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Single shot tender X-ray spectral measurements via the 3rd harmonic using bent crystals

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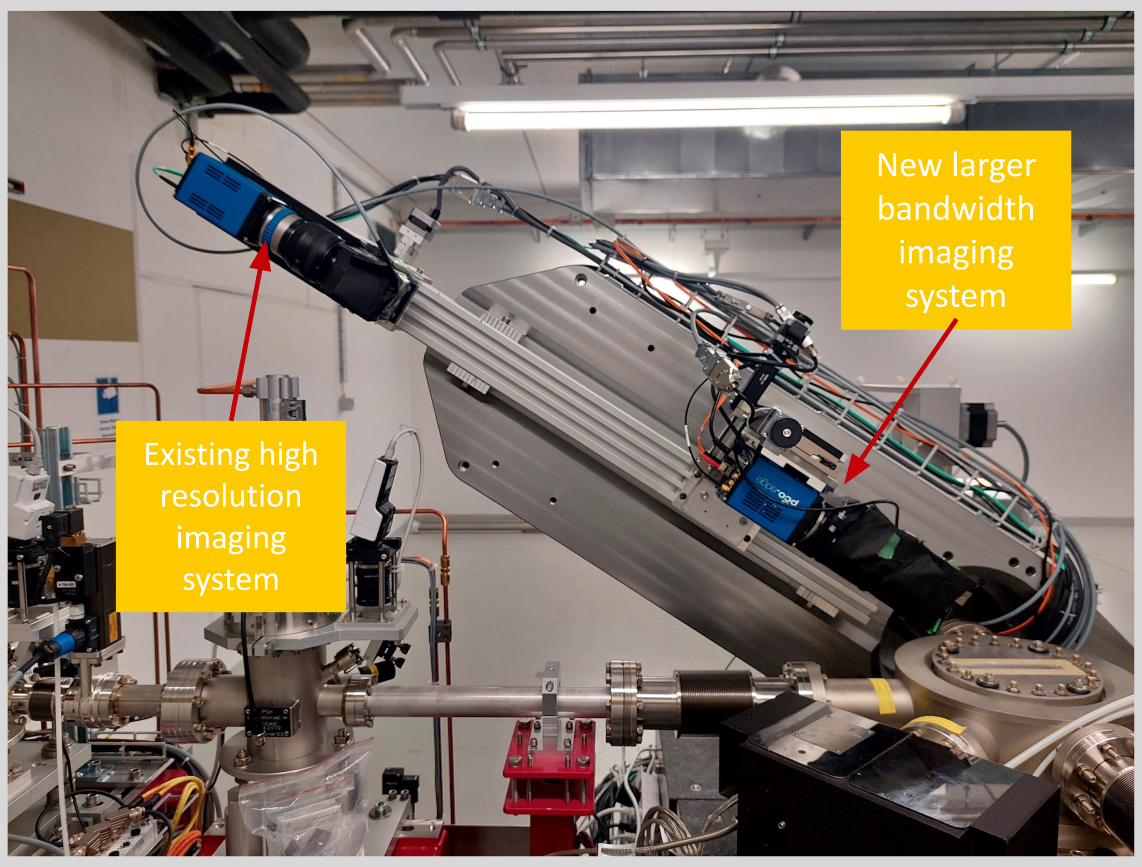
The tender X-ray region provides access to various absorption edges, such as sulfur, chlorine, and silicon, which are of particular interest for developing organic semiconductors. Direct measurement of the X-ray spectrum in the energy region between 2.5 –4.0 keV is challenging and typically suffers from poorer energy resolution from ruled gratings or lower efficiency from scattering-based approaches. Presented here is use of a bent crystal spectrometer to measure the 3rd harmonic of the fundamental 2.5 keV FEL output.

Adaption to existing spectrometer

The existing bent crystal spectrometer at the hard and tender X-ray FEL (Aramis) at SwissFEL was modified with an additional imaging system to measured the dispersed X-rays from a bent crystal. Using a bent crystal to disperse the X-ray beam was first demonstrated at LCLS[1], and the use with beam sampling gratings to provide an online measured[2] was adapted to a beamline spectrometer at SwissFEL[3]. The design however is incompatible to measure tender X-ray directly as the dispersed X-ray pass through a beryllium window and are detected in air.

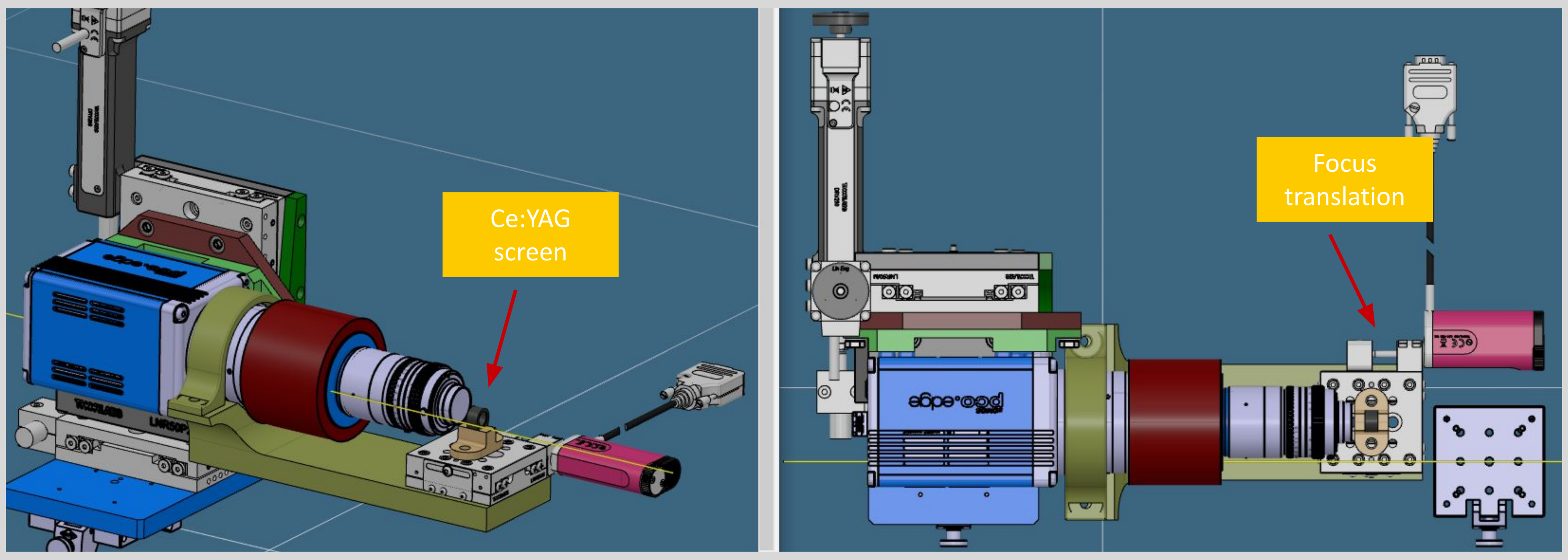
1. D. Zhu, Appl. Phys. Lett. 101, 034103 (2012)
2. M. Makita, Optica 2, 912-916 (2015)
3. J. Rehanek et al 2017 JINST 12 P05024

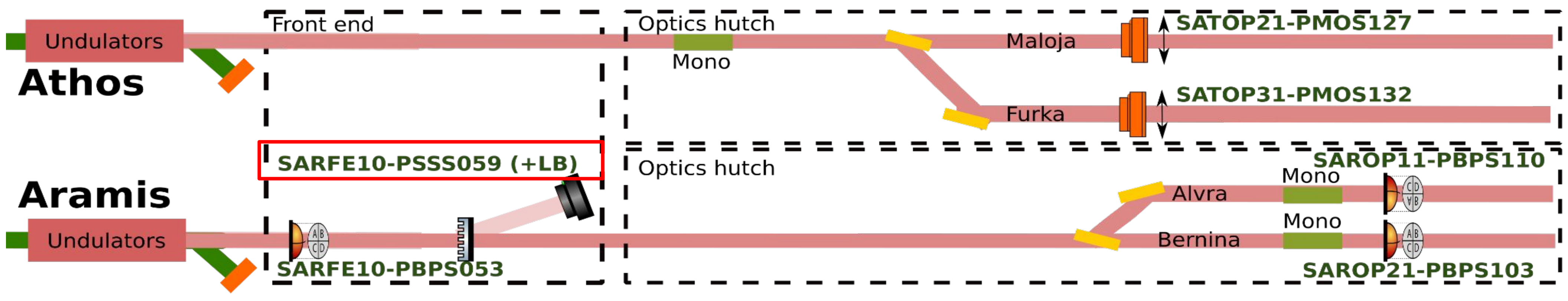


Design

The additional 2D imaging system was mounted approximately 25 cm from the dispersive crystal. In this position the width of the dispersed X-ray is less giving a higher signal to noise on the detector, key for the weaker 3rd harmonic signal. Using a Ce:YAG to down convert the X-ray photons to visible light, the Ce:YAG surface was imaged with a PCO.edge CMOS camera with an approximate 5 x 5 mm^2 field of view and 10 um resolution.

The imaging setup can moved out the the dispersed beam to allow the X-rays to be detected with the existing imaging system.

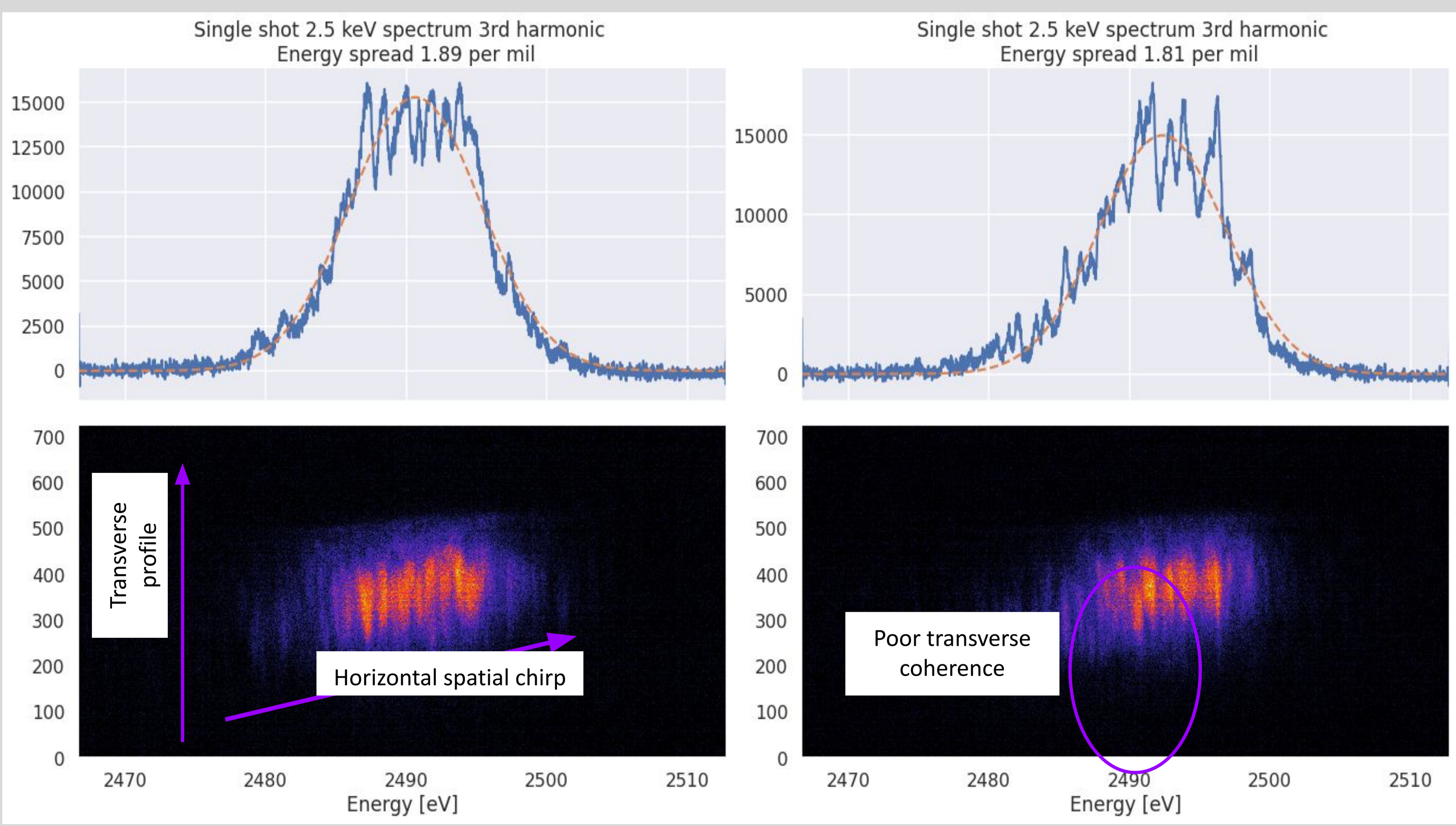




Single shot measurement

To measure the bandwidth of the 2.5 keV fundamental, the beamline single shot spectrometer is tuned to the 3rd harmonic at 7.5 keV. Using a Si220 bent crystal with a radius of curvature of 75 mm, the dispersed X-ray were imaged in the Ce:YAG. The crystal was aligned to the main FEL beam.

Example single-shots are shown below where the energy axis has been divided by 3 to plot as the fundamental energy. The top figures are a sum over the y axis with a Gaussian fit to provide an estimate of the energy spread - a key performance metric for the FEL.



The 2D imaging of the spectrometer also provides further information about the FEL pulse. The vertical axis on the plots corresponds to the transverse horizontal beam profile. In this case a horizontal spatial chirp is seen in the beam. Furthermore the SASE modes across the horizontal profile and not homogeneous, displaying a poor transverse coherence. This is to be expected for the 3rd harmonic.

Conclusion

Demonstrated here is single shot measurement of the 3rd harmonic of 2.5 keV. The measured data provide a measure of the fundamental frequency energy spread - a key metric for machine optimisation. The validity of the measurement was confirmed with scans of the beamline monochromator over both the fundamental and 3rd harmonic energies where a good agreement in the measured energy spreads were observed.

The imaging nature of the spectrometer provides further information of the transverse coherence of the 3rd harmonic pulses.

Monochromator comparison

The validity of the spectral measurement was confirmed by scanning the beamline monochromator over the both the fundamental 2.5 keV and the 3rd harmonic at 7.5 keV. Figure A is a plot of the transmitted flux of the mono and figure B upper figure the average of 500 3rd harmonic shots. The fitted Gaussians return and energy spread of 2.4 and 2.6 ‰ respectively in good agreement.

Figure C is a plot of the transmitted flux of the mono scanned over the 3rd harmonic at 7.5 keV returning a relative energy spread of 2.6 ‰.