European XFEL

Undulator Commissioning Spectrometer for the European XFEL

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Wolfgang Freund, WP74 European XFEL
wolfgang.freund@xfel.eu

DESY HELMHOLTZ ASSOCIATION

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Requirements

- Photon based calibration scan of K vs. gap for each segment
  - acquire spectrum (scan mono, sort by E_e) for different gap settings of a single segment at one given E_e
  - gap range: 10mm – 40mm (SASE1)
  - minimization of ΔK between pairs of segments
  - target: $\Delta K \rightarrow 0$ among all segments (no taper)
  - K-precalibration in magnetic lab to $\Delta K \sim 10^{-4}$ (gap tuned with micron accuracy)
- Adjustment of phase

General requirements

- large acceptance: ~12mm spot size, due to large distance to undulator
- two parallel beams for quadrupole kick method (~25mm horizontal)
- retractable for FEL operation
- compact design, due to space limitations

	Photon energy range	Core range
SASE1&2	3-25 keV	5-18 keV
SASE3	0.28-3 keV	0.4-2 keV

Requirements

- Required accuracy of K-measurement
  - Pierce parameter $\rho \cong 3\text{x}10^{-4}$ for λ=0.1nm

$$\frac{\Delta\lambda}{\lambda} \leq \rho \quad \approx bandwidth\ /\ 2$$

$$K_{rms} = \frac{\lambda_U\, e\, H_{rms}}{2\pi\, m_e c^2}$$

$$\lambda = \frac{\lambda_U}{2\gamma^2}\left[1 + \frac{K^2}{2}\right]$$

with $H_{rms} = \frac{H_{peak}}{\sqrt{2}}$ $\gamma = \frac{E}{m_e c^2}$

$$\Delta\lambda = \left(\frac{\delta\lambda}{\delta K}\right)\Delta K = \frac{\lambda_U K}{2\gamma^2}\Delta K$$

$$\boxed{\frac{\Delta K}{K} < \rho\left[\frac{1}{K^2} + \frac{1}{2}\right]}$$

λ	bandwidth	ρ= BW/2	K	ΔK	ΔK / K
[Angstroem]	[%]			< (1+K^2/2)/K*ρ	[1E-4]
1	0,08	0,0004	3,3	0,000781	2,4
4	0,18	0,0009	6,1	0,002893	4,7
16	0,3	0,0015	6,8	0,005321	7,8

$$\lambda = \frac{\lambda_U}{2\gamma^2}\left[1 + K_{rms}^{\ 2}\right]$$

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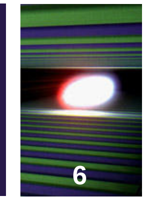
Requirements to electron beam

- single bunches (FEL) up to full bunch train (few undulator segments)
- bunch charge 1nC
- electron energy 10 GeV or 14 GeV (17.5 GeV)
- electron beam energy jitter < 2×10^{-4}
- energy chirp < 2×10^{-4}
- electron energy measurement resolution < 2×10^{-4} (bunch / averaged): high relative accuracy / high reproducibility
- beam position jitter / pointing stability minimum requirement: 30 µm / 0.5 µrad
- electron energy scan over +/- 1.5% (within ~10s)

Crystal setup



Si 111 crystal reflections

Photon energy	Si 111	Si 333	Si 444
2050 6Å	74.68° 414 µrad 0.224 eV	Bragg angle Acceptance angle Energy resolution	
2400 5.2Å	55.47° 187 µrad 0.30 eV		
3100 4Å	39.63° 105 µrad 0.42 eV	-	-
6200 2Å	18.6° 46.5 µrad 0.90eV	73.08° 31.5µrad 63meV	-
12400 1Å	9.175° 21 µrad 1.77 eV	28.58° 5 µrad 0.12 eV	39.63° 5 µrad 75meV
24800 0.5Å	4.57° 10.7 µrad 3.5 eV	13.84° 2.24 µrad 0.24 eV	18.6 ° 1.9 µrad 0.15eV
40000 0.31Å	2.83° 6.6 µrad 5.74eV	8.53° 1.36 µrad 0.39eV	11.4° 1 µrad 0.23eV

Crystal geometry

- channel cut crystals for high accuracy
- asymmetrical cut for increased acceptance angle
- big reflection surface for acceptance of 12 mm beam
- fundamental energy below 2400 eV only by observation of harmonics (SASE3)

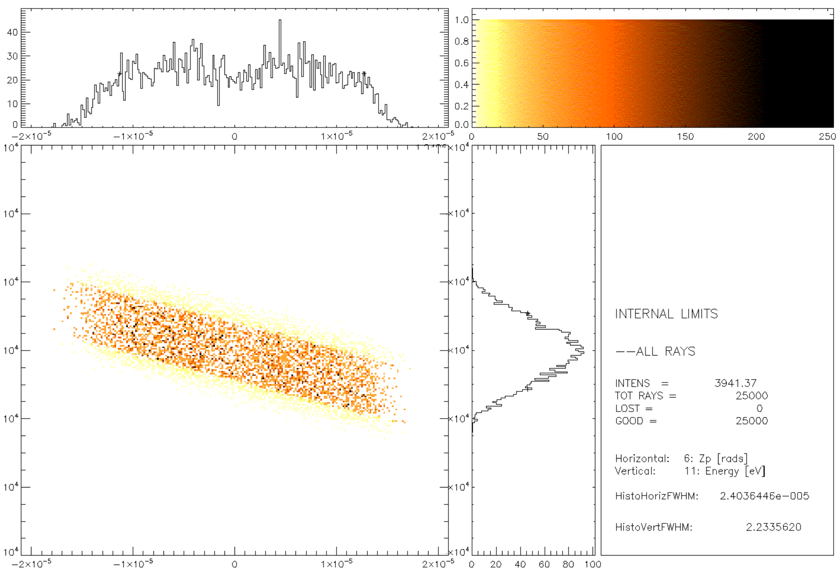
Raytracing (Shadow / XOP)

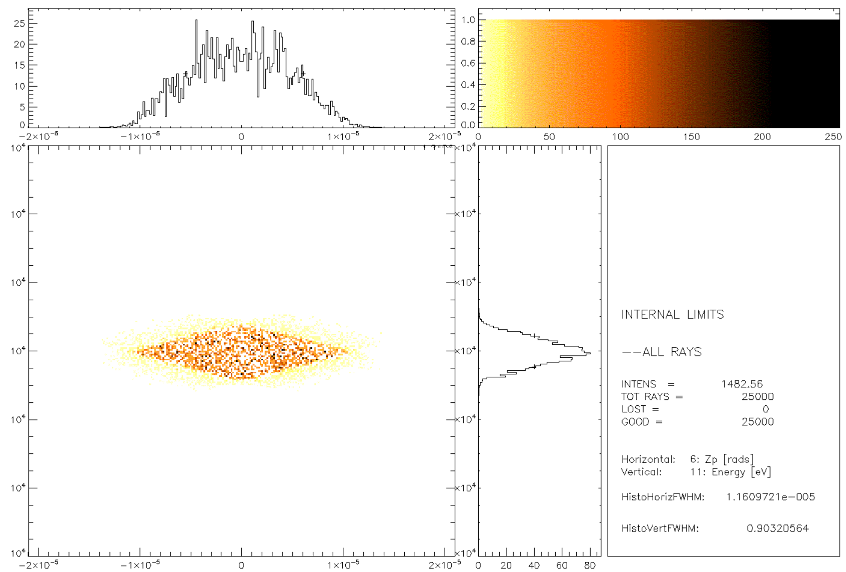
2-bounce case:

- without second monochromator stage
  (or 2nd stage rotated out of beam)
- easier to adjust with harmonic Bragg reflections

4-bounce case (Bartels geometry):

- second monochromator stage
- higher energy resolution (for 111 reflection)





Energy versus vertical (dispersive) position: Si 111; E_{ph}=12.4 keV

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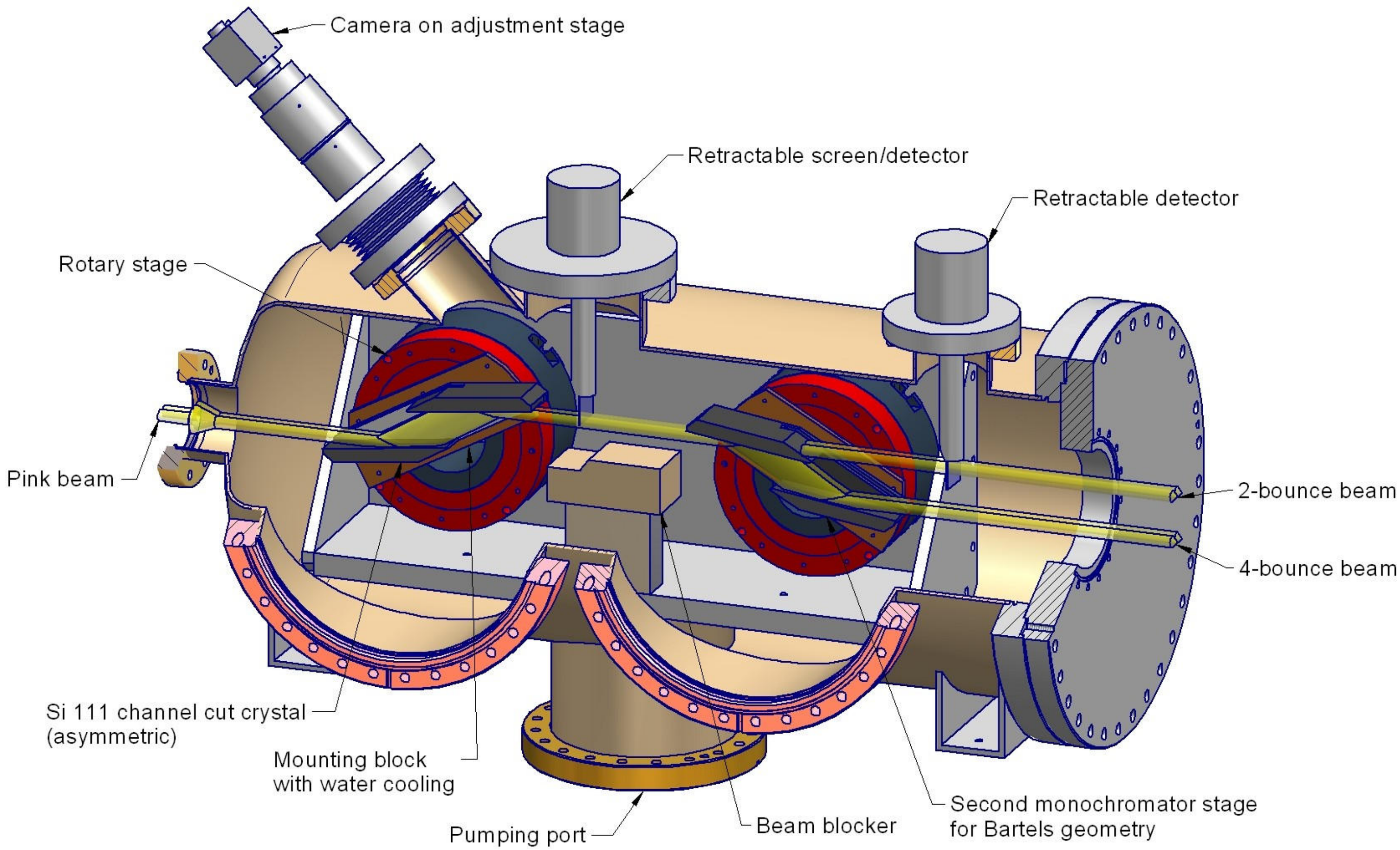
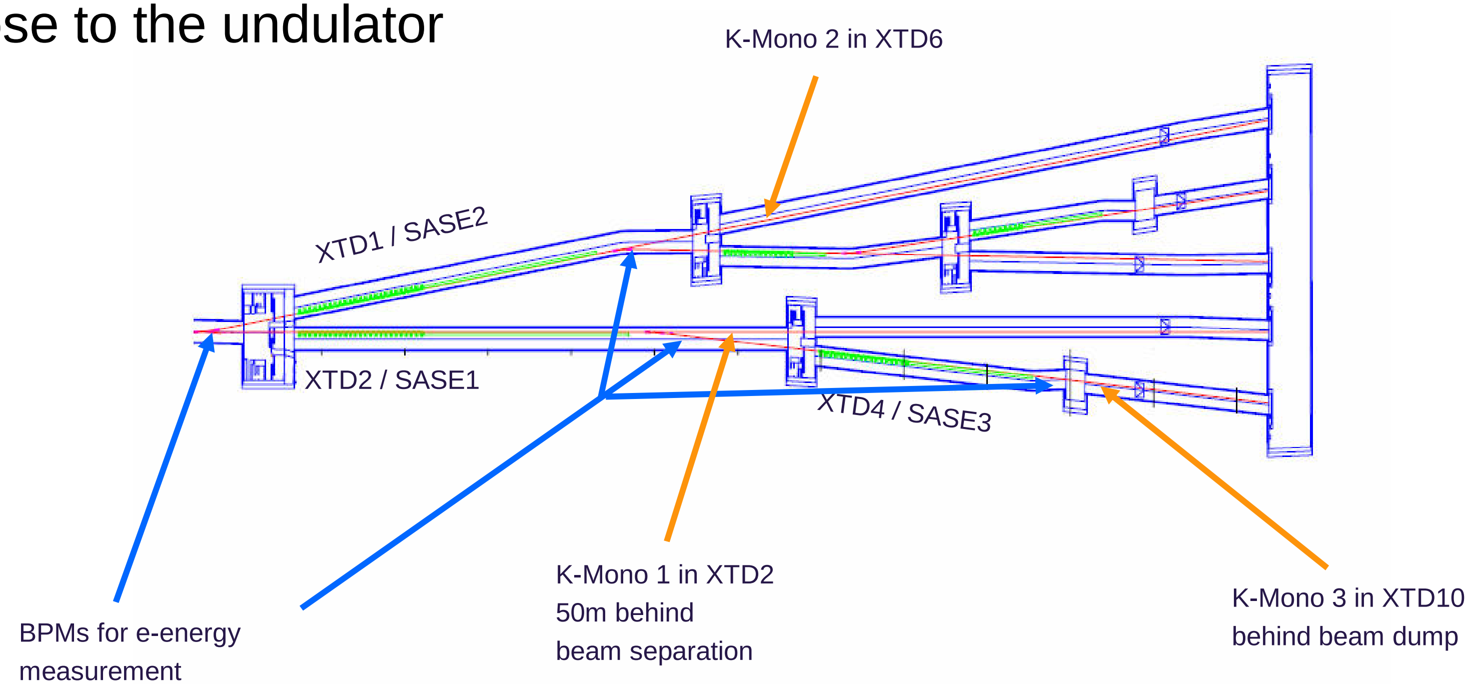
Setup (concept)



Position of K-Monos

- before mirrors and other optical elements which limit the acceptance
- after beam separation
- close to the undulator



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Quadrupole kick method

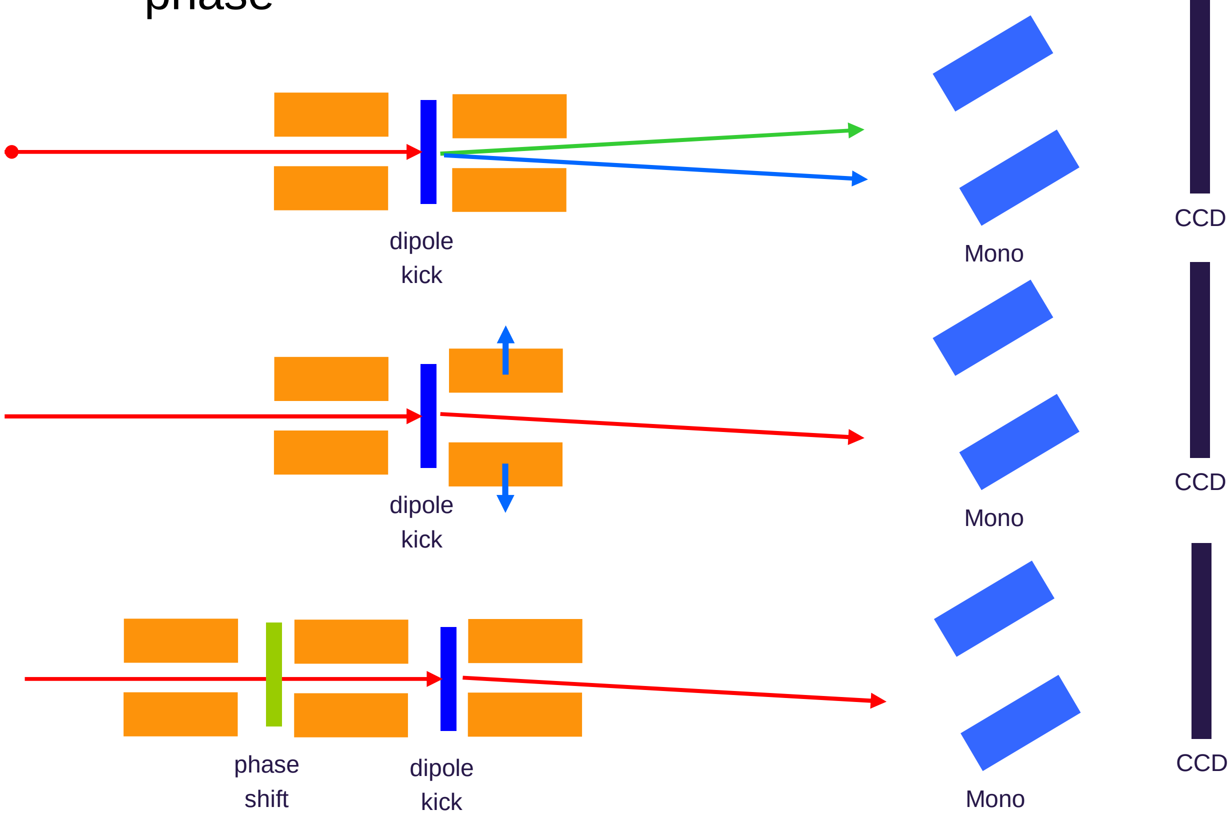
- Only the radiation of two adjacent undulator segments is examined. Between the segments a quadrupole kick deflects the electron beam by ~ 20 µrad

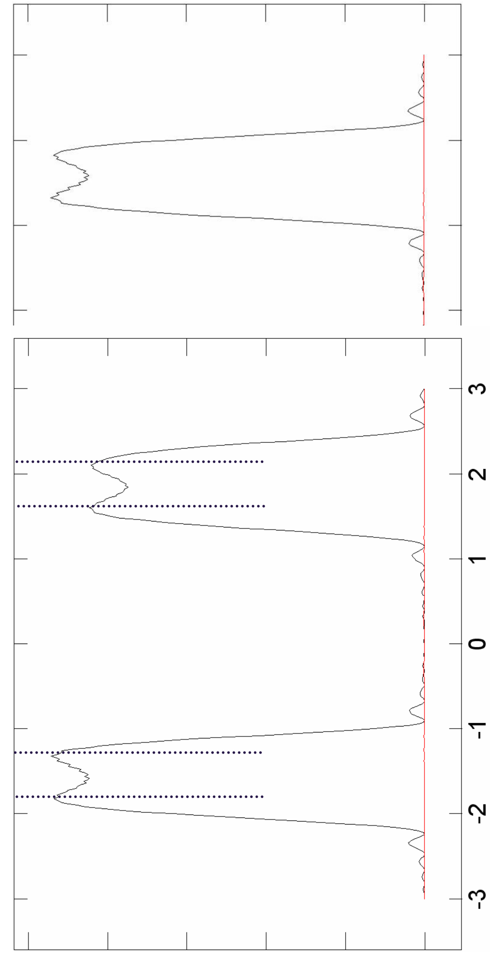
- The intensity profiles of the two segments are spatially separated and can be directly compared. When observing the radiation produced by a single bunch, the energy jitter effect disappears. Due to the low intensity a sensitive detector, e.g. an x-ray CCD, is mandatory.
[Takashi Tanaka, *Undulator Commissioning Strategy for SPring-8 XFEL,* Poster, FEL09]

- Averaging of up to 2700 bunches of one bunch train increases the signal to noise ratio. The requirements to DAQ are quite relaxed (10Hz frame rate). However, this integrating mode implies availability of long bunch trains of spontaneous radiation for undulator commissioning.

Photon-based commissioning of the undulators using spontaneous radiation

- undulator segments adjustment
  - tilt & offset (relative to electron beam trajectory)
  - gap
  - phase

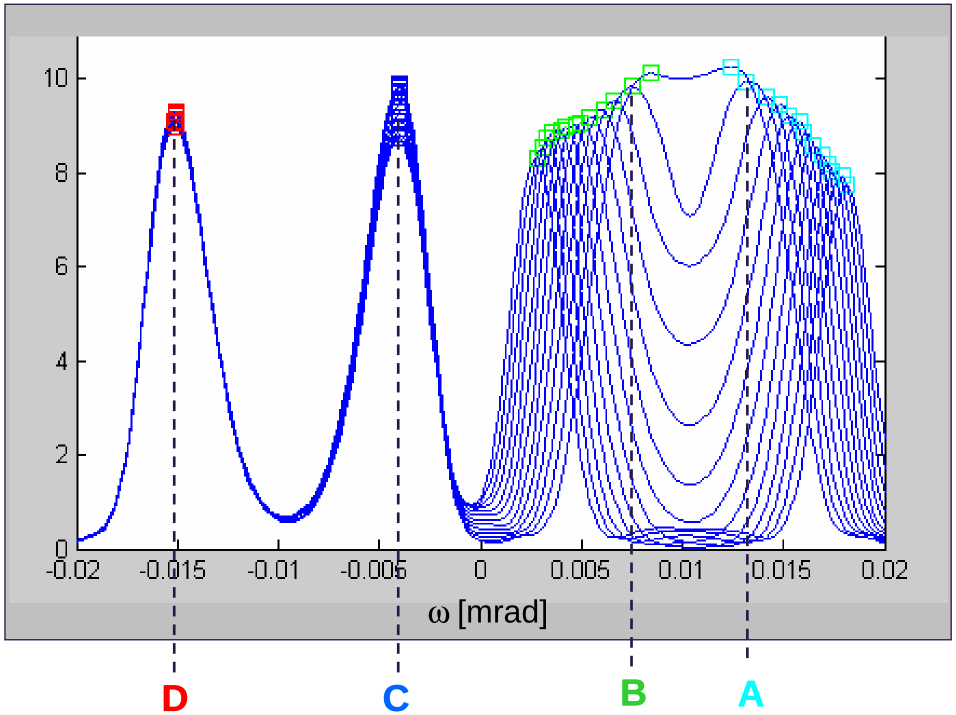




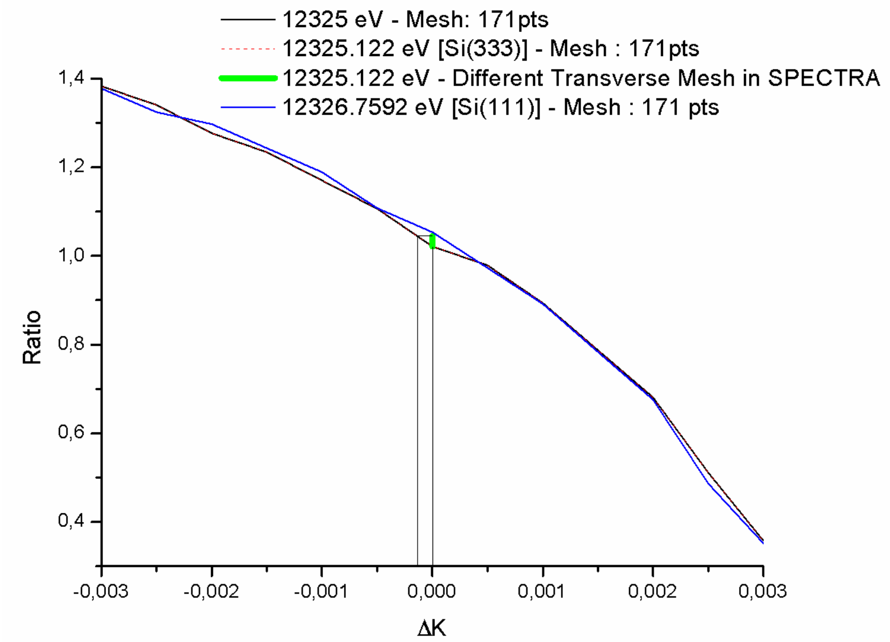
flux density [photons/sec/mm^2/0.1%BW] from 2 segments at z=100m at 12385eV with a (+/-) kick of 0,02 T

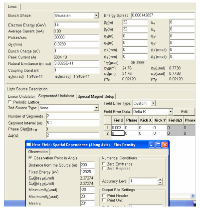
Takashi Tanaka, *Undulator Commissioning Strategy for SPring-8 XFEL*, Poster, FEL09

Simulation: pairwise ΔK tuning with kick



- real BW of monochromator
- accuracy + mesh effects
- S/N for 2D image ?!





Parameters

Ratio $\frac{-}{-}$

work with Gianluca Geloni

Thank you for your attention !

References:

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