AI Driven Experiment Calibration and Control

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Naomi Jarvis
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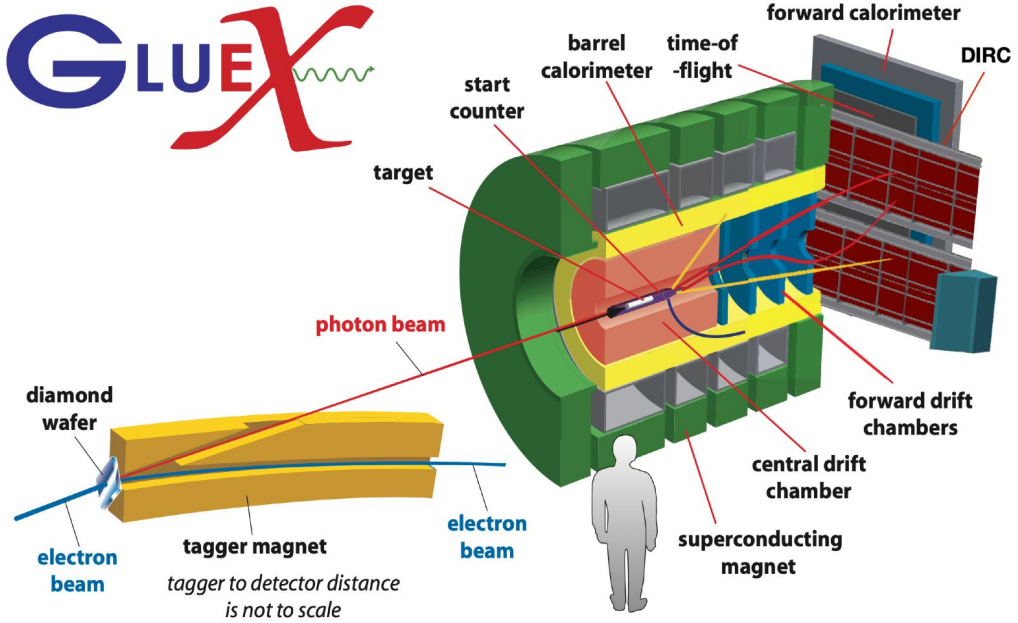
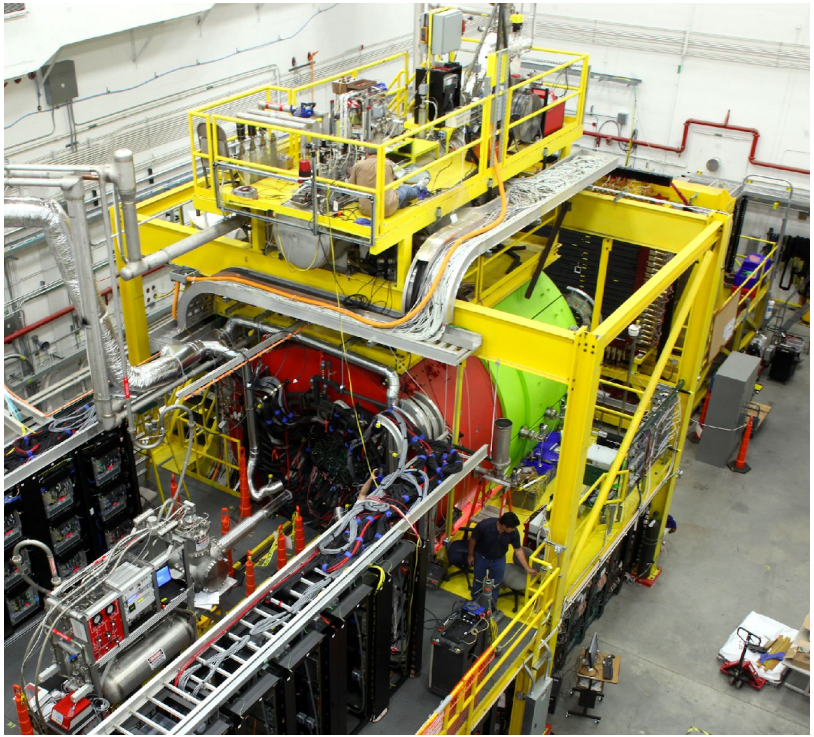
The Gluonic Excitations Experiment: GlueX

GlueX detector located in Hall D at Jefferson Lab, VA

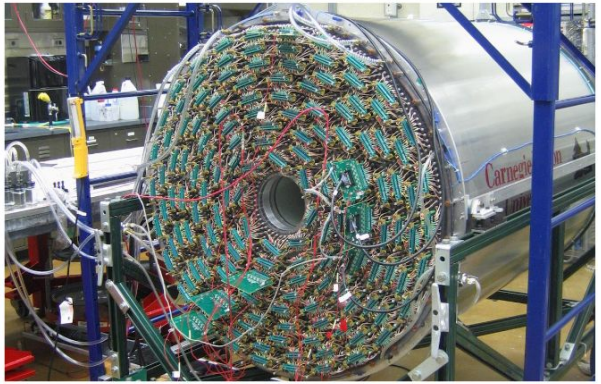




The GlueX Central Drift Chamber

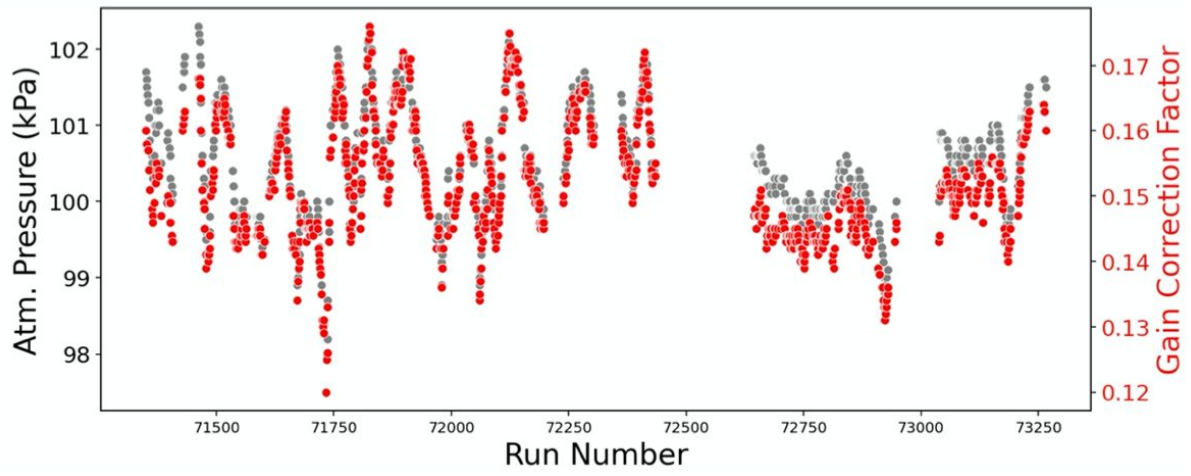
Used to detect and track charged particles with momenta p > 0.25 GeV/c

- 1.5 m long x 1.2 m diameter cylinder
- 3522 anode wires at 2125 V inside 1.6 cm diameter straws
- 50:50 Ar:CO_2 gas mixture
- **Requires two calibrations: chamber gain and time-to-distance**



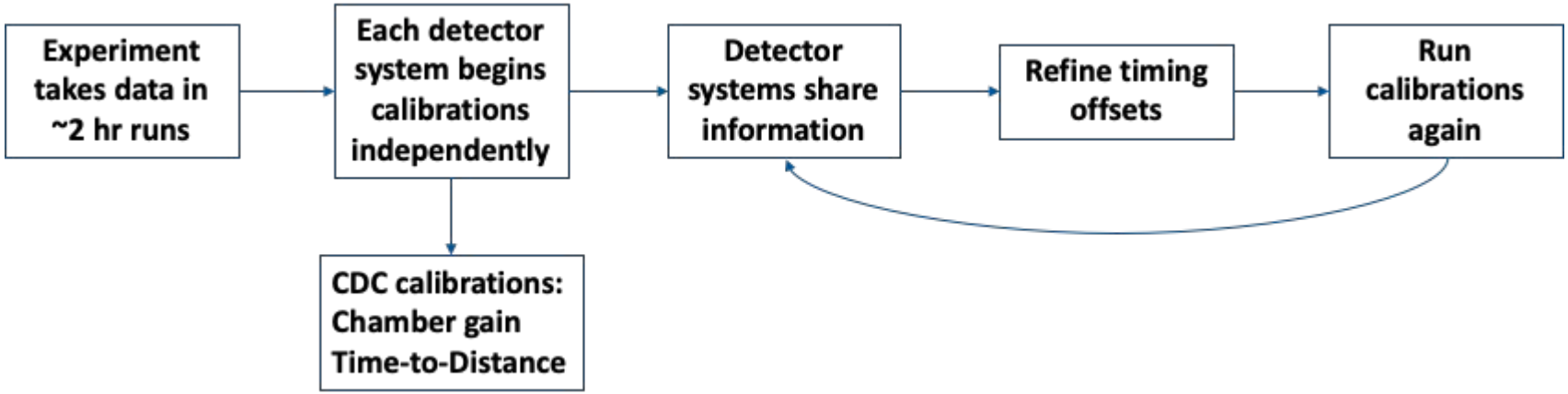
Calibrating Drift Chamber Gain

- CDC gain calibrations have the most variation **+/- 15%**
- If we know what gain to expect before taking data, we can **adjust the high voltage to stabilize the gain**
  - Perhaps eliminating the need to perform gain calibrations at all…



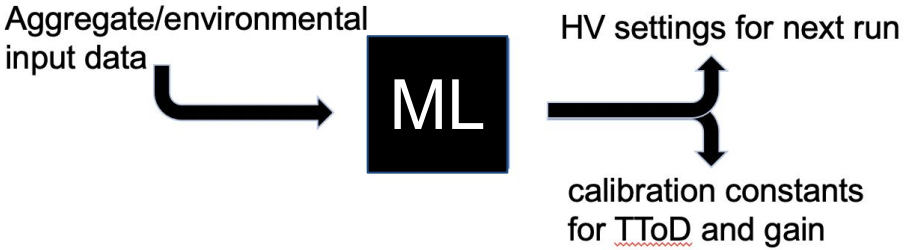
Motivation

- Detector calibrations cause a significant delay between data collection, analysis, and publication
- Calibration can be made more efficient using AI
  - Less CPU time, less personal attention from experts
  - Get to the point of “fine-tuning” calibrations with less iterations



Goals

- ML-recommended HV setting to maintain GlueX Central Drift Chamber gain
- **Have ML determine calibration constants as quickly as possible**
- Apply to other detector systems



Diverse Data = Better Model

2020 and 2021 Run Periods: 601 production runs

2020 ↑ high voltage board current (mean 9.0 uA), pressure (mean 100.5 kPa), gas temperature (299.2 K)

2021 ↓ high voltage board current (mean 0.9 uA), pressure (mean 99.9 kPa), gas temperature (299.8 K)

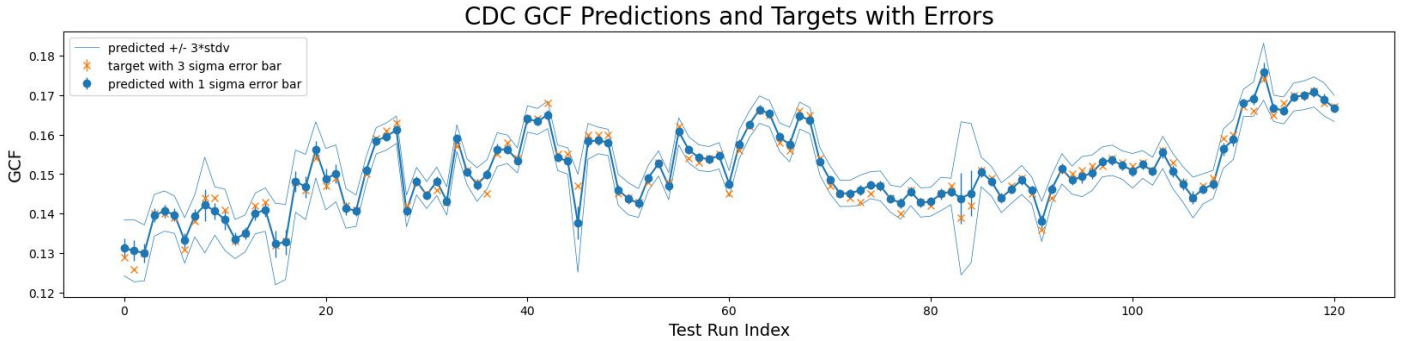
We pressure balanced high, medium, low atm. pressure for both 2020 and 2021

Training: 430 runs: 2020; 50 runs: 2021

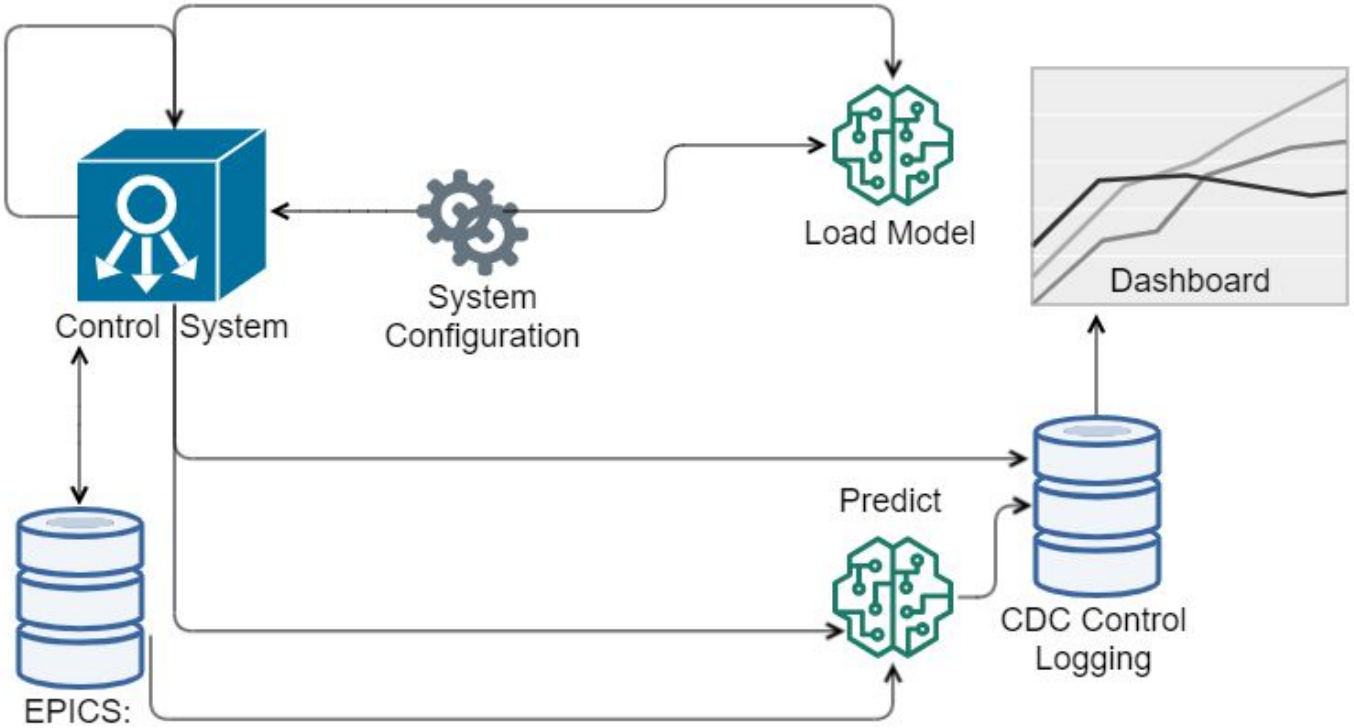
Test: 106 runs: 2020; 15 runs: 2021

Gaussian process with a trained prior

max %err	MAPE	# > 3% err	# > 5% err
4.8%	0.84%	3	0



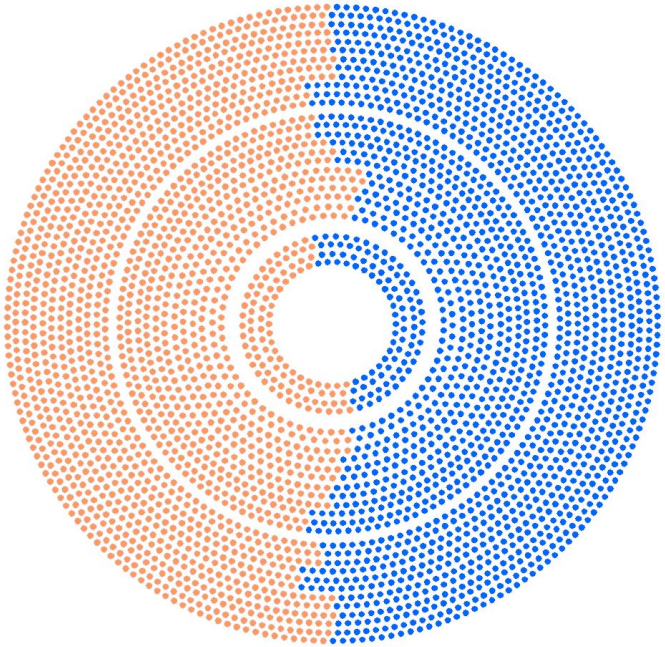
Modular System: RoboCDC



Experimental Physics and Industrial Control System

Deployment 1 – Cosmic Ray Test

- Sorted high voltage boards (HVB) into two groups:
  - AI Tuned
  - Constant: 2130 V (5V higher than normal to compensate for no beam)
- ML
  - Update every 5 minutes
  - Completely autonomous
- Should see the gain stabilized for the Tuned group



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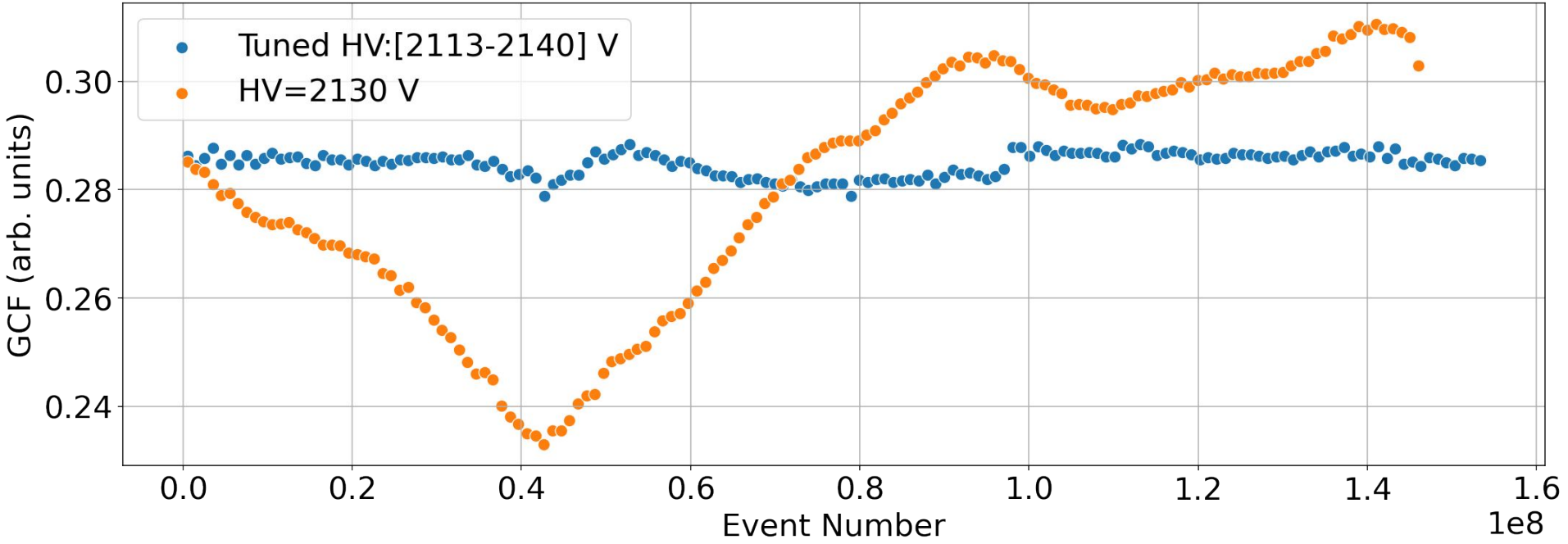

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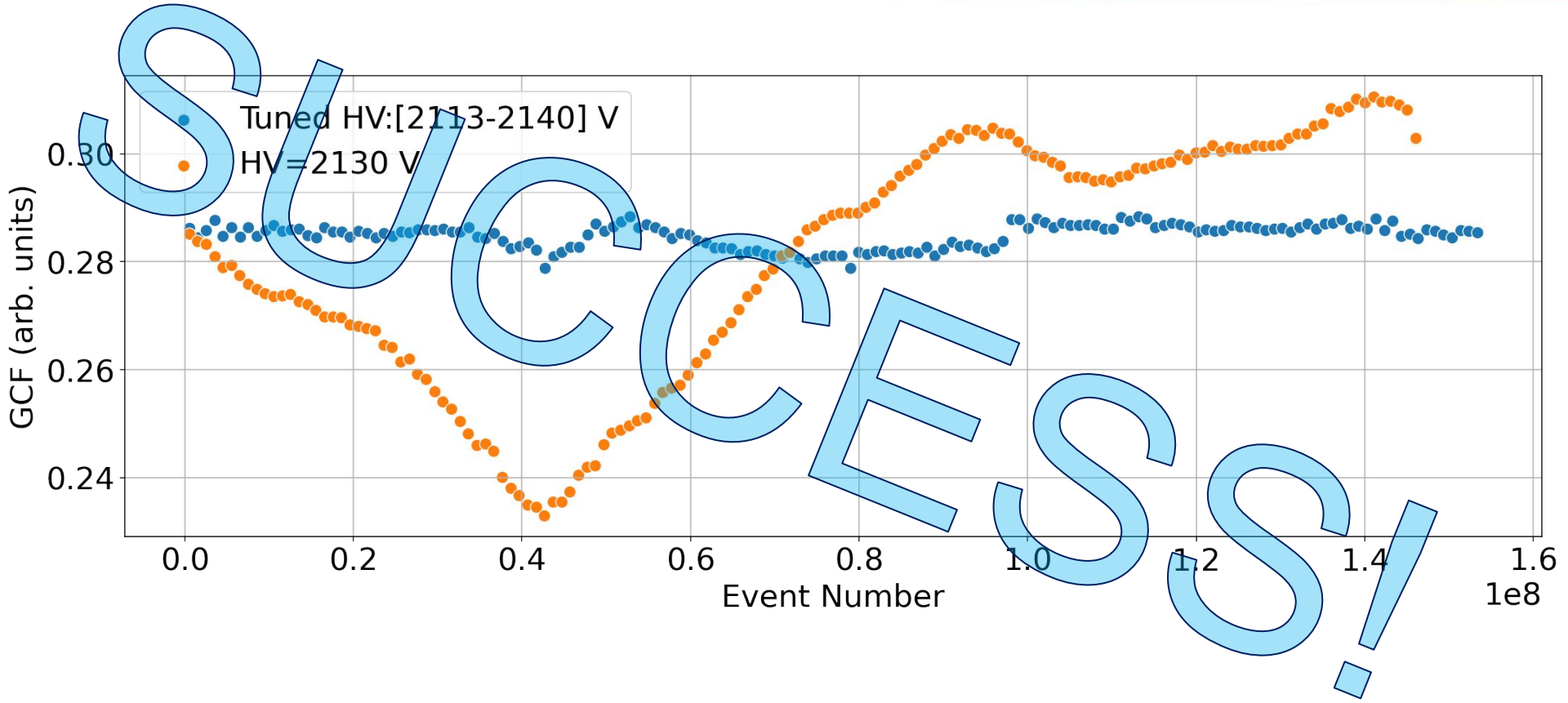
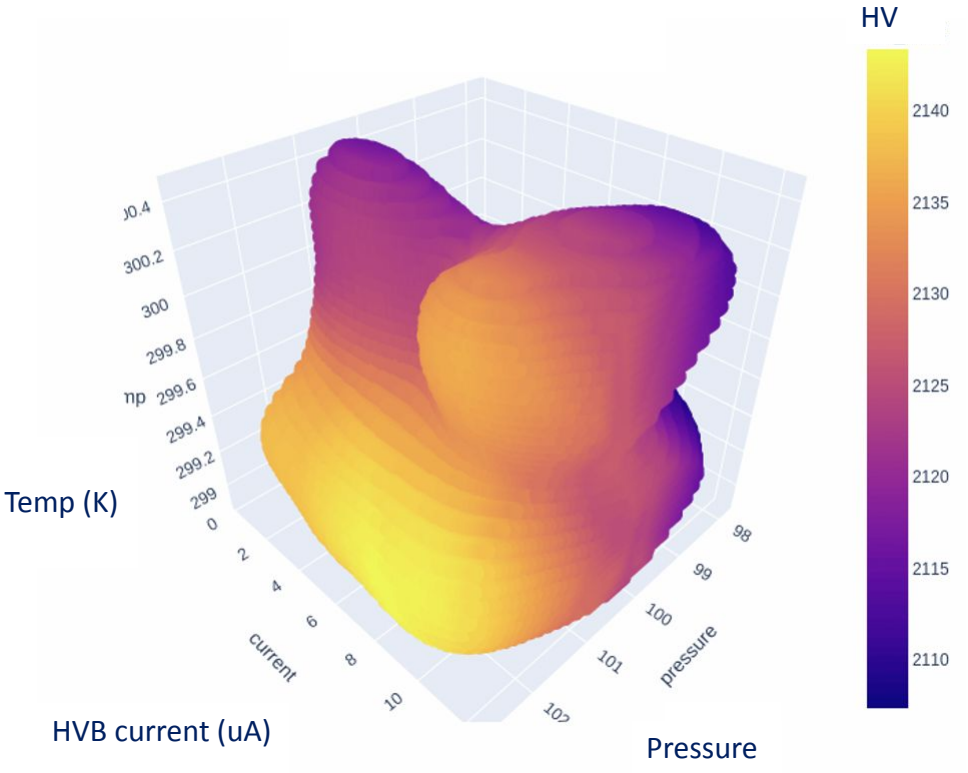


SUCCESS!

Deployment 2 – Charged Pion Polarizability May-June 2022

- RoboCDC used automatically at the start of each 2h run
- Use recommended HV if std <= 3% ideal GCF
- Otherwise, use the closest ‘confident’ HV in Euclidean distance on the uncertainty mesh
- Reverted to 2125V for empty target runs
- Low stakes - CDC not critical for CPP run period
- CPP: unusual running conditions
  - Different target in different location
  - Low beam current



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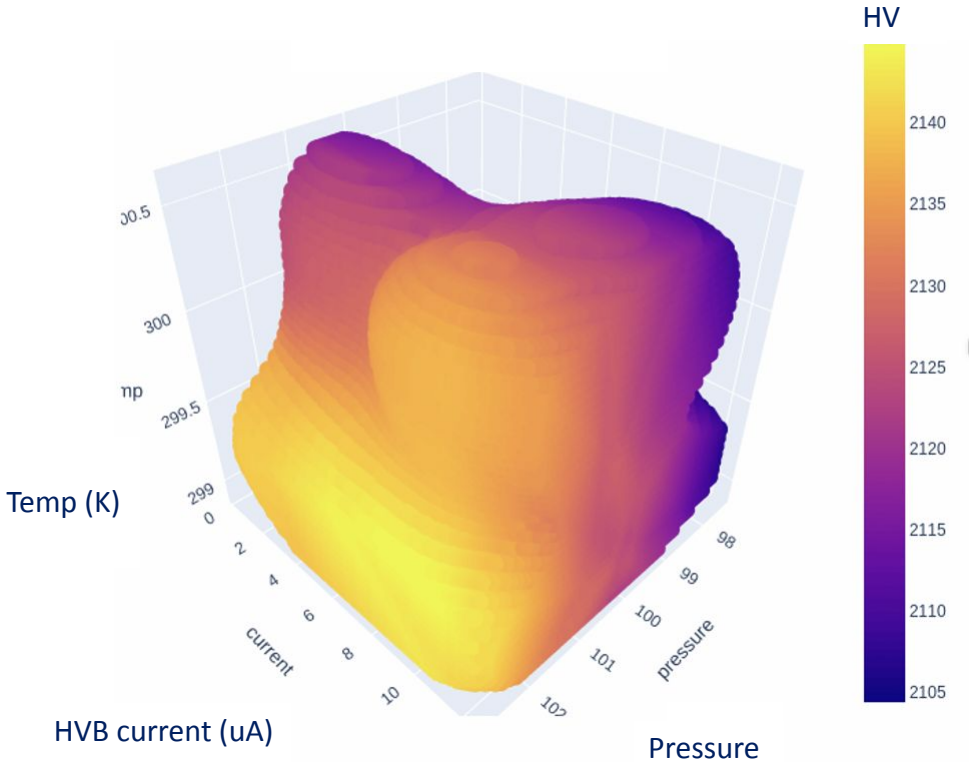
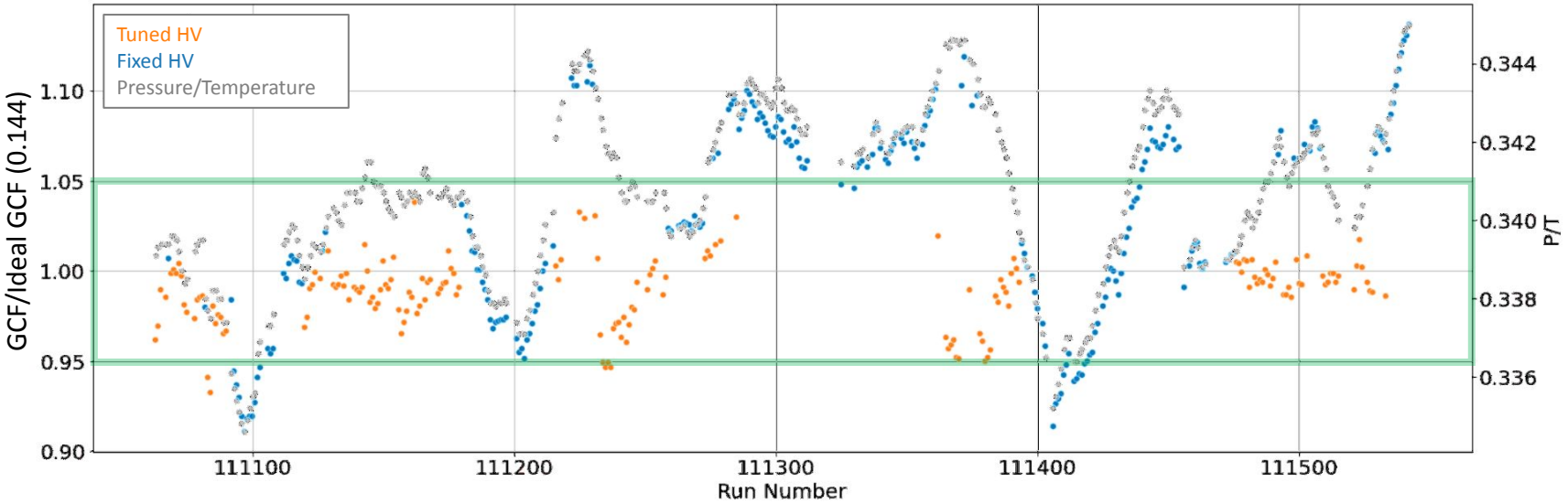


Deployment 3 – PrimEx-η June-Dec 2022

- GCF obtained from dE/dx after the run
- Preliminary results show GCF predominantly within 5% of ideal value for runs with tuned HV
- Plot of GCF/ideal for tuned HV and fixed HV also shows pressure/temperature



Calibration of the Forward Calorimeter

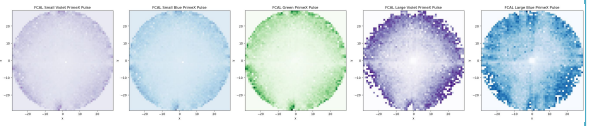
Diana McSpadden, Cullan Bedwell,
Abhijeet Chawhan, Julie Crowe

University of Virginia

Traditional Calibration:

- iterative over π^0s
- Requires particle reconstruction
- Statistics sometimes difficult

Can we use the LED monitoring system and Machine Learning?



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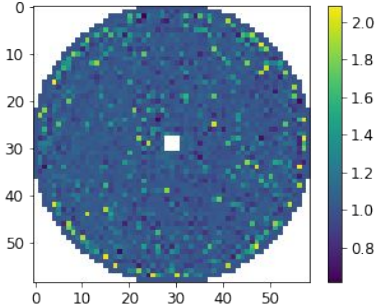
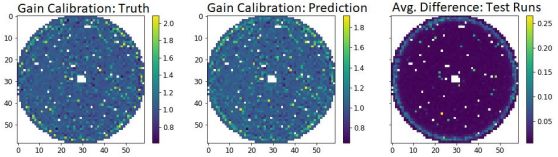
Gain calibration values

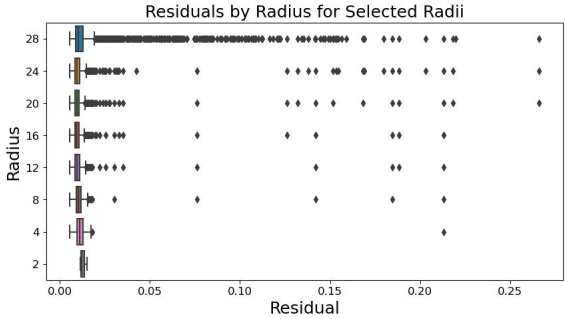


Can ML learn traditional calibrations?



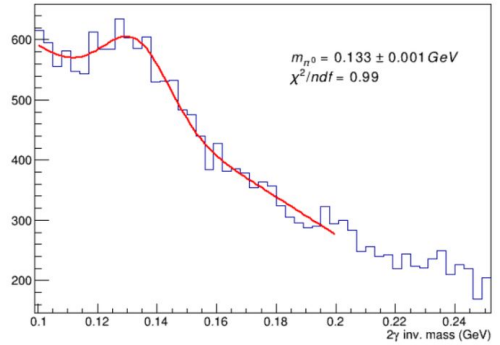
Average results over 5-fold cross validation

dataset	fold idx	average residual ↓	mape ↓	mse ↓
unmasked	average	0.258	23.848	5.183
masked	**average**	**0.027**	**2.370**	**0.004**



Initial Physics Comparison

- Does prediction accuracy result in good physics results?
- We have an initial π^0 analysis
  - Single run, entire FCAL



- π^0_{PDG} mass: **134.98 MeV**
- Using our calibrations: **133.31 MeV**

Jefferson Lab

Conclusion

- Implemented a Gaussian process to predict the gain correction factor from environmental conditions
  - Can exploit this prediction to compute a recommended HV via comparisons to an ideal gcf

- Deployed a system that serves as an interface between the ML model, the EPICS Archiver, and the GlueX Controls system
  - It is uncertainty aware
  - It has been in production for over 4 different deployments
  - Stabilizes the gain within 5% of ideal

- Begun work on calibrating the FCAL using the LED data

Acknowledgements

- Jefferson Science Associates, LLC operated Thomas Jefferson National Accelerator Facility for the United States Department of Energy under U.S. DOE Contract No. DE-AC05-06OR23177

- This work was supported by the US DOE as LAB 20-2261.

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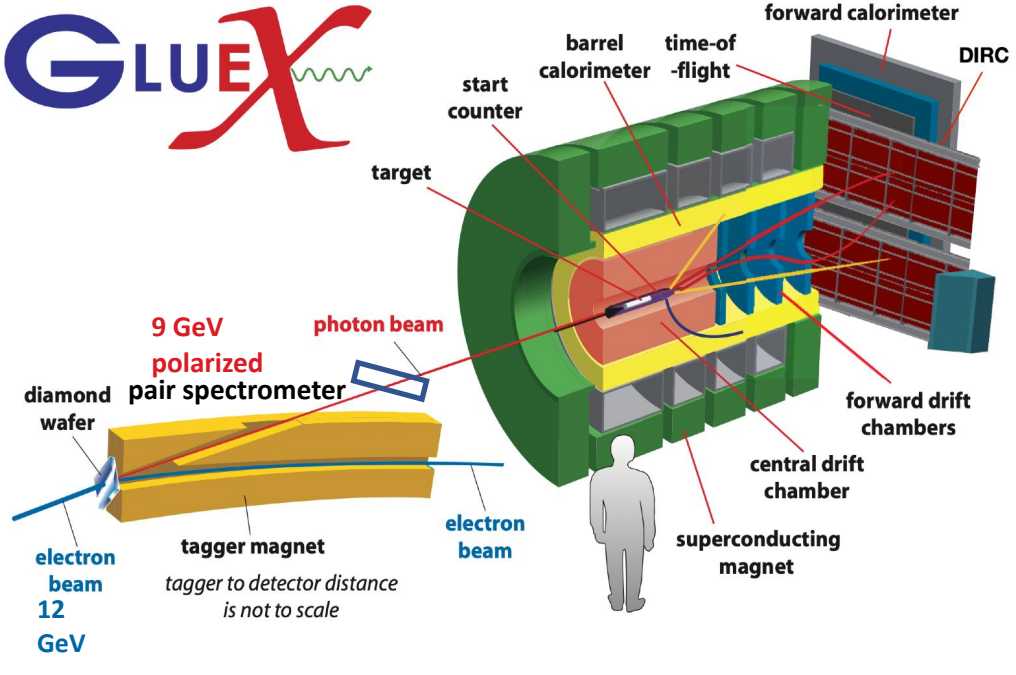
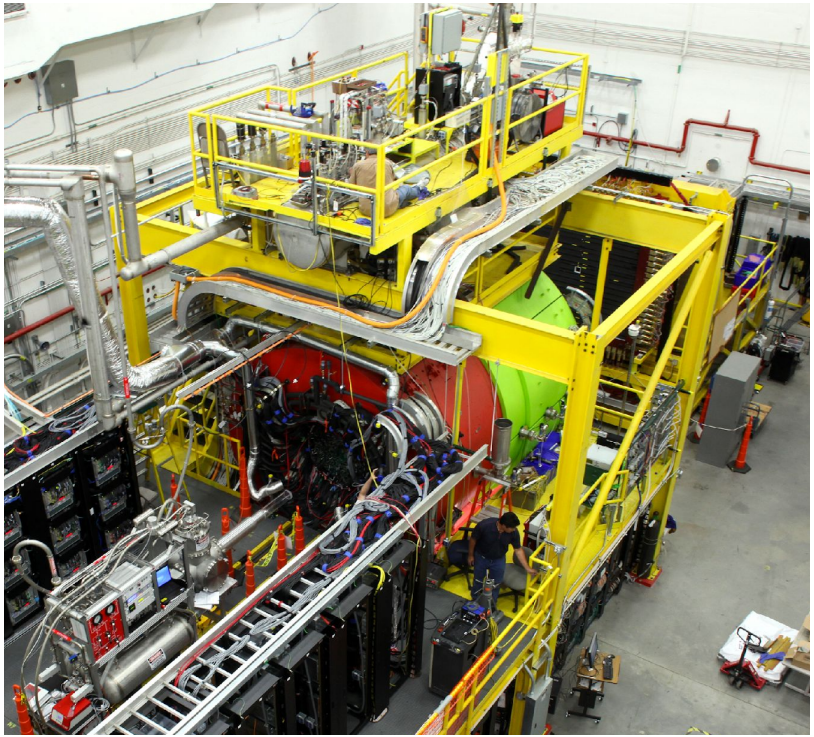
GlueX acknowledges the support of several funding agencies and computing facilities: www.gluex.org/thanks.

GlueX

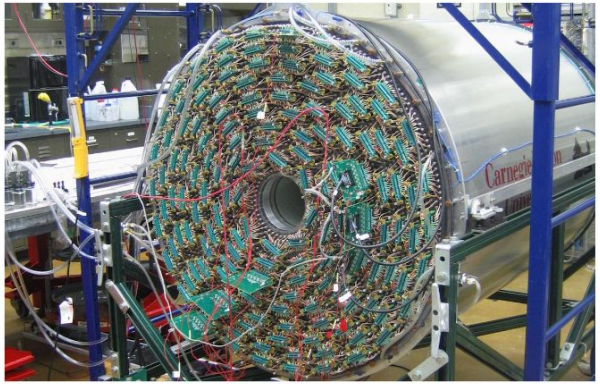
GlueX detector located in Hall D at Jefferson Lab, VA





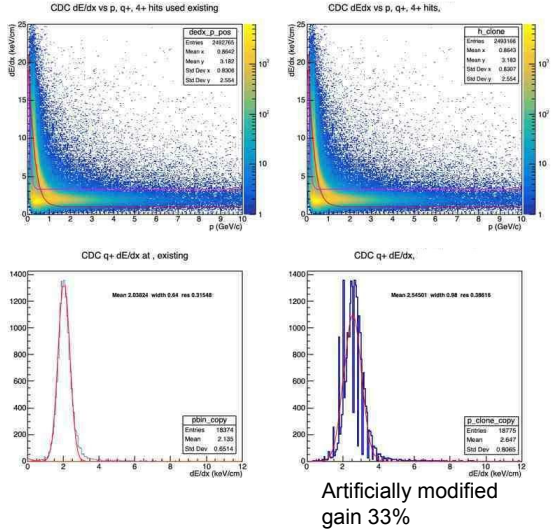
Introducing the CDC

- 1.5 m long x 1.2 m diameter cylinder
- 3522 anode wires at 2125 V inside 1.6 cm diameter straws
- 50:50 Ar/CO_2 gas mix
- Used to detect and track charged particles with momenta p > 0.25 GeV/c
- **Requires two calibrations: chamber gain and time-to-distance**



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



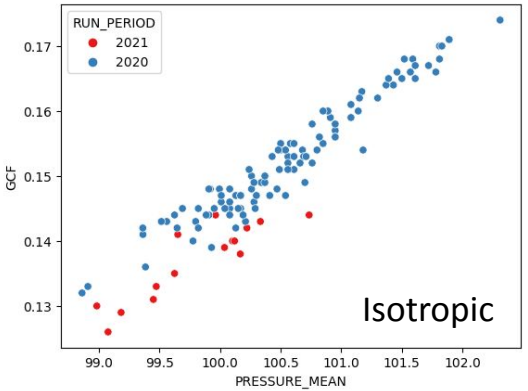
- **CDC gain calibrations** have the most variation **+/- 15%**
- If we know what gain to expect before taking data, we can **adjust the HV to maintain constant gain**
  - Perhaps eliminating the need to perform gain calibrations at all…

Our model

2020 and 2021 Run Periods: 601 production runs

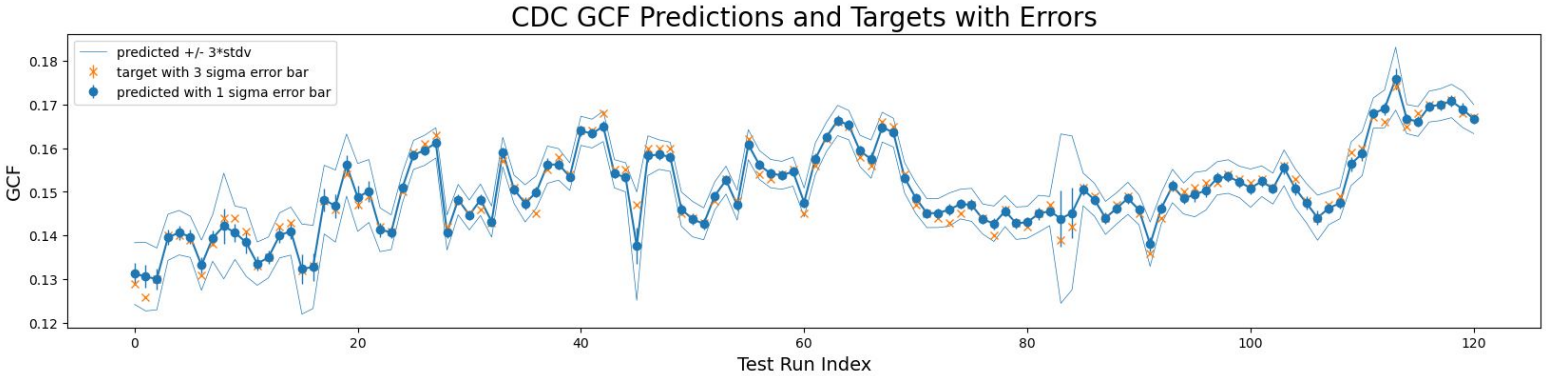
- 2020 run period had ↑ high voltage board current (mean 9.0 uA), ↑ pressure (mean 100.5 kPa), gas temperature (K) is the same
- 2021 run period high voltage board current (mean 0.9 uA), pressure (mean 99.9 kPa)
  - Provides a diversity of data
- Pressure balanced between high, medium, low atm. pressure for both 2020 and 2021 run periods
- Training: 480 runs
  - 2020: 430 runs
  - 2021: 50 runs
- Test: 121 runs
  - 2020: 106 runs
  - 2021: 15 runs

	max %err	MAPE	# > 3% err	# > 5% err
isotropic	4.8%	0.84%	3	0
anisotropic	4.7%	0.90%	4	0



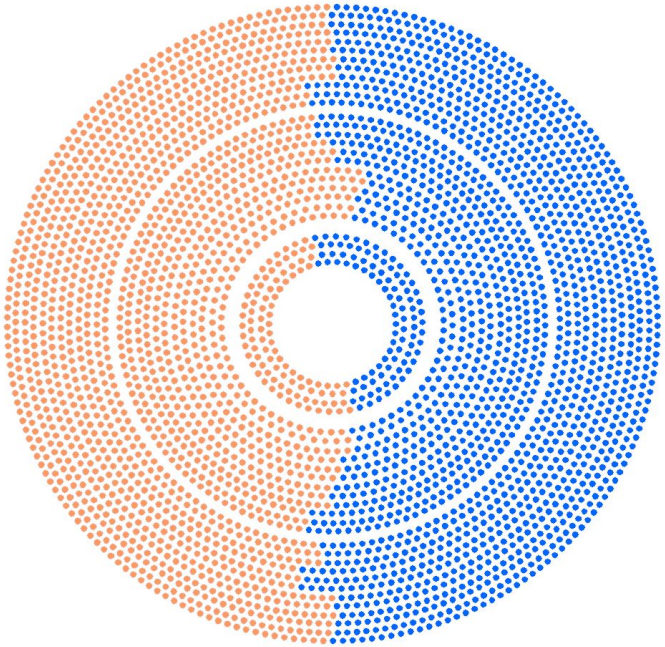
Gaussian process with a trained prior

- Compared isotropic and anisotropic kernels – similar performance



Cosmics Test

- Split the CDC into **2 halves**
  - Leave one side at a **fixed HV**
  - Let the **AI control the other**



- AI
  - Update the HV every 5 min
  - **Completely autonomous**

- Should see the AI system side's gains stabilized

Conclusions

- A system has been developed to interface between the ML model and both the EPICS Archiver and GlueX controls system
  - A gaussian process has been trained to predict the gain correction factor from environmental conditions
    - Can exploit this prediction to compute a recommended HV via comparisons to an ideal gcf
  - It is uncertainty aware
  - It has been in successful production over multiple deployments
  - Stabilizes the gain within 5% of ideal

- Begun work on calibrating the FCAL using the LED data