AI Experimental Calibration and Control

Thomas Britton[§], Michael Goodrich[§],
Naomi Jarvis*, Torri Jeske[§], Nikhil Kalra[§],
David Lawrence[§], Diana McSpadden[§],
Kishansingh Rajput[§]

[§]Thomas Jefferson National Accelerator Facility
*Carnegie Mellon University

Annual Budget

Summary of expenditures by fiscal year (FY)*:

	FY20 ($k)	FY21 ($k)	FY22 ($k)	Totals ($k)
a.) Funds allocated	270	270	270	810
b.) Actual Costs to date	270	270	27	567

total award for 3 years: $810k

- Mostly labor cost

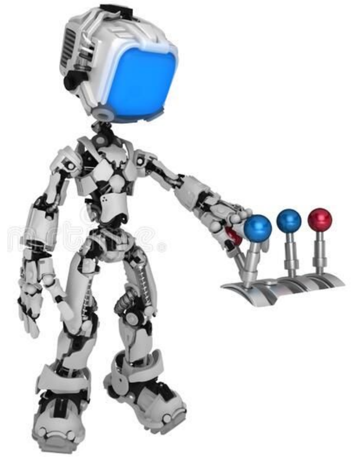
**n.b. funds come at end of fiscal year so are actually spent during the following fiscal year*

Motivation

- Sensitive detectors need to be calibrated to obtain optimal resolution
- Calibrations cause a delay between data collection and analysis (weeks-months)
  - Multiple iterations are needed to converge to final set of constants

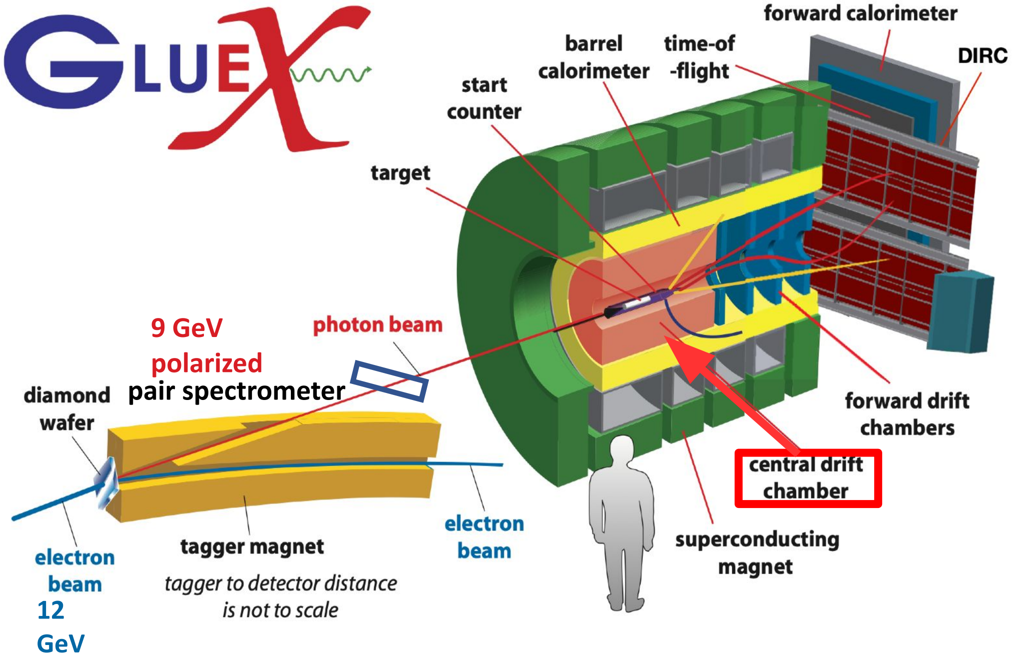
Main Goal:

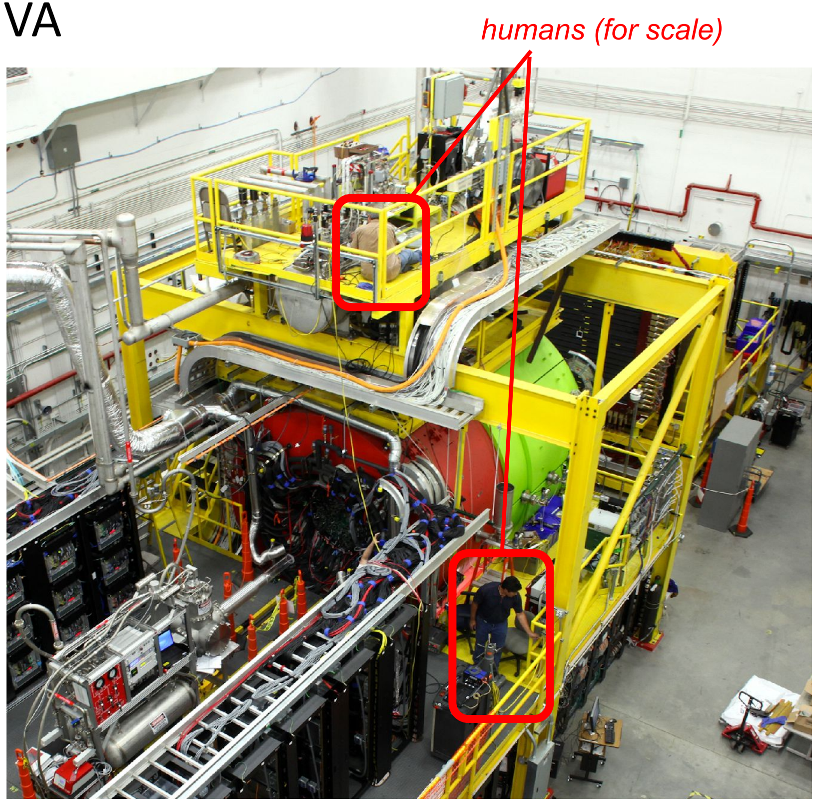
Dynamically adjust the controls of a sensitive detector to reduce or eliminate the need for calibration



The GlueX Detector

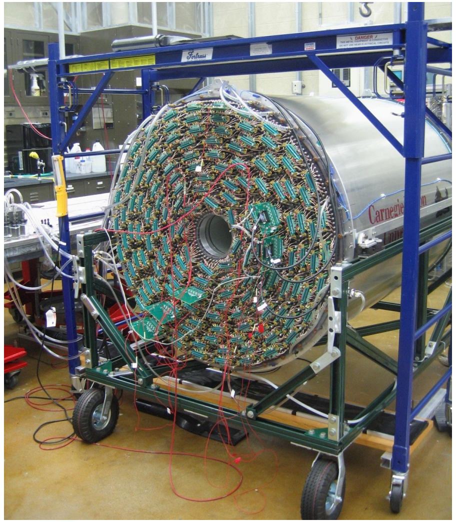
GlueX detector located in Hall D at Jefferson Lab, VA

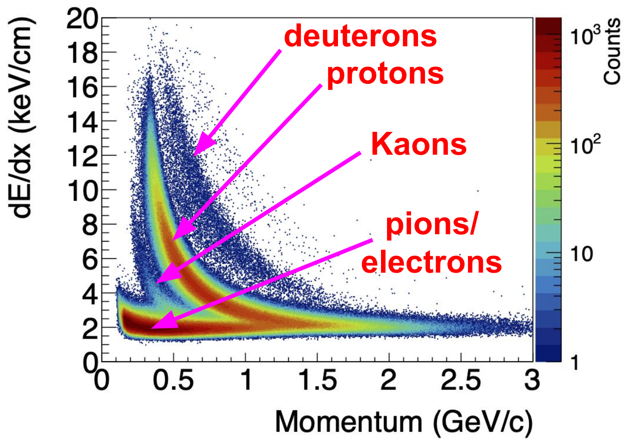




The CDC (= Central Drift Chamber)

- 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

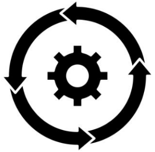




Motivation: Conventional vs. Online, ML Calibration Paradigms

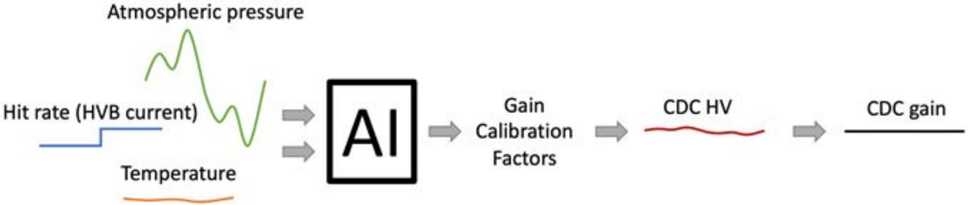
Conventional

- **Calibrate**: calibration values **iteratively,** produced after the experiment
  - **~2 hour runs**
- **Control**: CDC operating voltage is ***fixed*** at 2125 V

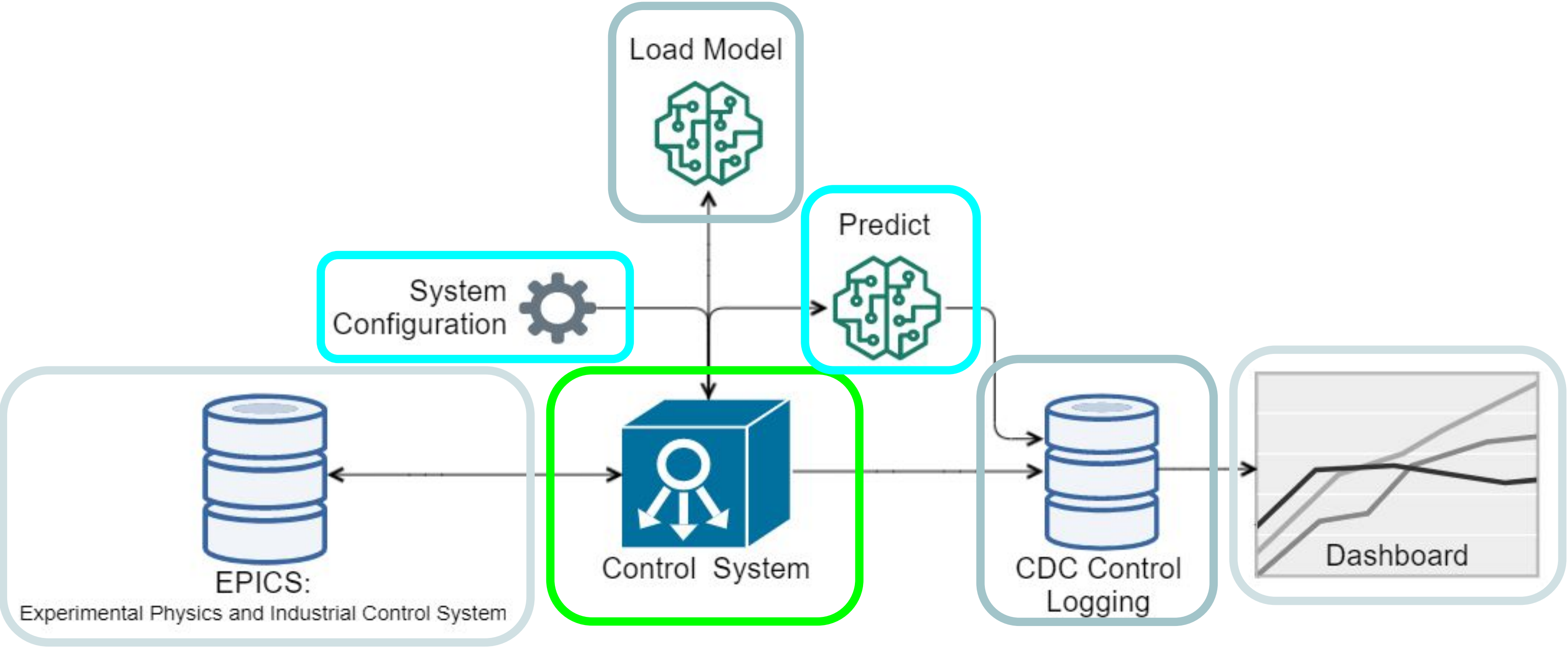


Online and ML

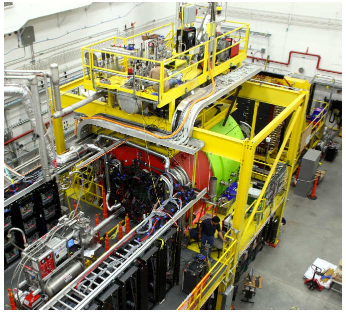
- **Control**: Stabilize detector response to changing environmental/experimental conditions by ***adjusting*** CDC HV
- **Calibrate**: **online** calibration values produced during the experiment



Integrating AI/ML into Control System

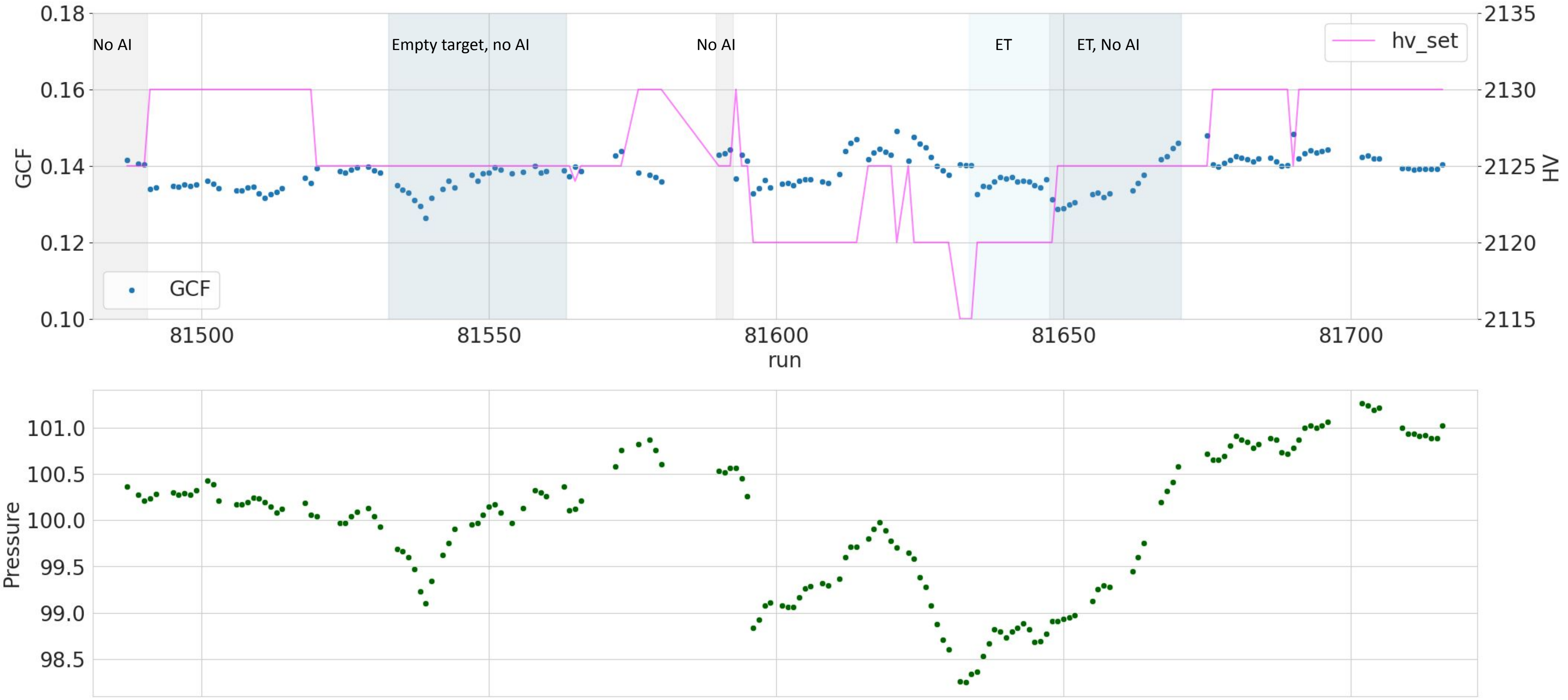


Fall 2021 Beam Test

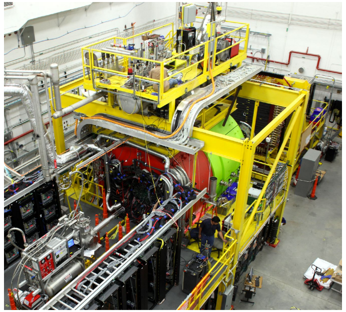


- Mid-October to early November 2021
- PrimEx-η running with GlueX Detector in Hall-D
    - Run plan was to have small amount of data with Solenoid on but most with it off
- Planned to test AI system over 2 days when solenoid was on
- Background levels were improved significantly with solenoid on
    - PI’s changed plan and ran with it on for ~2weeks 
    - Atmospheric pressure did not change as much as we wanted 

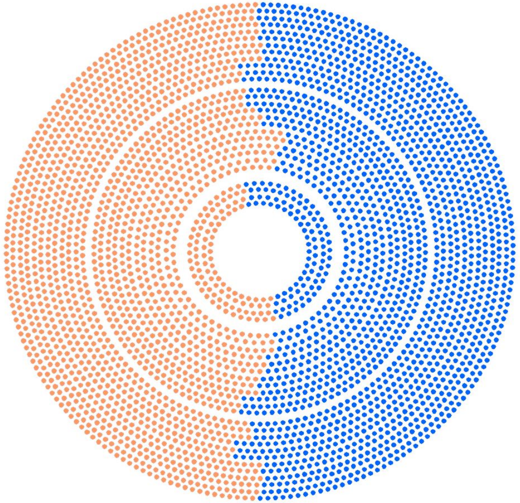
Gain correction factors from conventional calibrations



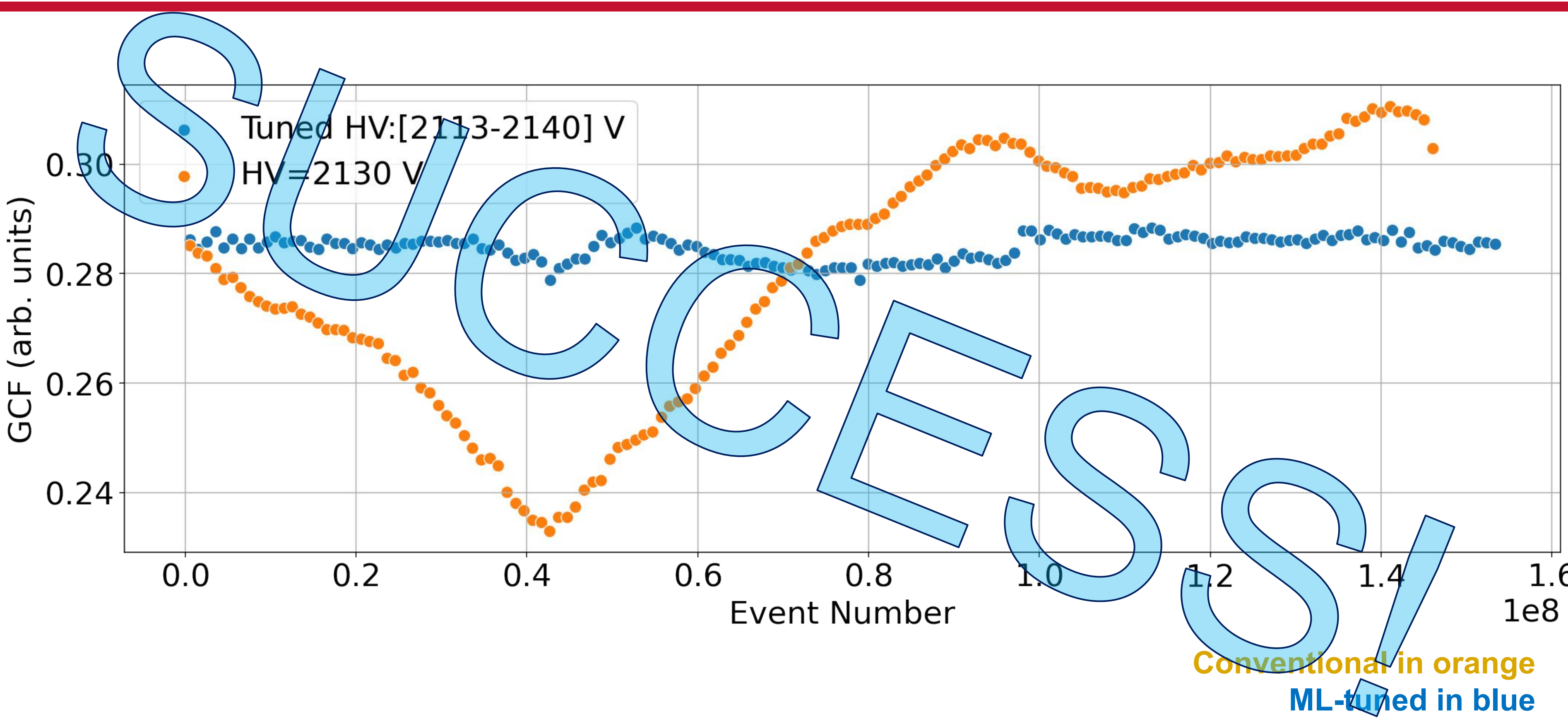
Automation Test with Cosmic Rays



- Two weeks in March 2022
- Half of sense wires controlled by AI/ML. Other half used HV
- Fully automated with AI/ML adjustments every 5 minutes
- No beam. Cosmics only.



Cosmics Test Results



Conventional in orange
ML-tuned in blue

The Gaussian process model

EPSCI
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ML Technique

Gaussian Process (GP)

- 3 features:
  - **atmospheric pressure** within the hall
  - **Gas temperature** within CDC
  - **CDC high voltage board current** -> a measure of intensity of the electron beam current within the CDC
- 601 runs from 2020 and 2021 run periods
  - 536 and 65 respectively
  - Pressure balanced for low, medium and high pressure
  - 80 / 20 train test split
- **1 target**: the traditional Gain Correction Factor (**GCF**)
- GP calculates PDF over admissible functions that fit the data
- GP provides the standard deviation
  - we can exploit for uncertainty quantification (UQ)
- We used a popular GP kernel:
  - Radial Basis Function + White
  - Compared isotropic (1 length scale) and anisotropic (length scale per input variable) kernels

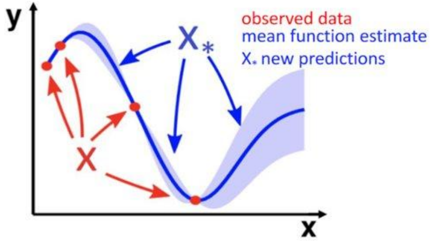


Illustration training a Gaussian process

We can exploit the standard deviation for uncertainty quantification (UQ).

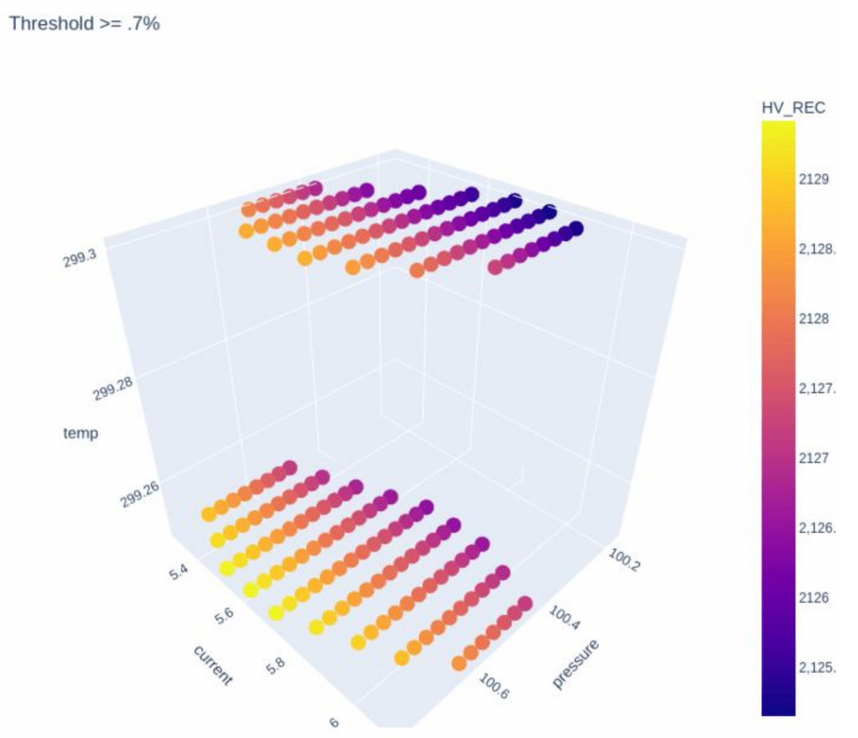
Our goal was better than a 5% error

RBF kernel (length scale(s))		RMSE	Mean |% err|
Isotropic (1.412)	0.97	0.002	0.8%
Anisotropic (1.4,1.17,.171)	0.97	0.002	0.8%

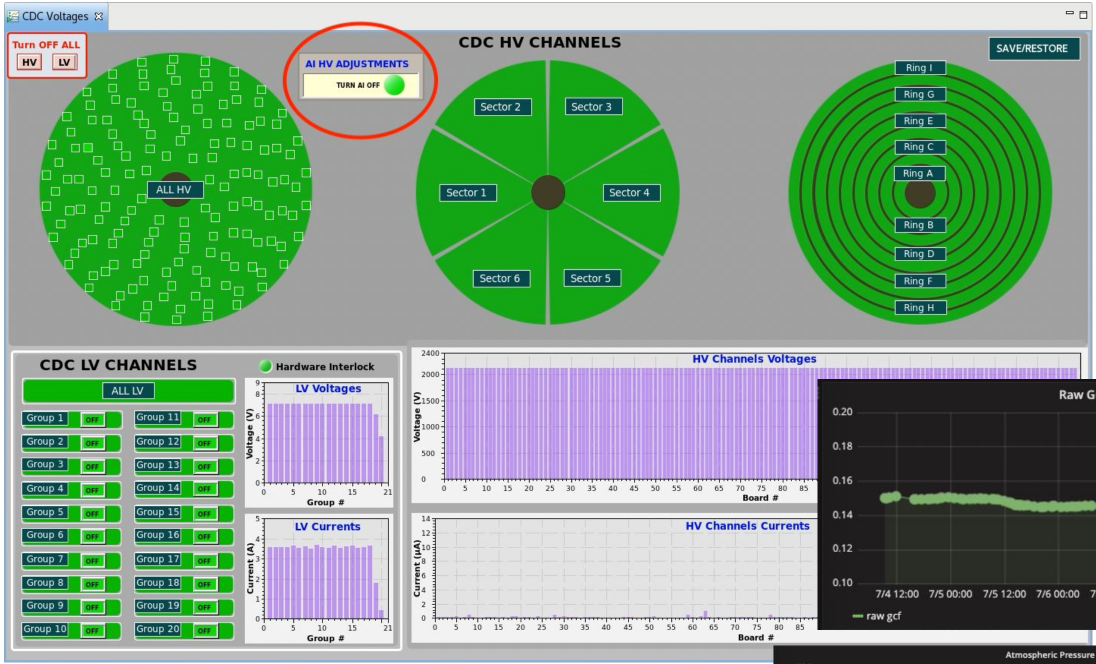
Uncertainty Quantification

An approach we are investigating is creating a system to automate the learning process as environmental and experimental conditions change:

1. A system that knows when it is **certain** and **control** the experiment
2. Says "I don't know" when **uncertain**, and **collects** more data and "**learns**"
3. Online retraining, evaluation of retrained model…
4. Implement the retrained model that should be certain for more conditions

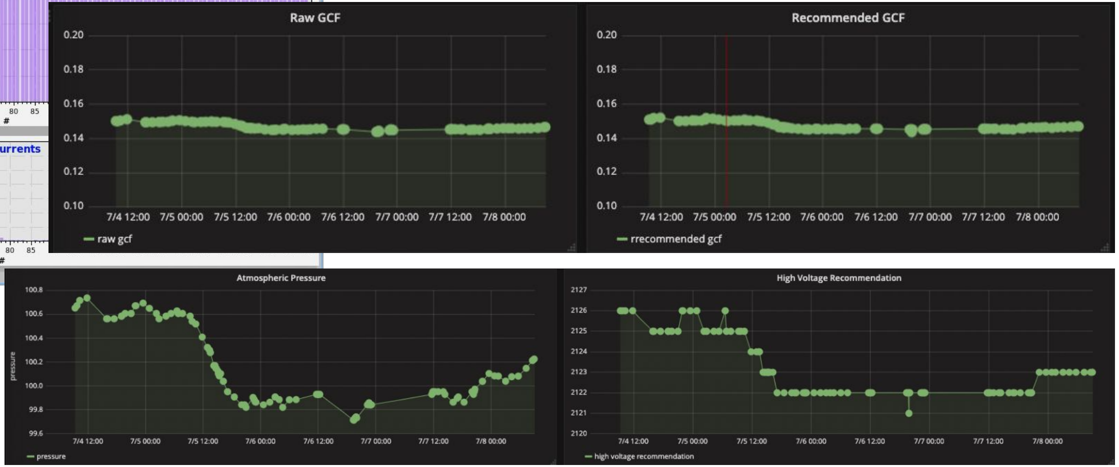


Integrating AI/ML into Standard Operations



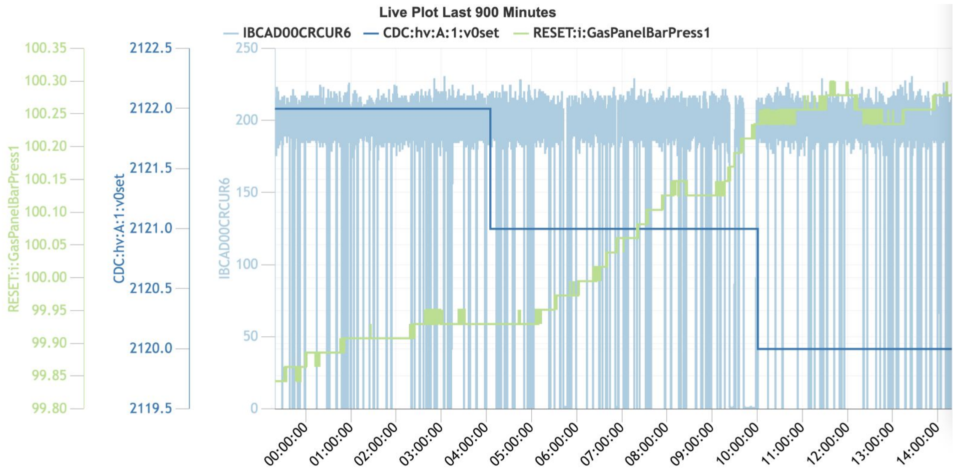
A switch was added to CDC Control GUI to allow shift takers to disable the AI/ML control completely.

Monitoring of the entire system was put onto a Grafana server.



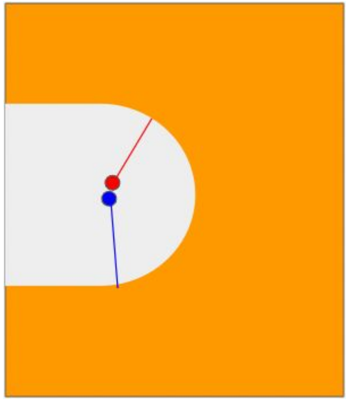
Observed Behavior that was Unexpected

Plot to the right shows HV setting was dropping while atmospheric pressure was rising during period of constant beam current. This is the opposite of what is expected.



Issue turned out to be due to using point on surface of minimum acceptable uncertainty with the minimal Euclidean distance to actual point in feature space.

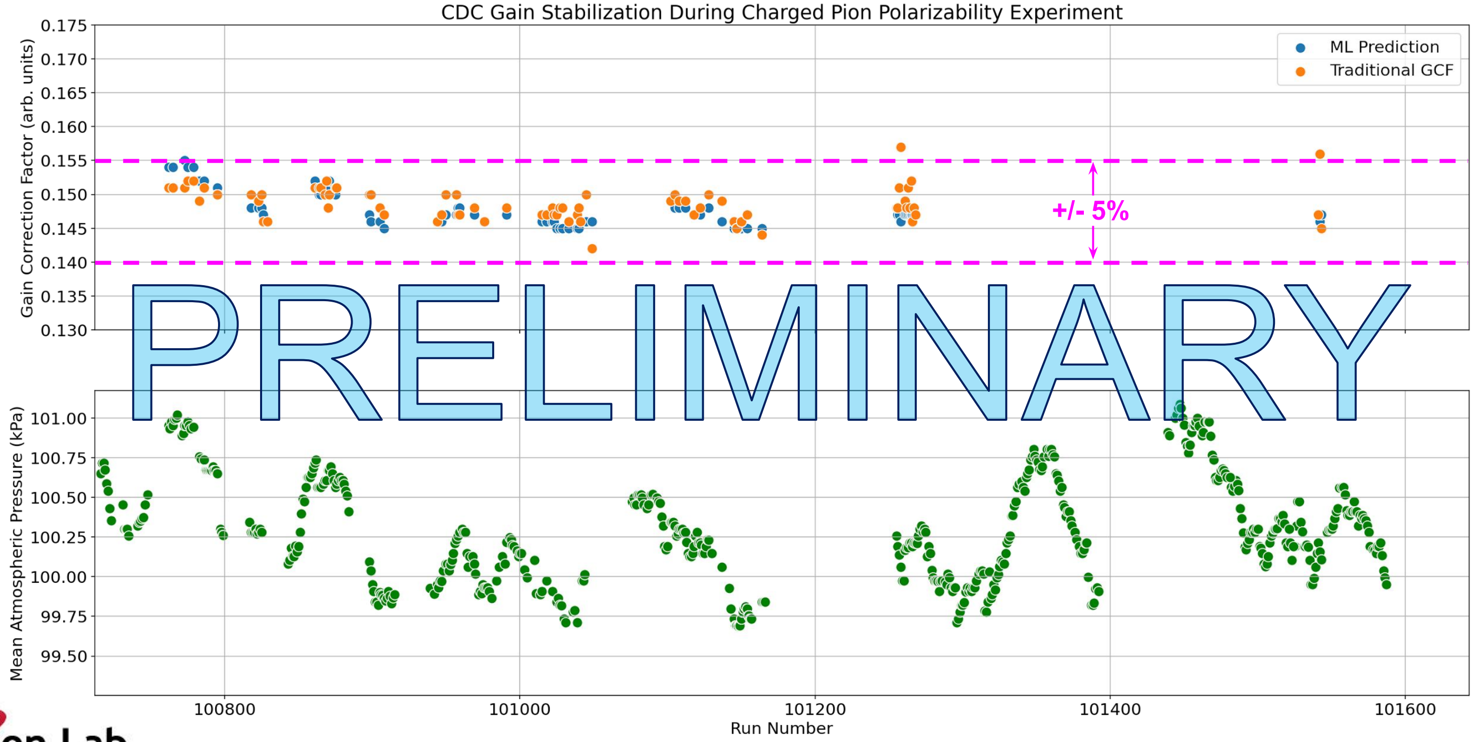
A small change in location in feature space could result in a large change in the projected location on the surface of uncertainty.



n.b. the GCF value was actually still within the few percent tolerance for operations.

Fully Automated System Deployed

- Charged Pion Polarizability (CPP)
  - Used RoboCDC at the start of each run in the experiment



Fully deployed system during CPP Experiment in Summer 2022

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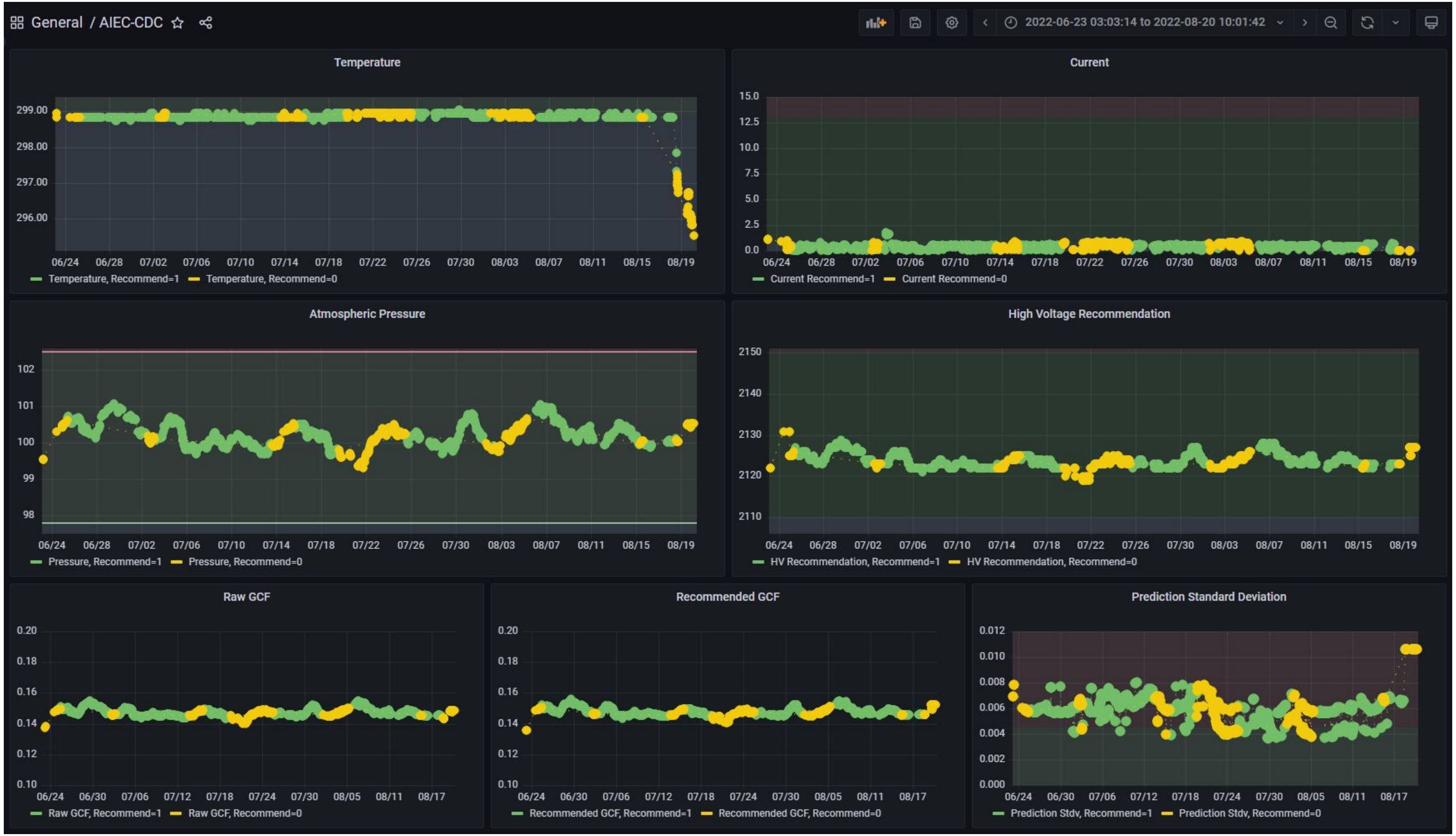

Future

- Successfully proposed as capstone project for UVA Data Science Department Master's program
  - Started meeting with 4 students. They will start work in earnest in Spring Semester

- Focus will shift to 2880 element E/M calorimeter
  - Sophisticated LED monitoring system
    - Four sections (acrylic sheets), each with 720 PMTs flashed by 100 LEDs
    - Varying proximities between each PMT and LED

Milestones	
FYQtr	**Description**
FY23Q2	• Review historical data. • Prepare data sets including FCAL-LED skim files and existing calibrations. • Develop model(s) to extract relative calibration constants from LED events.
FY23Q3	• Map the relation between gain and HV • Implement policy for detecting and dealing with problem PMTs.
FY23Q4	• Integrate automated system for AI/ML control of FCAL PMT HV • Automatic generation of calibration constants into operations

Summary

- Successfully reproduced calibration constants using AI model using same inputs as classic method
- Successfully ***predicted*** GCF calibrations using environmental data from GlueX 2018 and 2020 runs
- Successful ***preliminary beam test*** where AI suggested HV settings resulting in more stable GCF
- Successful ***automation test*** using cosmic rays
- Successful ***deployment*** of UQ aware system for CPP experiment in summer 2022
    - Now part of standard operations
- UVA Capstone proposal accepted to work with DS students on automating Calorimeter in 2023

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

References

GlueX Detector NIM A**987**, 164807 (2021)

GlueX Central Drift Chamber NIM A962, 163727 (2020)

GPR: https://arxiv.org/pdf/2009.10862.pdf

Experimental Physics and Industrial Control System https://epics.anl.gov/

Garfield – Simulation of Gaseous Detectors

Backup slides

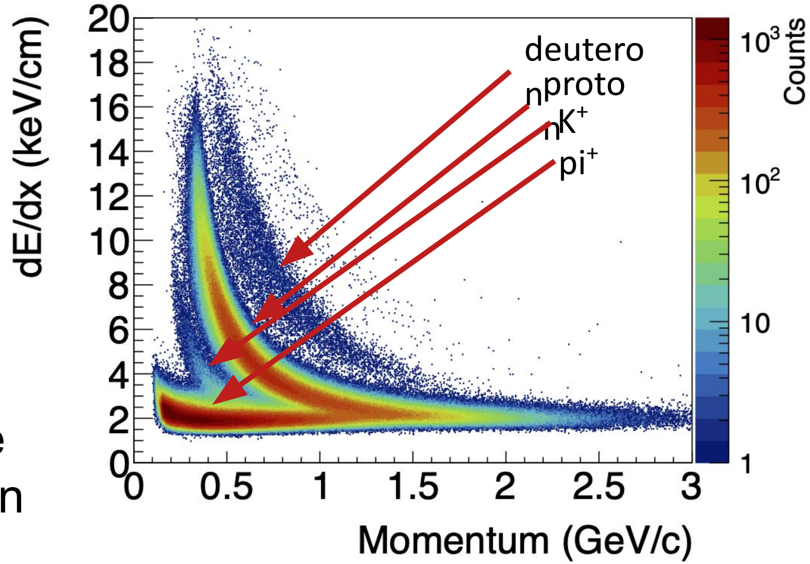
Milestones			
FYQtr	**Description**	**Due Date**	**Status**
FY21Q1	Setup accounts, post job descriptions and form hiring committees.	12/23/2020	✓
FY21Q2	Hiring committee completes interview process and new hires for project are in place	3/31/2021	✓
FY21Q3	New hires able to calibrate GlueX CDC detector using existing system.	5/1/2021	✓
FY21Q3	System in place to extract data from Hall-D EPICS archive and GlueX raw data/reconstructed data into form suitable for machine learning.	6/15/2021	✓
FY21Q4	Candidate network topologies identified along with initial dataset to be used for training.	9/30/2021	✓
~~FY22Q1~~	*After some investigation found there were issues with implementing this on the time scale of the project* ~~Able to calibrate CLAS12 DC detector using existing systems.~~	~~12/23/2021~~	~~started~~
FY22Q2	System in place to extract data from Hall-B EPICS archive and CLAS12 raw data/reconstructed data into form suitable for machine learning.	3/31/2022	✓

Milestones			
FYQtr	**Description**	**Due Date**	**Status**
FY22Q3	Plan developed and software machinery in place to test prototype system using current best model for GlueX CDC detector with cosmic rays. System will provide suggestions to shiftworkers for new settings.	6/30/2022	✓
FY22Q4	Model review and refinement. Performance of initial model choices reviewed and decisions made on whether new model development is needed or refinement of existing models. Plan for next stages of development in place based on results of review.	9/30/2022	✓
FY23Q1	Plan developed and software machinery in place to test prototype system using current best model for CLAS12 DC detector with cosmic rays. System will provide suggestions to shiftworkers for new settings.	12/23/2022	
FY23Q2	Performance evaluation complete.	3/31/2023	
FY23Q3	Documentation in place for system deployment and operation.	6/30/2023	
FY23Q4	System deployed in standard experimental hall operations in Hall-B and Hall-D (pending collaboration approval)	9/30/2023	

please see revised milestones on slide 18

CDC Calibrations

- Gain affects PID selections in analysis
  - Sensitive to environmental conditions
    - Atmospheric pressure
    - Temperature
  - Sensitive to experimental conditions
    - Beam conditions change with the experiment



•**Traditionally**:

•GCF obtained from Landau fit to amplitude

•Calibration constants are generated per run

•Approximately 2 hours of beam time

HV Channel Segmentation (Prepping for Cosmics Test)

GlueX CDC

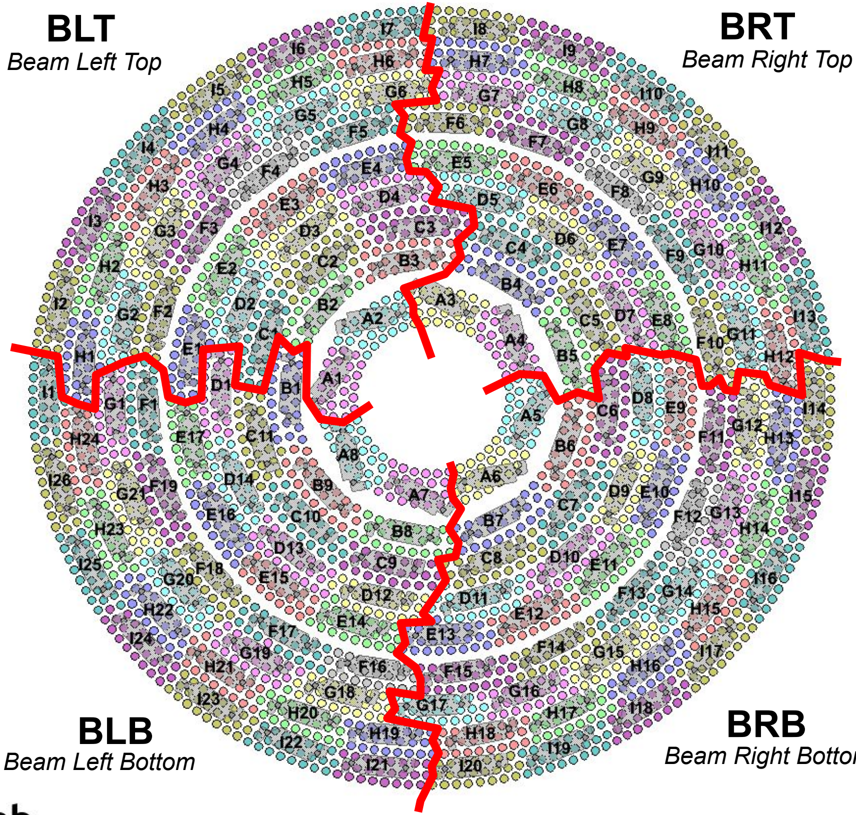
View from upstream

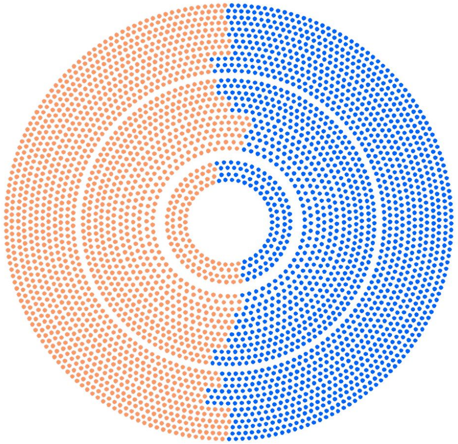
A: 1-2
B: 2-3
C: 1-3
D: 2-4
E: 1-4
F: 2-5
G: 2-6
H: 1-6
I: 2-7

BLT
Beam Left Top

BRT
Beam Right Top

A: 3-4
B: 4-5
C: 4-5
D: 5-7
E: 5-8
F: 6-10
G: 7-11
H: 7-12
I: 8-13





A: 7-8
B: 1,8-9
C: 9-11
D: 1, 12-14
E: 14-17
F: 1,16-19
G: 1,18-21
H: 19-24
I: 1,21-26

BLB
Beam Left Bottom

BRB
Beam Right Bottom

A: 5-6
B: 6-7
C: 6-8
D: 8-11
E: 9-13
F: 11-15
G: 12-17
H: 13-18
I: 14-20

Split the CDC into **2 halves**

- Leave one side at a **fixed HV (conventional)**
- Let the **ML control the other**
- **Autonomously** adjust HV every 5 min