Sensitivity Studies for a Gaseous Argon Near Detector for DUNE

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IOP Joint HEPP, APP and NP Conference

10th April 2024

Imperial College London

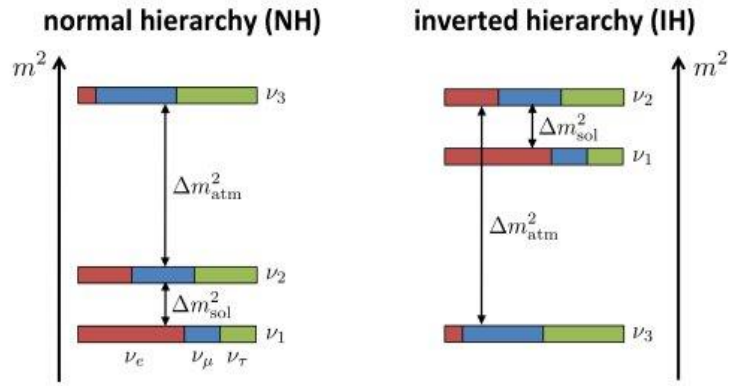
DUNE

Overview

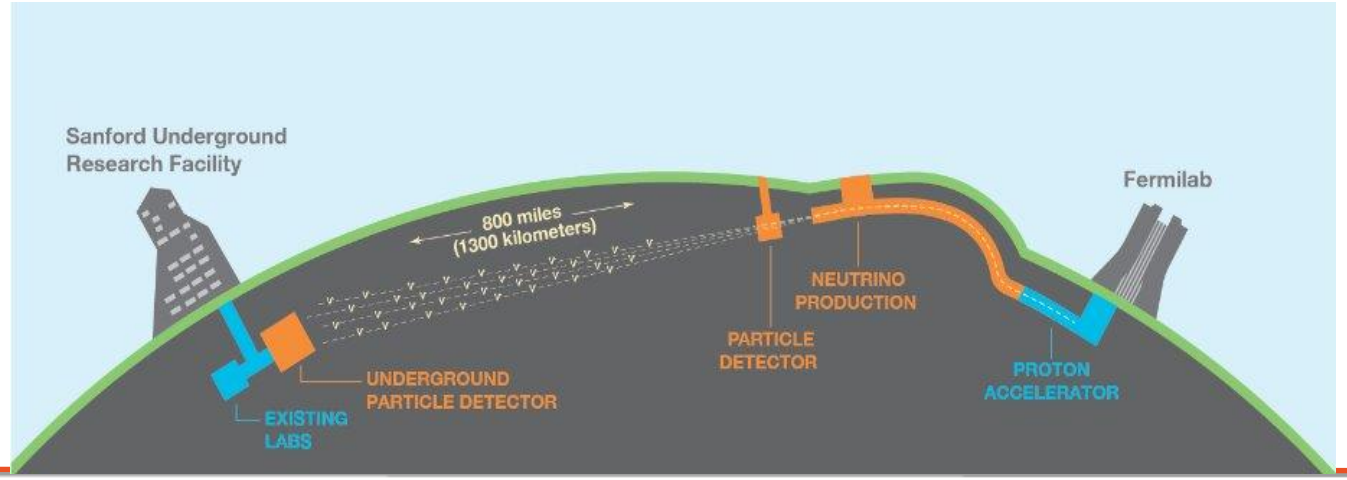
- Neutrino Oscillations and The Deep Underground Neutrino Experiment (DUNE)
- Gaseous Argon Near Detector (ND-GAr)
- Studying the impact of ND-GAr on Oscillation Parameters
- Teststand of an Overpressure Argon Detector (TOAD)

Neutrino Oscillations and DUNE

- Flavour oscillations described by **PMNS Matrix** and **mass differences**: θ_{ij} , δ_{CP} , $\Delta m^2_{ij} = m^2_i - m^2_j$
  - Value of δ_{CP} → potential **CP violation** in leptons → **matter-antimatter asymmetry**
  - Mass hierarchy → Normal vs Inverted Ordering
- DUNE
  - **Highest intensity wideband beam** in a neutrino oscillation experiment
  - Near Detector: ~574 m from neutrino source, Far Detector: ~1300 km downstream
  - Physics Program: **Precision PMNS Testing**, BSM studies, solar, atmospheric & supernovae neutrinos
  - **Phased** Experiment: Phase II will bring upgrades to beam, Near and Far Detectors

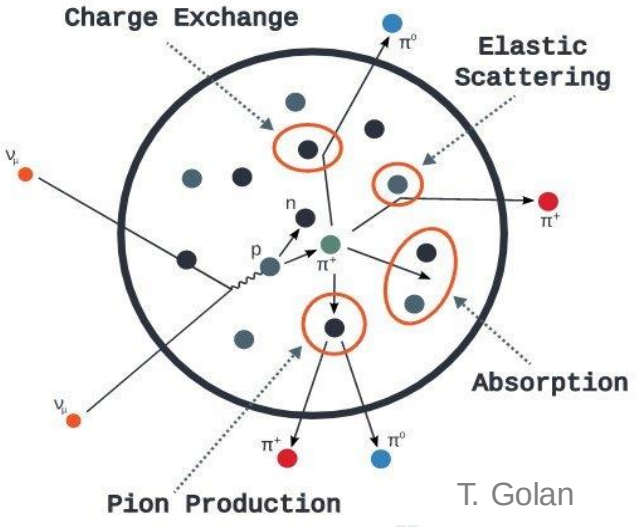


JUNO Collaboration/ JGU-Mainz

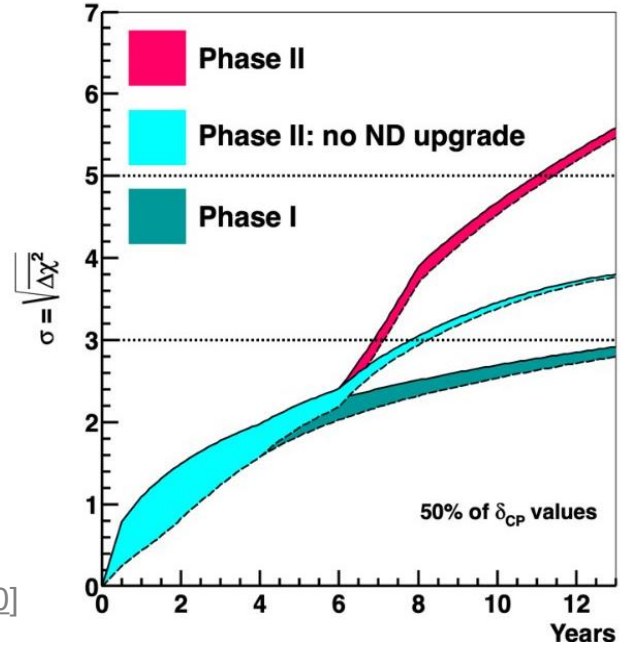


ND-GAr

- Cross section/neutrino interaction model uncertainties need to be **constrained**
  - **Final State Interactions** not yet fully understood, difficult to reconstruct true initial interaction vertex and therefore true neutrino energy
  - **Low energy threshold** makes ND-GAr able to detect low energy hadrons (tens of MeV)
  - Tuning nuclear models with data from more **inaccessible energy regions**



T. Golan



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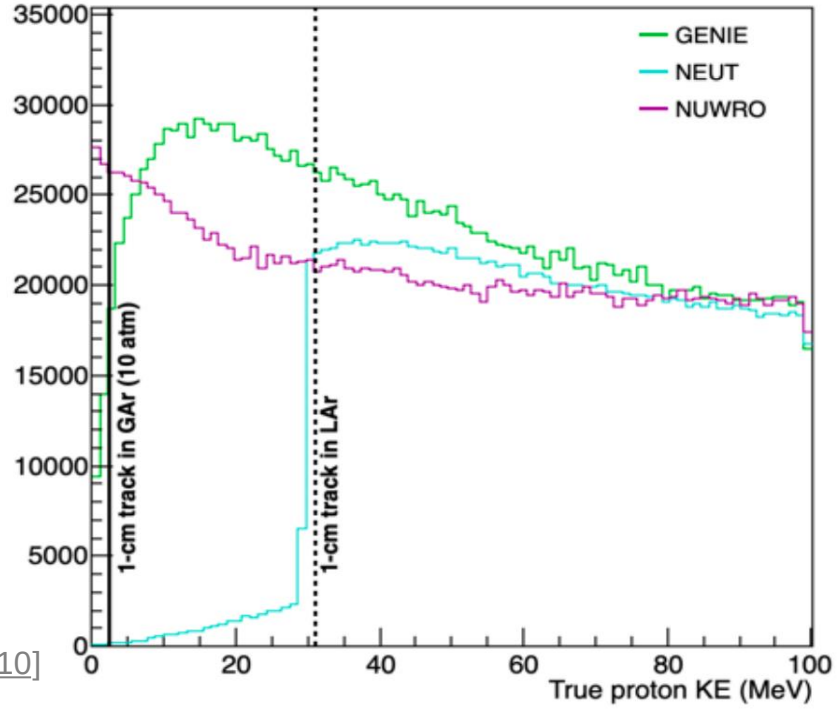

[2103.13910]

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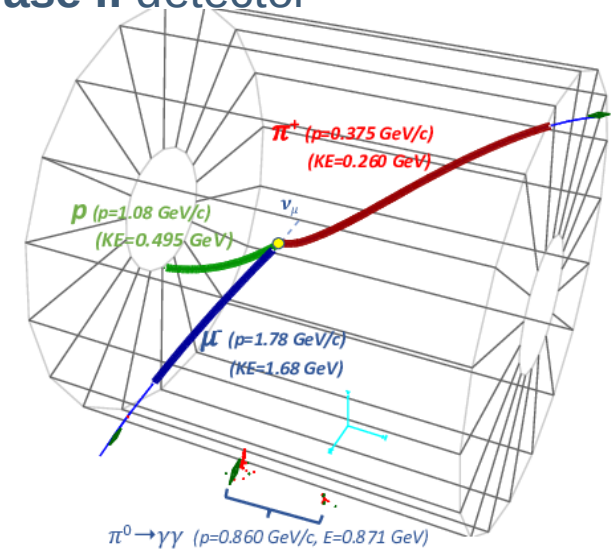
ND-GAr

- Liquid Argon used for Near and Far Detector time-projection chambers (ND-LAr and FD)
- ND-GAr: A **magnetised** high-pressure gas time-projection (**HPgTPC**) chamber surrounded by an electromagnetic calorimeter (**ECAL**)
- **Low density** → **lower momentum threshold** for detection → constrain physics of low energy neutrino interactions
- Strongly recommended in P5 report in 2023
- **DUNE Phase II** detector



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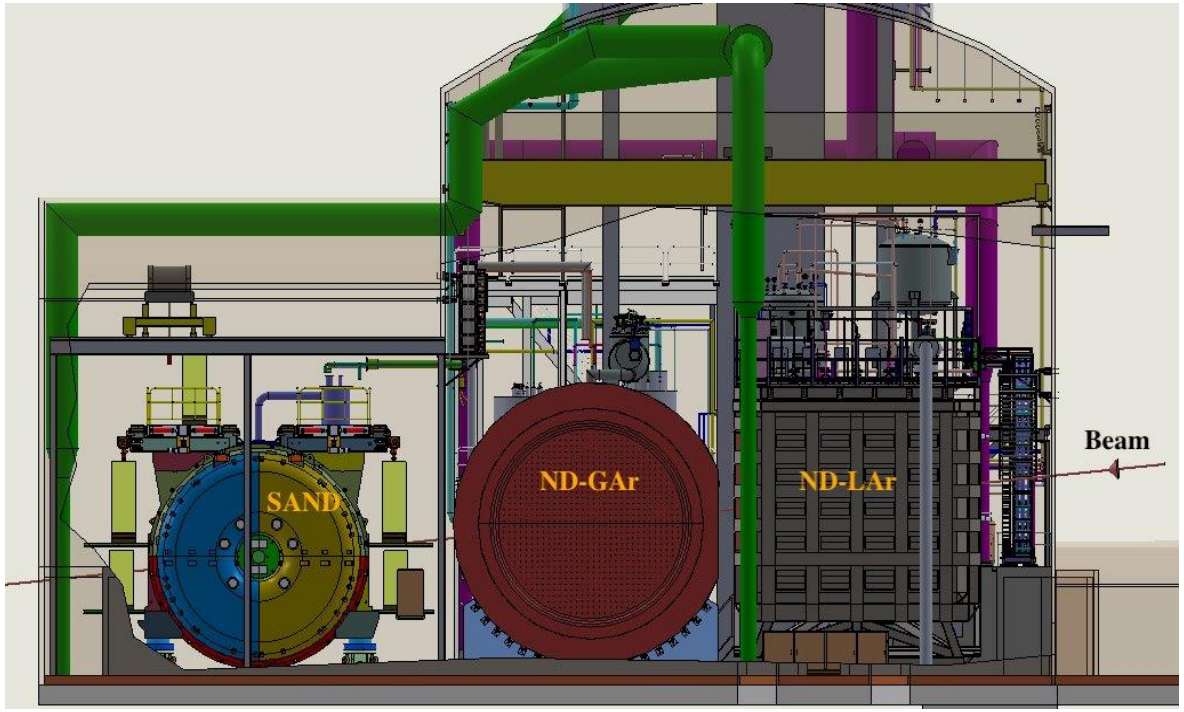

[2203.06281]

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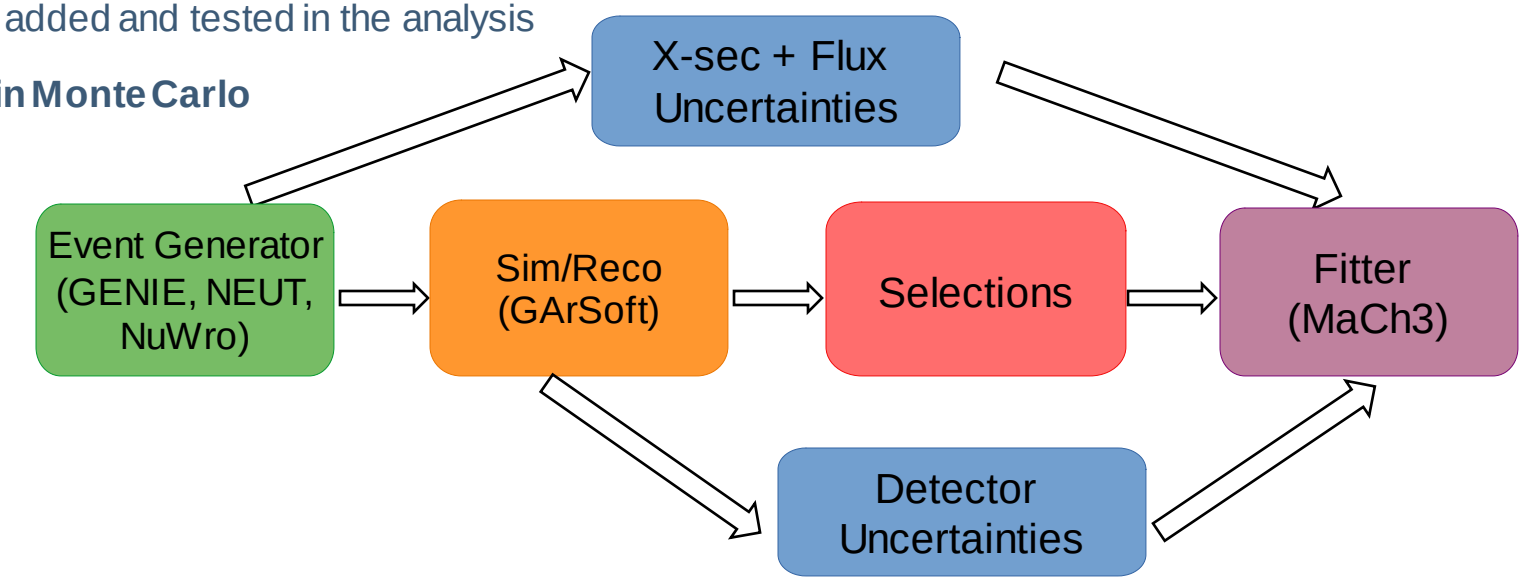
Studying the impact of ND-GAr on Oscillation Parameters

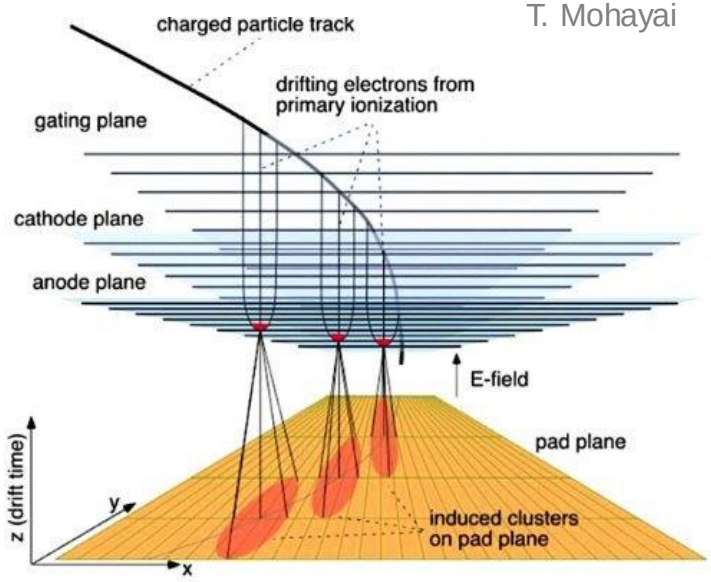
- The **design** of ND-GAr will be **physics driven**:
  - We need to **maximise the impact** ND-GAr has on the oscillation result
  - Re-optimise the **design requirements** e.g.: Strength of B-field, Optimal Pressure, Resolution
- With a **reliable interface** from Event Generators to the long baseline (LBL) analysis:
  - Sensitivity to the **different neutrino interaction models** with ND-GAr
  - Any changes to the ND-GAr **design** can be tested and compared
  - The effect of any **new systematics** can also be added and tested in the analysis
  - MaCh3 is a **Bayesian fitter** using **Markov Chain Monte Carlo**
  - DUNE currently has ND-LAr + FD implemented in the LBL analysis with MaCh3.
  - **I will be adding ND-GAr samples to the fit**

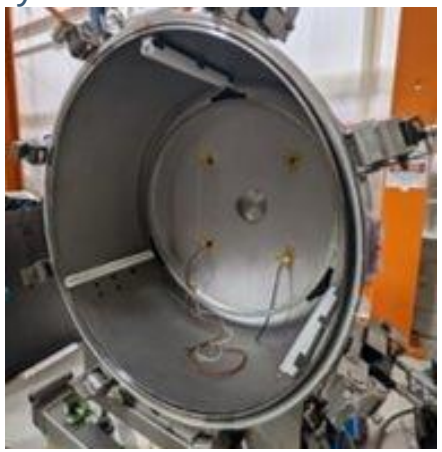


TOAD

- Will be useful in quantifying our **detector uncertainties** in the LBL analysis
- Teststand of an Overpressure Argon Detector
  - **Full slice test** of the HPgTPC component of ND-GAr
  - ~ 1 m^3 pressure vessel operating at 5 barA with an Ar-CH_4 gas mixture, using a multi-wire proportional chamber with pad readout
- Utilising the MCenter Tertiary Beam at FNAL – **low energy hadron beam** (~200 MeV)
- I led the commissioning effort of TOAD last year at FNAL as run coordinator
  - Ready to take beam data from **May 2024**

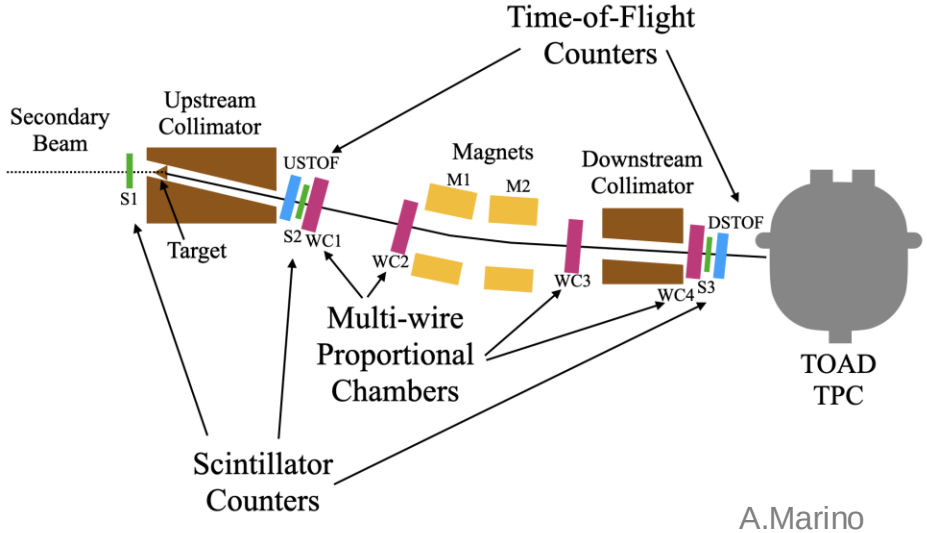
T. Mohayai




Drift Cathode

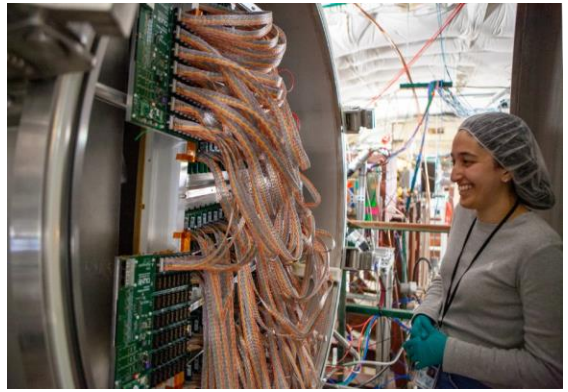

Field Cage + Terminator

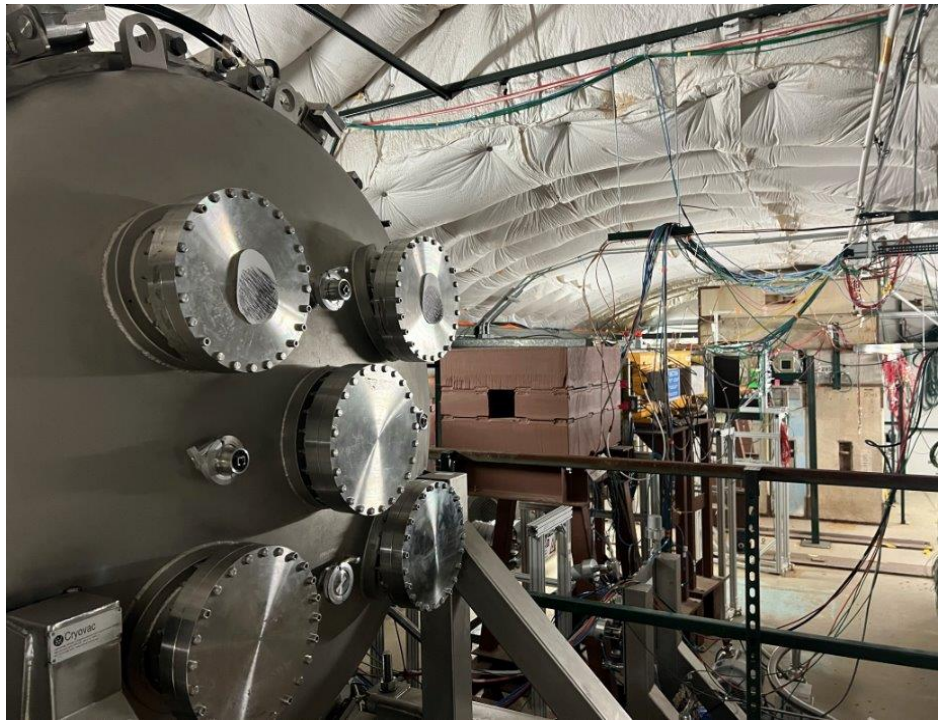

OROC



A.Marino

TOAD





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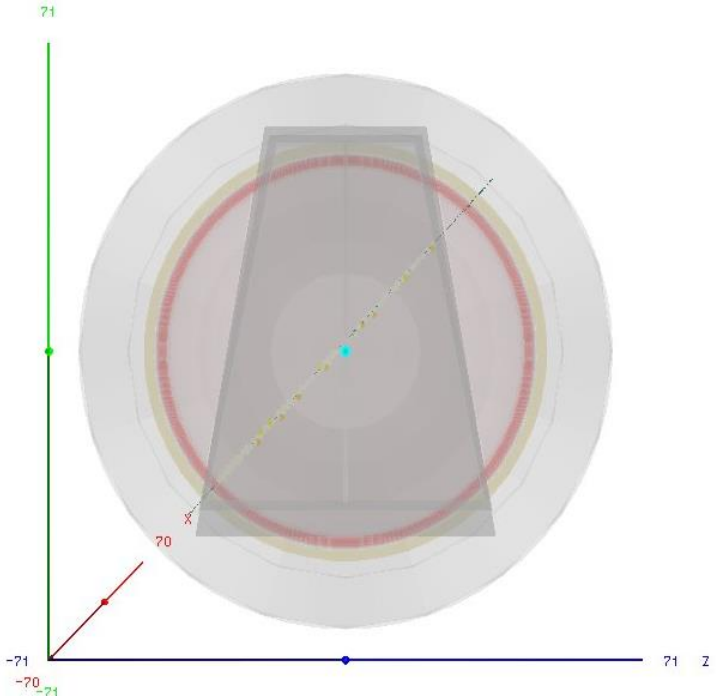
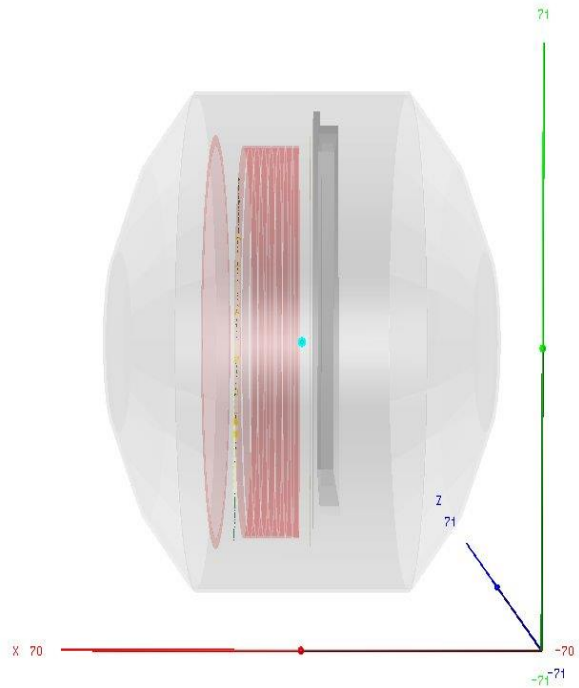
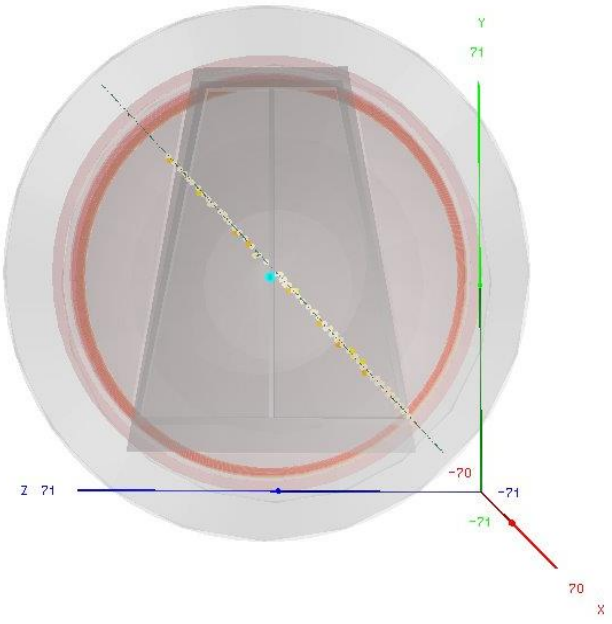
TOAD DAQ and Reco

- Integration of the TOAD data readout into the **DUNE-DAQ** framework – **first ND prototype** to do so
- Integration of TOAD into the simulation and reconstruction software
- The pipeline from **electronics hardware** to **DAQ** to **reconstruction software** is complete and ready for the beam test
- Event displays with simulated muon tracks passed back through reconstruction







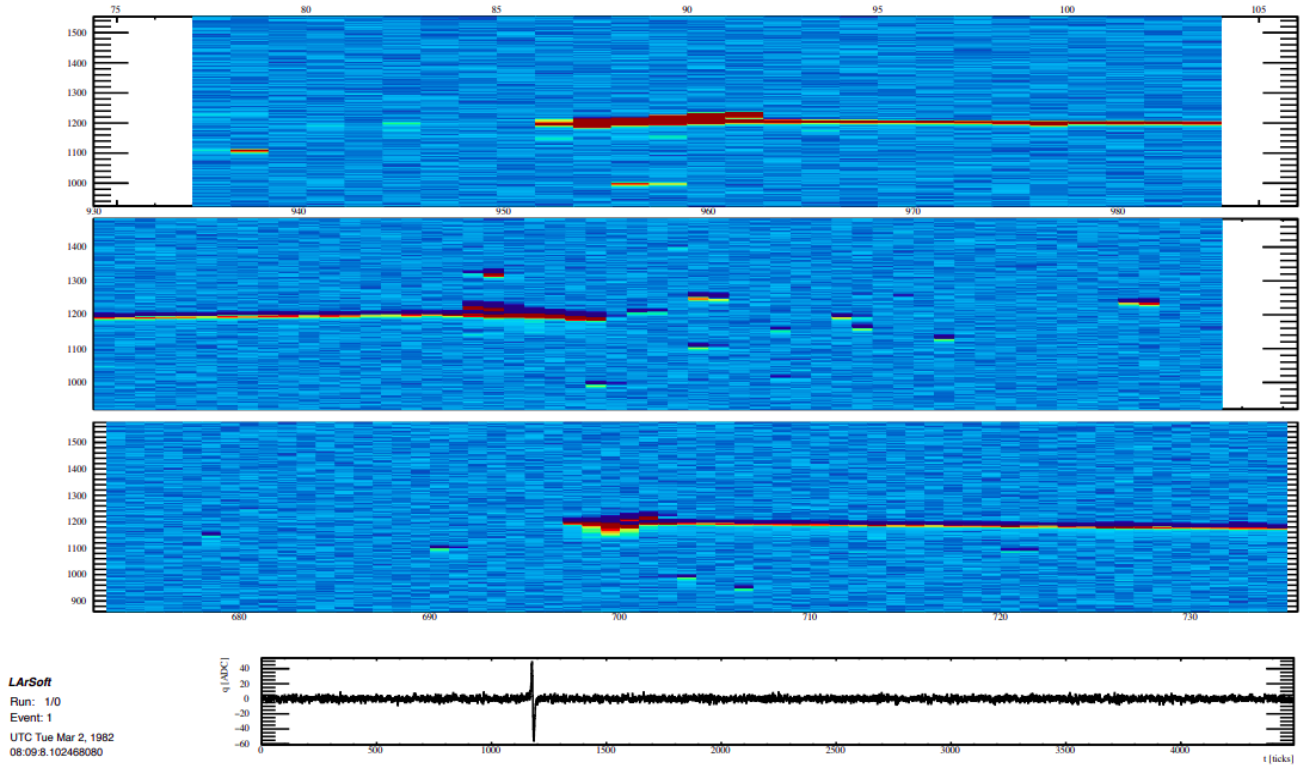
Conclusions

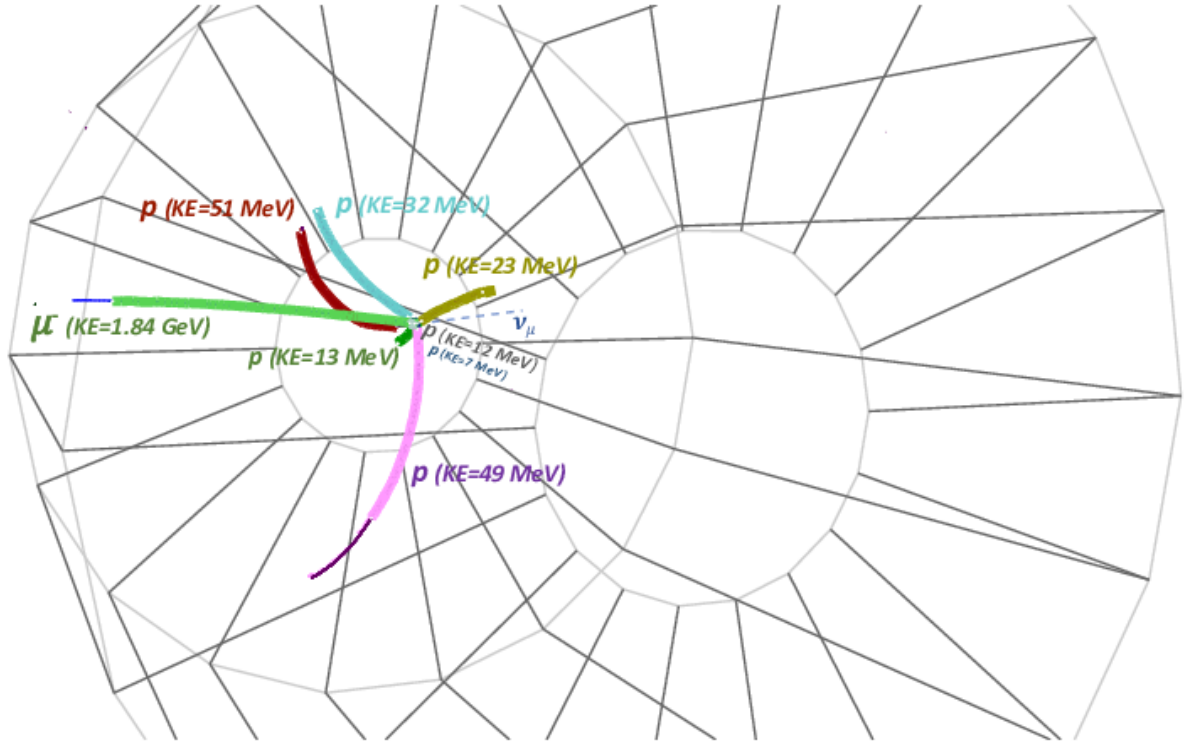
- We are developing **design requirements** for ND-GAr to deliver the physics needs of DUNE
- A **full end-to-end pipeline** for the LBL analysis, from Event Generators to Fitter has been completed
- ND-GAr samples have been integrated into the MaCh3 framework and I will carry out **sensitivity studies** for ND-GAr
- TOAD will be taking data **from May 2024 until July 2024**, with new readout electronics
- All this work helps in **understanding the systematics** which DUNE will have to constrain

Back Up

LAr vs GAr

- Same neutrino event, with one muon, 7 low energy protons and 9 neutrons shown in LAr vs GAr
- Longer tracks in GAr so better particle detection and reconstruction





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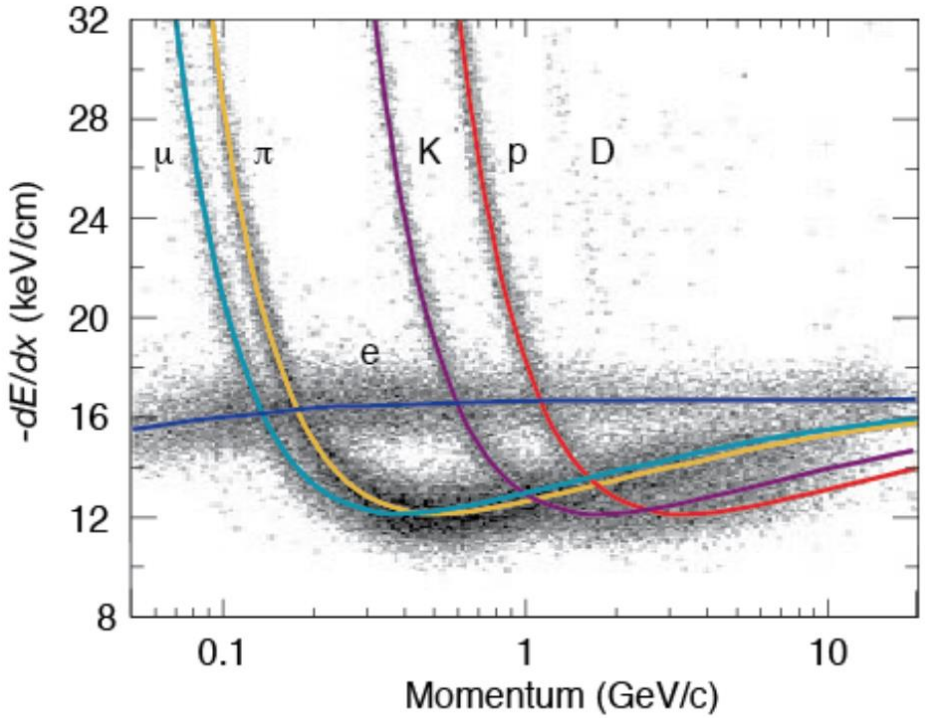
PID in GAr

- dE/dx-based particle identification in the TPC of the PEP-4 detector at SLAC [9906063]
  Used a gas mixture of 80:20 Ar-CH_4, operated at 8.5barA [10.1109/TNS.1983.4332223]



The DUNE Near Detector

- 3 Components:
  - Liquid Argon TPC (ND-LAr)
  - The Muon Spectrometer (Phase I)
    ND-GAr (Phase II)
  - System for On Axis Neutrino Detection (SAND)
- **ND-LAr:**
  - 50-60t fiducial mass liquid Argon TPC
    - Large event sample
    - Liquid argon target like the far detector
  - Charge and optical readout
  - High statistics for neutrino interactions in LAr
  - Flux uncertainties via neutrino-electron elastic scattering and low-nu events as high density
    - QCD free flux measurement
  - Provides precise constraints on flux and event rate
- **SAND:**
  - Fixed on-axis position in DUNE ND
  - LAr, tracker, ECAL, solenoidal magnet
  - Continuous monitoring of the on-axis neutrino flux and measures beam's time stability
  - Can compare to interactions in LAr