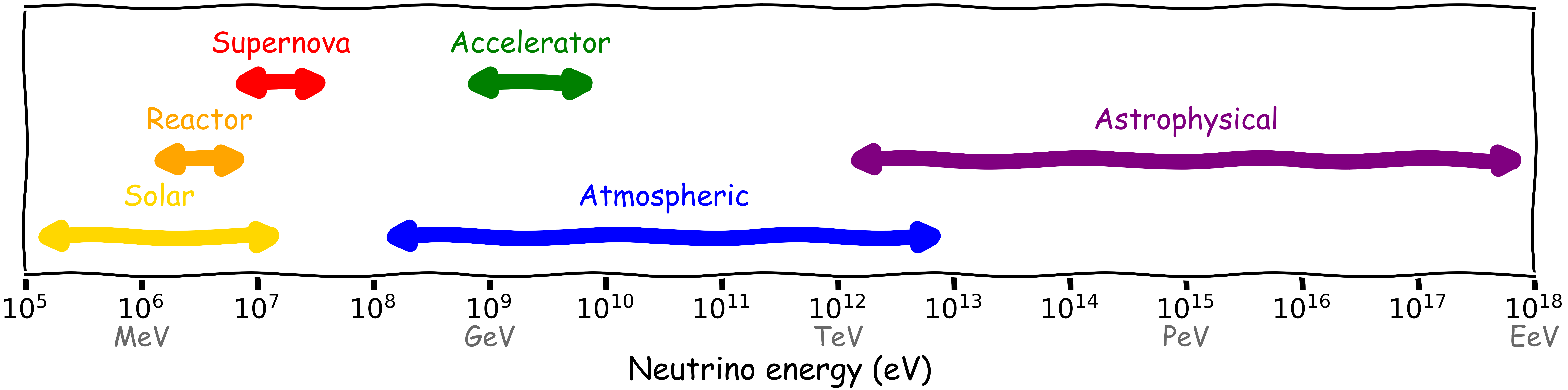
DUNE status and plans for first physics results

Jaesung Kim, University of Rochester
for the DUNE Collaboration

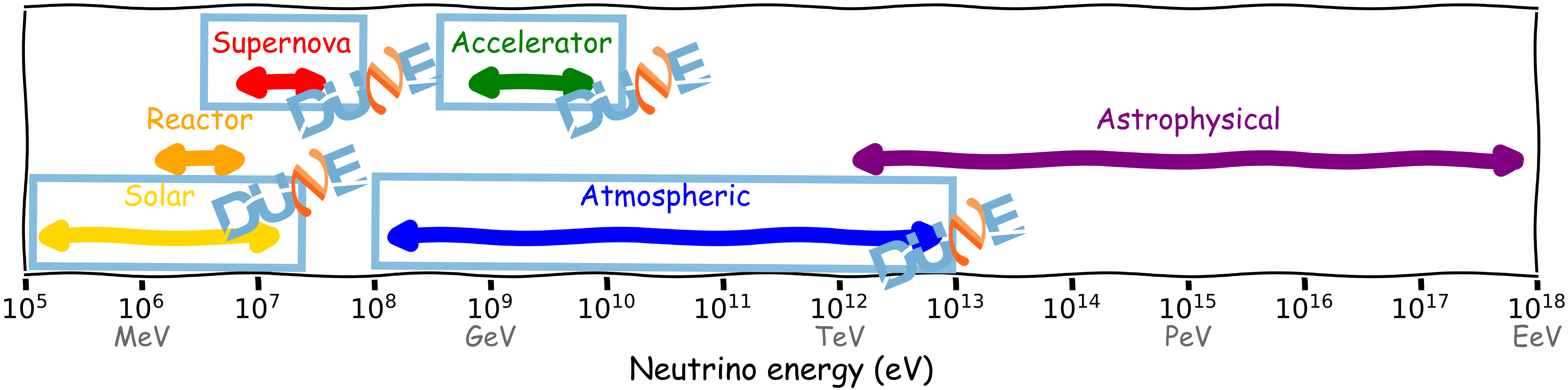
CIPANP 2025, Madison, WI
8-13 JUNE, 2025

Neutrino Sources for Experiments



- A broad array of experiments utilize neutrinos spanning a few MeV to hundreds of PeV[1]!

Neutrino Sources for Experiments

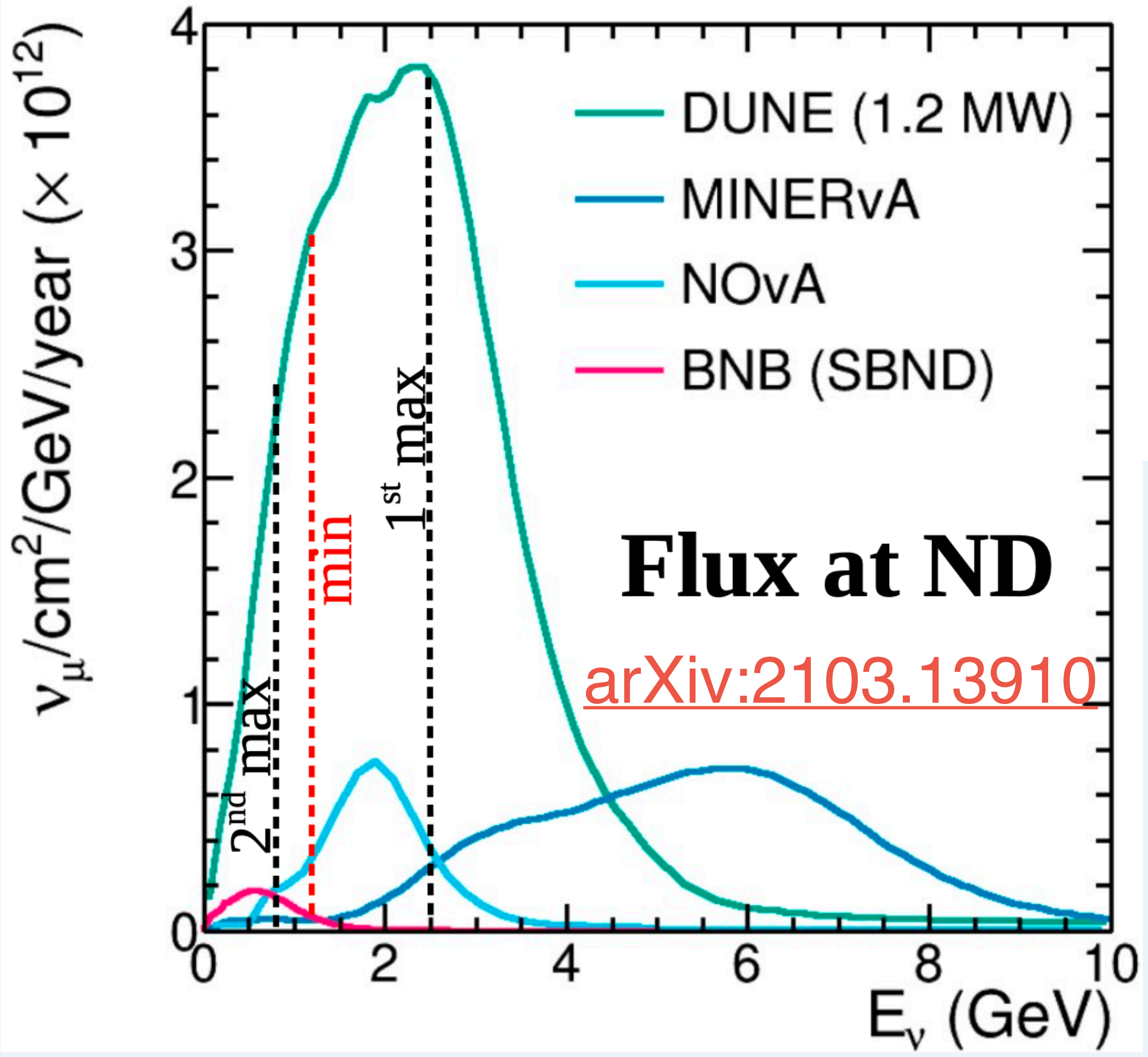


- A broad array of experiments utilize neutrinos spanning a few MeV to hundreds of PeV[1]!
- DUNE is capable of measuring various sources of neutrinos

DUNE Experiment: Overview

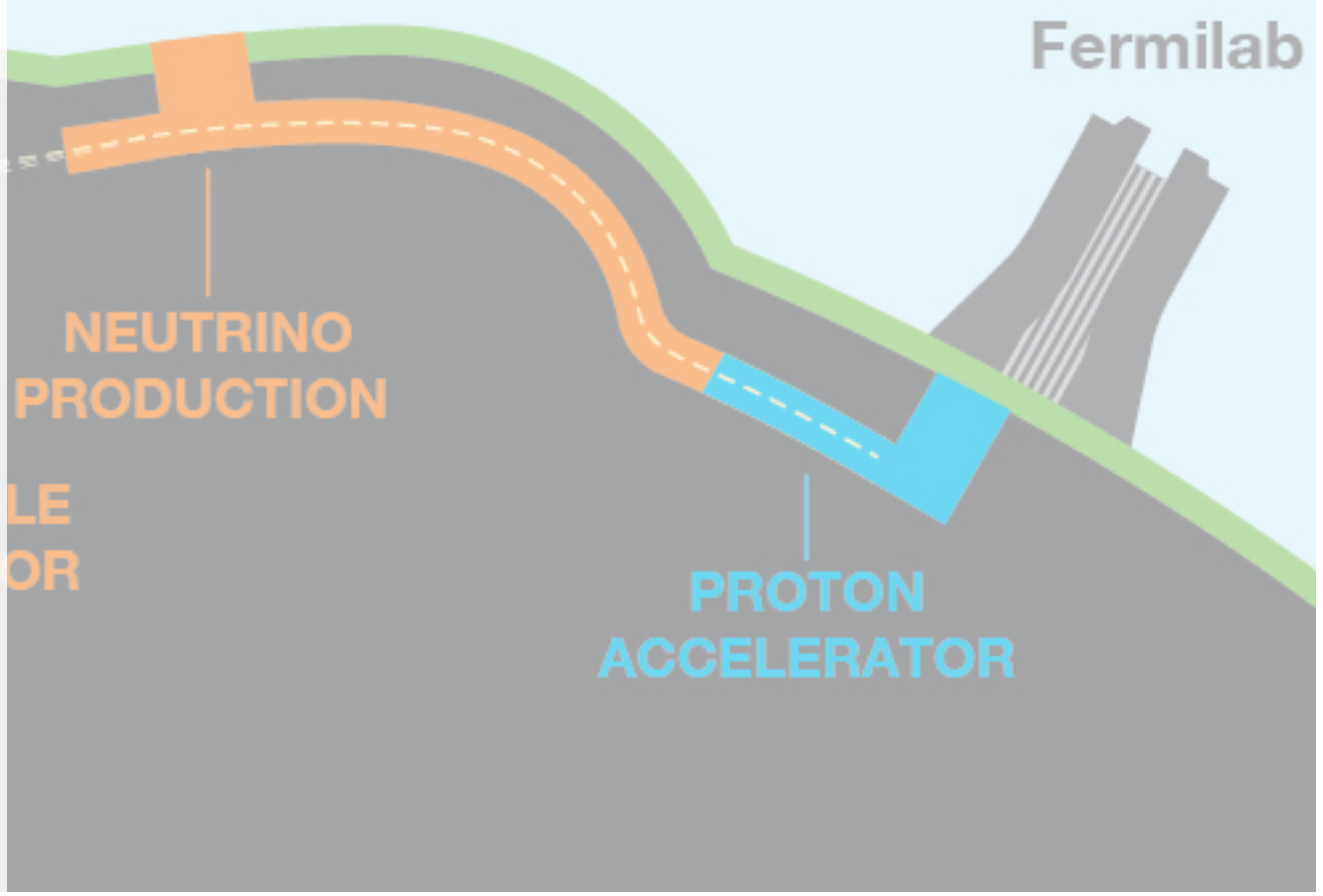
Long baseline neutrino experiment
- Neutrino travels ~1300 km
- Liquid-Argon TPC: Near and far detectors

DUNE Experiment: Beam

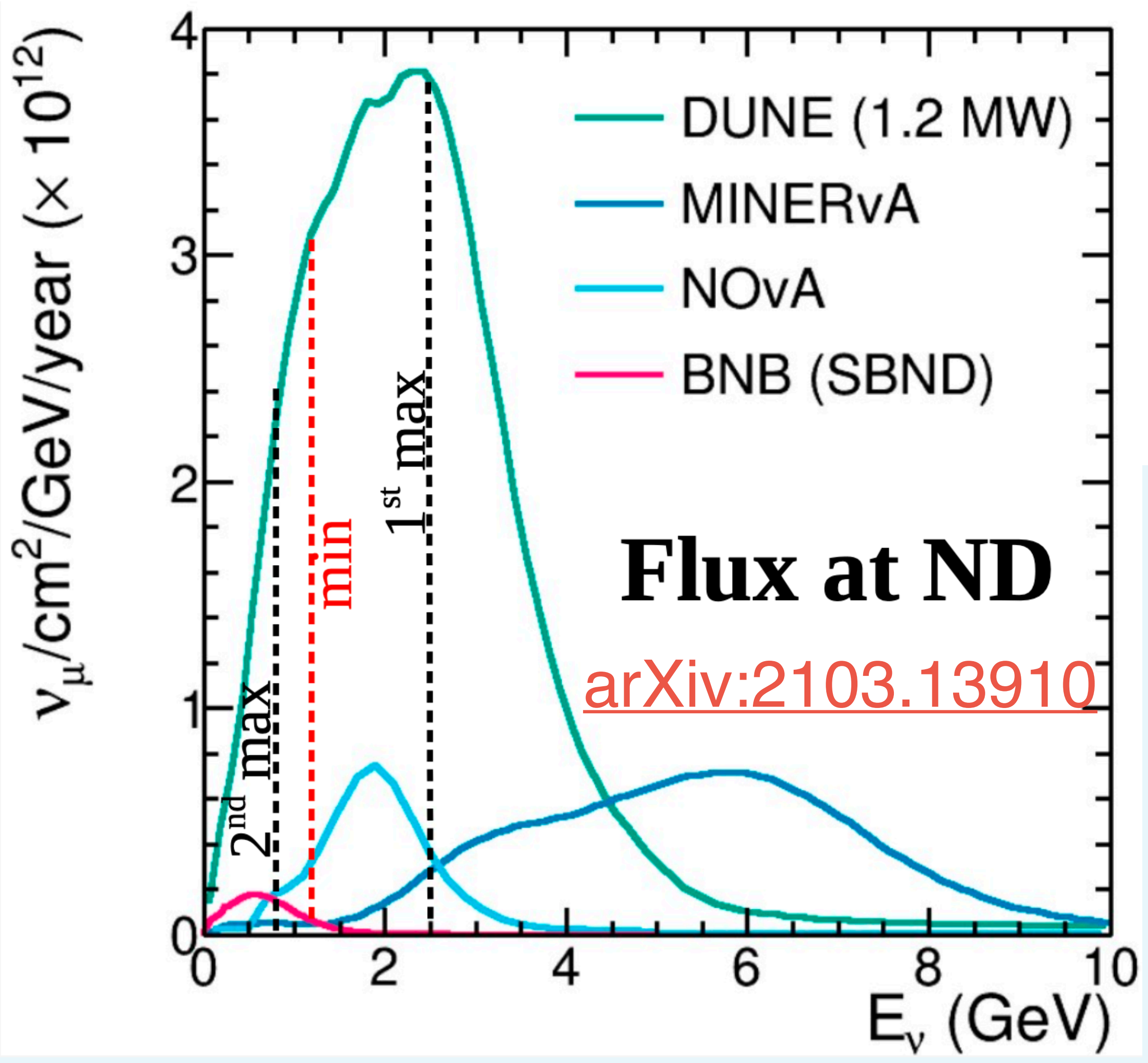


High intensity of neutrino beams

- PIP-II
  - Phase-I
    - LINAC upgrade (400→800 MeV)
    - 1.2 MW beam power achievable
  - Phase-II
    - ACE-MIRT
      - Reduced spill time, ~2 MW



DUNE Experiment: Beam



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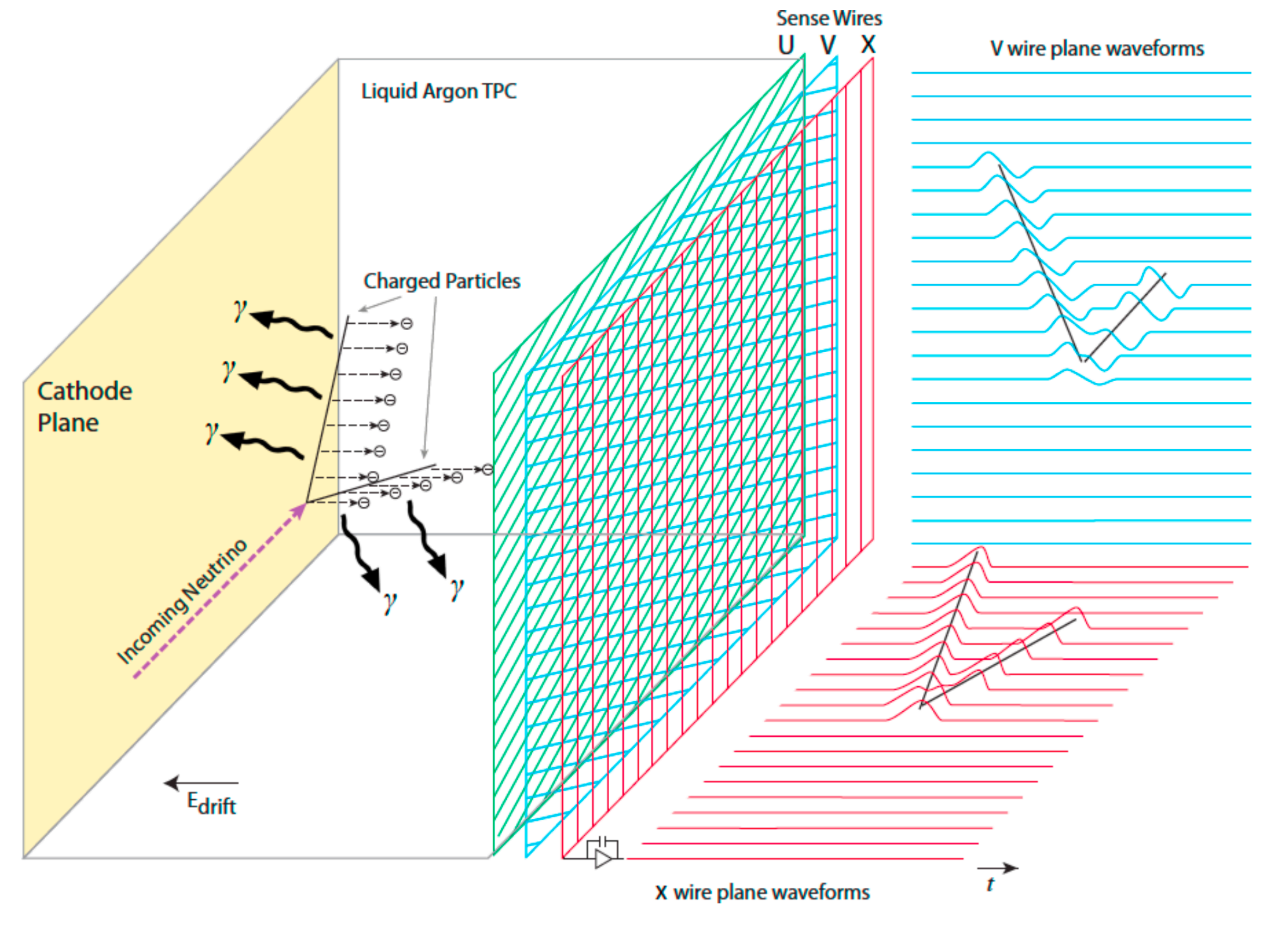
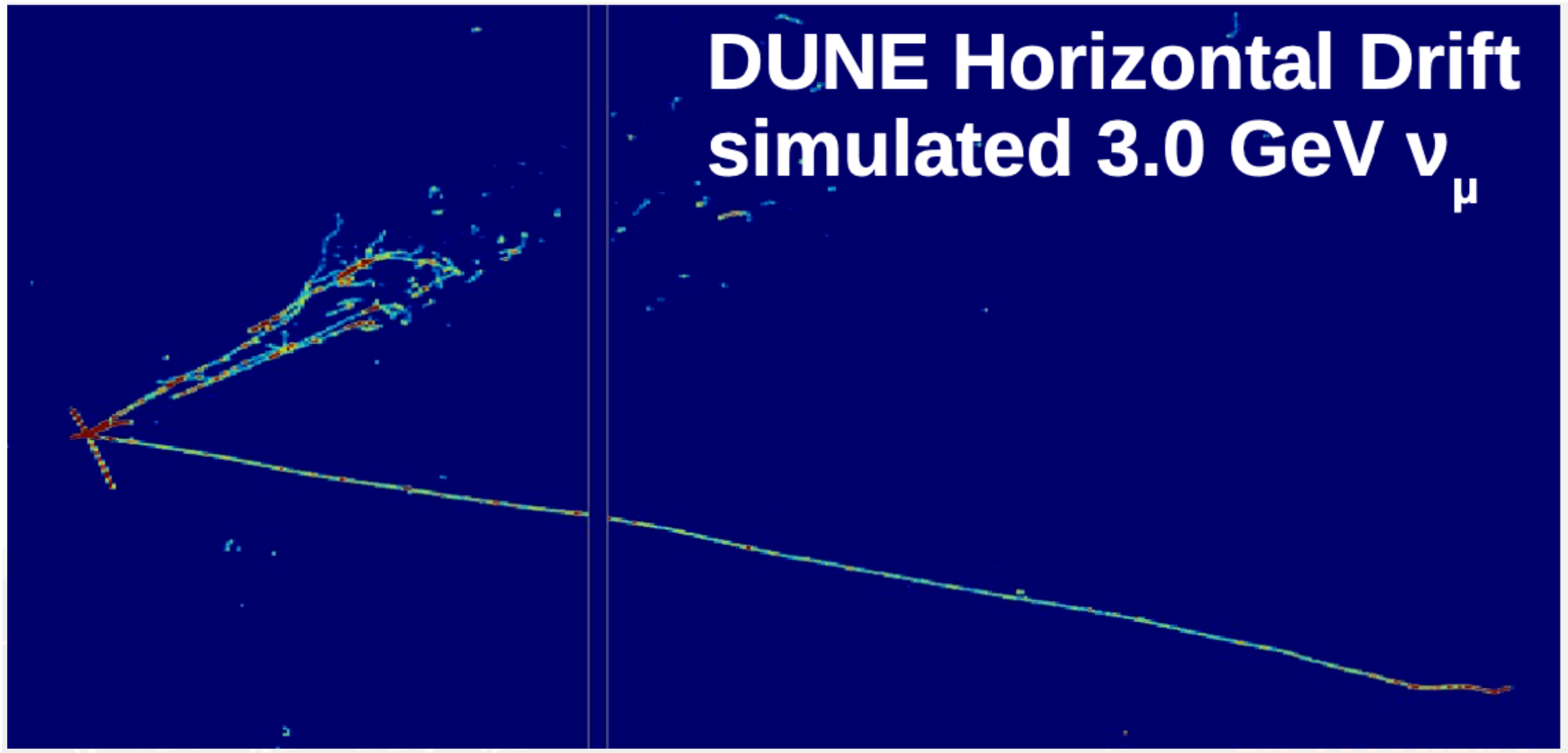
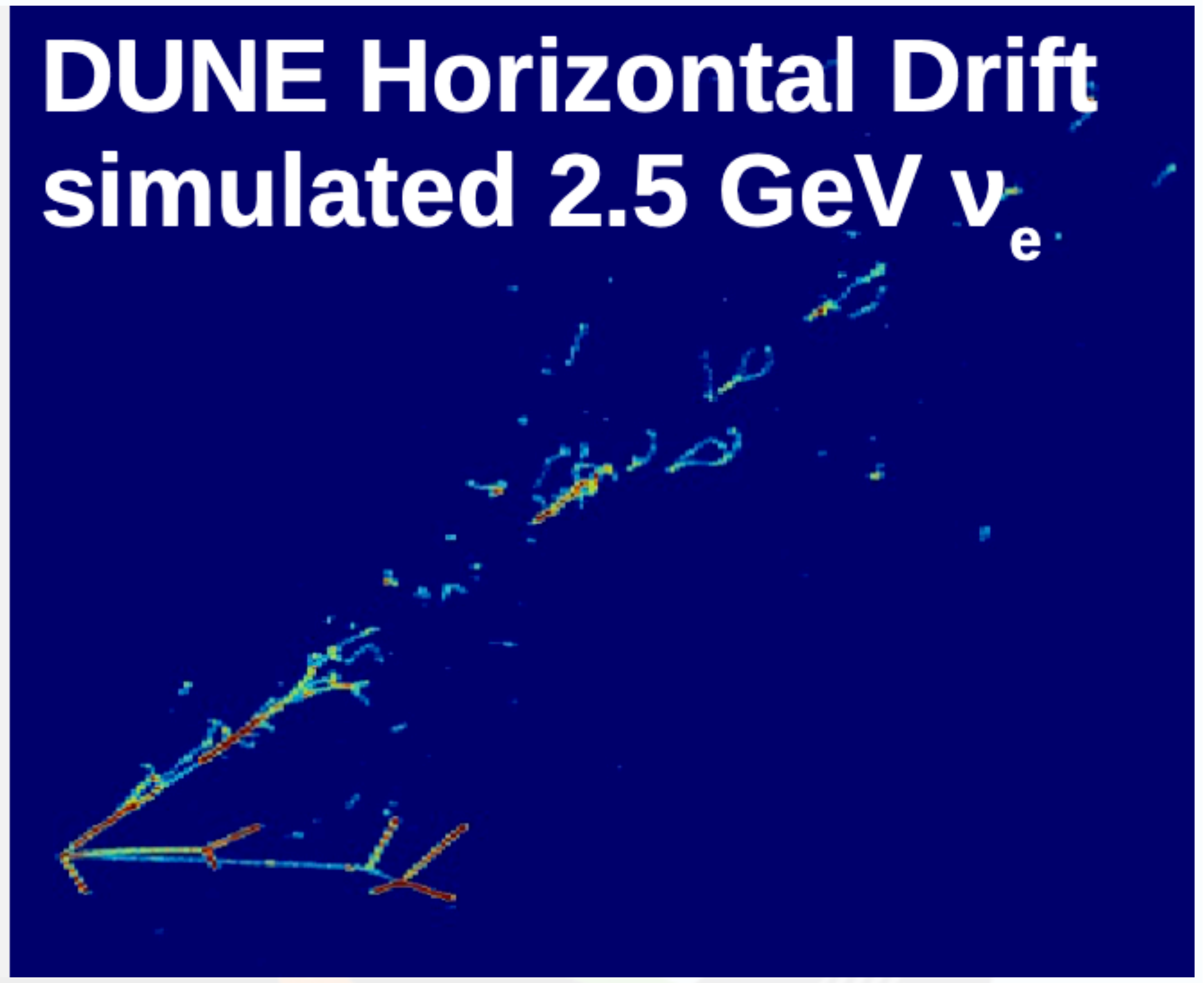
DUNE Experiment: LArTPC





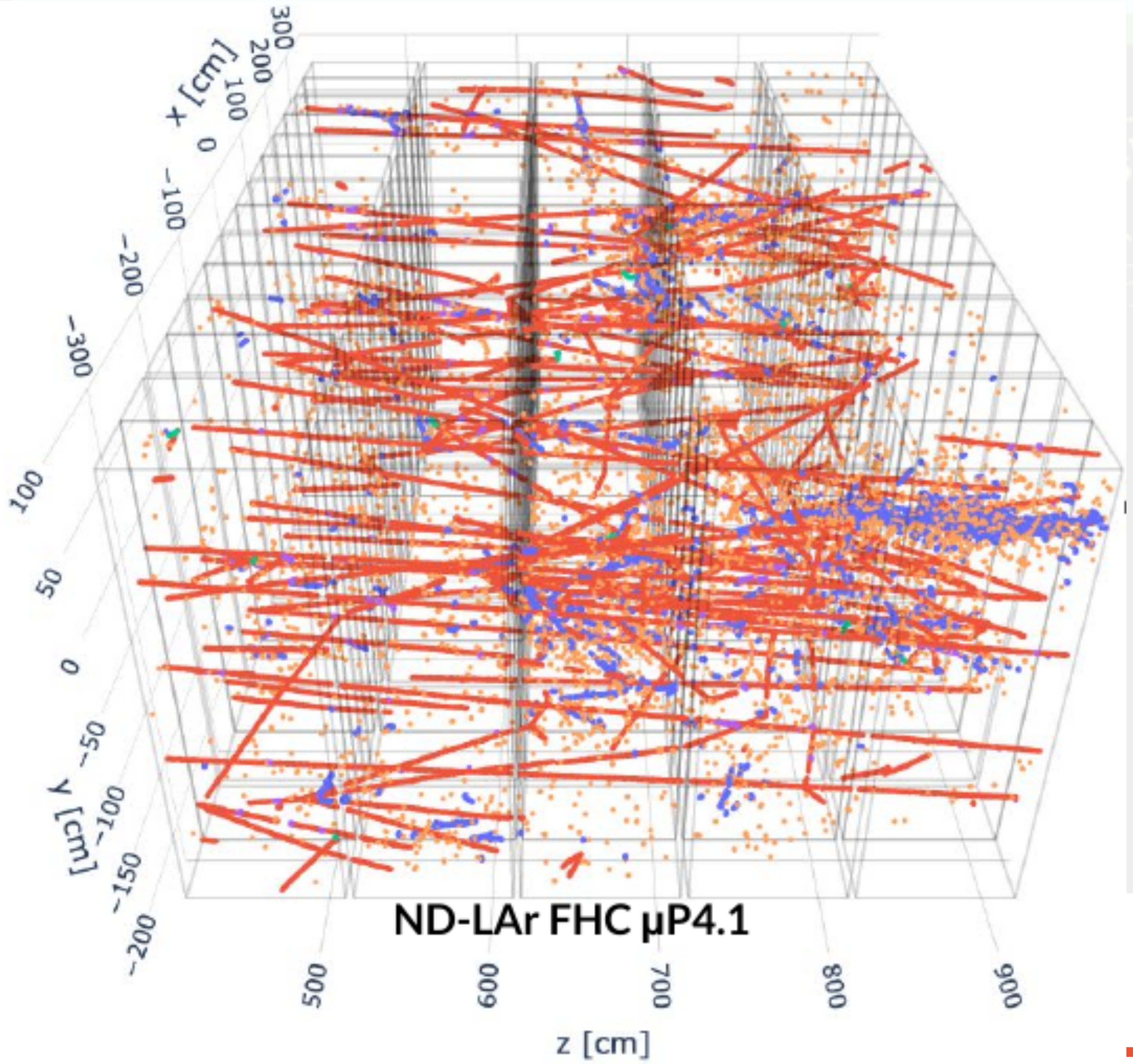


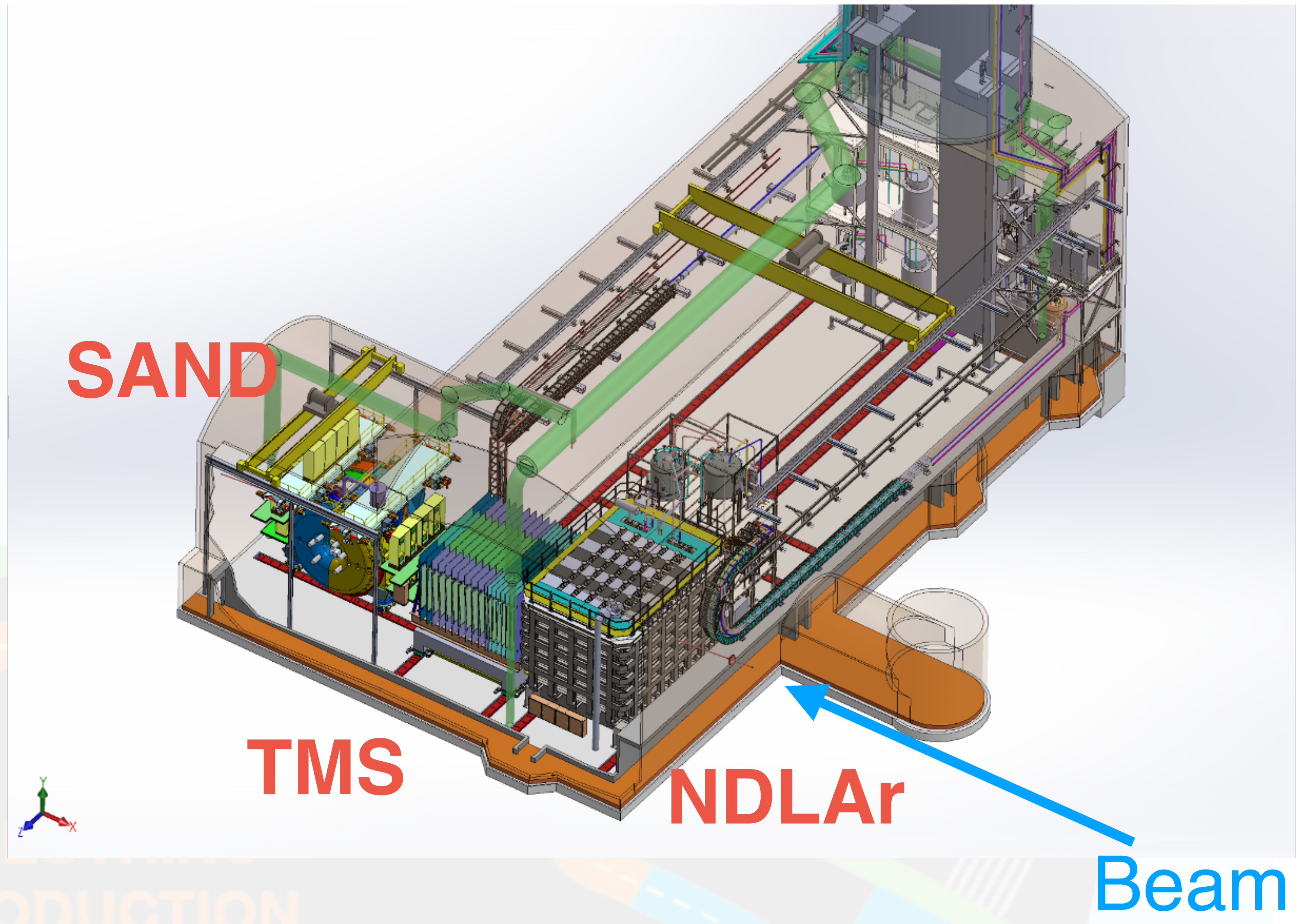
- DUNE Near and Far detectors use **Liquid Argon Time Projection Chamber (LArTPC)**
- 3D imaging of charged particle with calorimetry
- Hadron reconstruction (critical for E_ν), e/γ separation

DUNE Experiment: Near detector

ND-LAr

- 5×7 modules of pixelized LAr TPC
  - >14M ~4×4mm² pixel ROs
- Capable of handling large ***neutrino*** pileup

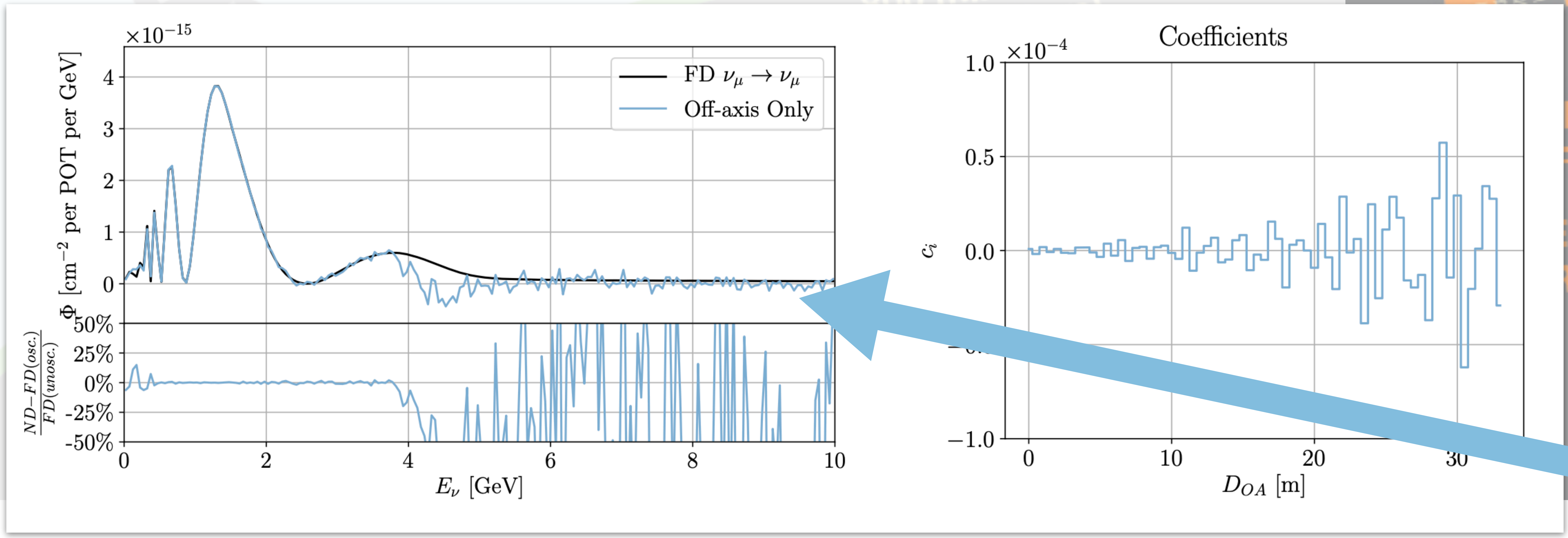


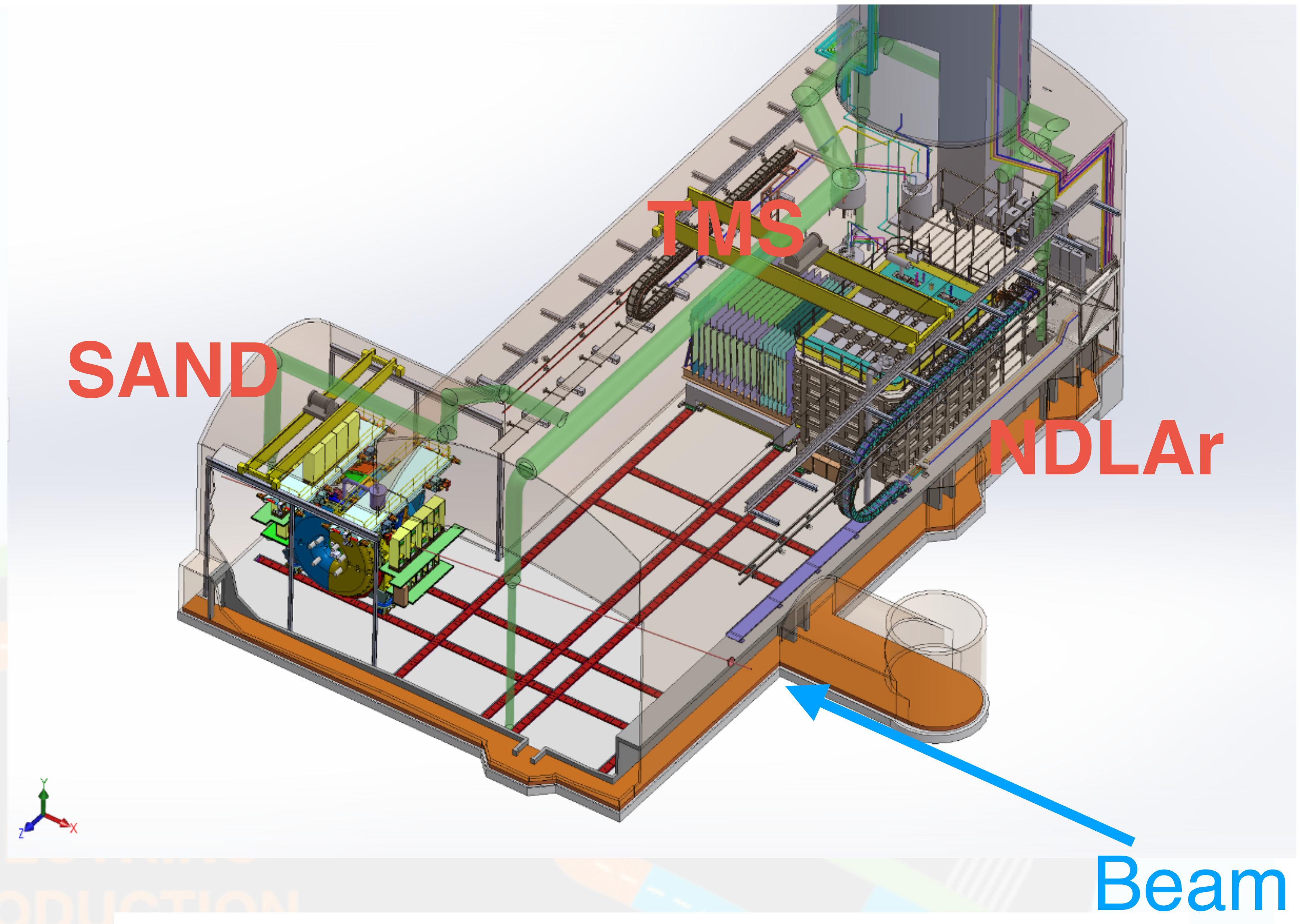


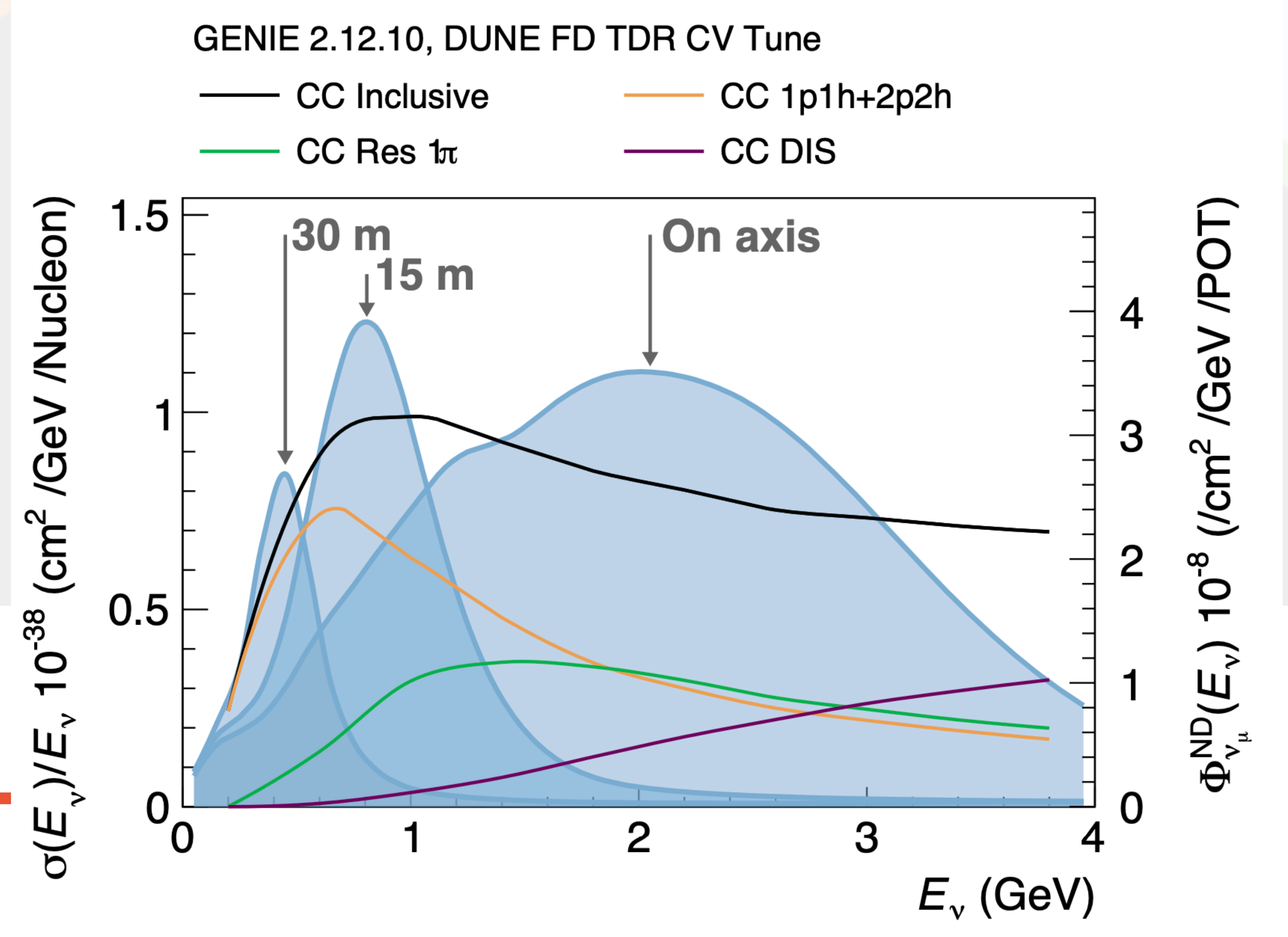
DUNE Experiment: Near detector

ND-LAr

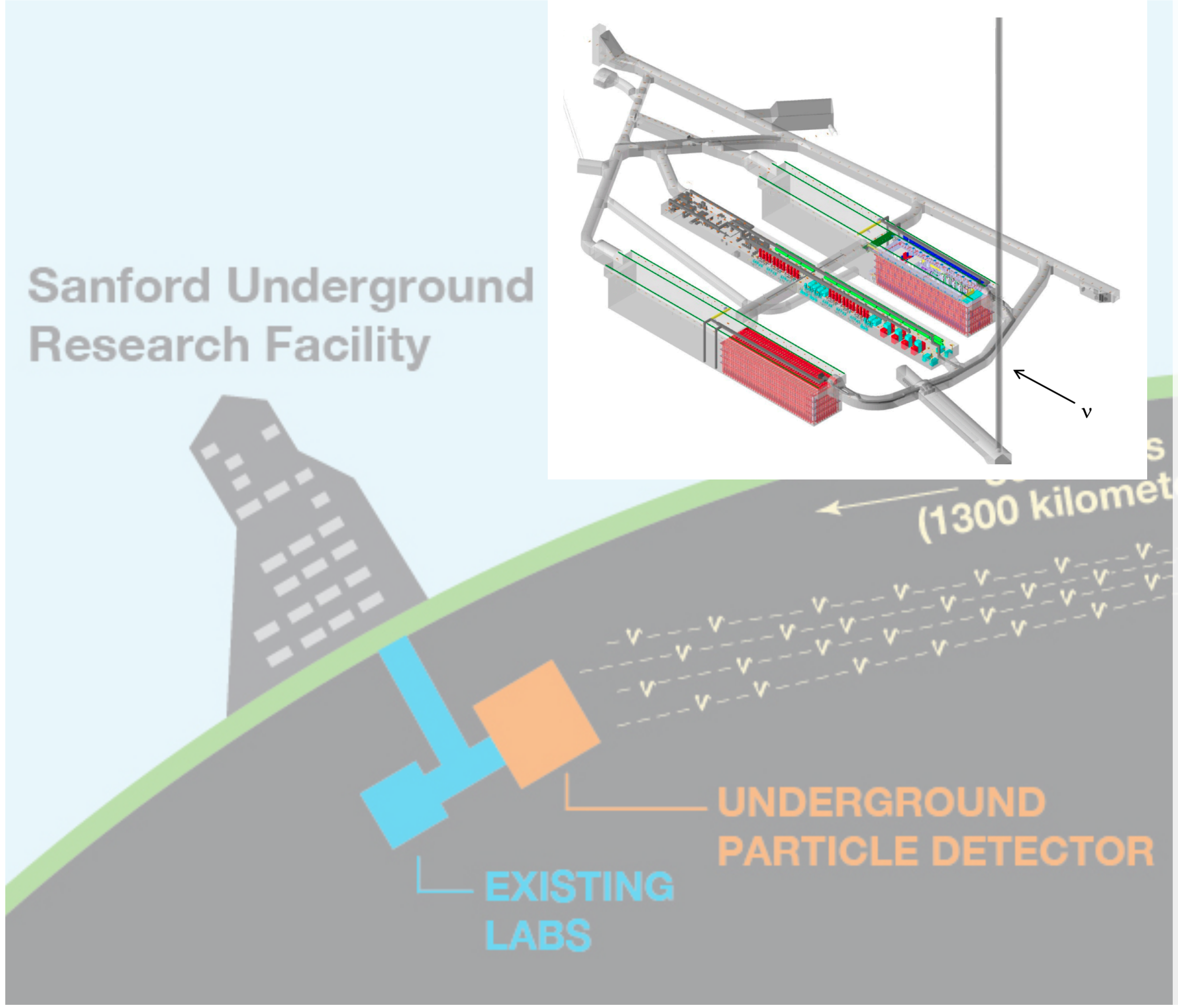
- Movable (28.5 m): PRISM technique
  - Linear combination of off-axis data to predict the flux at the far detector to predict a particular set of osc. params.







DUNE Experiment: Far detector

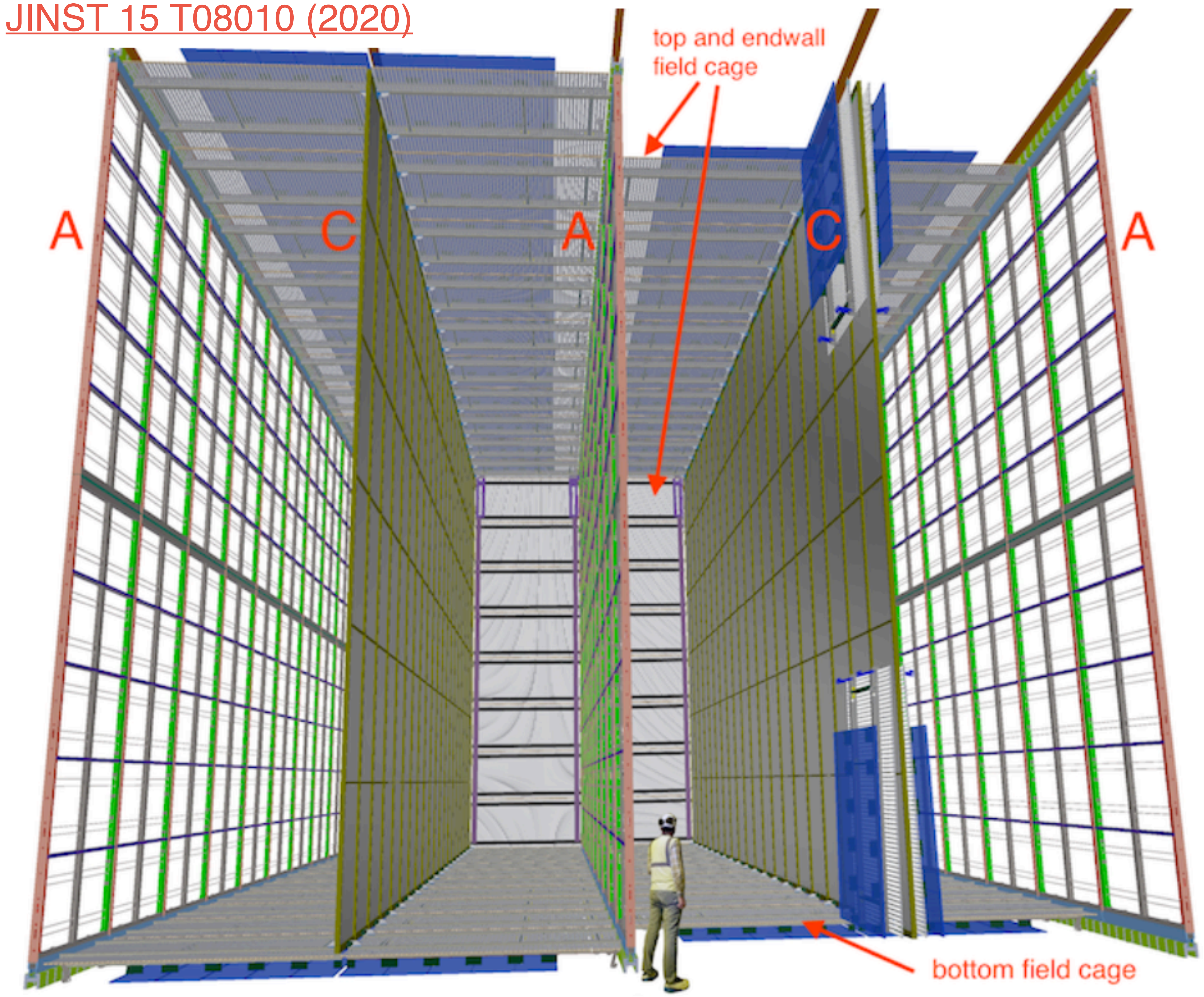


- 1,300 km from the target, 1.5km underground
- Four 17-kt LArTPC modules
  - 15.1m(w)×14.0m(h)×62.0m(l)
- Phase-I
  - Horizontal drift: 3.5m drift
  - Vertical drift: 6.5m drift
- Two more modules in Phase-II

DUNE Experiment: Far detector

Horizontal drift (HD)

JINST 15 T08010 (2020)



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DUNE Experiment: Far detector

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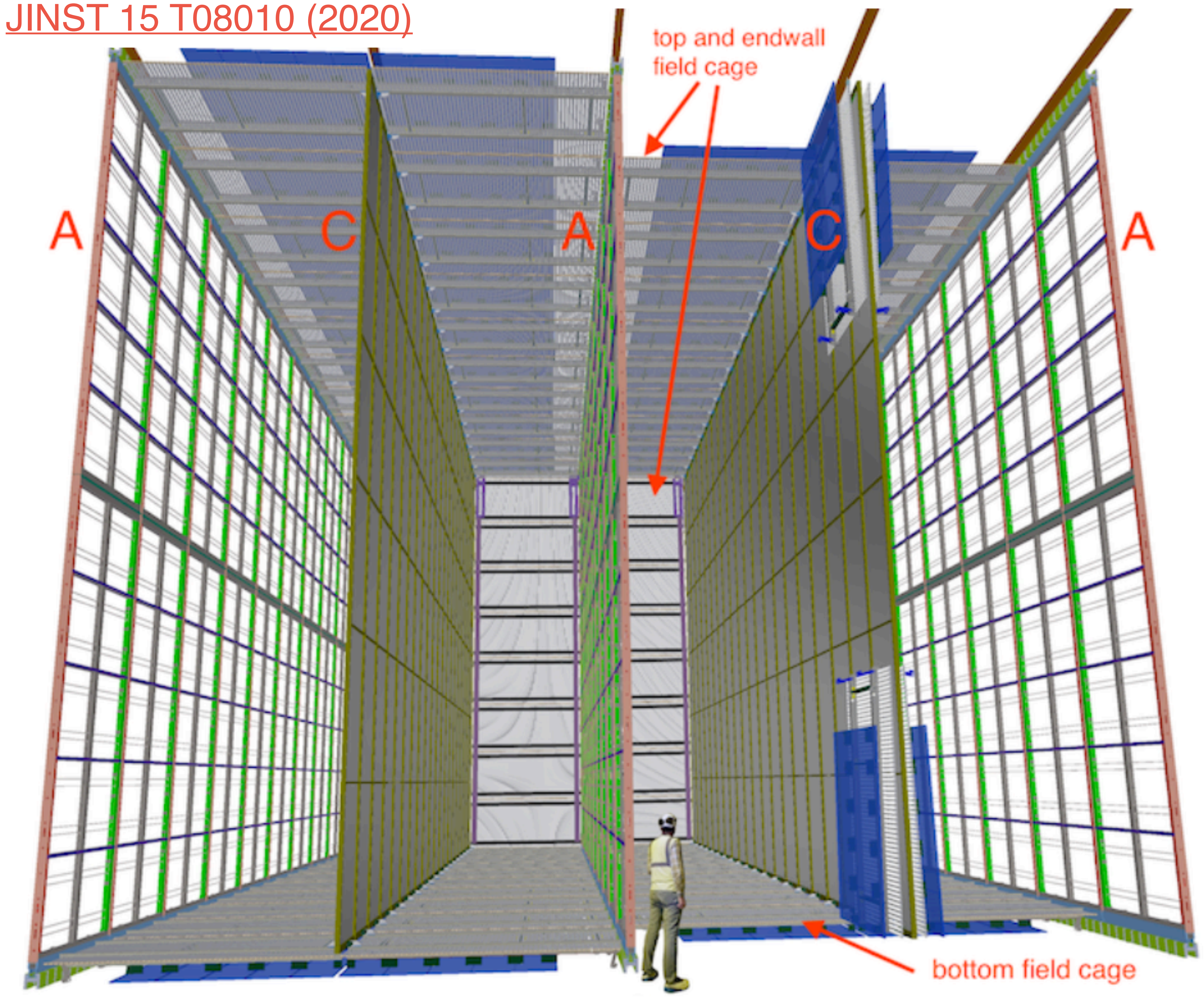
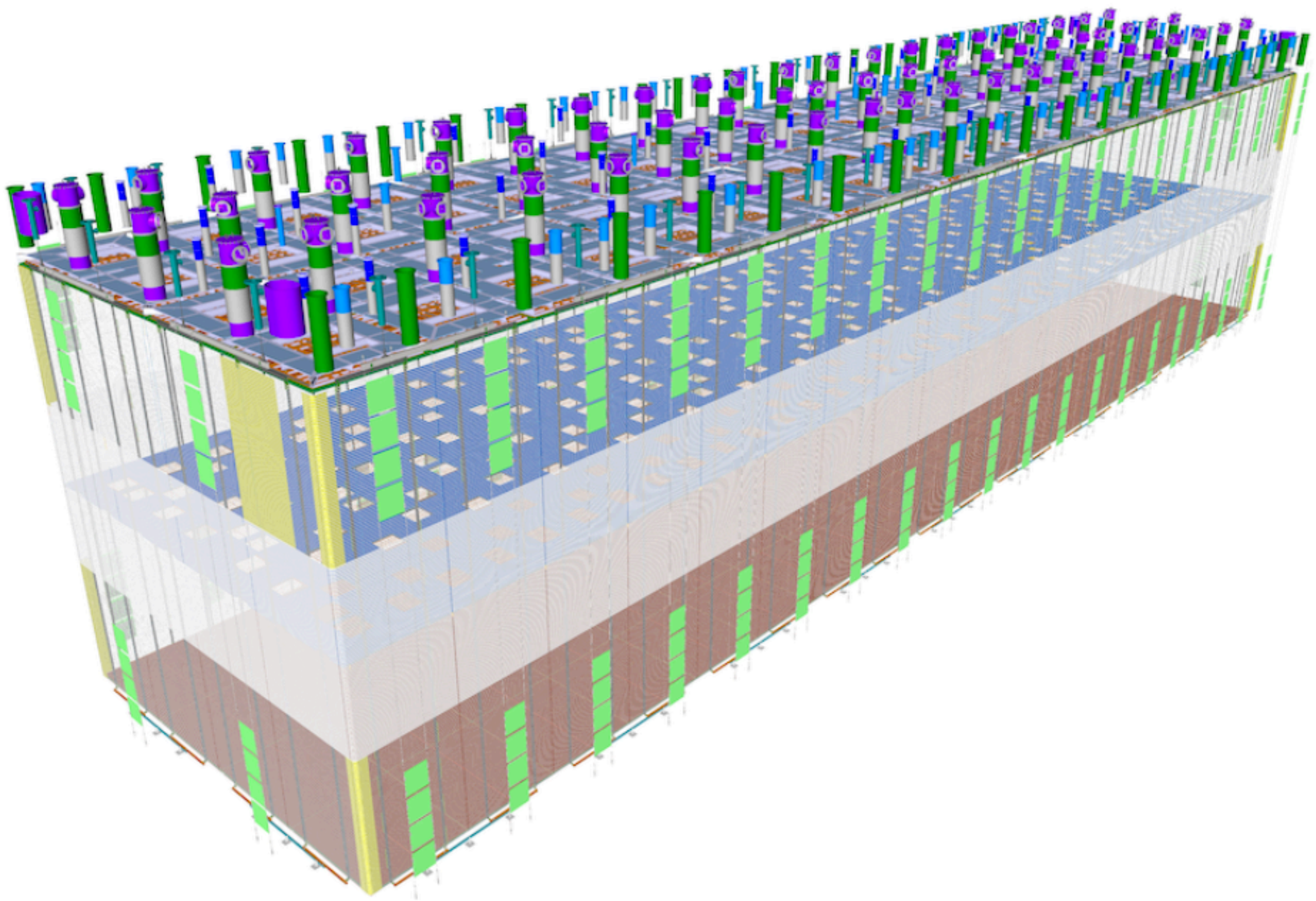


Vertical drift (VD)

from the target,

arXiv:2312.03130



DUNE Experiment: Far detector

- from the target,

Horizontal drift (HD)

JINST 15 T08010 (2020)

Vertical drift (VD)

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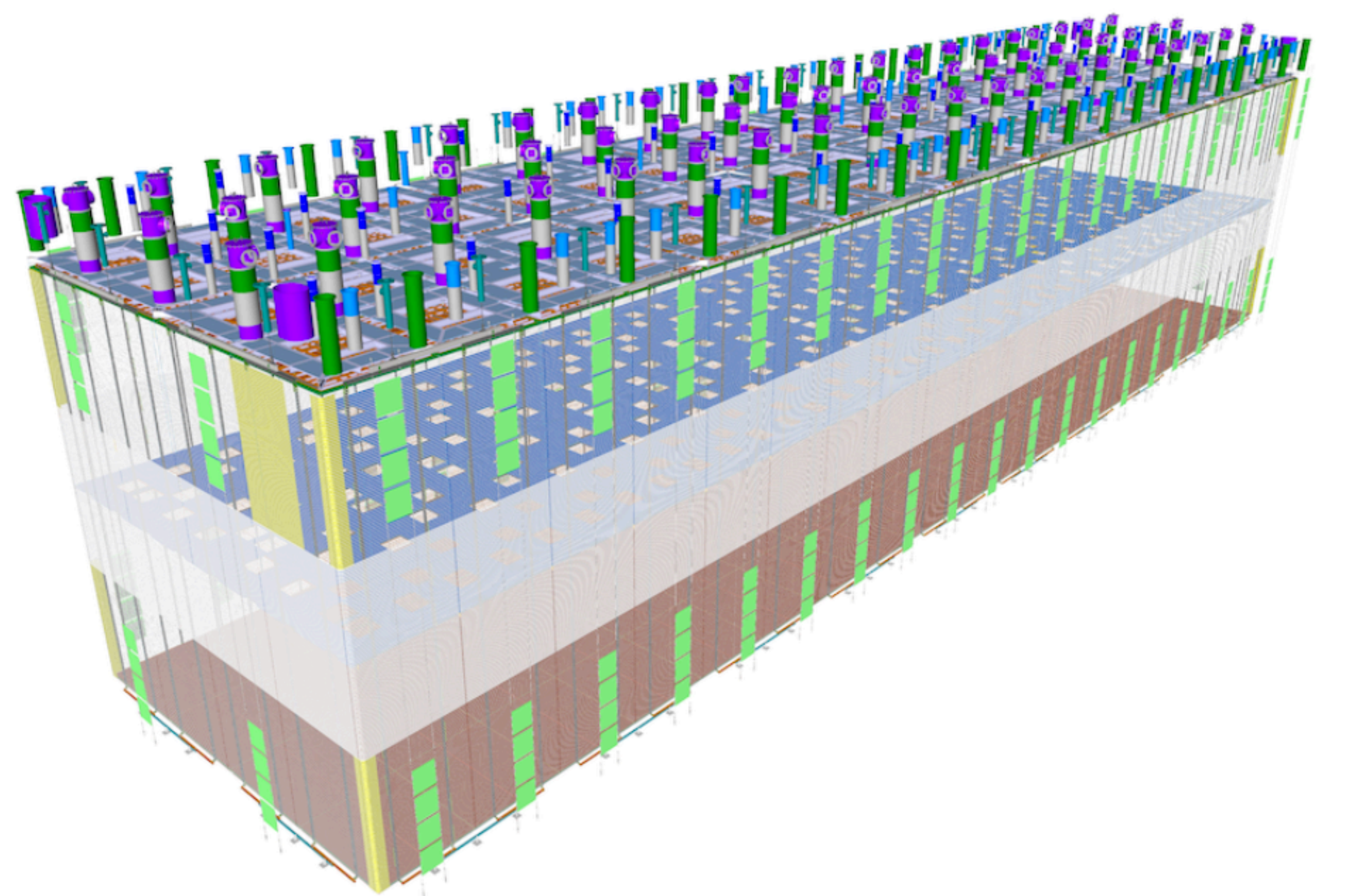
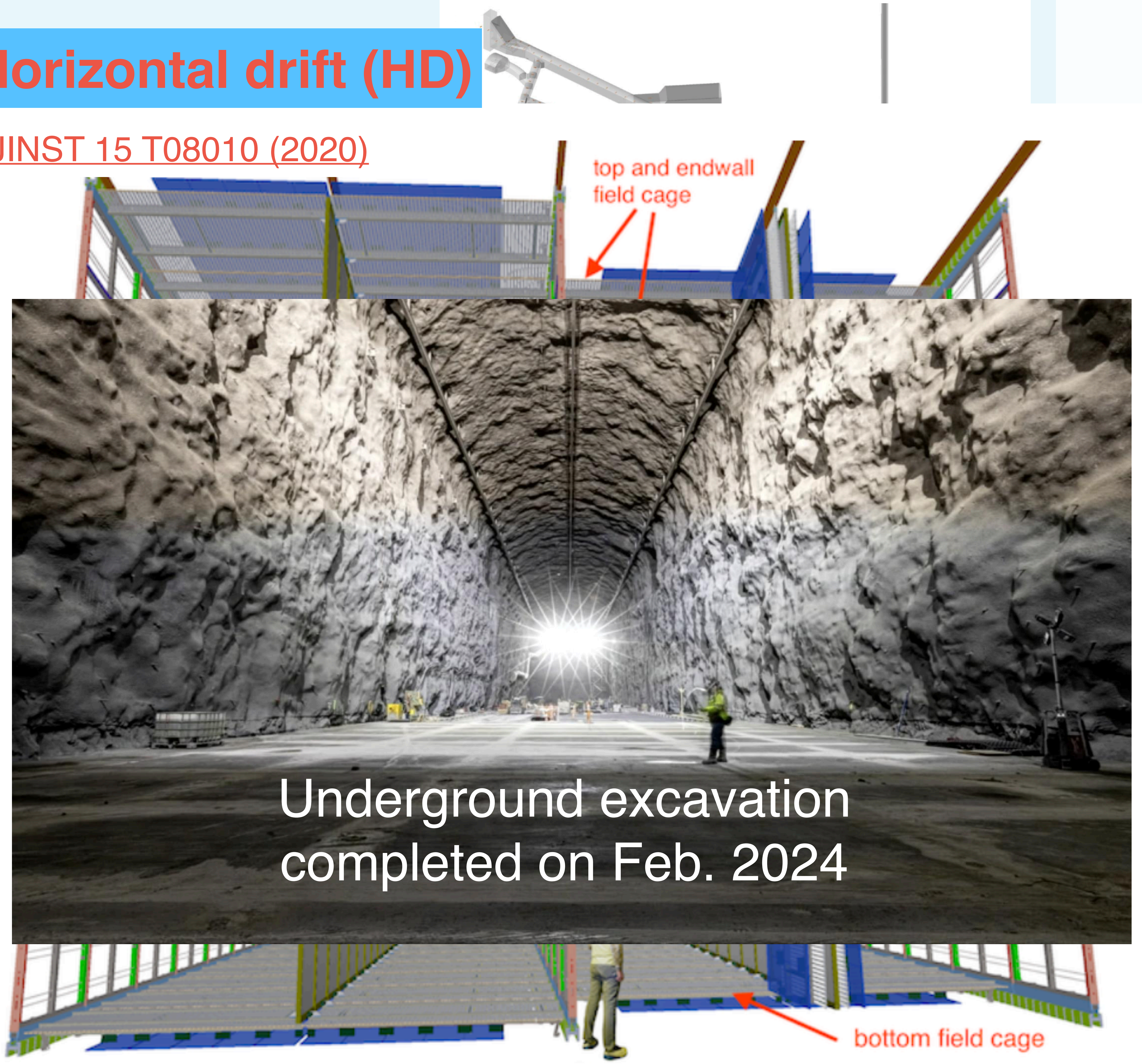


DUNE Experiment: Far de

Horizontal drift (HD)

[JINST 15 T08010 (2020)](#)



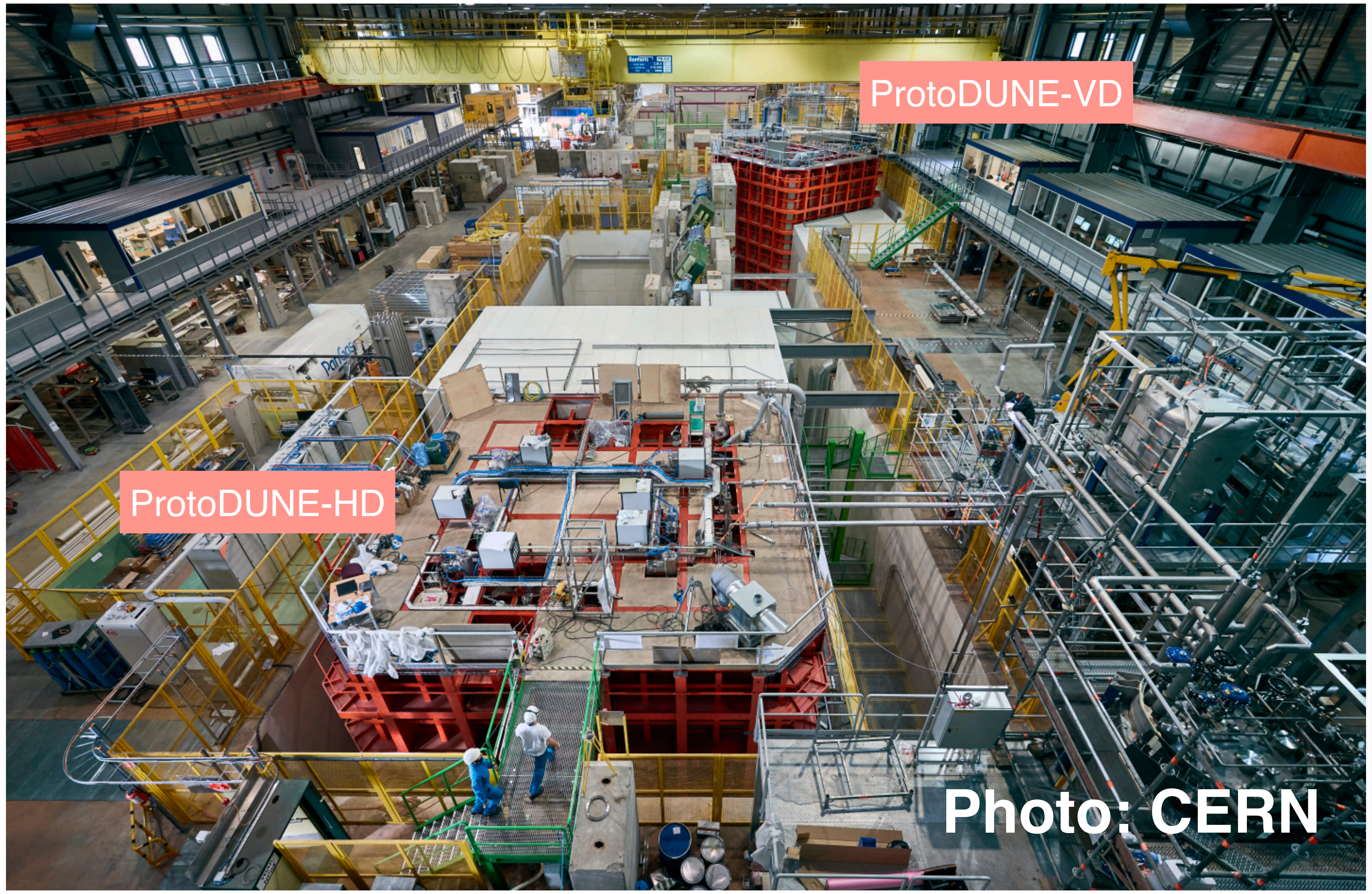
SURF to lower beams for DUNE cryostats starting next year

SDPB | By Lee Strubinger
Published May 12, 2025 at 10:36 PM CDT

Lee Strubinger / SDPB

Beams for the LBNF DUNE experiment in Rapid City.

DUNE Experiment: Far detector; Prototype



- DUNE Collaboration, "The track-length extension fitting algorithm for energy measurement of interacting particles in liquid argon TPCs and its performance with ProtoDUNE-SP data", arXiv:2409.18288, JINST 20 P02021 (2025)
- DUNE Collaboration, "First Measurement of the Total Inelastic Cross-Section of Positively-Charged Kaons on Argon at Energies Between 5.0 and 7.5 GeV", arXiv:2408.00582, Phys. Rev. D 110, (2024) 092011
- DUNE Collaboration, "Reconstruction of interactions in the ProtoDUNE-SP detector with Pandora", arXiv:2206.14521, Eur.Phys.J.C 83 618 (2023)
- DUNE Collaboration, "Identification and reconstruction of low-energy electrons in the ProtoDUNE-SP detector", arXiv:2211.01166
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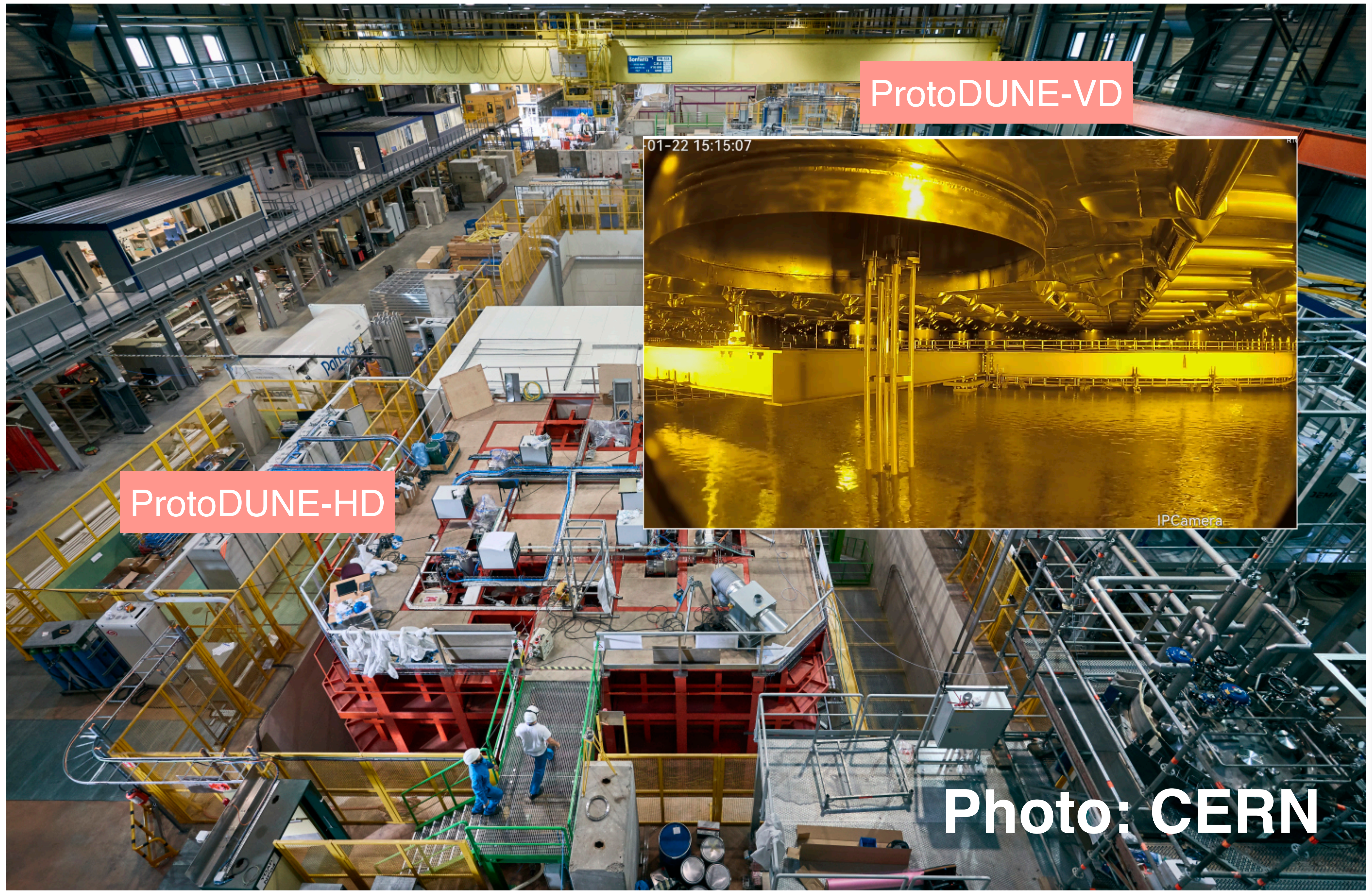
- DUNE Collaboration, "Scintillation light detection in the 6-m drift-length ProtoDUNE Dual Phase liquid argon TPC", arXiv:2203.16134, Eur.Phys.J.C 82 618 (2022)
- DUNE Collaboration, "First results on ProtoDUNE-SP liquid argon time projection chamber performance from a beam test at the CERN Neutrino Platform", arXiv:2007.06722, JINST 15 P12004 (2020)

- 1/20 in volume, but actual sized module prototypes @CERN neutrino platform
- Successful data-taking from ProtoDUNE-HD: publications!

DUNE Experiment: Far detector; Prototype



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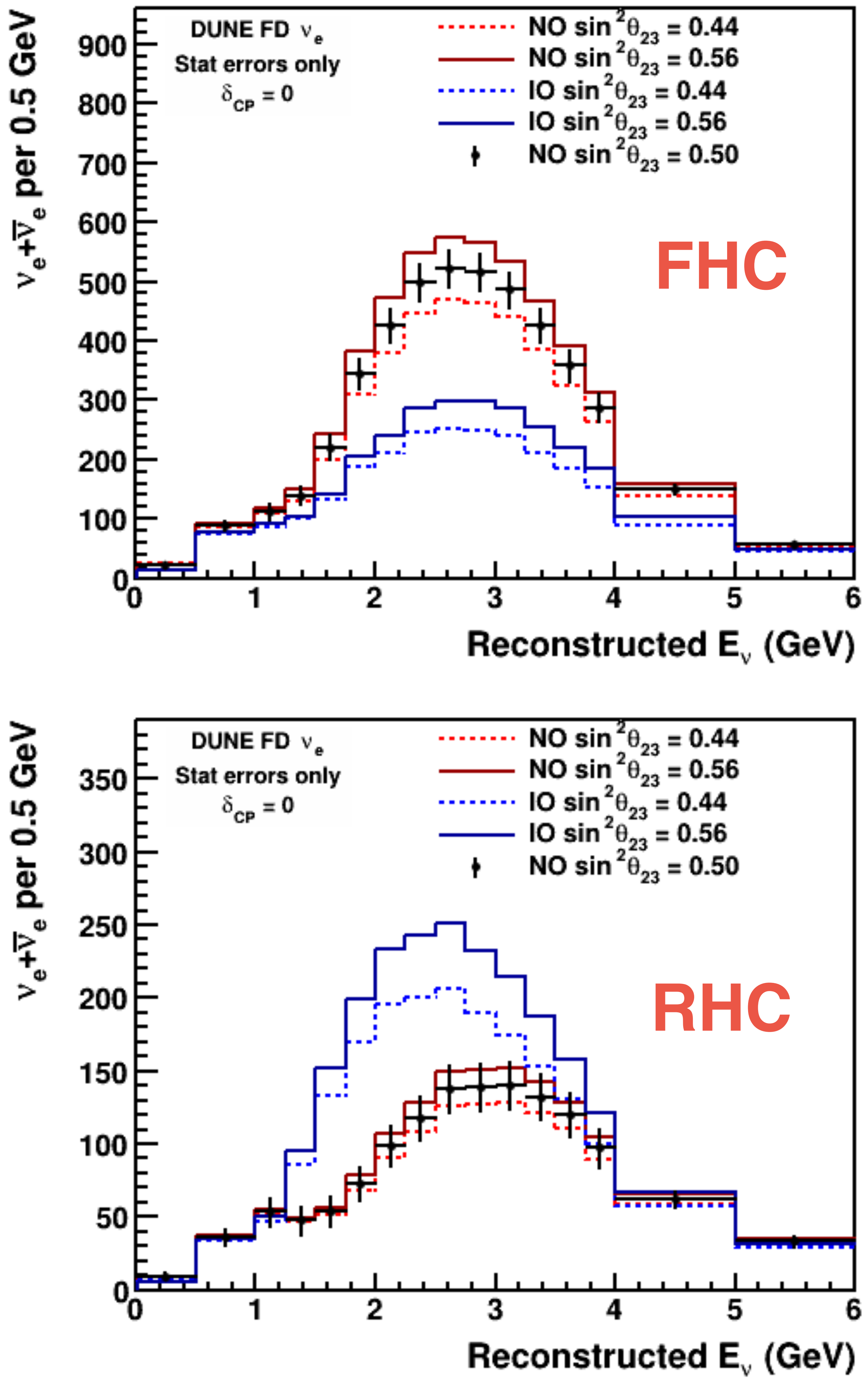
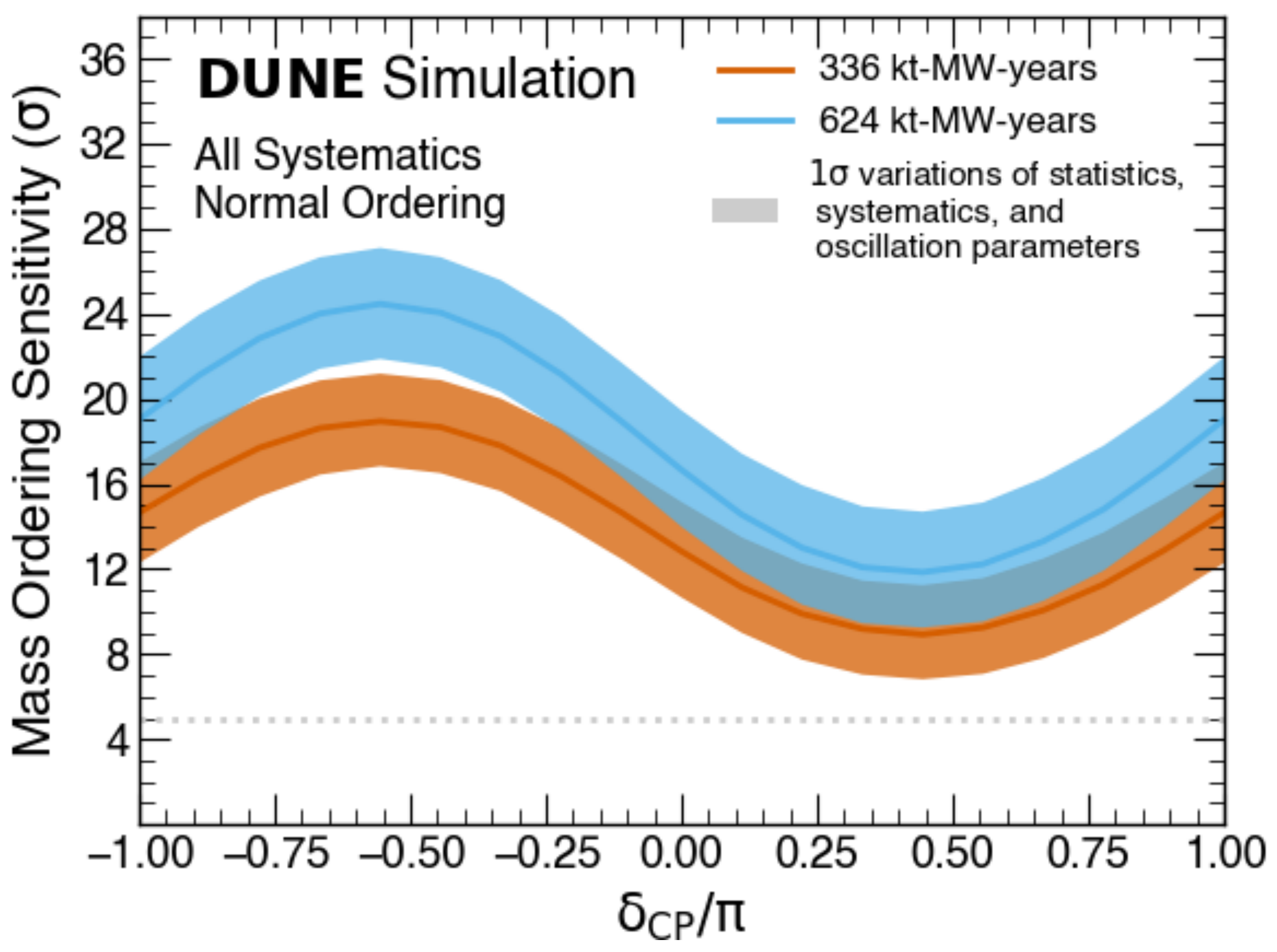
- 1/20 in volume, but actual sized module prototypes @CERN neutrino platform
- Successful data-taking from ProtoDUNE-HD: publications!
- ProtoDUNE-VD: LAr filling completed this January! Comm./data-taking this year

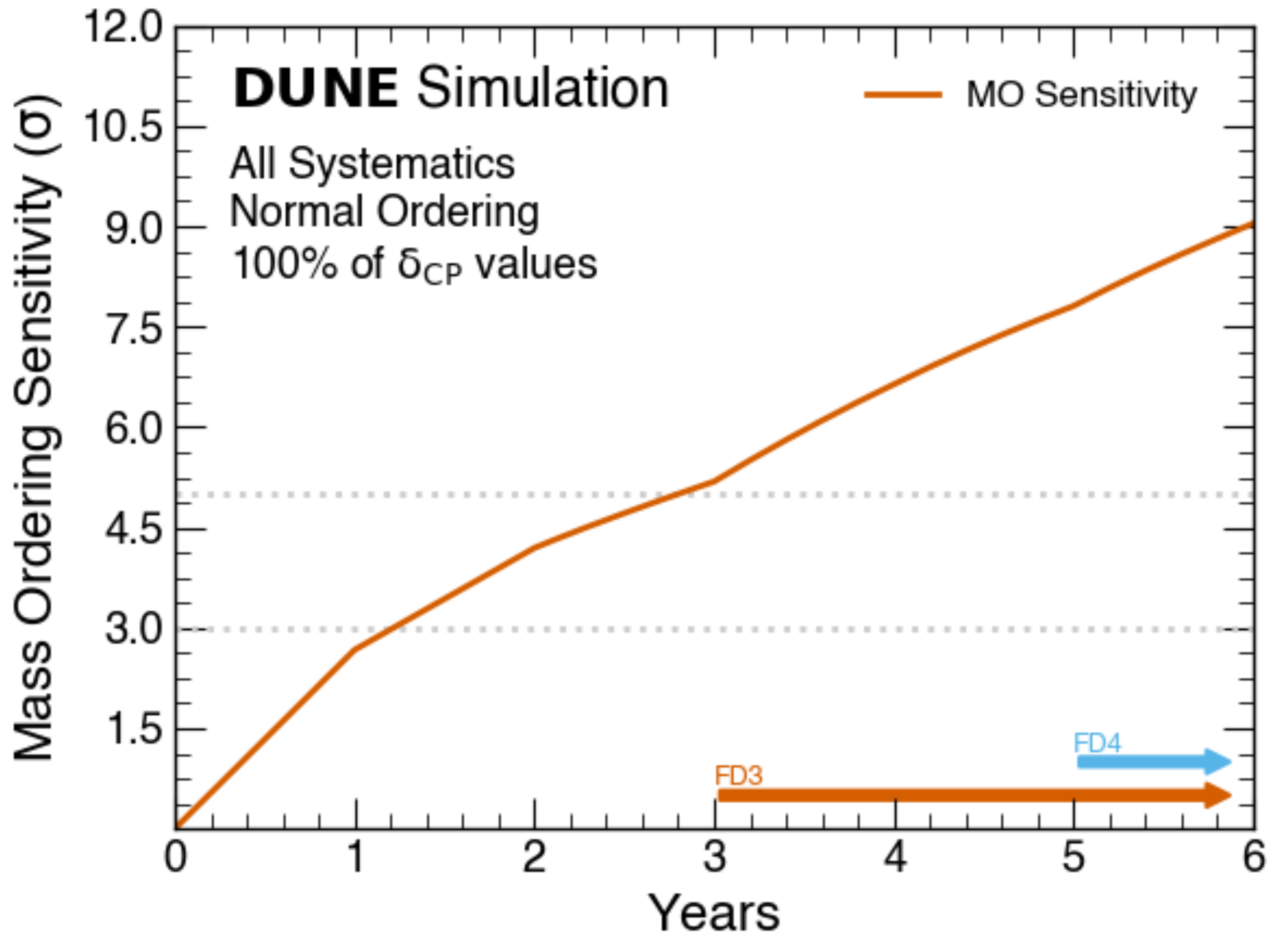
Physics overview: Oscillation; Mass ordering (MO)

Eur. Phys. J. C 80, 978 (2020)



- Appearance data is sensitive to mass ordering (NO vs IO)
- >5σ MO in ~3 years regardless of δ_{CP}!





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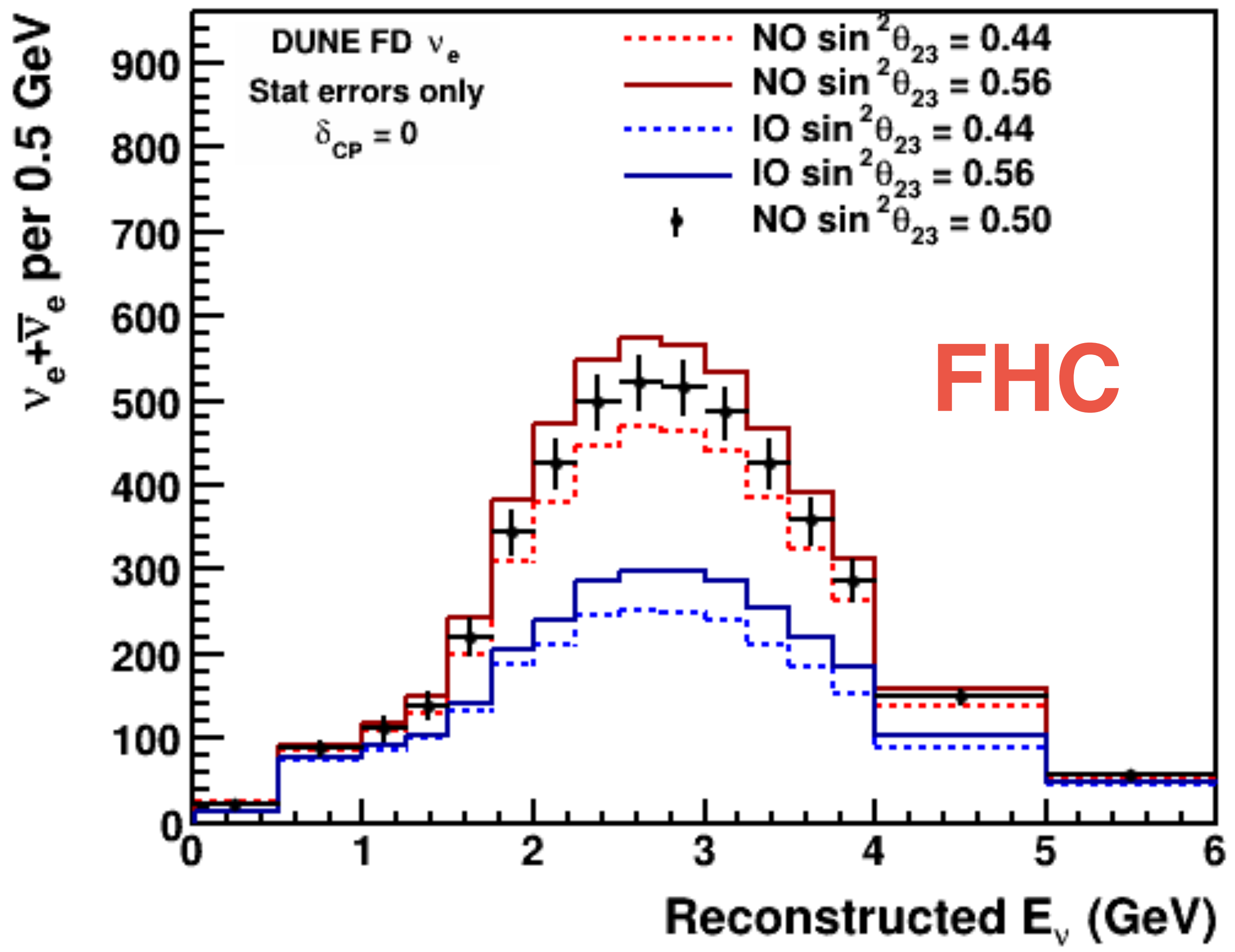

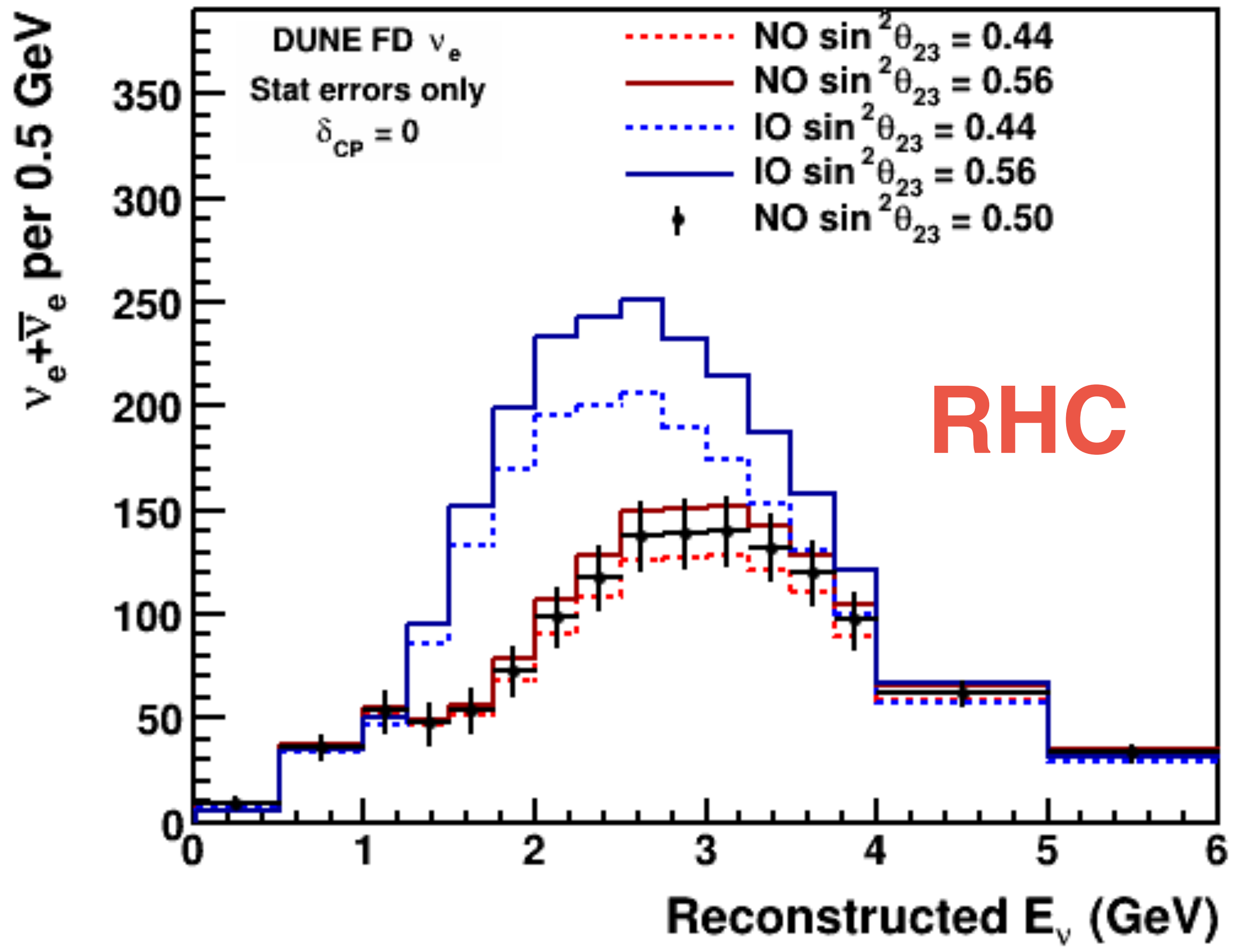

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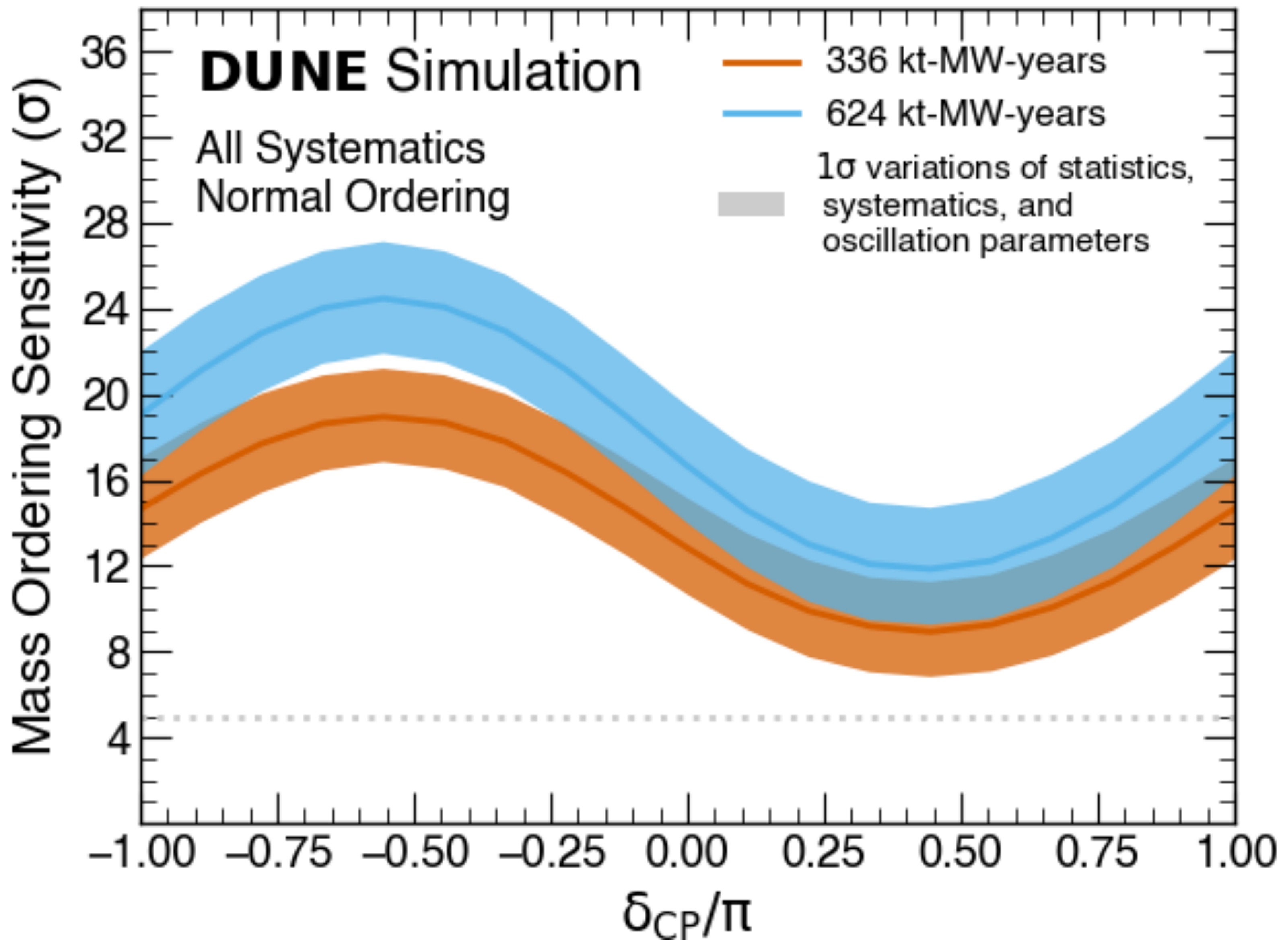

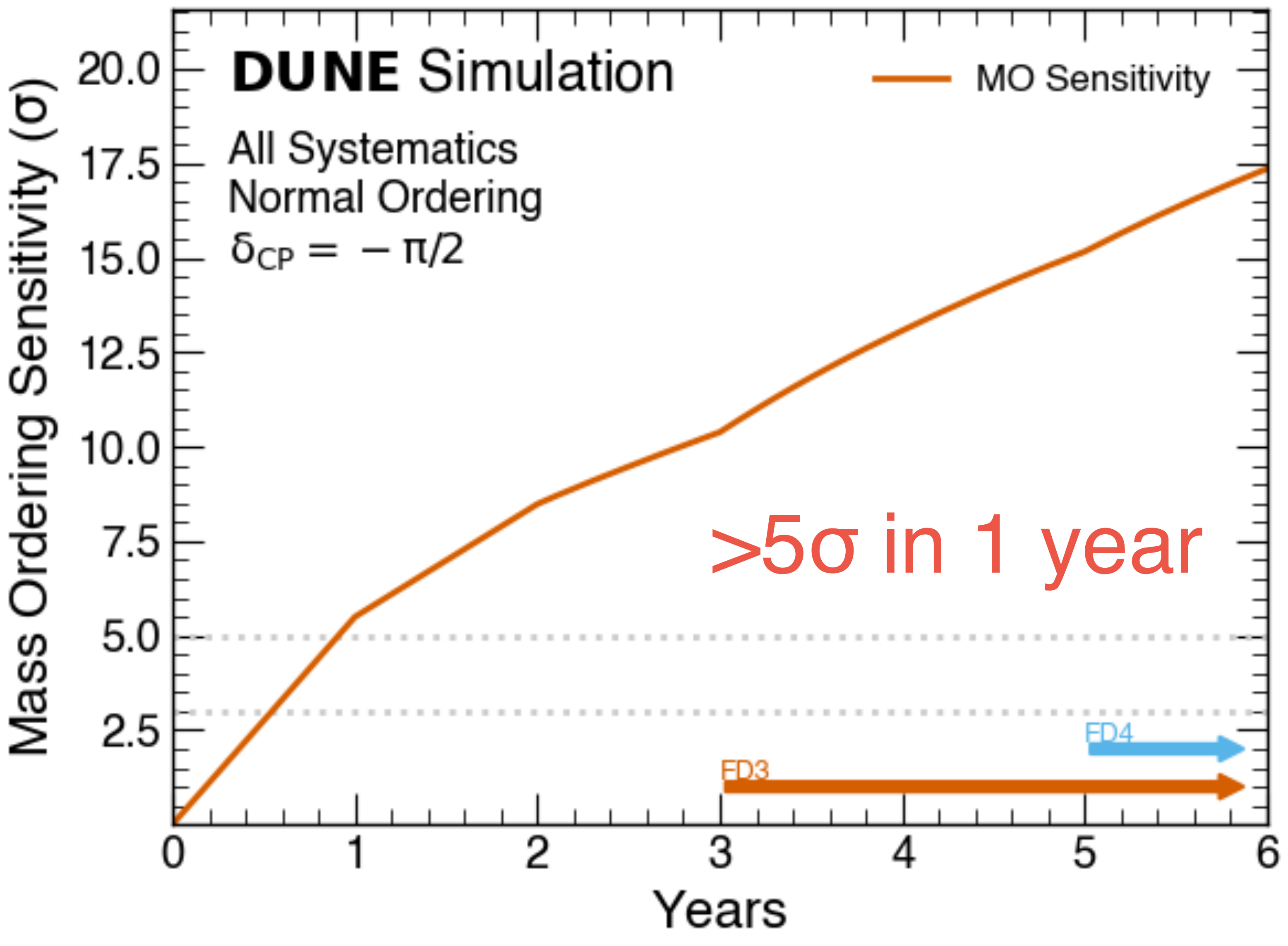

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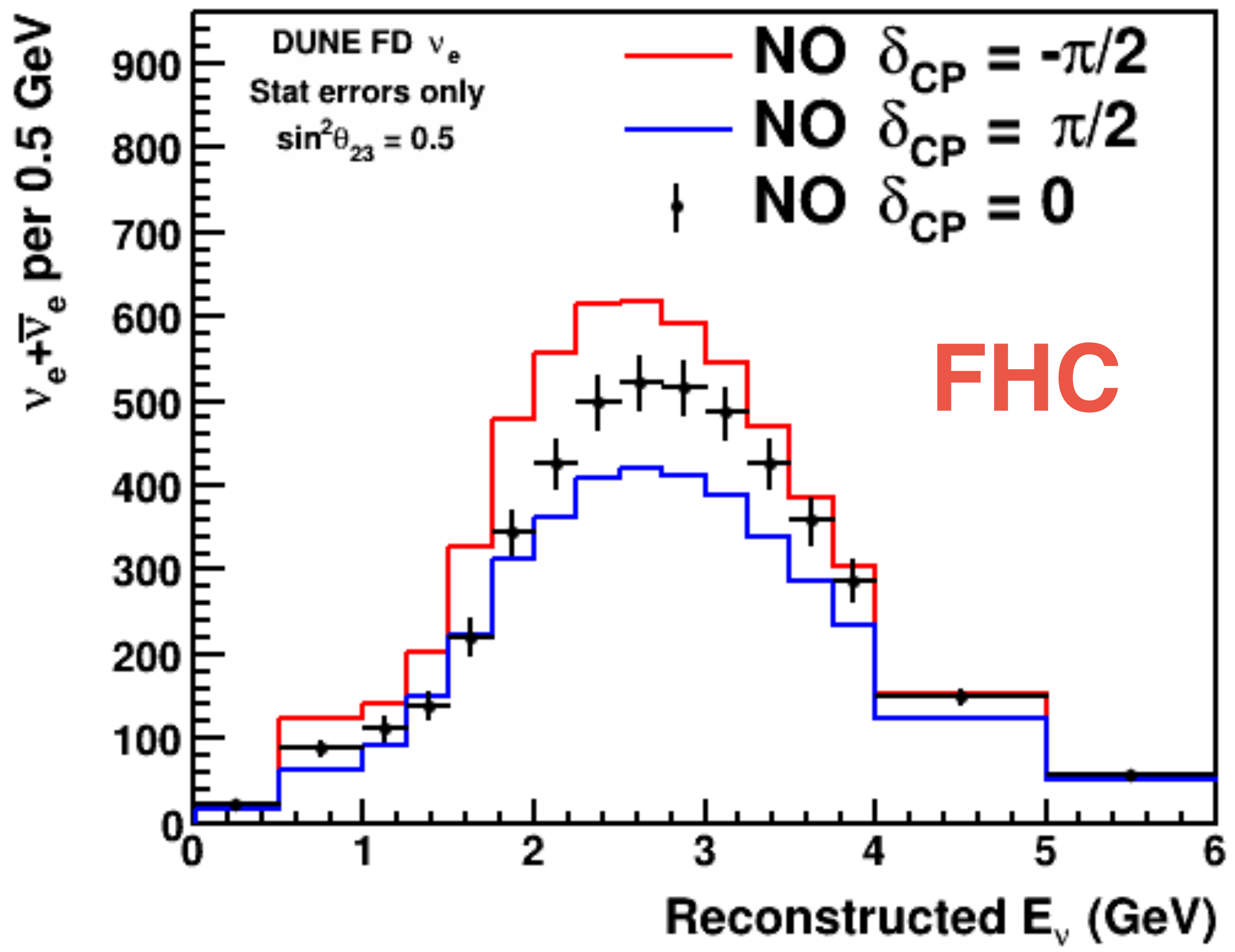

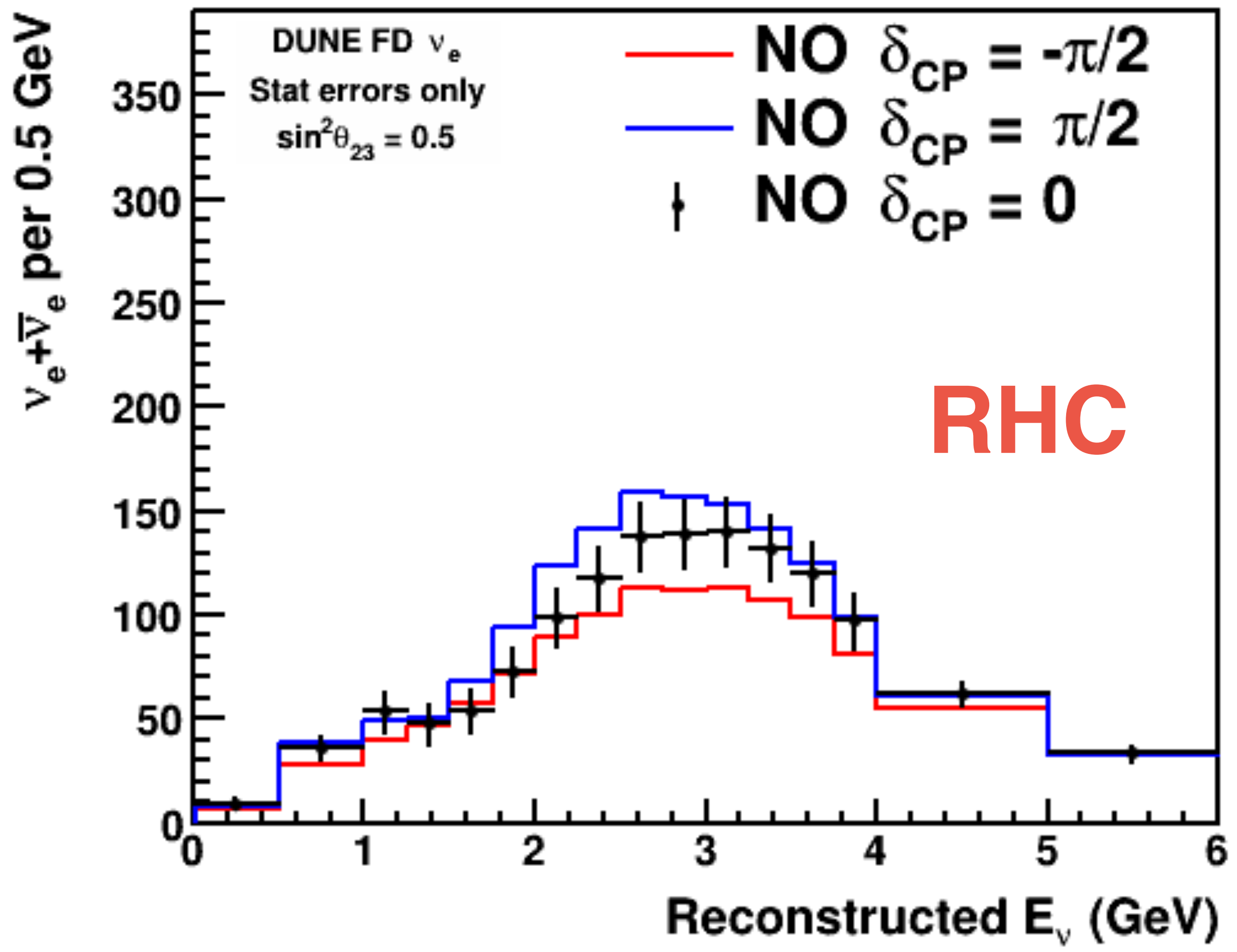

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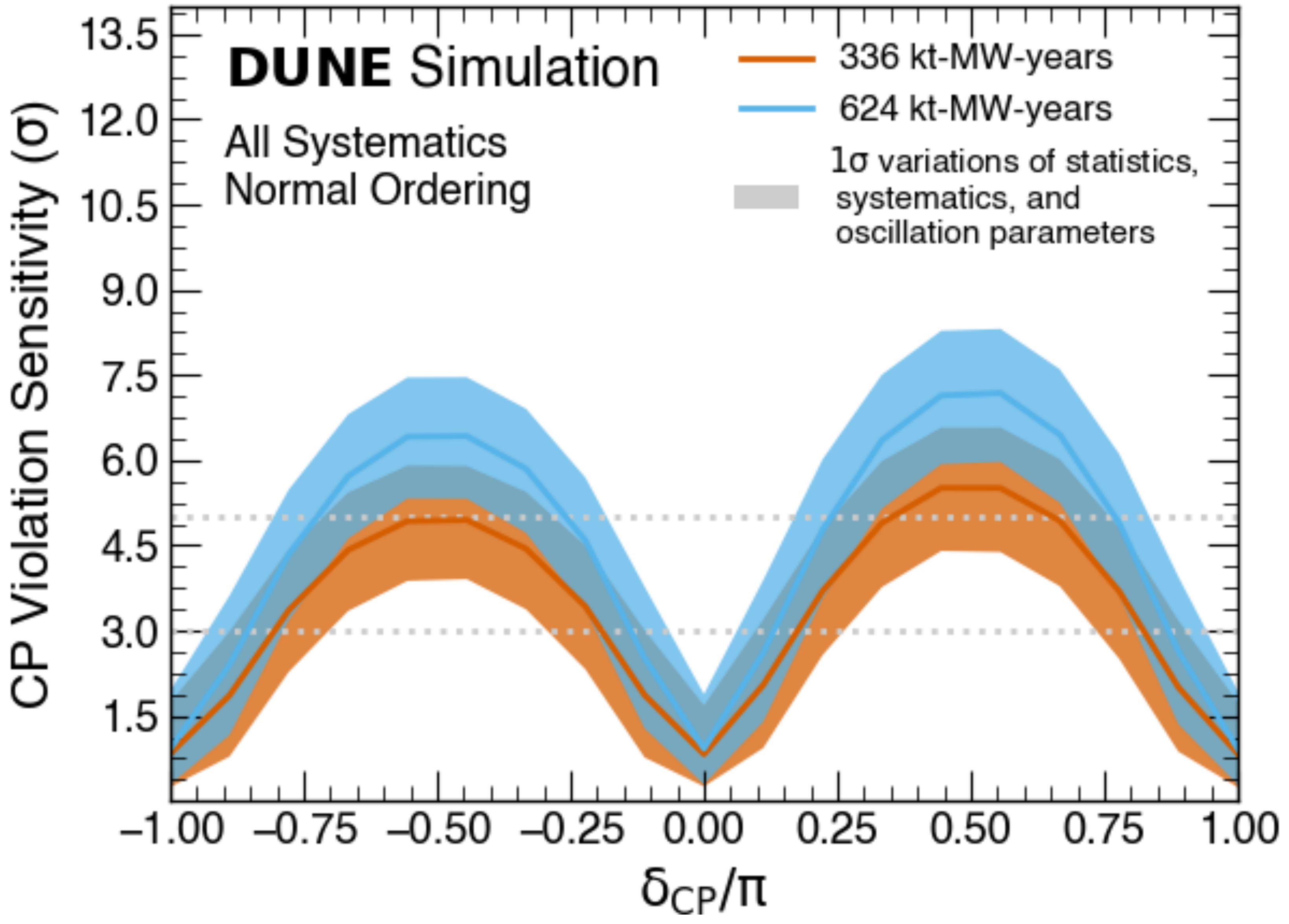

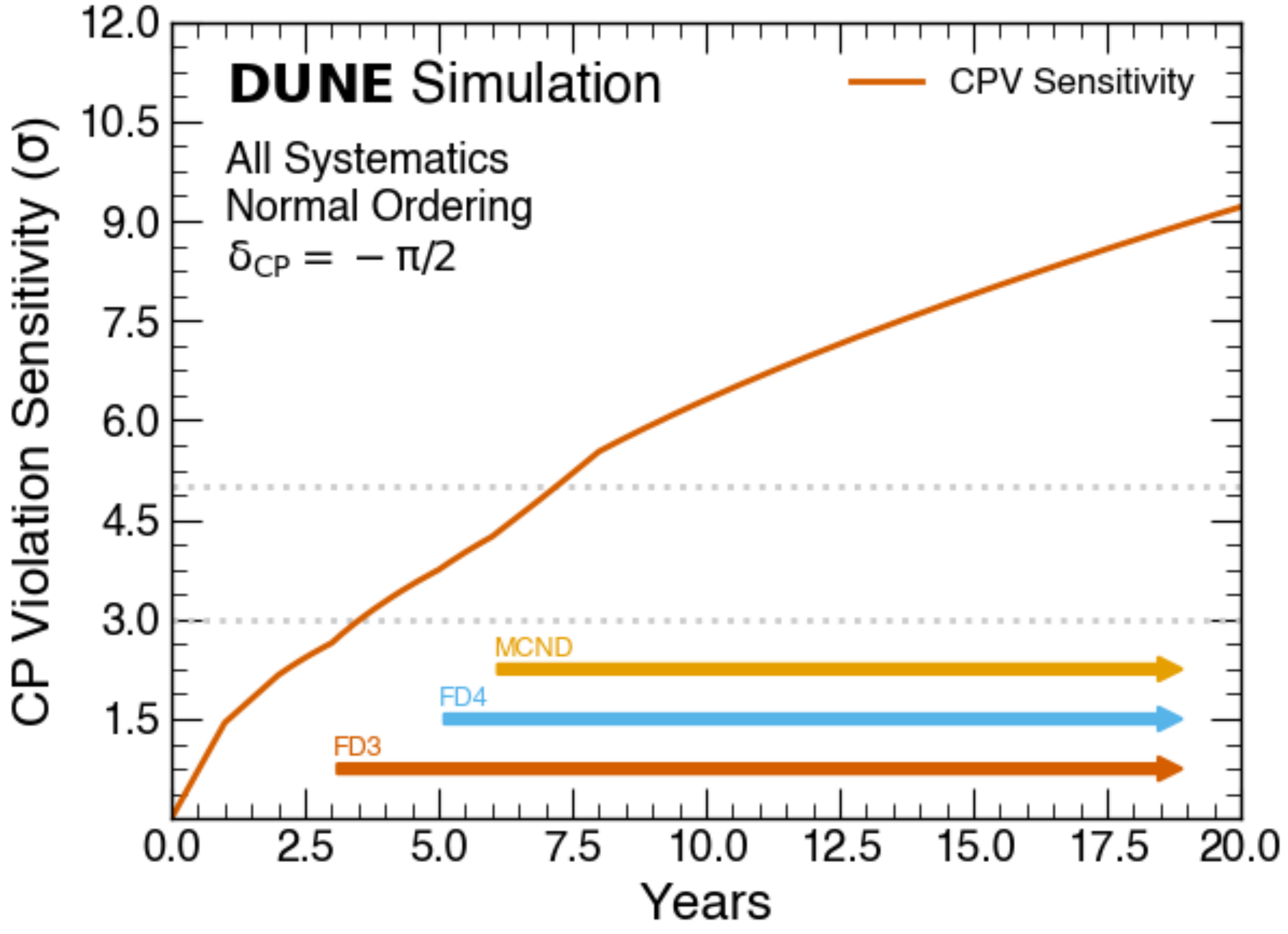

Physics overview: Oscillation; δ_{CP}

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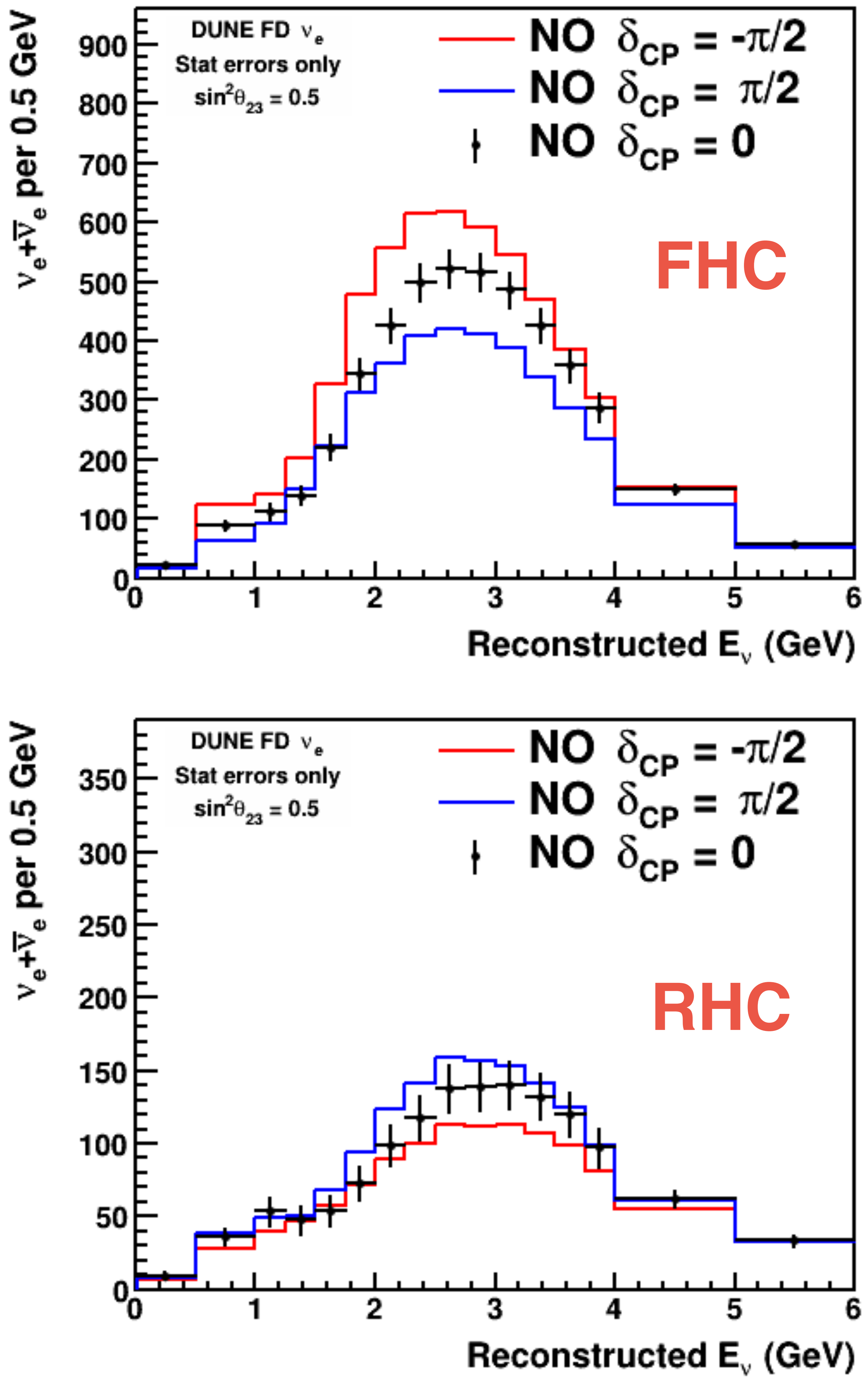
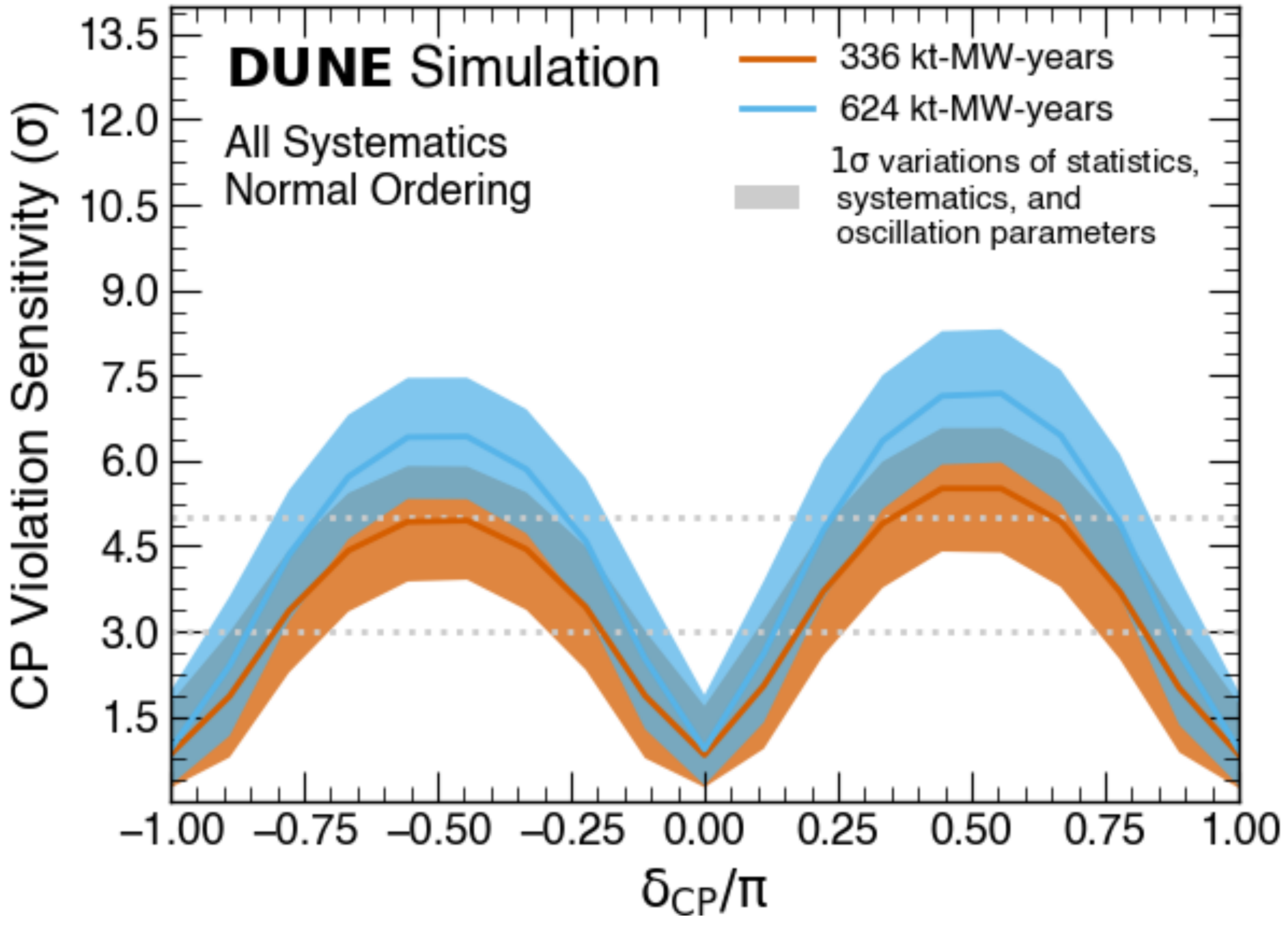
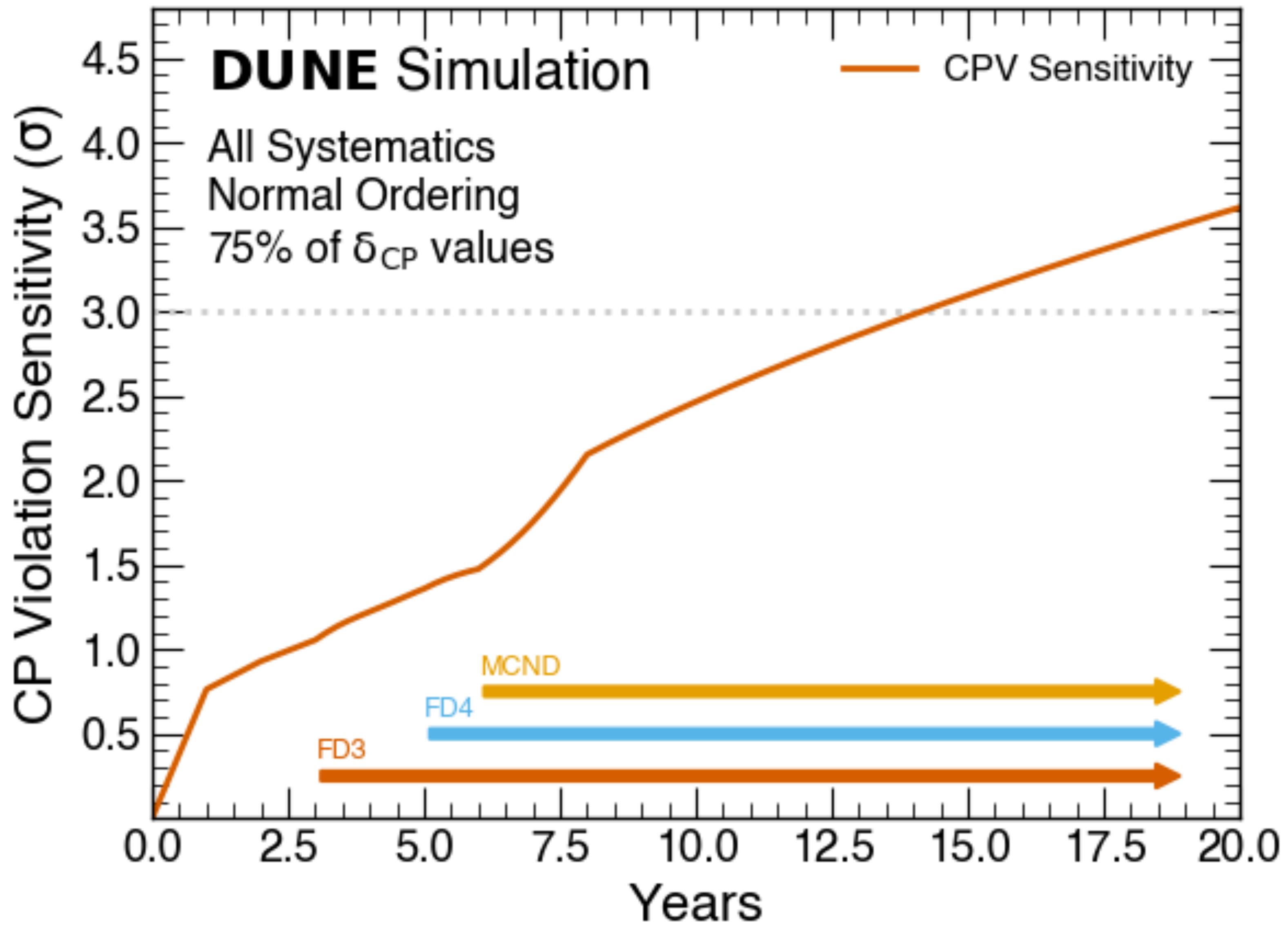


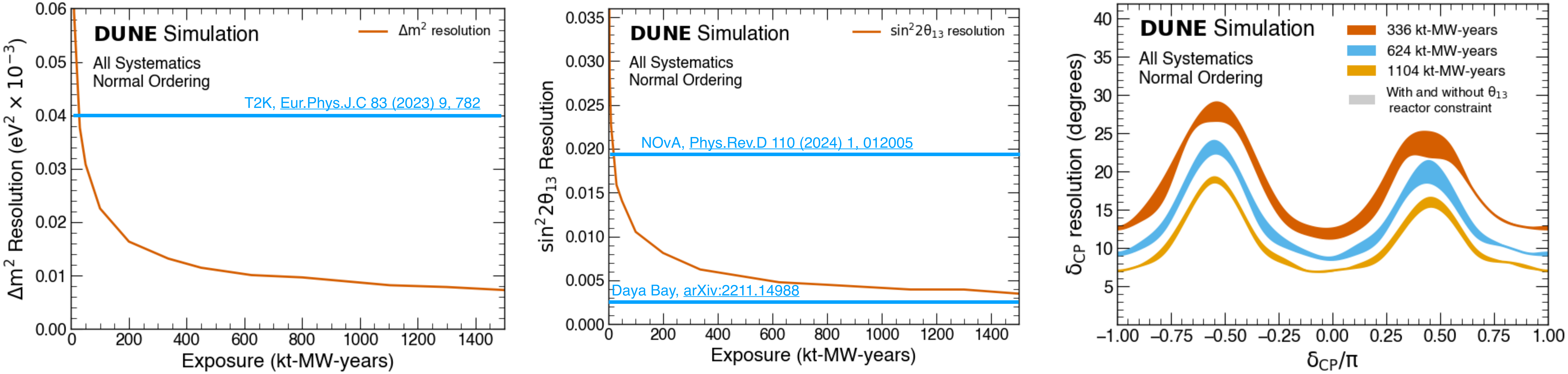
- Appearance data is sensitive to δ_{CP}
- Maximal δ_{CP}, >3σ in 3.5 years!
- 75% of δ_{CP} with >3σ with longer term





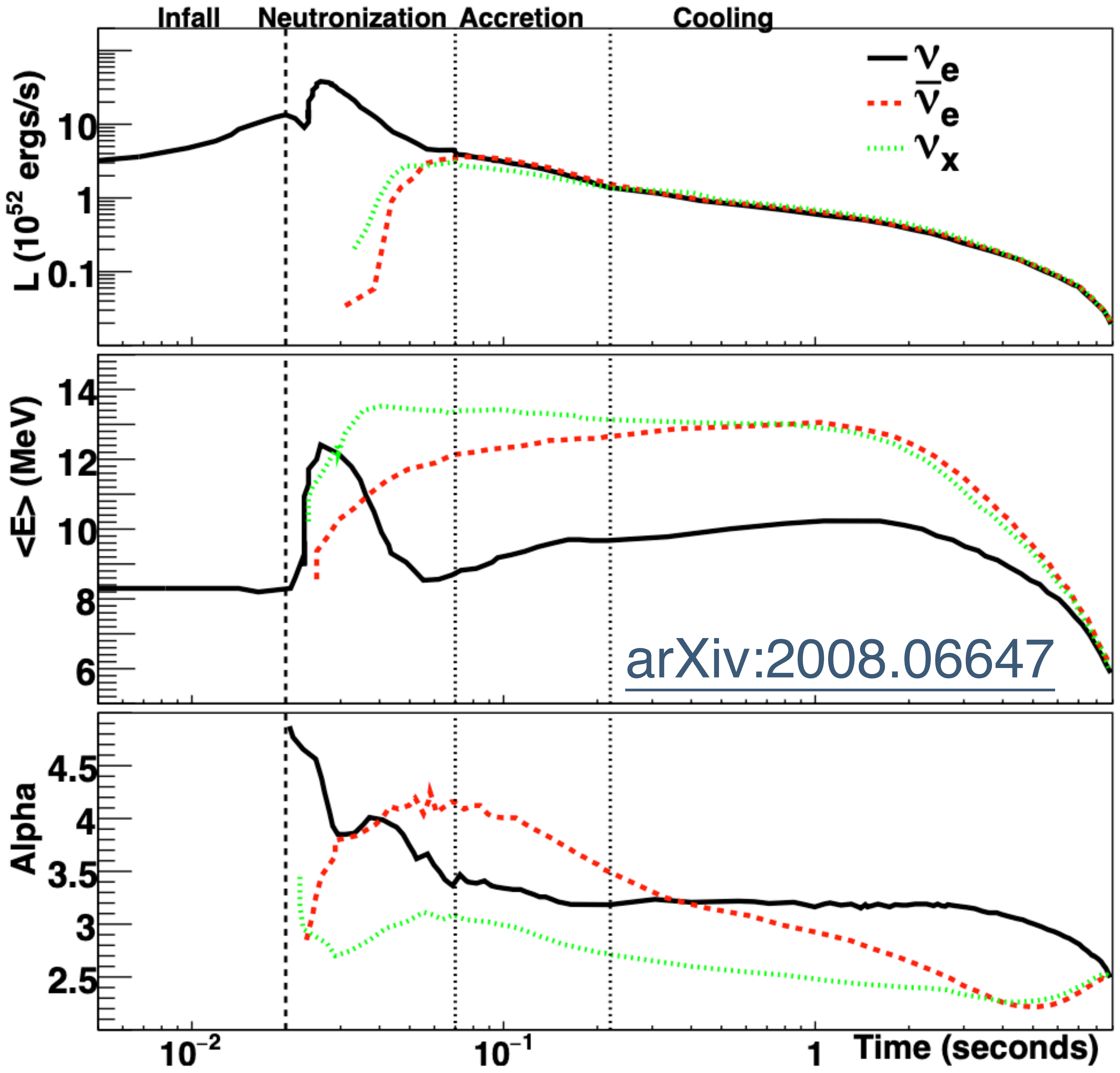
Physics overview: Oscillation; Precision

Eur. Phys. J. C 80, 978 (2020)

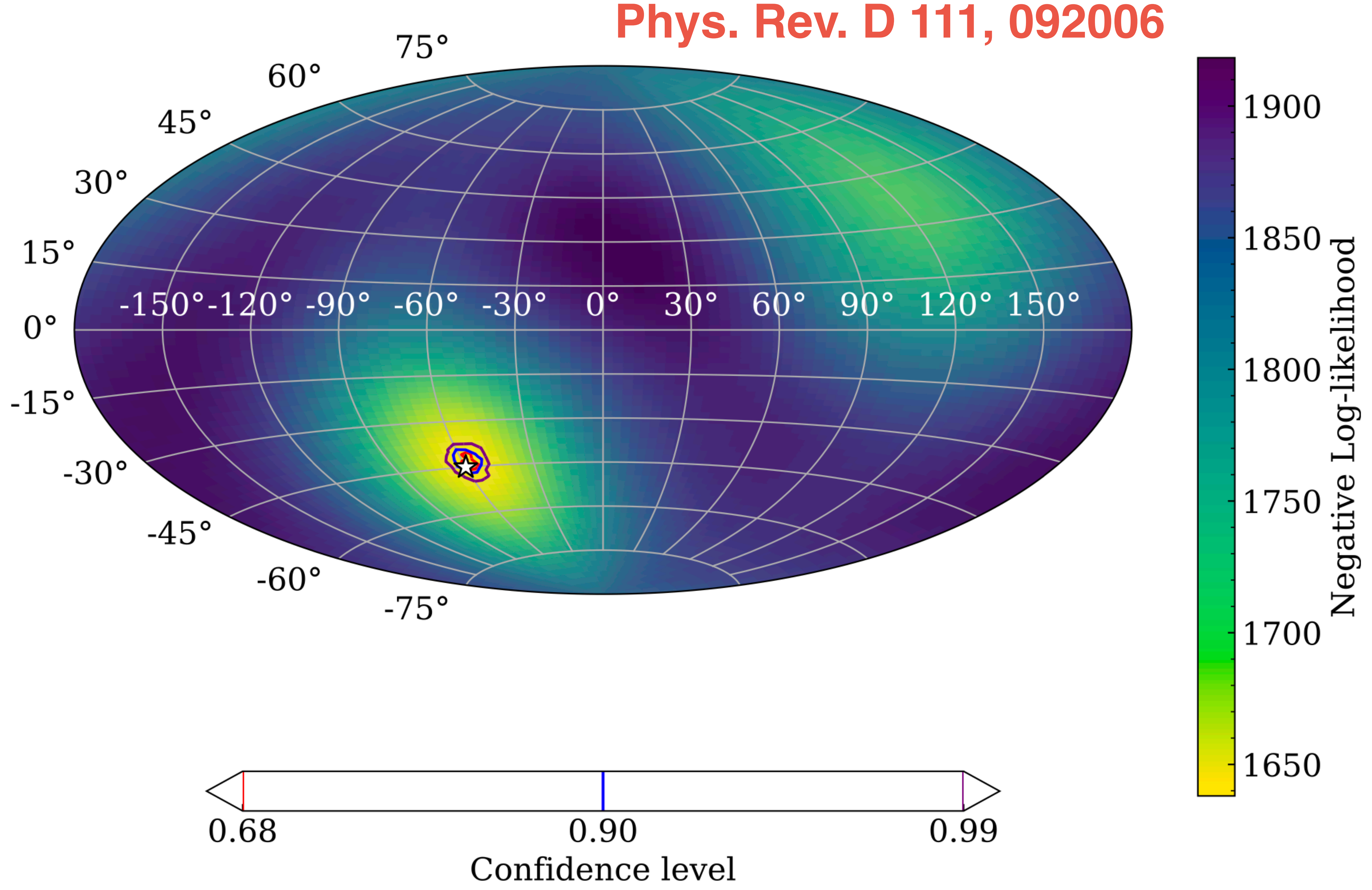


- Not only for discoveries, but DUNE will perform precision measurements
- θ_{13} resolution comparable to the reactor experiments
- 6-16° resolution on δ_{CP}

Physics overview: Supernova neutrino

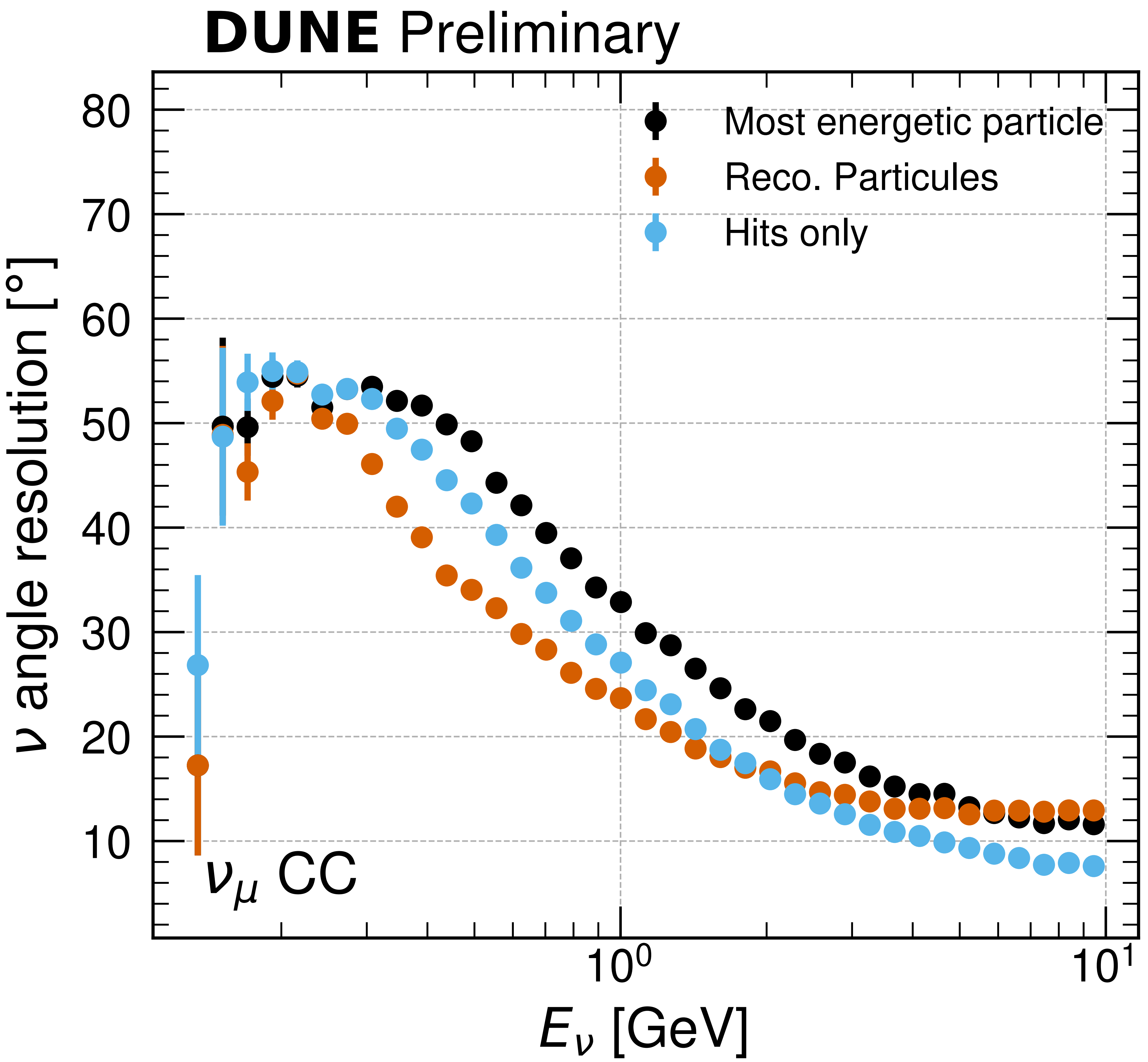


Phys. Rev. D 111, 092006



- Core-collapse supernovae is expected within the few-decade long lifetime of the experiment
- Tagging ν-e elastic scattering enables SN pointing ability: ~5° resolution with 40 kt, 10 kpc

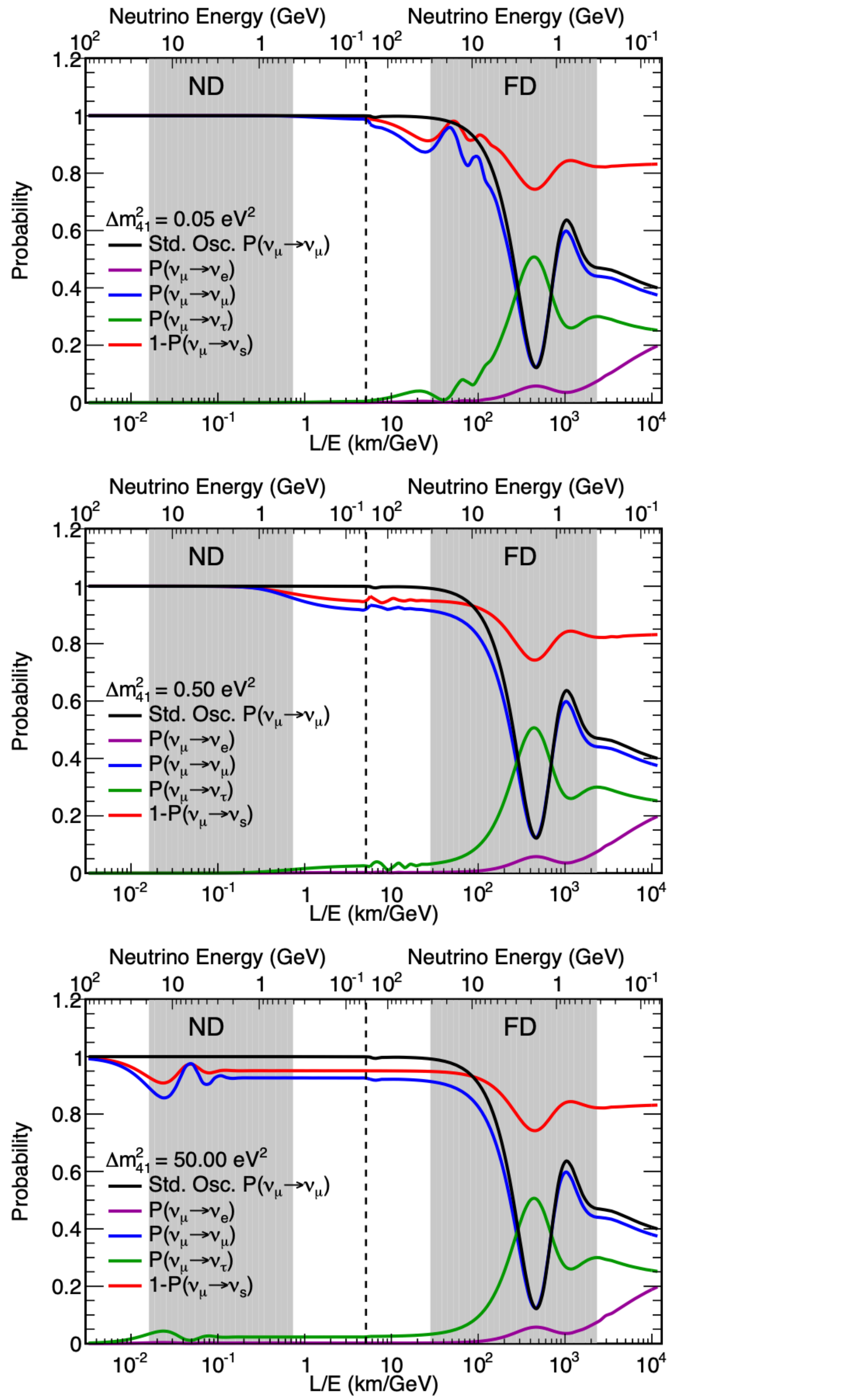
Physics overview: Atmospheric neutrino



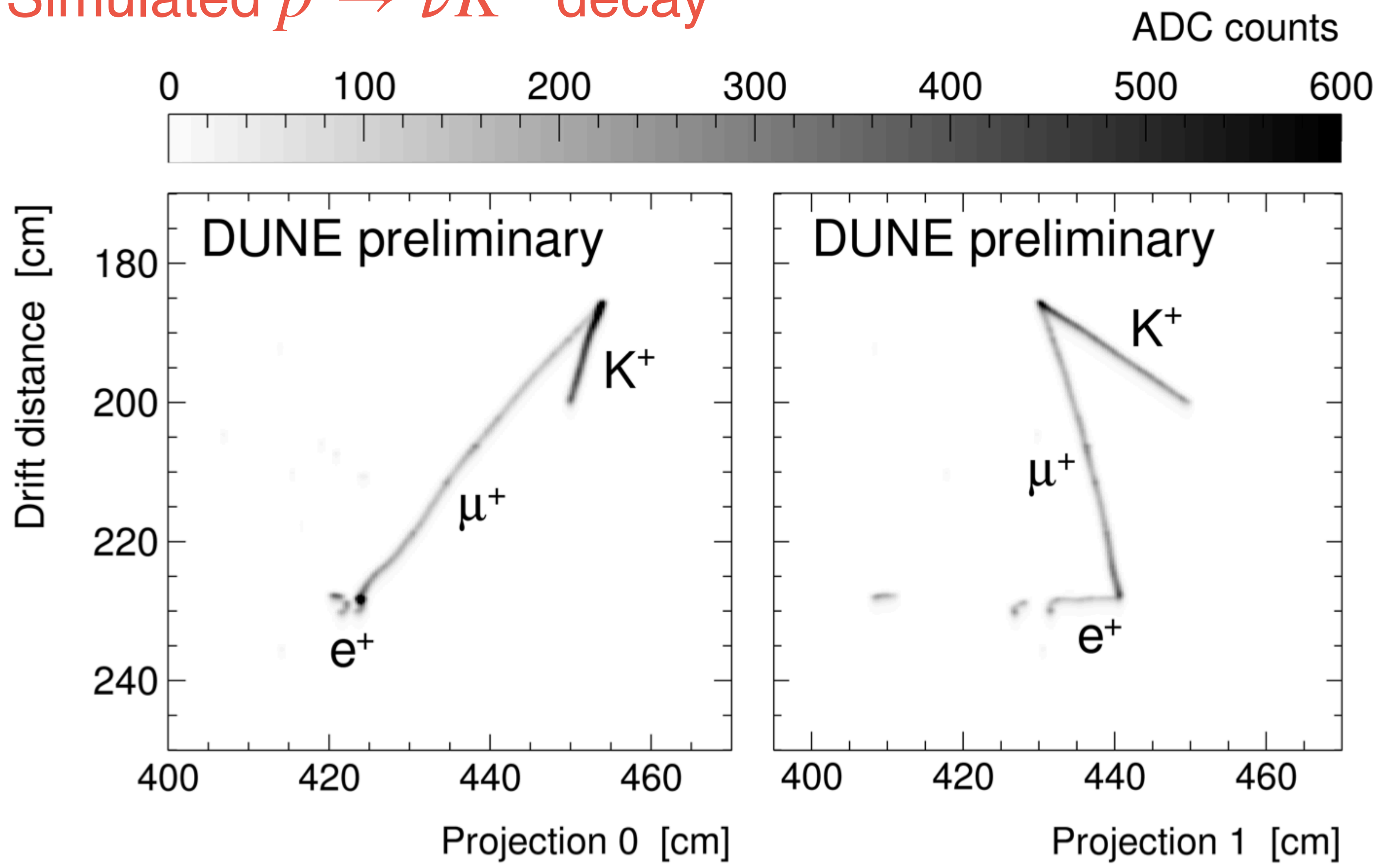
- Atmospheric neutrinos will be measured at the FD
  - Also one of the earliest measurements!
- Particle identification improves ***angular resolution*** for low energies (E_ν<1.0 GeV)
- Plan to combined with LBL analysis

Physics overview: Beyond the SM

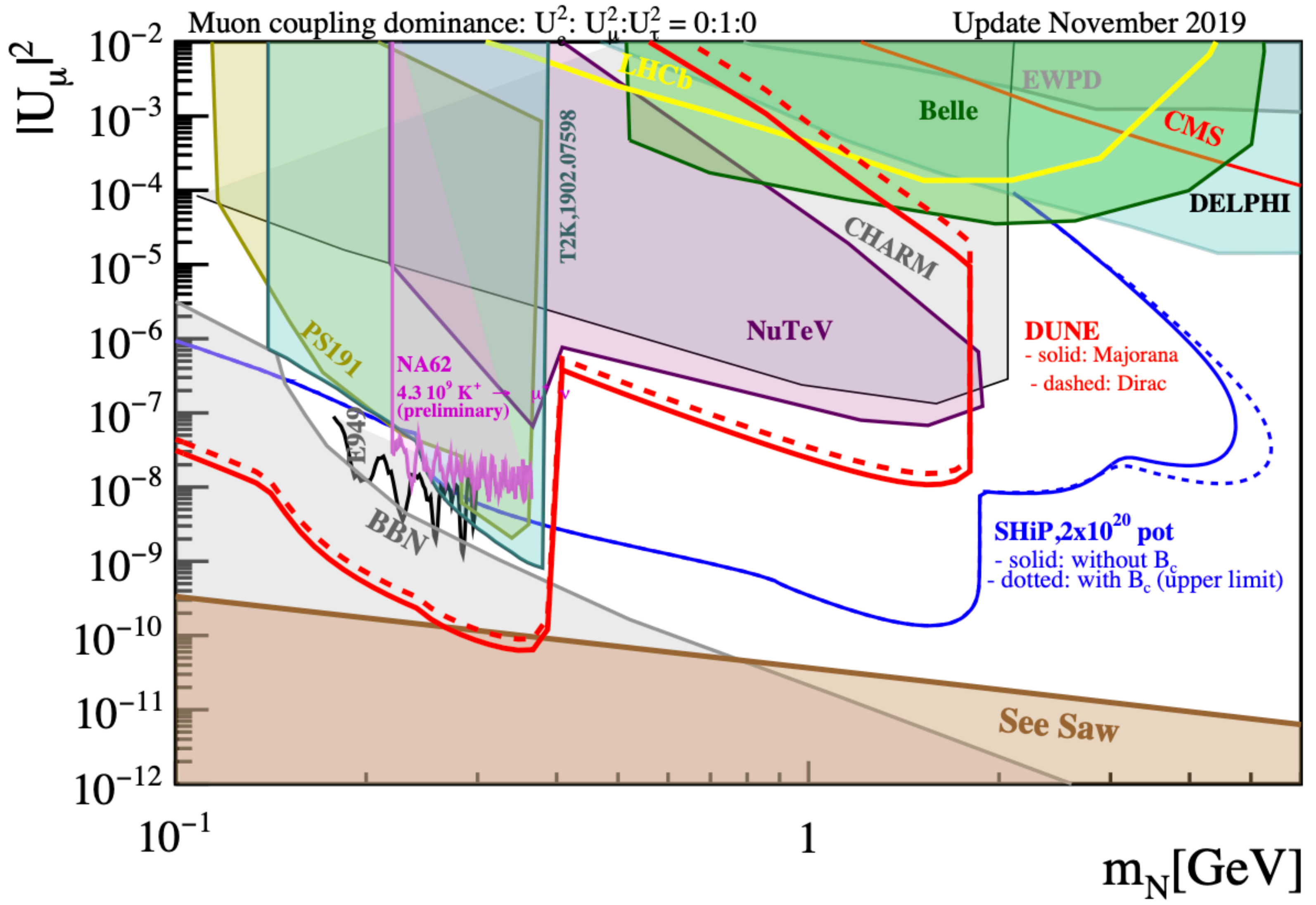
European Physical Journal C 81 (2021) 322
Osc. prob. with 3+1 scenario at DUNE



PoS(ICHEP2020)226
Simulated $p \to \bar{\nu} K^+$ decay



arXiv:2103.13910
HNL, 90% CL 12yrs data taking w/o bkgd. assumption.



- Large volume: proton decay
- High intensity: LDMs, HNLs...
- Sterile neutrino oscillations (ND-to-FD, or within ND)
- Long baseline: Non-standard interactions

Why study cross-section

NOvA: https://arxiv.org/abs/2108.08219

T2K: https://arxiv.org/abs/2305.09916

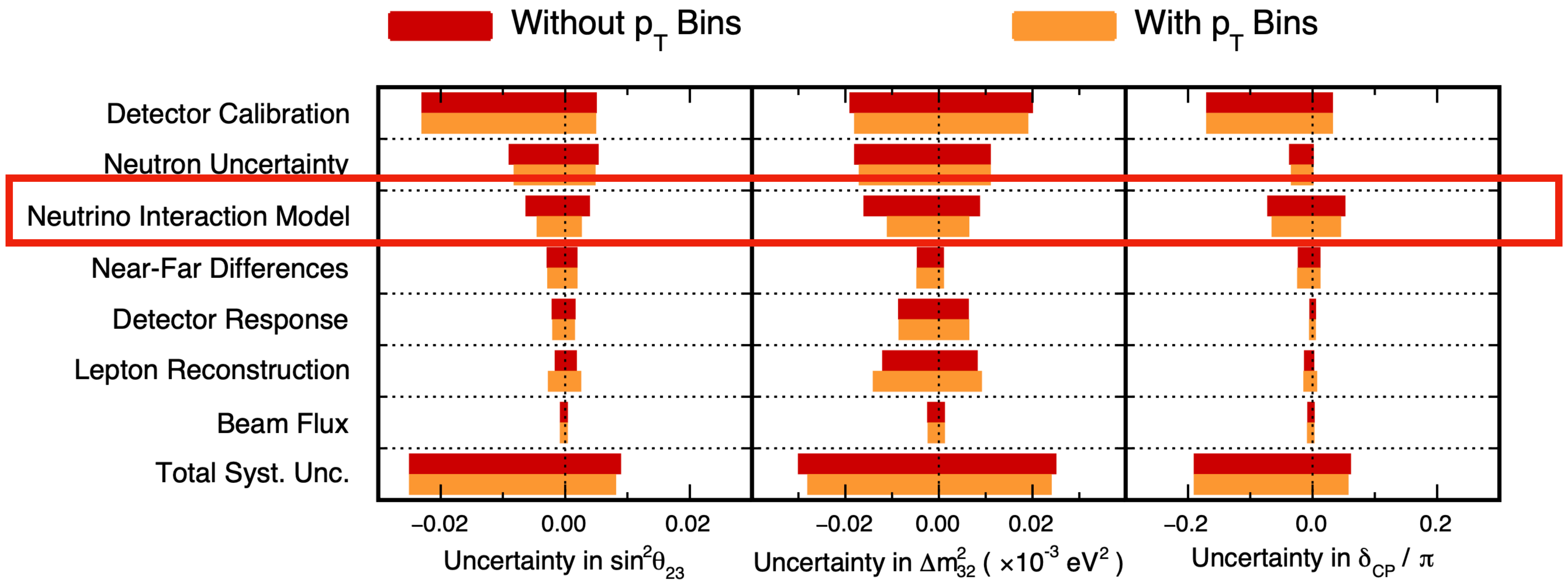


TABLE II. Uncertainties on the number of events in each SK sample broken down by error source after the near-detector analysis. The first two rows show the uncertainties when flux and crosssection systematics (constrained by the near detector) are propagated without correlation, whereas the third (Flux+Xsec) has smaller uncertainties due to the anticorrelations in the near-detector analysis, and corresponds to what is used in the analysis. "SK det." includes uncertainties from the SK detector response.

Error source (units: %)	$1R\mu$ ν-mode	$1R\mu$ $\bar{\nu}$-mode
Flux	2.9	2.8
Xsec (ND constrained)	3.1	3.0
Flux+Xsec (ND constr.)	2.1	2.3
SK-only Xsec	0.6	2.5
SK det.	2.1	1.9
Total	3.0	4.0

- Interaction uncertainties are the dominant source systematics for the LBL analyses

Why study cross-section

arXiv:2407.10962

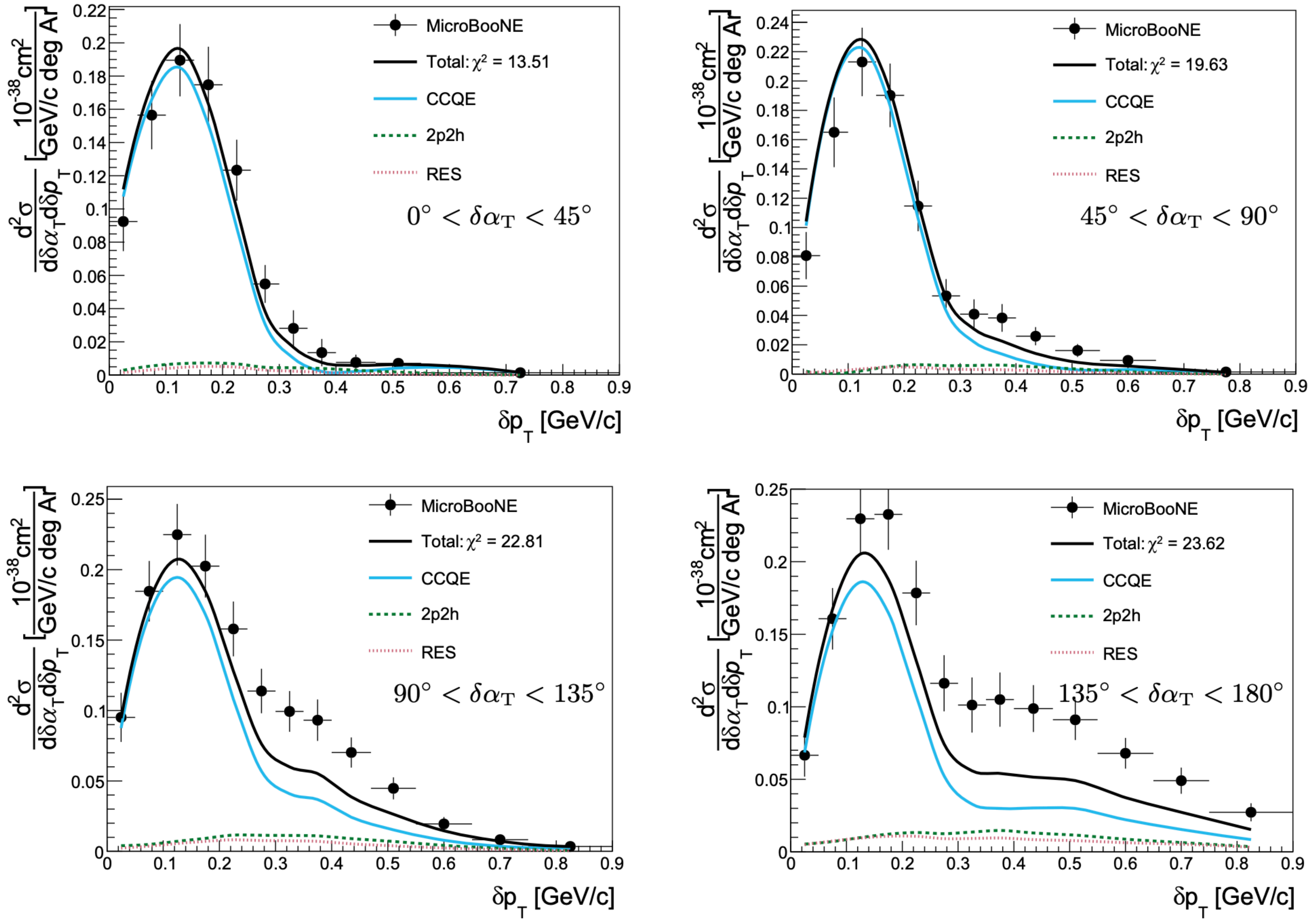
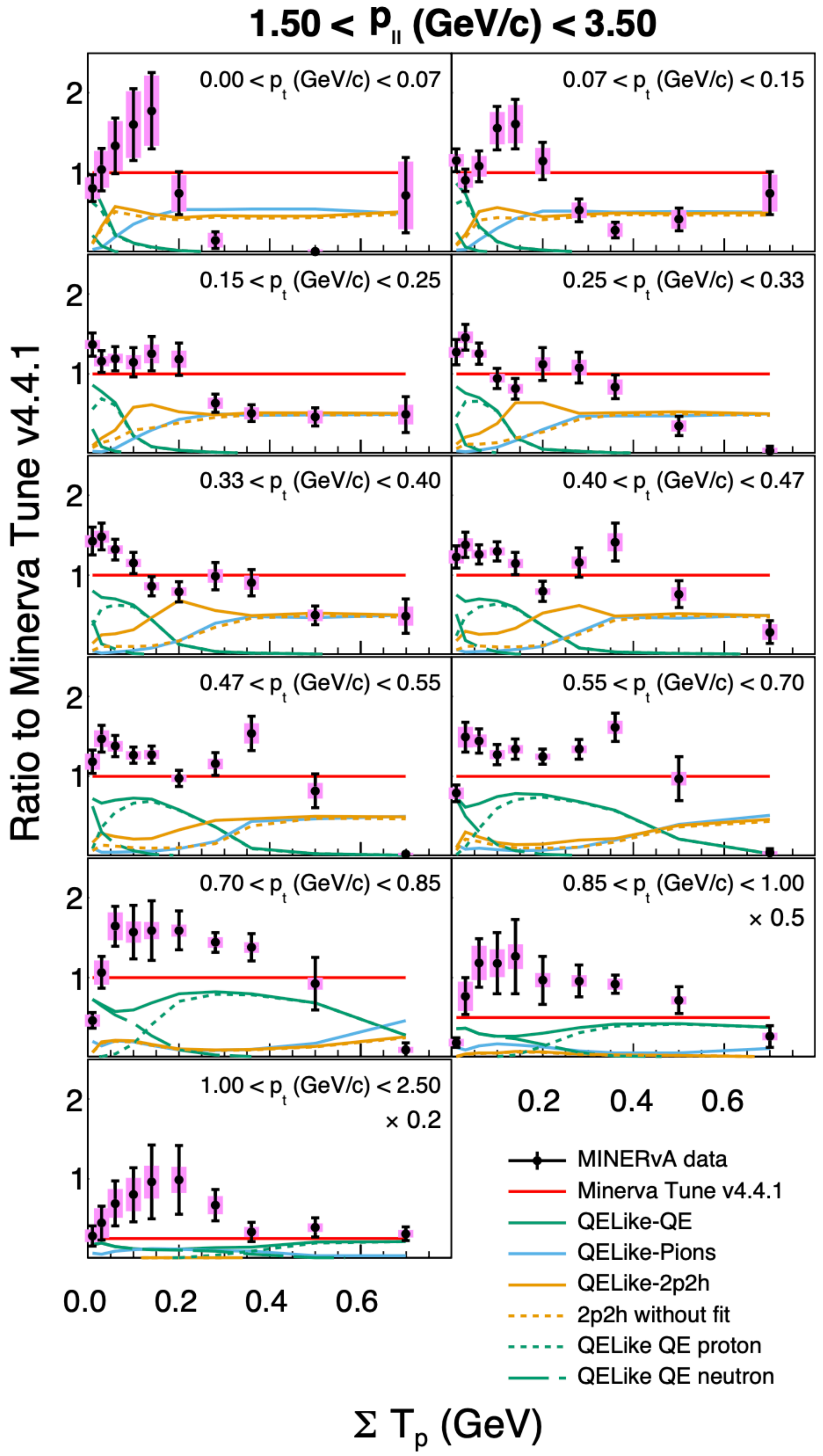


Fig. 4: Multi-differential cross-section as a function of δp_T and $\delta\alpha_T$ from MicroBooNE, compared with predictions using the combined SF* model. The figures showcase the breakdown by interaction mode into QE, 2p2h and resonant interactions (RES), spanning four regions of $\delta\alpha_T$.



arXiv:2203.08022
MINERvA triple-differential

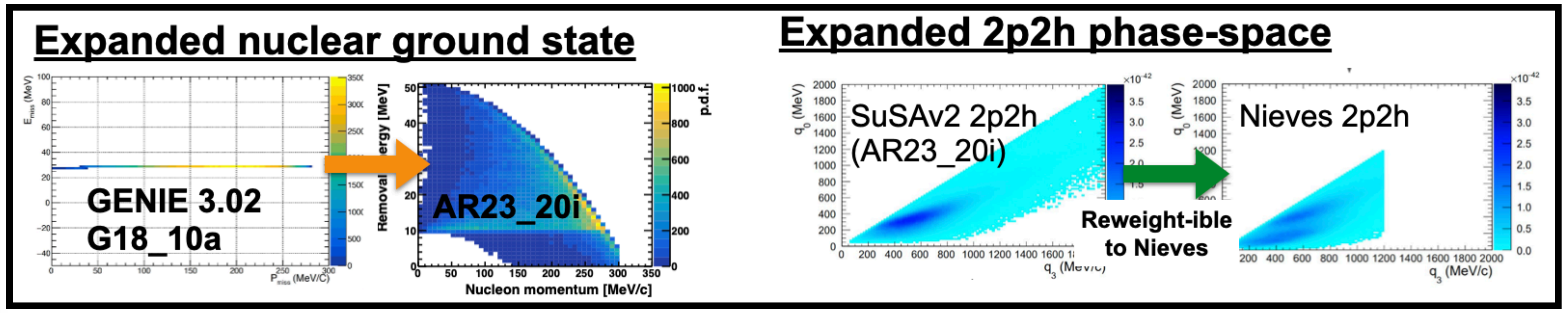
- Interaction uncertainties are the dominant source systematics for the LBL analyses
- Modeling neutrino-nucleus is not easy

Baseline model at DUNE

- GENIE is popularly used in neutrino event simulation
- DUNE developed a tune in GENIE: AR23_20i_00_000
  - Collection of model choices and sets of parameters in the event generation
  - Focus on ***reweight-ibility***: captures the model freedoms
  - The model has been adopted by the SBN experiments (ICARUS & SBND) and consideration by NOvA

- AR23_20i at glance..
  - Local Fermi Gas ground state + correlated high-momentum nucleon tail
  - Expansion of the phase space covered at generation time
  - Z-expansion form factor for CCQE interactions
  - SuSAv2 for 2p2h interactions
  - hA2018 for FSI modelling
  - Emission of de-excitation photons for Ar nuclei
  - Free nucleon tune from Phys.Rev.D 104 (2021) 7, 072009

Examples of "large phase space" for the flexibility



Suite of packages for studying cross-sections

NuSystematics / nusystematics

- We should be ready when ND is on!
  - Learn from on-going experiments on various neutrino spectra and targets
- A suite of neutrino cross-section data and dev. tools
  - NuSystematics
    - Provides a quick&easy framework for systematics development
    - Interfaced with external tools (e.g., fitter) and provides systematic reweights
    - Adopted by SBN and NOvA: Shared model and systematics by whole Fermilab neutrino community!
  - NUISANCE
    - Collection of neutrino x-sec measurements
    - Automated generator comparison
    - Developed systematics can be easily tested to measured cross-section data

You can plot this with NUISANCE!

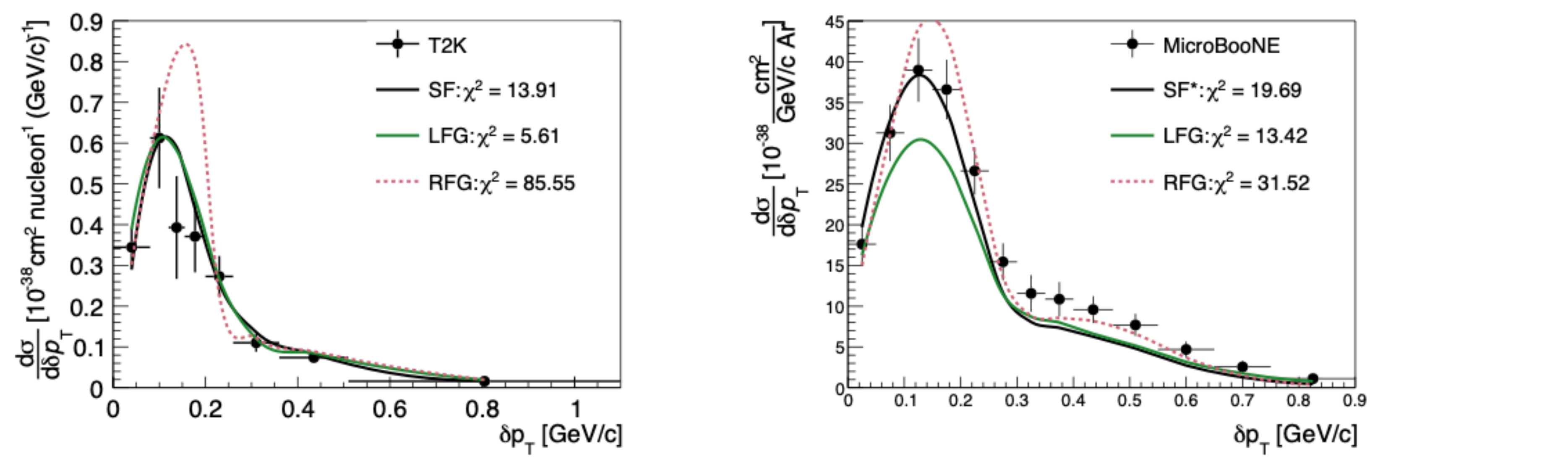


Fig. 5: Differential cross section as a function of δp_T using different nuclear model predictions compared with the measurements from T2K (left) and MicroBooNE (right). The different nuclear models are the NEUT SF, LFG and RFG models for T2K and the SF*, NEUT LFG and NEUT RFG models for MicroBooNE.

arXiv:2407.10962

Summary

- DUNE is a flagship long-baseline experiment
- LArTPC with outstanding tracking and calorimetry of final state particles
- Neutrino oscillation: from discovery to precision measurements
- .. and much more!
  - Solar, atmospheric and supernova neutrinos
  - Large volume, high intensity, long baseline provides fruitful physics beyond the standard model
- Current schedule of first FD operation at late 2029!

Thank you!


DUNE Collaboration meeting
at Fermilab, May 2025
ROBERT RATHBUN WILSON

Backup

DUNE Experiment: PRISM on-axis data

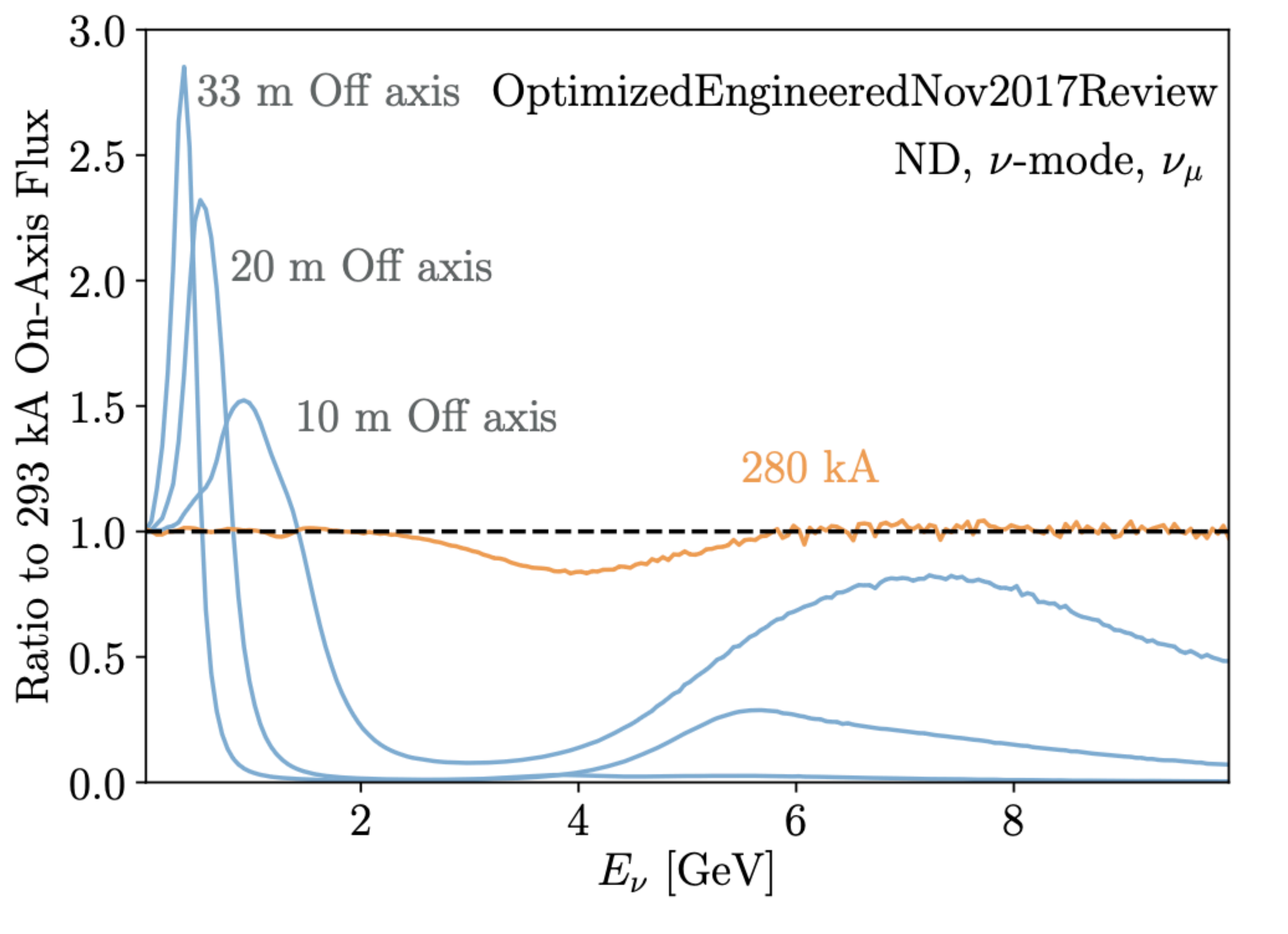
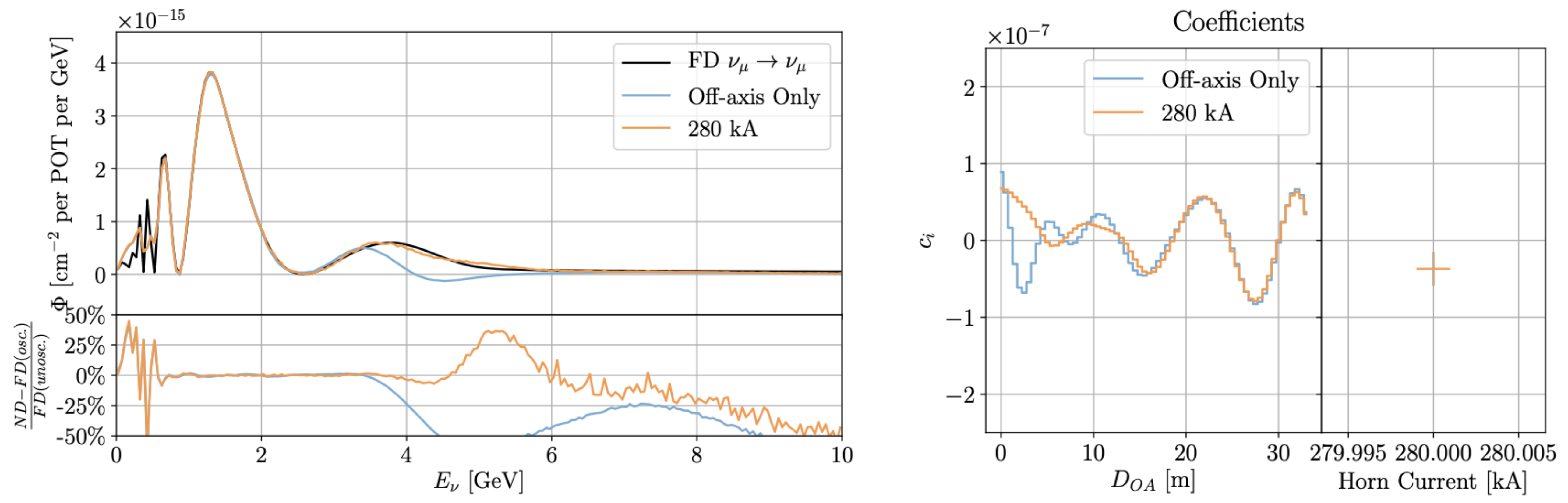


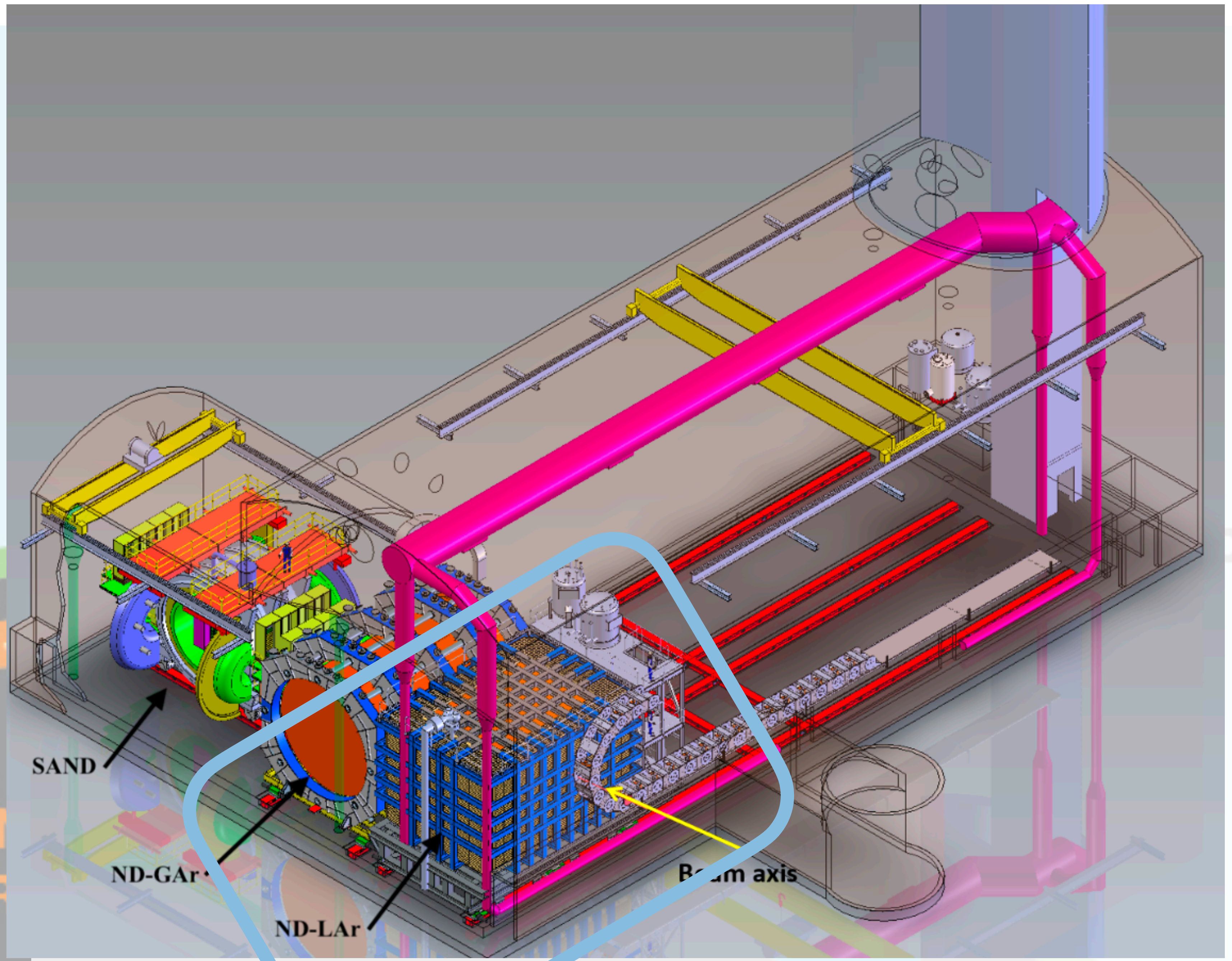
Figure 4.15: The ratio to the nominal on-axis flux is shown for three off-axis positions, and for on-axis running where the nominal 293 kA horn current has been lowered to 280 kA. The modified horn current provides an additional constraint just above the first oscillation maximum, with no effect at the lower energies sampled by the off-axis fluxes.



DUNE Experiment: Near detector

ND-LAr

- ~574m from the target
- ~60m underground
- 5×7 modules of pixelized LAr TPC
  - 12M 3×3mm² pixel ROs
- ~59M (20M) $\nu_\mu(\bar{\nu}_\mu)$-CC interactions per year in FHC (RHC)
- 450k (200k) $\nu_e + \bar{\nu}_e$-CC interactions per year in FHC (RHC)
- Capable of handling large pileup



Looking for something like this but official

DUNE Experiment: Near detector

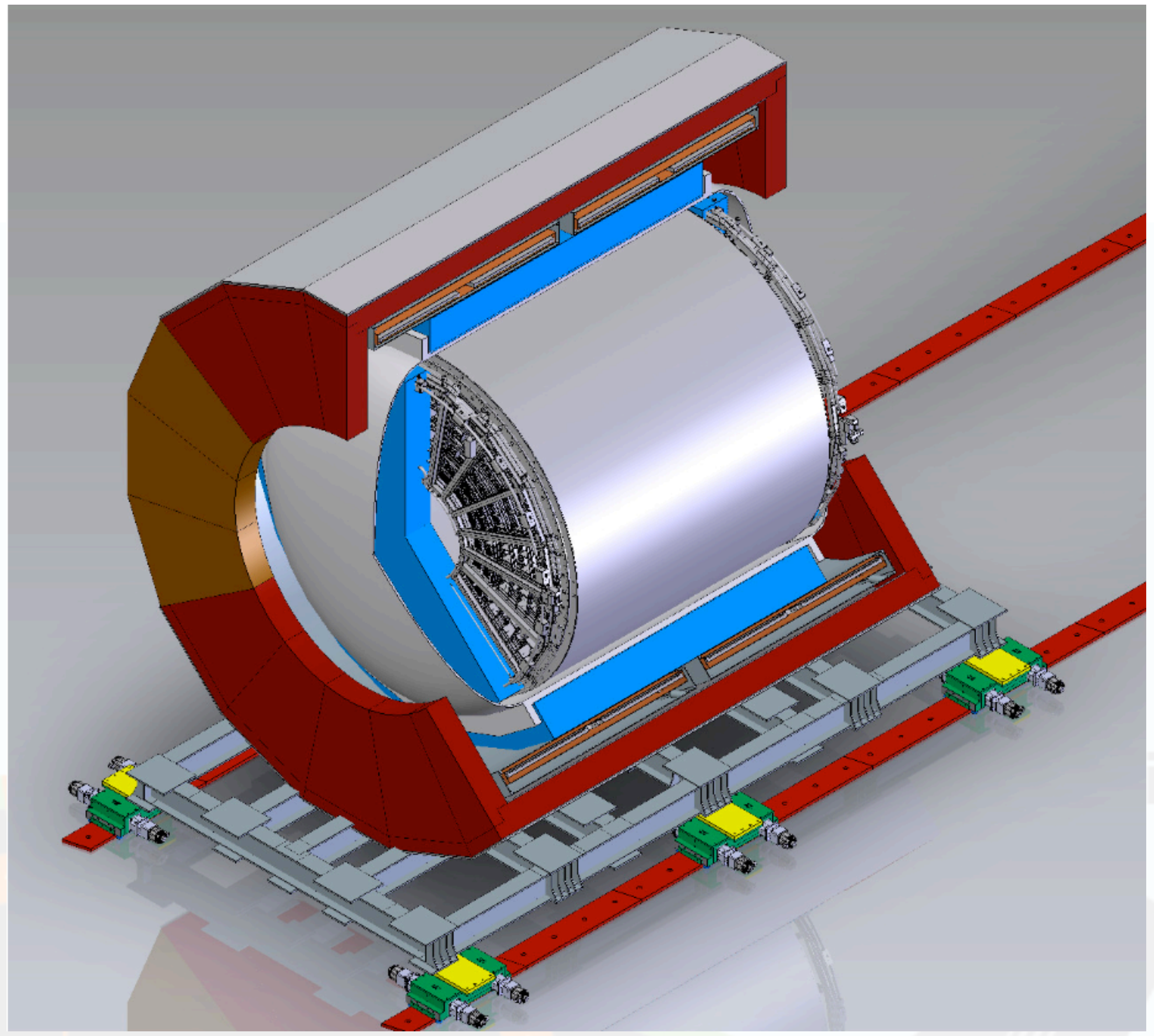
Muon Spectrometer

- Magnetized muon detector downstream of NDLAr
  - Particle multiplicity
  - TMS (NDGAr) in Phase-1(2)
    - Critical to ensure high acceptance

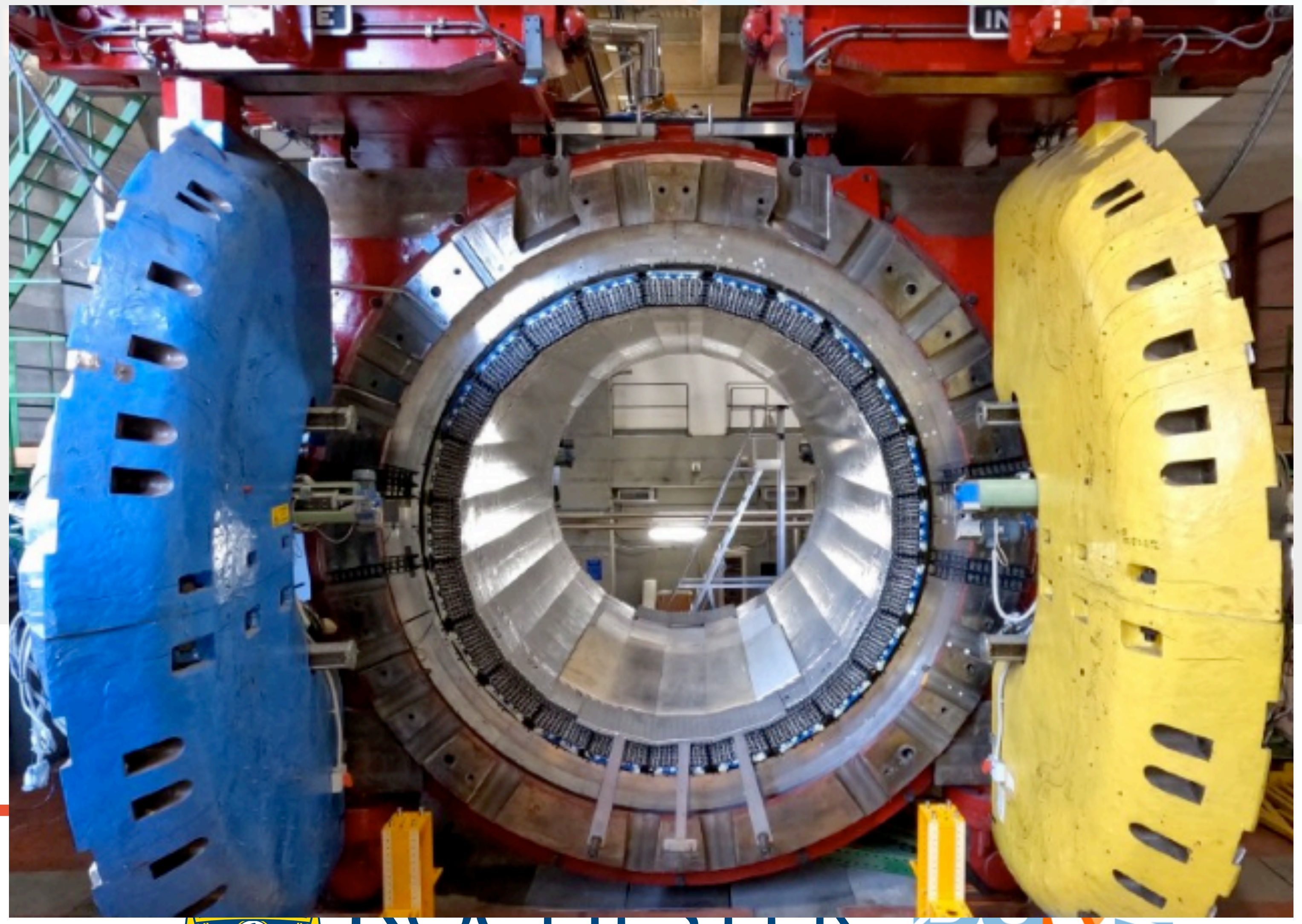
SAND

- On-axis beam monitor
- Re-purposed KLOE magnet&ECAL
- STT as inner tracker

Schematic of NDGAr



KLOE magnet and barrel ECAL



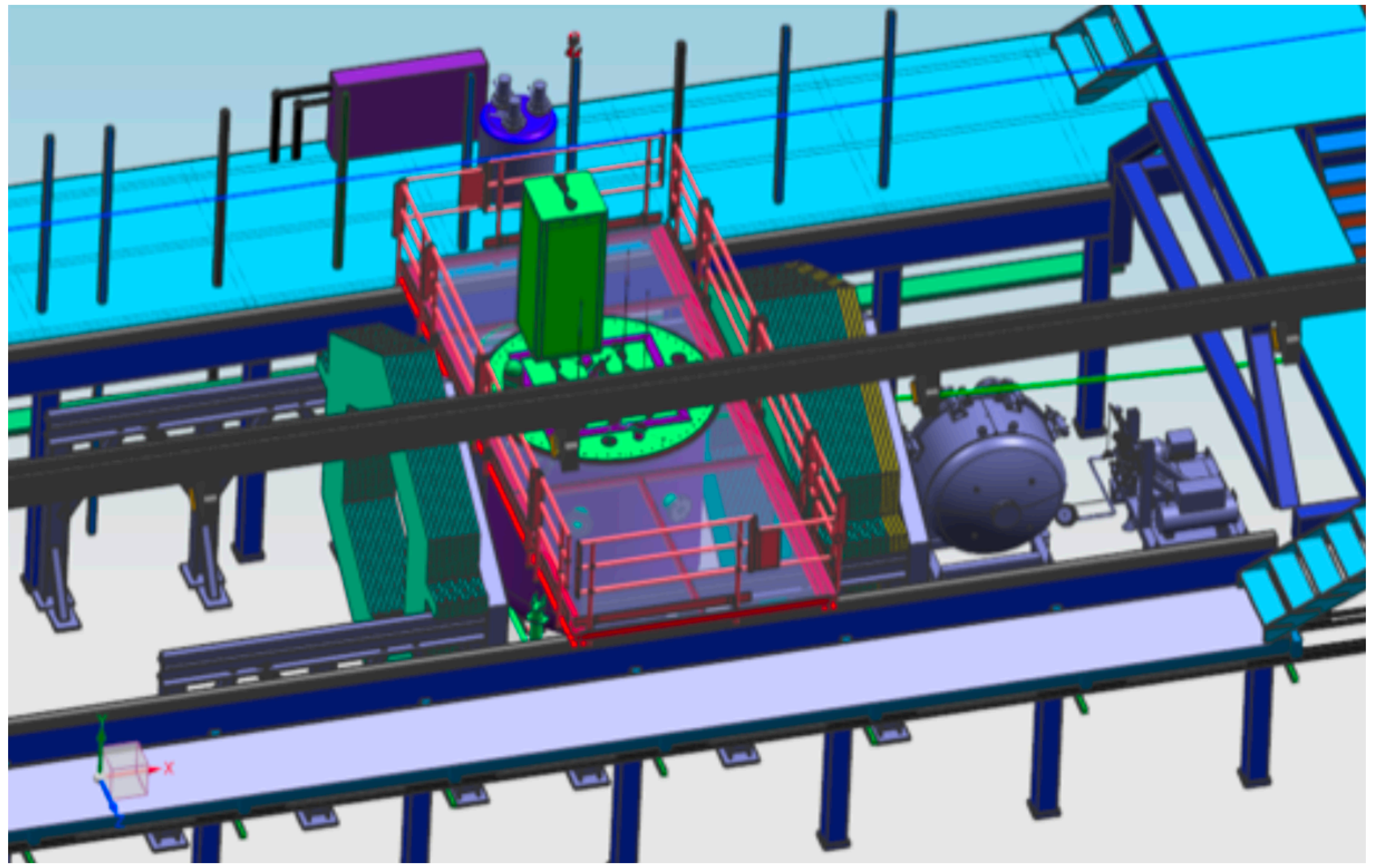
DUNE Experiment: Near detector; prototype

2x2 Demonstrator

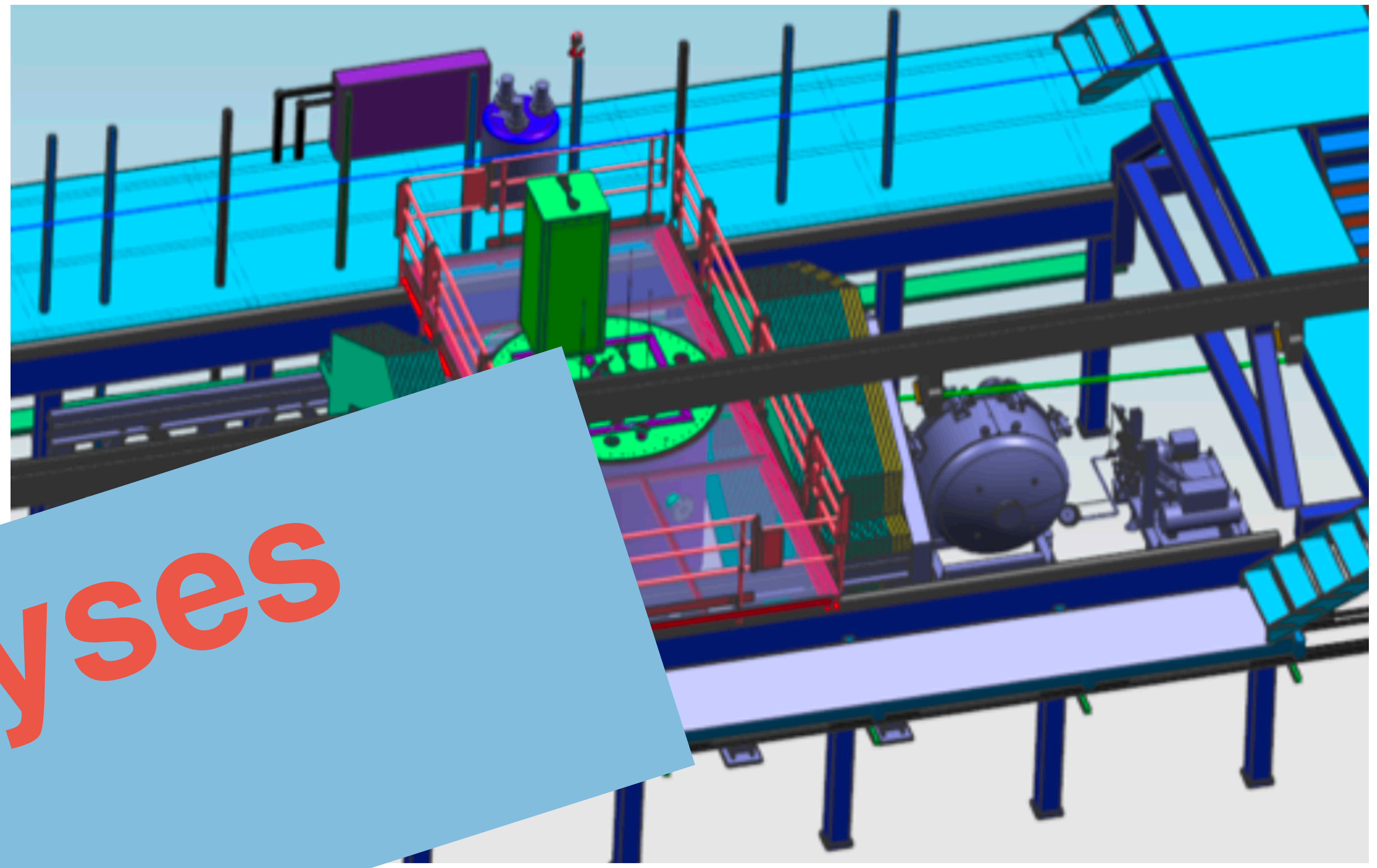
- @MINOS ND hall
- 2x2(=4) modules, ~60% size
- MINERvA scintillators repurposed
  - Matching to LArTPC for un-contained particles
- 4.5 days NuMI RHC data collected; 1.3×10^{19} POT, ~45k LAr interactions!

Full Scale Demonstrator

- @BERN
- Single equivalent size to the full NDLAr!
- ~3 days of cosmic data collected; ~75M cosmic interactions



DUNE Experiment: Near detector; prototype



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Full Scale Dem

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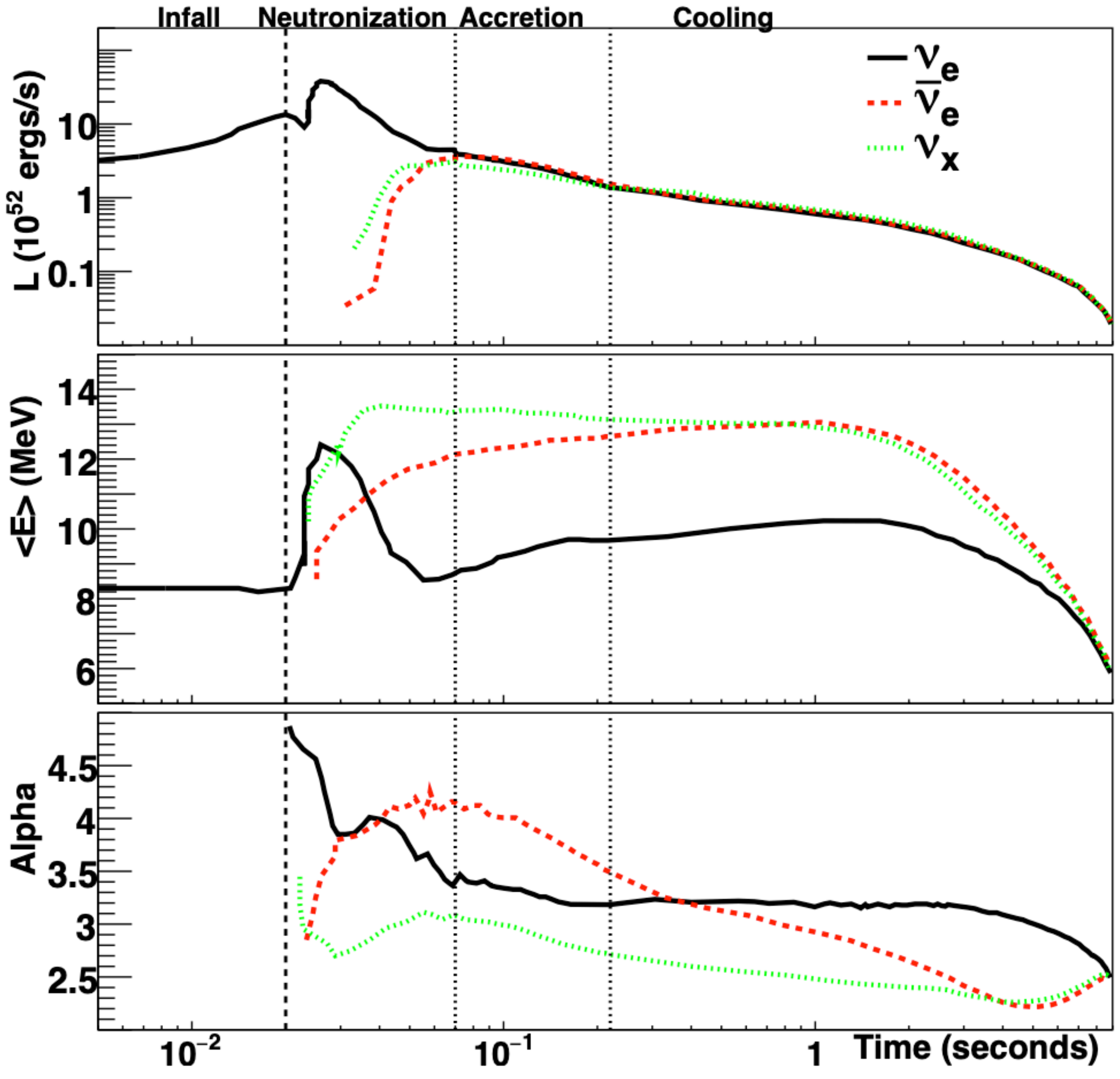
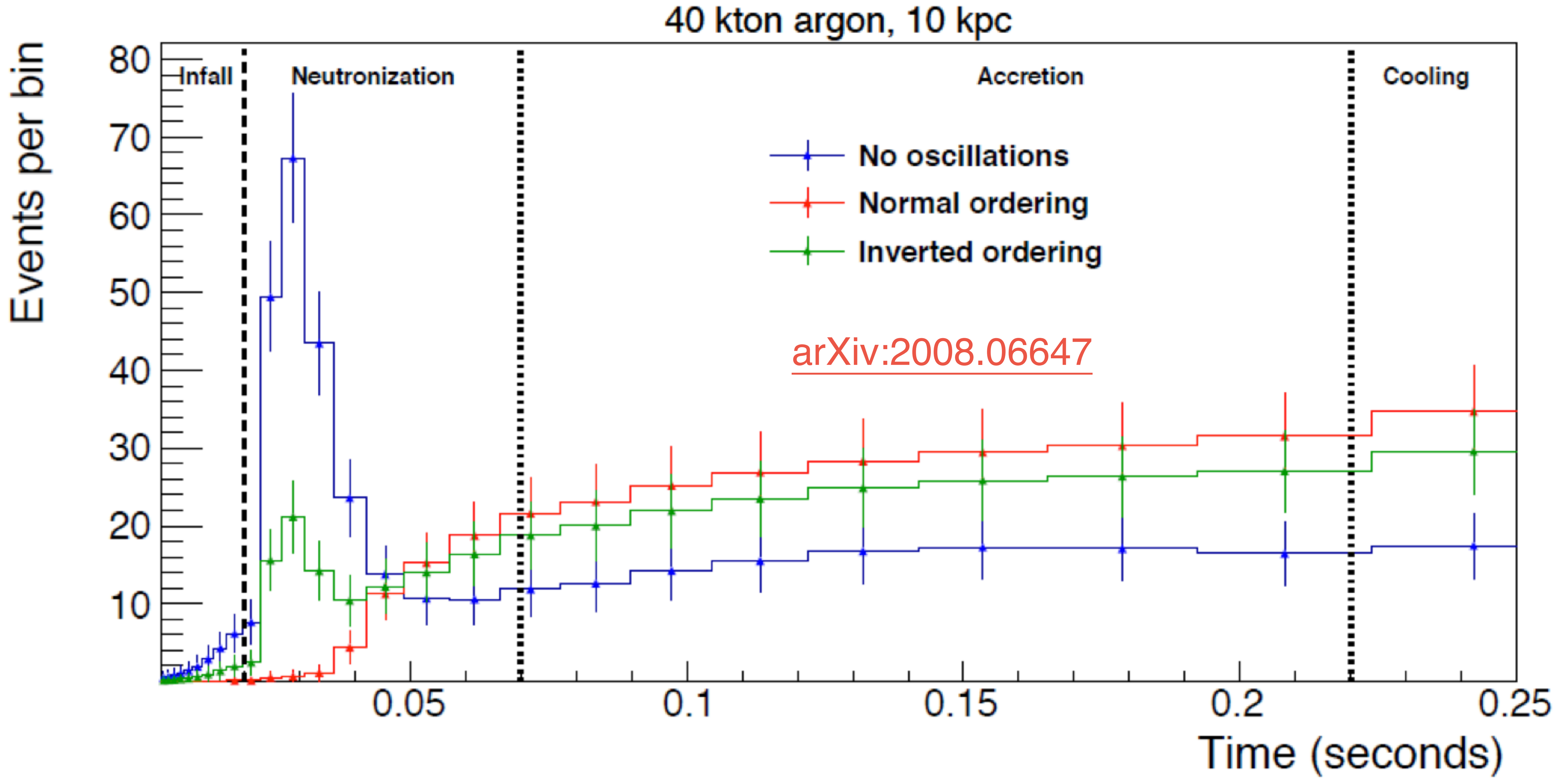
Actively data analyses on-going!

Physics overview: Supernova neutrino





- Core-collapse supernovae is expected within the few-decade long lifetime of the experiment
- Flavor, energy and time structure reveals supernova physics and the neutrino parameters

Physics overview: Supernova neutrino

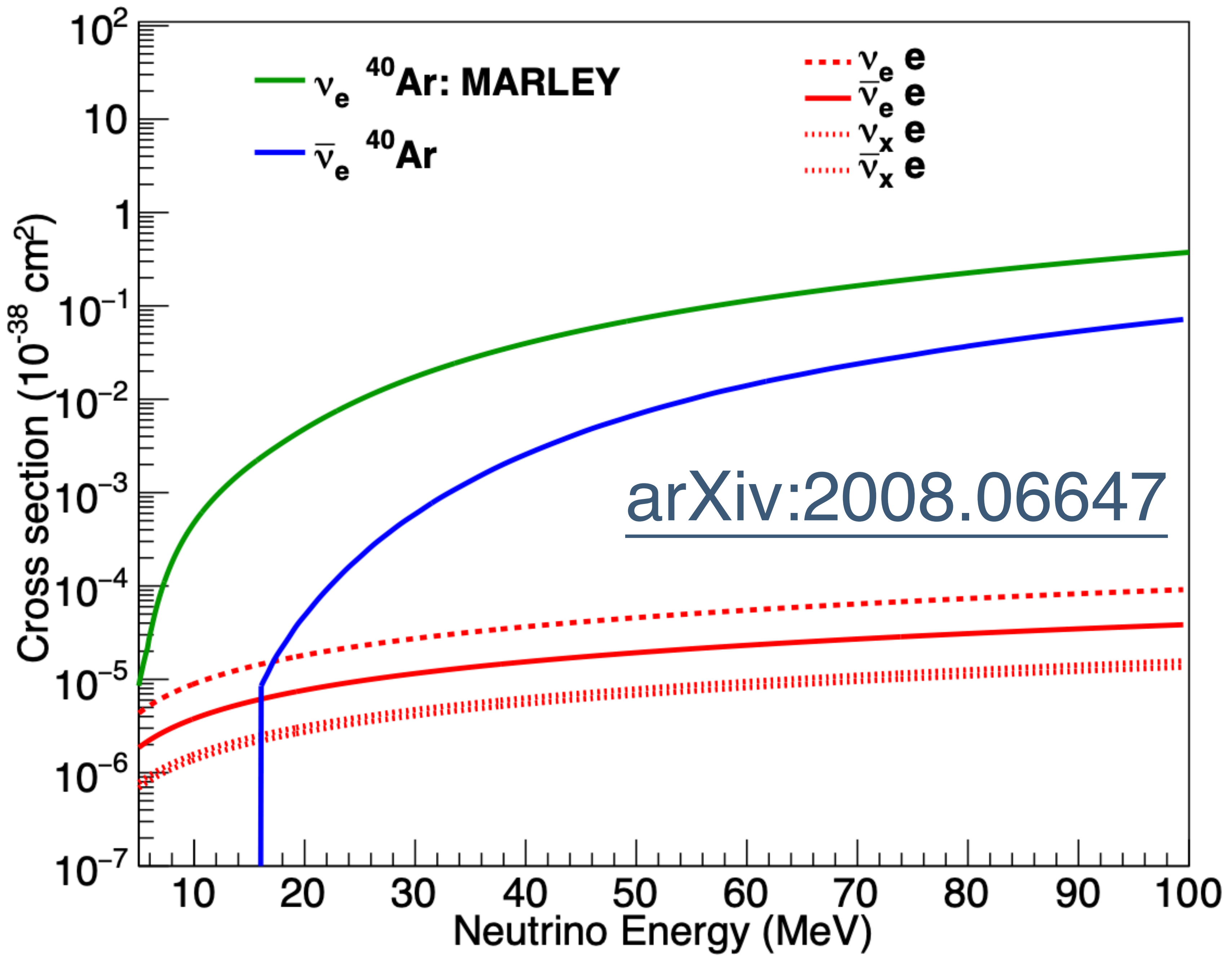


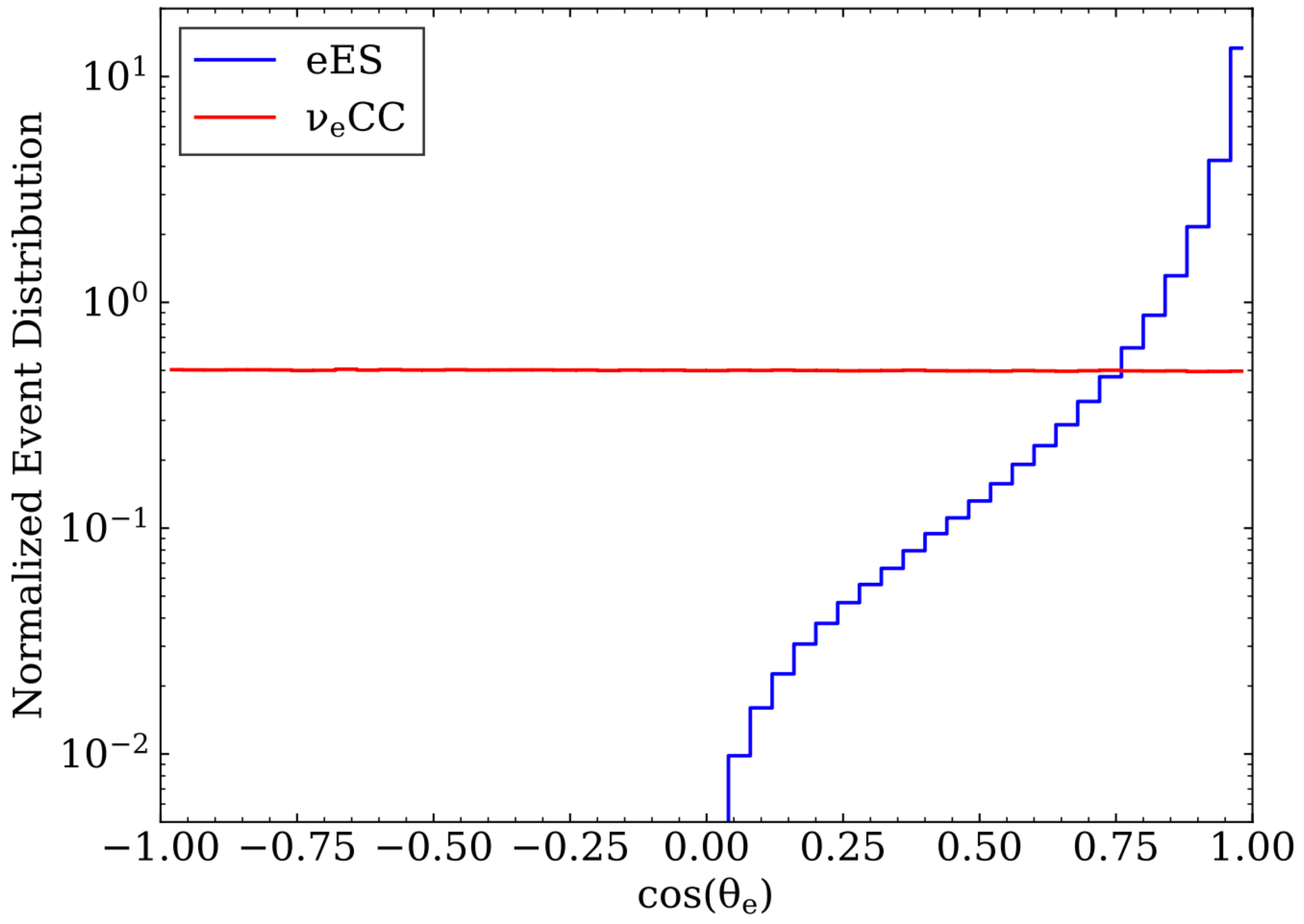
Fig. 3 Cross sections for supernova-relevant interactions in argon [6, 84] as a function of neutrino energy. The ν_e CC cross section shown in green (used for the studies here) is from MARLEY (see Sec. 5.2.1.) Inelastic NC cross sections have large uncertainties and are not shown.

$$\nu_e + {}^{40}Ar \rightarrow {}^{40}K^* + e^-$$

$$\bar{\nu}_e + {}^{40}Ar \rightarrow {}^{40}Cl^* + e^+$$

$$\bar{\nu}_{e,\mu,\tau} + e^- \rightarrow \bar{\nu}_{e,\mu,\tau} + e^-$$

Physics overview: Supernova neutrino



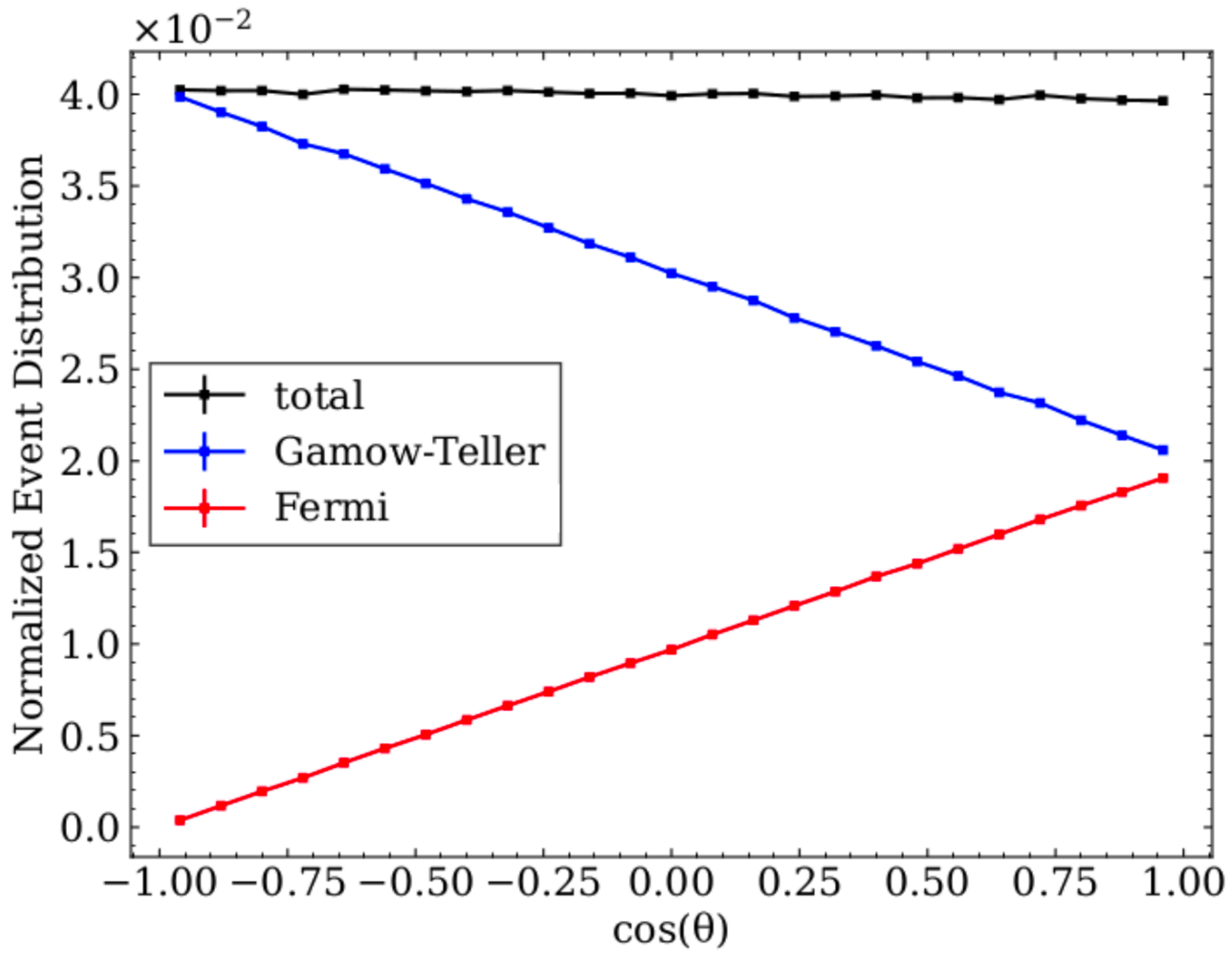
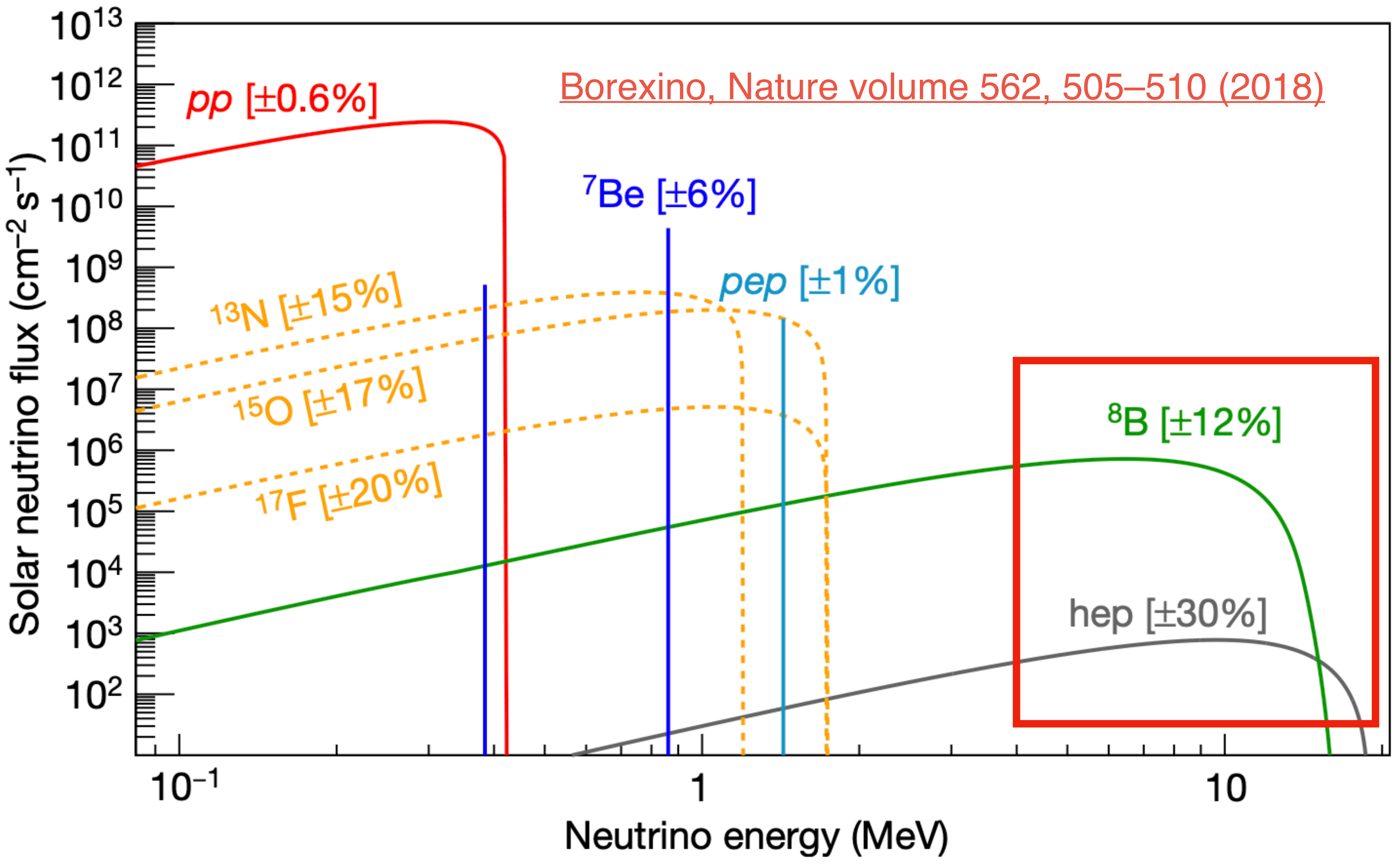
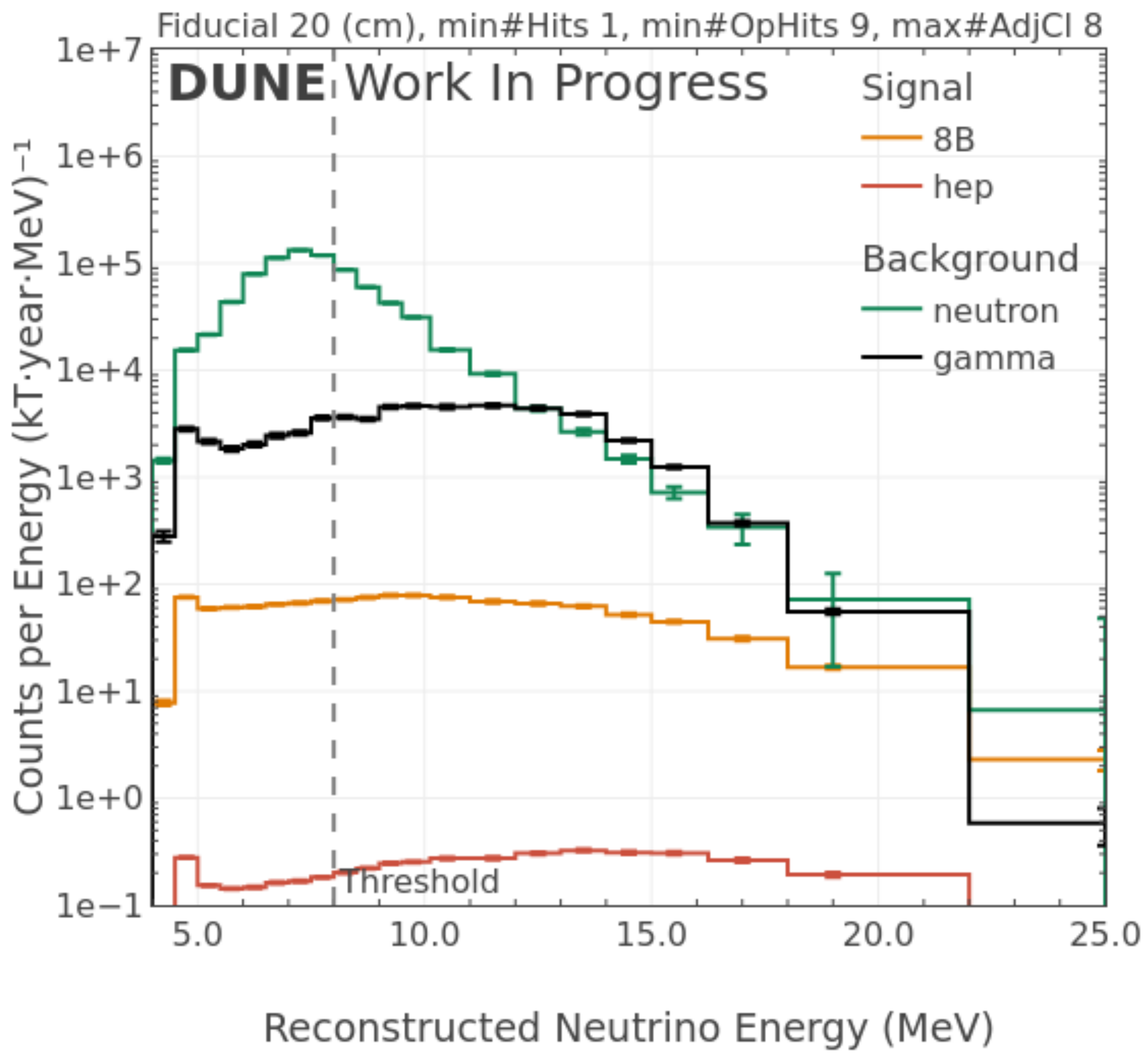


FIG. 3. The contribution of Fermi and Gamow-Teller transitions to the angular distribution for ν_eCC events, generated from MARLEY for the GVKM flux model. For this model's neutrino spectrum, the angular correlation cancels out to a good approximation.

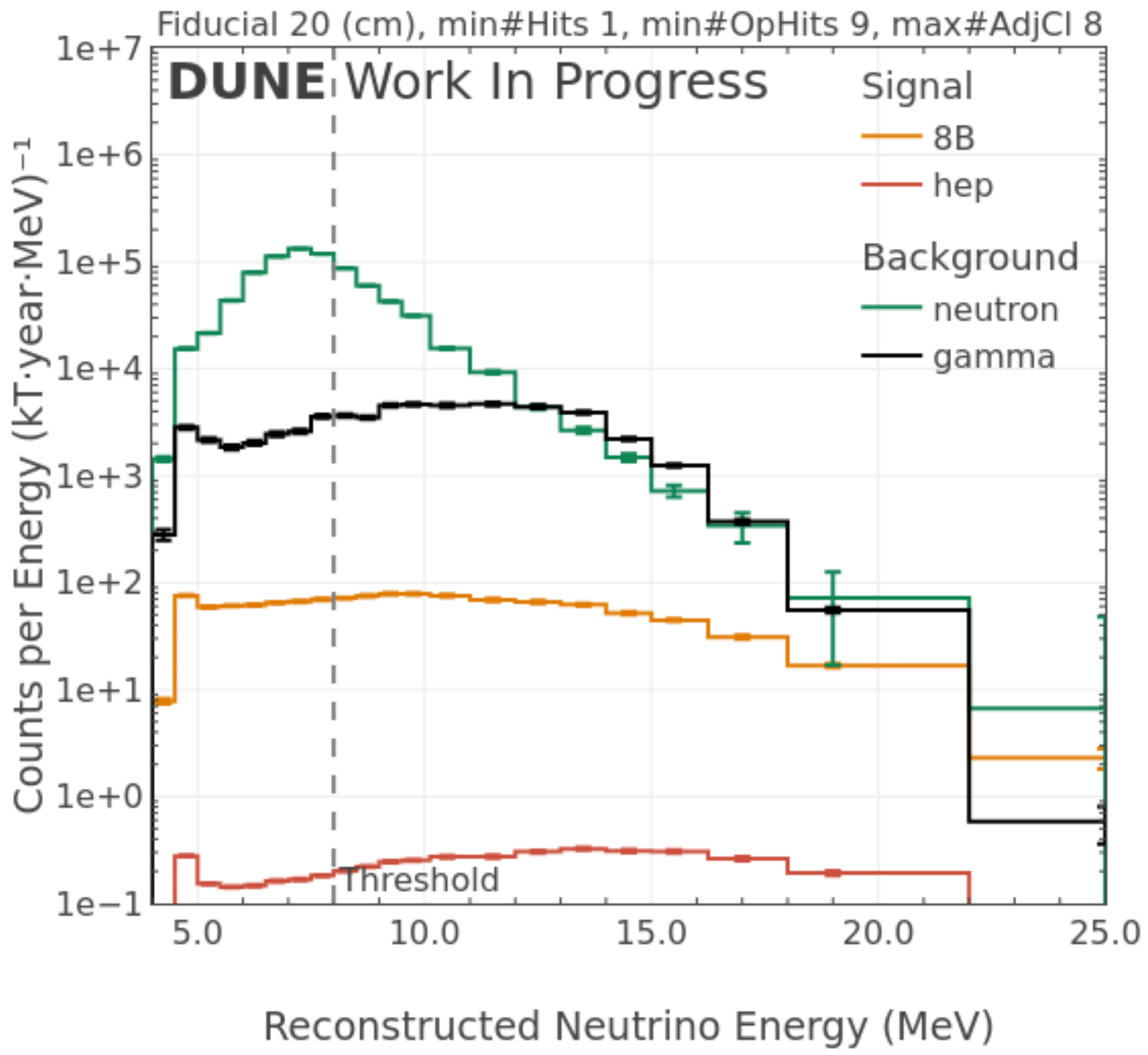
Physics overview: Solar neutrino

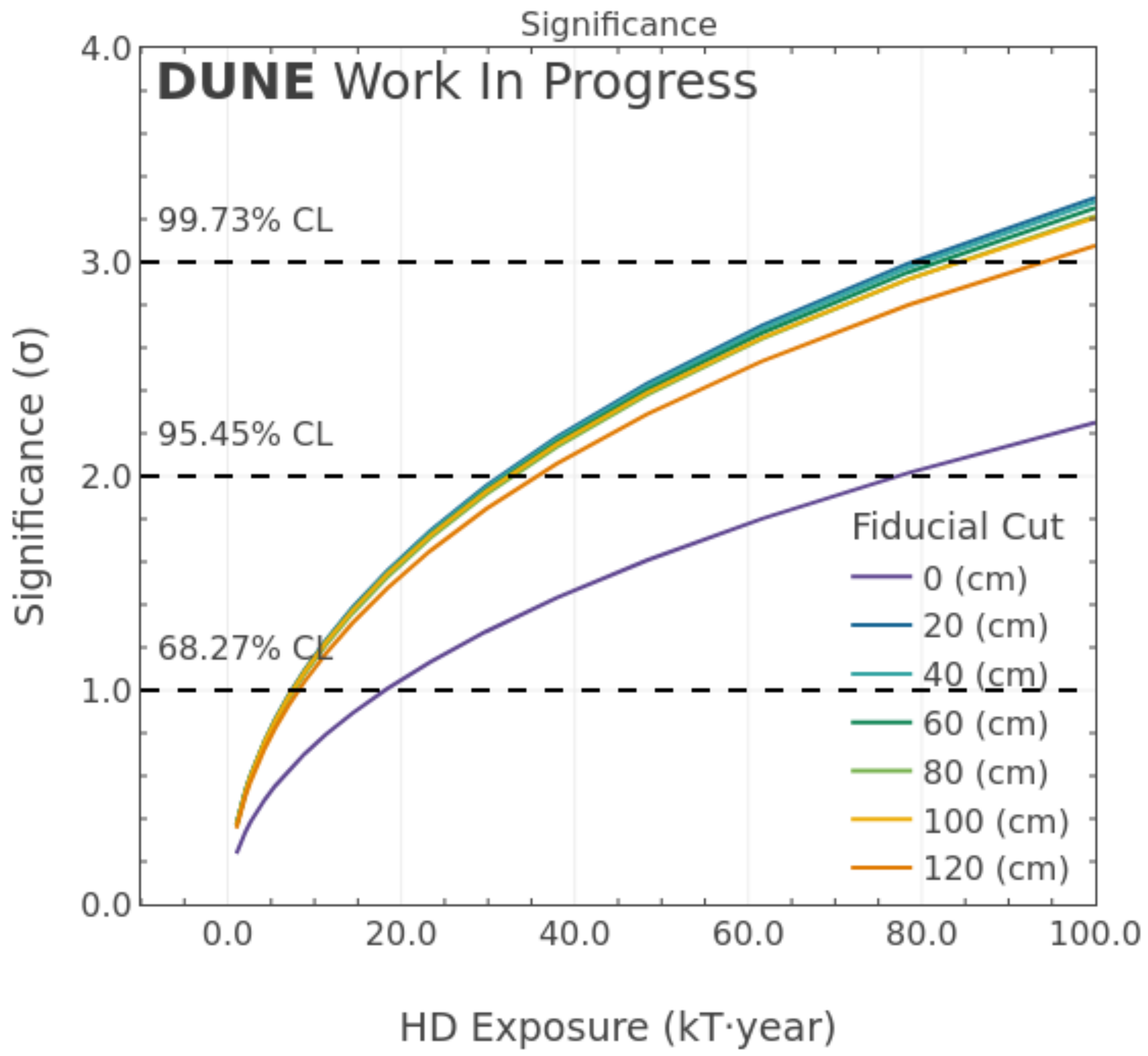


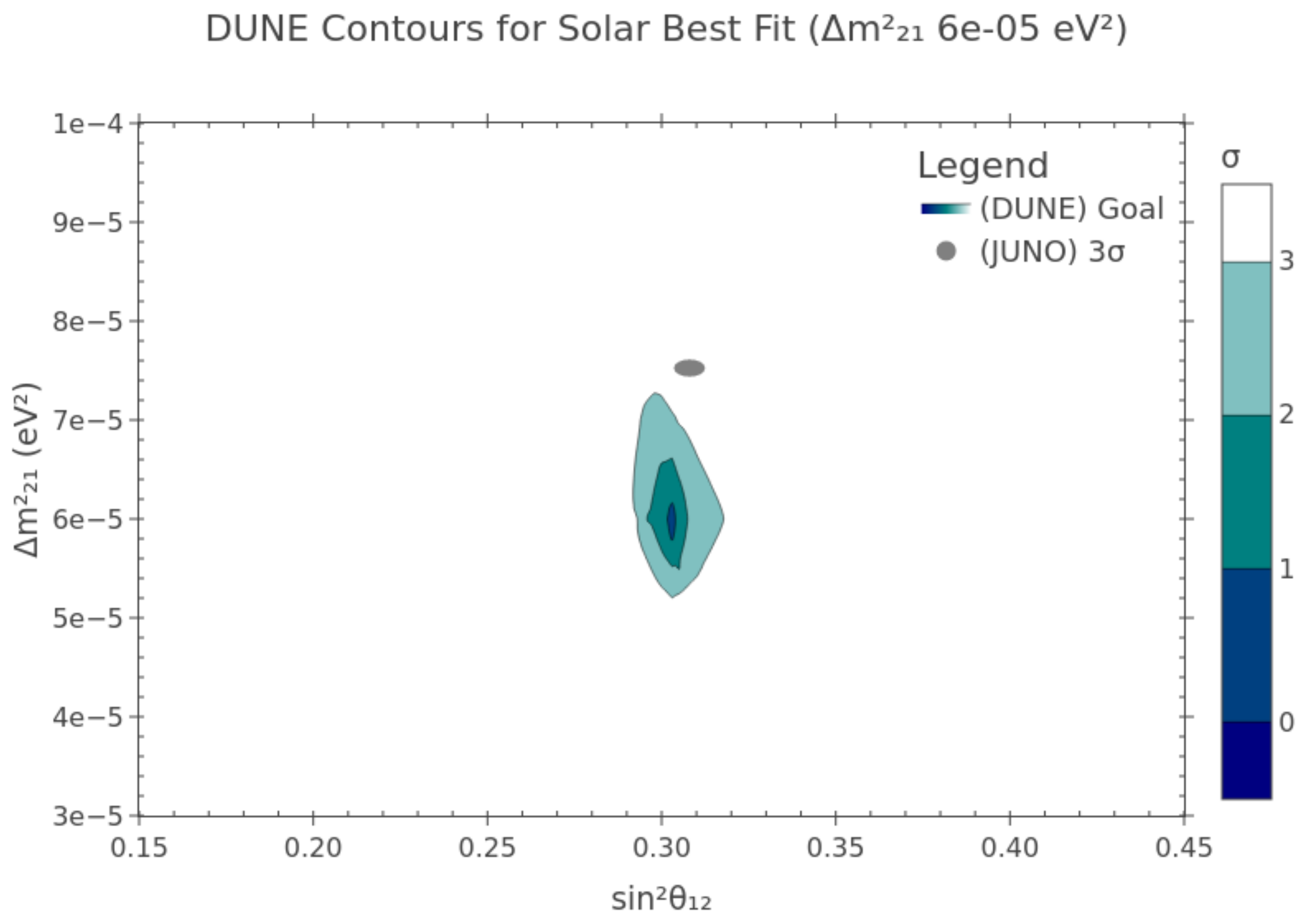


- ^{8}B and ***Hep*** neutrinos can be measured at the DUNE FD; one of the earliest measurements!
- Day-Night asymmetry through matter effects

Physics overview: Solar neutrino







- ^{8}B and ***Hep*** neutrinos can be measured at the DUNE FD; one of the earliest measurements!
- Day-Night asymmetry: solar neutrino parameters

J.Phys.Conf.Ser. 1342 (2020) 1, 012052

Physics overview: Atmospheric neutrino

Phys. Rev. X 13, 041055 (2023)

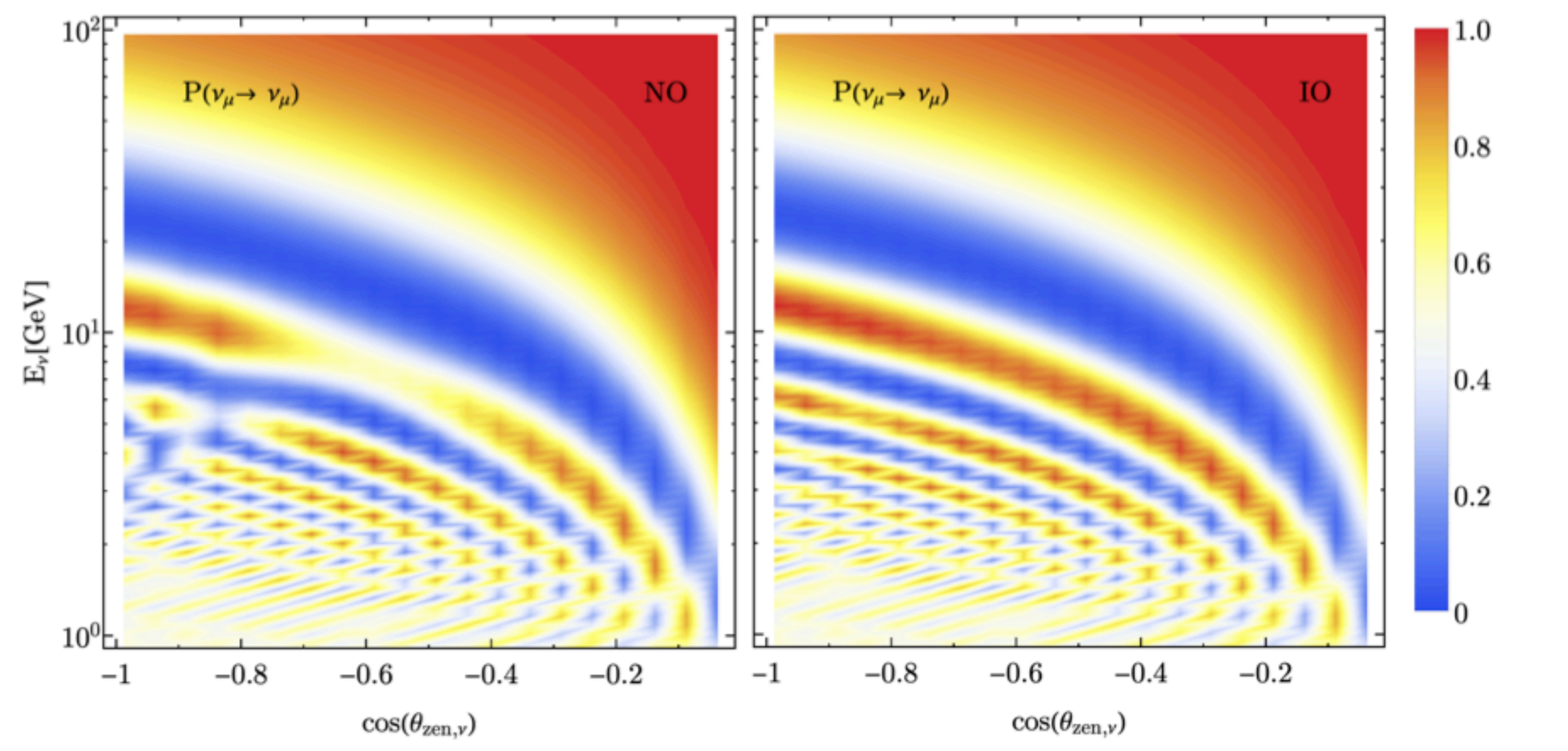


FIG. 8. **Muon-disappearance probability**. For energies above 1 GeV and all the trajectories crossing the Earth ($-1 < cos(\theta_{zen}) < 0.$), we have computed $P(\nu_\mu \to \nu_\mu)$ for normal (left) and inverted (right) mass ordering. We have considered the PREM for the Earth matter distribution.

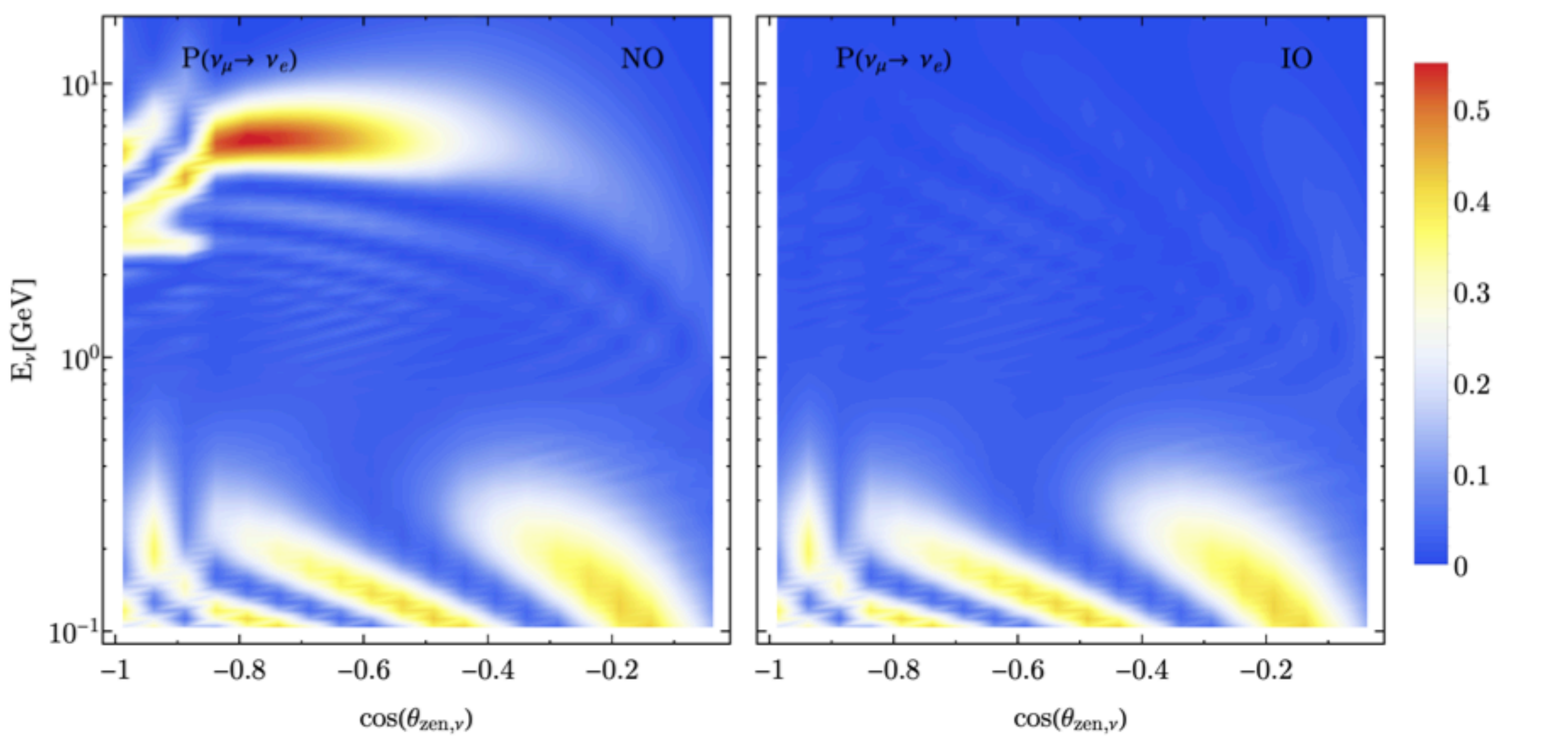
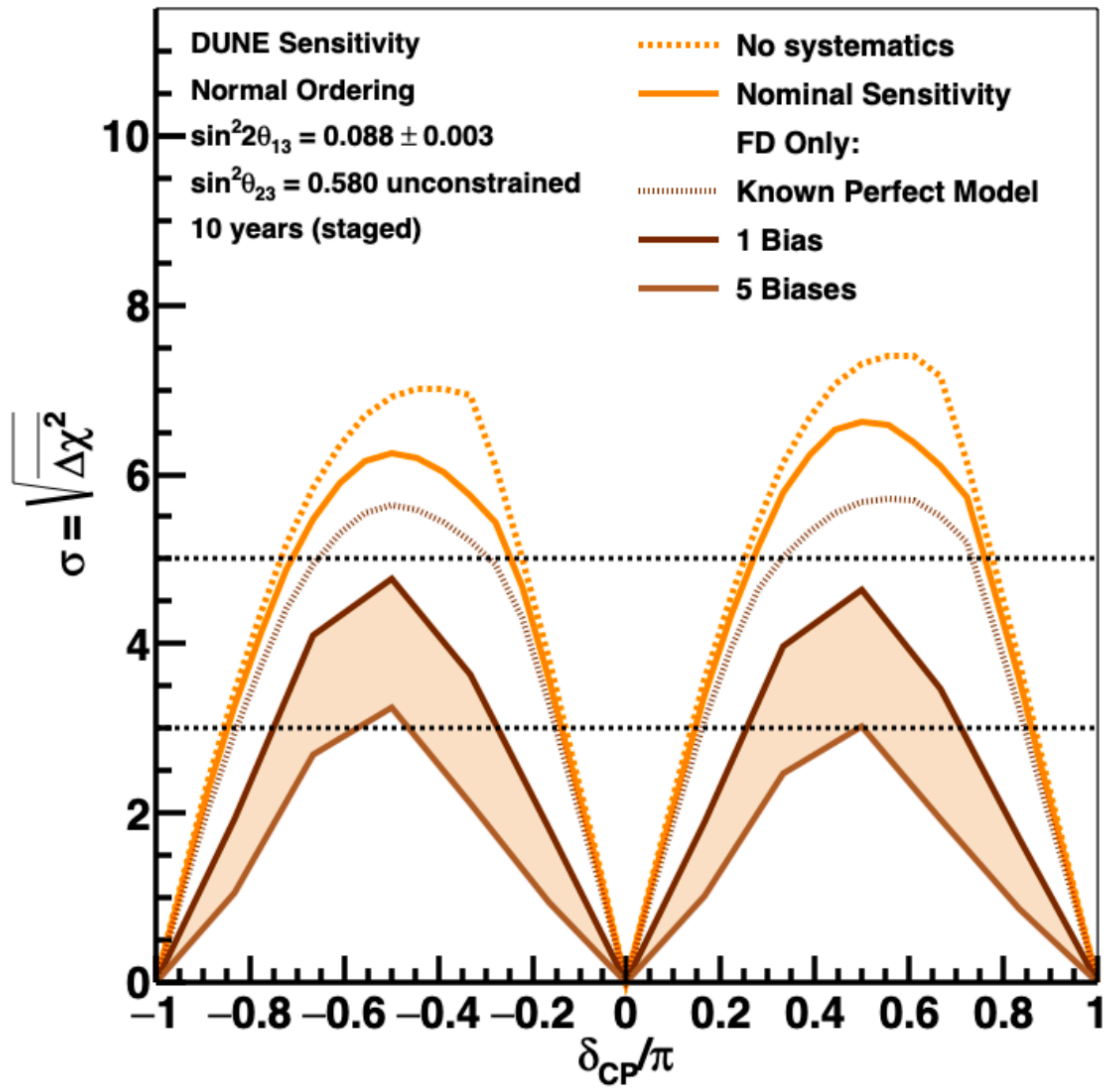


FIG. 9. **Electron-appearance probability**. Similar to Figure 8, we have computed $P(\nu_\mu \to \nu_e)$ for both mass orderings, normal (left) and inverted (right). In this case, we have considered neutrinos with energies between 0.1 GeV and 15 GeV.

Atmospheric oscillation probabilities

J.Phys.Conf.Ser. 1342 (2020) 1, 012052

Neutrino-nucleus cross-section at DUNE



Impact of incorrect x-sec model to the δ_{CP} sensitivity

Table of DUNE systematics uncertainty plans

A menu of NIUWG/DIRT2 systematic uncertainties

- Many in development

Ground state
Removal energy shape
SRC "tail" strength
Shell-like shape

CCQE
Z-exp FF (3-4 params)
RPA (5 params)
Optical potential (5 params)

2p2h
Normalisation
SuSAv2 to Valencia
Pair content
Energy dependence
Delta vs not delta
NN decay angle

Resonant pion production
MA, Mv, Norm
Pauli blocking
RPA + Opt Pot (TBD)
W shape
$\pi^{+/-}$ vs π^0 fraction tweaks
Resonance decay kinematics
Resonance broadening

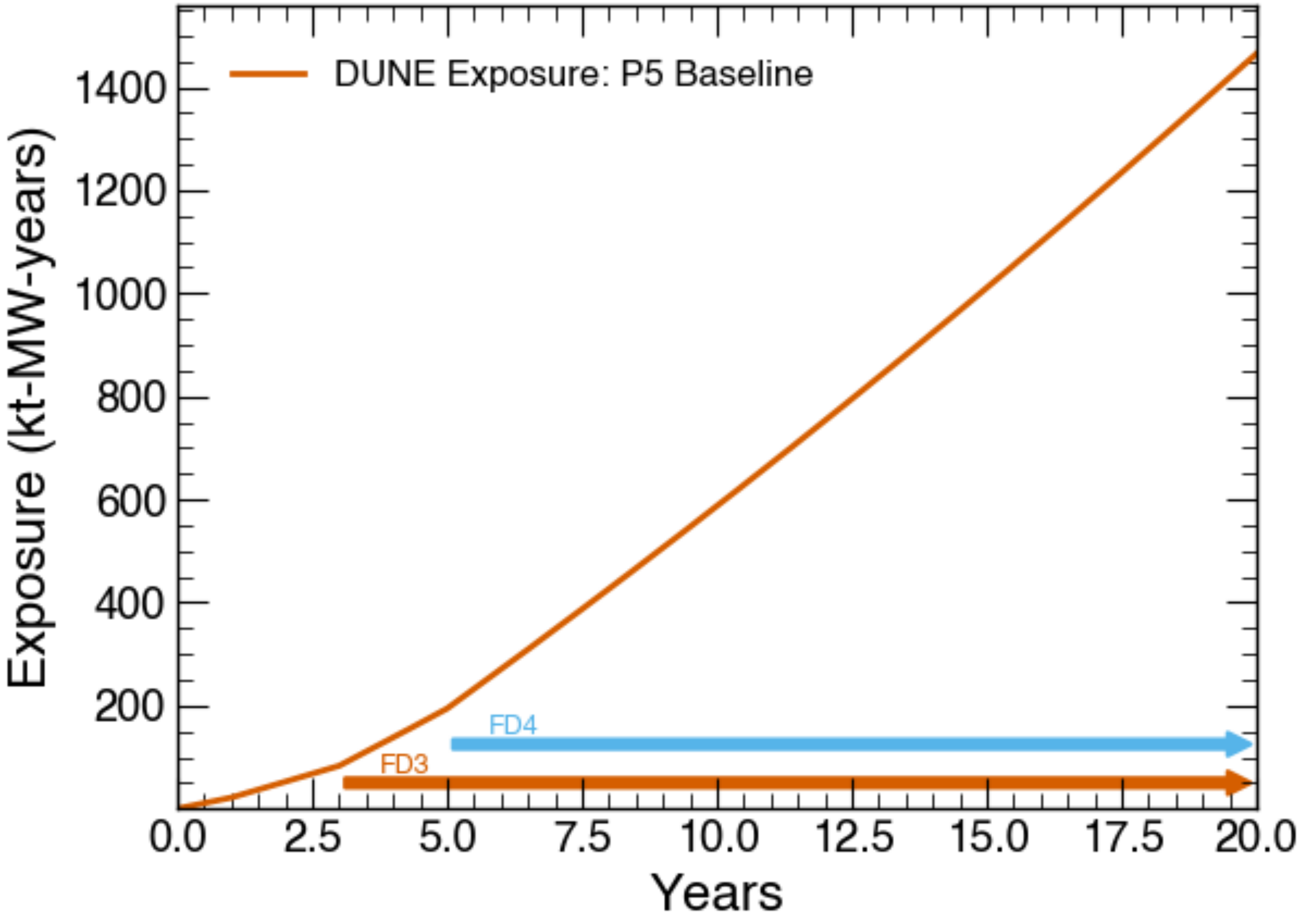
SIS/DIS
Transition region strength
AGKY dials
Bodek-Yang parameters
Non-RES low W contrib.
Multiplicity modifications
Alternative model (AMU)

FSI
hA pion fate dials
hA nucleon fate dials
π abs. pair fractions
hA to hN, INCL, G4BC

Misc
NC norms
Coh shape+norm
nue/numu ratio
nue/nuebar ratio
Ad-hoc neutron ejection

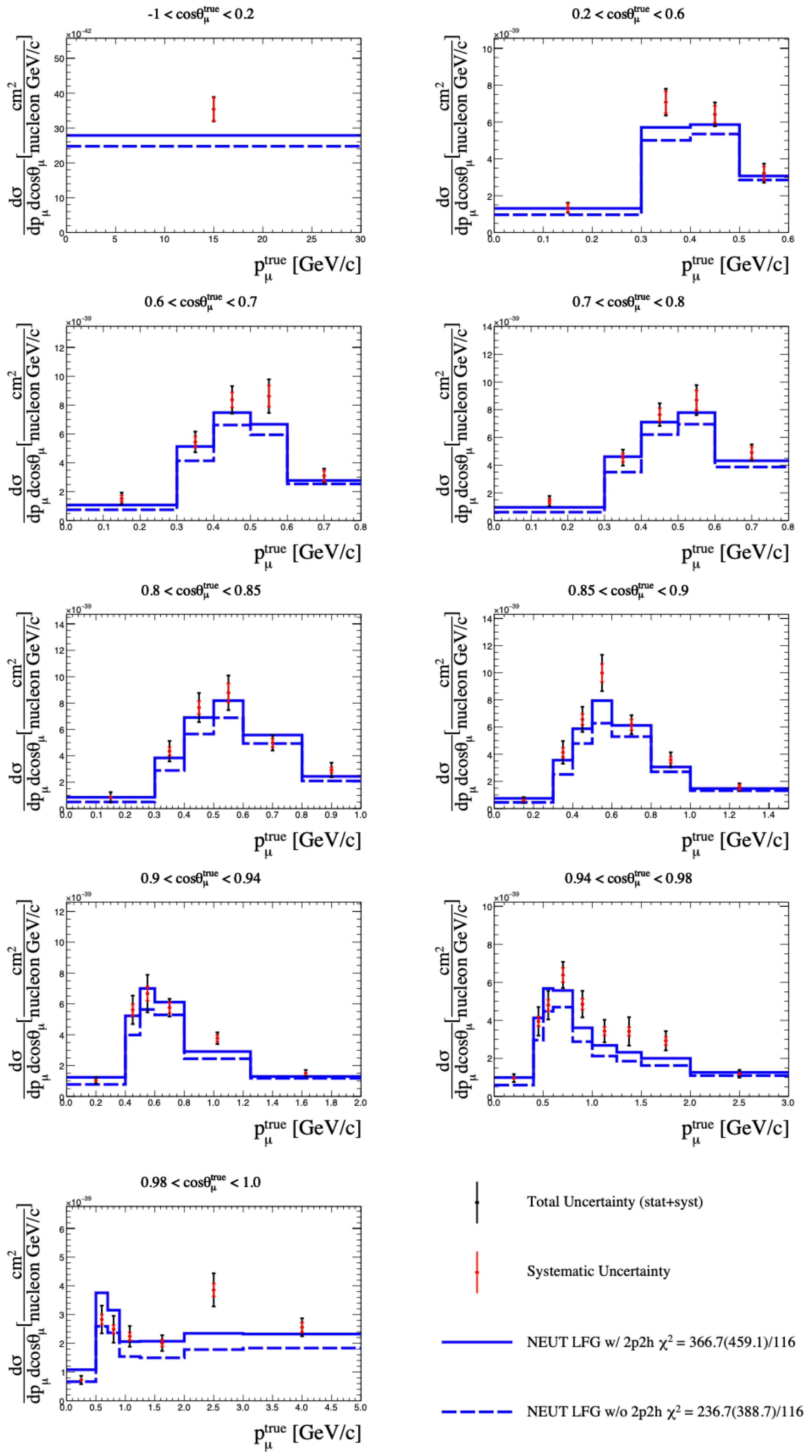
15.08.2024 Laura Munteanu - CEWG Seminar 35

DUNE Exposure



However, this schedule is now technically limited

T2K QE-like x-sec



Phys. Rev. D 101, 112001 (2020)