Pulse- and field-resolved THz diagnostics and intrinsic synchronization at TELBE

Min Chen

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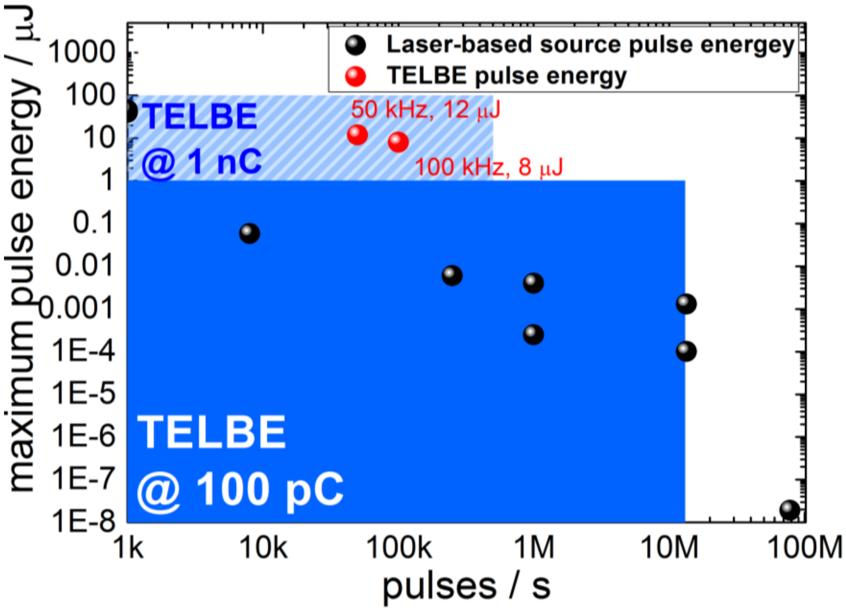
- Motivation
- Introduction of TELBE
- Pulse- resolved DAQ system
- Pulse- and field- resolved DAQ system
- Intrinsic synchronization technique
- Summary and outlook

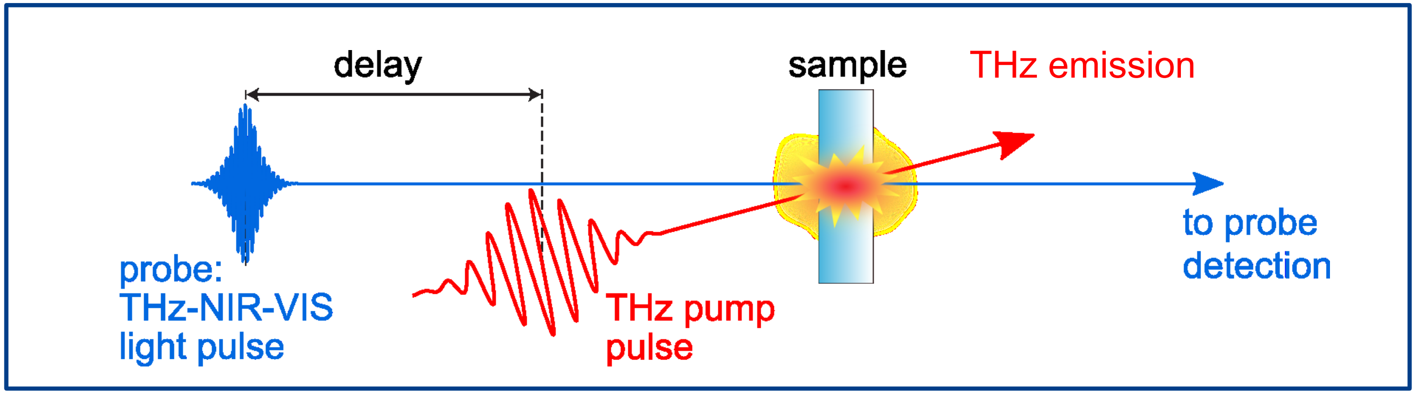
Motivation

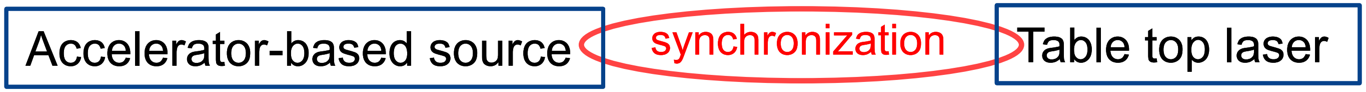


Why accelerator-based THz source ?

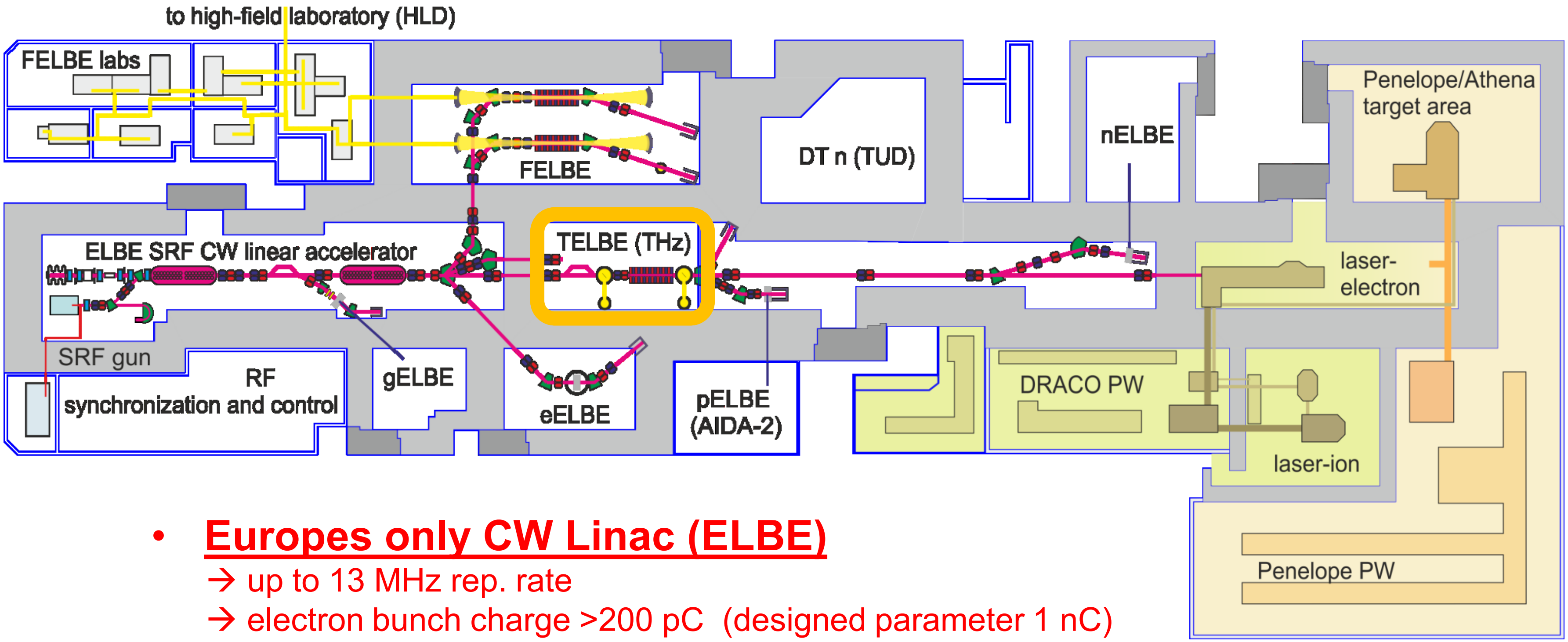
Some ideal parameters of THz source

- *High pulse energy (nonlinear THz optics)*
- *Narrow band source (selective excitation)*
- *High repetition rate (Near-field scanning optical microscope)*





TELBE user facility



- **Europes only CW Linac (ELBE)**
  → up to 13 MHz rep. rate
  → electron bunch charge >200 pC (designed parameter 1 nC)

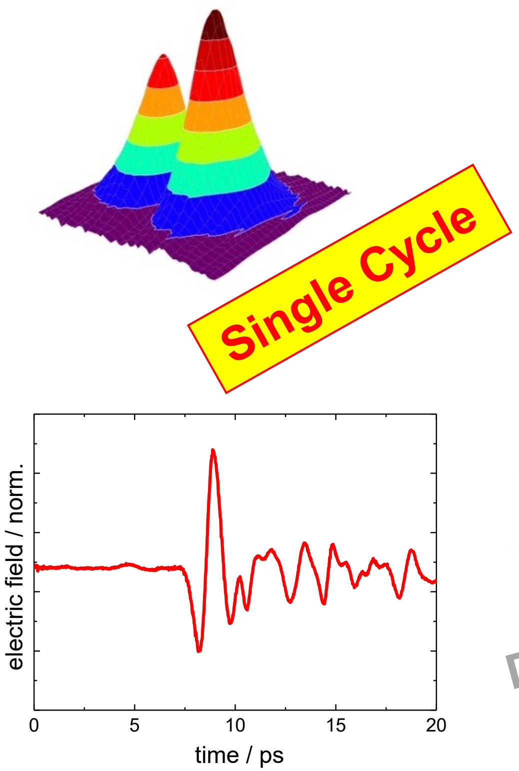
- **TELBE – superradiant THz facility**
  → High pulse energy (up to 12 μJ)
  → Narrow band source (10% bandwidth)
  → High repetition rate (up to 13 MHz)

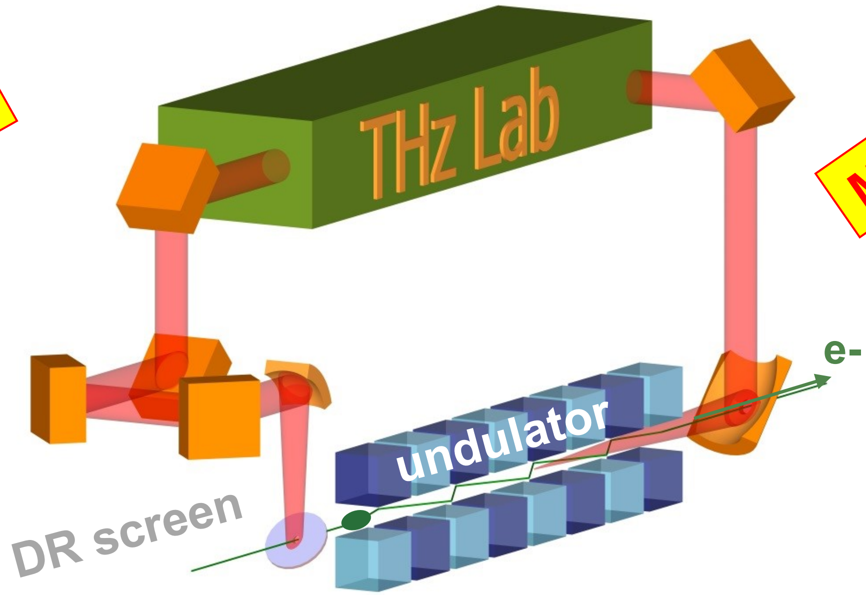
start of early-stage user operation: 08/2016

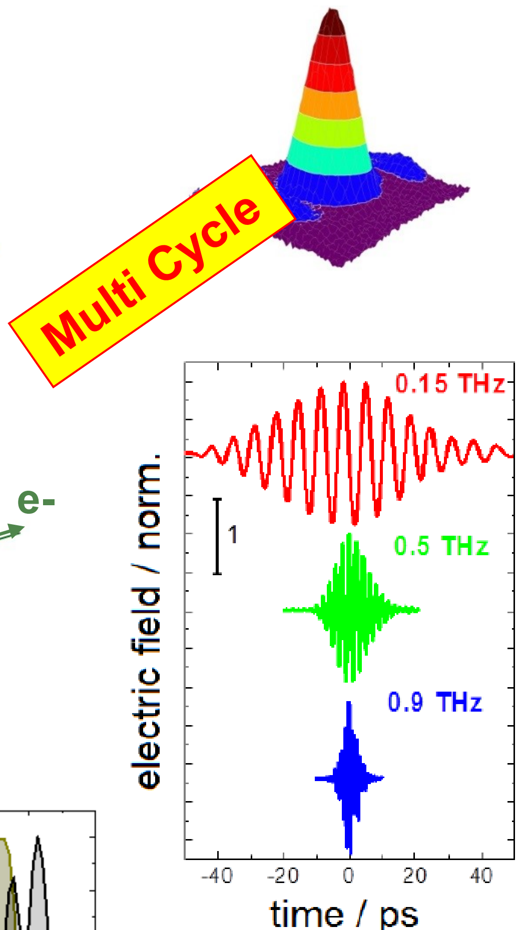
TELBE sources

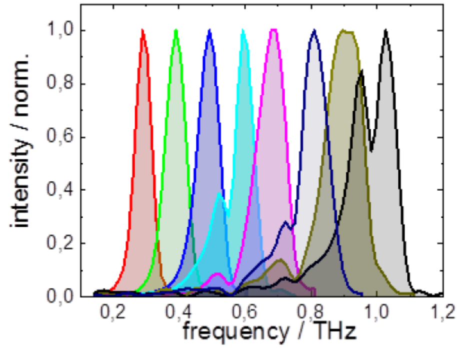
Coherent Diffraction Radiator (CDR) pulse

Undulator pulse



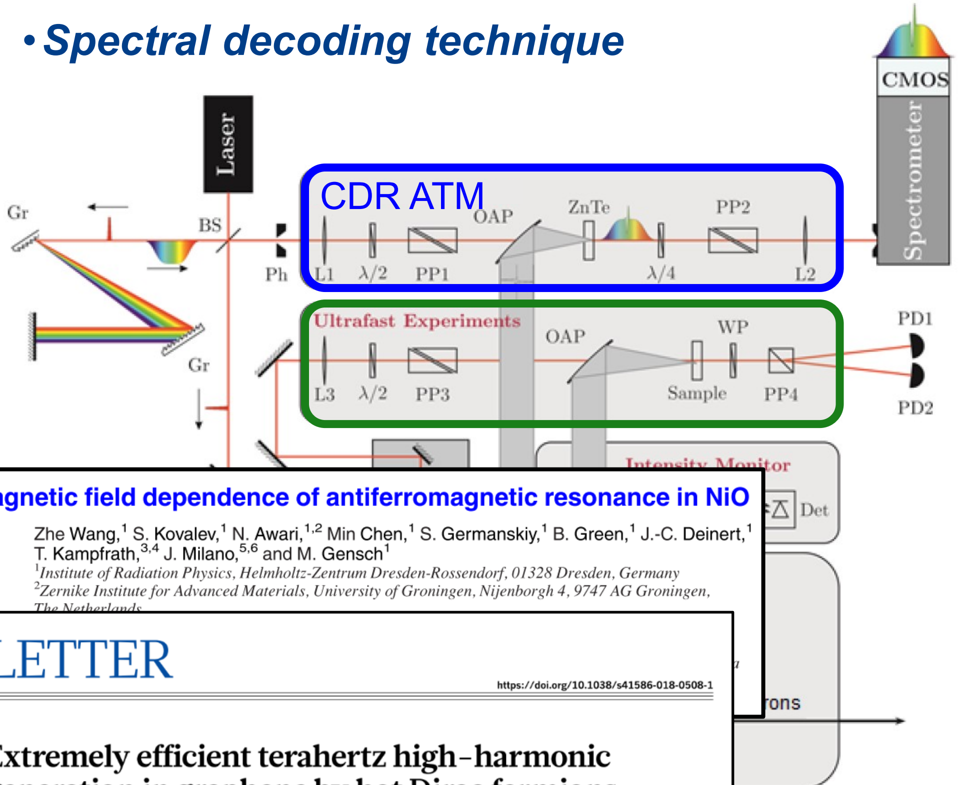




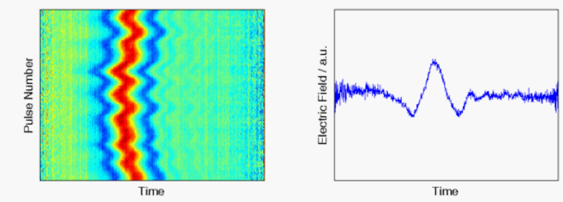


- ***Single arrival time monitor system (ATM)***
- ***→ Pulse-resolved @ 100 kHz rep. rate***

- ***Spectral decoding technique***

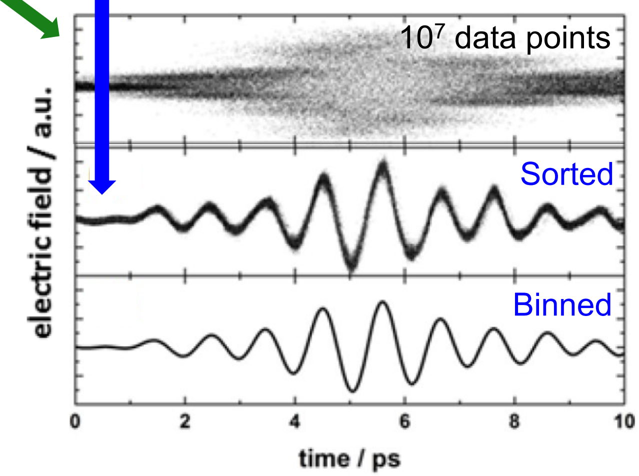


Determine arrival time from SD trace



Signal

Arrival time



Magnetic field dependence of antiferromagnetic resonance in NiO

Zhe Wang,[1] S. Kovalev,[1] N. Awari,[1,2] Min Chen,[1] S. Germanskiy,[1] B. Green,[1] J.-C. Deinert,[1] T. Kampfrath,[3,4] J. Milano,[5,6] and M. Gensch[1]

[1]Institute of Radiation Physics, Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany
[2]Zernike Institute for Advanced Materials, University of Groningen, Nijenborgh 4, 9747 AG Groningen, The Netherlands

LETTER

https://doi.org/10.1038/s41586-018-0508-1

Extremely efficient terahertz high-harmonic generation in graphene by hot Dirac fermions

Hassan A. Hafez[1,2,3,7], Sergey Kovalev[4,7], Jan-Christoph Deinert[4], Zoltán Mics[2], Bertram Green[4], Nilesh Awari[4,5], Min Chen[4], Semyon Germanskiy[4], Ulf Lehnert[4], Jochen Teichert[4], Zhe Wang[4], Klaas-Jan Tielrooij[6], Zhaoyang Liu[2], Zongping Chen[2], Akimitsu Narita[2], Klaus Müllen[2], Mischa Bonn[2], Michael Gensch[4]* & Dmitry Turchinovich[1,2]*

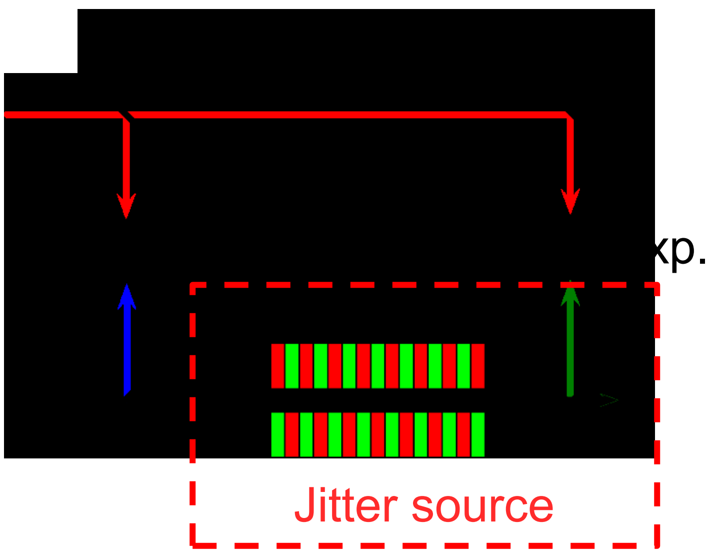
S. Kovalev et al., Struct. Dyn. 4, 024301 (2017)

Pulse- and field- resolved DAQ system

- ***Two sources are highly but not completely synchronized***

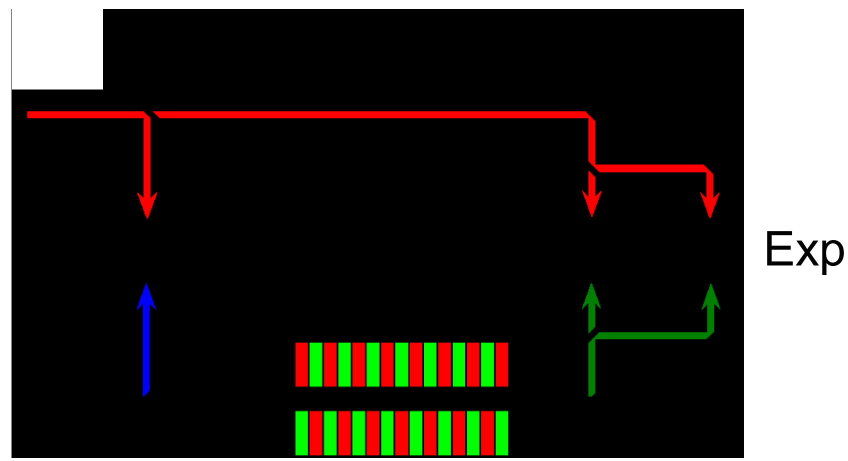
Limitations of single ATM

- ***Electron bunch fluctuation***
- ***Beamline ambient difference***
- ***Unclear jitter***

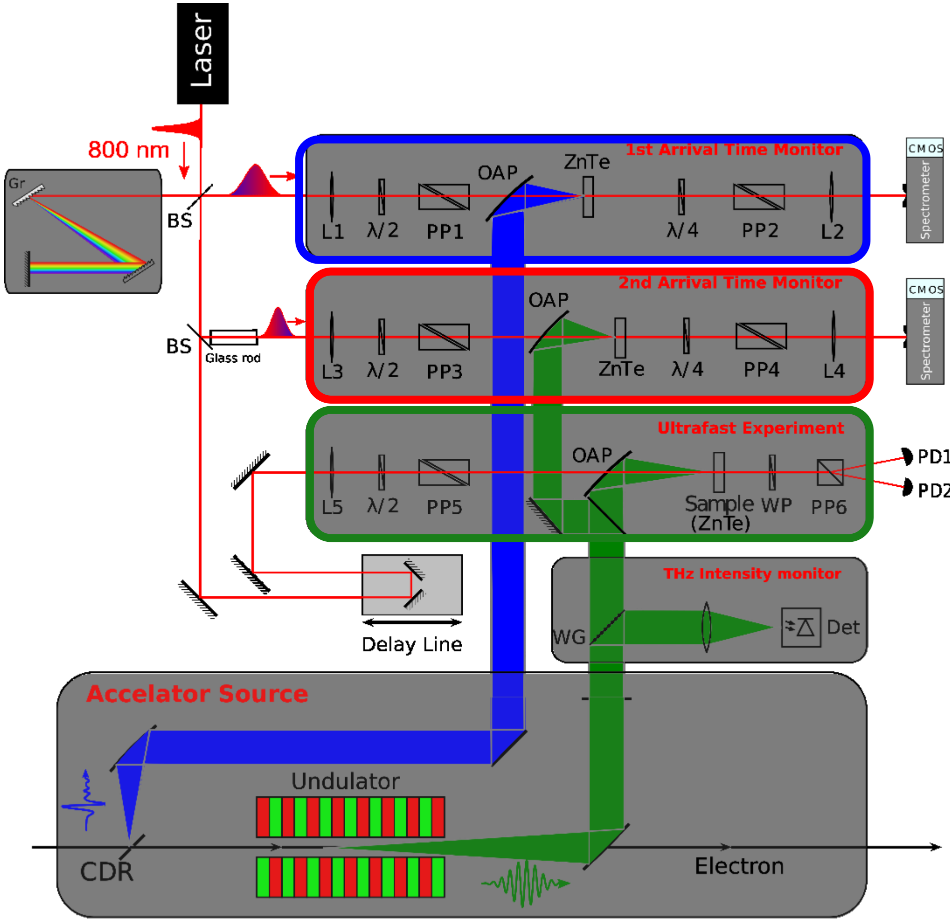


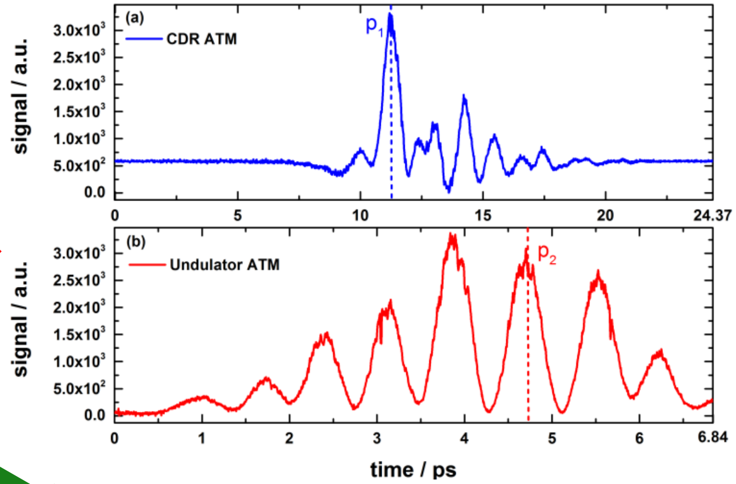
Benefits of double ATM

- ***Higher temporal resolution***
- ***Measure undulator pulse directly***
- ***Enables pulse and field-resolved photon diagnostics***



Sequential Arrival Time Monitor Scheme





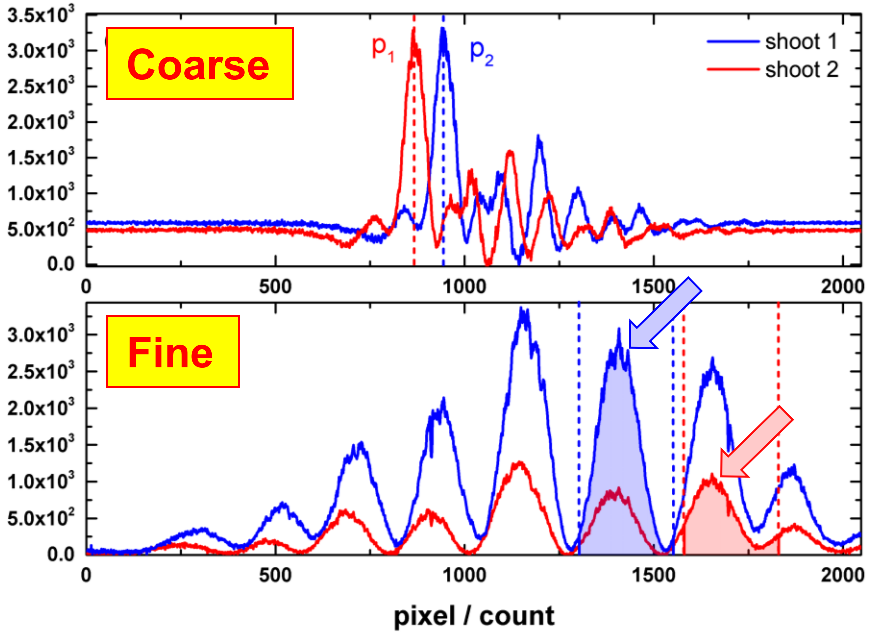
Amplitude of Signal

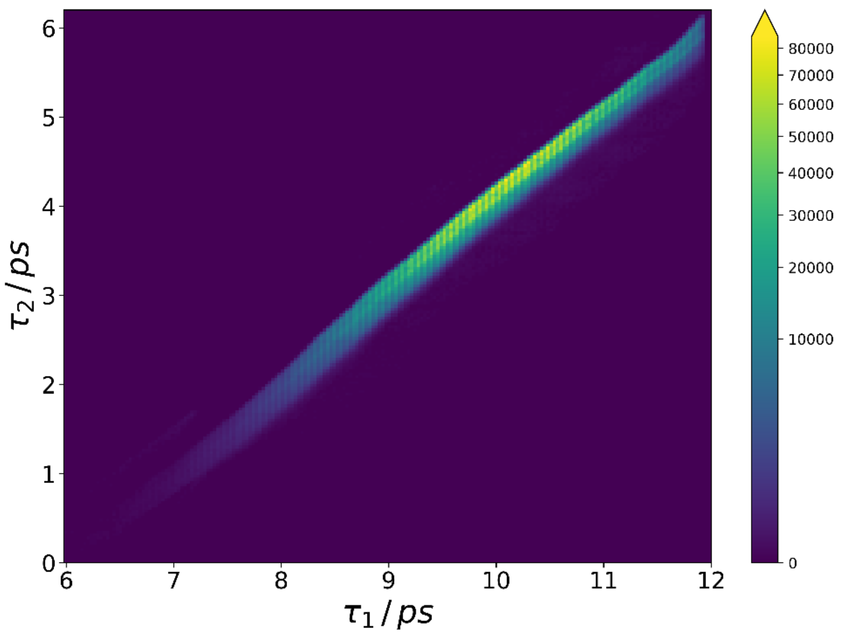
- **1% of undulator pulse power used for undulator ATM**

M. Chen, et al., Optics Express (2019), accepted

Arrival time determination

Determine arrival time from SD trace





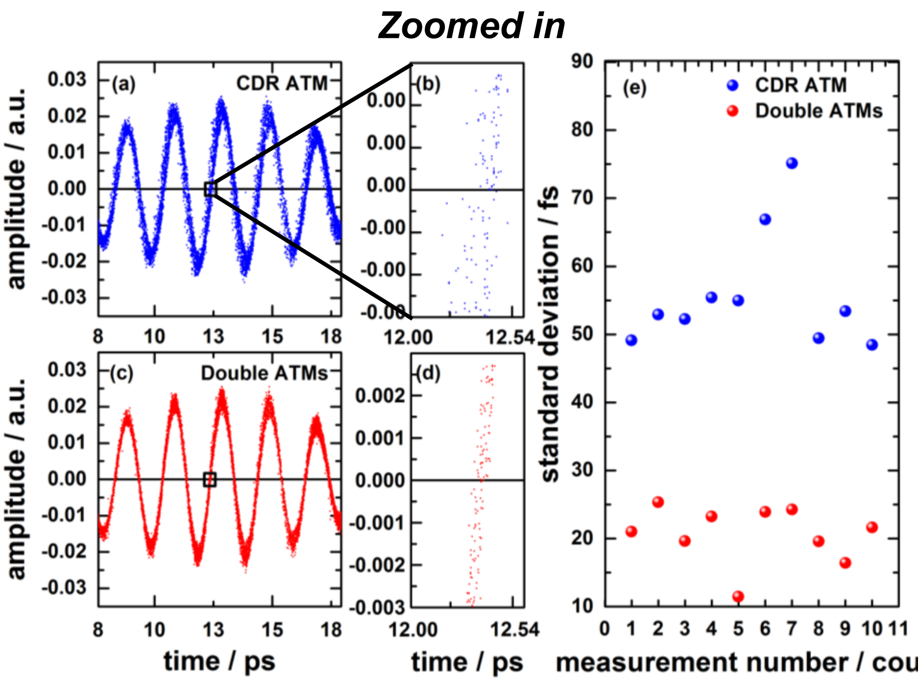
- ***Determine peak searching window of Undulator ATM by readout of CDR ATM (Coarse)***
- ***Read out undulator pulses intensity through peak amplitude***

- ***Quasi-linear relationship between τ_1 and τ_2***
- ***Broadening effect due to jitter between CDR and undulator source***

M. Chen, et al., Optics Express (2019), accepted

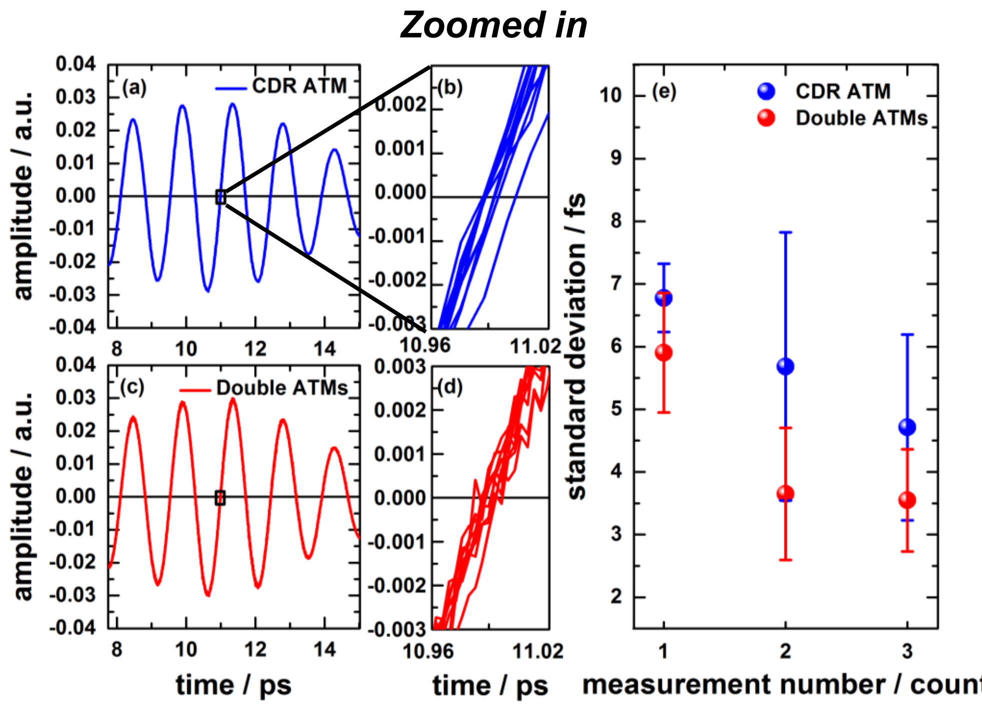
Comparison between single and sequential ATM

- ***Short-term** performance (single loop, 5 mins)*
- *Data are sorted but **not** binned*



- *Temporal resolution increase from 55 to **20 fs** (RMS)*
- *Short -term jitter compensation*
- *Avoid CDR-undulator jitter.*

- ***Long-term** performance (10 loops, 30 mins)*
- *Data are sorted **and** binned*



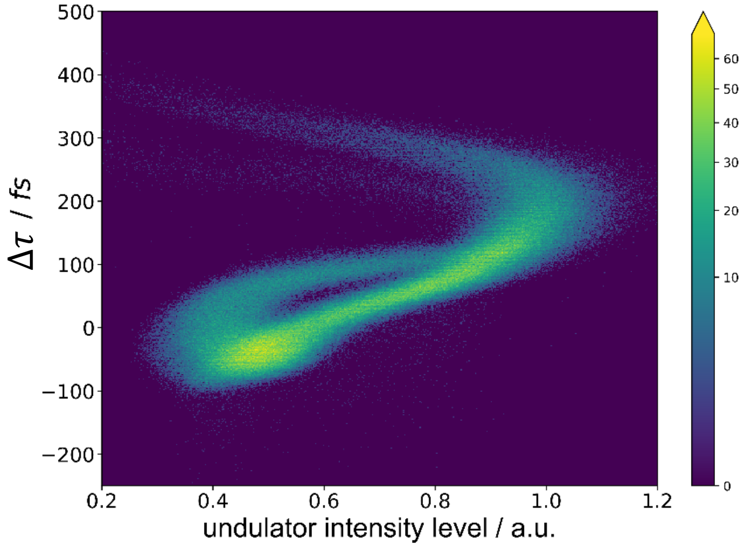
- *Temporal resolution increase from 6 to **4 fs** (RMS)*
- *Long-term drift compensation*
- *Temp. drifs of beamlines.*

- ***Temporal resolution** is estimated by RMS distribution of data points around zero-crossing positions*

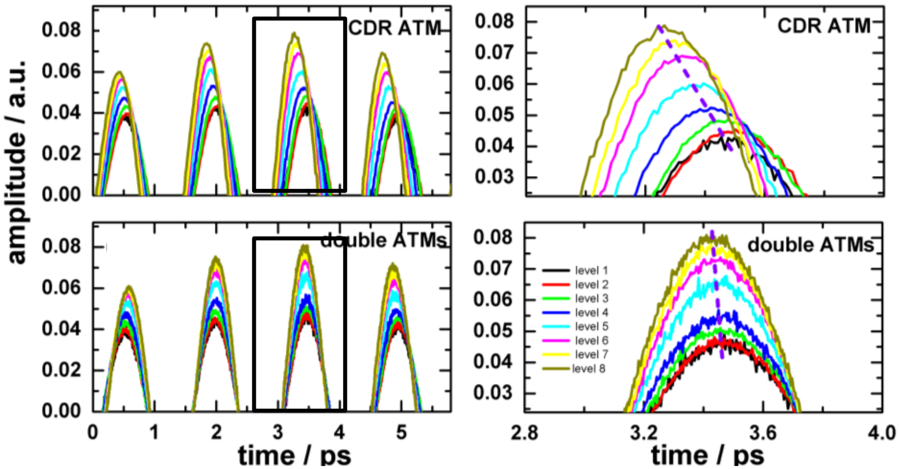
M. Chen, et al., Optics Express (2019), accepted

Correlation between Arrival time difference and undulator pulse intensity

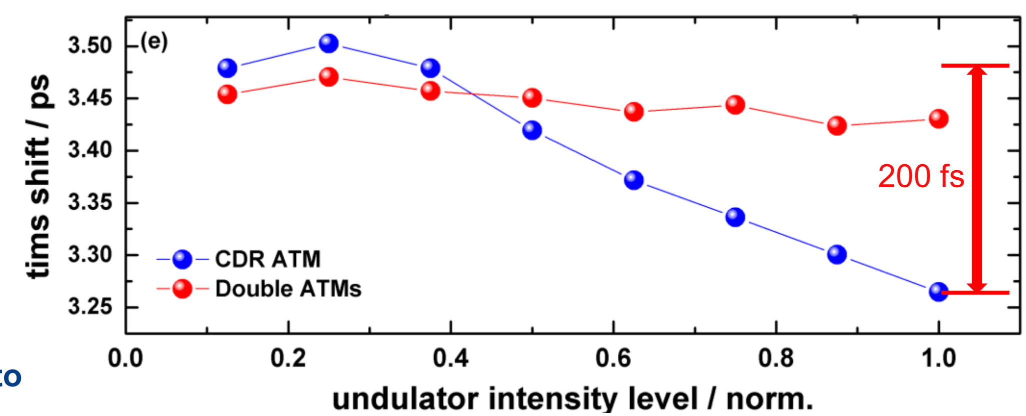
$\Delta\tau$ vs. undulator intensity level



EOS trace binned with different undulator intensity level



- $\Delta\tau$: **arrival time difference between CDR and undulator pulse**
- **Undulator intensity level: read out from undulator ATM**



- **Increase timing accuracy by decreasing pulse intensity correlated arrival time shift**
- **!!!Could be a new diagnostic tool investigating electron energy charge dispersion between undulato and CDR source !!!**

M. Chen, et al., Optics Express (2019), accepted

Intrinsic synchronization technique

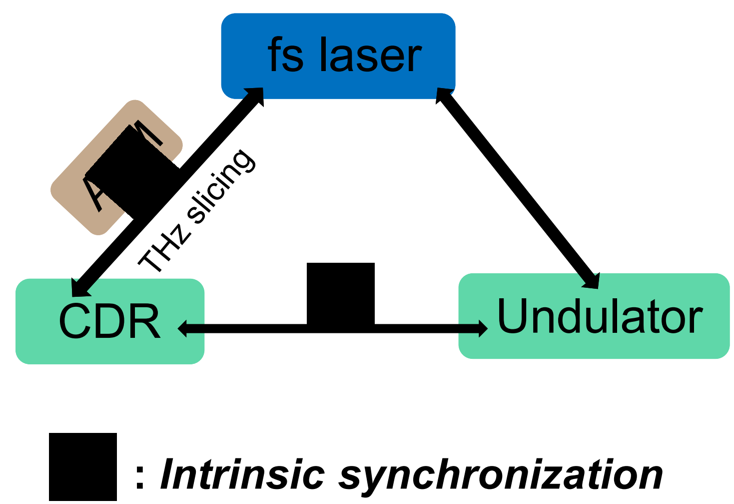
Limitations of the current arrival time monitor scheme

- ***Rep. rate is limited by the ATM speed** (currently @ 100 kHz)*
- ***Consumes large storage and computing resources***

Advantages of Intrinsic synchronization

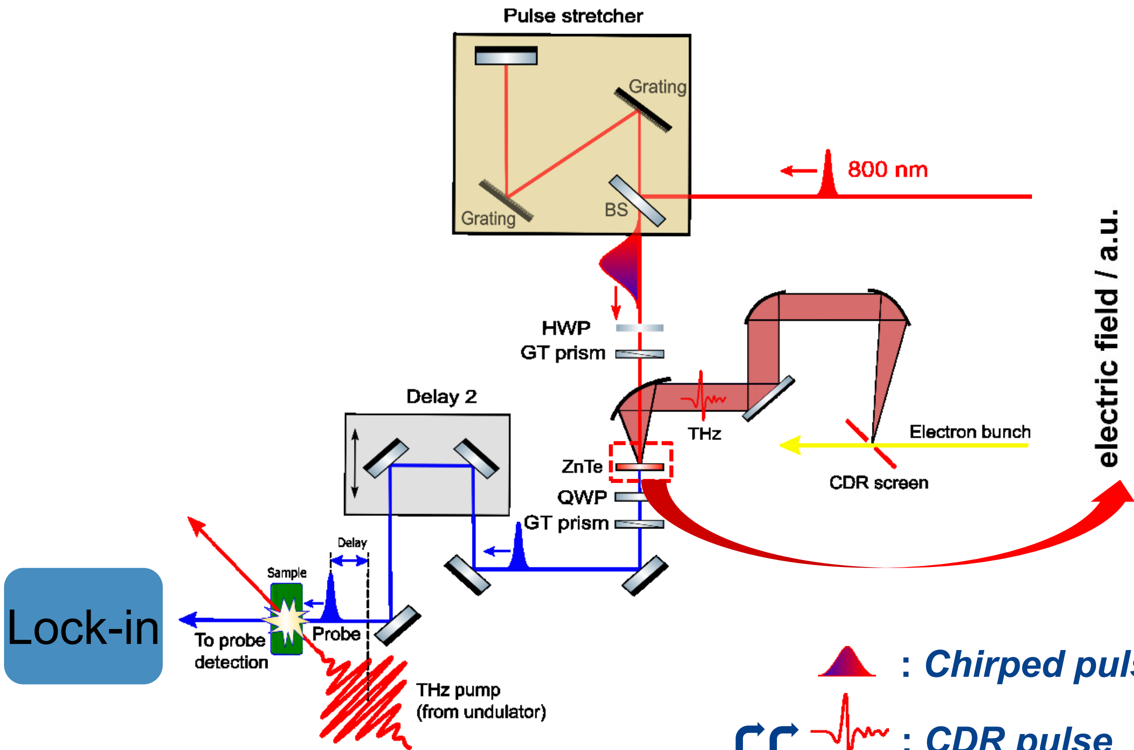
- ***Enable experiment requires high rep. rate (i.e. SNOM)***
- ***Real time experiment***
- ***Save spending on the big data technique***

Intrinsic synchronization scheme

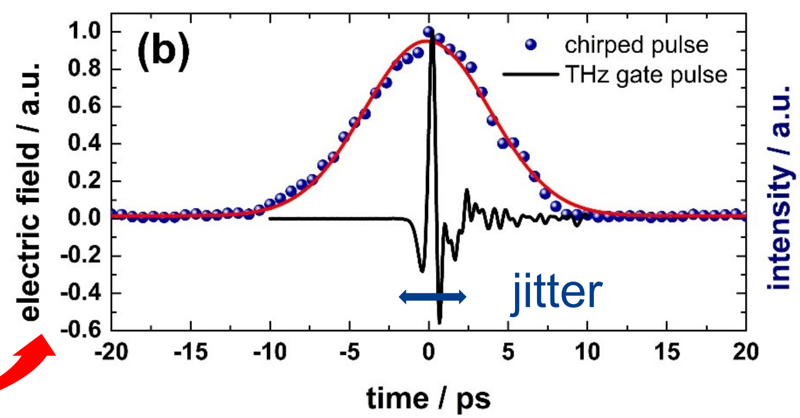


Intrinsic synchronization technique

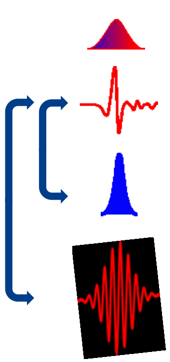
Experimental scheme



THz slicing



Intrinsically synchronized



: Chirped pulse

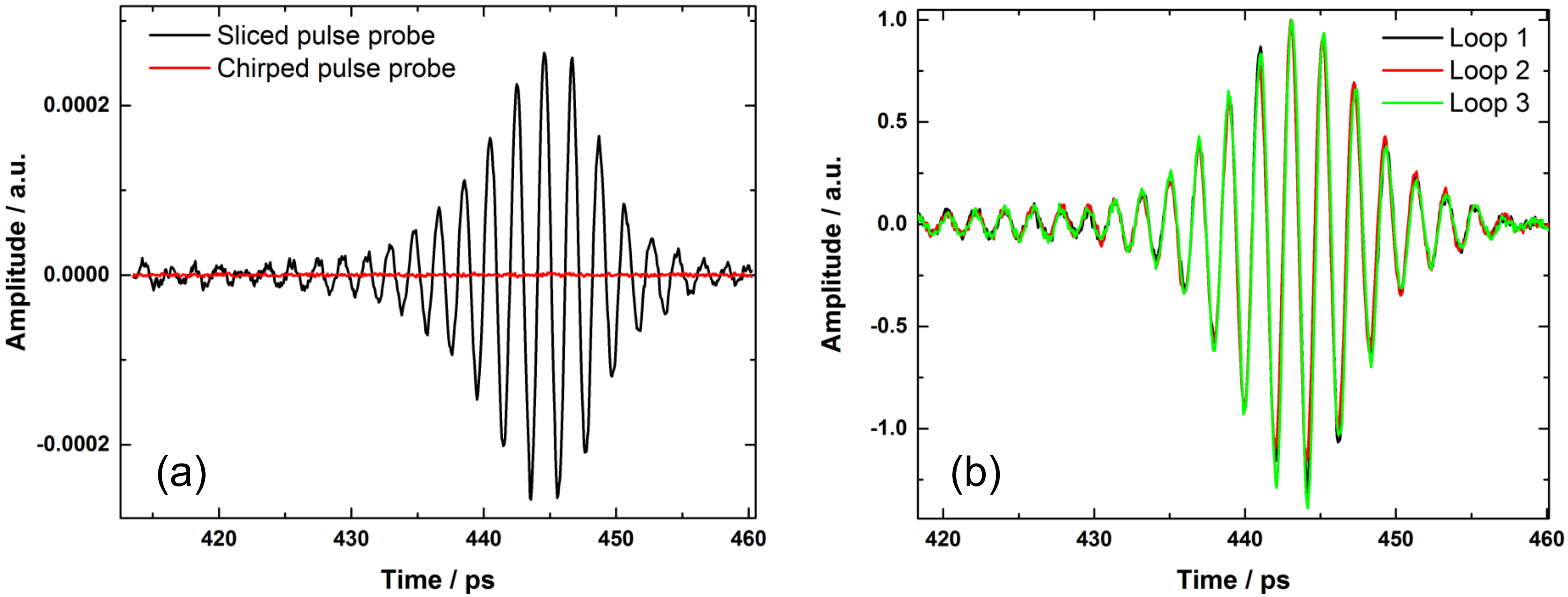
: CDR pulse

: Sliced pulse

: Undulator pulse

Intrinsically synchronized

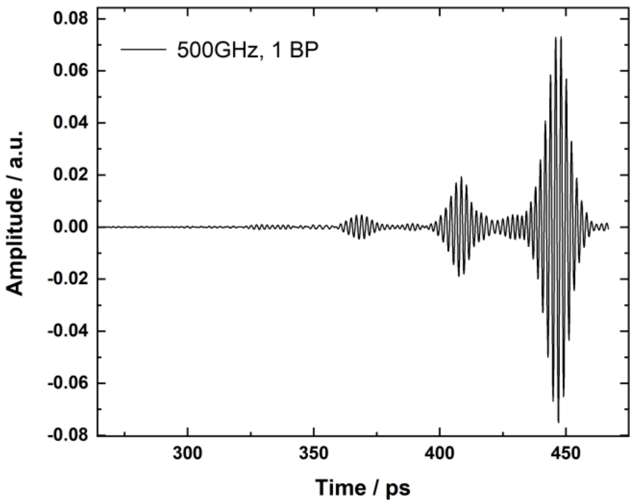
Experimental result

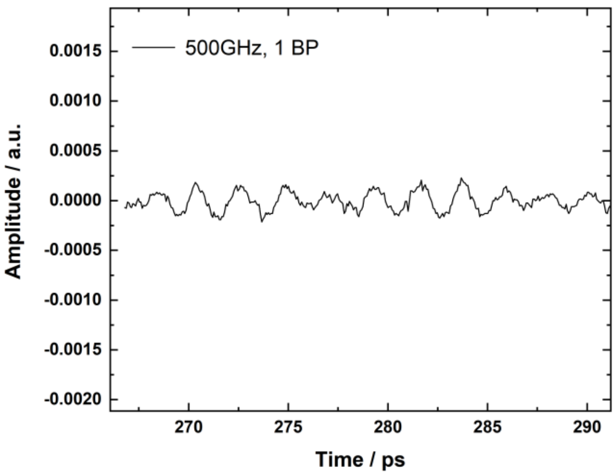


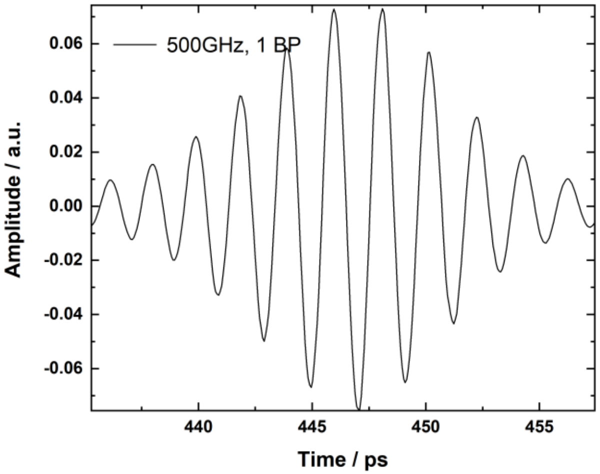
- ***Undulator tune to 500 GHz***
- ***3 EOS measurements probed with sliced pulse***

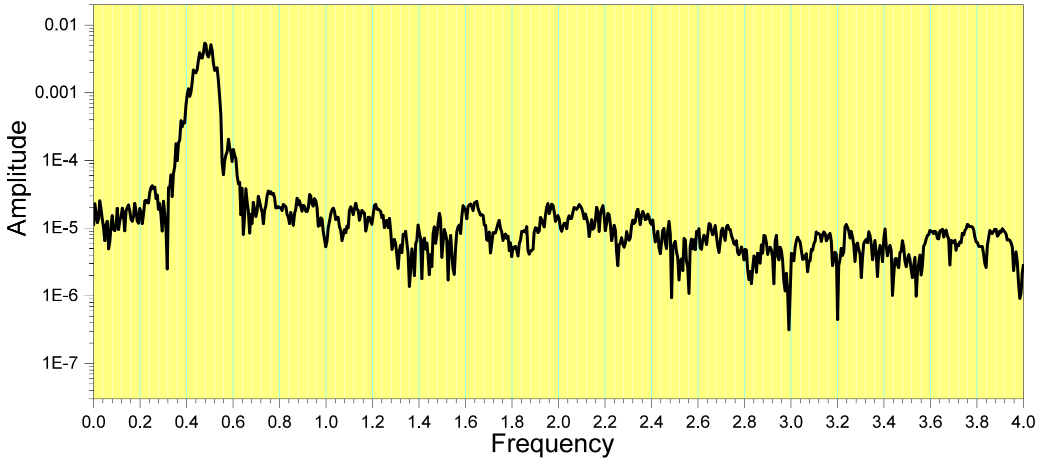
Intrinsic synchronization beamtime experiment

EOS, Spectrum @ 500 GHz, with 500 GHz BP filter



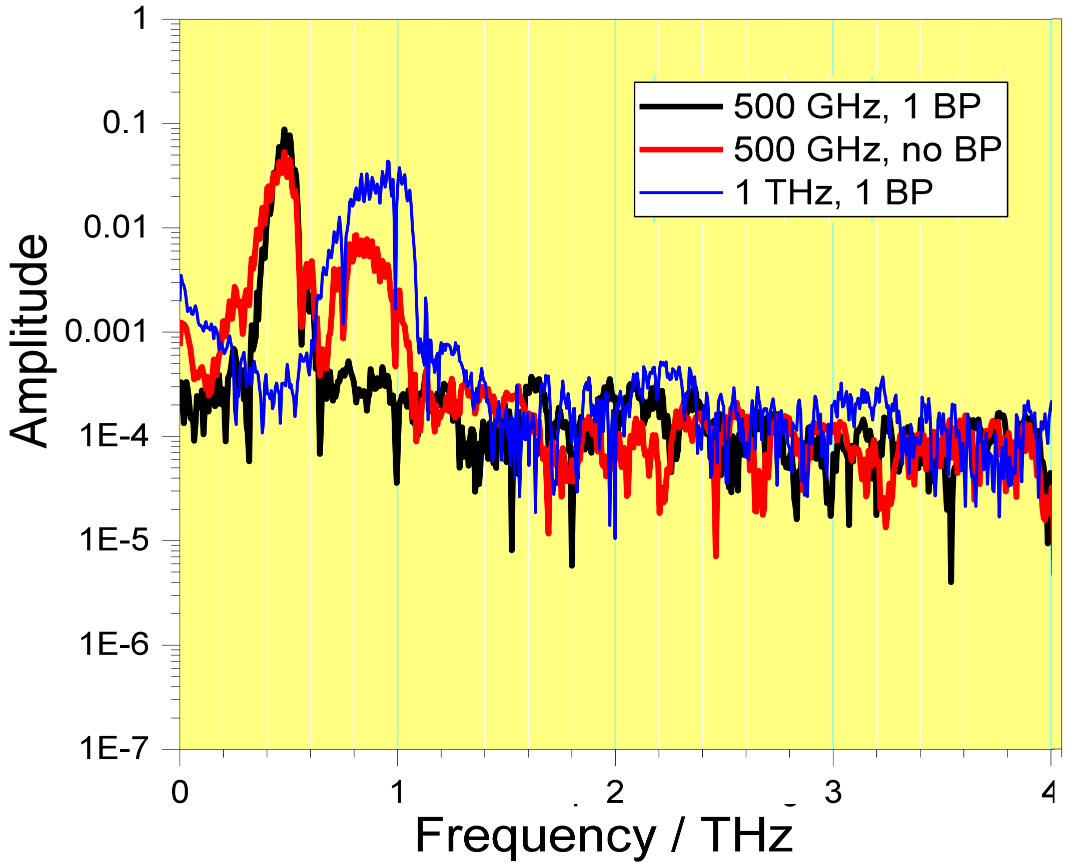






- ***SNR ratio is around 10^4***

Spectrum of EOS measurements under three different frequences



Conclusion & Outlook

- ***Online diagnostic can provide now sub-10 fs timing precision at high repetition rate***
- ***Suppress temperature drifts, jitter between two THz sources***
- ***New diagnostic tool for investigating origin of different instabilities***
- ***Demonstrated intrinsic synchronization between CDR and fs laser***

- ***Compress the sliced pulse further***
- ***Optimize the CDR pulse shape for high efficiency slicing***
- ***Use Fourier-transform-limited pulse for intrinsic synchronization***

Acknowledgement

Michael Gensch

Sergey Kovalev

Jan Deinert

Bert Green

Zhe Wang

Igor Ilyakov

Thales de Oliveira

Nilesh Awari

Semyon Germanskiy

Mohammed Bawatna

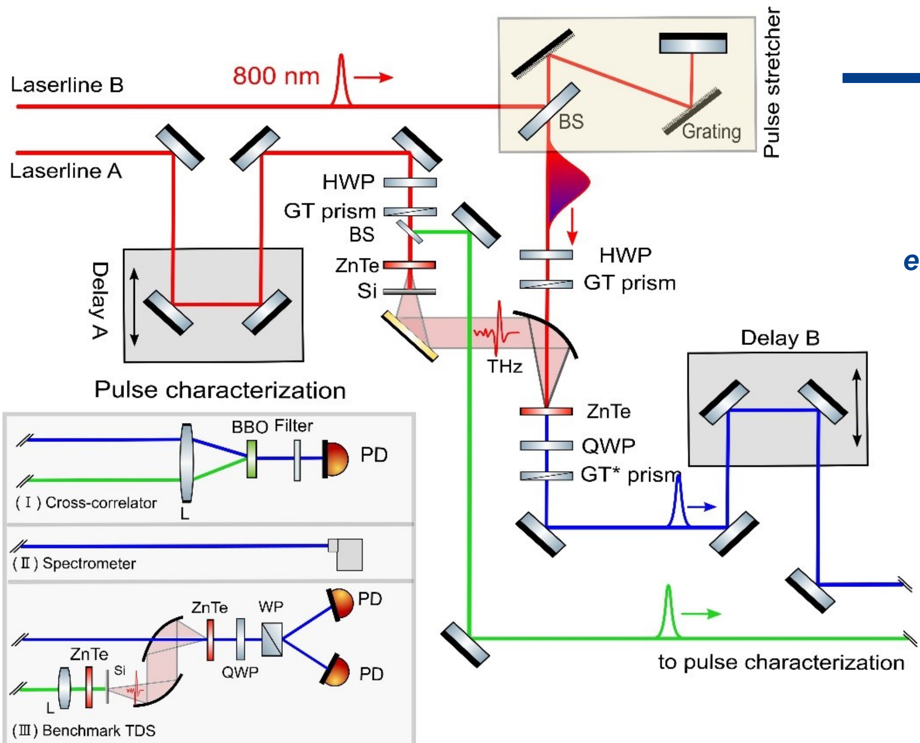
Comparision between techniques

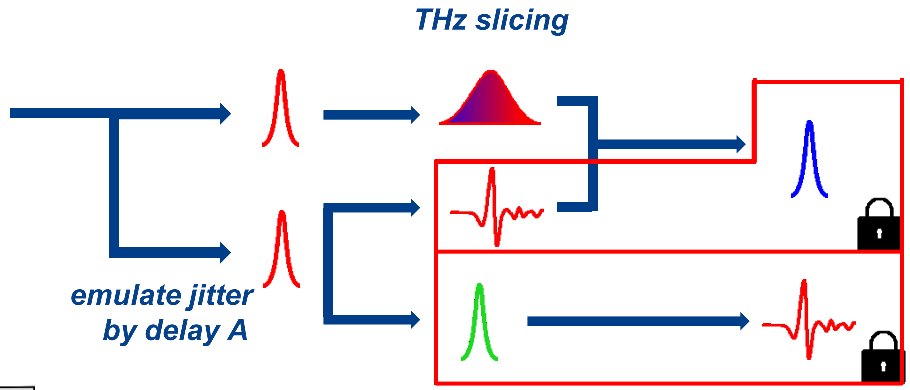
Feature	Single ATM	Double ATM	Intrinsic syn.
Temporal resolution, long term	50 fs (RMS)	22 fs (RMS)	almost jitter free
Temporal resolution, short term	6 fs (RMS)	4 fs (RMS)	almost jitter free
Pump pulse diagnostic (intensity, waveform)	No	Yes	No
Intensity correlated jitter	200 fs (RMS)	<25 fs (RMS)	200 fs (RMS)
Repetition rate	Current 100 KHz (Up to 140 kHz)	Current 100 KHz (Up to 140 kHz)	Up to MHz
Big data infrastructure	Required	Required	Not Required
Real-time lock-in experiment	No	No	Yes
Target experiment type (example)	High frequency HHG	High frequency HHG	SNOM Low frequency HHG

*

Intrinsic synchronization proof-of-principle exp.

Table-top experiment





: Sliced pulse

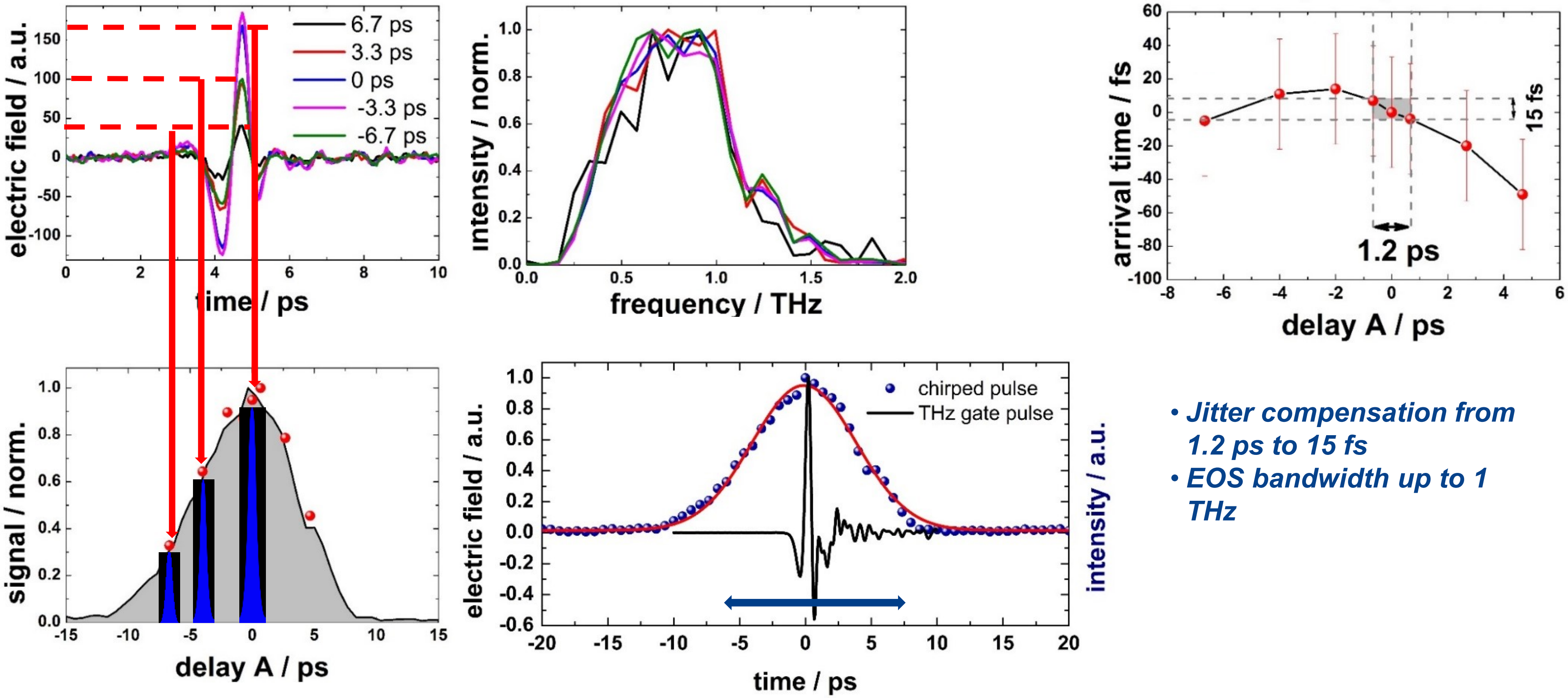
: Reference pulse

- *Delay A: emulate jitter source*
- *Single cycle THz pulse: emulated CDR pulse*

M. Chen, et al., Optics letters 43, 2213-2216 (2018)

Intrinsic synchronization proof-of-principle exp.

Experimental result

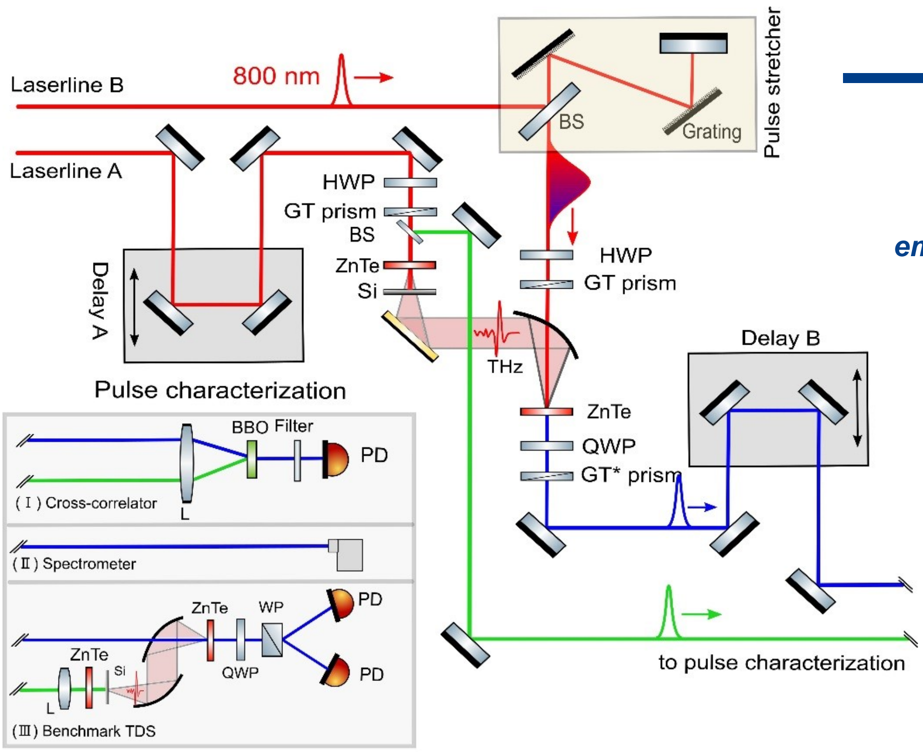


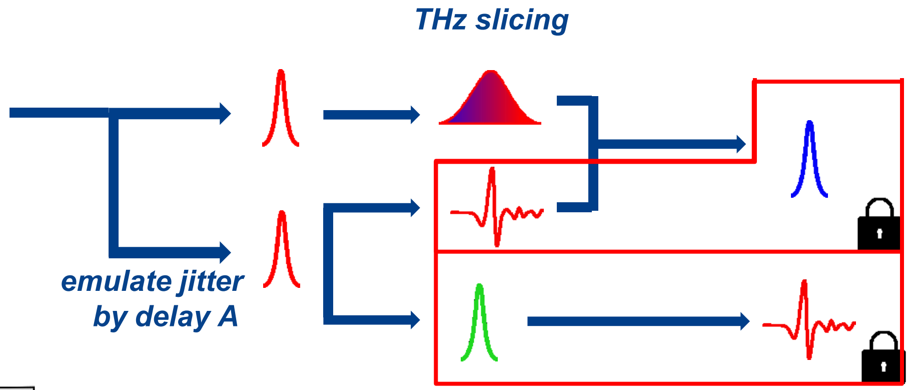
- ***Jitter compensation from 1.2 ps to 15 fs***
- ***EOS bandwidth up to 1 THz***

M. Chen, et al., Optics letters 43, 2213-2216 (2018)

DRESDEN concept HZDR

Table-top experiment





: *Sliced pulse*

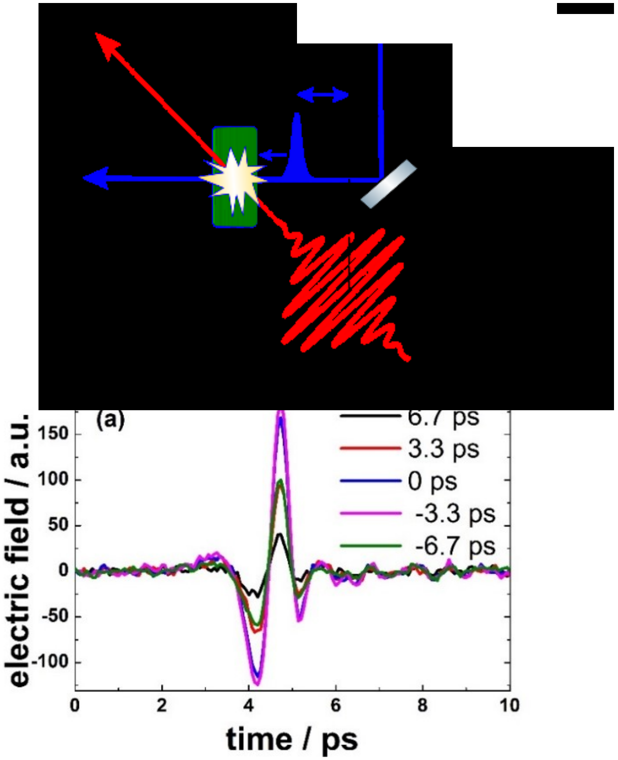
: *Reference pulse*

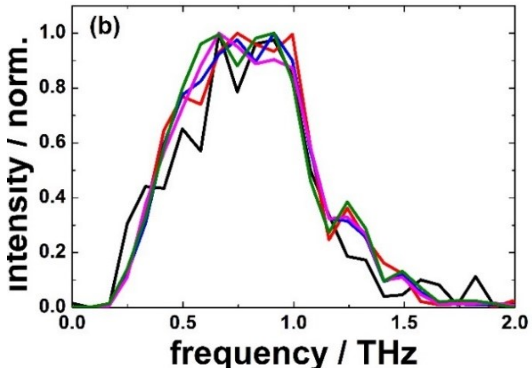
- *Delay A: emulate jitter source*
- *Single cycle THz pulse: emulated CDR pulse*

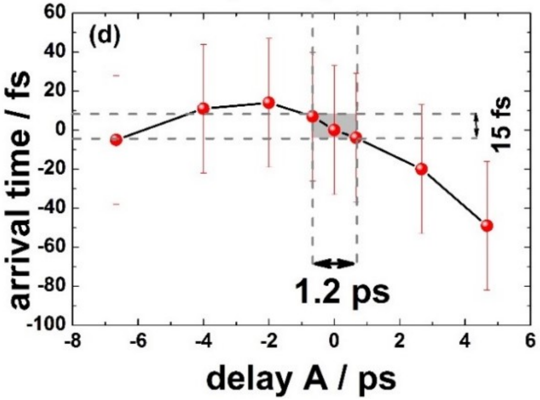
M. Chen, et al., Optics letters 43, 2213-2216 (2018)

Intrinsic synchronization proof-of-principle exp.

Experimental result



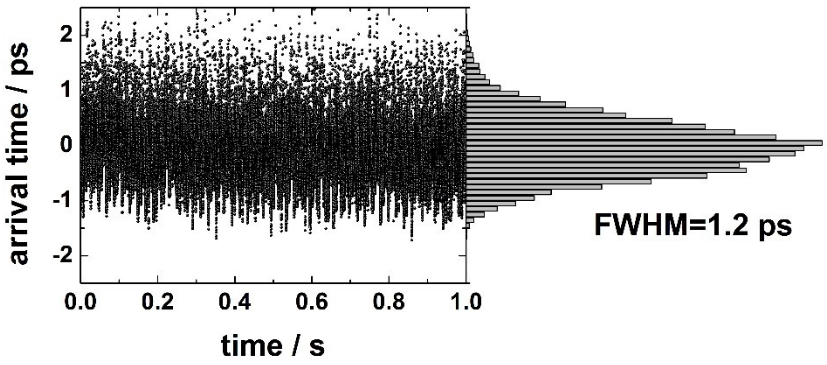




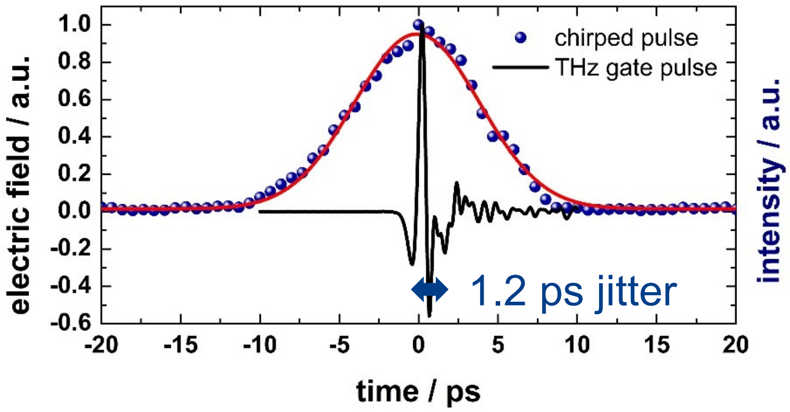
- ***Jitter compensation from 1.2 ps to 15 fs***
- ***EOS measurement bandwidth up to 1 THz***

M. Chen, et al., Optics letters 43, 2213-2216 (2018)

laser-undulator jitter in TELBE

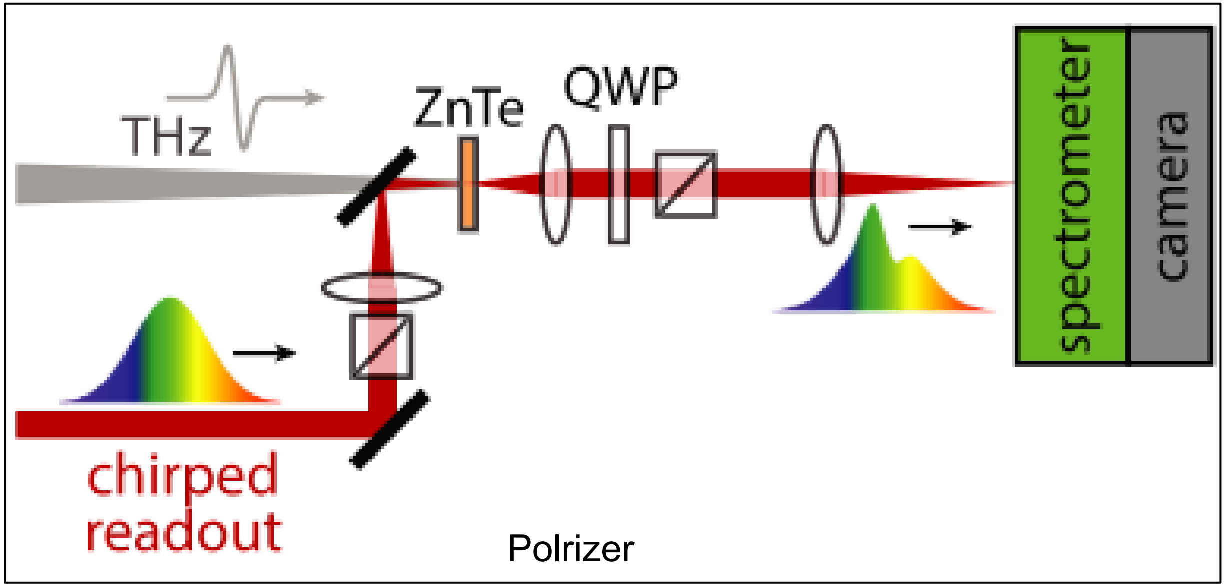


THz slicing



Sepctral encoding technique

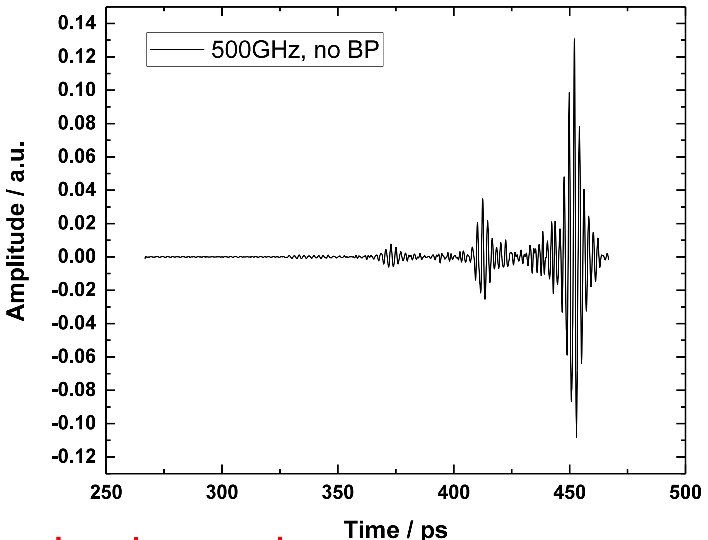
Spectral encoding setup

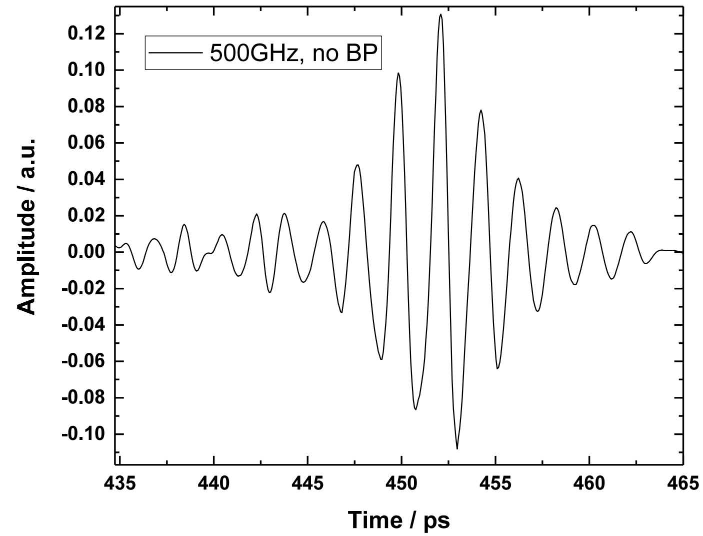


Taken from S. M. Teo et al, Rev. Sci. Instrum. 561, 86, 051301 (2015)

Intrinsic synchronization beamtime experiment

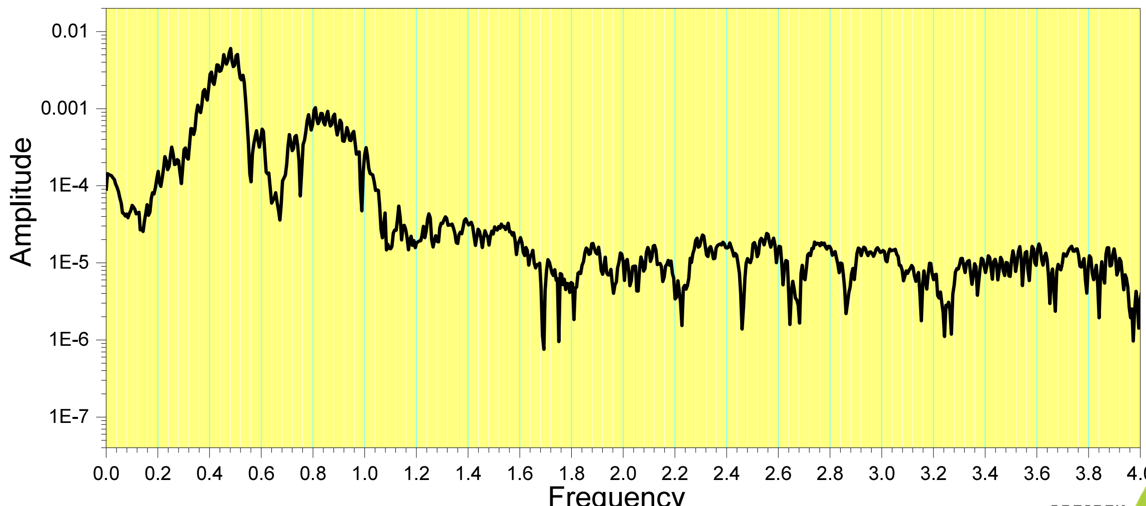
EOS, Spectrum @ 500 GHz, without BP filter



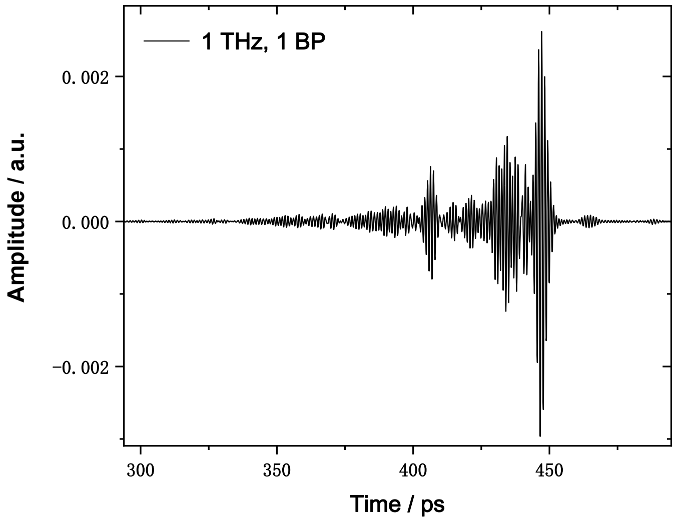


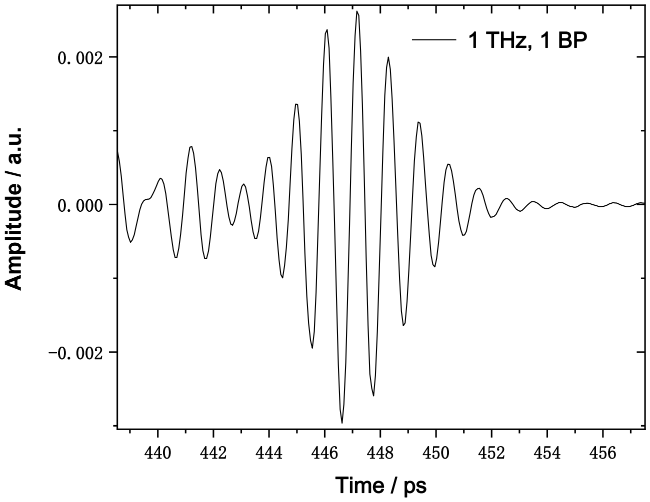
Zoom in

Sliced pulse probe

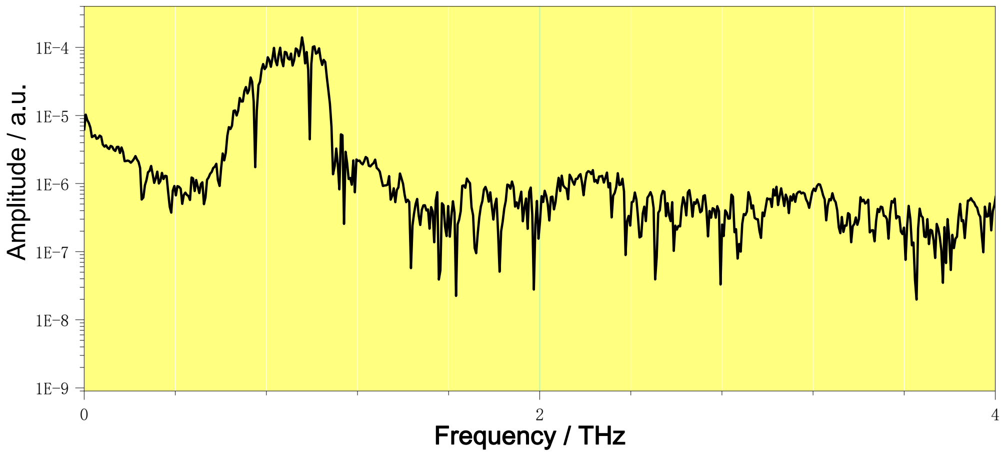


EOS, Spectrum @ 1 THz, with BP filter



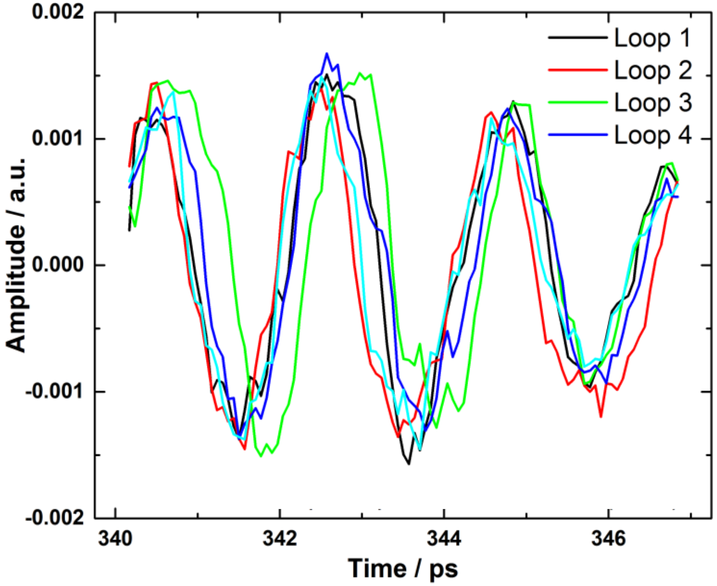


Sliced pulse probe

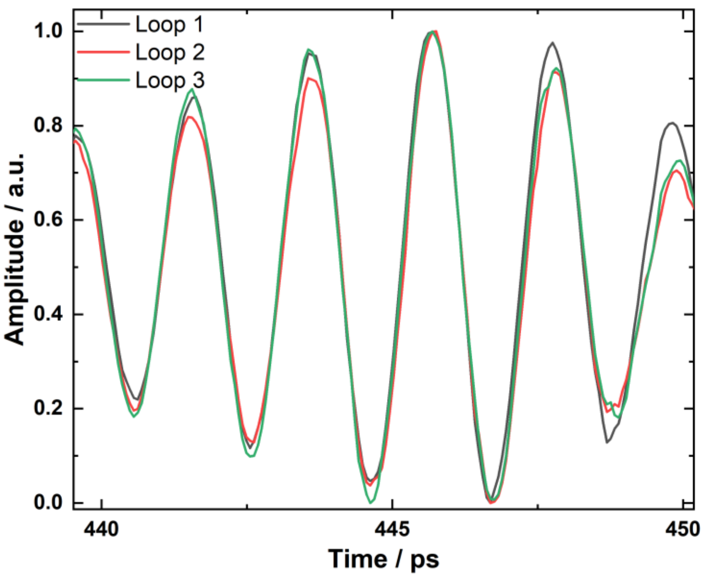


EOS measurements comparison

100 fs lase pulse probe



Sliced pulse probe



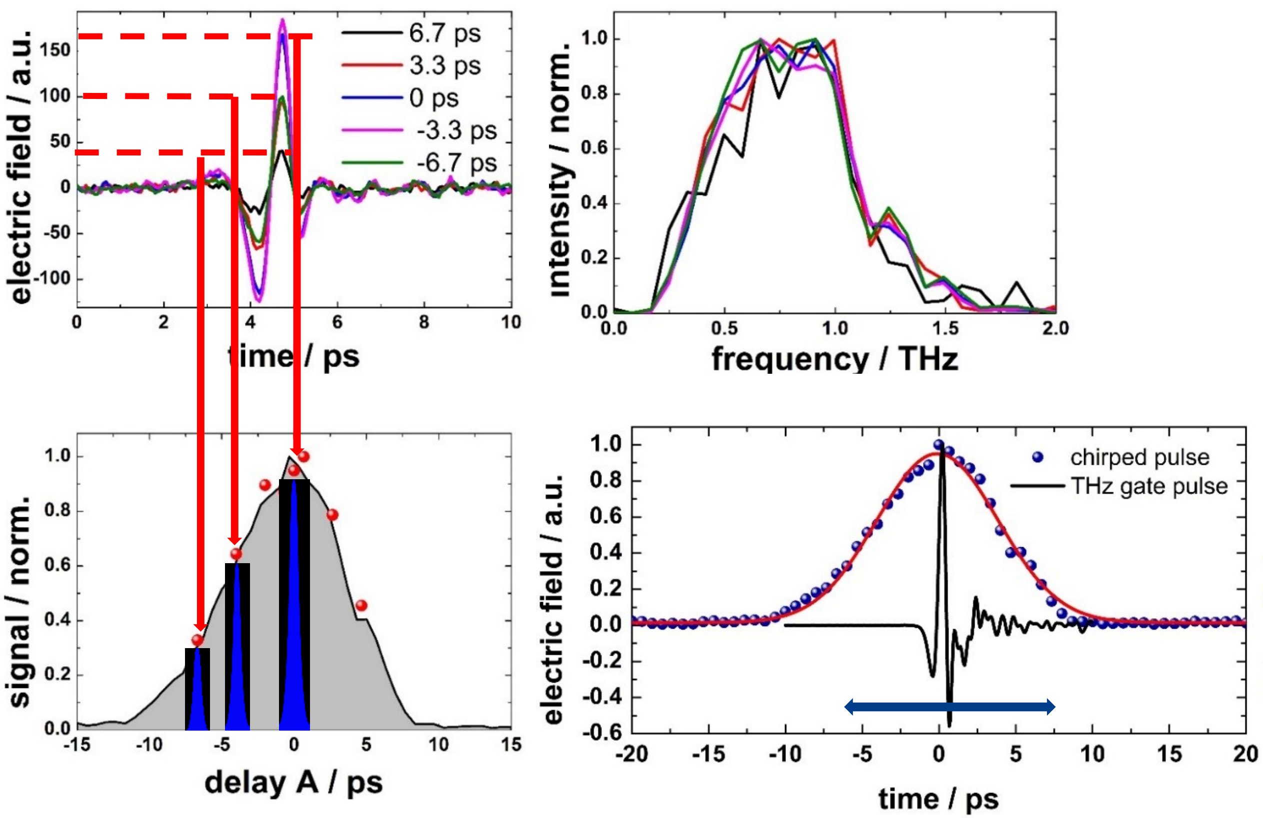
- ***Large time drift between EOS measurements***

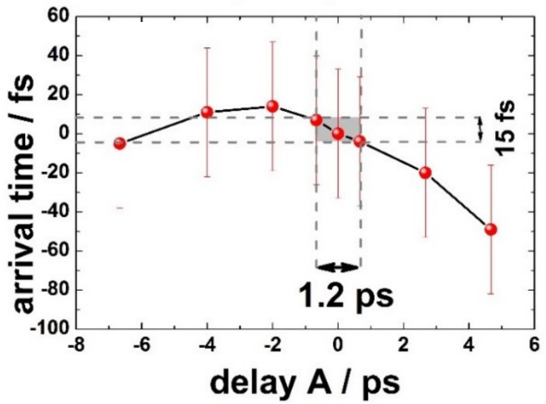
- ***No time drift between EOS measurements***

改变时间轴

Intrinsic synchronization proof-of-principle exp.

Experimental result





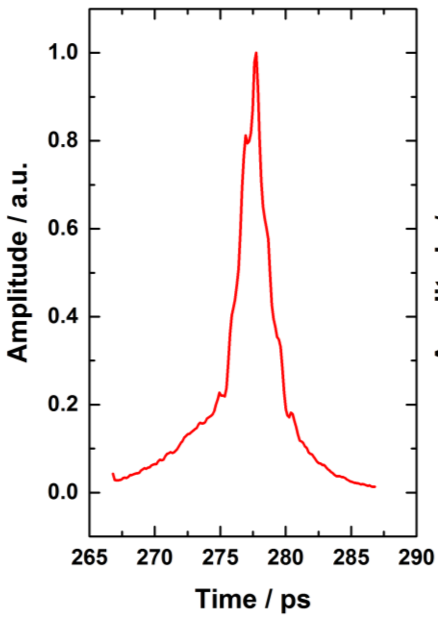
- *Jitter compensation from 1.2 ps to 15 fs*
- *EOS bandwidth up to 1 THz*

M. Chen, et al., Optics letters 43, 2213-2216 (2018)

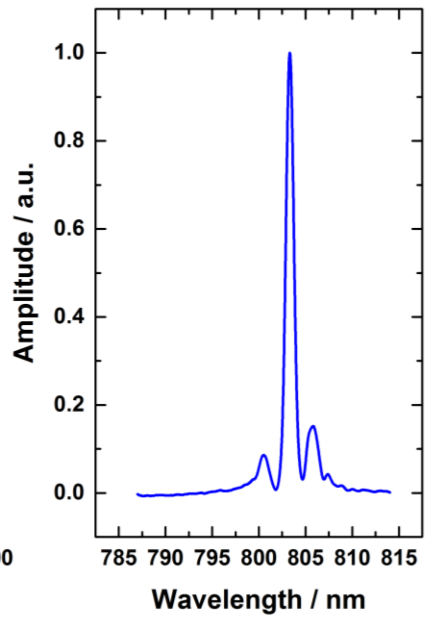
Intrinsic synchronization beamtime experiment

characterization of sliced pulse

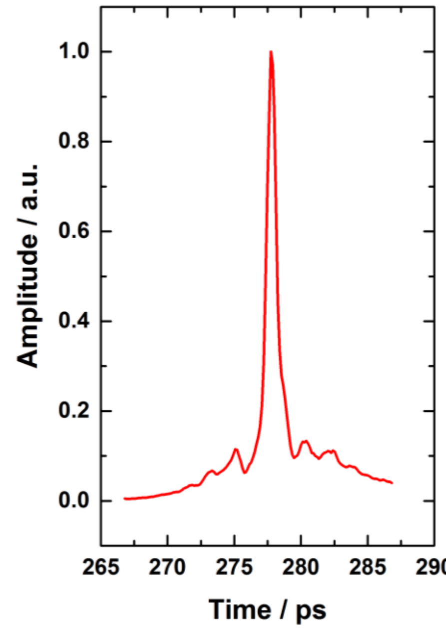
Autocorrelation



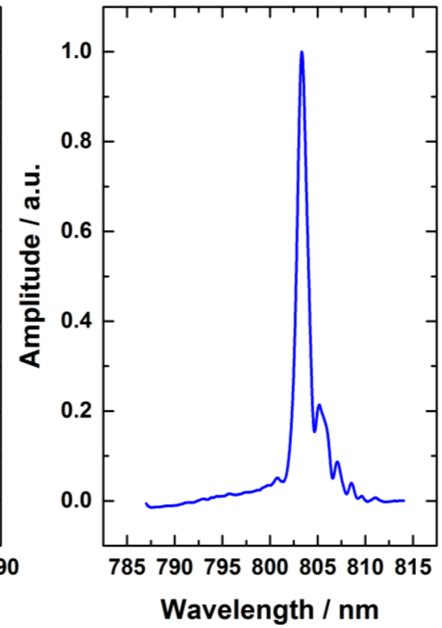
Spectrum



Autocorrelation



Spectrum



- ***Correlation between pulse duration and spectrum***
- ***Optimized sliced pulse duration is 280 fs (RMS)***