Progress in the Optimization of the FOCAL Crystal Spectrometer

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The FOCAL x-ray spectrometer is being developed for the accurate measurement of the 1s Lamb shift in one-electron heavy ions. In the **FO**cussing **C**ompensated **A**symmetric **L**aue geometry part of the possible wavelength resolution is traded off in favor of an increased sensitivity through a broadening of the crystal rocking curve [1].

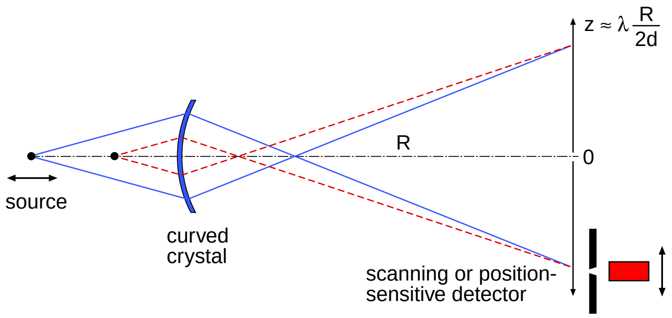

Figure 1: Principle of the x-ray optical arrangement used for systematic tests of the FOCAL spectrometer. The x-ray path is shown for one wavelength at two different locations of the gamma-ray source.

The spectrometer has been set up on a test bench where several systematic investigations were performed during the past year. Figure 1 schematically shows the x-ray optical arrangement with a movable x-ray source parked at two different positions. The x rays are dispersed along the positive and negative z axis in a symmetric way where the displacement is approximately proportional to the wavelength. Spectra obtained from a ^{169}Yb source were recorded either with a scanner equipped with a narrow slit and a conventional Ge(i) detector or with the new micro-strip germanium detector under development [2]. Recording the x-ray spectra for a couple of different gamma-ray lines and for a range of source-to-crystal distances, it is possible to map out the x-ray optics and the performance and possible deviations of the crystal from it's ideal cylindrical shape. Up to now such tests have solely been made with the scanner. A first test of the spectrometer in combination with the new micro-strip detector was made for a fixed source-to-crystal separation amounting to 300 mm compared to 2 m as the nominal radius of curvature of the crystal.

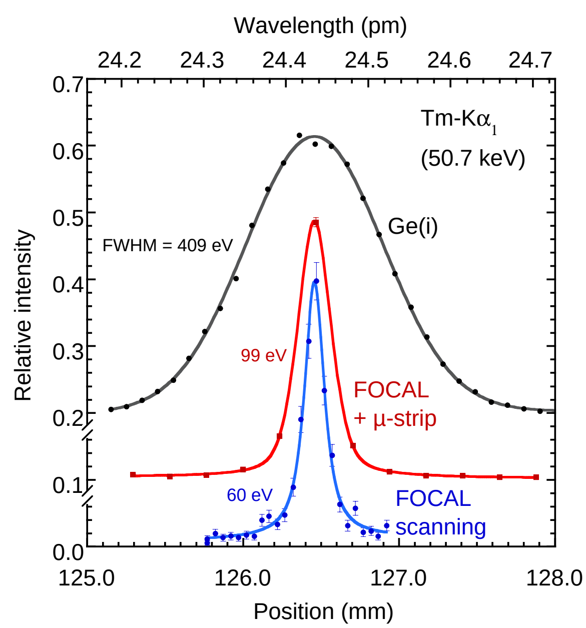

Figure 2: The wavelength profile of the Tm-Kα_1 line measured as the pulse-height spectrum of a conventional solid-state Ge(i) detector or measured with the FOCAL spectrometer equipped either with a position-sensitive micro-strip detector or in scanning mode.

Figure 2 compares measurements of the Tm-Kα_1 line near 50.7 keV from the decay of ^{169}Yb with FOCAL operated in scanning mode or with the micro-strip detector attached. For reference the pulse-height spectrum of the conventional Ge(i) is also included. The line widths of 150 μm (60 eV) and 250 μm (99 eV) for the scanner and for the micro-strip detector, respectively, are consistent with the expectations taking into account the slit width of 50 μm and the 235 μm combined stripe and gap width. Additionally the natural line width of 30 eV and the contribution from the rocking curve amounting to 40 eV have to be considered.

The present position sensitive detector has an area of 47 $\times$ 23.4 mm^2 and is structured with 200 stripes, each 200 μm wide, which are separated by grooves of 35 μm width. This prototype will soon be replaced by an upgraded version optimized in order to cover a substantial fraction of the astigmatic height of the spectral lines and to be position sensitive in *two* dimensions. This will be realized by etching grooves into both the front and rear surface of the germanium crystal.

For characterizing the silicon crystal, the source-to-crystal separation was varied between 260 and 550 mm. Gamma-rays near 50, 63 and 110 keV were reflected from different spots on the crystal that are offset by a distance ranging from $\pm$8 to $\pm$28 mm from the centre of the crystal. The results from these measurements revealed deviations of the curvature from the ideal cylindrical shape. In figure 3 the observed line widths are plotted as a function of the calculated position on the crystal. Going from the centre towards the edges of the crystal the width strongly increases. Presumably this is caused by the mechanical stress introduced in the bending device. We will try to reduce this effect by using only the inner region of a larger crystal and by a change of the design of the crystal bender.

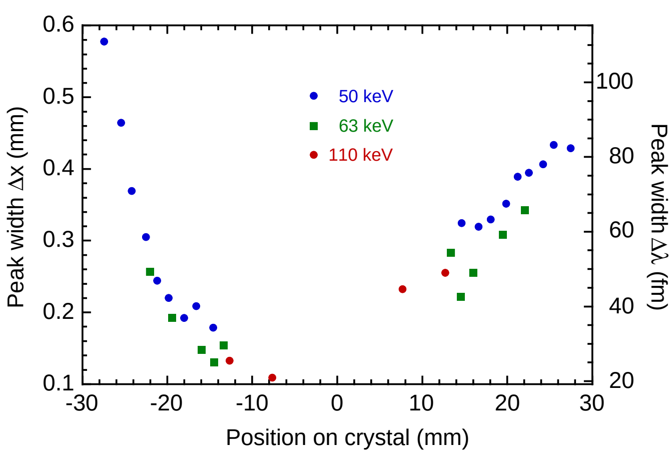

Figure 3: Observed line width for three different x-ray energies and for reflections occurring at different locations on the crystal.

For a more stringent test the crystal curvature was measured with synchrotron radiation at the optics beamline of the ESRF in Grenoble. There the white synchrotron beam was collimated down to a width of 0.5 mm with the secondary slits located at some 40 m downstream the bending magnet. The measurement setup is schematically illustrated in figure 4.

In a first step two *flat* silicon crystals having the same dimensions as the curved one, namely 80 $\times$ 40 $\times$ 1.5 mm^3, were prepared for the 220 reflection in the Laue case with an asymmetry angle of $\chi = 2^\circ$. The crystals were aligned using a scintillator detector and reflections were found in the non-dispersive (+1,-1) and dispersive (+1,+1) geometry by rotating the second crystal relative to the first one. The setup was tuned to a Bragg angle of 3.034° corresponding to approximately 61 kev x-ray energy. The first crystal, serving as a monochromator, was not touched anymore throughout the rest of the experiment.

In a second step the second crystal of the arrangement was replaced by the curved crystal to be tested and subsequently the (+1,-1) reflection was found. The x-ray beam incident on the curved crystal was shifted horizontally, in an approximately parallel way, in steps of 2 mm by means of an according movement of the secondary collimating slits in front of the experimental setup. For each translation Δx of the incident beam the Bragg reflection on the curved crystal was found by rotating the curved crystal.

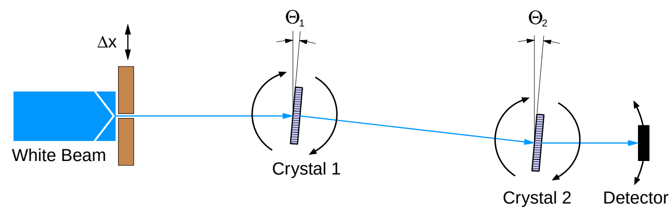

Figure 4: The two-crystal set up used at the optics beamline at the ESRF.

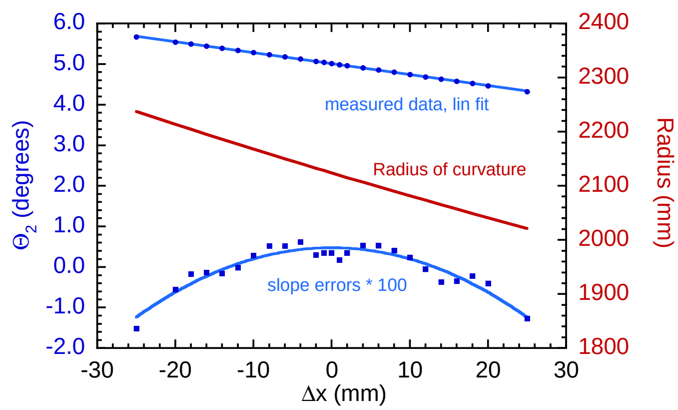

Figure 5: Curvature results obtained with the measurement illustrated in figure 4. From the deviations of the angular positions from a strict linear behavior the variation of the bending radius across the crystals long dimension is obtained.

The relation between the angular position θ_2 of the reflection maximum and the translation Δx is plotted in figure 5. For an ideal cylinder a straight line is expected. Small deviations from the linear fit are shown in the figure as *slope errors*, i.e. as the differences between the angular data measured and the linear fit. For better visibility the slope errors were multiplied by a factor of 100. From the smooth curve through the slope errors the variation of the radius of curvature across the crystals long dimension has been derived which is also plotted in figure 5. The $\pm$5% variation of the radius for a $\pm$25-mm excursion on the crystal is consistent with optical measurements using the crystals reflecting surfaces.

The present results were obtained for a trace centered on the crystal. As soon as an improved version of the bent crystal is assembled we will complement the curvature measurements tracing the crystal also in the anticlastic direction.

References

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[2] Th. Stöhlker et al., GSI Scientific Report 1999, p. 206. D. Protić et al., IEEE Trans. Nucl. Sci. to be published.