DUNE long-baseline oscillation physics sensitivity

Callum Wilkinson on behalf of the DUNE collaboration
Lawrence Berkeley National Laboratory
TAUP 2023, 28th August 2022

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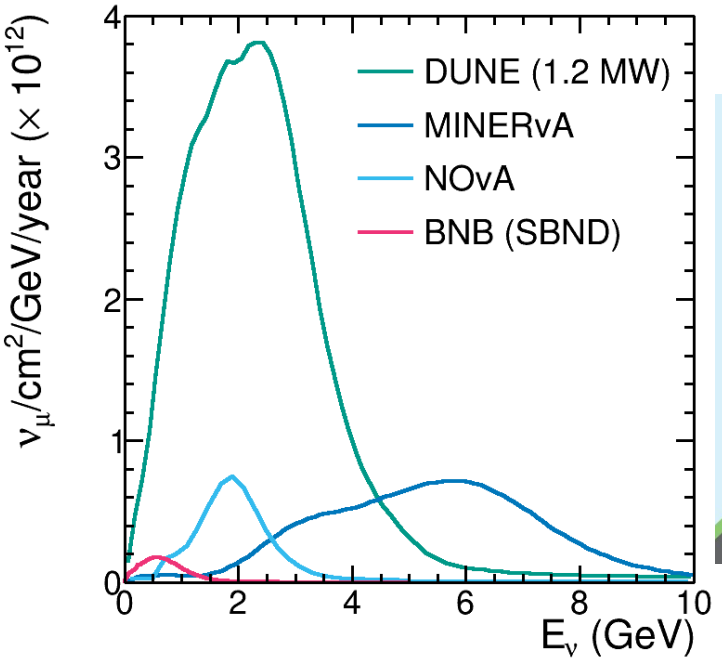
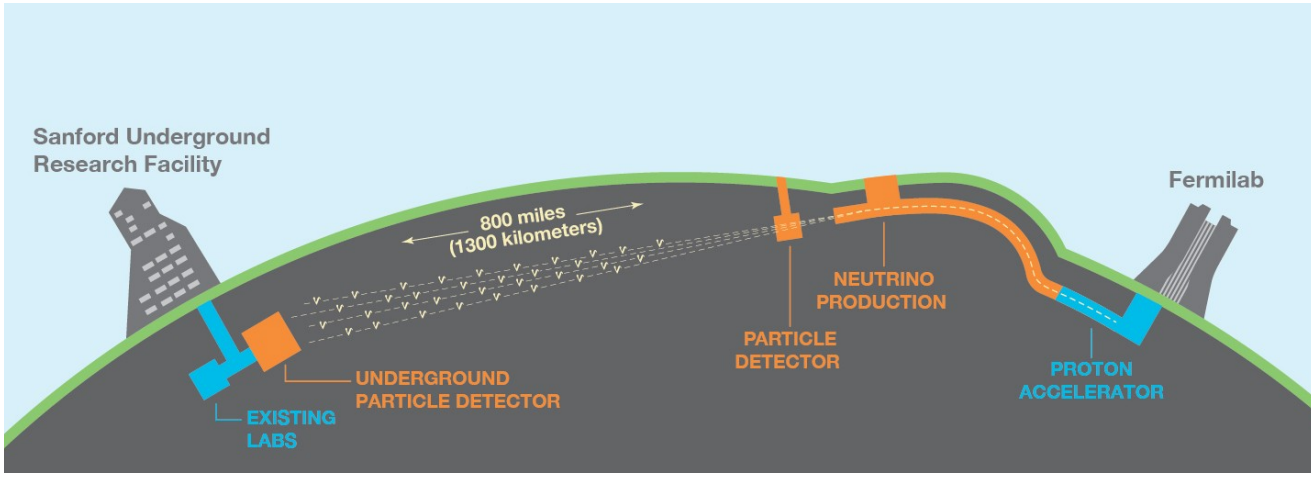
DUNE

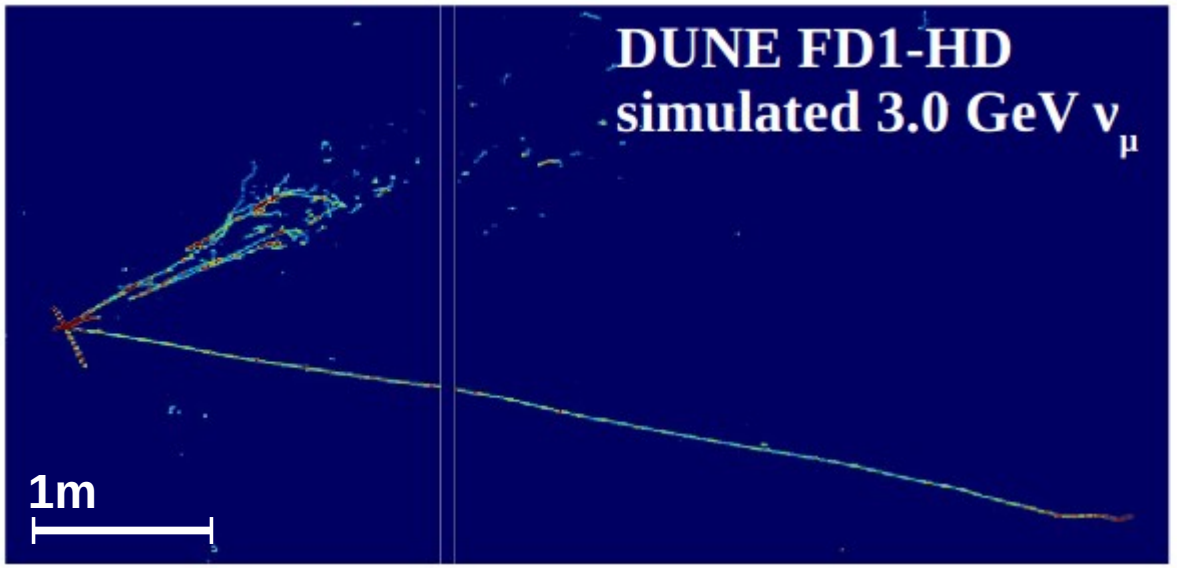
DUNE

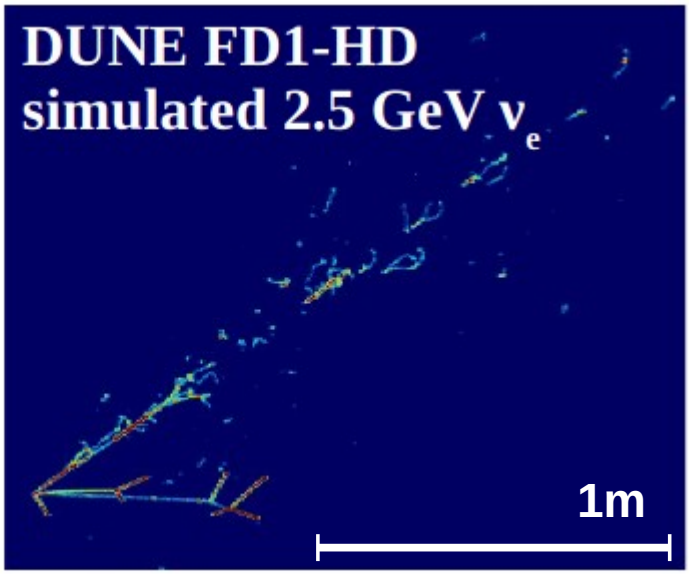




- L ≈ 1285 km; E_ν ≈ 2.5 GeV (*broad band*); liquid argon time projection chamber (LArTPC)
- Unprecedented intensity neutrino beam (1.2 → 2.4 MW)
- Near detector system at Fermilab
- 4 x 17 kt far detector modules at SURF

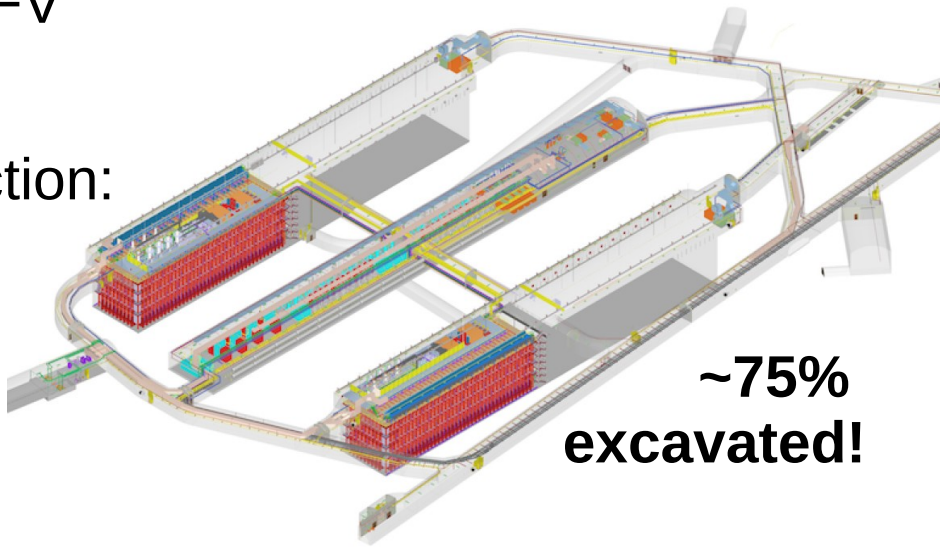
Far Detector (FD)





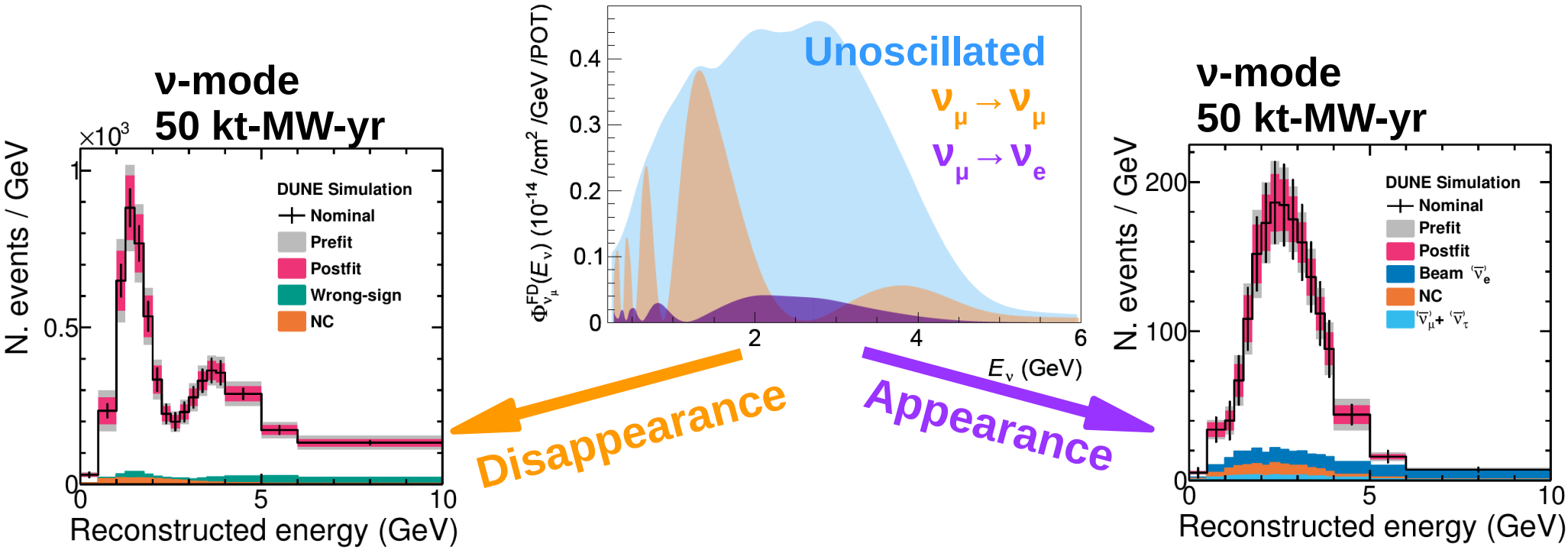
- 4 x 17 kt modules, minimum 10 kt FV each (initial 2 x LAr)
- Full FD1 simulation and reconstruction: PRD102, 092003 (2020)

See R. Huang's talk for details (Tuesday 14:45)



~75% excavated!

FD samples



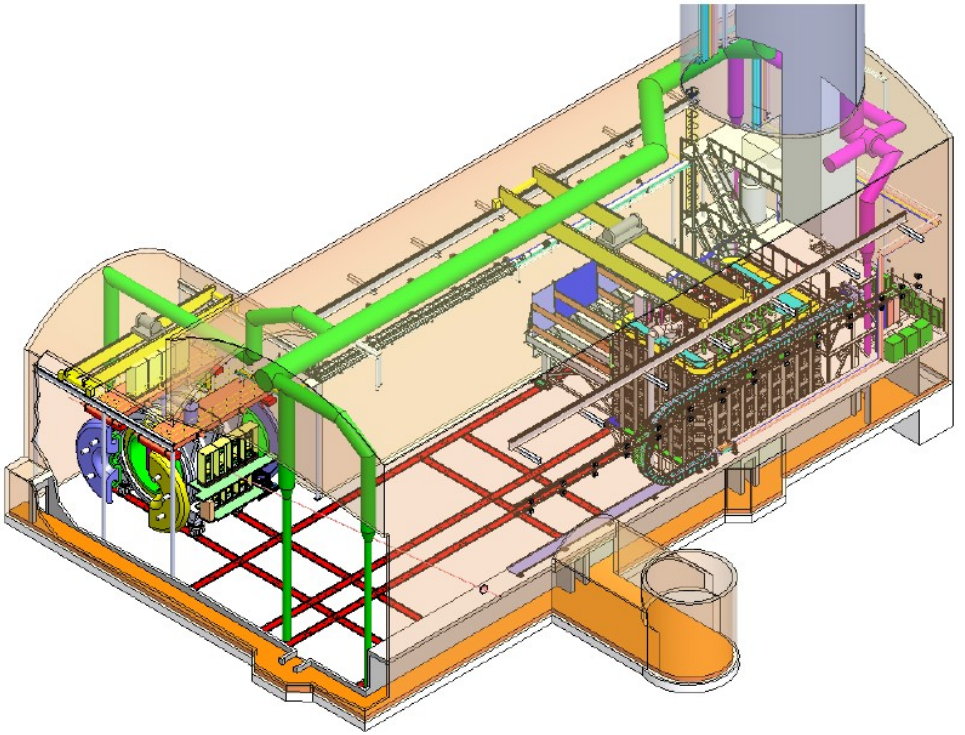
Four samples in analysis:

- ν_μ & ν_e
- In ν and $\bar{\nu}$ enhanced modes

Near Detector (ND)

Core requirements:

- Constrain neutrino flux
- Constrain $\nu/\bar{\nu}$-Ar interactions
- Exceed FD energy resolutions
- Tolerate high rate environment



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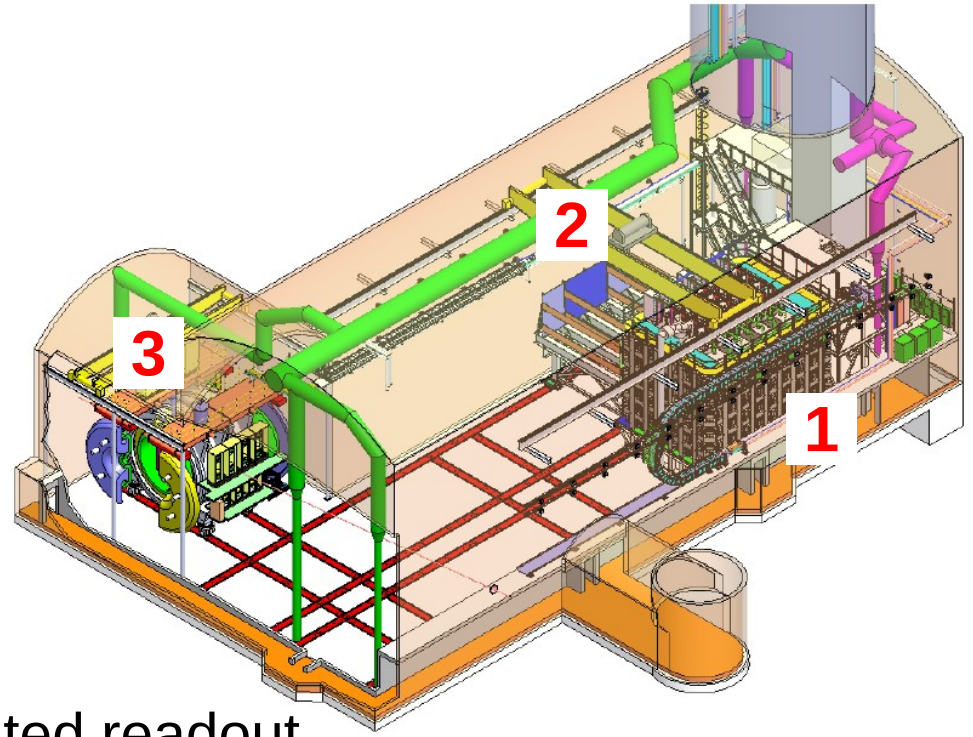


Three major components:

1 - Core 150 t LArTPC with pixelated readout

2 - Downstream magnetized tracker

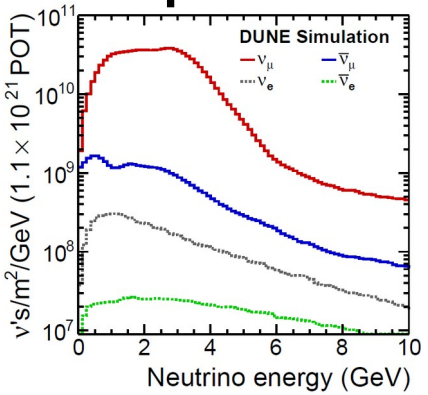
3 - SAND: dedicated beam monitor

See B. Russell's talk for details (Tuesday 14:30)

ND CDR: *Instruments 2021, 5(4), 31*

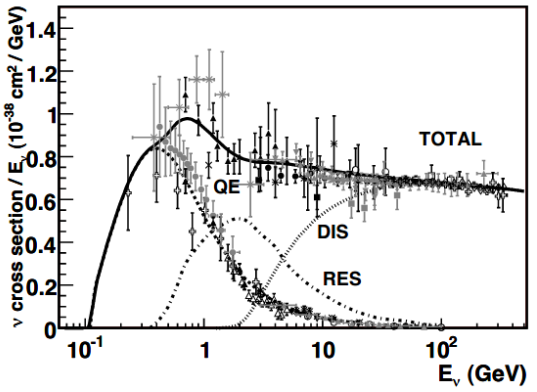
Analysis summary

Flux prediction

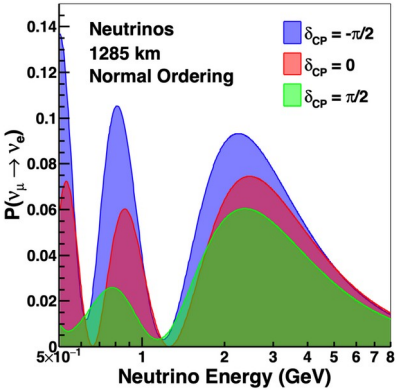


X

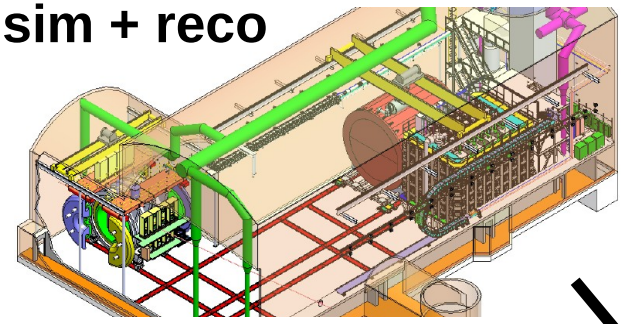
Interaction model



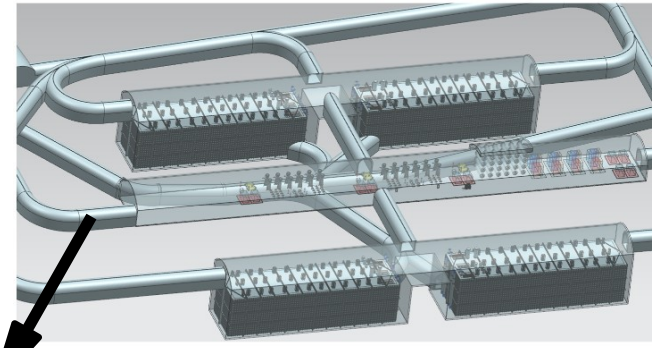
Oscillations



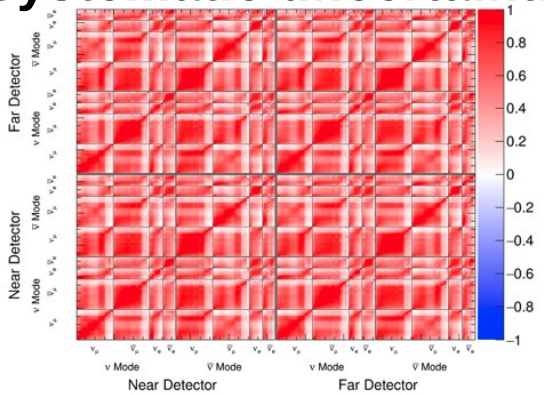
ND sim + reco



FD sim + reco



Systematic uncertainties



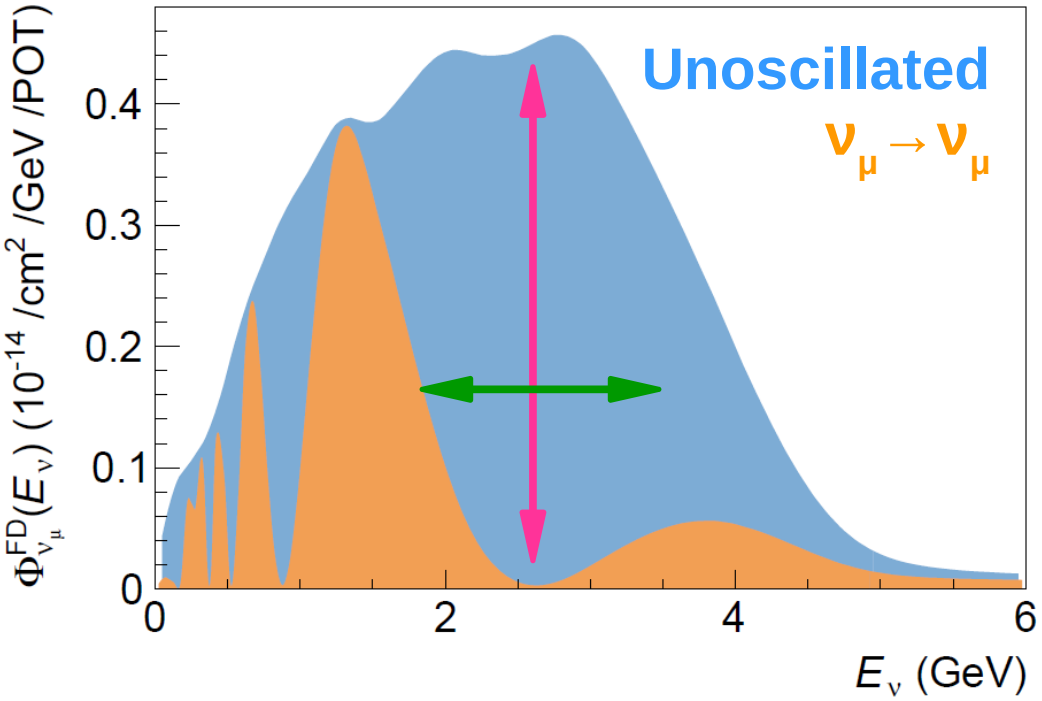
Fitting framework

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

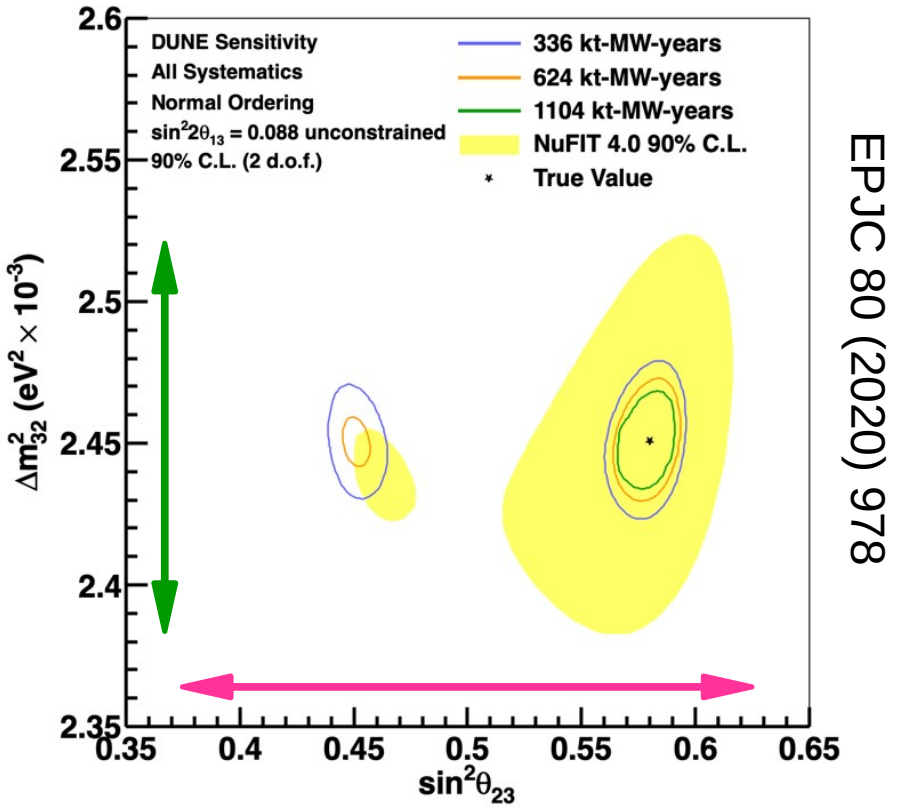
Muon (anti)neutrino disappearance

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

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



90% confidence



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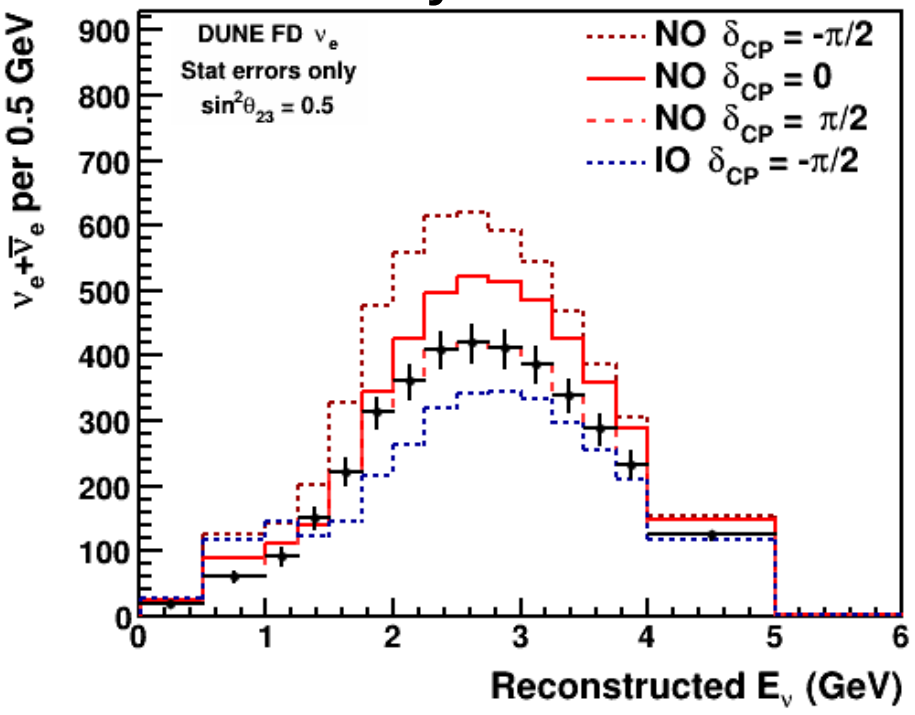
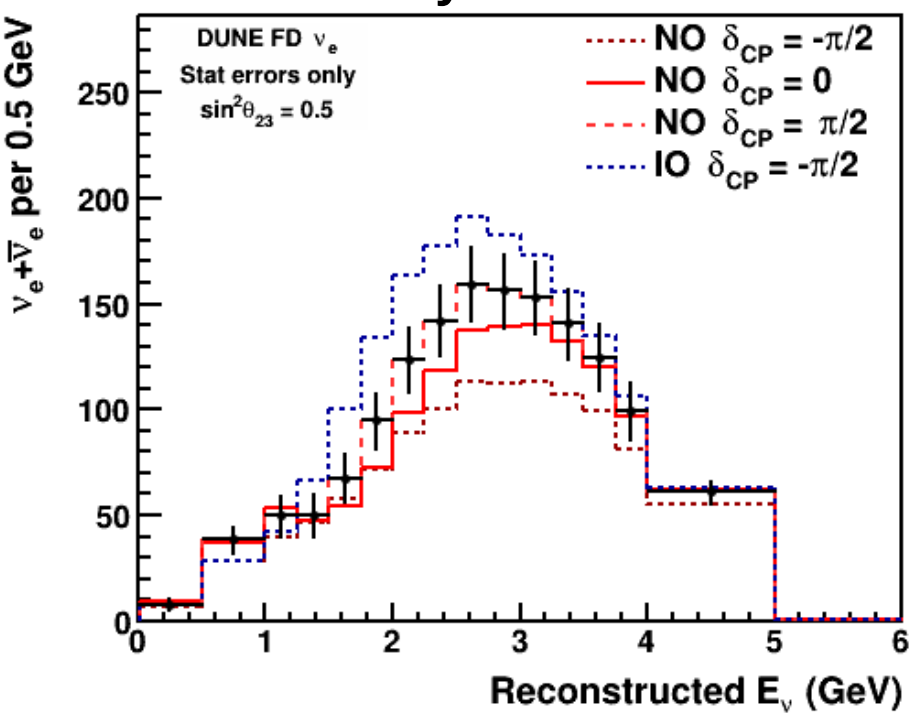
MO & CPV sensitivity

ν-mode
500 kt-MW-yr



$\bar{\nu}$-mode
500 kt-MW-yr



Sensitivity through a combination of ν_e and $\bar{\nu}_e$ samples.
Both rate and spectral shape matter

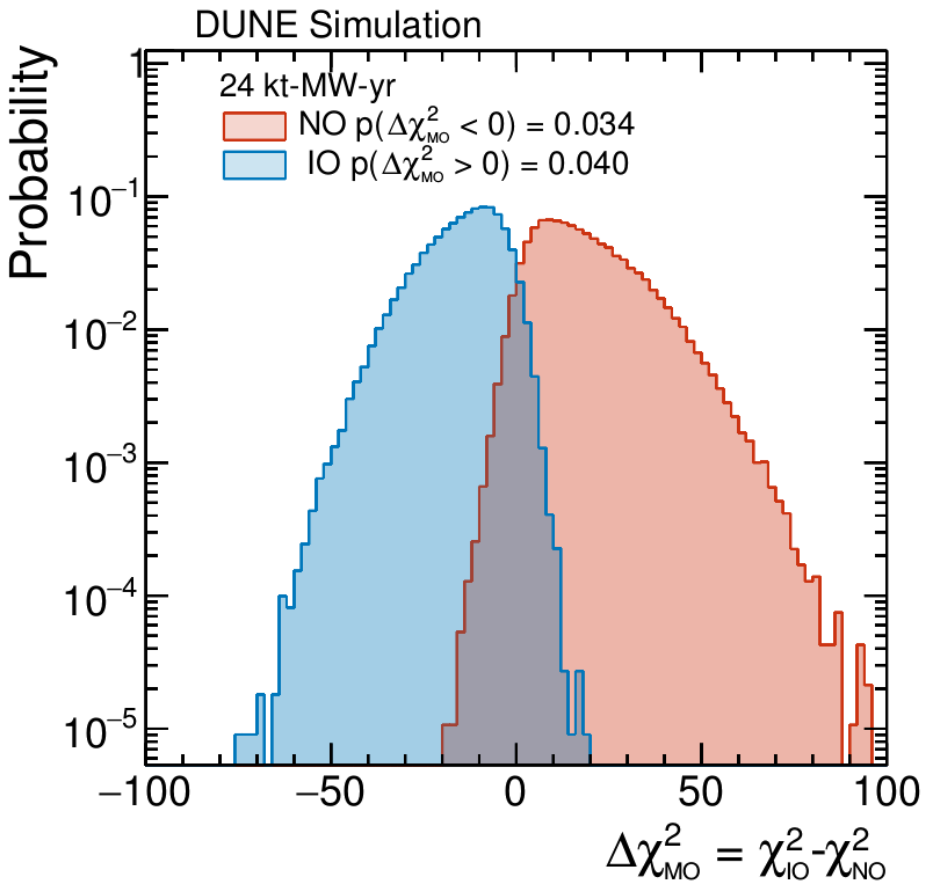
Toy throw study method

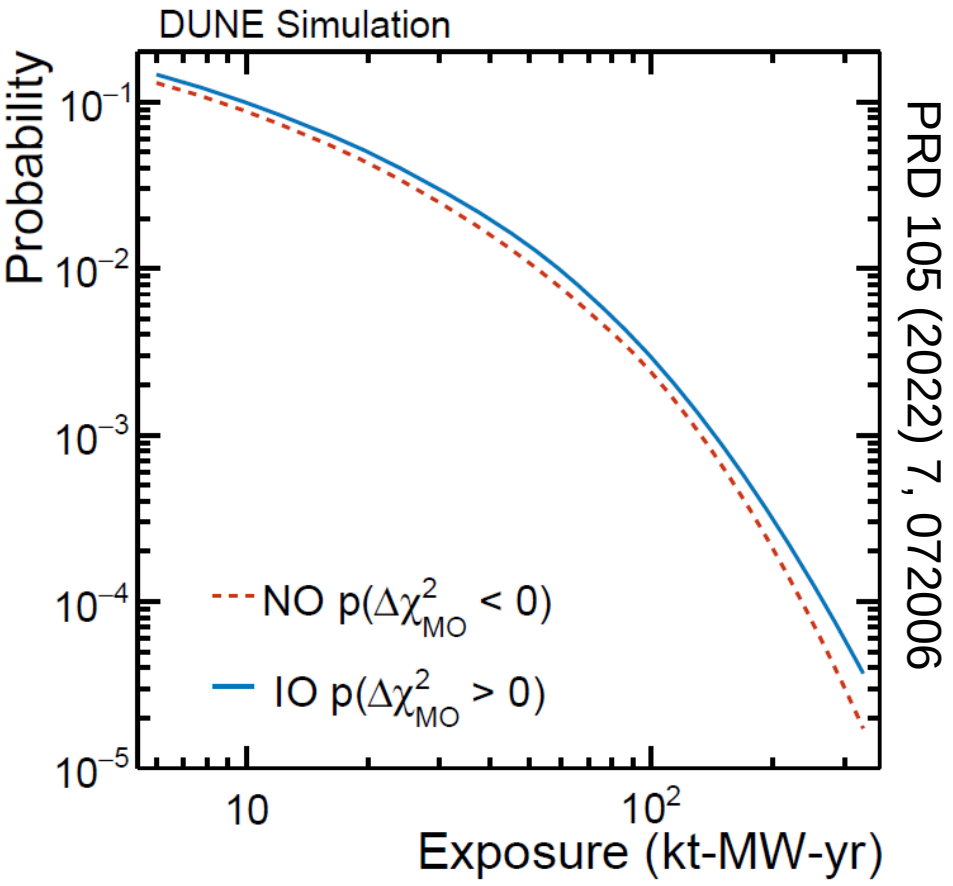
Parameter	Prior	Range
$\sin^2\theta_{23}$	Uniform	[0.4; 0.6]
$\lvert\Delta m^2_{32}\rvert$ ($\times 10^{-3}$ eV^2)	Uniform	|[2.3; 2.7]|
$\delta_{CP}/\ \pi$	Uniform	[-1;1]
θ_{13}	Gaussian	NuFIT 4.0*

*JHEP 01 (2019) 106

- For each toy throw:
  - Flux, detector and cross-section systematics thrown according to their prior uncertainty
  - Oscillation parameters thrown according to the table
  - Statistical throw applied
  - All parameters are allowed to vary
- All fits use all ND+FD samples, equal ν:$\bar{\nu}$ running, and apply a Gaussian penalty to θ_{13}

MO sensitivity



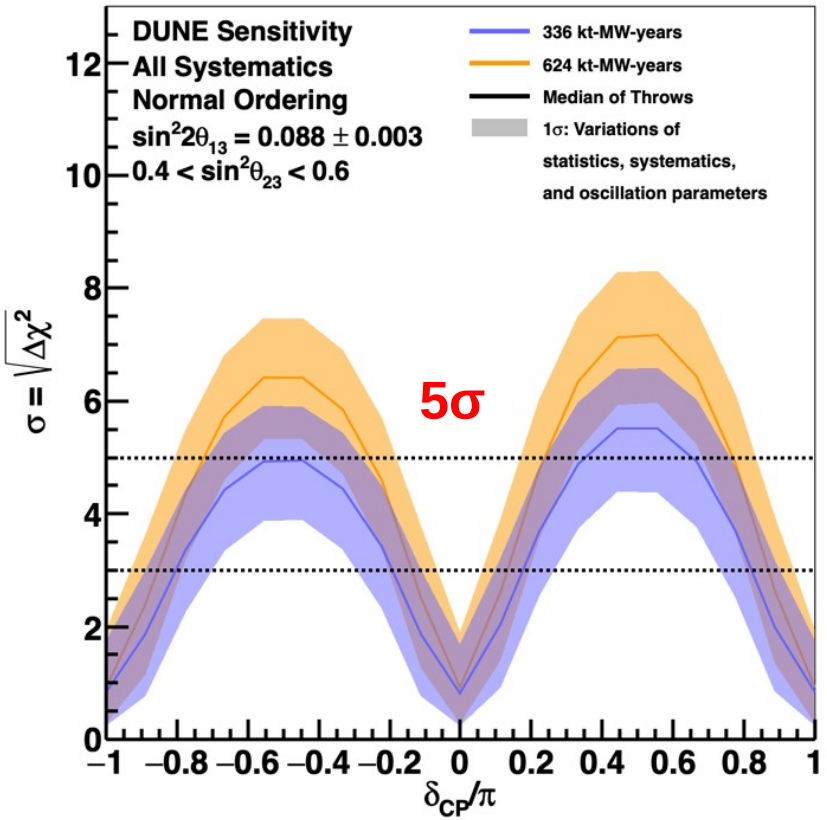


Strong MO potential with <u>short exposures</u>

Probability < 0.01 to prefer the wrong neutrino mass ordering after 66 kt-MW-yr

CPV sensitivity

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



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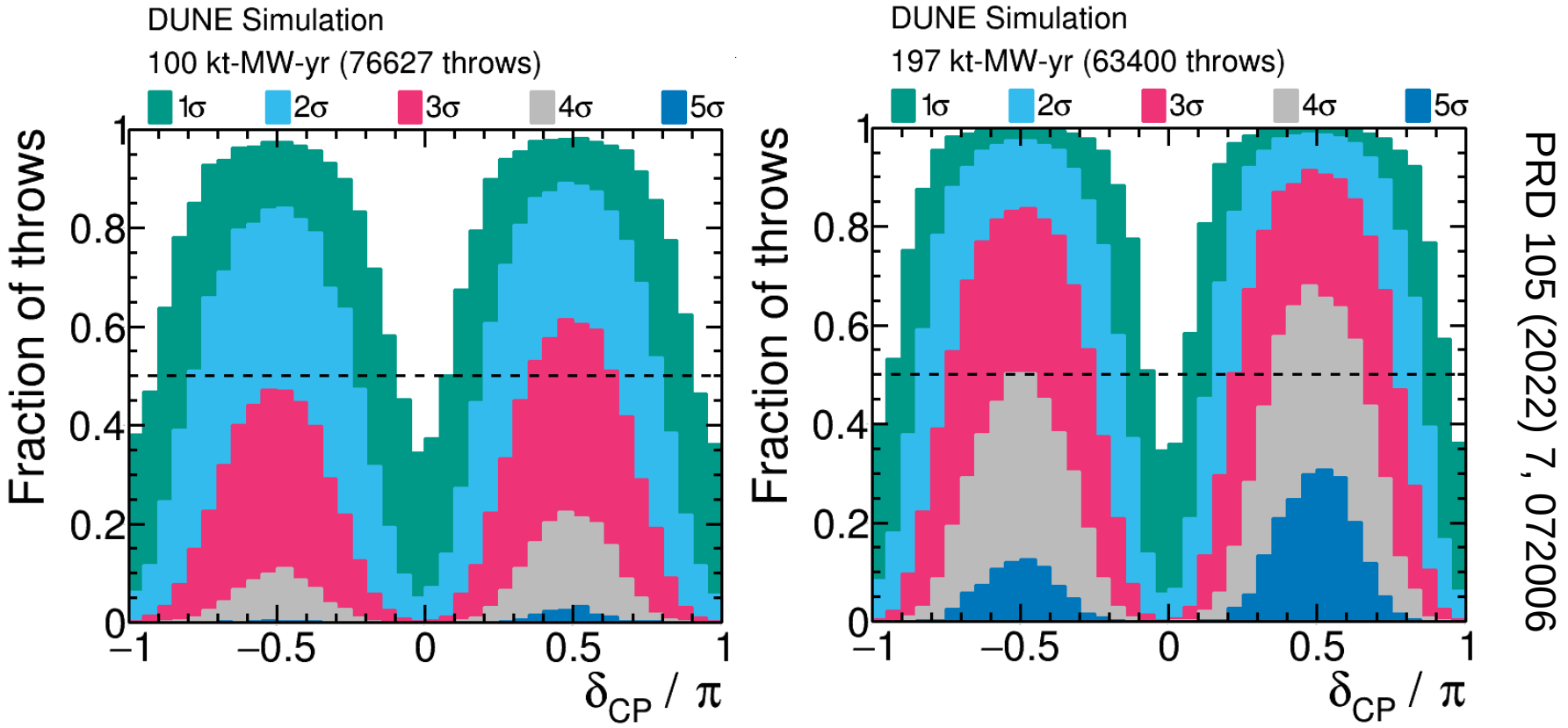
Median and central 68% of throws shown for 336 and 624 kt-MW-yr exposures

>5σ discovery potential for >50% of δ_{CP} values

CPV sensitivity

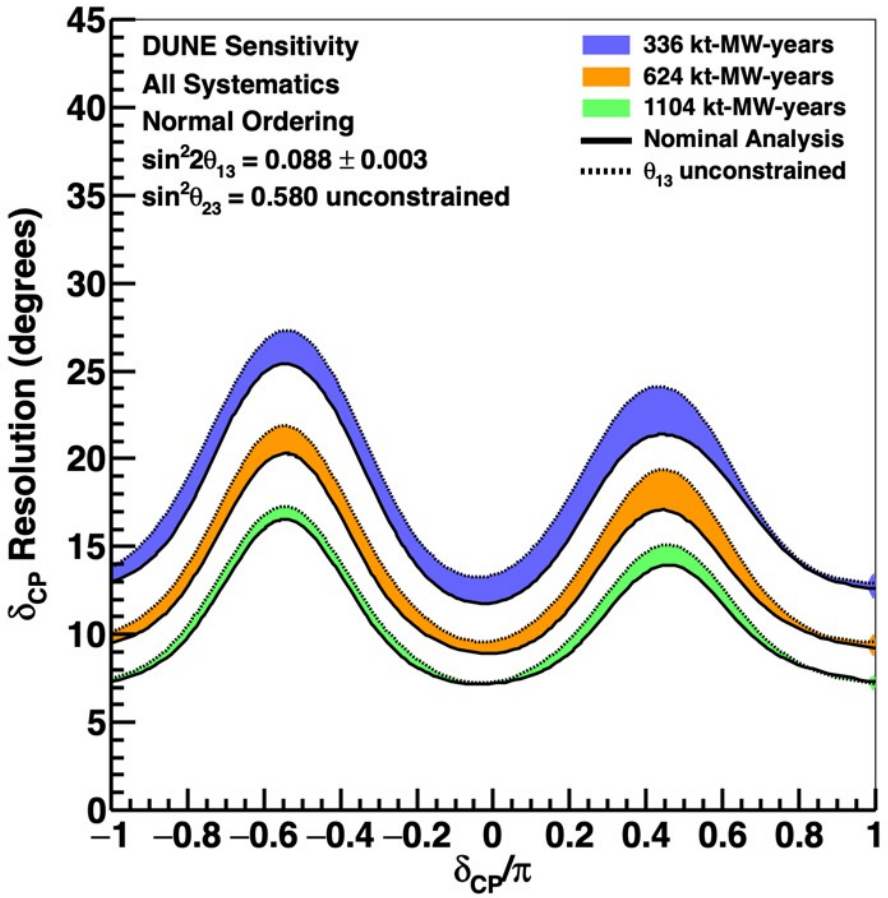


Syst.+stat. throws exceeding 1-5σ significance thresholds

≈100 kt-MW-yr, 3σ at maximal δ_{CP}

≈200 kt-MW-yr, 3σ for 50% of δ_{CP} values

δ_{CP} resolution



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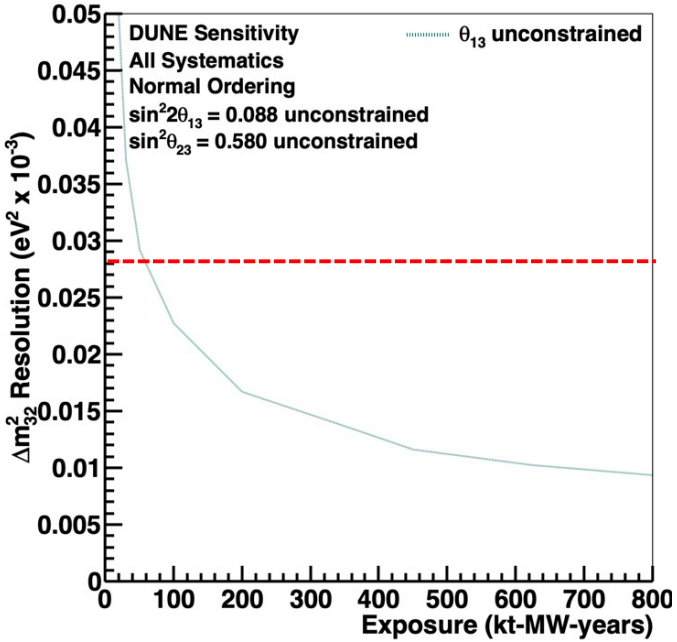
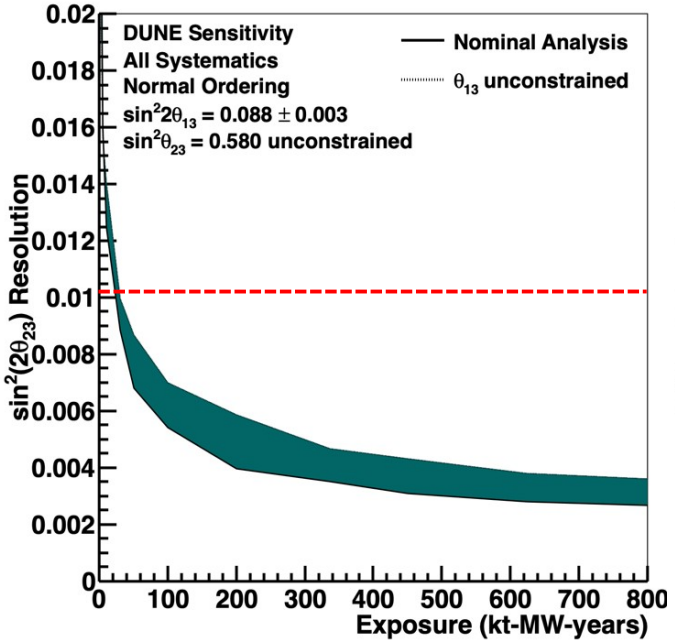
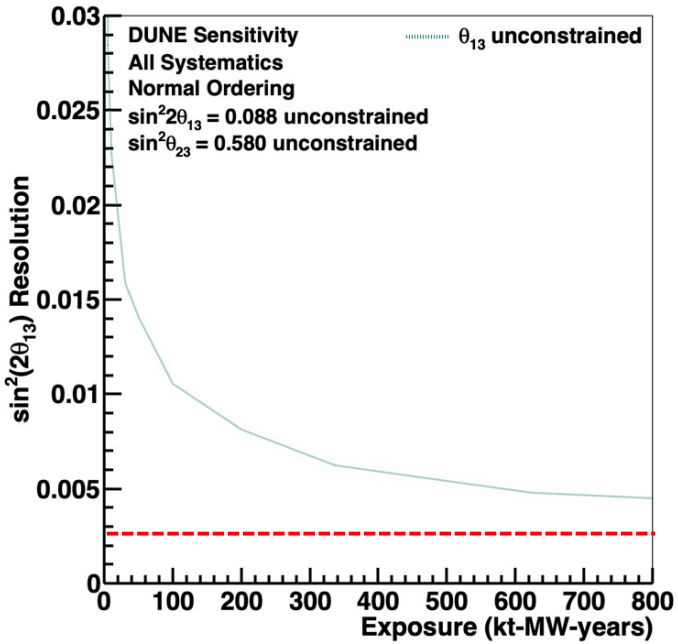
7–16° δ_{CP} resolution **regardless of true value**

Not just CPV!

DUNE precision measurements







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- Expected DUNE resolution vs exposure and **current global fit** (NuFit 5.0: JHEP 09 (2020) 178)
- Ultimate sensitivity approaches reactor θ_{13}
- Constrain δ_{CP}, Δm^2_{32}, θ_{23}, θ_{13} and MO with a single experiment

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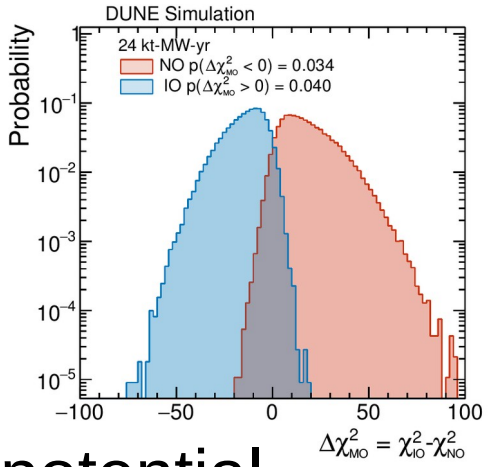
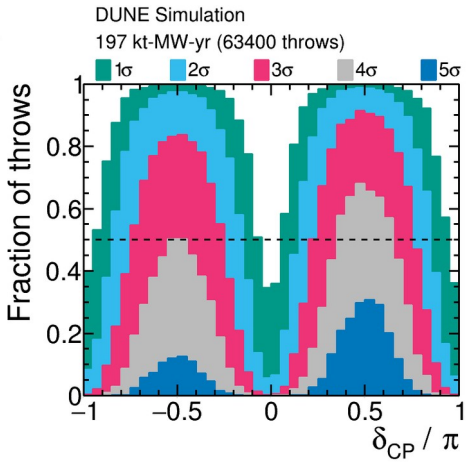
DUNE oscillation summary

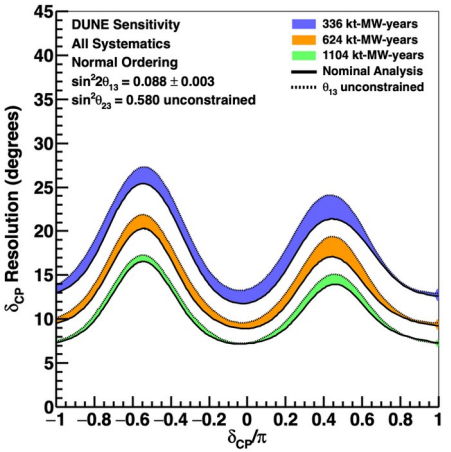
Unambiguous MO measurement





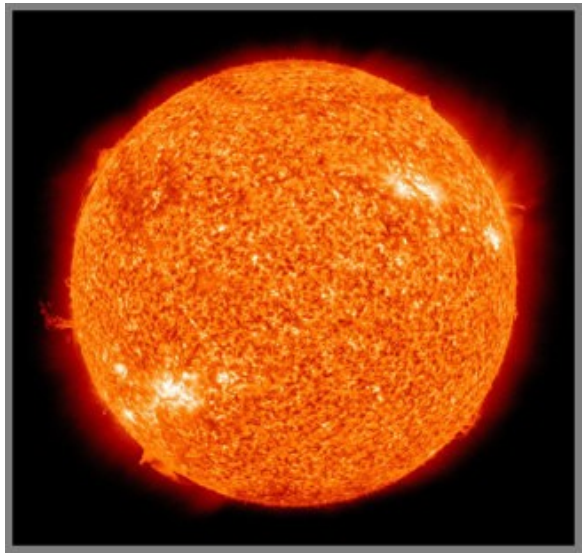
Strong CPV discovery potential

Precision osc. parameter measurements

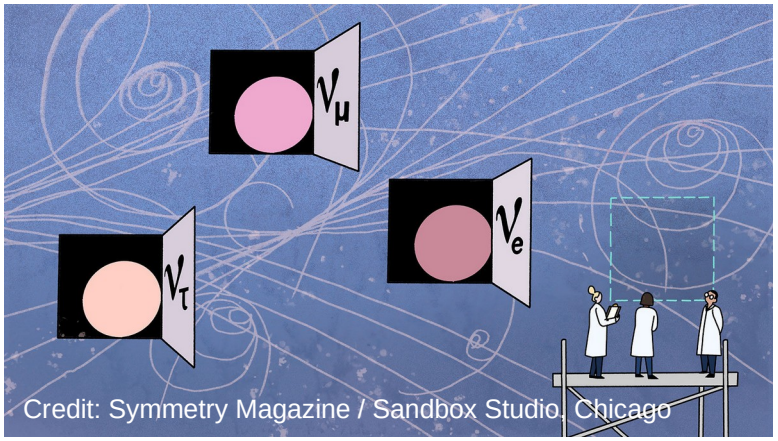


Broad spectral measurements will stress test the U_{PMNS} model – *is anything missing?*

Part of a broader physics program!

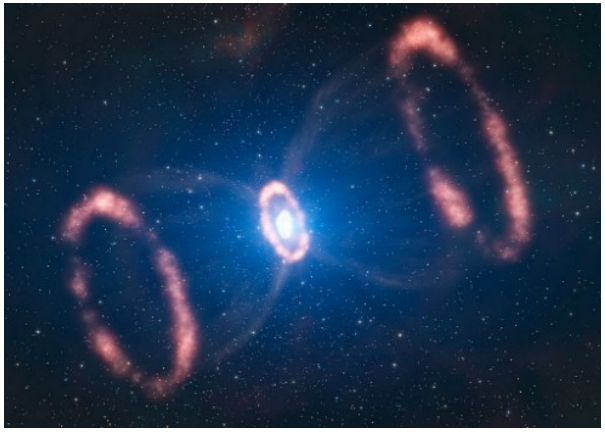


See C. Cuesta Soria's talk (Thursday 15:00)



Credit: Symmetry Magazine / Sandbox Studio, Chicago

Credit: Higgstan



See M. Sanchez's talk (Tuesday 9:30)