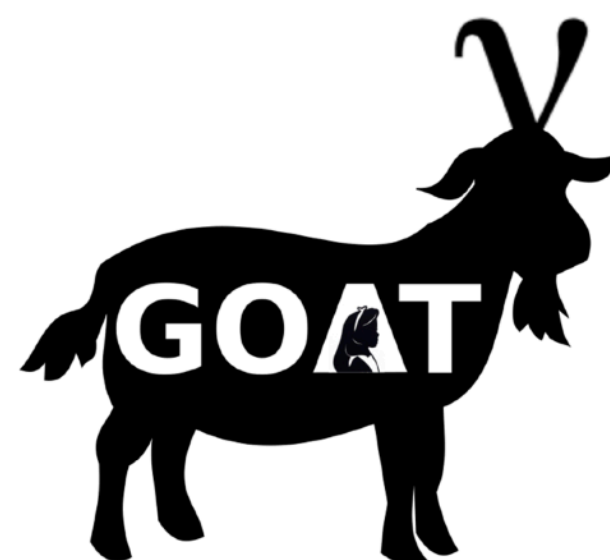




Advancing Detector R&D for High-Pressure Gaseous Argon TPCs in Precision Neutrino Physics

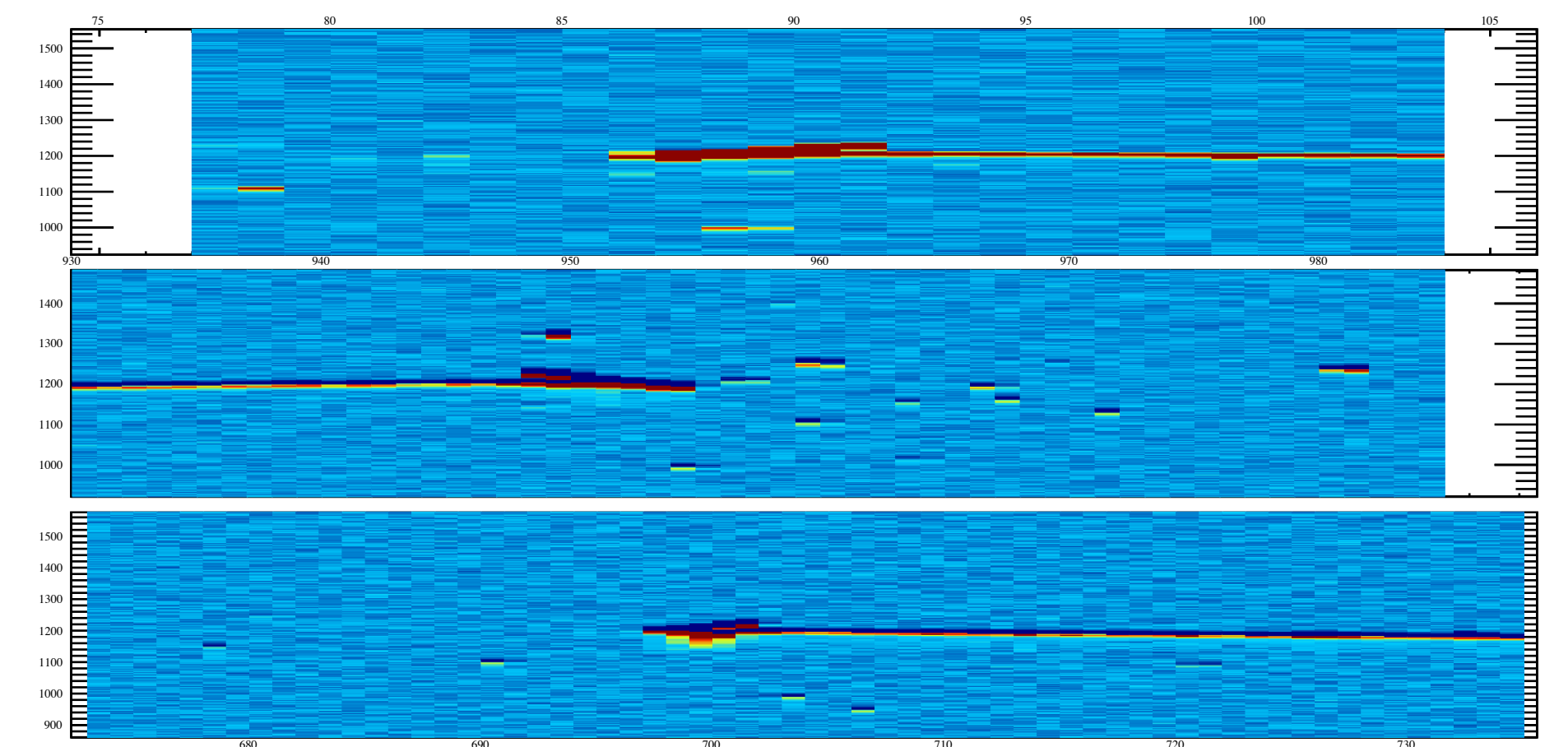
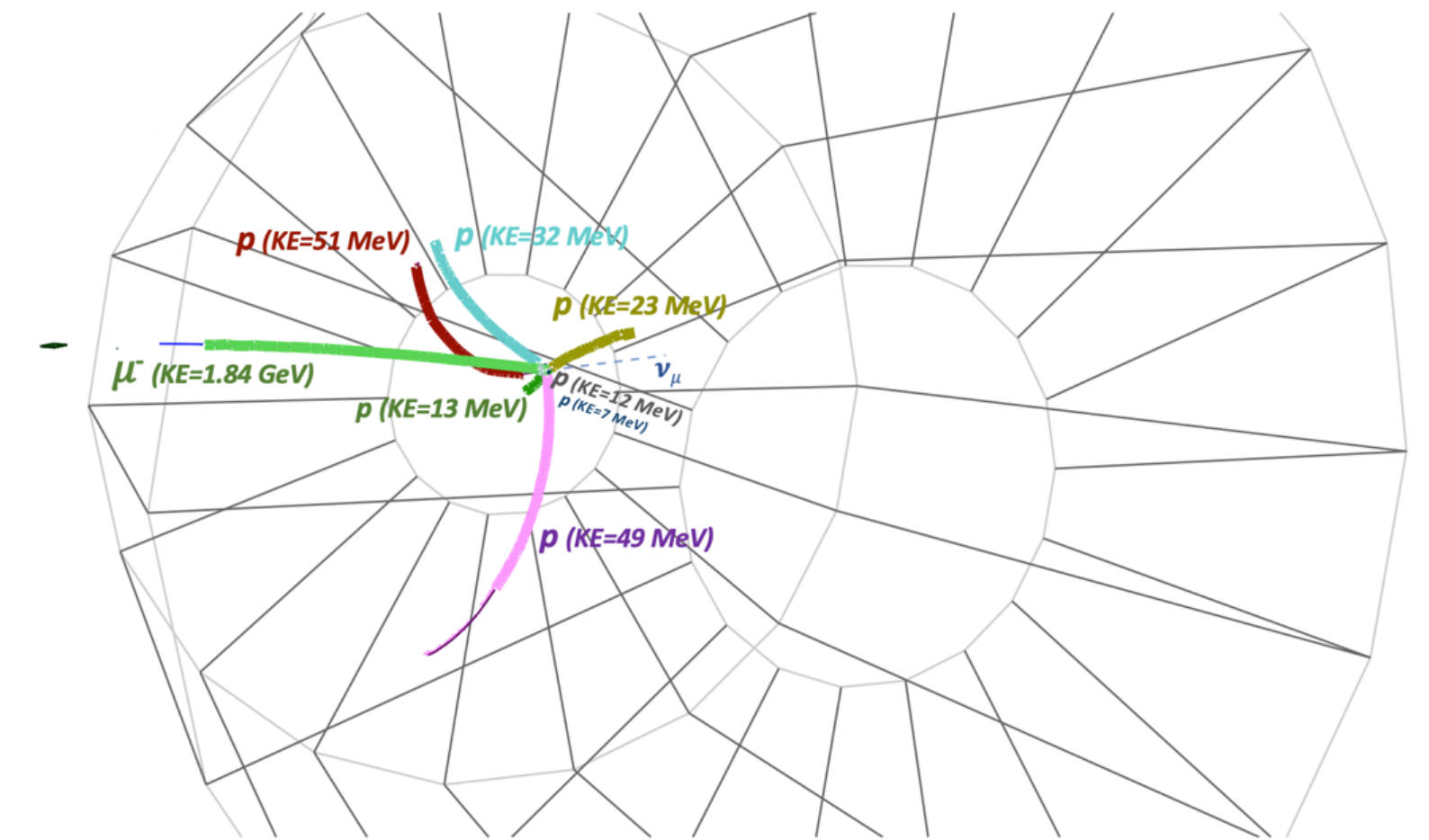
Francisco Martínez López
frmart@iu.edu

October 22, 2026
CPAD 2026 @ Seattle



Why high pressure?

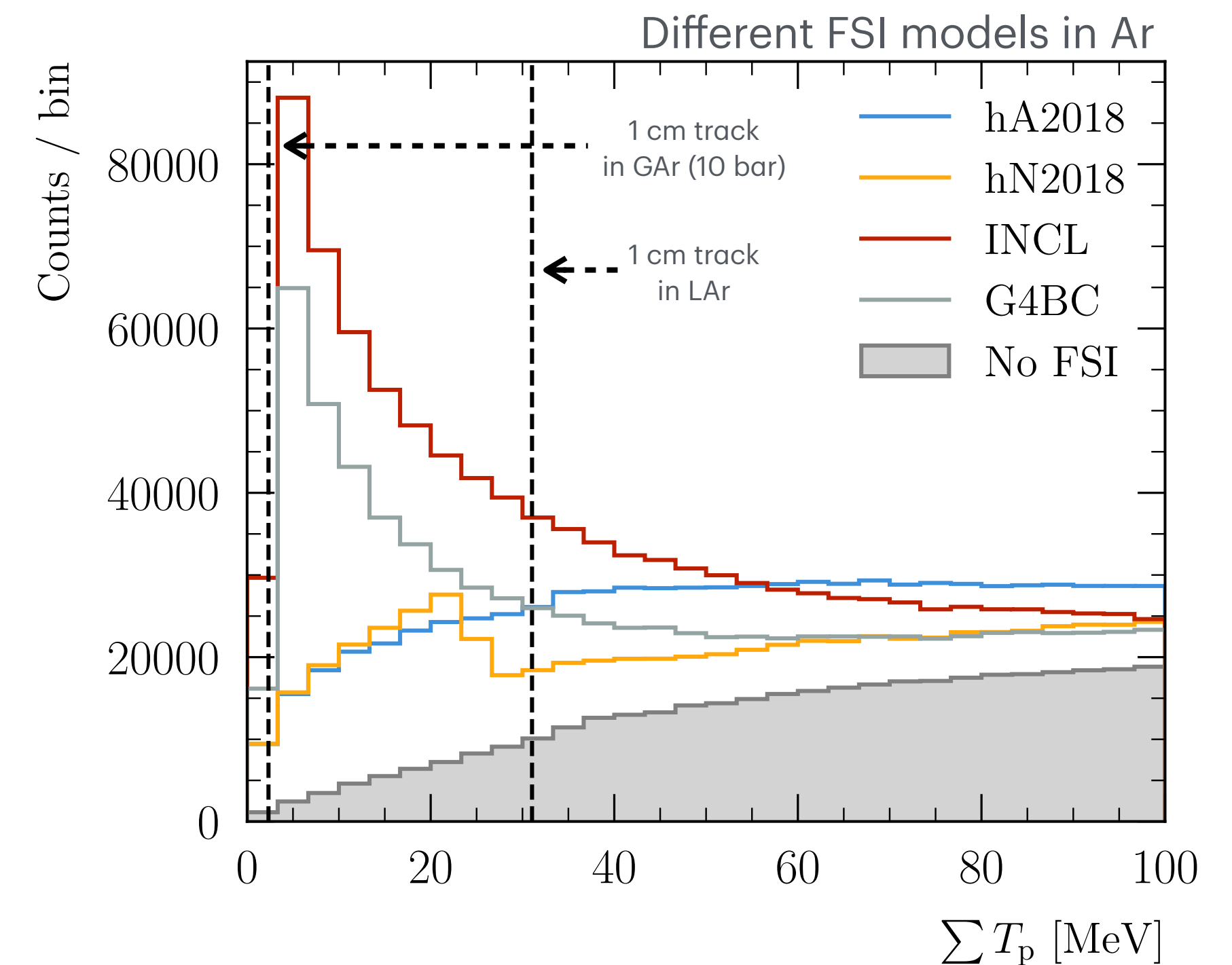
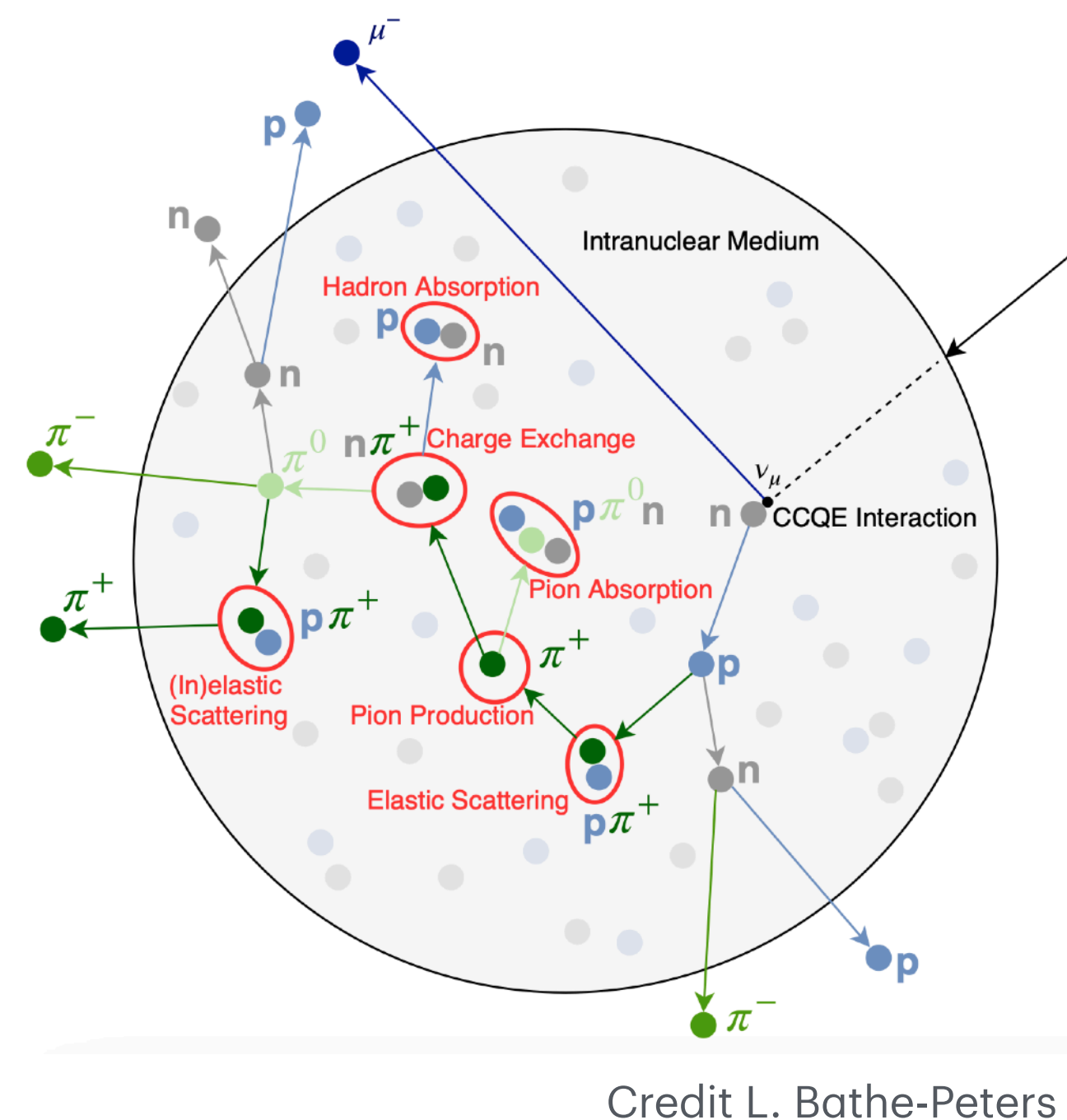
- Advantage for active target TPCs: reach ton scale without using liquid
- Event rates comparable to liquid TPCs:
 - CEvNS $\rightarrow 10^3$ events/ton/yr @ SNS
 - Accelerator neutrinos $\rightarrow 10^6$ events/ton/yr @ LBNF
- BSM opportunities: heavy neutral leptons, sterile neutrinos, dark tridents, ...



Same neutrino charged-current interaction in a 10 bar GArTPC (top) and a LArTPC (bottom)

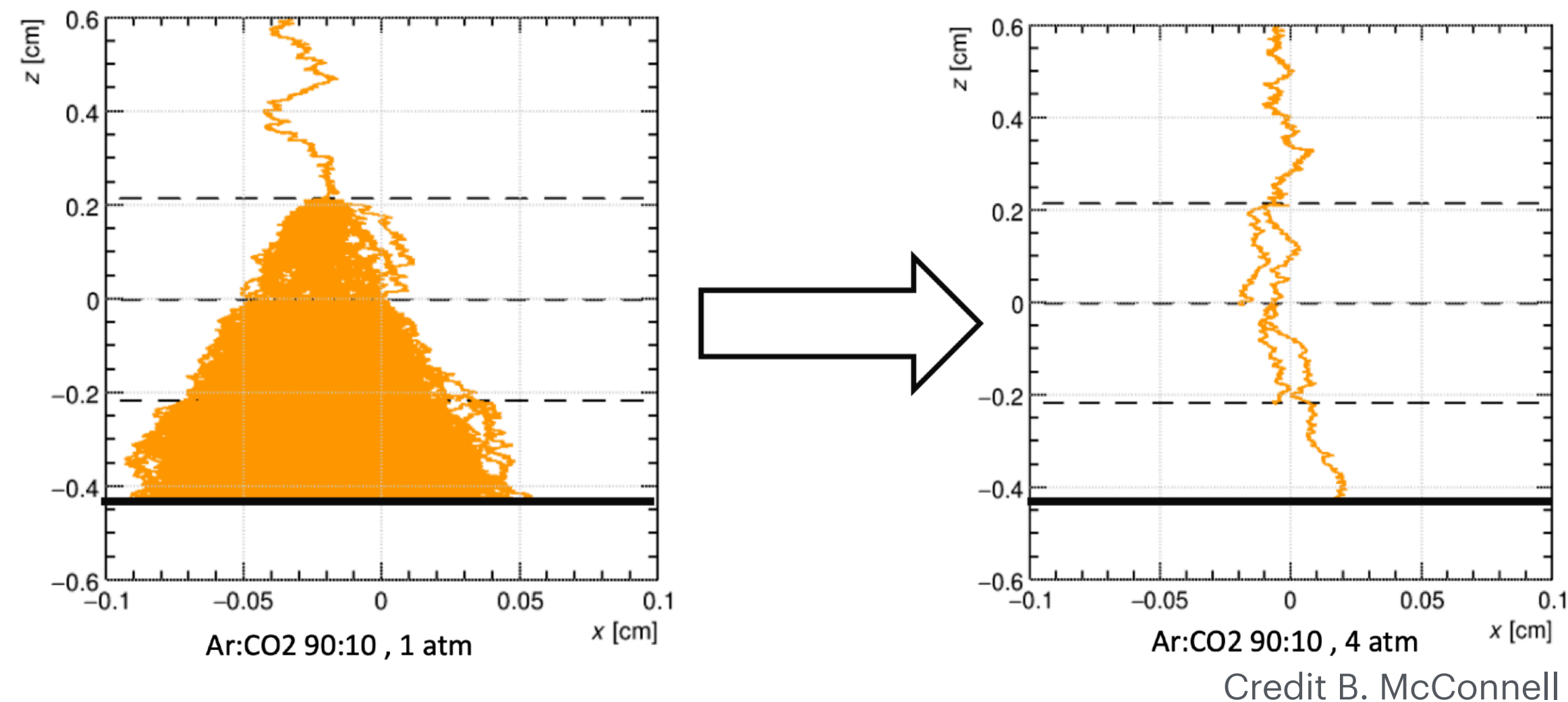
Physics case – neutrino interactions

- Neutrino interactions will be the leading source of systematic uncertainty for the next generation of neutrino oscillation experiments
- Reducing them requires better modelling of hadron rescattering inside complex nuclei
- Solution: measure multiplicity and kinematics of previously inaccessible $\mathcal{O}(\text{MeV})$ hadrons
- A HPgTPC can access this region below LAr thresholds



R&D knobs

- MPGDs rarely used for charge readout of high-pressure argon detectors
 - Higher voltages needed to match gain – instability
- Need to evaluate what detector optimisations help maintain stable operations for the target physics



Target mass



Pressure

Diffusion and
scintillation



Gas mixture

Gain and
stability



Charge
amplification

Noise and
dynamic range



Readout
electronics

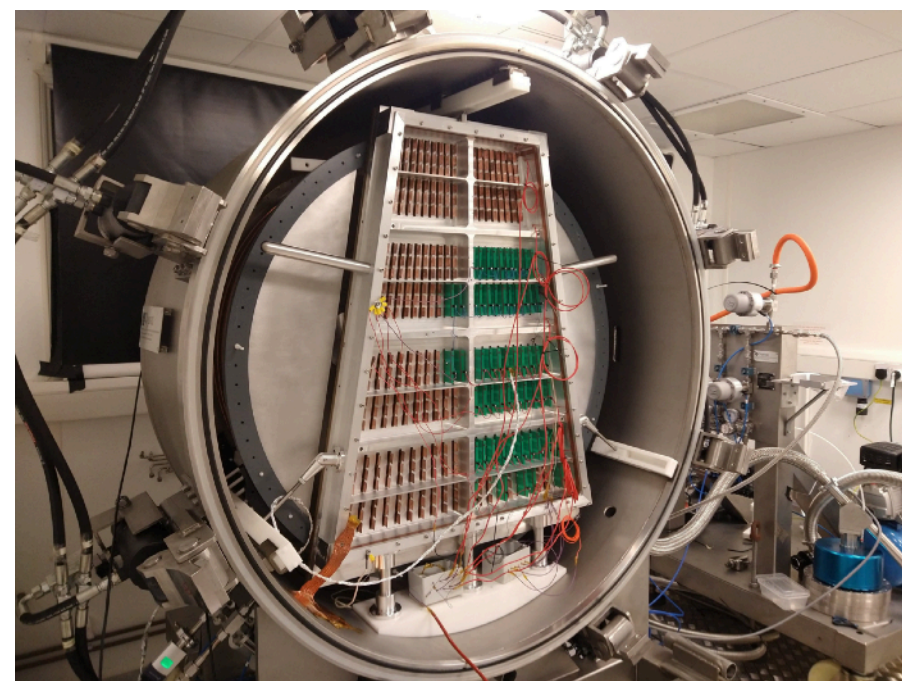
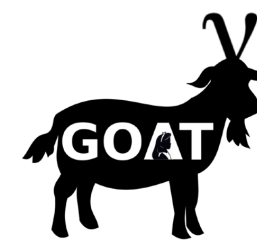
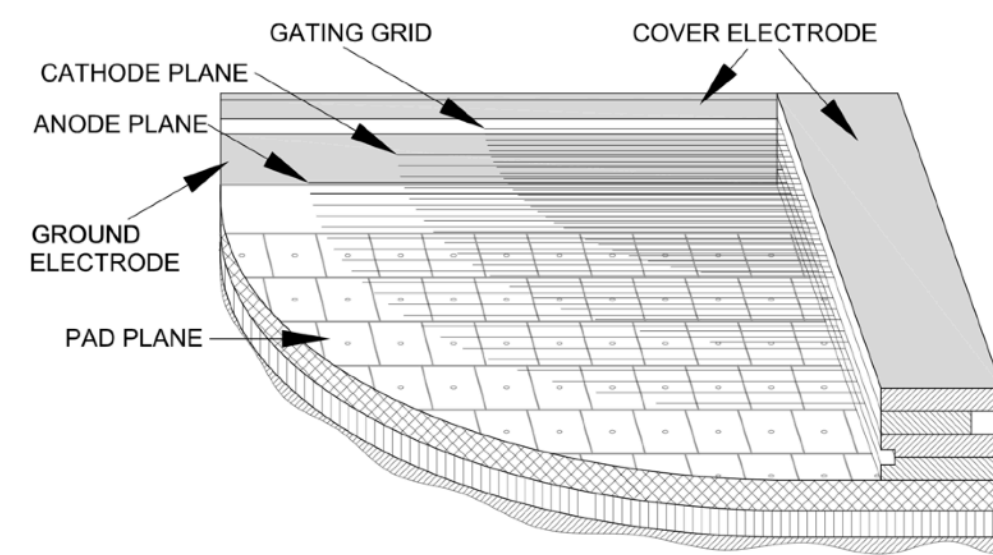
Resolution



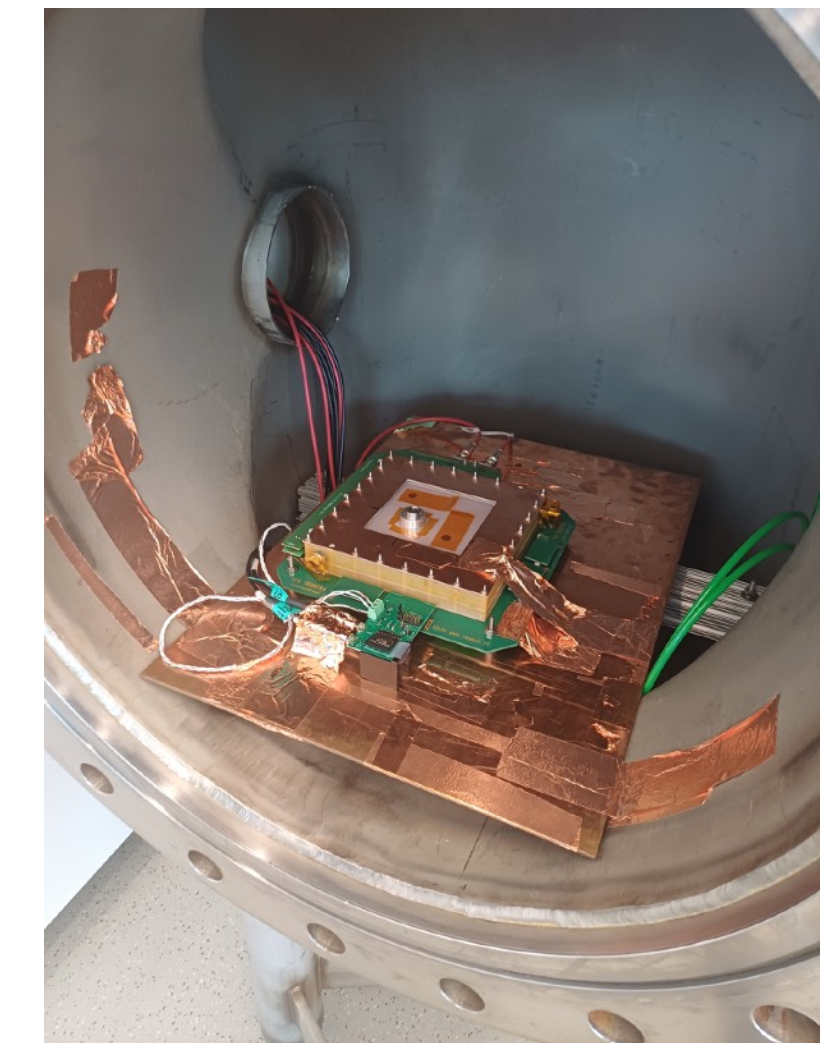
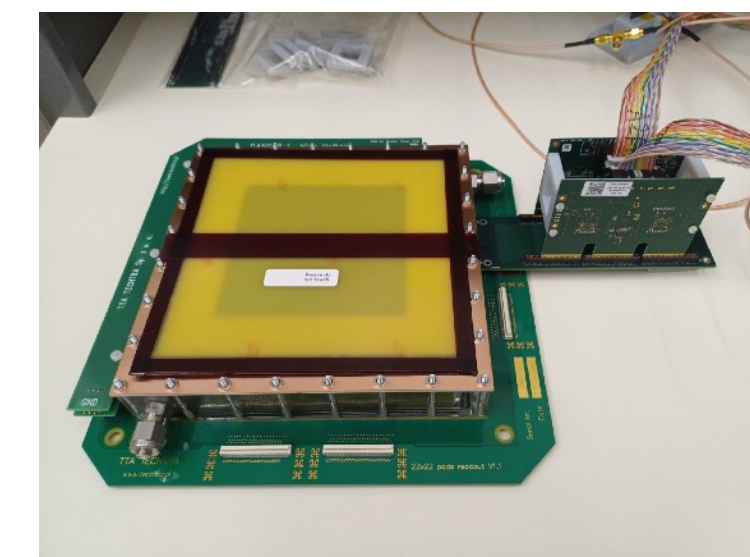
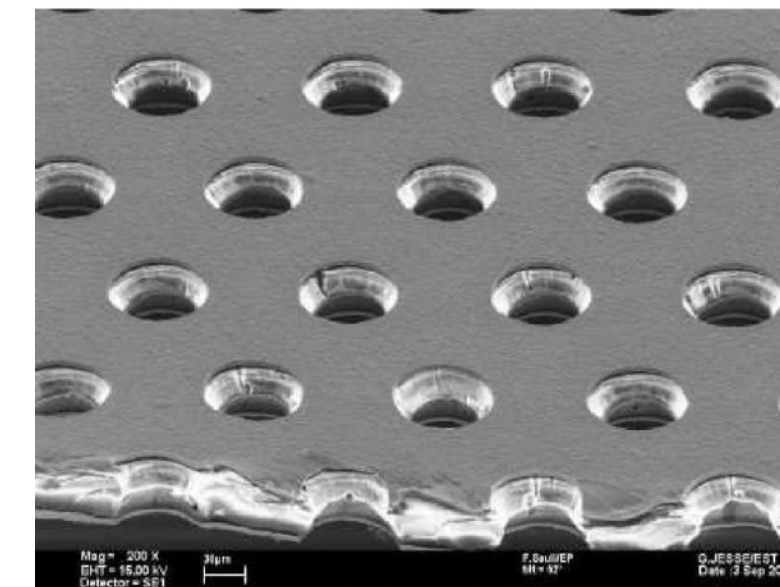
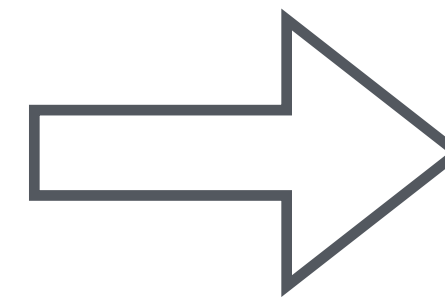
Pad pitch

Our R&D history

- Previous R&D focused on repurposing legacy MWPCs from ALICE
- New program focuses on operating GEMs in Ar-rich gas mixtures at high pressure



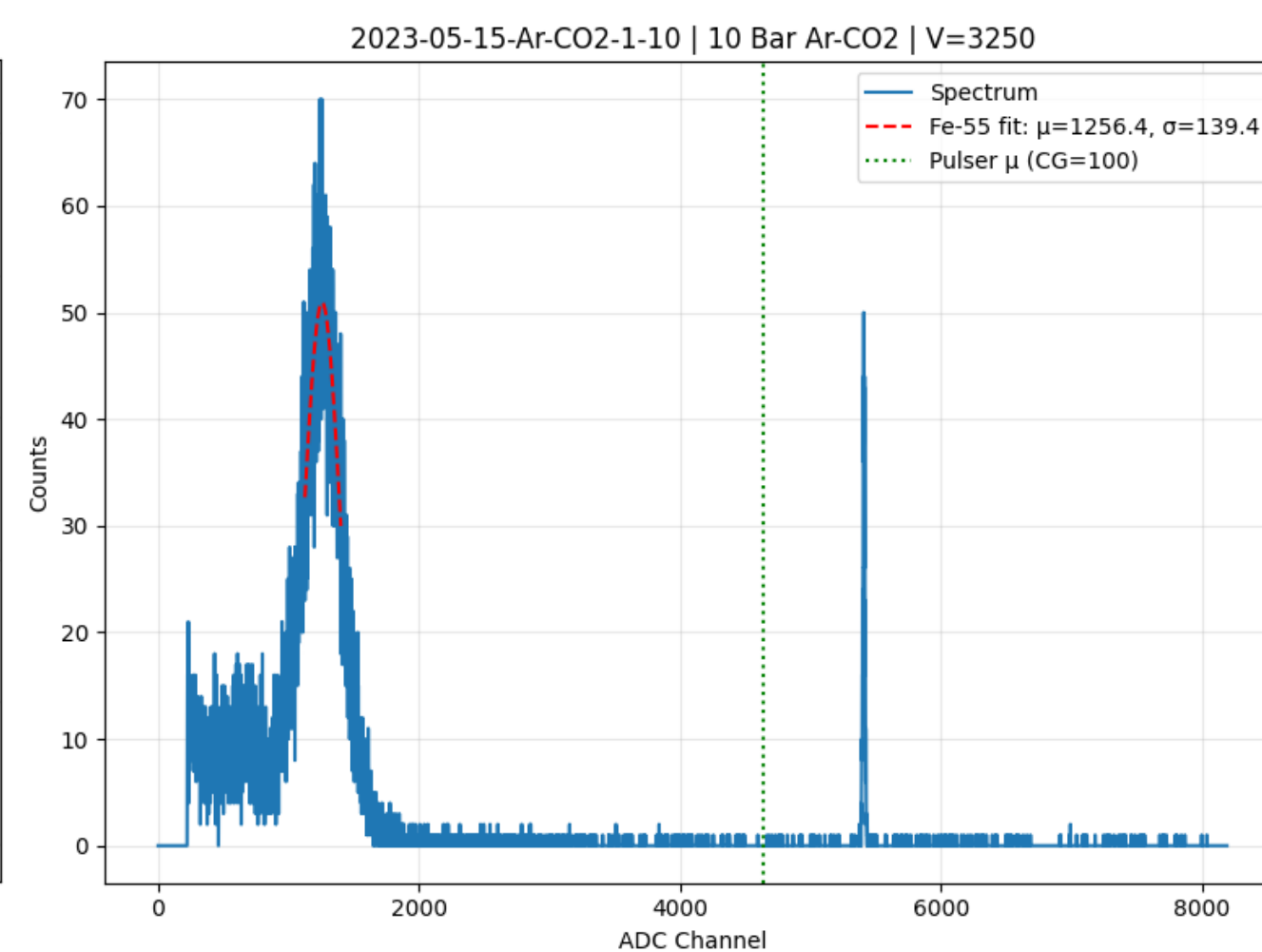
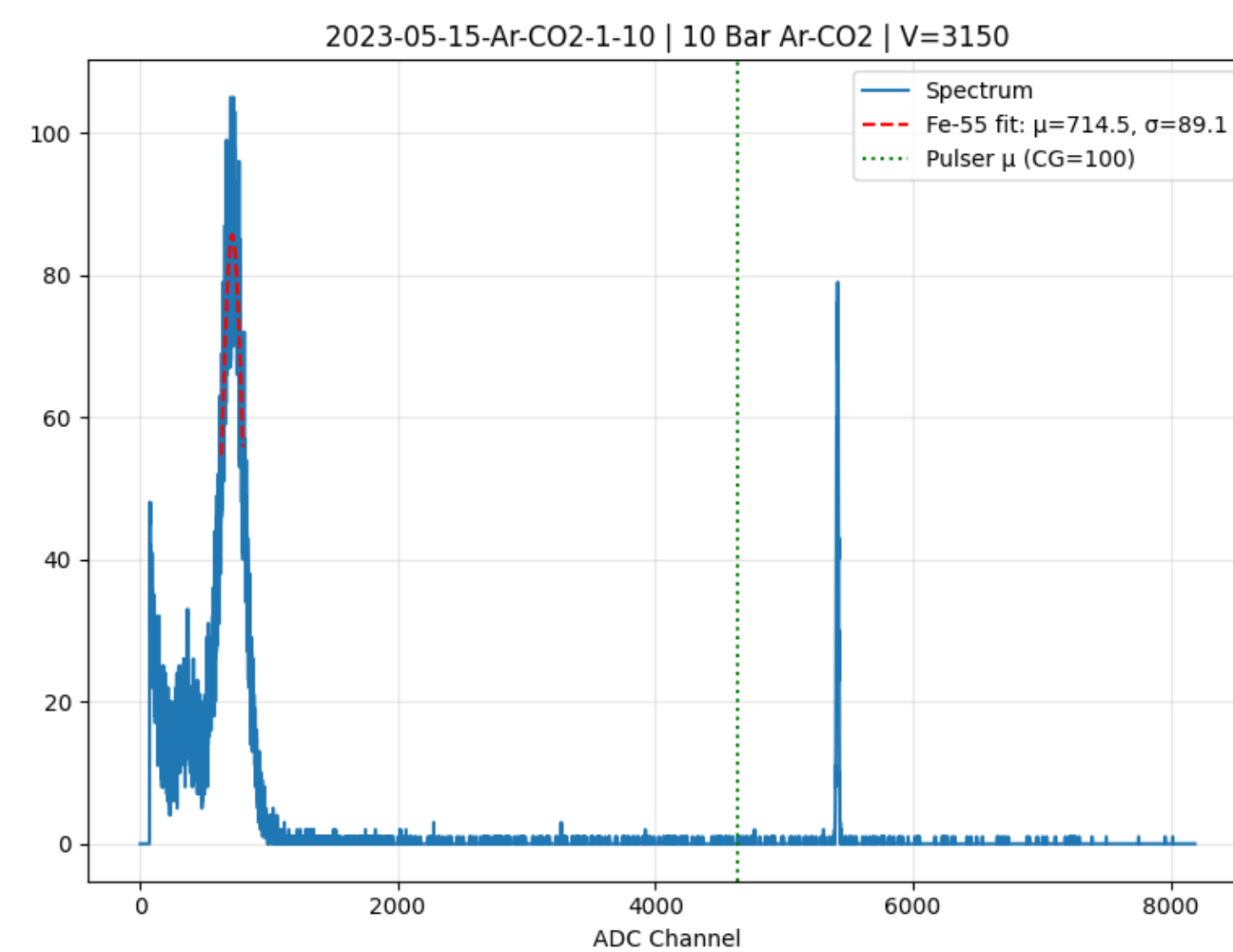
Previous MWPC R&D efforts @ UK and FNAL



Current GEM R&D efforts @ IU and FNAL

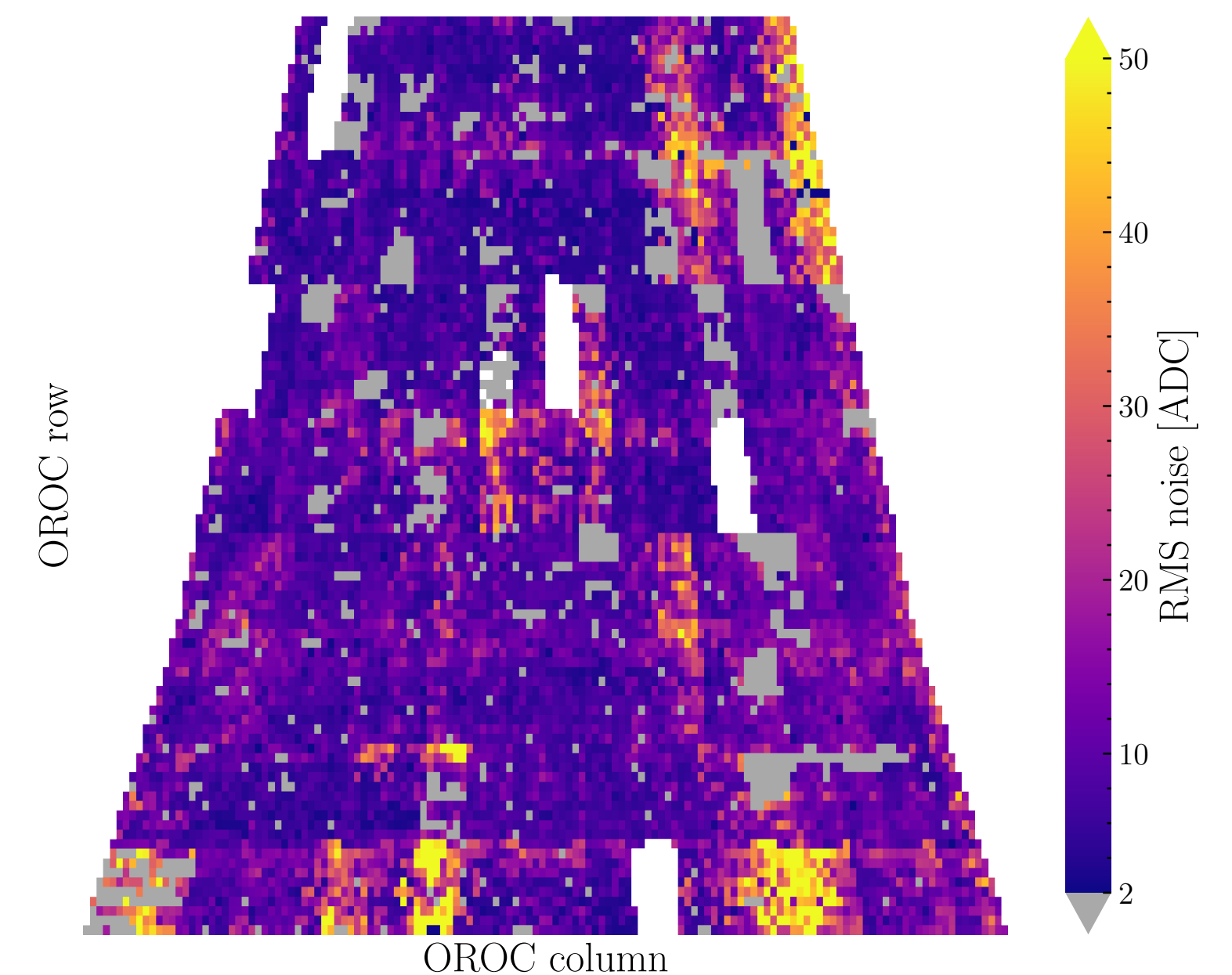
GOAT and TOAD

- Operated ALICE inner / outer MWPC in a pressure vessel rated to 10 bar / 5 bar
- GOAT measured gas gain at different voltages, pressures, and gas mixtures
- TOAD tested FPGA-based readout solution optimised for low-occupancy detector at high pressure



Example spectra from GOAT @ 10 bar

RMS noise distribution from TOAD @ 5 bar



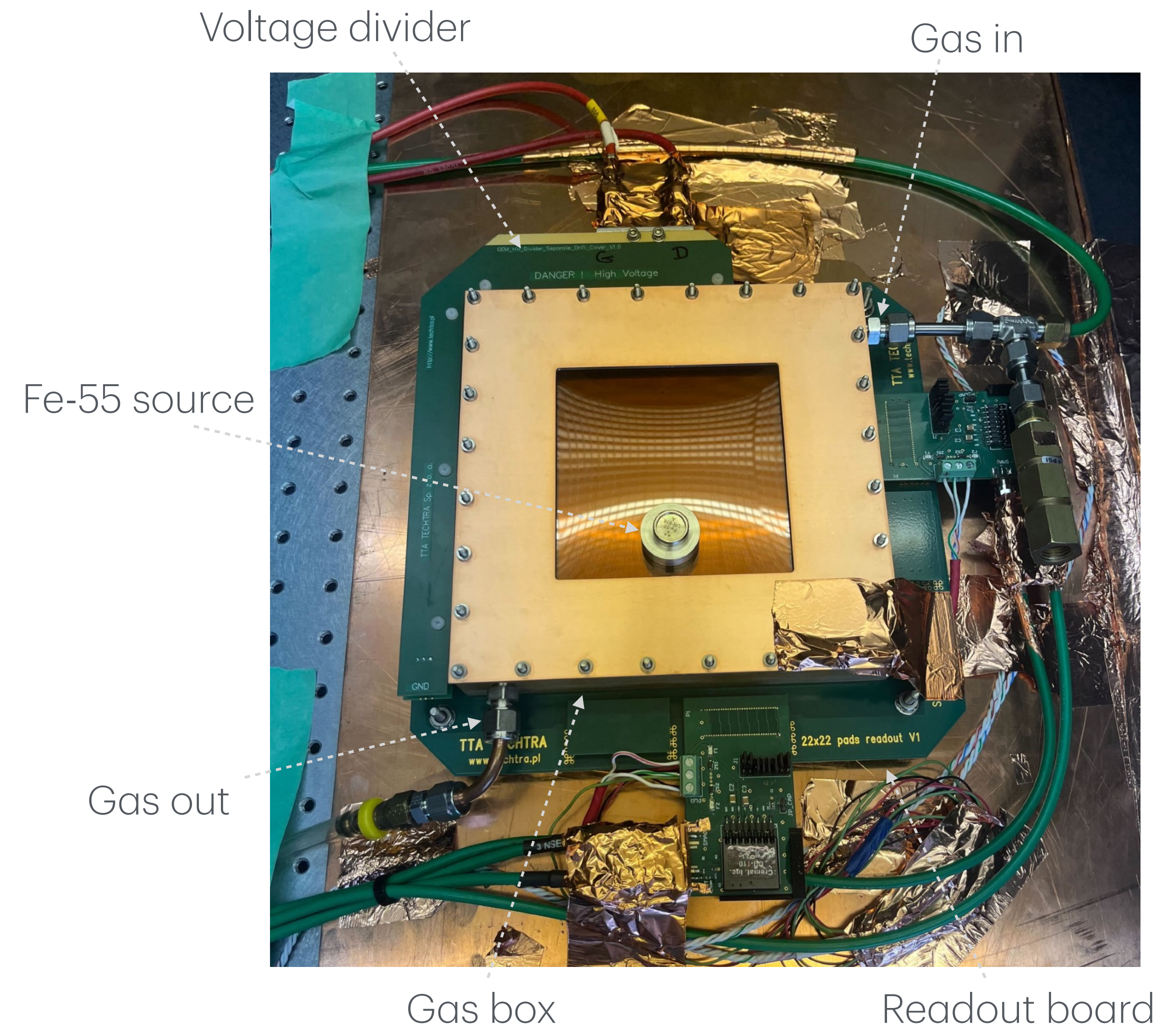
JINST 20 (2025) 12, P12023

GORG setup

- 10 x 10 cm² triple-GEM stack from Techtra TTA
- R&D launched under the 2022 Fermilab New Initiatives grant

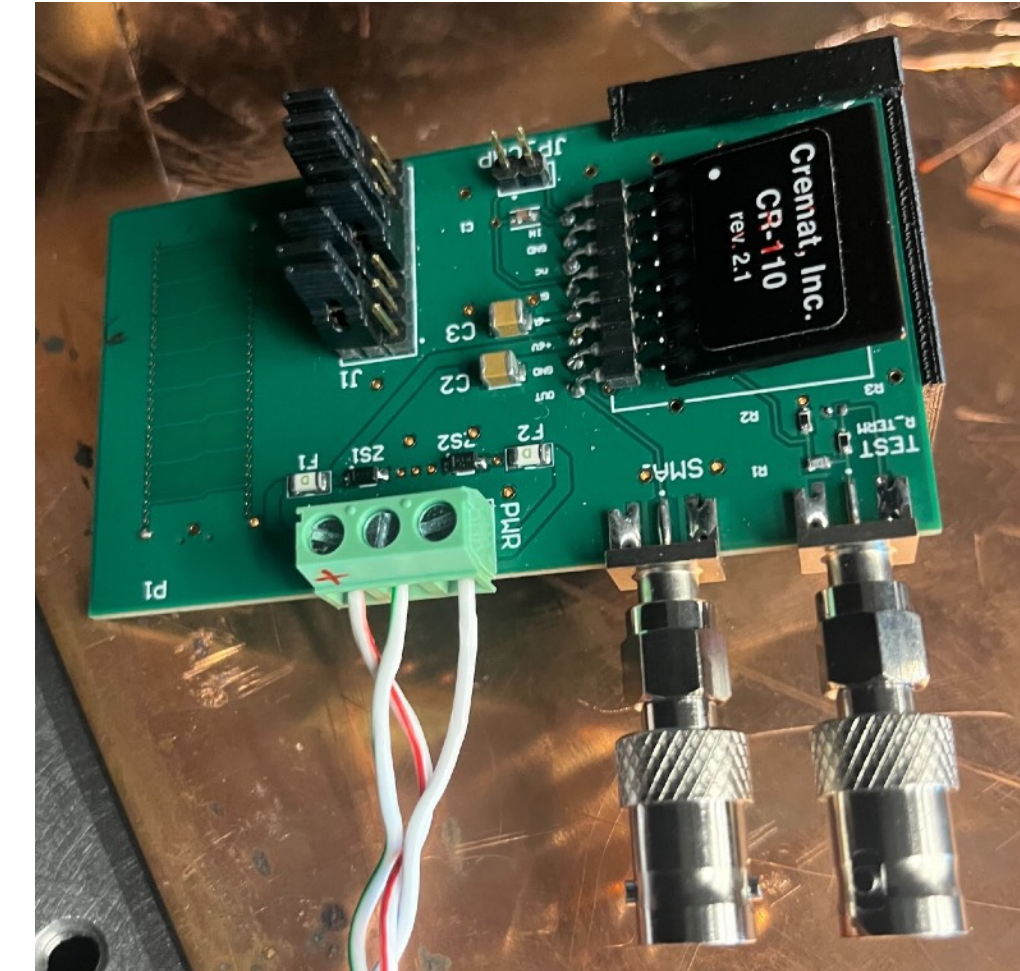


GORG @ FNAL

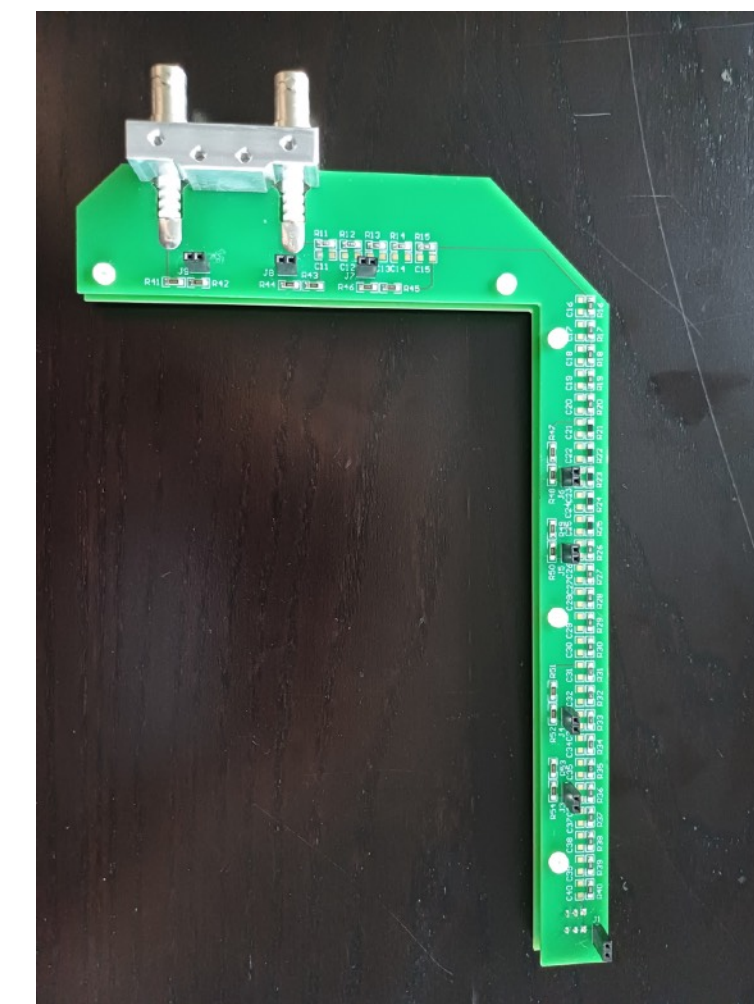


GORG setup

- Initial tests read out only a small group of pads (~20 combined into one channel)
- Custom board with Cremat charge-sensitive preamp for pulser calibration and signal readout
- First pressure scans used single-input HV divider with fixed GEM ratios
 - Split: GEM1 10.9%, GEM2 9.4%, GEM3 8.2%
- New HV board under testing, allows for biasing each GEM top and bottom independently



PCB with Cremat CSP



Techtra TTA HV divider

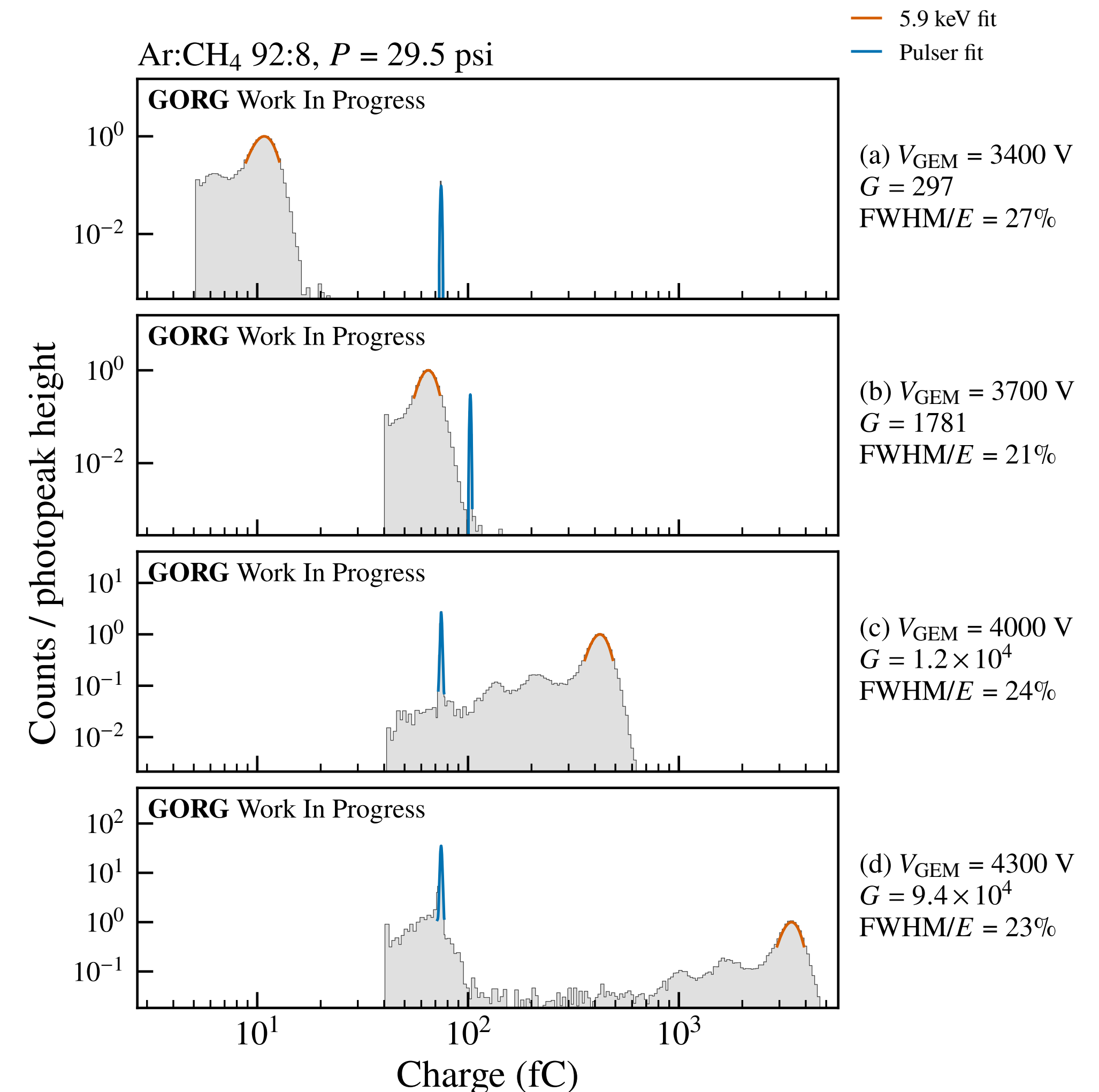


New custom HV board

GORG data taking

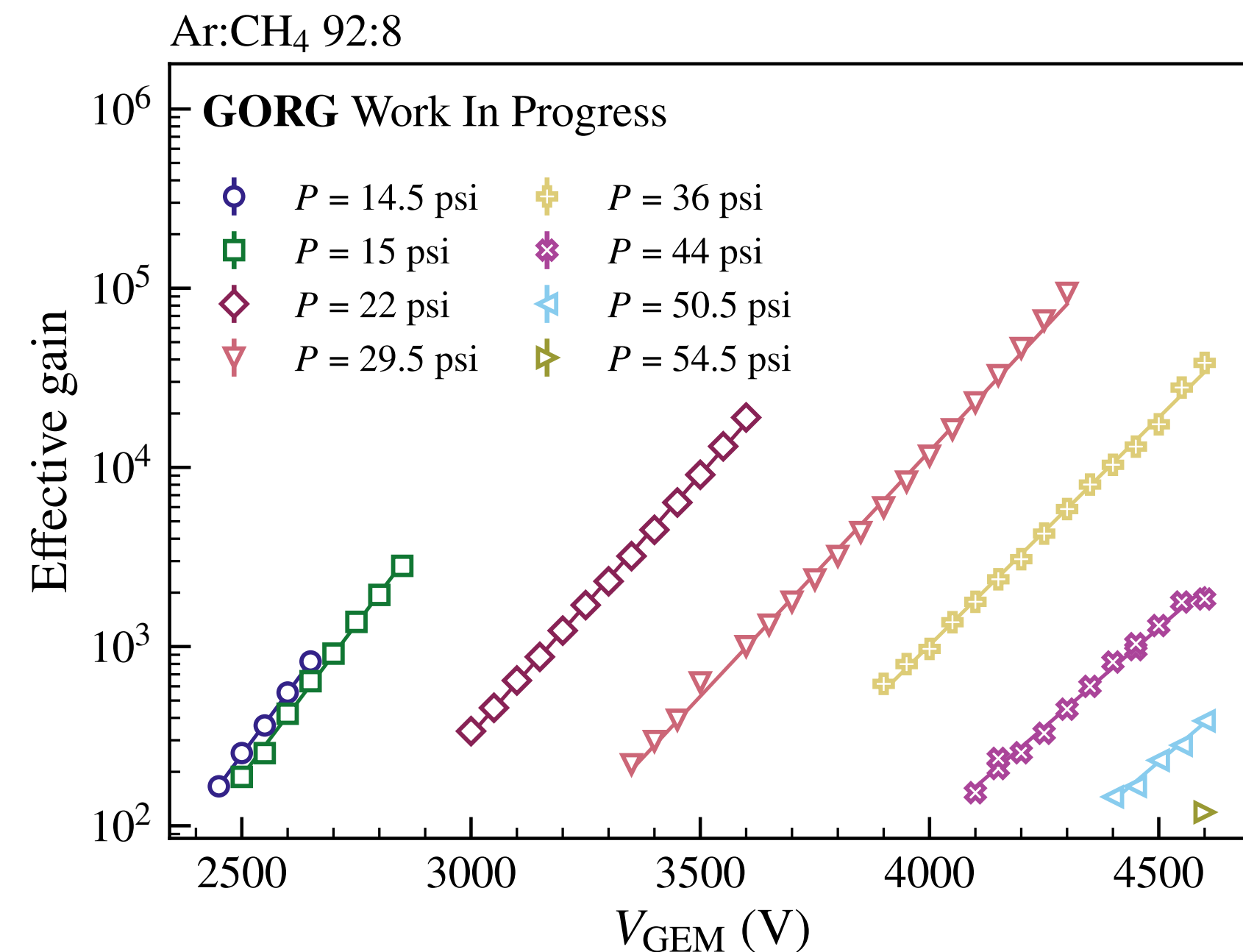
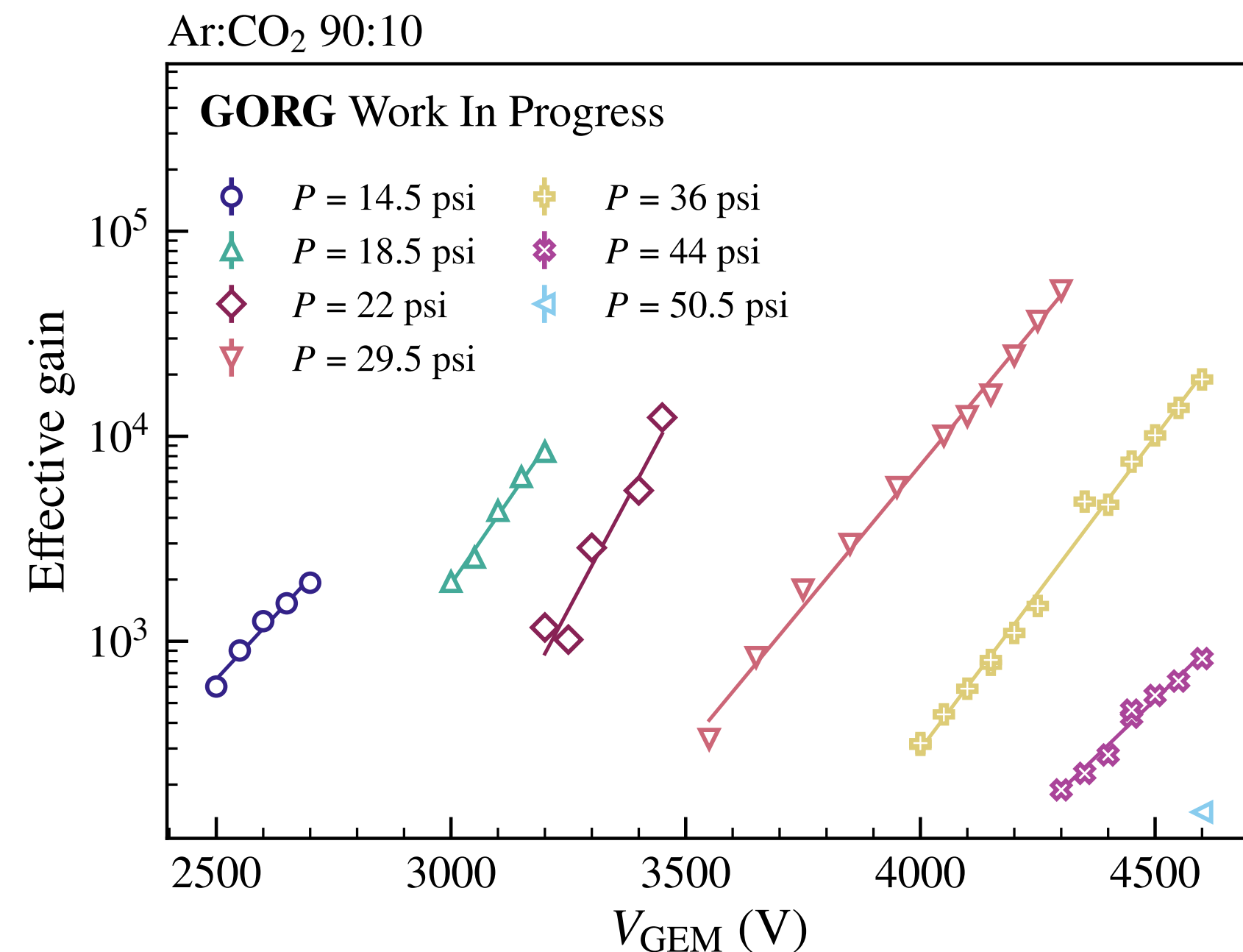
- Collimated Fe-55 source installed on top of GEM chamber targets the active pad region
 - Pulser injects known charge to spectrum
- Bench tests showed stable gain at atmospheric pressure
- First pressure runs successfully demonstrated gain scaling up to ~3.5 bar
- Ongoing upgrades will significantly expand configuration space (higher pressures, GEMs individually biased)

* V_{GEM} indicates voltage supplied to HV divider input



GORG pressure scans

- Stable triple-GEM operation up to 54.5 psi, achieved a gain ~ 100
- Limitations driven by setup, not GEMs – parameter scans non-exhaustive
 - HV capped each GEM at ~ 500 V, small leak limited operation to 4 bar



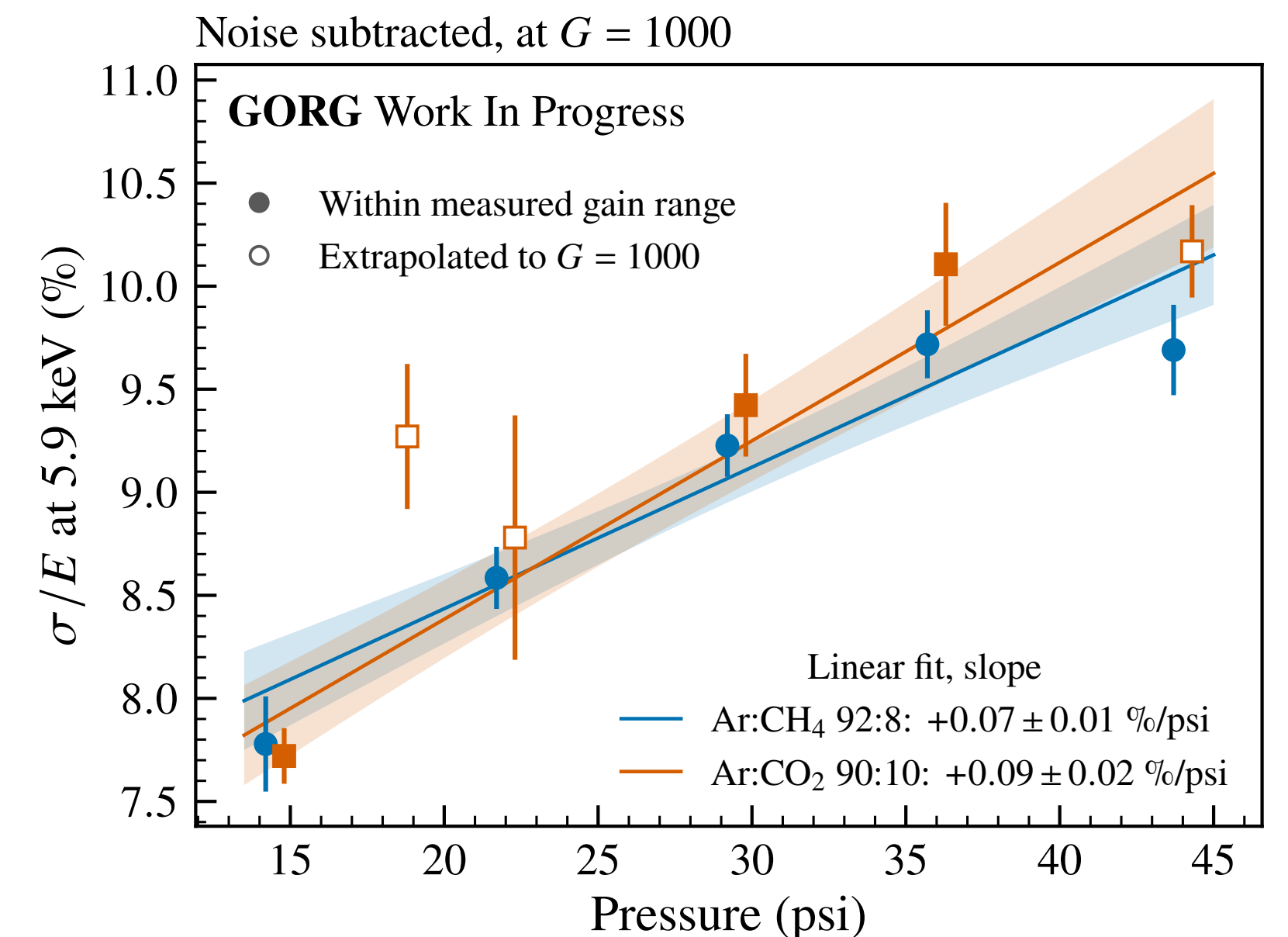
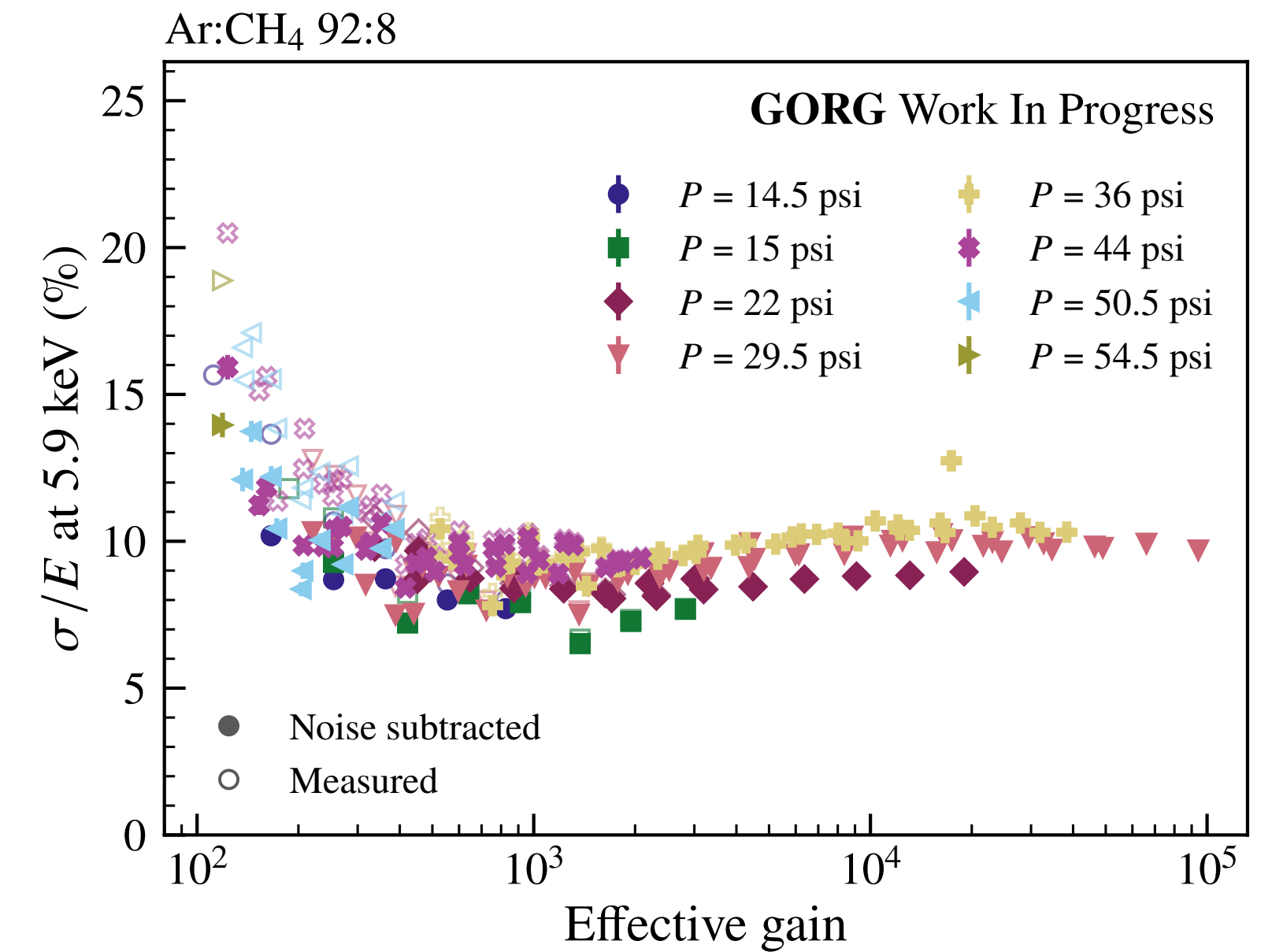
GORG pressure scans

- Measure energy resolution using width of photopeak
 - Subtract electronics noise using pulser spread:

$$\frac{\sigma}{E} = \frac{\sqrt{\sigma_{\text{peak}}^2 - \sigma_{\text{pulser}}^2}}{\mu_{\text{peak}}}$$

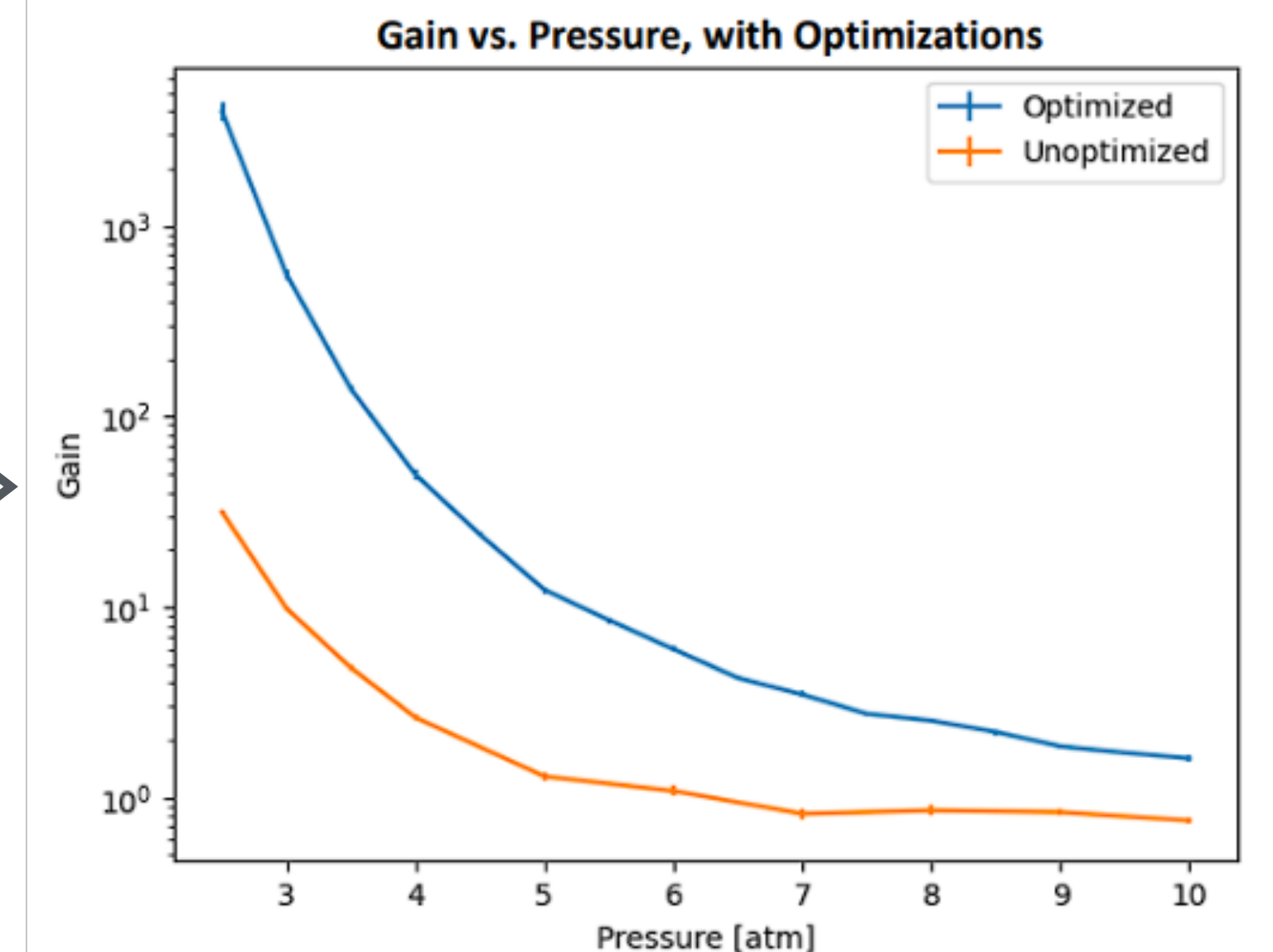
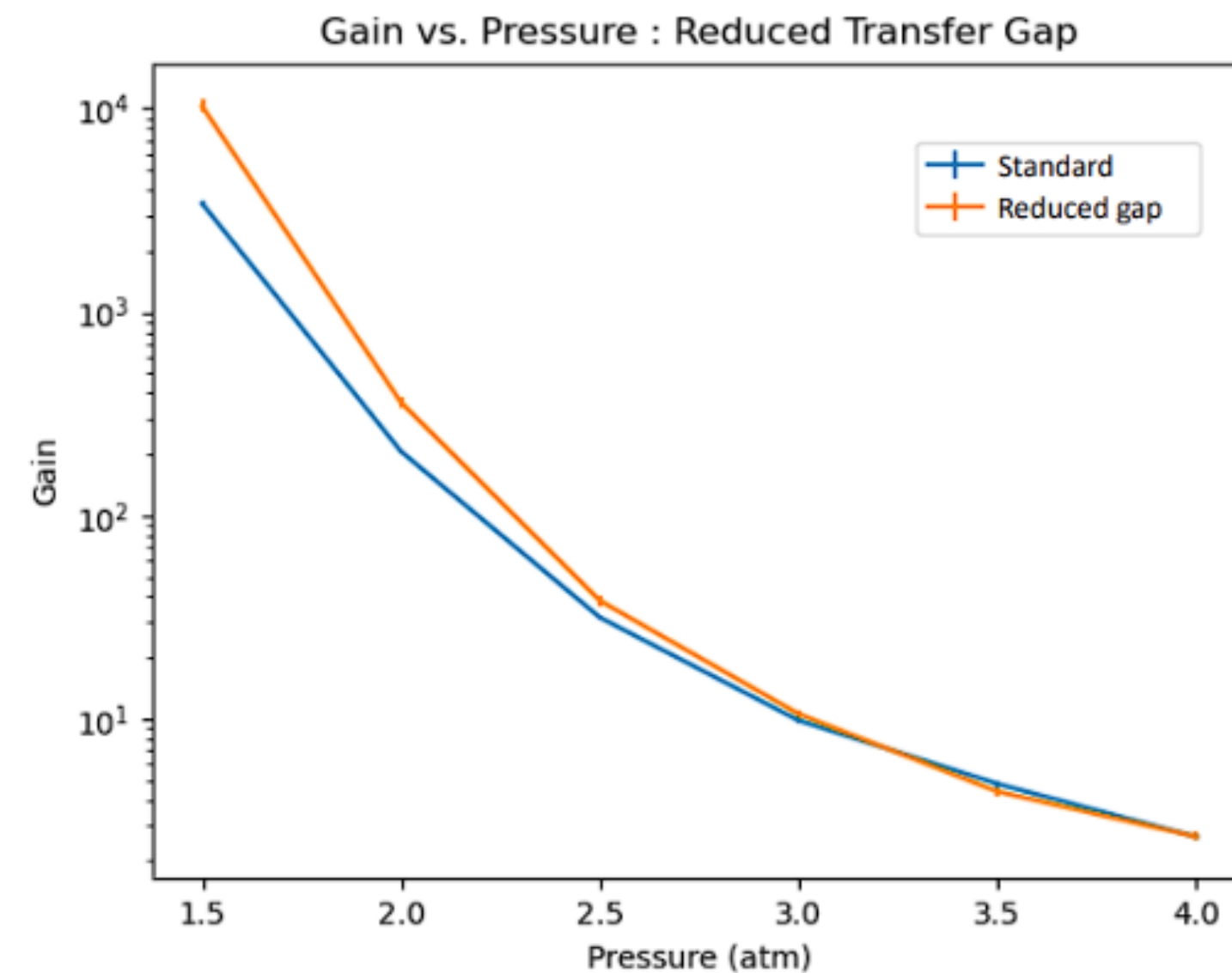
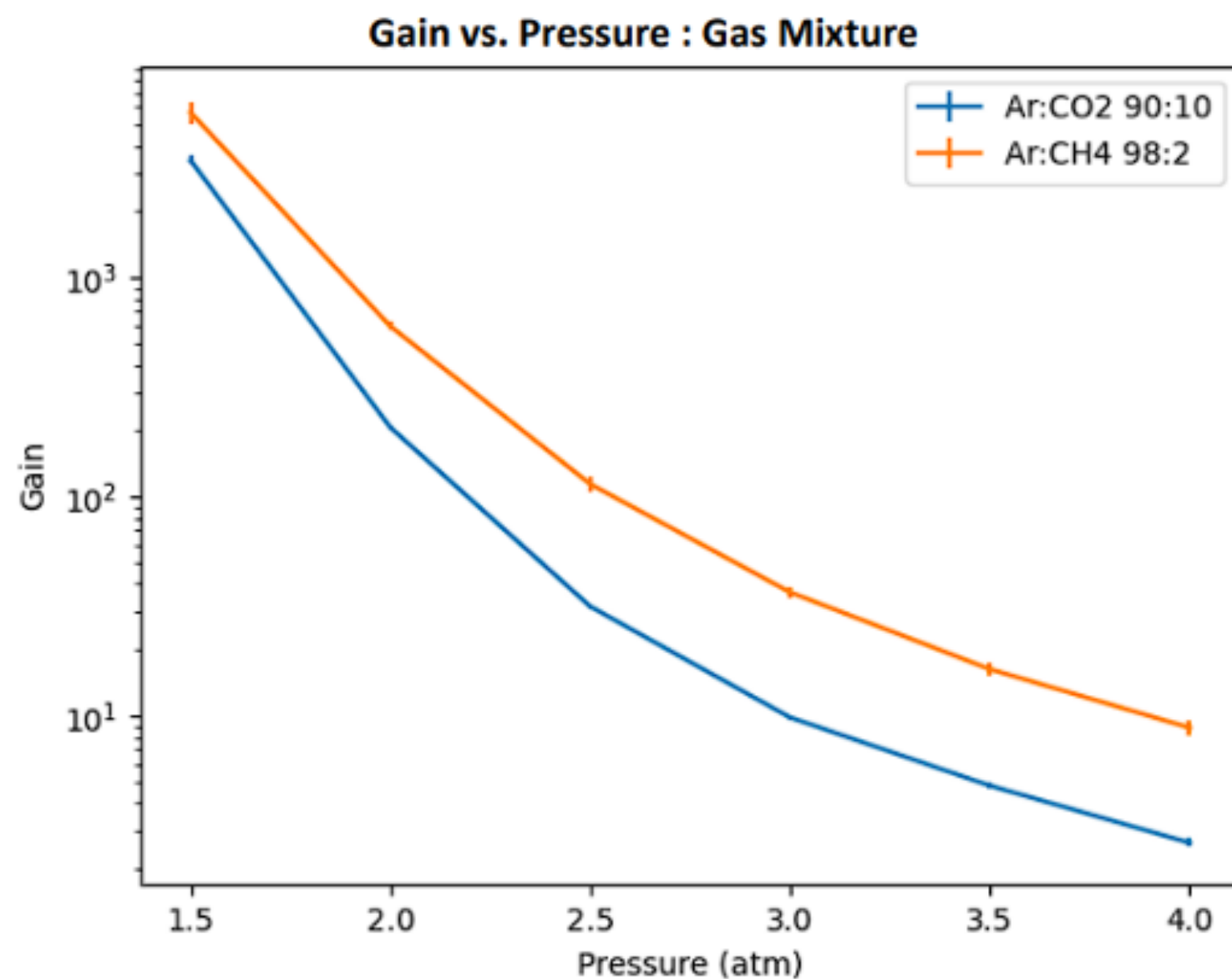
- Achieved energy resolution equal or better than that of previous ALICE MWPCs tests*
- Resolution degrades linearly with pressure at a fixed gain

*Eur.Phys.J.C 83 (2023) 12, 1139



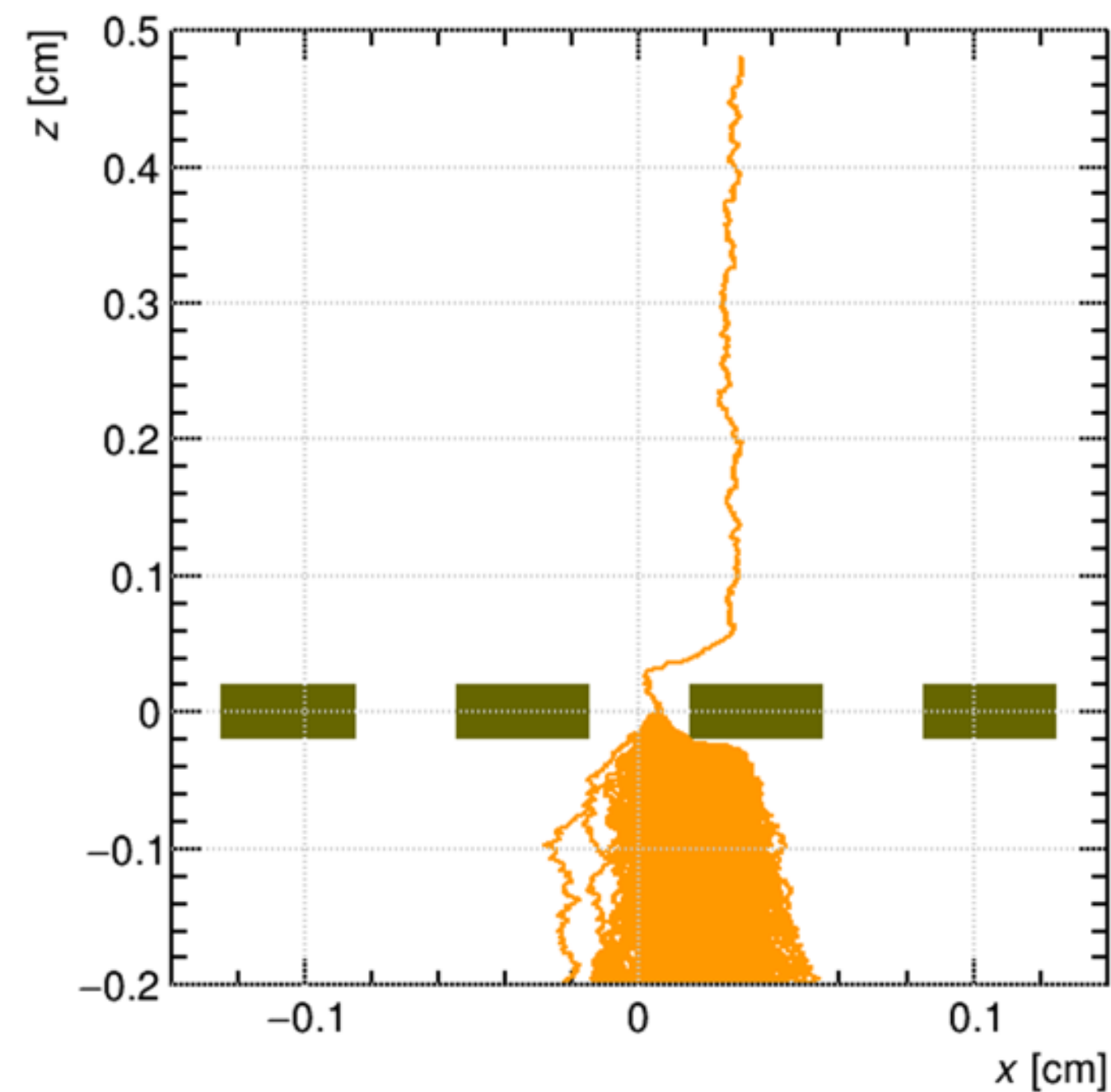
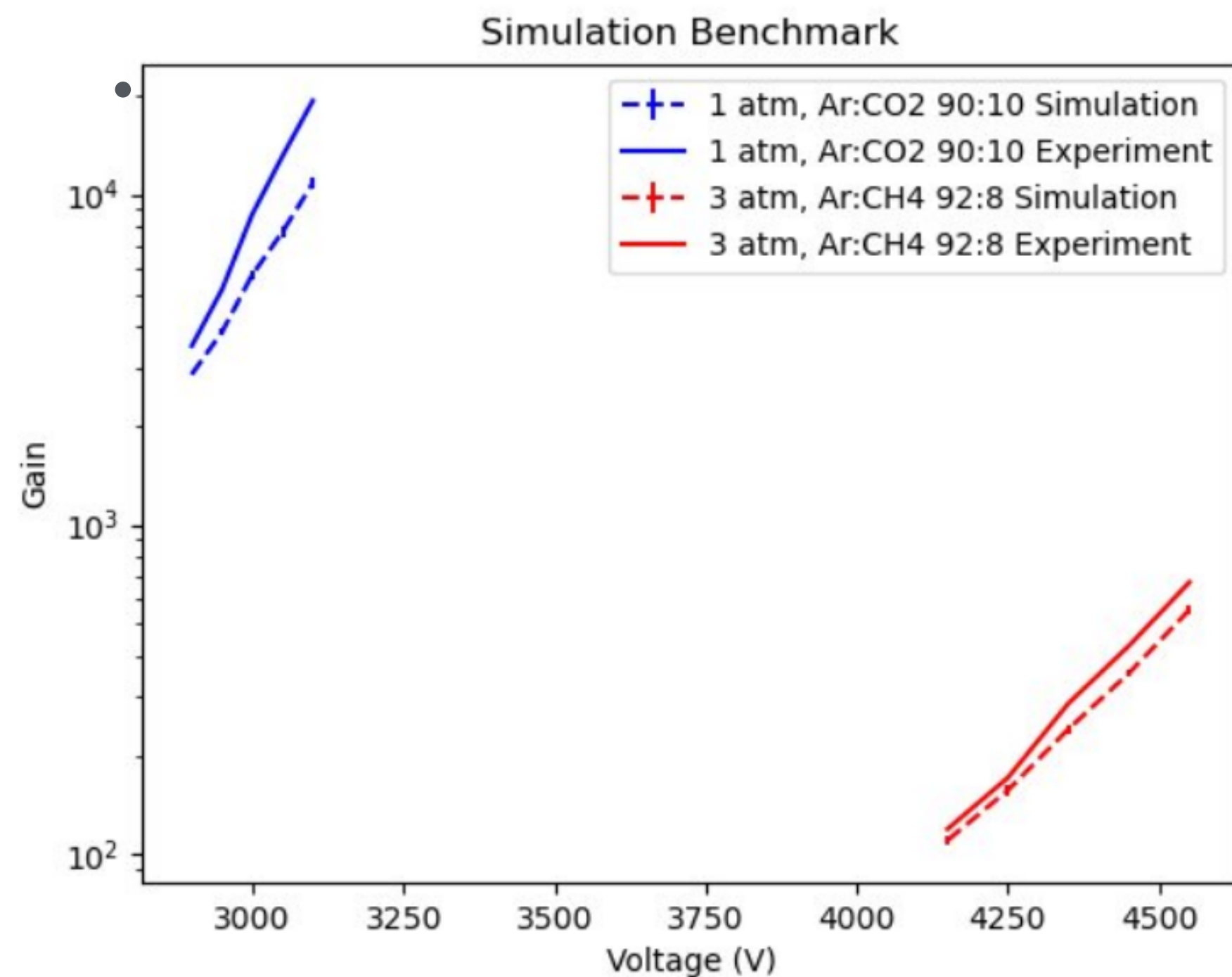
Garfield++ simulations

- Current simulation efforts explore performance of triple-GEM setup with variations of key parameters
- Goal: identify optimal setup for operation in high pressure



Garfield++ simulations

- Current simulation efforts explore performance of triple-GEM setup with variations of key parameters
- Goal: identify optimal setup for operation in high pressure



Example avalanche w/ thick GEM @ 1 bar

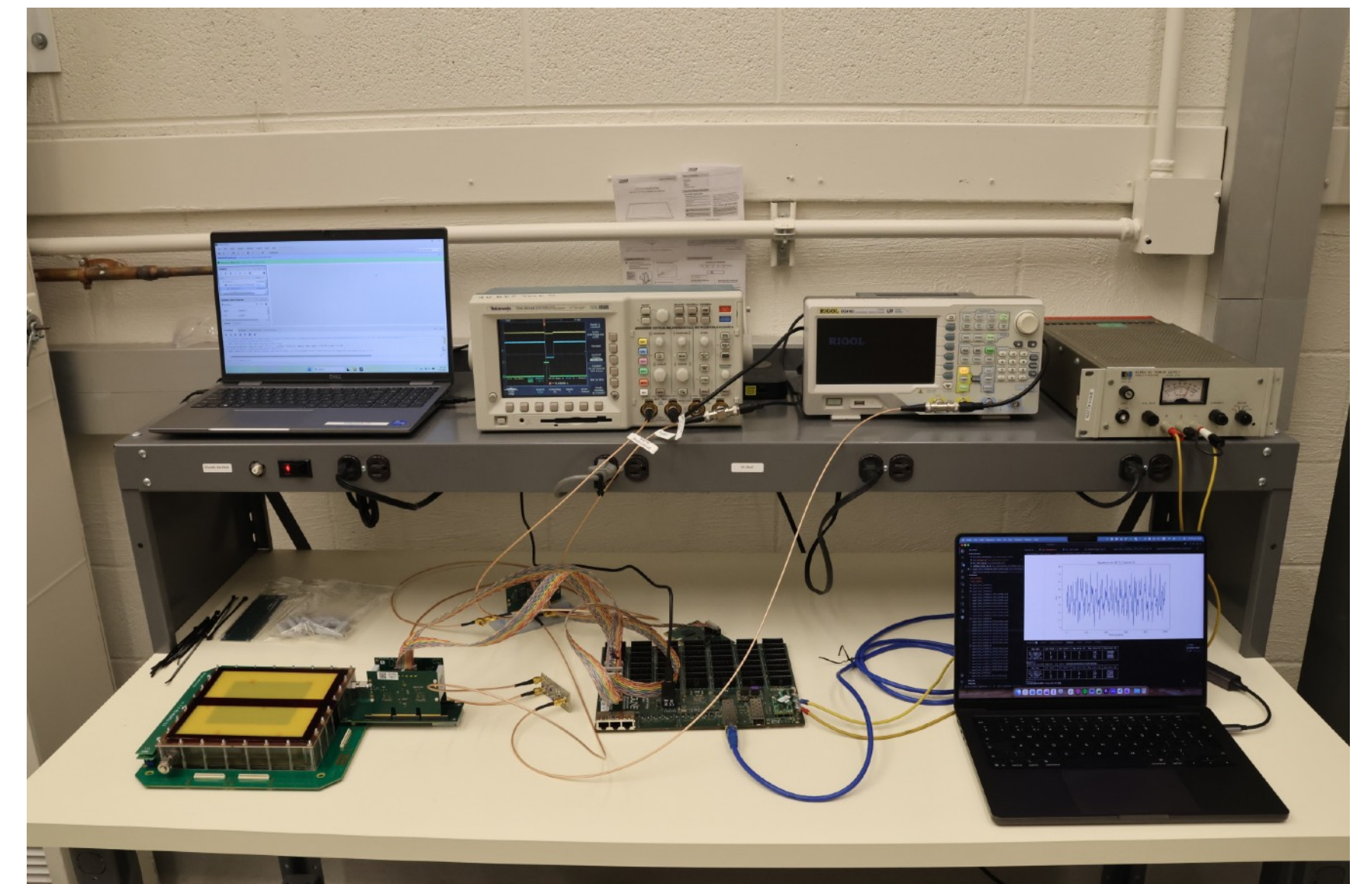
- Provides reference point for data comparisons
- Investigating performance of other MPGD detectors
 - e.g. thick GEMs

IU GEM lab

- Are we ready to build a ton-scale HPgTPC?
- Intermediate milestone: medium-sized (potentially) GEM-based demonstrator
- Operational regime is set by where required gain and acceptable signal-to-noise coexist
- New laboratory space at IU is paving the path for this!



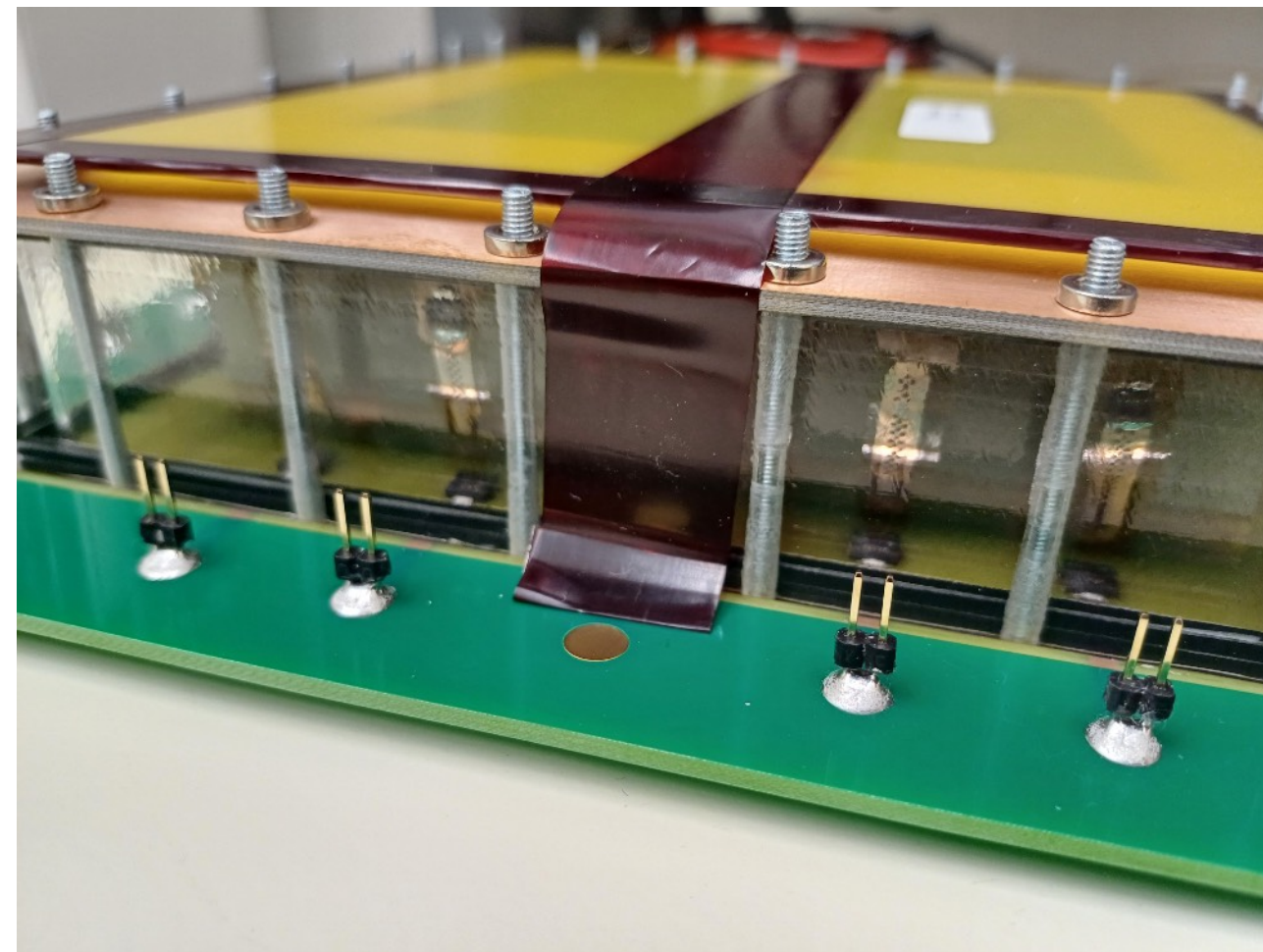
Lab space with ISO 7 cleanroom and crane



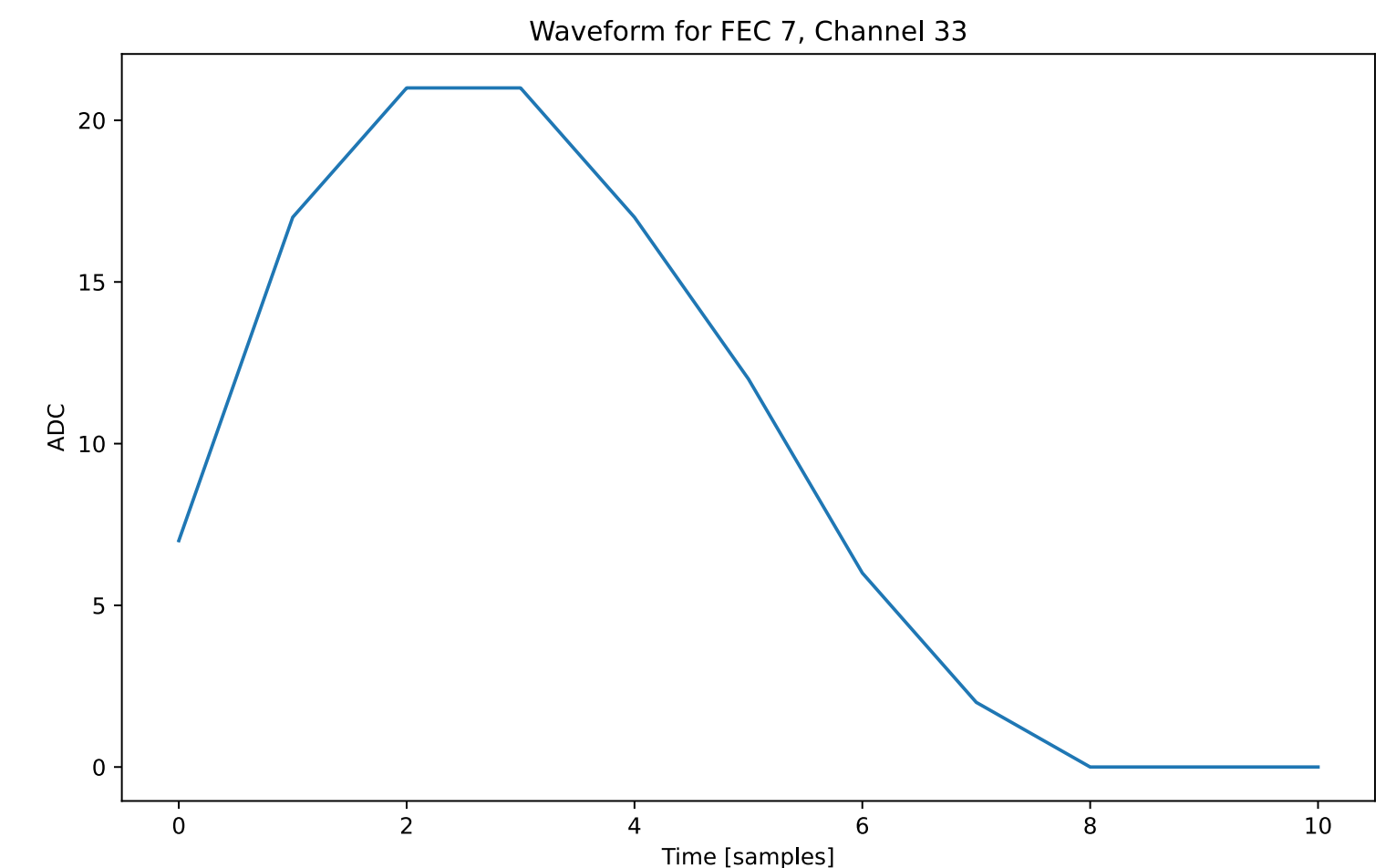
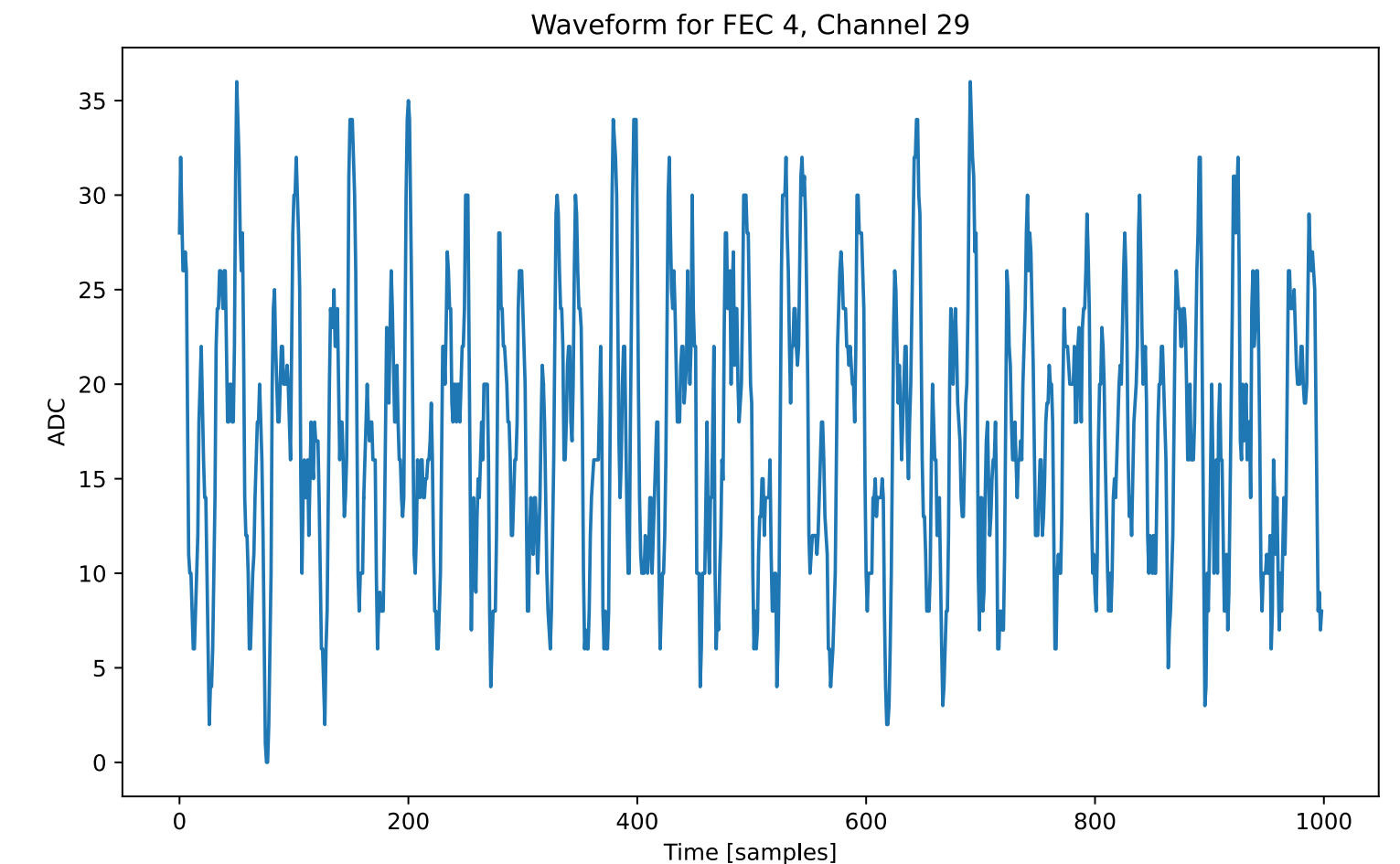
Electronics bench test

IU GEM lab status

- Working towards integrating FPGA-based (SAMPA) readout electronics with GEM-based detector
 - First bench tests exercised DAQ and slow controls chain
- Near term goals:
 - Characterise detector response with cosmic rays
 - Gain optimisation studies
 - Investigate discharge formation



New transparent gas box design



Noise waveform from fixed-length packet (top) and ROI waveform for injected pulse (bottom)

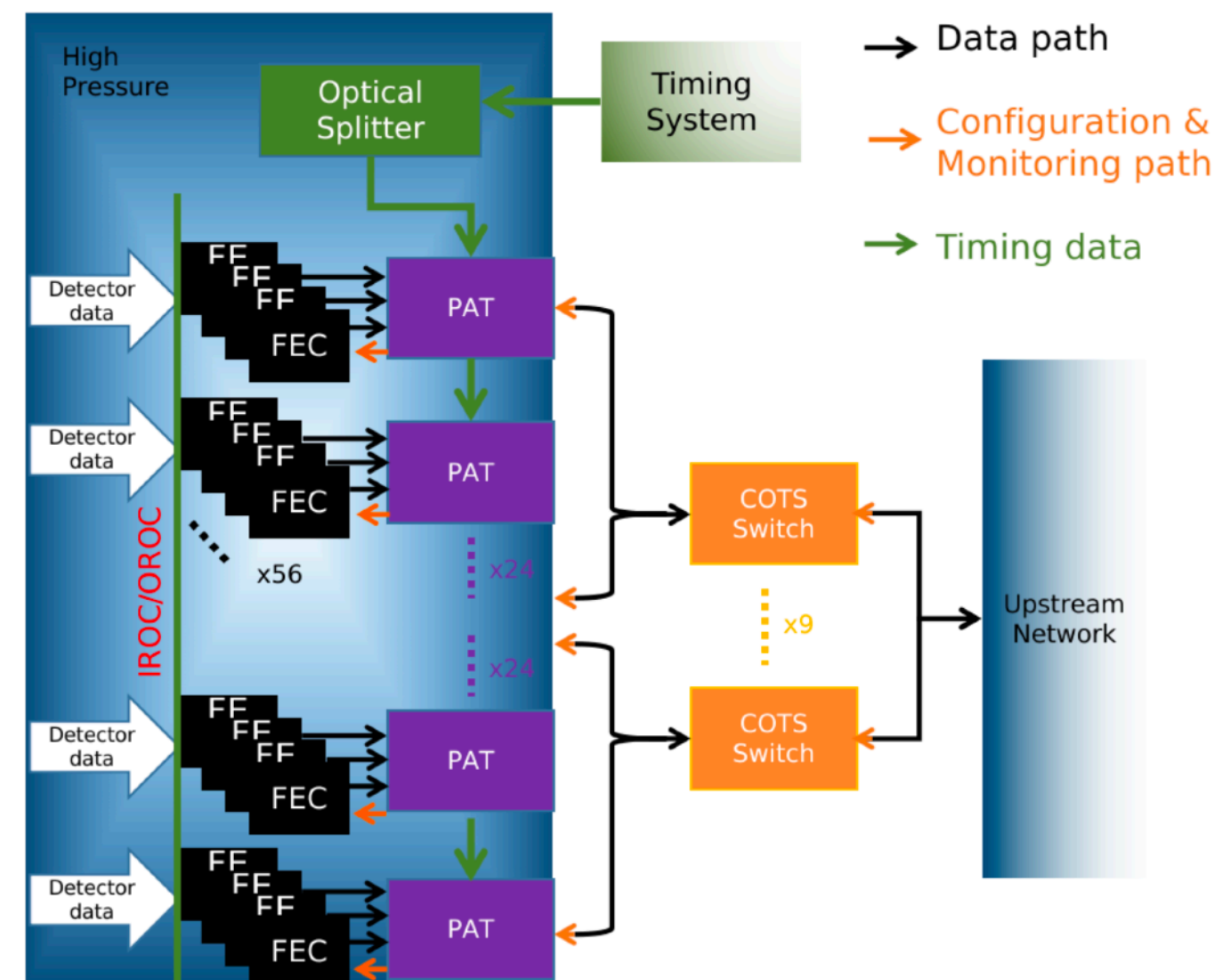
Conclusions

- Dense noble-gas TPCs can bridge liquid-scale mass and gas-scale imaging at low energy
- R&D goal is to chart the operational limits: define where stable gain and track structure can exist in high-pressure argon
- Triple-GEMs as a well-understood benchmark for gain stability
- Consistently held a min gain of ~ 100 up to 3.4 bar in an Ar-based mixture, with increased GEM voltage
- Higher-pressure scans with upgraded setup coming soon, mapping stability up to 10 bar with independent GEM bias control
- Integration of GEM detector with FPGA-based readout electronics underway

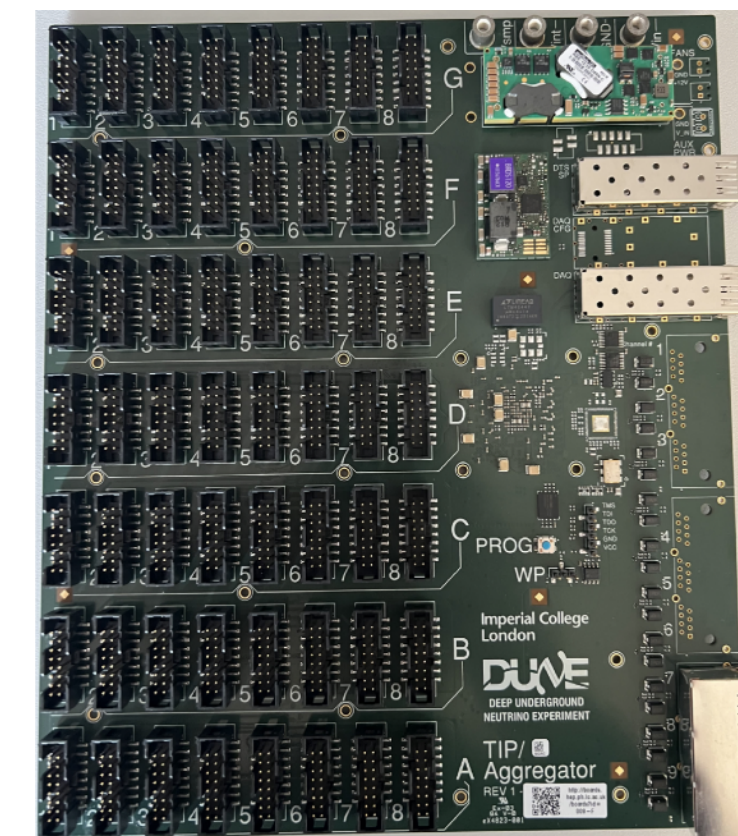
Backup slides

TOAD readout electronics

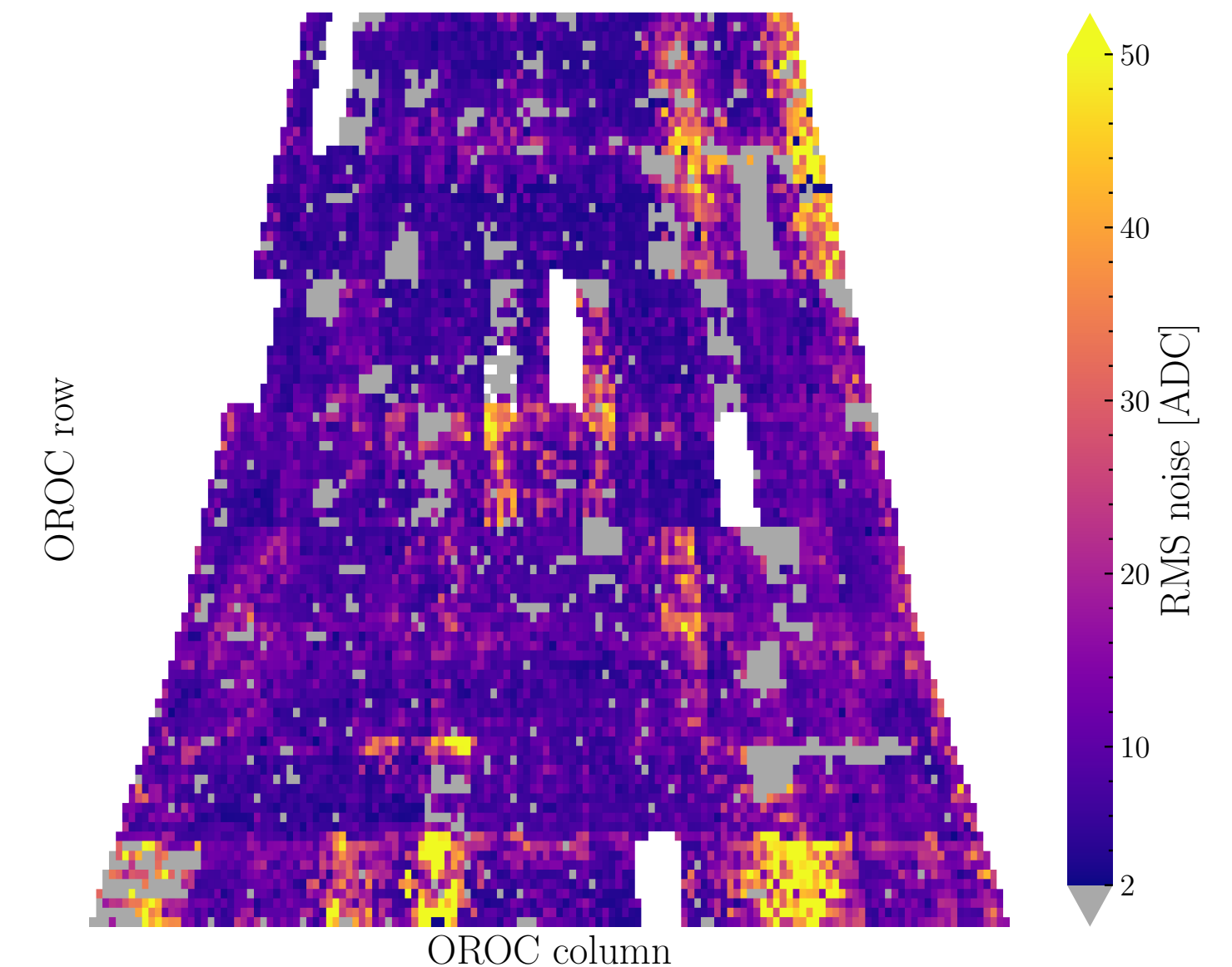
- Full slice test of readout electronics at high pressure
 - FPGA-based readout solution optimised for low-occupancy detector
- Operation was demonstrated up to 4.5 barA in a detector with ~10000 channels



Front-end card w/ 2 SAMPA ASICs



Power, aggregation, and timing (PAT) board



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