

Virtual Diagnostic For Longitudinal Phase Space Prediction at FACET-II

SLAC National Accelerator Laboratory
AAC 2026, UCLA

Presenter: Jinseo Park, PI: Claudio Emma



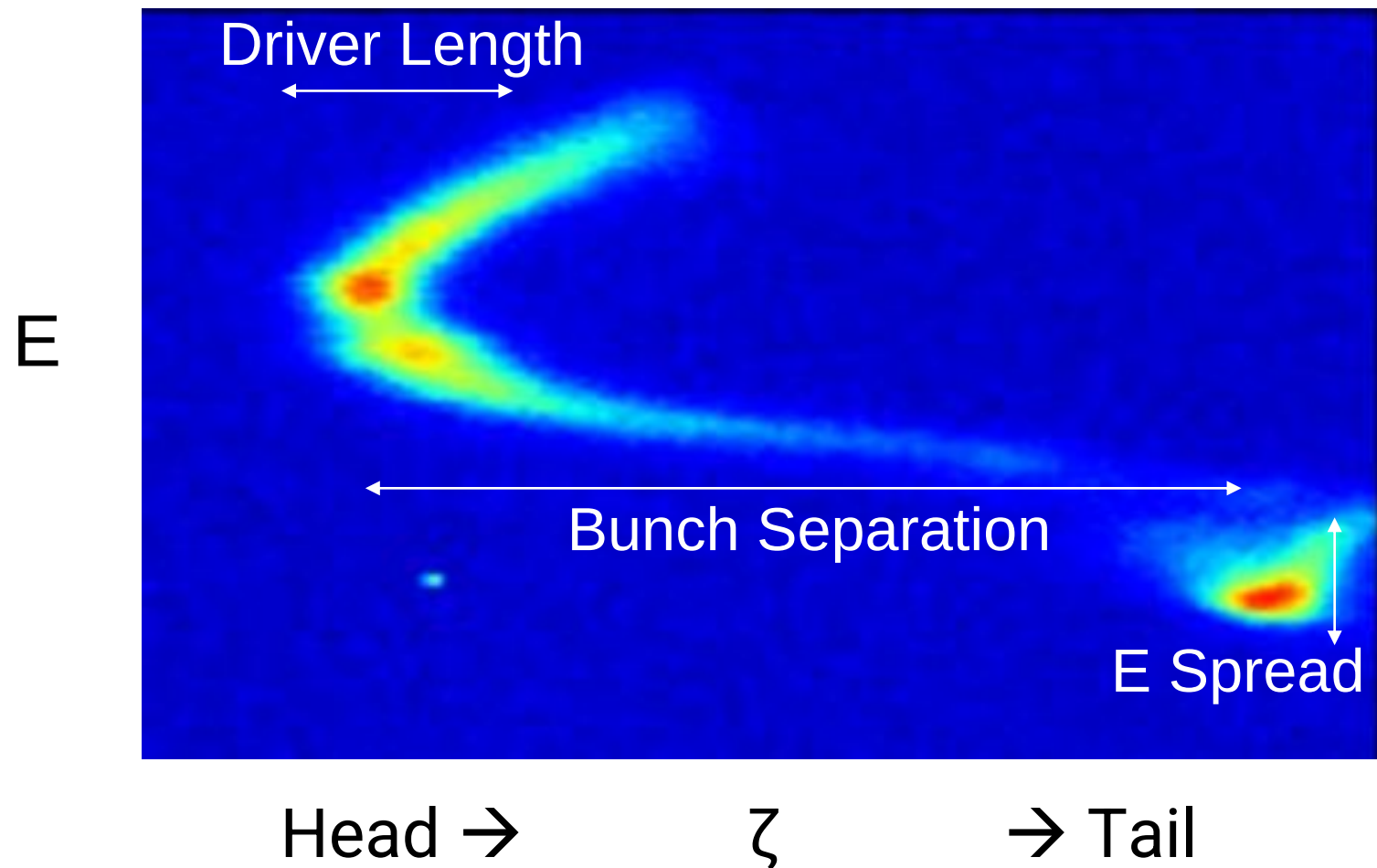
1. Motivation

2. Principle of Operation

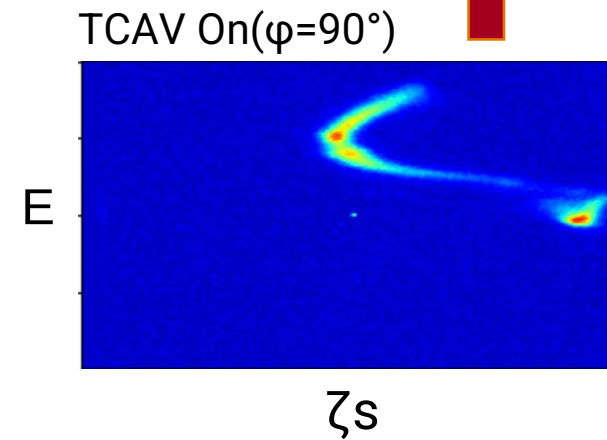
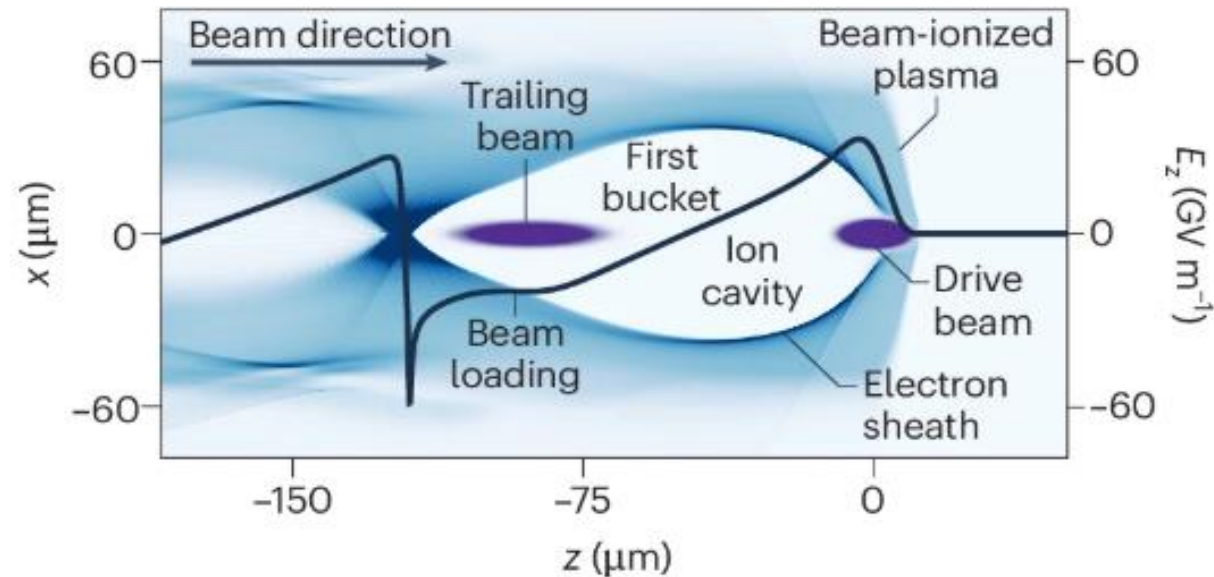
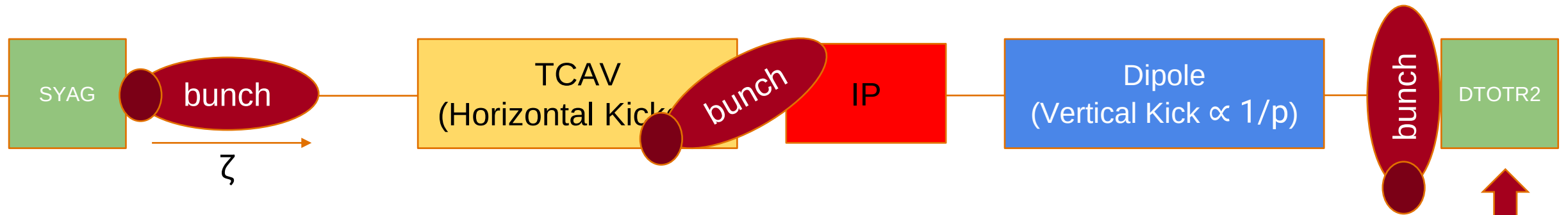
3. Results / Application

4. Current Research Direction

Longitudinal Phase Space



FACET-II S20 XTCAV Overview



Shot-to-Shot LPS Variation

3x3 Grid of Shots for Various BLEN Values - 15908, Cal = 1000 $\mu\text{m}/\text{deg}$, PSDL = 126.5 ps

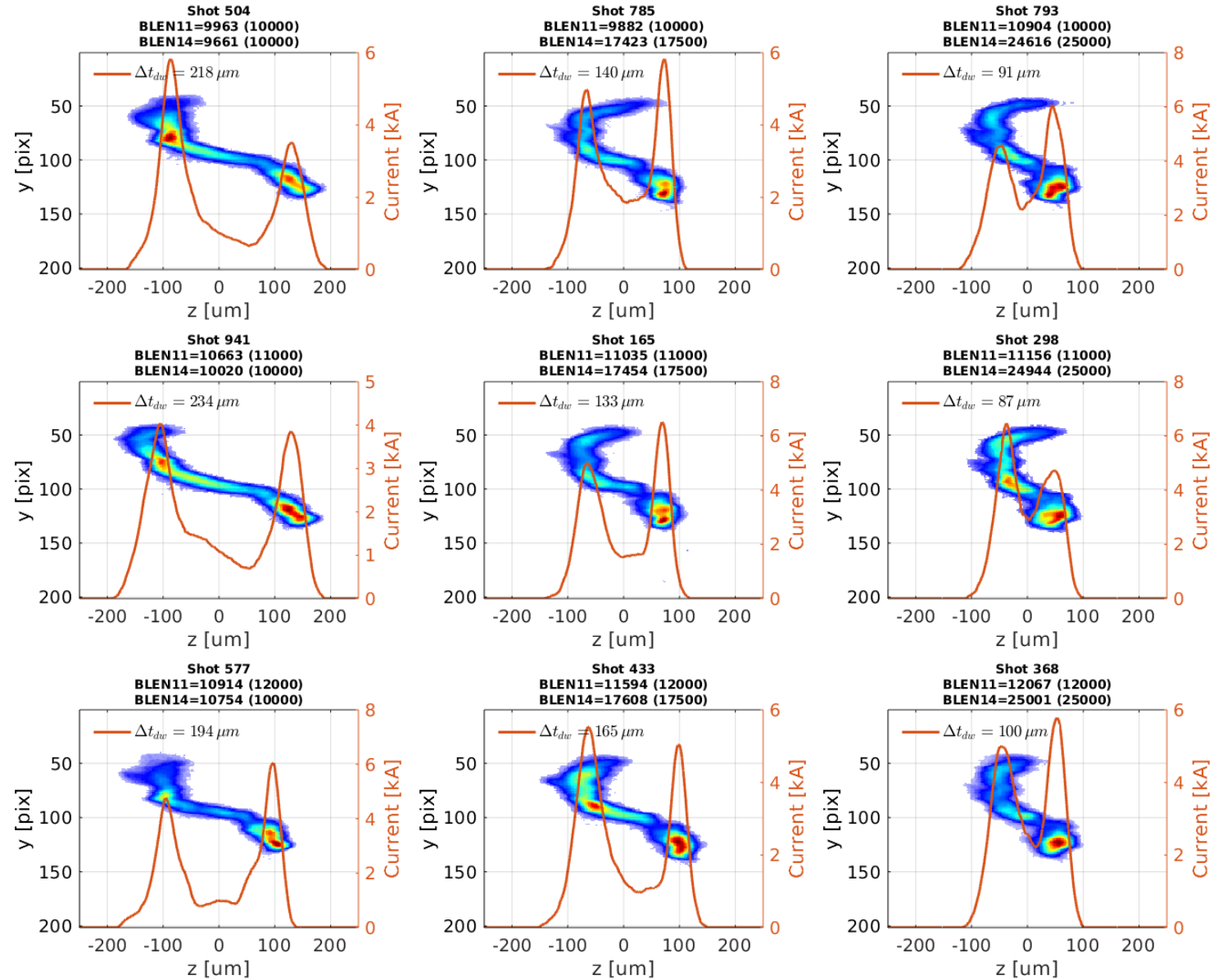


Figure provided by C. Emma

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Inference Model

Normalized PVs → Image Encoding

$[0, 1]^{\#PV} \rightarrow [0, 1]^{\text{EncodingDimension}}$

Example:

Random Forest (RF) Regressor

Image Model

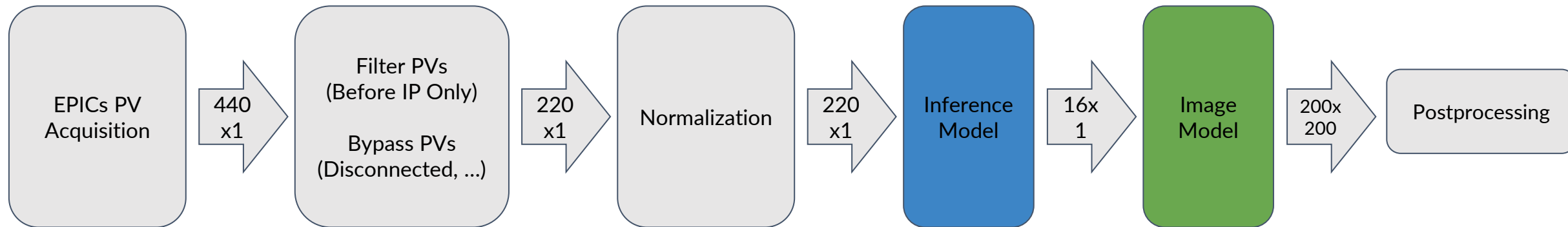
Image Encoding → Image

$[0, 1]^{\text{EncodingDimension}} \rightarrow \text{Image}$

EncodingDimension = 12-20

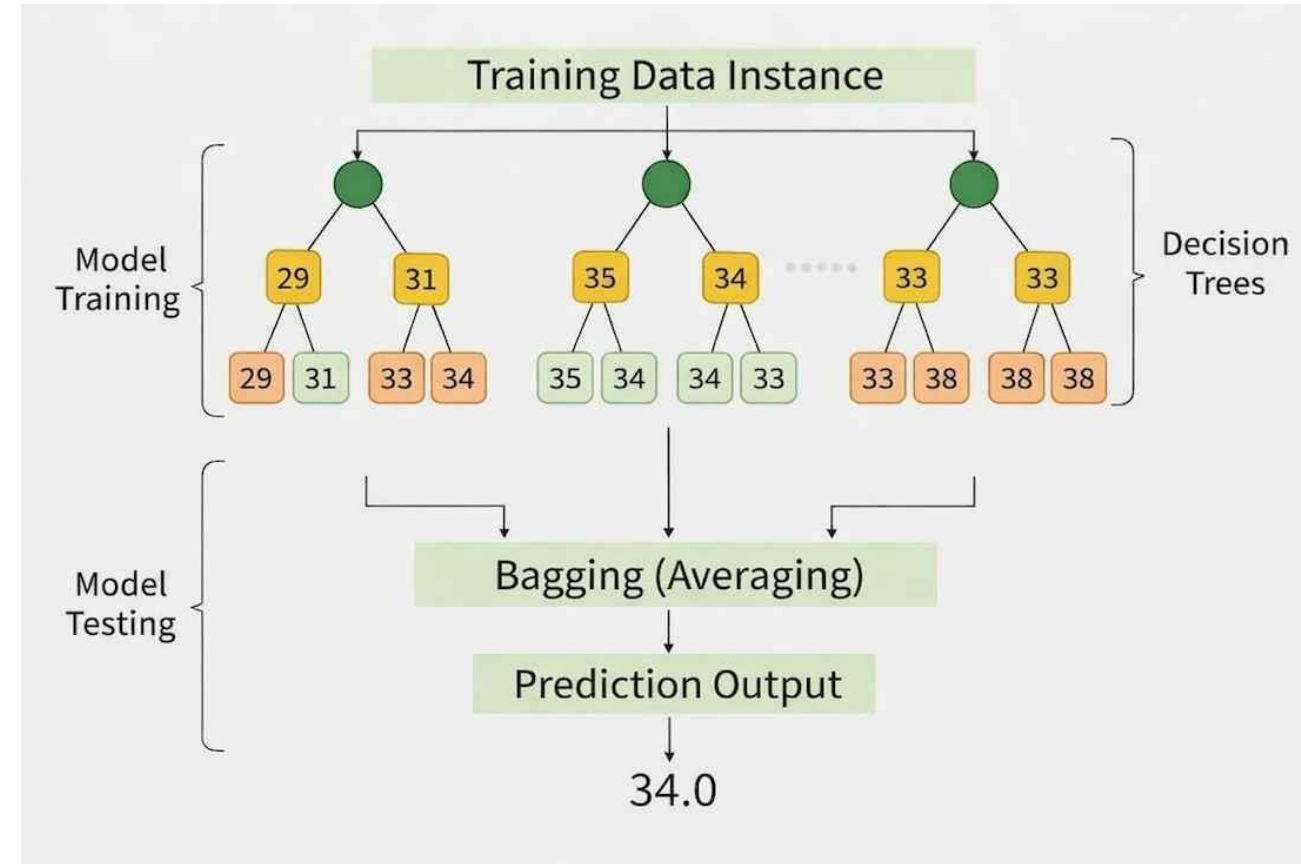
Example:

Convolutional Variational Autoencoder (CVAE)



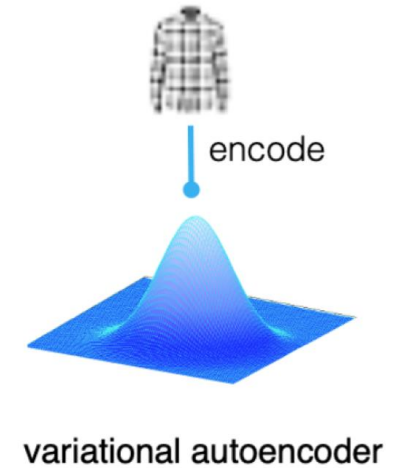
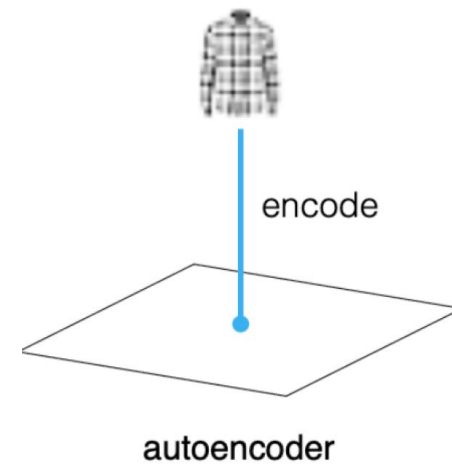
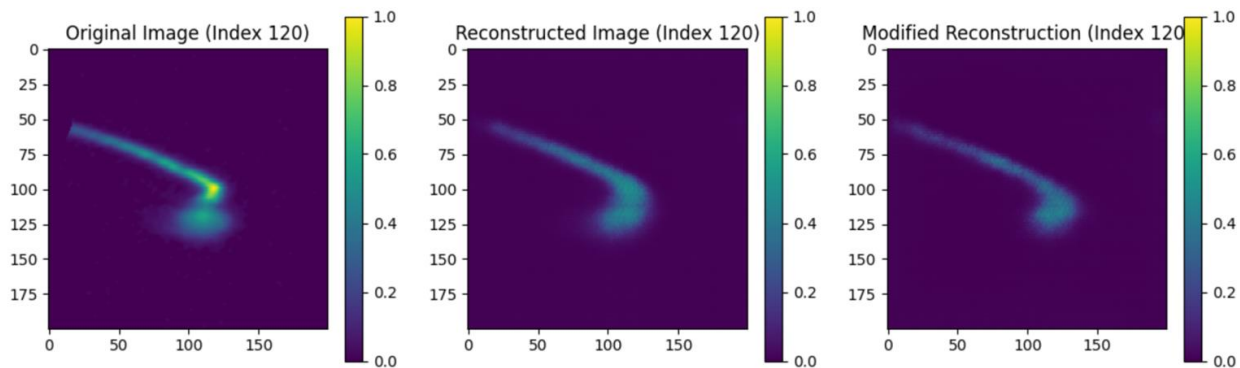
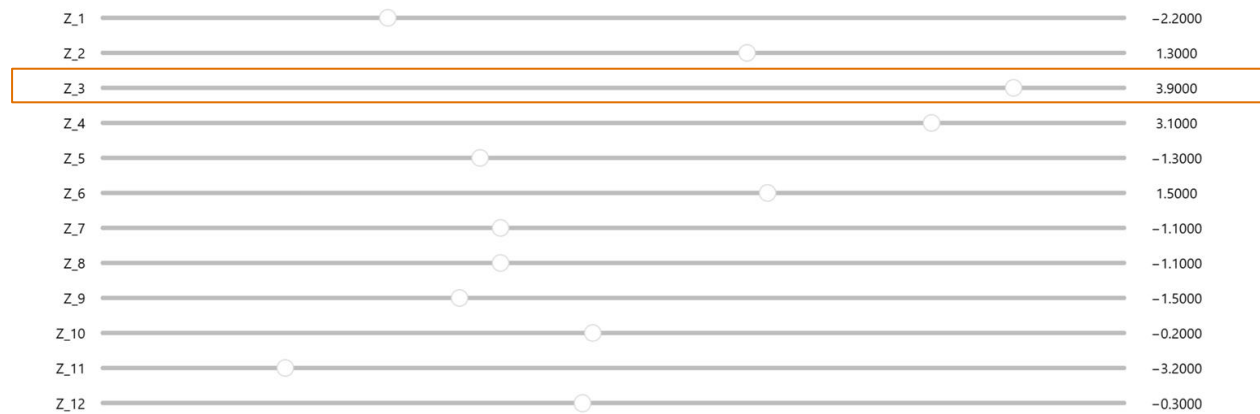
Inference: Random Forest

- Single feature(PV) is compared each branch
- Outputs latent encoding for the image model



<https://www.geeksforgeeks.org/machine-learning/random-forest-regression-in-python/>

Image: CVAE



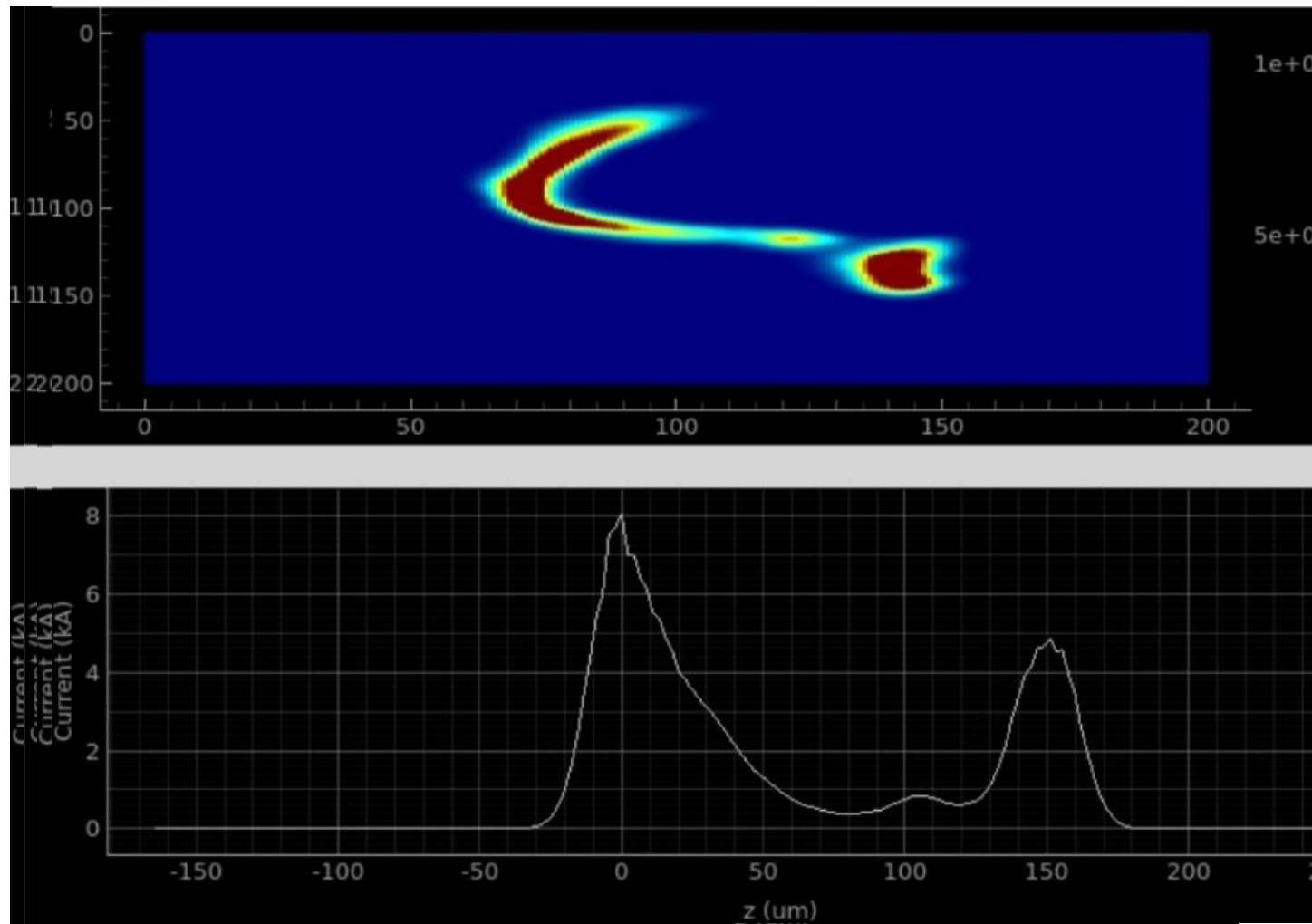
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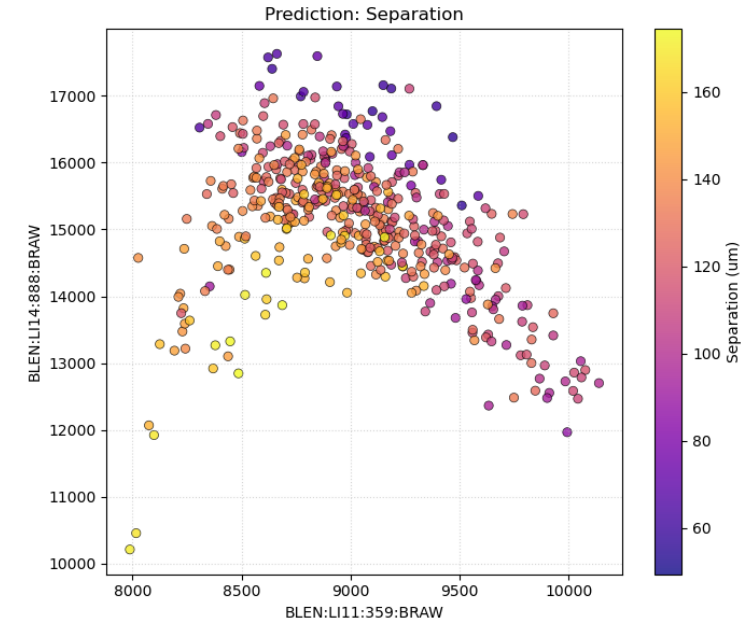
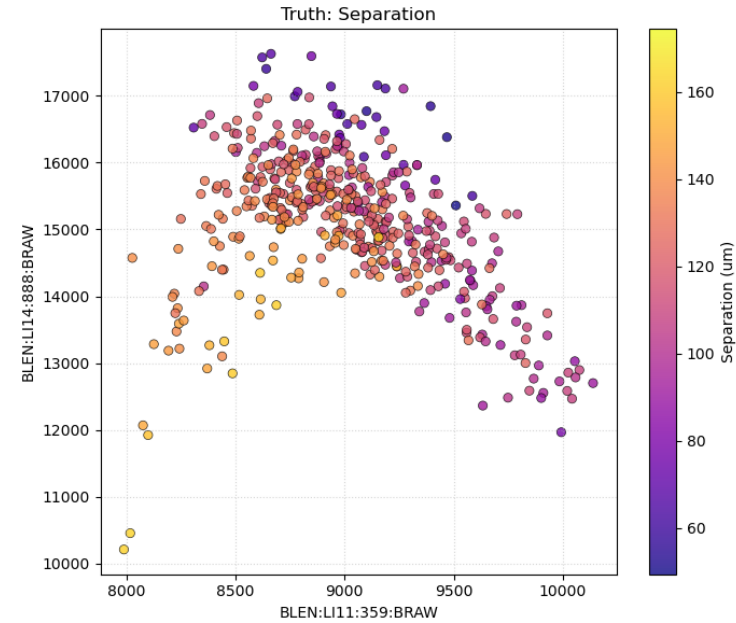
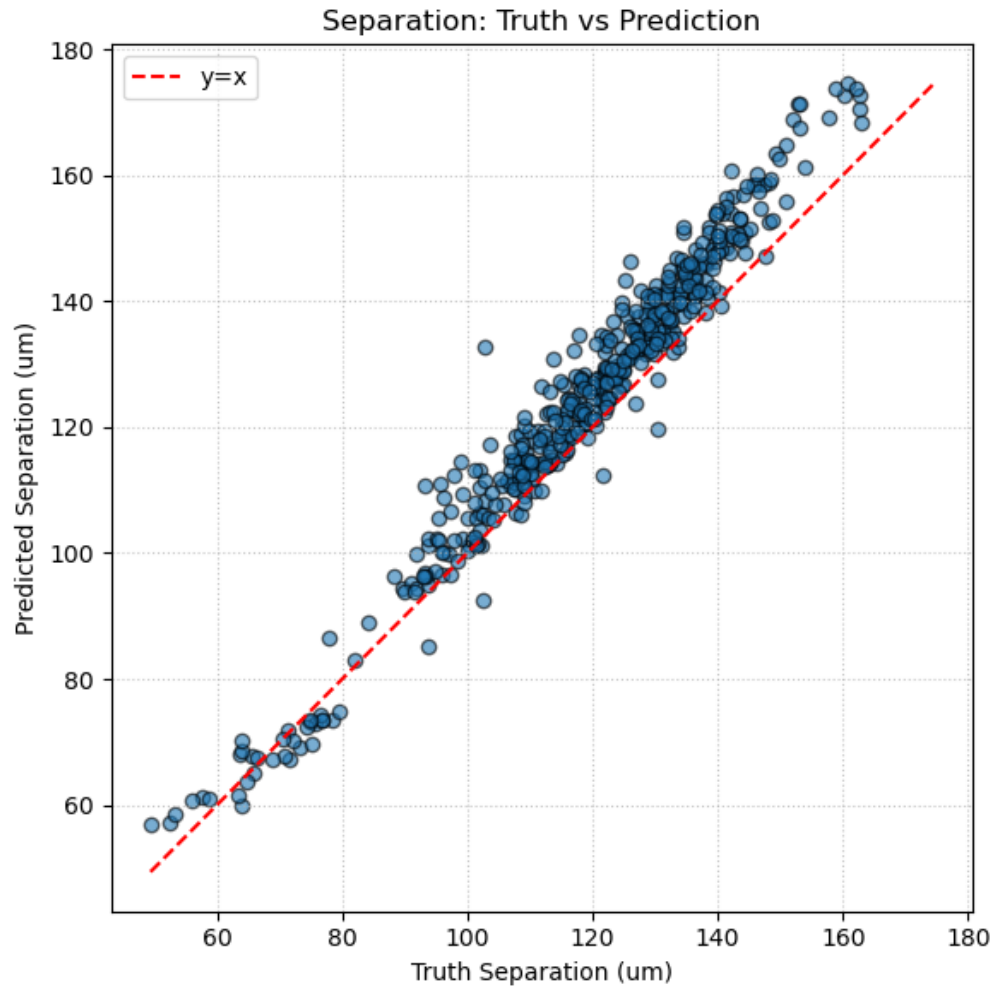
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Model Output

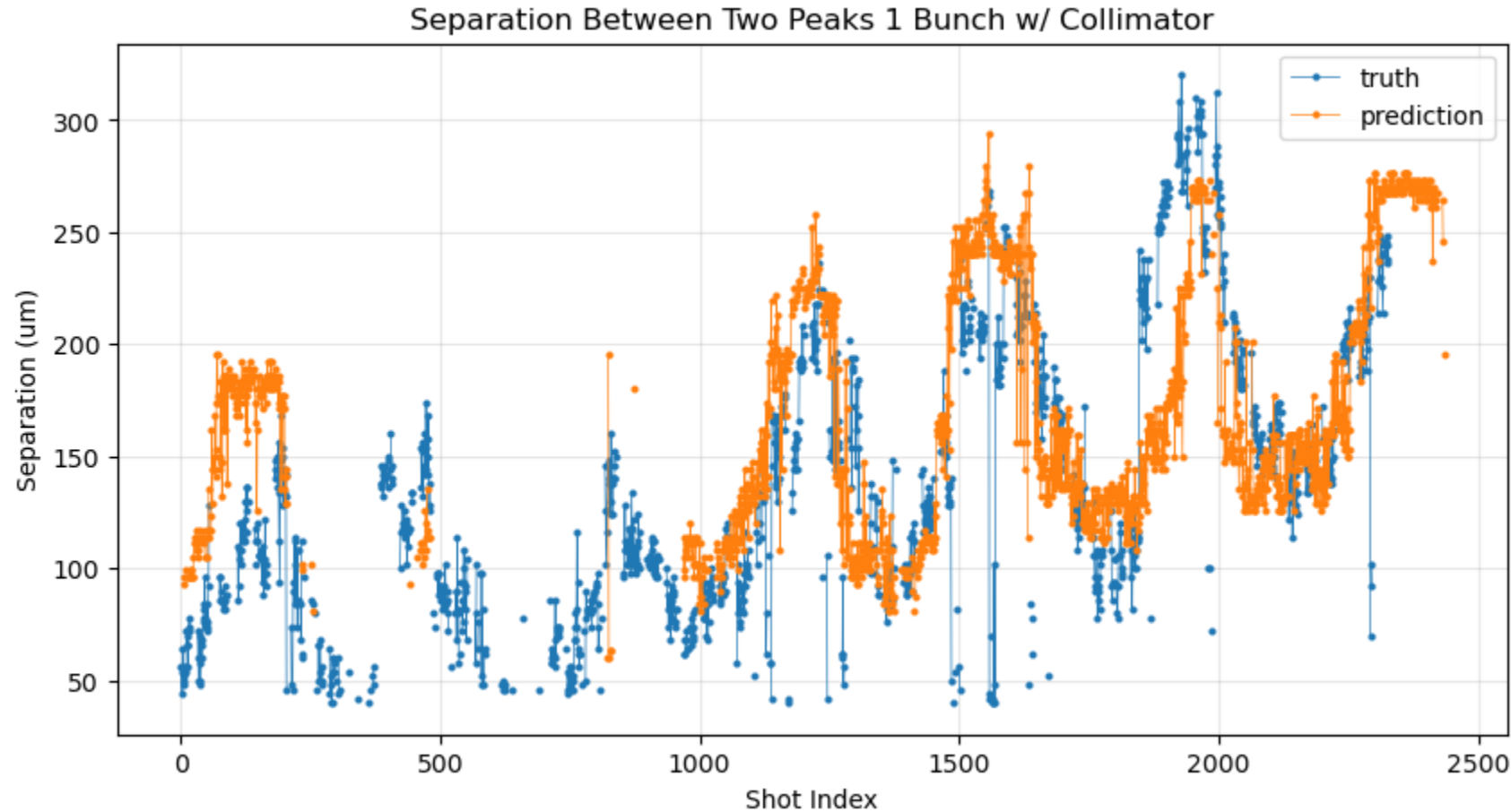
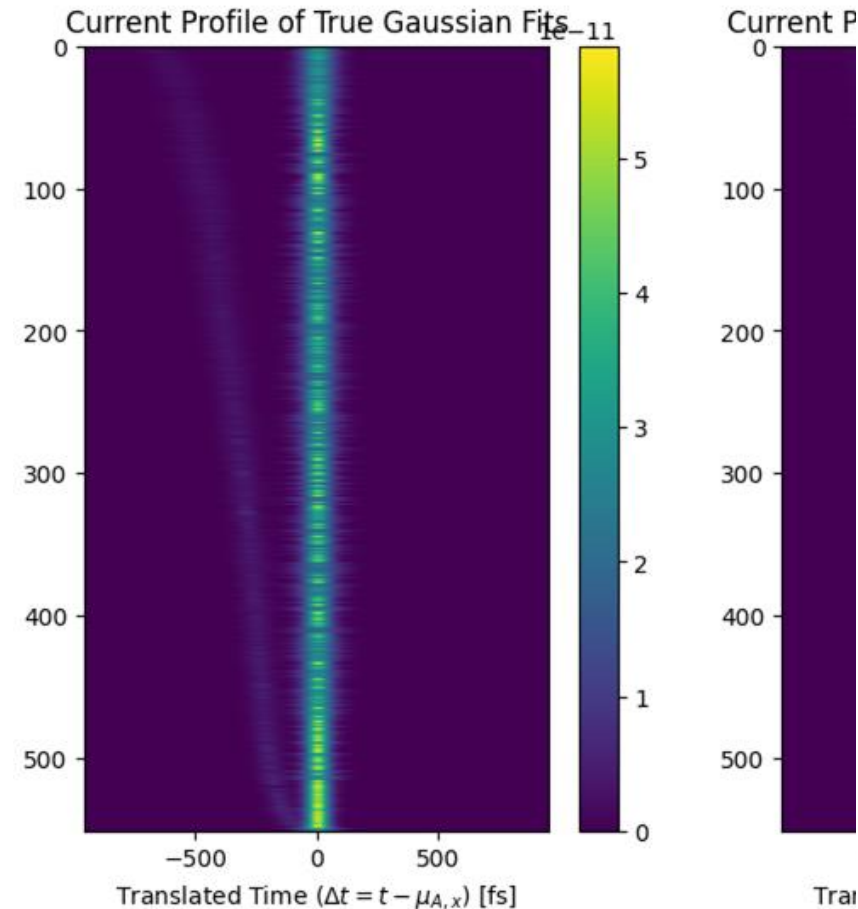


Current Profile Prediction



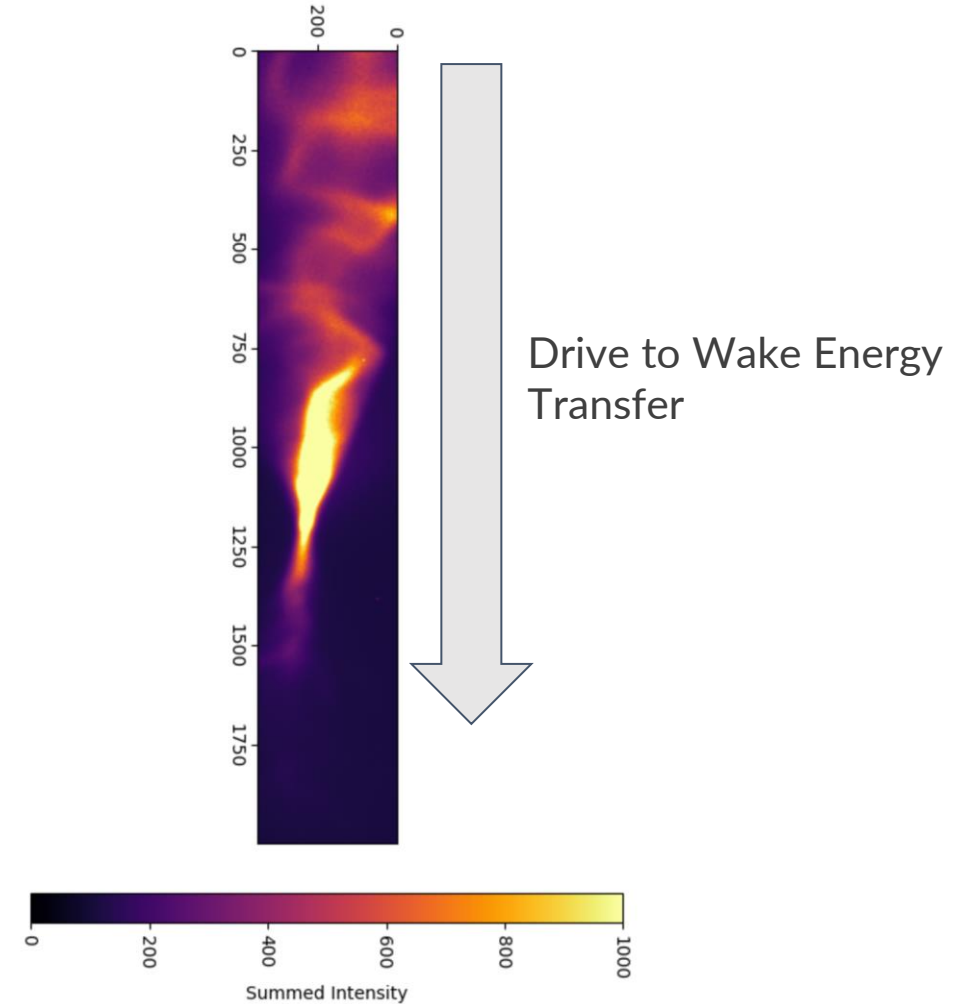
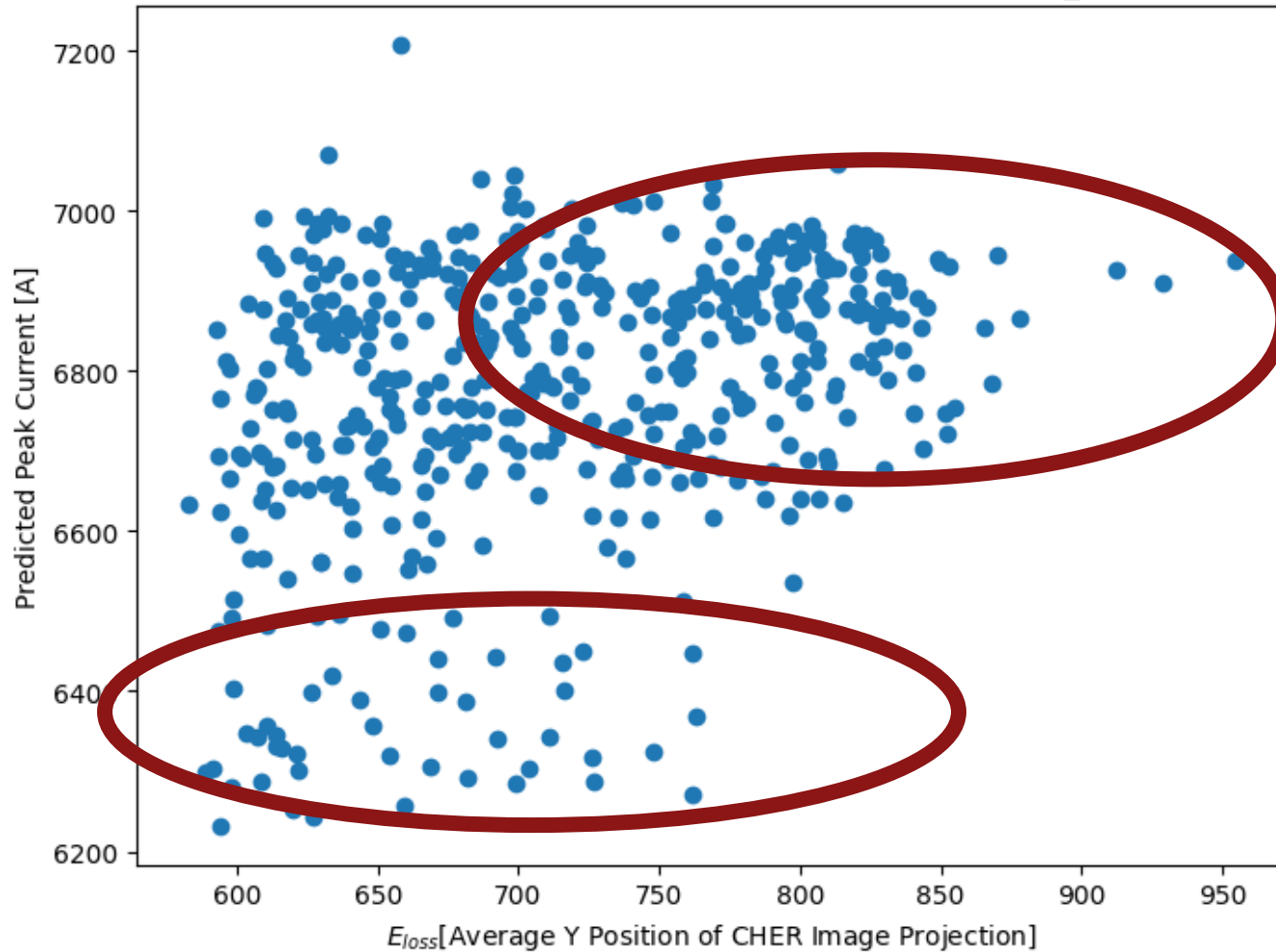
Current Profile Prediction

Current profile in Python, Matlab formats



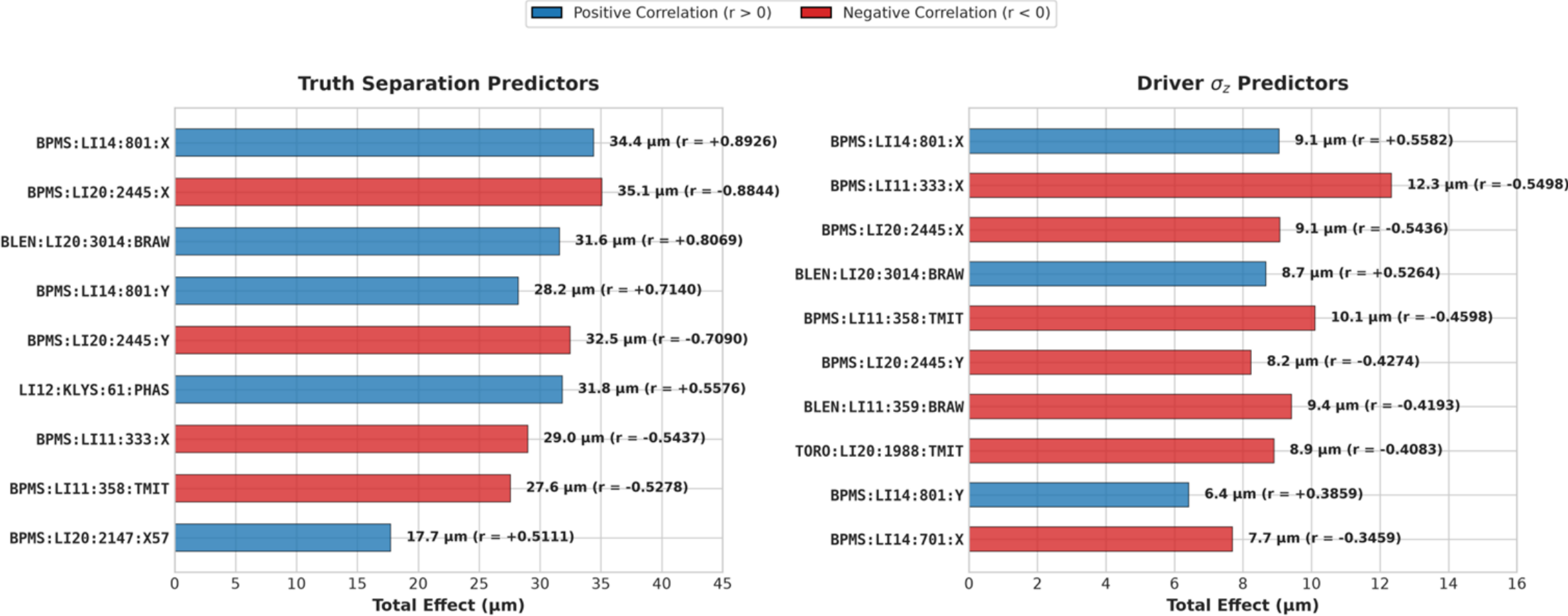
Offline Analysis: Plasma Interaction

CHER Image Average Y Position vs Peak Current [DAQ_15263]



Correlation Studies

Predictor Total Effects & Correlations (natural jitter 1000 shots)

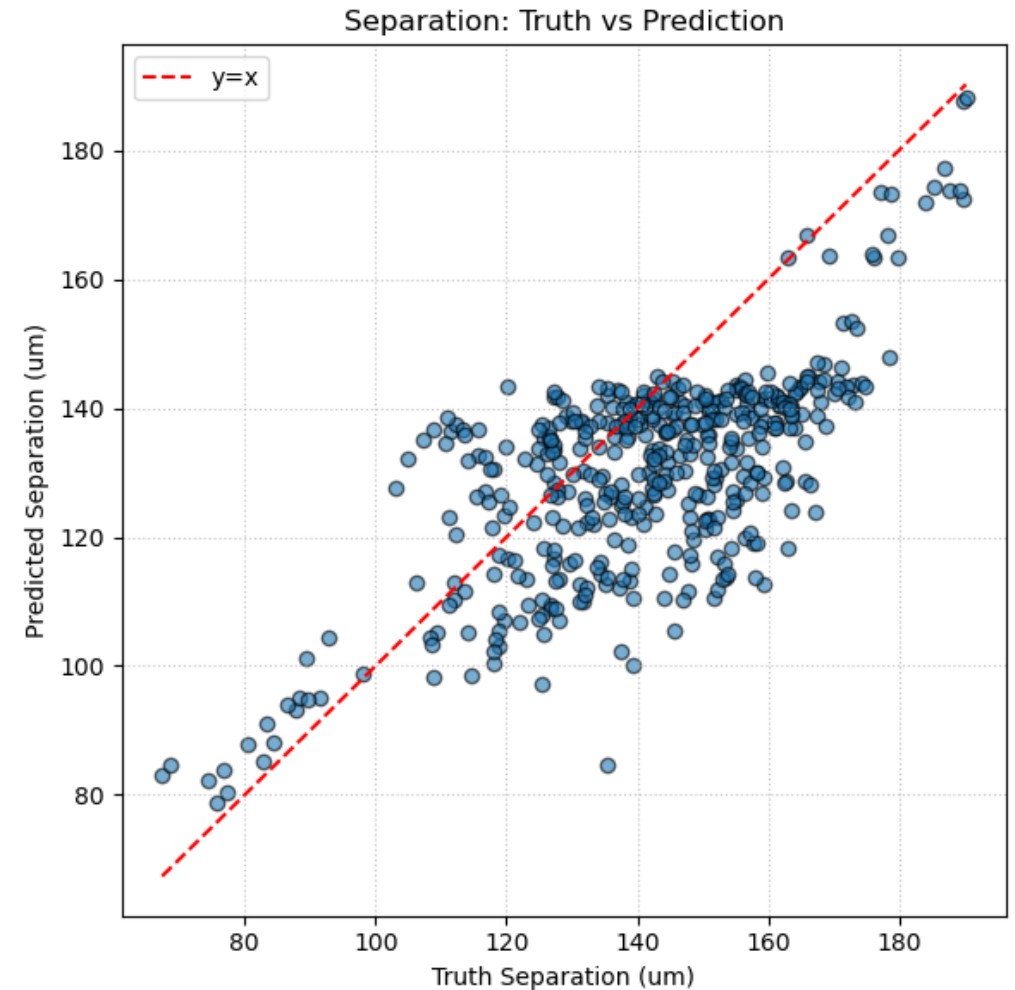


Anomaly Detection

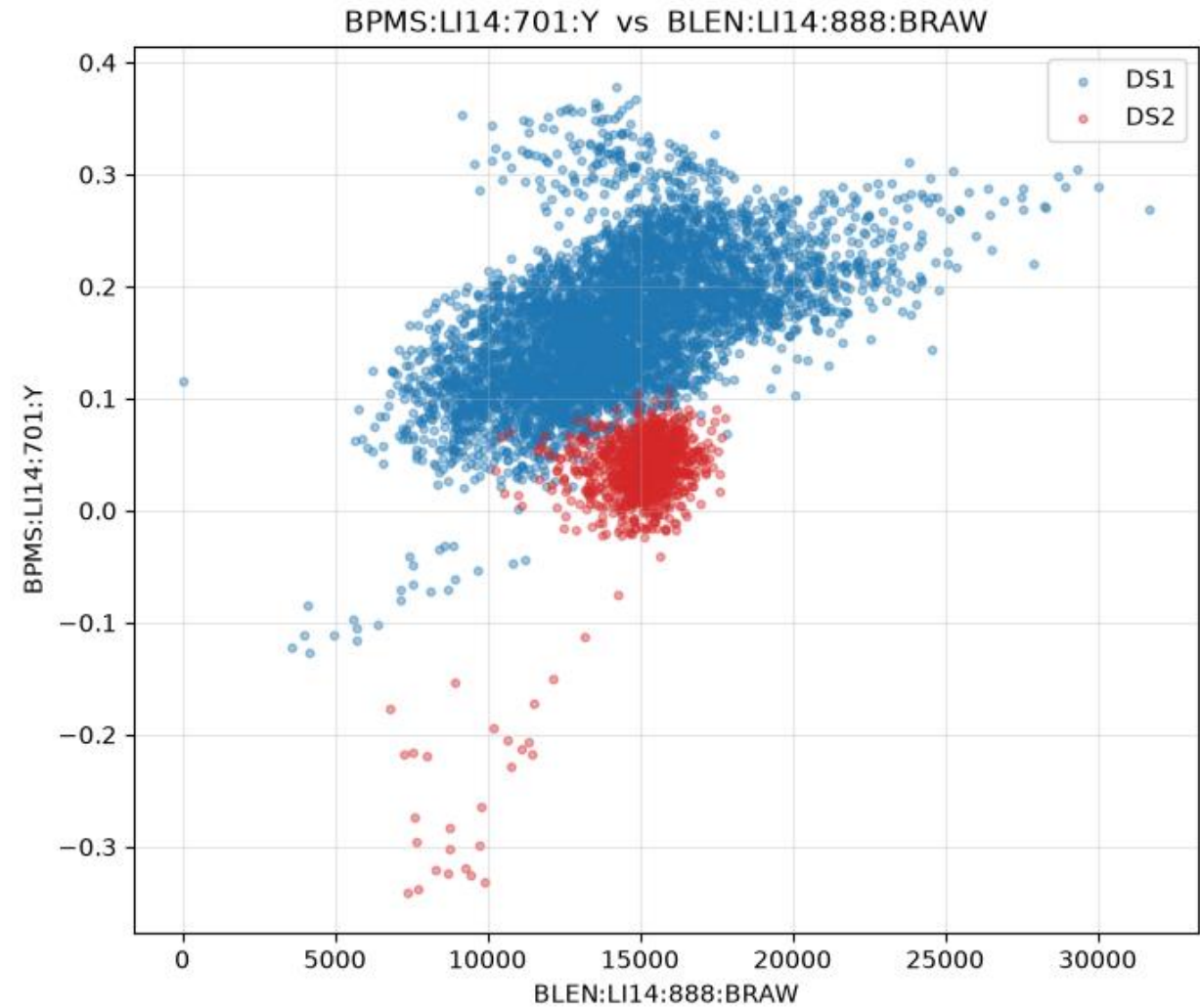
Persistent problem across the entire ML world:

Building Trust!

When models give us bad predictions..... Why?

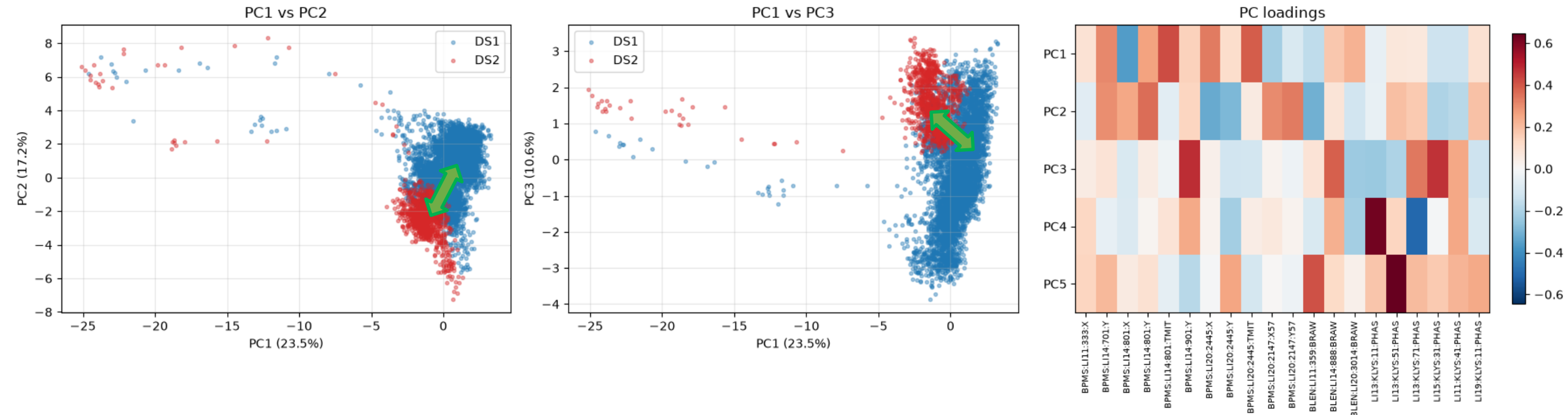


Anomaly Detection



Anomalies not immediately visible by checking any individual readout...
The inference model catches it in real time!

Real Time Confidence



Topological distance between training set and the current state, measured in real time

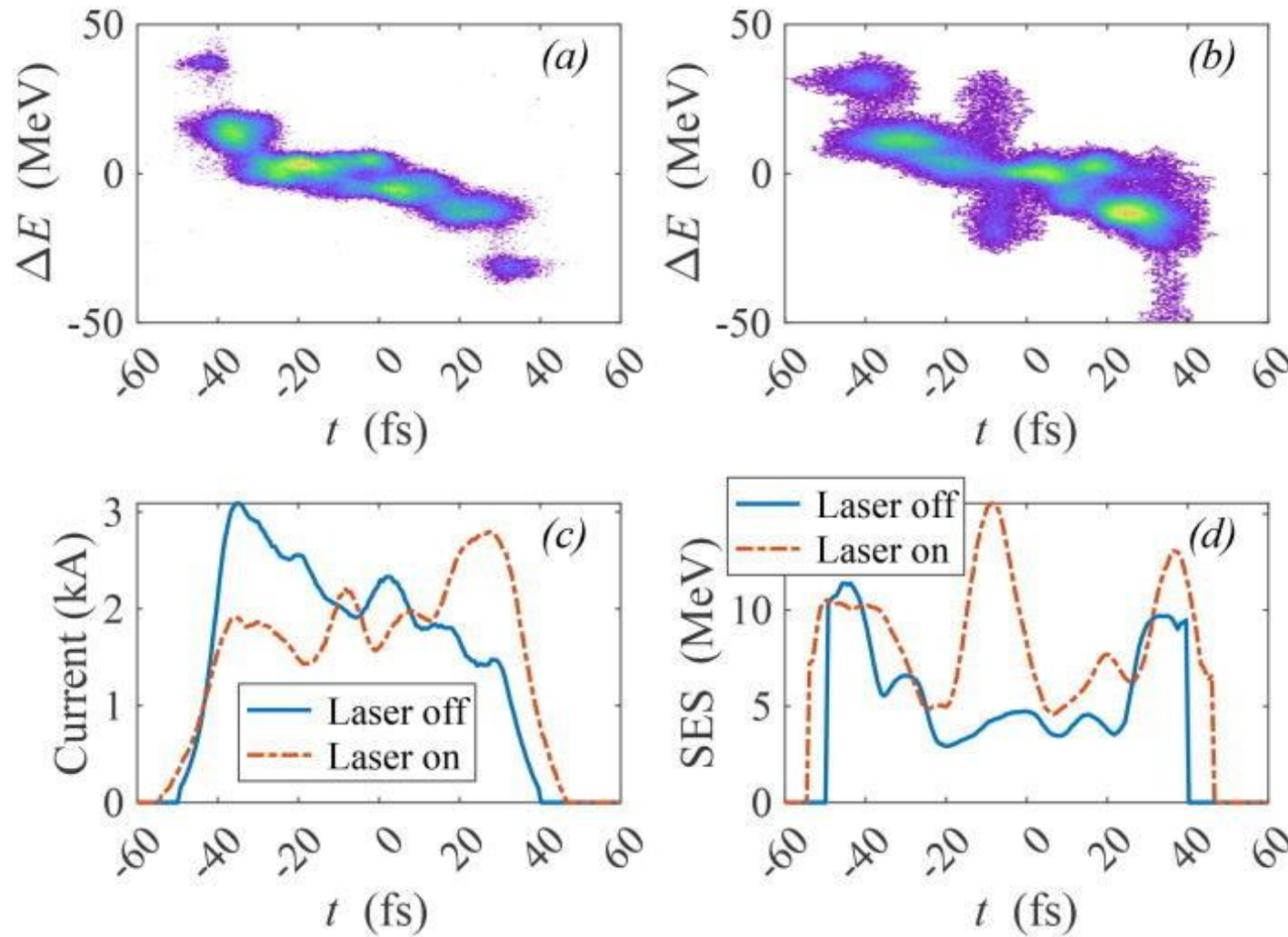
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LCLS XLEAP application



Li, Siqi & Zhang, Zhen & Alverson, Shawn & Cesar, David & Driver, Taran & Franz, Paris & Isele, Erik & Duris, Joseph & Larsen, Kirk & Lin, Ming-Fu & Obaid, Razib & O'Neal, Jordan & Robles, River & Sudar, Nick & Guo, Zhaoheng & Vetter, Sharon & Walter, Peter & Wang, Anna & Xu, Joseph & Marinelli, Agostino. (2024). "Beam à la carte": Laser heater shaping for attosecond pulses in a multiplexed x-ray free-electron laser. Applied Physics Letters. 125. 10.1063/5.0233468.

Also Check Out...

High-dimensional phase space reconstruction using generative modeling of beam distributions

Juan Pablo Gonzalez-Aguilera

Summary

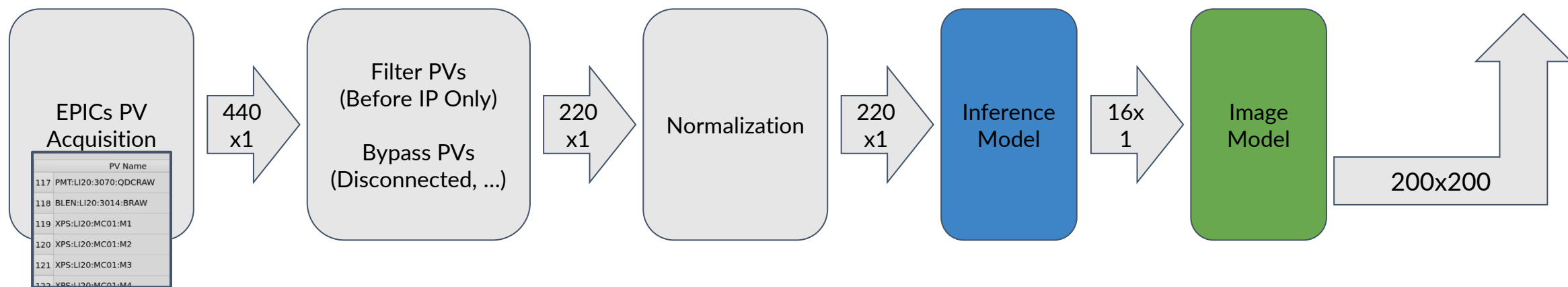
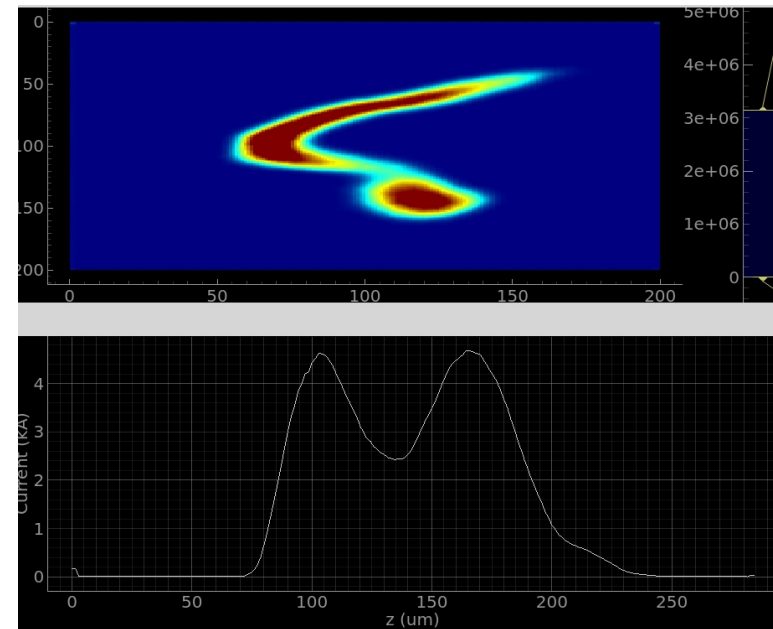
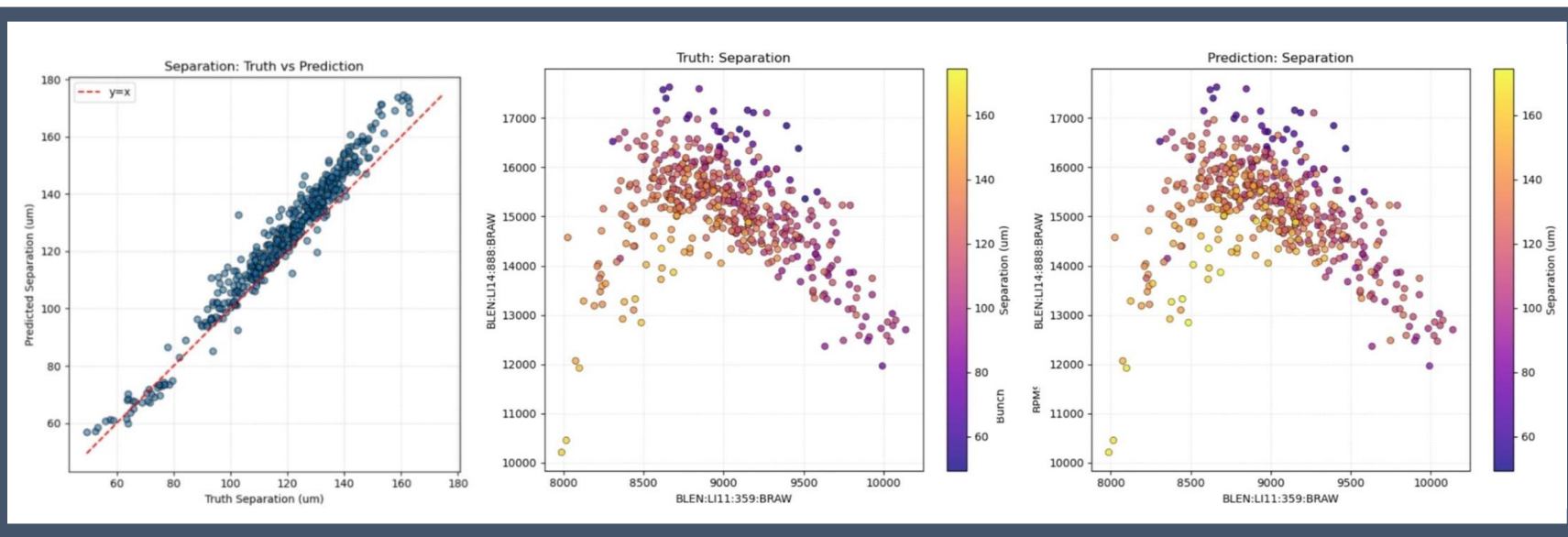
- Virtual Diagnostics accurately predicts LPS from nondestructive diagnostics.
- Prediction Confidence can be used for Real Time Anomaly Detection.

Acknowledgments

- **SLAC:** D. Storey, R. Hessami, K. Larsen, R. Robles, K. Swanson, C. Emma, A. Marinelli, Y. Ye, A. Kinderman, C.-E. Lin, T. Dalichaouch, D. Kalvik, A. Knetsch, S. Gessner, S. Corde, S. Rego, Z. Buschmann, R. Loney, J. Yocky,
 - A. Edelen, D. Cesar, A. Reed
- **Experimental Collaborations with:** E-300, E-338
- Special Thanks to: S. Amberkar, N. Majernik

Thank you for your attention

VTCAV: Virtual Diagnostic For Longitudinal Phase Space Prediction



Bunch Length Feedback System

L1 BLEN Count

L1 Energy BPM

L2 BLEN Count

L2 Energy BPM