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# LCLS Spontaneous Radiation with Reflection along the Beam Line in the Undulator Pipes\*

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## Abstract

Monte Carlo simulations of the spontaneous radiation at low and high energies up to the Near Experimental Hall entrance yield beam widths for use in the design of transport and diagnostic instruments in the Front End Enclosure.

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## LCLS Spontaneous Radiation with Reflection along the Beam Line in the Undulator Pipes

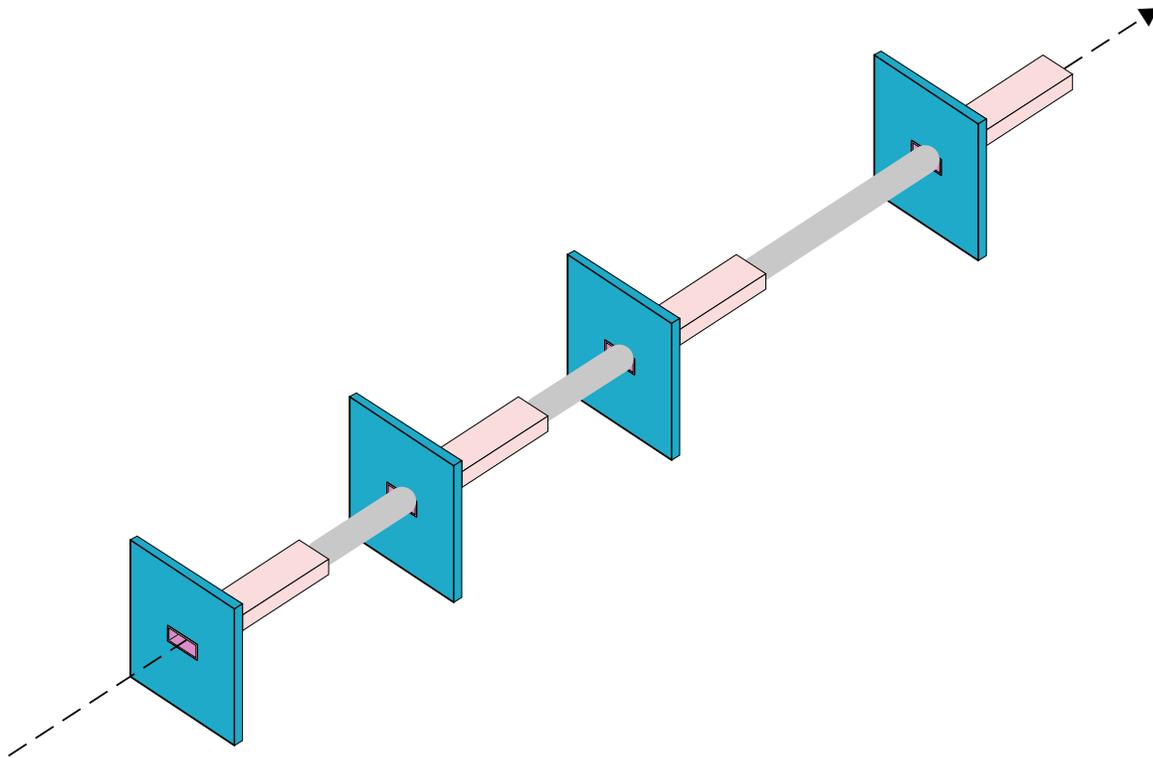
Some commissioning and alignment procedures for XTOD may rely on the use of the spontaneous radiation. Therefore we have modeled the spontaneous radiation between the Undulator and the Near Experimental Hall to derive numerical values of the expected beam width and of the energy deposition. The values are then used to determine aperture sizes and detector sensitivities.

We performed the calculations in three stages. The first was to generate an appropriate distribution of photons within the Undulator. The second was to simulate the emergence of the photons from the Undulator. The third was to propagate the photons (without any obstructing objects) to various points along the Z-axis up to the Near Experimental Hall entrance. We performed the simulations for low and high energies based on the spectral flux data supplied by Sven Reiche. These data sets were at 71 meters from the end of the Undulator for 4.5 and 14.08 GeV electrons.

In the first stage, we randomly generated ten million photons consistent with the spectral flux data. The initial photons were distributed uniformly in Z but only within the 33 Undulator segments each 3.4 meters long. The angular distribution was uniform about the Z-axis. The radial distribution was proportional to

$$e^{-\left(\frac{1}{2} \frac{\text{radius}^2}{\sigma^2}\right)}$$

where SIGMA was 30.1 microns. No photons were initially placed in the short and long breaks between Undulator segments.

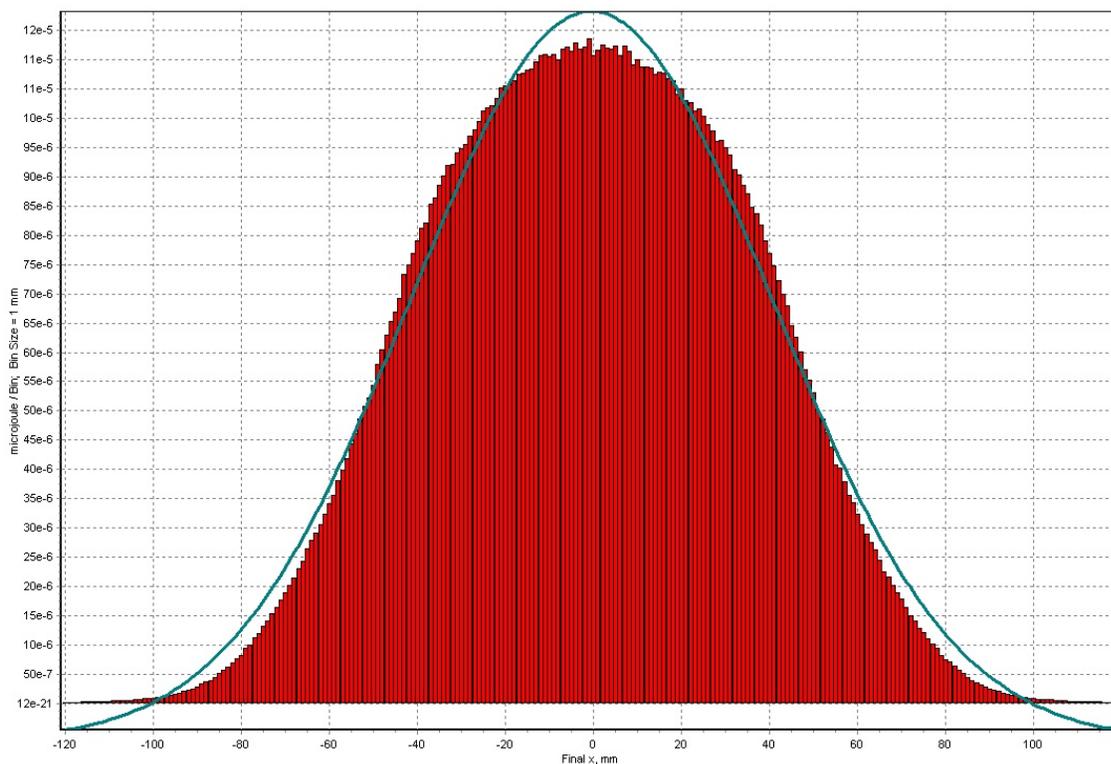


In the second stage, we propagated the photons through a model of the Undulator pipes out to  $Z=650$  meters. The diagram above (which is not drawn to scale) illustrates the model. The rectangular pipes were modeled as aluminum pipes with 1 mm thick walls, though in reality they are stainless steel with aluminum coating. Most of the rectangular pipes were 3.467 meters long except the pipes after long breaks that were 3.4665 meters long. The inside dimensions of the rectangular pipes were 5 x 10 mm. For modeling purposes, we wanted to stop any photons that escaped in the breaks from propagating down stream, so the model included baffles or collars at the front of each rectangular pipe consisting of tantalum one centimeter thick. In each break there are two circular pipes. Immediately after each rectangular pipe (except the last one) is an 8 mm inside diameter copper pipe coated with aluminum. This is the pipe through the quadrupole magnet. We modeled it as an aluminum tube. Following the 8 mm tube is a 10 mm inside diameter tube going down to the next rectangular pipe. This was also modeled as though it were an aluminum tube. The 8 mm tubes were 123.1 mm long. The 10 mm tubes were 143.2 mm in length for the short breaks and 708 mm for the long breaks. The remaining space was treated as low-pressure air. The propagation model included the photoelectric effect and high energy Compton scattering off of free electrons. The aluminum surfaces were modeled as perfectly reflecting, the consequence of which is that nearly all the energy emerges from the undulator. At low energy, 0.0059% is absorbed in the Undulator pipes while 99.9941% arrives at  $Z=650$ . At high energy, 0.0055% is lost in the Undulator while 99.9945% arrives at  $Z=650$ . In our model, the Undulator started at  $Z=515$  and ended at  $Z=646.52$  with the last rectangular pipe extending 33.5 mm beyond the end of the Undulator.

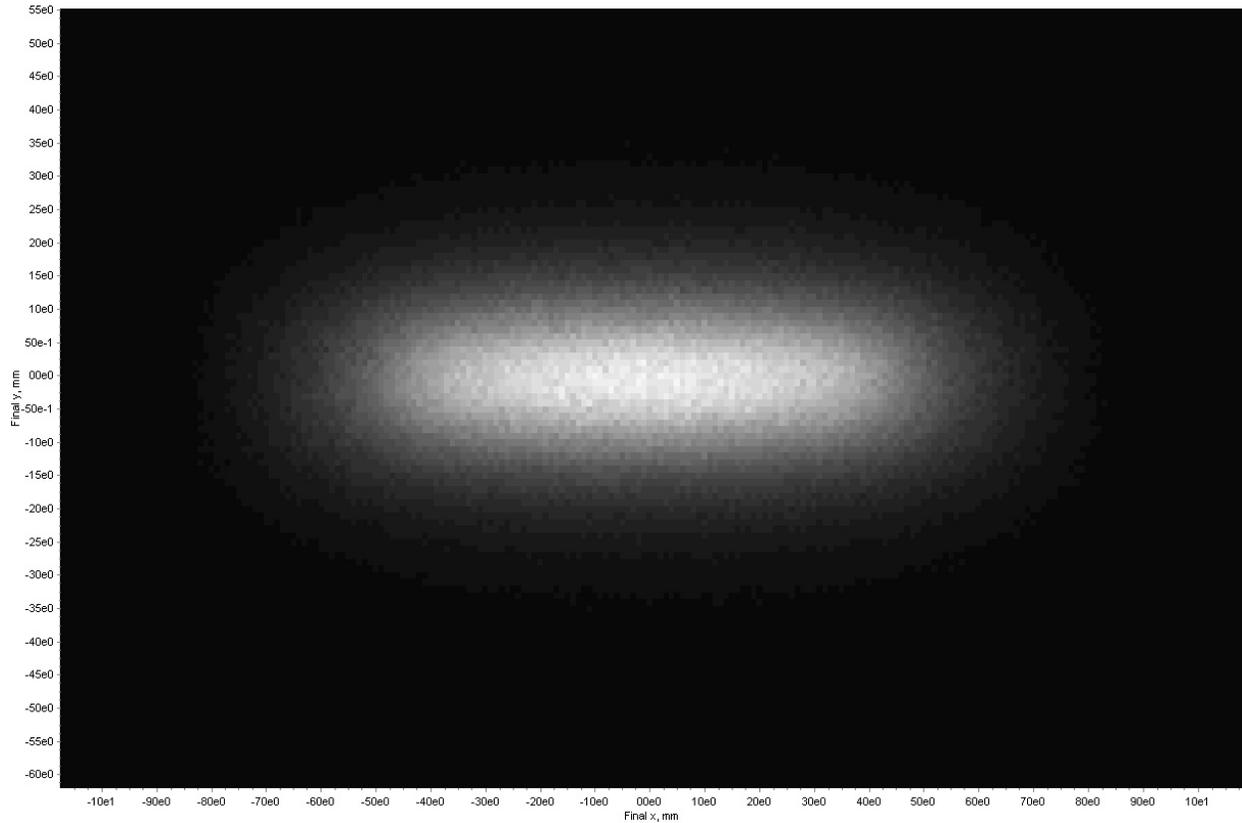
The output of the second stage includes a database with all the photon locations, energies, and directions. The third stage of the calculation consists of repeated runs to propagate the photons from that database to 17 selected  $Z$  locations further downstream. At each destination  $Z$  we projected the photon energies to the X-axis and fitted a Gaussian to the energy distribution. We likewise did a fit to the energy distribution projected on the Y-axis. The fundamental results are the sigmas of the X and Y Gaussian energy fits. Of course, the energy distributions are not true Gaussians, so the fits are only an approximation to the real distributions, but they are sufficient for choosing aperture sizes. In particular, the calculated Y distribution is a little narrower than the real distribution because the spectral flux data did not extend to large values of Y. Thus our initial photon distribution has few photons that will propagate to Y values that are larger than those in the spectra flux data. The table on the next page gives the sigmas in millimeters and the LCLS  $Z$  coordinate in meters. The LCLS  $Z$  coordinates are based on Pat Duffy's schematic of July 15, 2005 except the Fixed Mask and Slit A are one meter farther downstream than in the schematic.

Description	LCLS Z, m	Low Energy X Sigma, mm	Low Energy Y Sigma, mm	High Energy X Sigma, mm	High Energy Y Sigma, mm
	655.000	14.61	3.824	4.697	1.305
	665.000	17.81	4.734	5.702	1.561
	675.000	20.84	5.563	6.653	1.816
	685.000	23.74	6.345	7,566	2.062
	695.000	26.57	7.097	8.453	2.299
	705.000	29.35	7.827	9.321	2.532
Fixed Mask	708.475	30.30	8.077	9.619	2.612
Slit A	710.207	30.78	8.200	9.767	2.651
FEE Entrance	722.000	33.98	9.033	10.77	2.917
Gas Atten. Ent.	727.528	35.48	9.418	11.23	3.040
Gas Atten. Exit	733.528	37.10	9.834	11.73	3.173
Solid Attenuator	736.615	37.76	10.00	11.99	3.242
WFOVDI	740.700	39.03	10.33	12.32	3.333
Mirror Tank A Ent.	743.190	39.70	10.50	12.53	3.388
Mirror Tank B Ent.	746.875	40.69	10.75	12.83	3.469
Mirror Tank C Ent.	751.190	41.85	11.04	13.19	3.562
NEH Entrance	757.404	43.52	11.46	13.70	3.698

The following is an example of a histogram of the energy projected onto the X-axis at the wide field of view direct imager located at LCLS Z=740.7 m. The teal colored curve shows the Gaussian fit. The charge propagated was  $4.79 \times 10^{-6}$  nC.

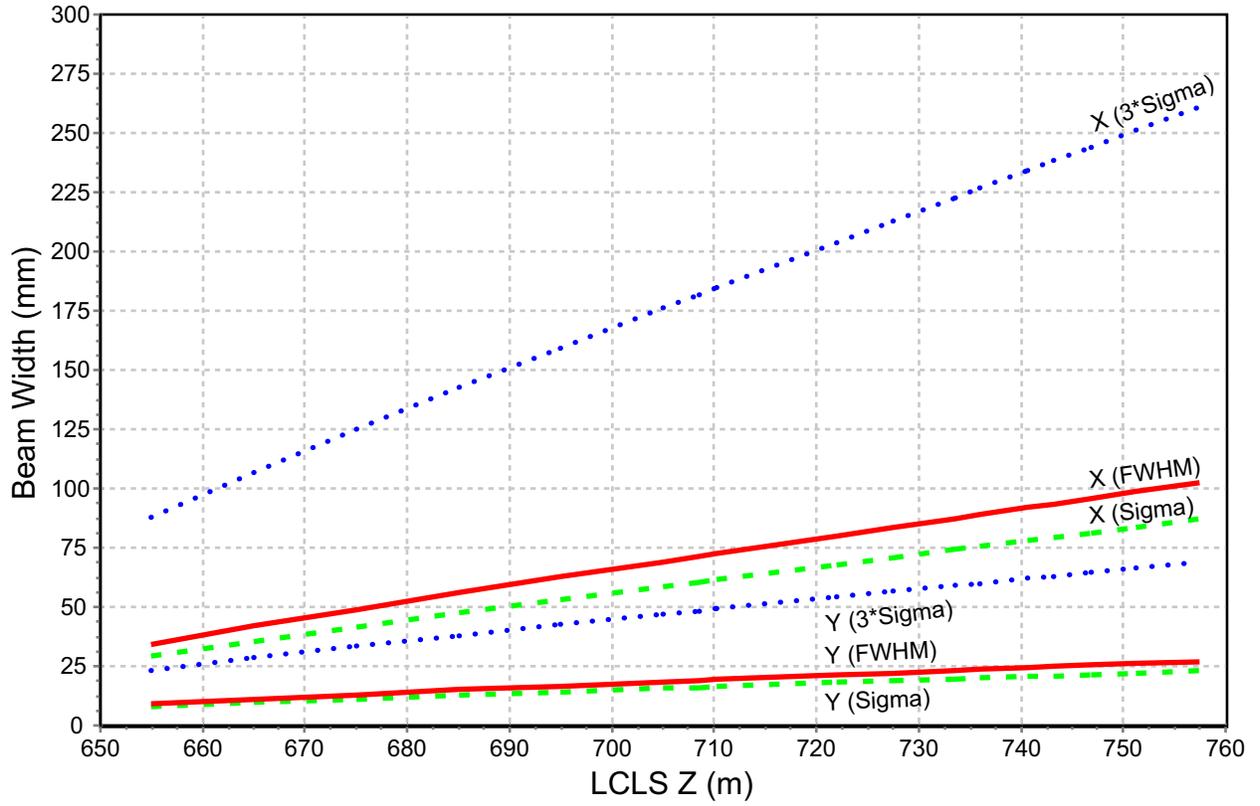


The scatter plot below is of the energy at the wide field of view direct imager.



We summarize the results with plots of the numbers in the above table. One plot is for low energy and another is for high energy. Each plot contains six lines. The dashed green lines are the X and Y sigma as a function of Z but doubled in order to give the diameter or beam width. For a true Gaussian distribution, an aperture width the size of the X green line and the height of the Y green line would permit 68% of the energy to pass. The dotted blue lines are triple the dashed green lines and therefore encompass what would be 99.73% of the energy if the Gaussian fit actually were the energy distribution. In a similar fashion, the solid red lines are 1.1774 times the green lines and are the full width half max or 76% of the energy.

# Low Energy Spontaneous Radiation



# High Energy Spontaneous Radiation

