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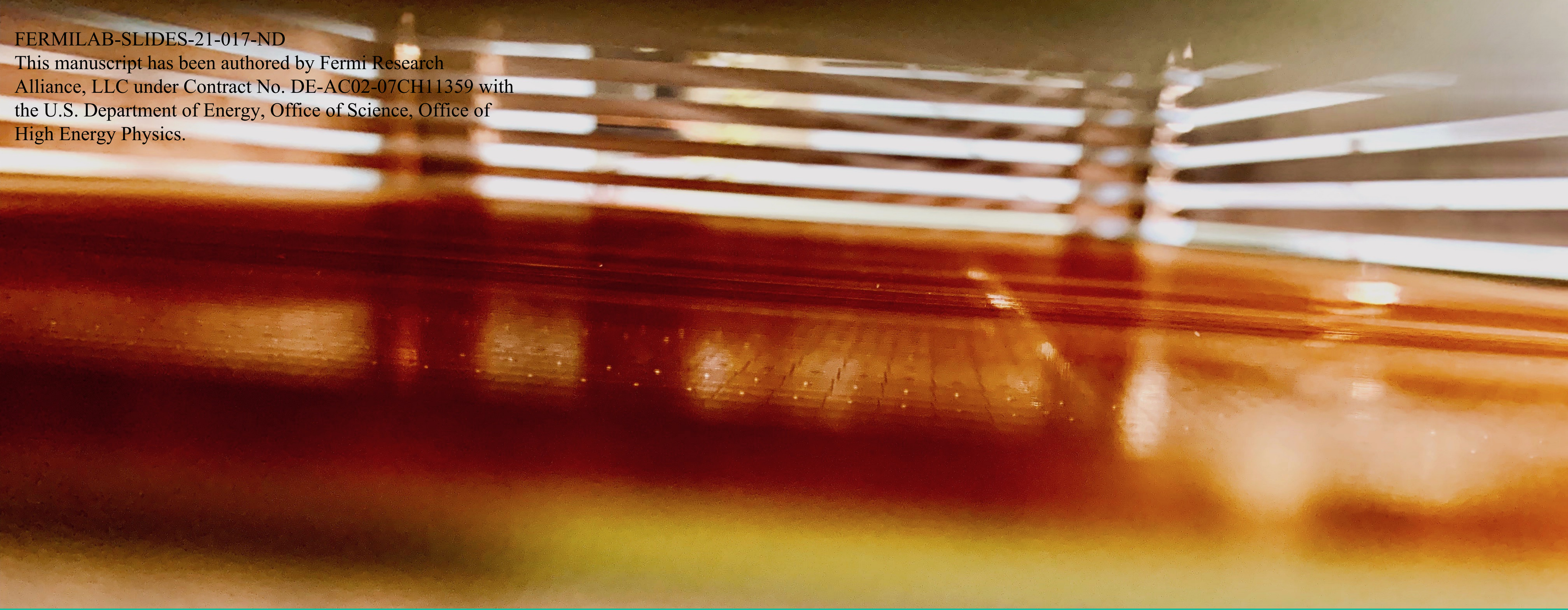

A High-Pressure Gaseous-Argon TPC (HPgTPC) as a Component of the DUNE Near Detector

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CPAD Instrumentation Frontier Workshop

March 19, 2021

DEEP UNDERGROUND NEUTRINO EXPERIMENT

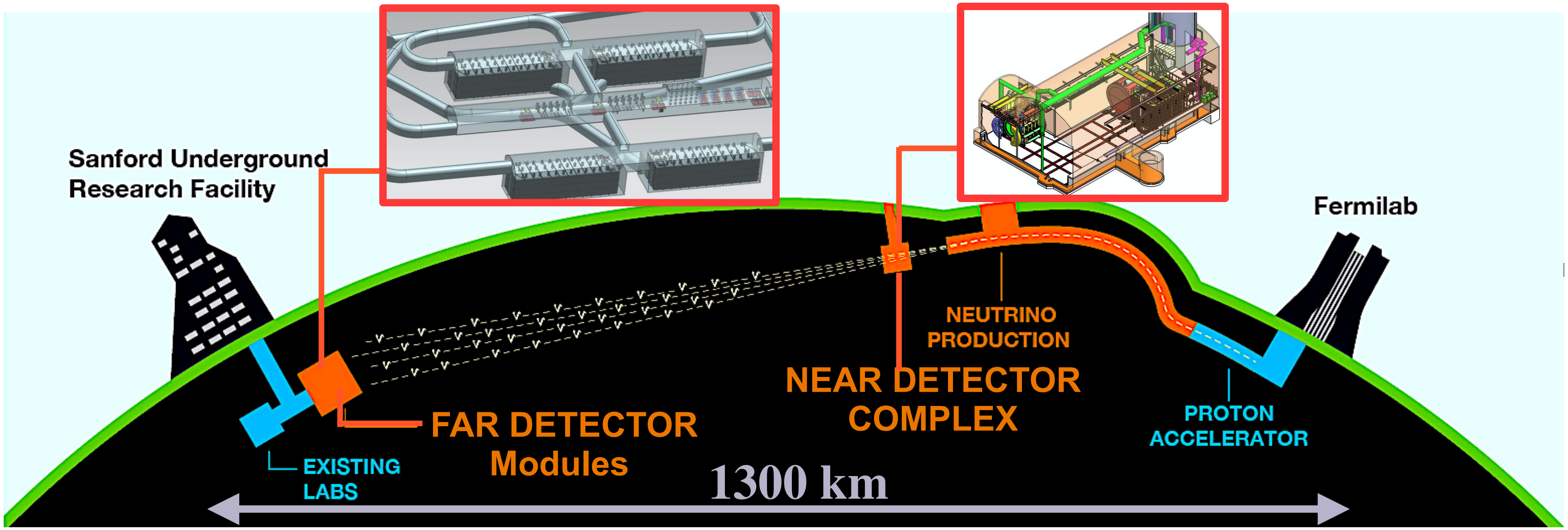
Fermilab

Outline

- DUNE
  - Primary Goal
  - Role of a High Pressure Gas-Ar TPC (HPgTPC)
- HPgTPC as a Component of a Near Detector:
  - Conceptual Design
  - Expected Performance
  - R&D Efforts
- Summary

Deep Underground Neutrino Experiment (DUNE)

Primary goal of DUNE is to **reduce the uncertainties in the oscillation measurements** to a few % level



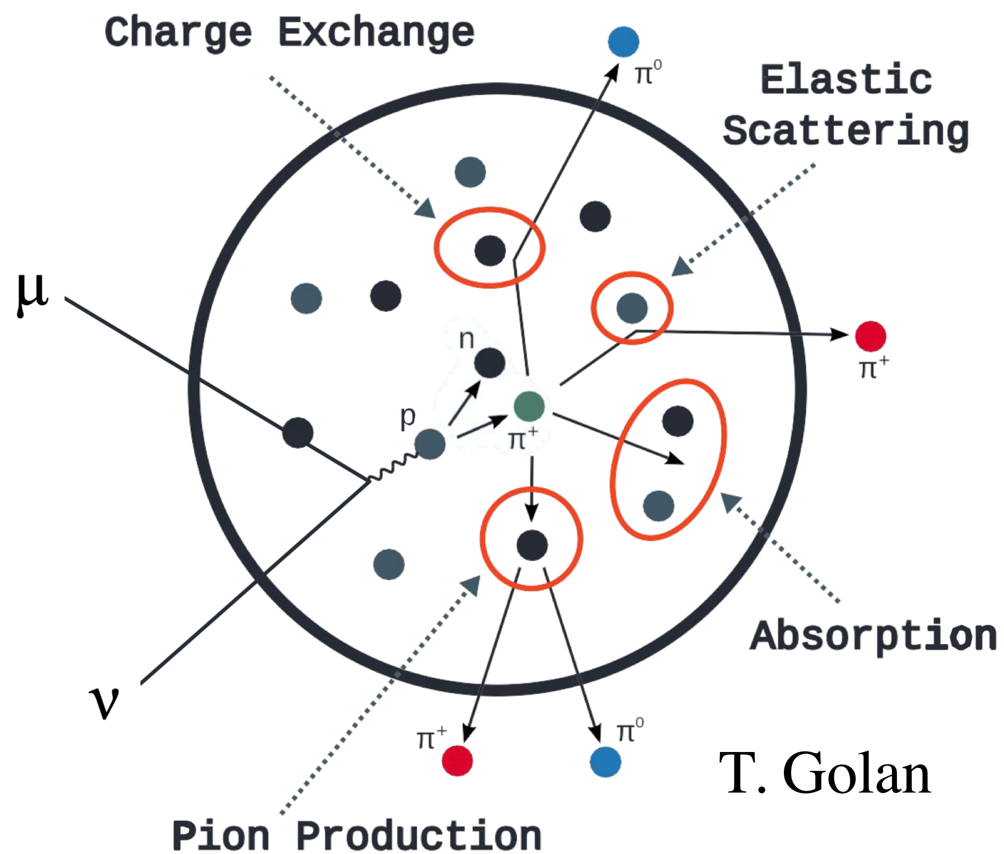
- The observable is the **ratio of appearance events** in the liquid Argon time projection chamber far detector (FD) modules to suite of near detectors (ND):

$$\frac{N^{FD}_{\nu_e}(E_{reco})}{N^{ND}_{\nu_\mu}(E_{reco})} = \frac{\int \overbrace{P_{\nu_\mu\to\nu_e}(E_\nu)}^{\text{oscillation probability}} \times \Phi_{\nu_e}(E_\nu) \times \sigma_{\nu_e}(E_\nu) \times \epsilon^{FD}_{\nu_e}(E_\nu) \times S^{FD}_{\nu_e}(E_\nu \to E_{reco})\, dE_\nu}{\int \Phi_{\nu_\mu}(E_\nu) \times \sigma_{\nu_\mu}(E_\nu) \times \epsilon^{ND}_{\nu_\mu}(E_\nu) \times S^{ND}_{\nu_\mu}(E_\nu \to E_{reco})\, dE_\nu}$$

- Near detector should constrain uncertainties in near to far extrapolation as well as the uncertainties in the **flux (Φ)**, **cross section (σ)** and **ν-energy (migration matrix S)** measurements and be a highly **efficient detector (ϵ)**

Dominant Sources of Uncertainty

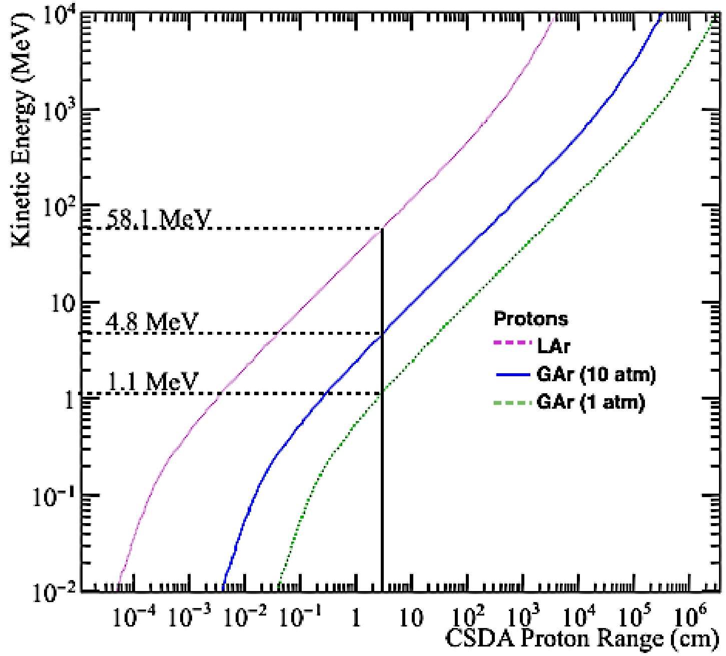
- Dominant sources of uncertainties are in cross sections/neutrino interaction models
- Nucleus is a complicated environment:
  - Initial state of nucleons, nuclear effects, and final state interactions not yet fully understood and modeled
  - Makes it difficult to infer the initial ν-interaction and ν-energy from final state topology, especially in heavier target nuclei

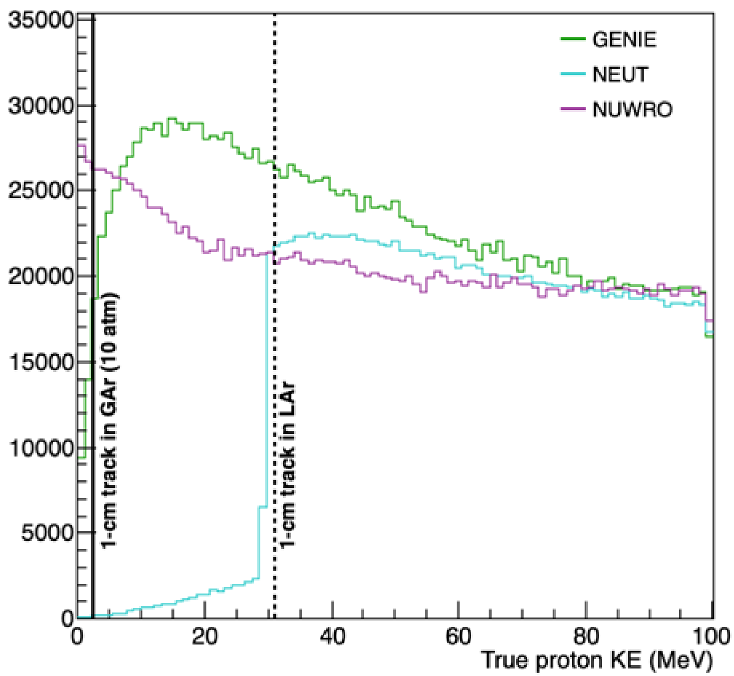


T. Golan

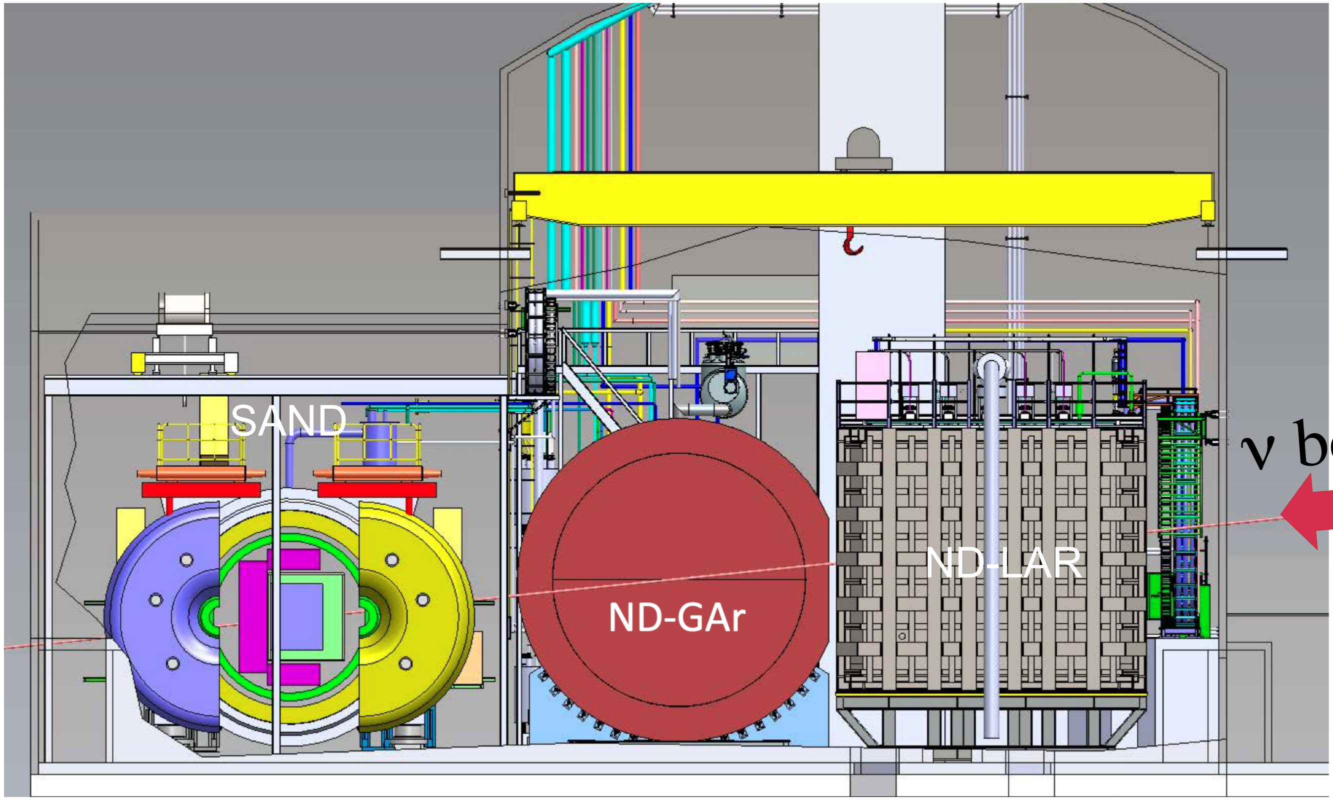
Role of a High Pressure Gas TPC

- HPgTPC can help constrain ν-interaction and cross section uncertainties:
  - Its lower density ($\rho_{LAr}/\rho_{GAr} \approx 85$ for 10 atm GAr) hence lower detection threshold makes it highly sensitive to lower energy charged particles that may not be seen in LAr
  - Reveal discrepancies between different neutrino event generators at lower energies & get closer at choosing a more accurate ν-interaction model as defined by our event generators GENIE, NEUT, & NUWRO





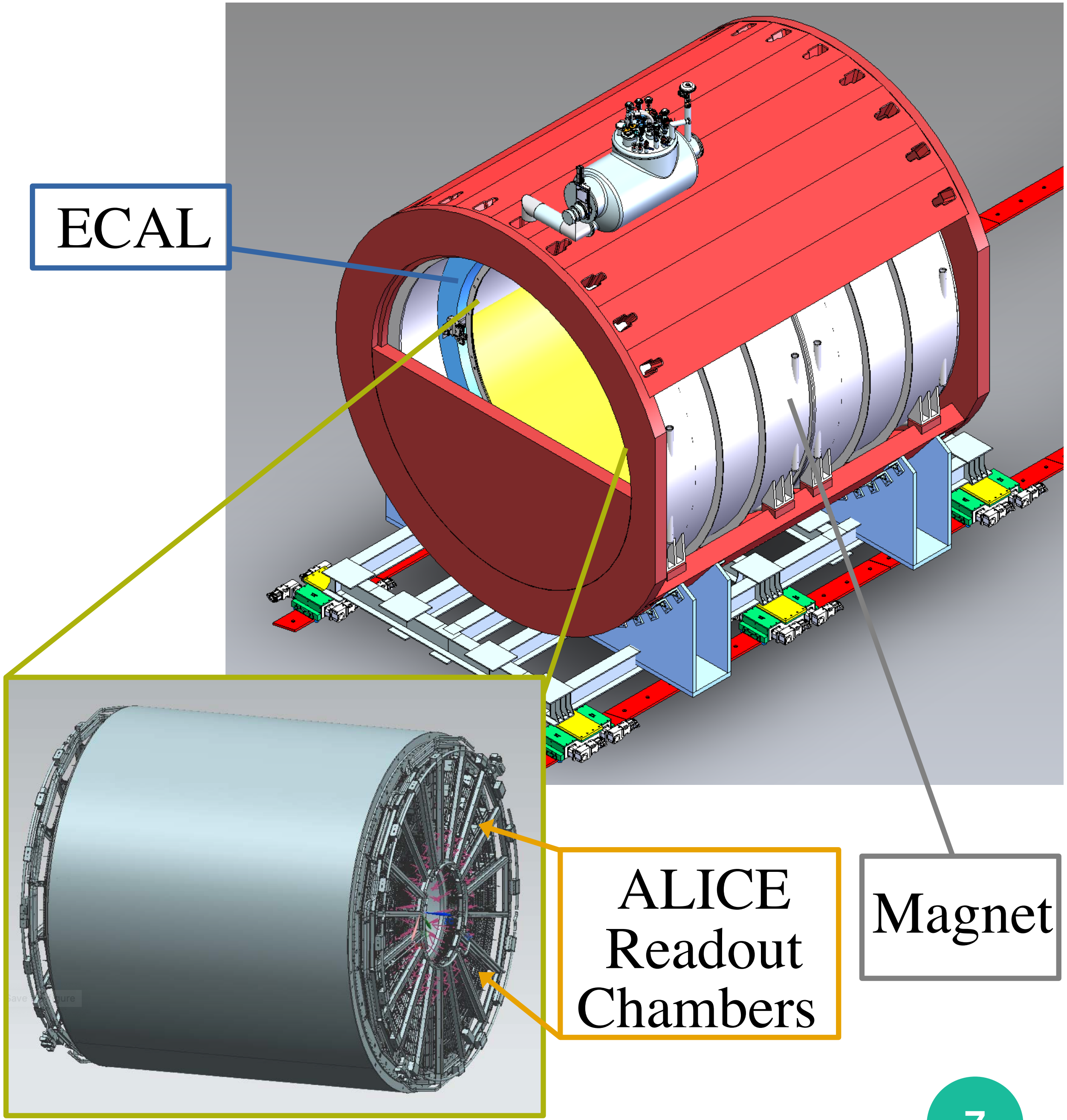
DUNE Near Detector Complex



- Near detector hall houses various near detector components:
  - ND-LAr, Liquid Argon time projection chamber
  - ND-GAr, magnetized **high pressure gaseous Argon time projection chamber (HPgTPC)** surrounded by ECAL calorimeter
  - SAND, system for on-axis neutrino detection (ND-LAr and ND-Gar move off-axis as part of the DUNE PRISM program)

ND-GAr Design

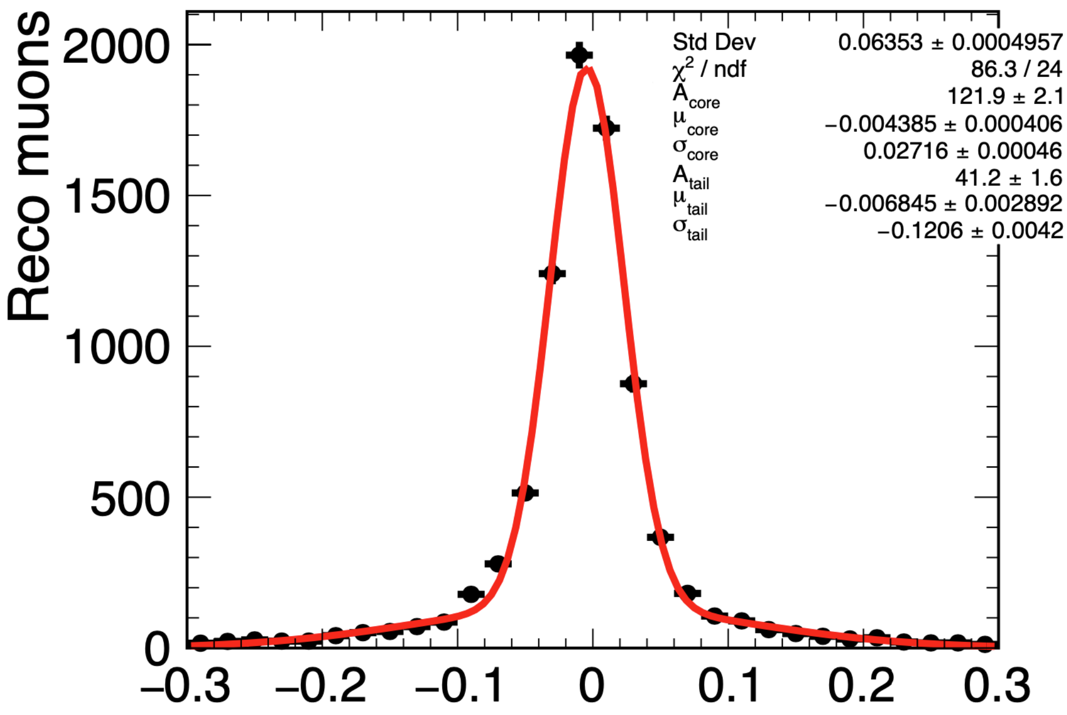
- ND-GAr design:
  - **High Pressure Gas Argon TPC (HPgTPC):**
    - Will re-use ALICE's readout chambers
    - Reference design Ar-CH_4 90-10 gas mixture (97% Ar interactions) at 10 atm
  - **HPgTPC** will be surrounded by **ECAL calorimeter** and **superconducting magnet**



HPgTPC Expected Performance

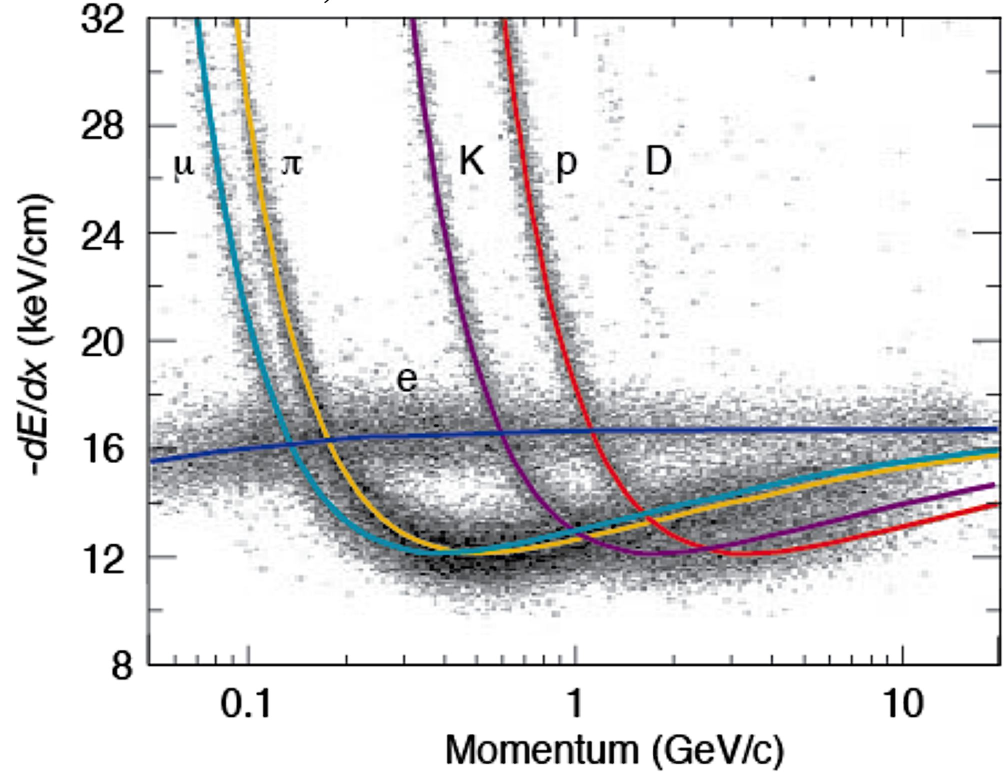
- TPC the size of **ALICE** when pressurized (pressure comparable to **PEP-4**) can collect 2M ν_μ CC events/ton of ^{40}Ar/year and reach the DUNE physics goals
- Performance comparable to **ALICE** and **PEP-4**:
  - Example: momentum resolution of 2.7% with latest HPgTPC reconstruction and excellent PID with dE/dx resolution comparable to PEP-4

DUNE Simulation

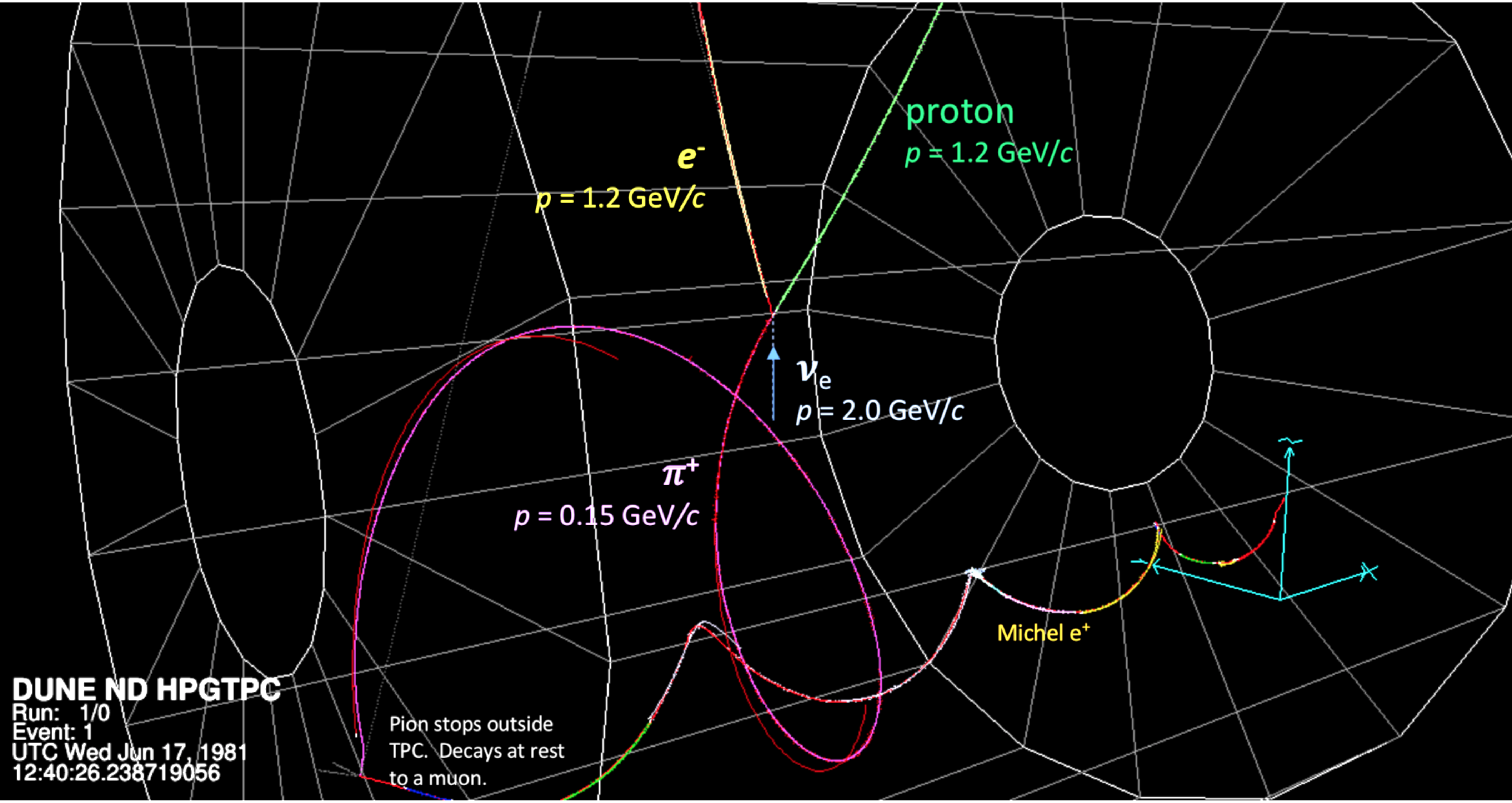


with full reco

PEP4, Ar–CH_4 = 80:20 @ 8.5 atm

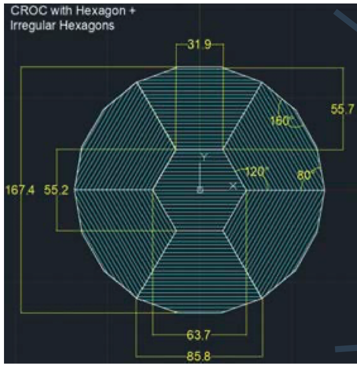


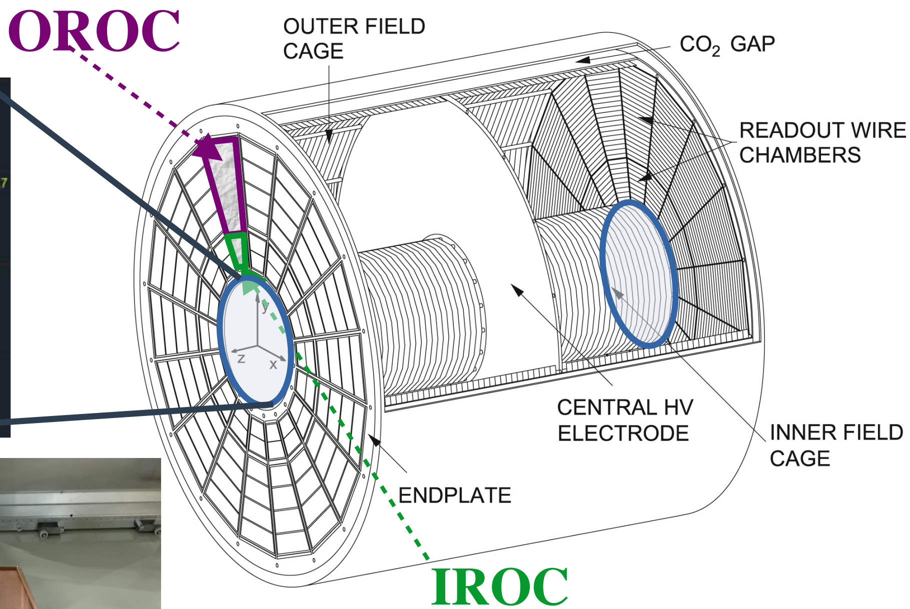
HPgTPC Expected Performance

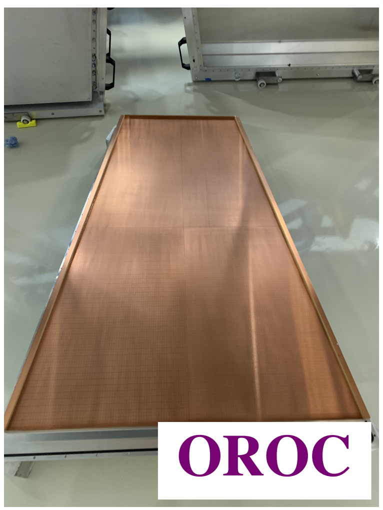


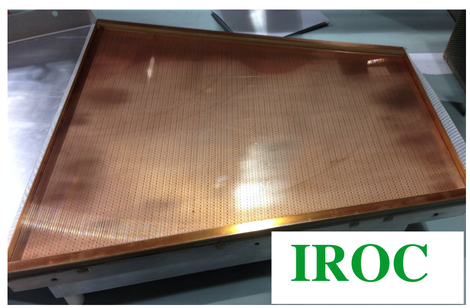
DUNE Simulation (with full reco)

R&D Efforts





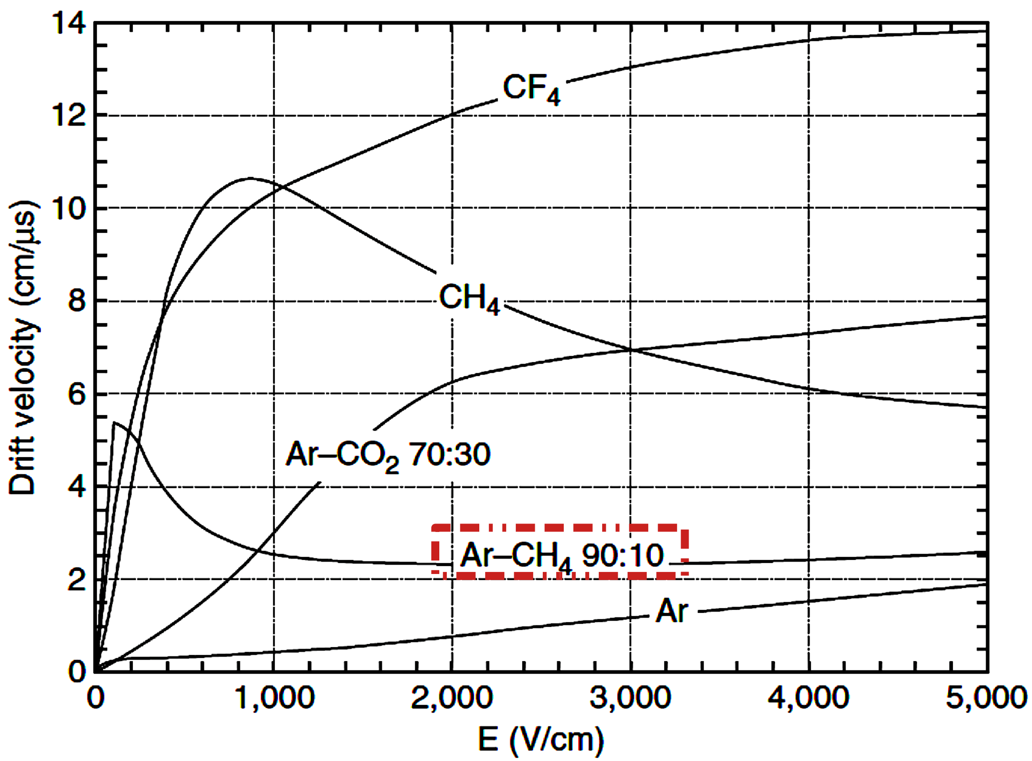


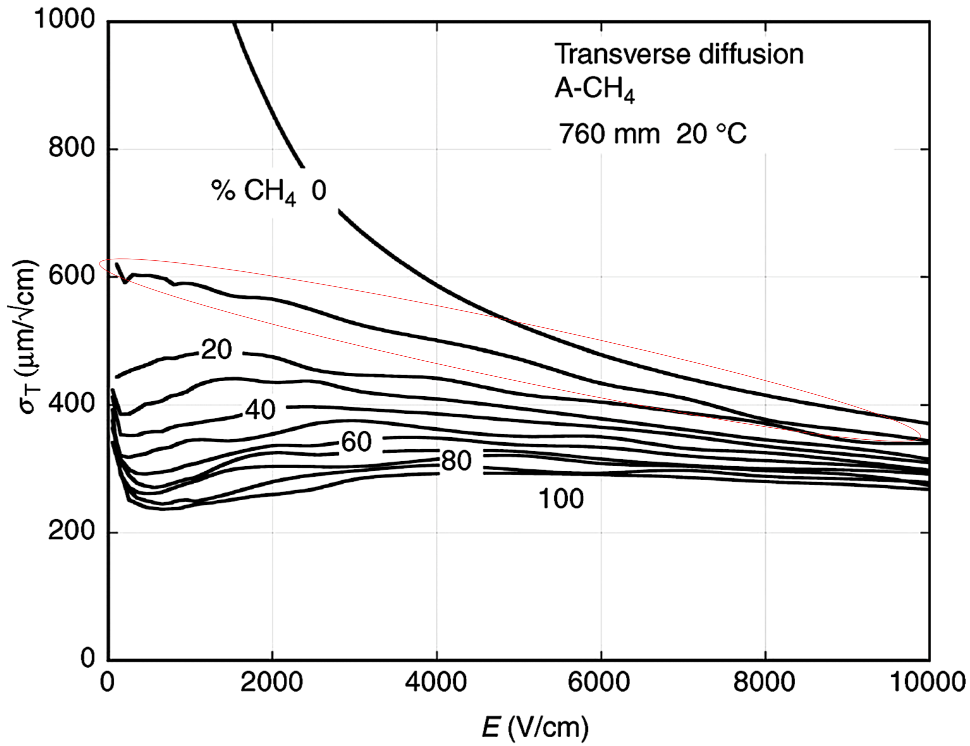


- Some of the required R&D on the acquired ALICE **inner** and **outer** readout chambers:
  - Test them @ various pressure points up to 10 atm – they operated at 1 atm in ALICE
  - Define a base gas mixture for them – Ar-CH_4 (97% of interactions on Ar), other gas mixtures also under investigation for their light properties and operational stability
- There is also R&D on building the **central readout chambers (CROCs)**

R&D Efforts

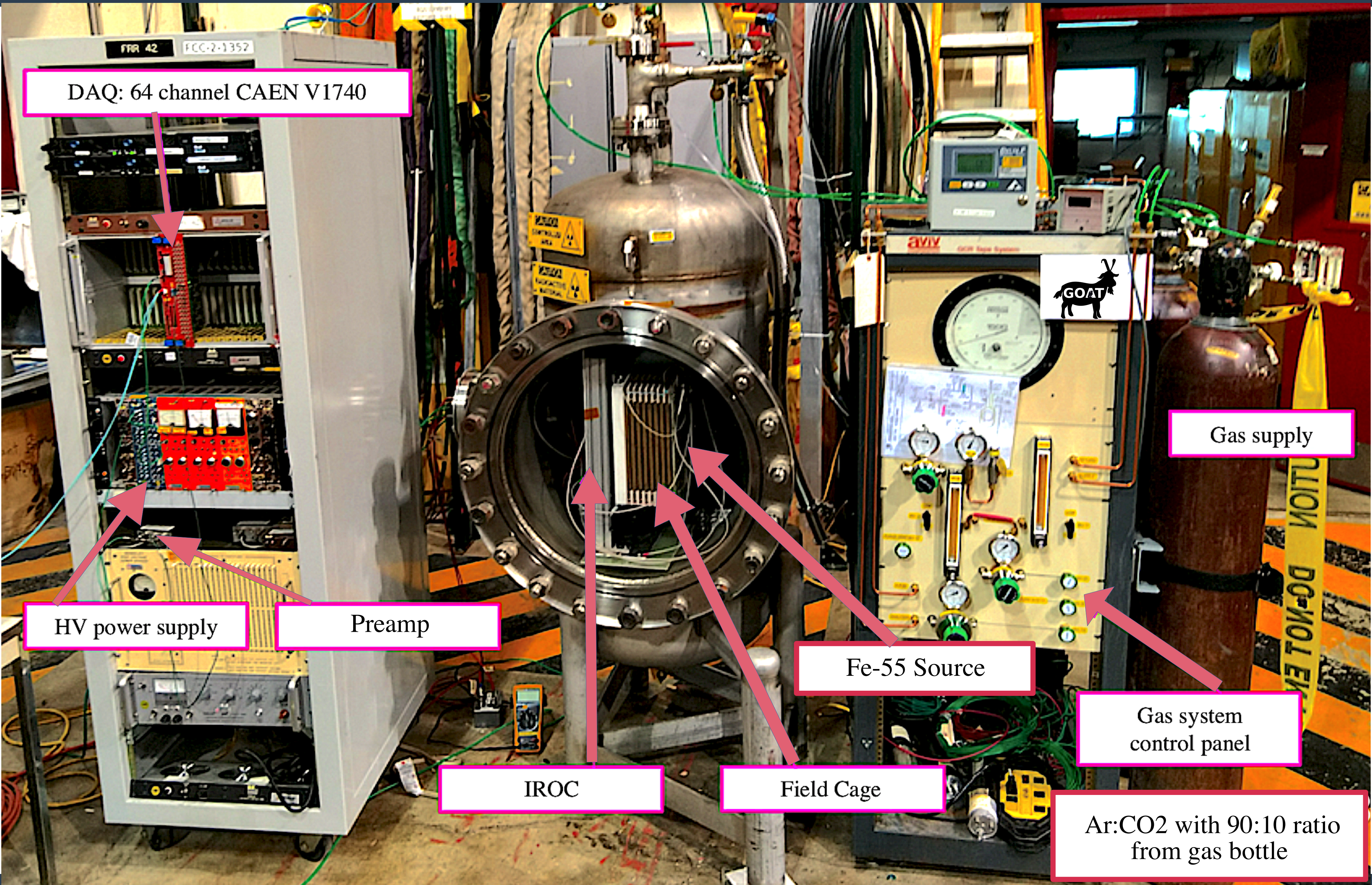
- Some of the criteria for choosing the right gas mixture and operating at high pressure:
  - ★ High drift velocity to control pile up
  - ★ Low diffusion for reasonable spatial resolution
  - ★ Strict purity requirements e.g. minimized O_2 and H_2O to prevent electron attachment
  - ★ High voltage supplied to amplification/anode wires to account for reduced gain at pressure > 1 atm (can also optimize the gas mixture)





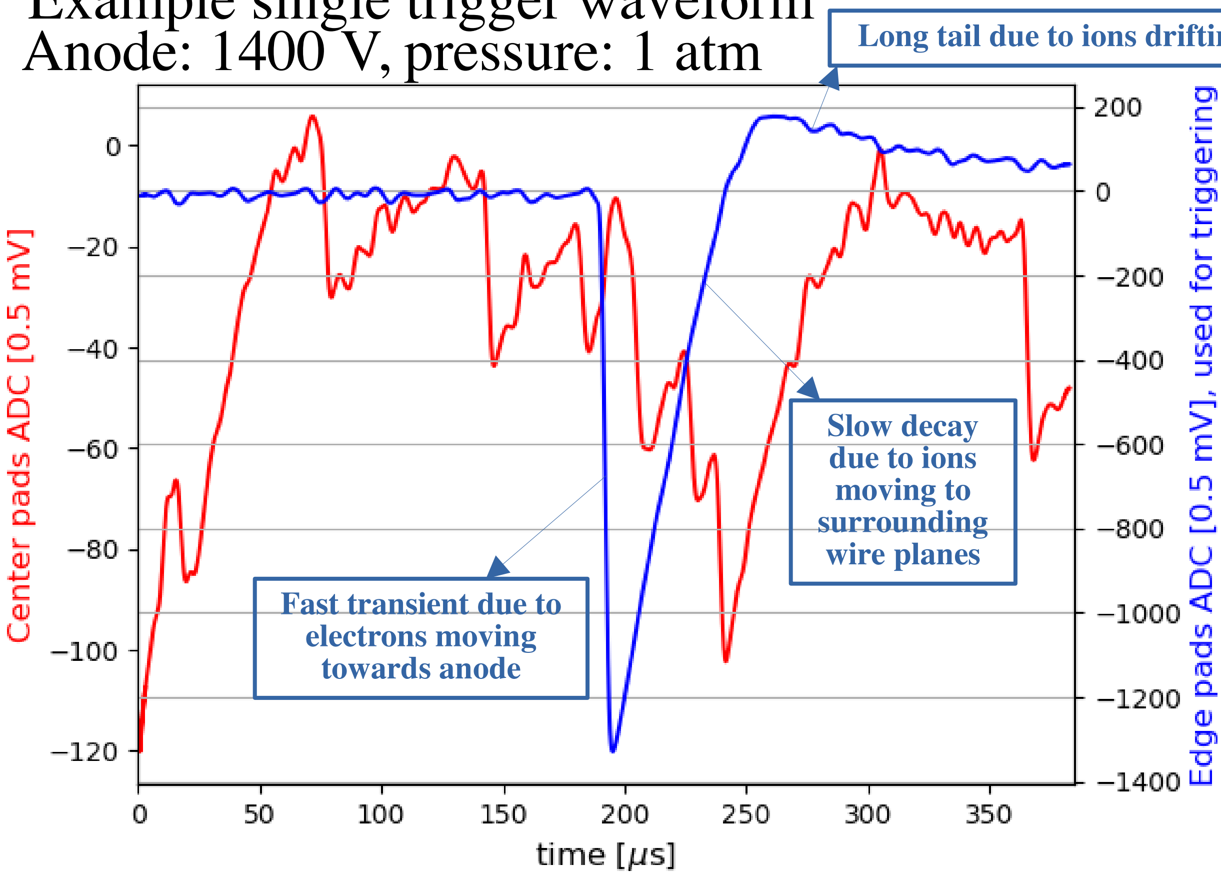
Sauli, F. "Gaseous Radiation Detectors: Fundamentals and Applications," Cambridge: Cambridge University Press. doi:10.1017/CBO9781107337701.006

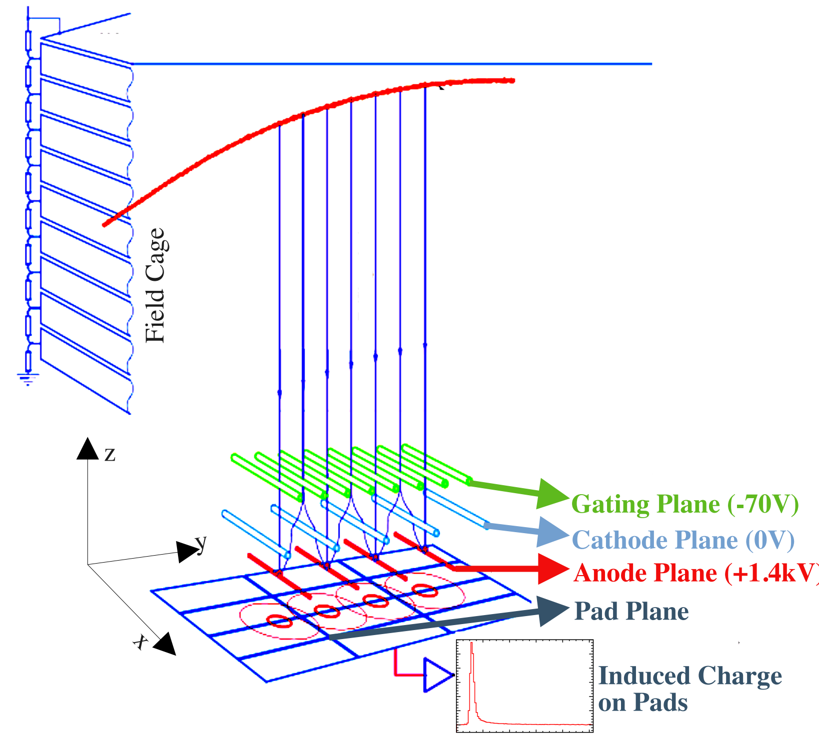
IROC Test Stand (GOAT) @ Fermilab



The Signal

Example single trigger waveform
Anode: 1400 V, pressure: 1 atm

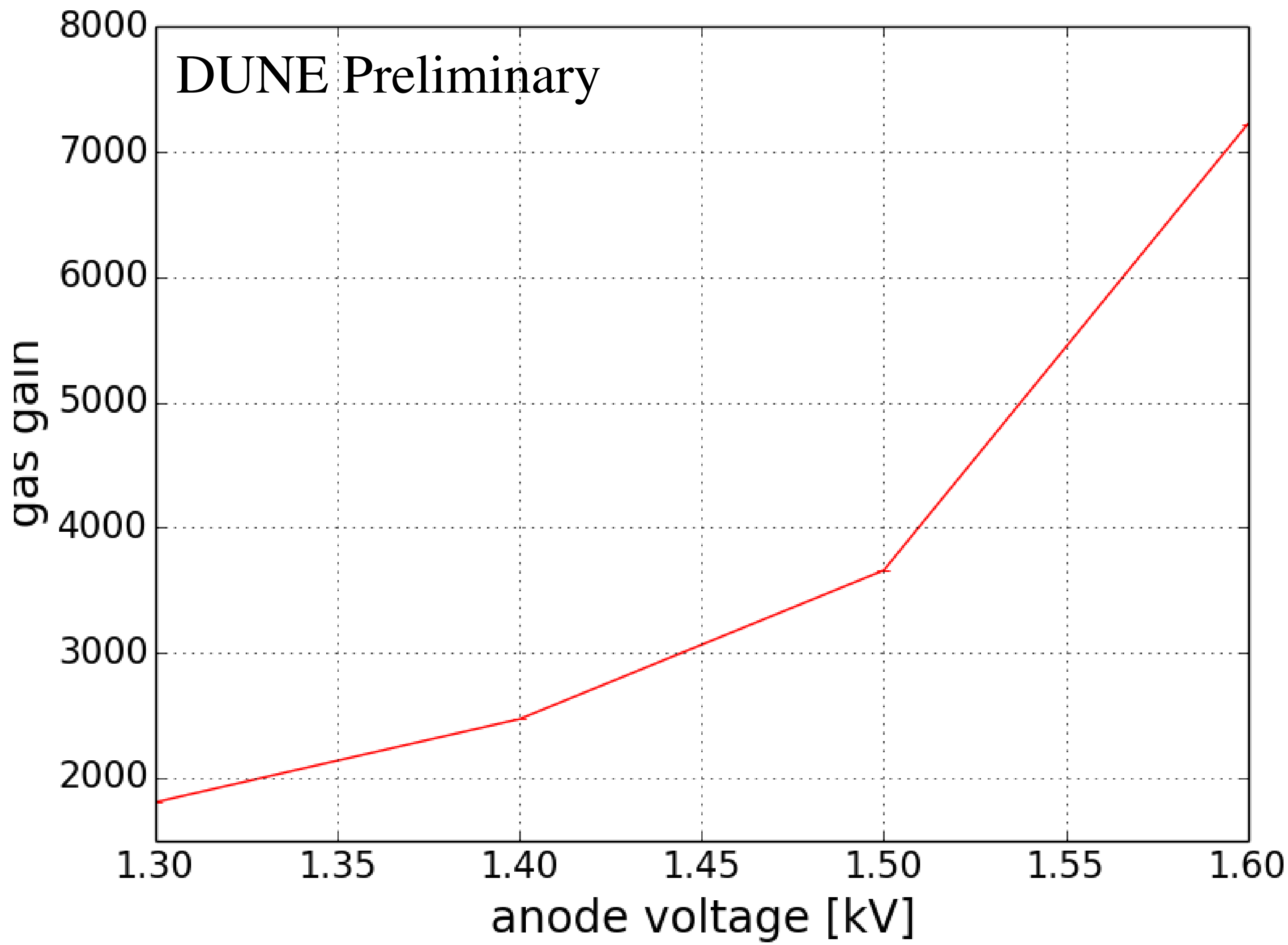




**note: charge sensitive inverting preamps used – signal shape slightly affected

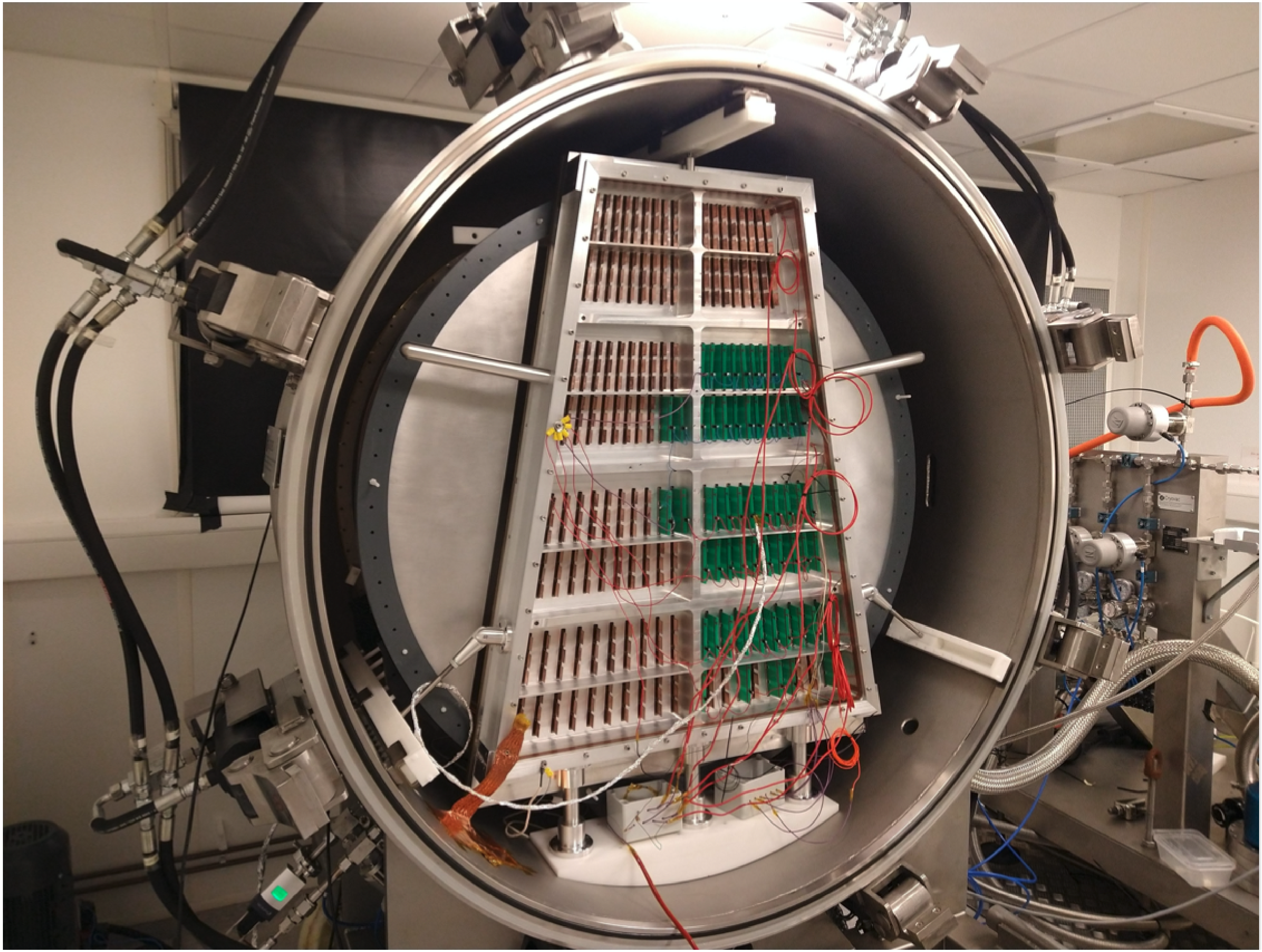
- “Edge pads” (blue) only readout cosmics (solid angle of the source only limited to “center pads”) – used for rejecting cosmic backgrounds
- Each peak in “center pad” waveform in red (with amplitude > peak-to-peak noise level) is an Fe-55 x-ray conversion

Gain at 1 atm Ar-CO_2 90:10

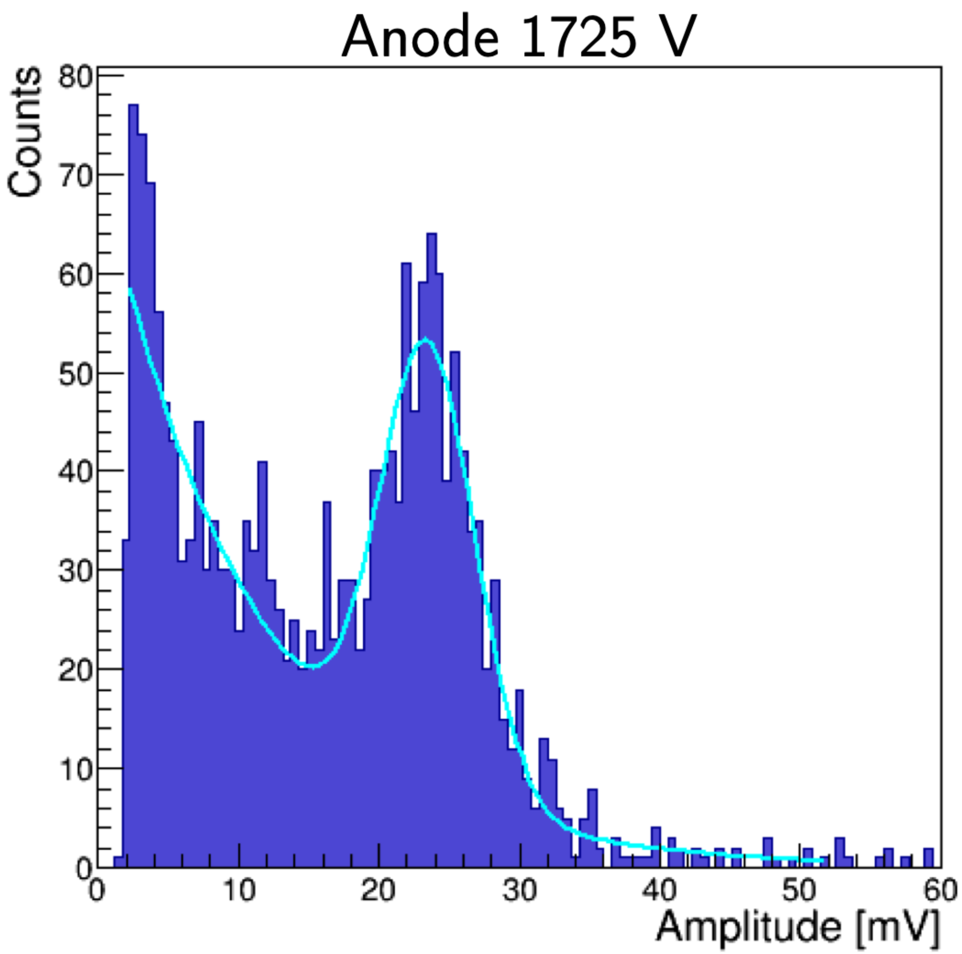


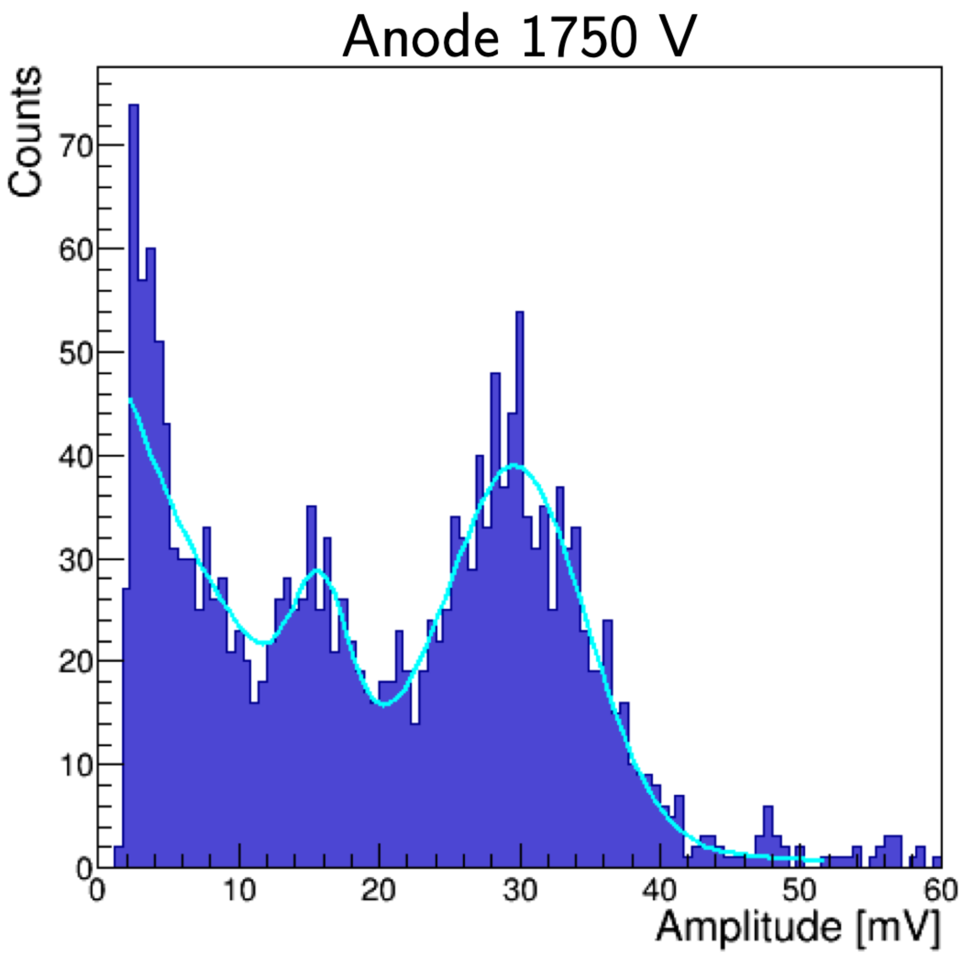
- The expected trend is present: for fixed pressure, a higher anode voltage results in higher gain

OROC Test Stand @ Royal Holloway University of London



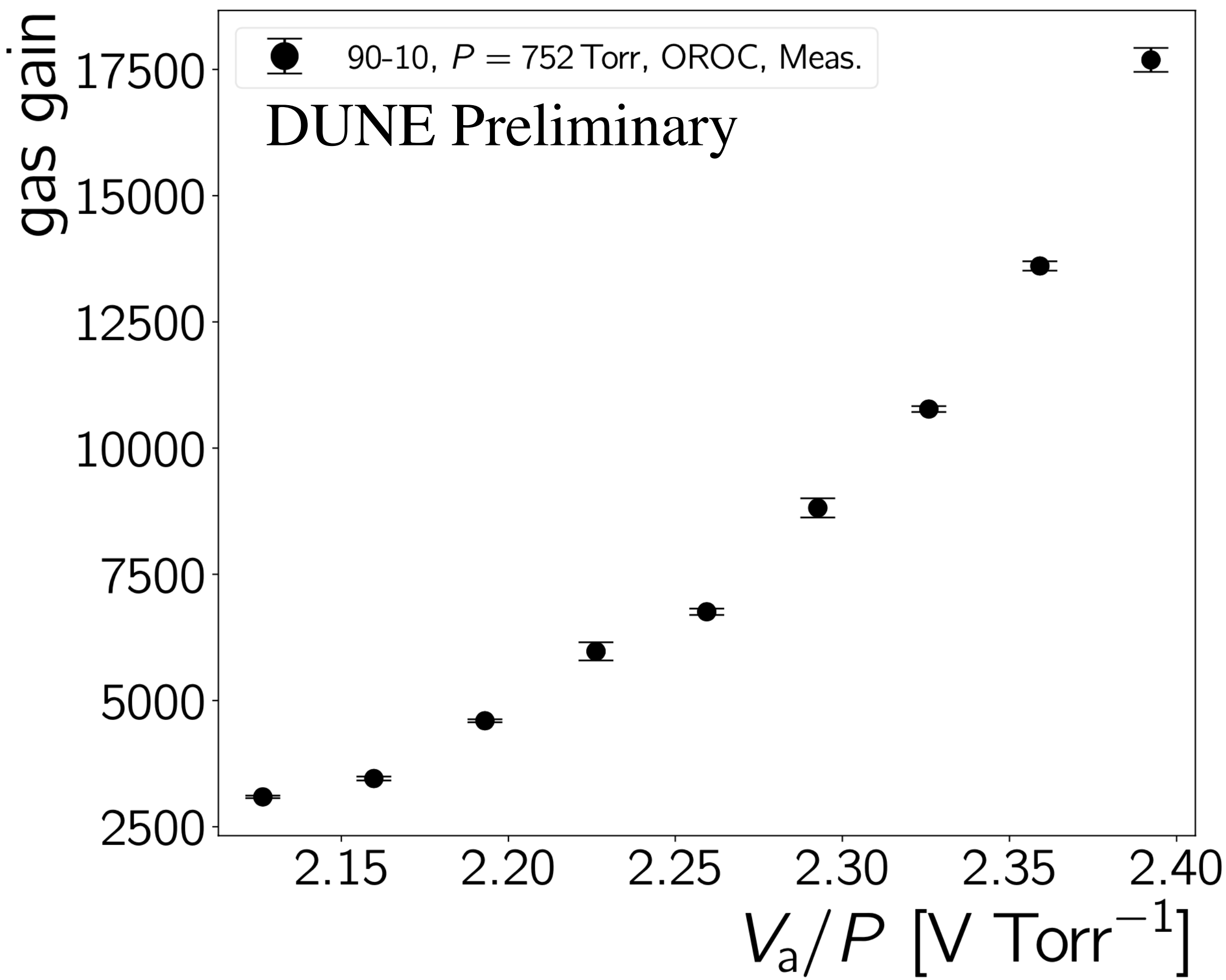
The Signal





- Typical amplitude spectrum of Fe-55 is observed
- As expected, at fixed pressure, when anode voltage is higher, the peak positions shift to higher amplitudes

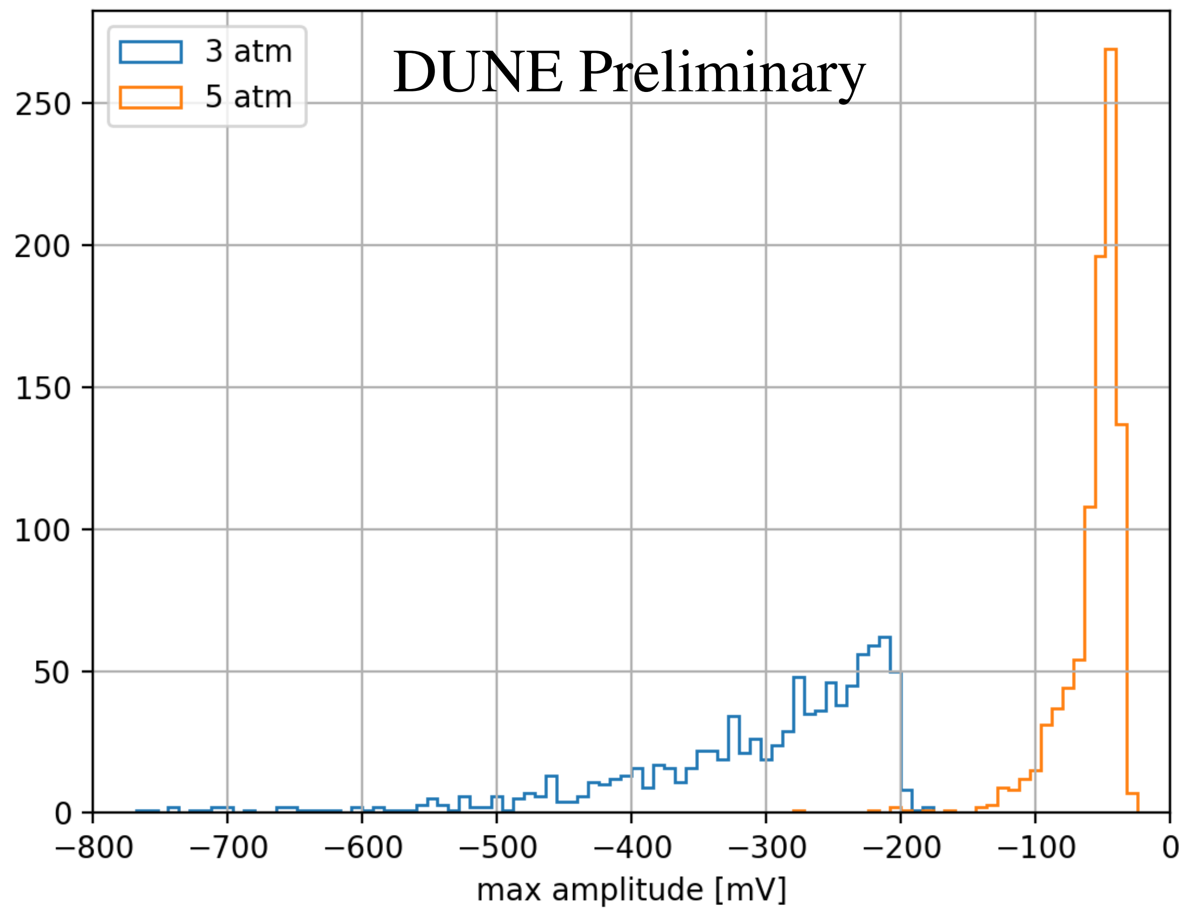
Gain at 1 atm Ar-CO_2 90:10



- The expected trend is present: for fixed pressure, a higher anode voltage results in higher gain

Higher Pressure Operation

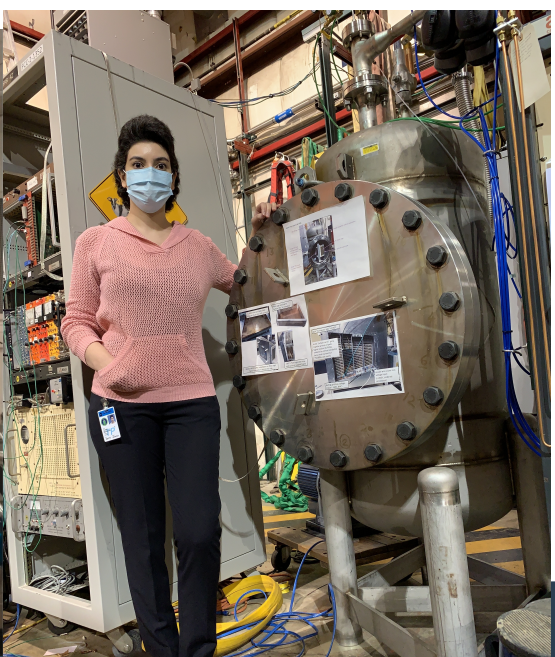
Peak Amplitude Per Trigger for a Fixed Anode Voltage



- @ fixed 1.9kV anode voltage, as pressure ↑, the peak amplitude (as expected) goes down
- Stay tuned for gain at > 1 atm!

Summary

- The HPgTPC is a crucial component of the near detector suite:
  - ★ Extends neutrino cross section measurements to lower energies in region where data are sparse and neutrino interaction models disagree
- We have test stands that primarily test the ALICE's inner and outer readout chambers as part of the on-going R&D efforts towards building a HPgTPC:
  - ★ In both test stands, we have calibrated the gain at 1 atm and we observe the expected trend
  - ★ We are also operating these readout chambers at high pressures; stay tuned for gain calibration at > 1 atm



Thank you!
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