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

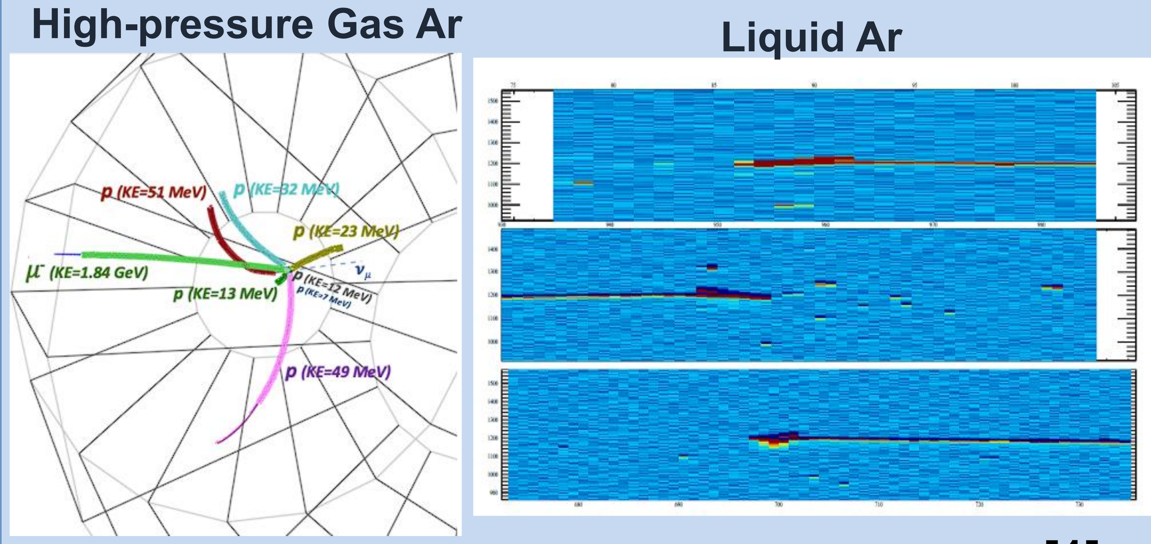
Achieving MeV-scale hadron tracking for DUNE Phase II

Brenna McConnell for the DUNE Collaboration
Indiana University

INDIANA UNIVERSITY

1. Physics Case: Seeing the Hadrons

- **Hadronic reconstruction is a systematic limitation in precision oscillation measurements.**
- Dense media stop low-energy protons in mm-cm blobs; in gas, low energy protons are reconstructable



[1]

Key observables to reconstruct: multiplicity, range, angle, and event topology

Design Principle

ND-GAr's low energy threshold can help constrain the nuclear model systematic that dominates oscillation measurement.

Why high pressure?

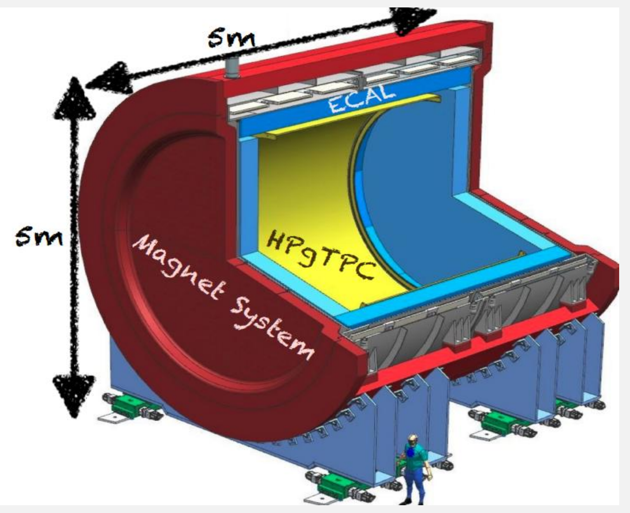
- 10 bar gas balances target mass and track length with realistic detector volume
  - *At 10 bar: ~1 ton gas TPC will record around one million events/year*
- Full angular acceptance gives access to hadron signatures that constrain FSI and nuclear effects

MPGDs at High Pressure

High pressure is essential, but **MPGD performance at high pressure is relatively unexplored,** motivating ongoing R&D efforts

References
[1] DUNE collaboration, DUNE Near Detector Conceptual Design Report, Instruments 5 (2021) 31
[2]N. Khan et al., *Readout electronics for low occupancy High-Pressure Gas TPCs*, arXiv:2507.17425 (2025).

2. Detector Concept and R&D Knobs

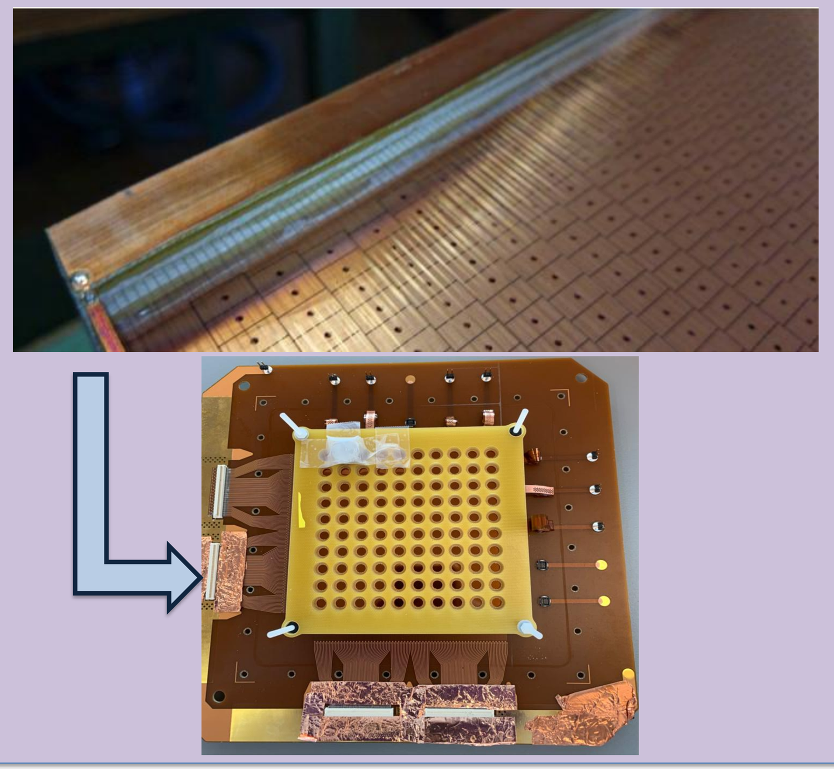


Phase II near detector concept: HPgTPC + ECAL + magnet/muon tagger [1]

R&D Map: Physics Needs → Detector Knobs

Physics Needs	Detector Knobs
Target Mass	Pressure
Diffusion Control + Scintillation	Gas Mixture
Charge Extraction	Field / Gaps
Gain + Stability	Charge Amplification
Noise + Dynamic Range	Readout Electronics

MWPCs from ALICE tested up to 10 bar, now transitioning to GEM-based readout (GORG + AGUILA)

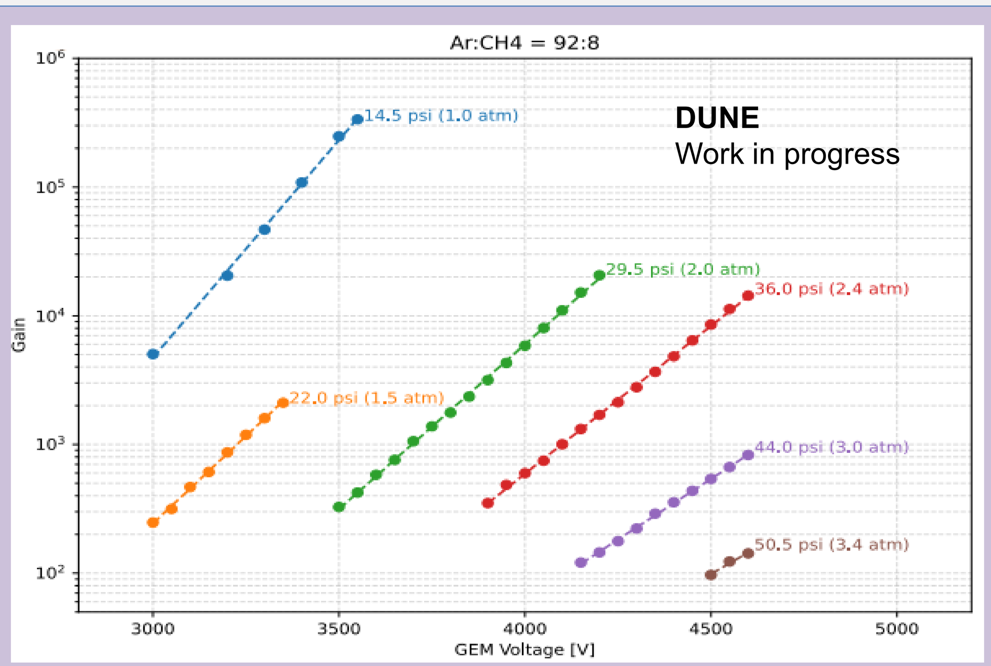


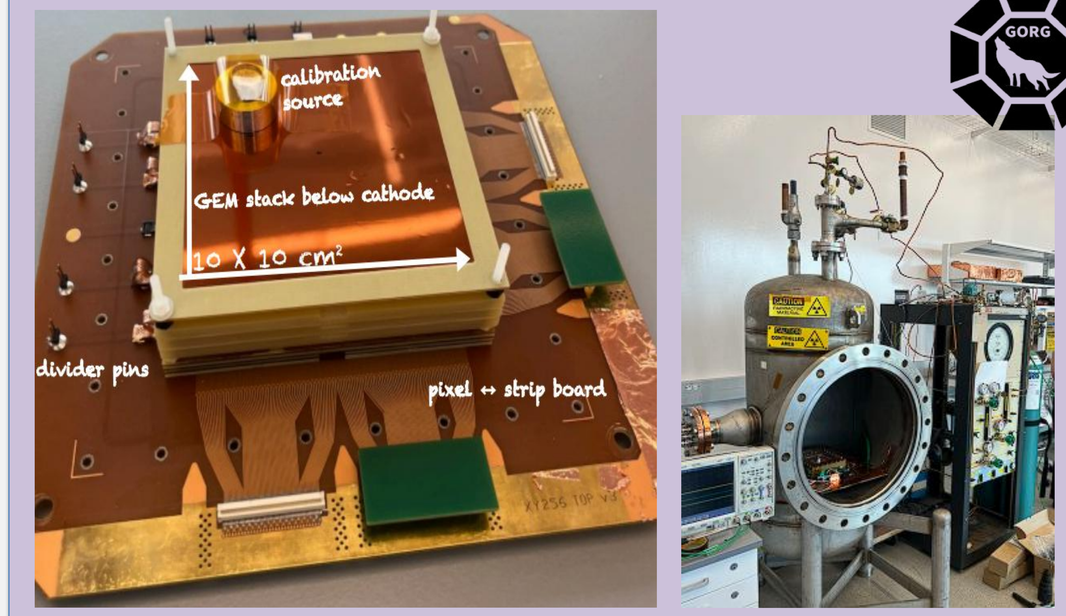
Near-term integrated test

Combine GEM gain, SAMPA electronics, pressure vessel operation, P-V-T monitoring, and gas-quality control in one realistic system.

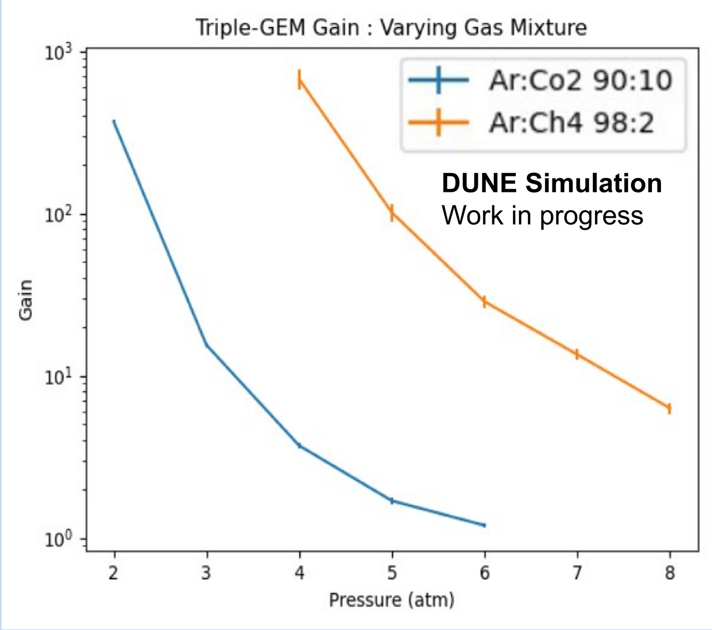
3. Charge Amplification at Pressure

Transition to modern MPGD readout focuses on GEMs, which offer finer granularity, tunable gain staging, and scalable geometry.





High pressure vessel tests with GORG at Fermilab– supported by Fermilab New Initiatives



Garfield++ studies: choice of gas mixture determines gain envelope

What we are learning:

- *Gain:* charge multiplication factor of primary ionization
  - Higher pressure → shorter average particle track length → decreased gain
- Increasing GEM operating voltage → increase gain at high pressure
- Gas mixture tuning controls ionization, diffusion, and electron transport

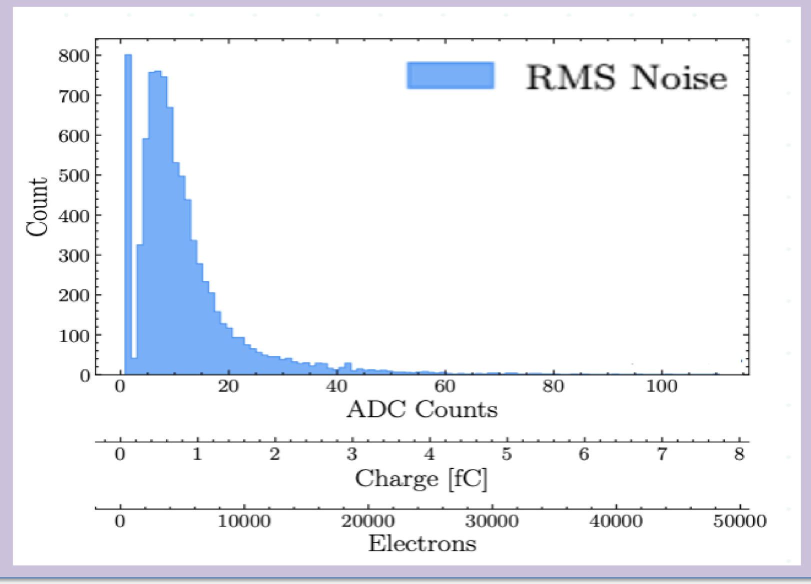
4. Electronics, noise, stability

Noise is a physics issue

Electronics noise sets whether gain at pressure becomes usable information. The R&D target is signal-to-noise margin under realistic pressure, temperature, and gas-purity conditions.

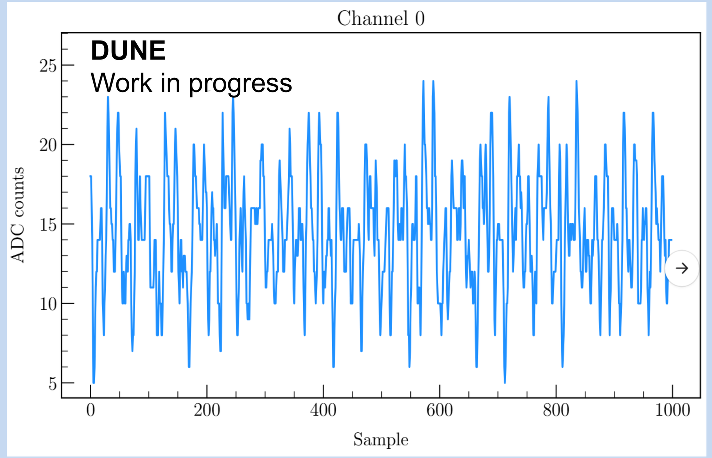
- **SAMPA readout operated in pressurized gas, defining scalable electronics path**

- **High pressure lowers avalanche gain and raises capacitance, making noise characterization a key detector performance metric**



[2]

- **AGUILA at IU is working toward integrating SAMPA electronics with a triple-GEM detector.**



First pedestal tests with SAMPA FECs complete

Takeaways

Gain at pressure
Map stable high-gain operation for GEMs and alternative MPGDs

Charge transport
Optimize gas mixtures + fields/gaps for diffusion, extraction, and stability

Integrated readout
Operate gain + SAMPA electronics + monitoring in one pressure vessel system

Physics reach
Deliver low-energy hadron acceptance that directly tests interaction models

DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT

This document was prepared by the DUNE Collaboration using the resources of the Fermi National Accelerator Laboratory (Fermilab), a U.S. Department of Energy, Office of Science, Office of High Energy Physics HEP User Facility. Fermilab is managed by Fermi Forward Discovery Group, LLC, acting under Contract No. 89243024CSC000002.