

Improving Pump Probe Timing Analysis for the LCLS-II Arrival Time Monitor

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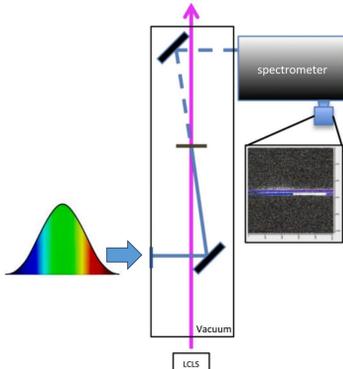
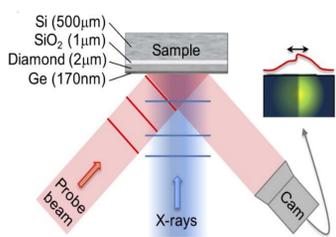


ARRIVAL TIME TAGGING AT LCLS

The majority of experiments at LCLS use a laser co-timed with the XFEL to measure dynamics in pump probe experiments. Due to the inherent timing jitter, LCLS implemented an **Arrival Time Monitor** (“Time Tool”) to measure the relative arrival time of the laser and X-ray for each shot.

Spatial Encoding

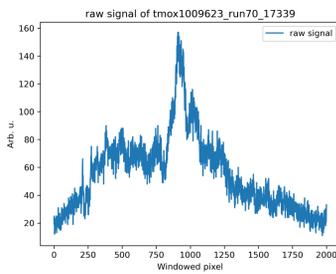
Spectral encoding



- When the X-ray arrives, it increases reflectivity, so laser reflection is stronger for the part arriving afterwards.
- This produces a sharp step-like edge in the spatial laser profile.

- Chirped laser maps delay onto wavelength.
- Transmission change appears as an edge in the spectrum.

LCLS-II Upgrade



LCLS-II will deliver up to 1MHz rep rate. The ATM employs a 1-D Piranha camera instead of a 2-D CCD camera for higher repetition rates. With all these changes, we need to update the analysis methods.

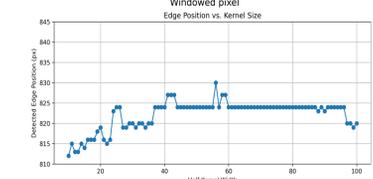
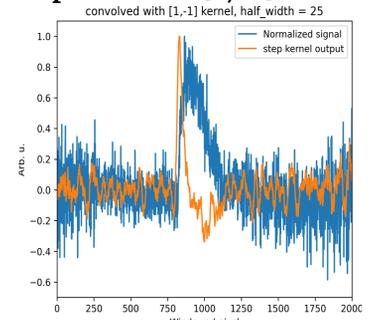
EDGE DETECTION ALGORITHM

We convolve the signal with a kernel:

$$(S * k) = \sum_{i=-\infty}^{\infty} S(x_i) k(x - x_i)$$

The convolution peak appears where the experimental edge aligns with the ideal step. The edge position is defined as the maximum of the convolved signal.

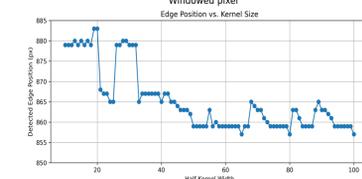
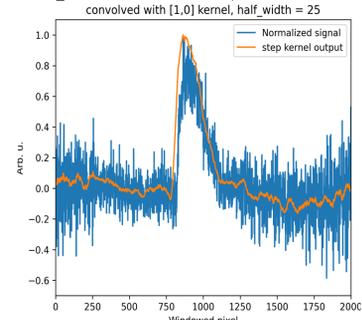
Step Function [1, -1] Kernel



$$k = [1, \dots, 1, -1, \dots, -1]$$

Half kernel size 25
The most stable edge position detection. **ADOPTED**

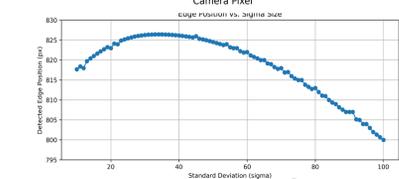
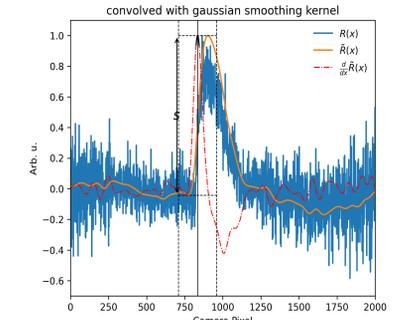
Step Function [1,0] Kernel



$$k = [1, \dots, 1, 0, \dots, 0]$$

Half kernel size 25

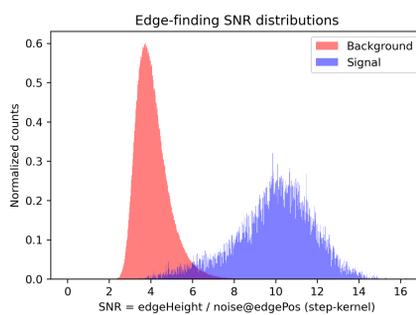
Gaussian Smoothing Kernel



$$k = -x \exp\left[-\frac{x^2}{2\sigma^2}\right]$$

Standard deviation 25

CONFIDENCE METRIC



We use probabilistic filtering based on signal-to-noise ratio (SNR). For all the signal shots and background shots, we build histograms. The probability of the detected edge being real is:

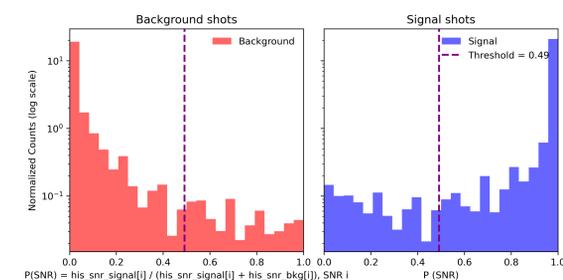
$$P(s) = \frac{H_{sig}(s)}{H_{sig}(s) + H_{bkg}(s)}$$

Signal Histogram Height at SNR s

Background Histogram Height at SNR s

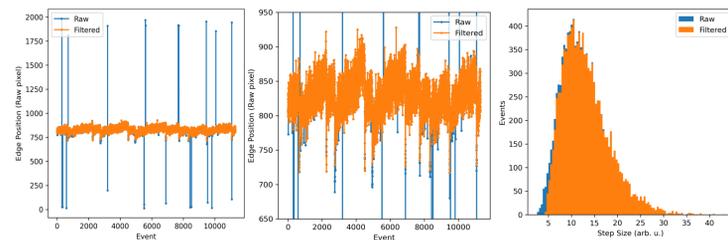
The probability within (1,0) appears in the region where two histograms overlap.

We perform ROC (Receiver Operating Characteristic) to get the threshold of the probability. We will keep all the signal shots when the confidence is greater than 50%



CONCLUSION

The step function kernel can stably detect the edge position, corresponding to where the edge starts. After the confidence metric filtering based on ~0.5 threshold, **96.25% of the events remain**. In Fig.6, the confidence matrix filtered out the small edge height and the outliers in the time series.



FUTURE WORK

Build up the confidence metric with real time edge detection to apply in online analysis. Implement optimal algorithm across hutch for offline analysis.

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- [1] Harmand, M. et al. (2013). Achieving few-femtosecond time-sorting at hard X-ray free-electron lasers. Nature Photonics (vol. 7). pp. 215-218.
- [2] Wang. Signal Processing in ATMANalyzer