SLAC NATIONAL ACCELERATOR LABORATORY

Advanced XTCAV Reconstruction algorithms

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Introduction

Time-energy electron bunch measurements enabled by the XTCAV are routinely used for LCLS experiments to retrieve the X-ray profile.
Current state of art XTCAV analysis however, requires the gas monitor detector pulse energy measurement to offset the electron bunch energy in order to match the pulse energy of the reconstructed profile, and a large lasing off baseline dataset.
The current approach therefore does not grant an independent pulse energy measurement and may become unusable for pair of pulses with large color separation.
We investigated two different methods of performing the reconstruction of hard X-ray self-seeded dataset. The first does not make use of the baseline set, but infers the lasing off energy by the time-dependent energy distribution on the lasing-on shots. The second one performs a full realignment in both time and energy between lasing on and lasing off. Both methods do not employ gas detector energy as input variable.

XTCAV

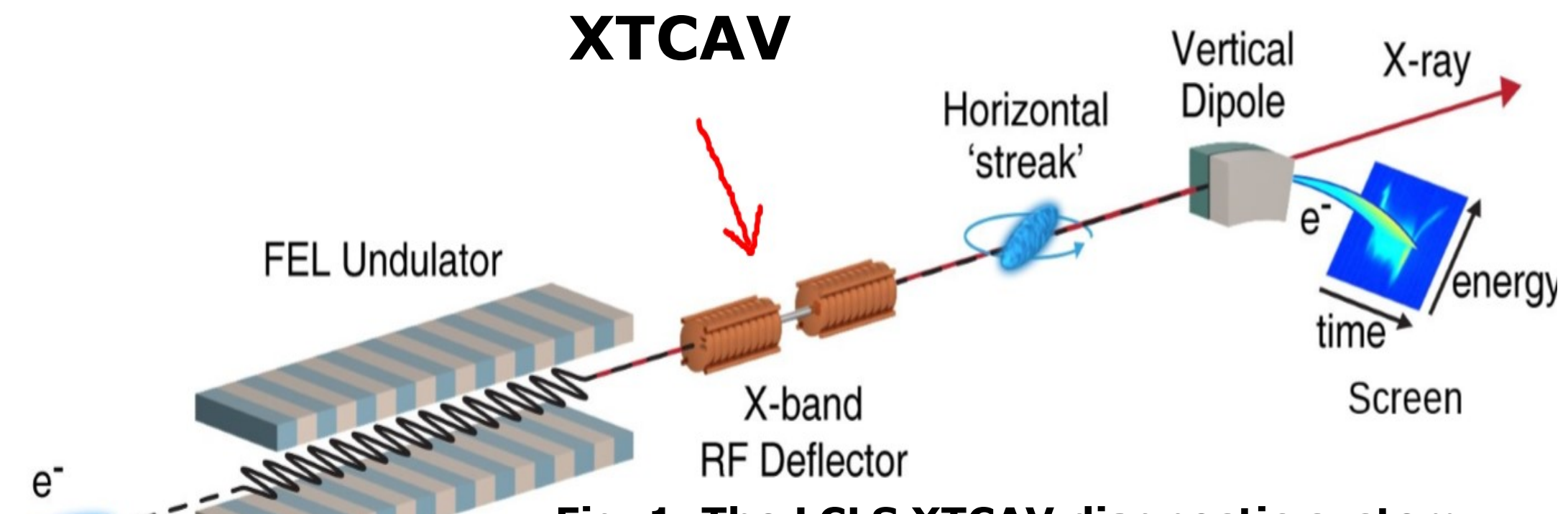


Fig. 1 The LCLS XTCAV diagnostic system, located after the undulator in the LCLS electron dump

Research

Scope & Objectives

Defining alternative XTCAV analysis methods suitable for non standard LCLS operation such as self-seeding or Fresh-slice without requiring gas monitor reading; and operating at typical LCLS operation point, in deep saturation.

Methods

Regular XTCAV Analysis:

The lasing-on shot's time slice average energies are compared to lasing-off shots. The lasing-off is picked on similarity of current profile. Time axes are aligned on current profile while energy axes are corrected with gas detector

$$P(t) = \left(E_{on}(t) - E_{off}(t) + O_{gdet}\right)I(t)$$

$$E_{x\text{-}rays} = \int_{-\infty}^{+\infty} P(t)dt$$

Analysis with lasing-on only:

In self-seeding and fresh-slice schemes only a fraction of the electrons effectively lose energy and participate in the lasing process. Each time slice present a distribution peak located at the energy level before the lasing process started. This is true as the energy shift performed by Ogdet(offset in equation above) superposes the lasing off energy with the energy distribution peak of the lasing on.
We call that energy the "most distributed energy" (E_d) although on other dataset trapped peak may be more intense.
Power is calculated as :

$$P(t) = \left(E_{on}(t) - E_d(t)\right)I(t) \qquad \textbf{(1)}$$

Bi-dimensional baseline realignment:

The concept of most distributed energy is still used, but the information is extracted on every baseline shot and on the lasing on shot to find the best match in both time and energy profile, thus giving both time and energy realignment.
The method is computationally heavier but improves the result on horn(edges) distribution, where the most distributed energy does not correspond to the barycenter location.

Procedures

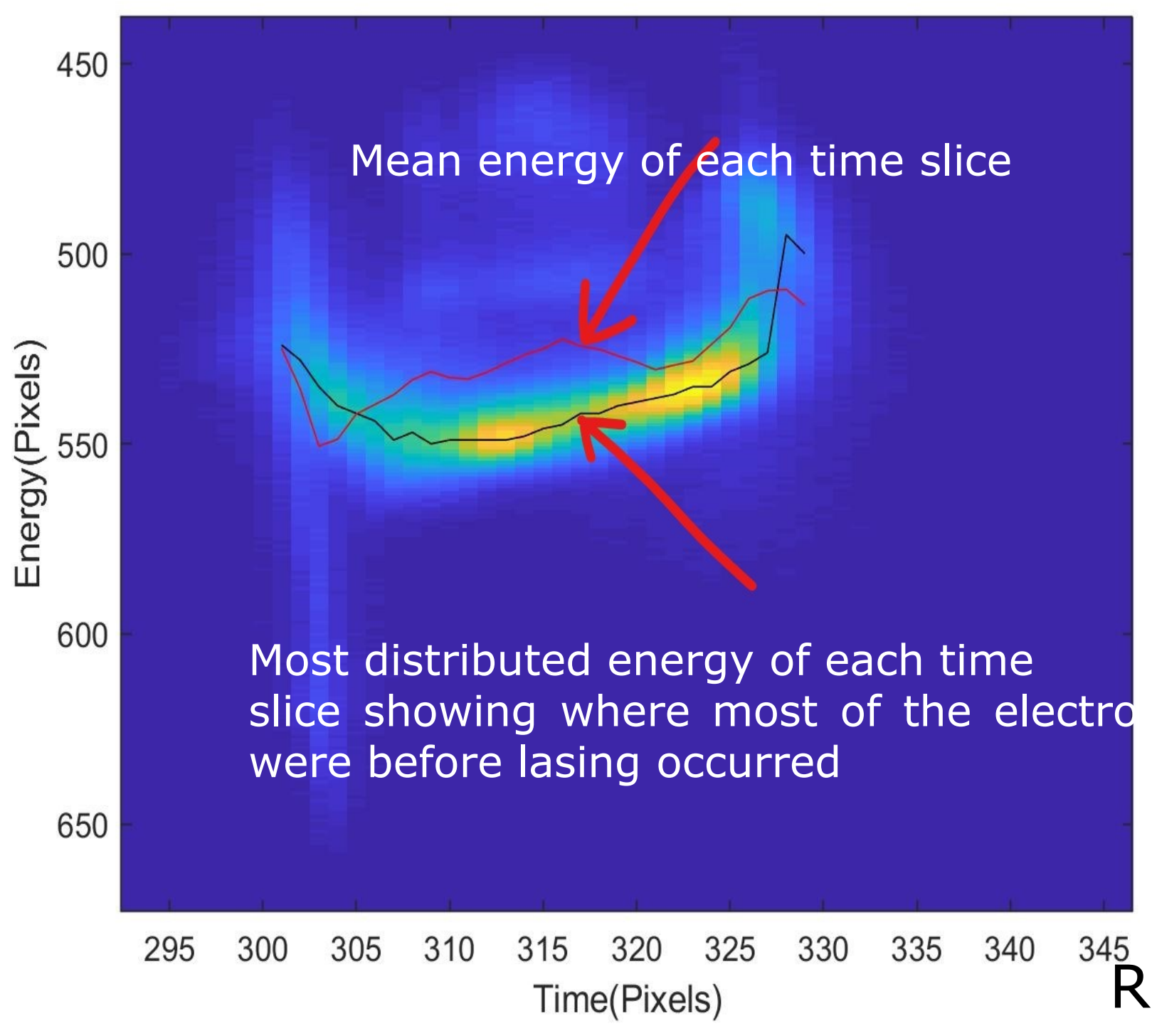
Lasing on only

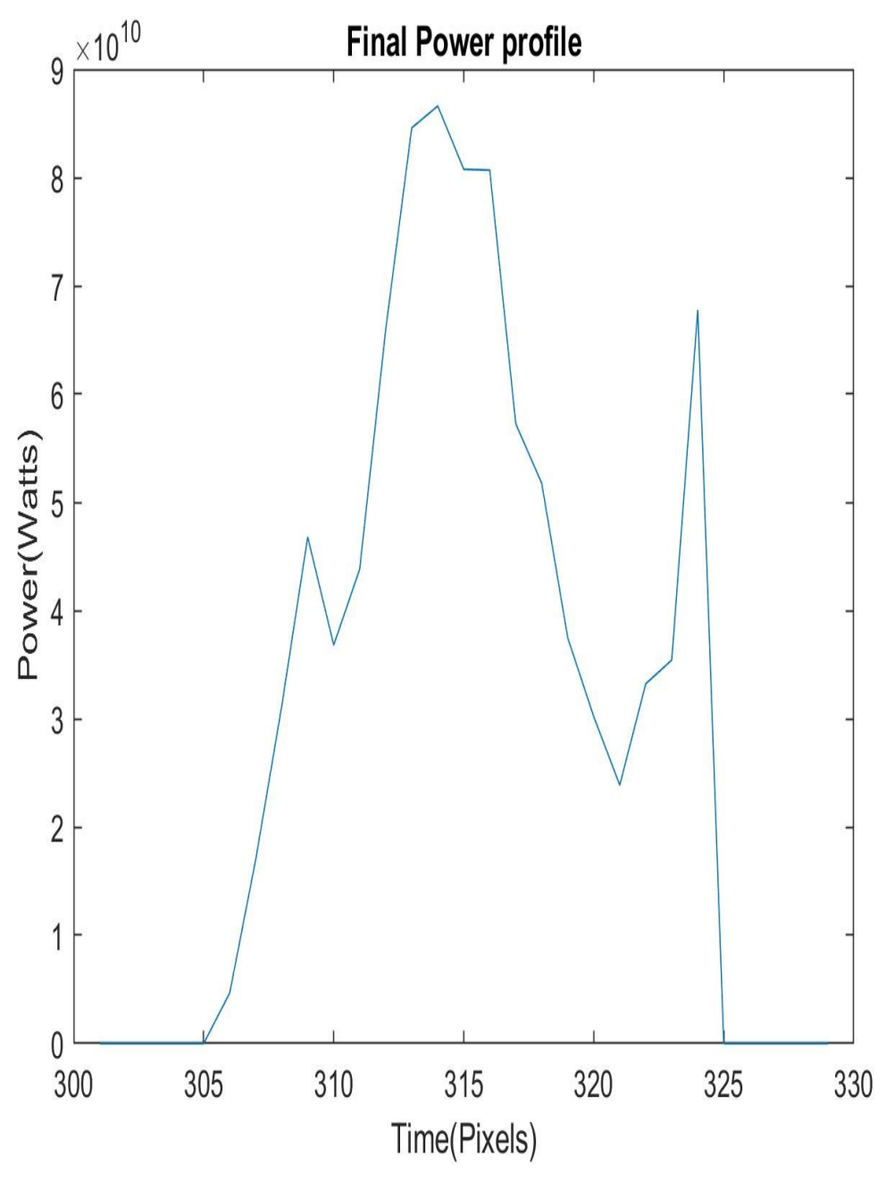
1. Load lasing on shot and subtract average Background noise (no beam)
2. *Apply Wiener and median filter to remove noise spectral components
3. Locate most distributed energy per each time slice
4. Compute the mean energy (first moment) of each time-slice
5. Apply equation **(1)**

Time-energy realignment

1. Load Background set (no beam), large baseline set, and a lasing-on shot.
2. Analyze baseline: subtract average background, de-noise(*), locate energy distribution peak per each time-slice. Piecewise interpolate the "chirp" profile.
3. Analyze lasing on shot: Subtract average background and de-noise(*), locate most distributed energy per each time slice. Piecewise interpolate the "chirp" profile.
4. Find "chirp"profile baseline-shot with the minimum distance from lasing on "chirp" profile
5. Compute the mean energy (first moment) of each time-slice for lasing on shot(Eon)
6. Cast lasing off image on lasing on with bi-cubic interpolation using time and energy offsets
7. Calculate first moments of each time-slice for lasing off (E_{off})
8. Apply equation **(1)**, but with E_{off} rather than E_d

(*) optional step

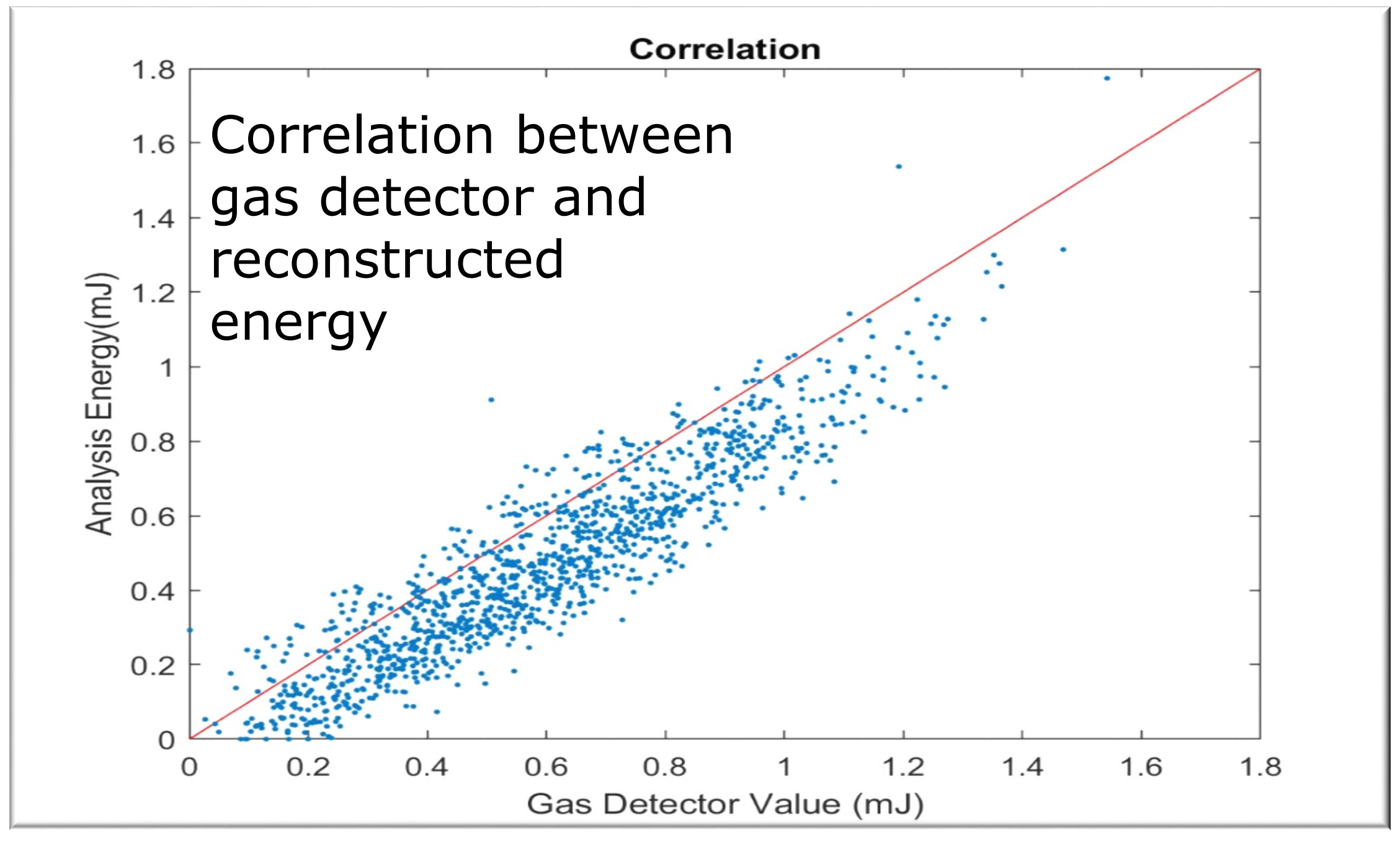




Reconstructed X-ray profile

Result

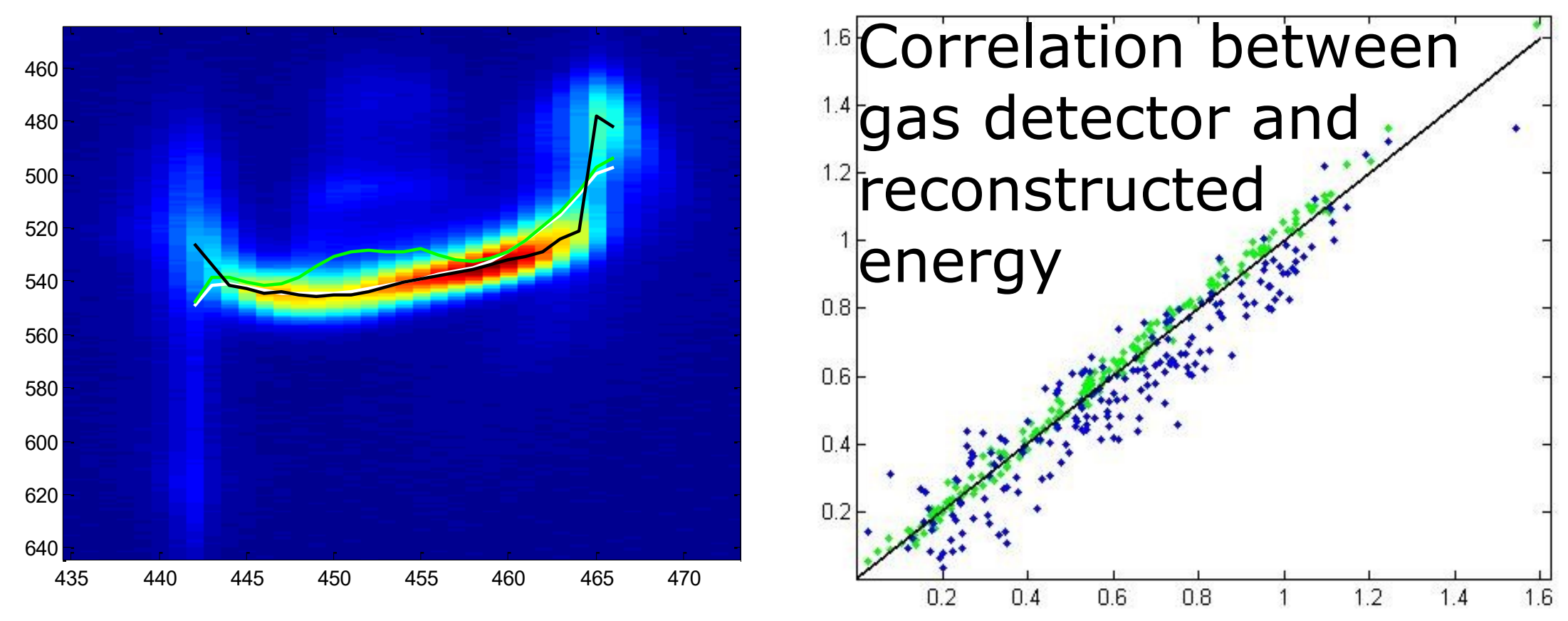
Lasing on only



Correlation between gas detector and reconstructed energy

Coefficient of correlation 0.924

Time-energy realignment



Correlation between gas detector and reconstructed energy

Coefficient of correlation 0.95, correct slope and offset

Challenges & Future work

- Some part of the image that do not participate in the lasing affect the analysis giving rise to the large dispersion of the correlation plot
- Even after subtracting the background noise and filtering it, some noise effects still occur giving rise to some inaccuracies.
- Background images show day to day very different Fourier domain noise.
- Fresh-slice shots are harder to deal with distribution head and tail
- Regular SASE may not show a clear most distributed energy
- Utilize machine learning to learn and deal with the parts of the images that do not participate in the lasing to improve correlation
- Implement this method on different dataset like regular saturated SASE, Fresh-slice configurations, etc.

Conclusion

This research shows a couple of successful results:

- Reconstruction of a self-seeded dataset without use of the gas detector information nor lasing off baseline with correlation coefficient with gas detector of 0.924.
- Correlation improves to 0.95 by using a baseline set, and has the correct slope and offset.
- May be retroactively used for LCLS user who took poor baseline datasets.

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