Beam Condition Forecasting with Non-destructive Measurements at FACET-II

Dr. Matthew Kilpatrick

Paul Moeller (RadiaSoft),

Robbie Watt, Brendan O'Shea (SLAC)

kilpatrick@radiasoft.net

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AI4EIC Workshop

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J. P. Edelen, D. T. Abell, D. L. Bruhwiler, S. J. Coleman, N. M. Cook, A. Diaw, J. Einstein-Curtis, C. C. Hall, M. Kilpatrick, B. Nash, I. V. Pogorelov, RadiaSoft LLC, Boulder, CO, USA
K. A. Brown, Brookhaven National Laboratory, Upton, NY, USA
C. Tennant, Thomas Jefferson National Laboratory, Newport News, VA, USA
P. Piot, Northern Illinois University, DeKalb, IL, USA
S. Calder, C. Hoffmann, Oak Ridge National Laboratory, Oak Ridge, TN, USA
A. L. Edelen, B. O'Shea, R. Roussel, SLAC, Menlo ParkCA, USA
E.-C. Huang, Los Alamos National Laboratory, Los Alamos, NM, USA

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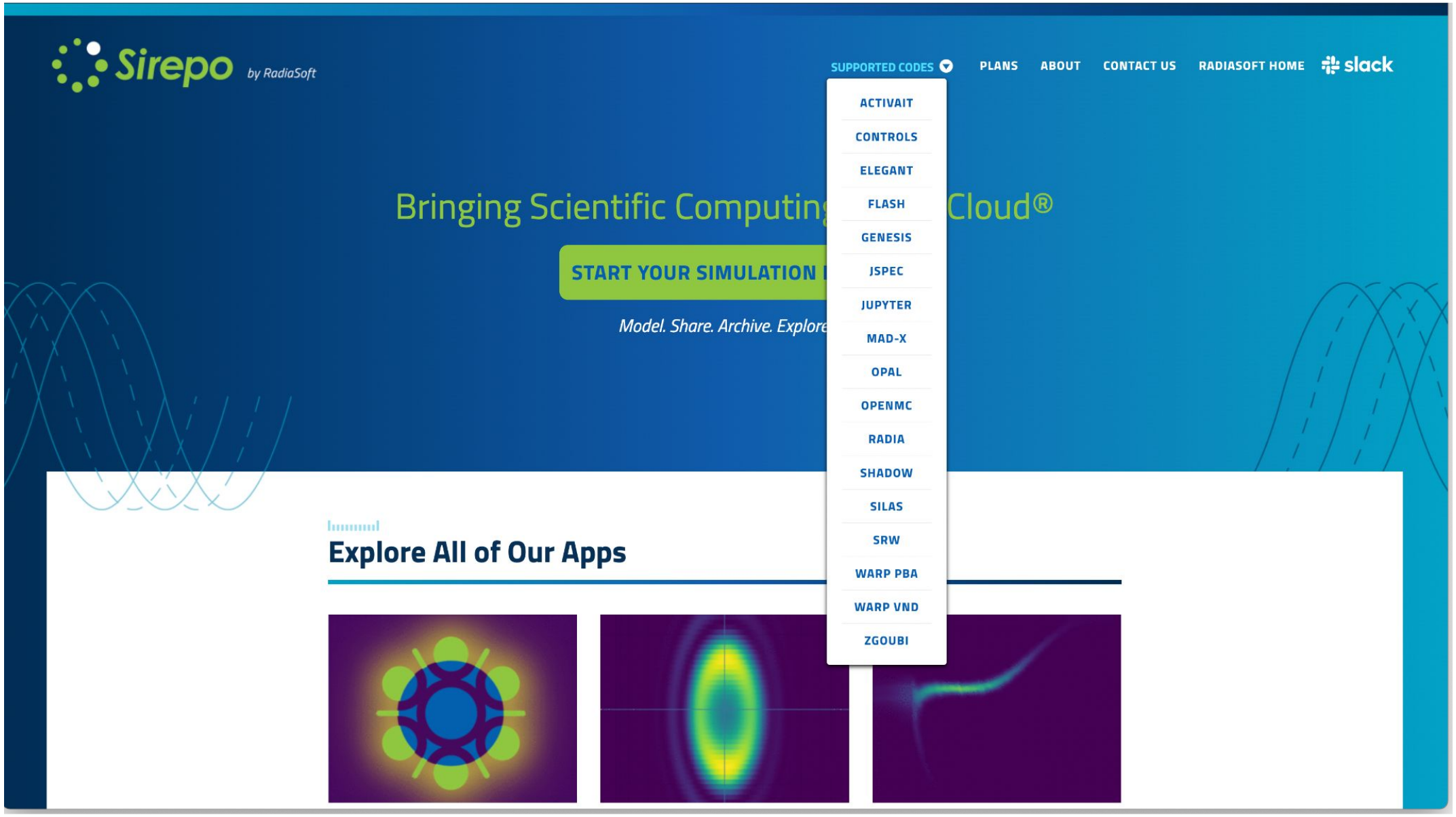


Project Technical Objectives

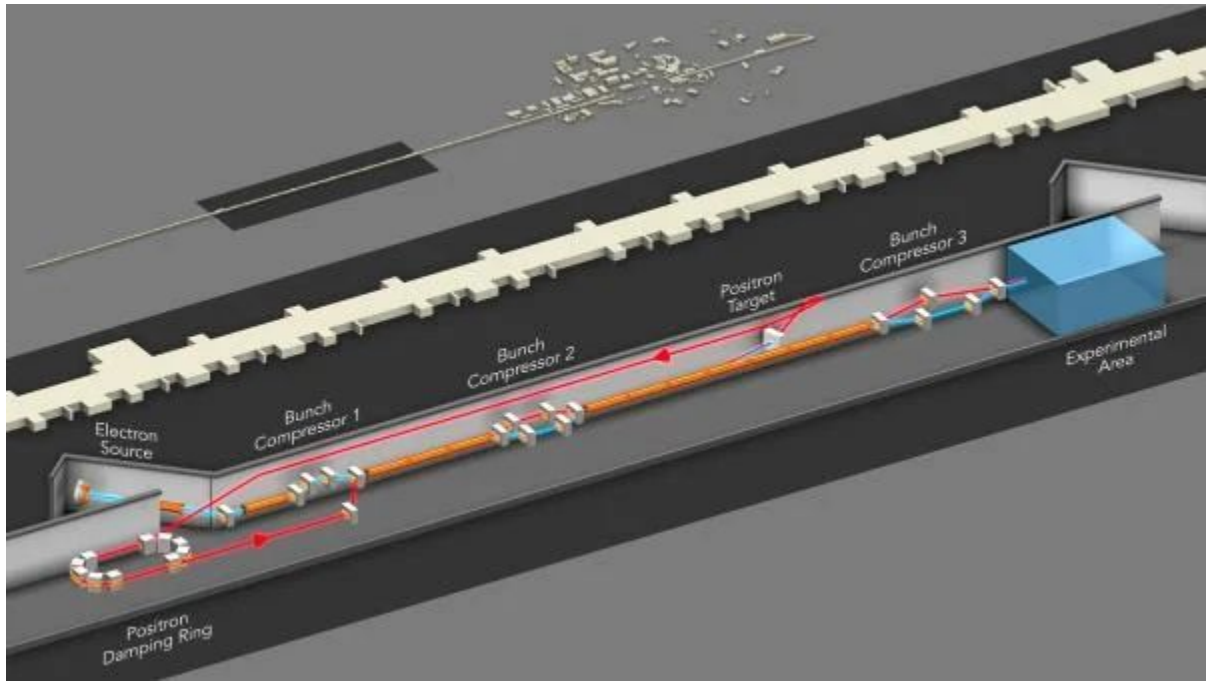
- This work has been funded as part of the DOE SBIR program with a Phase I award

- Develop models to predict downstream beam state given edge radiation measurements and future machine state given current machine state.
  - Design a novel Graph Neural Network (GNN) architecture that can predict edge radiation
  - We hope to be able to predict the downstream and future state of the machine
  - Encode edge radiation physics within the neural network

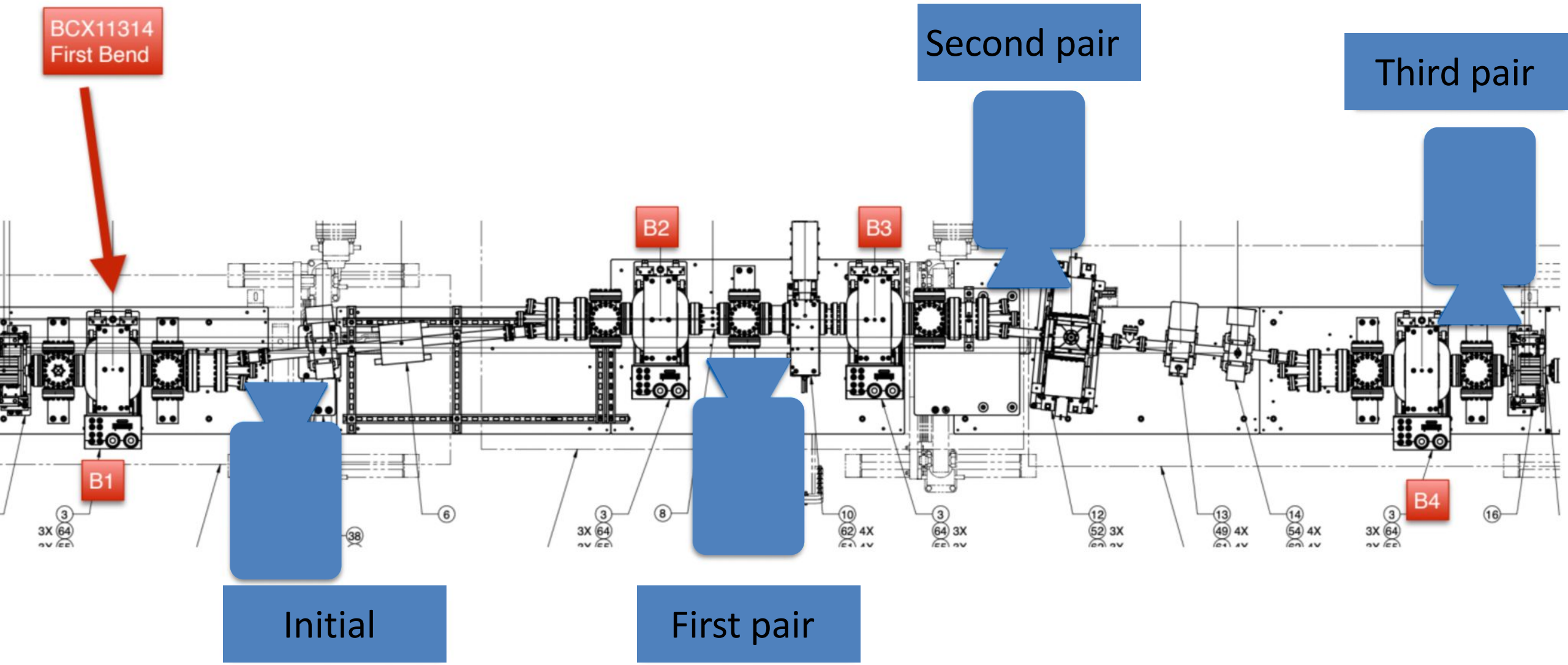
- Develop a framework to generate new machine states for use in beamline modeling.
  - Online framework to generate new machine states and simulate the edge radiation
  - In-browser execution and evaluation of model predictions

Measurements at FACET-II

- Test facility with user access
  - Provides high energy electron beam to samples at the end of the beamline
  - Beam diagnostic techniques using both destructive and non-destructive methods
  - Significant efforts made to improve non-destructive measurement techniques
- Benefits to non-destructive measurements
  - Destructive measurements cause chaotic perturbations to beam parameters
  - Many accelerator facilities utilize both measurement types
  - FACET-II upgraded cameras in mid-2023
  - Cameras measure non destructive edge radiation
- Edge radiation
  - Charged particle emits radiation due to far-field magnetic field effects
  - Depends on a variety of factors such as magnetic bending length



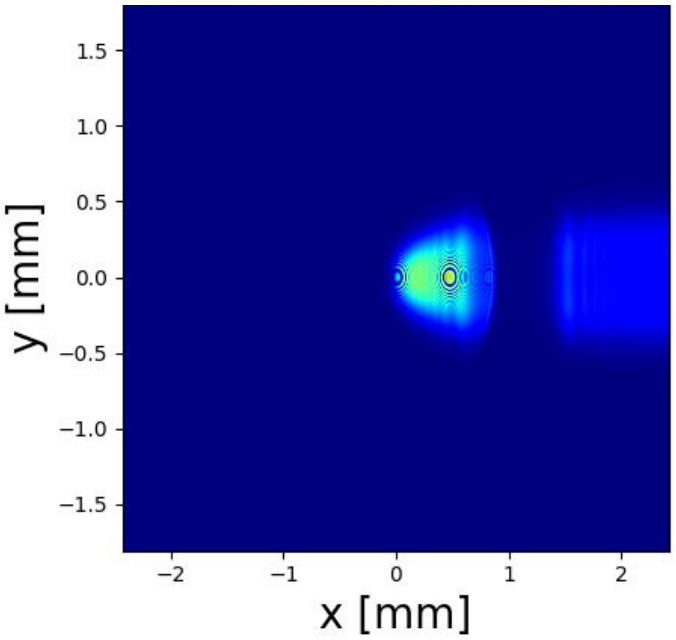
Beamline Setup



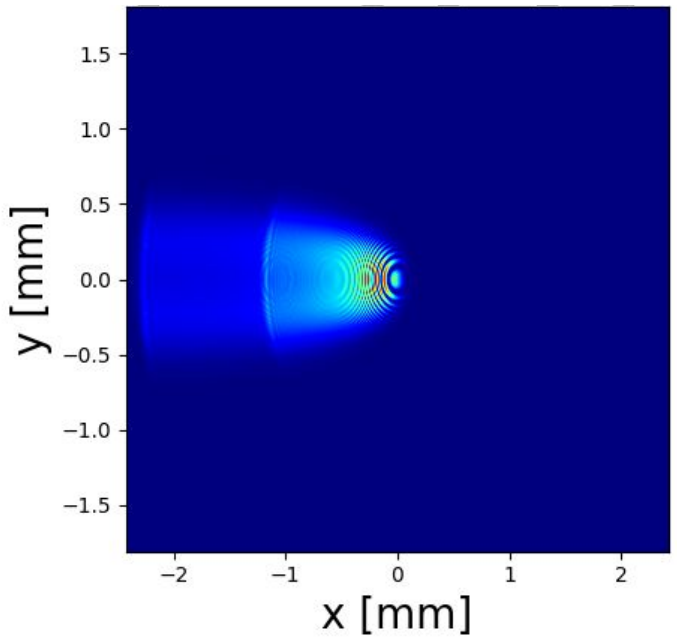
Beam Measurement Design

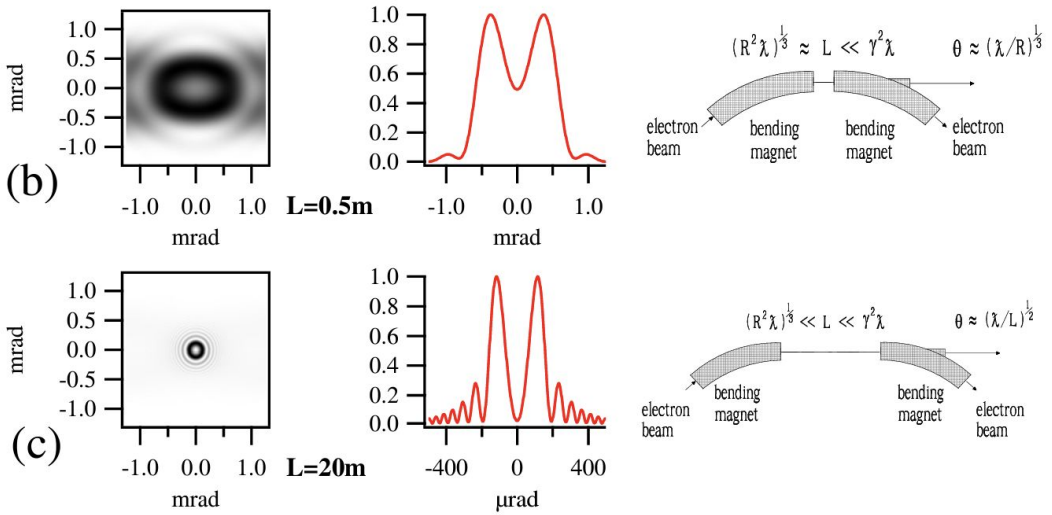
- Three pairs of bending magnets
  - Electron beam travels through chicane for beam quantification
  - Each pair of magnet edges provide constructive/deconstructive interference for measurement

First pair



Second pair

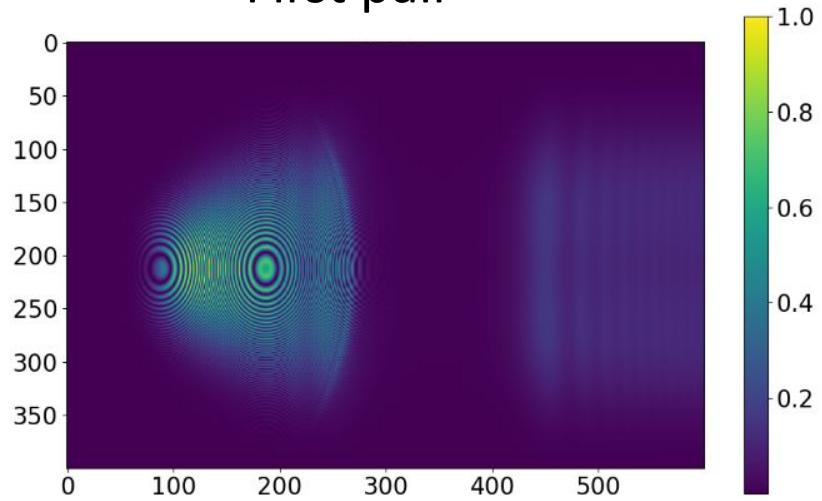




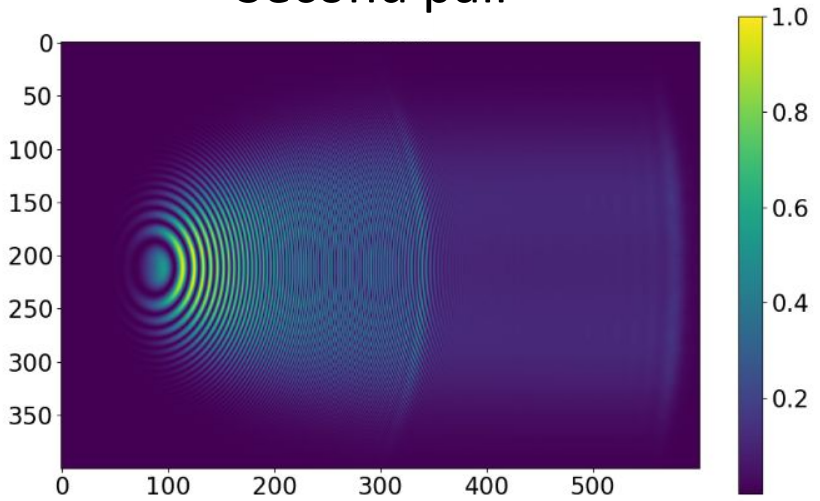
Simulating Edge Radiation

- SRW simulation for each magnet pair
  - Robust simulation of the frequency range
  - Parameter scanning to many datasets
  - Noise can be added to simulation to replicate real data
  - Inputs are any upstream measurement and output is any downstream measurement
- Real data…
  - Initial data has been taken
  - Current methods are being developed with simulation

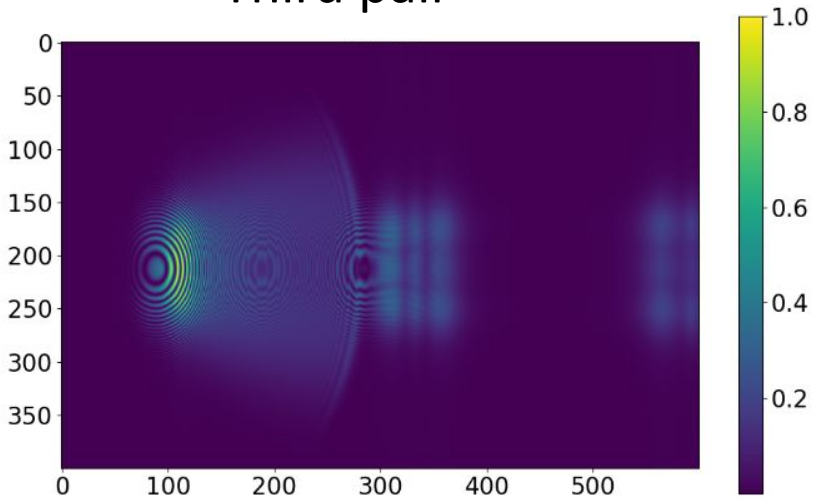
First pair



Second pair

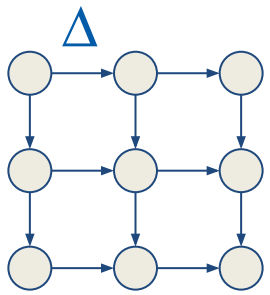


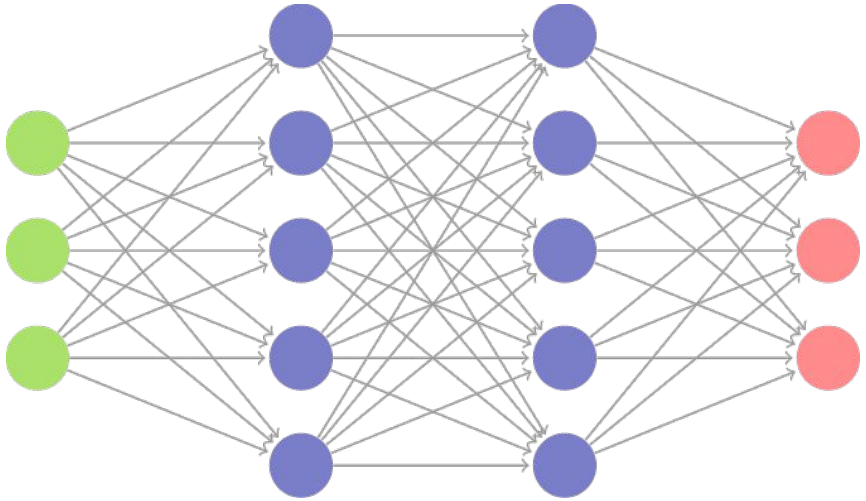
Third pair



Building the Model

- Graph representation
  - Each pixel is represented as a node
  - Intensities are used as node features
  - Pixel gradients are edge weights
  - Image sizes are 1024 by 1024
- Feedforward GNN
  - First bending image is fed through to then reconstruct second bending image
  - Can be any pair of images as long as the latter is downstream





$$X^{(l+1)} = AX^{(l)}W^{(l)}$$

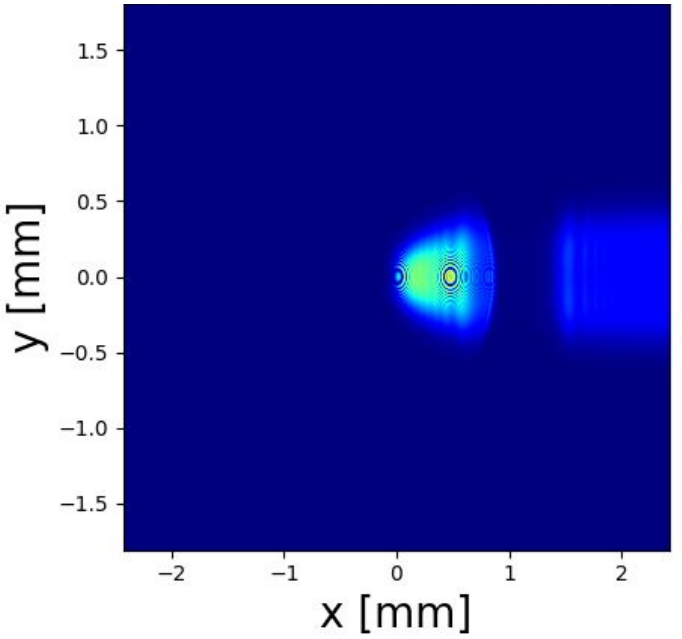
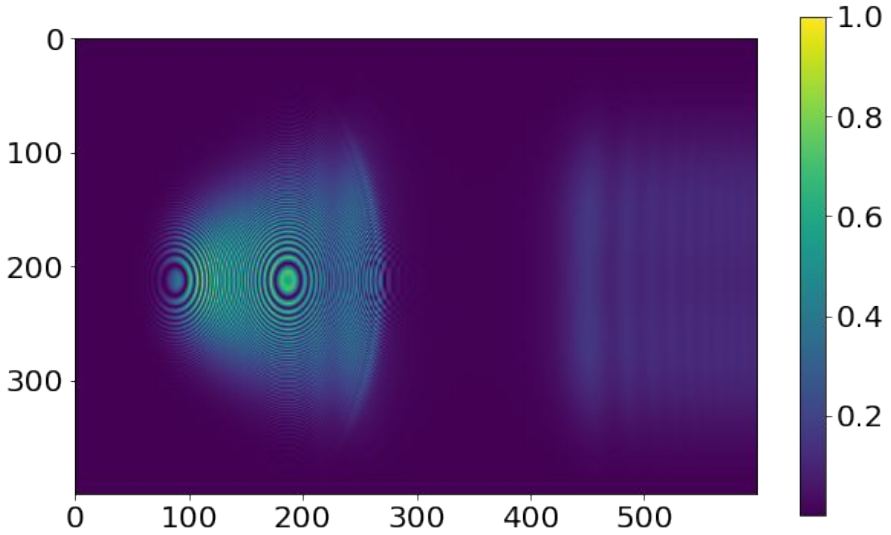
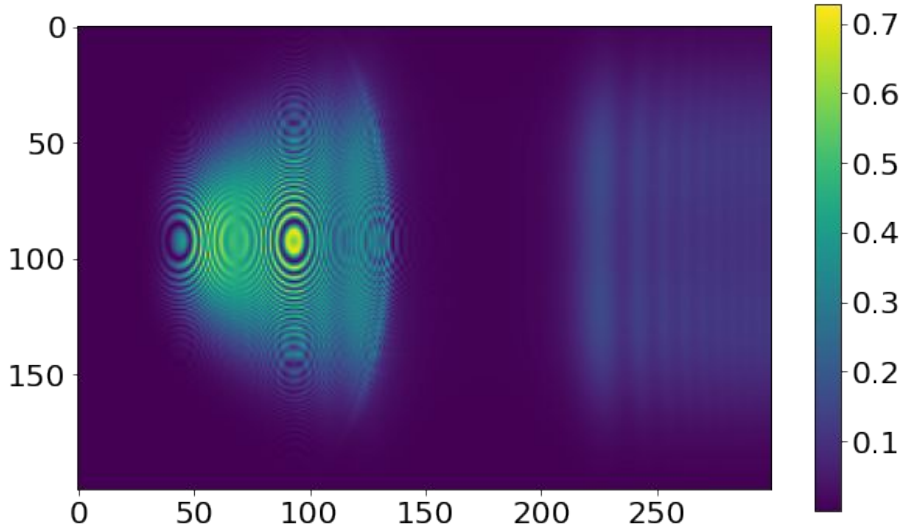
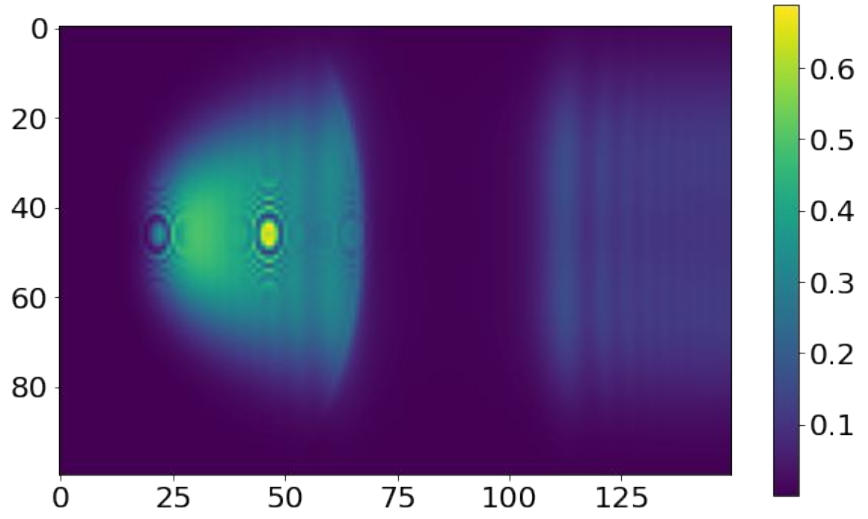
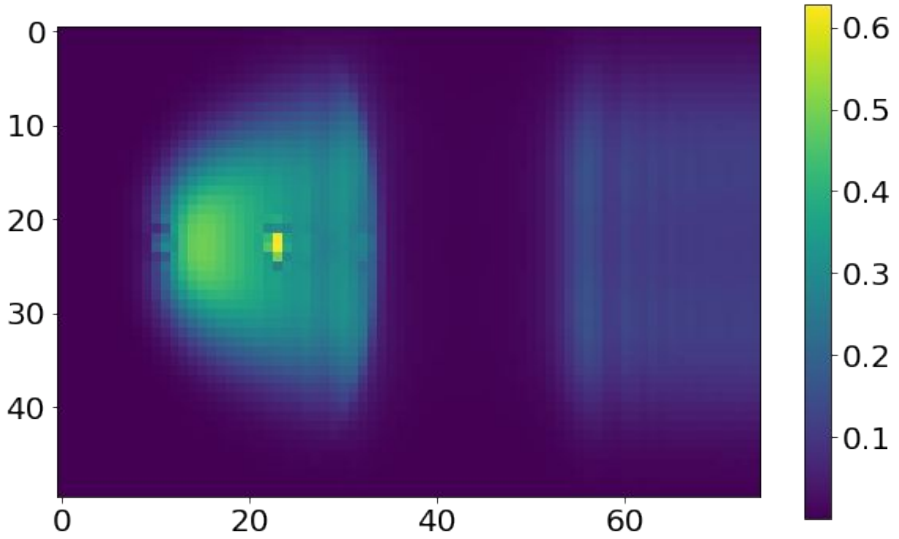


Image Resampling



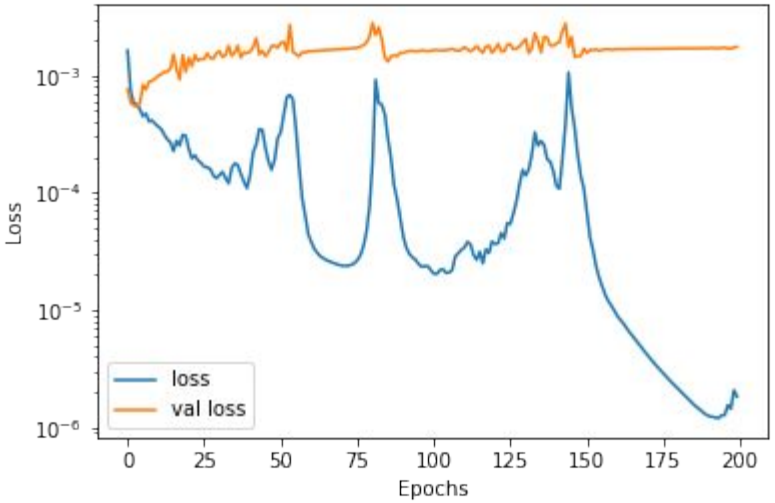




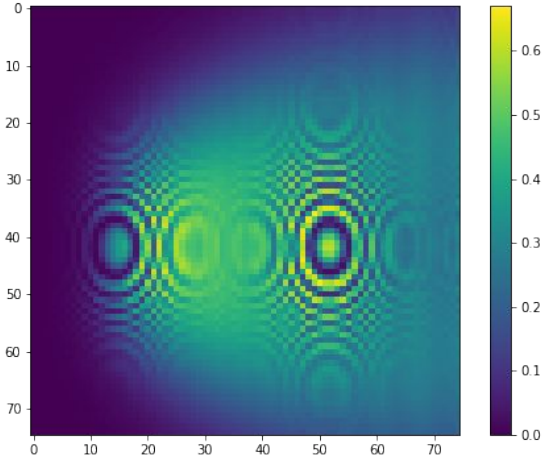


Training and Reconstruction

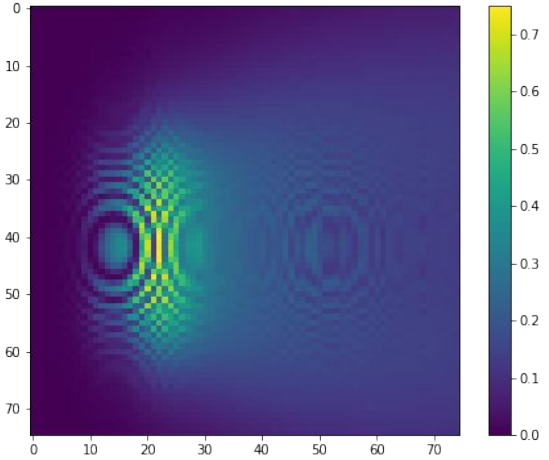
- Simple feed forward
  - Model is able to accurately reconstruct downstream radiation
  - Simple methods provide an overfitted model
  - Provides stepping stone to more complex methods
- Reconstruction on unseen test data
  - Accurately shows topology
  - Biased intensity reconstruction



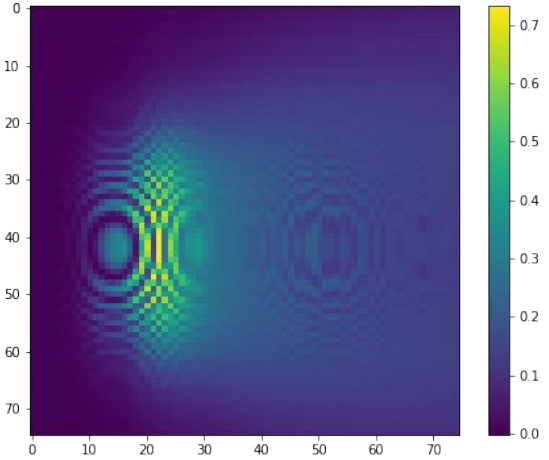
Input



Ground truth



Predicted



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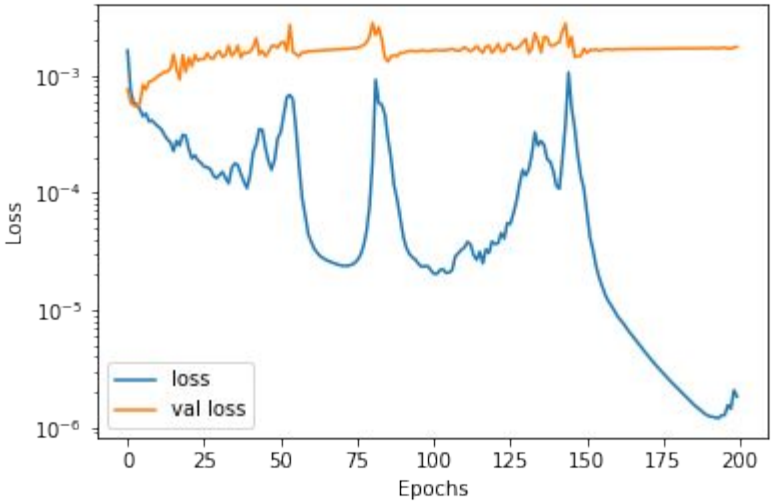

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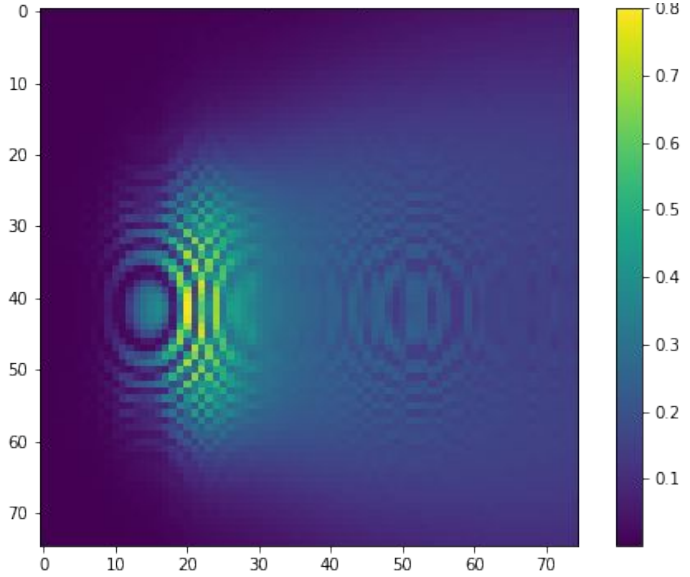

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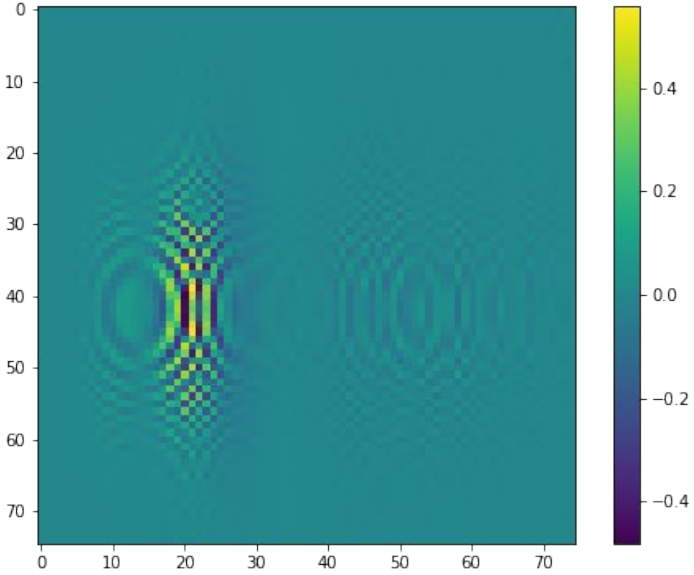
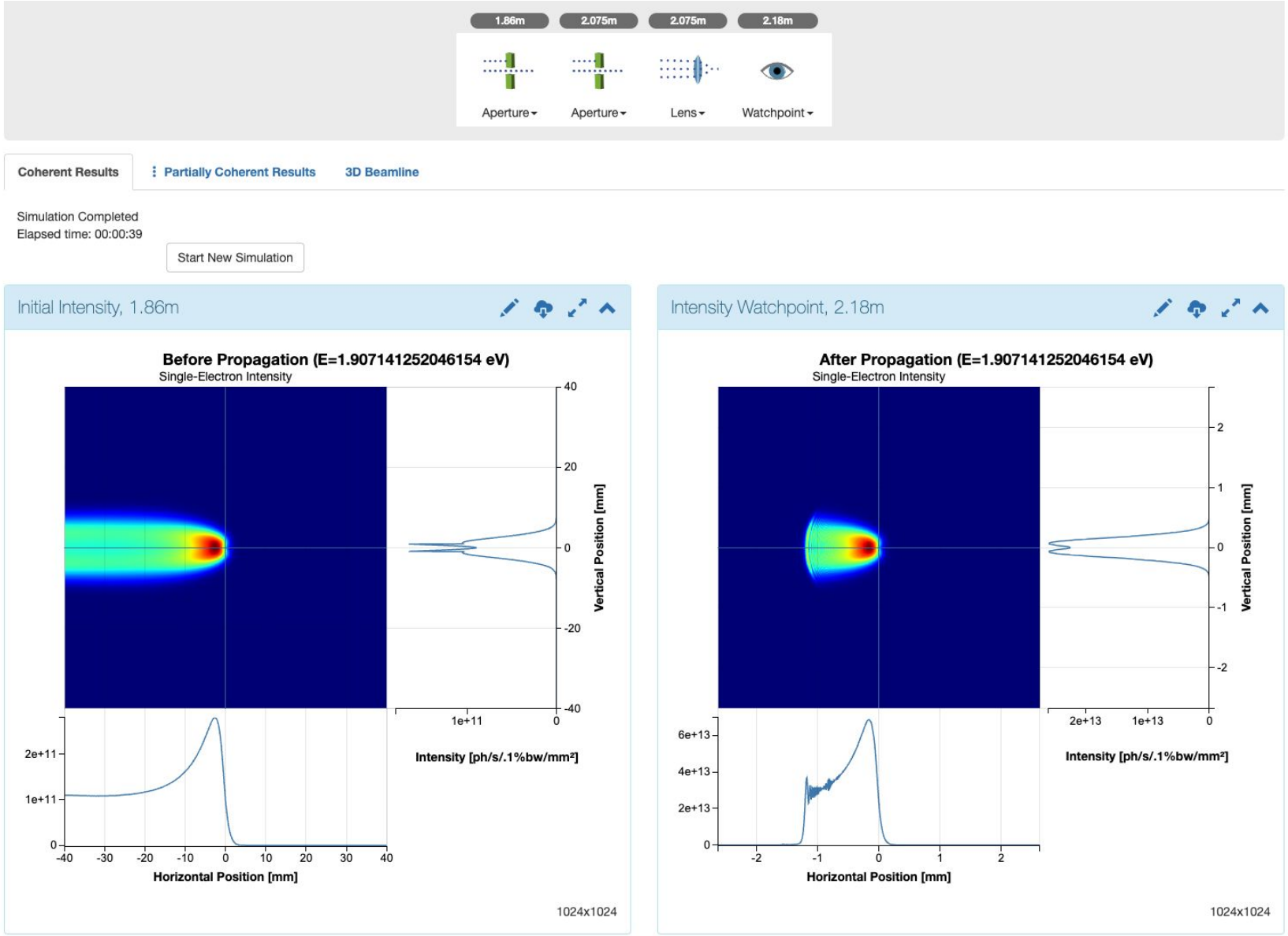


In-Browser SRW Simulation

- Online computing
  - Many processing nodes for faster computation time
  - Interactive edge radiation analysis
- Online model
  - Go from data generation to model training and evaluation
  - Monitoring reconstruction in real time



Future Work

- Project undergoing constant development at a SBIR Phase I project
  - Goals are a proof of concept!
  - Once shown we can move to Phase 2!

- Physics integration
  - Proven simple GNN shows accurate reconstruction of downstream dynamics
  - Incorporate beam physics within GNN latent space
  - Integrate within online computing framework

- Surrogate Modeling
  - Generate new possible beam states due to changes within the beamline
  - Investigate potential forecasting capabilities

Thank you!

Acknowledgements

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- SLAC Collaborators: Robbie Watt, Brendan O'Shea

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