TPC Test-stands: An Overview & Future Prospects

GOAT TOAD GORG GATO

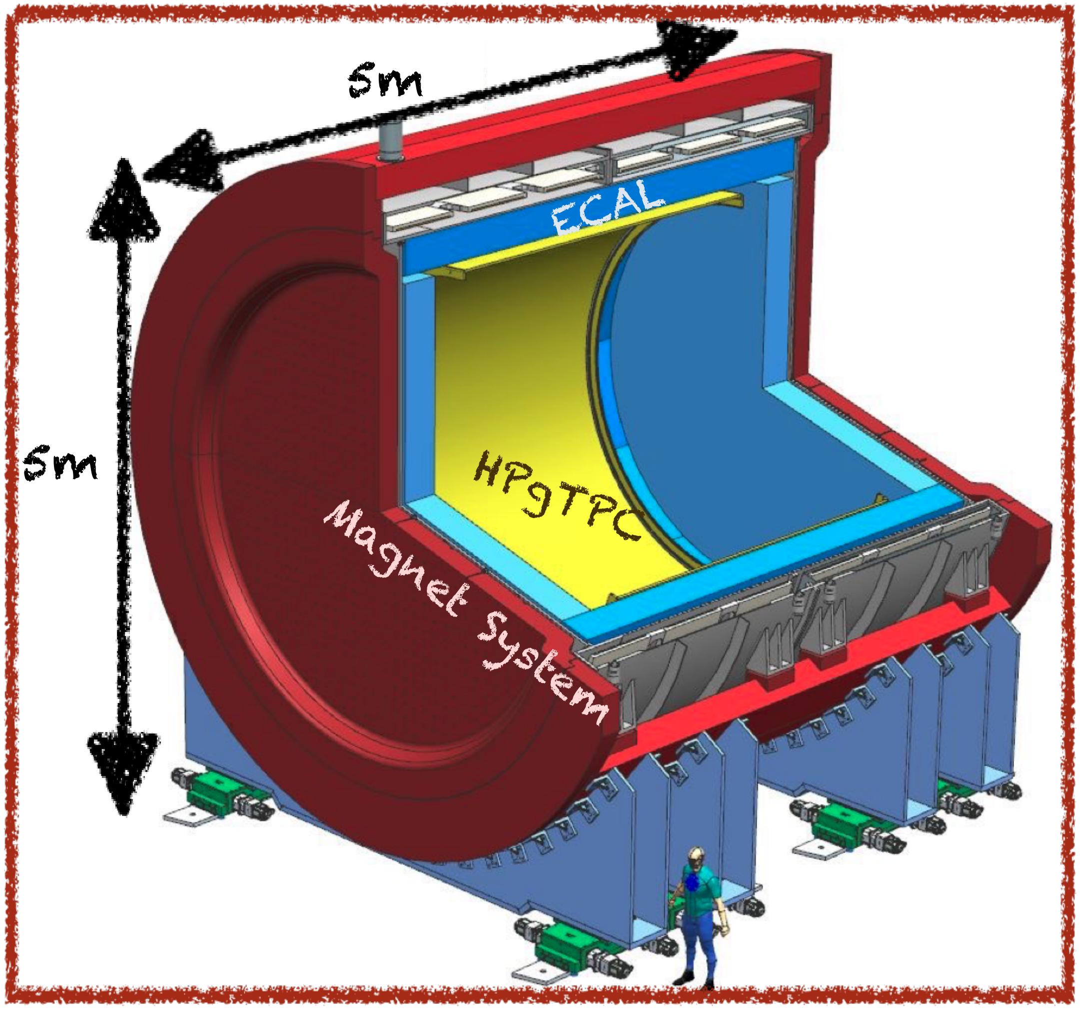
Tanaz A. Mohayai, FNAL
for the various active test stands

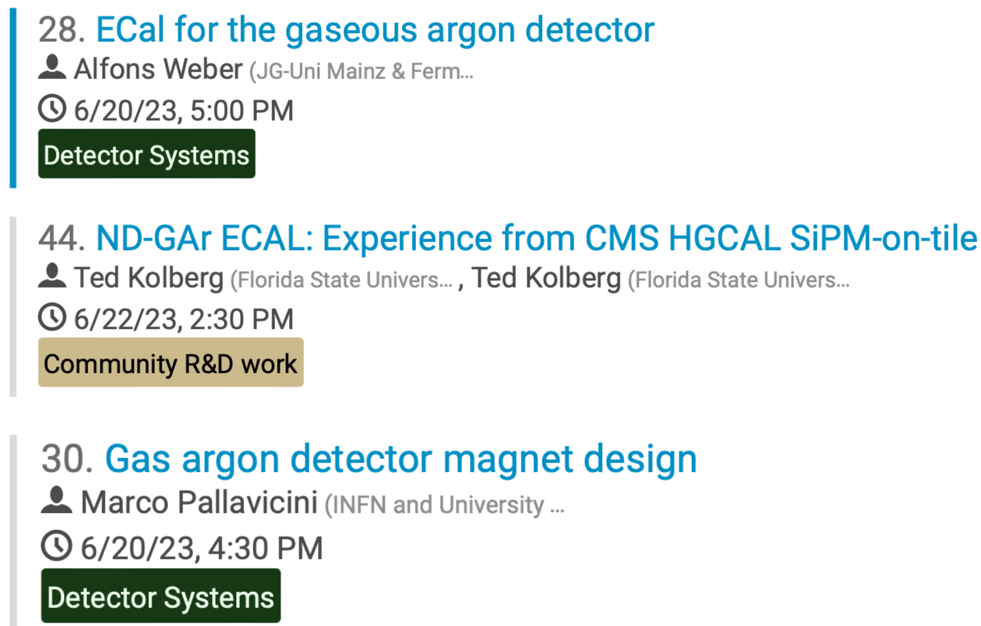
DUNE ND Phase II Workshop, Imperial College London

June 21, 2023

DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT

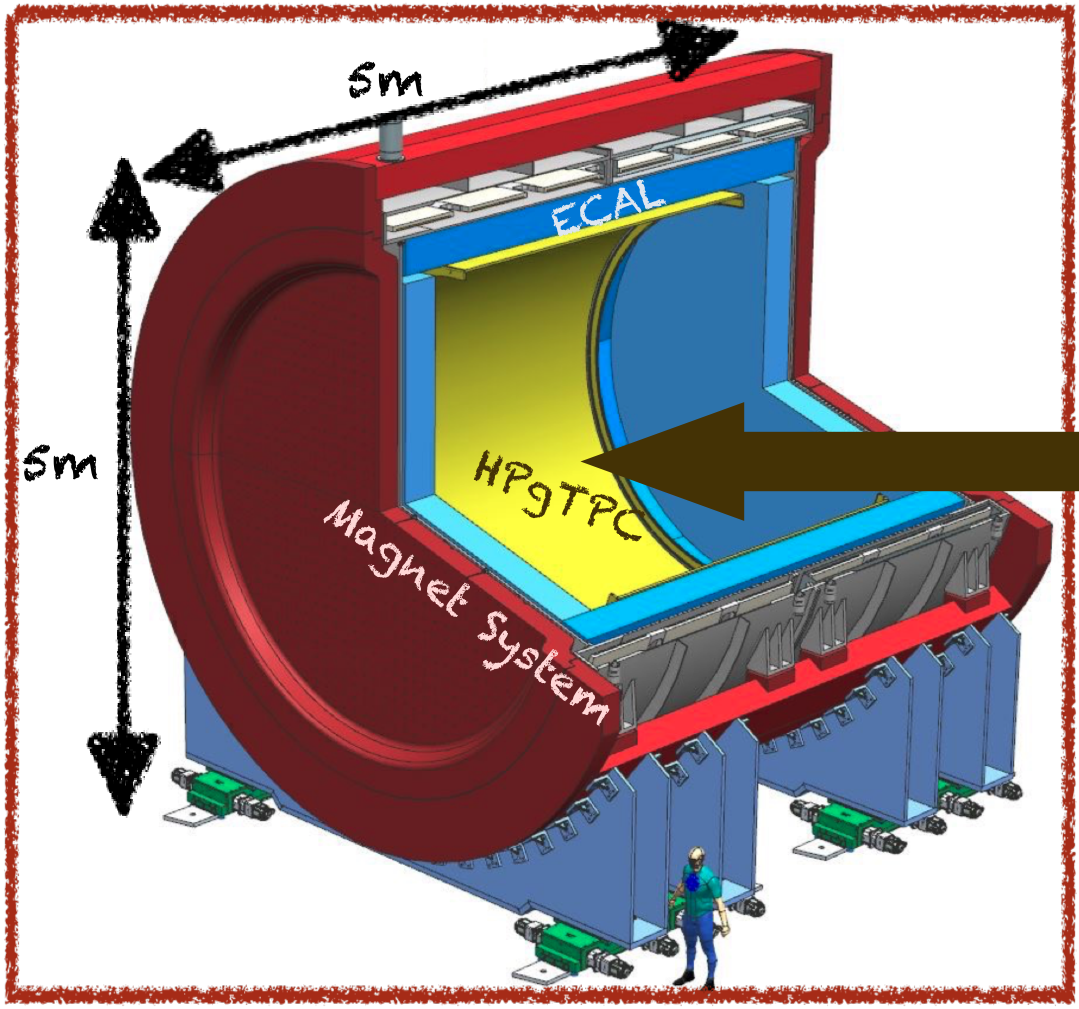
A Comprehensive Design for DUNE ND Phase II





- DUNE ND-GAr (formerly multi-purpose detector & sometimes the More Capable Near Detector Near Detector):
  - **A high pressure gaseous argon-based time projection chamber (HPgTPC)** surrounded by a **calorimeter, ECAL** & a **magnet system**

A Comprehensive Design for DUNE ND Phase II



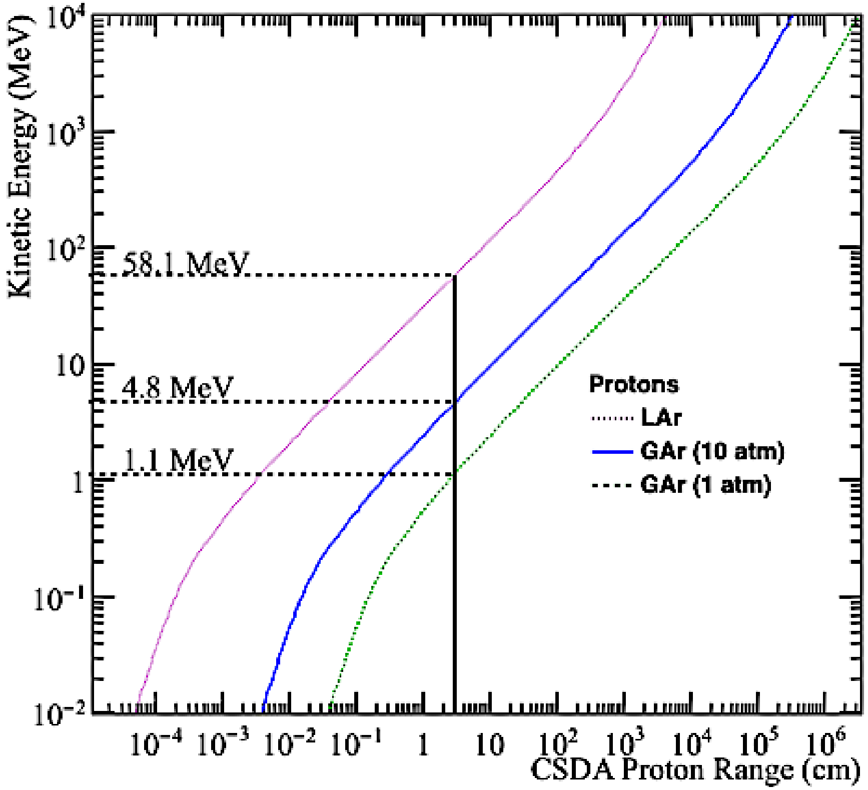
the focus of this talk is on HPgTPC R&D

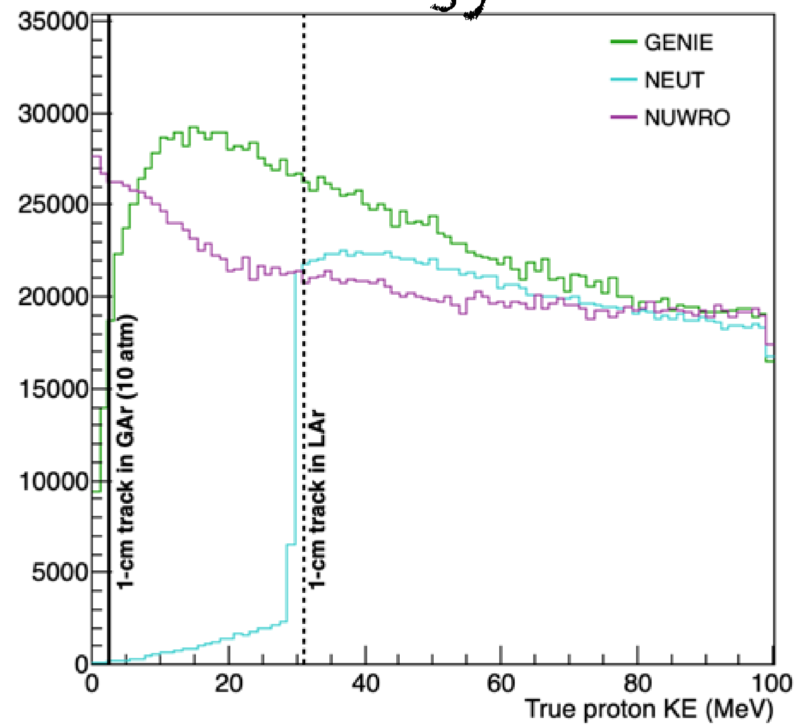
- DUNE ND-GAr (formerly multi-purpose detector & sometimes the More Capable Near Detector Near Detector):
  - **A high pressure gaseous argon-based time projection chamber (HPgTPC)** surrounded by a **calorimeter, ECAL** & a **magnet system**

HPgTPC R&D, Essential to DUNE's Physics Goals

- Design can be optimized to fulfill given physics requirement/s (once determined)
- e.g. optimize the gas mixture, develop the (charge & light) readout:
  - ★ High multiplication gain, enabling <u>low energy thresholds</u>
  - ★ High granularity/pixelization in the readout systems, enabling <u>low tracking threshold</u>

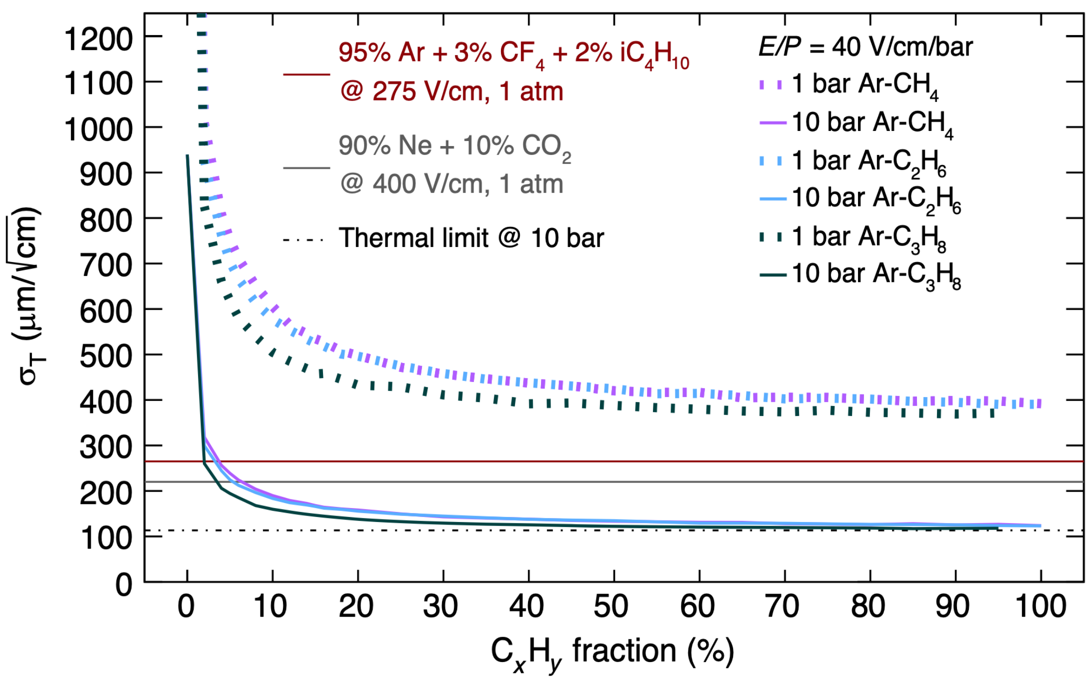
HPgTPC gives access to inaccessible regions of proton energy thanks to its low energy threshold





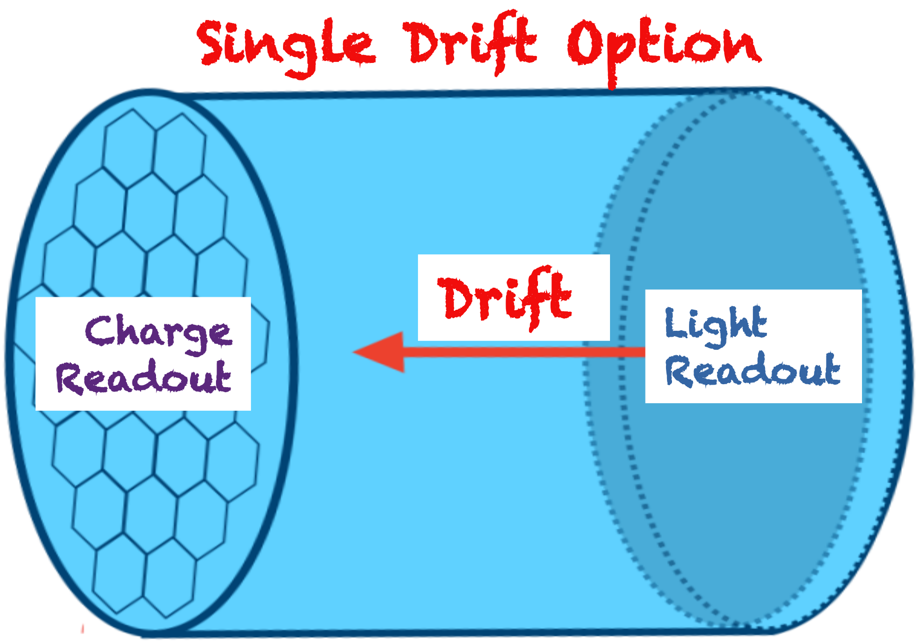
HPgTPC R&D, Essential to DUNE's Physics Goals

- Design can be optimized to fulfill given physics requirement/s (once determined)
- e.g. optimize the gas mixture, develop the (charge & light) readout:
  - High multiplication gain, enabling low energy thresholds
  - High granularity/pixelization in the readout systems, enabling low tracking threshold
  - Optimized pad response function & a better handle on diffusion, enabling a sub-mm spatial resolution



P. Hamacher-Baumann et al., Phys. Rev. D 102, 033005 (2020)

HPgTPC Gas Mixture Studies & Readout Systems



29. Light collection systems for the gaseous argon detector
Diego Gonzalez Diaz
6/20/23, 5:30 PM
Detector Systems

43. LAPPDs for ND-GAr
Mayly Sanchez (Florida State Univers...
6/22/23, 2:00 PM
Community R&D work

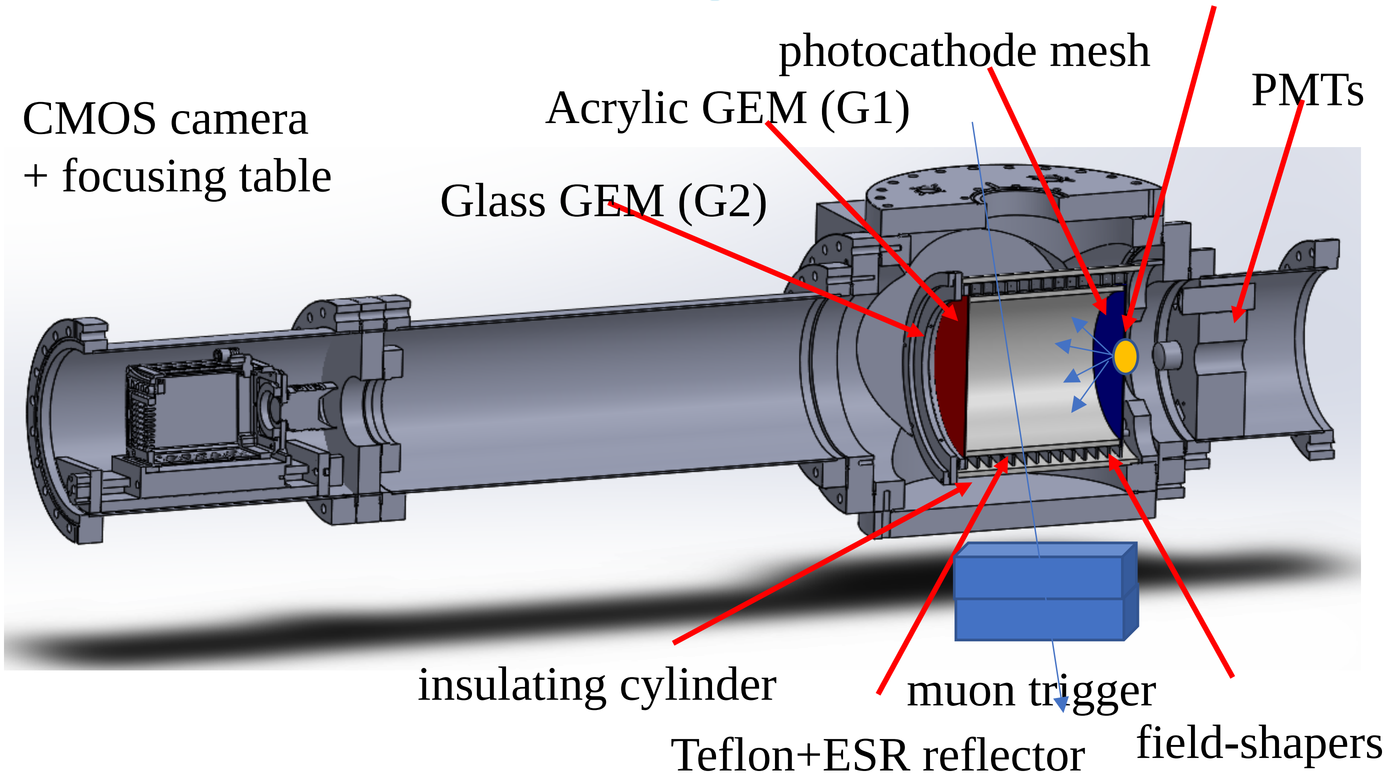
45. Scintillation of Ar-CF4 mixtures towards NDGAr
Pablo Amedo Martínez (Instituto Galego de F...
6/21/23, 11:30 AM
Community R&D work

46. Impurity mitigation in ND-GAr
Jacobo G. Baldonedo (Universidade de Vigo)
6/21/23, 12:00 PM
Community R&D work

- Choose an Ar-based gas mixture that does not quench the scintillation signal and meets purity requirements for a dual charge+light readout HPgTPC:
  - A number of contributions to these areas of R&D at this workshop

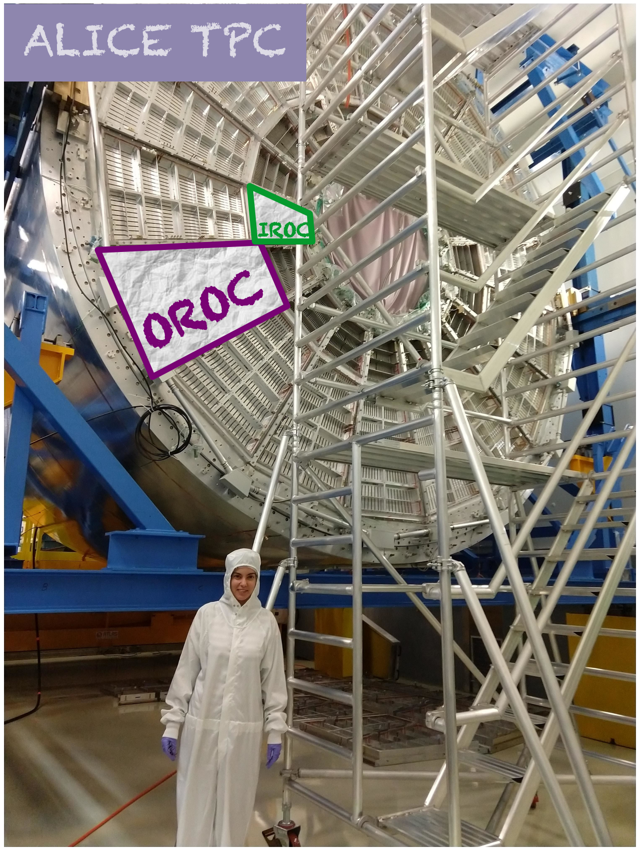
Example of an Optical Readout Demonstrator

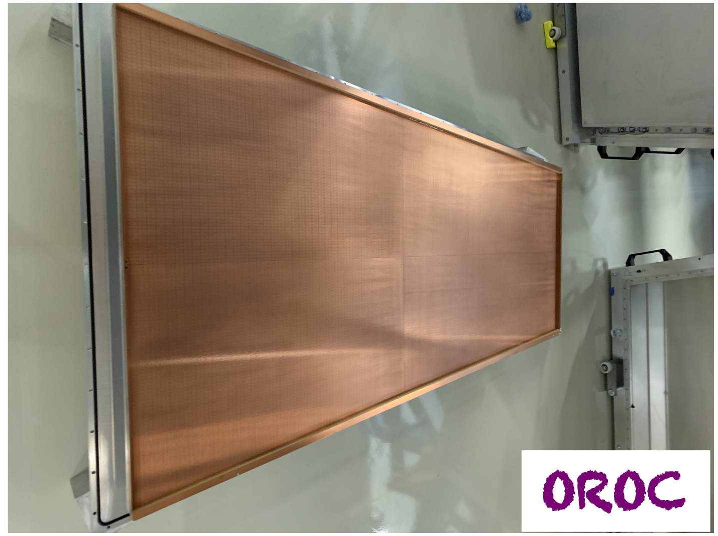
29. Light collection systems for the gaseous argon detector
Diego Gonzalez Diaz
6/20/23, 5:30 PM
Detector Systems

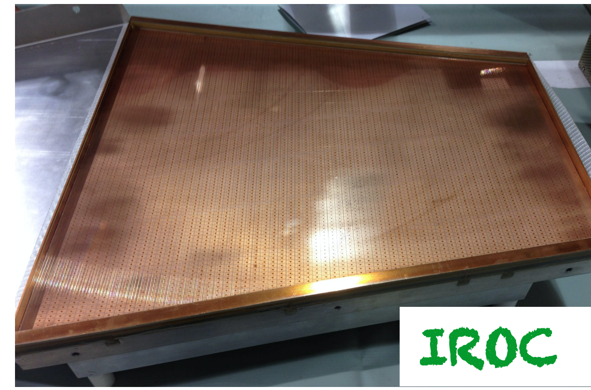


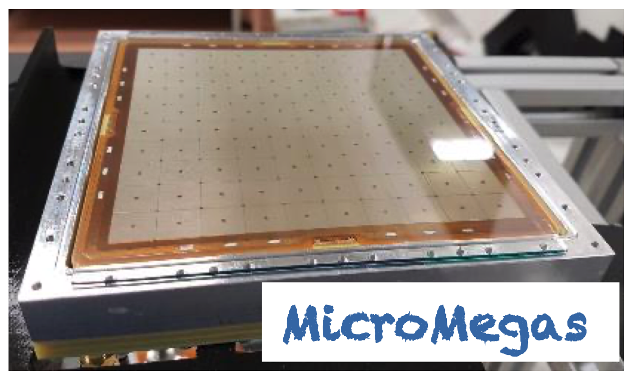
- Choose an Ar-based gas mixture that does not quench the scintillation signal and meets purity requirements for a dual charge+light readout HPgTPC:
  - A number of contributions to these areas of R&D at this workshop, **e.g. the R&D at IGFAE and IFIC in Spain to characterize optical gain**

HPgTPC Charge Readout

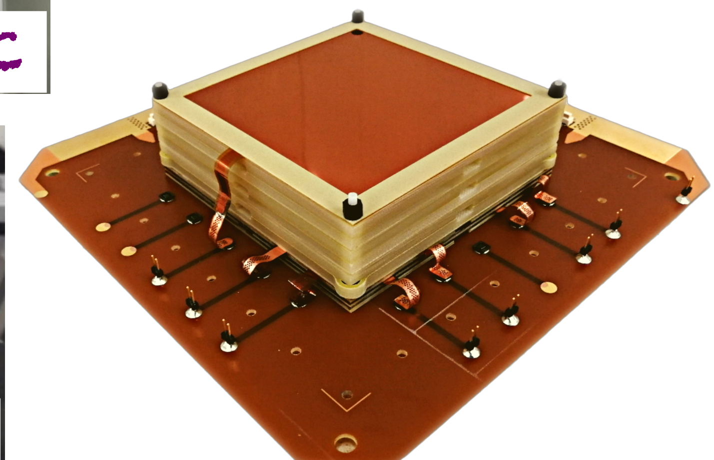








PICOSEC Micromegas Collaboration



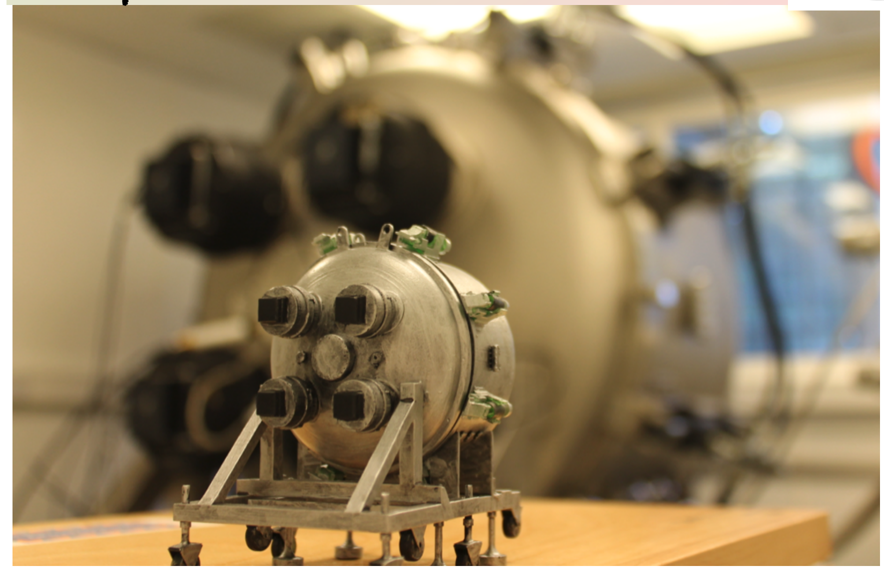
GEM

- For charge readout:
  - Reference design includes re-purposing the ALICE's multiwire chambers + readout system for the center
  - Could also develop new systems, e.g. GEMs, MicroMegas

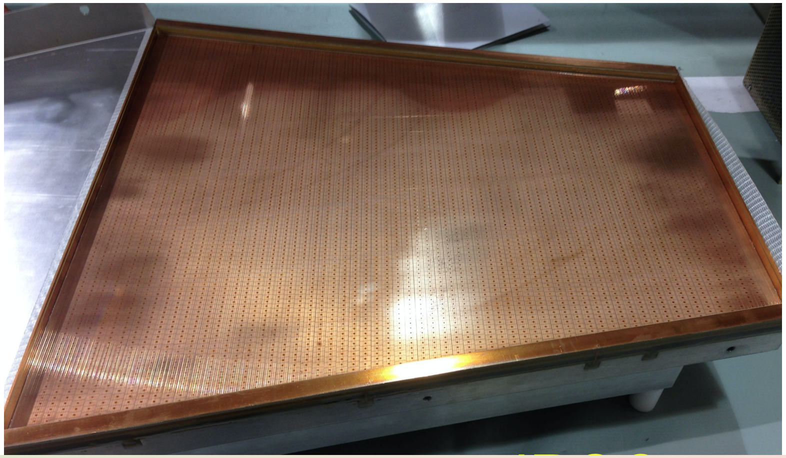
Test Stands for Developing the Charge Readout System

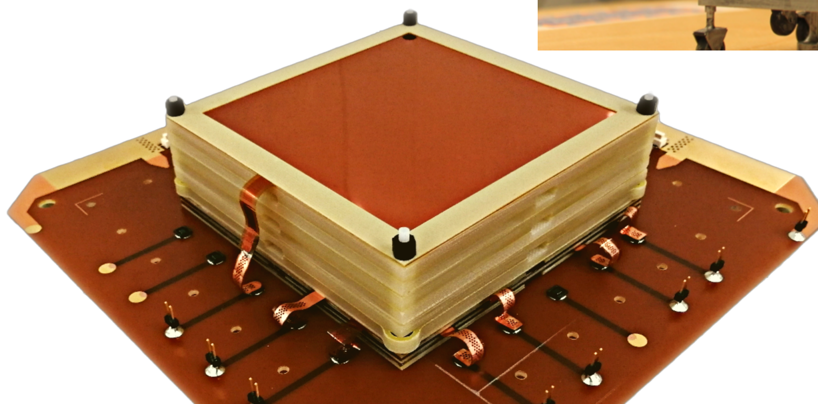
- Tests of **ALICE inner & outer multiwire chambers** (GOAT & TOAD) & a **Gas Electron Multiplier, GEM** (GORG)

ALICE chamber Testing – Test of Overpressure Argon Detector, TOAD



ALICE chamber Testing – Gas-Ar Operation of ALICE TPC, GOAT

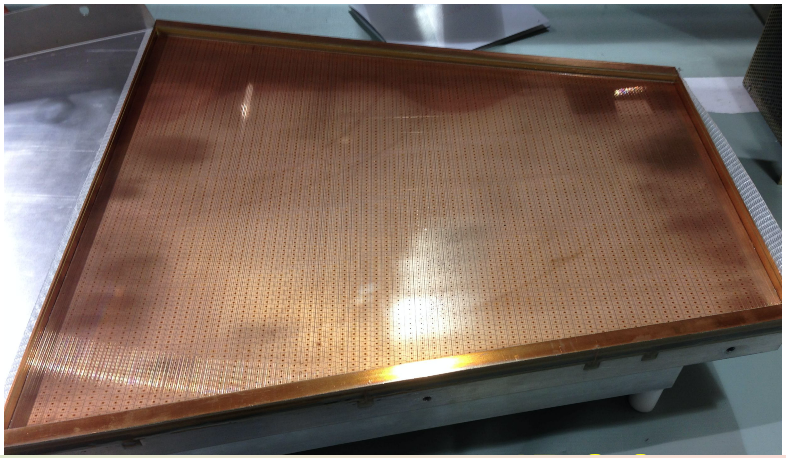




GEM Testing – GEM Over-pressurized with Reference Gases, GORG

Test Stands for Developing the Charge Readout System

- Tests of **ALICE inner & outer multiwire chambers** (GOAT & TOAD) & a **Gas Electron Multiplier, GEM** (GORG)



ALICE chamber Testing – Gas-Ar Operation of ALICE TPC, GOAT

ALICE chamber Testing – Test of Overpressure Argon Detector, TOAD

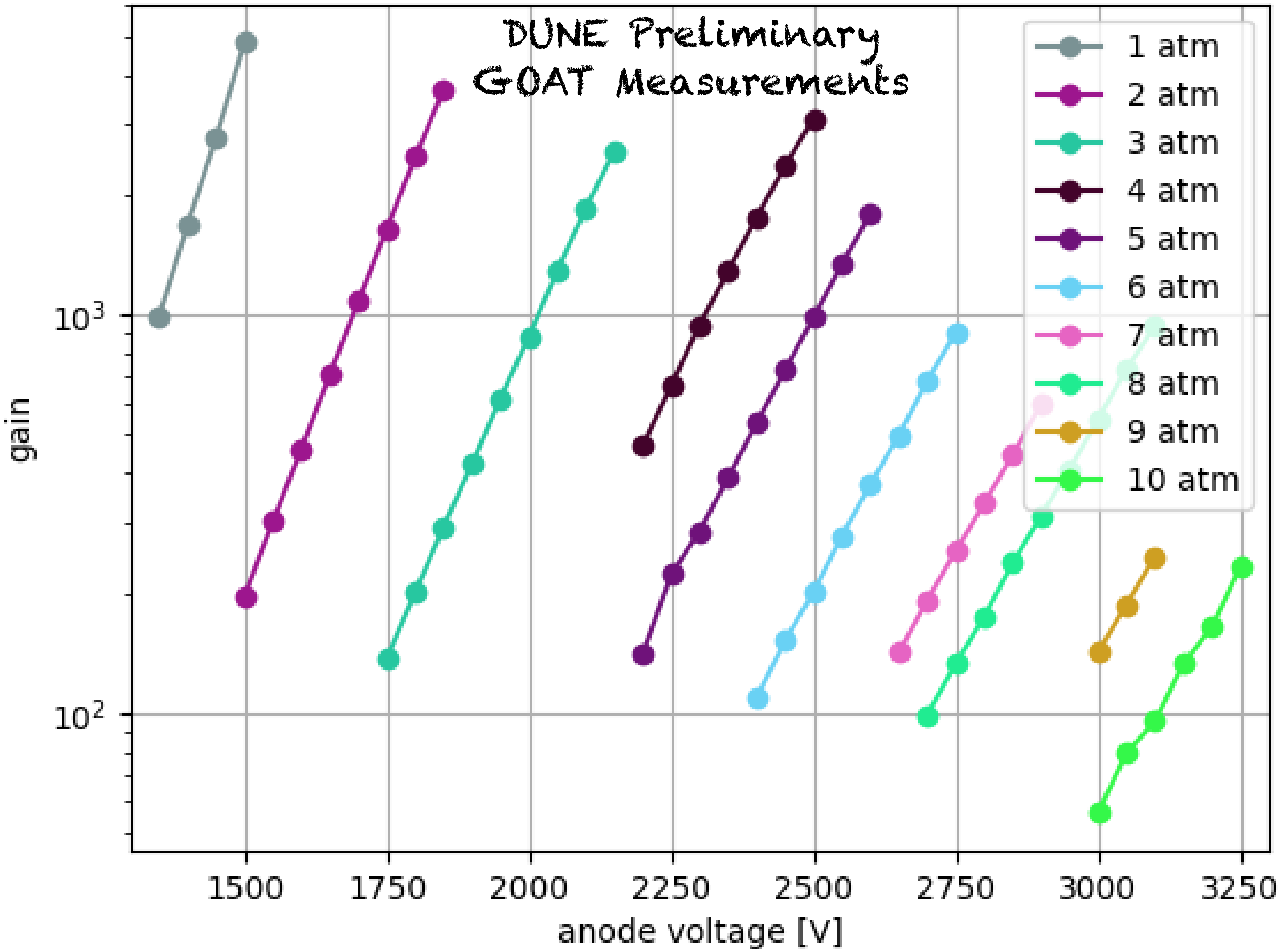
GEM Testing – GEM Over-pressurized with Reference Gases, GORG

GOAT Test Stand at FNAL

- The test stand includes a pressure vessel rated to 10 atm, housing an **ALICE inner readout chamber**
- Status: have demonstrated the functionalities of ALICE chambers up to 10 atm:
  - In ALICE, the chambers operated at 1 atm and at voltages <3kV

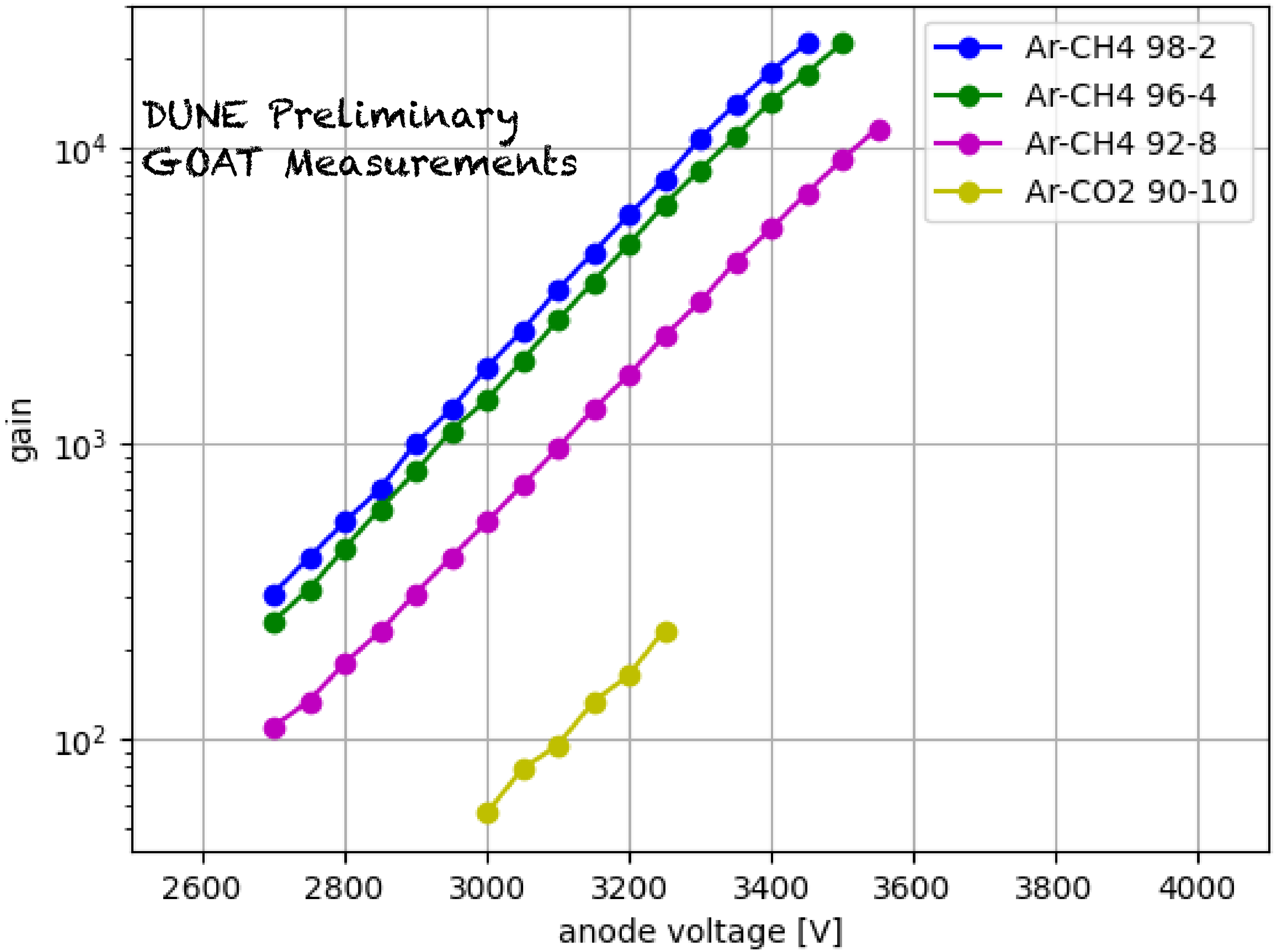
Gain Measurements

- At a fixed pressure, a **higher anode/multiplication wire voltage** results **in a higher gain**
- To keep the same gain, higher anode voltages needed at higher pressures



Gain Measurements

- ALICE inner chambers in 10 atm of Ar-CH4 mixtures:
  - Operate safely with a gain of 1000 at anode/multiplication wire voltages <3kV (the previous limit at which ALICE chambers operated)

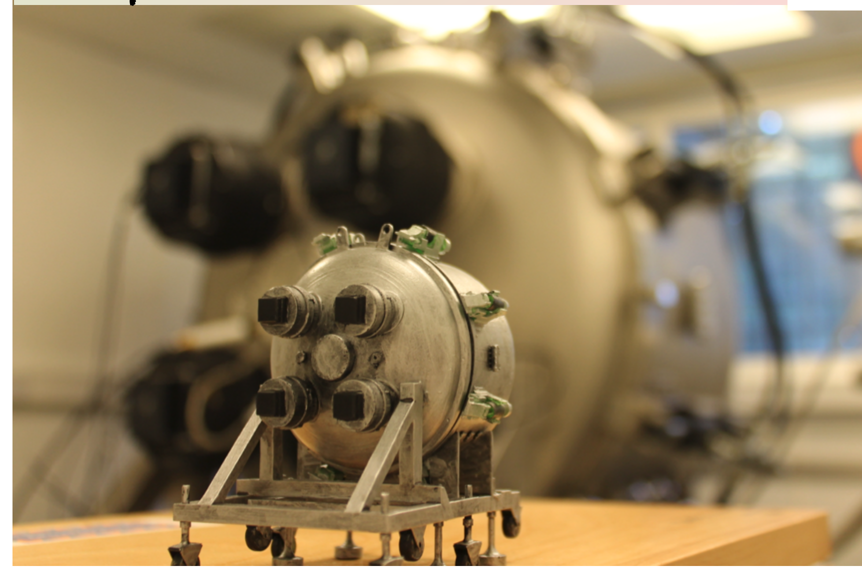


Test Stands for Developing the Charge Readout System

- Tests of **ALICE inner & outer multiwire chambers** (GOAT & TOAD) & a **Gas Electron Multiplier, GEM** (GORG)

ALICE chamber Testing – Gas-Ar Operation of ALICE TPC, GOAT

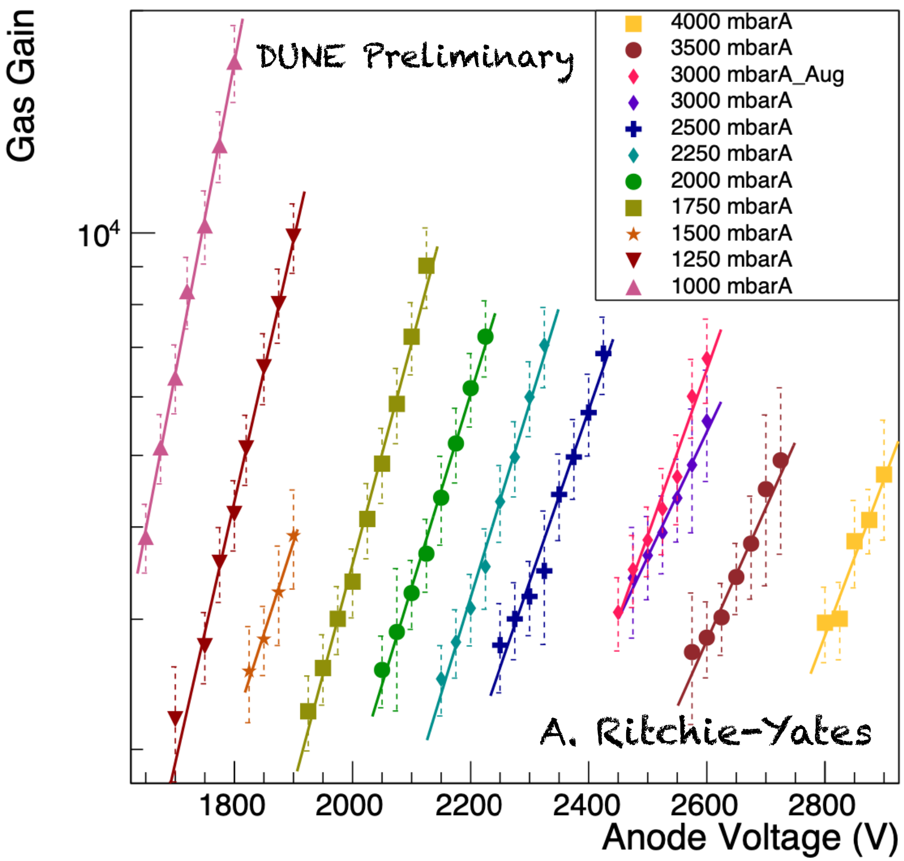
ALICE chamber Testing – Test of Overpressure Argon Detector, TOAD

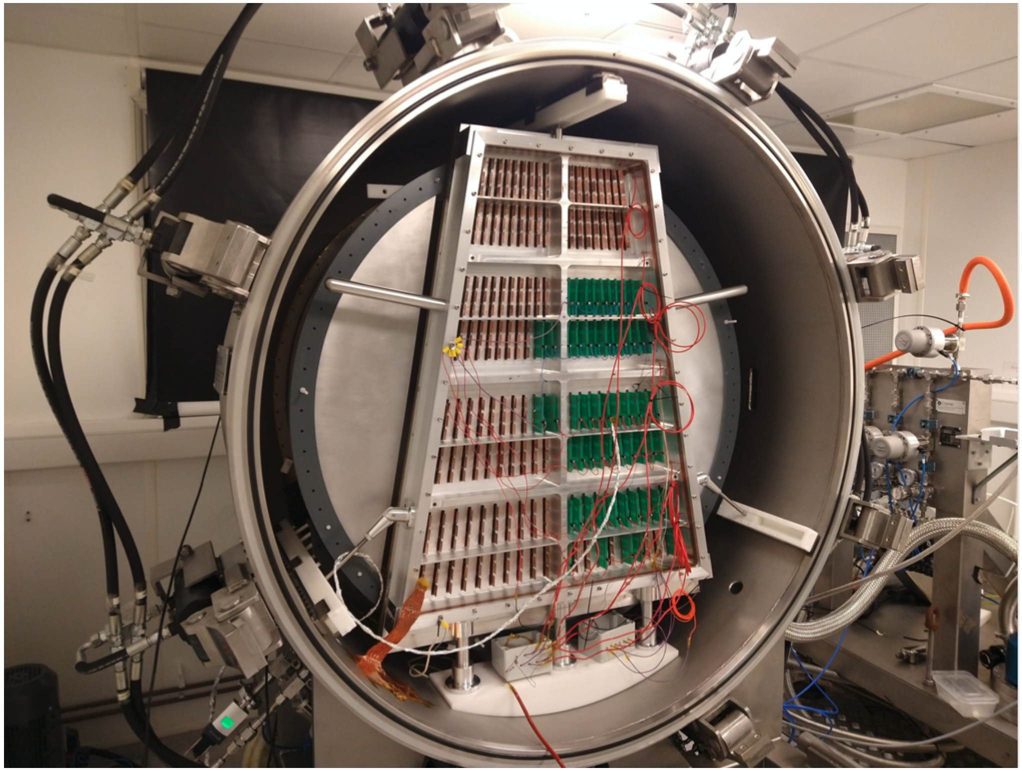


GEM Testing – GEM Over-pressurized with Reference Gases, GORG

TOAD Test Stand & Gain Measurements

- Hybrid charge-light readout (using CCDs) pressure vessel rated to 5 atm housing an **ALICE outer readout chamber**
- **Gain calibration** previously done at Royal Holloway

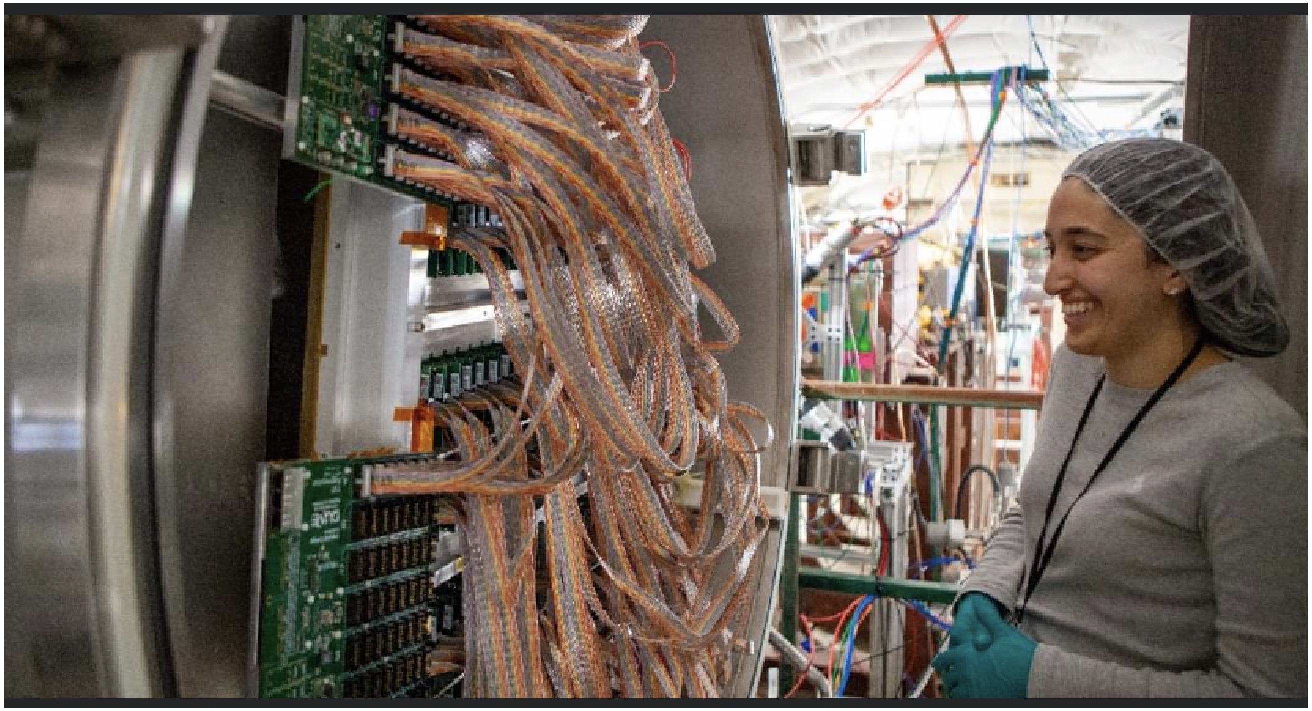




Deisting, Waldron et al., Instruments 2021, 5(2), 22

Test Beam Prototyping

- Led by N. Khan and P. Dunne
- Aims o demonstrate **long-term operation of readout chamber and performing a full slice test of electronics and DAQ**
- Full chain of DAQ and electronics installed and being tested; more on this from P. Dunne!

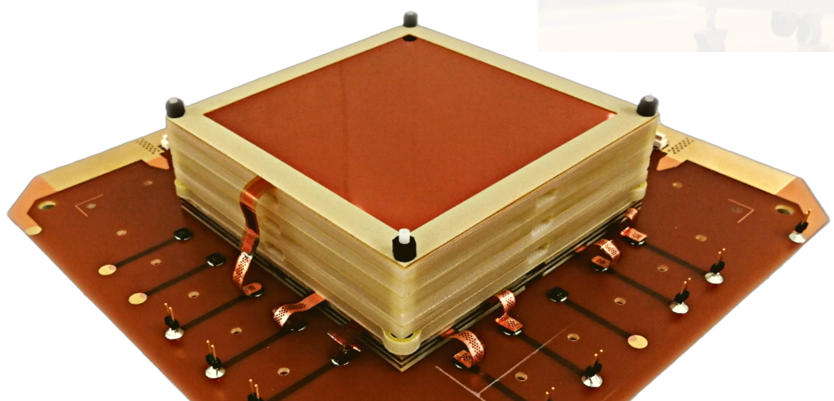


Test Stands for Developing the Charge Readout System

- Tests of **ALICE inner & outer multiwire chambers (GOAT & TOAD)** & a **Gas Electron Multiplier, GEM** (GORG)

ALICE chamber Testing – Gas-Ar Operation of ALICE TPC, GOAT

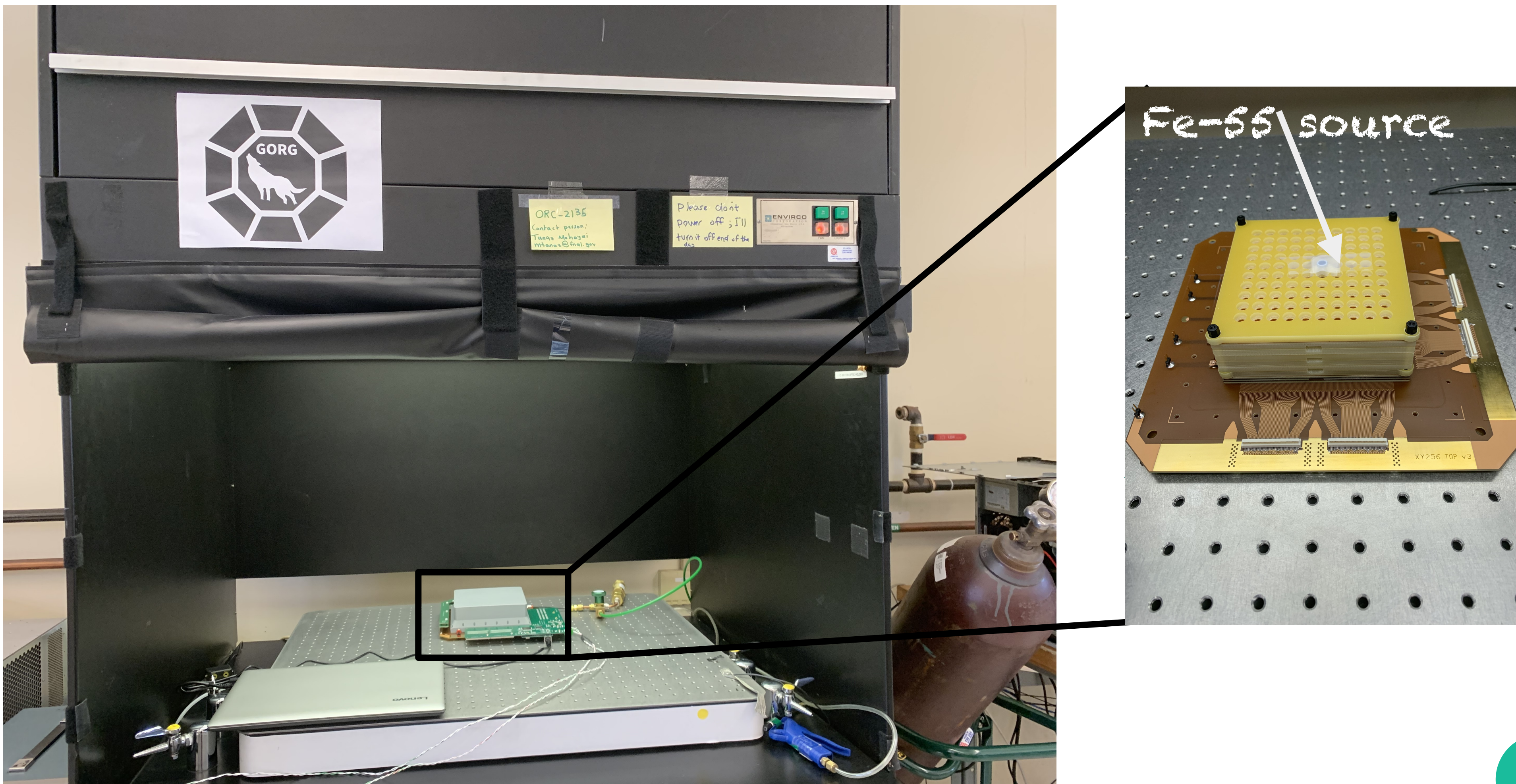
ALICE chamber Testing – Test of Overpressure Argon Detector, TOAD



GEM Testing – GEM Over-pressurized with Reference Gases, GORG

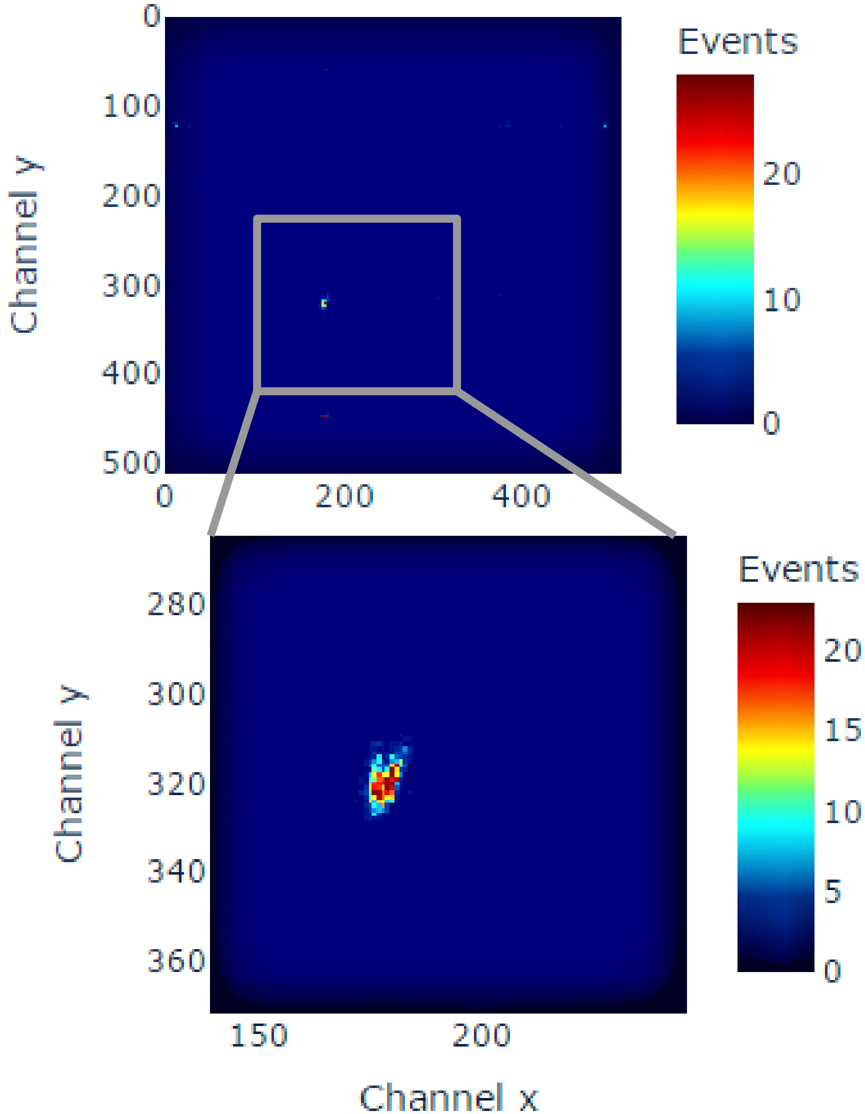
GORG Setup

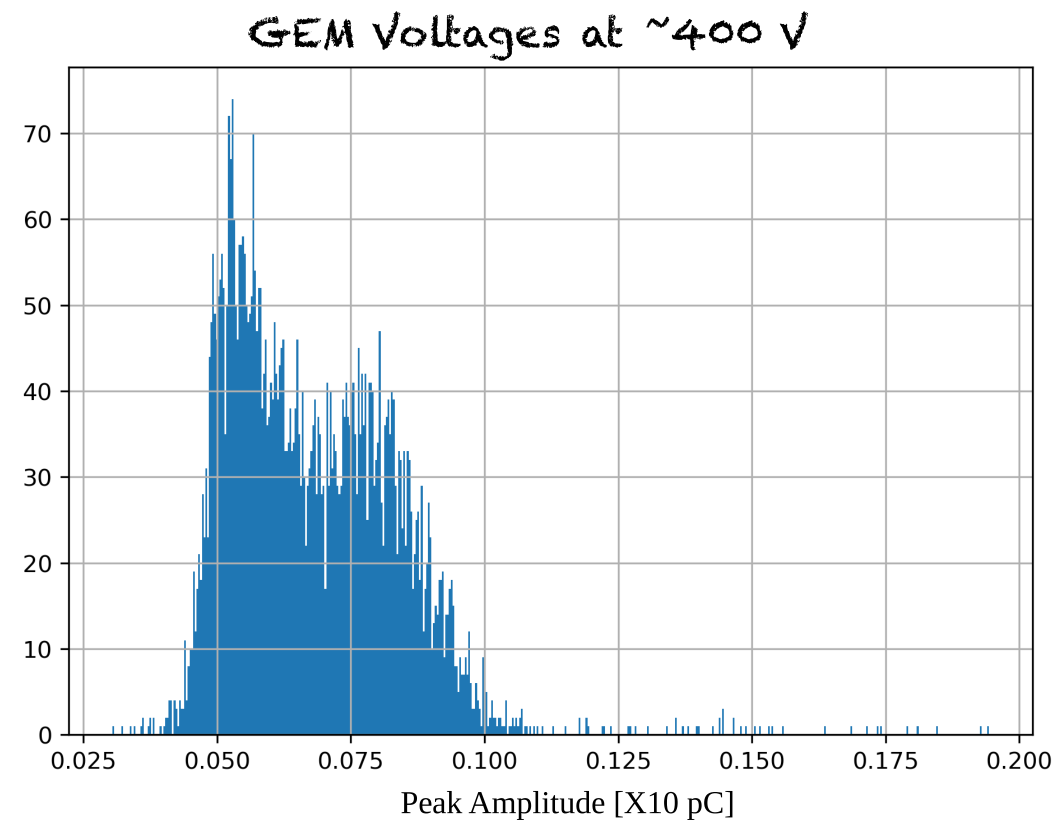
- T. M.'s *New Initiatives in detector R&D project*, includes a **Gas Electron Multiplier, GEM** stack with 3 foils + the drift cathode, procured in collaboration with Techtra TTA
- A **Full DAQ chain + HV divider**
- More on GEMs from K. Mavrokoridis



Bench Test @1 atm

- Indications of Fe-55 activity
- Next up: gain calibration at 1 atm, then to the GOAT pressure vessel!

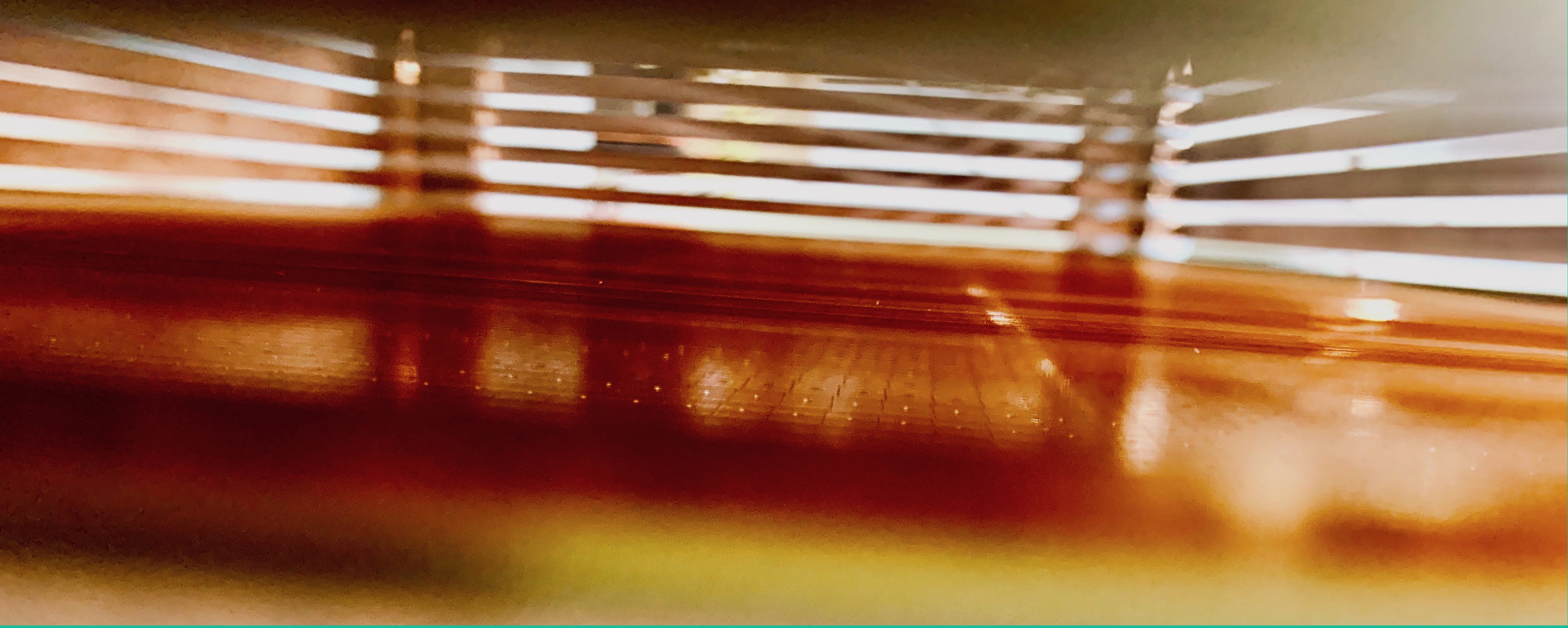




Summary & Future Prospects

- R&D efforts in the context of existing test stands are progressing well & are critical to ensure the high pressure gas TPC has the optimal readout system for DUNE to fulfill its physics requirements
- There are opportunities for new collaborators to join and to contribute their expertise!
  - e.g. CEvNS communities searching for low energy CEvNS signals and directional dark matter, EIC communities who in synergy to DUNE have plans in place to use pressurized gas argon TPCs, MicroMegas communities

- **Future prospects & open questions:**
  - Optimizing GEMs for pressurized gas medium, for both charge and light readout
  - Software optimizations (more on this from T. Junk later in the workshop) and evaluating physics impacts of gas mixtures and readout systems while determining physics requirements simultaneously
  - TOAD beam run + future beam runs with new readout systems, e.g. making use of Indiana University's neutron beam facility
  - Efforts on developing Micromegas or hybrid GEM+Micromegas
  - Let's discuss!



GOAT

DUNE TOAD

GORG

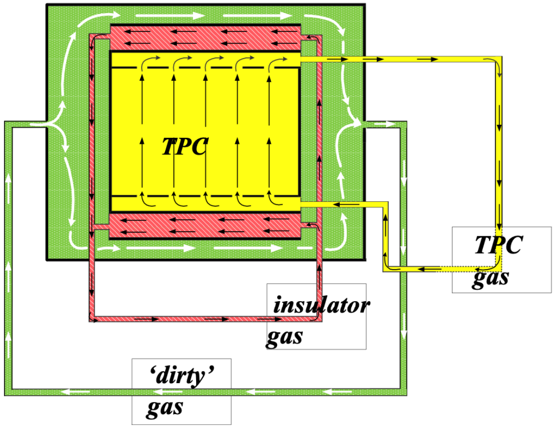
GATO

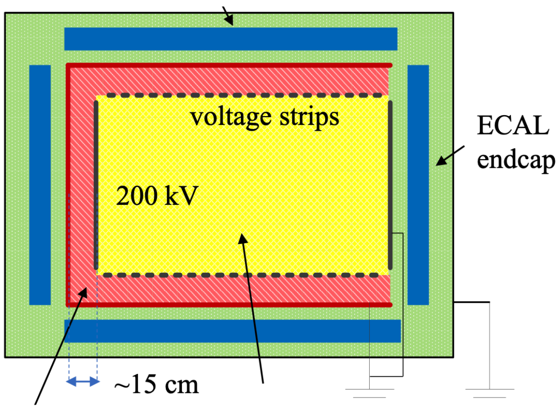
Your logo goes here!

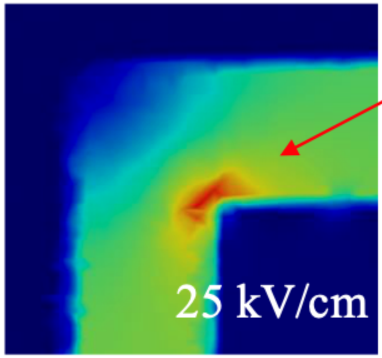
Additional Slides on Past R&D Efforts

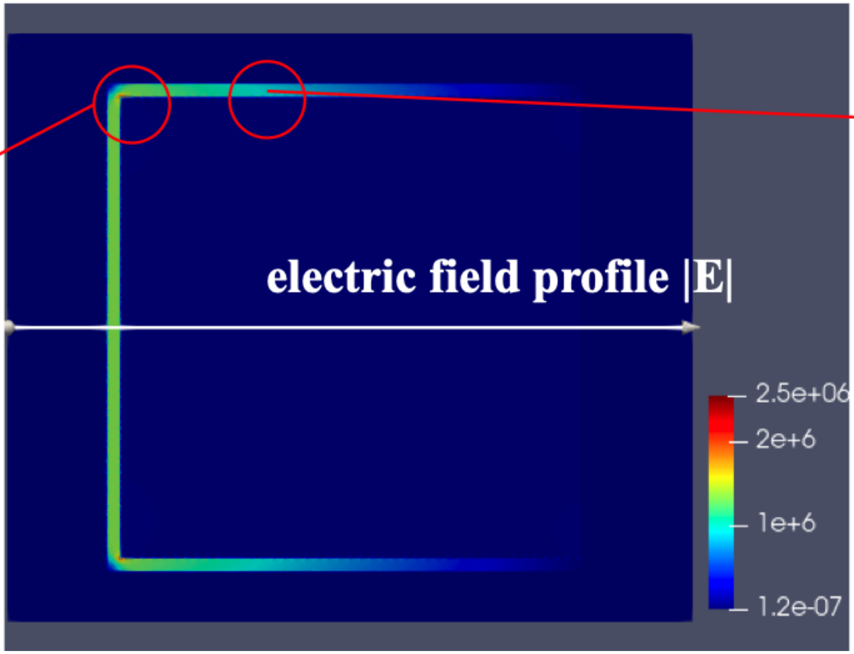
R&D Efforts

- Optimizing the design of the gas system and field cage (led by Indiana)

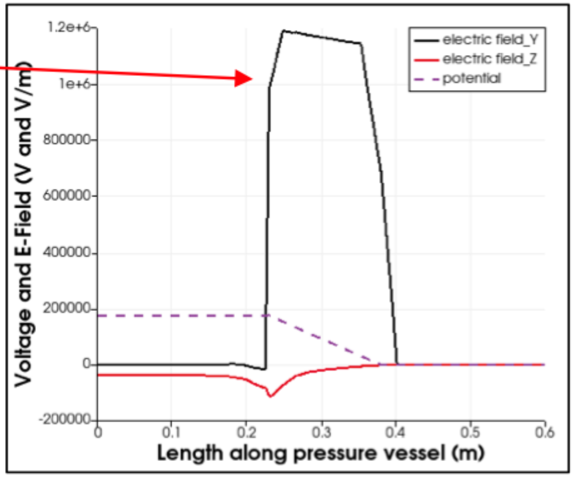






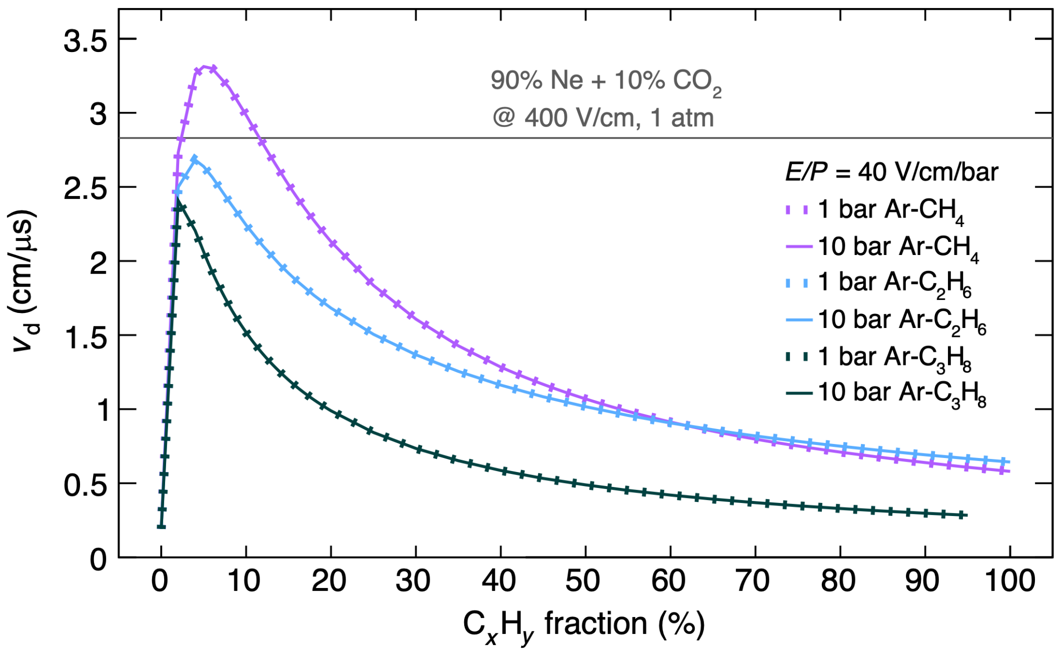


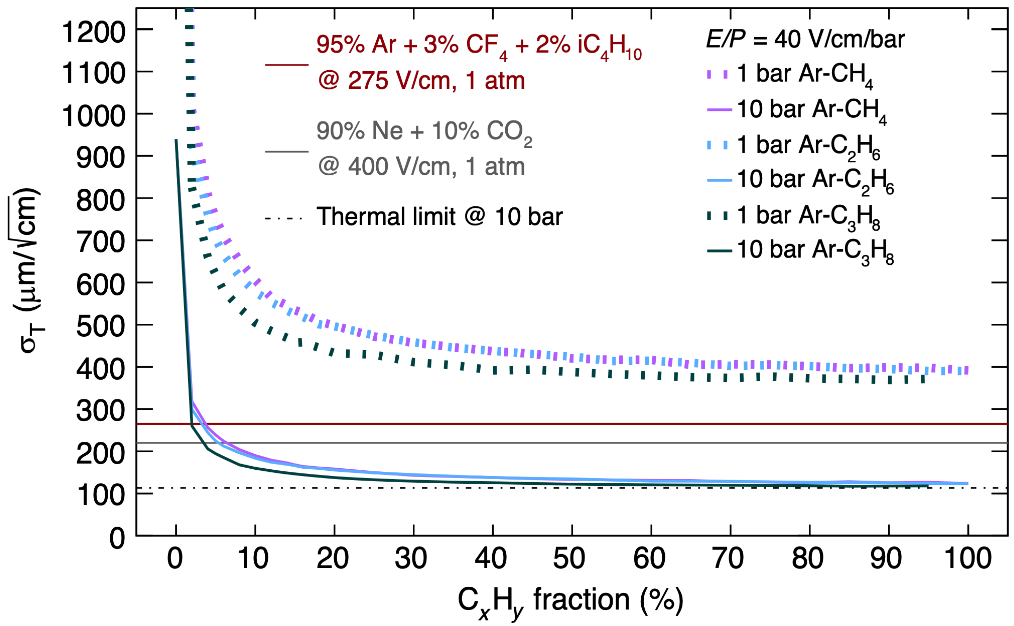
~12 kV/cm



R&D Efforts

- Defining a base gas mixture – reference is argon-based gas with 10% CH_4 admixture (97% of interactions on Ar) but can be optimized to:
  - Control pile up & minimize the effects from temp variations (drift velocity), improve spatial resolution (diffusion)

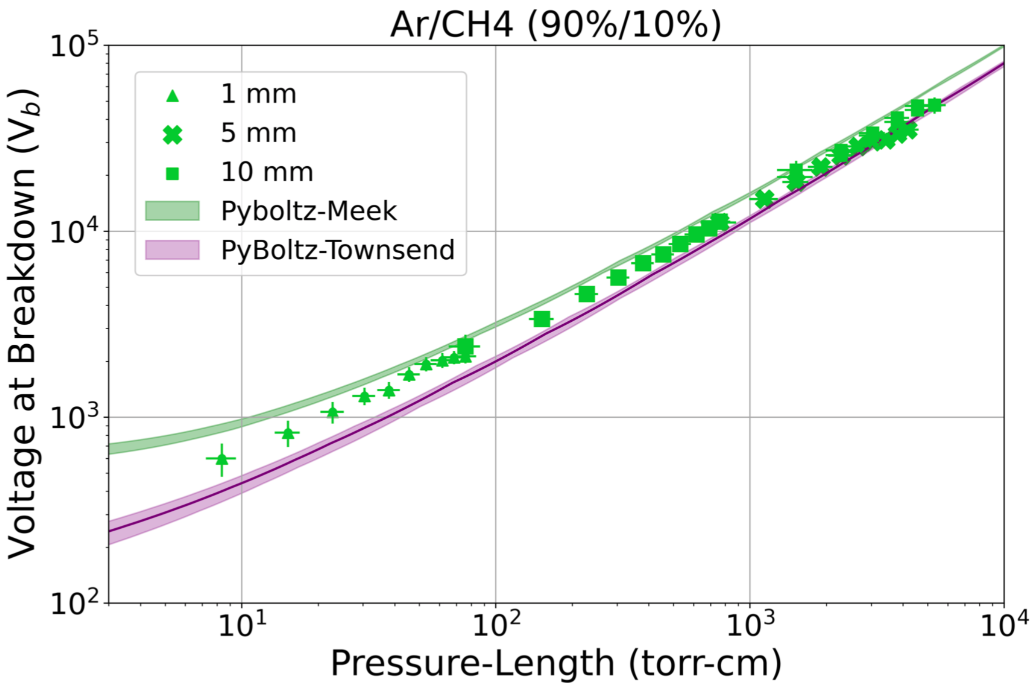




P. Hamacher-Baumann et al., Phys. Rev. D 102, 033005 (2020)

R&D Efforts

- Defining a base gas mixture – reference is argon-based gas with 10% CH_4 admixture (97% of interactions on Ar) but can be optimized to:
  - Maximize gas gain, while minimizing gas electrical breakdown

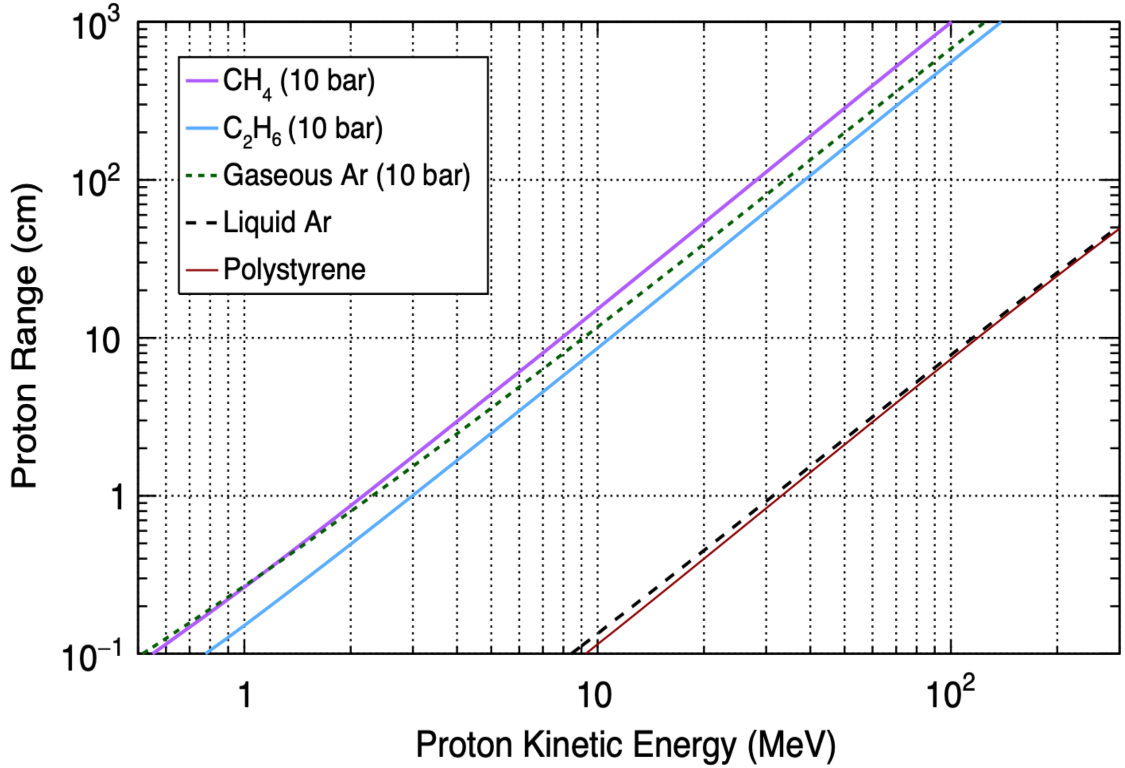


Norman, L. *et al.* Dielectric strength of noble and quenched gases for high pressure time projection chambers. *Eur. Phys. J. C* **82,** 52 (2022)

Projected Breakdown Voltage at 10 bar, 1 cm (kV)							
	Ar	Xe	Ar-CF_4	Ar-CH_4	Ar-CO_2	CO_2	CF_4
Townsend	**52.6**	**75.4**	61.7	63.9	68.6	129.5	179.7
Meek	69.9	98.9	72.1	80.3	87.3	**171.2**	**212.2**

R&D Efforts

- Defining a base gas mixture – reference is argon-based gas with 10% CH_4 admixture (97% of interactions on Ar) but can be optimized to:
  - Ability to operate with a hydrogen-rich gas mixture /make use of the CH4 dopant in the mixture to probe more fundamental neutrino-hydrogen interactions

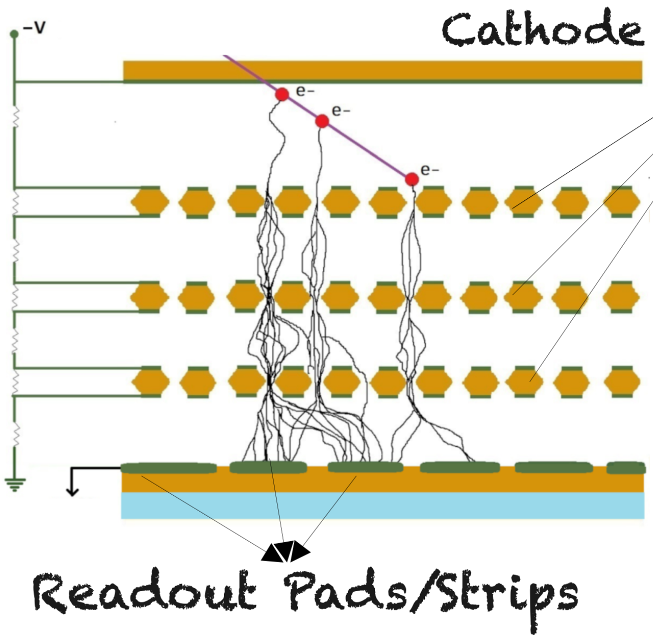


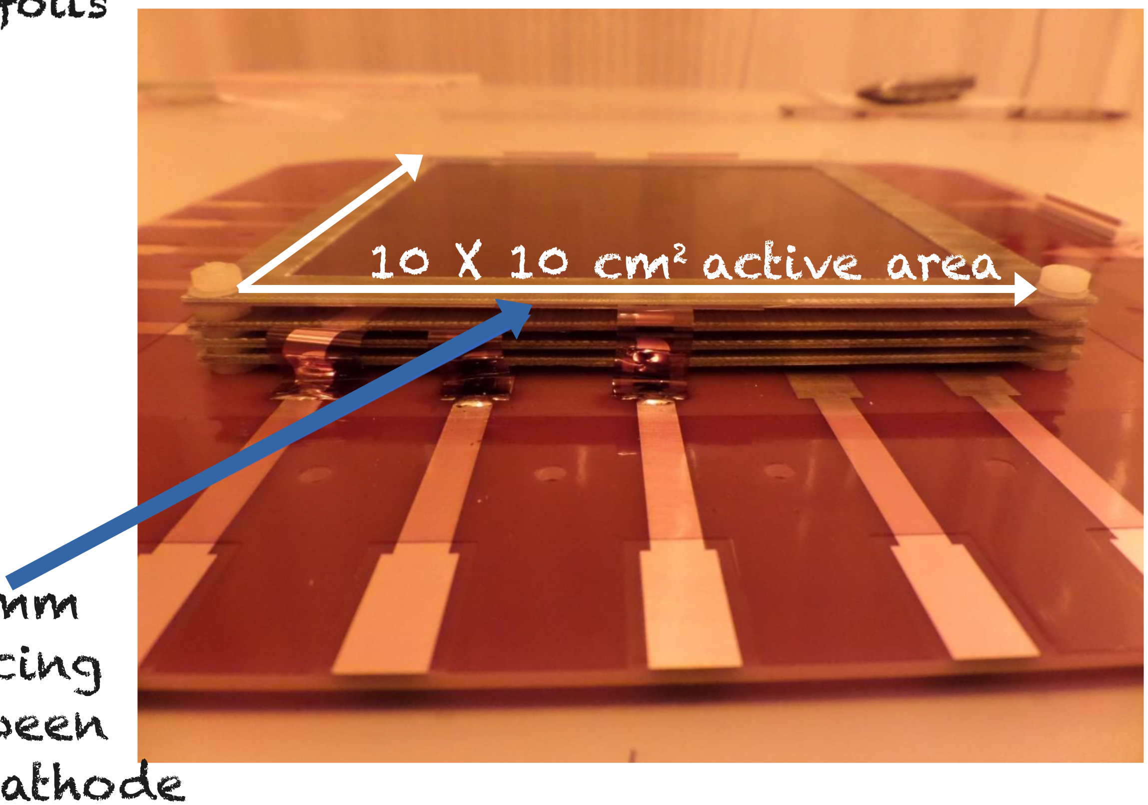
P. Hamacher-Baumann et al., Phys. Rev. D 102, 033005 (2020)

Backup Slides

GEM Readout

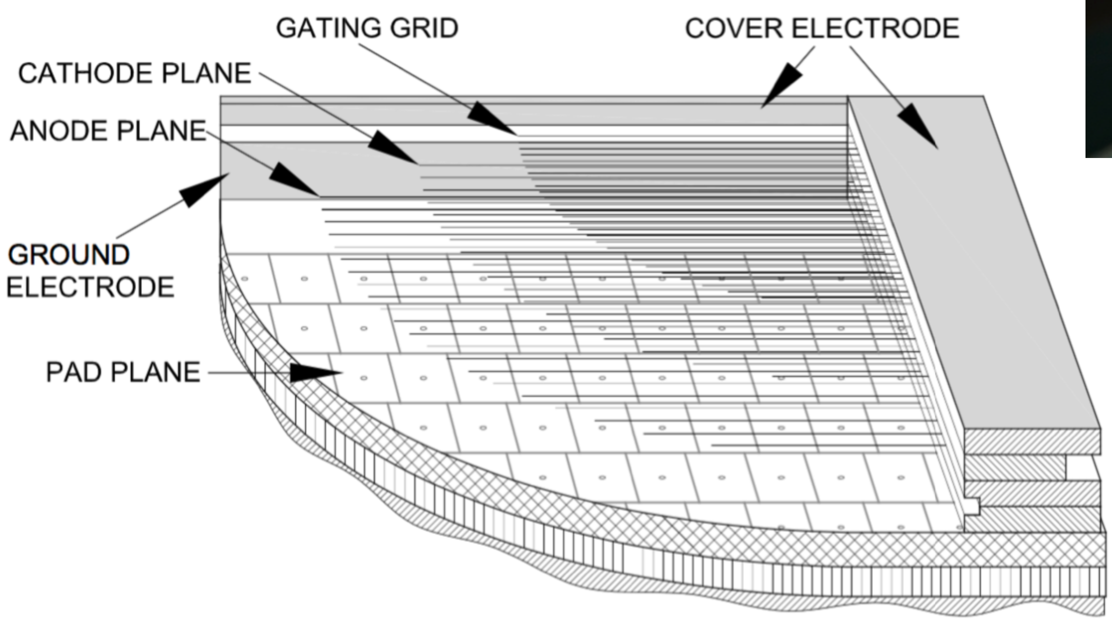
- T. M.'s *New Initiatives in detector R&D project*, includes a **Gas Electron Multiplier, GEM** stack with 3 foils + the drift cathode, procured in collaboration with Techtra TTA

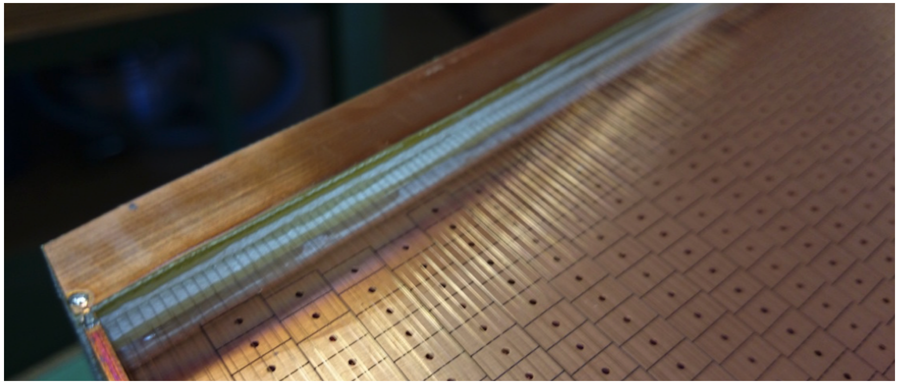


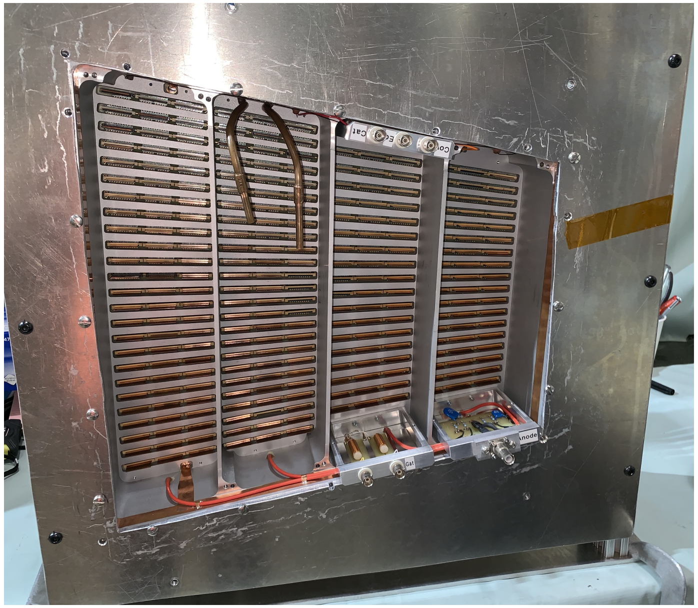


ALICE Chambers

- Gated pad readout w/ **multiplication by** the anode wires
- Connectors on the back side of the chamber route signals from the **pads to front end cards**

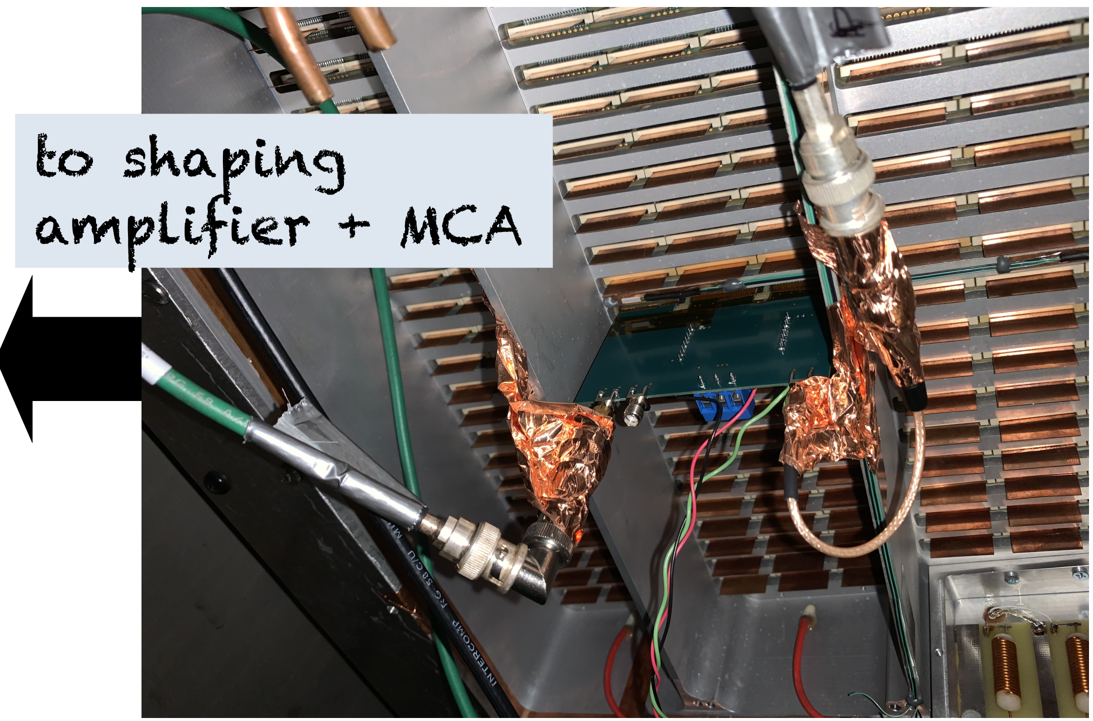


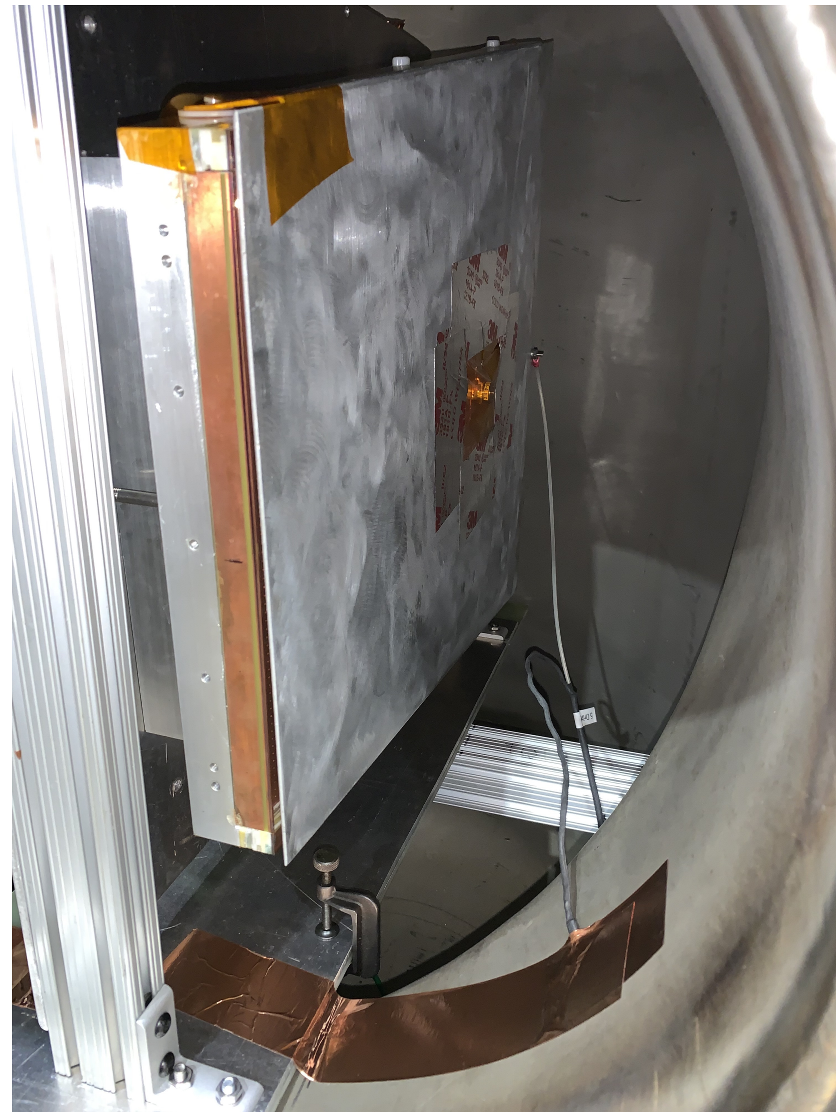




The GOAT Setup

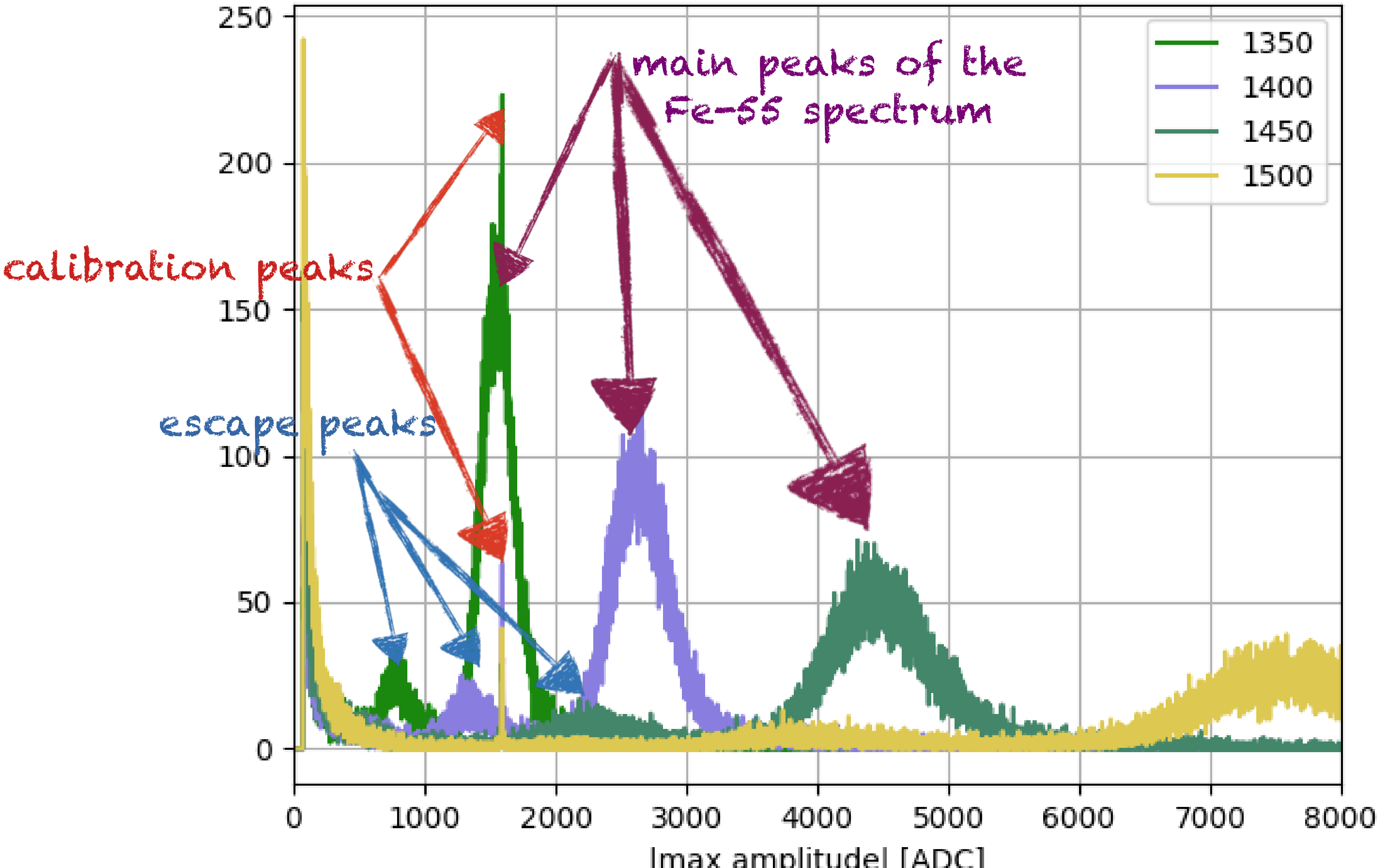
- Fe-55 source, used for gain calibration, is collimated to ensure that we are at the peak of the pad response
- A front-end card with a built-in preamp, routes the signal to a shaping amplifier and DAQ





Fe-55 Spectrum

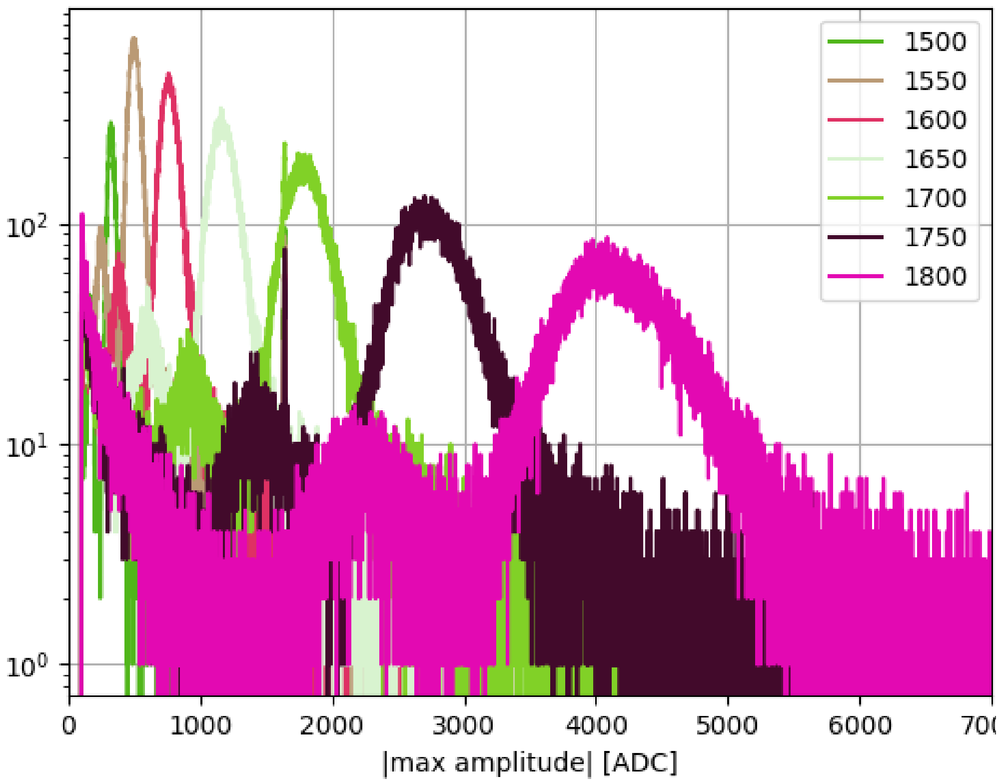
- Increasing the anode voltage shifts the peaks to higher amplitudes
- Calibration peaks are from pulsing the readout card directly, which corresponds to a known gain (~1000)

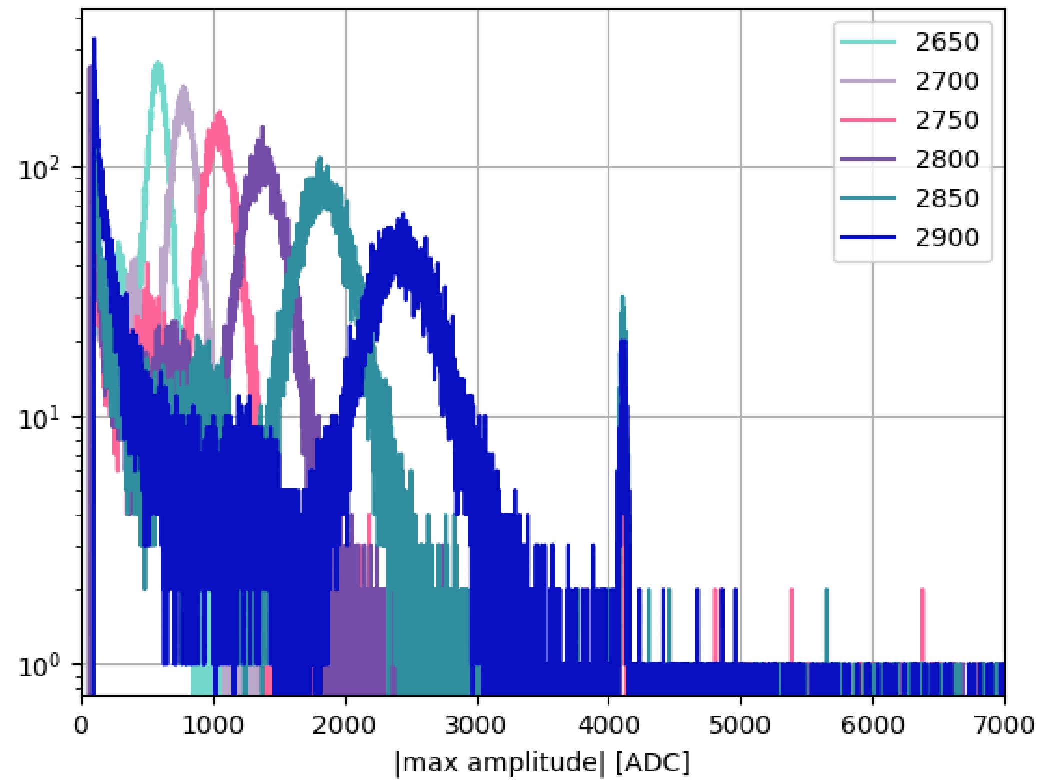


Fe-55 Spectrum

- At a fixed pressure, a higher anode voltage shifts the main peak of the Fe-55 spectrum to higher amplitudes

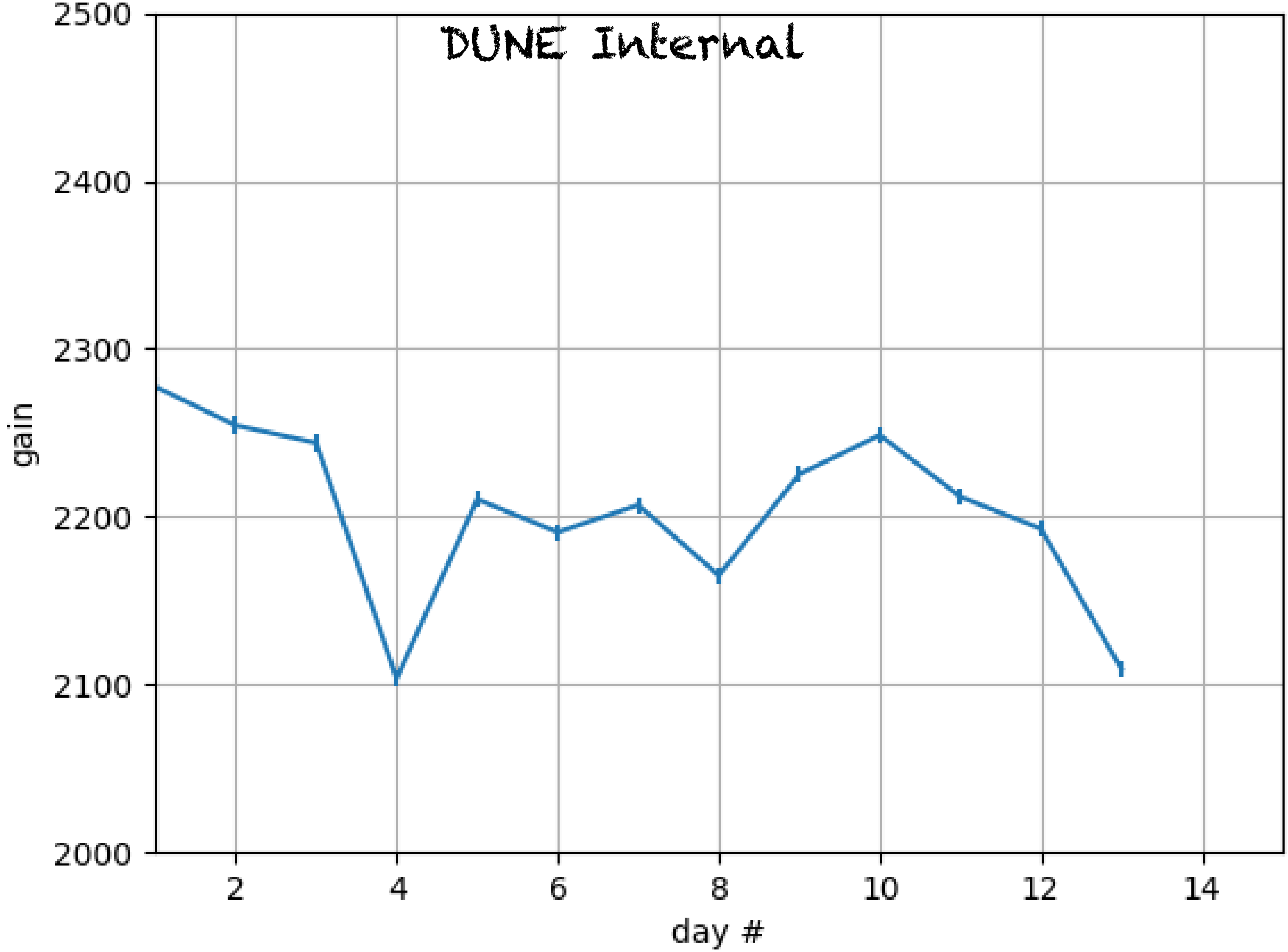
2 atm, Ar:C02 90:10 → 7 atm, Ar:C02 90:10





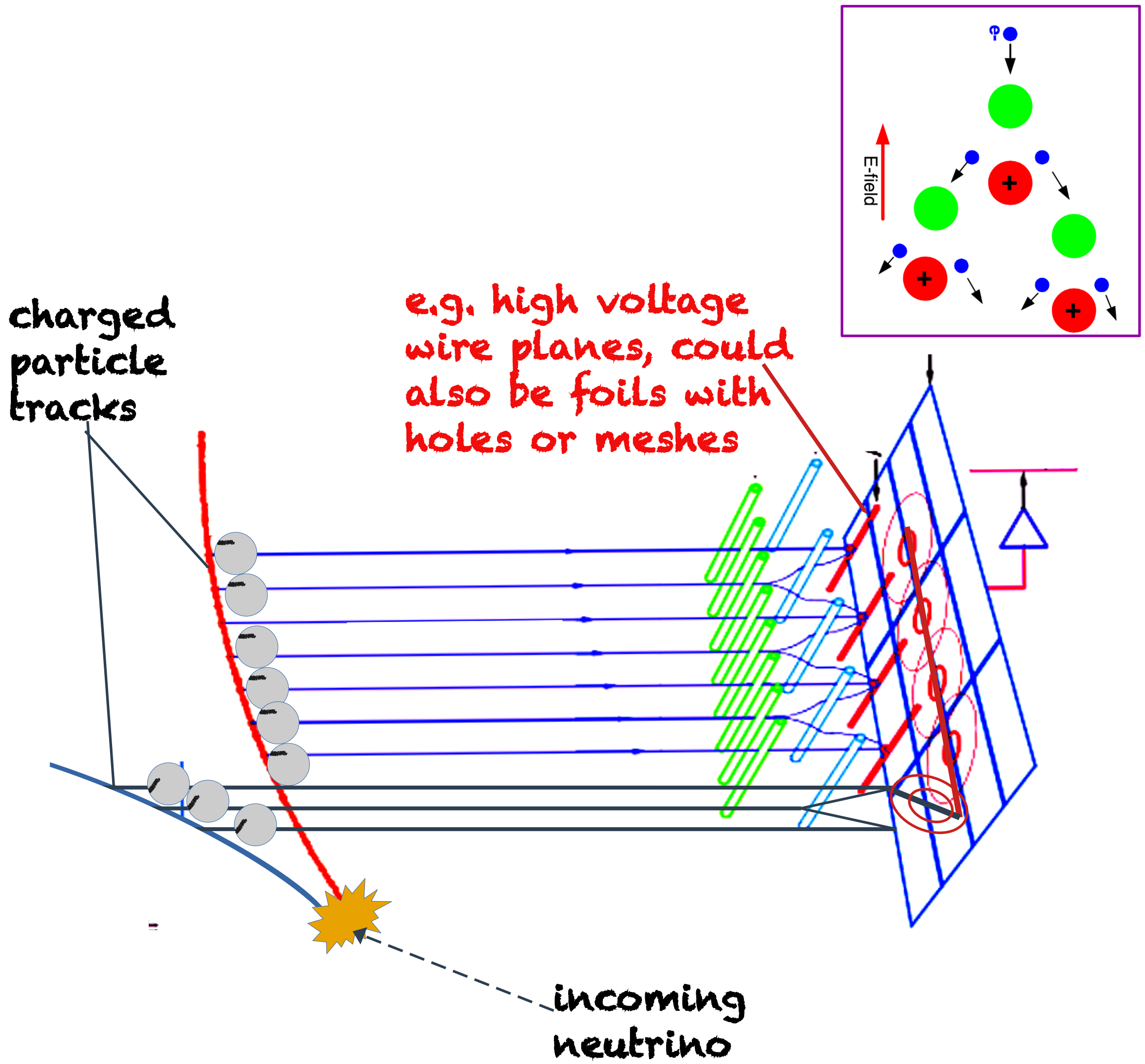
Gas Gain Stability

- Crucial to demonstrate that the gain is stable:
  - Gain variations are mainly due to temperature/pressure variations



Working Principles

- Readout system is designed such that supplied voltage can be tuned to multiply the original ionization electron by a certain factor – the larger the factor, called gas gain, the lower the detection threshold

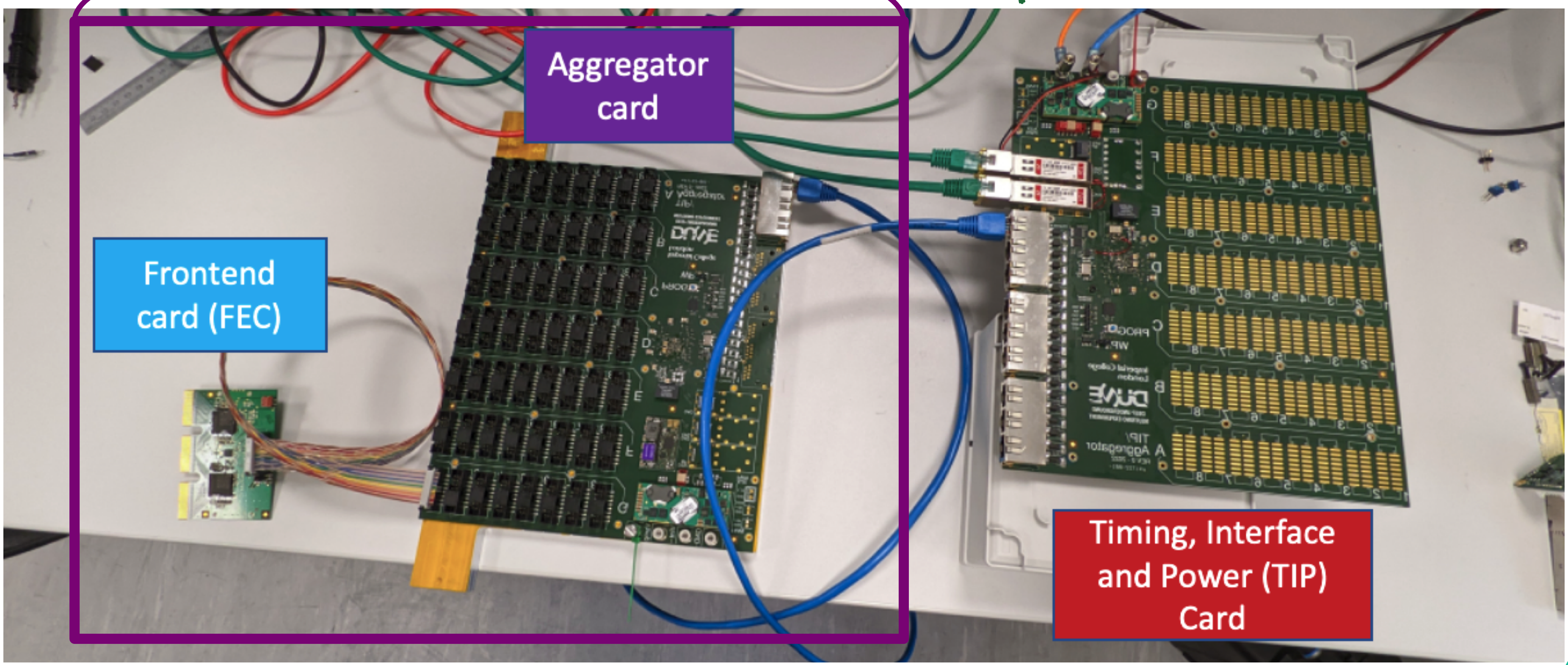


Electronics & DAQ for TOAD

- TOAD is also performing a full slice test of electronics and DAQ
  - ASIC-based **ALICE SAMPA cards** digitize the readout system (can be used for both ALICE MWPCs and GEMs)
  - An **FPGA-based aggregator** board is connected to cards, minimizing the number of feedthroughs
  - The **TIP cards** provide timing, control, and power

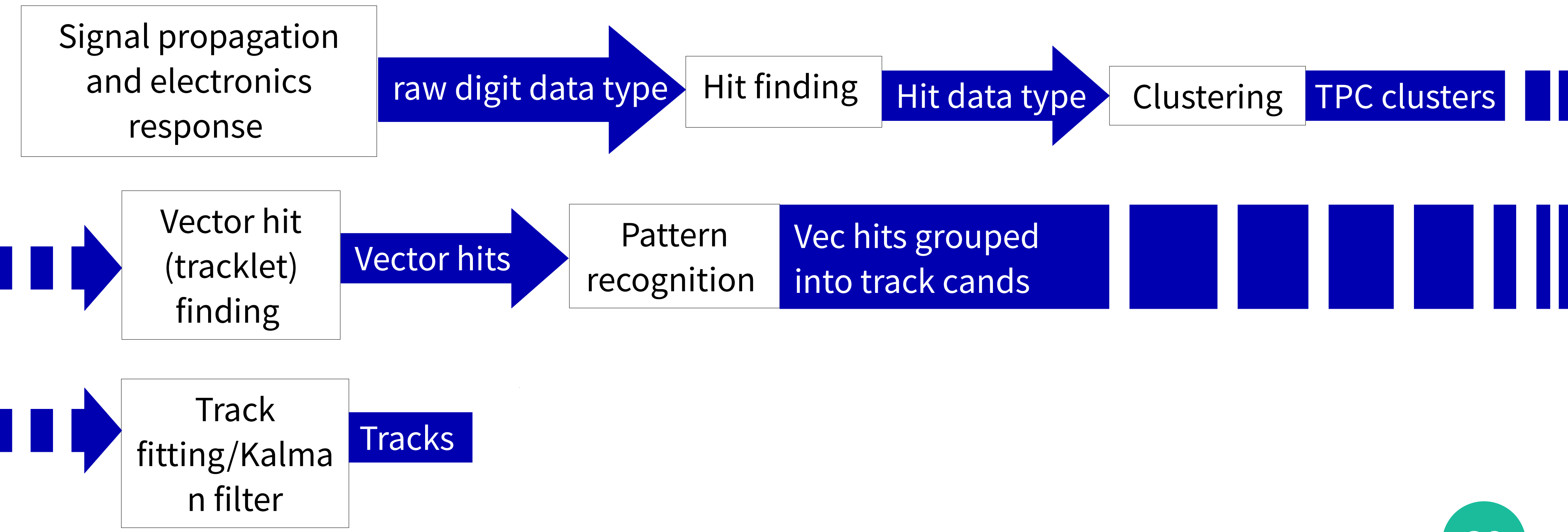
placed inside the pressure vessel

Imperial, Fermilab, Pittsburg



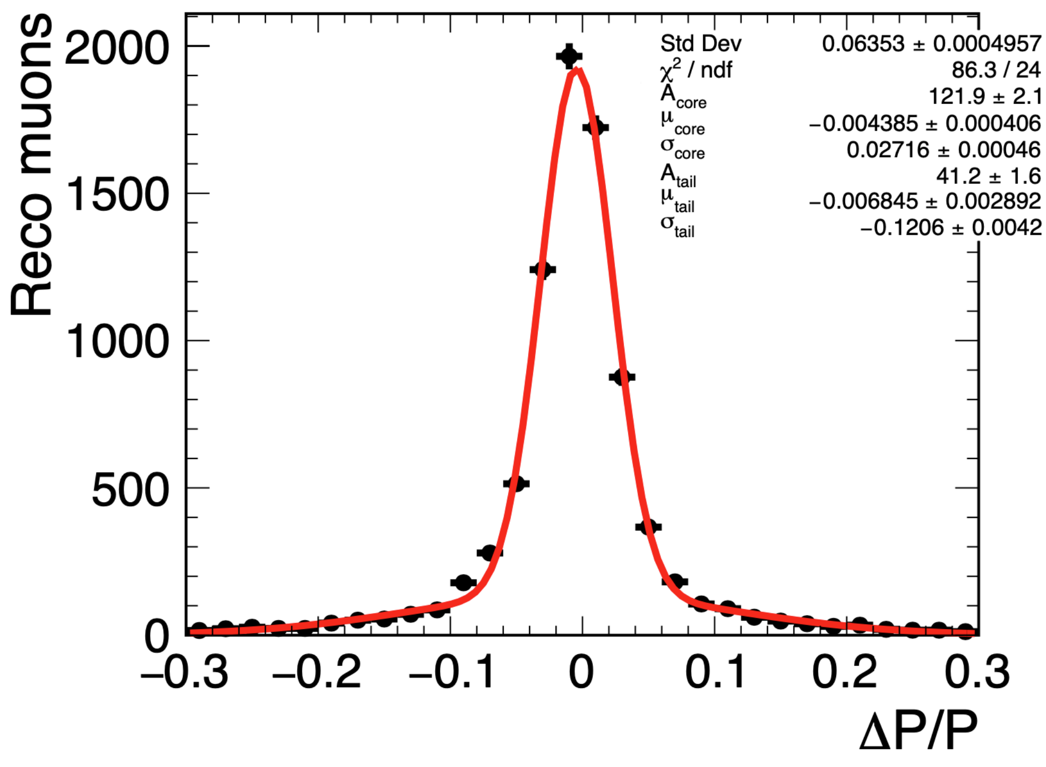
GArSoft, Full End-to-end Reco for ND-GAr

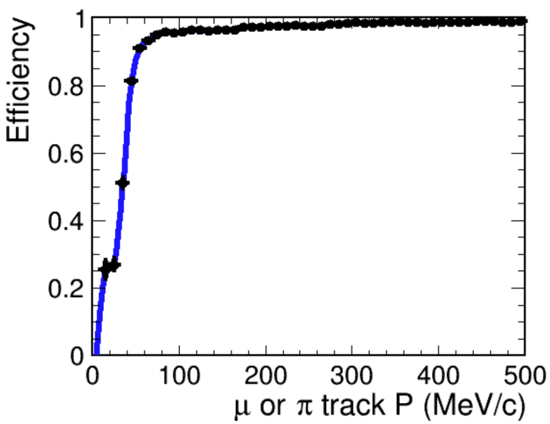
- Based on ART framework
  - Detailed detector modeling – drift, diffusion, field response, electronics response, digitization, clustering, pattern recognition and track fitting, with on-going optimizations
  - In addition to its own set of generators and G4 module, works with edepsim via the ConvertEdep2Art module
  - Outputs several intermediate data products as checkpoints (e.g. G4, DetSim, Reco), one final data product is an analysis tree, anatree, containing generator-, truth-, and reco-level info

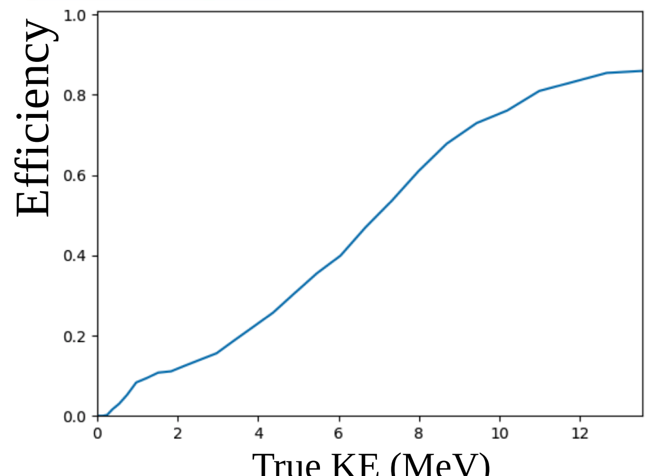


Projected Performance

- Momentum resolution and tracking efficiency from a sample of muon neutrino events: **2.7%** & **>90% for tracks with >40 MeV/c momenta**
  - Proton tracking efficiency from a sample of isotropic protons at the vertex: **>80% for proton tracks with >10 MeV energies**







DUNE Collaboration, A. Abed Abud et al. Instruments 5 no. 4, (2021) 31, arXiv:2103.13910 [physics.ins-det].