Recent longitudinal diagnostics studies at PhLAM

Serge Bielawski, Quentin Demazeux, Clément Evain, Christelle Hanoun, Fahem Kaoudoune, Eléonore Roussel, Christophe Szwaj

11th workshop on longitudinal diagnostics, June 2022

Collaboration network

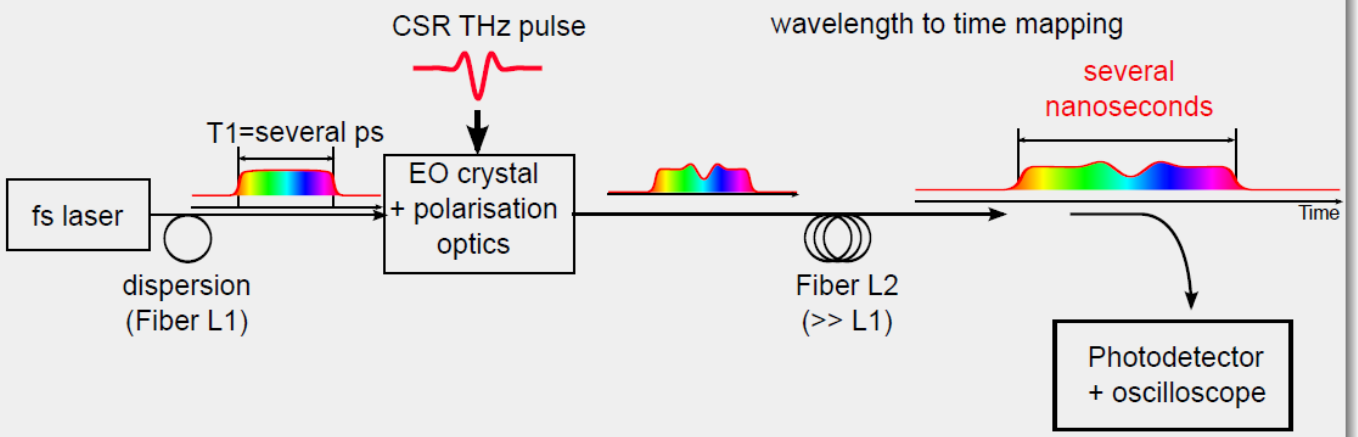
- Terahertz CSR, microbunching instability in storage rings: PhLAM-**SOLEIL** and KIT/**KARA** (ANR-DFG ULTRASYNC project 2020-2023). PhD of Christelle Hanoun
- **FERMI**– FEL & TeraFermi
- DESY (Bernd & Christo) – **EO @Eu XFEL, FLASH** in the near future. PhD of Quentin Demazeux (starting).
- **ELBE**

- Laser-Plasma Accelerator-based light sources: **COXINEL** project

- IJCLAB (Orsay): **TWAC** (Terahertz Wave Accelerator) EIC project

Starting point: Electro-Optic (EO) detection at high repetition rate at SOLEIL

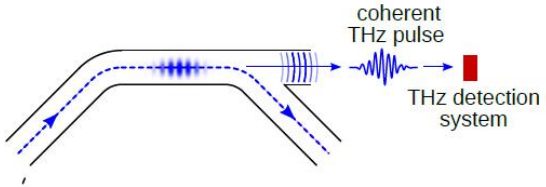
Main idea: photonic time-stretch, introduced by B. Jalali and coworkers (UCLA)
Coppinger et al., IEEE Trans. on Microwave Theory & Techniques, 47, 1309 (1999)
Time stretch and its applications Nature Photonics 11, 341 (2017)

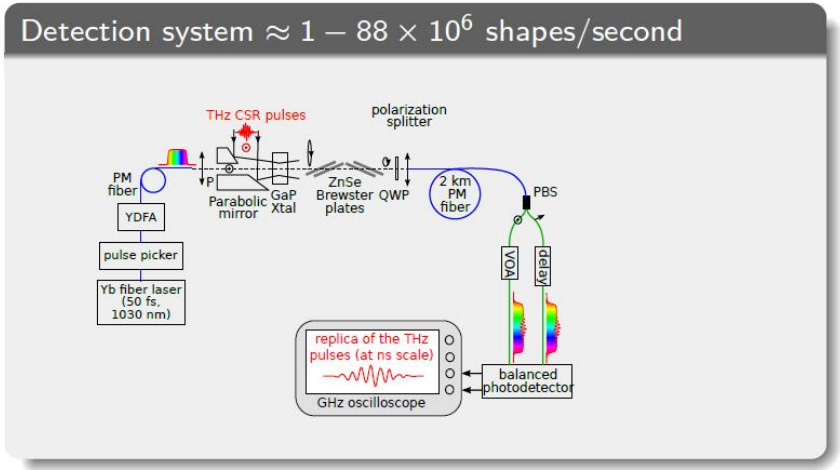


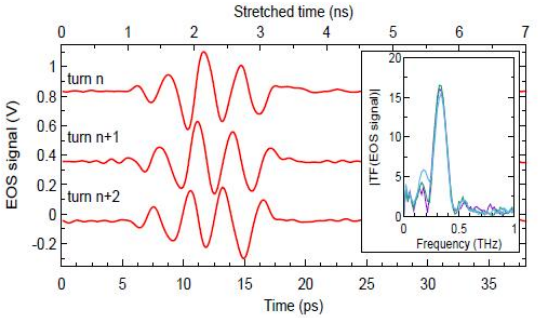
On the oscilloscope, we obtain a replica of the THz pulse that is "temporally stretched" by a factor $M = 1 + L_2/L_1$.
Example: $L_1 = 10$ m and $L_2 = 2$ km $\Rightarrow$ $M \approx 200$.
$\Rightarrow$ 5 GHz on the oscilloscope corresponds to 1 THz at the input.

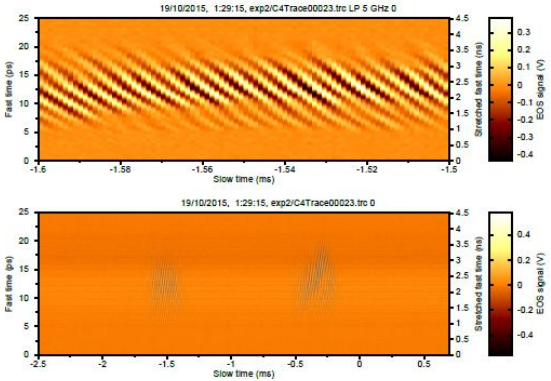
Note: EO strategy (using a 1030 nm laser) directly copied from the DESY/KIT/PSI system
[B. Steffen et al., RSI 91, 045123 (2020)]
-> Added a time-stretch readout

One of our best/prefered setup in 2017 (aiming at high sensitivity)



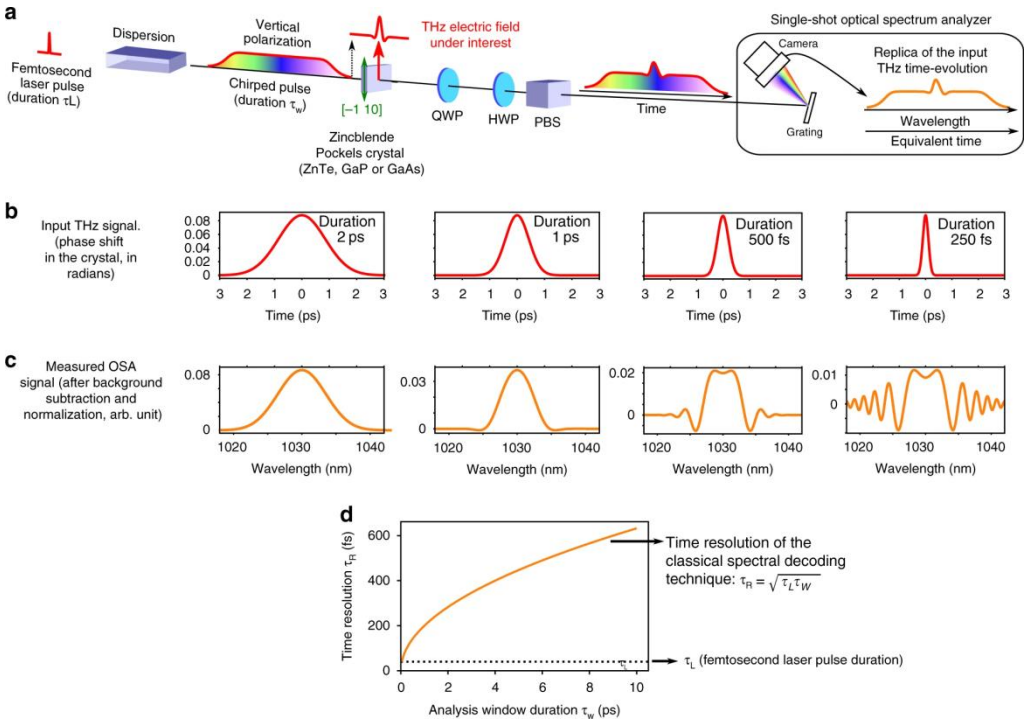






- SOLEIL with 8 bunches (~8 MHz rep. Rate), noise-eq input field ~2 V/cm over a 300 GHz BW [C. Szwaj et al., High sensitivity photonic time-stretch electro-optic sampling of terahertz pulses, Rev. Sci. Instr. 87, 103111 (2016), C. Evain et al., Phys. Rev. Lett. 118, 054801 (2017)]

Bandwidth limitation of spectrally decoded EO (either with time-stretch or optical spectrum analyzer readout)



Time resolution: $\tau_R = \sqrt{\tau_w \times \tau_L}$

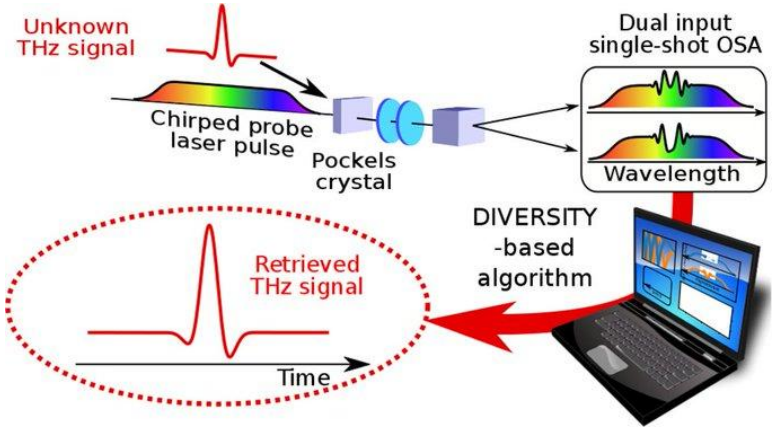
Example:

- 10 ps chirped pulse duration
- not-so-cheap 100 fs laser

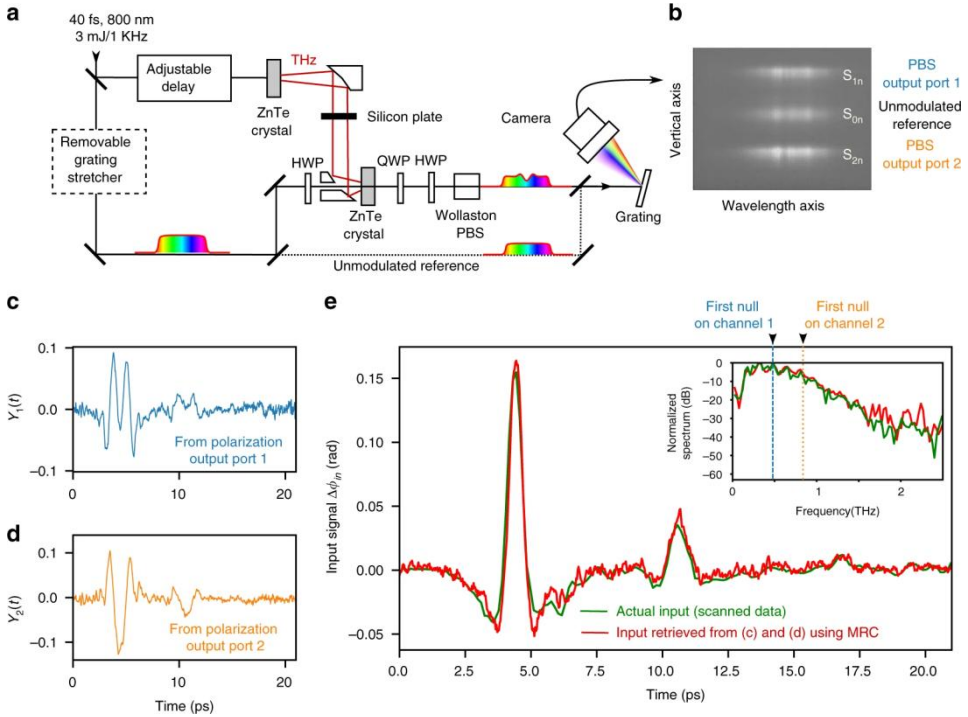
-> resolution ~ only 1 ps ☹

See [Sun, Jiang & Zhang, Analysis of terahertz pulse measurement with a chirped probe beam. Appl. Phys. Lett. 73, 2233–2235 (1998)]

Improving resolution using numerical reconstruction techniques
-> DEOS: Diversity Electro-Optic Sampling (PhLAM-DESY-UCLA collaboration)

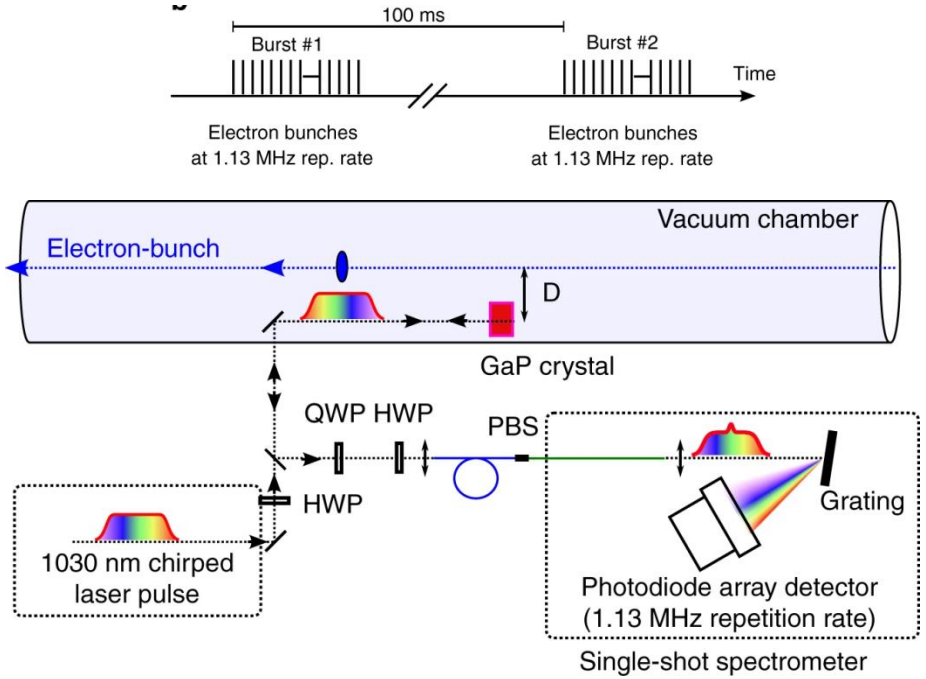


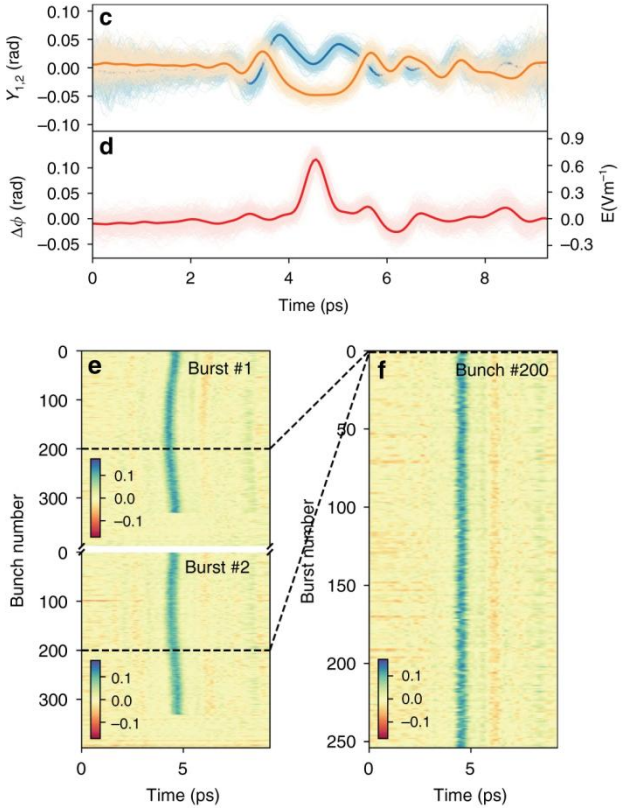
Ultimate resolution now limited by the laser and Xtal bandwidth.



E. Roussel, C. Szwaj, C. Evain, B. Steffen, C. Gerth, B. Jalali & S. Bielawski, Light Science & Applications 11, 14 (2022)

Test of DEOS in the accelerator context: Eu-XFEL, dec. 2018





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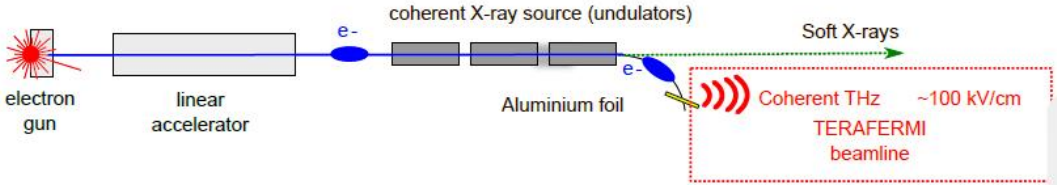
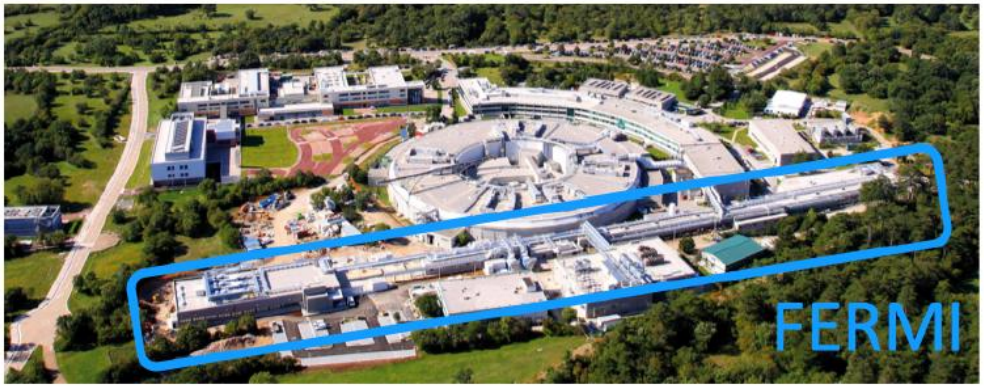
B. Jalali & S. Bielawski, Light Science & Applications 11, 14 (2022)

TeraFERMI: operation with a 1550 nm laser (+DEOS), april 2019

Eléonore Roussel, Clément Evain, Marc Le Parquier, Christophe Szwaj, Serge Bielawski (PhLAM)
Paolo Cinquegrana, Paola Di Pietro, Andrea Perucchi, Marco Veronese (FERMI)



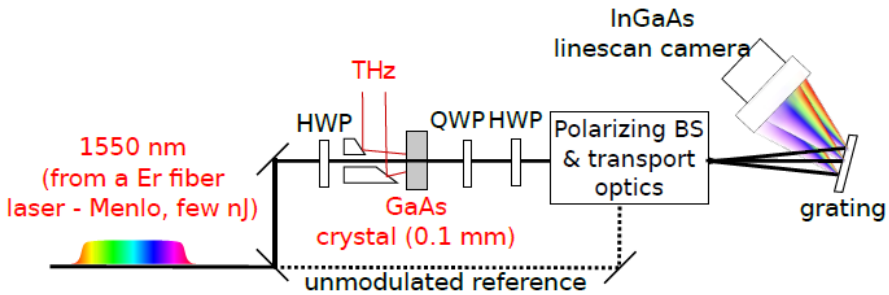


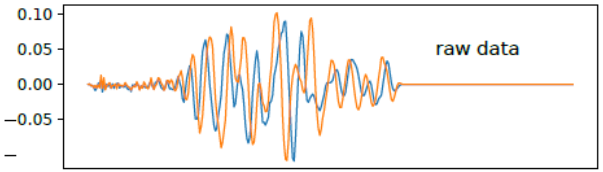
- High field (hundreds of kV/cm)
- wide bandwidth
- ...but **50 Hertz rep. rate (!)**

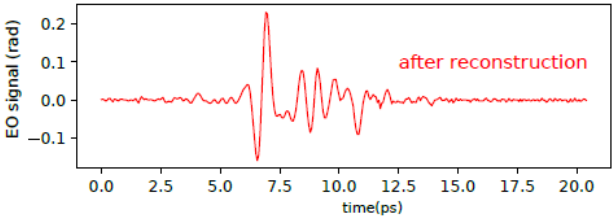
Is any user tempted to use "scan-based techniques"?? in these conditions (Fourier Transform spectroscopy, TDS...).

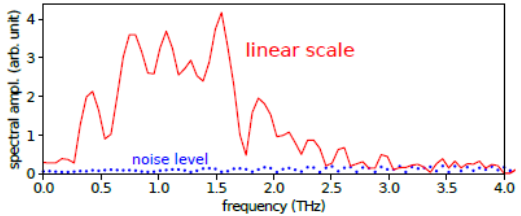
TeraFERMI: operation with a 1550 nm laser (+DEOS), april 2019

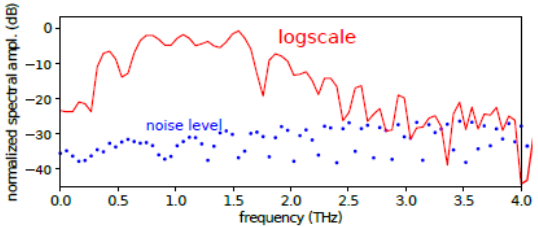
Note: TDS using a 1550 nm fiber laser











Eléonore Roussel, Serge Bielawski, Clément Evain, Marc Le Parquier, Christophe Szwaj (PhLAM)
Paolo Cinquegrana, Paola Di Pietro, Andrea Perucchi, Marco Veronese (FERMI)
In the framework of the METEOR project (E.R.).

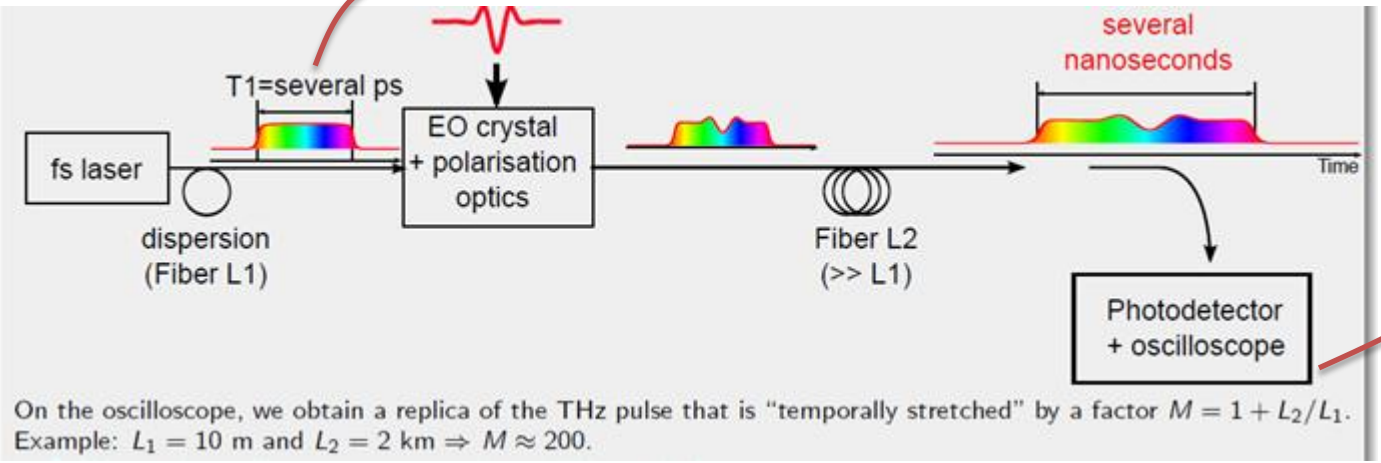
Test of time-stretch+DEOS reconstruction? -> ELBE 2021

Interesting schedule:
1 planned at the 10th workshop (2019) for Spring 2020
2 … rescheduled, re-rescheduled for August 2021
(PhD of Christelle Hanoun – see the ELBE poster)

Time-stretch: the readout bandwidth issue

At 1030 nm: reasonable stretch up to few nanoseconds, therefore:

- High BW ADC/oscilloscope required, 8-32 GHz in practice (expensive, low ENOB…)
- Or equivalently, we get a small number of samples/short time window



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Time-stretch: decreasing costs, increasing bandwidth and record duration

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- Or equivalently, we get a small number of samples

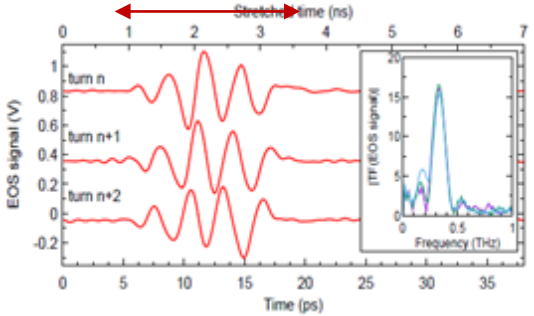
One solution explored: Use a 1550 nm Erbium laser (instead of a 1030 nm Yb laser)

- -> possibility to stretch typically 20x more

=> Less bandwidth required for the ADC/scope, 1 GHz or few GHz– See Christelle's poster

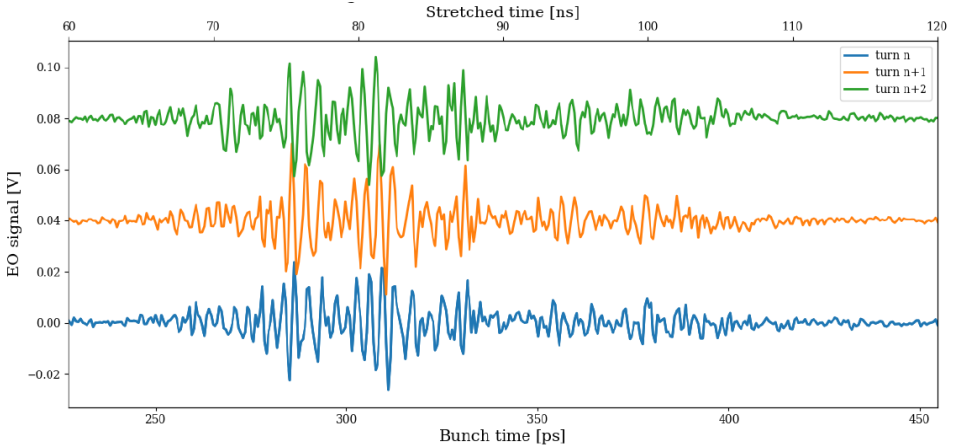
1030 nm, 6 GHz BW
(32 GHz + filtering)

Stretch ~2-3 ns



1550 nm, 3 GHz BW ADC

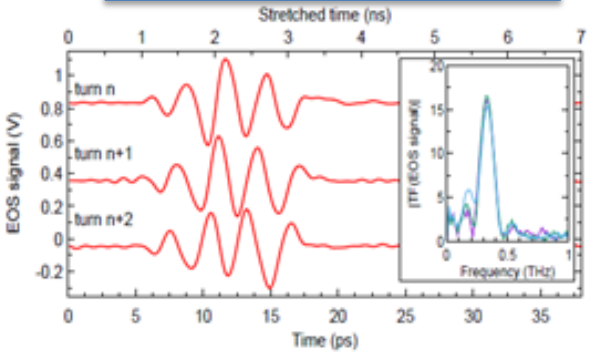
Stretch ~50 ns



Time-stretch: the readout speed issue

Second other solution explored: Develop a new, i.e, non-commercial ADC board with reasonable cost and tens of GHz BW**: THERESA project @KIT** (Michele)
-> see « Terahertz Sampling Rates With Photonic Time-Stretch for Electron Beam Diagnostics" by Olena Manzura
Third solution: Associate both solutions! (THERESA + 1550 nm)

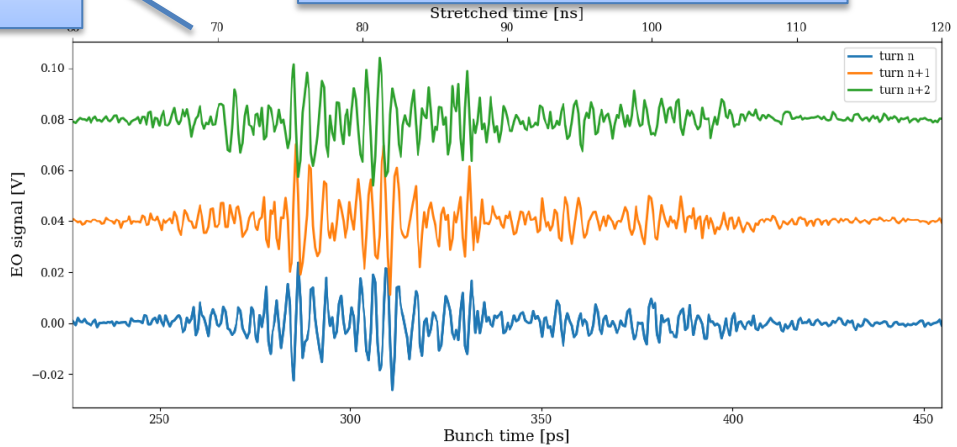
1030 nm – 6 GHz BW



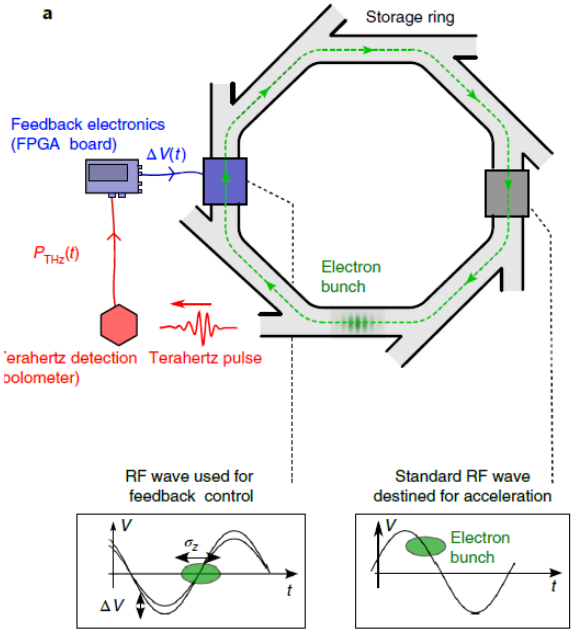
+ THERESA
=> ??

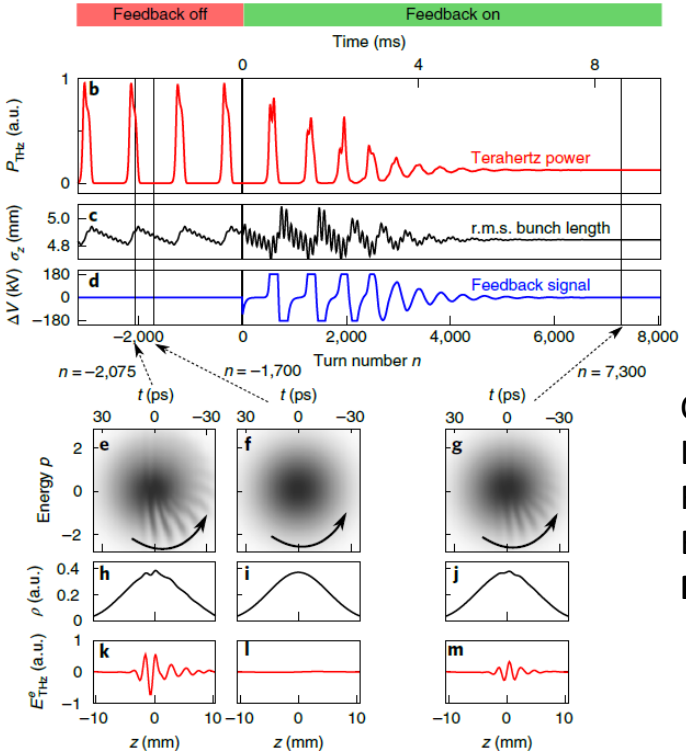
Other Applications?

1550 nm + 3 GHz BW ADC



Other WP of the ULTRASYNC ANR-DFG project:
Feedback control of the microbunching instability





Feedback strategy inspired by chaos control theory
In short -> stabilization of a regular solution, that pre-exists in phase space, in a unstable form (see poster)

C. Evain, E. Roussel, J. Rodriguez, M. Le Parquier, M.A. Tordeux, F. Ribeiro, M. Labat, N. Hubert, J.-B. Brubach, P. Roy, and S. Bielawski
Nat. Phys. 15, 635 (2019)

Conclusion and perspectives

EO studies (recent directions):

- Improvement of temporal resolution/BW -> DEOS (diversity-based) reconstruction method
- Tests in various situations: SOLEIL, DESY/EUXFEL, TeraFERMI, ELBE, table-top
- Cost reduction (of the readout) by working at the 1550 nm wavelength
- Joined project associating advanced electronics and time-stretch (THERESA)

Next steps, open questions:

- Joined work with Bernd Steffen -> Implement Diversity EO at FLASH, try to find new idea… See the poster by Quentin Demazeux.
- Big margin for improvements concerning time-stretch+DEOS… (at 1030 and 1550 nm)
- Application outside the field of accelerator physics? Need of single-shot EO for spectroscopy?
- TWAC project: low energy, sub 100 fs bunches… -> Measurement challenge. Foreseen: THz transverse streaking. See presentation by Guillaume Martinez