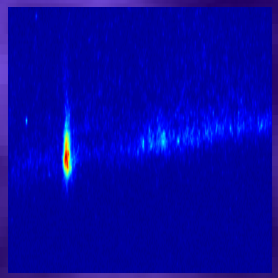

Electro-optical measurements of the longitudinal electron bunch profile at FLASH

Bernd Steffen (DESY)

for the EO@FLASH team
(FELIX, DESY, Daresbury, Dundee)

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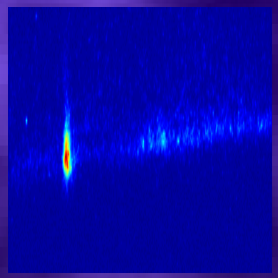
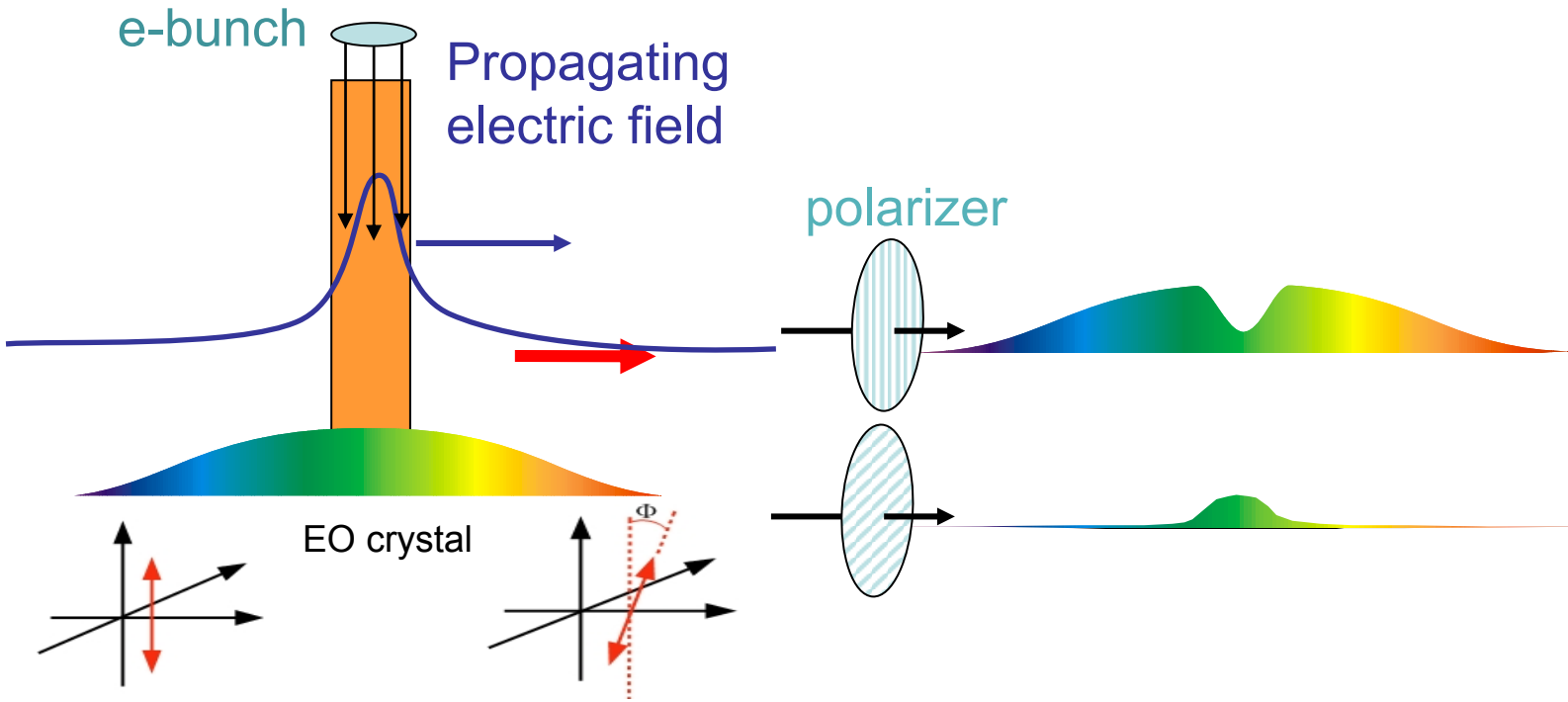


Electro-optic longitudinal bunch profile measurements

Convert bunch Coulomb field into optical intensity variation.

Coulomb field encoded into optical probe

Decoding: temporal intensity variations in single laser pulse



Effective polarisation rotation proportional to Coulomb field

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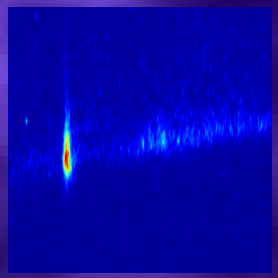
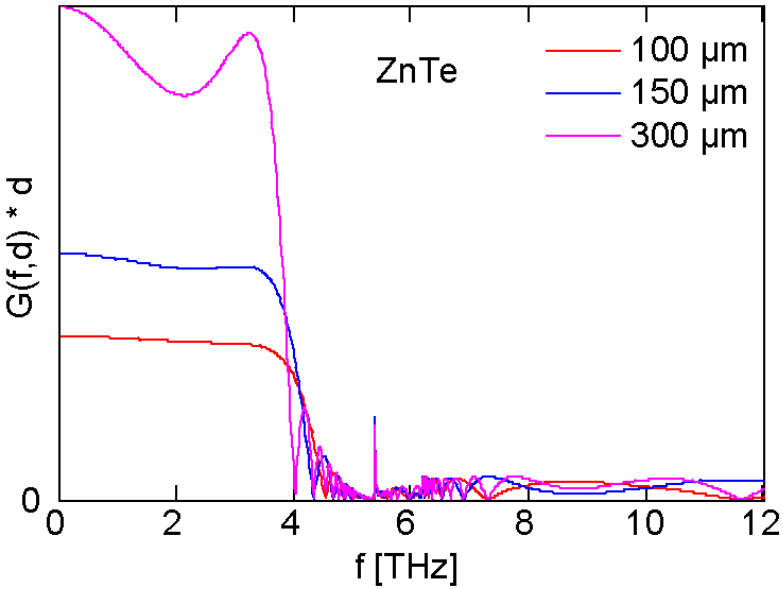
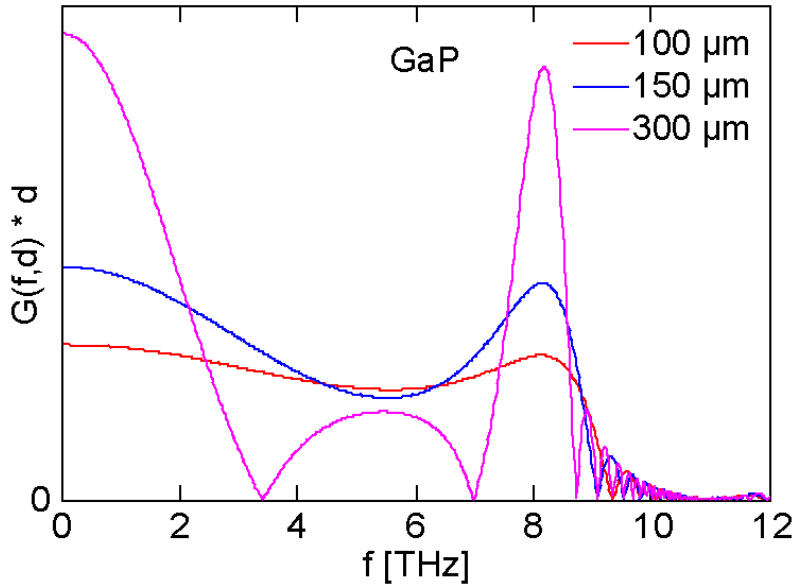


Electro-optic crystals





$$G(f,d) = \frac{2}{1+n(f)+i\kappa(f)} \frac{1}{d} \int_0^d \exp\left[i\,2\pi f\, z \left(\frac{1}{v_{ph}(f)} - \frac{1}{v_g} \right) \right] dz$$

Resolution limited by:
- Crystal phonon resonance
- Crystal dispersion
- Phase mismatch between Coulombfield (THz) and laser (optical)

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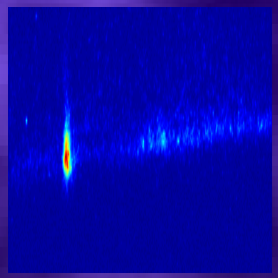
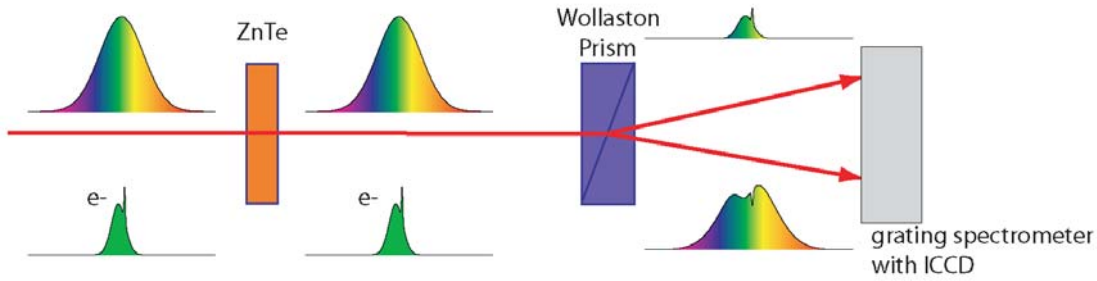


Crossed polarizer vs. balanced detection



Signal ~ $\sin^2(\Gamma/2) \approx 0.002$

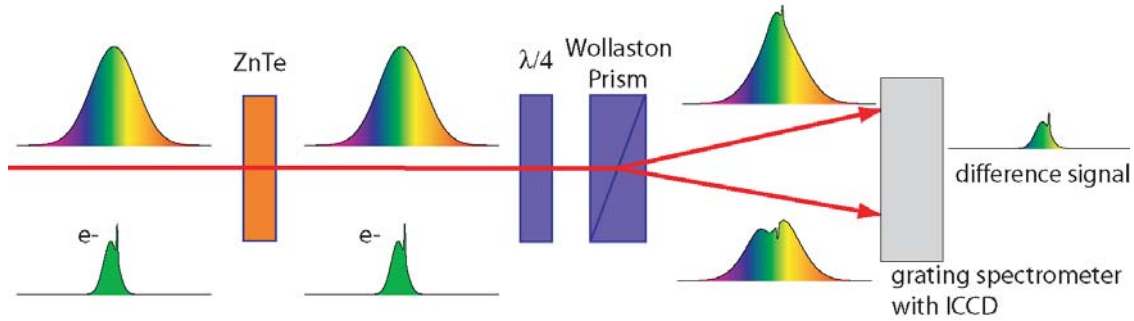
$\Gamma \sim E$ (Γ: phase difference between fast and slow optical axis)

$\Gamma \approx 5°$

+ small background
- nonlinear
- small signals

Difference signal ~ $\sin(\Gamma) \approx 0.09$

+ linear
+ bigger signals
- big background (50% of I_{max})



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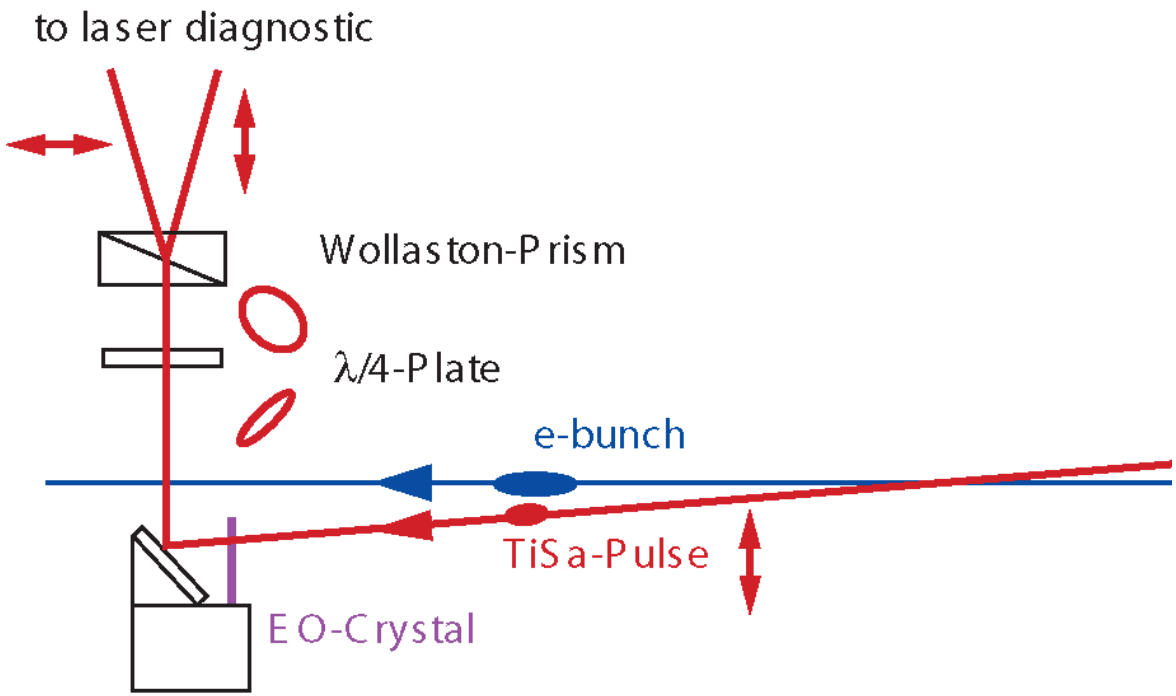
Experimental setup at the VUV-FEL



- the laser system is housed outside the accelerator tunnel including
  - 4 nJ, 15 fs Ti:Sa oscillator
  - 1 mJ, 30 fs Ti:Sa amplifier
- the laser beam is transported via a 20m vacuum transfer line
- current setup allows sampling, spectral and temporal decoding
- currently ZnTe (185µm) and GaP (170µm) crystal mounted

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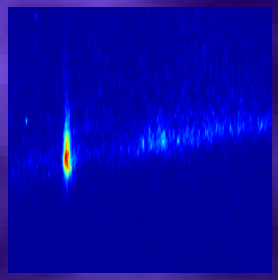
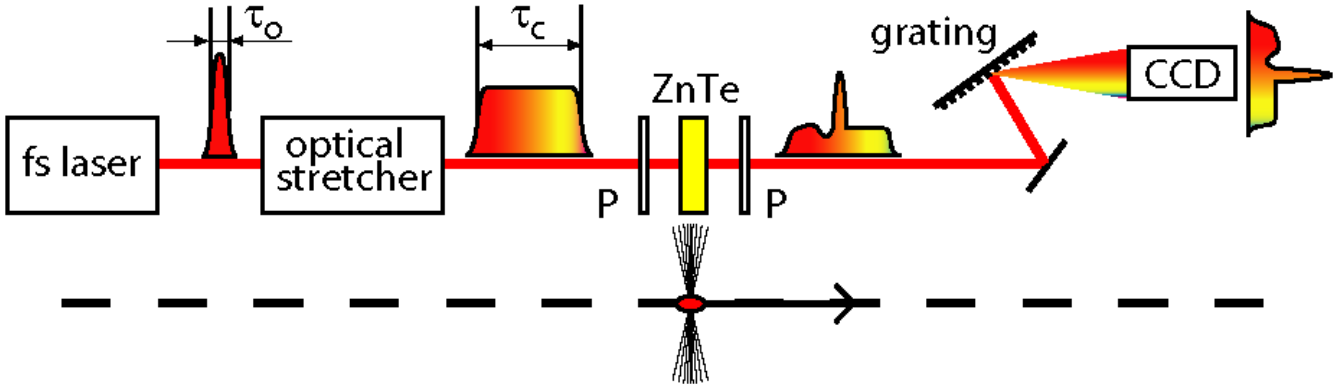


Spectral Decoding



- the laser pulse is stretched in a spectrally sorted way (chirped), the longitudinal structure of the bunch is therefore encoded in the spectrum

- the instantaneous bandwidth of the chirped pulse needs to be sufficient to represent the e-bunch structure

$$\tau_{\mathrm{lim}} \propto \sqrt{\tau_0 \tau_c}$$

• Problem: amplitude modulation by THz pulse creates additional frequency modulation,

⇒broadening and artificial structures

limit ≈ 250 fs (FWHM)

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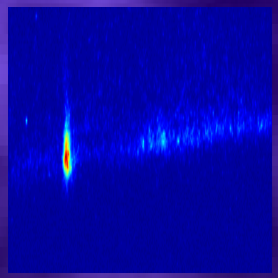
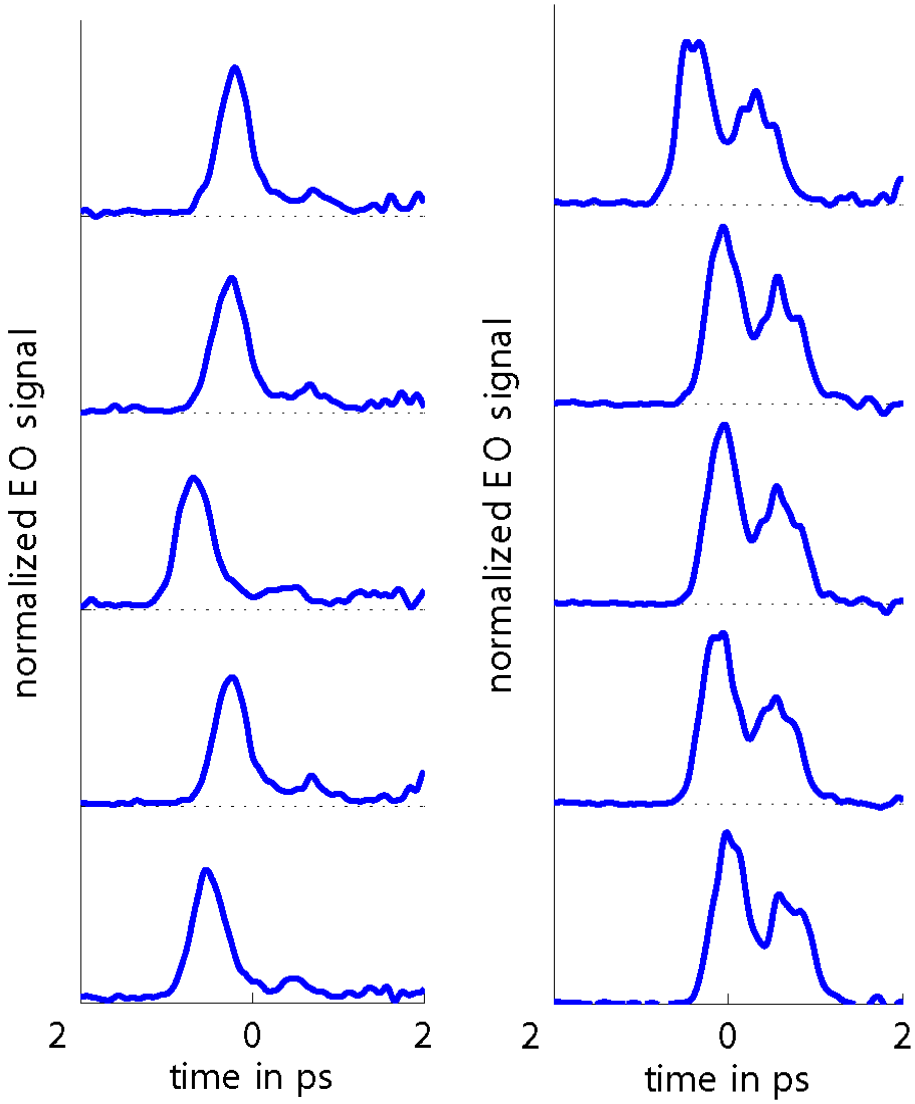


Spectral Decoding

left:
Compressed bunches during FEL operation, 400fs FWHM signal width

right:
Overcompressed Bunches

(300µm ZnTe)



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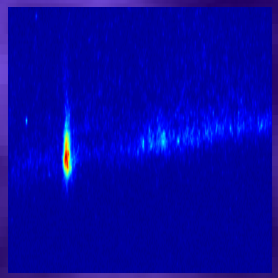
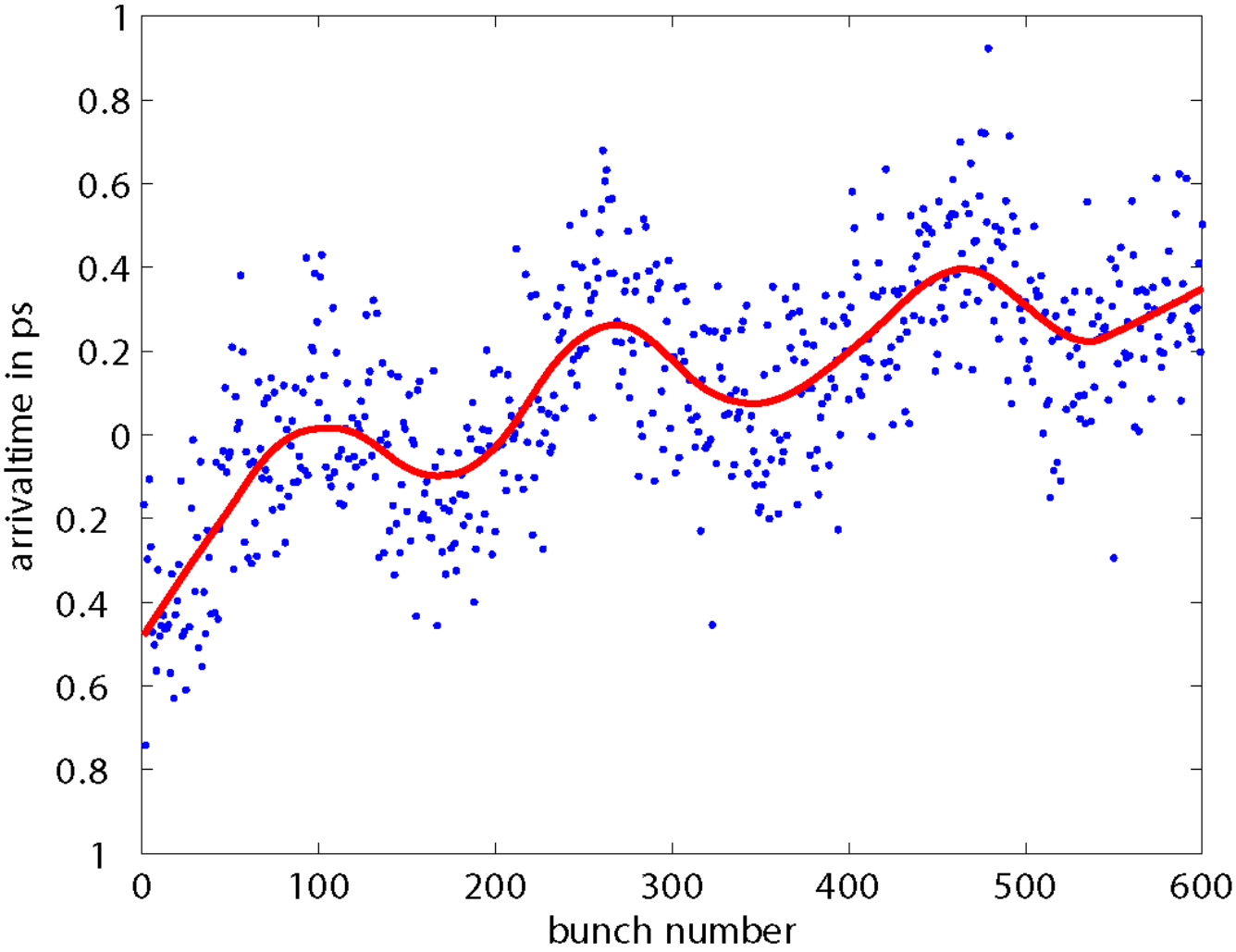


Time jitter measured by EO-SD



Time jitter detectable with 50 fs resolution:

- here 270 fs (rms) over 5 min incl. slow drifts
- without slow drifts typically <200 fs (rms)

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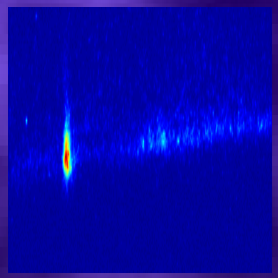
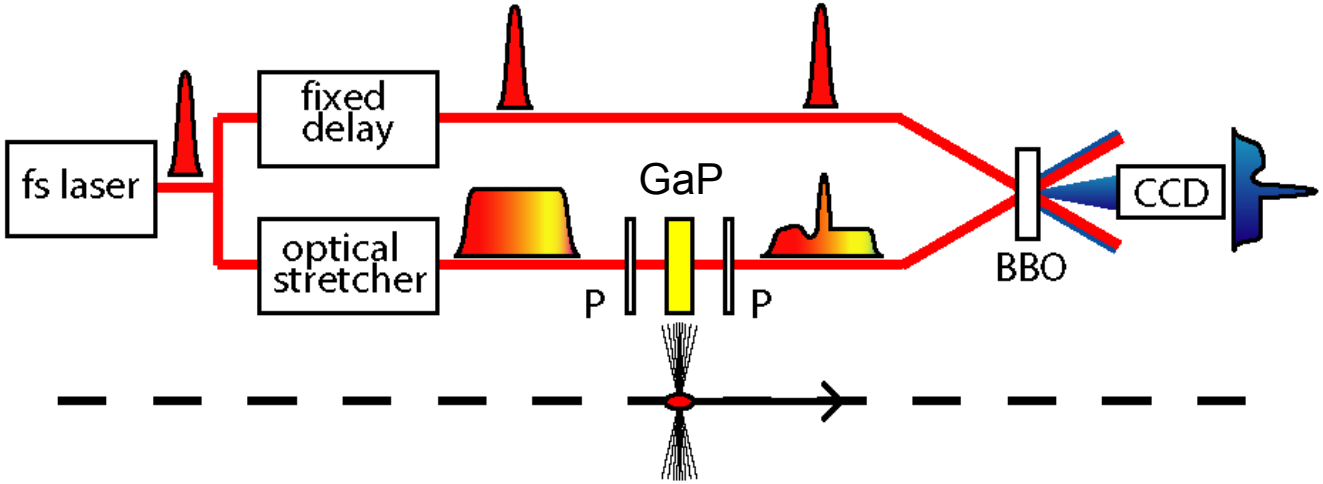
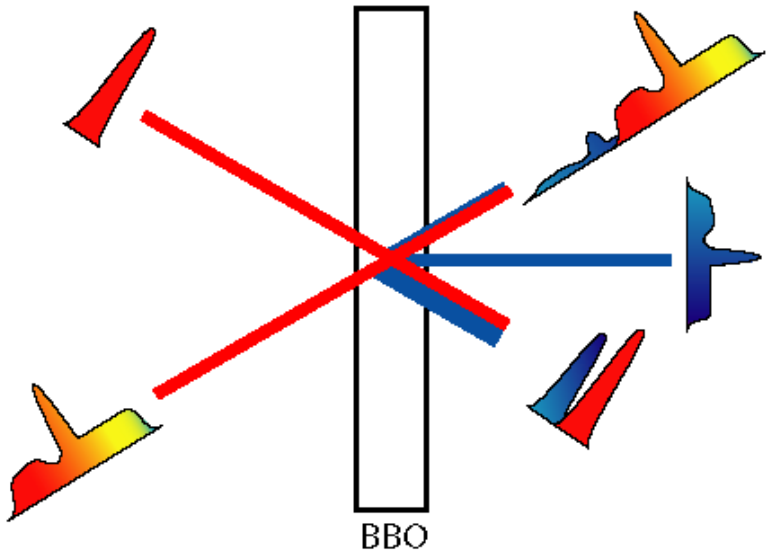


Temporal Decoding



- the chirped laser pulse behind the EO crystal is measured by a short laser pulse with a single shot cross correlation technique

- approx. 1mJ laser pulse energy necessary



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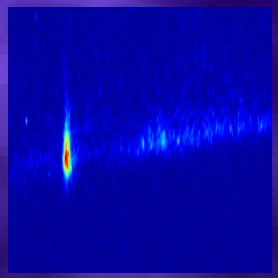
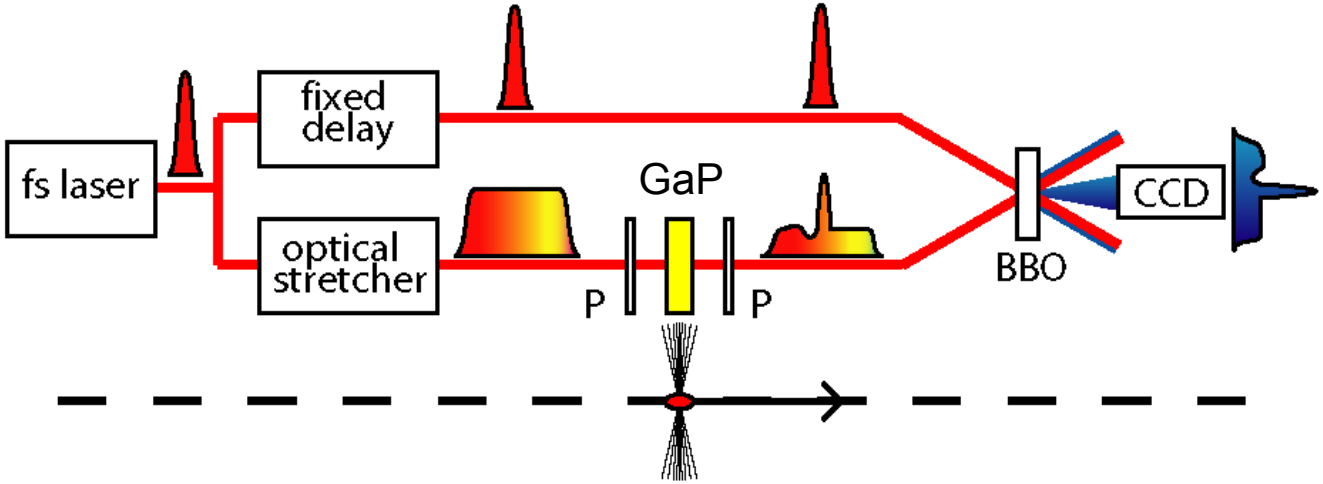


Temporal Decoding



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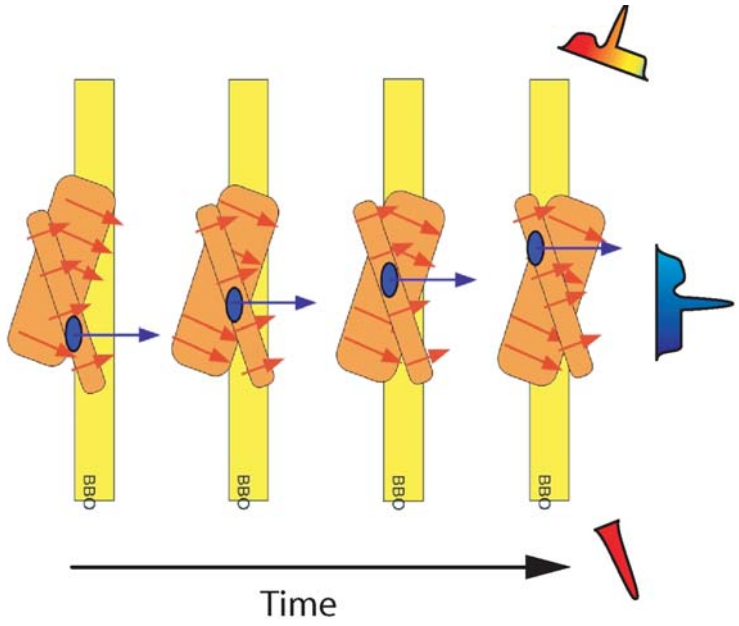

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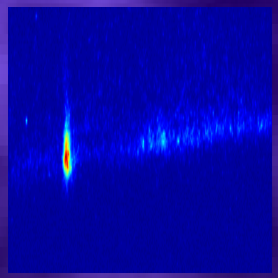
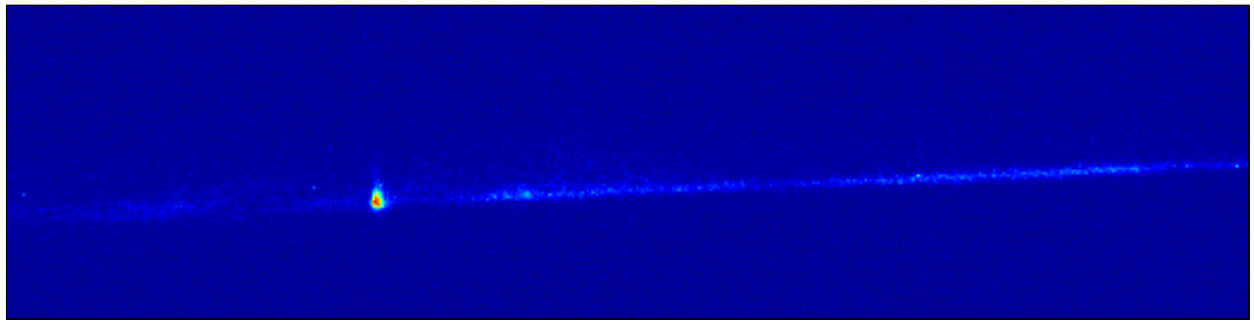
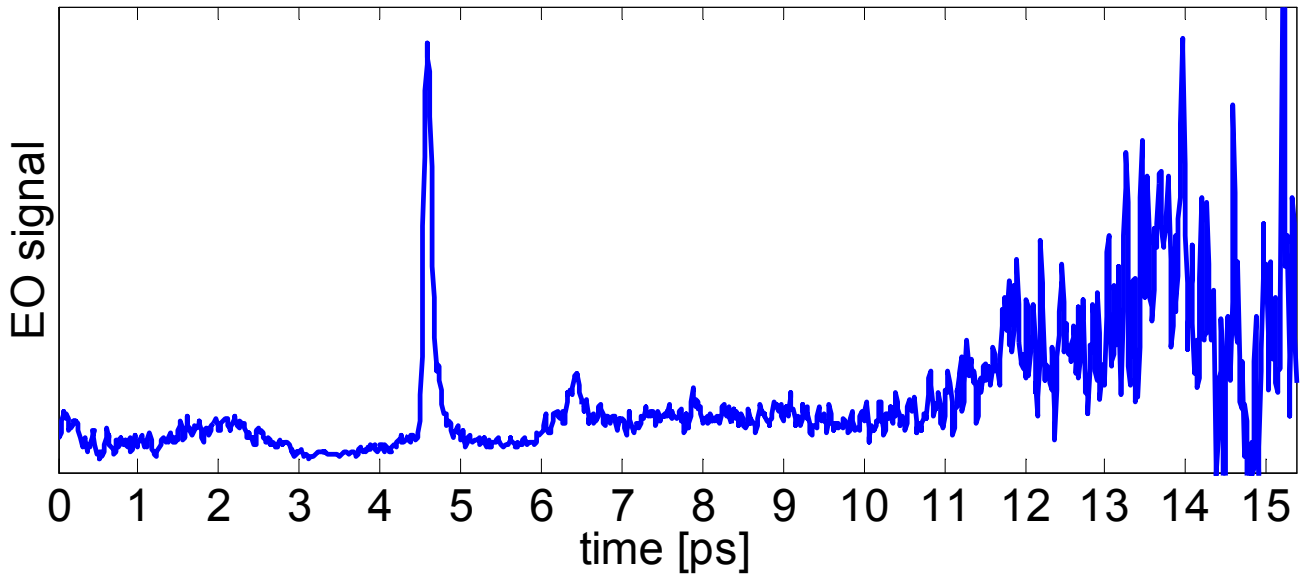


Temporal Decoding





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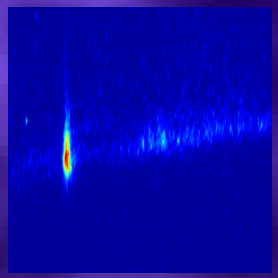
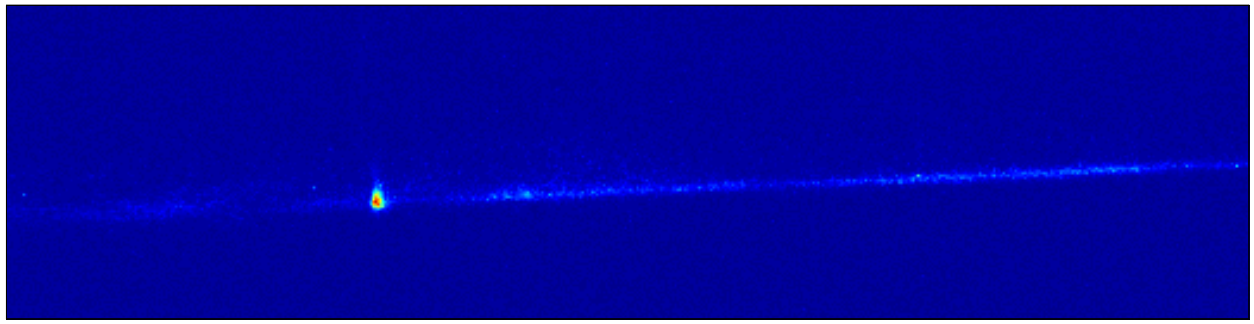
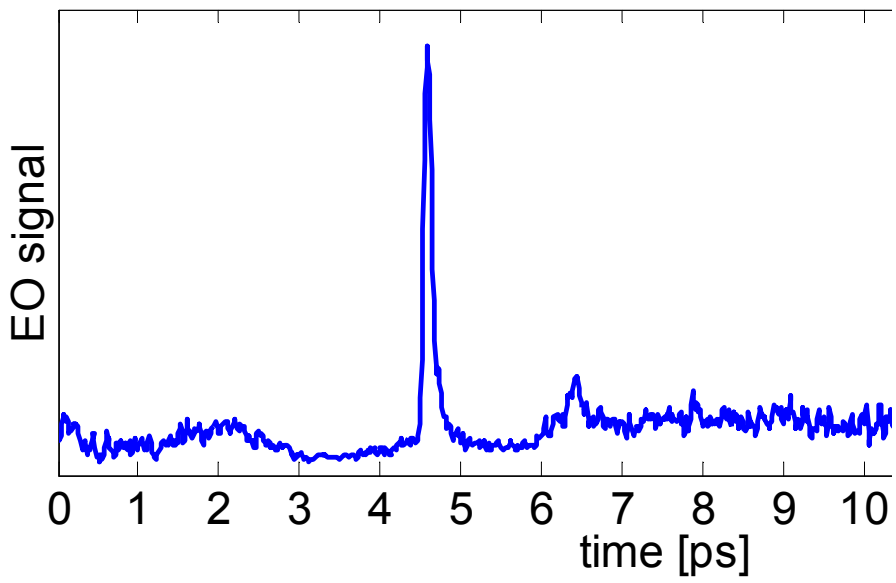
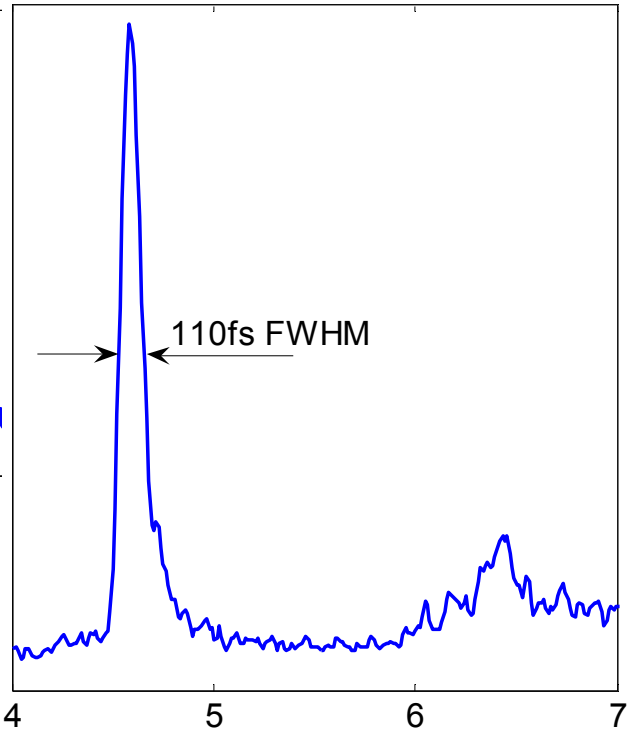


Temporal Decoding







Shortest EO signals seen: 110 fs (FWHM)
including optical resolution limits

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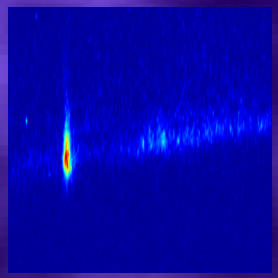

Deconvolution of the bunch profile

Image

↑ Resolution of camera/optics (25-30µm, 50fs)

"blue light"

↑ Res. of cross correlation (50fs)

EO-signal

↑ ~ $\sin^2(\Gamma/2)$, $\Gamma \sim E$

EO modulation on laser polarisation (Γ)

↑ Res. of EO crystal (120fs for 100µm GaP)

e-bunch charge profile

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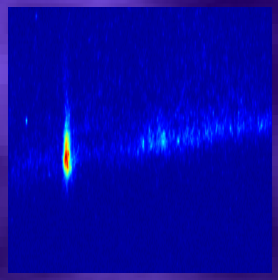

Deconvolution of the bunch profile

110fs

Deconvolution

(Lucy-Richardson algorithm)

90fs

Square root

120fs

<120fs

Image

Resolution of camera/optics (25-30µm, 50fs)

"blue light"

Res. of cross correlation (50fs)

EO-signal

~ $\sin^2(\Gamma/2)$, $\Gamma \sim E$

EO modulation on laser polarisation (Γ)

Res. of EO crystal (120fs for 100µm GaP)

e-bunch charge profile

⇒ Currently at the physical limit of the EO crystal!

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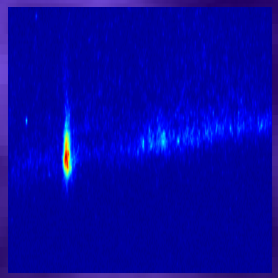
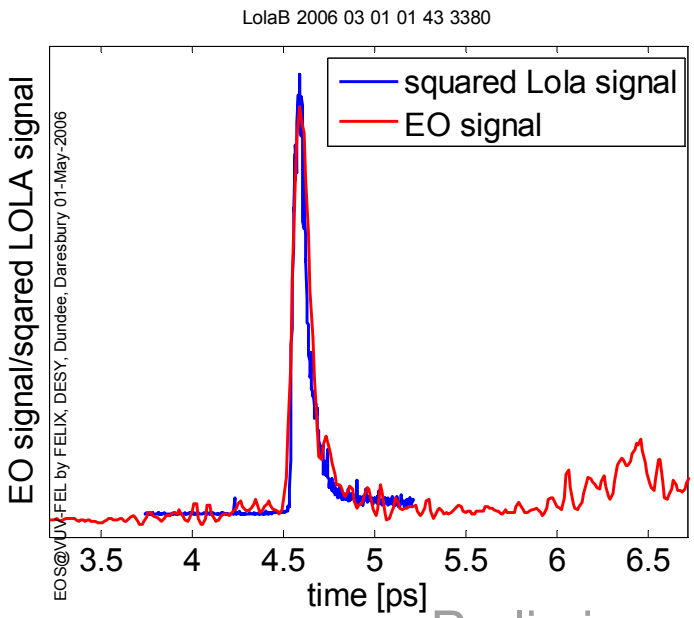
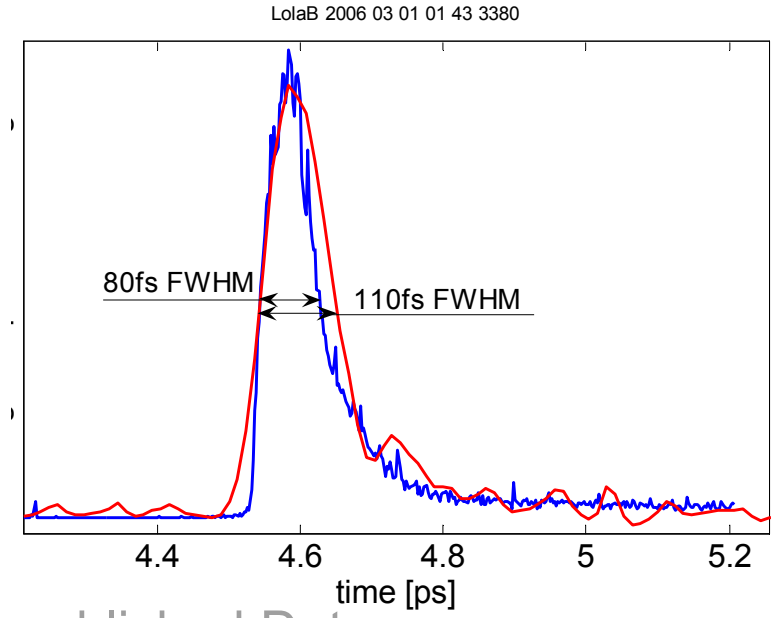


Comparison of EO and LOLA signals





Preliminary unpublished Data

SASE conditions

EO at first bunch, LOLA at second bunch in the same bunch train

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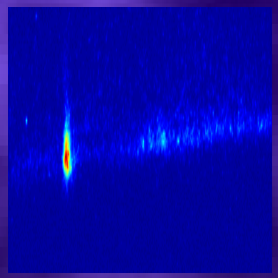

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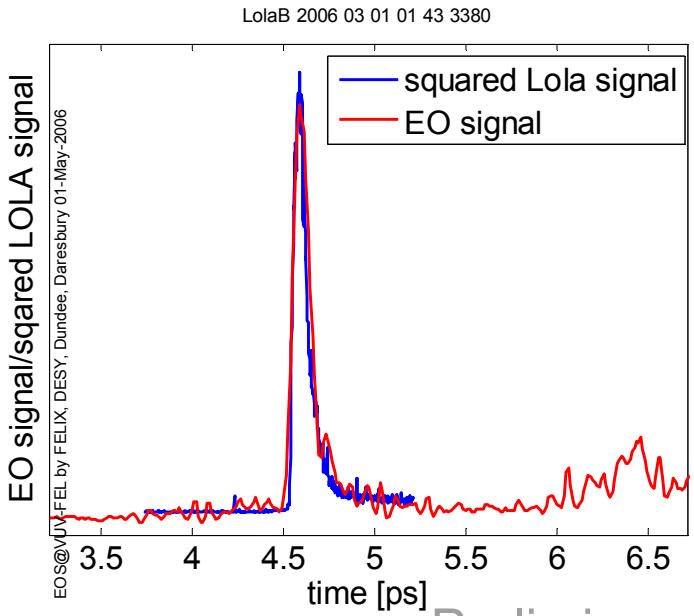

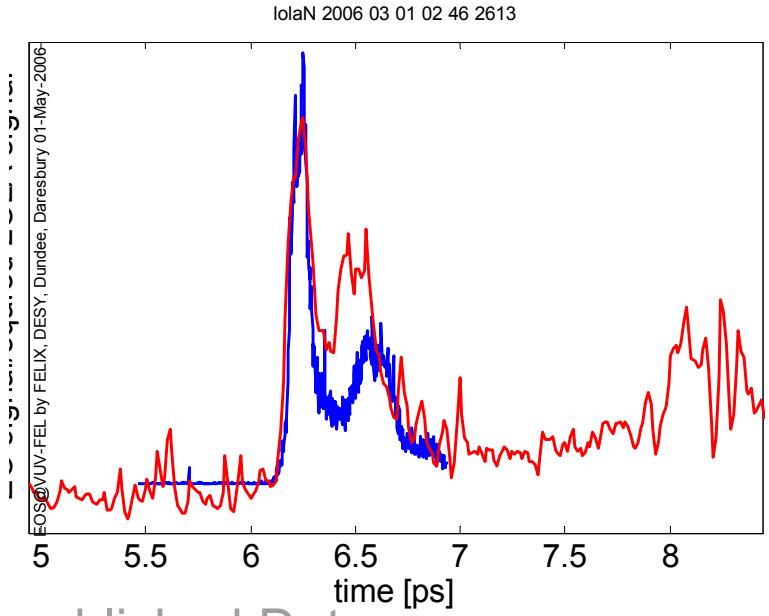

Preliminary unpublished Data

SASE conditions

ACC1 phase 1° overcompression

EO at first bunch, LOLA at second bunch in the same bunch train

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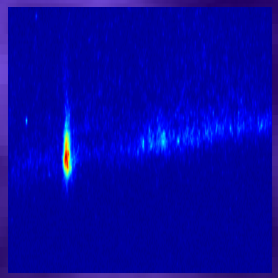
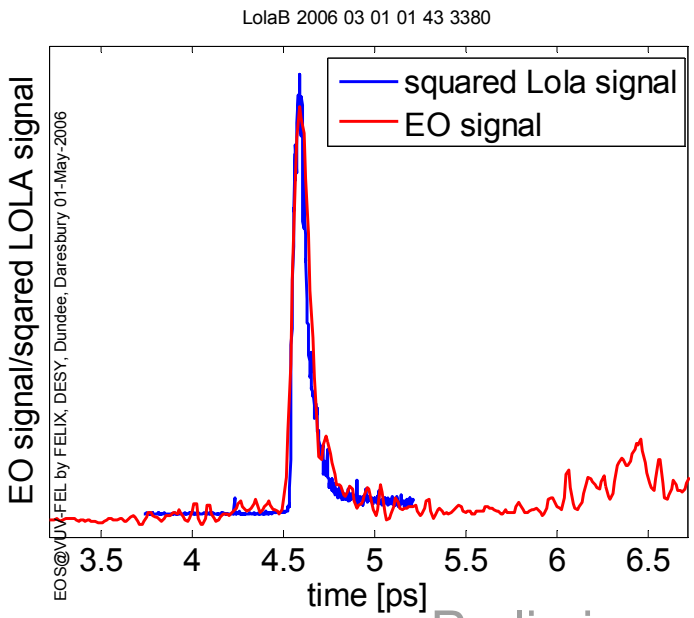
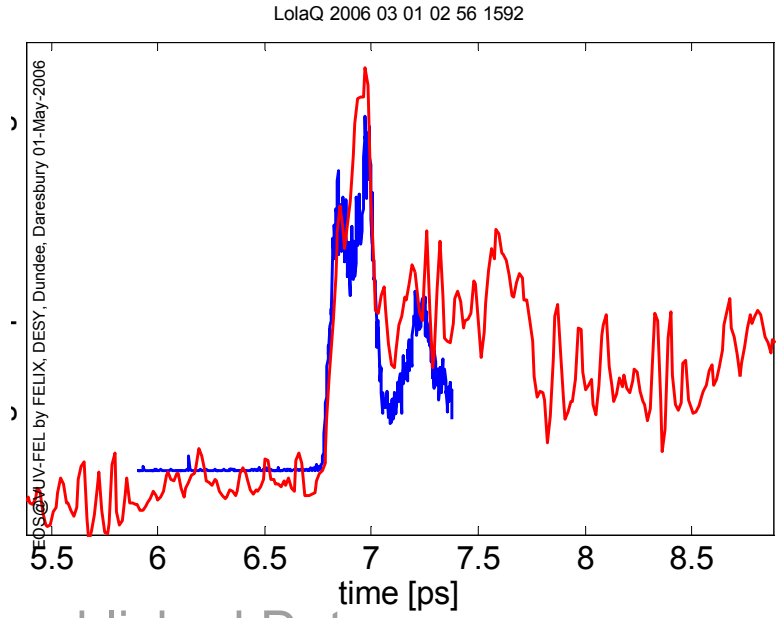


Comparison of EO and LOLA signals





Preliminary unpublished Data

SASE conditions

ACC1 phase 2° overcompression

EO at first bunch, LOLA at second bunch in the same bunch train

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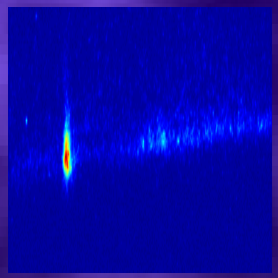
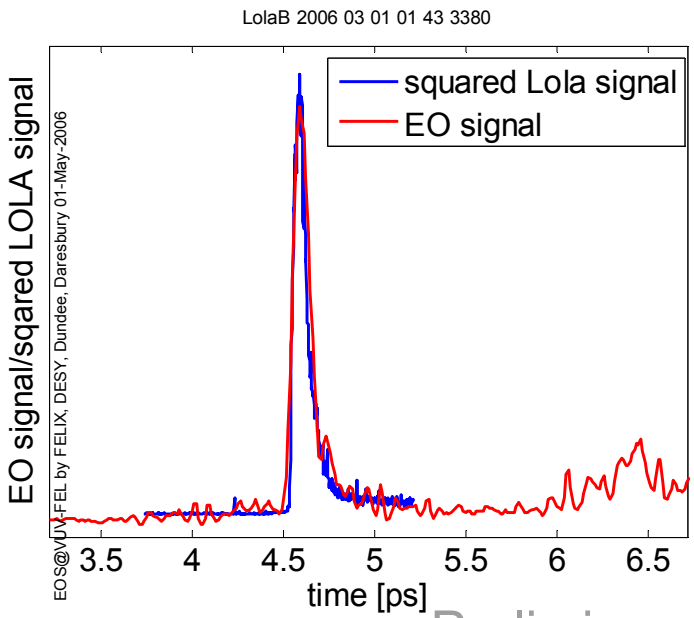
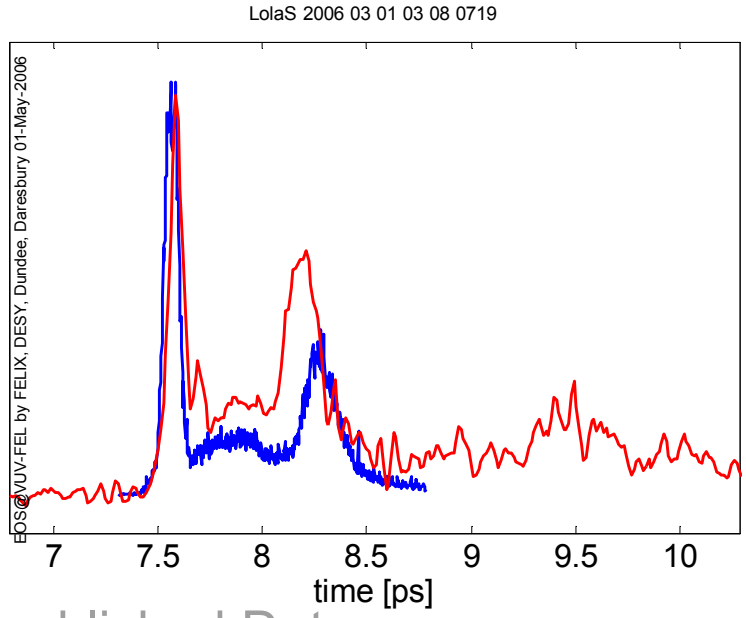


Comparison of EO and LOLA signals





Preliminary unpublished Data

SASE conditions

ACC1 phase 3° overcompression

EO at first bunch, LOLA at second bunch in the same bunch train

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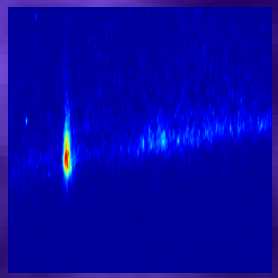
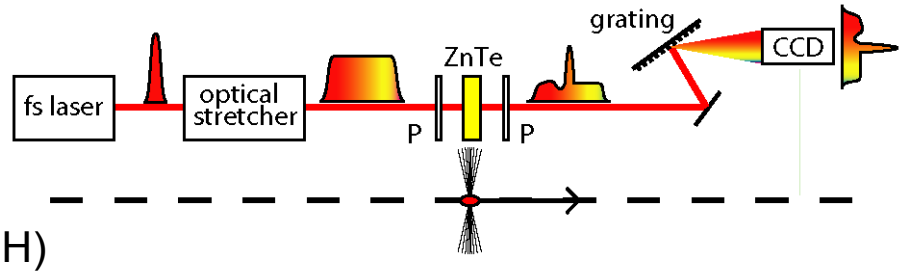
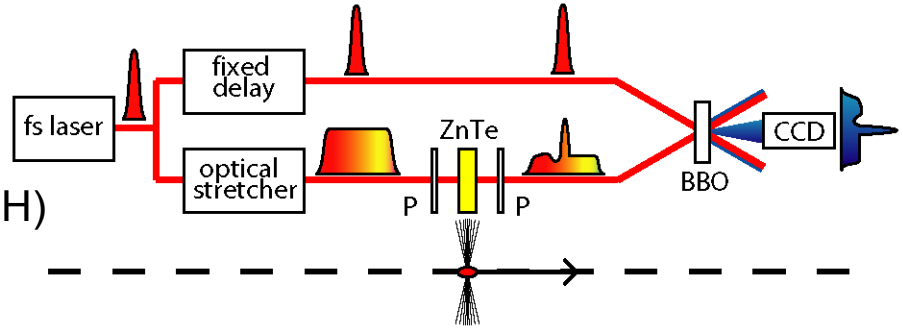


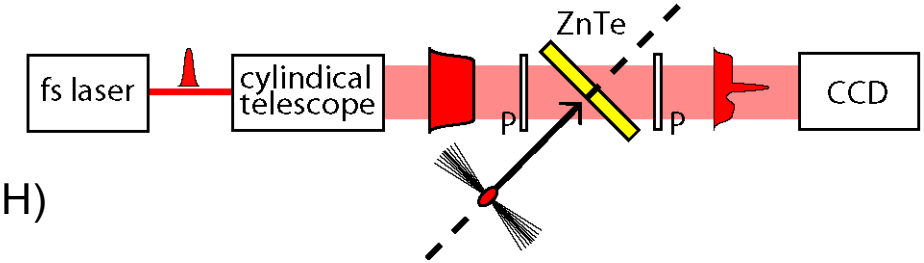
Spectral Decoding:
+ simple (laser) system
+ high repetition rate
- distorted signal for
  e-bunches < 200fs
  (400fs signal measured at FLASH)



Temporal Decoding:
+ large time window
+ high resolution: **120fs** (e-bunch)
  (110fs signal measured at FLASH)
- mJ laser pulse energy
- low repetition rate



Spatial Decoding:
+ simple laser system
+ high repetition rate
+ high resolution: **120fs** (e-bunch)
  (160fs signal measured at FLASH)
- more complex imaging optics



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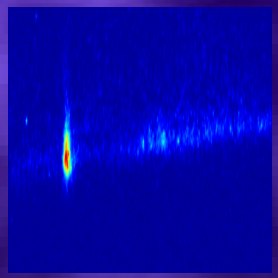

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