Flux Measurement Using the DUNE Near Detector

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DEEP UNDERGROUND NEUTRINO EXPERIMENT

SNOLAB July 2017

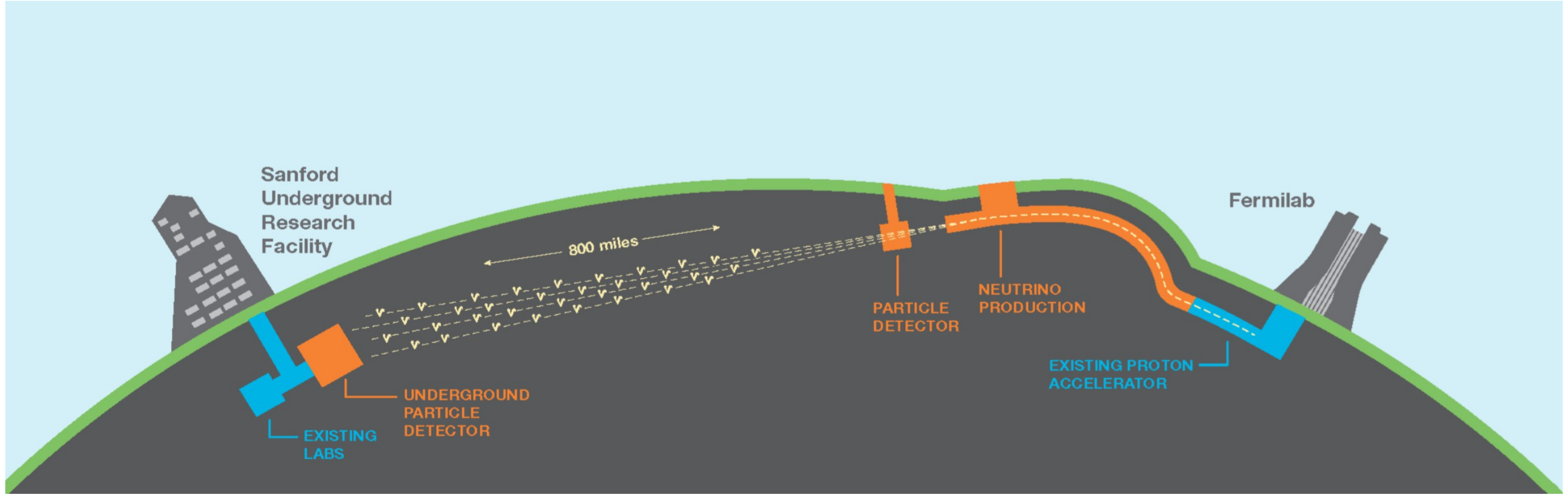
Deep Underground Neutrino Experiment - DUNE

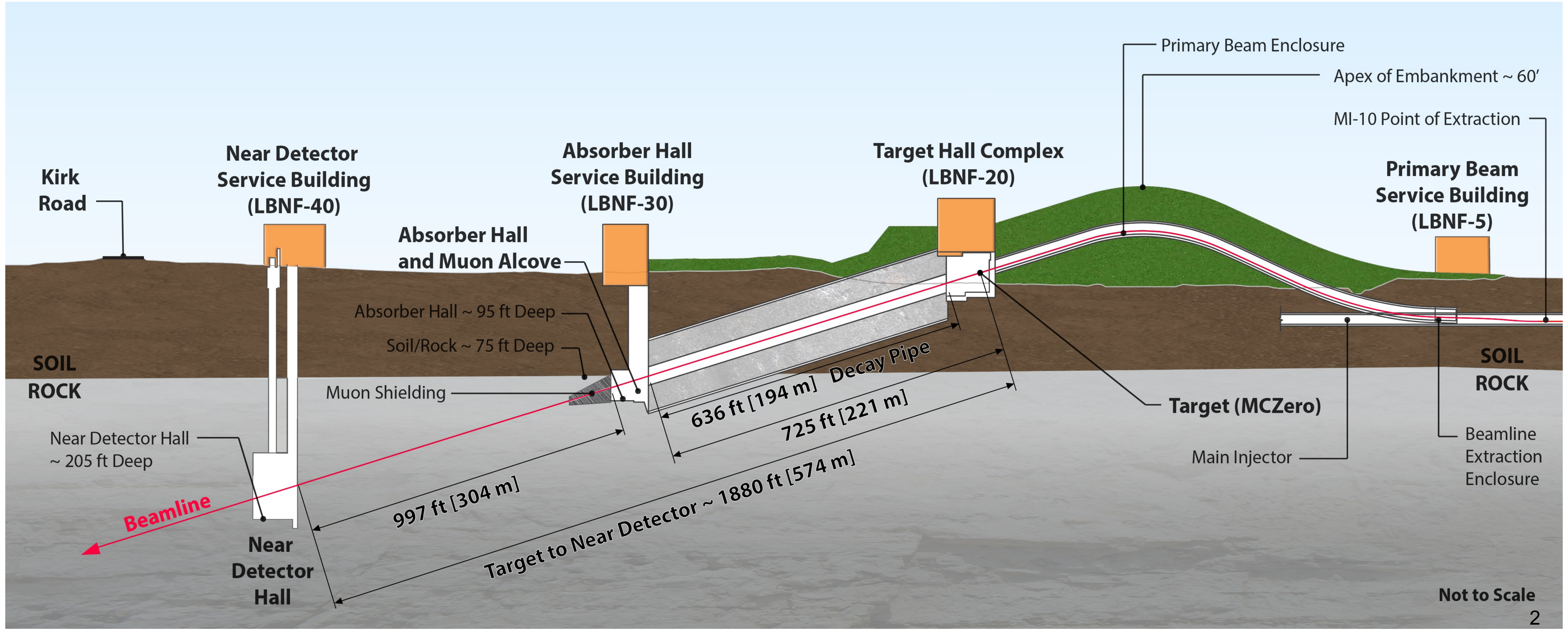
DUNE is a next generation long-baseline (1300 km) neutrino oscillation experiment

40 kt Liquid Argon (LAr) far detector 1.5 km underground in SURF, South Dakota

Multi MW neutrino beam from the LBNF at Fermilab

A near detector 574 m from the first focusing horn





See talk 173 Ernesto Kemp

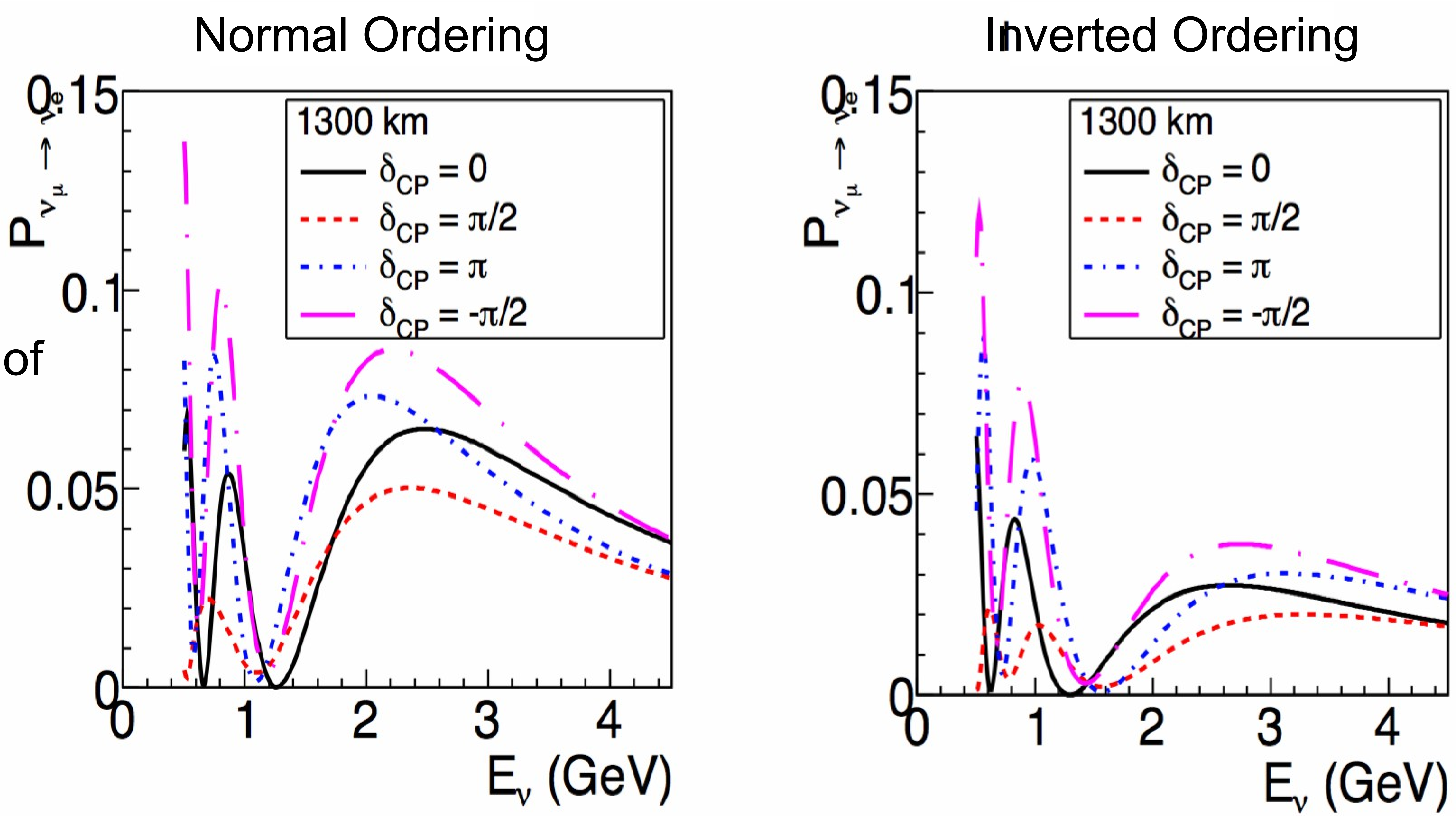
Primary Science Program

Measurement of leptonic CP violation

Determining neutrino mass ordering

Precision measurements of oscillation parameters

Nucleon decay and supernovae neutrinos



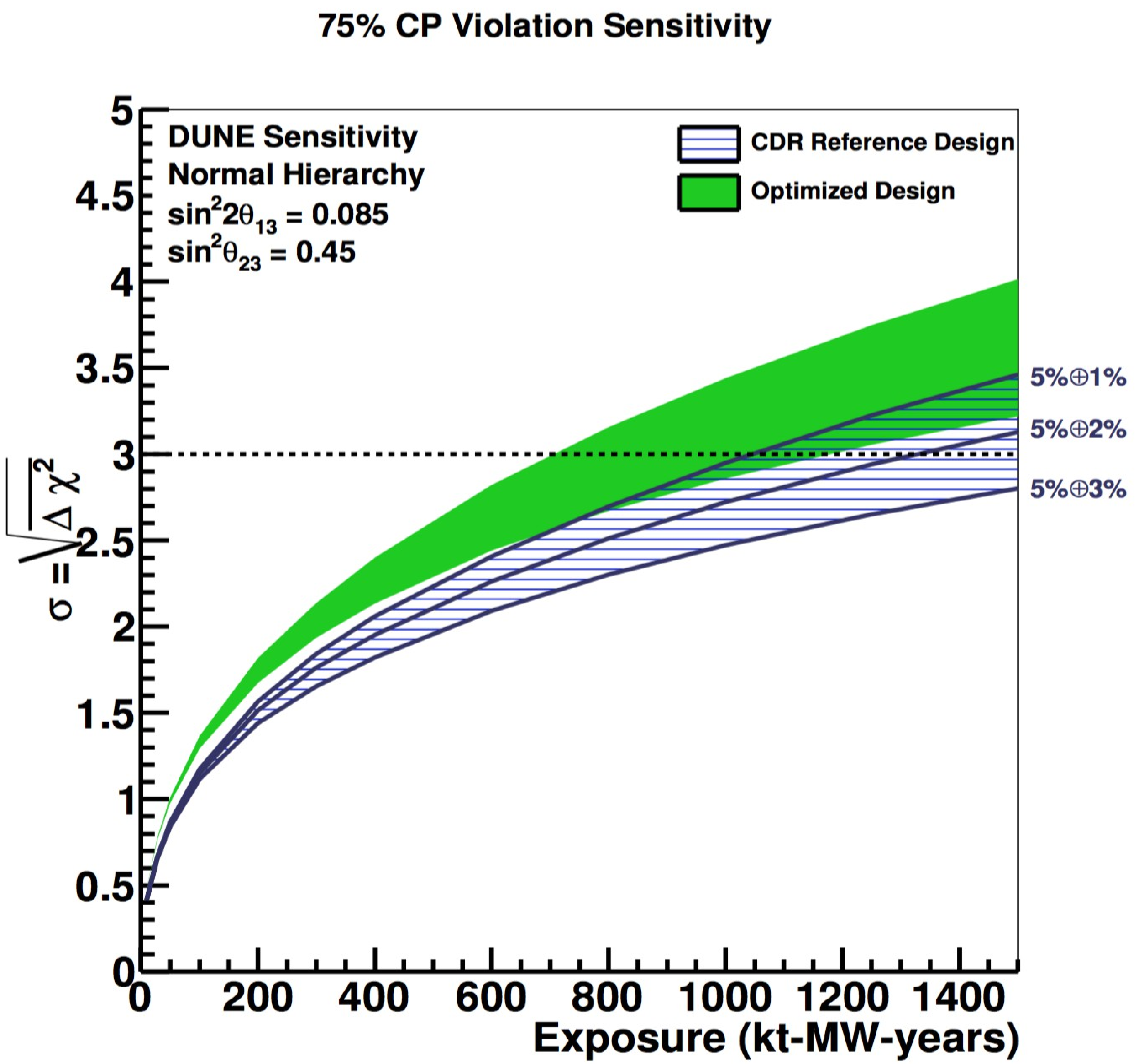
See talk 172 Lisa Whitehead

arXiv:1505.01891v3 Qian & Vogel

DUNE's Error Budget

Goal:
75% CP violation coverage at 3σ

Requirement:
combined rate and shape uncertainties < 2% uncorrelated uncertainty



arXiv:1512.06148 DUNE

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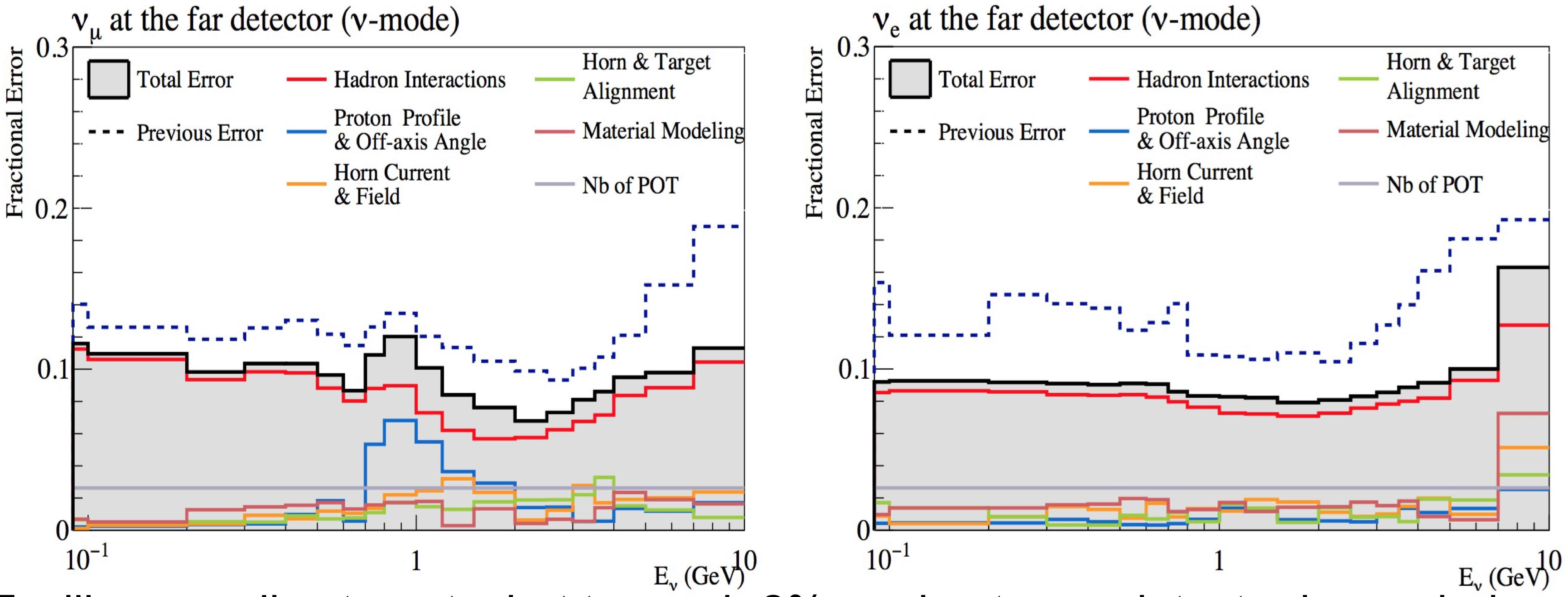
Constraining Uncertainty at the Target

Beam related uncertainties due to focusing and hadron production need to be minimized.

Using replica targets (NA61/SHINE), T2K reduced total flux uncertainties to 9%



JPS Conf. Proc. 12.010005 T2K

DUNE will use replica targets, but to reach 2% a robust near detector is needed

Constraining Uncertainties with a Near Detector

Ideally we'd measure:

$$P_{\mu e}(E_\nu) = \frac{\Phi^{\text{far}}_{\nu_e}(E_\nu)\mid_{l=l_{\text{far}}}}{\Phi^{\text{far}}_{\nu_\mu}(E_\nu)\mid_{l=0}}$$

What we can measure is:

Determined by near detector

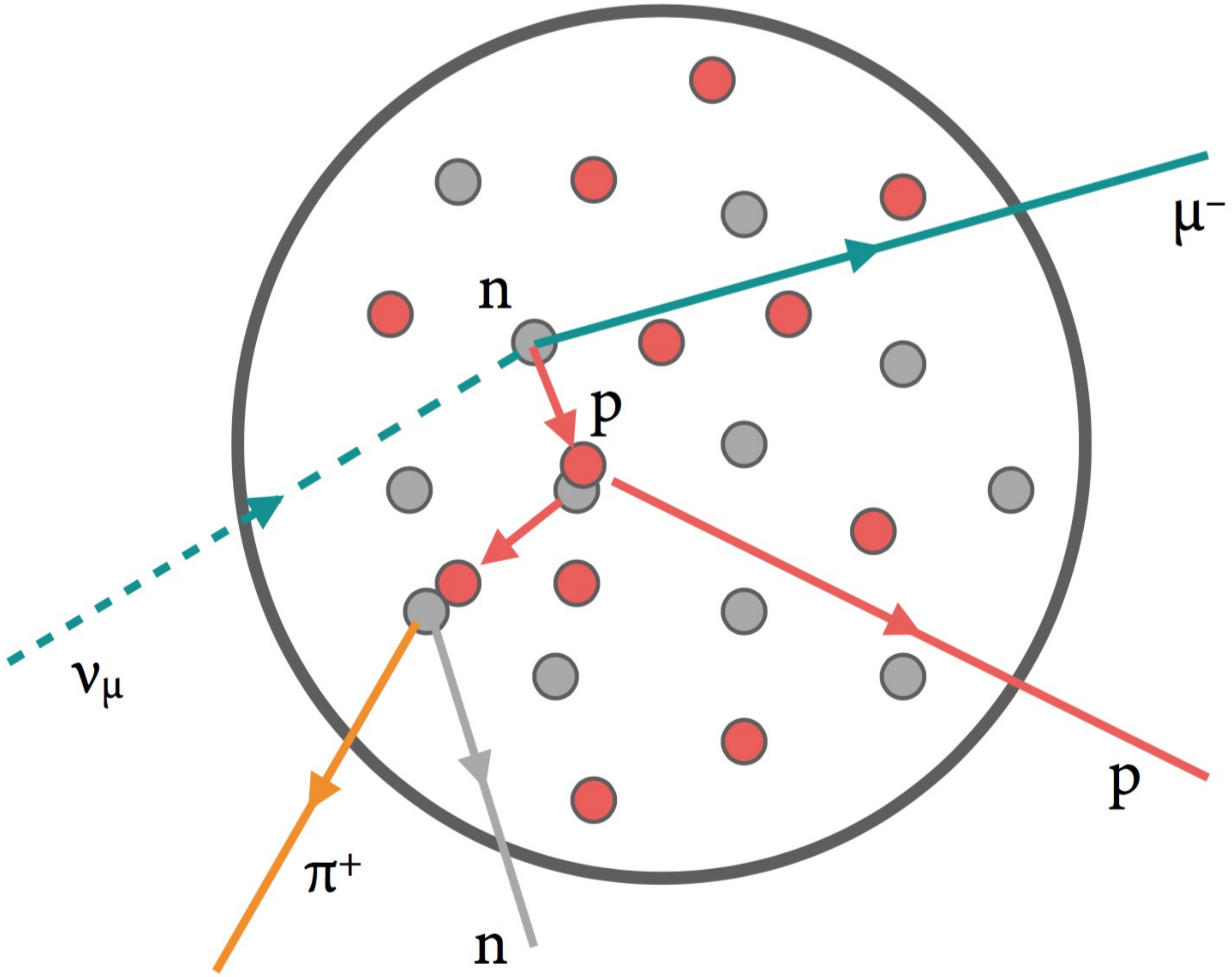
$$\frac{\mathrm{d}N^{far}_{\nu}}{\mathrm{d}E_{reco}} = \underline{D^{\text{far,inclus.}}_{\nu_e-\text{CC}}(E_{reco};E_\nu)}\,\underline{\sigma^{\text{inclus.,Ar}}_{\nu_e-\text{CC}}(E_\nu)}\,P_{\mu e}(E_\nu)\,\underline{\Phi^{far}_{\nu_\mu}(E_\nu)\mid_{l=0}}\,\mathrm{d}E_\nu$$

...unfortunately, there are strong correlations in energy, flux, & cross-section

Neutrino-Nuclear Cross Sections

Cross section systematics limit the sensitivity for any long-baseline experiment

This will improve for DUNE with measurements from SBN (ICARUS, uBooNE, & SBND), and continual improvements of interaction models.



The near detector will carry out precision measurements of almost all final state particles from nuclear interactions.

Mitigating cross section uncertainties in flux measurements requires standard candles.

Standard Candles

Constrain the flux via processes with known cross-section:

Neutrino-electron elastic scattering

Decouples normalization systematics (x-sec, detector response, & BG)
Independent constraint on absolute flux normalization

Low-ν (low hadronic recoil energy) ν_μ CC process

Decouples shape systematics (x-sec, detector response, & BG)
Independent constraint on ν_μ energy spectrum (flux shape at near detector)

Neutrino-Electron Scattering

Signal:

Single, **very** forward going electron (0.5 to 8 GeV)

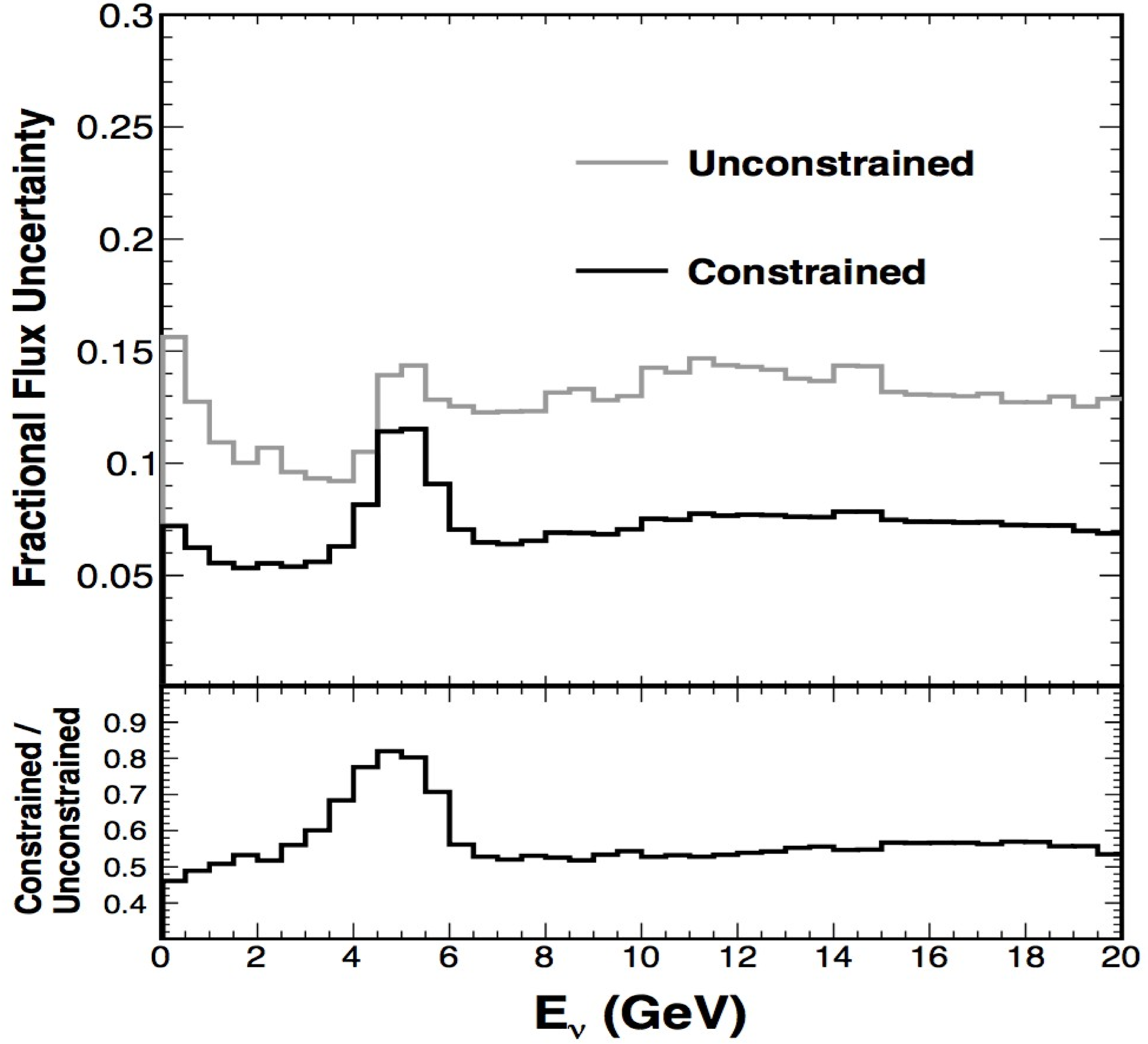
Theoretical uncertainty on cross section <1%

Requirements:

Minimum of 5 t target mass to keep statistical uncertainty <1%

BG rejection requires good angular resolution (<5 mrad)

Used by MINERvA to constrain NuMI flux from 9% to 6%, with only 135 ±17 events



arXiv:1512.07699 MINERvA

Low-ν Process

Signal:

Single, energetic (1 to 8 GeV), **very** forward going muon

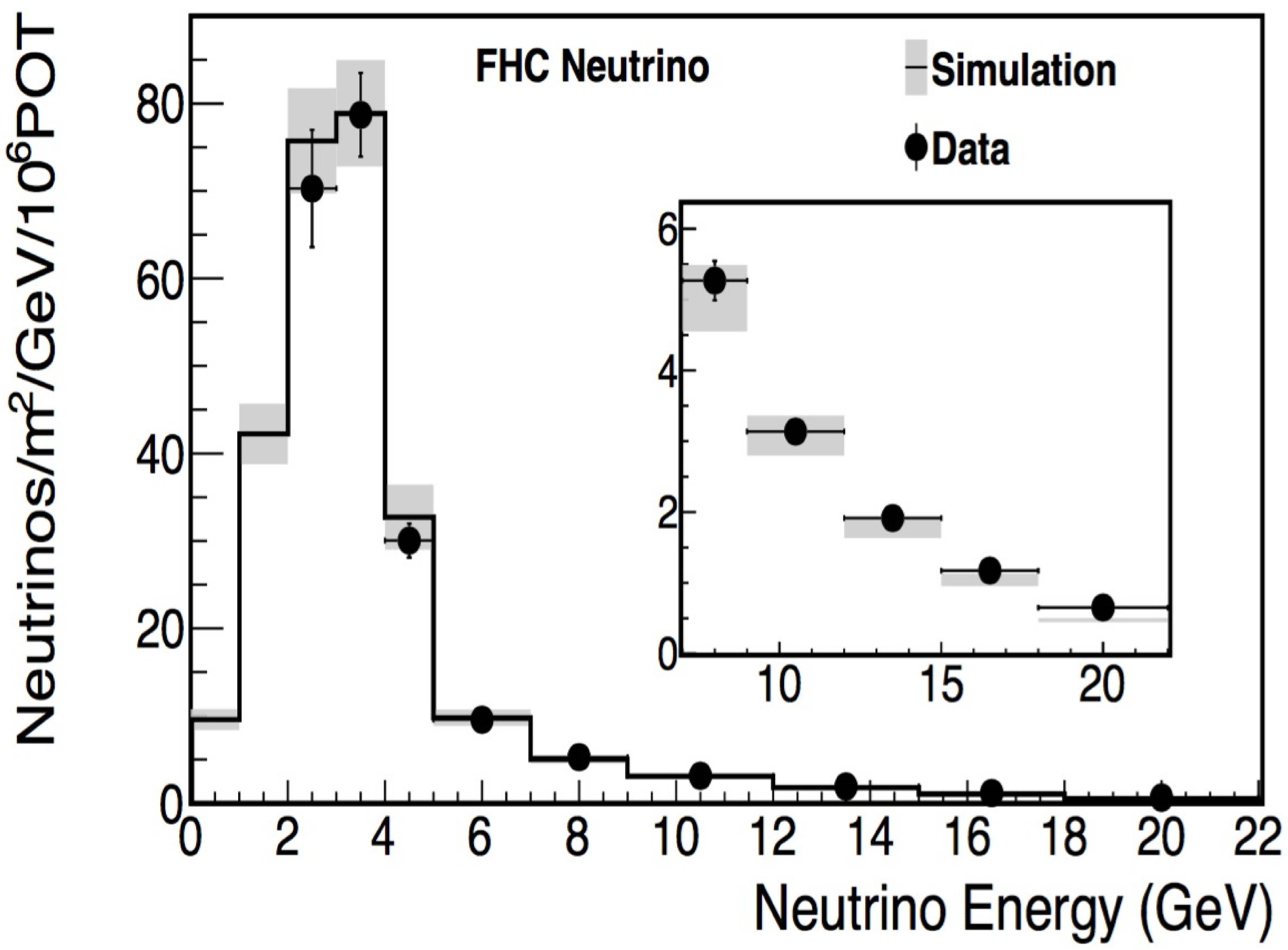
Theoretical uncertainty on cross section <5% above 1GeV

Critical BG: Energetic missed neutrons

Requirements:

Sufficient mass to recover a reasonable fraction on of neutron energy. ~70% is sufficient to suppress BG

Successfully used by MINERvA MINOS, CCFR, & NuTeV



arXiv1610.04746 MINERvA (L. Ren Thesis)

Near Detector (at 574 m) Event Rates (per tonne at 10^{20} POT)

Production mode	ν_μ Events on Ar (Carbon)	$\overline{\nu}_\mu$ Events on Ar (Carbon)
CC QE ($\nu_\mu n \to \mu^- p$)	30,000 (28,000)	13,000 (15,000)
NC elastic ($\nu_\mu N \to \nu_\mu N$)	11,000 (11,000)	6,700 (68,00)
CC resonant ($\nu_\mu p \to \mu^- p \pi^+$)	21,000 (24,000)	0 (0)
CC resonant ($\nu_\mu n \to \mu^- n \pi^+ \, (p\pi^0)$)	23,000 (21,000)	0 (0)
CC resonant ($\bar{\nu}_\mu p \to \mu^+ p \pi^- \, (n\pi^0)$)	0 (0)	83,00 (7,800)
CC resonant ($\bar{\nu}_\mu n \to \mu^+ n \pi^-$)	0 (0)	12,000 (8,100)
NC resonant ($\nu_\mu p \to \nu_\mu p \pi^0 \, (n\pi^+)$)	7,000 (9,200)	0 (0)
NC resonant ($\nu_\mu n \to \nu_\mu n \pi^+ \, (p\pi^0)$)	9,000 (11,000)	0 (0)
NC resonant ($\bar{\nu}_\mu p \to \bar{\nu}_\mu p \pi^- \, (n\pi^0)$)	0 (0)	3,900 (4,300)
NC resonant ($\bar{\nu}_\mu n \to \bar{\nu}_\mu n \pi^-$)	0 (0)	4,700 (4,300)
CC DIS ($\nu_\mu N \to \mu^- X$ or $\overline{\nu}_\mu N \to \mu^+ X$)	95,000 (92,000)	24,000 (25,000)
NC DIS ($\nu_\mu N \to \nu_\mu X$ or $\overline{\nu}_\mu N \to \overline{\nu}_\mu X$)	31,000 (31,000)	10,000 (10,000)
CC coherent π^+ ($\nu_\mu A \to \mu^- A \pi^+$)	930 (1,500)	0 (0)
CC coherent π^- ($\overline{\nu}_\mu A \to \mu^+ A \pi^-$)	0 (0)	800 (1,300)
NC coherent π^0 ($\nu_\mu A \to \nu_\mu A \pi^0$ or $\overline{\nu}_\mu A \to \overline{\nu}_\mu A \pi^0$)	520 (840)	450 (720)
NC elastic electron ($\nu_\mu e^- \to \nu_\mu e^-$ or $\overline{\nu}_\mu e^- \to \overline{\nu_\mu} e^-$)	16 (18)	11 (12)
Inverse Muon Decay ($\nu_\mu e \to \mu^- \nu_e$)	9.5 (11)	0 (0)
Total CC	170,000 (170,000)	59,000 (61,000)
Total NC+CC	230,000 (230,000)	84,000 (87,000)

We now expect 10 times these rates per year (operating at 10^{21} POT)

Near Detector Design requirements

Large target mass (argon to minimize near-far systematics)

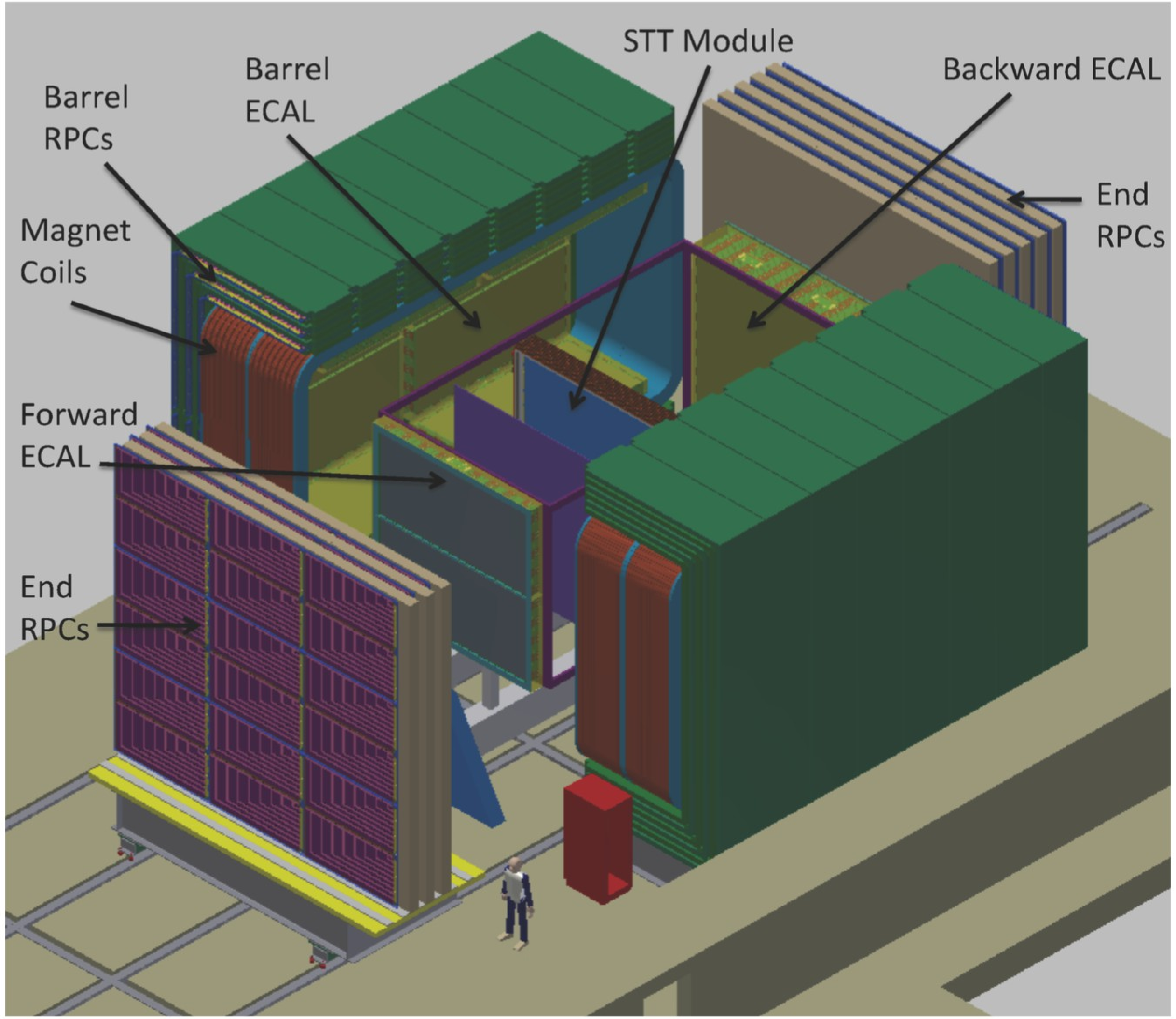
High angular and tracking resolution

Low detection thresholds

Particle ID of electrons, muons, pions, Kaons, & protons

Charge separation

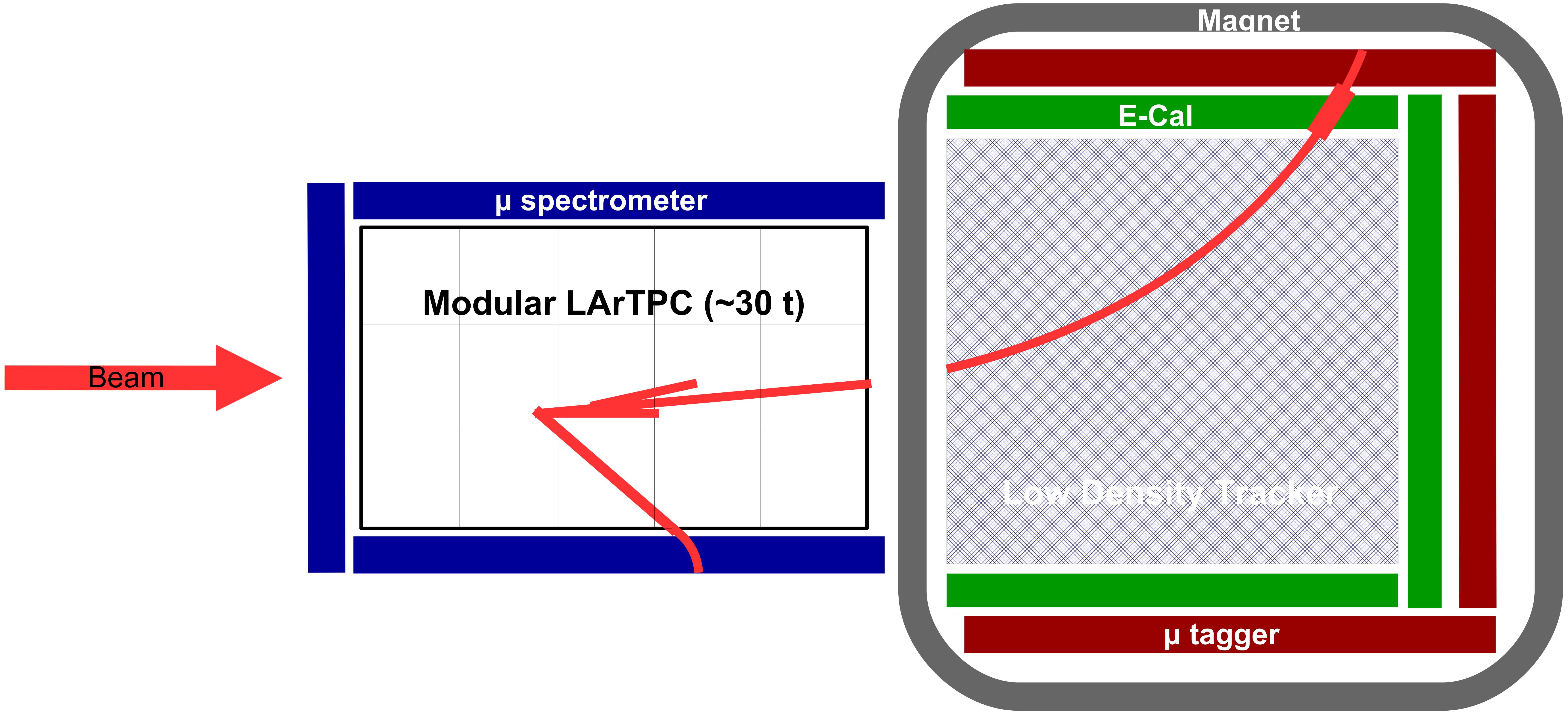
Maximal acceptance



CDR reference design: Fine Grain Tracker (FGT)

The DUNE Near Detector

The current collaboration concept design is a ‘hybrid’ LArTPC + tracking detector.



Modular LAr-TPC: high statistics -Ar interactions, assessment of LArTPC response.

Low Density Tracker: precision characterization of ν-nucleus interactions, complementary signal vs. BG discrimination. Possibly FGT or GArTPC.

Summary

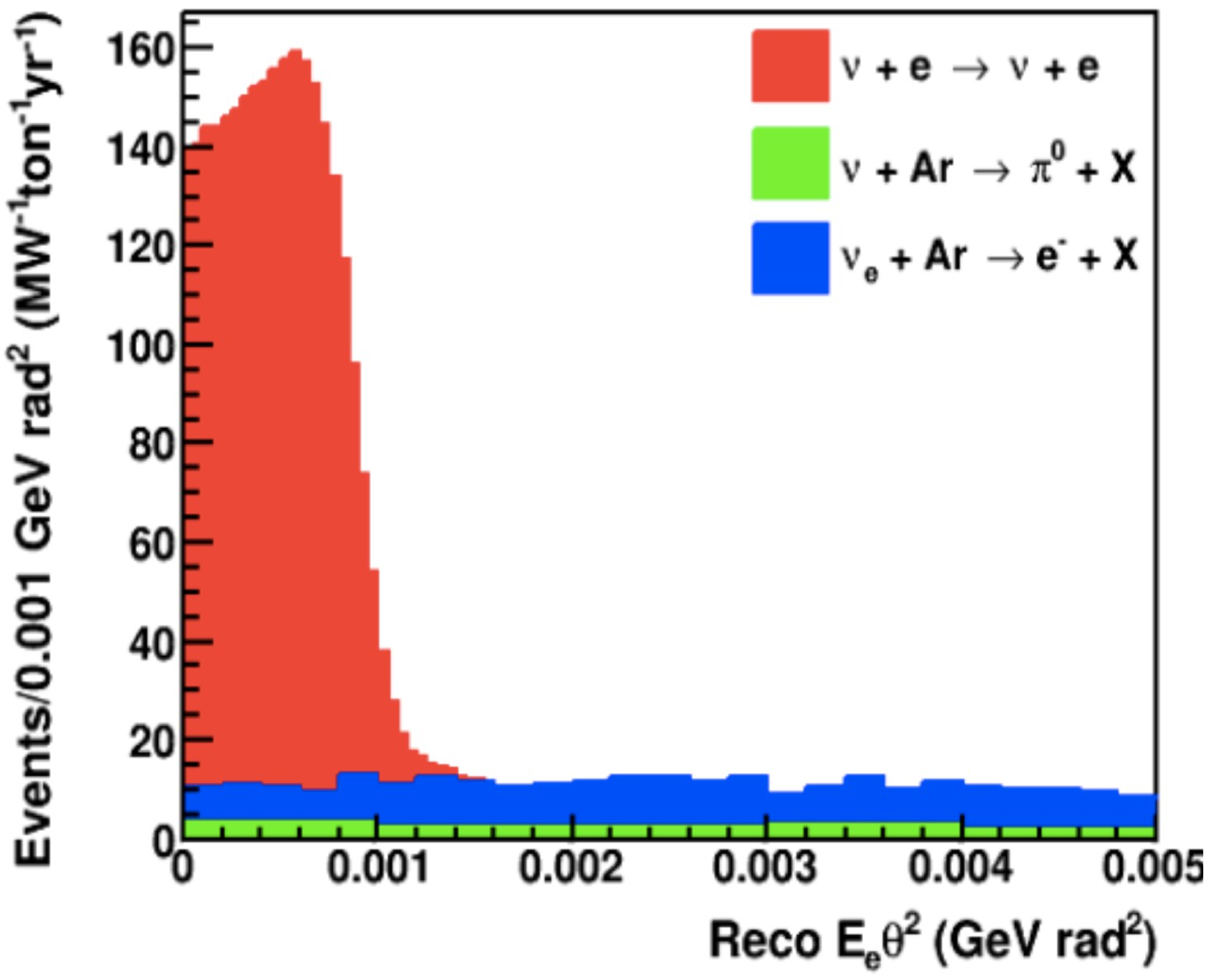
DUNE is a next gen long-base line oscillation experiment, with the primary purpose of observing leptonic CP violation and solving the neutrino mass ordering.

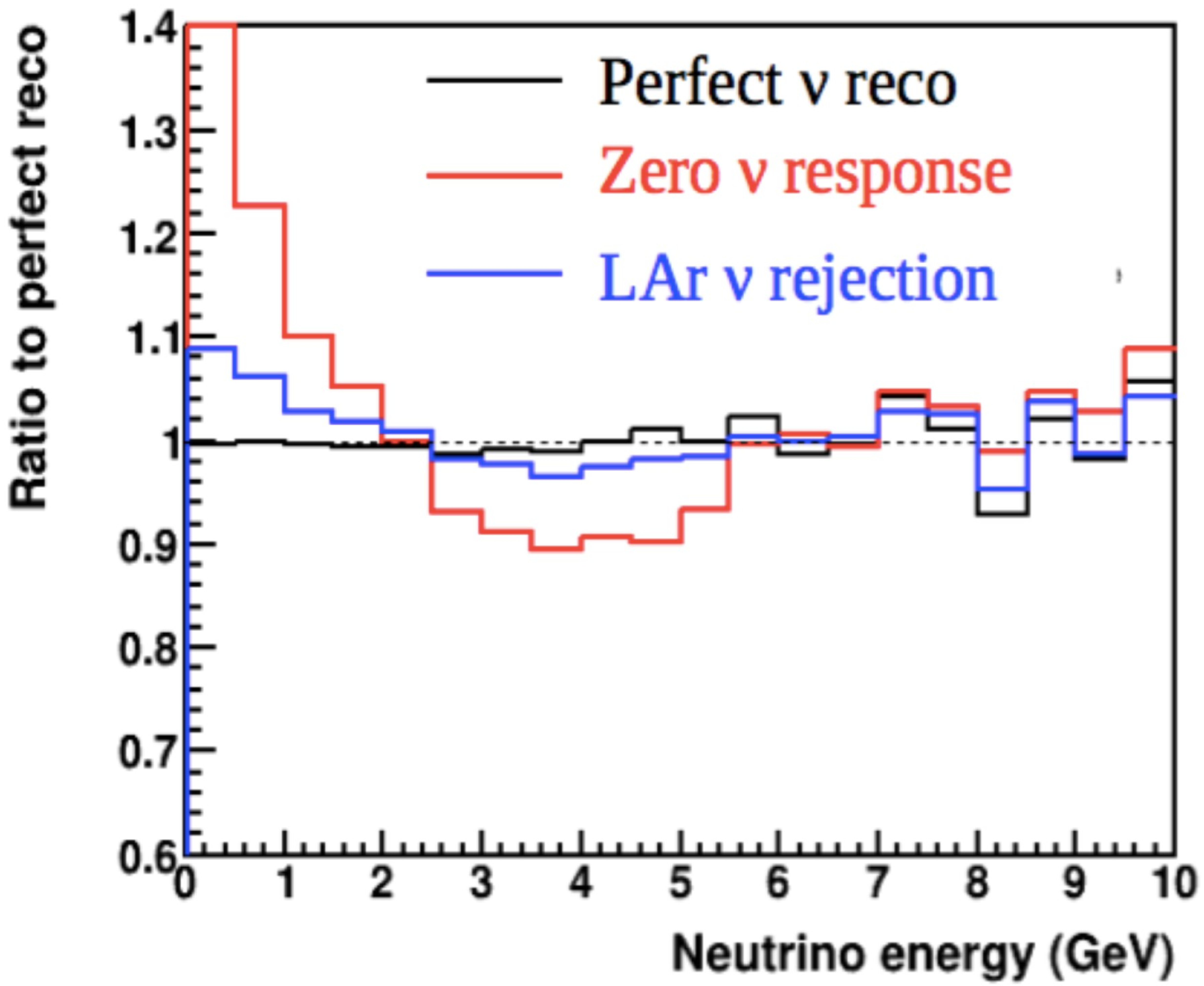
Rate related uncorrelated uncertainty must be kept below 2% to ensure 75% CP violation coverage at 3 sigma sensitivity.

A near detector will be used to reduce the uncertainty on flux normalization and shape, independent of cross section uncertainties.

The current near detector design meets the requirements for constraining sensitivity. Nonetheless, the design is being augmented to include a larger Argon mass and minimize detector systematics near to far.

Backup: Signals





C. Marshall LBNL

Backup: Fine Grain Tracker (FGT)

Excellent vertex separation and tracking resolution

Large overall mass for flux constraint (mostly carbon)

Multiple targets: Ar, Ca, C...

Argon gas targets in pressurized 140 bar carbon fiber tubes