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

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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
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):

\[
\frac{N_{\nu_e}^{FD}(E_{reco})}{N_{\nu_\mu}^{ND}(E_{reco})} = \frac{\int P_{\nu_\mu \to \nu_e}(E_\nu) \times \Phi_{\nu_e}(E_\nu) \times \sigma_{\nu_e}(E_\nu) \times \epsilon_{\nu_e}^{FD}(E_\nu) \times S_{\nu_e}^{FD}(E_\nu \to E_{reco}) \, dE_\nu}{\int \Phi_{\nu_\mu}(E_\nu) \times \sigma_{\nu_\mu}(E_\nu) \times \epsilon_{\nu_\mu}^{ND}(E_\nu) \times S_{\nu_\mu}^{ND}(E_\nu \to E_{reco}) \, dE_\nu}
\]

- Near detector should constrain uncertainties in near to far extrapolation as well as the uncertainties in the **flux** ($\Phi$), **cross section** ($\sigma$) and **$\nu$-energy** ($S$) measurements and be a highly **efficient detector** ($\epsilon$).
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 $\nu$-interaction and $\nu$-energy from final state topology, especially in heavier target nuclei.
Role of a High Pressure Gas TPC

- HPgTPC can help constrain $\nu$-interaction and cross section uncertainties:
  - Its lower density $(\rho_{\text{LAr}}/\rho_{\text{GAr}} \approx 85$ 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 $\nu$-interaction model as defined by our event generators GENIE, NEUT, & NUWRO.
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-CH₄ 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 $\nu_\mu$ 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**

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with full reco
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**PEP4, Ar–CH$_4$ = 80:20 @ 8.5 atm**
HPgTPC Expected Performance

DUNE Simulation (with full reco)
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**

IROC  
OROC  
CROC  
ALICE TPC
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 $\text{O}_2$ and $\text{H}_2\text{O}$ 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)

IROC Test Stand (GOAT) @ Fermilab

- DAQ: 64 channel CAEN V1740
- HV power supply
- Preamp
- IROC
- Fe-55 Source
- Field Cage
- Gas supply
- Gas system control panel
- Ar:CO2 with 90:10 ratio from gas bottle
The Signal

Example single trigger waveform

Anode: 1400 V, pressure: 1 atm

- Fast transient due to electrons moving towards anode
- Slow decay due to ions moving to surrounding wire planes
- Long tail due to ions drifting back into the field cage volume

**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
The expected trend is present: for fixed pressure, a higher anode voltage results in higher gain.
OROC Test Stand @ Royal Holloway University of London
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.
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!
Questions are welcome, here or via email: mtanaz@fnal.gov
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