AI Experimental Calibration and Control

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GlueX
Jefferson Lab
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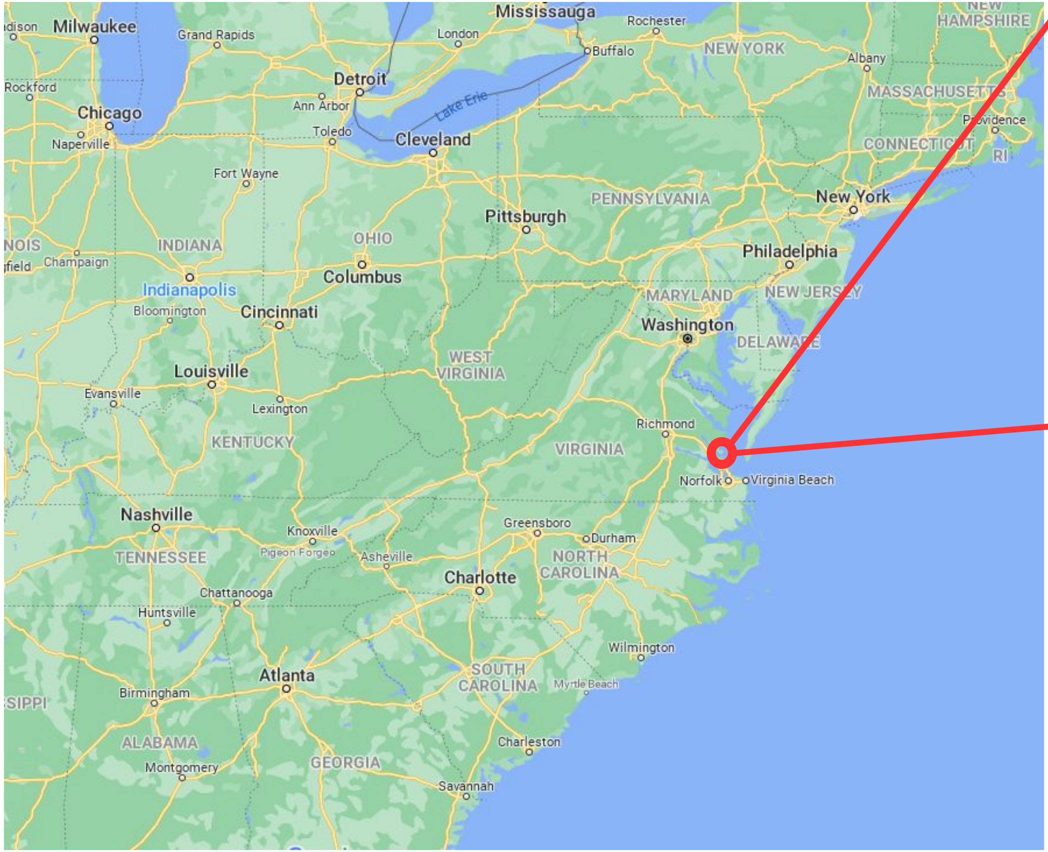
JLab

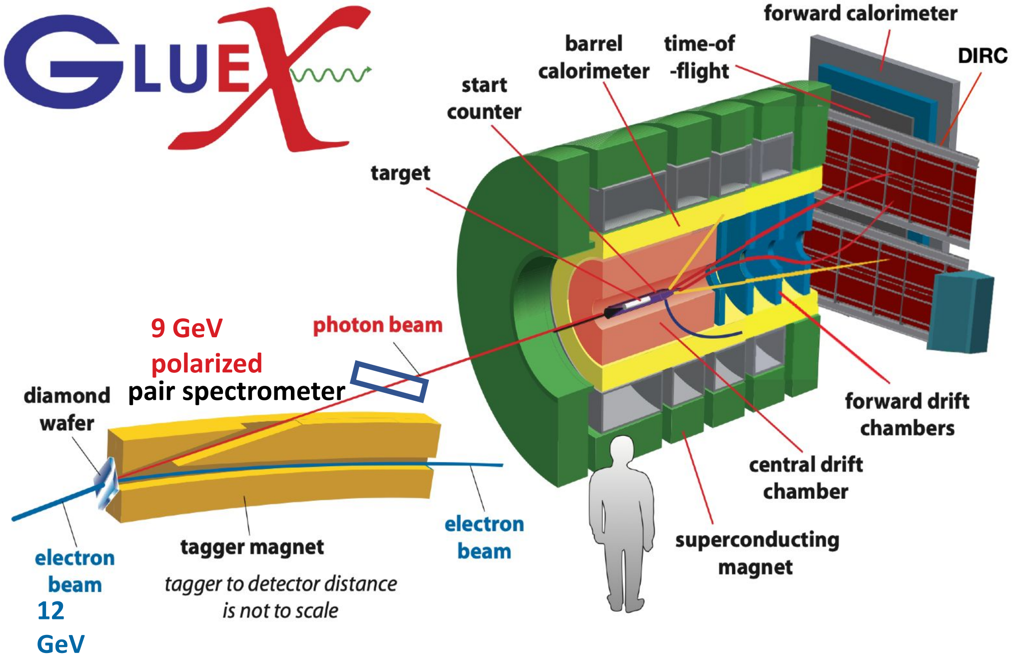


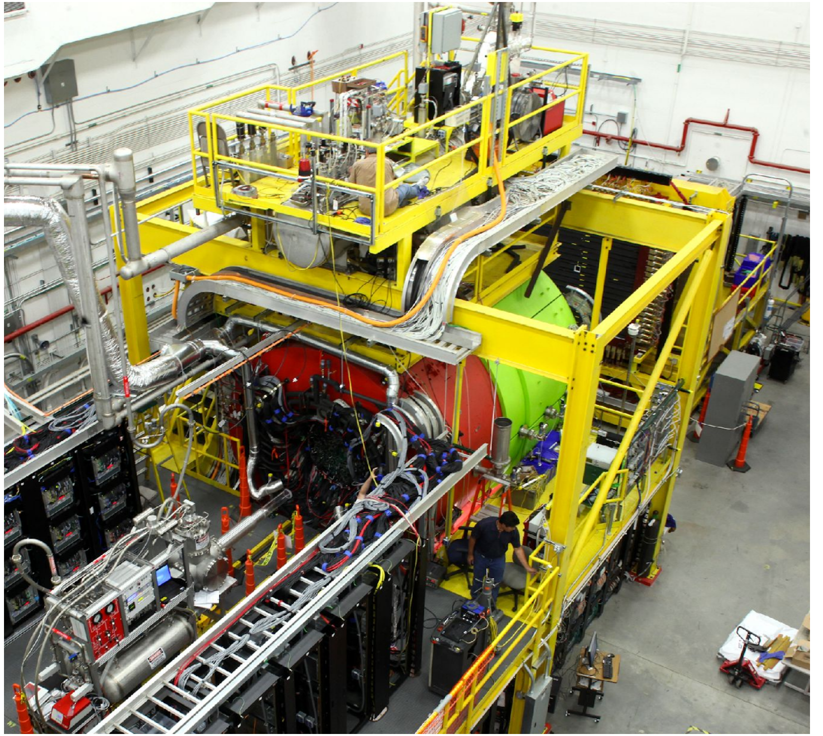
4 experimental halls
Up to 12 GeV electron beam

Focusing (initially) on **HallD**

GlueX

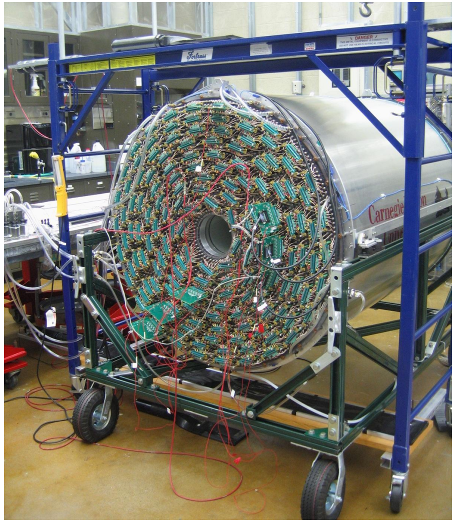
GlueX detector located in Hall D at Jefferson Lab, VA

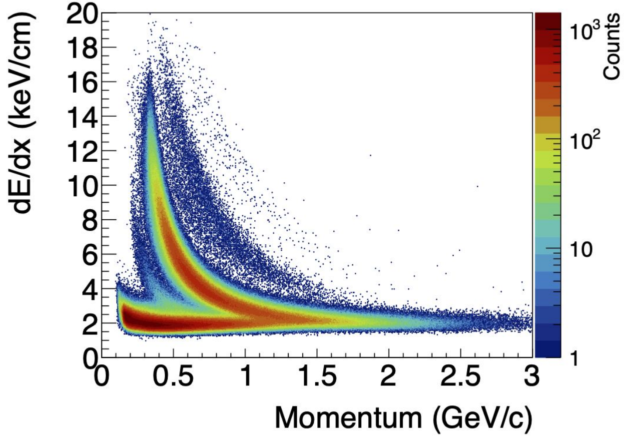




The CDC

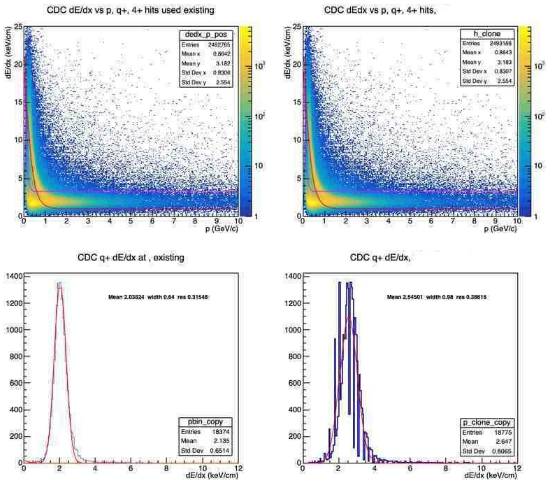
- 1.5m long x 1.2m diameter cylinder; central hole for beam, target and start counter scintillators
- 3522 anode wires at 2125V inside 1.6cm diameter straw
- Ar/CO2 gas mix, approx. 30 Pa above atmospheric pressure
- Measures drift time and deposited charge





Motivation

- Calibrations cause a delay between data collection and analysis
- At present several calibration rounds are used, due to interplay between subdetector calibrations
- Calibration could be made more efficient using AI (less iterations)
  - Less cpu time
  - Less personal attention from experts
  - * We expect to fine-tune the calibrations in the usual way
- **CDC gain calibrations** have the most variation **+/- 33%**

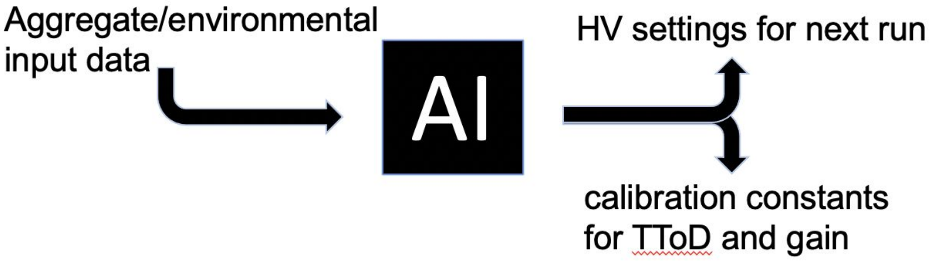


Artificially modified gain 33%

- If we know what gain to expect before taking data, we can **adjust the HV to maintain constant gain**
  - Perhaps eliminating the need to perform gain calibrations at all…

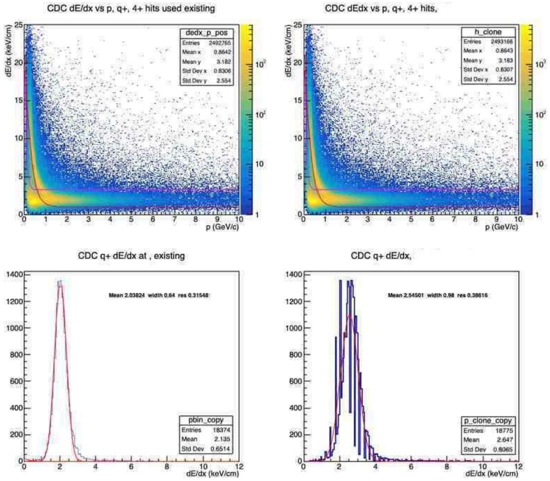
Goals

- AI-recommended HV settings to maintain GlueX Central Drift Chamber gain
  - E.g. Chamber gain is sensitive to atmospheric pressure
- **Have neural network determine calibration constants as quickly as possible**
  - **Reduce time for offline calibration**
- Apply tech to other detector systems such as CLAS12 spectrometer



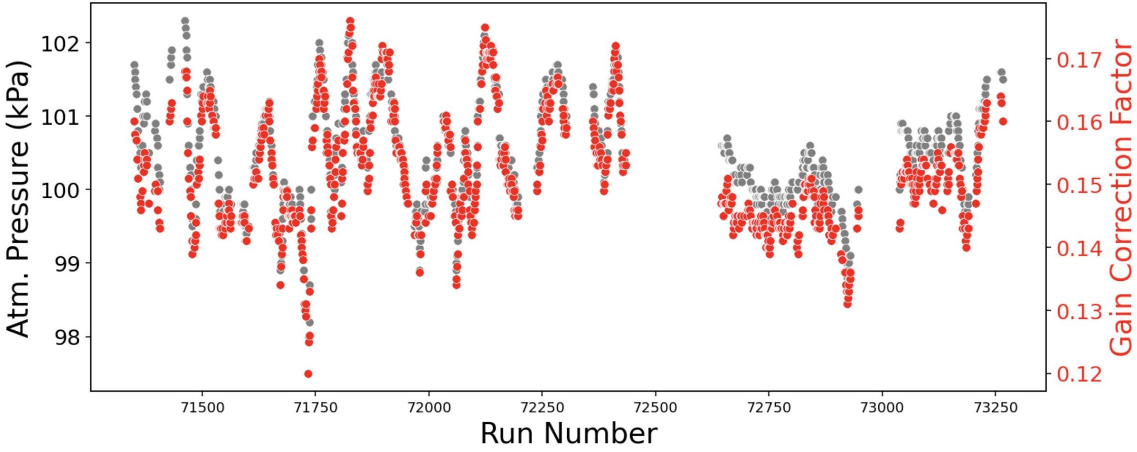
Plan of attack

- Start with the gains
  - Use **traditional methods as “ground truth”**
- Develop a voltage recommender
  - Stabilize gains
- Time-to-distance
  - First with traditional methods
  - Then with physics based methods
- Application to other experiments

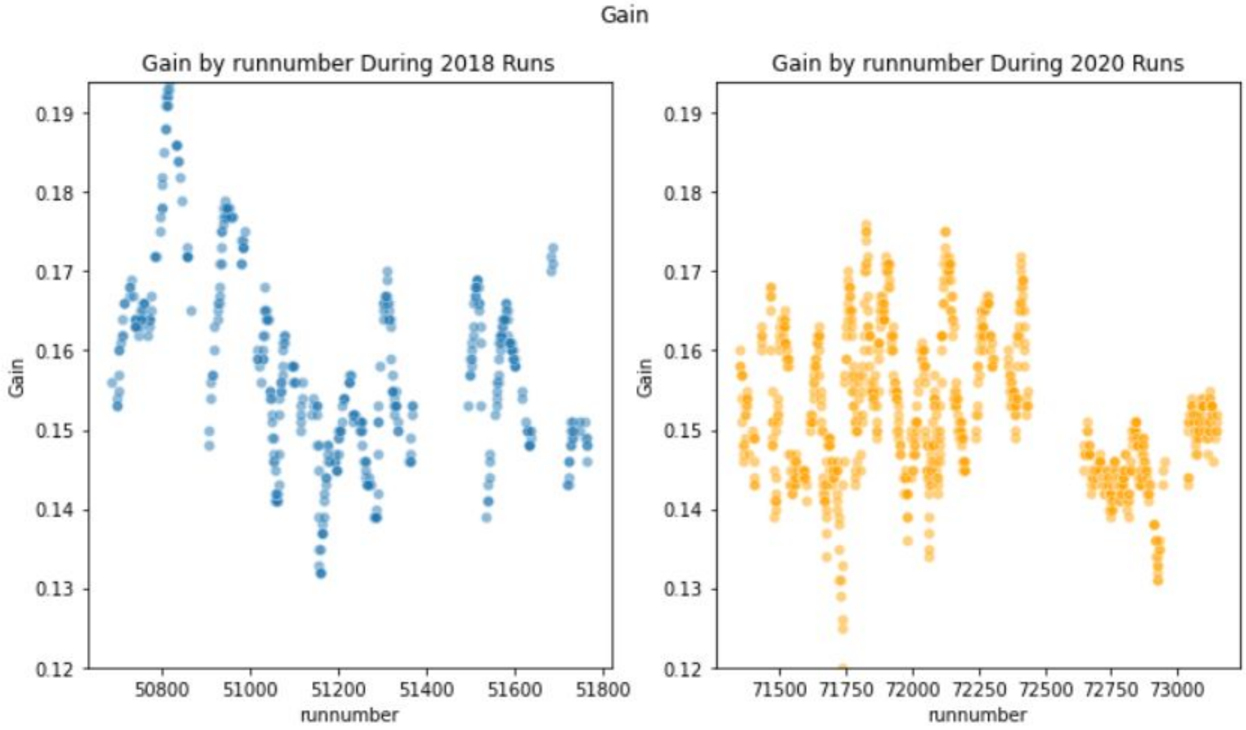


CDC gains

- Time to distance -> track-fitting, vertex resolution and dE/dx resolution
- Gain -> stable dE/dx throughout the run, affects PID selections in analysis. Environmental conditions, eg atmospheric pressure, affect the chamber gain
- Data-taking divided into *runs* (up to 2h), each session of data taking spans several months



CDC gains



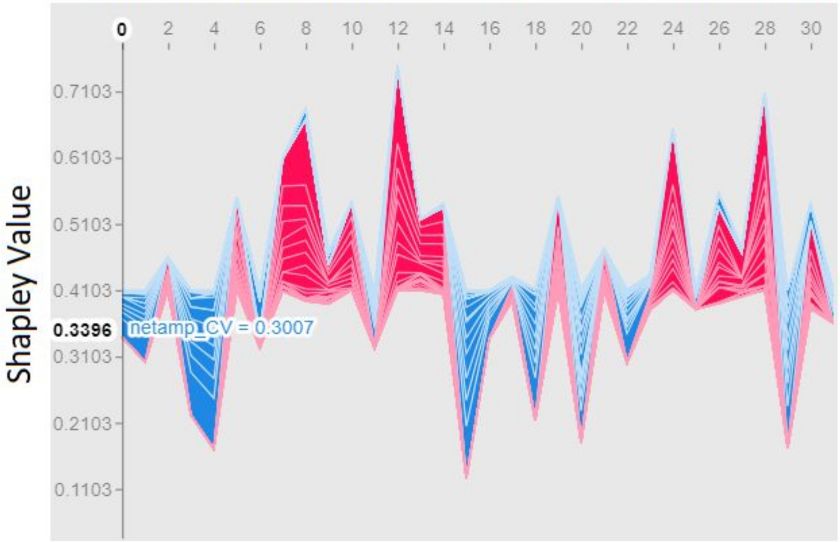
Can we use AI to predict existing gain constants to within ~1%?

CDC gains

For regression problems, there are a number of available evaluation methods.

We implemented Shapley values.

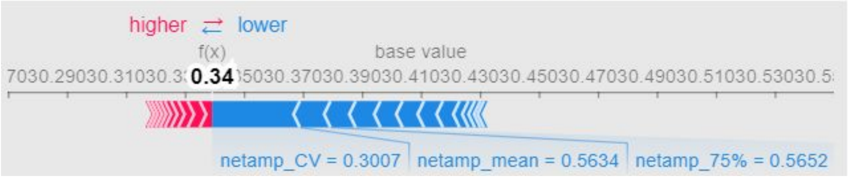
Non-linear relationship of 39 features on Gain constant



Test data set

"The Shapley value is a framework originally proposed in the context of game theory to determine individual contributions of a set of cooperating players" - Explaining Deep Neural Networks and Beyond: A Review of Methods and Applications | IEEE Journals & Magazine | IEEE Xplore

The first test data set run:
effect of features on Gain constant for this run



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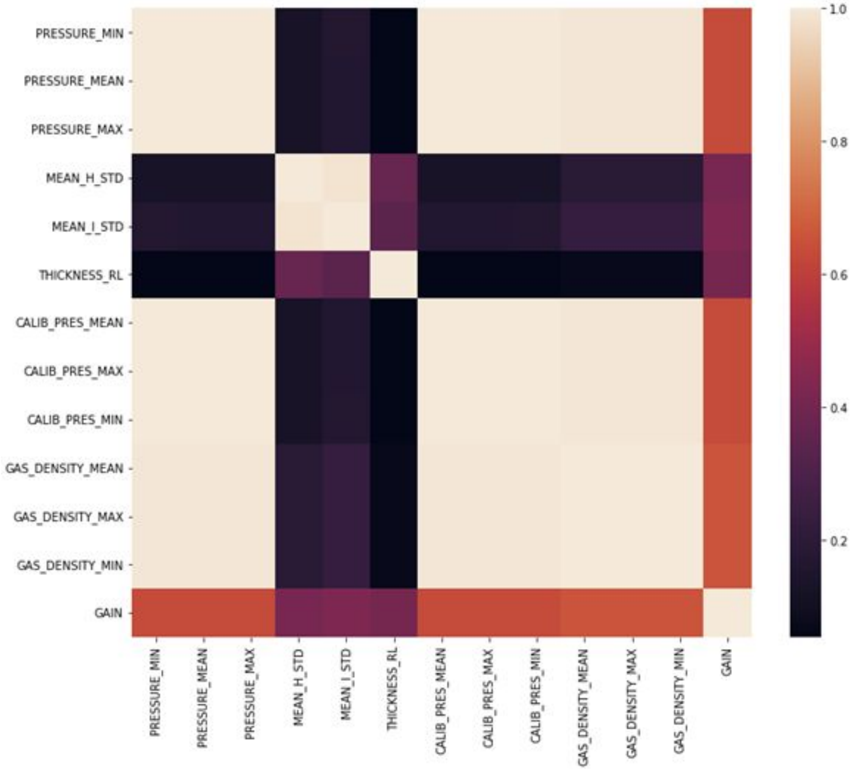
Feature importance

Input Features:

- Aggregate features per run from experimental data and EPICS system:
    - Netamp = pulse height - pedestal, momentum, track angle, drift time

- Split data into train and test sets:
    - 438 runs from 2018
        - 350 train
        - 88 test
    - 897 runs from 2020
        - 717 train
        - 180 test

- **Iterate feature importance** to help with feature engineering and minimize needed data/model size

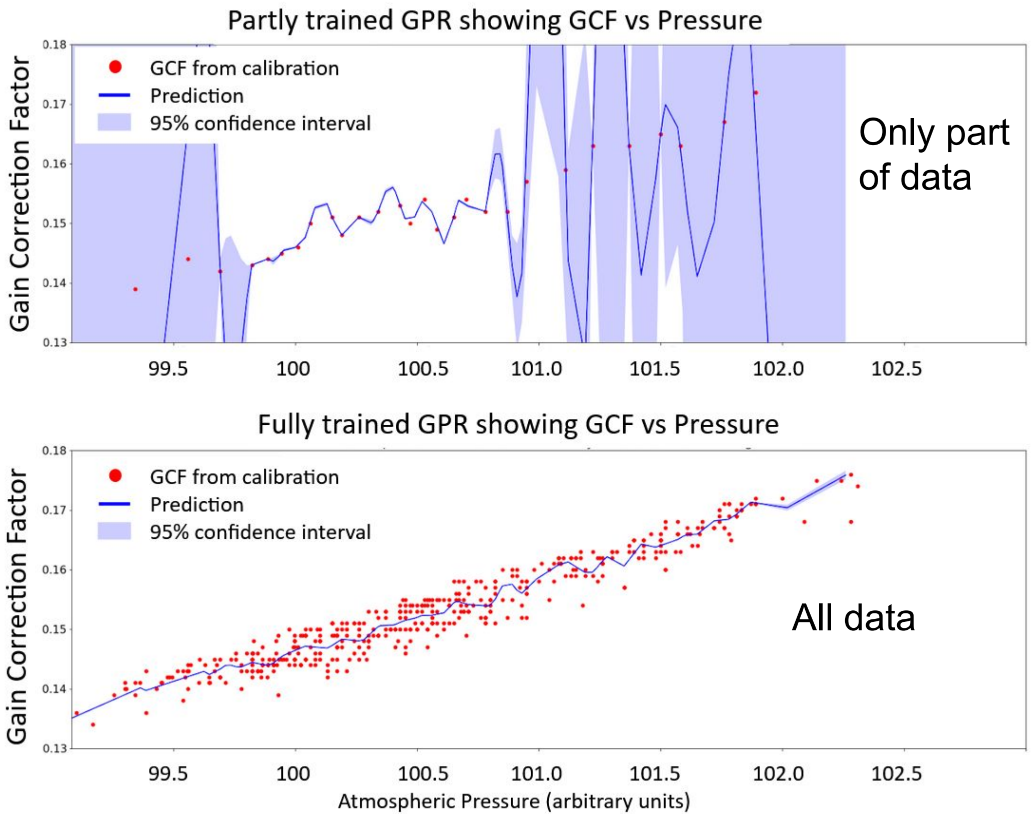


Gaussian Process Regression (GPR)

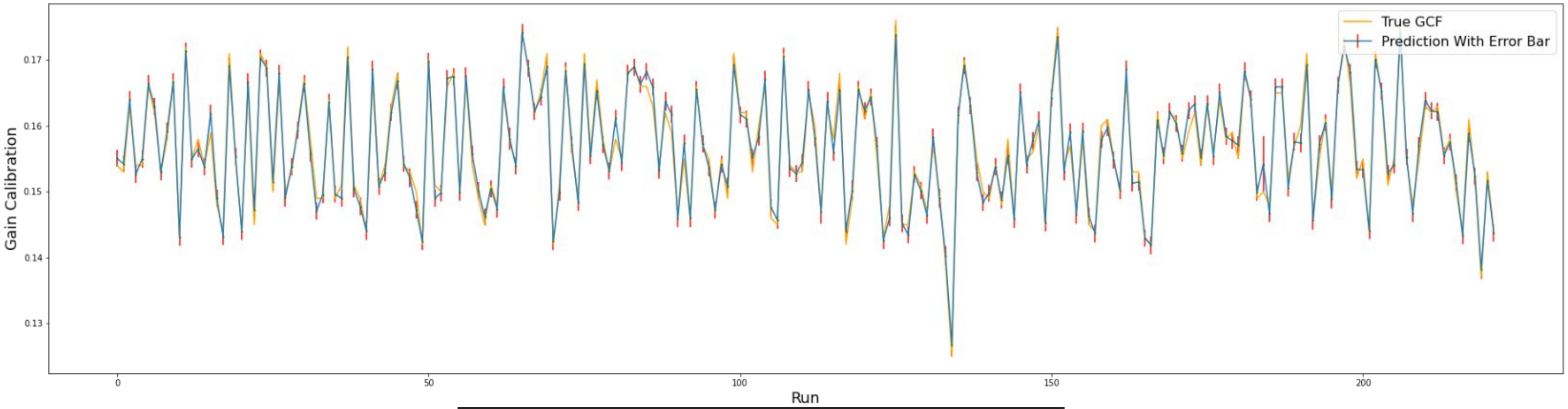
2020 run data (filtered)
- 430 training observations
- 106 testing observations

AI/ML methods applied:
NN,
Random Forest,
XGBoost,
GPR

Gaussian Process Regression
- Suited to small data set
- Provides uncertainty quantification



CDC gains results




```
Predictions on 222 Training and Test Data Sets
_______________________________________________
Minimum Different Between Truth and Pred: 0.000005
Maximum Different Between Truth and Pred: 0.005996
Mean Different Between Truth and Pred: 0.001026
Minimum Perc Dif: 0.000029
Maximum Perc Dif: 0.039976
Mean Perc Dif: 0.006556
Mean GCF: 0.15697727272727272
------------------------------
IF WE JUST USED THE MEAN GAIN INSTEAD OF PREDICTION?:
Minimum Perc Dif Between Truth and Mean Truth: 0.000145
Maximum Perc Dif Between Truth and Mean Truth: 0.145820
Mean Perc Dif Between Truth and Mean Truth: 0.044877
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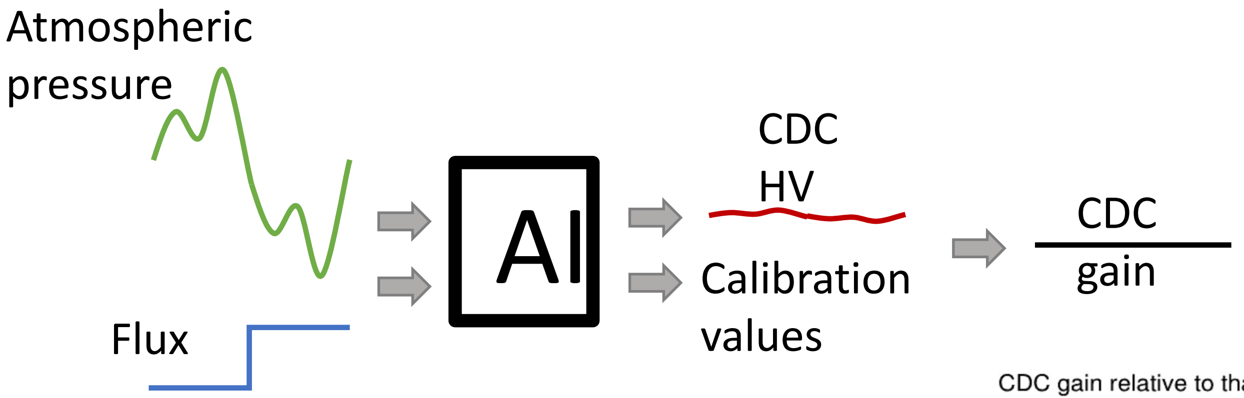
AI solution better than just using the mean gain

HV controls + gains

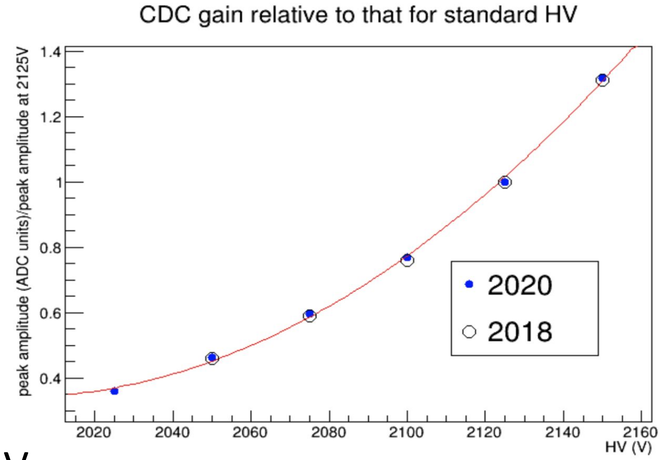


- AI predicts Gain Correction Factor (GCF) for 2125V

- Ask AI for ideal GCF, at std pressure (101.3 kPa)
- Ask AI for expected GCF at pressure right now

- Calculate relative change in gain needed

- Use known behaviour of relative gain vs HV to find desired HV



time-to-distance

- Current calibration method produces 6 unique calibration constants from fit to data

$$d(t) = f_\delta \left(\frac{d_0(t)}{f_0} P + 1 - P \right)$$

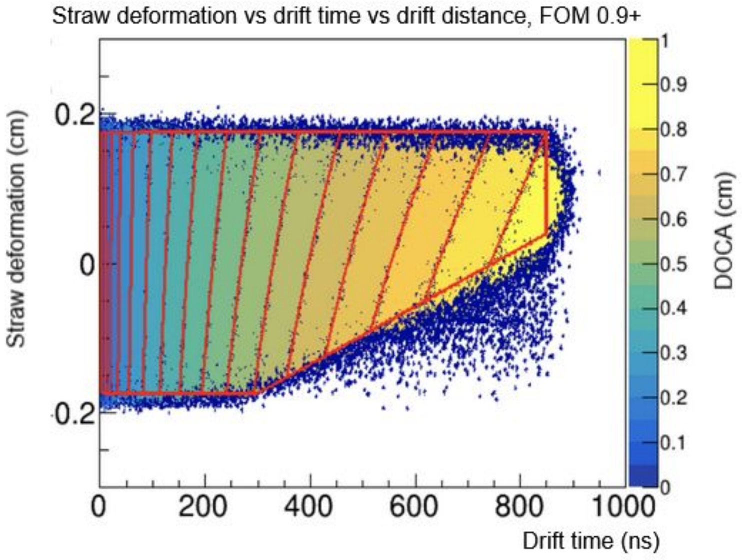
$$f_\delta = a\sqrt{t} + bt + ct^3$$

$$f_0 = a_1\sqrt{t} + b_1 t + c_1 t^3$$

$$a = a_1 + a_2|\delta|$$

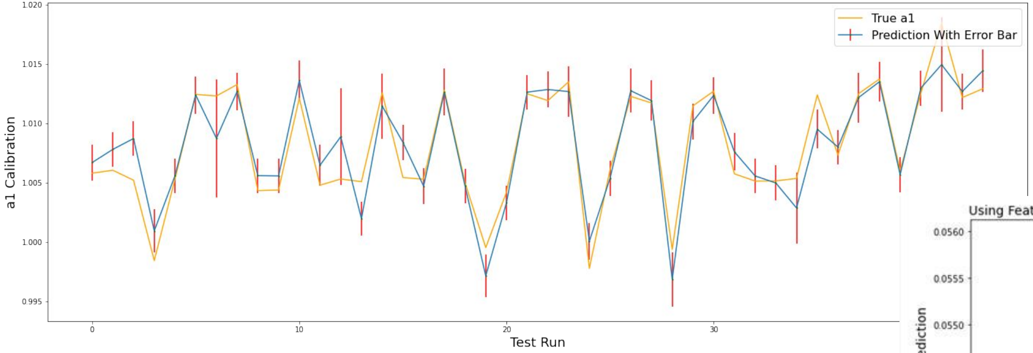
$$b = b_1 + b_2|\delta|$$

$$c = c_1 + c_2|\delta|$$



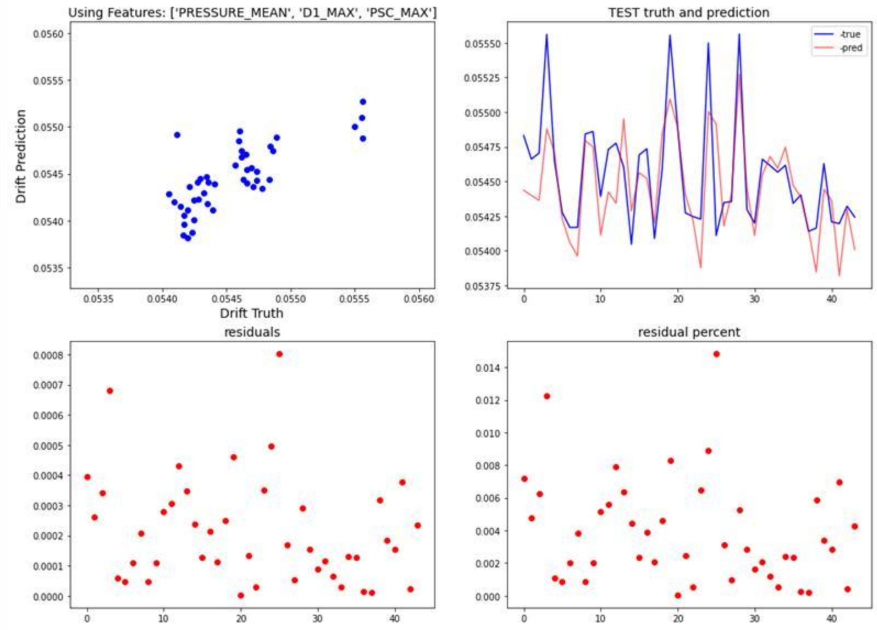
Model development for calibration constants is in very early stages

Early results



A1 has the biggest effect so concentrating efforts here

First results look promising



Future work

- Calibrate 2018 and 2020 runs with both predicted gain correction factor and time-to-distance calibrations
  - evaluate IF and "how many" iterations of traditional calibration are needed to equate to the AI’s calibration.
- Evaluate the data collected in 2021 (where AI was setting the voltage)
  - determine if stabilization of gain (through HV control) is improving the stability of dE/dx and thus improving things like PID
  - Integrate the AI-recommended voltage into existing control software for ease of expert evaluation and use.
- Apply Gain and Time-To-Distance AI to other detectors, i.e. CLAS12

Conclusion

- Promising early results:
  - Very preliminary results show we can decrease time to calibrate
  - Have taken parasitic data in which the AI “controls” the CDC HV.
    - Will analyze for gain stability

- There is a need to explore physics based metrics for success
  - Have seen the result of beam trips affecting the “ground truth” and thus the model