Beam commissioning of SACLA Soft X-ray FEL beamline driven by a compact dedicated linac

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SPring-8 angstrom compact free electron laser

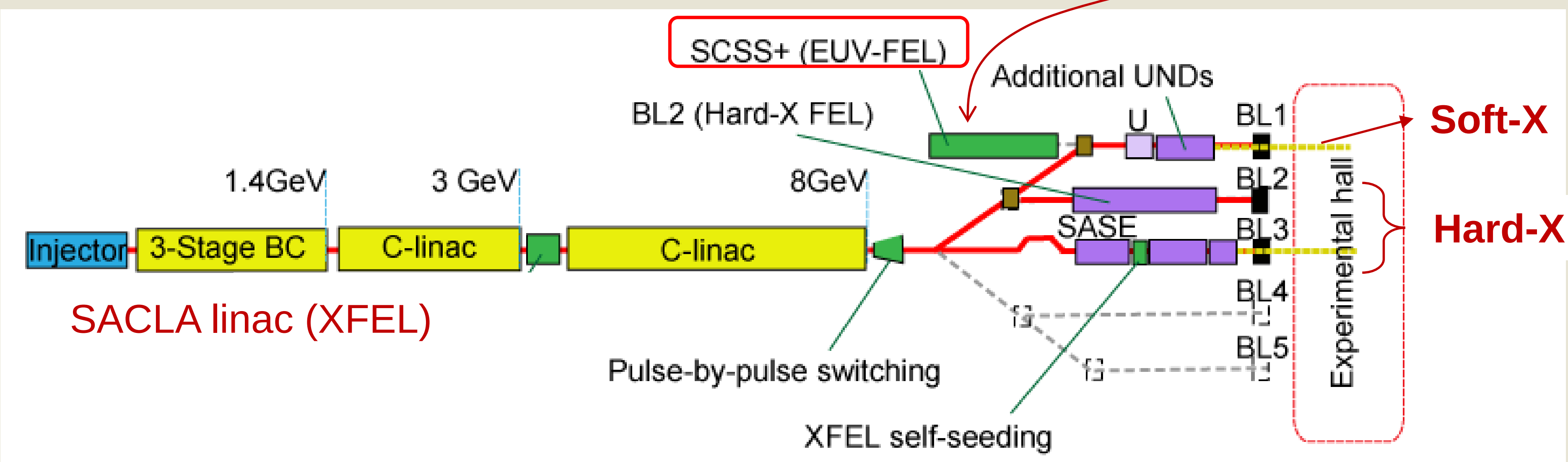
Outline

- Overview of the soft X-ray FEL beamline in SACLA
- Accelerator commissioning
- SASE performance
- Summary

Soft X-ray FEL beamline in SACLA

SCSS
(2005-2013)

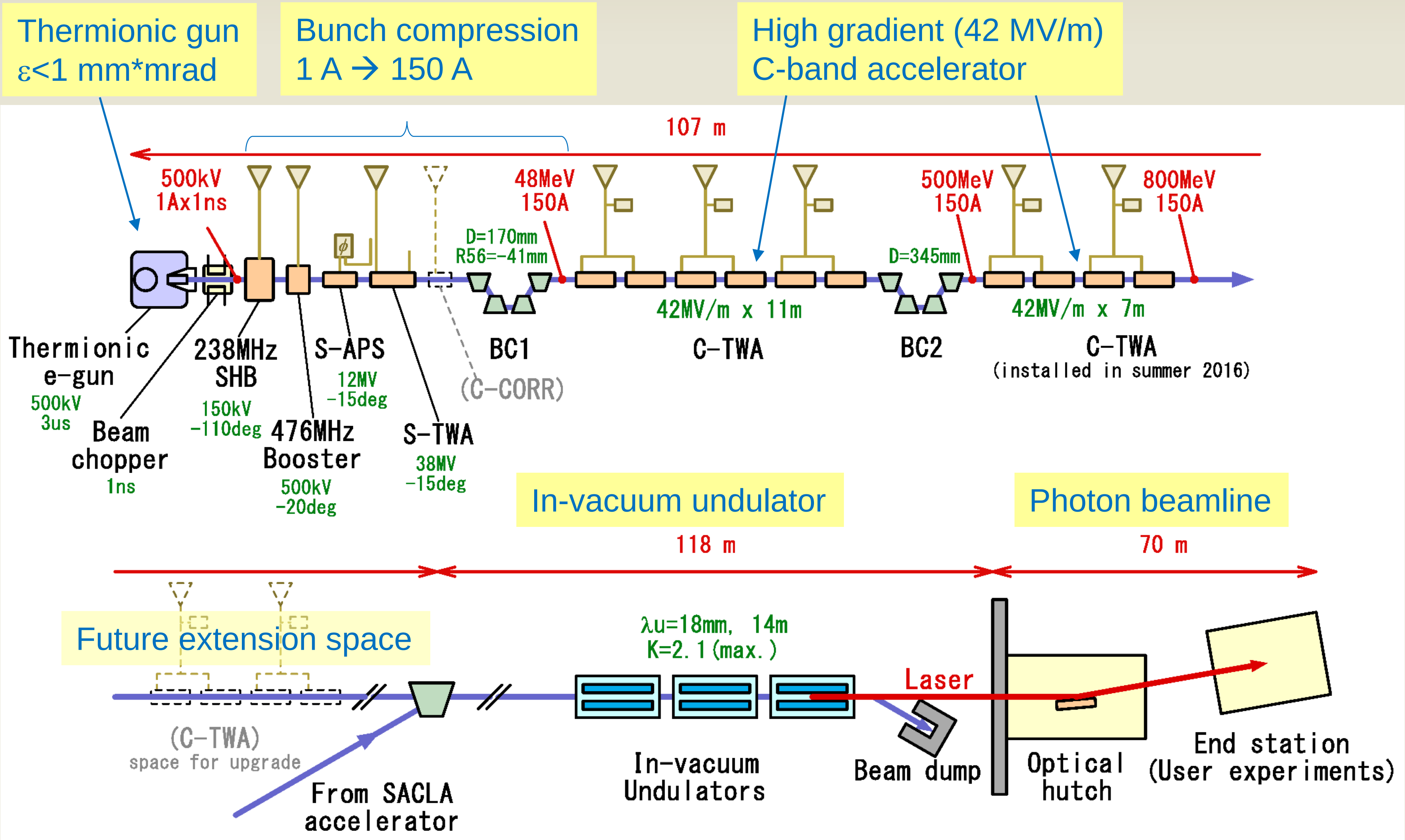
- 2005-2013 Prototype accelerator "**SCSS**"
- Move to **SACLA-BL1** and rearranged as "**SCSS+**".
  - Add accelerator: 250 MeV → 500 MeV
  - Add undulator: λ_u=15mm, K=1.5, 9m → λ_u=18mm, K=2.1, 14m
  - Replace LLRF and HVPS for better stability and reliability.
- 2015 "SCSS+" commissioning started. Lasing at 40 eV.
- 2016 User run started. 500 MeV → 800 MeV, .



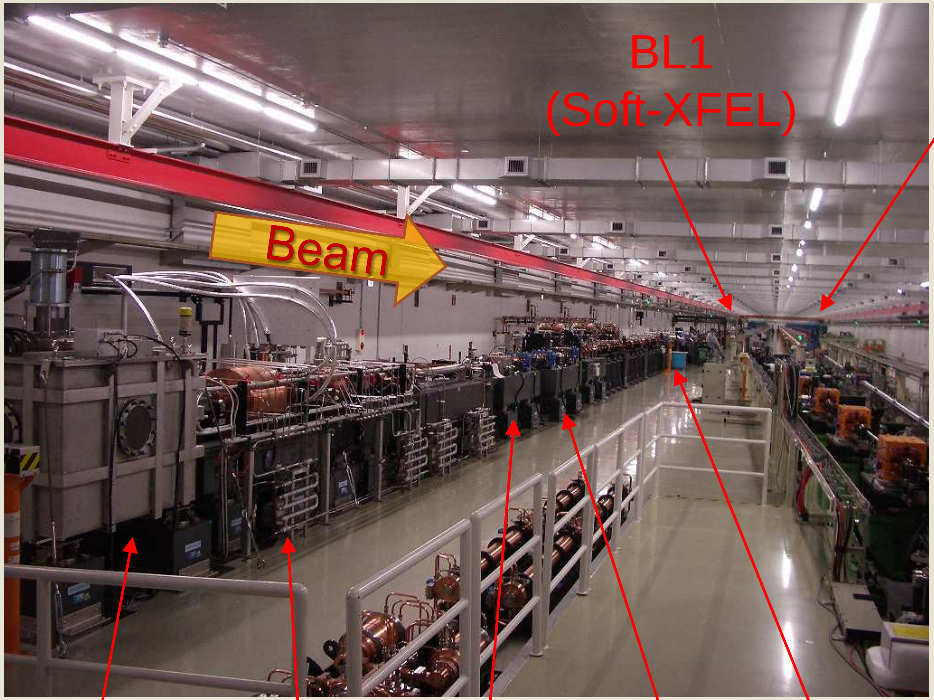
Operation parameters

		SCSS+ / BL1	SACLA（BL3）
Electron beam	Energy	350～800 MeV	5～8 GeV
	Charge	250 pC	250 pC
	Peak current	～150 A	～10 kA
	Bunch length	600 fs (FWHM)	～10 fs (FWHM)
	Repetition rate	60 pps	30～60 pps
Undulator	Undulator length	14 m	106 m
	Undulator	18 mm	18 mm
	K-value	1.5～2.1	1.5～2.6
FEL	Photon energy	20～110 eV (60～11 nm)	5～15 keV (0.2～0.08 nm)
	Pulse energy	～25 μJ/pulse	～600 μJ/pulse

SCSS+ accelerator configuration



Photograph of the accelerator and undulator



SACLA-BL3
(Hard-XFEL)

E-gun
Buncher cavities
BC1
C-band linac
BC2

Beam dump
In-vacuum undulators
Front-end

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Accelerator commissioning & diagnostics

- Sept. 2015~ beam commissioning in a similar way to SCSS and SACLA.
- Oct. 2015 First SASE lasing at 40 eV, with 500 MeV beam.
- Transverse property of the beam
  - Trajectory Cavity-BPM
  - Envelope Screen monitor (Alumina, OTR, YAG)
  - Charge CT, Cavity-BPM
  - Beam loss Fiber loss monitor
- Longitudinal property of the beam
  - Beam energy Chicane (BC1, BC2) magnets
  - Bunch length No temporal deflection cavity in SCSS+

    Fast CT several 100 ps

    Coherent TR monitor ~several 10 ps

    RF zero phasing method ~ sub ps

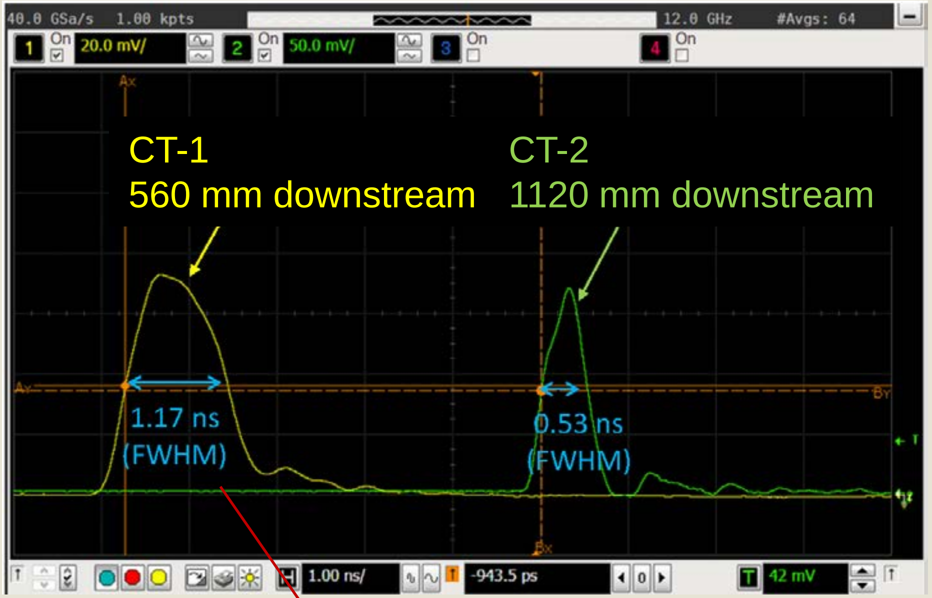
    Streak camera ~ several 100 fs

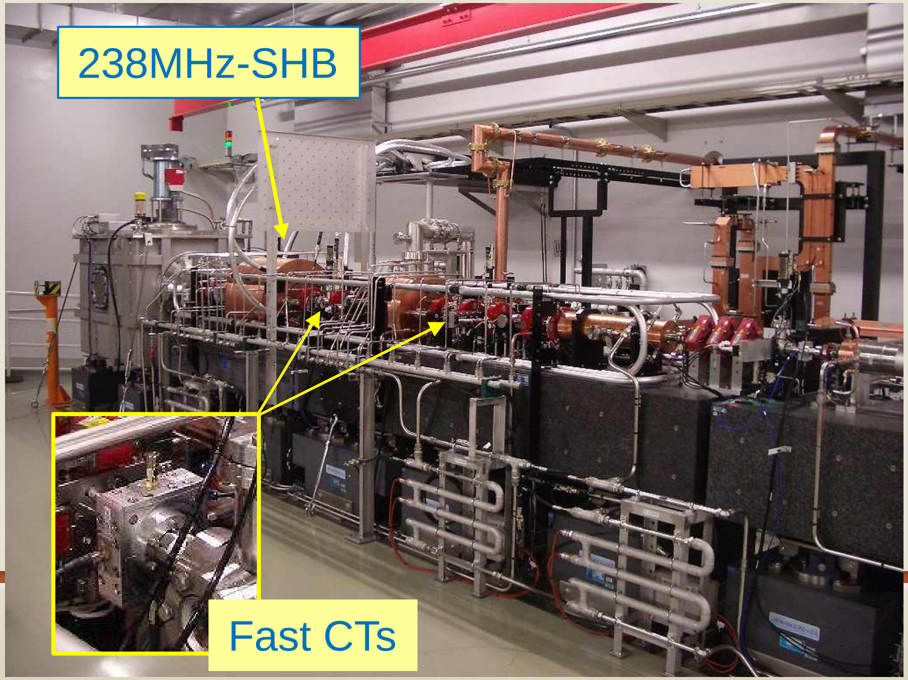
    CSR monitor

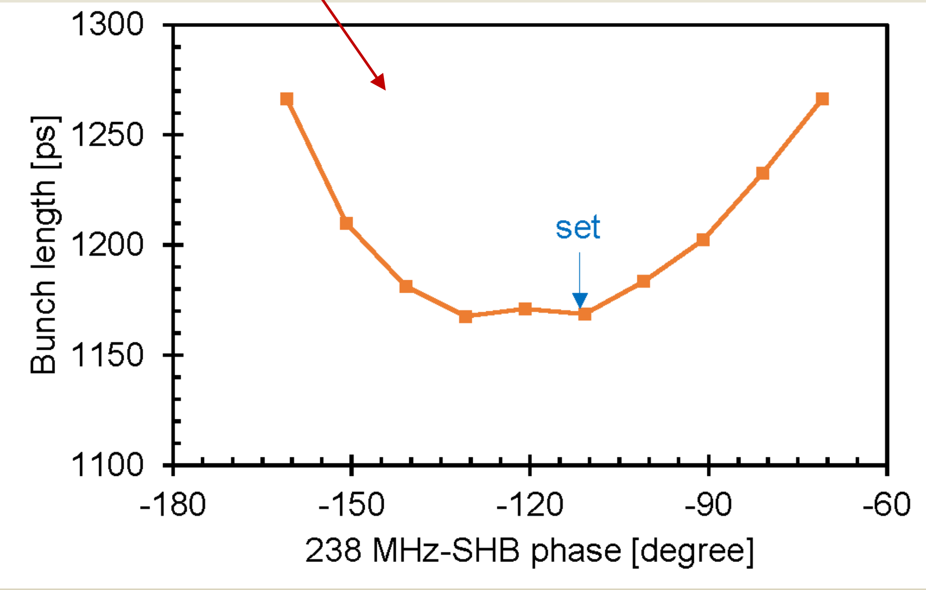
We show in next slides…

Tuning of velocity bunching at 238 MHz-SHB

- Energy chirp ±150 kV
- Measure the pulse width of two CT signals.
- Adjust RF phase to compress the bunch length.

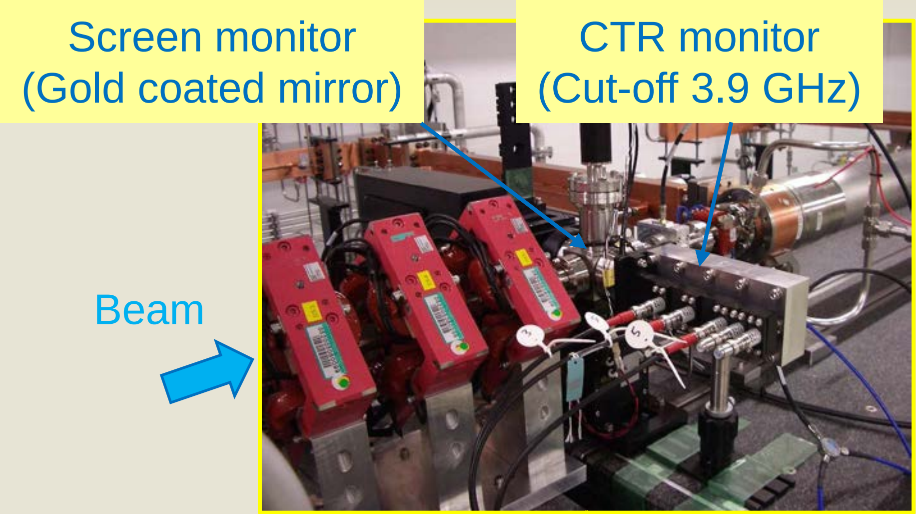


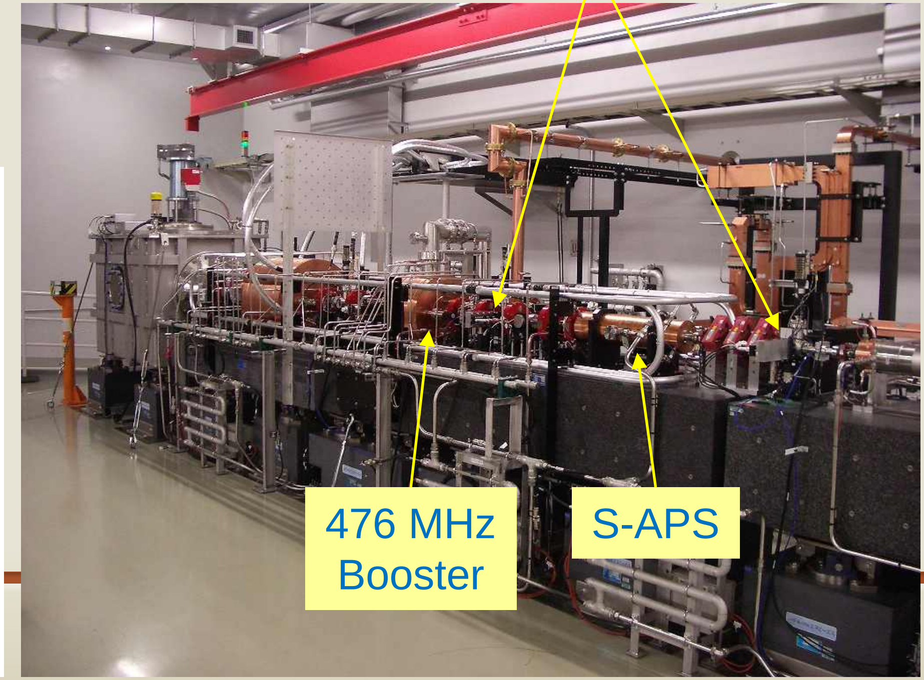


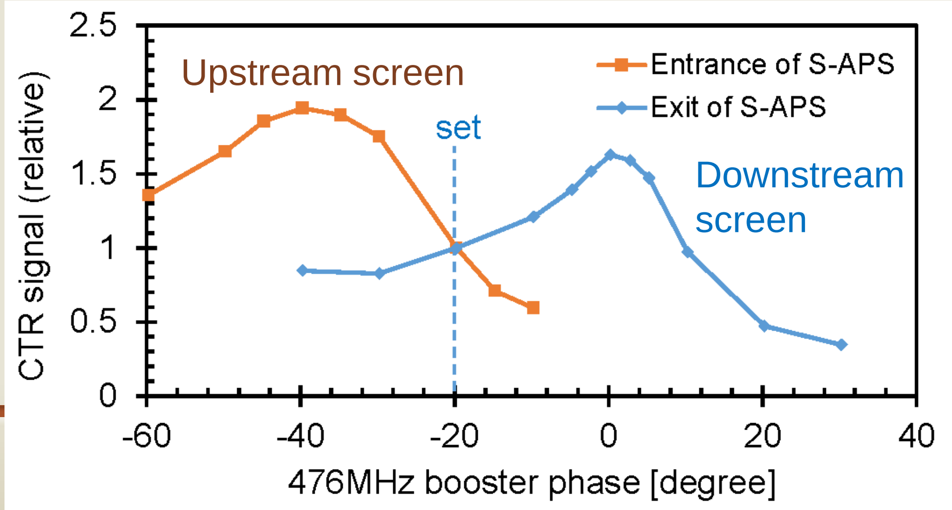


Tuning of velocity bunching at 476 MHz Booster

- Accelerates the beam to 1 MeV and adjust the focal point of the velocity bunching.
- Compressed bunch emits coherent transition radiation (CTR) at two screen monitors.
- CTR is detected with waveguide cut-off filters.

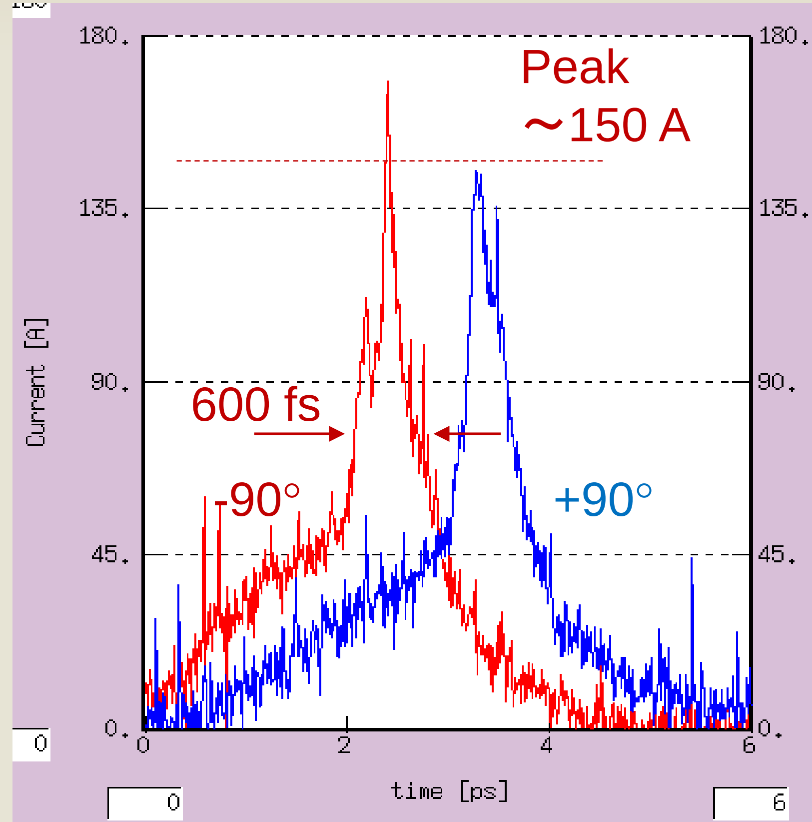


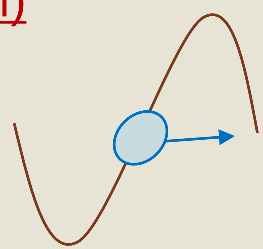


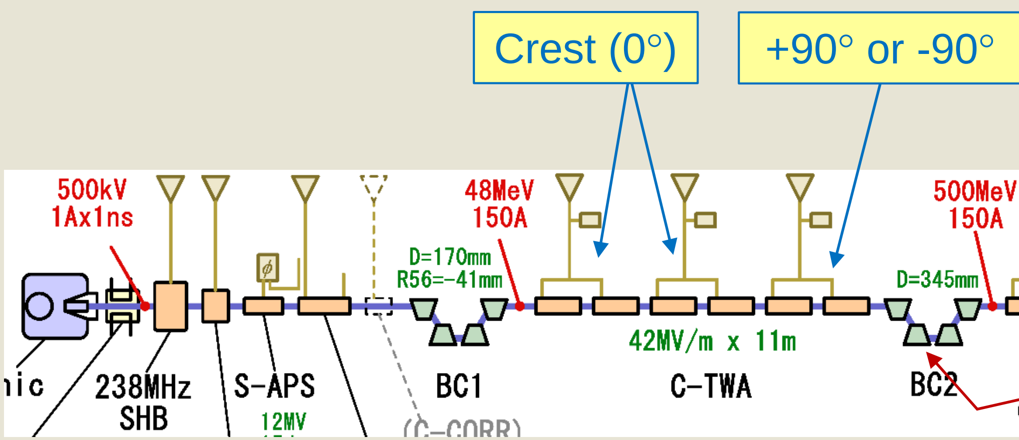


Bunch length measurement after BC1

- One of the C-TWA is set at +90° or -90° from the crest.
- Temporal coding as an energy chirp.
- Energy distribution is measured at BC2.
- **Bunch length 600 fs** (FWHM)
- **Peak current 150 A**







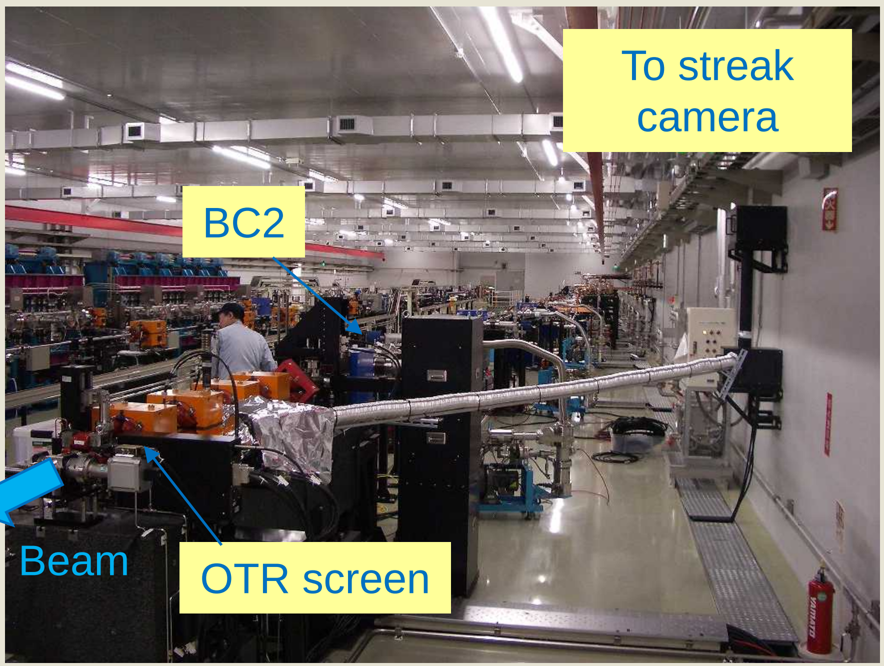
Measure the energy profile at the screen monitor.

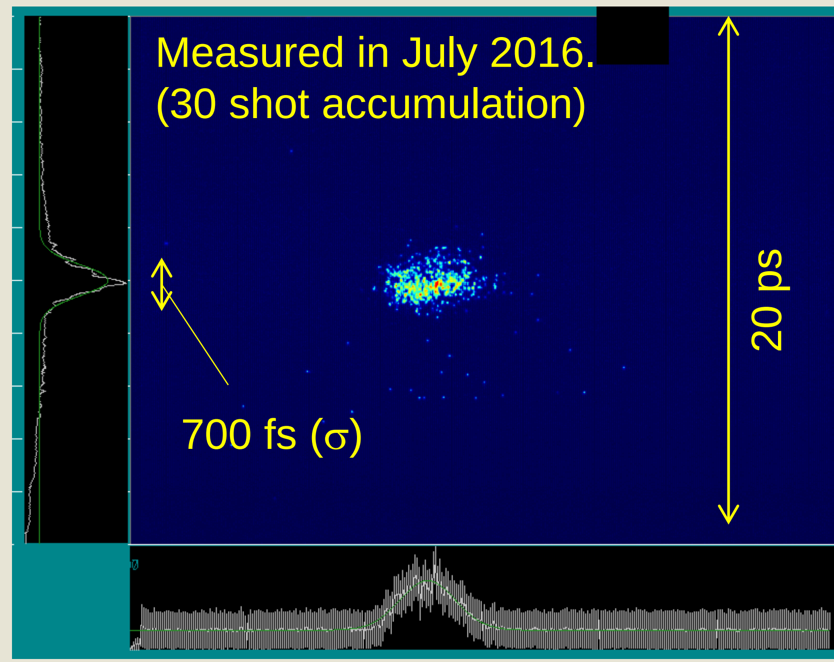
Bunch length measurement using streak camera

- Measure temporal width of OTR using Hamamatsu FESCA-200.
- Since OTR is weak, image of 30 shots are accumulated.

(align the center of the distribution in each shot, for timing jitter correction)

- Temporal resolution ~ several 100 fs.





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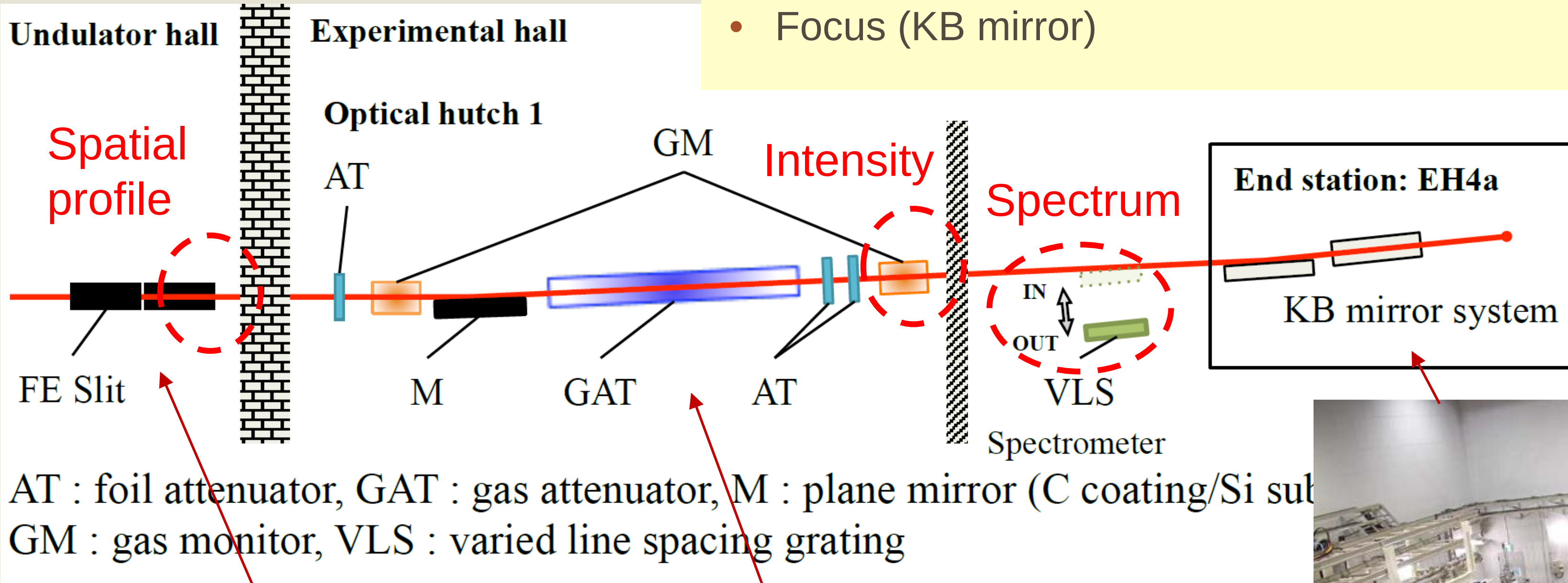
Photon beamline at BL1

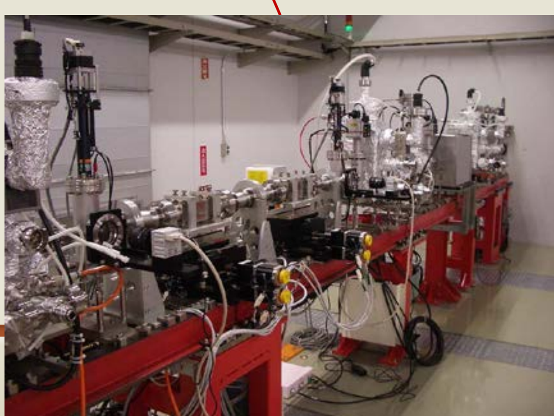
Transport & handling

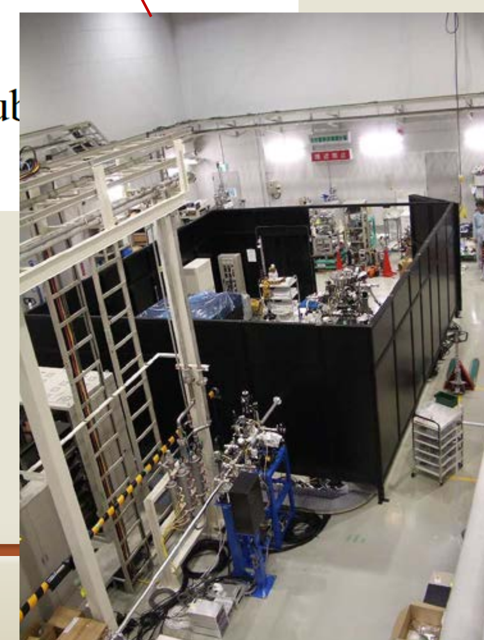
- Front end slit
- Mirror
- Attenuator (gas, foil)
- Focus (KB mirror)

Diagnostics

- Gas intensity monitor
- YAG screen monitor
- Spectrometer

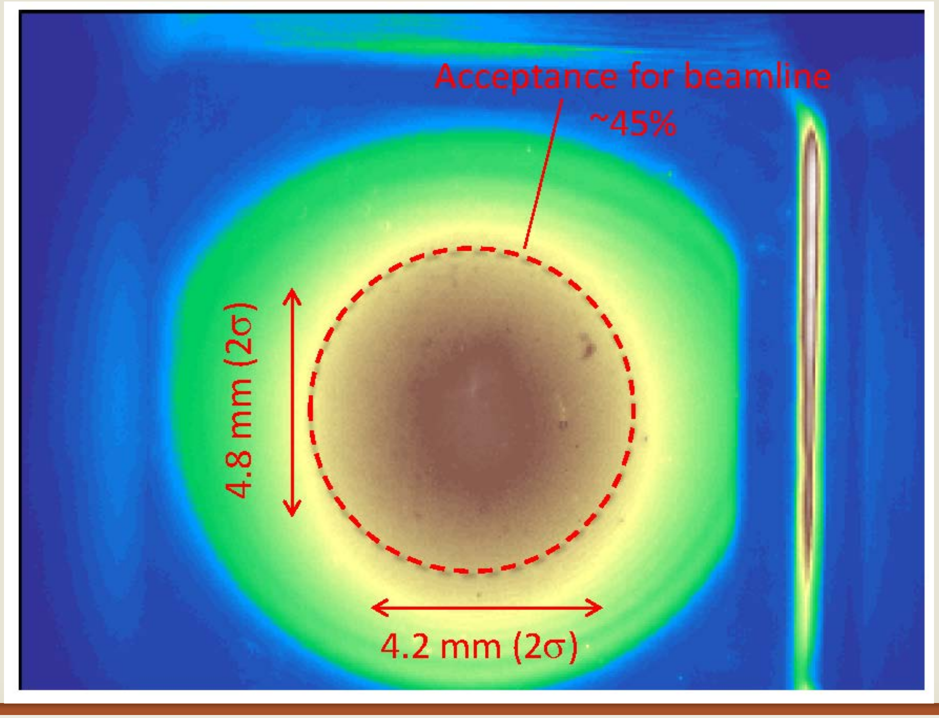






SASE spatial profile at YAG screen monitor

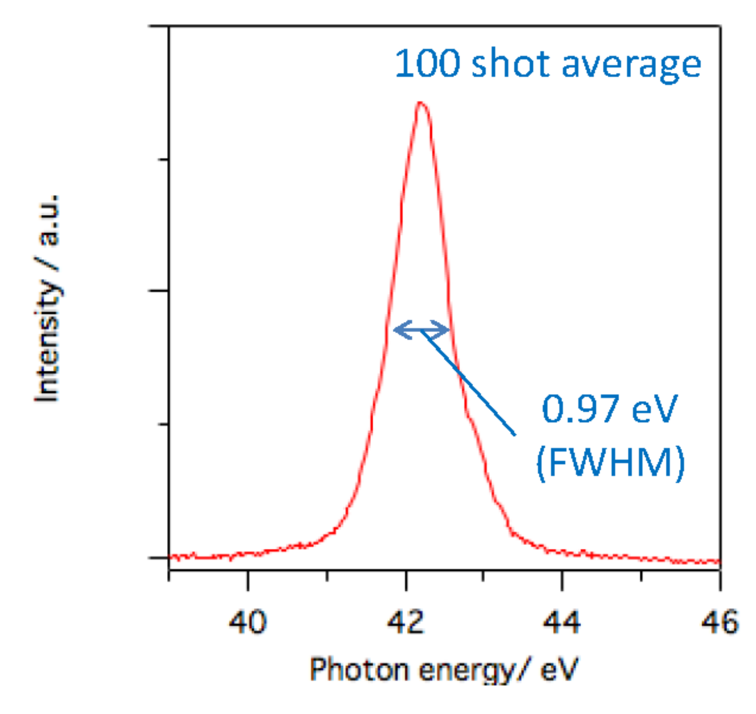
- Large photon divergence, due to low energy
- Small aperture (ϕ 6 mm) at the gas attenuator cuts the SASE.
  - 42 eV（K=2.1)　　　Transmission ～45%
  - 62 eV（K=1.5）　　　Transmission　70～80%
- We plan to replace the small aperture.



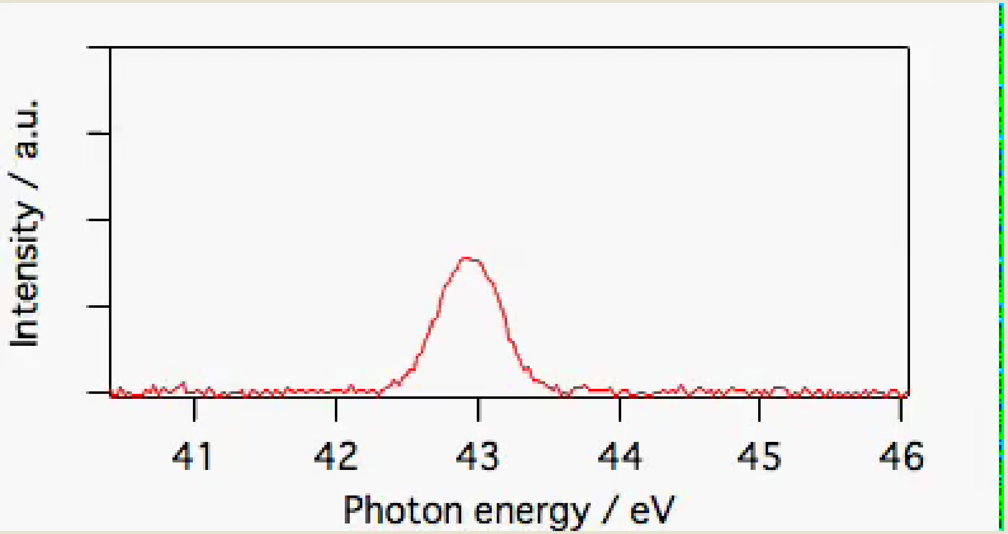
Spatial profile after front-end slit
42 eV

SASE energy spectrum

- Grating-type singleshot spectrometer
- Spectral width ～1 eV (FWHM)
- Photon energy is stable within the spectral width.



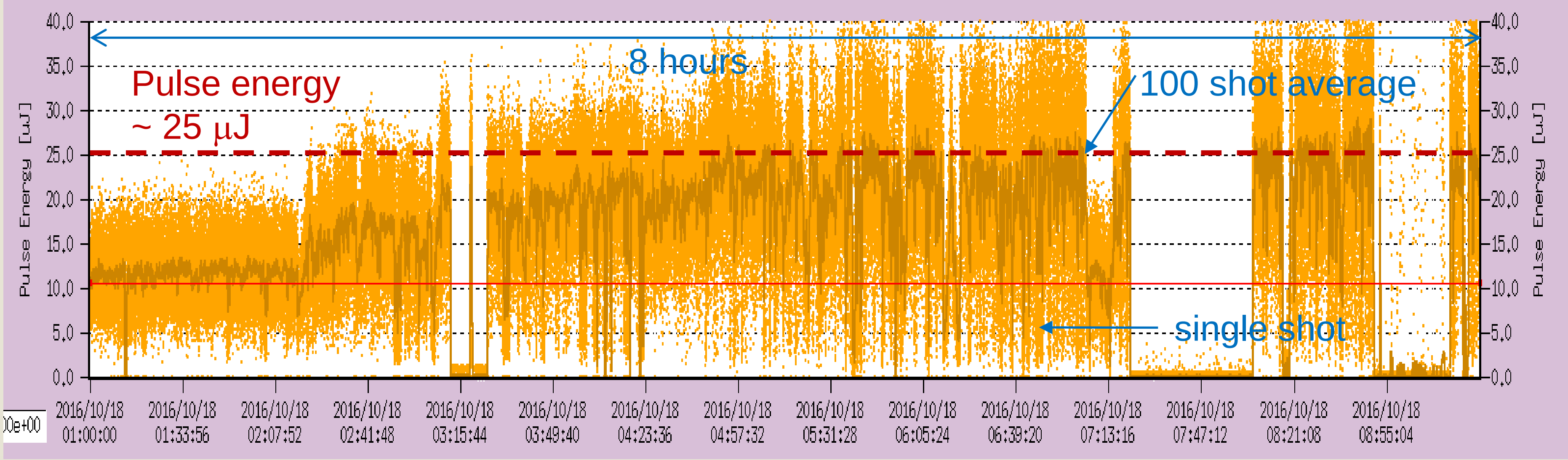
Single shot spectrum



SASE intensity (pulse energy) at 41 eV

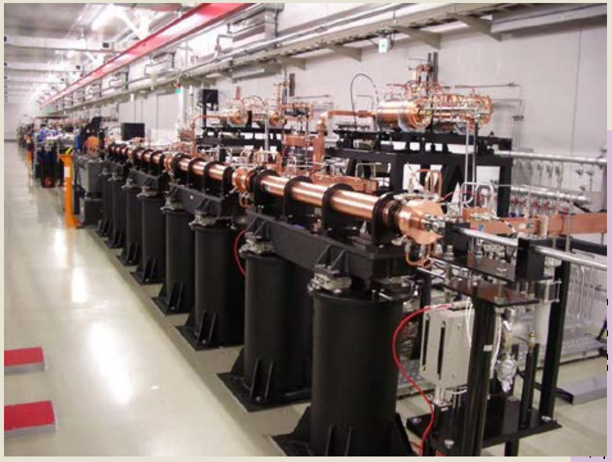
- Monitored with two argon gas monitors.
- Absolute intensity was calibrated with calorimetric method.
- Typical pulse energy ~25 μJ at experimental hall (50 μJ at undulator)
- Shot-by-shot fluctuation～30%（σ） SASE is not saturated?

Trend graph of the pulse energy
500 MeV, K=2.1, 41 eV



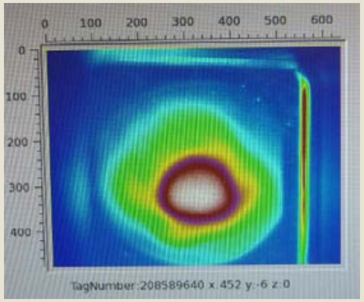
Beam energy upgrade (500 MeV → 800 MeV)

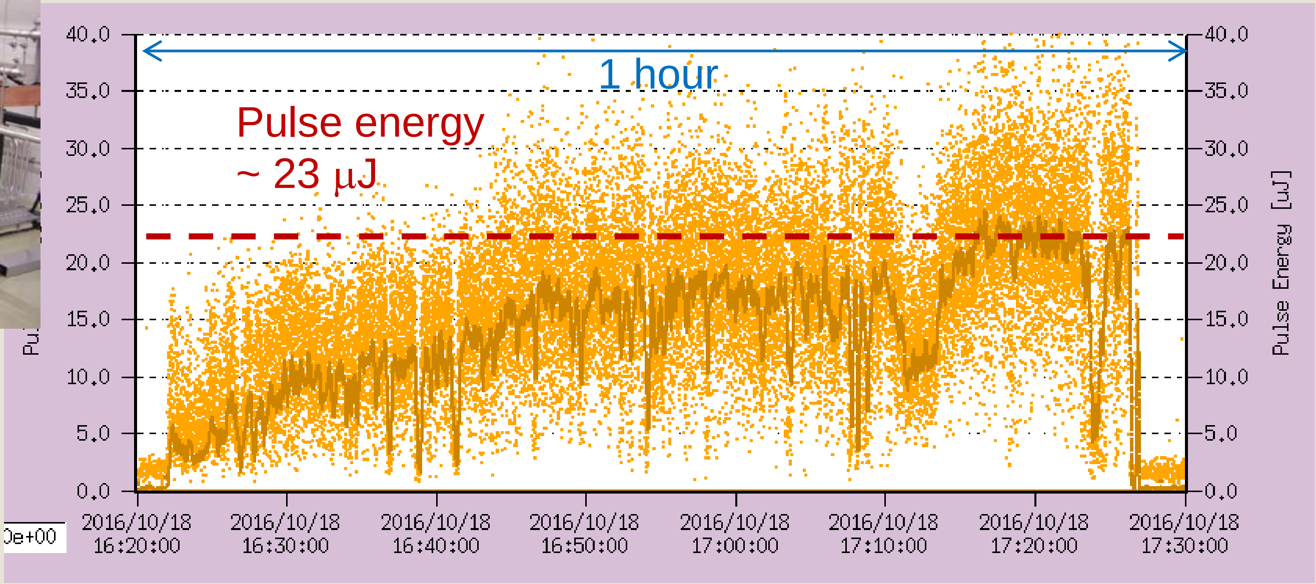
- Two C-band linac units was installed in this summer.
- Last week we started the commissioning with 800 MeV beam energy.
- Photon energy 110 eV (11 nm) (preliminary)
- SASE pulse energy ~ 23 μJ (preliminary)



C-band linac
42 MV/m,1.8 m x 4 columns

SASE profile
Smaller divergence





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Summary and future plan

- Soft X-ray FEL beamline was constructed at SACLA-BL1, which was the relocation and upgrade of “SCSS”
- Commissioning was started in September 2015.
- User run was started in July 2016.
- Intense SASE radiation is obtained in wide energy range.

〇 Electron beam energy   350~800 MeV

〇 SASE photon energy   20～110eV

△ SASE pulse energy   ～25 μJ（50 μJ at the undulator）

△ Shot-by-shot fluctuation   ～30%   …not yet reach to SASE saturation.

Future plan

- Higher peak current, with a harmonic cavity (C-band) at BC1
- Add a C-band linac for higher energy (available space up to 1.7 GeV).
- Add an undulator segment for more pulse energy.
- Seeded FEL, …