ML for Experiment Calibration and Control

Towards online calibrations and control with the GlueX Central Drift Chamber

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Streaming Readout X

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AI for Experimental Controls Group

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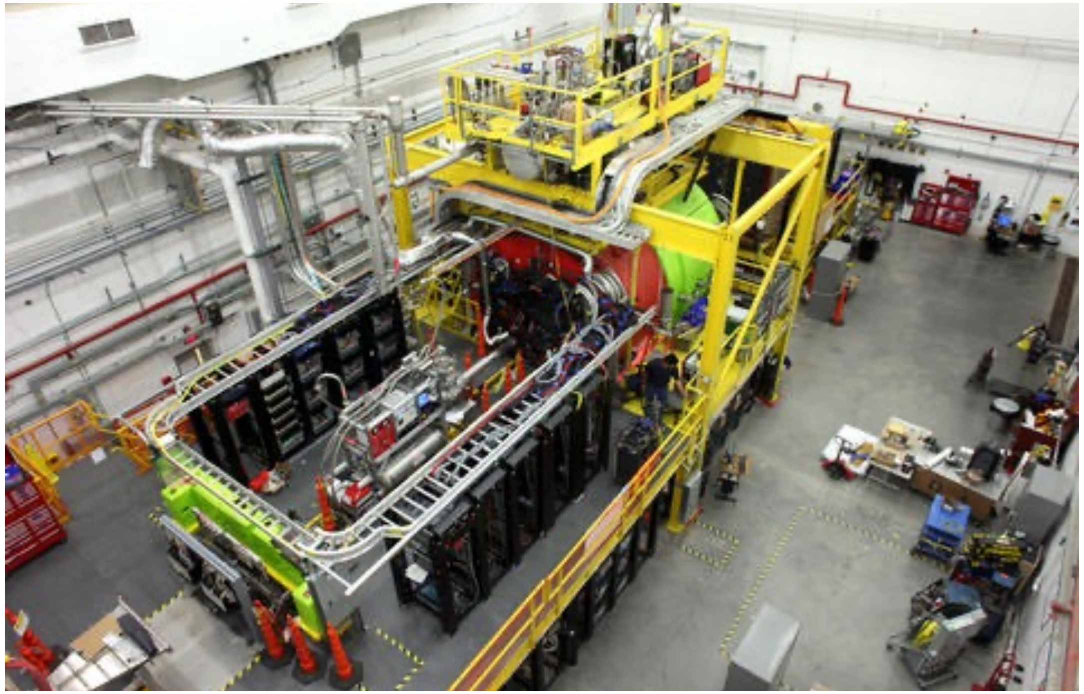
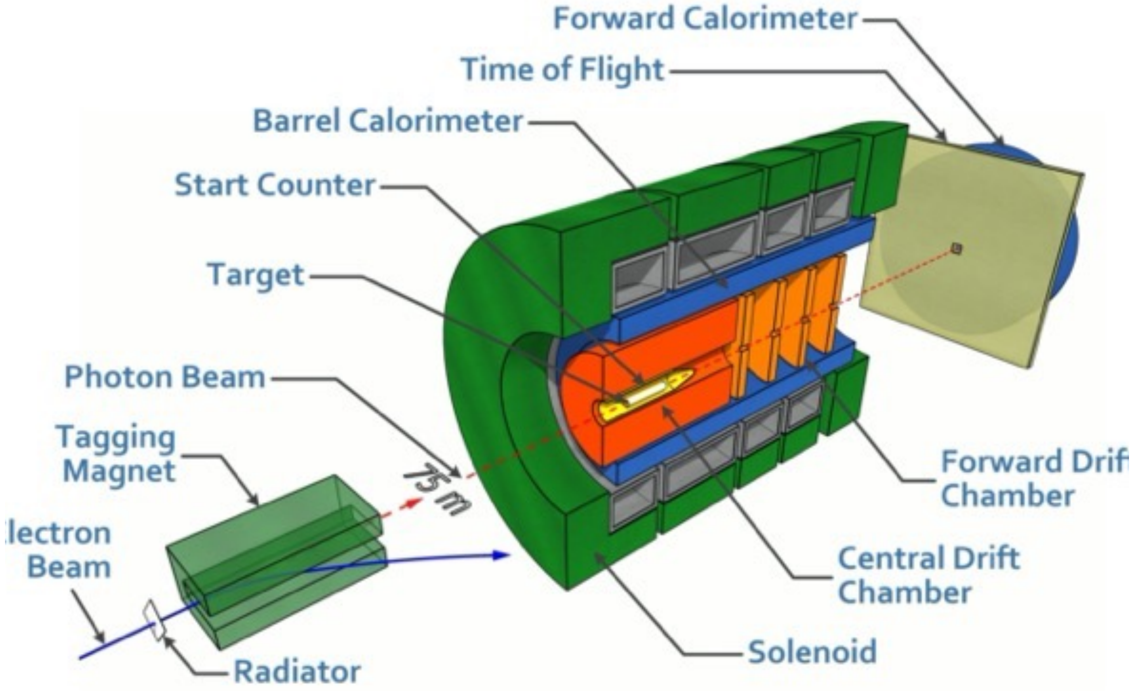
The Gluonic Excitations Experiment in Hall D

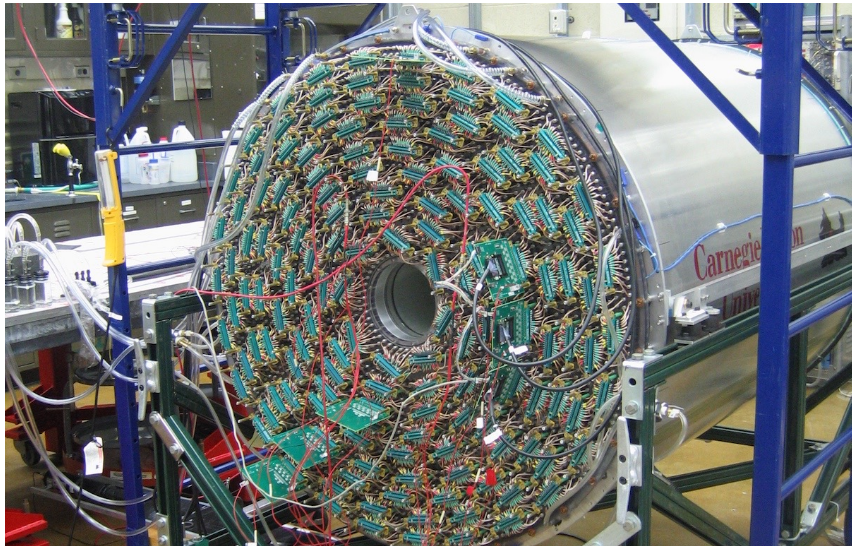
- Designed to search for exotic hybrid mesons produced in photoproduction reactions and study the hybrid meson spectrum

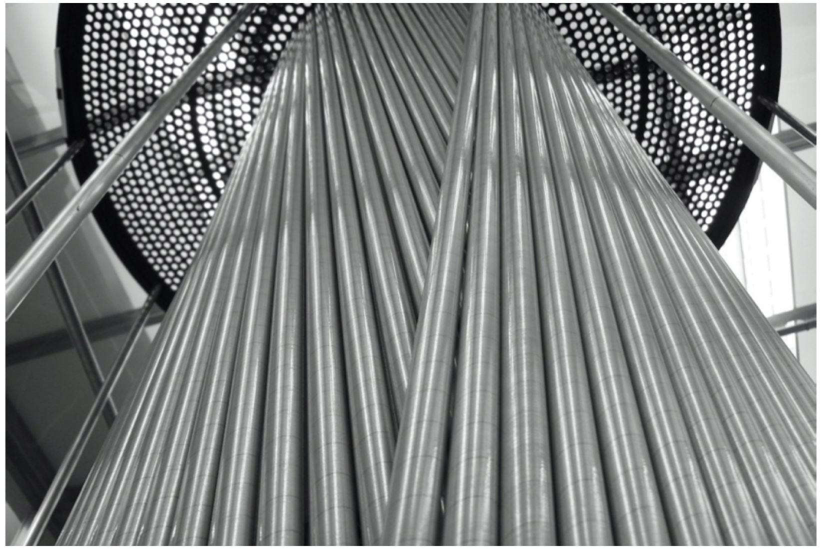




GlueX Central Drift Chamber

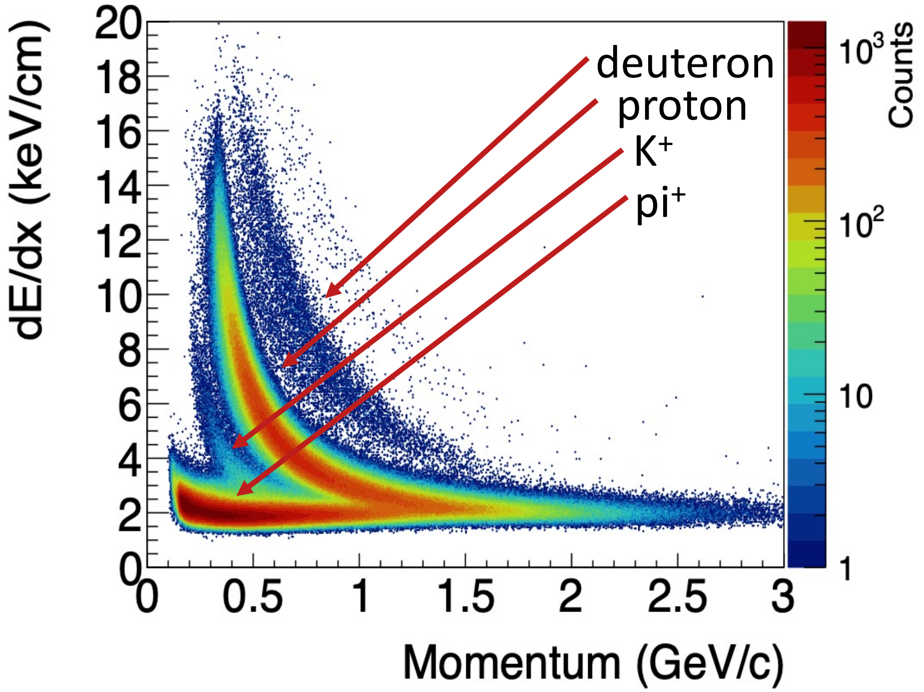
- 1.5 m long x 1.2 m diameter cylinder
- 3522 anode wires at 2125 V inside 1.6 cm diameter straws
- 50:50 Ar/CO_2 gas mix
- Used to detect and track charged particles with momenta p > 0.25 GeV/c
- **Requires two calibrations: chamber gain and time-to-distance**





Offline CDC Calibrations

- Gain: affects PID selections in analysis
  - Sensitive to environmental and experimental conditions
  - **Gain correction factor obtained from Landau fit to pulse height, fine tuned using dE/dx**



- Time to distance: track fitting, vertex and dE/dx resolution
  - Non-analytic fit function generates 6 unique calibration values

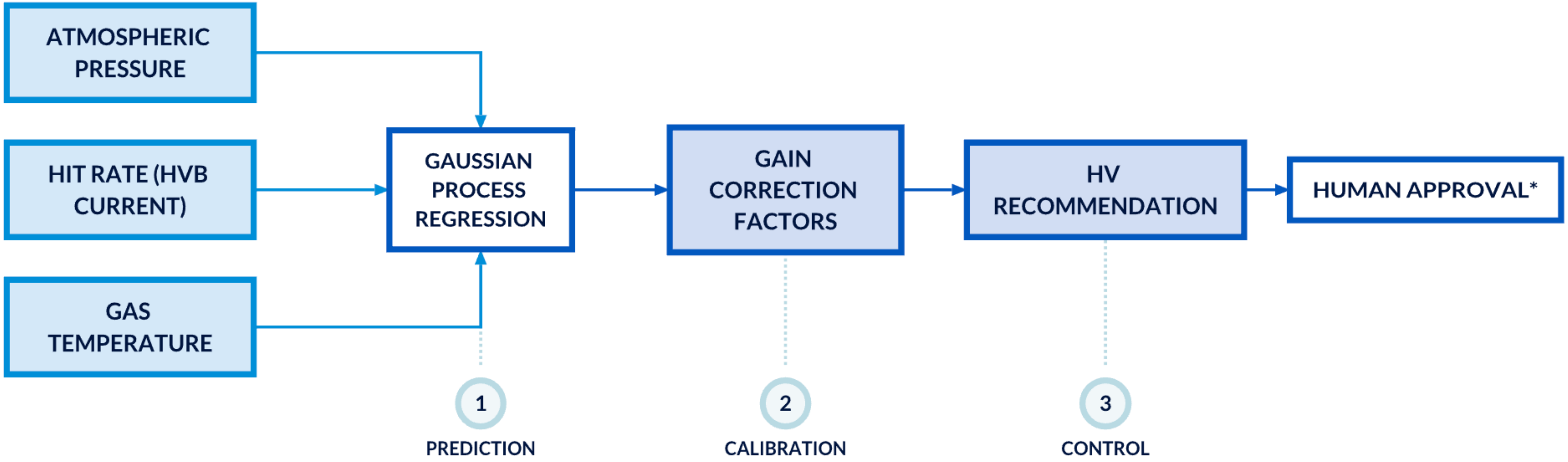
- Calibration values are extracted from fitting histograms (produced via reconstruction software) on a per run basis
  - requires significant computing time, attention from experts

Challenges (in no particular order)

- Quick training and inference times
- Readily available input features
- Robustness to out-of-domain experimental conditions
- Safety constraints
- Interfacing with detector experts and shift takers
- Trustworthiness
- Physics based evaluation metric(s)

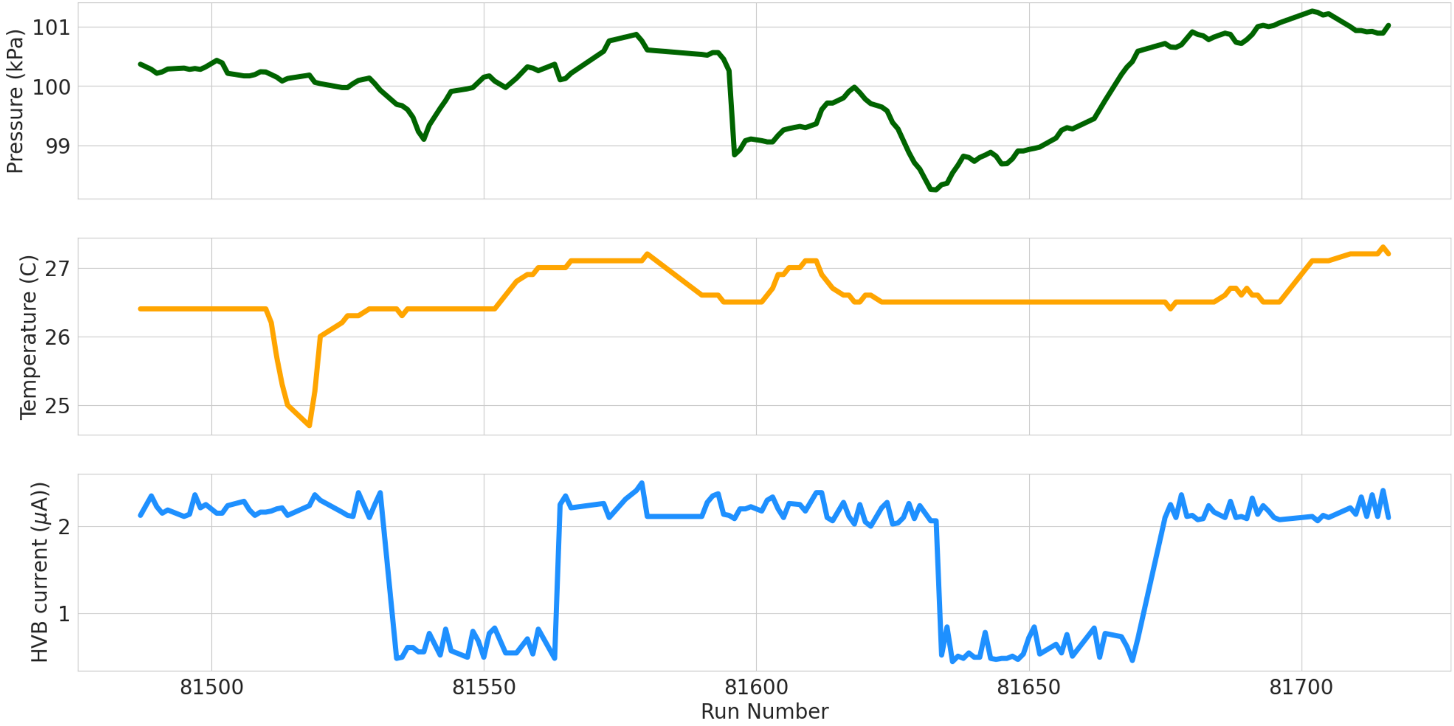
Online Calibration and Control with the GlueX Central Drift Chamber

- Maintain consistent detector response to changing environmental/experimental conditions by adjusting CDC HV
- Produce calibration constants during data taking



Input Features

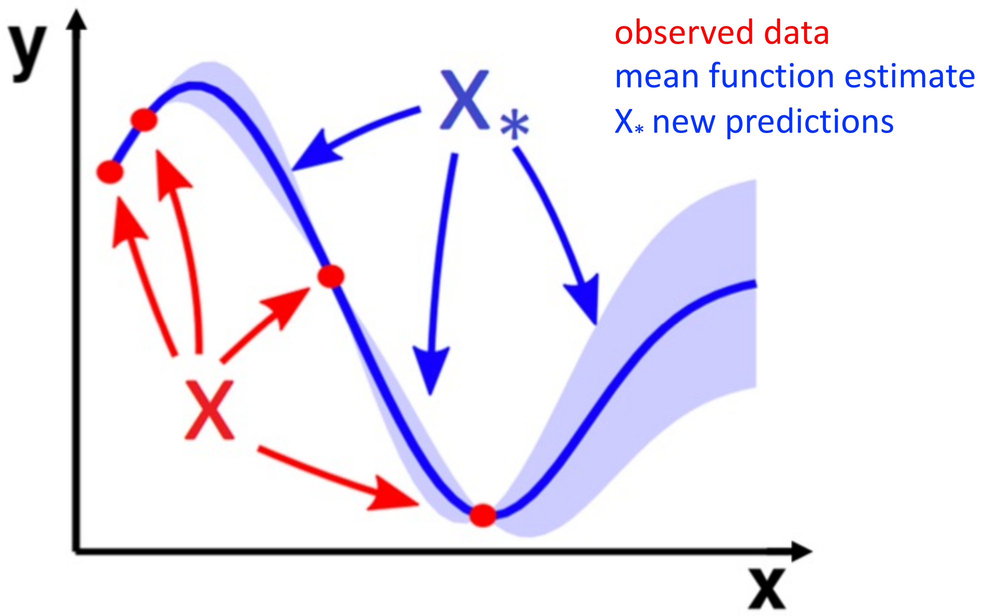
- Data extracted from Experimental Physics Industrial Controls System (EPICS)
- Initial input features generated from:
  - Atmospheric pressure
  - Gas temperature
  - Current drawn from CDC HV boards
- Readily available during the experiment



Production data from 2021 Run Period

Gaussian Process Regression

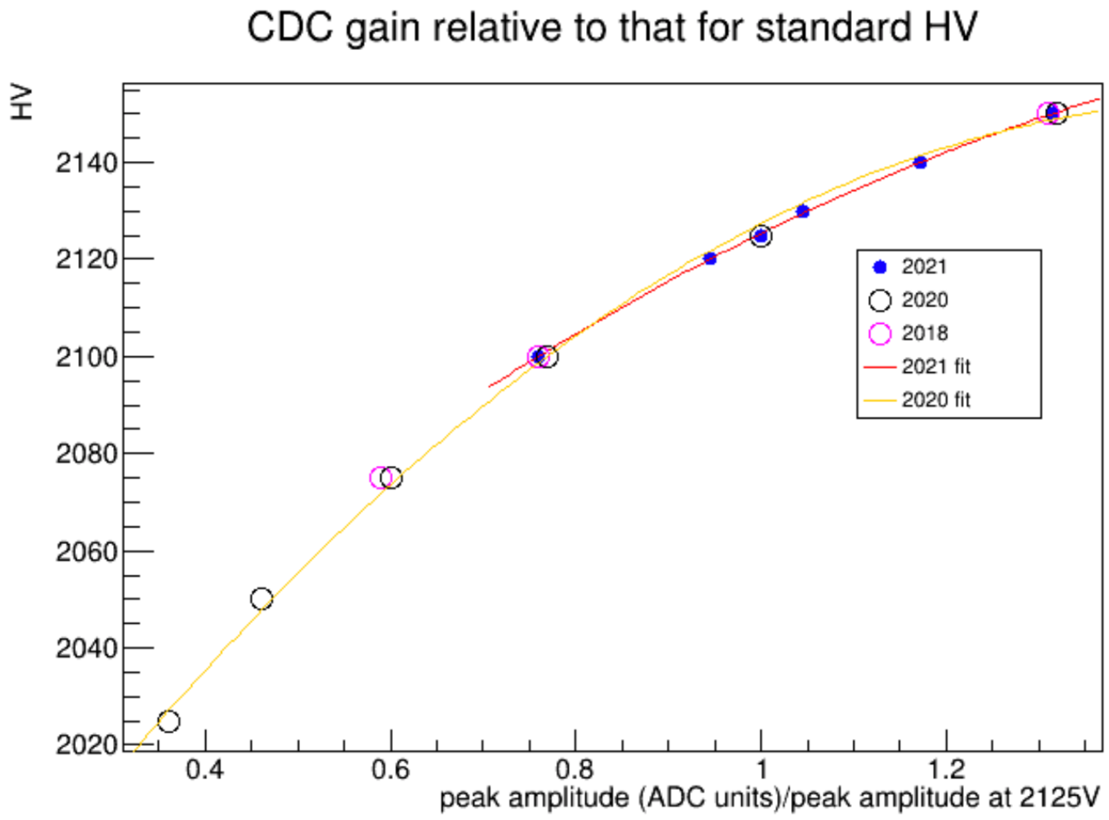
- Gaussian process: probability distribution over possible functions that fit a set of points
- Suited to small data set
- Provides uncertainty quantification
  - Important for creating trustworthy AI
- Very fast training and inference
  - 100 iterations took 84 seconds to train on 4 x86_64 CPUs with 1 GB RAM
  - Inference takes 3 ms



Jefferson Lab

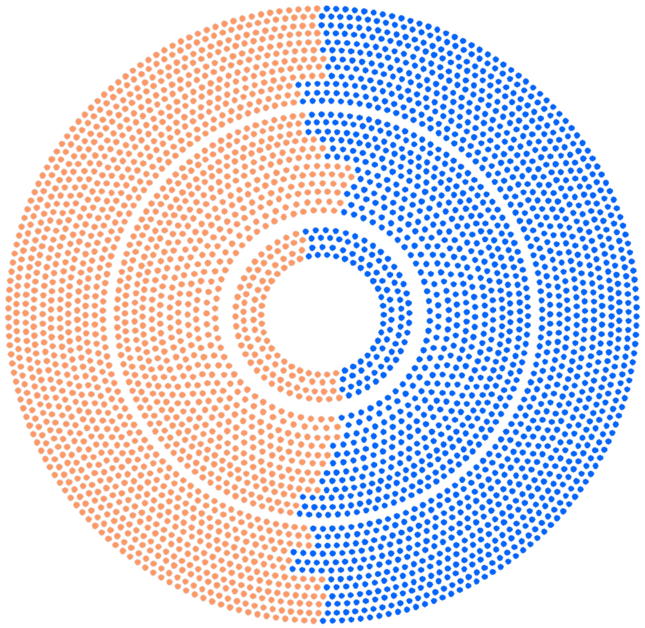
HV Adjustment

- Utilize HV scan data from past experiments in Hall D
- Recommendation obtained from fit to HV as function of peak amplitude relative to that at 2125 V



Cosmics Test Setup

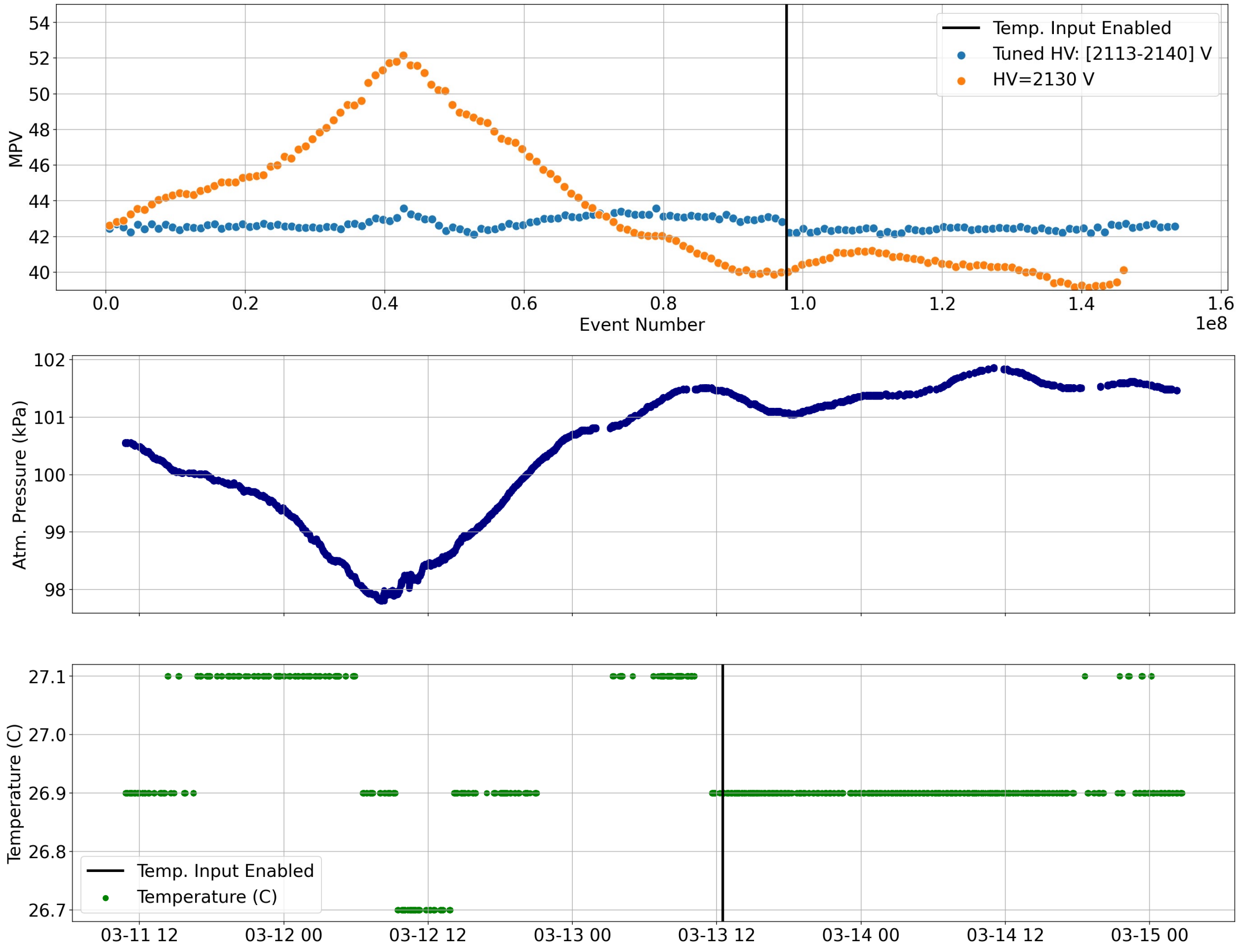
- Goals:
  - Test drive the AIEC software
  - Demonstrate the CDC gain is stable
- Split CDC in half:
  - One side set to 2130 V
  - Other side set to HV recommended by the AI
- Fully automated
  - EPICS queried every minute, HV adjusted every 5 min.
    - HV allowed to vary between 2110 and 2150 V
  - All information, activity logged in database
  - Remote monitoring



Schematic of downstream view of CDC, with straws HV control status indicated

Cosmics Test Results

- Compare MPV (Peak height, ADC units) values during each run for both sides of CDC
- Peak heights from AI-tuned side of CDC show dramatic reduction in pressure dependence compared to constant HV

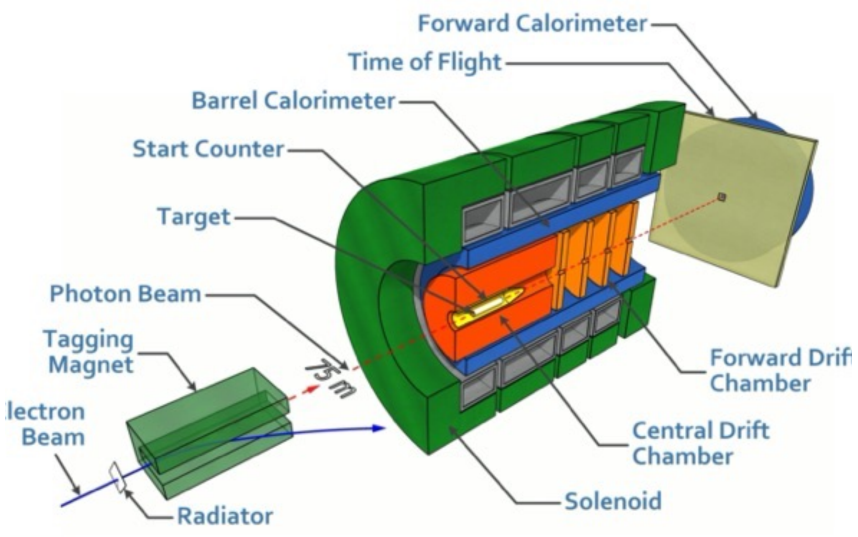


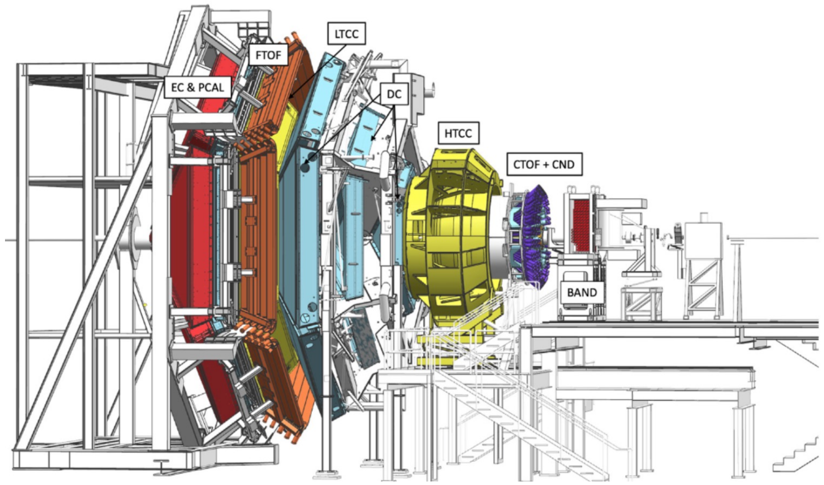
ML System During Production Running

- Adjust HV setting at run boundaries (~2h of data taking)
- Implemented pressure alarm to notify shift takers of significant pressure changes since the start of run
- Interface with shift takers to monitor system
- Improving robustness:
  - How to respond to inferences that have high uncertainty?
  - How to respond to out-of-domain inferences?
  - How to respond to out-of-bounds HV recommendation?

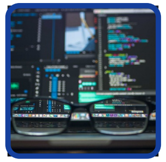
Applications to Other Detector Systems

- Exploring ML for calibrations control for:
  - GlueX FDC (Forward Drift Chamber)
    - Similar gain calibration to CDC
  - GlueX BCAL (Barrel Calorimeter)
    - Pedestal values fluctuate with crate temperature, requires manual adjustment of baseline
  - GlueX TOF (Time-of-Flight)
  - CLAS12 ECAL PMT Gain (Calorimeter in Hall B)



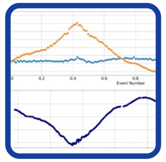


Conclusions and Next Steps



Proof of concept

- Demonstrated autonomous control of CDC

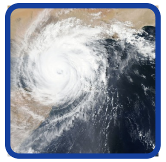


Gain stabilization

- CDC chamber gain was stabilized even with changing environmental conditions

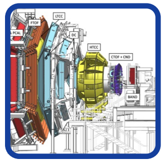
Reduce computing resources

- Predictions generated in ~3 ms vs. days with traditional method



Robustness

- Making further improvements to utilize uncertainty, appropriate control for rare out-of-domain inferences

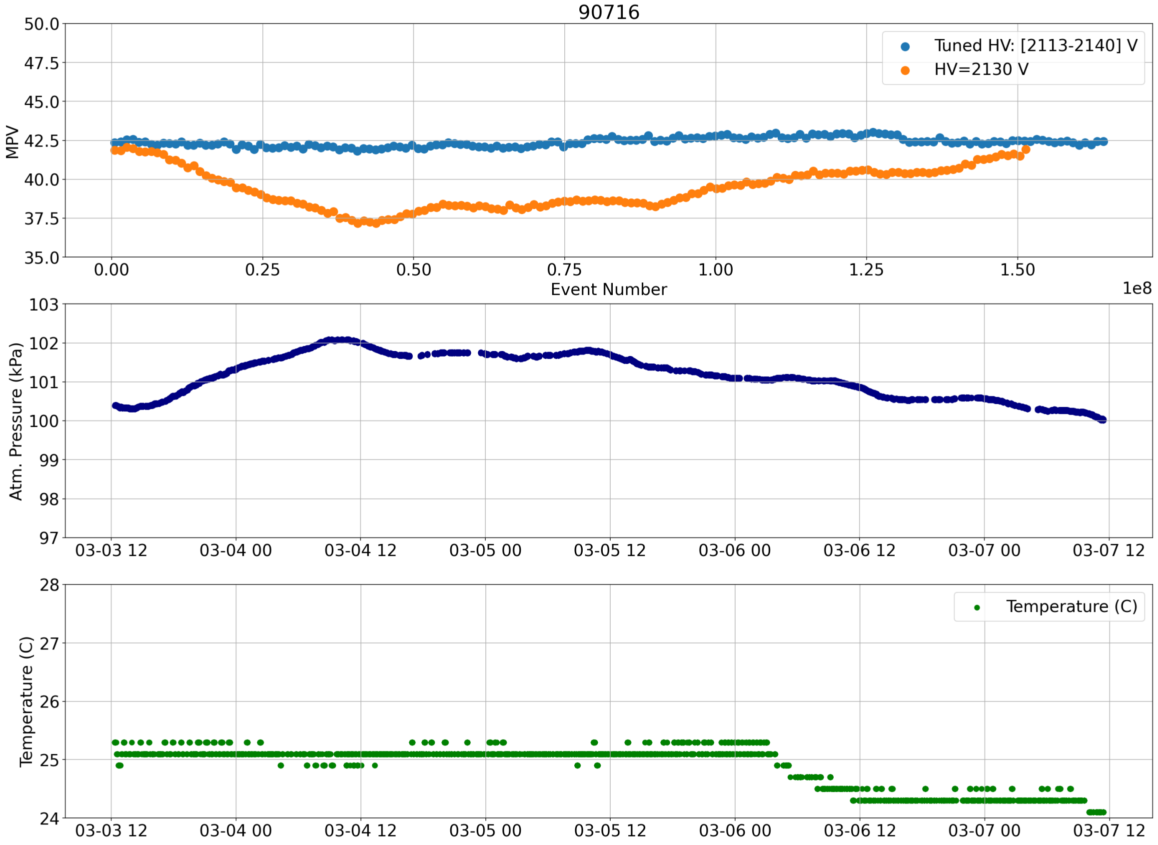


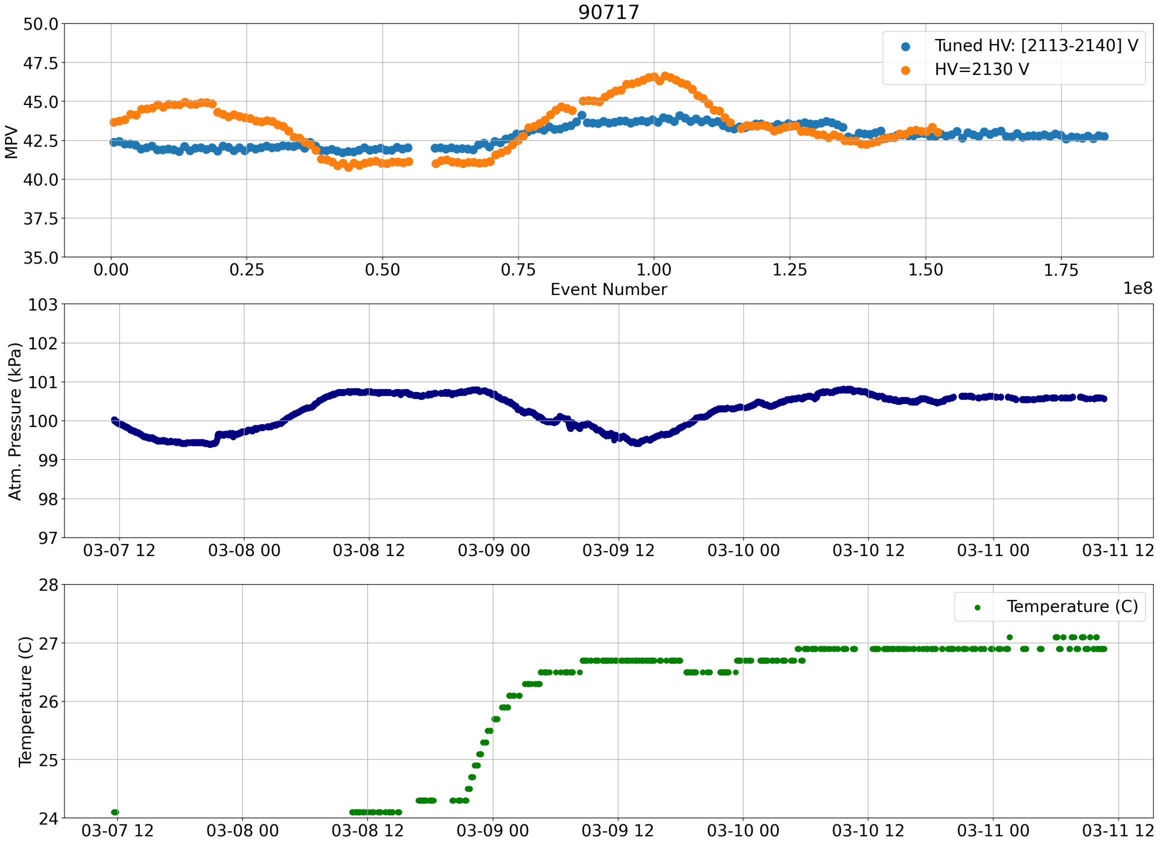
Applications to other detectors

- Potential to make predictions for multiple detectors at once

Backup slides

Cosmics Test Results





Cosmics Test Results