Stable nano-beam handling by upgrading beamline optics and experimental stations for advanced nano-scale analyses

Haruhiko OHASHI
hohashi@spring8.or.jp

JASRI / RIKEN
SPring-8

Collaborators

H. Yamazaki, H. Yumoto, T. Koyama, Y. Senba, T. Takeuchi, Y. Terada, M. Suzuki, N. Kawamura,
M. Mizumaki, N. Nariyama, K. Takeshita, A. Fujiwara T. Uruga, S. Goto, M. Yamamoto, M. Takata and T. Ishikawa

(JASRI/RIKEN SPring-8)

Outline

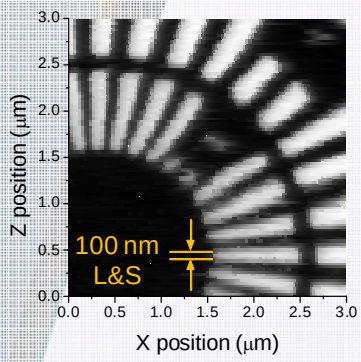
◆**Introduction**

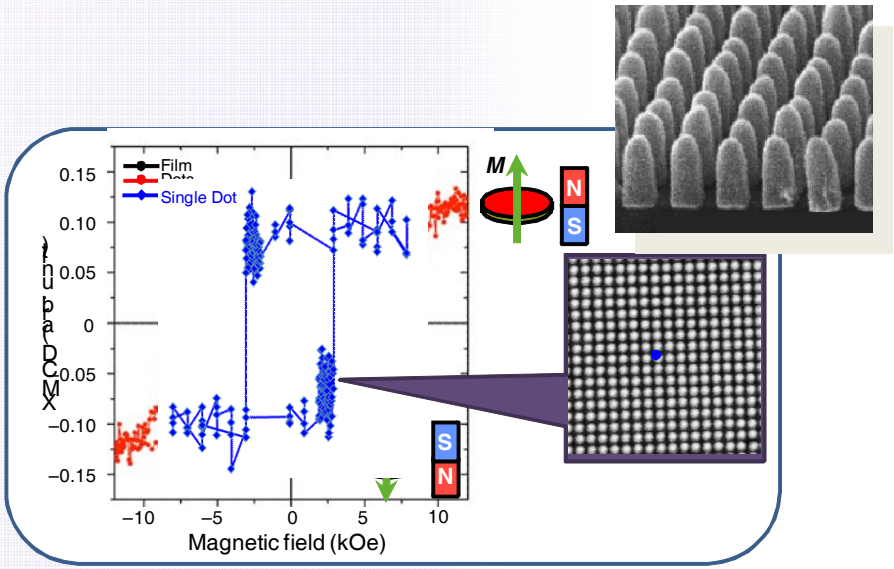
Key issues of BL optics for handling stable nano-beam

◆**Technical background of recent upgraded BL optics for utilization of stable nano beam**

◆**Highlight at upgraded beamline for nano spectroscopy**

◆**Outlook and Summary**





Outline

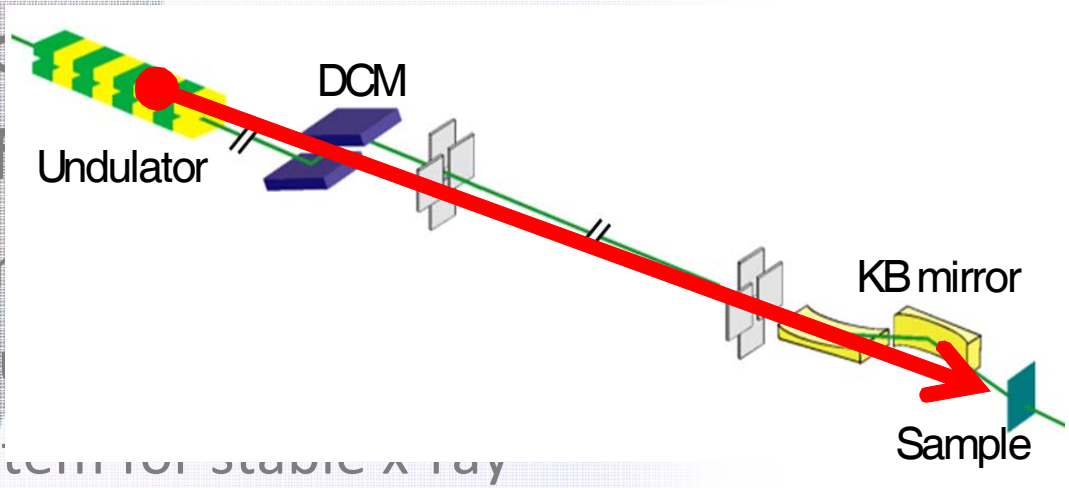
◆**Introduction**

Key issues of BL optics for handling stable nano-beam

◆**Technical background o**

f

1. Stable double monochrom
2. Dedicated experimental h
3. High precise KB mirror system for stable x-ray



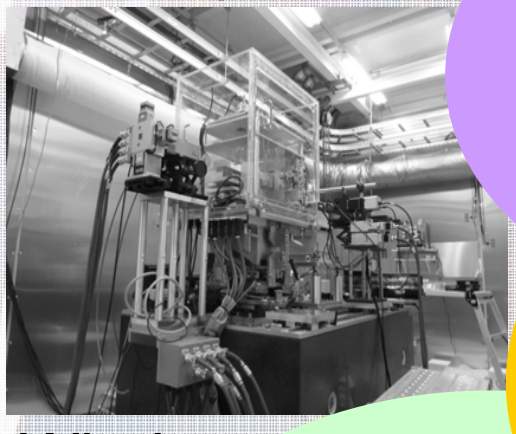
◆**Highlight at upgraded beamline for nano spectrosopy**

Nano-beam analysis in a single magnetic dot at BL39XU

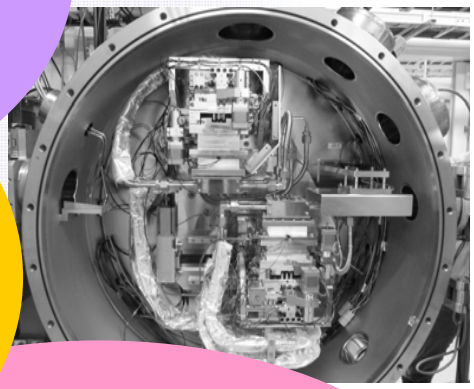
◆**Summary & outlook**

Key issues of beamline optics

Mirror manipulator



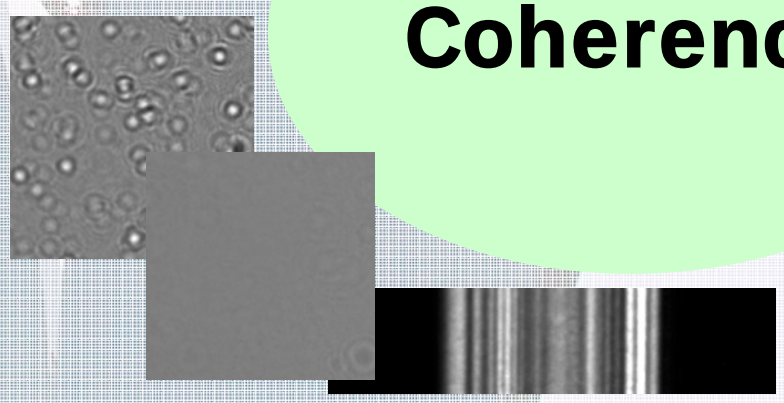
Monochromator, Environment



Stability

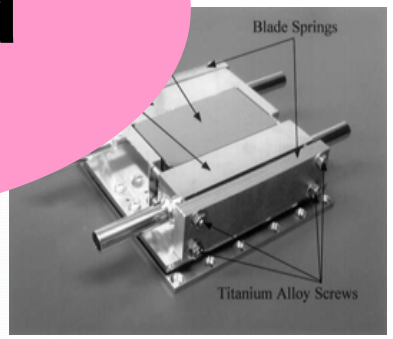
Beamline Optics

Mirror, Window, Crystal

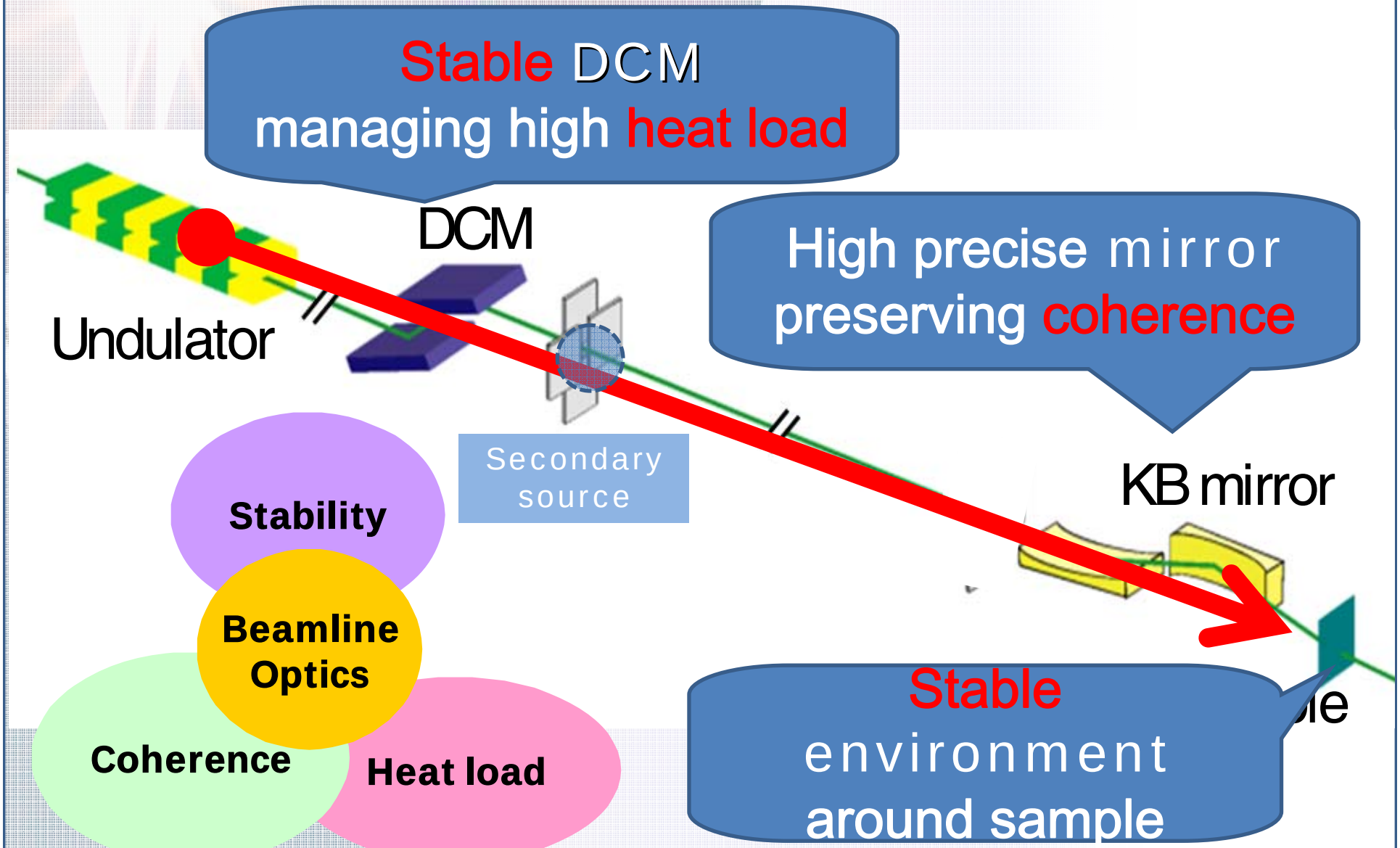


Coherence

Heat load

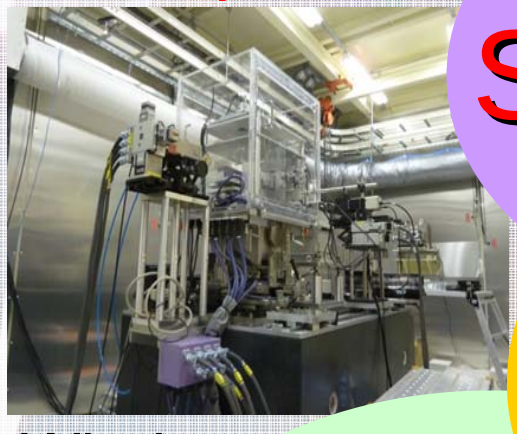


Key issues of beamline optics for handling stable nano-beam

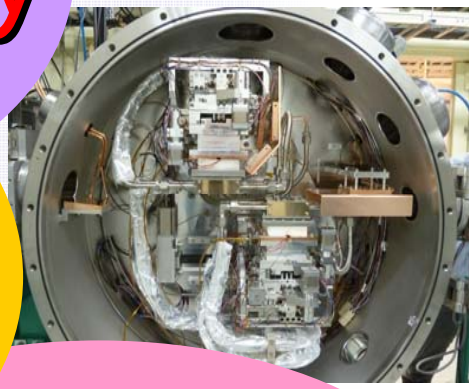


The routine utilization of nano beam

Mirror manipulator



Monochromator, Environment

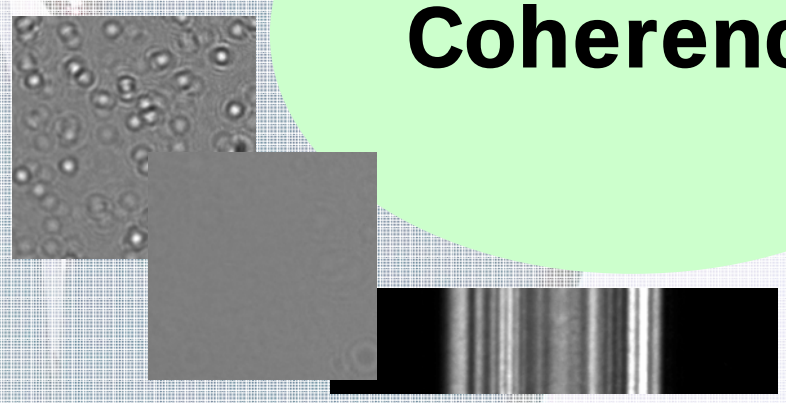


Stability

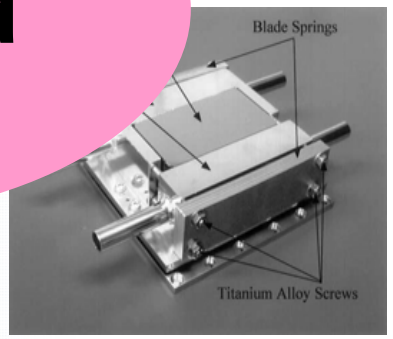
Beamline Optics

Mirror, Window, Crystal

Coherence



Heat load



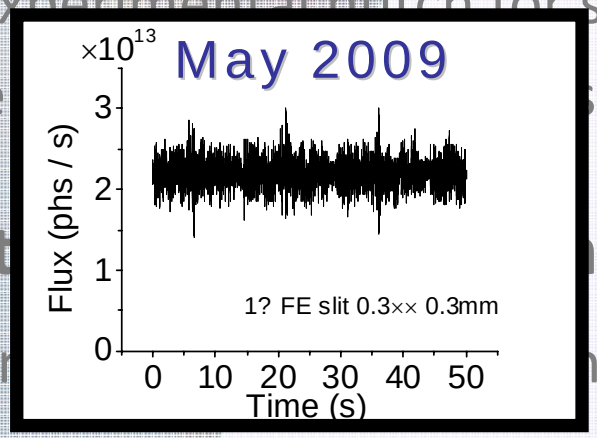
Outline

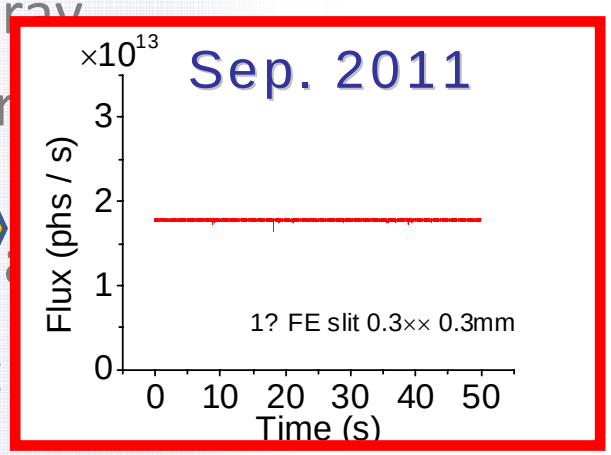
◆**Introduction**

Key issues of BL optics for handling nano beam

◆**Technical background of upgraded BL optics for utilization of stable nano beam**

1. Stable double monochromator with LN2 cooling
2. Dedicated experimental hutch for stable x-ray
3. High precise stable x-r





◆**Highlight at**

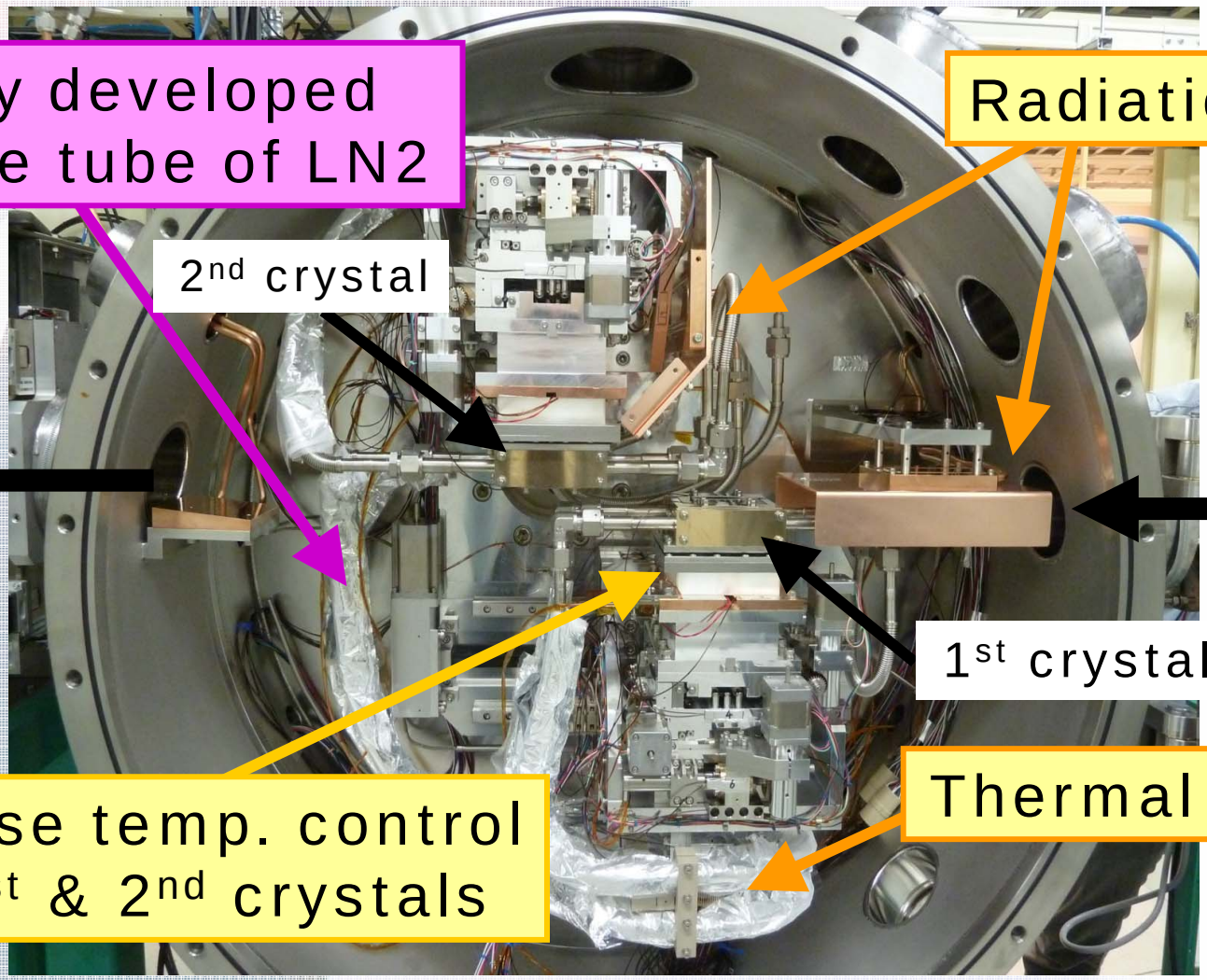
Nano-beam ar netic dot

◆**Summary**

New stable monochromator

for short term stability

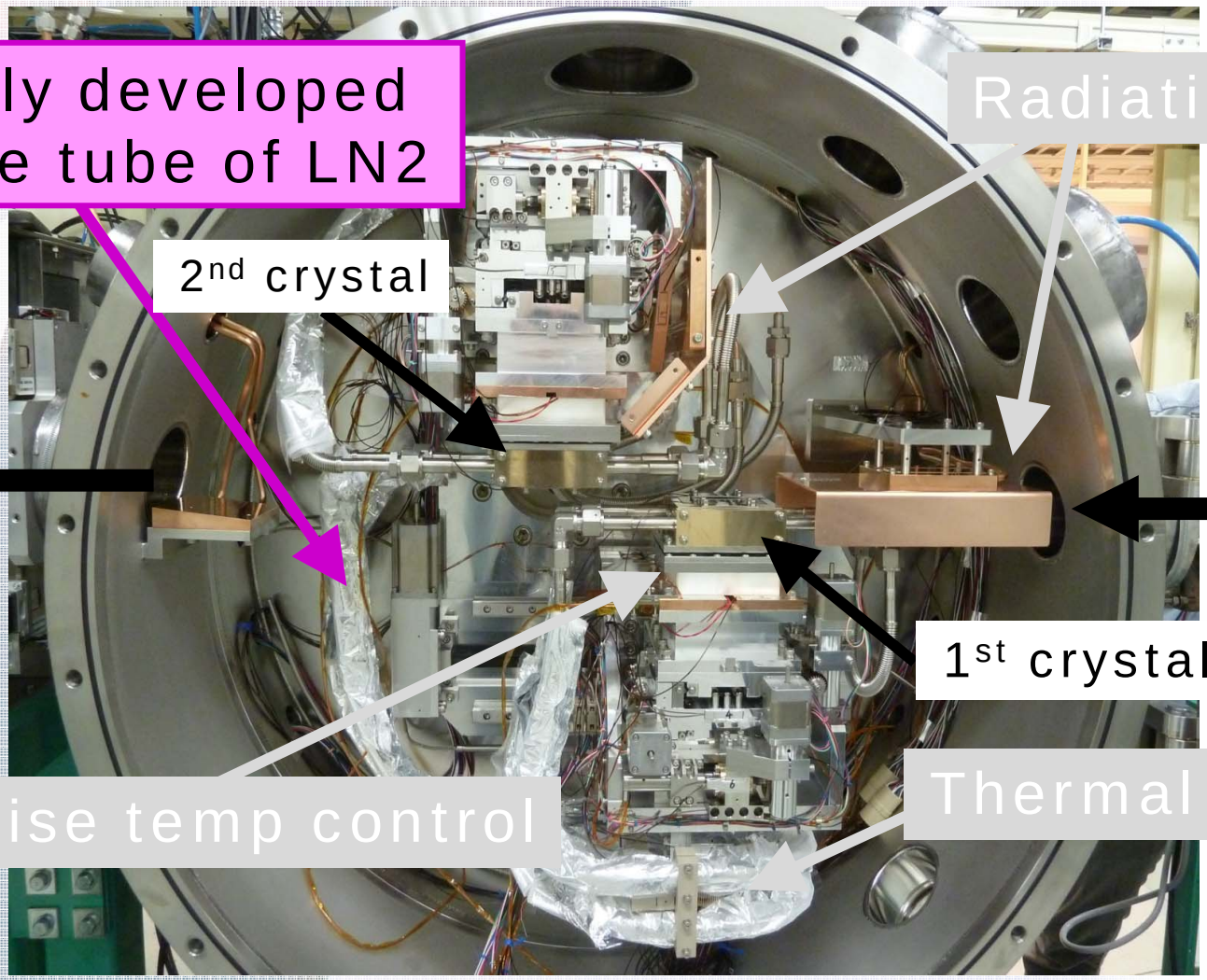
for long term stability



New stable monochromator

for short term stability

for long term stability



Coolant flexible tube

for short term stability

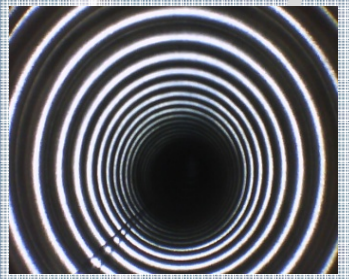
Water cooling

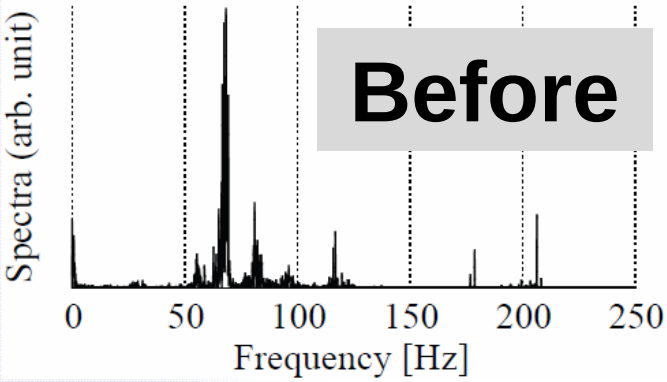
Waviness inside tube→Turbulence→Vibration

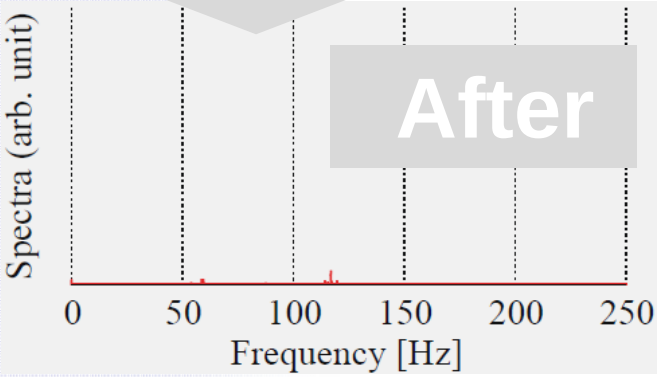
Instability of x-ray intensity

Smoothing inside tube

Installing Urethane tube







Coolant flexible tube

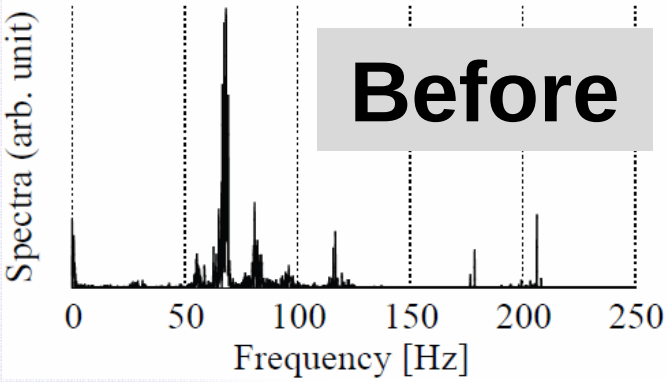
for short term stability

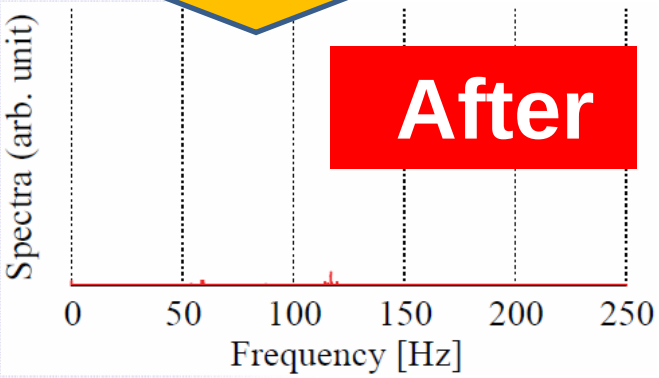
Water cooling

Waviness inside tube → Turbulence → Vibration

Smoothing inside tube

Installing Urethane tube





Coolant flexible tube

for short term stability

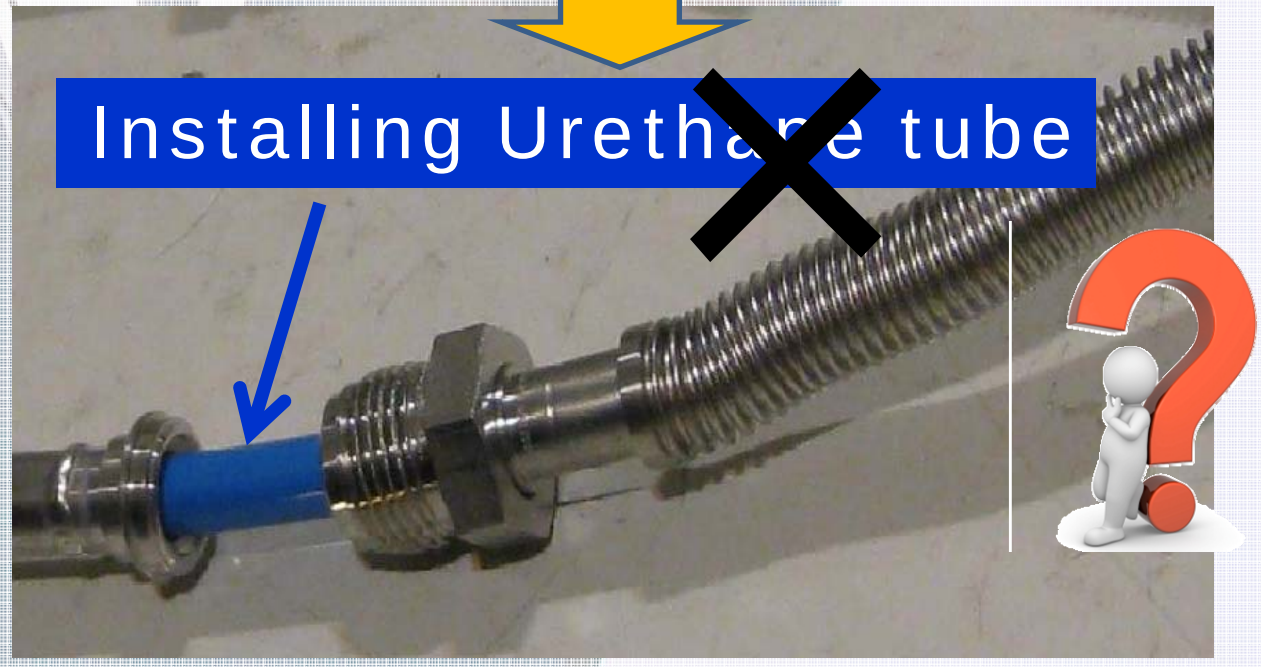
Water cooling

Waviness inside tube→Turbulence→Vibration

Smoothing inside tube

*Almost DCMs of undulator BL at SPring-8 are cooled by **LN2***

Installing Urethane tube



LN2 cooling

LN2 temp.
Flexibility
Smooth

for short term stability

New Coolant flexible tube

for LN2 cooling

Sleeve of alumina mesh

- **Less vibration**
- **Flexibility at LN2**
- **Resistance to radiation**
- **Low pressure loss**
- **Compatibility**

Developed at SPring-8 in Jan. 2011
Commercially available from Feb. 2012

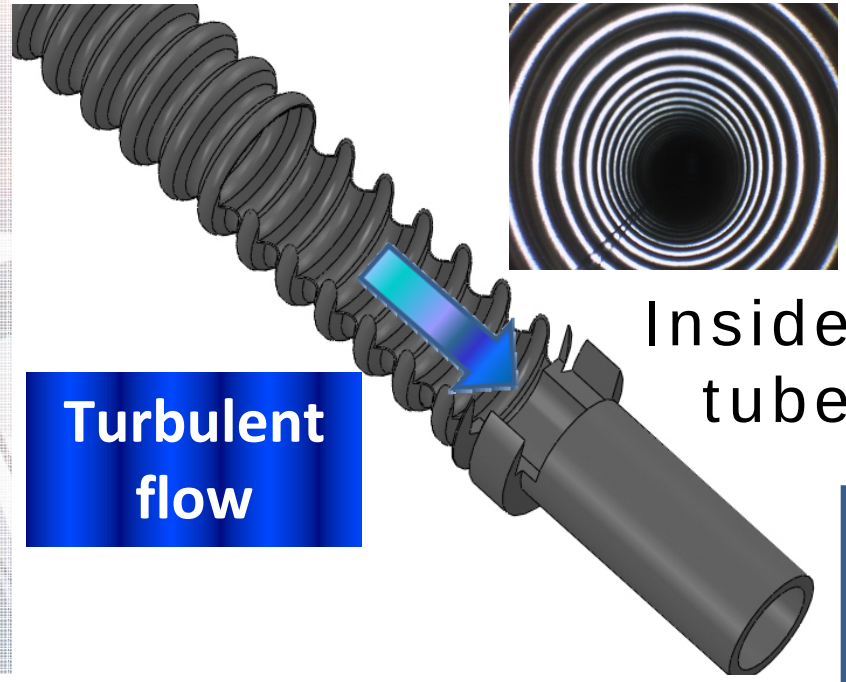
ClearFlowFlex™

Collaborated with ORK Co. Ltd
Patented by RIKEN, JASRI, ORK

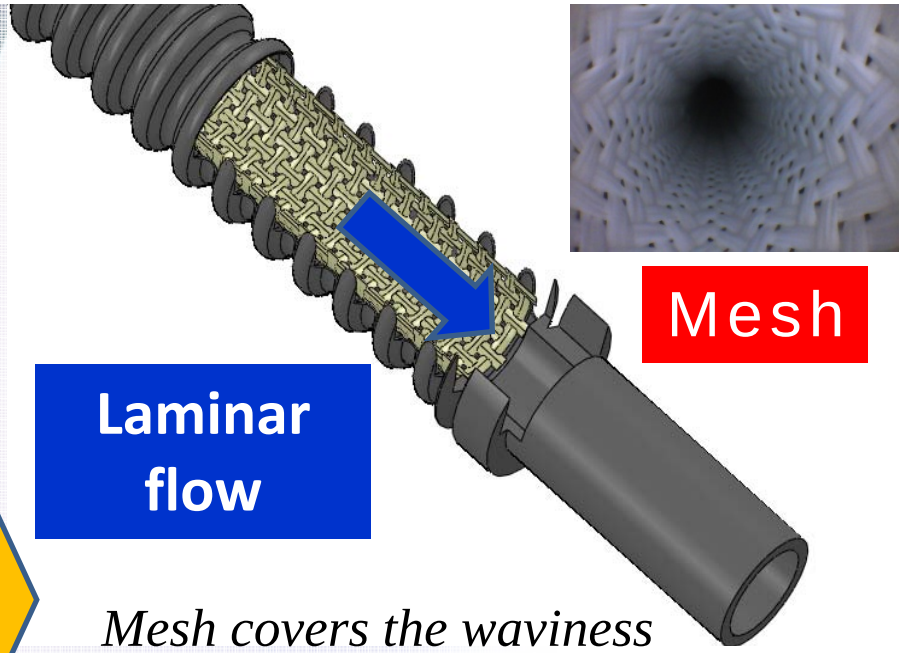
Coolant flexible tube

for short term stability

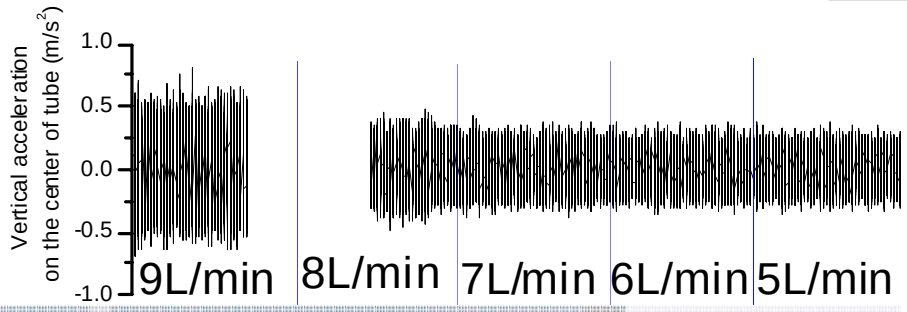
Standard

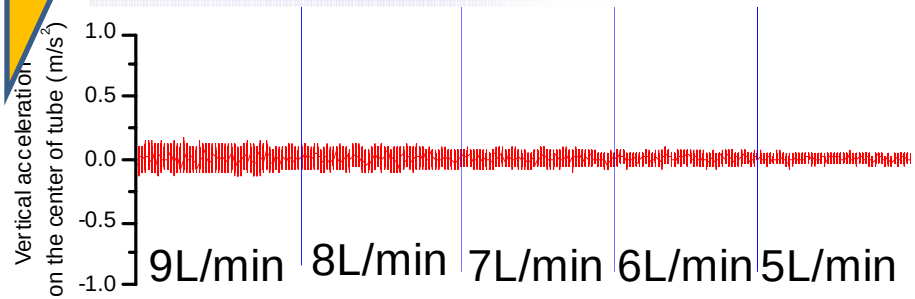


Clear Flow Flex™



Mesh covers the waviness





100sec

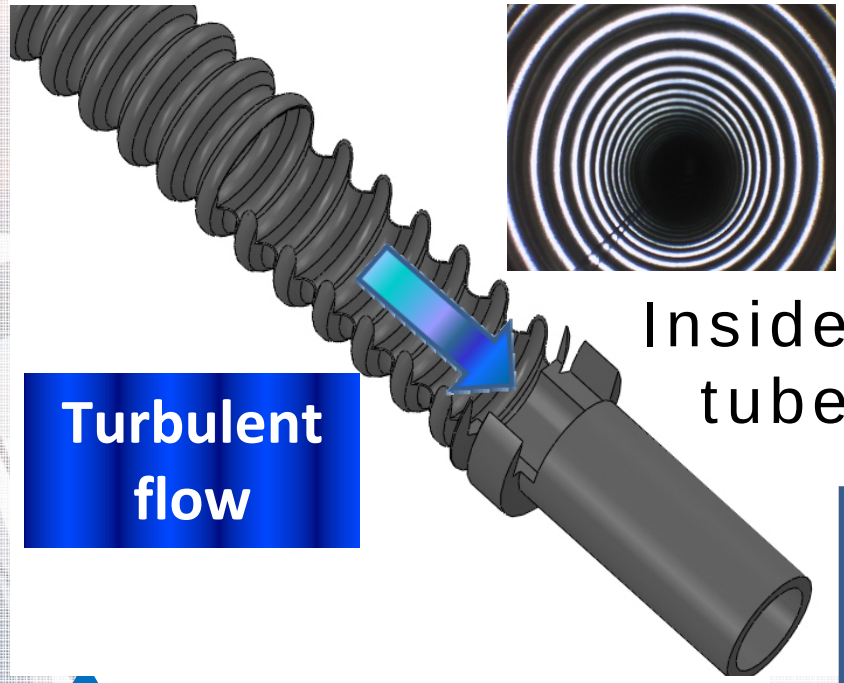
Acceleration on the tube

The vibration is reduced for all flow rate.

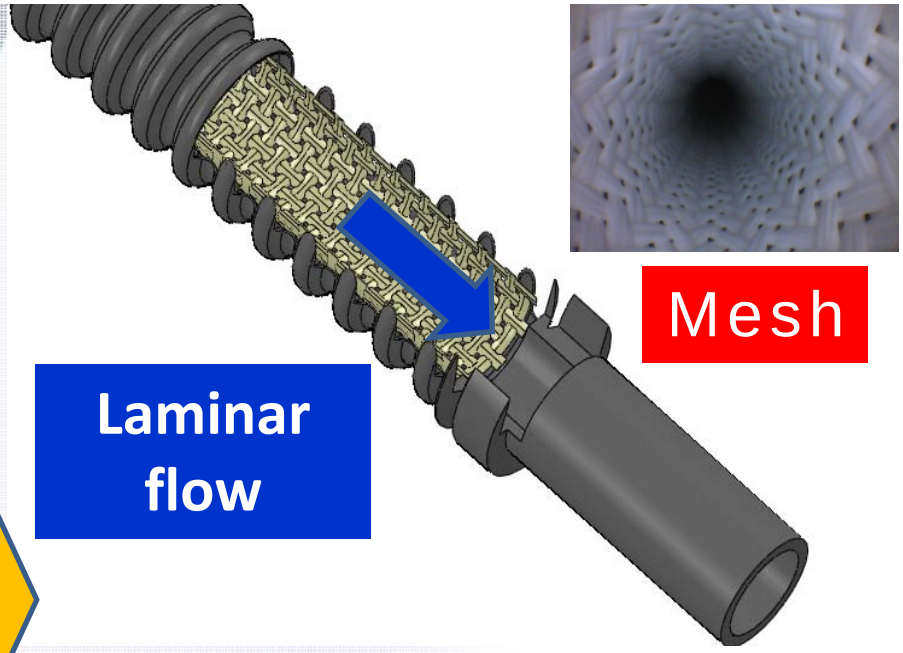
Coolant flexible tube

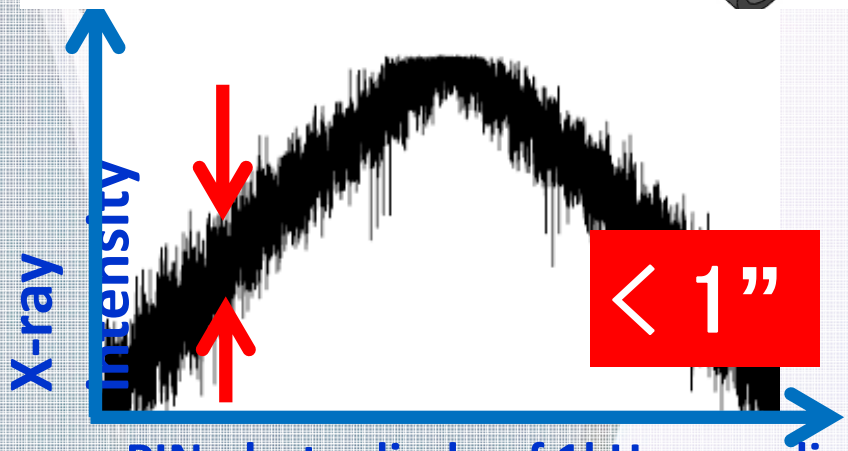
for short term stability

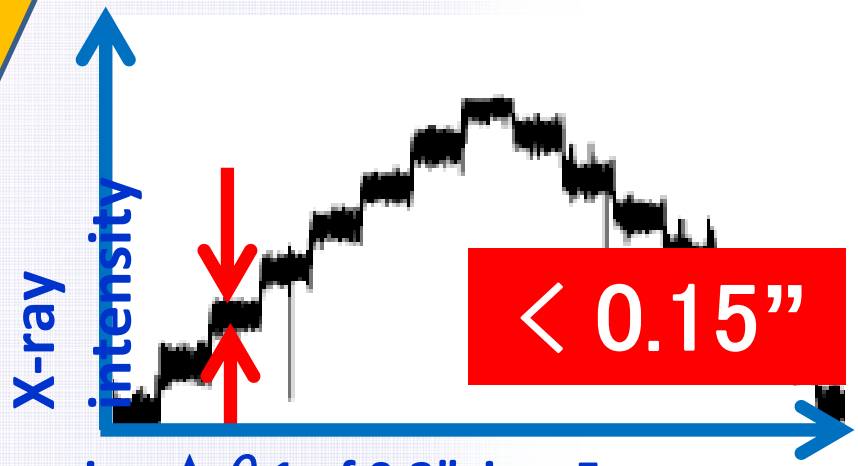
Standard



Clear Flow Flex™





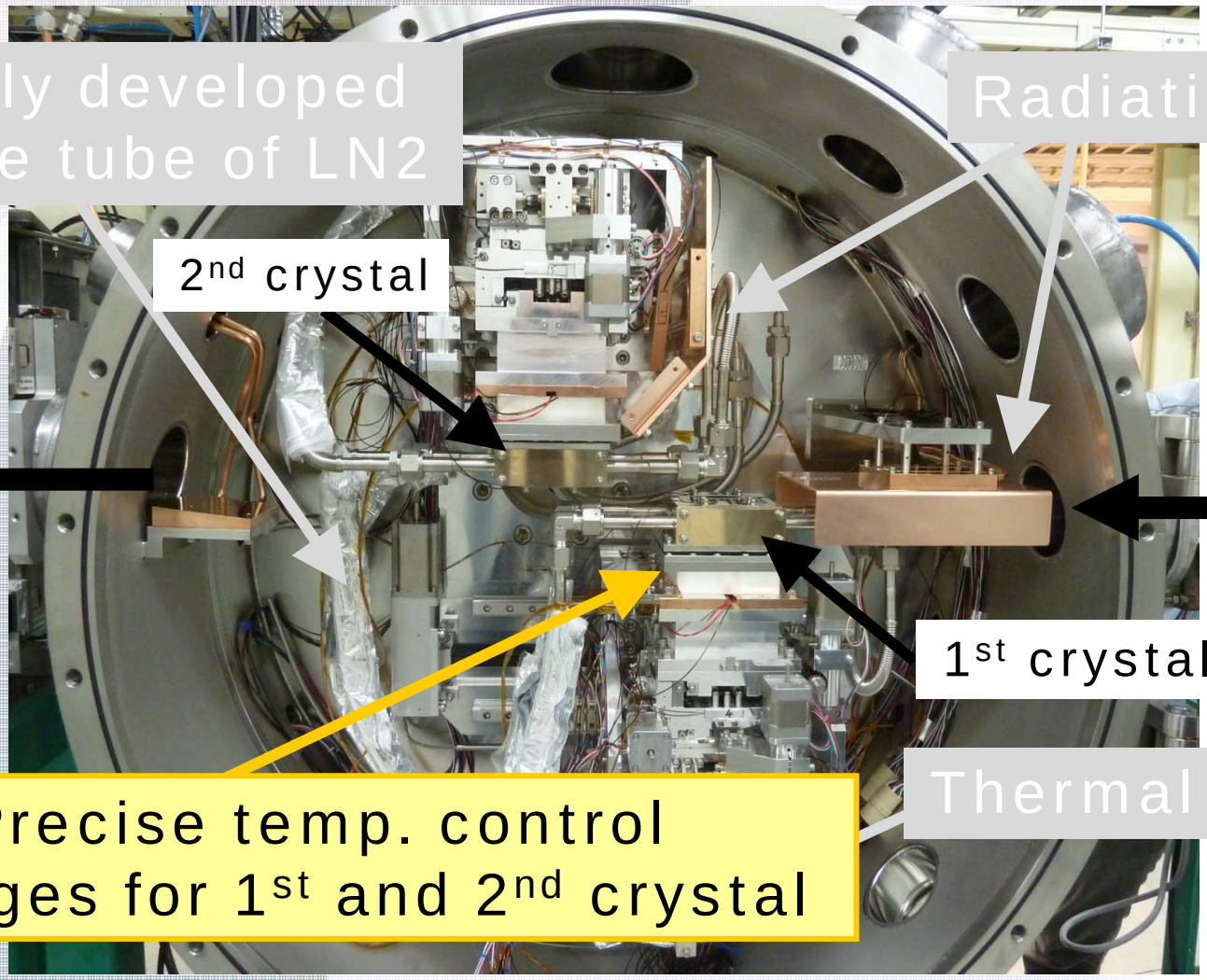


PIN photo diode of 1kHz sampling as stepping $\Delta\theta$ 1 of 0.2” in a 5 sec-

New stable monochromator

for short term stability

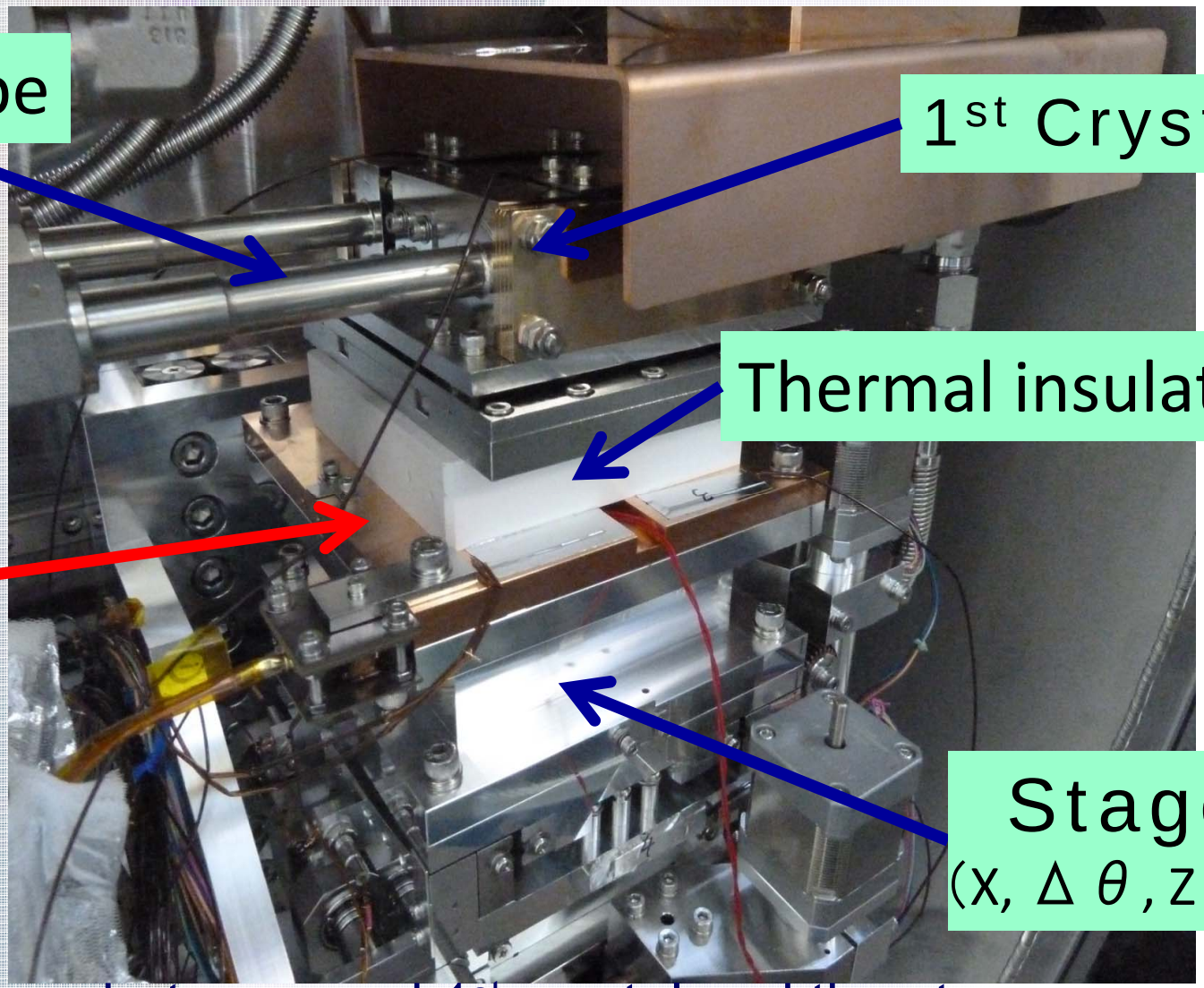
for long term stability



For long term stability

Precise T control in DCM

Instability for long term results from temperature change.



T～LN_2

↓

Heater

↓

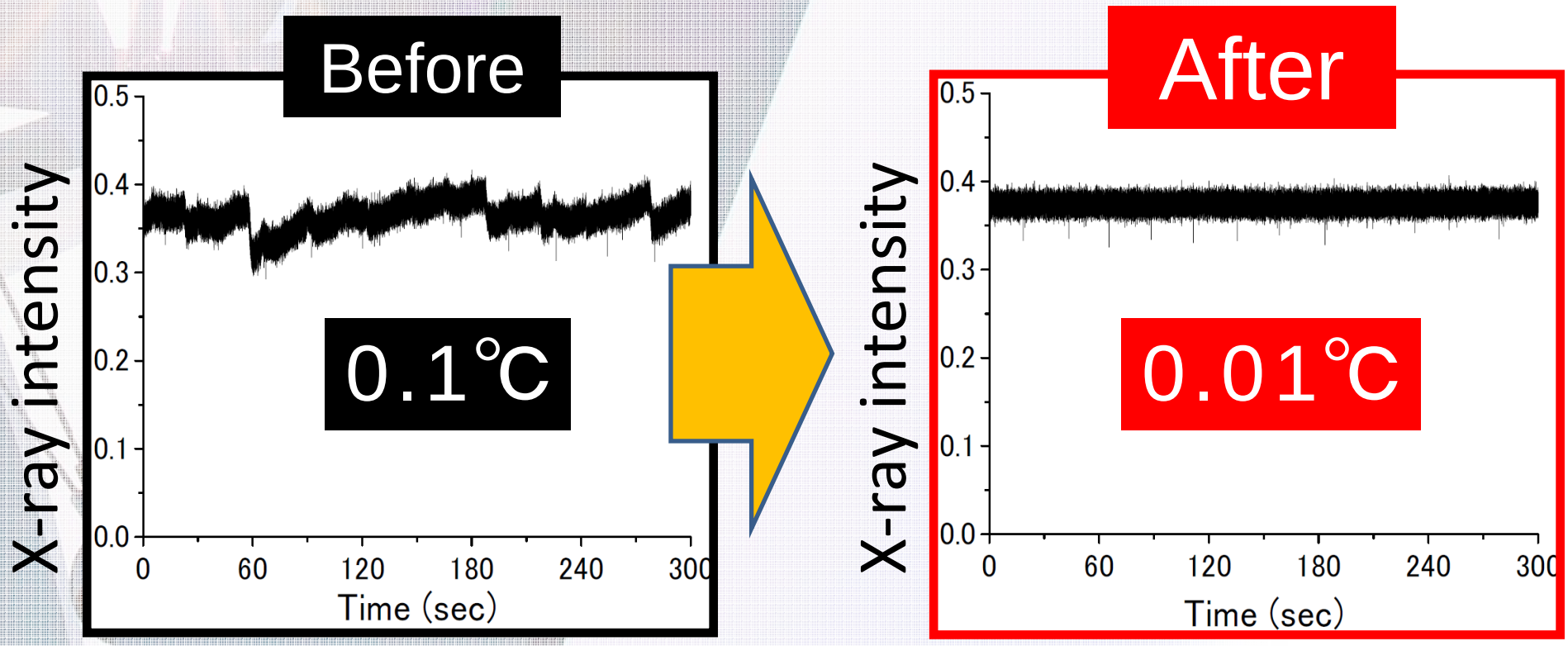
T～RT

The photo around 1st crystal and the stage

For long term stability

Precise T control in DCM

X-ray intensity was disturbed by temperature change .

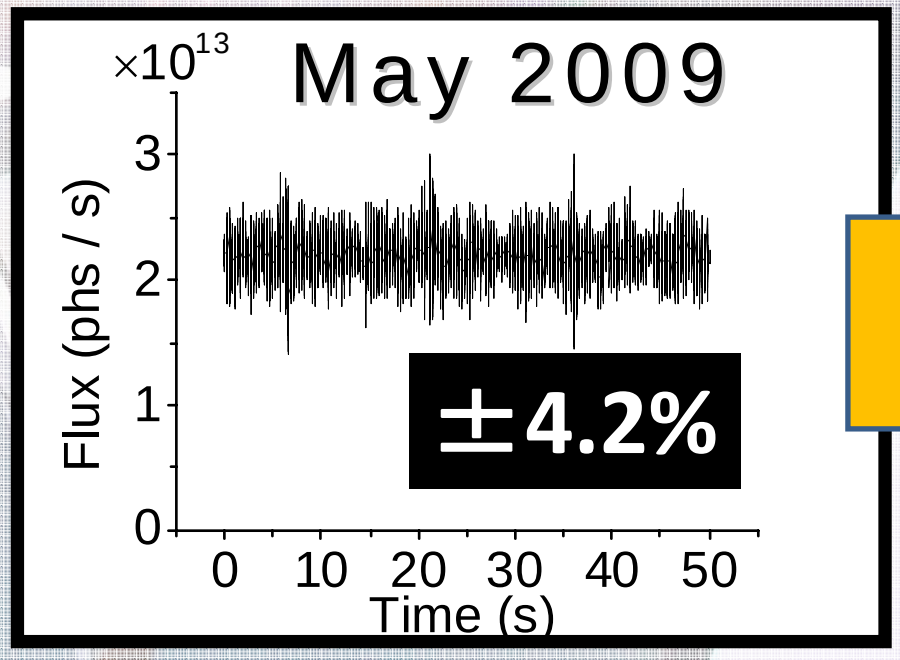


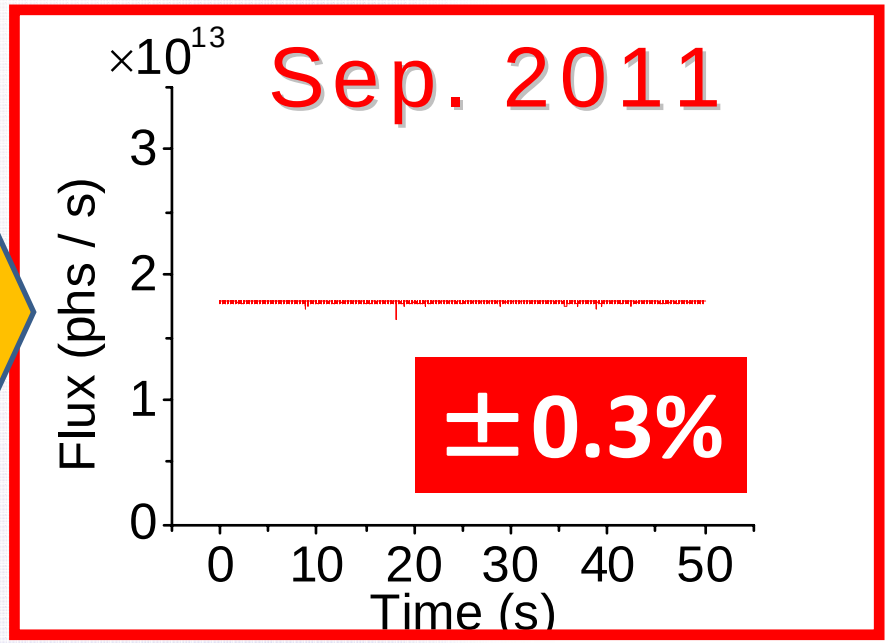
Long term stability is improved
by controlling precisely temperature of stage in DCM

For long term stability

Stability of x-ray intensity

Upgraded DCMs with LN2 succeeded in stability, which is comparable to water cooling DCM.





*The new DCMs with LN2 have been installed at **3 BLs in 2011** and **4 BLs in this F.Y.** will be upgraded.*

Outline

◆**Introduction**

Technologies of ultimate nano-focusing at SPring-8

◆**Technical background of upgraded BL optics for utilization of stable nano beam**

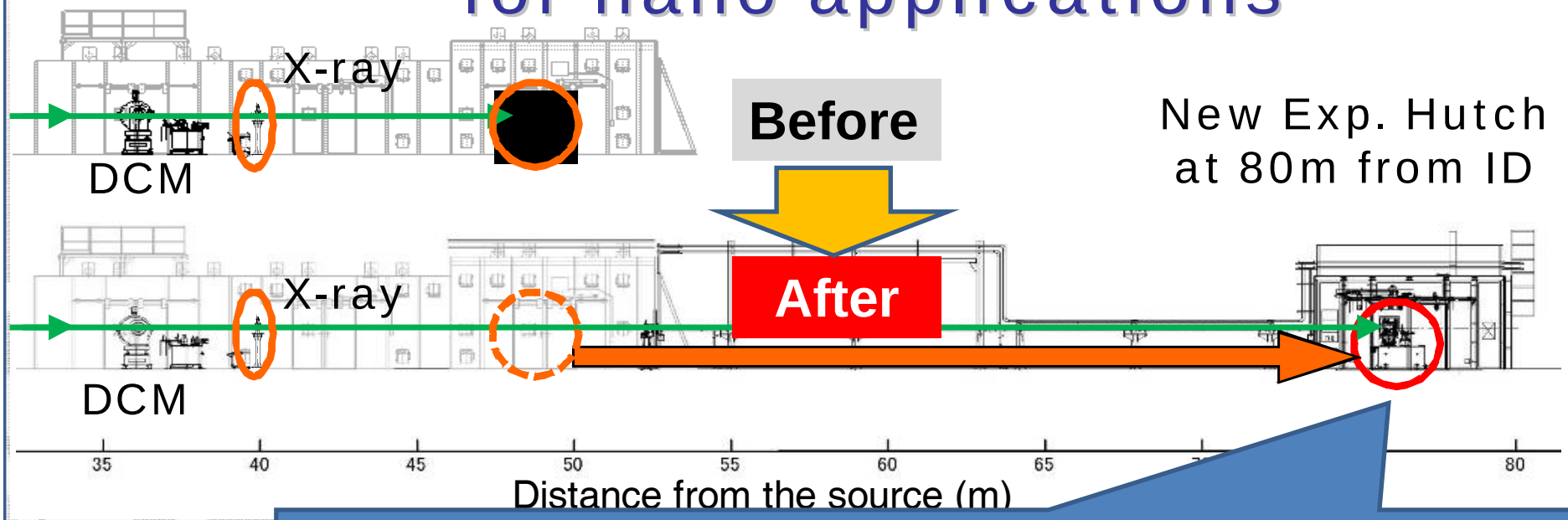
1. Stable double monochromator
2. Dedicated experimental hutch for stable x-ray
3. High precise KB mirror system for stable x-r

◆**Highlight at upgraded beamline for na**

Nano-beam analysis in a single magnetic dot

◆**Outlook and summary**

Dedicated experimental hutch for nano applications

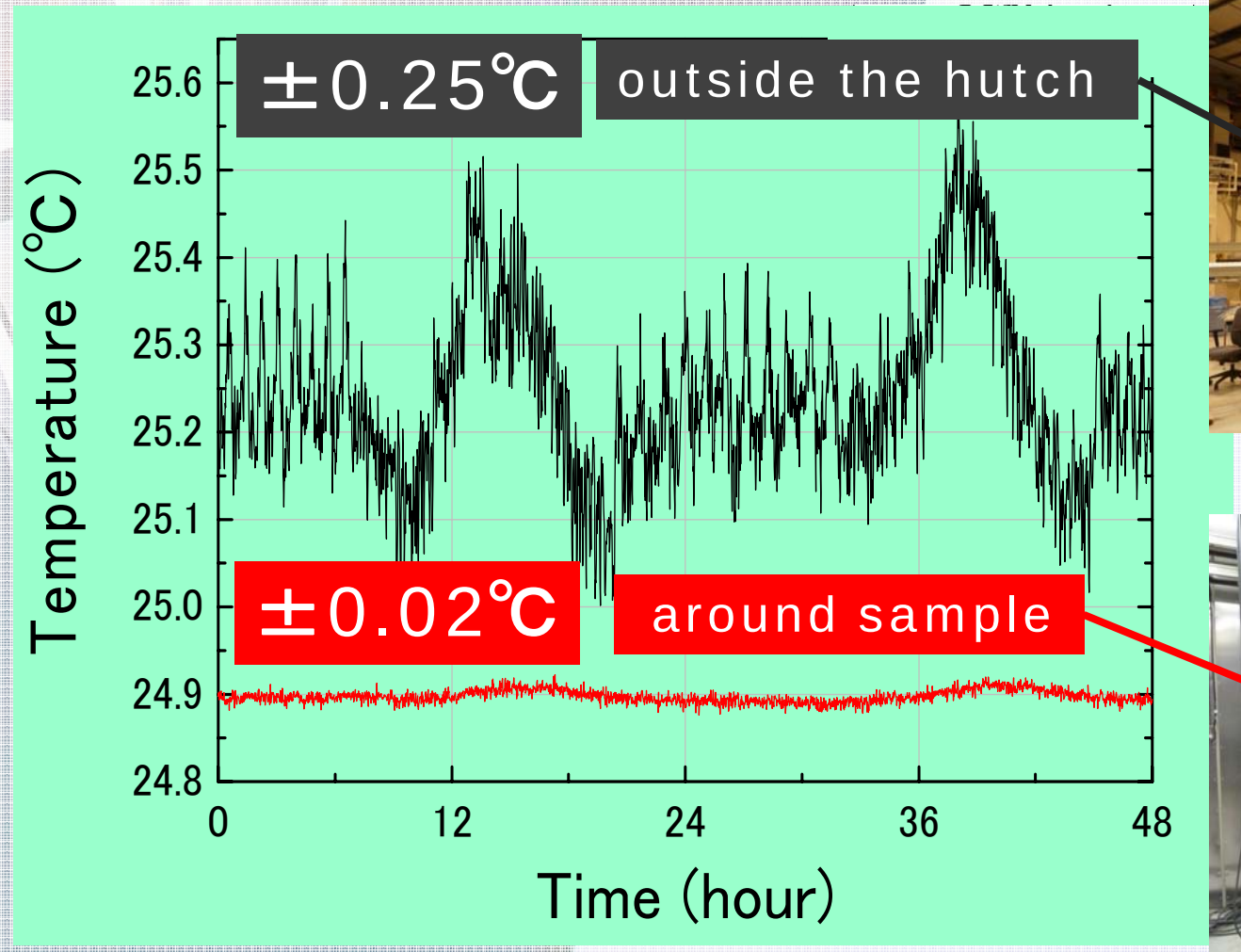


Thermal insulator is installed in the wall. It is also effective in sound isolation.

High precise air conditioner of 0.01 degree is also equipped.

Dedicated experimental hutch for nano applications

High precise temperature control



Outline

◆**Introduction**

Technologies of ultimate nano-focusing at SPring-8

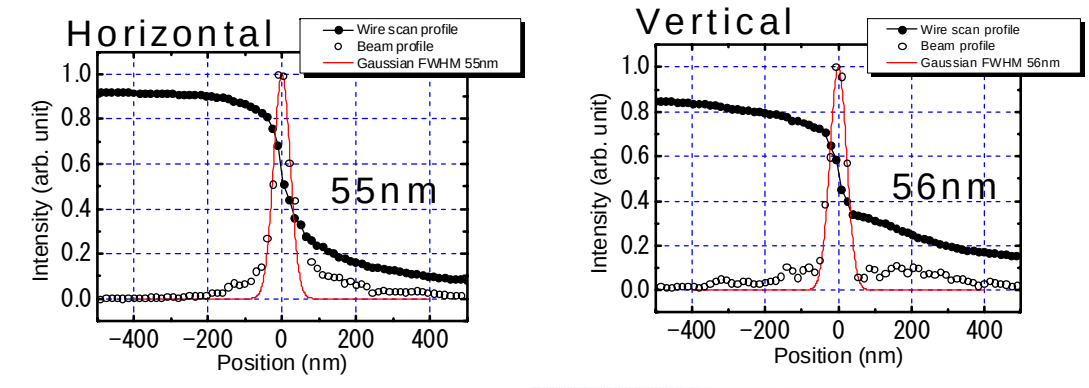
◆**Technical background of upgraded BL optics for utilization of stable nano beam**

1. Stable double monochromator
2. Dedicated experimental hutch for stable x-ray
3. High precise KB mirror system for stable x-ray

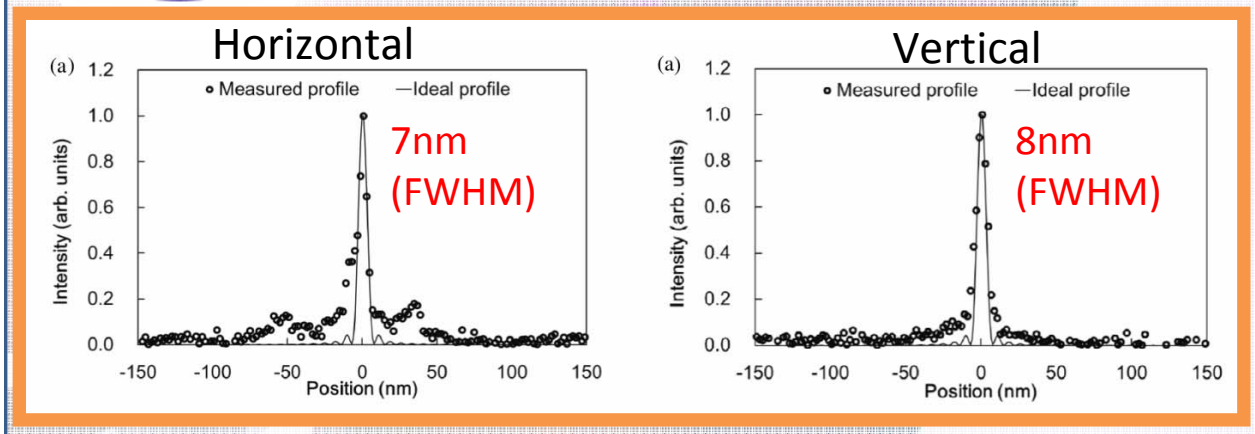
◆**Highlight at upgraded**

Nano-beam analysis in a si

◆**Outlook and summary**



Sub-10 nanometer focusing



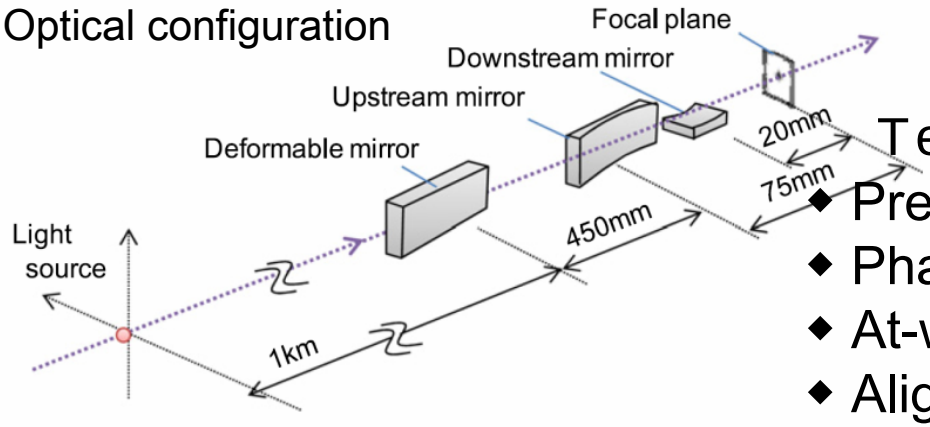
Prof. Yamauchi (Osaka Univ.)

K. Yamauchi et al. "Single-nanometer focusing of hard x-rays by Kirkpatrick–Baez mirrors"
J. Phys.: Condens. Matter **23** 394206 (2011)

@1 km long beamline (BL29XUL)

X-ray energy 20 keV

Optical configuration



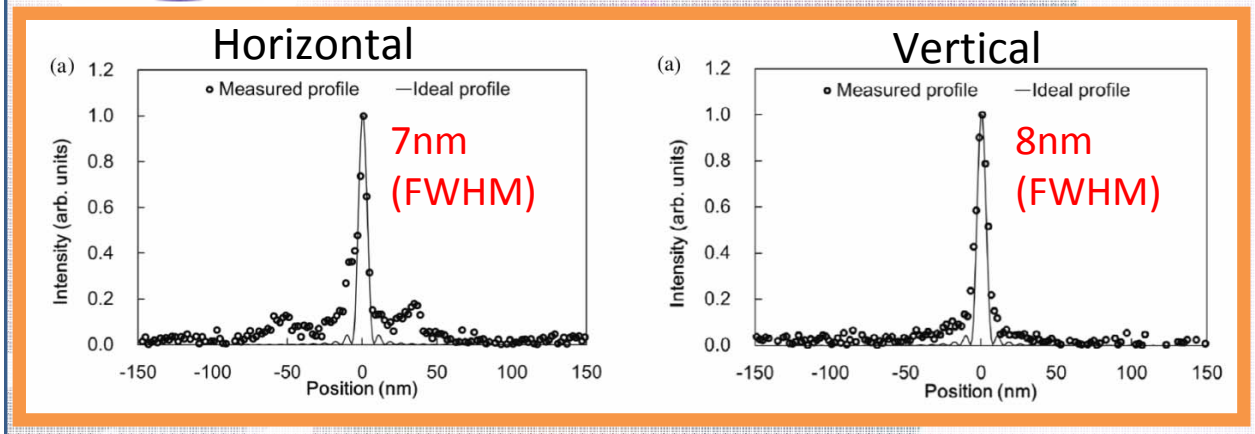
Sub-10 nm point focus was realized

Technologies for nano focusing

- Precision multilayer mirror for larger NA
- Phase compensator by deformable mirror
- At-wavelength wavefront sensing method
- Alignment procedure
- High precise mirror
- Mirror manipulator

SPring-8 collaborated with Osaka Univ. realized ultimate point focusing of 7nm horizontally and 8 nm vertically at 1km beamline. An extremely precise optical system for hard-x-ray nano-focusing was uniquely developed.

Sub-10 nanometer focusing



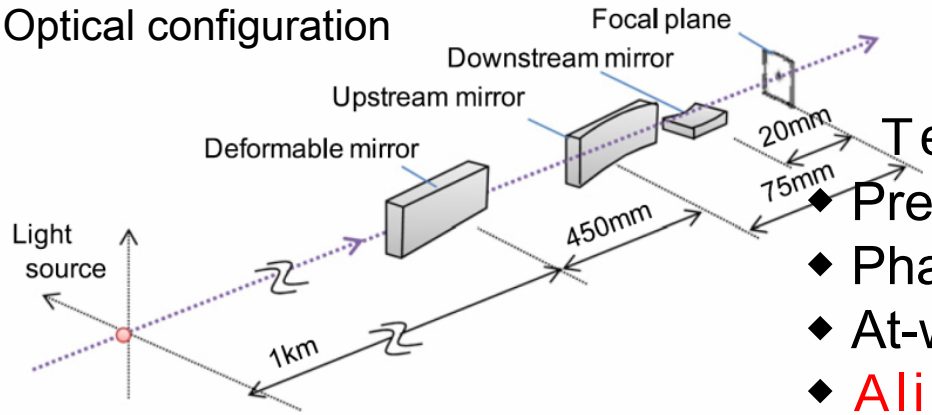
Prof. Yamauchi (Osaka Univ.)

K. Yamauchi et al. "Single-nanometer focusing of hard x-rays by Kirkpatrick–Baez mirrors" J. Phys.: Condens. Matter **23** 394206 (2011)

@1 km long beamline (BL29XUL)

X-ray energy 20 keV

Optical configuration



Sub-10 nm point focus was realized

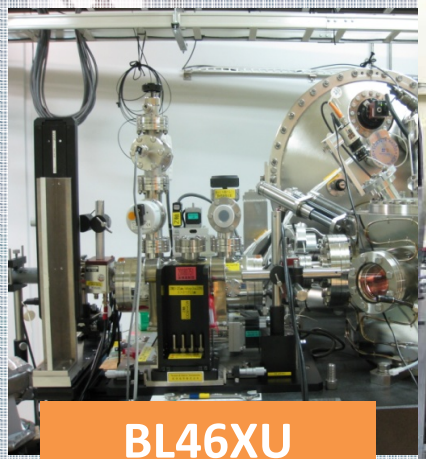
Technologies for nano focusing

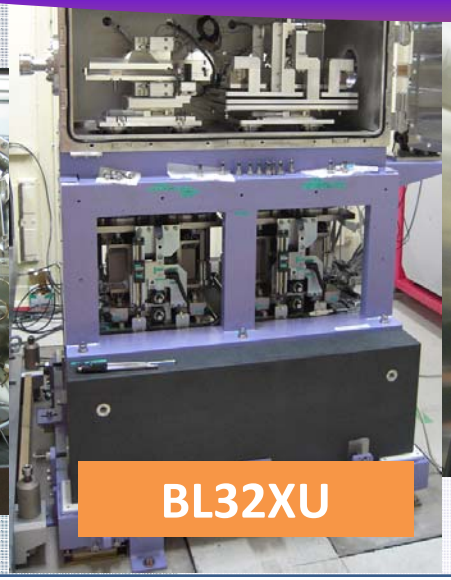
- Precision multilayer mirror for larger NA
- Phase compensator by deformable mirror
- At-wavelength wavefront sensing method
- Alignment procedure
- High precise mirror
- Mirror manipulator

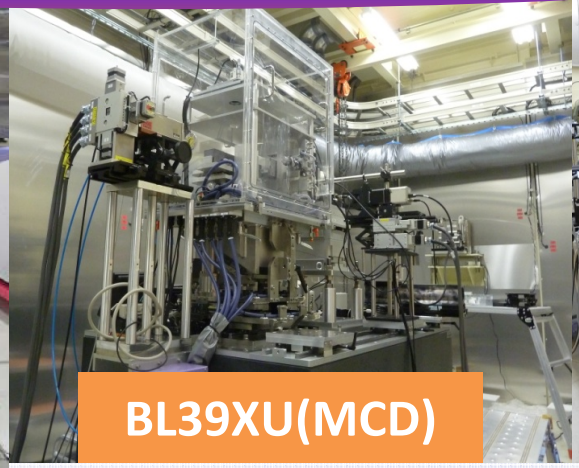
Based on the developed technologies, we promote of the routine utilization of 100 nm beam at standard BLs

Installed focusing mirror system

12 sets of focusing mirror system
(2009～2012)



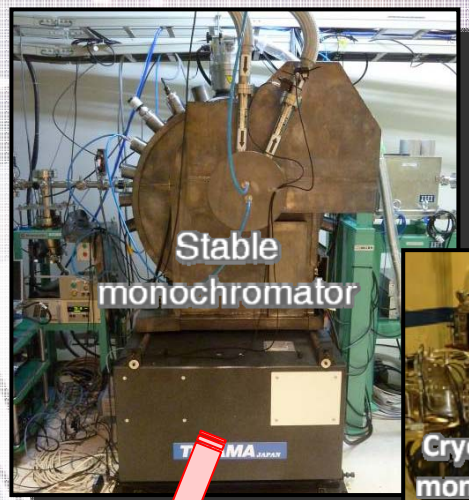


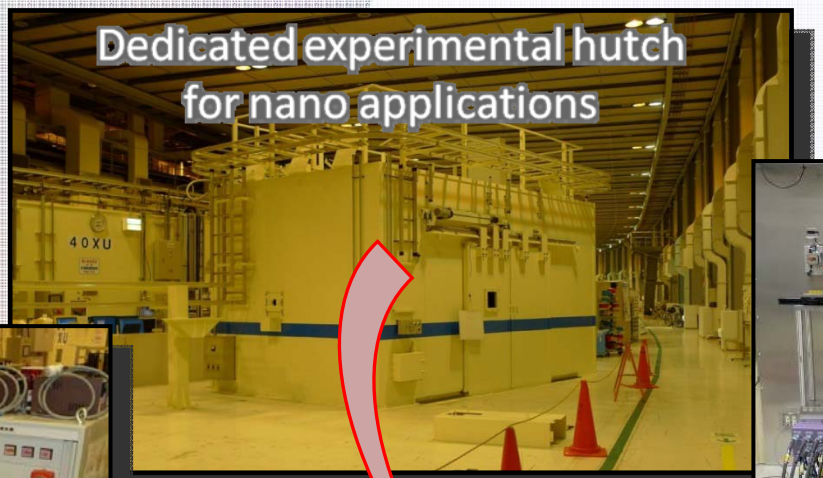


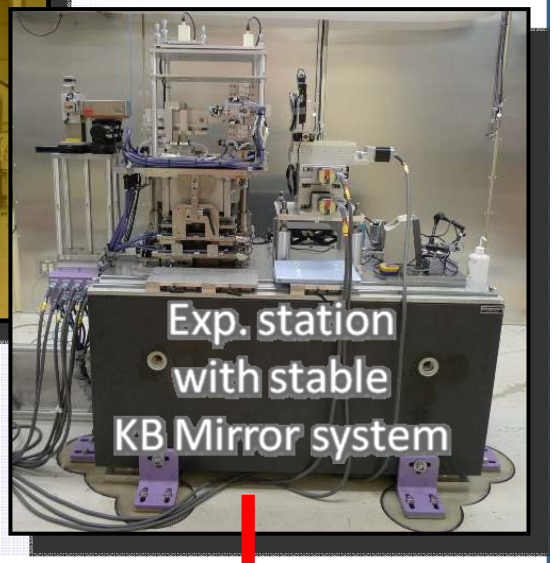
BL36XU, BL33XU, SACLA-BL3…

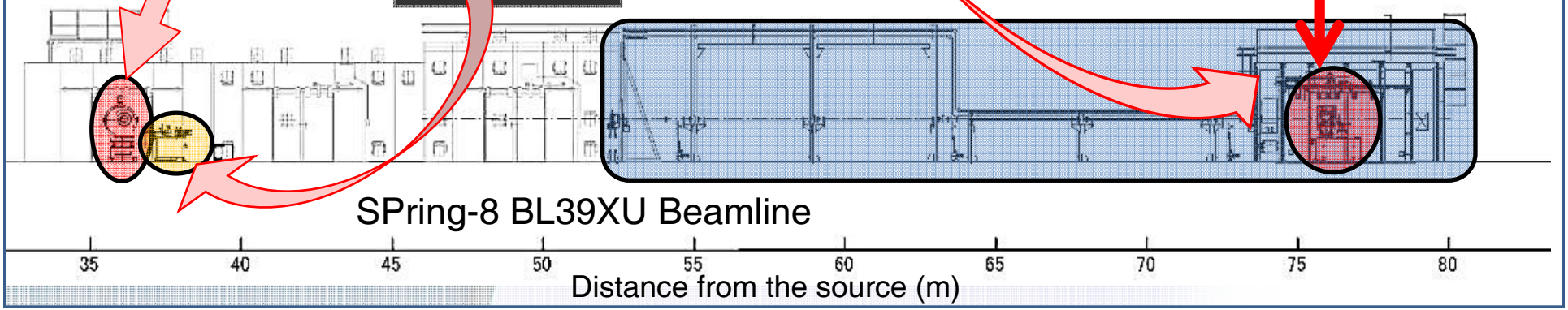
Fully Upgraded BL37XU, BL39XU for nano applications in 2011

Routine nano-spectroscopy of XAFS, XRF and XMCD using stable 100 nm beam

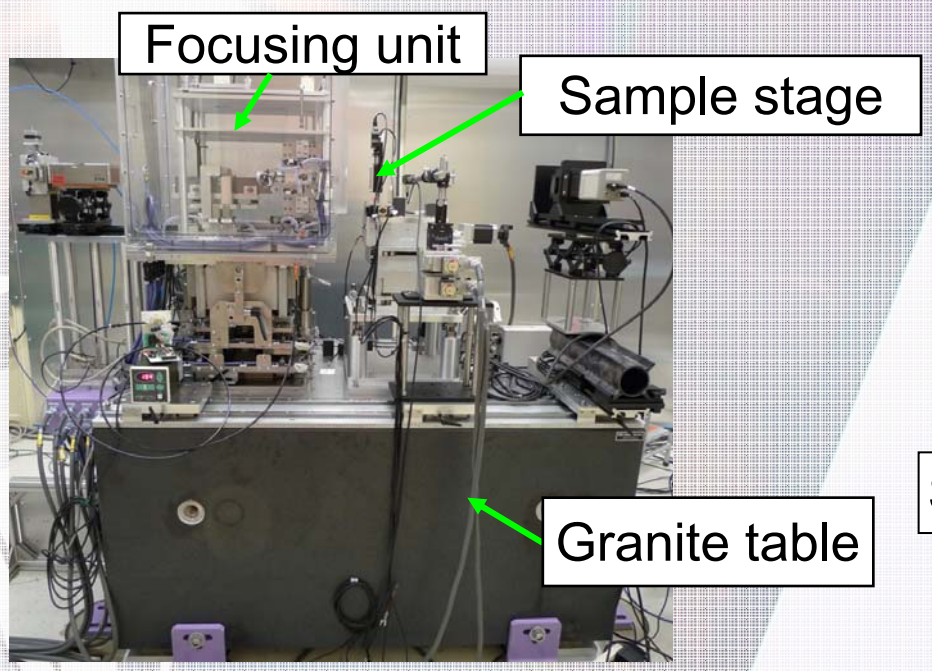


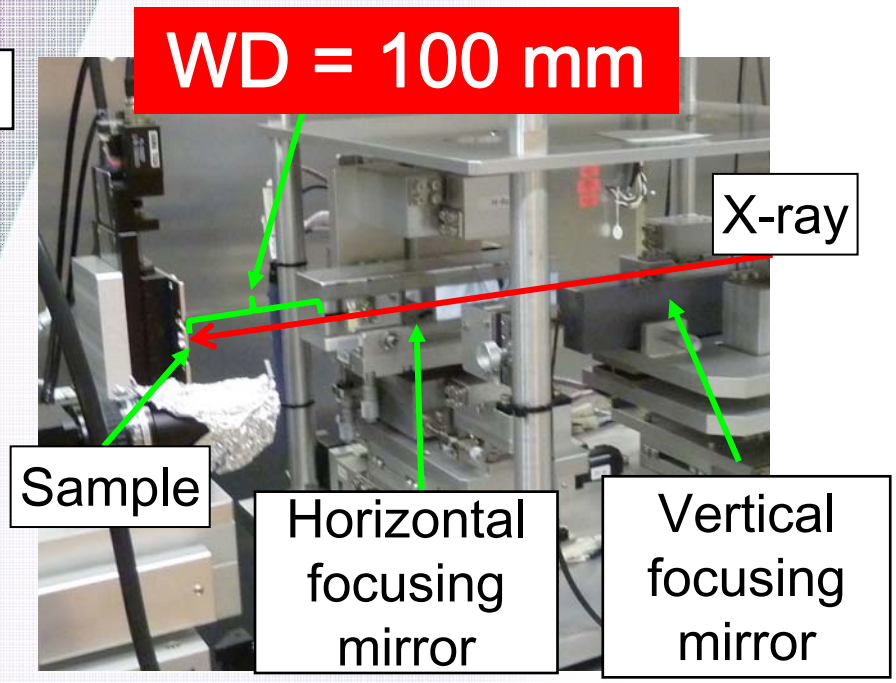






Experimental station at BL39XU for nano-XMCD, XAFS and XRF





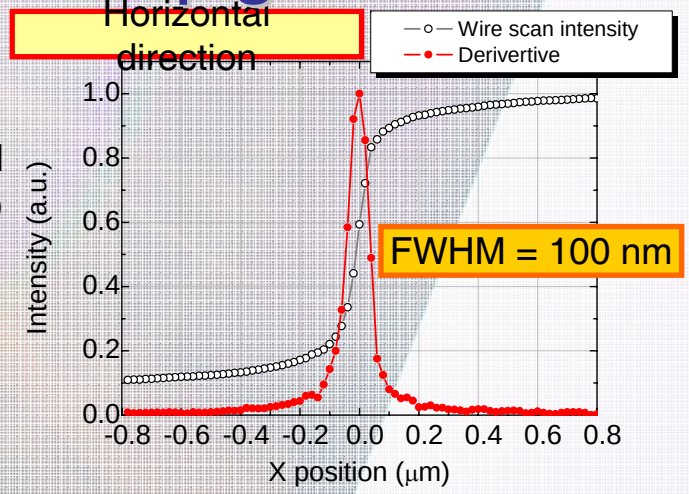
Parameters of elliptical mirrors for BL39XU

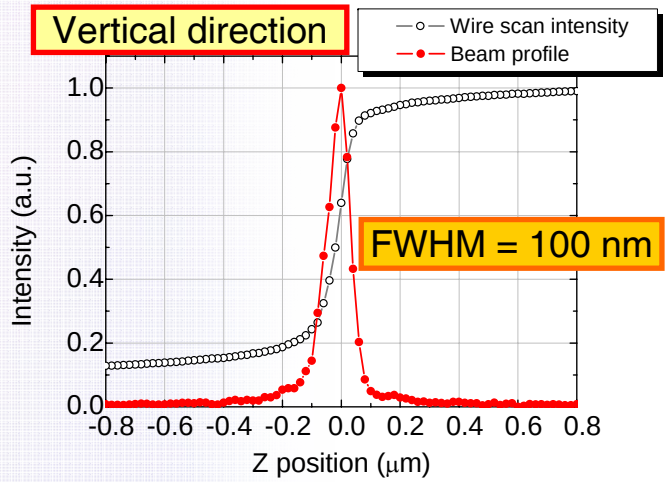
	Vertical focusing Mirror	Horizontal focusing mirror
Surface profile	Ellipse	Ellipse
Substrate material	Silicon	Quartz
Surface coating	Rh 50 nm	Rh 50 nm
Mirror length	300 mm	200 mm
Mirror size	300 × 50 × 50 mm^3	200 × 50 × 50 mm^3
Glancing incident angle	4.0 mrad	3.8 mrad
Focal length	460 mm	200 mm
Aperture size	1200 μm	760 μm
Demagnification ratio	1/78	1/180

Performance of focused x-rays at the upgraded beamline in 2011

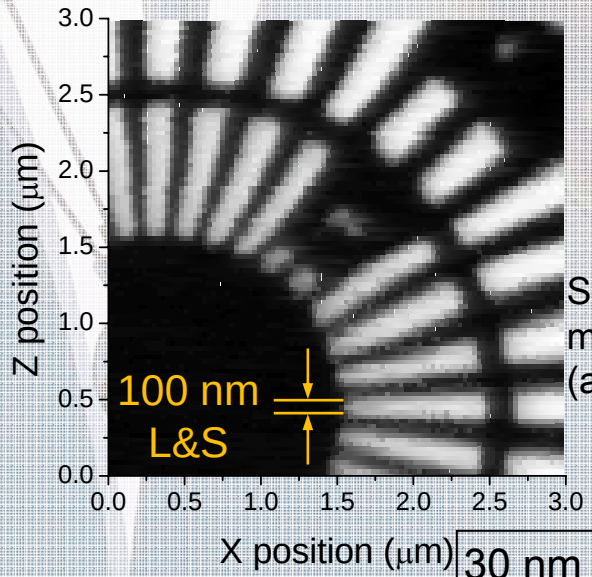
Focusing beam size

Knife edge scanning method
(200 μmϕ Au wire for knife edge)
X-ray energy = 12.4 keV





For the stability test, 2D map of test chart



Scanning transmission microscopy (absorption contrast)

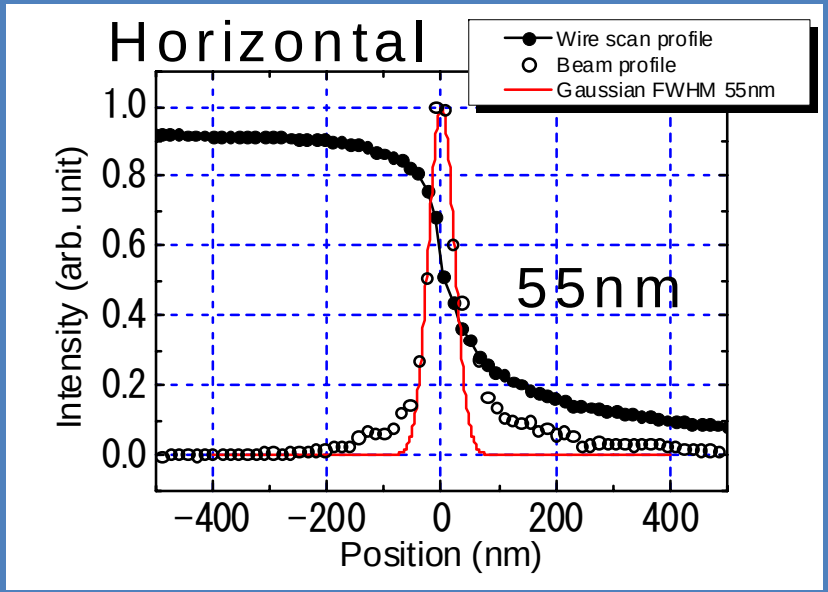
30 nm step, 100×100 pix
exposure time: 0.1 sec/pix
scan time: 1.5 hr

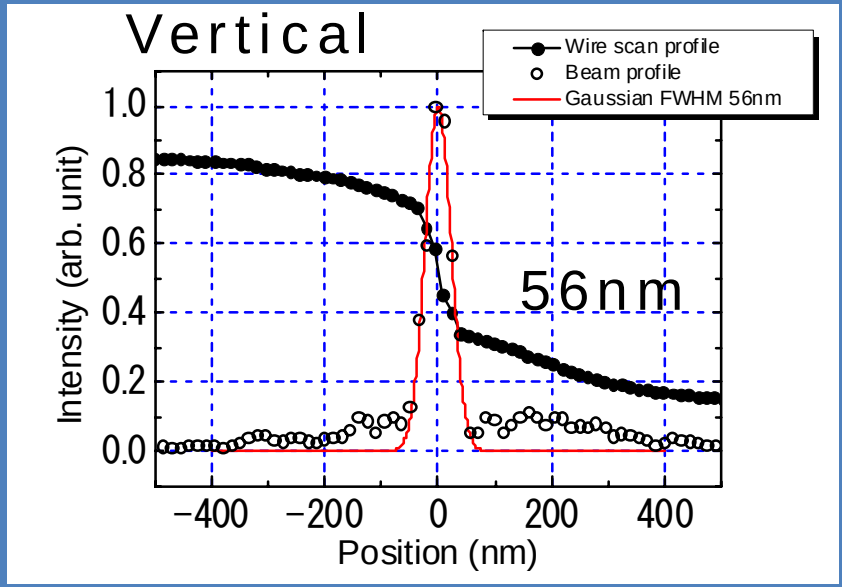
Stable 100 nm × 100 nm focusing beam can be available in public beamlines.

The full upgrade at both BLs has been completed with *"No dark time"* by standardization of stable BL optics.

Recent improvement: Smaller size and Higher flux

High resolution mode : with secondary source





High flux mode : without vertical secondary source

10^{12} phs /sec / 300×300nm^2 / $\Delta E/E=10^{-4}$

at 10keV (BL37XU, BL39XU)

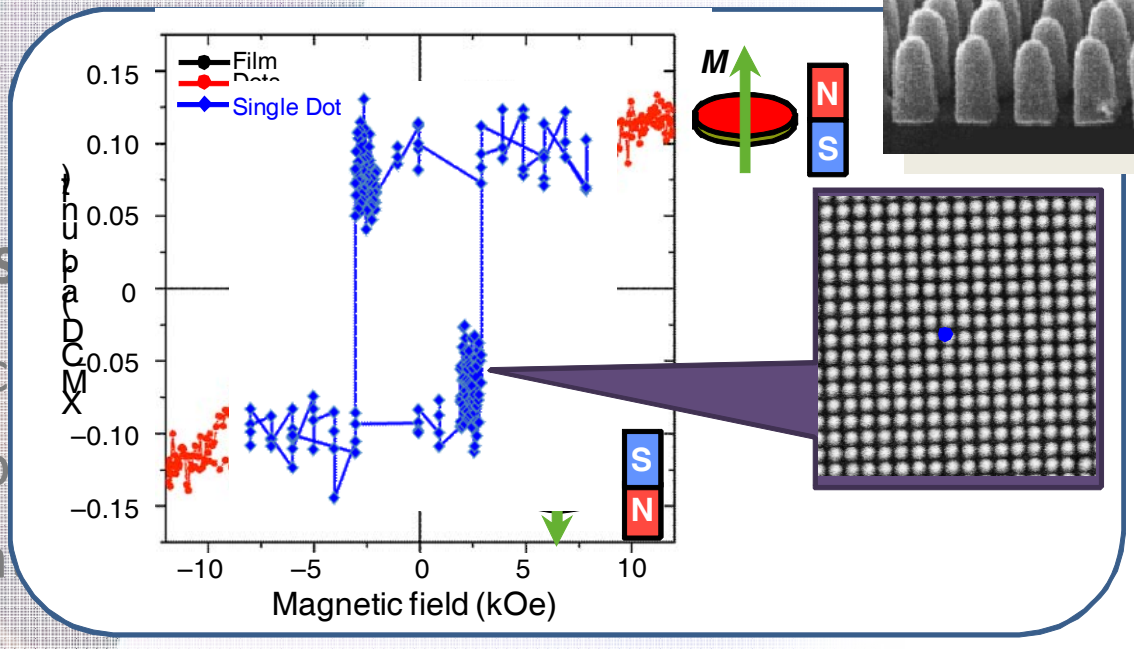
Outline

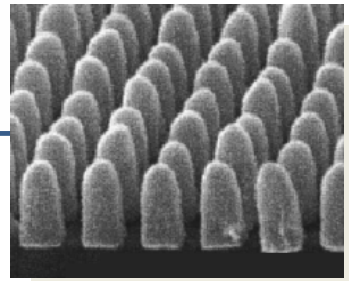
◆**Introduction**

Technologies of ulti

◆**Upgraded BL optics**

1. Stable double monoc
2. High precise KB mirro
3. Dedicated experimen





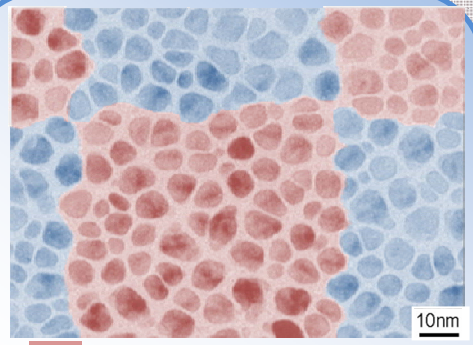
◆Highlight at upgraded beamline for nano spectroscopy

Analysis in a single magnetic dot at BL39XU

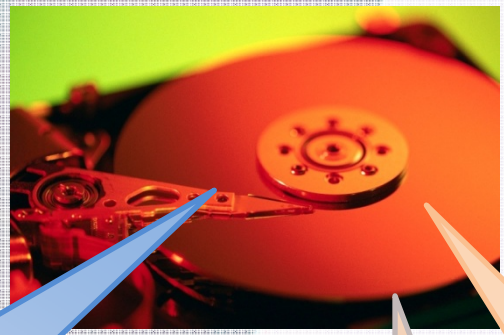
◆**Summary**

Application : Analysis in a single magnetic dot

Conventional Granular Media

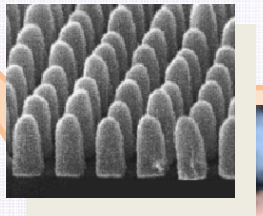


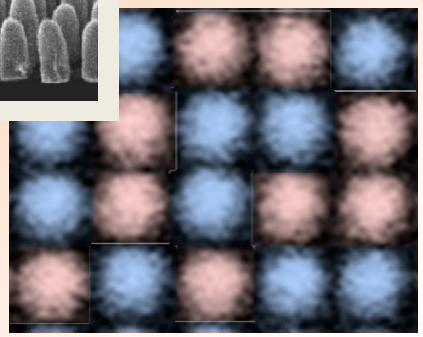
1 : 上向き磁化
0 : 下向き磁化



Next generation
>> 1 T bit/inch^2

New bit-patterned Media

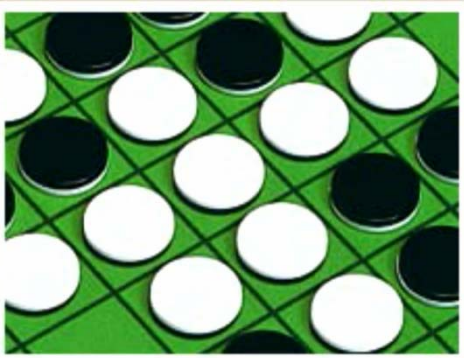




1 : 上向き磁化
0 : 下向き磁化

Each dot records magnetization.

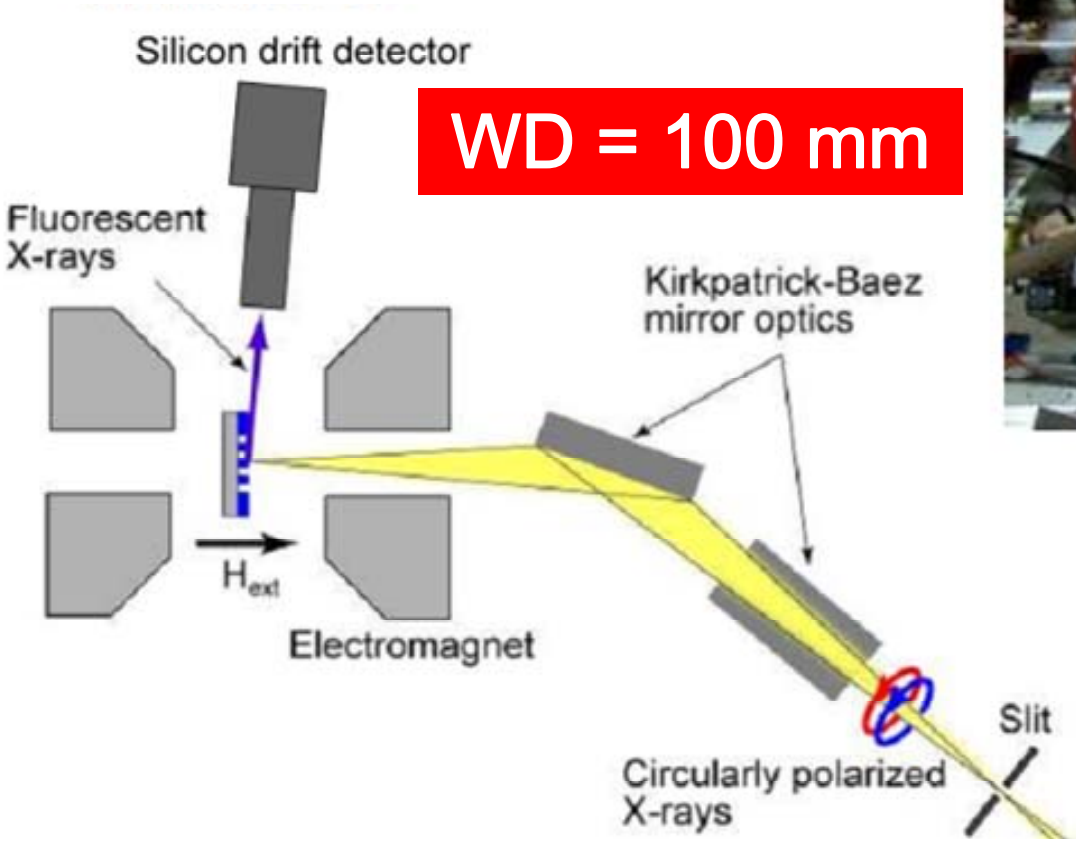
What magnetic properties
& magnetization reversal process
in a single dot ?

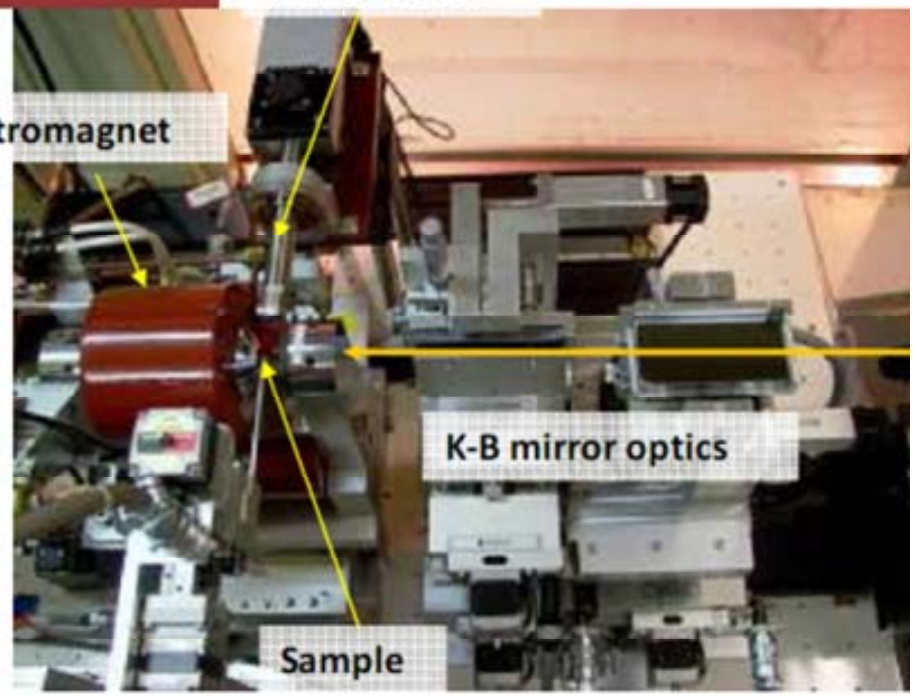


Application : Analysis in a single magnetic dot

Beamline: BL 39 XU in SPring-8

Element-Specific Hard X-ray Magnetic Circular Dichroism (MCD) Measurements



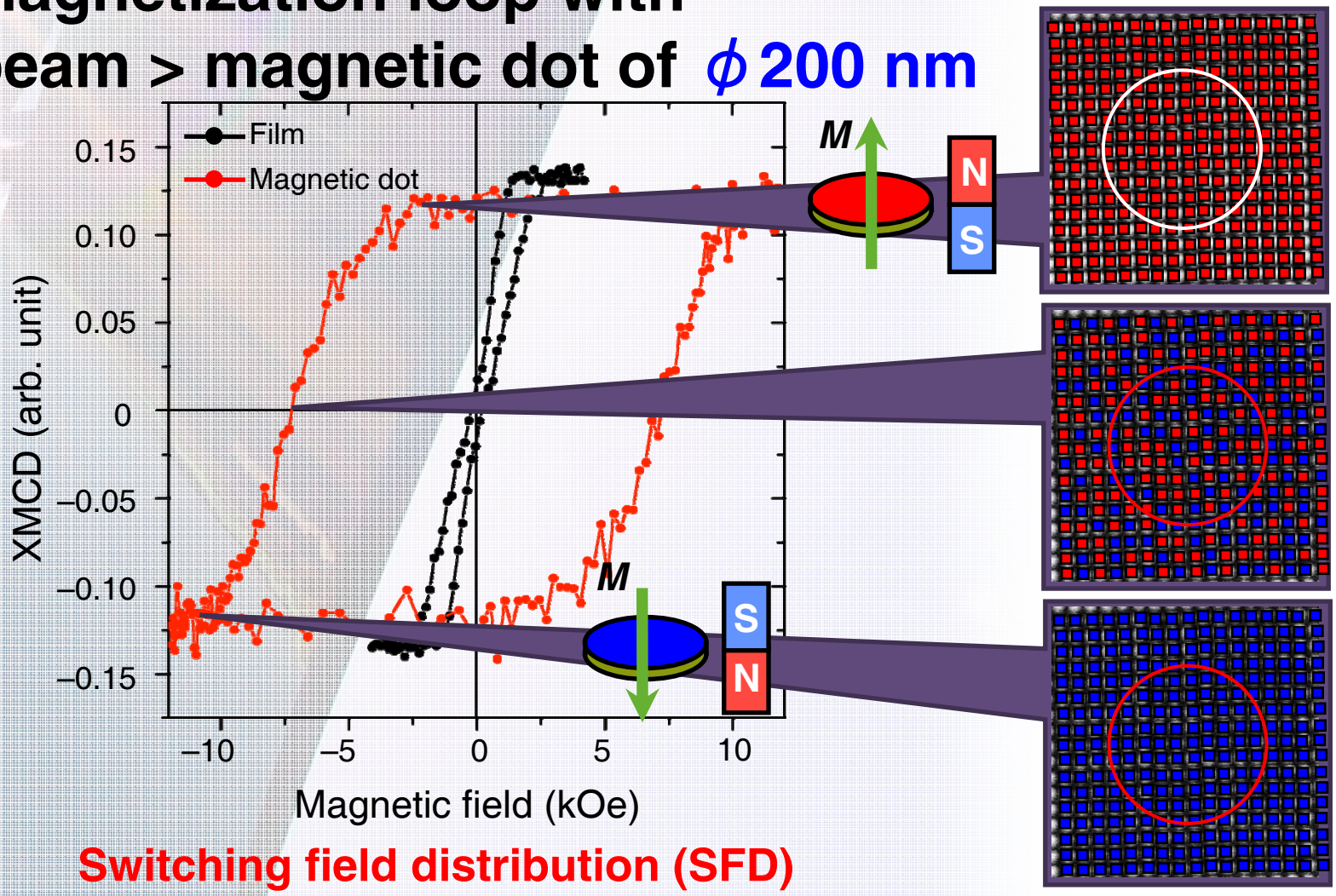


The experimental station for XMCD, XAFS and XRF combined with focusing system was installed at BL39XU l in 2011. Electromagnet is equipped to measure magnetization reversal process.

Application: Analysis in a single magnetic dot

Before upgrade

XMCD magnetization loop with 1 μm beam > magnetic dot of ϕ200 nm



Switching field distribution (SFD)

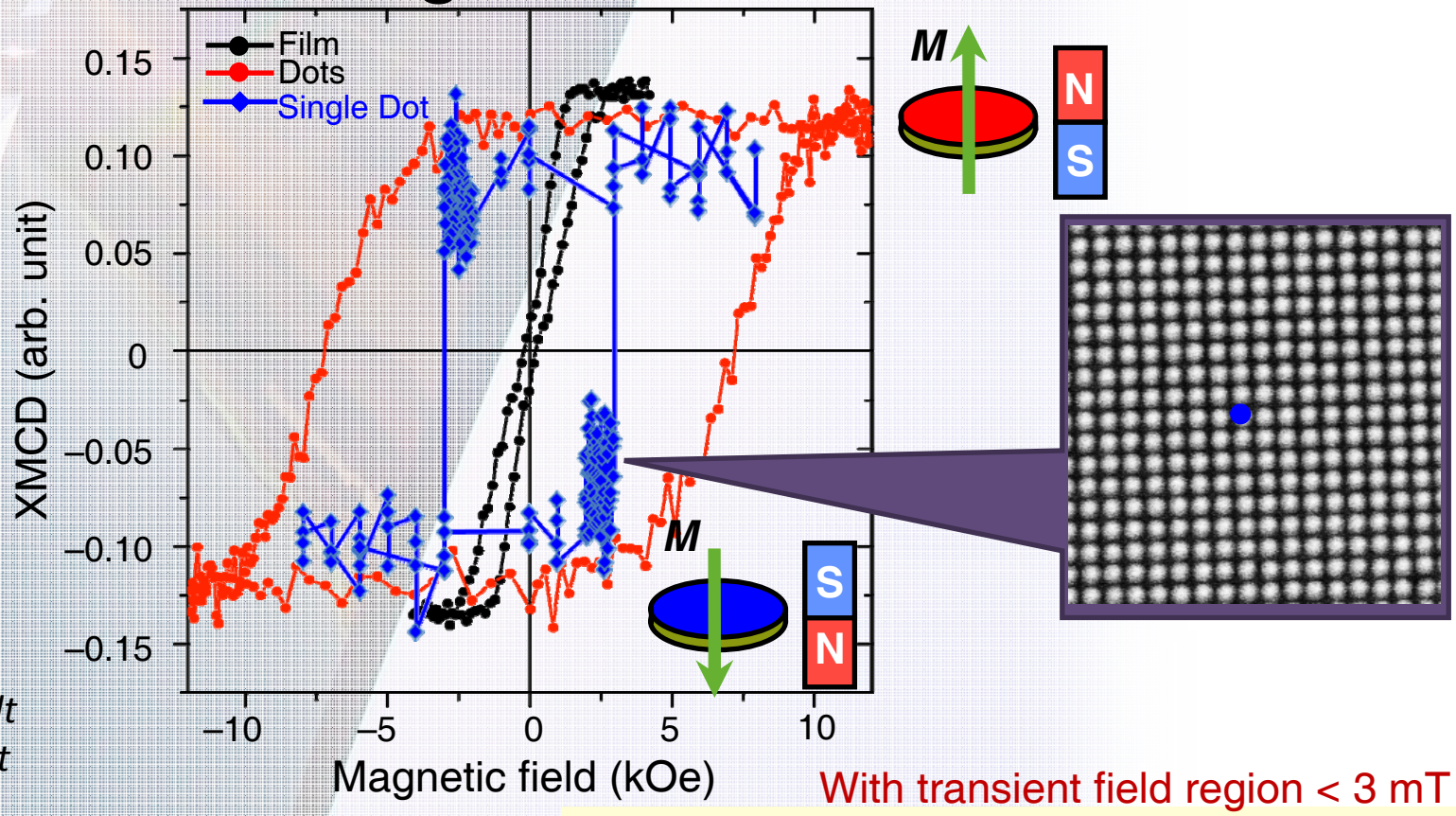
Y. Kondo et al., J. Mag. Mag. Mat. **320,** 3157 (2008)

The magnetization reversal was wider than thin film and not rapid raise.

Application: Analysis in a single magnetic dot

After upgrade

XMCD magnetization loop with 200 nm beam ~ magnetic dot of ϕ 200 nm



Preliminary result
Published not yet

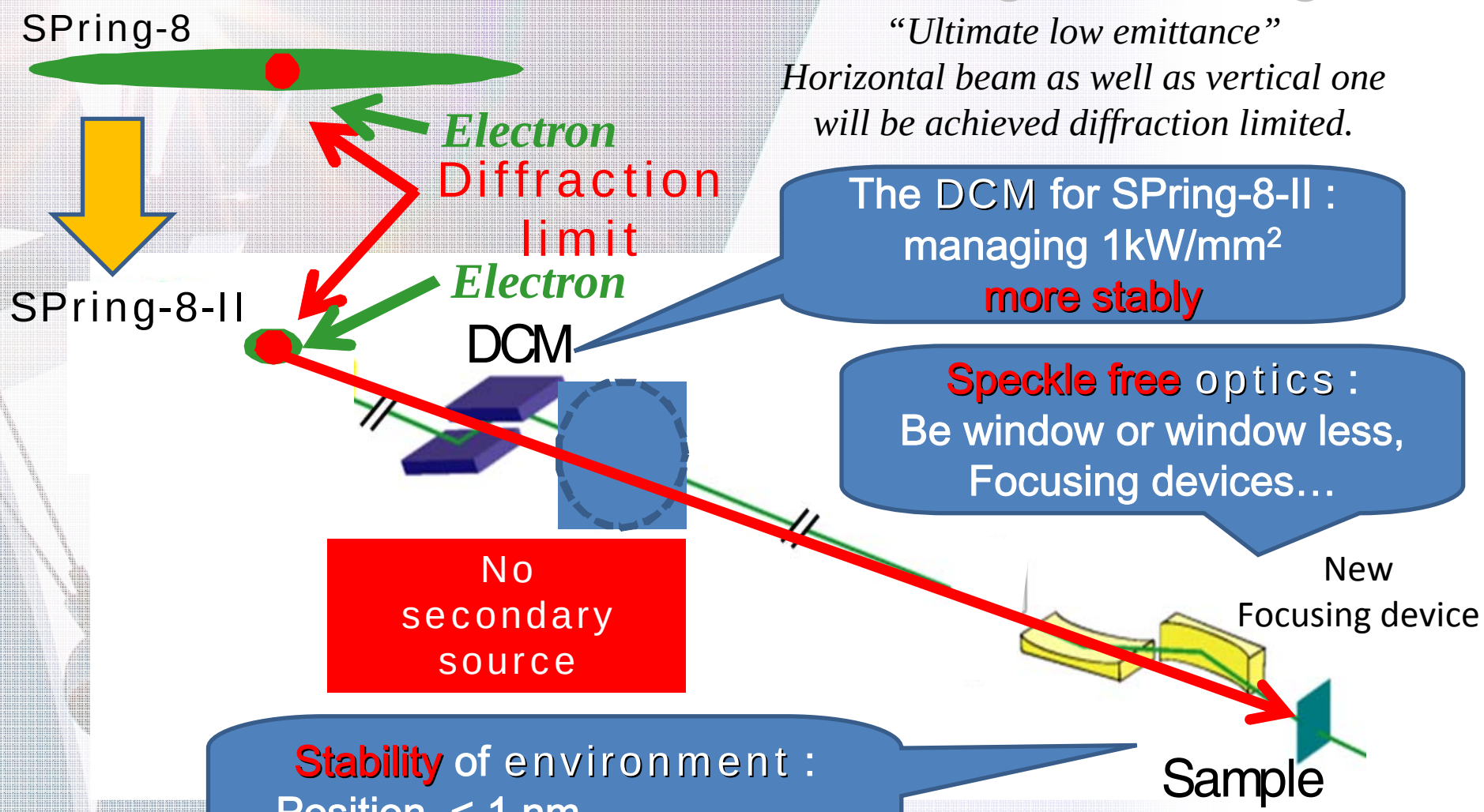
With transient field region < 3 mT

Single dot: rapid magnetization reversal

-Single (at least a few) domain inside the dot
-Coherent switching of magnetization

Outlook :
Towards "ultimate ring" SPring-8-Ⅱ

"Ultimate low emittance"
Horizontal beam as well as vertical one will be achieved diffraction limited.



The DCM for SPring-8-II : managing 1kW/mm² more stably

Speckle free optics : Be window or window less, Focusing devices…

Stability of environment :
- Position < 1 nm
- Angular < 10 nrad

10^{14} phs / sec
@□50 nm²

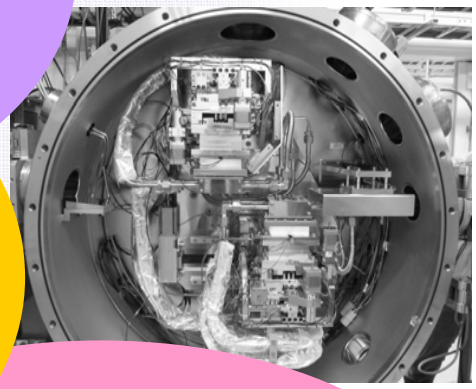
Please see http://www.spring8.or.jp

Outlook :
Towards "ultimate ring" SPring-8-Ⅱ

Mirror manipulator

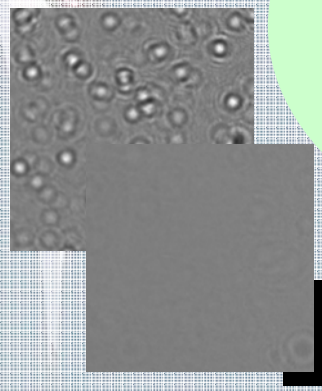
Stability
10 nrad

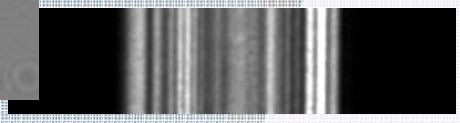
Monochromator,
Environment



BL optics for SPring-8-Ⅱ

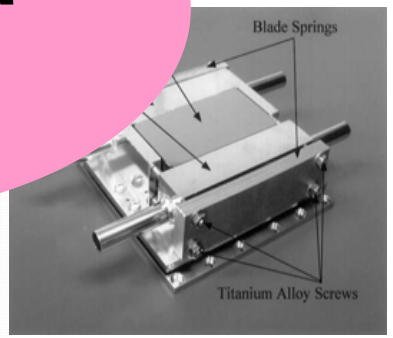
Mirror, Window,
Crystal





Coherence
speckle free

Heat load
1kW/mm2



Summary

We have developed and installed stable beamline optics such as monochromators, the dedicated experimental hutches, and new experimental station with focusing mirror system with no dark time at BL37XU and BL39XU.

Focusing beam performance (BL37XU, BL39XU)

	High resolution mode	High flux mode
Focusing beam size:	60 nm × 60 nm～	300 nm × 300 nm
Focusing photon flux:	$>10^{9}$ photons/s	$>10^{12}$ photons/s

Scanning transmission microscope

2D scan image of Siemens star pattern

The finest structure of 100 nm L&S was successfully resolved

Analysis in a single magnetic dot

XRF, XAFS, XMCD analyses of a single magnetic dot of 200 nm diameter have been demonstrated.

Acknowledgement

K. Yamauchi, T. Matsuyama (Osaka Univ.),
H. Mimura (Tokyo Univ.) for focusing system
Y. Kondo (AIT) for sample of magnetic dot

This research was partly supported by "Low-Carbon Research Network (Lcnet)" funded by the Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan.

Special thanks to
Dr. Yin and organizing committee
for warm hospitality

Thank you
for your kind attention!

謝謝 你们的关注!

Xiexie nimen de guan zhu.

ご清聴ありがとうございました！