TRANSVERSE SIZE AND DISTRIBUTION OF FEL X-RAY RADIATION OF THE LCLS*

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Abstract

Understanding and controlling the transverse size and distribution of FEL x-ray radiation of the LCLS at the SLAC National Accelerator Laboratory is discussed. Understanding divergence, source size, and distributions under various conditions is a convolution of many effects such as the electron distribution, the undulator alignment, micro-bunching suppression, and beta-match. Measurements of transverse size along the x-ray pulse and other studies designed to sort out the dominant effects are presented and discussed.

INTRODUCTION

During commissioning and operation of the Linac Coherent Light Source (LCLS) x-ray Free Electron Laser (FEL) at the SLAC National Accelerator Laboratory x-ray beam size, shape and divergence at various points under various conditions have been studied.

The conditions discussed are the 8keV design FEL generation, with measurement and simulation, then results from experimental perturbations from the design. Followed by perturbation by the mirror system for the hard xray case, with measurement and simulation.

MEASUREMENTS

Quality of data taken primarily on YAG screens some at normal incidence and some at 45 degrees data relies on a series of careful setup steps. To avoid saturation of either the YAG crystal or camera, adequate filtering either in the beam and/or in front of the camera is employed.

On the other hand, too much attenuation in the x-ray beam with the materials employed will reduce the fundamental to the point that the third harmonic will significantly influence any measurements. 1% to 10% transmission is typically allowed for these measurements depending on the incoming xray intensity in millijoules.

Another concern is background subtraction, which must include the spontaneous radiation from the undulator. Typically an oscillation is induced in the undulator suppressing lasing and background data is collected.

CSR (coherent synchrotron radiation) from the final bending magnet string can also contaminate the images, particularly upstream of the hard xray mirrors, so a 1μm thick carbon foil is inserted in the Xray Diagnostic Chamber upstream of all xray intensity profile monitors.

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In cases where additional unidentified uniform background radiation is observed only when lasing, cutting the image to a small region of interest is employed though the difference to the other method of background subtraction becomes very small as the photon energy goes up. This background could possibly be due to fluorescent gas in the attenuating and intensity detection systems, or perhaps CSR bouncing off the chamber walls.

Method of Attenuation

High quality beryllium attenuators were originally used, but due to observed "speckle" in the beam have since been replaced with silicon, diamond, sapphire, and fused silica attenuators for the hard xray (>2keV) regime. Nitrogen gas is used for 2keV down to 480eV.

Linearity

Measurement linearity is verified by correlating pulse-to-pulse data from the YAG camera pixel intensity sum with gas detectors [1]. The gas detectors are normalized to the measured energy loss of the electrons due to the lasing process, and are linear over the typical intensity jitter range.

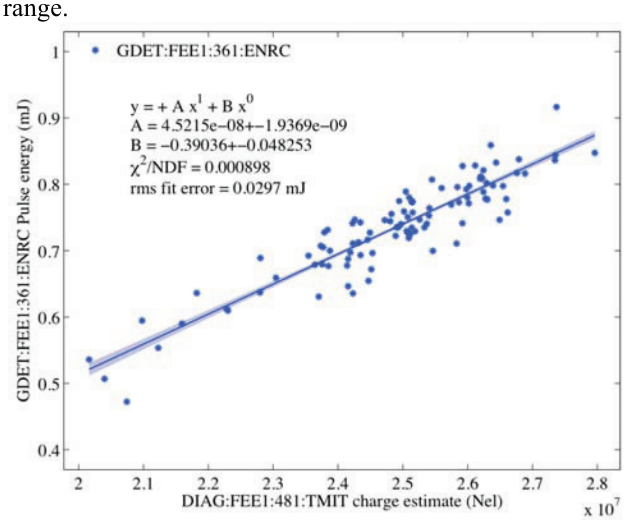

Figure 1: Gas detector in mJ (vertical axis) versus camera pixel intensity sum (horizontal axis) is plotted as a linearity check.

SIMULATION AND MEASUREMENT

Distribution at the end of the undulator from Genesis simulation (figure 2) is qualitatively strikingly similar to beam measurement (figure 3), though simulation is near field and measurement far field.

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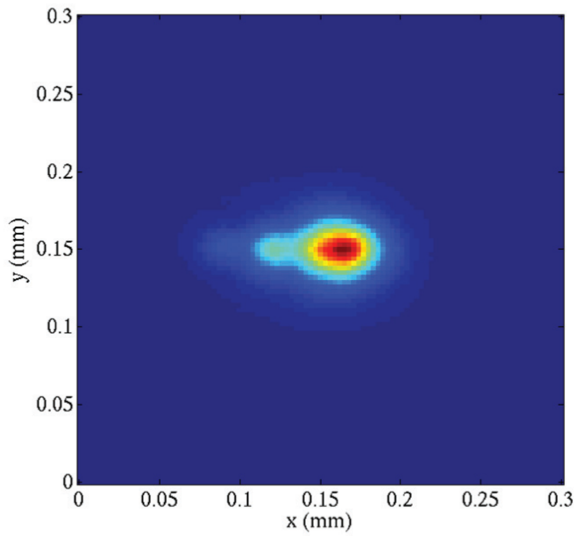

Figure 2: Start to end 8.3keV, 3kA Genesis simulation. Xray profile at the end of the undulator which is near field.

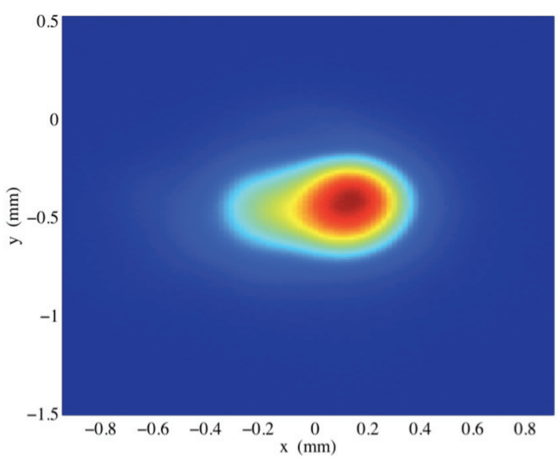

Figure 3: Measured hard xray image at the "direct imager" YAG profile monitor about 87m from the end of the undulator, 8.3keV and 3kA as in simulation. This is far field, though qualitative similarities to simulation are striking.

Microbunching and CSR

In both Genesis simulation and measurement, when compression is turned down to a peak current of about 1kA the beam becomes more gaussian (not shown).

Hard xrays from 150pC electron beam shown in figure 4 are more gaussian than from 250pC electron beam in figure 3. While at 150pC and the laser heater is turned off however, this distribution becomes worse (figure 5). CSR [2] due to microbunching [3] is implicated by this heater on/off (figures 4 & 5) data as well as the peak current observation.

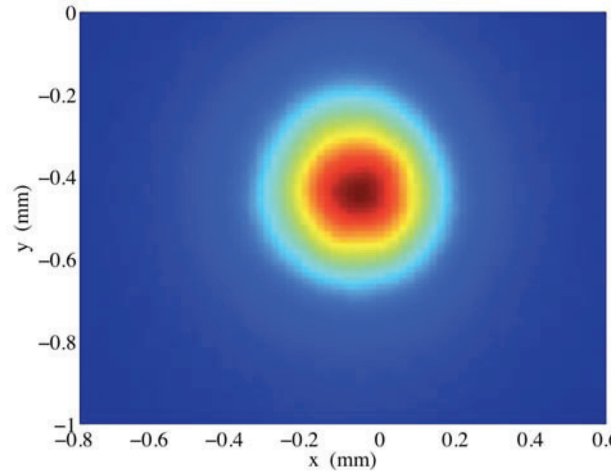

Figure 4: Hard xray beam profile measurement at the "direct imager" from 150pC electron beam with laser heater on and well aligned.

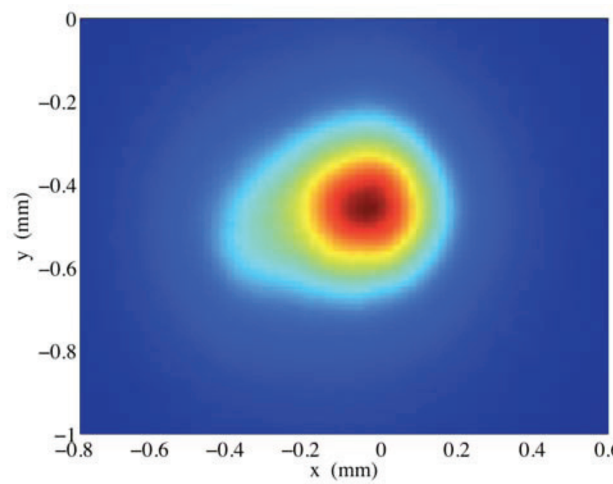

Figure 5: Hard xray profile measurement at the "direct imager" from 150pC electron beam with laser heater off.

Size and Divergence

Measurement of the impact of electron beta match into the undulator has been done. Smallest recorded xray beam sizes were achieved when the match was nearly perfect. Deviation from matched condition showed response in the xray beam size (see figure 6).

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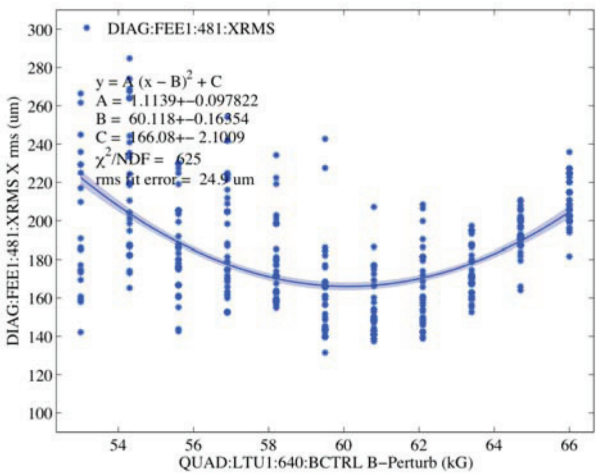
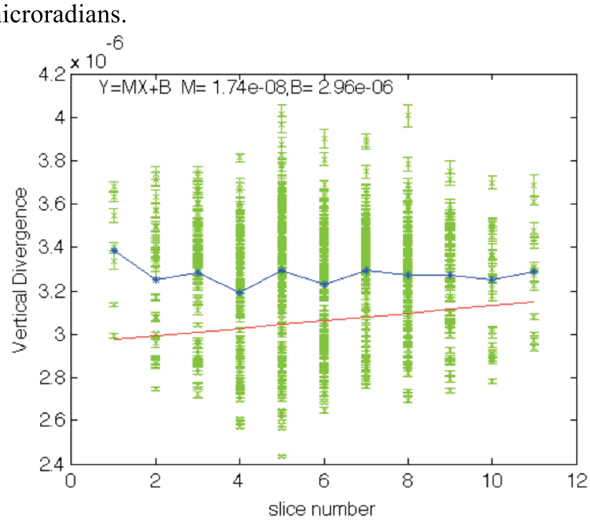


Figure 6: Scan of a matching quadrupole around the matched value (horizontal axis) shows xray horizontal beam size dependence (vertical axis) at the "direct imager".

This variation from matched condition was predicted to have a strong effect by simulation in 2001 [4].

Divergence of longitudinal slices of the beam (slice divergence) was measured though the errors were large due to intermittent lasing. The method employed was to use a slotted foil [5] within the second bunch compressor chicane to ruin lasing in all but a small longitudinal slice of the beam. Data was taken at 3 intensity profile monitors (different z positions) with many data points per slice and multiple scans at each monitor.

Given the large errors due to fluctuations in the lasing of the slices, data is consistent with little or no divergence change along the beam. Vertical axis is FWHM at about 3 microradians.



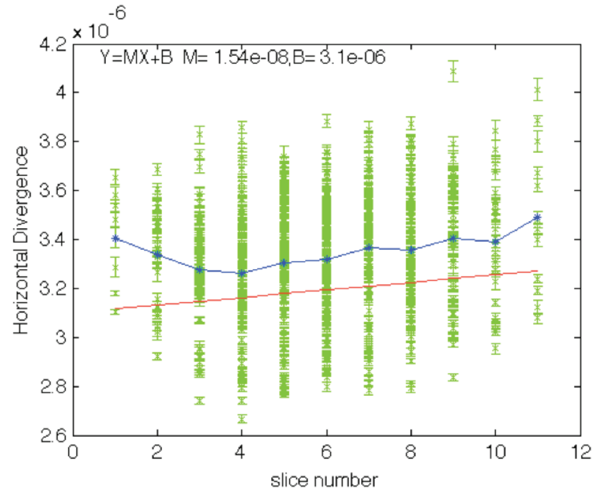
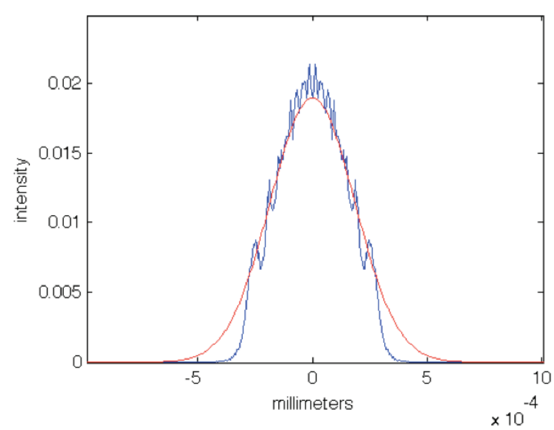


Figure 7: Slice (horizontal axis) FWHM divergence measurement (vertical axis in radians or ignore the exponent and read microradians). Each green point is a fitted size from a beam profile measurement with an associated error bar from the fit. Blue is the un-weighted mean for each slice and red is the weighted fitted line to all the data.

After Hard Xray Mirrors

Two effects from hard xray mirrors are seen on intensity profile monitors after the mirrors, some interference lines come from cutting the beam (figure 8), but by far the dominant effect is from the figure error (figure 9). Figure 10 shows the impact of overfilled mirrors with figure error included where simulation at an XPP intensity profile monitor matches measurement.



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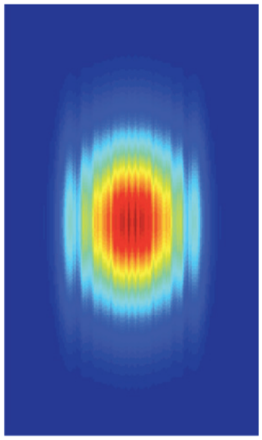

Figures 8: Simulation of profile monitor upstream of XPP (Xray Pump Probe instrument) with an ideal gaussian beam overfilling the mirrors, but no figure error is included. Projections on the top plot, blue to horizontal, red to vertical.

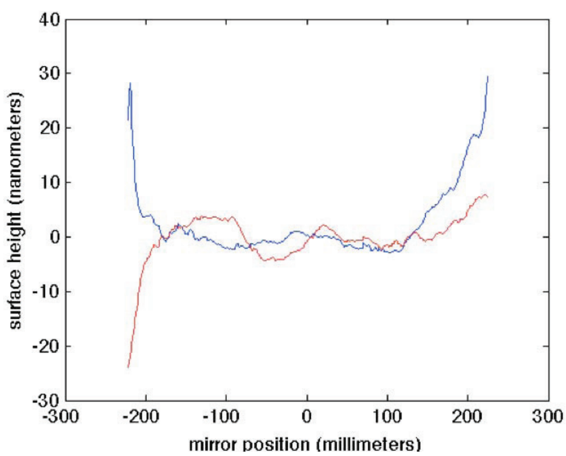

Figure 9: Nanometers height (figure flatness) over the two hard xray mirrors.

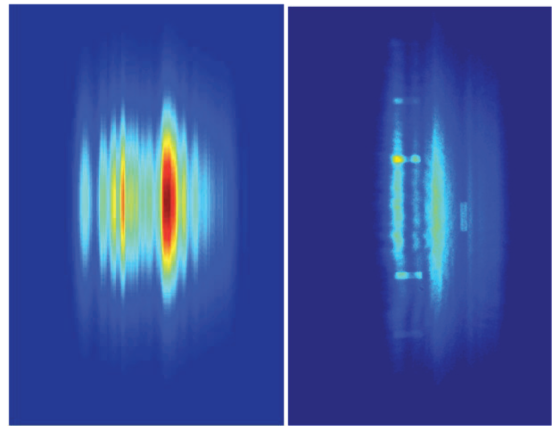

Figure 10: Left is simulation including figure errors, right is measurement at the XPP monitor (courtesy of David Fritz). There was some upstream clipping on the left side. Tic marks are 200microns apart for scale.

SUMMARY

The overall FEL performance of the LCLS is still setting precedents, and our understanding continues to improve. Data quality of diagnostics is key and care needs to be taken to assure good data. The hard xray divergence varies from 2-4 microradians FWHM and is presumed to vary primarily with match condition into the undulator. This is in the range of FEL theory prediction. Mirror figure quality is the dominant factor in hard xray beam non-uniformity delivered to the experimental hutches. It is clearly in the interest of XFELs to push the state-of-the-art in mirror metrology and manufacture.

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