Retreat on XFELO Sciences

X-ray Optics: Introduction

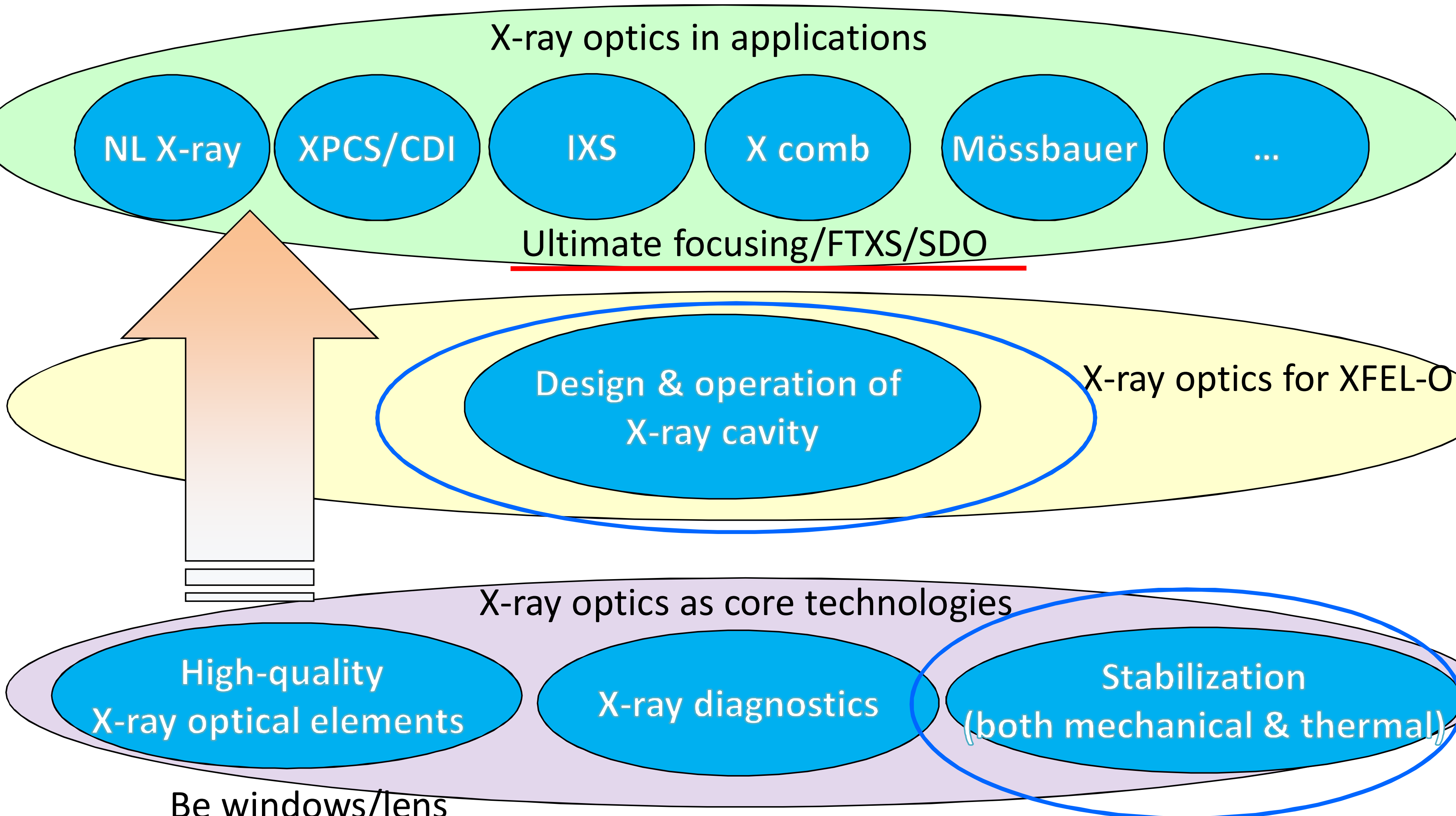
Makina Yabashi & Yuri Shvyd'ko

June 30, 2016 @SLAC

Remarks

- **Ideal** light sources allows us to innovate x-ray optics & beamline devices in much **simpler** schemes; Chance to bring **new ideas**
- Synergy and distinction in XFEL-O, SASE-XFEL, and DLSR

Map on "X-ray optics"



Be windows/lens

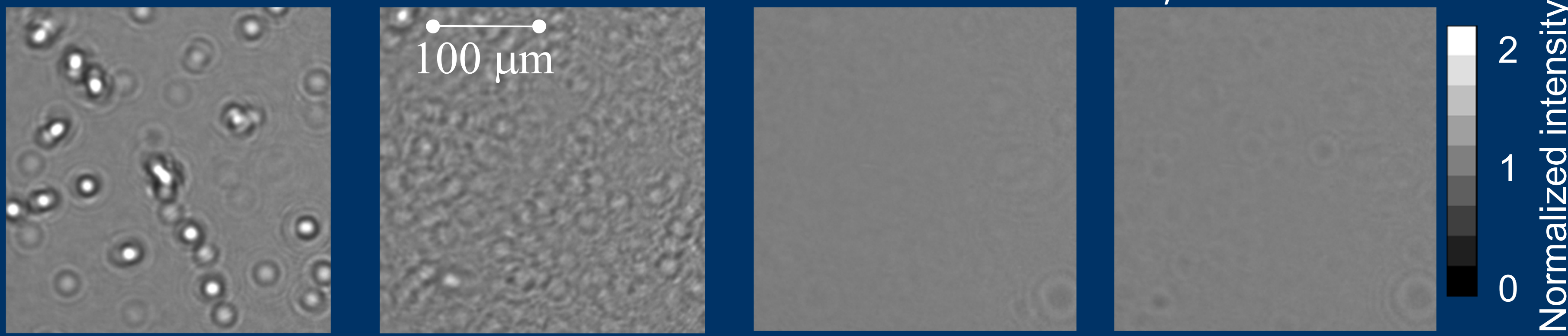
Mirrors

Diamond crystals

Speckle-free Be foils & mirrors

Be window

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

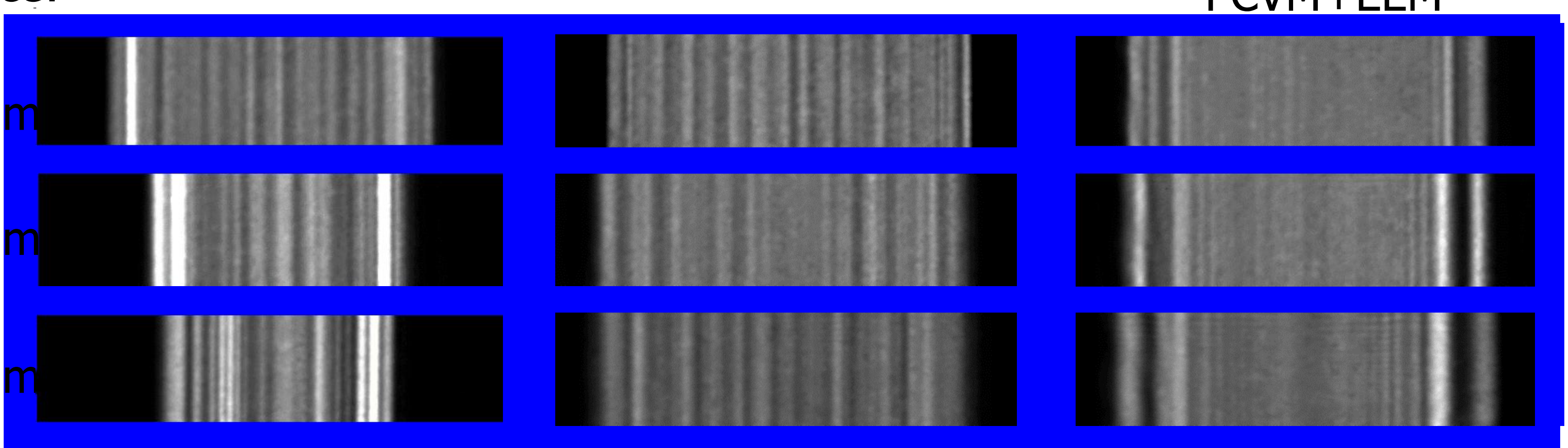
t ~ 50 um: thicker foils under development

Mirror

Mori et al. Proc. SPIE 2001, 30

Distance: Pre-machined PCVM PCVM+EEM

166 mm
566 mm
966 mm

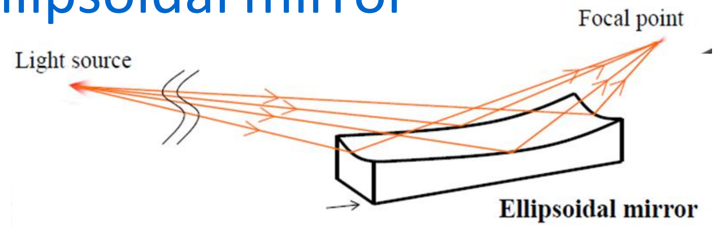


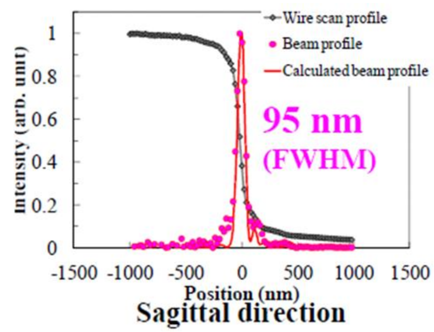
Recent activities on mirror developments

Focusing/collimating

Adaptive KB optics

Ellipsoidal mirror



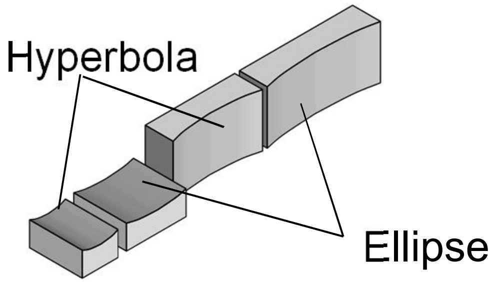


Yumoto-san (SPring-8)

Imaging

Advanced KB

R. Kodama et al., *Optics Letters* (1996).



- Achromatic
- Wide FOV (Abbe sine condition)
- Sub-100 nm res

Matsuyama et al., OE 9746 (2015); in preparation (2016) Osaka U

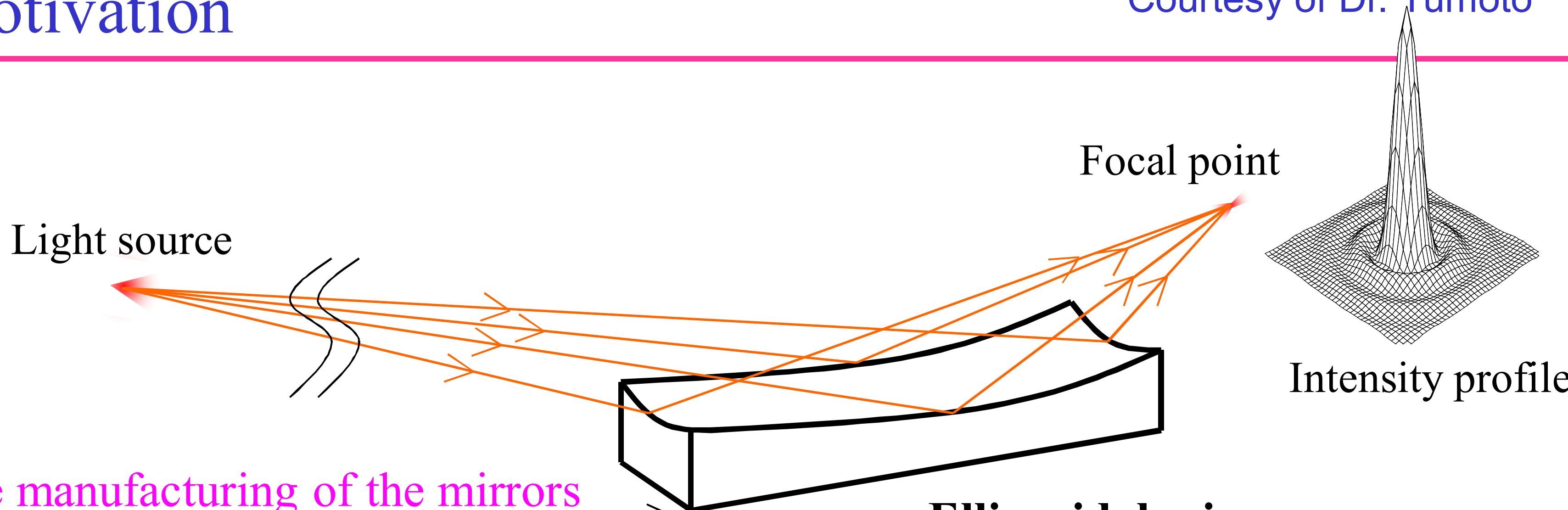
Wolter mirror

Electroforming technique

Mimura et al., JPB **48** 244002 (2015) U Tokyo

Motivation

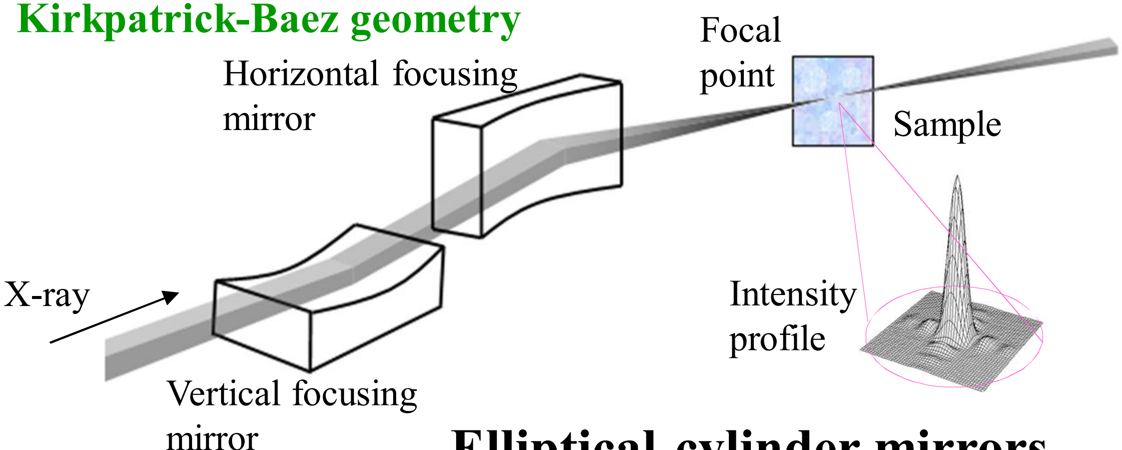
Courtesy of Dr. Yumoto



Ellipsoidal mirror

The manufacturing of the mirrors is challenging.

Kirkpatrick-Baez geometry



Elliptical-cylinder mirrors

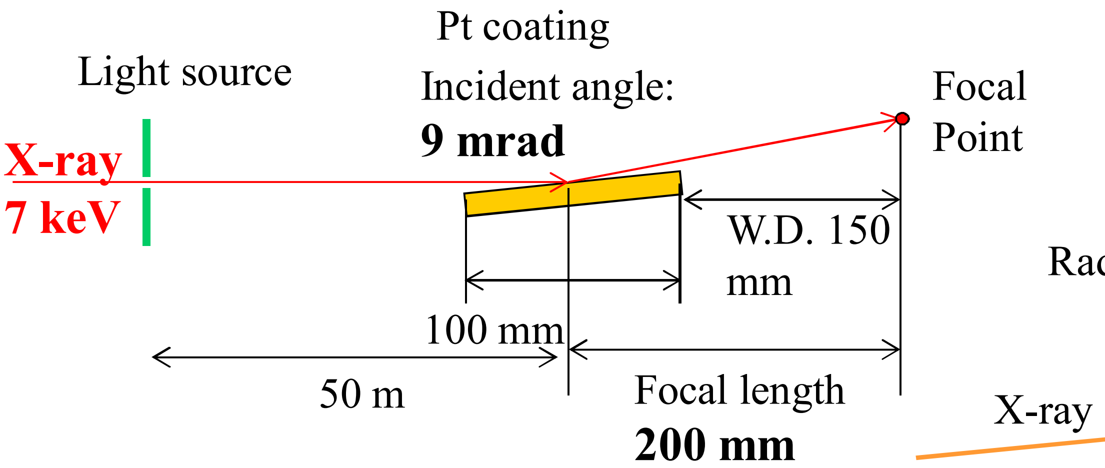
Advantage

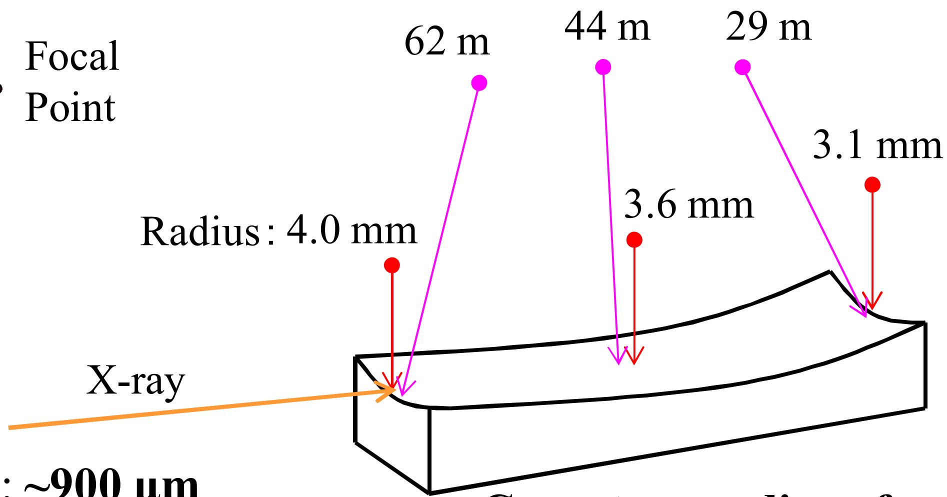
- **High focusing efficiency**
- **Simple mirror manipulator**
- **Position stability improvement of focusing beam**

Focusing device & collimator for many applications

Optical design of ellipsoidal mirror –*Target*–

Courtesy of Dr. Yumoto

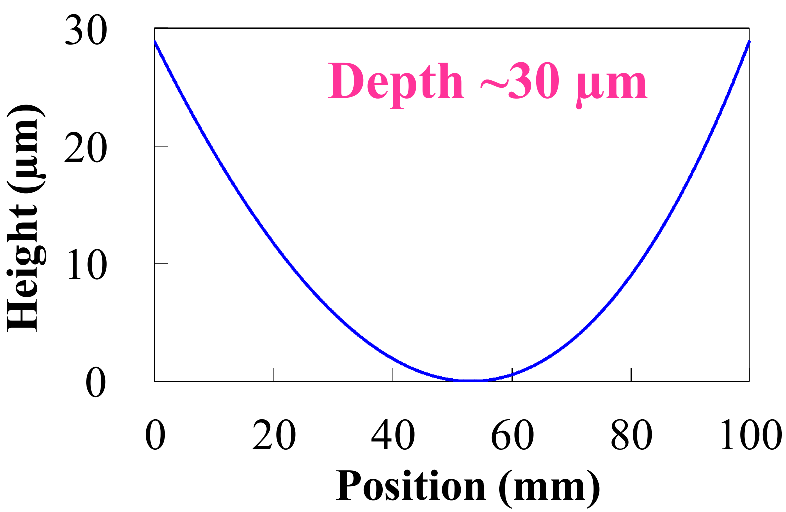




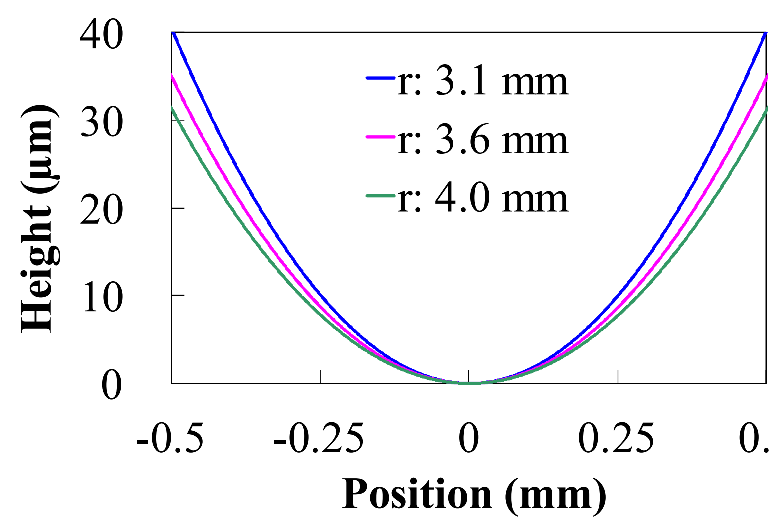
Curvature radius of ellipsoidal mirror

Spatial acceptance in the longitudinal direction: **~900 µm**

Diffraction-limited focusing beam size: **~35 nm**



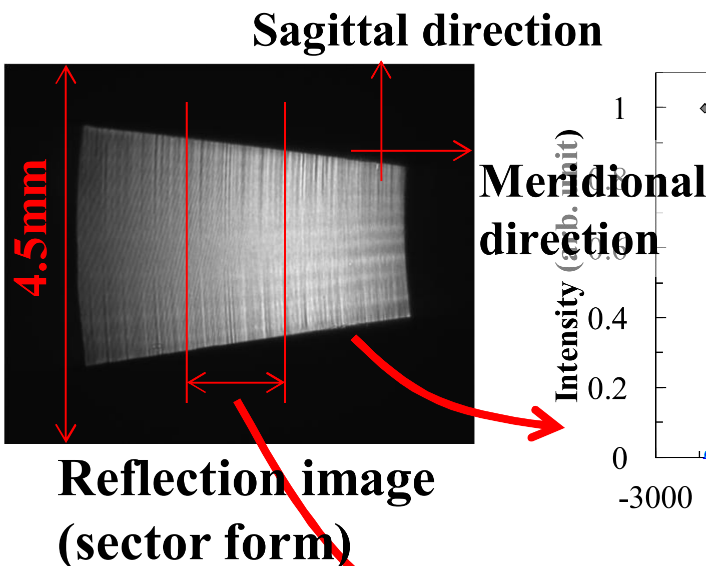
Long axis direction



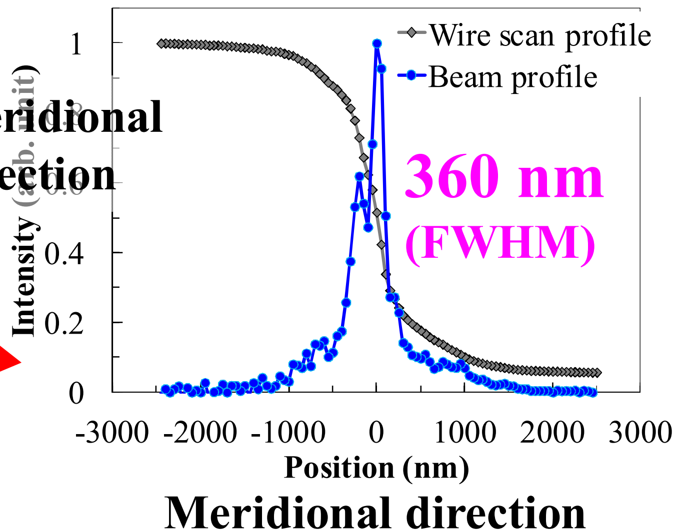
Short axis direction

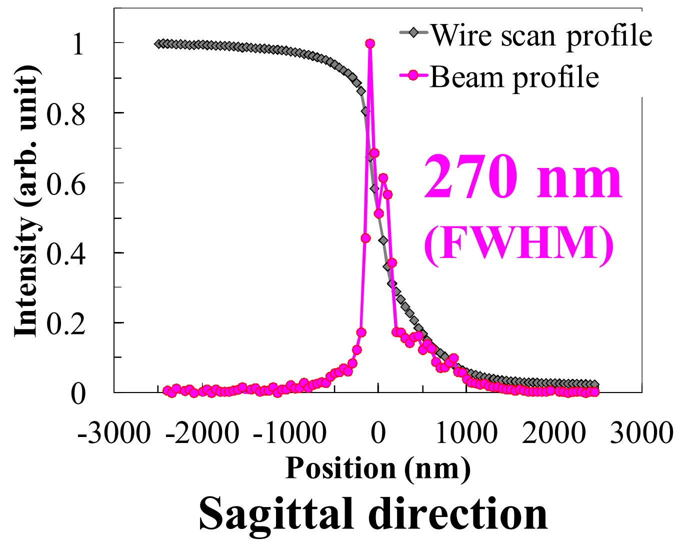
Surface profiles

Measured focusing beam profiles at 7 keV



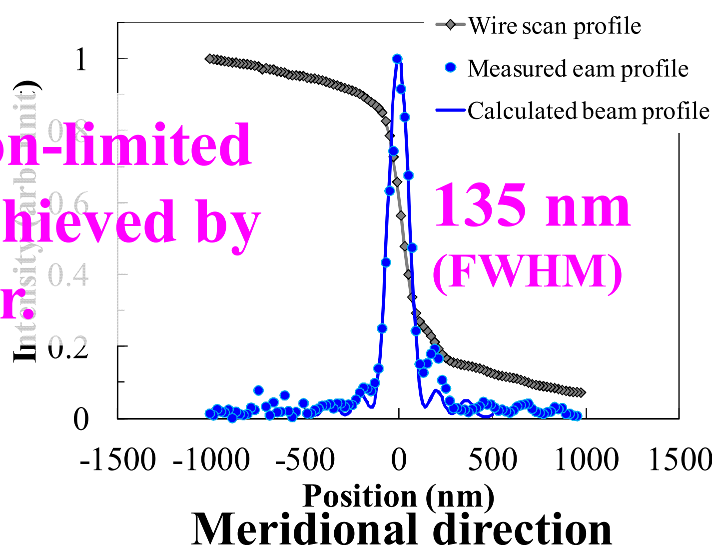
Full aperture: $0.45 \times 93\ mm^2$

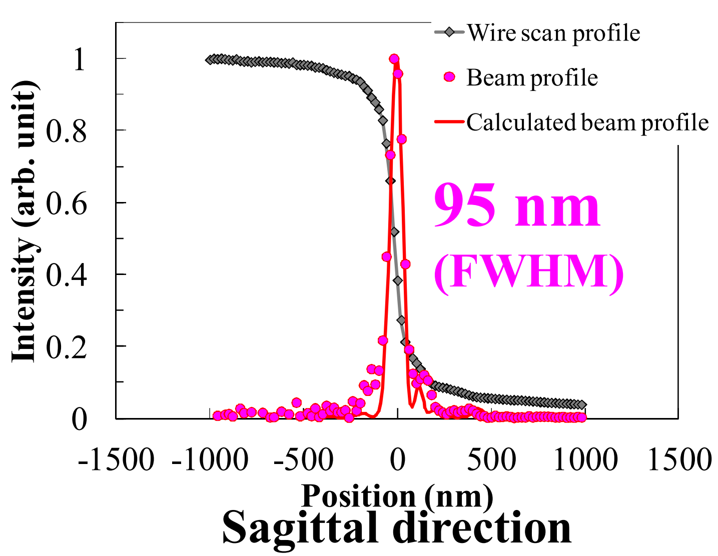




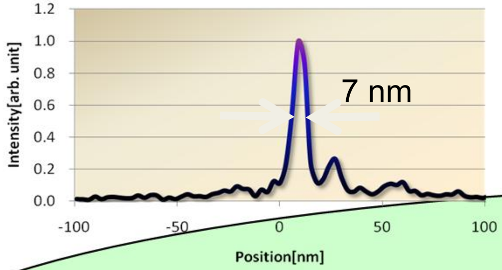
Sub-aperture: $0.45 \times 27\ mm^2$

Nearly diffraction-limited focus size was achieved by ellipsoidal mirror.

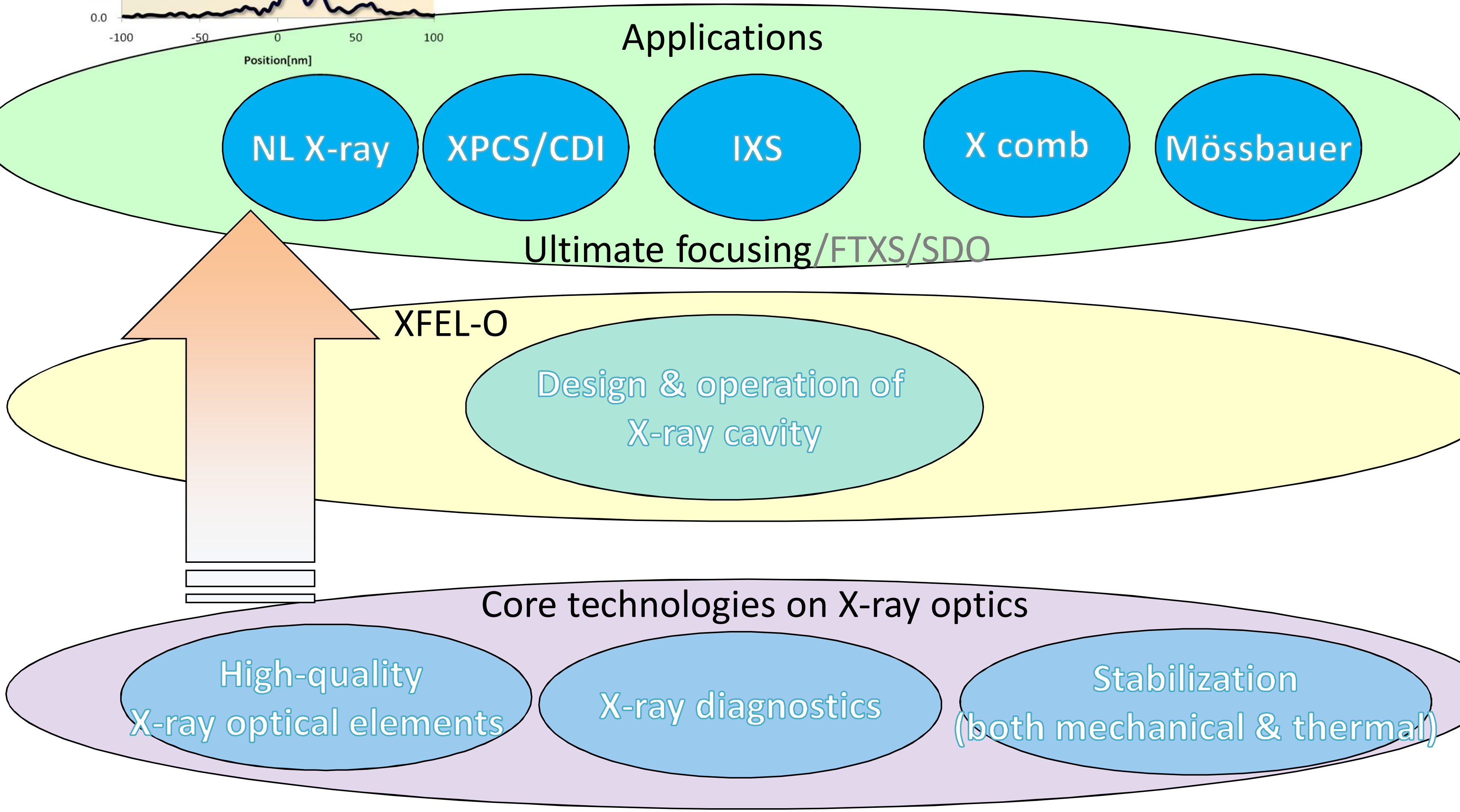




“X-ray Optics”



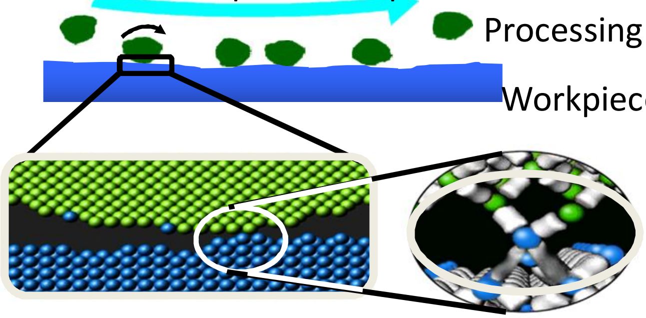
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Intensity[arb. unit]
7 nm
-100
-50
0
50
100
Position[nm]



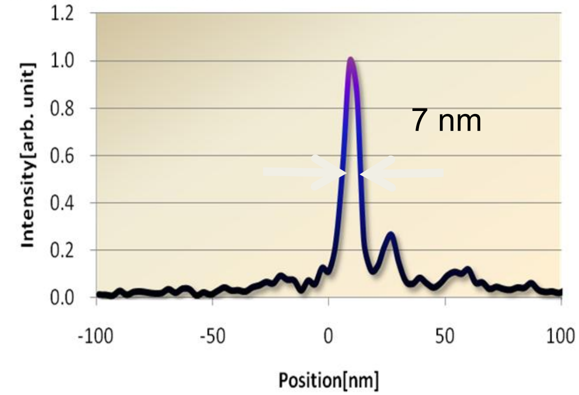
Applications
NL X-ray
XPCS/CDI
IXS
X comb
Mössbauer
Ultimate focusing/FTXS/SDO
XFEL-O
Design & operation of X-ray cavity
Core technologies on X-ray optics
High-quality X-ray optical elements
X-ray diagnostics
Stabilization (both mechanical & thermal)

Ultimate focusing with mirrors

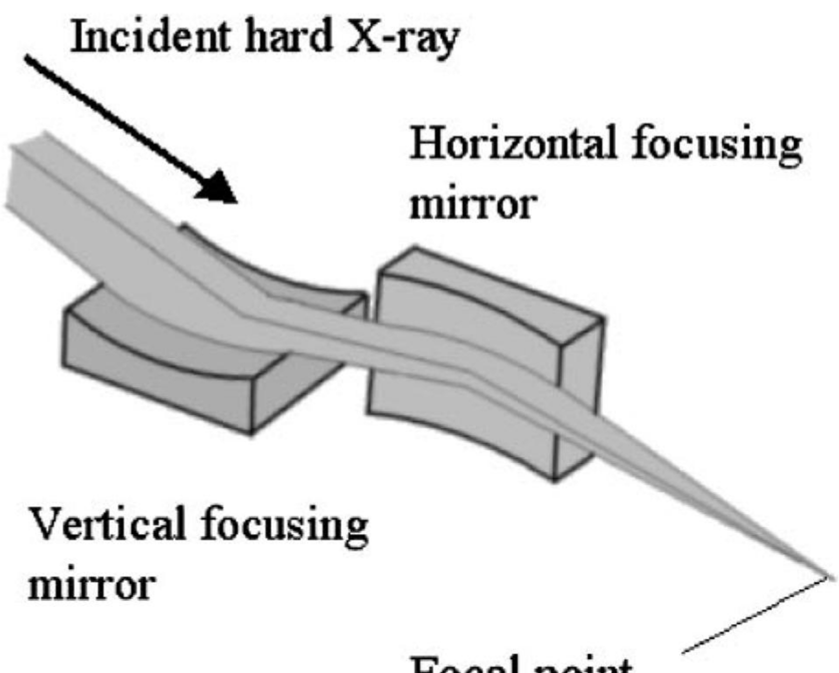
大阪大学
OSAKA UNIVERSITY

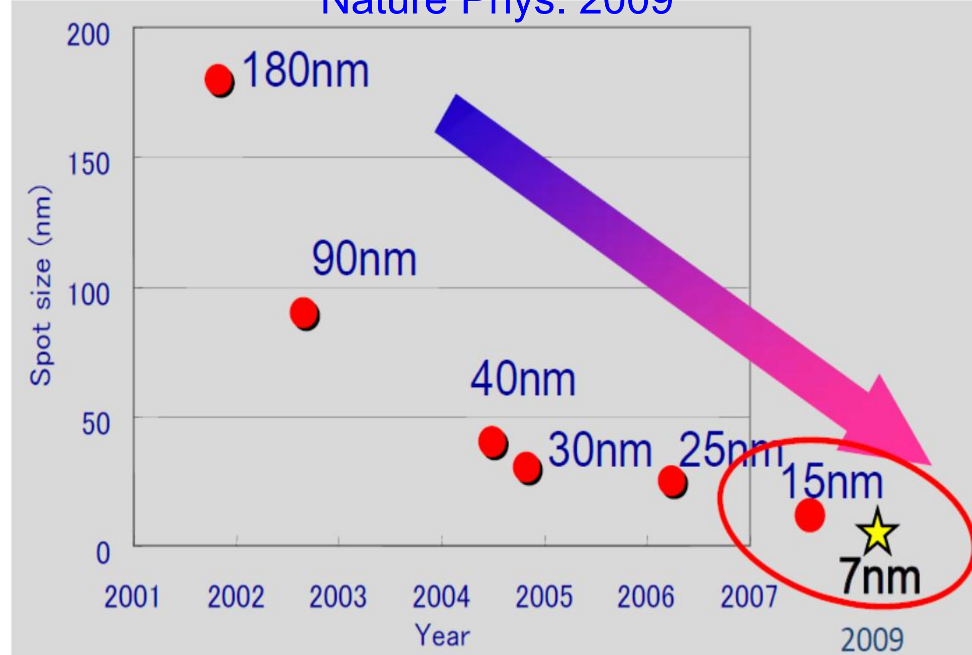


Schematic view of EEM

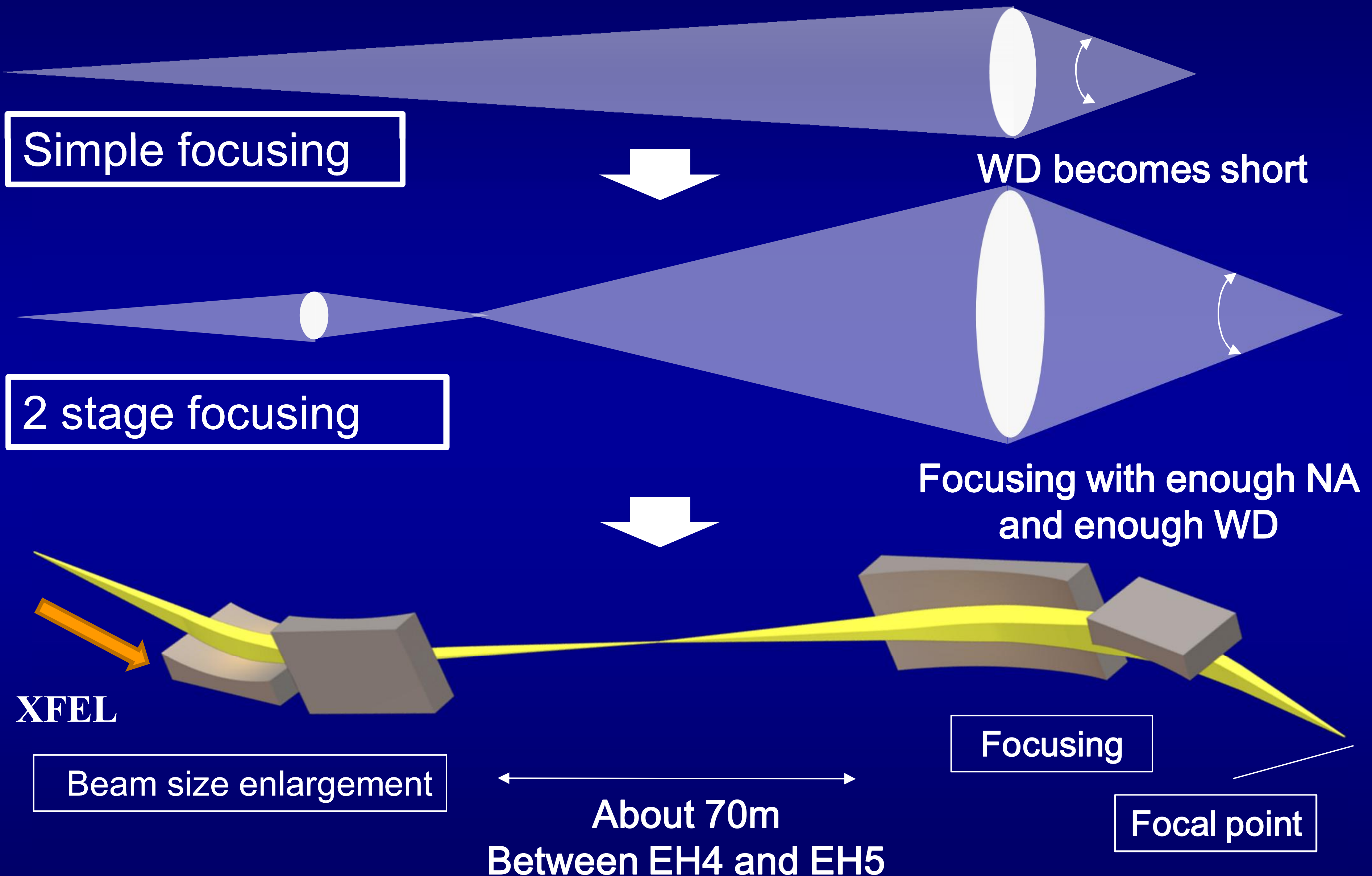


K. Mimura et al.
Nature Phys. 2009



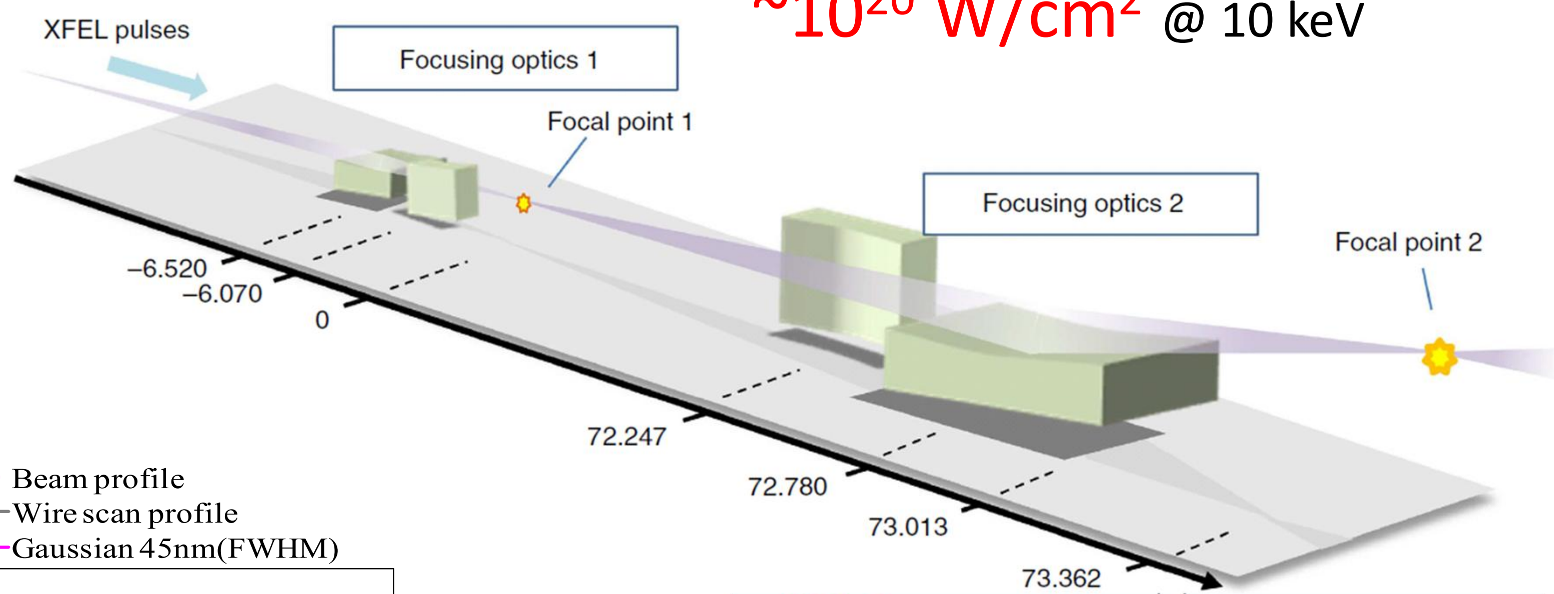


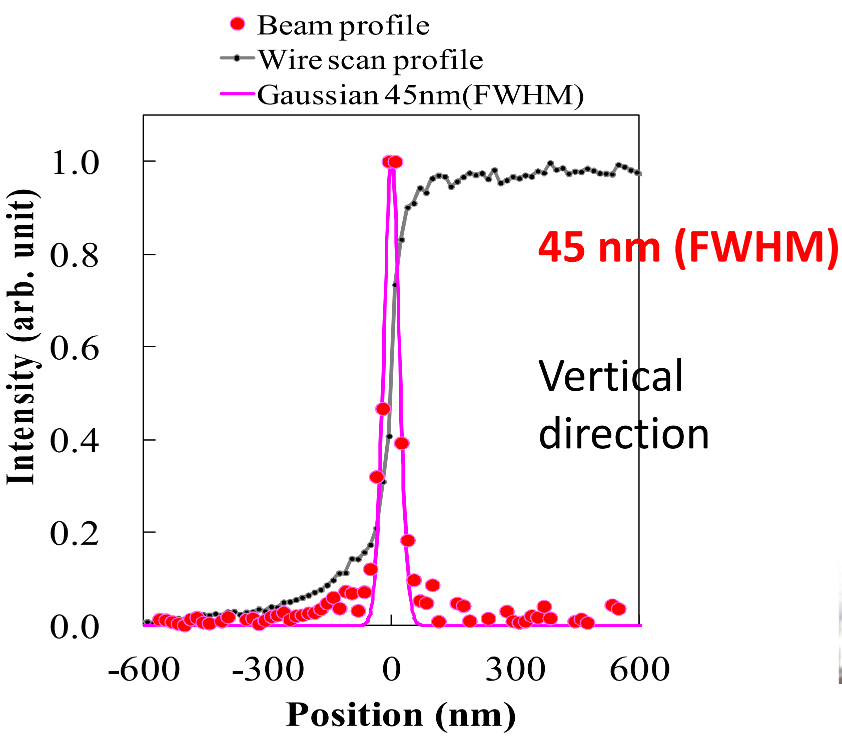
Low divergent beam → limitation of NA



Two-stage focusing system

~10^{20} W/cm^2 @ 10 keV






nature COMMUNICATIONS

ARTICLE

Received 17 Sep 2013 | Accepted 4 Mar 2014 | Published 30 Apr 2014
DOI: 10.1038/ncomms4539

Generation of 10^{20} W cm^{-2} hard X-ray laser pulses with two-stage reflective focusing system

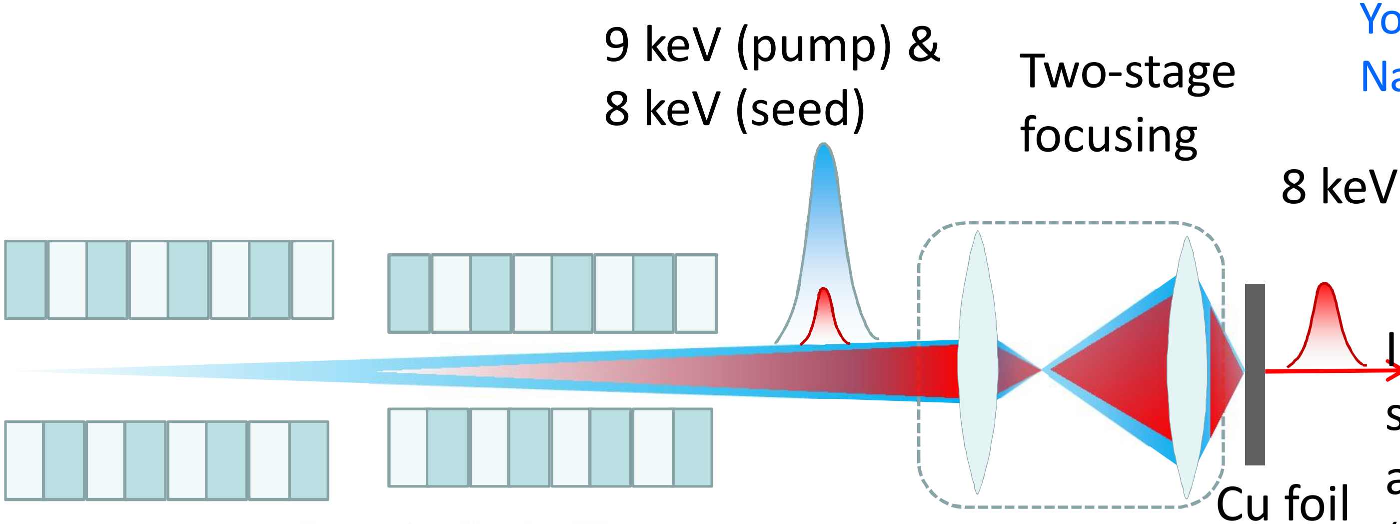
Hidekazu Mimura[1,*], Hirokatsu Yumoto[2,*], Satoshi Matsuyama[3,*], Takahisa Koyama[2], Kensuke Tono[2], Yuichi Inubushi[4], Tadashi Togashi[2], Takahiro Sato[4], Jangwoo Kim[3], Ryosuke Fukui[3], Yasuhisa Sano[3], Makina Yabashi[4], Haruhiko Ohashi[2,4], Tetsuya Ishikawa[4] & Kazuto Yamauchi[3]

Mimura et al, Nature Commun 5 3539 **(2014)**

Mimura-san Yamauchi-sensei Ohashi-san Yumoto-san

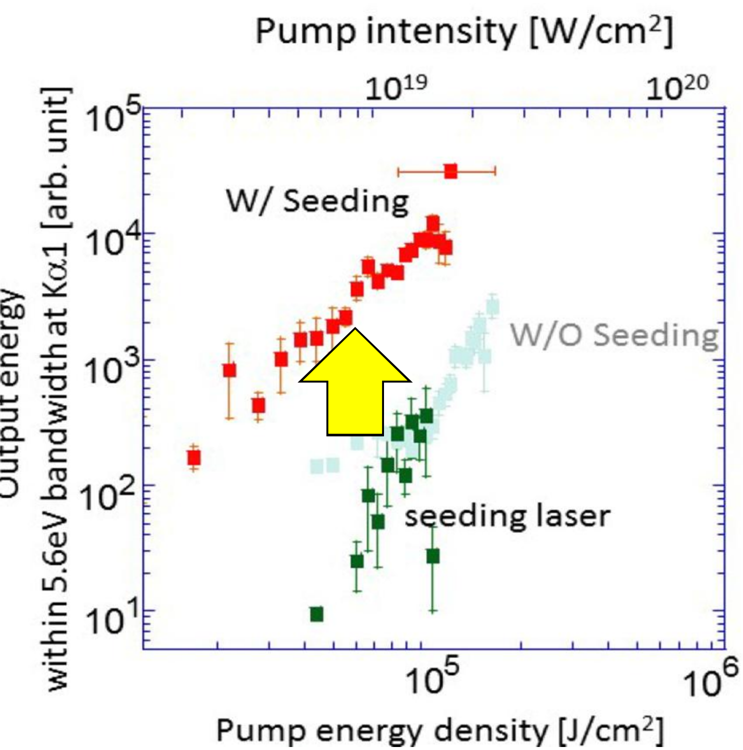
Cu Kα atomic laser

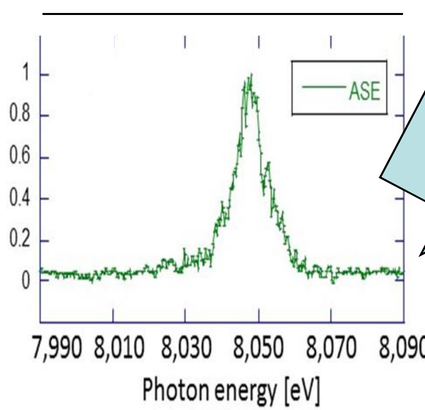
Yoneda *et al.*,
Nature **524**, 446 (2015)

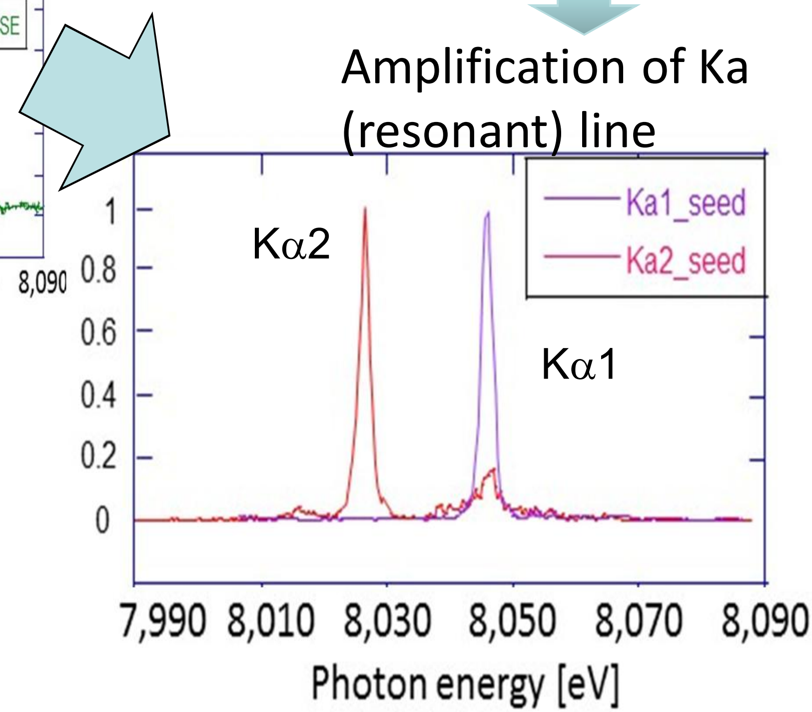


Intense pump x-rays strip K-shell electrons and generate "population inversion"

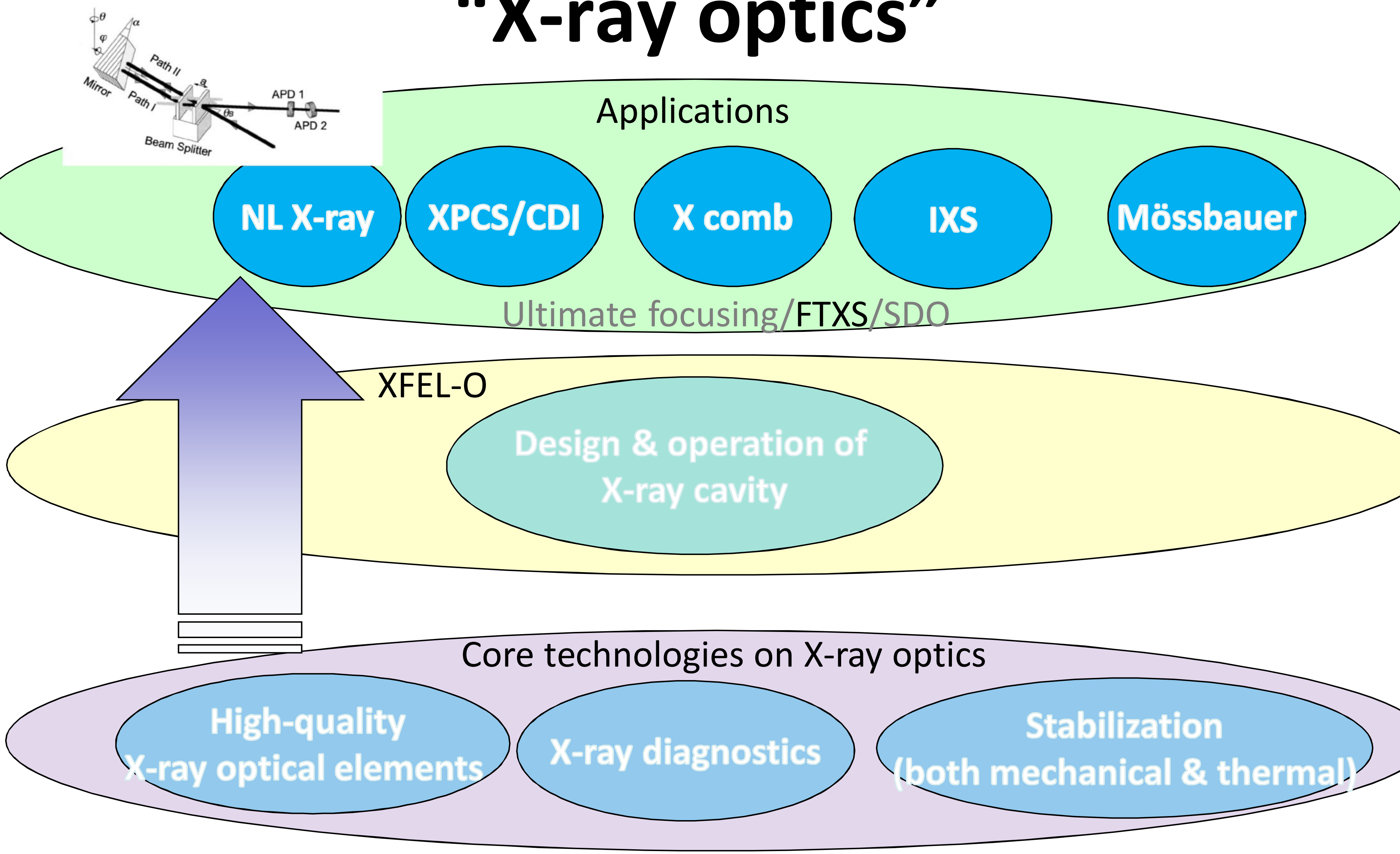
Amplification of Ka (resonant) line







“X-ray optics”


θ
φ
α
Path II
Mirror
Path I
θB
APD 1
APD 2
Beam Splitter
Applications
NL X-ray
XPCS/CDI
X comb
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Ultimate focusing/FTXS/SDO
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Design & operation of
X-ray cavity
Core technologies on X-ray optics
High-quality
X-ray optical elements
X-ray diagnostics
Stabilization
(both mechanical & thermal)

FTXS

Tamasaku et al, APL 83 (2003) 2994

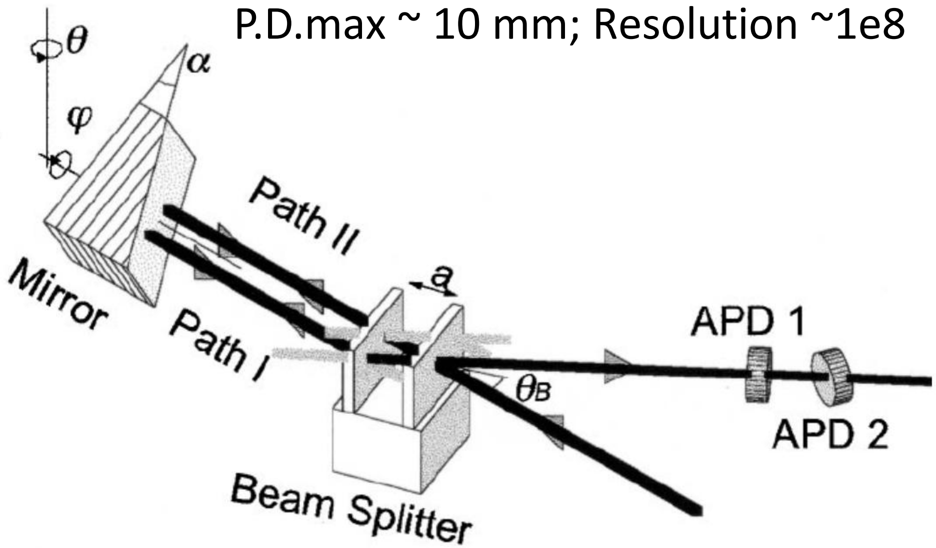
APPLIED PHYSICS LETTERS VOLUME 83, NUMBER 15

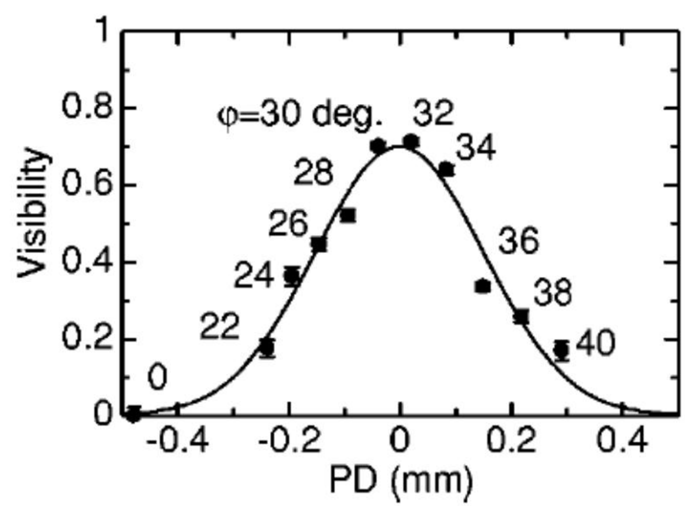
High-resolution Fourier transform x-ray spectroscopy

Kenji Tamasaku[a)] and Tetsuya Ishikawa
SPring-8/RIKEN, Mikazuki, Hyogo 679-5148, Japan

Makina Yabashi
SPring-8/JASRI, Mikazuki, Hyogo 679-5198, Japan

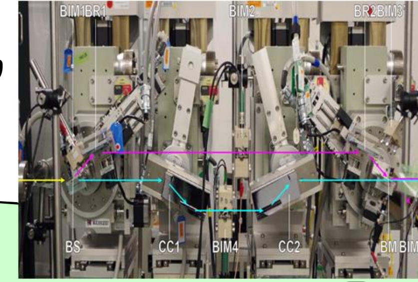
Si 14 6 0 @ 17.36 keV
P.D.max ~ 10 mm; Resolution ~1e8





Ultrafast pulse duration facilitates measurement of interferogram

“X-ray Optics”



Applications

- NL X-ray
- XPCS/CDI
- X comb
- IXS
- Mössbauer

Ultimate focusing/FTX/SDO

XFEL-O

Design & operation of X-ray cavity

Core technologies on X-ray optics

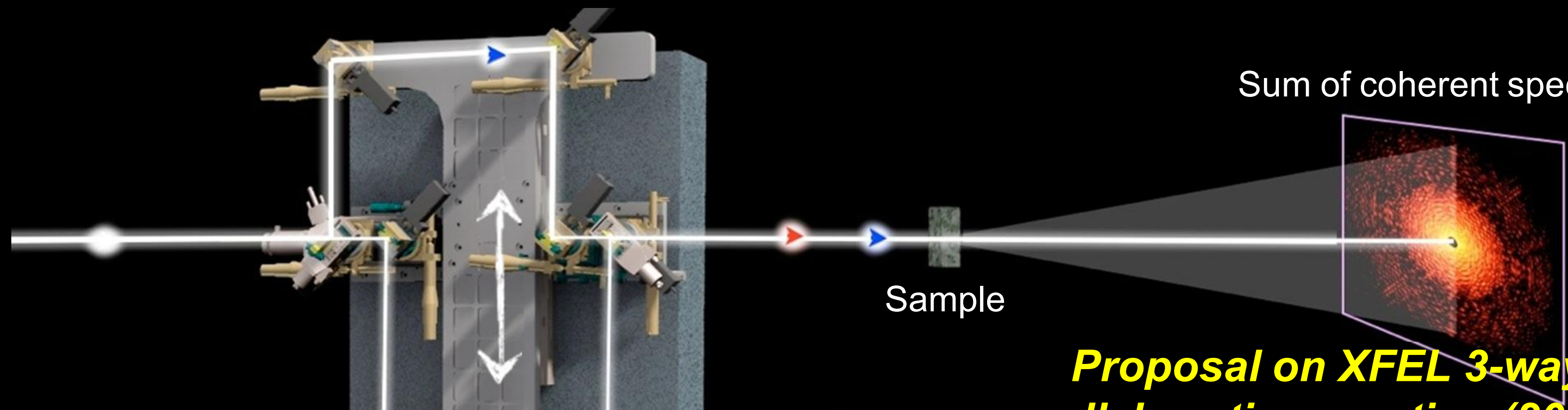
- High-quality X-ray optical elements
- X-ray diagnostics
- Stabilization (both mechanical & thermal)

First split-and-delay optics for HX

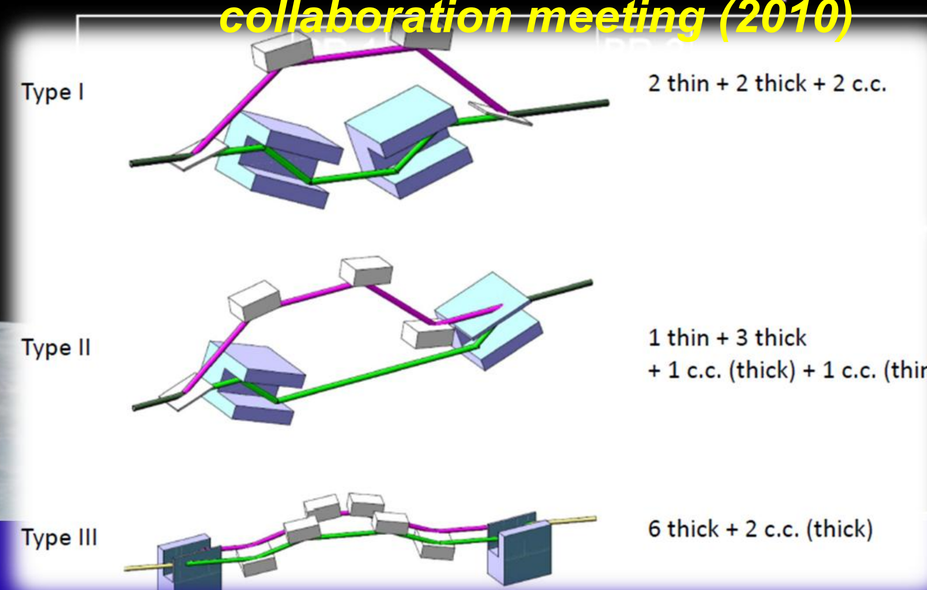
Courtesy of Gerhard Grübel

W. Roseker *et al.*, Opt. Lett., **34** (2009).
W. Roseker *et al.*, J. Synchrotron Rad., **18** (2011).
W. Roseker *et al.*, Proc. SPIE, **8504** (2012).

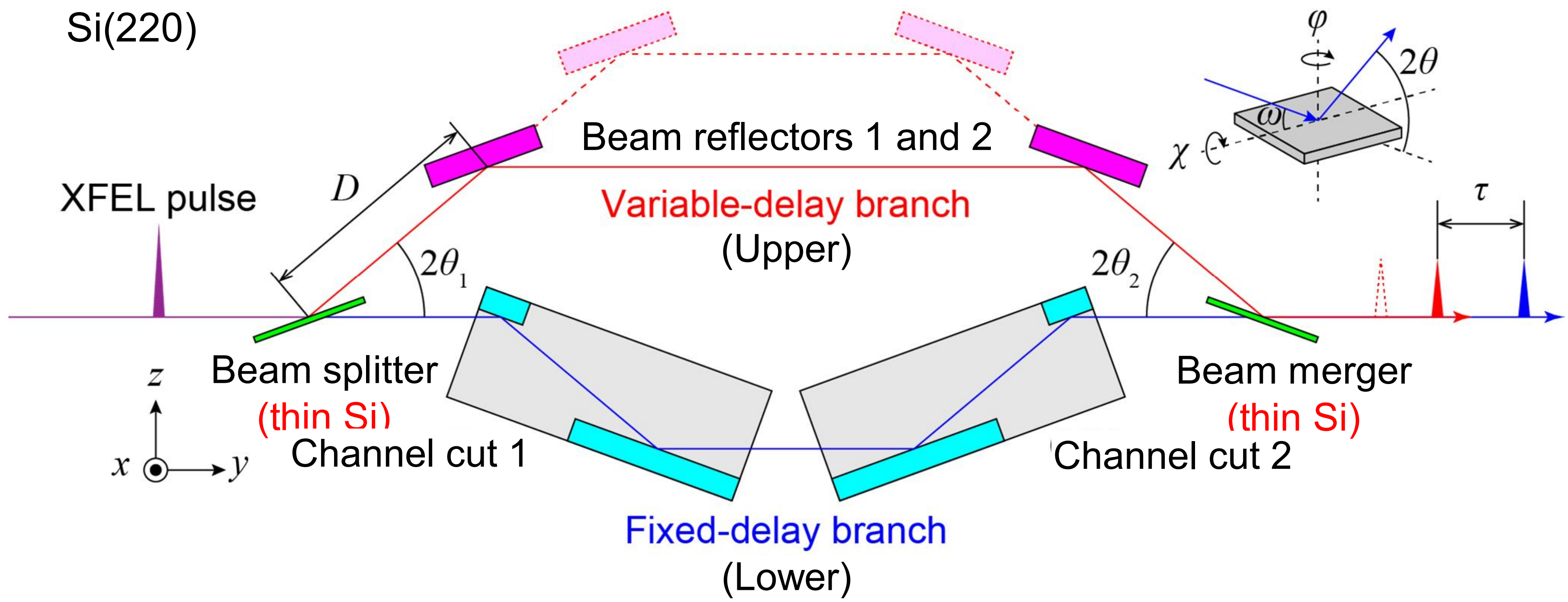
Based on Bragg diffraction and
90° scattering with Si(511) or (422)



Proposal on XFEL 3-way collaboration meeting (2010)



SDO configuration



Osaka-san
(Osaka U → SACLA)

Crystal diffraction:
Large time delays (>ps)
High energy resolutions ($\Delta E/E$ < $1\text{x}10^{-4}$)

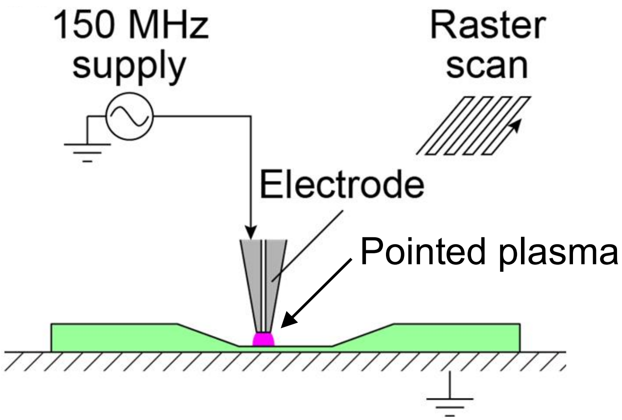
Two independent delay branches:
Enables access to time zero

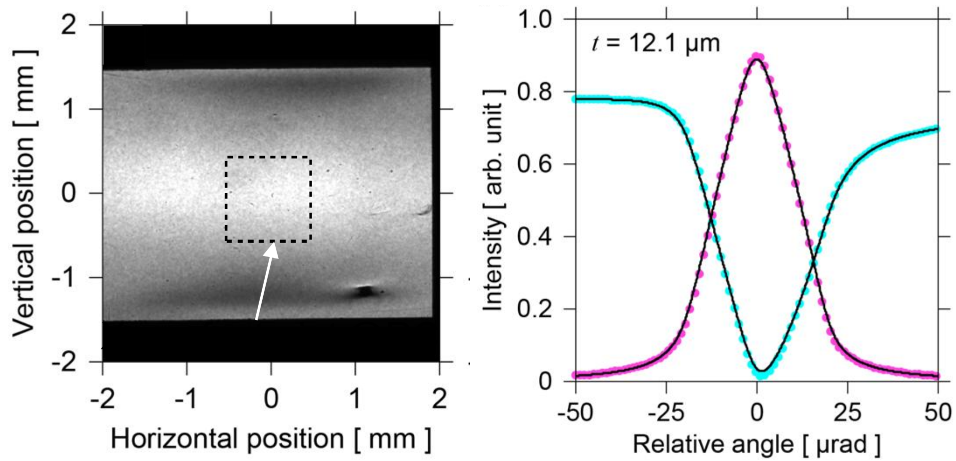
Use of channel cuts:
Much stabilized operation

Key optical devices

Thin crystal beam splitter/merger:

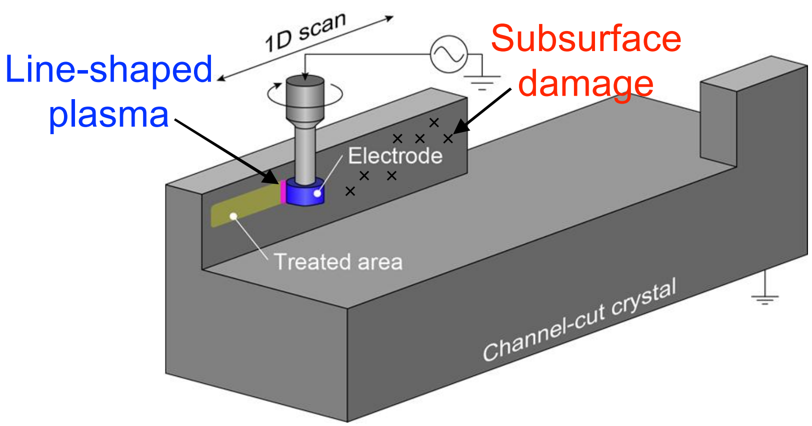
T. Osaka et al., OE **21**, 2823 (2013).

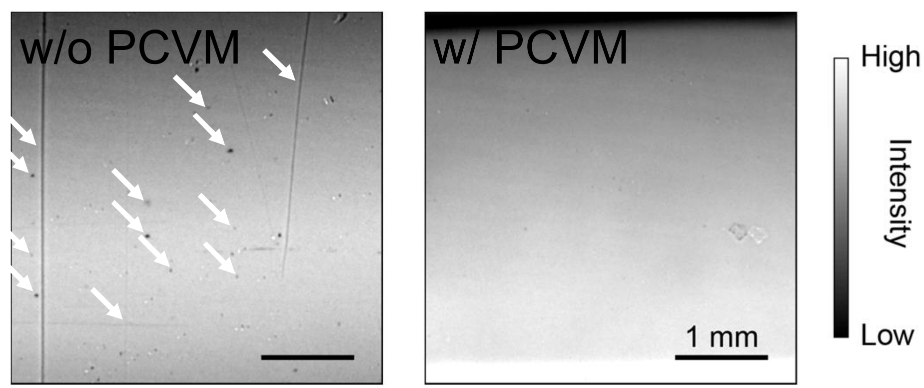




Channel cut crystals:

T. Hirano, T. Osaka et al., in reviewed.

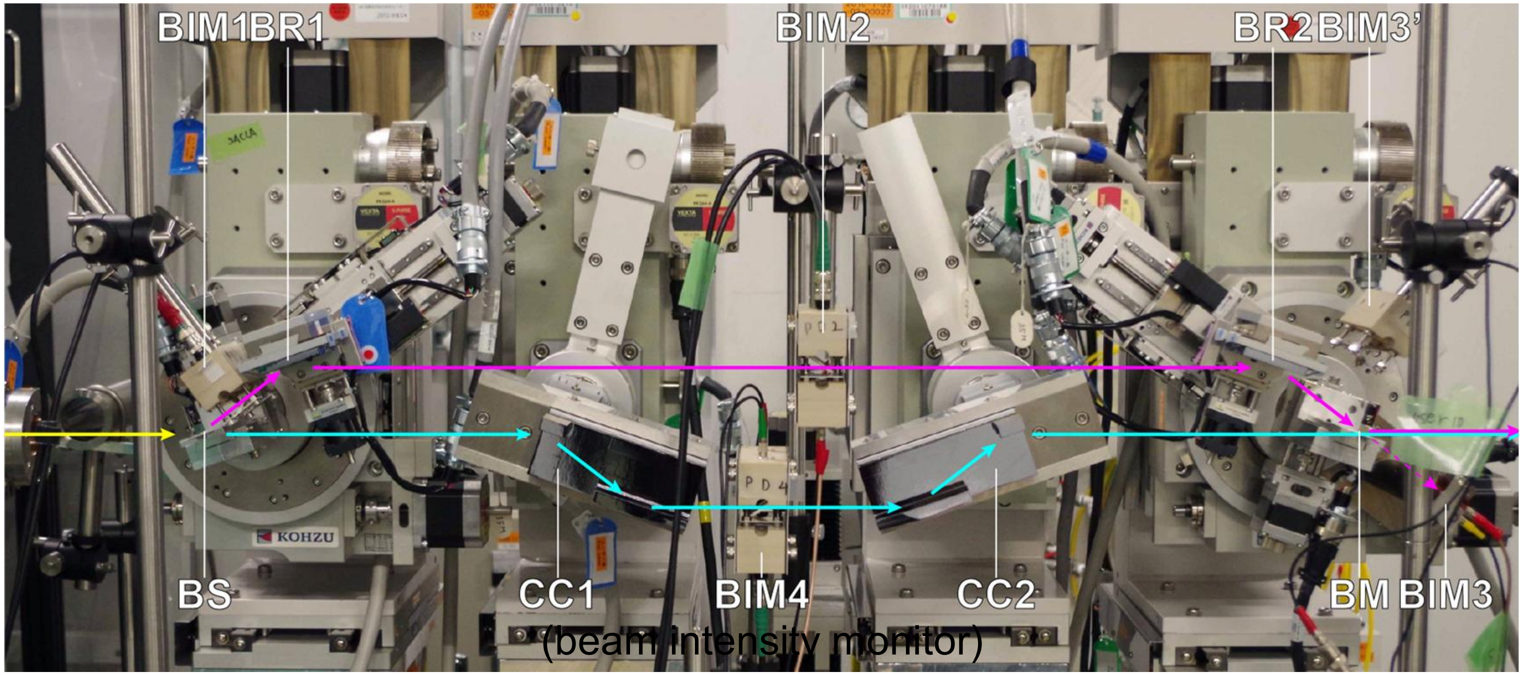




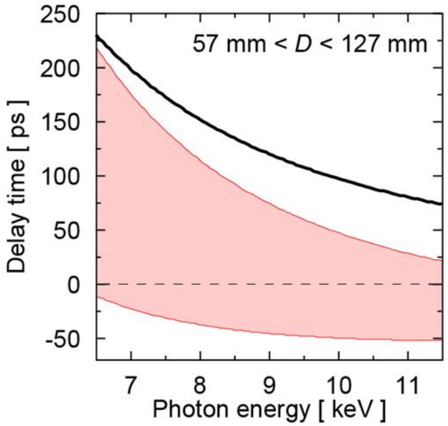
Both crystal devices were fabricated using a plasma etching technique.

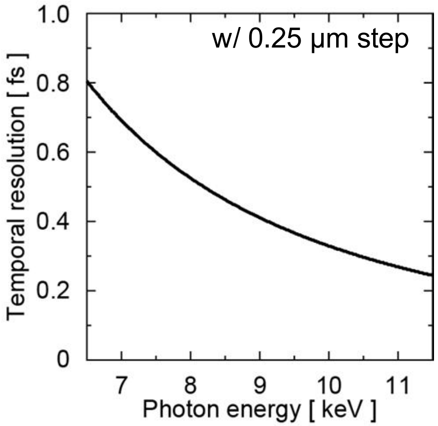
PCVM: non-physical contact, damage-free, controllable plasma size

Prototype SDO



Built with all commercial components for motion control.
Each intensity diagnostic module consists of thin Kapton film scatter and photodiode.





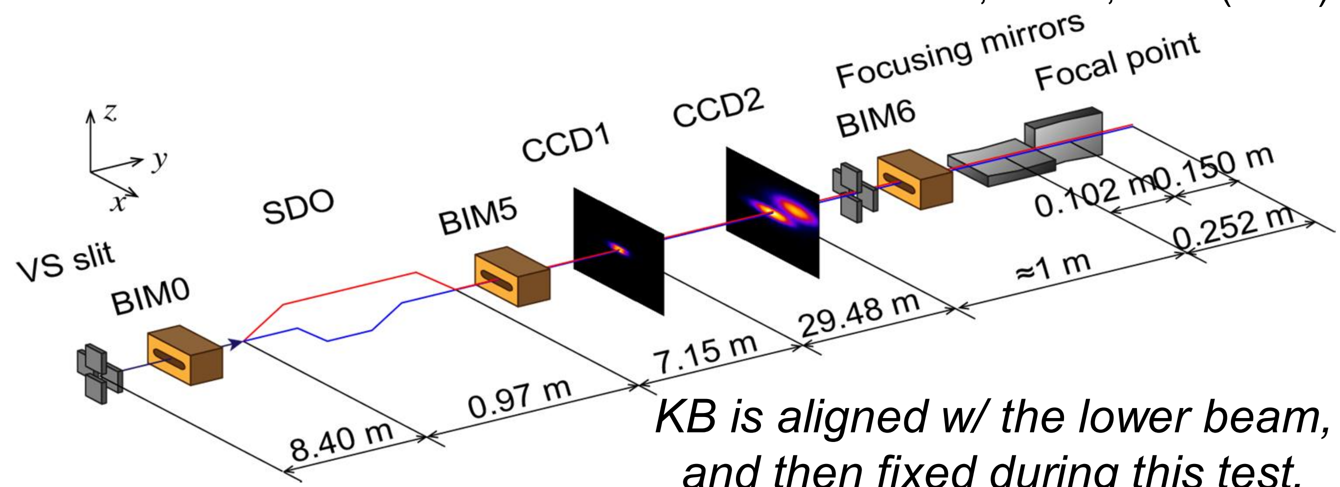
Photon energy range
6.5 keV ~ 11.5 keV

Delay time range @10 keV
−50 ~ +47 ps w/ <1 fs step
(up to 220 ps @6.5 keV)

Performance test @SPring-8

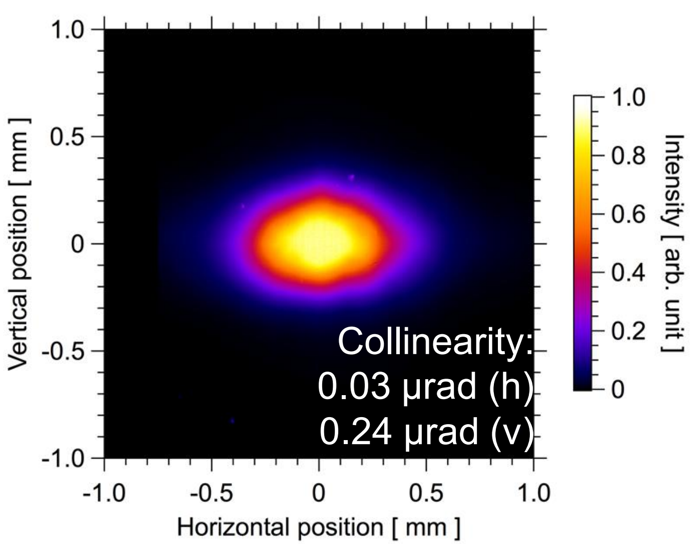
T. Osaka et al., OE **24**, 9187 (2016)

<u>BL29XUL</u>
w/ Si(111) DCM
E = 10 keV (±0.35 eV)
τ ~ +45 ps
VS slit: 10 × 10 μm^2

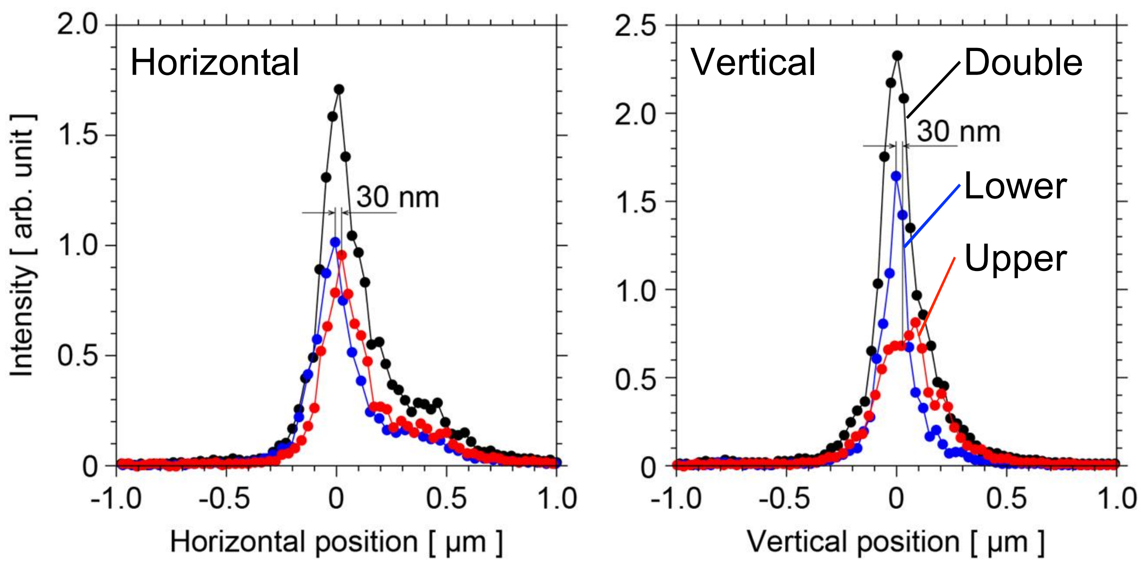


KB is aligned w/ the lower beam, and then fixed during this test.

Double beam profile @CCD2



Focal profiles



Sub-urad alignment accuracy achieved

End