The DUNE experiment

PANIC 2021

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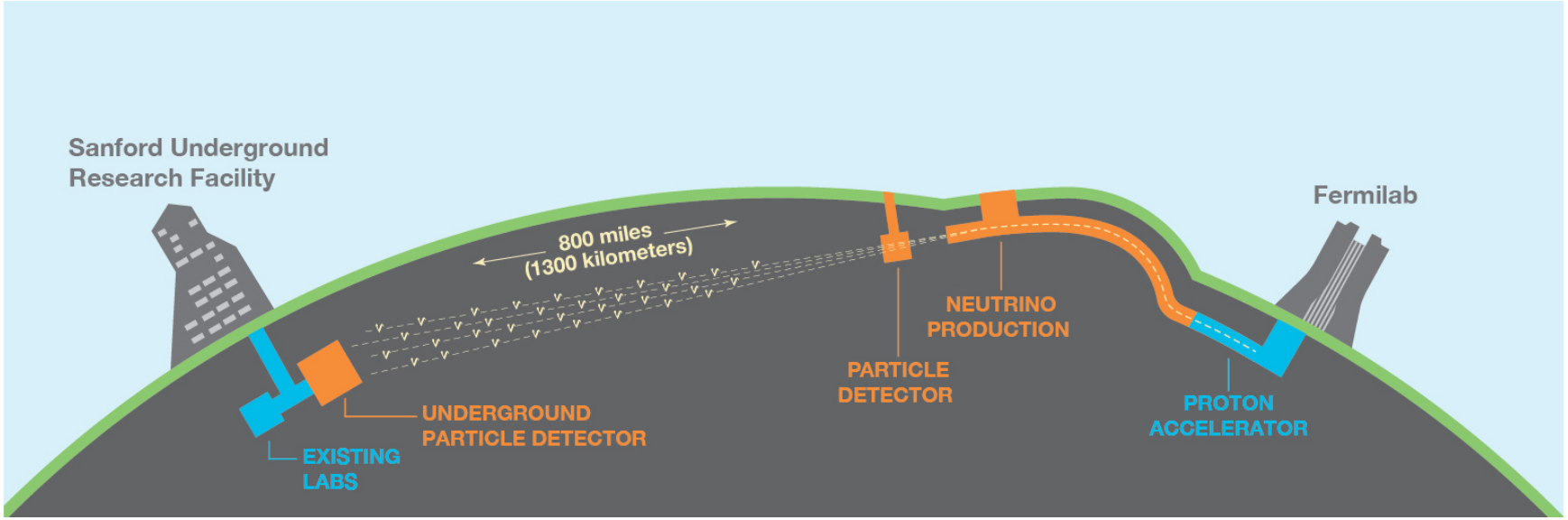
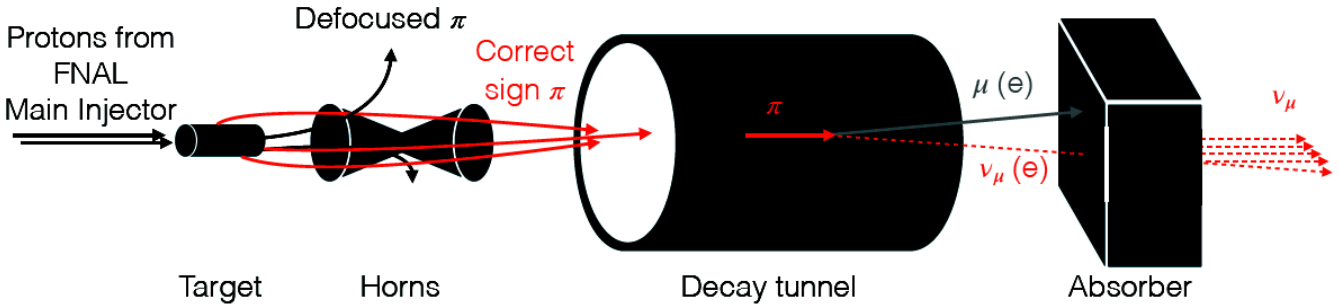
BERKELEY LAB

DUNE

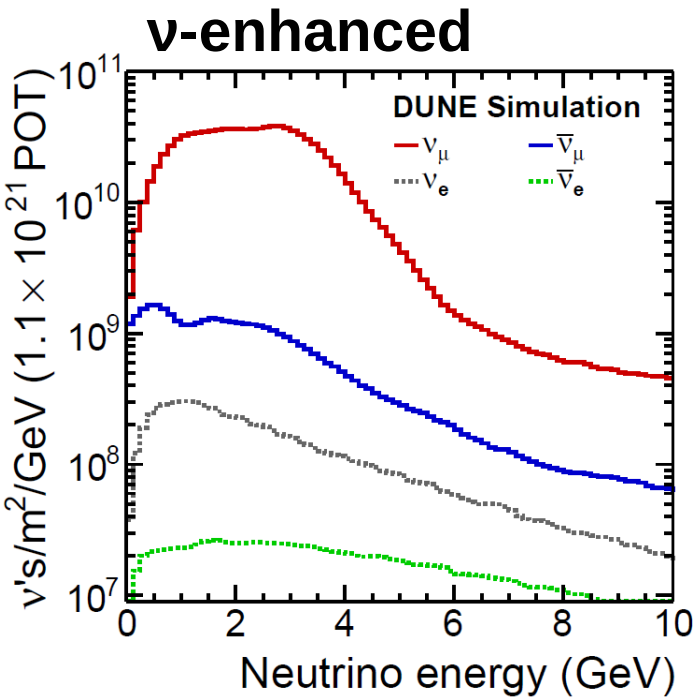


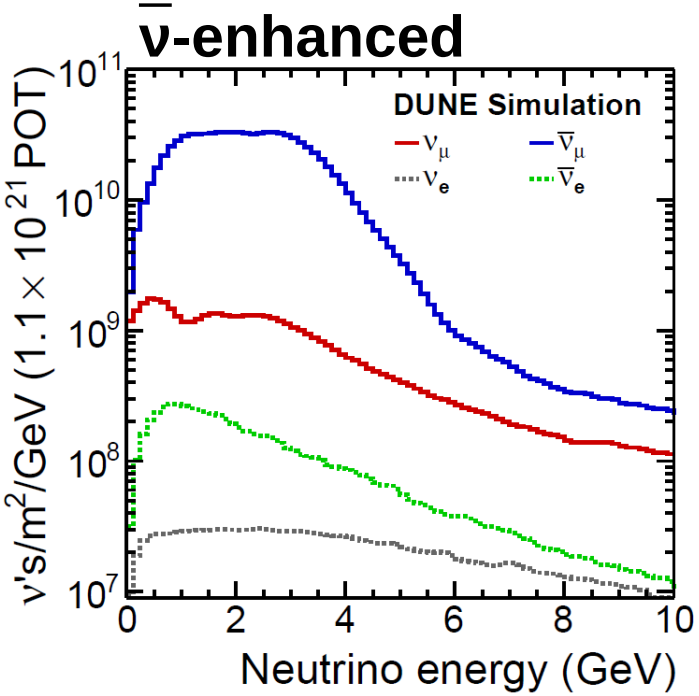
- >1300 people, >200 institutions, 33 countries + CERN
- Future flagship neutrino oscillation experiment
- Three major components: beam, near detector, 4 x 17 kt LAr far detector modules
- **Rich physics program:** BSM studies; supernovae; solar neutrinos; three-flavor oscillation measurements

Beam



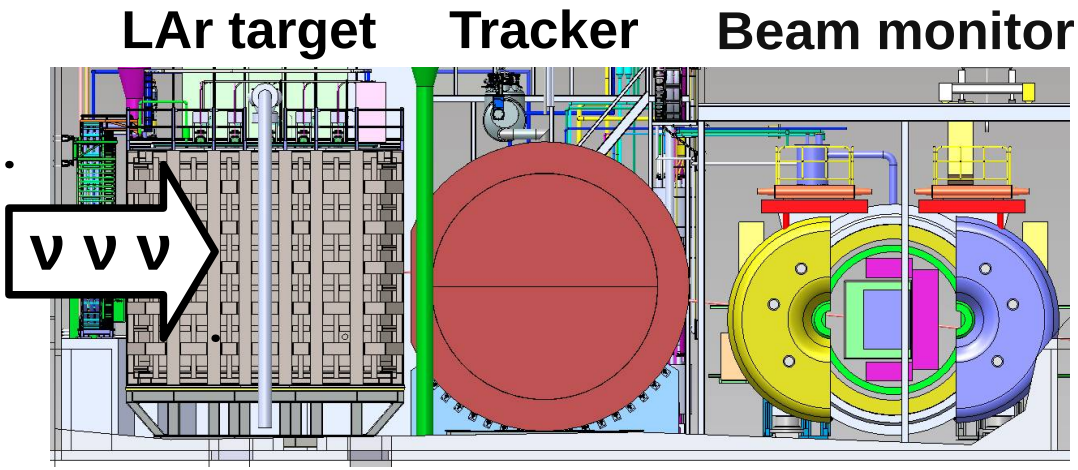
$$\pi^{\pm} \rightarrow \mu^{\pm} + \overset{(-)}{\nu}_{\mu}$$

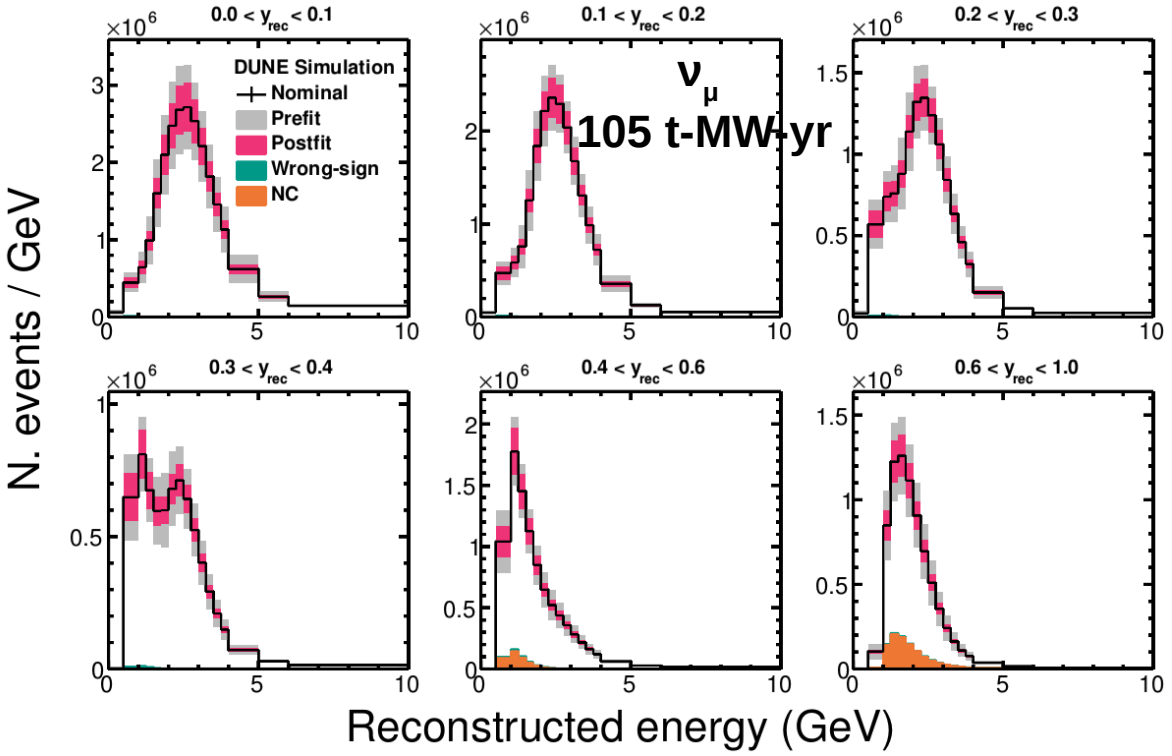




- Produce neutrino beam by focusing charged pions and allowing them to decay
- Can operate in neutrino and antineutrino enhanced modes
- 1.2 MW with planned 2.4 MW upgrade – ramp-up schedule under development

Near Detector (ND)





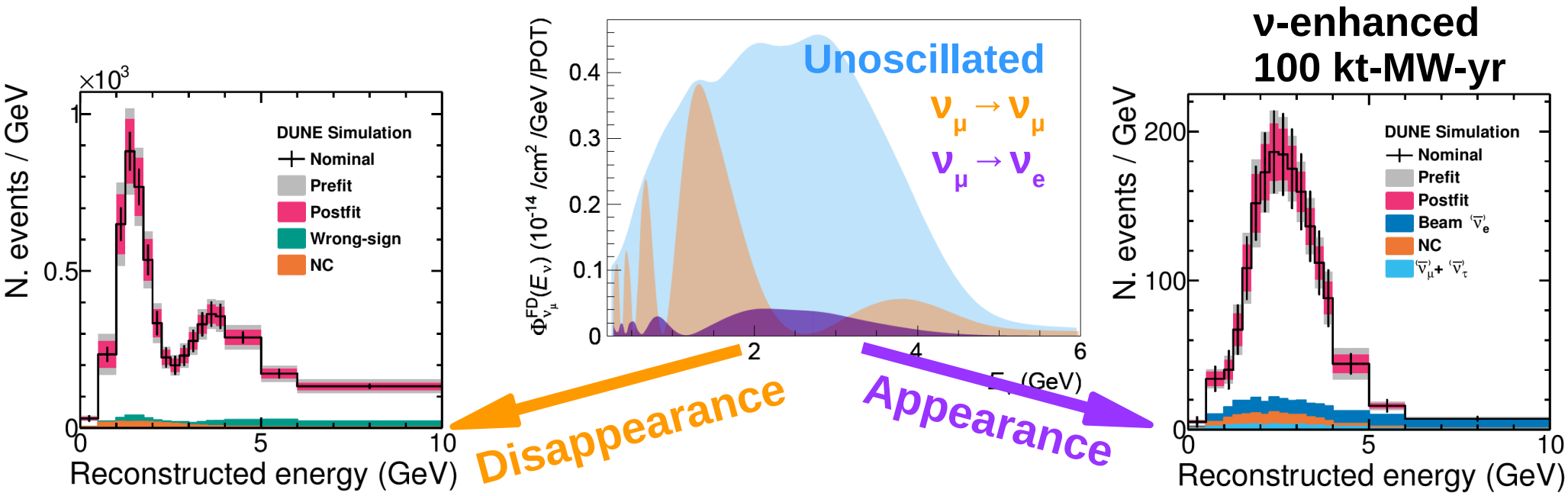
Suite of complementary detectors under active development

Currently, simple implementation in the long-baseline analysis:

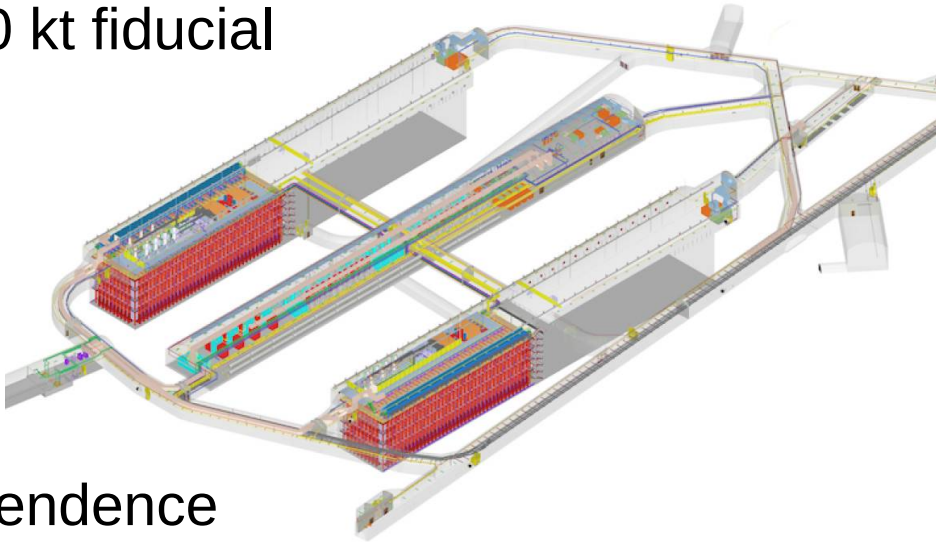
- Events from 65 t (FV) LAr target
- Parameterized reconstruction
- Muons contained or measured in tracker
- CC-inclusive $\overset{(-)}{\nu}_\mu$ samples in ν and $\bar{\nu}$ enhanced modes

See recent ND-CDR
arXiv:2103.13910

Far Detector (FD)

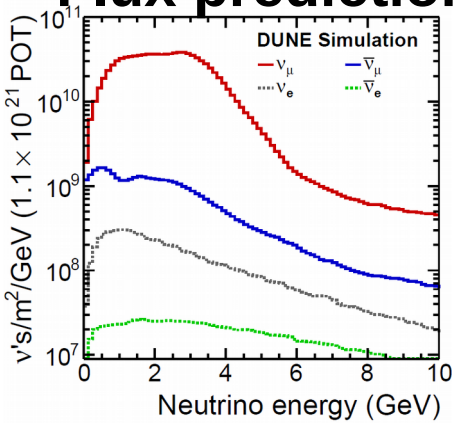


- 4 x 17 kt LAr modules, minimum 10 kt fiducial volume each
- Full simulation and reconstruction: [PRD102, 092003 (2020)]
- Four samples in analysis: ν_μ & ν_e in ν and $\bar{\nu}$ enhanced modes
- Exposure in kt-MW-yr to avoid dependence on module construction and beam schedules



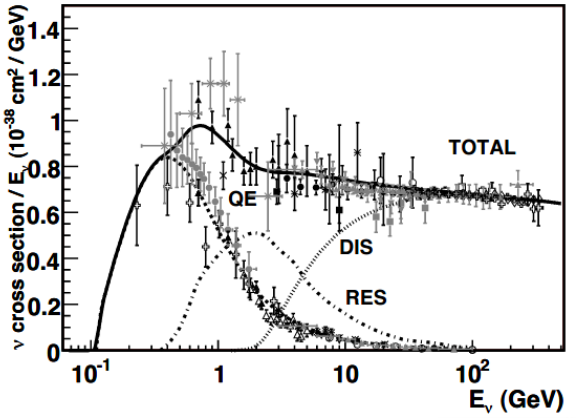
Analysis summary

Flux prediction

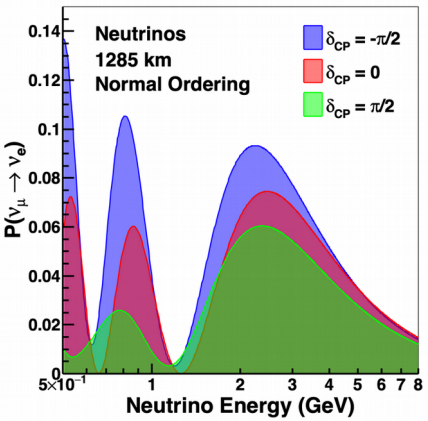


X

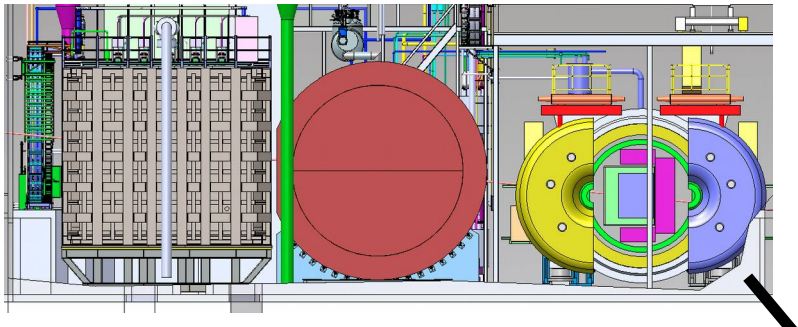
Interaction model



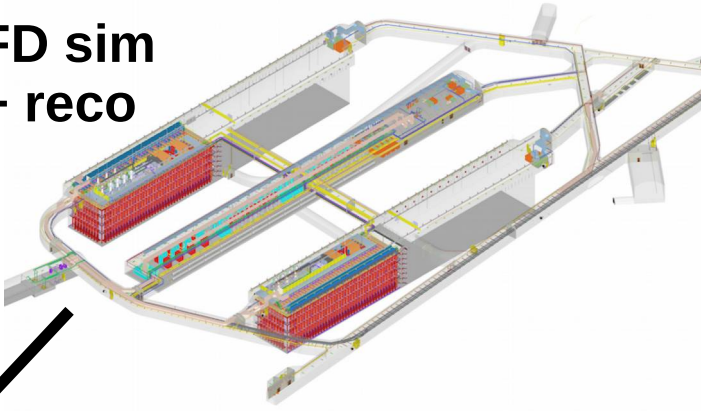
Oscillations



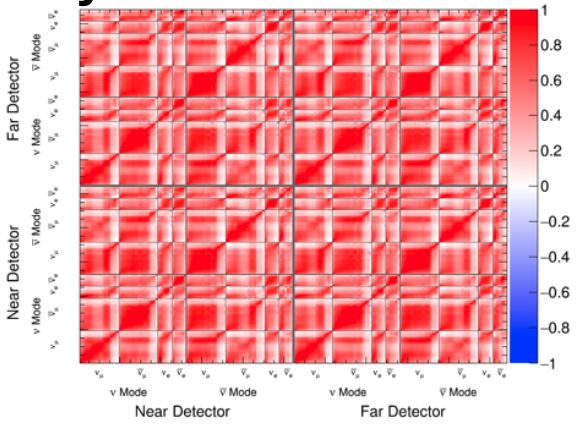
Parameterized ND sim + reco



FD sim + reco



Systematic uncertainties



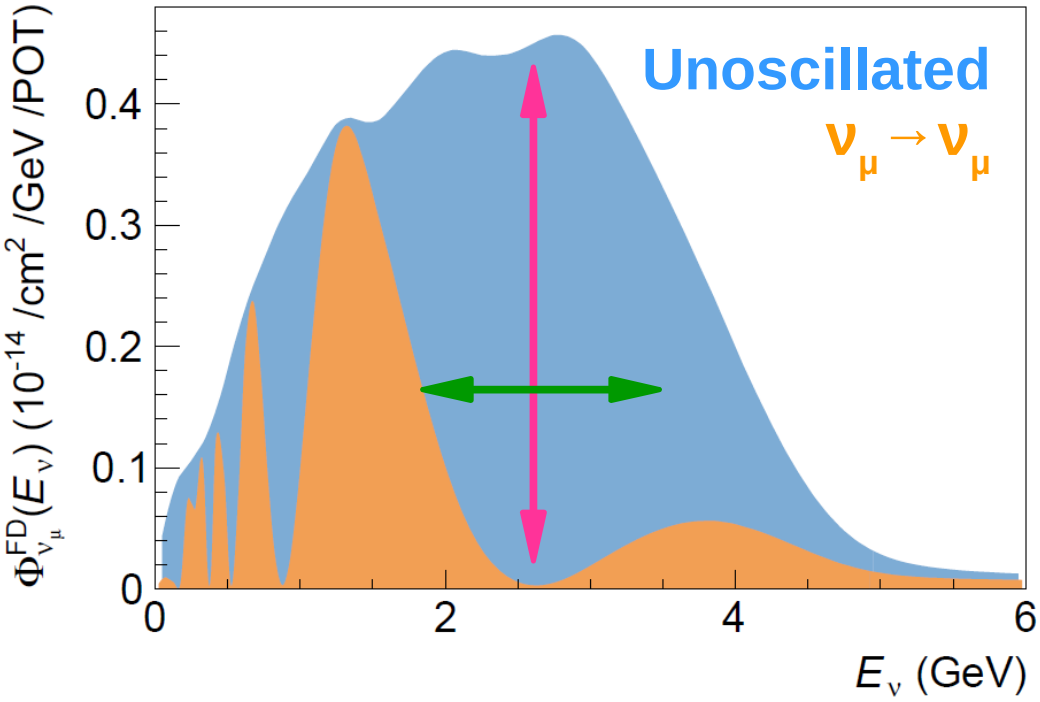
Fitting framework

$$\chi^2(\vec{\vartheta}, \vec{x}) = 2 \sum_i^{N_{\text{bins}}} \left[M_i(\vec{\vartheta}, \vec{x}) - D_i + D_i \ln \left(\frac{D_i}{M_i(\vec{\vartheta}, \vec{x})} \right) \right] + \sum_j^{N_{\text{systs}}} \left[\frac{\Delta x_j}{\sigma_j} \right]^2$$

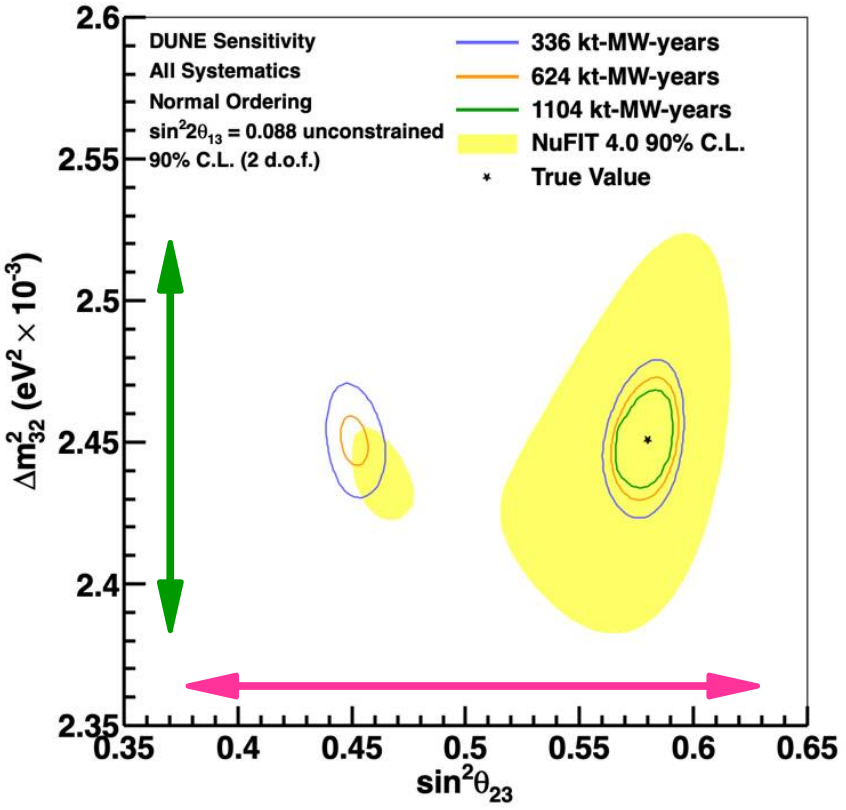
Disappearance parameters

$$P(\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_\mu) = 1 - \left(\cos^4\theta_{13}\sin^2 2\theta_{23} + \sin^2 2\theta_{13}\sin^2\theta_{23}\right)\sin^2\Phi_{32} + \ldots$$

$$\Phi_{ji} = \frac{1.27\Delta m^2_{ji} L}{E_\nu}$$



90% confidence



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Electron (anti)neutrino appearance

$$P(\overset{(-)}{\nu}_{\mu} \rightarrow \overset{(-)}{\nu}_{e}) = \sin^2\theta_{23}\sin^2 2\theta_{13}\frac{\sin^2(\Phi_{31}-aL)}{(\Phi_{31}-aL)^2}\Phi_{31}^2$$

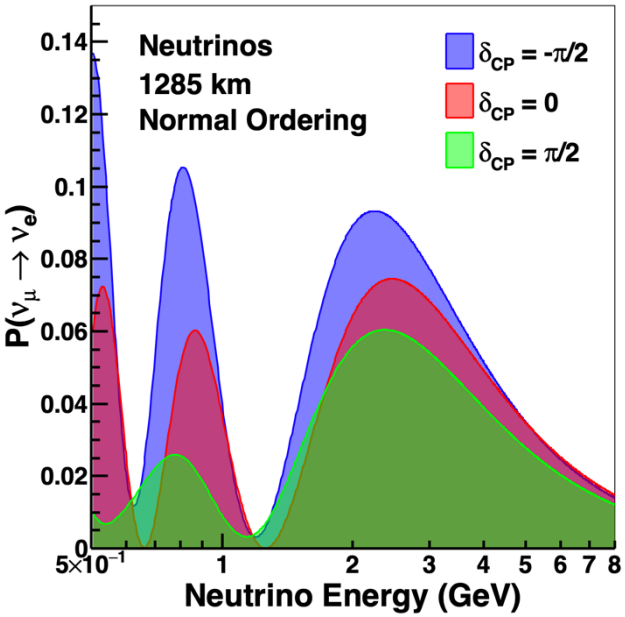
$$+ \sin 2\theta_{23}\sin 2\theta_{13}\sin 2\theta_{12}\frac{\sin(\Phi_{31}-aL)}{(\Phi_{31}-aL)}\Phi_{31}\frac{\sin(aL)}{(aL)}\Phi_{21}\cos(\Phi_{31} \pm \delta_{CP})$$

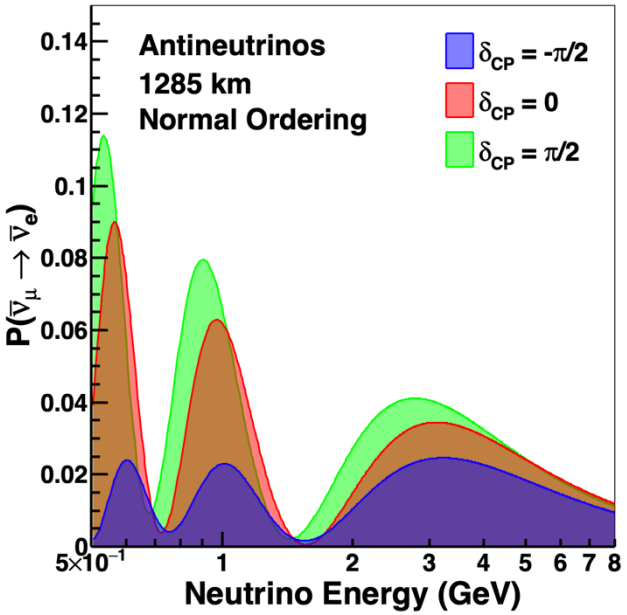
$$+ \ldots$$

$$\Phi_{ji} = \frac{1.27\Delta m^2_{ji} L}{E_\nu} \qquad a = \pm\frac{G_F N_e}{\sqrt{2}}$$

Sign change for ν_e and $\bar{\nu}_e$

Interplay between mass ordering and CP-phase

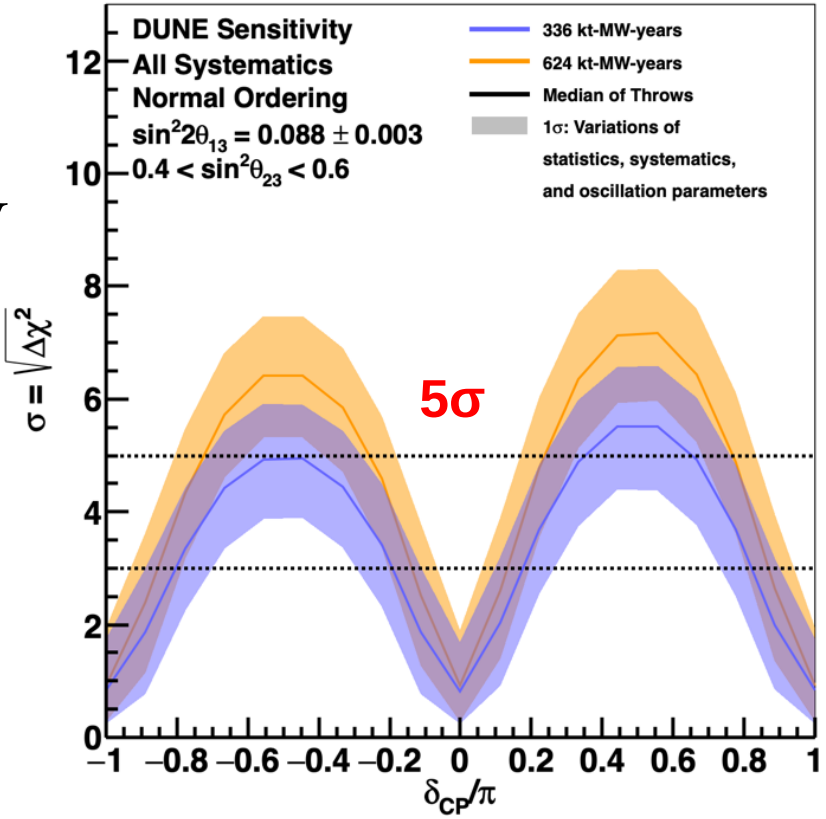




Matter effect increases with E_ν, Enhances MO sensitivity

CPV sensitivity

$$\Delta\chi^2 = \chi^2_{0,\pi} - \chi^2_{\mathrm{CPV}}$$



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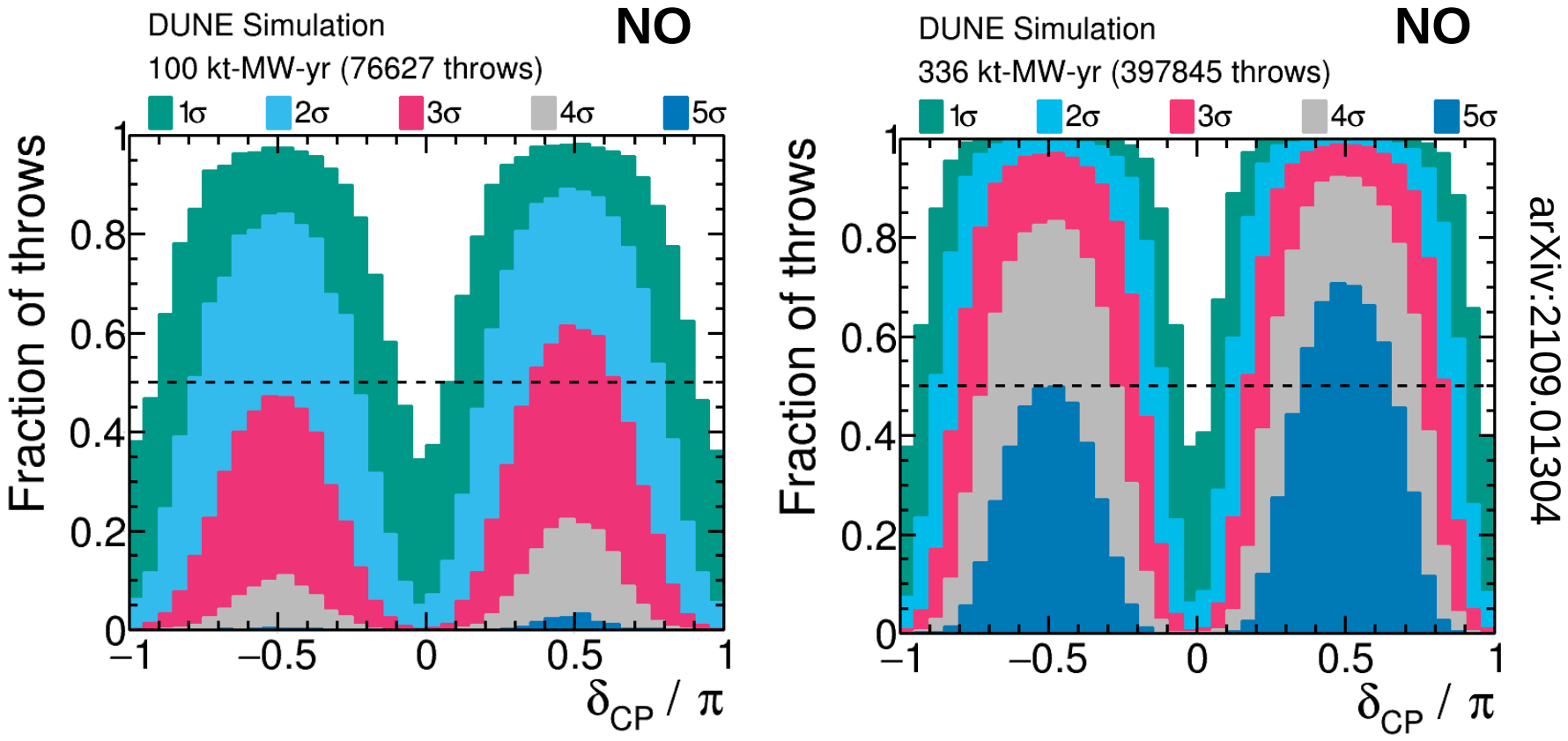
Produced from a large ensemble of throws for true NO

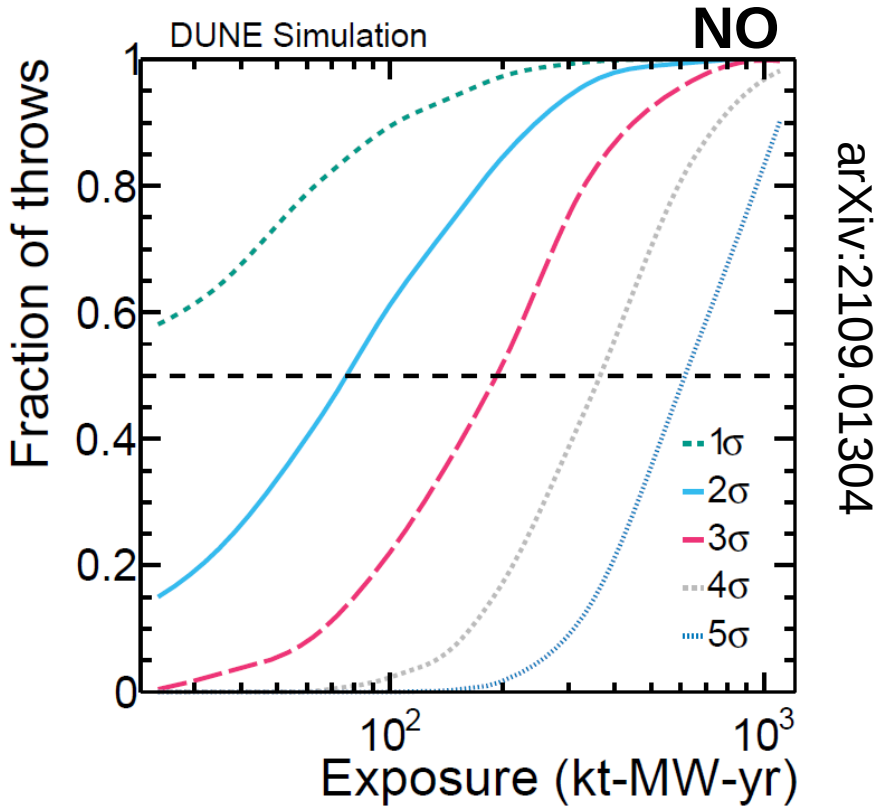
Median and central 68% of throws shown for 336 and 624 kt-MW-yr exposures

CPV sensitivity



Fraction of throws that exceed each 1-5σ significance threshold as a function of true δ_{CP} for two exposures

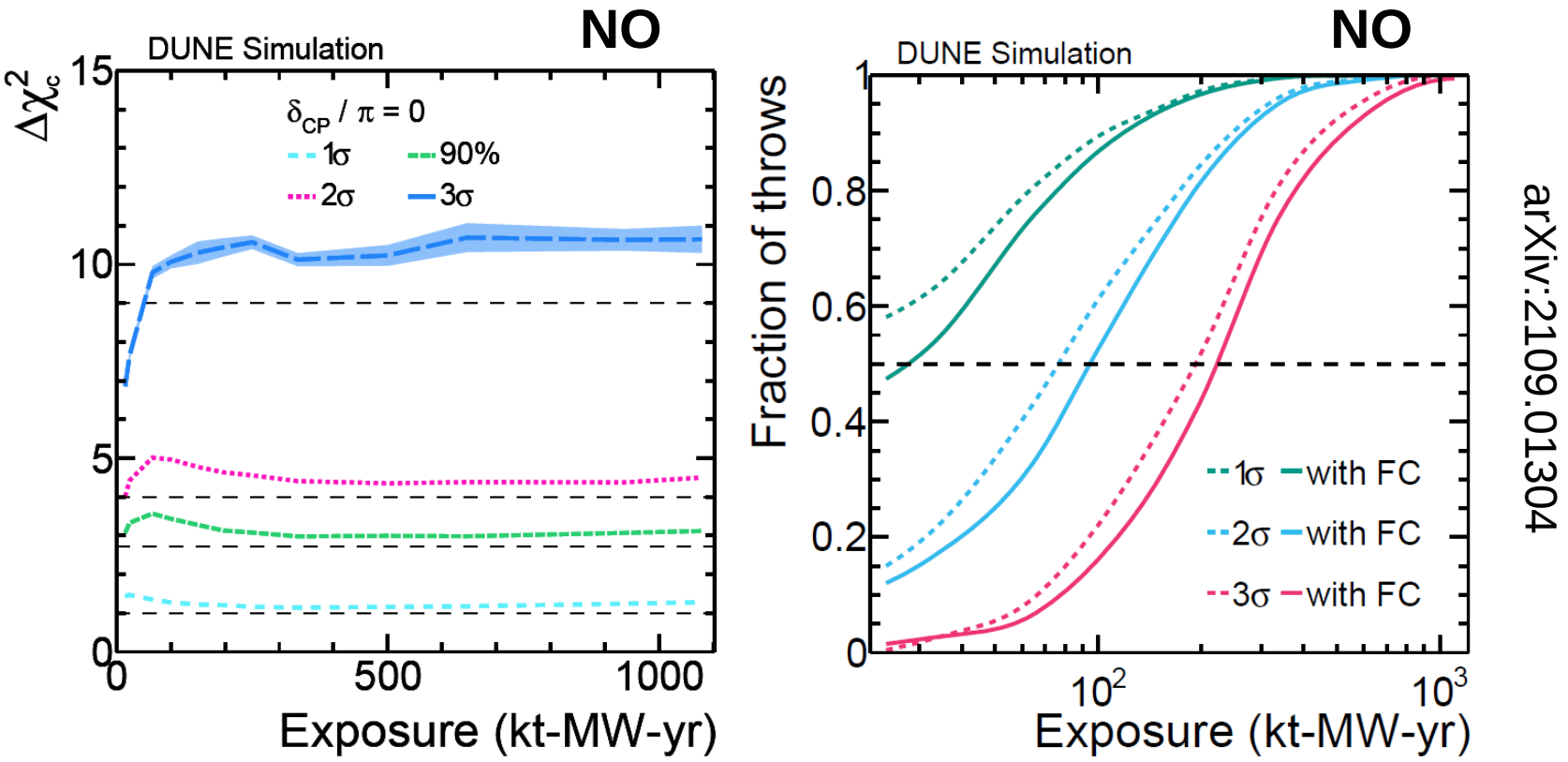
CPV sensitivity over time



Behaviour as a function of exposure can be extracted, here shown for 50% of true δ_{CP} values

Median sensitivity for 50% δ_{CP} values above 3σ (5σ) after 197 (646) kt-MW-yr

FC CPV sensitivity over time

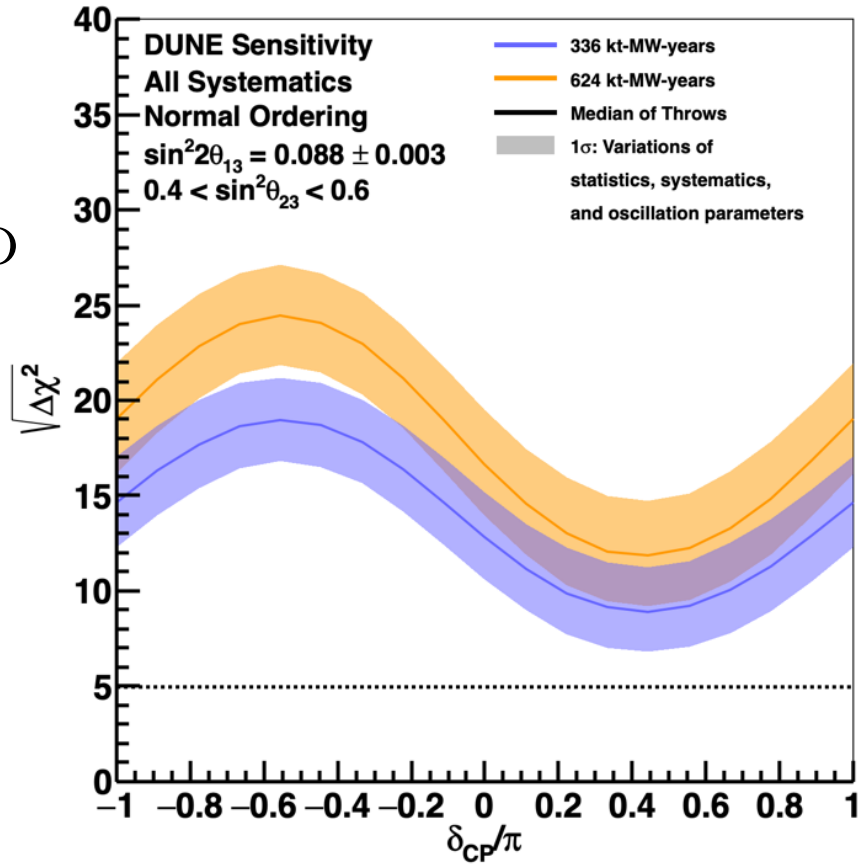


Fraction of throws that exceed 1-3σ for 50% of true δ_{CP} values, with and without FC corrections

FC corrections computationally prohibitive above 3σ

Mass ordering (MO) sensitivity

$$\Delta\chi^2 = \chi^2_{\mathrm{IO}} - \chi^2_{\mathrm{NO}}$$



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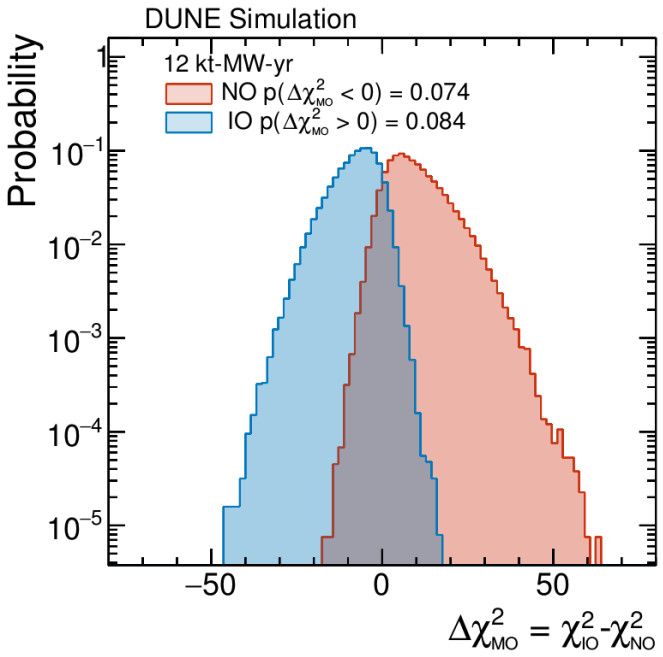
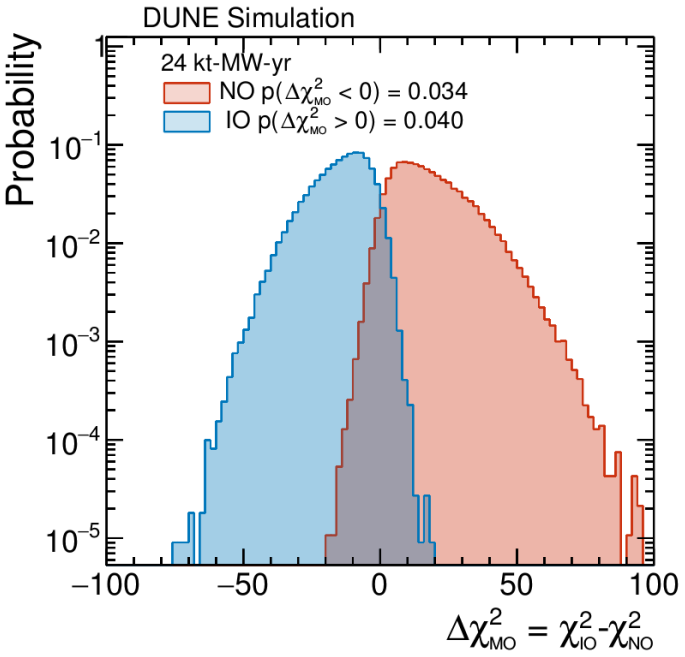
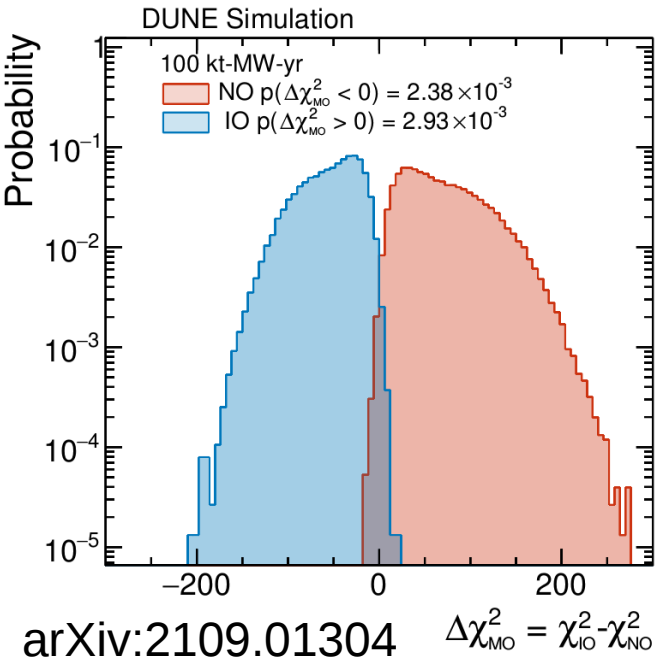
Previous MO results used simple $\sqrt{\Delta\chi^2}$ metric. Clear power to resolve the mass ordering, but non-nested parameters make interpretation challenging

MO sensitivity





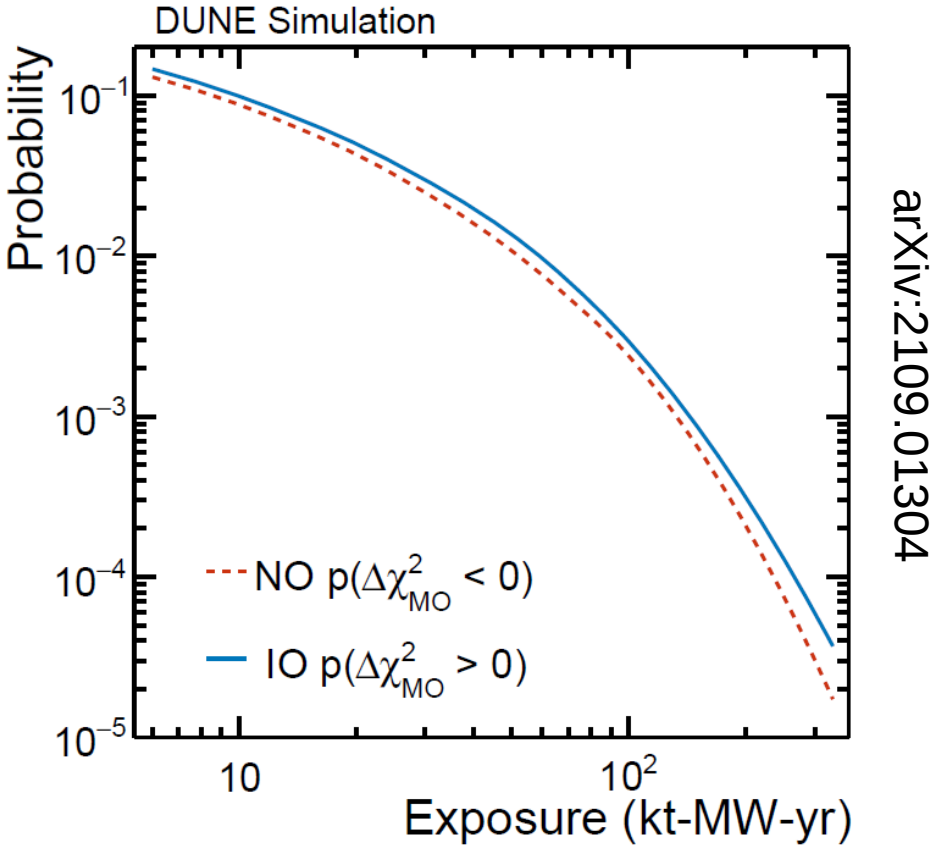


arXiv:2109.01304

Distributions of the test statistic $\Delta\chi^2_{MO}$ for true NO and IO, for several exposures

Clear sensitivity to MO from relatively small exposures

MO sensitivity



The probability for preferring the wrong neutrino mass ordering can be extracted as a function of exposure

Probability < 0.01 by 66 kt-MW-yr for both orderings

Conclusions

- DUNE has explored its three-flavor oscillation sensitivity with a parametrized ND and full FD sim+reco
- Median CPV sensitivity:
  - 3σ for $\delta_{CP}=\pm\pi/2$ after 100 kt-MW-yr
  - 3σ (5σ) for 50% δ_{CP} values after 197 (646) kt-MW-yr
- FC corrections do not significantly degrade CPV sensitivity
- Strong MO statements can be expected after short (~12 kt-MW-yr) exposures
- Improvements expected when full ND information is incorporated into the analysis