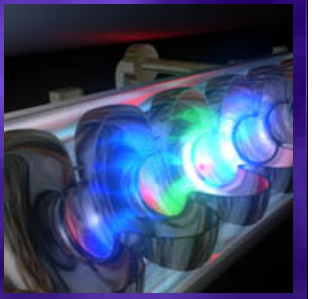

Electro-optical measurements of the longitudinal electron bunch profile

Bernd Steffen (DESY)

for the EOS@VUV-FEL team
(FELIX, DESY, Dundee, Daresbury)

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Vacuum-Ultraviolet
Free-Electron Laser

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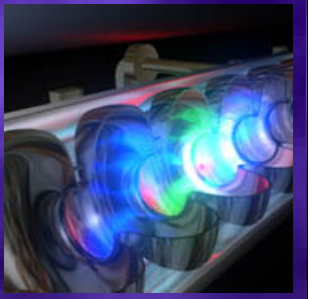

- Basics
- Methods of EO-measurements
  - Electro-optic Sampling
  - Spectral Decoding
  - Temporal Decoding
  - Spatial Decoding
- Measurements at the VUV-FEL

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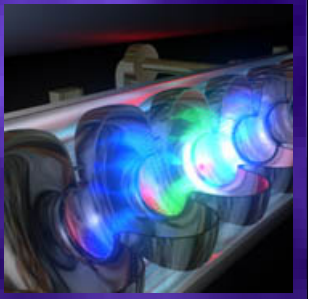
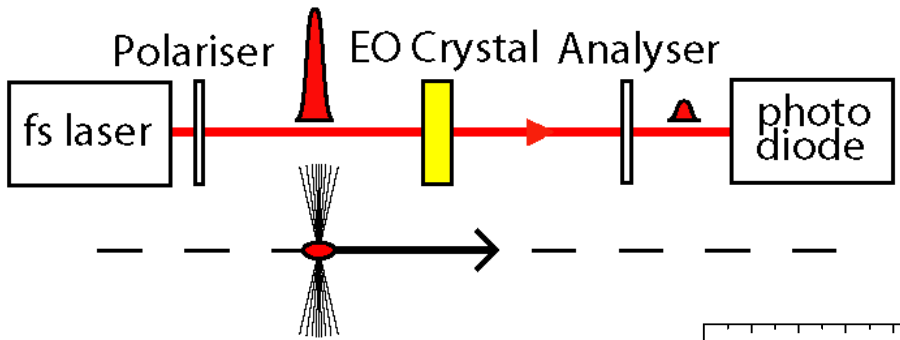
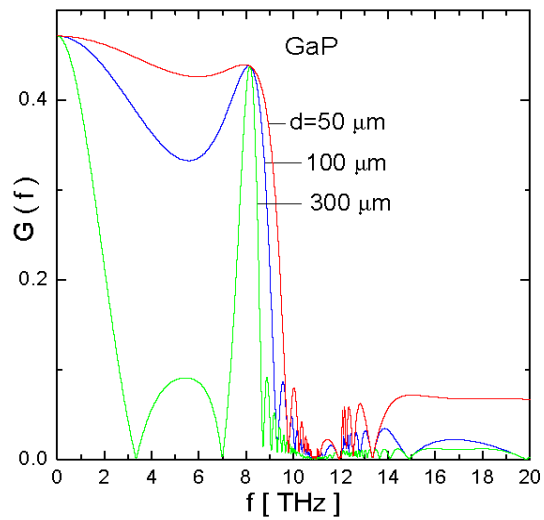


Electro-optical e-bunch profile measurements

- The electric field (Coulombfield of the e-bunches) induces birefringence in the EO crystal.
- The rotation of the polarisation of the laser pulse due to the birefringence is proportional to the field strength i.e. the longitudinal bunch profile.



Resolution limited by:
- Crystal resonance
- Crystal dispersion
- Phase mismatch between Coulombfield (THz) and laser (optical)
- Measurement of the polarisation change of the laser pulse



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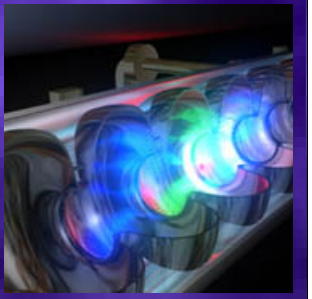
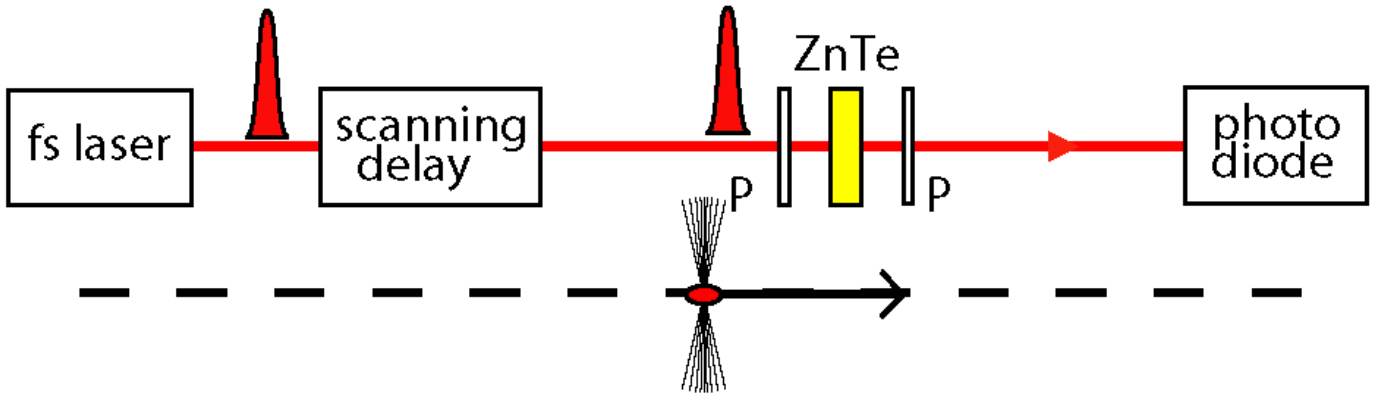


Electro-optic Sampling



- the bunch profile is sampled by changing the delay between e-bunch and a femtosecond laser pulse

- commonly used in THz spectroscopy (pump-probe)

- technically simple, highest resolution

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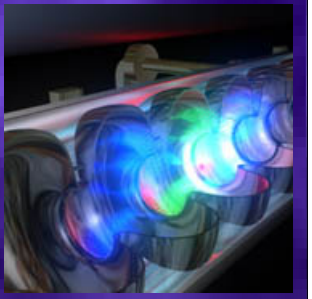
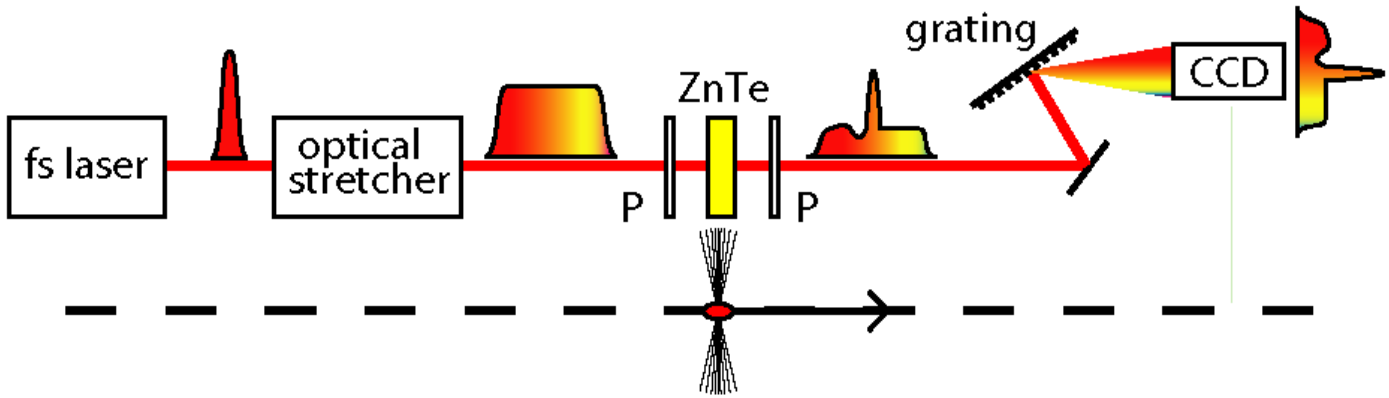


Spectral Decoding



- 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

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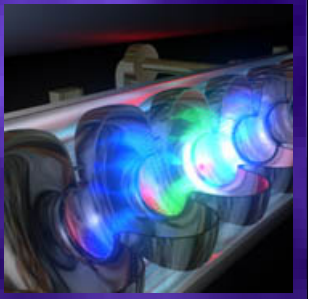
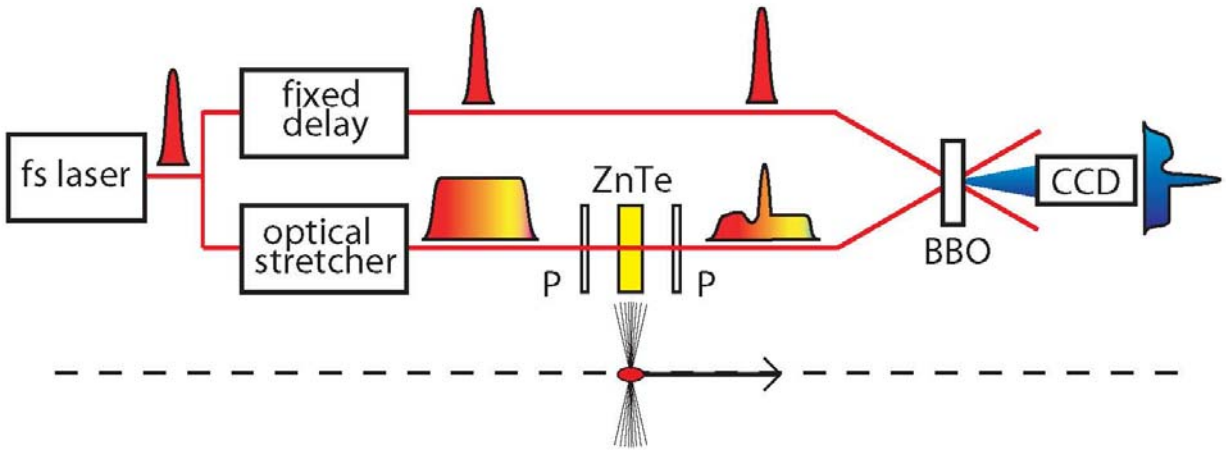
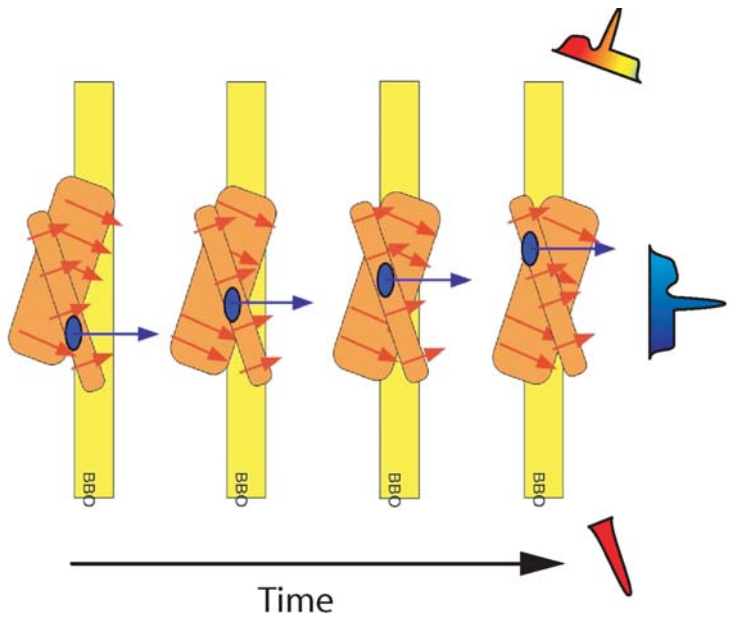


Temporal Decoding



- 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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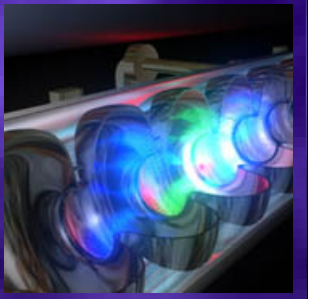
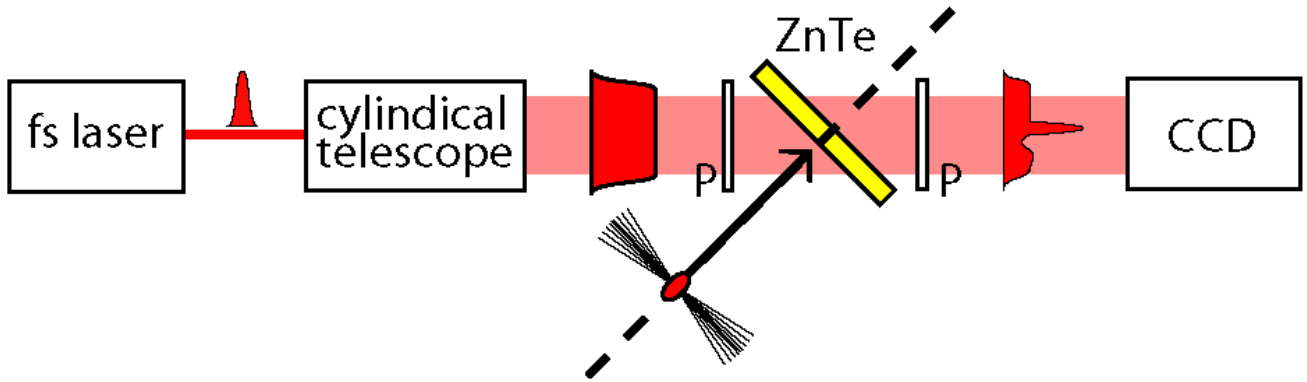


Spatial Decoding



- the femtosecond laser pulse is focused as a line image to the crystal and passes the crystal at an angle

- the bunch length is transferred to the spatial structure of the laser

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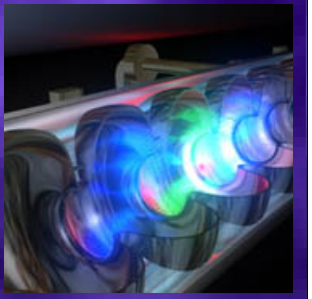
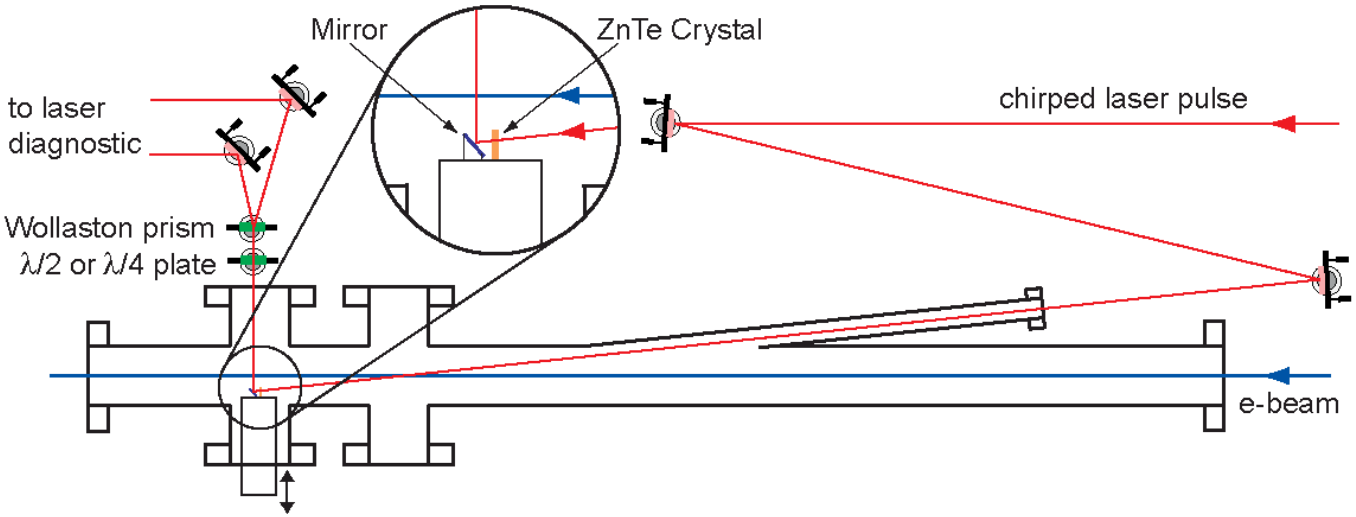


Experimental setup at the VUV-FEL



- the laser system is housed outside the accelerator tunnel including
  - 4 nJ, 15 fs Titan-Sapphire oscillator
  - 1 mJ, 30 fs Titan-Sapphire amplifier
- the laser beam is transported via a 20m vacuum transfer line
- current setup allows sampling, spectral and temporal decoding
- currently ZnTe (50-350µm) and GaP (30-150µm) crystal mounted

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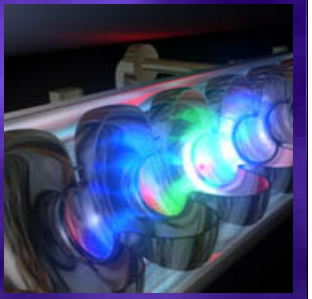
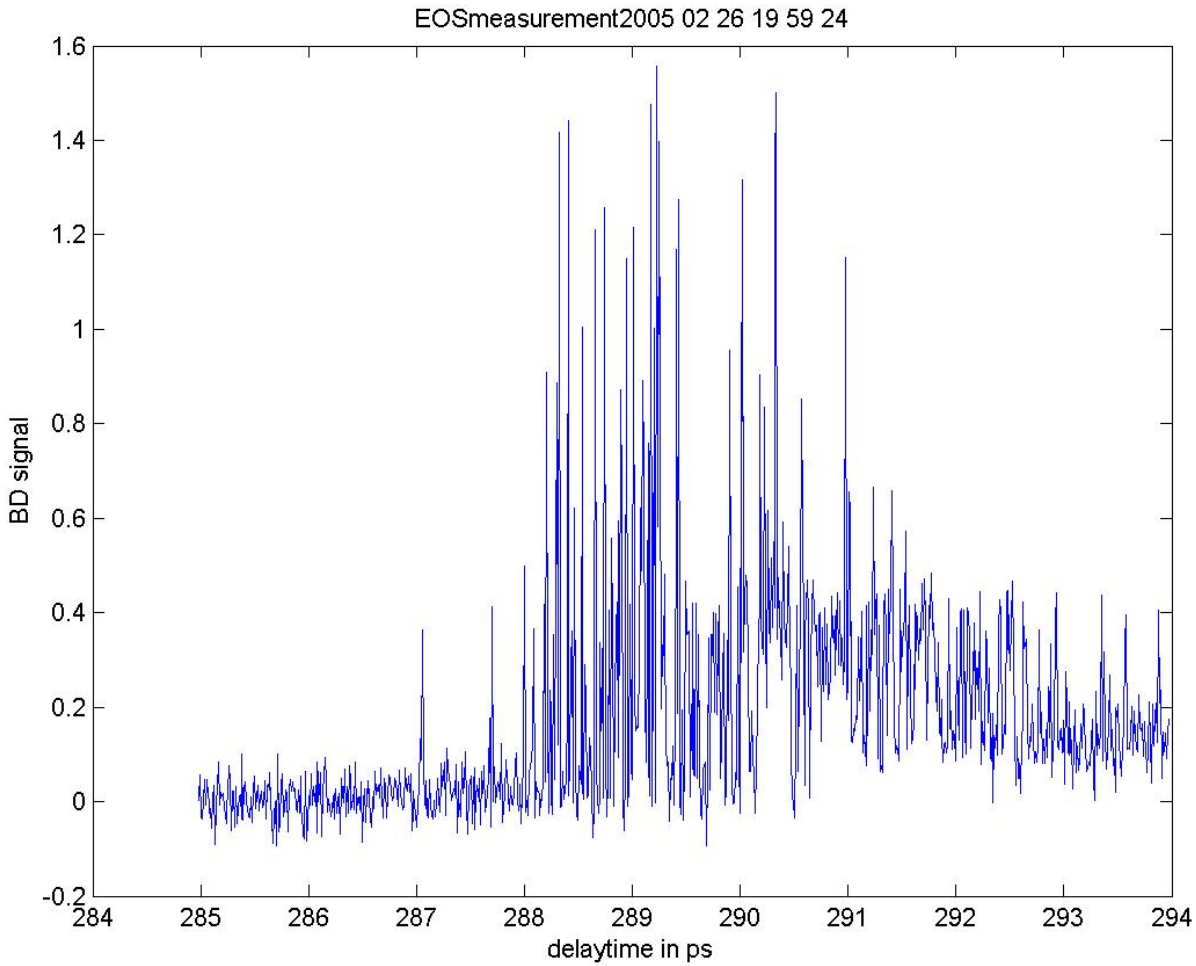


Electro-optic Sampling

No bunch profile measurable due to time jitter:

Single shot measurements needed!



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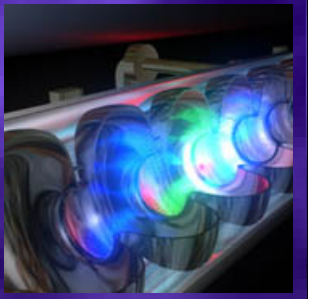
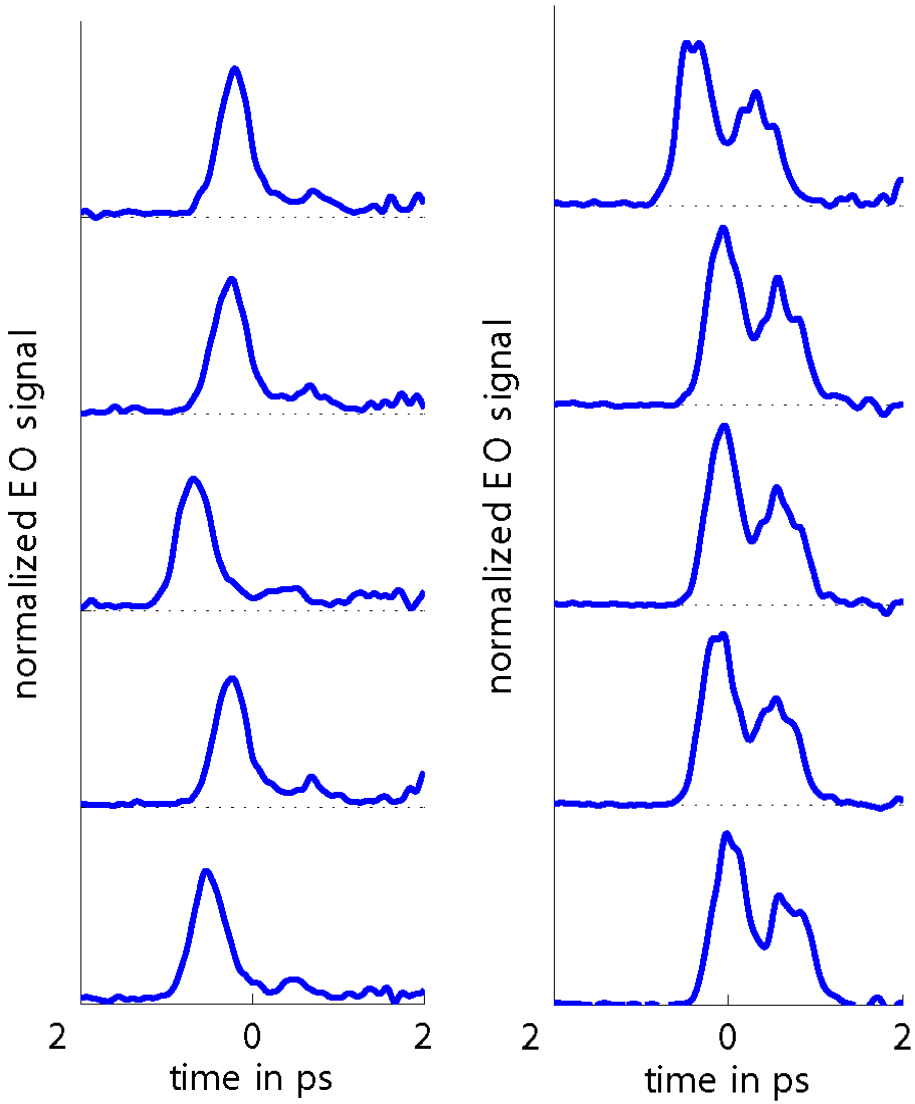


Spektral Decoding

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

right:
Over compressed bunches



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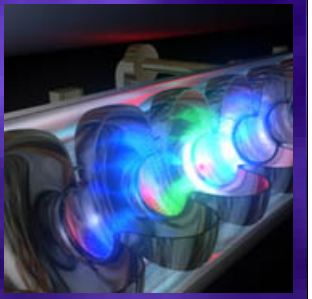
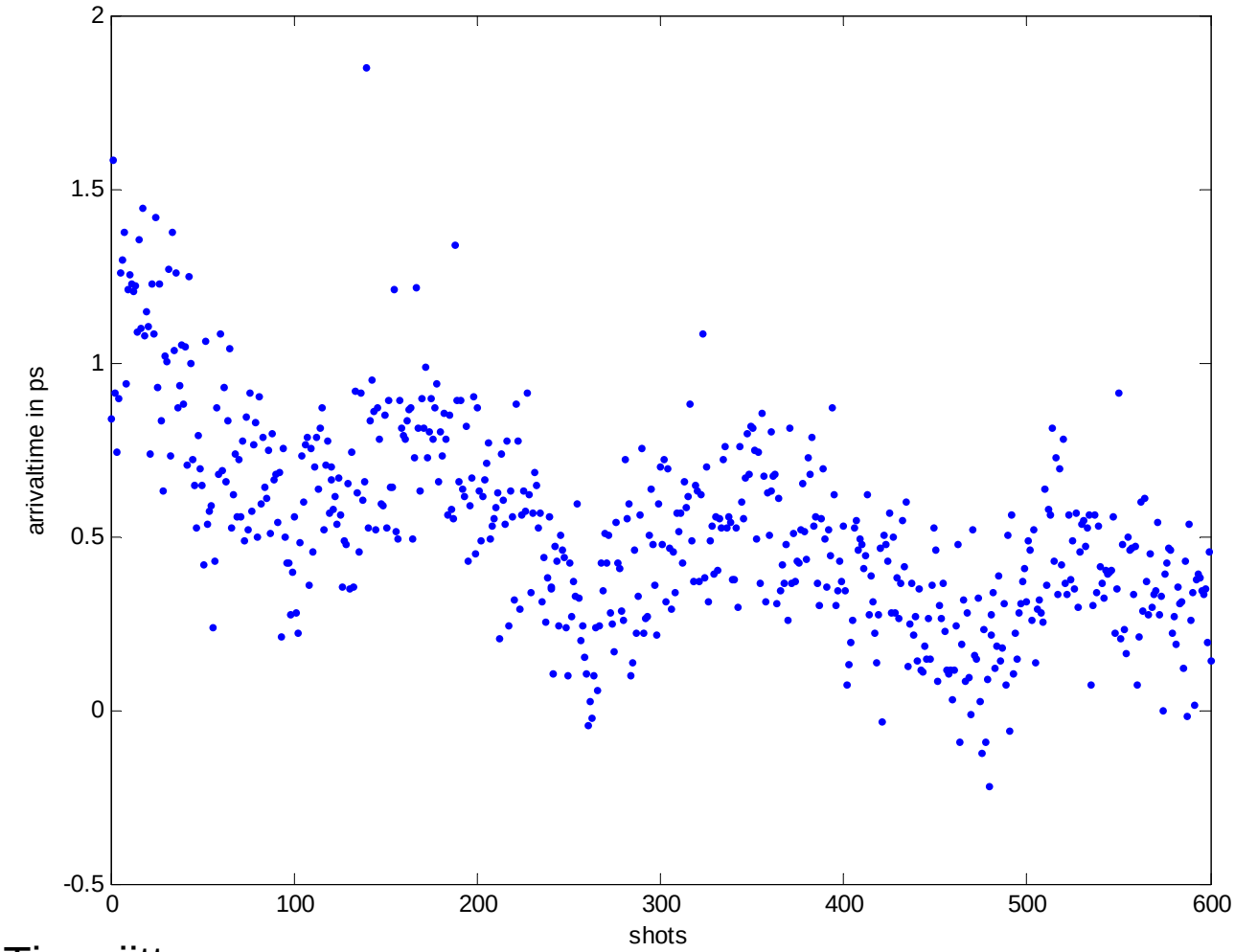


Time jitter measured by EO-SD



Time jitter:
- here 530 fs (rms) over 5 min incl. slow drifts
- without slow drifts typically 200 fs (rms)

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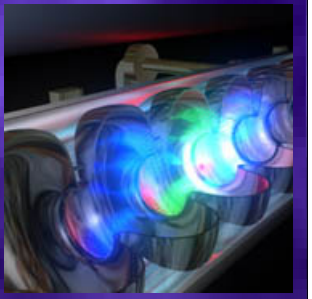
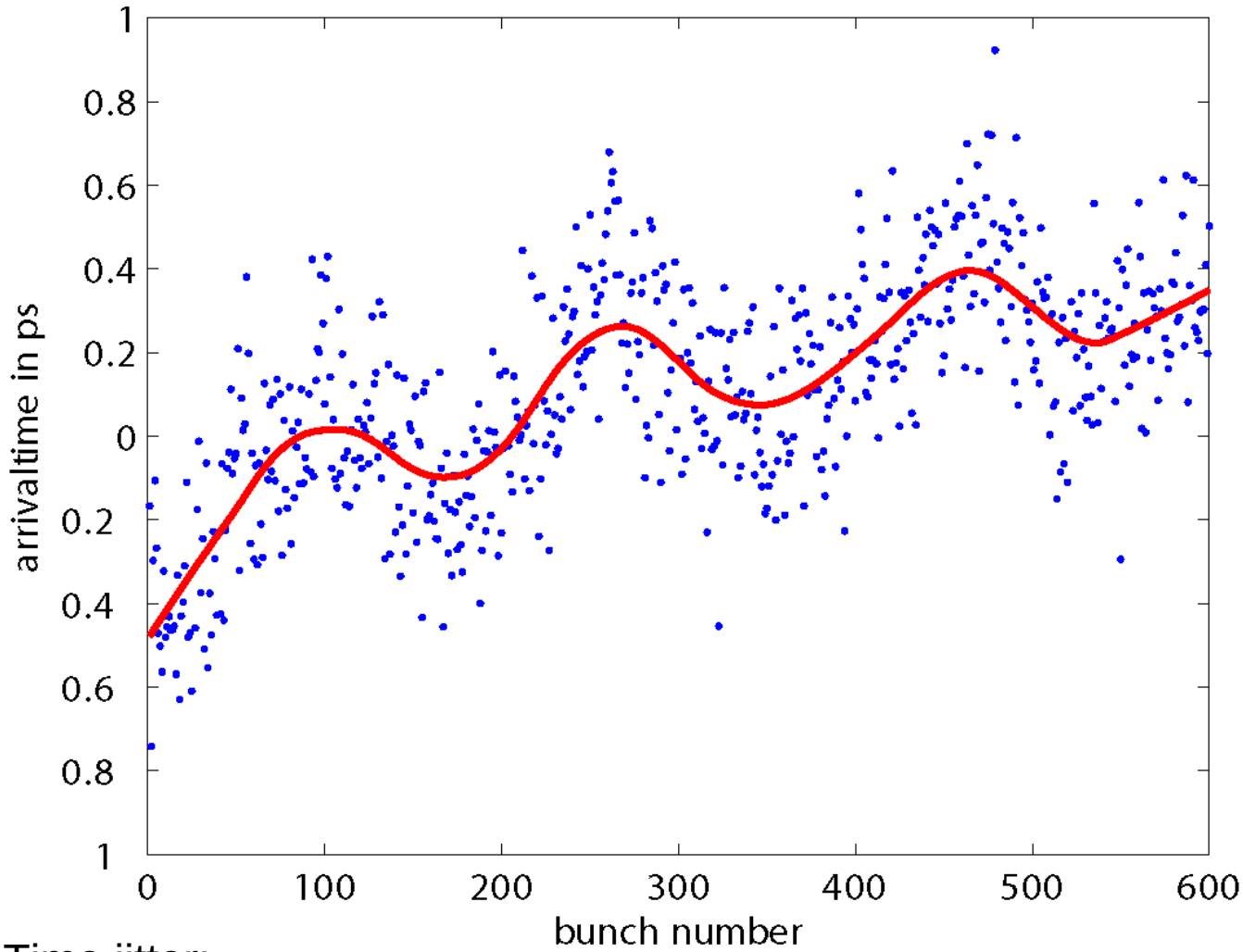


Time jitter measured by EO-SD



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

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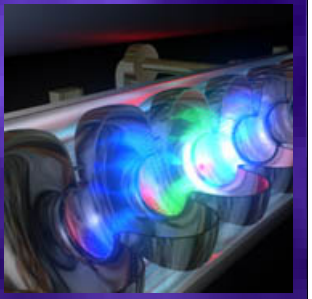
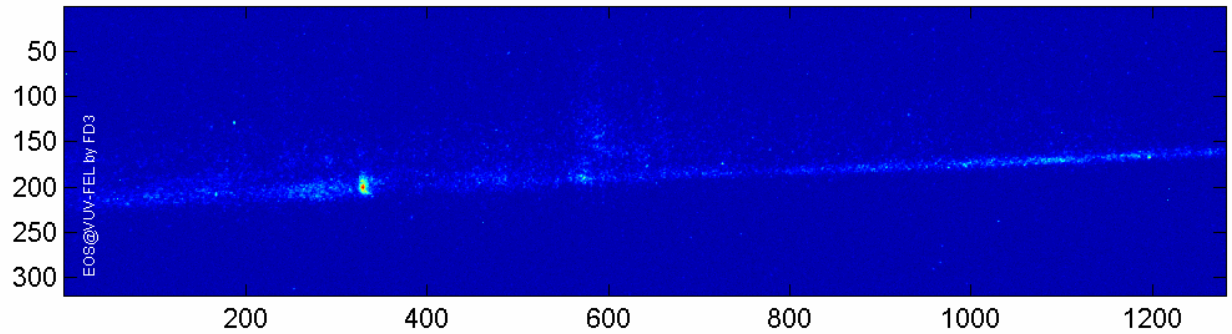
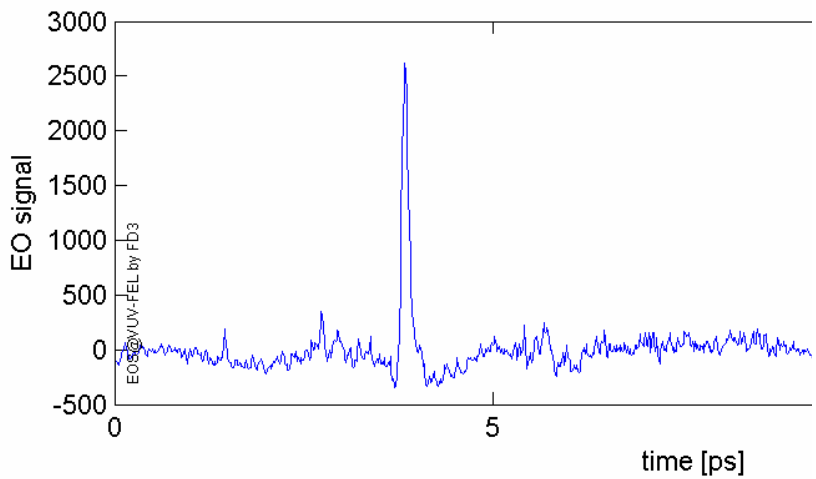
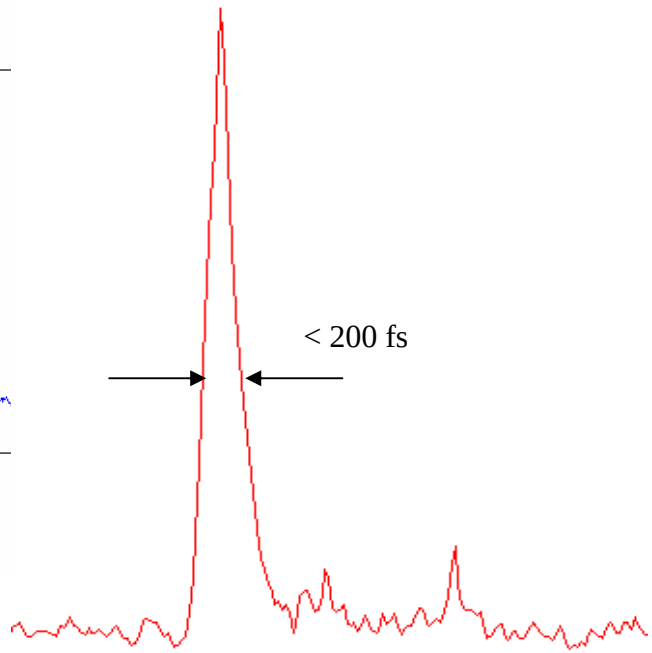


Temporal Decoding







Shortest EO signals seen: 120 fs (FWHM), corresponding to 170 fs (FWHM) e-bunch

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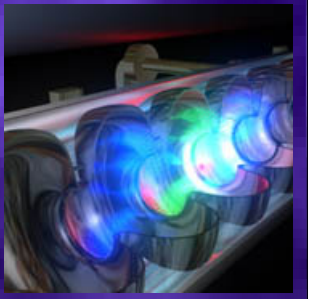
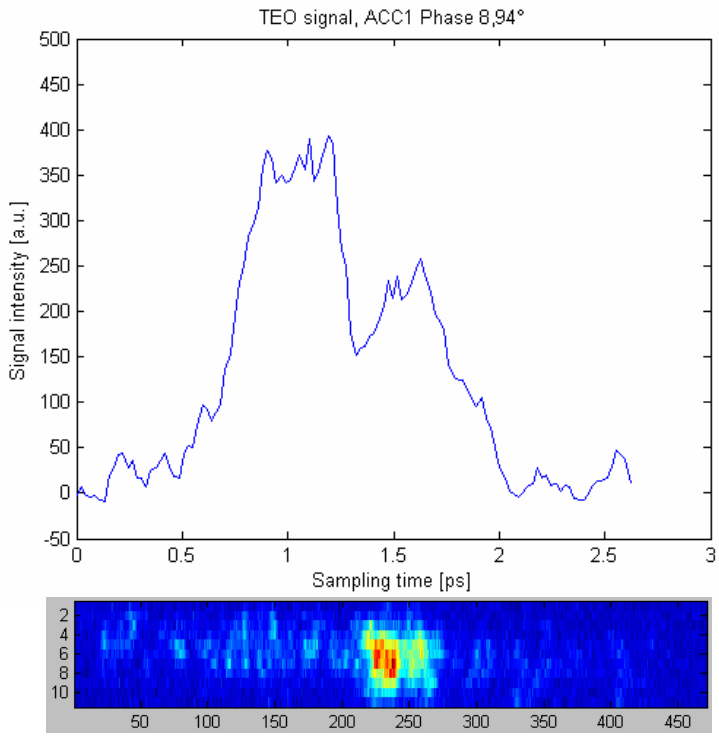
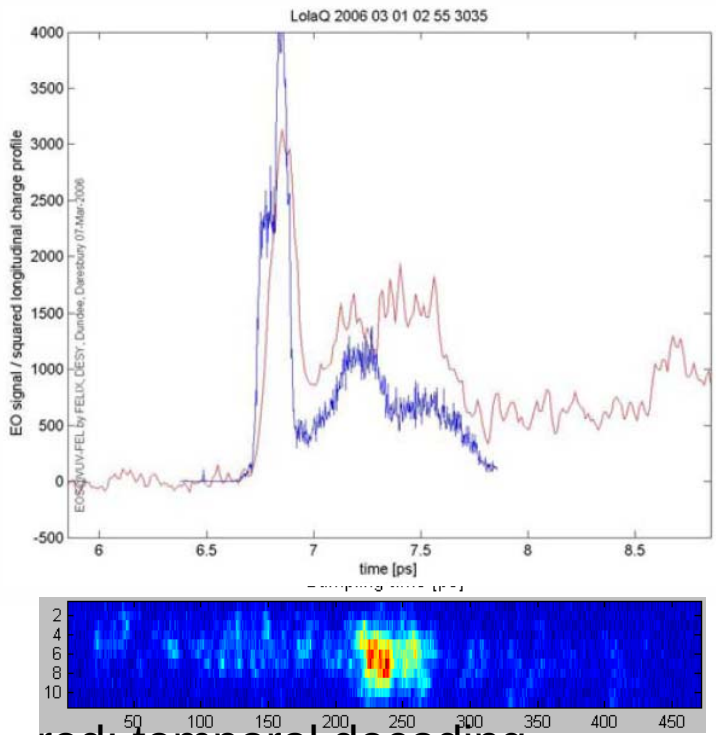


Spatial Decoding

Second EO setup at the VUV-FEL to measure e-bunch timing at the undulator





from Armin Azima et al., DESY

spatial decoding

red: temporal decoding
blue: squared signal from a transverse deflecting cavity ('electron steak camera') measurement

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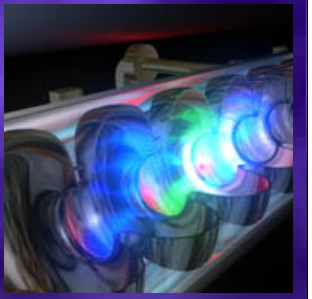

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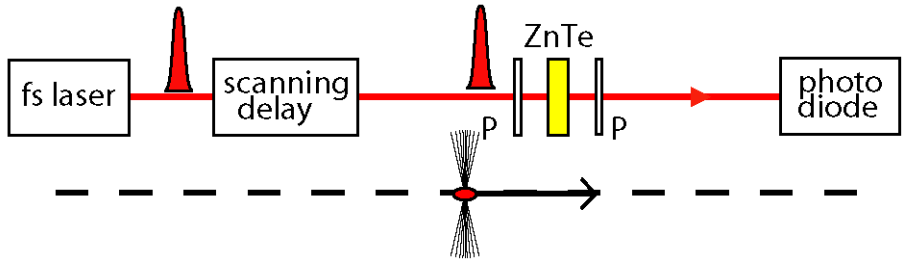
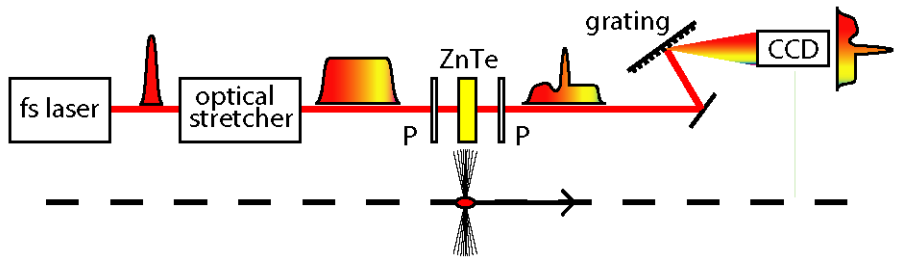
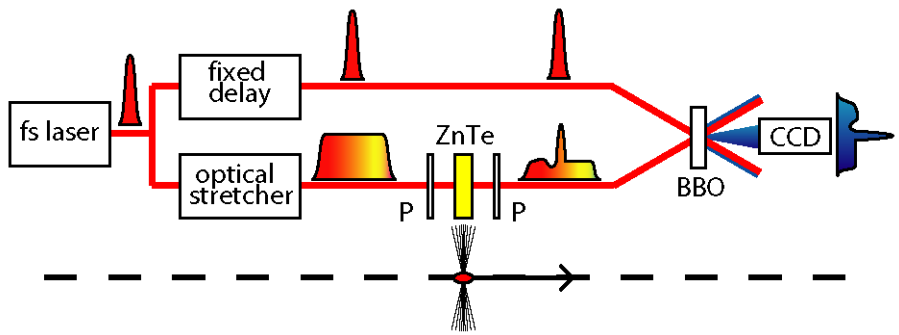
Electro-optic Sampling :
+ simple (laser) system
+ arbitrary time window
+ high resolution
- no single bunch



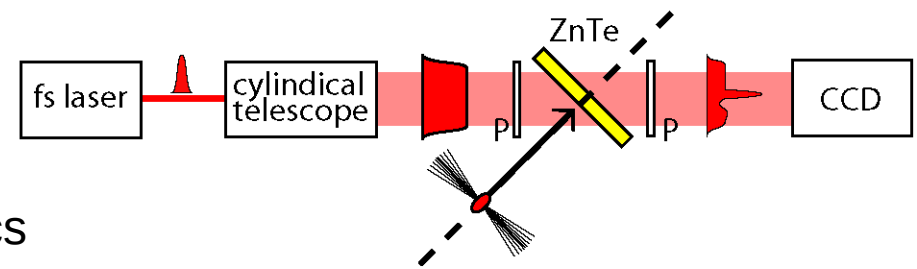
Spectral Decoding:
+ simple (laser) system
+ high repetition rate
- limited resolution (**500fs**)
- distorted signal for e-bunches < 200fs



Temporal Decoding:
+ large time window
+ high resolution (**150fs**)
- mJ laser pulse energy
- low repetition rate



Spatial Decoding:
+ simple laser system
+ high repetition rate
- limited resolution (**400fs**)
- more complex imaging optics



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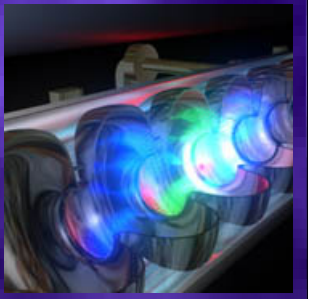

Thanks to

- G. Berden (FELIX)
- S. Jamison (Univ. of Abertay, Dundee)
- J. Phillips (Univ. of Dundee)
- E.-A. Knabbe, H. Schlarb, B. Schmidt, P. Schmüser (DESY)
- A. Azima (Hasylab, DESY)

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