Investigating and Improving XFEL Pulse Behavior with Wavefront Data

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Objective

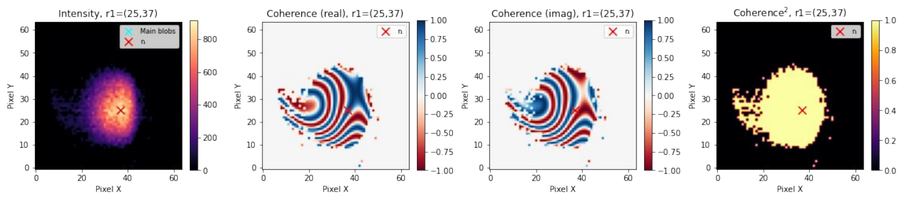
Experiments with the LCLS XFEL has led to the accumulation of a large amount of data through wavefront sensors, spectrometers, and various other instrument arrays equipped on the beamline. This data can then be used to analyze the coherence properties and content of the beam, critical measures of beam behavior and performance.

Performance Indicator-Transverse Coherence:

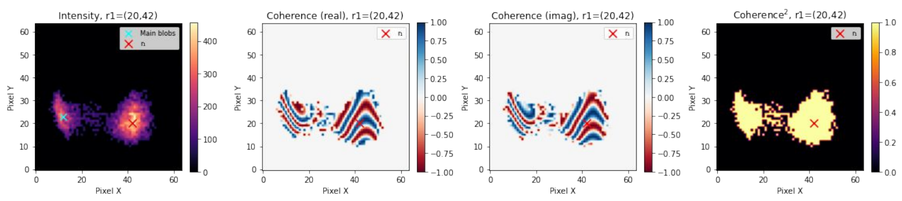
Transverse Coherence Analysis of XFEL Pulses

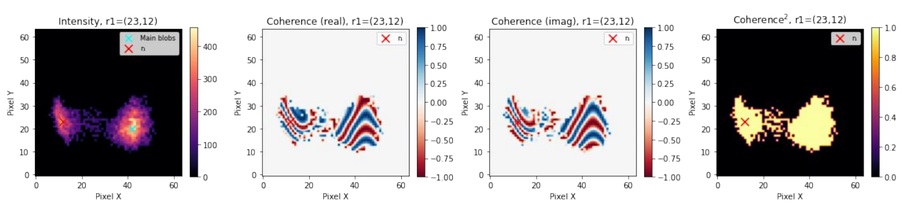
1) Field Reconstruction:
   - Complex electric field E(r) is reconstructed from recovered amplitude and phase data for each index.
2) Reference Point Selection:
   - Local intensity maxima in |E(r)|^2 are identified as reference points r1.
3) Two-Point Correlation Function:
   - For each r1, the two point correlation function is computed:
   - $\gamma(r1, r2) = E^*(r1)E(r2) / \sqrt{(|E(r1)|^2|E(r2)|^2)}$
   - Calculated for against all points r2 in the field.
4) Coherence Factor Calculation:
   - For each r1, the coherence factor is then computed as the average $|\gamma(r1, r2)|^2$ across all r2.
5) Comprehensive Analysis:
   - Process repeated for all detected r1 points across the beam profile.
   - Analysis performed on all indexes to capture entire run.
6) Coherence Characterization:
   - Two point correlation function gives complex number which gives magnitude and phase angle between the two points.
   - Coherence factor quantifies degree of coherence from 0 to 1 and represents the average spatial coherence of the entire field relative to its local maxima.

Intensity and Coherence Plots for index with one detected local maxima

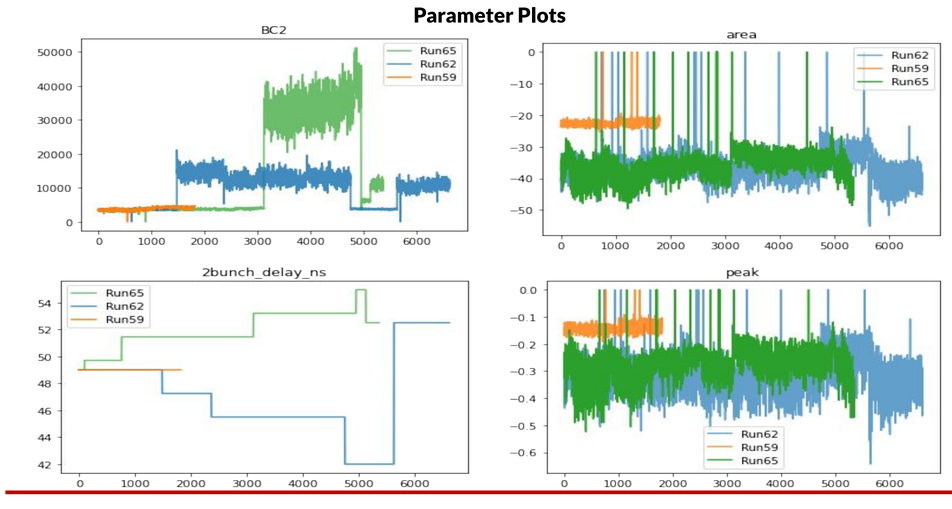


Intensity and Coherence Plots for index with two detected local maxima





Parameter Plots



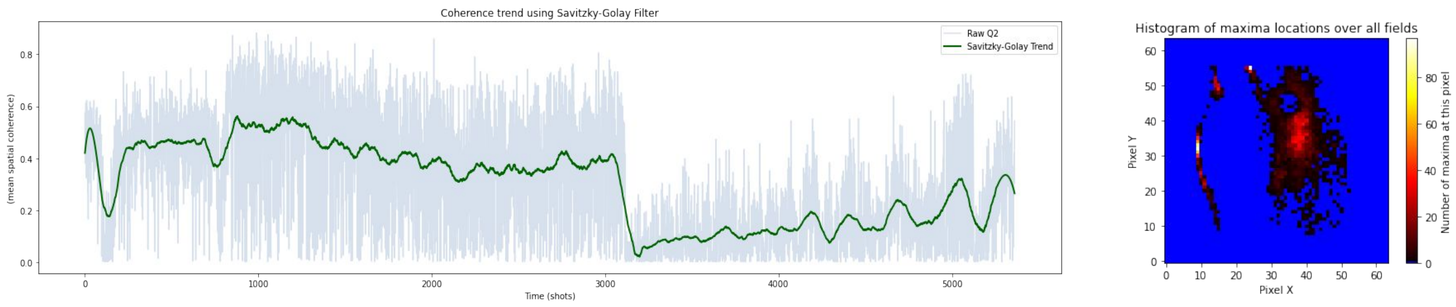
Run Data Visualization

Data used in this experiment is comprised of 3 runs which each incorporate around 1000-6000 individual index measurements

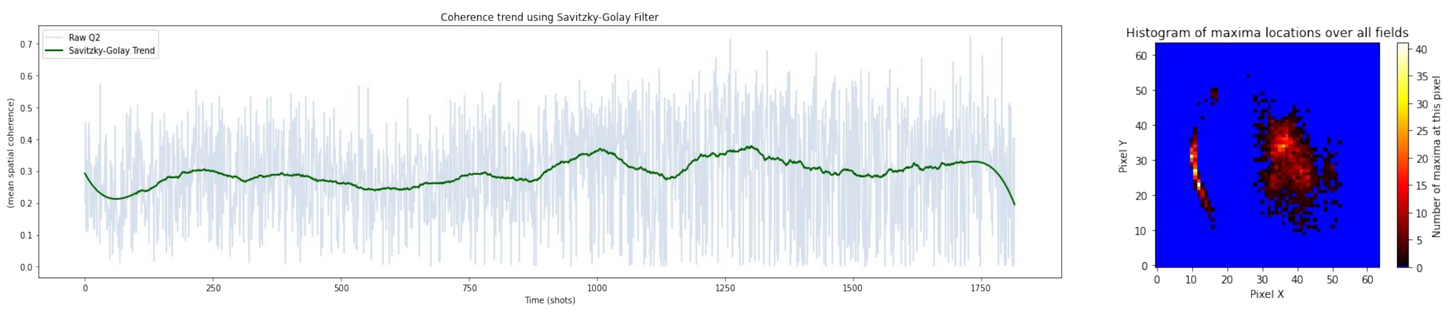
Mean Spatial Coherence Plot and Savitzky-Golay Trend Line

Detected Maxima Location Plot

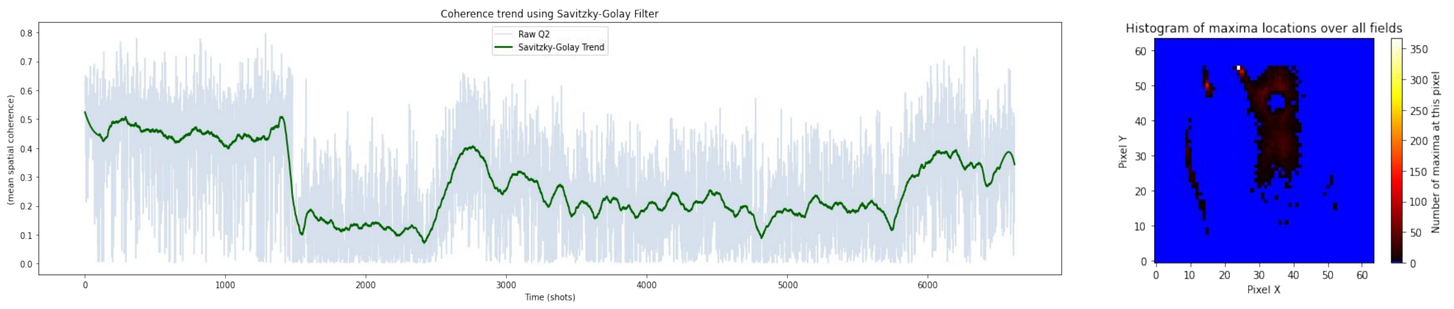
Run 65



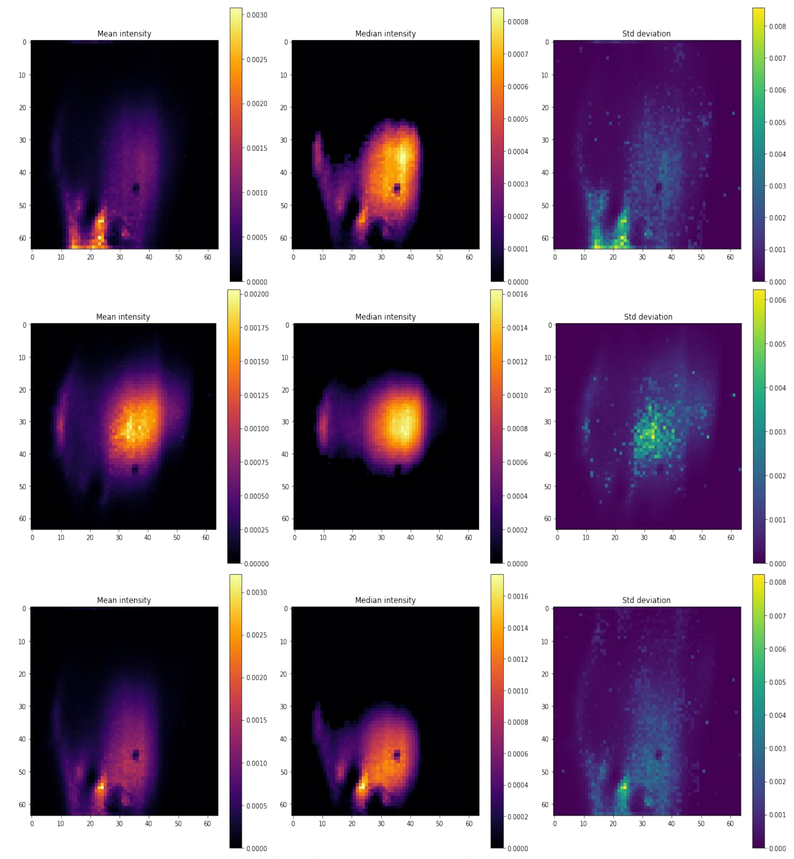
Run 59



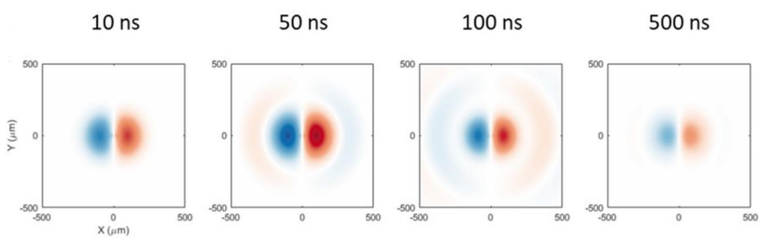
Run 62



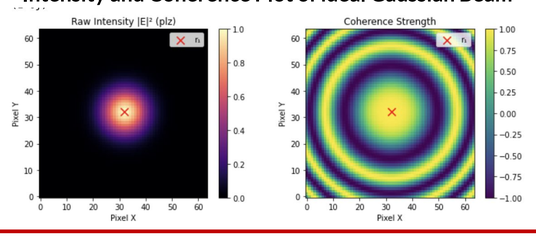
Mean, Median, and Standard Deviation of Intensity Profiles



Generic Simulated Diffraction with Varying Delays



Intensity and Coherence Plot of ideal Gaussian Beam



Analysis and Future Work :

Visualization of key performance indicators, achieves a comprehensive overview of beam behavior across experimental runs. Plots of coherence and reveal subtle fluctuations as well as pronounced step-changes in the trend lines, possibly indicative of shifts in system alignment.

Intensity profile plots provided valuable spatial information, highlighting dominant beam shape and symmetry. The maxima distribution plots were particularly effective at localizing regions of high intensity, offering insight into the underlying mode content and possible presence or emergence of diffraction.

Together, these visualizations may help to address systemic versus random behavior that might otherwise have been overlooked with summary statistics alone.

Future work would incorporate tuning XFEL machine and undulator properties in hopes of achieving more specific beam properties and behavior using machine learning.

ACKNOWLEDGEMENTS

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2) TRANSVERSE-COHERENCE PROPERTIES OF THE FEL AT THE LCLS - Yuantao Ding
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