Undulator commissioning spectrometer for the European XFEL

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Introduction

Photon based commissioning of the European XFEL undulators will require a precise adjustment of the K-parameters of all undulator segments and phasing between these segments. The LCLS approach with a double channel-cut monochromator is a good basis for adaptations, which are necessary in order to get a conceptual design for the three SASE undulators at the European XFEL. We have to take into account the large gap setting range and wavelength ranges of 0.5 to 4Å for SASE 2 and 4 to 16Å for SASE 3, respectively. The spectrometer will analyze spontaneous radiation from single segments up to the full undulator length. In order to apply the spectrometer to the soft X-ray region of SASE 3, the use of 3rd or 5th order harmonics is an option.

Requirements

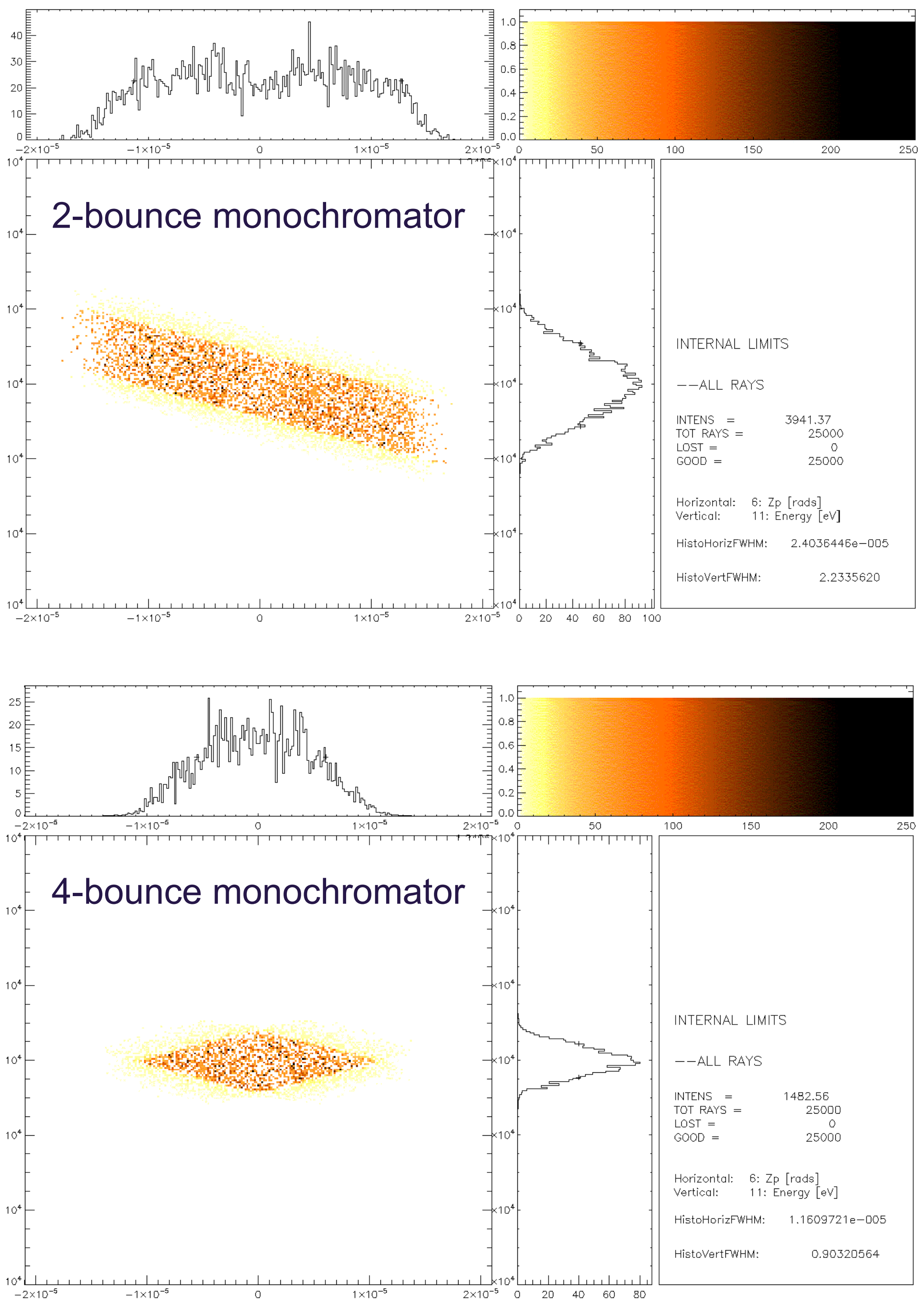
All undulator segments must be tuned to the same K (except for an additional taper), but the absolute K value needs not to be determined with the same accuracy. The K-parameter is determined by means of the measurement of the photon energy E_{ph} .

$$K_{peak}=\sqrt{2}\sqrt{\gamma^2\frac{\lambda}{\lambda_u}-1-\gamma^2\theta^2} \quad \Bigg| \quad \gamma=\frac{E_e}{m_e c^2}$$

θ = observation angle (=zero)
λ_u = undulator period
λ = fundamental wavelength

- Accuracy: $\Delta E/E < 3\times10^{-4}$ (at E_{ph}= 12.4keV)
- Photon energy range for SASE 1&2: 3-25keV (core range 5-18keV)
  Photon energy range for SASE 3: 0.28-3keV (core range 0.4-2keV)
  (For SASE 3 fundamental above 2keV or higher harmonics)
- Time pattern for commissioning: single bunches at 10Hz is the minimum requirement, where the heat load is negligible. The full heat load with the last two undulator segments and the full bunch train (27000 per sec) would be approx. 10W, which is the basis for the water cooling design.
- Acceptance of two parallel beams with a minimum diameter of 10mm for quadrupole kick method.
- The spectrometer must be retractable for FEL operation

Figure 1:
Si 111 ; E_{ph}=12.4 keV
Energy versus vertical (dispersive) position
Raytracing results from Shadow / XOP



K-determination

Three different methods for K/gap-determination are taken into account (for details please refer to the cited papers):

- Gap tuning: The energy spectrum of one undulator segment is measured (by switching off the others), in order to find its present gap setting, which then has to be adjusted. Alternatively the gap can be varied at a fixed observation energy for maximizing the intensity. [1: M.Tischer et al]
- Steepest slope: All but two adjacent undulator segments are 'switched off' by opening the gap. Spectra of the fundamental (or a harmonic) are measured (by variation of E_e) for different gap settings of one segment while the other segment is kept fixed. For the setting with the steepest slope of the high energy edge, the K-parameters match best. [2: J.Welch et al]
- Quadrupole kick: Also here only the radiation of two adjacent undulator segments is examined. Between the segments a quadrupole kick deflects the electron beam by up to 20 µrad. So the intensity profiles of the two segments are spatially separated and can be directly compared. When observing the radiation produced by just one electron bunch, the energy jitter effect disappears. Due to the low intensity a sensitive detector, e.g. an x-ray CCD, is mandatory. [3: T.Tanaka]

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° 2.24µrad 0.24 eV	18.6 ° 1.9 µrad 0.15eV
49600 0.25Å	2.28° 2.3 µrad 7 eV	6.9° 1.1 µrad 0.5 eV	9.175° 1 µrad 0.23eV

Table 1:
Si 111 Bragg reflections

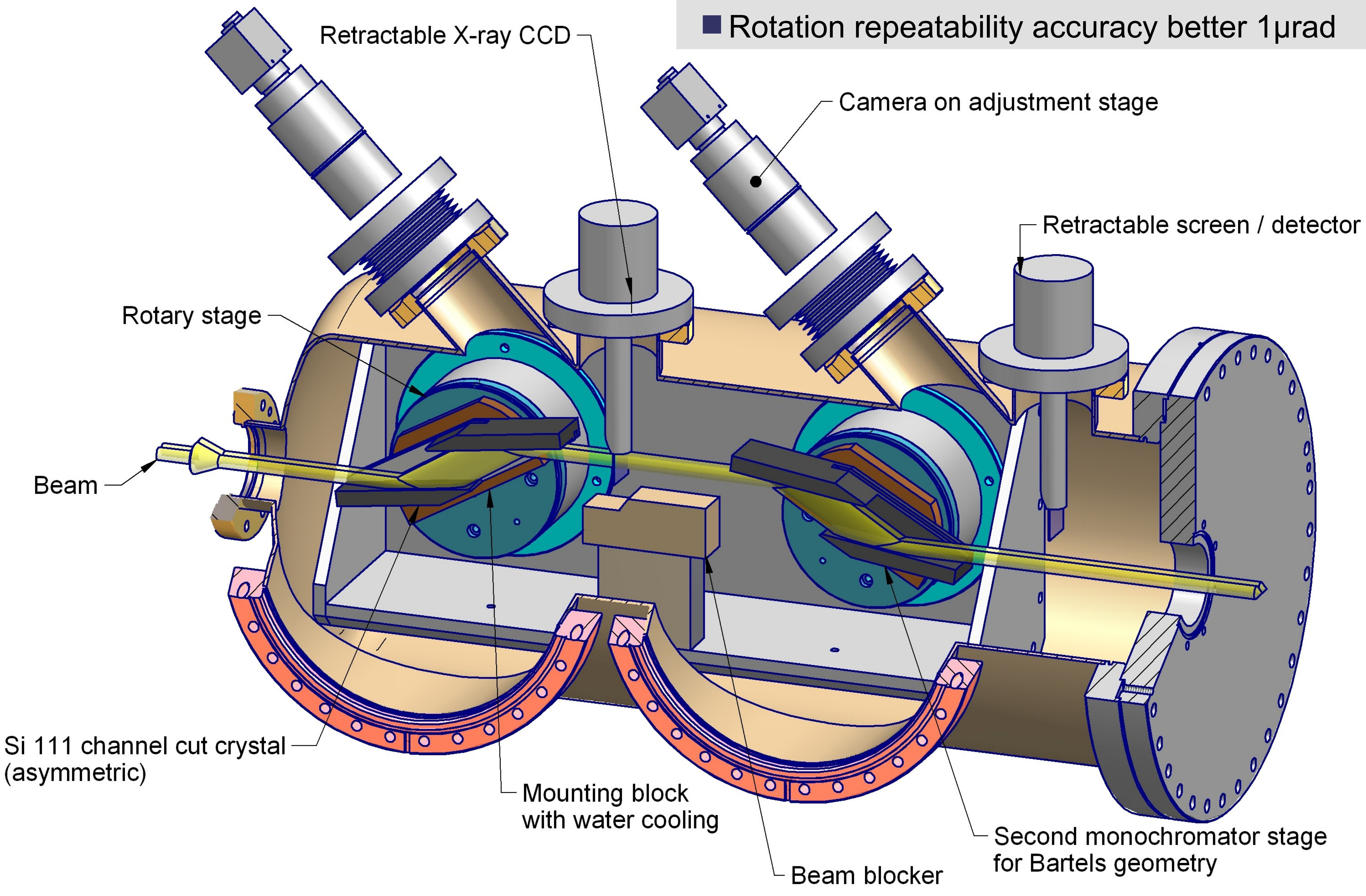
Setup

- Channel cut 8° asymmetric Si 111 crystal (increased acceptance angle)
- Acceptance angle >5µrad for all energies
- Water cooling for temperature equalization
- Second monochromator stage for Bartels geometry with higher energy resolution and inline geometry. It also allows slight detuning for suppression of higher harmonics.
- Retractable screen and/or detector (X-ray CCD)
- CCD camera / screen for imaging high or time integrated intensity (could alternatively be positioned in a separate chamber behind the K-Mono)
- X-ray CCD for low intensity and single bunch imaging
- Diode detector for integral measurements

Specifications

- Bragg angle range: 12° to 68°
- Energy range:
  2.2keV to 10keV (30keV) for Si111 (Si333)
- $\Delta E/E = 2\times10^{-4}$ (1×10^{-5}) for Si111 (Si333)
- Rotation repeatability accuracy better 1µrad

Figure 2:
Spectrometer setup – retraction and adjustment mechanism not shown



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