Operation and R&D Status of SXR-HHG-Seeding at SCSS and HXR-Self-Seeding at SACLA

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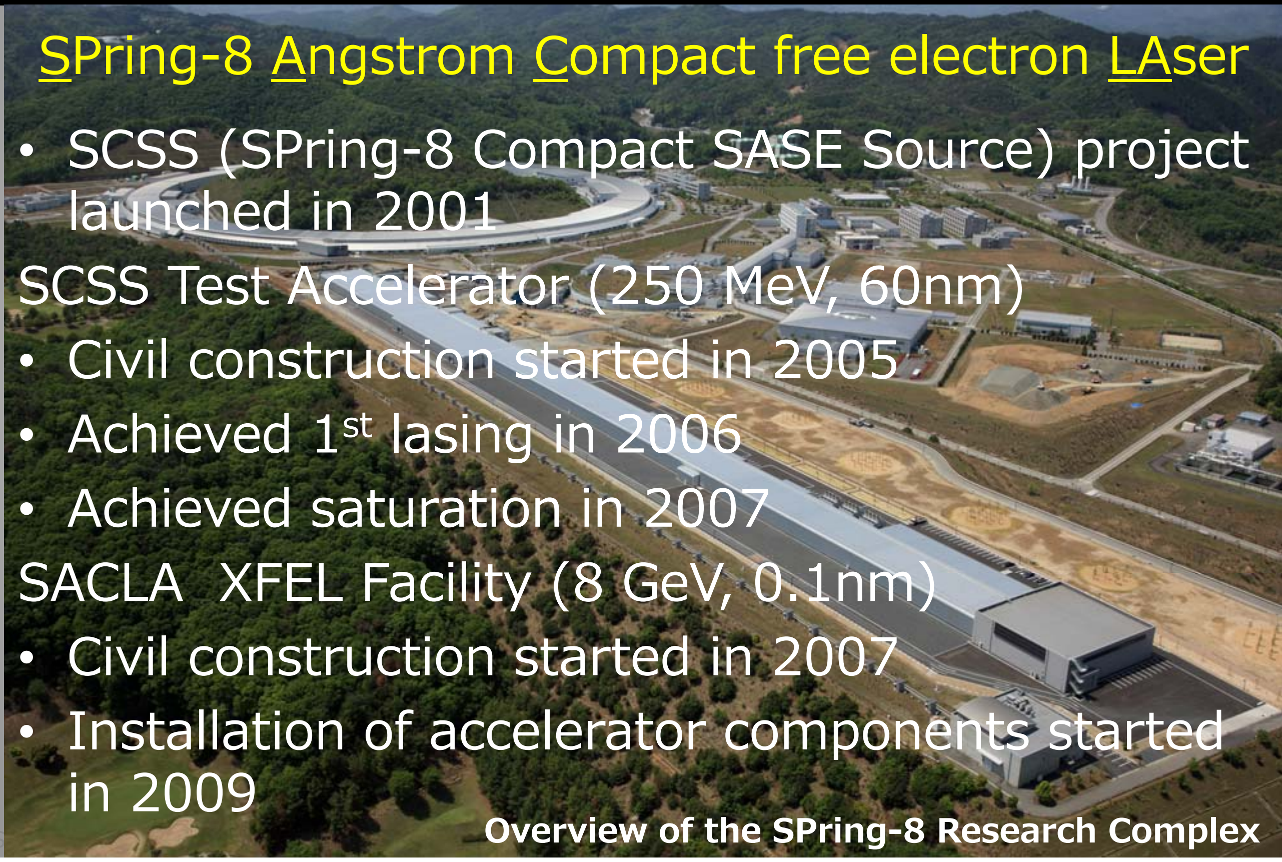
RIKEN XFEL Division

On behalf of all the staffs contributed to
HHG-seeded EUV-FEL (SCSS) and improvements of SACLA

Outline

- Status of SACLA Facility
- SXR-Seeding at SCSS Test Accelerator
  - Overview & History
  - Improvements and Recent Results
  - Future Perspective
- HXR-Self-Seeding Option at SACLA
  - Design Study
  - Current Status
- Summary

History of SACLA (1)



SPring-8 Angstrom Compact free electron LAser

- SCSS (SPring-8 Compact SASE Source) project launched in 2001

SCSS Test Accelerator (250 MeV, 60nm)

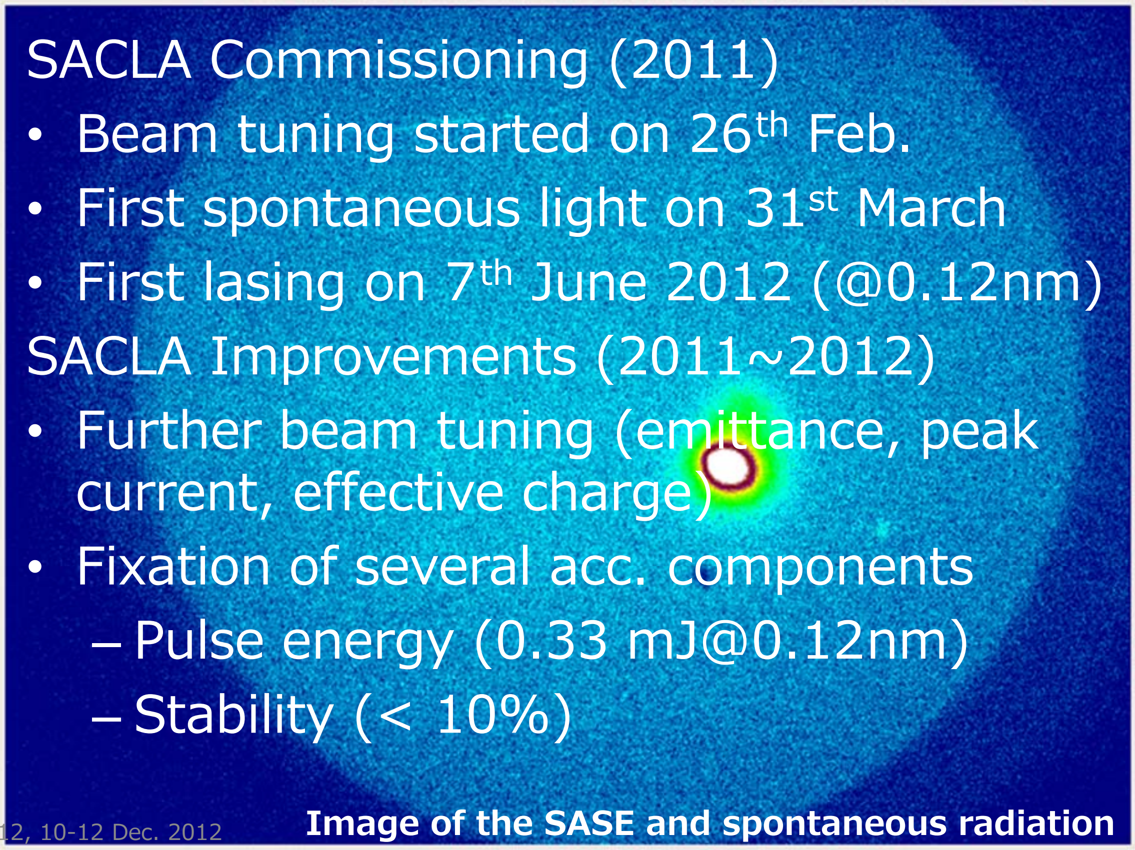
- Civil construction started in 2005
- Achieved 1st lasing in 2006
- Achieved saturation in 2007

SACLA XFEL Facility (8 GeV, 0.1nm)

- Civil construction started in 2007
- Installation of accelerator components started in 2009

Overview of the SPring-8 Research Complex

History of SACLA (2)



SACLA Commissioning (2011)

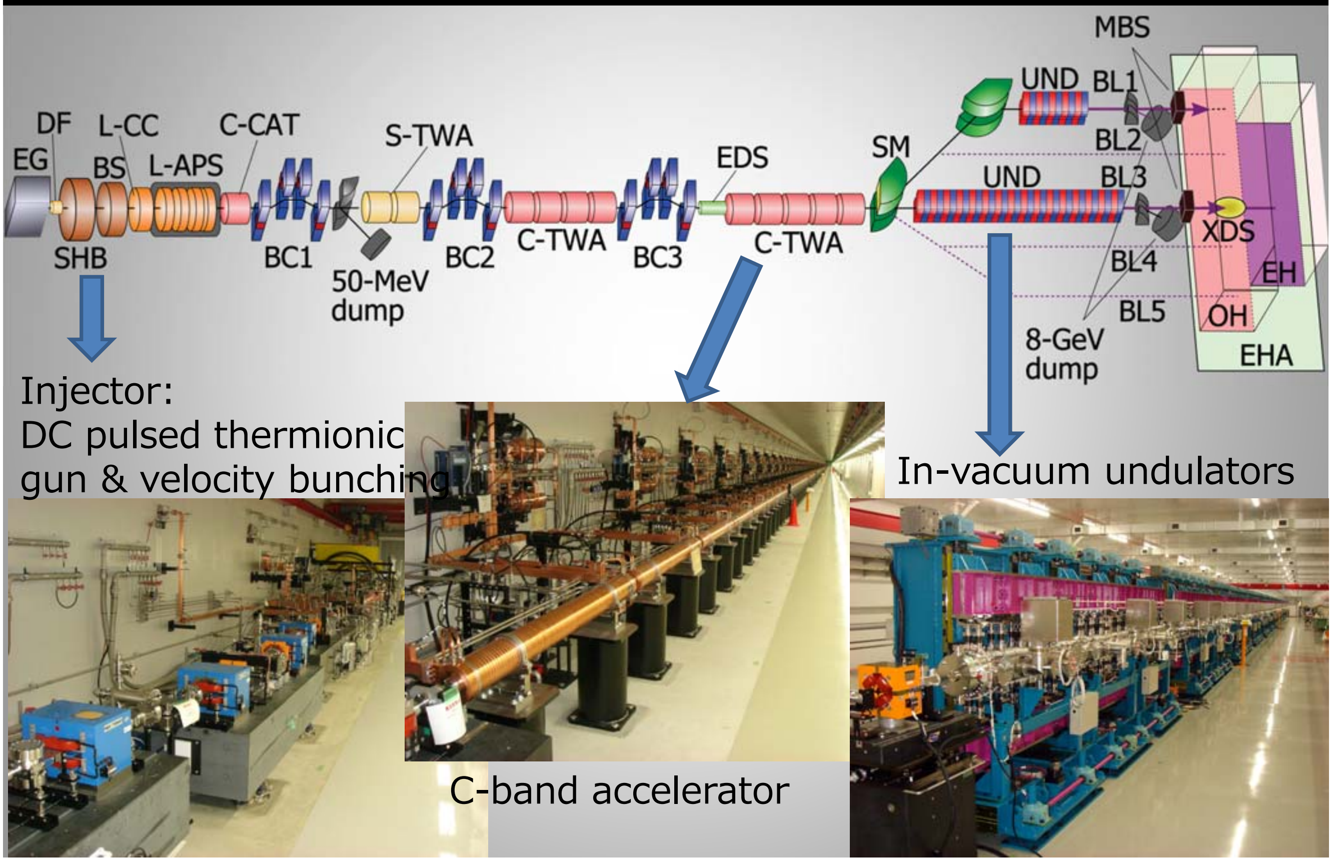
- Beam tuning started on 26th Feb.
- First spontaneous light on 31st March
- First lasing on 7th June 2012 (@0.12nm)

SACLA Improvements (2011~2012)

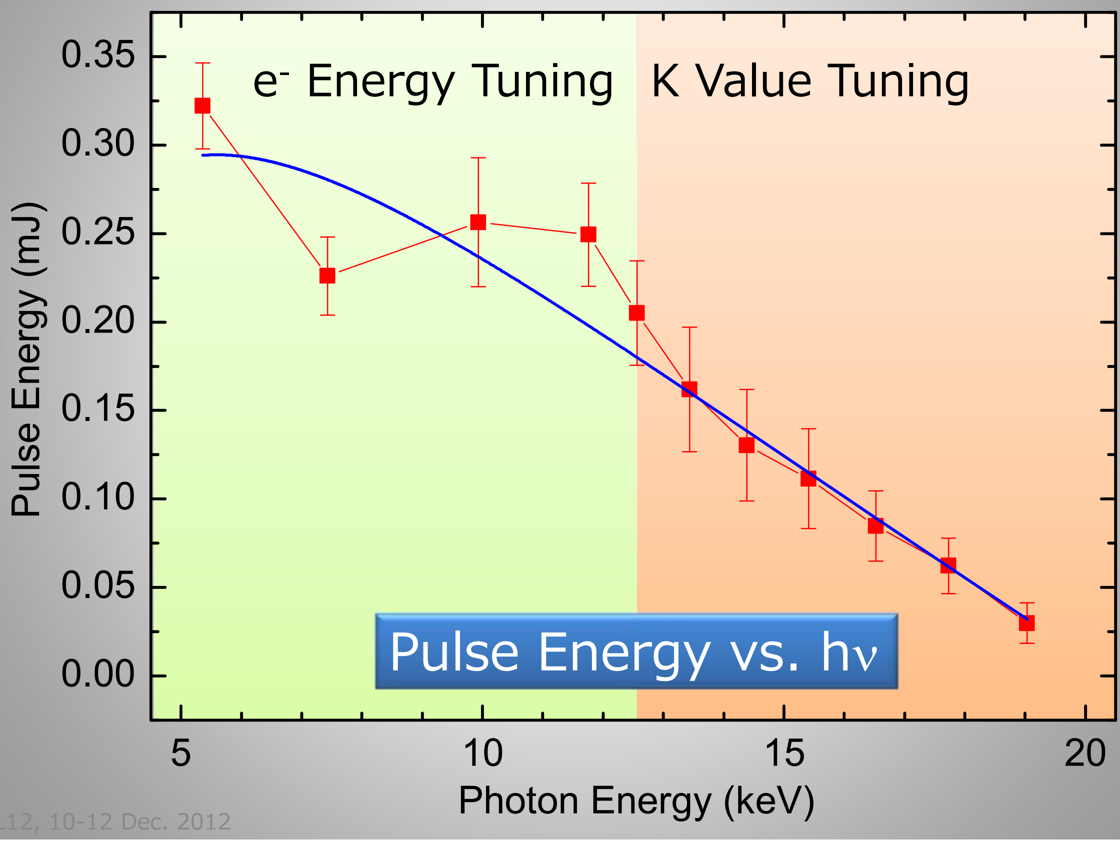
- Further beam tuning (emittance, peak current, effective charge)
- Fixation of several acc. components
  - Pulse energy (0.33 mJ@0.12nm)
  - Stability (< 10%)

Image of the SASE and spontaneous radiation

Overview of SACLA Facility

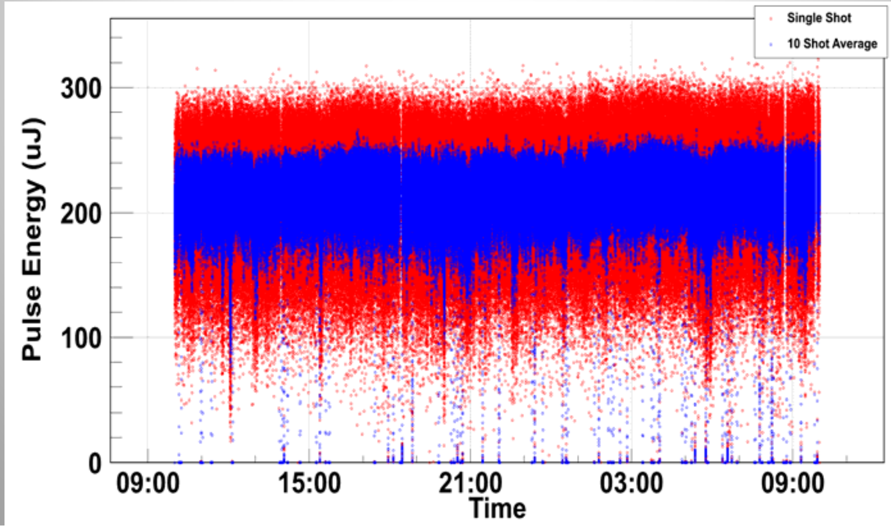


Status of SACLA Facility (1)



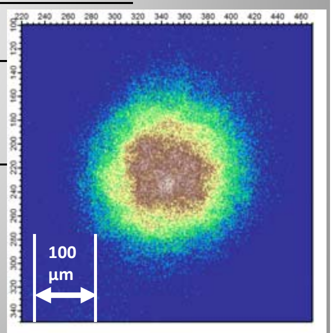
Status of SACLA Facility (2)

- Stability of SASE Beam
  - Pulse energy fluctuation < 10%
  - Pointing stability < 20% of σ_x, σ_y
  - Energy (wavelength) stability < 0.1%



Available XFEL performance:

	Design	Achieved
Photon energy & Intensity	<20 keV sub-mJ/pls	4~7 keV (>300uJ/pls) 7 ~ 8% 7~12 keV (>100uJ/pls) ~10% 12~15 keV (>10 uJ/pls) 15 keV以上 (~ 1uJ/pls) < 20 %
Peak power	>30 GW	~ 10 GW
Pulse duration	6~30 fs	~ 20 fs ?
Rep rate	60 Hz	10 Hz



※ Note that, the intrinsic SASE fluctuation is 7-8 % (σ).

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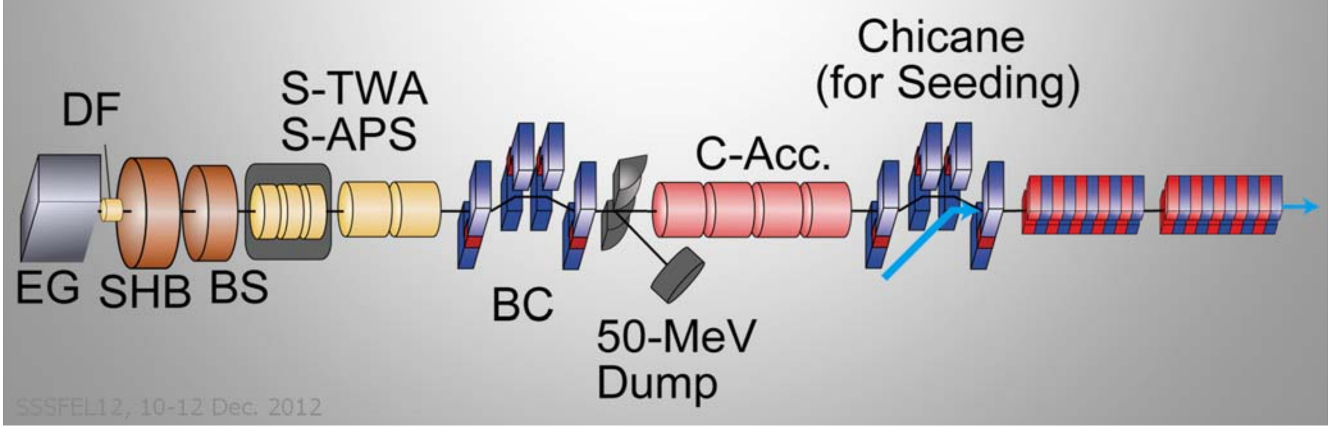
Seeding at SCSS Test Accelerator

- SCSS Test Accelerator
  - Constructed and operated to demonstrate the concept of SACLA (250MeV, 60nm)
  - Just in front of the undulator section, a chicane has been installed to inject a laser beam for seeding experiments



History of Seeding Experiments

Date	Event	Condition	Reference
June 2006	The first SASE amplification with our new machine concept	250 MeV, 49nm	
Dec. 2006	Seeding at **160 nm**	150 MeV, HHG 5^{th}	G. Lambert et al., Nat. Physics 4, 296 (2008)
Sept. 2007	SASE saturation	250 MeV, 50~60nm	T. Shintake et al., Nat. Photonics. 2, 559 (2008)
Oct. 2010	Seeding at **61 nm**	250 MeV, 300 fsec HHG **13^{th}**	T. Togashi, et al., Opt. Exp. 19, 317 (2011)
March 2011	The first test of Arrival time monitor (relative timing btw. e-bunch and HHG with EO sampling)		H. Tomizawa, BIW2012, Newport News, VA (2012)
July 2012	Seeding at **61 nm** **(hit rate: ~30%)**	250 MeV, 600 fsec HHG **13^{th}**	H. Tomizawa, et al., LINAC2012, Tel-Aviv (2012)
July 2012	Experiments with stabilized seeded FEL at **61 nm**		to be submitted

Task force in our collaboration for HHG-seeding

Supports for this projects:
- RIKEN/JASRI XFEL project
- SCSS test accelerator operation team (Engineers)

Financial supports :
- RIKEN extreme photonics (Dr. Midorikawa)
- MEXT X-ray free electron laser utilization research (Prof. Kaoru Yamanouchi, The University of Tokyo), *"Pump and probe experiment of atom, molecule and cluster by XFEL light and advanced laser light"*

Japan Atomic Energy Agency, Quantum Beam Science Directorate
M. Aoyama, K. Yamakawa,
Synchrotron SOLEIL
Marie E. Couprie

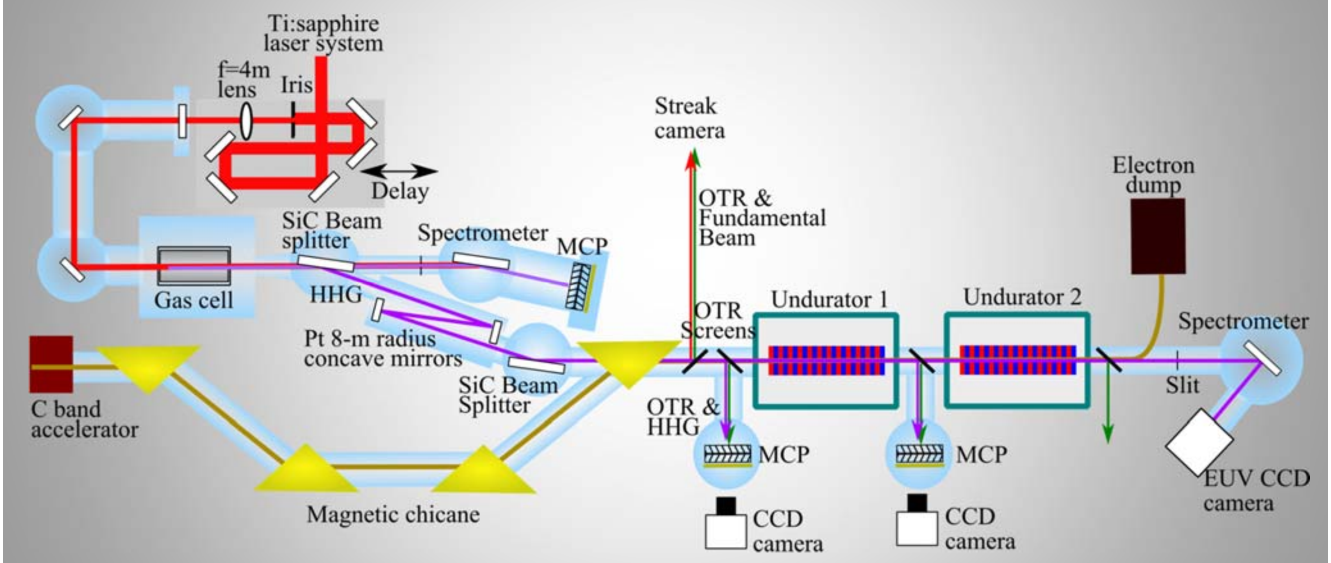
THE UNIVERSITY OF TOKYO

JAEA

RIKEN

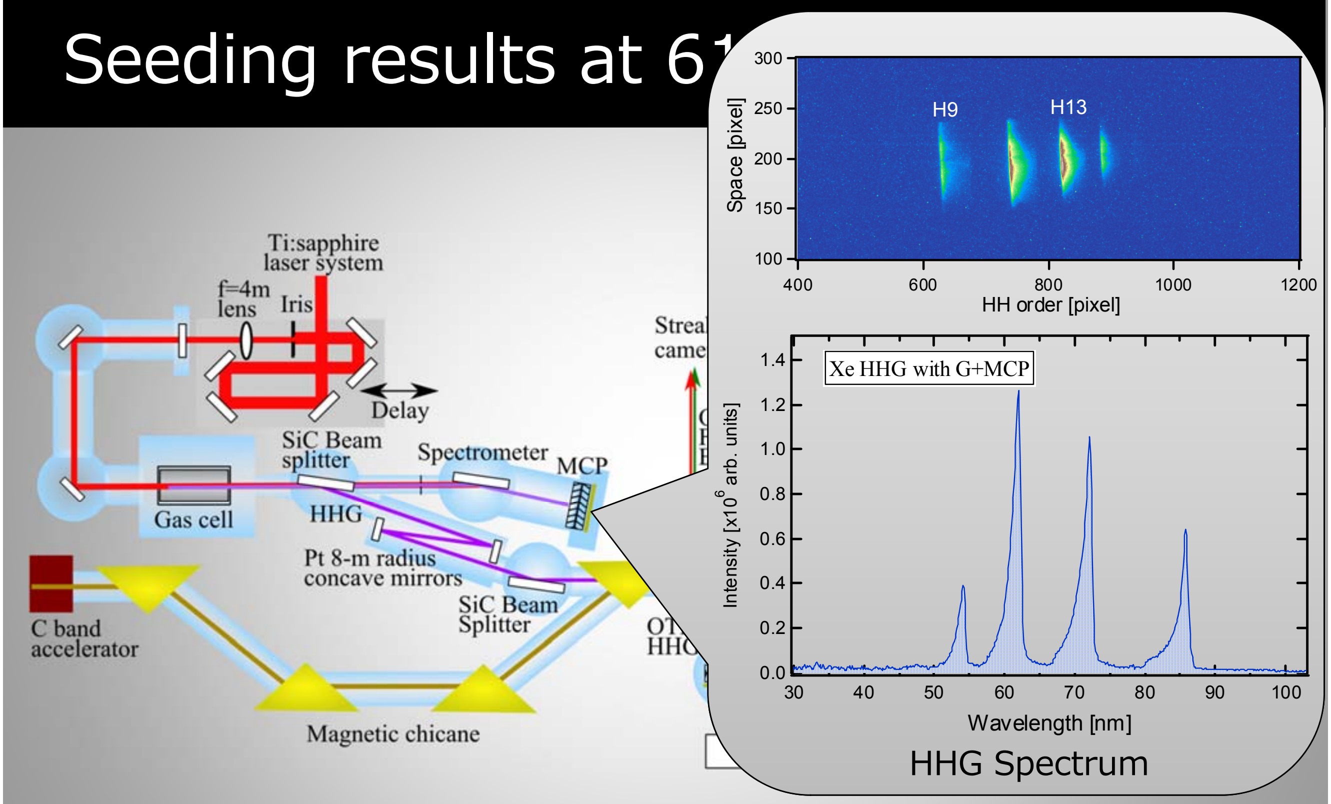


Seeding results at 61 nm in 2010 (1)



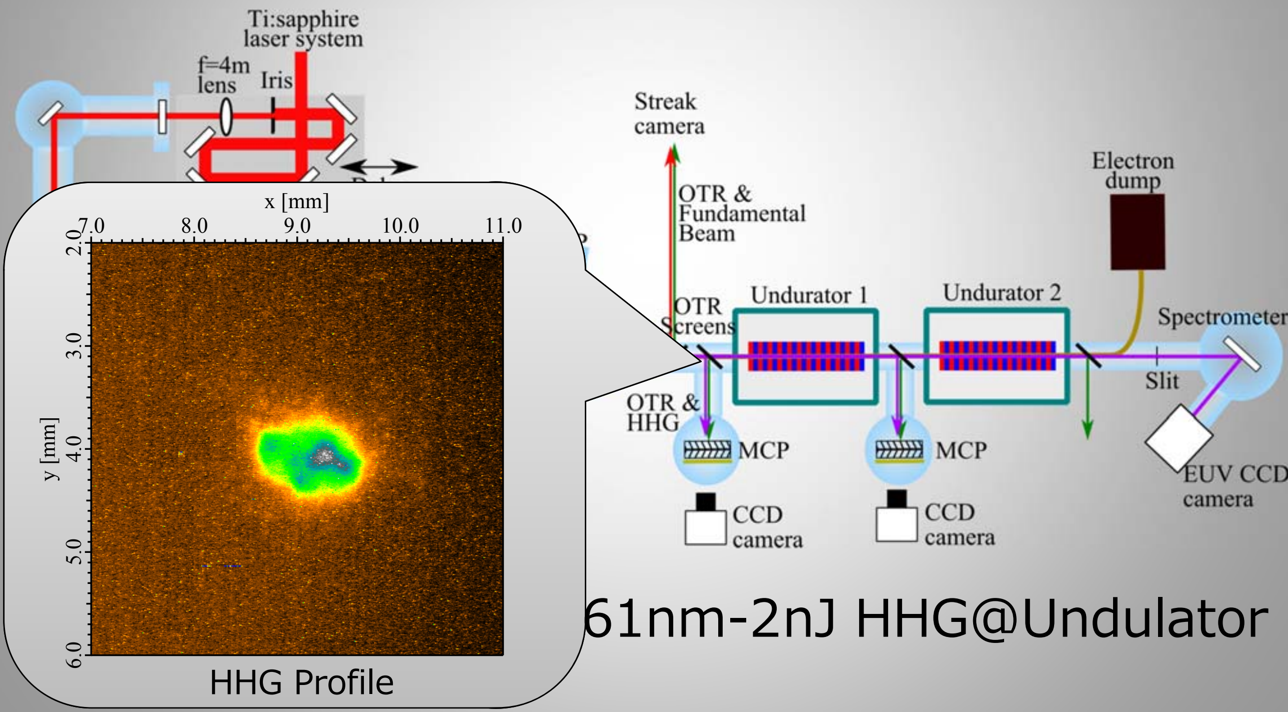
61nm-2nJ HHG@Undulator

Seeding results at 61

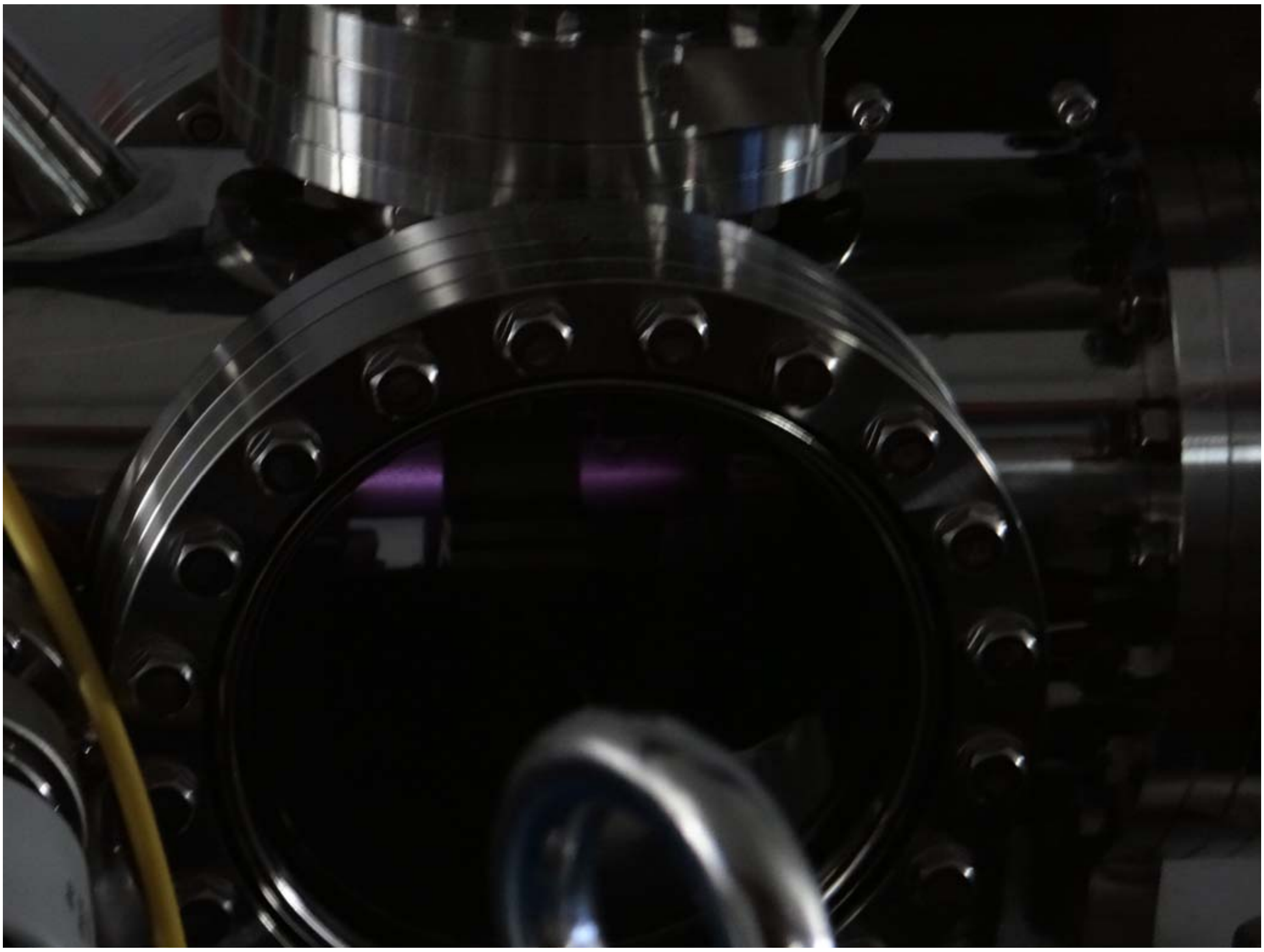


61nm-2nJ HHG@Undulator

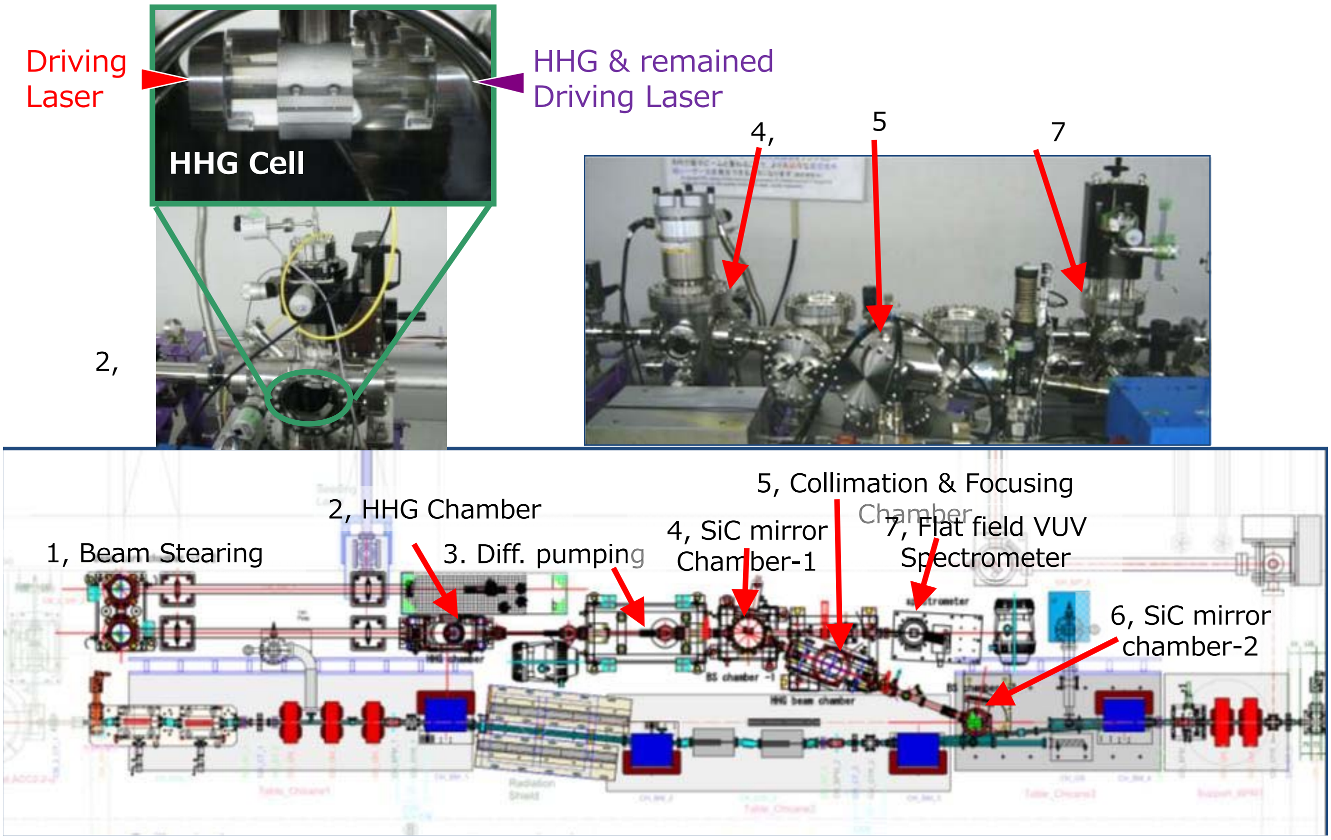
Seeding results at 61 nm in 2010 (1)



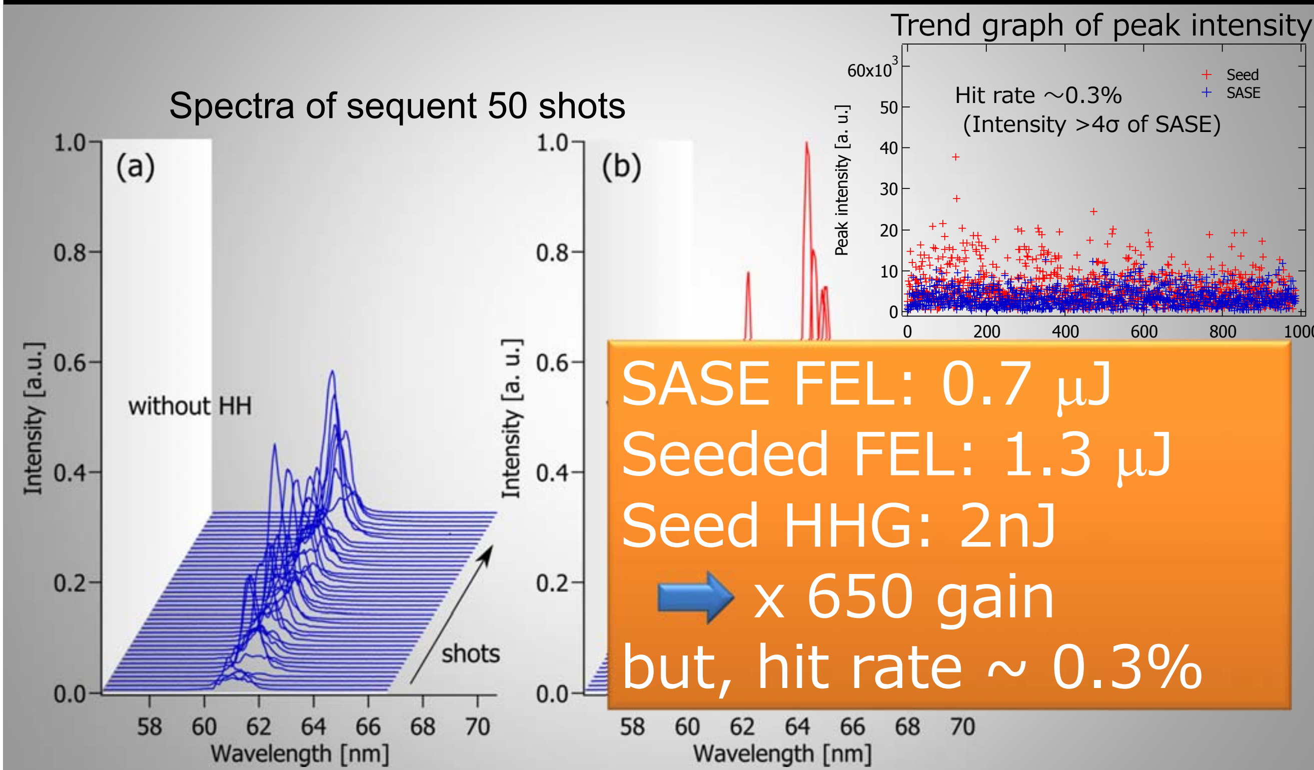
61nm-2nJ HHG@Undulator



Experimental setup: HHG and injection



Seeding results at 61 nm in 2010 (2)

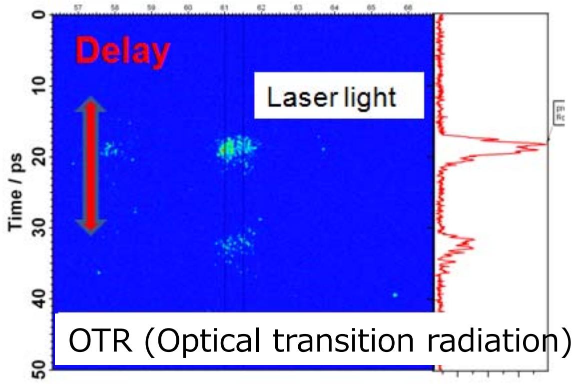


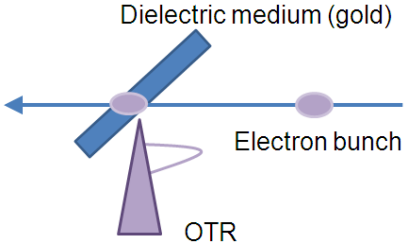
SASE FEL: 0.7 μJ
Seeded FEL: 1.3 μJ
Seed HHG: 2nJ
➡ x 650 gain
but, hit rate ~ 0.3%

T. Togashi *et. al*., Optics Express, Vol. **19** Issue 1, pp.317-324 (2011)

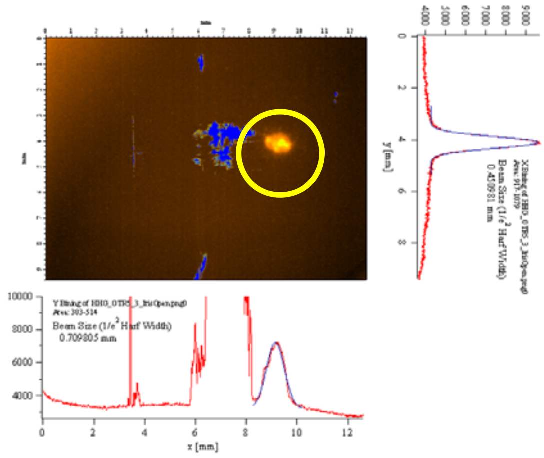
Optimization of temporal and spatial overlap between e-bunch and driving HH-laser pulse

Temporal Overlap





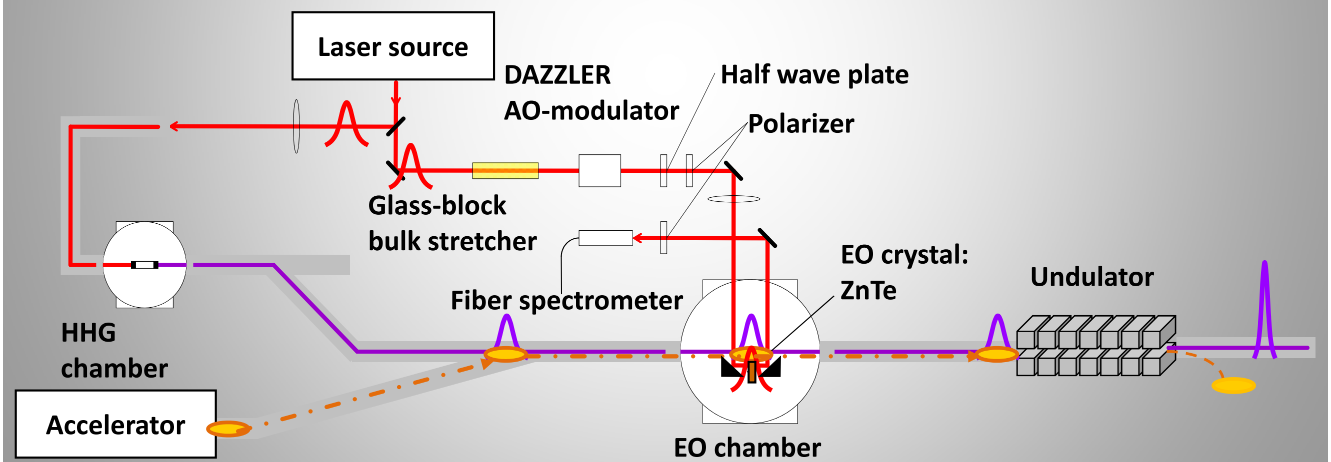
Spatial Overlap



- MCP + Phosphor Screen + CCD
- Before and after 1st undulator

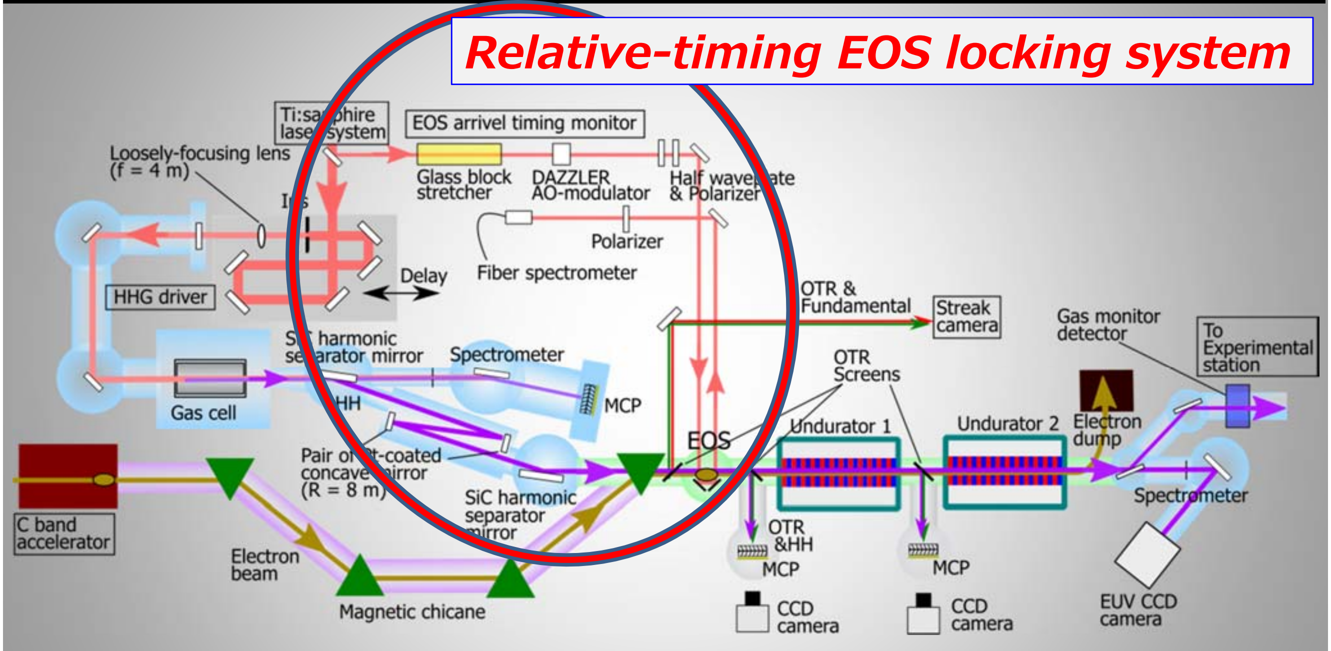
Improvement of Hit Rate (~2012) (1)

- Bunch length stretched (0.3⇨0.6 psec)
- Arrival time monitor by means of EO-sampling implemented



H. Tomizawa, Linac2012, Tel-Aviv

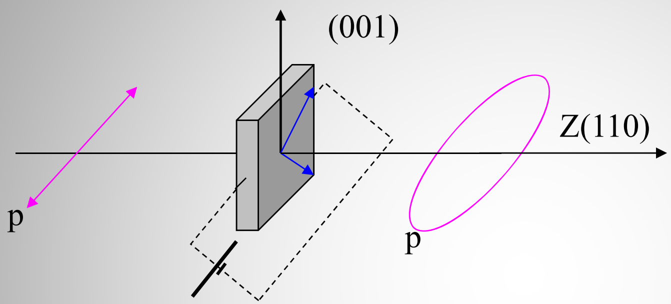
Improvement of Hit Rate (~2012) (2)



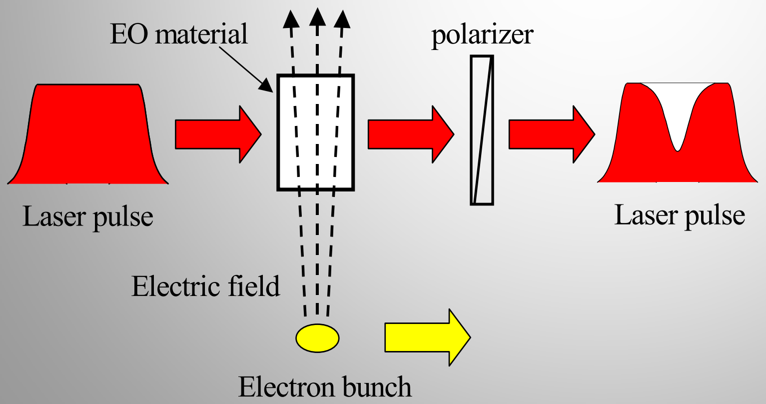
61nm-2nJ HHG@Undulator

Principle of EOS (Electro-optic Sampling)

Pockel's effect (ZnTe)

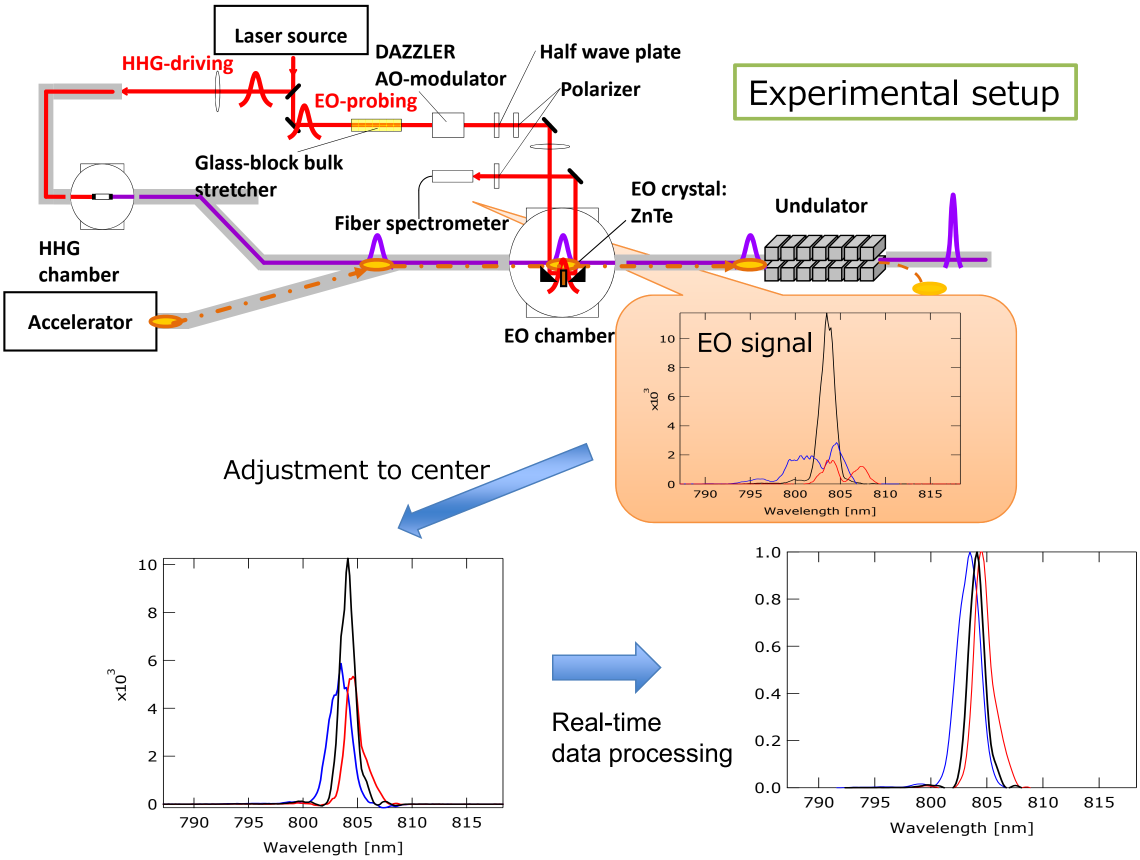


By detecting this phase shift we will know the electrical field

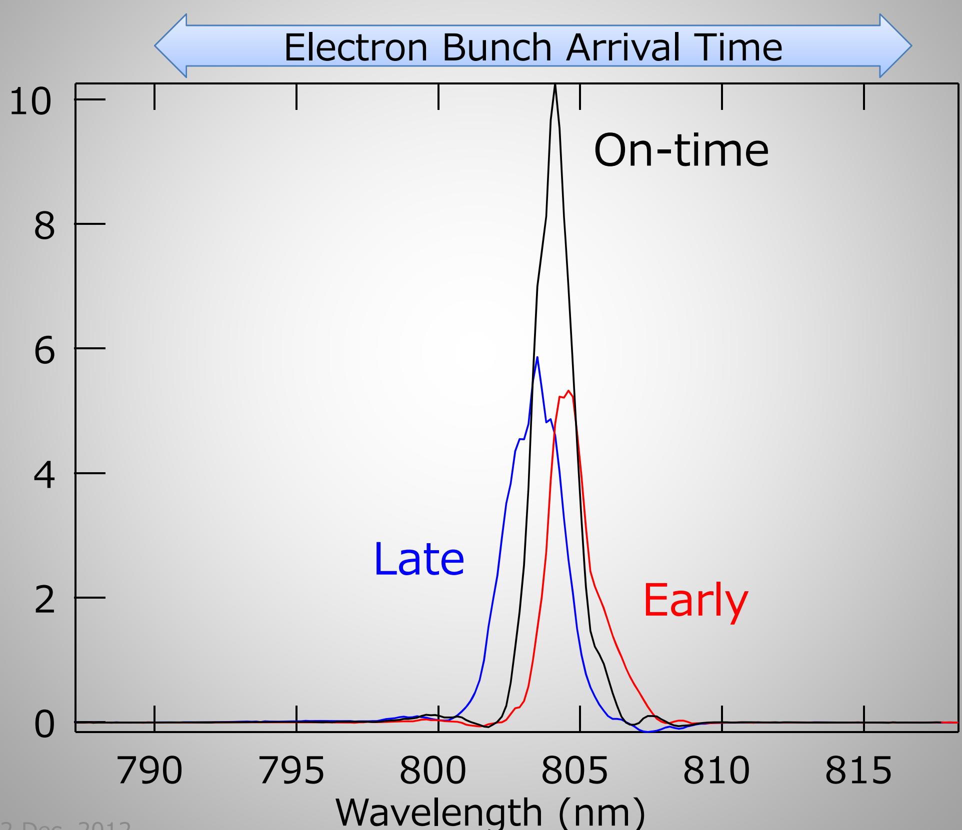


- Spectral decoding
- Temporal decoding
- Spatial decoding

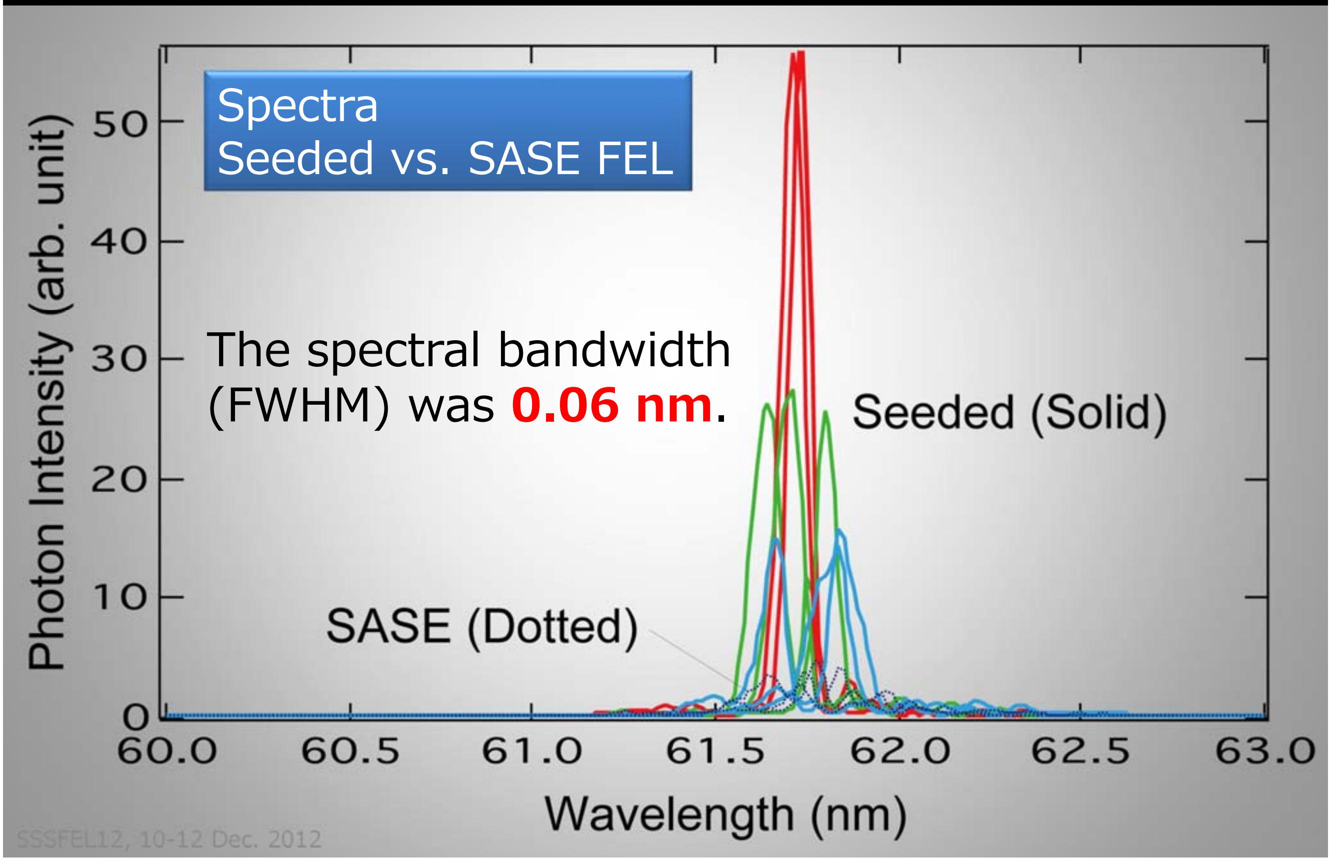
Timing feedback with EO



Improvement of Hit Rate (~2012) (3)



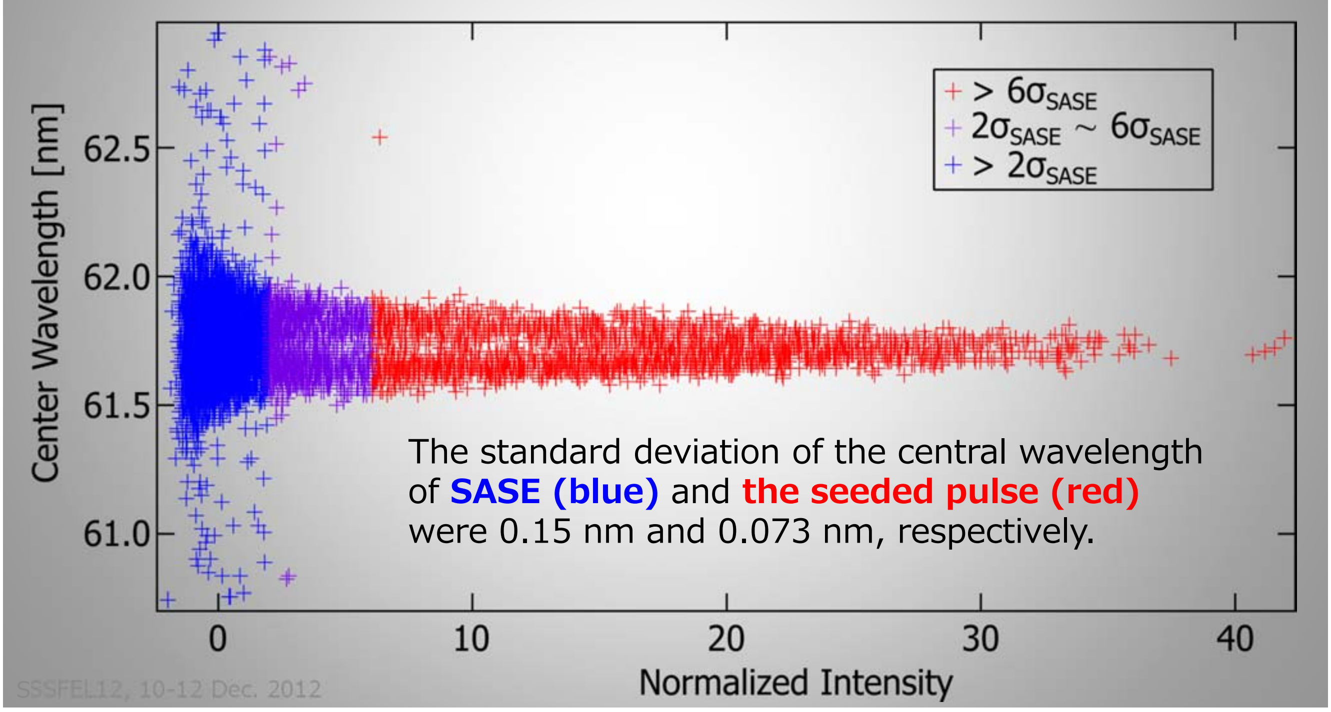
Seeded FEL Performances (2012) (1)



Seeded FEL Performances (2012) (2)

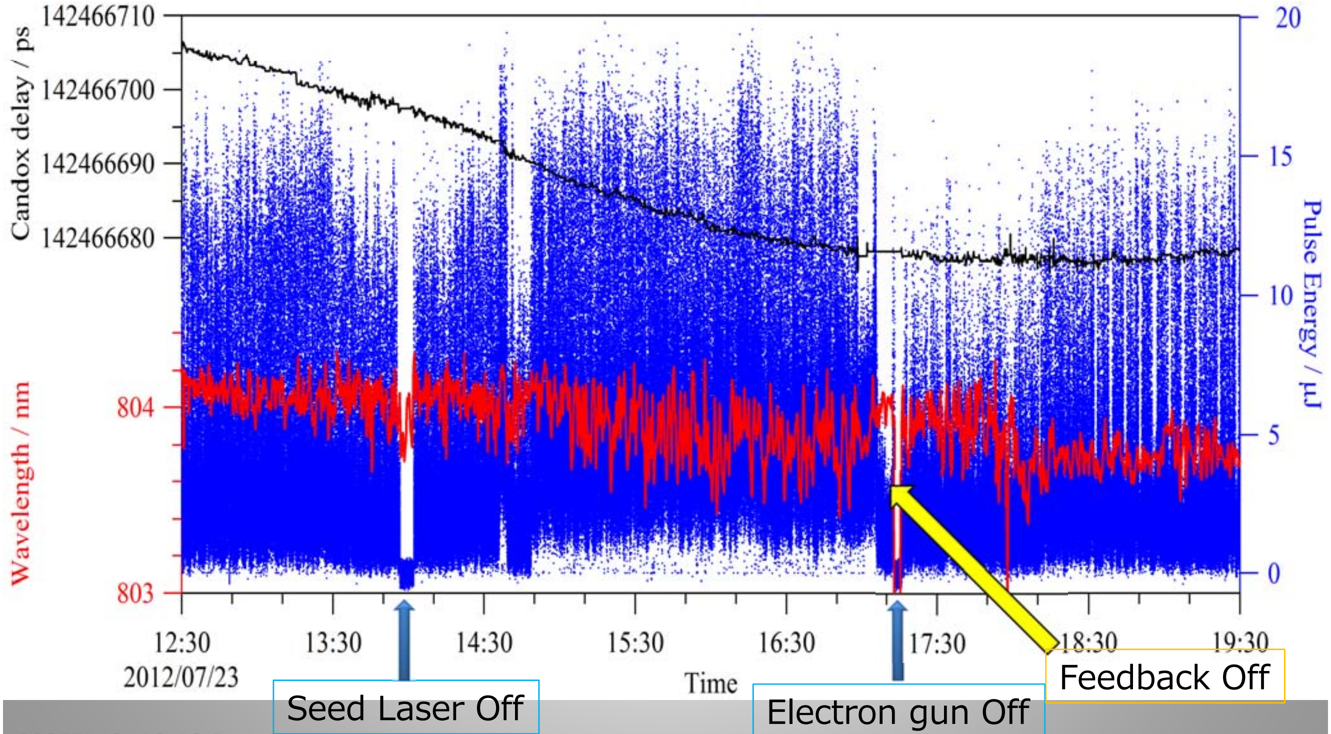
Seeded FEL Performances (2012) (3)

The correlation data plot between the normalized intensity and central wavelength for 10000 shot data



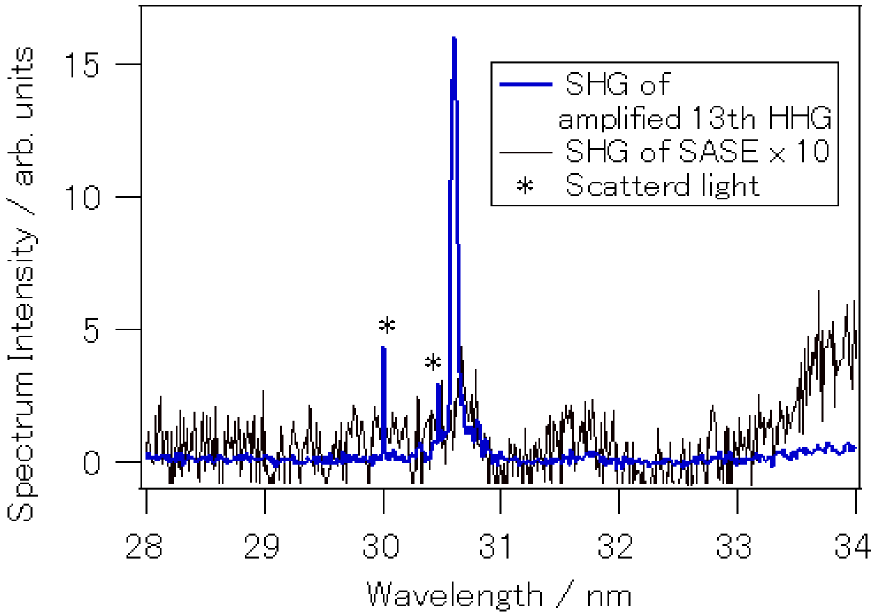
Seeded FEL Performances (2012) (4)

Seeded FEL Long Term Stability



The Second harmonic generation of 61.5 nm

SHG of 13th HHG (30.7 nm) (off axis emission)

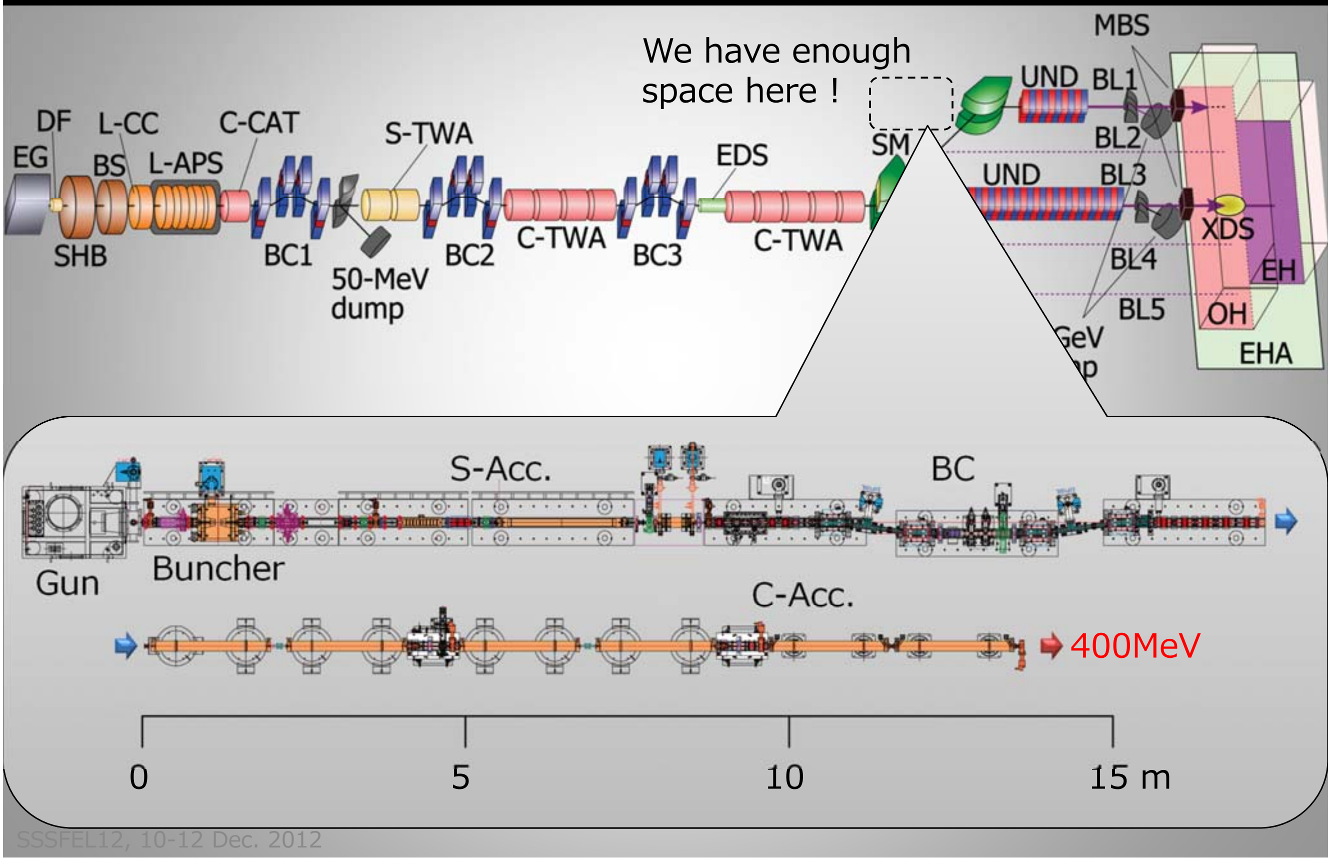


Energy contrast to SASE-FEL > 100

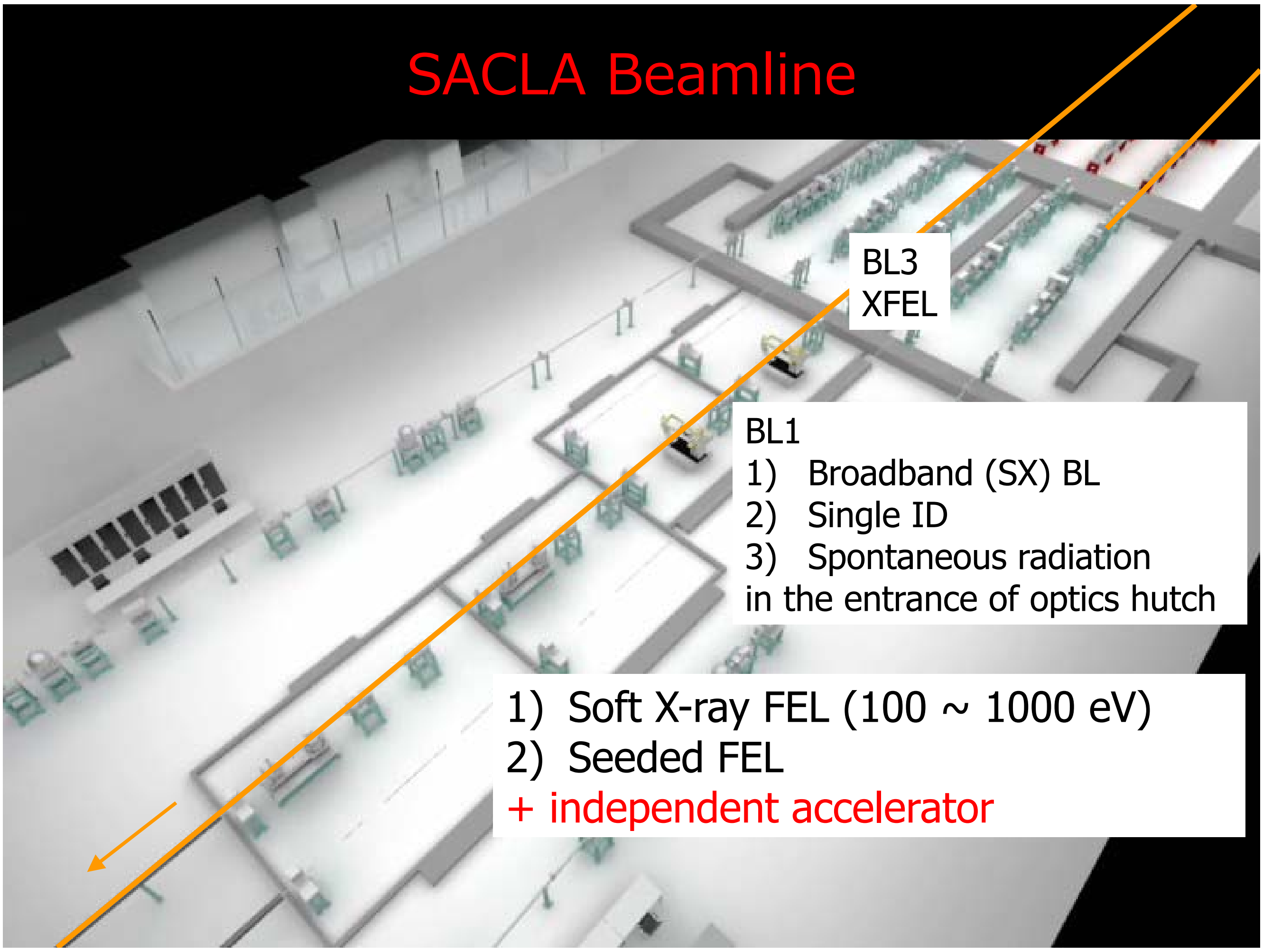
Future Perspective

- SCSS test accelerator is going to be decommissioned in June 2013
- Accelerator components moving to BL1@SACLA (SCSS+)
  – Dedicated beamline to EVU & SXR regions
  – Start with 400 MeV & 30~50 nm, to be extended to 1.4 GeV & **3 nm**
- Seeding method under exploration (self seed, HHG, HGHG,..)

Initial Machine Layout of ***SCSS+***



SACLA Beamline



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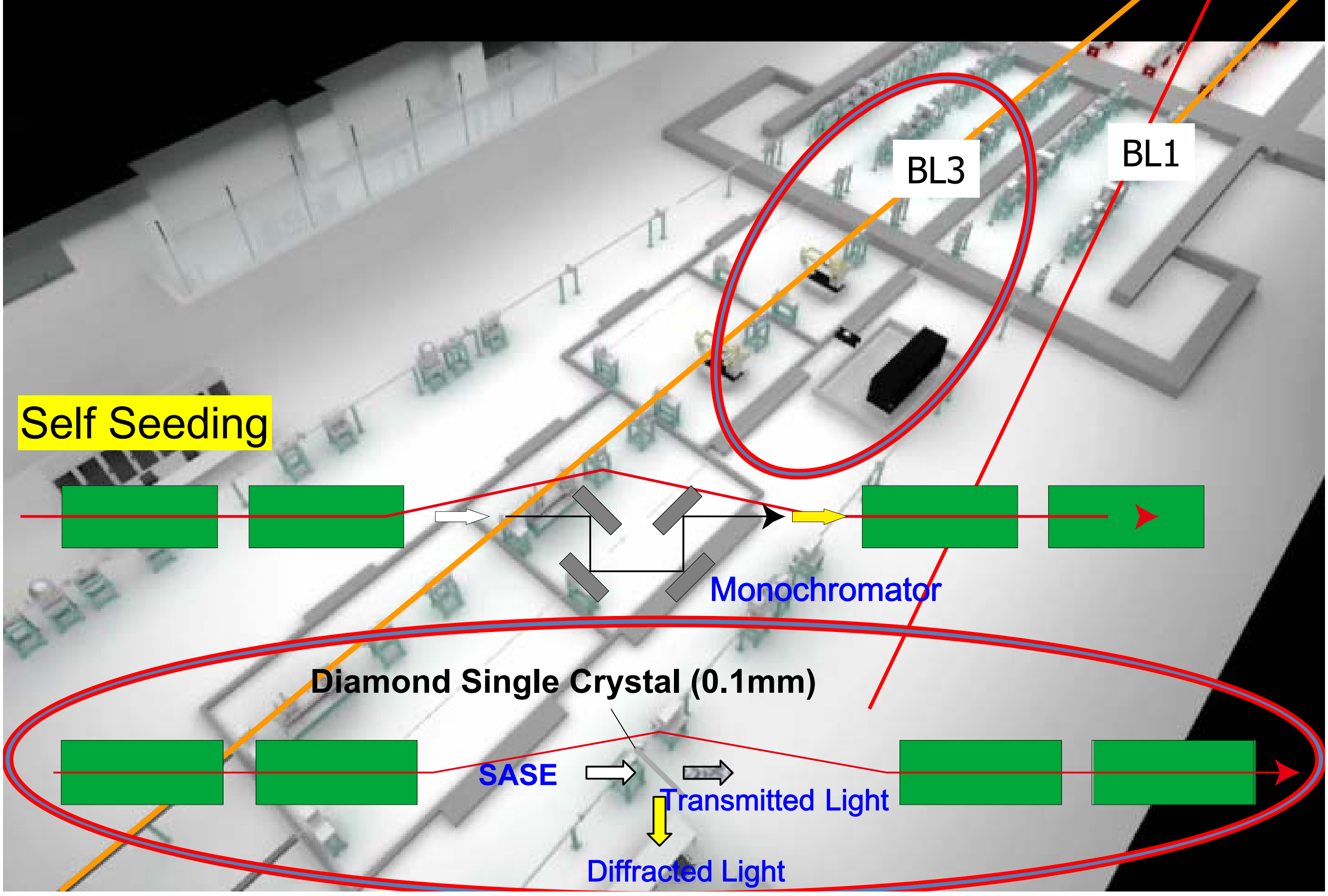
Seeding Option at SACLA

- Upgrade program at SACLA for HXR-seeding in progress
- Successful demonstration of the self-seeding scheme at LCLS urges us to go ahead with the same (?) scheme
- Numerical study to optimize the self-seeding configuration finished (preliminary)

SACLA Beamline



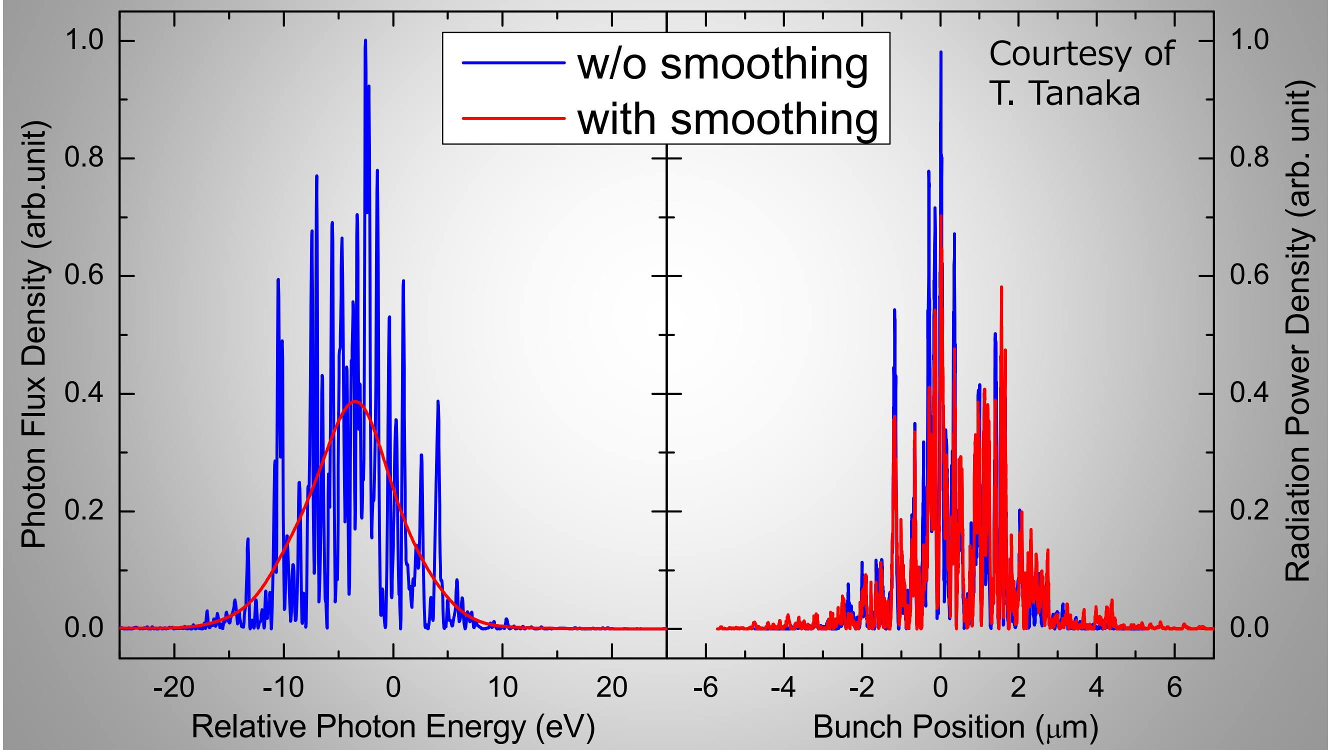
Numerical Technique for Optimization

- Introduction of "Mode Energy" as a figure of merit for seeded FEL

$$E_{mode} = \frac{E_{pulse}}{M_T} \quad \begin{array}{l}\text{(pulse energy)} \\ \text{(\# temporal modes)}\end{array}$$

- Numerical operation for smoothing the spiky SASE spectrum
  - Simulate the averaged seed power after the monochromator
  - Apply LPF on the complex amplitude of radiation with the phase kept unchanged

Numerical Smoothing Example



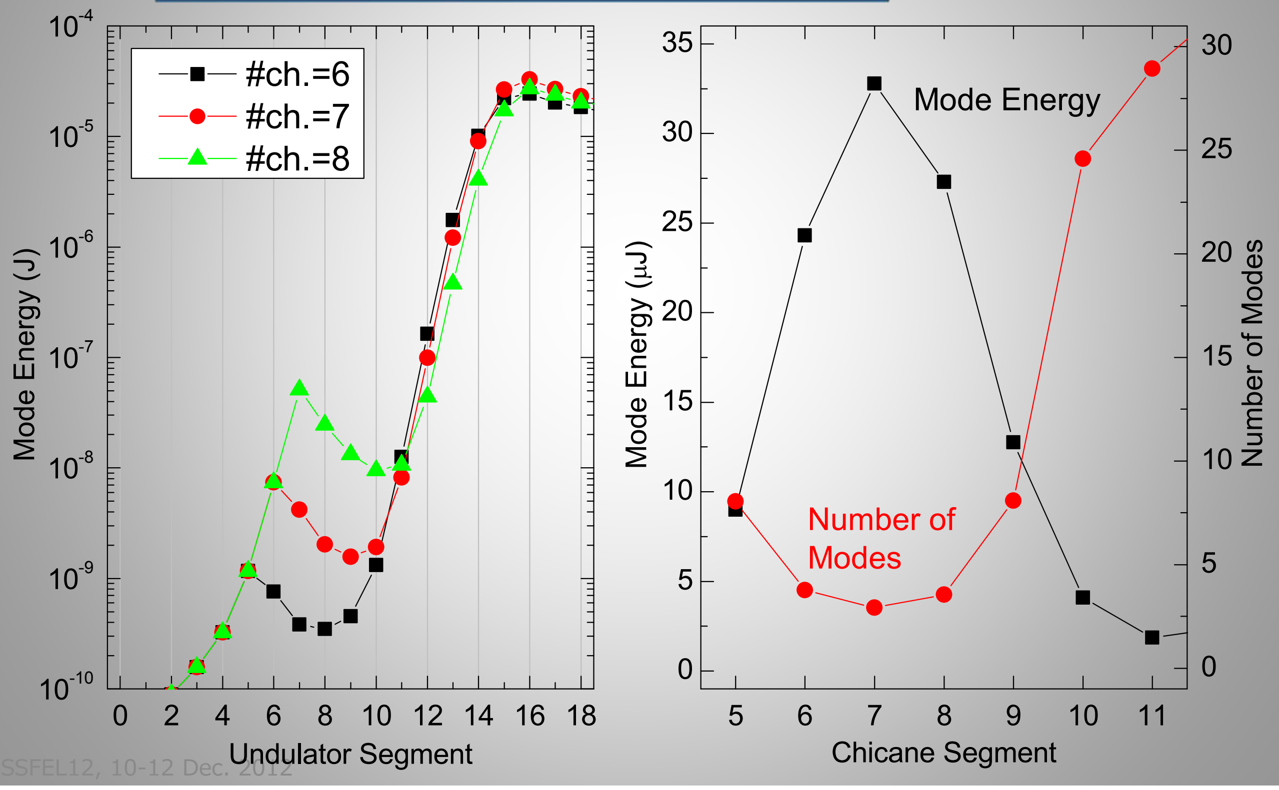
What to Optimize?

- Monochromator configuration
  - C (400): transmission (as in LCLS)
  - C (400): reflection
  - Si (111): reflection
- Position of SS chicane (to be replaced with an undulator)
- Undulator taper and extra undulators to be added

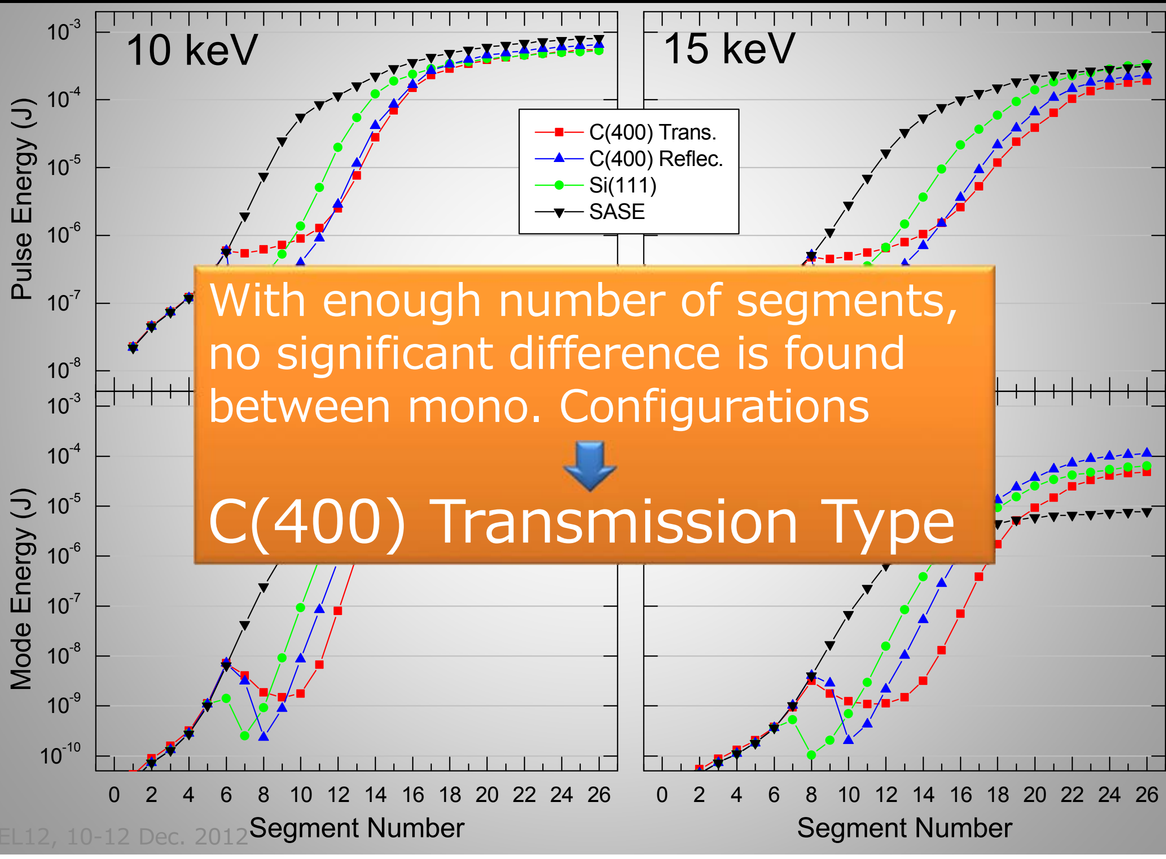
Segment for Chicane Insertion

C(400), Transmission, 10keV, Δt optimized

Courtesy of T. Tanaka



Monochromator Configuration

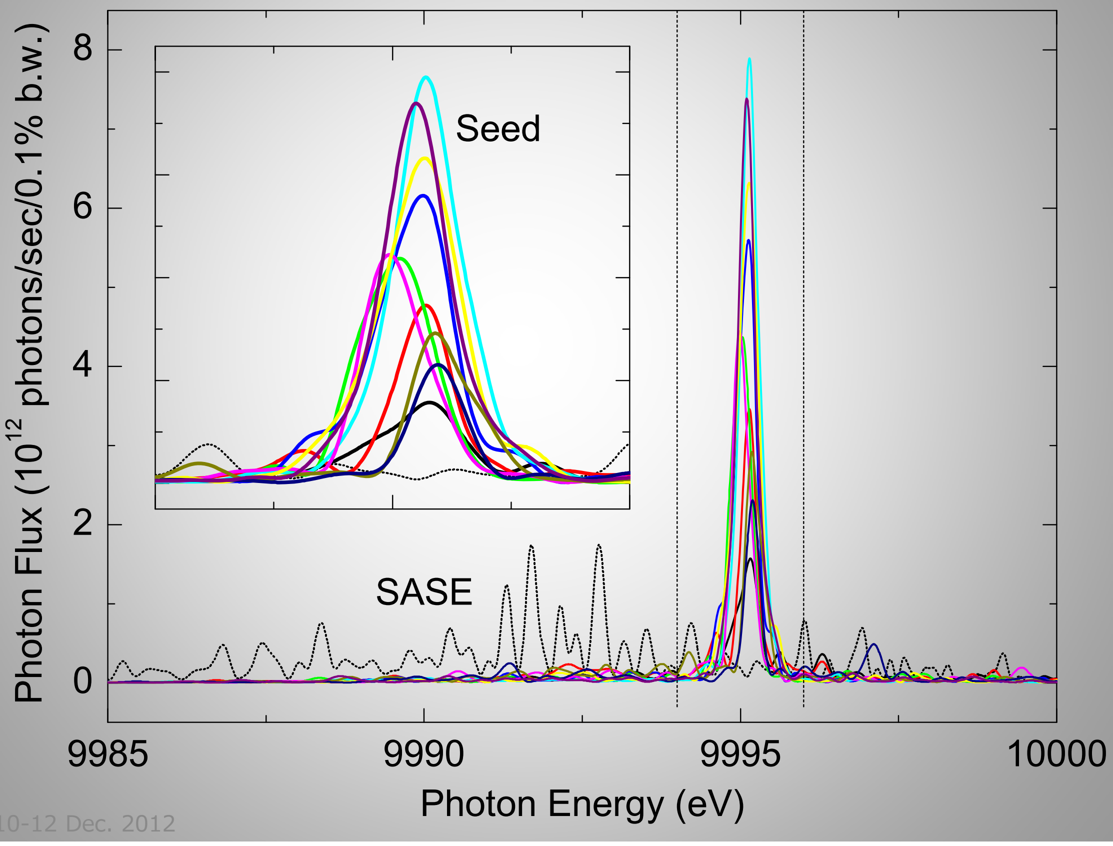


With enough number of segments, no significant difference is found between mono. Configurations

C(400) Transmission Type

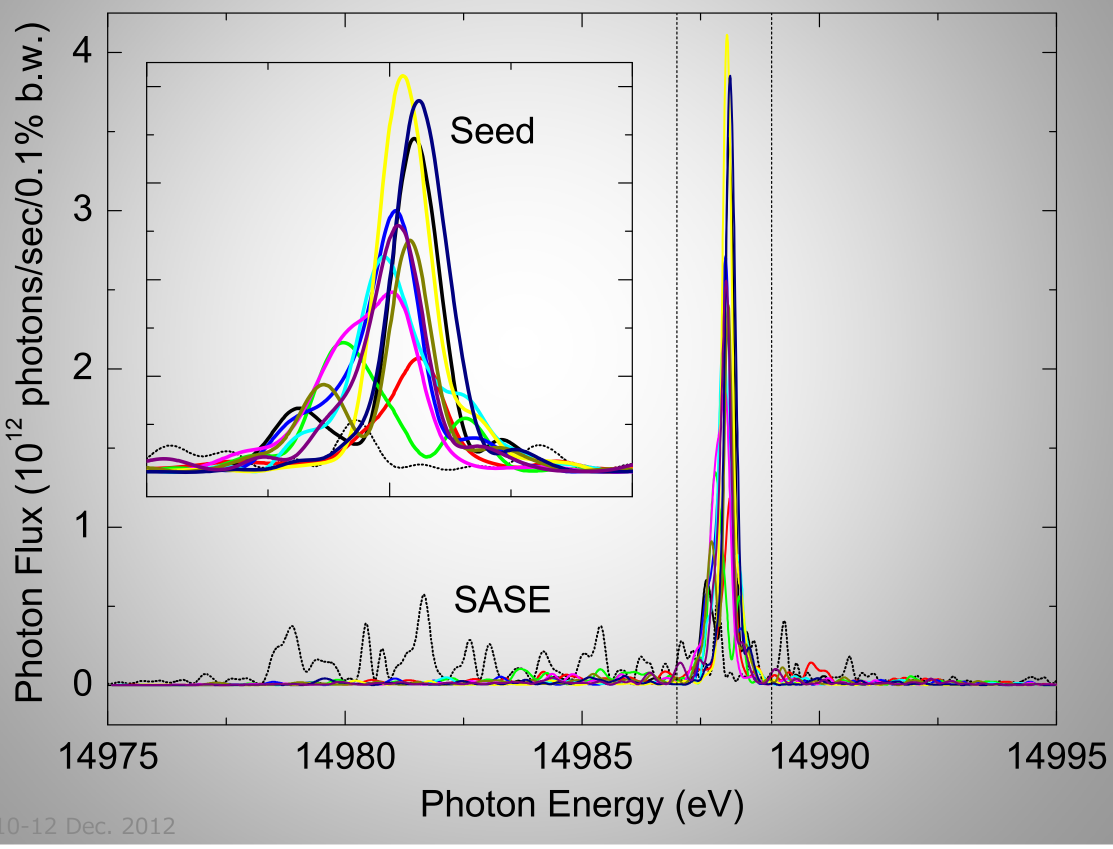
Courtesy of T. Tanaka

Expected Performance (10keV)



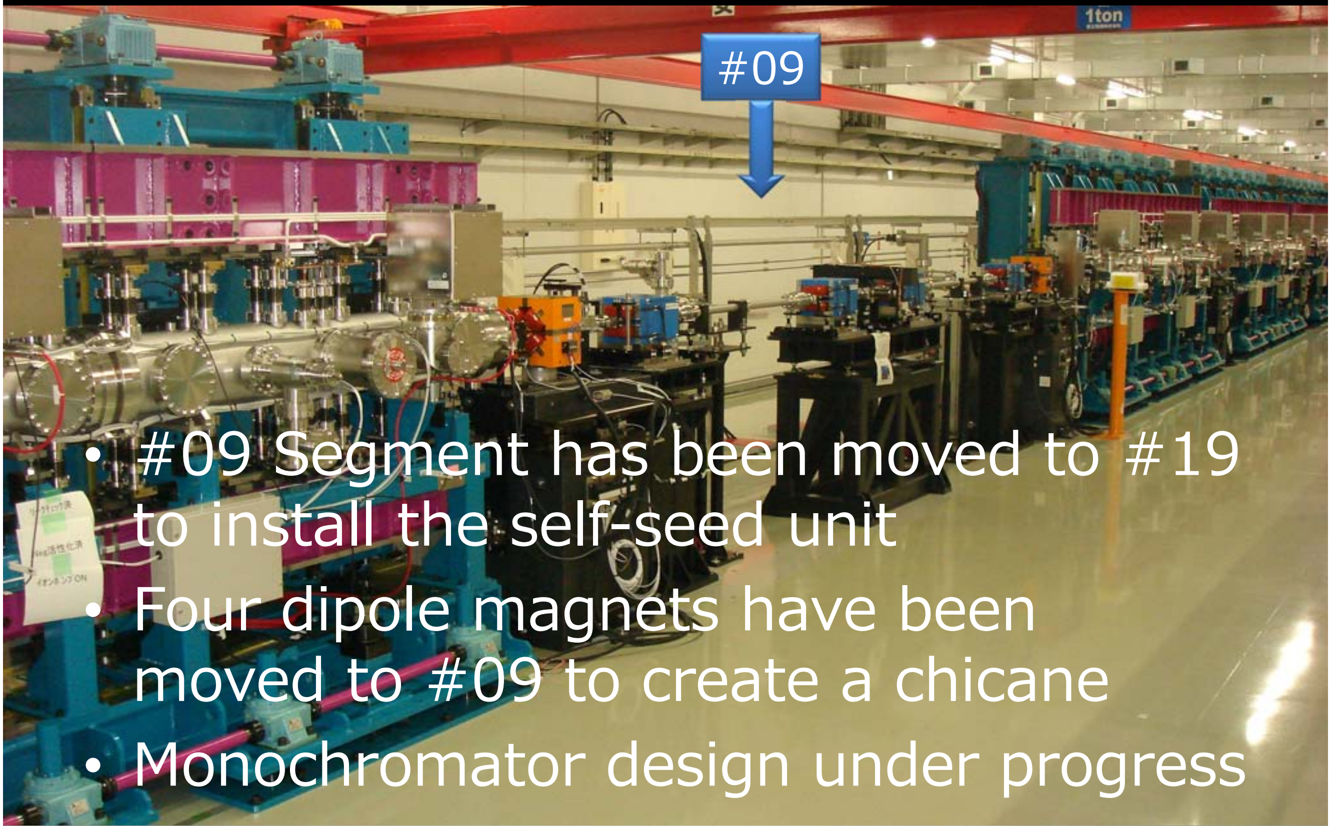
Courtesy of T. Tanaka

Expected Performance (15keV)



Courtesy of T. Tanaka

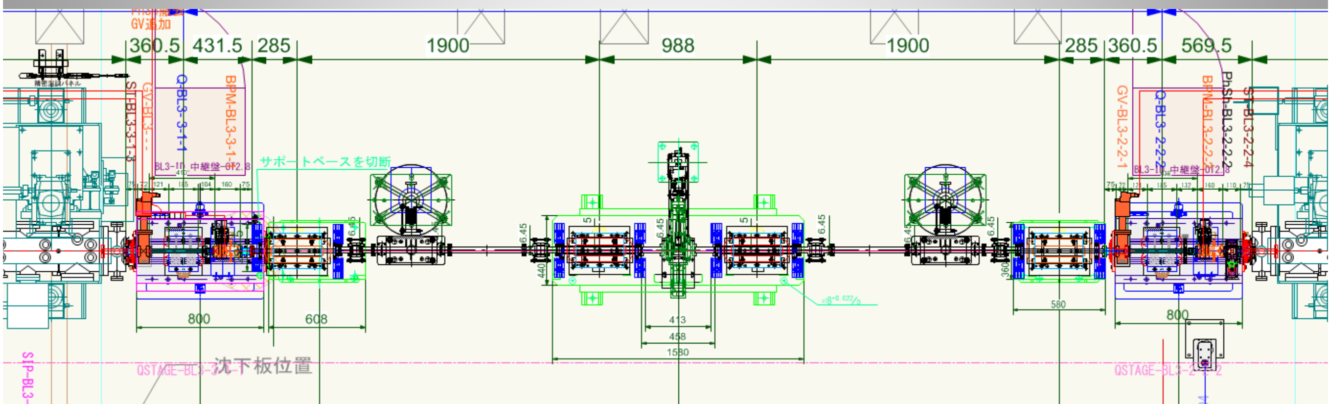
Current Status toward Self-Seeding



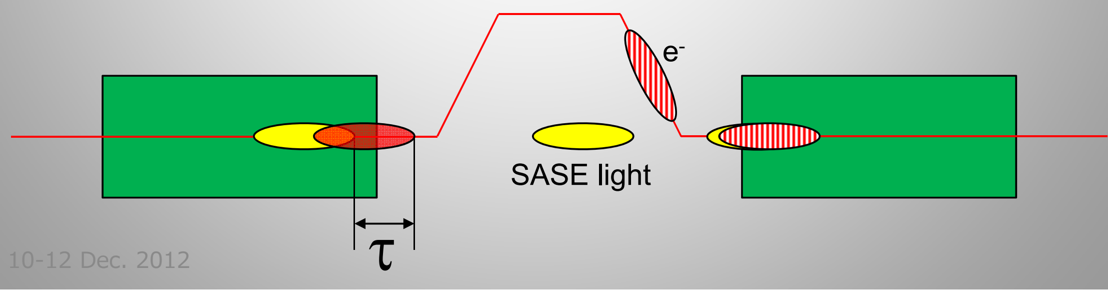
- #09 Segment has been moved to #19 to install the self-seed unit
- Four dipole magnets have been moved to #09 to create a chicane
- Monochromator design under progress

Pulse Length Estimation with Chicane*

*Gianluca Geloni, Vitali Kocharyan and Evgeni Saldin, “Ultrafast X-ray pulse measurement method”, DESY10-008

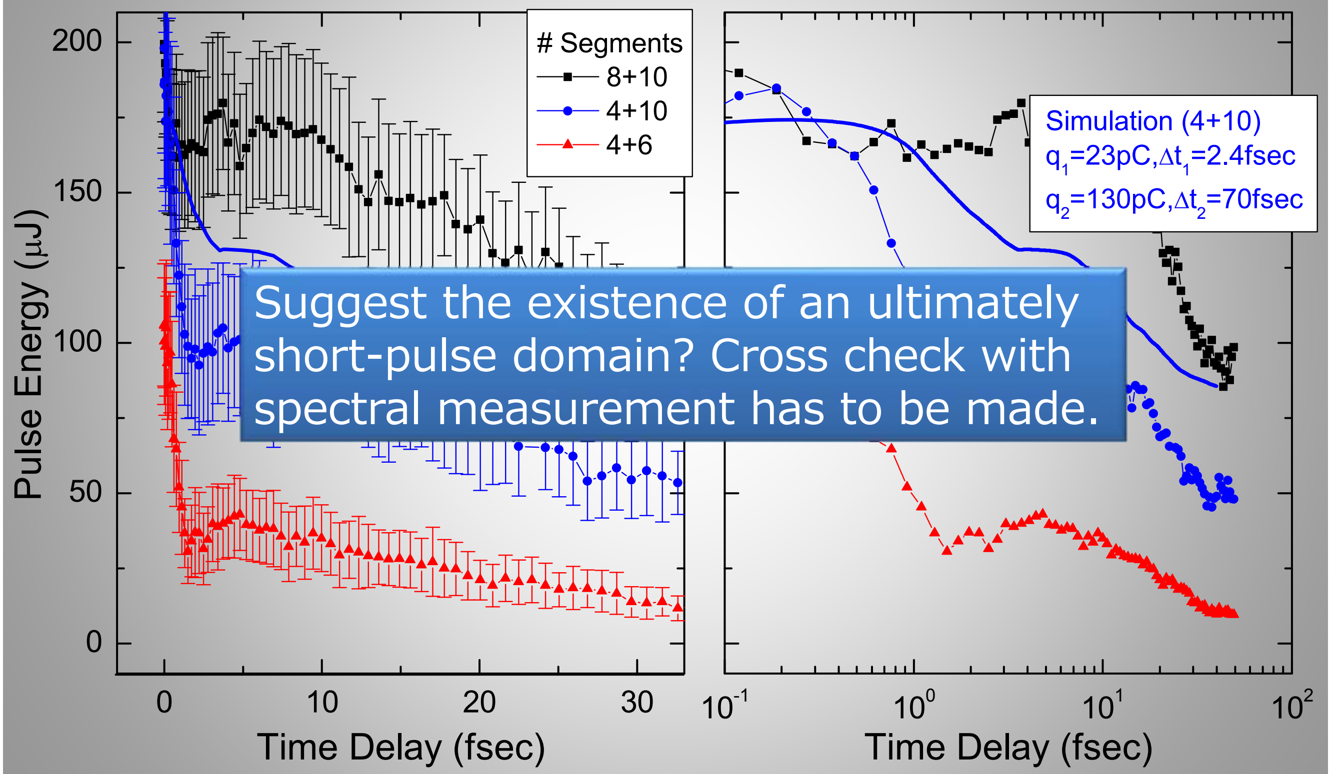


Self-Seeding scheme is also self-calibrated system!



SSSFEL12, 10-12 Dec. 2012

Experimental Results



Suggest the existence of an ultimately short-pulse domain? Cross check with spectral measurement has to be made.

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Summary

- In SACLA, two seeding options have been explored intensively :
  - EUV and SXR-region: HHG Seeding
  - HXR-region: Self seeding
- Recent R&D to improve the hit rate at the SCSS test accelerator has proven the capability of HHG seeding
- Commissioning for HXR-self seeding is scheduled next September, after installation of the monochromator

Seeding results with EO-Timing feedback