Beamline Challenges

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Reference:

J. Synchrotron Rad. **21** (2014) 976-985, “Optics for Coherent X-Ray Applications”

Detailed consideration of Optics: Shunji’s Talk this afternoon

X-ray DLSRs

Higher average brilliance,
Higher degree of transverse coherence

Smaller Focal Size
Localized Info through

Diffraction
Scattering
Spectroscopy
Imaging

Coherence Related
Applications

Single-Particle CDI
ptychography
Correlation Spectroscopy

Time-Tracing
for
Spontaneously Fluctuating Systems

Higher Degree of Transverse Coherence

High Speed 2D Detector

nsec, nm resolution space-time tracing

Complementary to XFEL, which are most suitable for single-shot destructive measurements with ultra-intense femtosecond X-ray pulses

Retrospect

- The biggest challenge of beamline at the 3rd generation X-ray SR sources was High Heat Load optics.
- The cryogenic cooling gave us a solution, but the optics vibration with the cooling is yet to be solved.
- After achieving sufficient cooling, the effect of coherence became apparent.

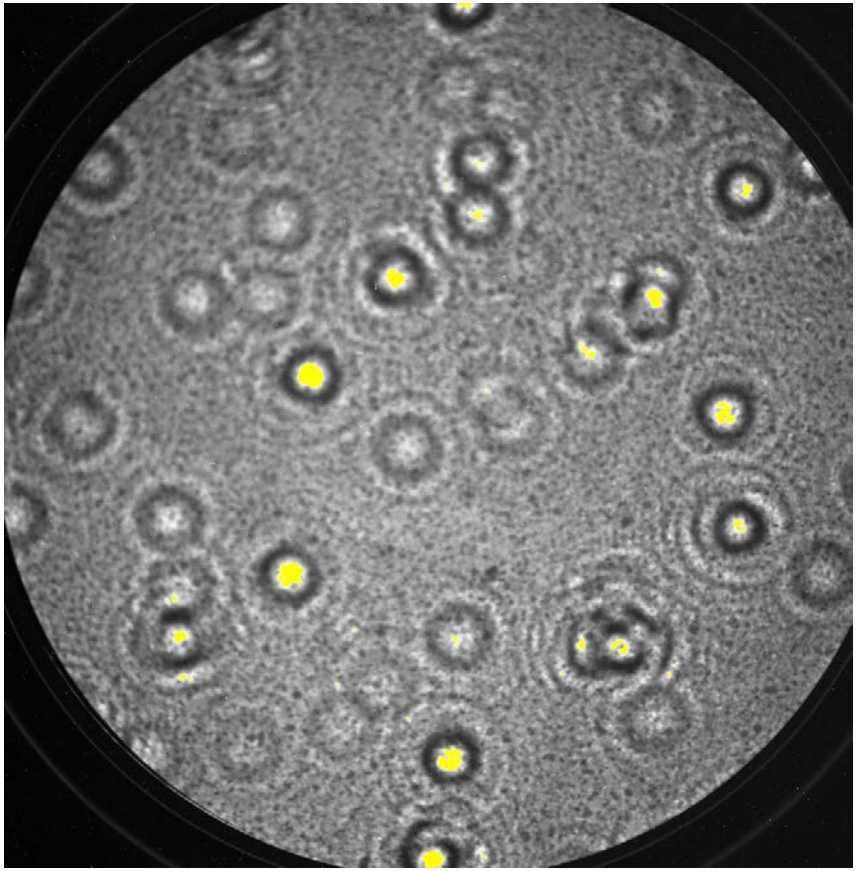
Diffraction Limited SR

- Reduced electron beam emittance
- Enhanced lateral coherence of the photon beam

- Experience at the1 km beamline can help

Coherent X-Rays

Be Window Image at 1 km End-Station



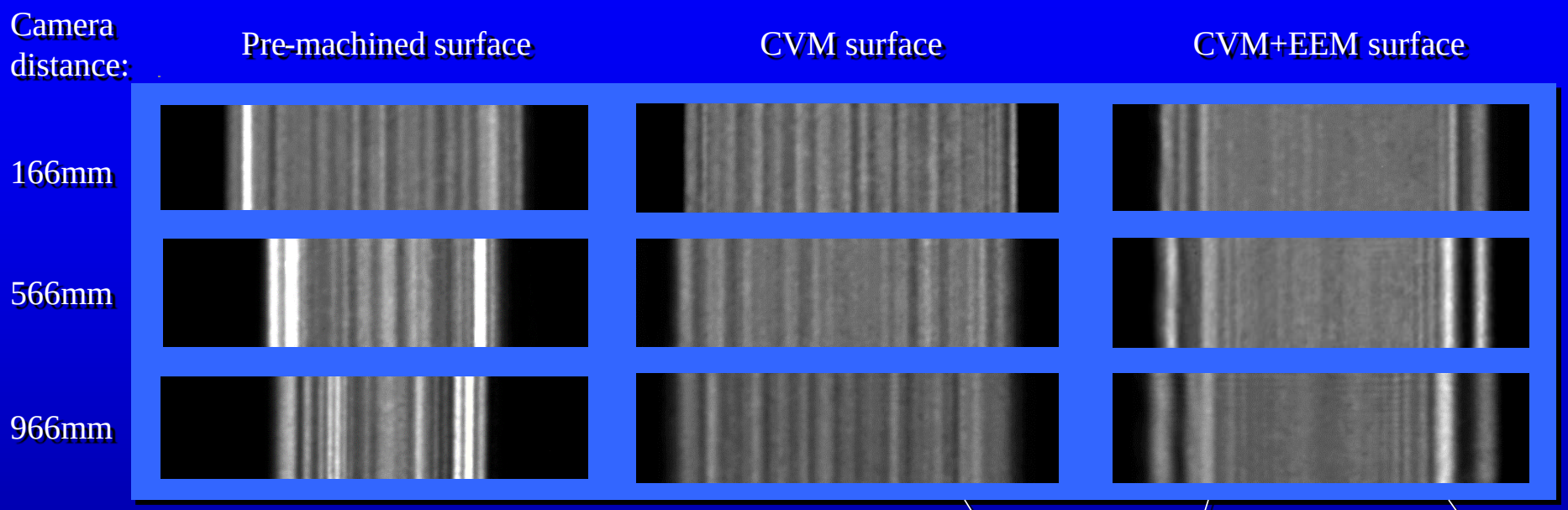
Field of View 0.48 mm ×0.48 mm

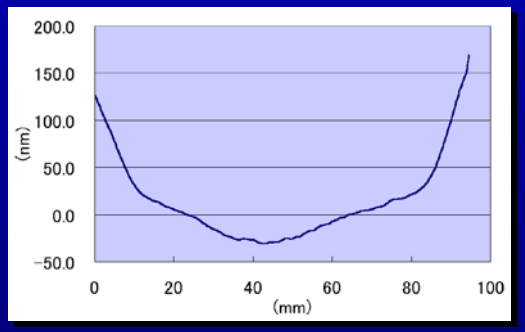
Detector Resolution 480 nm

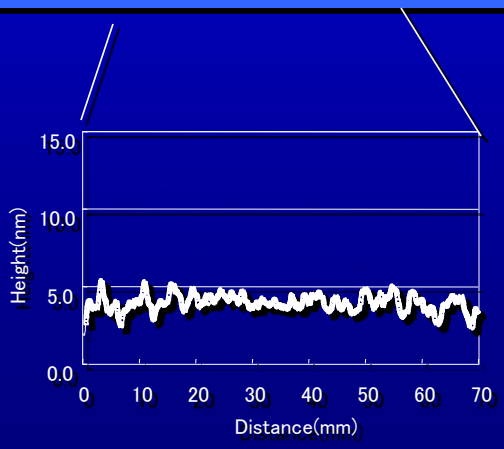
E = 16 keV (λ ~ 78 pm)

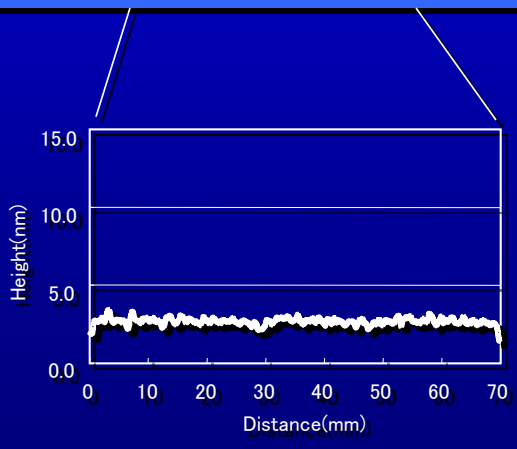
Reflected Beam from Mirrors

Incident angle : 1.2mrad / Mirror length : 100mm / Mirror material : Silicon single crystal (001)







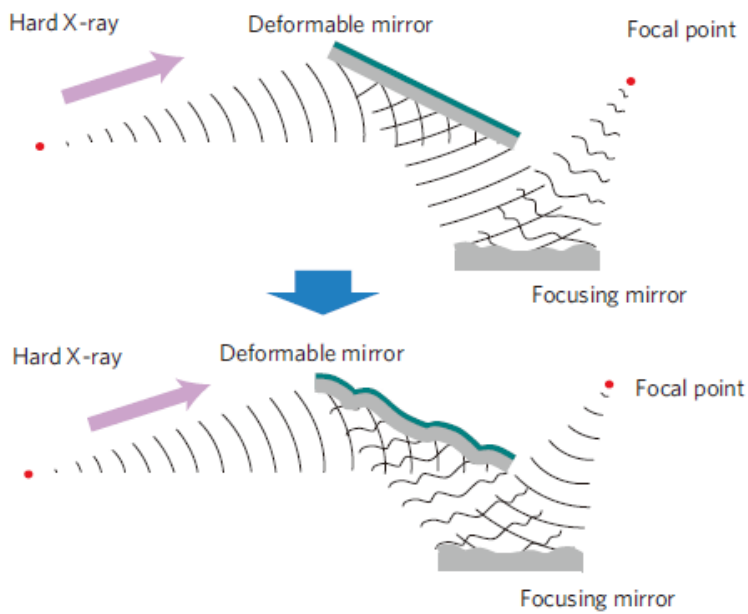


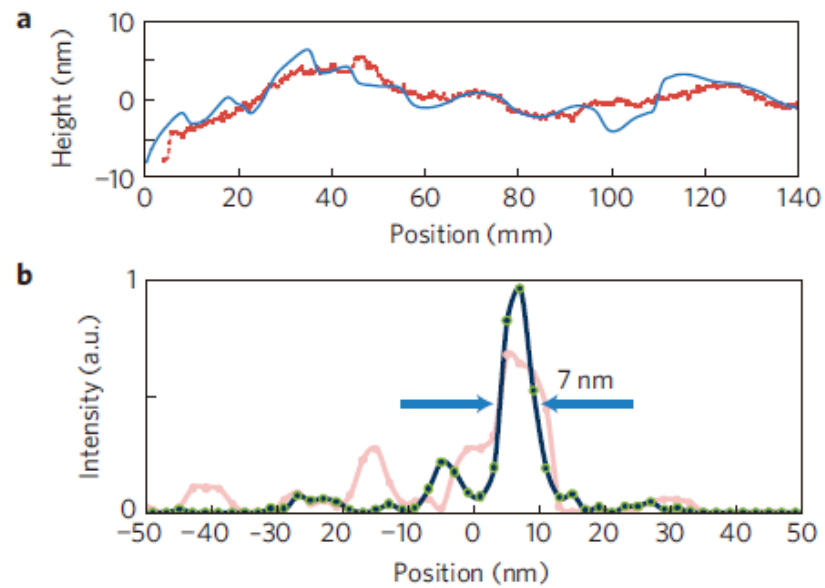
Yamauchi

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]





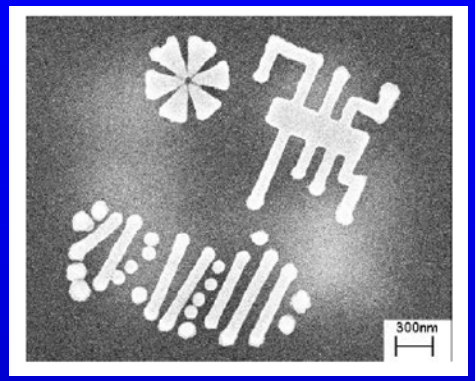
At the 1 km BL. Demagnification factor could be made extremely small due to very long source-optics distance.

Coherent X-rays at General Beamlines

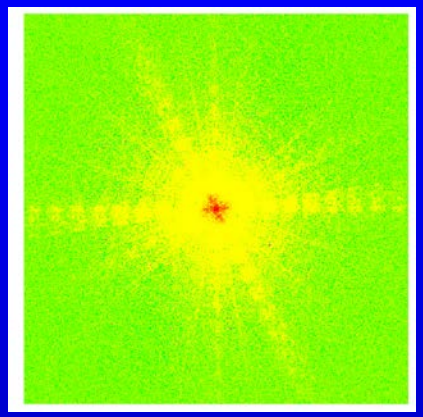
- With appropriate pinholes placed downstream of the monochromator, we could extract coherent X-rays.
- The first hard X-ray as well as 3D Coherent Diffraction Imaging was demonstrated in 2002 by Miao.
- 100 nm focusing is routinely available using KB mirrors.

3D Diffraction Nanoscopy

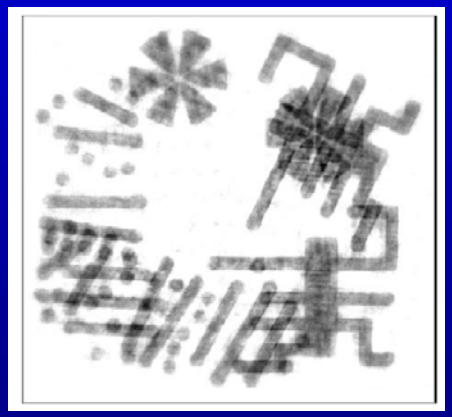
Two Layer Ni Pattern **8 nm resolution**



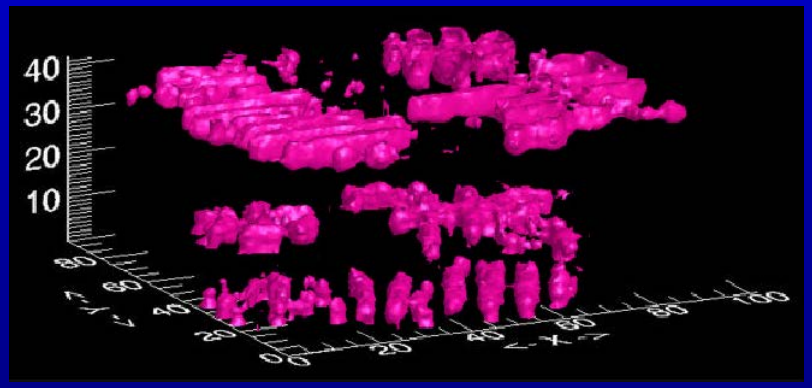
SEM image of Ni pattern on SiN



Coherent Scattering Pattern



2D Reconstructed Image
(<10 nm resolution)

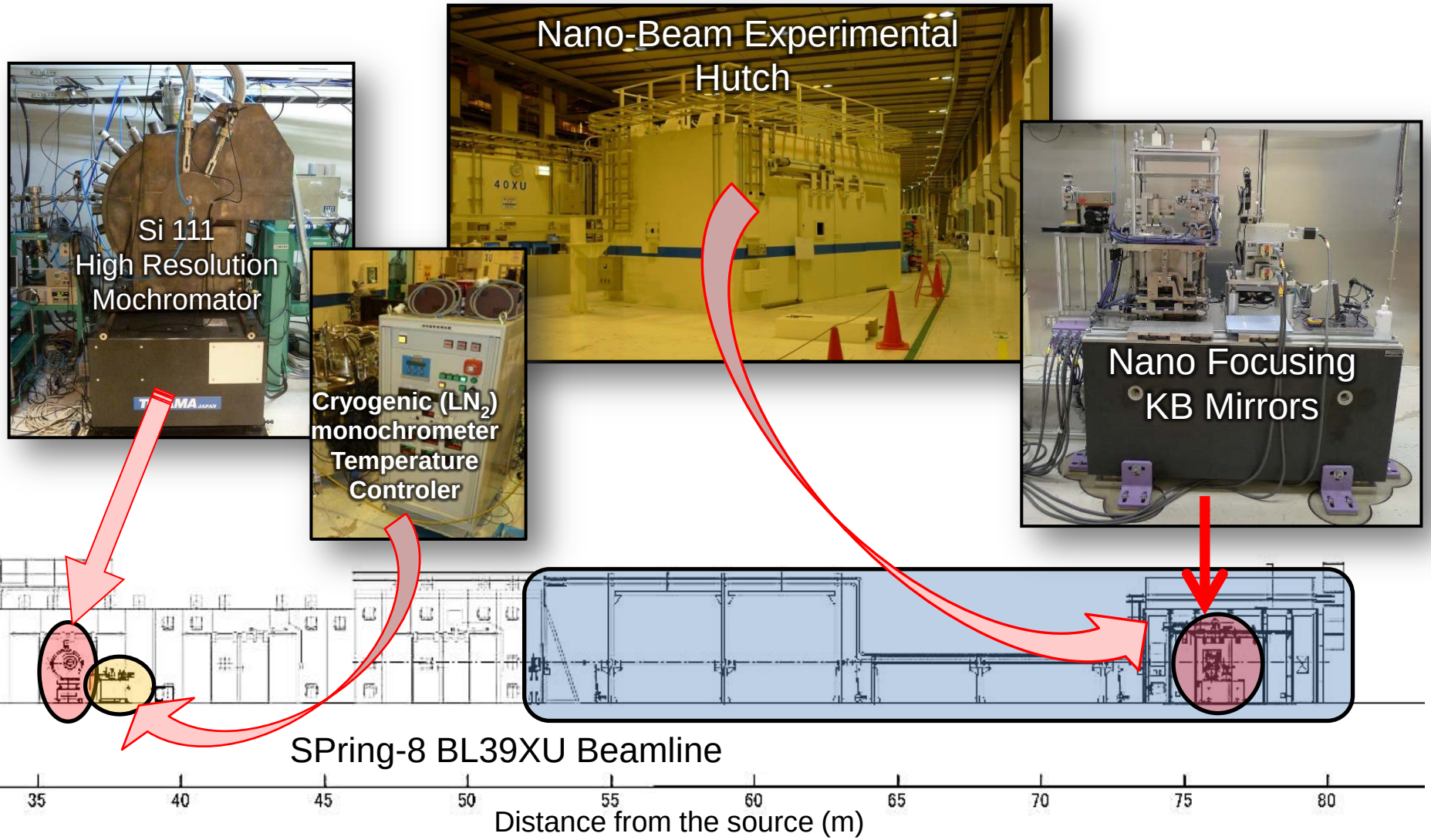


3D Reconstructed Image (~50 nm resolution)

Miao, et al. PRL (2002)

Nano Beamline Upgrading; BL37XU & BL39XU

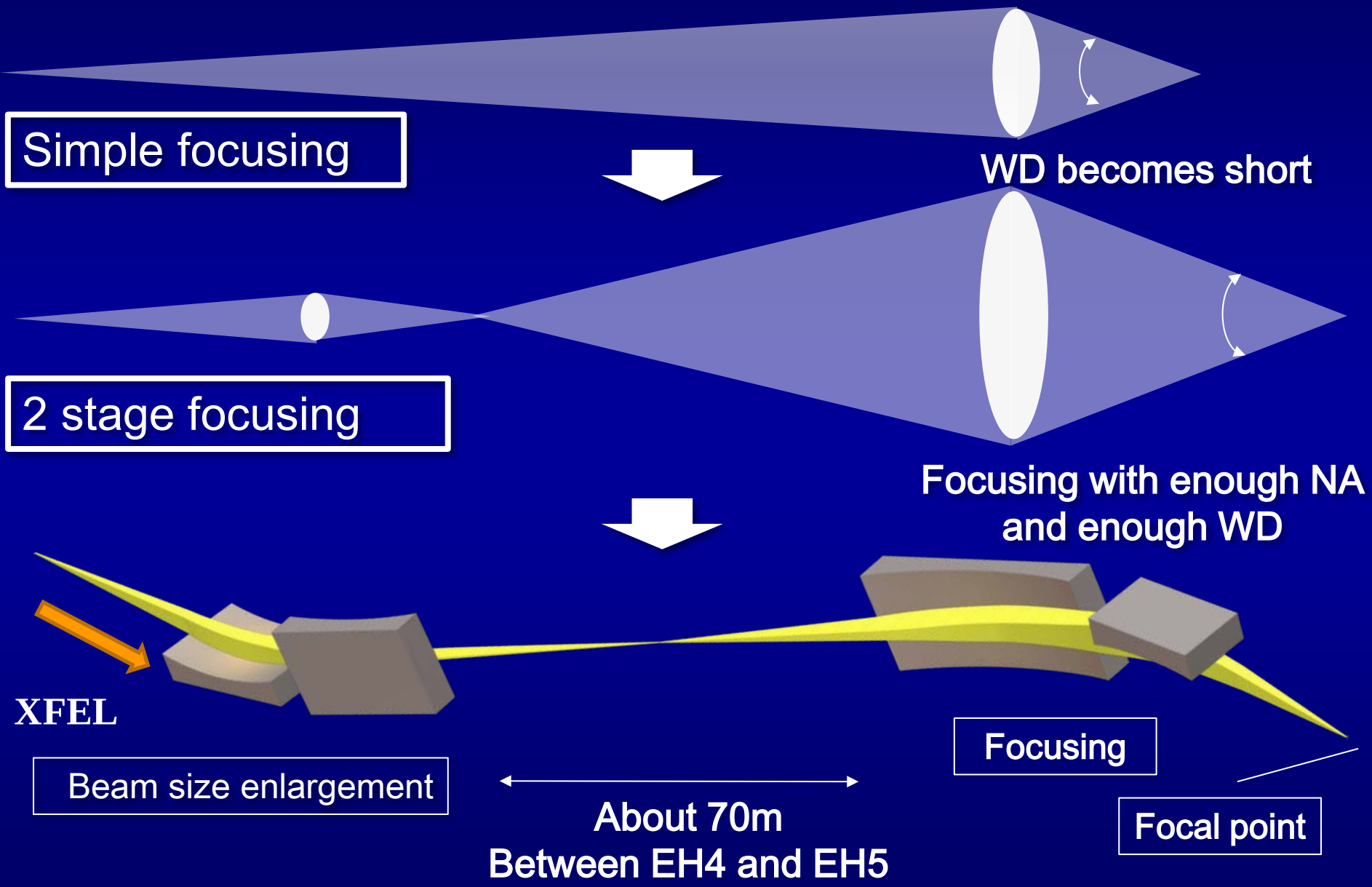
High Brilliance, 100nm Size and Highly Stable Beam
has been achieved by
Advanced Focusing Optics & Temperature Control Techniques developed at SPring-8



Further Downsizing of the focal spot

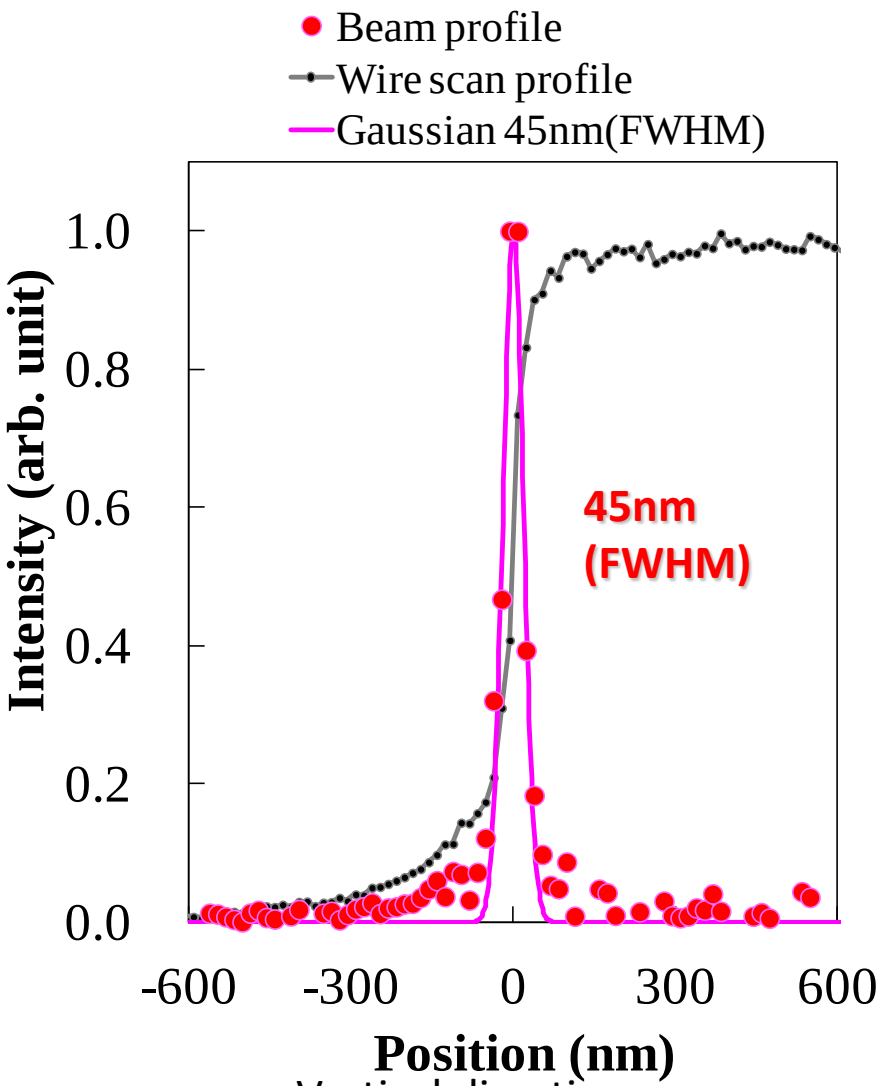
- 2 stage focusing has been successfully applied at SACLA beamline.

2-stage focusing for creating smaller spot

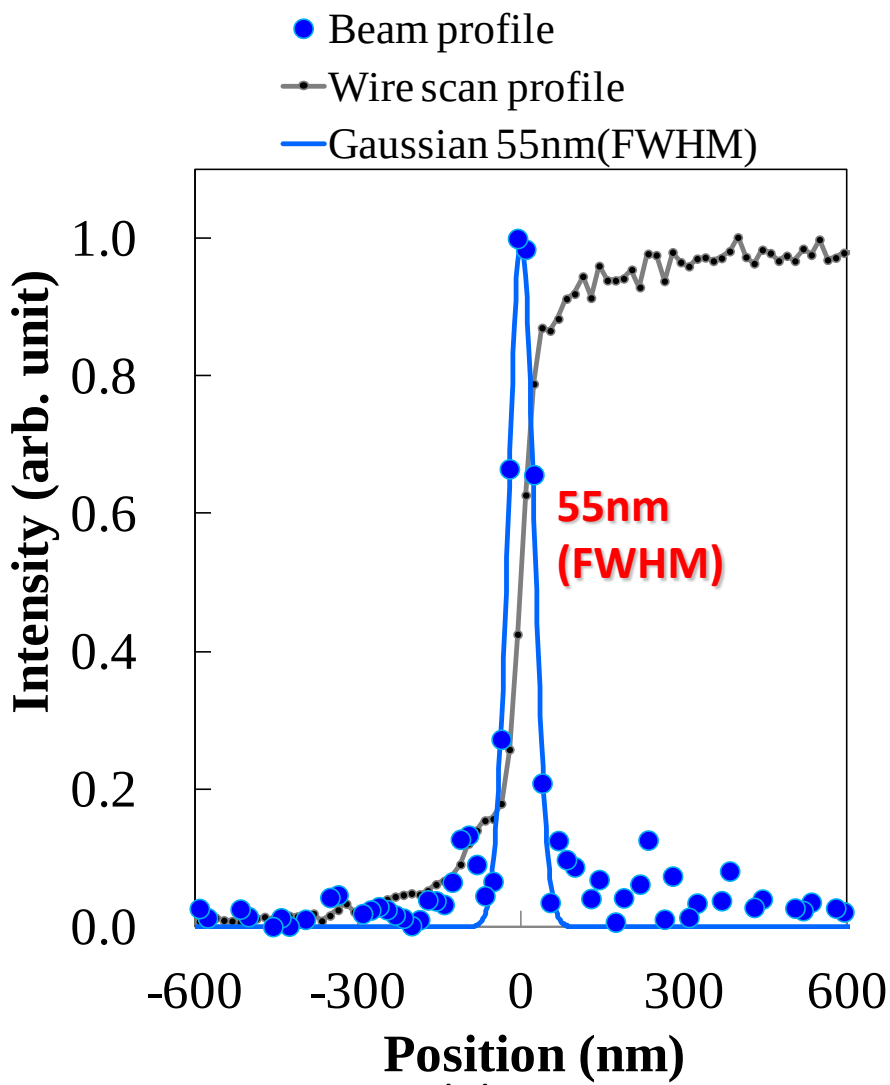


~50 nm Focusing: Results

H. Mimura et al., Nature Comm. 5 (2014) doi:10.1038/ncomms4539



Vertical direction

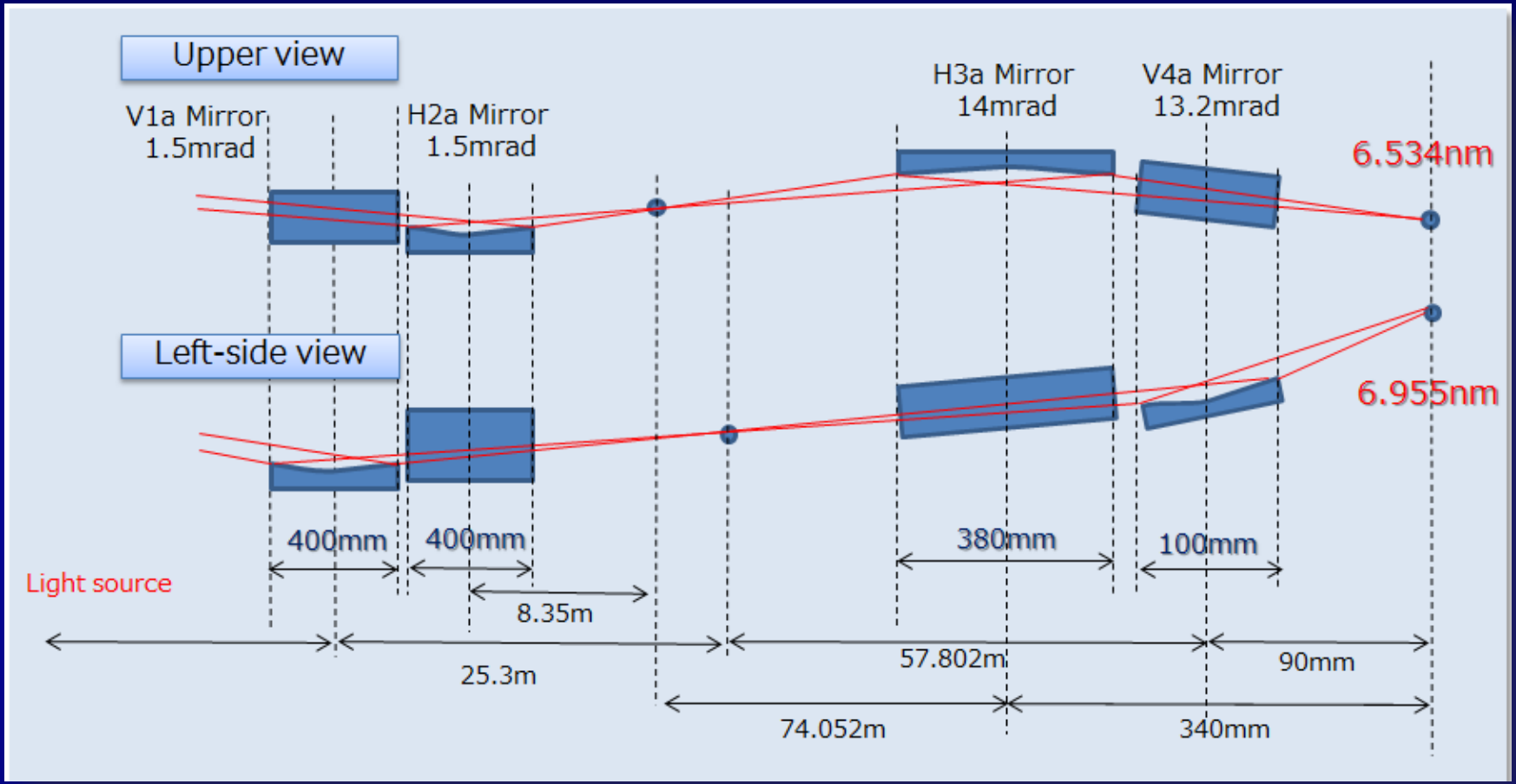


Horizontal direction

~10^{20} W/cm^2

X-ray energy: 10keV

Design for single nanometer focusing (Prof. Yamauchi)



mirror	Total reflection		Multilayer	
	Mirror A	Mirror B	Mirror A'	Mirror B'
Glazing incidence angle(mrad)	1.5	1.5	14.0	13.2
Mirror length (mm)	400	400	380	100
Multilayer period (nm)			3.08 ~ 6.59	3.29 ~ 7.17

~10^{22} W/cm^2

Problems encountered at 1 km BL

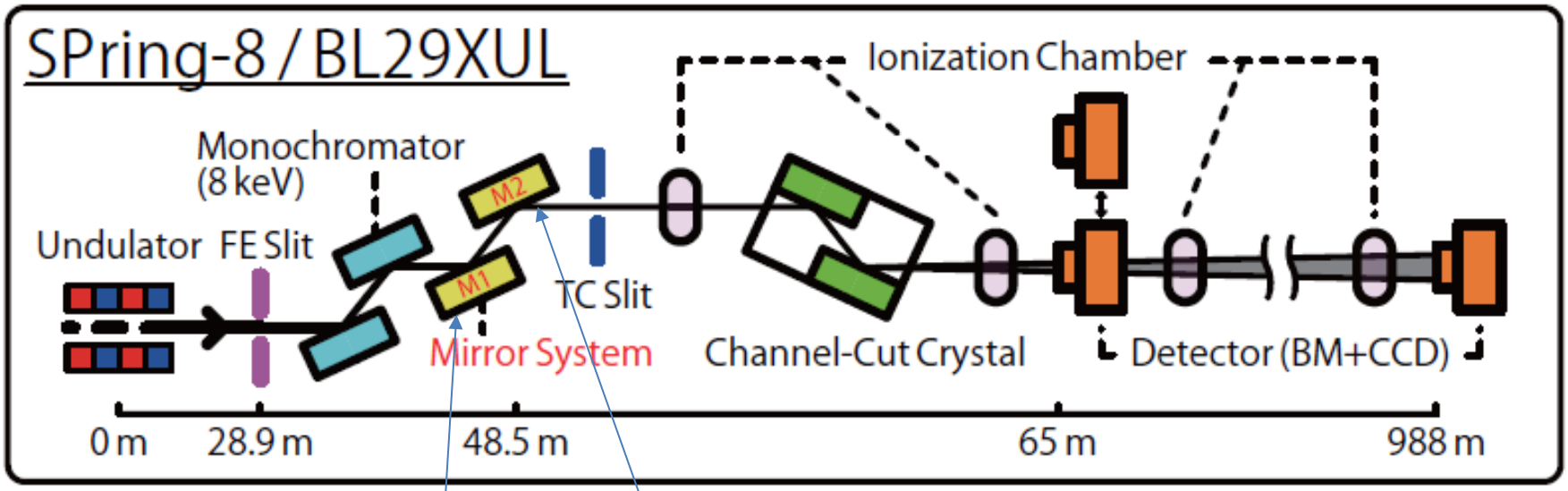
- Beam stability in the storage ring
  - 1 km beamline offers a very good monitor for beam stability
- Optics Stability
- Coherence Preservation
  - Need virtual source after the DCM
- Mechanical Stability
- Building Vibration (Air Conditioner, Cooling Water)

These problems have been partially solved by the R&Ds using the 1 km beamline, but not completely addressed for the full utilization of the coherence.

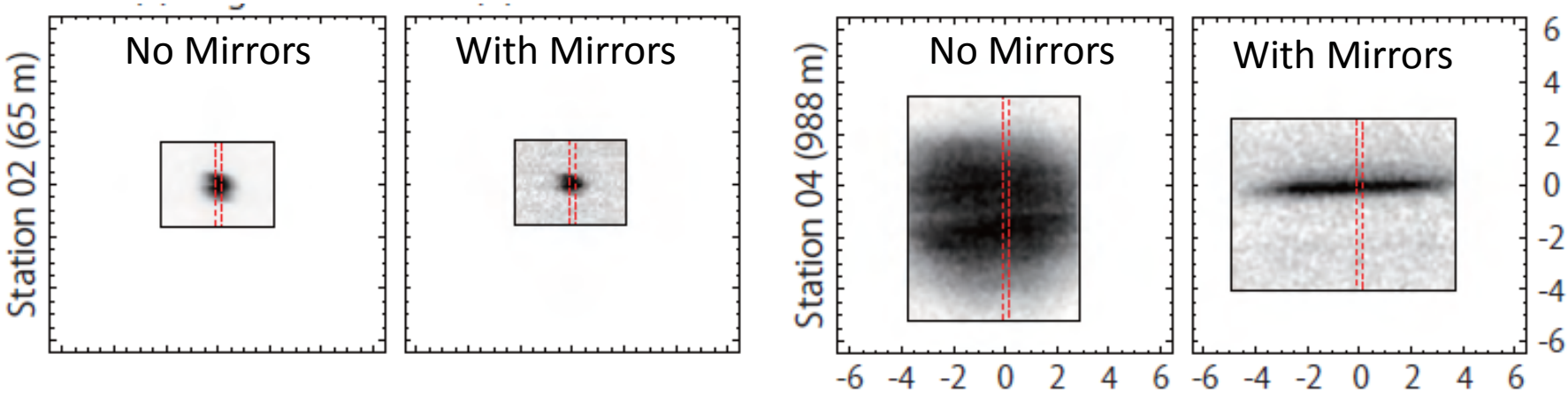
Parabola Mirrors

- Parabola mirrors can reduce the angular divergence of the X-ray beam (1D) without affecting the spectral distribution.
- Achieve higher performance for smaller sources.
- Fabricated recently by Yamauchi Group (Osaka Univ.) and tested at the 1 km beamline by Takei and Kohmura.

Parabola Mirror

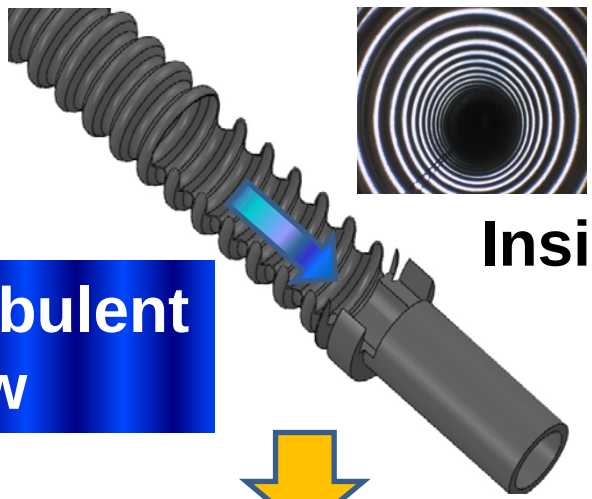


Flat Mirror Parabola Mirror



Reduction of Vibration of LN_2 Flow

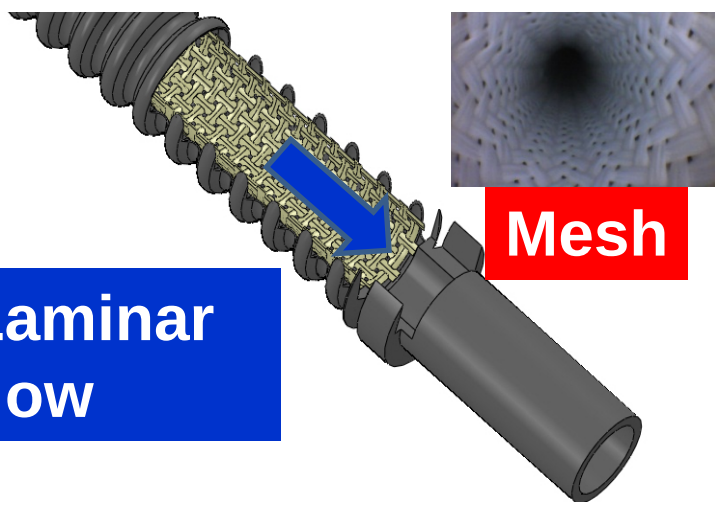
Conventional



Inside

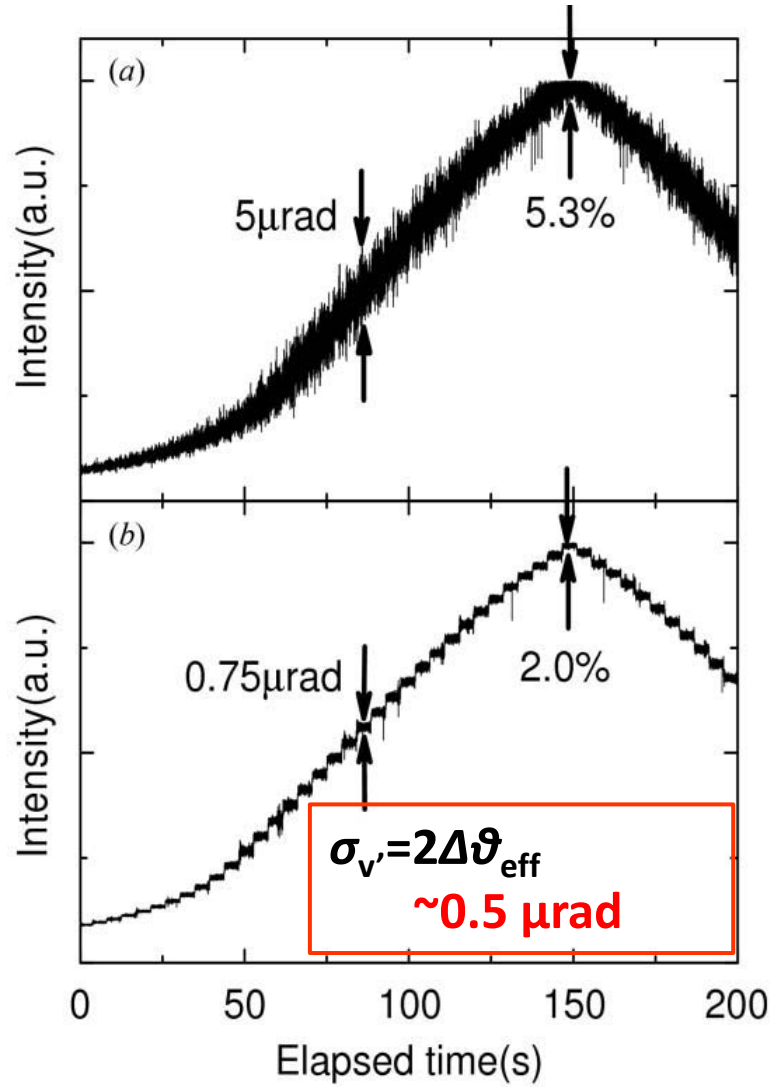
Turbulent flow

Clear Flow Flex™



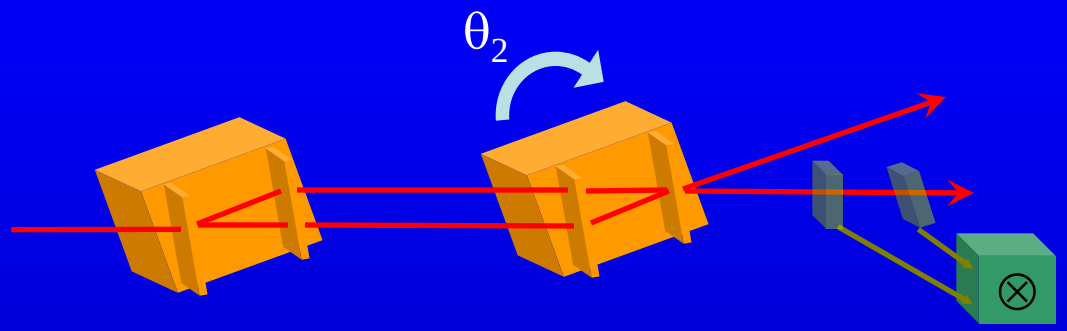
Mesh

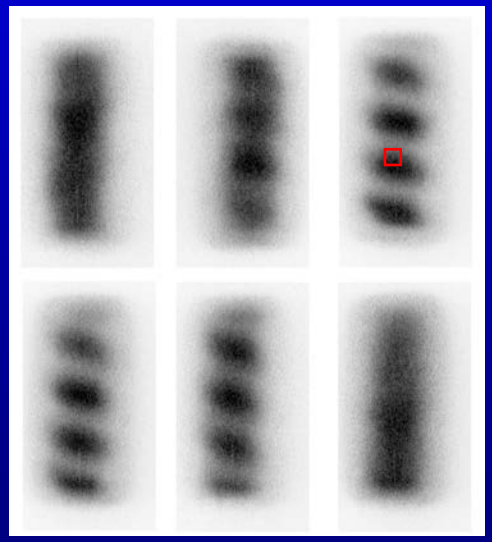
Laminar flow



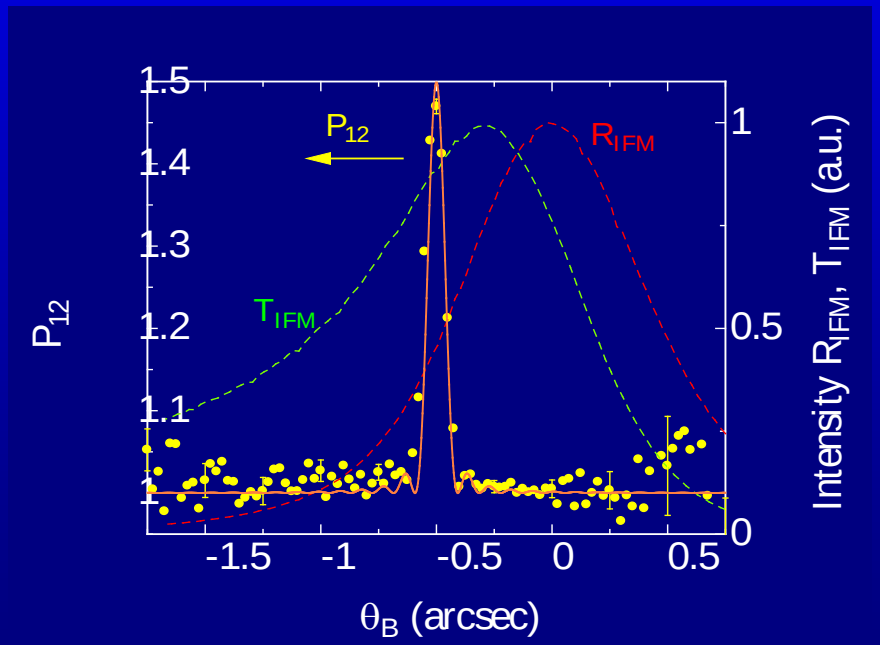
H. Yamazaki *et al., J. Phys.: Conf. Ser.* **425**, 052001 (2013)

Bicrystal interferometer



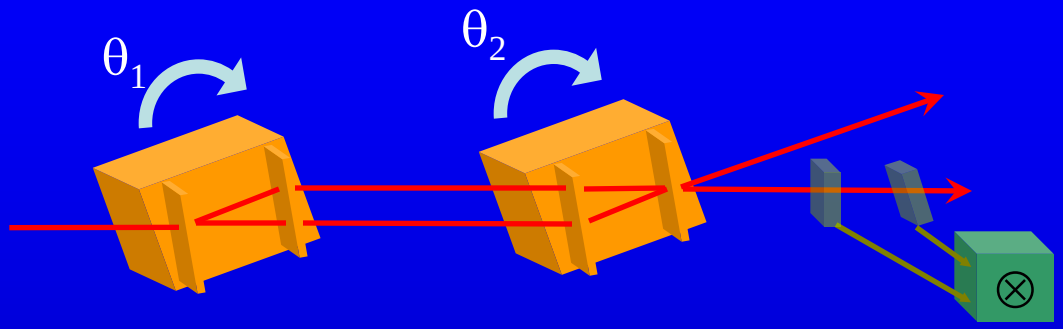


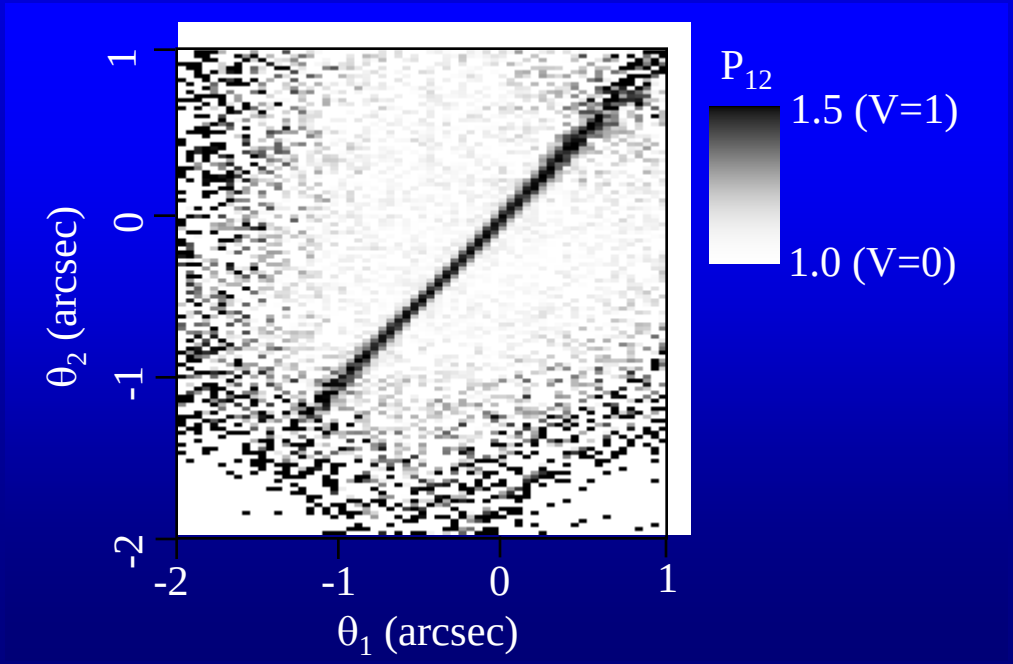
Exposure time = 2 ms



Tamasaku wt al. PRL

Bicrystal interferometer





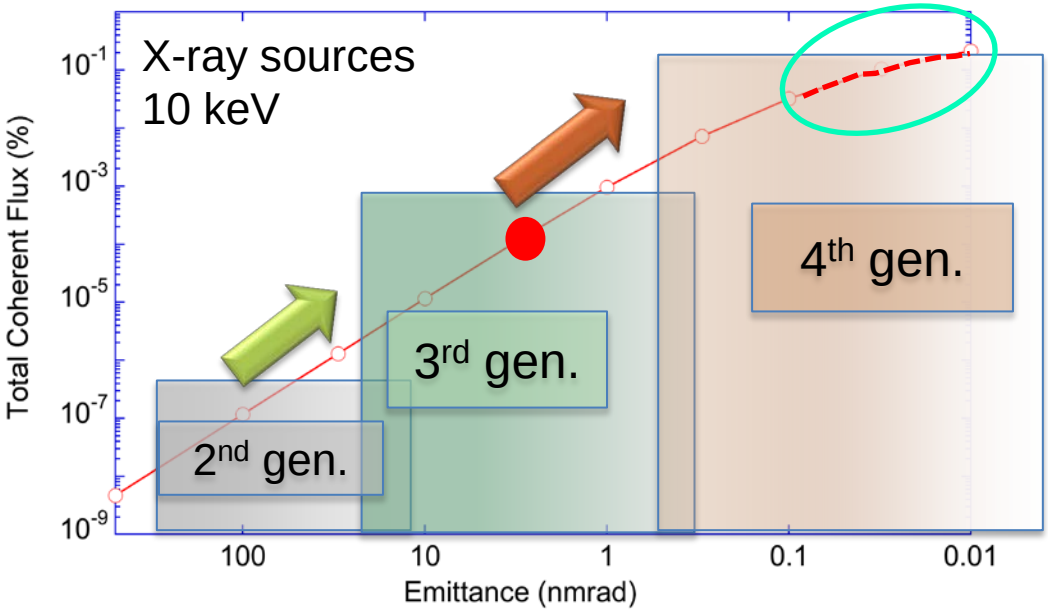
SPring-8 Upgrade: SPring-8-II

To achieve the ultimate SR source performance under the existing boundary condition

- Atoms and molecules in real materials, whether they are organic or inorganic, are working in a certain environment.
- However, in most cases atomic-resolution observations use samples that are separated from the real environment and purified in order to observe their unique characteristics in isolation.
- Advances in X-ray sources have enabled the atomic-level observation of materials within a working environment.

Upgrade Goals

- To provide a wide range of users with *highly coherent and brilliant X-rays* by reducing the electron beam emittance in the storage ring to *less than 100 pm·rad.*
- To open for operation *in early 2020s*



SPring-8 and SACLA

We will have a DLSR and an XFEL in the same site.
Best mixing and demarcation of these two facilities would be our challenge.

Energy-Saving at the Facilities

- SR facilities have been contributed to develop the energy-saving technologies.
- However, I believe the facilities themselves should become higher energy-efficient.
- Energy efficiency of most of hardware for the facility has been much improved during these 20 years.
- SPring-8-II upgrade is aiming at more than 20% reduction of energy consumption from SPring-8 in 2010.

XFEL vs. SR

XFEL
- High peak brilliance with fs pulses
- Applicable for small, complex samples
- Measure-before-destroy

- Sample will be damaged in a single shot

SR
- High average brilliance w high rep rate
- Deliver X-rays to dozens of beamlines
- Moderate peak intensity

- Sample will not be damaged in a single shot
- Sample change can be traced
- Suitable for extracting information with correlation techniques (CT, time-course)

New regime of X-ray science

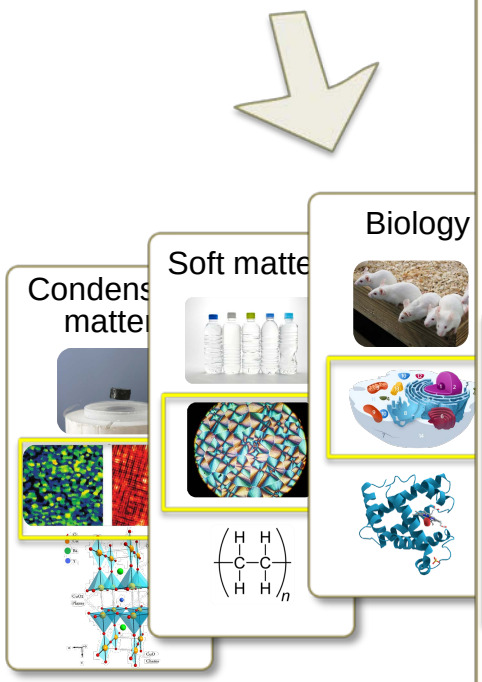
Towards diffraction-limited source
Enhanced brilliance

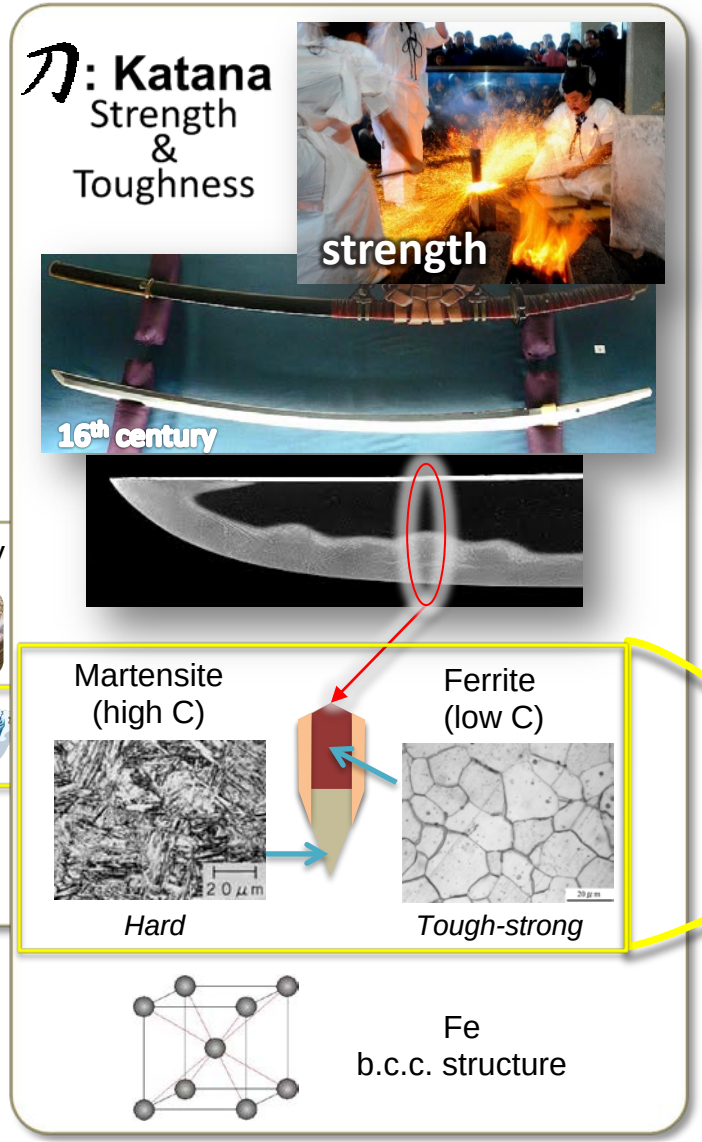
SPring-8 Upgrade : Scientific Motivation

For many phenomena, we know ***how*** they happen,
but don't know ***why*** they happen.

Inhomogeneous / Hierarchic / Composite - system

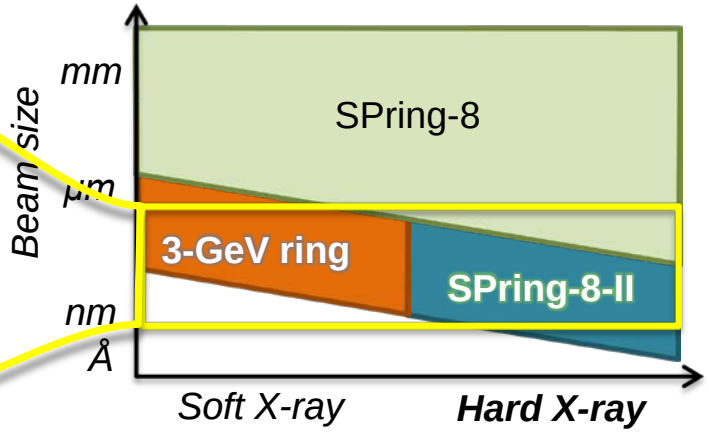
Homogeneous system





Nano-Scopy:

- Nano-Diffraction
- Nano-Spectroscopy
- Nano-Imaging



Further Challenges

- **For coherent radiation, no optics would be the best optics.**
  - Reduce the number of optical components
    - KB focusing mirror ⇒ ellipsoidal focusing mirror
    - Paraboloidal collimation mirror
  - Be window
    - Defect Free window
    - Differential Pumping; Windowless BLs
- **High-Speed, High-Resolution, Wide-Dynamic Range 2D Detectors**
  - Fast 3D rendering

Concluding Remarks

- The first phase beamlines of DLSR could be prepared by using existing technologies
- As in the case of the 3rd generation facilities, real problems will become apparent after we observe the light.
- It would be extremely difficult to stabilize the beam in nm/nrad range.
- For some coherence-related measurements, utilization of higher order coherence, rather than the first order coherence, may help.