High-Pressure Gaseous Argon TPC for the DUNE Near Detector

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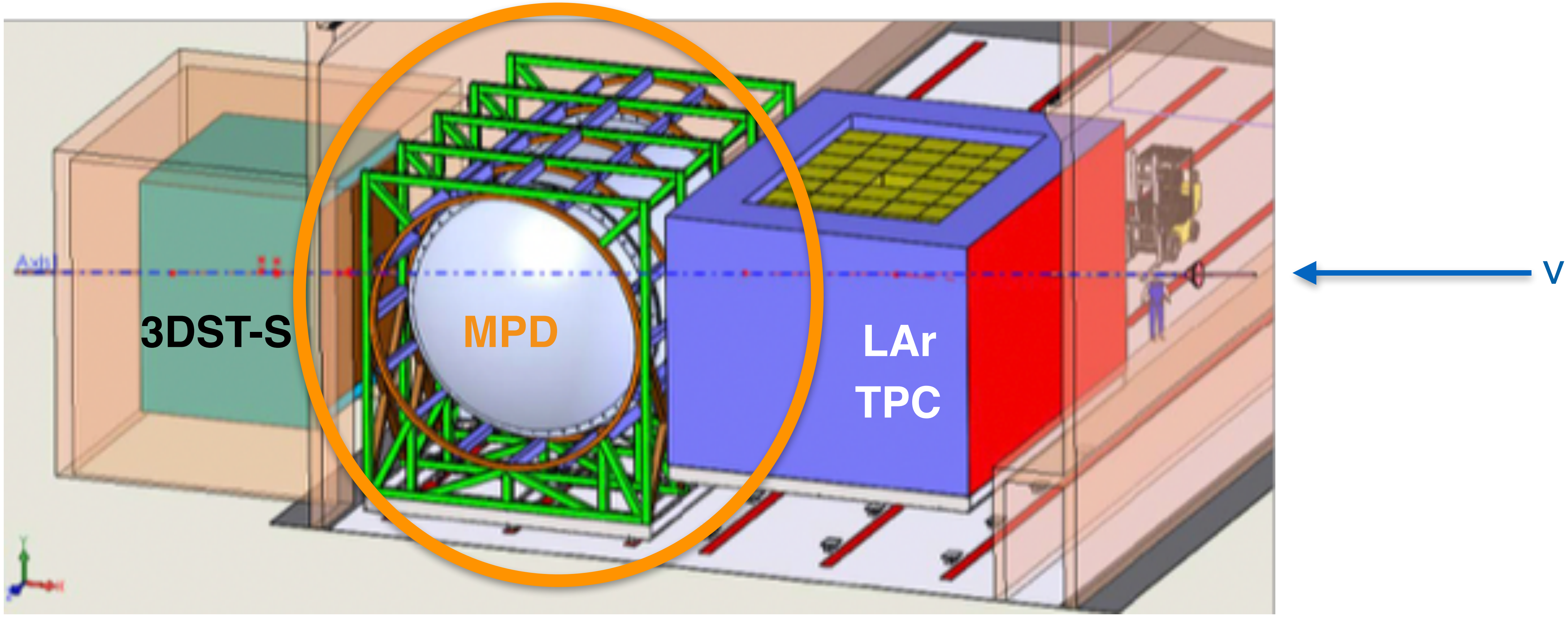
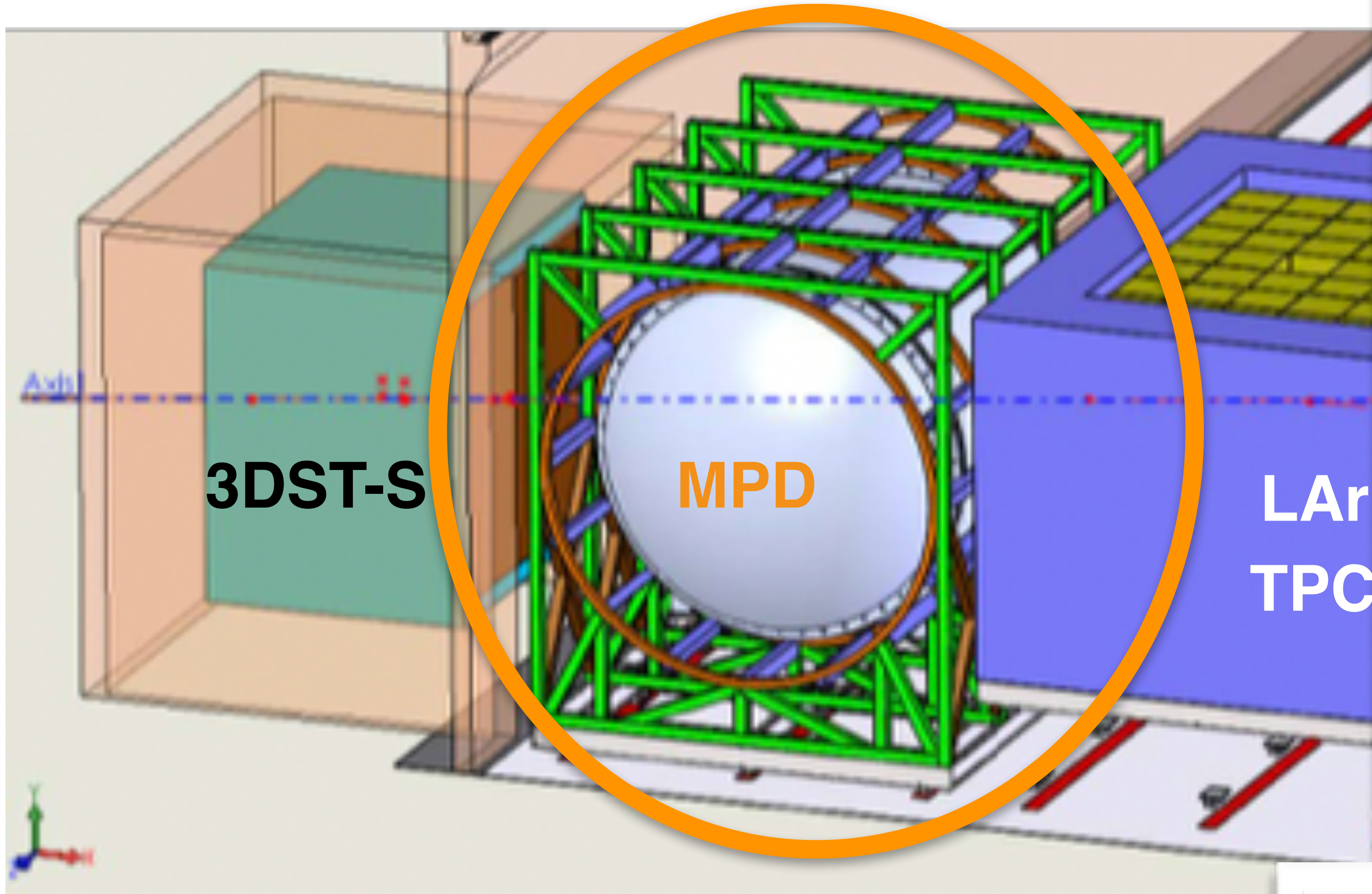
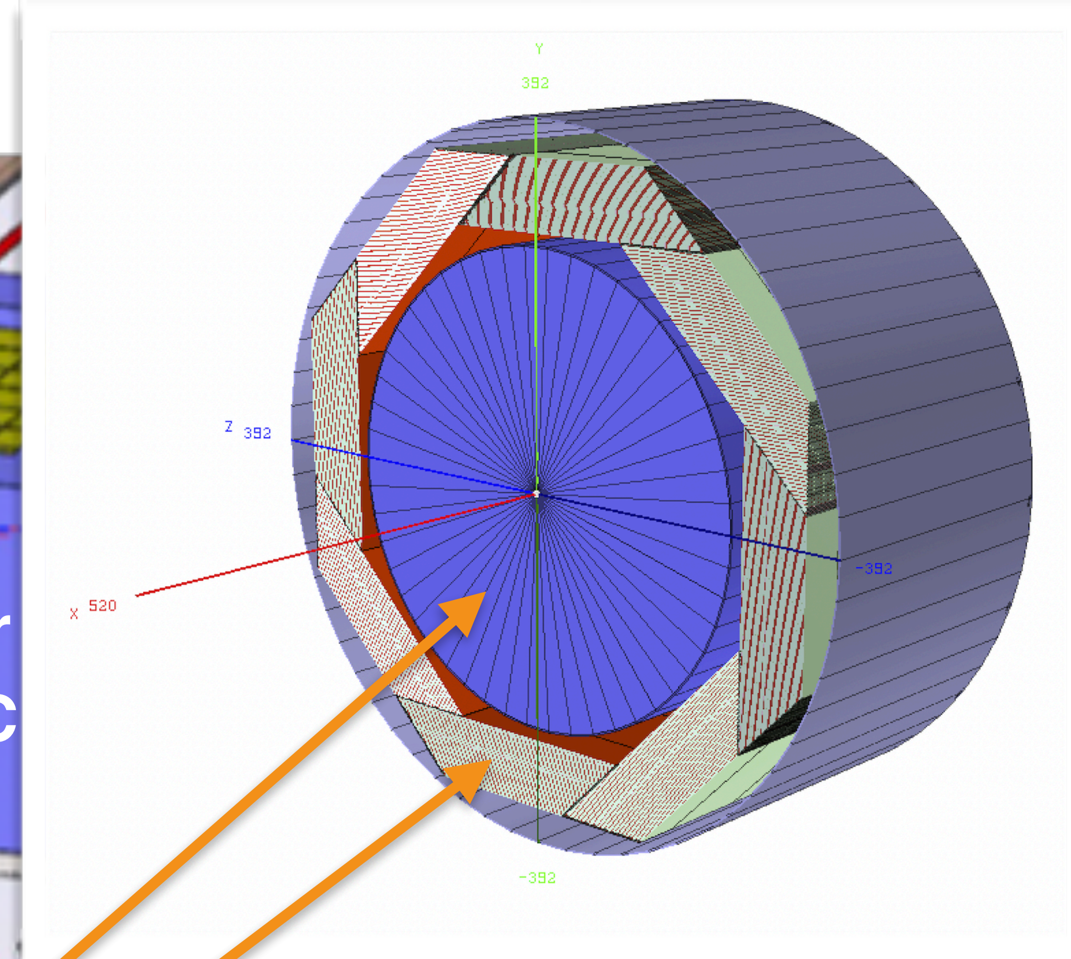
The DUNE Near Detector



“Multi-Purpose Detector” (MPD)

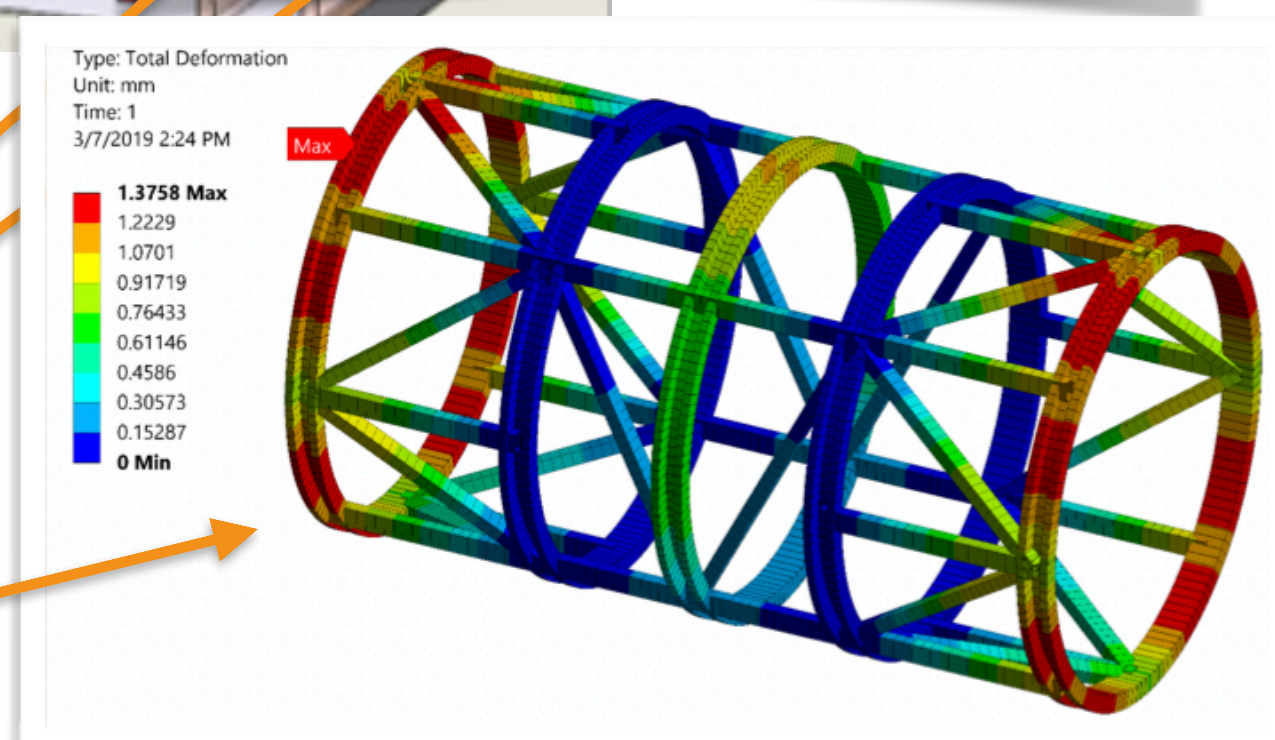
The DUNE Near Detector





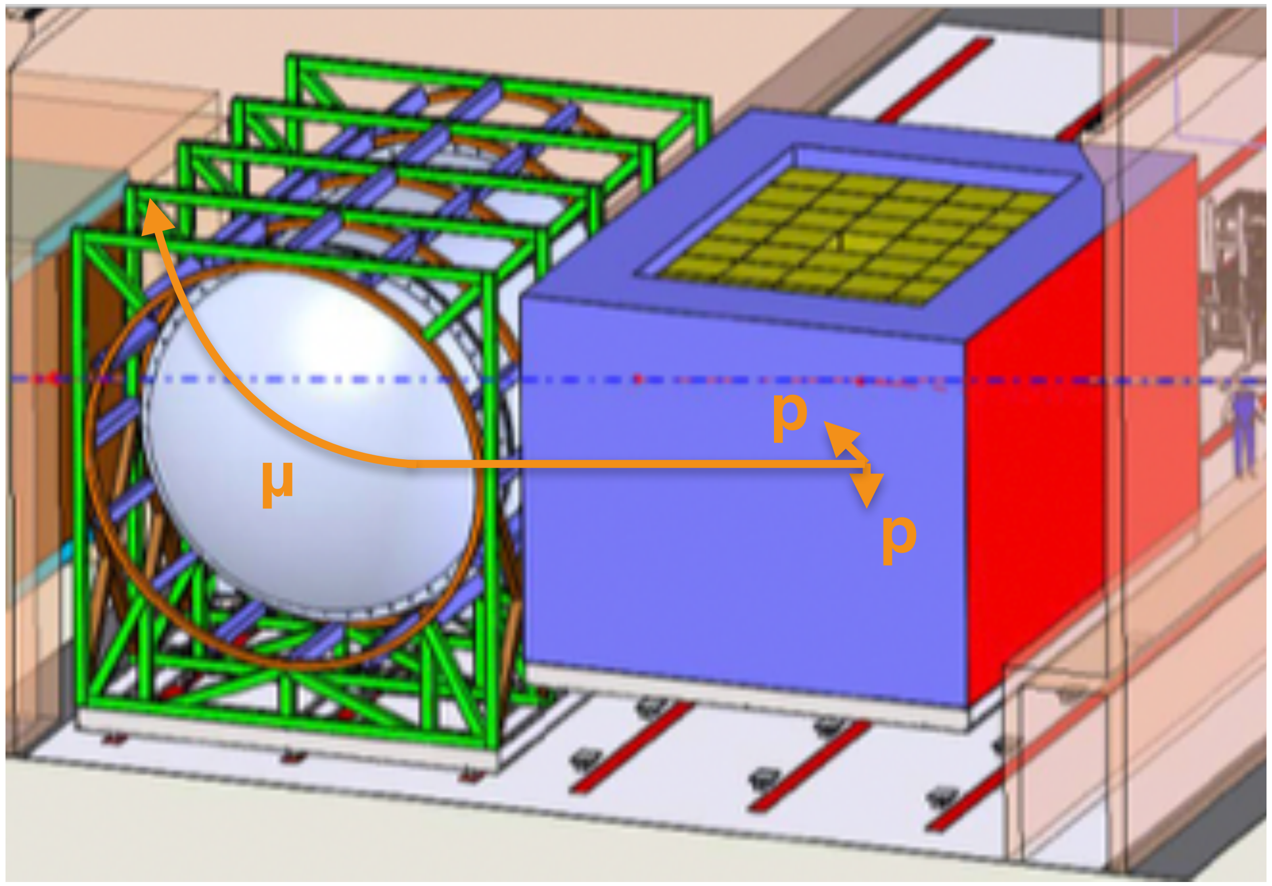
“Multi-Purpose Detector” (MPD)

- High Pressure gaseous Argon TPC (HPgTPC)
- …surrounded by an ECal
- …in a magnetic field (0.5 T) provided by a superconducting Helmholtz-coil-like magnet



MPD in the DUNE Oscillation Analysis

- Measure particles from interactions in LArTPC
  - Mostly **forward-going muons**
  - Measure **momentum** of higher-energy muons with high resolution by curvature
  - Measure **sign of charged particles** → distinguish ν from anti-ν interactions, measure wrong-sign component of (anti)neutrino beam



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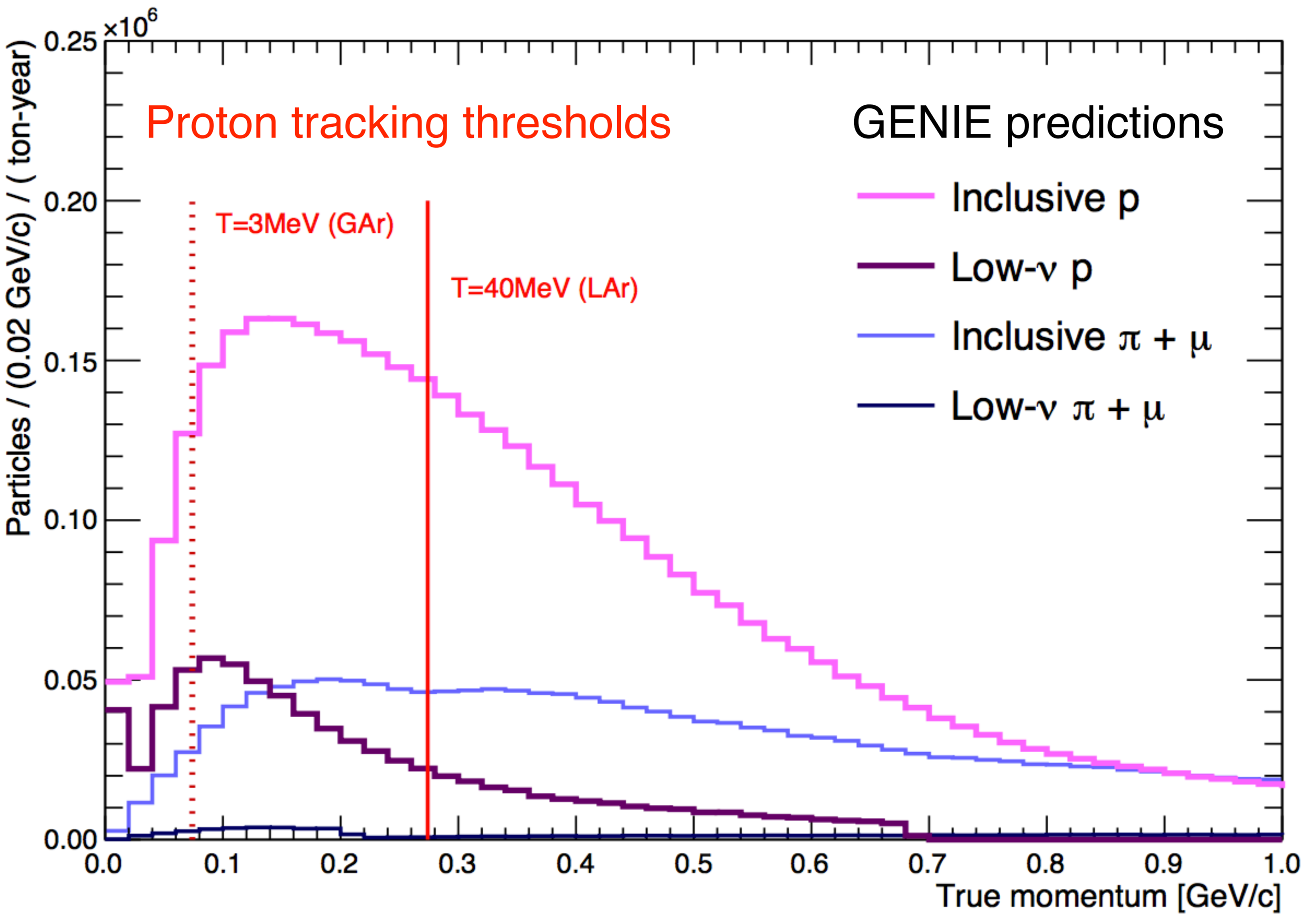
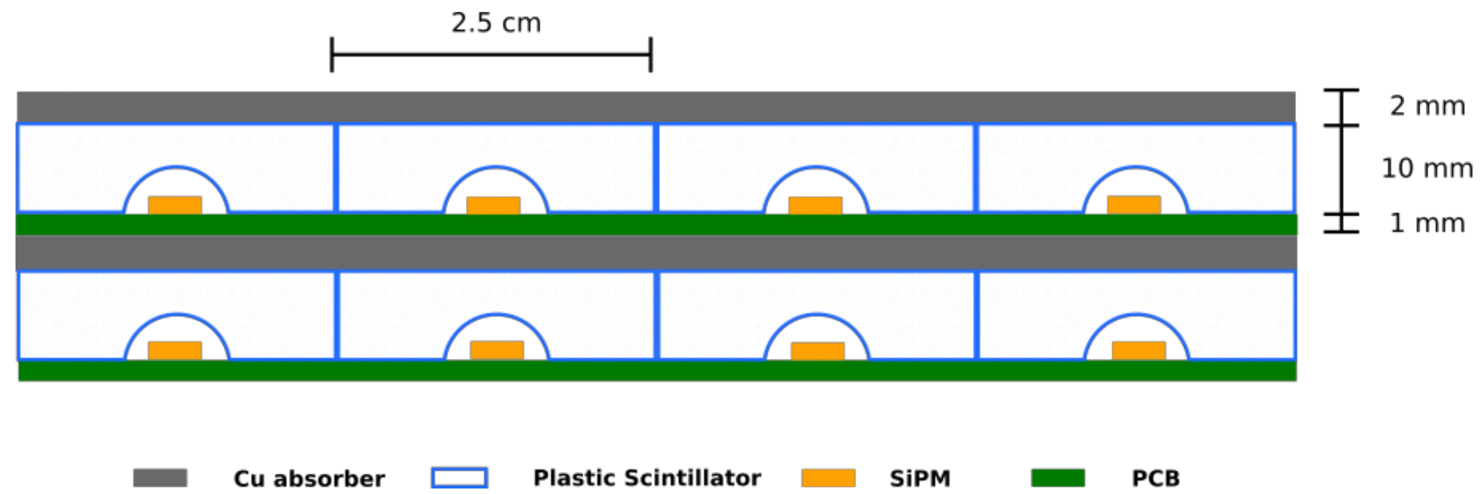


- Sample of neutrino interactions in the HPgTPC
  - **Same target** (argon), **same beam** as LAr
  - Significantly **lower thresholds** → understand neutrino interactions on Argon in detail, improve models at both near and far detector, **reduce uncertainties**
  - **Flat acceptance** over full angular range → mirrors far detector acceptance

The Multi-Purpose Detector

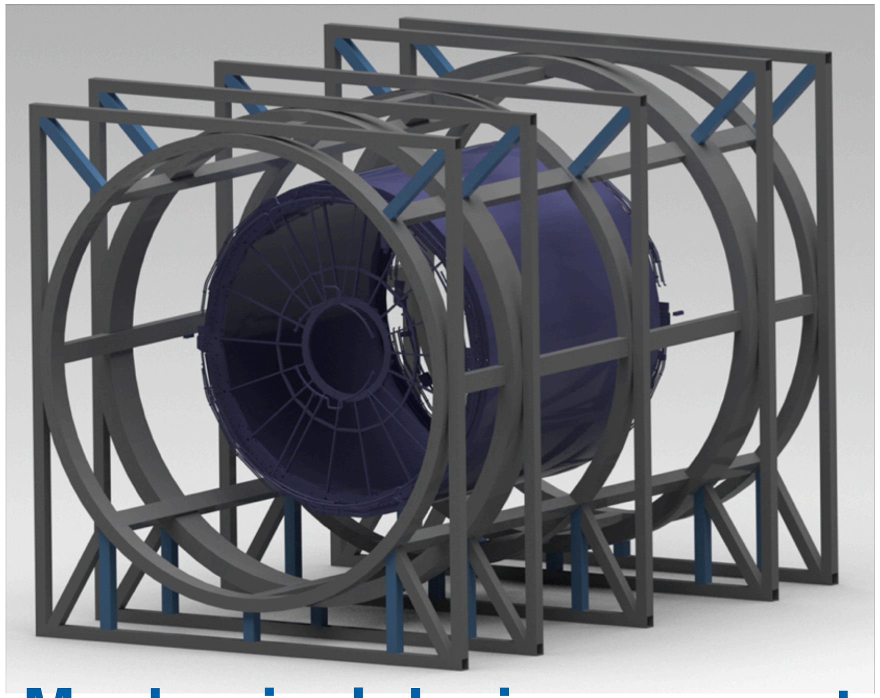
- ECal:
  - Measure energy and direction of electromagnetic showers
    - Reconstruct photons
    - π^0 backgrounds to ν_e
    - External backgrounds
  - Detect neutrons (studies ongoing)
  - Provides fast timing: t_0 for reconstruction in HPgTPC



Prototype ECal design uses tiles and strips of scintillator

Tiles → inner layers: very good granularity, angular resolution

Strips → outer layers: high granularity not as important

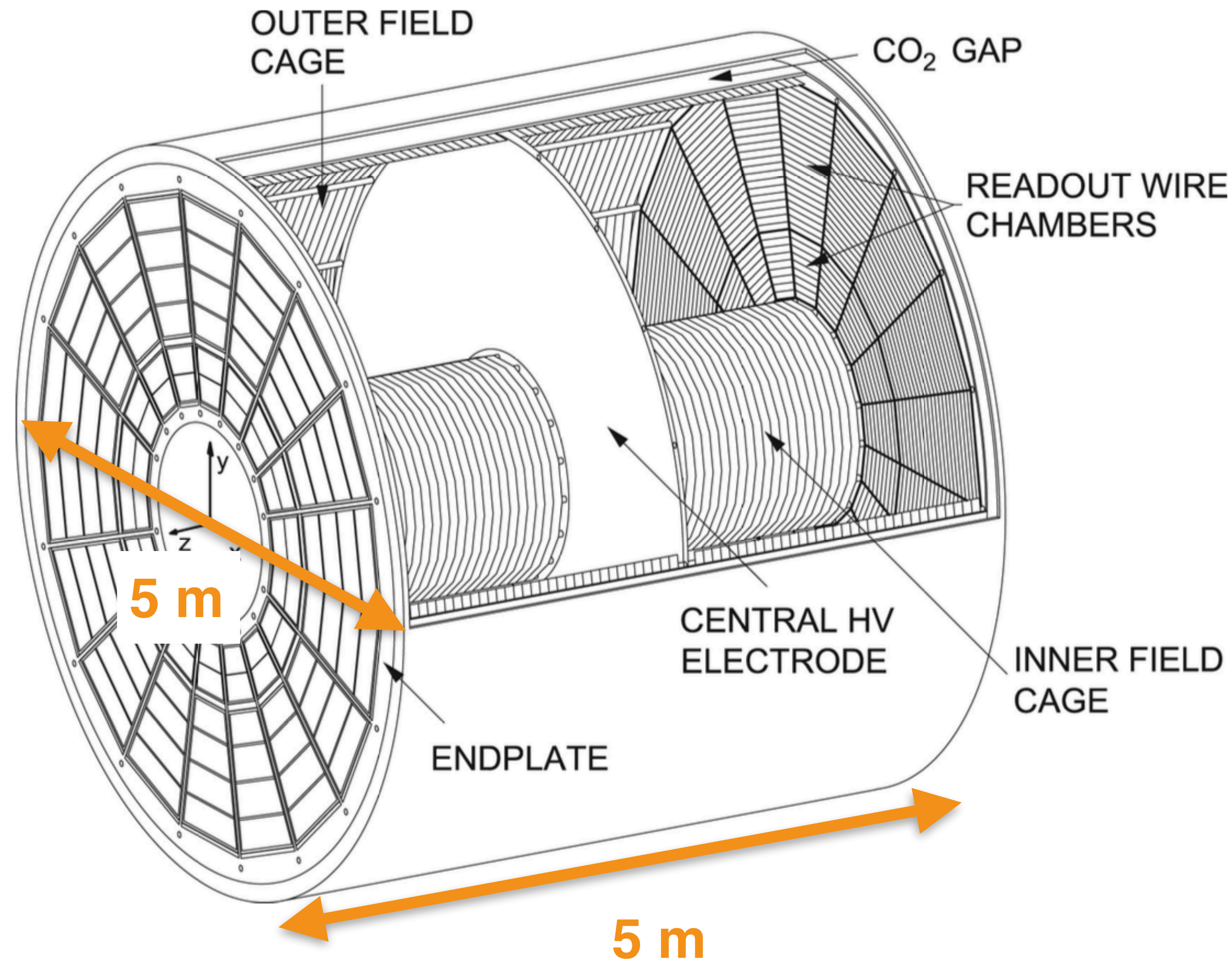


Mechanical design concept

- Magnet:
  - 0.5 T magnetic field
    - distinguish ± charged particles
    - Measure momentum of exiting particles
  - Helmholtz coil design minimizes material

The Multi-Purpose Detector: HPgTPC

- Central detector: **H**igh **P**ressure **g**aseous-argon **T**ime **P**rojection **C**hamber (HPgTPC)
- Design inspired by **ALICE TPC**
  - ALICE TPC is being refurbished now
  - We have the readout chambers



- …with a few changes
  - **Higher pressure: 10 atm** instead of 1 atm
  - Gas mixture: 90:10 Ar:CH4
    - 1 t fiducial mass
    - **97% of fiducial neutrino interactions will be on argon nuclei**
  - Need to fill in central hole
  - Considering other TPC design ideas (e.g. field cage, calibration infrastructure) from experiments such as sPHENIX and NA49

ALICE readout chamber acquisition

Why high pressure?

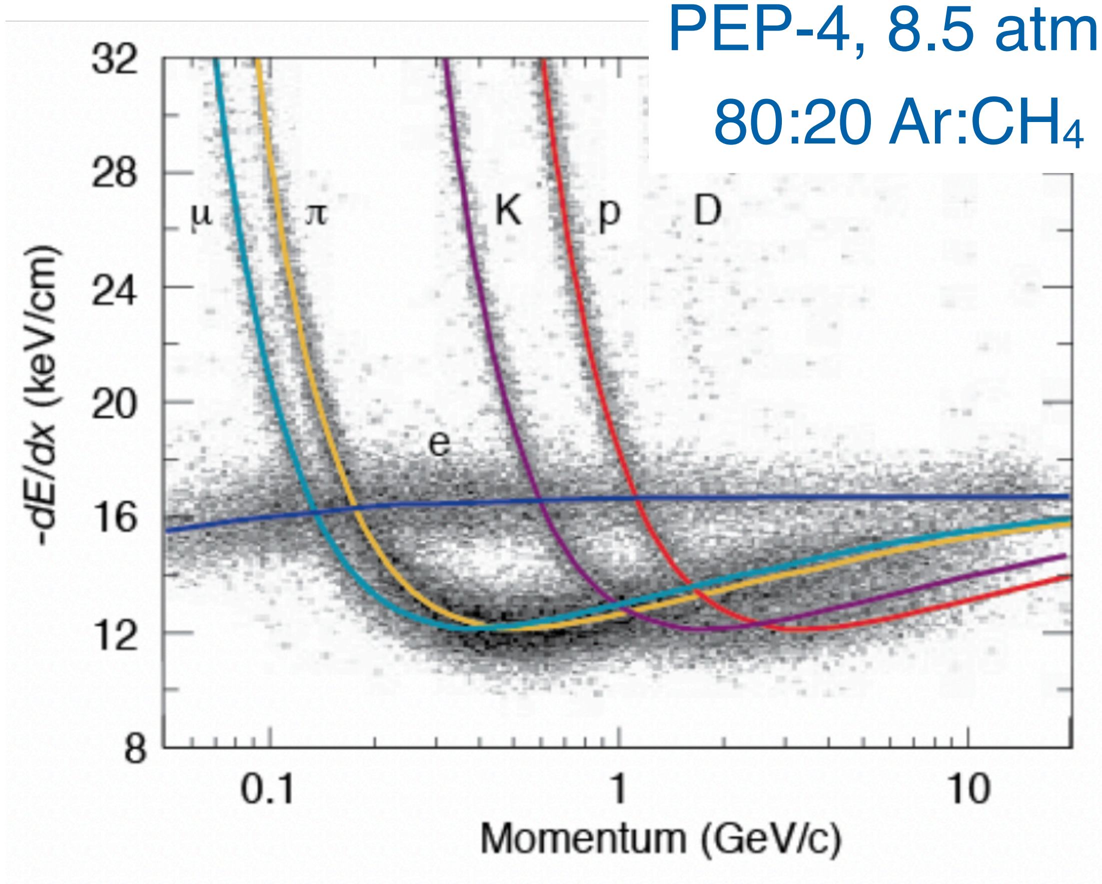
Increasing the pressure of the gas gets us…

- **Larger statistics** for sample of neutrino interactions in the gas
  - Separate set of interactions on Argon, independent of LAr
  - Different energy reconstruction, detector systematics
  - Lower thresholds than LAr

- Better **particle identification** for particles that stop in the gas (from interactions in the gas or in the liquid)
  - Secondary importance compared to above

Event type	*Events per year in HPgTPC (ν-mode beam)*
ν_μ CC	1.4×10^6
ν_μ-bar CC	5.2×10^4
ν_e CC	2.0×10^4
ν_e-bar CC	4.8×10^3

PEP-4, 8.5 atm, 80:20 Ar:CH_4

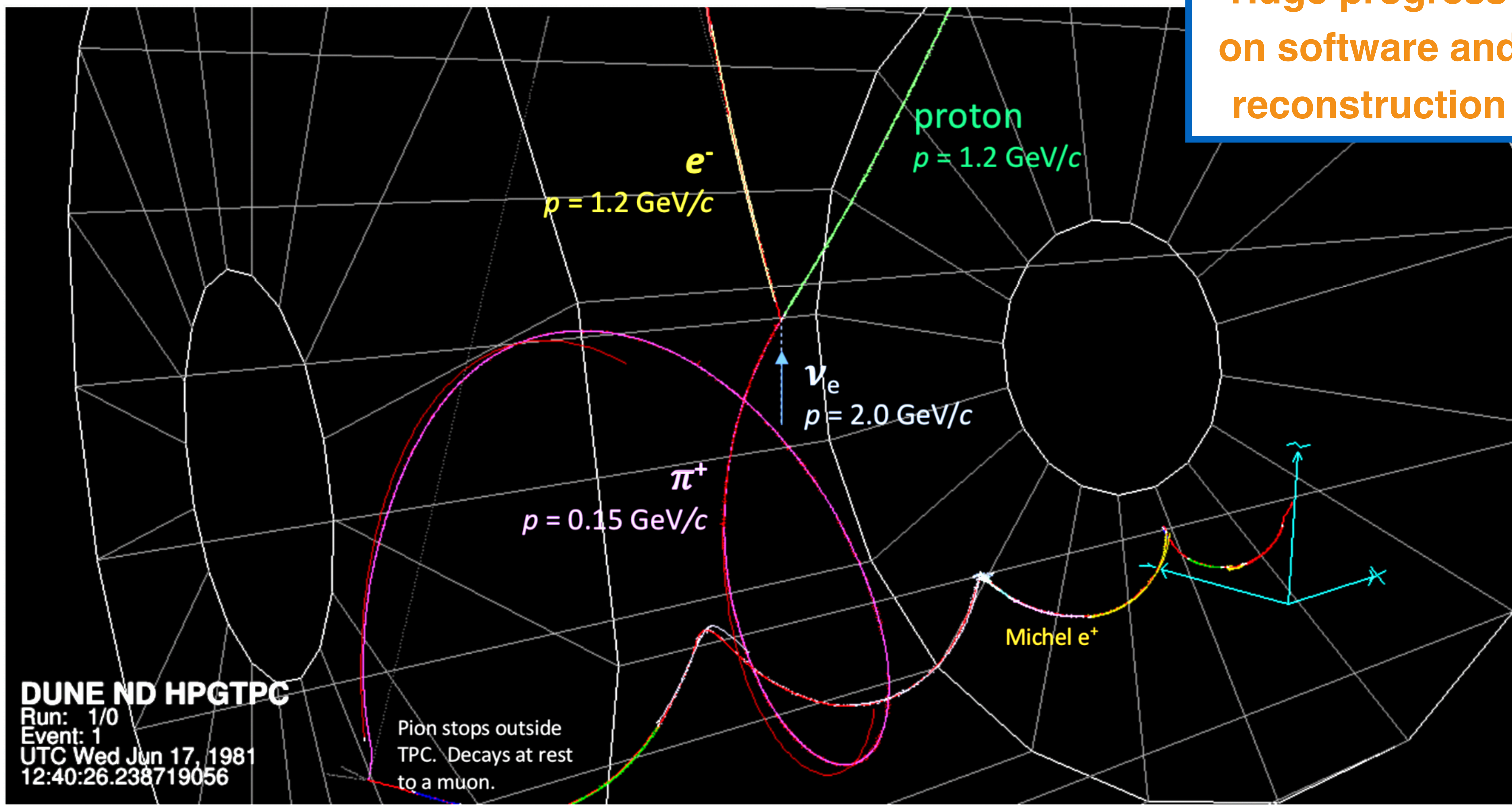


What do we expect to see in the HPgTPC?

A simulated and reconstructed ν_e charged current event:

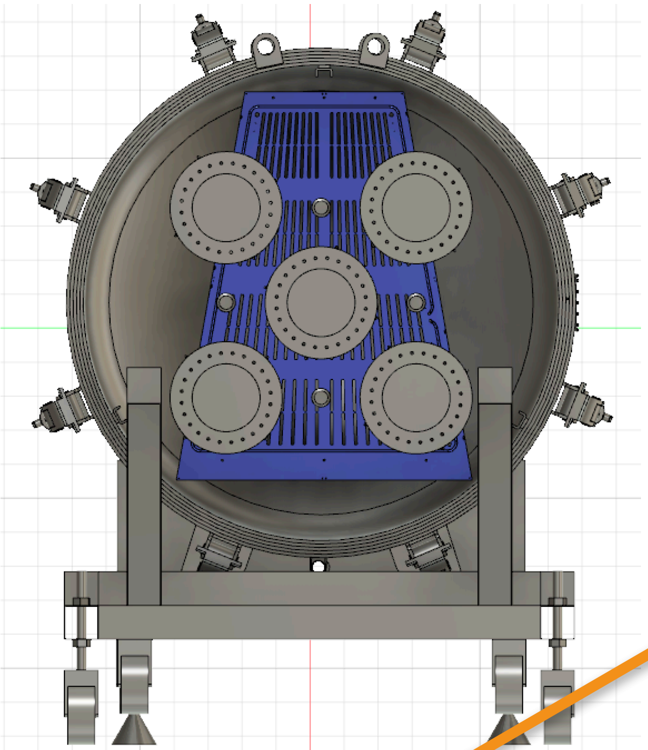
$$\nu_e + Ar \rightarrow e^- + \pi^+ + p + n$$

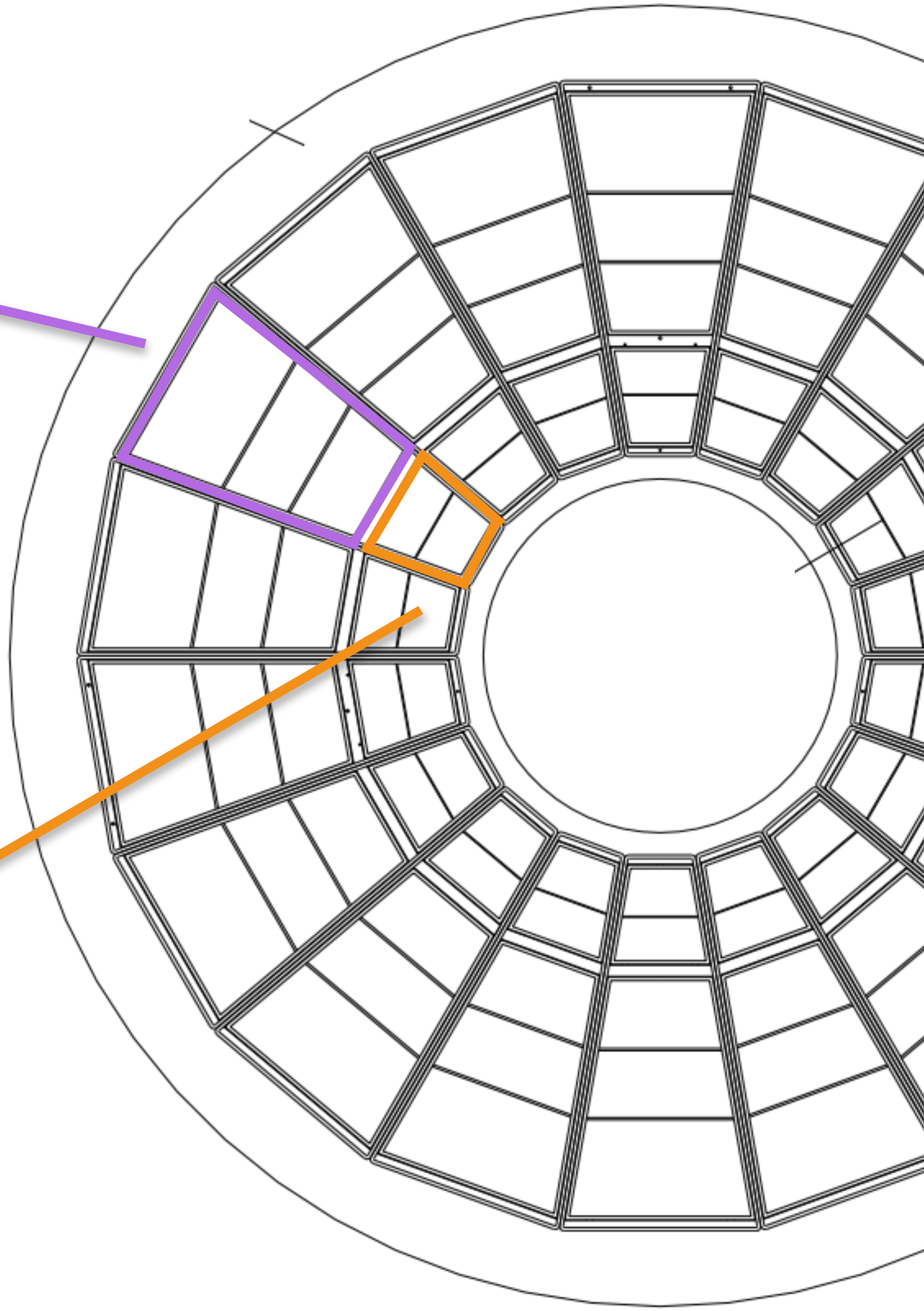
Huge progress on software and reconstruction



HPgTPC test stands

- Outer Read Out Chamber (OROC)
  - 1 m long x 86 cm at widest point
  - Test stand at Royal Holloway, University of London

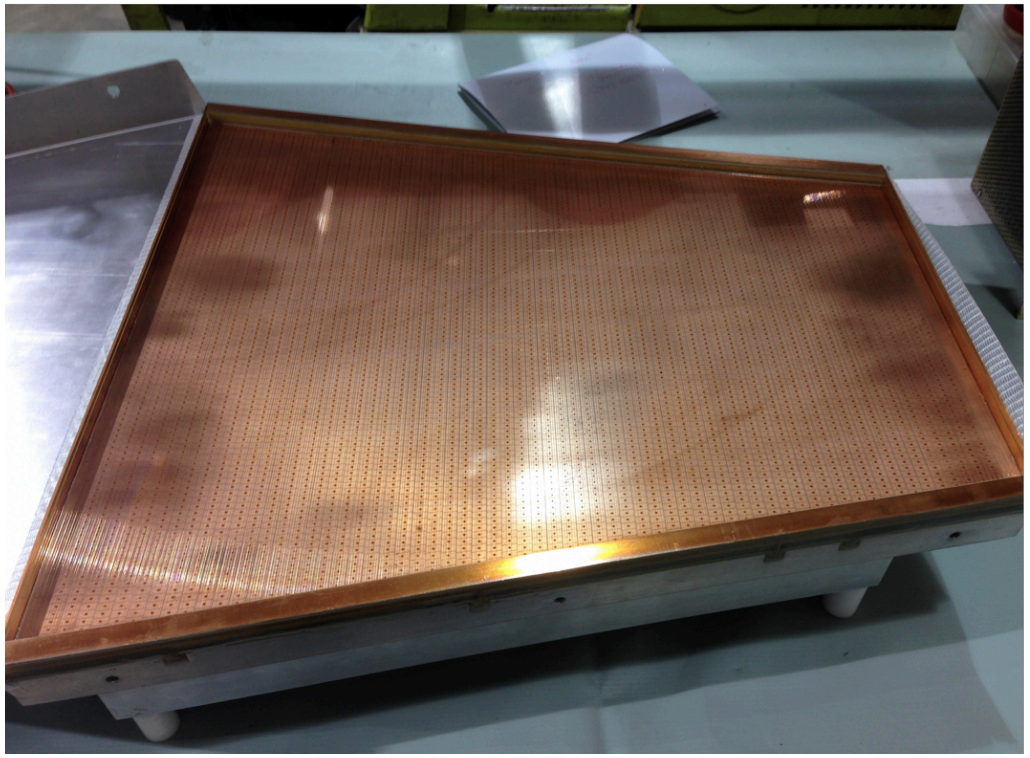




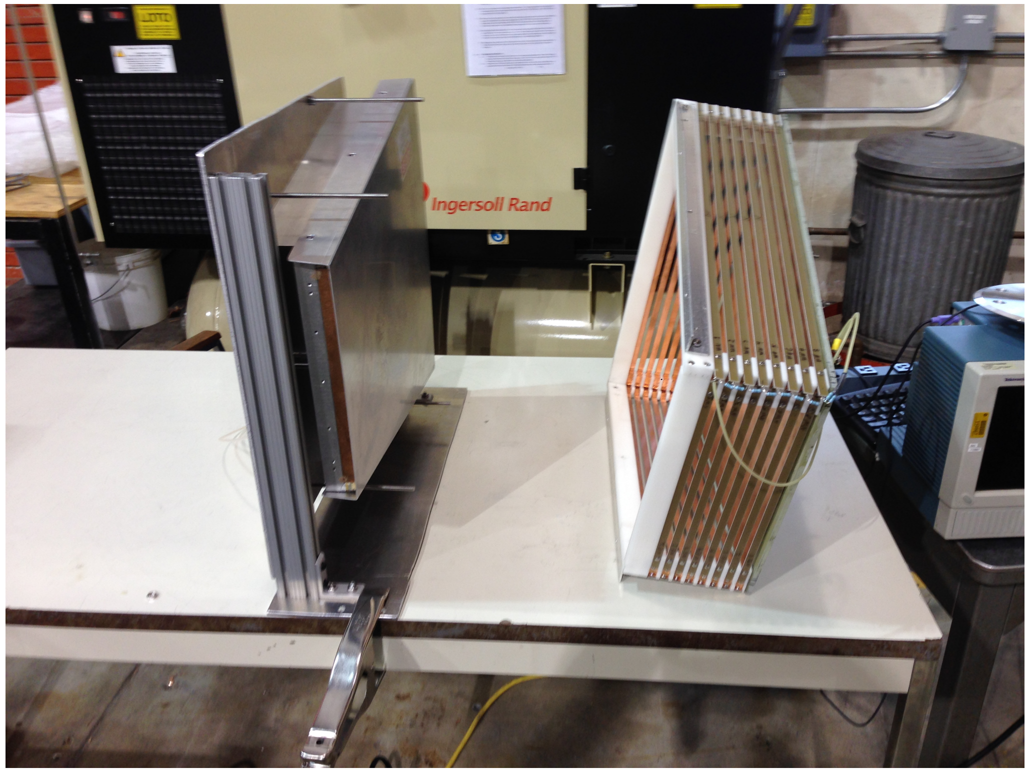
- Inner Read Out Chamber (IROC)
  - 40 cm long x 45 cm at widest point
  - Test stand at Fermilab

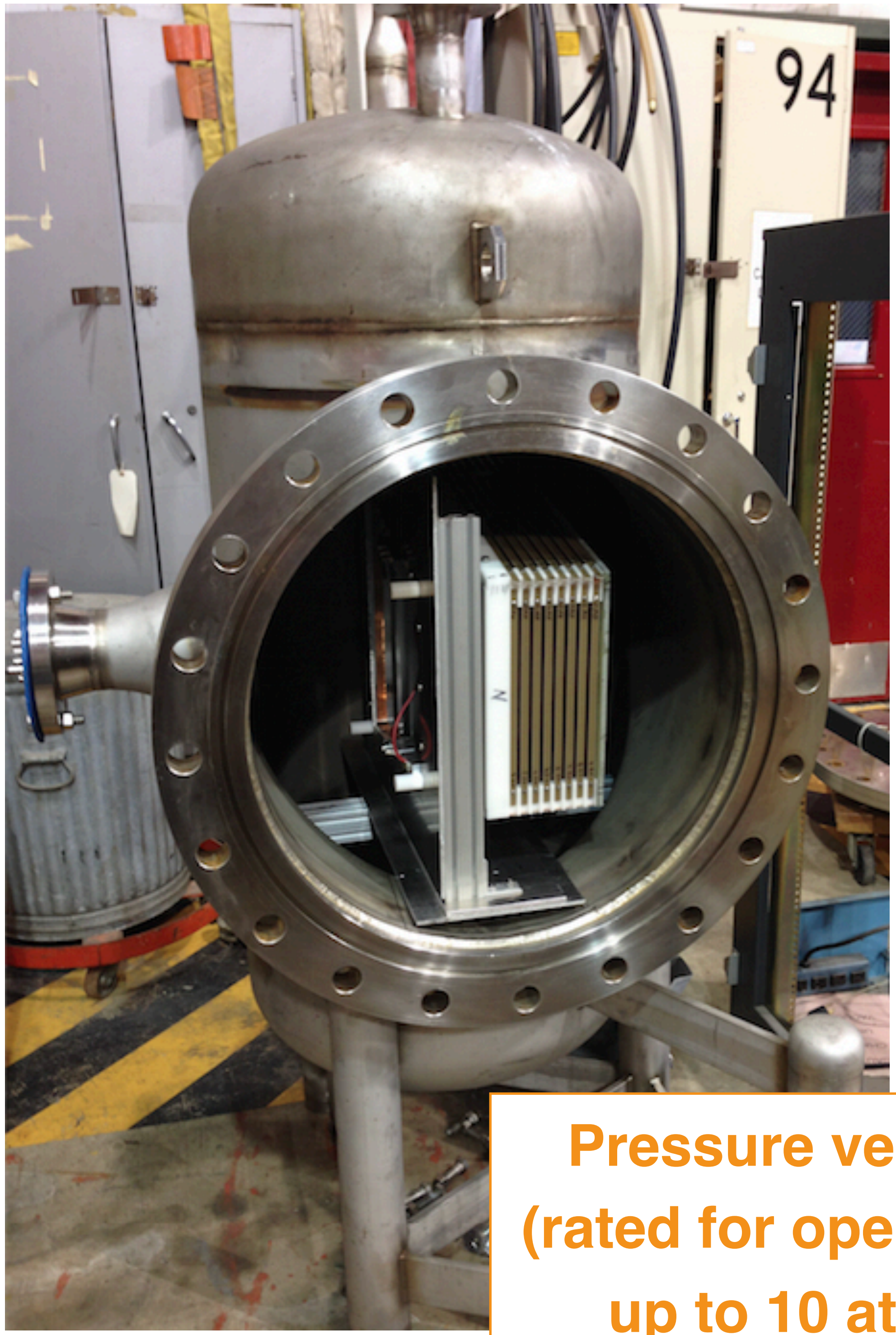
Fermilab test stand:
GOAT (Gaseous-argon Operation of the ALICE TPC)

IROC



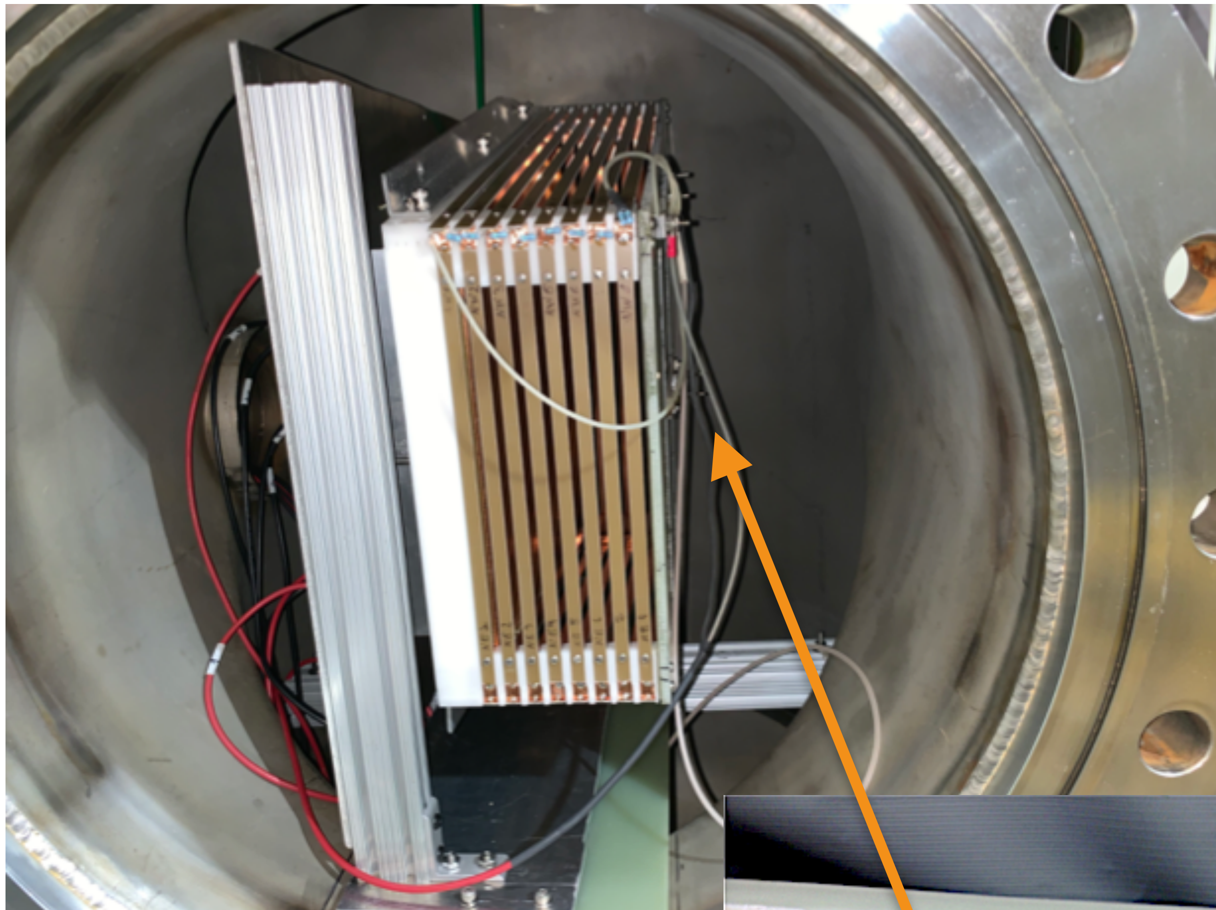
Field Cage

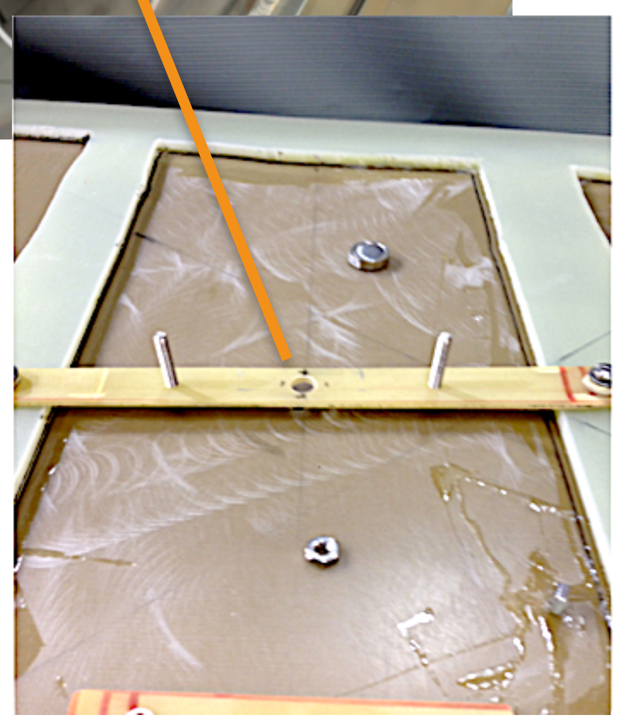




Pressure vessel (rated for operation up to 10 atm)

Initial tests at low pressure (1 atm)





^{55}Fe source installed on back of HV drift electrode

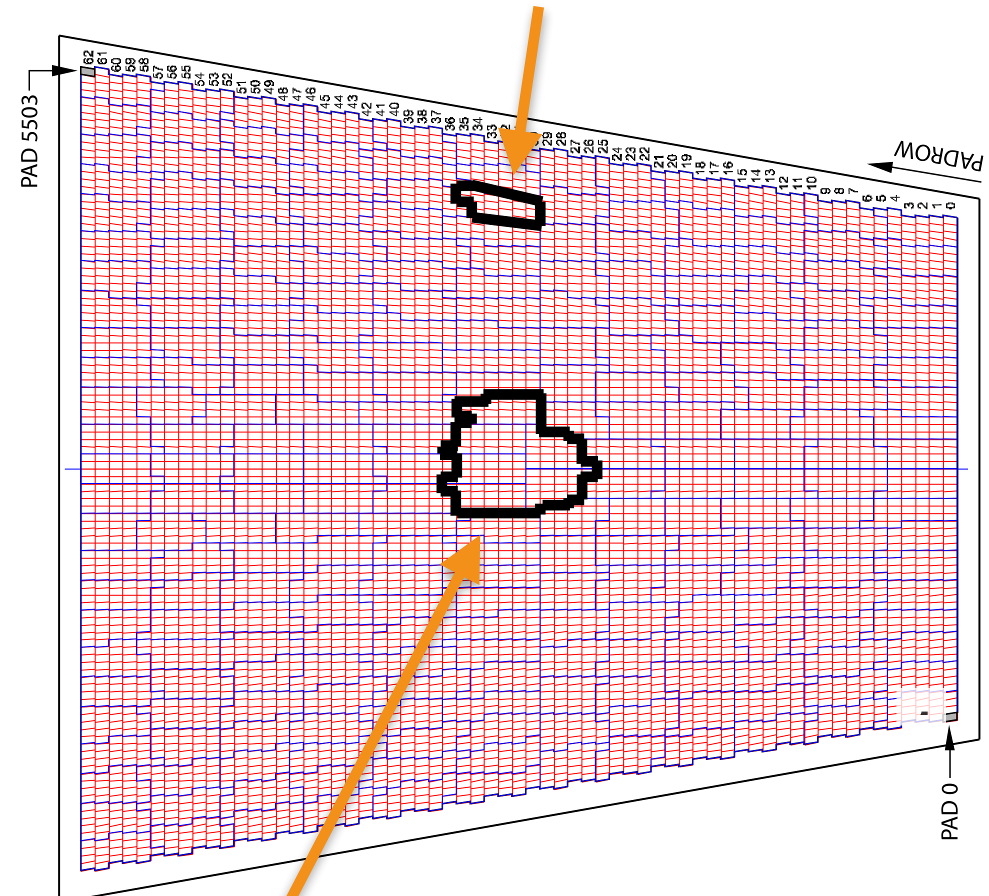
→ x-rays enter volume through small hole

Chain together multiple readout pads:

Reference region

→ away from source

→ should see backgrounds only



Active region

→ immediately below source

→ should see large signal from 55Fe

Fermilab

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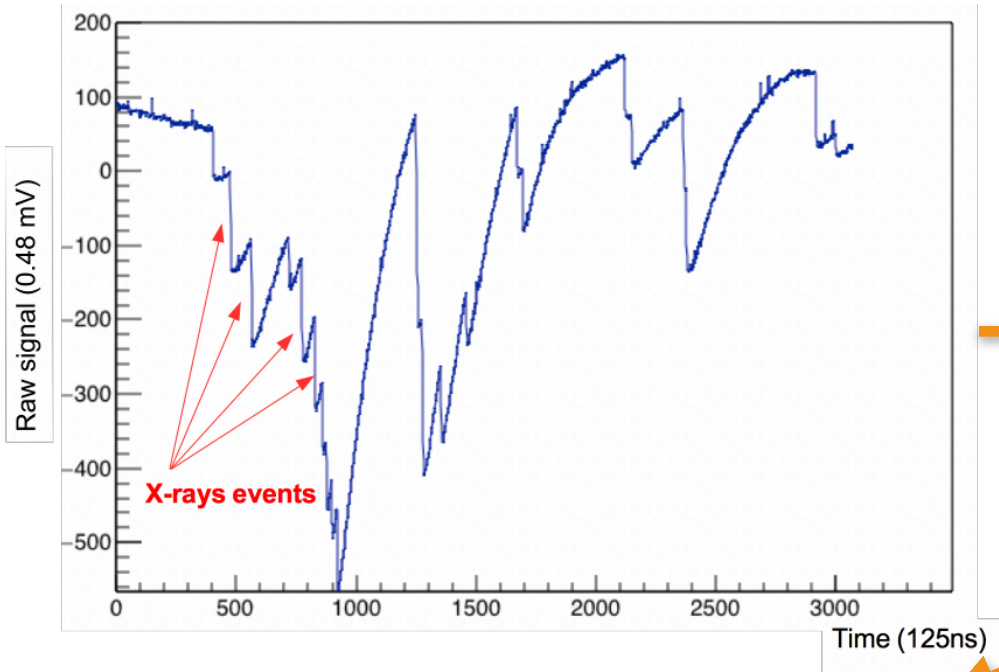
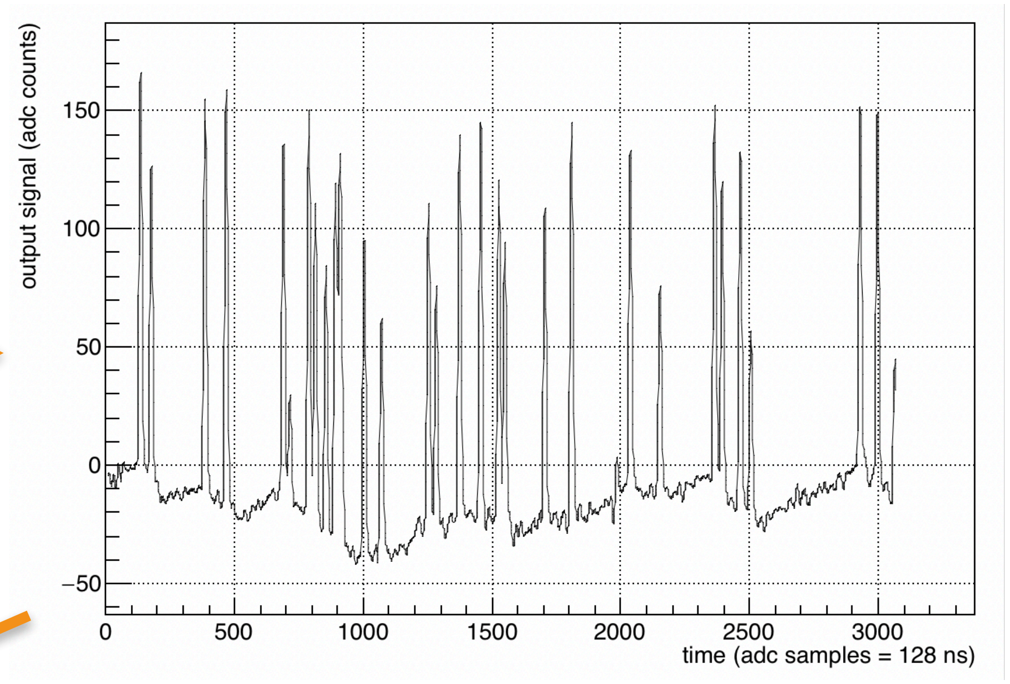
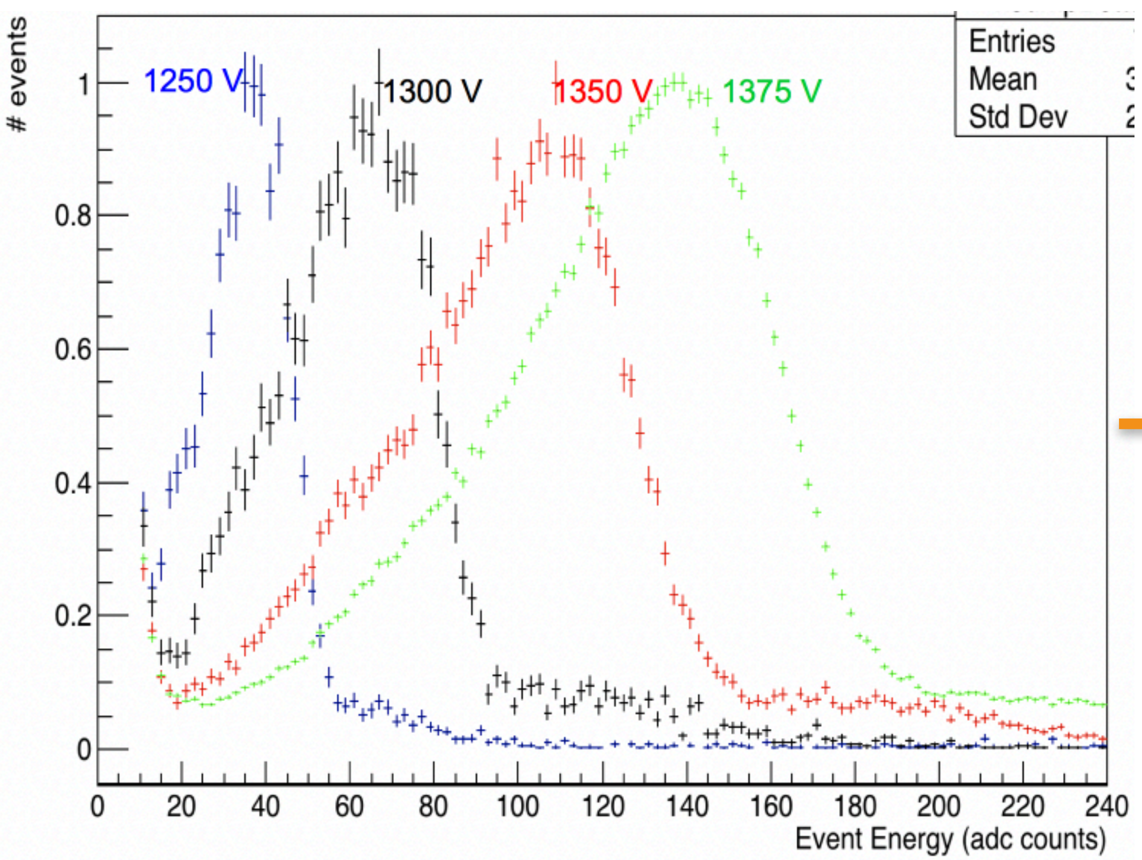
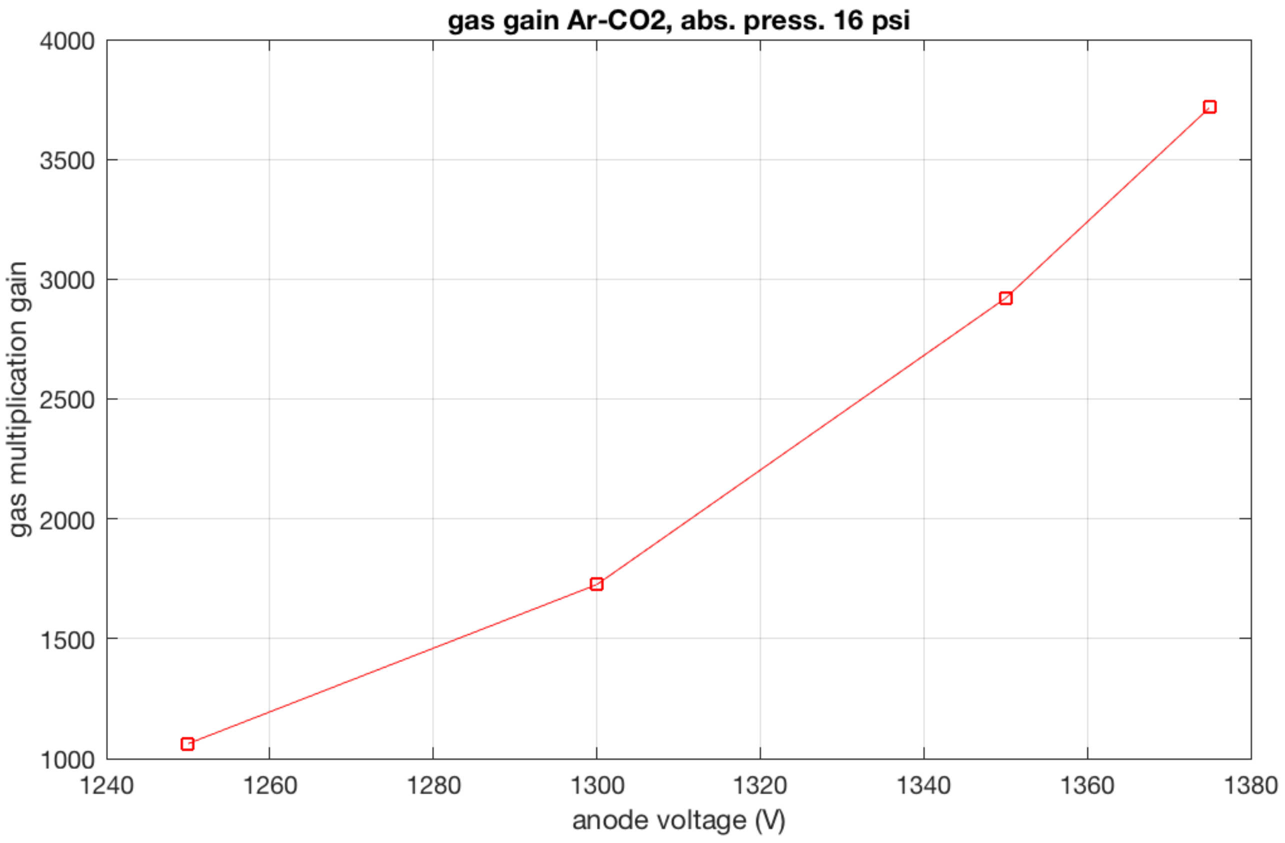








Next step: high-pressure operation

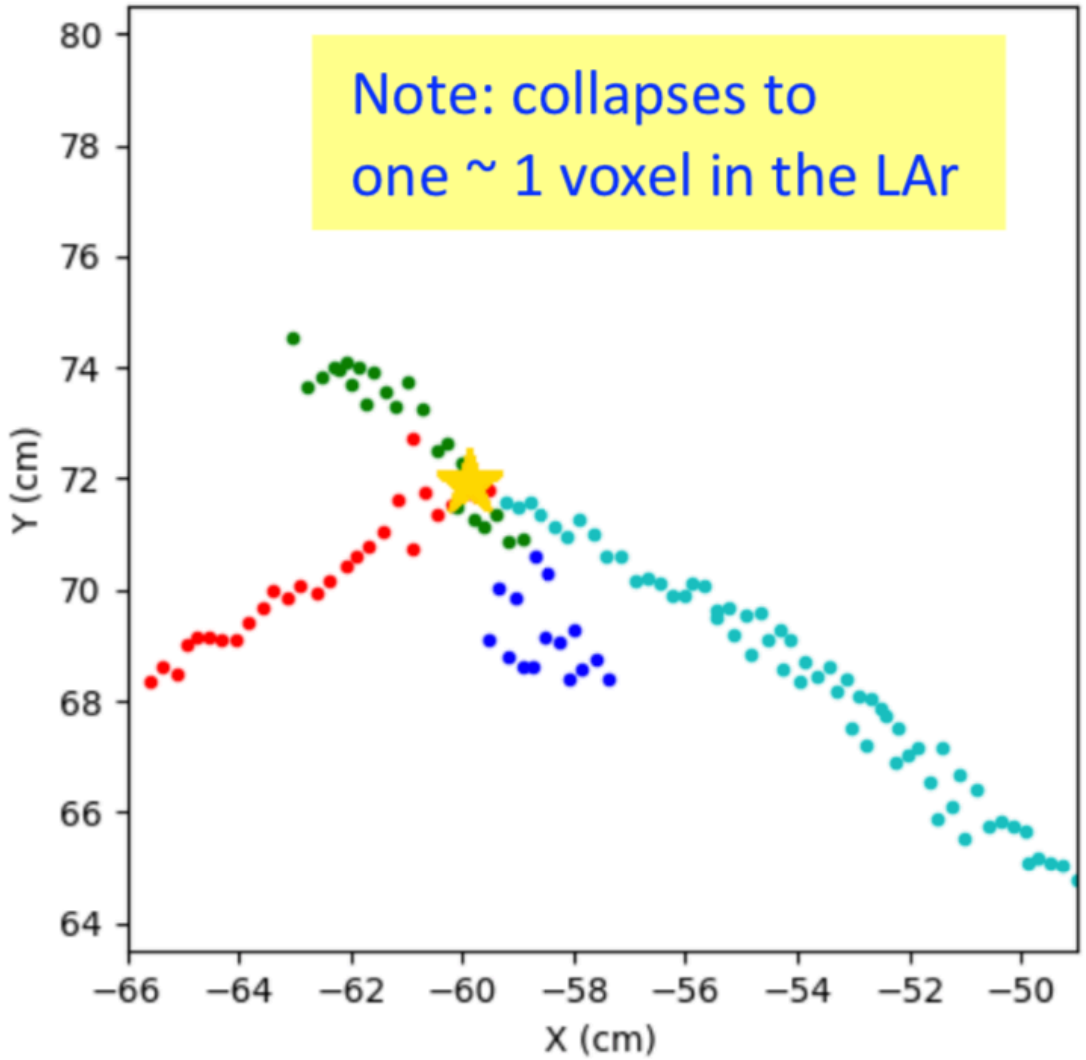
- Next step is to move to high pressure
  - Increase pressure from 1 atm to 10 atm in multiple steps
  - repeat the gain measurement at each pressure setting
- Important test:
  - We know that ALICE chambers work well at 1 atm
  - Electrostatic calculations say should also work well at higher pressures
  - Best to verify by testing as-built chambers
  - Important proof of principle for DUNE ND design
- Received Fermilab clearance for high-pressure operation end of July 2019
- Tests ongoing as we speak - watch this space!

Summary

- The Multi-Purpose Detector is a vital component of the DUNE near detector
  - High-pressure gaseous-argon TPC
  - …surrounded by an ECal
  - …in a 0.5 T magnetic field
- Provides **high-resolution measurement** of particles exiting the LAr, and an **independent sample** of interactions on the **same target** in the **same beam** with different detector effects and much **lower thresholds**
- Plan to reuse **ALICE TPC readout chambers**: full TPC design inspired by ALICE with additional input under consideration from ideas implemented in other running gaseous TPCs
- Current test-stand efforts are ongoing to characterize ALICE readout chambers and prove feasibility of **high-pressure operation**

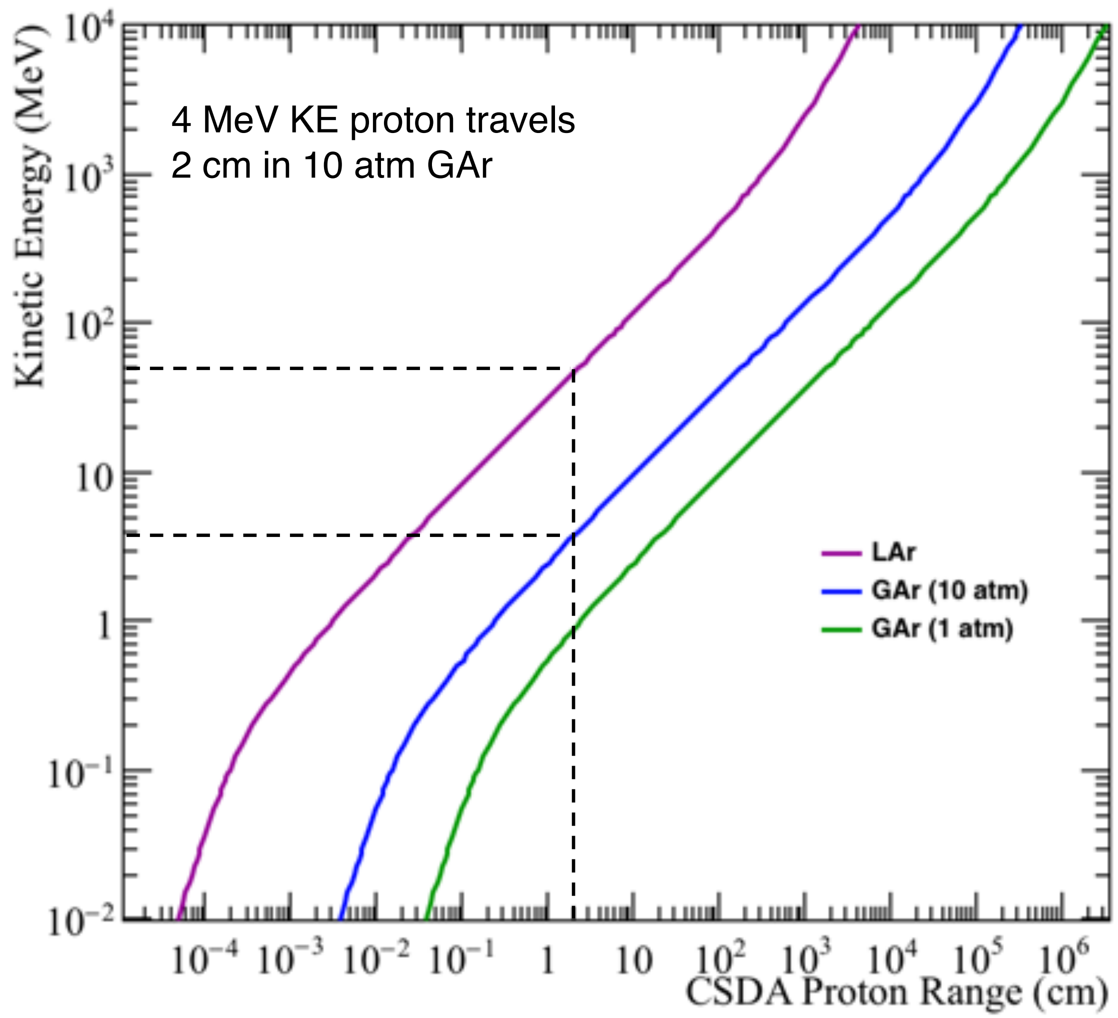
Finding Low Energy Tracks

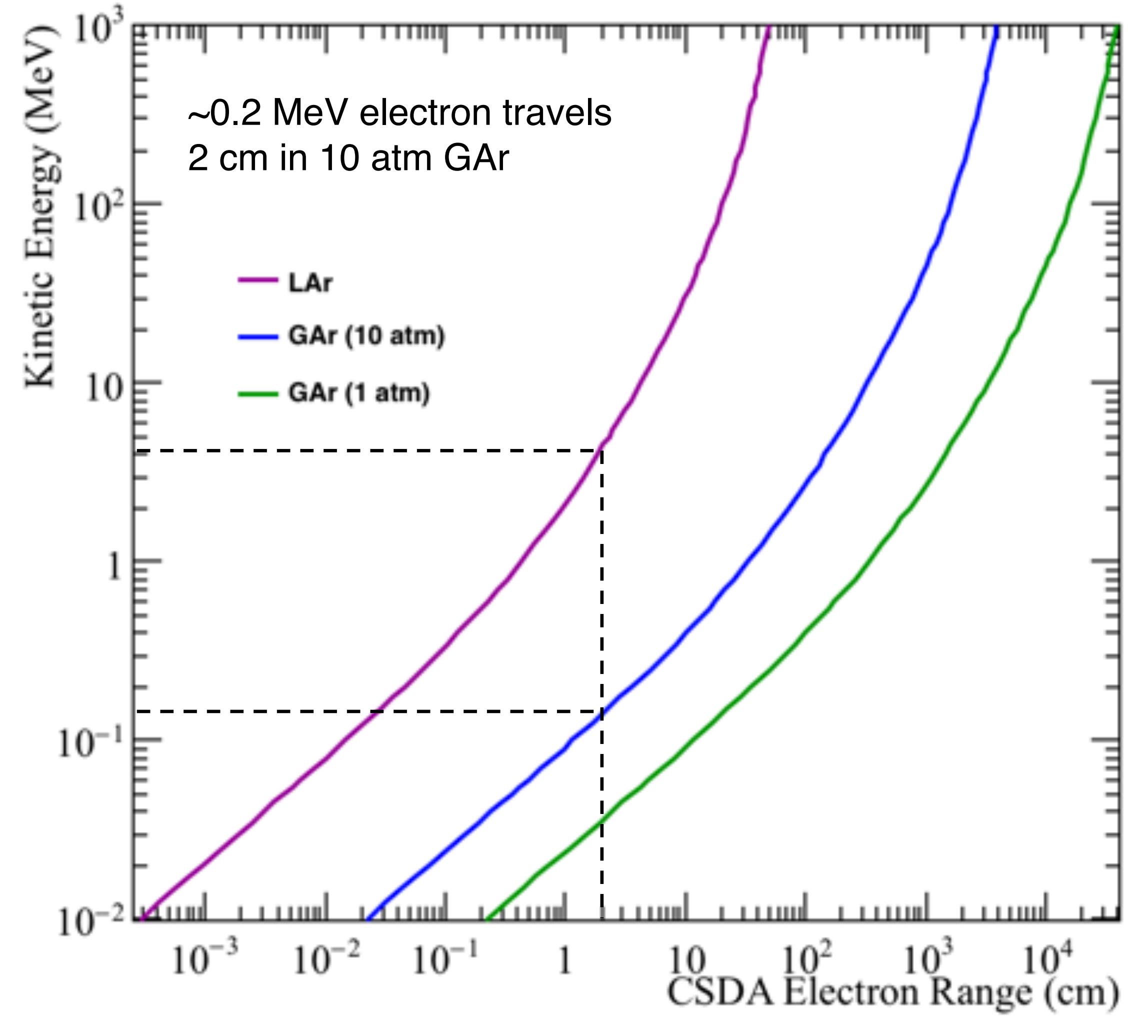
- Average occupancy per beam spill in the DUNE HPgTPC is small, but local occupancy (near the interaction vertex) can be large, with many particles exiting a single point



- Simulation of multiple protons exiting a single interaction point, each in the range ~3-15 MeV KE
- RANSAC-based clustering algorithm + neural net energy estimate
- First pass achieves efficiencies:
  - ~20% for 5 MeV protons
  - ~80% for 10 MeV protons
  - Improvement expected with additional work in this area

LAr vs Gar track range





- Lower density allows lower thresholds for identifying and reconstructing tracks
  - Better measurements of low energy particles ejected in neutrino interactions → improvements to neutrino interaction generators