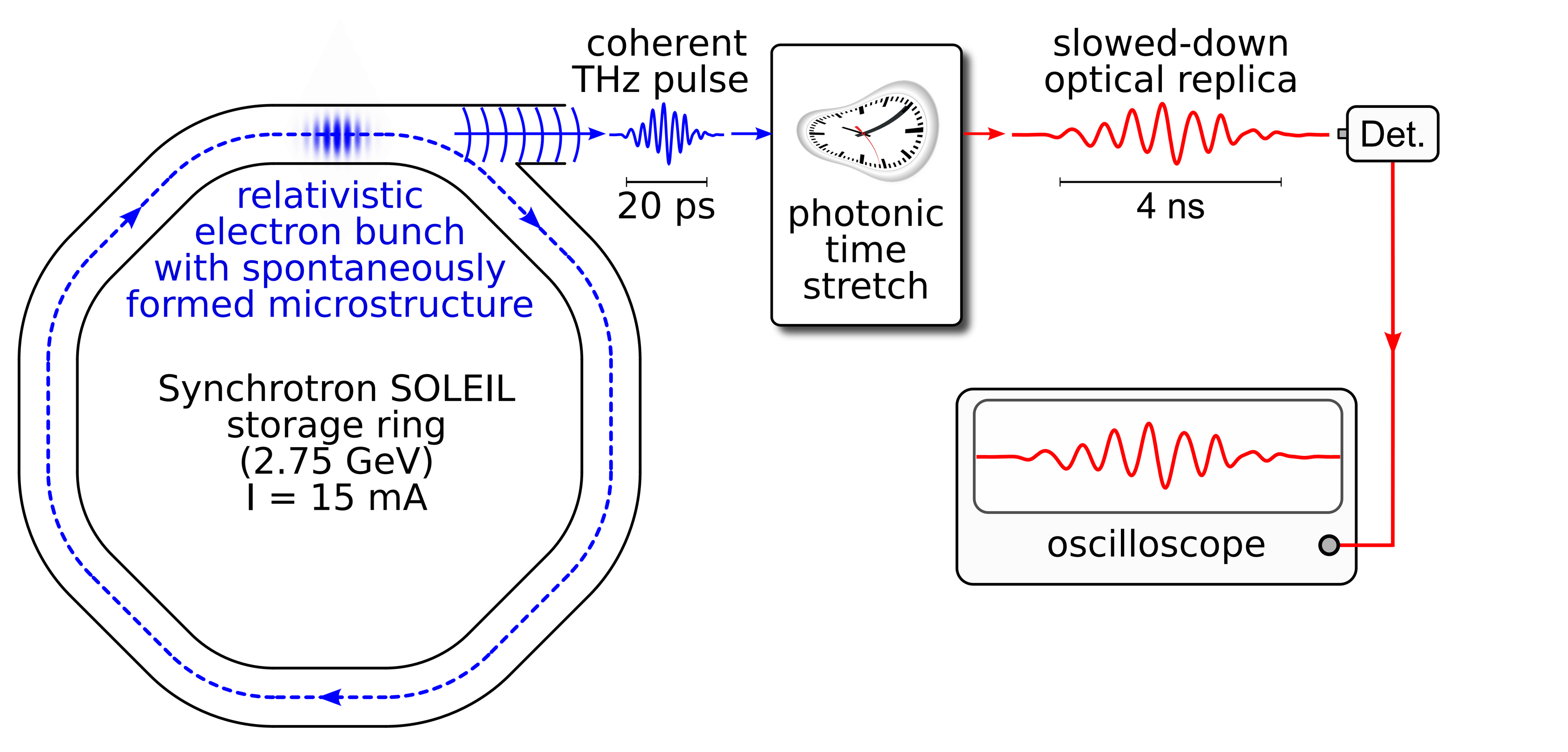
A SINGLE-SHOT HIGH-REPETITION RATE ELECTRO-OPTIC DETECTION OF SHORT PULSES USING THE PHOTONIC TIME-STRETCH STRATEGY

E. Roussel (eleonore.roussel@elettra.eu), C. Evain, M. Le Parquier, C. Szwaj, S. Bielawski (PhLAM, Lille, France)
L. Manceron, J.-B. Brubach, M.-A. Tordeux, J.-P. Ricaud, L. Cassinari, M. Labat, M.-E. Couprie, P. Roy (Synchrotron SOLEIL, Gif-Sur-Yvette, France)

Abstract

In accelerator-based light sources, there is a growing need for high repetition rate, single-shot, characterization of electron bunch shapes and THz pulses. At moderate repetition rate, an efficient strategy consists in encoding the ultrafast information onto a laser pulse, which is subsequently analyzed (electro-optic sampling). However, these methods usually require cameras as the final detector, which represents a bottleneck in the quest for high-repetition rates. A promizing candidate for breaking this "high repetition rate barrier" is the so-called photonic time-stretch technique. In this poster, we present the first results obtained with time-stretch in the accelerator context: Electro-optic sampling of successive terahertz bursts of coherent synchrotron radiation at SOLEIL[1], with 88 MHz acquisition rate (and picosecond resolution). In practice, the time-stretch is potentially realizable as a relatively simple upgrade of existing setups (provided it is possible to imprint the ultrafast signal on chirped laser pulses). Finally we also present a performance analysis, including a comparative study of standard and time-stretched electro-optic sampling setups.

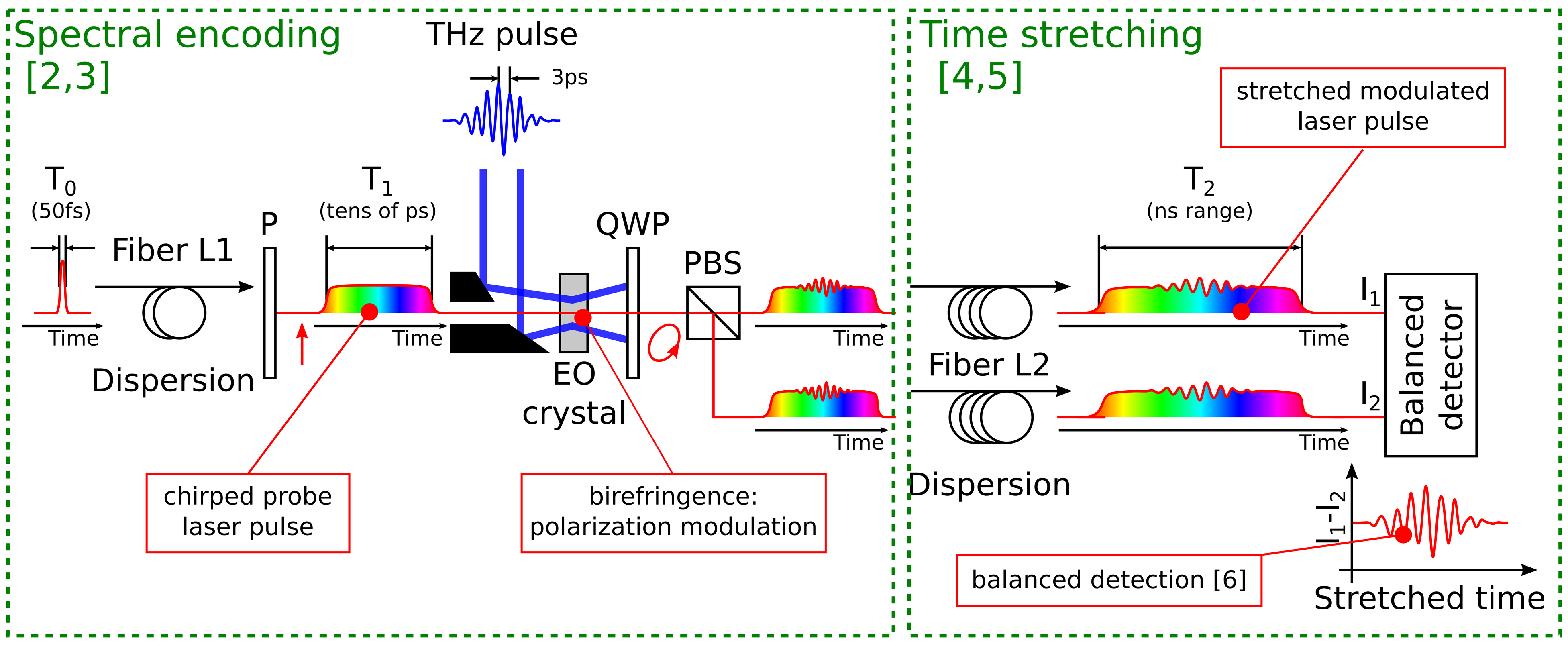
General principle of the experiment



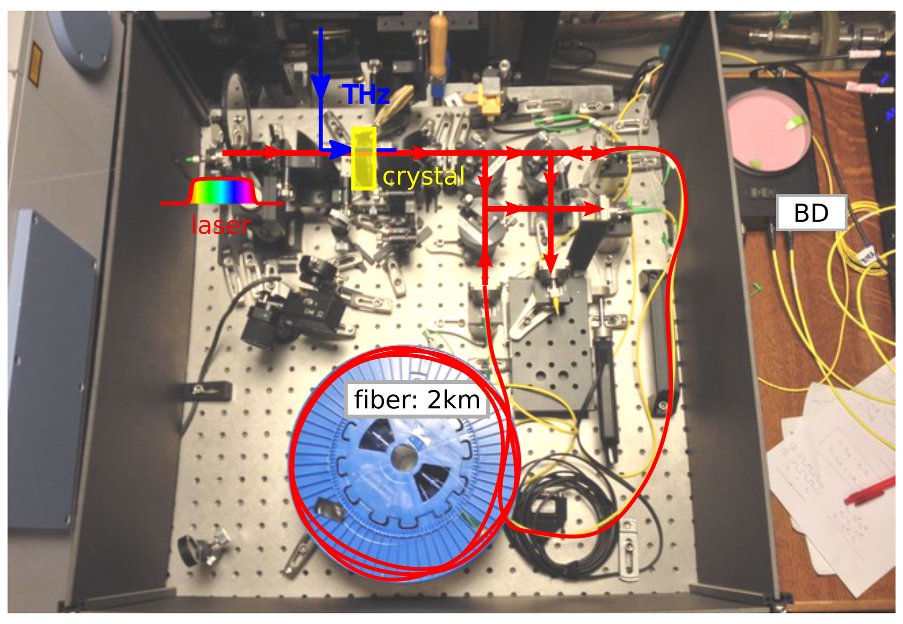
* Relativistic electron bunch with microstructures at ps scale
* Revolution frequency: 0.84 MHz
* Detection strategy: to "slow-down" the information at the ns scale, and to use conventional oscilloscope for recording

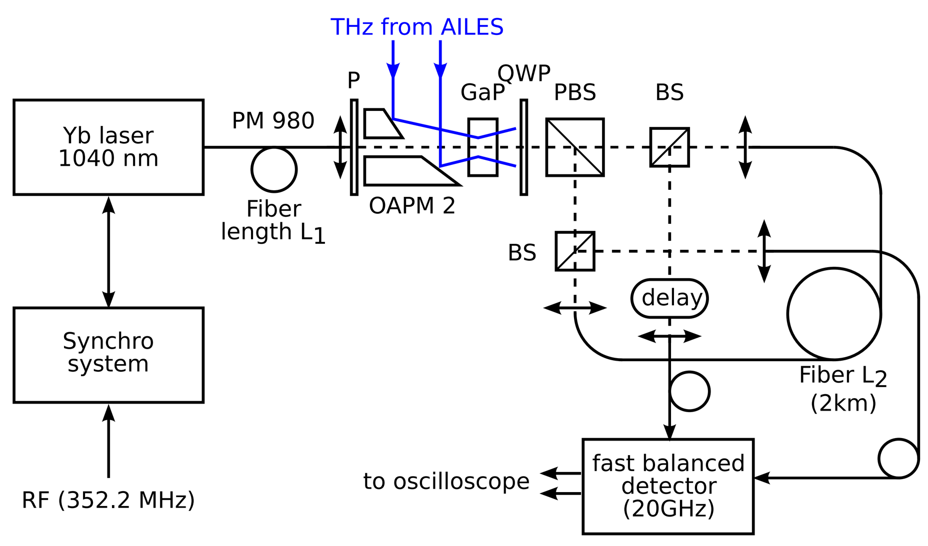
Time-Stretch Spectrally Encoded Electro-Optic Detection (TS-EOSD)

TS-EOSD device for slowing down the signal, while keeping a high sensitivity



TS-EOSD setup on the AILES infrared beamline at Synchrotron Soleil





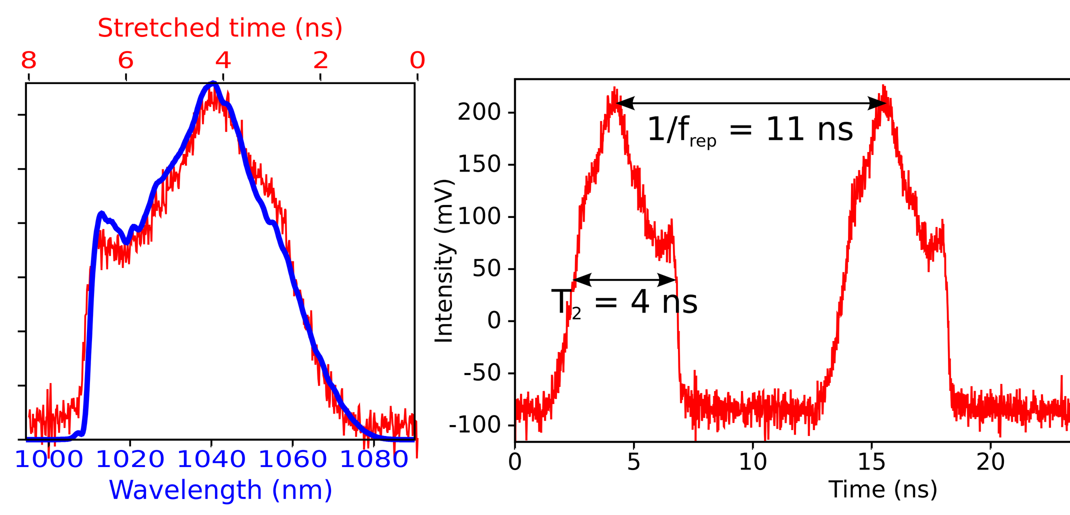
* EO effect in GaP crystal
  --> phase retardation

$$\Delta\Phi = \frac{2\pi d}{\lambda} n_0^3 r_{41} E_{THz}$$

* Balanced detected signal

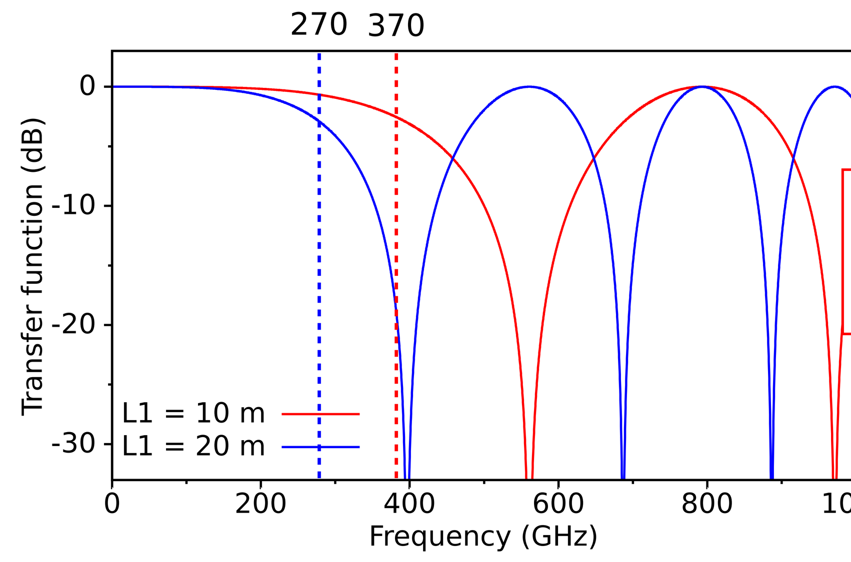
$$I_{det} = I_0 \sin\Delta\Phi \approx I_0 \Delta\Phi$$

* Wavelength-to-time mapping and Trade-off between acquisition rate and stretch factor



$$T_2 = \left(1 + \frac{L_2}{L_1}\right) T_1 = M T_1$$

* Penalty dispersion --> limited bandwidth

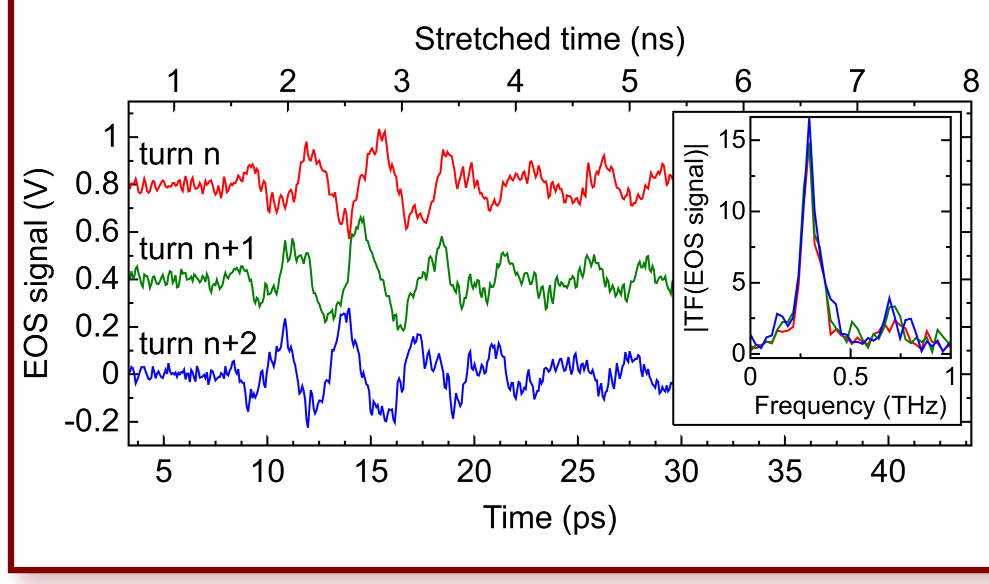


$$H(f_m) = \cos^2\left(2\pi^2 \beta_2 \frac{L_2}{M} f_m^2\right) \approx \cos^2\left(2\pi^2 \beta_2 L_1 f_m^2\right)$$

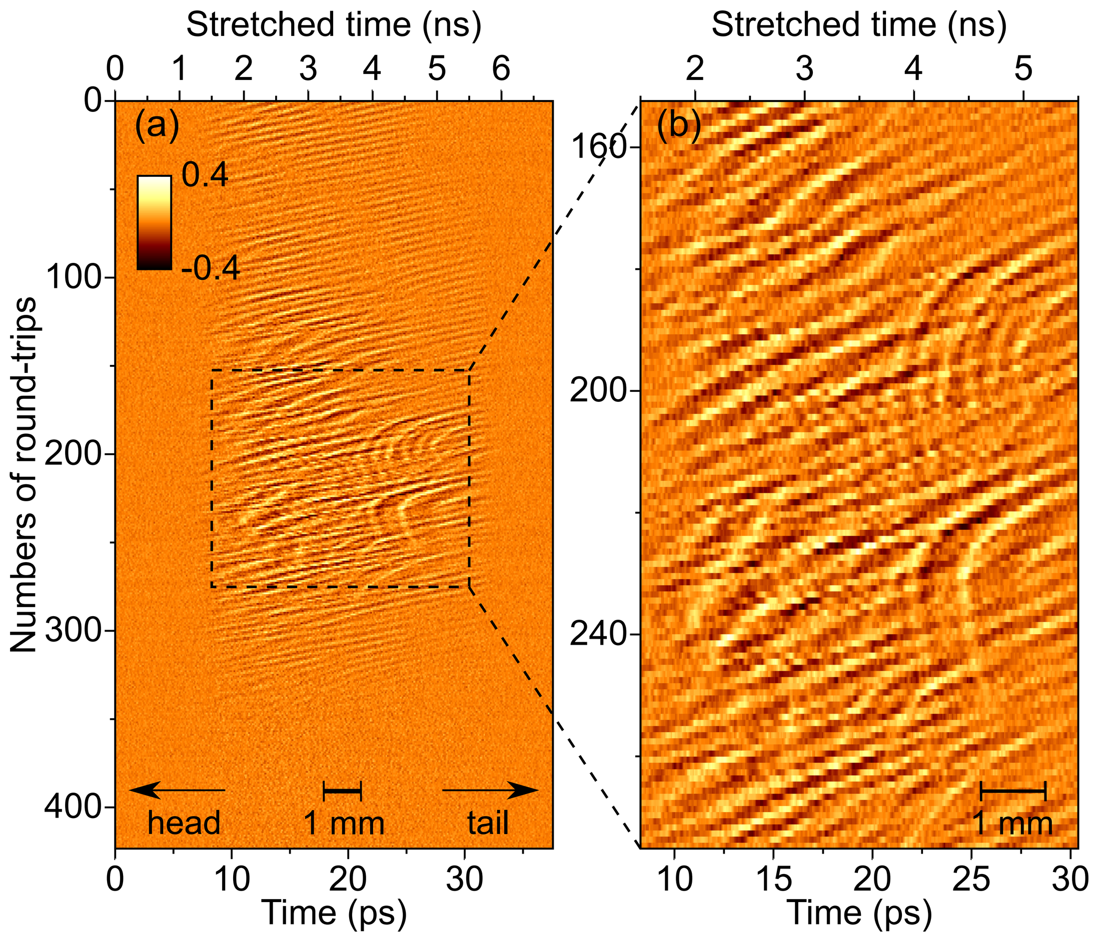
Experimental results

Single-shot recordings of 3 successive turns in the storage ring (i.e. one shot every 1 µs). Upper scale: time scale at the oscilloscope input. Lower scale: real time of the phenomenon.

Fiber lengths: L1 = 10.5 m, L2 = 2 km
--> Stretch factor M = 1 + L2/L1 = 190.



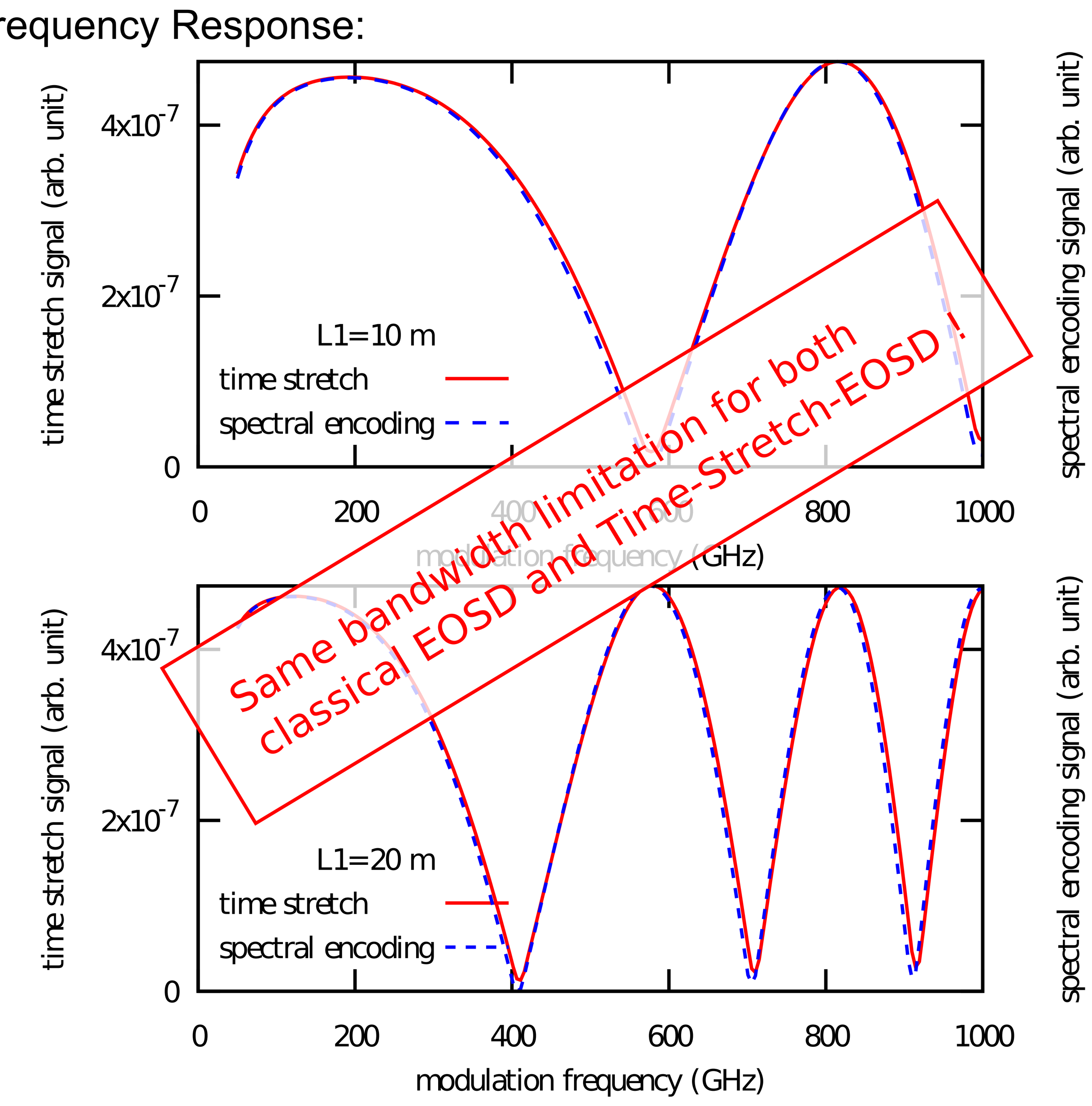
Temporal evolution of CSR pulses versus number of round-trips



Comparison between TS-EOSD and EOSD

Time-Stretch-EOSD: use dispersion in fiber
Classical EOSD: use of spectrometer

Frequency Response:



Conclusion

We presented a novel strategy for recording short pulses in the ps, sub-ps range. The time-stretch spectrally encoded electro-optic detection (TS-EOSD) allows single-shot, high-acquisition-rate and high-sensitive detection of CSR pulse shapes. We apply the TS-EOSD setup to the direct real-time monitoring of THz CSR pulses emitted during the microbunching instability at Synchrotron SOLEIL. The transfer of this photonic technique to accelerator physics can be effective in other situations than THz CSR that require high acquisition rate single-shot measurements.

[1] E. Roussel et al., Scientific Reports **5**, 10330 (2015).
[2] Müller et al., Phys. Rev. ST Accel. Beams **15**, 070701 (2012).
[3] Hiller et al., IPAC'13, p. 500 (2013).
[4] Coppinger et al., IEEE Transactions on Microwave Theory and Techniques, **47**, 1309 (1999).
[5] Han, and Jalali, Journal of Lightwave Technology, **21**, 3085 (2003).
[6] Wong et al., Journal of Lightwave Technology, **29**, 3099 (2011).