AI Experimental Control (and calibration) --GlueX Central Drift Chamber

The AI for Experimental Controls (**AIEC**) Team:

Thomas Britton, David Lawrence, Naomi Jarvis*, Diana McSpadden, Torri Jeske, and Nikhil Kalra

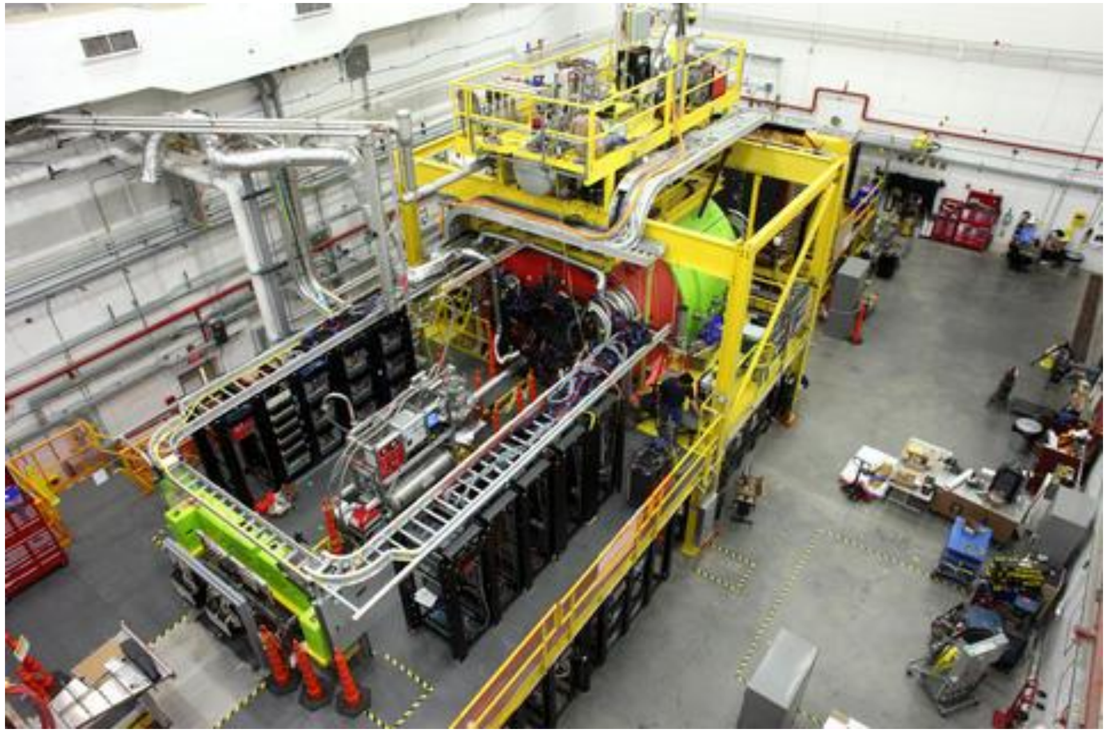
Thomas Jefferson National Accelerator Facility, VA, USA

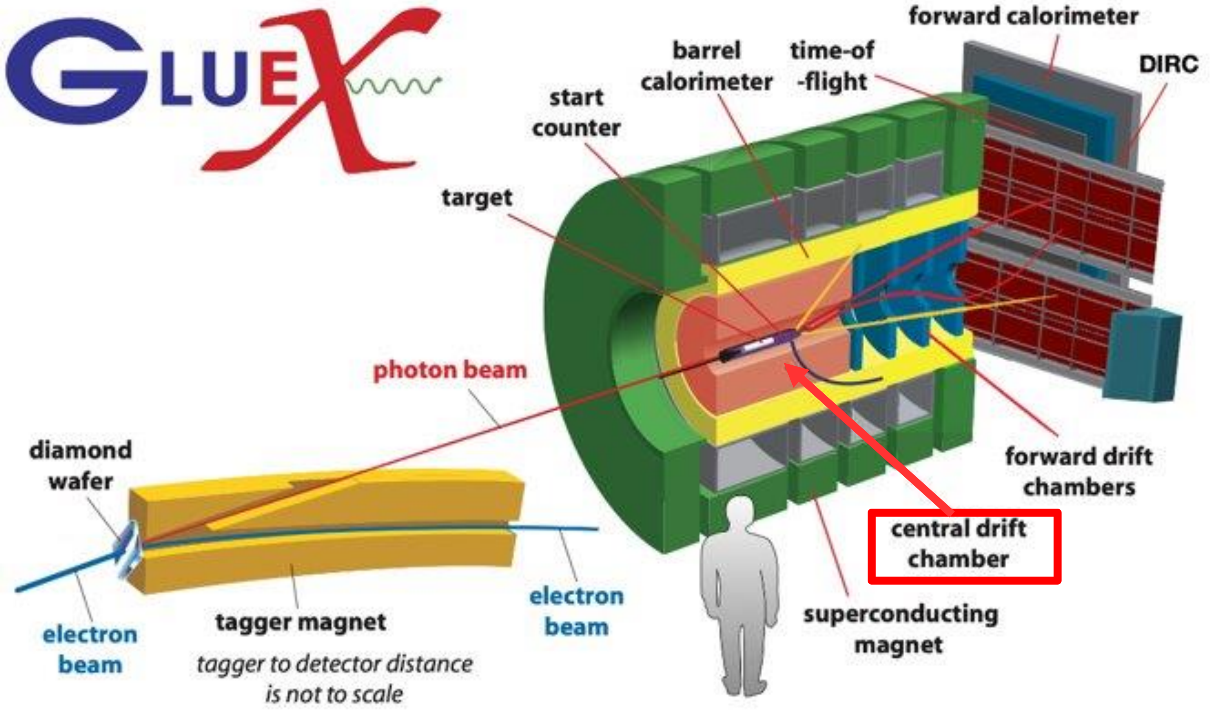
*Carnegie Mellon University, PA, USA

AI4EIC 2022

GlueX Experiment at Jefferson Lab

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





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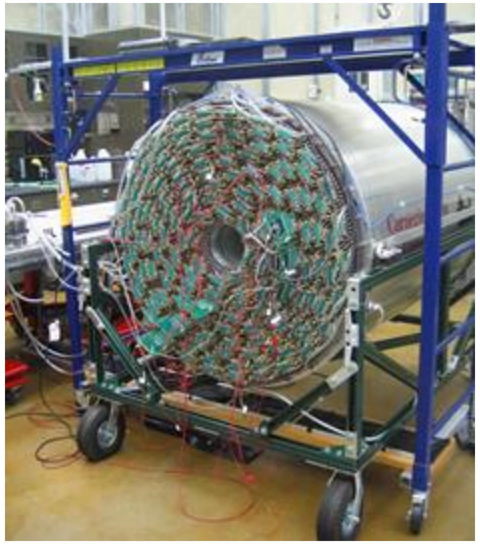
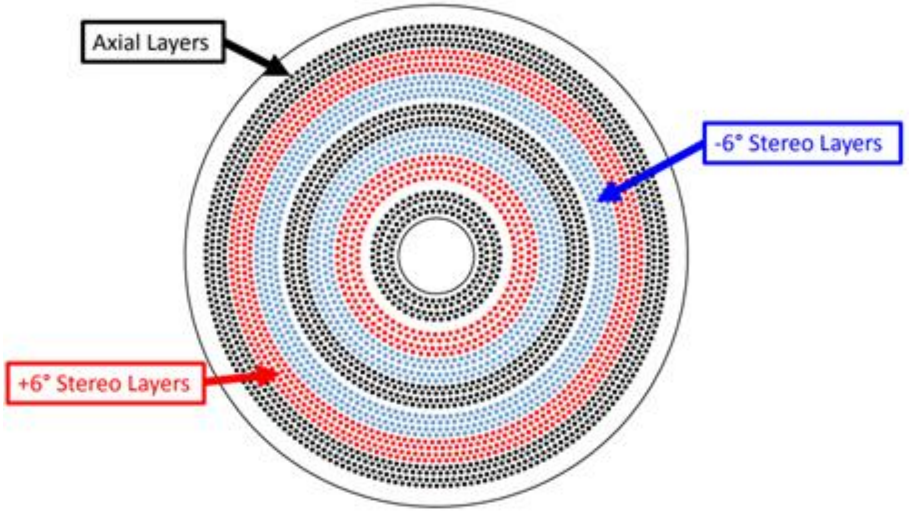
GlueX Central Drift Chamber (CDC)

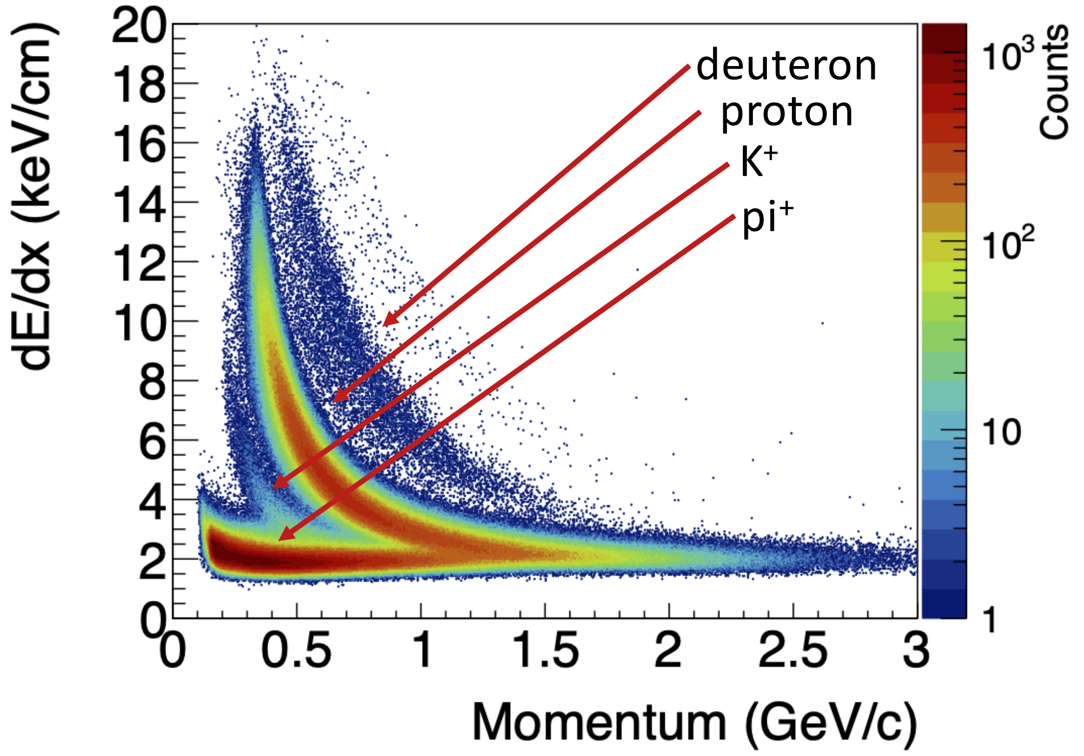
- **Used to detect and track charged particles with momenta p > 0.25 GeV/c**
- 1.5 m long x 1.2 m diameter cylinder
- 3522 anode wires at 2125 V inside 1.6 cm diameter straws
- 50:50 Ar/CO_2 gas mix

- Requires two calibrations: **chamber gain** and drift **time-to-distance**
  - **Gain Correction Factor (GCF)**:
    - GCF calibrations have most variation +/- 15%
- Has **one** control: **operating voltage**
  - Nice to start with something simple/easy to vet





- Gain affects PID selections in analysis
  - Known sensitivity to environmental conditions
    - Atmospheric pressure
    - Temperature
  - Known sensitivity to experimental conditions
    - Beam conditions change with the experiment
  - **Traditionally**:
    - GCF obtained from Landau fit to amplitudes
      - Post **<u>iterative</u>** ttod
    - Calibration constants are generated per run
      - Approximately 2 hours of beam time



Partly due to atm changes

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Conventional Calibration and Motivation for ML

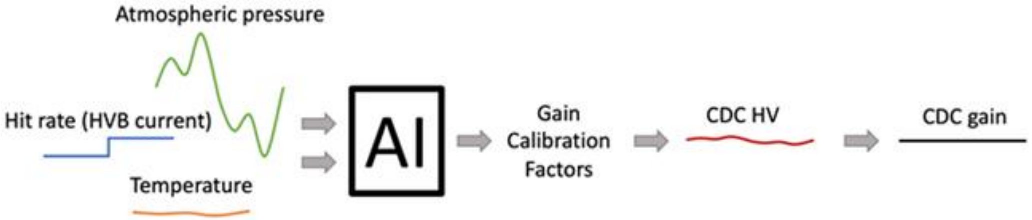
Motivation: Conventional vs. Online, ML Calibration Paradigms

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



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Approach

- Can we predict existing GCF and calculate the recommended HV using data that is readily available before/as a run begins/while running?
  - Similar for time to distance

- Can we control the HV of the CDC to stabilize gain during an experiment?
  - Think coarse and fine adjustment
  - Potential removal of the need to calibrate

- Does the system generalize for differing conditions?
  - How well?
  - Do we trust interpolations and extrapolations?
  - Uncertainty quantification (UQ)
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Uncertainty
by craiyon.com

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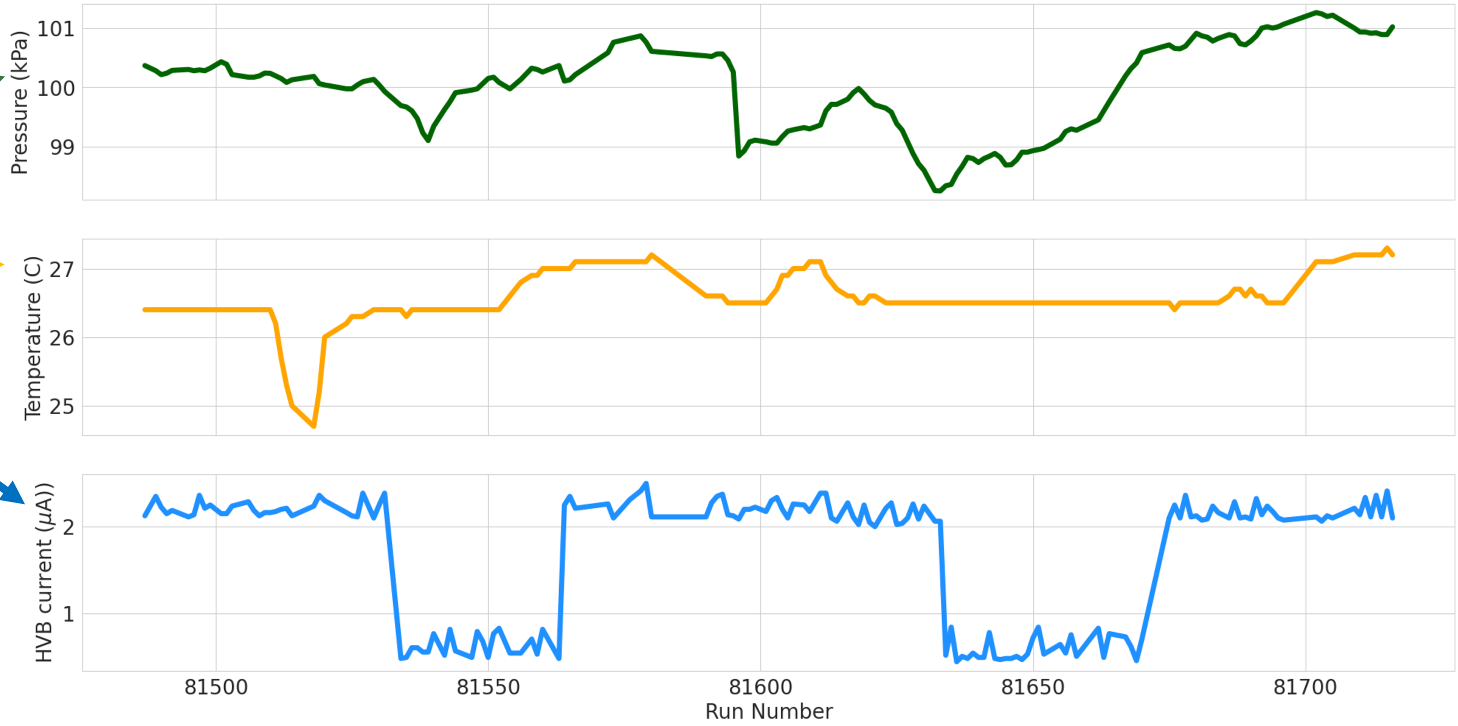
Can we predict GCFs: our input features

Can we predict GCFs using data that is **readily available as a run begins**?

For input features:

- Data extracted from Experimental Physics Industrial Controls System (EPICS)
  - Atmospheric pressure
  - Gas temperature
  - Current drawn from CDC HV boards (proxy for beam current)
- All readily available during the experiment
- Not dependent on other detectors
  - No reconstruction!



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Can we predict GCFs: our model

ML Technique

Gaussian Process (GP)

- 3 features:
- **atmospheric pressure** within the hall
  - **temperature** within CDC
  - **CDC high voltage board current** -> a proxy for the intensity of the electron beam current
  - 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 basic GP kernel:
  - Radial Basis Function + White
  - Tested isotropic (1 length scale) and anisotropic (length scale per input variable) kernels

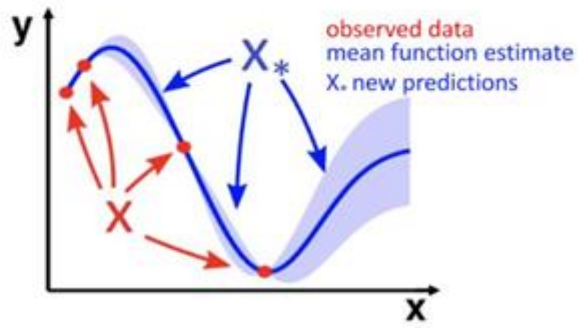

Illustration training a Gaussian process

Threshold was better than 5% error

RBF kernel (length scale(s))	R^2	RMSE	Mean |% err|
Isotropic (1.412)	0.97	0.002	0.8%
Anisotropic (1.4,1.17,.171)	0.97	0.002	0.8%

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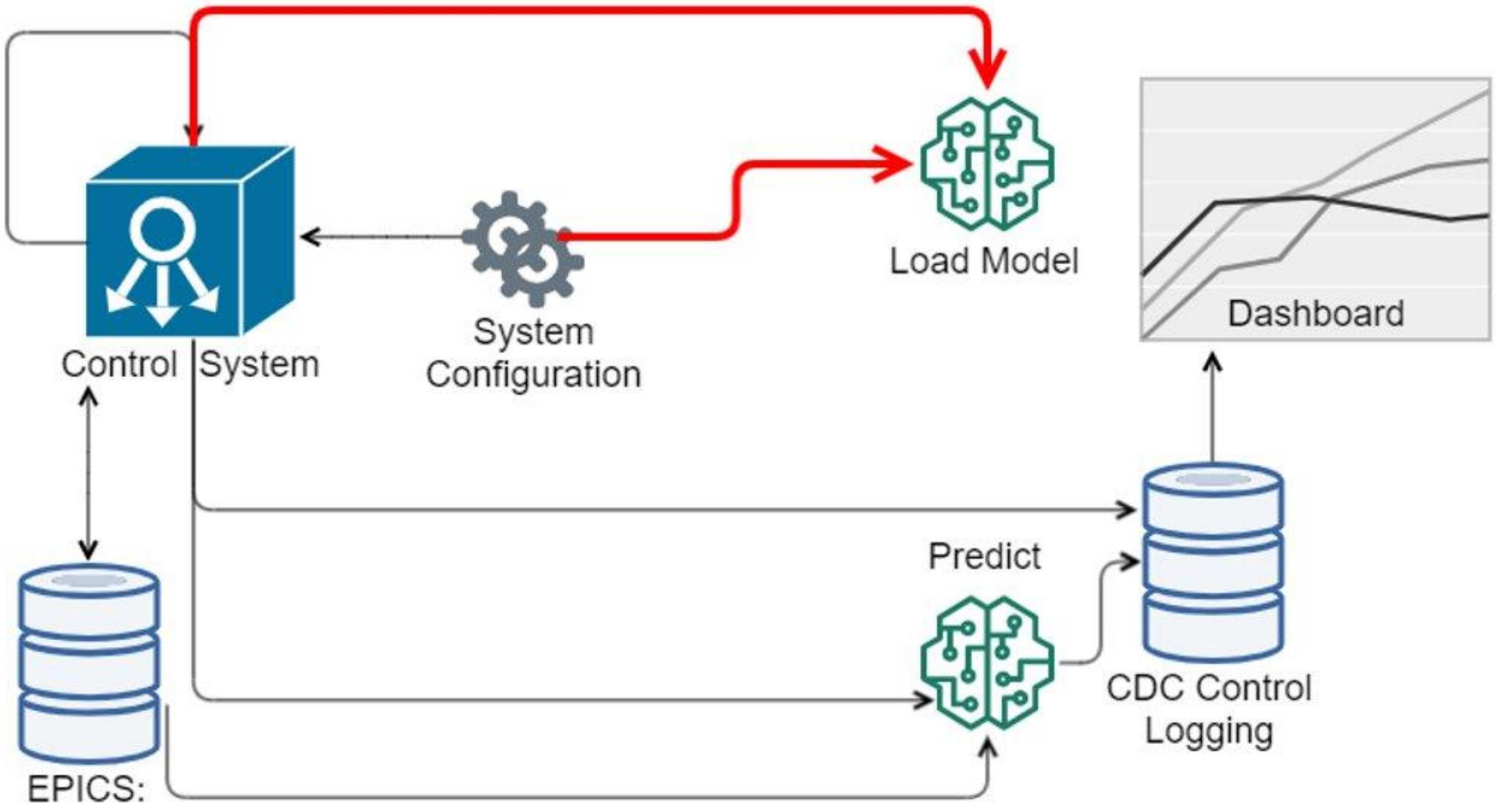
The system

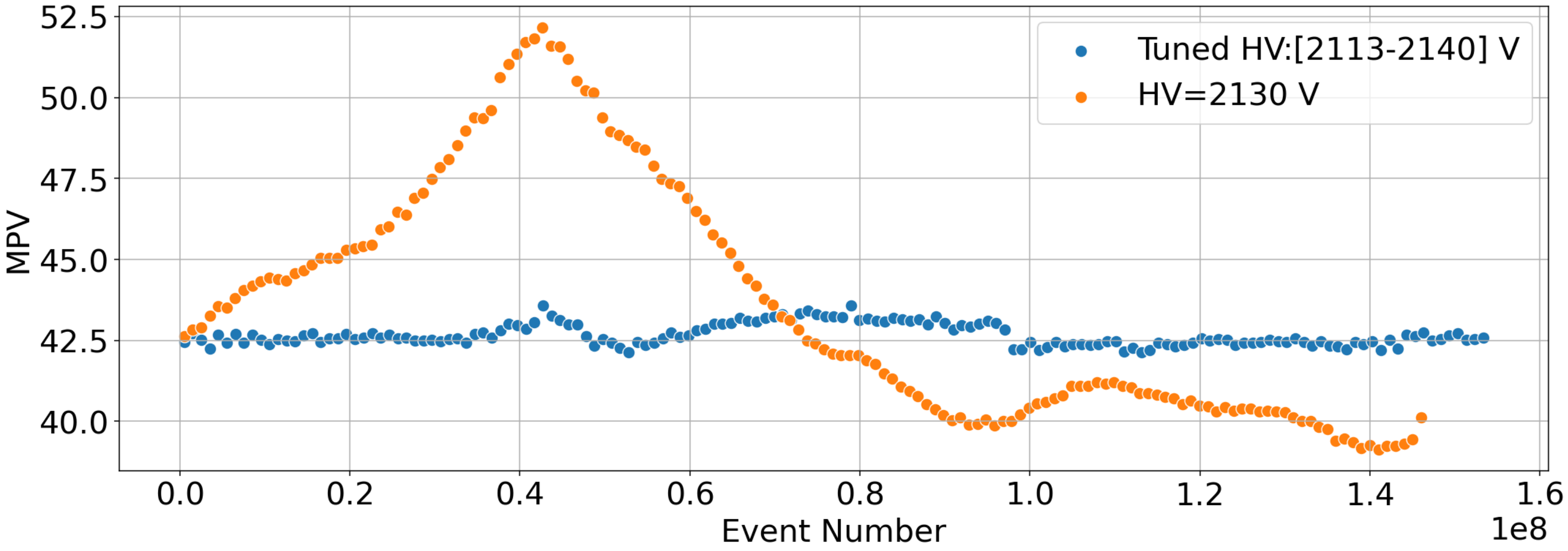


Experimental Physics and Industrial Control System

- On the fly configuration
  - Always on. Not always recommending/controlling
- **UQ threshold dictates projection**
  - Never be too far out of bounds
- Full logging for future investigations
  - Interpretability studies

Commissioning (cosmics)

*MPV to gcf is just a scaling

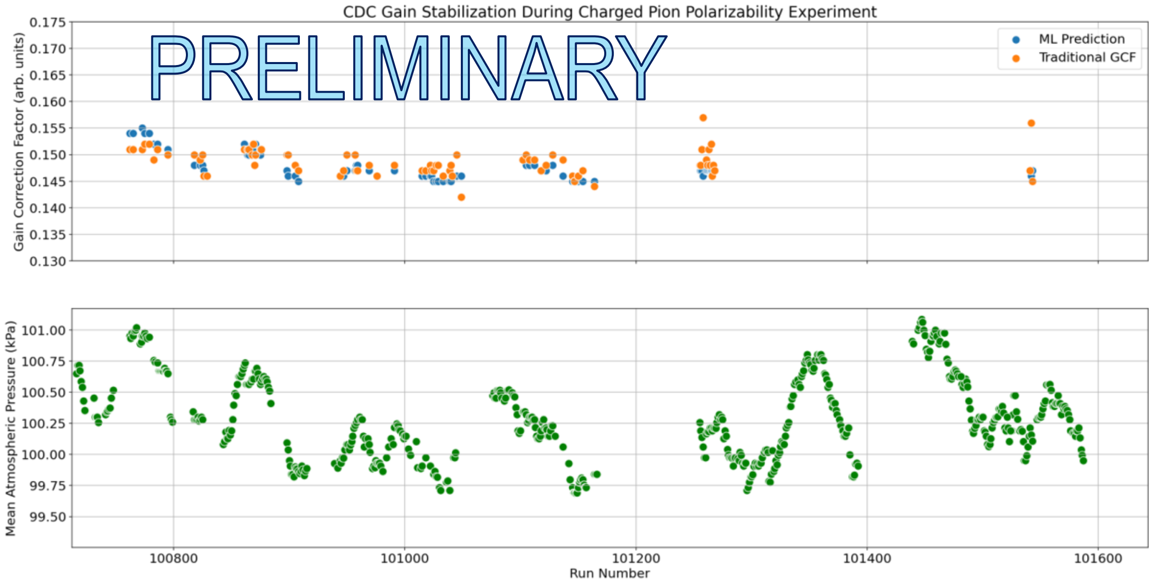


Big success!

- Half the CDC (orange) at fixed HV
- The other half (blue) had its high voltages adjusted every 5 minutes
- The drop at 1.0 was due to a temperature adjustment to bring things back in line with nominal running
  - It is a small effect

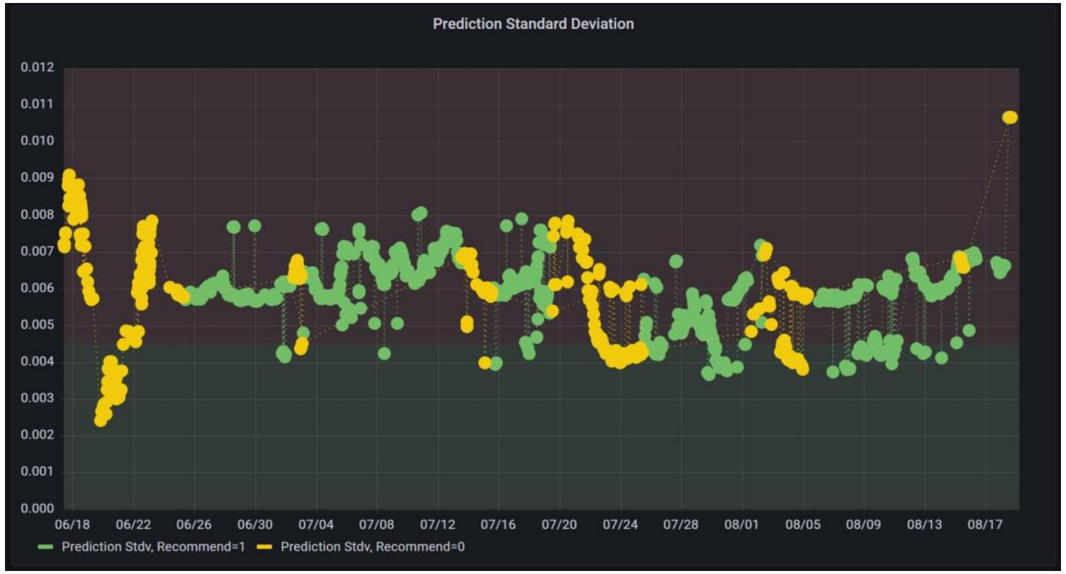
Running (CPP)

- Differences to GlueX
  - Lower hvbi
  - Quarter of the CDC electronics borrowed for a CPP specific downstream detector
  - Solid target
- Update HV at start of run
- Atmospheric pressure didn't see as wild variations
  - If only we could control the weather....
- Almost all the time was spent well above our UQ bubble
  - ~.006



HV not controlled

HV controlled



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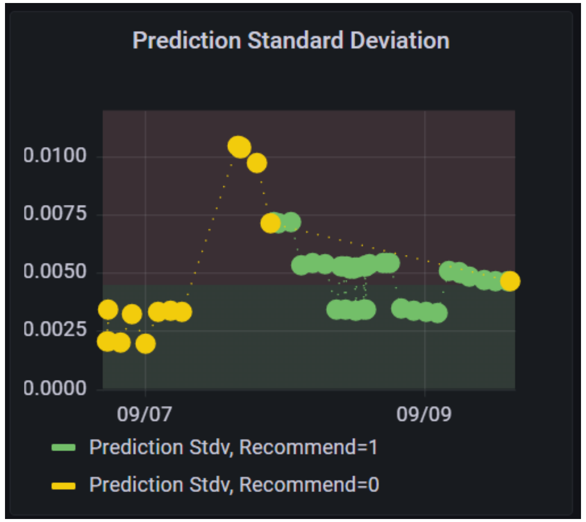
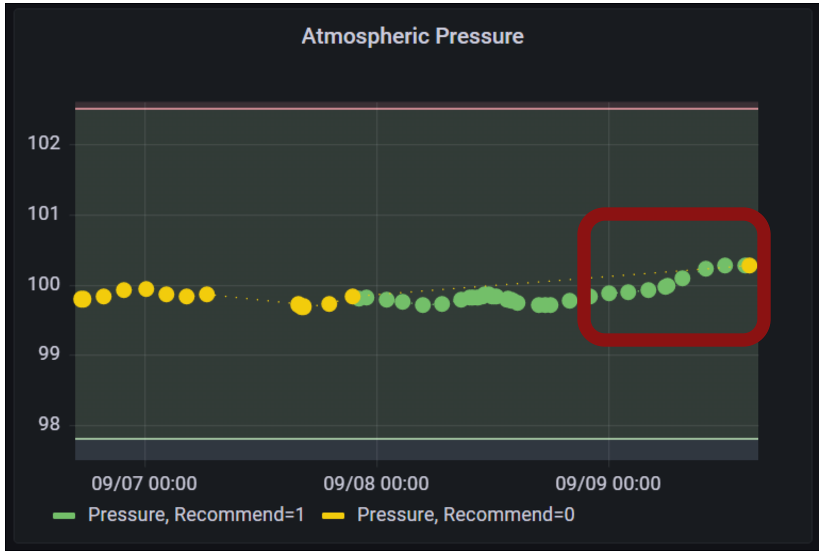
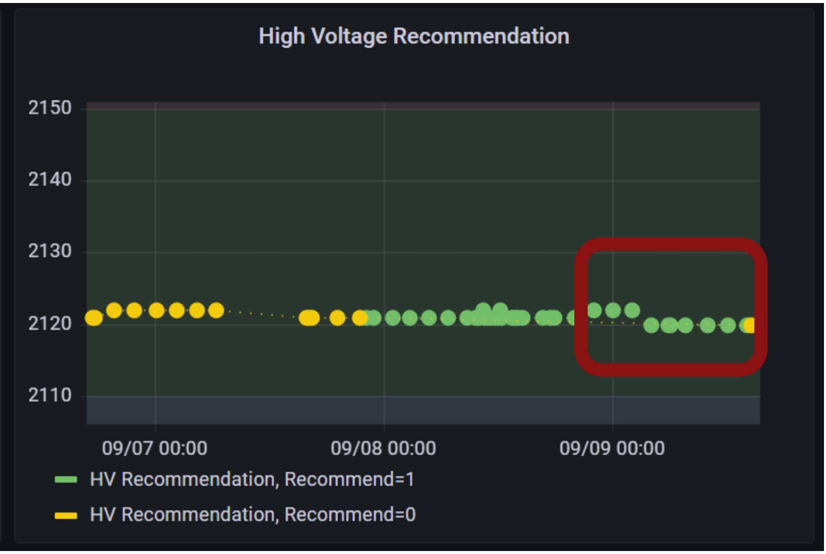
Running (Primex)

- Also dissimilar to GlueX
  - Lower current but closer to nominal running
  - Whole CDC
  - Much closer to the uncertainty threshold



- Update HV at start of run not during



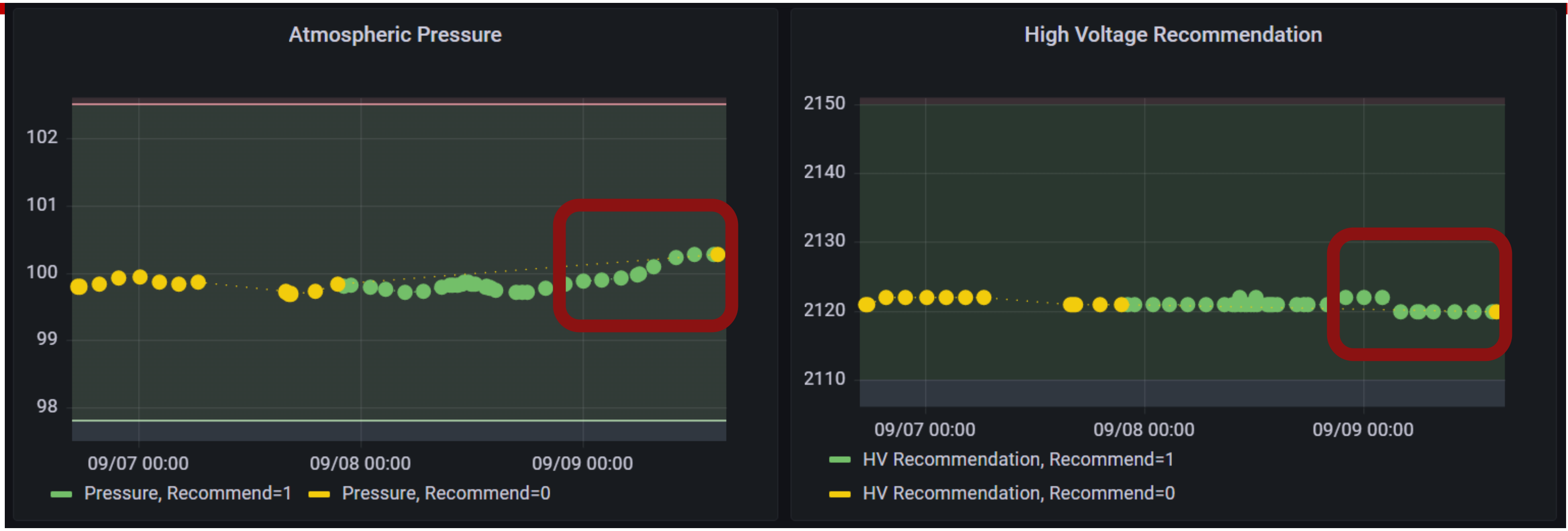


- Anomalous behavior seen
  - Up atm should be up HV
    - Everything else flat

- Why?

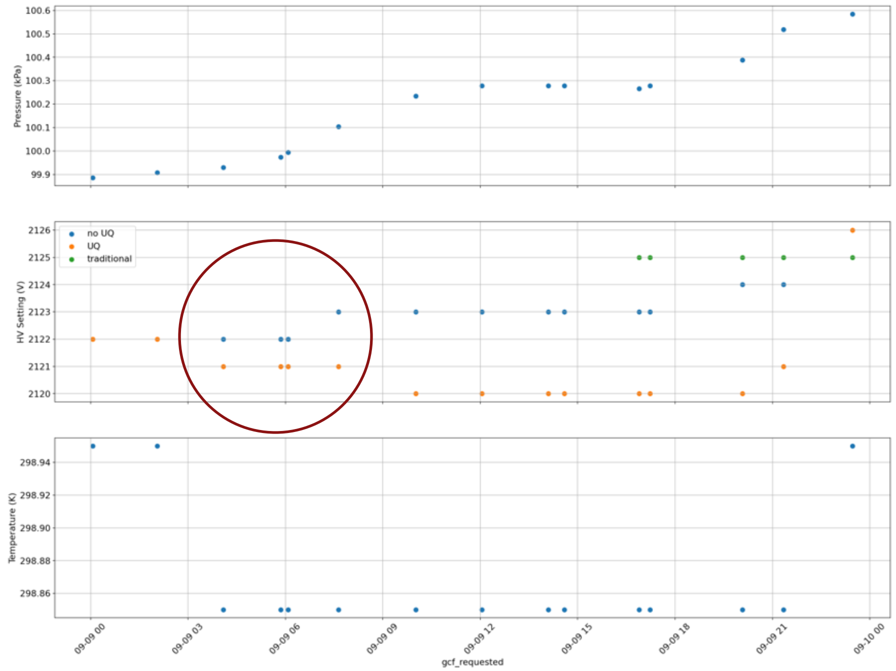
Anomalous behavior

- How bad is it?
  - 1% diff in gain ~ 1V diff
  - Maximal error 4V => gain error of 4%
    - Below our 5% target



- Still within tolerances

- Looking at the UQ corrected HV versus the raw HV we see a bifurcation
  - Anomalous behavior strictly from the UQ correction



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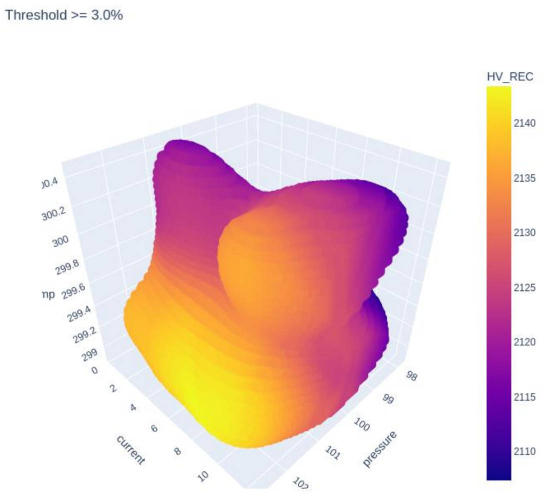
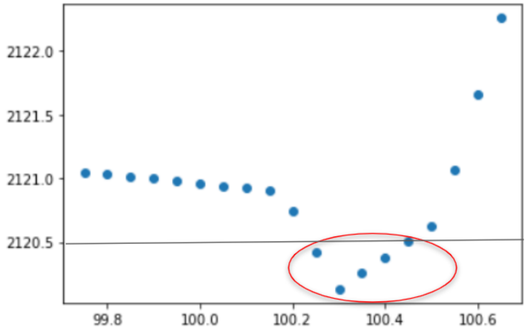
Subtleties

- Our uncertainty surface is not really a bubble
  - By that I mean purely convex
- Any dents or divots can affect the projection
  - Imagine being at the center of a bowl, tiny movements can send you from one side of the bowl to the other possibly with drastically different HV recommendations
- Maybe we didn't see this in CPP because the distance away from the surface was much greater
  - When you are far from the surface it takes much greater motion to switch points of projection



The “divot” in our uncertainty vertices

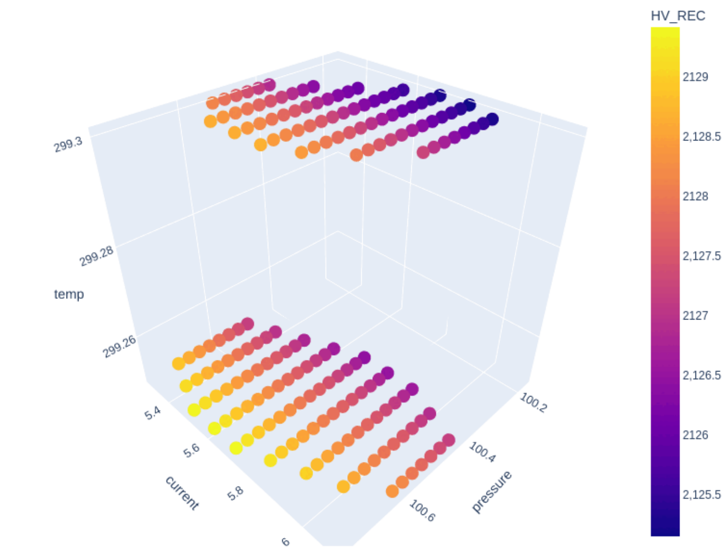


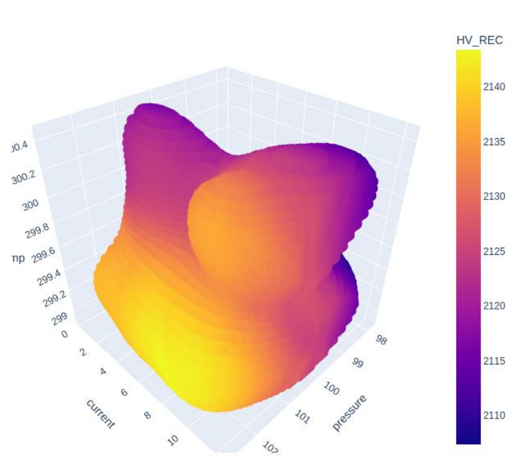
Here is one! In a slice of our surface

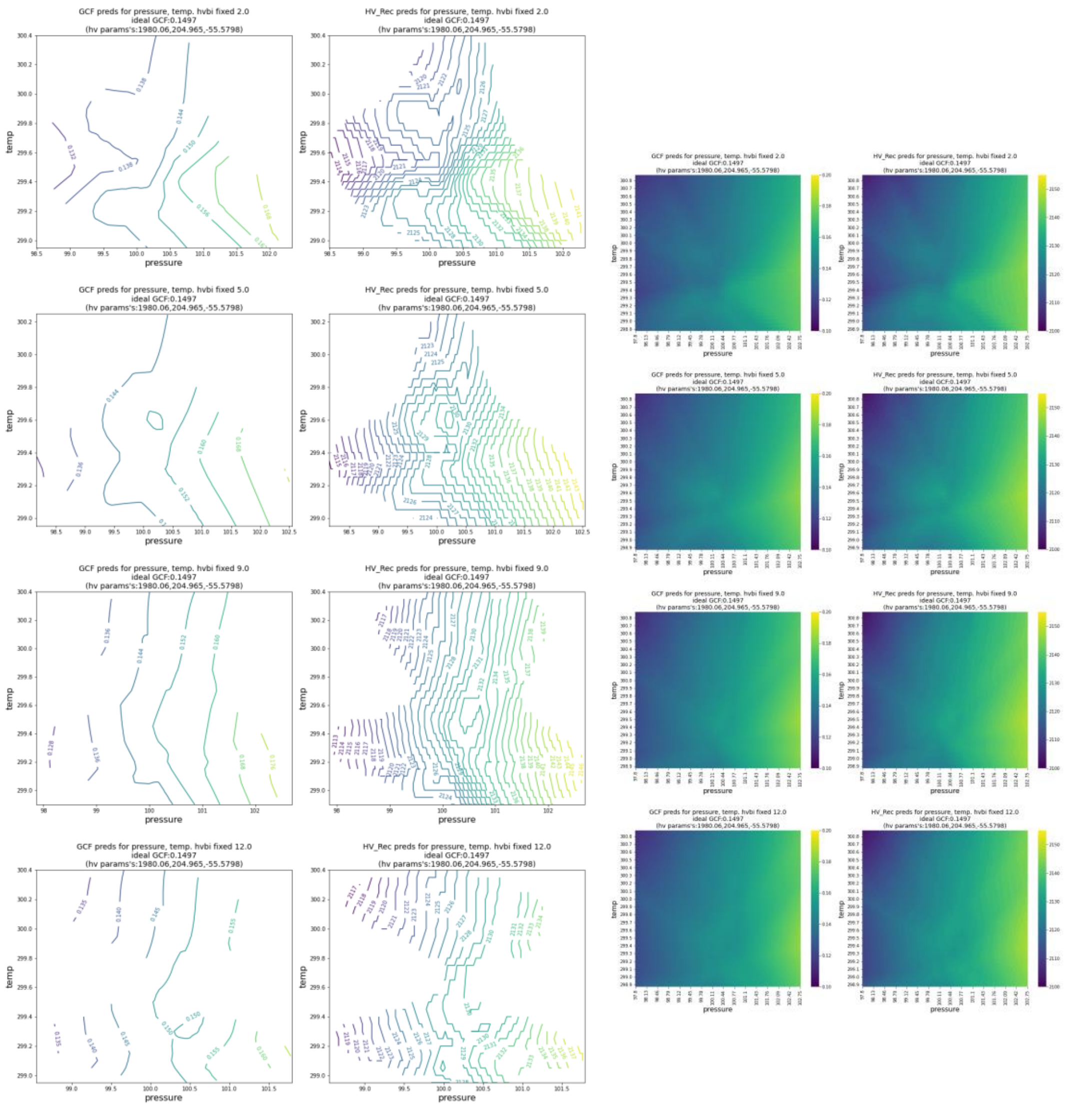
```
Raw HVBI: 9.0, Raw Temp: 298.85
Raw Pressure:  99.9298 UQ_Pressure:  99.95  UQ_hvbi:  9.0  UQ_temp:  298.9  UQ_GCF:  0.1429838685738982  HV_REC:  2120.979390944207 HV_REC rounded:  2121.0
Raw Pressure:  99.9734 UQ_Pressure:  99.95  UQ_hvbi:  9.0  UQ_temp:  298.9  UQ_GCF:  0.1429838685738982  HV_REC:  2120.979390944207 HV_REC rounded:  2121.0
Raw Pressure:  99.9952 UQ_Pressure:  100.0  UQ_hvbi:  9.0  UQ_temp:  298.9  UQ_GCF:  0.14295539905939414  HV_REC:  2120.960577904075 HV_REC rounded:  2121.0
Raw Pressure:  100.104 UQ_Pressure:  100.1  UQ_hvbi:  9.0  UQ_temp:  298.9  UQ_GCF:  0.14289618130074316  HV_REC:  2120.9214342124624 HV_REC rounded:  2121.0
Raw Pressure:  100.235 UQ_Pressure:  100.25  UQ_hvbi:  9.0  UQ_temp:  298.9  UQ_GCF:  0.14213505840759677  HV_REC:  2120.4169039125636 HV_REC rounded:  2120.0
Raw Pressure:  100.279 UQ_Pressure:  100.3  UQ_hvbi:  9.0  UQ_temp:  298.9  UQ_GCF:  0.14170531958731739  HV_REC:  2120.1308776985165 HV_REC rounded:  2120.0
```

Analysis/Debugging the Black Box

- Plot the surface and the point(s) of measurements
  - Ends up being a bug in projection but indicates a closer look at the UQ
- Looks less like pancakes/a bubble and more like swiss cheese
  - Pockets of space that are "inside" but above UQ







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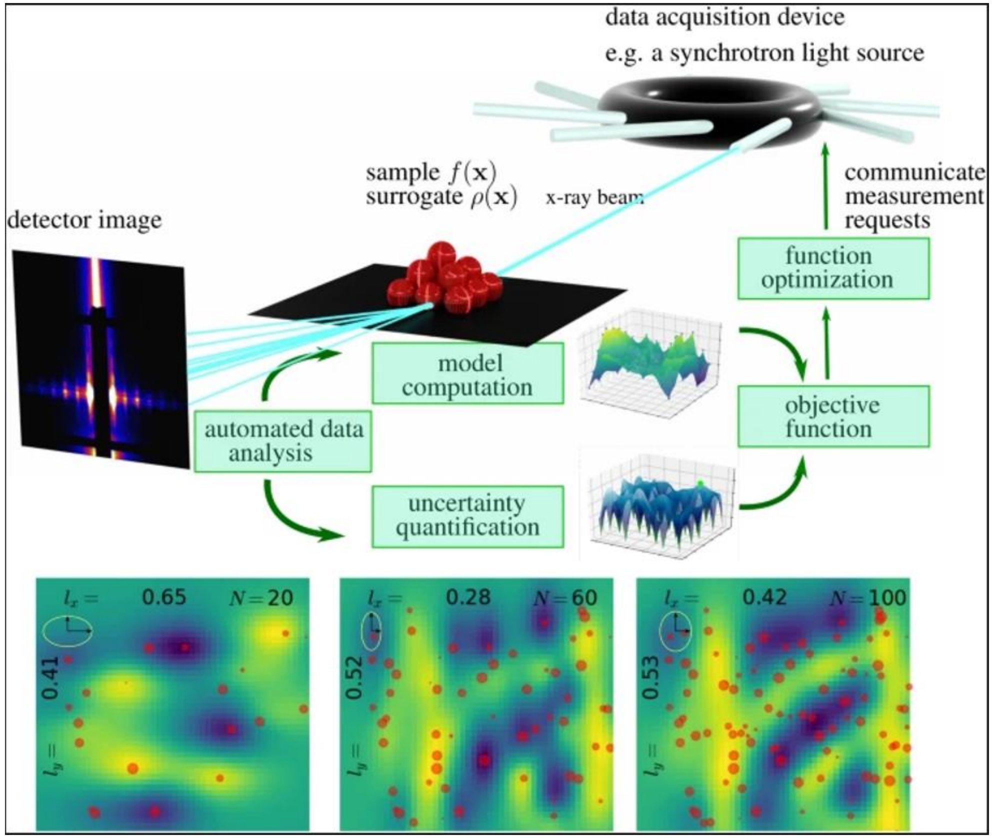
Towards Self-Learning

- One application of ML is in experimental design (parameter selection)
  - Better/more efficient than exhaustive grid search
  - Based on the idea that all data is not created equal

- Turning things on its head, it may be possible to use a similar system to decide whether it is better for us to take new data or use our projection
  - Complex error surface

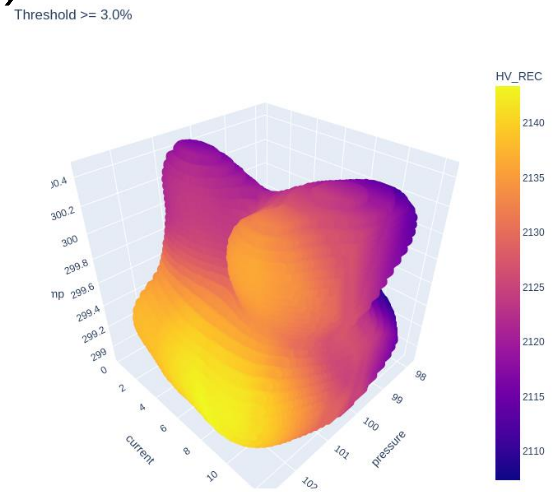
- There are lots of avenues for research into UQ and its actionable utilization

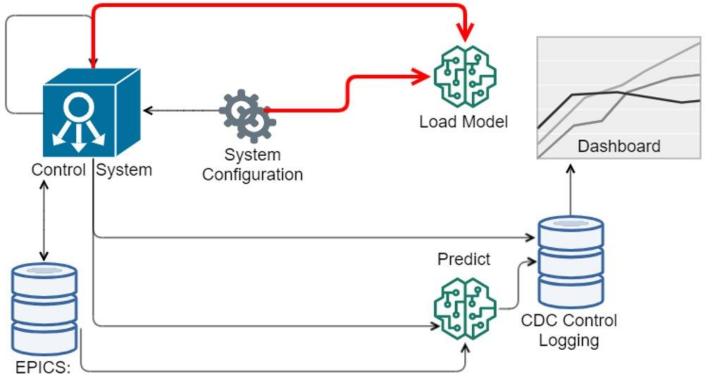


https://www.nature.com/articles/s41598-020-74394-1

Conclusions/Future

- Successfully deployed an AI system to control and calibrate the GlueX CDC
  - ~ 1% error in predicting gcf (<< promised 5%)
  - Able to stabilize gcf via HV control
  - The system is reconfigurable on the fly
  - Uses estimated UQ in an actionable way
    - Lots of subtilties and avenues for research
      - Complex 3D surface
      - Limited data in some dimensions
        - Islands of data





Experimental Physics and Industrial Control System

- Looking to finishing TtoD
  - HV dependence so a bit of bootstrapping probably required

- Probing other detectors and systems to apply these techniques
  - Potential self-learning to enable eminently deployable system which will only control when "confident" and efficiently learn when not

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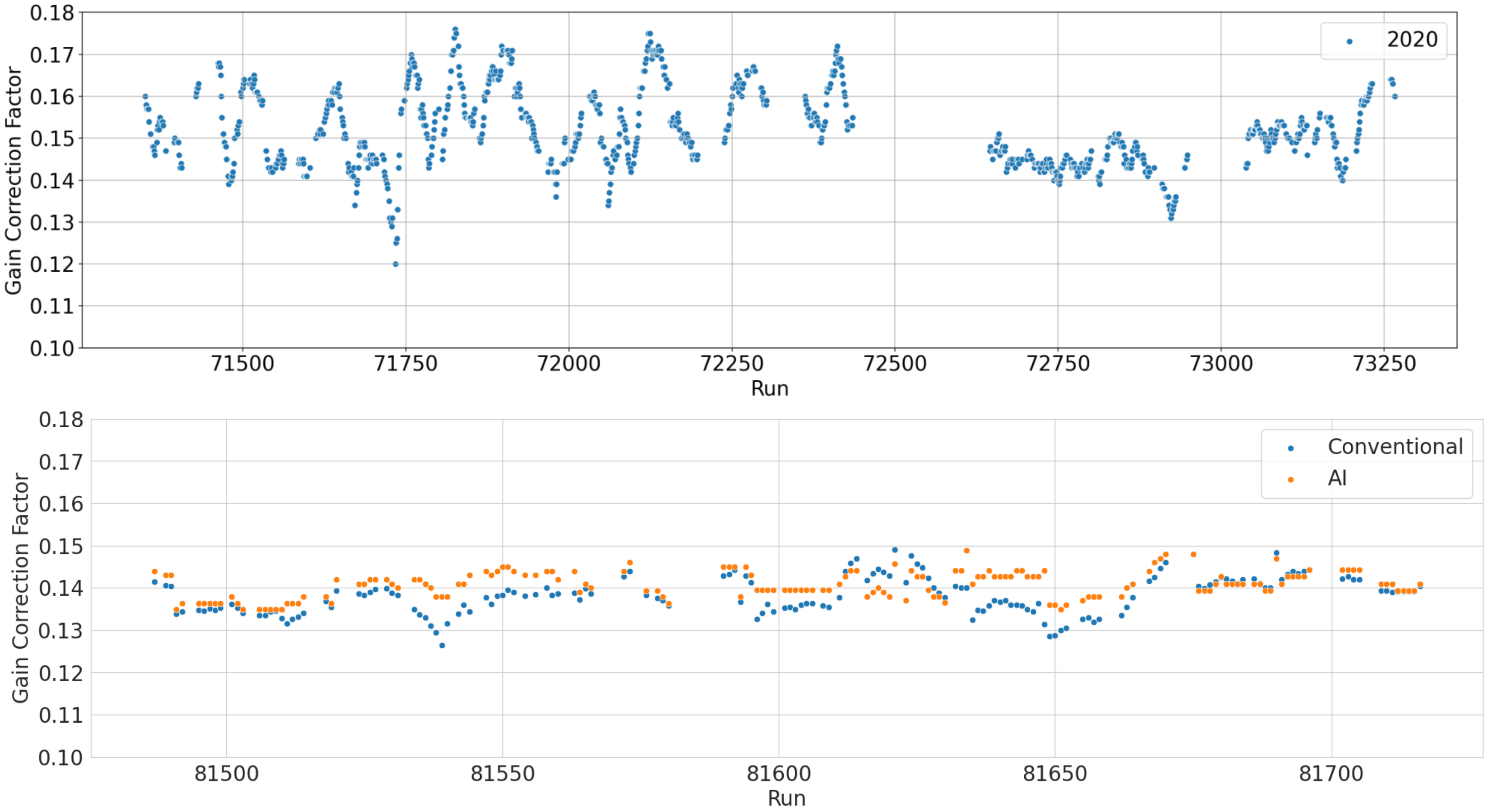
Backup slides

Calibrations with AI: Gain

- AI generated calibration constants agree with conventional gain calibration results
- GCF are more stable compared to GlueX 2020 run period



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