Carnegie Mellon University

Using Machine Learning to control the GlueX Central Drift Chamber

Naomi Jarvis
Carnegie Mellon University

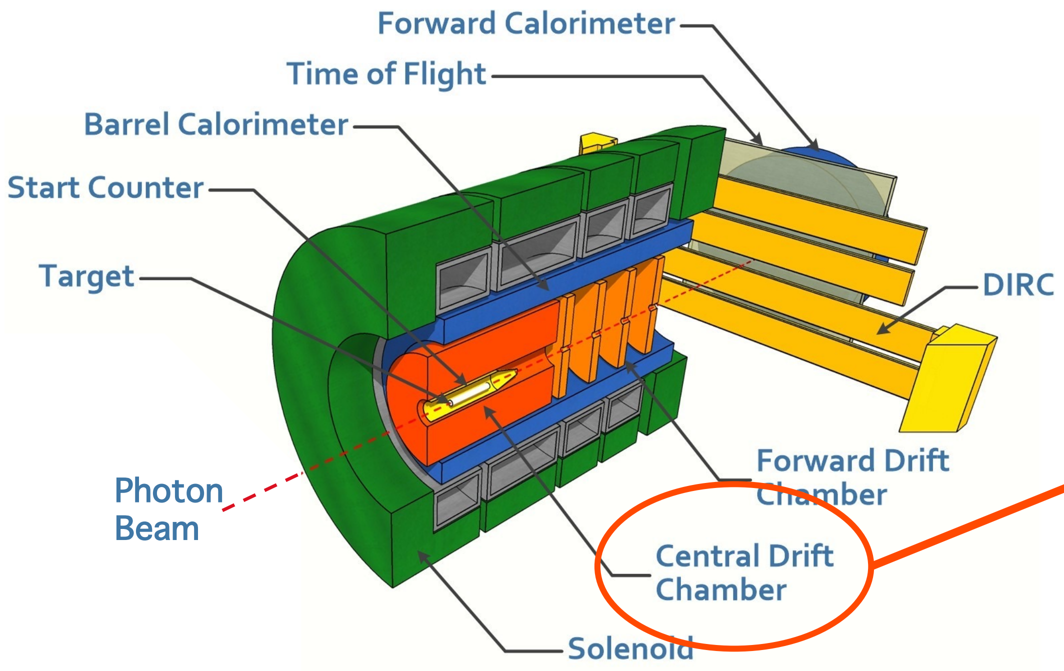
Thomas Britton, Torri Jeske, David Lawrence, Diana McSpadden
Experimental Physics Software and Computing Infrastructure
Jefferson Laboratory

AI for Experimental Controls Team

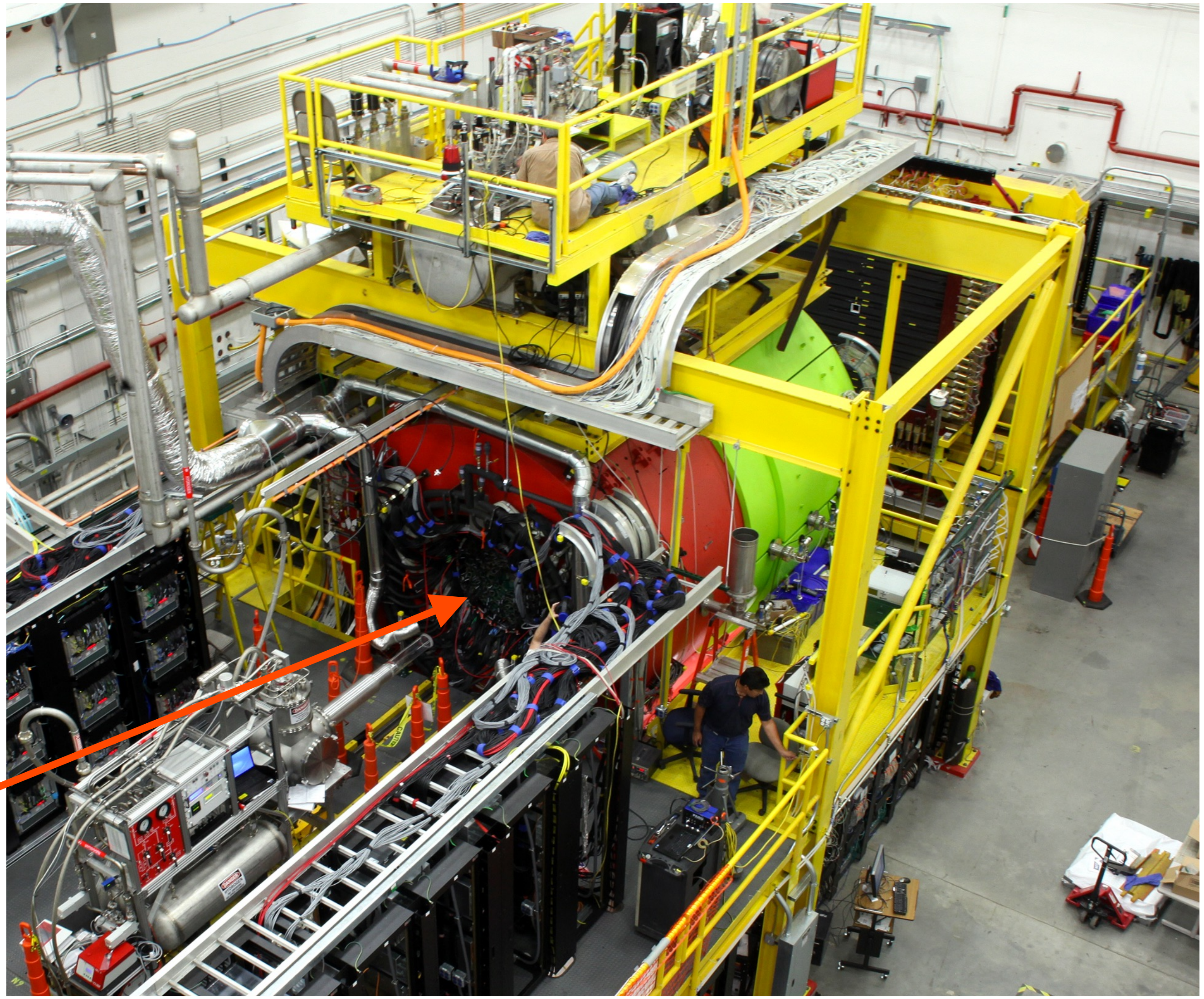
Outline: Development and deployment of AI/ML system for calibration and control

- Focused on GlueX Central Drift Chamber (CDC)
- Modular system could be applied to other detectors

- GlueX: meson photoproduction experiment, searching for exotic hybrids

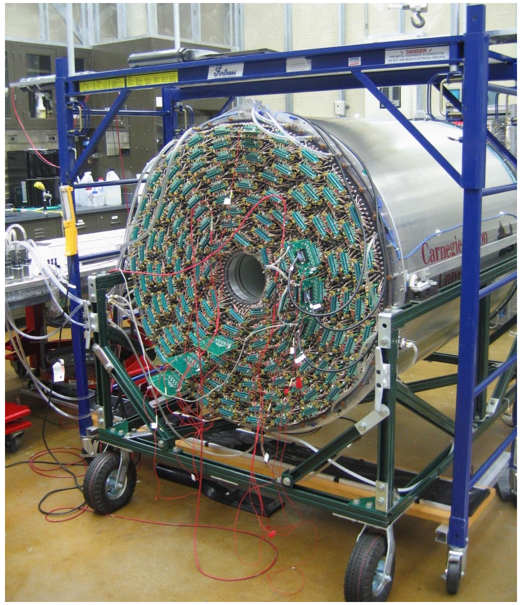


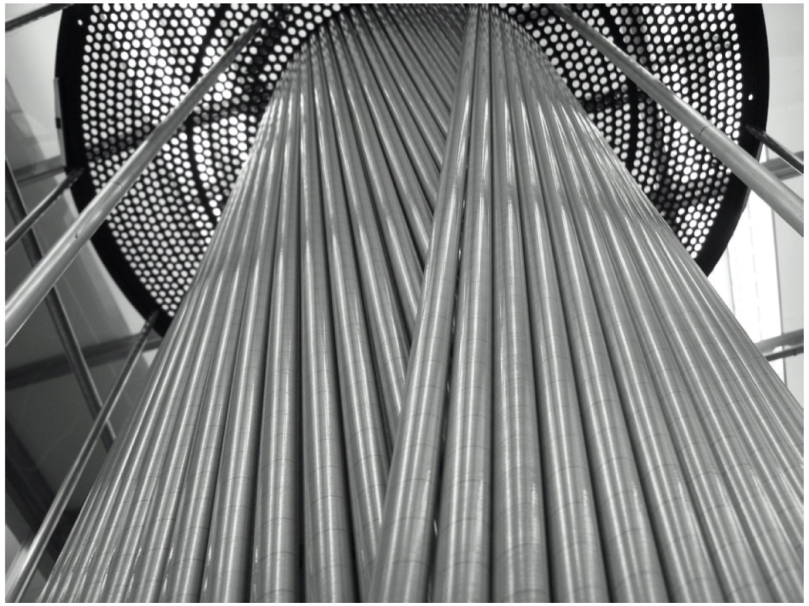
GlueX detector located in Hall D at Jefferson Lab, VA



GlueX Central Drift Chamber (CDC) – charged particle tracking and identification

- 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 straws
- Ar/CO2 gas mix, approx. 30 Pa above atmospheric pressure
- Used for tracking and PID – measures drift time and deposited charge





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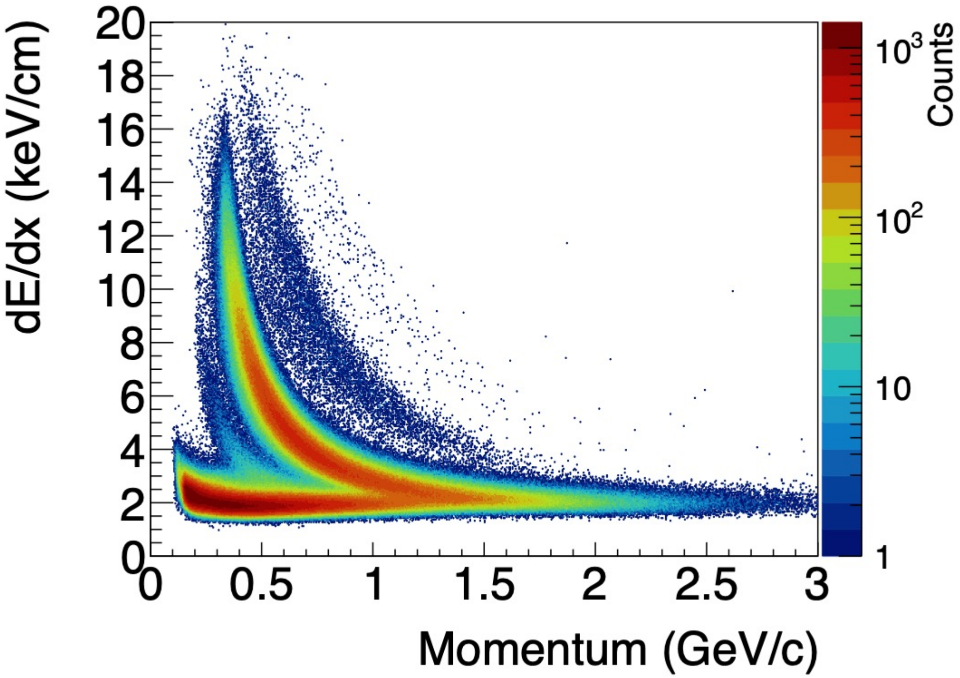
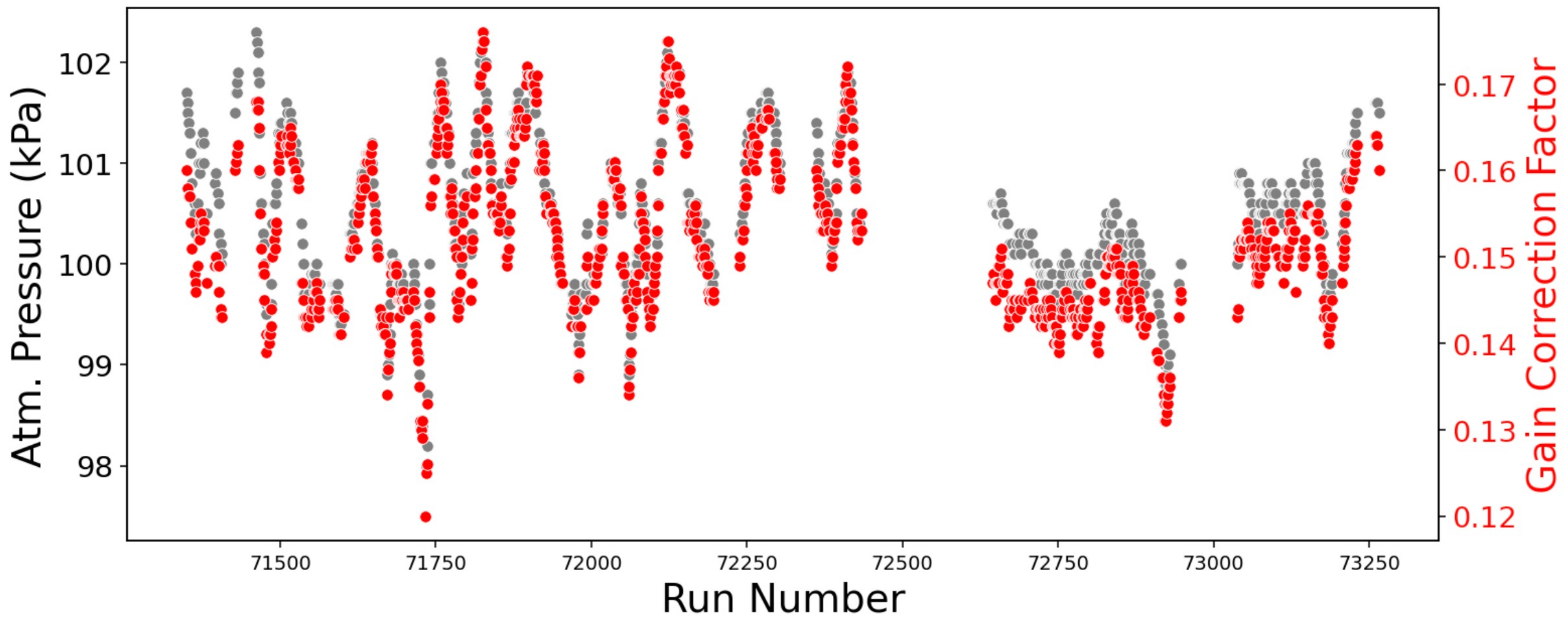


Atmospheric pressure and CDC dE/dx

- CDC gain varies +/- 15% with gas density and also with hit rate (stable within run period)



- Runs limited to 2h or less – pressure alarm asks for new run, could be 30 mins when weather front is passing over
- Data calibrated after the run period ends, iterative, coordinated with other subsystems, takes months to complete

- HV could be adjusted for constant gain. Could we do this with AI/ML? What would be the effect on drift times?

Evaluating impact of tuned HV on drift times

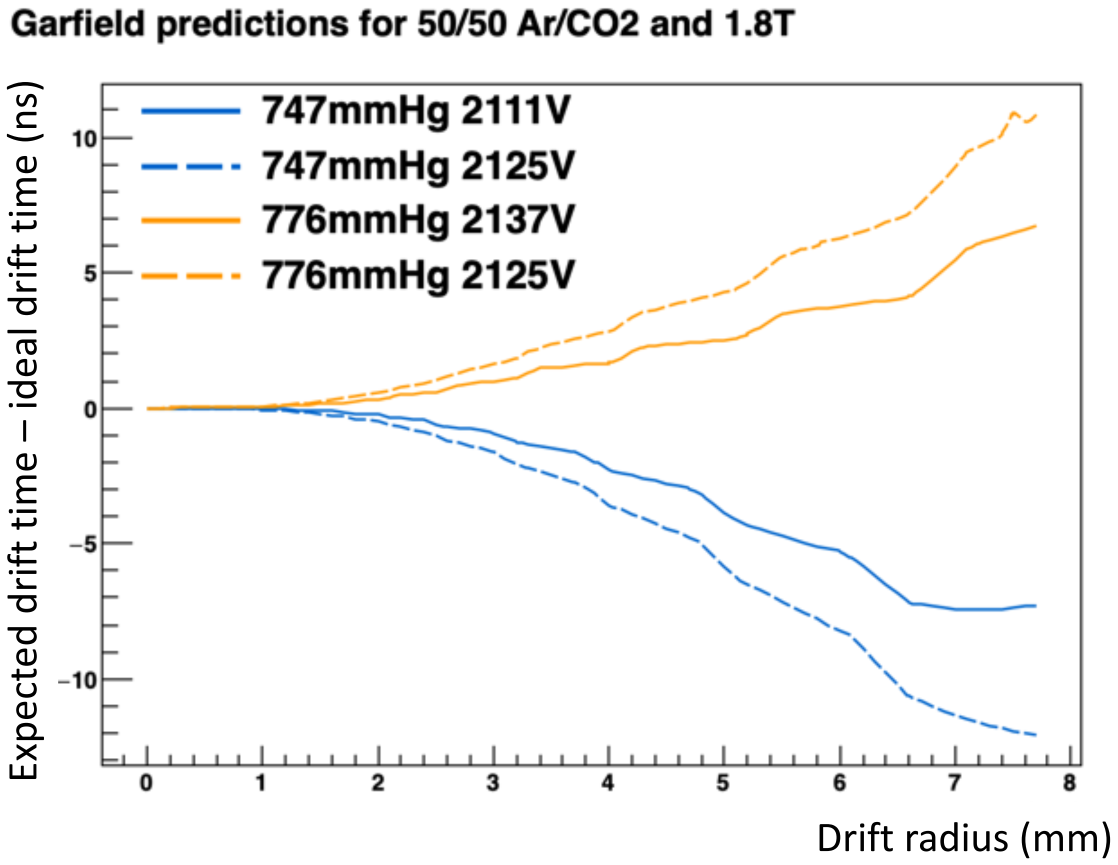
- Drift time to distance conversion uses a table of ideal drift times simulated for standard pressure and nominal HV 2125V (GARFIELD). Calibration accounts for imperfect straws and pressure.
- Ideal drift times are at 2125V and 760mmHg
- Simulated drift times at pressure extremes for fixed HV 2125V and HV tuned for constant gain.
- Plot shows expected – ideal drift time vs drift radius

  Dashed lines: 2125V

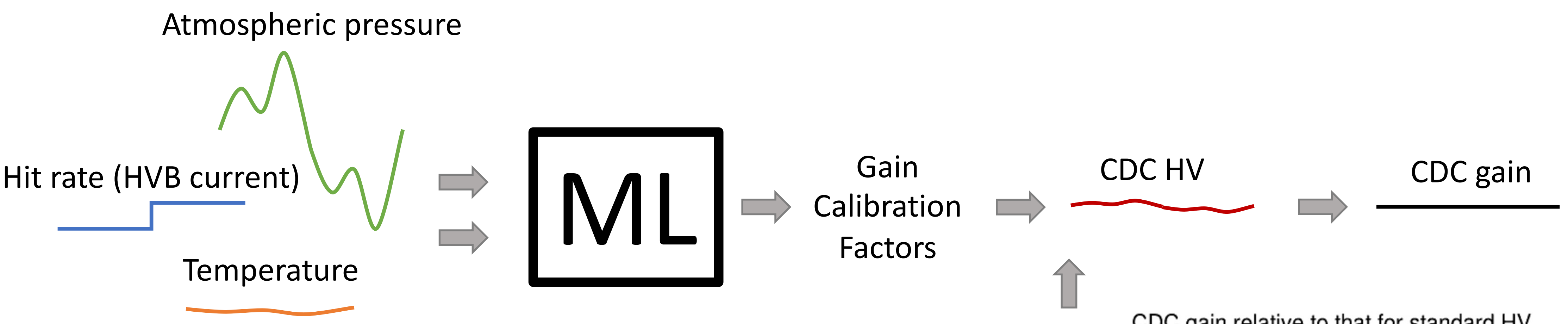
  Solid lines: tuned HV

- Drift time differences are small
- Most hits are at small drift radius (geometry)
- Differences for tuned HV < differences for 2125V

- Tuned HV should improve the position resolution slightly



Strategy for ML to control the CDC for stable gain and quicker calibration

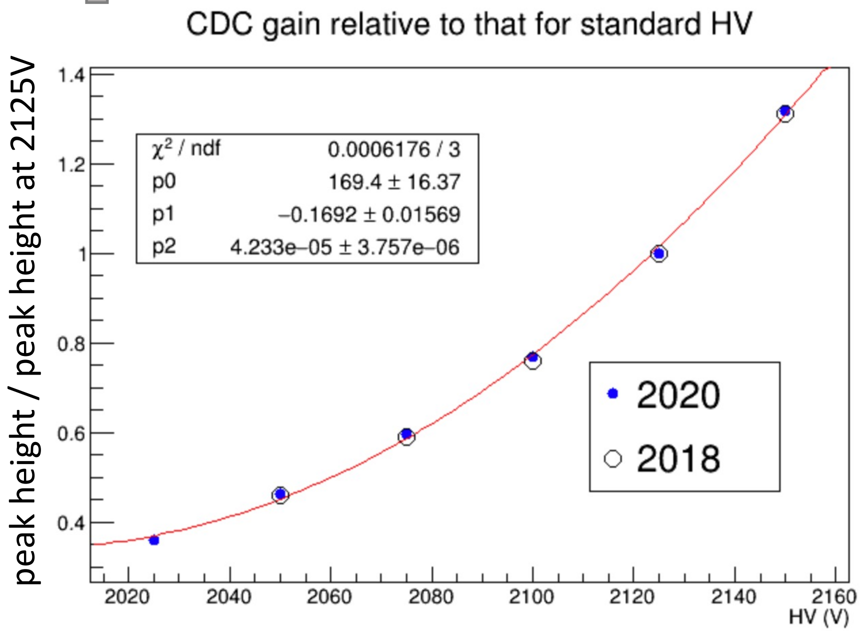


- Train ML model to predict GCF from EPICS data + existing calibrations

  [Experimental Physics Industrial Controls System]

  Logs pressure, temperature, HVB current

  Logged continuously since 2016
- Extract new measurements from EPICS at the start of each run
- Calibrate without reconstruction or dE/dx (fine-tune later)



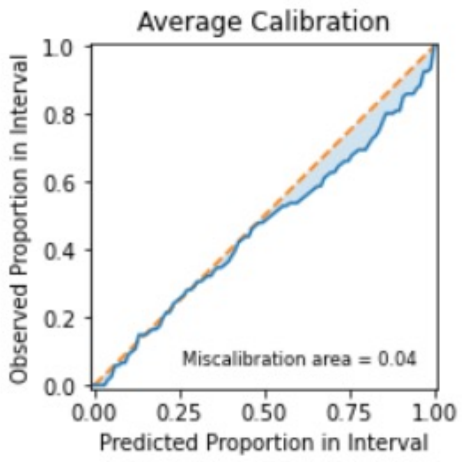
ML technique: the Gaussian Process model

- 3 features: P, T, HVB current
- 1 target: Gain Correction Factor (GCF)

- 601 runs, 536 from 2020 and 65 from 2021
  - 80 / 20 train test split
  - Pressure balanced for low, medium and high pressure

- GP calculates PDF over admissible functions that fit the data
- GP provides the standard deviation – use this for UQ
- Used a popular GP kernel: Radial Basis Function + White
  - Compared isotropic (1 length scale) and anisotropic (length scale per input variable) kernels

Validation of uncertainty quantification (UQ)

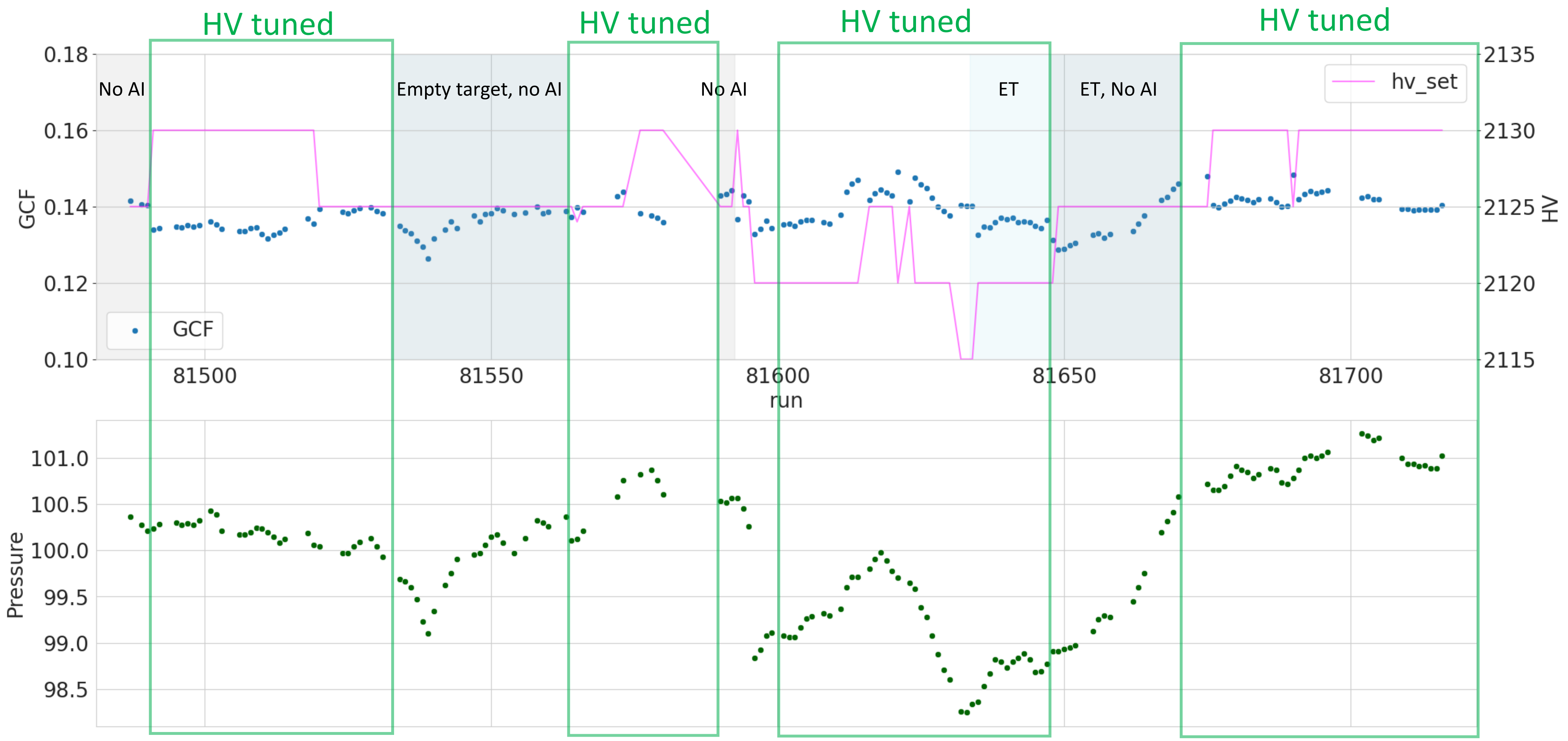


Our goal was better than a 5% error

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%

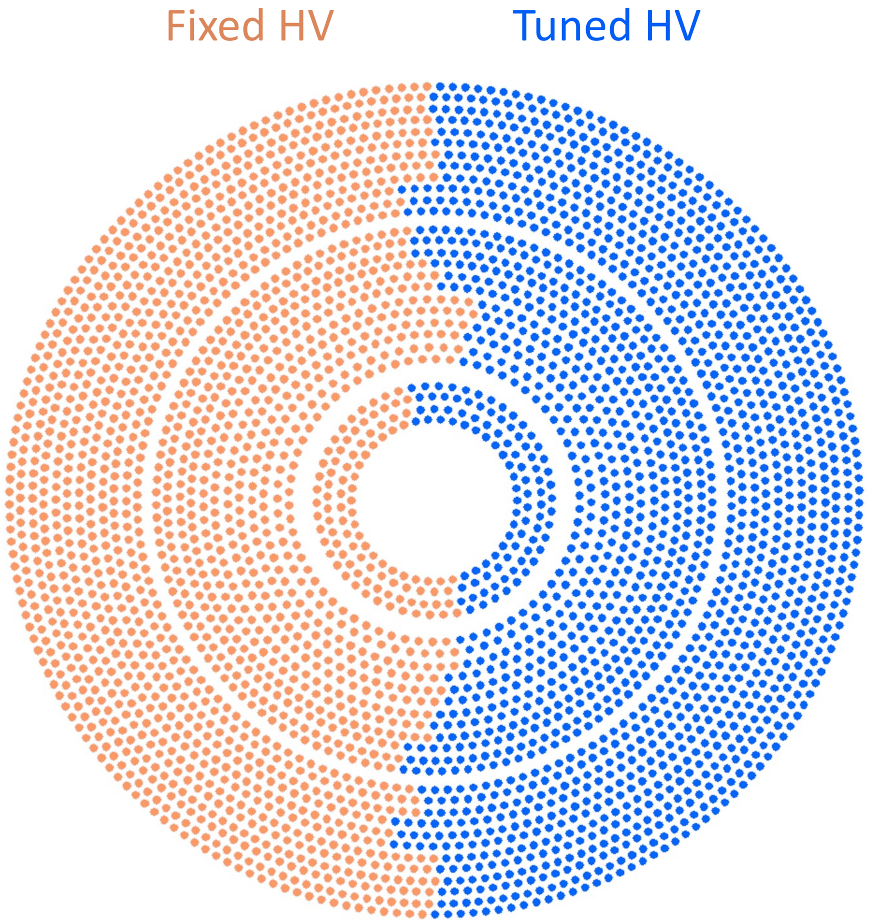
Deployment 1 of 4 – Operational testing during PrimEx Nov 2021

AI-tuned HV was rounded to the nearest 5V.   GCFs were obtained from dE/dx later on. The AI was not used for some runs.



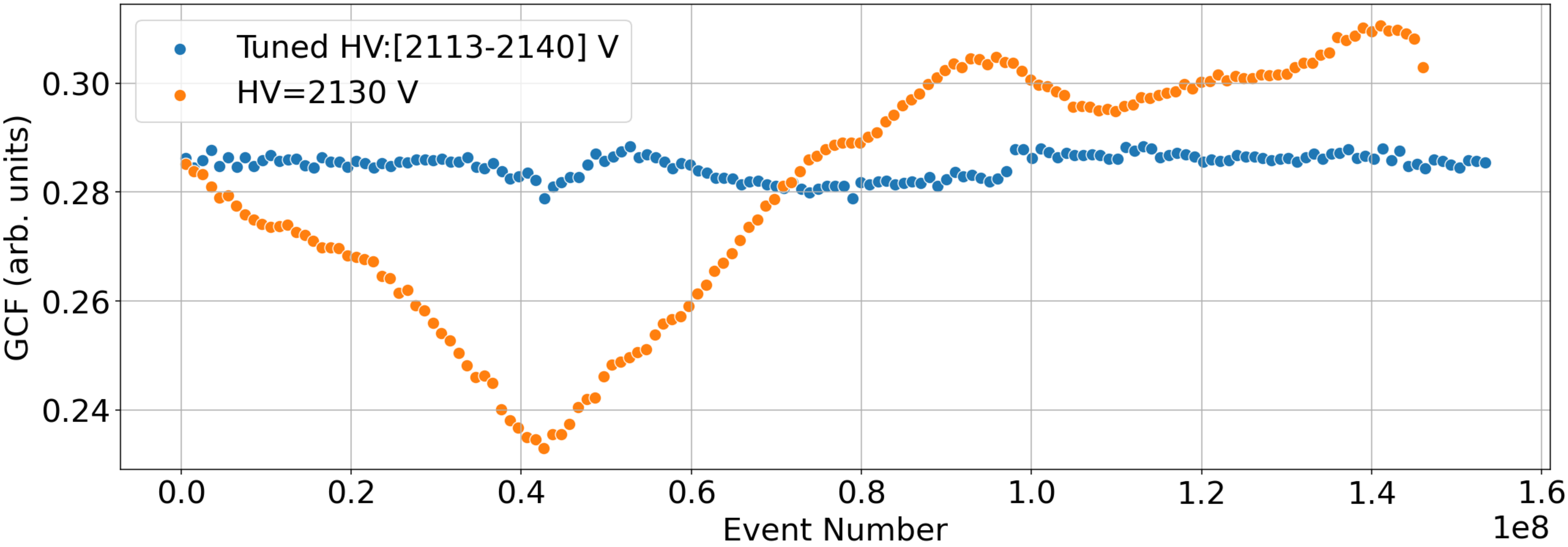
Deployment 2 of 4 – testing autonomous operation with cosmic rays

- CDC HVBs sorted into 2 groups
  - Fixed HV
  - Tuned HV
- RoboCDC software developed
  - Harvested EPICS, ran ML, adjusted HV, logged its actions
  - Autonomously, every 5 minutes
- Collected data for 2 weeks
- Hoped to see ML-tuned side’s gains stablized

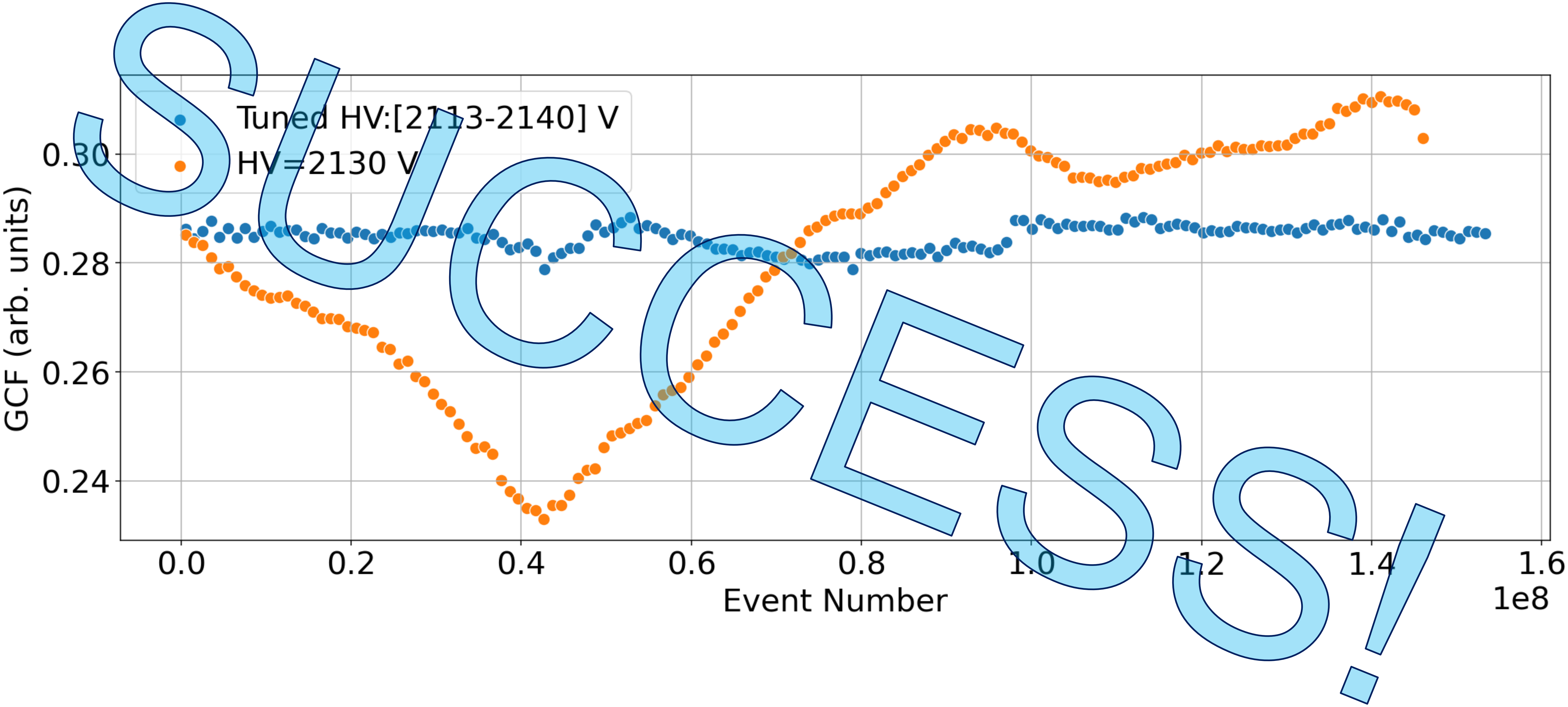


End-on view of the CDC wire locations

Deployment 2 of 4 – testing autonomous operation with cosmic rays



Deployment 2 of 4 – testing autonomous operation with cosmic rays



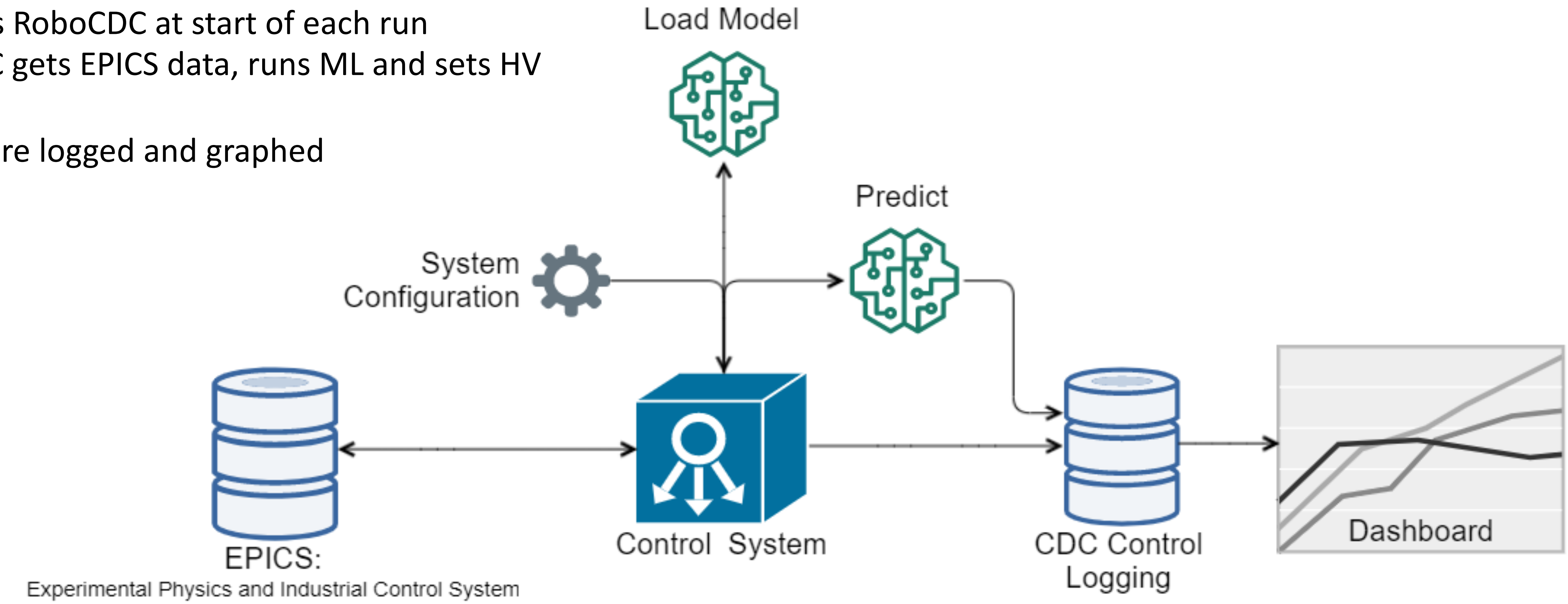
RoboCDC: Integrating AI/ML into the control system

- RoboCDC is modular and flexible – experts can update model on demand

- Experts configure ideal GCF at start of experiment

- Shift crew has one on/off button for RoboCDC
- DAQ calls RoboCDC at start of each run
- RoboCDC gets EPICS data, runs ML and sets HV

- Actions are logged and graphed



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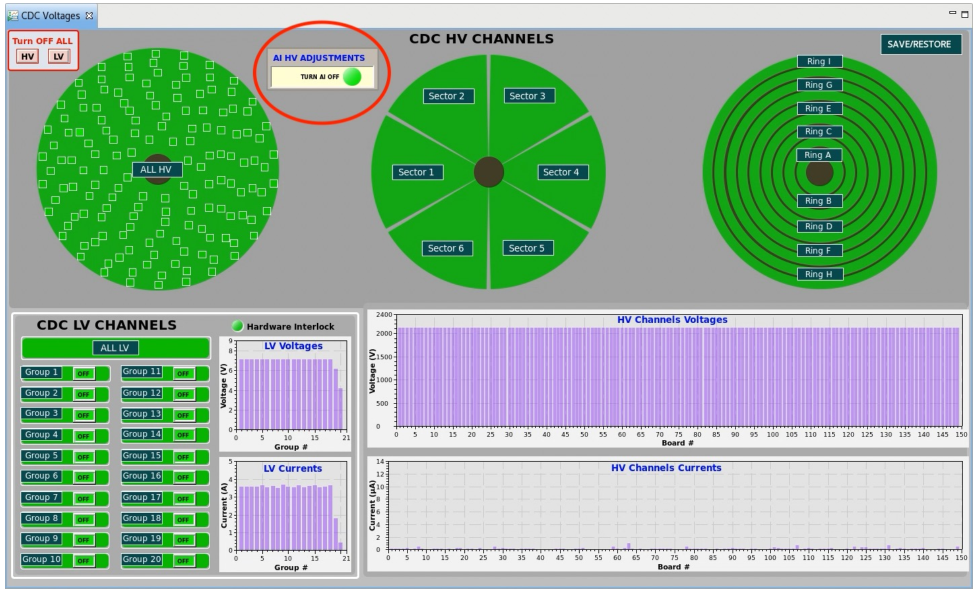


Deployment 3 of 4 – Charged Pion Polarizability May-June 2022

- RoboCDC used automatically at the start of each 2h run

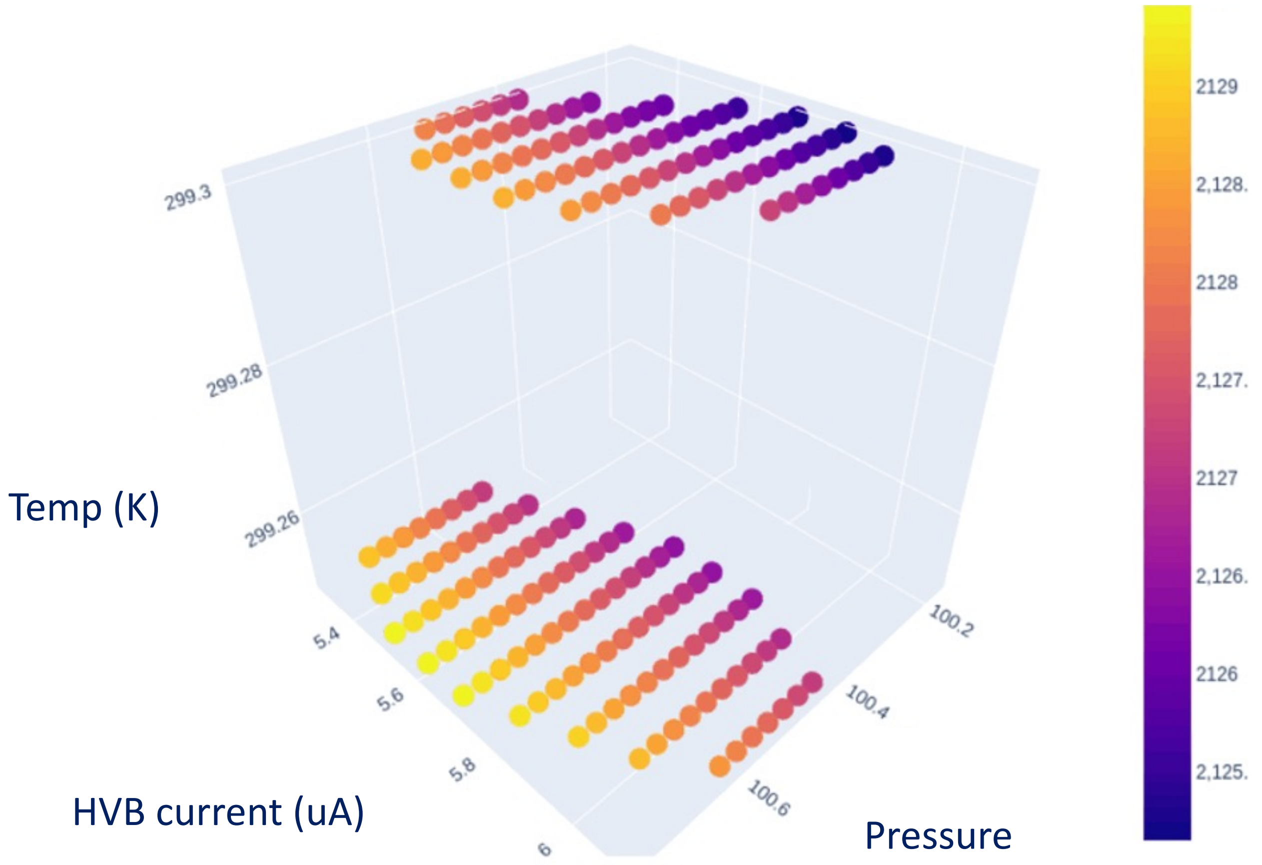
- Used recommended HV if std deviation $\leq$ 3% ideal GCF
- Otherwise used the closest 'confident' HV
  in Euclidean distance on the uncertainty mesh

- Reverted to 2125V for empty target runs

- Low stakes – CDC not critical for CPP

- Unusual running conditions
  - different target in different location
  - low beam current

HV for GCF with $\sigma \leq 0.7\%$



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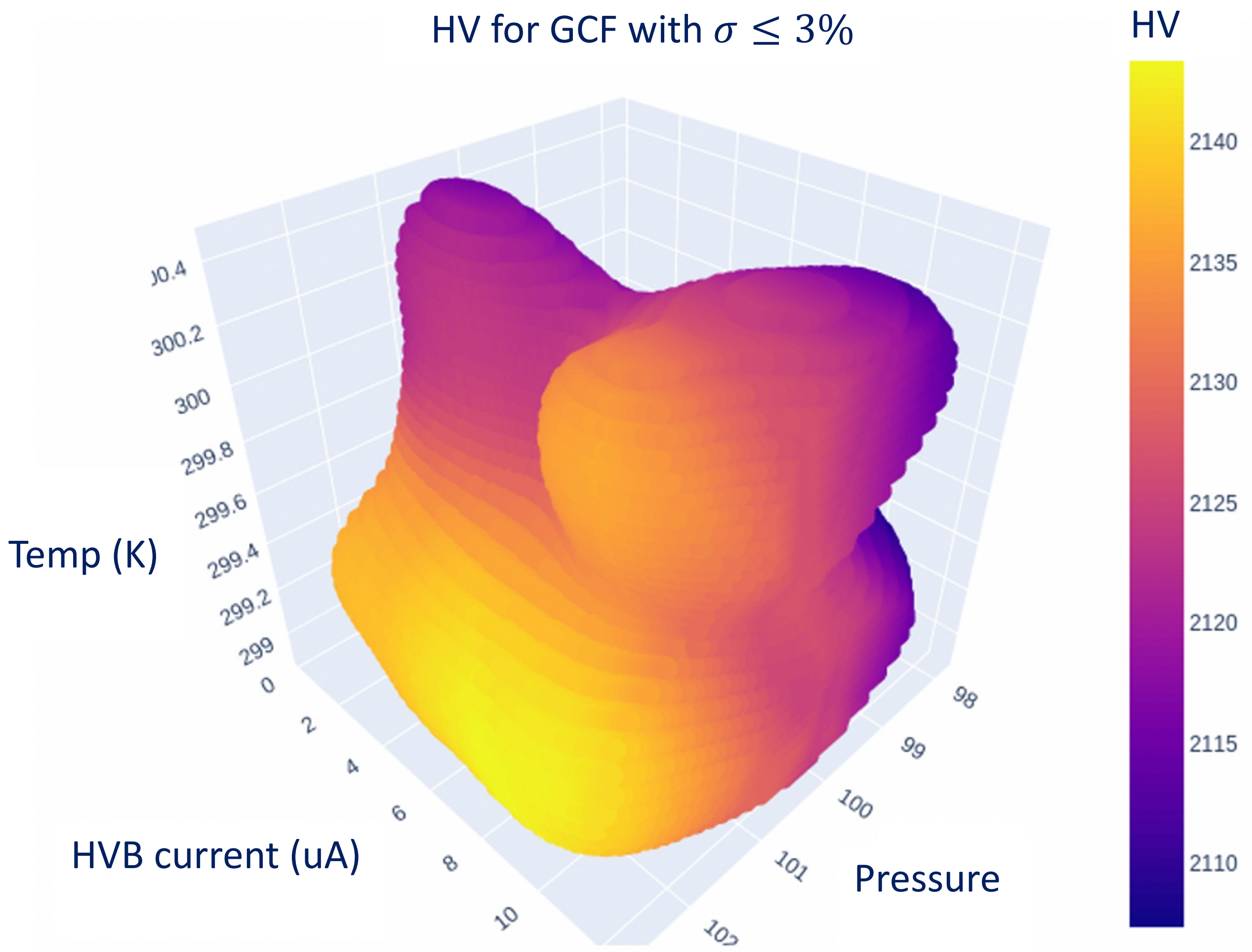

Deployment 3 of 4 – Charged Pion Polarizability May-June 2022

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    - different target in different location
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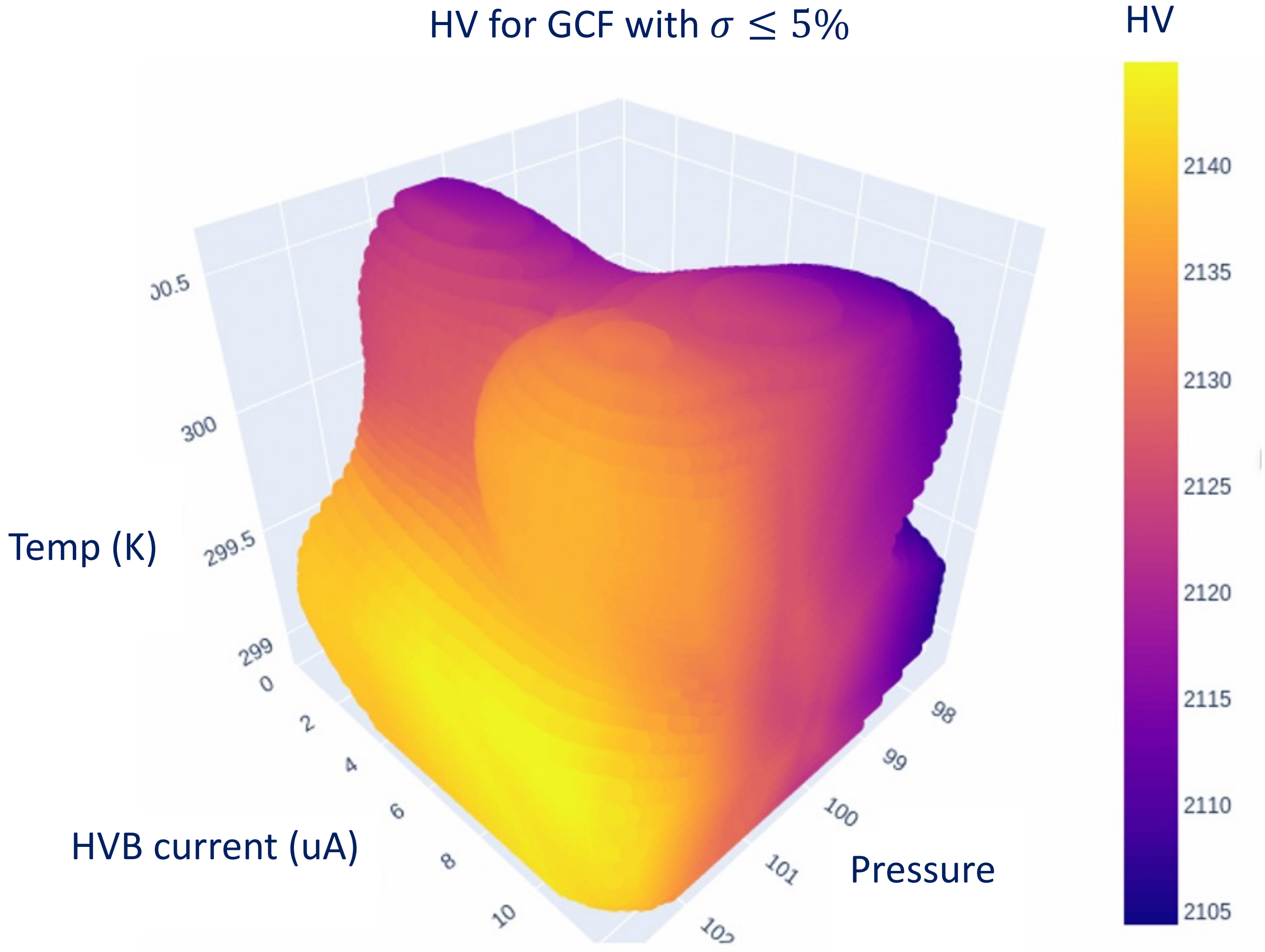
HV for GCF with $\sigma \lesssim 5\%$

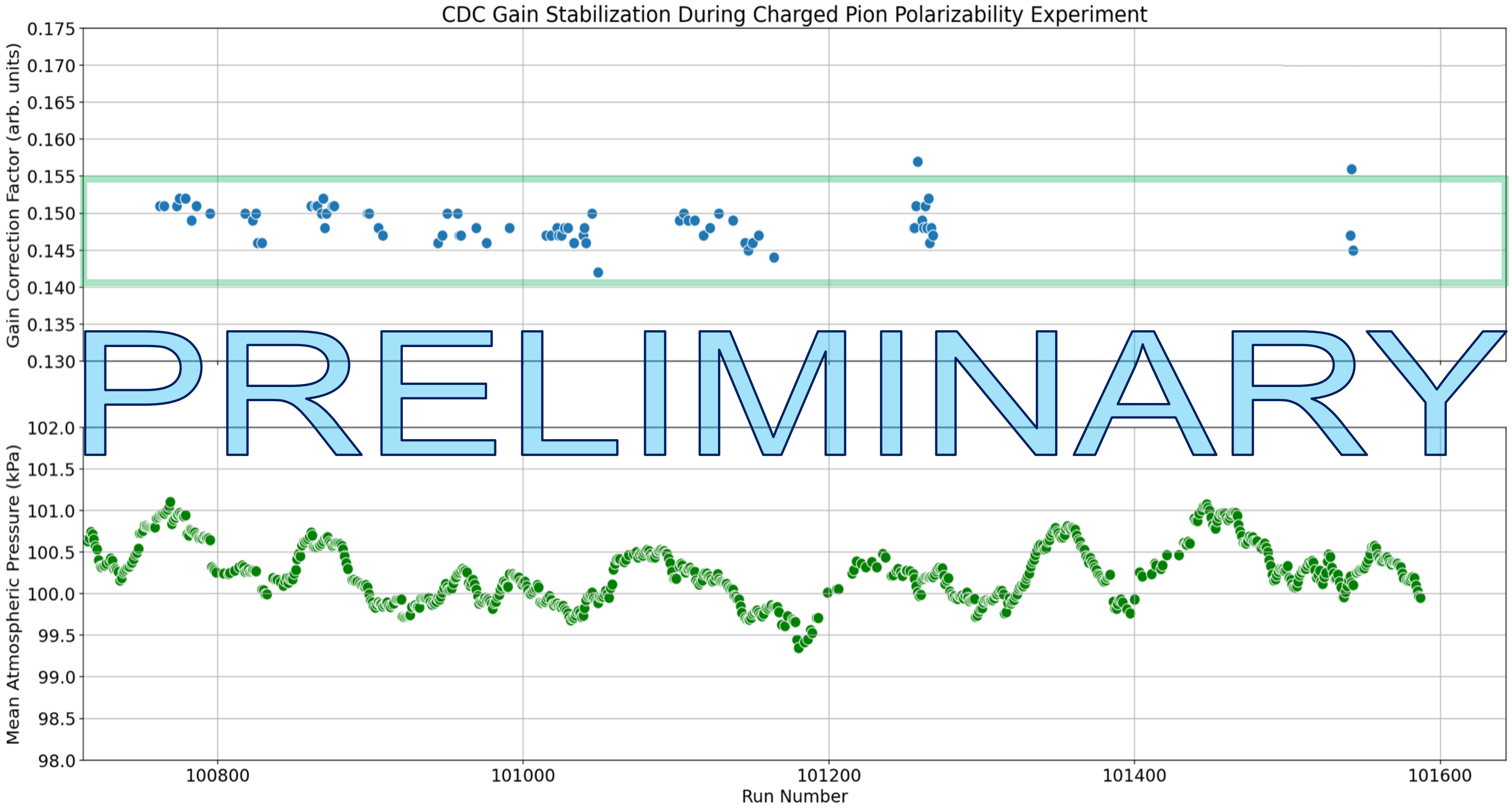


Deployment 3 of 4 – Charged Pion Polarizability May-June 2022

- Preliminary results show gain and pressure stability.
- Y-axis range of plots set to usual range for pressure and GCF with fixed HV

GCF

Pressure



Deployment 4 of 4 – PrimEx-η June-Dec 2022

- RoboCDC used automatically at the start of each 2h run

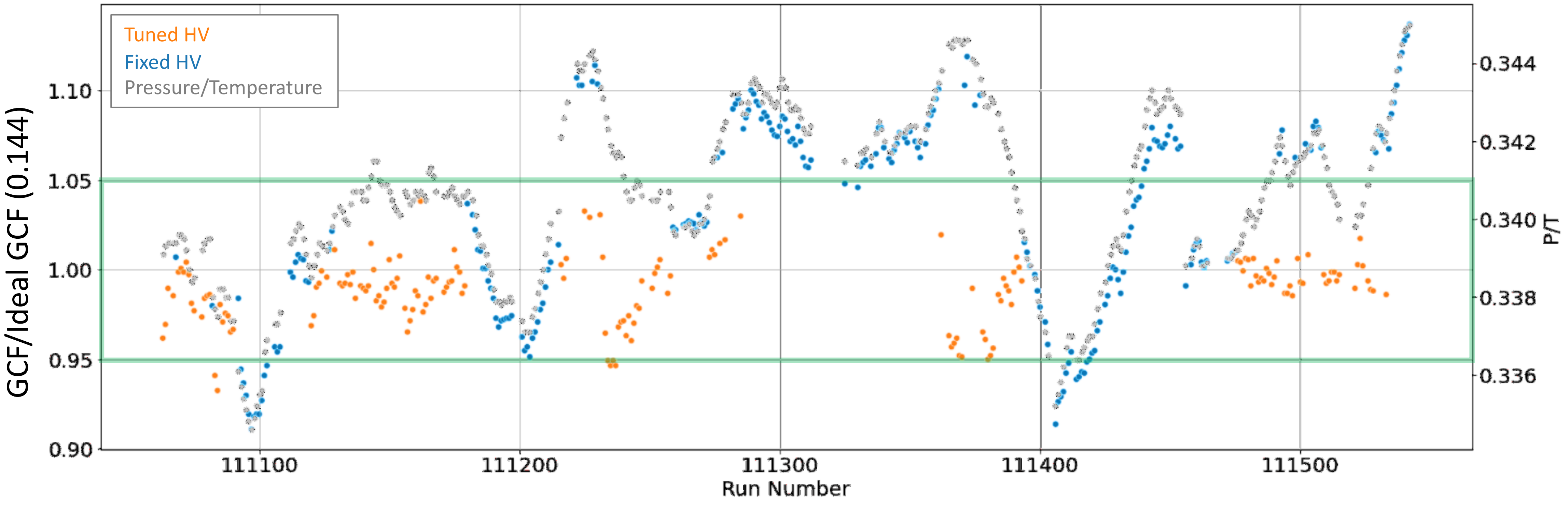
- Used recommended HV

    - if std deviation $\leq$ 3% ideal GCF
    - if the target status in EPICS is ‘full and ready’

- Otherwise used 2125V to expand our training dataset.
- Possibility of automatic data collection, retraining, redeployment in the future.

Deployment 4 of 4 – 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



Development chart

Run period	Experiment	Training data for GP	Operation
Oct 2021	PrimEx-η	GlueX 2020	Shift crew ran script HV set in 5V steps
Feb 2022	Cosmics	GlueX 2020 + PrimEx 2021	RoboCDC - autonomous operation HV set in 1V steps
May 2022	CPP	GlueX 2020 + PrimEx 2021	RoboCDC integrated into control system
Oct-Dec 2022	PrimEx-η	GlueX 2020 + PrimEx 2021	Auto-2125 for UQ Auto-2125 for ET
Jan-Mar 2023	GlueX	Gluex 2020 + PrimEx 2021 + GlueX 2018?	Auto-2125 if not enough beam in 30s before start of run

Summary

- Trained a Gaussian Process model with drift chamber environmental values – pressure, gas temperature, HVB current.

- Developed control software RoboCDC; now integrated into standard running.
- No special action required from shift crew.

- Gained practical experience from 4 sessions in 2021-2022.
- Results look good: gain stable within 5%.

- Using uncertainty quantification to determine when to switch off gain-stabilization and collect more training data.

- RoboCDC will be used for GlueX runs later this month.

- The modular control software could easily be adapted for other detector systems.

Acknowledgements

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

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