Overview of the DUNE Near Detector's Multi-Purpose Detector

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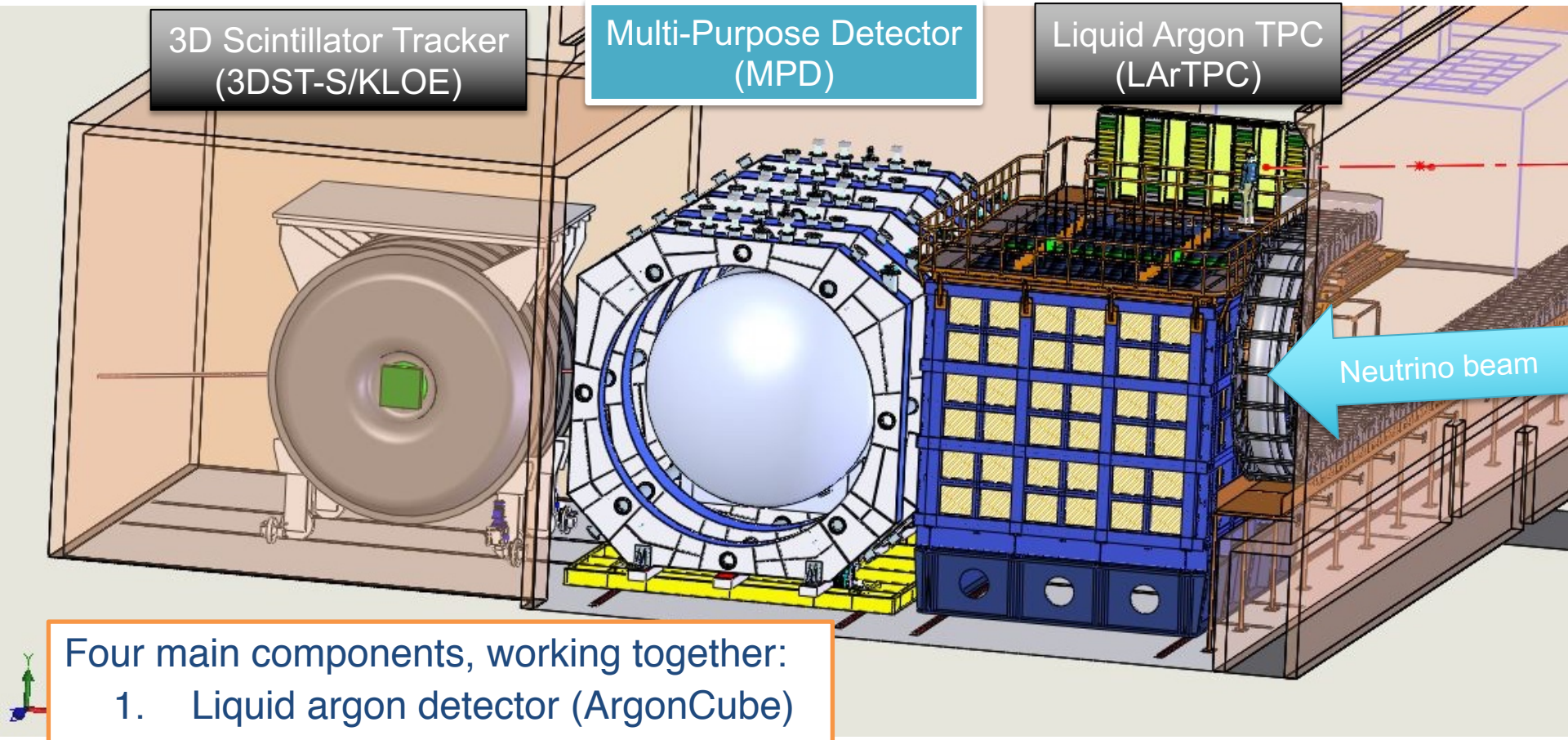
6th DUNE Near Detector Workshop @ DESY

October 21-23, 2019



Four main components, working together:

1. Liquid argon detector (ArgonCube)
2. Downstream tracker with gaseous argon target (MPD)
3. LAr and GAr systems can move to off-axis fluxes (DUNE PRISM)
4. On-axis flux monitor with neutron detection capability (3DST-S/KLOE)

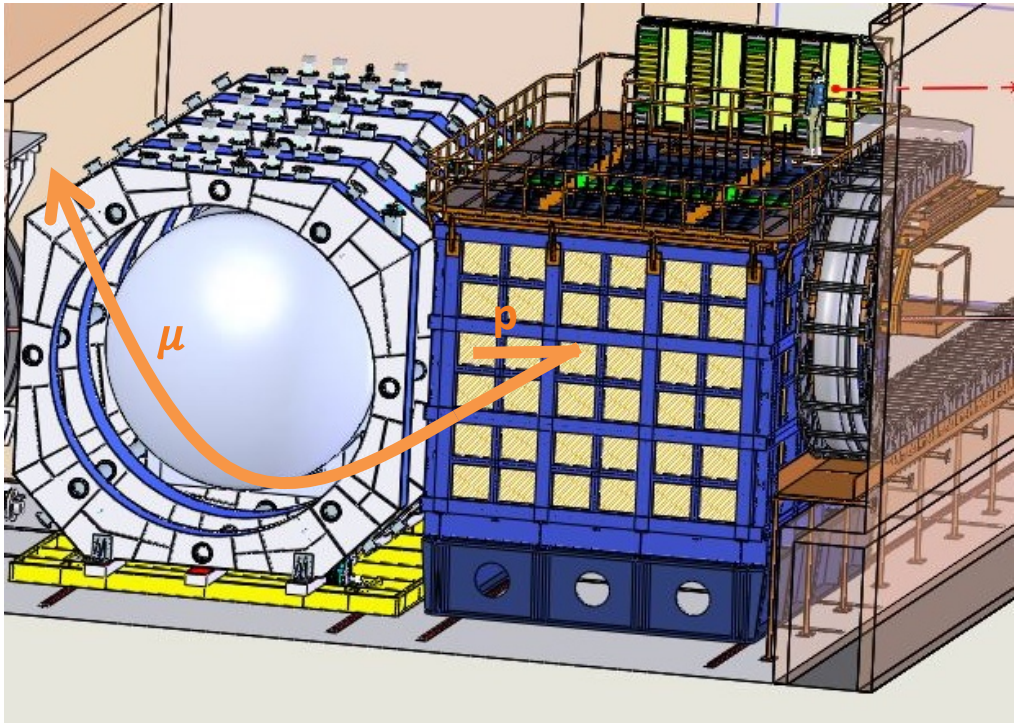
The Near Detector Suite

MPD Basic Considerations

- **Magnetic spectrometer for LAr detector, consisting of a high-pressure gaseous TPC + ECAL + muon tagger**
  - Acceptance (covers high energy forward-going muons exiting the LAr)
  - Minimize material between LAr and MPD
- **Flavor-specific measurements by tagging lepton/sign**
  - Distinguish neutrinos from anti-neutrinos ➔ measure the wrong-sign component of the (anti)neutrino beam
- **Observe neutrino-argon interactions with:**
  - Sign-selection, magnetic spectrometry
  - Full 4π coverage
  - Very low tracking thresholds
  - Minimal secondary interactions

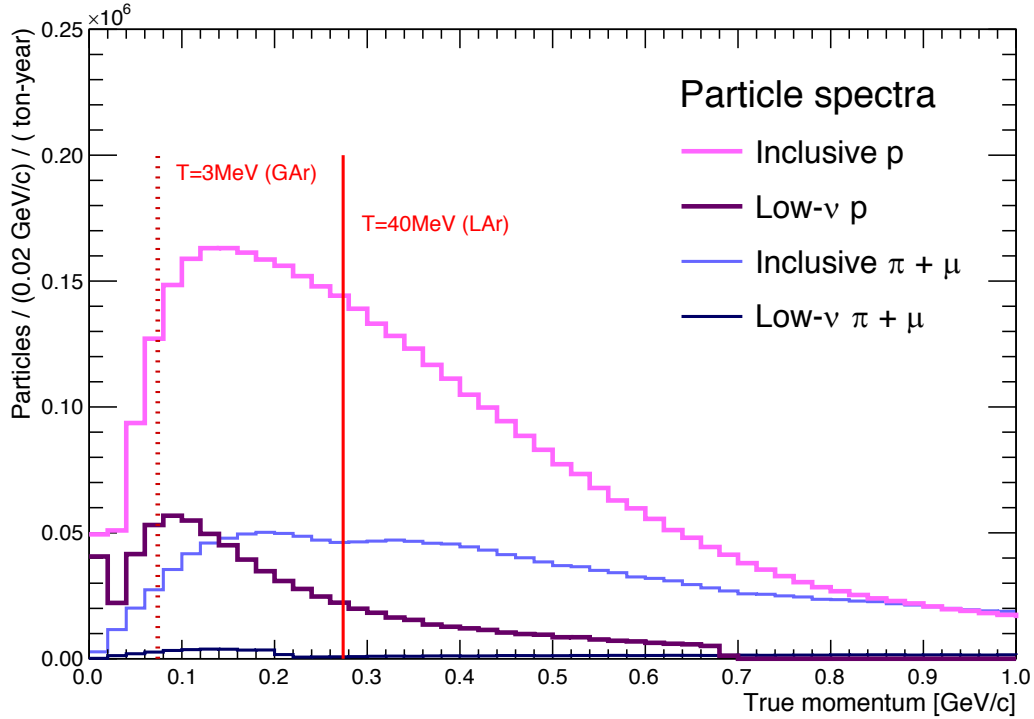
  } Allows disentangling secondary interactions and detector response in LAr
- **Powerful tool in transferring measurements from near to far detector**
  - Same target nucleus, more capable detector
  - Similar acceptance as far detector

MPD as a spectrometer



- **Measure particles exiting the LArTPC**
  - Mostly forward-going muons
  - Measure momentum of high-energy muons by curvature in B field
  - Measure sign of charged particles
    - Allows event-by-event distinction of neutrinos from antineutrinos
    - Direct measurement of wrong-sign component of (anti)neutrino beam

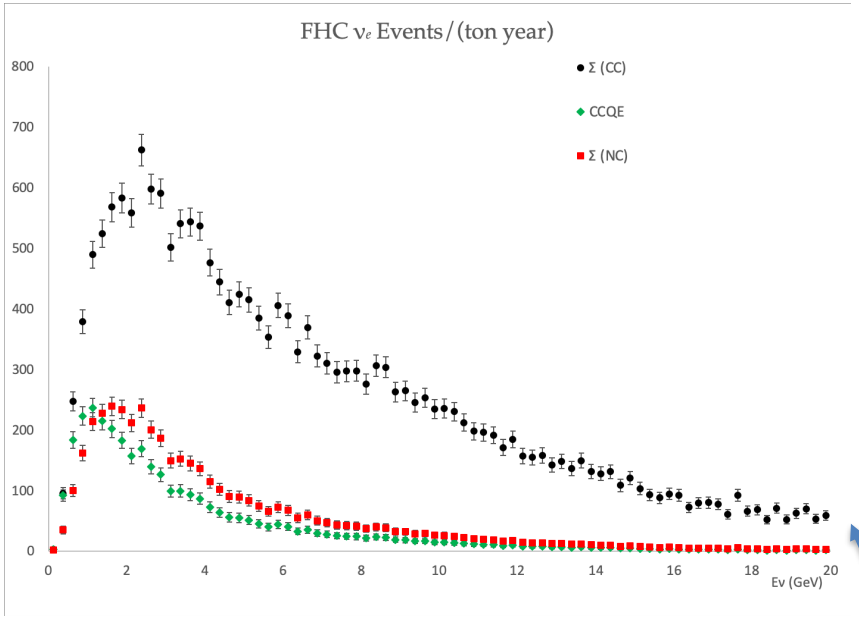
MPD as a target

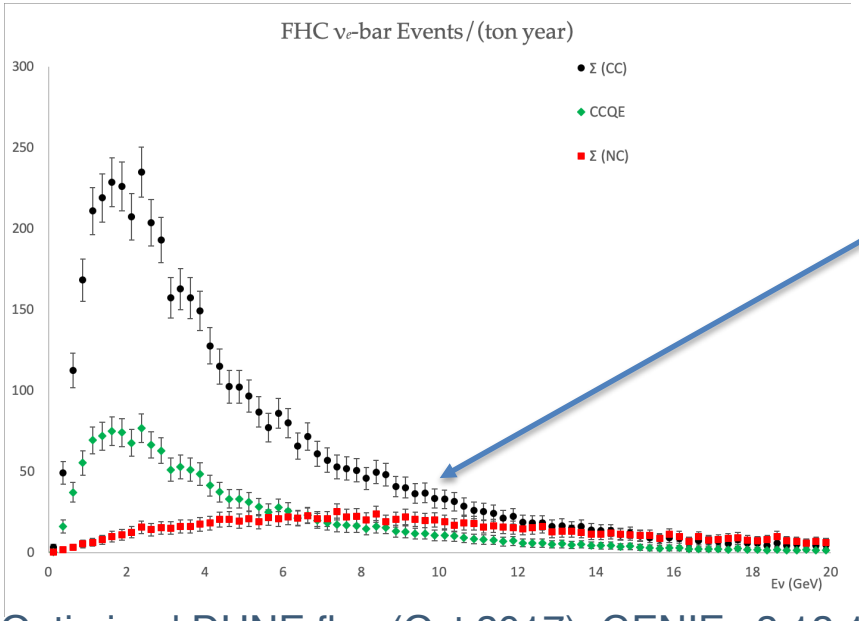


- **Independent sample of neutrino interactions in the gas TPC**
  - Same target (argon), same beam as LAr
  - Significantly lower thresholds
    - Understand neutrino interactions on argon in detail, improve models at both near and far detector, reduce uncertainties
  - Flat acceptance over full angular range
    - Mirrors far detector acceptance

MPD Event Rates

FHC (neutrino mode)



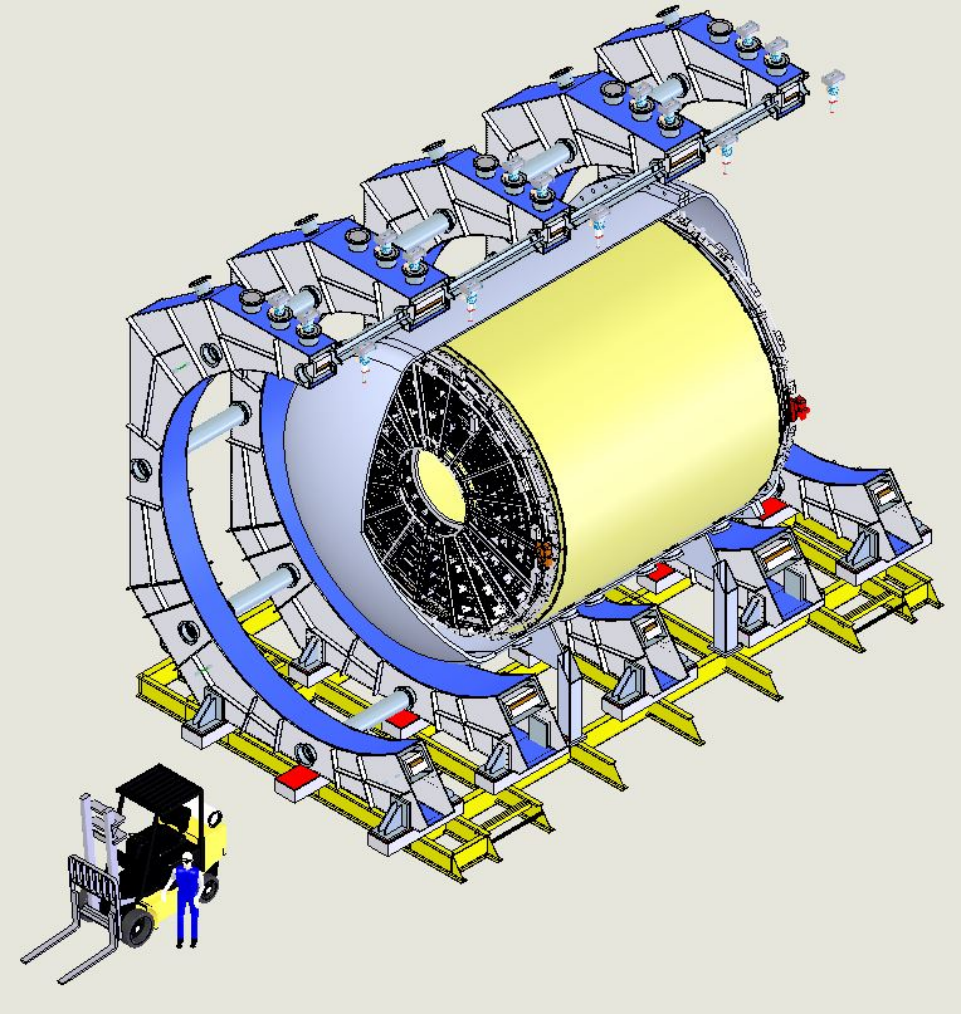


Event category	Number of events per ton-year of argon
ν_μ CC total	1.4 x 10^6
Anti-ν_μ CC total	526k
ν_e CC total	20k
Anti-ν_e CC total	4.8k
ν_μ NC total	476k
Anti-ν_μ NC total	22k
ν_e NC total	4.4k
Anti-ν_e NC total	1k

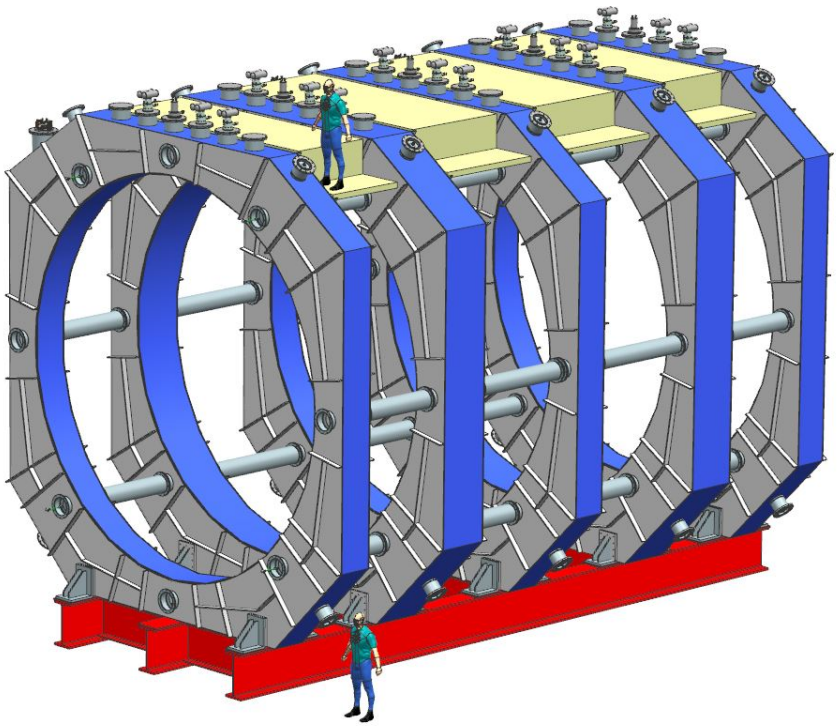
Optimized DUNE flux (Oct 2017), GENIE v2.12.10

MPD Concept

- **Fully active low-density tracker with surrounding EM calorimeter and muon tagger**
- **Open-geometry superconducting magnet**
  - 0.5 T central field
  - Design in progress
  - Alternate designs also under consideration



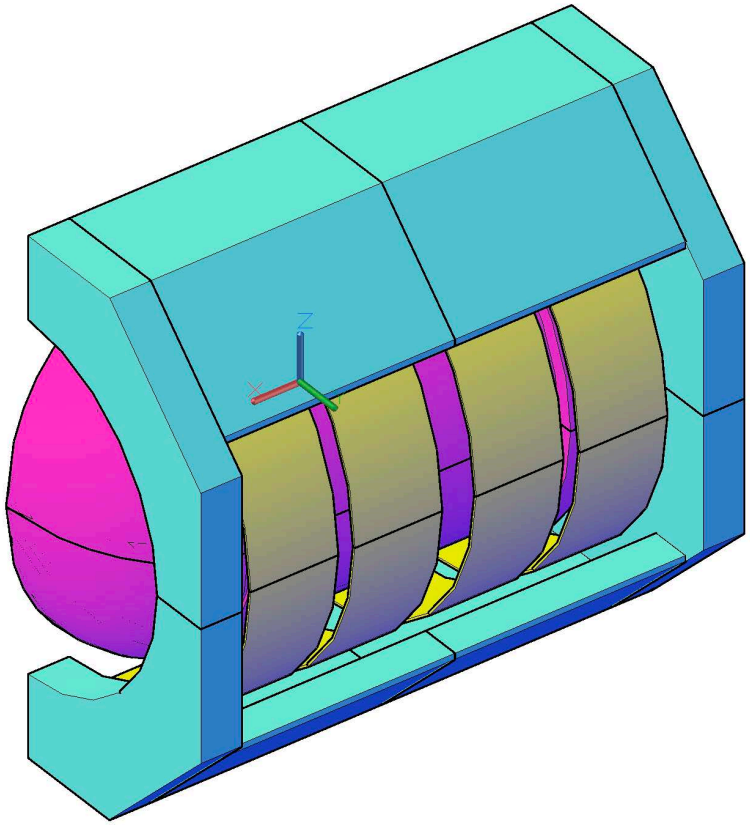
MPD Magnet: Reference Design



- Superconducting 3-coil Helmholtz system with 2 superconducting bucking coils
  - Central field 0.5 T
  - Inner radius 3.5m
- Requirements:
  - Must have large acceptance for particles exiting LAr
  - Must minimize magnet mass

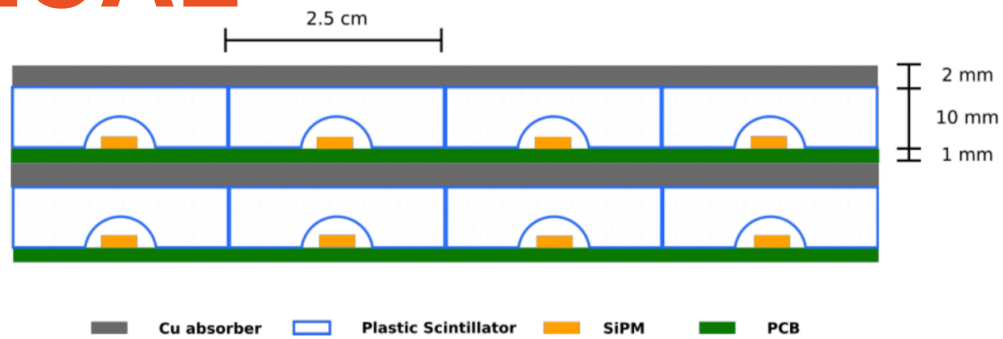
Basic magnetic, cryostat, and structural designs are complete.

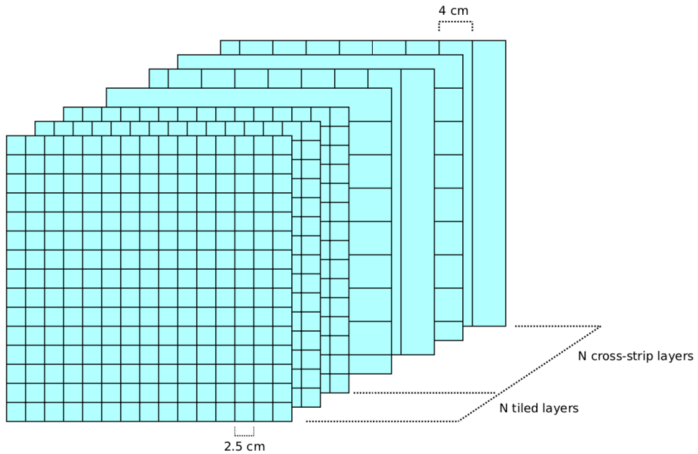
MPD Magnet: Alternate Designs



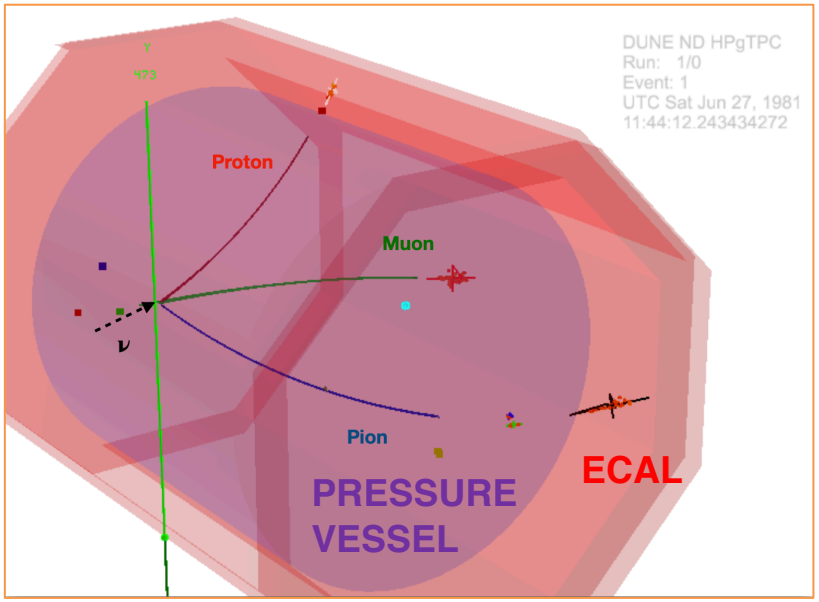
- Alternate magnet designs under investigation
  - Solenoid w/partial return yoke
- More discussion Wednesday

ECAL





Preliminary design inspired by CALICE, with scintillator tiles and strips.
Optimization in progress

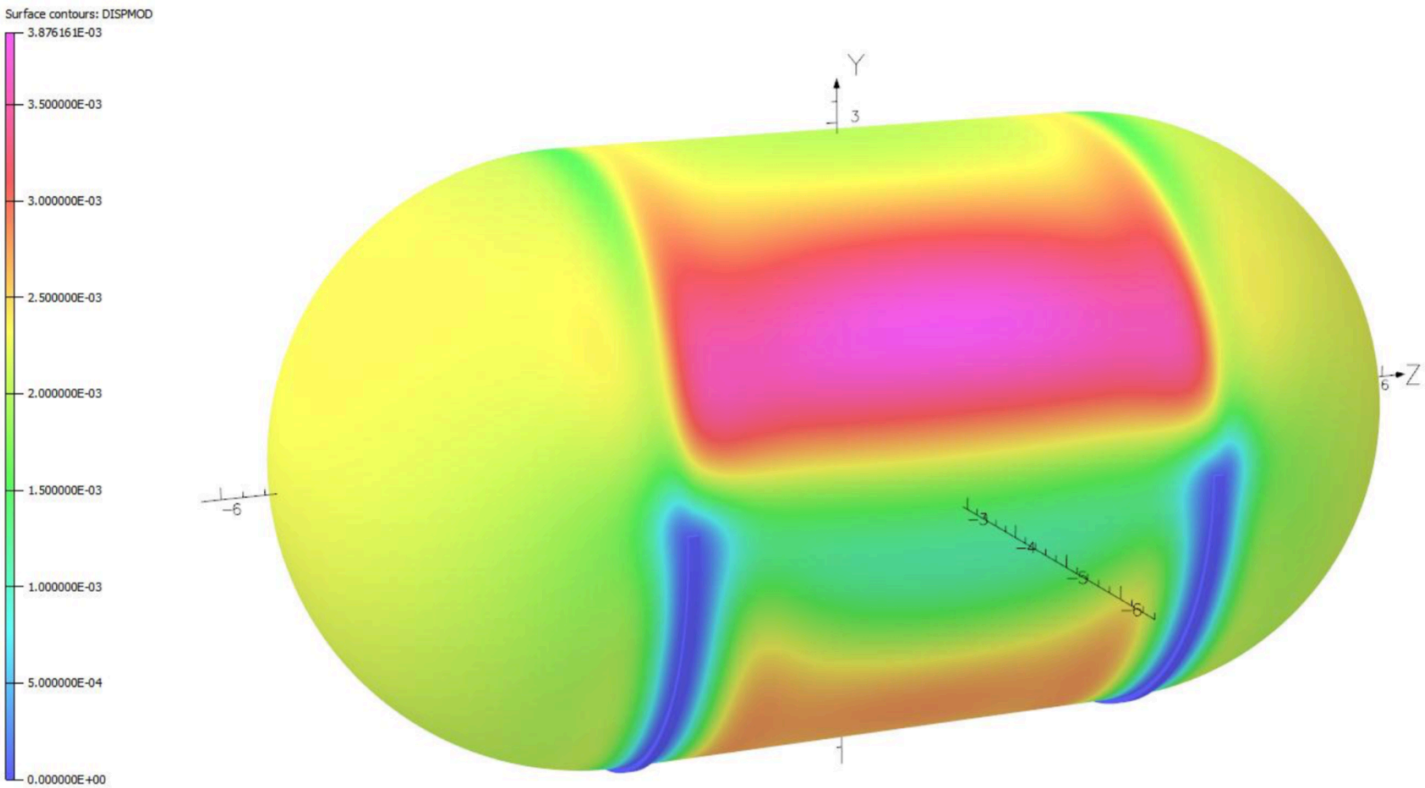


Surrounds the TPC to:

- Provide fast timing t_0 for reconstruction in the gas TPC
- Measure energy and direction of EM showers
  - Tag/reject neutral pions & photons as backgrounds to ν_e
  - Tag/reject external backgrounds
- Measure energetic neutrons

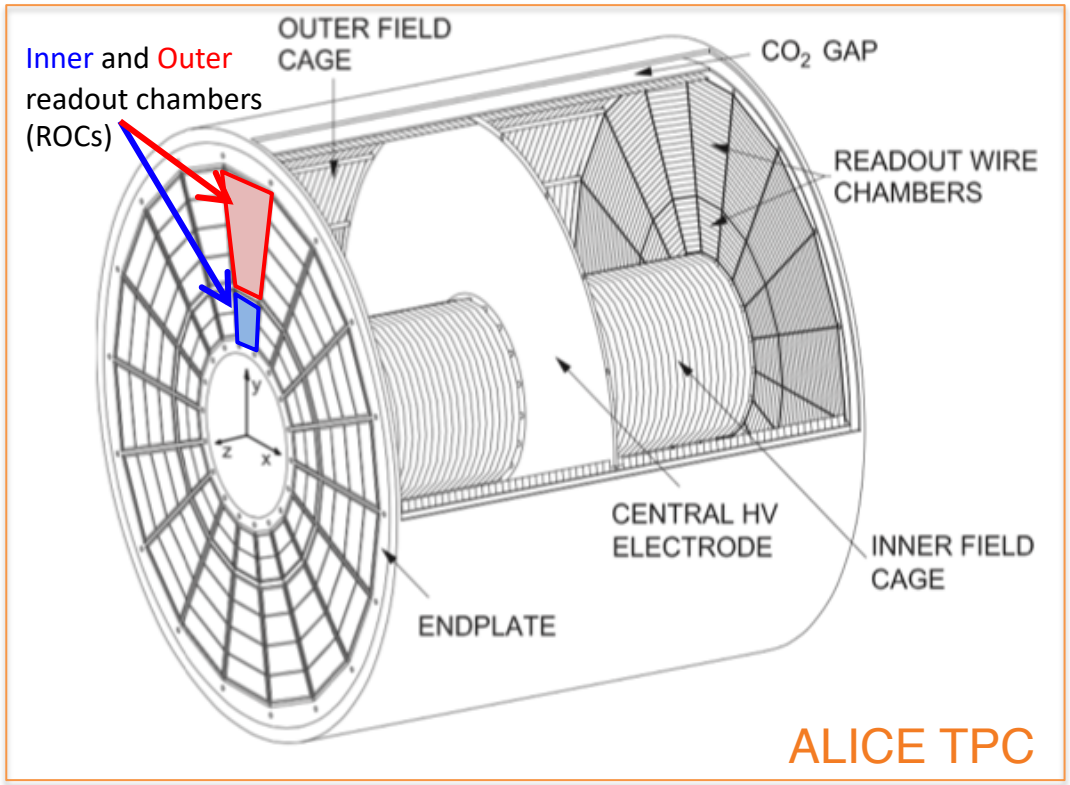
Pressure Vessel

- Pressure vessel design optimization is underway
- So far, have achieved significant reduction in thickness of pressure vessel walls (~0.4 X_0, with Al alloy and structural ribs)



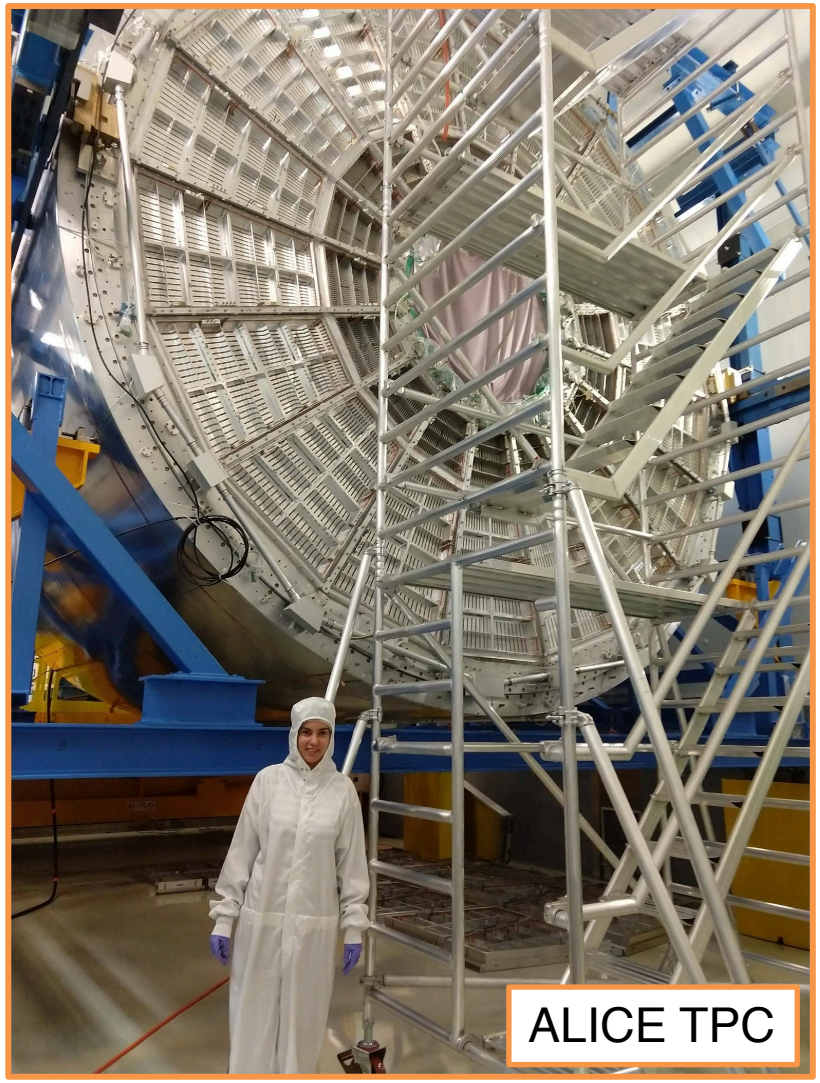
High-Pressure Gaseous Argon TPC

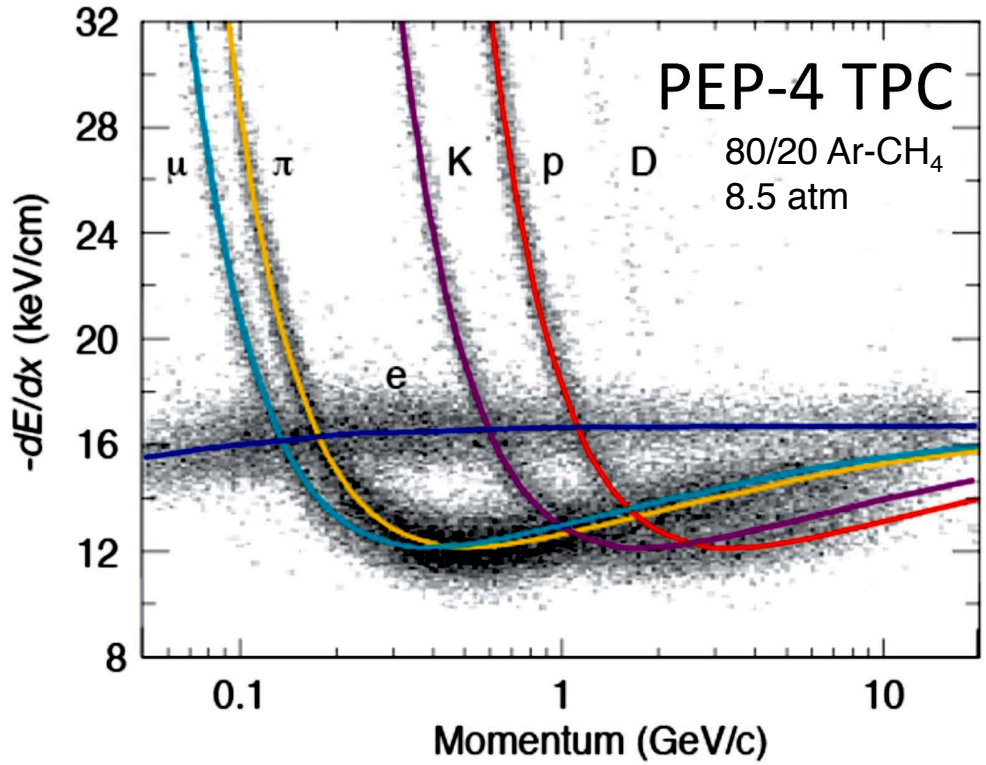
- For a reasonable neutrino sample size, would like ~1-ton fiducial mass
  - But also need to keep the TPC to a reasonable size → pressurize the gas
  - At 10 atm pressure: 1.5M CC ν_μ events per ton-year



- Assuming we can operate at 10 atm, the ALICE TPC is about the right size…
  - Geometrically, 5m diameter & 5m length gives good coverage of particles exiting the LArTPC
  - With the ALICE upgrade to GEM Readout Chambers (ROCs) this past summer, **the original MWPC ROCs are now available for reuse**

High-Pressure Gaseous Argon TPC

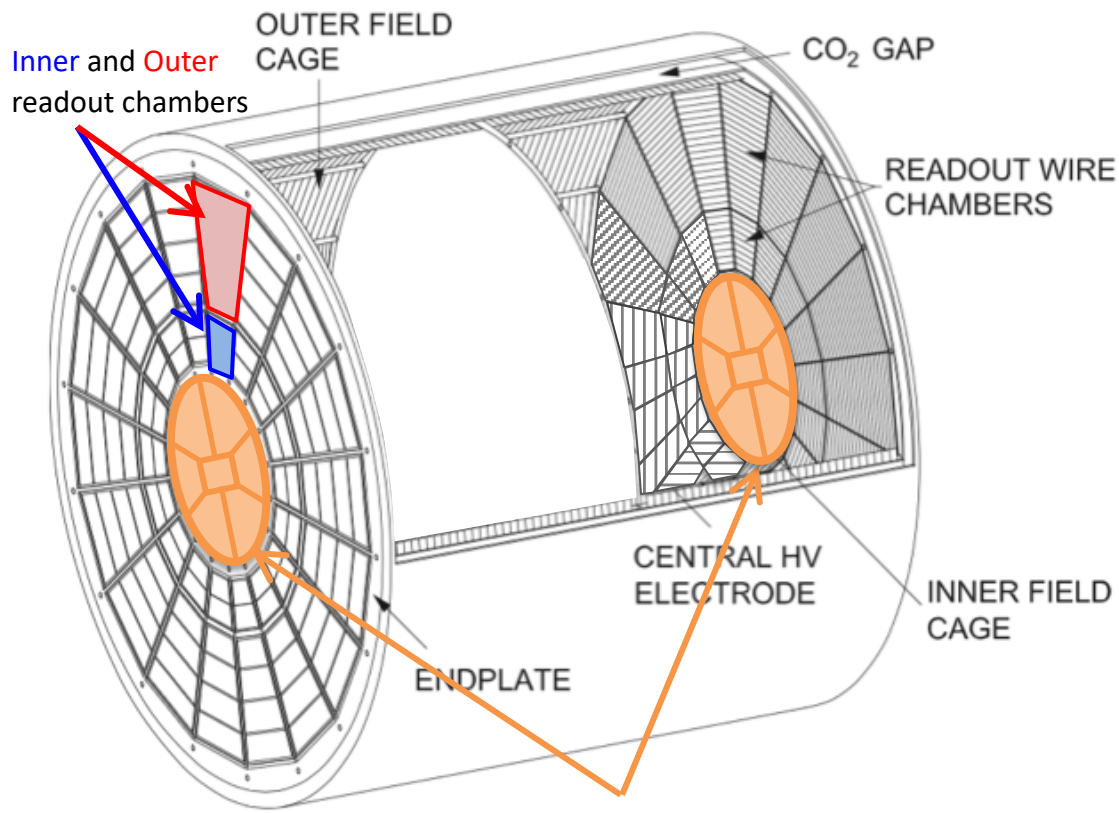




Expect ~ 2% dE/dx resolution based on PEP-4

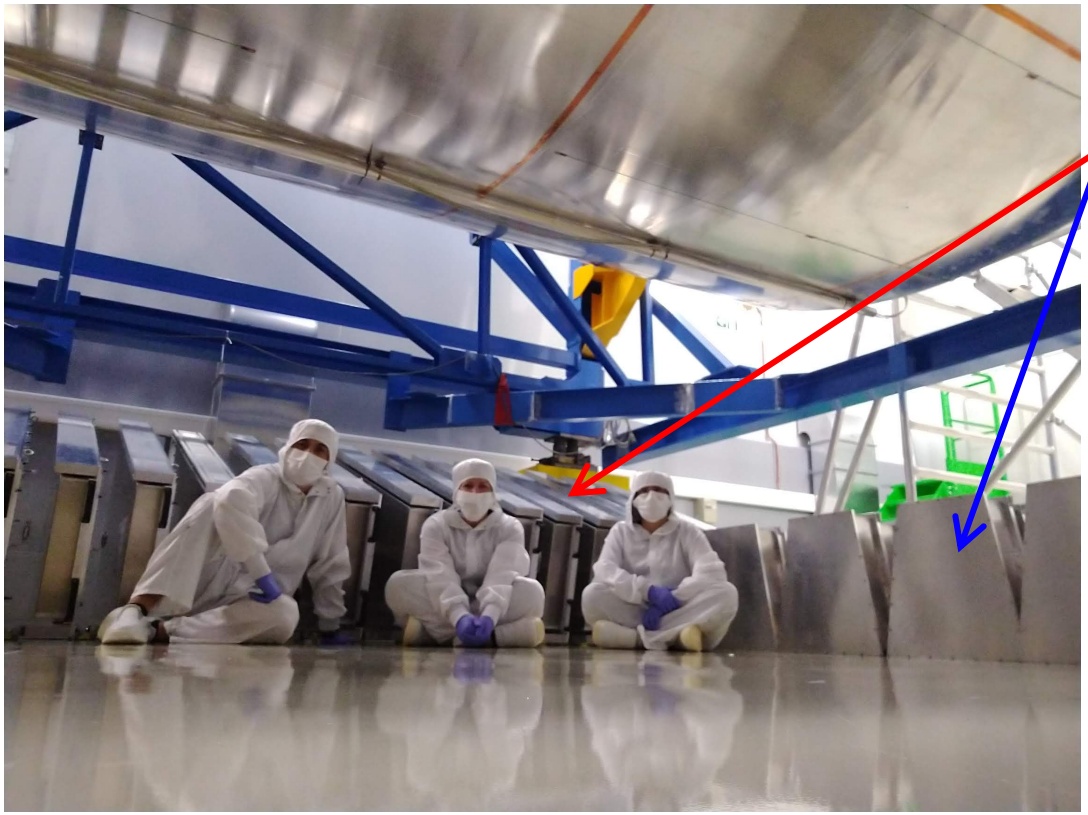
DUNE's HPgTPC: a new purpose for ALICE's old ROCs

- **ALICE-like TPC, with a few modifications**
  - Need to build new readout chambers to fill the central region of each endcap
  - No inner field cage
  - Hosted inside a pressure vessel
- **At 10 atm, the DUNE HPgTPC would have 1.8 tons active mass (1-ton fiducial)**
  - Base assumption for gas mixture 90/10 Ar/CH_4
  - 97% of neutrino interactions are on Ar nuclei

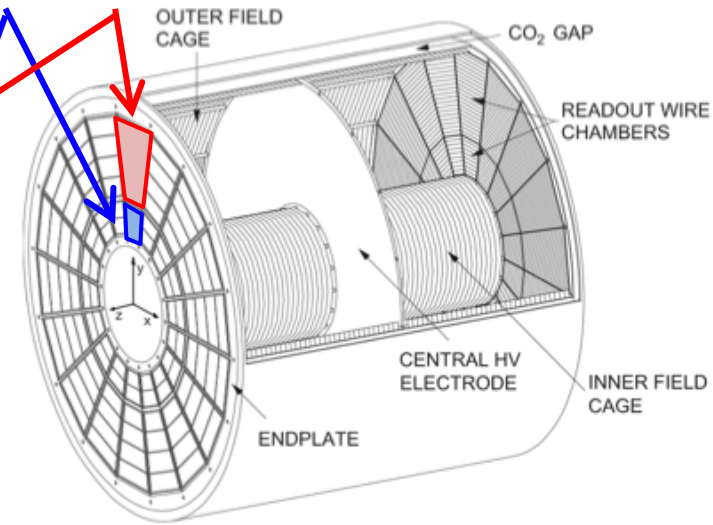


New Central Readout Chambers to be designed and built

Readout Chambers



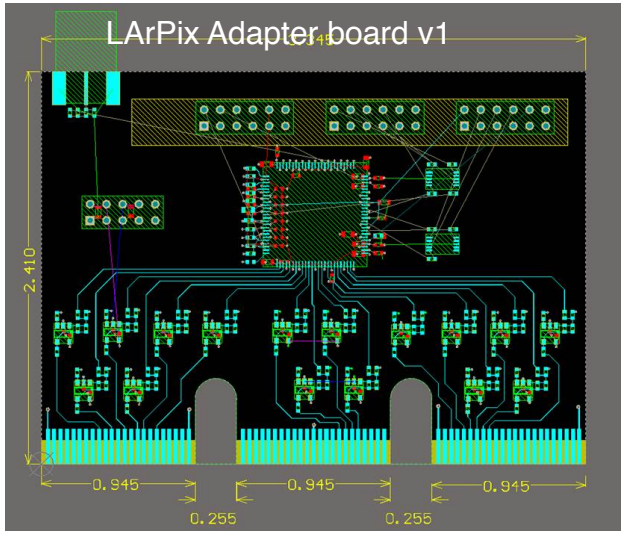
Inner and Outer readout chambers

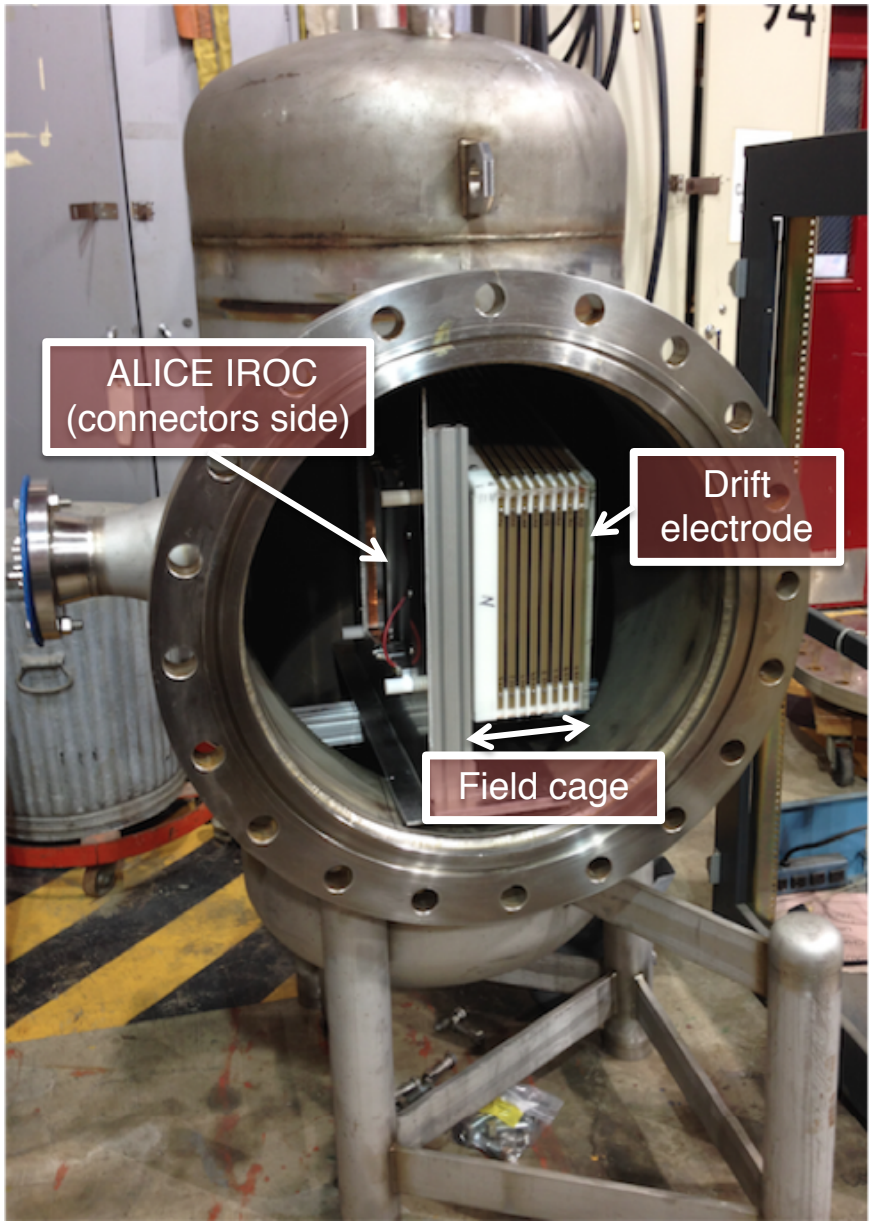


- This summer, DUNE team acquired all 36 inner readout chambers + 36 outer readout chambers

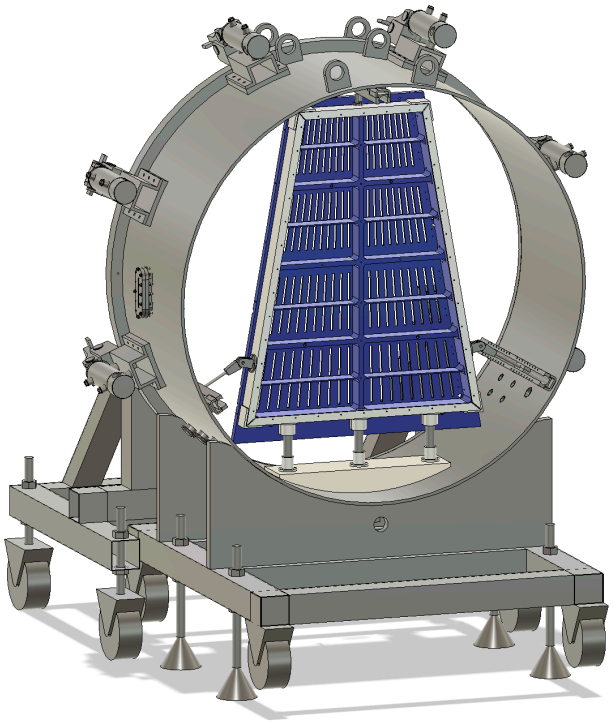
IROC Test Stand

- At Fermilab
  - Pressure vessel rated to 10 atmospheres
  - Can accommodate 1 IROC with a short (~10 cm) drift region
- Planned tests
  - Verify high-pressure operation
  - Gas gain & gas mixture tests
  - Development of full readout chain, synergistic with LArTPC readout (LArPix ASIC developed at LBNL)





OROC Test Stand

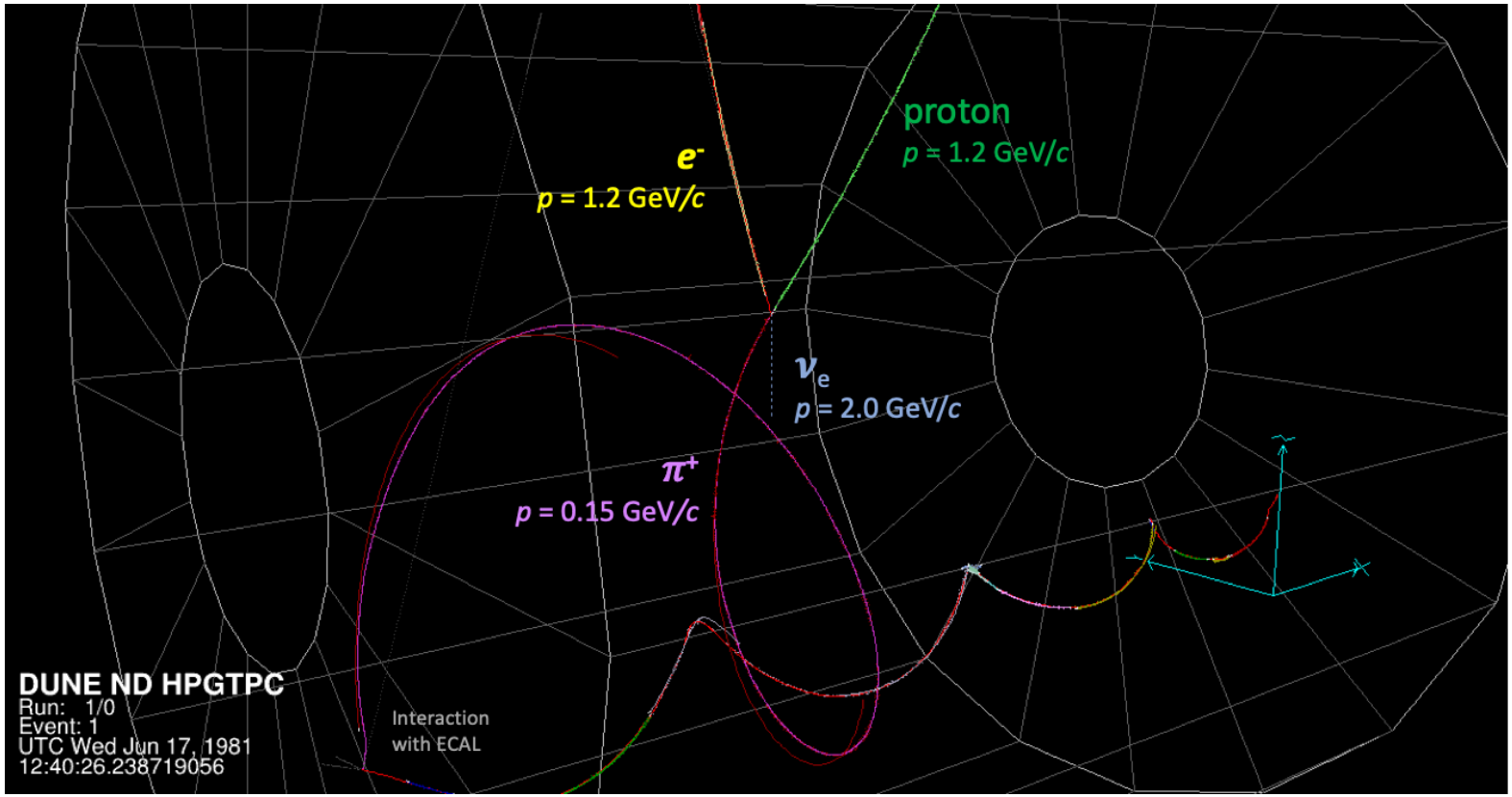


- At Royal Holloway University of London
  - Pressure vessel rated to 5 atmospheres
  - Can accommodate 1 OROC and a ~40 cm drift region
- Planned tests
  - Verify high-pressure operation
  - Gas gain & gas mixture tests
  - Readout via Imperial College London cards based on the CMS APV25 chip

MPD Software/Simulations

- Two main efforts
  - **GArSoft framework with full reconstruction and start at PID**
    - Many parts in place: event generation, geometry, particle interactions and energy deposition, drift & diffusion, digitization, hit-finding and clustering, pattern recognition, track fitting, ECAL digitization, ECAL reconstruction, ionization-based PID, deep learning algorithms for very short tracks, preliminary vertex-finding, preliminary TPC-ECAL track matching
    - Still to do: TPC field response and electronics response, optimization of pattern recognition, optimization of track fitting, optimization of TPC-ECAL track matching, full ECAL energy reconstruction
    - Several MPD stand-alone analyses underway with these tools
  - **Parameterized MPD reconstruction & PID**
    - ND Software Integration group has been working to put in place a full spill simulation with all near detector components and surrounding rock
    - Parameterization of “reco” variables used as input for long baseline analysis and for other analyses

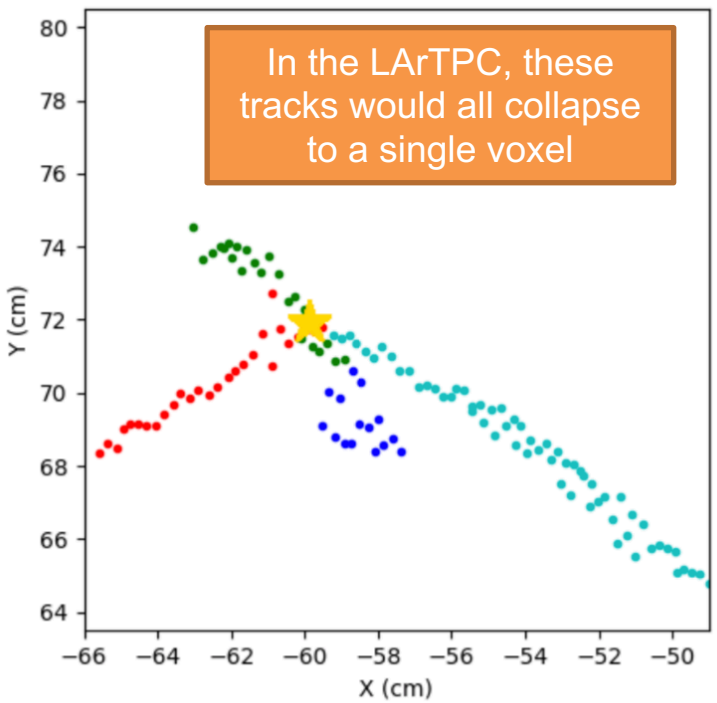
Event Reconstruction

- 

Fully reconstructed neutrino interaction in HPgTPC using GArSoft

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

Summary

The DUNE MPD is planned to be a highly capable detector that:

- Provides a large acceptance muon spectrometer for the LAr detector with minimal dead material between LAr and HPgTPC
- Collects a statistically significant independent sample of neutrino interactions on argon gas
  - precise view of *ν*-Ar interactions with very low threshold, sign selection, and minimal secondary effects
- Provides capability to tag and analyze all components of the neutrino beam (ν_μ, anti-ν_μ, ν_e, anti-ν_e)

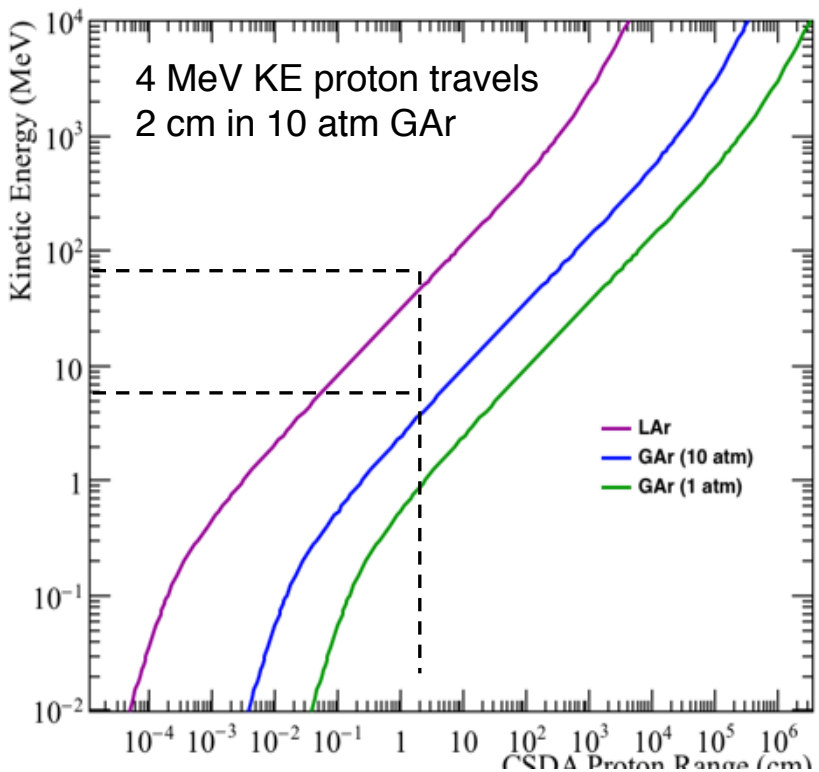
Thank you!

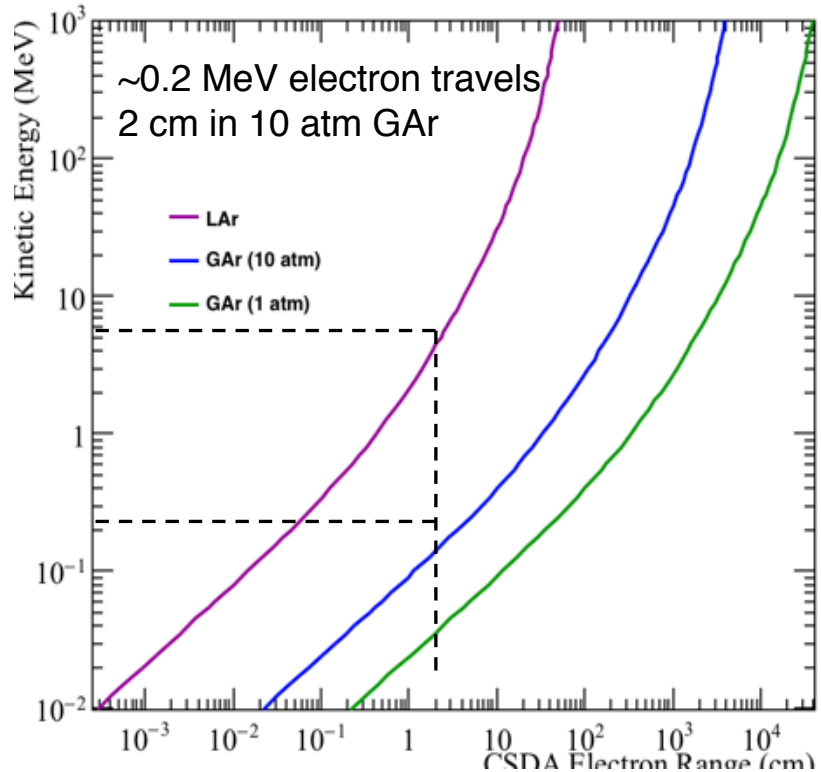
Extras

Table 4.2: Readout pads.

	Pad size [mm^2]	Number of rows	Number of pads
Inner chamber ($84.1 < r < 132.1$ cm)	4×7.5	64	5 732
Outer chamber ($134.6 < r < 198.6$ cm)	6×10	64	6 038
Outer chamber ($198.6 < r < 246.6$ cm)	6×15	32	4 072
TPC total		160	570 312

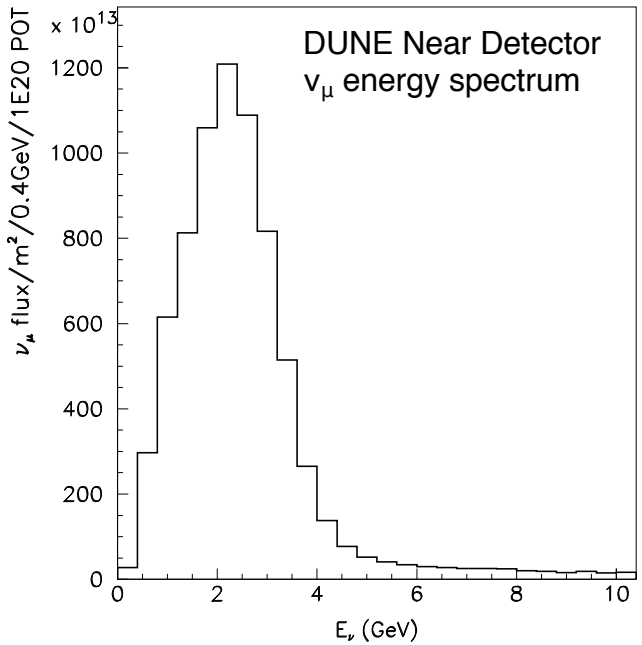
LAr vs. GAr range

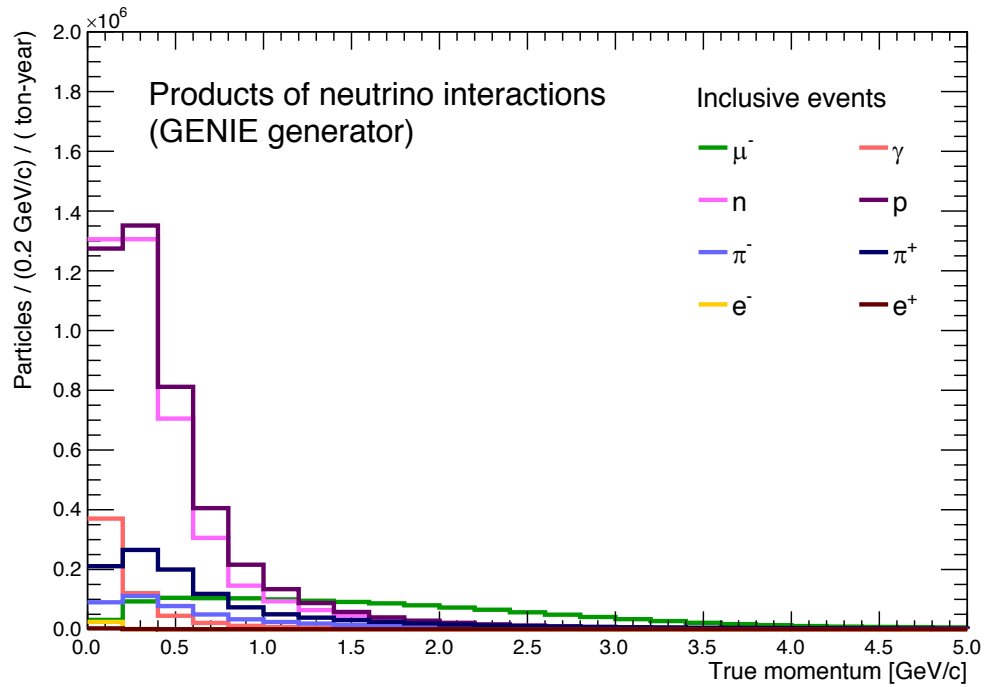




- Lower density allows lower thresholds for identifying and reconstructing tracks
  - Better measurements of low energy particles ejected in neutrino interactions → improvements to neutrino interaction generators

Expected energy spectra





- We can only detect the *products* of the neutrino interactions and reconstruct the neutrino energy from these outgoing particles
- Most interaction products have momenta < 1 GeV/c
  - Need a low density tracker to successfully measure the lowest energy interaction products
  - But must balance desire for low density with need for high statistics (1 atm pressure in an ALICE-sized TPC would not provide enough neutrino interactions → must go to higher pressure)

Purpose/Goals of the MPD

Measure particles that leave the LArTPC and enter the MPD

- Forward-going muons are not well contained by the LAr

Provide data to constrain neutrino-nucleus interaction systematic uncertainties

- Independent sample of neutrino events on same (argon) target nucleus
- Lower energy particle detection thresholds than LAr

Precisely and accurately measure all components of the flux (ν_μ, $\overline{\nu_\mu}$, ν_e, $\overline{\nu_e}$)

- Event-by-event sign selection
- ν_e / $\overline{\nu_e}$ separation

Reconstruct neutrino energy via spectrometry and calorimetry

Constrain LArTPC detector response and selection efficiency

Measure energetic neutrons from neutrino-argon interactions via TOF with the ECAL (desired)