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SIMULATION OF X-RAY OPTICS FOR PHOTON DIAGNOSTICS AT XFEL

Introduction:

- **The lasing process at theEuropean XFEL is based on SASE principle; so the X-ray pulses created in the undulators have to be characterized by photon diagnostics in order to find and tune this process and provide beam information to users.**
- **For commissioning of the single segments of the SASE-undulators (use of K-Monochromator), spontaneous radiation will be used.**
- **For simulations of Single-Shot Spectrometers we assume complete SASE radiation.**

RAY[1]

Simulate Optical systems up to 10 elements
Beamline design tool
Geometric Optics

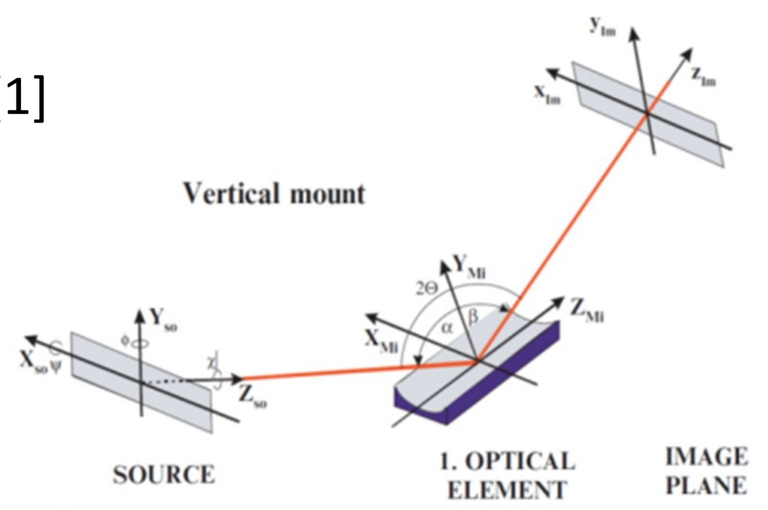
Sources

- Point
- Dipole
- Undulator
- External source files from WAVE [3]

Optical elements

- Reflection Mirrors
- Crystals (graded)
- Gratings (VLS)
- Transmission zone plates (cooperation Prague Uni.)
- Reflection zone plates (cooperation King's College London)

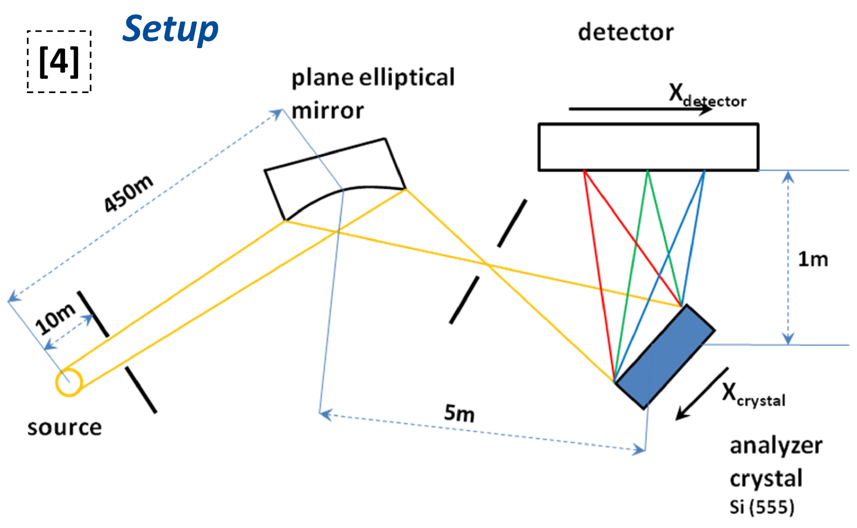
COORDINATE SYSTEM OF RAY



Single-Shot Spectrometer

Setup

[4]



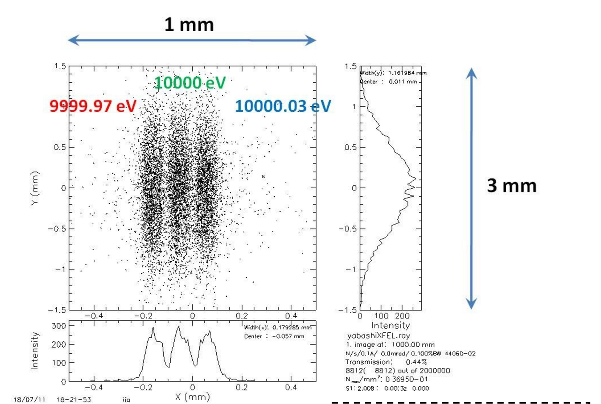
Crystal design

Parameters for simulation

source:
- $\sigma_{x,y}$ = 17 µm
- $\sigma_{x,y}'$ = 1.1 µrad
- energy: 10 keV

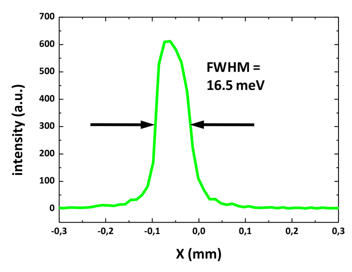
crystal:
- silicon (555)
- size: 30 x 5 mm²
- Bragg angle: 81.3°

plane elliptical mirror:
- size: 500 x 60 mm²
- grazing inc. angle: 0.4°
- entrance arm: 450 m
- exit arm: 0.50 m
- coating: platinum 30 nm
  roughness: 0.3 nm

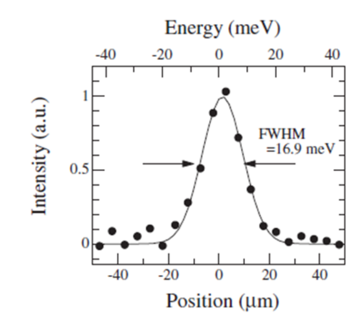


Slope Errors (@mirror):
0.5'' x 1.5'
(saggital x meridional)

Simulation



Experiment



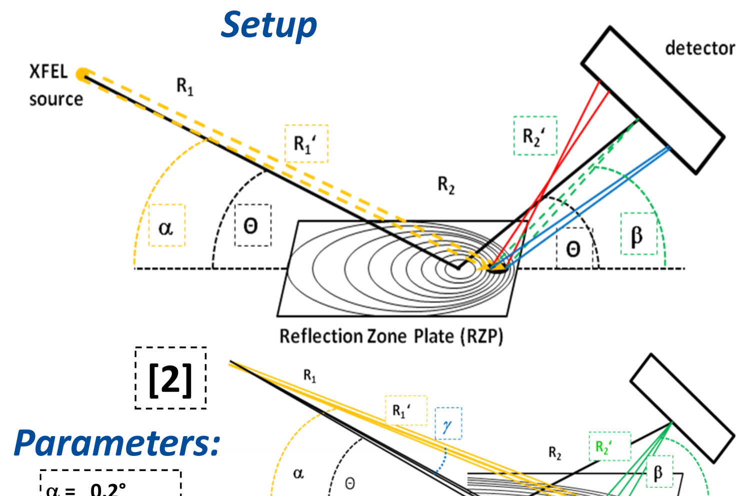
Yabashi et al.

FIG. 3. Spatial profile of dispersed beam (lower axis). The corresponding energy scale is shown on the upper axis.

Good agreement!

Reflection Zone Plate

Setup



[2]

Parameters:

α = 0.2°
E = 10 keV
d_{av} = 100 nm

$$\alpha = \tan^{-1}\left(\frac{R_1 \sin\Theta}{R_1 \cos\Theta + x}\right)$$

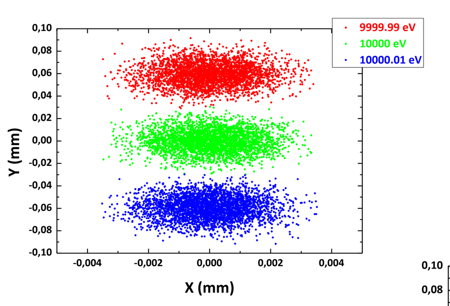
$$\beta = \tan^{-1}\left(\frac{R_2 \sin\Theta}{R_2 \cos\Theta - x}\right) = \cos^{-1}\left(\cos\alpha - \frac{\lambda}{d}\right)$$

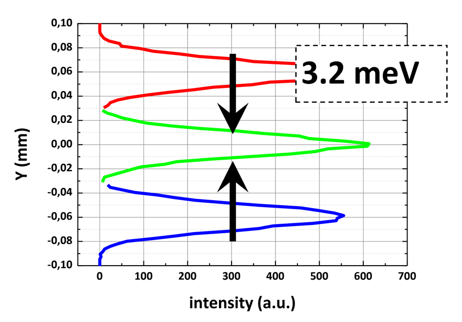
$$d = \frac{\lambda}{(\cos\alpha - \cos\beta)}$$

$$d = \frac{\lambda}{(\cos\alpha - \cos\beta)} \Rightarrow \beta = 2.861°$$

$$\Theta = \arctan\left(\frac{1}{\left[0.5\left(\frac{1}{\tan\alpha} + \frac{1}{\tan\beta}\right)\right]}\right) \Rightarrow \Theta = 0.3739°$$

γ = 0.1739° ≈ 3.039 mrad; R_1' ≈ 280 m; R_2' ≈ 20 m





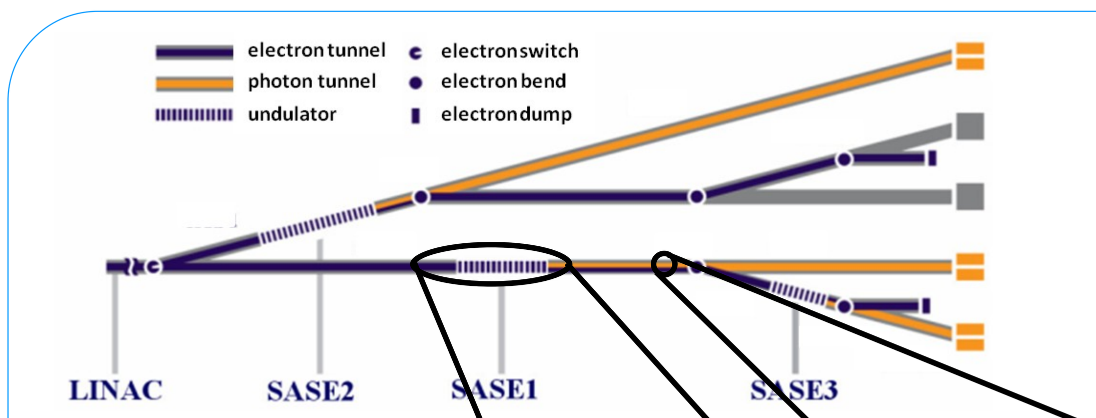
Comparison of the two designs

Crystal design:
- resolution: ΔE = 30 meV / 0.1 mm
- dispersion: 300 meV / mm (1 m after CR) (Yabashi: 1 eV / mm)
- FWHM: 16.5 meV (55 µm)
- slope errors: < 1.0 arcsec (state of the art: 0.3 arcsec)
- fabrication time: app. 8-12 months

RZP design: (10 keV)
- resolution: ΔE = 10 meV / 60 µm
- dispersion: 167 eV / mm (20 m after RZP)
- FWHM: 3.2 meV (20 µm)
- slope errors: 0.1 - 0.2 arcsec (estimated)
- fabrication time: app. 1-3 months

RZP design: (1 keV)
- resolution: ΔE = 1 meV / 60 µm
- dispersion: 16.7 eV / mm (20 m after RZP)
- FWHM: 0.327 meV (19.6 µm)
- slope errors: 0.1 - 0.2 arcsec (estimated)
- fabrication time: app. 1-3 months

K-Mono

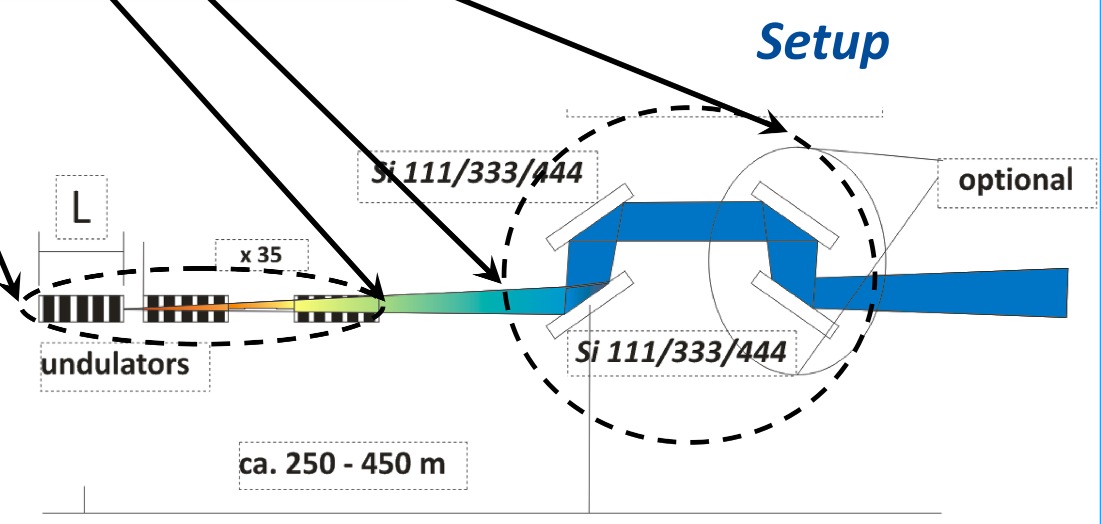


Setup

2 x Si 111 (333) channel-cut monochromators

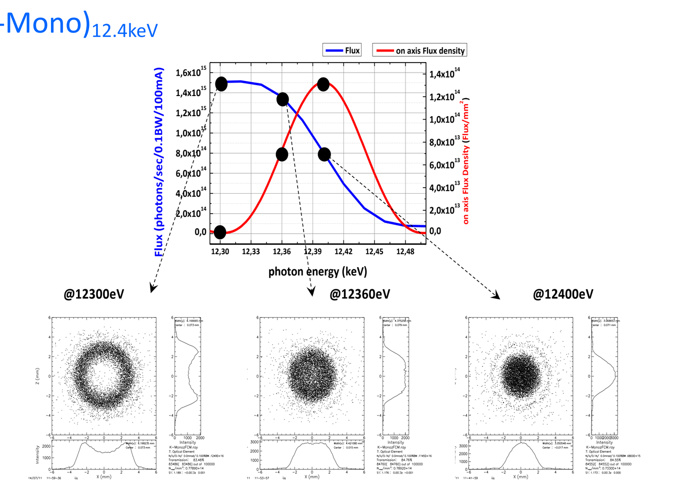
Energy resolution:

photon energy (keV)	ΔE (eV)	ΔE / E
5	0.49	1×10^{-4}
10	1.2	1×10^{-4}
	0.065	6.5×10^{-6}
20	2.3	1×10^{-4}
	0.104	5×10^{-6}



Goal: determination of spontaneous radiation of one undulator segment with $\Delta K/K \approx 10^{-4}$

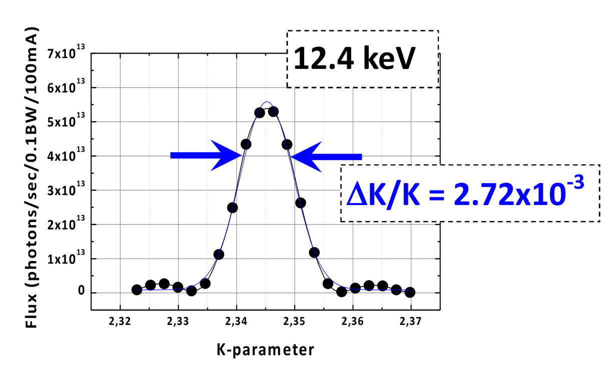
$\Delta E/E$ (K-Mono)$_{12.4keV}$
1×10^{-4}



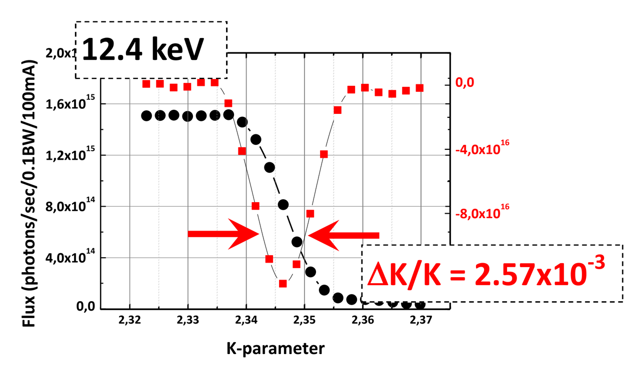
Electron beam parameters:
Electron energy: 14 GeV
Emittance: 0.97 mm mrad
Beta function: 32 m
$\sigma_{x,z}$ = 34 µm
$\sigma_{x,z}'$ = 1 µrad

Undulator parameters:
Period length: 40 mm
No. of periods: 125
Gap-range: 10-28 mm

Flux through pinhole (1 mm²)

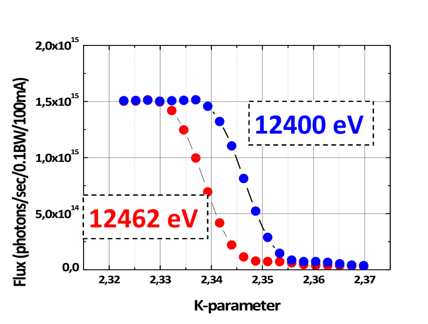


Flux without pinhole

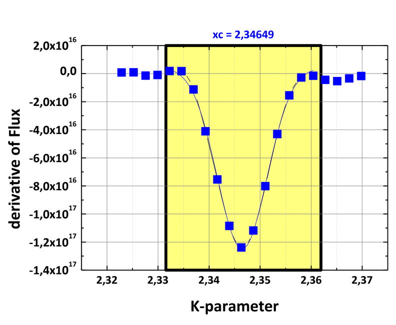


Centroid method

Flux without pinhole

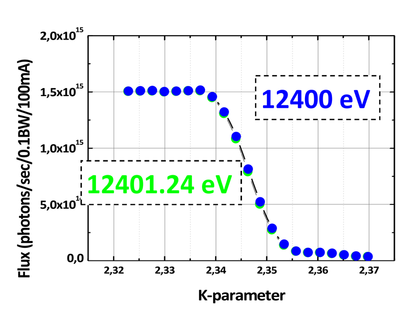


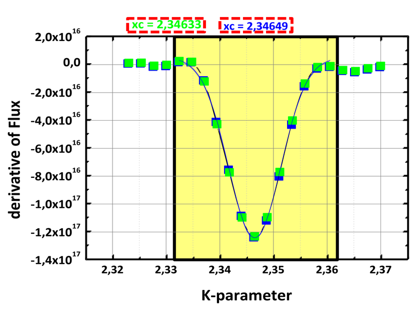
Differentiate, Gaussian fit



E_{ph1} = 12400 eV	Center @ K = 2.34649
E_{ph2} = 12462 eV	Center @ K = 2.33853
$\Delta E/E = 5\times10^{-3}$	$\Delta K/K = 3.39\times10^{-3}$

Best achieveable precision:





$\Delta E/E = 1\times10^{-4}$
$\Delta K/K = 6.81\times10^{-5}$

Goal is achieved! - Mission completed!

Conclusions:

- **Raytracing tool RAY is used to perfom simulations of diagnostic spectrometers for XFEL**
- **External source files of WAVE have been implemented in RAY**
- **The ΔK/K value can be determined with a precision < 10^{-4}**
- **Two designs for single-shot spectrometer were simulated**
  - **Crystal design calculations agree with experimental results of Yabashi; FWHM: 16.5 meV (@E = 10 keV)**
  - **RZP design has an energy resolution of 3.2 meV (@ E = 10 keV) (0.327 meV @ 1keV)**

[1] Franz Schäfers, „The BESSY raytrace program RAY", Modern Developments in X-Ray and Neutron Optics, Springer Series in Optical Sciences, Volume 137, (2008), 9-41
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[3] Michael Scheer, „Beschleunigerphysik und radiometrische Eigenschaften supraleitender Wellenlängenschieber", HU Berlin, PhD-thesis (2008)
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[5] Alexei Erko et al., „A raytracing code for zone plates", Proc. SPIE Vol. 5536, 61-70 (2004)
[6] Jan Grünert, „Photon diagnostics requirements and challenges at the European XFEL", Proceedings of FEL2009, Liverpool, UK, MPOC56 (2009)
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Gianluca Geloni, „Open Announcement of Simulation Code Benchmark", European XFEL, (2010 - updated 2011)

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