Machine learning-based construction of LPS simulator at EuXFEL

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2022/12/06

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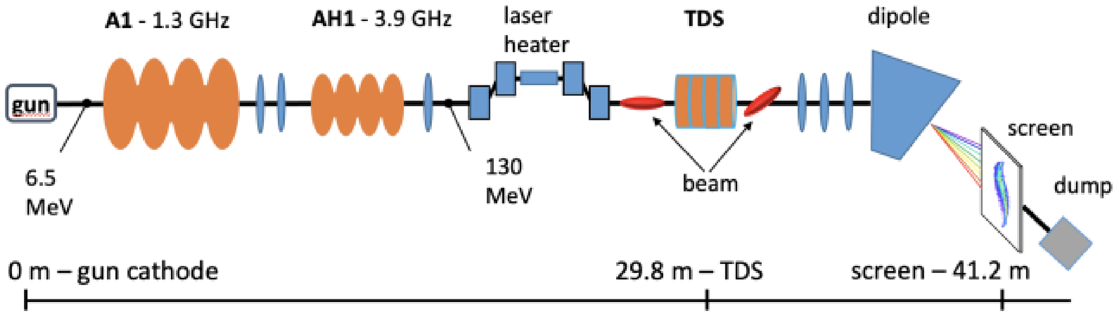
Beam longitudinal phase space acquisition

- Streak the bunch using transverse deflecting structure or CDR spectroscopy
  - Destructive method for entire LPS measurement upstream the undulators
  - Resolution limitation



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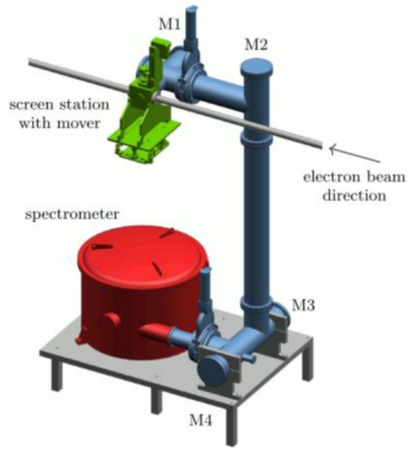

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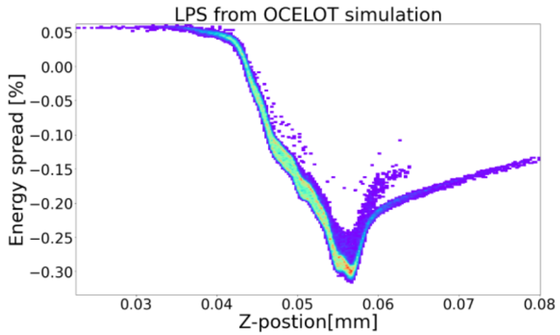
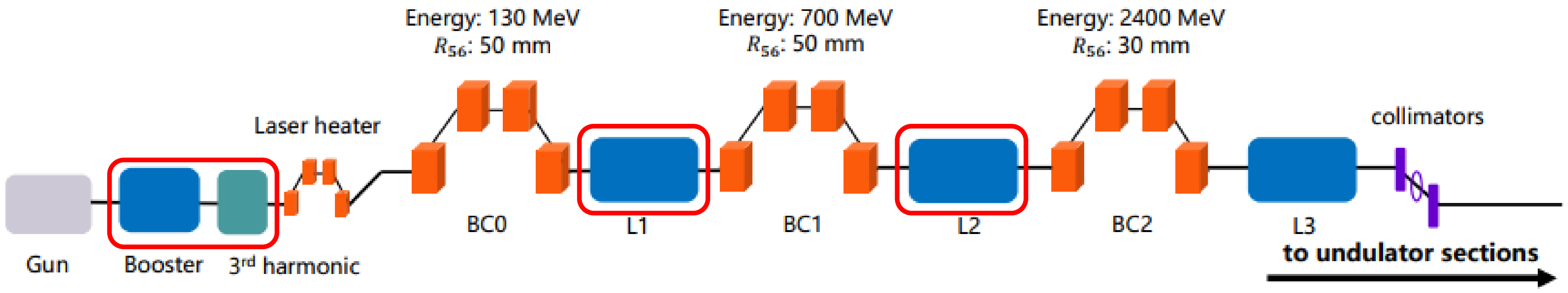
- Beam dynamics simulations
  - High-fidenlity tracking
  - Collective effects



Surrogate model construction for fast and reliable prediction of beam LPS distribution

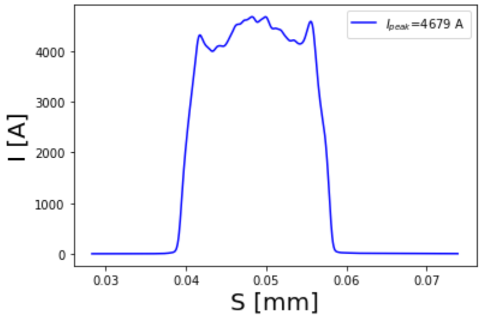
Beam dynamics simulations with OCELOT

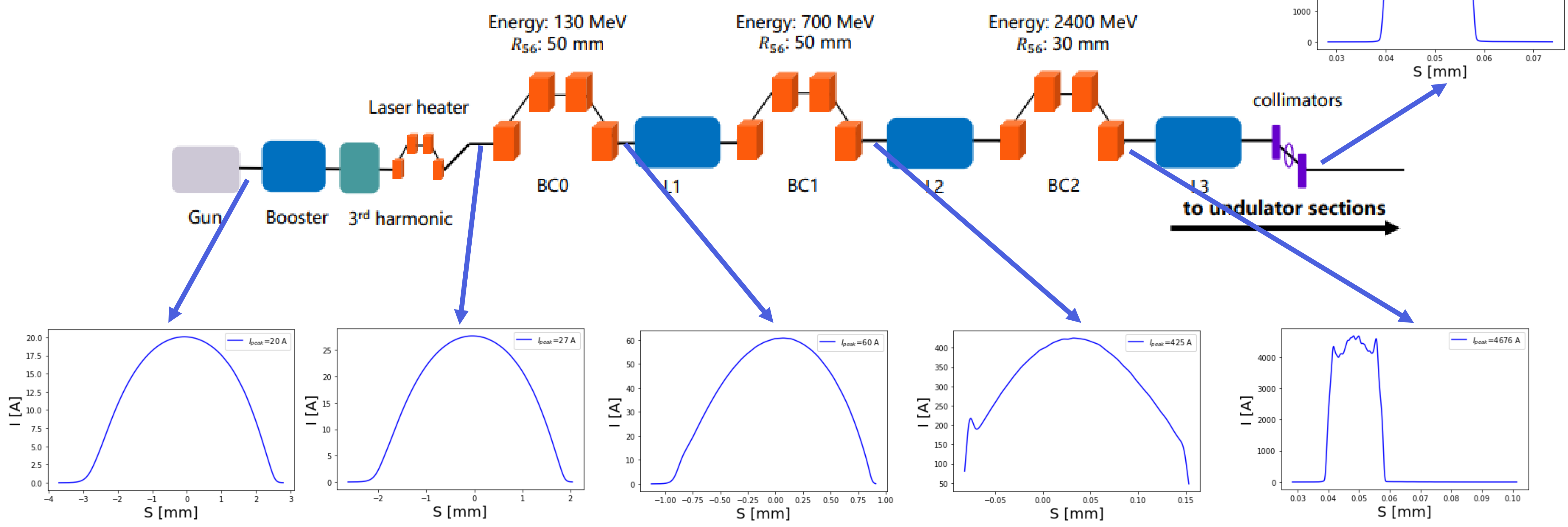


- Track the beam from gun cavity to the collimator section
- Collective effects (CSR, wakefields, space charge) involved
- Tuning knobs: RF settings upstream the compressors

RF parameters	Min_Value	Max_Value
I1_chirp	-9.3	-8.3
I1_curvanture	120	190
I1_skewness	22000	28000
L1_chirp	-10.9	-9.4
L2_chirp	-12.7	-8.5

Compression scenario at EuXFEL





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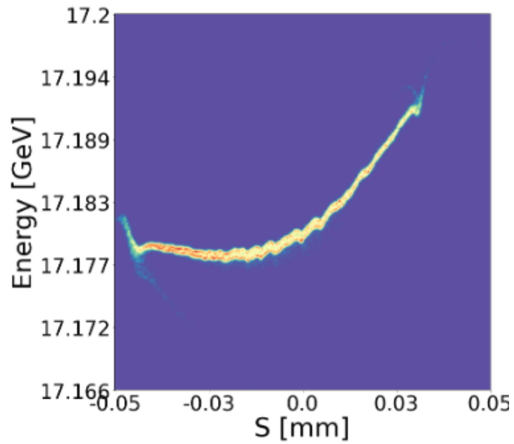
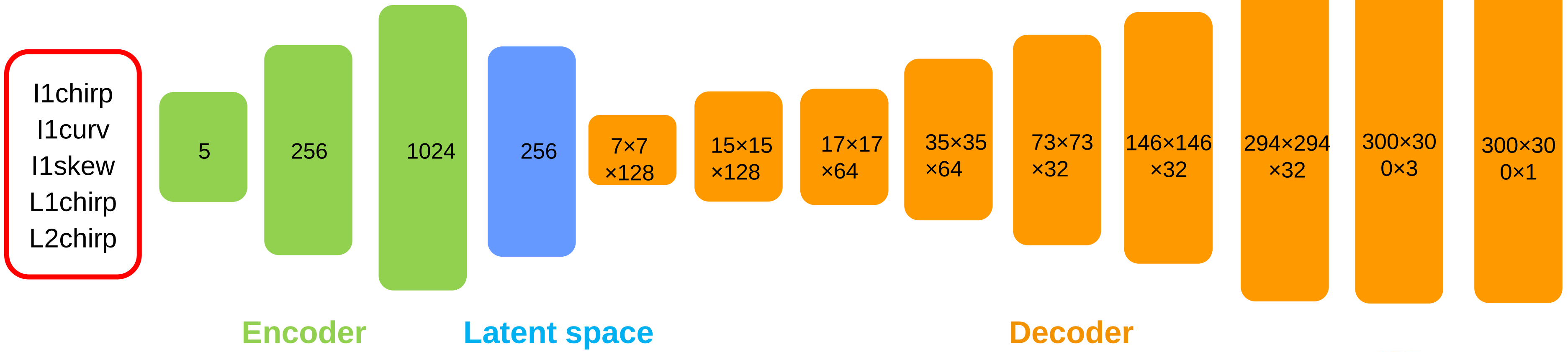
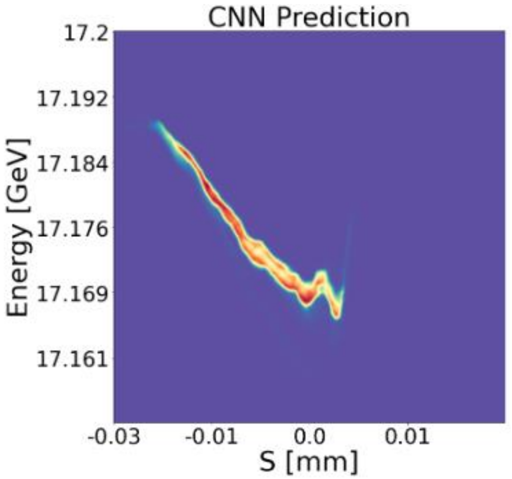
Prediction of LPS distribution based on Image

- Predict it directly based on image processing
  - Image with specific pixel size
  - Resolutions for two axes



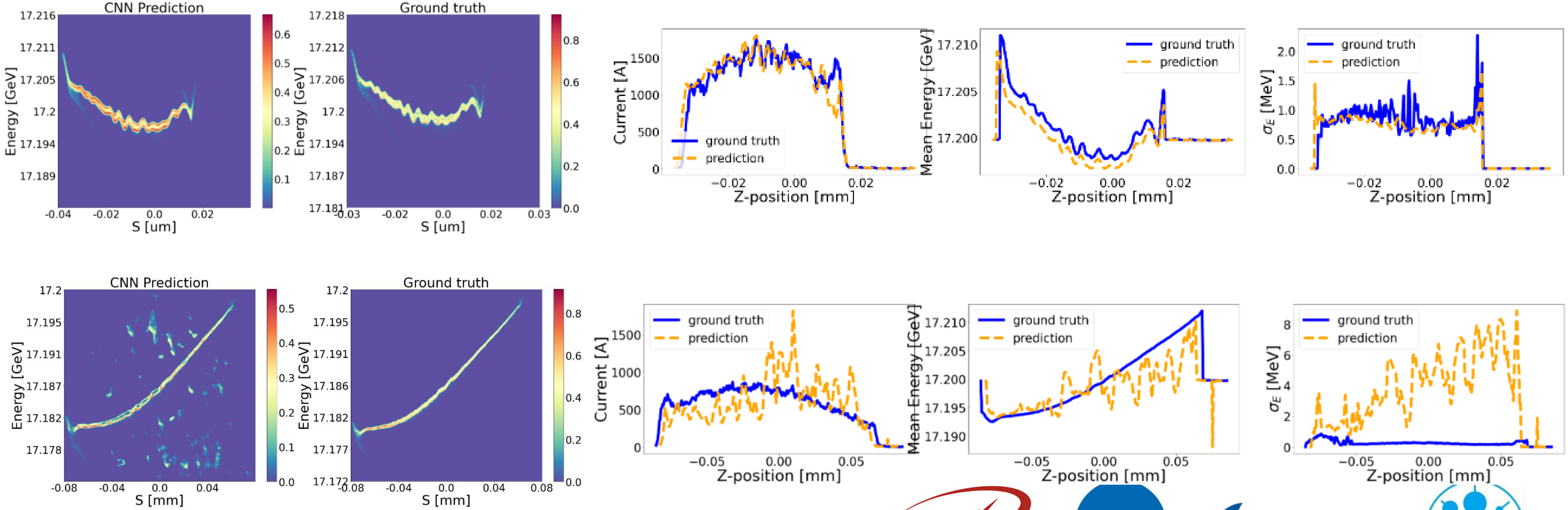
- Convolutional encoder-decoder neural network





Prediction of LPS distribution based on Image

- Beam slice parameters can be evaluated based on the reconstructed LPS
  - Detail in the 2D distribution can be predicted
  - Noise in the image spoils the slice analysis



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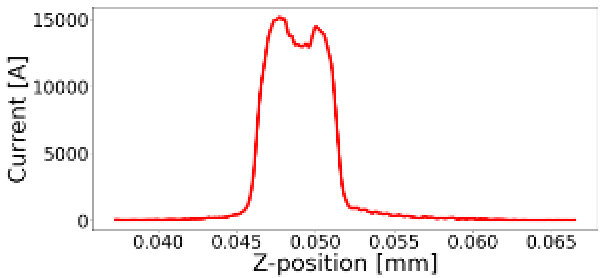
Prediction of LPS distribution based on slice beam parameters

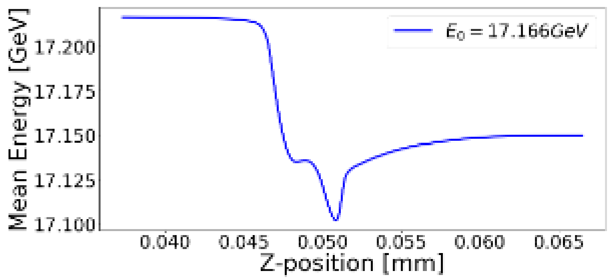
Machine parameters → Neural network → Beam properties

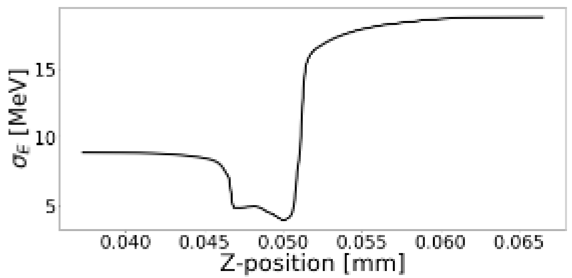
- RF settings upstream each compressors

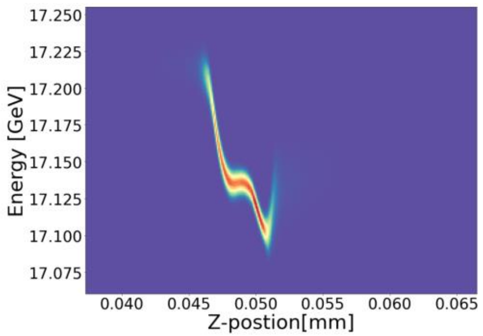
- Slice mean energy
- Slice energy spread
- Current profile

- Reconstruct it based on slice beam properties distributions
  - Energy distribution (slice mean energy and slice energy spread)
  - Longitudinal position distribution (current profile)



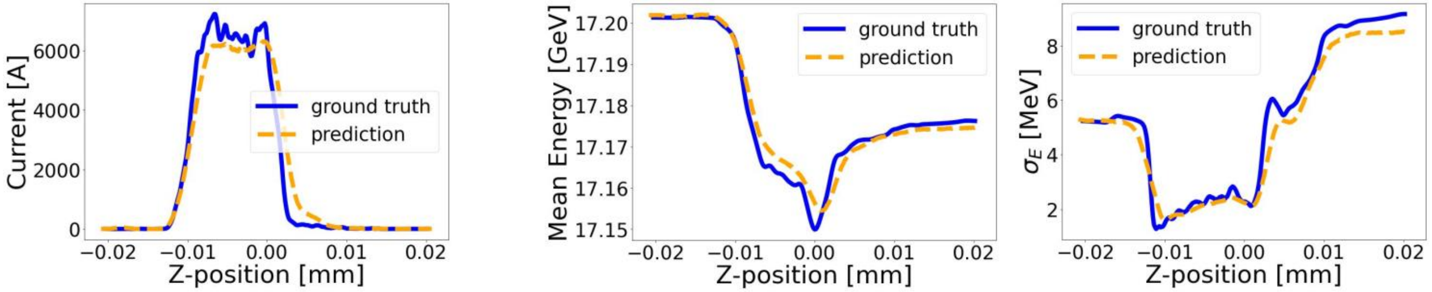


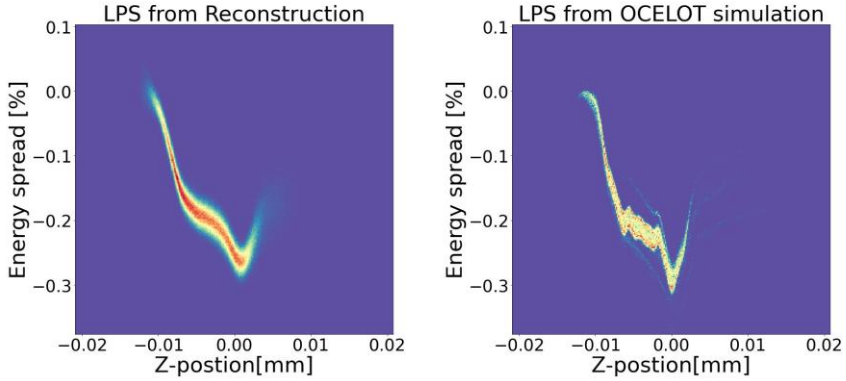




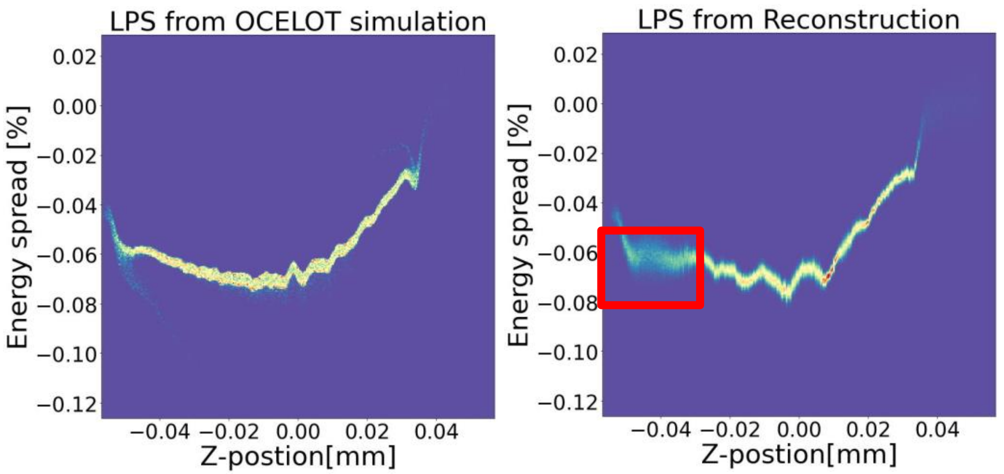
Prediction of LPS distribution based on slice beam parameters

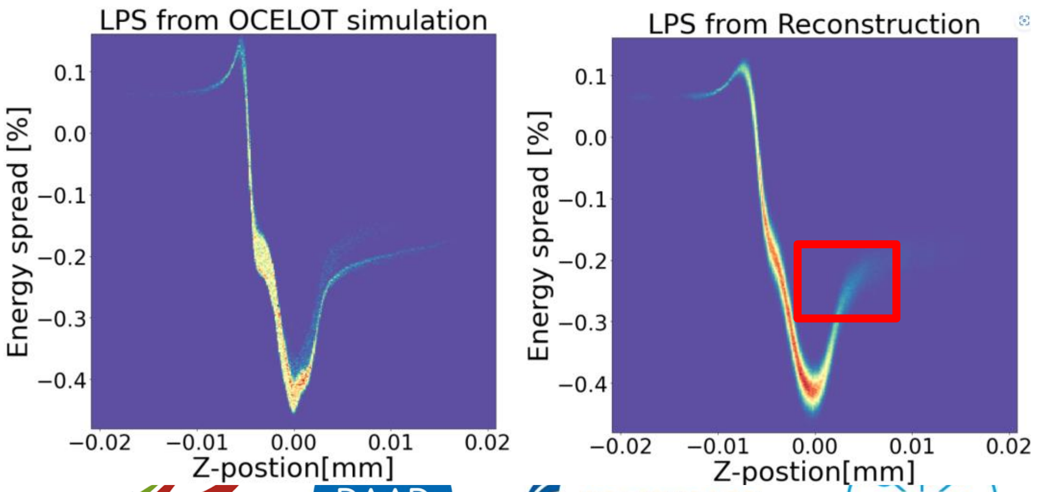
- Explicit prediction of slice beam properties:





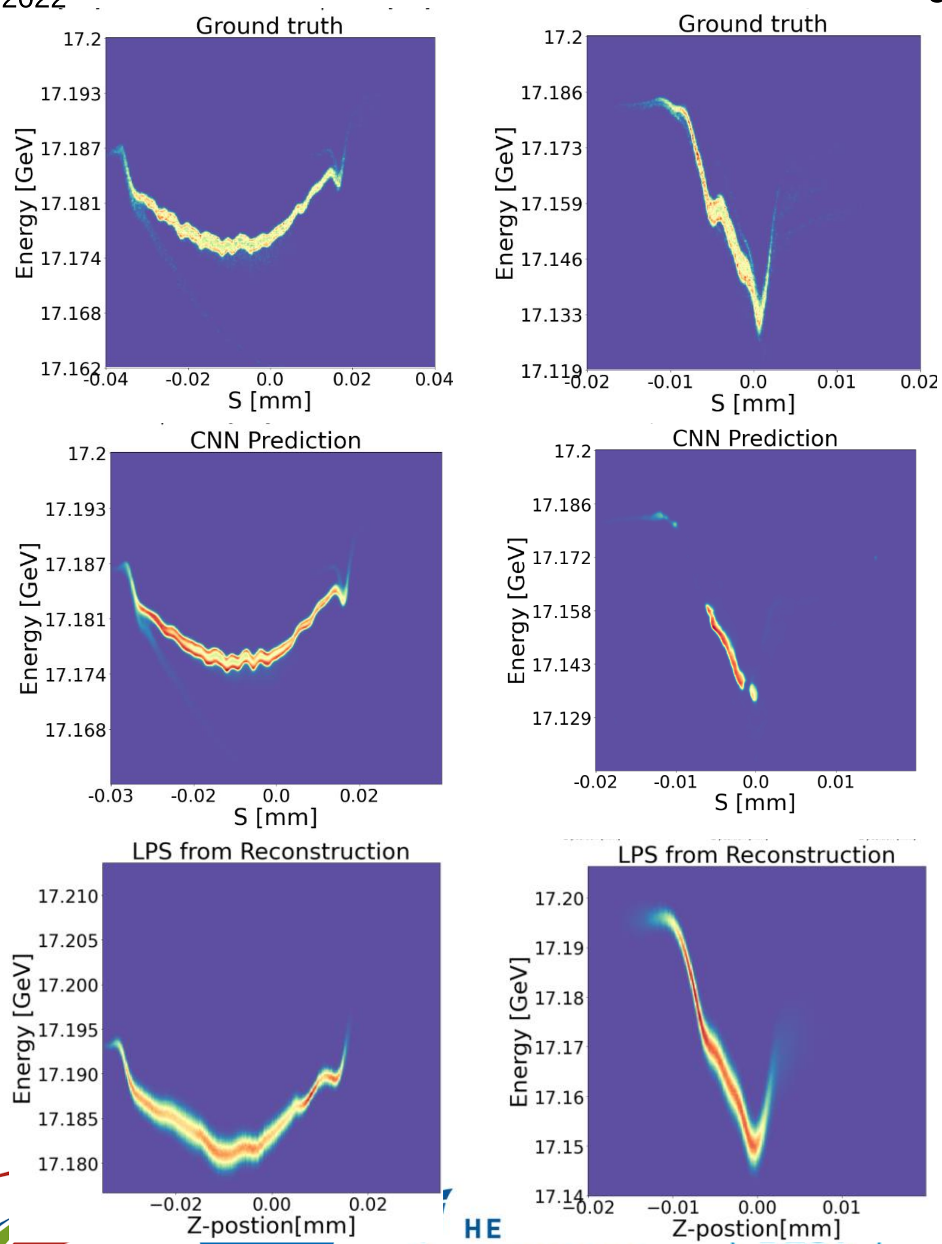
- Information lost during LPS distribution reconstruction



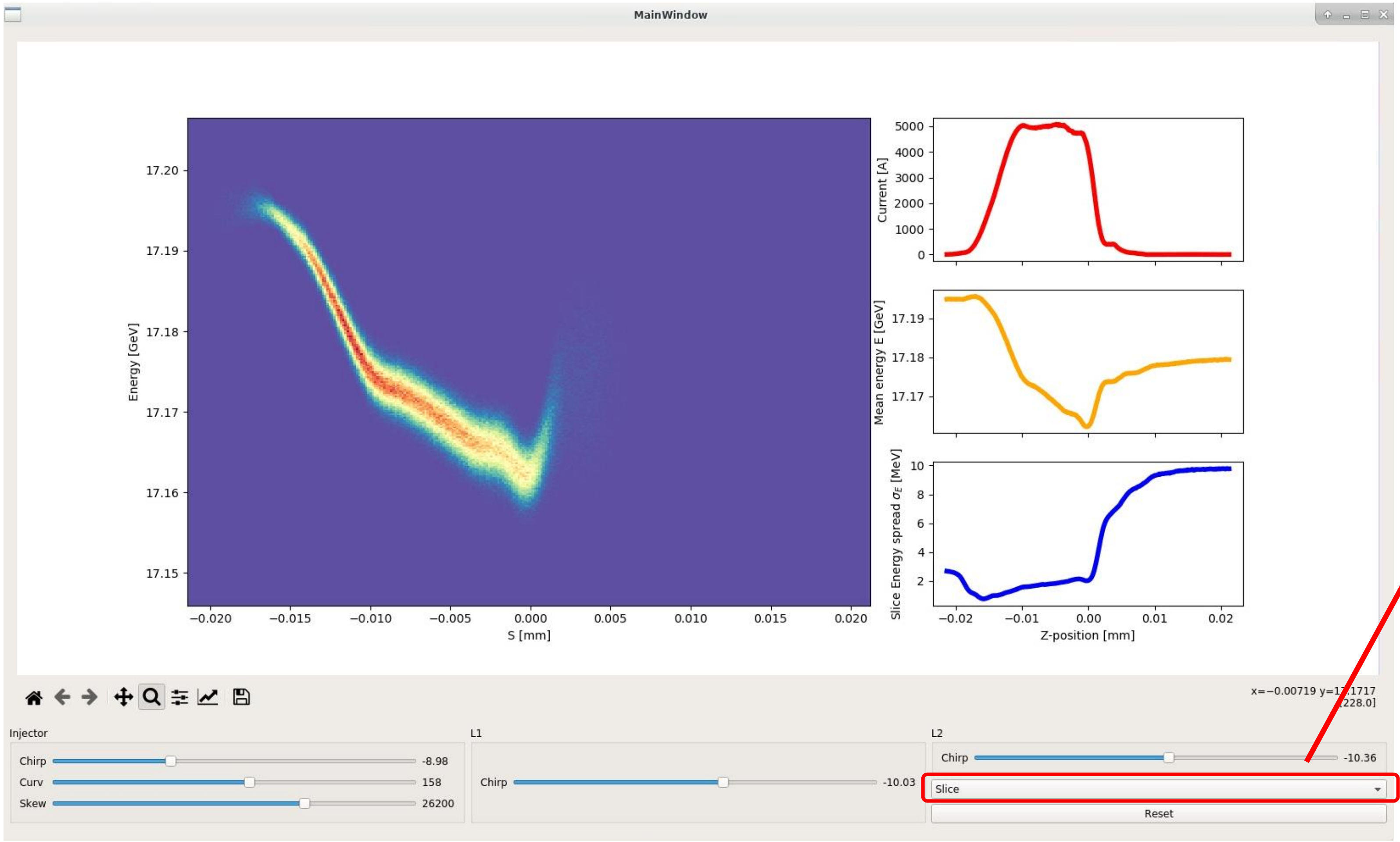


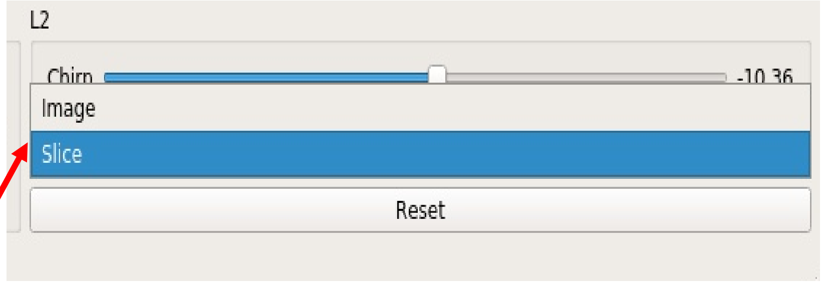
Comparison of the two approaches

Properties	Image-based	Slice-based
Structural complexity	High	Low
Computational expense	High	Low
Training duration	8 hours	5 minutes
microstructure accuracy in 2D distribution	High	Low
Slice beam distribution accuracy	Low	High



LPS estimator GUI development





Summary

- Achievements
  - Demonstrate the **accuracy and feasibility** of neural networks for surrogate model construction
  - Two approaches have been developed to provide LPS prediction
  - GUI is developed for interacting with the model

- Outlook
  - Further applications: beam dynamics optimizaiton, new beam configuration design, etc
  - More functions to be integrated: data generator, training model, physical simulation, etc
  - Model performance test in the BKR