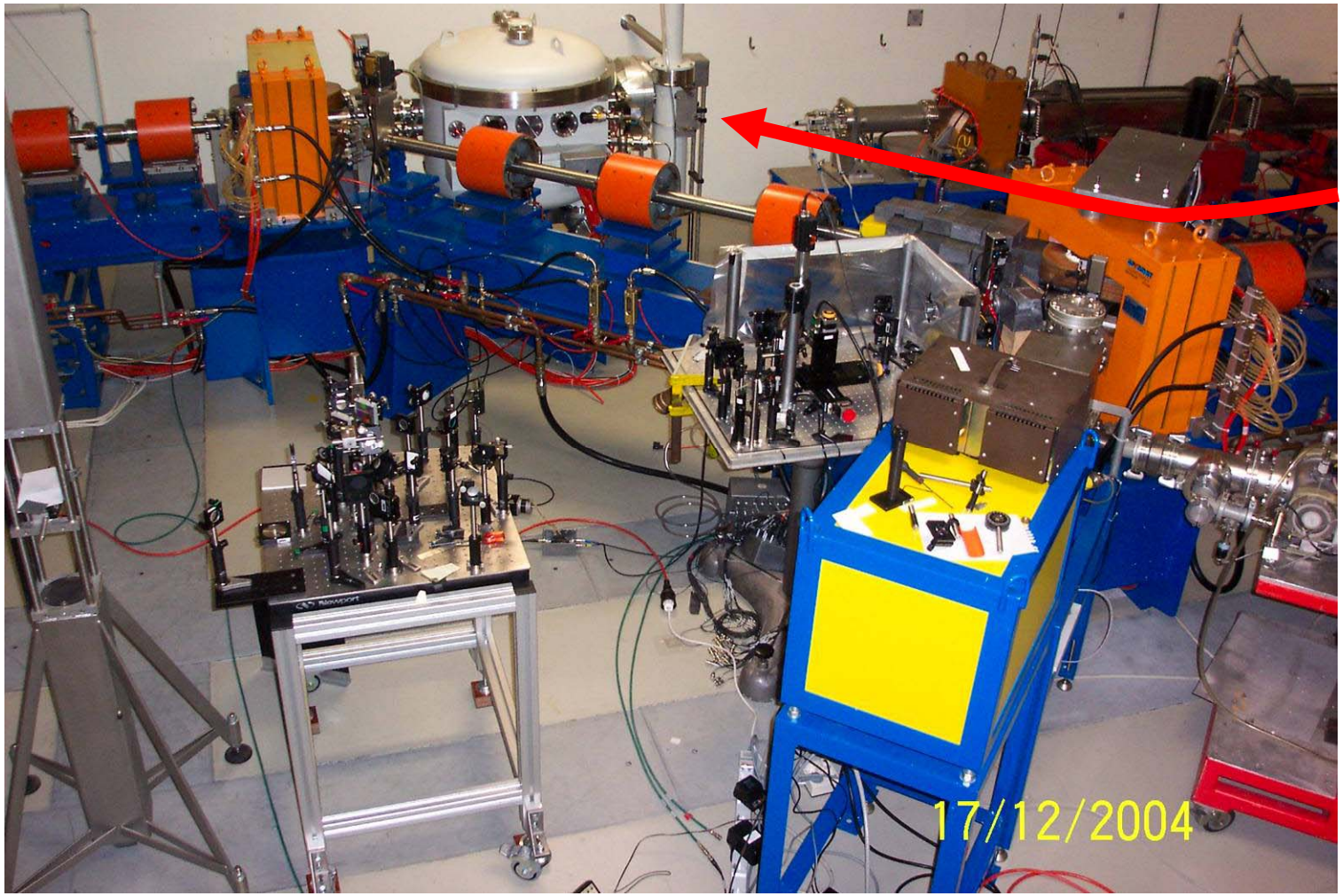


bunch sampling rate < 1 kHz

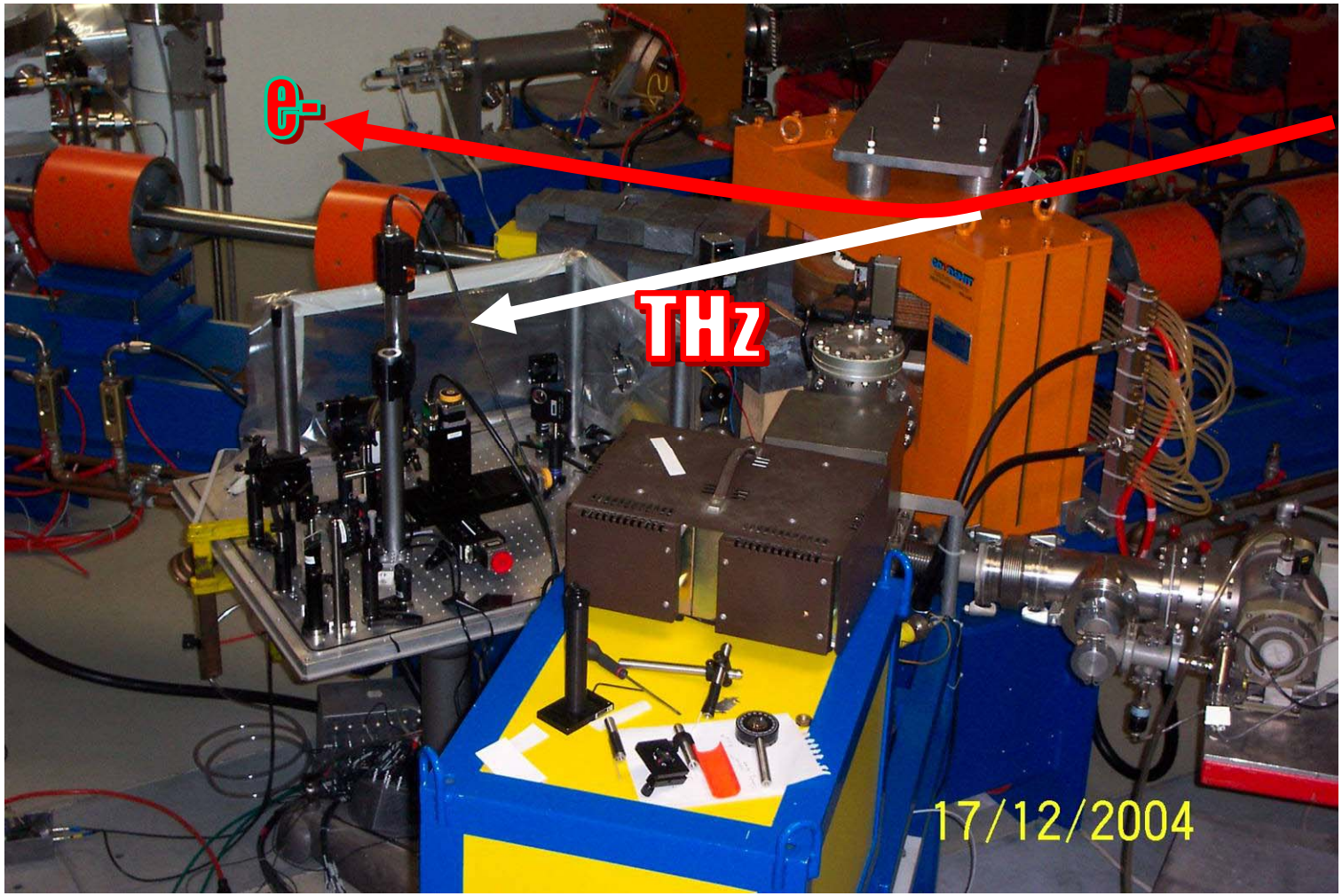
(could envisage ways for rapid sampling of a pair of bunches)

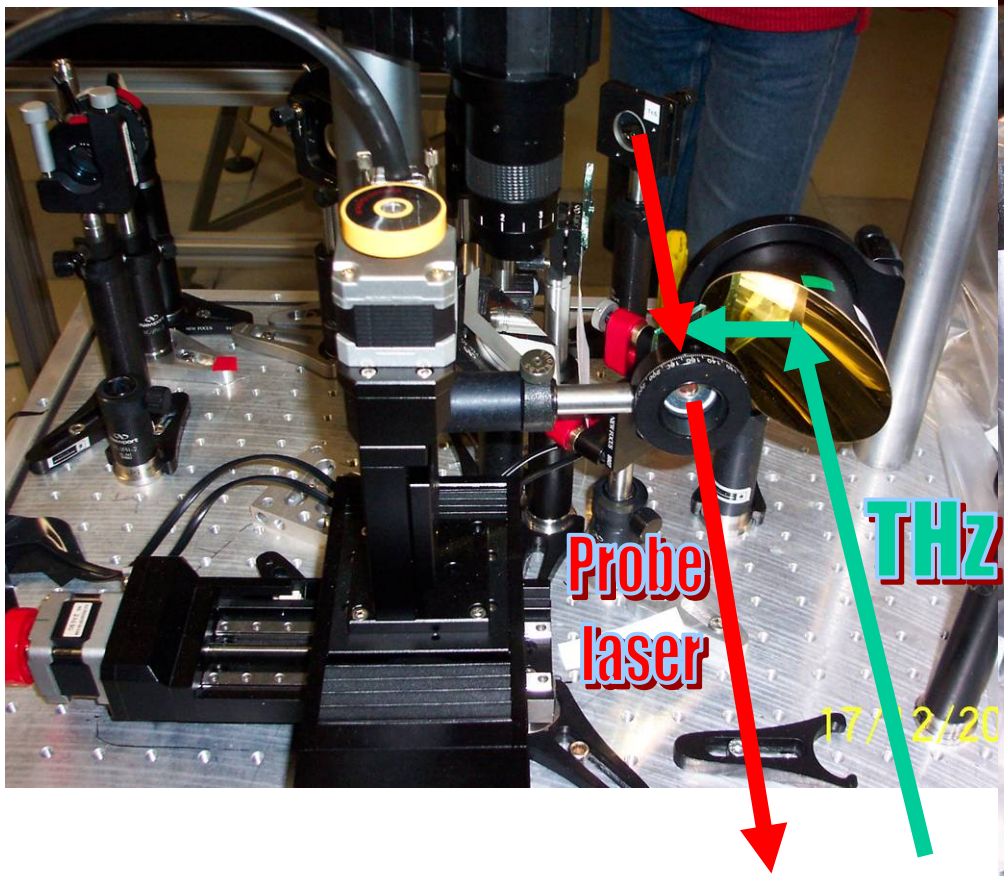
Additional timing jitter measurement (or synchronisation?) between photoinjector laser and EO probe laser?

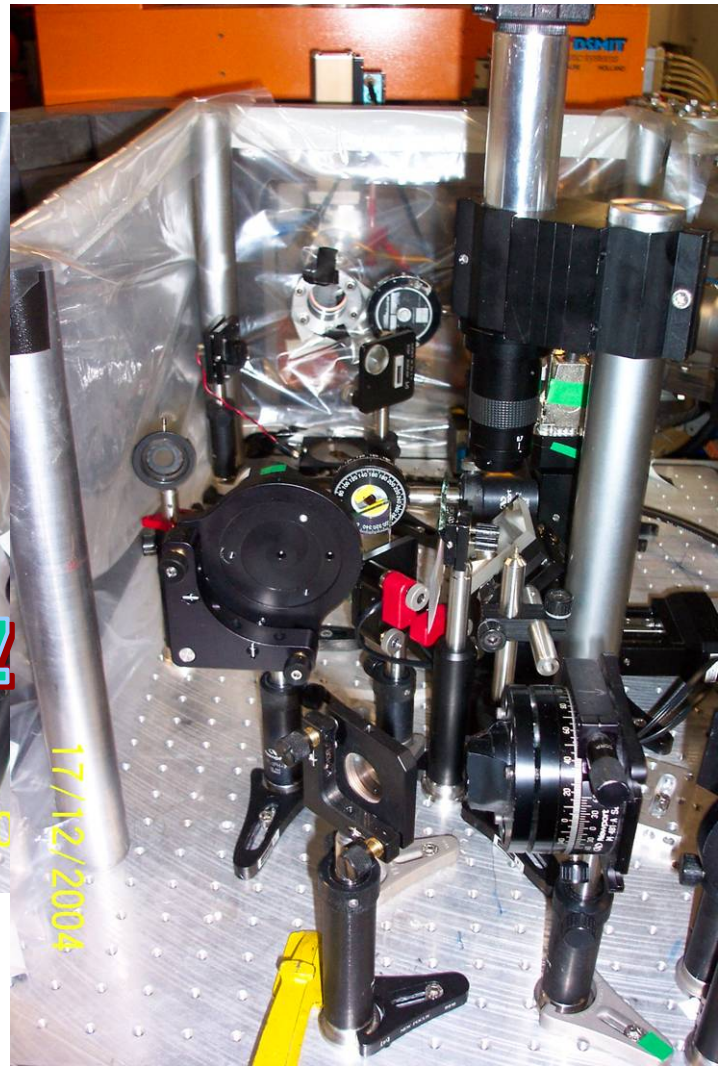
Electro-optic detection of edge radiation..



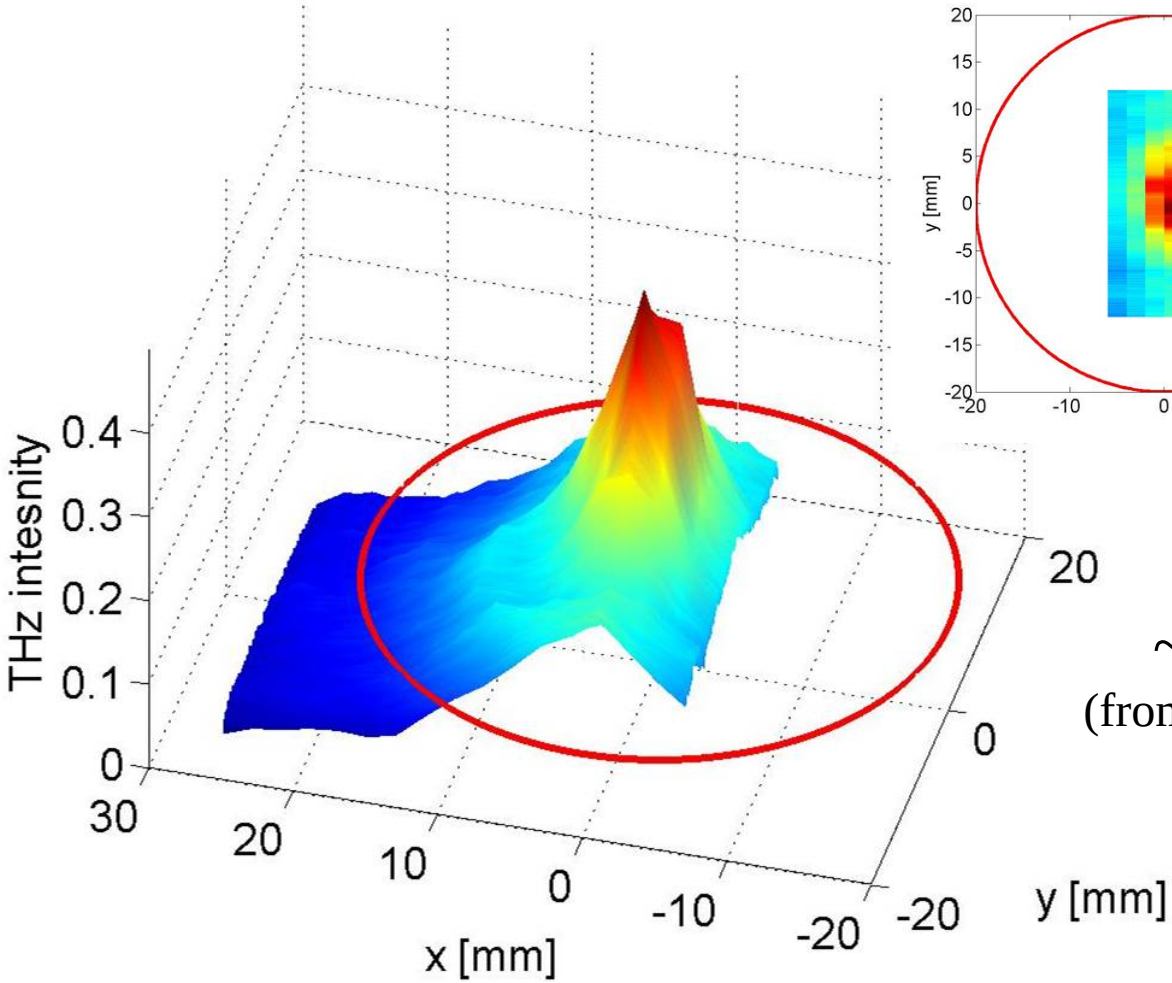
Electro-optic detection of edge radiation..

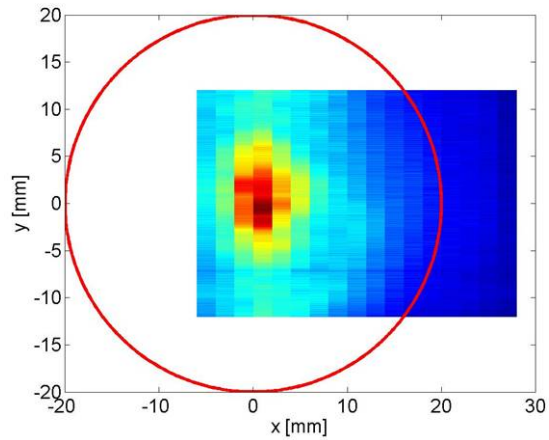



Probe
laser
THz


17/12/2004

Edge radiation beam profile: exit window





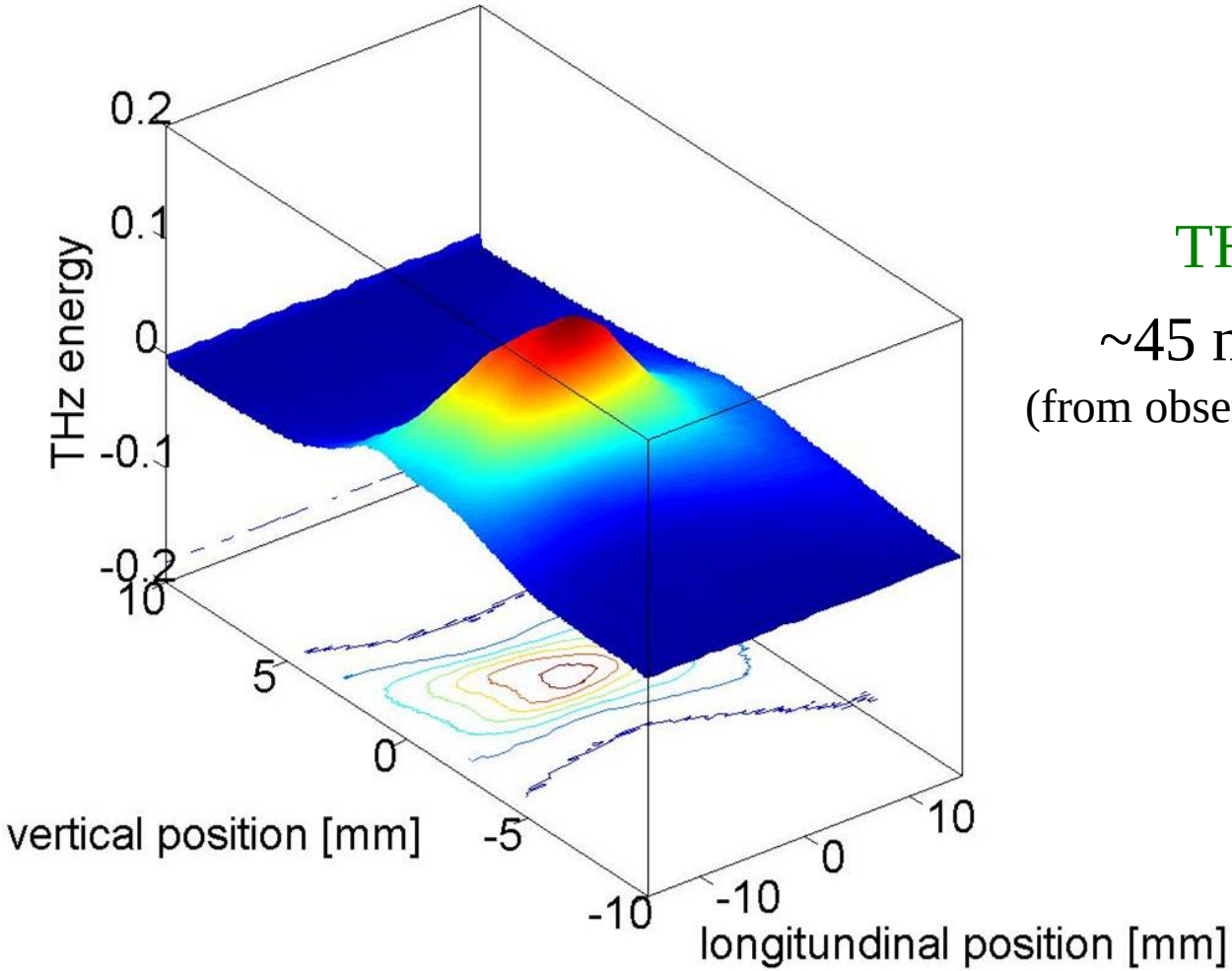
THz pulse energy

~0.3 μJ/electron bunch

(from observed ~1.8 mJ/macrobunch)

Bend radius ρ=0.39m
200pC, 44 MeV

Edge radiation beam profile: EO detection focus



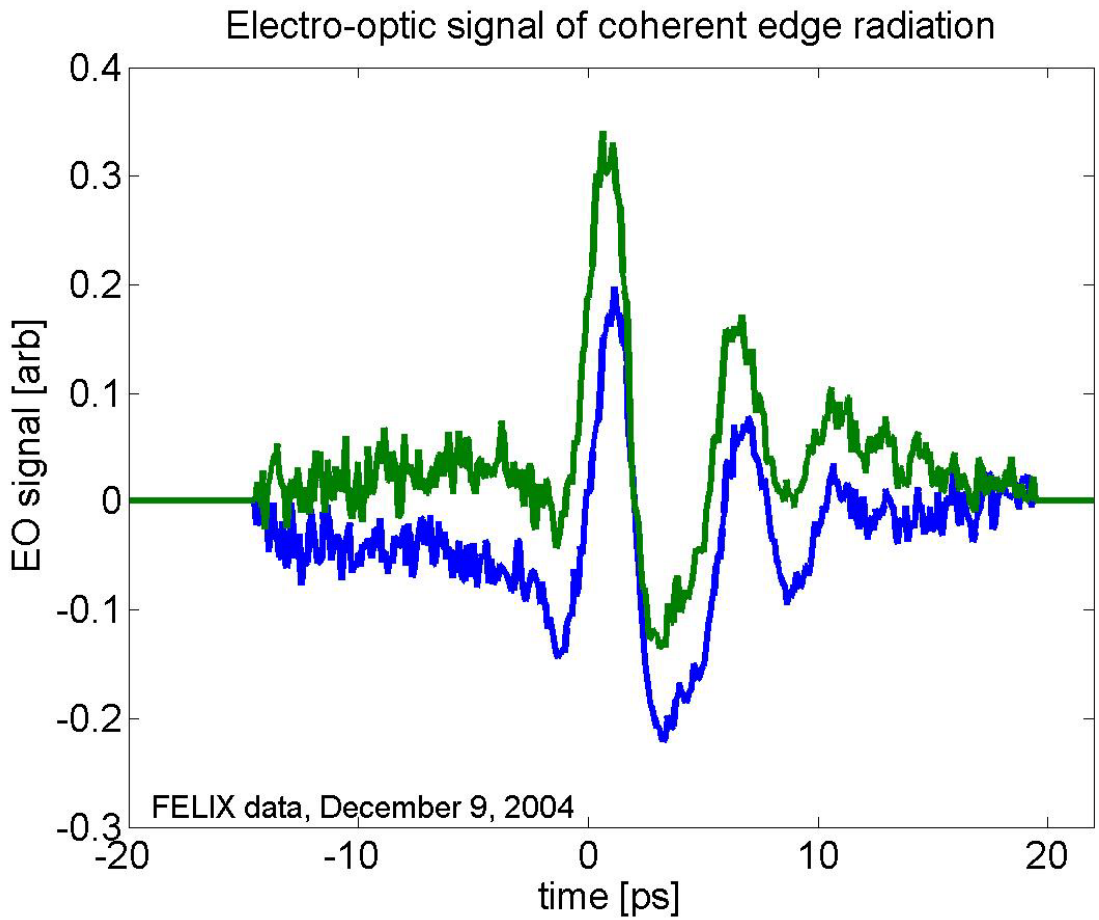
THz pulse energy

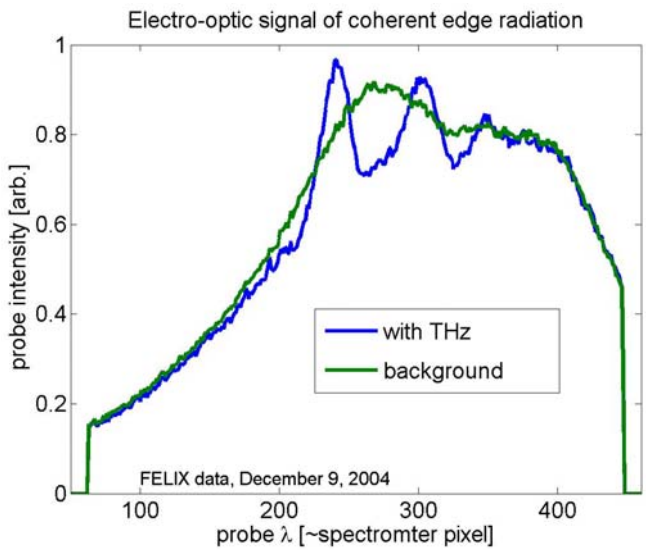
~45 nJ/electron bunch

(from observed ~280μJ/macrobunch)

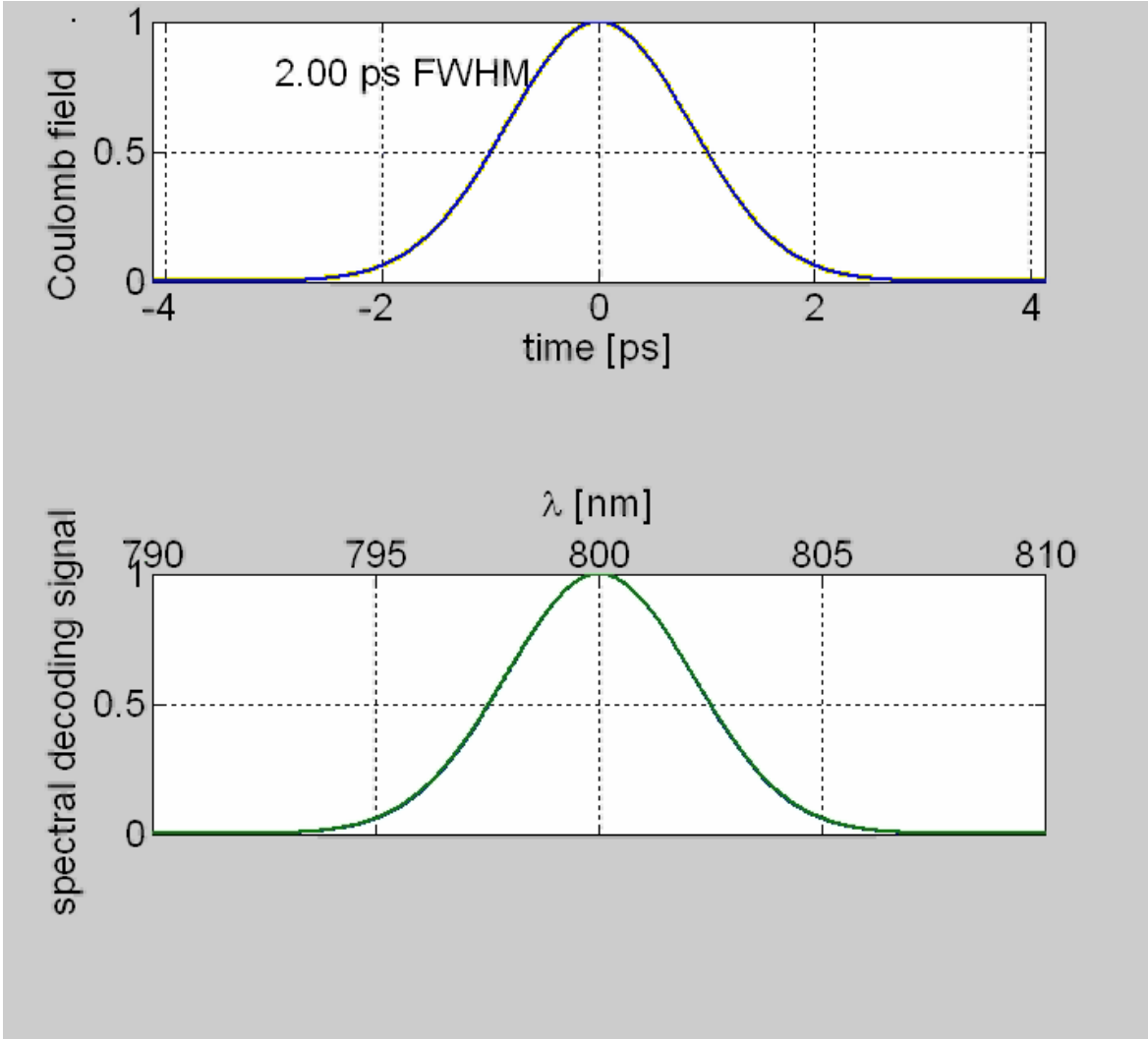
Electro-optic detection of edge radiation..

using spectral decoding technique

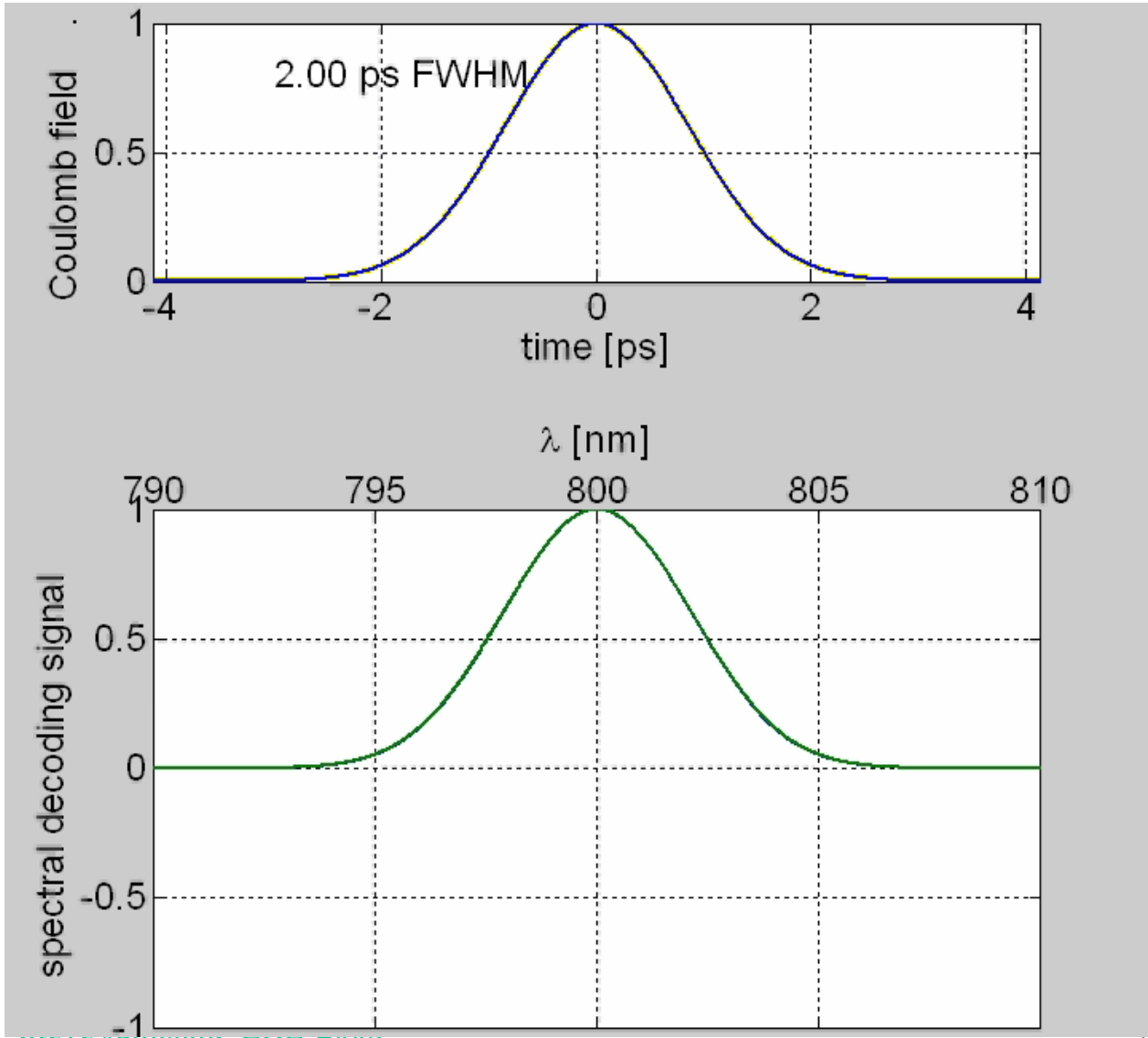




Spectral decoding signal as bunch length decreases – zero-background detection



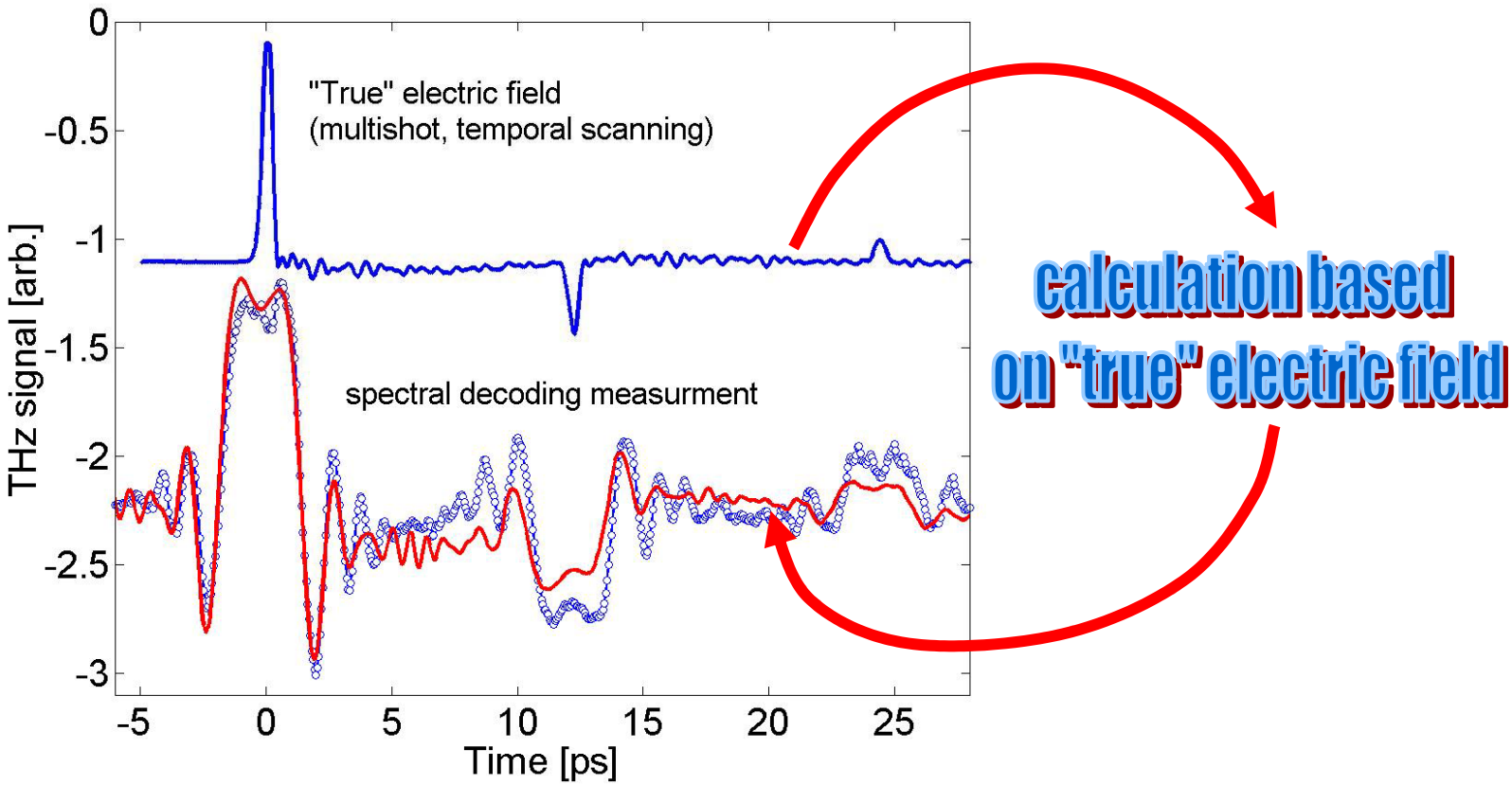
Spectral decoding signal as bunch length decreases – balanced detection



Potential for fast measurement of….

- oscillation magnitude
  ~ 1/(bunch length)
- peak position
  => bunch synchronisation

Observation oscillating features of spectral decoding



Jamison et al. Opt. Lett. **18** 1710 (2003)

Summary…..

Capabilities of EO detection

- Demonstrated profile measurement of 650fs FWHM bunches, 300pC
- Present time resolution of ~300fs,
- Real-time bunch shape monitoring and adjustment
- Challenges remain in getting sub-200fs resolution (materials, EO response deconvolution, ...)
- Many variations of EO detection possible
  – scope for addressing specific diagnostic requirements

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(alpha-X project on wakefield accelerator driven FEL)

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Real time beam adjustment

(beam-steering towards crystal)