Towards coherent ultrafast spectroscopy at IR-FELs

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Introduction:

Background:

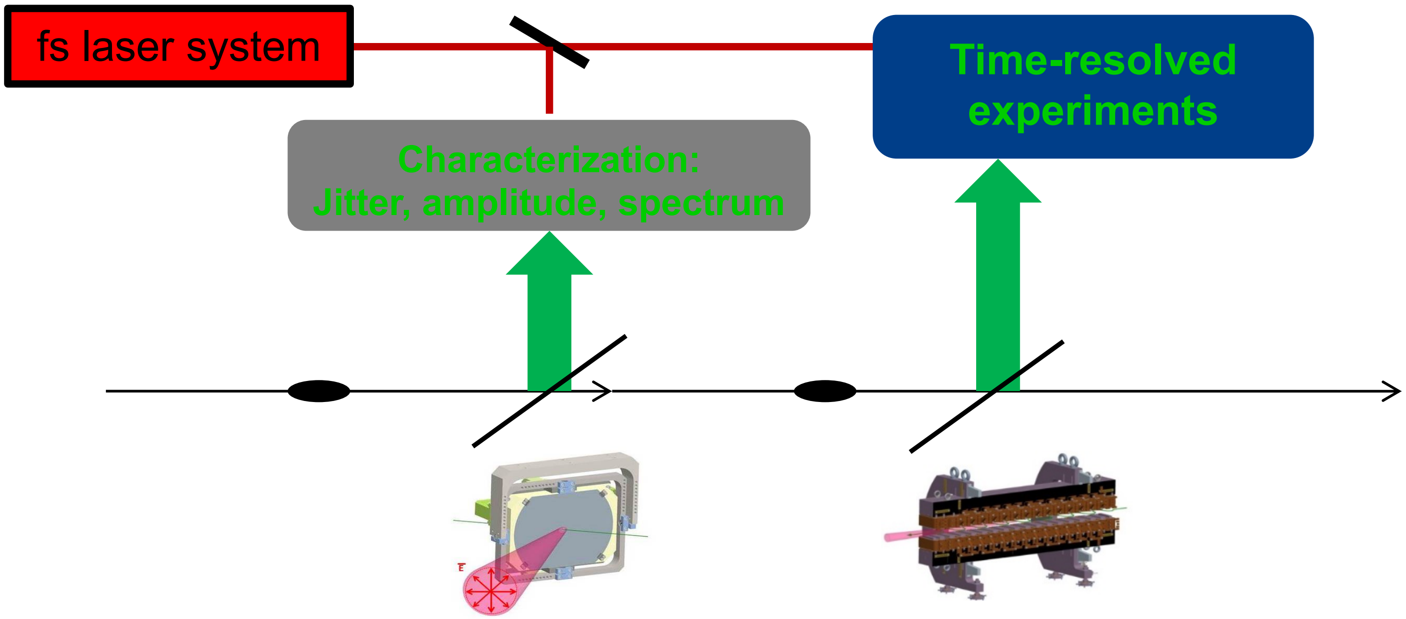
- Accelerator-based sources can provide unique parameters of radiation that is important both for fundamental research and applications.
- A big interest on THz/IR range is attributed to selective ground state excitation, THz nonlinearities, coherent phase control etc.
- Problem: conventional techniques to study field-induced effects (time-resolved techniques) often not working, require adaptations
- Pulse-resolved detection as a way to overcome various accelerator instabilities, but tested only for superradiant (**CEP stable**) sources.

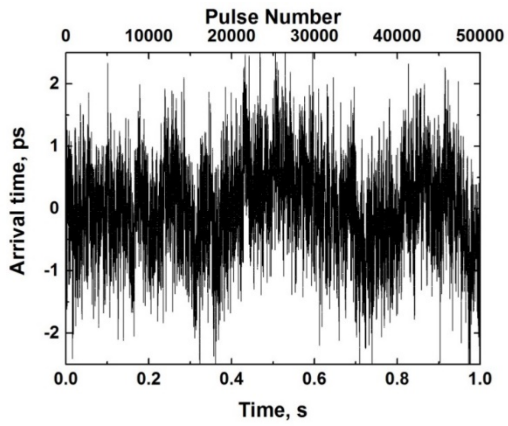
Motivation:

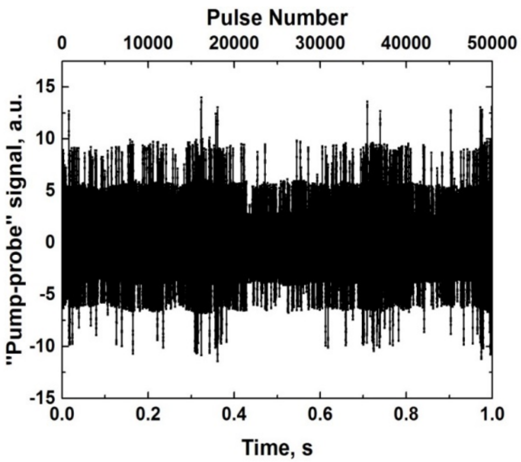
- FEL can provide tunable radiation with extreme spectral brightness → ideal for selective excitation.
- FEL oscillators are **not CEP stable**, so new techniques are needed to determine the phase of each pulse at the high repetition rate.
- Important for FEL-seeded superradiant accelerator based sources (such as DALI) in planning
- Up to now: no results on coherent spectroscopy using CEP-unstable sources.

Here, we demonstrate: the CEP-instability problem can be solved by phase-resolved detection, and coherent spectroscopy can be employed at IR-FELs

Pulse-resolved detection concept:



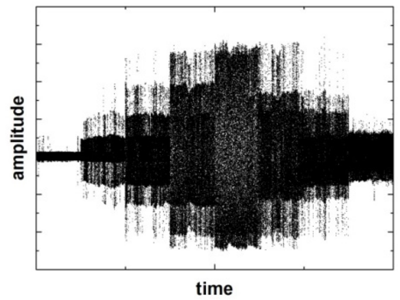


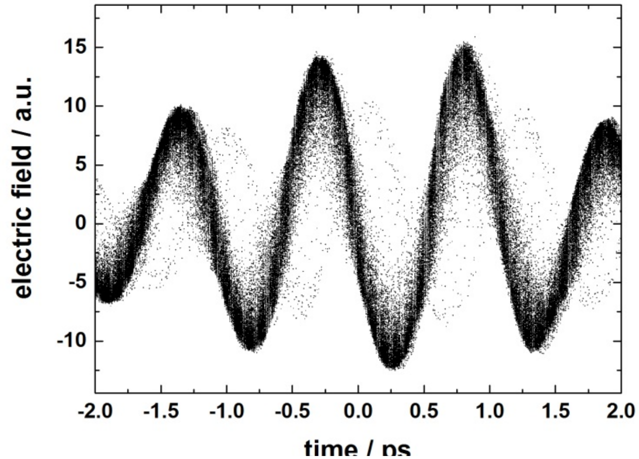


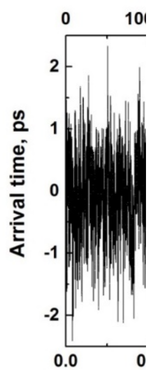
DRESDEN concept

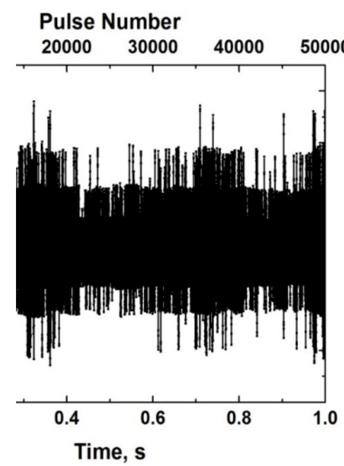
fs laser system

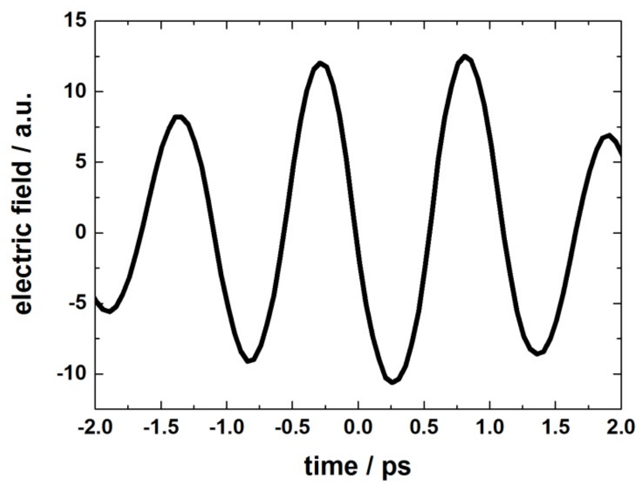
Time-resolved experiments







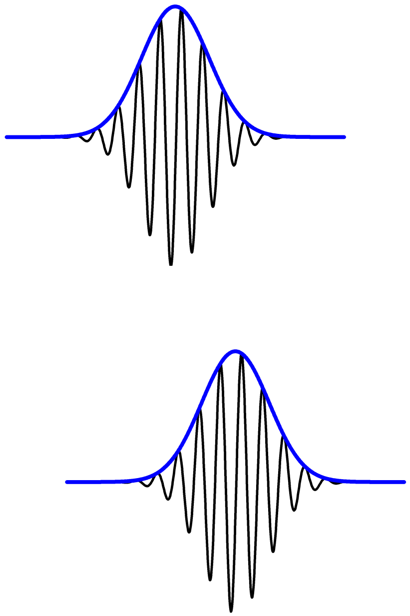




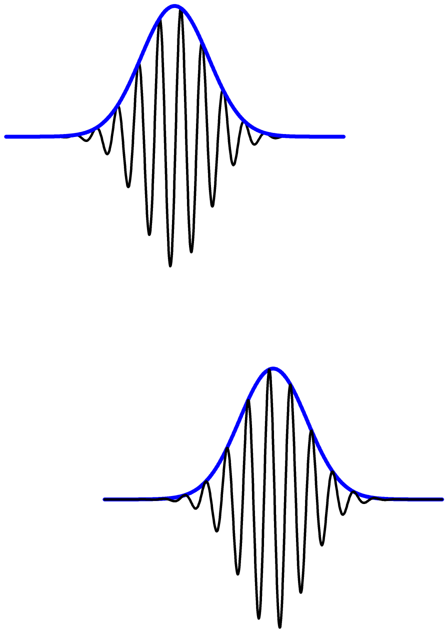
CEP fluctuation problem at FEL oscillators:

Pulse-resolved detection:

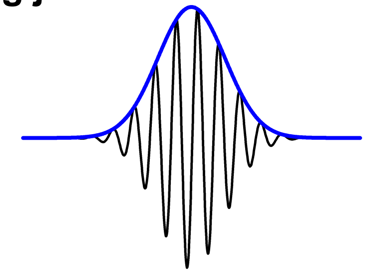
CEP stable sources



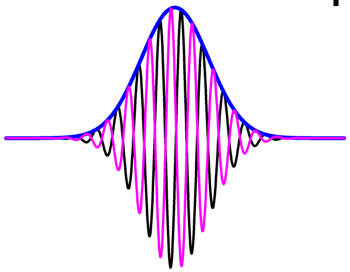
CEP unstable sources



Timing jitter is the most critical parameter



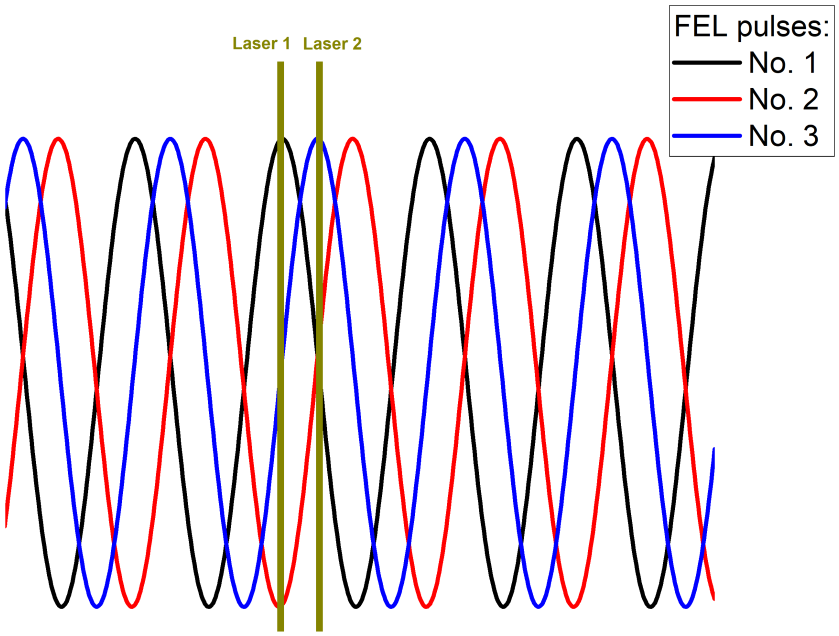
Phase is the most critical parameter



Phase-resolved detection concept:

Solution: measure the FEL phase for each shot and correlate it with experiment.

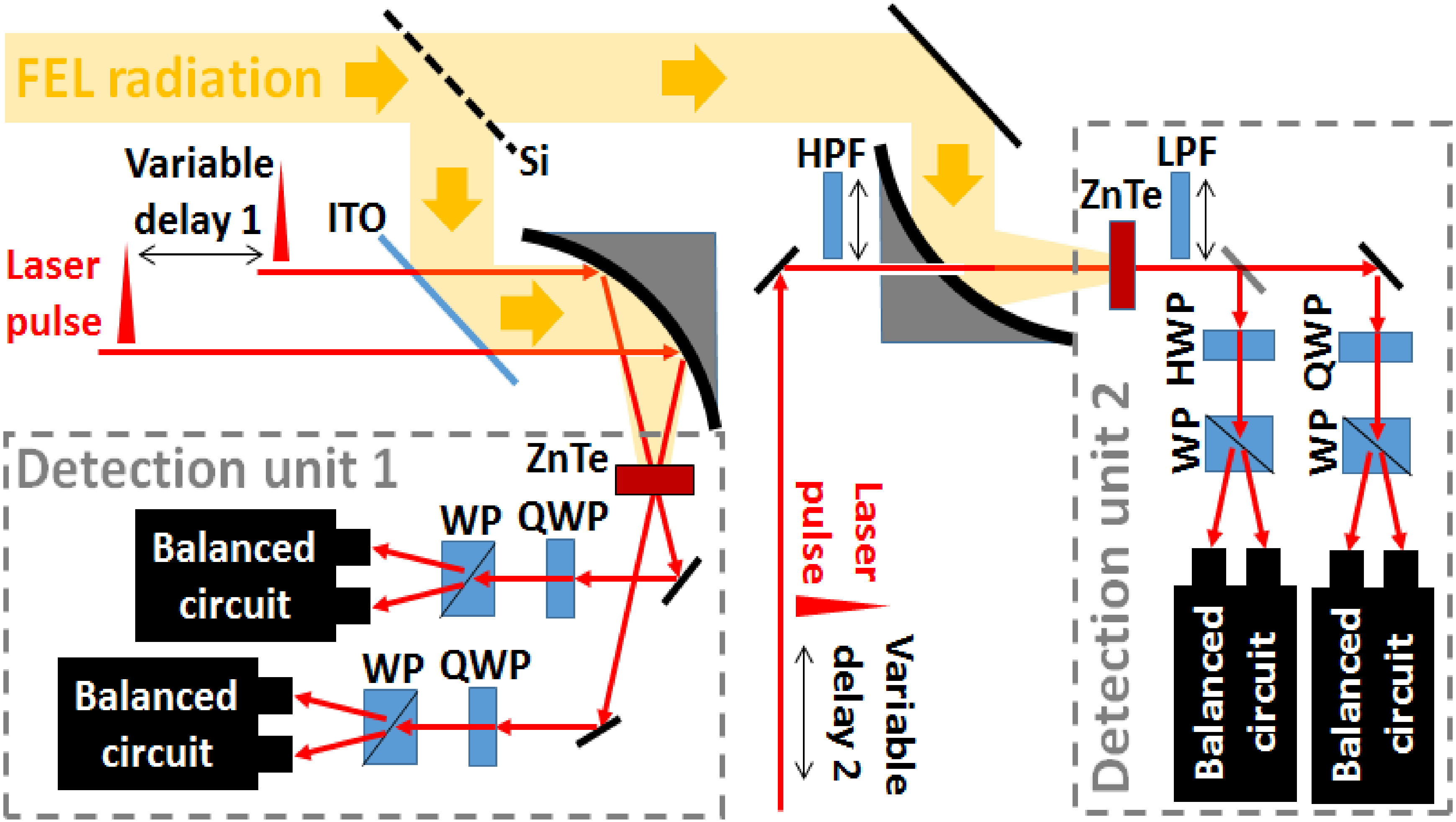
Challenges:
- High repetition rate (13 MHz);
- Narrow bandwidth;
- Spectral decoding cannot be applied;



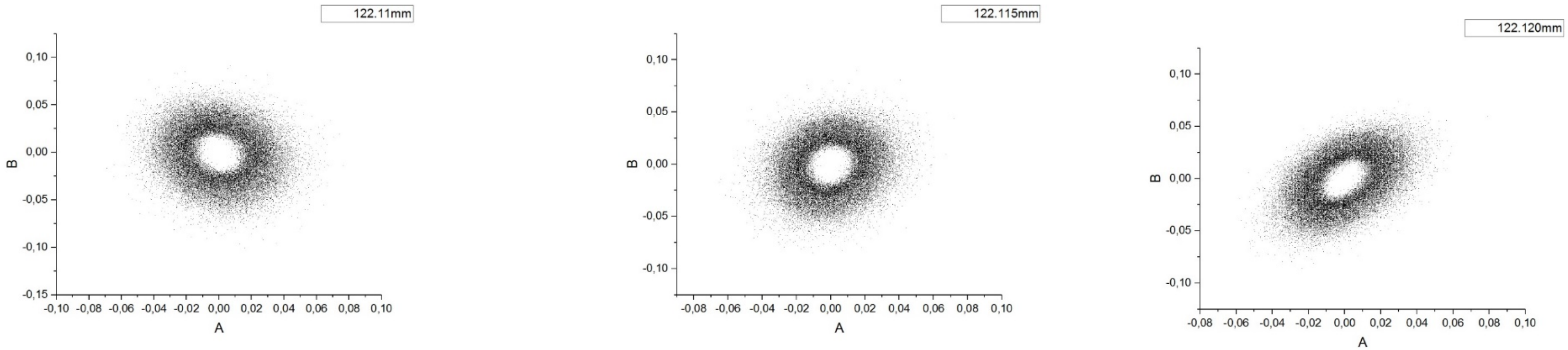
FEL phase can be determined by using two laser pulses;

Or by measuring electric field and its derivative with a single pulse.

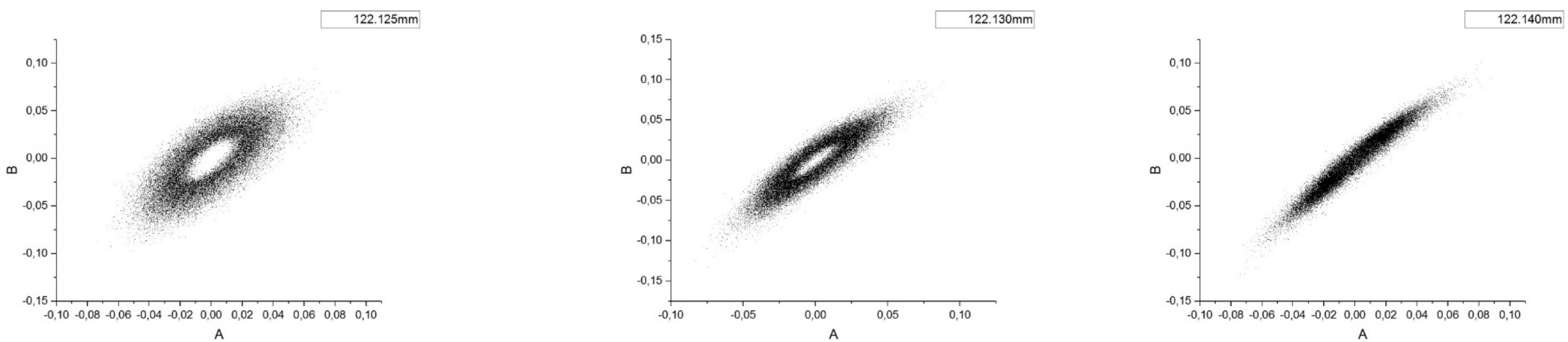
Experimental setup:



Results: phase determination

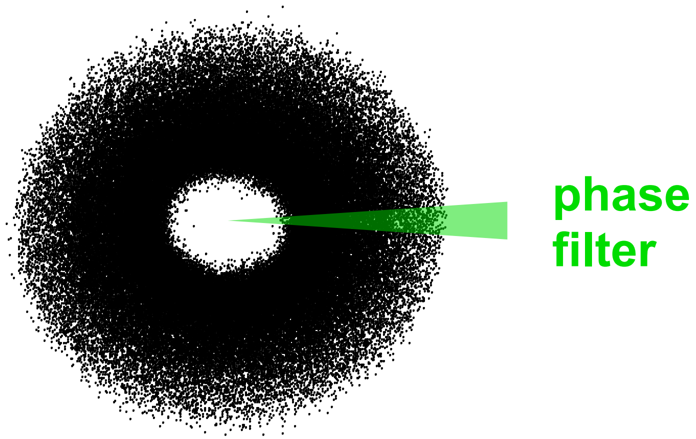


When two lasers are separated by quarter wavelength the phase can be determined

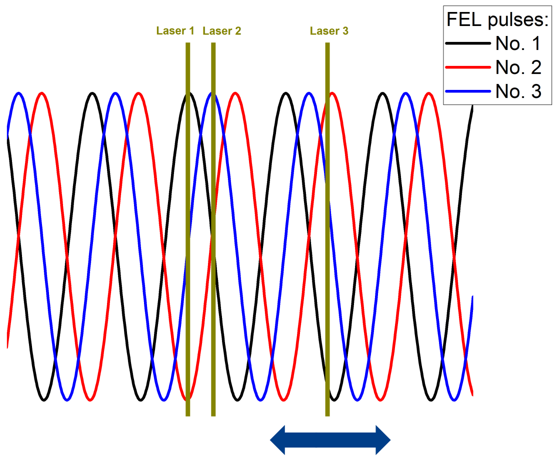


Results: phase determination

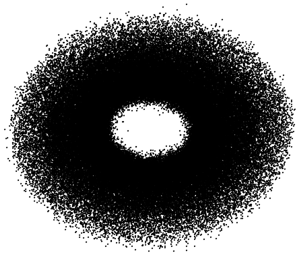
Polar Plot of the FEL phase
(40000 pulses)

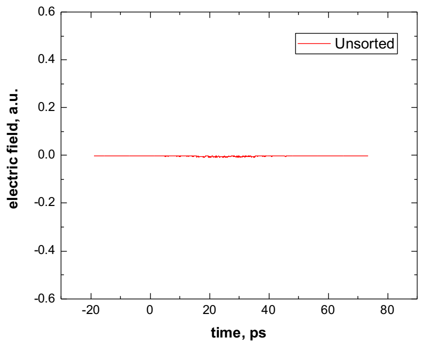


Results:



Laser 1 and 2 are fixed
Laser 3 is scanning

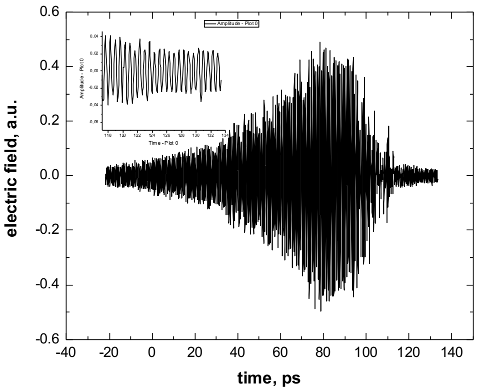




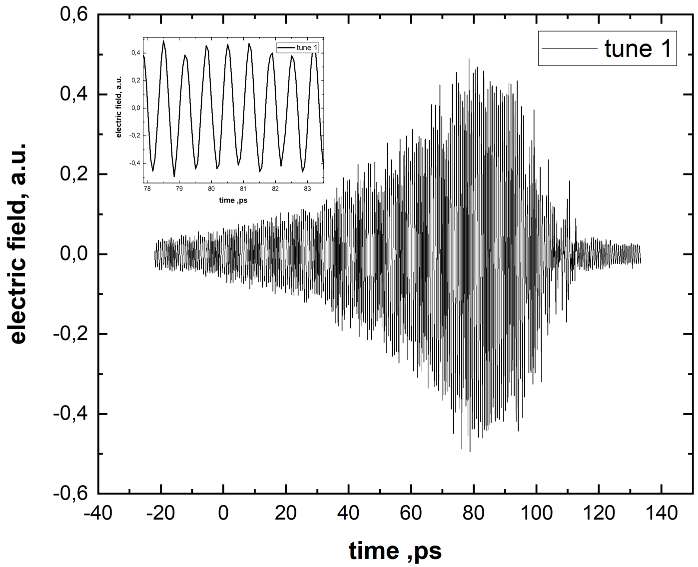
Electro-optic sampling

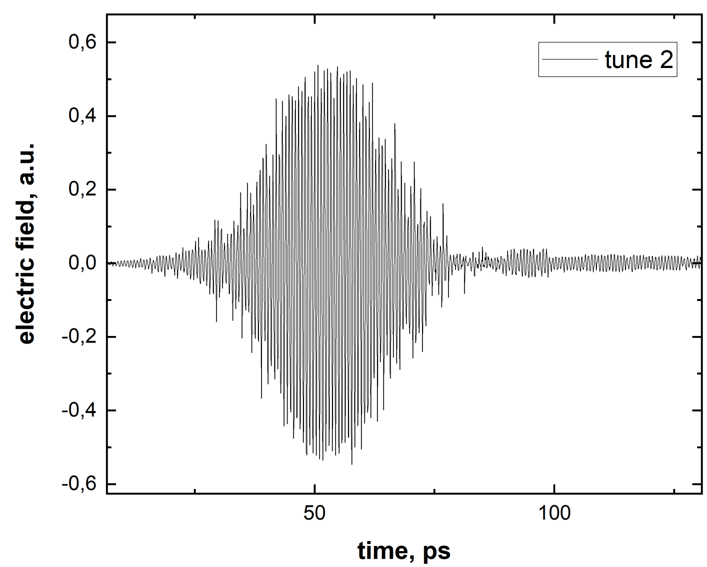
Using standart detection: all phases

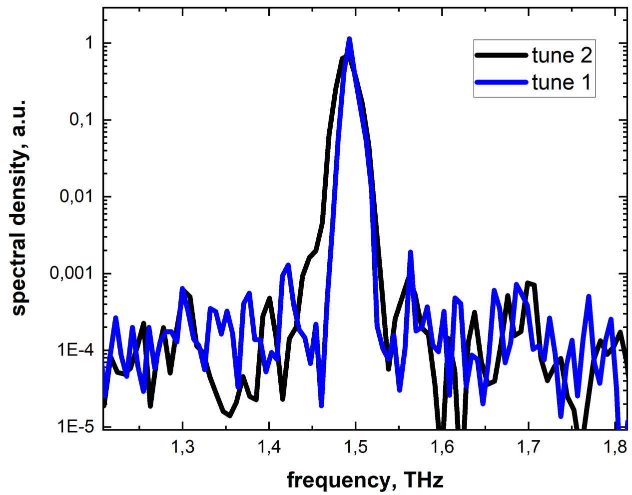
Using phase filter



Results:



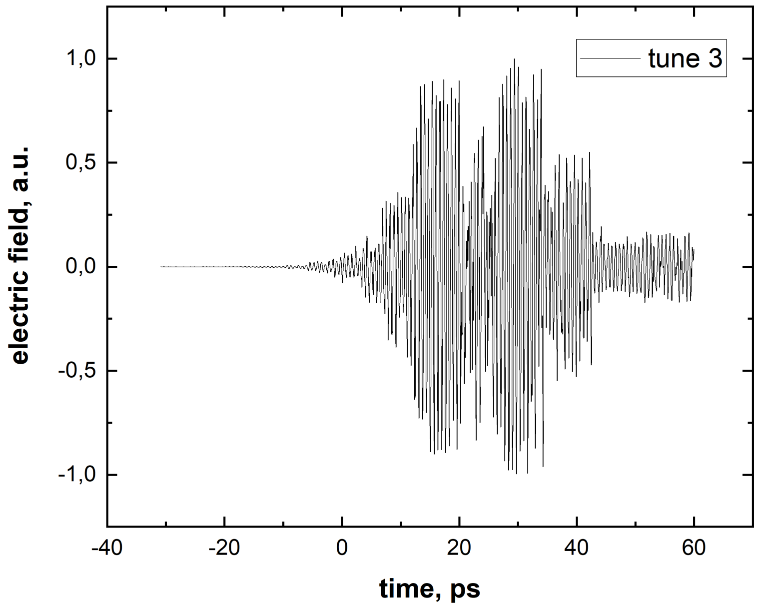


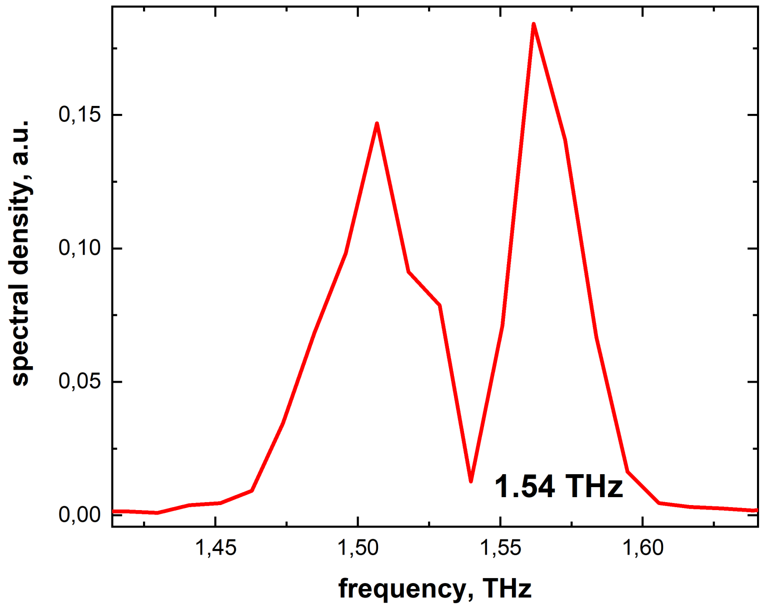


DRESDEN concept

HZDR

Results:





Dip in the frequency corresponds to water absoprtion line (1.542 THz)

Conclusion:

- Pulse-resolved detection can be applied to CEP-unstable sources, such as IR-FEL oscillators or others.
- Using phase compensation / filtering, coherent spectroscopy is feasible, e.g. field driven dynamics can be observed.
- Opens new research area for accelerator-based sources

Next steps:

- Timing jitter monitoring / compensation;
- Organic EO crystals to cover 10 THz range;
- Benchmarking other schemes, as this was just the first attempt

Thank you for your attention.

EUCALL

DFG Deutsche Forschungsgemeinschaft
German Research Foundation

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DRESDEN concept

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