NuFACT 2022

The Path to Precision: Role of the DUNE Near Detectors

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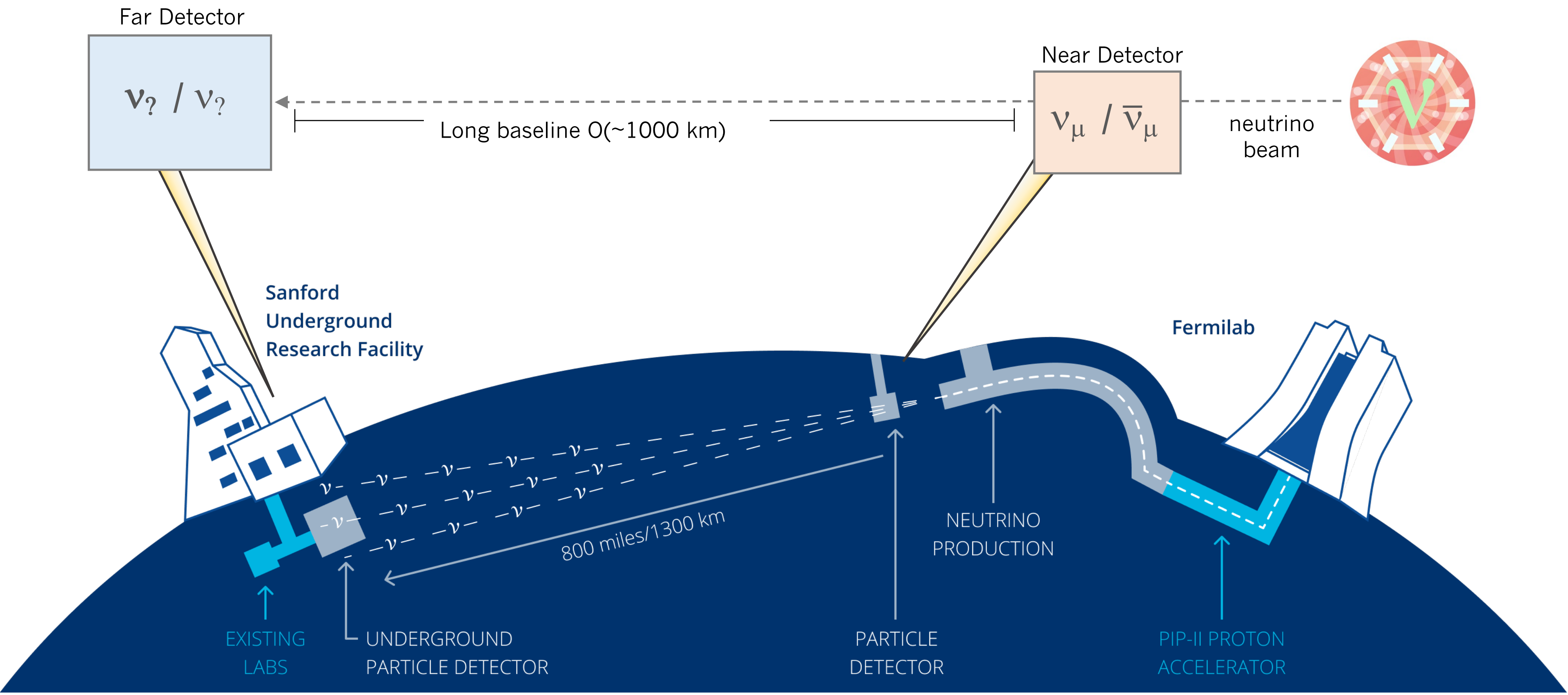
(on behalf of the DUNE Collaboration)

Aug 4, 2022

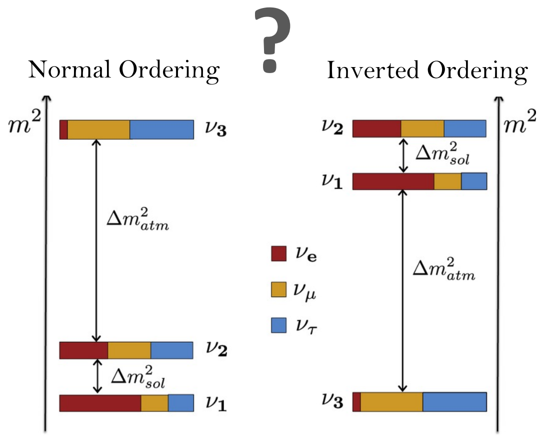
The DUNE Experiment

- The Deep Underground Neutrino Experiment is a long-baseline oscillation experiment that will use the most intense accelerator neutrinos from the LBNF beam and detect them at SURF 1300 kms away.

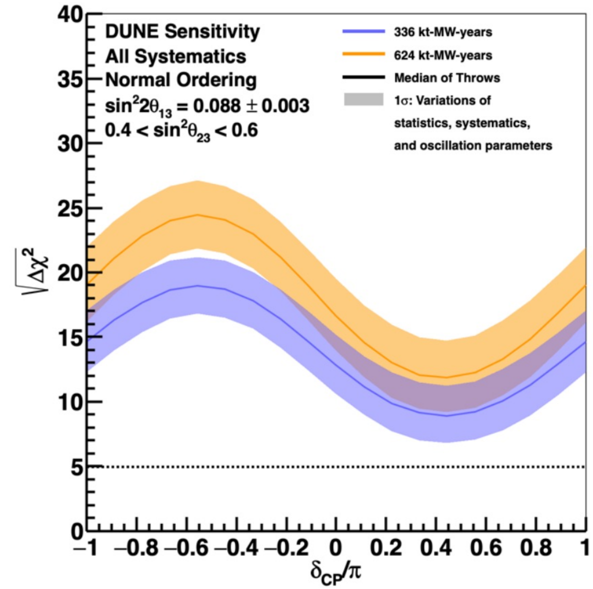


DUNE ~~Physics~~ oscillation Physics Goals* : Discovery

☞ DUNE Oscillation by C. Wilkinson



Mass Ordering: Normal or Inverted?



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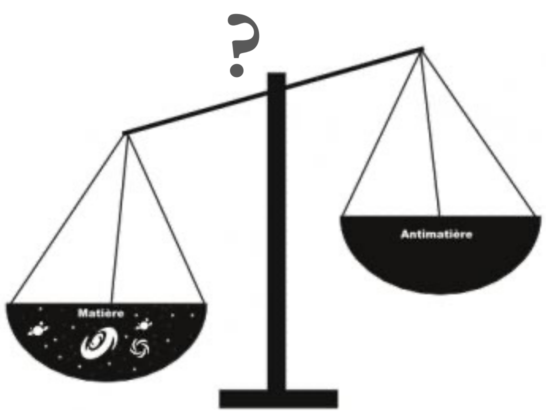
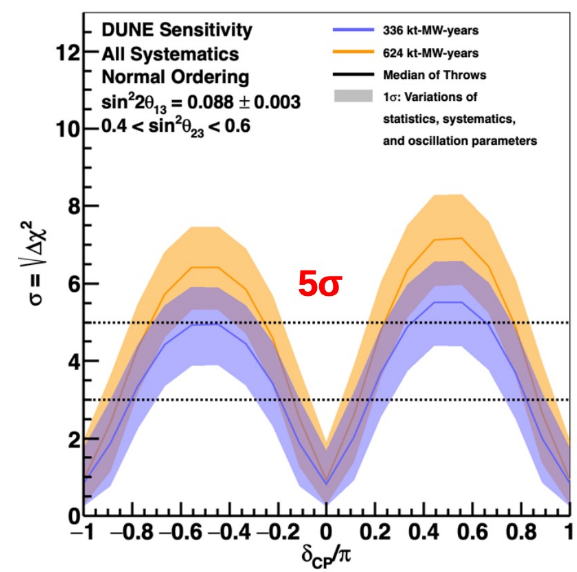


δ_{CP}: Do neutrinos violate CP?

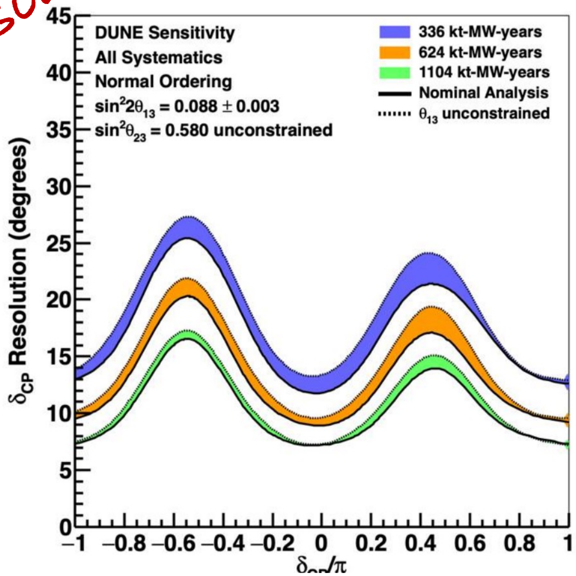


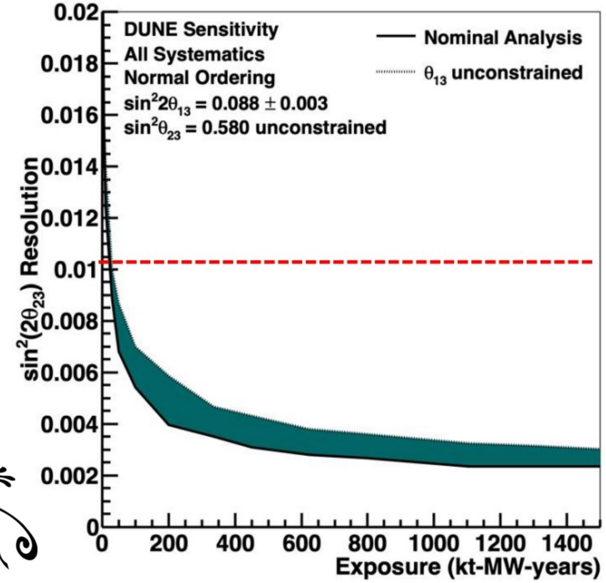
EPJC 80 (2020) 978

*other cool searches for supernova, DSNB, BSM physics and sterile searches not included here!

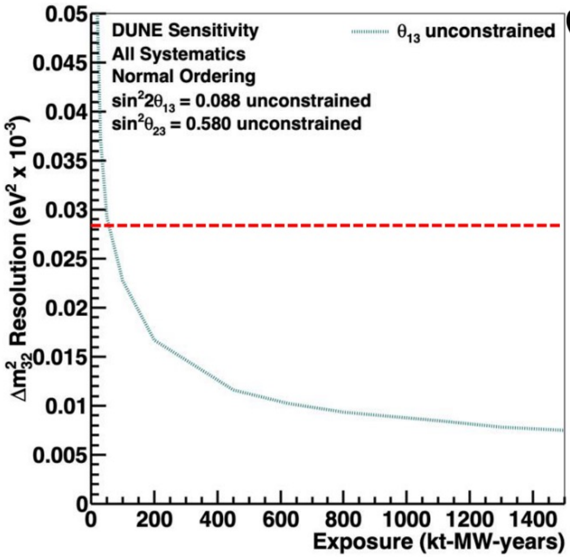
DUNE oscillation Physics Goals* : Precision

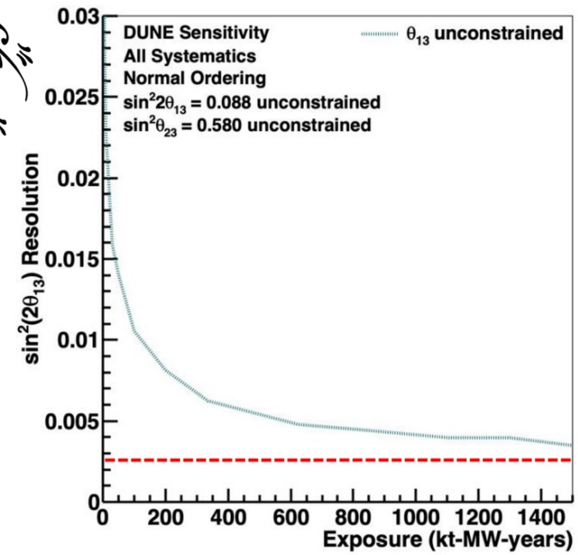
☞ DUNE Oscillation by C. Wilkinson





Unambiguous high precision measurements of Δm^2_{32}, δ_{CP}, θ_{23} and θ_{13} with a single experiment.





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*other cool searches for supernova, DSNB, BSM physics and sterile searches not included here!

DEEP UNDERGROUND NEUTRINO EXPERIMENT

Long-Baseline Oscillations

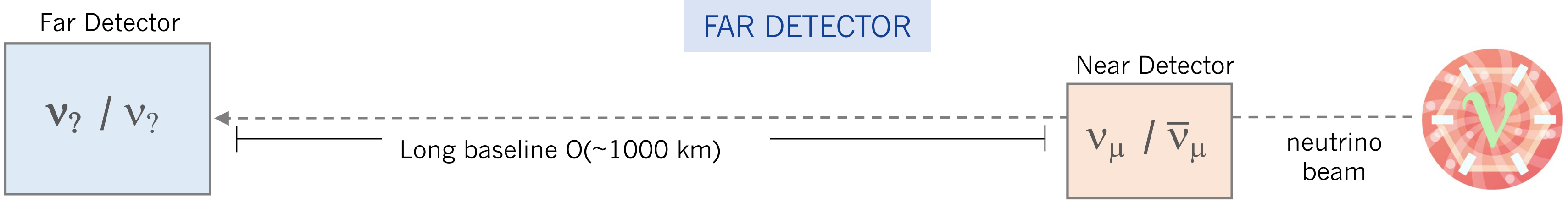
NEAR DETECTOR

Event rate — cross-section — oscillation probability

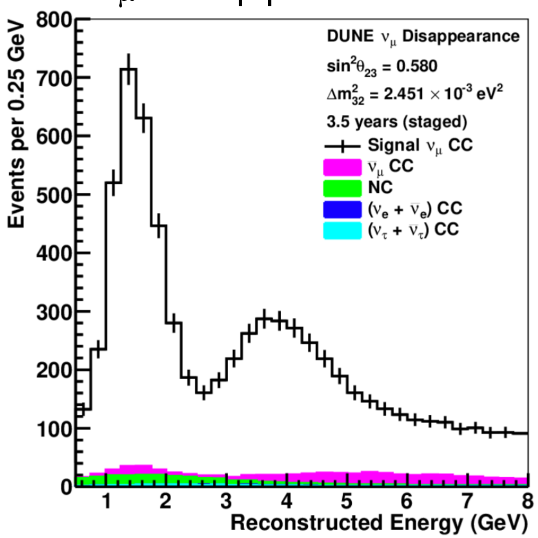
$$R(\vec{x}) = \phi(E_\nu) \times \sigma(E_\nu, \vec{x}) \times \epsilon(\vec{x}) \times P(\nu_A \to \nu_B)$$

neutrino flux — detector response

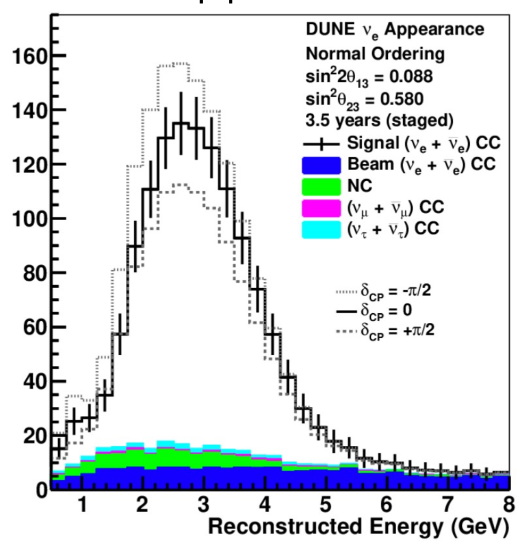
FAR DETECTOR



ν_μ disappearance



ν_e appearance



To measure oscillation:

- Observe the energy spectrum of flavor-tagged neutrinos at the FD.
- Predict the neutrino energy spectrum for varying neutrino oscillation parameters.
- Systematic errors in the prediction result in degradation in precision and sensitivity.
- ND must constraint a priori uncertainty for each input in the prediction

The Near Detector

Objective: Predict the observed neutrino spectrum at the FD

Requirements

- Measurements transferable to the FD
- Constrain the cross-section model
- Measure the neutrino flux
- Obtain measurement with different fluxes
- Monitor time variations of the neutrino beam
- Operate in high-rate environment

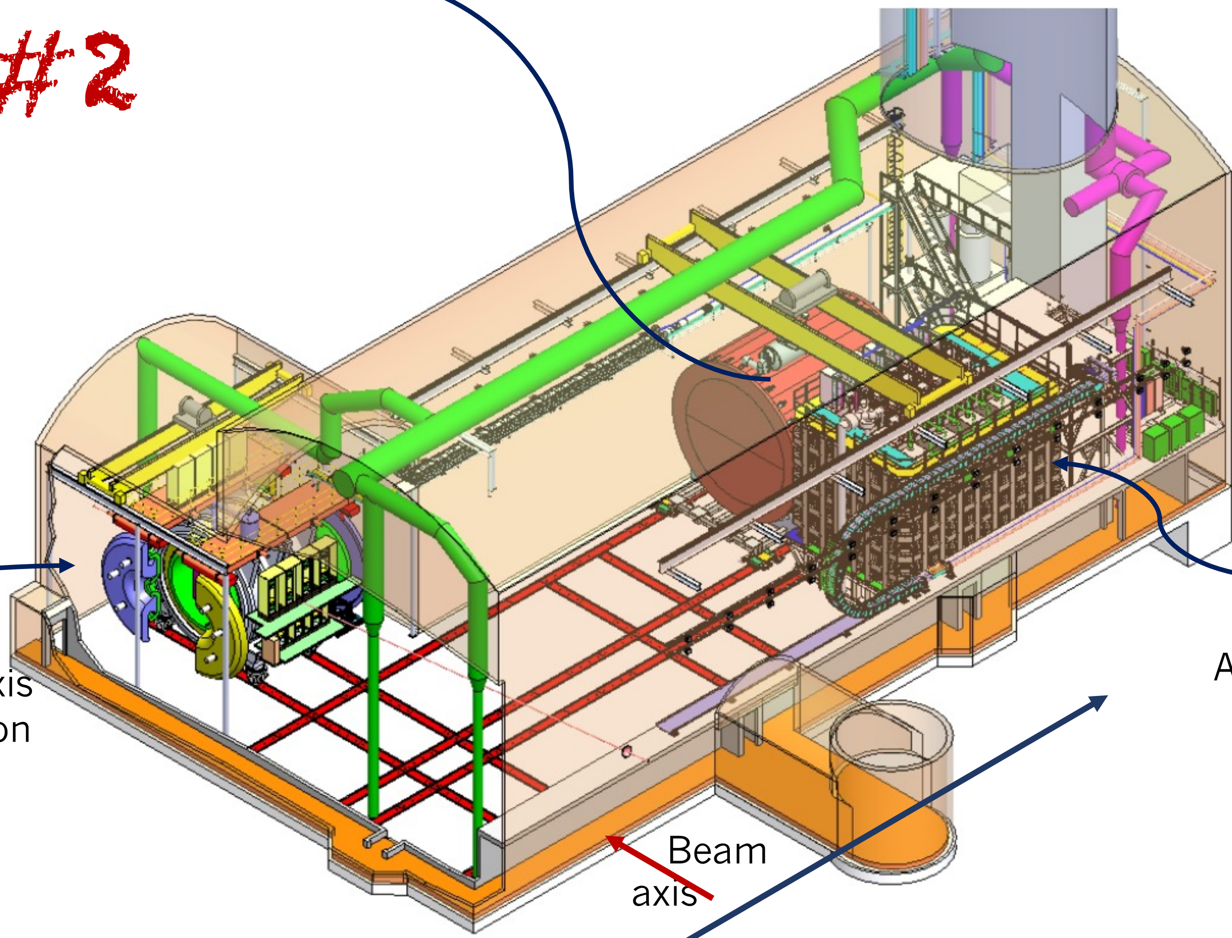
Never go on a long baseline adventure without a near detector – Anonymous.

arXiv 2103:13910 DUNE ND CDR

DUNE ND Overview

Downstream Magnetized Tracker

#2



ND-LAr

#1

Array of modular LArTPCs.

SAND

System for On-Axis Neutrino Detection

#4

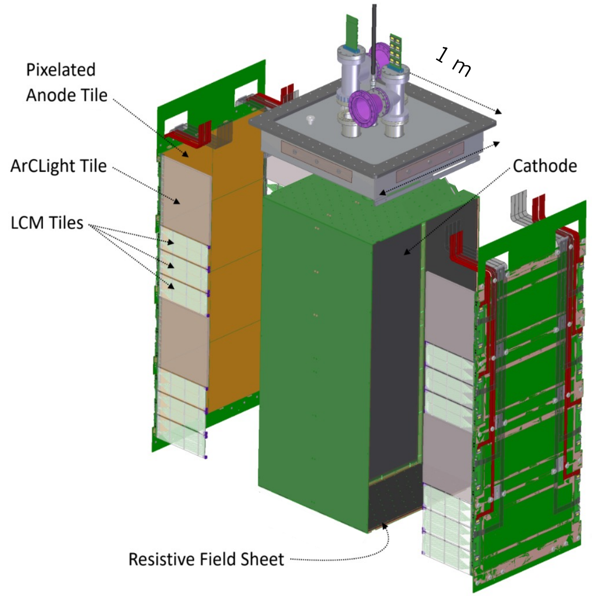
PRISM #3

System for moving the LArTPC and tracker up to 30m transverse to the beam

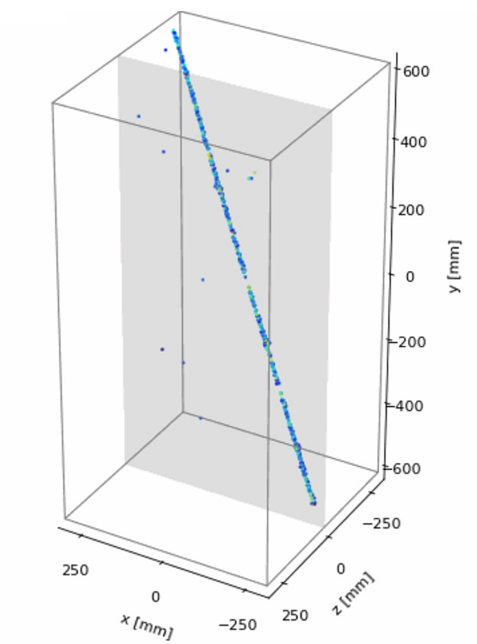
ND-LAr

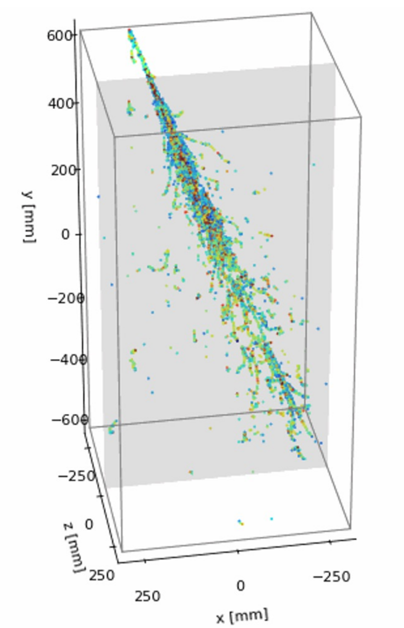
☞ ND-LAr Prototype talk by J. Wolcott

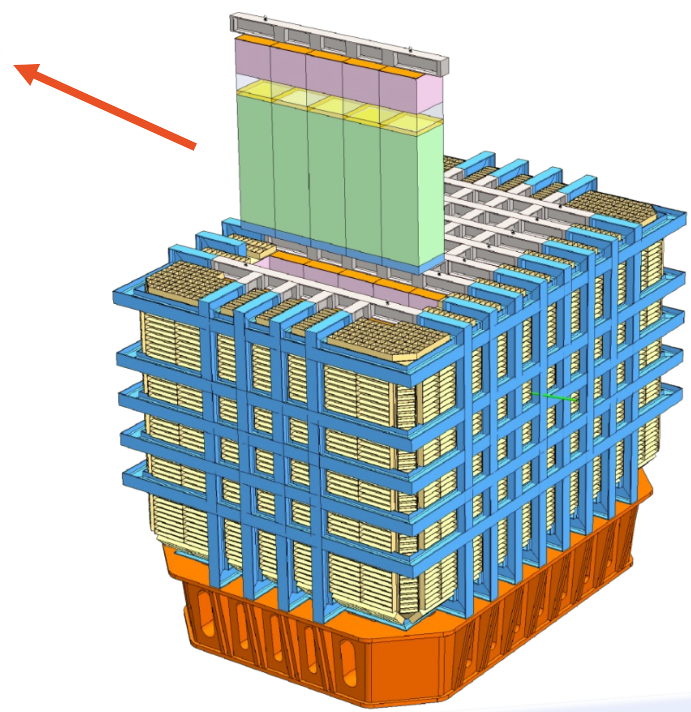
Core Requirements :
- Liquid Ar target in functionally identical detector as FD.
- Constrain flux via ν+e elastic scattering.
- Precise constraints on event rates (flux × cross sections) in LAr



Design :
- 5 x 7 array of 1m x 1m x 3m TPC modules with ~50t fiducial volume
- Modular design to tolerate high event rate environment.
- Pixelated charge readout for true 3D imagining of particle tracks.



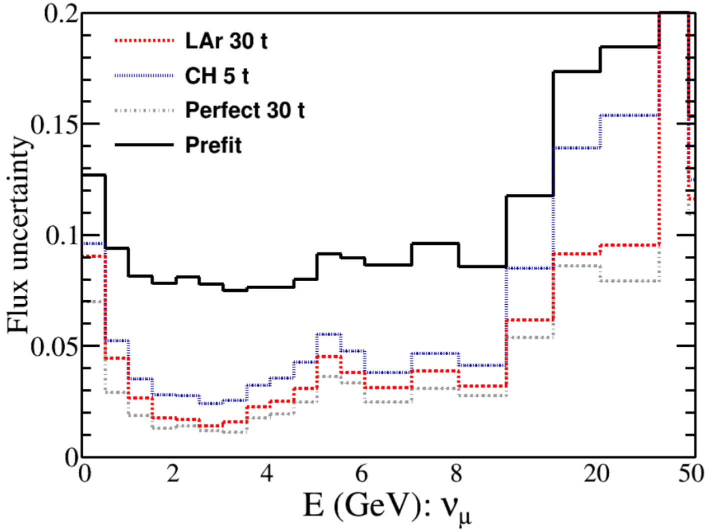


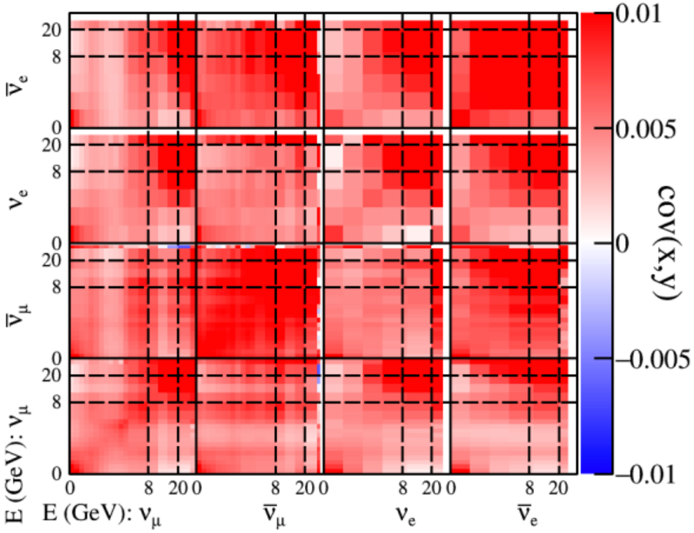


ND-LAr

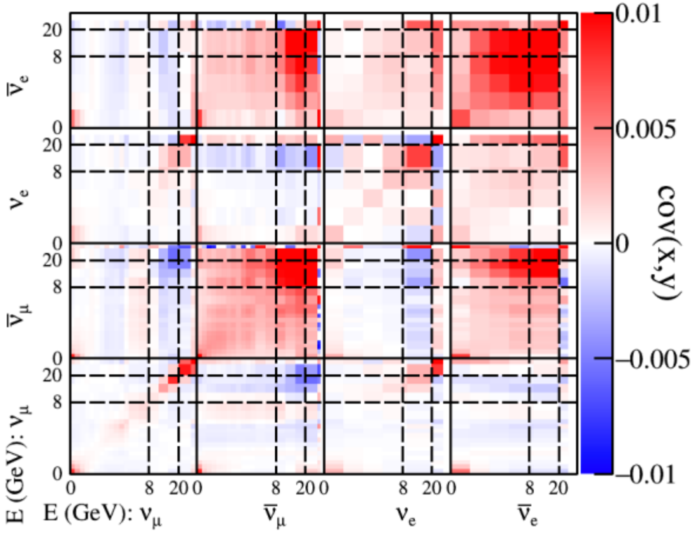
- ν-e scattering events serve as a "standard candle" with precisely known cross section.
- Provide powerful constraint on overall flux normalization.
- Reduction in systematics from ~8% to ~2% in the flux peak.

arXiv:1910:10996





FHC pre-fit



FHC post-fit

Magnetized Muon Tracker

Base Requirement : Downstream tracking of muon tracks exiting ND-LAr

Temporary Muon Spectrometer → **High Pressure Gaseous Argon TPC (ND-GAr)**

Phase I → A More Capable Near Detector → Phase II

Phase I:

- A 100-layer magnetized steel range stack for measuring charge and momentum of exiting muon tracks.
- Cost-effective detector built using existing technology.

Phase II:

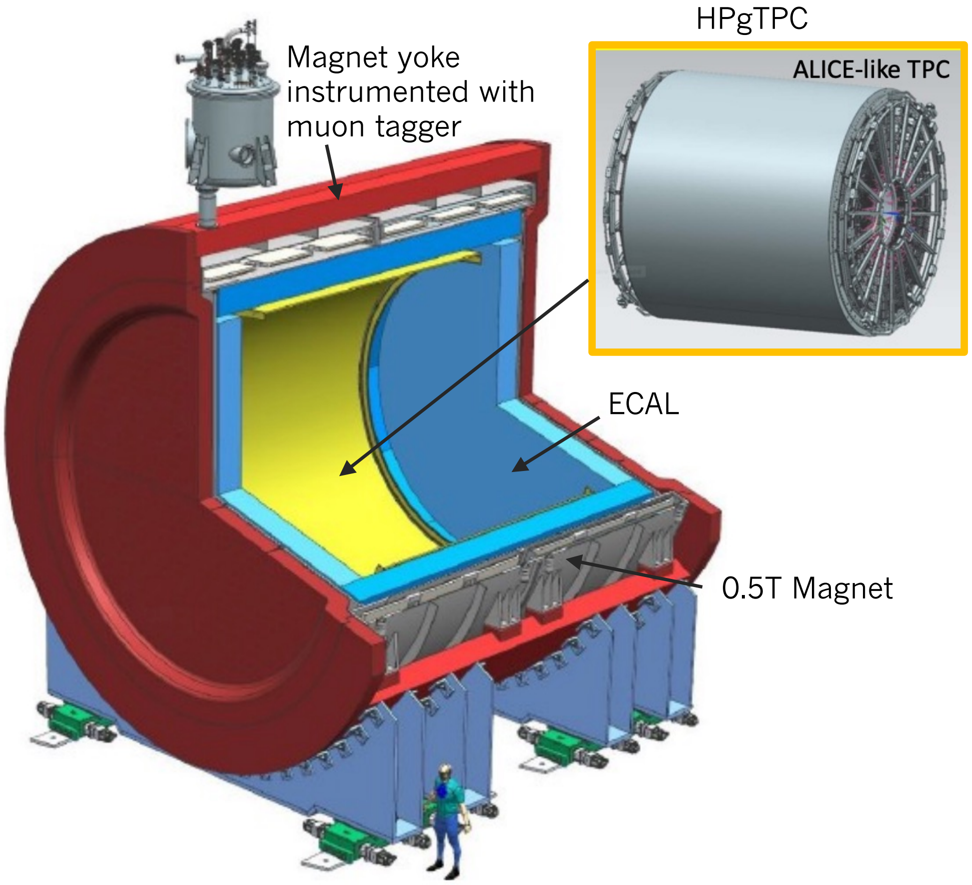
- High pressure gas Argon TPC with electromagnetic calorimeter.
- Measure ν-Ar interactions with low thresholds to better understand the hadronic system.

ND-GAr

Core Requirement : Downstream tracking of muon tracks exiting ND-LAr + low threshold tracking of hadronic system providing fine tuning of cross-section measurements

Main design capabilities:

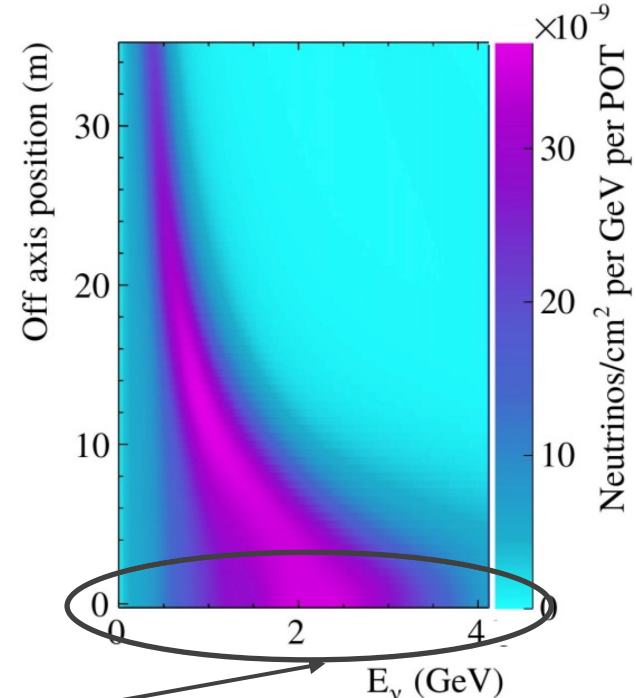
- Excellent PID,
- tracking efficiency,
- momentum resolution
- 4π coverage
- Minimal secondary interactions
- Low threshold : high sensitivity to low energy protons or pions
- Measure exclusive final-state topologies

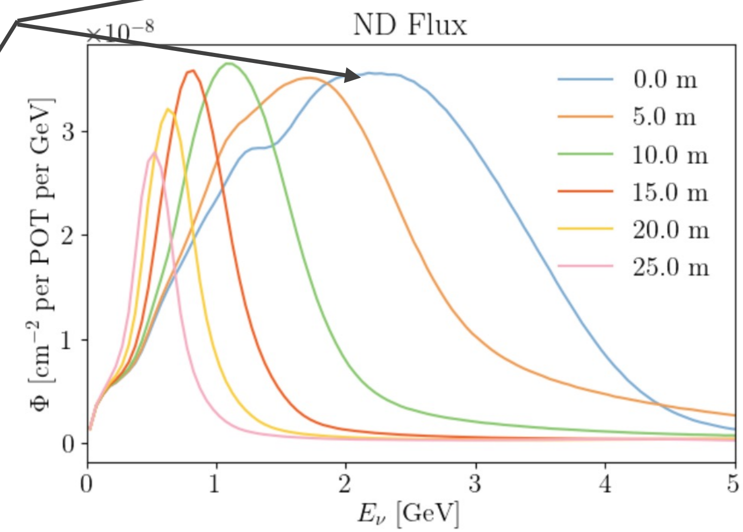


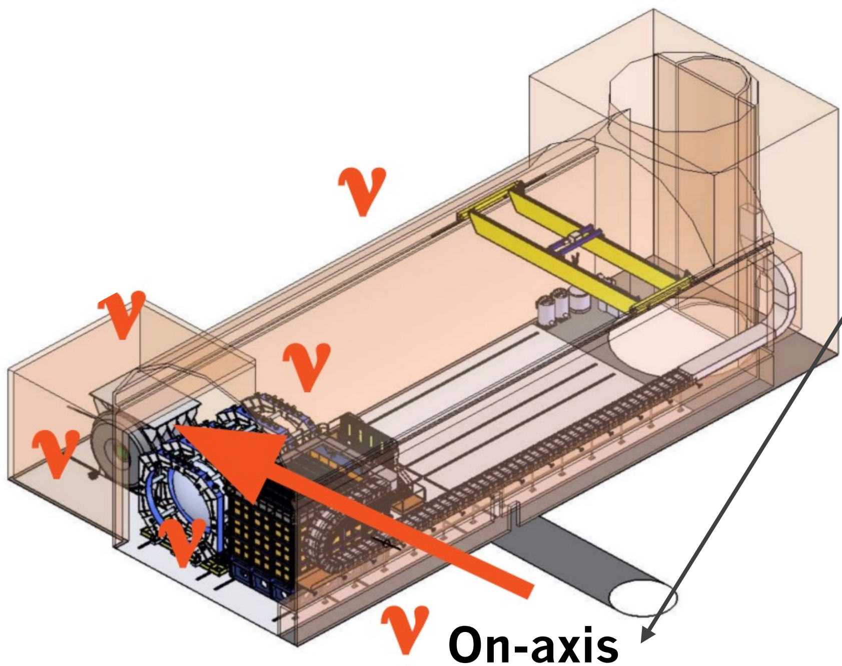
PRISM

Core Requirement:
Data driven cancelation of energy dependence uncertainties in flux, cross sections.

Design:
PRISM is a mechanism for moving ND-LAr + tracker detector systems **28.5 m** transverse to the beam direction to sample neutrino flux at multiple off-axis position.







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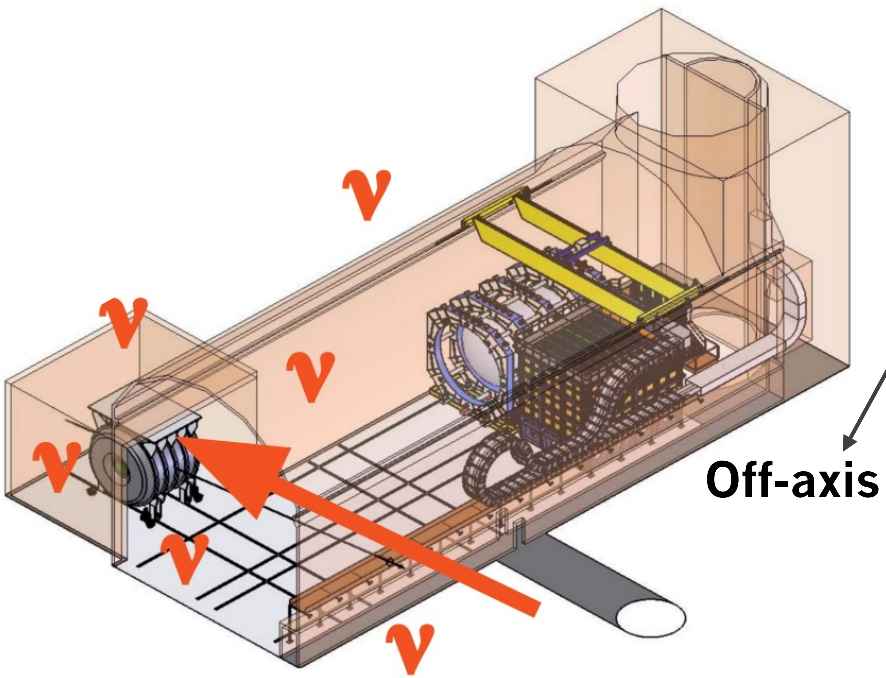
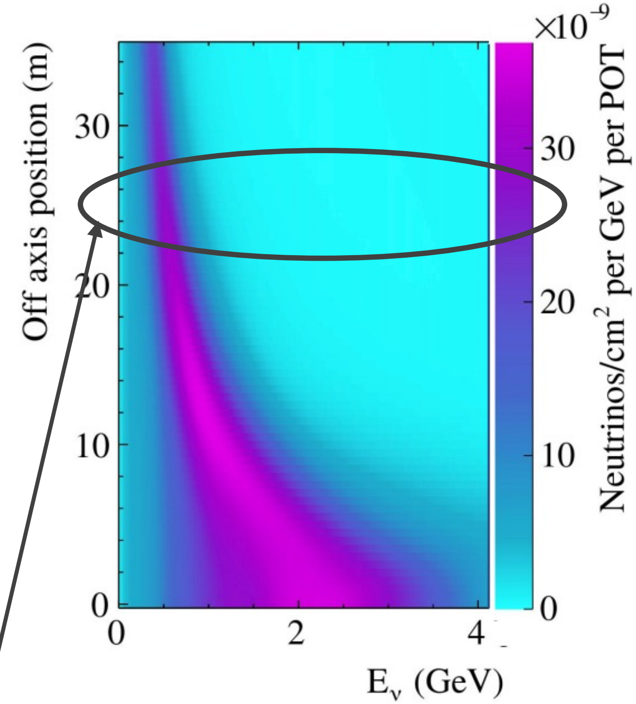
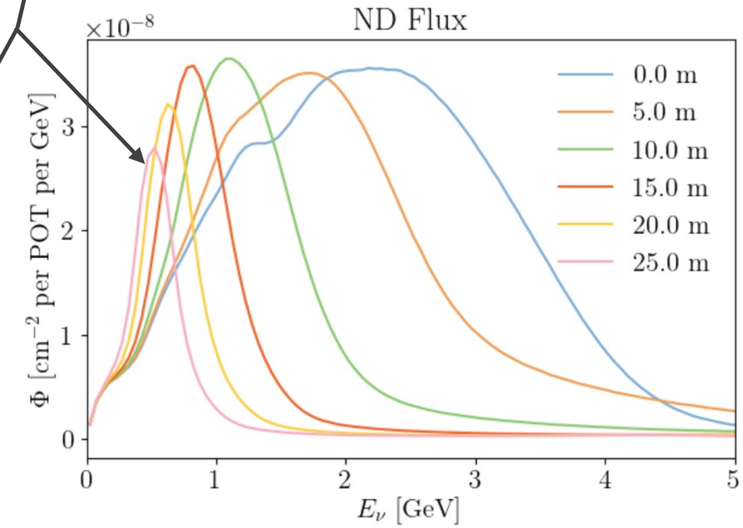


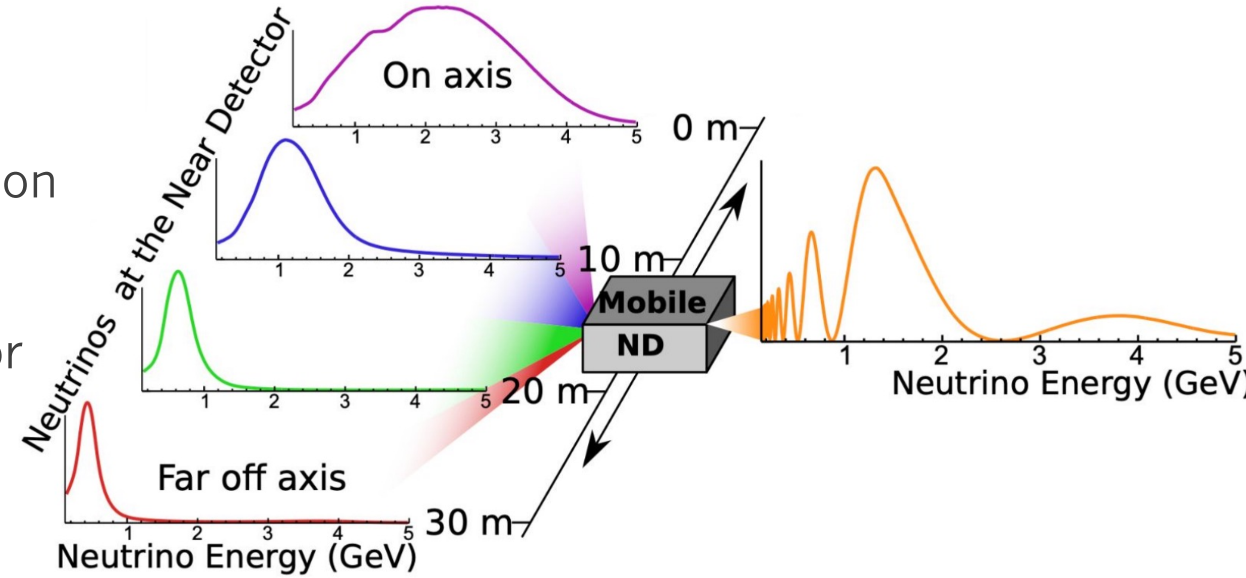




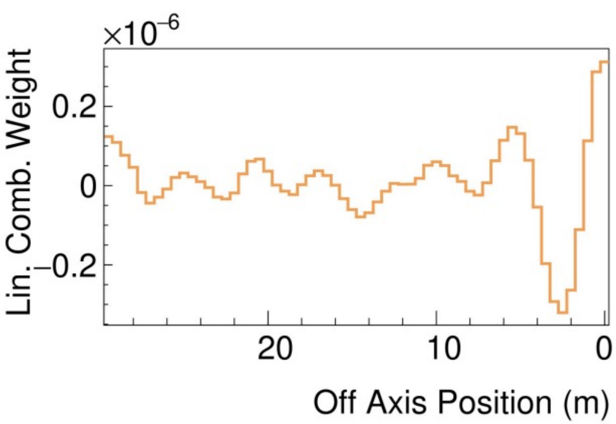
DEEP UNDERGROUND NEUTRINO EXPERIMENT

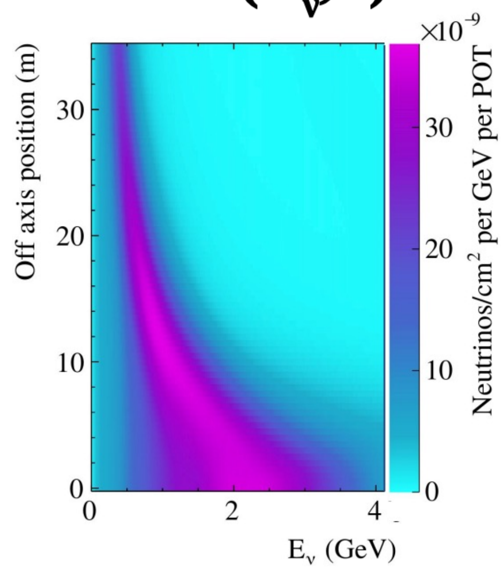
PRISM

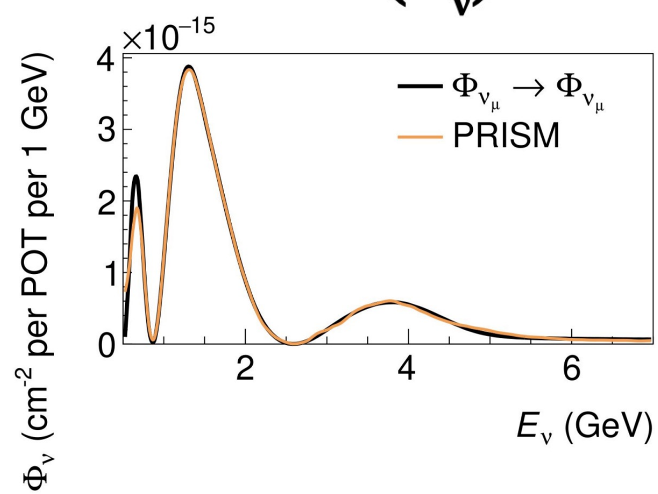
Using a linear combination of ND flux at various off-axis position, we can construct a prediction for the oscillated FD flux.



$$C(x) \cdot \Phi^{ND}(E_\nu, x) = \Phi^{FD}(E_\nu)$$

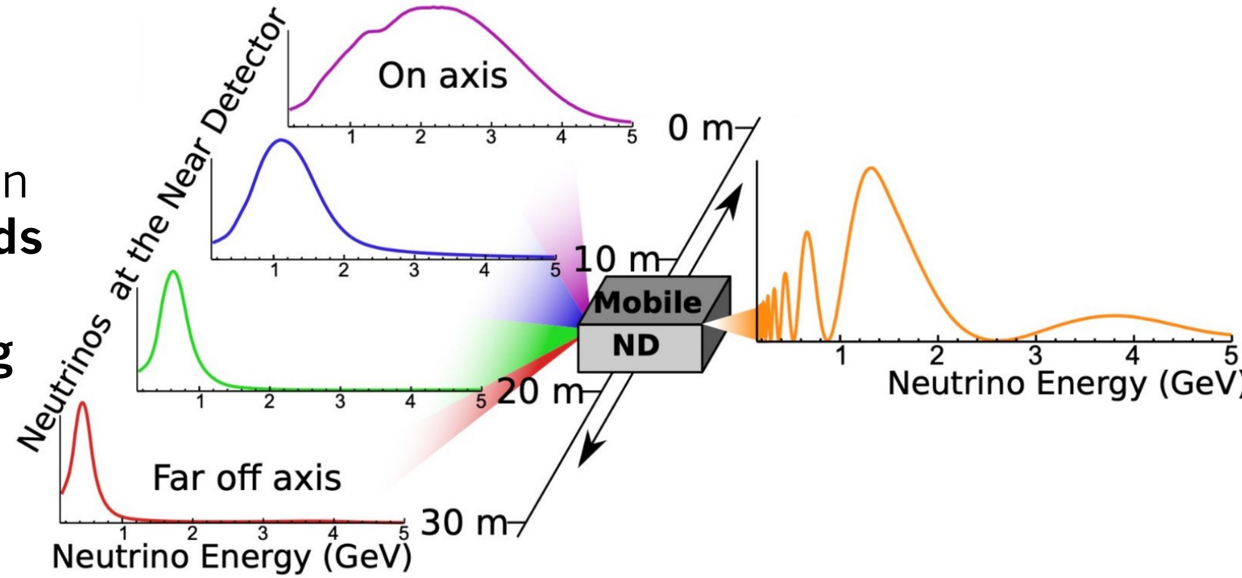




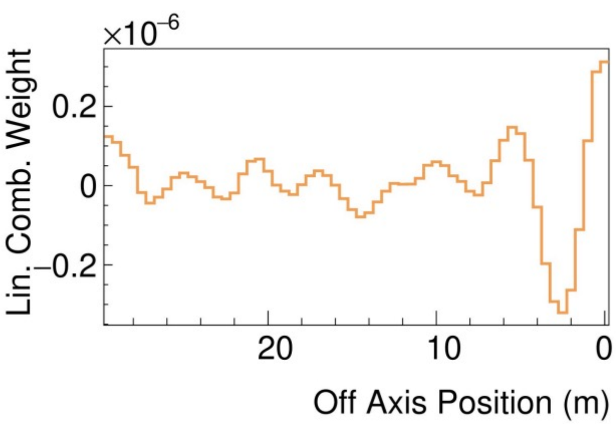


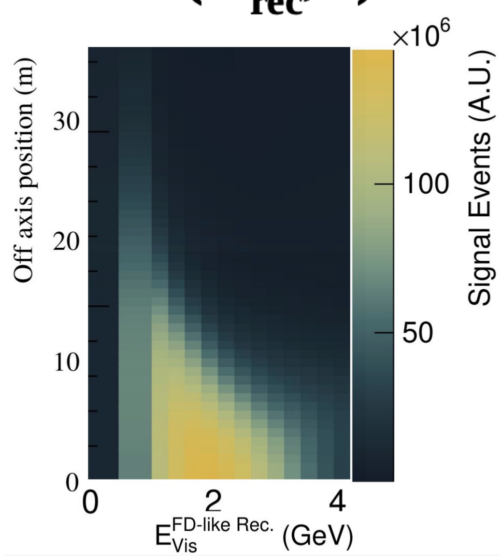
PRISM

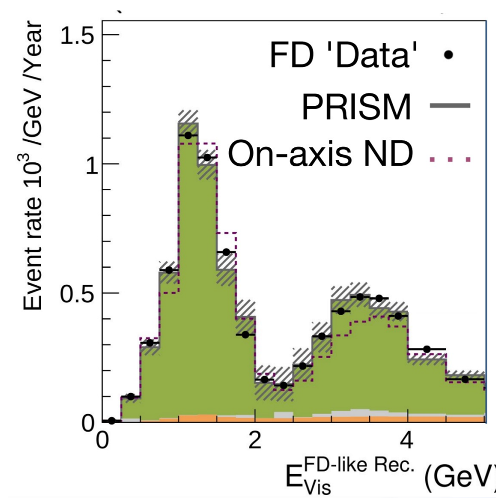
ND data driven prediction using only flux MC. **Avoids dependence on cross section model to leading order.**



$$\mathbf{C(x)} \cdot \mathbf{D^{ND}(E_{rec},x)} = \mathbf{R^{FD}(E_{rec})}$$



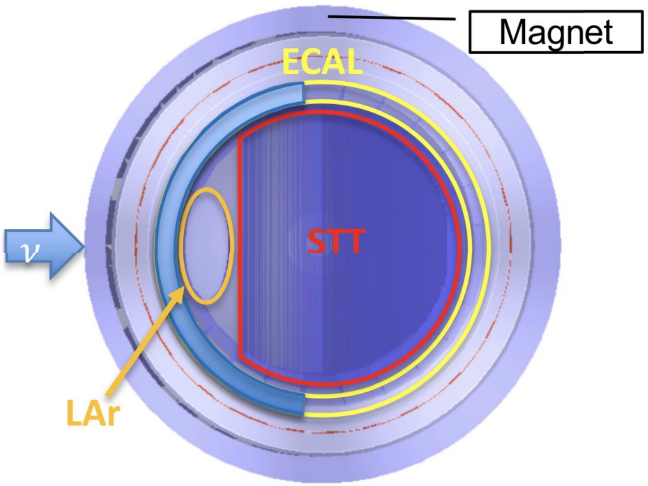


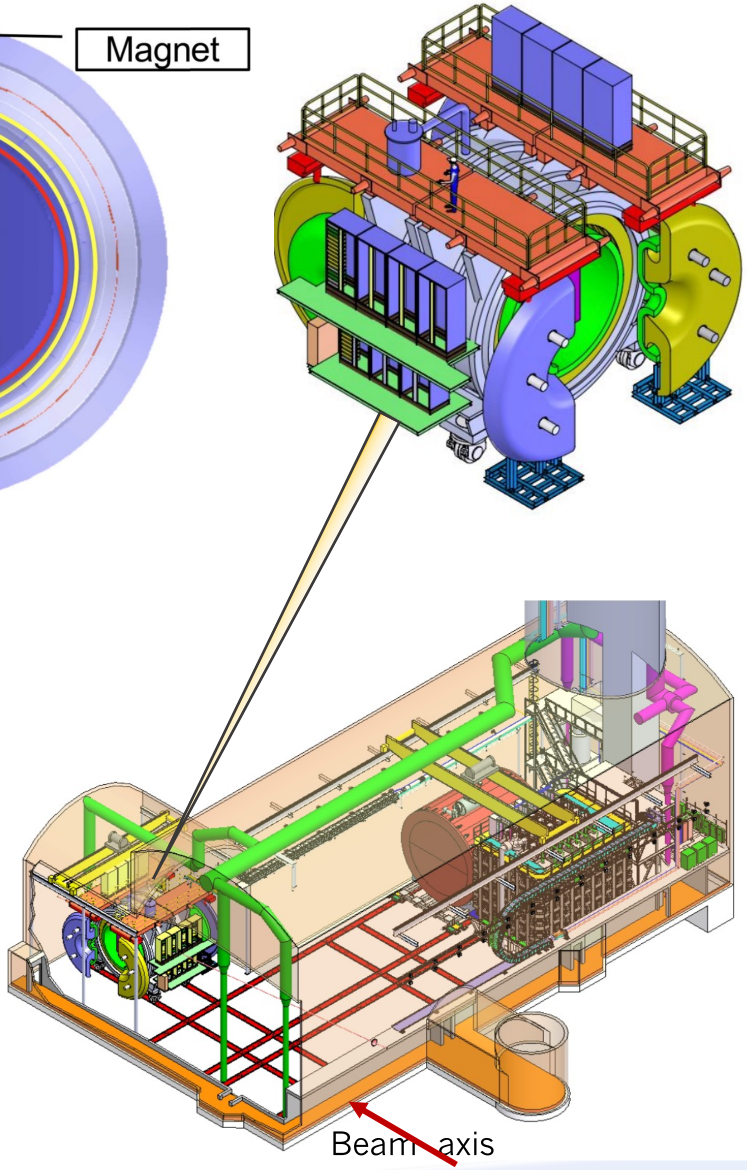


DEEP UNDERGROUND NEUTRINO EXPERIMENT

SAND

Core Requirement : Continuous monitoring of the on-axis flux to determine flux stability and trigger quick response to any beamline geometry change.





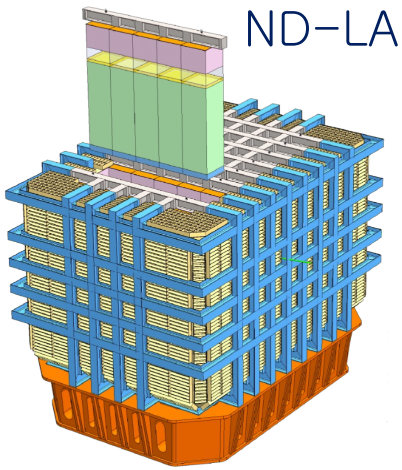
Design:

- Inner straw-tube tracker (STT) surrounded by an electromagnetic calorimeter (ECAL) inside a large solenoidal magnet.
- ECAL and magnet are repurposed from the KLOE experiment
- STT provides CH and C targets for comparison with world cross section data
- Inner Liquid Ar target provides ND-LAr cross check

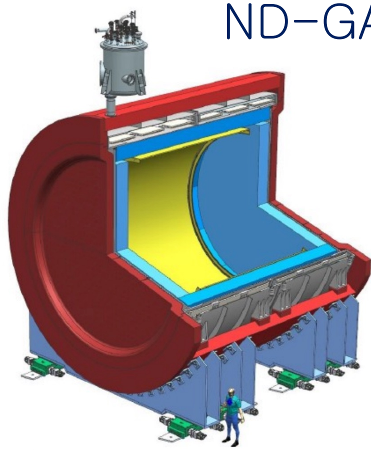
Integrated ND SUITE

DUNE PRISM

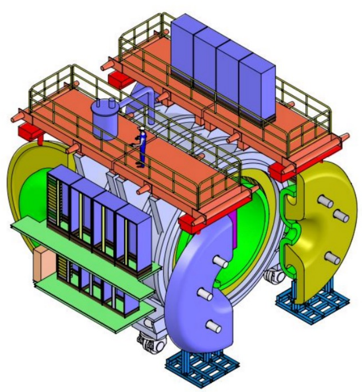
ND-LAr



ND-GAr



SAND



- ✓ Measurements transferable to the FD
- ✓ Constrain the cross-section model
- ✓ Measure the neutrino flux
- ✓ Obtain measurement with different fluxes
- ✓ Monitor time variations of the neutrino beam
- ✓ Operate in high-rate environment

Summary

- The DUNE ND detectors fulfill different roles and provide crucial constraints on neutrino flux and cross-section uncertainties.

- The full suite of highly capable DUNE ND detectors are necessary to achieve the precision requirement on neutrino oscillation measurements.

- The ND data will provide a wealth of information to measure neutrino-nucleus interactions with low thresholds and high resolution, search for physics beyond the standard model and dark matter!