TUPLB10 (Poster: TUPB080)

Non-destructive Real-time Monitor to measure 3D-Bunch Charge Distribution with Arrival Timing to maximize 3D-overlapping for HHG-seeded EUV-FEL

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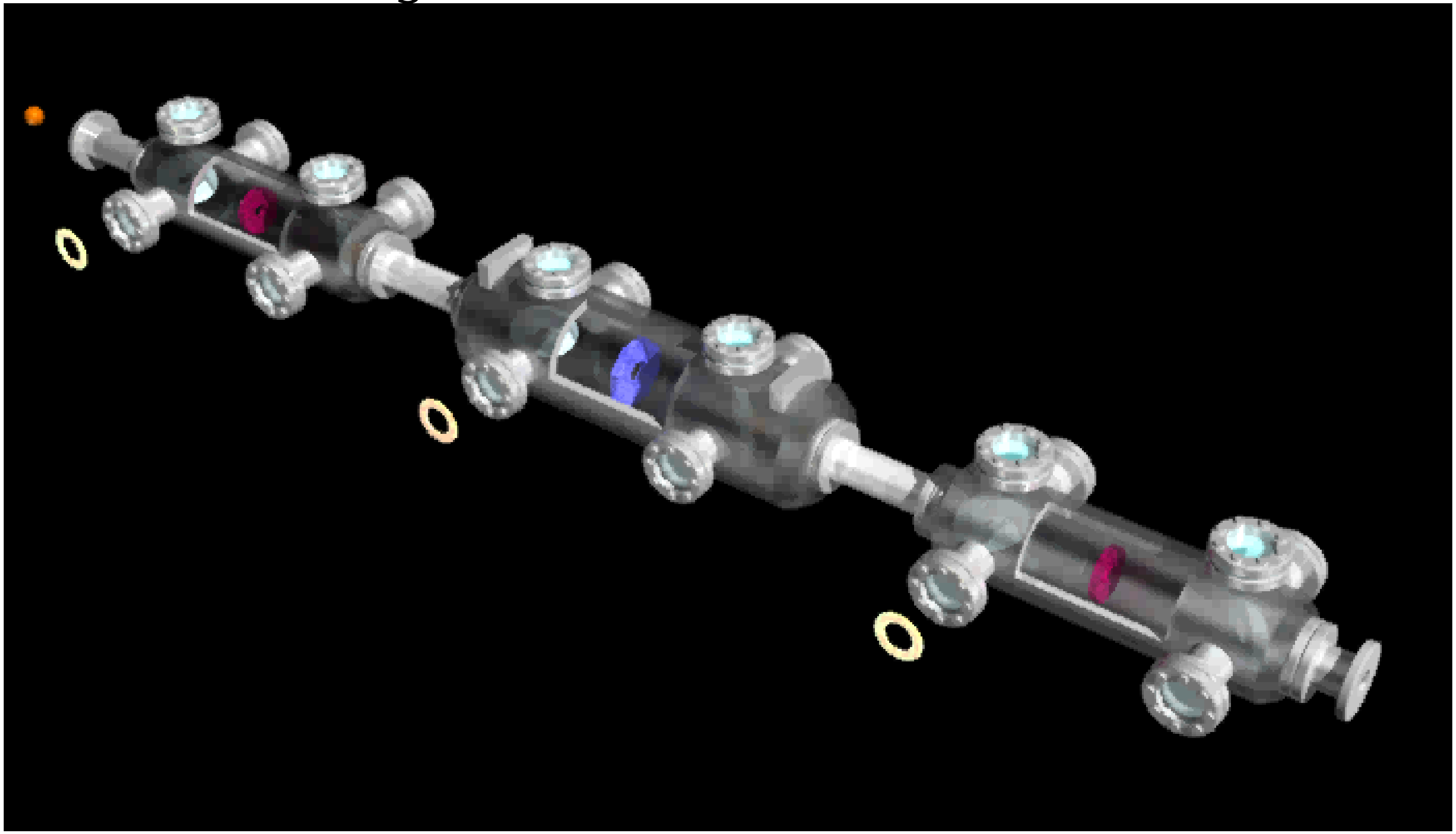
On behalf of all the staffs contributed to

HHG-seeded EUV-FEL (SCSS) at SPring-8

3D bunch shape monitor (BCD: Bunch Charge Distribution)

Three sets of 3D-BCD elements: de/en-coding to de/o- multiplexing

Non-destructive, Shot-by-shot Real-time Monitor to measure 3D-Bunch Charge Distribution



The purpose of development 3D-Bunch measurements

Bunch duration measurements based on EO Sampling

- Nondestructive, single-shot, real-time measurements are reliable for :
  (XFEL) online beam adjustment during operation with SASE lasing.
  (Seeded FEL) feedback on 3D-overlap between e-bunch and HHG-pulse.
  (Our HHG-drive laser pulse and EO-probe pulse are the common pulse.)

- Sub-picosecond temporal resolution ~ Up to now, the highest resolution of 130 fs (FWHM) is reported from DESY [1].

3D bunch shape monitor with a temporal resolution of femtosecond [2-3]

- Developments of probe laser, EO crystal and optics for high temporal resolution to obtain 30-fs temporal resolution

- 3D bunch shape monitor (3D bunch charge distribution monitor: 3D-BCDM)
  Single-shot measurements for both longitudinal and transverse distribution.

[1] G. Berden et al., Phys. Rev. Lett. 99 (2007) 164801

[2] H. Tomizawa, et al., in Proc. of FEL 07, Novosibirsk, Russia (2007) 472

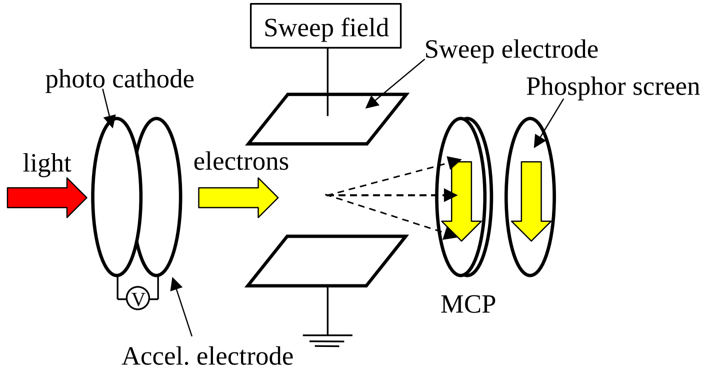
[3] H. Tomizawa, Japan Patent Application No. 2007-133046

Sub-picosecond bunch duration measurements I

i) Streak Camera [1-3]

The best temporal resolution is **300 fs (FWHM)**

when we use "> 700 nm light for injection" + "Fastest sweep field"



Cherenkov radiation enters photocathode.

λ~< 500nm: resolution of Streak Camera is ~ >500fs (FWHM)

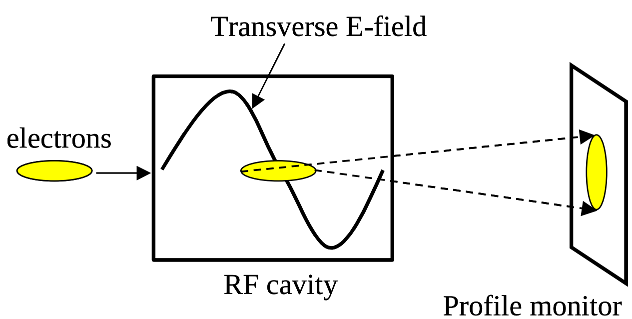
Photoelectrons are swept by E-field to obtain the temporal distribution.

Space charge effect and initial velocity distribution of photoelectrons limits resolution.

ii) RF deflector

High precise with high resolution, but **destructive**.

It was installed to XFEL **@1.4GeV** [4] (The total length became large ~15 m).



Electron bunches enters RF cavity.

Electrons are swept by RF field to obtain the temporal distribution

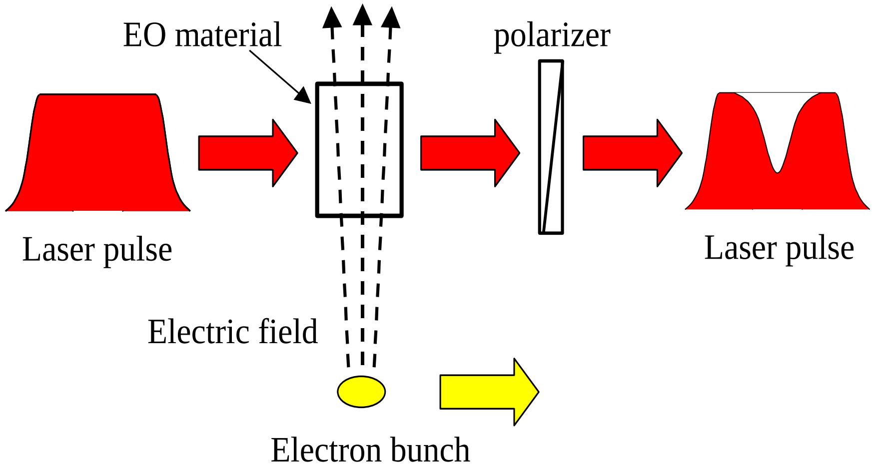
[1] H. Tomizawa, Proc. of 5th PASJ, 2008, 129, [2] M. Uesaka, Femtosecond beam science, Inperial College Press (2005)
[3] M. Uesaka et al., IEEE Trans. Plasma Sci. 28 (2000) 1084
[4] H. Ego et al., in Proceedings of EPAC 08, Genova, Italy (2008) 1098

Sub-picosecond bunch duration measurements II

iii) E-field measurements based on EO detection

Non-destructive single-shot measurements are possible [1]

Temporal resolution of 130 fs (FWHM) is reported using temporal decoding [2]



Refractive index inside EO crystal changes when Coulomb field is applied.

Laser probe pulse synchronized with electron bunch is injected into EO crystal

The polarization-state modulation of laser probe pulse is detected.

Several techniques for EO detection

a) Temporal decoding: temporal distribution of laser pulse is measured

b) Spectral decoding: spectral distribution of linear-chirped laser pulse is measured.

In this bunch shape monitor, we adopt spectral decoding.

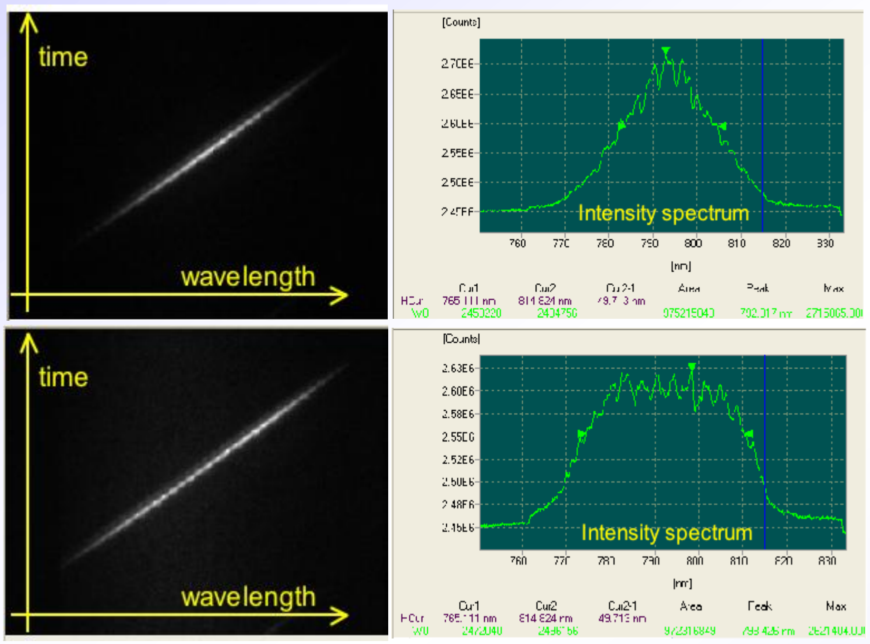
[1] I. Wilke et al., Phys. Rev. Lett., 88 (2002) 124801, [2] G. Berden et al., Phys. Rev. Lett., 99 (2007) 164801

Measurement (Decoding) methods of EO Sampling :

(a) Temporal Decoding

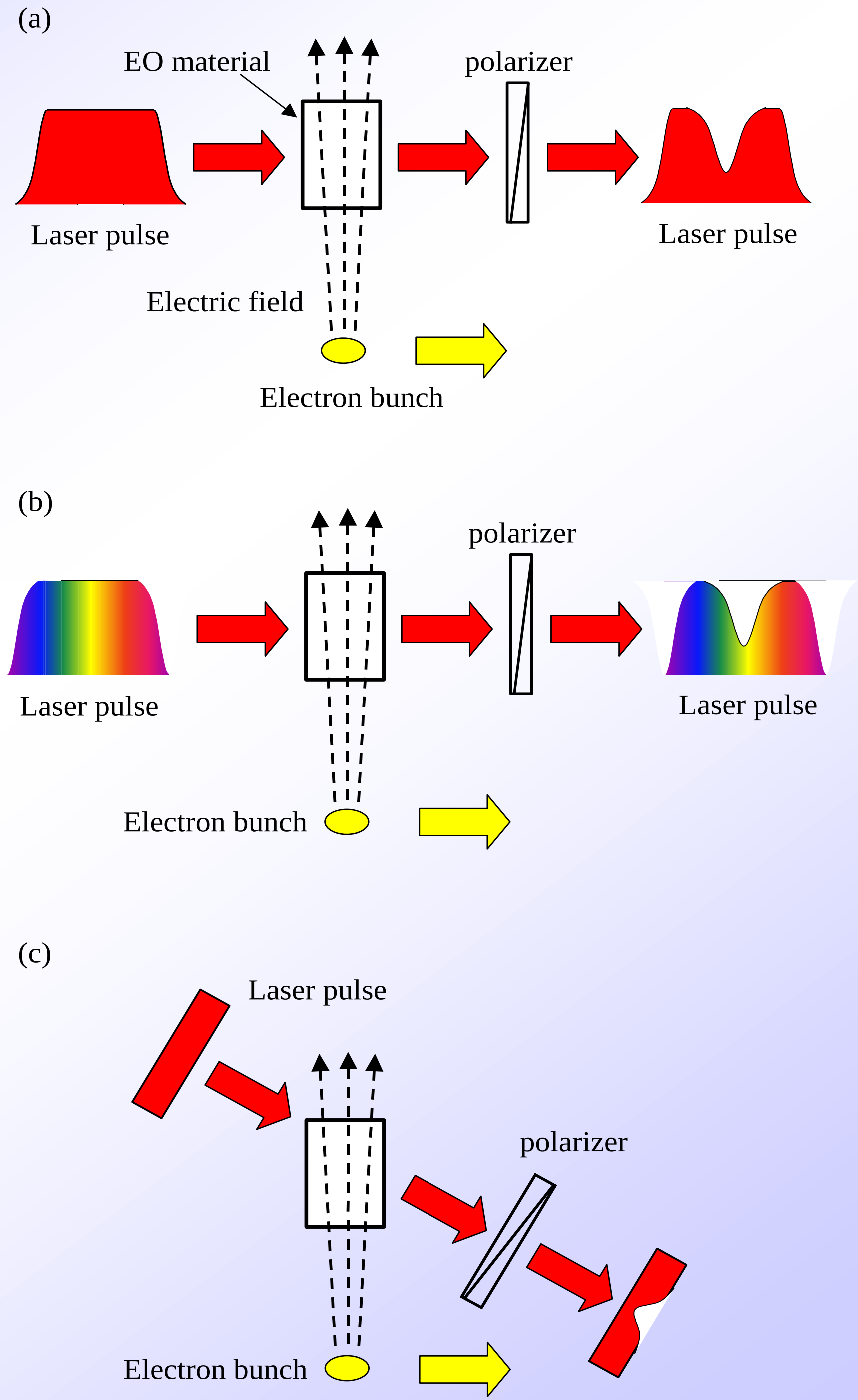
(b) Spectral Decoding

(c) Spatial Decoding



Measurements of linear-chirped laser probe pulse with Spectrograph Streak camera:

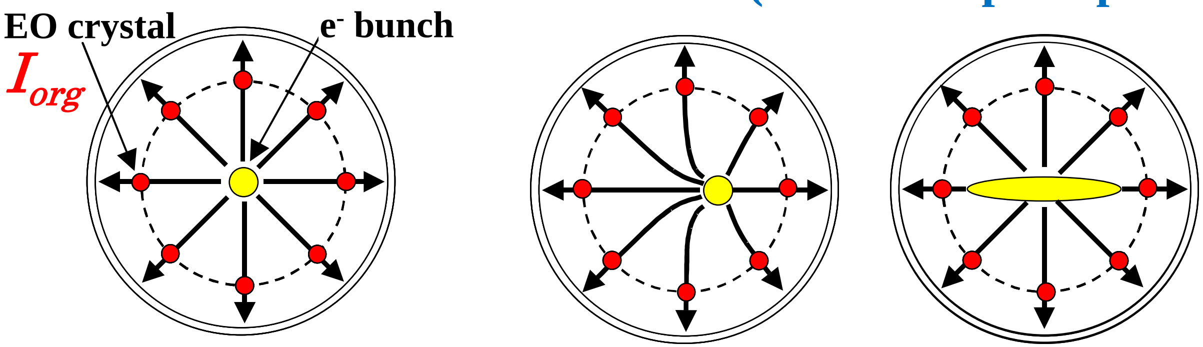
The upper is an original laser probe pulse (constant chirp rate). The lower is squarely shaped spectral intensity distribution by DAZZLER AO-modulator.



Transverse detection:

2D moment of bunch slice as transverse detection

A) Boundary condition of metal vacuum chamber (like Multi-pickup BPM)



At center of EO-detectors Center shifted Elliptical shape

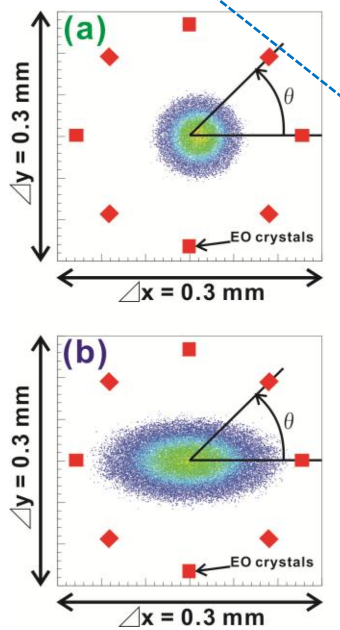
B) Situated in free space (3D-BCD EOS)

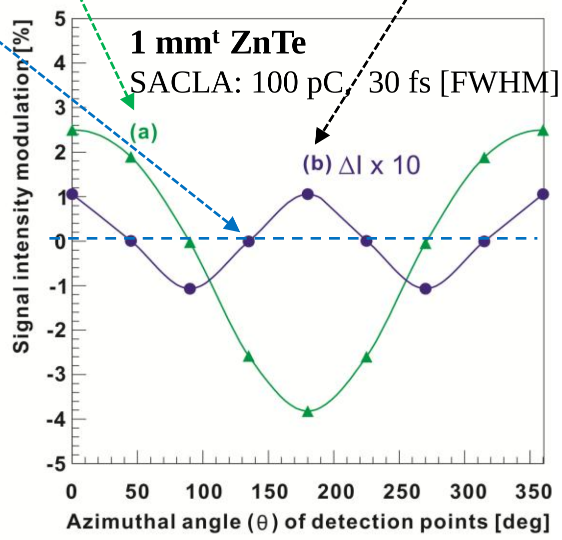
Probe points on EO-crystal edges located 2-mm from center of bunch slices.

(a) 10-μm transverse shift e⁻ beam (40 μm [rms])
(b) ellipse-shaped slice (150 μm [rms] in major axis)

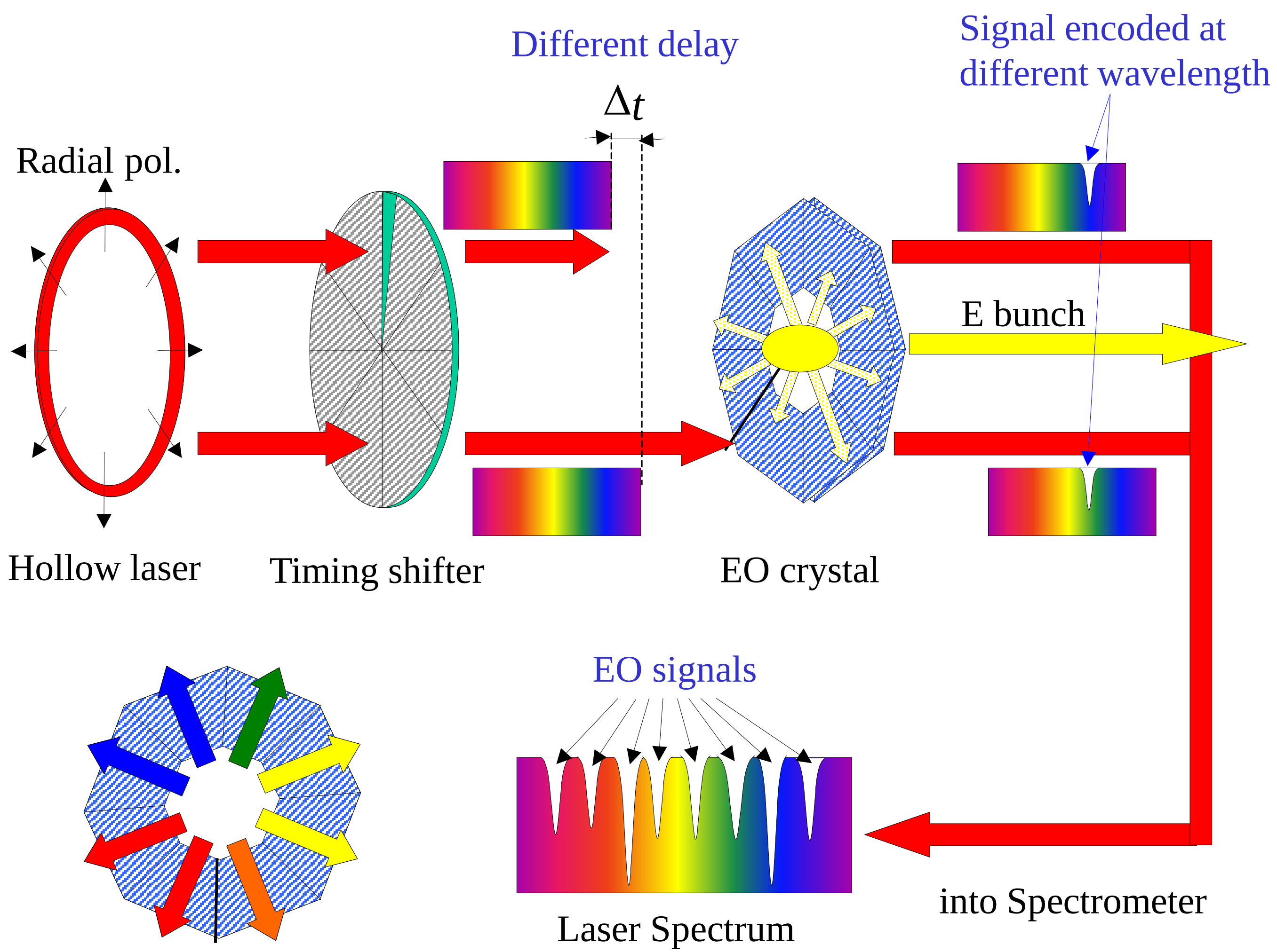
$$\Delta I = \frac{I_{sig} - I_{org}}{I_{org}},$$

$$I_{sig} = I_0 sin^2\left(\frac{\pi}{2\lambda}\Delta nL\right).$$



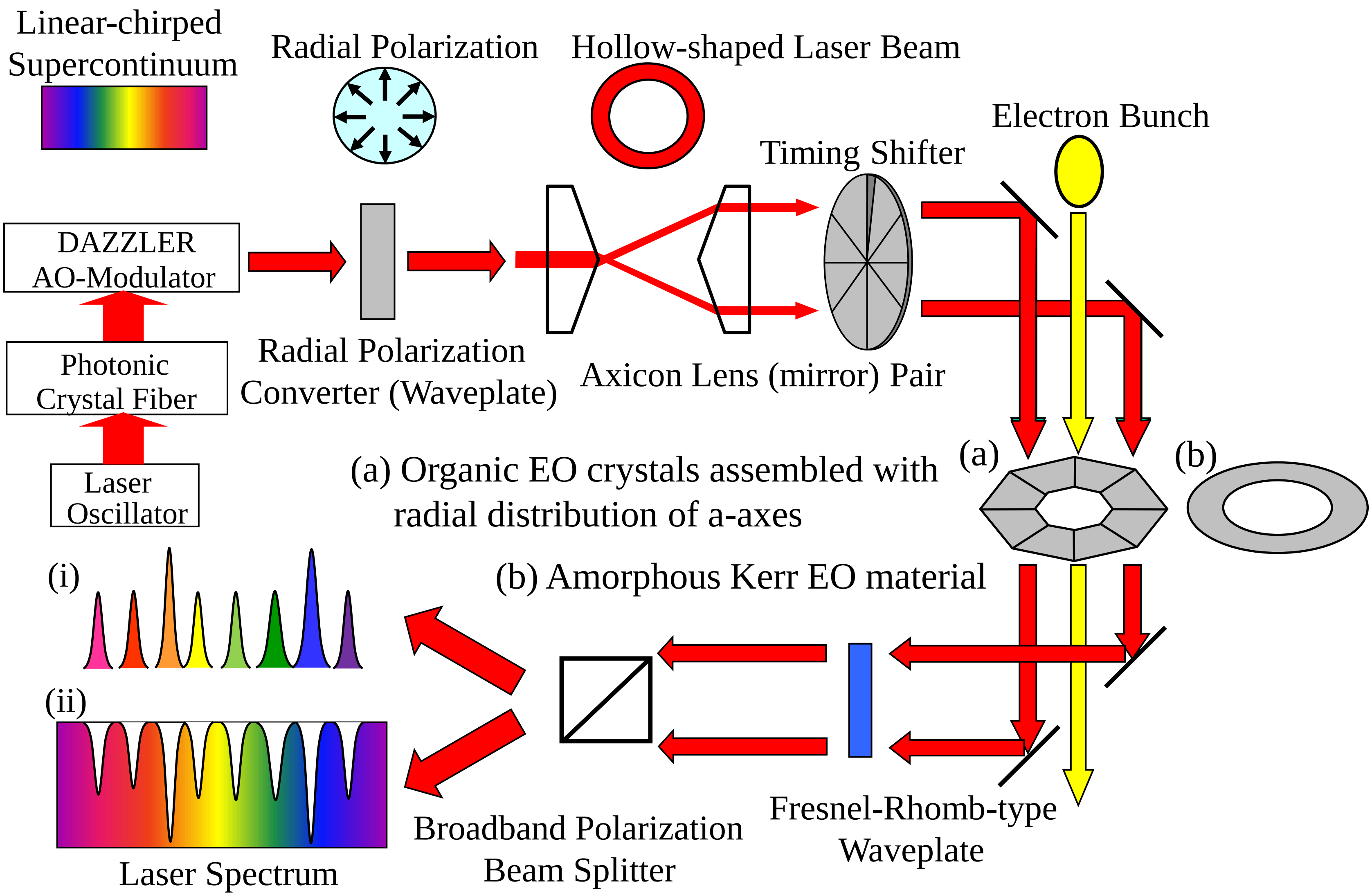


3D bunch shape monitor (One element of 3D-BCDM) II



- Hollow-shape radial-polarized laser pulse to probe at the EO crystals.
- Timing shifter to apply temporal delays for each EO-sector (without limits of Rep. rate)
- Square spectrum to guarantee real-time measurements

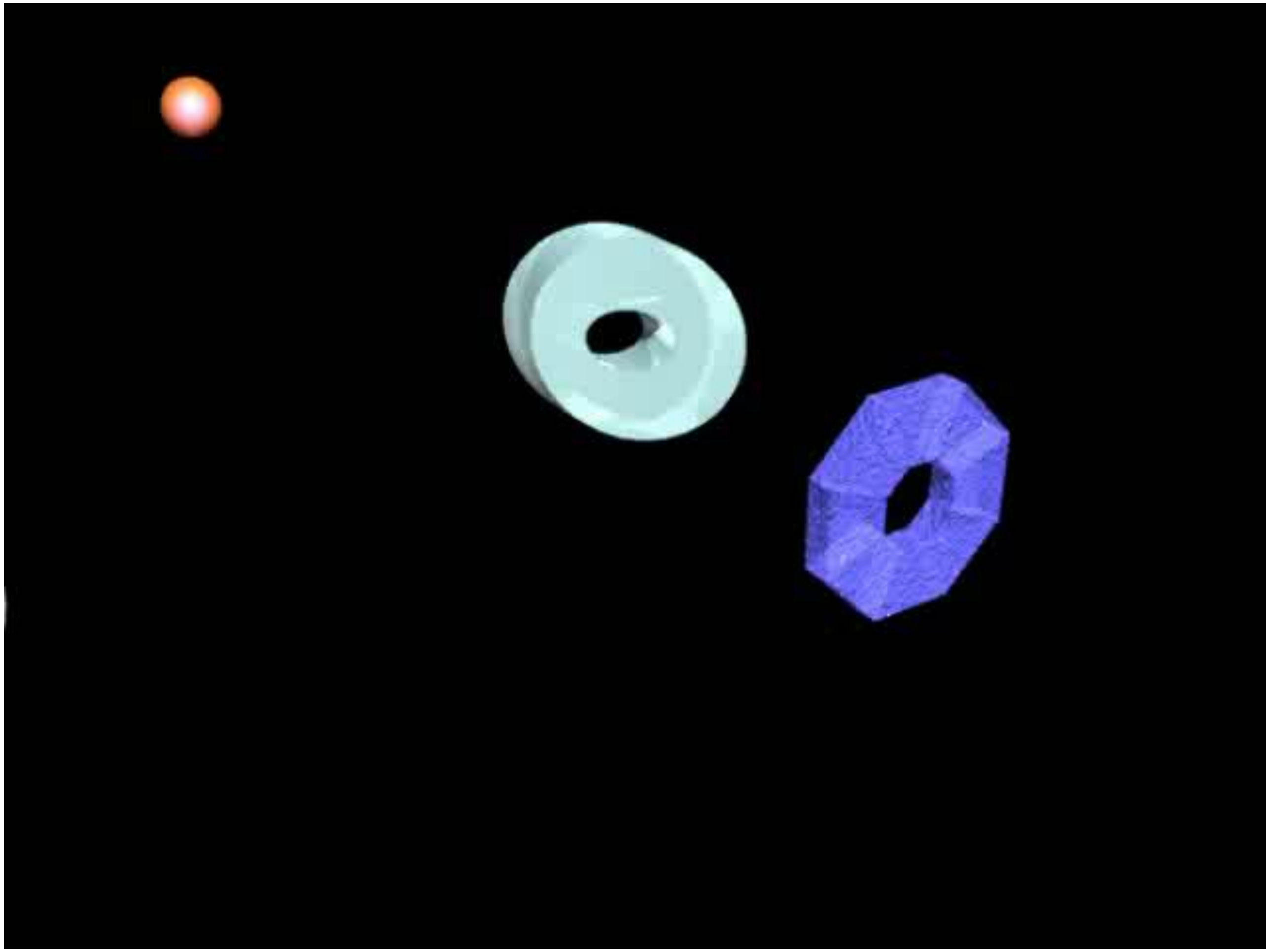
3D bunch shape monitor (One element of 3D-BCDM) [2]



[2] H. Tomizawa, H. Hanaki, and T. Ishikawa,
"Non-destructive single-shot 3-D electron bunch monitor with femtosecond-timing all-optical system for pump &probe experiments," Proc. FEL2007, Novosibirsk, Russia, 2007 pp. 472-475.

3D bunch shape monitor (One element of 3D-BCDM) [2]

Eight EO-crystals are probed by single hollow laser beam , simultaneously



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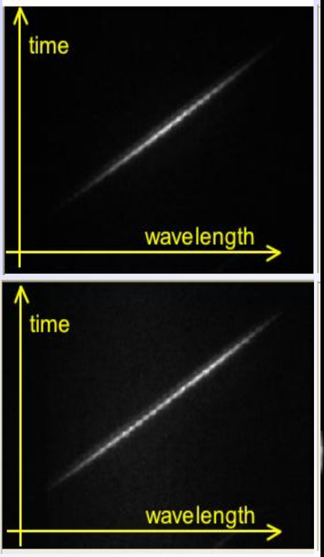
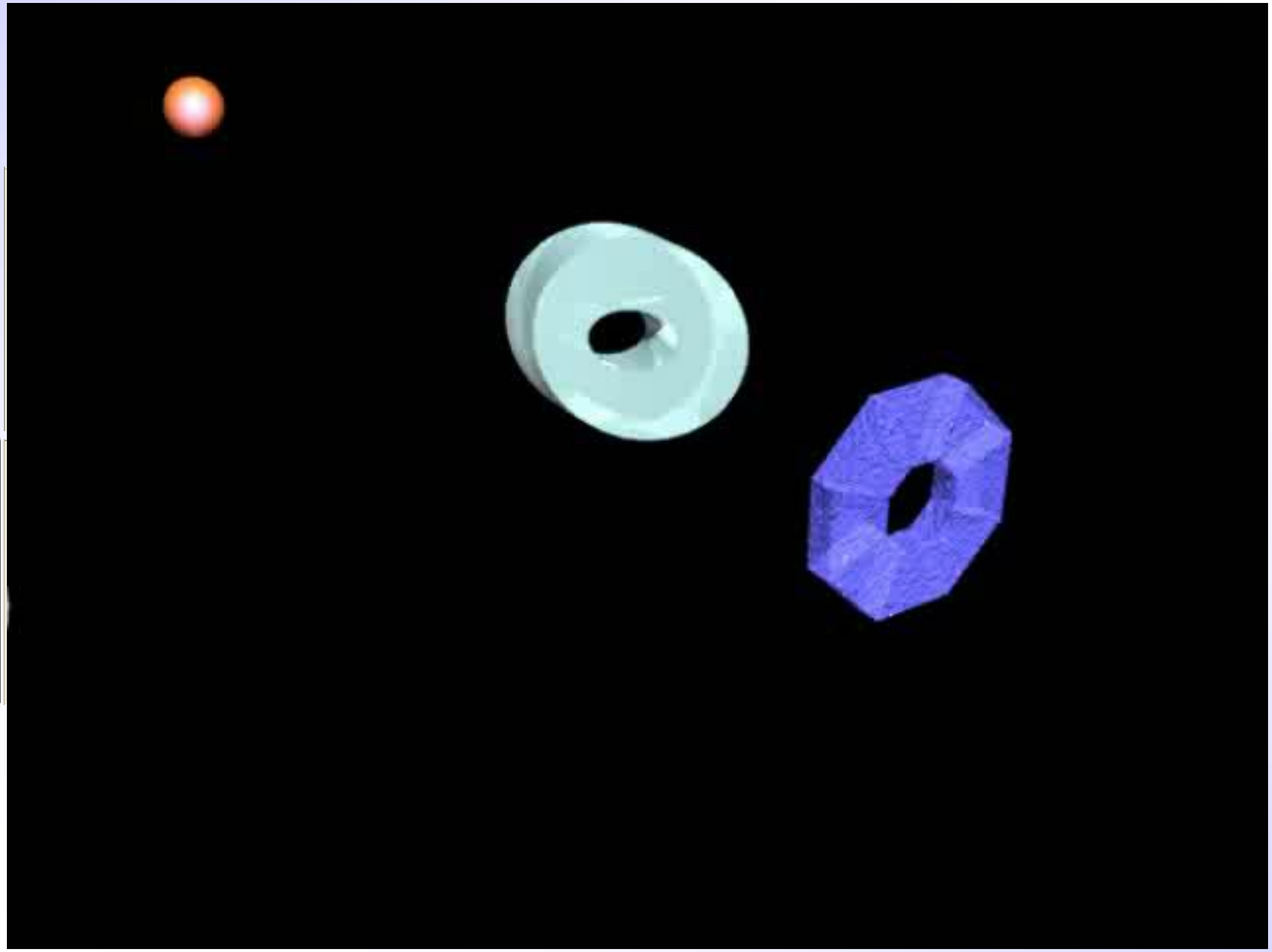
3D bunch shape monitor (One element of 3D-BCDM) [2]

Linear-chirp (Constant Chirp Rate) used for Spectral decoding.





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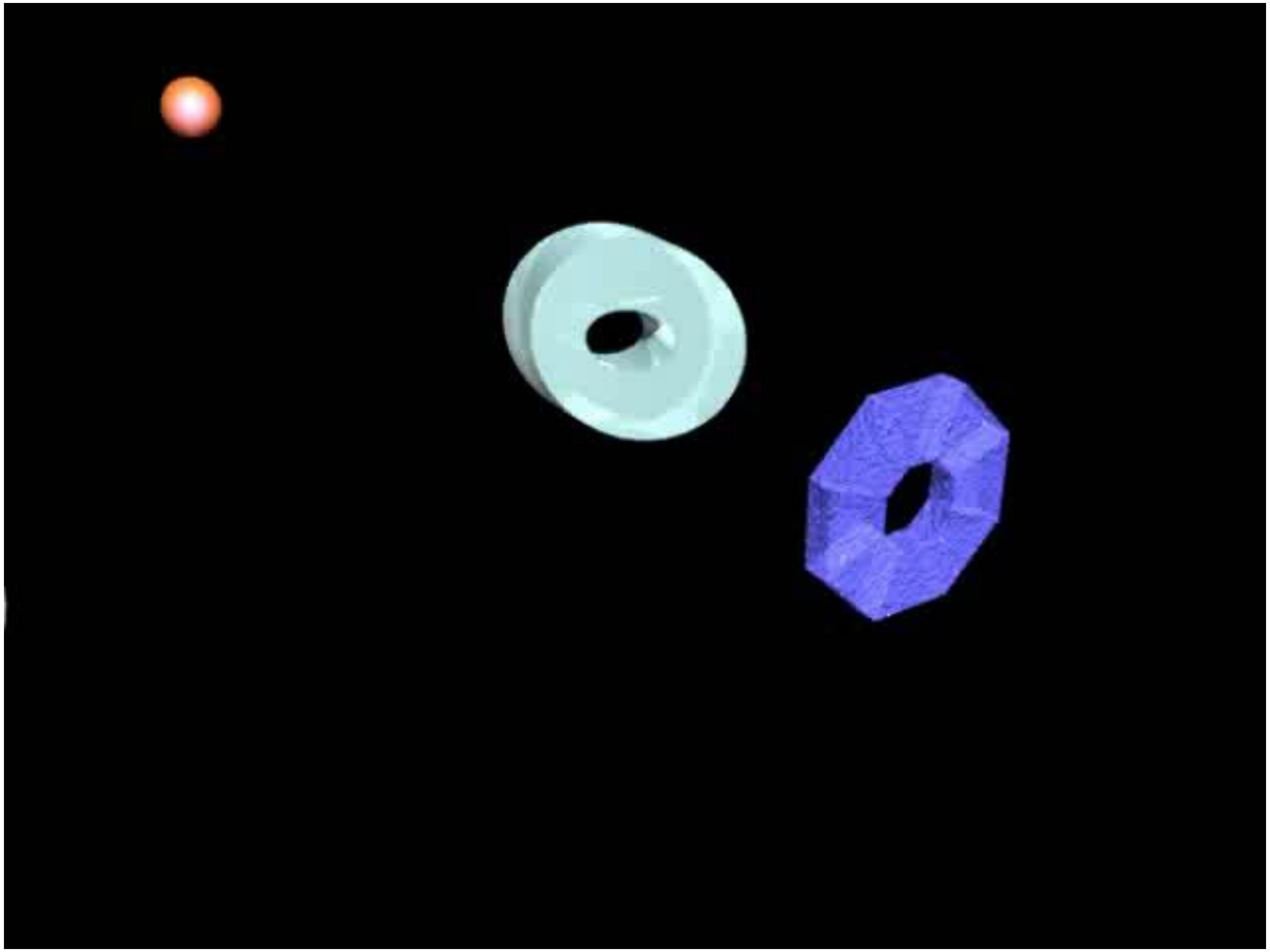
3D bunch shape monitor (One element of 3D-BCDM) [2]

Radial Polarization of linear chirped hollow laser pulse with broad bandwidth:



[2] H. Tomizawa, H. Hanaki, and T. Ishikawa,
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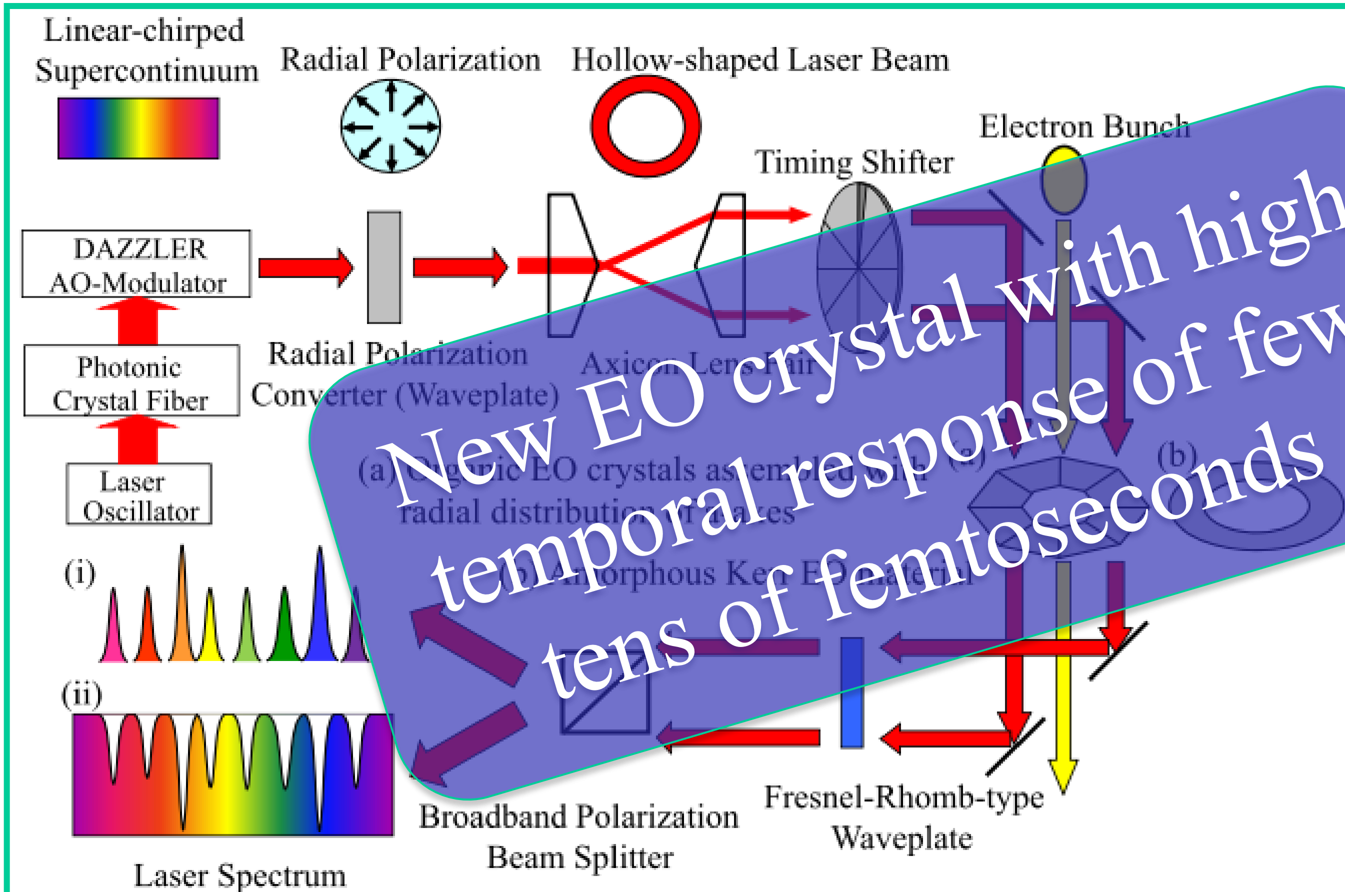
Key technologies to be developed for femtosecond 3D-BCDM

Supercontinuum generation: Photonic crystal fiber

Supercontinuum propagation: Spectrum modulation by DAZZLER + Developments of optics

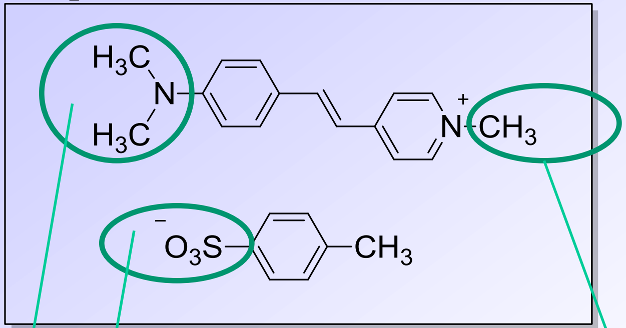
Radial polarization: Liquid crystal

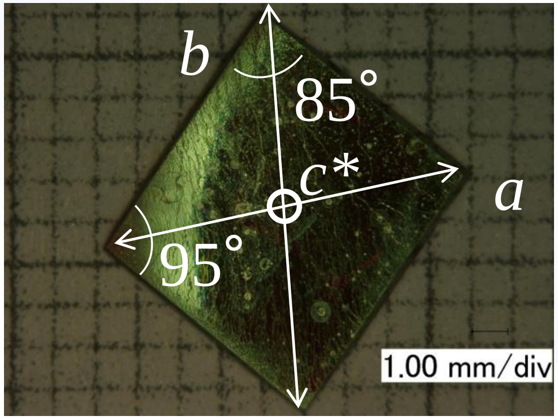
Hollow shape: Axicon mirror (lens) pair



New EO crystal with high temporal response of few tens of femtoseconds

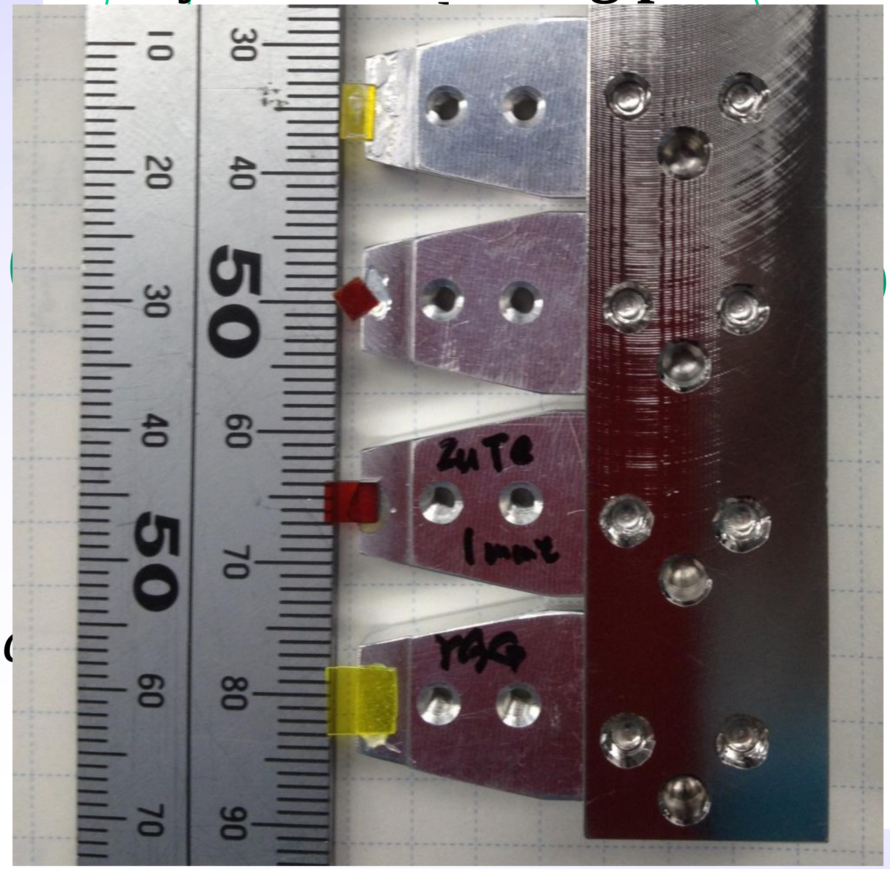
Developments of DAST EO-detector *towards to Res. 30fs!!*

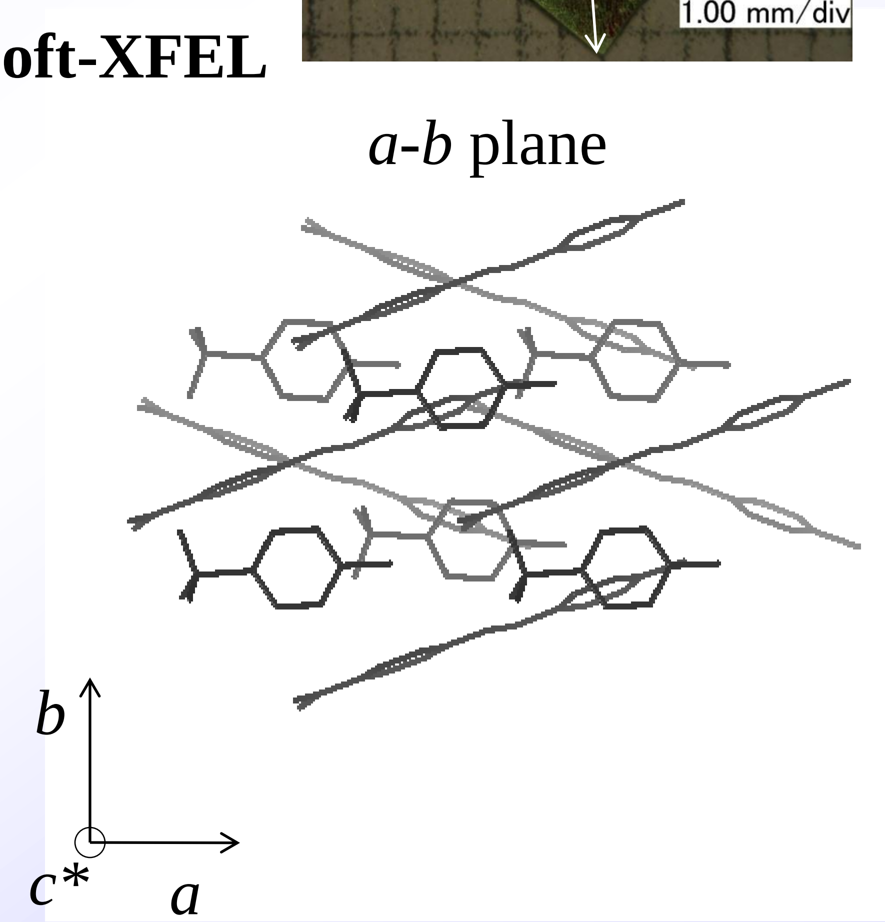




• **Mission for real-time monitoring**

bunch-by-bunch seeding pulse at Soft-XFEL





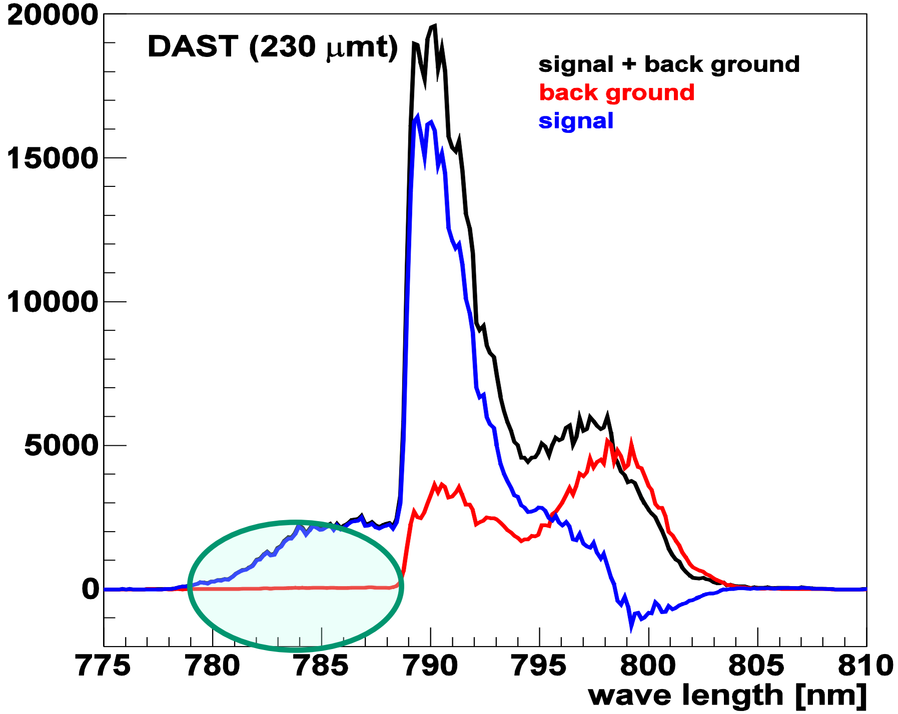
Estimation: temporal response of DAST EO ~30 fs [FWHM]!!

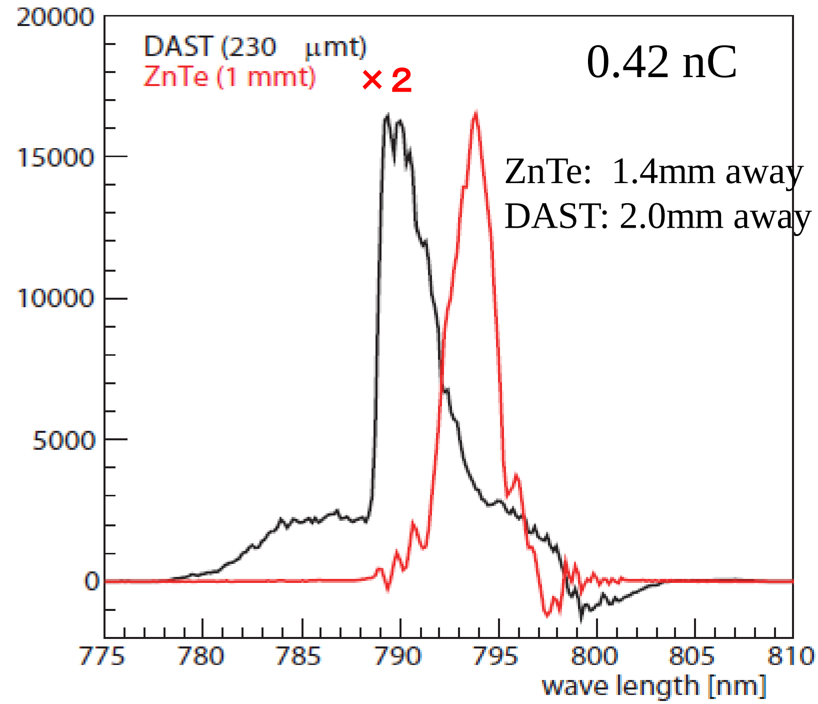
ZnTe and GaP has phonon absorption at 6 THz and 11 THz, respectively.
⇒THz pulse shape is distorted by the dispersion at THz region.

For 30-fs resolution, *EO crystal is required which is transparent for 0 -30THz*.

DAST : n1=2.4, n2=1.68, n3=1.62, r11=77pm/V, r21=42pm/V, r13=15pm/V @800nm

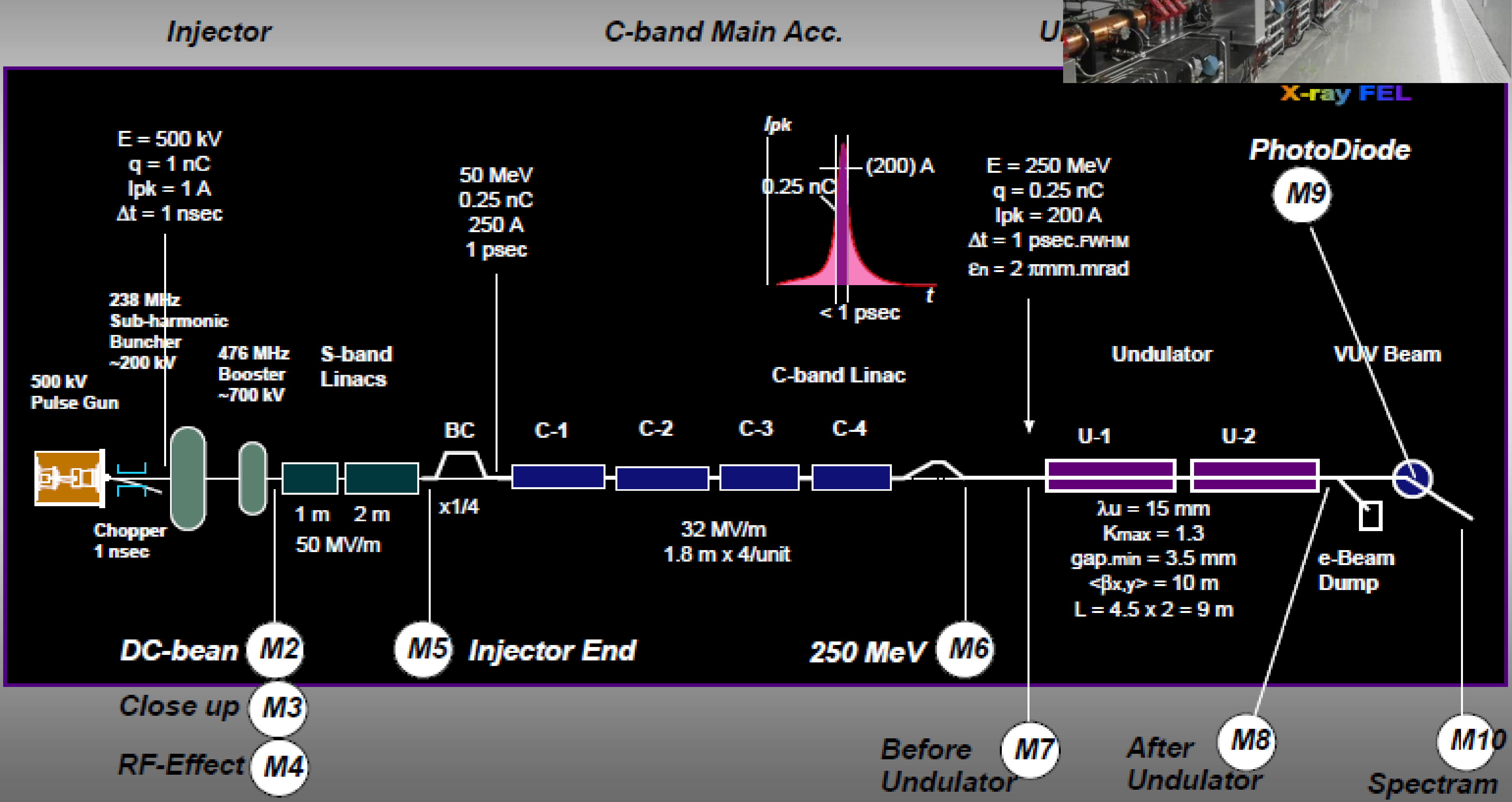
In 2011, we measured electron bunches via EO-Sampling with DAST at VUV-FEL (SCSS). It was the first EOS-measurements in the world ***(We observed a spectral broadening. It indicates that DAST is higher response than ZnTe < 50fs [FWHM])***.





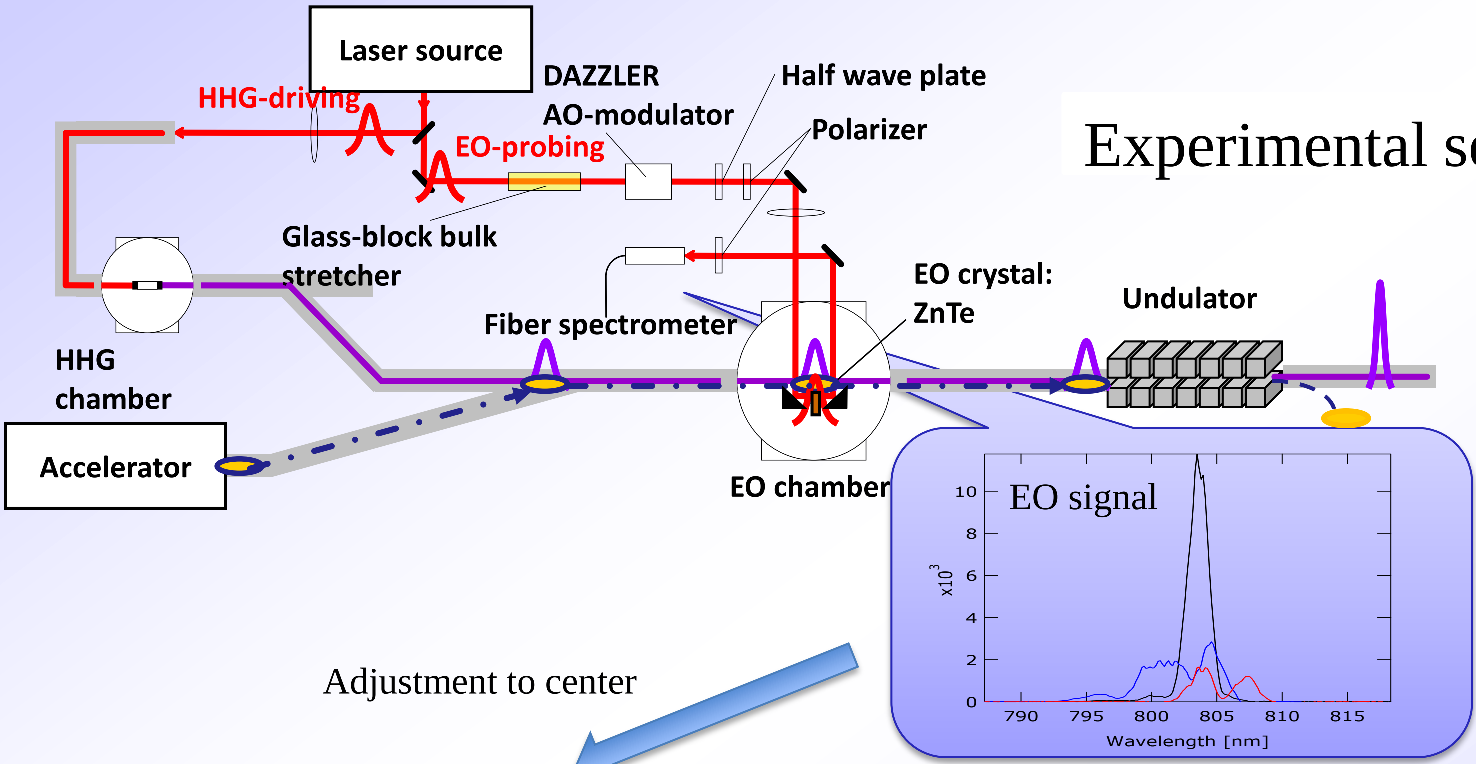
Prototype Test Acc. (Seeded EUV-FEL)

- Mission for the prototype machine (1/32 scale model of SACLA)
  - Feasibility Test of HHG-based Seeding
  - Pilot Experiments with Seeded FEL

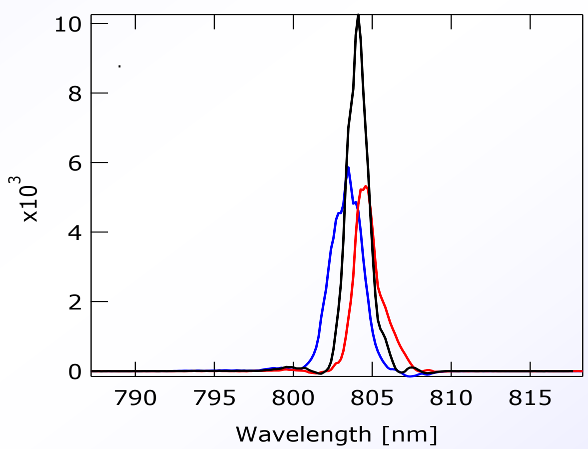


Timing feedback with EO

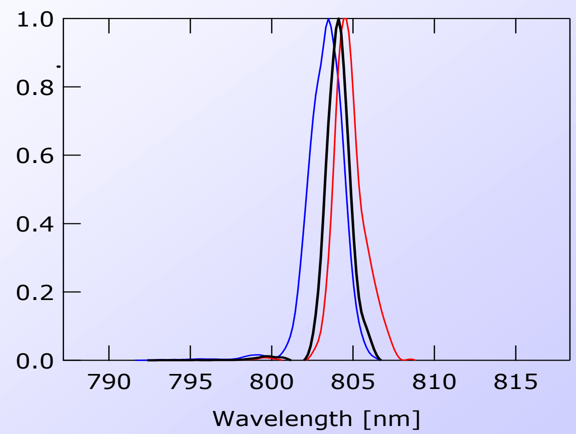
Experimental setup



Adjustment to center

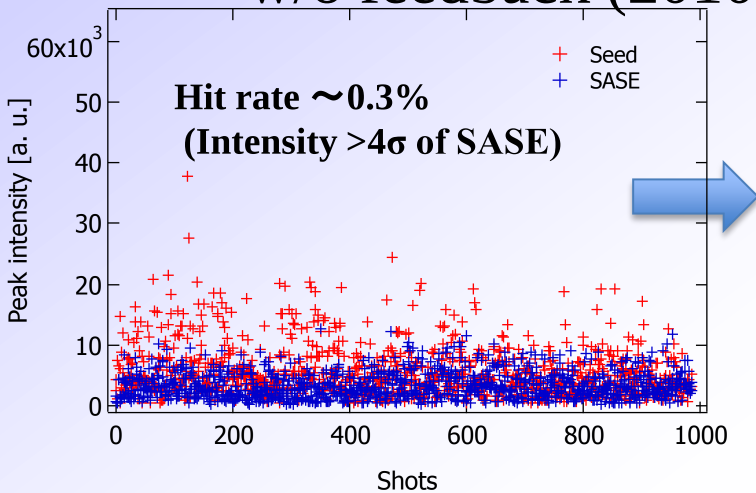


Real-time
data processing

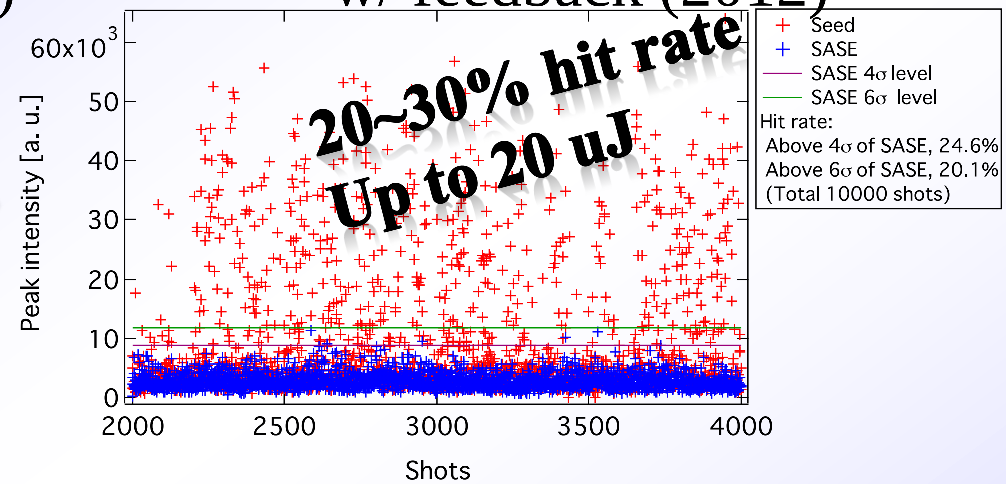


Seeding result with Timing feedback

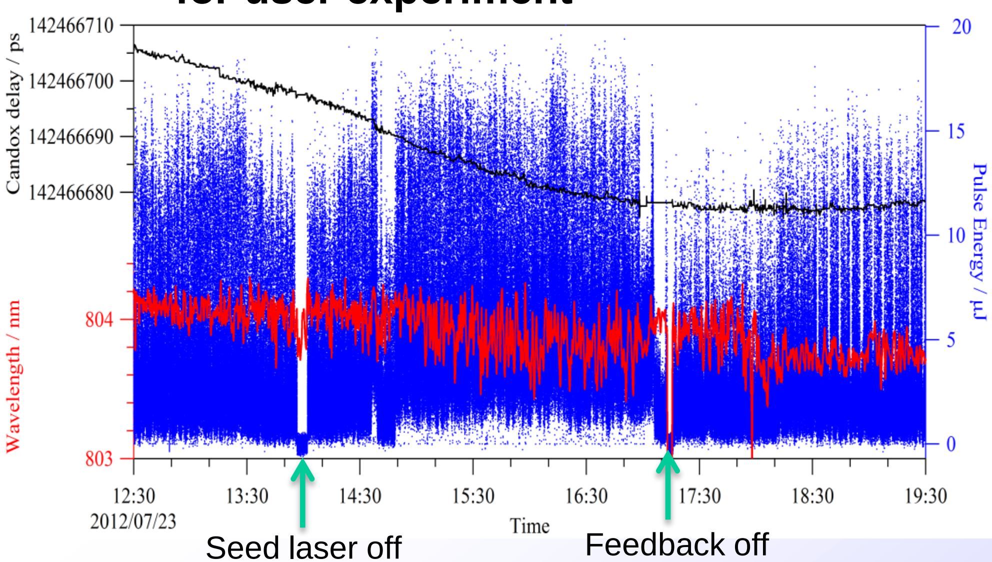
w/o feedback (2010)

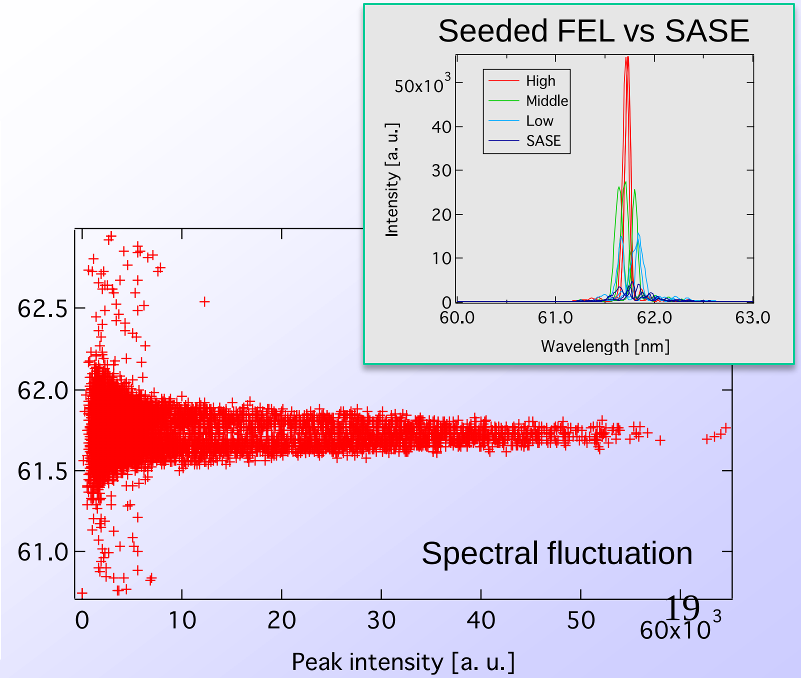


w/ feedback (2012)



Half-day synchronization for user experiment





All of you are welcome at our poster TUPB080 !!

3D bunch shape monitor (BCD: Bunch Charge Distribution)

Three sets of 3D-BCD elements: de/en-coding to de/o- multiplexing