PAUL SCHERRER INSTITUT

Diffractive optics for focusing and characterization of hard X-ray free electron laser radiation

Petri Karvinen[1], Simon Rutishauser[1], Sergey Gorelick[1], Aldo Mozzanica[1], Dominic Greiffenberg[1], Jacek Krzywinski[2], David M. Fritz[2], Henrik Till Lemke[2], Marco Cammarata[2], Christian David[1]

(1) Paul Scherrer Institut, 5232 Villigen PSI, Switzerland
(2) SLAC National Accelerator Laboratory, Menlo Park, CA 94025, USA

Motivation

Conventional Fresnel zone plates (FZPs) and diffraction gratings, commonly used at hard X-ray synchrotron sources, are quickly damaged by the high heat loads imposed by intense XFEL radiation.

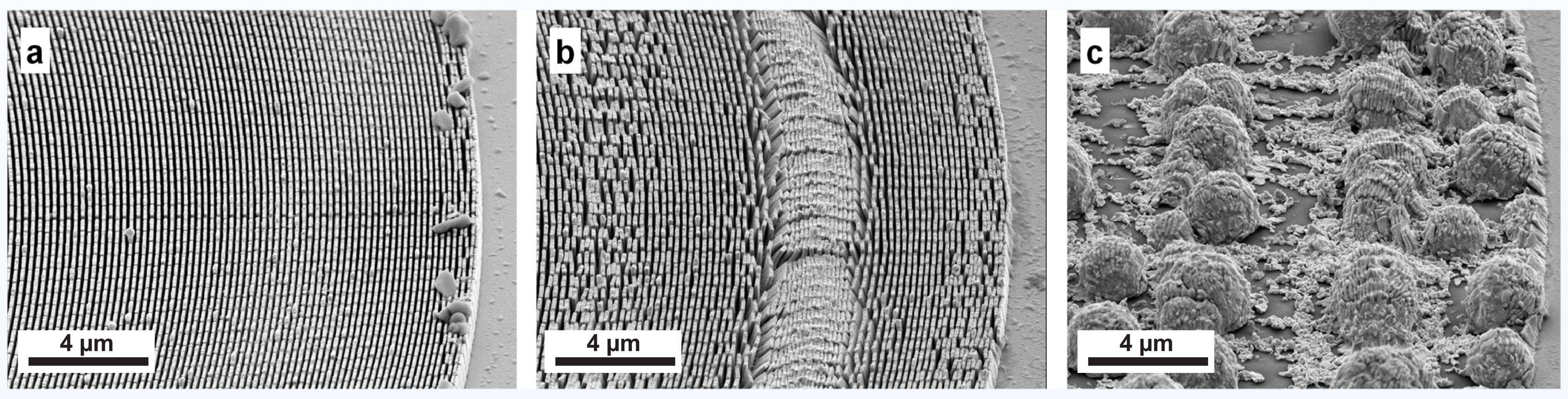

Figure 1: Gold Fresnel zone plates exposed to 8 keV FEL pulses at LCLS. (a) no irradiation, (b) after 1000 pulses, (c) after 10 000 pulses.

Diamond optics

The high melting point, good thermal conductivity and low X-ray absorption make diamond a suitable material for optics that can withstand the high power density of a free electron laser. No damage was observed on diamond based FZPs after 10 000 LCLS shots.

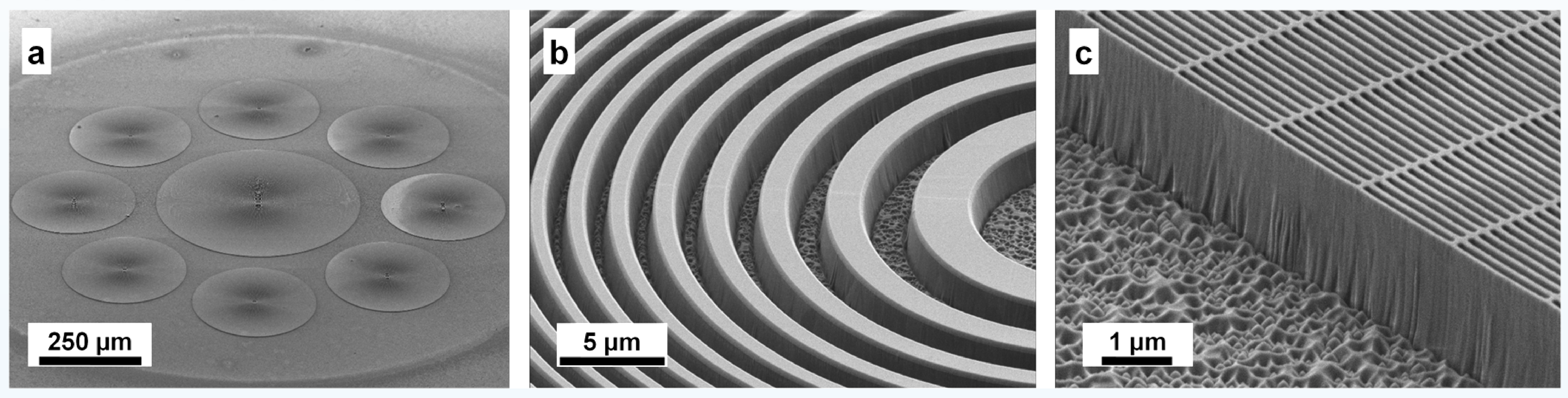

Figure 2: Diamond Fresnel zone plates used to focus LCLS beam. (a) overview, (b) central zones, (c) 100nm wide outermost zones.

Nanofocusing of hard XFEL radiation with diamond Fresnel zone plates

Diamond based FZPs with diameter of 500 µm and outernmost zone width of 100 nm were used at LCLS. The focusing properties were analyzed using the imprint method (Fig. 3), observing a 320 nm focus (FWHM) limited by chromatic aberrations (Fig. 4). [1]

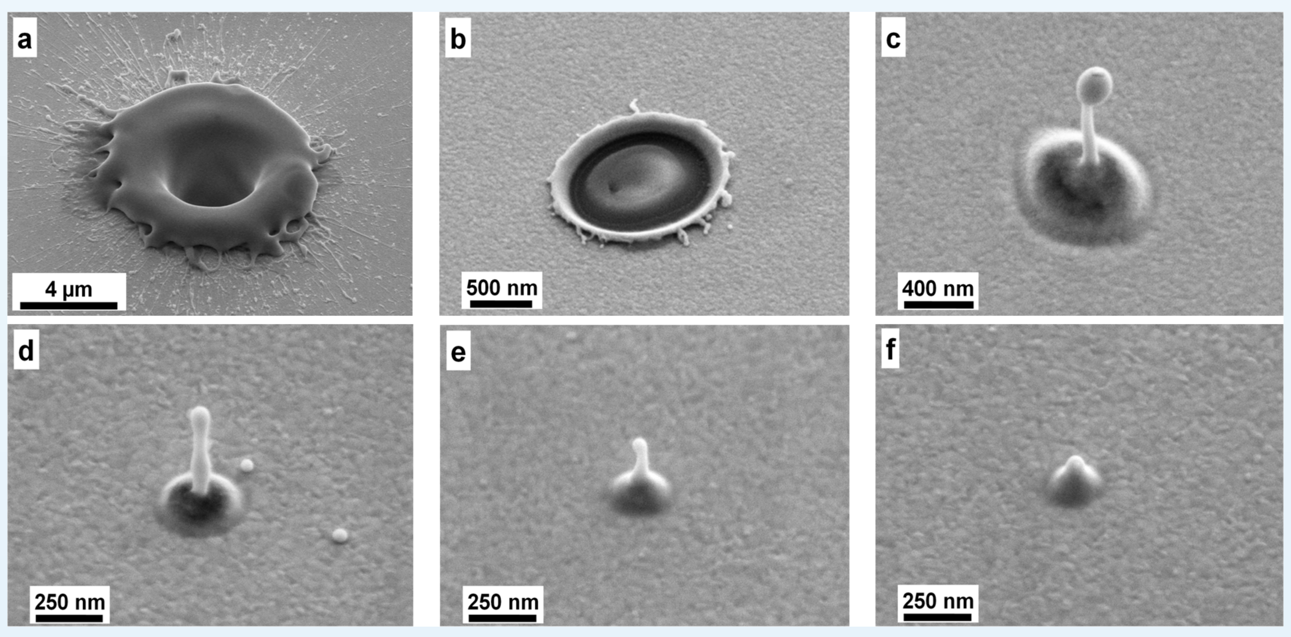

Figure 3: SEM images of 8 keV XFEL shot imprints on Au coated glass substrates. The beamline attenuators were used to make imprints with different pulse energies, ranging from unattenuated beam with ~5x10^{-5}J pulse energy and 3.5 µm imprint diameter (a) to ~2x10^{-8}J pulse and 190 nm imprint (f).

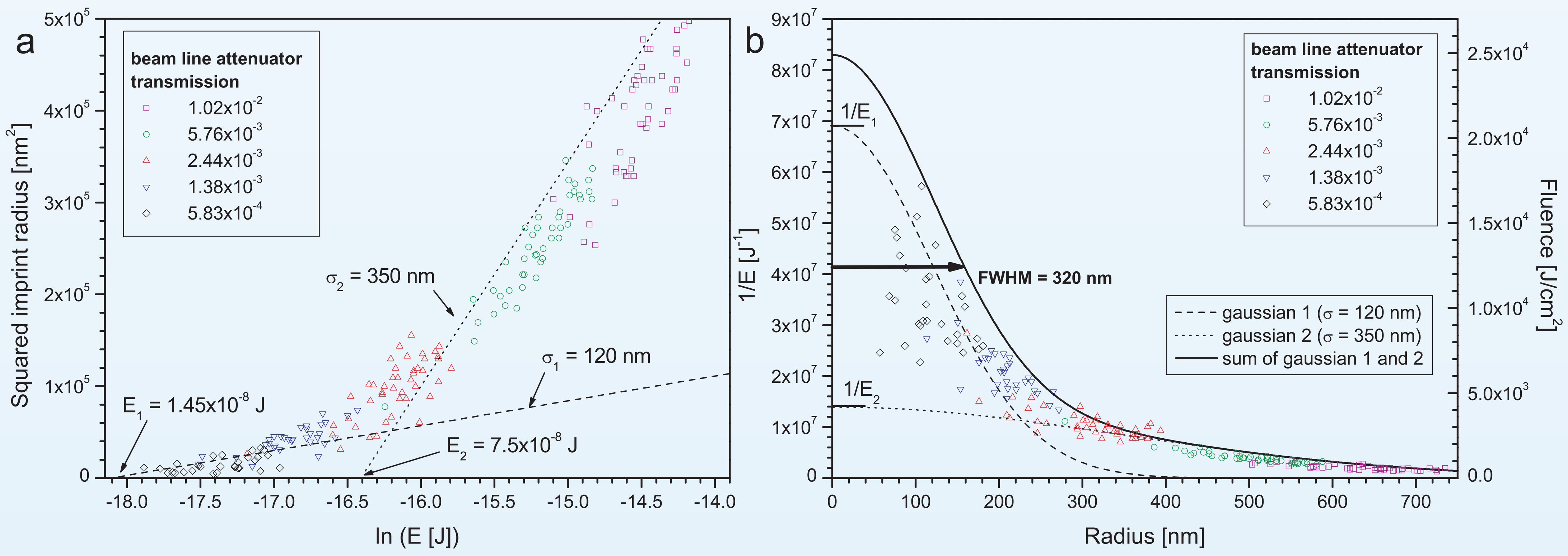

Figure 4: (a) The squared imprint diameters as a function the logarithm of the pulse energy reveals two regions that can be approximated by straight lines corresponding to a double-Gaussian spot. (b) Beam profile derived from the same data set. Knowing the pulse length, total energy and zone plate efficiency peak power densities of approximately 4x10^{17} W/cm^2 can be calculated.

A non-invasive single shot spectrometer setup based on a focusing diamond grating

A spectrometer setup based on a diamond grating and a charge integrating microstrip detector (Gotthard) in grazing incidence was used to measure single shot spectra of the LCLS beam. The grating diffracts only a small fraction (less than 1%) of the beam, making the setup ideal for monitoring purposes.

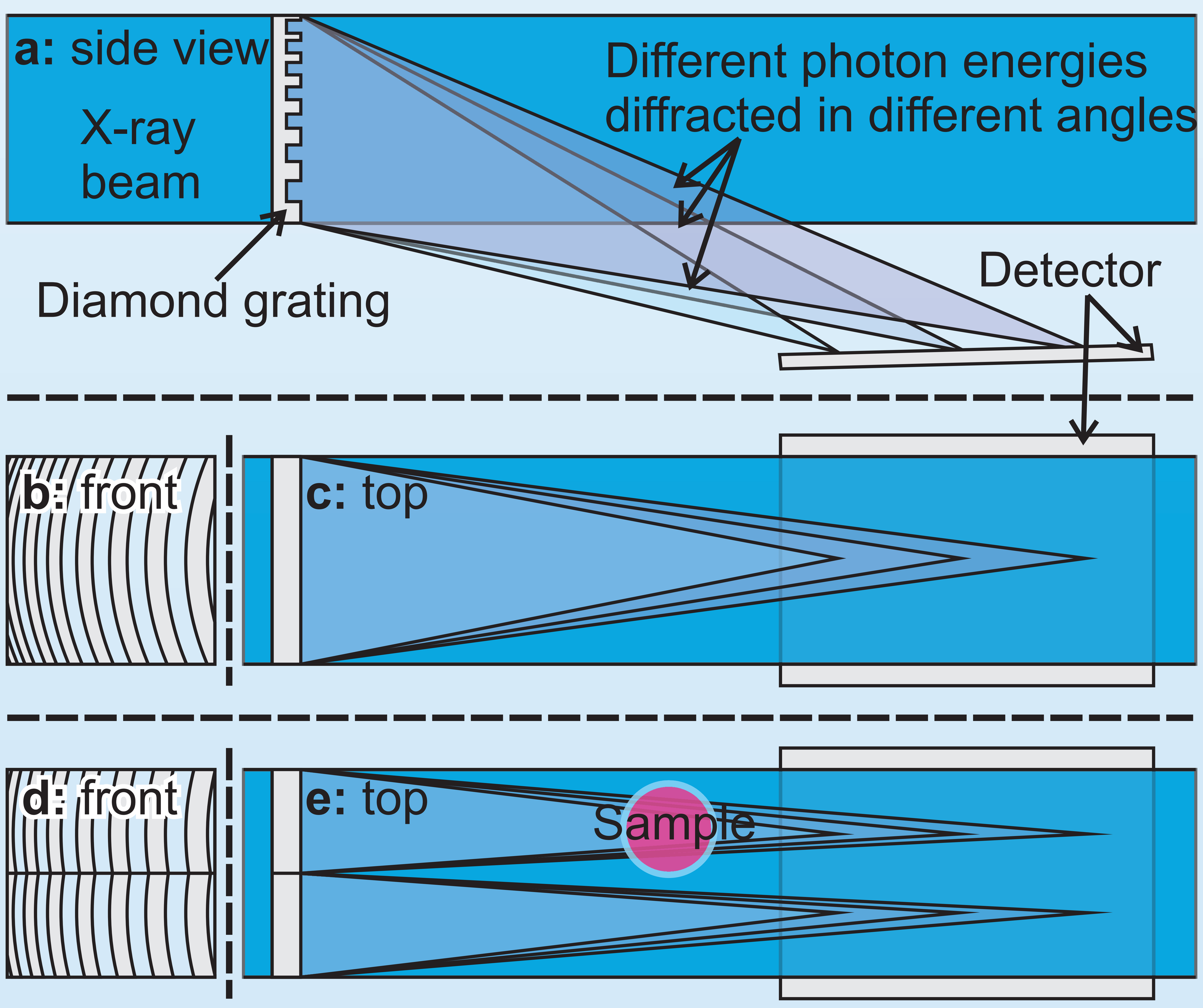

Figure 5: Schematic diagrams of setups based on diamond spectrometer gratings (a) side view, (b) and (c) front- and top views of a setup producing one focus, respectively (d) and (e) front- and top views of a setup producing two foci for spectroscopy with single-shot reference spectra.

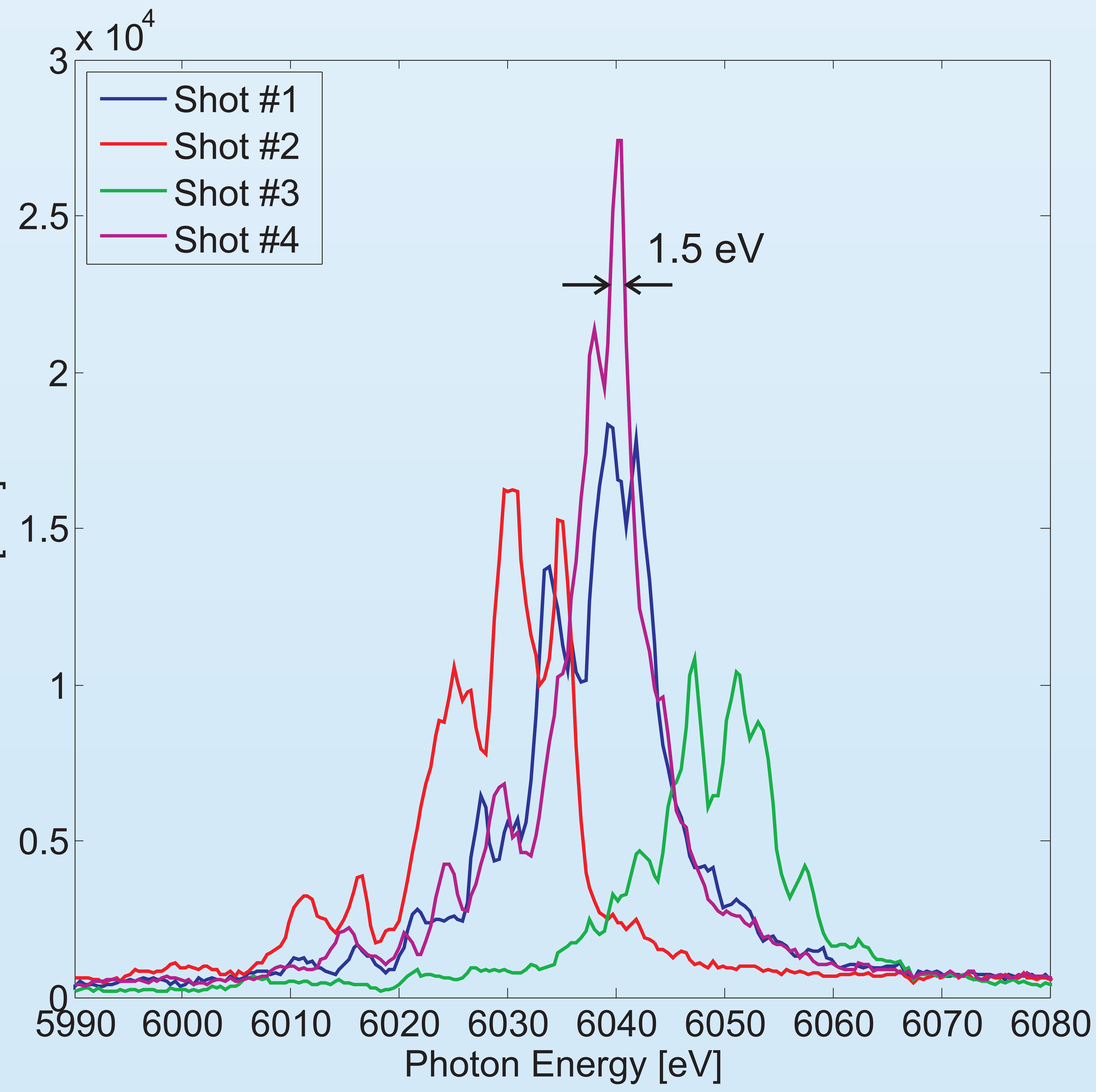

Figure 6: Single shot spectra of four consecutive XFEL shots, measured at LCLS.

[1] "Nanofocusing of hard X-ray free electron laser pulses using diamond based Fresnel zone plates", C. David, S. Gorelick, S. Rutishauser, J. Krzywinski, J. Vila-Comamala, V.A. Guzenko, O. Bunk, E. Färm, M. Ritala, M. Cammarata, D.M. Fritz, R. Barrett, L. Samoylova, J. Grünert and H. Sinn, *Sci. Rep.* **1** (2011) , 57