Photon Diagnostics Activities in Shanghai
(for SXFEL or SHINE Project)

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on behalf of photon diagnostic group

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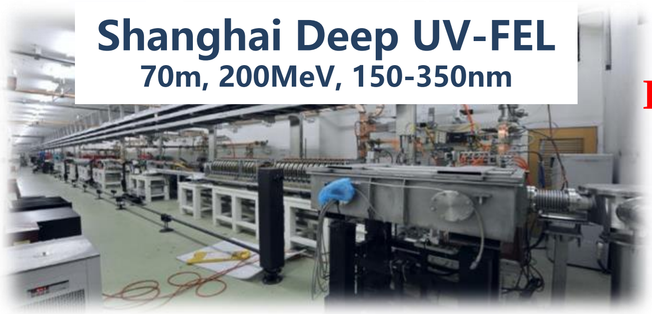
Outline

1. Overview of photon diagnostics development

2. High resolution X-ray spectrometer

3. X-ray coherence apparatus and measurement

Free Electron Laser Facility in China



Shanghai Deep UV-FEL
70m, 200MeV, 150-350nm

Test Facility
HGHG, EEHG
(2009)

Dalian Coherent Light Source
150m, 300MeV, 50-150nm

User Facility
HGHG
(2016)

Shanghai X-ray FEL Test Facility
300m, 840MeV, 9-40nm

Test Facility
EEHG
HGHG (cascaded)
(2020)

Shanghai X-ray FEL User Facility
530m, 1.6GeV, 2-10nm

User Facility
SASE + SEEDING
(2021, 2022)

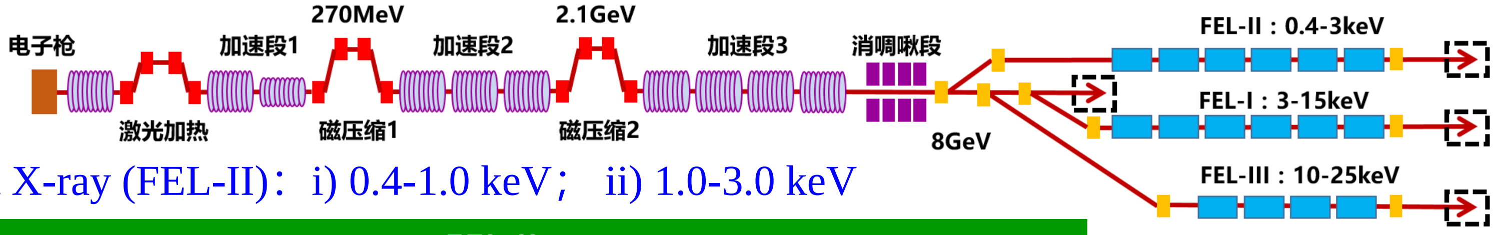
Shanghai high rep-rate XFEL and extreme light

硬X射线自由电子激光用户装置

SHINE Project

User Facility
SASE + Seeding Scheme
(2025, 2026)

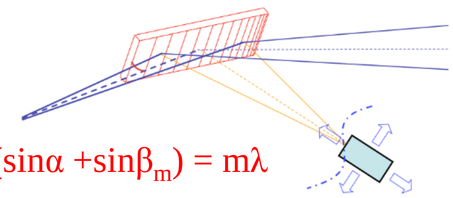
X-ray Diagnostics for SHINE (0.4 – 25 keV)



Soft X-ray (FEL-II)： i) 0.4-1.0 keV； ii) 1.0-3.0 keV

FEL-II		
Photon Energy Range (keV)	0.4 - 1.0	1.0 - 3.0
Nominal Pulse Energy (μJ)	>1000	>300
FWHM bandwidth (ΔE/E)	0.19% @0.9keV	0.11% @2.0keV

VLS Grating



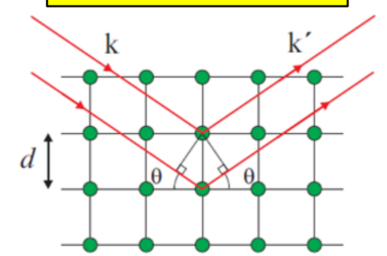
$d\ (\sin\alpha + \sin\beta_m) = m\lambda$

Hard X-ray： i) FEL-I 3.0-15keV, ii) FEL-III 10-25keV

FEL-I		
Photon Energy Range (keV)	3.0 - 10.0	10.0 - 15.0
Nominal Pulse Energy (μJ)	>150	> 43
FWHM bandwidth (ΔE/E)	0.12% @7keV	0.09% @12.4keV

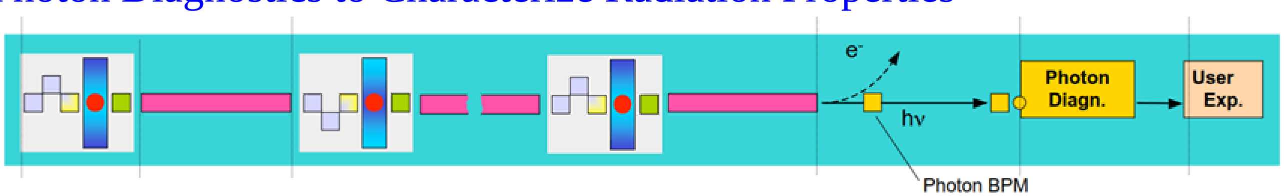
FEL-III		
Photon Energy Range (keV)	10.0 - 15.0	15.0 - 25.0
Nominal Pulse Energy (μJ)	>150	> 43
FWHM bandwidth (ΔE/E)	0.051% @15keV	0.033% @25keV

Bragg Crystal



$2d \sin\theta_m = m\lambda$

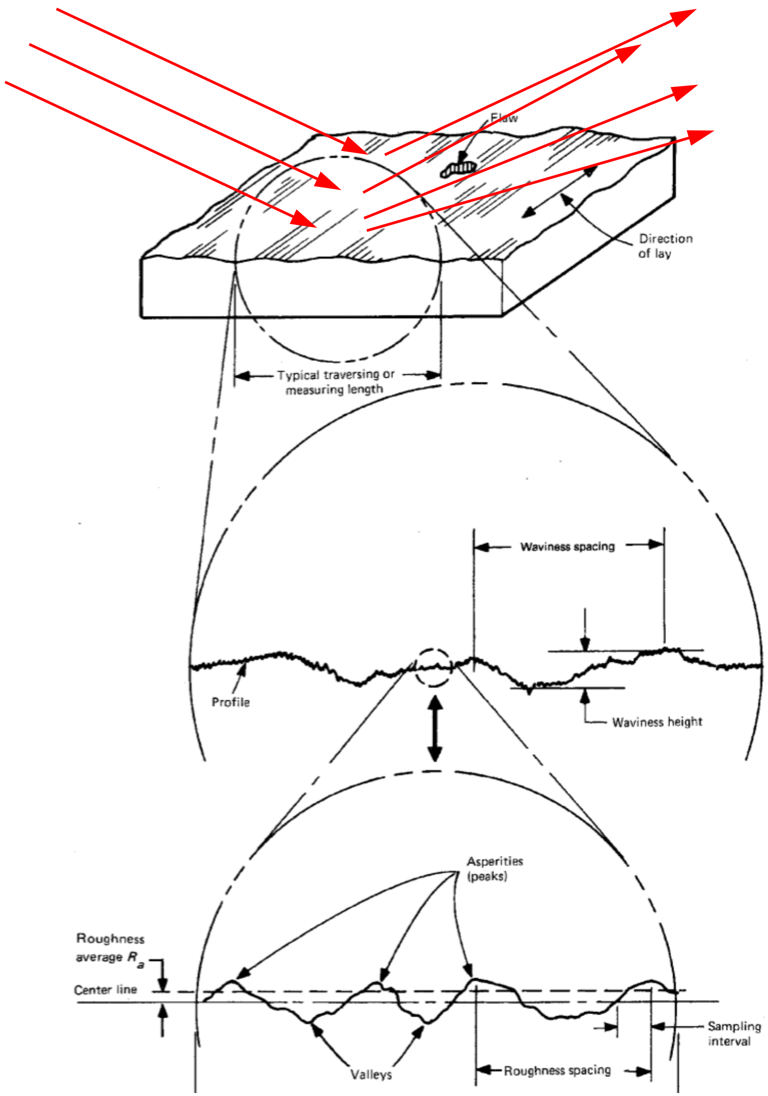
Photon Diagnostics to Characterize Radiation Properties

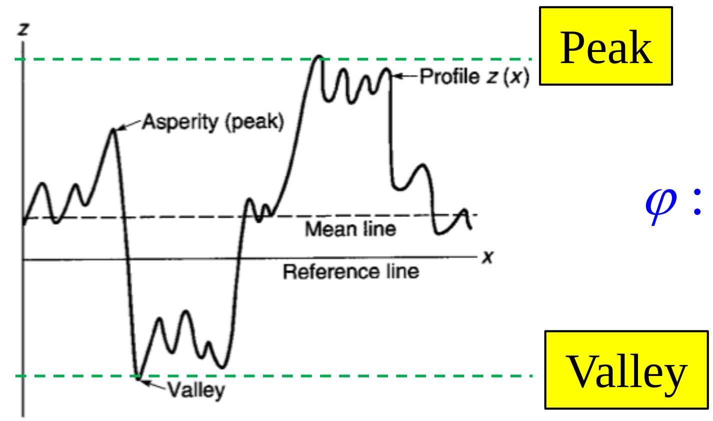


Frame-work of X-ray FEL Photon Diagnostics

- Radiation intensity or XFEL pulse energy (single shot resolution)
- Beam spot size and transverse intensity distribution (at the source point and along the beam lines); Beam position and transverse fluctuations
- **Spectrometer** (central wavelength, spectral width and distribution profiles)
- Undulator commissioning & alignment device – K-monochromator
- Beam divergence & X-ray laser transverse mode at the far field
- X-ray pulse arrival time (pump-probe pulse delay and temporal jitter)
- **X-ray pulse duration**, longitudinal intensity (or temporal) distribution profile, and **X-ray pulse longitudinal coherence** etc.
- **Wave-front coherence** and distortion due to reflection and transport
- The beam properties at the beam focus, the Rayleigh length and curvature of wave-front

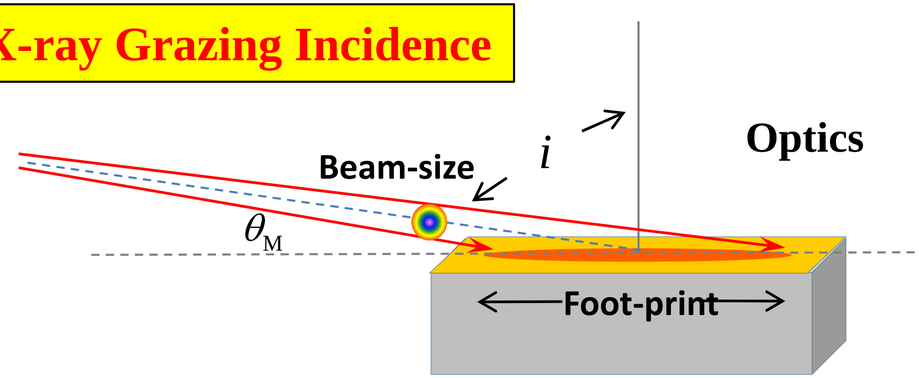
X-ray Optics





$$\varphi : \frac{2\pi}{\lambda} \sin\theta\Delta h$$

X-ray Grazing Incidence



Refraction Index in Air $n \cong 1$

Refraction Index of Coating Material

$$n'(\lambda) = 1 - \Delta(\lambda) + i\beta(\lambda)$$

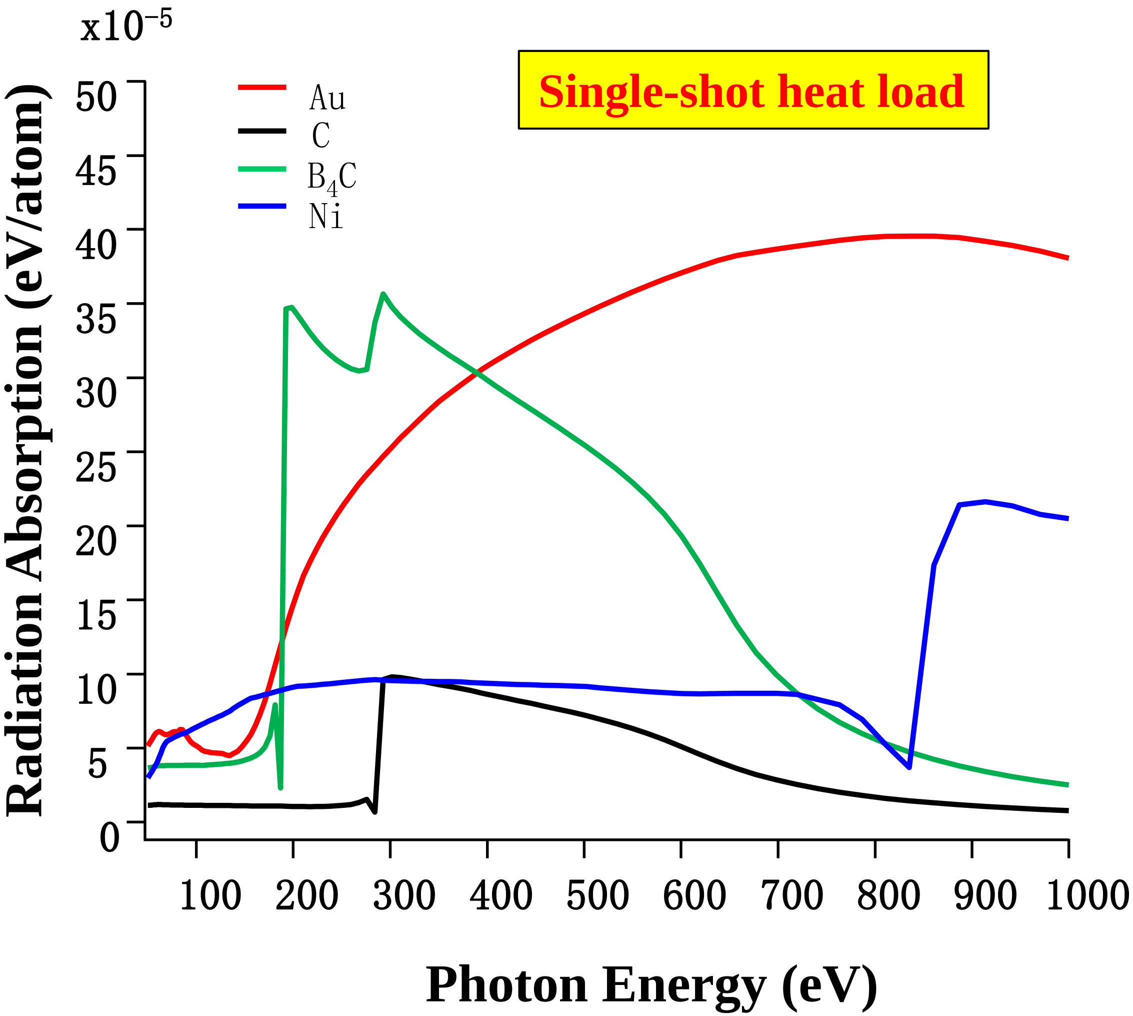
Optical Aberrations

Radiation Damage

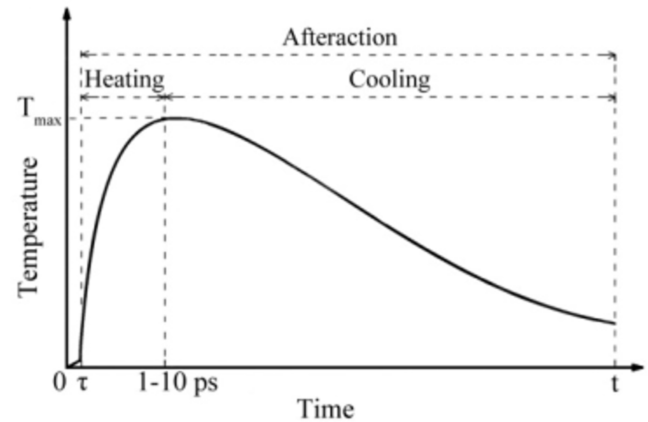
X-ray Radiation Heat Load for Grazing Incidence

$W_{radiation} << W_{damage} \sim 3k_B \cdot T_{melting}$ [eV/atom]

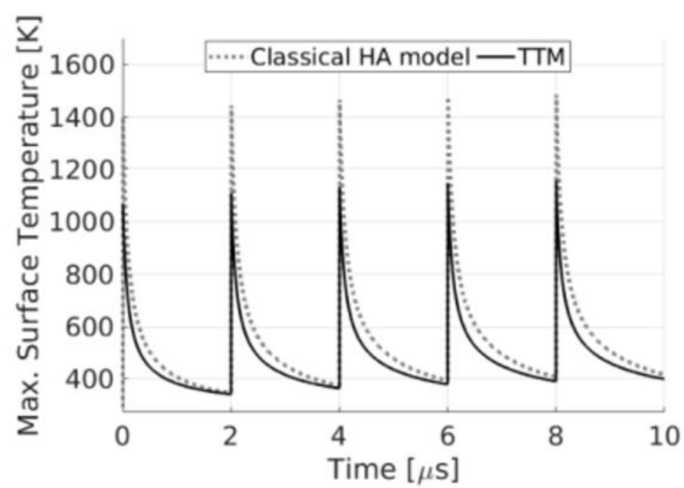
Damage Threshold: ~0.1eV/atom



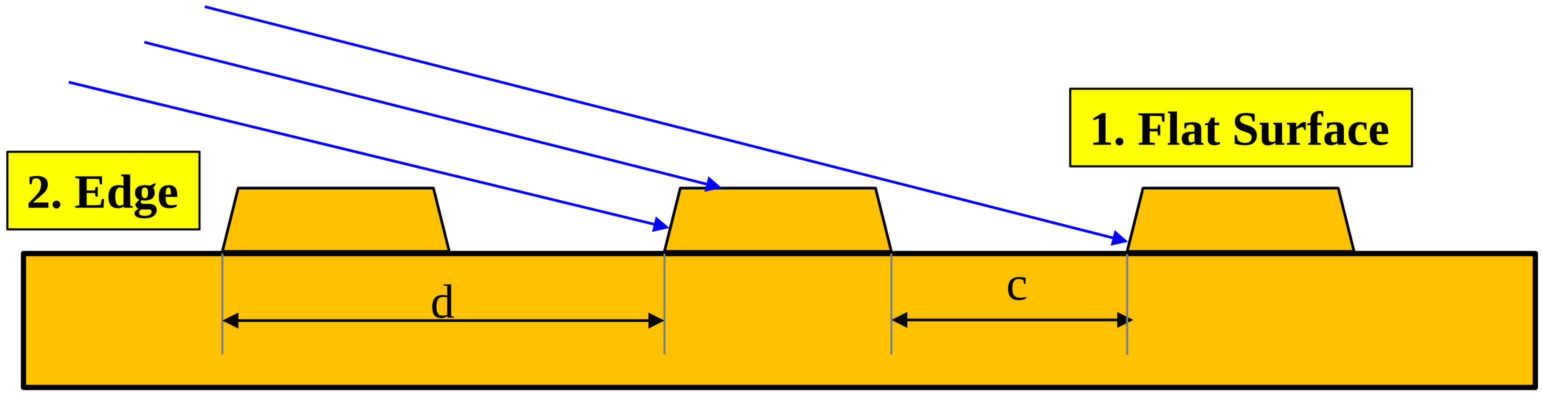
Single-shot Effect



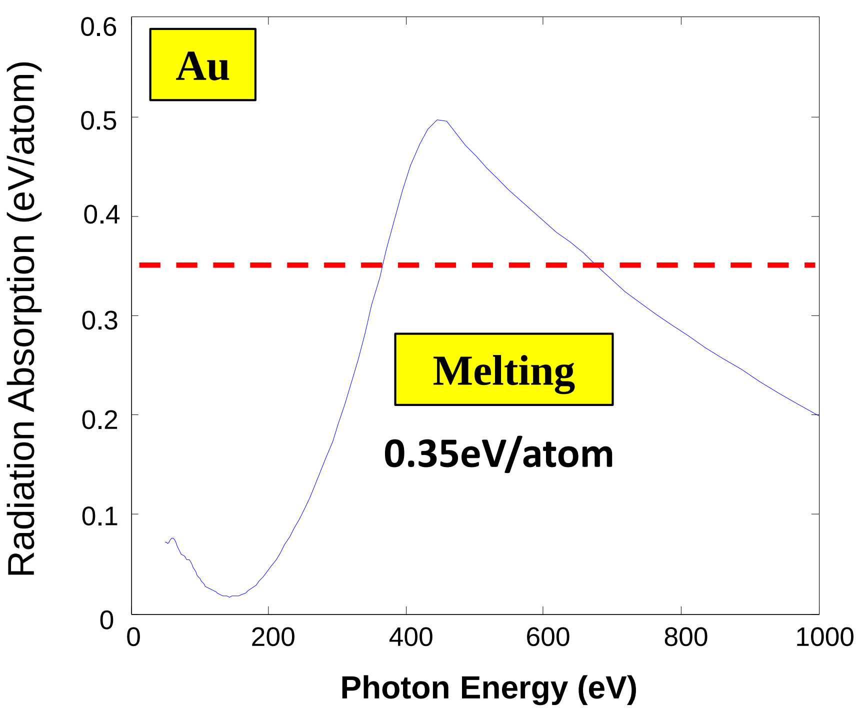
Accumulative Effect

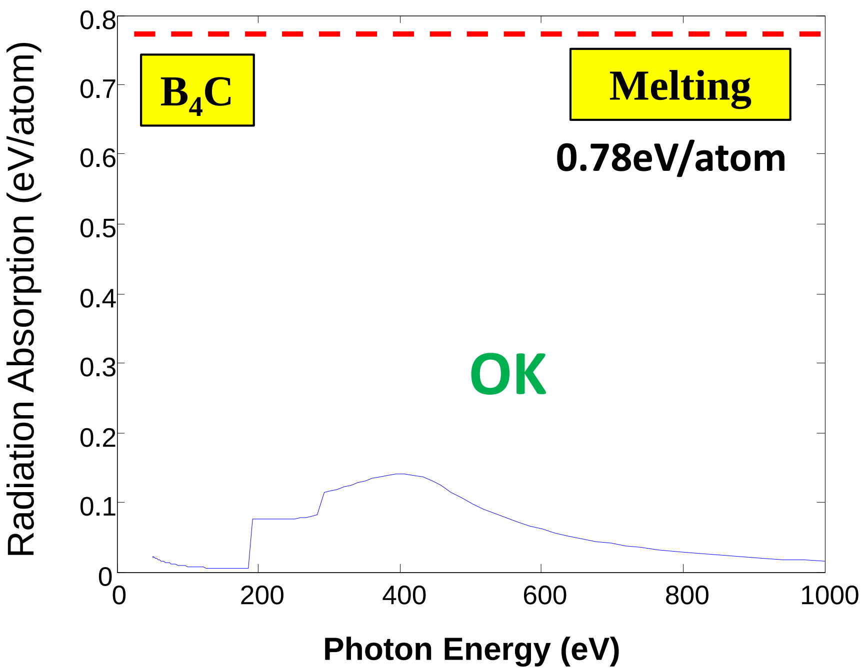


Radiation Heat Load for Grating Laminar Profile

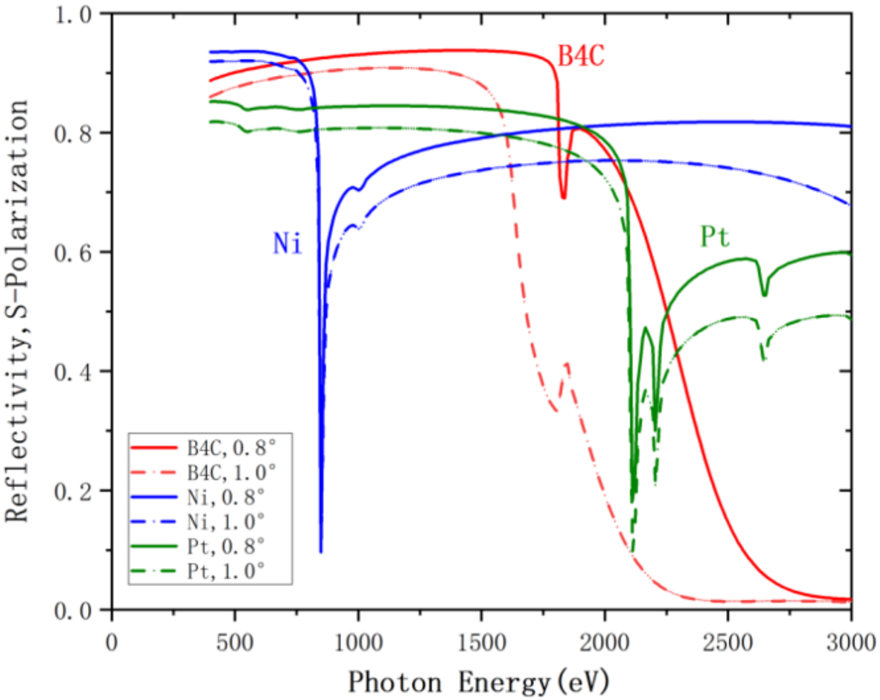


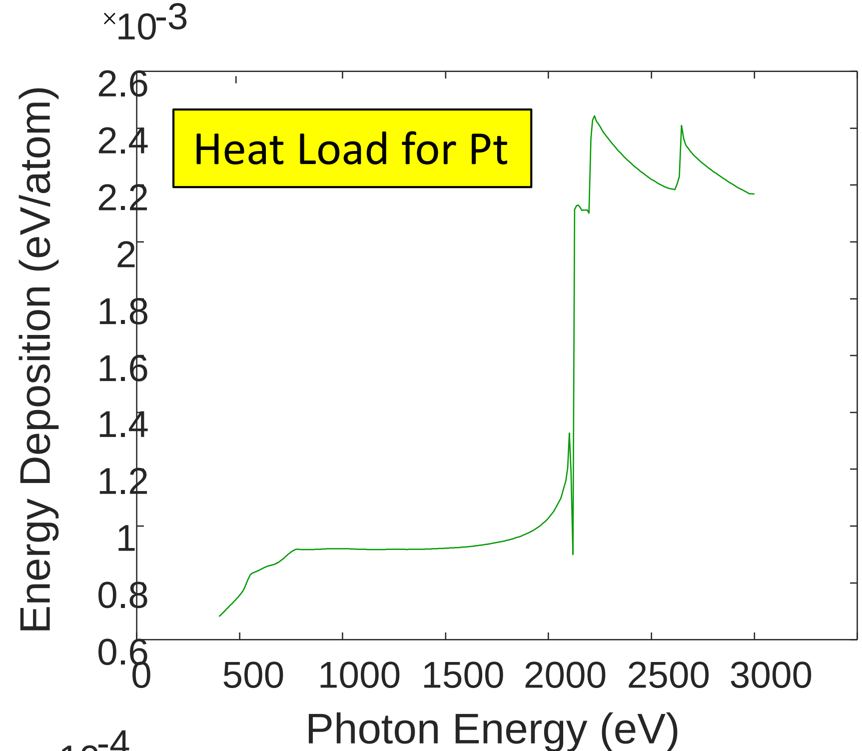
Heat load would increase significantly for small incidence angle





Coating Solution for 0.4-3keV

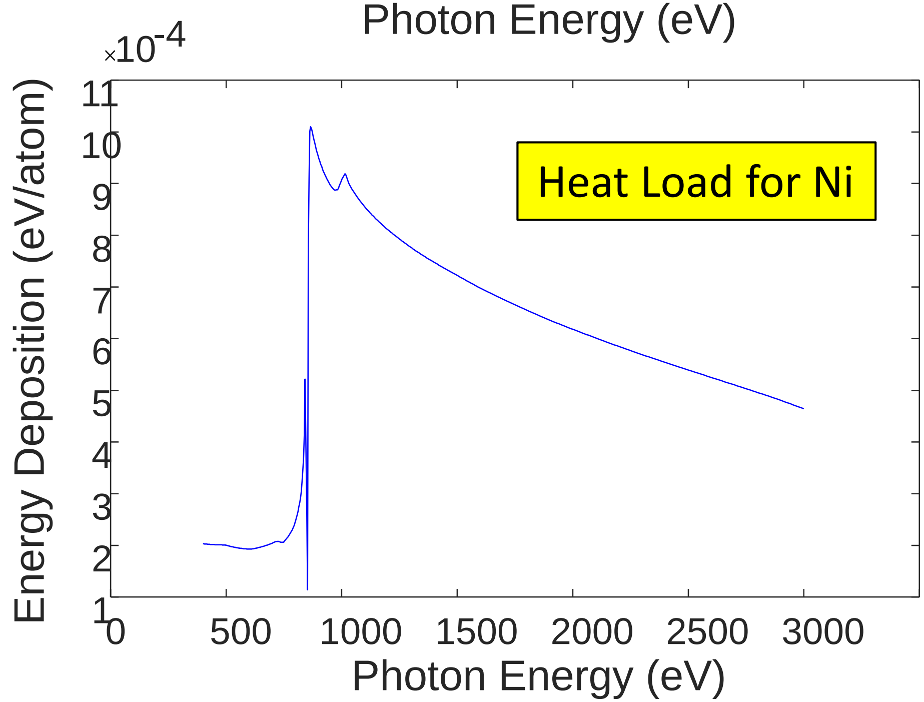




grazing incidence on metallic surface

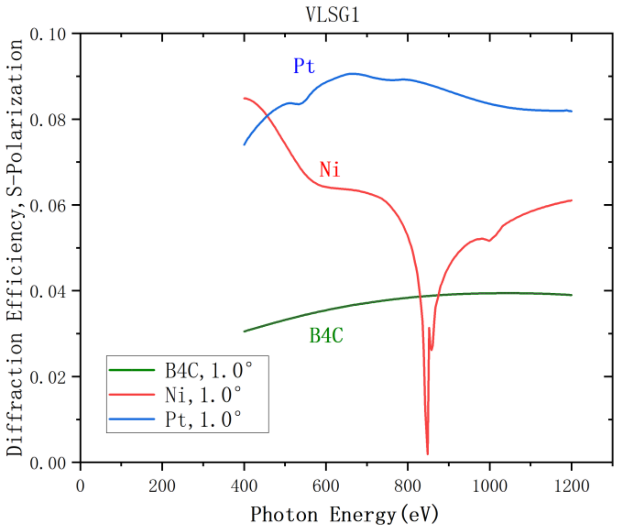
Pt（400-1500eV）

Ni（1000-3000eV）

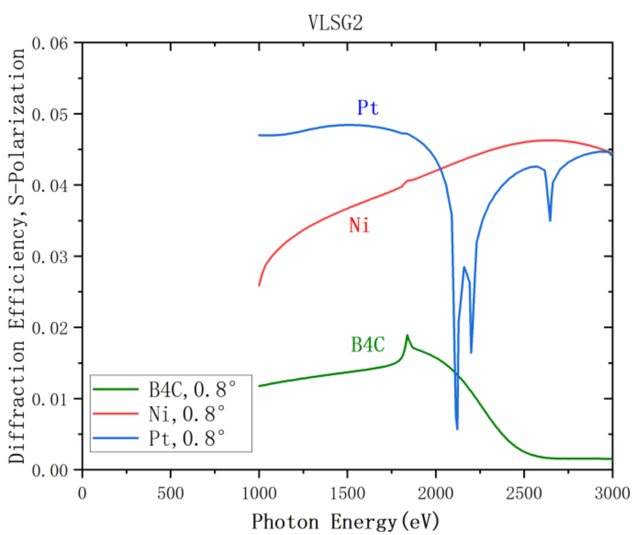


Diffraction Efficiency and Heat Load for Blazed Grating

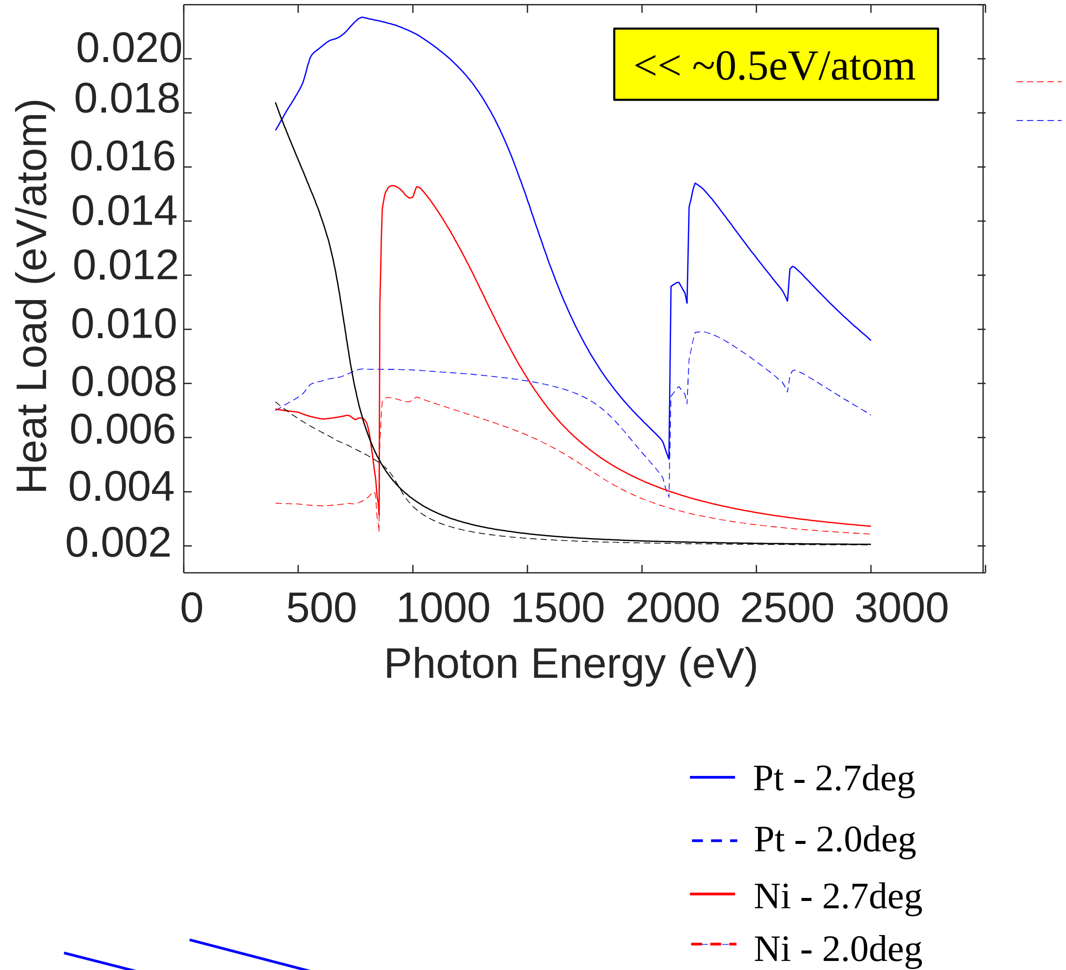
i) Pt (<1.2 keV), Diffraction Efficiency > 7.5% (1st)

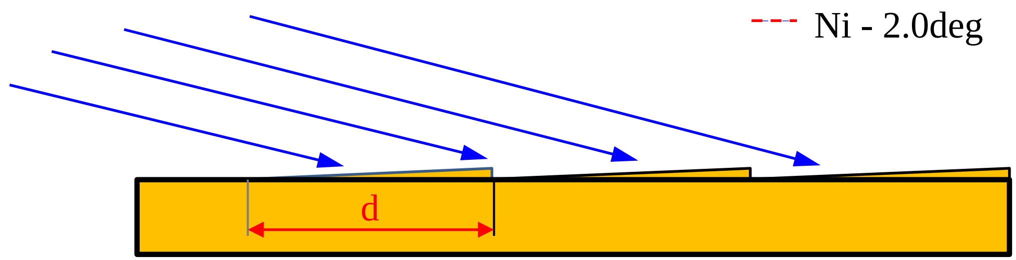


ii) Ni (>1.2keV)， Diffraction Efficiency >4.0% (1st)



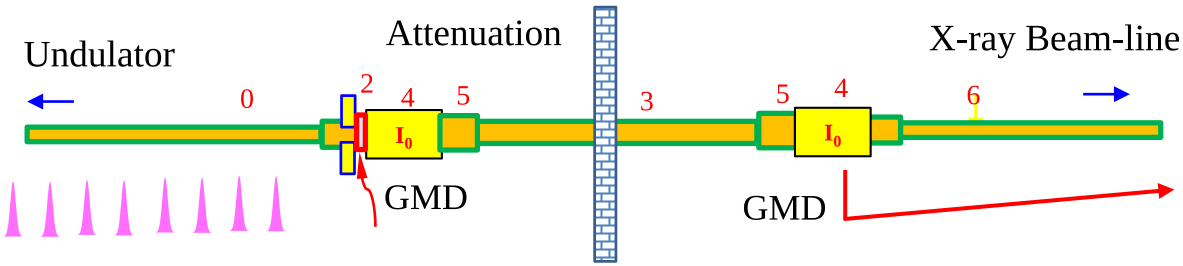
Heat load for blazed grating

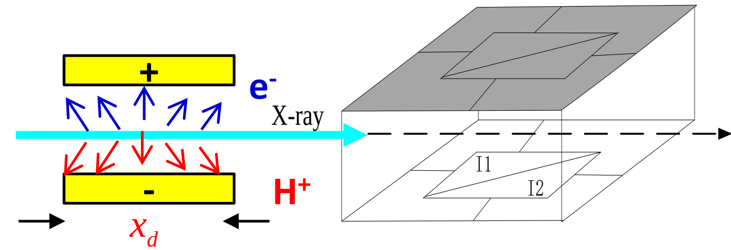


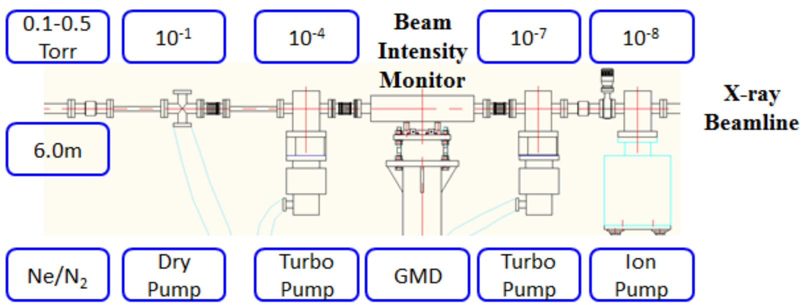


Blazed angle: 1-2°

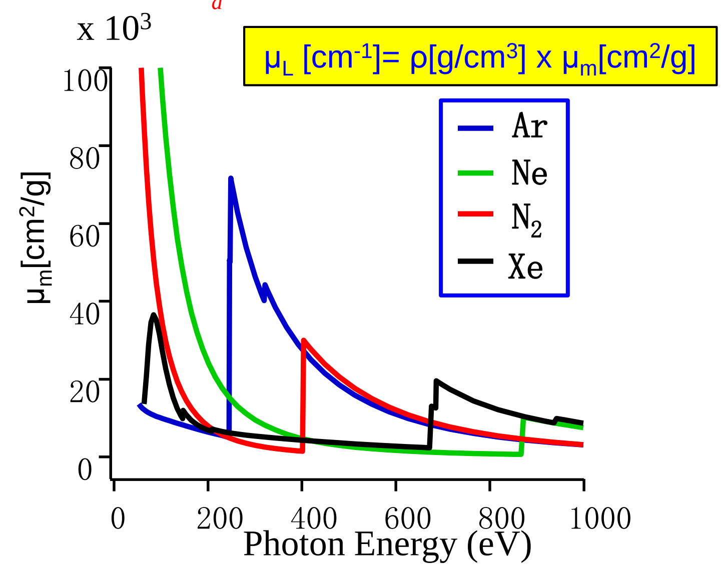
1) X-ray Gas Attenuation & Gas Monitor Detector



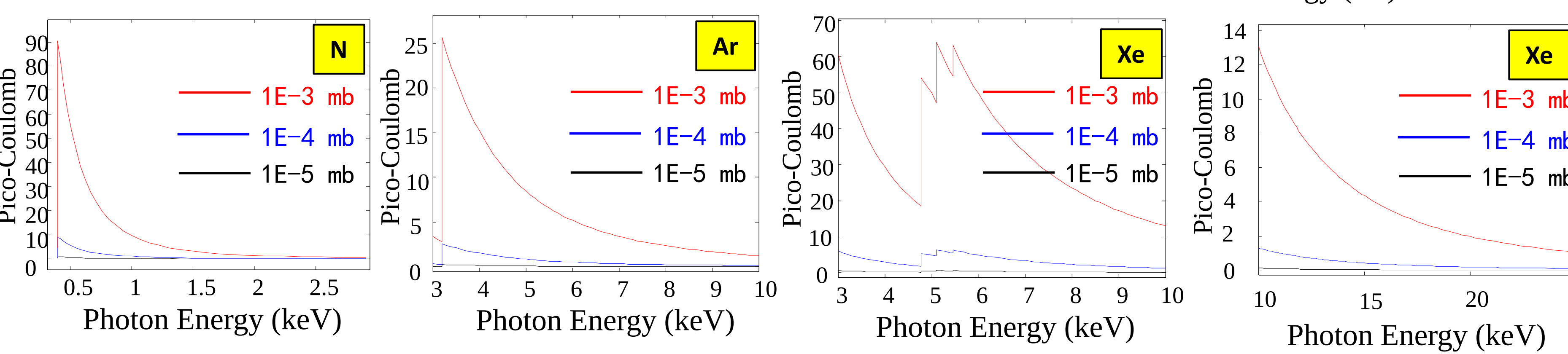




$$I(x) = I_0 \cdot \exp[-\mu_L \cdot x]$$



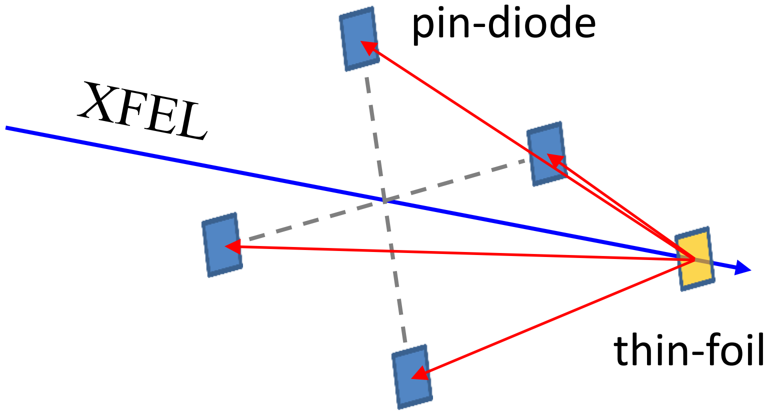
XFEL pulse (single-shot) induced Charge in GMD

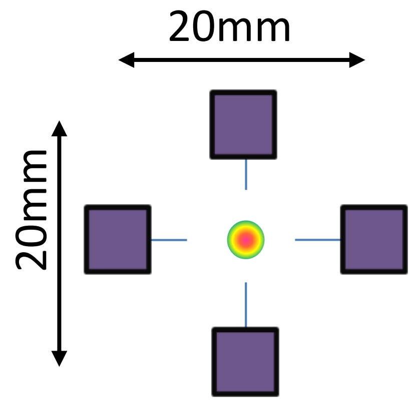


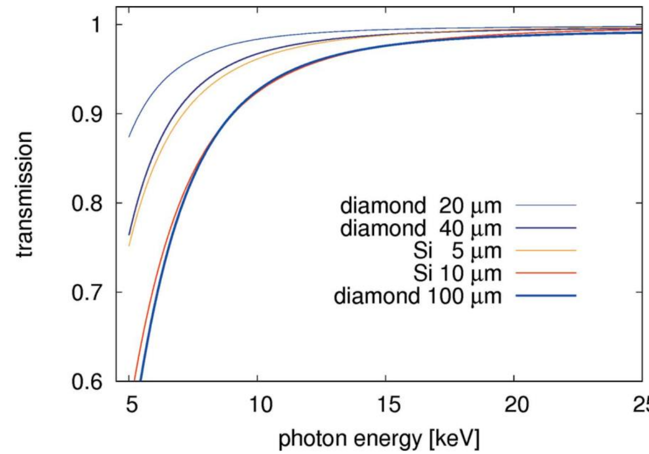
$$Q_c = \eta \cdot \times [1 - \exp(-\mu_L \cdot x_d)] \times N_{ph} \cdot \frac{E_{ph}}{E_b} \times e \approx \eta \cdot \mu_L \cdot x_d \cdot \frac{E_{pulse}}{E_b} \times e$$

Average Current: $I_c = Q_c \times Rep\_rate$

2) Back-scattering On-line X-ray Intensity/Position Detector



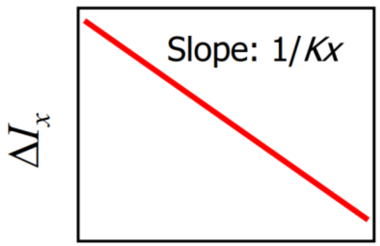


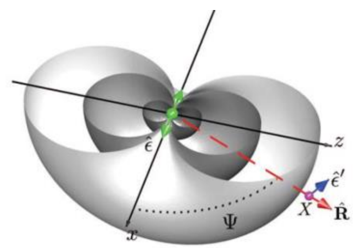


Intensity $I \propto (I_L + I_R + I_U + I_D)$

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

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

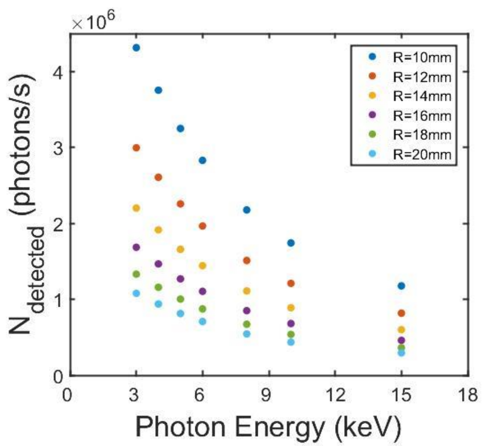




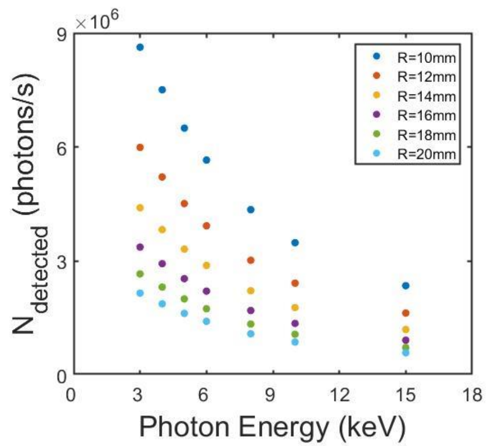
$$\frac{E_{rad}(R,t)}{E_{in}} \propto \left(\frac{e^2}{m}\right)\frac{e^{ikR}}{R}\sin\Psi$$

'Scattering Photon #' vs. 'Sample Distance' & 'Sample Thickness'

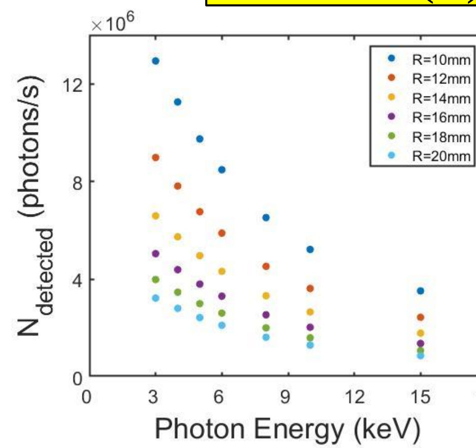
Diamond (C)



d=10 μm



d=20 μm

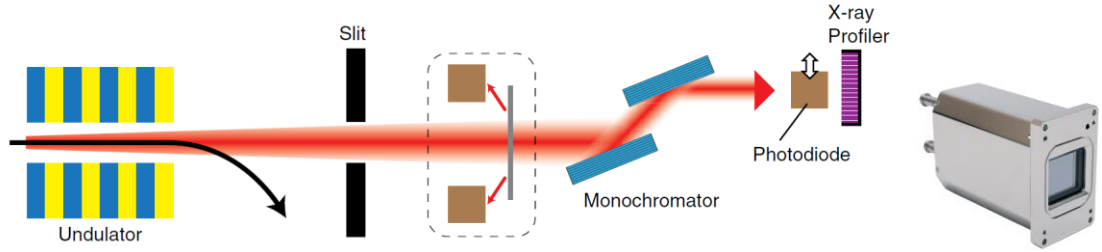


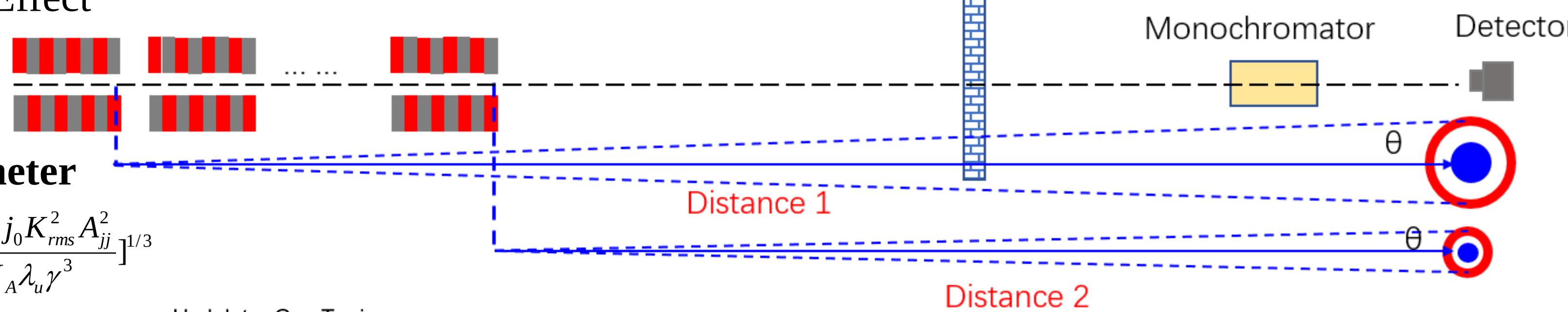
d=30 μm

3) XFEL Undulator Commissioning Device – K-mono

Undulator Gain

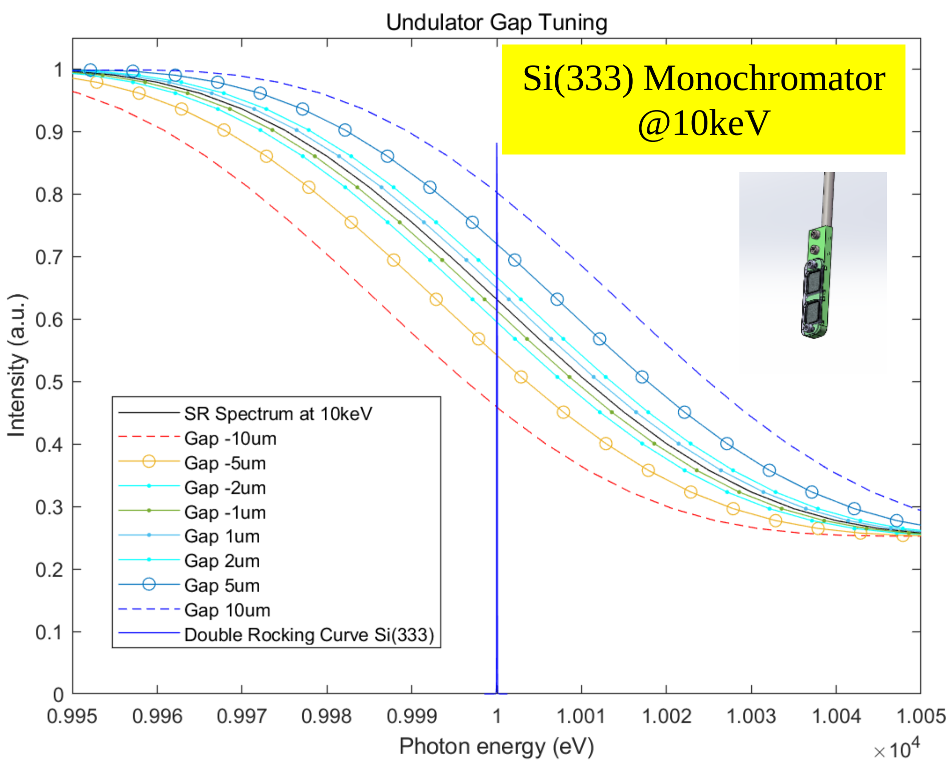
1) Beam Trajectory
2) Undulator Magnet Pole Field:
   A) Beam Height Position, B) Magnet Gap
3) Intersection Phase
4) Wake Field Effect



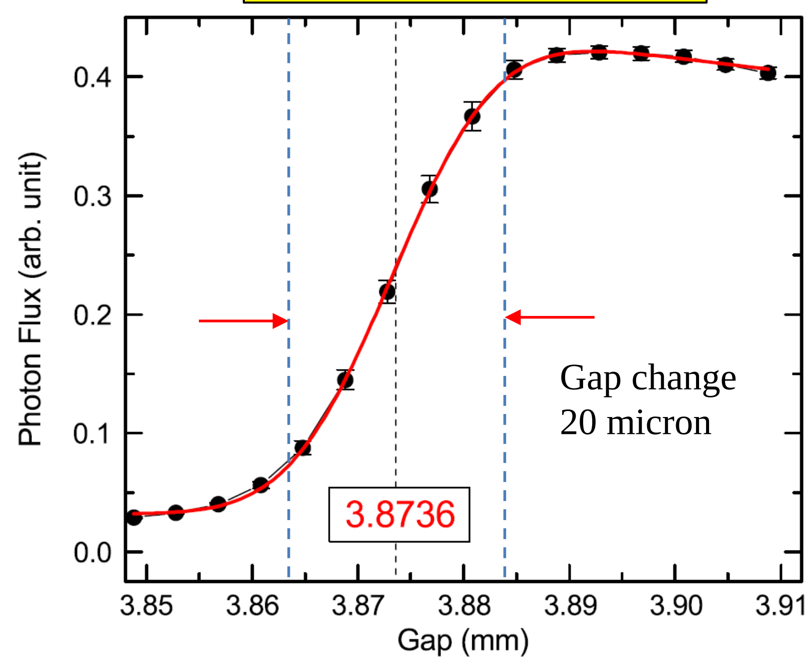


Pierson Parameter

$$\rho_{1D} = \frac{\lambda_u}{4\pi}\left[\frac{4\pi^2 j_0 K_{rms}^2 A_{jj}^2}{I_A \lambda_u \gamma^3}\right]^{1/3}$$



Resolution power > 1/ρ



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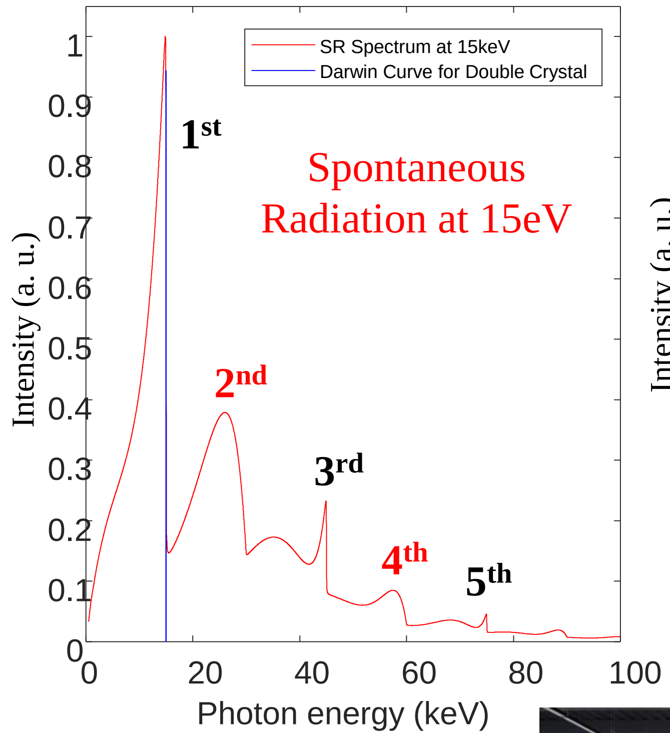
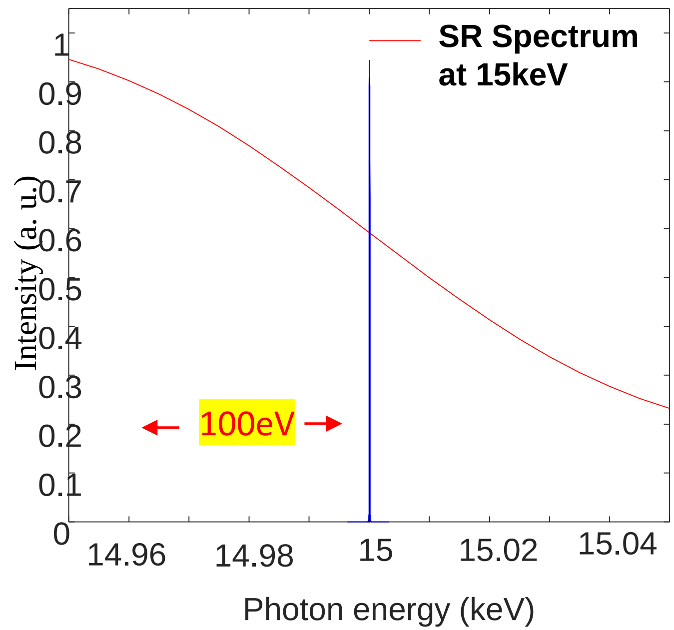
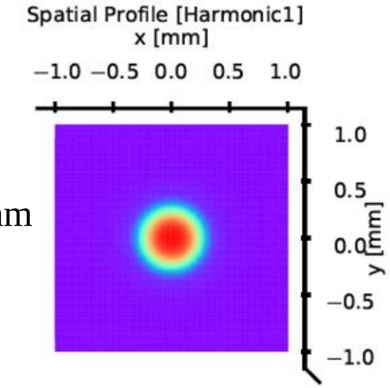




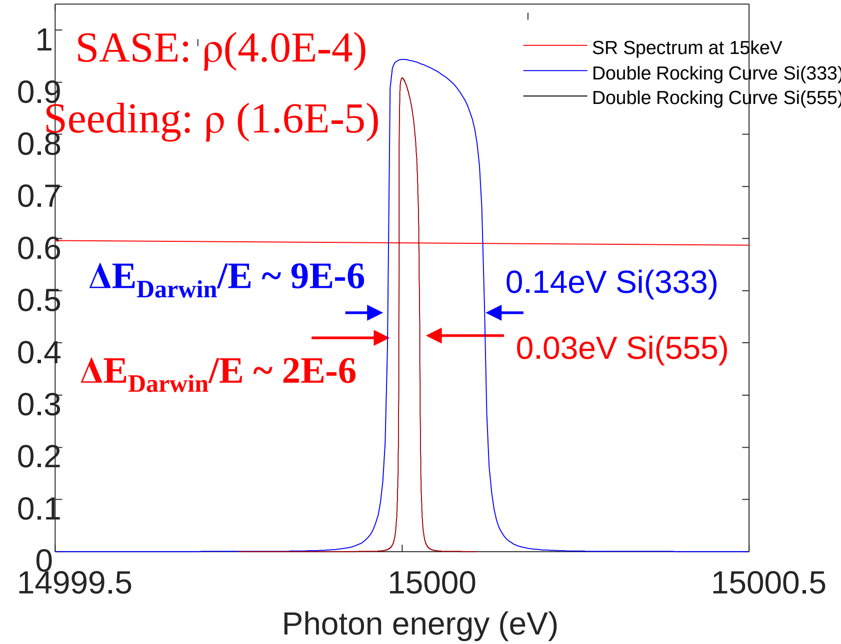


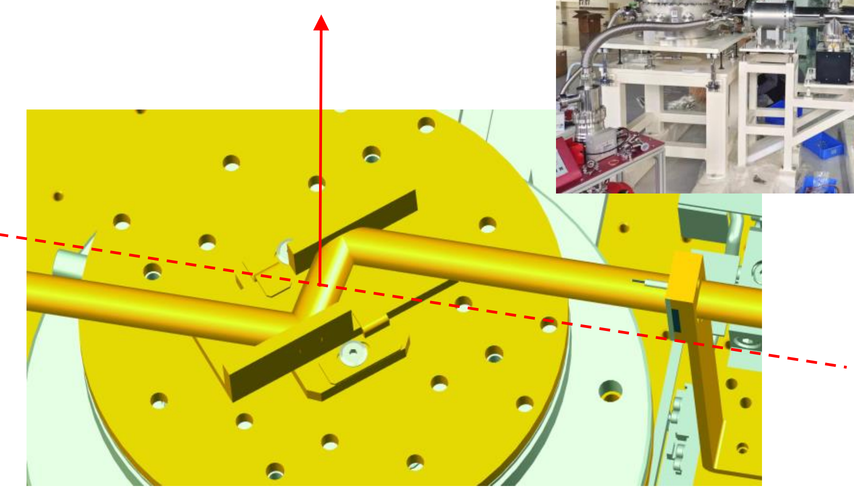
Beam size: 1.17-2.34 mm (FWHM)

Photon # per pulse after Si(333) K-mono: 3.1×10^3

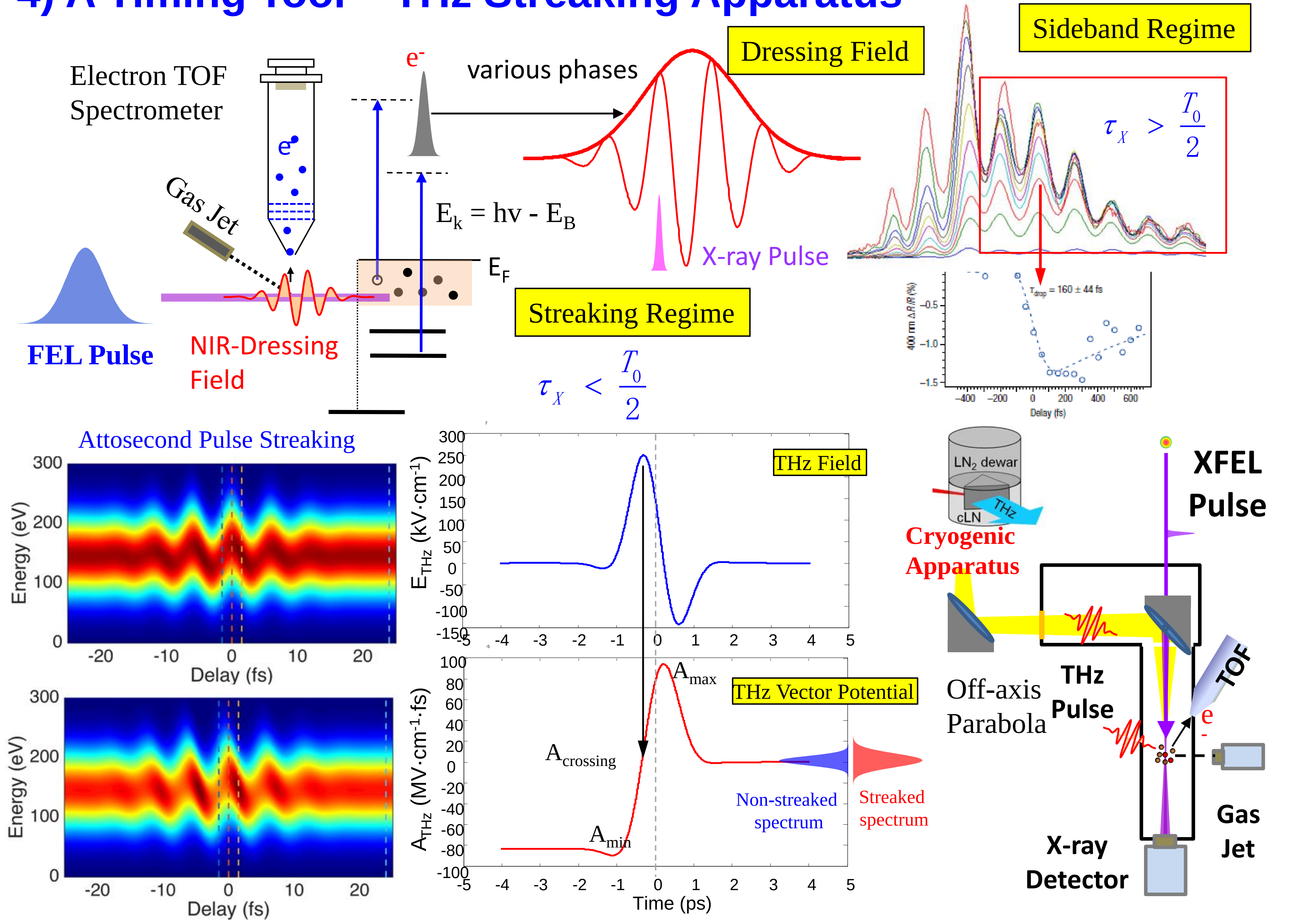
Photon #/pixel/pulse: 0.41-0.10

K-mono for FEL-I (SHINE)



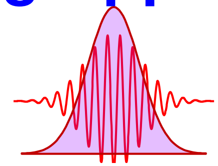


4) A Timing Tool – THz Streaking Apparatus



4) A Timing Tool – THz Streaking Apparatus

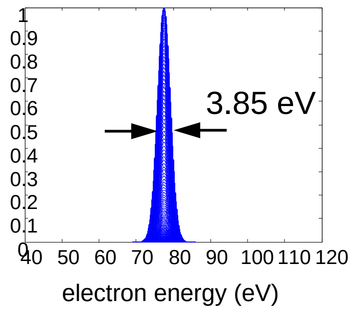
THz Field Strength: ~ **0.3 MV/cm**



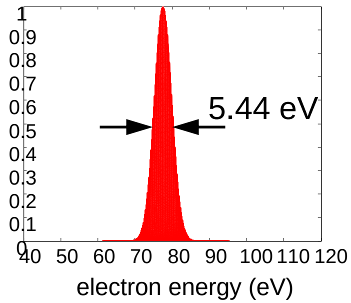
Pulse Length

Pulse Arrival Time

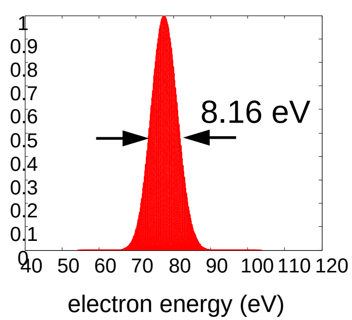
Non-streaked XUV Spectrum



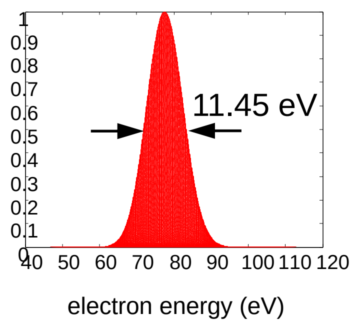
E_{THz} ~100kV/cm



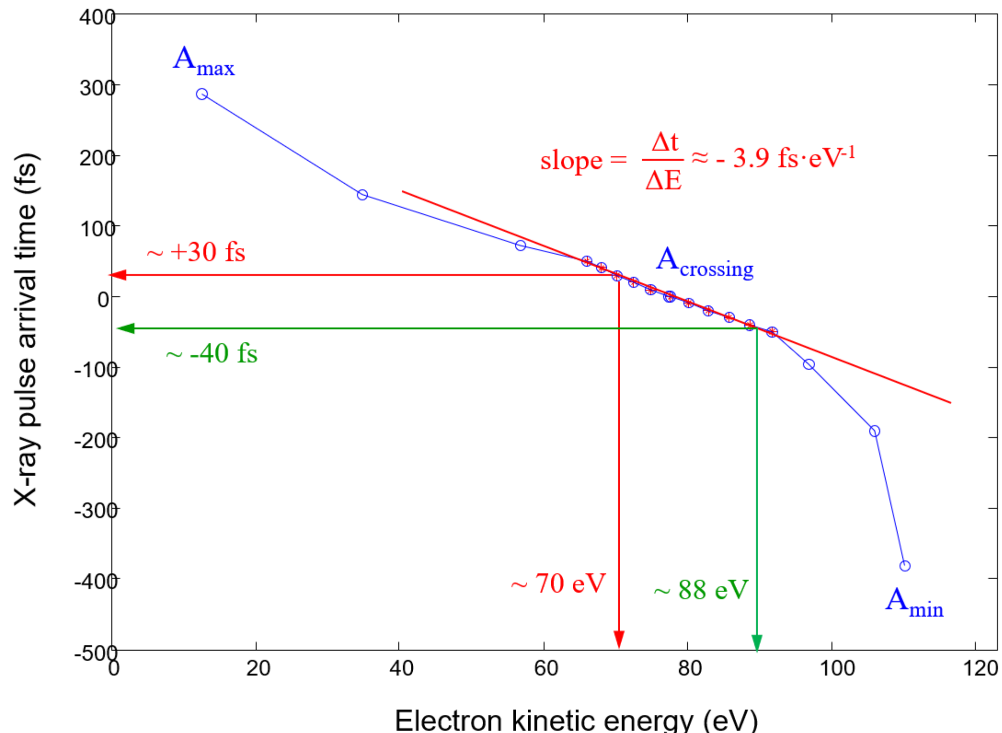
E_{THz} ~200kV/cm



E_{THz} ~300kV/cm

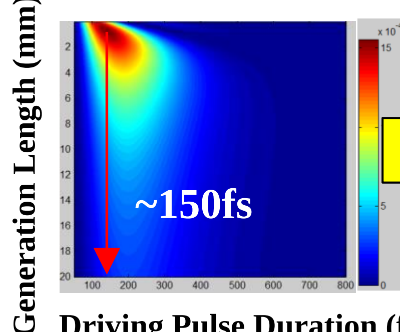


Simulation for X-ray pulse arrival time



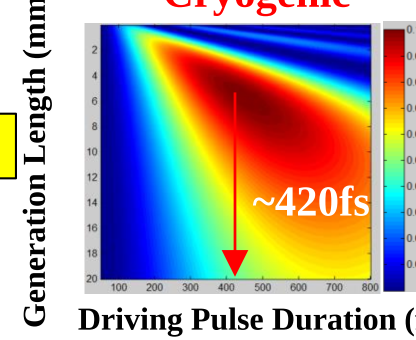
"Chromatic effect in a novel THz generation scheme", **New Journal Physics,** vol.**19**, pp.113025 (2017).

Room Temp.



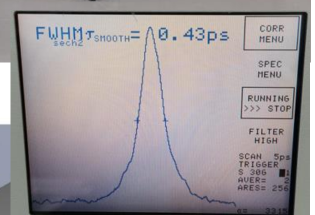
α = 10cm^{-1}

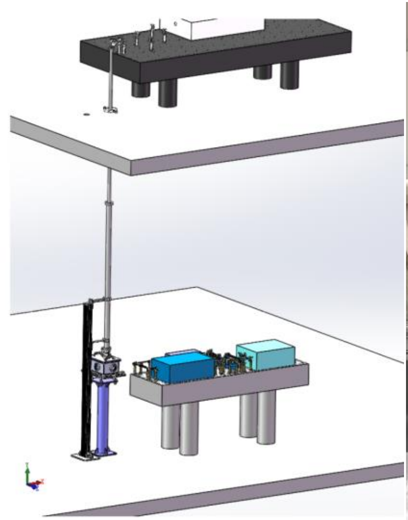
Cryogenic

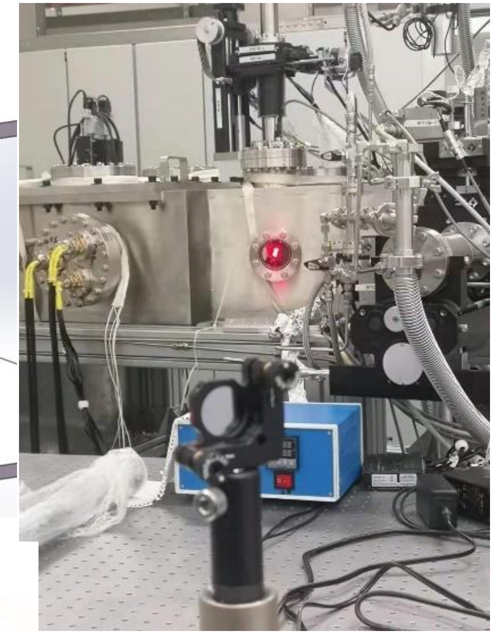


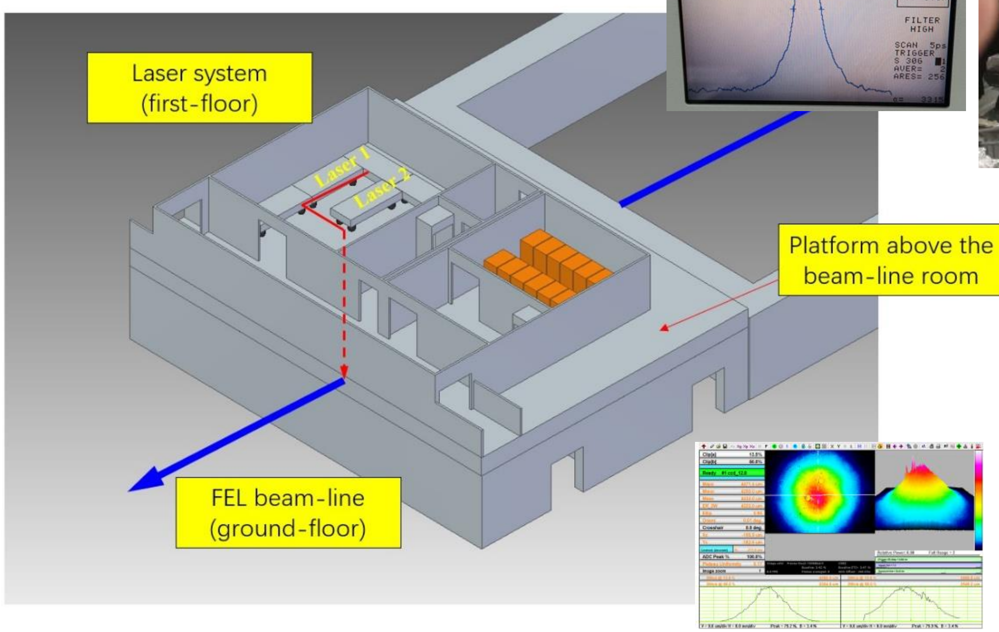
α = 1cm^{-1}

4) A Timing Tool – THz Streaking Apparatus









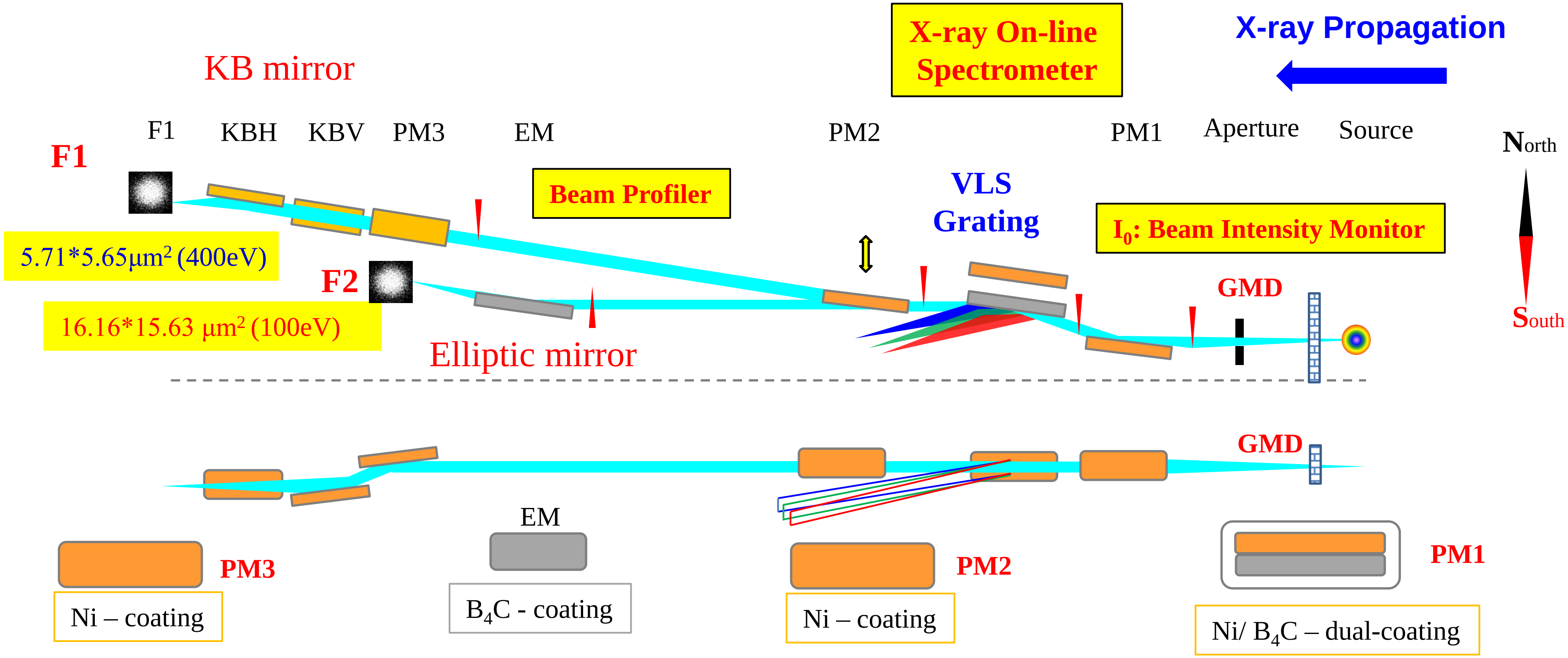
Outline

1. Overview of photon diagnostics development

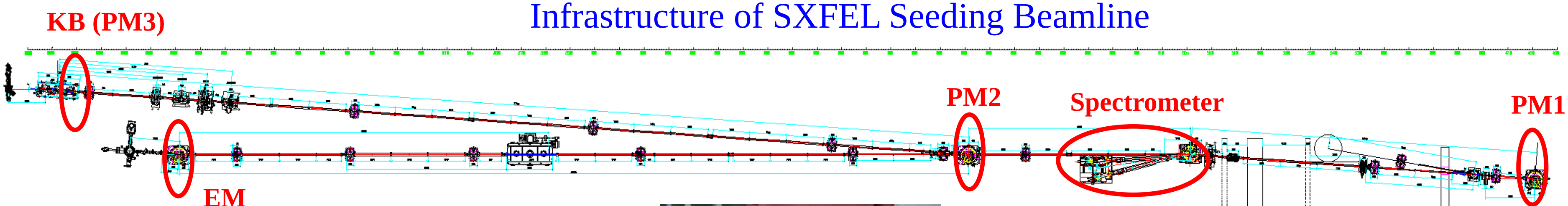
2. High resolution X-ray spectrometer

3. X-ray coherence apparatus and measurement

The Beam-line Layout for Seeded SXFEL (UF)



Infrastructure of SXFEL Seeding Beamline



Photon Energy

100eV-620eV

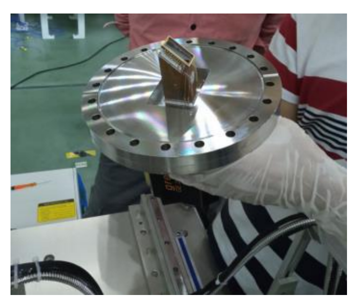
Pulse Length

50-200fs

Bandwidth

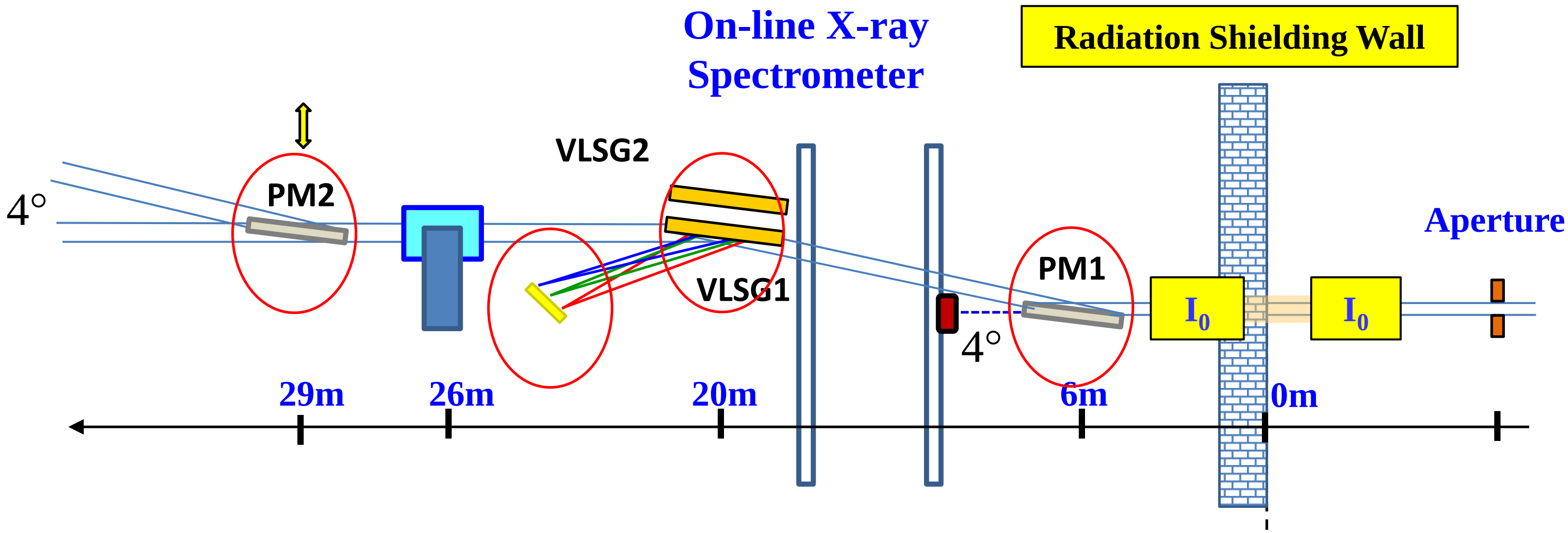
~0.03% (100eV)

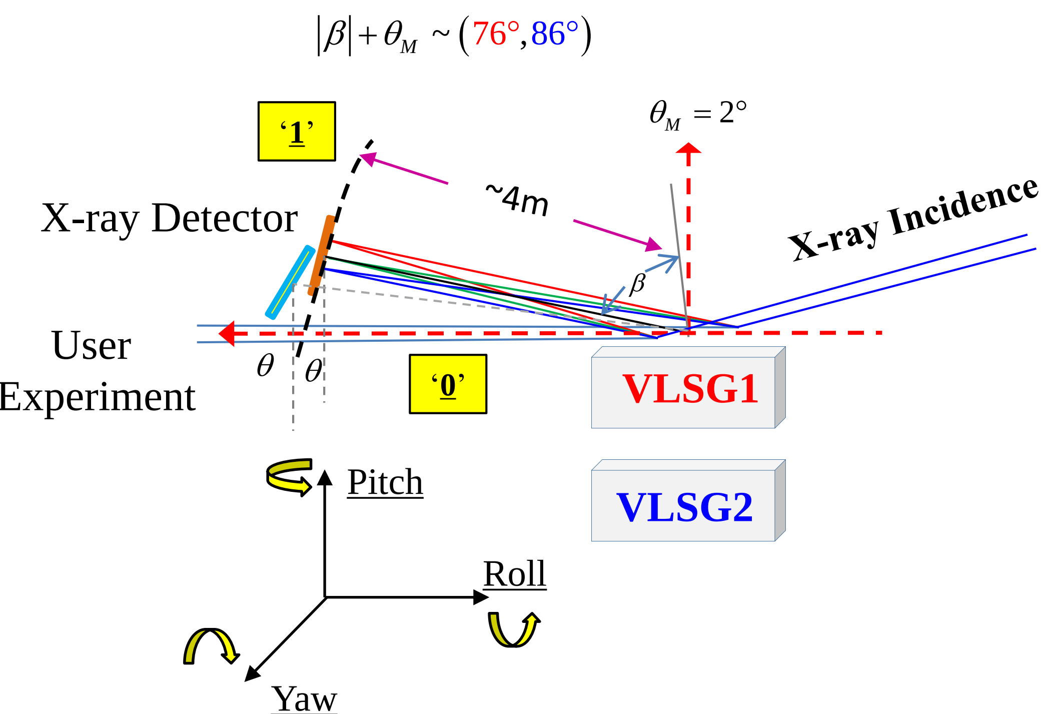
0.01~0.02% (200-400eV)



- VLS Grating Soft X-ray Spectrometer

Development of X-ray spectrometer



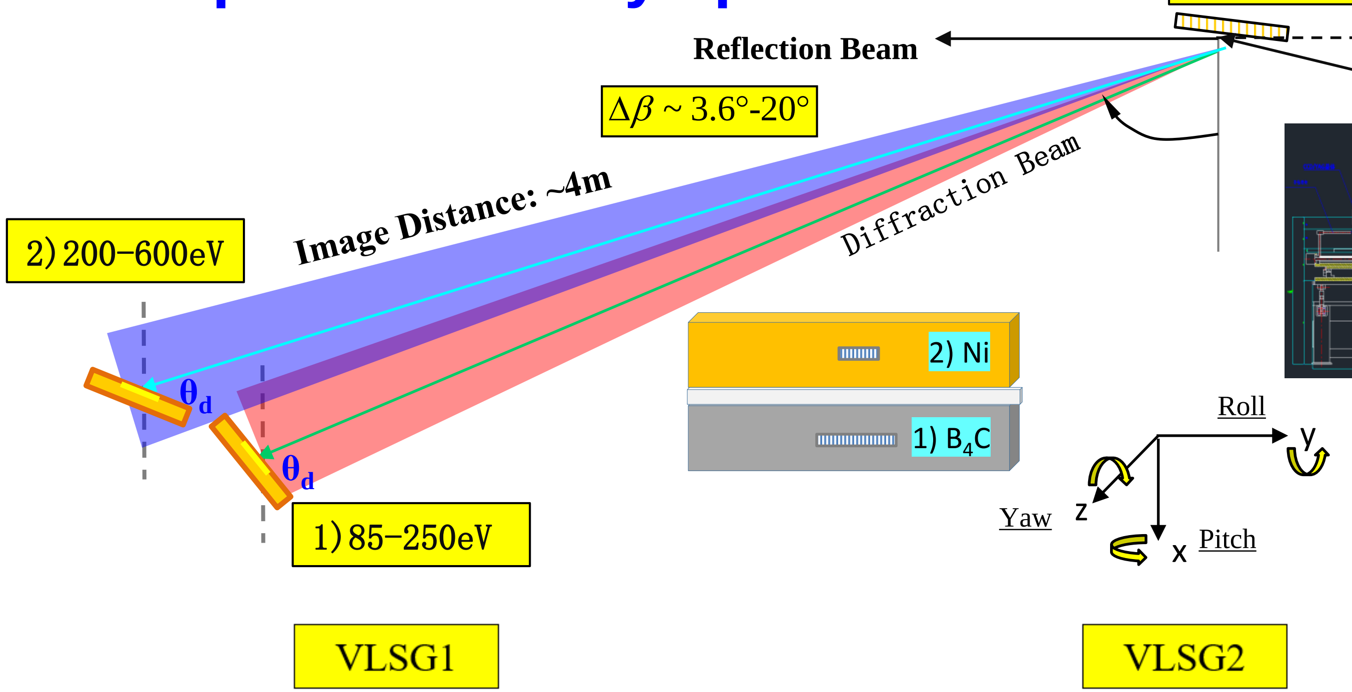


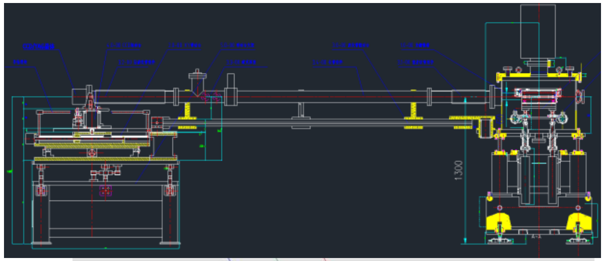
Variable line spacing (VLS) Law

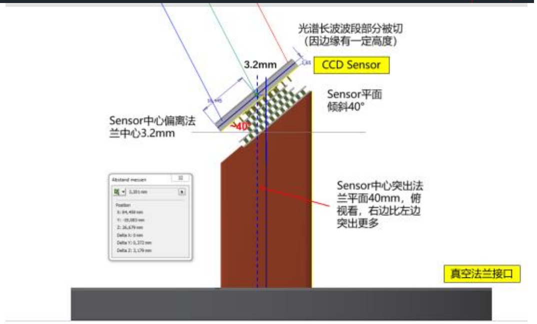
$$n(w) = D_0 + D_1 w + D_2 w^2 + D_3 w^3$$

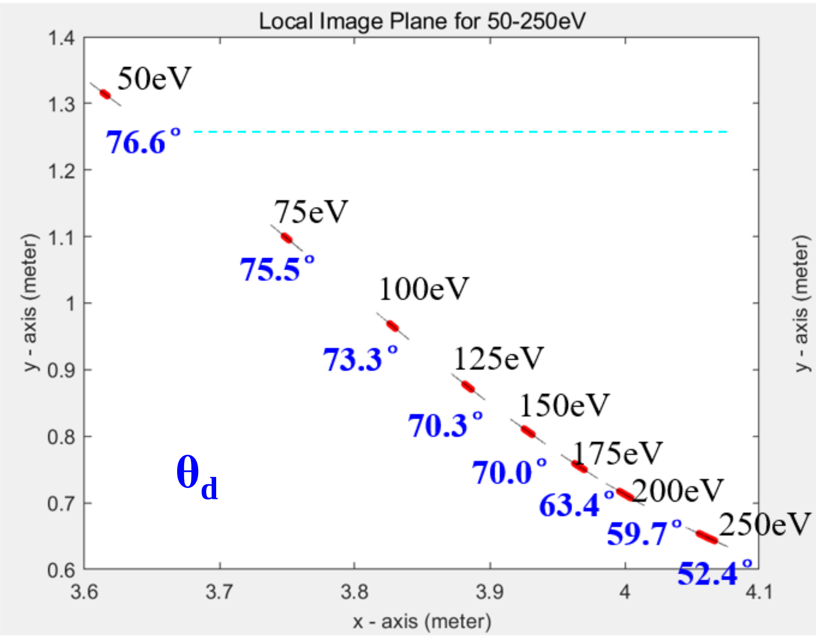
x [mm]	y [mm]	Groove density [mm^{-1}]
-40		2347.595
-30		2360.461
-20		2373.389
-10		2386.339
0	0	2399.336
+10		2412.377
+20		2425.454
+30		2438.575
+40		2451.735

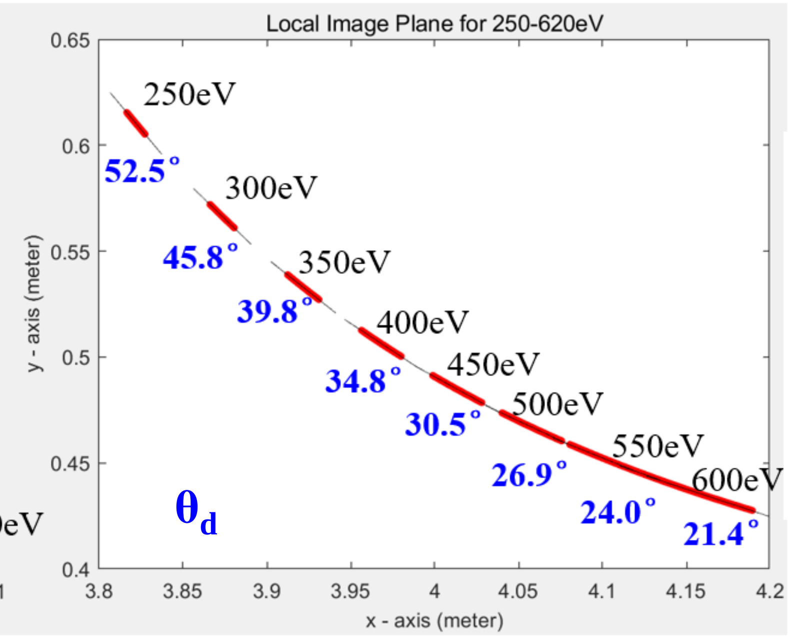
Development of X-ray spectrometer

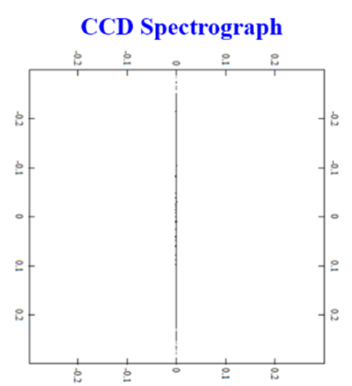










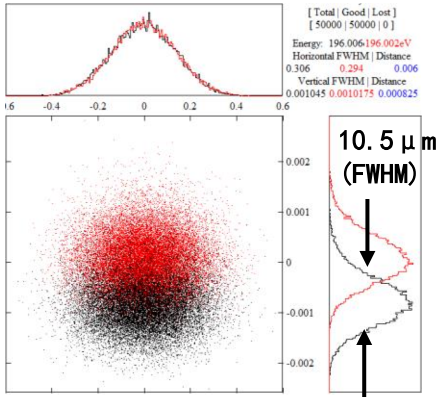


Ray Tracing to Verify the Resolving Power

1. The Resolving Power for VLSG1: 85-250eV (5-15nm)

196eV

196.0047eV

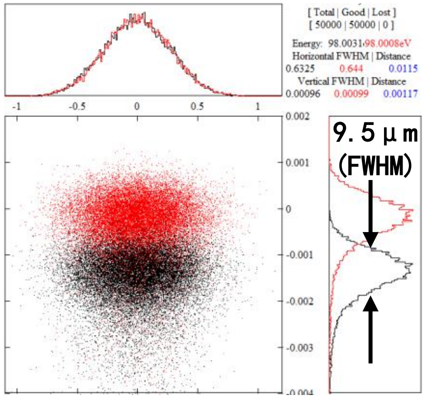


Source Size: 300μm (rms)
Divergence: 22μrad (rms)

$$\frac{E}{\Delta E} \sim 2.5\times10^4$$

98eV

98.00233eV

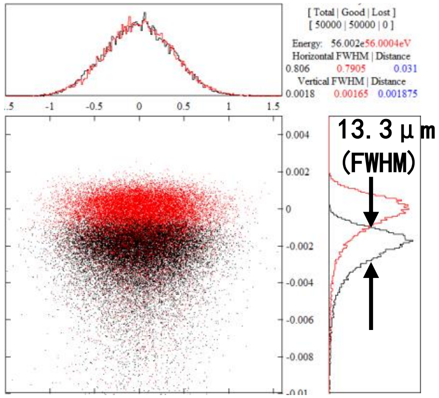


Source Size : 380μm (rms)
Divergence : 44μrad (rms)

$$\frac{E}{\Delta E} \sim 3.6\times10^4$$

56eV

56.0018eV



Source Size : 700μm (rms)
Divergence : 60μrad (rms)

$$\frac{E}{\Delta E} \sim 4.2\times10^4$$

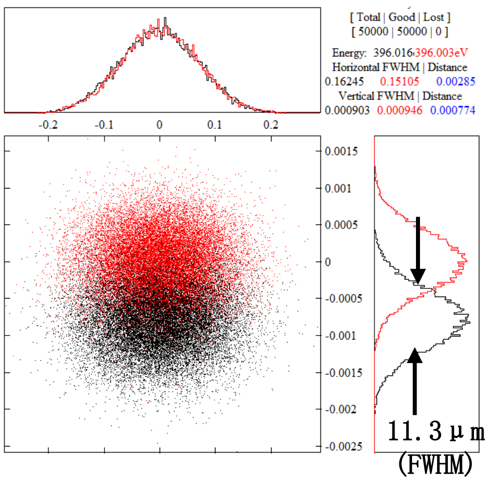
Slope Errors: Meridional 0.5μrad, Sagittal 2μrad

Ray Tracing to Verify the Resolving Power

2. The Resolving Power for VLSG2: 200-600eV (2-6nm)

396eV

396.0132eV

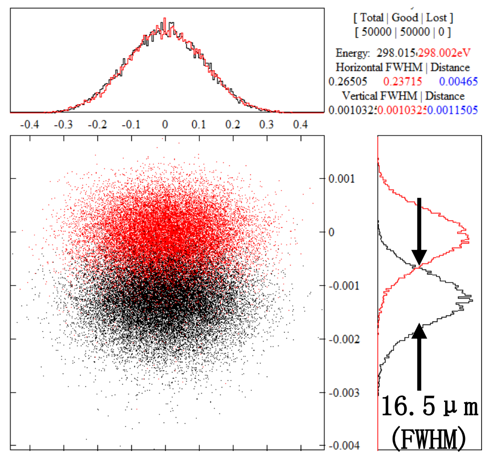


Source Size : 160μm (rms)
Divergence : 11μrad (rms)

$$\frac{E}{\Delta E} \sim 2.1\times10^{4}$$

298eV

298.0123eV

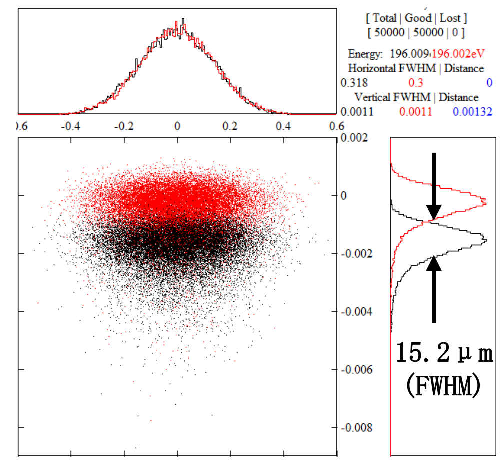


Source Size : 270μm (rms)
Divergence : 18μrad (rms)

$$\frac{E}{\Delta E} \sim 2.2\times10^{4}$$

196eV

196.008eV



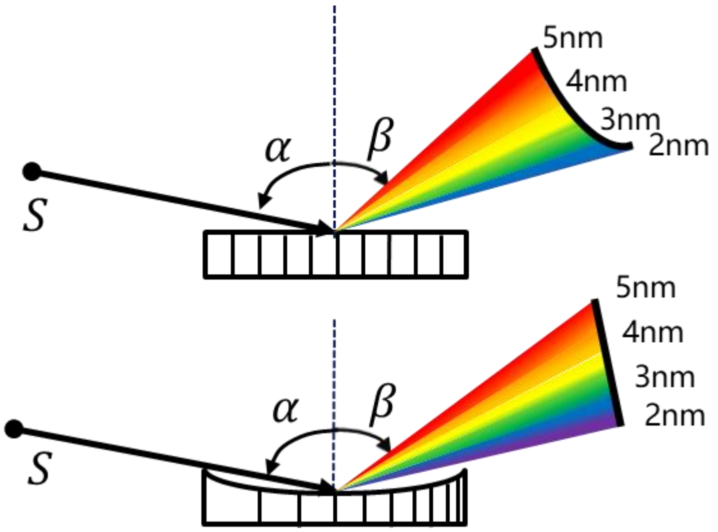
Source Size : 300μm (rms)
Divergence : 22μrad (rms)

$$\frac{E}{\Delta E} \sim 2.4\times10^{4}$$

Slope Errors: Meridional 0.5μrad, Sagittal 2μrad

Sagittal Confined High-resolution Broadband Spectrometer

Resolving Power



Spectral Intensity

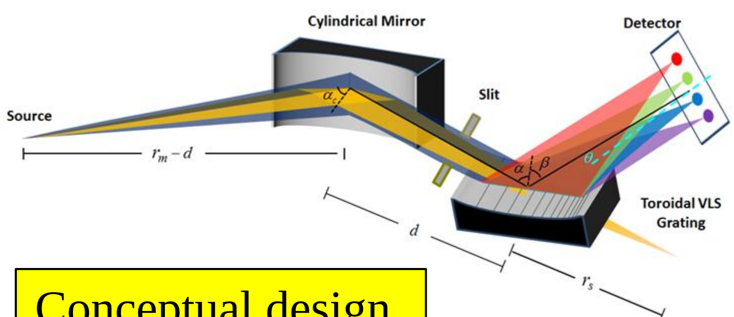
"Water window" (2–5 nm) provides excellent contrast for C or O atoms and components

$$n(w) = \frac{1}{d_0}\left(1 + \frac{2b_2}{R}w + \frac{3b_3}{R^2}w^2 + \frac{4b_4}{R^3}w^3 + \dots\right) \quad [1]$$

Letting $D_0 = (1/d_0)$, $D_1 = (2b_2/d_0R)$, $D_2 = (3b_3/d_0R^2)$, $D_3 = (4b_4/d_0R^3)$, equation (1) is simplified to

$$n(w) = D_0 + D_1 w + D_2 w^2 + D_3 w^3 \quad [2]$$

Implementing varied line spacing (VLS) grating on concave substrate



Conceptual design

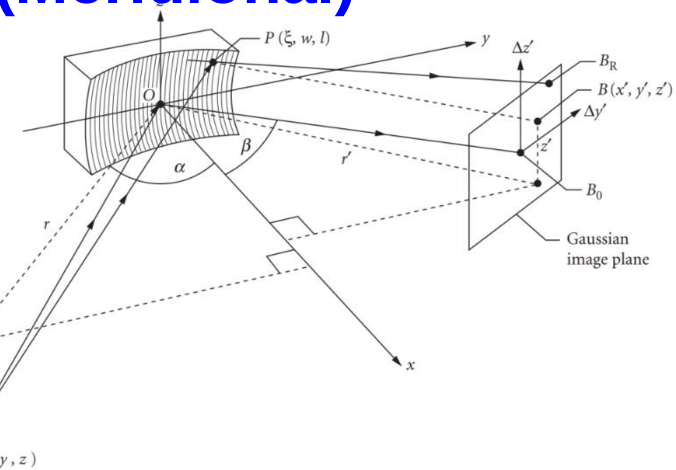
$$r_{20}'(\lambda) = \frac{\cos^2\beta(\lambda)}{D_1(\lambda_0)\, m\lambda - \left(\frac{\cos^2\alpha}{r_m} - \frac{\cos\alpha}{R}\right) + \frac{\cos\beta(\lambda)}{R}}$$

VLS Coefficient

Meridional Radius

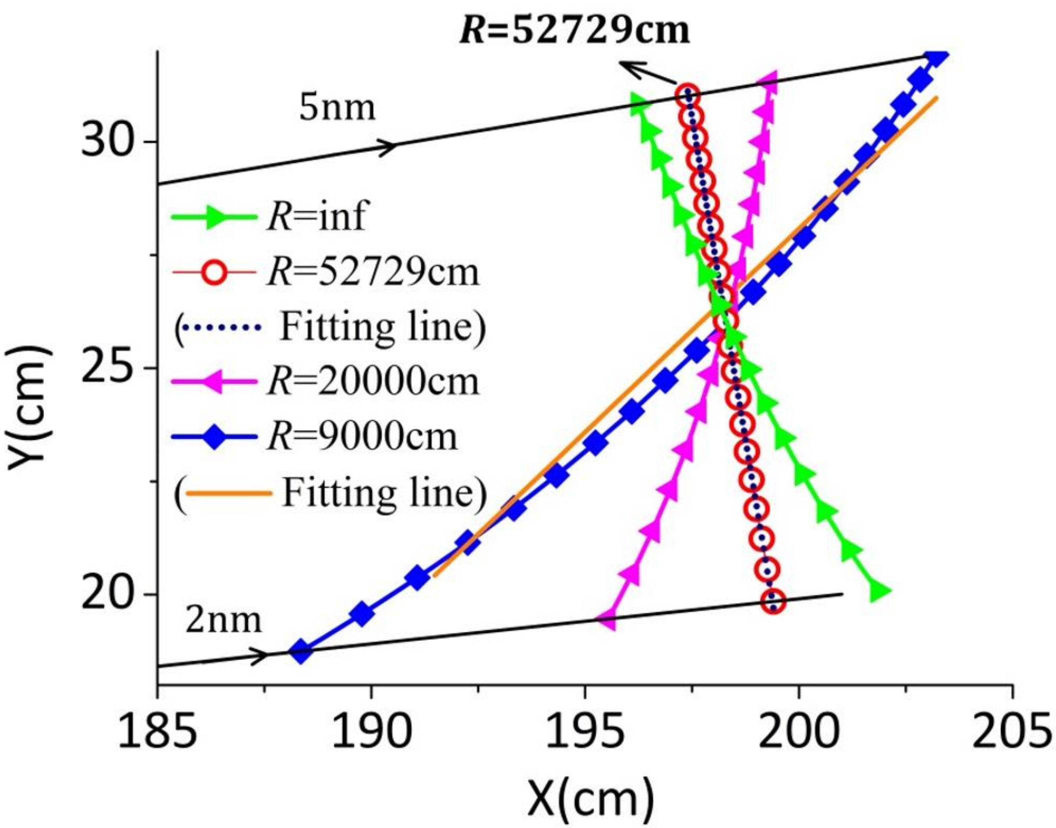
Achieve Flat-field in Detector Domain (Meridional)

$$r_{20}'(\lambda) = \frac{\cos^2\beta(\lambda)}{D_1(\lambda_0)\, m\lambda - \left(\frac{\cos^2\alpha}{r_m} - \frac{\cos\alpha}{R}\right) + \frac{\cos\beta(\lambda)}{R}}$$



An unique set of parameters for Optimal Design

e.g. Fixed Object Distance: r_m~10m
Image Distance: $r'_{20}(\lambda_0)$~2m



The first order VLS coefficient

$$D_1(\lambda_0) = \frac{1}{m\lambda_0}\left(\frac{\cos^2\alpha}{r_m} - \frac{\cos\alpha}{R}\right) + \frac{1}{m\lambda_0}\left[\frac{\cos^2\beta(\lambda_0)}{r'_{20}(\lambda_0)} - \frac{\cos\beta(\lambda_0)}{R}\right]$$

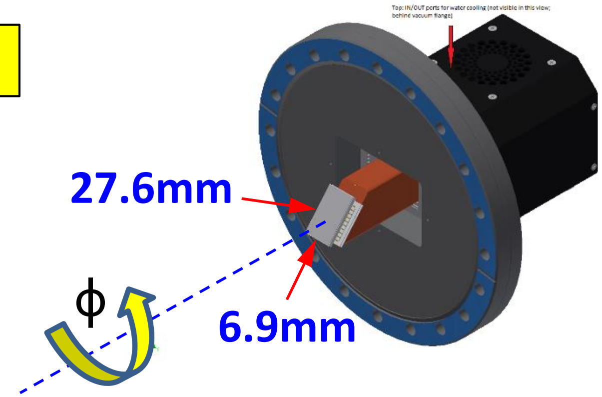
The deviation of the actual detection curve and ideal focal curve

$$\delta_m = \sqrt{\frac{\sum\left(r_{20}'(\lambda) - r'_{\text{detector}}(\lambda)\right)^2}{N}}$$

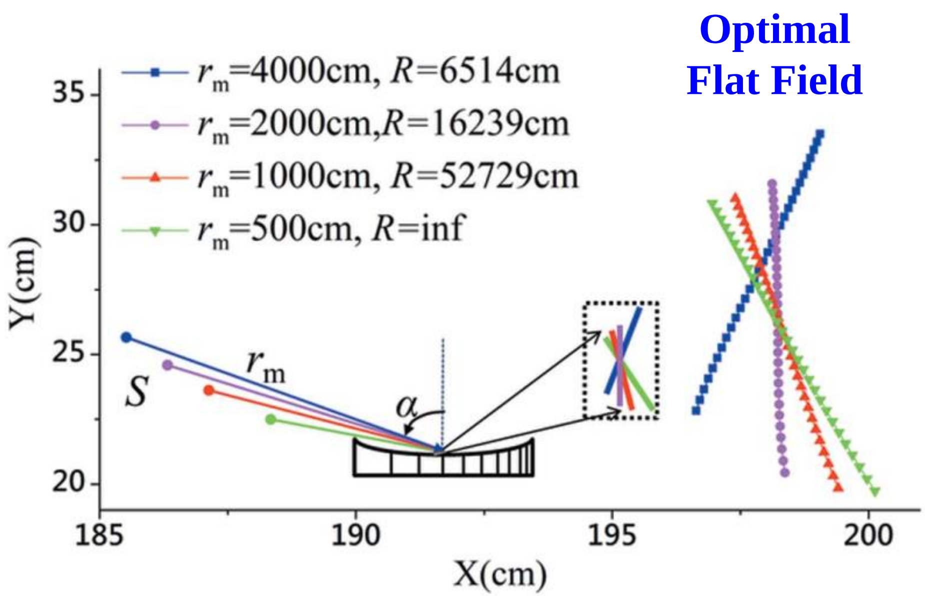
Optimal Design for Various Object Distances

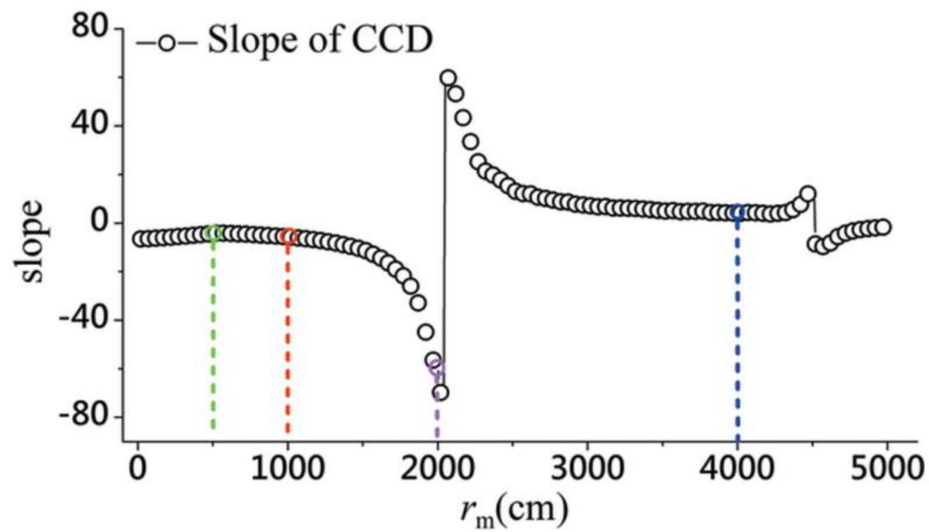
Monochromatic beam footprint on the detector

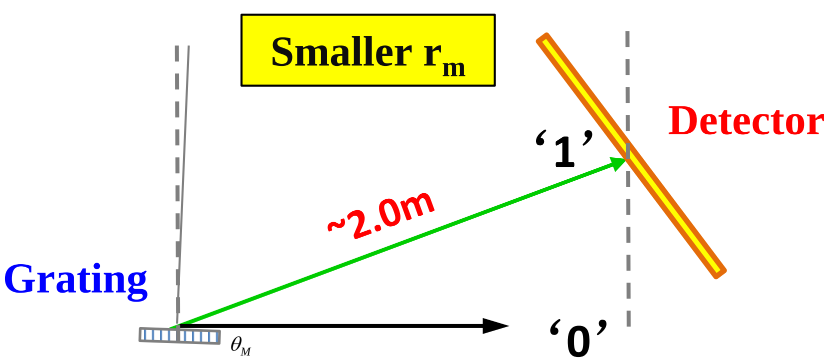
$$\sigma_{\mathrm{d}}^{(\mathrm{FWHM})} = \sigma_{\mathrm{S}}^{(\mathrm{FWHM})} \frac{\cos\alpha}{\cos\beta} \frac{r'_{20}}{r_{\mathrm{m}}} \frac{m}{\cos\theta}$$

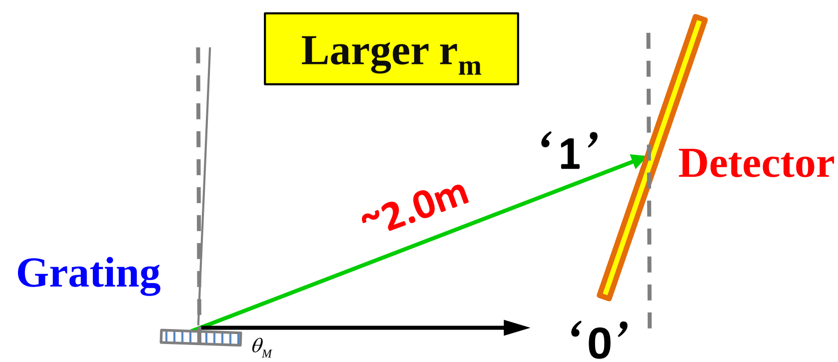


X-ray Detector



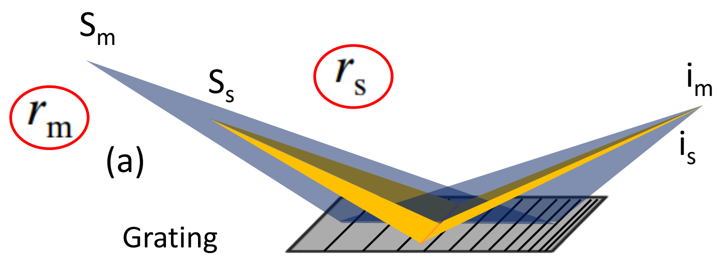




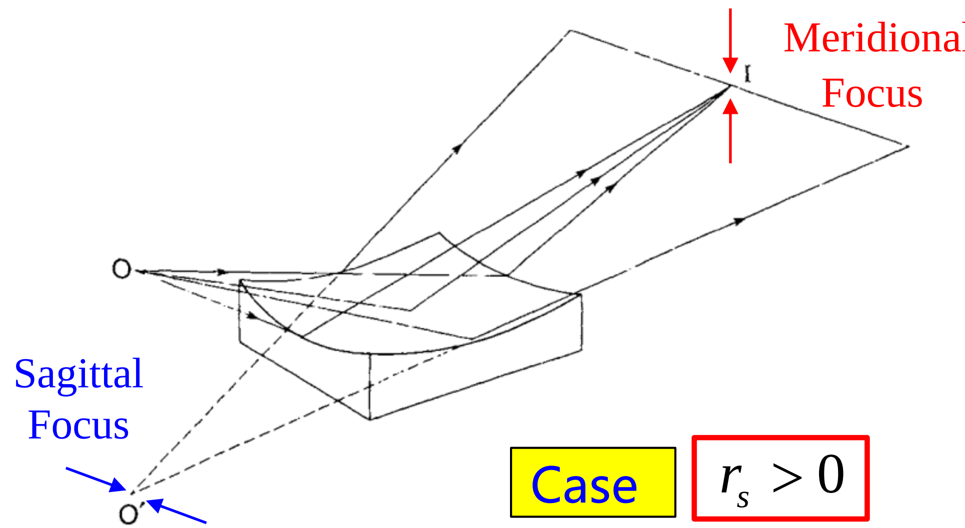


Sagittal Focus to Enhance the Spectral Intensity

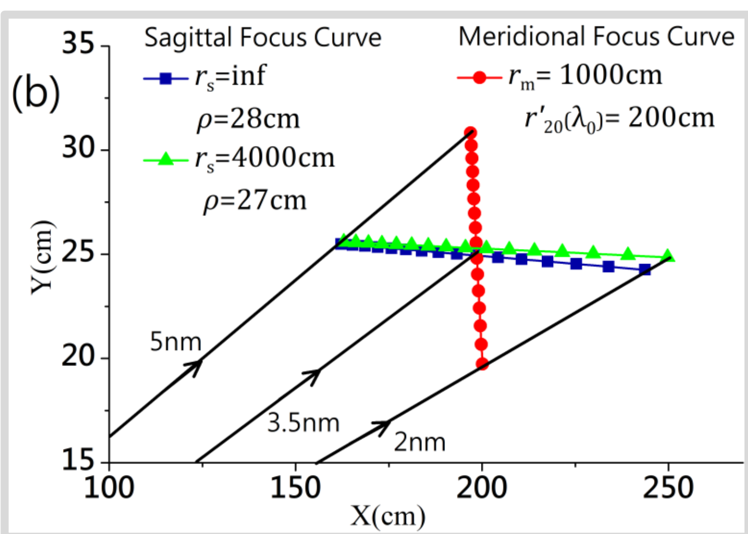
Flat or Spherical Substrates Cause 'Astigmatism'

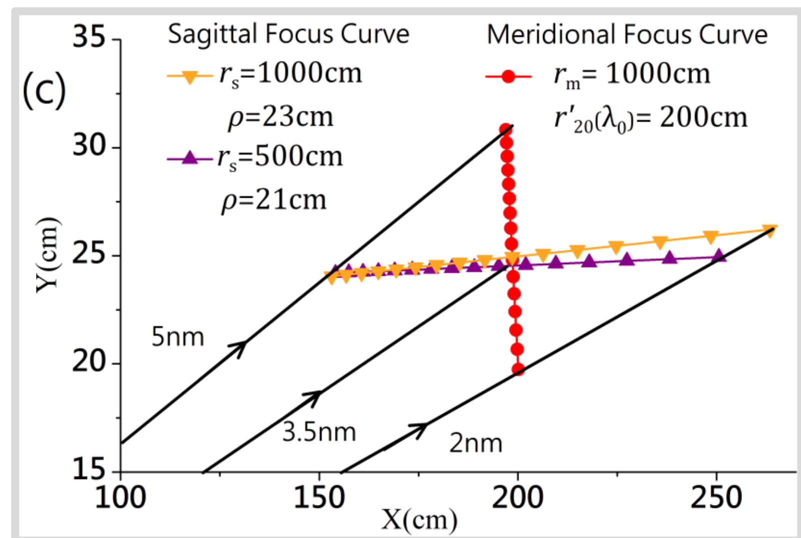


$$r_{02}'(\lambda) = \frac{1}{\dfrac{\cos\alpha + \cos\beta(\lambda)}{\rho} - \dfrac{1}{r_s}}$$



Case $r_s > 0$

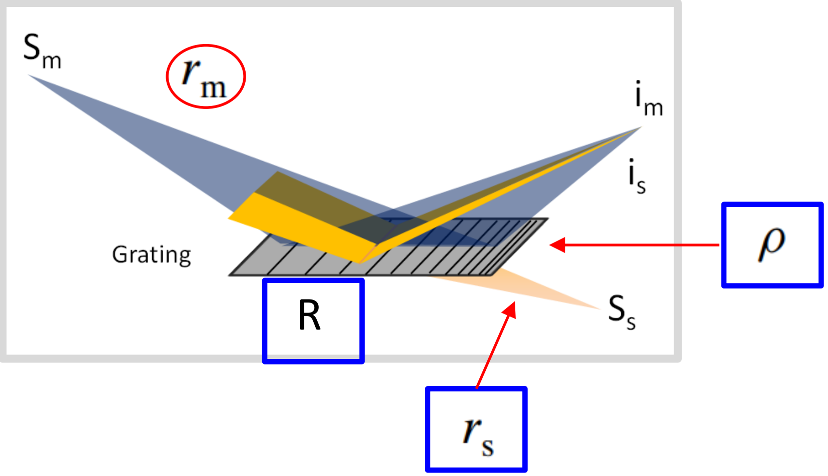




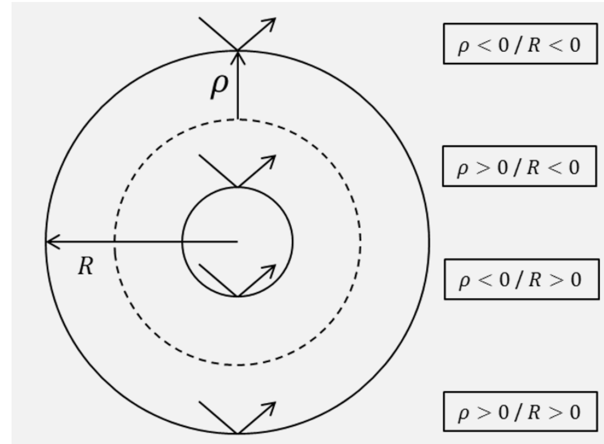
The "positive" sagittal object distance can't correct "Astigmatism" for the whole photon energy range.

Sagittal Focus to Enhance the Spectral Intensity

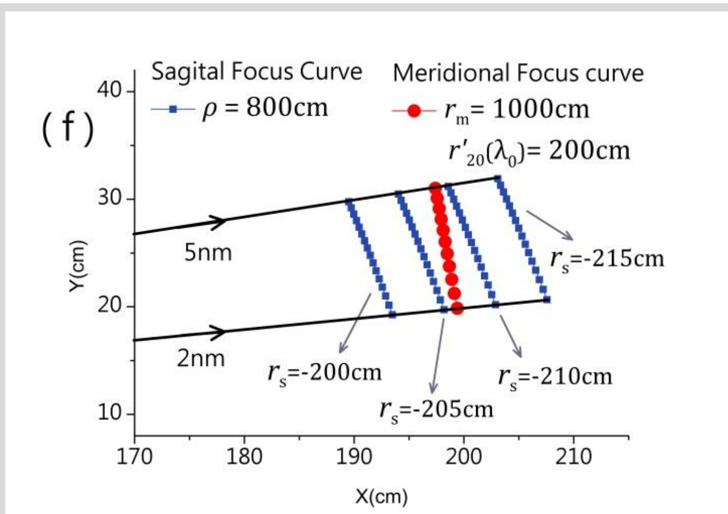
Sources in "Meridional" or "Sagittal" separated

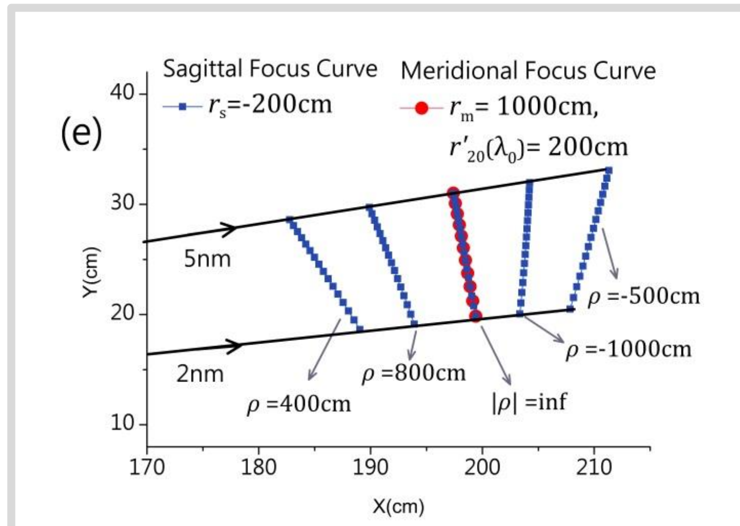


Various Toroidal Profile



Case $r_s < 0$

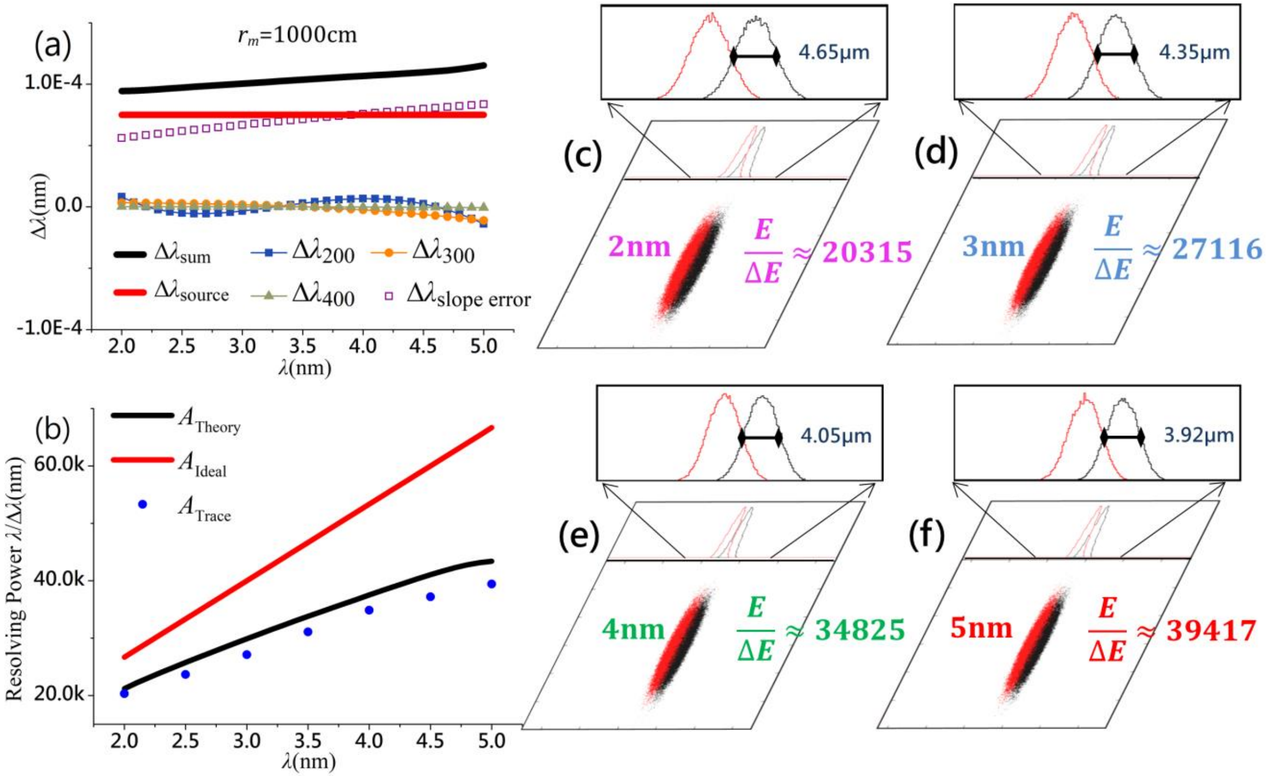




The sagittal object distance 'r_s' (negative) and sagittal radius of the grating 'ρ' are two variables for system optimization!

Demonstrate High Resolving Power for Sagittal Confined Spectrometer

Effective Meridional Size: 50μm(rms)
Divergence Angle: 20μrad(rms)



$$\sigma_{\mathrm{d}}^{(\mathrm{FWHM})} = \sigma_{\mathrm{S}}^{(\mathrm{FWHM})} \frac{\cos\alpha}{\cos\beta} \frac{r'_{20}}{r_{\mathrm{m}}} \frac{m}{\cos\theta}$$

Realistic Beam Foot-print @ Detector

Sagittal Beam Size @ Detector For the Overall Energy Range

< 50μm

Ideal Resolution $$A_{\mathrm{ideal}} = \frac{\lambda r_{\mathrm{m}} D_0}{\sigma_{\mathrm{s}}^{(\mathrm{FWHM})} \cos\alpha}$$

Realistic Resolution $$A_{\mathrm{theory}} = \frac{\lambda}{\Delta\lambda_{\mathrm{sum}}}$$

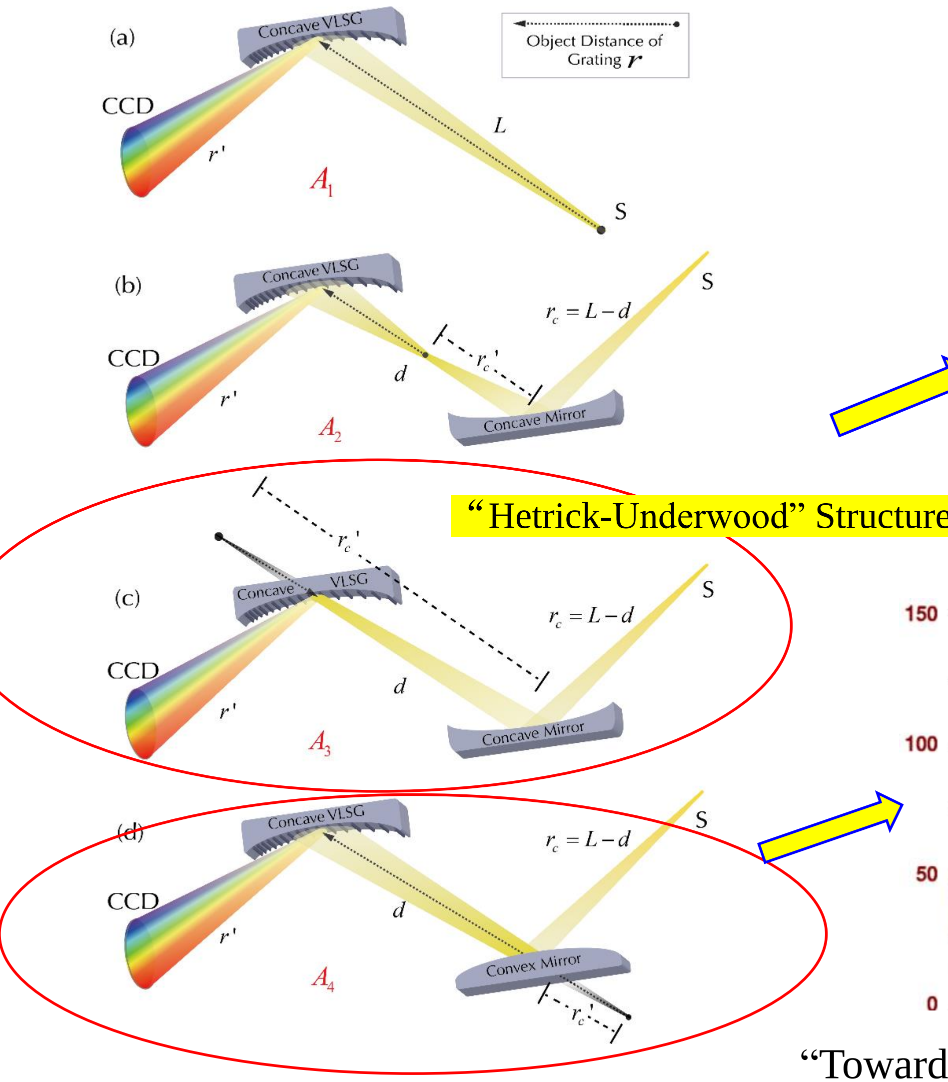
$$\simeq \lambda\left[\Delta\lambda_{\mathrm{so}}^2 + (\Delta\lambda_{200} + \Delta\lambda_{300} + \Delta\lambda_{400})^2 + \Delta\lambda_{\mathrm{se}}^2\right]^{-1/2}$$

Optimal Design Structure

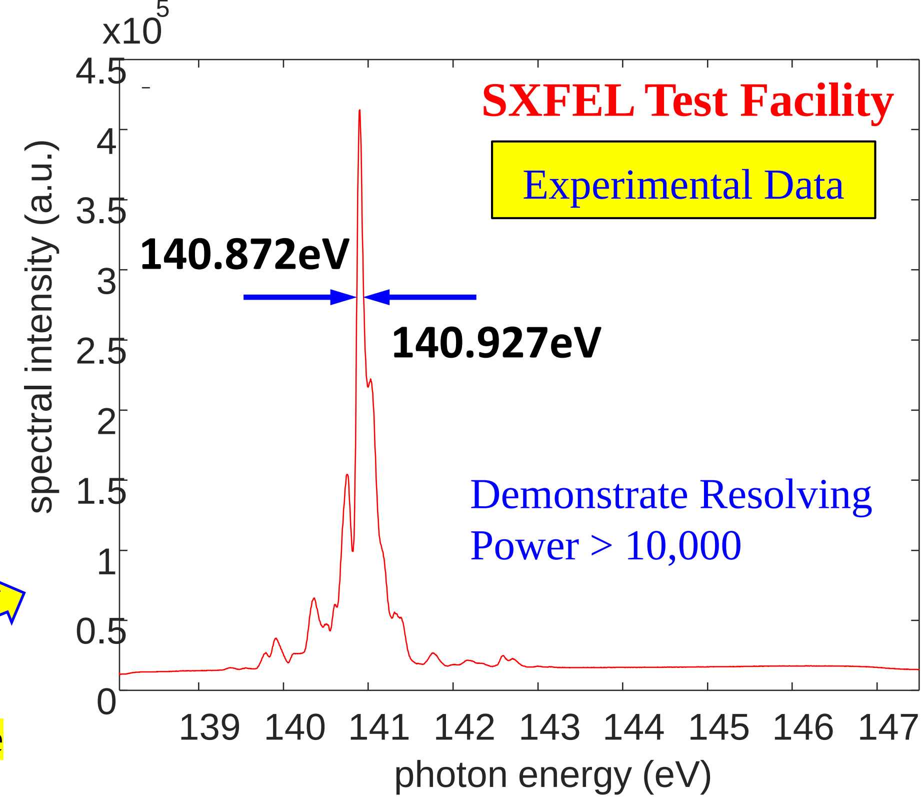
1. High resolution (20k-40k)
2. Intensity enhancement (sagittal <50μm)
3. Flat-field for entire water window

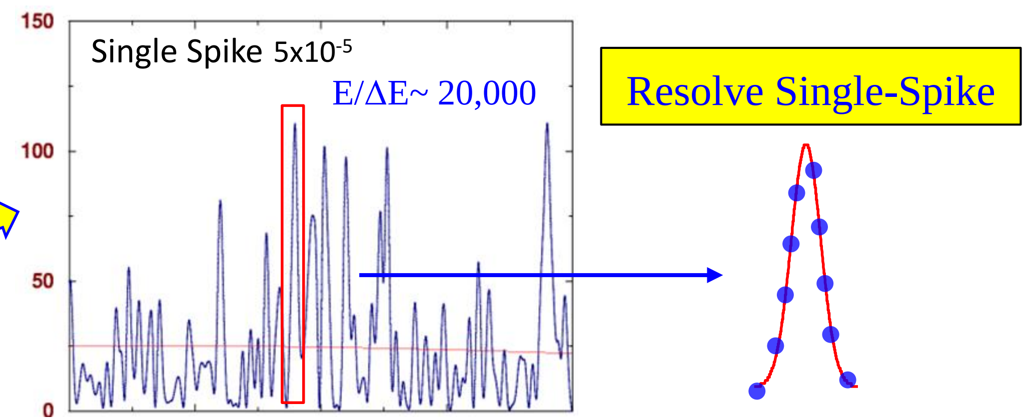
J. Synchrotron Radiation, vol.**25**, pp.738 (2018)

Pursuing Extremely High Resolving Power >100,000



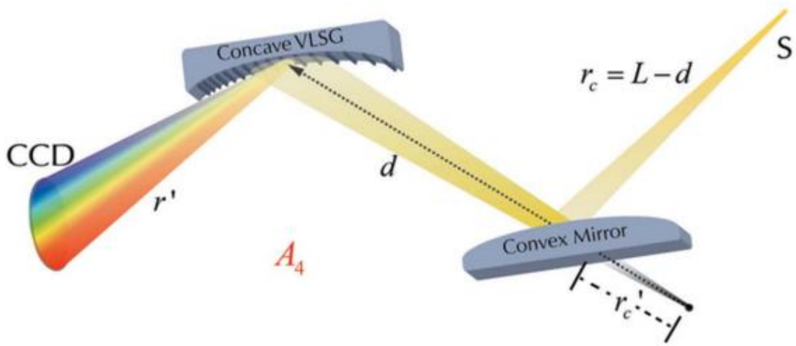
Desired Resolving Power > 100,000

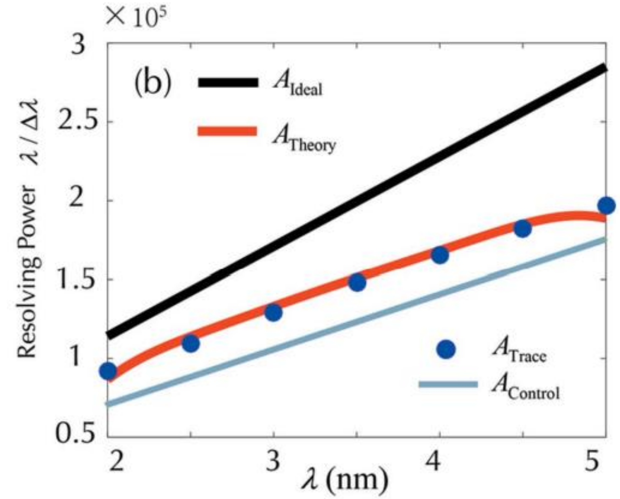


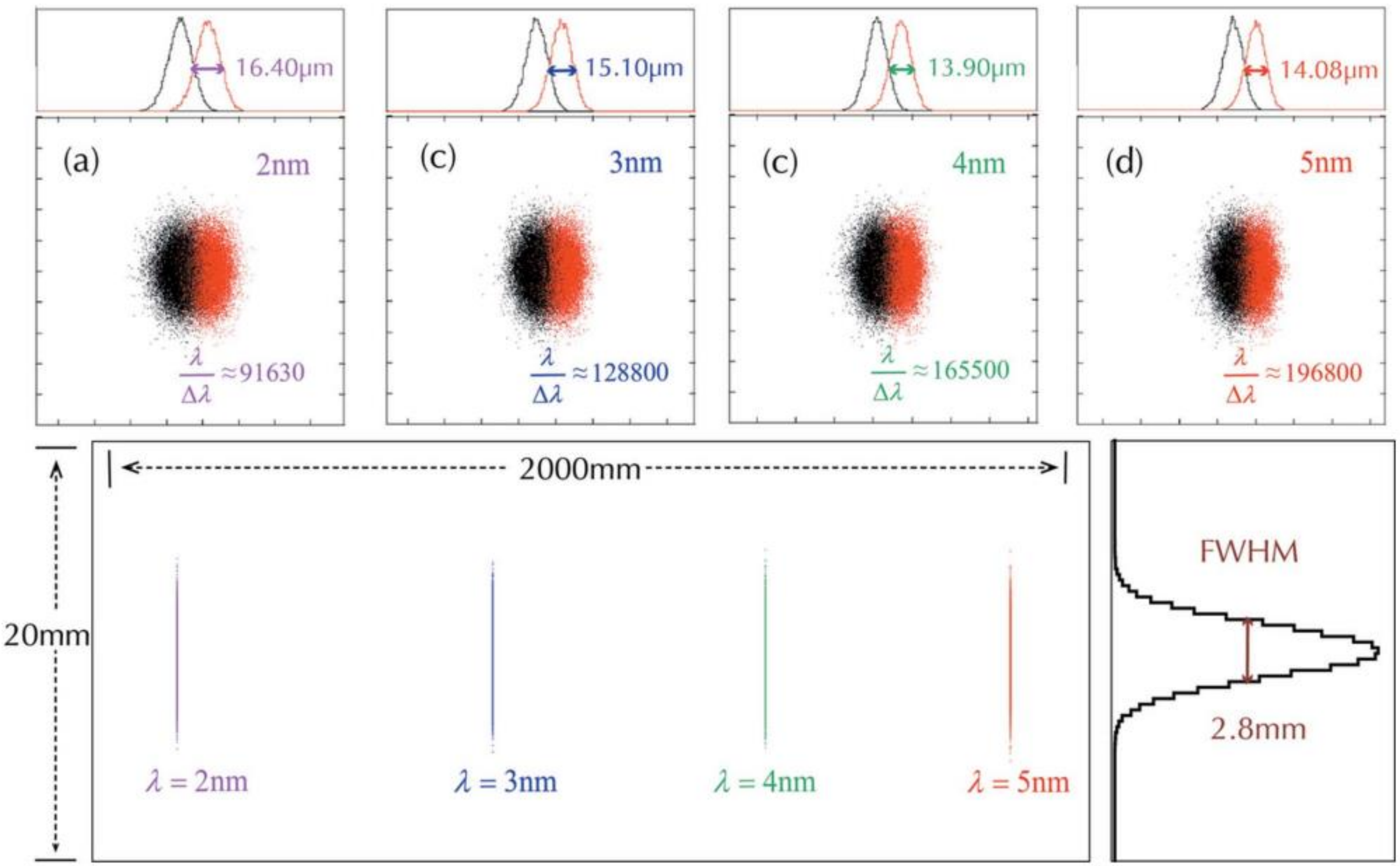


"Towards an extremely high-resolution broadband flat-field spectrometer in water window", **J. Synchrotron Radiation**, vol.**26**, pp.1058 (2019).

Pursuing Extremely High Resolving Power >100,000

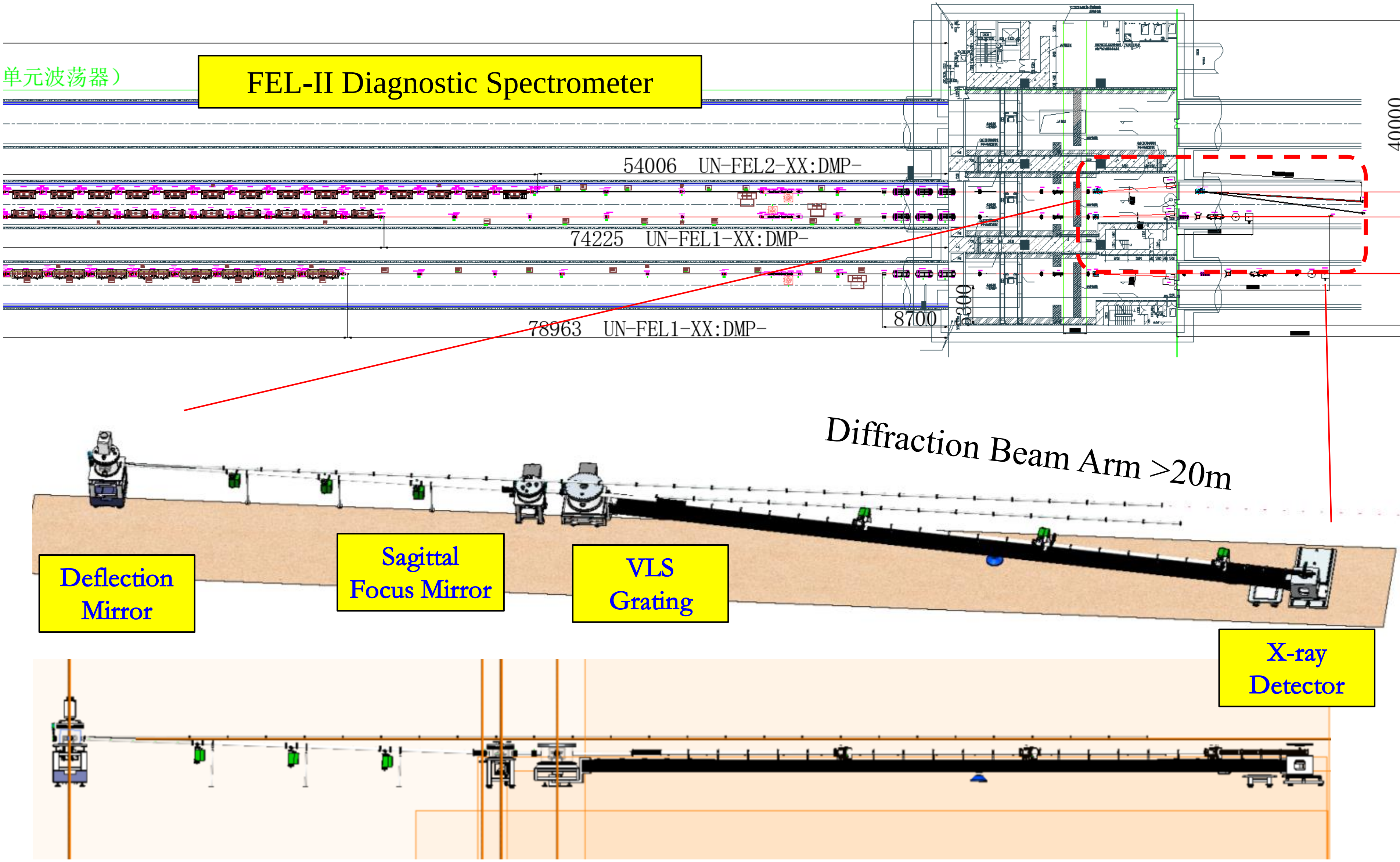




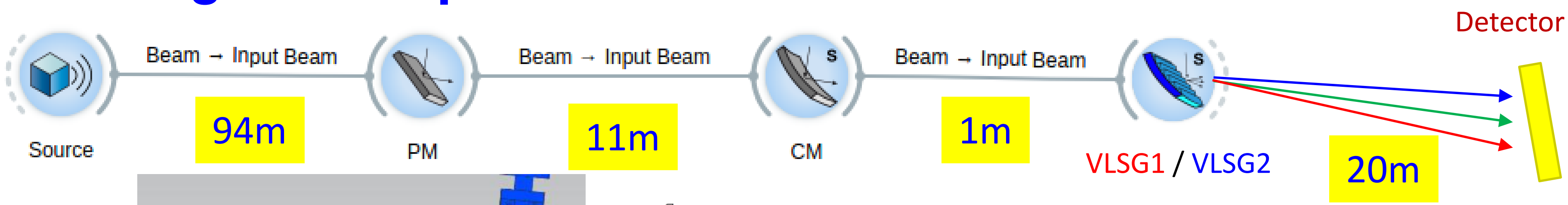


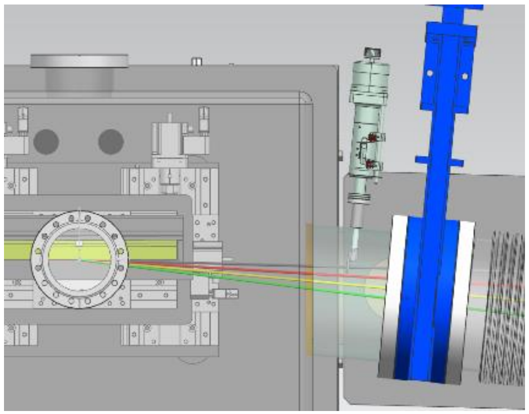
Conceptual design

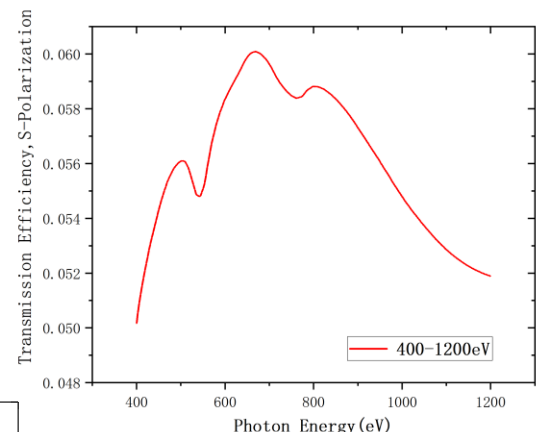
Developing Diagnostic Spectrometer for the FEL-II Beamline of SHINE Facility

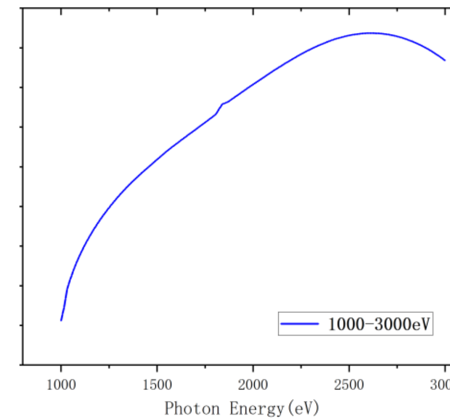


The Overall Transport Efficiency and Resolving Power of the Diagnostic Spectrometer



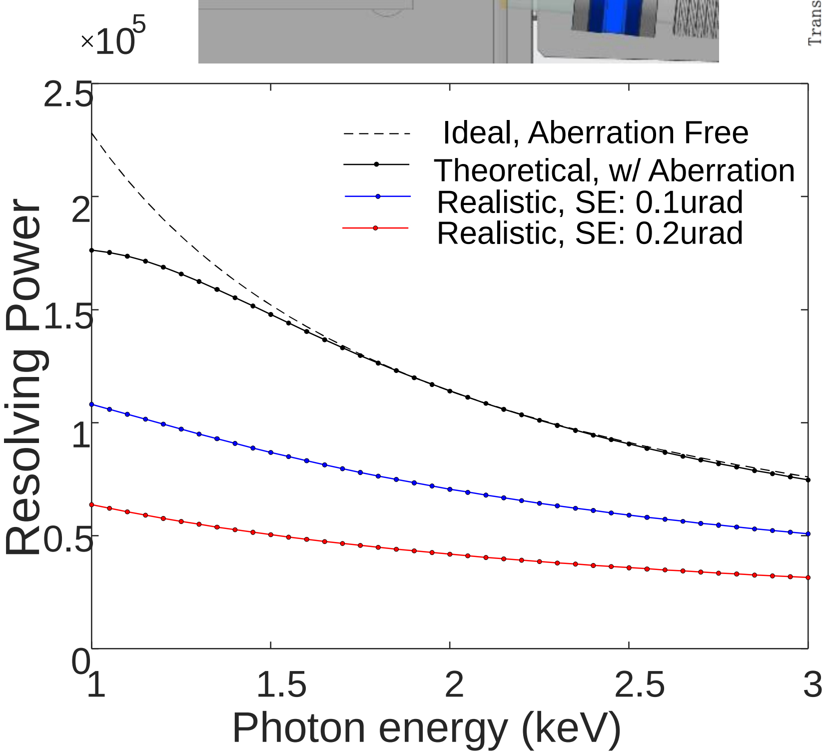






The overall transport + diffraction efficiency 5-6% for 400-1200eV

The overall transport + diffraction efficiency 1.5-3.0% for 1-3keV



$$A_{\mathrm{ideal}} = \frac{\lambda r_{\mathrm{m}} D_0}{\sigma_{\mathrm{s}}^{(\mathrm{FWHM})} \cos\alpha}$$

$$A_{\mathrm{theory}} = \frac{\lambda}{\Delta\lambda_{\mathrm{sum}}} \simeq \lambda\left[\Delta\lambda_{\mathrm{so}}^2 + (\Delta\lambda_{200} + \Delta\lambda_{300} + \Delta\lambda_{400})^2 + \Delta\lambda_{\mathrm{se}}^2\right]^{-1/2}$$

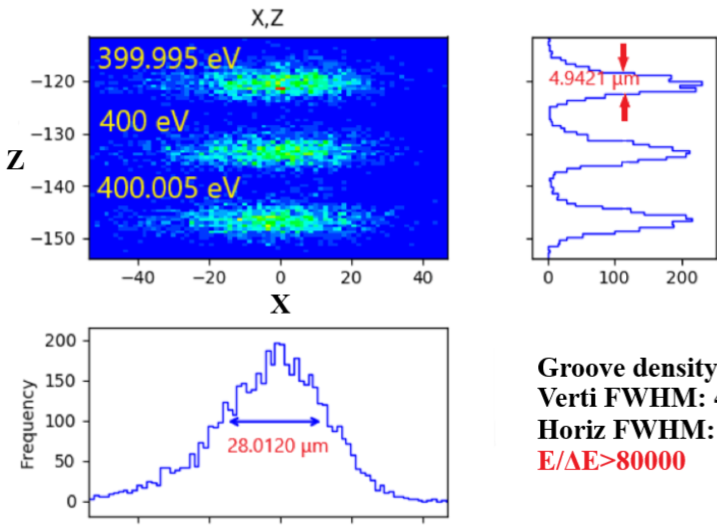
30,000 – 80,000

Ray Tracing to Demonstrate the Resolving Power

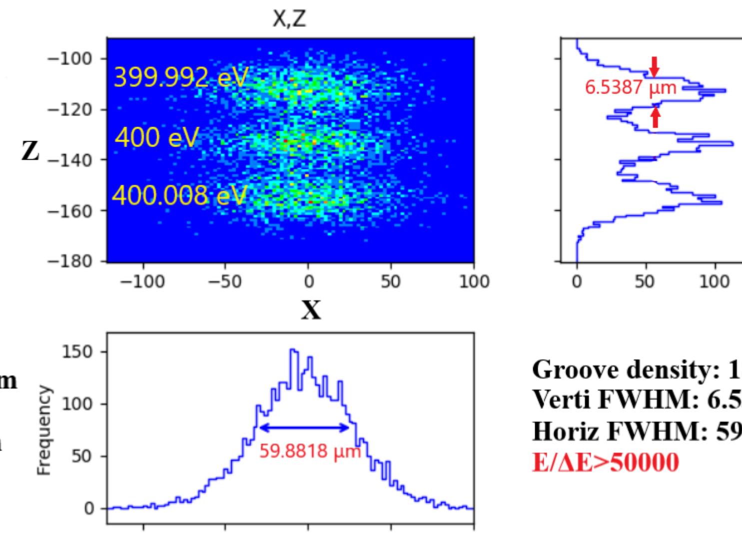
Ideal optics w/o fabrication errors

Realistic optics w/ fabrication errors

400eV

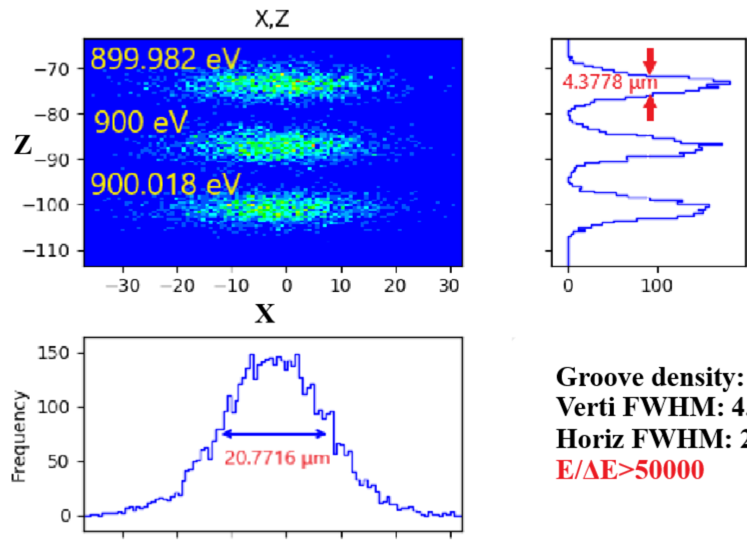


Groove density: 1800ln/mm
Verti FWHM: 4.9421µm
Horiz FWHM: 28.0120µm
E/ΔE>80000

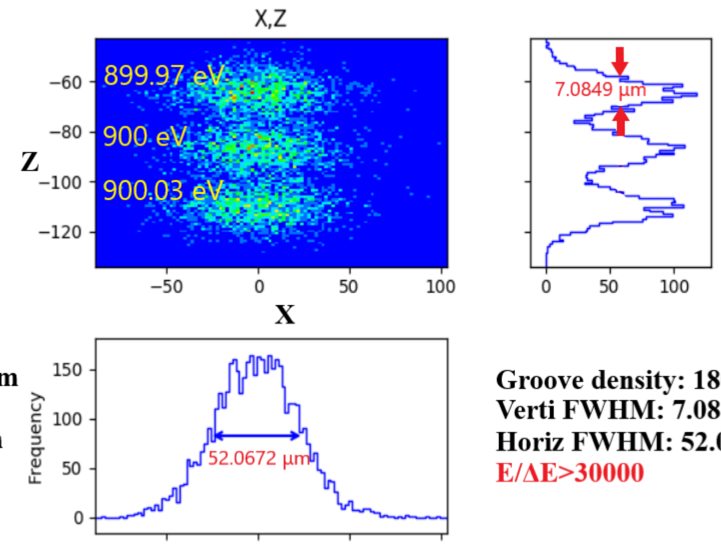


Groove density: 1800ln/mm
Verti FWHM: 6.5387 µm
Horiz FWHM: 59.8818 µm
E/ΔE>50000

900eV



Groove density: 1800ln/mm
Verti FWHM: 4.3778µm
Horiz FWHM: 20.7716µm
E/ΔE>50000



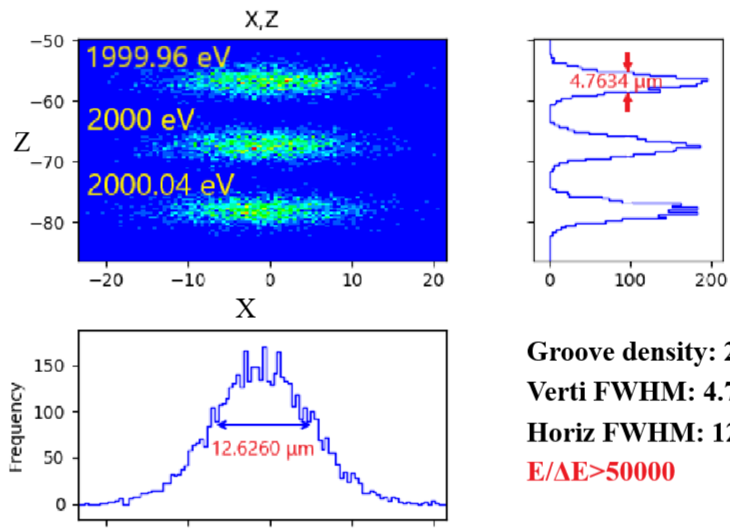
Groove density: 1800ln/mm
Verti FWHM: 7.0849 µm
Horiz FWHM: 52.0672 µm
E/ΔE>30000

Ray Tracing to Demonstrate the Resolving Power

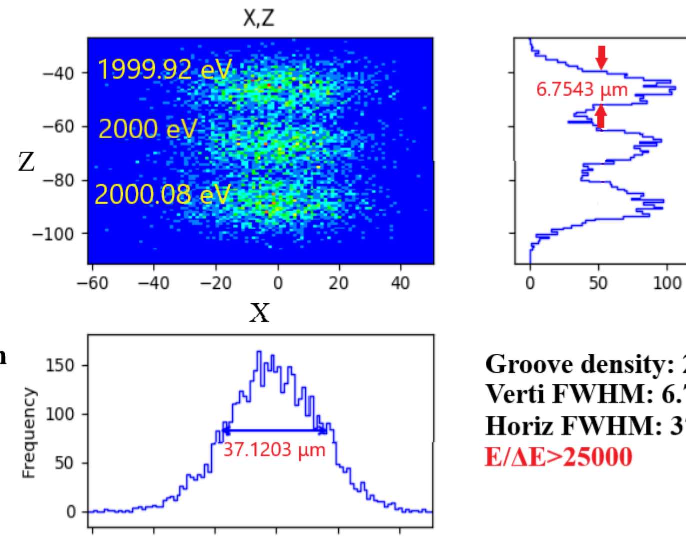
Ideal optics w/o fabrication errors

Realistic optics w/ fabrication errors

2000eV

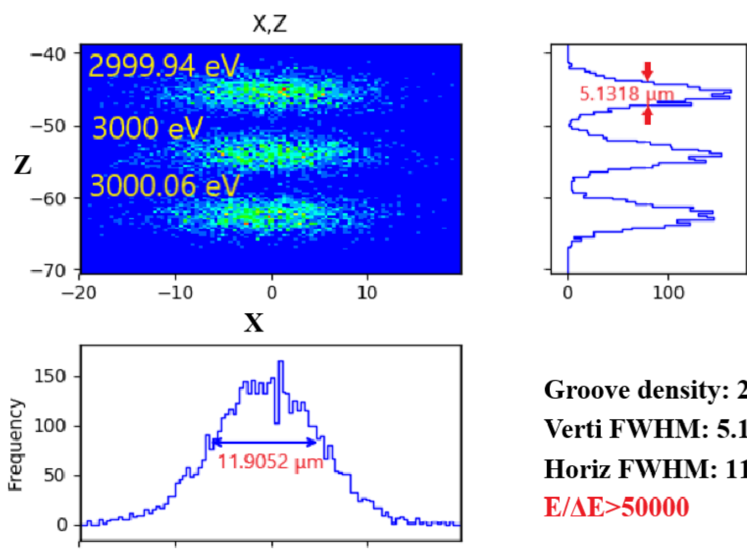


Groove density: 2400ln/mm
Verti FWHM: 4.7634µm
Horiz FWHM: 12.6260µm
E/ΔE>50000

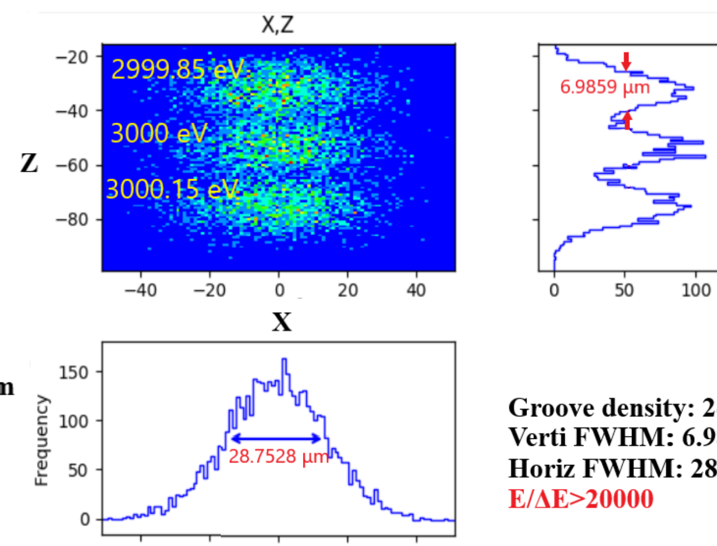


Groove density: 2400ln/mm
Verti FWHM: 6.7543 µm
Horiz FWHM: 37.1203 µm
E/ΔE>25000

3000eV



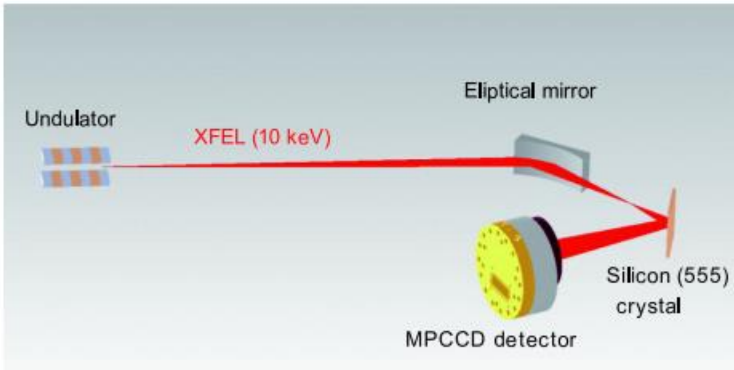
Groove density: 2400ln/mm
Verti FWHM: 5.1318µm
Horiz FWHM: 11.9052µm
E/ΔE>50000



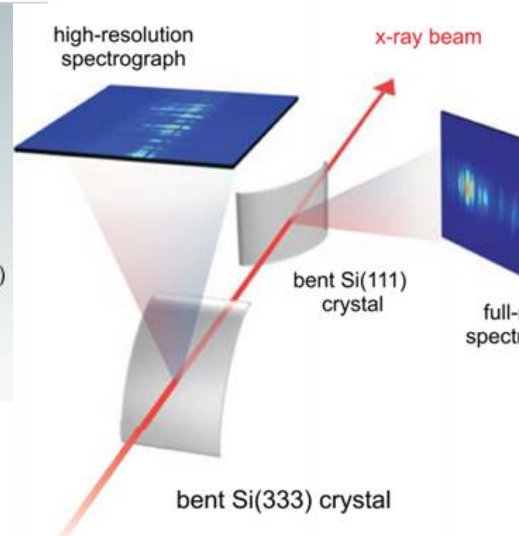
Groove density: 2400ln/mm
Verti FWHM: 6.9859 µm
Horiz FWHM: 28.7528 µm
E/ΔE>20000

- Bent Crystal Hard X-ray Spectrometer
  (conceptual design - double diffraction scheme)

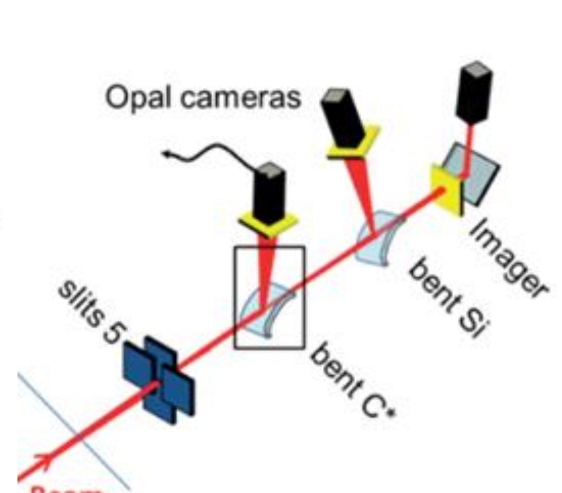
Bent Crystal Hard X-ray Spectrometer



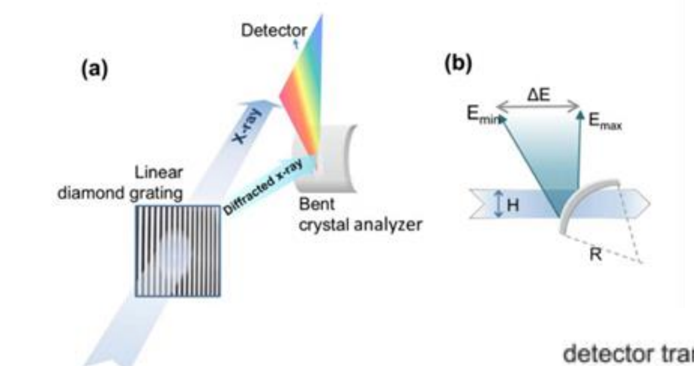
Inubushi，SACLA，2012



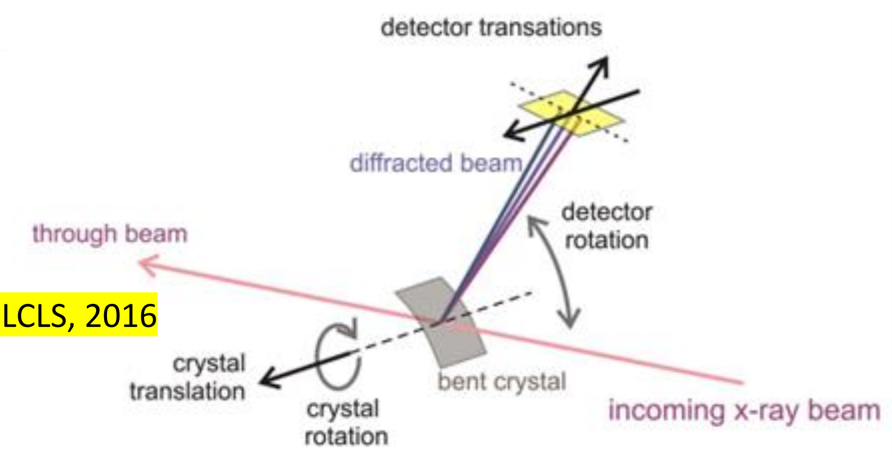
Zhu Diling，LCLS,2012



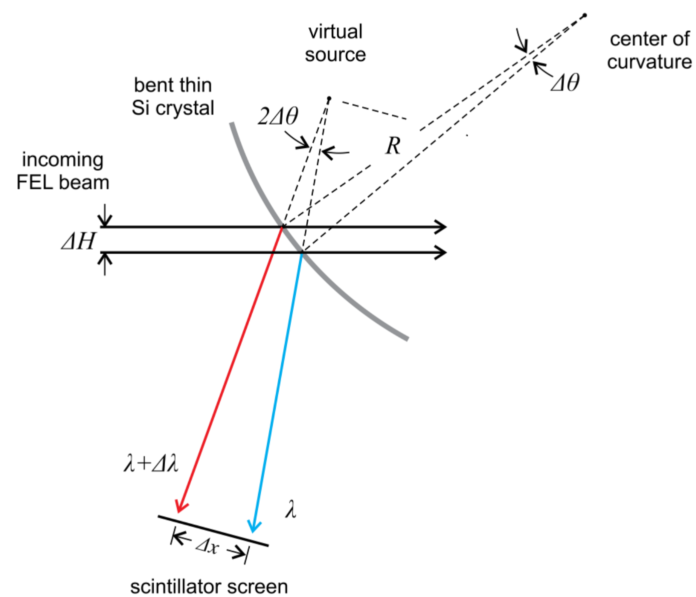
Boesenberg，LCLS，2017



Mozzanica，LCLS,2015



David Rich，LCLS, 2016



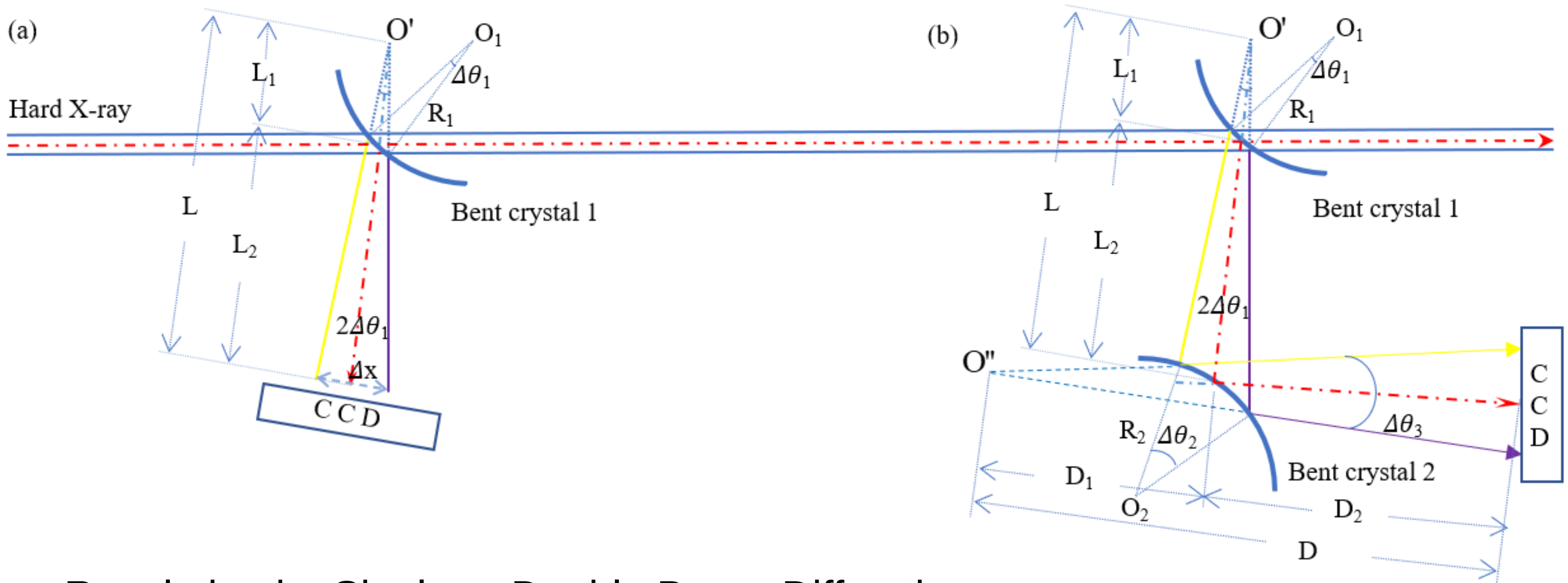
Bent Crystal Hard X-ray Spectrometer

第 42 卷 第 11 期/2022 年 6 月/光学学报

光学学报

Abstract Based on design algorithms of hard X-ray spectrometers in advanced light sources around the world, high energy resolution is realized by adopting cylindrically bent Bragg crystals. A new structure of a double diffraction spectrometer is proposed, which can achieve 2×10^5 energy resolution of single pulse in the photon energy range of 3–25 keV. The energy resolution performance of the spectrometer is verified by theoretical analysis and numerical calculation. And a broad spectrum with bandwidth beyond 1% can be reconstructed via mechanical scan. This technique can potentially be used to measure the fine structure in self-amplified spontaneous emission (SASE) spectra within hard X-ray spectral range for Shanghai High Repetition Rate hard X-ray free electron laser (XFEL) and Extreme Light Facility (SHINE), and it can be applied to detection and application of the cutting edge user scientific researches demanding high resolving power, preserving important merit of value in science and technology.

Key words X-ray optics; spectrometer; strongly bent cylindrical crystals; hard X-ray free electron laser; single shot online measurement



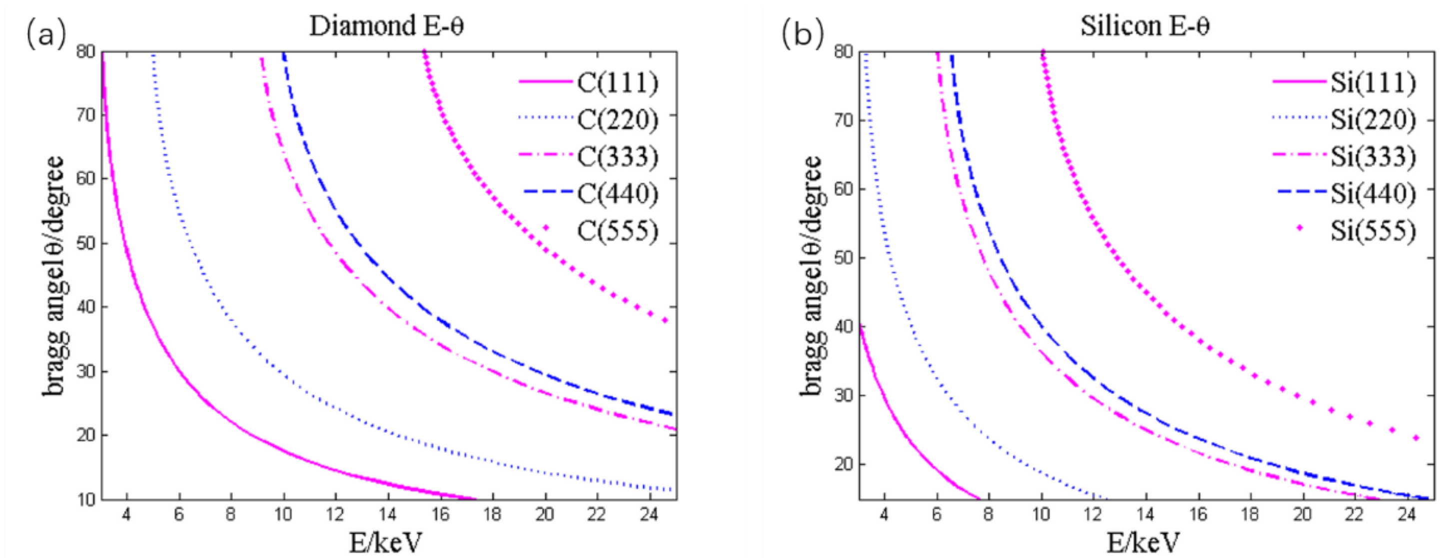
Energy Resolution by Single or Double Bragg Diffraction

$$\left(\frac{E}{\Delta E}\right)_1 = 2\times\tan\theta_1\times\left(\frac{R_1\times\sin\theta_1}{2}+L_2\right)/p$$

$$\left(\frac{E}{\Delta E}\right)_2 = \frac{D}{p}\cdot\tan\theta\cdot\left(\frac{R_1\cdot\sin\theta+2L_2}{R_2\cdot\sin\theta}+1\right)$$

Bent Crystal Hard X-ray Spectrometer

Diamond (C) **Silicon (Si)**

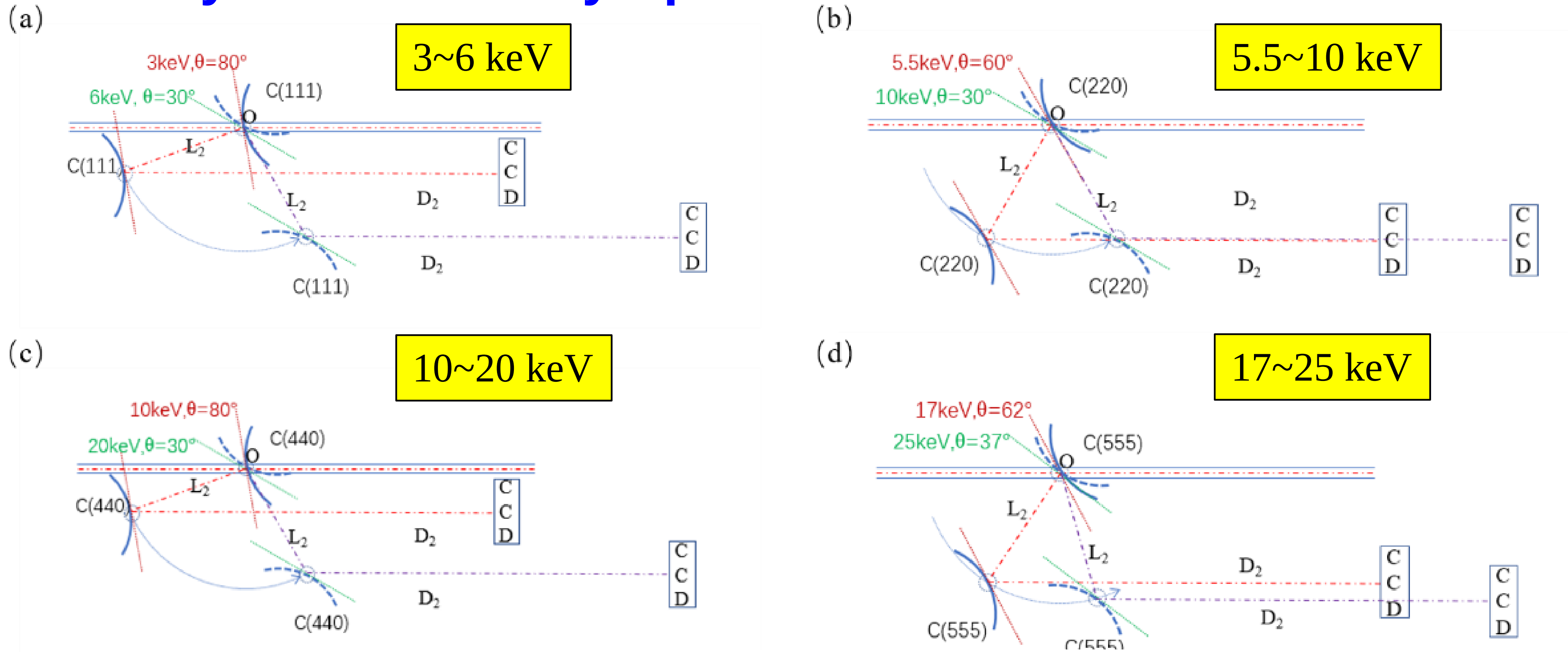


Analysis results of energy segments for different diamond and silicon crystals. (a) Bragg diffraction angle for diamond in energy range of 3-25keV; (b) Bragg diffraction angle for silicon crystals in energy range of 3-25 keV.

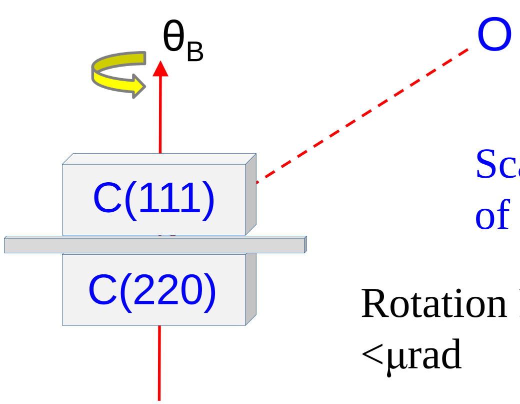
Table 1 Lattice spacing of two crystals (silicon and diamond) with six different crystal orientations

Crystal orientation	111	220	333	400	440	555
Spacing of silicon /nm	0.3135	0.1920	0.1045	0.1358	0.0960	0.0627
Spacing of diamond /nm	0.2059	0.1261	0.0686	0.0892	0.0631	0.0412

Bent Crystal Hard X-ray Spectrometer

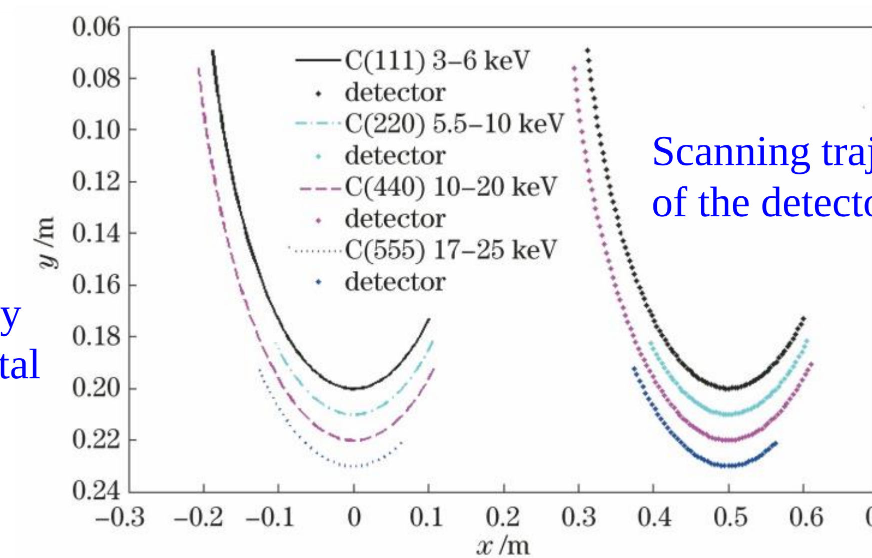


Working algorithm of double diffraction spectrometer



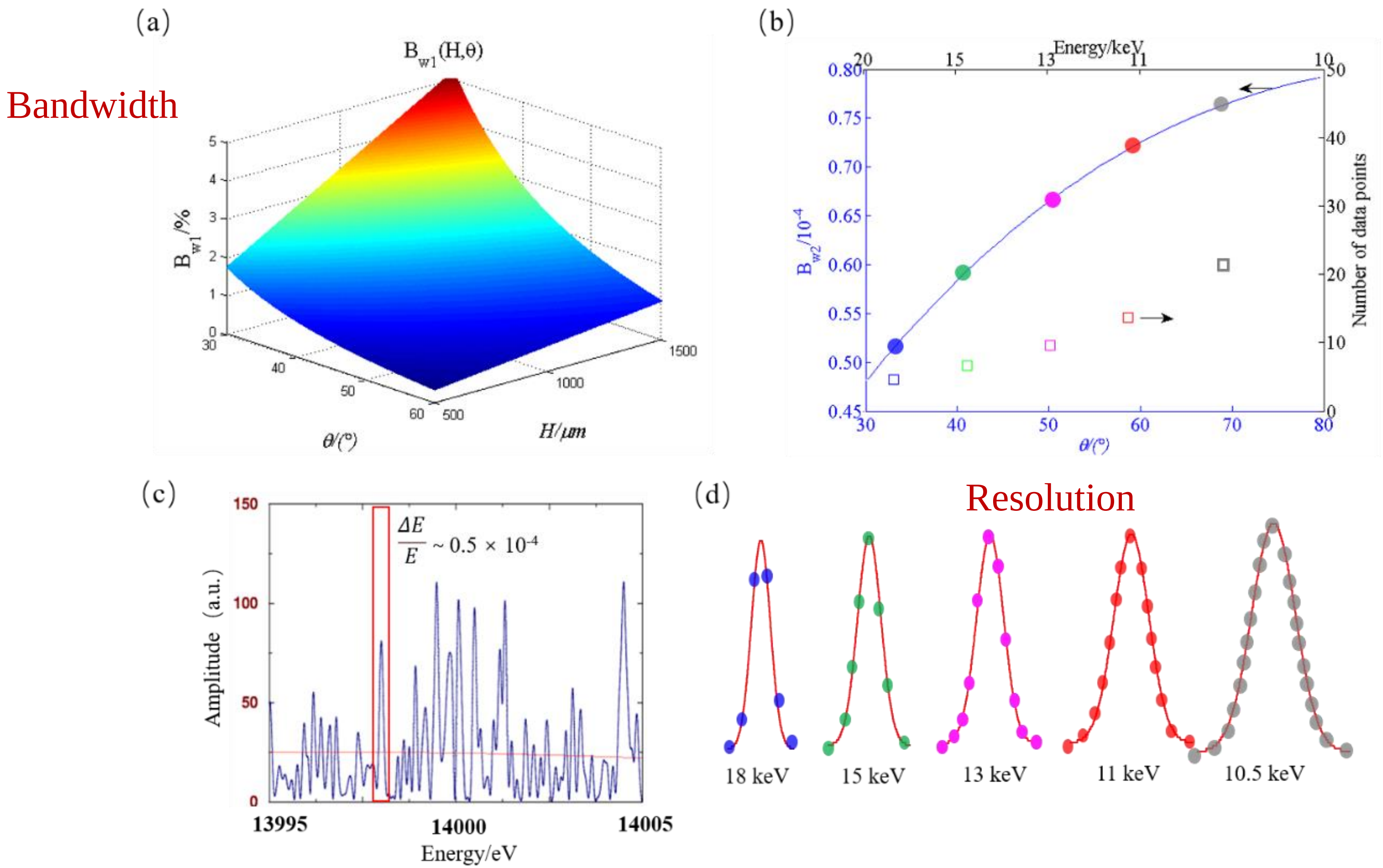
Scanning trajectory of the second crystal

Rotation Precision: <μrad



Scanning trajectory of the detector

Bent Crystal Hard X-ray Spectrometer



Tune the detection range of the spectrometer to fit for a typical bandwidth of single spike in SASE spectrum at various photon energies.

The ultimate goal: Resolve single spike feature for SASE spectra in hard X-ray regime.

Outline

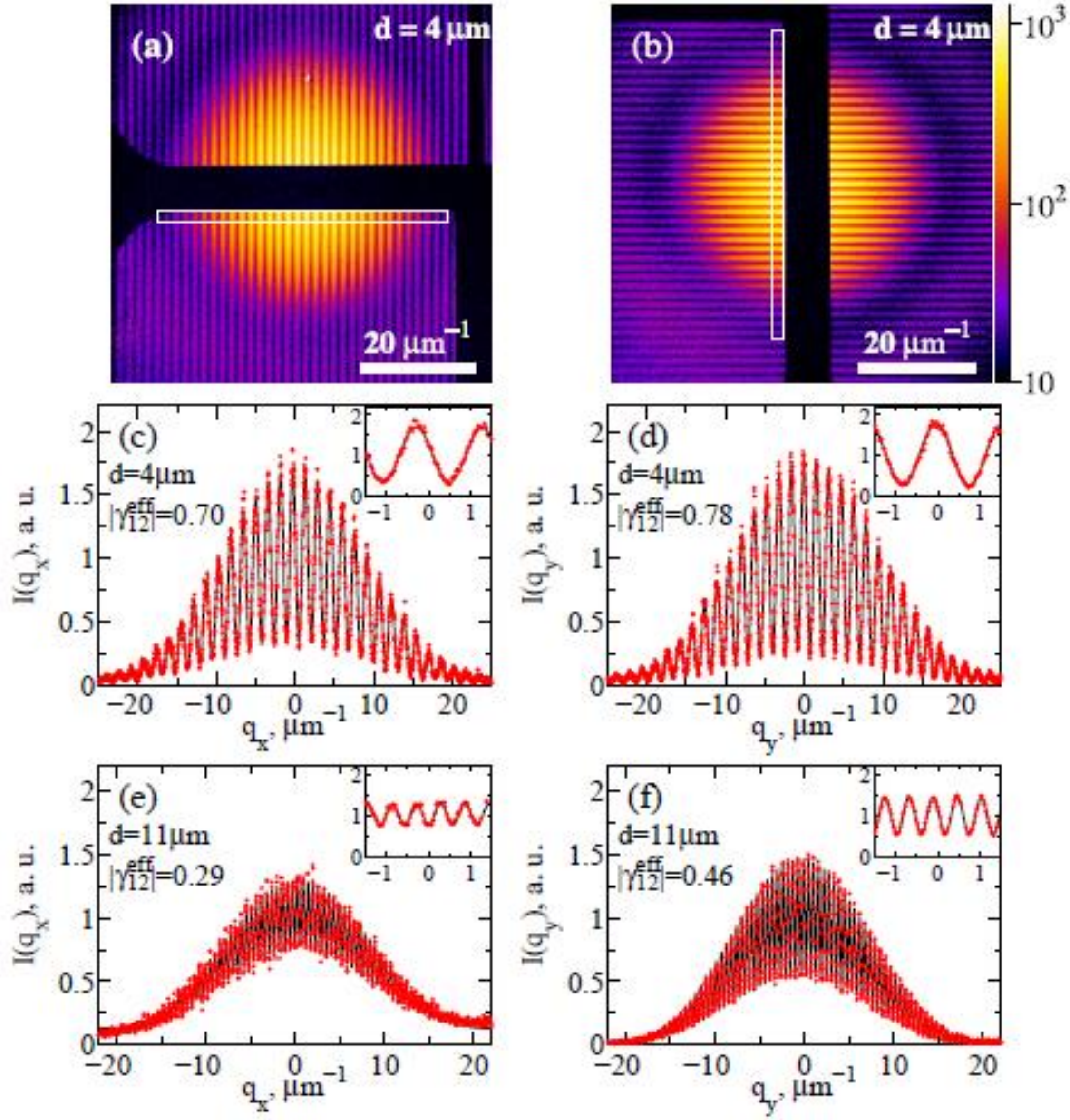
1. Overview of photon diagnostics development

2. High resolution X-ray spectrometer

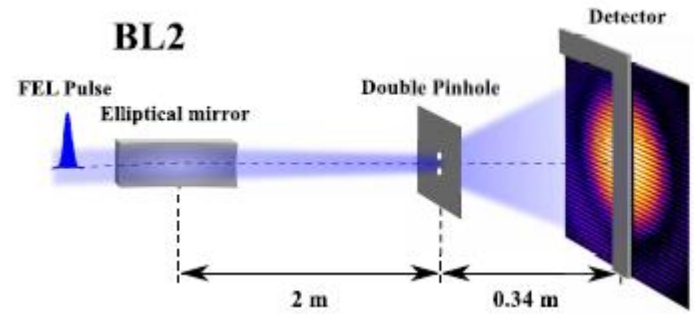
3. X-ray coherence apparatus and measurement

XFEL Transverse Coherence Measurement

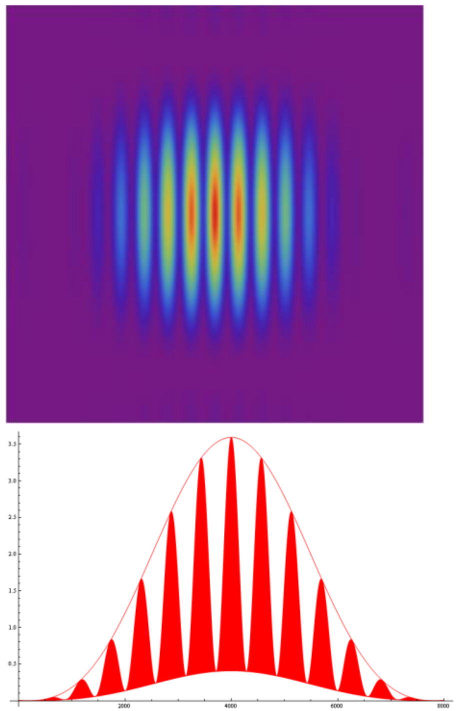
Horizontal Vertical



A Singer et. al. ***Optical Express*** (2012)



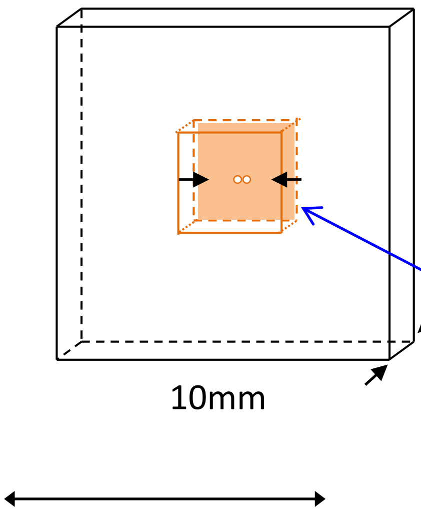
$$I = 2\left(\frac{2J_1(v)}{v}\right)^2 \cdot \{1 + \left|\frac{2J_1(u)}{u}\right| \cdot \cos[\beta_{12}(u) - C \cdot u \cdot v]\}$$



Simulation: Coherence **80%**

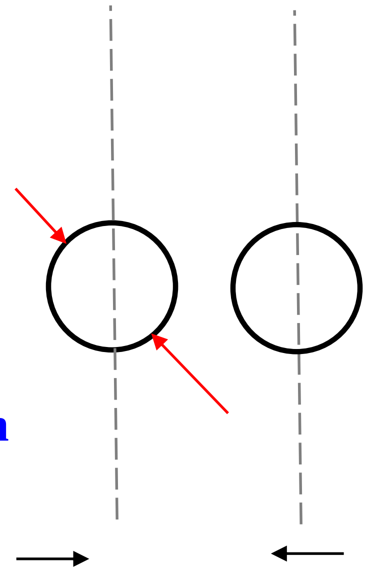
Fabricate Diffraction Screen to Calibrate Wavefront Coherence

Si– wafer

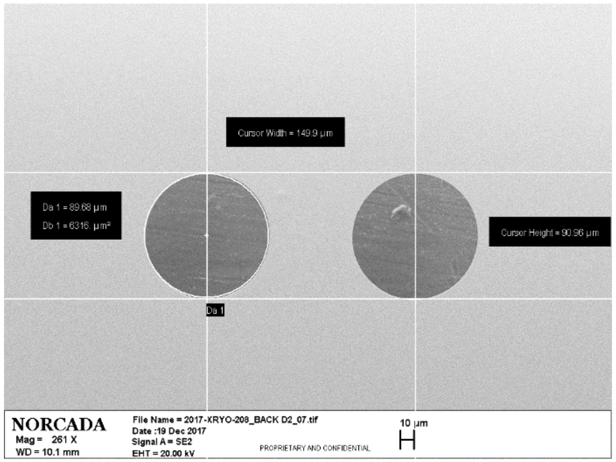


Au thin foil on Silicon Wafer

Sub-100μm

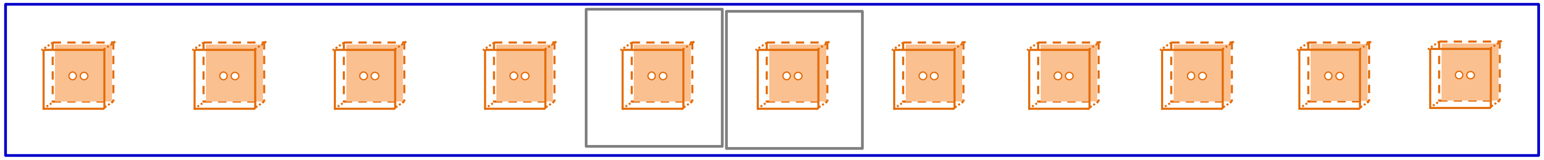


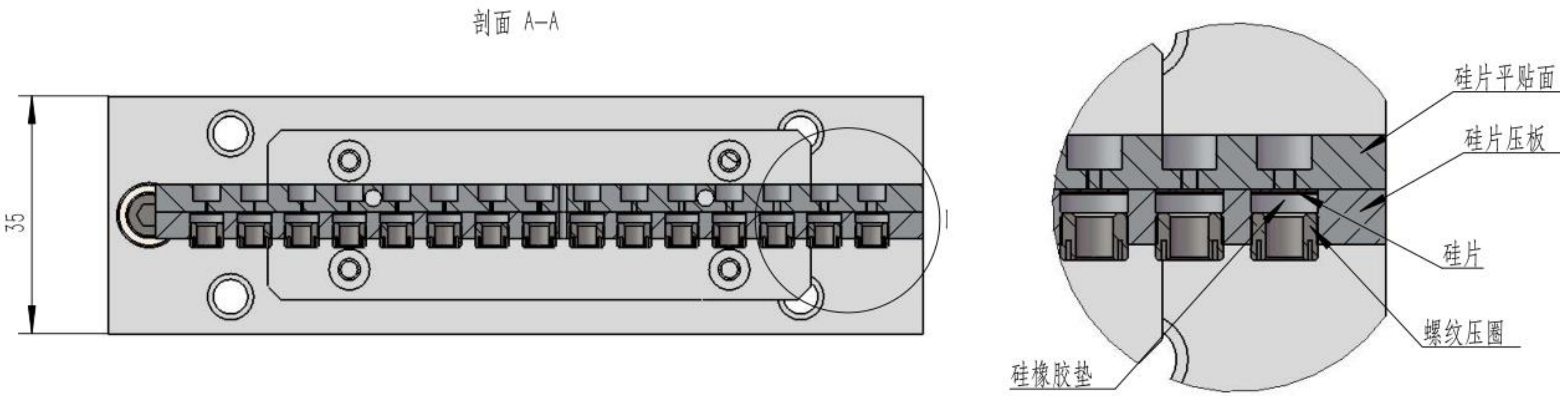
0.12 – 3mm



XUV to Soft X-ray Regime

Various Spacing for Two Diffraction Apertures



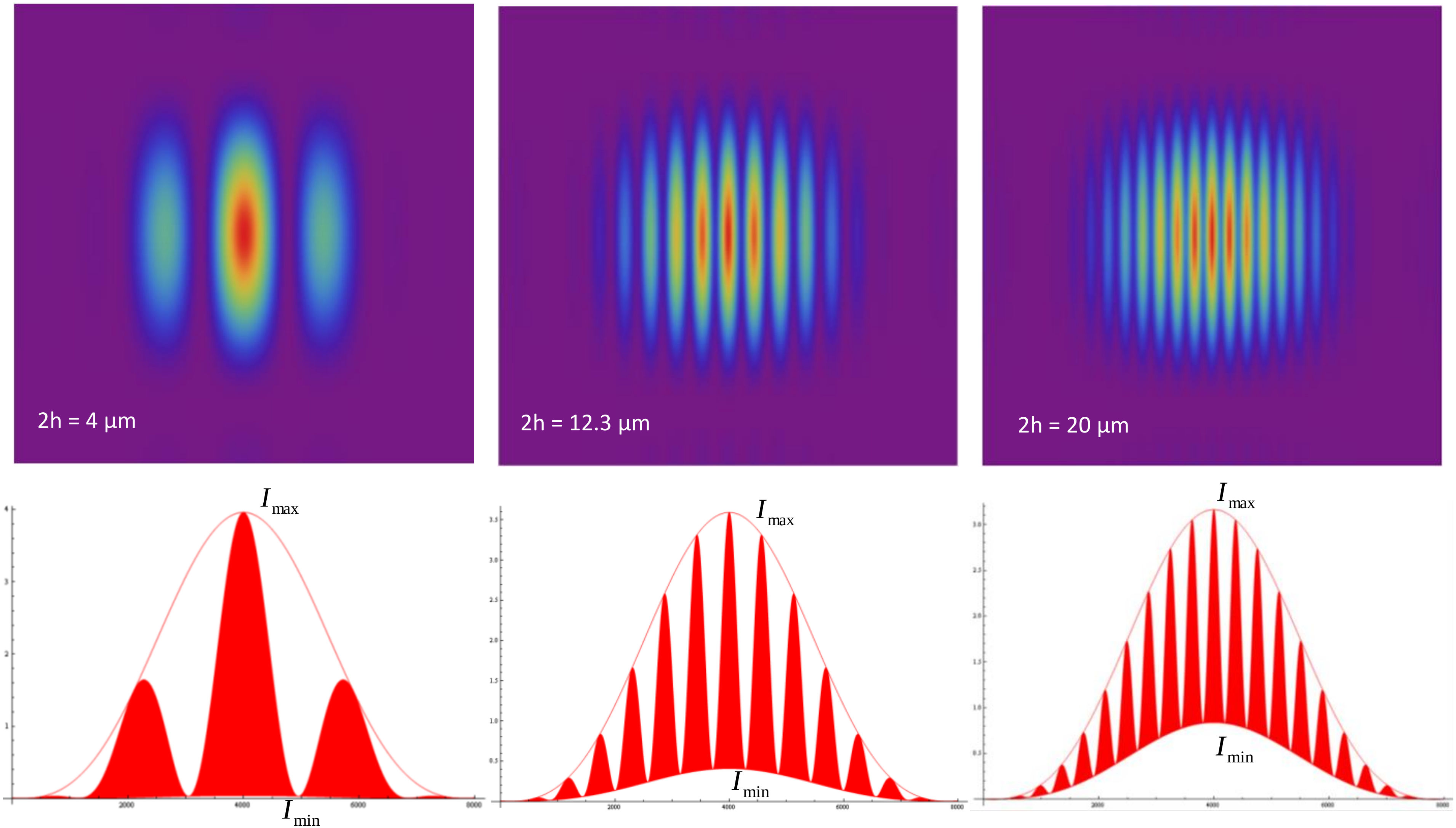


Simulated Signal for Transverse Coherence Measurement

$$I = I_1 + I_2 + 2 \cdot \sqrt{I_1 I_2} \left|\tilde{\gamma}_{12}(\tau)\right| \cos\left[\beta_{12}(u) - \delta(\tau)\right]$$

$$V = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} = \left\{2\sqrt{I_1 I_2} / (I_1 + I_2)\right\} \left|\gamma_{12}(\tau)\right| \approx \left|\gamma_{12}(\tau)\right| = \left|\frac{2J_1(u)}{u}\right|$$

Beam focus mode



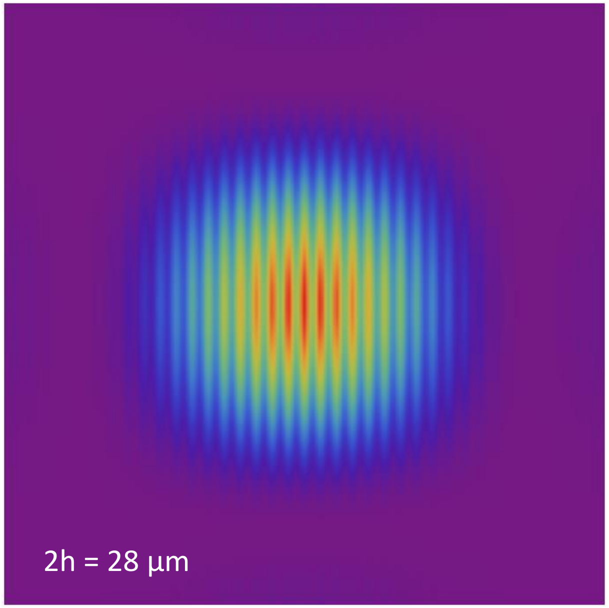
V= 0.98 | V = 0.796 | V =0.581

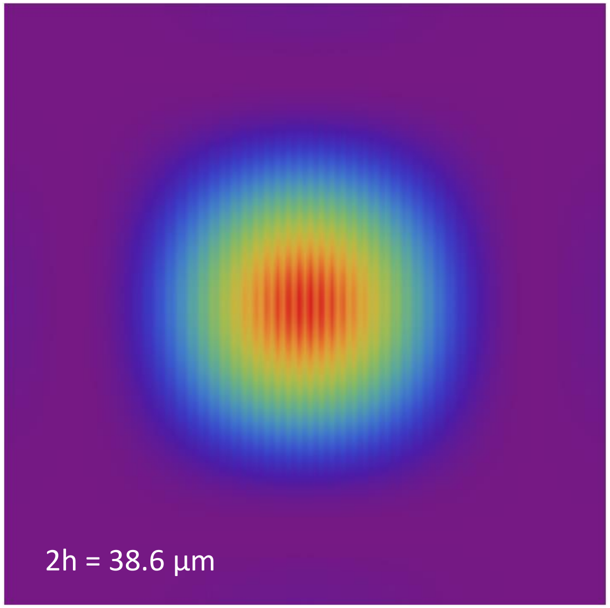
Simulated Signal for Transverse Coherence Measurement

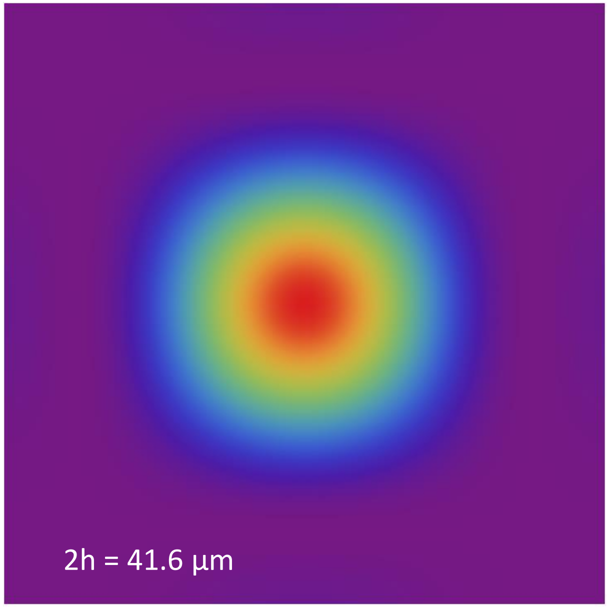
$$I = I_1 + I_2 + 2\cdot\sqrt{I_1 I_2}\,\left|\tilde{\gamma}_{12}(\tau)\right|\cos\left[\beta_{12}(u) - \delta(\tau)\right]$$

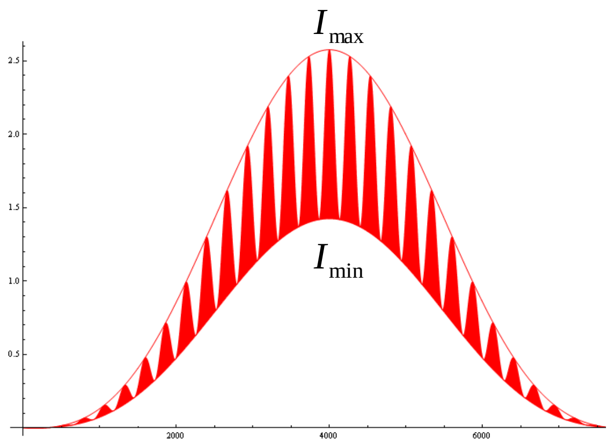
$$V = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} = \left\{2\sqrt{I_1 I_2}\,/(I_1 + I_2)\right\}\left|\gamma_{12}(\tau)\right| \approx \left|\gamma_{12}(\tau)\right| = \left|\frac{2J_1(u)}{u}\right|$$

Beam focus mode

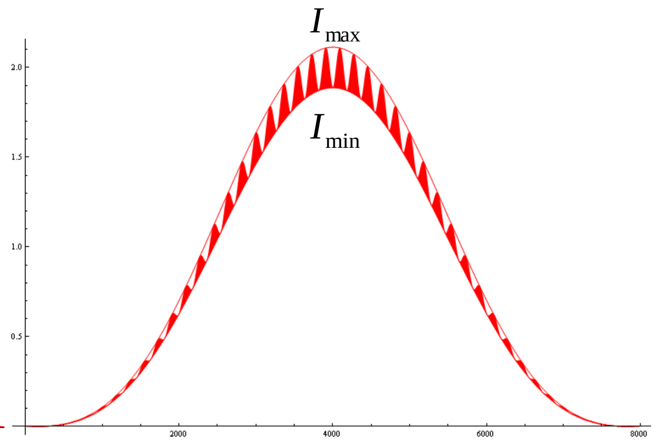




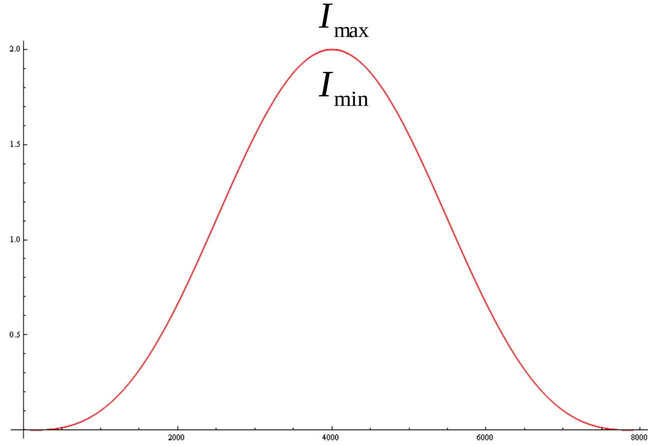




V = 0.288

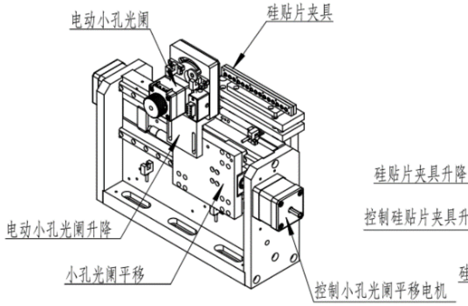


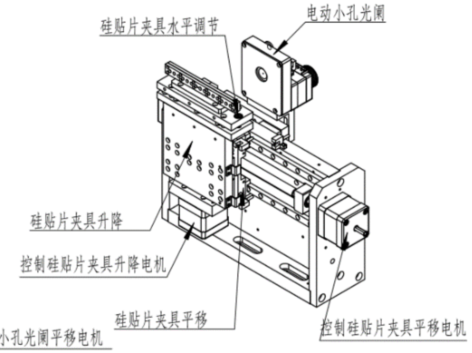
V = 0.0566

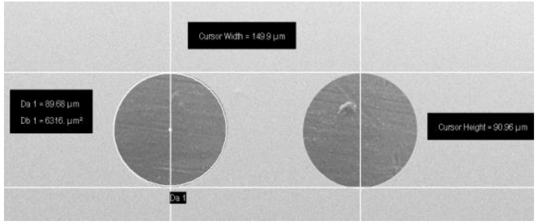


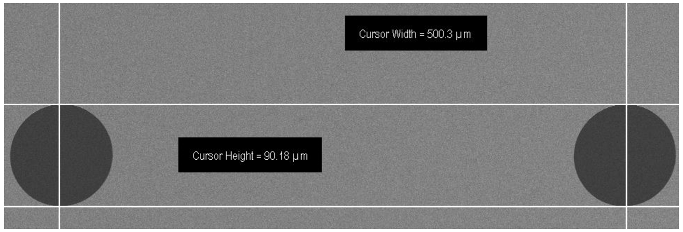
V = 0.00058

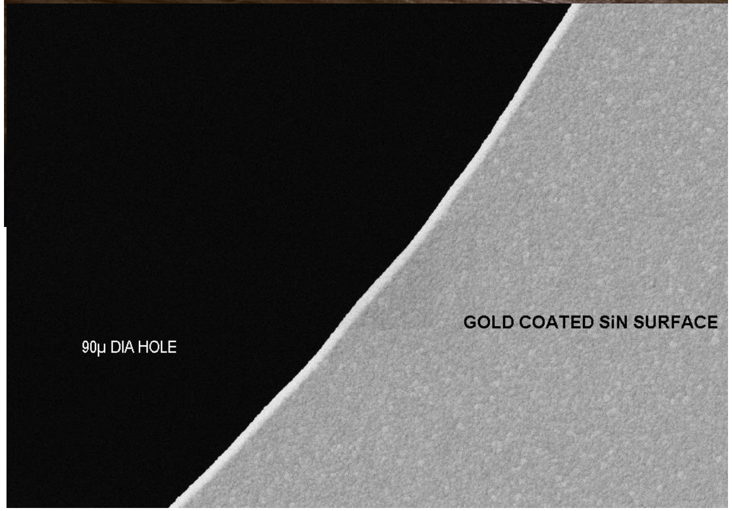
Diffraction Sample Installation & Test

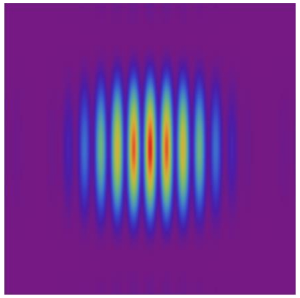




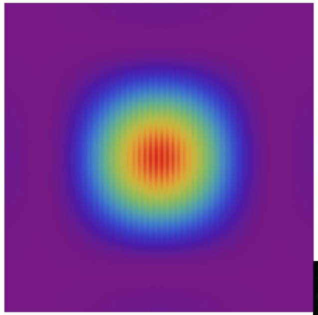


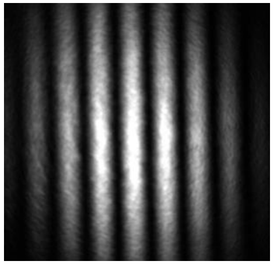




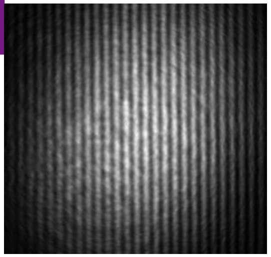


Sim.

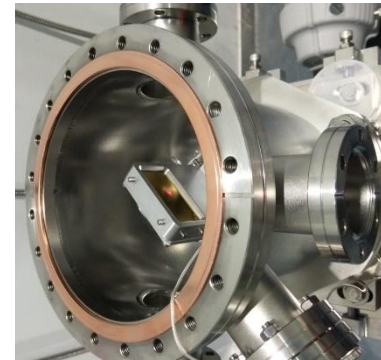


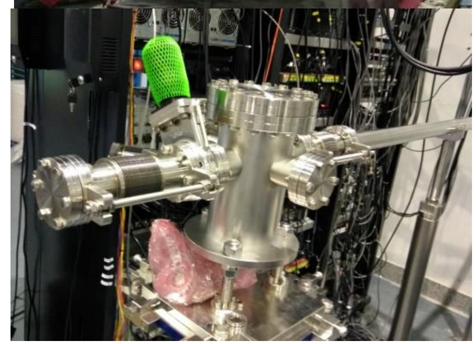


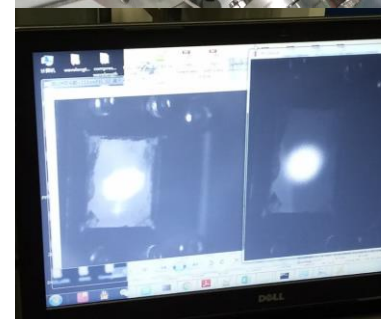
Exp.

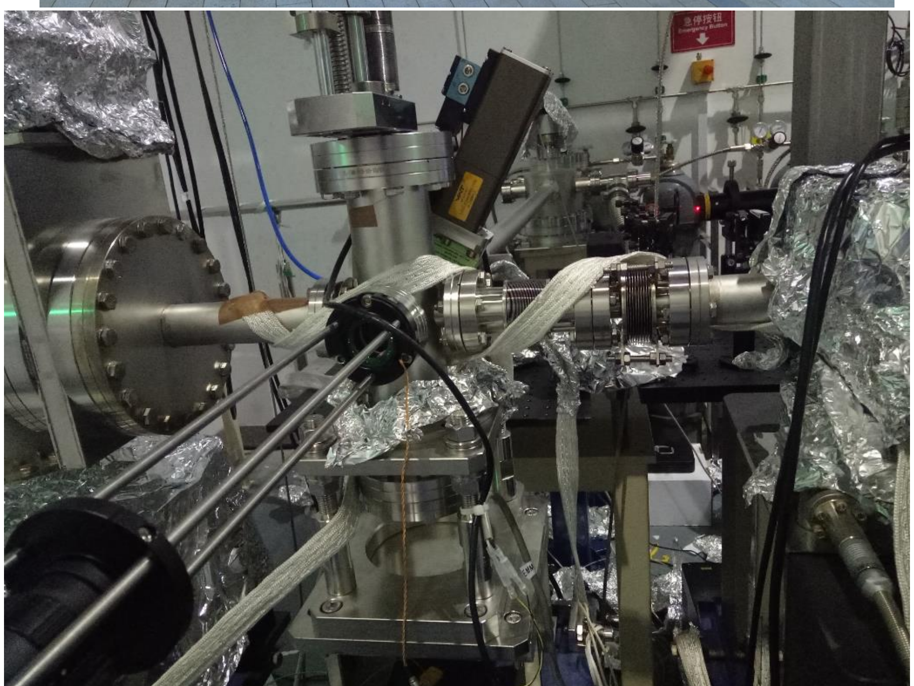


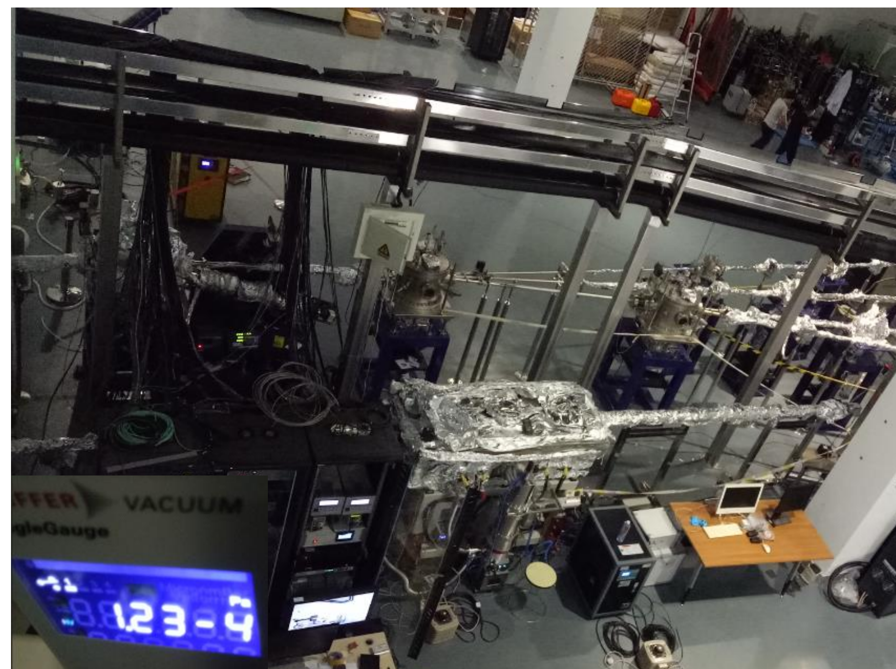
First Experiment at DCLS







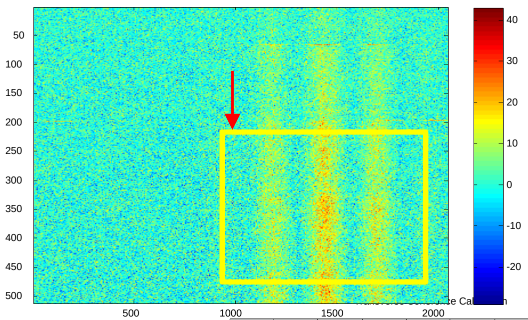


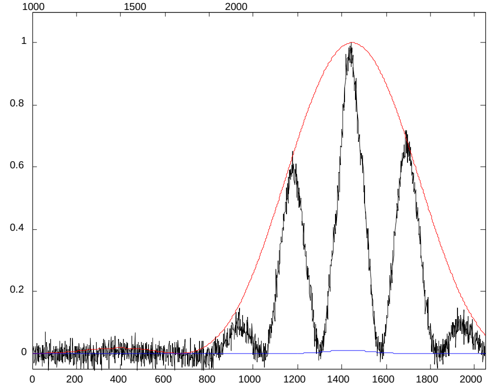


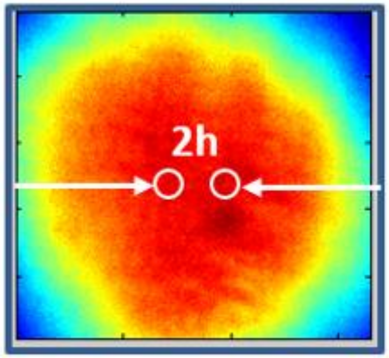
Transverse Coherence of DCLS

(DCLS: 50-150nm)

60nm



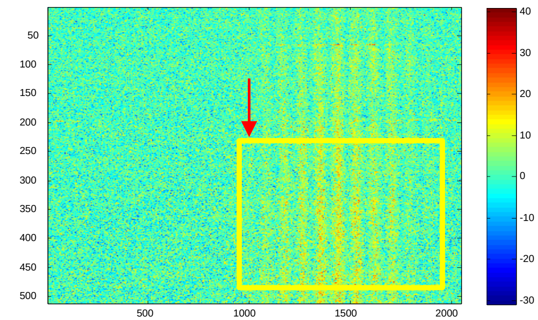


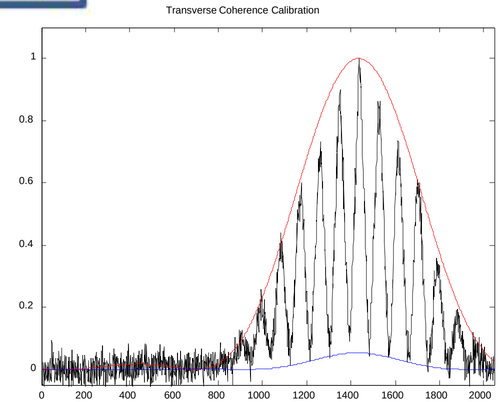


Beam size: 3mm (FWHM)

200μm

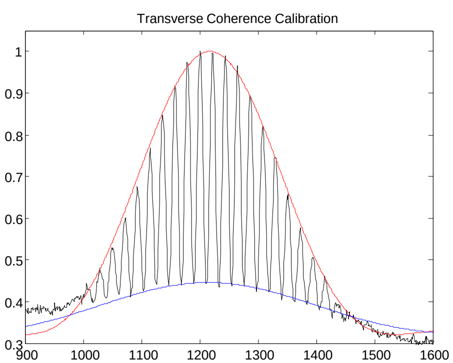
>96%





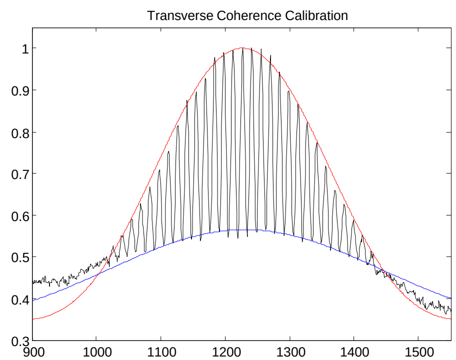
600μm

>89%



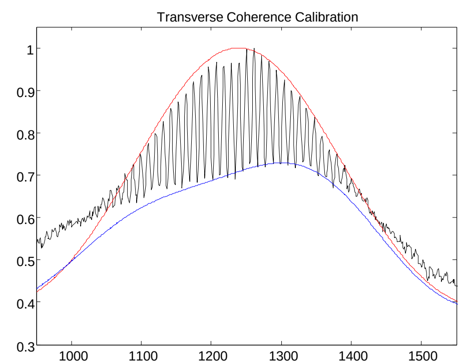
1000μm

68%



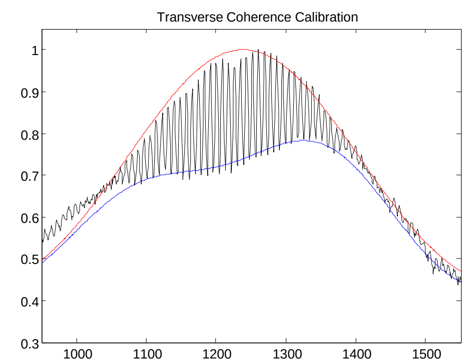
1500μm

50%



2000μm

23%



2500μm

10%

Measure the Longitudinal Coherence for X-ray FEL Pulse

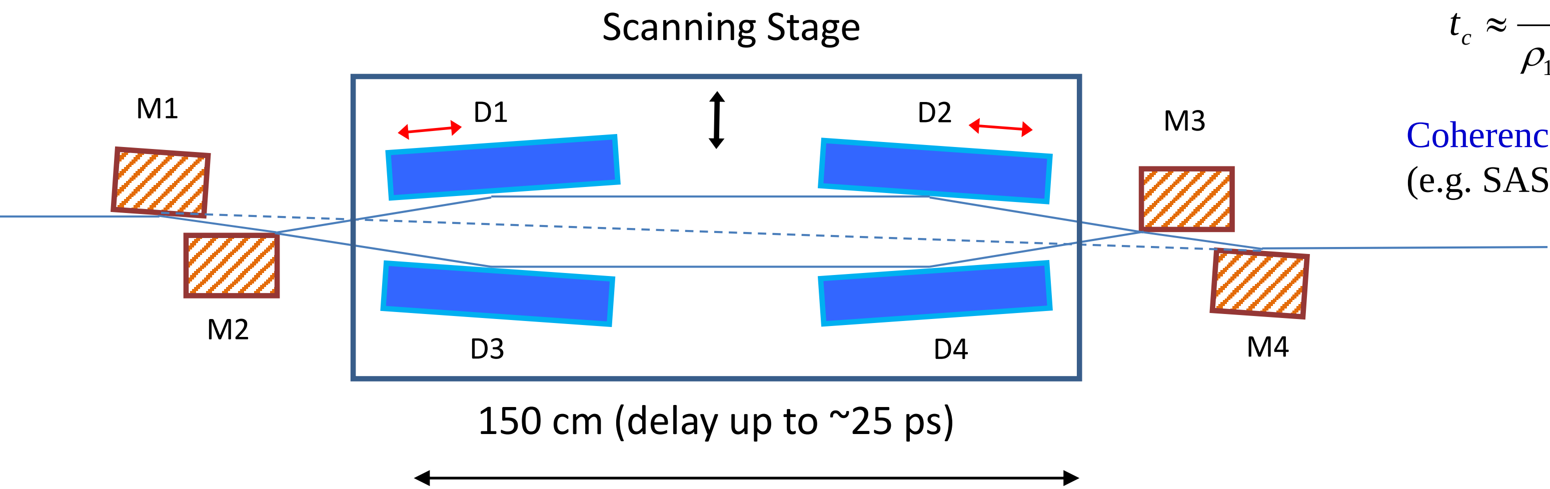
For DCLS & SXFEL Facilities

Pulse-front Splitting & Delay Generation

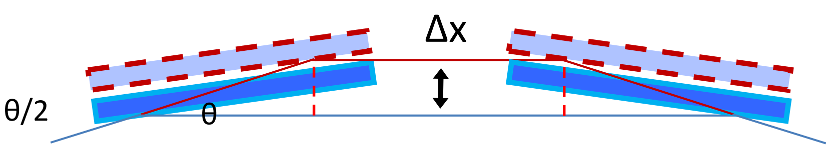
$$t_c \approx \frac{\lambda}{c}\left(\frac{\lambda}{\Delta\lambda}\right)$$

$$t_c \approx \frac{\lambda}{\rho_{1D}\cdot 2\pi c}\sqrt{\frac{\pi\cdot\ln N_c}{18}}$$

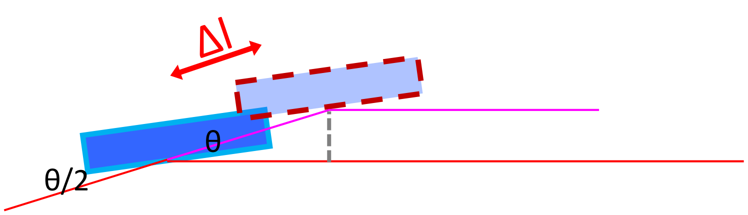
Coherence Time: ~2 fs
(e.g. SASE pulse ~200eV)



A） Scan Stage



B） Guide Rail



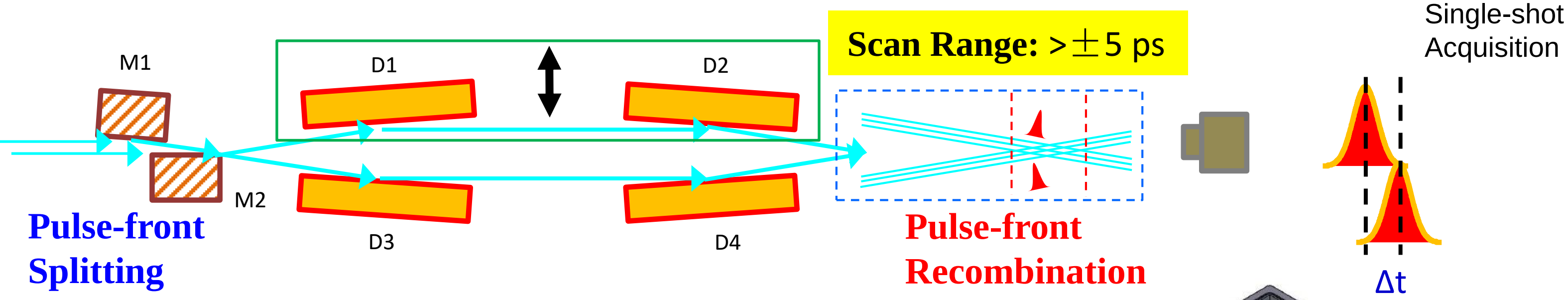
Coarse Delay:

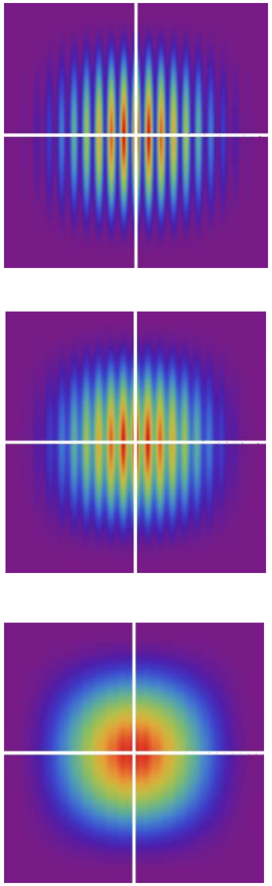
<200 as/μm

Fine Delay:

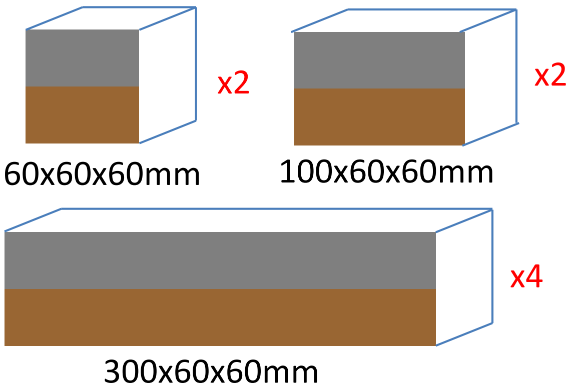
<20 as/μm

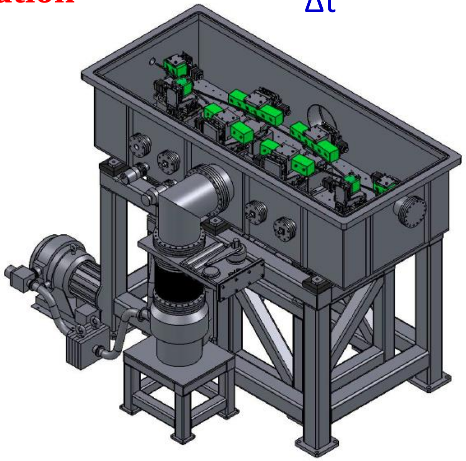
Instrument for Longitudinal Coherence Measurement

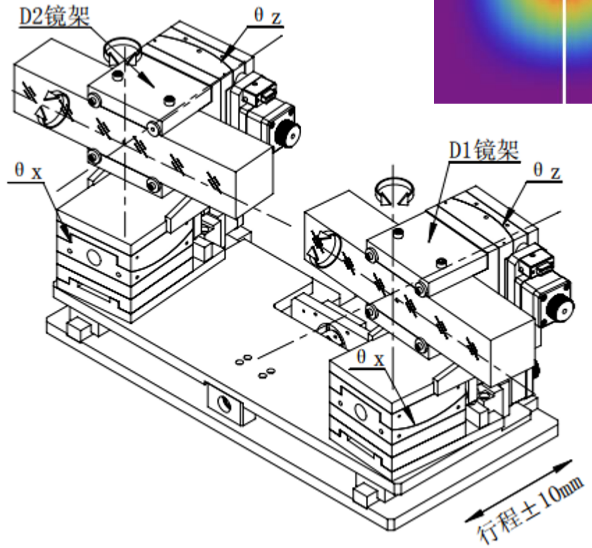




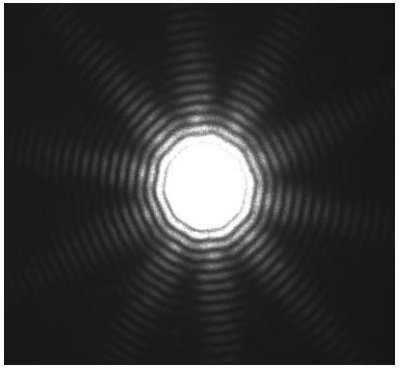
Dual Coating Mirrors

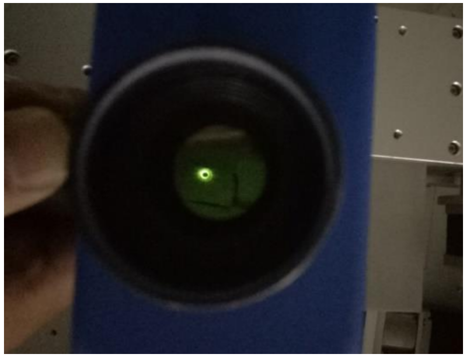






Precise Alignment

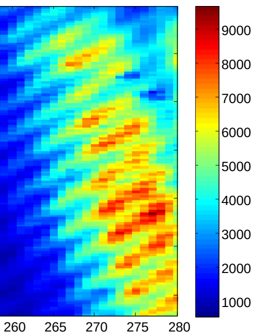




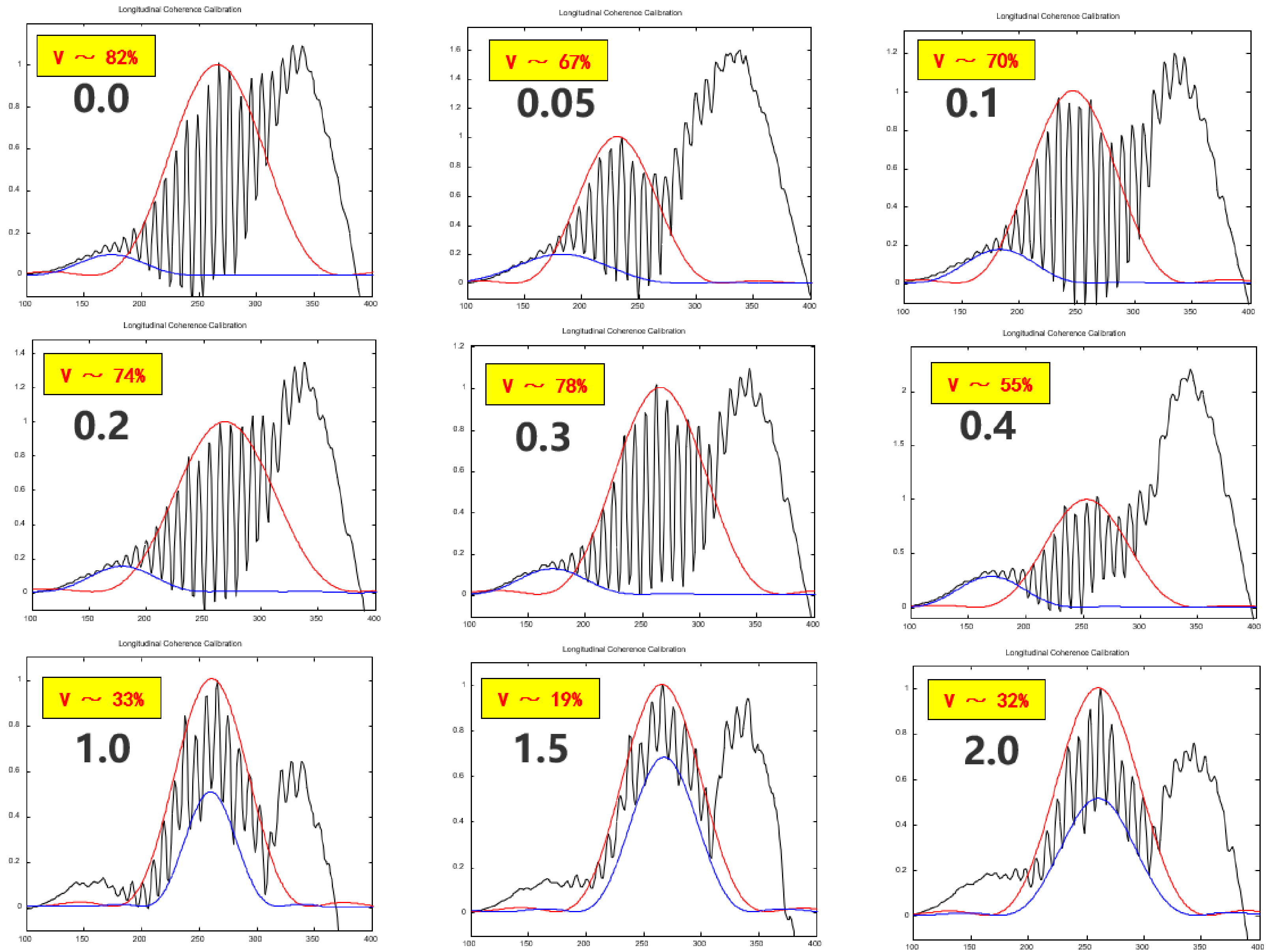
Longitudinal Coherence of DCLS

(DCLS:60-150nm)

60nm



Typical Interference Fringe



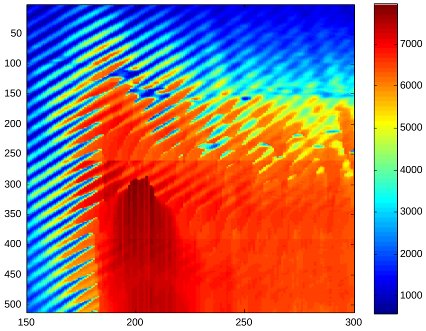
(Black number) various inter-mutual delays for the splitting pulse

Longitudinal Coherence Measurement for DCLS

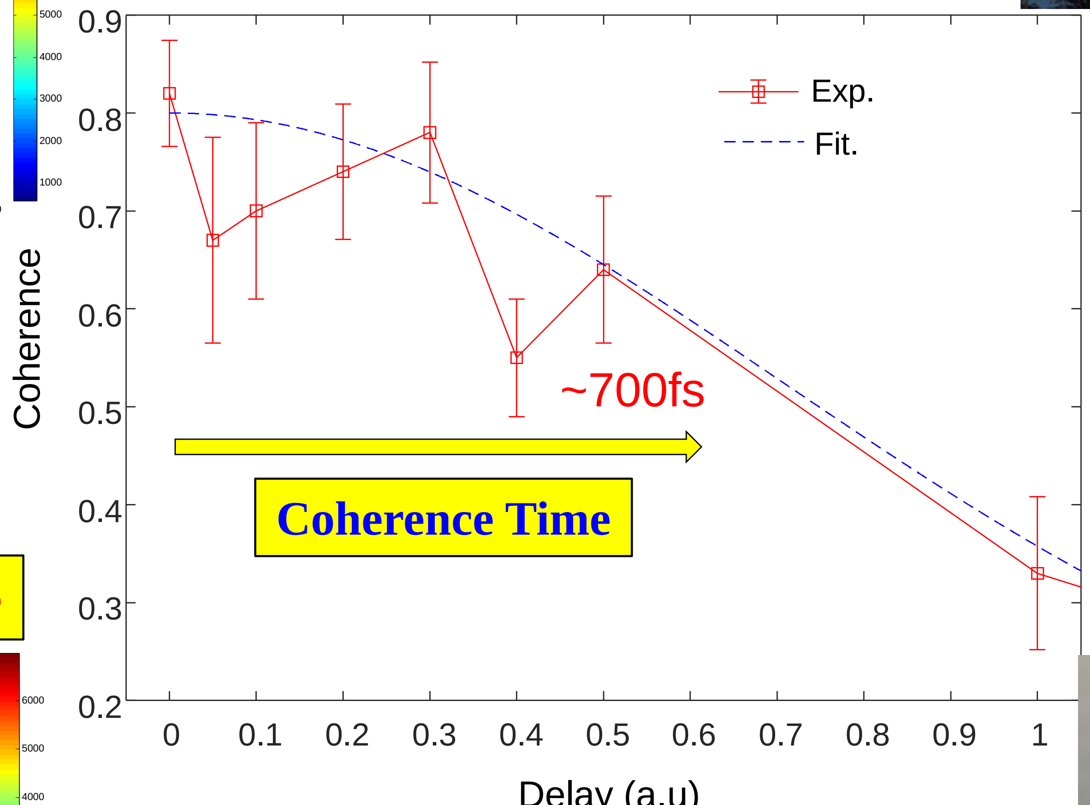
60nm

Pico-second Mode

High Coherence

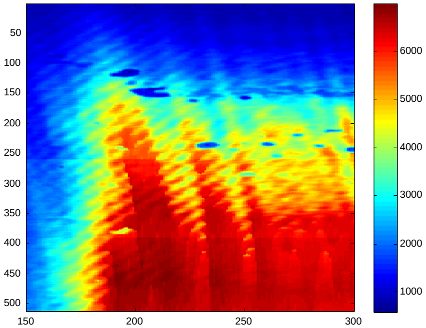


Longitudinal Coherence Length



ps ?

Low Coherence



Unpublished Data

Summary

SHINE

FEL-II 0.4-3keV FEL-I 3-15keV FEL-III 10-25keV

1. Overview of photon diagnostics development for SXFEL and SHINE project, including but not limit to:
   a) On-line XFEL intensity/position monitor
   b) Undulator commissioning device – K-mono
   c) Timing diagnostics
2. High resolution X-ray spectrometer development
3. DCLS coherence measurement: preliminary results

Acknowledgment

SXFEL/SBP Project and Teams

SHINE Project: Accelerator Division、Beamline and Photon Science Division

Thank you for attention !