First Demonstration of EOS 3D-BCD Monitor to Maximize 3D-Overlapping for HHG-seeded FEL

Related Poster: WEPC35 (18th Sep.)

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XFEL Division /SPring-8

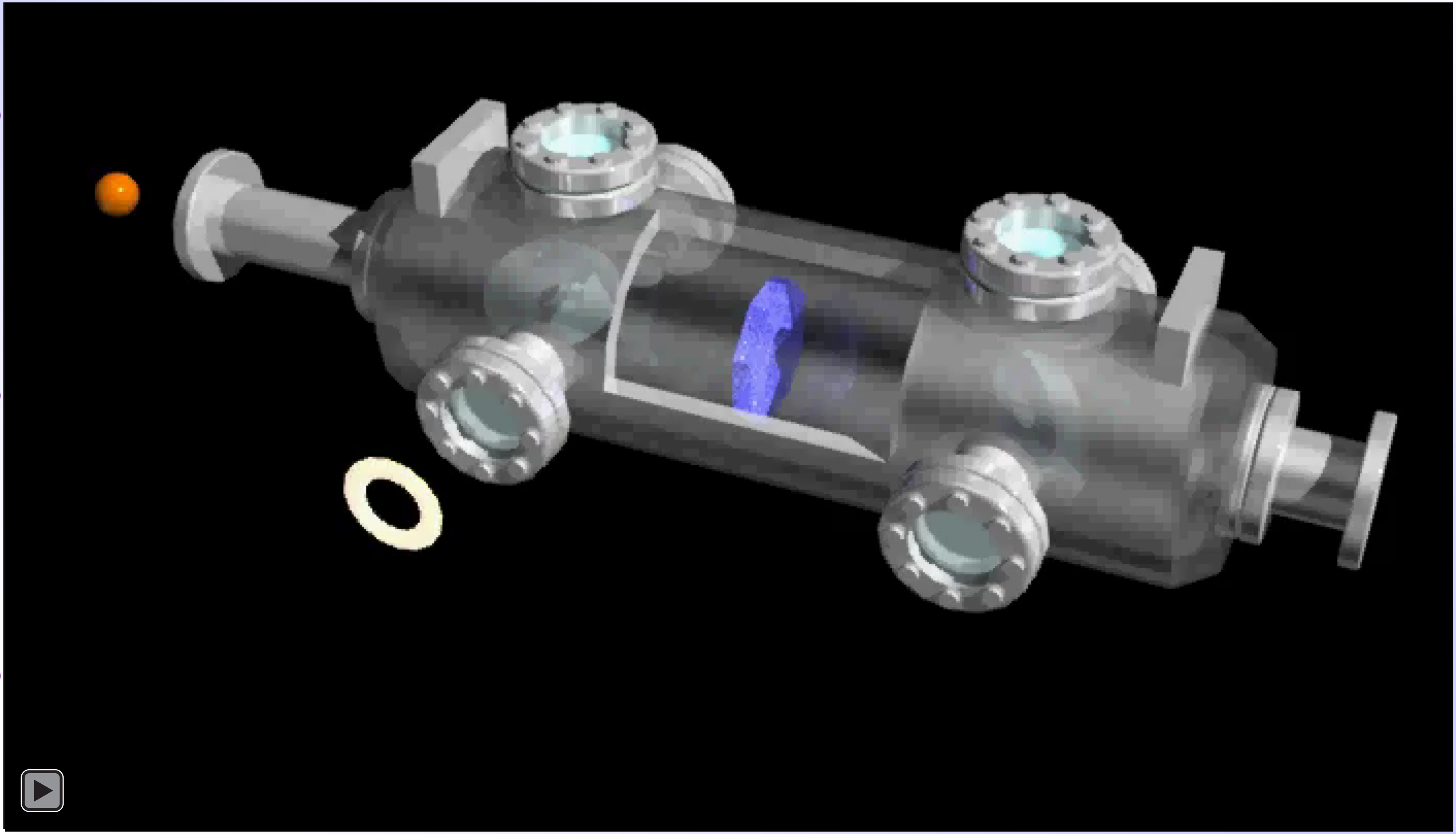
On behalf of all the staffs contributed to
HHG-seeded EUV-FEL (SCSS) at SPring-8

Outline

- Introduction of 3D-Bunch Charge Distribution monitor
- EOS- timing & pointing feedback for HHG-seeded FEL (6D phase space overlapping)
- Summary of improvement seeding conditions with EOS seeder-locking
- Further developments towards 30-fs resolution

Outline

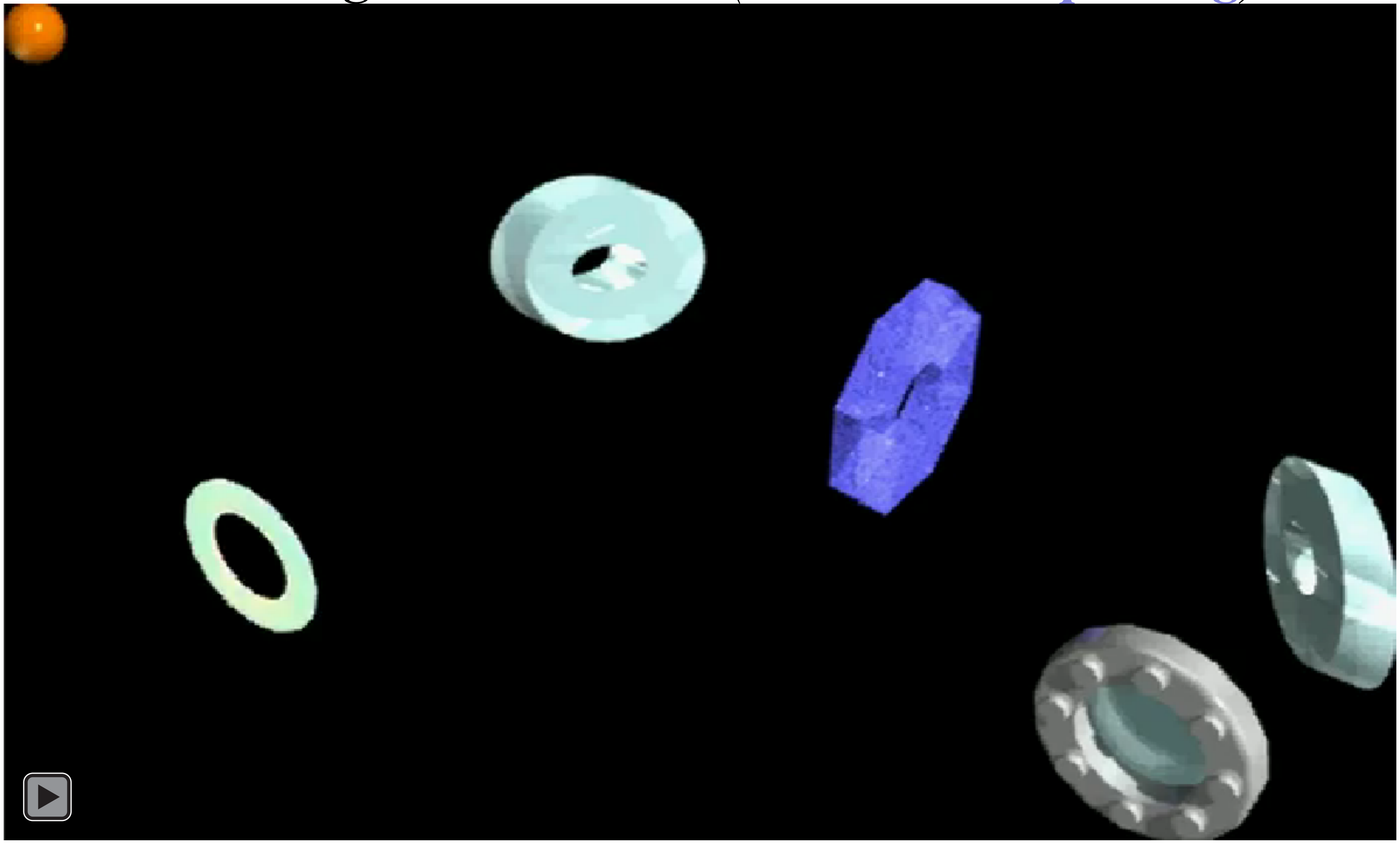
- Introduction of 3D-Bunch Distribution monitor



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 (**3D-EO-multiplexing**)*



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) with **ZnTe** 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

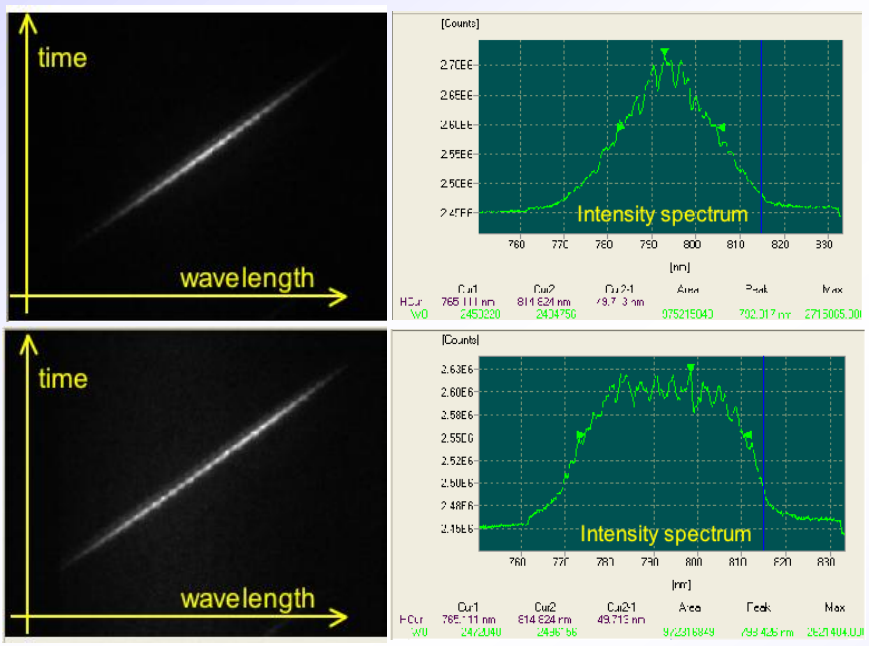
Longitudinal (temporal) detection:

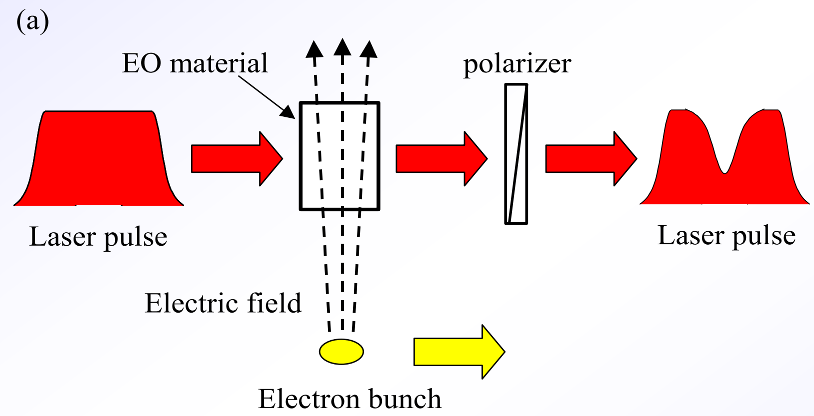
Measurement (Decoding) methods of EO Sampling :

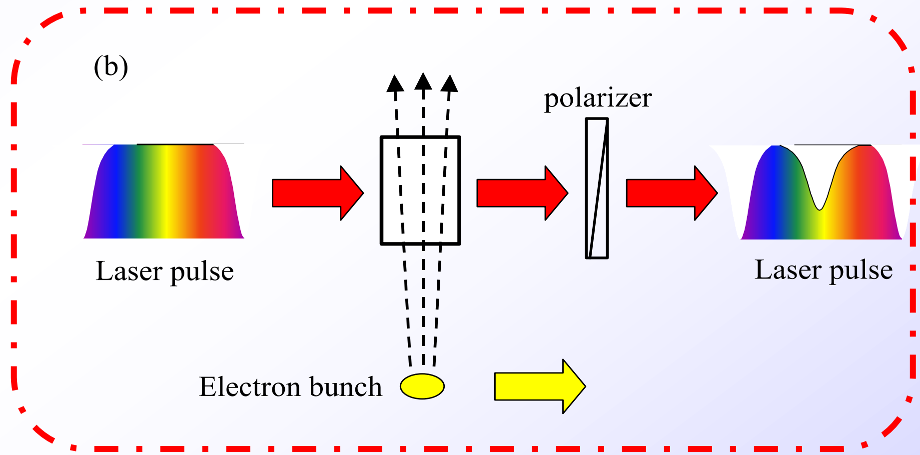
(a) Temporal Decoding

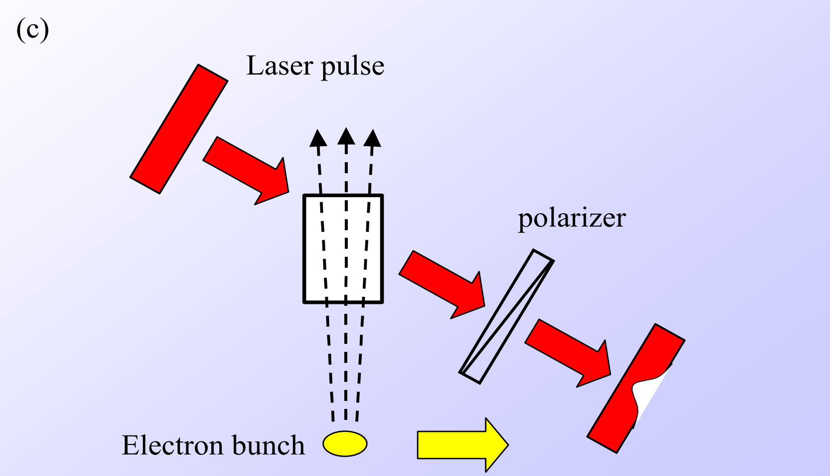
(b) Spectral Decoding

(c) Spatial Decoding









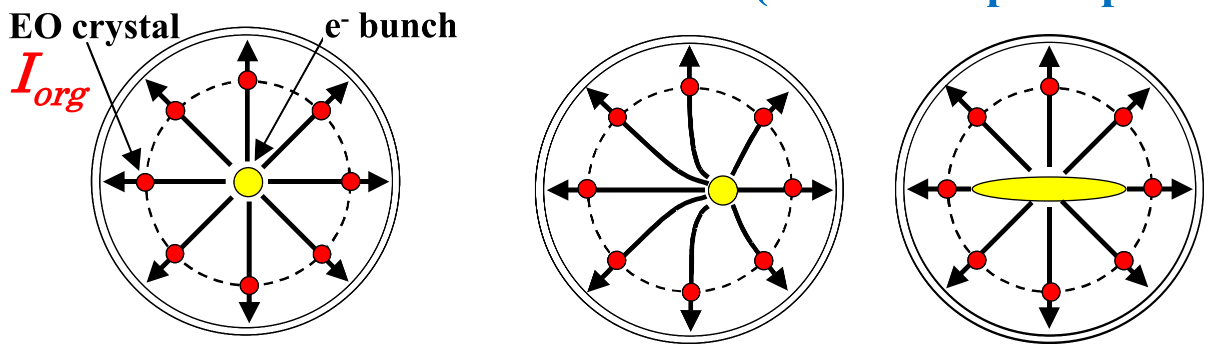
Measurements of linear-chirped laser probe pulse with Spectrograph Streak camera:

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)

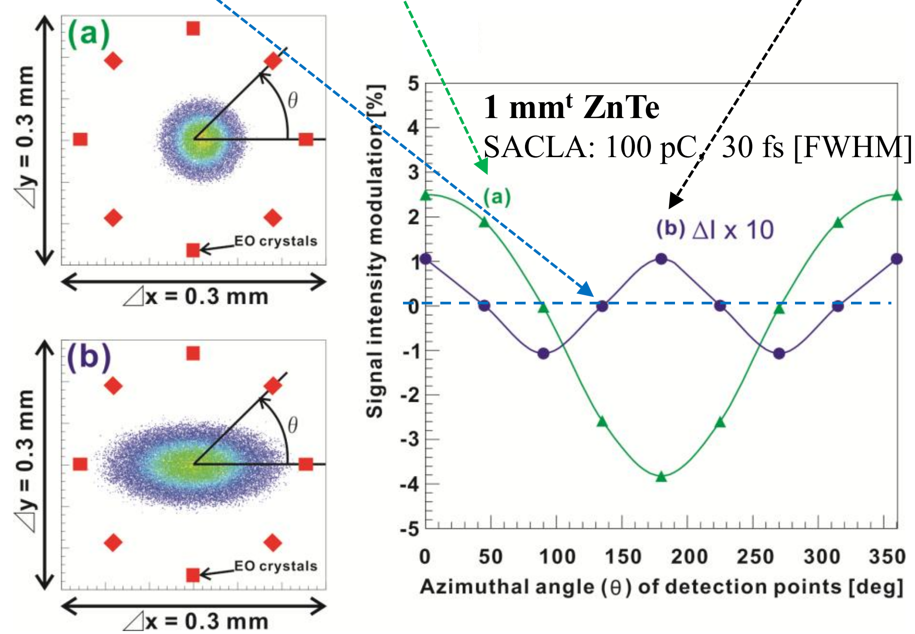
Probe points on EO-crystal edges located 2-mm from center of bunch slices.

(a) 10-μm transverse shift e⁻ beam (40 μm [rms])

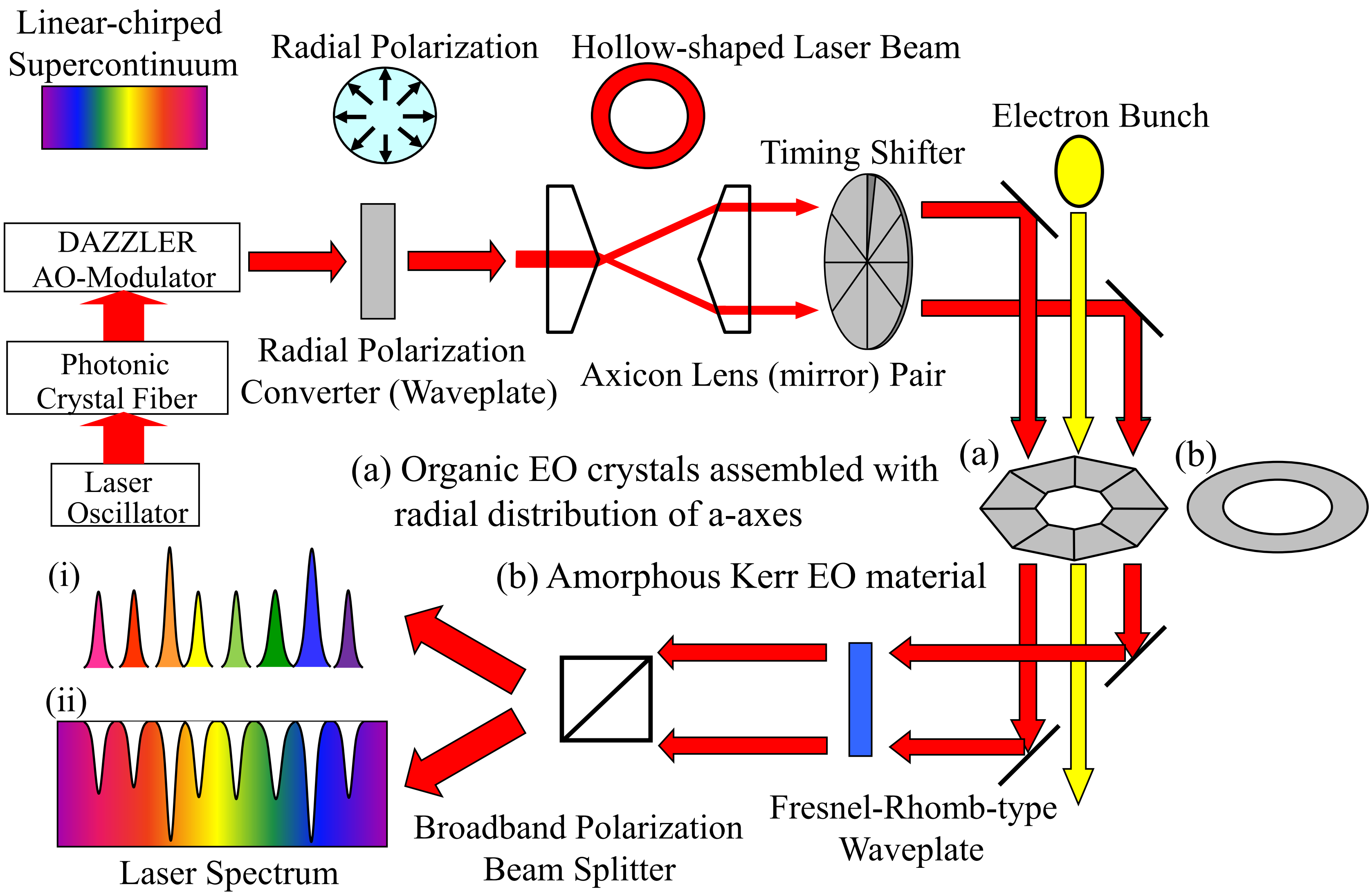
(b) ellipse-shaped slice (150 μm [rms] in major axis)

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

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



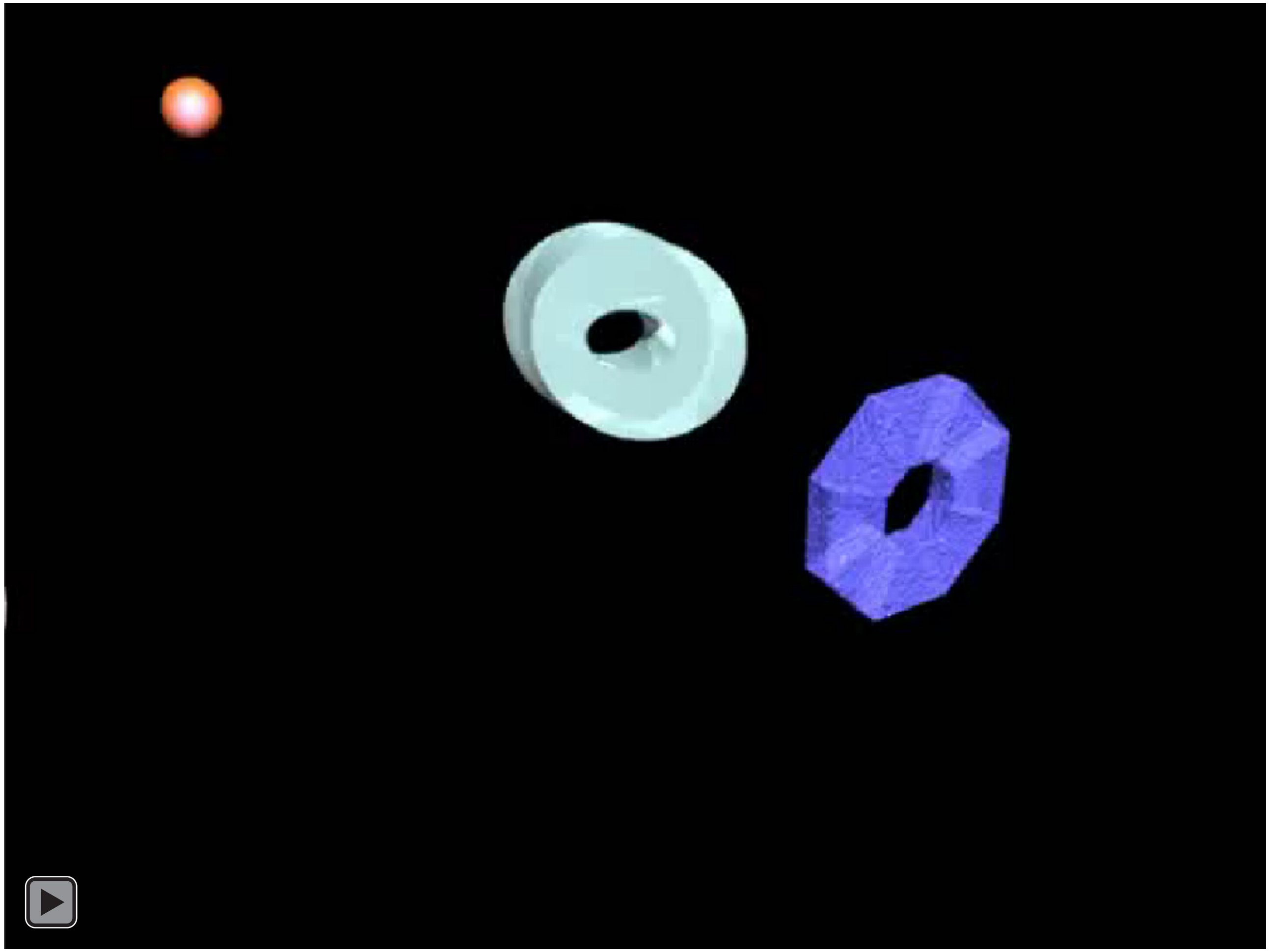
3D bunch shape monitor (One element of 3D-BCDM) [2]



[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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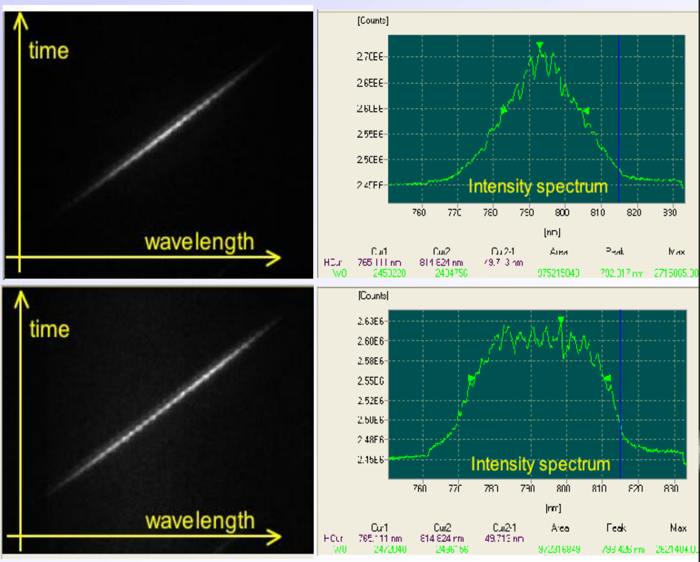

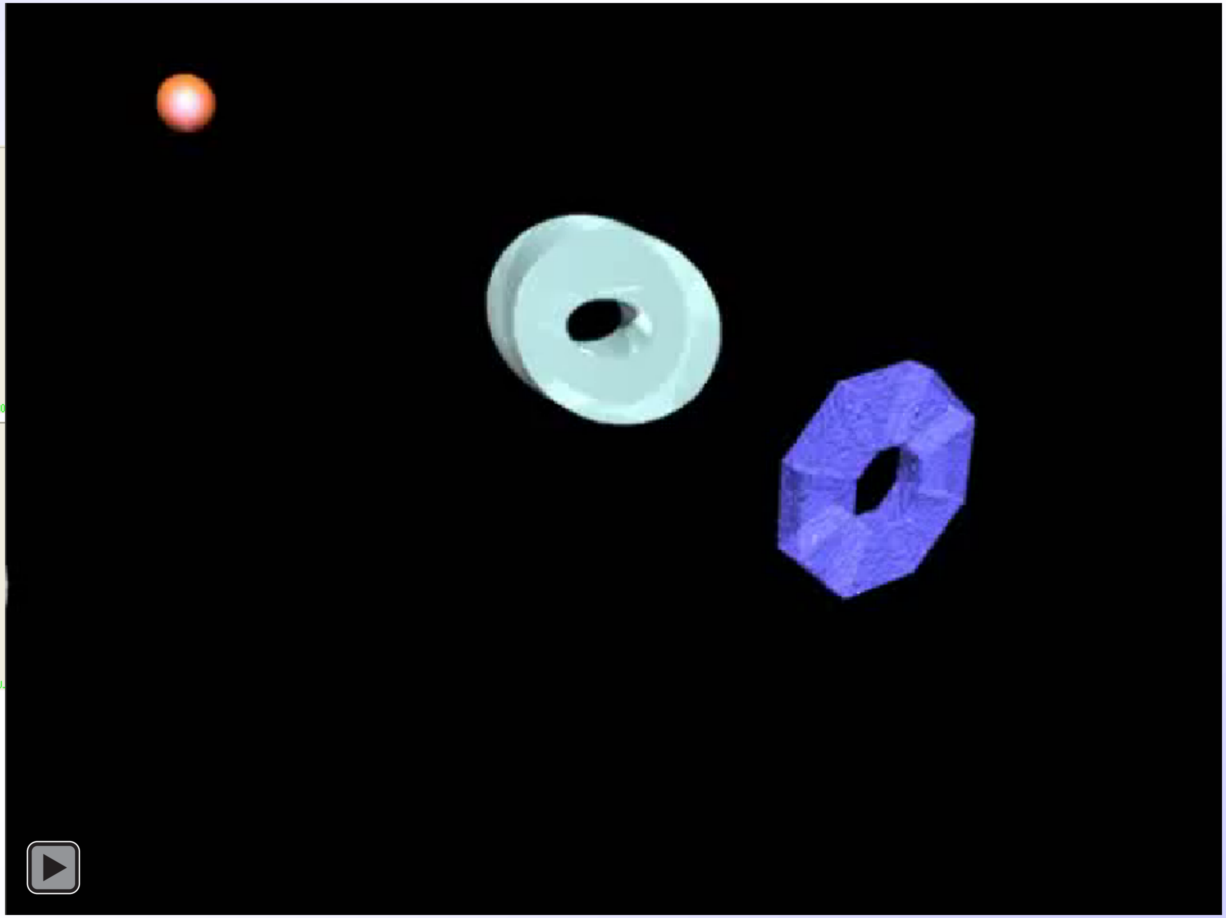

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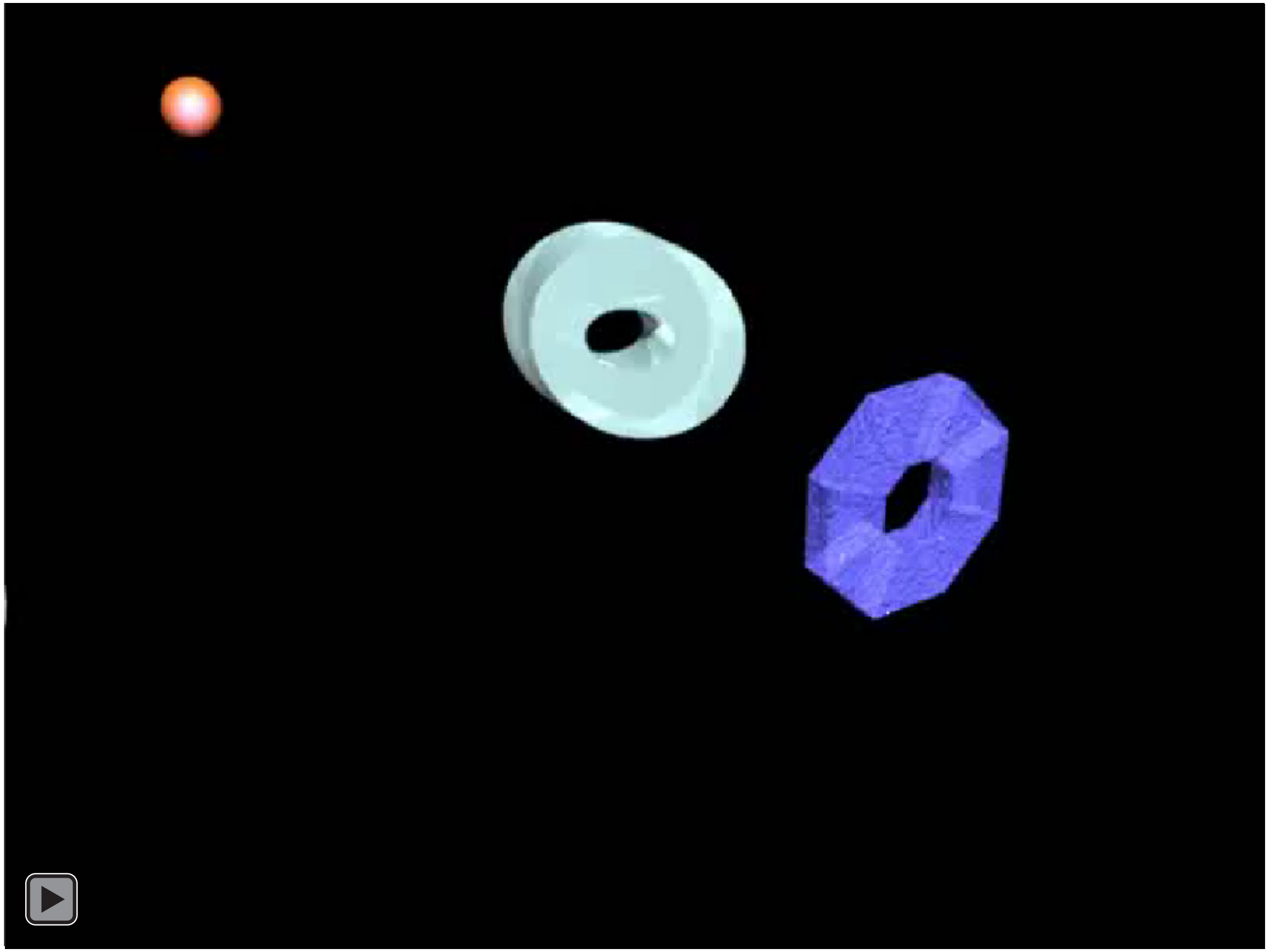
3D bunch shape monitor (One element of 3D-BCDM) [2]

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



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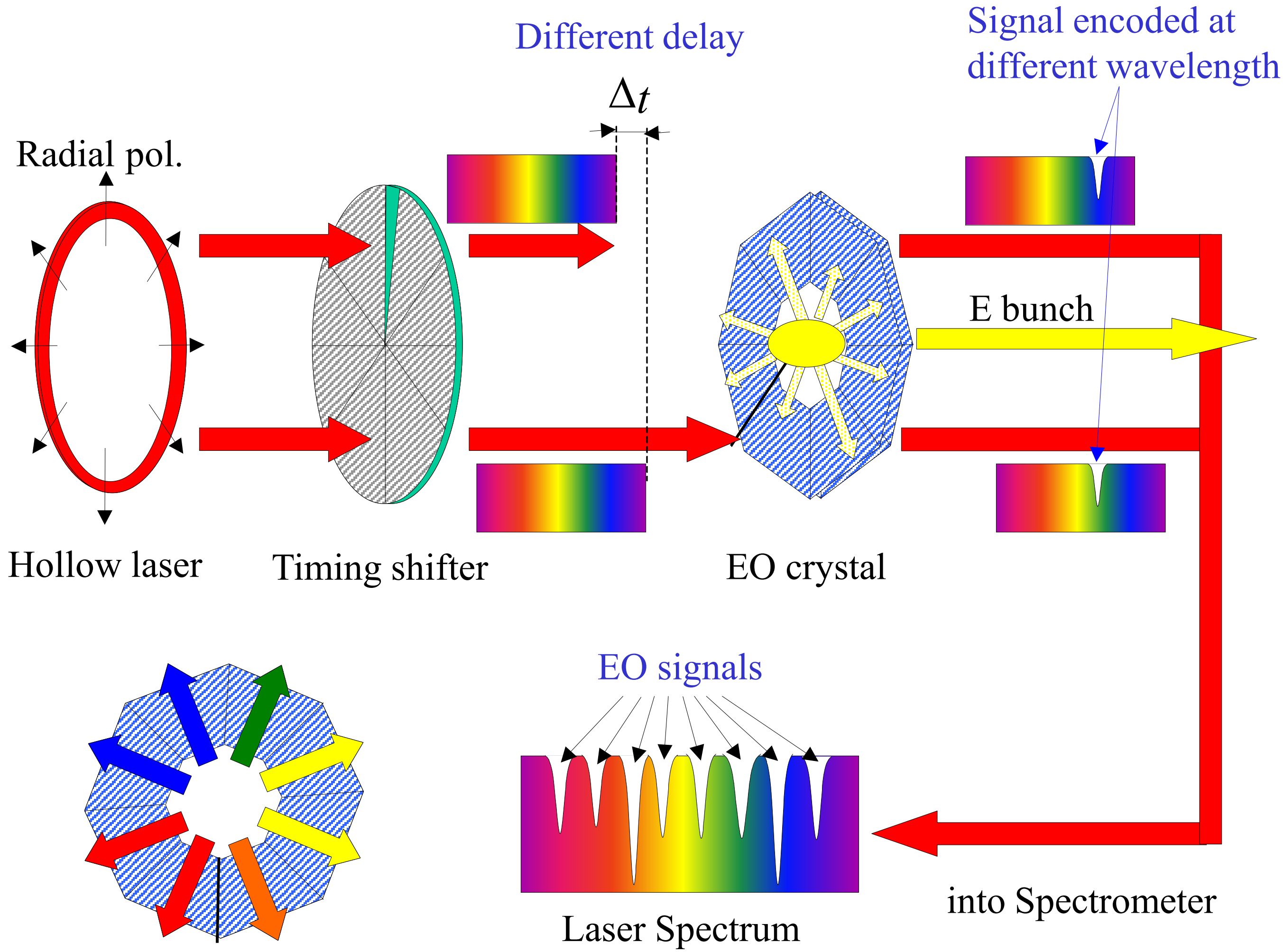
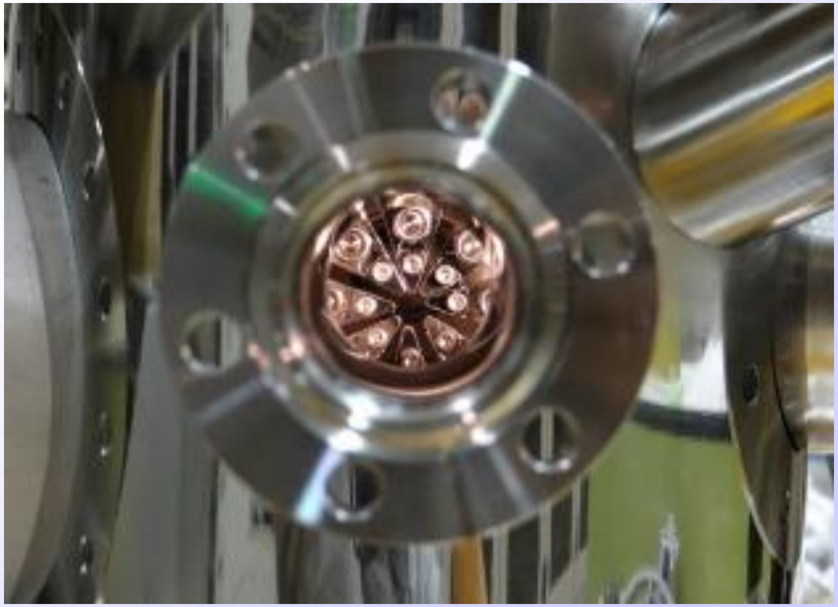
The principle of 3D bunch monitor



- 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-EOS chamber to measure 3rd order charge moments of bunch slice

8 EO-crystal assemble holder



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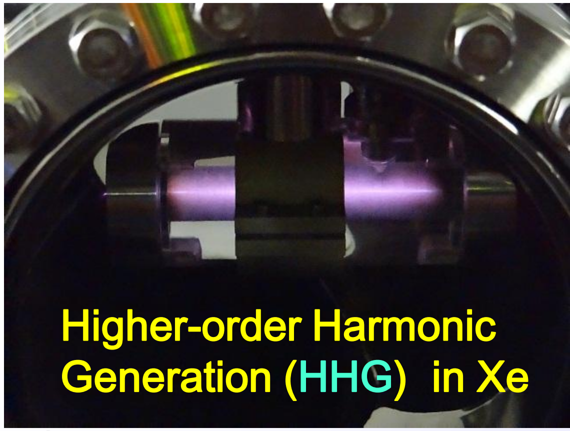
- EOS- timing & pointing feedback for HHG-seeded FEL (6D phase space overlapping)
- Summary of improvement seeding conditions with EOS seeder-locking
- Further developments towards 30-fs resolution

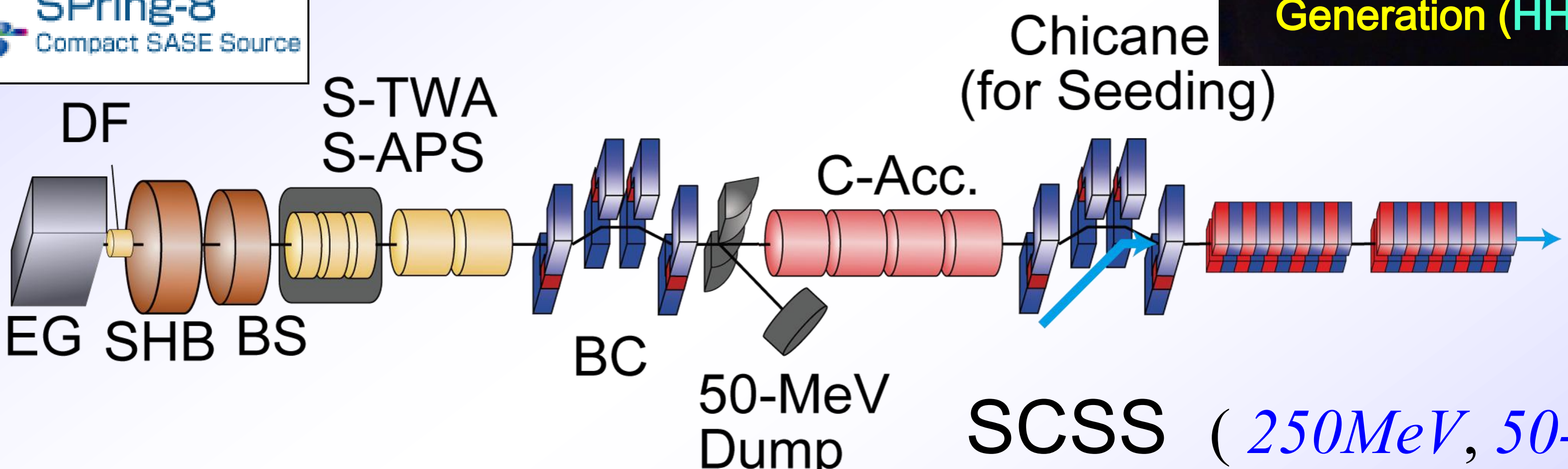
Prototype SCSS Test Acc. (Seeded EUV-FEL)

- Mission for the prototype machine
- Feasibility Test of HHG-Seeding
  - Development & pilot user experiments of HHG-seeded FEL

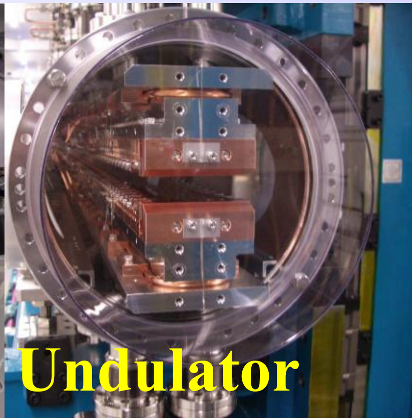
1/32 scale model of SACLA



SPring-8 Compact SASE Source

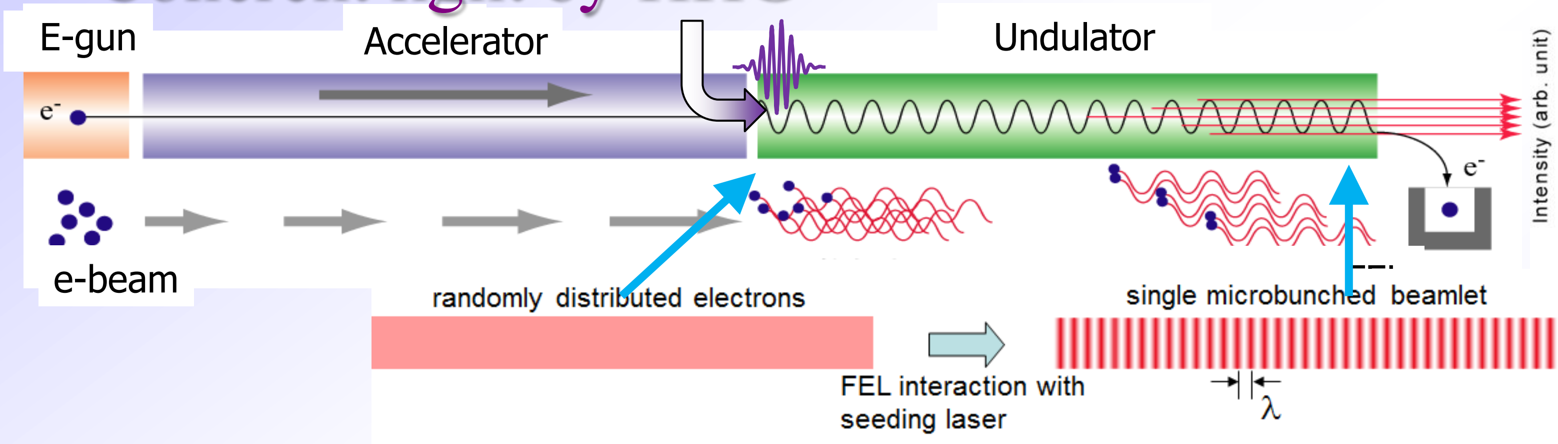


SCSS (*250MeV*, *50-60nm*)

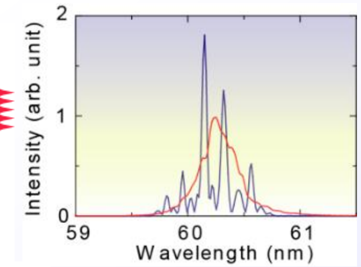


Seeded FEL with HHG (Higher-order Harmonic Generation)

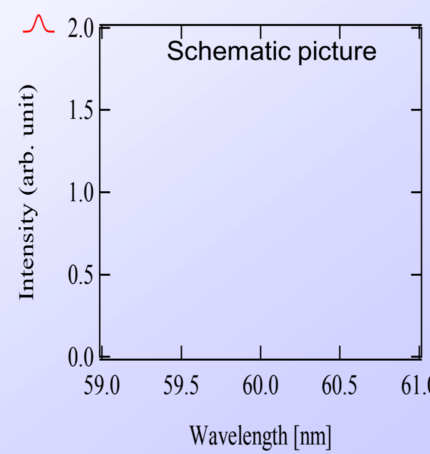
Coherent light by HHG



SASE-FEL



Seeded FEL



Difficulties of HHG-seeded FEL

We have to synchronize independent Pulse Machine Systems (HHG pulse & e-bunch).

Overlapping in 6D phase space under compressed both of HHG-pulse and e-bunch.

6D phase space overlap for seeded FEL

	Size (x, y) FWHM	**Time (t)** FWHM	**Wavelength (E)** (Energy)
Electron bunch	~ 500 μm	300-600 fs	61.7 nm
HHG seed pulse	~ 1 mm	~ 50 fs	61.7 nm

To kill timing jitter, both pulse/bunch covers each other!

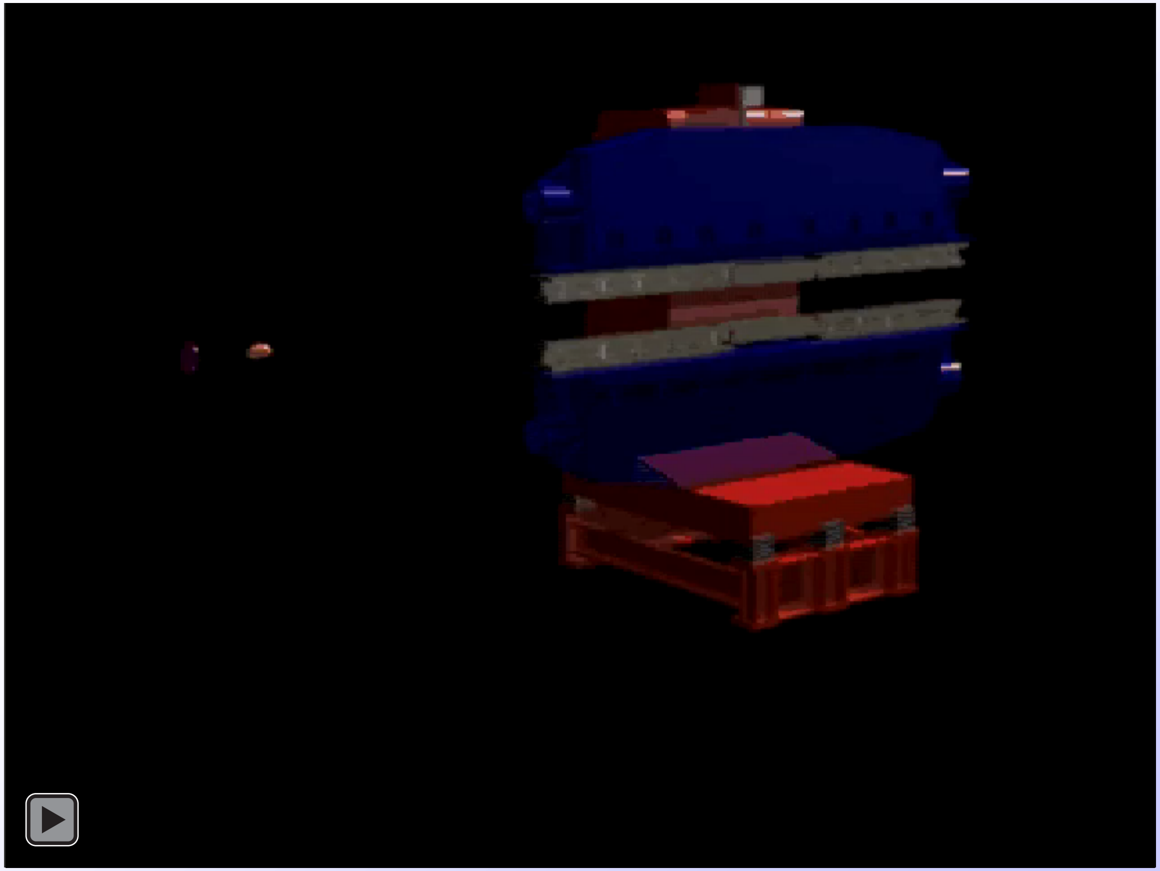
6D Phase Space

Centroid positions (Transverse size): X, Y

Momenta (Divergence): θx, θy

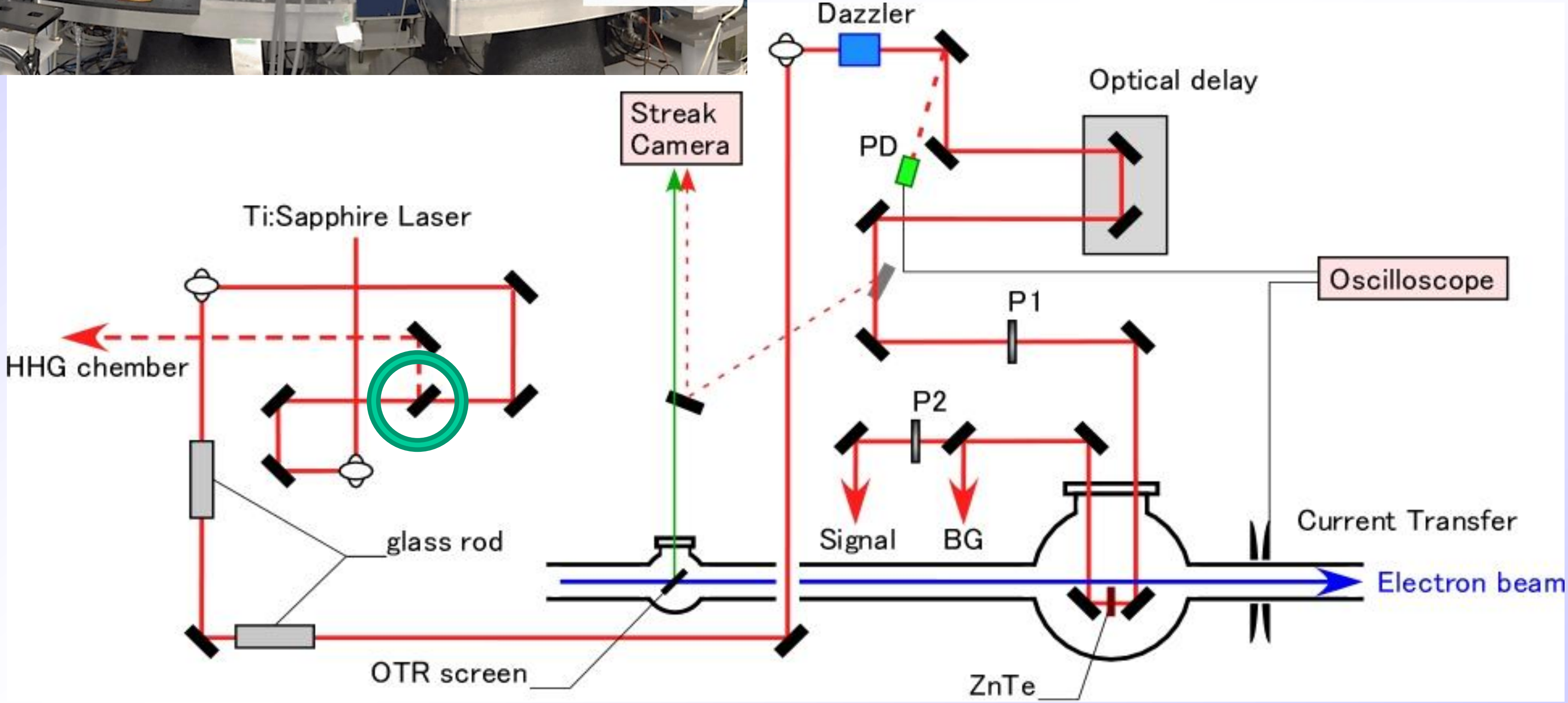
Time : t

Energy (Central Wavelength): E



Measurement of arrival timing with EOS for feedback

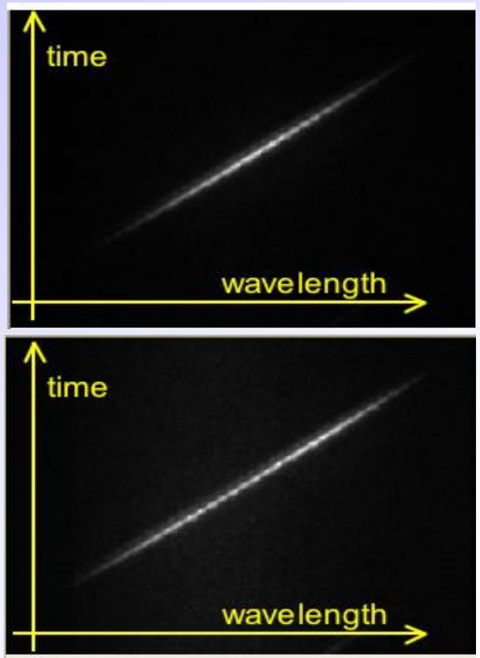
PD : photo diode
P1, P2 : polarizer (crossed Nicols)
OTR : optical transition radiation

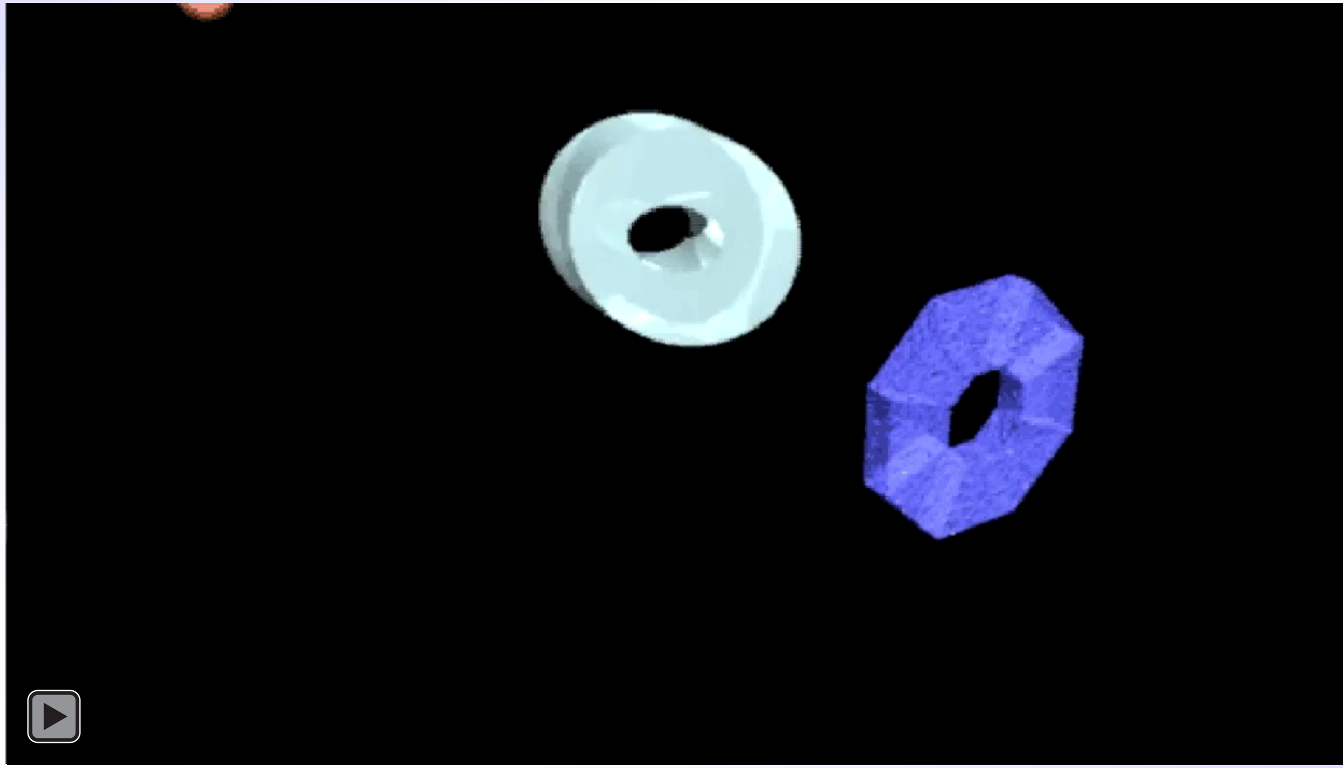


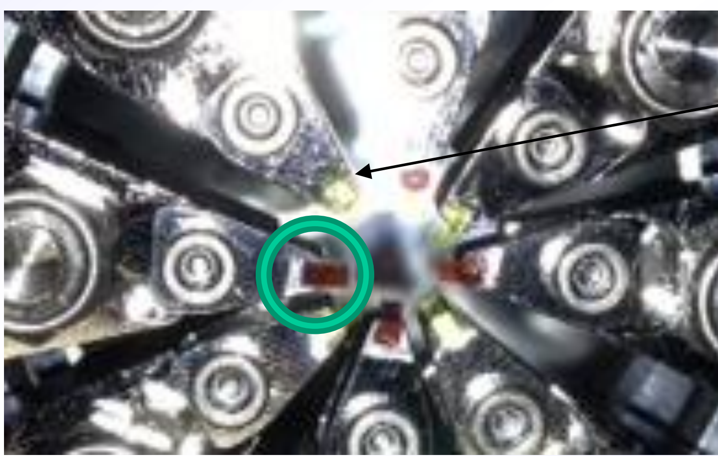
- EO prove laser was produced from HHG-driving laser for seeding.
- High-dispersion glass-rod (n = 1.96, L = 20 cm) for a linear chirp pulse (175 fs → ~14 ps)

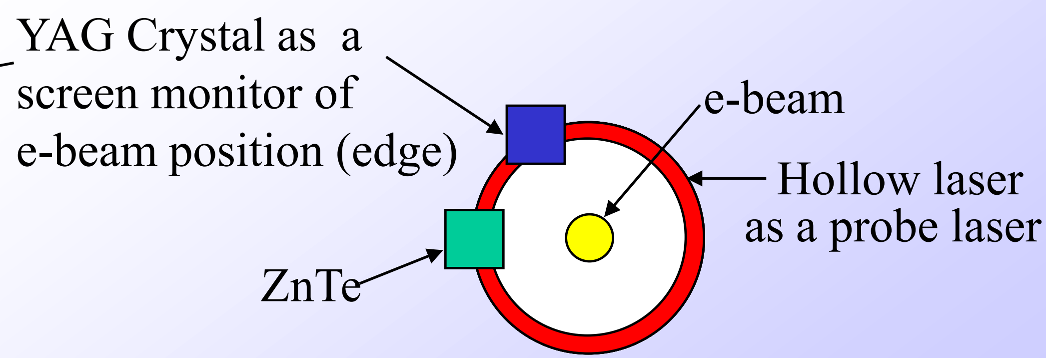
Arrival timing monitor and BPM function

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



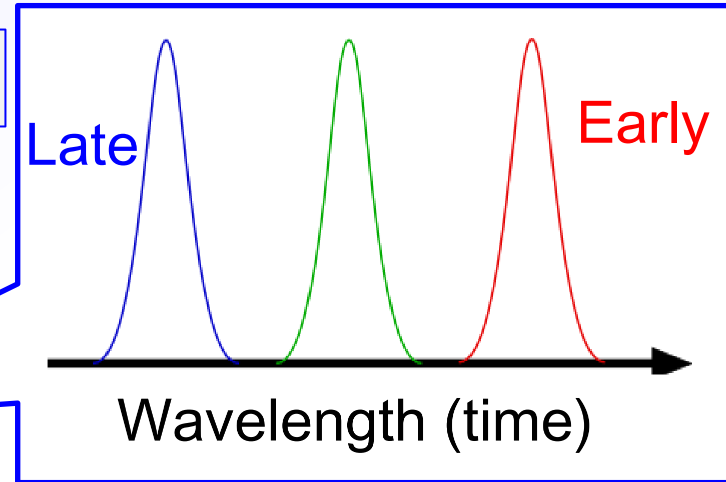


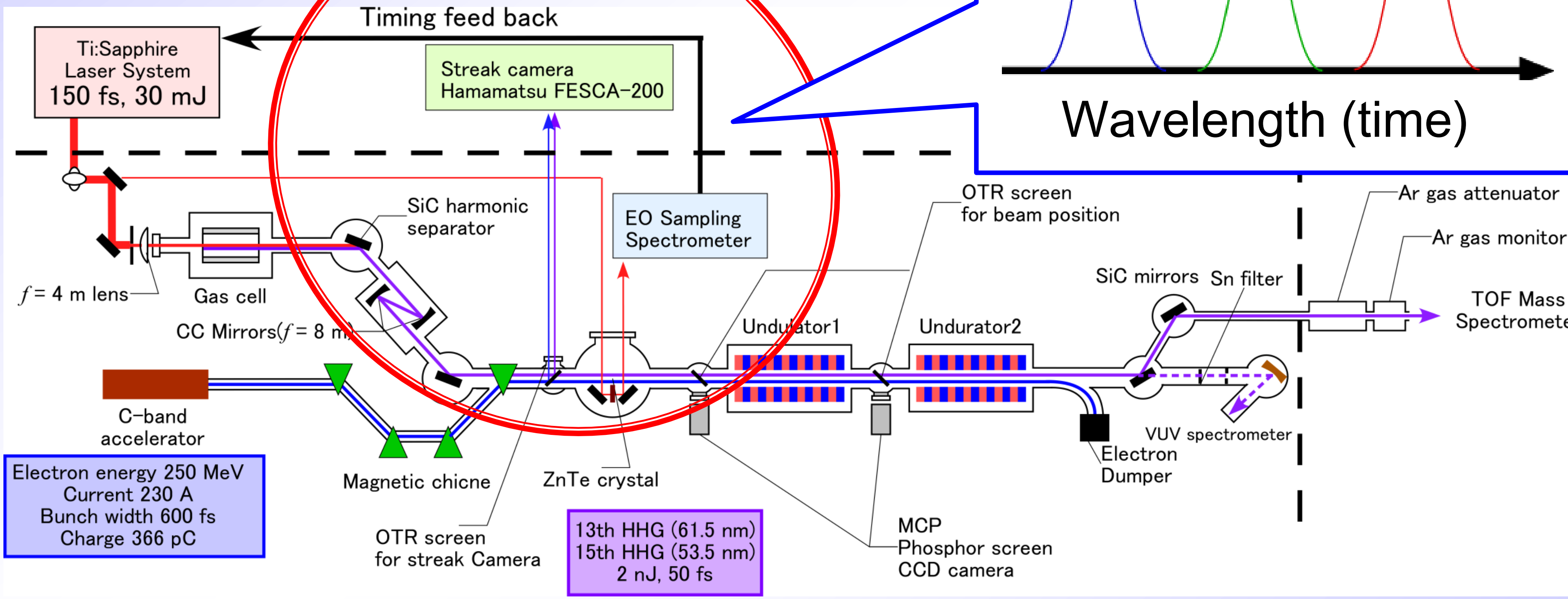




Improvement of Hit Seeding Rate

Relative-timing EOS-locking system

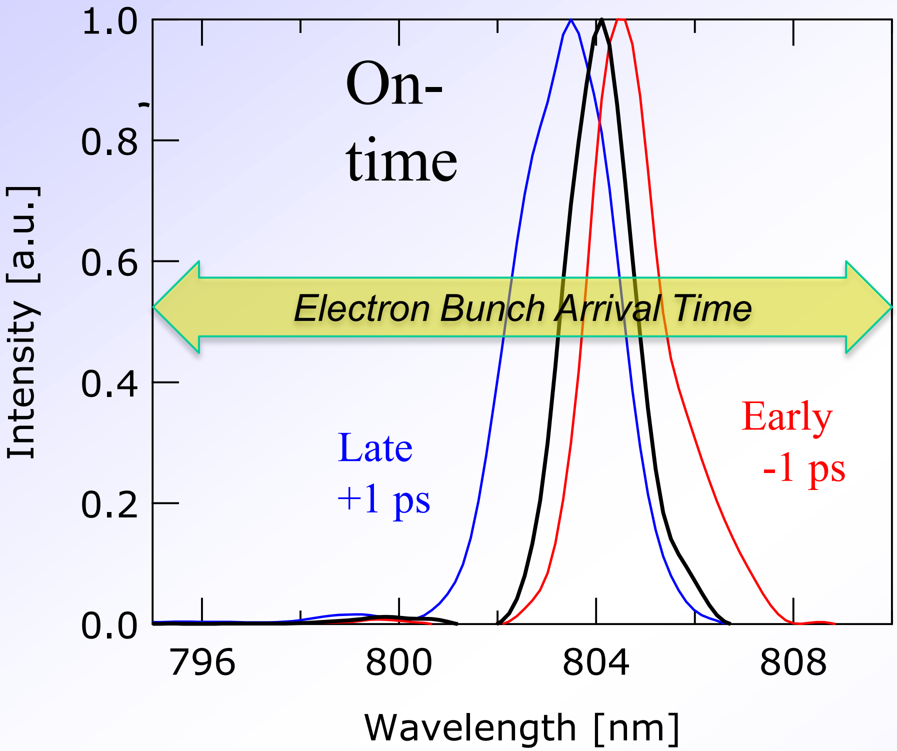




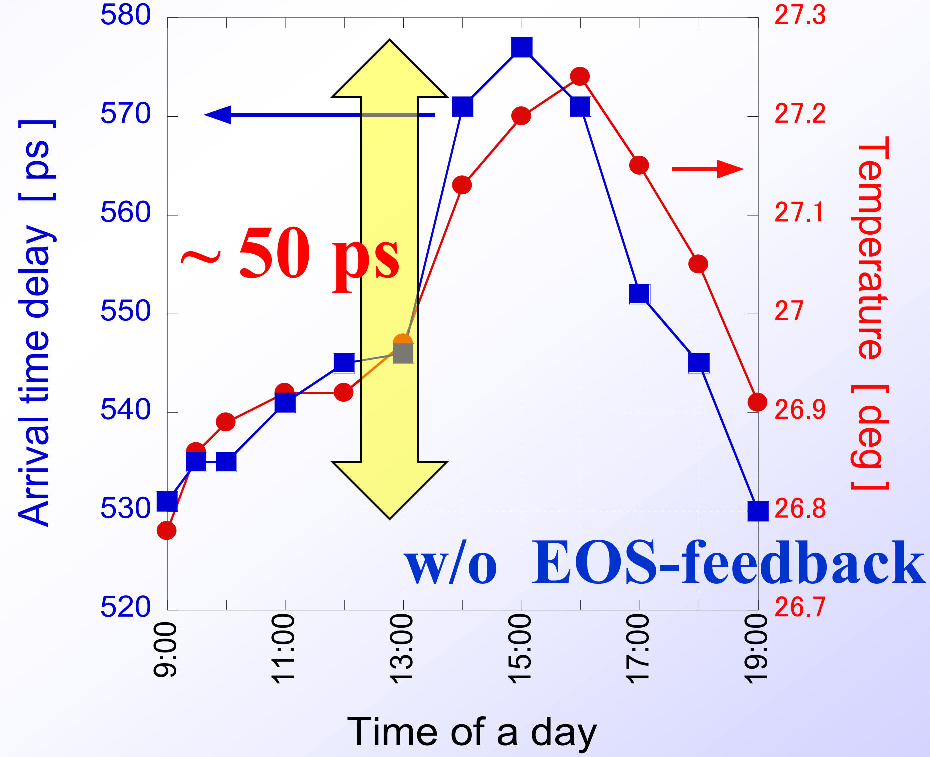
61nm-2nJ HHG@Undulator

Relative timing-drift monitored by EOS

The spectra of EOS signal pulses decoded as the timing shifts from the best seeding condition (On-time)



"Relative" timing drift between the electron bunch and the laser pulse



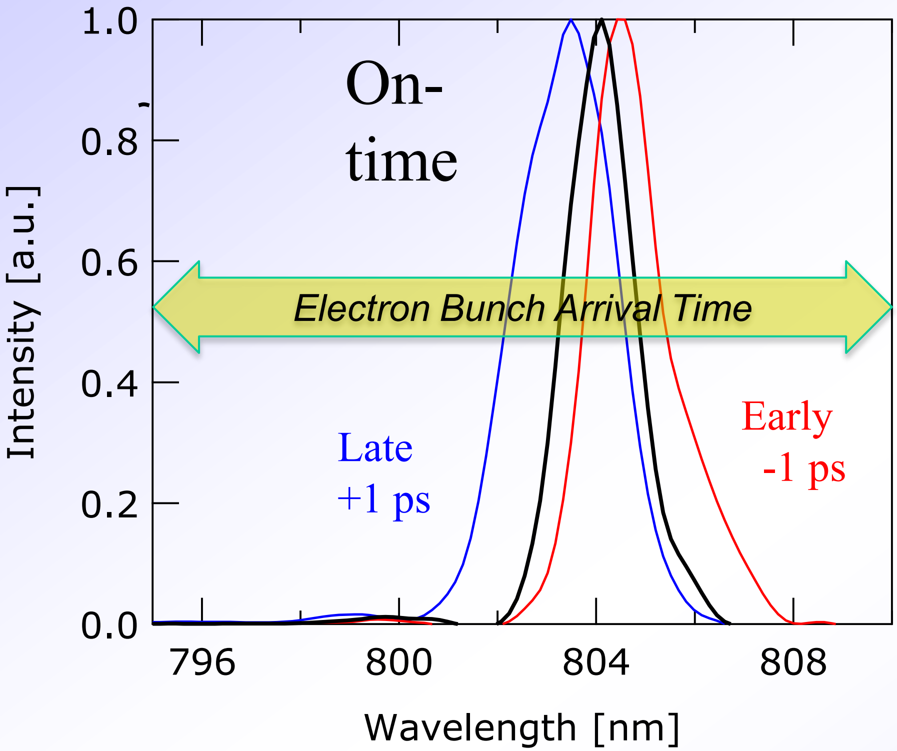
The arrival-time drift is calculated automatically with the computer program in terms of the peak position of the EOS signals.

The arrival-time drift of electron bunch : ***~50 ps for ½ day***

Dynamic Range (Plateau) of EO-probe was limited by 2 ps !!

Relative timing-drift monitored by EOS

The spectra of EOS signal pulses decoded as the timing shifts from the best seeding condition (On-time)



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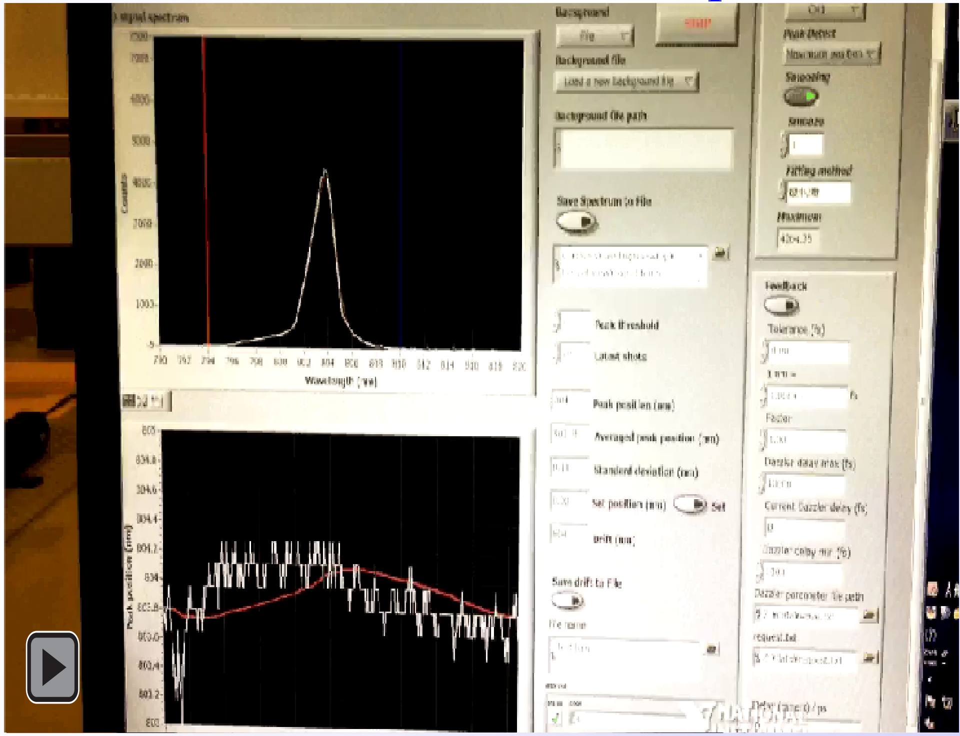


Time of a day

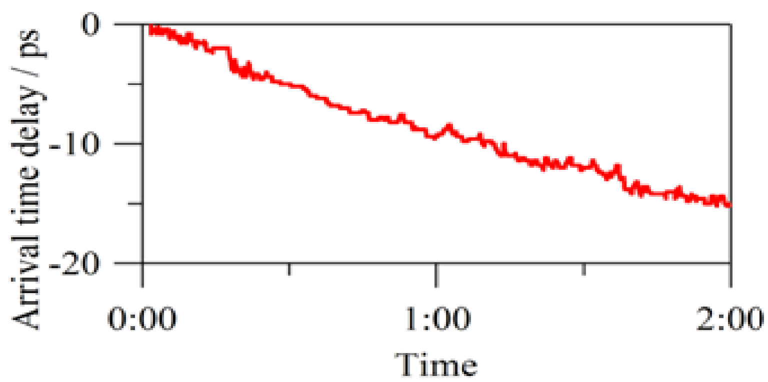
The arrival-time drift is calculated automatically with the computer program in terms of the peak position of the EOS signals.

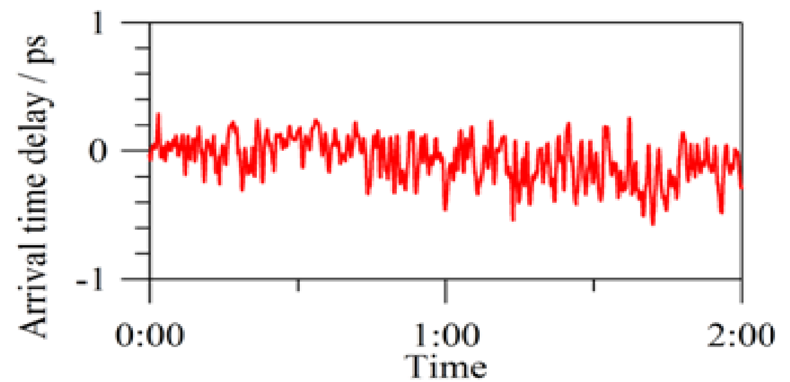
The arrival-time drift of electron bunch : ***~50 ps for ½ day***

Dynamic Range (Plateau) of EO-probe was limited by 2 ps !!

Performance of the Active feedback system to minimize the timing drift

Relative timing drift is actively compensated by using the EO signal





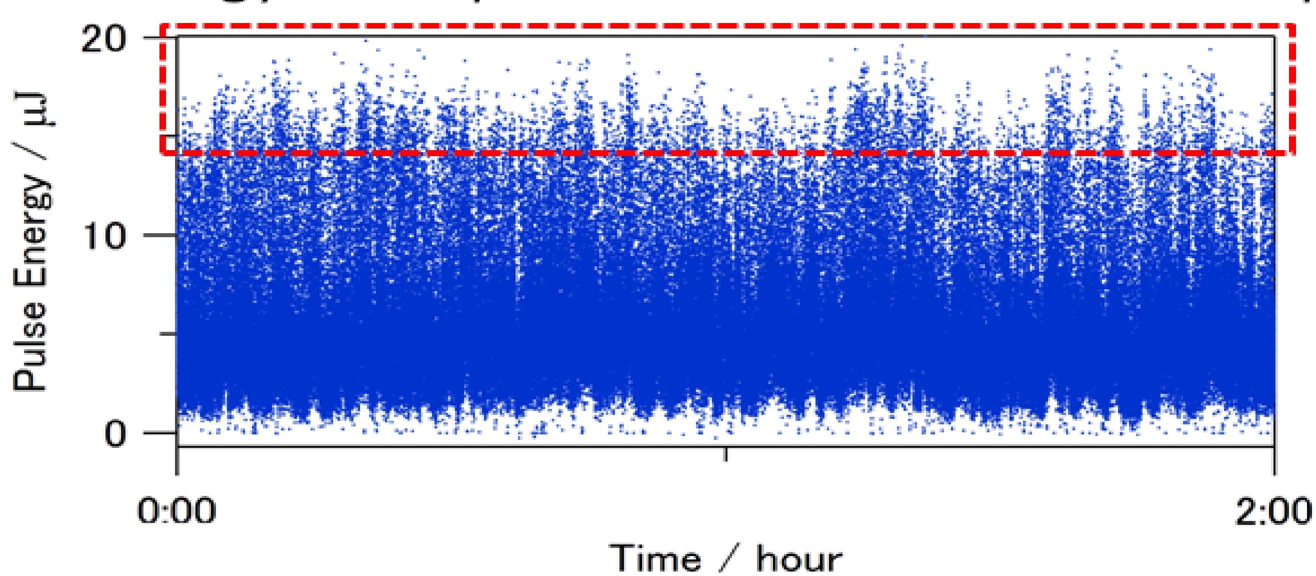
Timing drift > 15 ps

w/o EOS-feedback

Timing drift < **500 fs (p-p)**

w/ EOS-feedback

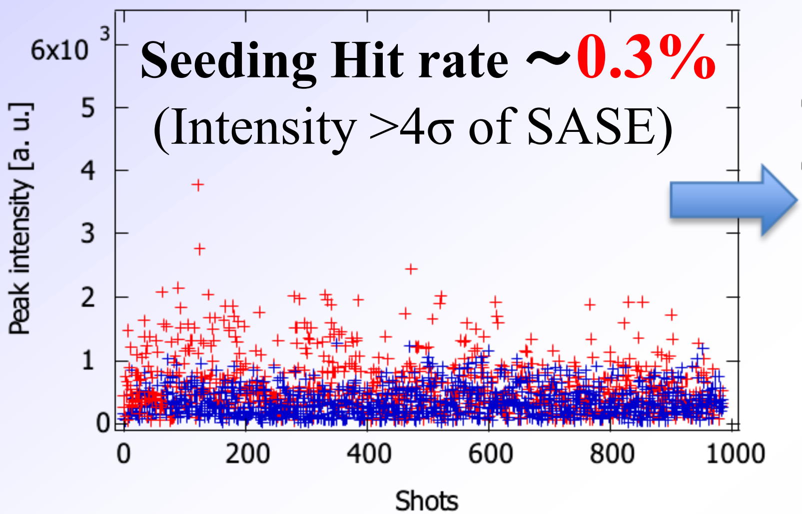
Output energy of amplified 13th-order harmonic pulses



Improvements of FEL Performances (2010 → 2012)

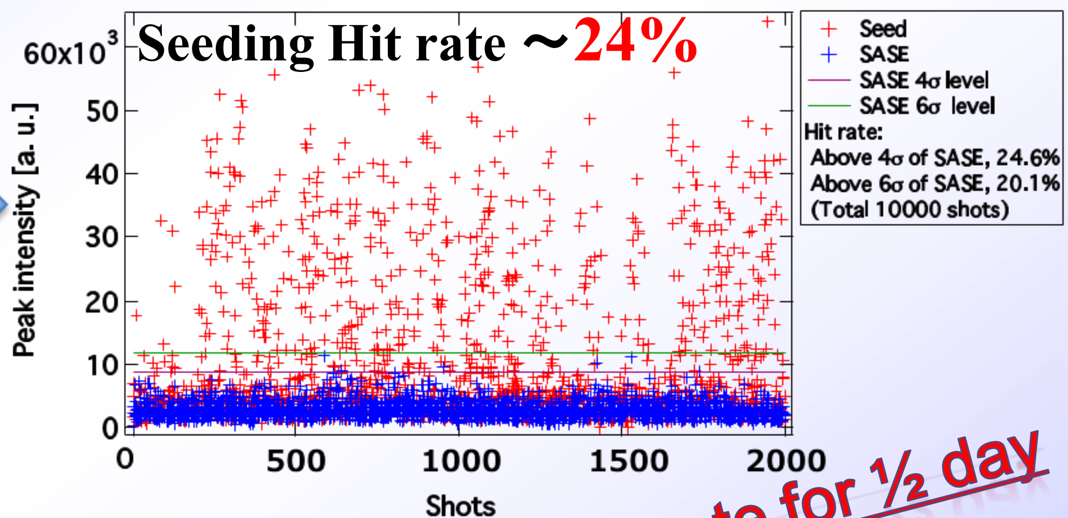
Previous result (2010)

w/o feedback



This result (2012)

w/ feedback



- Seeded FEL output was 1.3 μJ
- The seeding operation was only obtained less than 10 minutes.

~30% seeding hit rate for ½ day
Up to 20 μJ

By using the EOS-based timing-drift system, the HH seeded FEL succeed to continuously operate about a half day which is the machine time of SCSS accelerator with 20-30% hit rate.

Feedback On/Off tests on Seeded FEL operation (2012)

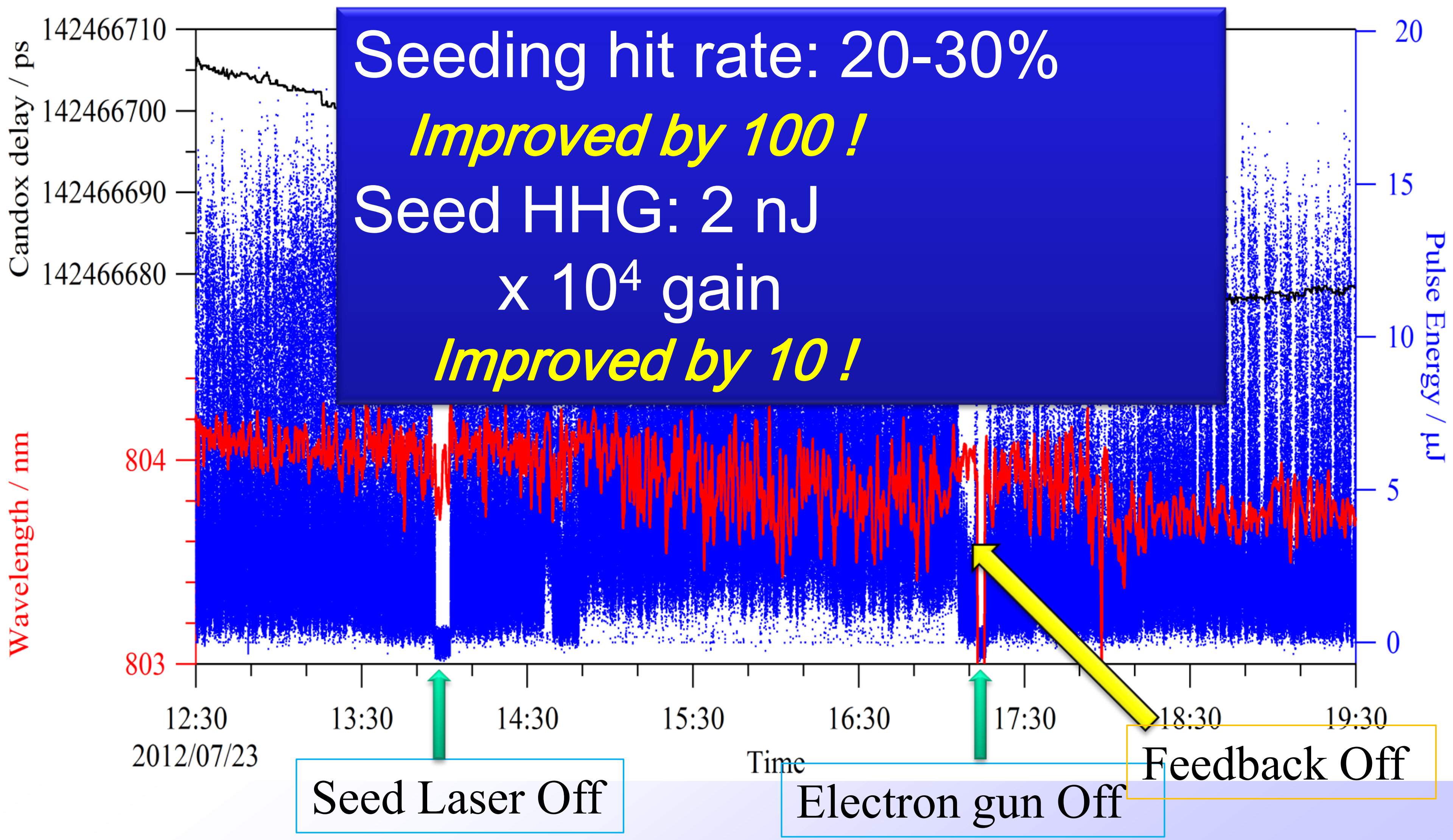
Seeding hit rate: 20-30%

Improved by 100 !

Seed HHG: 2 nJ

x 10^4 gain

Improved by 10 !



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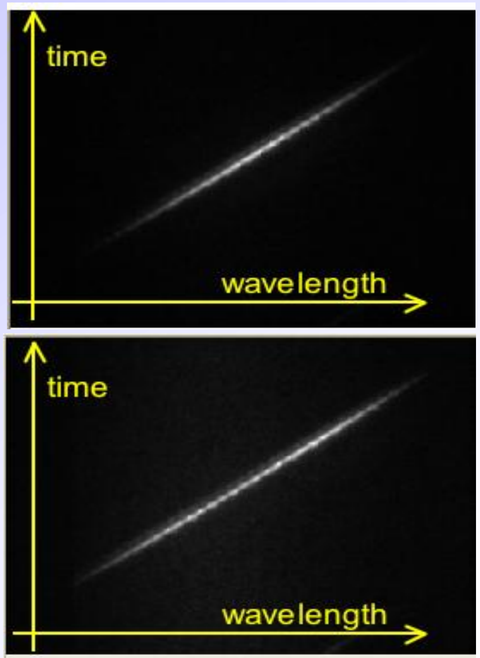
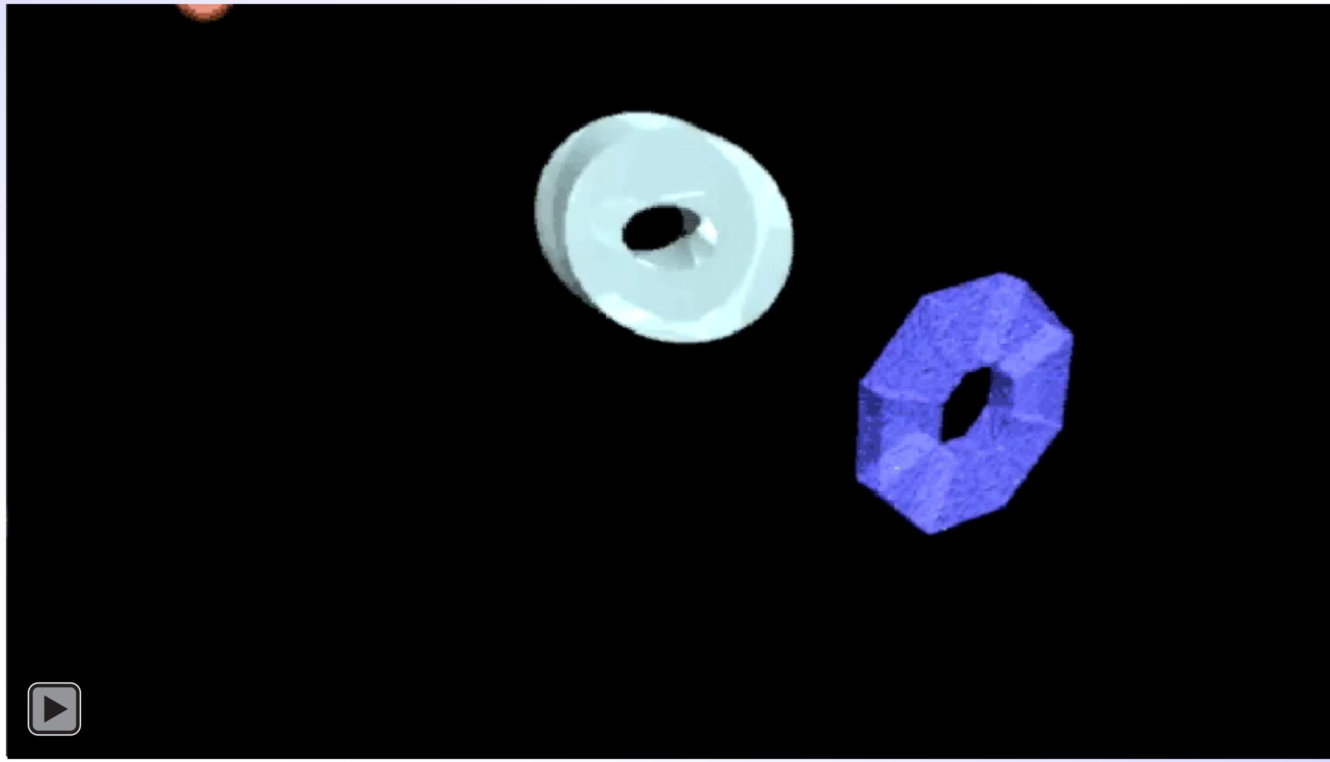
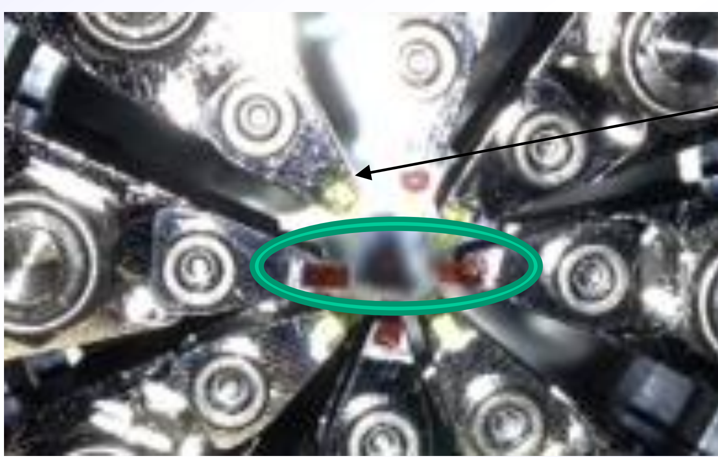
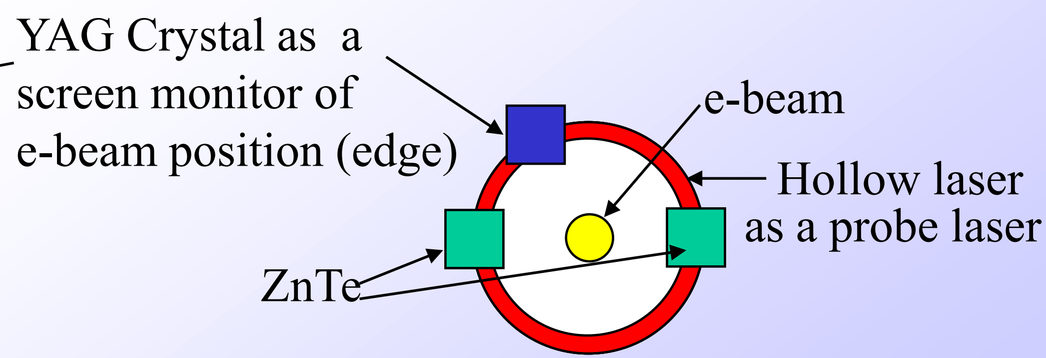


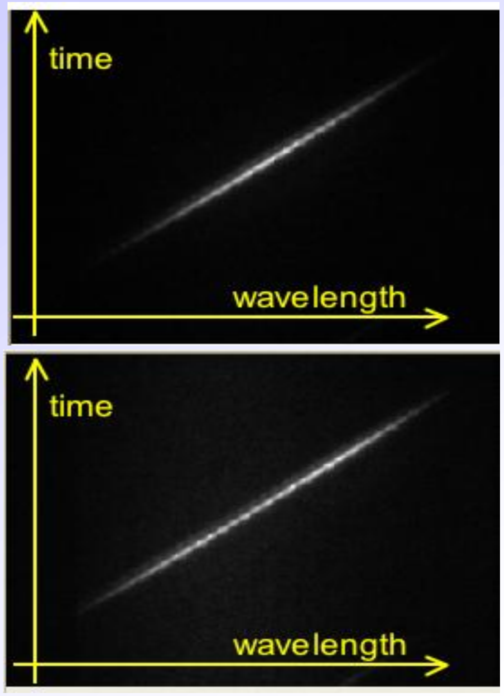




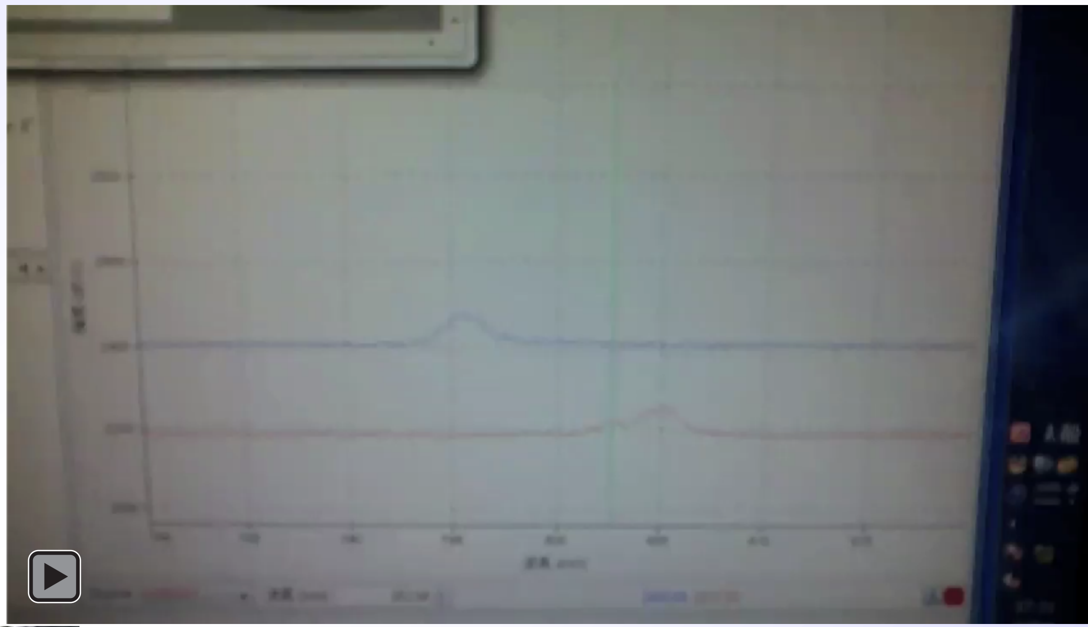


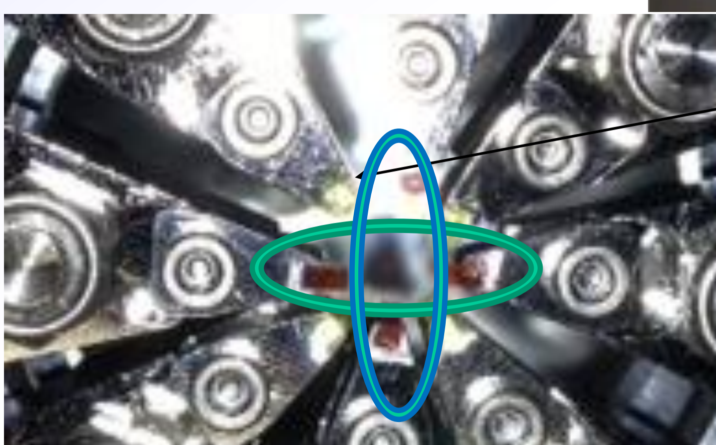
EOS-BPM to measure Relative Pointing Stability

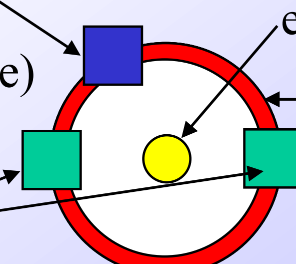
Linear-chirp (Constant Chirp Rate) used for Spectral decoding.



Demonstrations of 3D-EOS measurements @SCSS HHG-seeded FEL



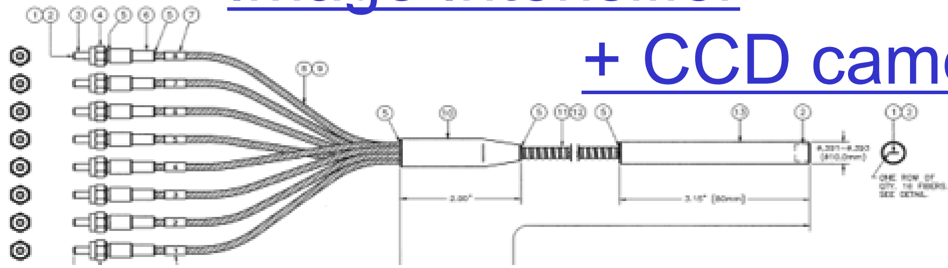


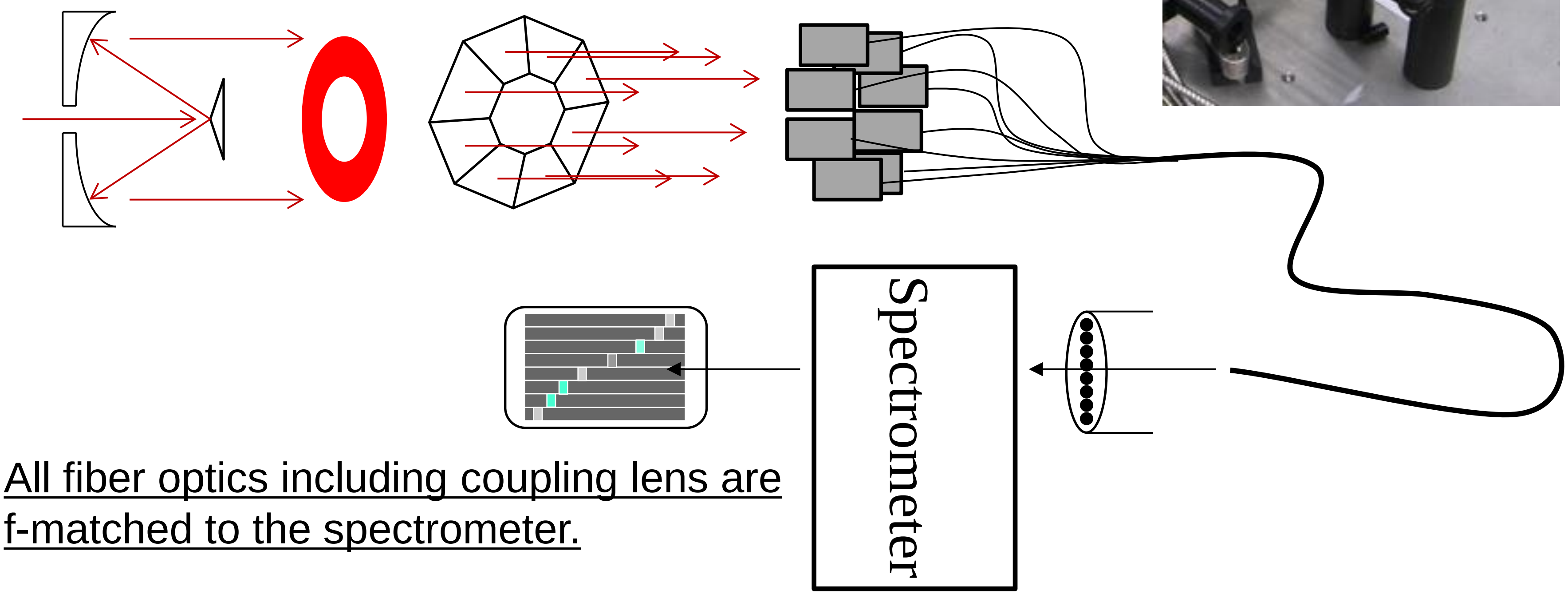


New Decoder : Spectrograph Tech.

Image Intensifier

+ CCD camera





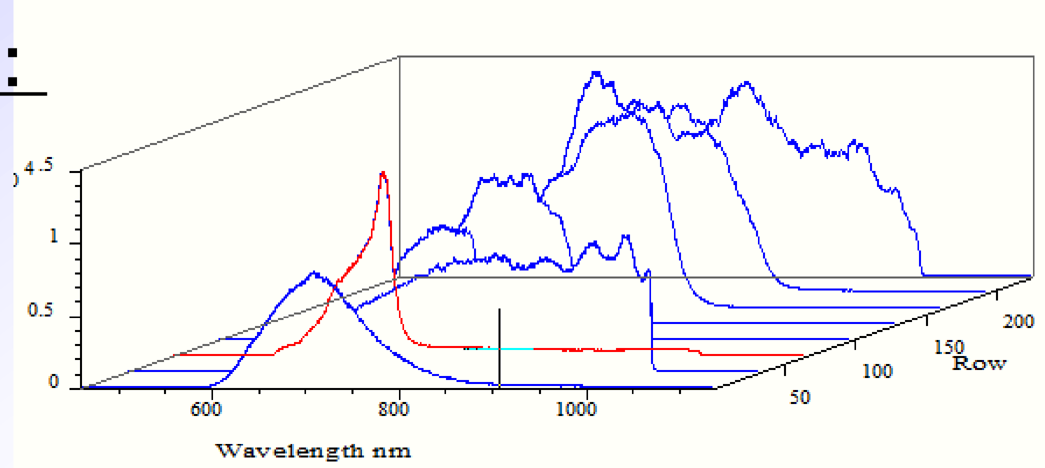
All fiber optics including coupling lens are f-matched to the spectrometer.

- It makes single-shot measurements without using a timing-shifter.

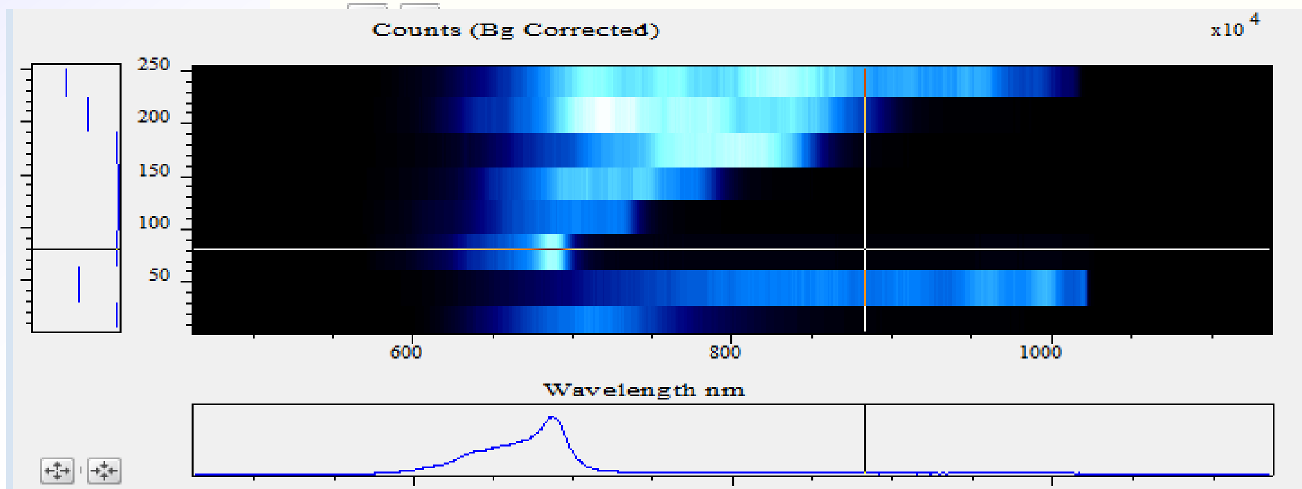
In the case of 8 track, it is possible bunch-by-bunch measurements @204 Hz (86 Hz (with refreshing time)).

8ch (track) Spectrographs :

Integrated each tracks to get spectra



Spectrograph

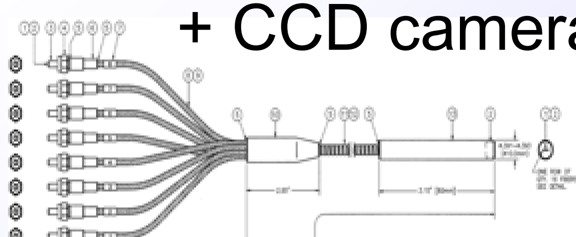


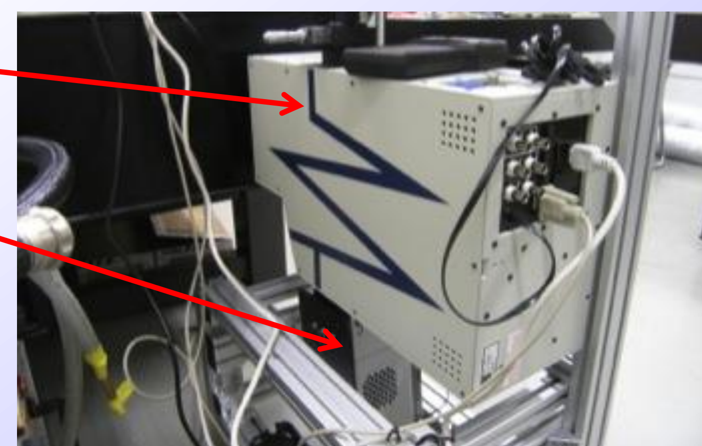
8-divied Fiber bundle

Spectrometer

Image Intensifier

+ CCD camera





Outline

- Introduction of 3D-Bunch Charge Distribution monitor
- EOS- timing & pointing feedback for HHG-seeded FEL (6D phase space overlapping)
- Summary of improvement seeding conditions with EOS seeder-locking
- Further developments towards 30-fs resolution

Summary

- **We demonstrated 3D-EOS as feedback sys for seeding.**
- Introducing EOS-feedback, continual operation
- Dramatically improve seeding condition (2010)
- Short term of timing drift (or jitter) < 500 fs (p-p)

	2010 (w/o EOS-feedback)	2012 (w/ EOS-feedback)
FEL pulse energy	1.3 μJ (max.)	20 μJ (max.)
Seeding hit rate	0.3 %	20 – 30 %
FEL gain	x 650	x 10^4
Continual operation	< 10 min.	> 1/2 day

- We demonstrated transverse detections to improve relative pointing with diagonal pairs of EO crystals (New spectrograph Tech.)

For longitudinal detection tawards 30fs temporal res.)

i) Organic EO crystal

DAST crystal: it has been used for the broadband THz source.

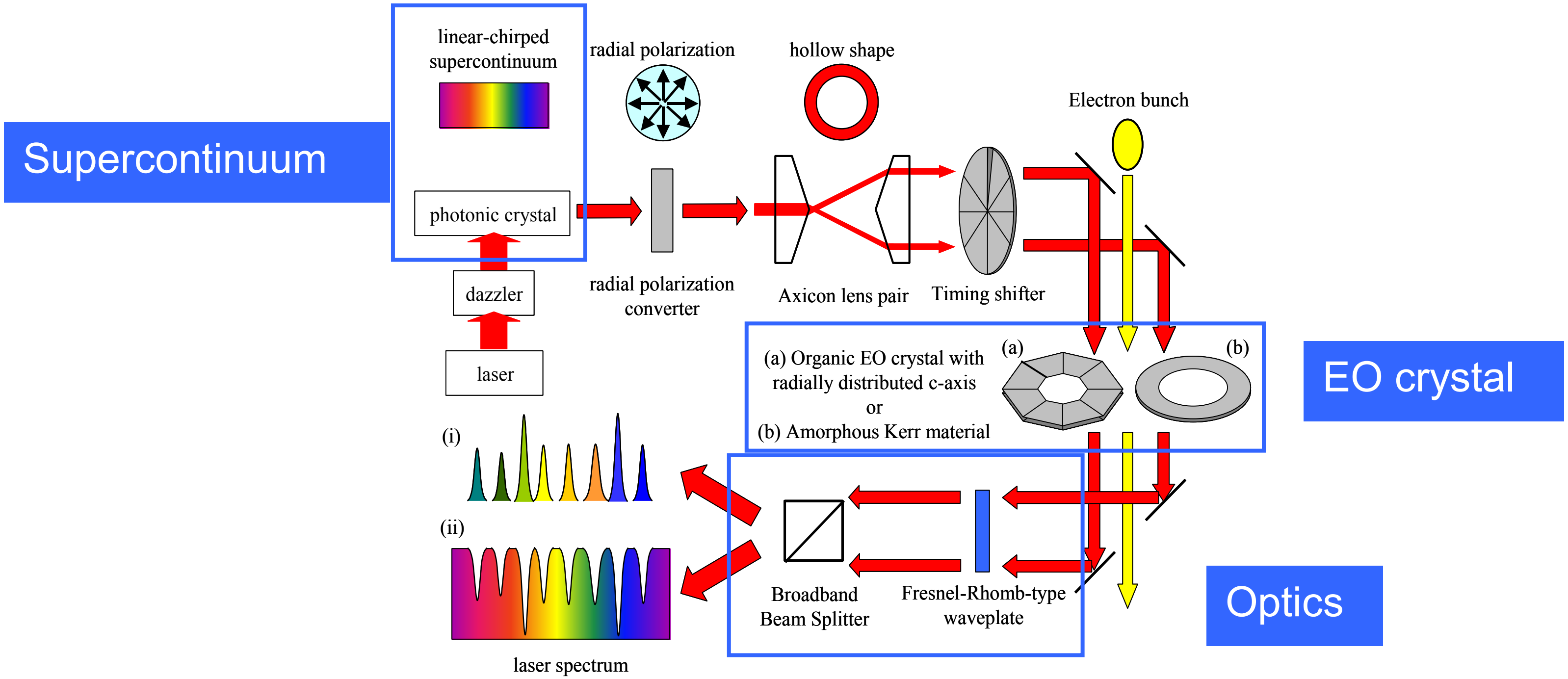
ii) Supercontinuum generation

Using Photonic crystal fiber

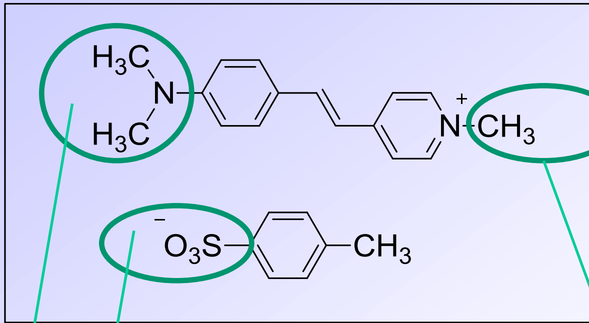
iii) Broadband Optics for supercontinuum

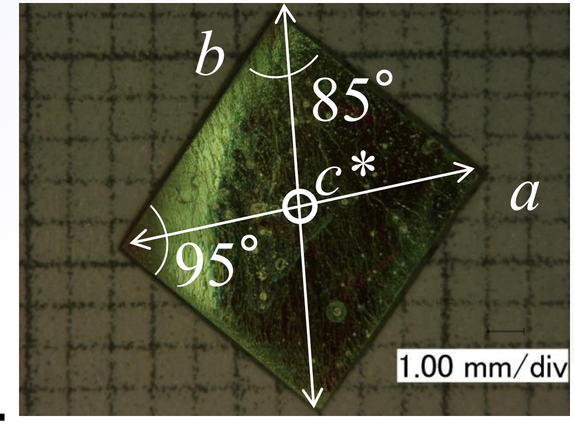
a) waveplate and polarized beam splitter

b) AO modulator to make chirping purely linear with chirp scanning Tech.



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

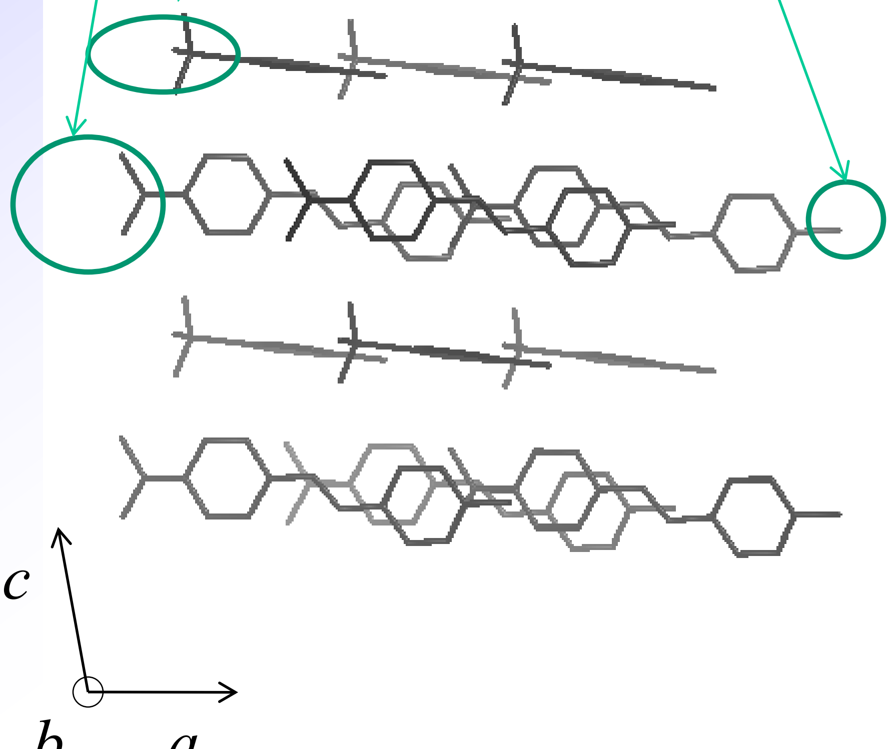




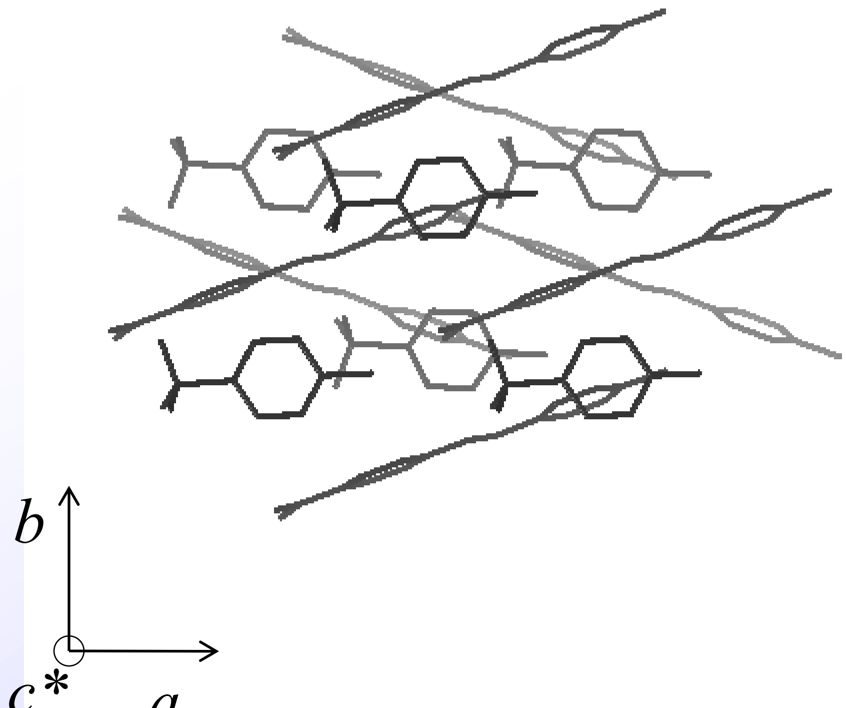
- **Mission for real-time monitoring**

bunch-by-bunch seeding pulse at Soft-XFEL

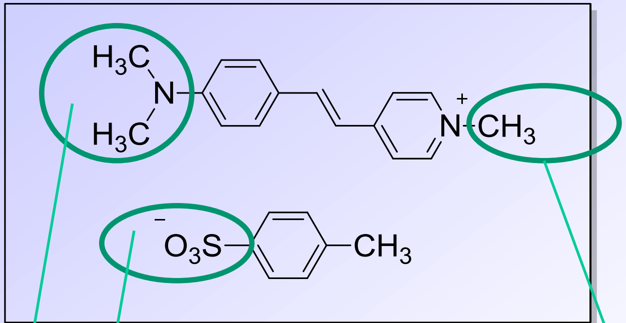
a-*c* plane

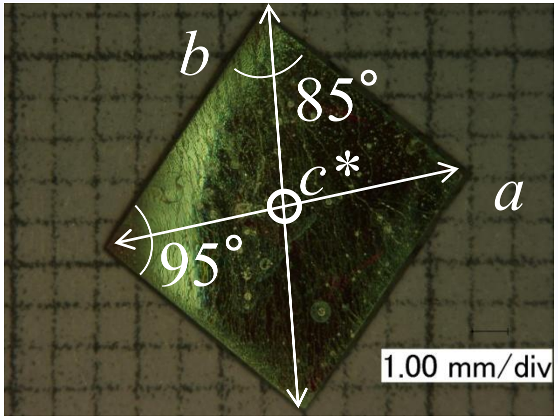


a-*b* plane



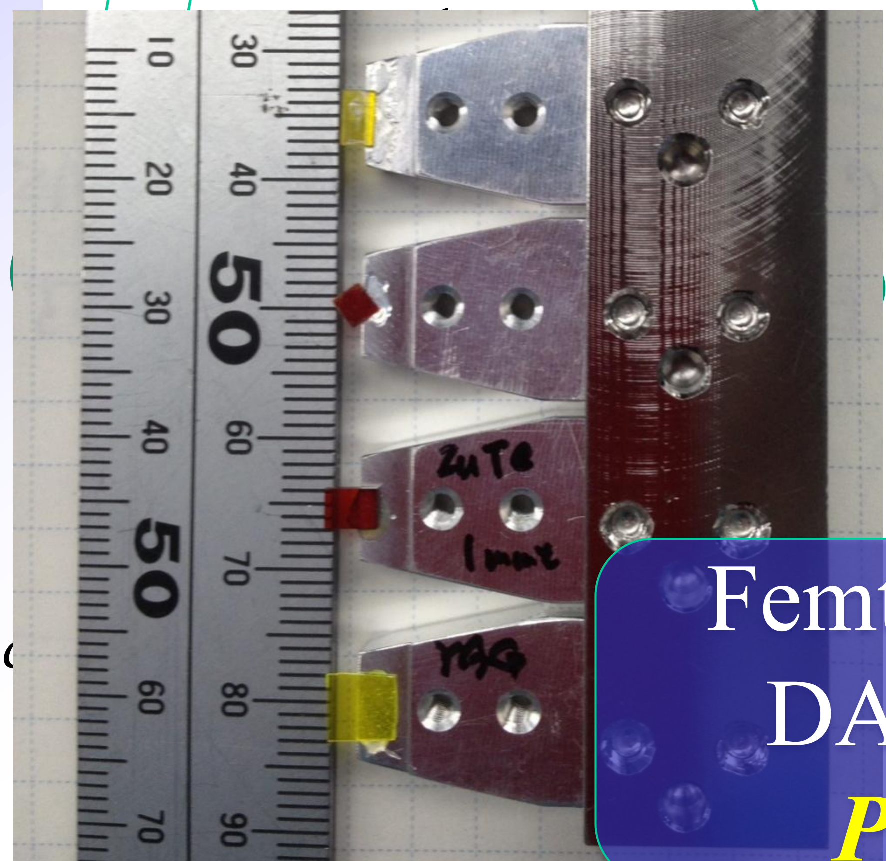
Developments of DAST EO-detector *towards to Res. 30fs!!*



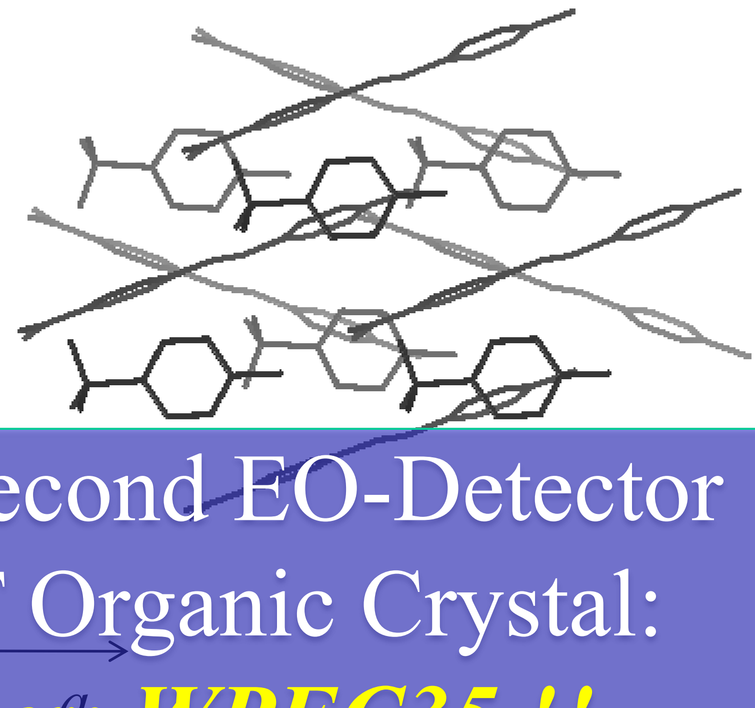


- **Mission for real-time monitoring**

bunch-by-bunch seeding pulse at Soft-XFEL

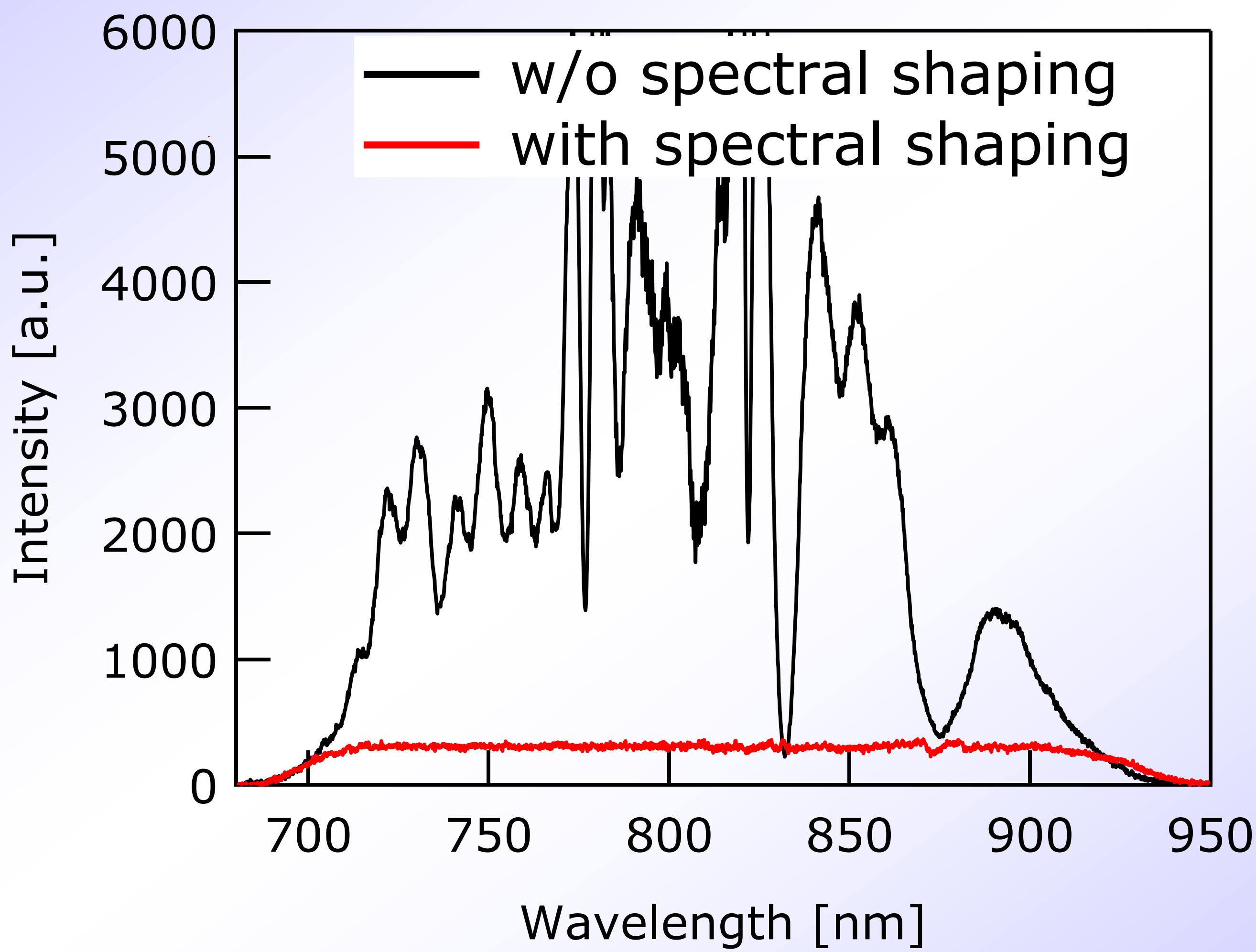


a-*b* plane



Femtosecond EO-Detector
DAST Organic Crystal:
Poster: WPEC35 !!

Enlargements of Dynamic Range with octave-band flattop Spectrum

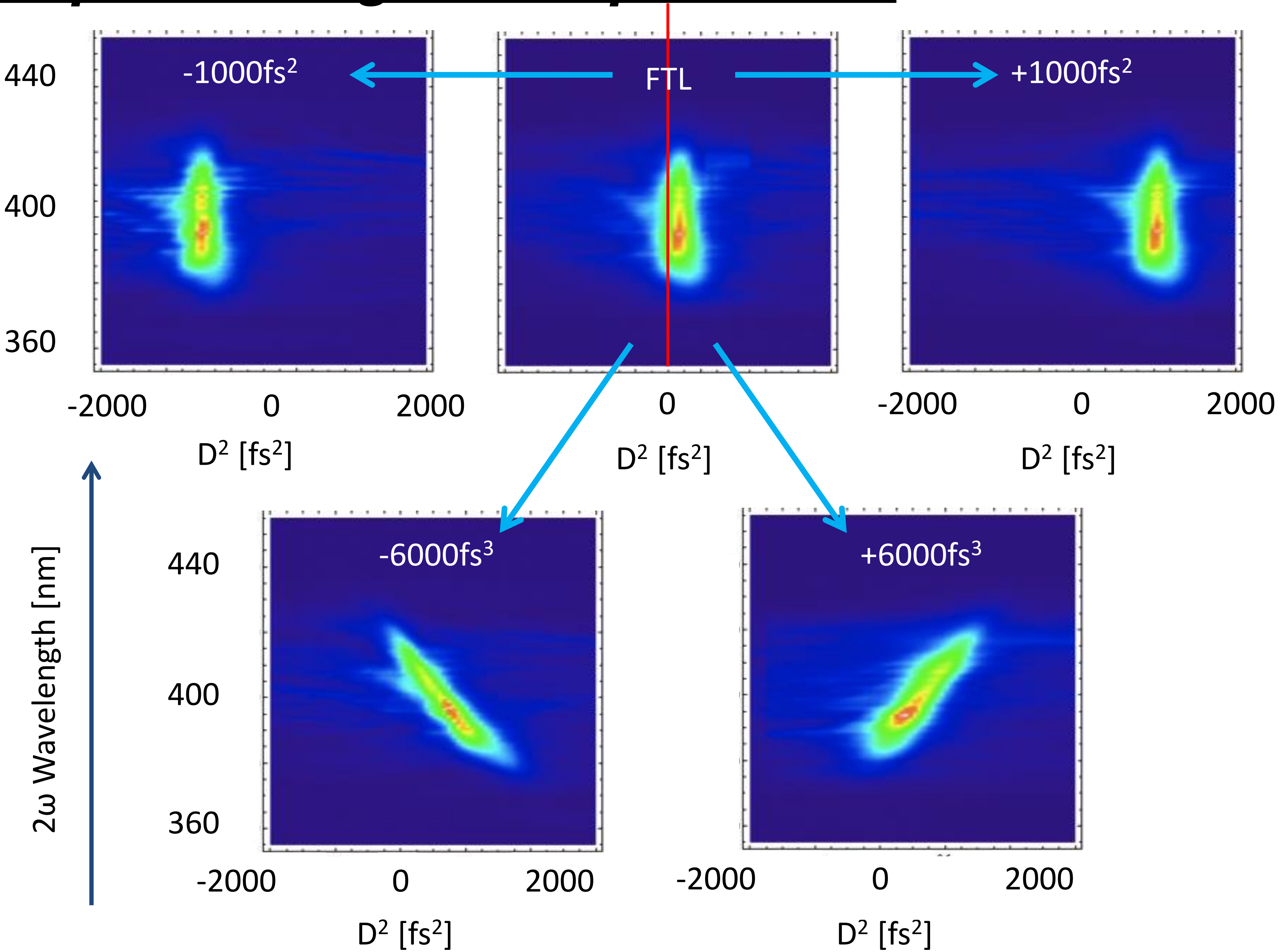


Clipping efficiency: 12%

Diffraction efficiency: 20% ==> 50% (w/ 50W RF amplifier)

Chirp scanning to add pure GDD

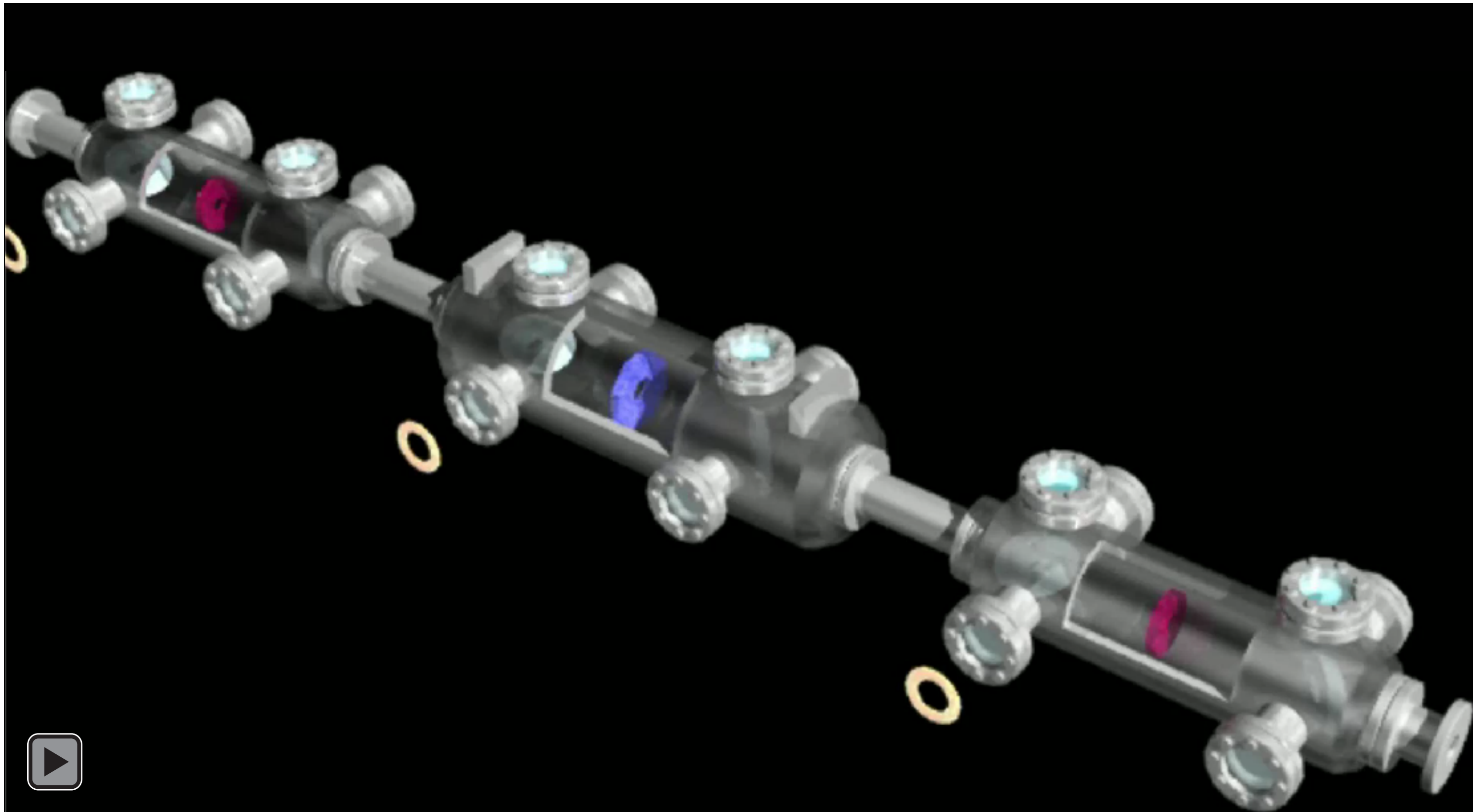
Chirp Rate: 40fs/nm



All of you are welcome at our poster ***WPEC35 !!***

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

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



Thank you for your kind attention !