“Technologies”

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Dean Haeffner (APS)

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Photon technologies for DLSR

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Dec 10, 2013 @SLAC

Contents

1. Basic parameters & performance
2. Technological challenges
   1. Stabilities
   2. Wavefront preservation
   3. Beamline concepts

Design Strategy of SPring-8 II

1. Reduction of emittance with keeping robust, stable operation

   8 GeV -> 6 GeV, DBA -> 5BA, 3 nm.rad -> 100 pm.rad

2. Keep high photon energy range (smaller λ_U) without energy gap (K_{max} ~2.3)

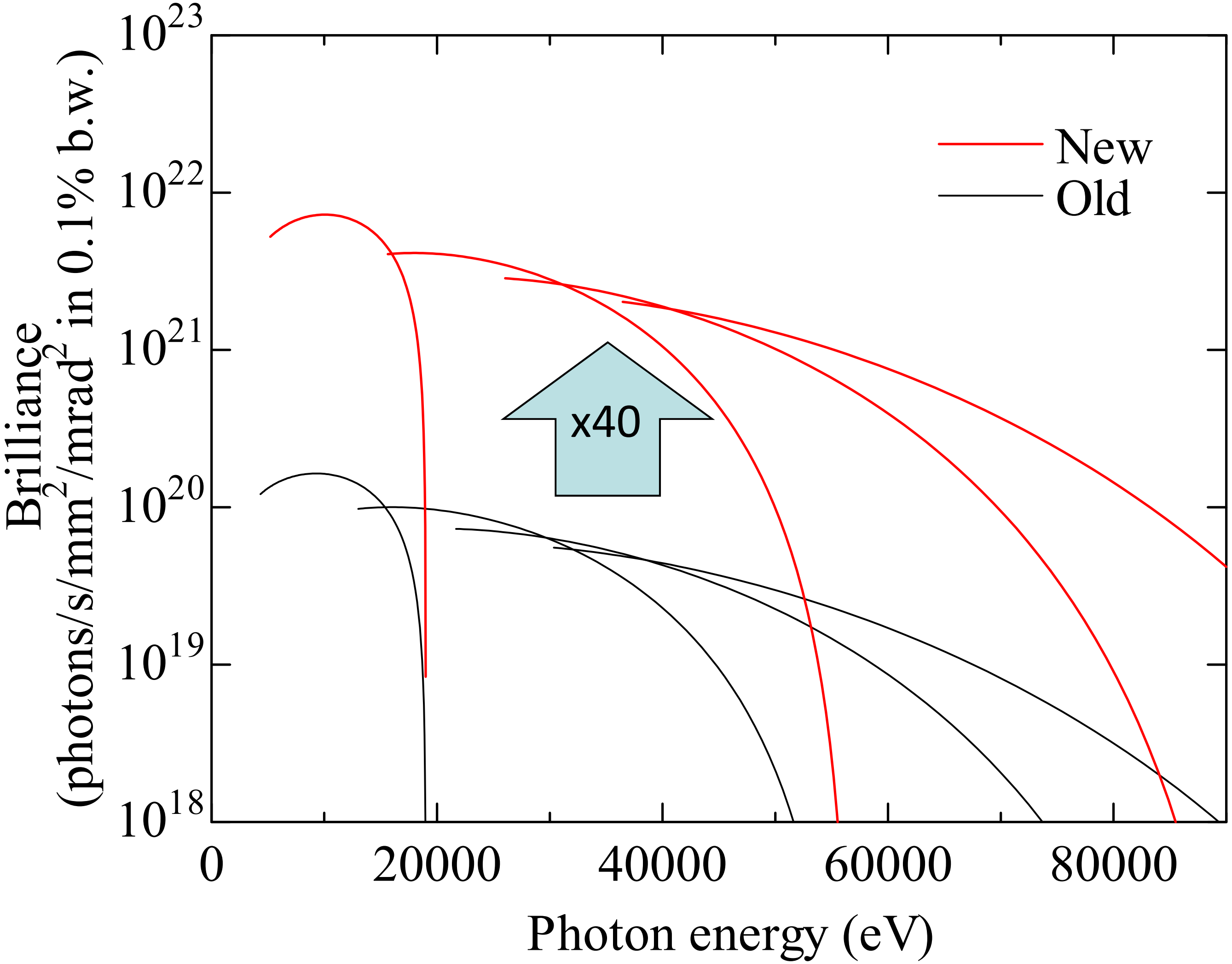
$$\lambda = \frac{\lambda_U}{2\gamma^2}\left(1 + \frac{K^2}{2}\right)$$

$$\frac{32\ mm}{(8\ GeV)^2} = \frac{18\ mm}{(6\ GeV)^2}$$

Basic Parameters

	SPring-8	SPring-8 II
Beam Energy (GeV)	8	6
Natural emittance w/o ID (pm.rad)	3400	142
Natural emittance w ID (pm.rad)		109
H-V coupling (%)	0.2	10
Beam current (mA)	100	100
RMS Bunch length (ps)	17	5.3
Horizontal beam size (um)	297.9	18.0
Horizontal divergence (urad)	12.3	5.5
Vertical beam size (um)	6.2	4.2
Vertical divergence (urad)	1.1	2.4
Undulator length (m)	4.5	3.6
Undulator period (mm)	32	18
Undulator period number	140	200

Brilliance



10^{23}
10^{22}
10^{21}
10^{20}
10^{19}
10^{18}
Brilliance
(photons/s/mm^2/mrad^2 in 0.1% b.w.)
New
Old
x40
0
20000
40000
60000
80000
Photon energy (eV)

Increase of coherent flux

Transverse coherence length $s_x = \frac{\lambda L}{2\pi\sigma_x}$

@10 keV, 74 m from source

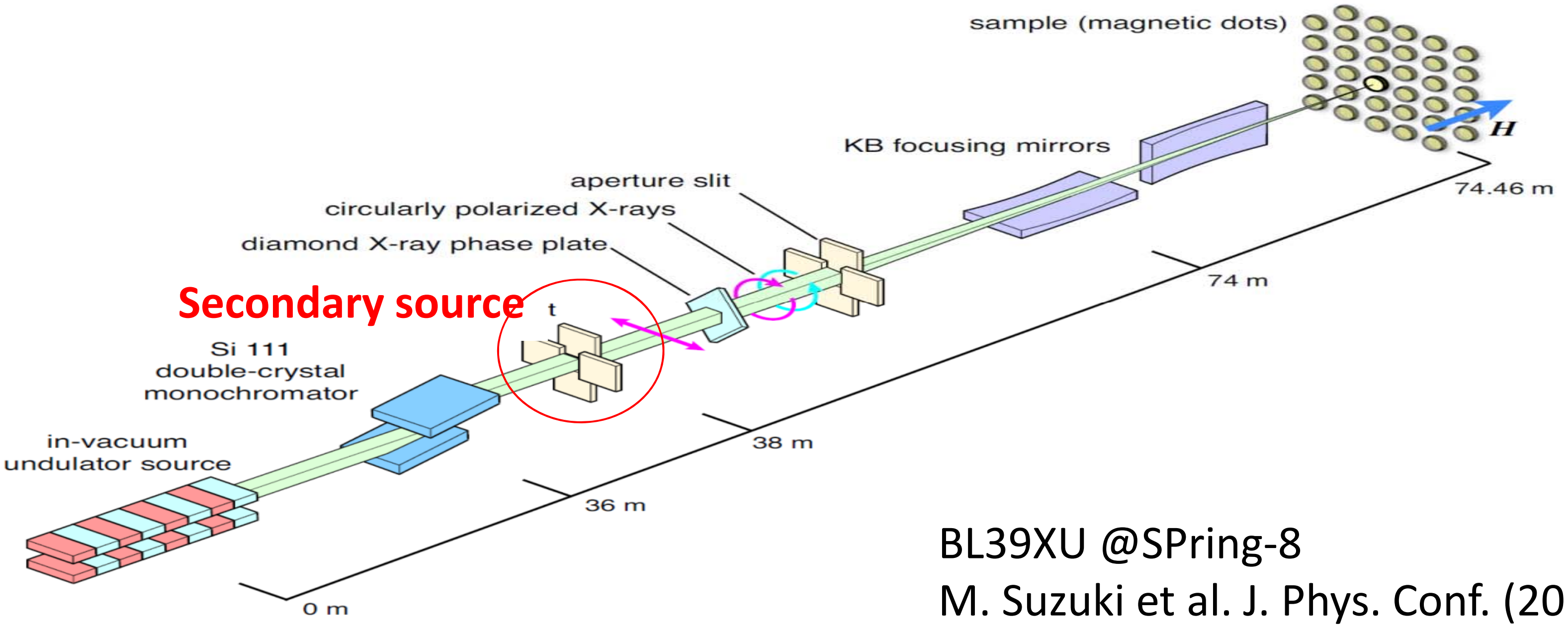
	SPring-8	SPring-8 II
Source size σ_x (um, rms)	298	18.2
Coherence length s_x (um, FWHM)	11.1	182
Beam size (um, FWHM)	2400	1200
Photon flux after aperture s_x (sec^{-1} w Si 111)	5e11	2e13

x40

Proportional to Brilliance

Courtesy of M. Suzuki (SP8)

Nano-focusing beamline



BL39XU @SPring-8
M. Suzuki et al. J. Phys. Conf. (2013)

	SPring-8		SPring-8 II
Secondary source size (μm)	18(H) x 8(V)	-	-
Fo		8(V)	170(H) x 120(V)
Pho (s			~1e14

LETTERS
PUBLISHED ONLINE: 22 NOVEMBER 2009 | DOI: 10.1038/NPHYS1457

nature physics

Breaking the 10 nm barrier in hard-X-ray focusing

Hidekazu Mimura[1]*, Soichiro Handa[1], Takashi Kimura[1], Hirokatsu Yumoto[2], Daisuke Yamakawa[1], Hikaru Yokoyama[1], Satoshi Matsuyama[1], Kouji Inagaki[1], Kazuya Yamamura[3], Yasuhisa Sano[1], Kenji Tamasaku[4], Yoshinori Nishino[4], Makina Yabashi[4], Tetsuya Ishikawa[4] and Kazuto Yamauchi[1,3]

Available photon flux

Any merits for users who care only photon flux ?
(rather than brilliance or coherence)

Reduction of horizontal emittance

-> Smaller x-ray beam size

-> Enables to decrease aperture size and heatload for optics

-> Could enhance photon flux by increasing undulator periodic number (or stored current)

Comparison of X-ray spatial profiles and heat loads

8 GeV, 100 mA, λu=32 mm, K=2.4 N=140

2.1 mm

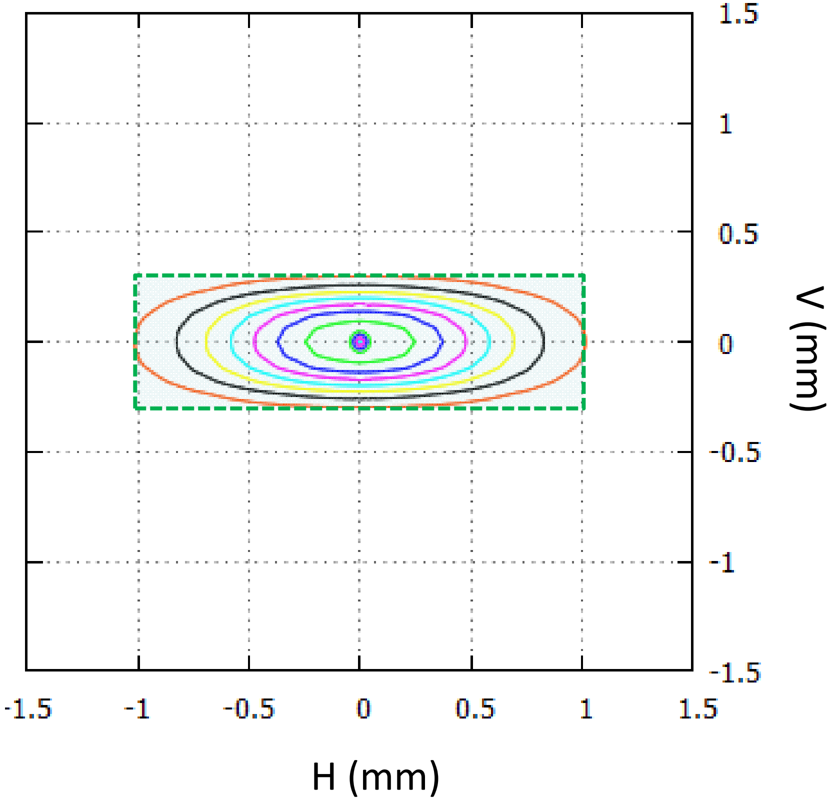
0.6 mm | 640 W

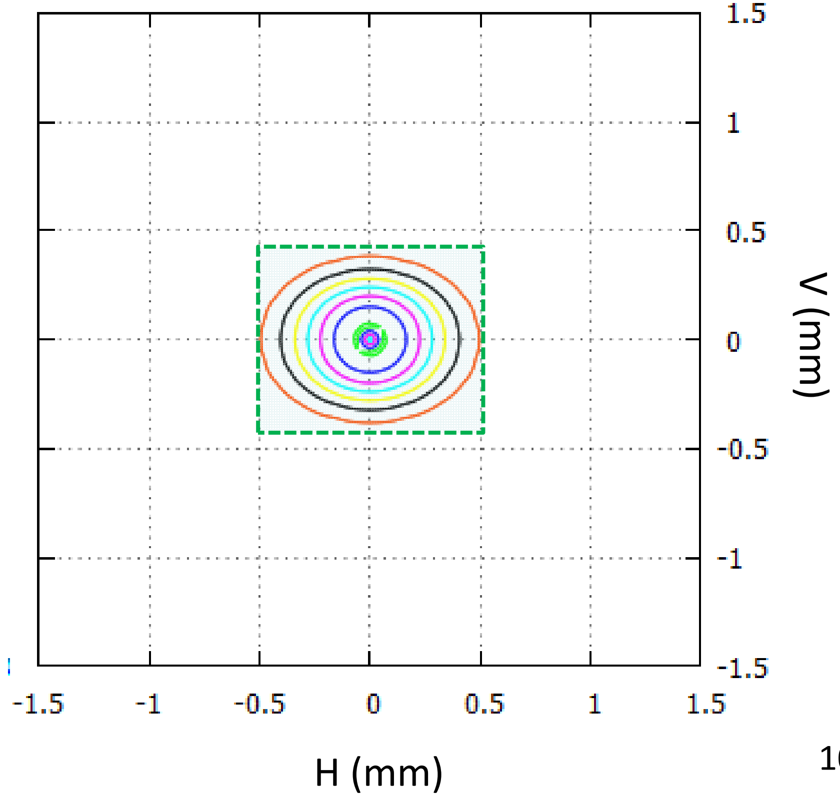
6 GeV, 100 mA, λu=18 mm, N=200

1.0 mm

0.8 mm | 330 W

@ 30 m from source





Comparison of X-ray spatial profiles and heat loads

8 GeV, 100 mA, λu=32 mm, N=140

1.1 mm

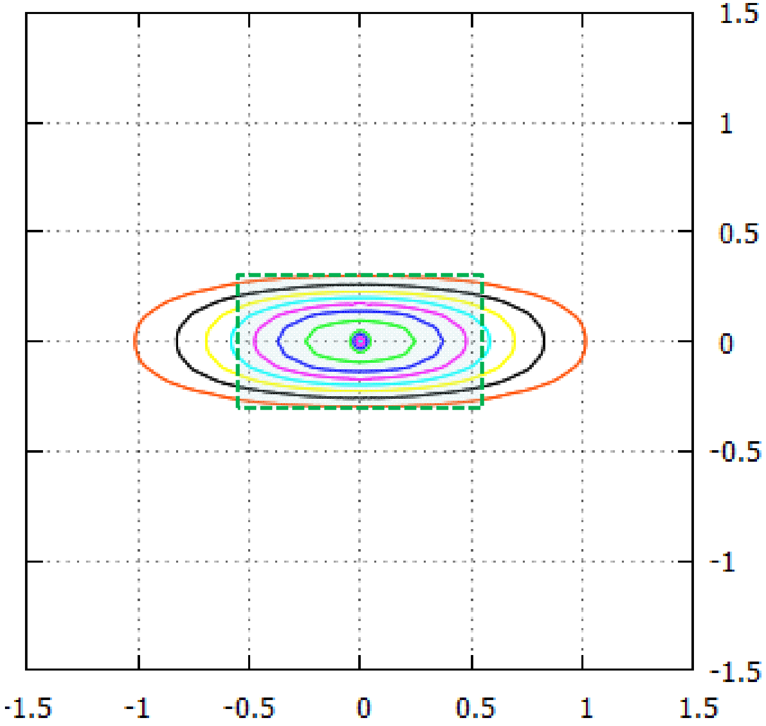
0.6 mm | 340 W

6 GeV, 100 mA, λu=18 mm, N=200

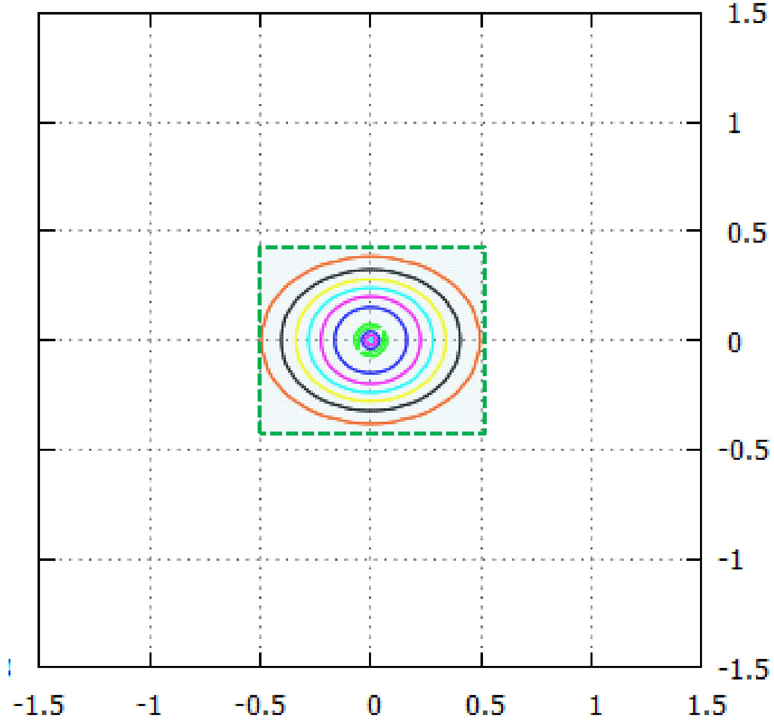
1.0 mm

0.8 mm | 330 W

30 m from source

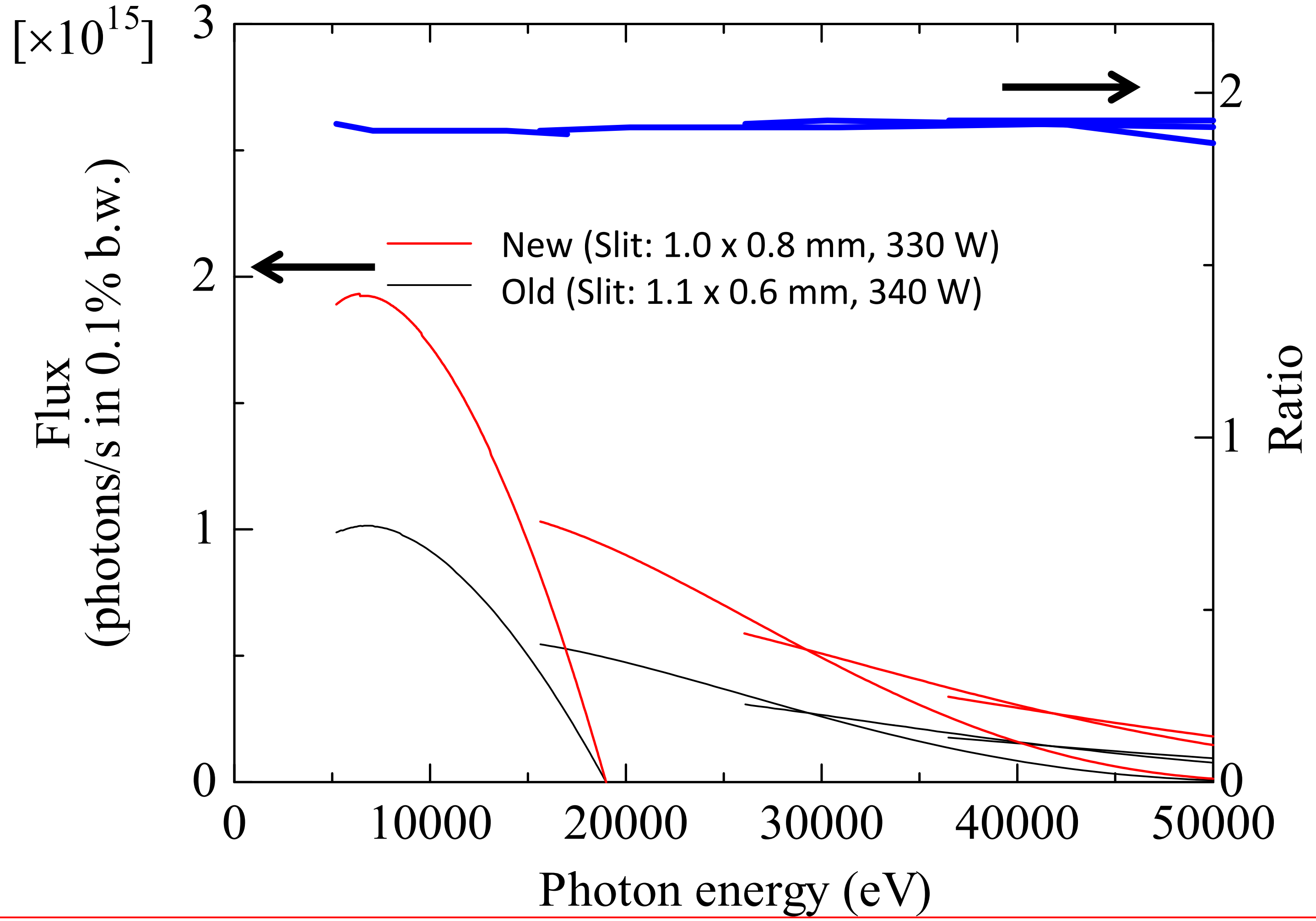


R_{eff} (partial flux/total flux) ~ 70%



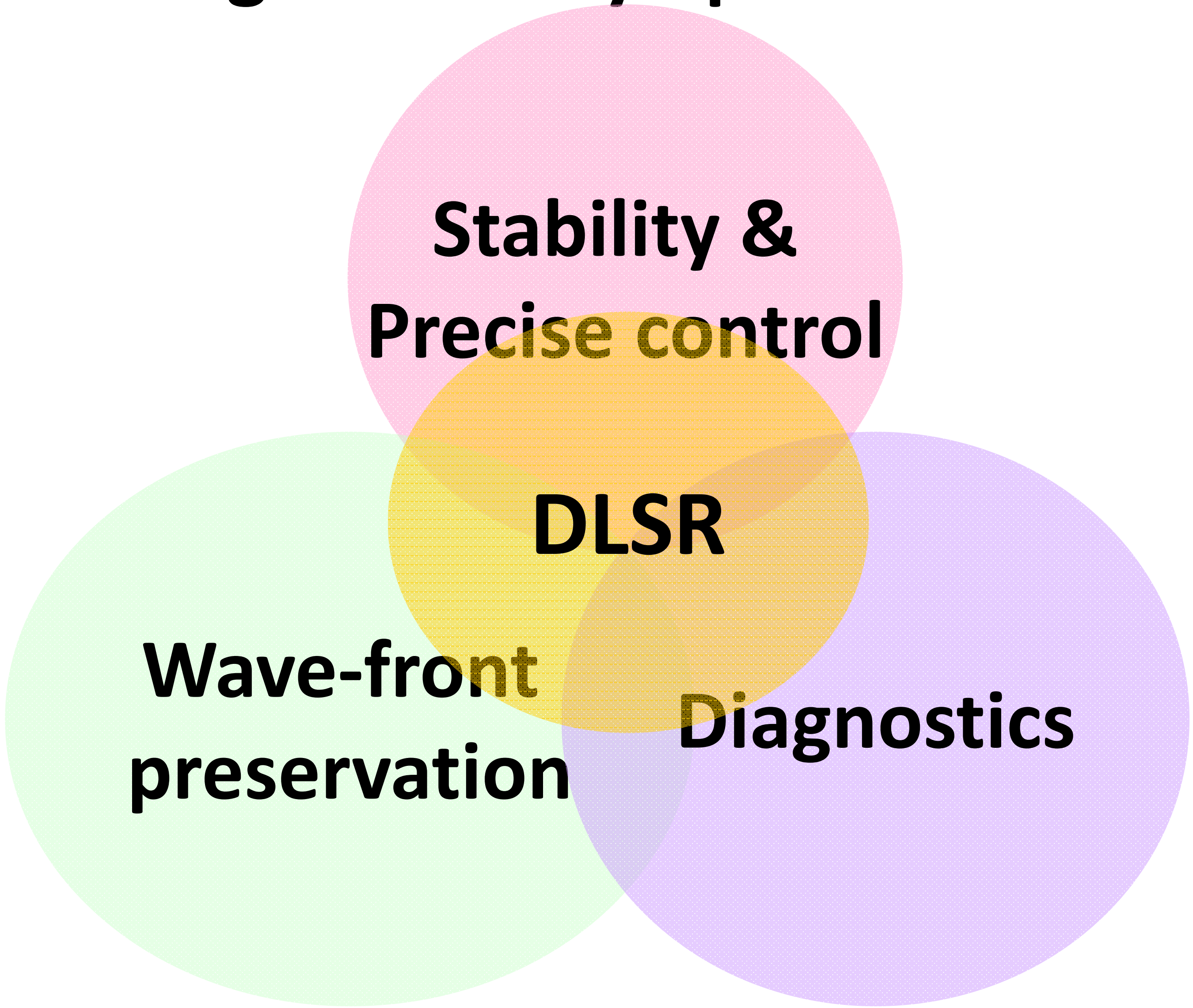
R_{eff} ~ 90%

Comparison of available flux with fixed heat load



Available flux could be doubled for wide wavelength range

Challenges of X-ray optics for DLSR



Stability

(1) Removal of secondary source after DCM

Vibration of e-beam and x-ray optics in vertical direction (= deflection direction of DCM) should be sufficiently suppressed

Tolerance: $\delta_y \ll \frac{\sigma_y}{L} = \frac{10\ um\ (FWHM)}{70\ m} = 0.13\ \text{urad}$

(2) Stabilization of nano-focused beam

Tolerance: $\delta \ll \frac{s}{L} = \frac{10\ nm\ (FWHM)}{0.1\ m} = 0.1\ \text{urad}$

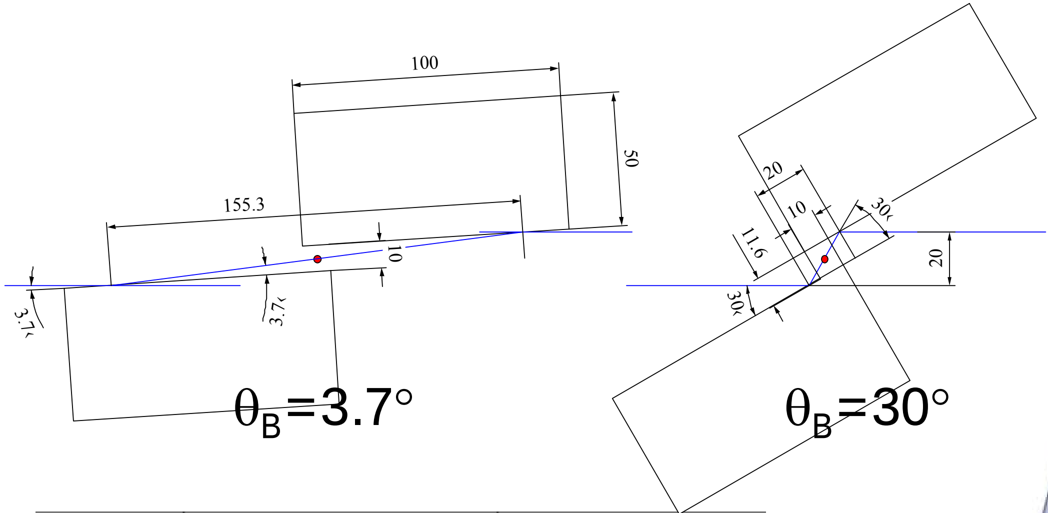
Target stability: 10 nrad

Stability improvement of DCM (I)

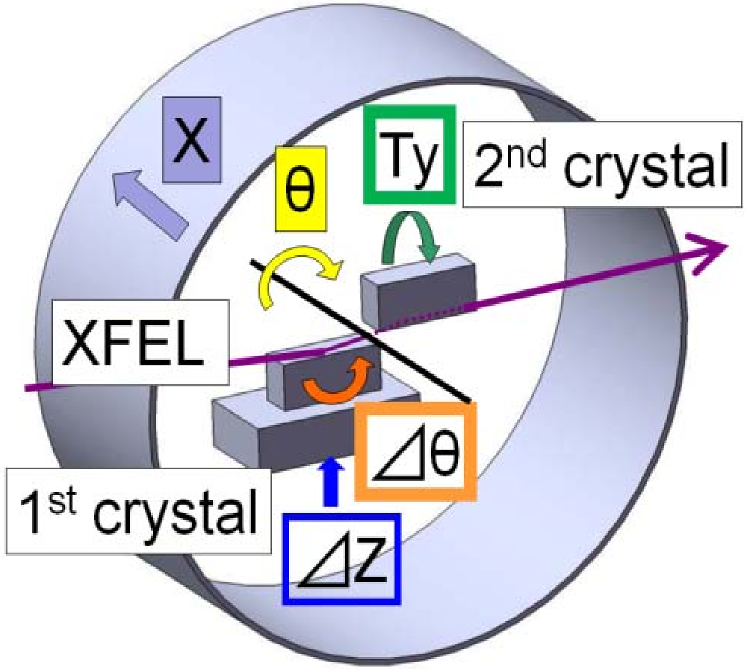
Reduction of number of axis & range: tested at SACLA

H. Ohashi et al. NIM A710, 139 (2013)

Use large (90mm) Si crystals with small offset (20mm)

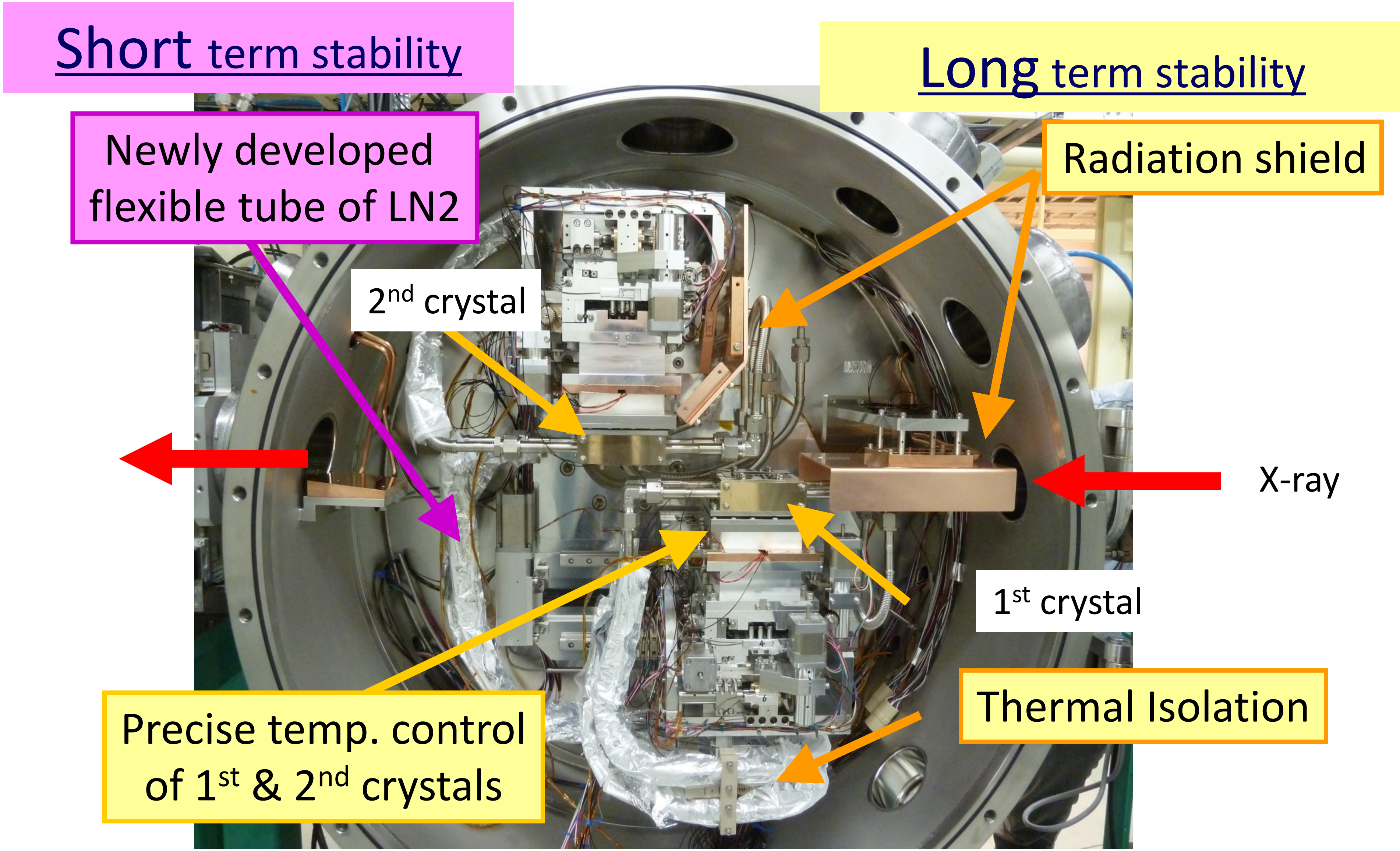


Axis	Range	Resolution
θ	-1～30 [deg]	1 [μrad]
X	60 [mm]	0.1 [mm]
⊿θ	±0.5 [deg]	0.1 [μrad]
⊿Z	±1 [mm]	10 [μm]
Ty	±0.5 [deg]	1 [μrad]



Stability improvement of DCM (II)

high-heat load issues @ SPring-8



for short term stability

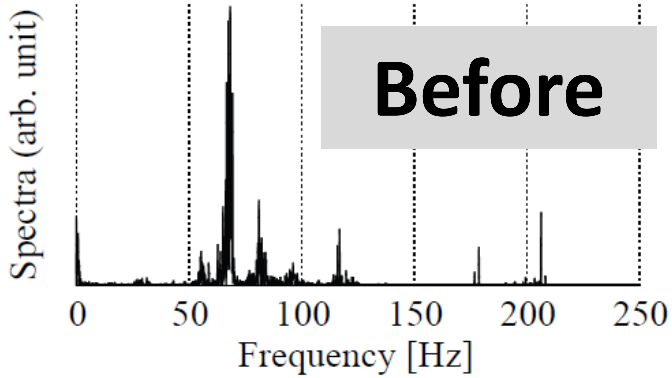
Coolant flexible tube

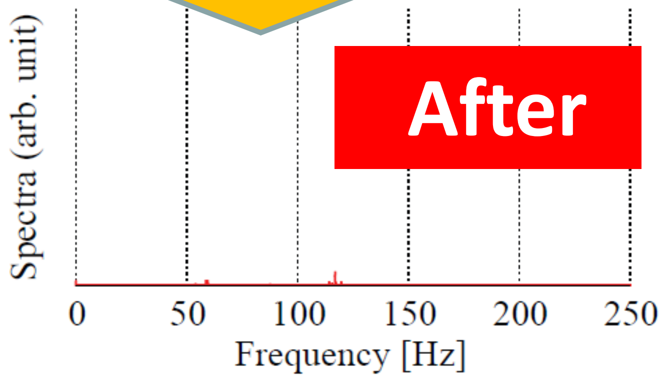
Water cooling

Waviness inside tube → Turbulence → Vibration

Smoothing inside tube

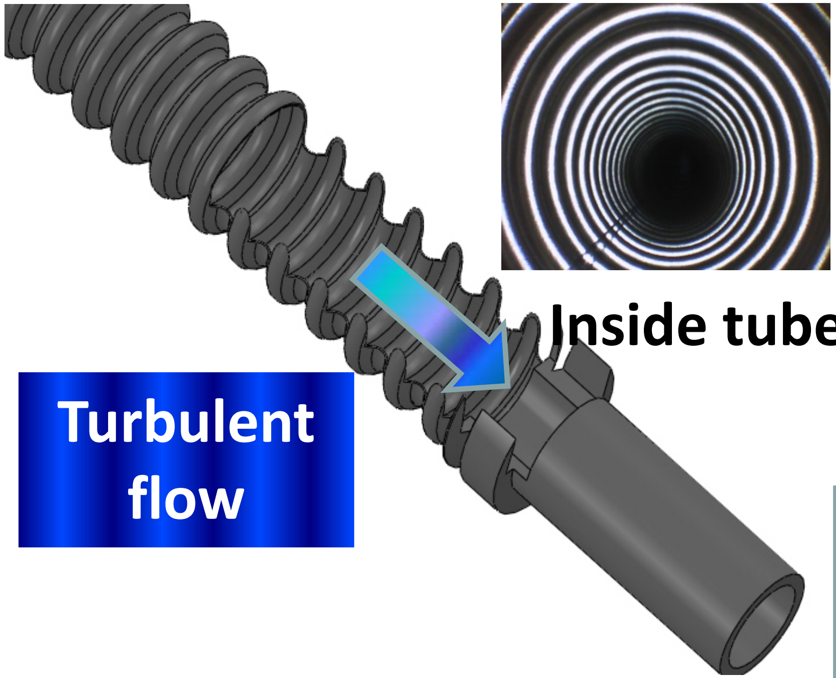
Installing Urethane tube



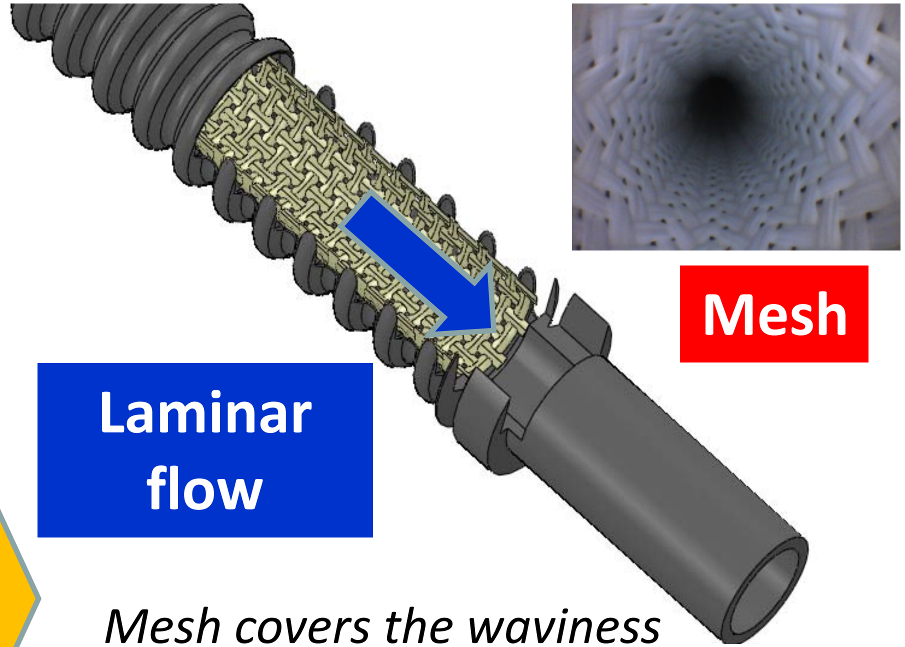


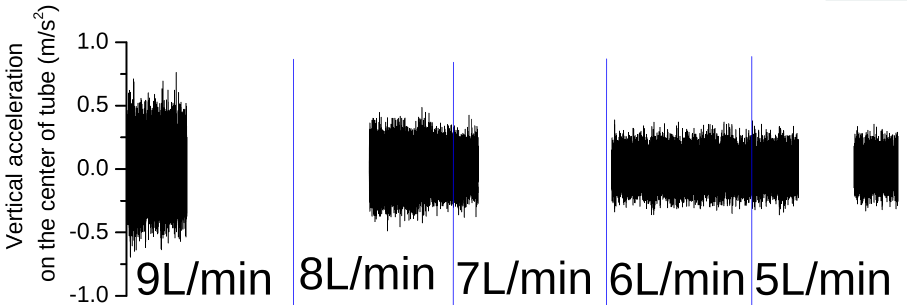
Coolant flexible tube for LN

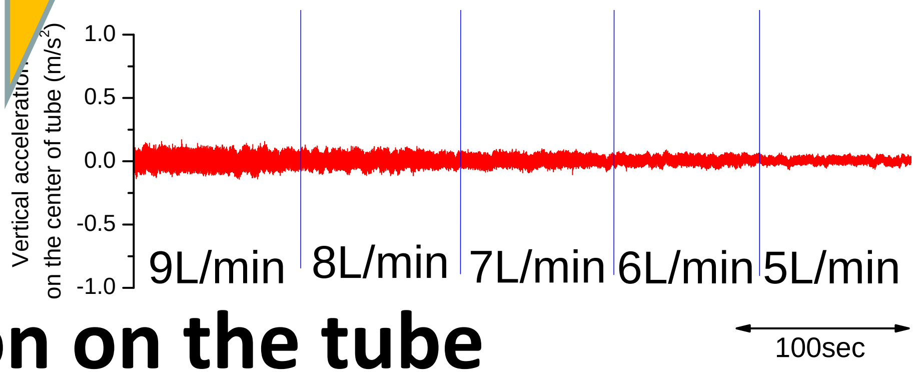
Standard



Clear Flow Flex™







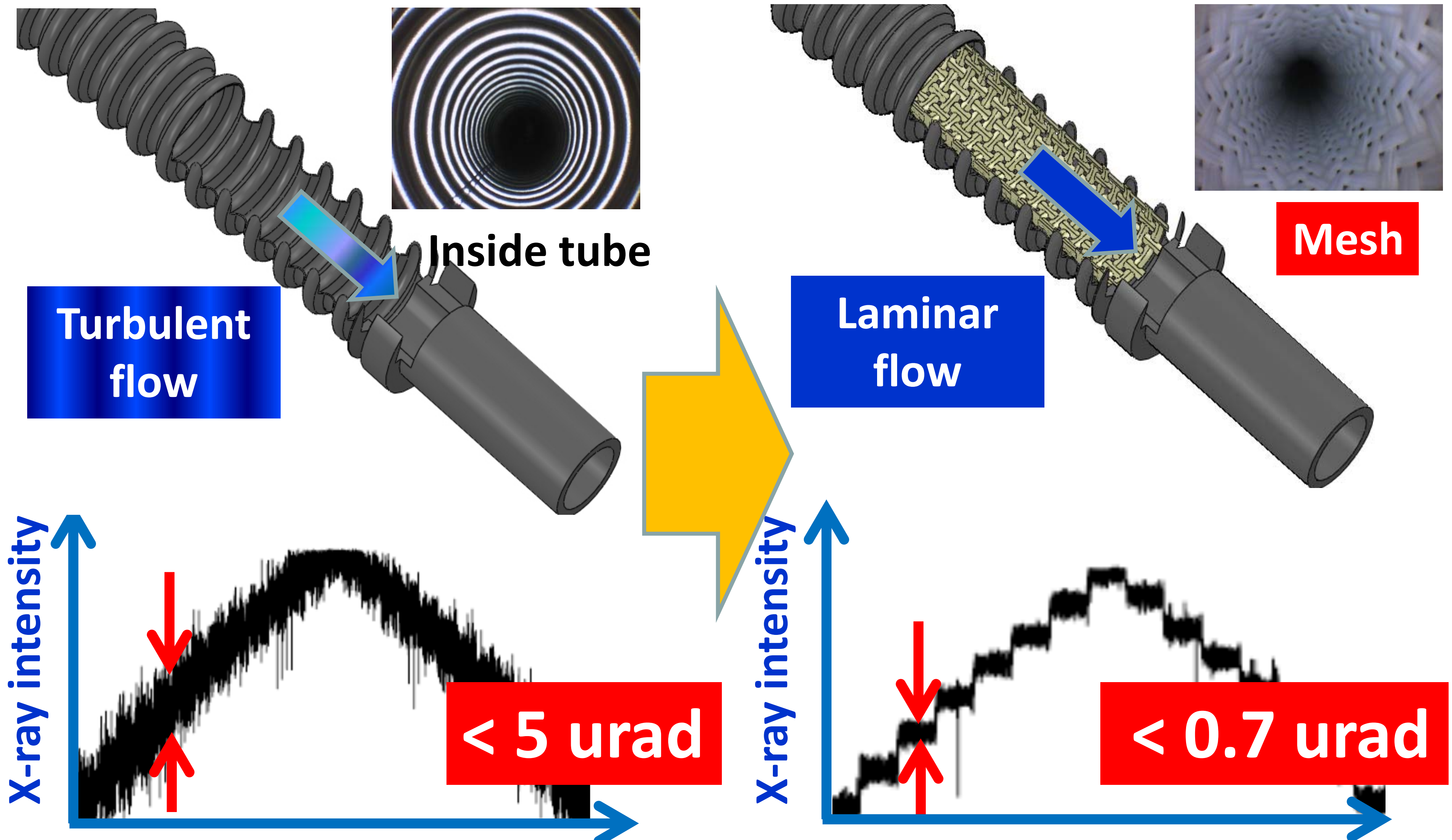
Acceleration on the tube

The vibration is reduced for wide range of flow rate *for short term stability*

Coolant flexible tube for LN_2

Standard

Clear Flow Flex™

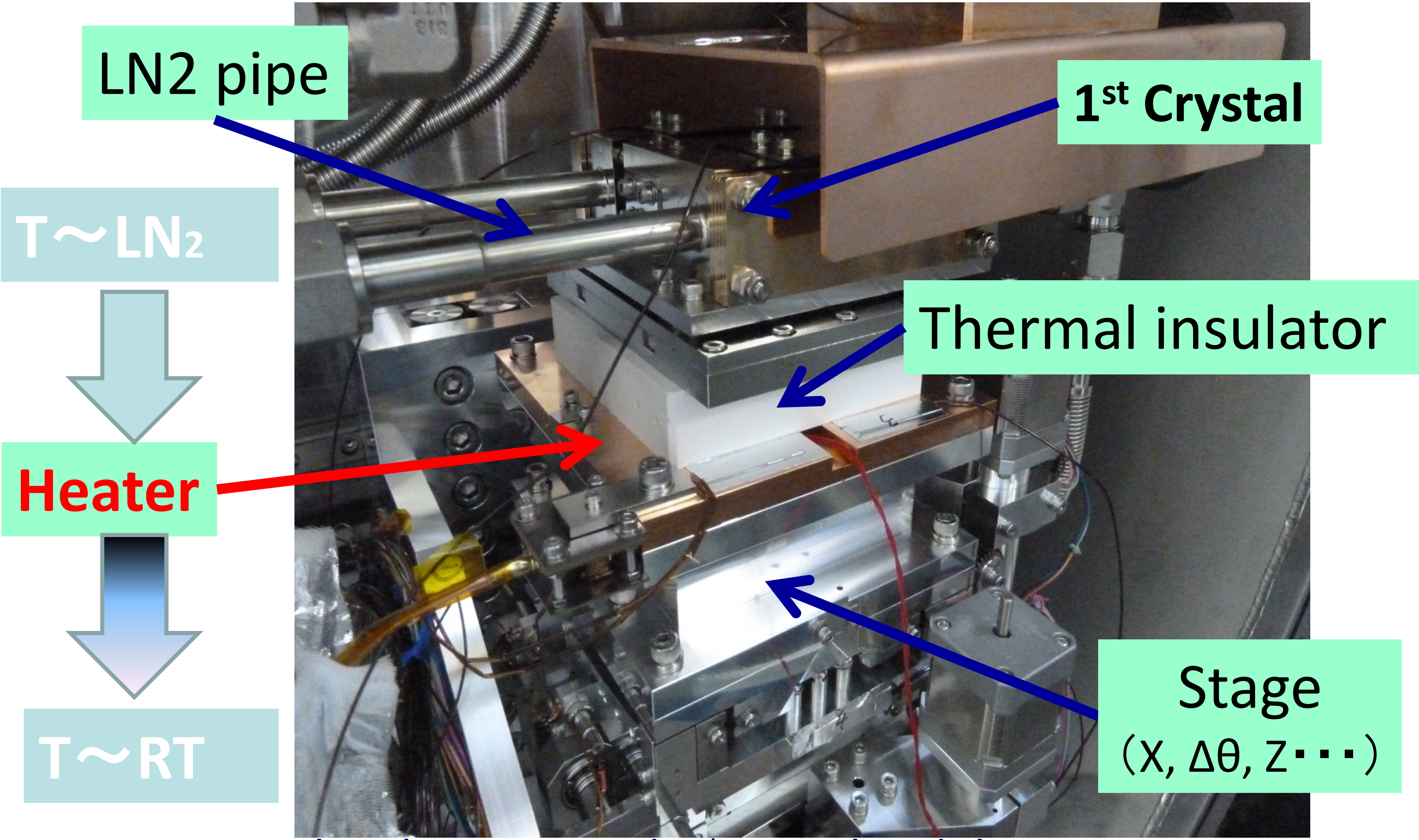


PIN photo diode of 1kHz sampling as stepping Δθ1 of 1 urad in a 5 sec-interval

For long term stability

Precise temperature control in DCM

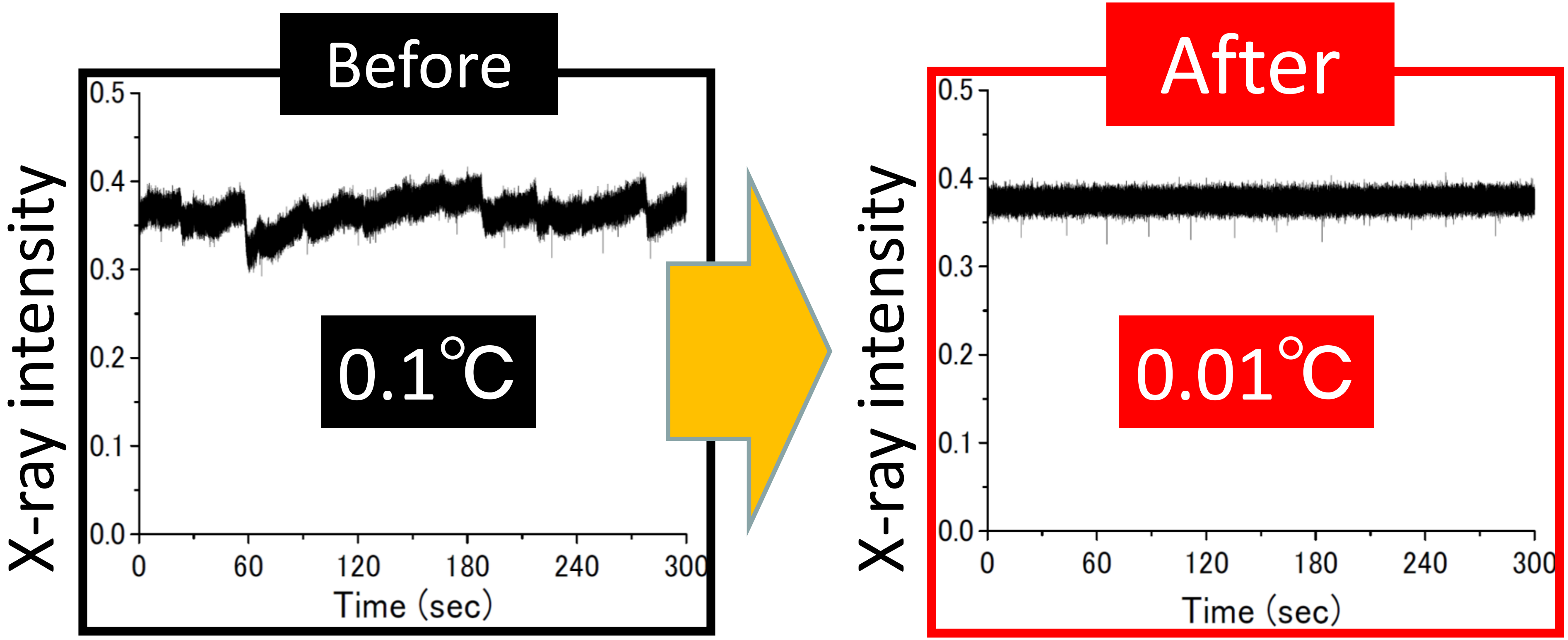
Temperature drift causes long-term instability



The photo around 1st crystal and the stage

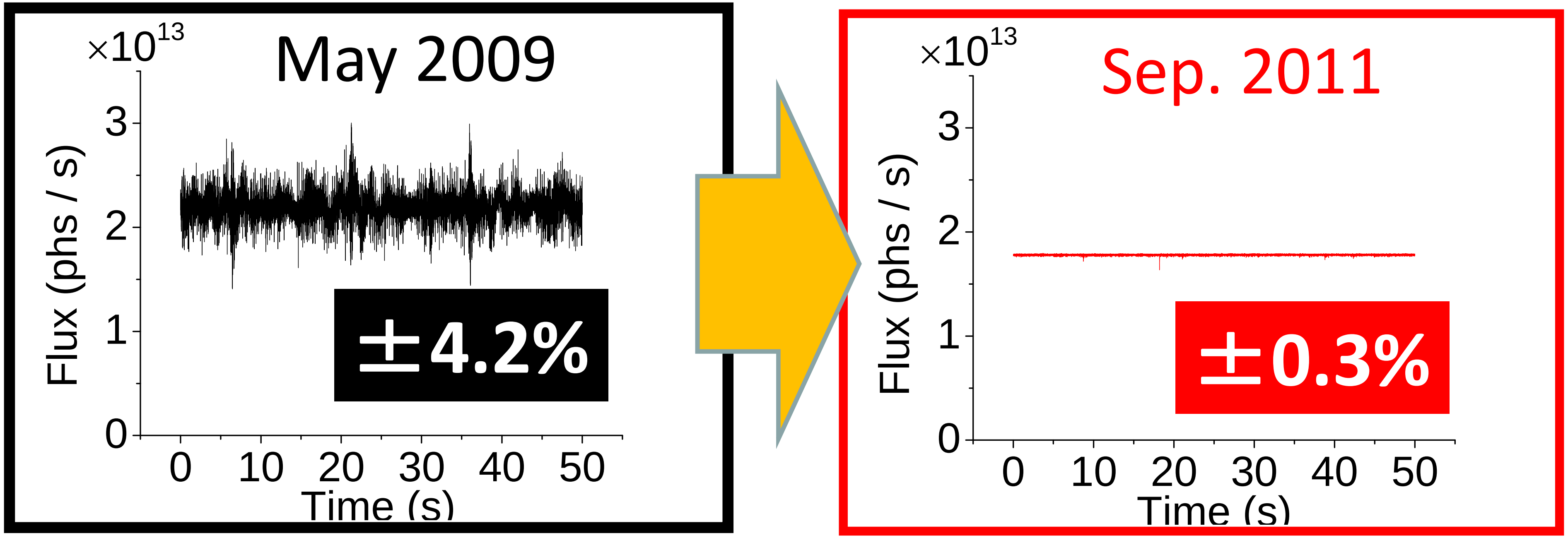
For long term stability

Correlation between Temperature and X-ray intensity

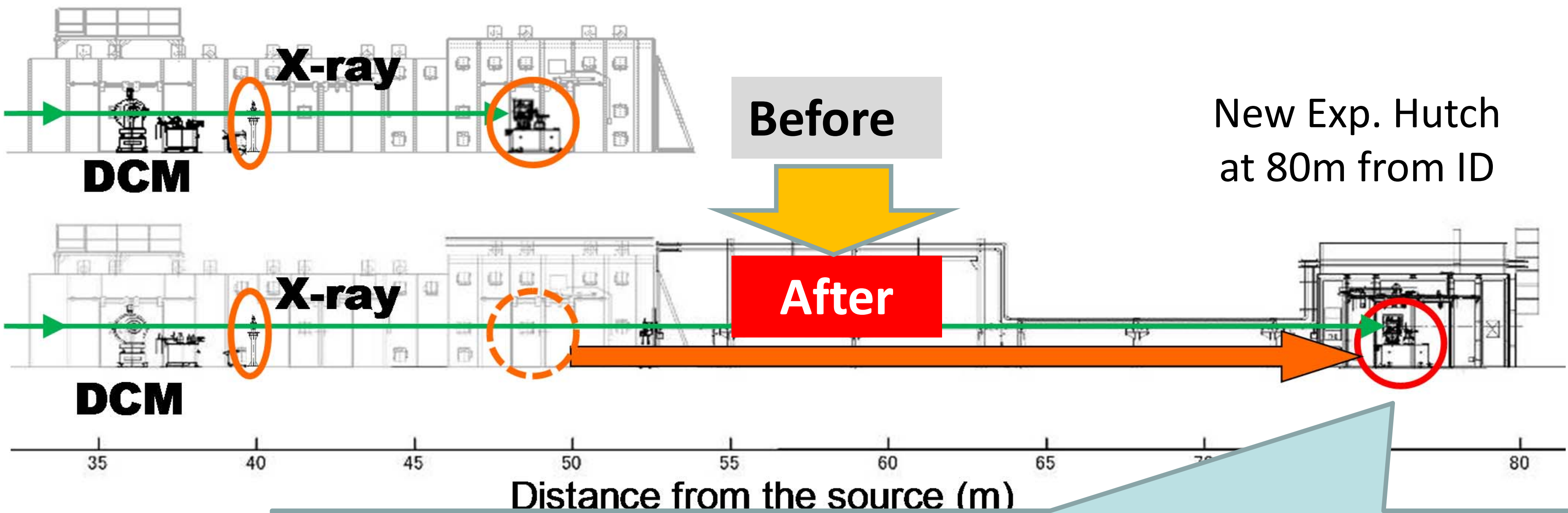


Stability of x-ray intensity

Stability of DCMs with LN2 cooling is now comparable to those with water cooling

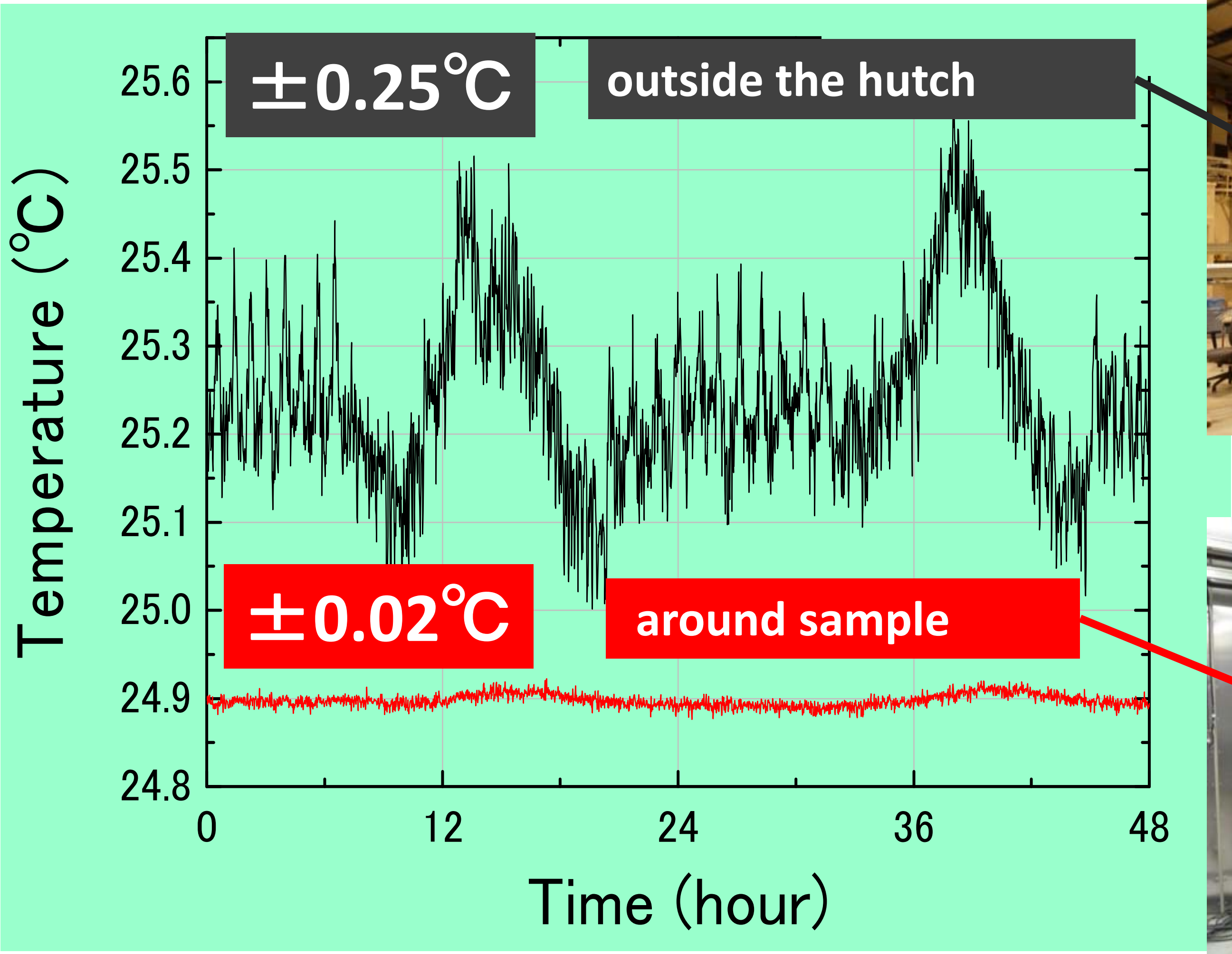


Dedicated experimental hutch for nano applications



Dedicated experimental hutch for nano applications

High precision temperature control

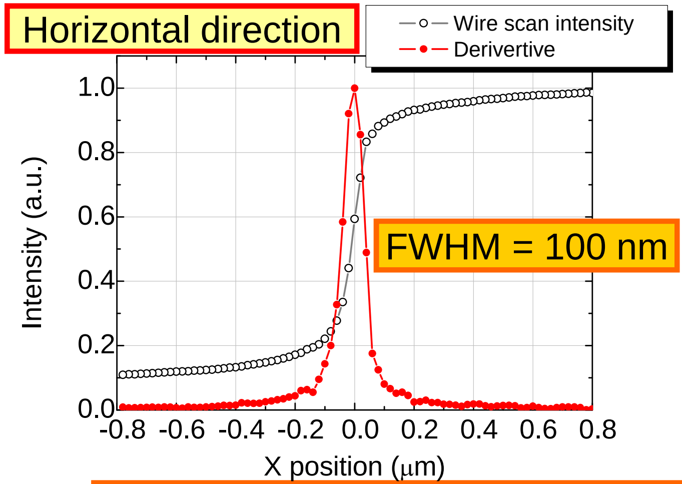


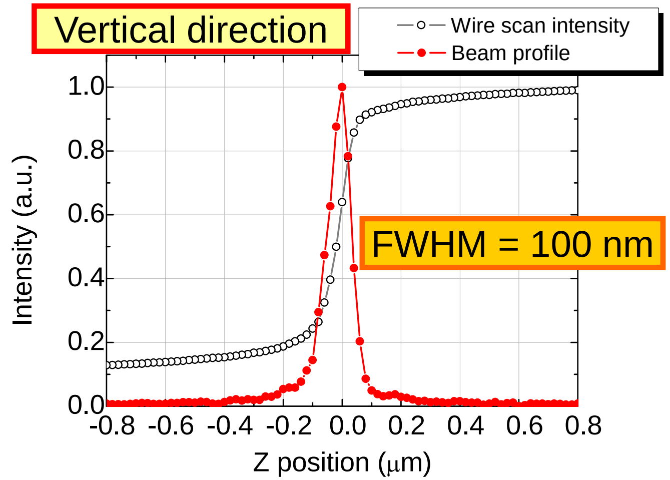
Focusing beam performances –100 nm probe–

H. Yumoto (SPring-8)

Focusing beam size

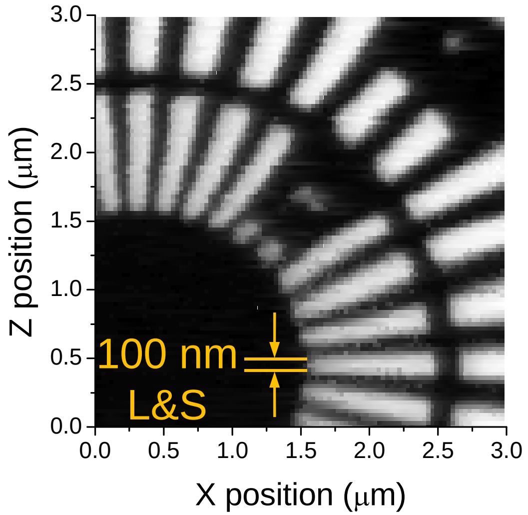
Knife edge scanning method
(200 μm ϕ Au wire)
X-ray energy = 12.4 keV





Stable 100 nm focusing beam is available in public beamlines

Stability test with 2D map of test chart

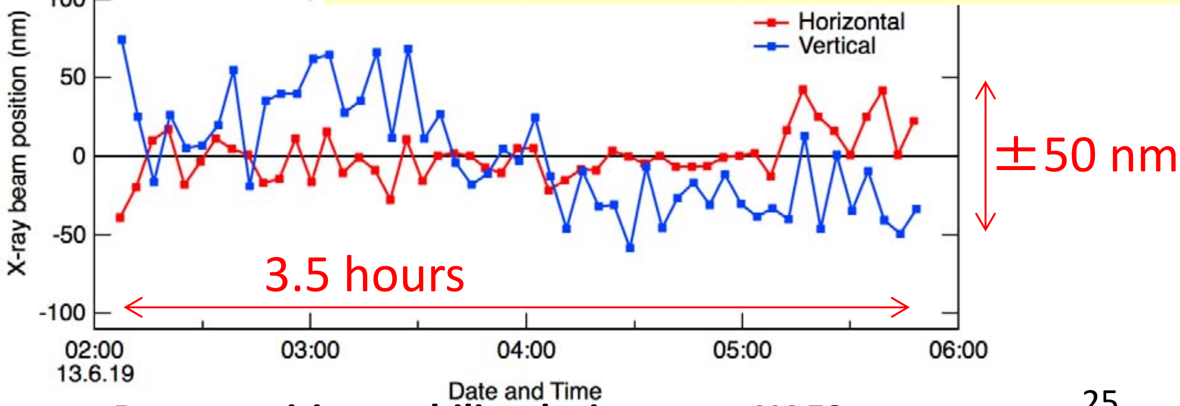


Scanning transmission microscopy (absorption contrast)

30 nm step, 100×100 pix
exposure time: 0.1 sec/pix
scan time: 1.5 hr

Position stability

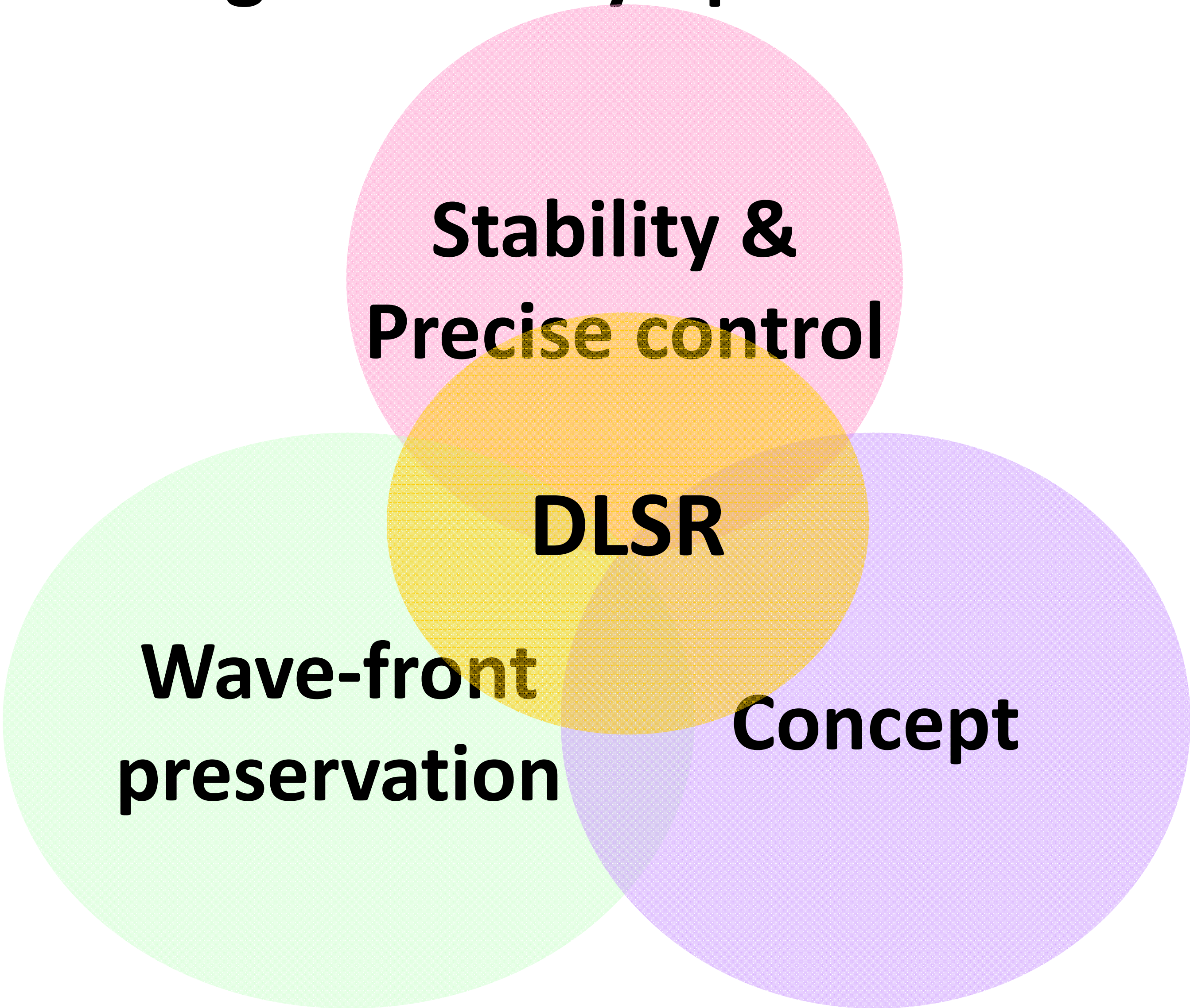
Horizontal: < ±50 nm/3.5 hours
Vertical: < ±75 nm/3.5 hours



Beam position stability during nano-XAFS scan

Courtesy of Drs. Fons (AIST), Sekizawa (UEC), Suzuki (SPring-8)

Challenges of X-ray optics for DLSR



Speckle-free properties

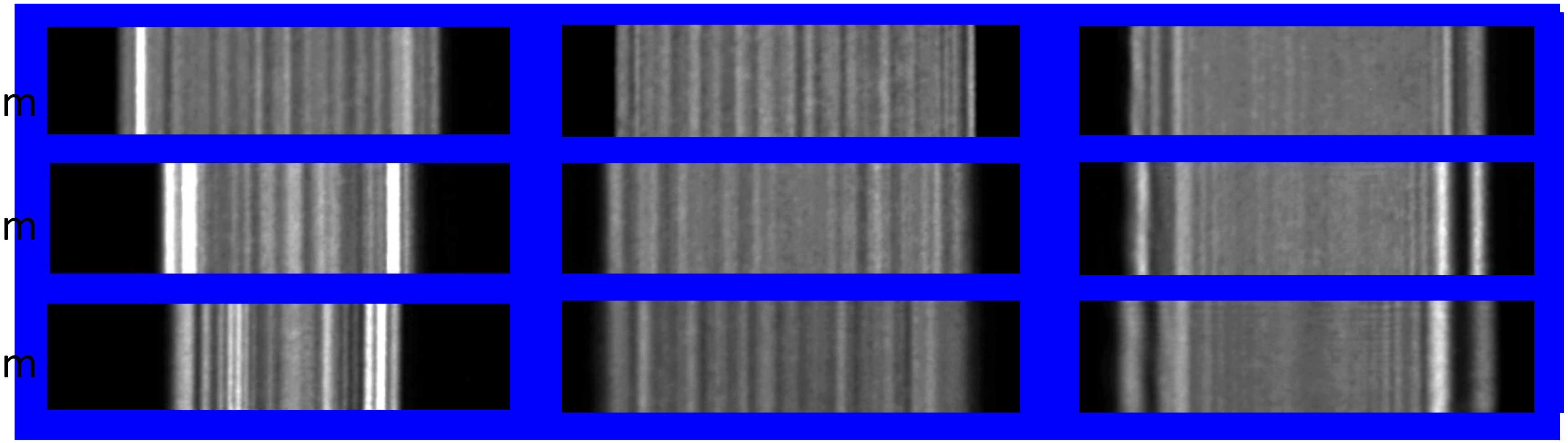
Mirror

Prof. Yamauchi
(Osaka U)

Mori et al. Proc. SPIE 2001

Distance: Pre-machined | PCVM | PCVM+EEM

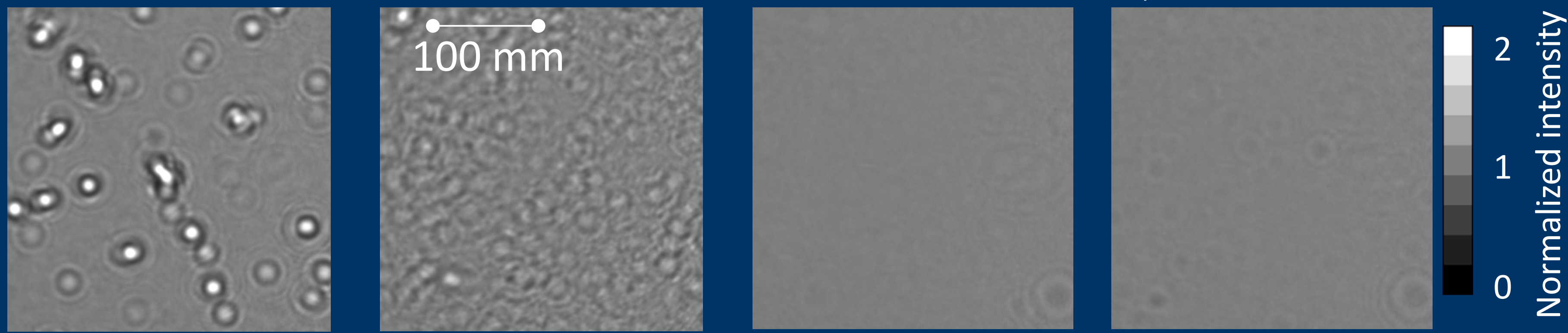
166 mm
566 mm
966 mm



Be window

S. Goto (SP8)

Goto et al. Proc. SRI 2007, 1057



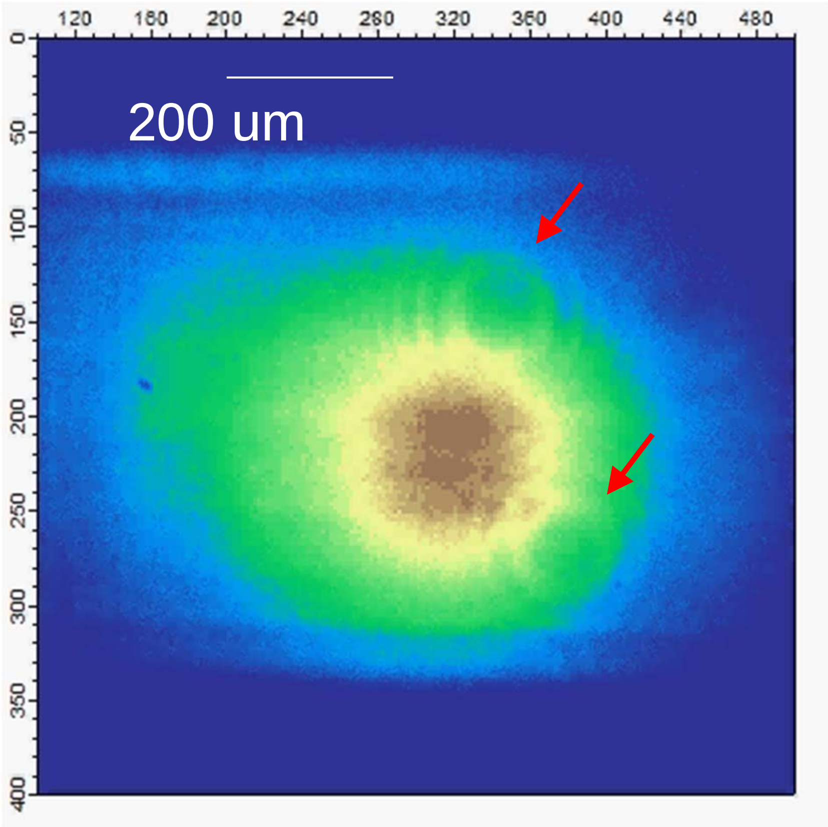
Polished O-30
(HIP powder foil)
100 nm p-v

Polished IF-1
(Ingot foil)
100 nm p-v

Polished PVD
50 nm p-v

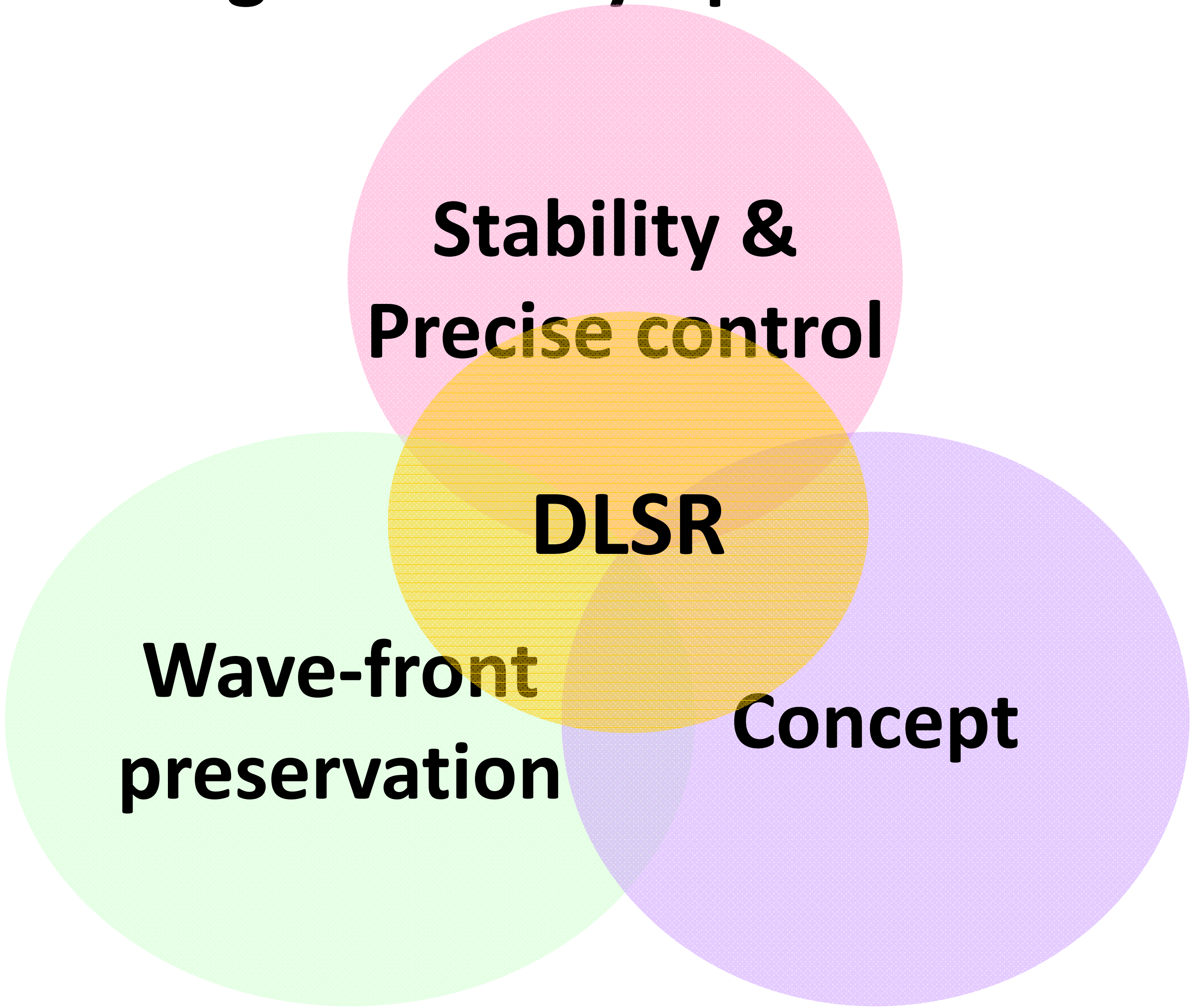
Kapton

Wavefront preservation: example at SACLA

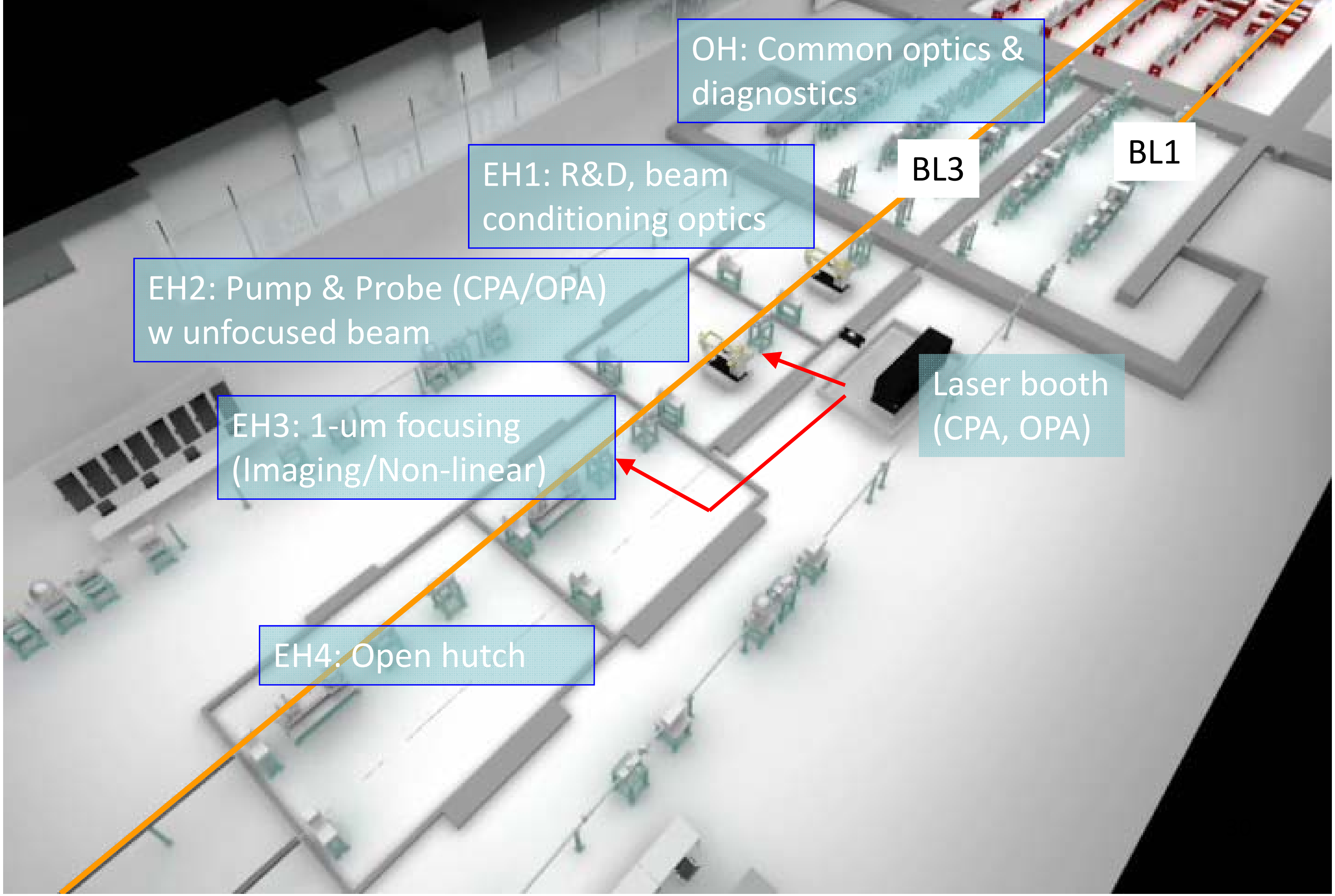


Two plane mirrors + 3 Be windows (50 umt)
Mostly OK, but small speckles due to particle contamination are observable

Challenges of X-ray optics for DLSR



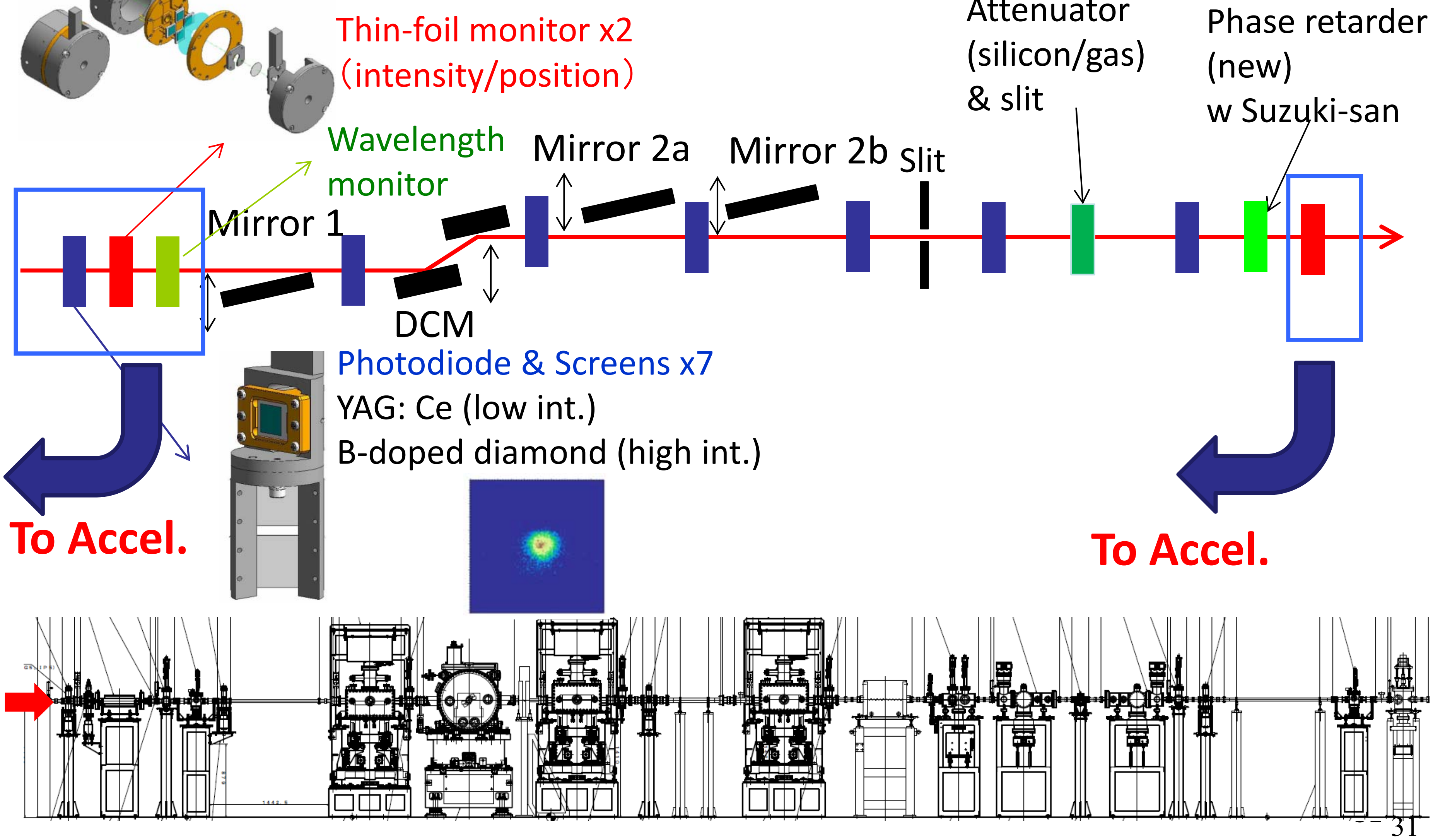
Design of SACLA Beamline



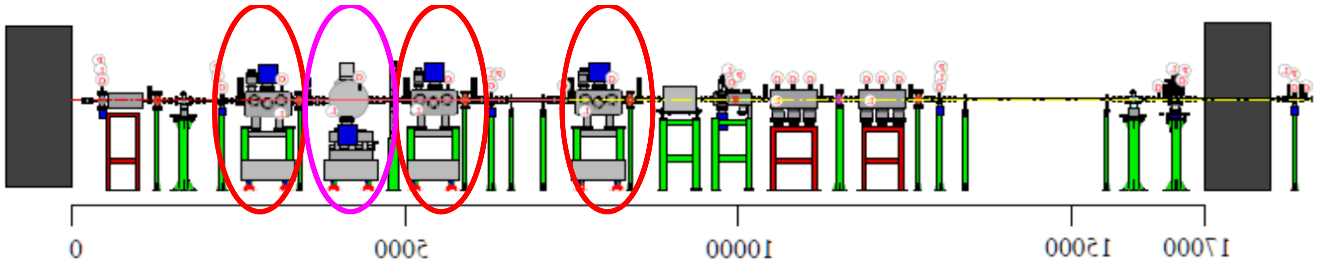
SACLA beamline

Tono et al, New J. Phys. **15**, 083035 (2013)

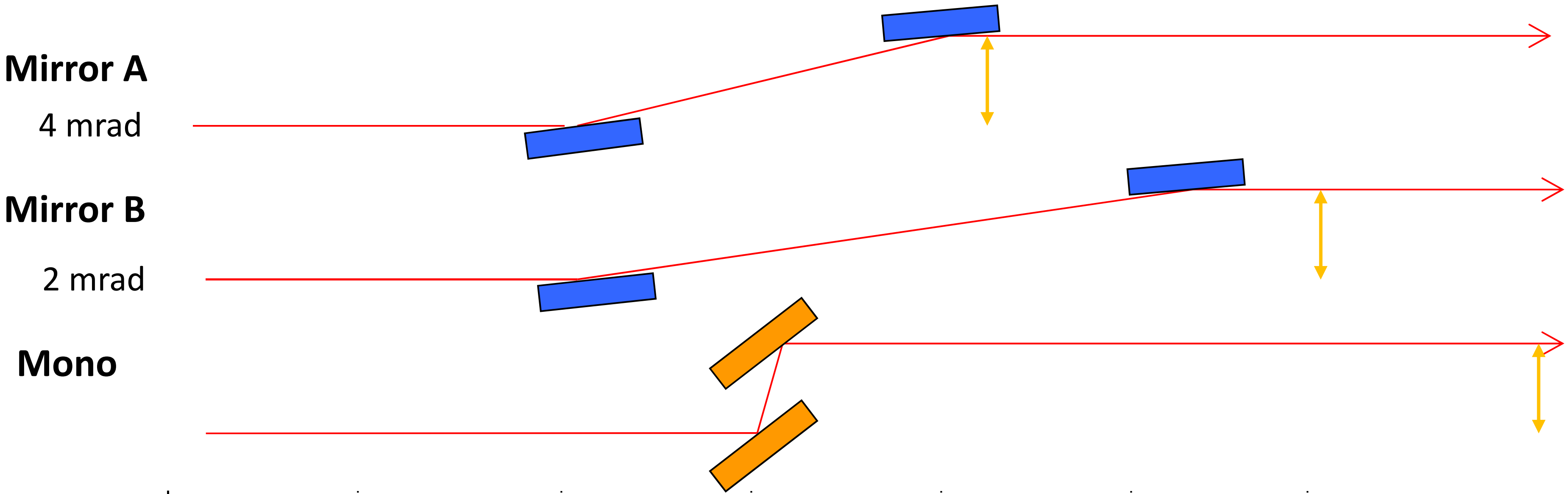
1. Switchable optical components for covering different band pass
2. X-ray diagnostics for stable machine operation

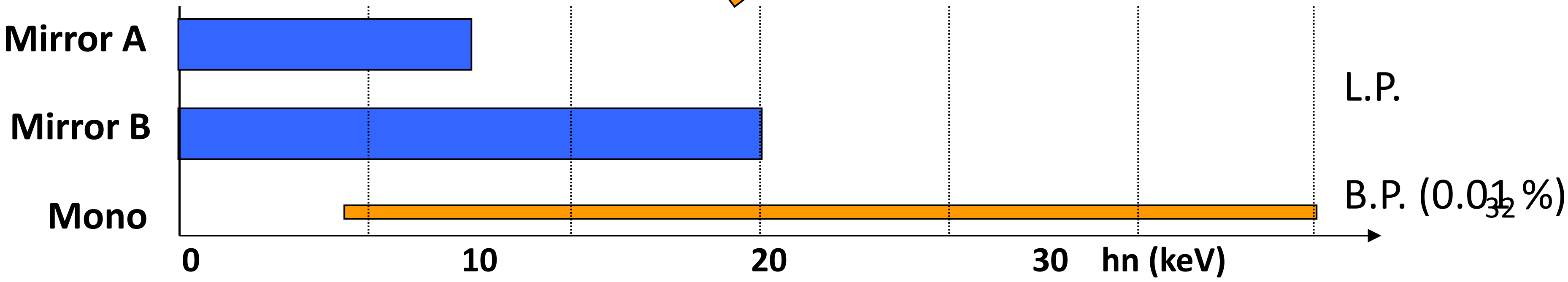


Main Optics

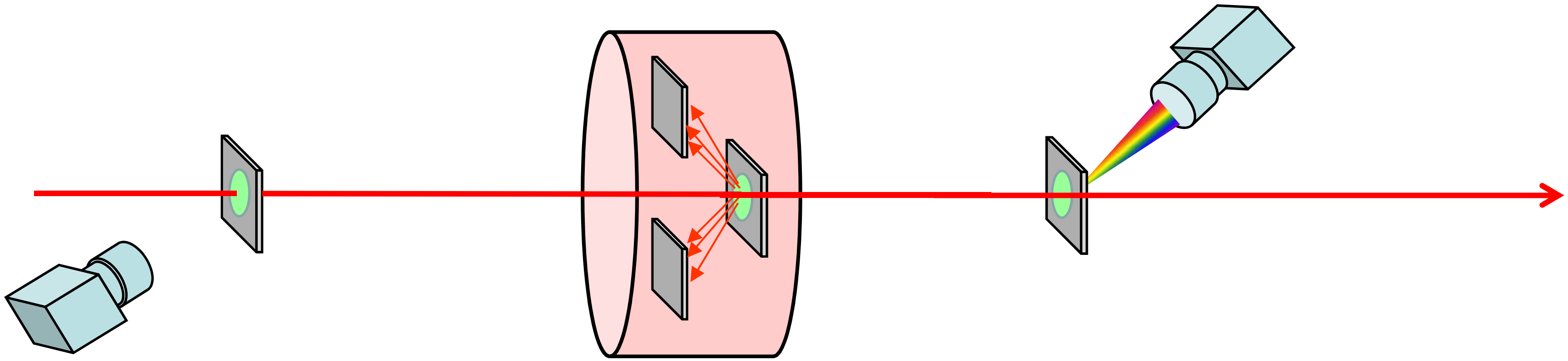


- Double mirror A; Double mirror B: Lower photon energy with wider b.w.
- Double-Crystal Monochromator: Higher photon energy with finer b.w.
- Fixed Exit design (20-mm offset) with exclusive utilization





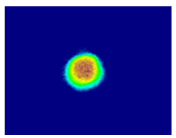
Non-invasive photon diagnostics used for daily operation of SACLA



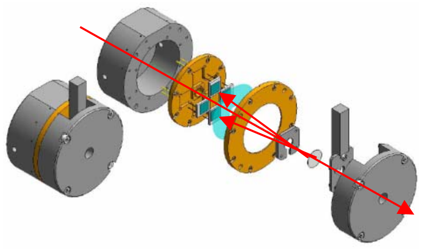
1. Profile monitor

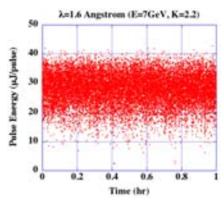
2. Thin-foil monitor

3. Thin-foil spectrometer

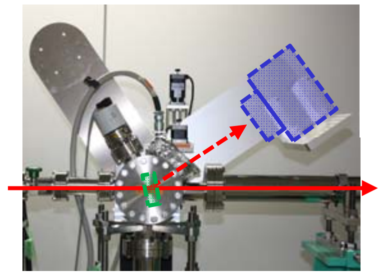


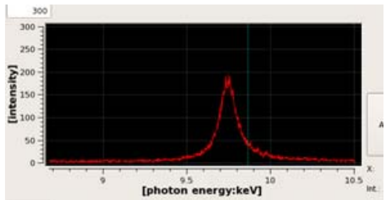
B-doped diamond





Intensity/position

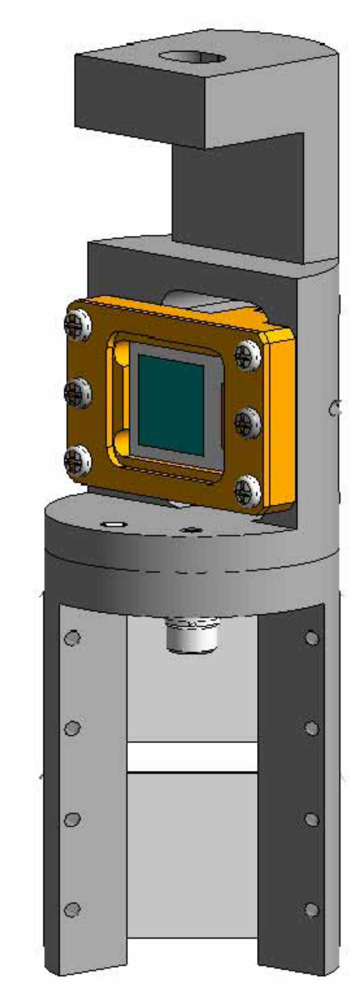




Spectrum

Screen monitor

T. Kudo, K. Tono et al.

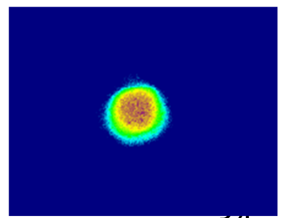


Phosphor screens

Si PIN photodiode
(intensity measurement)

Ce:YAG plate
(high sensitivity)

B-doped diamond film
T>99% (10-um t) for HX
Speckle-free
-> On-line monitor

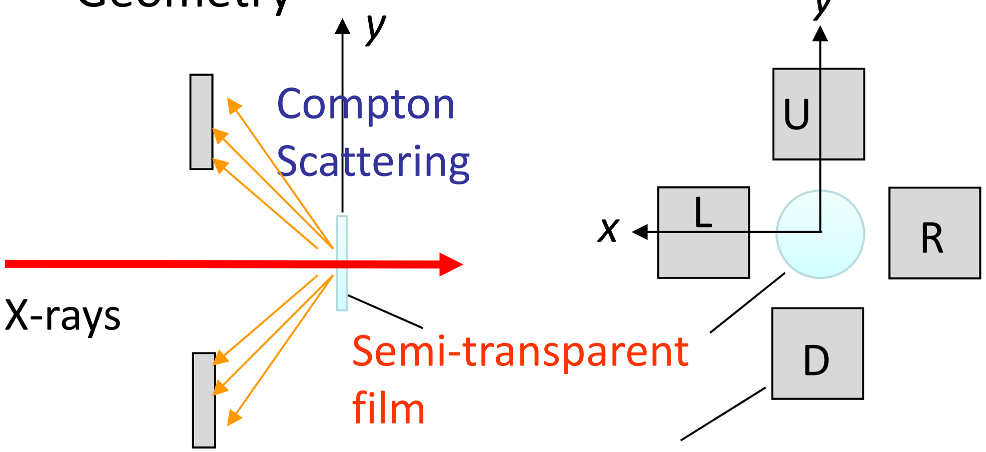


Thin-foil monitor

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

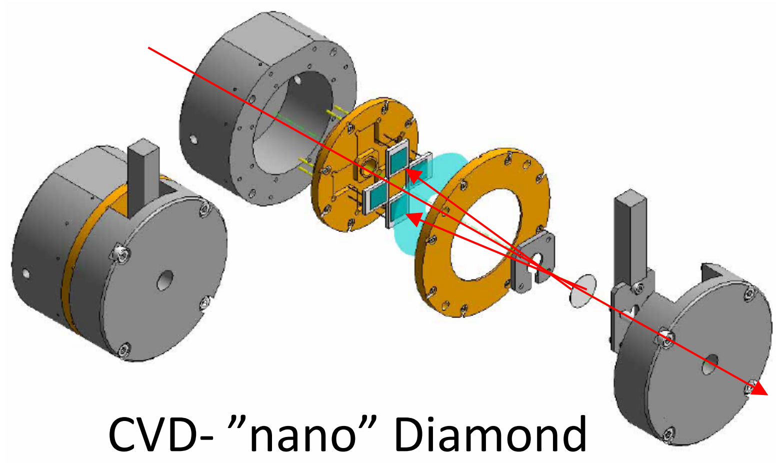
Collaboration with LCLS

Geometry



Photodiode

Quadrant-photodiodes
Hamamatsu, S3590-09
t300 um, 10 x10 mm²



CVD- ”nano” Diamond
15 um t

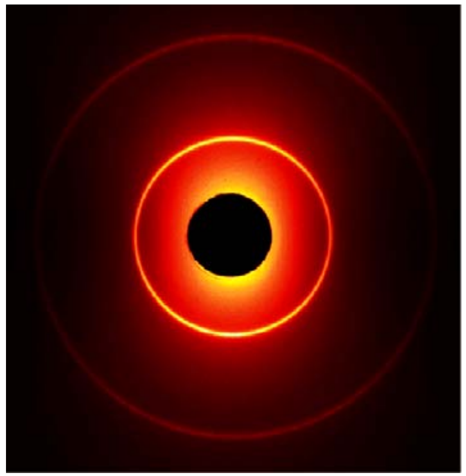
Intensity

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

Position

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

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

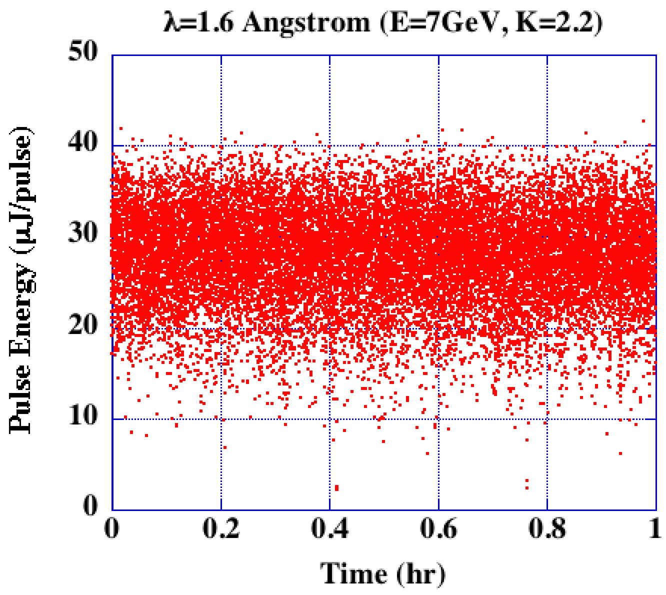


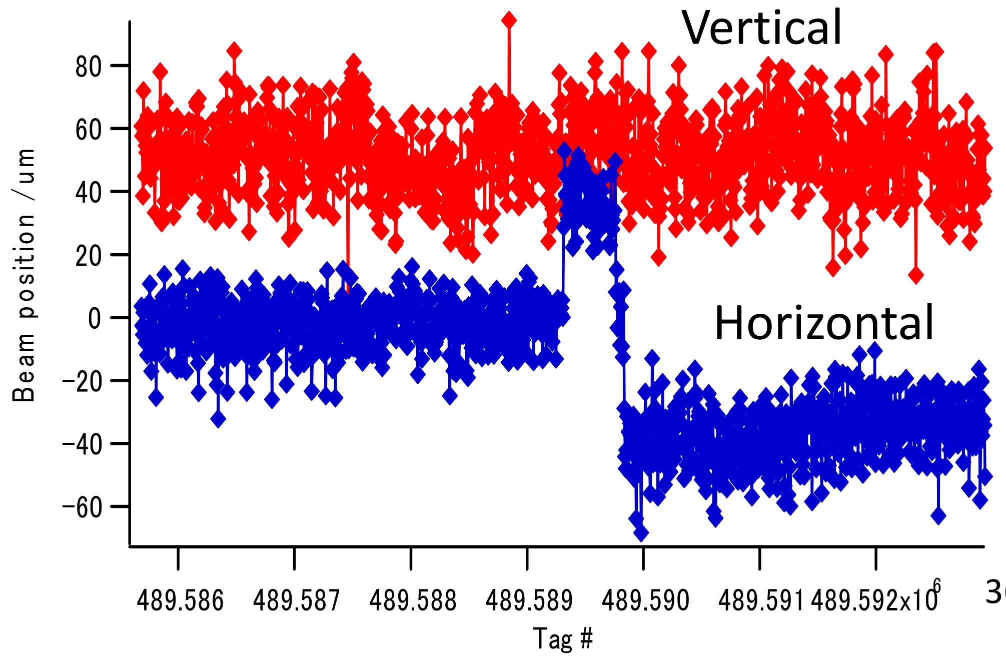
Feedback with on-line photon diagnostics

Intensity & Positional information: Used for correction of slow drift of e-beam parameters

Suitable for compensating long-term drift of beam position

Combine two monitors 1 um resolution, 50 m separation = 20 nrad





XFEL vs. DLSR

XFEL
- High peak brilliance with fs pulses
- Applicable for small, complex samples
- Measure-before-destroy
  - Sample will be damaged in single shot

DLSR
- High average brilliance w high rep rate
- Deliver x-rays to several tens beamlines
- Moderate peak intensity
  - Sample will not be damaged in single shot
  - Sample change can be traced
- Suitable for extracting information with correlation techniques (CT, time-course)

New regime of X-ray science

- Combinative development of S&T

- Identification of advantages

End