DUNE experiment physics

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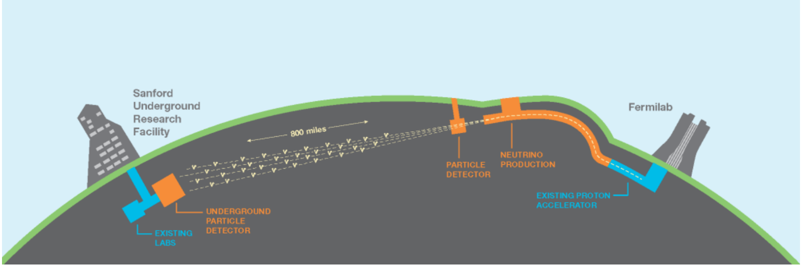
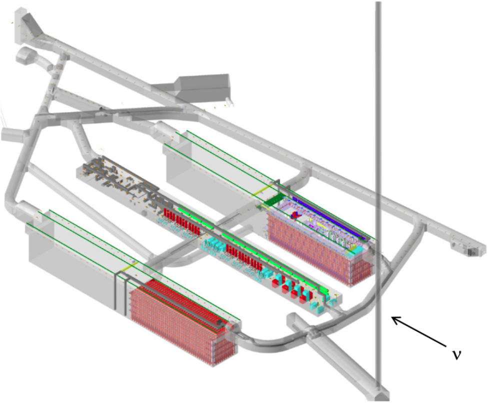
DUNE overview

- Deep Underground Neutrino Experiment
  - Broad-band neutrino beam sent from Fermilab to Sanford Underground Research Facility (baseline of $\sim$ 1300 km)
  - Multi-component near detector (including a liquid argon component)
  - Liquid argon far detector with eventual 68 kt mass (4×17 kt modules)

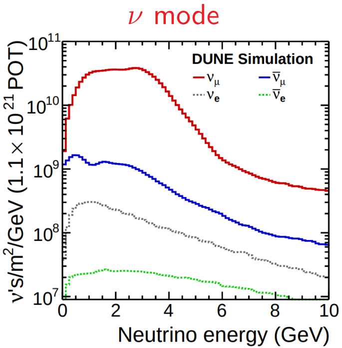


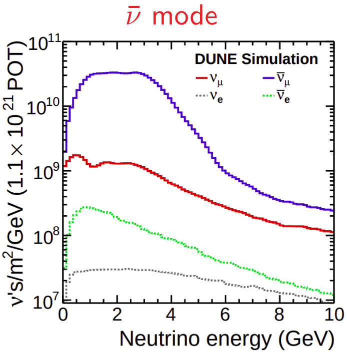
Far detector (FD)

- Far detector is located 1500 m underground at SURF
- Consists of 4 modules, each with a total (fiducial) mass of 17 kt (10 kt)
- The first of these modules will use single-phase technology
- The collaboration is developing single-phase and dual-phase options for the other modules



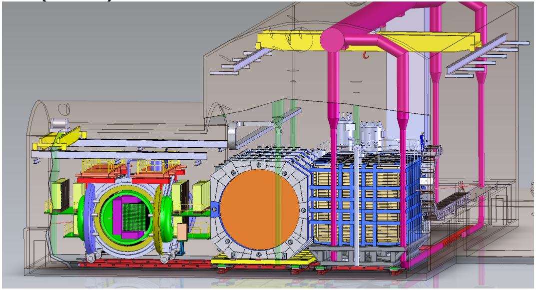
$\nu/\bar{\nu}$ beam





- Beam of mainly ν_μ (when running in neutrino enhanced mode) or mainly $\bar{\nu}_\mu$ (when running in antineutrino enhanced mode)
- Measured in multi-component near detector

Near detector (ND)



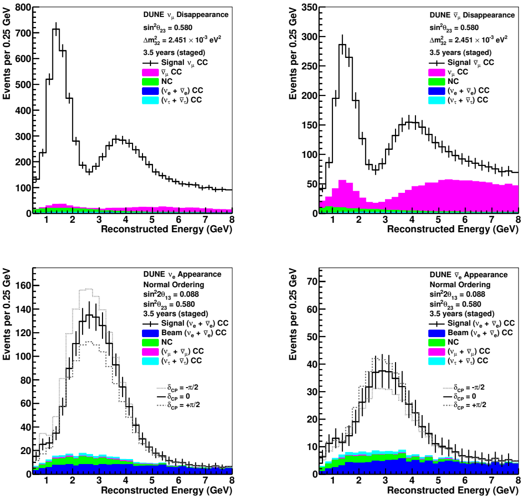
- Neutrino beam measured in multi-component near detector 574 m from target
    - Consists of both a liquid and gaseous argon component and a beam monitor
- Allows characterisation of beam as well as constraining cross-section uncertainties
- See P. Dunne's talk "*Status of the DUNE near detector*" for further details

DUNE physics program

- **Long baseline $\nu/\bar{\nu}$ oscillation physics**
  - Measurement of δ_{CP} and potential CP violation by neutrinos
  - Neutrino mass hierarchy determination, Δm^2
  - Measurements of θ_{23} and θ_{13}
- **Supernova neutrino bursts**
  - C. Cuesta's talk: "*Core-Collapse Supernova Burst Neutrinos in DUNE*"
  - A. J. Roeth's talk: "*Supernova Neutrino Pointing with DUNE*"
- **BSM processes** (see D. Kim's talk: "*BSM Physics Prospects at DUNE*")
  - Nucleon decay (see C. Alt's talk: "*Nucleon decay search at DUNE*")
  - $n - \bar{n}$ oscillation (see Y.-J. Jwa's talk: "*Neutron-antineutron oscillation search with DUNE*")
  - Non-standard interactions
  - Sterile neutrino searches

Long baseline sensitivites

ν mode $\bar{\nu}$ mode



- Far detector samples use full simulation and reconstruction including Convolutional Neural Network for identifying neutrino flavour
- See "*Neutrino interaction classification with a convolutional neural network in the DUNE far detector*" – `arXiv:2006.15052`

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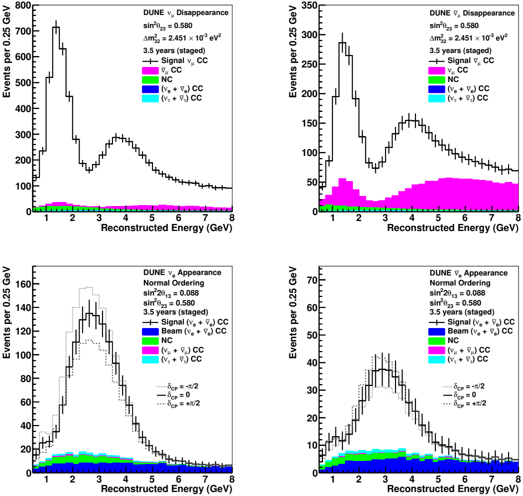
Long baseline sensitivites

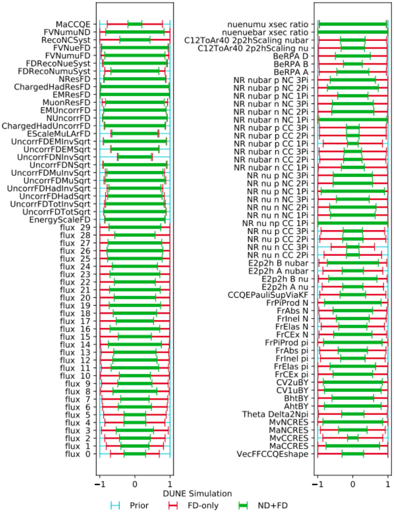
ν mode $\bar{\nu}$ mode



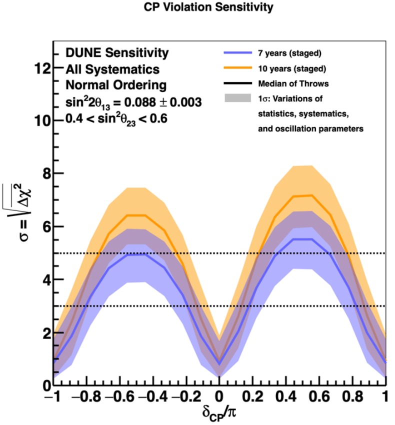
- Sensitivities determined using 4-component fit of FD data along with a constraint from the ND
- Full suite of systematics used
- Full results available in "*Long-baseline neutrino oscillation physics potential of the DUNE experiment*" – `arXiv:2006.16043`
- For Asimovs, NuFit 4.0 best fit points used

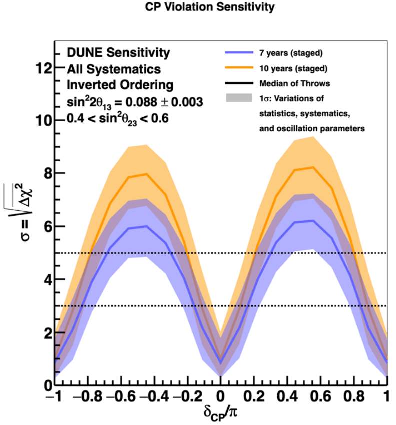
Treatment of systematics

- **Flux**: Vary hadron production models and design parameters of the beamline
- **Neutrino interaction**: Used both reweighting parameters built into neutrino interaction generator (GENIE) as well as custom weightings developed for this analysis
- **Detector**: Uncertainties on detector response for various particle types
- Right: constraint on systematics with and without ND constraint



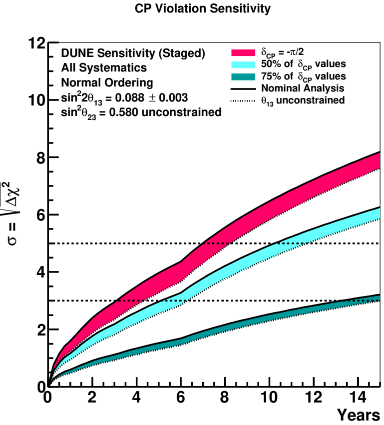
CPV sensitivity





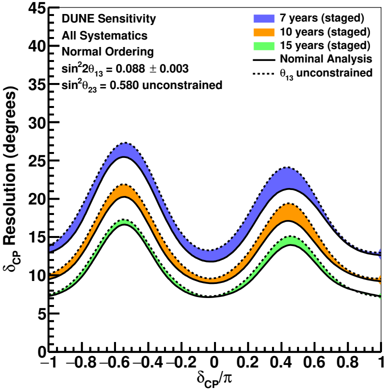
- After 10 years (staged), there is significant CP violation ($\delta_{CP} \neq 0, \pi$) discovery potential across true values of δ_{CP} and for both hierarchies

CPV sensitivity over time



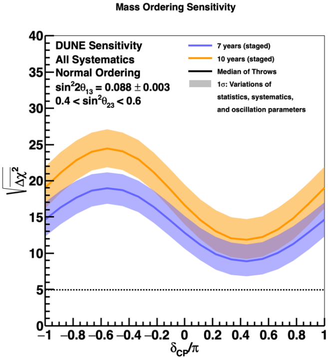
- After 10 years (staged) of running, discovery potential reached for 50% of true δ_{CP}
- After 15 years (staged), evidence of CPV for 75% of δ_{CP} values

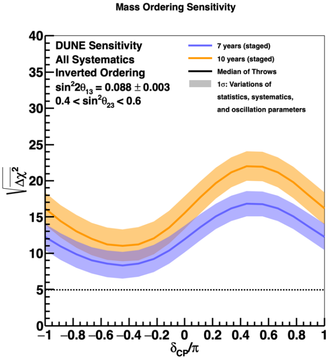
δ_{CP} resolution



- After 10 years (staged) running, δ_{CP} resolution is $10^\circ - 20^\circ$
- Moving to longer exposures, resolution drops to even lower levels

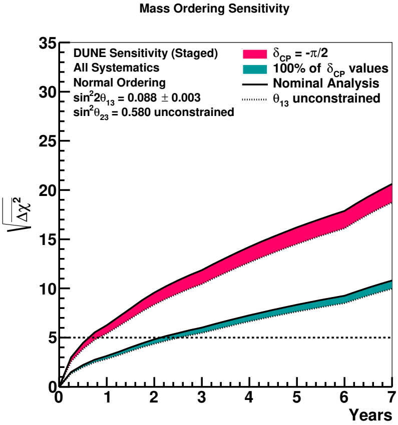
Mass ordering sensitivity





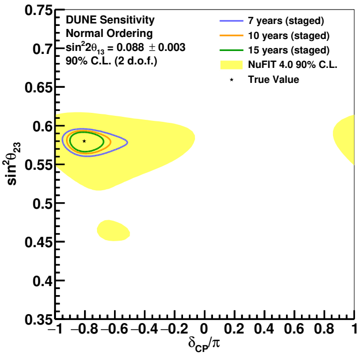
- Obtain a definitive answer for the mass hierarchy within 7 years (staged), regardless of the values of the other oscillation parameters

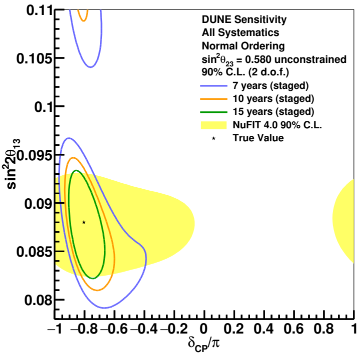
Mass ordering sensitivity over time



- After 2 years, for all values of δ_{CP} the mass ordering is measured to 5σ

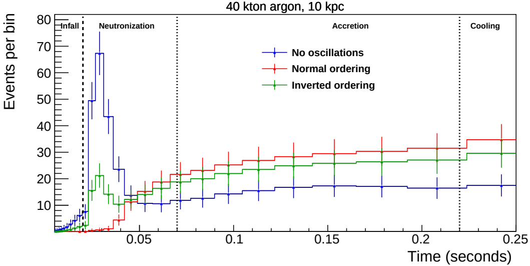
Precision measurements of θ_{23} and θ_{13}





- DUNE will allow a precision measurement of the value of θ_{23} which will exceed the current limits
- After 15 years (staged) of running, DUNE's θ_{13} measurement will be comparable with reactor experiments

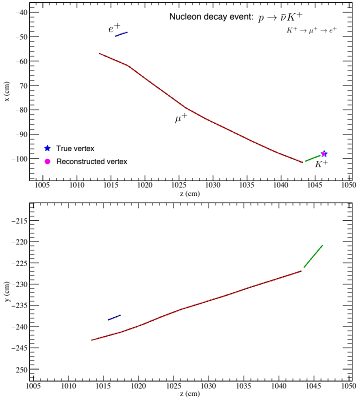
Supernova neutrino bursts



- DUNE will also be sensitive to neutrinos emitted by a galactic core-collapse supernova
  - Primarily through channel: $\nu_e + ^{40}\text{Ar} \rightarrow e^- + ^{40}K^*$
  - Not only will this provide information about the physics of supernova core-collapse but it could also give some hints about the oscillation physics
  - Upcoming paper: "*Supernova Neutrino Burst Detection with the Deep Underground Neutrino Experiment*"

Beyond the standard model physics

- **Nucleon decay**
  - Large far detector mass allows searches for proton decay
  - DUNE will be especially sensitive to the decay channel $p \to K^+\bar{\nu}$
- **Non-standard interactions**
  - Non-standard matter effects may be visible in the DUNE far detector due to the long baseline
- Many other prospects detailed in upcoming paper: "*Prospects for Beyond the Standard Model Physics Searches at the Deep Underground Neutrino Experiment*"



Summary

- DUNE will enable an exciting physics program
  - Measurement of possible CPV in lepton sector
  - Measurement of neutrino mass hierarchy
  - Precision measurements of other oscillation parameters
  - Supernova neutrino burst physics
  - Many BSM searches
- DUNE FD Technical Design Report Volume II (arXiv:2002.03005) contains more details on physics possibilities
- Series of publications either available or planned which are made up of parts of this volume of the TDR
- **22 other DUNE talks at ICHEP this year**

Backup

Assumed staging plan

- Start of beam run: two FD module volumes for total fiducial mass of 20 kt, 1.2 MW beam
- After 1 year: add one FD module volume for total fiducial mass of 30 kt
- After 3 years: add one FD module volume for total fiducial mass of 40 kt
- After 6 years: upgrade to 2.4 MW beam
- 50%/50% ratio of neutrino to antineutrino data assumed

NuFit 4.0 Parameters

		Normal Ordering (best fit)		Inverted Ordering ($\Delta\chi^2 = 4.7$)	
		bfp $\pm 1\sigma$	3σ range	bfp $\pm 1\sigma$	3σ range
without SK atmospheric data	$\sin^2\theta_{12}$	$0.310^{+0.013}_{-0.012}$	$0.275 \to 0.350$	$0.310^{+0.013}_{-0.012}$	$0.275 \to 0.350$
	$\theta_{12}/^\circ$	$33.82^{+0.78}_{-0.76}$	$31.61 \to 36.27$	$33.82^{+0.78}_{-0.76}$	$31.61 \to 36.27$
	$\sin^2\theta_{23}$	$0.580^{+0.017}_{-0.021}$	$0.418 \to 0.627$	$0.584^{+0.016}_{-0.020}$	$0.423 \to 0.629$
	$\theta_{23}/^\circ$	$49.6^{+1.0}_{-1.2}$	$40.3 \to 52.4$	$49.8^{+1.0}_{-1.1}$	$40.6 \to 52.5$
	$\sin^2\theta_{13}$	$0.02241^{+0.00065}_{-0.00065}$	$0.02045 \to 0.02439$	$0.02264^{+0.00066}_{-0.00066}$	$0.02068 \to 0.02463$
	$\theta_{13}/^\circ$	$8.61^{+0.13}_{-0.13}$	$8.22 \to 8.99$	$8.65^{+0.13}_{-0.13}$	$8.27 \to 9.03$
	$\delta_{CP}/^\circ$	215^{+40}_{-29}	$125 \to 392$	284^{+27}_{-29}	$196 \to 360$
	$\frac{\Delta m^2_{21}}{10^{-5}\ \text{eV}^2}$	$7.39^{+0.21}_{-0.20}$	$6.79 \to 8.01$	$7.39^{+0.21}_{-0.20}$	$6.79 \to 8.01$
	$\frac{\Delta m^2_{3\ell}}{10^{-3}\ \text{eV}^2}$	$+2.525^{+0.033}_{-0.032}$	$+2.427 \to +2.625$	$-2.512^{+0.034}_{-0.032}$	$-2.611 \to -2.412$

- NuFIT 4.0 (2018), www.nu-fit.org, JHEP 01 (2019) 106 – arXiv:1811.05487