A Browser Based Toolkit for Improved Accelerator Controls

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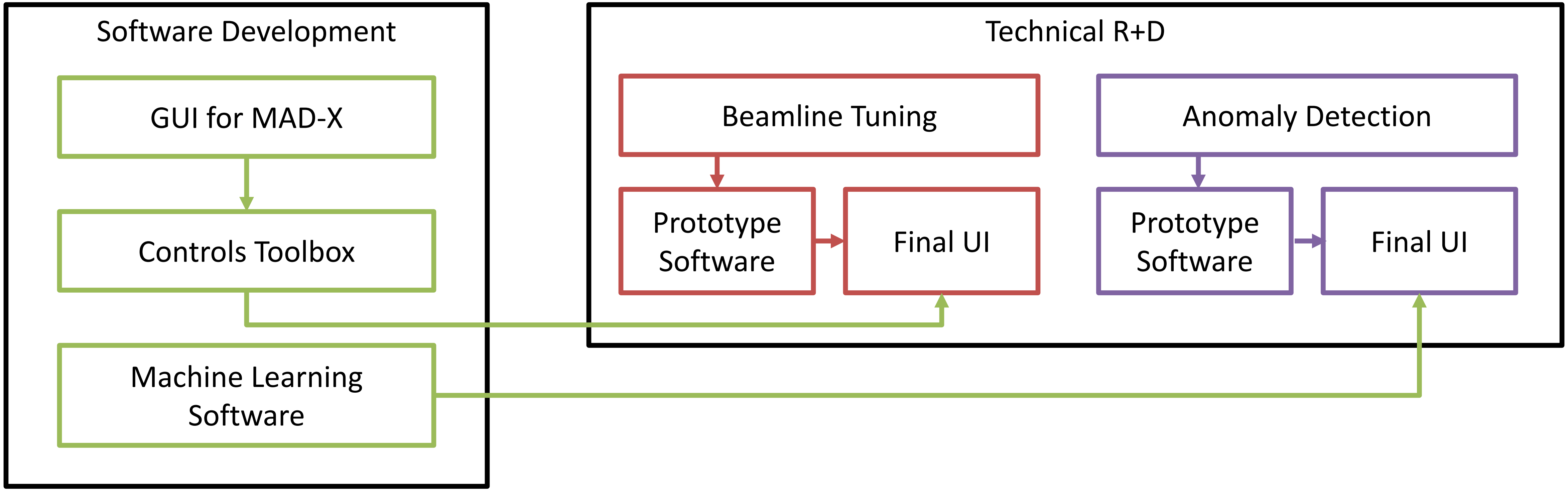
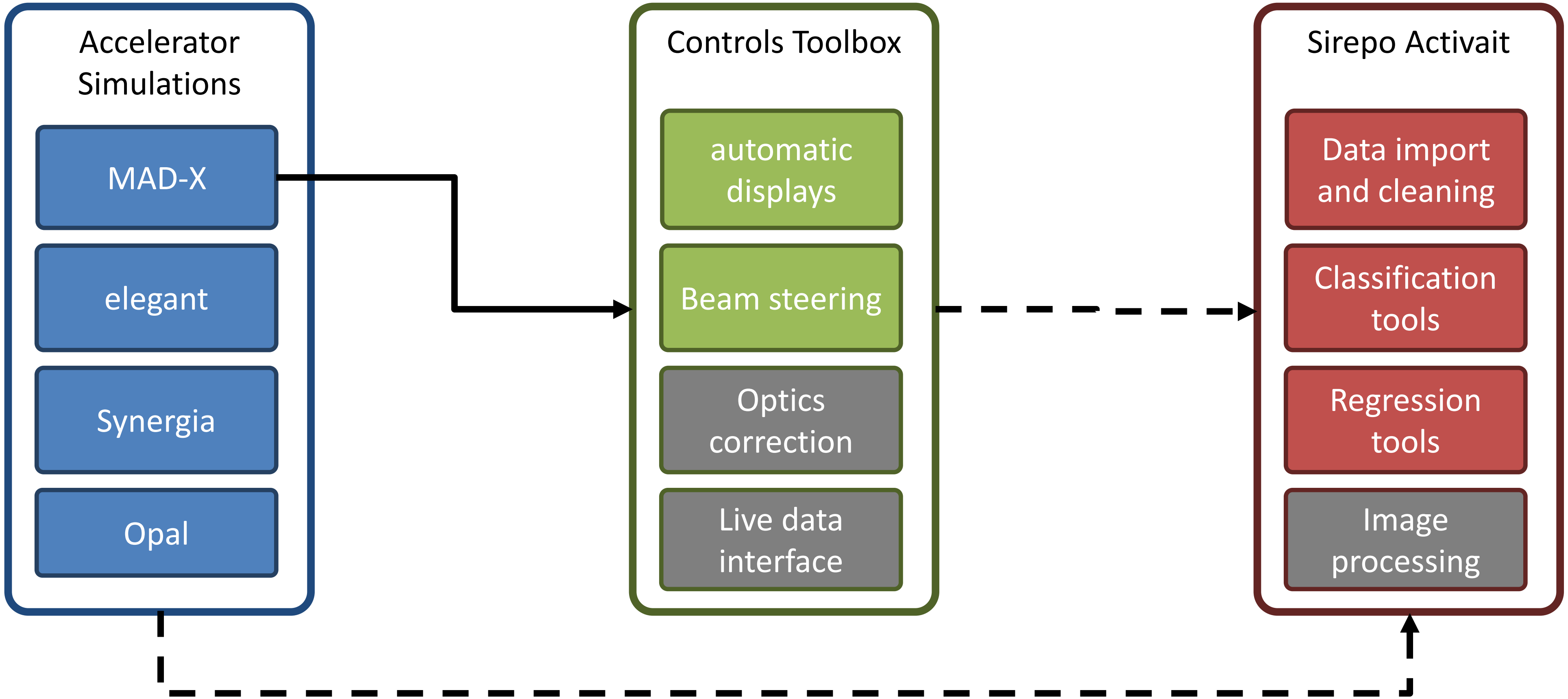
Project objectives

- 1) Demonstrate the deployment of custom control interfaces using our web-based toolbox
- 2) Test rapid reconfiguration of the BNL ATR Line between 5 and 10 GeV/u
- 3) Test a machine-learning based smart-alarm system at the CEBAF polarized electron source



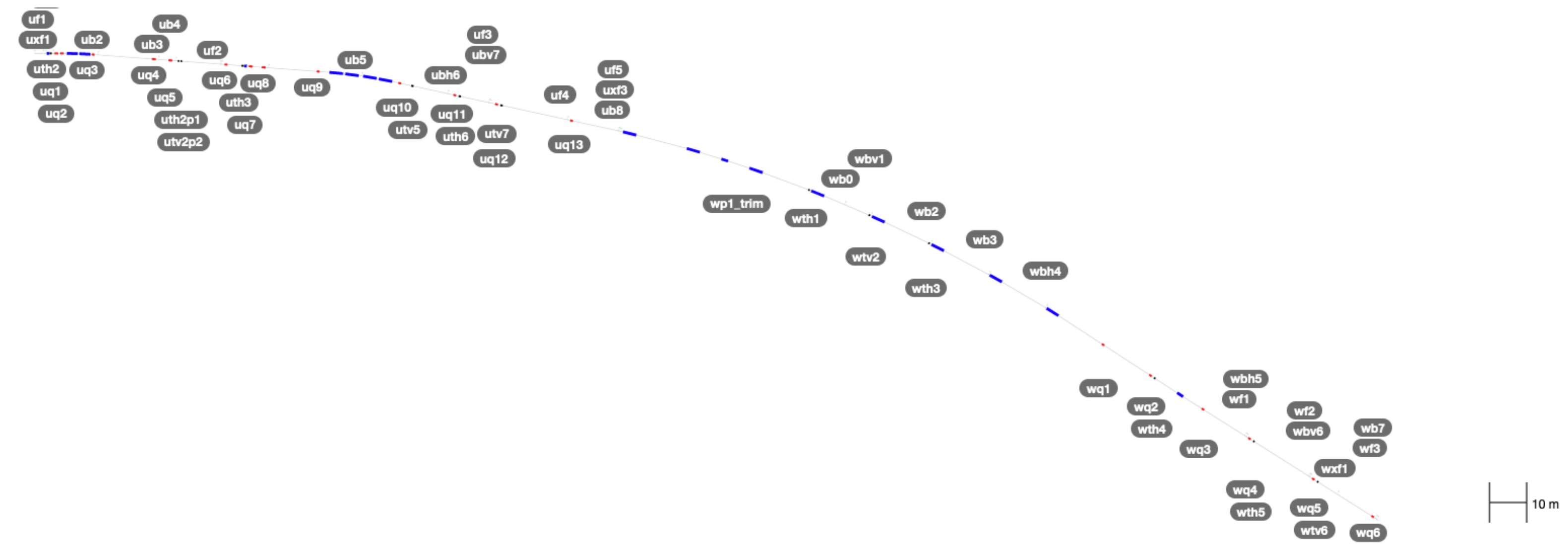
A Browser Based workflow for Accelerator Controls



Automated creation of control room displays

- Build a lattice in MAD-X and use our controls application for optimization
  - Controls display is generated automatically
  - Provides scalar settings and readings
  - Magnet transfer maps can be specified via upload of a CSV file
- Magnet excitation curves used to compute currents
- Beam offset shown in the twiss parameter plot.
  - Online model capabilities are available

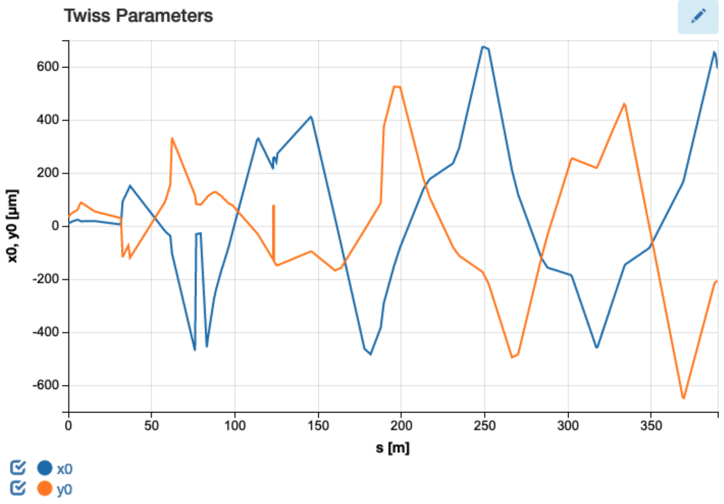
Beamline



Kicker Current [A]		
uth2	0.000000	
uth2p1	0.000000	
utv2p2		0.000000
uth3	0.000000	
utv5		0.000000
uth6	0.000000	
utv7		-0.000000
wp1_trim		0.000000
wth1	0.000000	
wtv2		0.000000
wth3	0.000000	
wth4	0.000000	
wth5	-0.000000	
wtv6		-0.000000

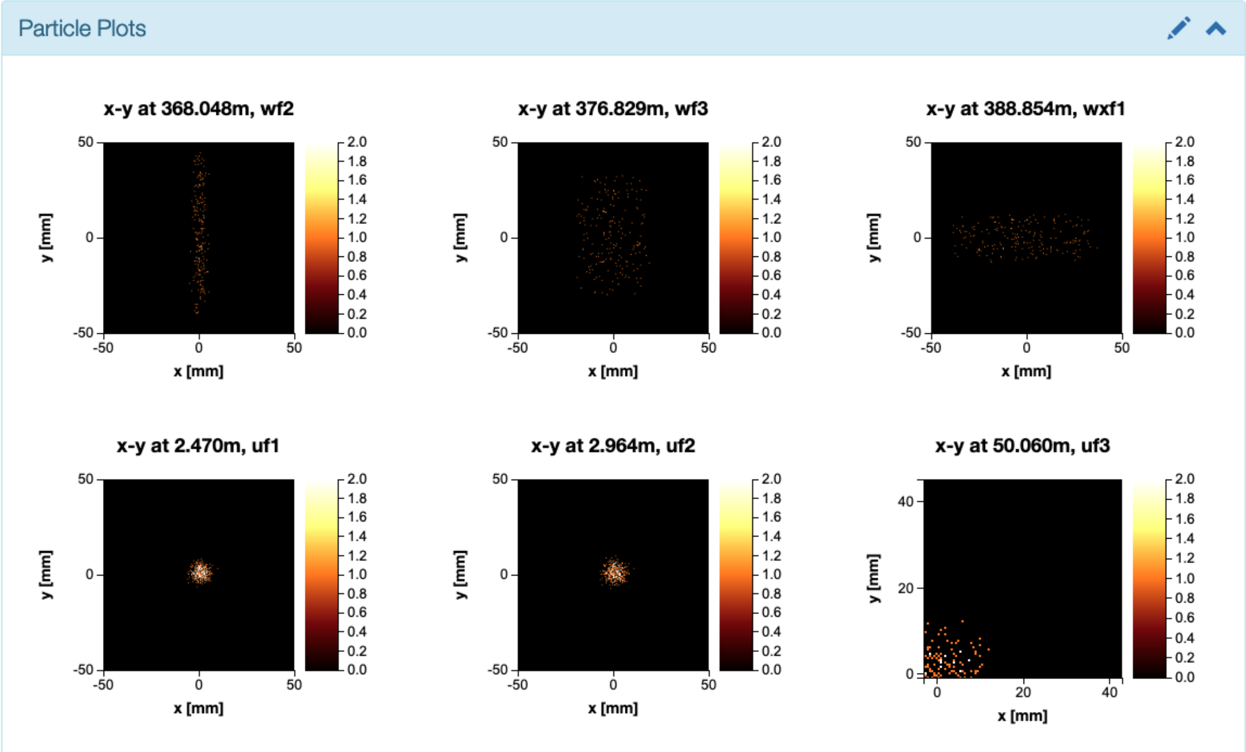
Quadrupole Current [A]	
uq1	0.009615
uq2	-0.009398
uq3	0.002222
uq4	-0.005050
uq5	0.004962
uq6	0.000000
uq7	0.004068
uq8	-0.005547
uq9	0.003419
uq10	-0.002595
uq11	0.004954
uq12	-0.004015
uq13	0.003664
wq1	-0.003990
wq2	0.003687
wq3	-0.004475
wq4	0.004107
wq5	-0.003832
wq6	0.004516

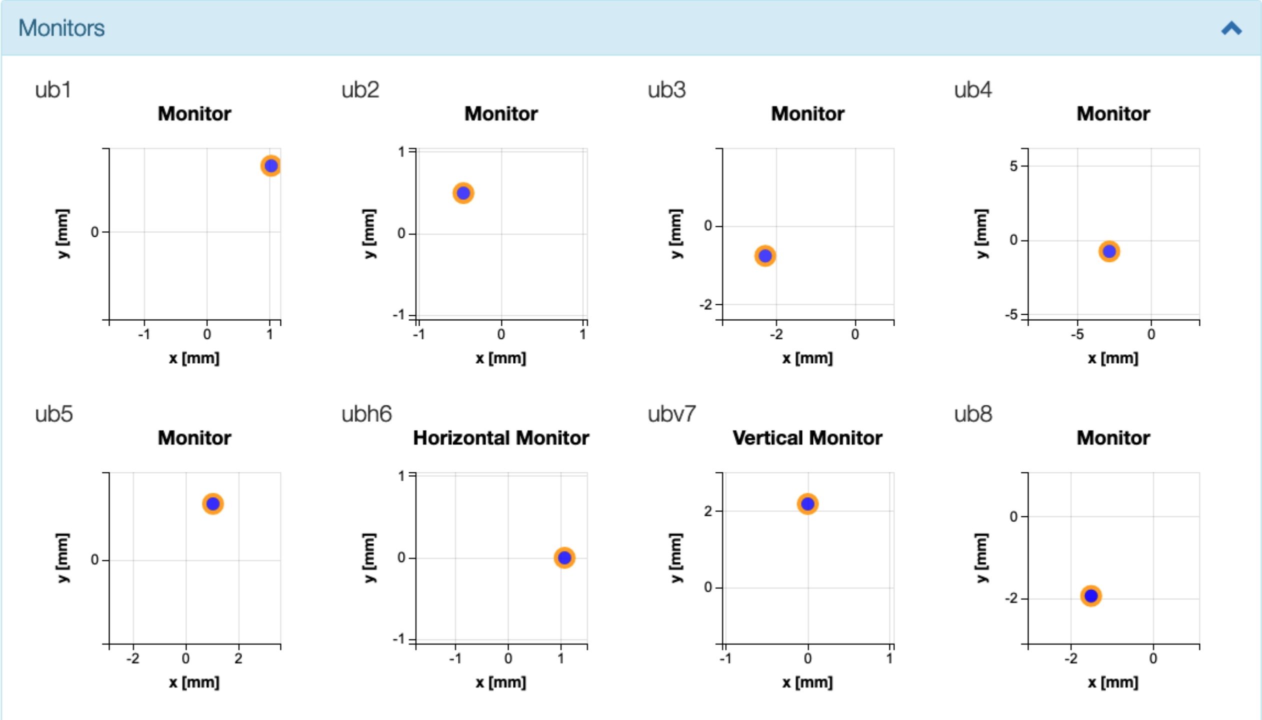
Monitor [m]		
ub1	0.000022	0.000058
ub2	0.000017	0.000053
ub3	0.000101	-0.000108
ub4	0.000143	-0.000110
ub5	-0.000254	0.000128
ubh6	0.000289	
ubv7		0.000075
ub8	0.000067	-0.000161
wb0	0.000202	0.000027
wbv1		-0.000074
wb2	0.000664	-0.000171
wb3	0.000224	-0.000487
wbh4	-0.000114	
wbh5	-0.000087	
wbv6		-0.000606
wb7	0.000614	-0.000209



Diagnostic displays

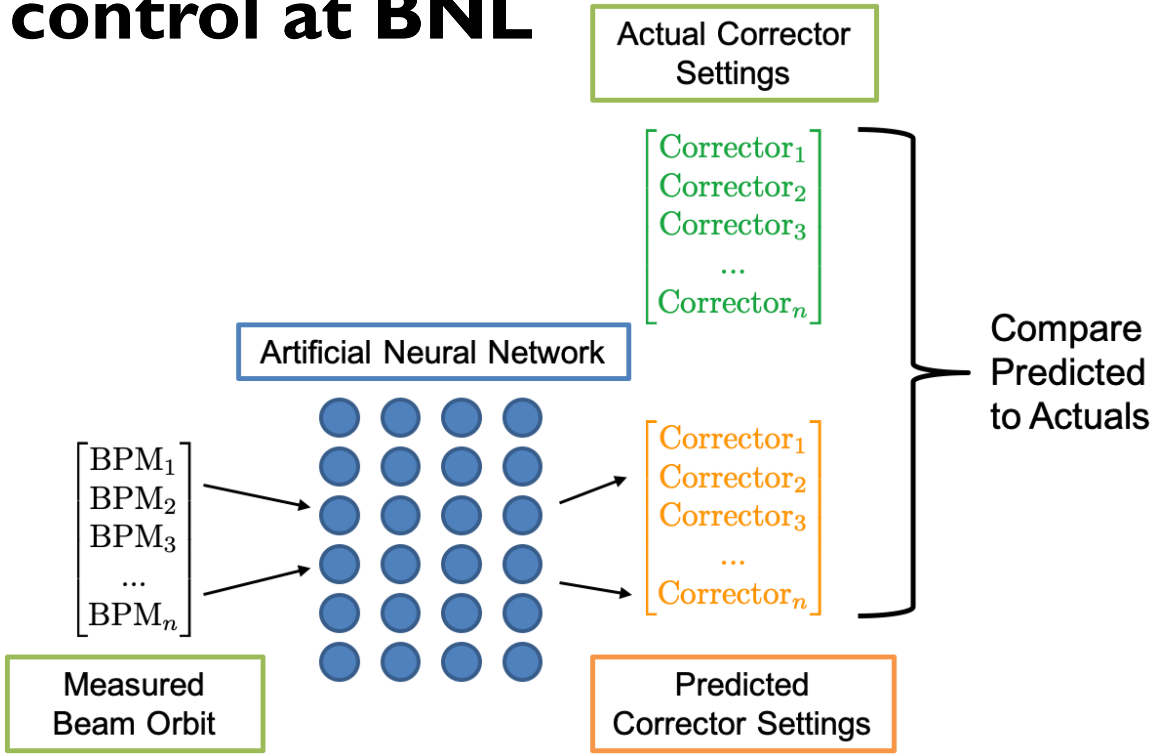
- Diagnostic displays show the output from BPMs and from screens.
- Screens update live as the simulation is running or if it is getting data from the control system
- We have tested our ability to pull data from the control system and make settings from the browser
- Optimization setup can be used to optimize on a simulation or on data from the machine

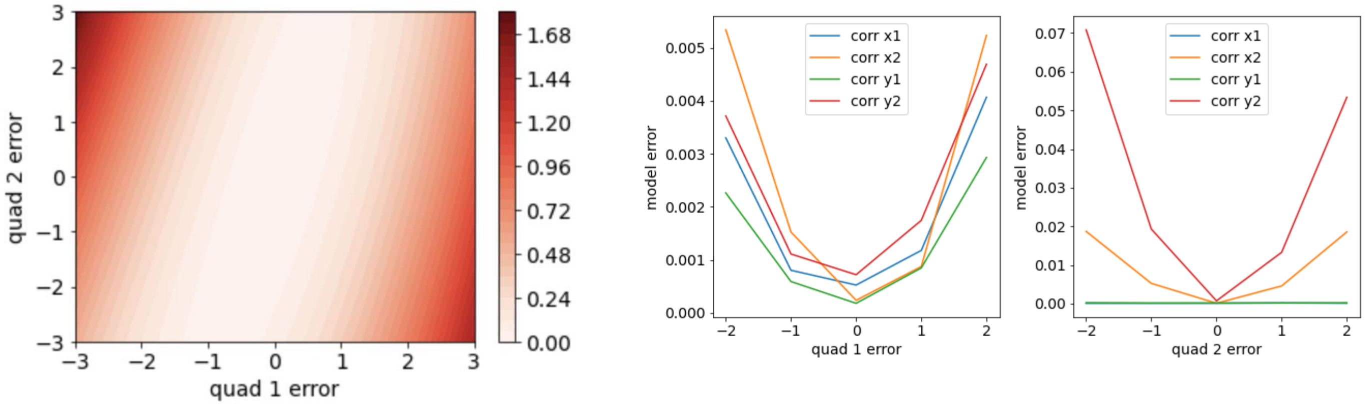




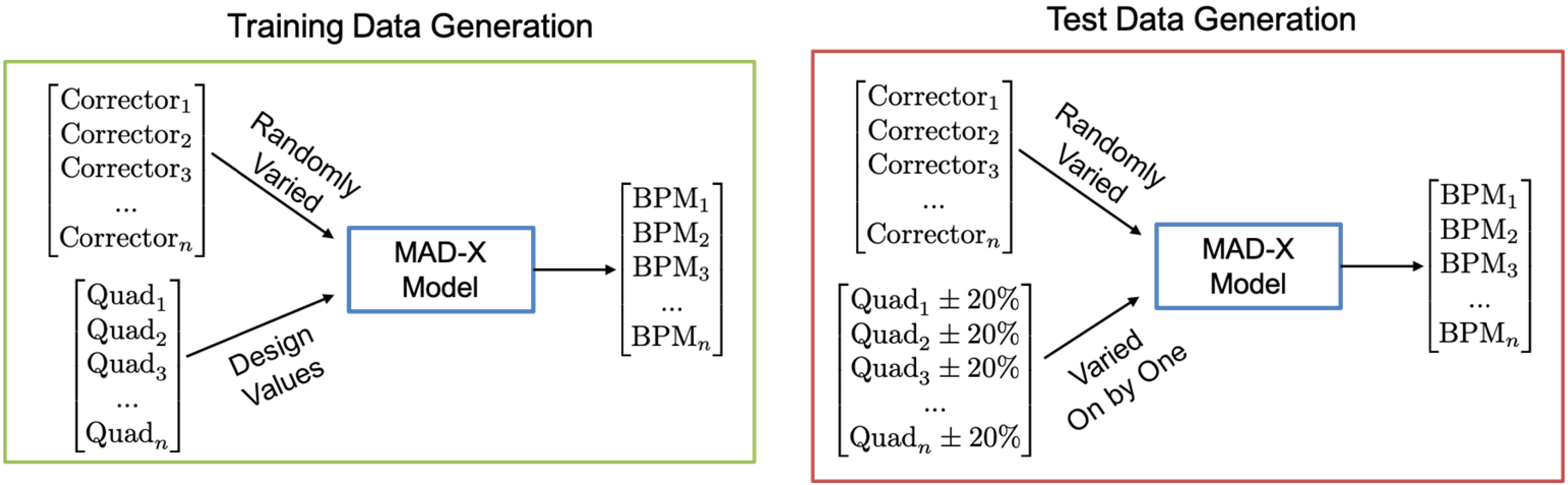
Inverse models for diagnostics and control at BNL

- Inverse models as a diagnostic in a supervised fashion
  - Direct comparison between predicted settings and actual settings informs operations of a potential anomaly with that magnet
- Inverse models as a diagnostic in an unsupervised fashion
  - Assumptions
    - model errors are caused by other beamline elements
    - each beam-line element will have a unique error signature
- Inverse models for tuning
  - Minimize error between predicted settings and actual settings by varying quads
  - Right: model error as a function of quad strength error



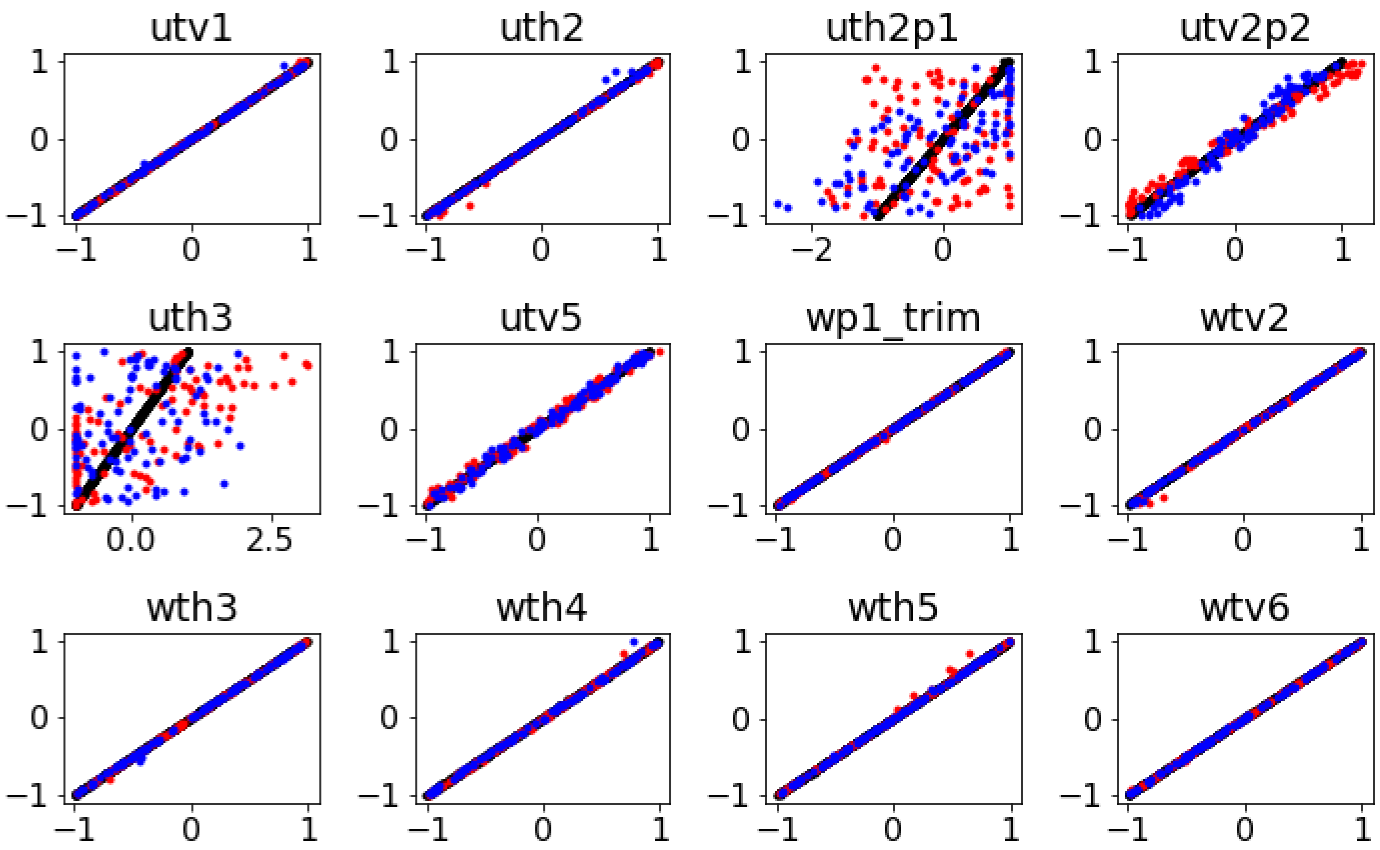


AGS to RHIC transfer line study



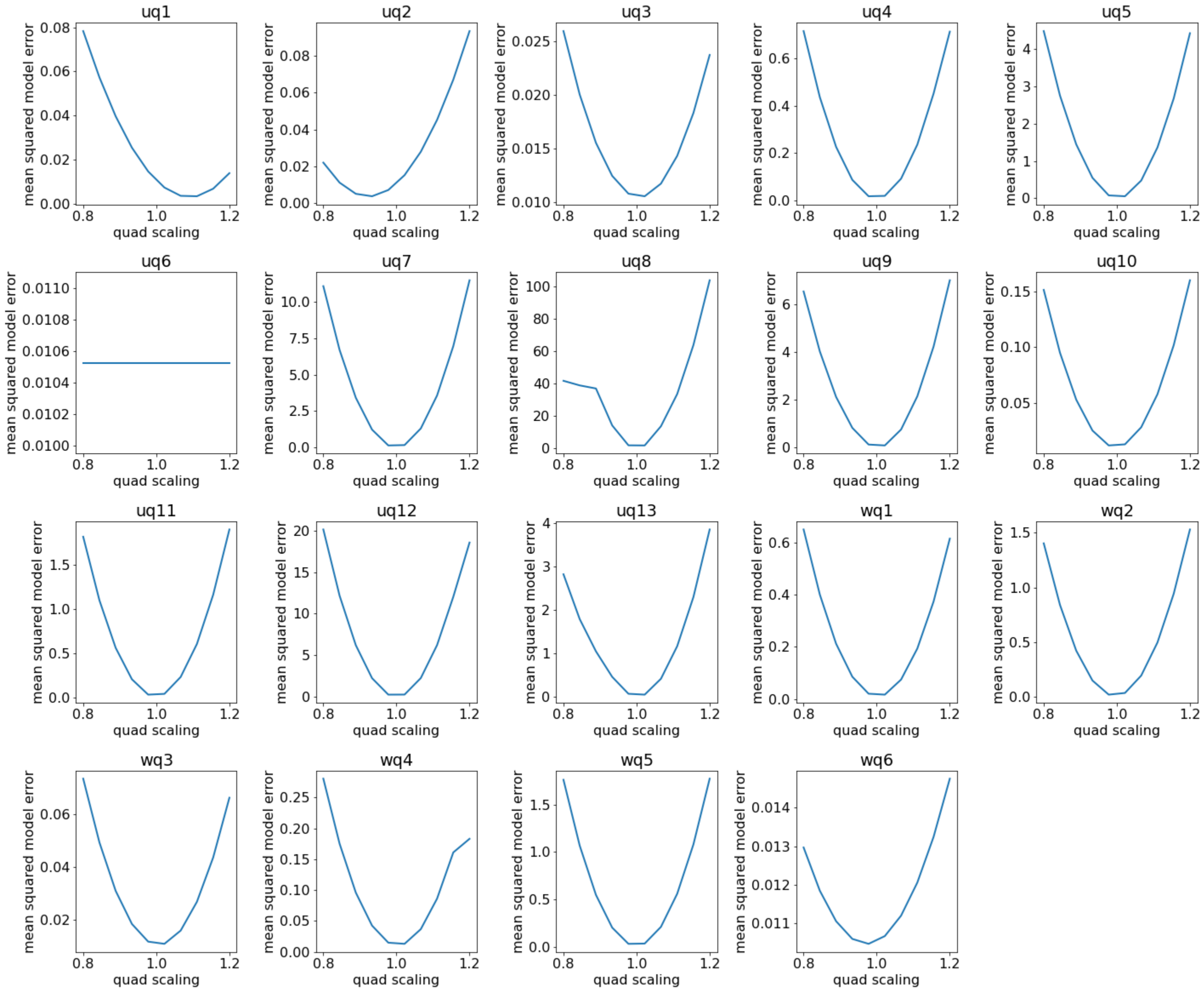
AGS to RHIC transfer line study

- Right: Predicted corrector settings vs the ground truth for the validation set
  - Black: without quadrupole errors
  - Red: a single quadrupole error of -20%
  - Blue: a single quadrupole error of +20%



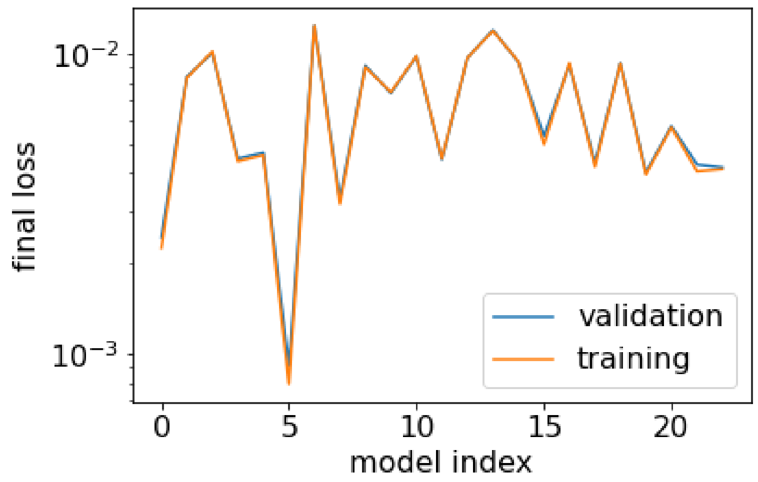
Computing the Model Loss as Quadrupoles are Varied

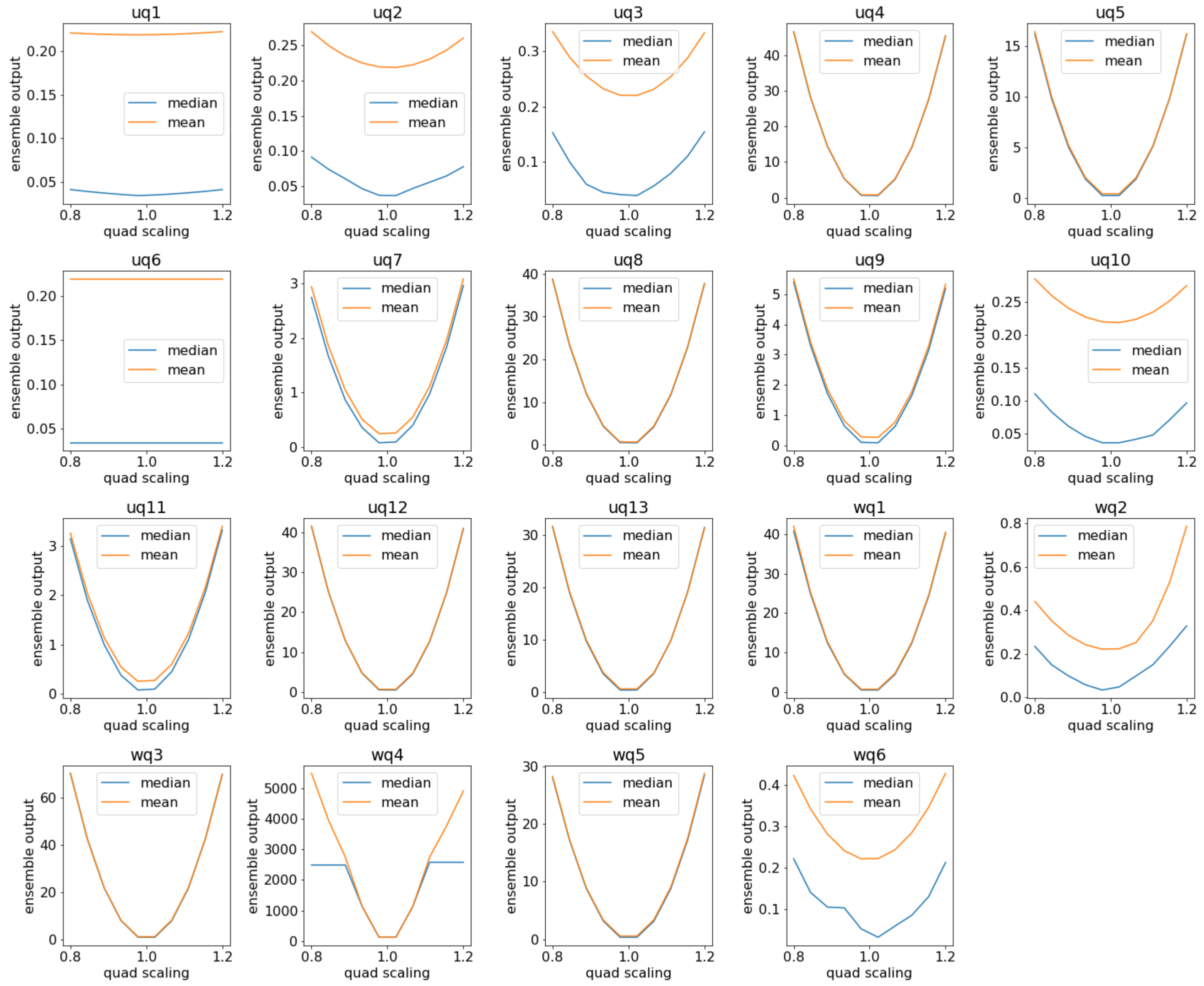
- Model trained for 100k epochs
- Individually varied the quads over a range of plus or minus 20% excitation
- All quads show sensitivity except uq6
- Many quads have minima at 1.0 with some offset
  - Longer training time can improve this
  - Ensemble methods may be more efficient



Consider an Ensemble of Models

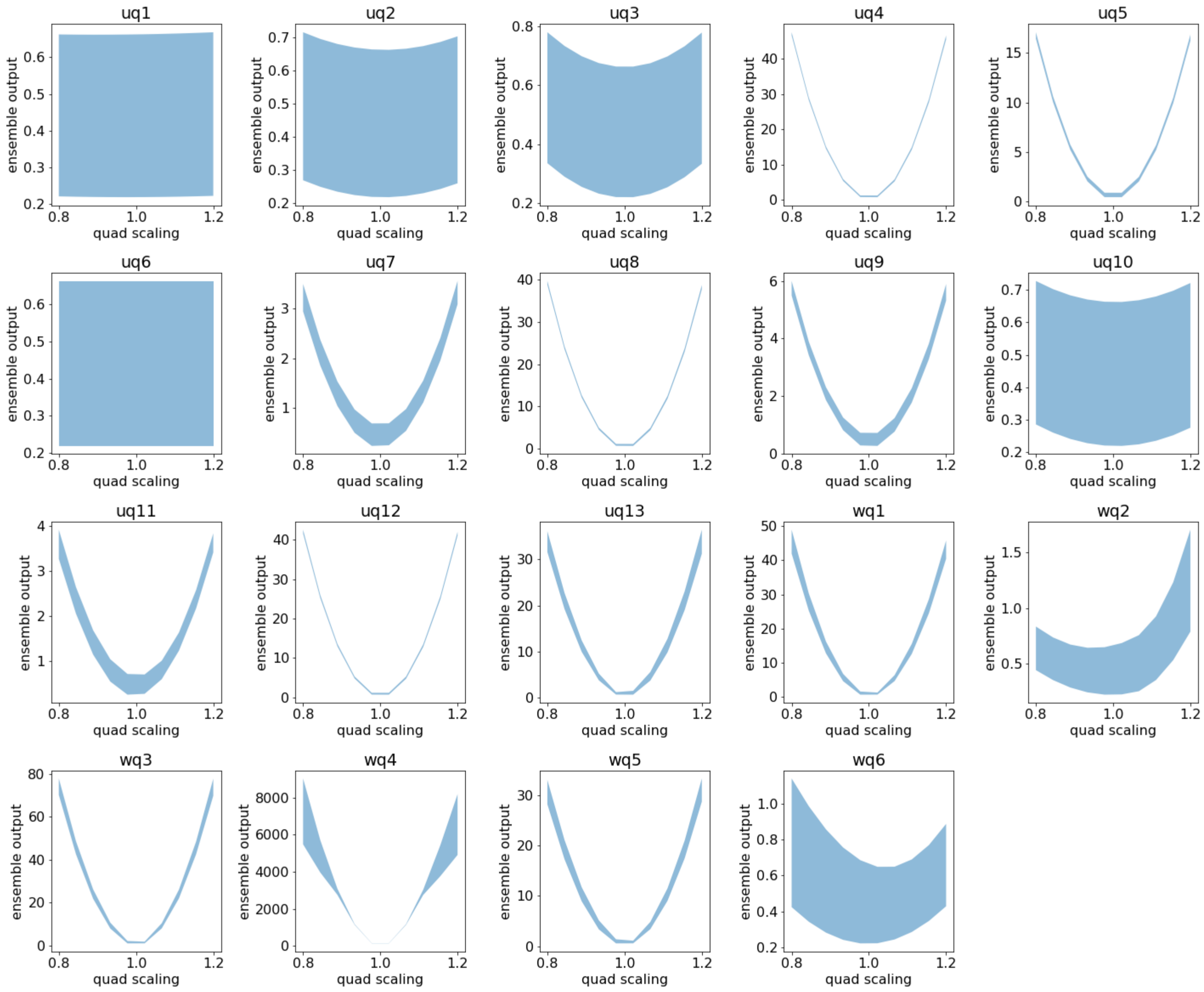
- Trained 23 different models
  - Same training and validation data and architecture
  - Different random initializations
- Bottom: final training and validation loss foe each model
- Consider median and mean for output of the ensemble
- Examine the ensemble output as you vary the quad strengths
- Right: Ensemble output as a function of quad strength variation
  - Note clearly defined minima at or very close to 1.0 for all cases except uq6
  - This is an improvement over slide 16 where some quads do not have well defined minima





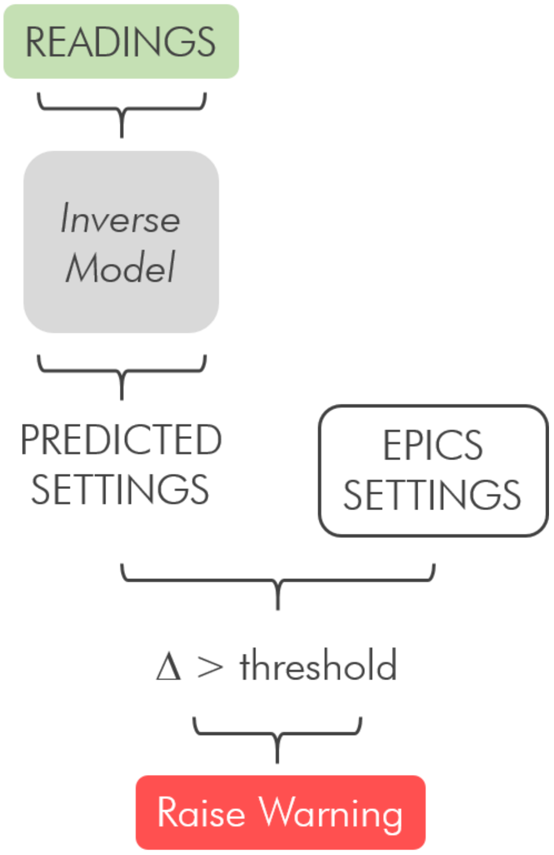
Consider an Ensemble of Models

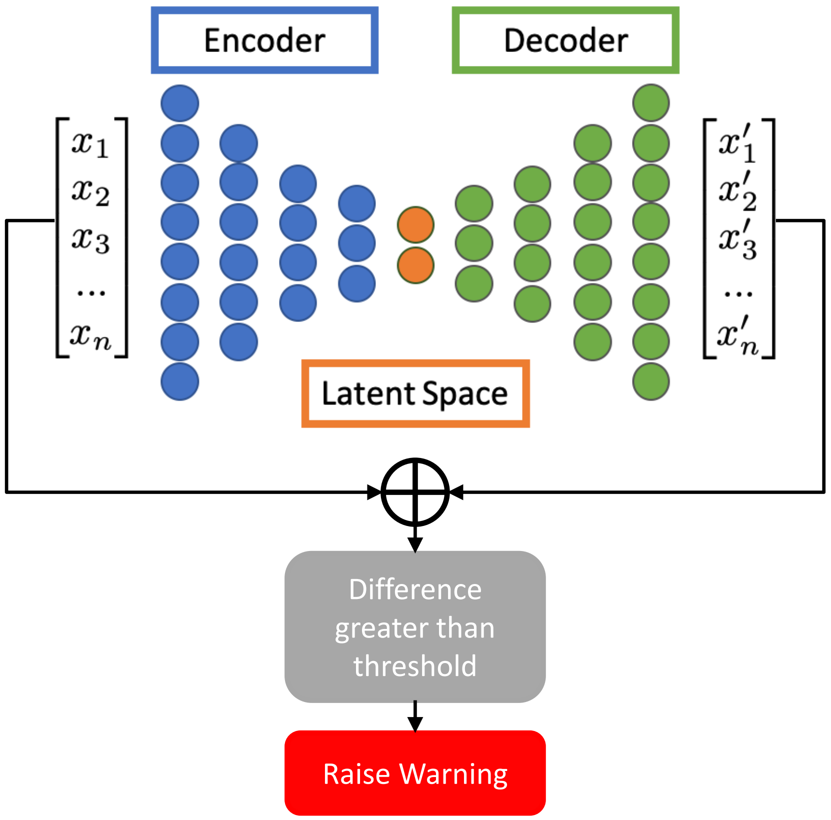
- Consider median and mean for output of the ensemble
- Examine the ensemble output as you vary the quad strengths
- Right: Mean ensemble metric showing one standard deviation in the ensemble output
  - Note clearly defined minima at or very close to 1.0 for all cases except uq6
  - This is an improvement over slide 16 where some quads do not have well defined minima



A Smart Alarm System for the CEBAF Injector

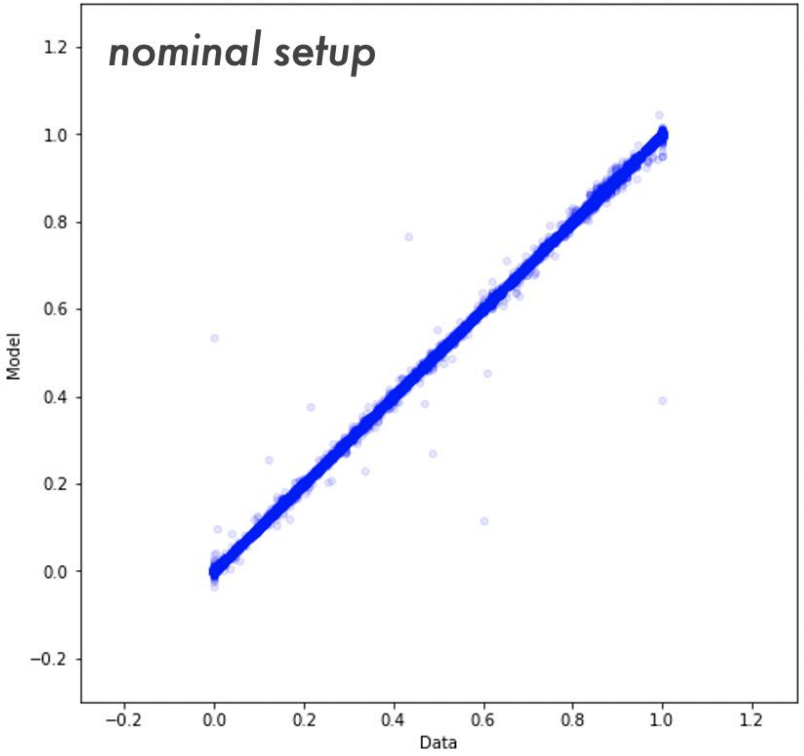
- Alarm systems typically alert operators when there is a problem with the beam
  - Often does not provide much information on what caused the alarm
  - Diagnosing the problems is time consuming for operators
- Use machine learning to automate the root-cause-analysis effort
  - Autoencoders quantify similarities or differences between machine states
  - Inverse models use actual measurements to predict settings

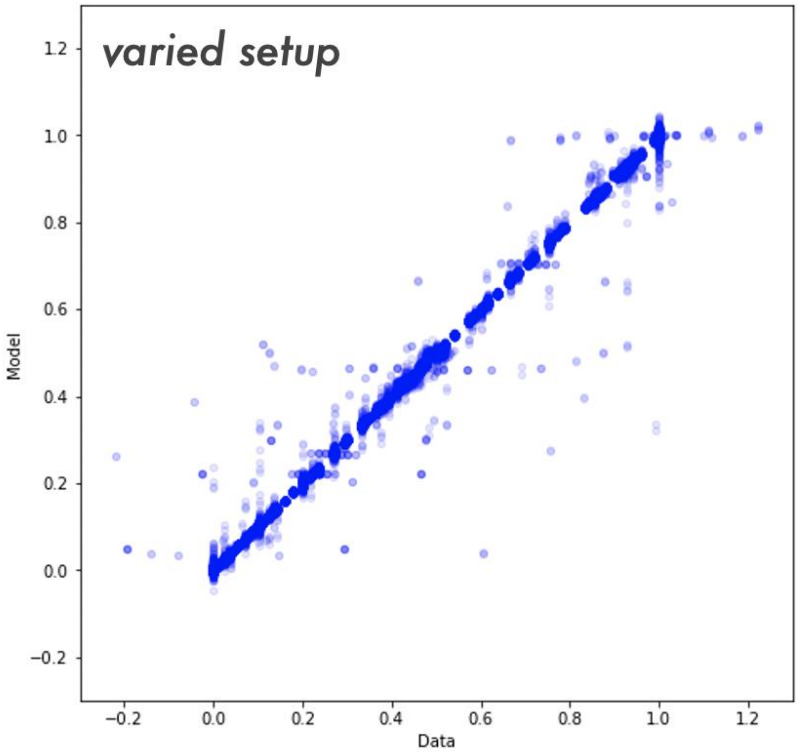




A Smart Alarm System for the CEBAF Injector

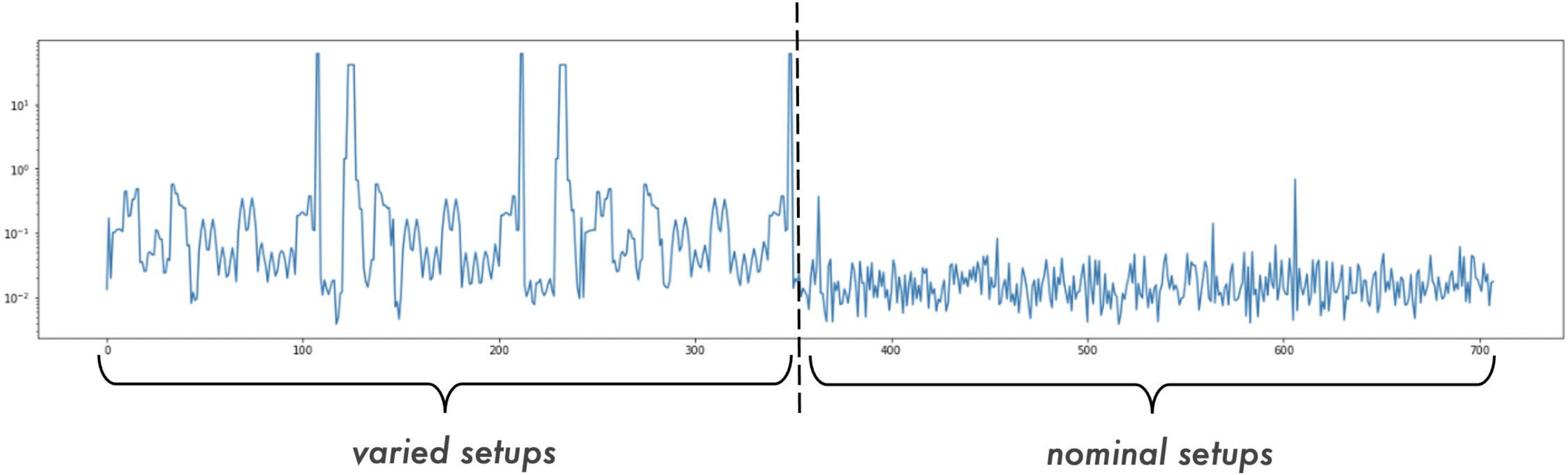
- Data collected during two different operational modes.
  - First during normal operations
  - Second during a dedicated machine study where parameters were varied
- Neural network inverse model is trained to predict settings from readings
  - Left: Model prediction vs the ground truth for the validation data from the nominal setup
  - Right: Model prediction vs the ground truth for the test data (study data)





A Smart Alarm System for the CEBAF Injector

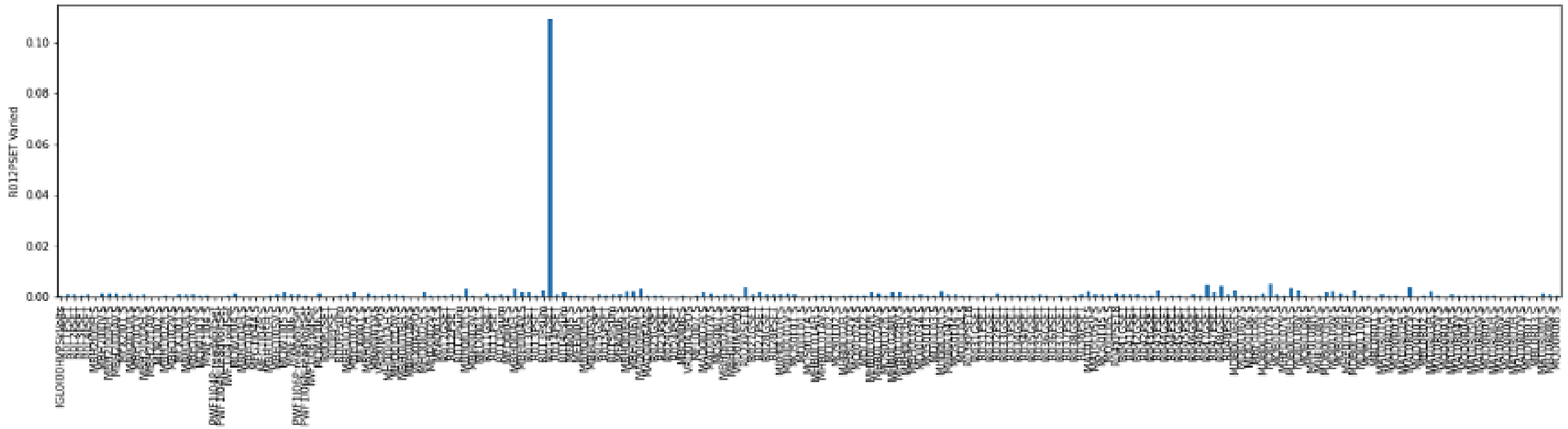
- RMS error of the predicted settings by parameter for the machine study (left) and the nominal setup (right).
- The difference is indicative of the model being able to detect variations in the machine state.



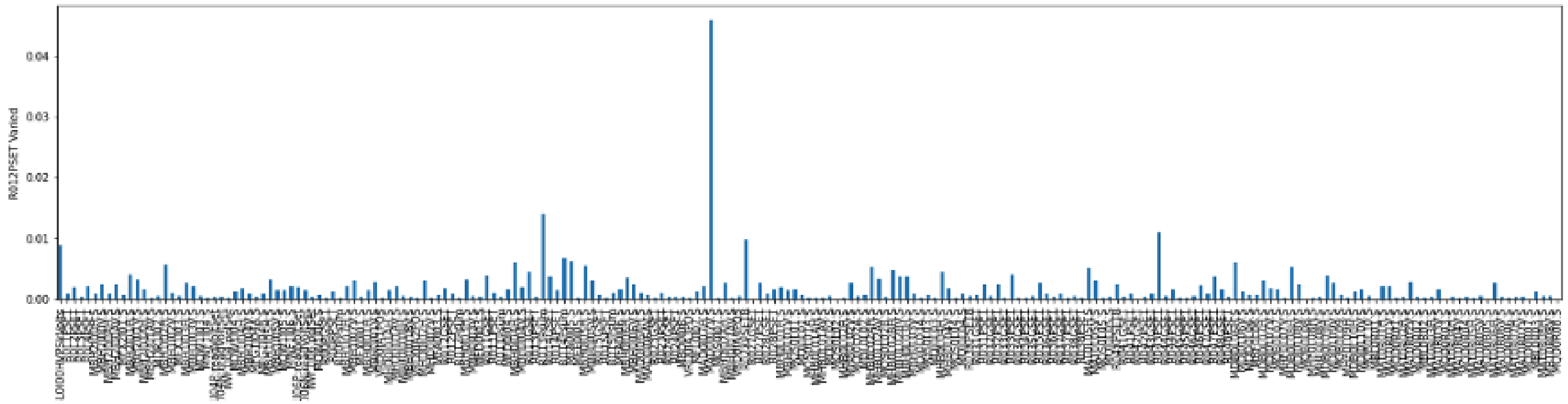
A Smart Alarm System for the CEBAF Injector

- Identifying individual errors using the inverse model
  - Top: model error is a maximum for R014GSET which is the parameter that changed
  - Bottom: model error is maximum for MAD0107V which is the parameter that was changed

R014GSET → 28.28



MAD0I07V.BDL → 20.9



Conclusions / Future work

- Smart alarm system at Jlab
  - Algorithm development nearing completion, publication in preparation (Expected completion within the Phase II)
  - Next step: implementation for use during operations (Planed work for a Phase IIB proposal / other funding source)
  - Transfer techniques to other accelerators (Planed work for a Phase IIB proposal / other funding sources)
- Beamline control algorithms at BNL
  - Algorithm development nearing completion, publication in preparation (Expected completion within the Phase II)
  - Next step: test algorithm during dedicated machine studies, targeting the next operational cycle (Planed work for a Phase IIB proposal / other funding sources)
  - Transfer techniques to other accelerators and develop generalized formula for deploying this system (Planed work for a Phase IIB proposal / other funding sources)
- Controls toolbox and GUIs
  - GUI has been tested at BNL without beam
  - Next step is to test the GUI during a beam study (Planed work for a Phase IIB proposal / other funding sources)
  - Incorporate GUIs into regular operations (Planed work for a Phase IIB proposal / other funding sources)

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