DEOS: A New Scheme for Recording Electron Bunch Shapes With High Resolution and Record Recording Length - Principle and Tests at EuXFEL

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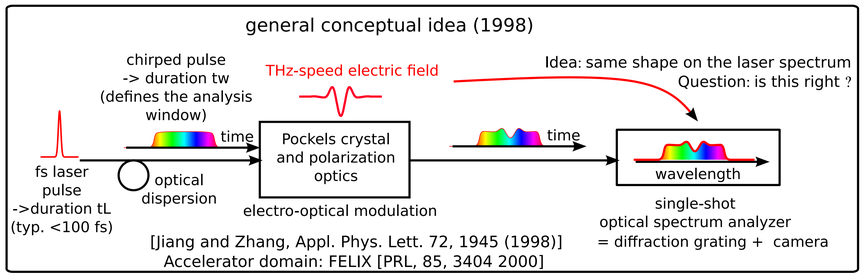
general conceptual idea (1998)

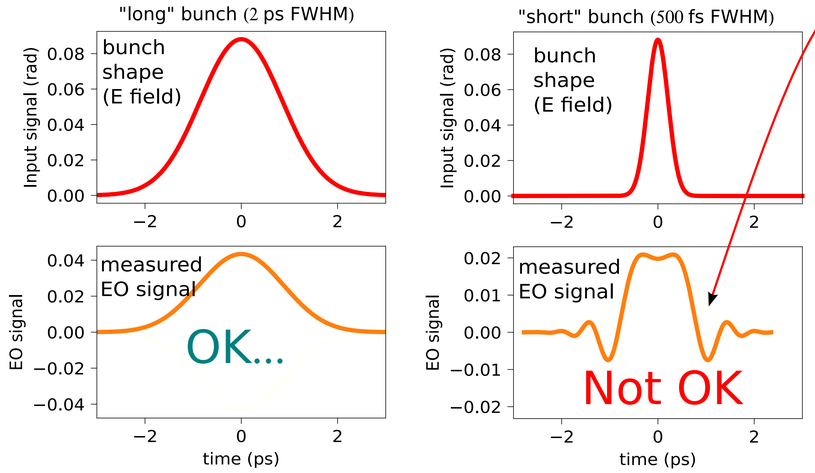


[Jiang and Zhang, Appl. Phys. Lett. 72, 1945 (1998)]
Accelerator domain: FELIX [PRL, 85, 3404 2000]

Extensive studies and developments at FELIX, SLS, DESY, KARA, Daresbury, PhLAM, SOLEIL...

Major issue: temporal resolution (i) known since 1998 (ii) strong limitation for bunch shape measurements

Example (simulation): laser tL=40 fs analysis window tw=10ps



strong deformations when "input duration is too short"
-> resolution usually defined as:

$$\tau_R \approx \sqrt{\tau_L \times \tau_w}$$

τ_L: laser duration (compressed)

τ_w: analysis window chirped laser pulse duration

Example: 100 fs laser, 10 ps analysis window -> only 1 ps resolution !!
=> In short: (i) the resolution is >> laser pulse duration
(ii) the issue is worse when long windows of analysis are needed

See: Sun, F., Jiang, Z. & Zhang, X.-C. Analysis of terahertz pulse measurement with a chirped probe beam. Applied Physics Letters 73, 2233 (1998).

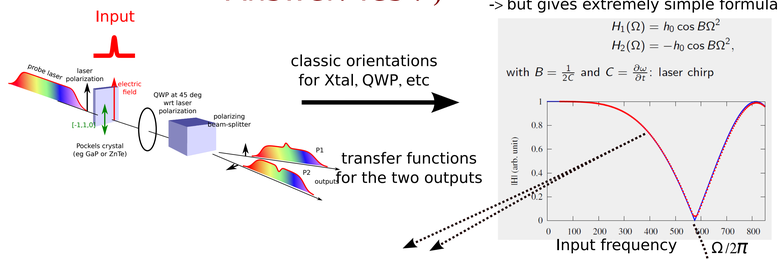
Note: sometimes coined the term "Fourier limit"

(1) Theory & New approach in Fourier space

Question: is it possible to calculate transfer function(s) between the input field and the measured EO signal?

Answer: Yes :-)

- requires non-trivial analytical work...
-> but gives extremely simple formula

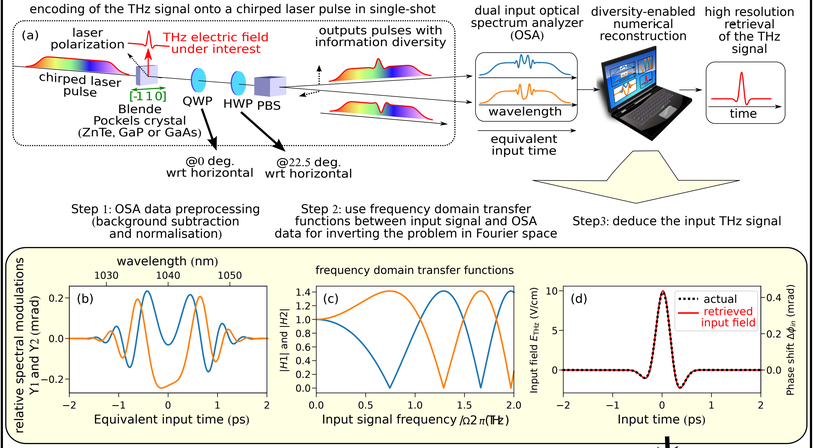


(i) same transfer functions on the two ouputs
(ii) ZEROS at particular frequencies

First conclusion from this new point of view?
* We explain these deformations
* it SEEMS IMPOSSIBLE to retrieve the input from the output in those "classic" setups, since spectral INFORMATION IS LOST

(2) Main poster theoretical result: possibility to retrieve the input using "information diversity"

Key point: For other optics orientations the transfer functions can be DIFFERENT on the two outputs (and with interleaved zeros)



Considerable temporal-resolution improvement
-> Now limited by laser duration :-)
(or Xtal or spectrometer, whichever one dominates)

$$\tau_R \approx \sqrt{\tau_L \times \tau_w}$$

Main points of the MRC retrieval algorithm

Transfer functions

$$H_1(\Omega) = \sqrt{2}\cos\left(B\Omega^2 + \frac{\pi}{4}\right)$$

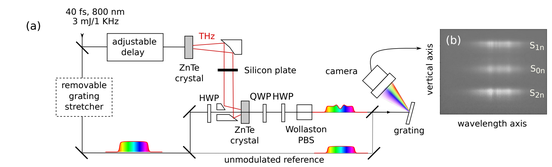
$$H_2(\Omega) = -\sqrt{2}\cos\left(B\Omega^2 - \frac{\pi}{4}\right)$$

Find the unknown input X_R, using Maximum Ratio Combining (MRC):

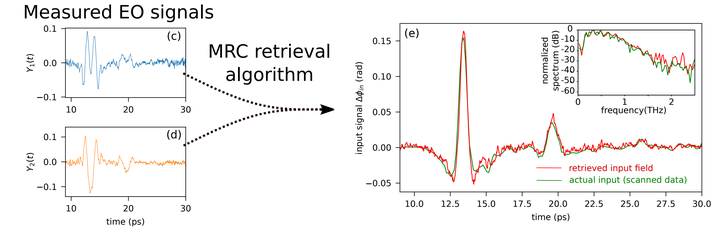
$$X_R = \frac{H_1 Y_1 + H_2 Y_2}{|H_1|^2 + |H_2|^2} \quad (2)$$

Note: frequency space: $X_R = X_R(\Omega)$, etc.
$Y_1(\Omega)$ and $Y_2(\Omega)$: measured EO signals

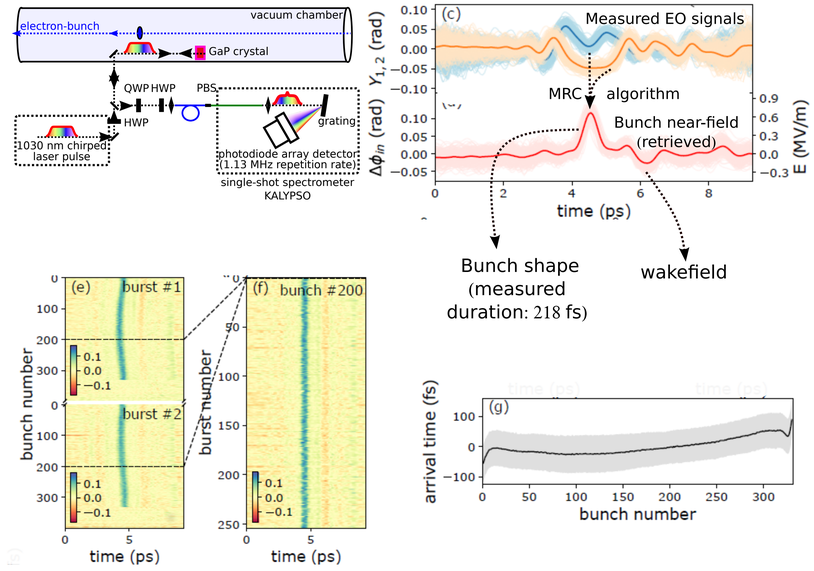
(3) Table-top test of DEOS using a known THz source



Measured EO signals



(4) Experiments at Eu-XFEL



Main conclusion: DEOS allows bunch shapes to be measured
- over long observation windows
- without trade-off on resolution
and requires minor modfication of existing diagnostics

See details in: https://arxiv.org/abs/2002.03782

See also:
- Phase diversity concepts in the time-stretch method
[Han & Jalali IEEE trans. Microw. Th. & Tech. 53, 1404 (2005)]
- Electro-optic sampling at Eu-XFEL
[B. Steffen et al., RSI 91, 045123 (2020)]

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