
High-pressure gaseous argon

in the DUNE near detector

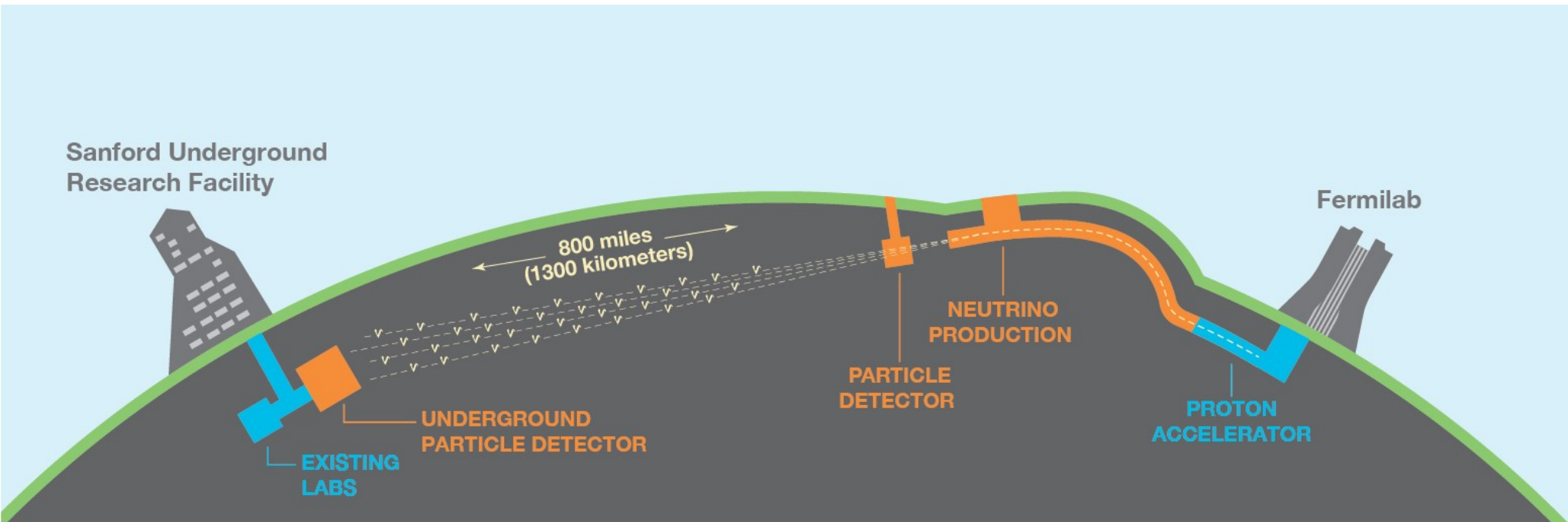
Andy Furmanski, on behalf of the DUNE collaboration
CPAD 2019
Madison, Wisconsin



DUNE

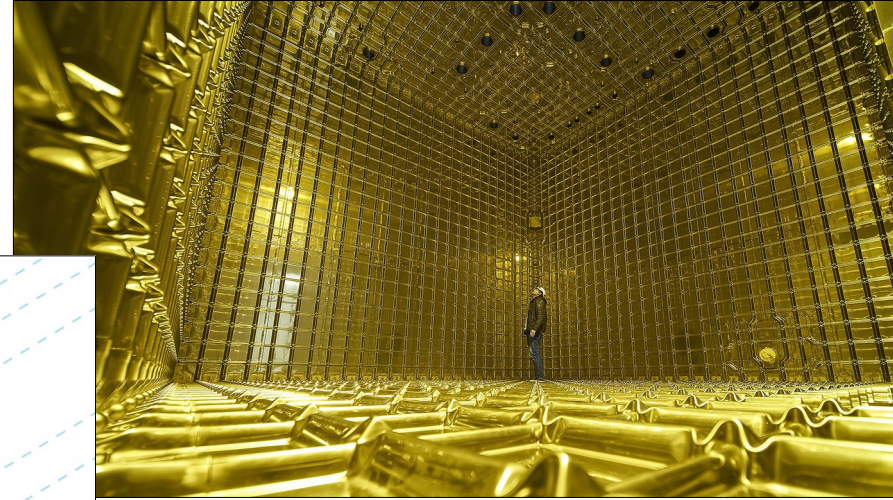
Deep Underground Neutrino Experiment:

Next-gen long-baseline neutrino oscillation experiment running from Fermilab (Illinois) to SURF (South Dakota)



The DUNE far detector

- 40 kt of liquid argon (fiducial)
- 1 mile underground
- 1300 km from beam source



Long-Baseline Neutrino Facility
South Dakota Site

Ross Shaft
1.5 km to surface

Neutrinos from
Fermi National
Accelerator Laboratory
in Illinois

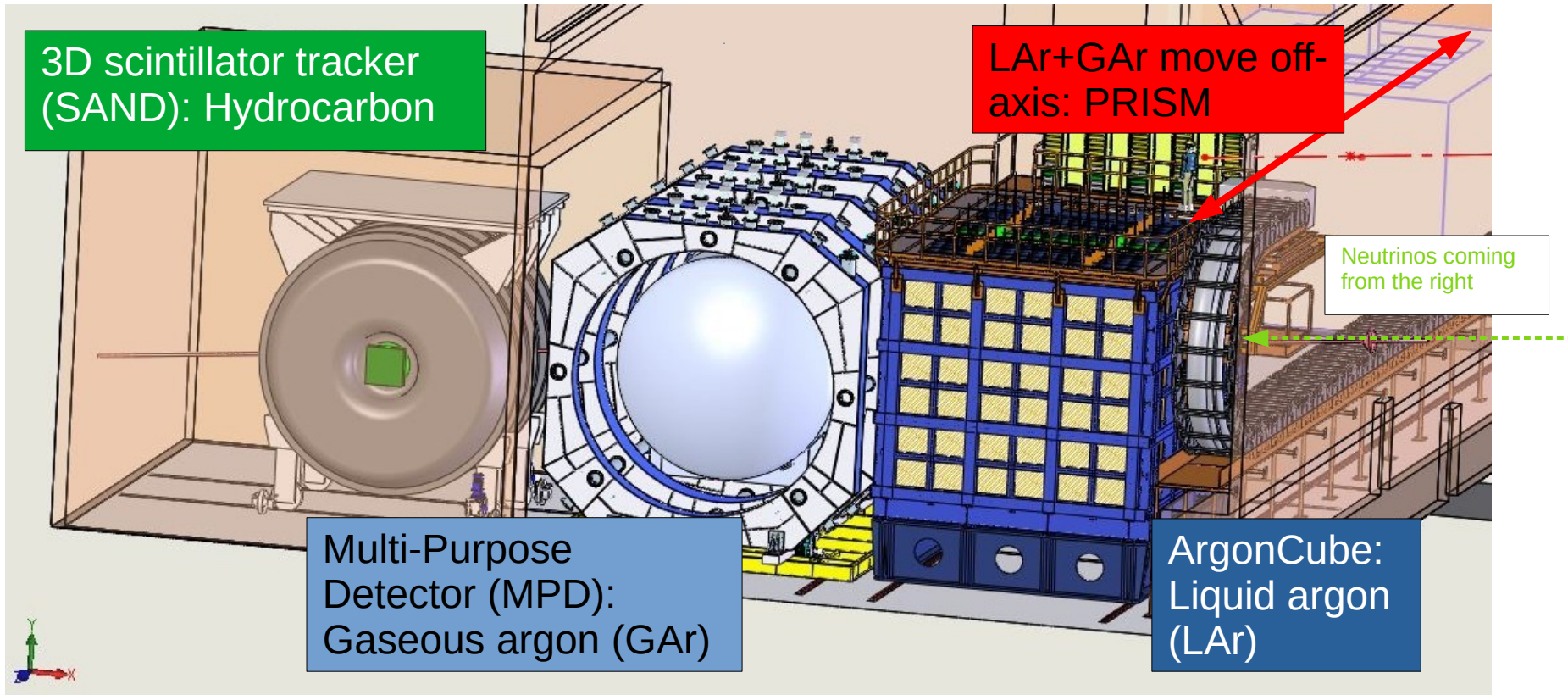
Facility
and cryogenic
support systems

One of four
detector modules of the
Deep Underground
Neutrino Experiment

4850 Level of
Sanford Underground
Research Facility

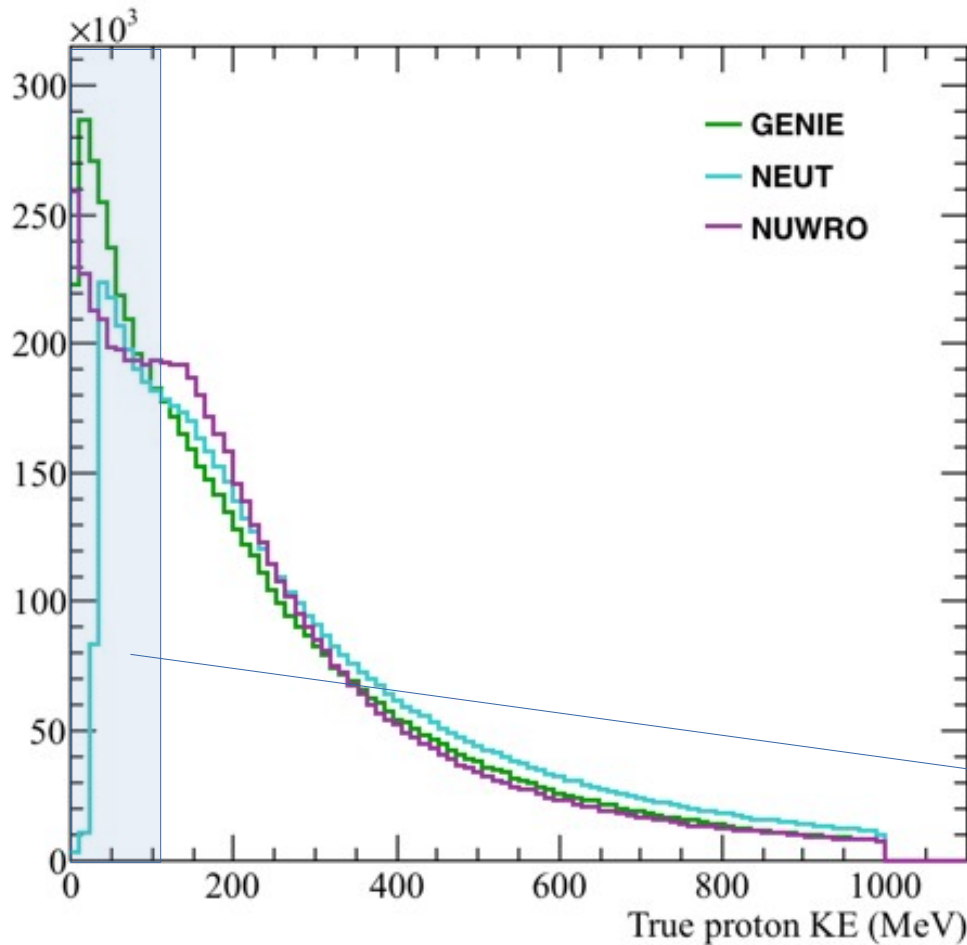


The DUNE near detector

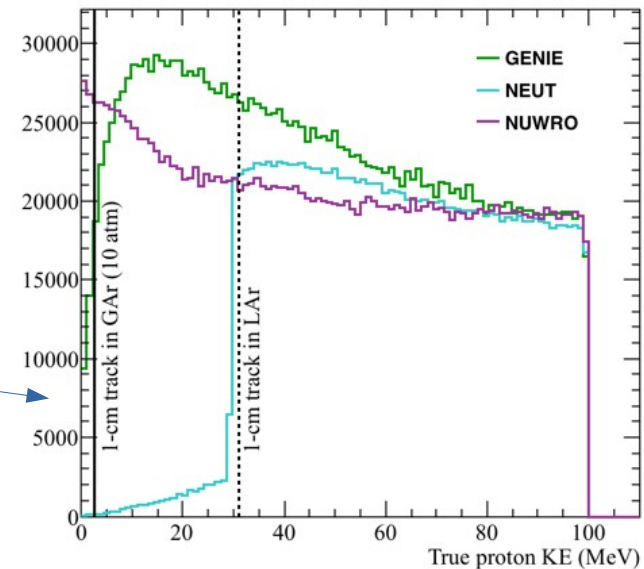


A highly capable near detector complex is critical for reducing flux and cross section uncertainties for DUNE's physics goals!

Why use a gas detector?

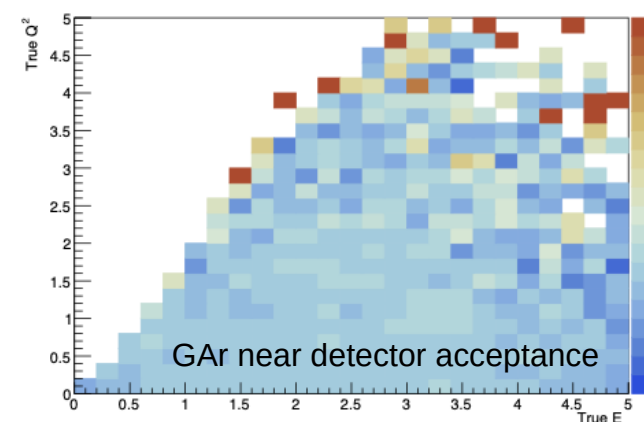
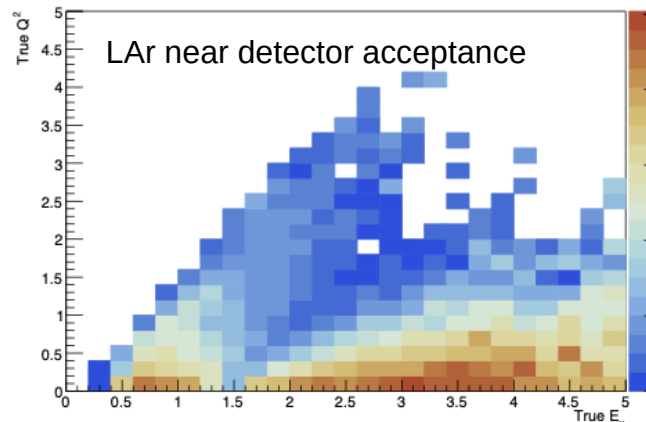
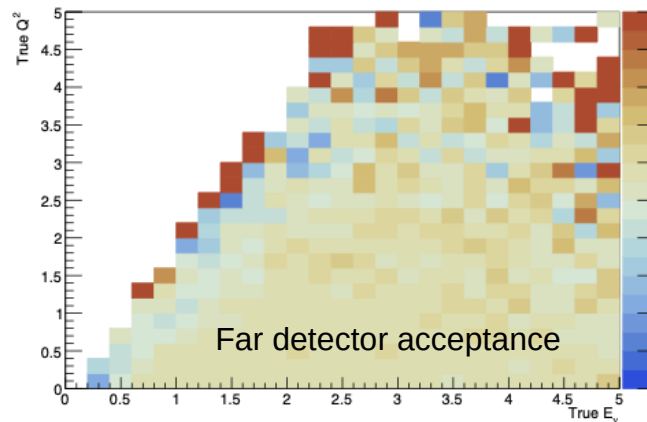


- Gas detector provides:
 - **Lower thresholds**
 - Fewer showers
 - Better hadron and electron energy measurements
 - Photons, neutrons need an ECAL
- **Complementary measurements** to the liquid



More reasons to use gas!

- Even angular acceptance
 - Magnet provides good momentum measurement for all particles
 - Liquid near detector is too small to contain many events
- **Cross-check acceptance/efficiency** and model dependence



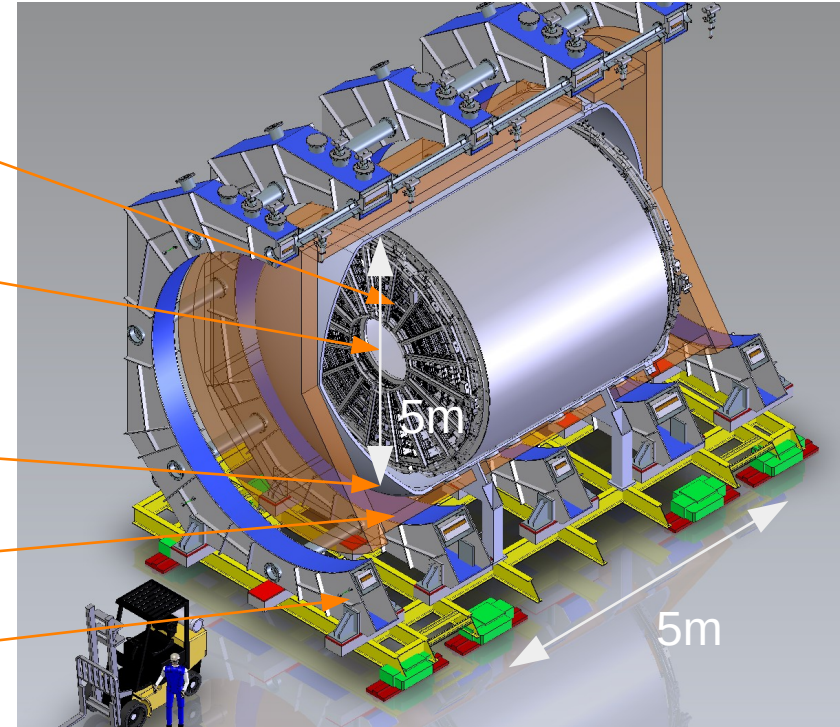
MPD - requirements

- As a muon spectrometer:
 - Reasonable momentum resolution → magnet for curvature
 - Particle ID
 - Cross-sectional area matched to LAr
- As a neutrino target:
 - 1000 kg fiducial mass of argon → high pressure
 - Measure photons, neutrons → ECAL
 - Excellent PID
 - Low thresholds (few-MeV for protons) → spatial resolution

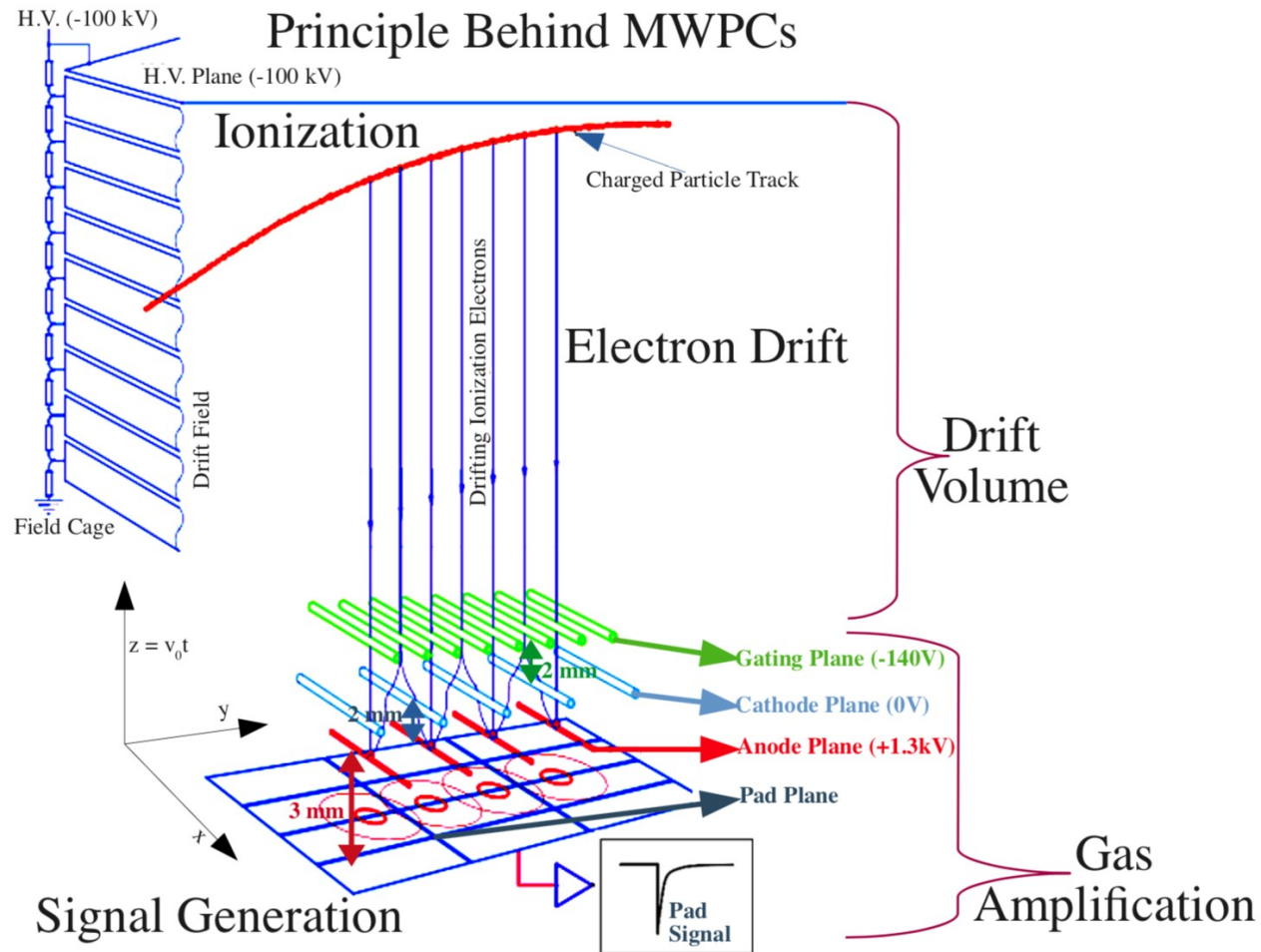


MPD baseline design

- Re-use the ALICE TPC readout chambers (already in-hand)
- New central readout chambers
 - New field cage, support structure, etc
- Pressure vessel at 10atm
- Surrounding ECAL (from new)
- Magnet (multiple designs being considered)
 - Will be instrumented as a muon catcher

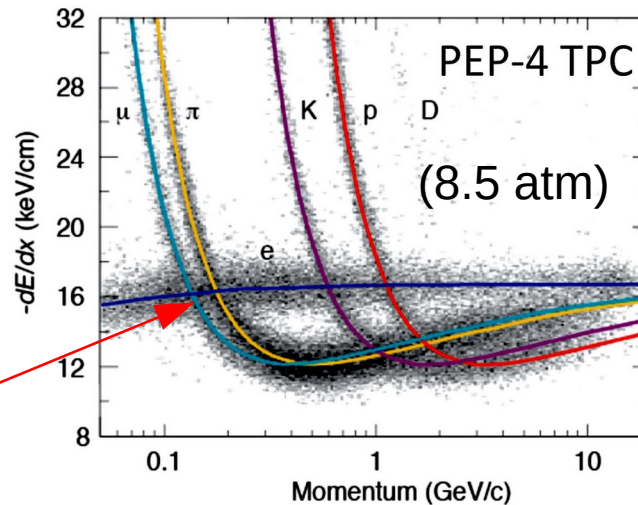


Gas readout



Gas TPC expected performance

- Few-percent momentum resolution ($\sim 3\%$ below 1 GeV)
 - ALICE achieved $< 1\%$
- Few-percent dE/dx measurements



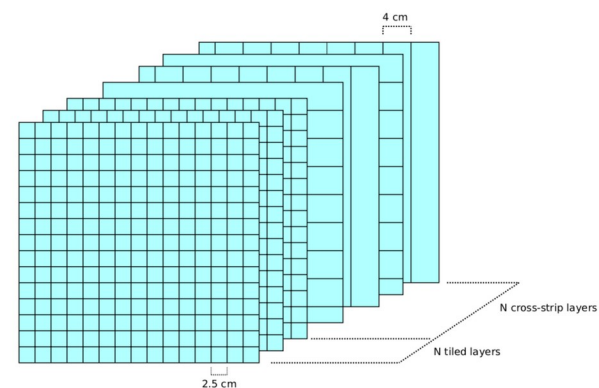
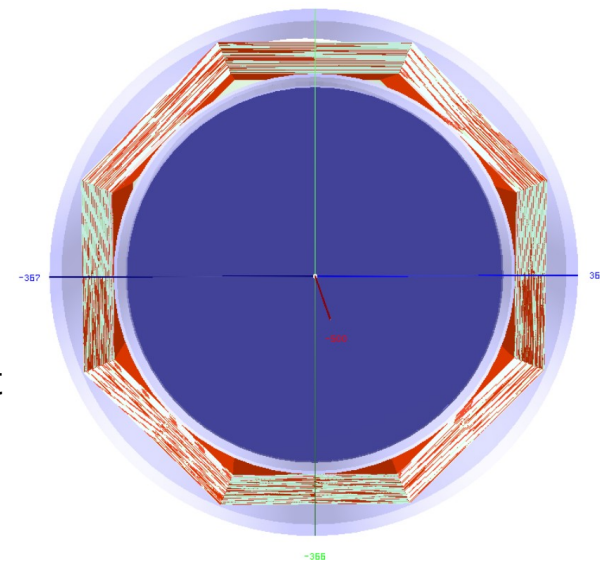
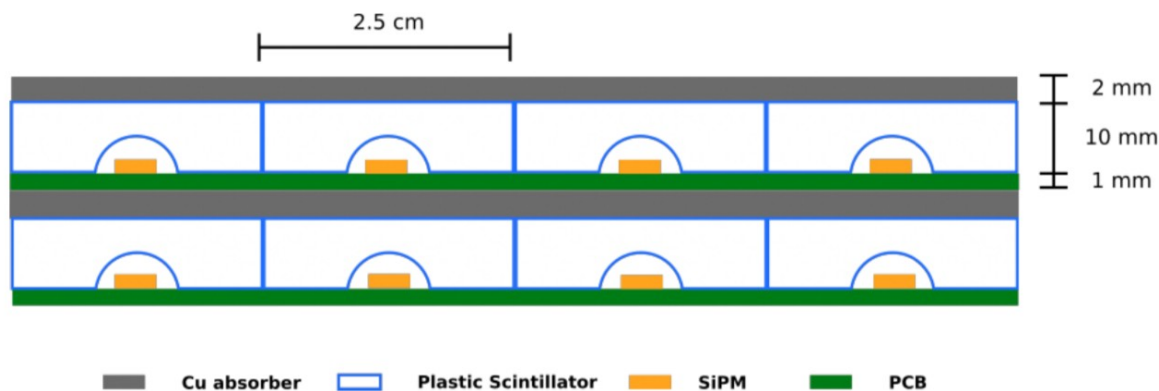
ECAL/muID used to ID particles where these lines crossed

DUNE baseline design uses the same 90:10 Ar:CH₄ mixture as PEP-4



ECAL design

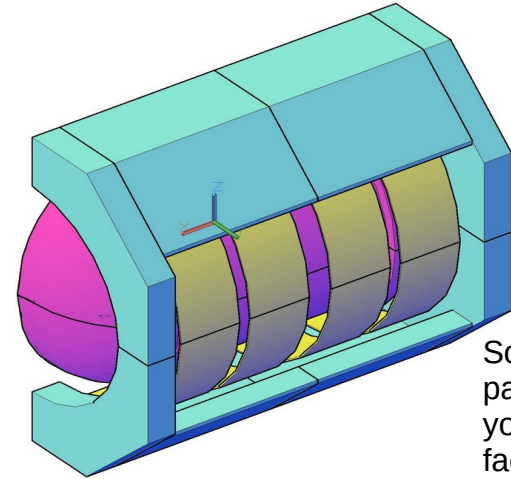
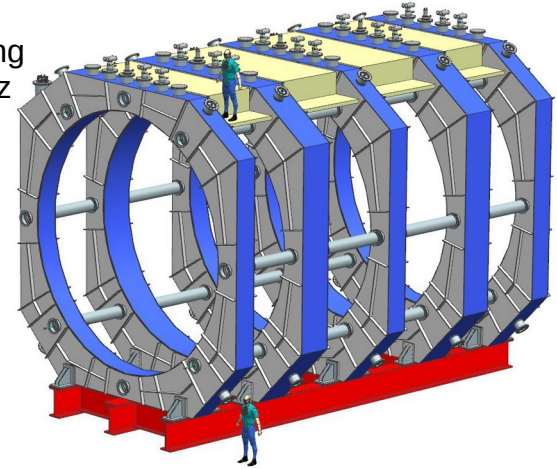
- Based on CALICE design
- Combination of scintillator tiles (inner) and strips (outer)
 - High-granularity inner provides photon direction and good energy resolution
- Fast timing for t_0 for TPC
 - Maybe neutron TOF too → leads to O(ns) timing resolution requirement
- Optimisation in progress
- ~50% of pions won't interact in the ECAL



Magnet design

- Exploring various options
- Considerations:
 - Field uniformity
 - Stray field
 - Total space needed
 - **Material between liquid and gas**
- Instrument magnet as a muon catcher
 - Solves the mu/pi problem in the ECAL

Superconducting
3-coil Helmholtz
with 2 bucking
coils

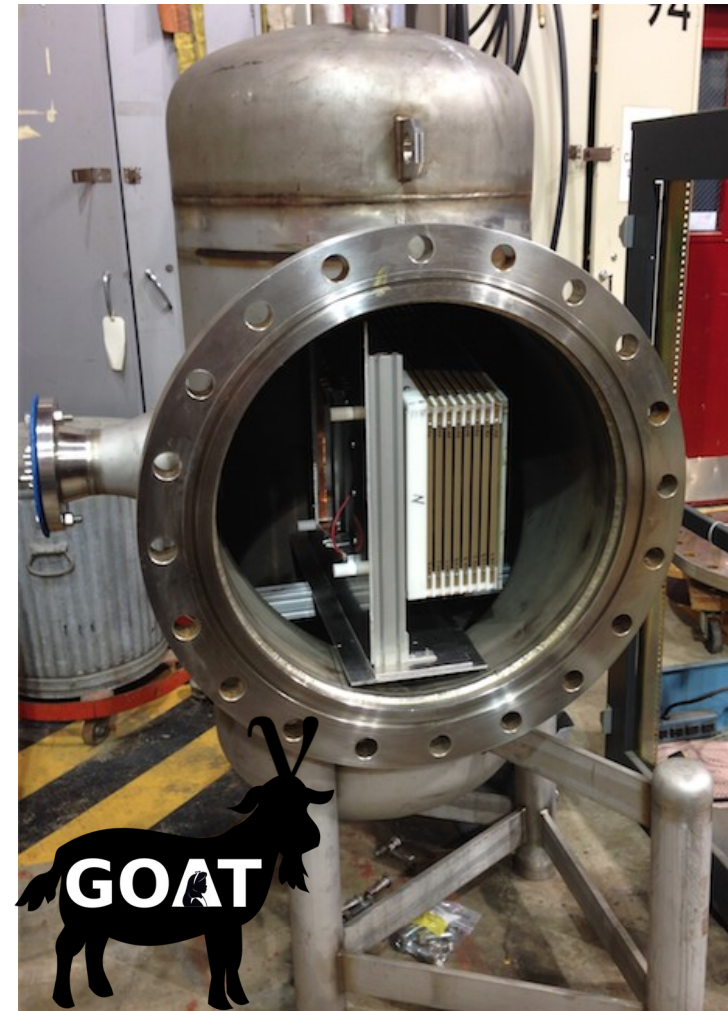


Solenoid with
partial return
yoke (no front
face)

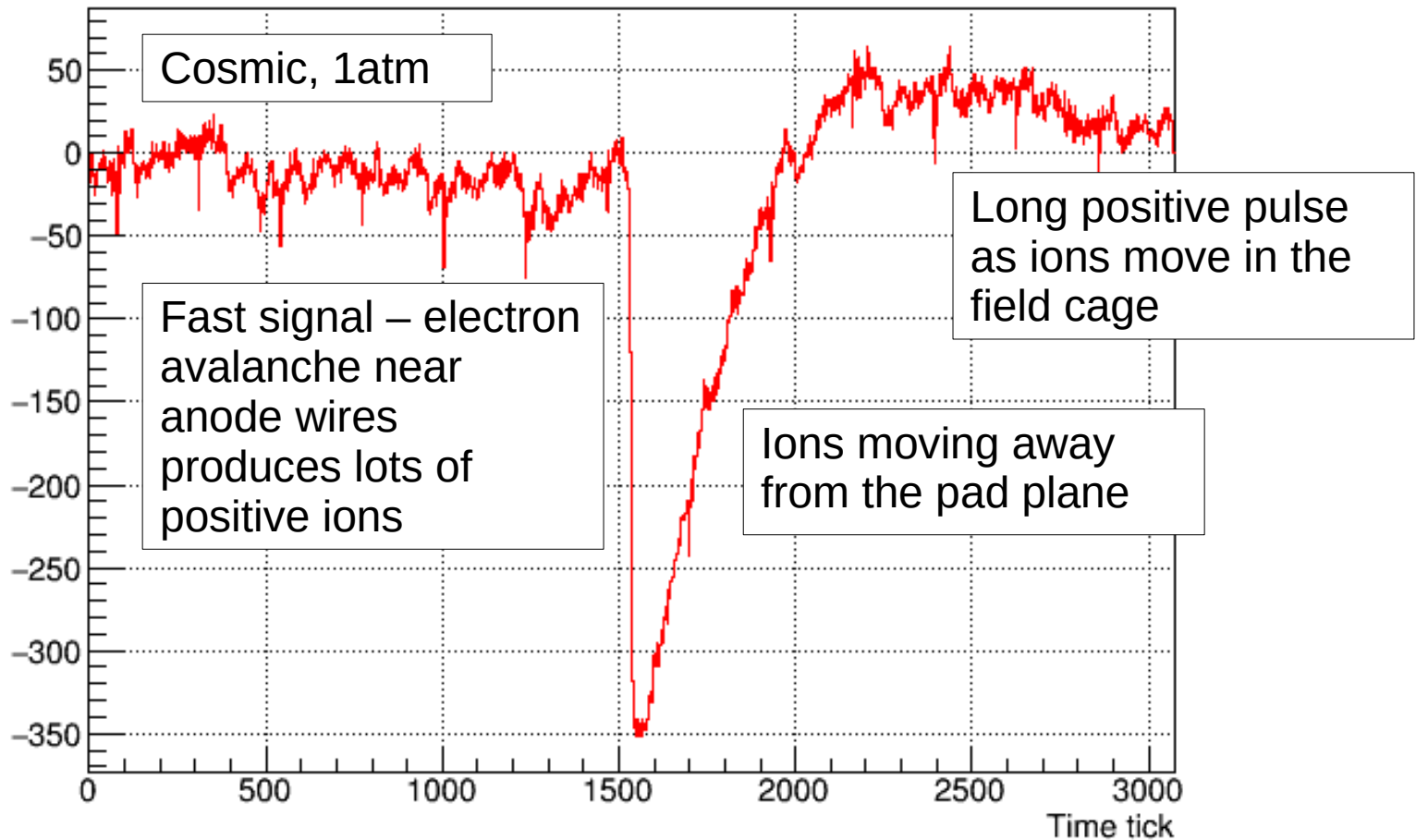


R&D – FNAL test-stand

- Test at FNAL:
 - Using one of the ALICE inner chambers
 - Small field cage and cathode to form drift region
 - Pressure vessel rated to 10 atm
- Planned measurements:
 - Gas gain for different gas mixtures at various pressures
 - Demonstrate successful drift and readout at 10 atmospheres!
 - Currently operated up to 5 atm
 - Test of readout electronics planned for use (as much overlap with liquid as possible)
 - LArPix, Qpix?

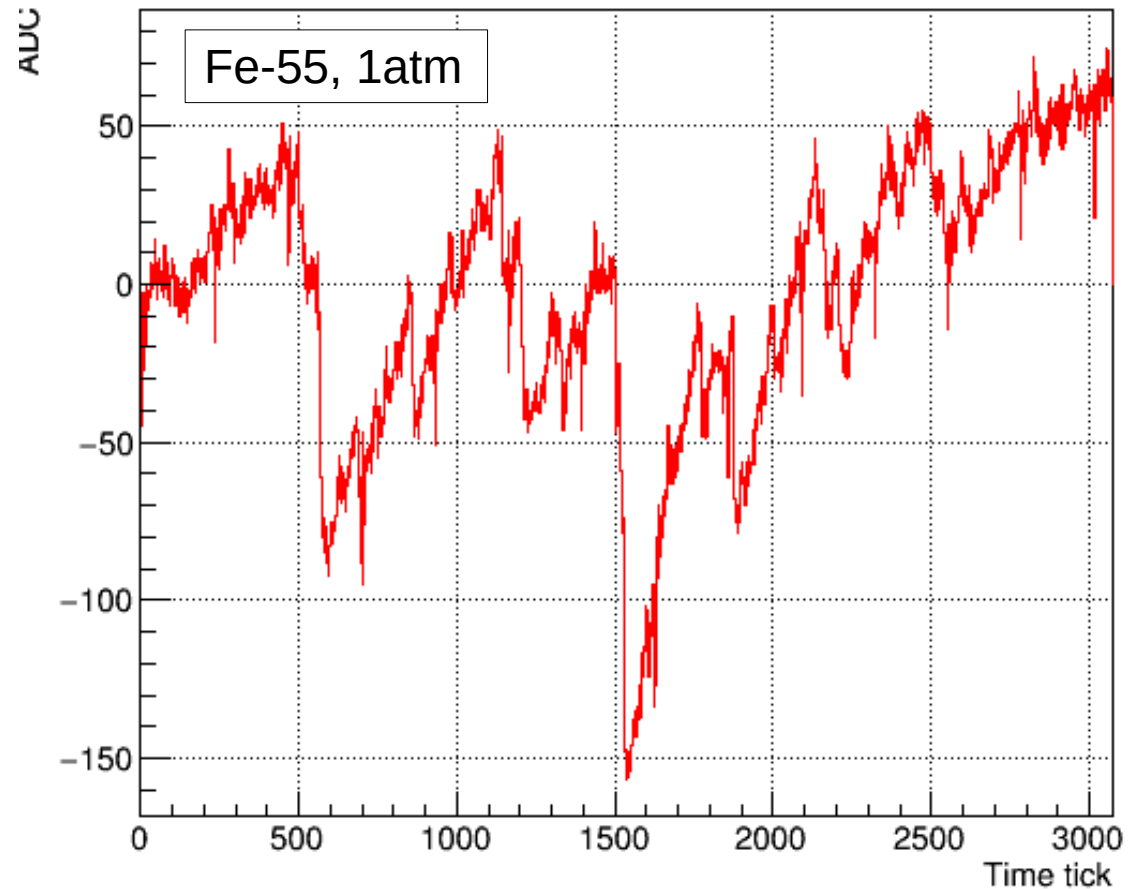


First pulses



Iron-55 source pulses

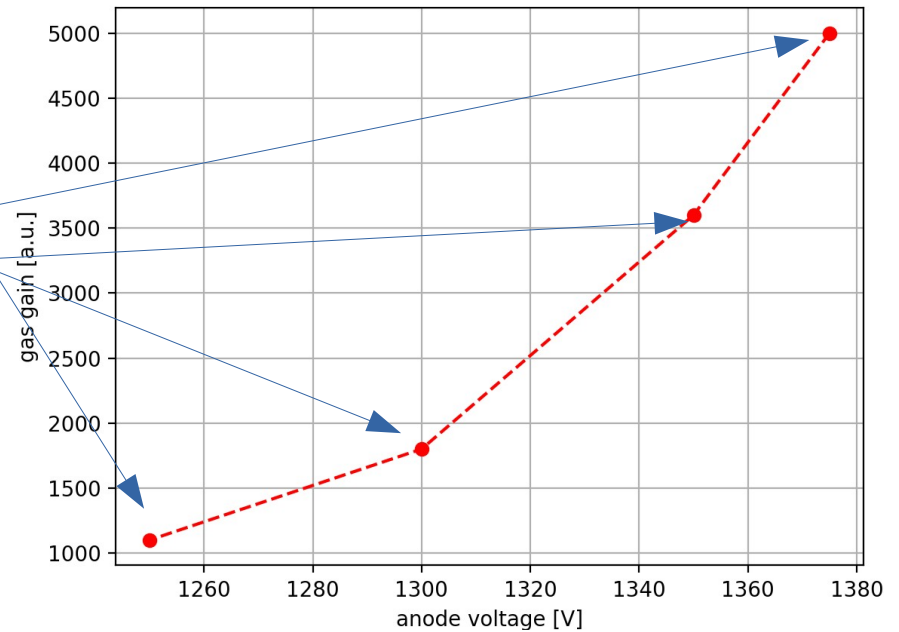
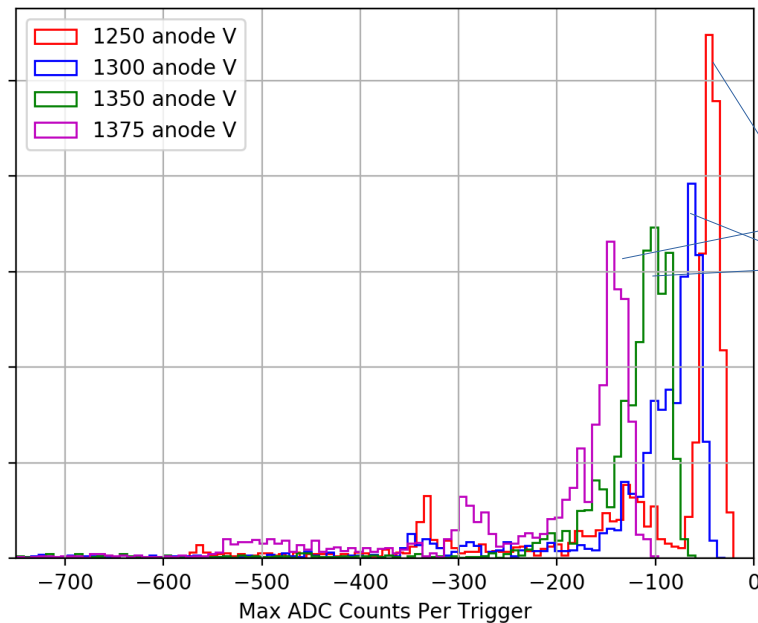
- Fe-55 source (X-rays)
- Frequently observe multiple pulses close together



Preliminary gain measurement

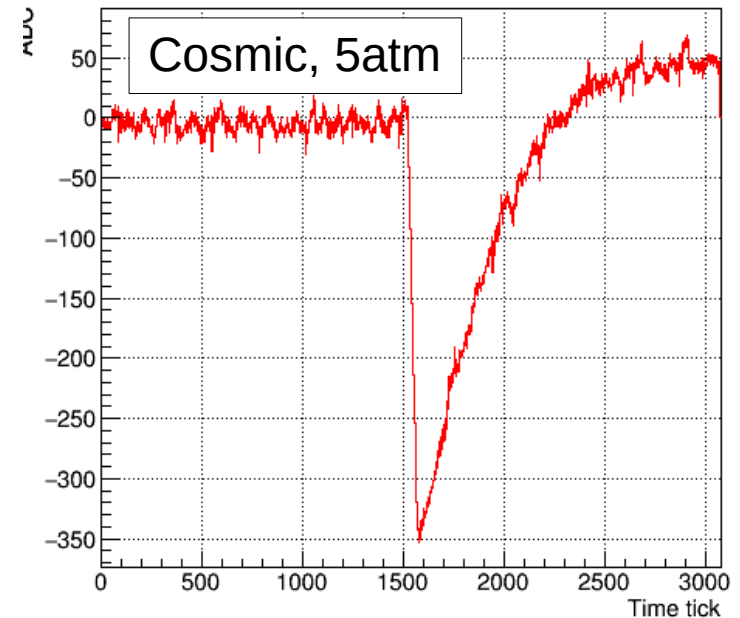
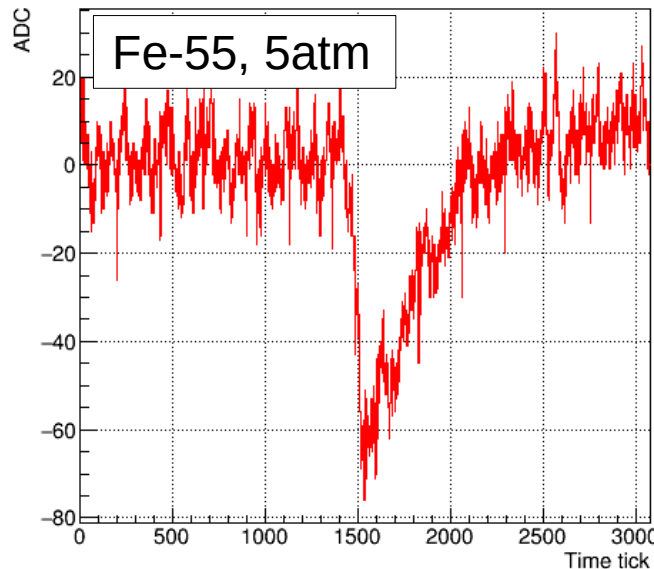
- Pulse height used to infer gain
- Gain measured at various anode voltages
 - Results agree with our expectations

1 atm
Fe-55 source



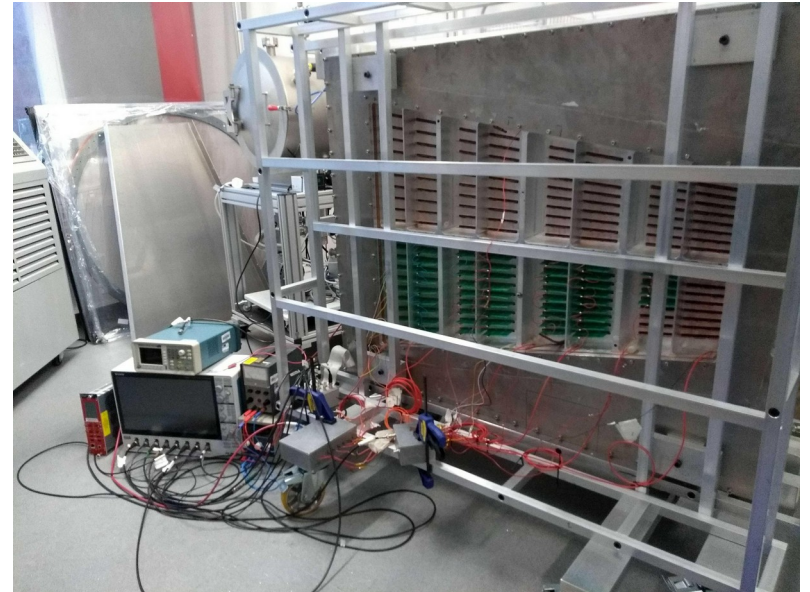
High-pressure testing

- Successfully run at 5 atmospheres
 - Gas gain drops as expected
 - Next stop – 10 atmospheres!



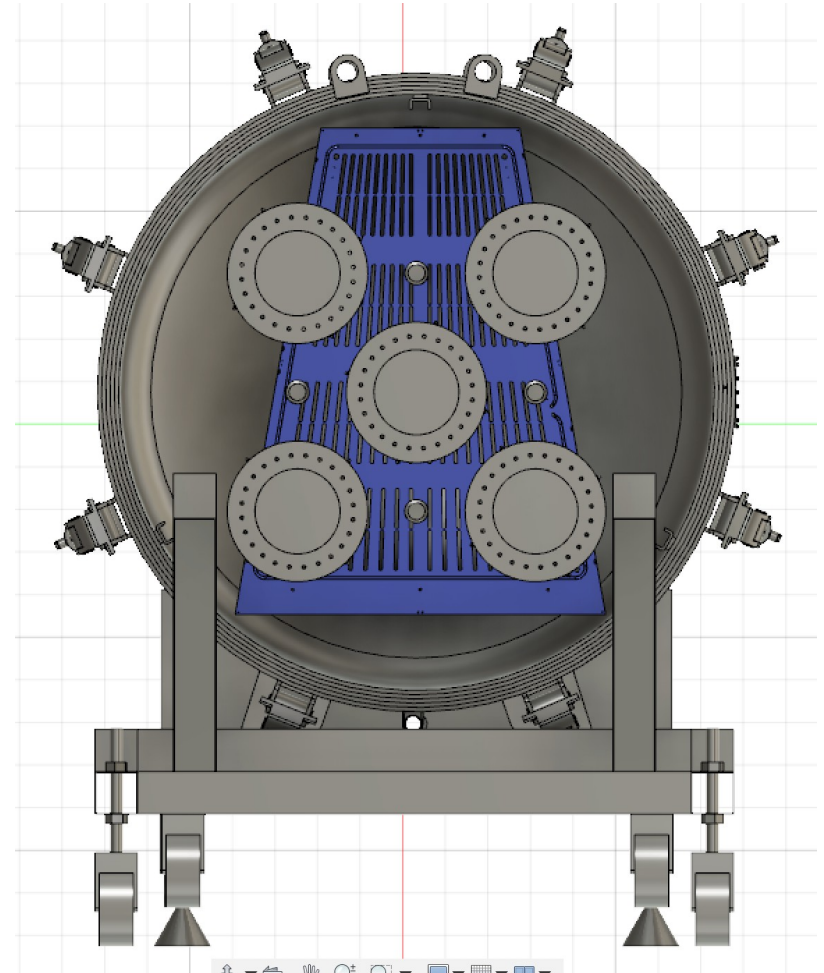
RHUL test-stand

- Royal Holloway University of London are testing an ALICE outer chamber
 - Still in the gas-tight transport box
- Currently testing at 1atm

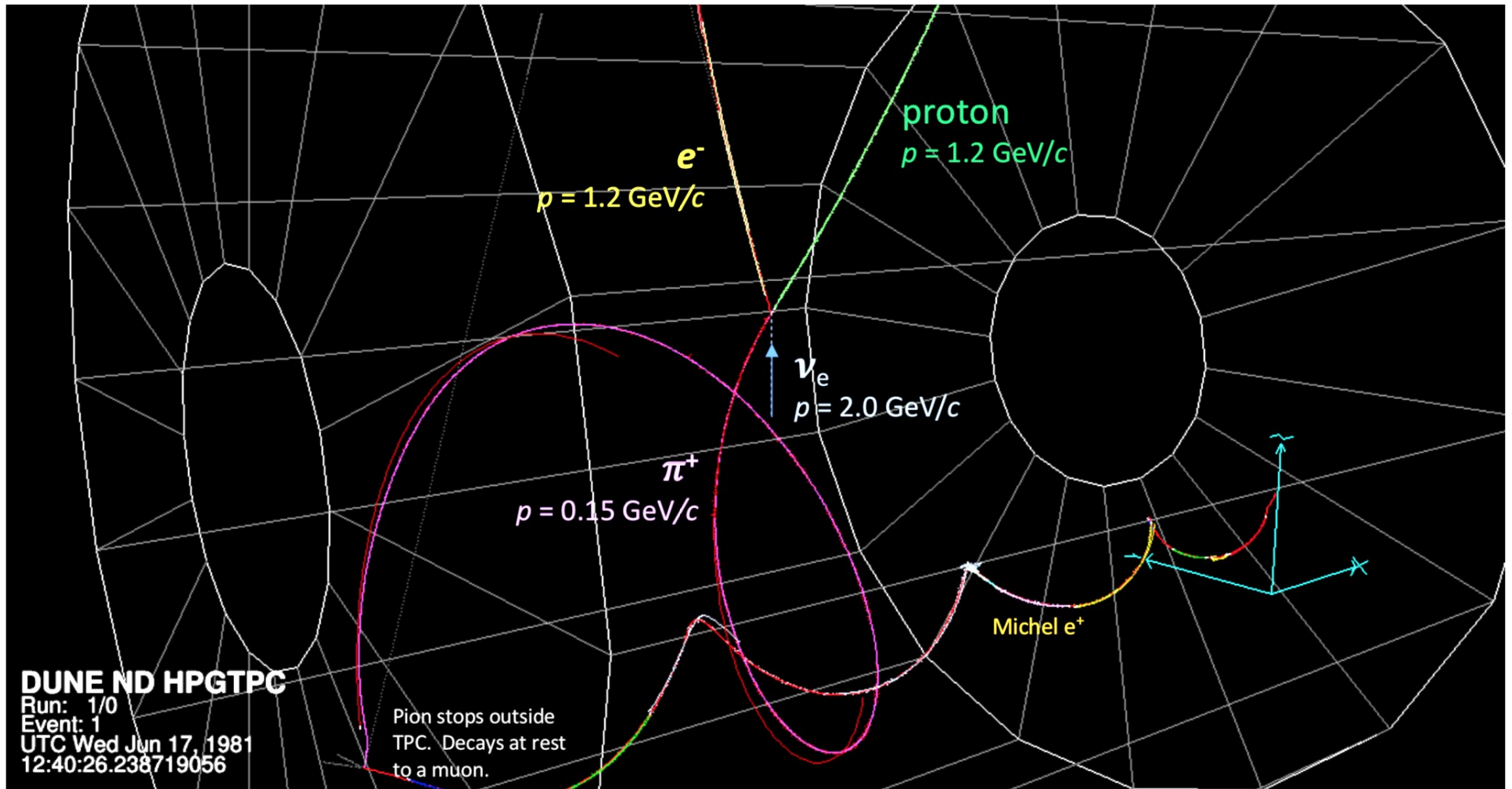


RHUL: coming up

- Transfer to a pressure vessel rated to 5 atmospheres
- A tight fit!
- Make the same measurements as GOAT



Simulations



Conclusions

- DUNE has designed a capable near detector complex
- High-pressure gas TPC as a spectrometer and an independent neutrino target is a crucial part of the design
- High-pressure gas TPC design based on ALICE is maturing
- R&D in the US and the UK is making good progress



Thank you for listening



Backups

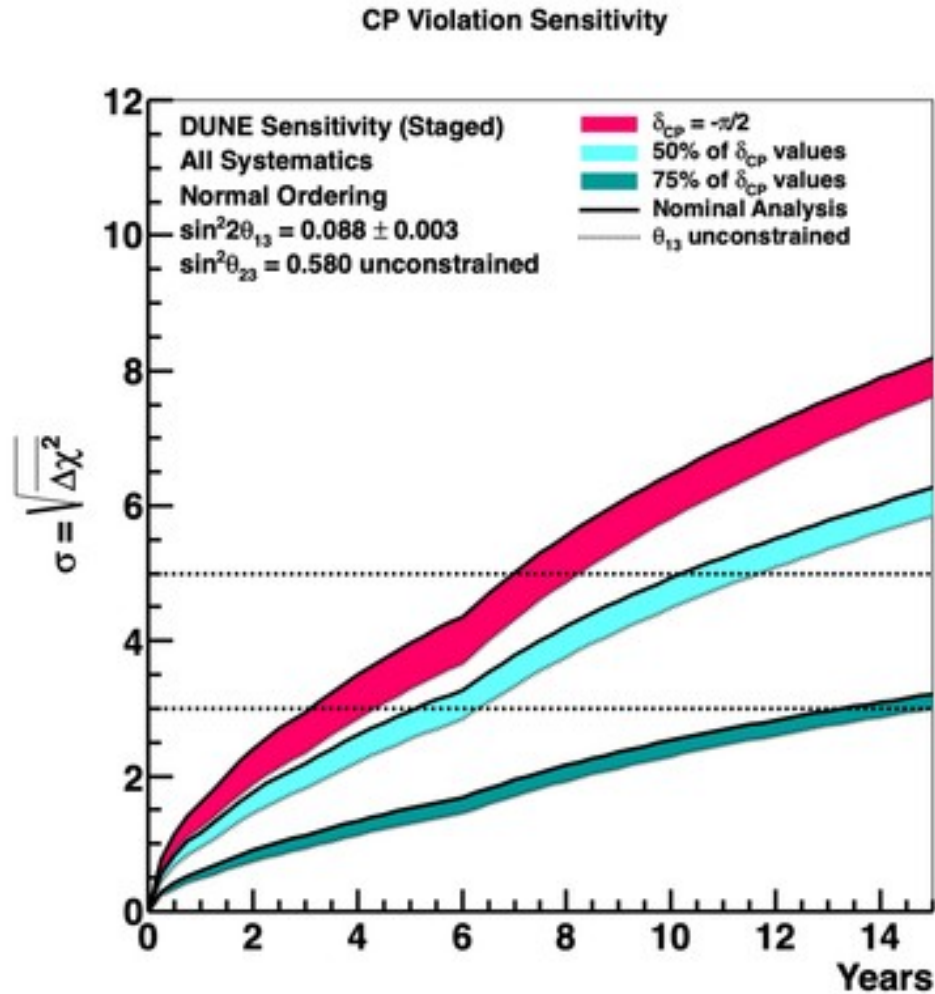


DUNE physics goals

- Long-baseline (accelerator):
 - Determination of neutrino mass hierarchy
 - Observation of CP-violation in the lepton sector (if the universe is kind)
- Other:
 - Supernova detection and measurement
 - Baryon number violation (nucleon decay)
 - BSM searches, both accelerator and non-accelerator

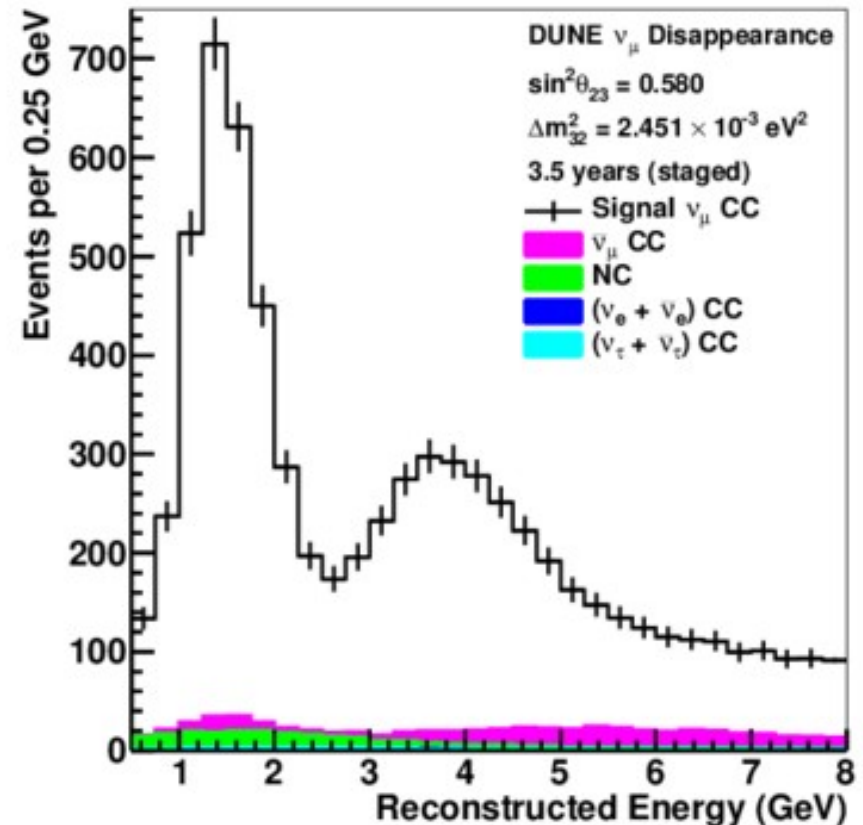


DUNE sensitivity

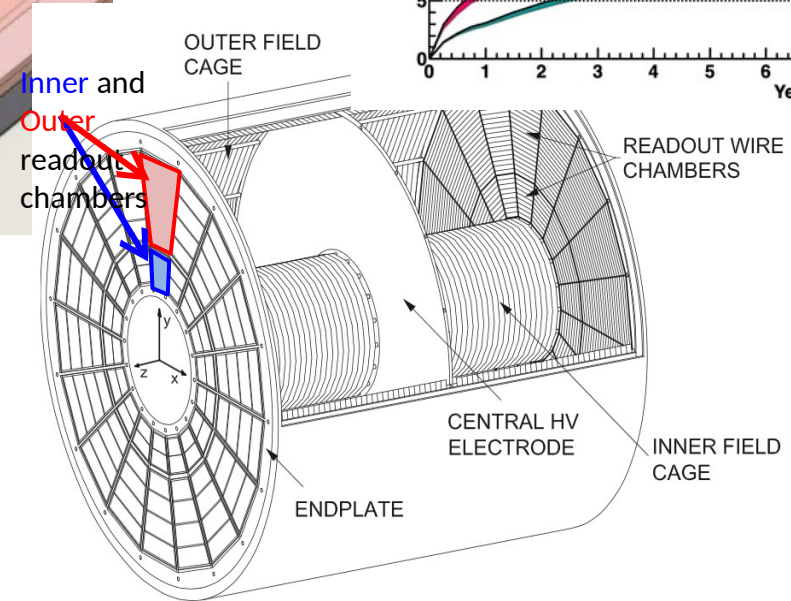
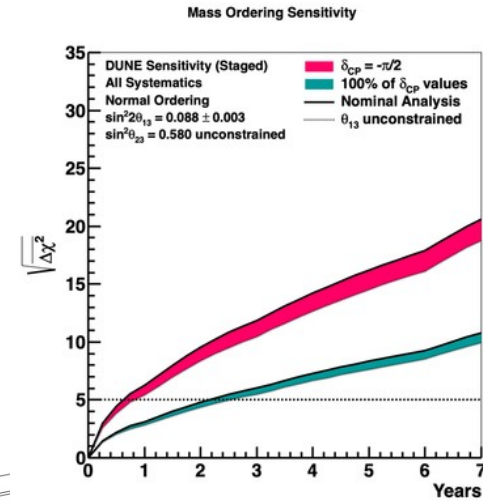
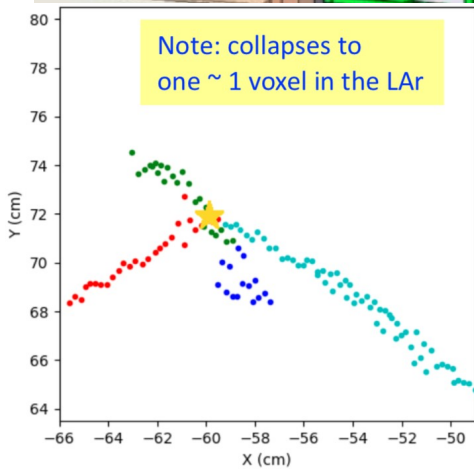
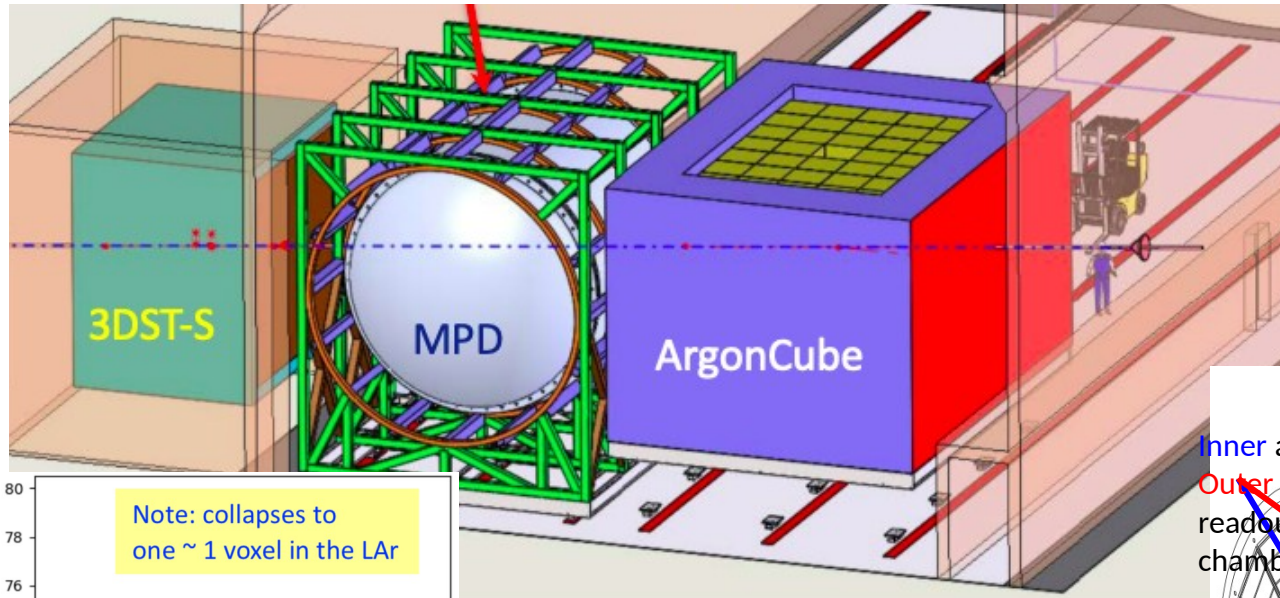


DUNE long-baseline analysis

- Measure event rate vs (reconstructed) neutrino energy at far-detector
- Compare to predictions with various oscillation parameters
 - Infer best-fit parameters!
- Uncertainties in flux, cross sections lead to uncertainties on oscillation measurement
 - Solution - measure the flux and cross sections at a near detector!



More HpgTPC images



Detecting light in gaseous Ar

- Studying the ability to read out scintillation signals too
 - For a t_0 tag if entire interaction is contained
 - Not critical for primary DUNE physics program
 - Not being pursued for DUNE



GOAT details

- $1\text{ADC} = 0.48\text{mV}$
- $1\text{ tick} = 128\text{ns}$

