“Jitter measurement by electro-optical sampling”

VUV-FEL at DESY

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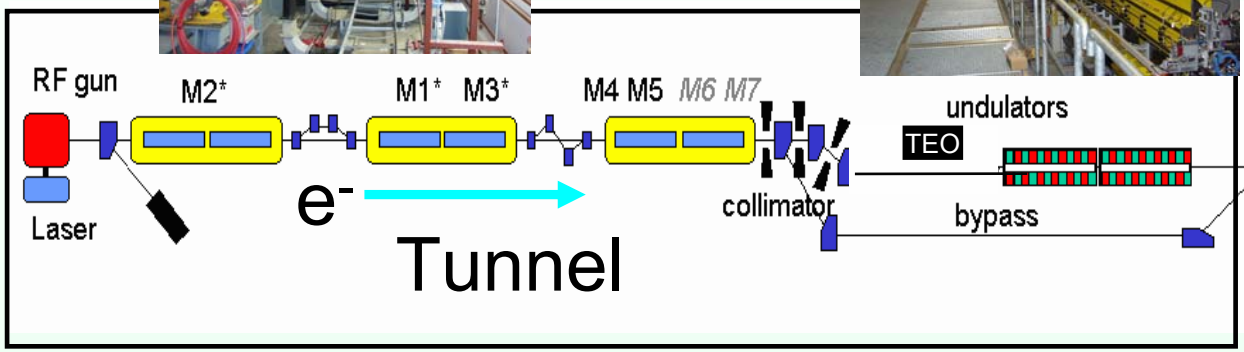
The VUV-FEL

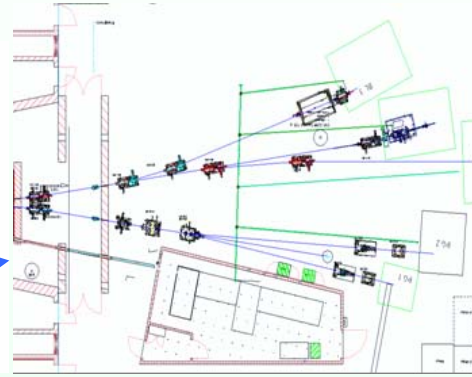
VUV-FEL
Vacuum-Ultraviolet
Free-Electron Laser

Accelerator (TESLA)

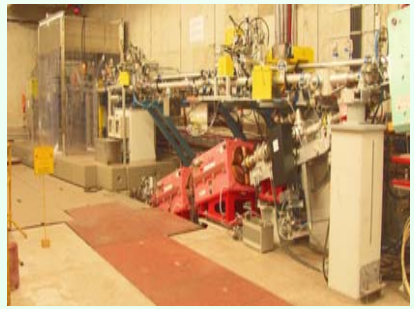
Undulator

"SASE" – self amplified spontaneous emission





FEL-experimental hall



Bending magnet

- **Wave length of VUV-λ : 15 - 50 nm (now)**
- **Energy per VUV- pulse: up to 150 µJ**

- **Charge of electron bunch: 1nC**
- **Energy of electron bunch: 480 MeV**
- **Duration of UV-pulse / e⁻-bunch : ≈ 20-70fs**

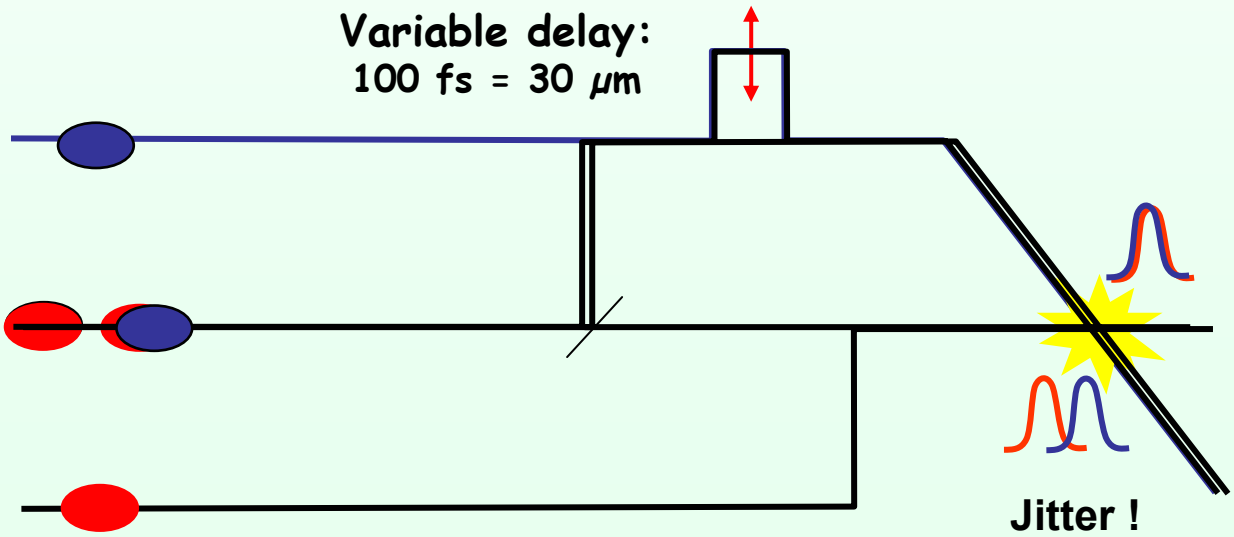
Time-resolved “pump-probe” measurements

VUV-FEL
Vacuum-Ultraviolet
Free-Electron Laser

We need 2 laser pulses :

- One initiating a reaction (so-called “**pump**”)
- Second one looking what happened (so-called “**probe**”)
- Doing the same measurement with different set of pulses and delays multiple times, scans the evolution of the reaction time-resolved.

→ **Pump-probe experiment**



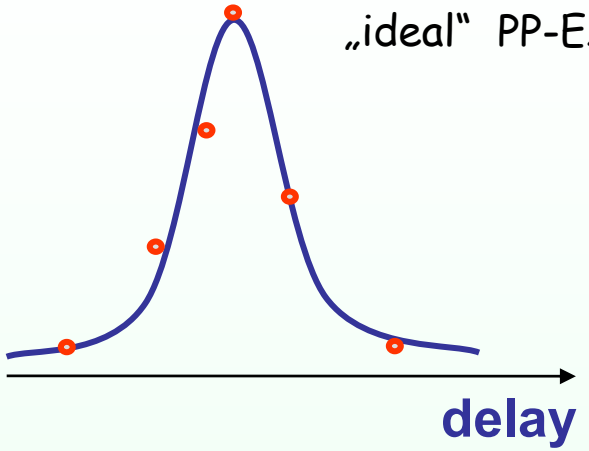
Problem

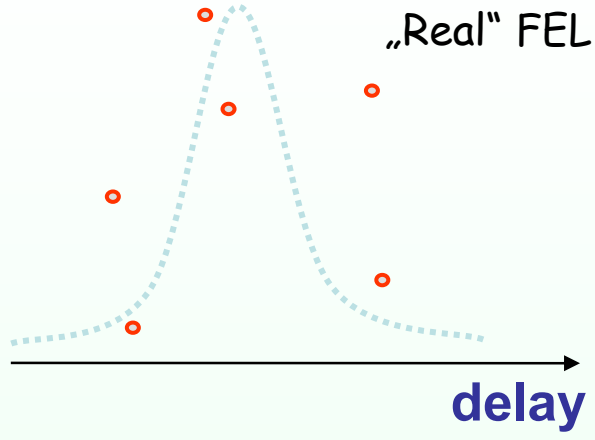
- Jitter of arrival time of VUV-FEL pulse is of the order of 500fs-1ps RMS on a long time scale (hours) and of 100-200fs for a short time scale (minutes).
- There is no easy way to correct this.

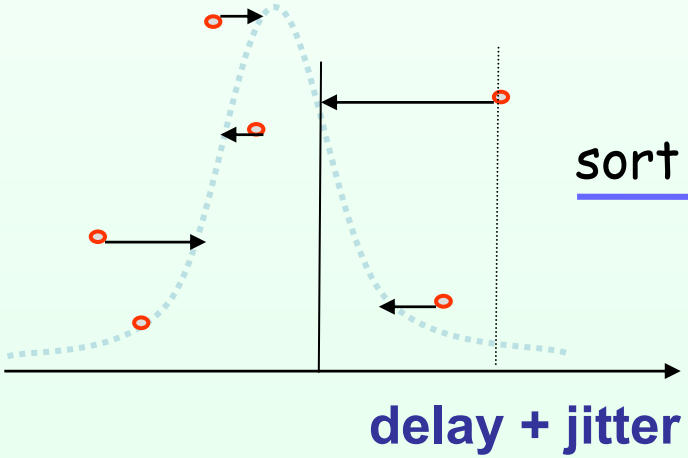
→ **Solution:** Measurement of relative arrival time between opt. laser pulse and FEL pulse and "sort" data points afterwards to correct jitter

➡ "Jitter-problem is reduced to the problem of measuring the jitter"

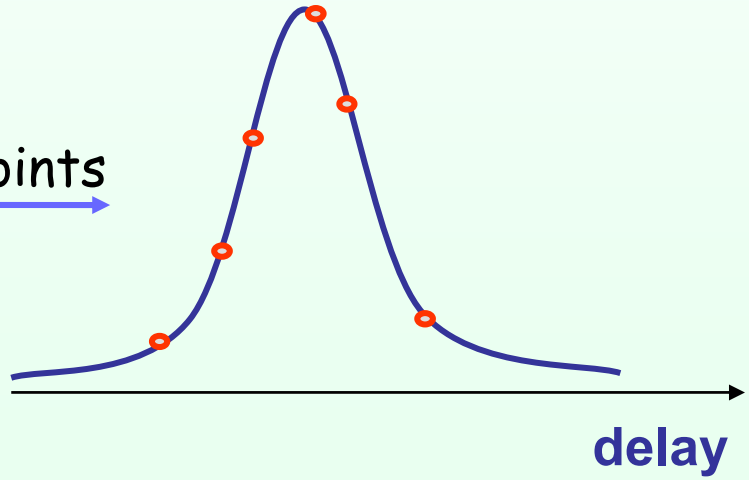
Sorting pump-probe data







sort data points

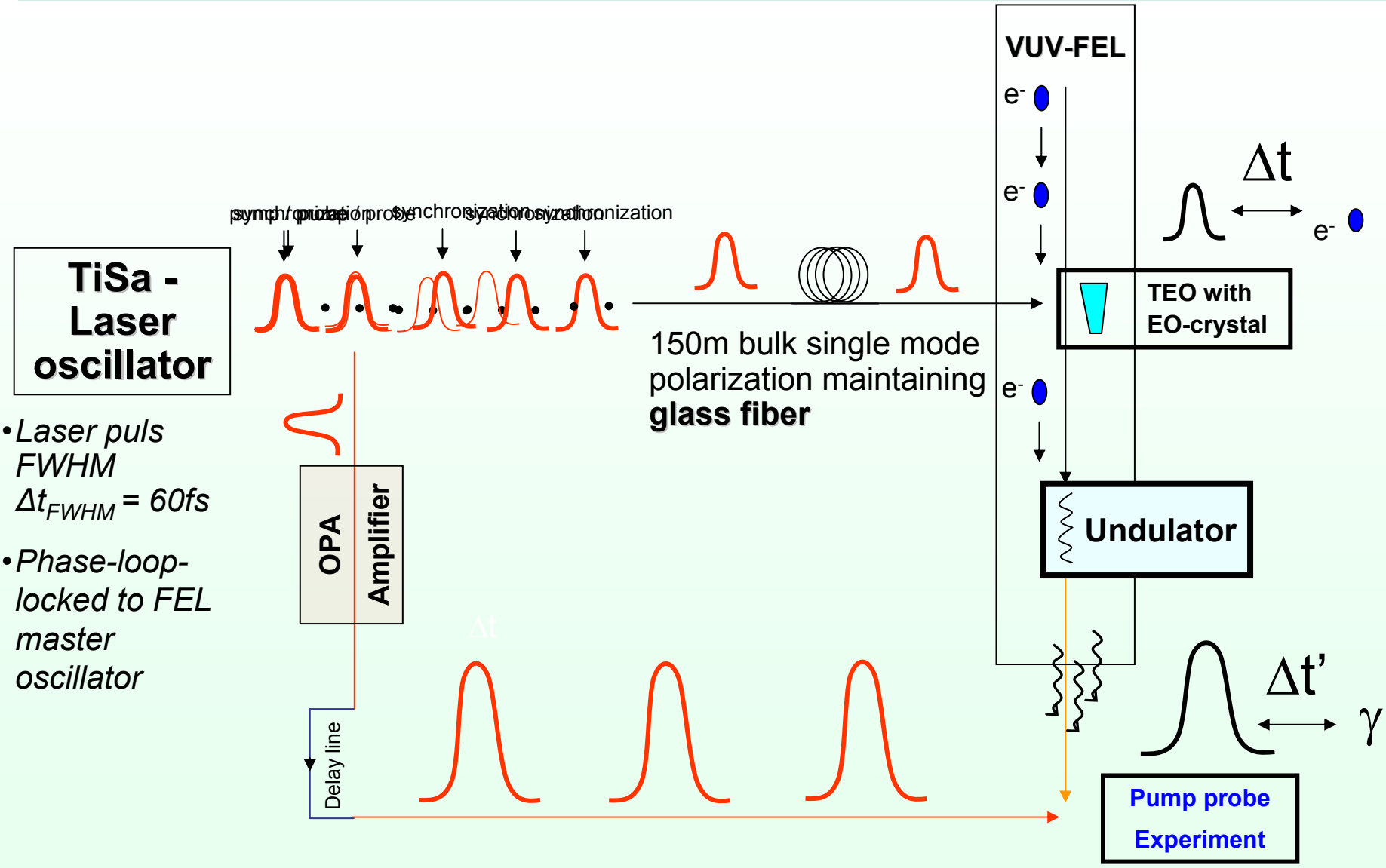


→ Jitter measurement done by the Timing by Electro-Optical sampling exp., "TEO" - Experiment

The Timing electro optical sampling experiment

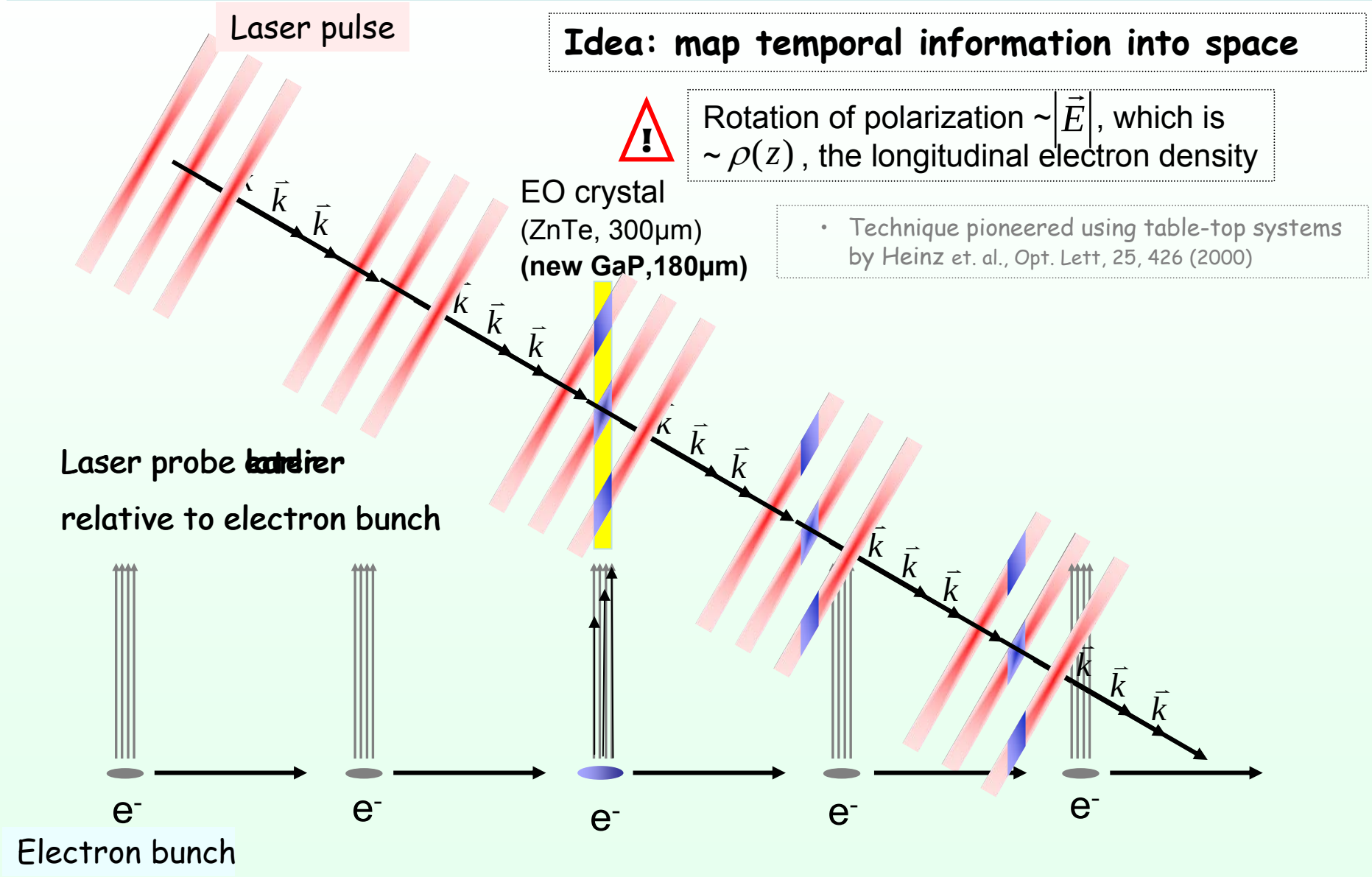
- TEO: “Timing electro optical sampling”
  - correlation between an optical laser pulse and the electric field of an electron bunch
  - based upon Pockel’s effect
- Purpose:
  - jitter measurement for pump probe experiments
  - electron bunch analyzing

Timing-Electro-Optical principle

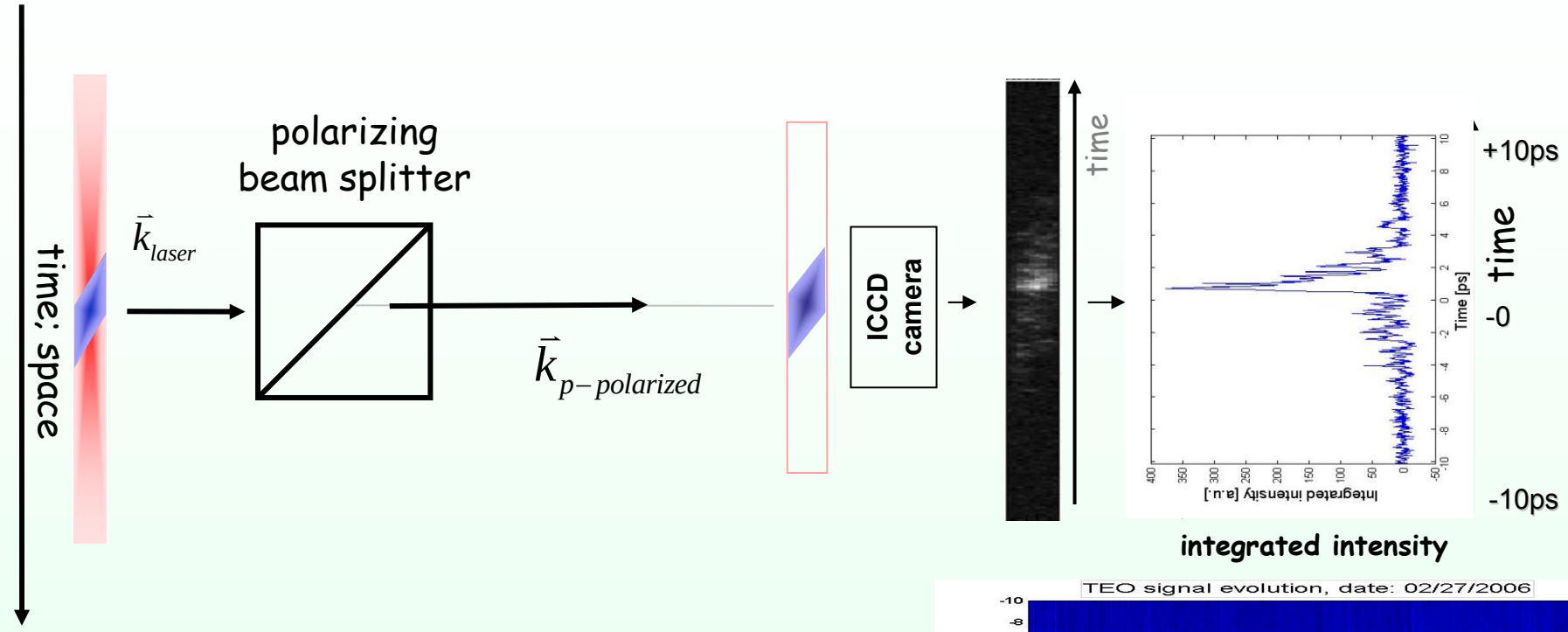


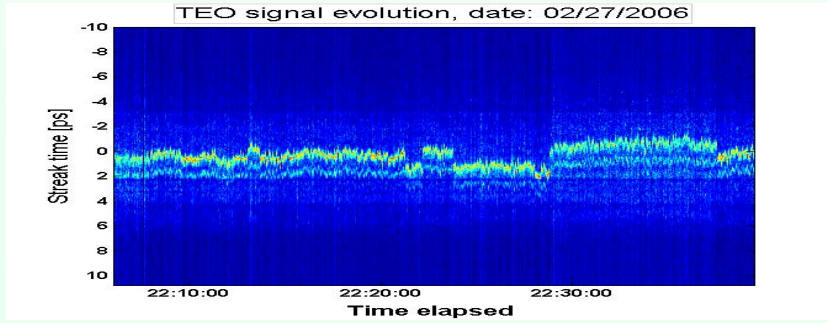
$\Delta t = \Delta t' \pm 60fs$ shown by "Cavalieri et al., Phys. Rev. Letters., **94,** 114801 (2005)"

TEO signal detection



TEO signal detection



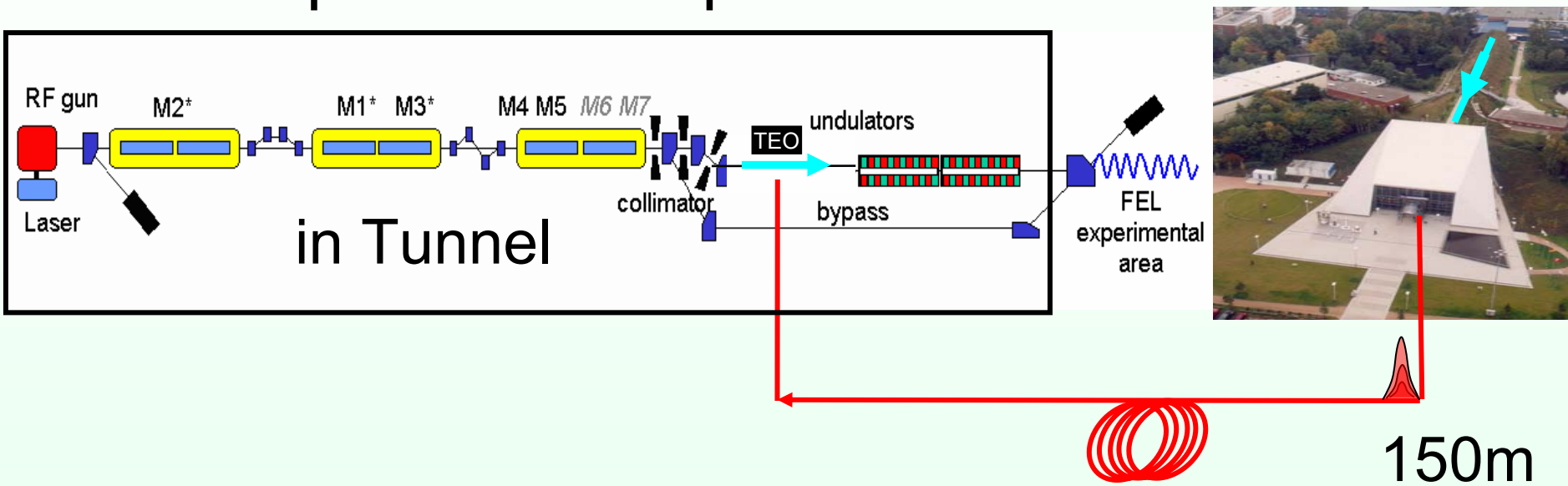


- **Arrival time and duration of bunch is encoded on profile of laser**

Temporal resolution of Pump-Probe exp. is given by the precision of the jitter measurement, which will be better than 50 fs.

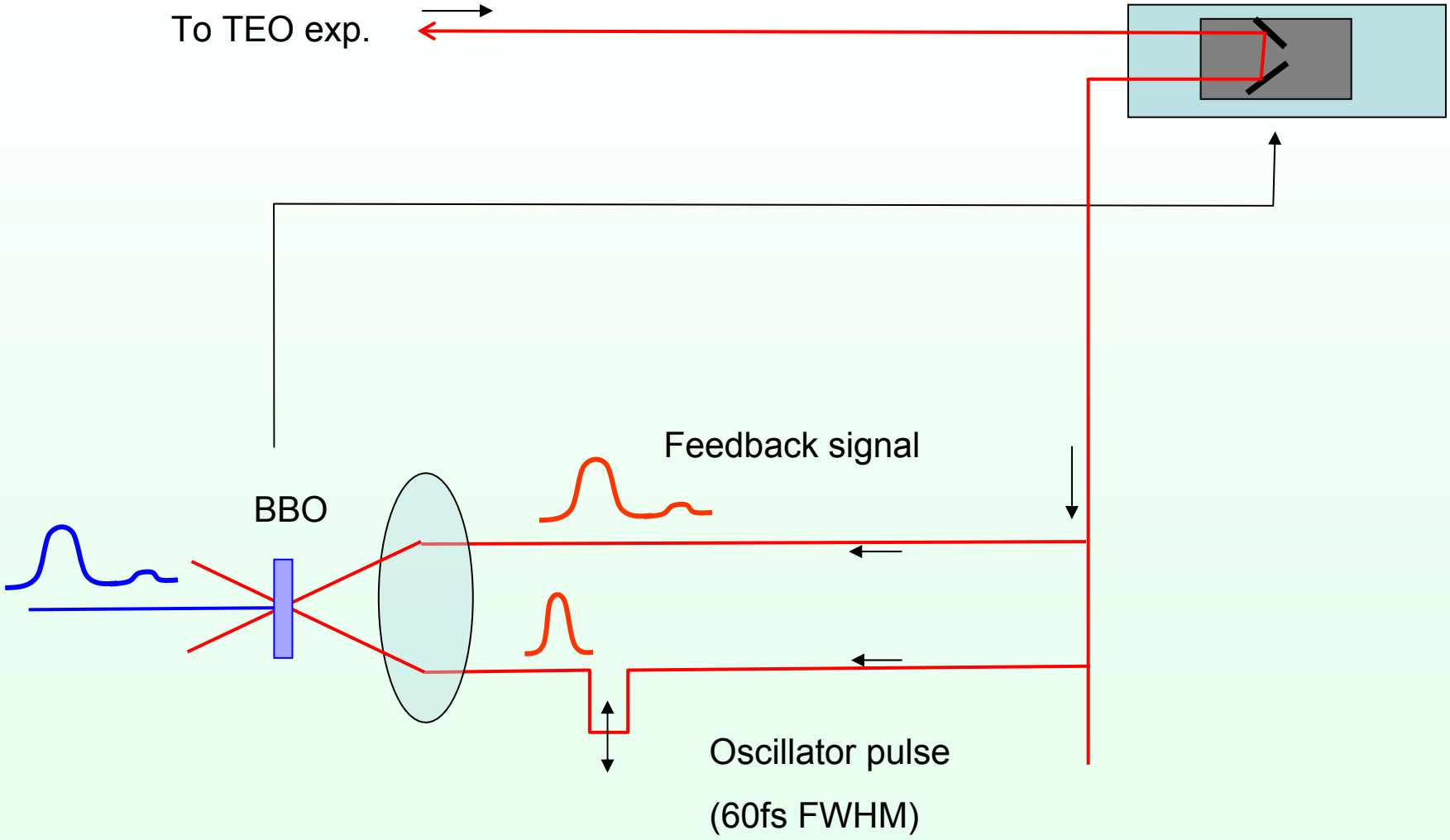
Dispersion during pulse transport

- Transport of laser pulse

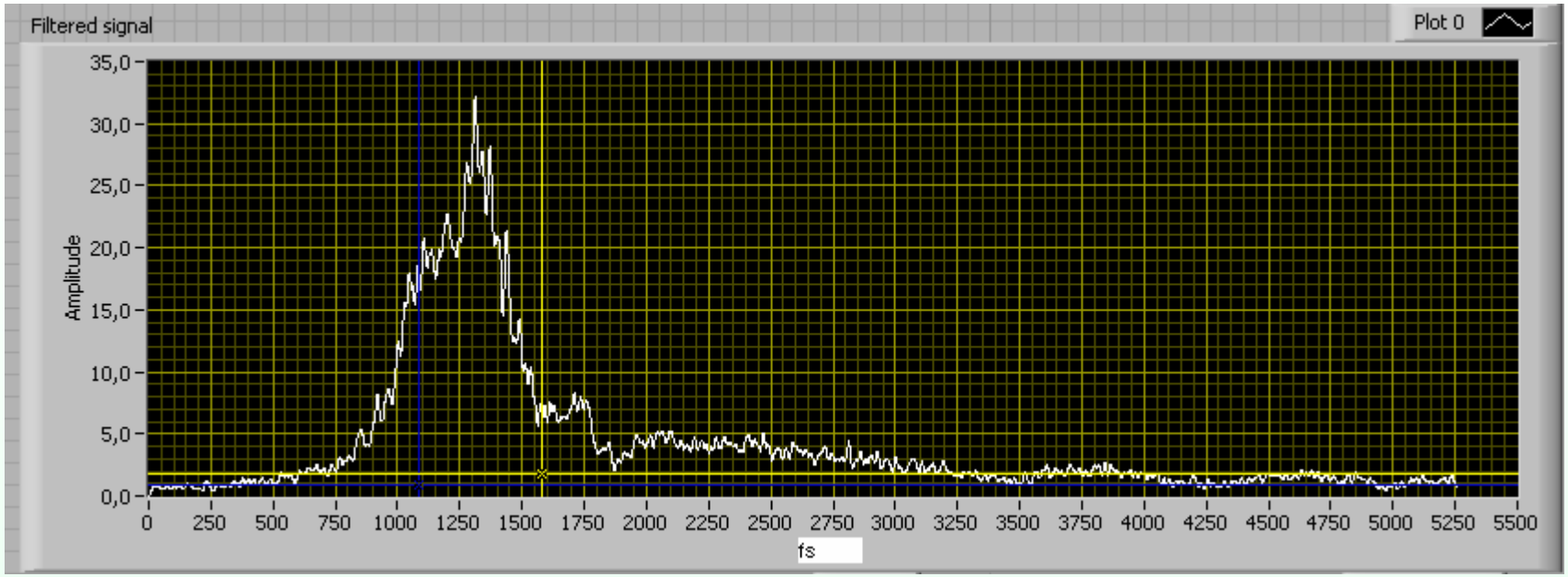


- **Pulse in fiber will be broadened (**50 fs to 0,4 ns**) and distorted due to high order dispersion** (~100 pulses seen)
- Temperature change delays pulse due to fiber expansion → fiber length compensation necessary → feedback loop

Feedback signal measurement

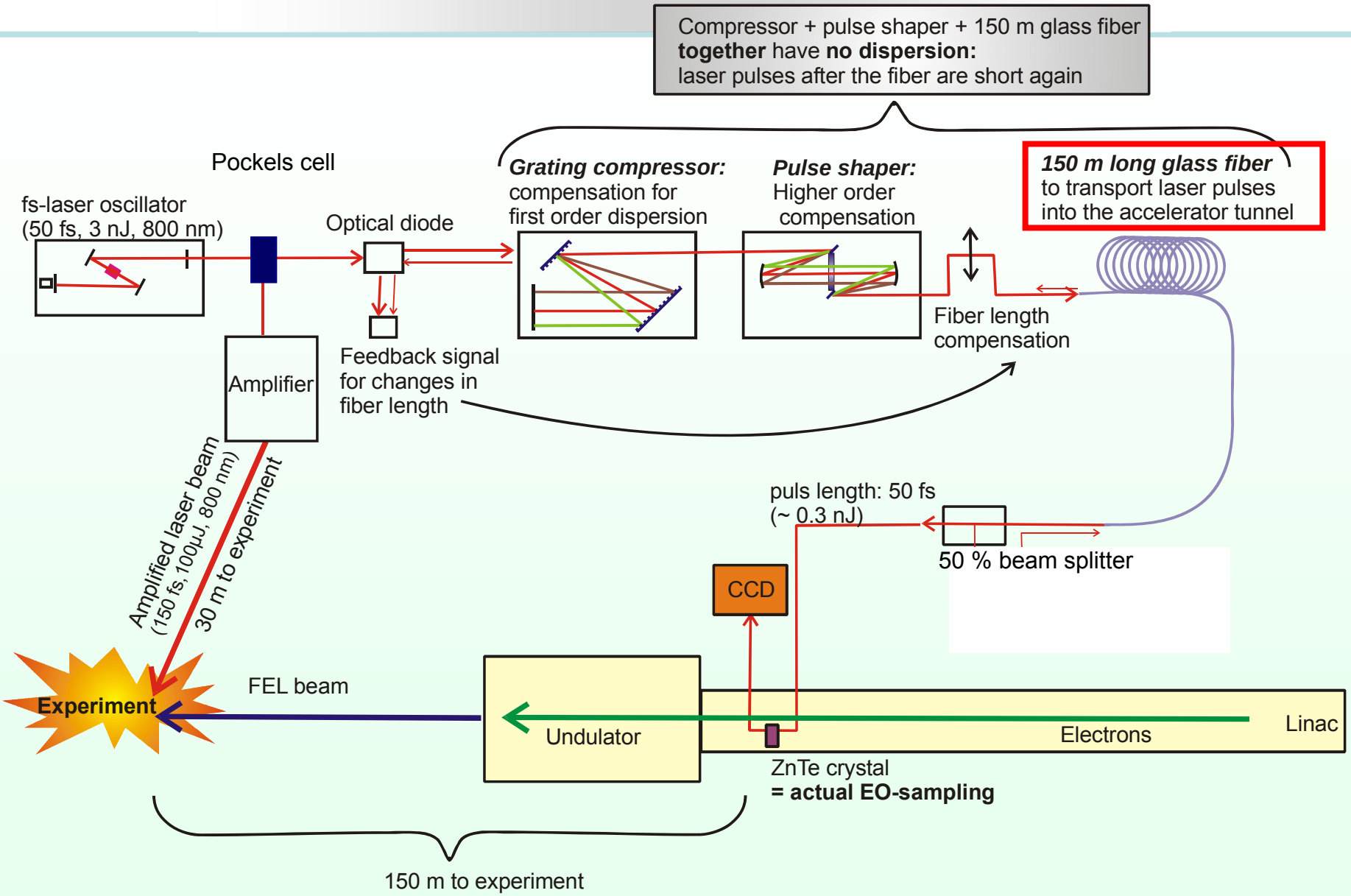


Feedback signal



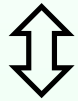
- FWHM 500fs, very sensitive to phase compensation
- Read out every minute
- Mean feedback signal delay measured by feedback loop from day to day: ~10-15 ps

TEO overview



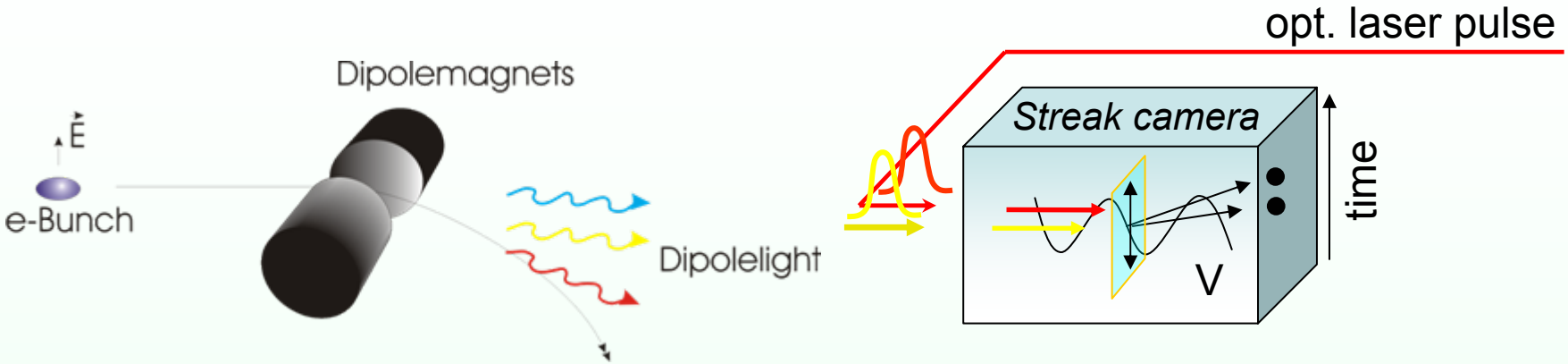
Jitter measurement – comparison

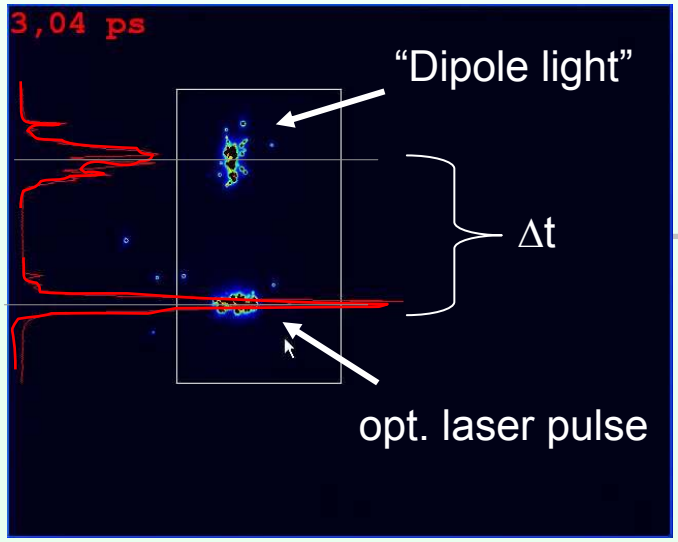
- Timing Electro-Optical Sampling

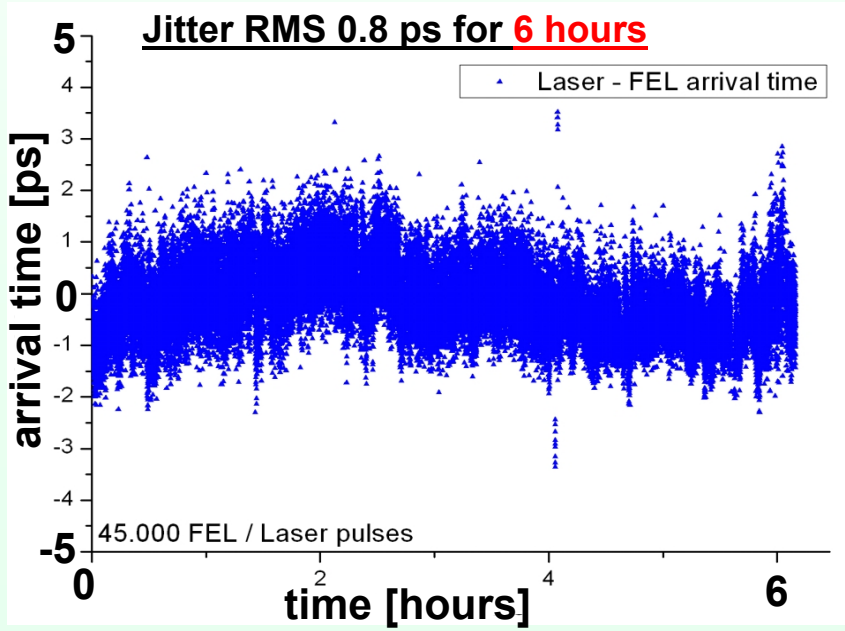


- Dipole light and streak camera

Jitter measurement - Streak camera

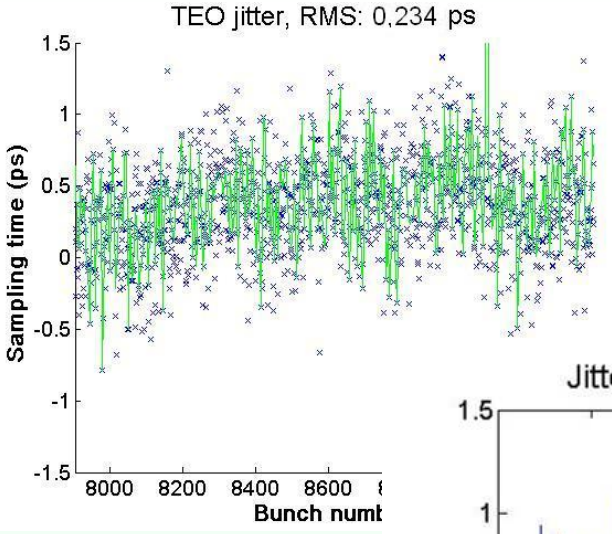


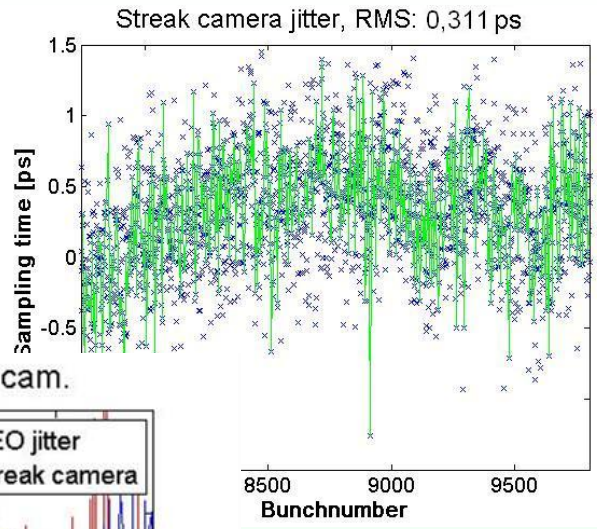


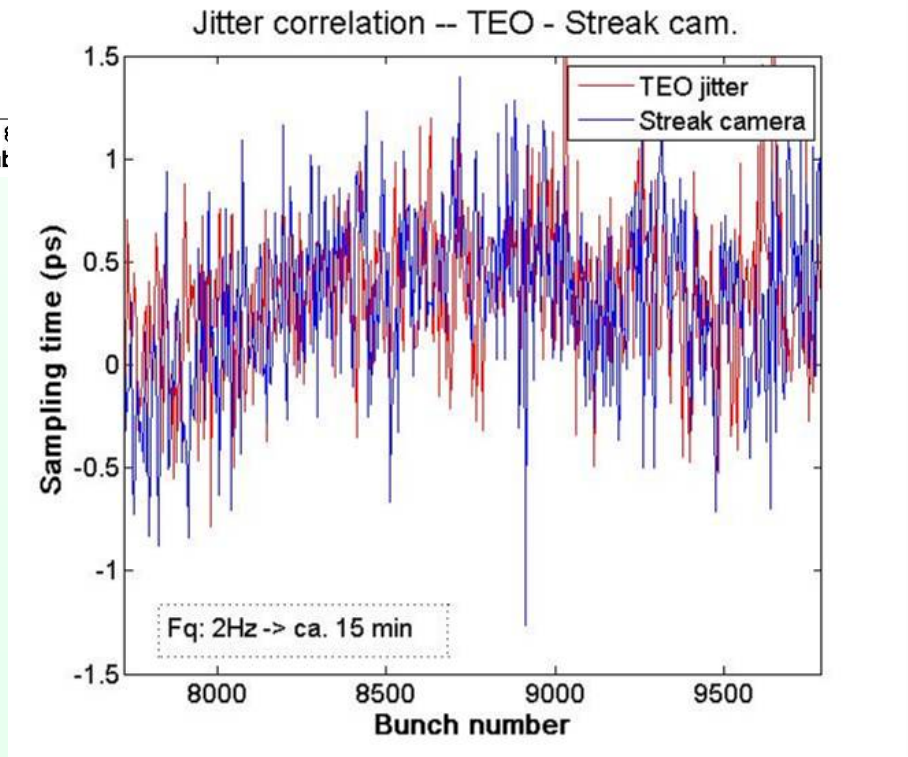


Streak camera – temporal resolution 2ps

Jitter measurement – Streak camera vs. TEO

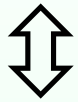




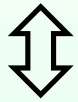


Electron bunch analysis

- Transverse RF cavity electron streak camera



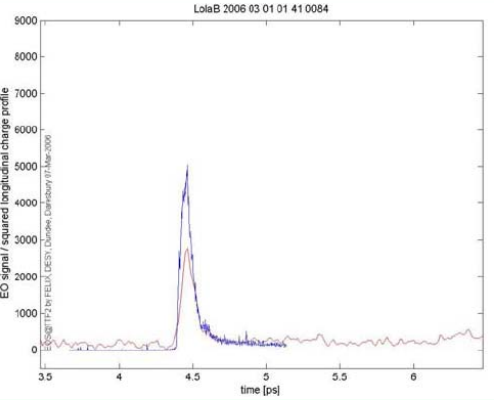
- Electro-optical sampling with temporal decoding

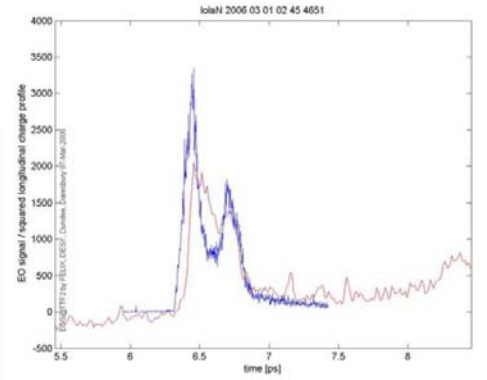


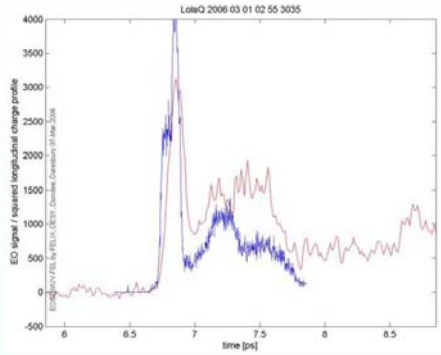
- Timing Electro-Optical Sampling

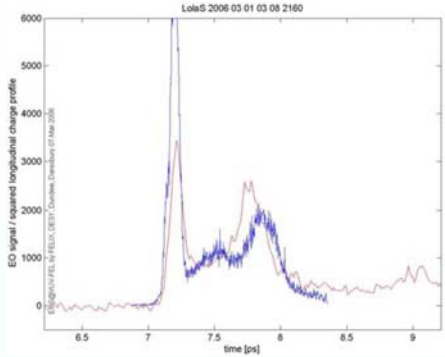
Accelerator phase tuning – LOLA and EOS

VUV-FEL
Vacuum-Ultraviolet
Free-Electron Laser







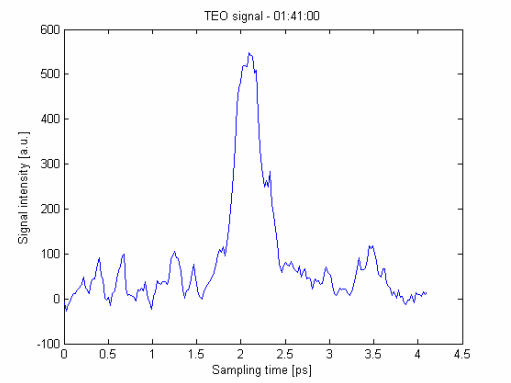


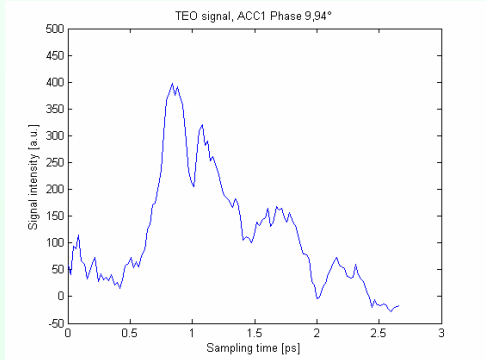
Compressed

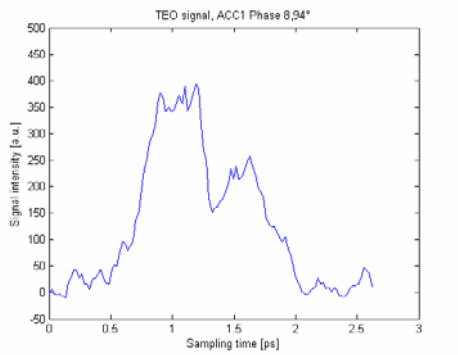
Δ1°

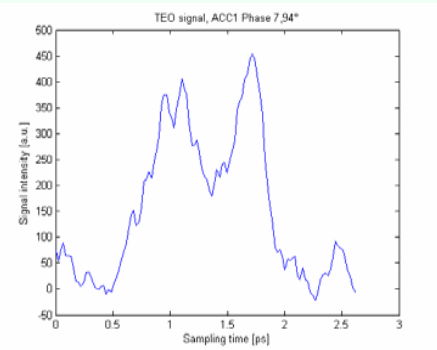
Δ2°

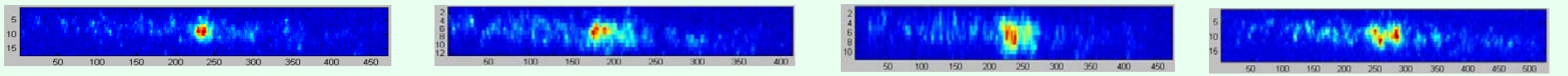
Δ3°











Electron bunch structure measured by LOLA, EOS temp and TEO

Conclusion & Outlook

- built a system, that provides jitter data for user pump-probe experiments
- by now we have a 200 – 300 fs resolution for the measured jitter
- Electron bunch shape can be monitored online and noninvasive
- changed crystal from ZnTe (wedged) to GaP, plain, 180µm thickness

<u>Still to do</u>:

- Compare with a Pump Probe experiment
- improve time resolution and signal strength

Acknowledgments

Thanks are going to:

Photon diagnostic:

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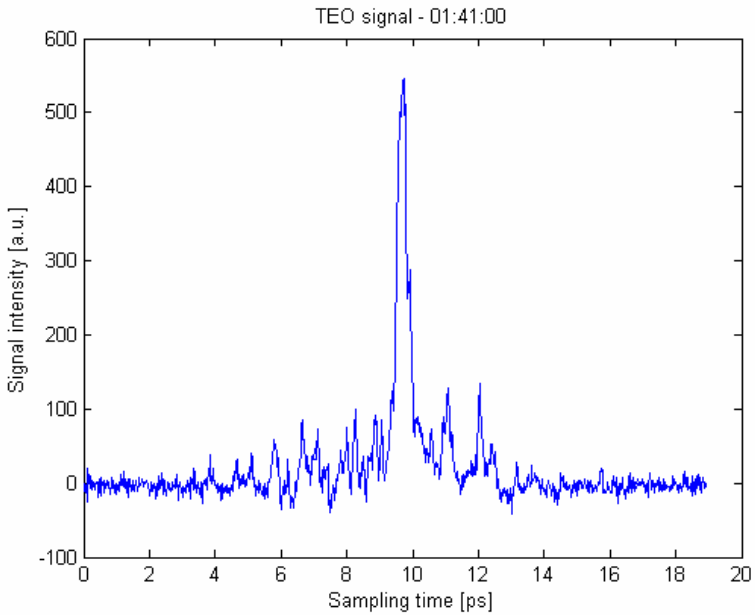
Accelerator group:

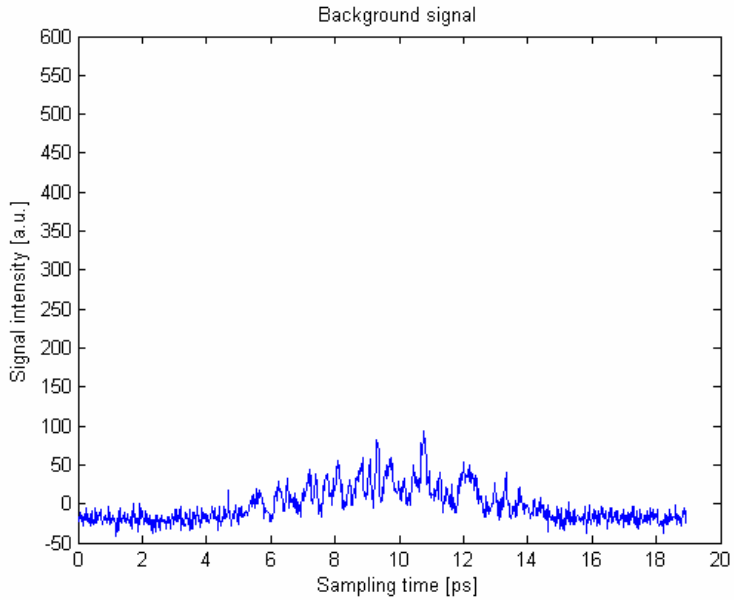
Holger Schlarb, Bernd Steffen, Peter Schmueser

and Klaus Sengstock.

END

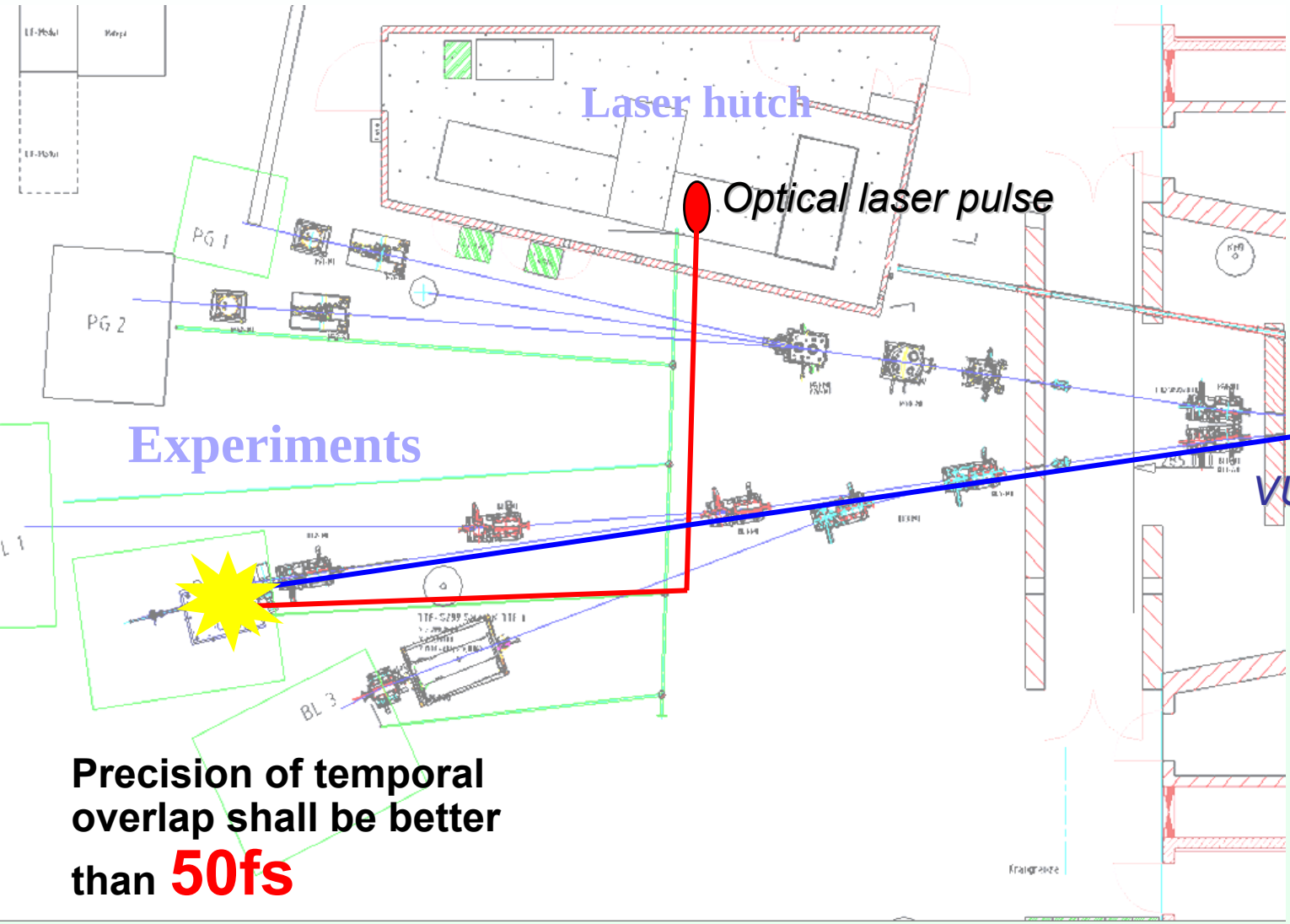
Experimental results TEO





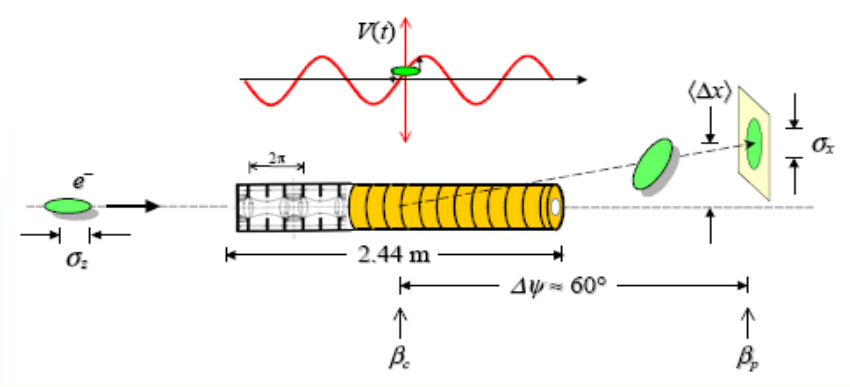
- 10-90% edge rise time: 300fs
- Amplitude and signal to noise ration varies strongly

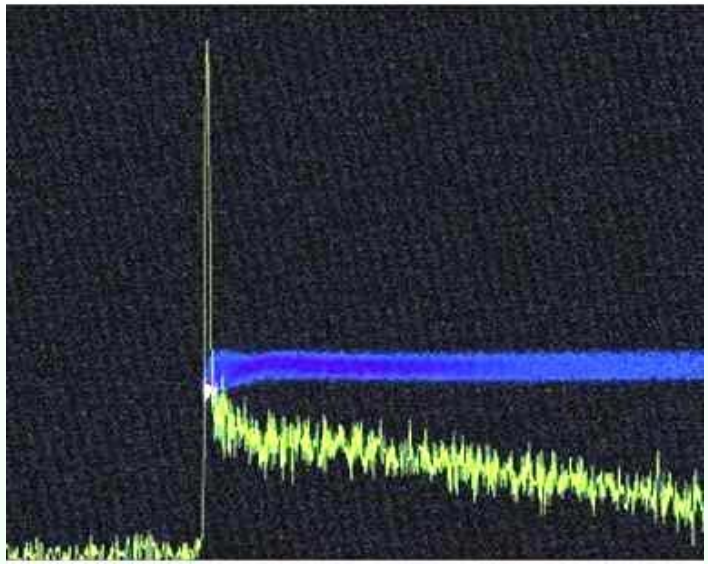
Pump-probe exp. with VUV-FEL



Precision of temporal overlap shall be better than 50fs

e-Bunchstreak camera – “LOLA”

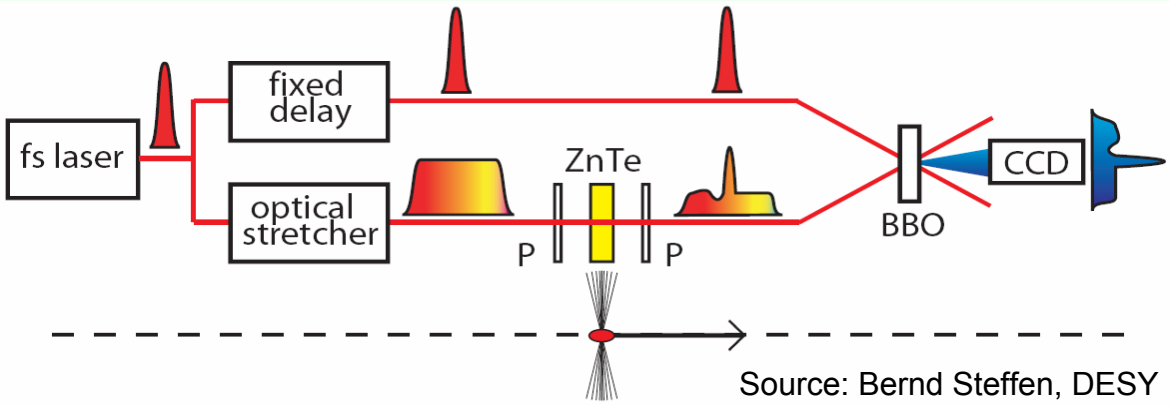




- Measurement of longitudinal beam profile with transverse deflecting RF-cavity
- Electron bunch is “streaked”
- Temporal resolution ~10fs

Electro-Optical-Sampling by Temporal Decoding (EOS)

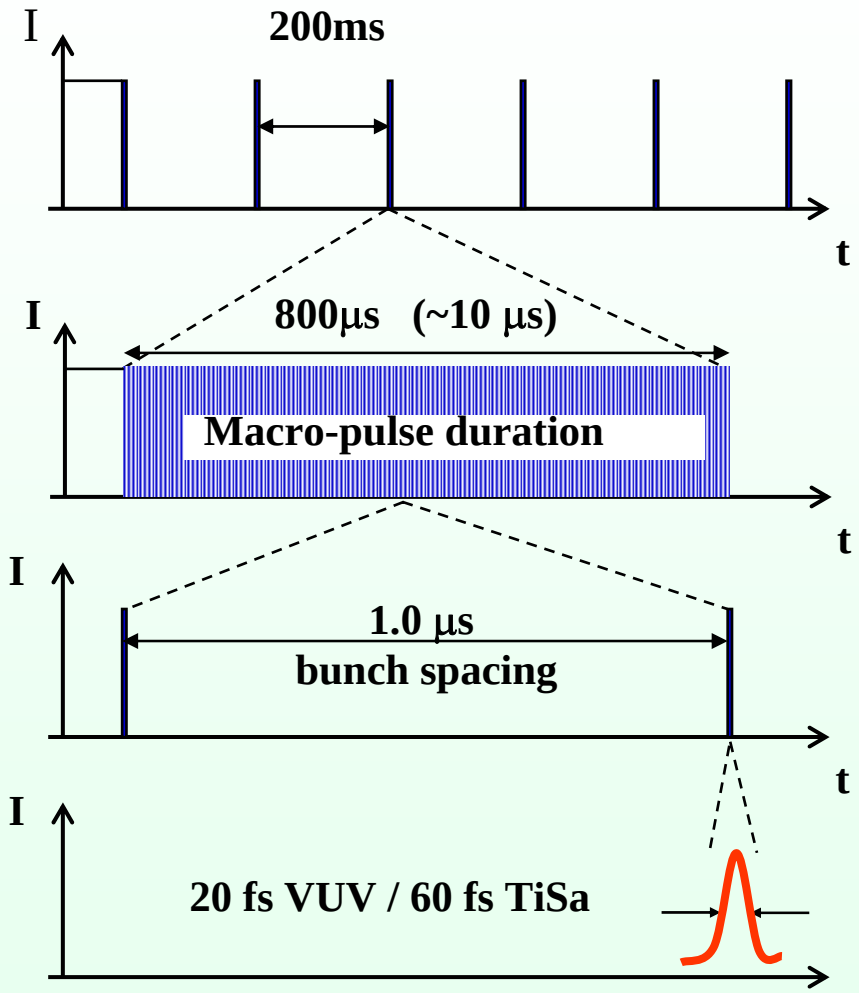
- e^--electron density is encoded spectrally and temporally
- The temporal information is read out by a nonparallel cross-correlation with the uncompressed bunch (convolution with a “delta”-peak)



Source: Bernd Steffen, DESY

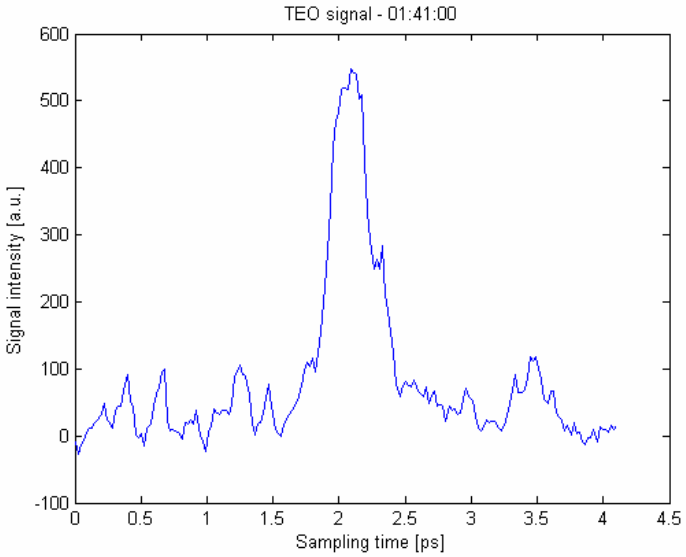
Time structure

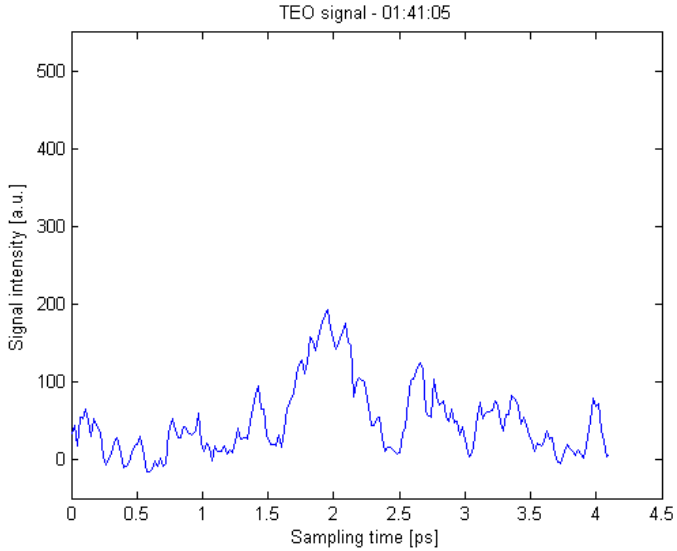
- Macro pulse

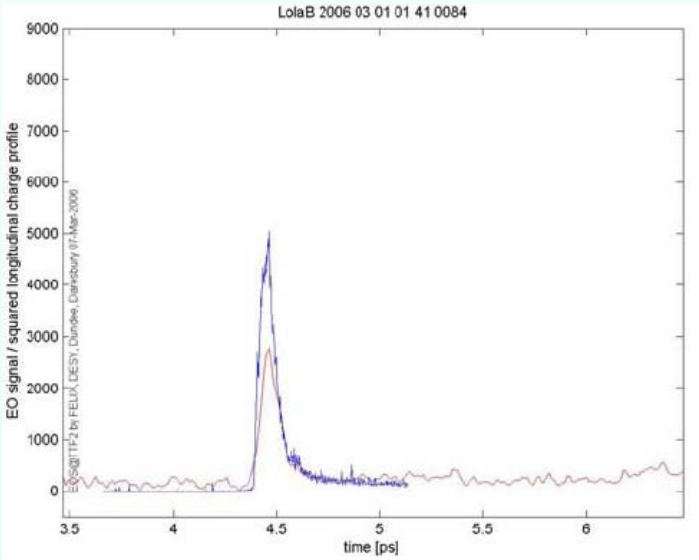


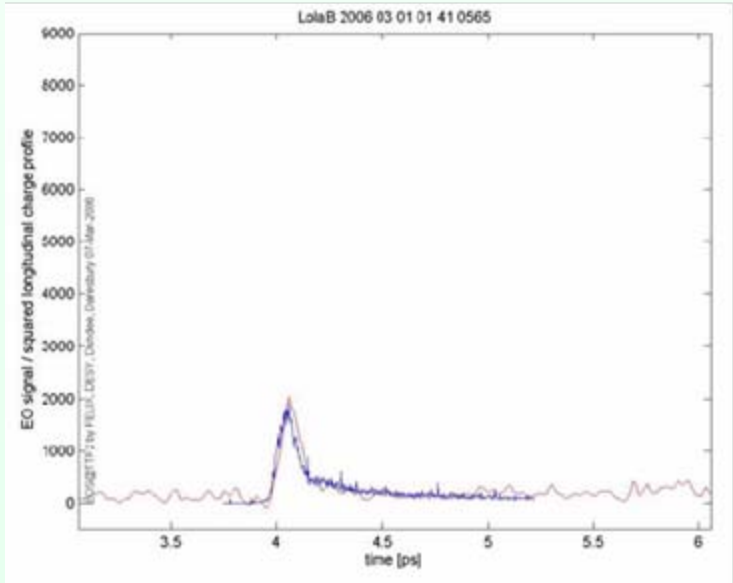
- Electron bunch / photon pulse

Comparison with LOLA and EOS









- Phase of accelerator field 10.94Deg ⇔ Almost perfect bunch compression