BERKELEY LAB

Accelerator Neutrino Oscillation Experiments: This Generation and Next

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Snowmass Community Summer Study

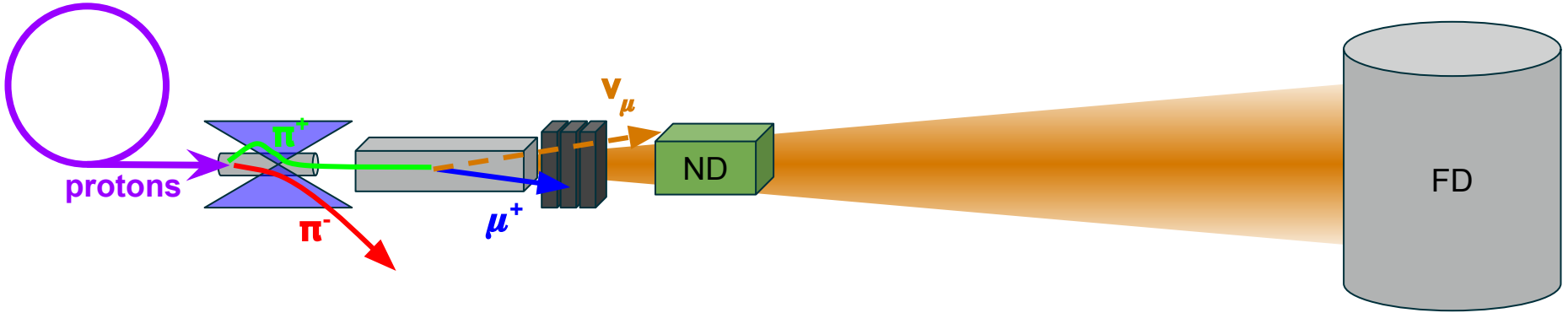
Early Career Session

Introduction

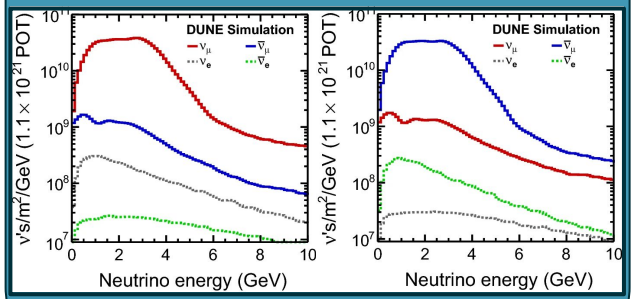
- Operating long-baseline accelerator neutrino oscillation experiments will transition into the next generation of experiments in the next decade
  - This generation: T2K + NOvA
  - Next generation: T2HK + DUNE
  - Both pairs of experiments offer complementary
  - Getting the most information out of the data sets from the current generation of such experiments is an important exercise that can inform the process of bringing up the next generation of experiments

- Disclaimer: I am a T2K and DUNE collaborator, but I am speaking today as a(n early career) member of the Neutrino community.

Long-Baseline Accelerator Neutrino Oscillations

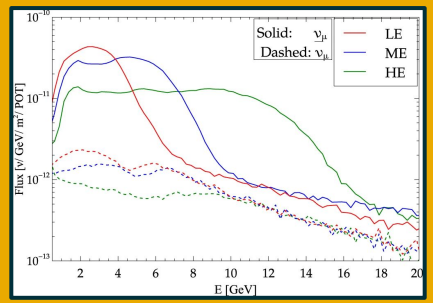


Operate in ν OR ν̄ mode



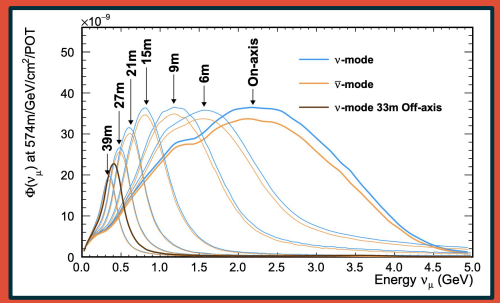
Abi, B., Acciarri, R., Acero, M.A. et al. Long-baseline neutrino oscillation physics potential of the DUNE experiment. Eur. Phys. J. C 80, 978 (2020)

Tunable neutrino source



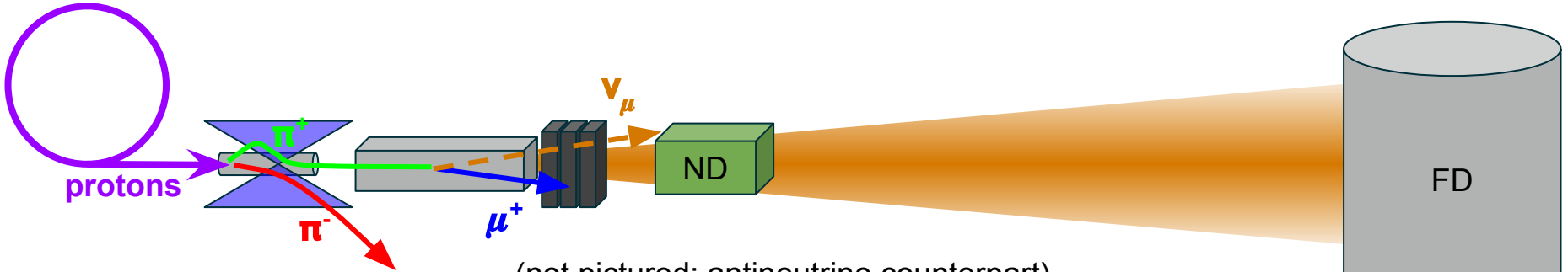
Masud, M., Bishai, M. & Mehta, P. Extricating New Physics Scenarios at DUNE with Higher Energy Beams. Sci Rep 9, 352 (2019)

The off-axis "trick"

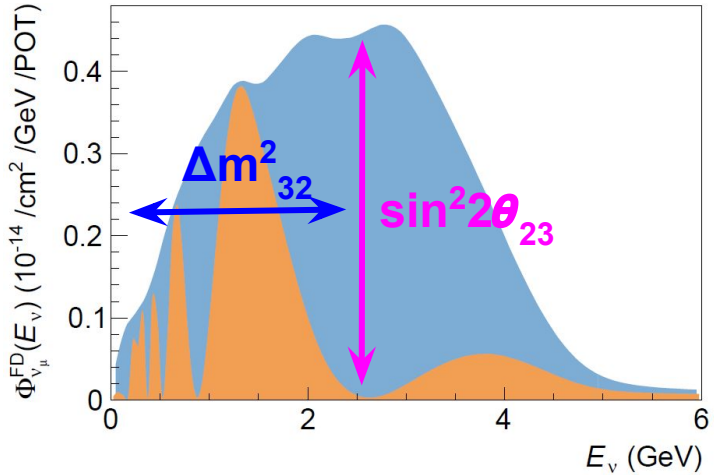


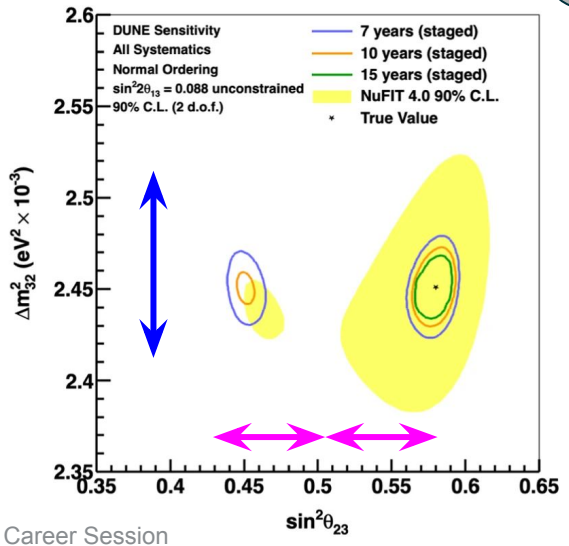
Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume II: DUNE Physics. arXiv:2002.03005

Long-Baseline Accelerator Neutrino Oscillations

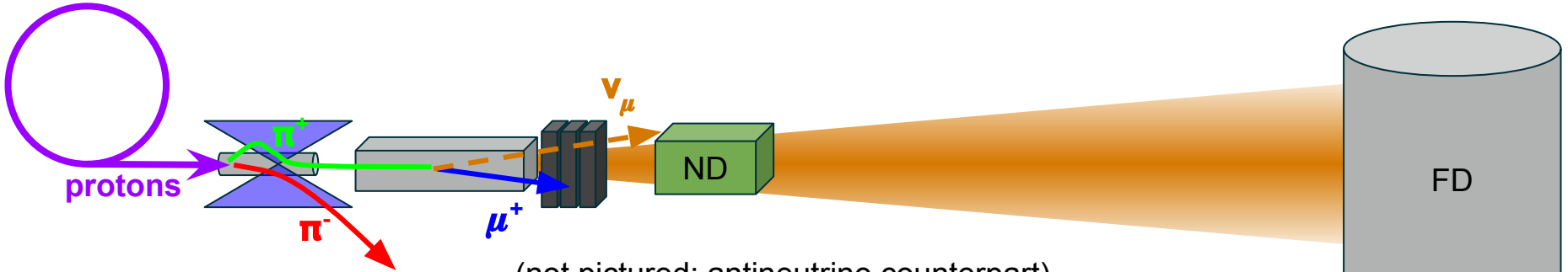


(not pictured: antineutrino counterpart)





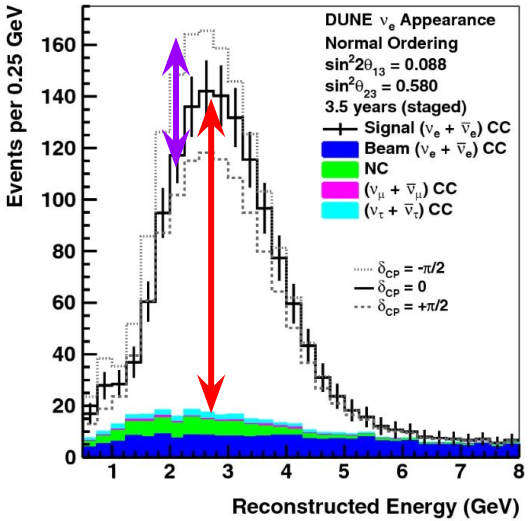
Long-Baseline Accelerator Neutrino Oscillations

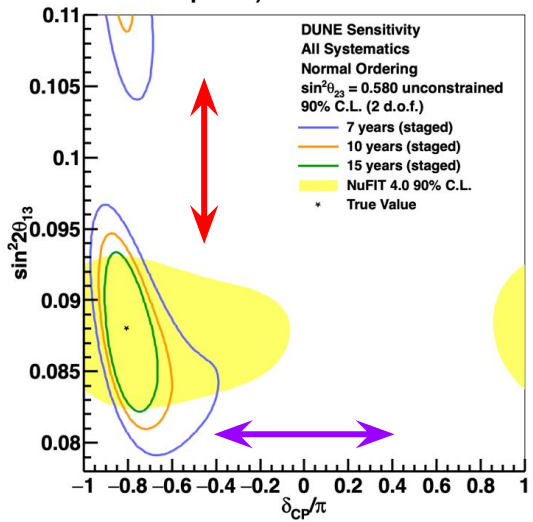


(not pictured: antineutrino counterpart)

δ_{CP}

$\sin^2\theta_{23}$ & $\sin^2\theta_{13}$





Current Generation Experiments

T2K	NOvA
Flux peak ~600 MeV	Flux peak ~2 GeV
295 km baseline	810 km baseline
CCQE dominant interaction mode	Broad mix of interaction modes
Reconstruct energy from lepton kinematics	Calorimetric energy reconstruction
FD 2.5° off axis	FD 1.5° off axis
Different ND and FD technologies	Functionally identical ND and FD
ND constrains systematics in the model (*fit*)	ND *tunes* FD pred. without fitting

Current Generation Experiments

T2K far site

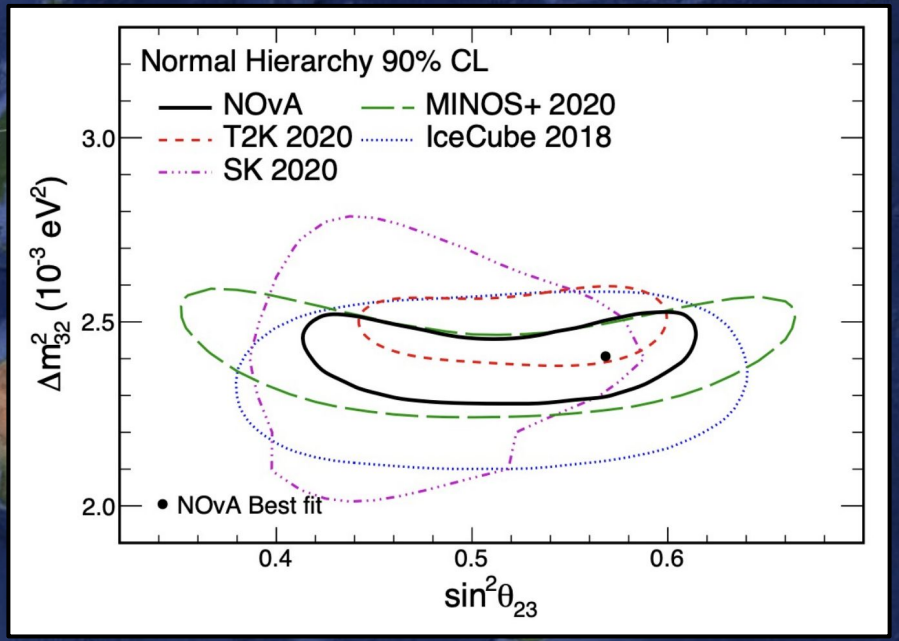
T2K near site

Japan

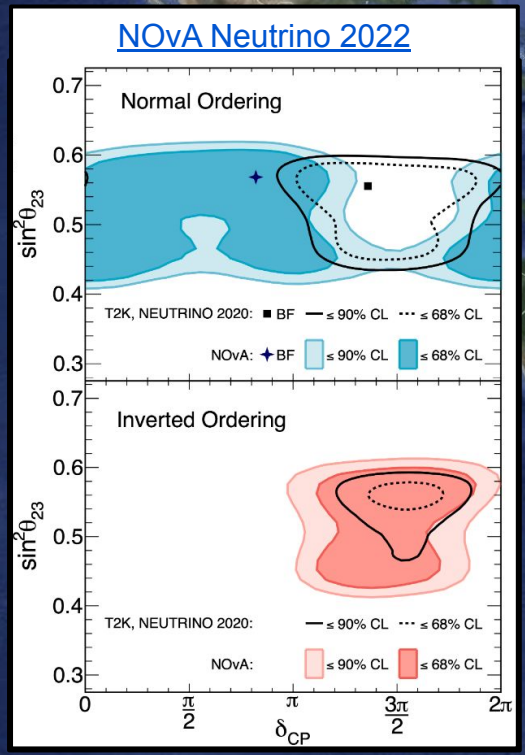
NOvA far site

NOvA near site

USA



NOvA Neutrino 2022



Current Generation Experiments

NOvA far site

NOvA near site

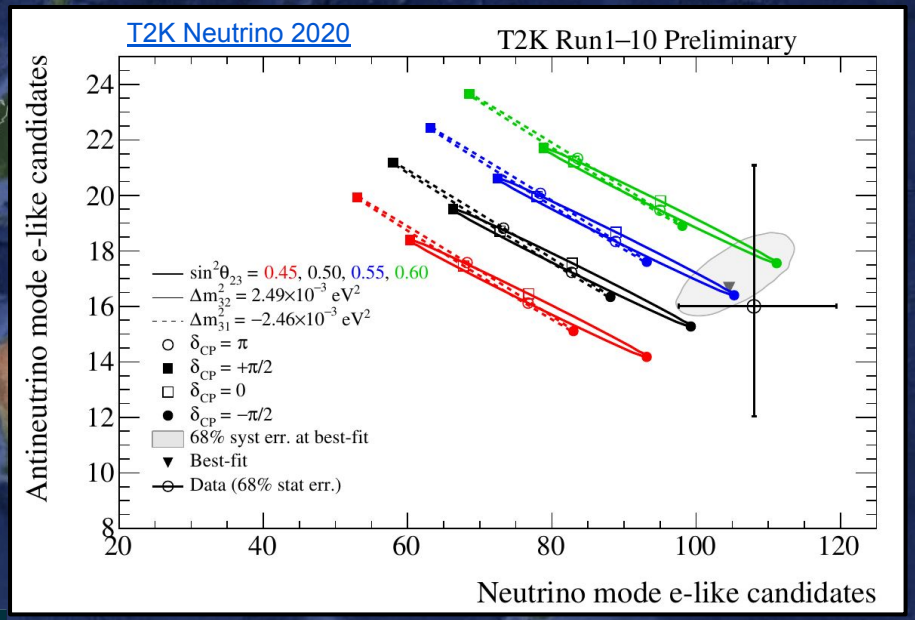
USA

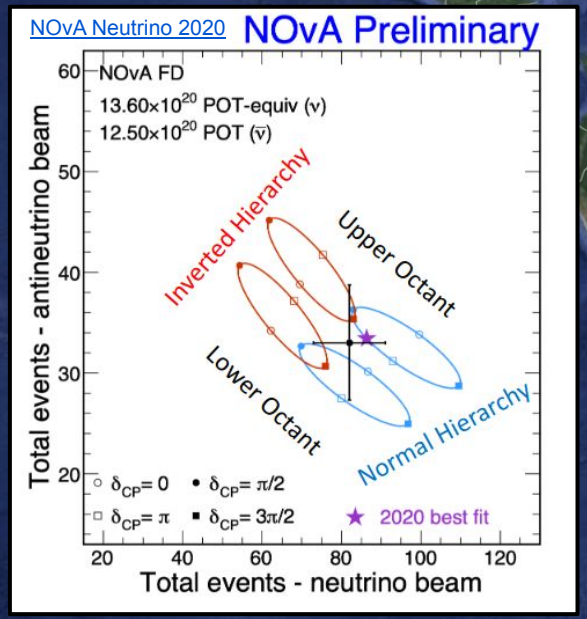
T2K far site

T2K near site

Japan

Complementarity that breaks degeneracies otherwise present in standalone experiments.





Current Generation Experiments

T2K far site

T2K near site

Japan

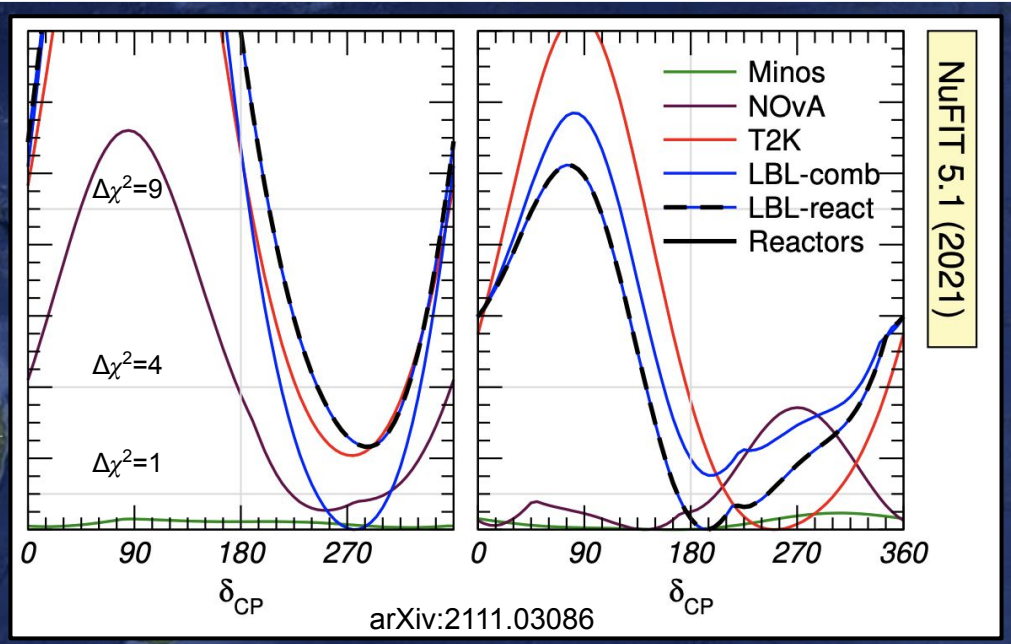
NOvA far site

NOvA near site

USA

Complementarity that breaks degeneracies otherwise present in standalone experiments.

Inverted ordering



Normal ordering

Current Generation Experiments

NOvA far site

NOvA near site

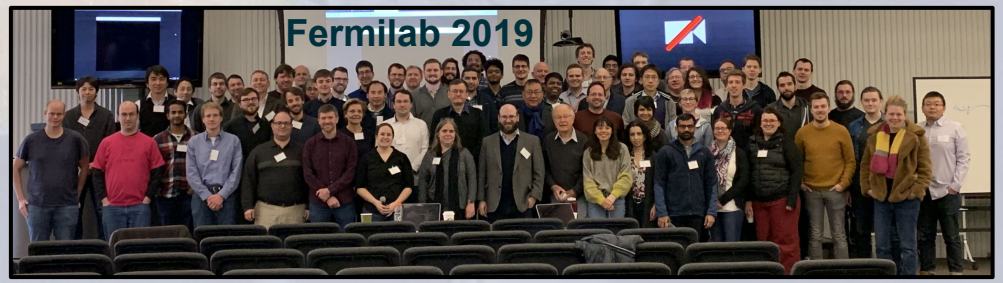
USA

T2K far site

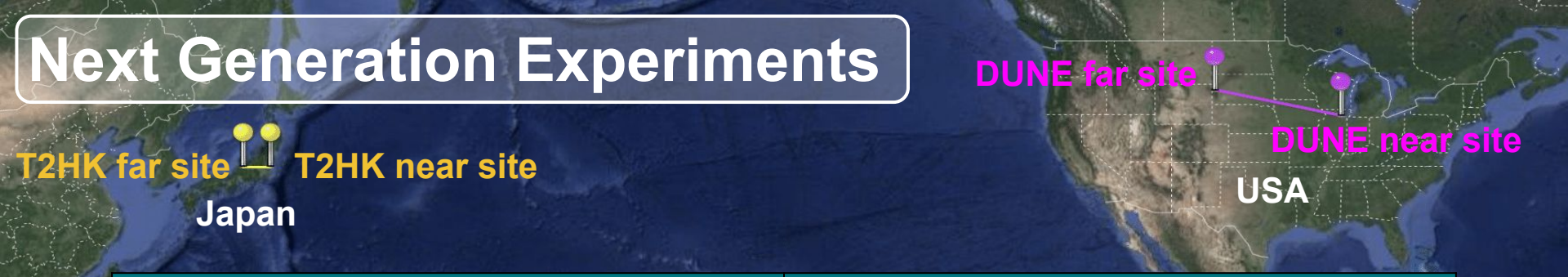
T2K near site

Japan

- NOvA and T2K collaborations pursuing joint analysis
- Exploit the aforementioned complementarity and leverage all of the sophisticated analysis tools/considerations from each standalone experiment
- Targeting a release this year - stay tuned!



Next Generation Experiments



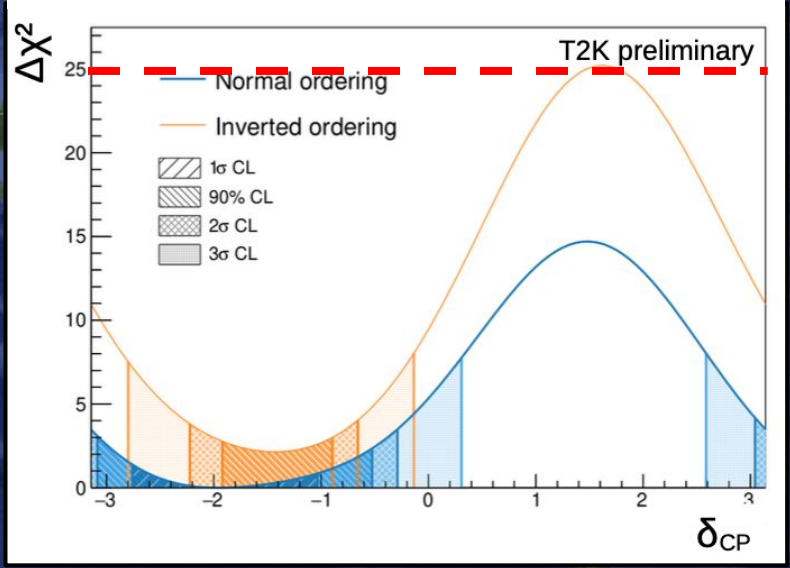
T2HK	DUNE
Flux peak ~600 MeV, narrow band	Broad band beam up to ~5 GeV
295 km baseline	1300 km baseline
CCQE dominant interaction mode	Broad mix of interaction modes
FD 2.5° off axis	FD on axis
Water Cherenkov FD (258 kton total H_2O)	LArTPC FD (1st two modules)
1.3 MW beam	1.2 MW → 2.4 MW beam
ND280 upgrade, IWCD + PRISM concept	Performant ND complex + PRISM concept

Next Generation Experiments

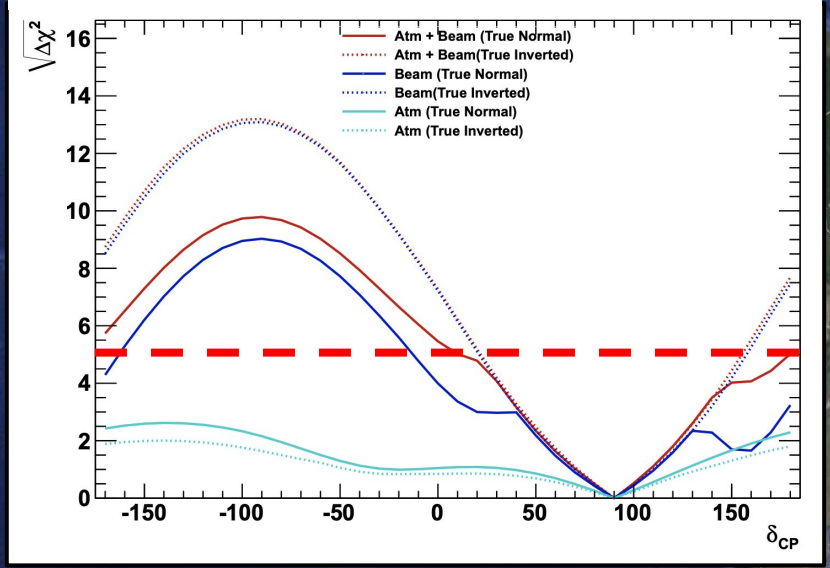
T2HK far site
T2HK near site
Japan

DUNE far site
DUNE near site
USA

T2K Neutrino 2022 (data)



T2HK Asimov (true dcp = 90°, NH assumed)



Next Generation Experiments

DUNE far site

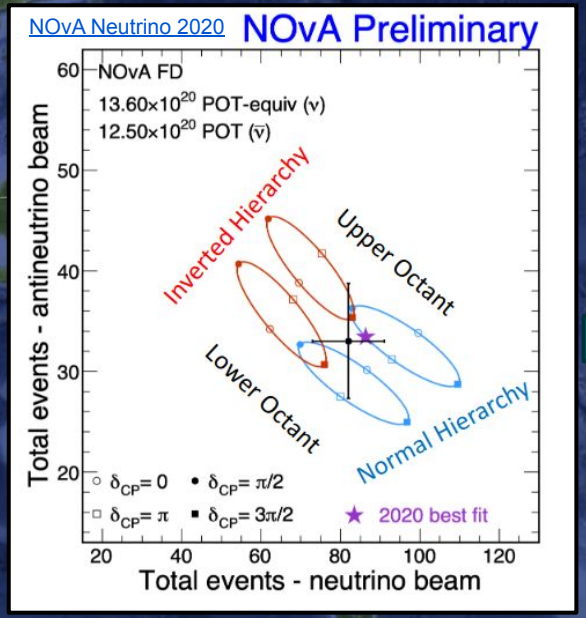
DUNE near site

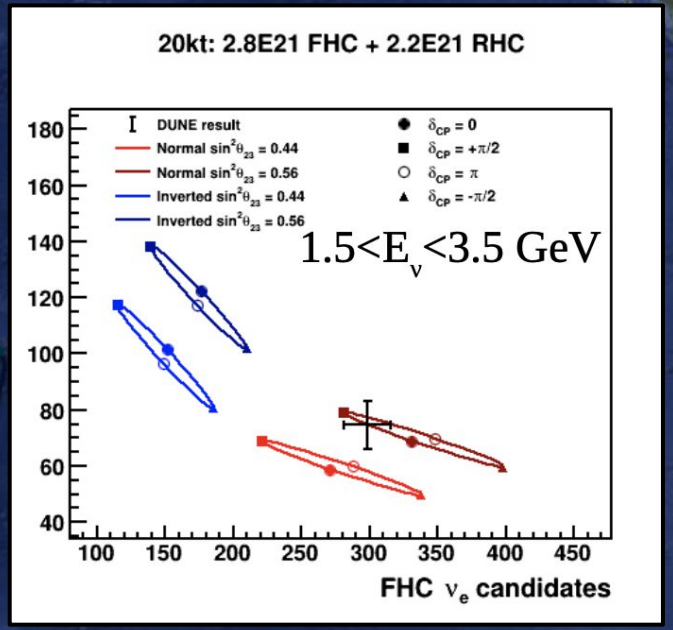
USA

T2HK far site

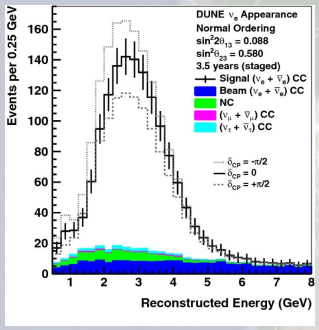
T2HK near site

Japan





NB: DUNE'S wideband beam offers more oscillation information in it's spectral shape than shown here.



Next Generation Experiments

DUNE far site

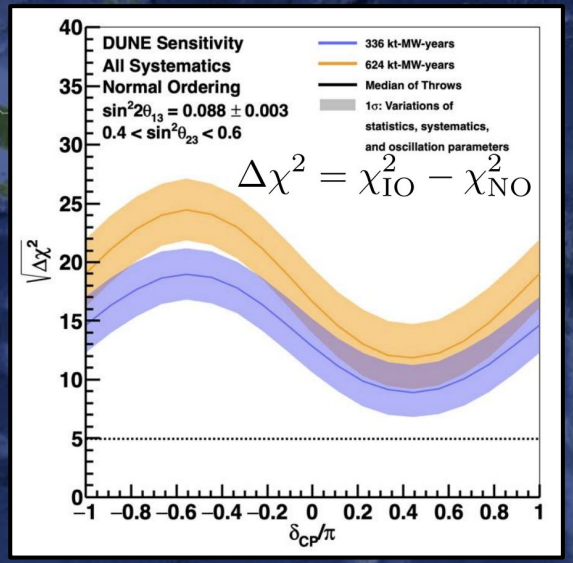
DUNE near site

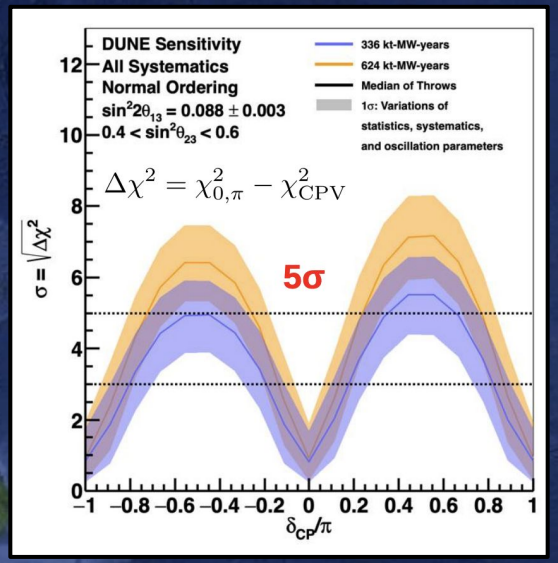
USA

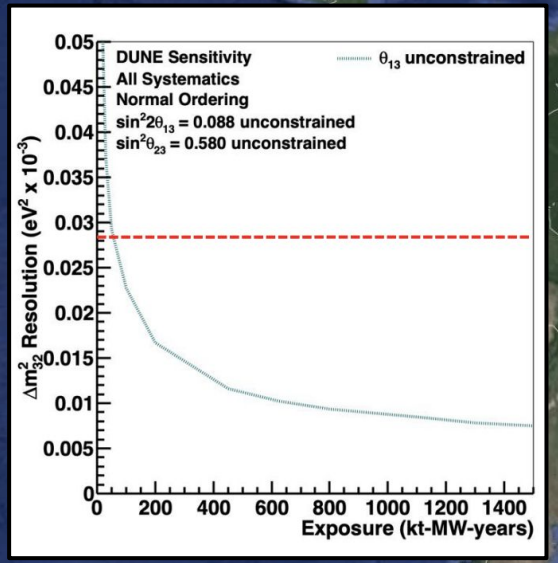
T2HK far site

T2HK near site

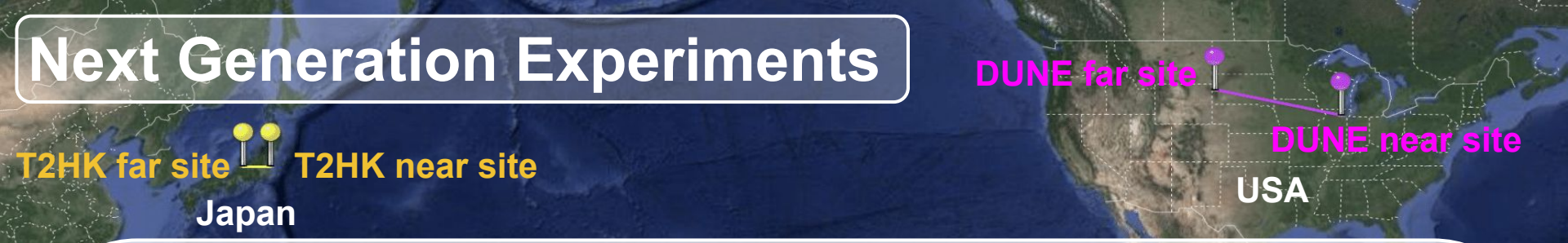
Japan







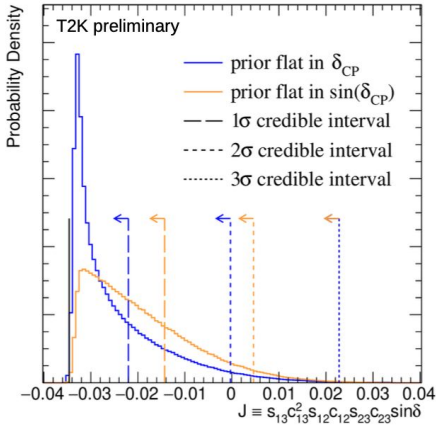
Next Generation Experiments

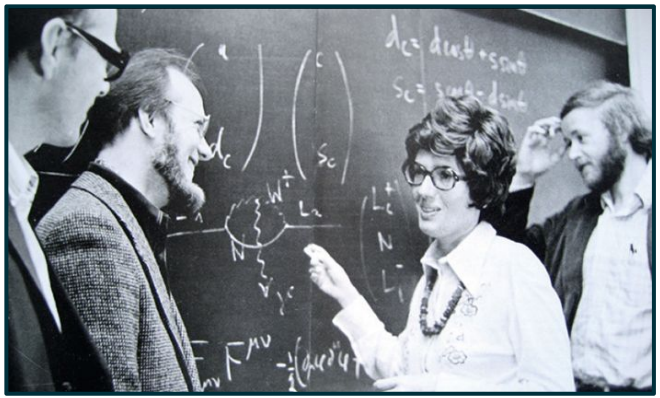


- Intense neutrino beams and massive far detectors will enable unprecedented statistics → systematics all the more crucial
- Complementarity, much like that of NOvA and T2K, becomes even more powerful
  - Mass ordering from DUNE break degeneracies in T2HK appearance rates
  - Different systematics; extra scrutiny when comparing oscillation results (a great thing!)
  - If ∃ NSI, would manifest in the signals differently due to very different baselines
  - Different sensitivities to different oscillation parameters can be leveraged in joint analysis
  - Highly complementary physics programs outside of 3-flavor oscillations as well

Closing

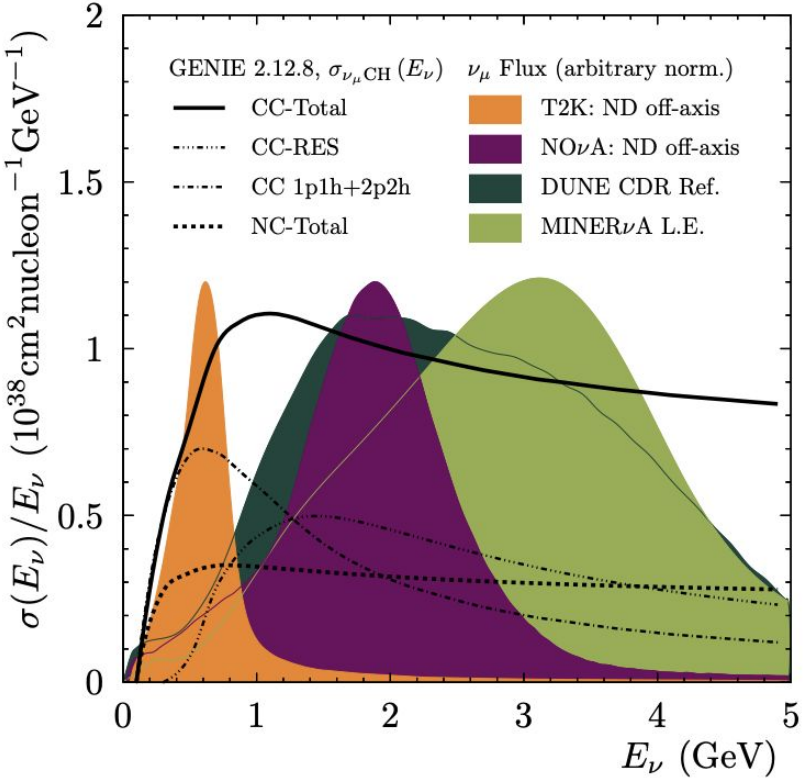
- In the precision era of LBL accelerator **ν** oscillation experiments, firm understanding of systematics (incl. e.g. NSI) will be all the more crucial
  - Multiple, complementary experiments helps
  - Current generation of experiments offers a great testbed
- Listening to our colleagues on the theoretical/phenomonological side about how to best communicate results from our data





Backup

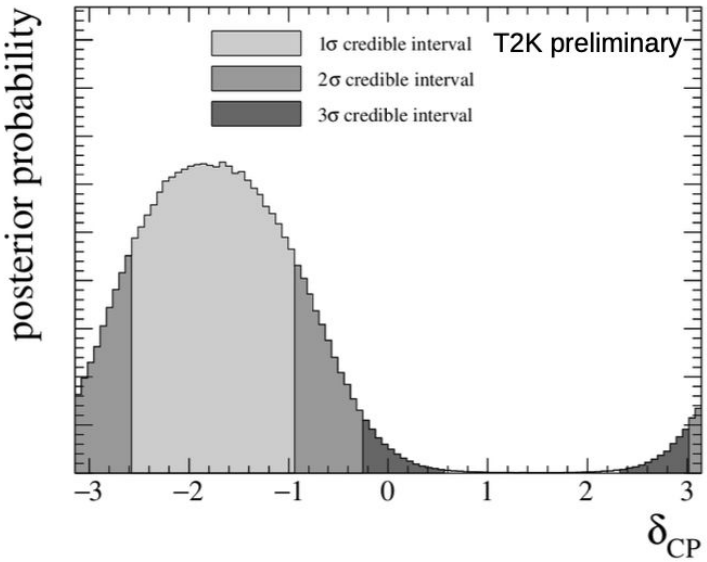
Accelerator Neutrino Fluxes

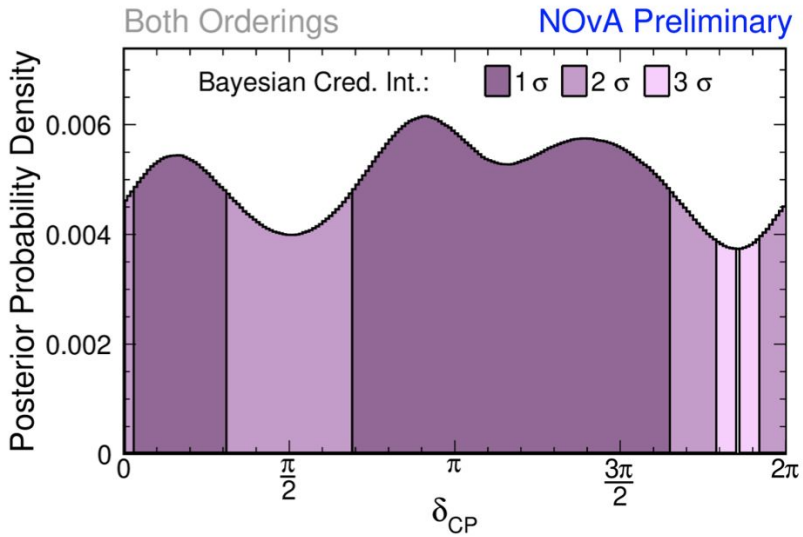


K. Mahn, C. Marshall, & C. Wilkinson, Progress in Measurements of 0.1–10 GeV Neutrino–Nucleus Scattering and Anticipated Results from Future Experiments. Annual Review of Nuclear and Particle Science 68:1, 105-129 (2018).

δ_{CP} results marginalized over hierarchy

@ Neutrino 2022





NOTE: Different convention for δ_{CP} range (which is 2π periodic)