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Capabilities of the DUNE Near Detector Complex

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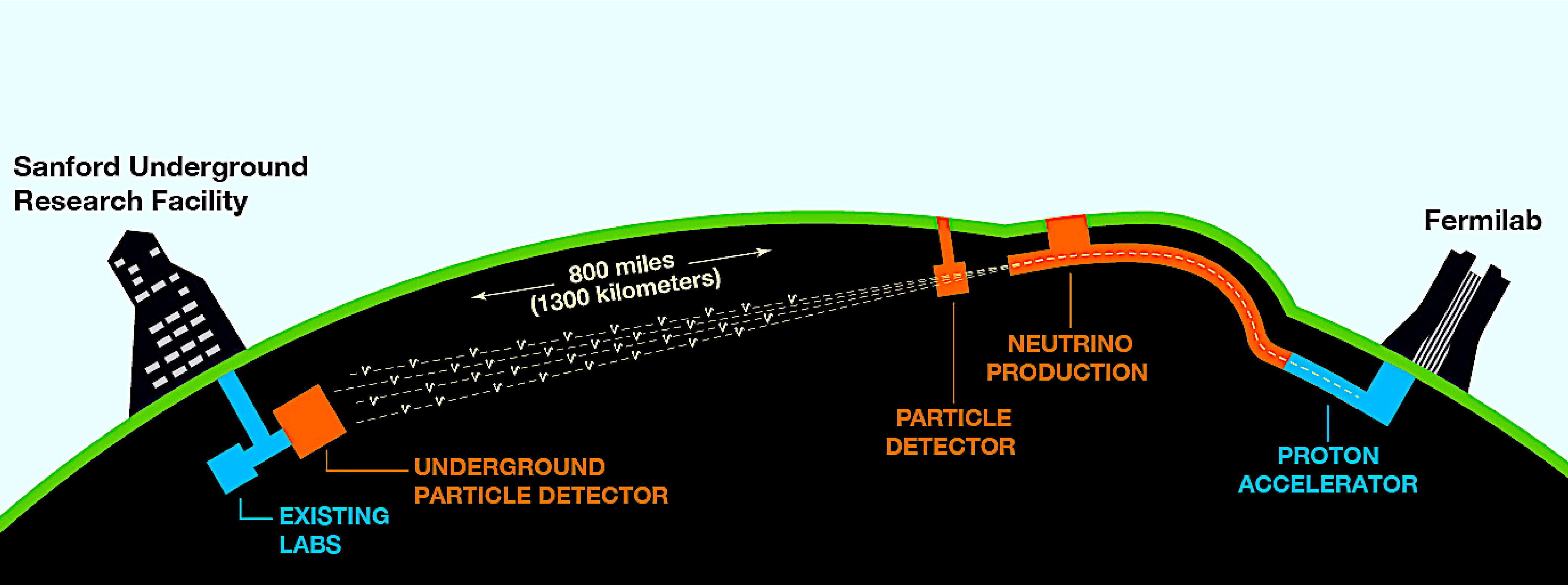
DEEP UNDERGROUND NEUTRINO EXPERIMENT

Fermilab

Outline

- Outlook on Deep Underground Neutrino Experiment, DUNE
  - Overview of its rich physics program
- Near Detector Complex of DUNE
  - Its overall design
  - Overview of the physics that it enables
  - Its components and examples of their capabilities
- Summary

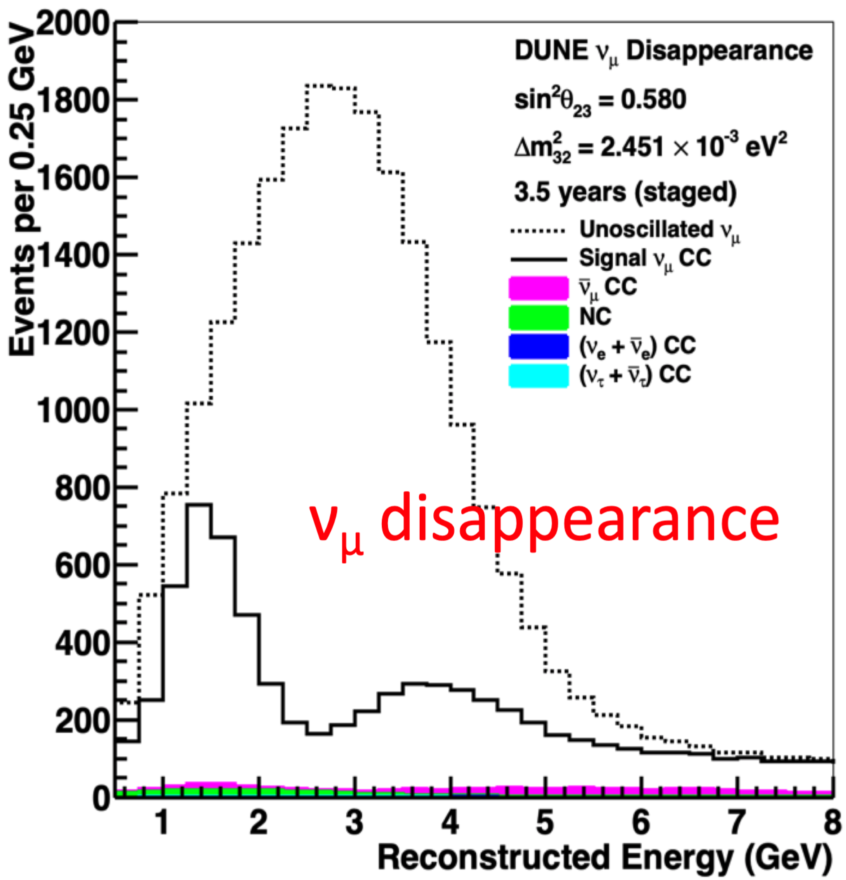
Deep Underground Neutrino Experiment, a Long-baseline Neutrino Experiment

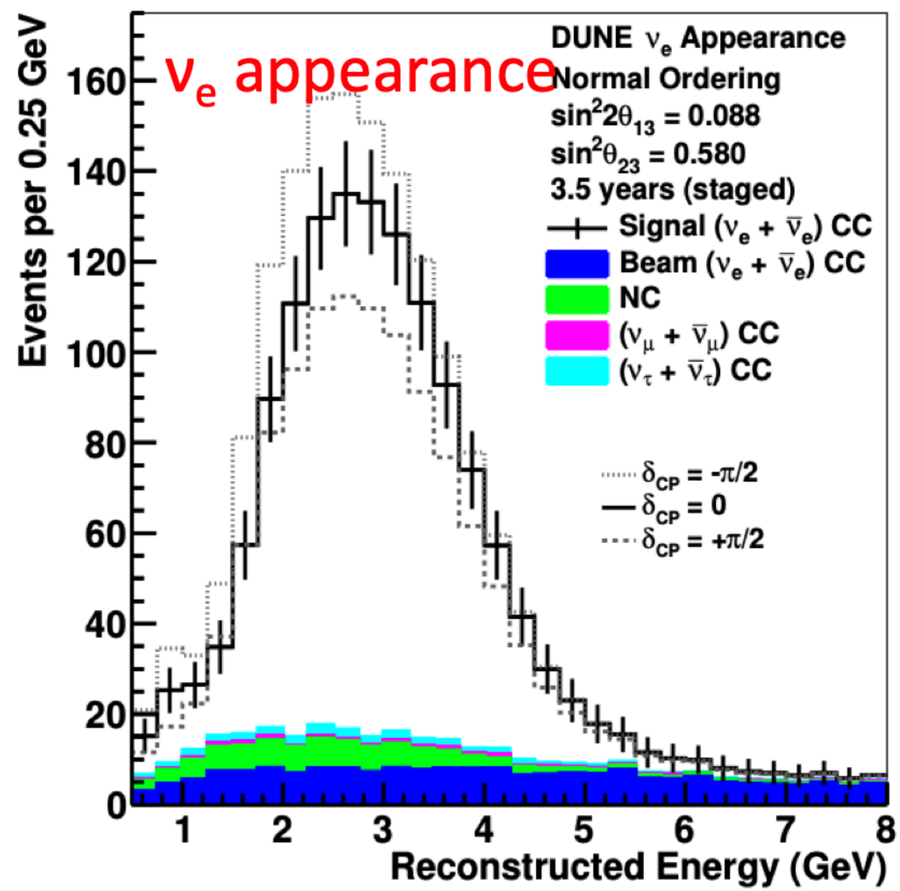


- 1.2 MW, upgradable to 2.4 MW high-intensity, wide-band neutrino beam
  - Produced at Fermilab and sent to Sanford Underground Research Facility, 1300 km away
- 40 kT liquid Argon time projection chamber far detector
- Highly capable near detector complex:
  - Precise neutrino cross-section measurements and characterization of the spectrum and flavor composition of the beam

DUNE’s Rich Physics Program

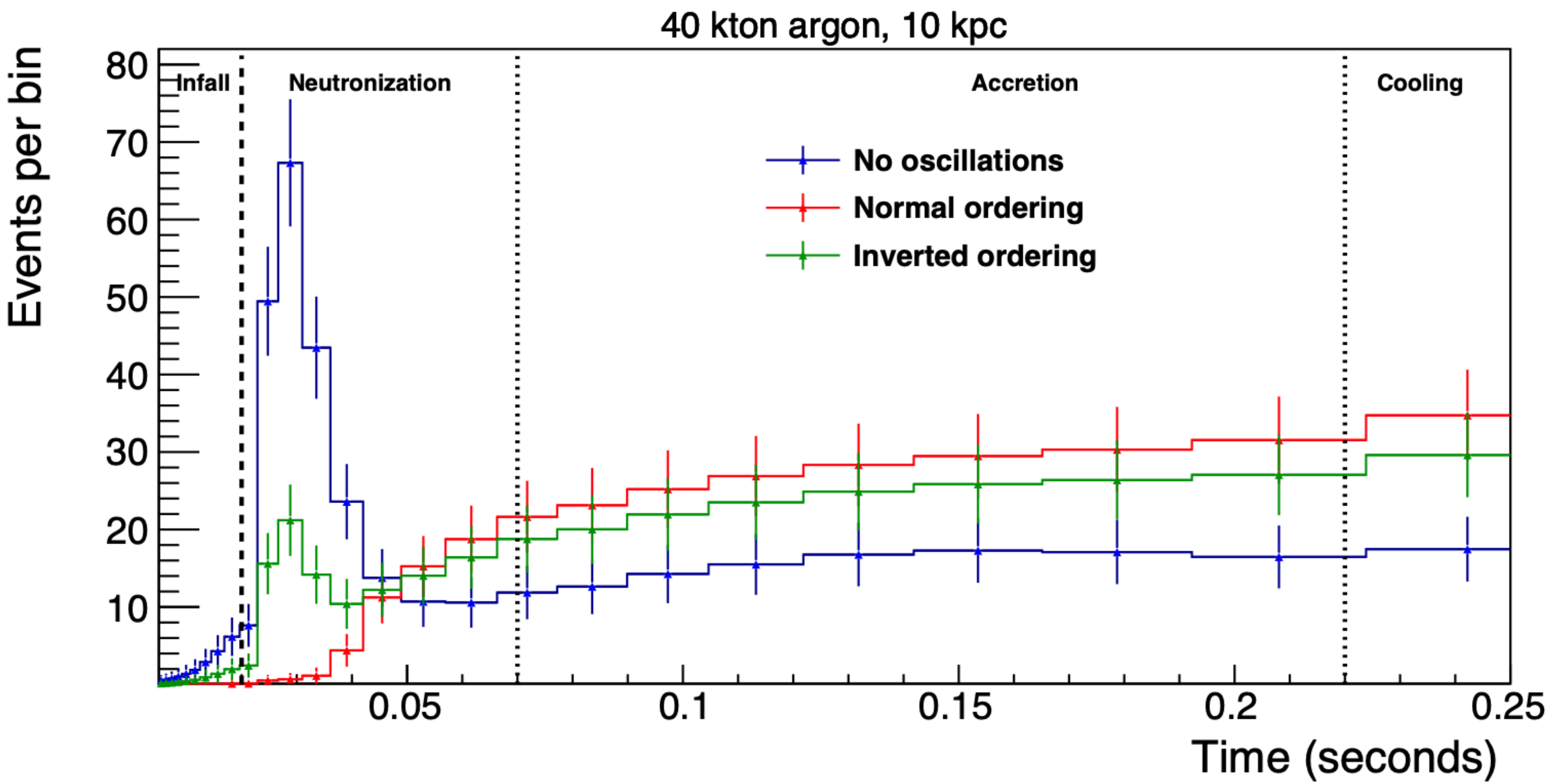
- Oscillation physics program:
  - Measurement of the leptonic CP violation
  - Determining the neutrino mass hierarchy
  - Precise measurement of PMNS parameters





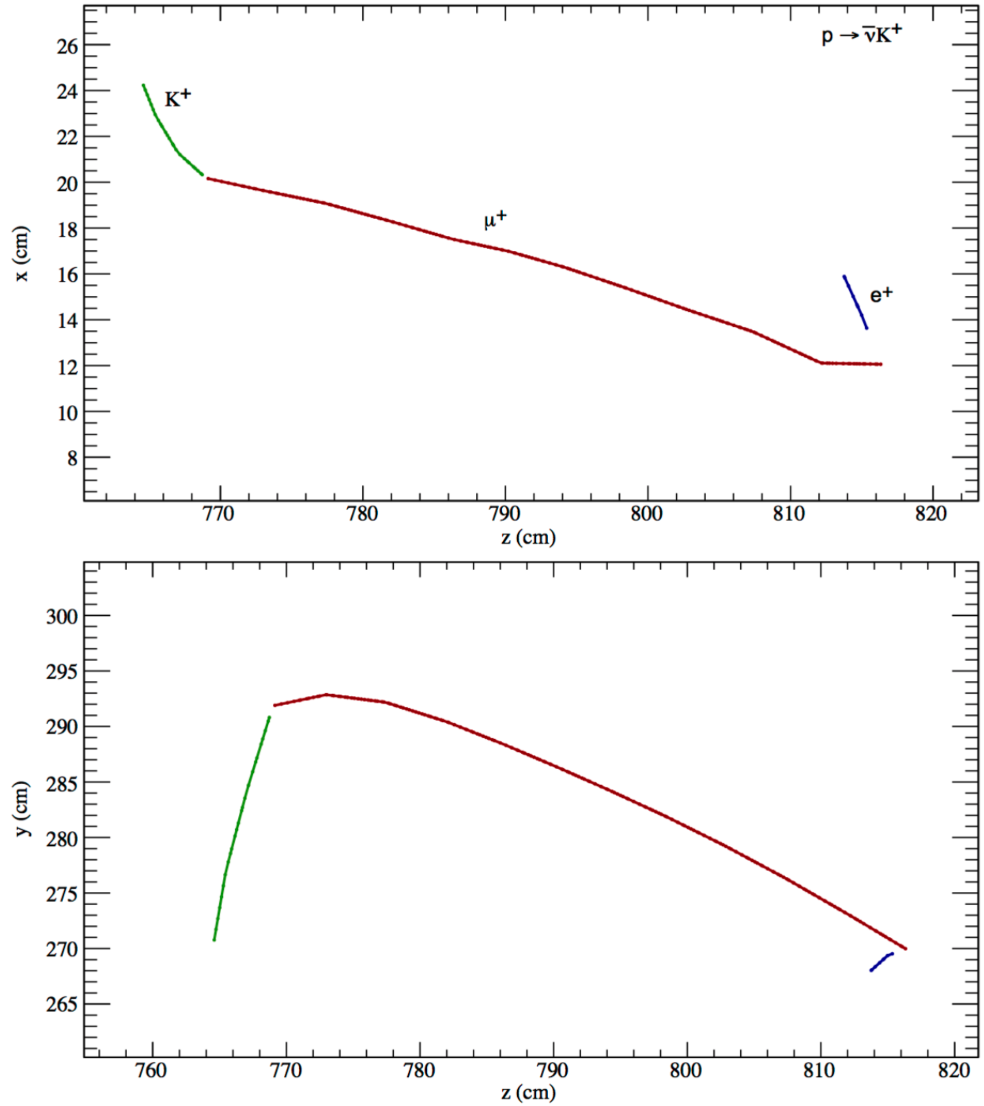
DUNE's Rich Physics Program

- Supernova physics program:
  - Characterization of the time and flavor profile of supernova neutrinos for insight into collapse and evolution of supernova
  - Take advantage of LArTPC's unique sensitivity to ν_e flavor



DUNE's Rich Physics Program

- Beyond standard model program, e.g. baryon number violation:
  - ★ LAr TPC technology well-suited to certain proton decay channels



DUNE’s Rich Physics Program

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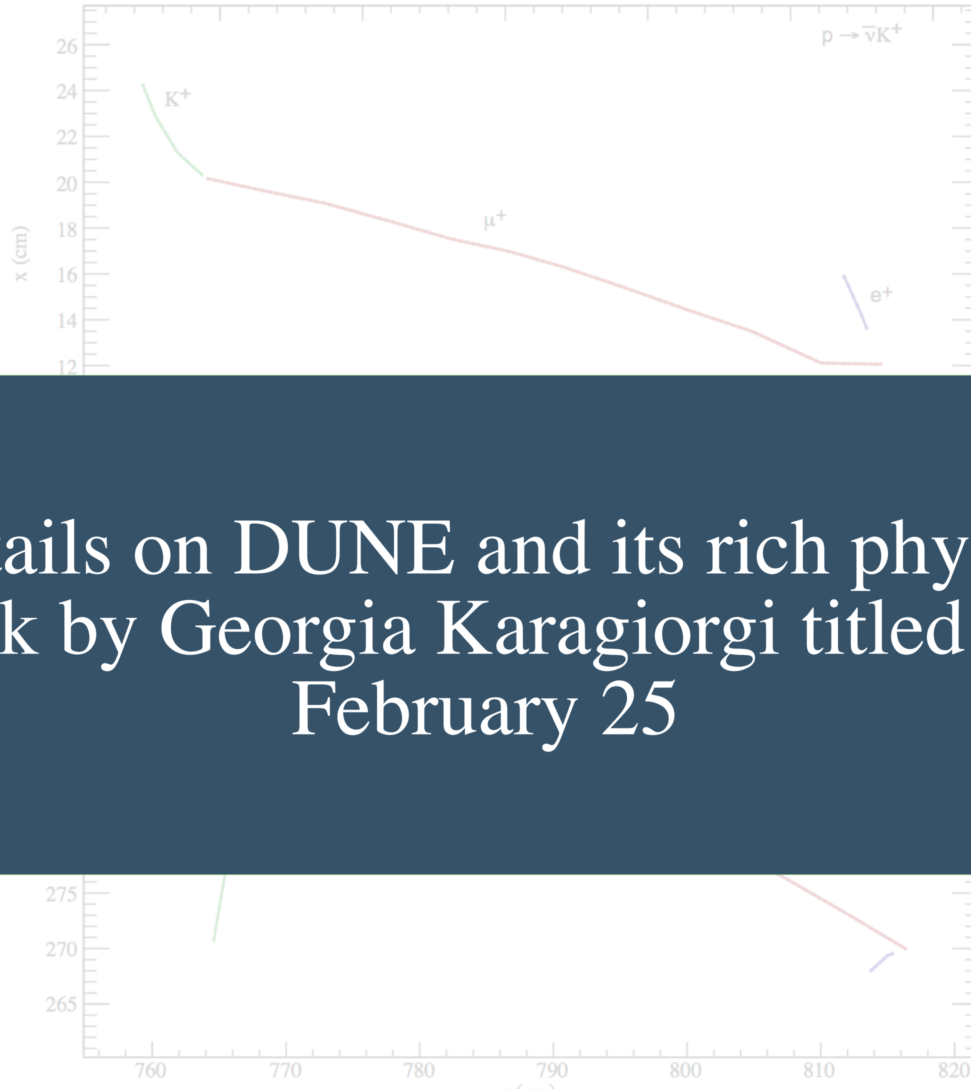
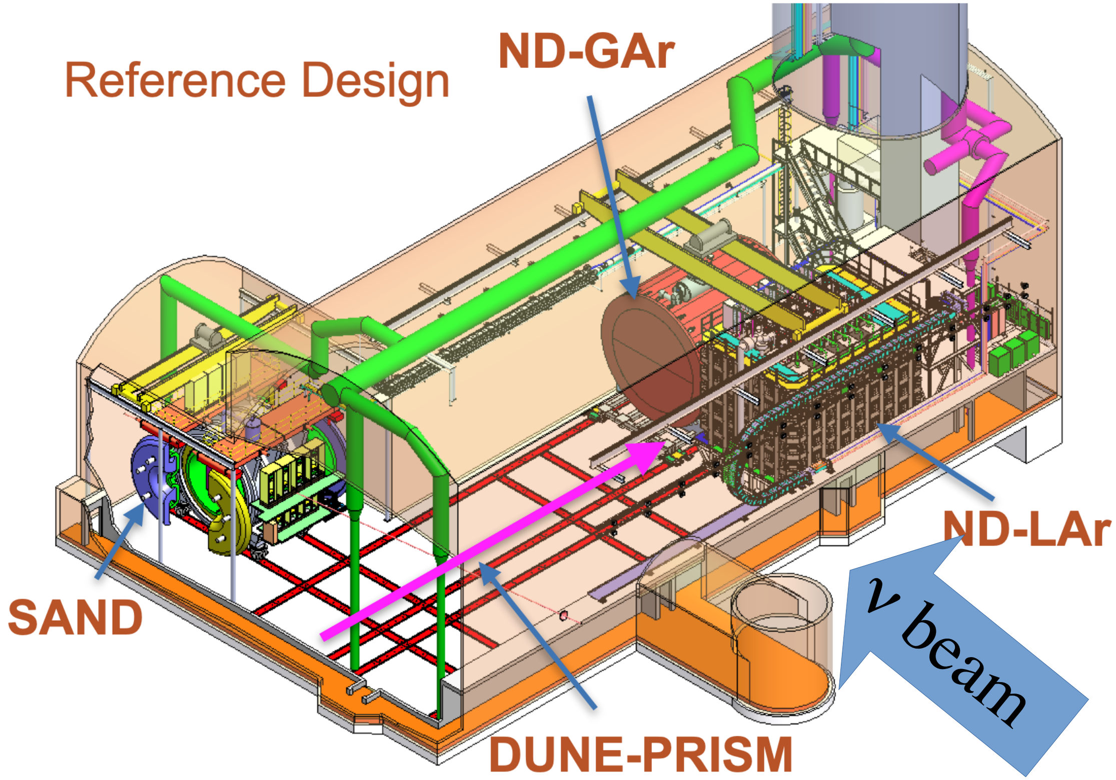
  - LAr TPC technology well-suited to certain proton decay channels



For more details on DUNE and its rich physics program, see the talk by Georgia Karagiorgi titled **DUNE** on February 25

DUNE Near Detector Complex



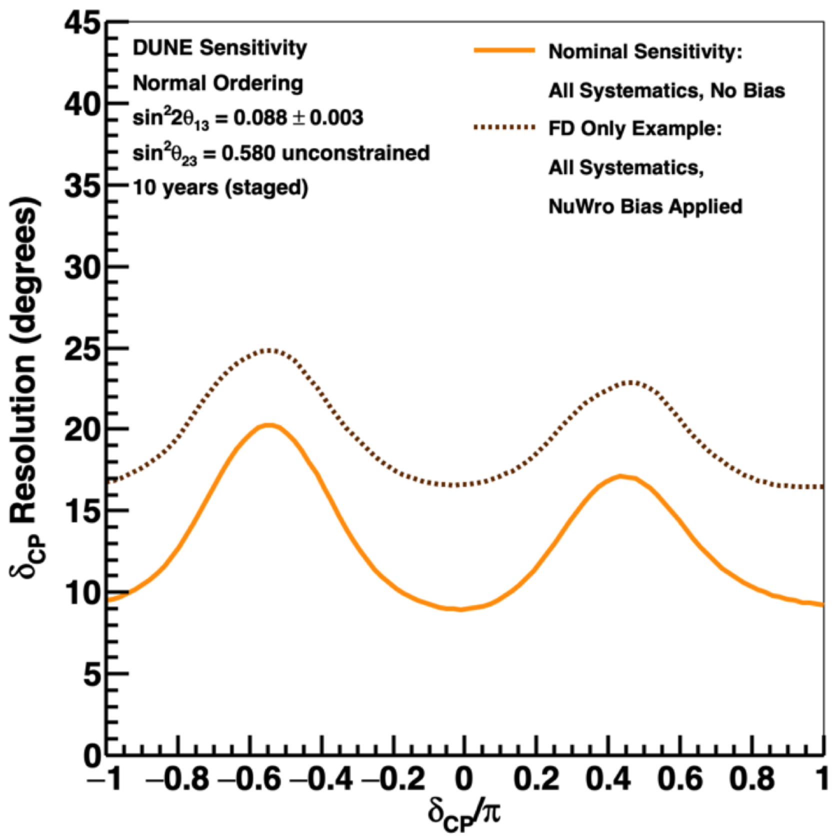
- Near detector hall houses various near detector components and enables the DUNE PRISM program:
  - ND-LAr ArgonCube, Liquid Argon time projection chamber
  - ND-GAr, magnetized gaseous Argon time projection chamber surrounded by ECAL calorimeter
  - SAND, system for on-axis neutrino detection

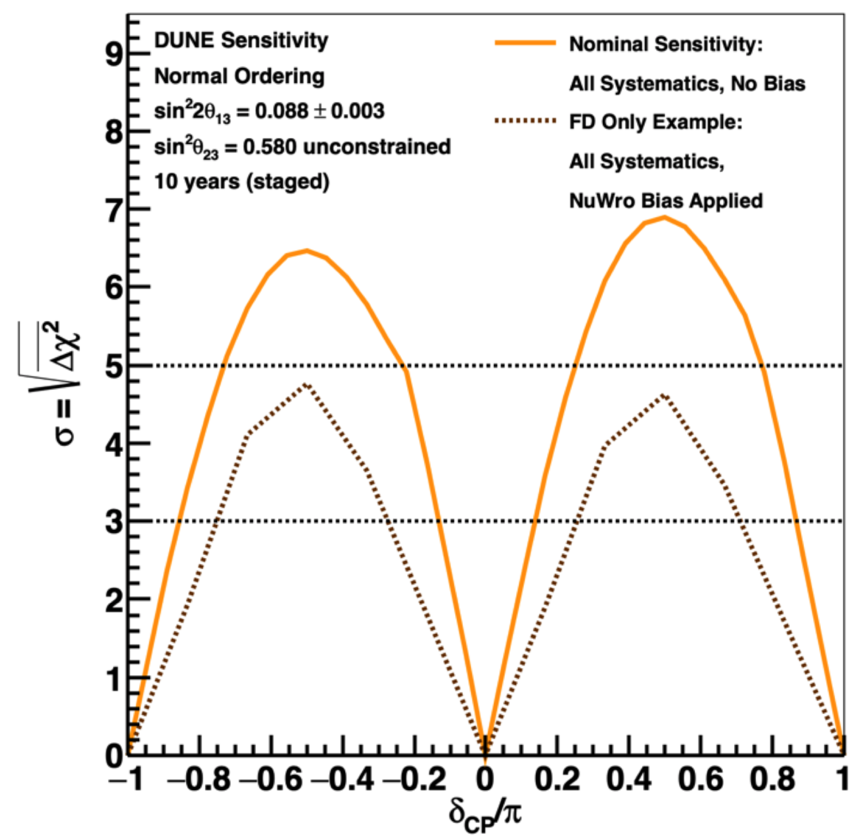
Physics Enabled by Near Detector Complex – Overview

- Primary goal of the near detector complex:

$$N^{FD}_{\nu_e}(E_{reco}) = \int P_{\nu_\mu \to \nu_e}(E_\nu) \times \Phi_{\nu_e}(E_\nu) \times \sigma_{\nu_e}(E_\nu) \times \epsilon^{FD}_{\nu_e}(E_\nu) \times S^{FD}_{\nu_e}(E_\nu \to E_{reco})\, dE_\nu$$

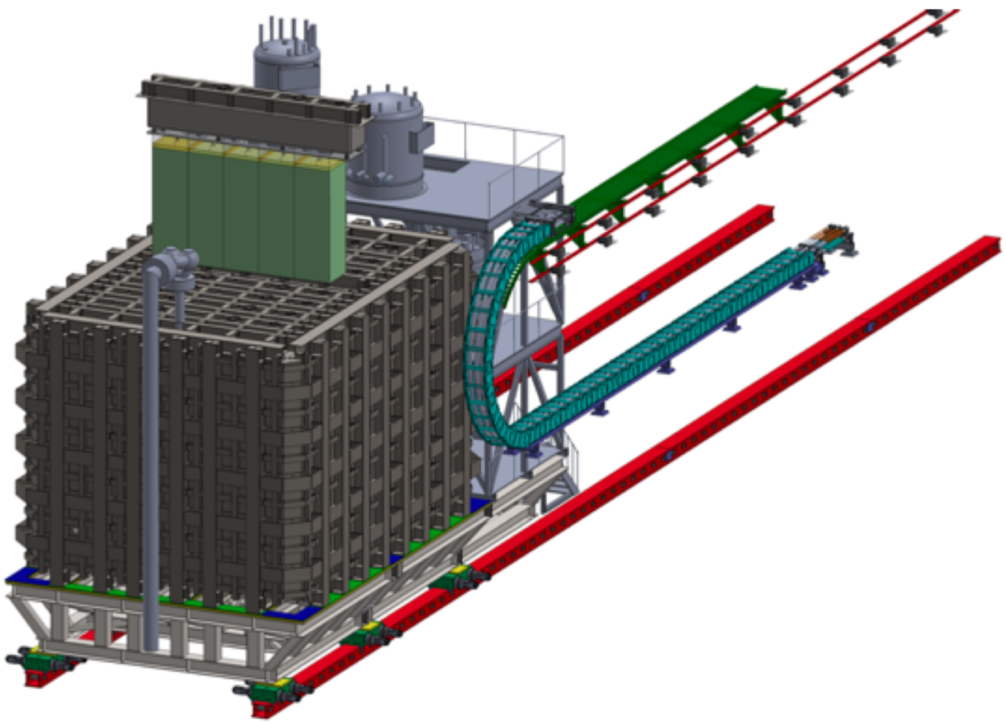
  - ★ Constraining uncertainties in near to far extrapolation + measure flux, Φ, cross section, σ, and ν-energy (migration matrix S)





ND-LAr ArgonCube – Design

- Key design features:
  - Same target nucleus as the far detector, 50t fiducial mass
  - Designed to mitigate high event rates:
    - Modular design with 35 1m x 1m x 3.5m modules
    - Pixelated charge readout – LArPix

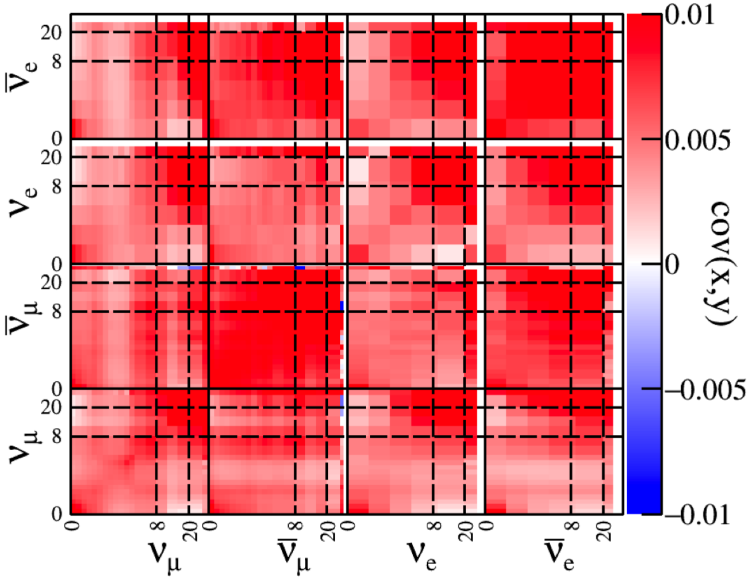


prototype module 0
field cage

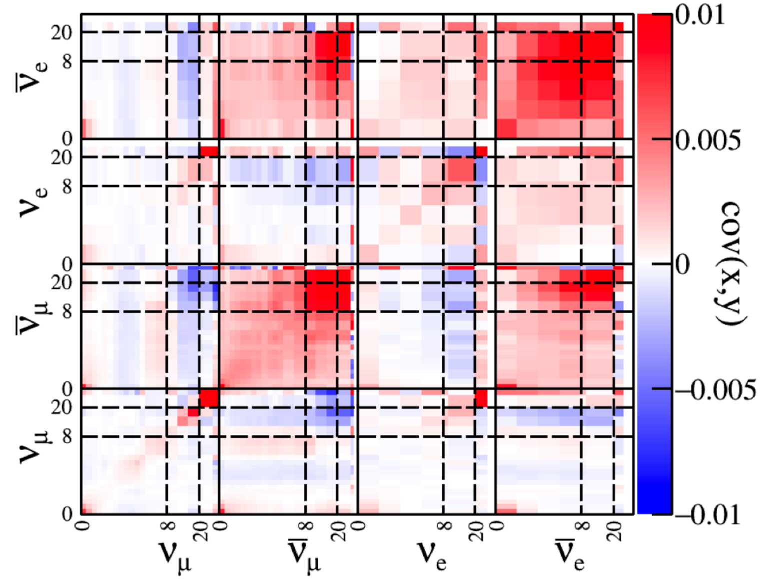
ND-LAr ArgonCube – Capabilities

- Key capabilities:
  - Collects a high stat independent ν_μ CC interactions on Ar
    - e.g. precisely measures absolute and relative flux using the ν-e elastic scattering data

FHC mode	total	accepted	0.5 GeV to 4.0 GeV	accepted
ν_μ CC	8.2×10^7	3.0×10^7	5.9×10^7	2.4×10^7
$\bar{\nu}_\mu$ CC	3.6×10^6	1.4×10^6	1.1×10^6	4.6×10^5
NC total	2.8×10^7	1.6×10^7	1.9×10^7	1.3×10^7
ν_μ CC0π	2.9×10^7	1.6×10^7	2.6×10^7	1.3×10^7
ν_μ CC1$\pi^\pm$	2.0×10^7	7.5×10^6	1.7×10^7	6.0×10^6
ν_μ CC1π^0	8.0×10^6	2.9×10^6	6.5×10^6	2.2×10^6
ν_μ CC3π	4.6×10^6	7.2×10^5	1.7×10^6	3.8×10^5
ν_μ CC other	9.2×10^6	7.4×10^5	1.5×10^6	3.1×10^5
$\nu_e + \bar{\nu}_e$ CC	1.4×10^6	6.6×10^5	4.5×10^5	3.3×10^5
$\nu + e$ elastic	8.4×10^3	7.2×10^3	5.3×10^3	4.2×10^3



without ND-LAr constrain

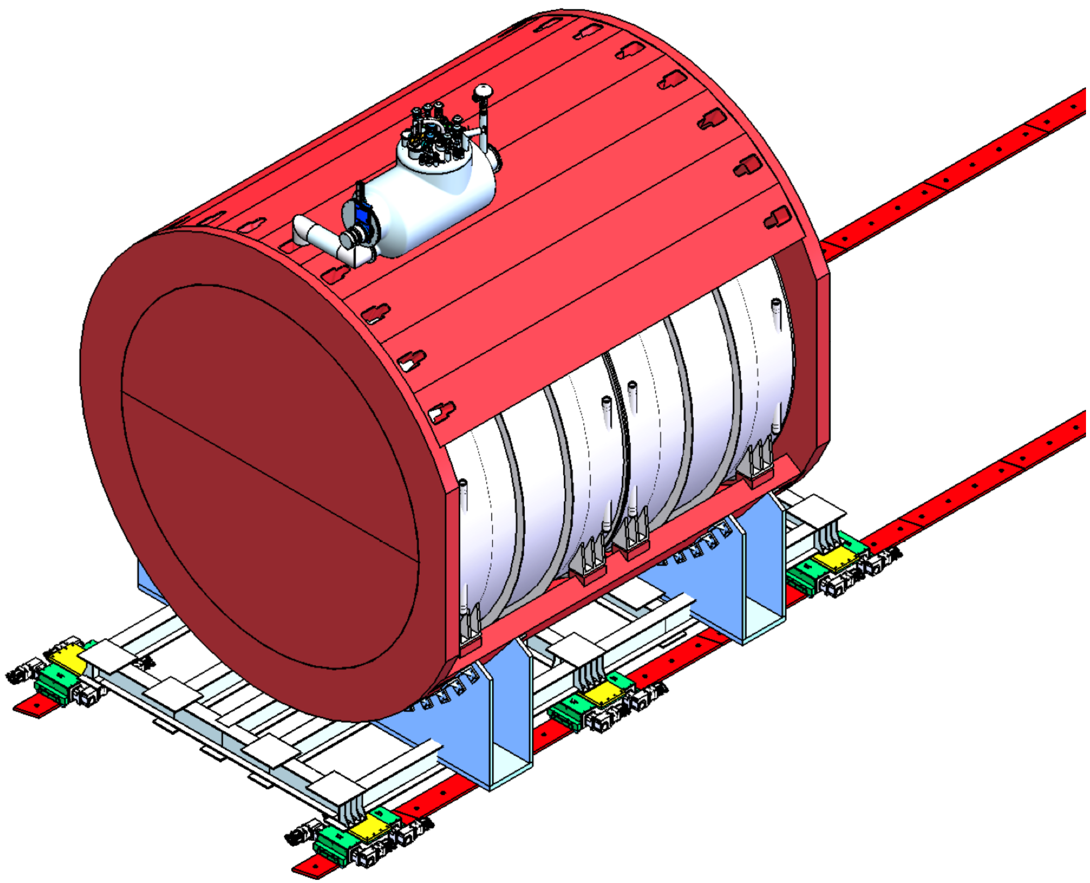


with ND-LAr constrain

10.1103/PhysRevD.101.032002

ND-GAr – Design

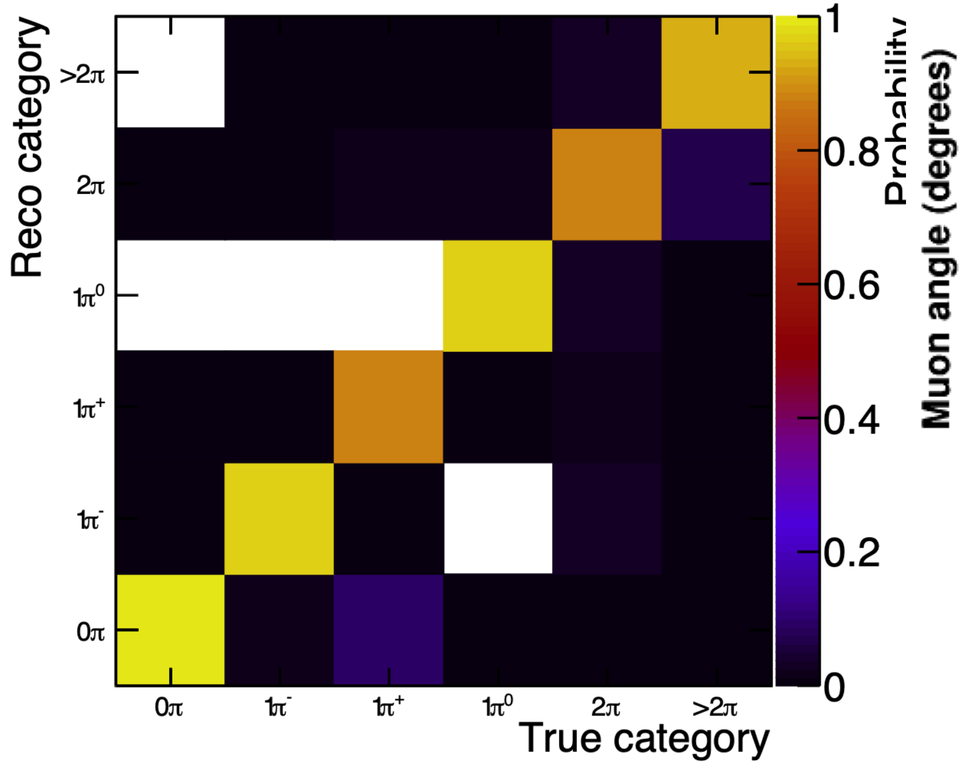
- Key design features:
  - Has a High Pressure Gas Argon TPC (HPgTPC) at its core; will be a copy of ALICE TPC (acquired ALICE's multiwire chambers will be re-purposed for HPgTPC)
  - Ar-CH_4 90-10 baseline gas mixture (97% Ar interactions) at 10 atm
  - ECAL calorimeter & superconducting magnet surround the HPgTPC

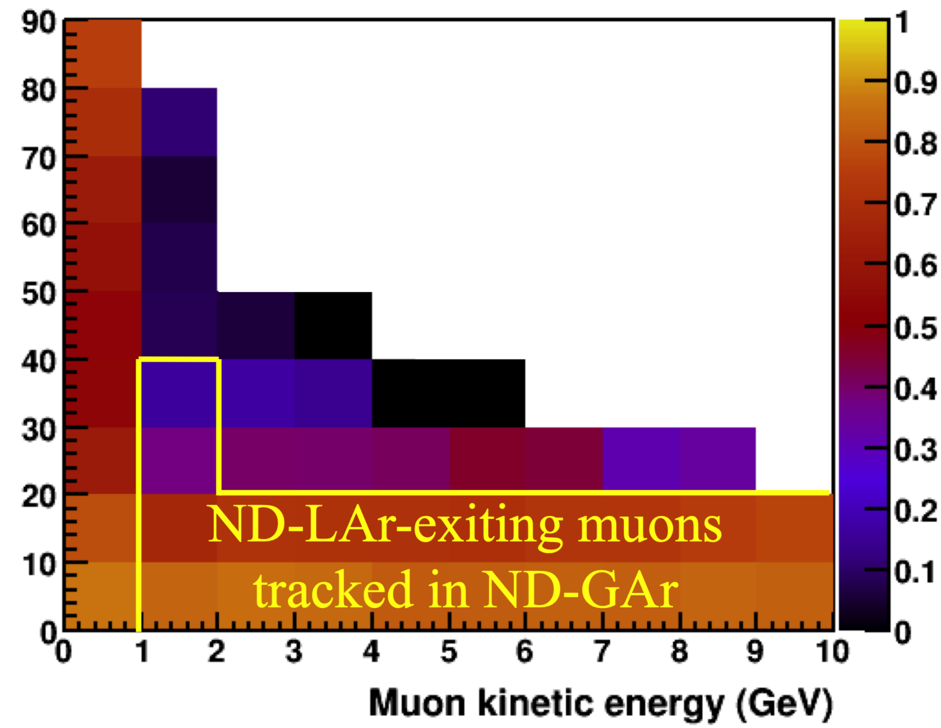


ND-GAr – Capabilities

- Key capabilities:
  - Designed to reconstruct & sign-tag ND-LAr exiting tracks + collect an independent sample of ν-Ar interactions + lower detection threshold than ND-LAr
  - PEP-4-like PID & tracking:
    - e.g. can be used to select exclusive multi-π final state samples for further constraining any uncertainties

FHC Beam		RHC Beam	
Process	Events/ton/yr	Process	Events/ton/yr
All ν_μ-CC	1.64×10^6	All $\bar{\nu}_\mu$-CC	5.26×10^5
CC 0π	5.85×10^5	CC 0π	2.36×10^5
CC $1\pi^\pm$	4.09×10^5	CC $1\pi^\pm$	1.51×10^5
CC $1\pi^0$	1.61×10^5	CC $1\pi^0$	4.77×10^4
CC 2π	2.10×10^5	CC 2π	5.21×10^4
CC 3π	9.28×10^4	CC 3π	1.66×10^4
CC K_s	1.20×10^4	CC K_s	2.72×10^3
CC $K^\pm$	4.57×10^4	CC $K^\pm$	4.19×10^3
CC other	1.27×10^5	CC other	1.62×10^4
All $\bar{\nu}_\mu$-CC	7.16×10^4	All ν_μ-CC	2.72×10^5
All NC	5.52×10^5	All NC	3.05×10^5
All ν_e-CC	2.85×10^4	All ν_e-CC	1.84×10^4
$\nu e \rightarrow \nu e$	170	$\nu e \rightarrow \nu e$	120





ND-GAr – Capabilities

- Key capabilities:
  - Reconstructs & sign-tags ND-LAr exiting tracks + collects an independent sample of ν-Ar interactions
  - PEP-4-like PID & tracking + lower detection threshold than ND-LAr:
    - e.g. can be used to select exclusive multi-π final state samples for further constraining

FHC Beam Process	Events/ton/yr	RHC Beam Process	Events/ton/yr
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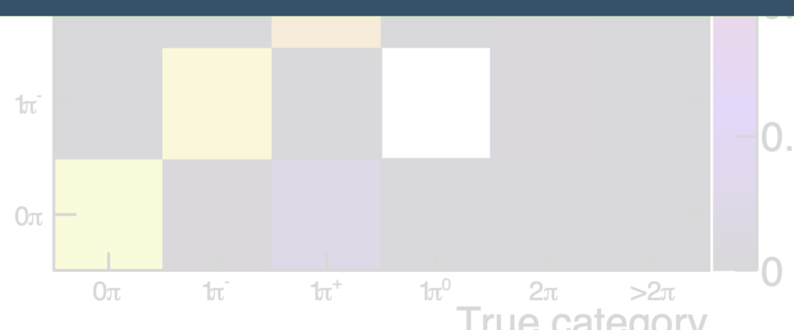
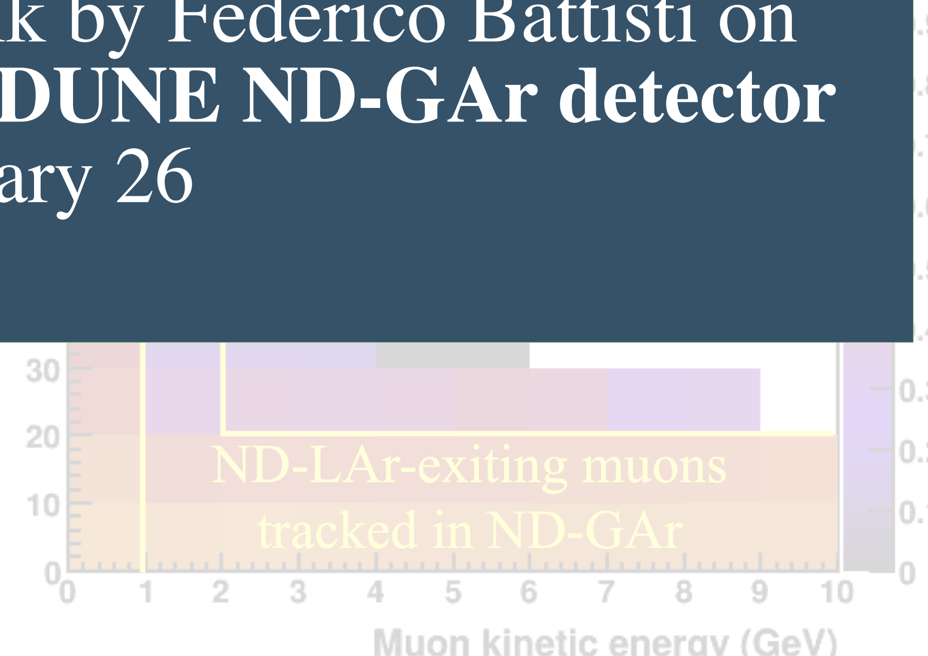
All NC	5.52×10^5	All NC	3.05×10^5
All ν_e-CC	2.85×10^4	All ν_e-CC	1.84×10^4

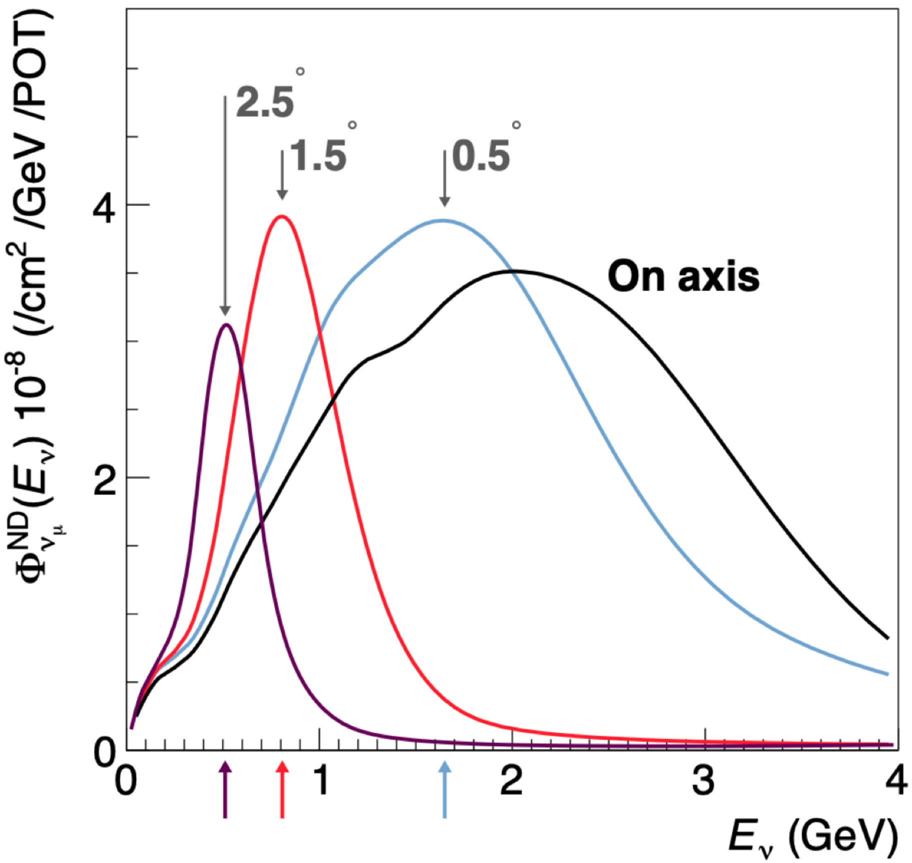
For more details, see the talk by Federico Battisti on **Physics potential with the DUNE ND-GAr detector** on February 26

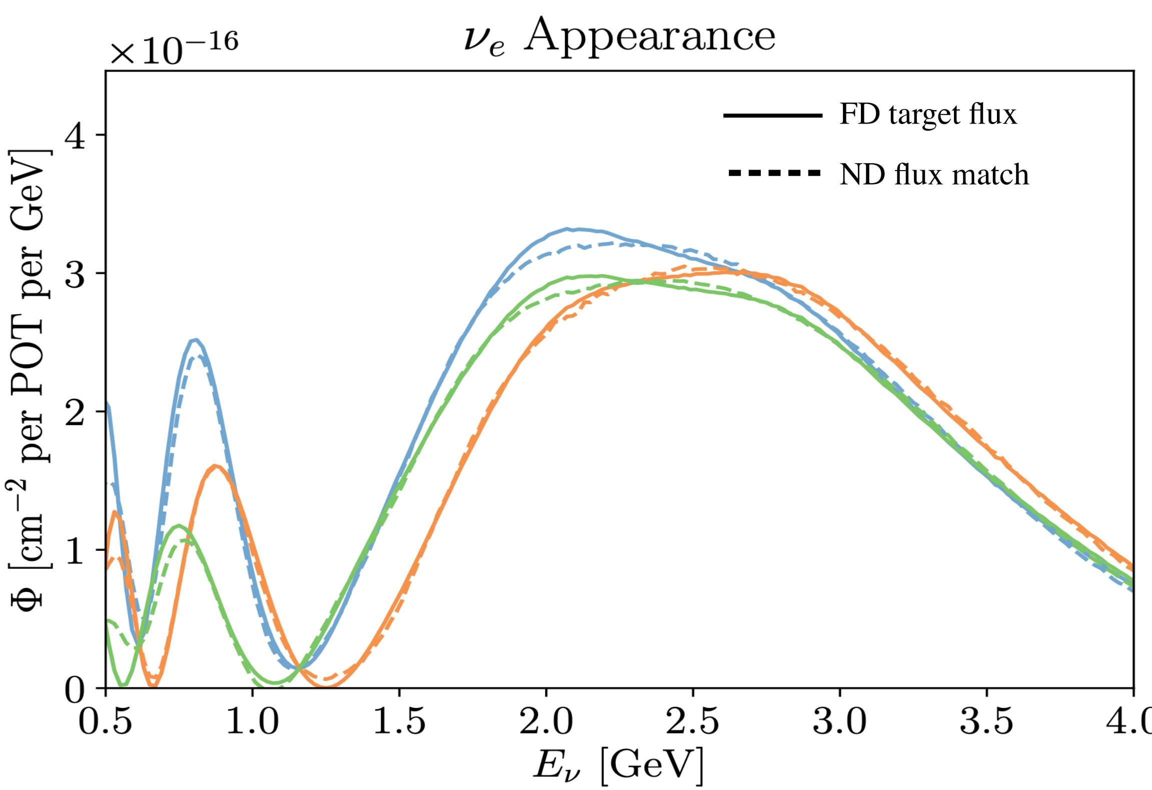




DUNE PRISM

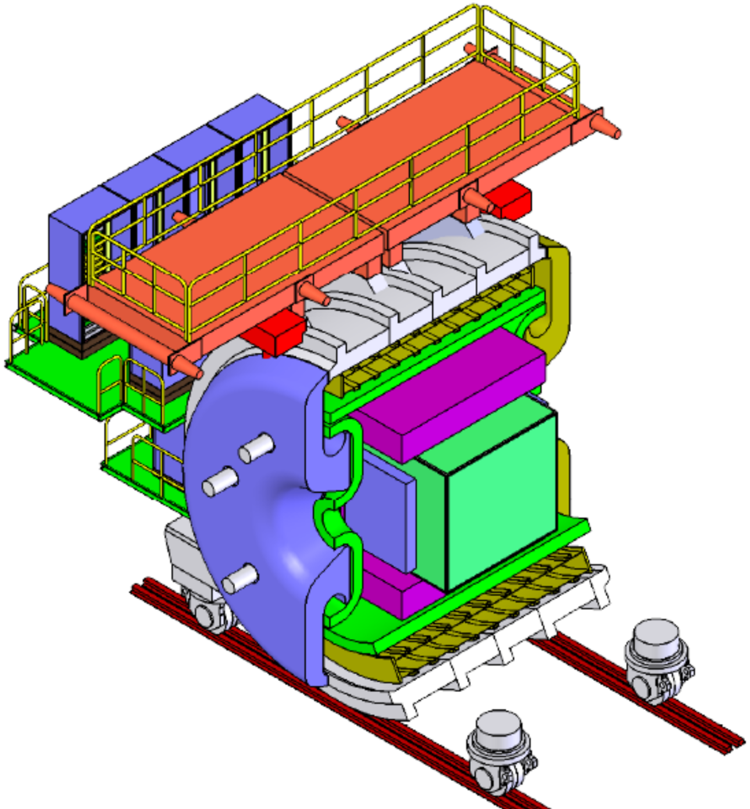
- Move ND-LAr and ND-GAr to various off-axis positions to collect off-axis flux data:
  - Can predict oscillated neutrino event spectra at FD with reduced model dependencies
  - Provides a handle for de-convolving flux & cross section uncertainties

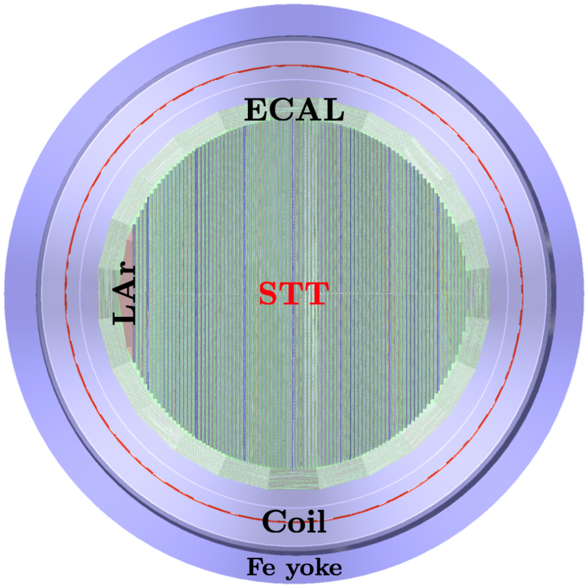


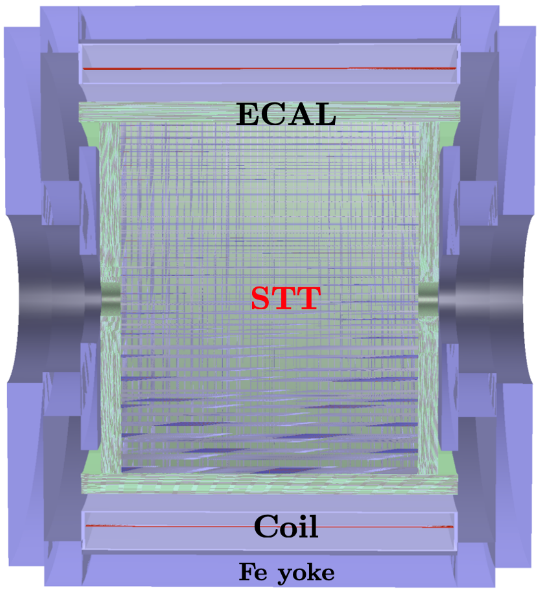


SAND – Design

- Key design features:
  - Designed to measure the on-axis beam
  - KLOE magnet + ECAL making up the outer layers
  - Central tracking options:
    - 3D segmented plastic scintillator (3DST) + TPCs
    - 3DST + Straw Tube Tracker (STT)
    - STT-only
  - Design is being finalized

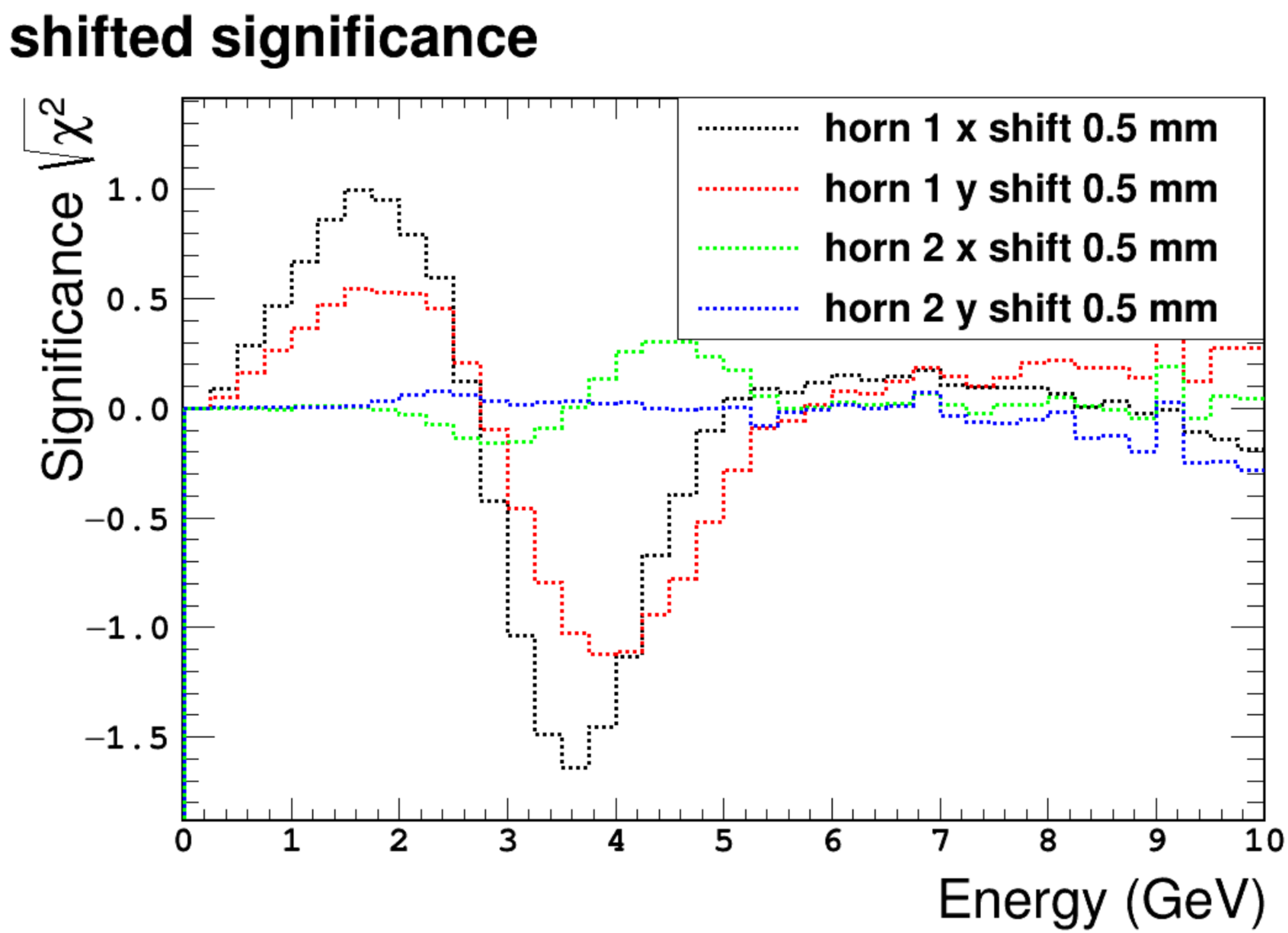






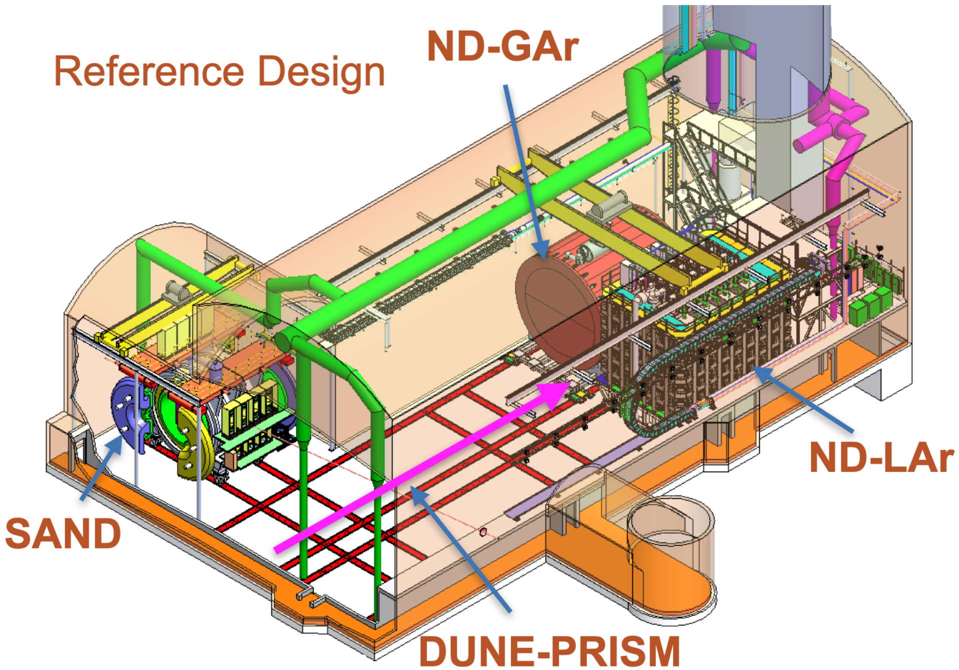
SAND – Capabilities

- With ND-LAr and ND-GAr moving to off-axis positions, SAND remains on-axis to measure any changes in the beam parameters:
  - e.g. can measure the spectral shift in the reconstructed neutrino energy for different horn shifts



Summary

- DUNE near detector components and program consist of:
  - ND-LAr
  - ND-GAr
  - SAND
  - DUNE PRISM
- Near detector components and program enable a very precise measurement of oscillation parameters
- The design of the various near detector components add unique and important capabilities to DUNE's overall physics program



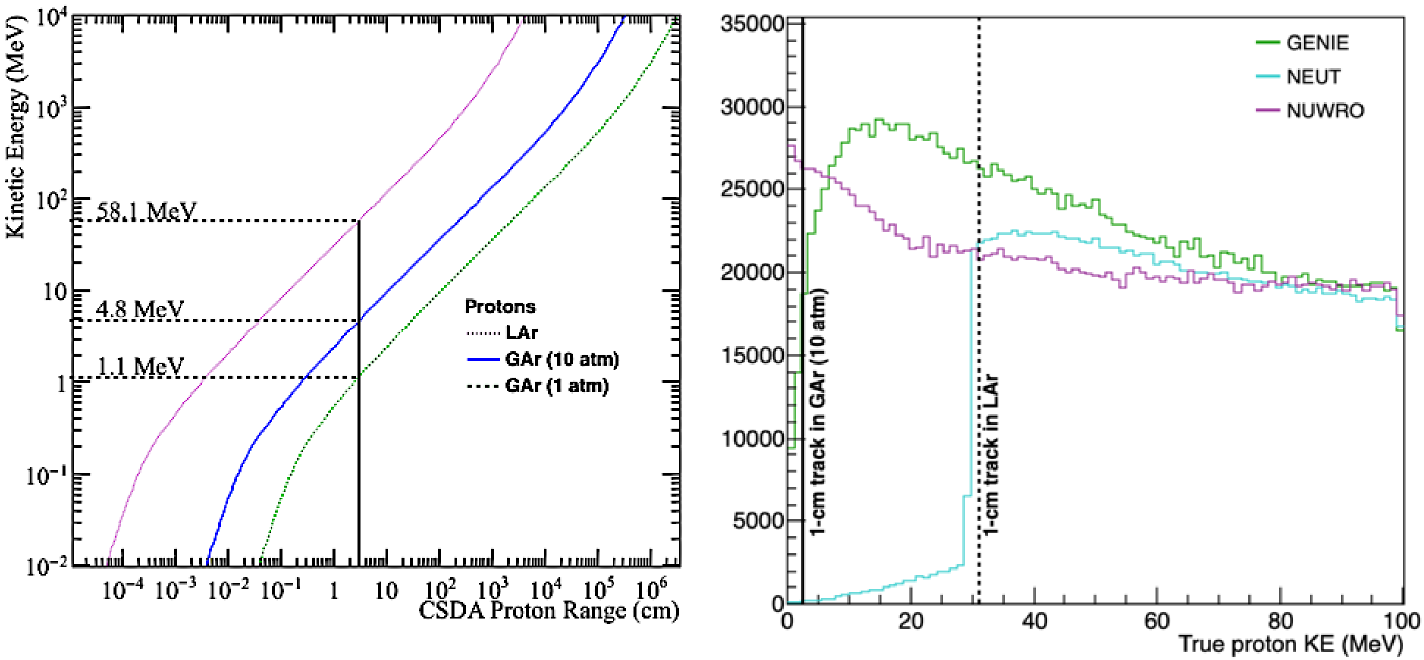
Thank you!

Questions are welcome, now or on Slack or via email (mtanaz@fnal.gov)

Additional Slides

ND-GAr – Capabilities

- Key capabilities:
  - ★ Lower density ($\rho_{LAr}/\rho_{GAr} \approx 85$ for 10 atm GAr) compared with ND-LAr, more sensitivity to lower energy charged particles that may not be seen in ND-LAr
  - ★ Reveals discrepancies between different neutrino event generators for choosing a more accurate ν-N interaction model @ lower energies



ND-GAr – Capabilities

- Key capabilities:
  - More specifically, the excellent PID and tracking can help select exclusive multi-π final state samples for further reducing any bias in δ_{cp}