中国科学院 上海高等研究院
SHANGHAI ADVANCED RESEARCH INSTITUTE CHINESE ACADEMY OF SCIENCES

SSRF 上海同步辐射光源
Shanghai Synchrotron Radiation facility

Study on Synchrotron Radiation X-ray 2D Energy Spectrum Imaging

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Optical group, Shanghai Synchrotron Radiation Facility

2023. Nov. 07

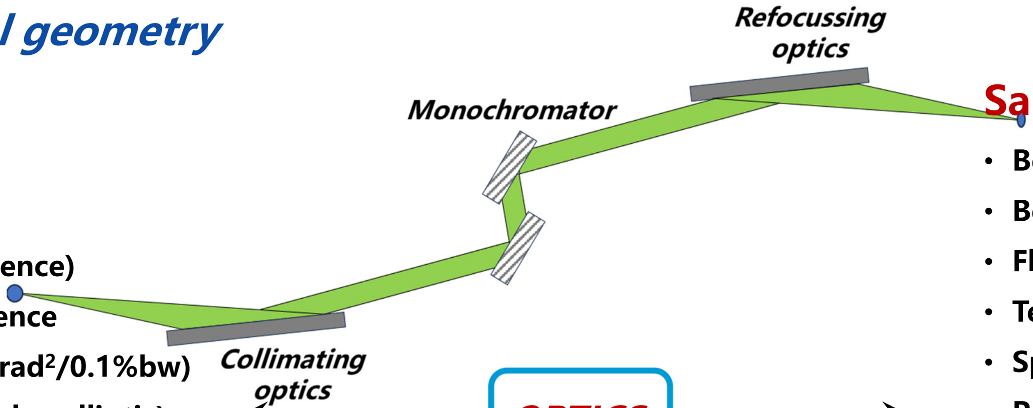
Beijing China

Outline

- ◆Beamline properties
- ◆2D imaging of the crystal diffraction
  - I. DuMond diagrams of crystal Bragg-case
  - II. Measurement of the Wave in Vertical direction
  - III. Application of 2D energy spectrum imaging
- ◆Summary

一、Beamline properties

□ *Typical optical geometry*



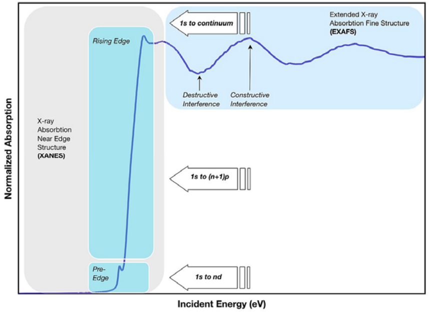
Source

- Spectrum (ΔE/E)
- Emittance (size x divergence)
- Degree of spatial coherence
- Brilliance (ph/s/mm²/mrad²/0.1%bw)
- Polarisation (linear, circular, elliptic)

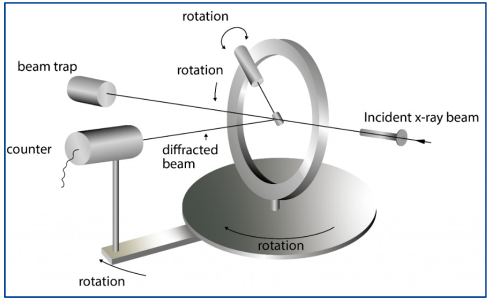
OPTICS

Sample

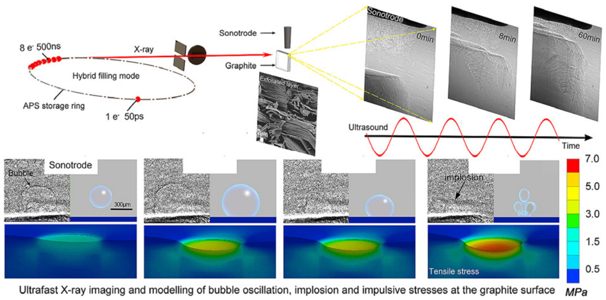
- Beam size (μm)
- Beam divergence (μrad)
- Flux (ph/s)
- Temporal coherence (ΔE/E)
- Spatial coherence
- Polarisation



XAFS（Energy resolution，Stability, High-order harmonics)



XRD（Energy resolution，Flux)



X-ray Imaging（Flux, Stability)

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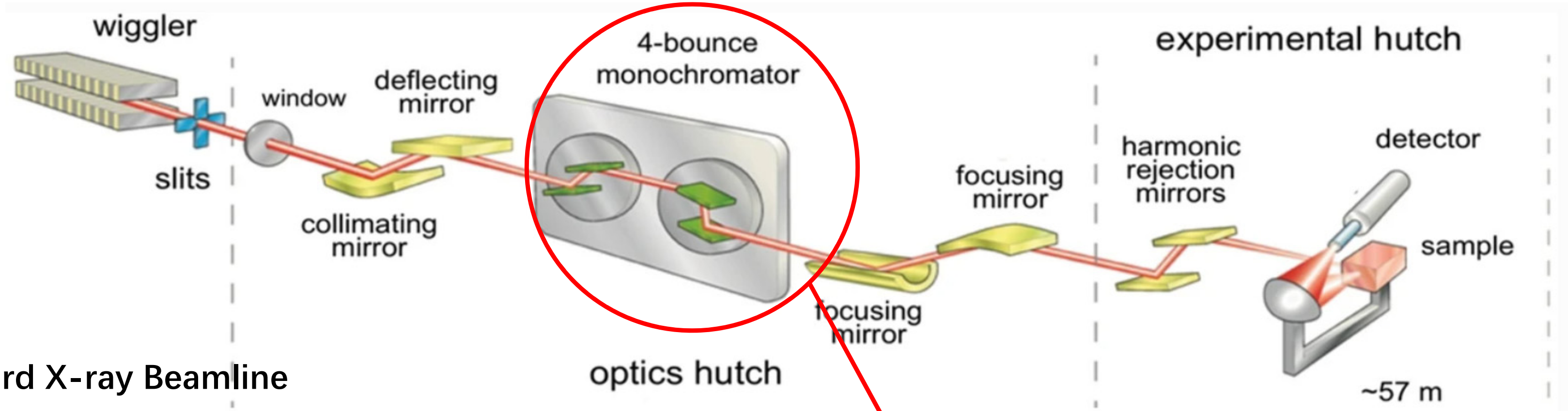
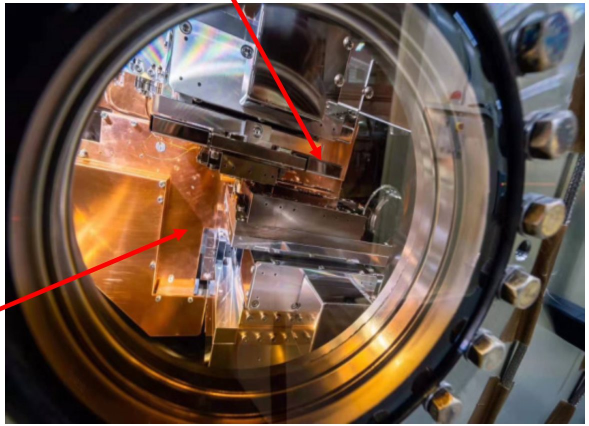
一、Beamline properties



Hard X-ray Beamline

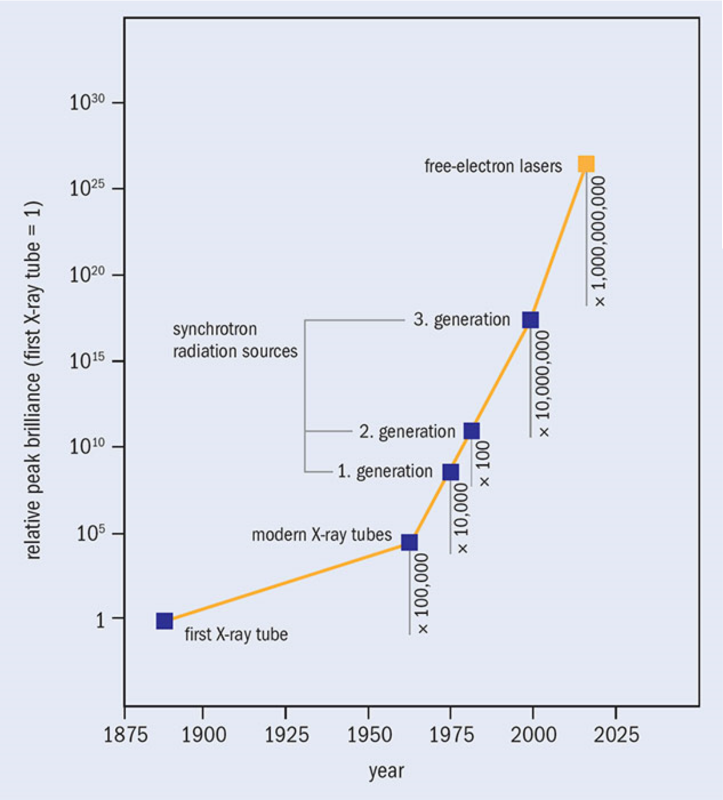
No.	Optical Element	Function
1	Slits	Size Difine
2	Be window	Vacuum isolation
3	Mirror	Collimate、focus、Harmonic rejection
4	Crystal	Dispersion beam
5	Multilayer	Dispersion beam
6	CRL、Zone Plate	Collimate、focus



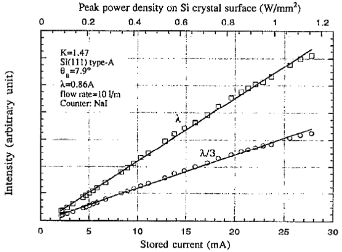
- Bragg Axis control
- Crystal parallelism
- Vibration
- Crystal deformation
- crystals detune
- **Cooling**
- Control
- …

Stephen P. Cramer, X-Ray Spectroscopy with Synchrotron Radiation, Chapter4;

一、Beamline properties



Historical evolution of the peak brilliance In various X-ray Source



TRISTAN BL-NE3@1994

Cooling method	X-ray energy (keV)	Total power (W)	Power flux (W/mm²)	Expected bending (µrad)	Rocking curve FWHM (µrad)
Conduction	12	28	1.1	22	32
Conduction	12	270	1.0	200	190
Microchannel	12	29	1.1	22	40
Microchannel	12	235	0.9	185	50
Pin-post	14.4	75	0.2	50	70
Pin-post	14.4	430	1.0	245	93

Stanford@1995

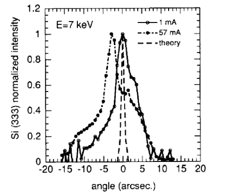


Fig. 2. Theoretical silicon 333 double-reflection and rocking curves measured at 1 and 57 mA ring current. The total power and power density were approximately 330 W and 1.7 W/mm², respectively, at 57 mA. The beam footprint on the crystal was 11 × 18 mm².

ESRF BL-3@1994

Beamline	ID06	ID06	ID06	ID18
Undulator	U18	U32	U18 + U32	3 × U20
Period (mm)	18	32		20
Length (m)	2.0	1.6		4.8
Gap (mm)	8.30	13.55		11
Deflection parameter K	0.878	1.636		0.63
Fund energy (keV)	13.848	4.616		14.413
$d_{src/primary\ slits}$ (m)	27.8	27.8	27.8	27
$H_{primary\ slit}$ (mm)	2.0	2.0	2.0	2.0
$V_{primary\ slit}$ (mm)	1.0	1.0	1.0	1.0
Window/filters	0.3 mm diamond + 1 mm Be			0.3 mm diamond
P_{total} (W)	352	188	540	438.3
Pa_{max} (W mm^{-2})	193.0	98.0	291	256

ESRF@2013

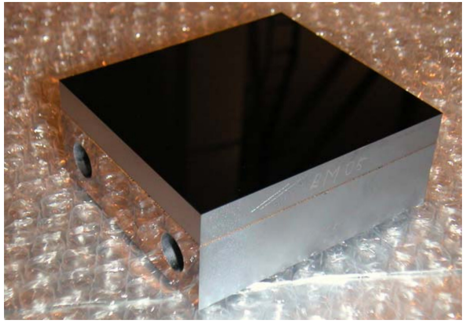
	SPECTRA	SRCALC	XOPPY
H polarization			
Power (W) in 460 mm × 10 mm	2070	2128	2101
Power (W) in 100 mm × 2.4 mm	239	247	225
Peak power density (W mm^{-2})	1.01	1.13	1.04
V polarization			
Power (W) in 460 mm × 10 mm	2070	2122	2126
Power (W) in 100 mm × 2.4 mm	216	249	227
Peak power density (W mm^{-2})	1.01	1.12	1.05

APS@2020

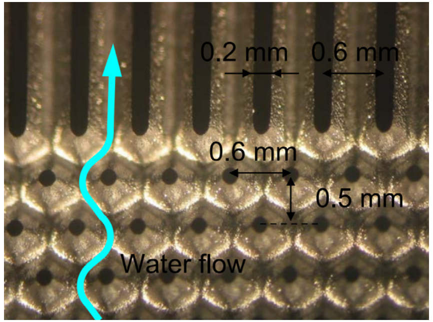
Parameter	Unit	SASE 1	SASE 2		SASE 3		
Electron energy	GeV	17.5	17.5	17.5	17.5	17.5	10.0**
Wavelength	nm	0.1	0.1	0.4	0.4	1.6	6.4
Photon energy	keV	12.4	12.4	3.1	3.1	0.8	0.2
Peak power	GW	20	20	80	80	130	135
Average power*	W	65	65	260	260	420	580
Photon beam size (FWHM)	µm	70	85	55	60	70	95
Photon beam divergence (FWHM)	µrad	1	0.84	3.4	3.4	11.4	27
Coherence time	fs	0.2	0.22	0.38	0.34	0.88	1.9

EuXFEL@2019

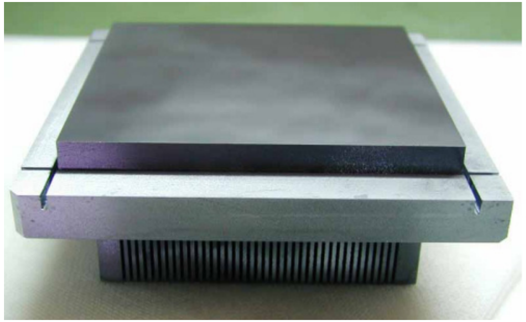
一、Beamline properties



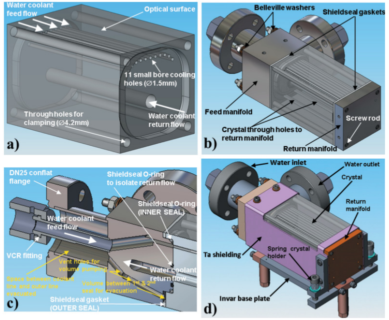
Spring-8 (2005)



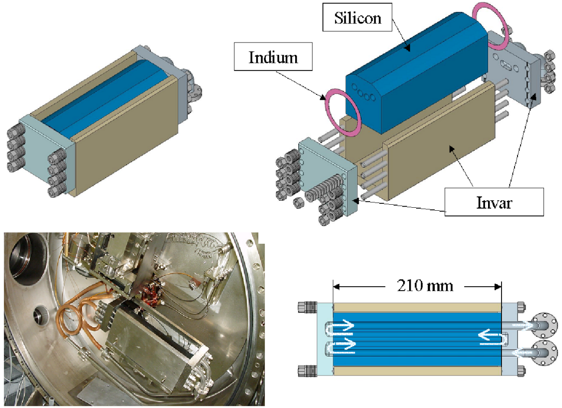
Spring-8 (2008)



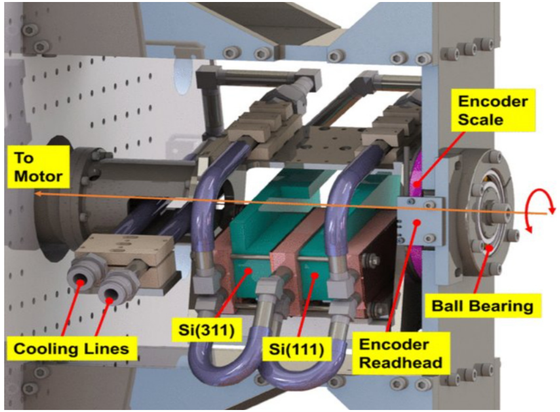
Spring-8 (2009)



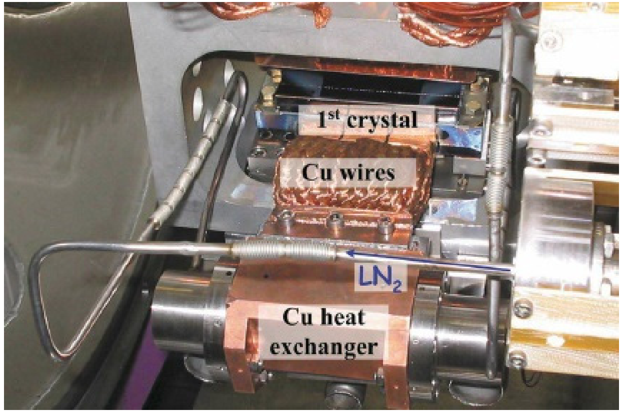
Diamond Light Source (2018)



ESRF (2006)



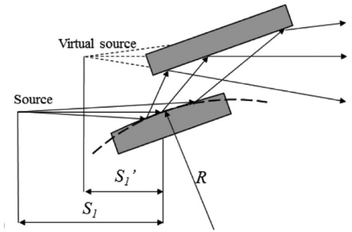
SLS (2015)



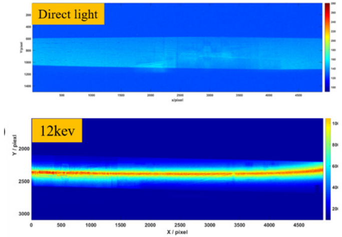
ESRF (2005)

SSRF

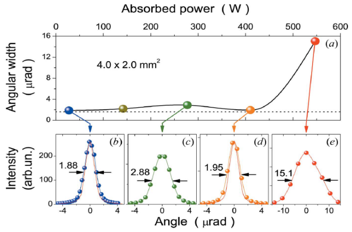
一、Beamline properties



Focus beam

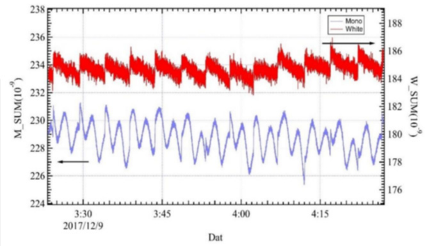


Beam imaging

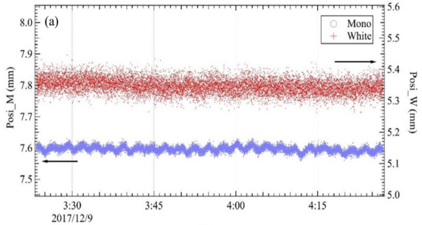


Energy resolution

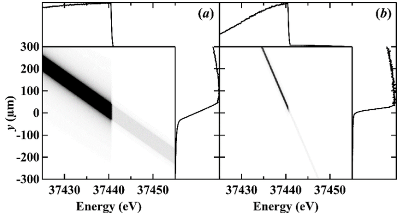
Beam stability (Position、Energy、Flux)



Photon flux

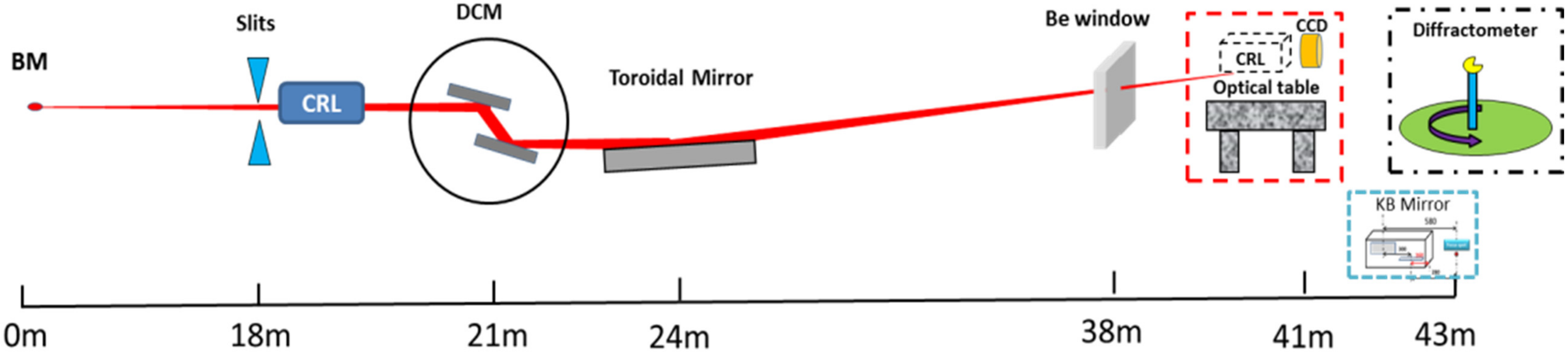


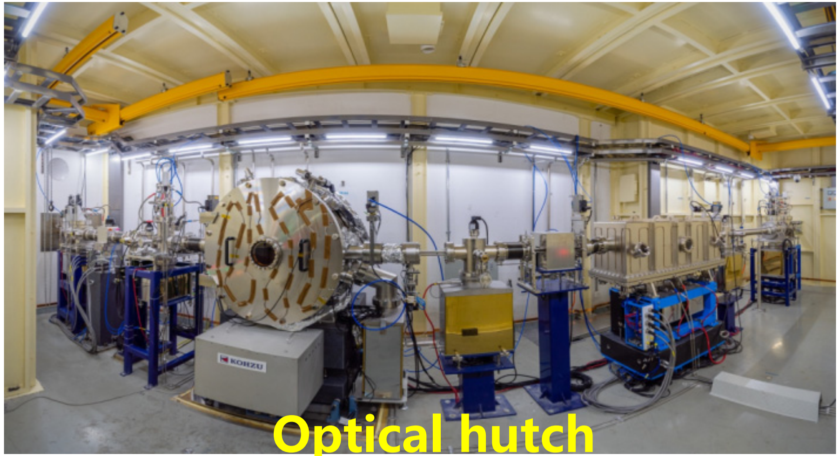
Beam position



Beam energy

一、Beamline properties





一、Beamline properties

XXX Beamline		X-ray test beamline
5~20keV	Energy range	4~100keV
μm	Beam size	30 μm~100mm
$1X10^{11}$phs/sec@10keV	Photon flux	$1X10^{8}$phs/sec@60keV
~10^{-4}	Energy resolution	white~10^{-6}
Sample	Experiment	LEGO
Papers...	Experiment output	Instruments

Outline

- ◆Beamline properties
- ◆2D imaging of the crystal diffraction
  - I. DuMond diagrams of crystal Bragg-case
  - II. Measurement of the Wave in Vertical direction
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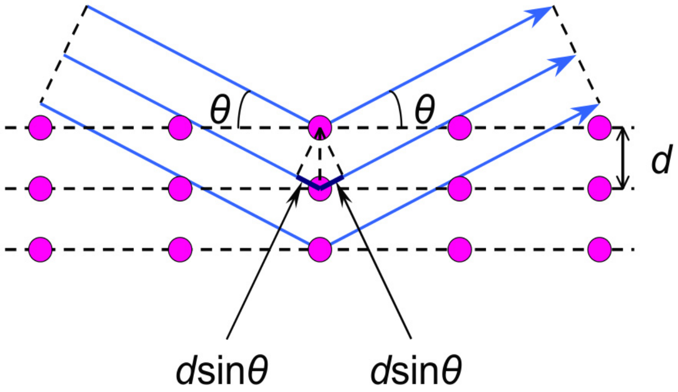
- ◆Summary

二、2D imaging of the crystal diffraction

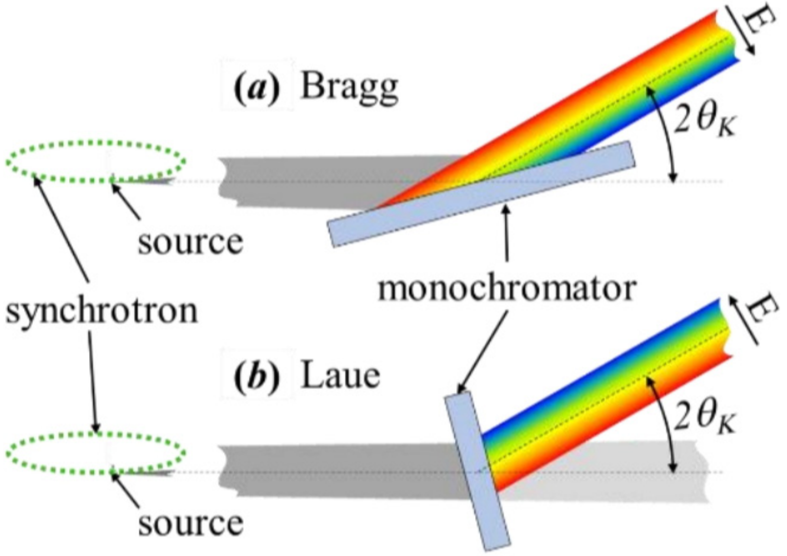


Bragg's law of difraction

$$2d(\text{Å})\sin(\theta) = n\lambda(\text{Å}) = n\frac{12.4}{E(keV)}$$

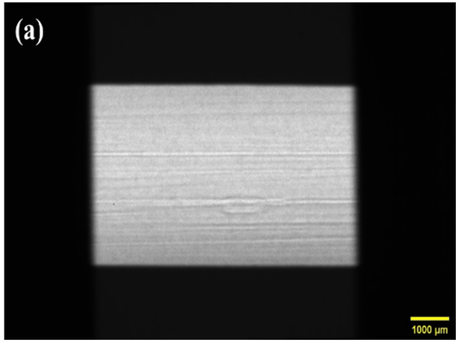
d: Latiice *(d)*-spacing,
θ: glancing angle,
λ: X-ray wavelength
10 keV : 1.24 Å,
1 Å : 12.4 keV

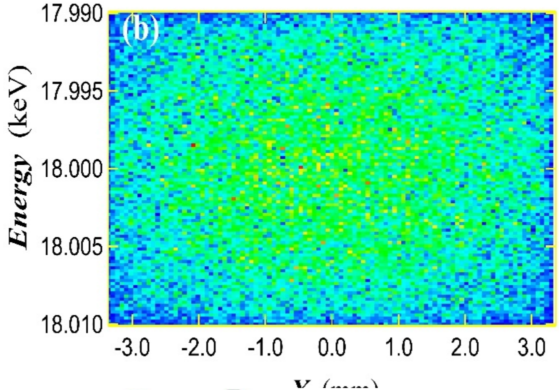
Crystal diffraction principle

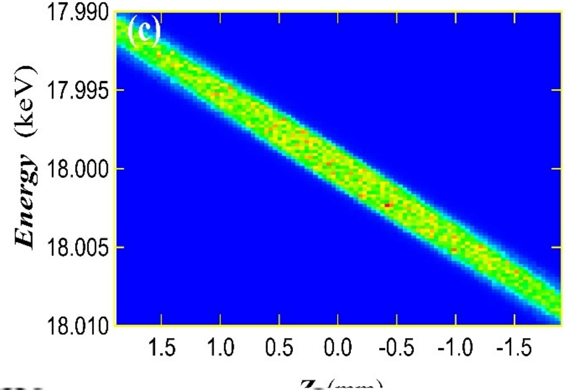


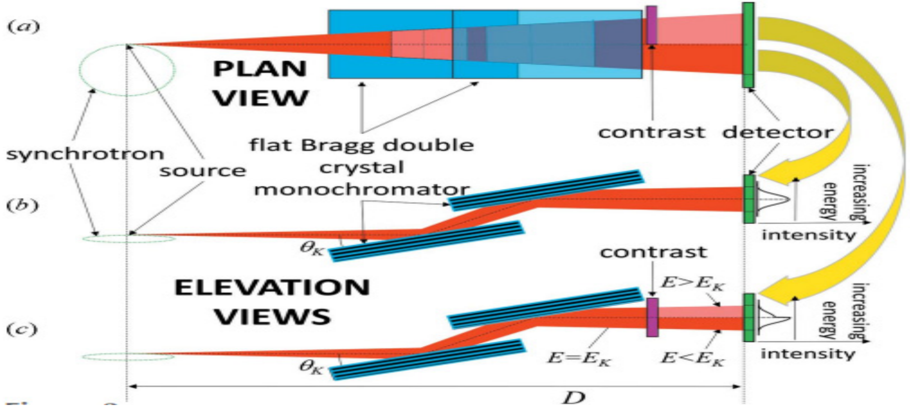
$$\frac{\Delta E}{E} = \frac{\Delta\lambda}{\lambda} = \Delta\theta\cot\theta$$

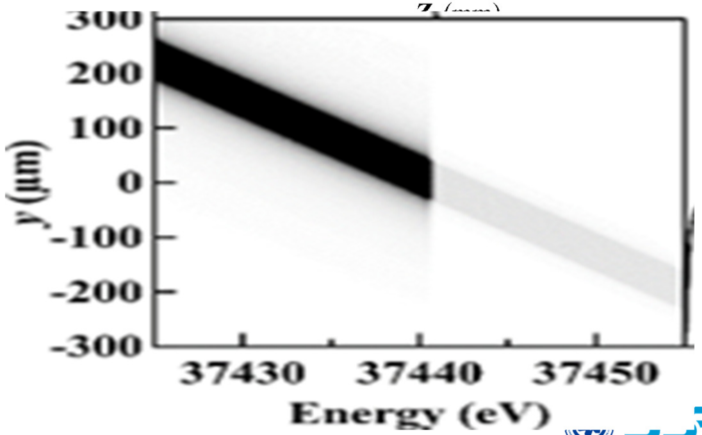
二、 2D imaging of the crystal diffraction





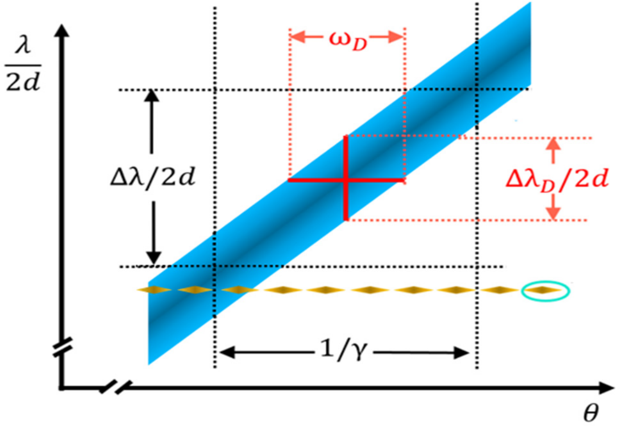




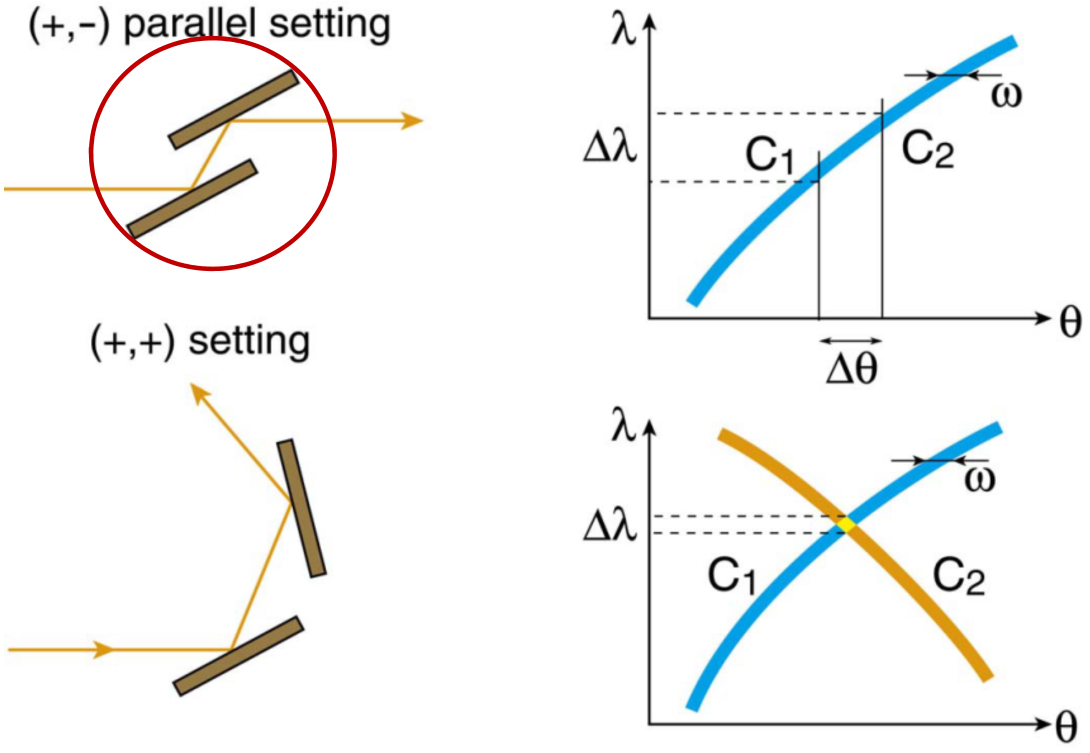


I. DuMond diagrams of crystal Bragg-case

$$\lambda = 2d\sin\theta$$

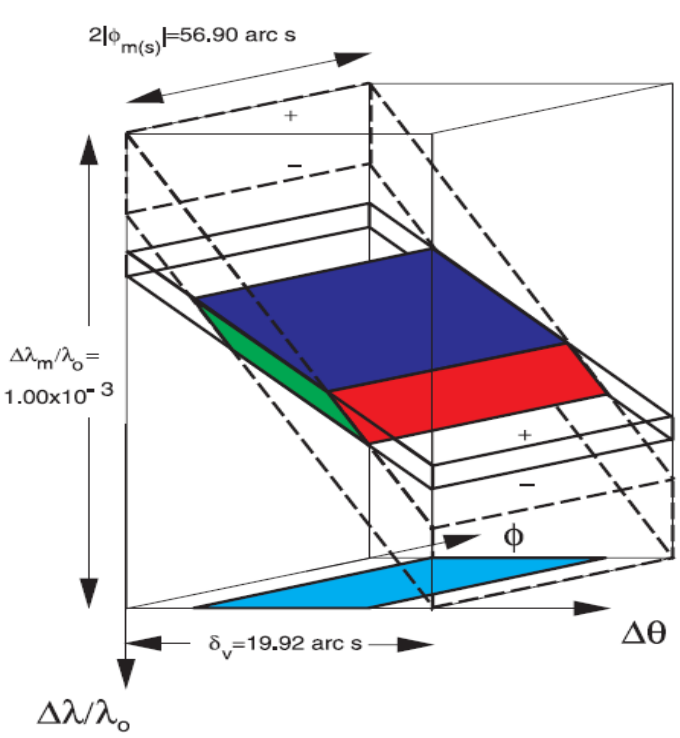


Single crystal DuMond diagram

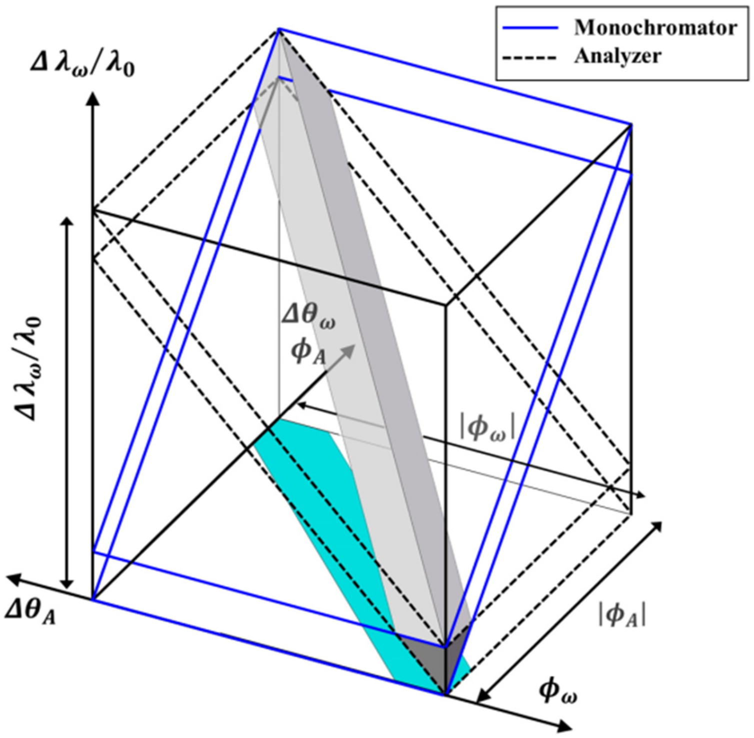


Double crystal DuMond diagrams

I. DuMond diagrams of crystal Bragg-case

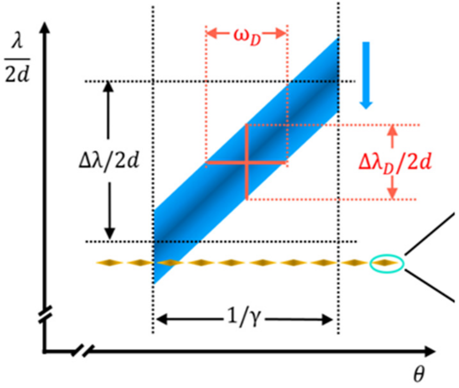


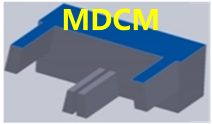
3D DuMond diagram of parallel crystal

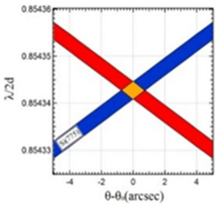


3D DuMond diagram of orthogonal crystal

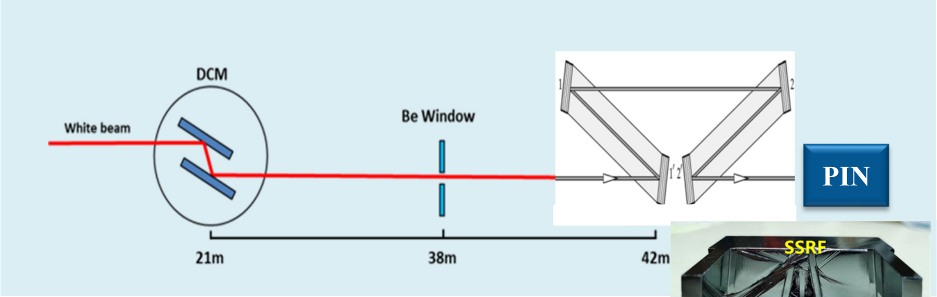
I. DuMond diagrams of crystal Bragg-case

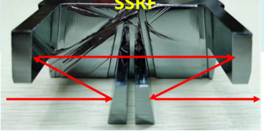




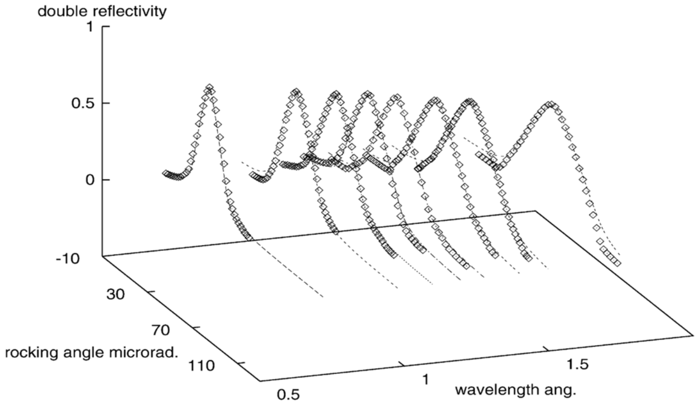


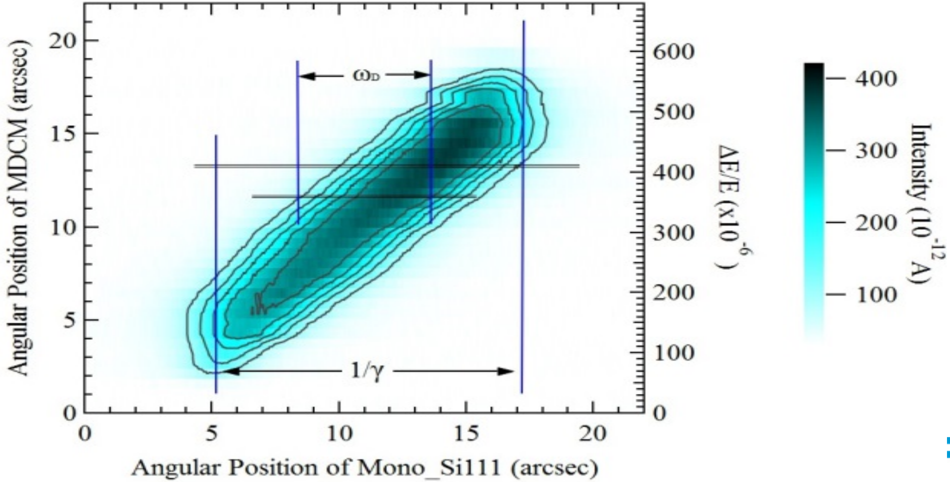
Energy resolution：10^{-6}



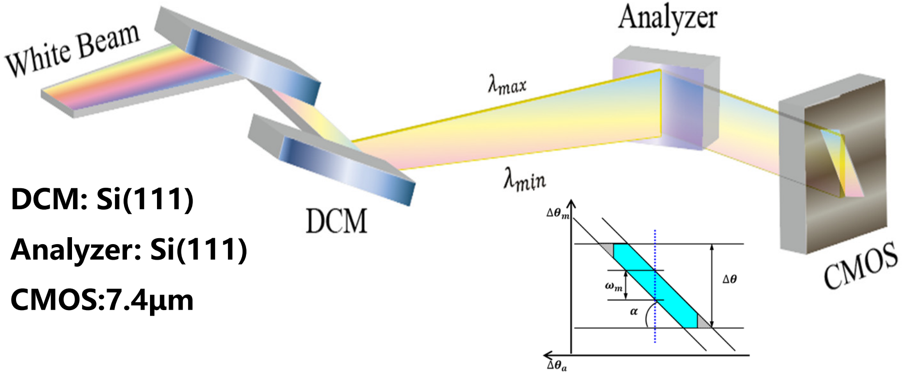


Measurement optical layout





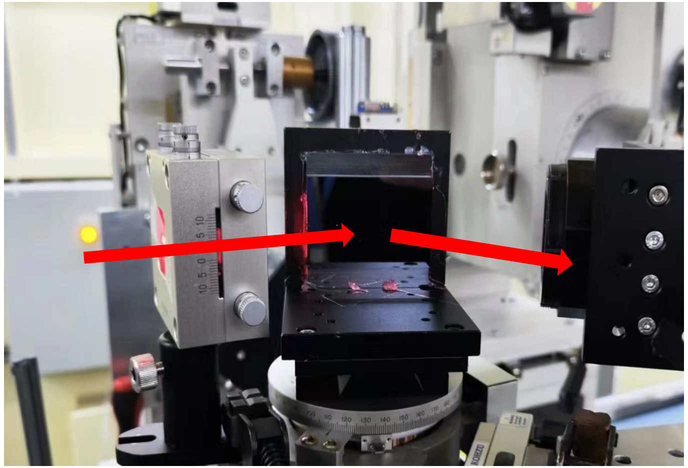
II. Imaging of the orthogonal crystal

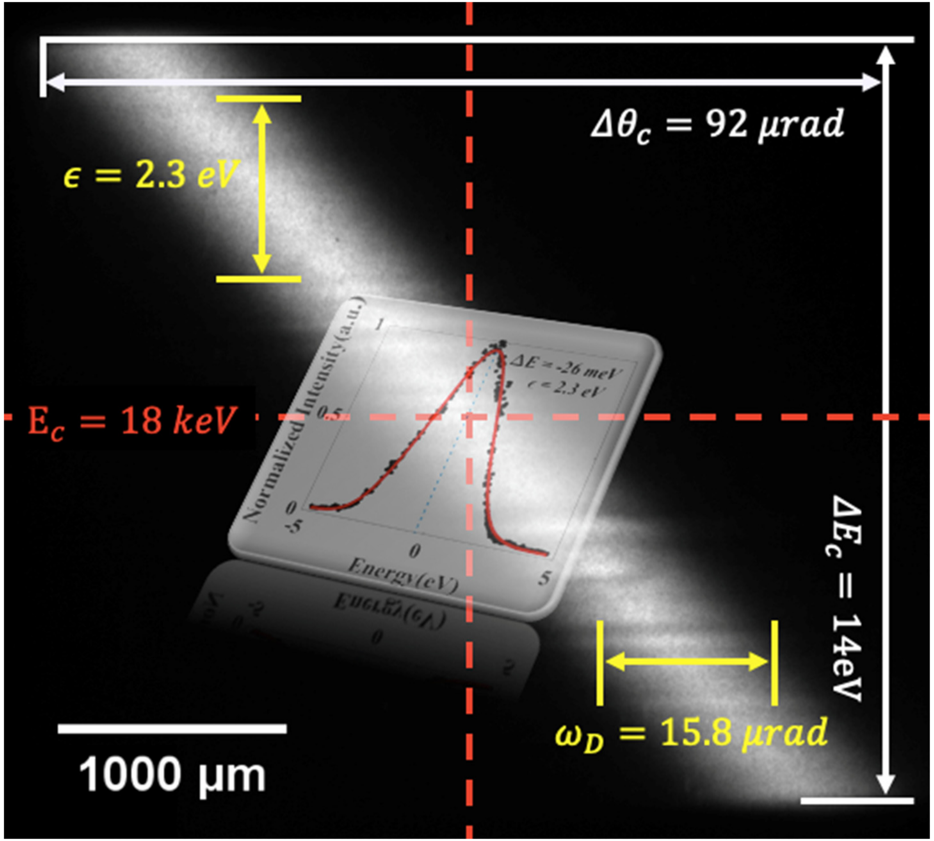


DCM: Si(111)

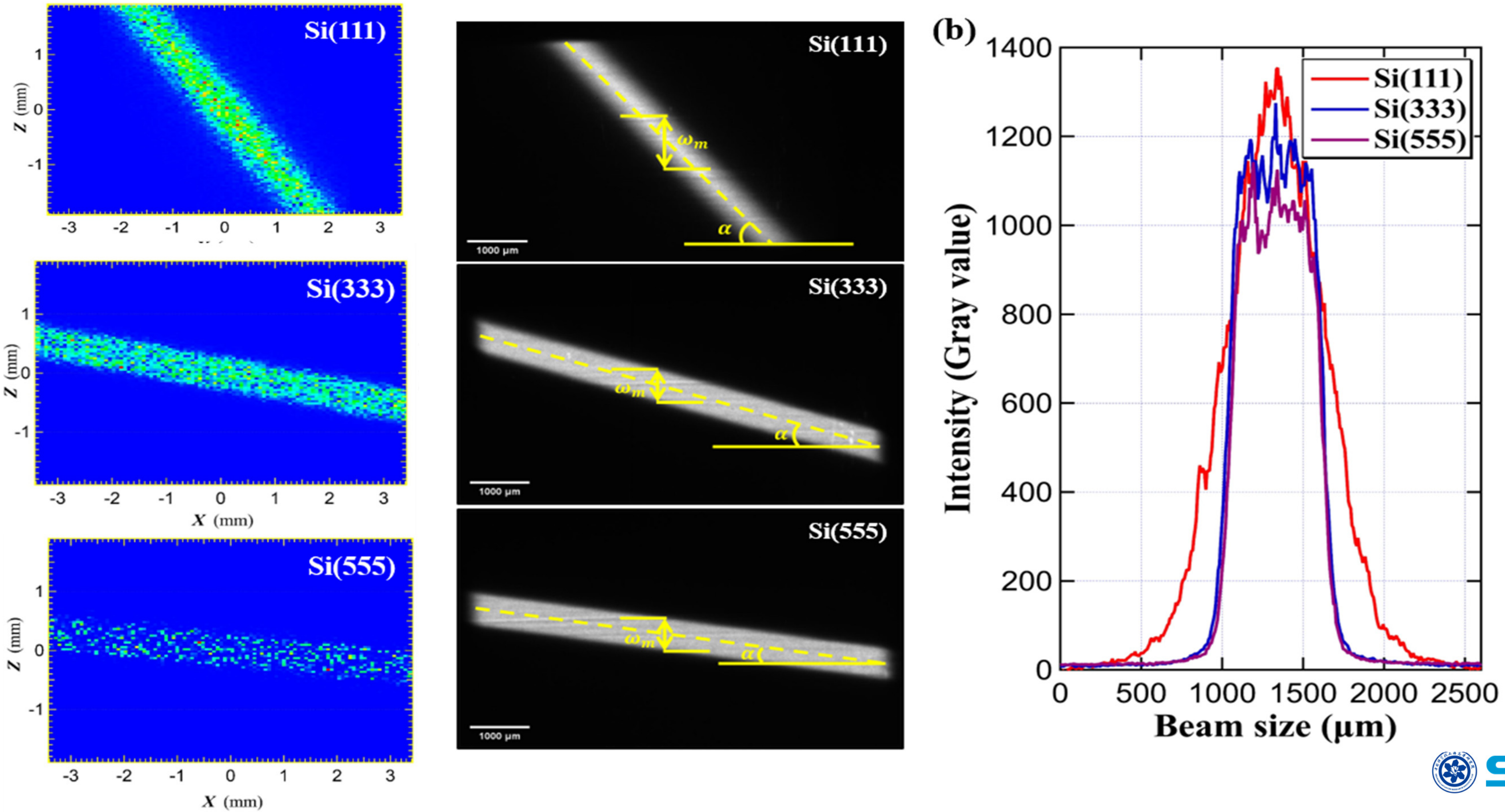
Analyzer: Si(111)

CMOS:7.4μm



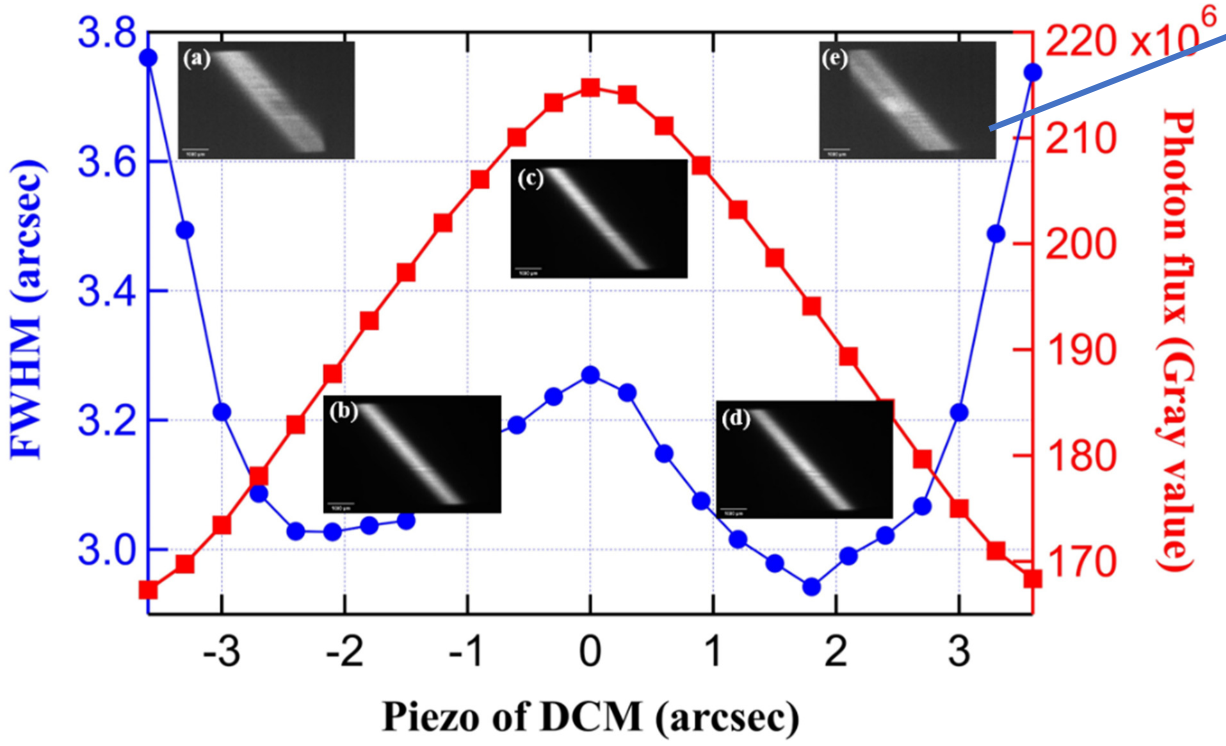


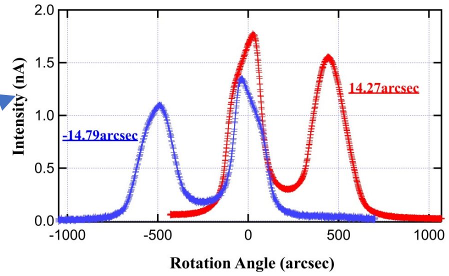
II. Imaging of the orthogonal crystal



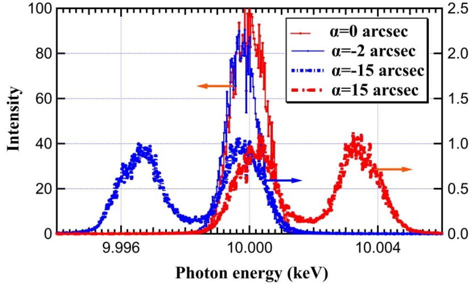
II. Imaging of the orthogonal crystal

Crystla detune





Si555 Measured @10keV

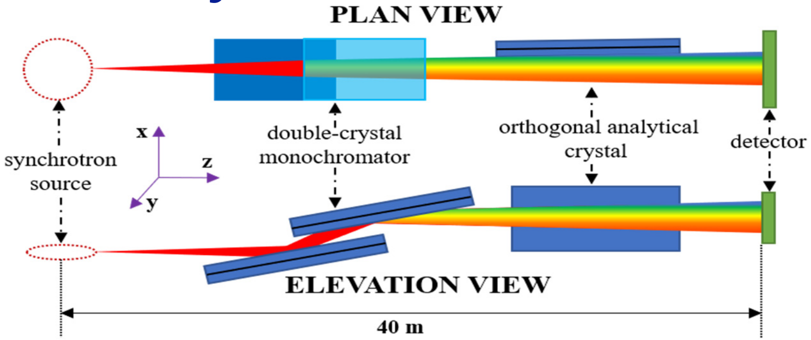


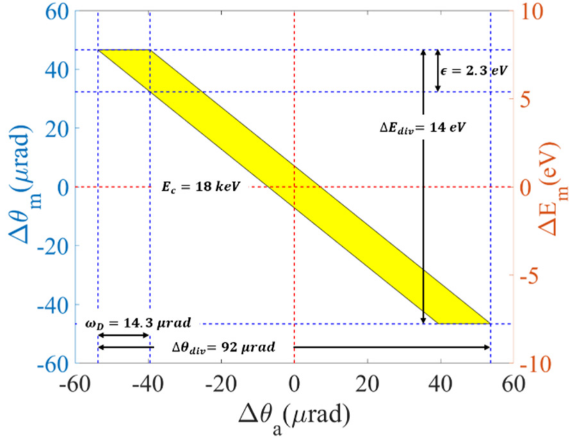
Simulation with XOP

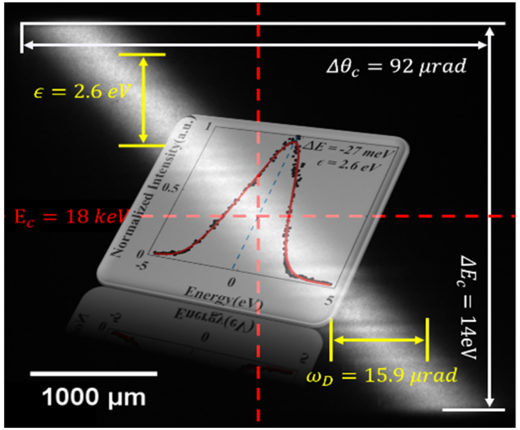
SSRF

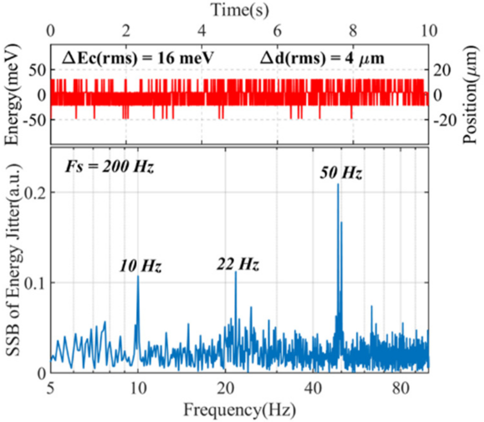
III. Application of 2D energy spectrum imaging

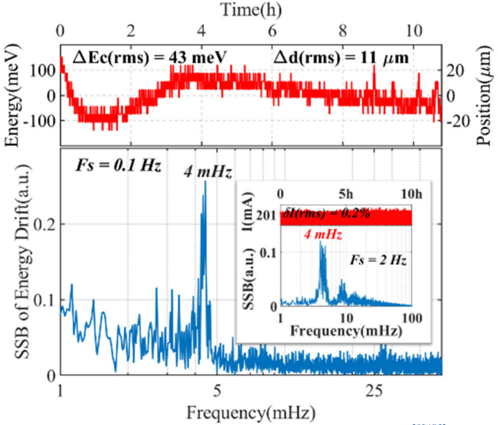
DCM Stability





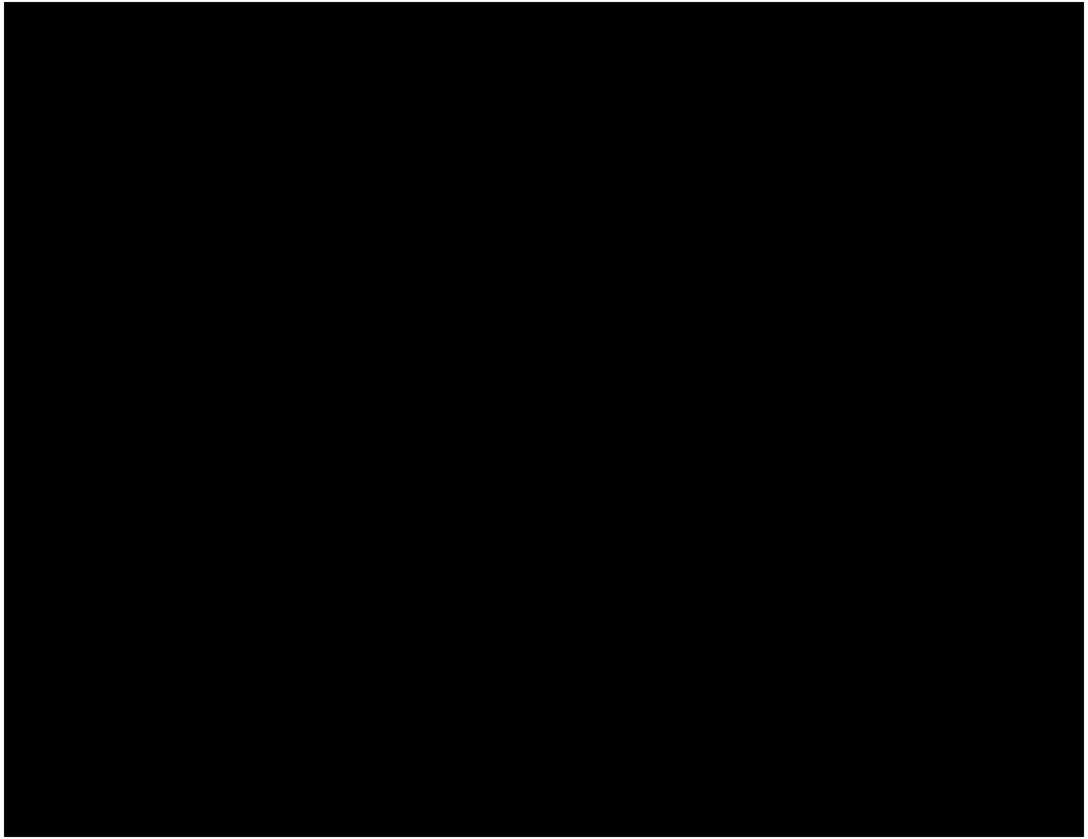






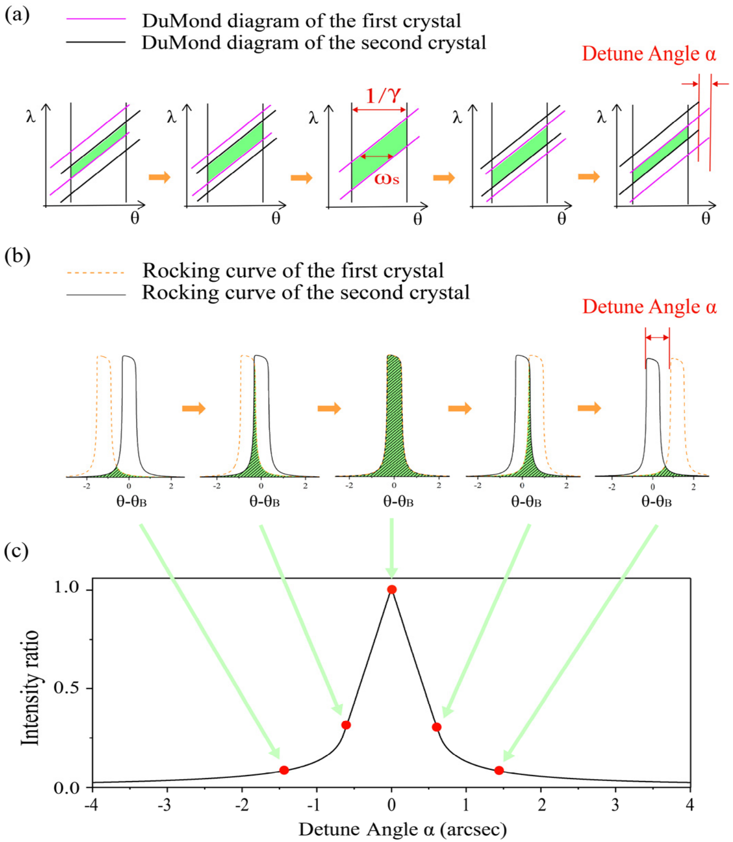
Shangyu Si, Zhongliang Li, Lian Xue and Hongxin Luo, Applied Optics, 62(18), 2023.

III. Application of 2D energy spectrum imaging



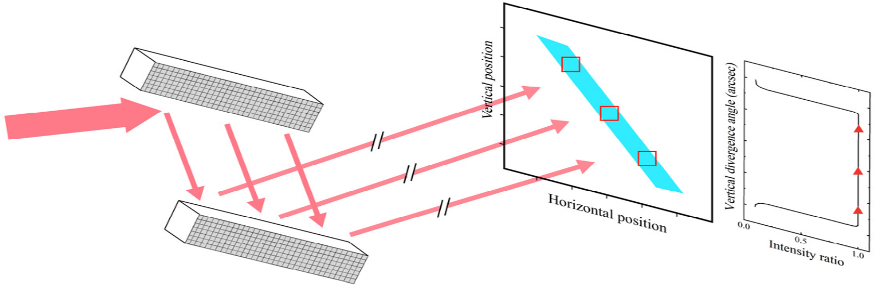
The imaging with different ring current

III. Application of 2D energy spectrum imaging

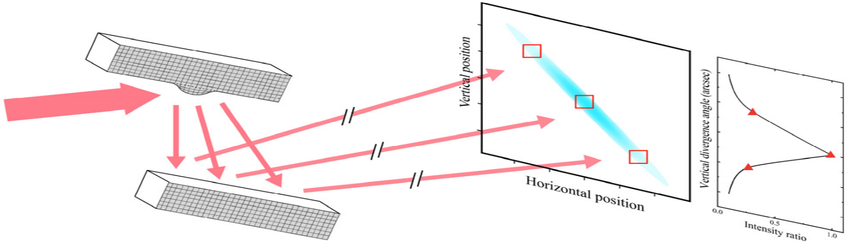


Double crystal detune

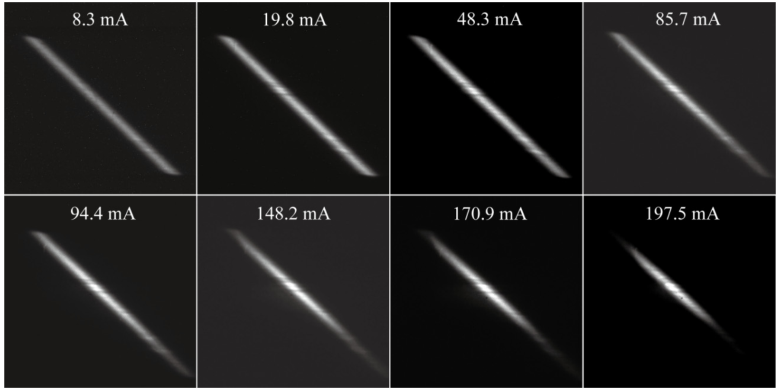
DuMond diagram of the crystal no deformation

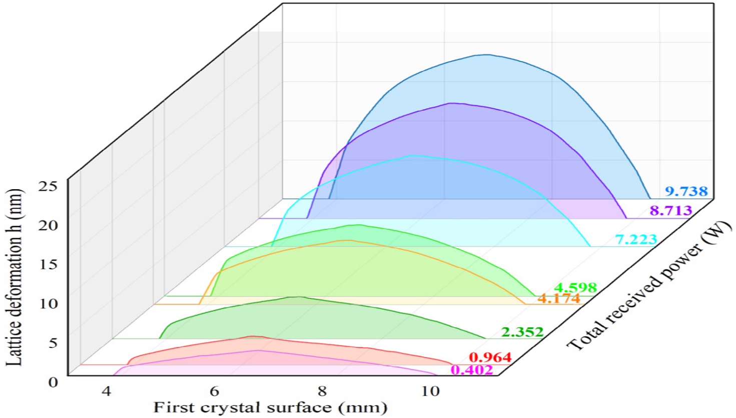


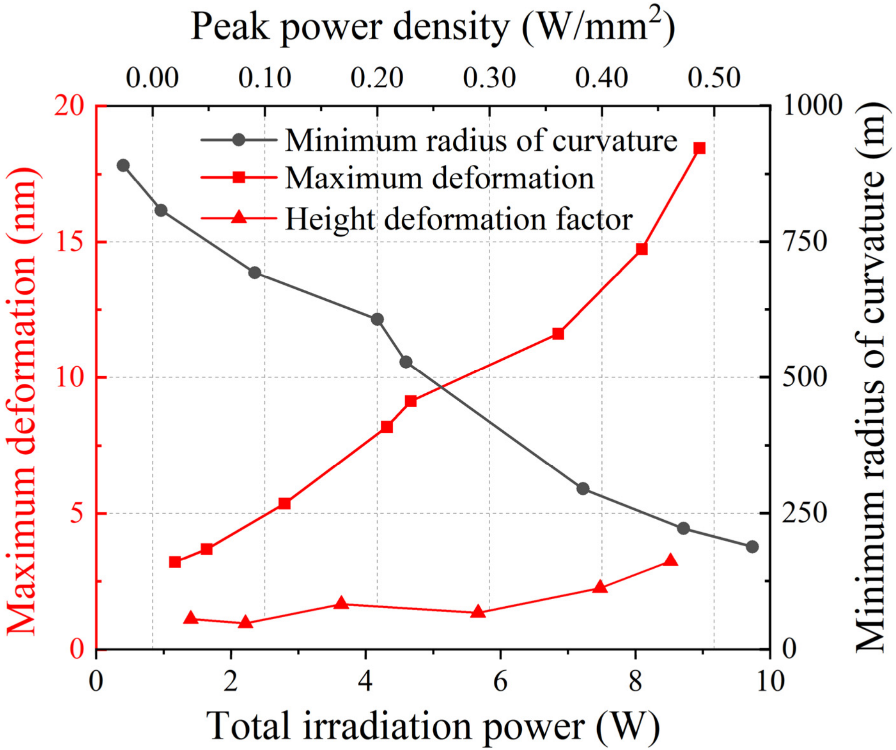
DuMond diagram of the crystal with thermal deformation



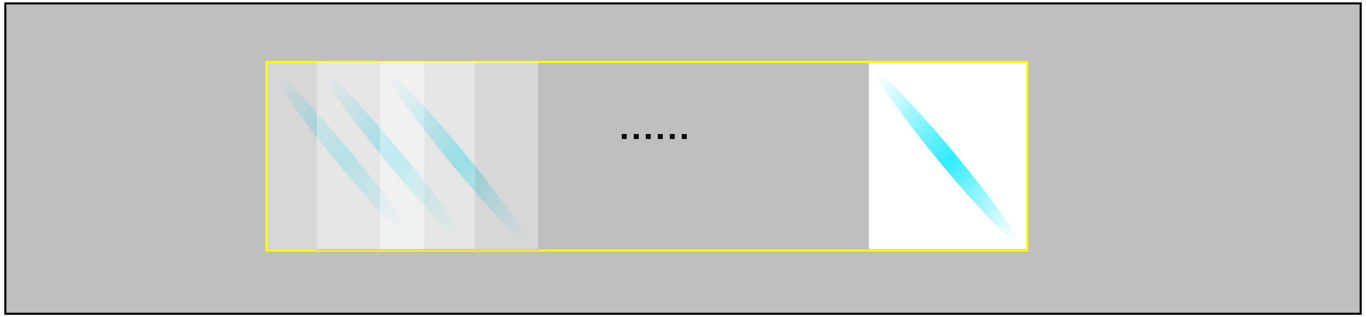
III. Application of 2D energy spectrum imaging

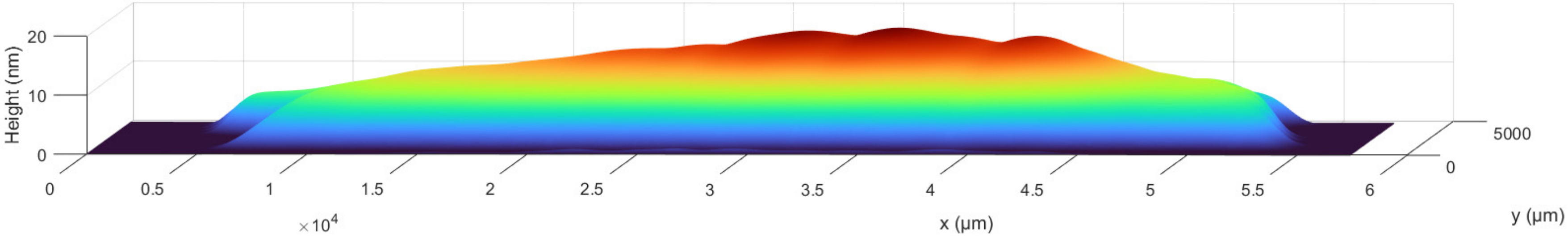


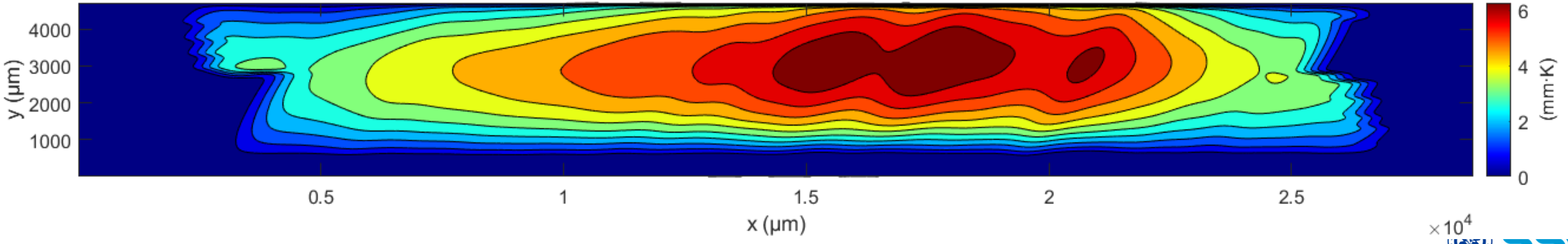




III. Application of 2D energy spectrum imaging



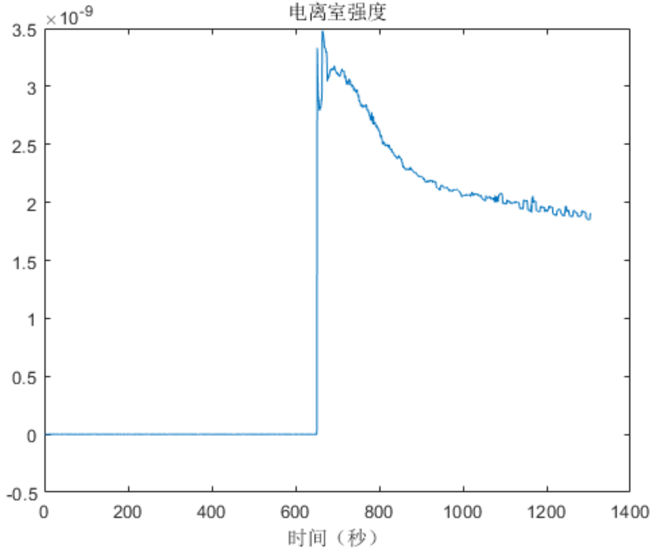




III. Application of 2D energy spectrum imaging

Liquid nitrogen cooling monochromator

Thermal deformation transient result



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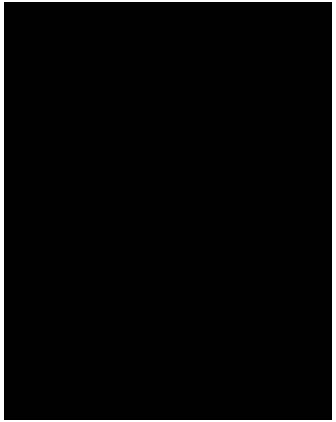
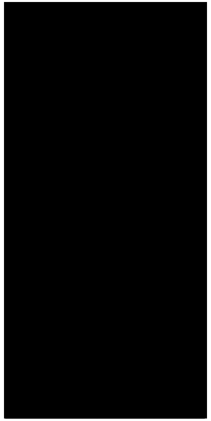
Outline

- ◆Beamline properties
- ◆2D imaging of the crystal diffraction
  - I. DuMond diagrams of crystal Bragg-case
  - II. Measurement of the Wave in Vertical direction
  - III. Application of 2D energy spectrum imaging
- ◆Summary

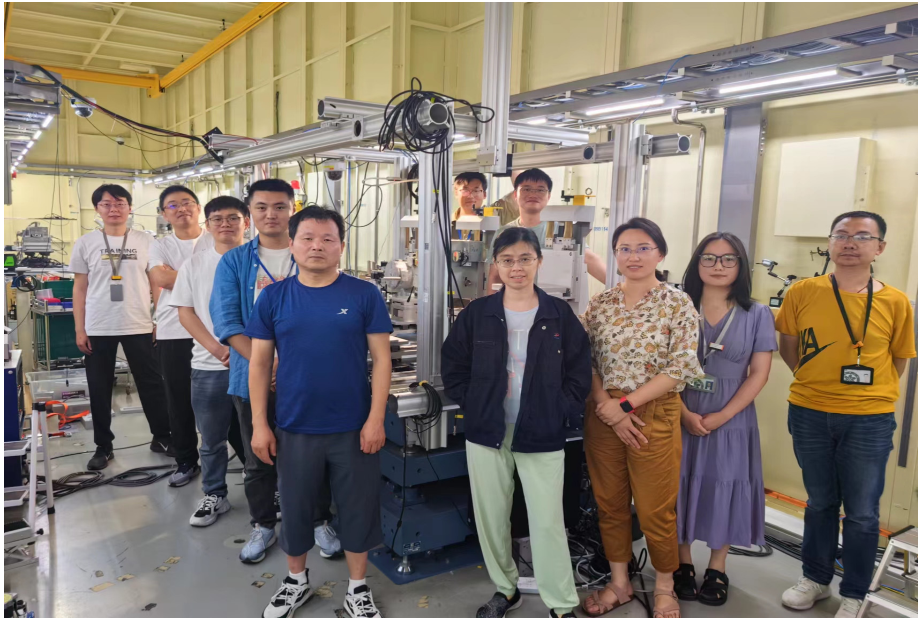
3、Summary

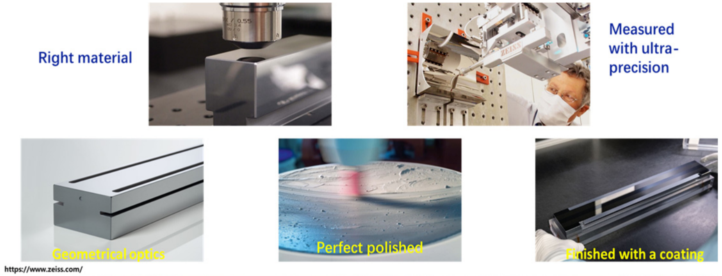
- The orthogonal crystal measured beam DuMond diagrams with one figure
- The method was used to measure energy resolution of DCM， thermal deformation of crystal and stability of DCM
- Used the method to design the position monitor

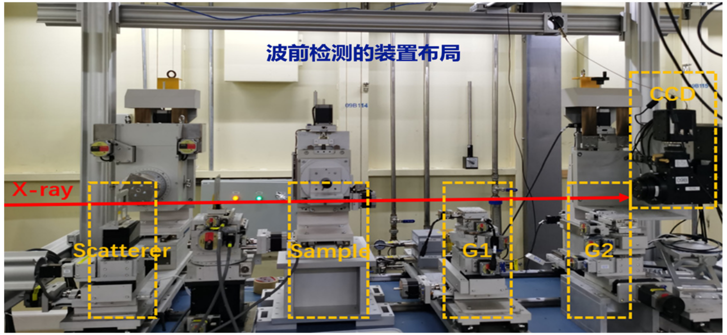




"If you can not* measure *it， you can not improve it."

——Lord Kelvin







SSRF
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Thanks for your attention!
谢谢!