An overview of the requirements & the challenges for beamline optics at the next-generation sources

XFELs and state-of-the-art SRs

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SPring-8 Joint Project for XFEL

Collaborators

SPring-8 Joint Project for XFEL (RIKEN and JASRI)

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H. Yumoto, H. Kimura, Y. Senba, S. Goto
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Osaka University

K. Yamauchi, Y. Sano, H. Mimura

Spring has come !

Cherry blossoms "SAKURA" in full bloom.

Japan – XFEL

SACLA さくら

SPring-8 Angstrom Compact Free Electron LAser

Outline

(1) Introduction :

Characteristics of photons

at 3GLS & NGLS (Next Generation Light Sources)

Requirements for BL optics at NGLS

(2) Current status of SACLA

(3) Challenges of BL optics at SACLA

(4) Summary

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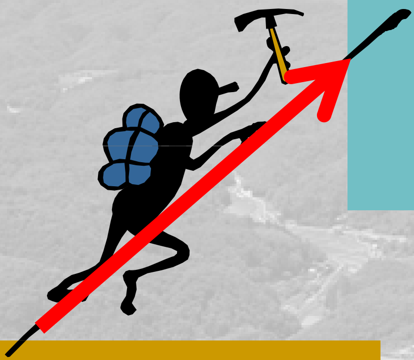
Advances of SR sources have stimulated to develop new BL technologies.

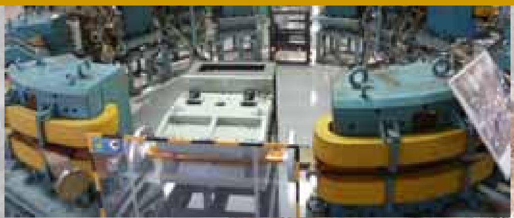


3GLS : 1990's

low-emittance storage rings w undulators

2GLS : 1970's

dedicated storage ring



Vacuum compatible monochromator

Managing high heat load
Micro/nano focusing

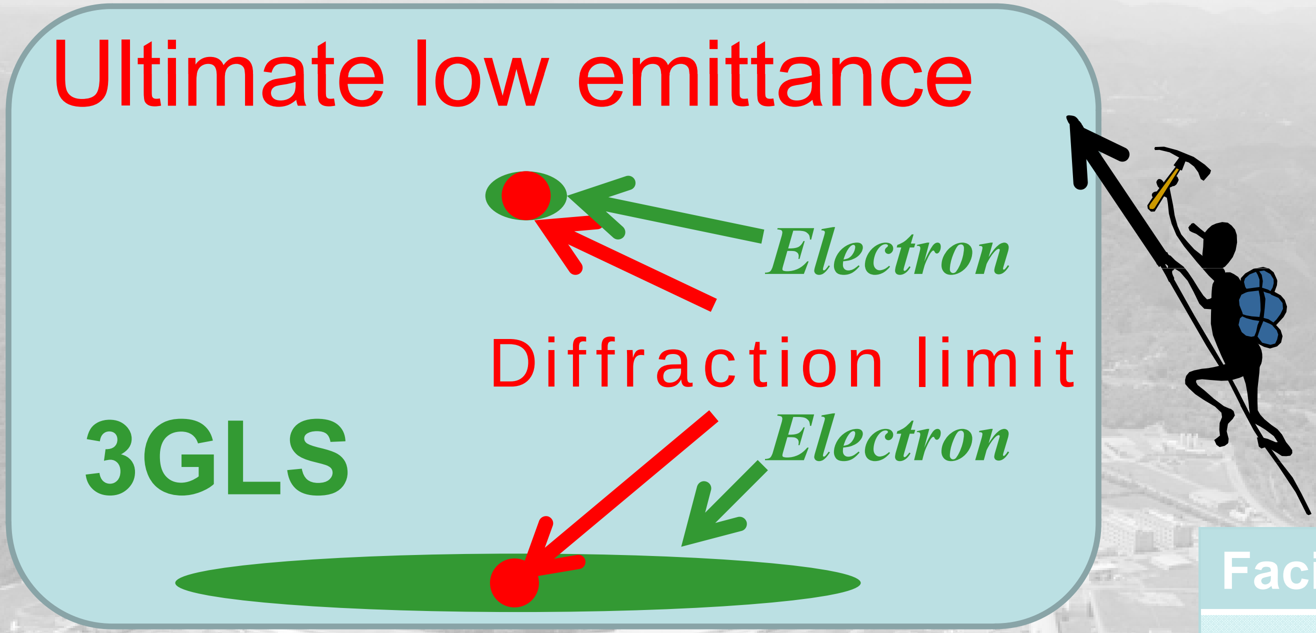
Next generation light sources

Single-pass

Storage ring

What's difference ?
3GLS & these NGLSs

Towards Next Gen Light Source storage ring

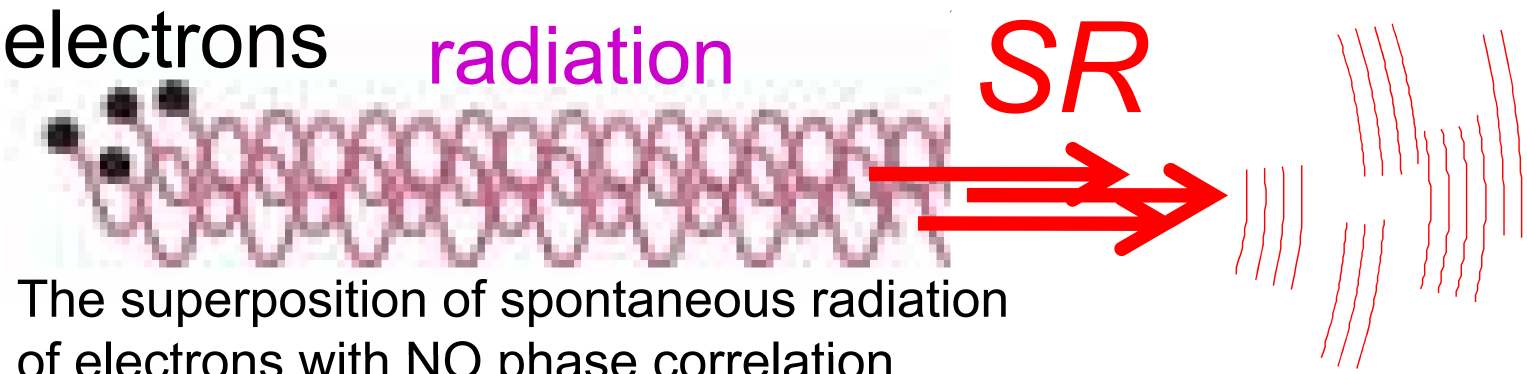


3GLS

Facility	Energy	Emittance
SPring-8	8 GeV	3400 pm・rad
PETRA-III	6 GeV	1000 pm・rad
NSLS-II	3 GeV	800 pm・rad
MAX-IV	3 GeV	300 pm・rad
PEP-X ?	4.5 GeV	240 pm・rad

Ultimate low emittance → spatial coherent x-rays

Towards Next Gen Light Source single-pass FEL



The superposition of spontaneous radiation of electrons with NO phase correlation

Phase correlated electrons bunched in short comparable to the wavelength of x-rays

Phase correlated electrons → Coherent x-rays Short pulses

Typical characteristics of photons at 3GLS & Next GLS (Ultimate Ring , XFEL)

	3GLS (SPring-8)	Ultimate Ring	XFEL (SACLA)
Pulse width	ps	ps	fs
Peak Brilliance	10^{22}	$\times 10^{2}$	$\times 10^{10}$
Spatial Coherence	0.1%	～100%	

The key issue for BL optics at Next Generation Light Source

both XFEL and state-of-the-art SR

To handle and apply ***the coherent x-rays***

→ XFEL (SACLA)

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(1) Introduction :

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Three big project

	USA	Europe	Japan
	LCLS	European XFEL	SACLA
Total length	2 km (of 4 km)	3.3 km	**0.7 km**
E-beam energy	14 GeV	17.5 GeV	8 GeV
Wavelength	0.15 nm	0.085 nm	0.06 nm
Rep rate	120 Hz	**27,000 Hz**	60 Hz
Operation	**2009~**	2014~	2011~

First

High rep. rate

Compact

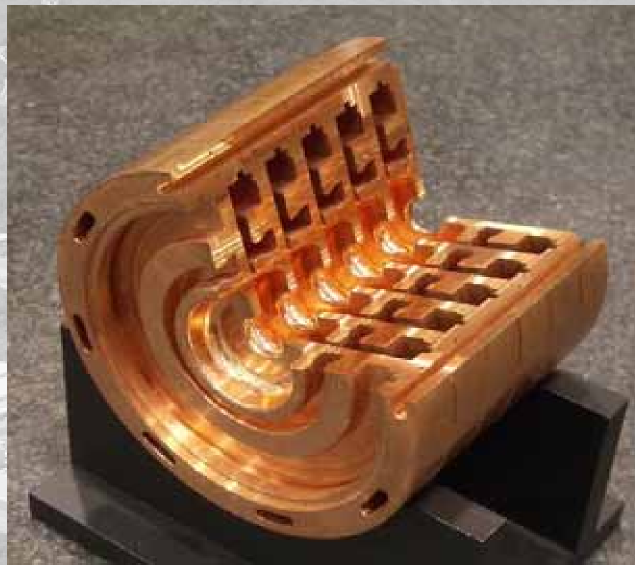
Concept of Compact XFEL (SACLA)

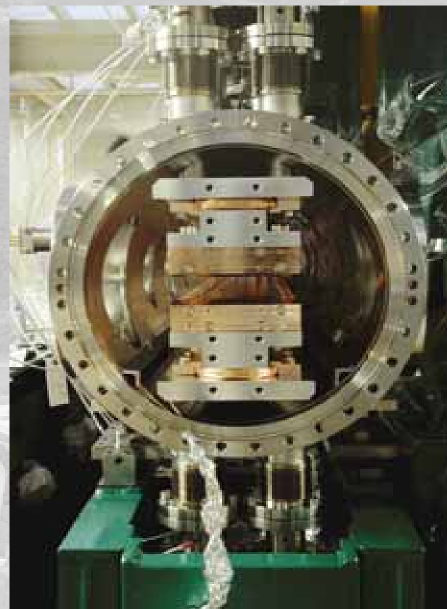
High-quality Electron source
Small emittance
even at low-energy operation

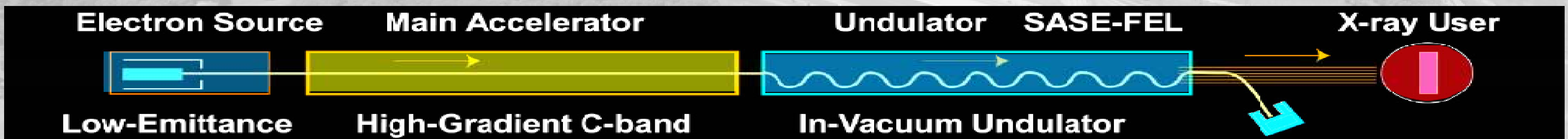
High-gradient C-band linac

Short-period, in-vacuum undulator
Suppression of acc. energy
for hard x-ray production

Togawa et al.,
PRST (2007)







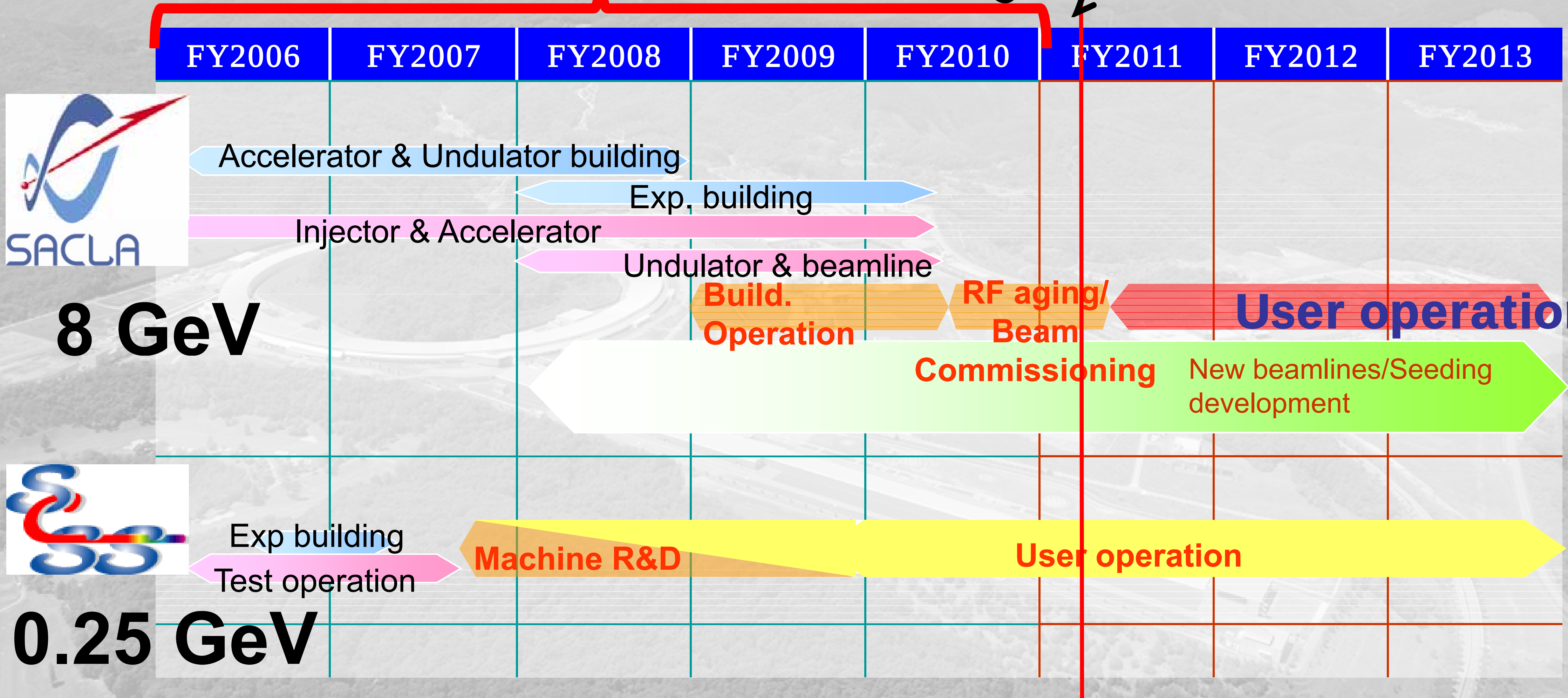
Compact : 8 GeV, 700 m→ 0.06nm

Roadmap

Under commissioning toward lasing

1st period

Construction has been completed



Aerial view of the SPring-8 site

SACLA (SPring-8 Angstrom Compact Free Electron Laser)

5-year construction (April 2006 ~ March 2011)

User operation Early 2012~

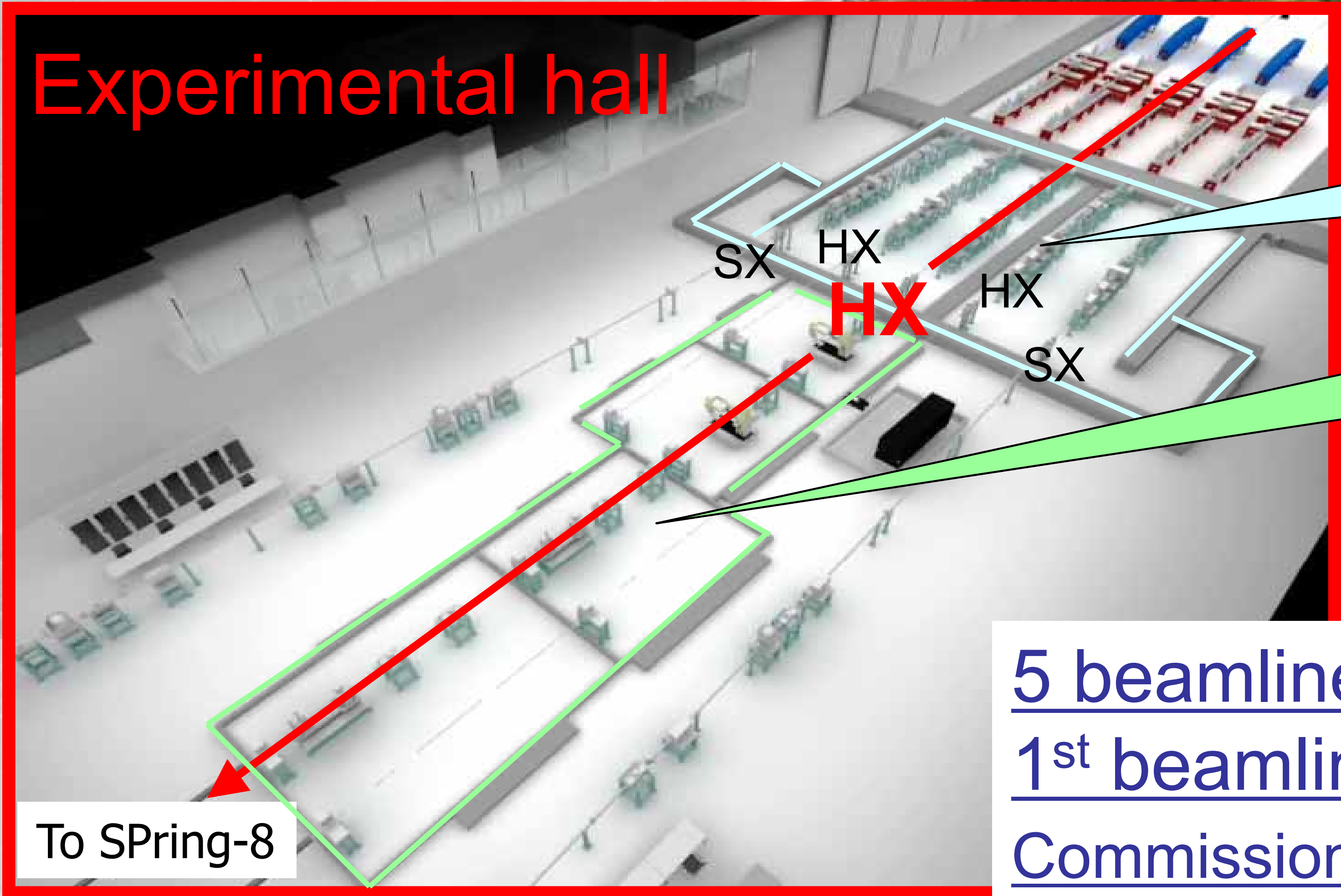
Accelerator

C-band tubes in the tunnel

Undulator

18 undulators for BL3
λu 18mm × N 5000
90 m long

SACLA beamline



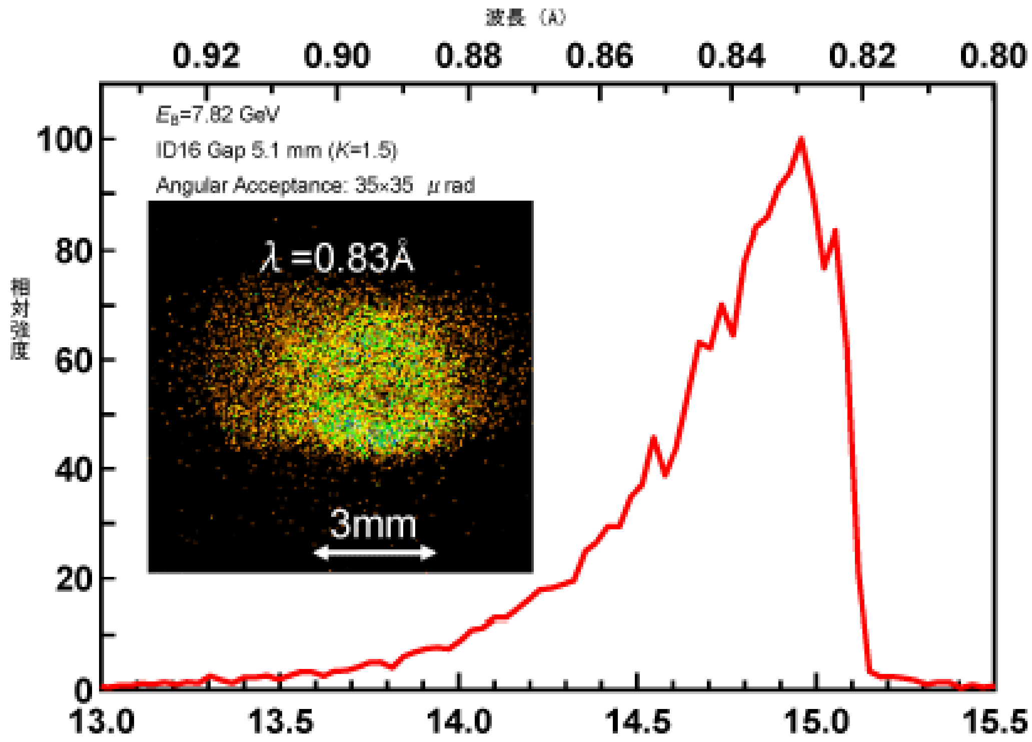
5 beamlines can be installed.

1st beamline (BL3) :

Commissioning started March 2011.

First x-ray (undulator radiation) at SACLA, **March, 2011**

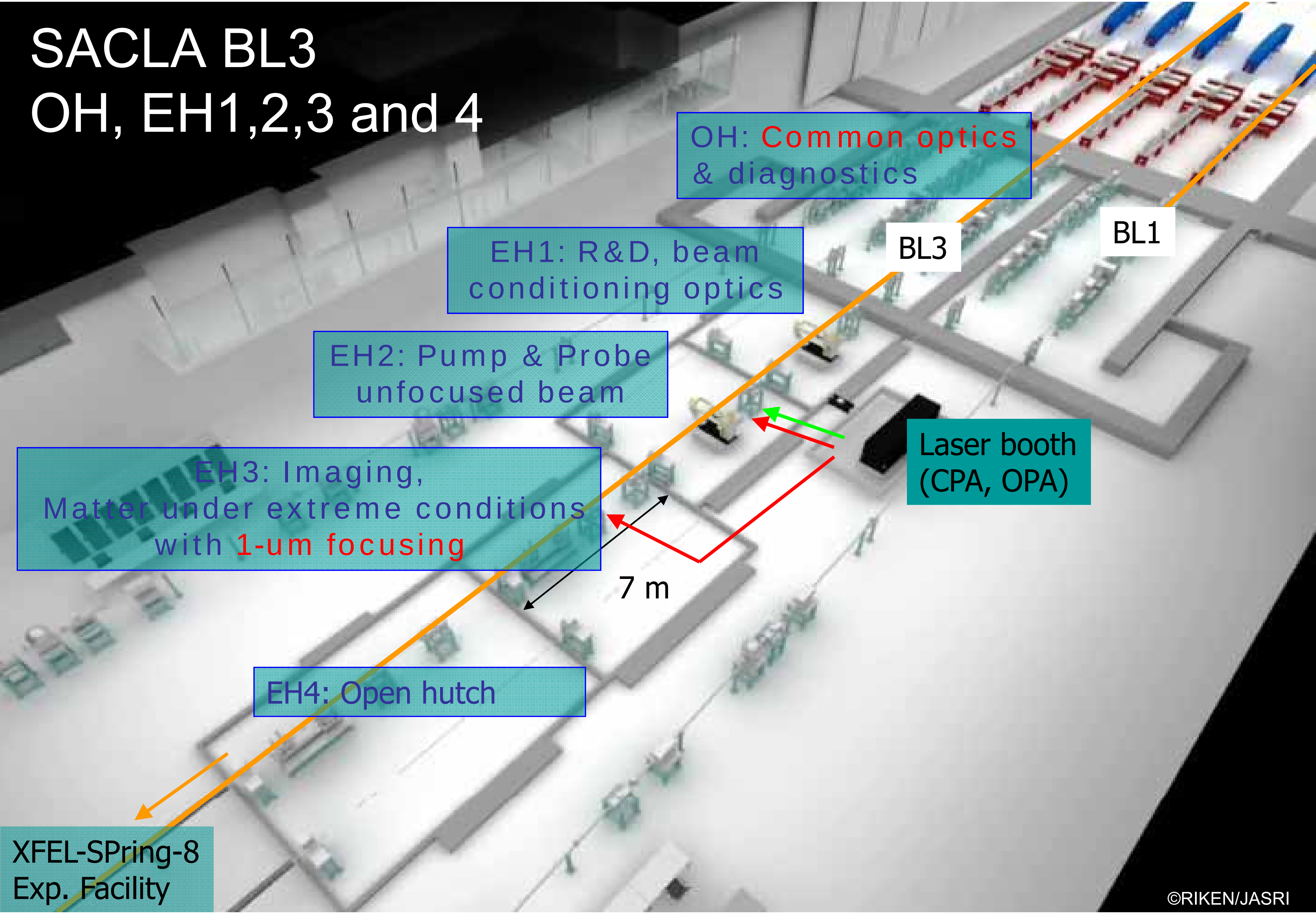
X-ray at optics hutch after monochromator



Photon Energy (keV)

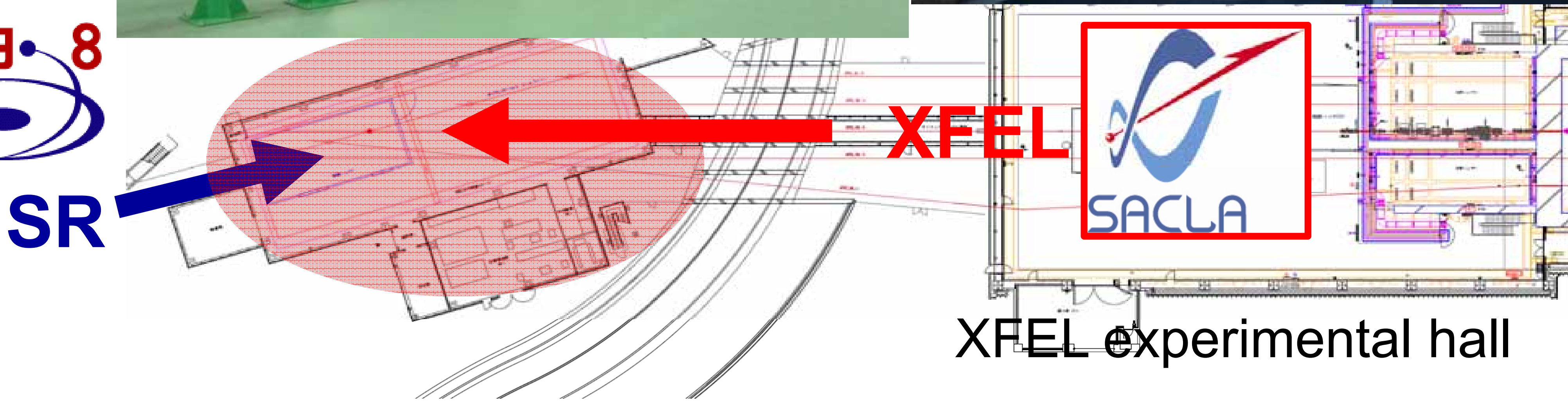
Press release : 2011/3/29 http://www.spring8.or.jp/ja (*only Japanese*)

SACLA BL3
OH, EH1,2,3 and 4



XFEL-SPring-8 Experimental Facility

Start construction in August, 2010
Completed in March, 2011



Pump-Probe Experiment with
XFEL + SPring-8 Undulator Radiation

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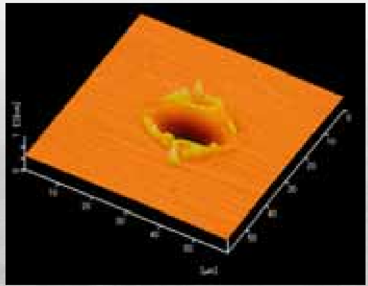
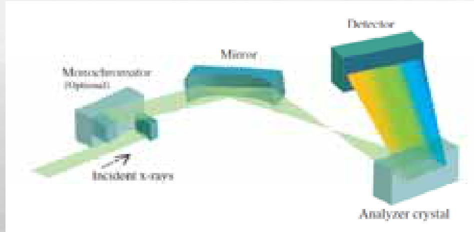
(3) Challenges of BL optics at SPring-8/SACLA

(4) Summary

BL optics for handling XFEL

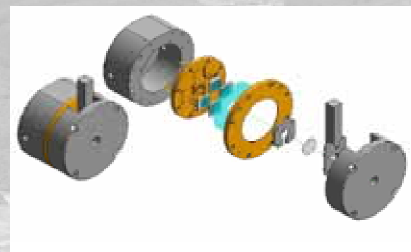




Pulsed nature

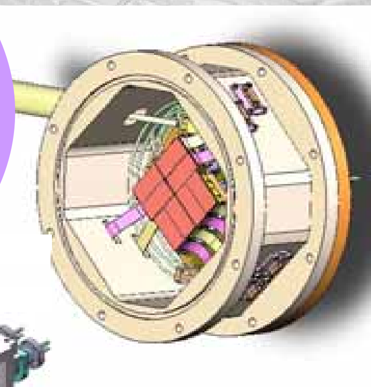
Mirror, Window, Beam splitter, crystal

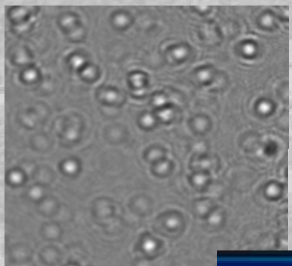
XFEL

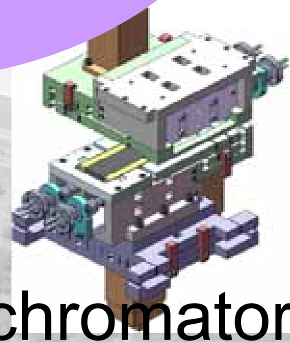


Coherence

Shot-to-shot fluctuation







Manipulator of mirror & monochromator

Requirements for XFEL optics

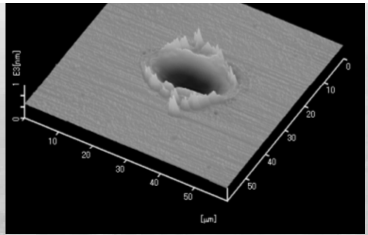
XFEL

Pulsed nature

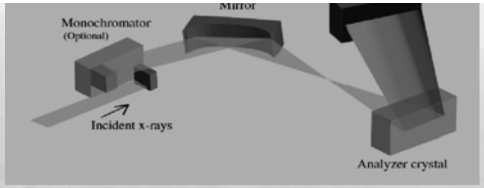
Coherence

Shot-to-shot fluctuation

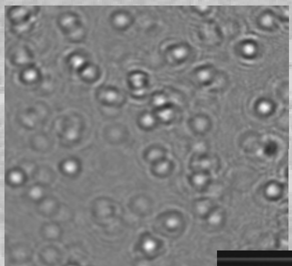
Damage-free optics

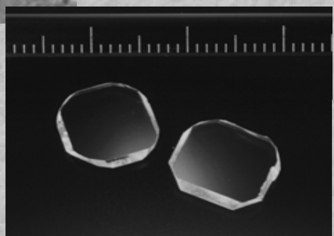


fs-synchronization

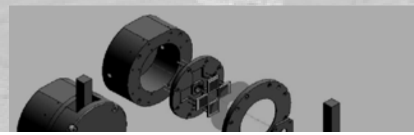


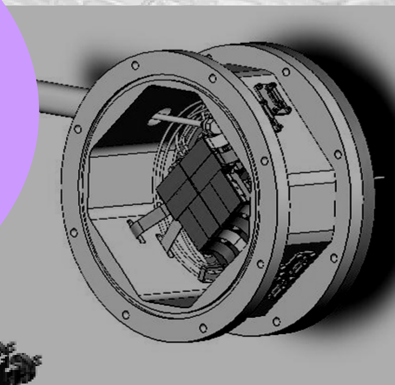
Speckle-free optics



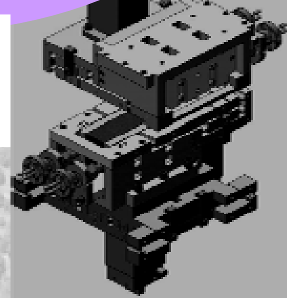


Shot-by-shot diagnostics



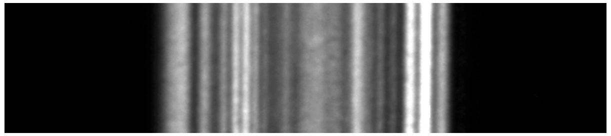


Stable system

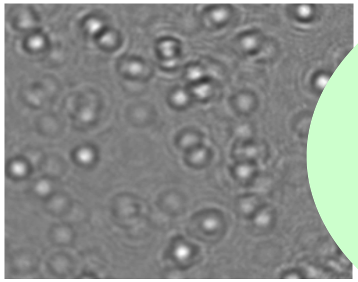


XFEL handling at beamline

Mirror, window
Beam splitter



Speckle-free optics



Metrology
@1km-BL

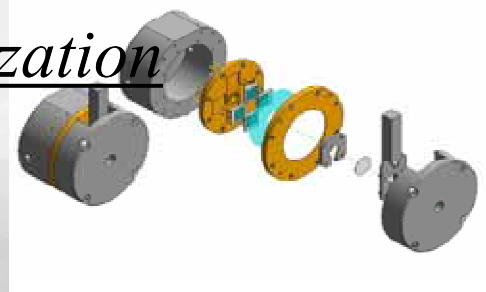
Pulsed nature

XFEL

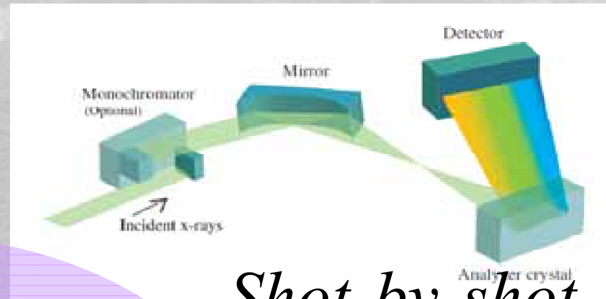
Coherence

Shot-to-shot fluctuation

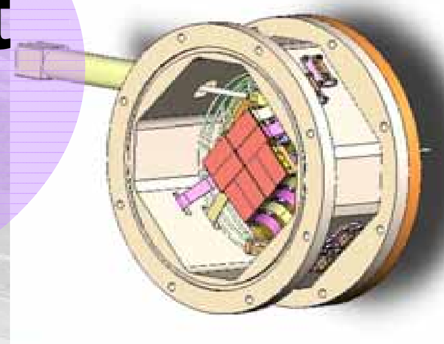
fs-synchronization



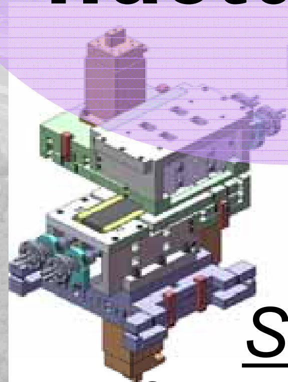
Damage-free optics



Shot-by-shot diagnostics



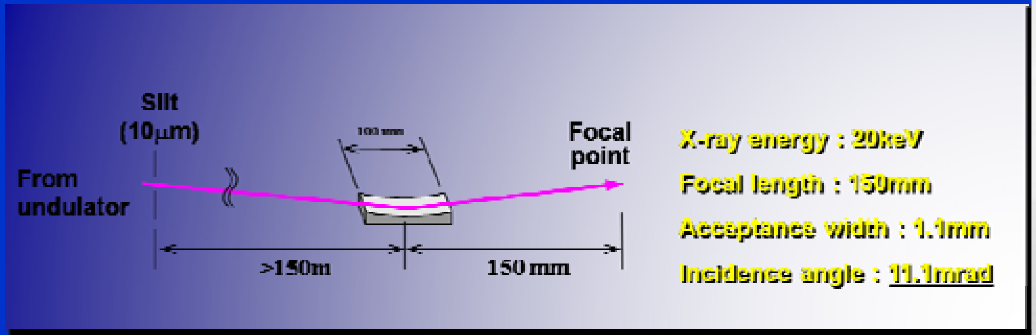
Fast 2D-detector
& DAQ

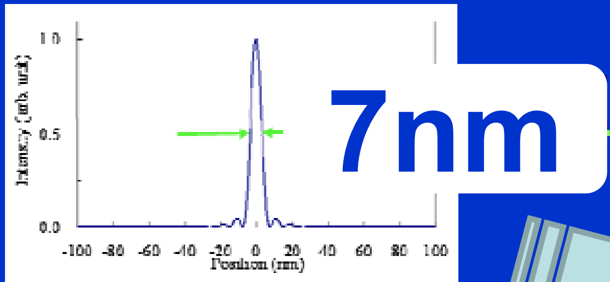


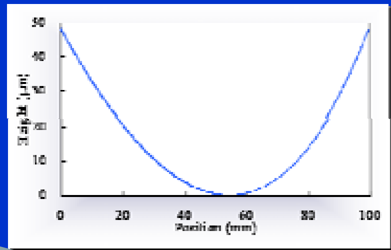
Stable system
Mirror & monochromator

Hard-X-ray *sub-10nm* focusing at 1km-BL

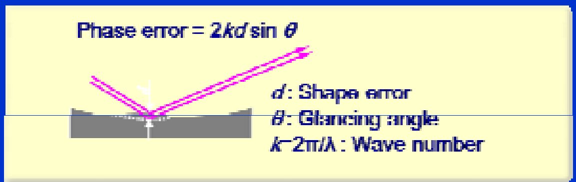
To realize Sub-10nm focusing K-B mirrors

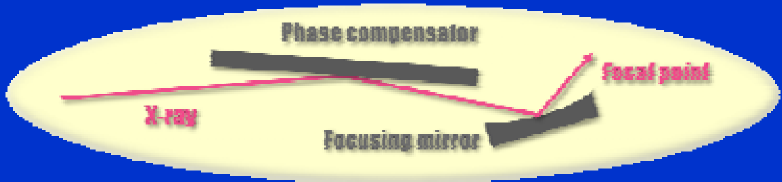






Design concept

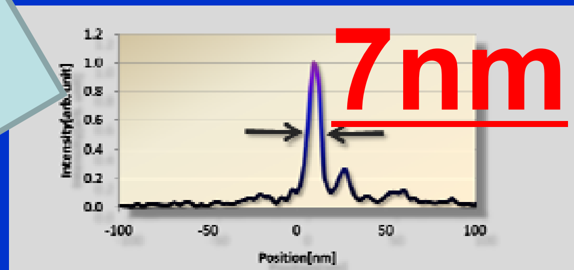




★Glancing angle of compensator mirror should be designed smaller.
(However, Consequently the length of the compensator becomes longer)

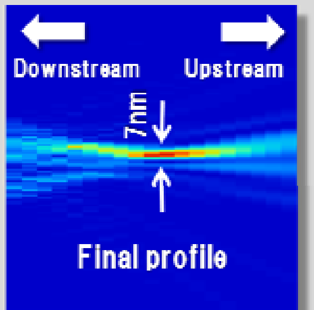
Required figure accuracy of the compensator mirror becomes lower.

Demonstration of on-site phase compensation



Profile at focal point

Compensated phase profile
(shape of compensation mirror)



Maximum phase compensated here was λ/2.
λ was 0.06 nm.

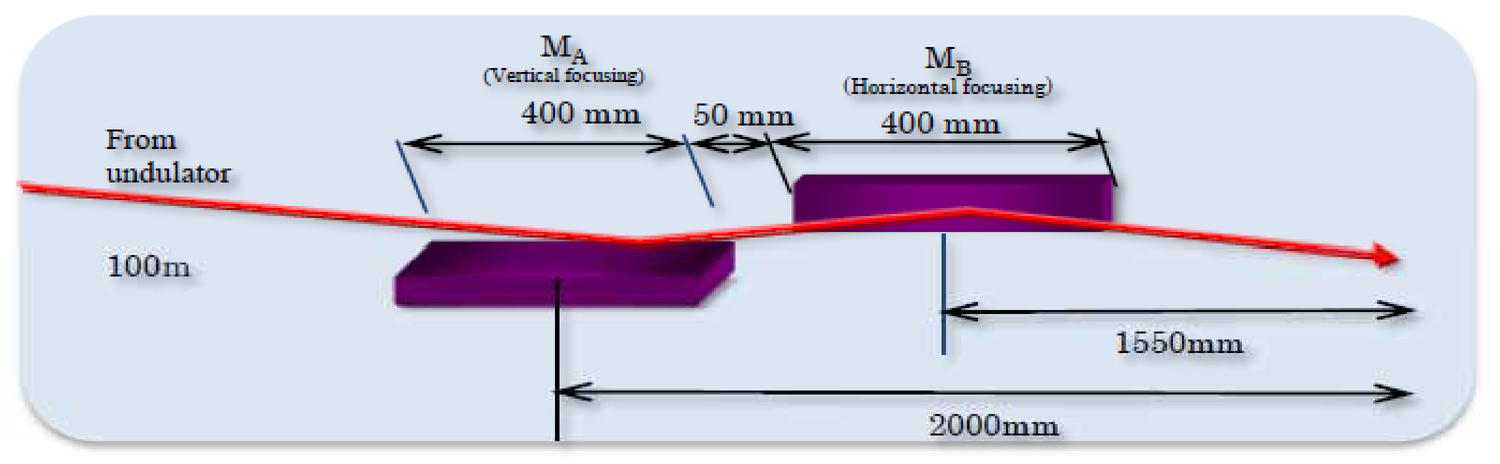
Beam waist structure

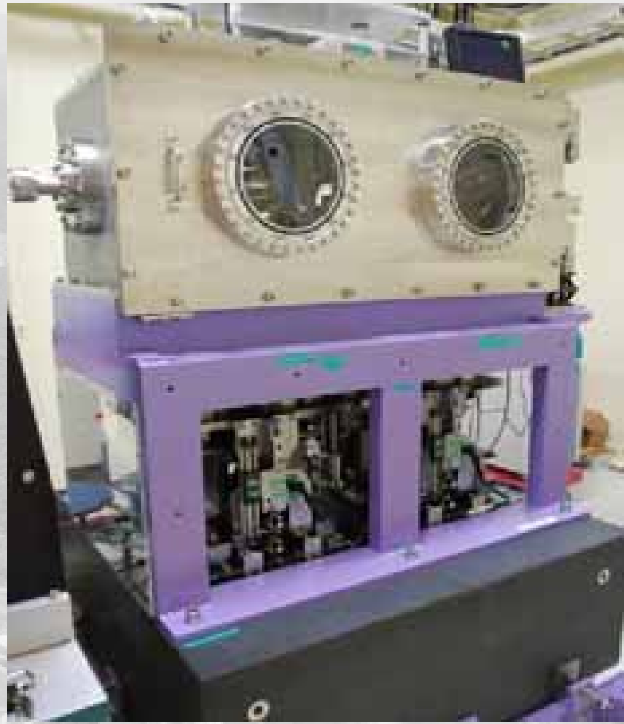
H. Mimura et al.
Nature physics, Nov. 2009

Focusing mirror for XFEL

1. Focusing system for multi purpose

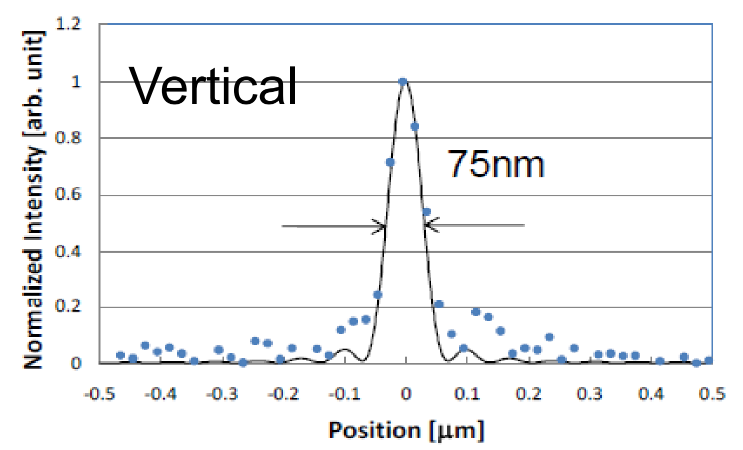
Focus size ~ 1 μm, Speckle-free
Working distance ~1 m
UHV compatible manipulator

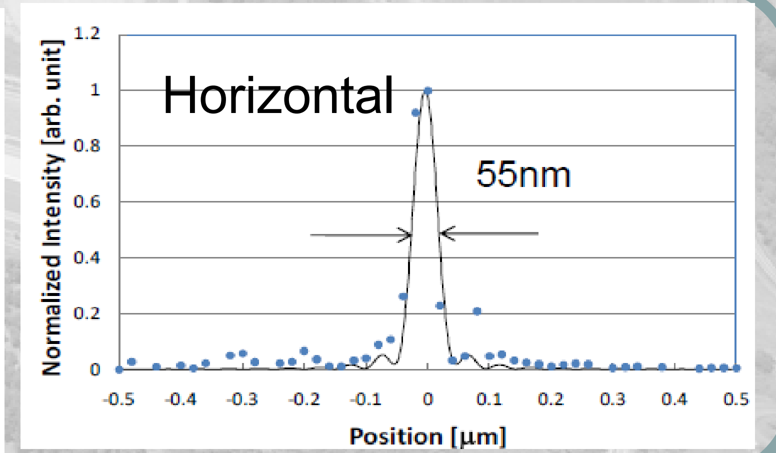




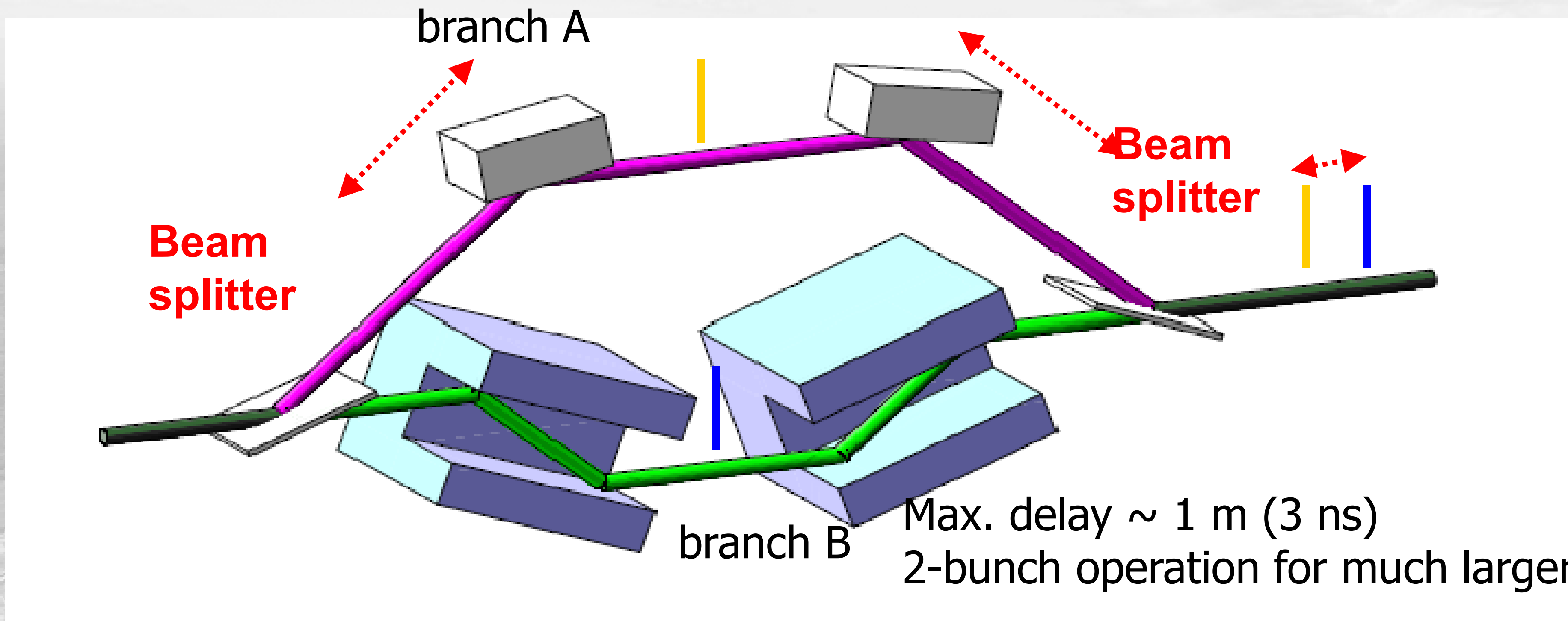
2. Focusing system
for example,
intense laser science

Focus size ~ sub-μm



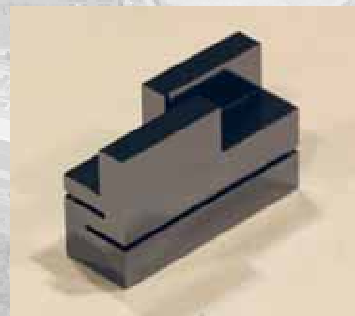


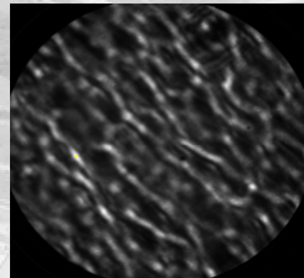
X-ray autocorrelator



Max. delay ~ 1 m (3 ns)
2-bunch operation for much larger delay

- Components: 2 channel-cut crystals +
  2 thick (flat) crystals +
  2 thin (flat) crystals
- Simple geometry with wavelength tunability
- Channel-cut: Large size & speckle-free quality





Diffraction image of channel-cut

Bragg beam splitter

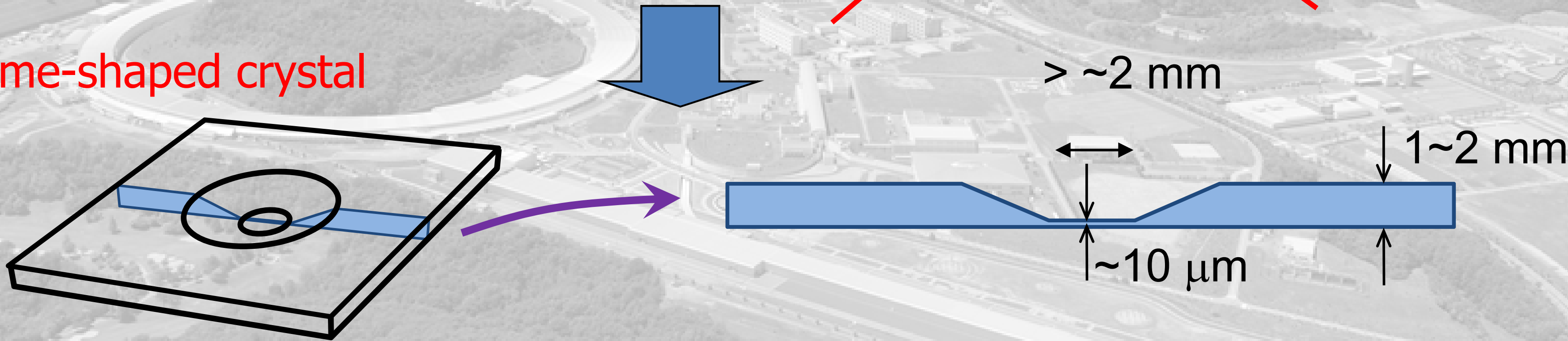
SPring-8-SLAC-DESY Collaboration

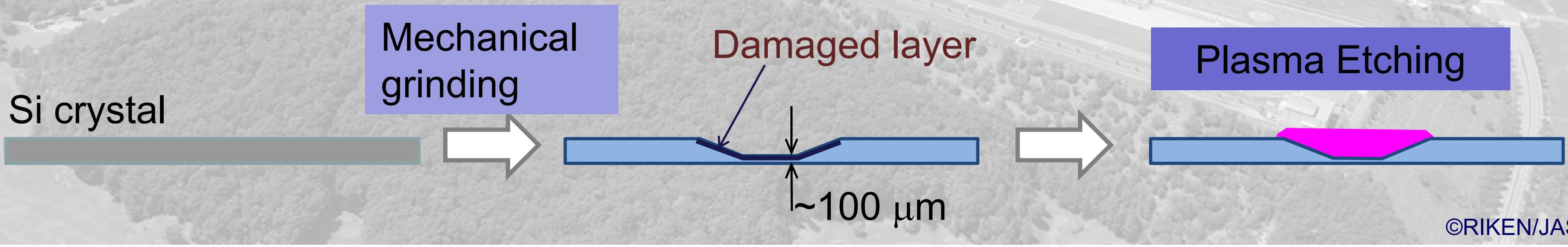
K. Yamauchi, Y. Sano, T. Osaka,
H. Mimura (Osaka Univ.)
K. Tono, M. Yabashi (SPring-8)

Requirement

- Thickness: 20 um to a few um
- Bent-free (<<urad)
- Strain-free
- Flatness
- Any orientation

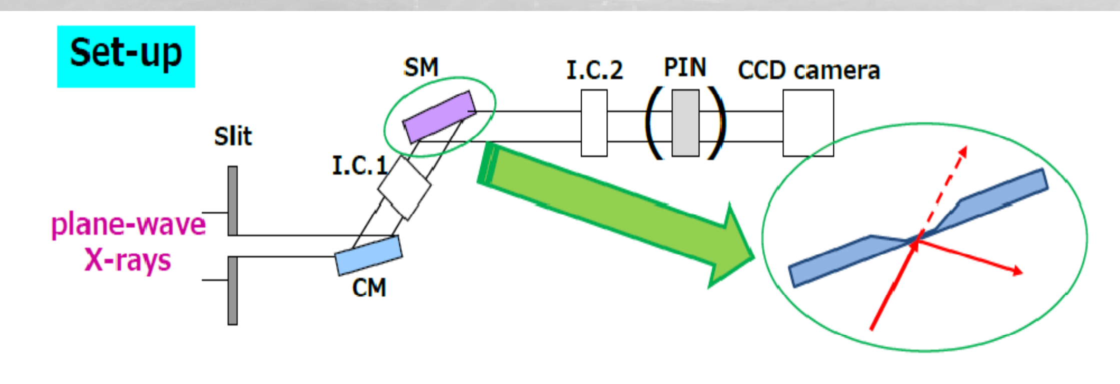
Frame-shaped crystal

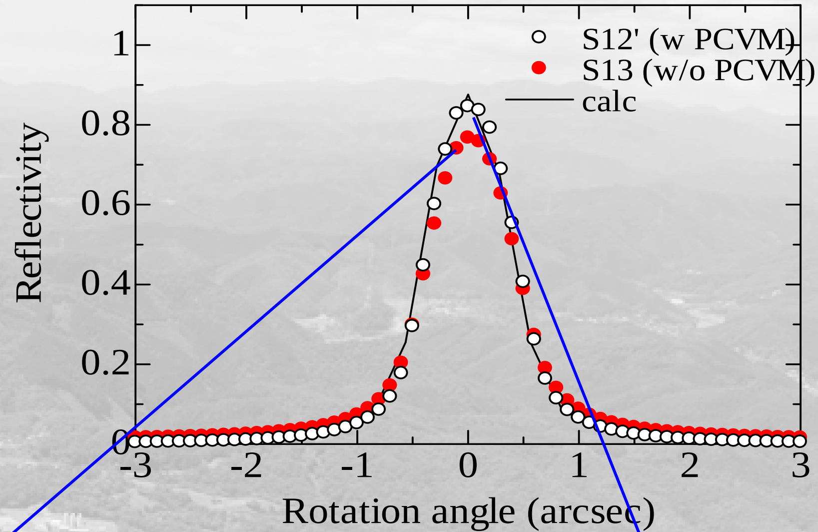


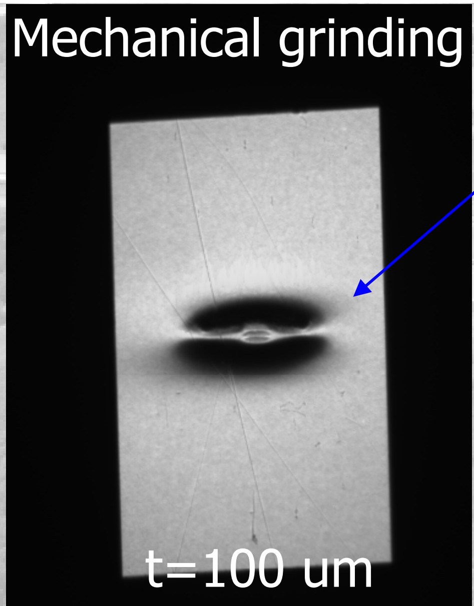


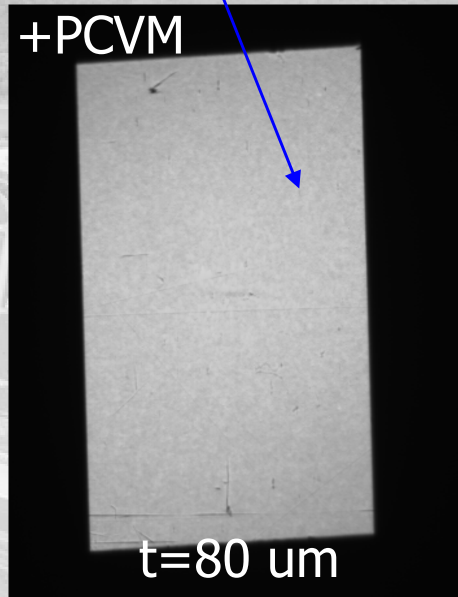
Beam splitter by plasma chemical machining

Plane-wave topograph @ 1 km BL
E=15 keV Si 511





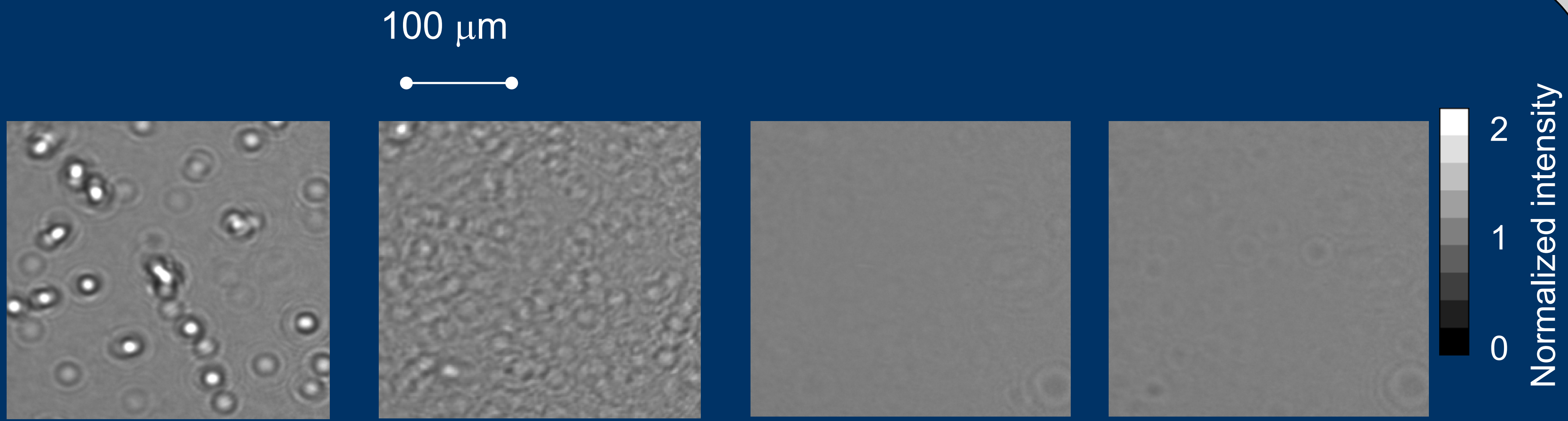




Speckle-free Be window

@1-km beamline (SPring-8 BL29XU-L)

E=12.4 keV, *d*= 1400 mm



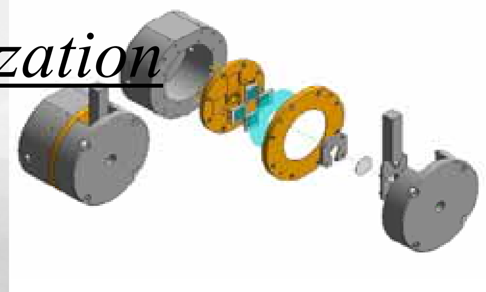
Polished O-30 (HIP powder foil) 100 nm p-v	Polished IF-1 (Ingot foil) 100 nm p-v	**Polished PVD 50 nm p-v**	Kapton

S. Goto et al., AIP conf. proc. **705** (2004) 405

- ***We can check the quality of wavefront preserving optics***
- ***by coherent x-rays at 1-km BL before installing XFEL-BL.***

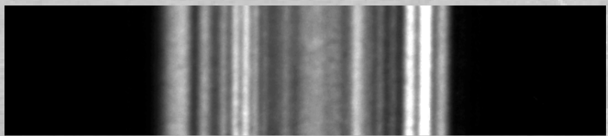
XFEL handling at beamline

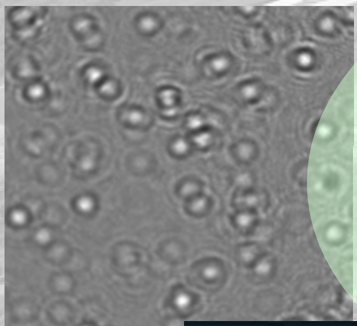
fs-synchronization



Speckle-free optics

Mirror, window
Beam splitter





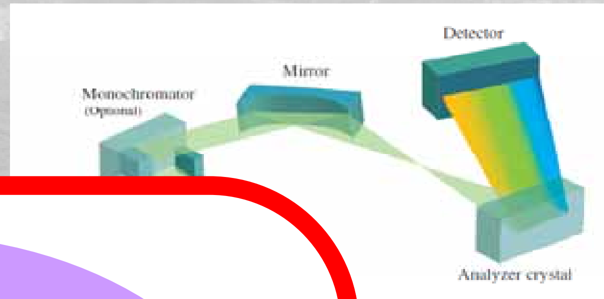
Pulsed nature

XFEL

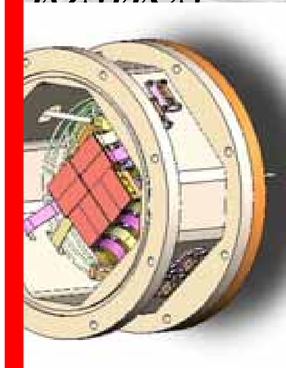
Coherence

Shot-to-shot fluctuation

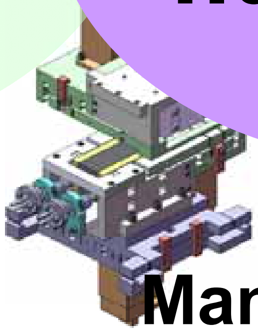
Damage-free optics



-by-shot
nostics



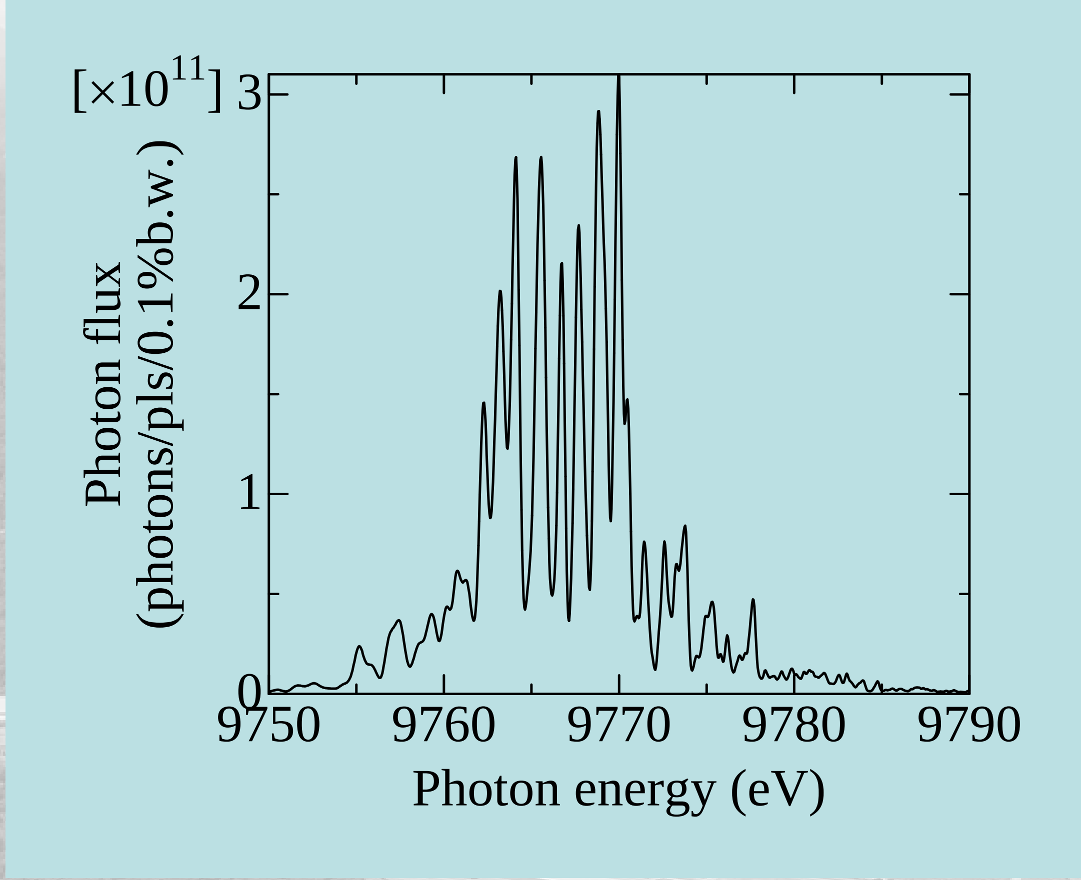
-detector
& DAQ



Stable system

Manipulator for mirror & monochromator

Shot-to-shot fluctuation



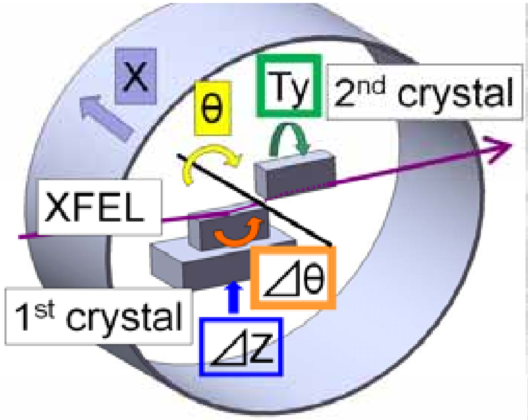
SASE source has shot-to-shot fluctuation

→ ***To handle the coherent x-rays stably***

Monochromator *for XFEL BL*

- Contamination-free ⇒ ***UHV-compatible***
- High stability ⇒ ***New manipulator developed***
- Use of large (90mm) Si with small offset (20mm)
  - No sliding surface ⇒ Flexure hinges
  - High resolution⇒ Piezo liner actuator

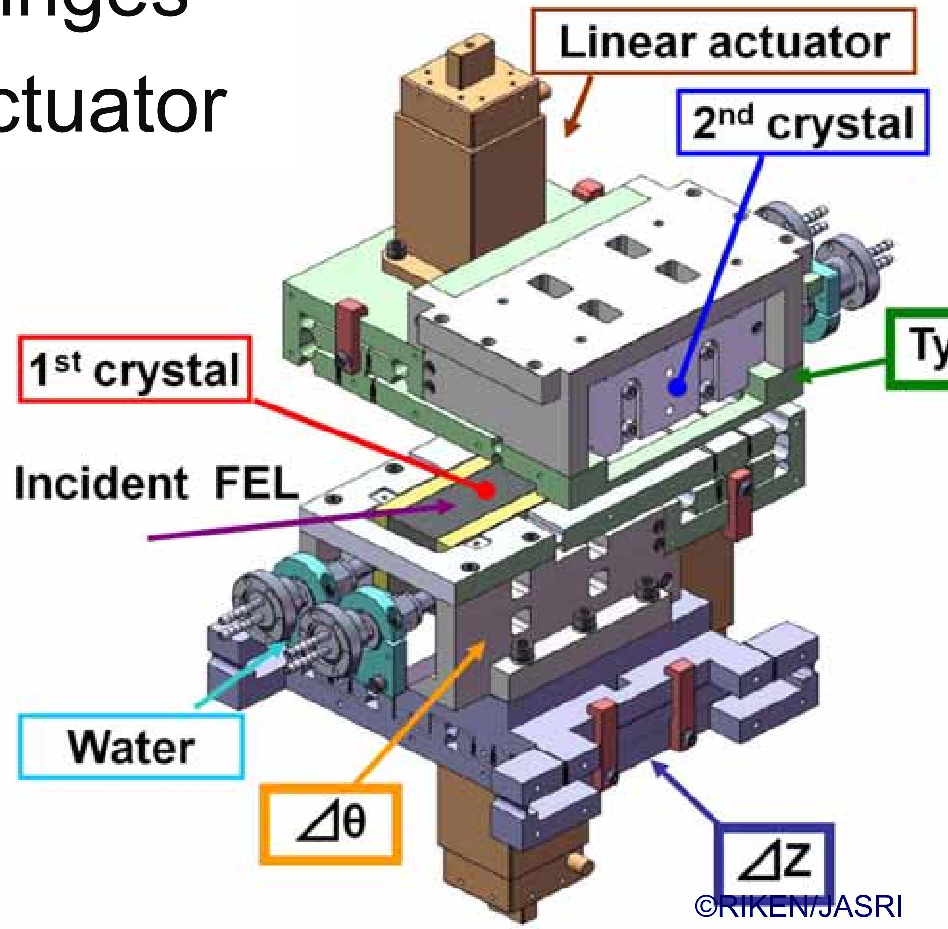
Axis	Range	Resolution
θ	-1～30 [deg]	1 [μrad]
X	60 [mm]	0.1 [mm]
⊿θ	±0.5 [deg]	0.1 [μrad]
⊿Z	±1 [mm]	10 [μm]
Ty	±0.5 [deg]	1 [μrad]



➡ ***High-stable stages***

<0.1 μrad for 30 min

<1 μrad for 24 hr



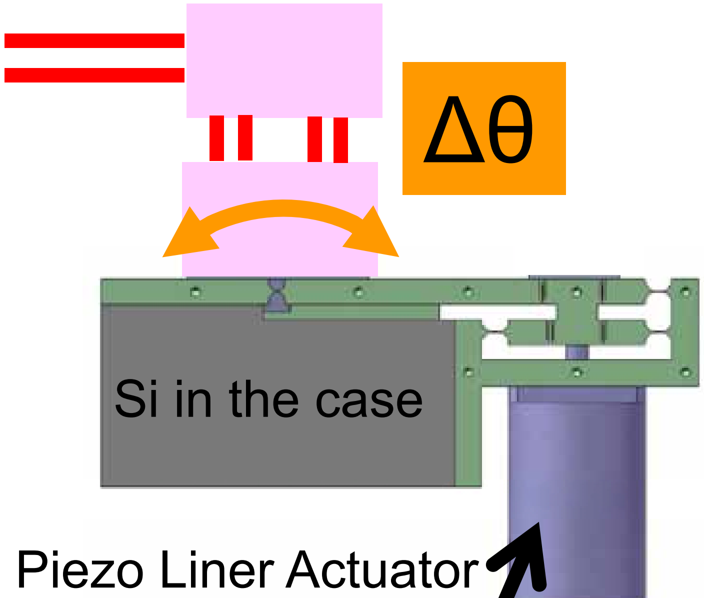
DCM : Typical results of Δθ

Requirements of Δθ

- » Resolution 0.1 μrad
- » Range ±0.5 deg
- » Stability <0.1 μrad / 0.5 hr

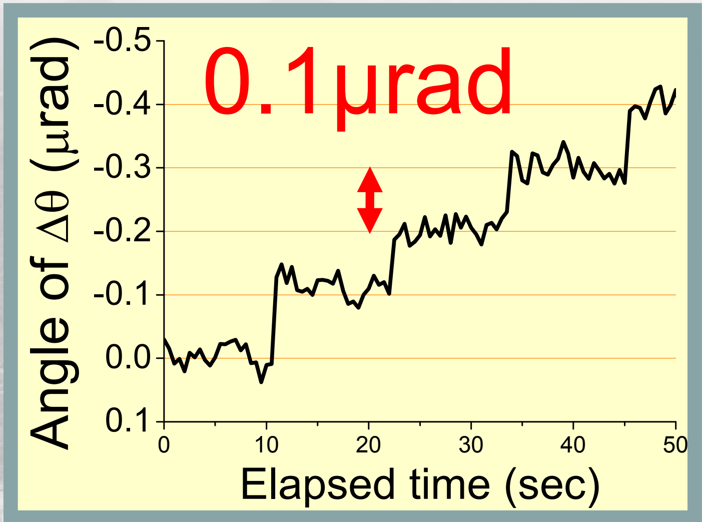
Measurement

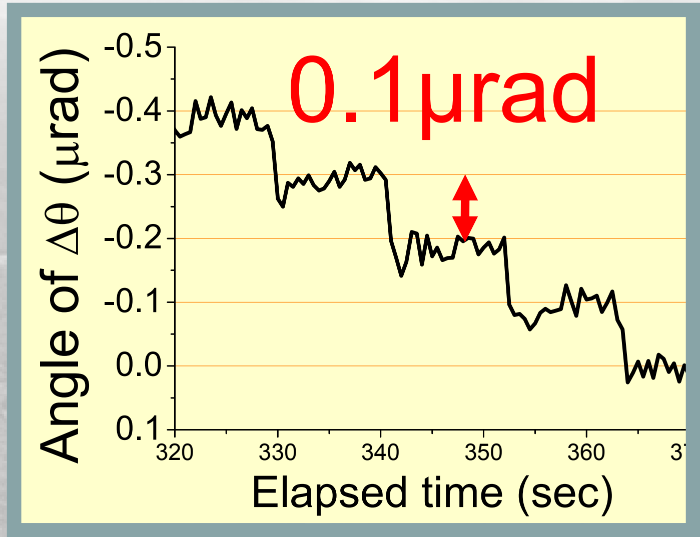
- » Laser interferometer
  Renishaw plc (XL-80)

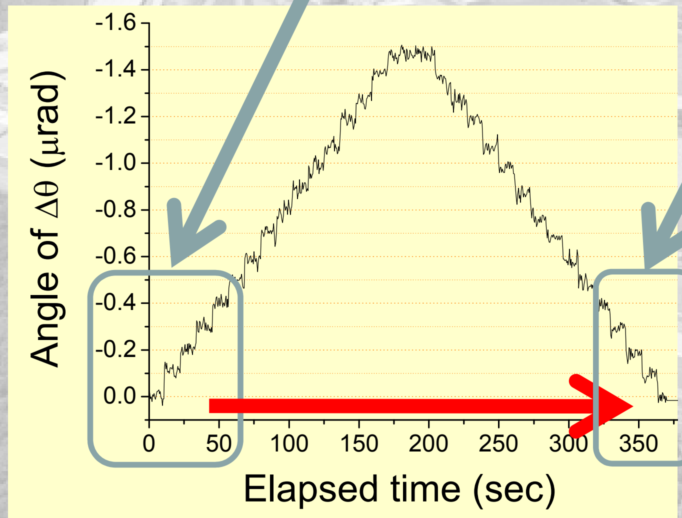


Piezo Liner Actuator
10nm → 0.1 μrad

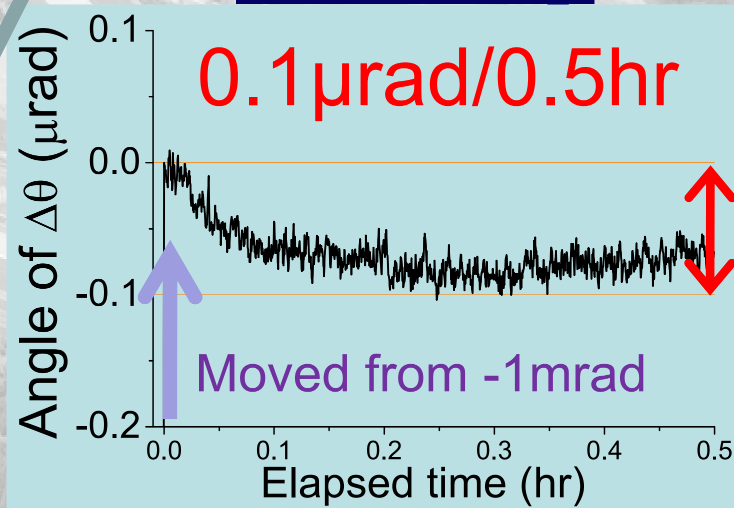
Resolution







Stability

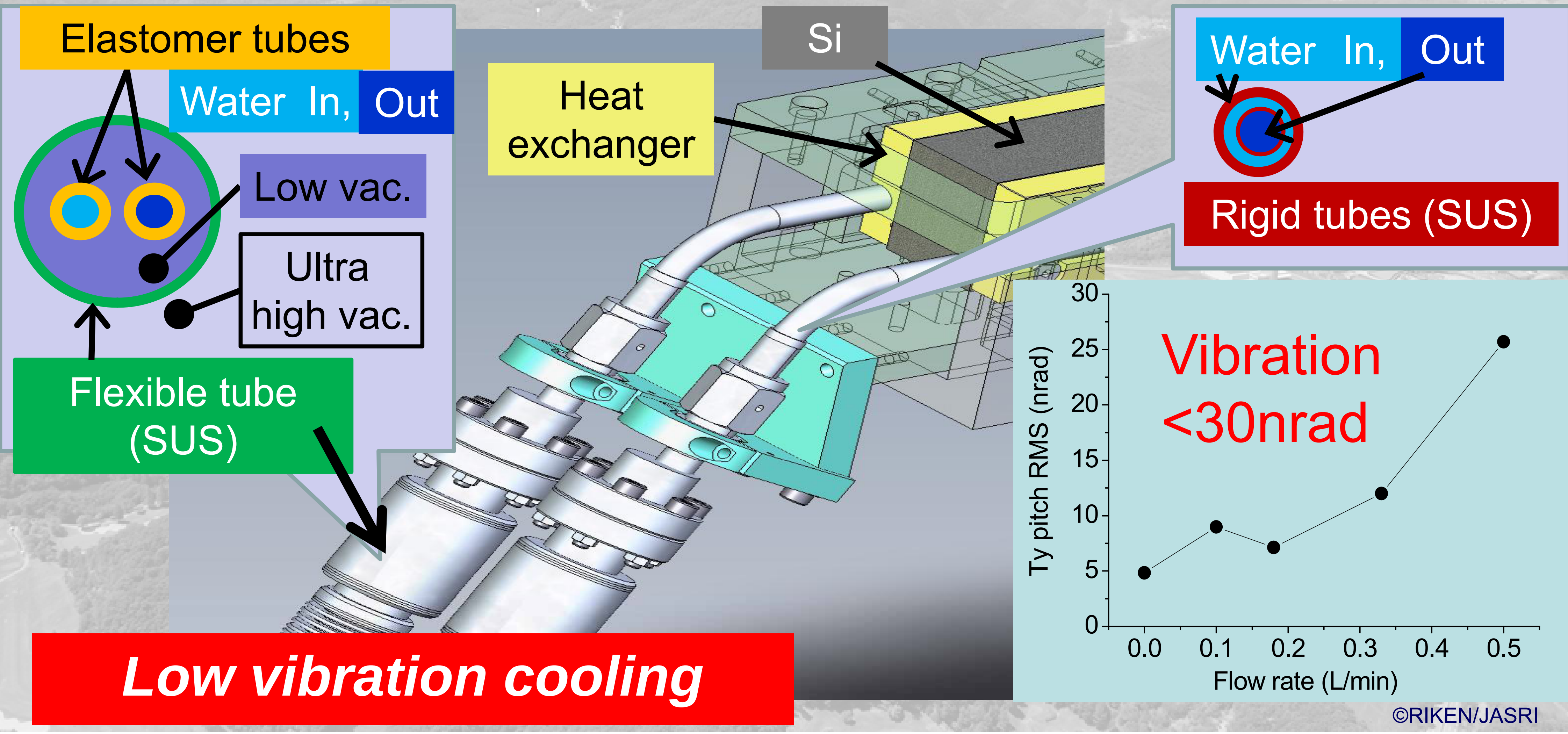


High precise and high stable stage

DCM : Cooling tubes

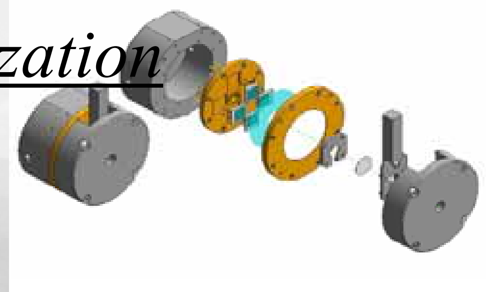
- to prevent water tubes from dragging the crystal

"*Double tubing*" is soft and stable in vacuum.



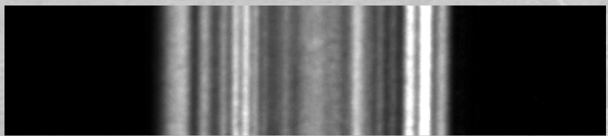
XFEL handling at beamline

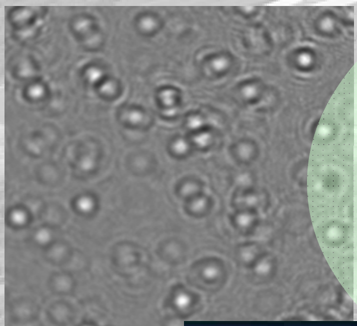
fs-synchronization

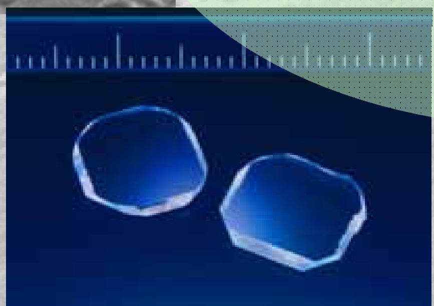


Speckle-free optics

Mirror, window
Beam splitter







Pulsed nature

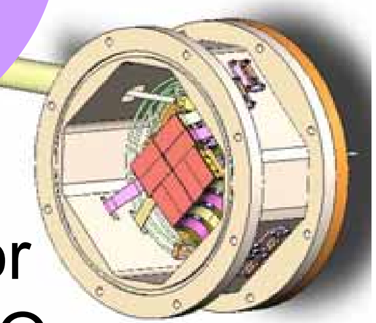
Damage-free optics

XFEL

Coherence

Shot-to-shot fluctuation

Beam intensity
&position
monitor



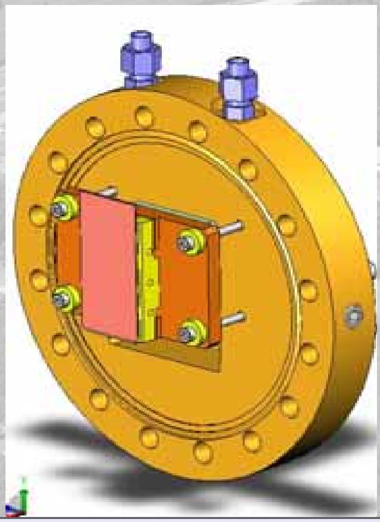
Fast 2D-detector
& DAQ

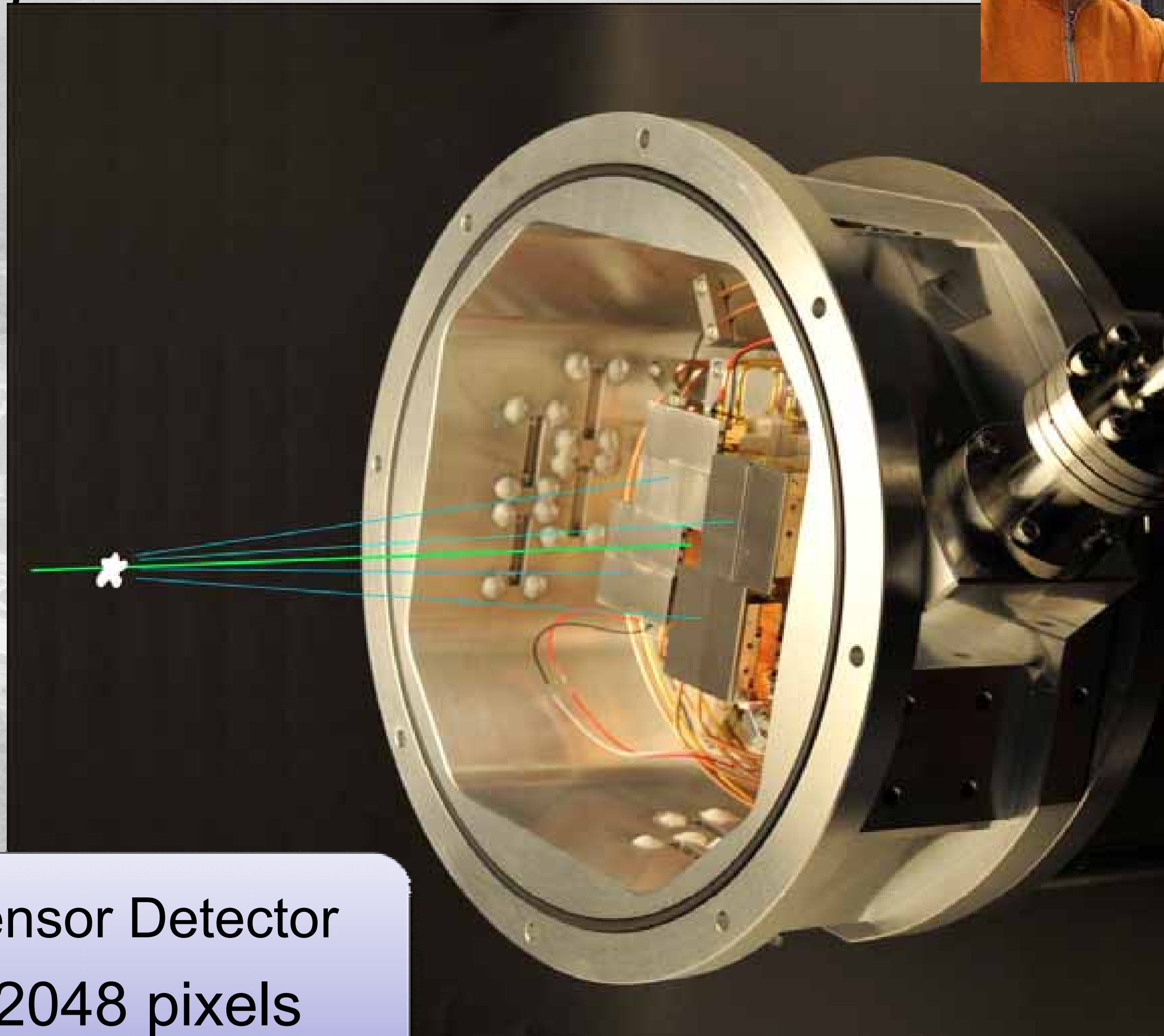
MPCCD: *Day-One Detector*

T. Hatsui

Multi-port CCDs : *Day-One Detector for many applications*

- *Max 3 000 ph.@6 keV □50 μm*
- *Noise 0.18 ph. @ 6 keV*
- *Q.E. 80 % at λ= 2* **Å**
- *Q.E. 20 % at λ= 1* **Å**





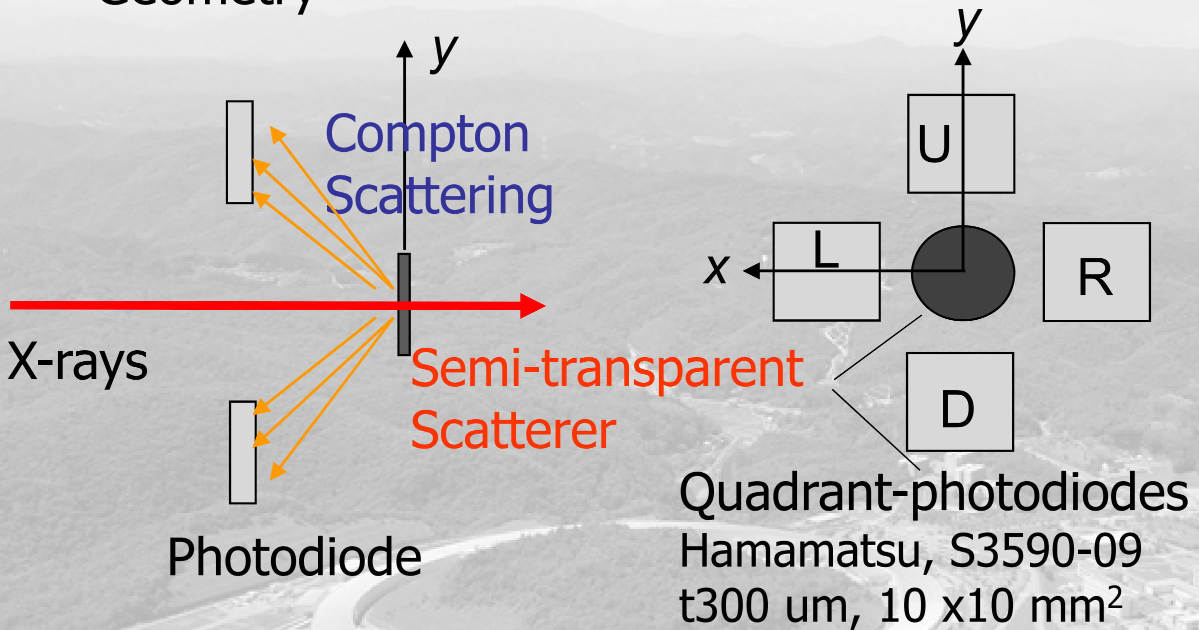
Single Sensor Detector
512 x 1024 pixels

Octal Sensor Detector
2048 x 2048 pixels

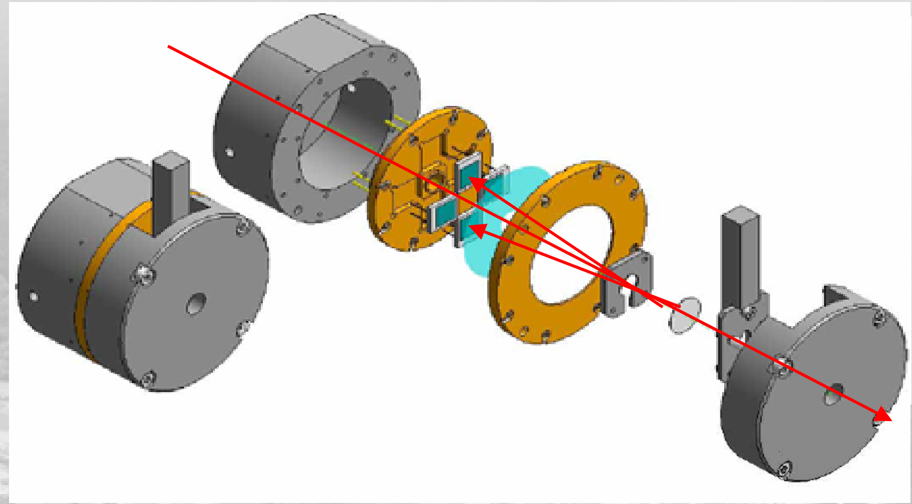
Intensity/Position monitor: Thin-foil monitor

K. Tono, T. Kudo, M. Yabashi (SPring-8)
Collaboration with SLAC (Y. Feng, D. Fritz, J. Hastings)

Geometry



Apparatus



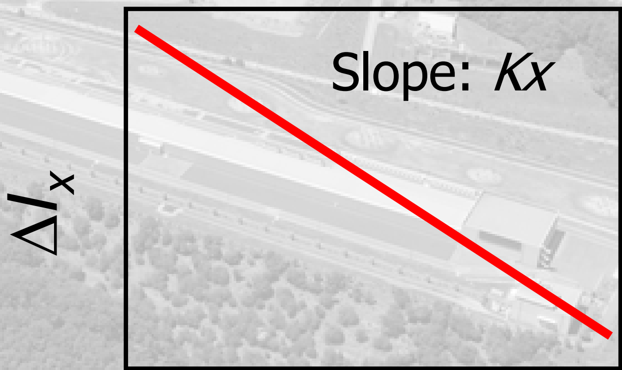
Intensity

$$I = I_L + I_R + I_U + I_D$$

Position

$$x = K_x \frac{I_L - I_R}{I_L + I_R} = K_x \Delta I_x$$

$$y = K_y \frac{I_U - I_D}{I_U + I_D} = K_y \Delta I_y$$



K. Tono et al., *RSI* **82**, 023108 (2011)

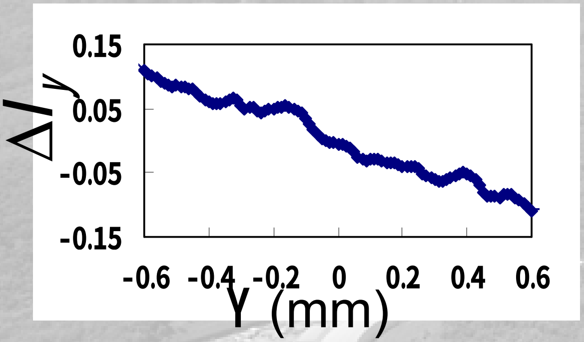
Scattering profile

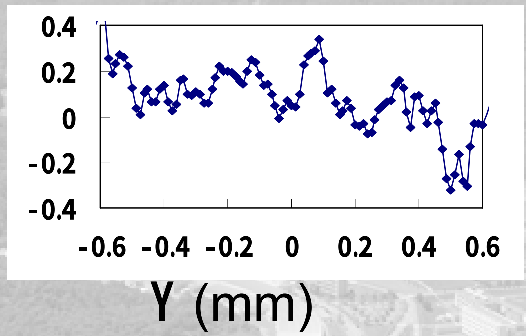
K. Tono et al., *RSI* **82**, 023108 (2011)

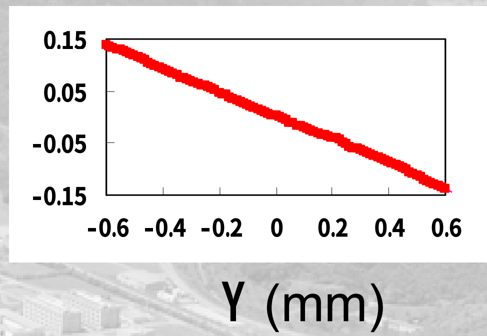
Compton scattering + Debye-Scherrer ring (except for Si_3N_4)

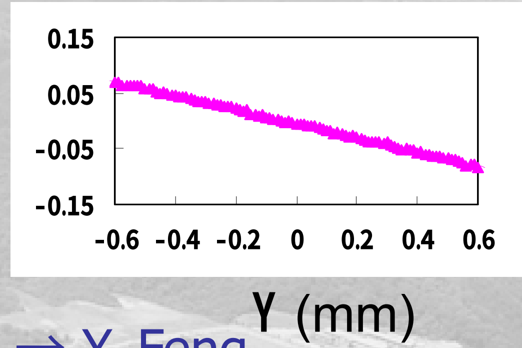
Grain-free pattern obtained from CVD nanocrystal (~30 nm) diamond

PVD-Be 100 umt	CVD-Diamond 30 umt	CVD- "nano" Diamond 15 umt	Si_3N_4 0.5 umt

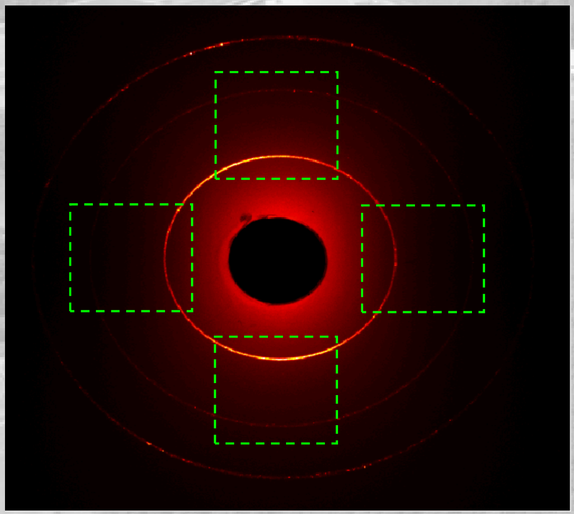


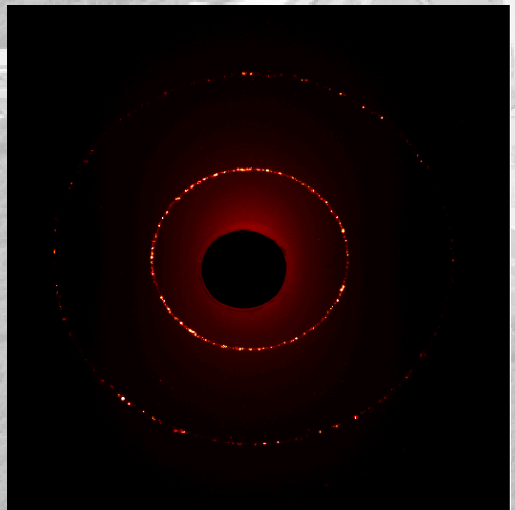


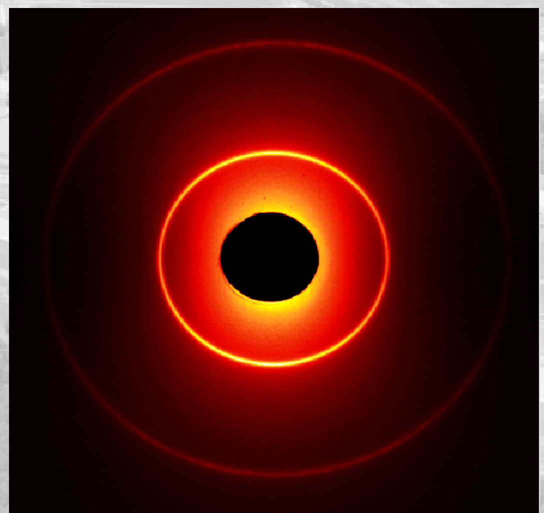


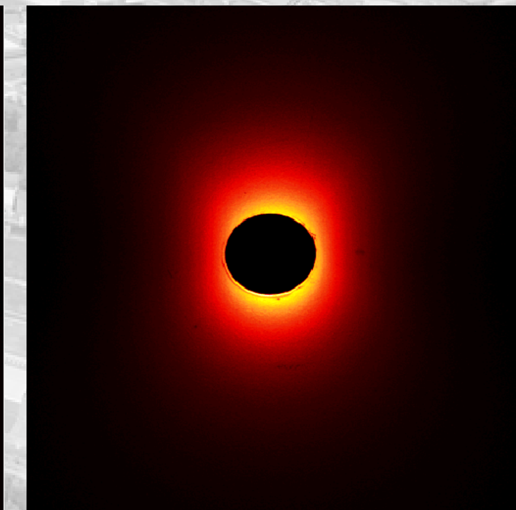


→ Y. Feng









high δ / β low

Summary

1. The key issue for BL optics at NGLS both XFEL and state-of-the-art SR is to handle and apply the coherent x-rays.

2. Speckle-free, damage-free optics and highly stabilized optical system are required for NGLS.

3. SPring-8 Angstrom Compact Free Electron Laser (SACLA) just starts commissioning.

Acknowledgement

ISOC of ACOTP11
K. Sawhney, S. Alock,
R. Barrett, D. Cocco, M. Idir,
F. Siewert,
and
S. Fletcher, S. Hartrampf,
L. Holland

Thank you for your kind attention!

As for earthquake in Japan,

a lot of friends around the world assist us.

We express the deep sense of appreciation