AI for Experiment Control and Calibration

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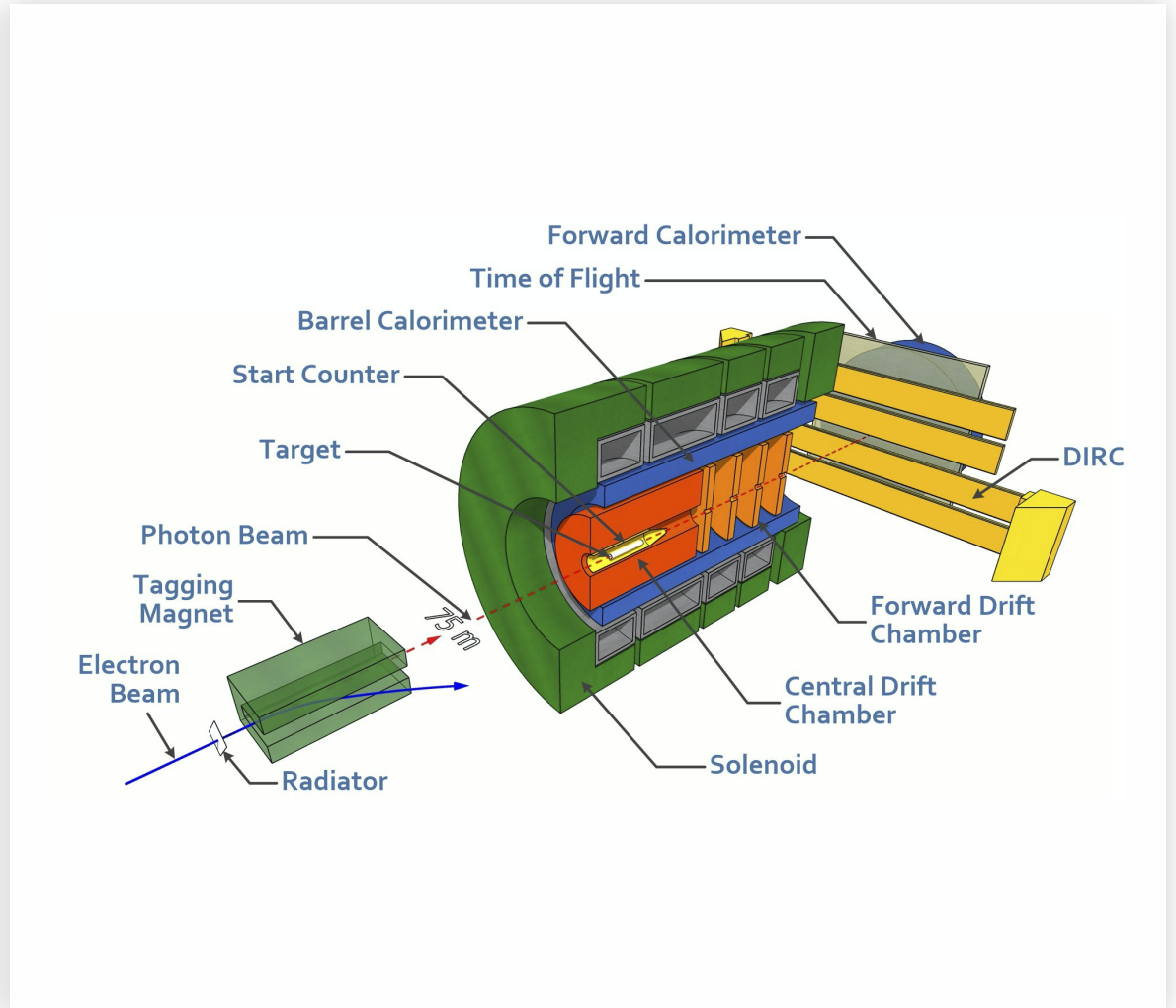**Nikhil Kalra**

Data Science

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Naomi Jarvis
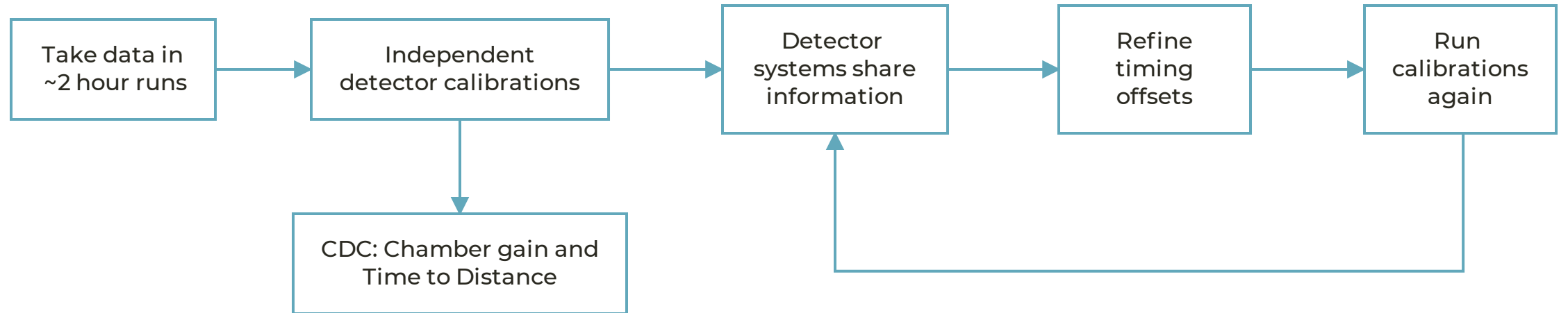
Carnegie Mellon University

Hall D @ Jefferson Lab

Designed to search for and measure exotic hybrid mesons produced in photoproduction reactions

Offline calibrations

Iterative and *time consuming*

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┌─────────────┐     ┌─────────────────┐     ┌─────────────────┐     ┌──────────┐     ┌──────────────┐
│ Take data in│ ──> │   Independent   │ ──> │    Detector     │ ──> │  Refine  │ ──> │     Run      │
│ ~2 hour runs│     │ detector        │     │ systems share   │     │  timing  │     │ calibrations │
│             │     │ calibrations    │     │ information     │     │ offsets  │     │ again        │
└─────────────┘     └─────────────────┘     └─────────────────┘     └──────────┘     └──────────────┘
                            │                        ▲                                       │
                            ▼                        └───────────────────────────────────────┘
                    ┌─────────────────┐
                    │ CDC: Chamber    │
                    │ gain and        │
                    │ Time to Distance│
                    └─────────────────┘
```

Time scale for calibrations is on the order of months, increasing the time between data taking and publication.

GlueX Central Drift Chamber

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

- **Detector specs**

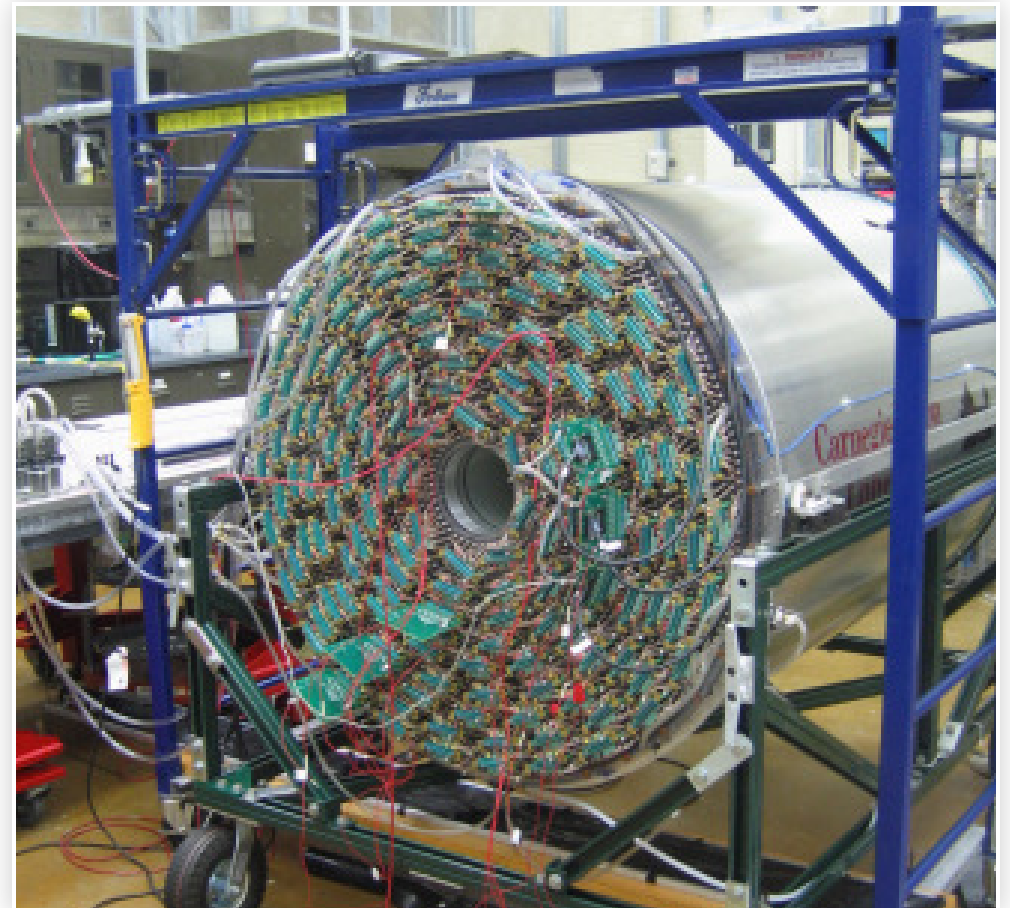 1.5 m long x 1.2 m diameter cylindrical, straw tube chamber

  3522 anode wires **traditionally held at 2125 V**

  50:50 Ar/CO_2 gas mixture

- **Two main calibrations:**

  Chamber gain and drift time to drift distance

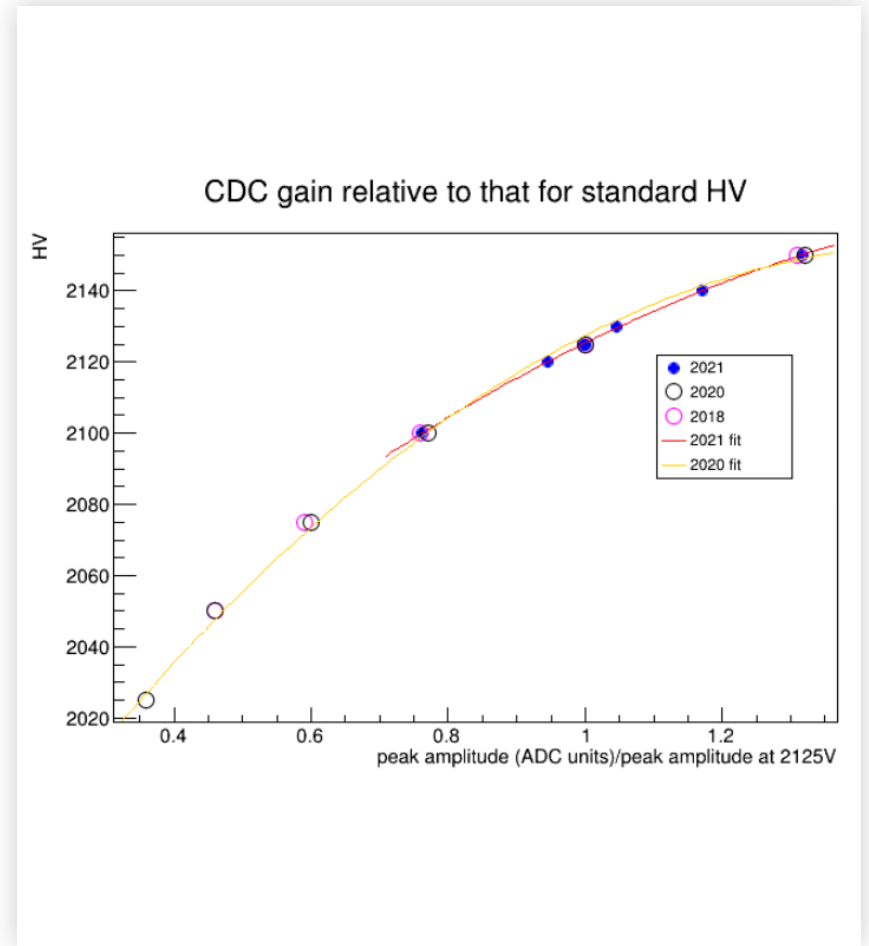 Affects PID selection in analysis via dE/dx

Standard CDC Operation

- **High voltage scans are performed at the start of each run period**

  Look at ratio of ADC peak heights as a function of high voltage

- **HV kept constant at 2125 V**

- *We will use this relationship later to determine the HV recommendation*

Traditional calibration workflow

- ## Produce histograms run-by-run in a monitoring launch

 This involves running reconstruction over a lot of raw data files for every run

- ## Run ROOT macros to perform fits to histograms

  Extract fit parameters, do analysis, etc

  For the CDC, a python script calls a separate root macro, then various text files containing different fit parameters and statistics are generated

- ## Eventually, upload constants to database

  GlueX has an extensive Calibration Constants Database (CCDB)
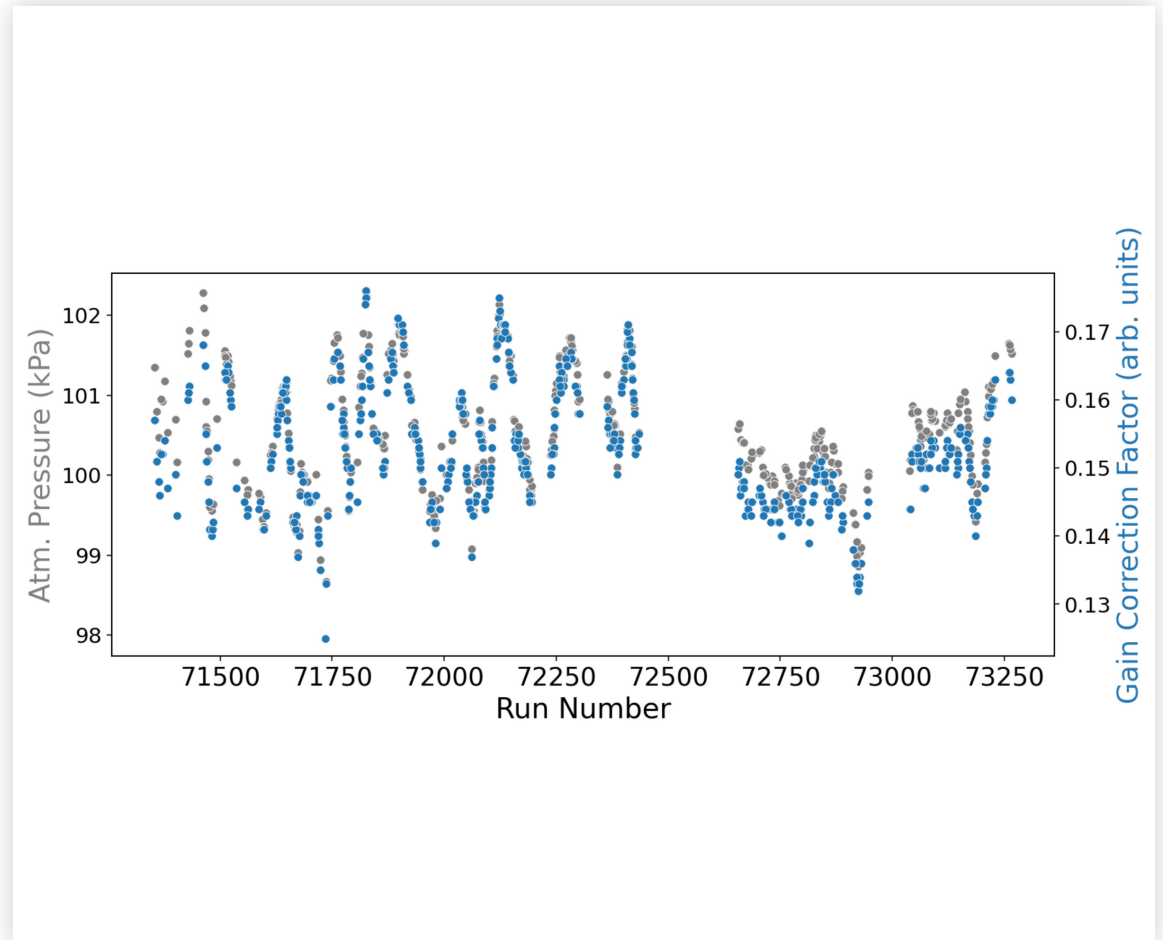
Challenges

There's a lot of them!

Offline vs Online Calibrations

1. Safety constraints
2. Control policies
3. Trustworthiness
4. There's always a bug we didn't account for

User Interface/ Experience

1. Interpretable UI for shift takers
2. Easy control ON/OFF button
3. Physics based evaluation metric

Data Science

1. Quick training and inference time
2. Readily available input features
3. Robustness to out-of-domain inferences
4. Uncertainty Quantification

Gaussian Processes

Supervised learning method used to solve regression and probabilistic classification problems

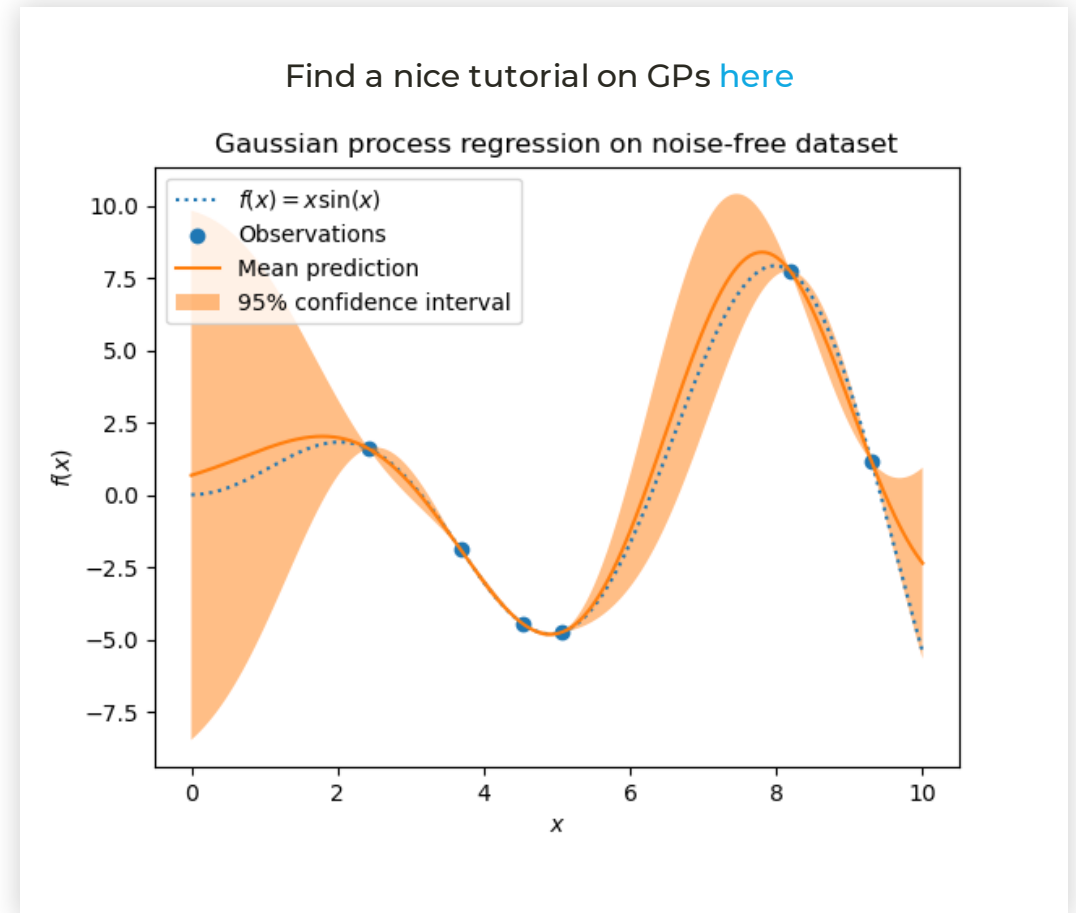- ## Suited for small datasets
  ~430 training runs, 106 testing

  Existing calibrations used as target values
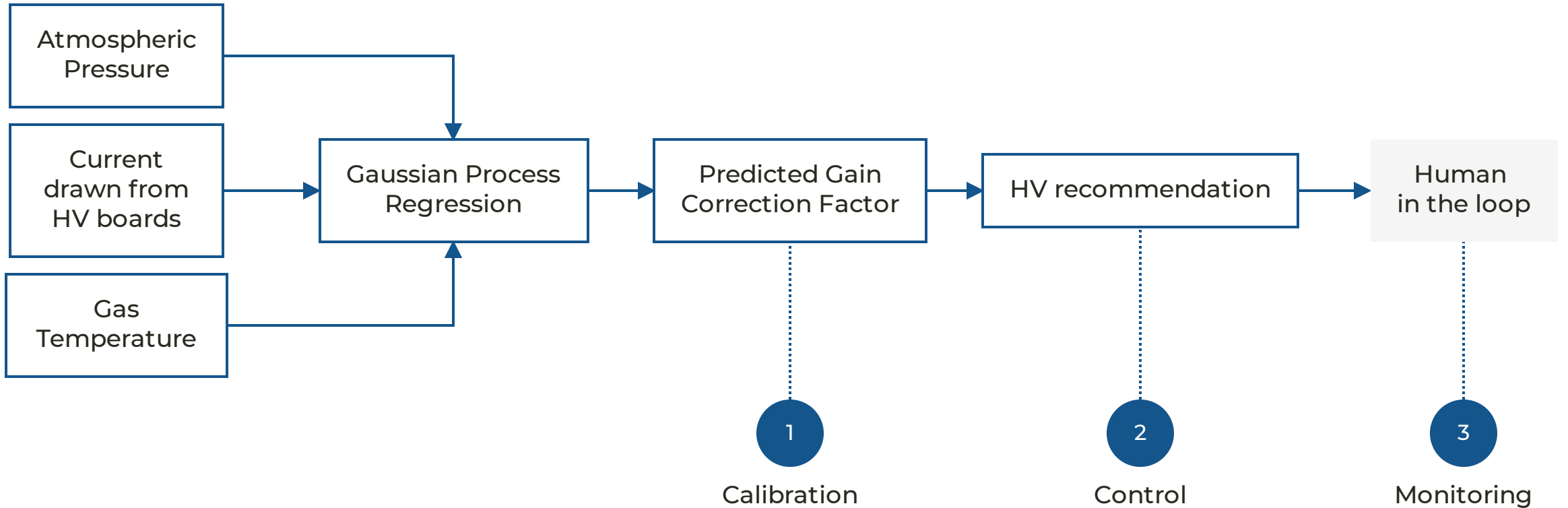
- ## Provide uncertainty quantification
  GPs give mean and standard deviation of the output when predicting

- ## Fast training and inference
  Inference is obtained in ~3 ms

Find a nice tutorial on GPs here

Gaussian process regression on noise-free dataset

Legend:
- $f(x) = x\sin(x)$
- Observations
- Mean prediction
- 95% confidence interval

Online Calibration with roboCDC

First deployment was in early October, 2021. Shift crew were responsible for running the script and adjusting the high voltage.

Cosmics test

- **~2 weeks of cosmics running to test roboCDC**

  Mid-March of 2022

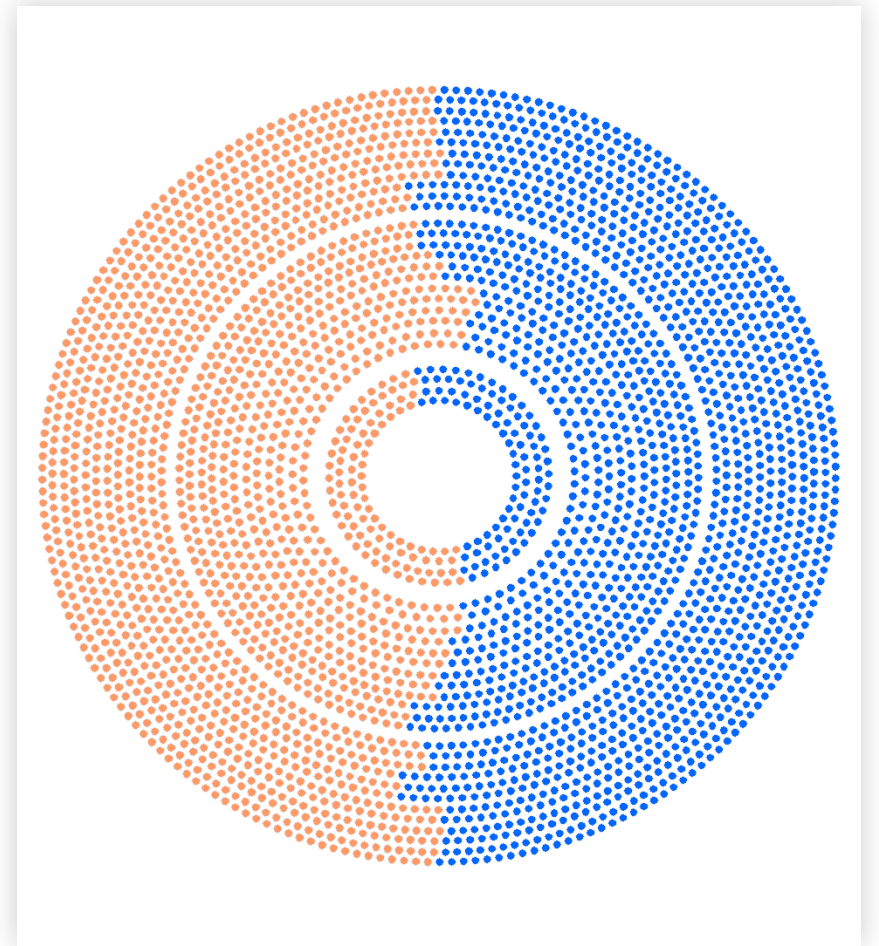- **Split CDC in half via software**

  Orange: set to 2130 V

  Blue: Tuned HV [2110,2140]

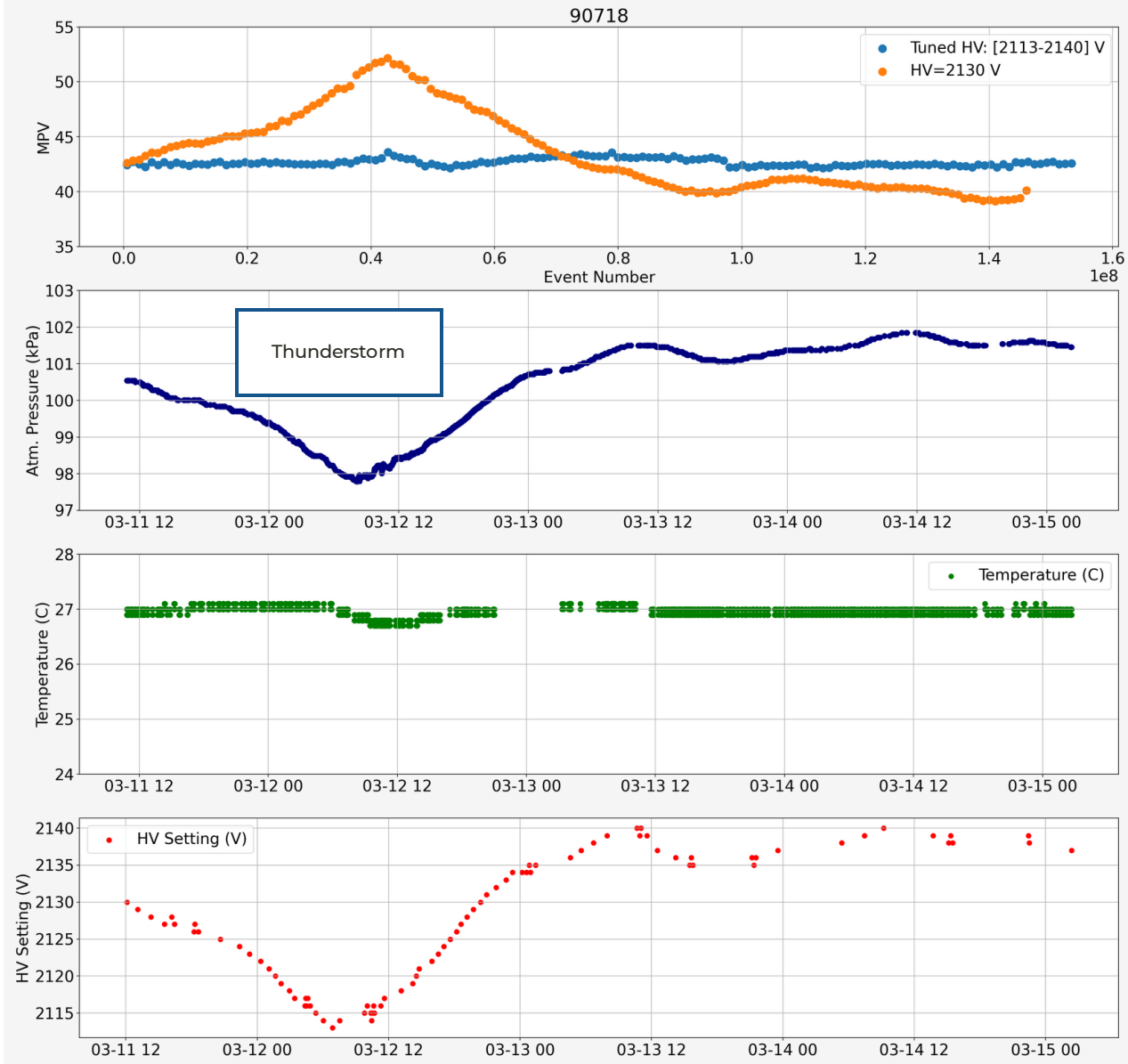- **HV would be adjusted every 5 minutes**

  Thomas and I made sure the DAQ didn't freeze

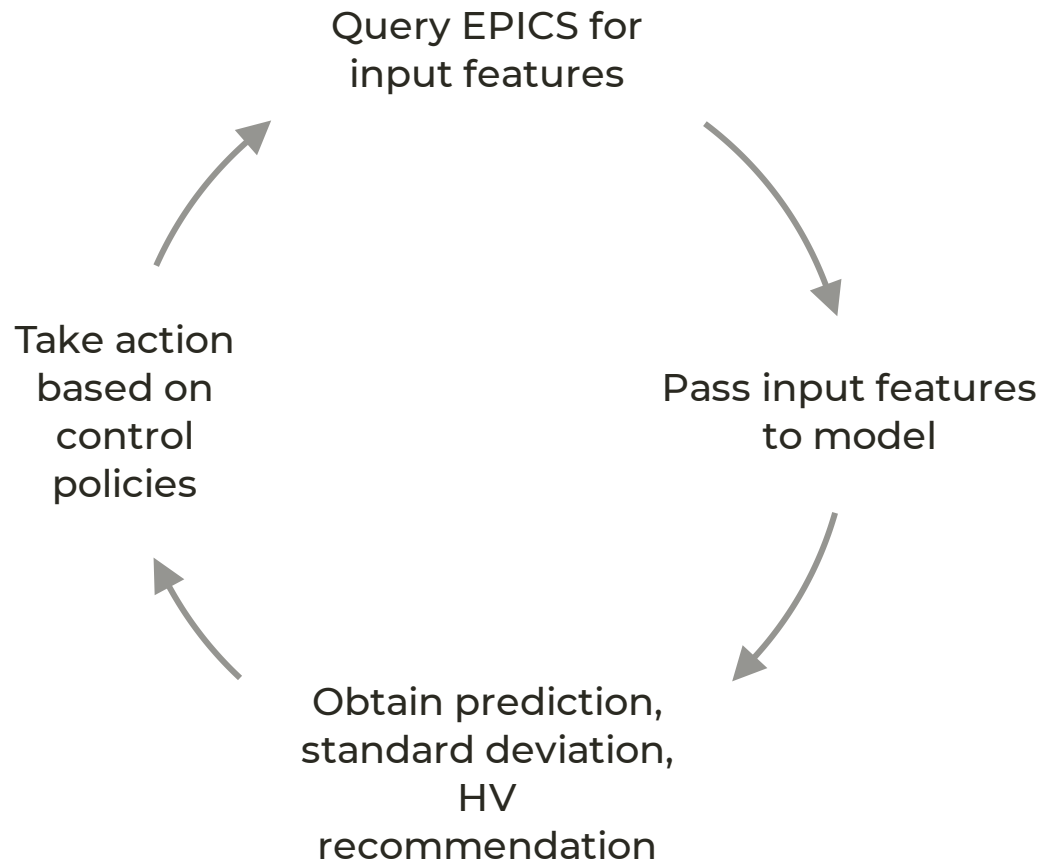 Naomi Jarvis did a skiathlon (she really trusted us :))

Cosmic Test Results

- Run 90718 corresponds to about 3 days of data taking

  Orange: fixed HV

  Blue: Tuned HV

- Adjusting the HV setting produces stable gain correction factors even in the presence of changing environmental variables.

Implementation in counting house

Query EPICS for
input features

Pass input features
to model

Obtain prediction,
standard deviation,
HV
recommendation

Take action
based on
control
policies

- Script is run asynchronously on DAQ GO

- All information and action logged into database

- Changes implemented via config file

Control Policies

As they are now, not an exhaustive list

- ## Defined range of allowed HV settings
  Determined by detector expert

- ## High Uncertainty
  Determine closest point to region of certainty, use that HV setting

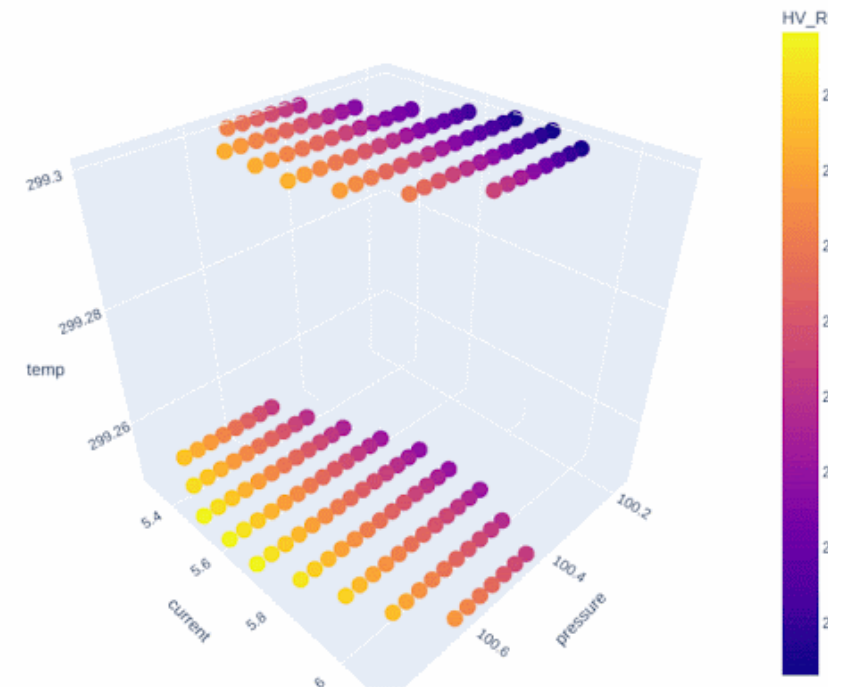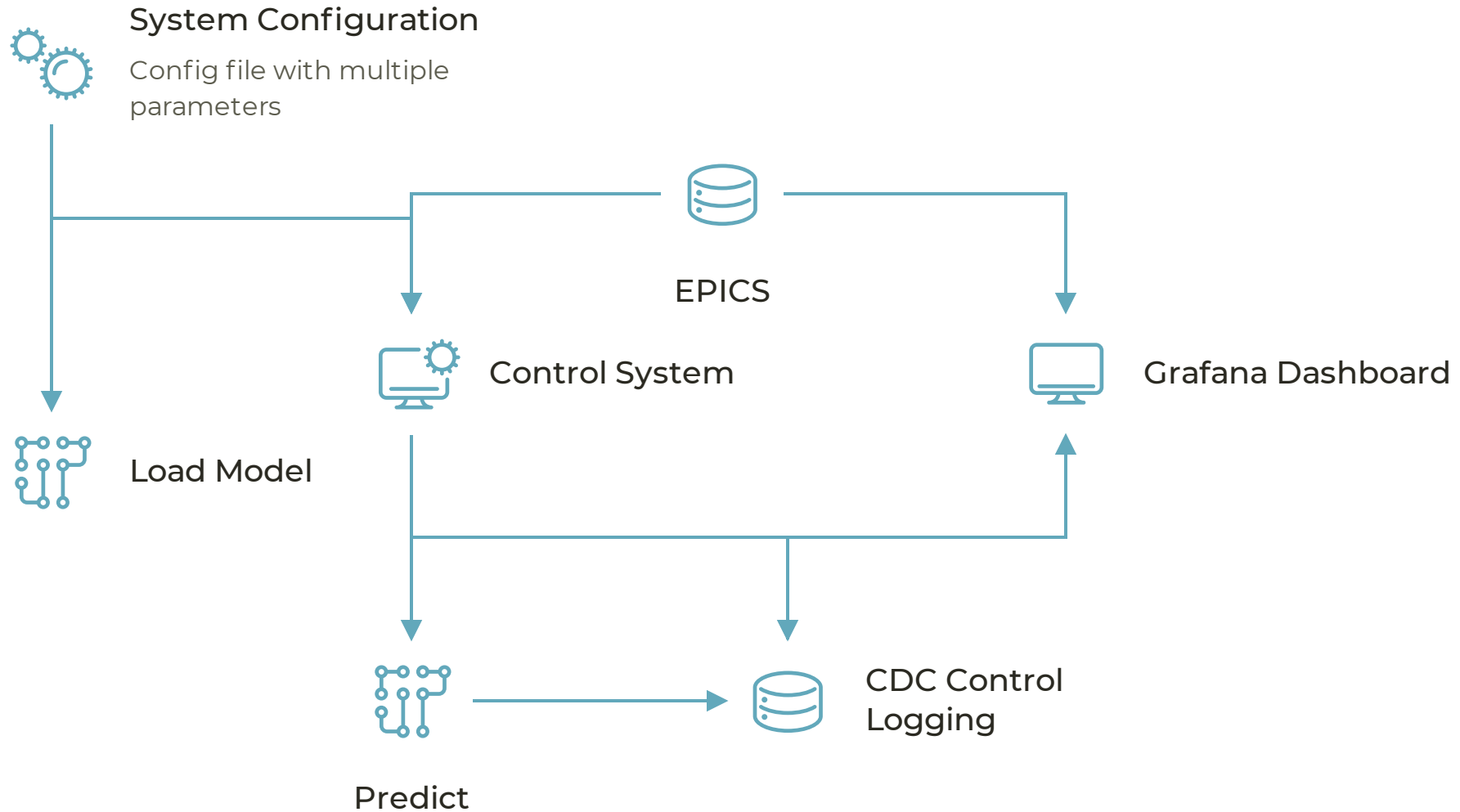 OR

  Revert to 2125 V and take more data

- ## "Trusting humans"
  If roboCDC detects a HV setting outside of our allowed range, we do nothing and assume there is something else going on (e.g., high current tests)

Control System Overview

System Configuration
Config file with multiple parameters

EPICS

Control System

Grafana Dashboard

Load Model

CDC Control Logging

Predict
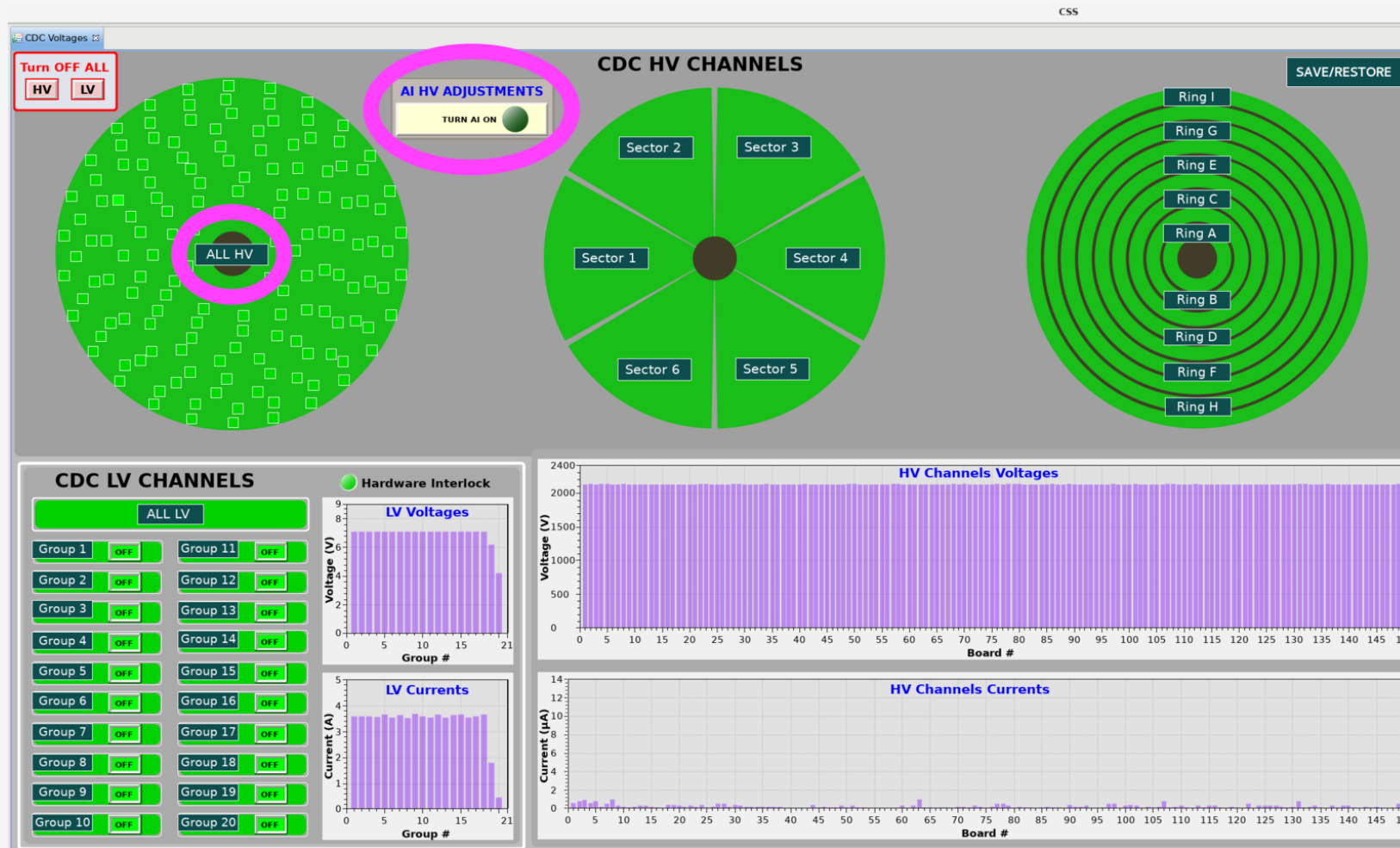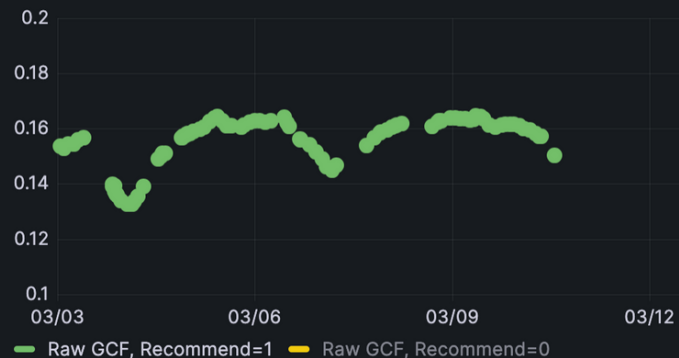
Control GUI

Shift crew can turn off ML based control with button press

The ON/OFF button hasn't been pressed without explicit direction from Naomi

Monitoring: Grafana

Raw GCF

0.2				
0.18				
0.16				
0.14				
0.12				
0.1				
03/03	03/06	03/09	03/12	

— Raw GCF, Recommend=1   — Raw GCF, Recommend=0

Recommended GCF (Raw, or UQ-Corrected GCF)

0.2				
0.18				
0.16				
0.14				
0.12				
0.1				
03/03	03/06	03/09	03/12	

— Recommended GCF, Recommend=1
— Recommended GCF, Recommend=0

Prediction Standard Deviation

0.005				
0.004				
0.003				
0.002				
0.001				
0				
03/03	03/06	03/09	03/12	

— Prediction Stdv, Recommend=1   — Prediction Stdv, Recommend=0

AIEC: CDC Control: Only Recommended

| gcf_requested ↓	pressure	temp	current	hvset	raw_gcf	recommended_gcf	stdv	hv_recommend	Recon
2023-03-10 13:16:...	100.3880	299.85	9	2125	0.1503	0.1503	0.00220	2121	
2023-03-10 08:27...	100.9970	299.85	9	2125	0.1573	0.1573	0.00206	2125	
2023-03-10 07:40...	100.9980	299.85	9	2126	0.1573	0.1573	0.00207	2125	
2023-03-10 06:24...	101.0630	299.85	9	2126	0.1582	0.1582	0.00214	2126	
2023-03-10 04:20...	101.1510	299.85	9	2127	0.1595	0.1595	0.00230	2126	
2023-03-10 02:05...	101.1940	299.85	9	2127	0.1600	0.1600	0.00239	2127	
2023-03-10 00:24...	101.3030	299.85	9	2128	0.1610	0.1610	0.00268	2127	

Results and Current Status

- HV is now regularly changed during the experiment

- Time to Distance calibration results are indistinguishable from traditional operation

- Both sets of calibration constants can be readily obtained at the start of each run

  The starting values for the time to distance parameters are strongly correlated with atmospheric pressure.
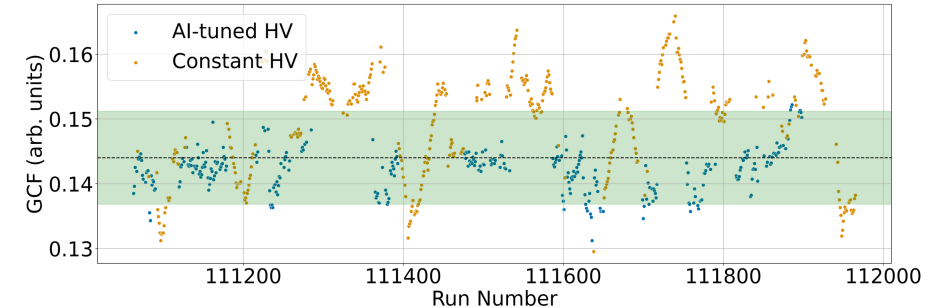
RESULTS FROM THE PRIMEX RUN PERIOD

faulty pressure sensor
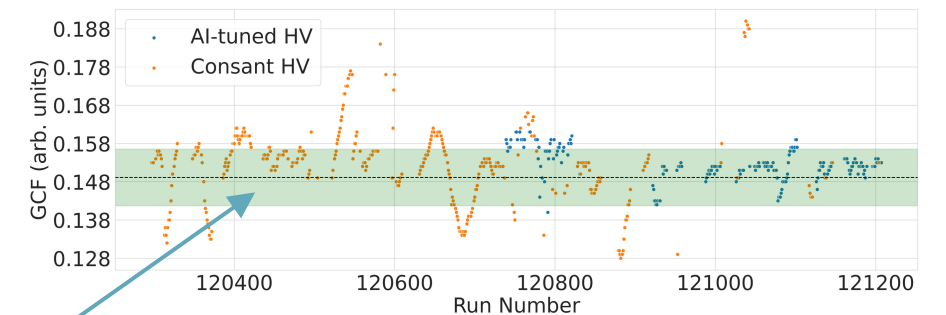
RESULTS FROM GLUEX2023 RUN PERIOD

References:

1. **Final report**: https://arxiv.org/abs/2402.13261

General References

1. GlueX:10.1016/j.nima.2020.164807
2. CDC: 10.1016/j.nima.2020.163727
3. CLAS12: 10.1016/j.nima.2020.163419

Contact information

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GlueX Calibrations

Run dependent calibrations