WG1: Neutrino Oscillation Summary

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NuFact 2024, September 21st, 2024

WG1 Talks

- 11 related plenary talks, 28 talks in parallel sessions + multi-experiment analyses satellite workshop

Mon: Current experiment results (5)

Tue: Future experiment sensitivities (5)

Tue: Near detectors in oscillation analyses (4)

Thu: WG 1x3 Neutrino fluxes (4)

Thu: WG 1x5 BSM → WG5 summary (5)

Fri: New ideas (5)

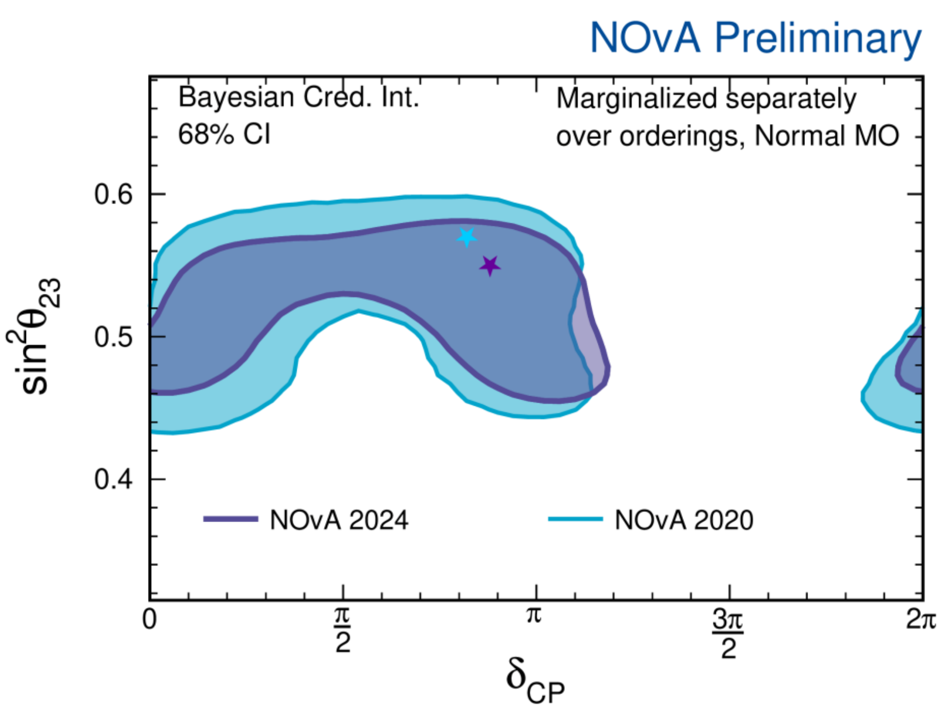
What are the current and future systematic limitations on oscillation measurements and what can we do to address them?

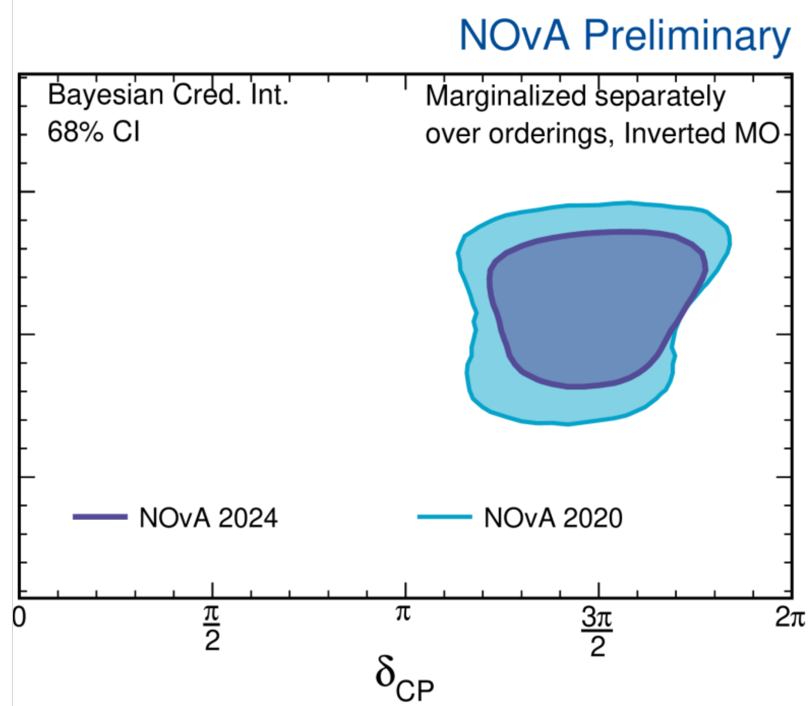
How can we best combine experimental data to achieve the most accurate results?

What are the needs for hadron production measurements for the future experiments?

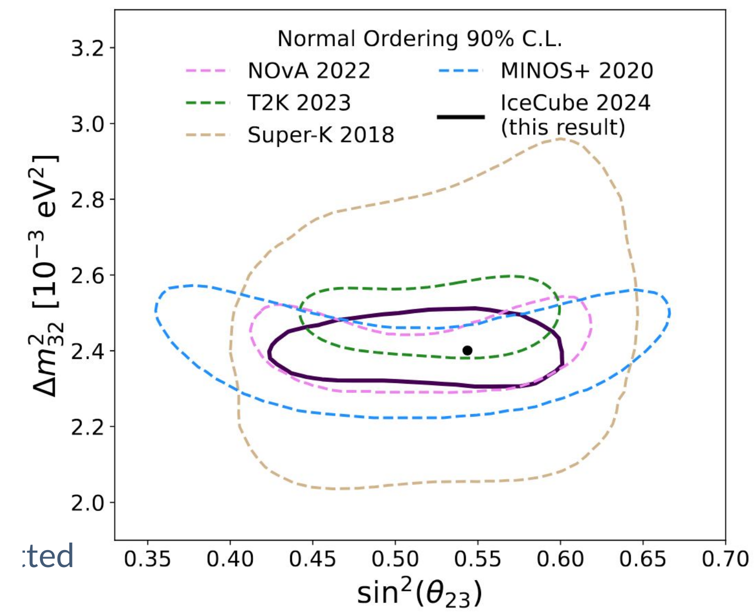
What are the next steps for a unitarity test?

Current Results





IceCube DeepCore

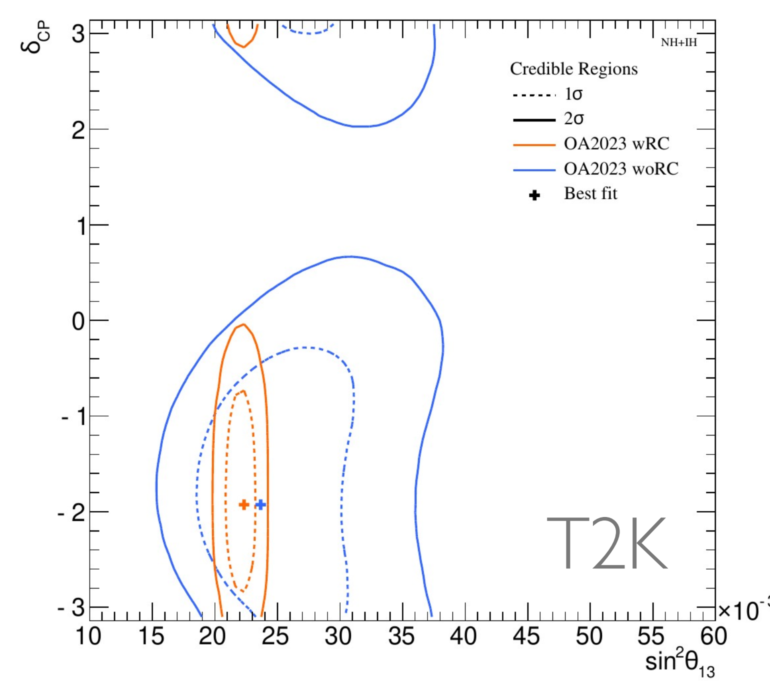


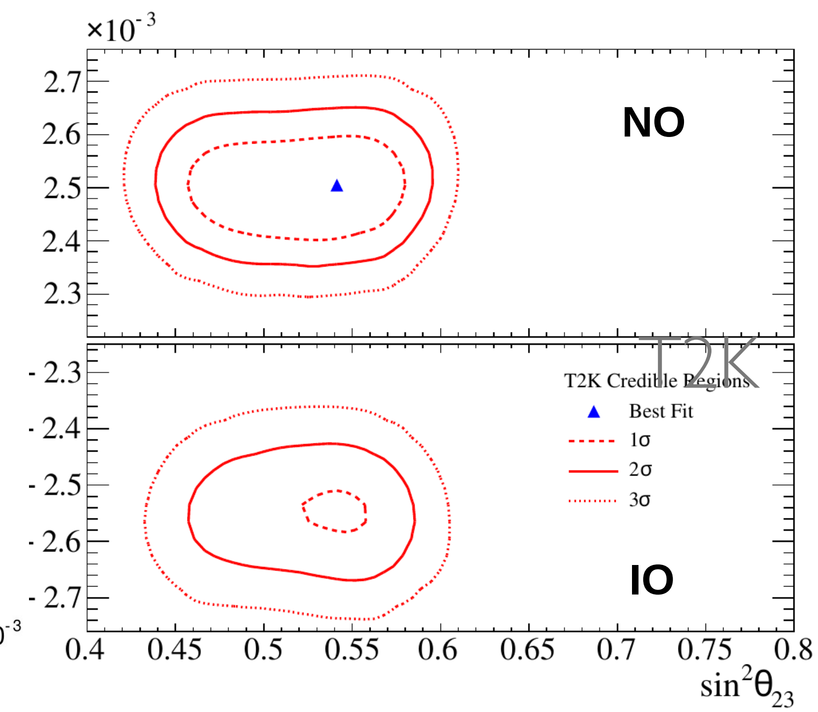
NOvA: J. Trokan-Tenorio

T2K: E. Atkin

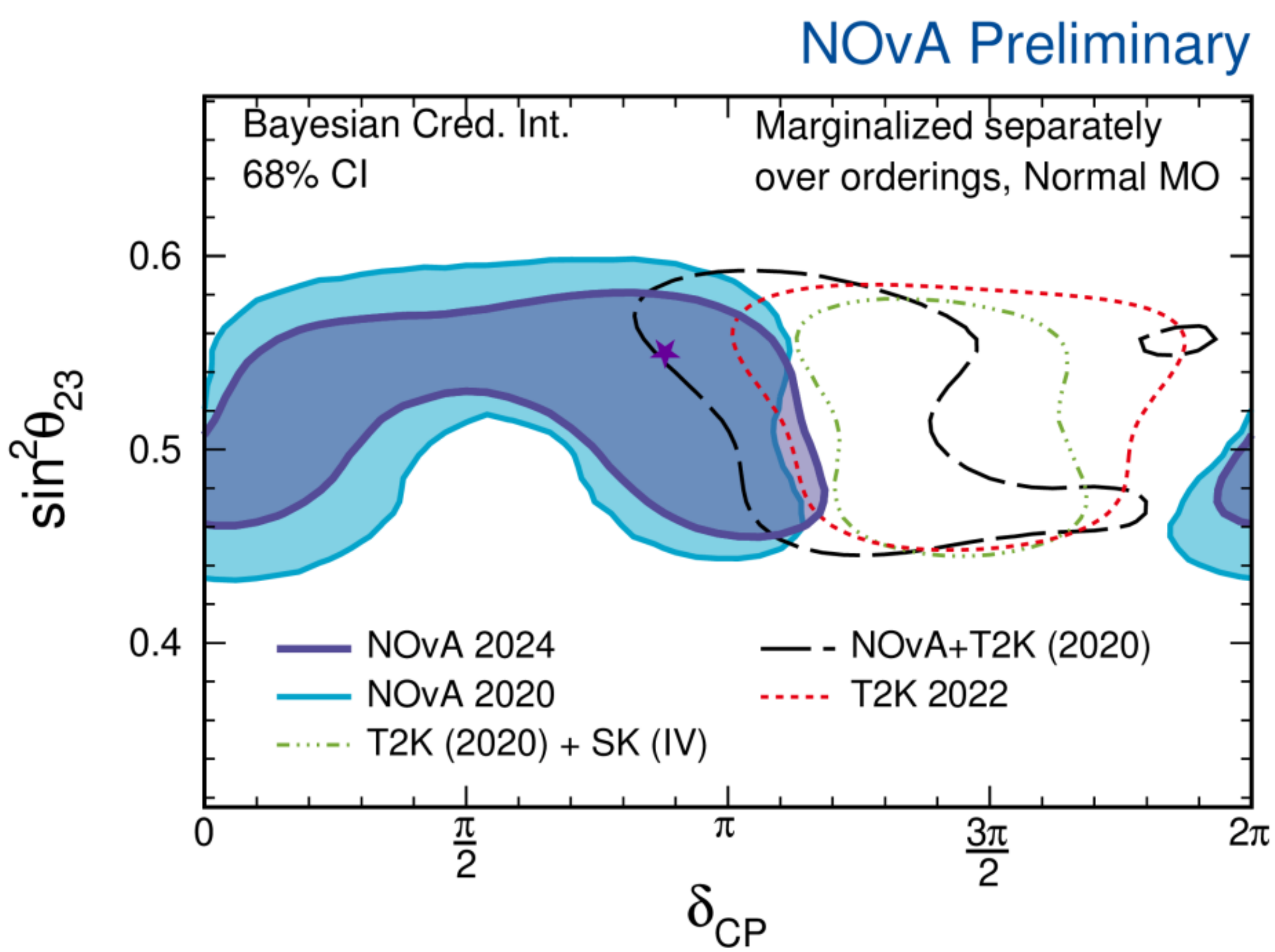
IceCube DeepCore: F. Mayhew

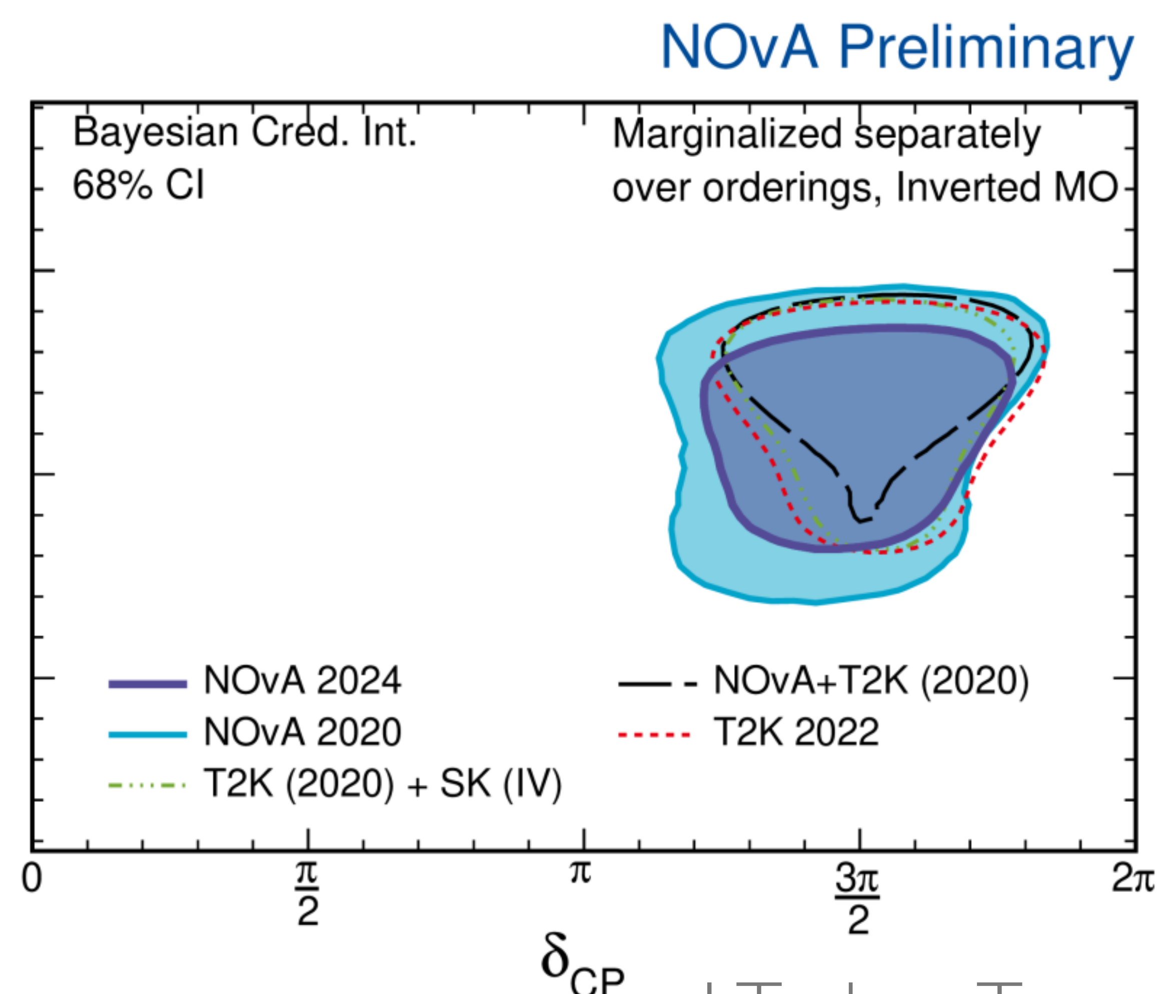
All favor normal mass ordering





Comparison





J. Trokan-Tenorio

NOvA and T2K prefer similar regions with the inverted mass ordering, but different regions with the normal mass ordering

Mass Ordering Sum Rule

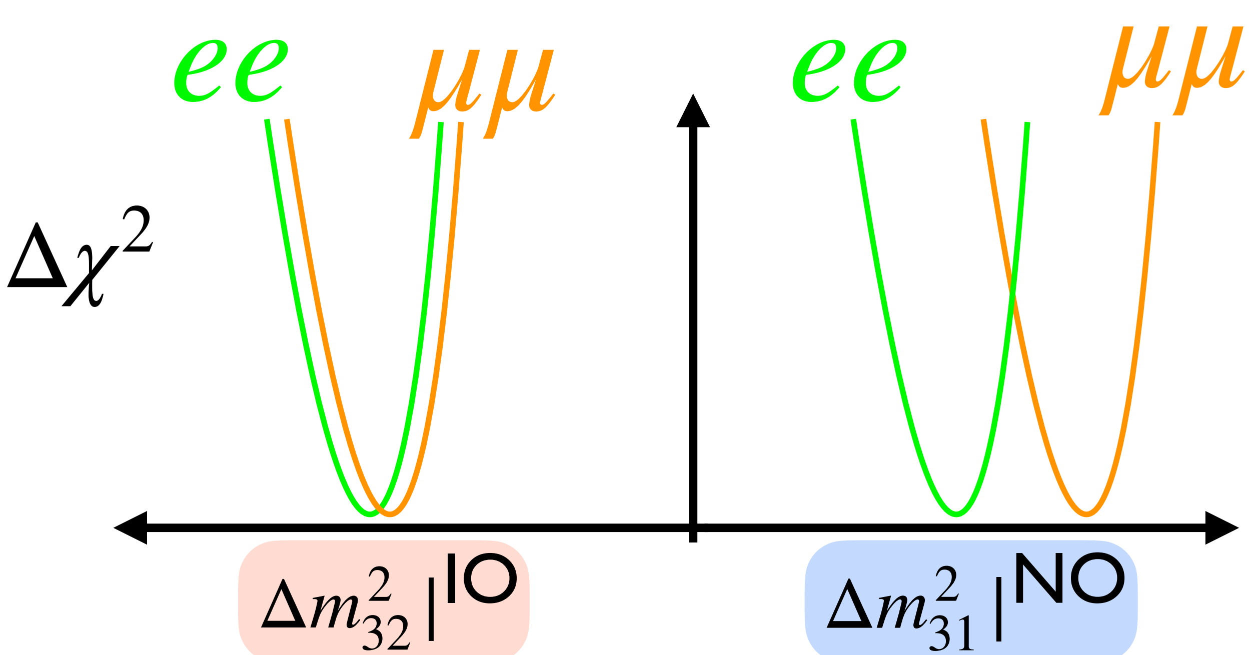
$$\left(\Delta m^2_{31}|^{\text{NO}}_{\mu\ \text{disp}} - \Delta m^2_{31}|^{\text{NO}}_{e\ \text{disp}}\right) + \left(|\Delta m^2_{32}|^{\text{IO}}_{e\ \text{disp}} - |\Delta m^2_{32}|^{\text{IO}}_{\mu\ \text{disp}}\right) = \left(2\cos 2\theta_{12} - 2\sin\theta_{13}\,\widehat{\cos\delta}\,\right)\Delta m^2_{21}$$

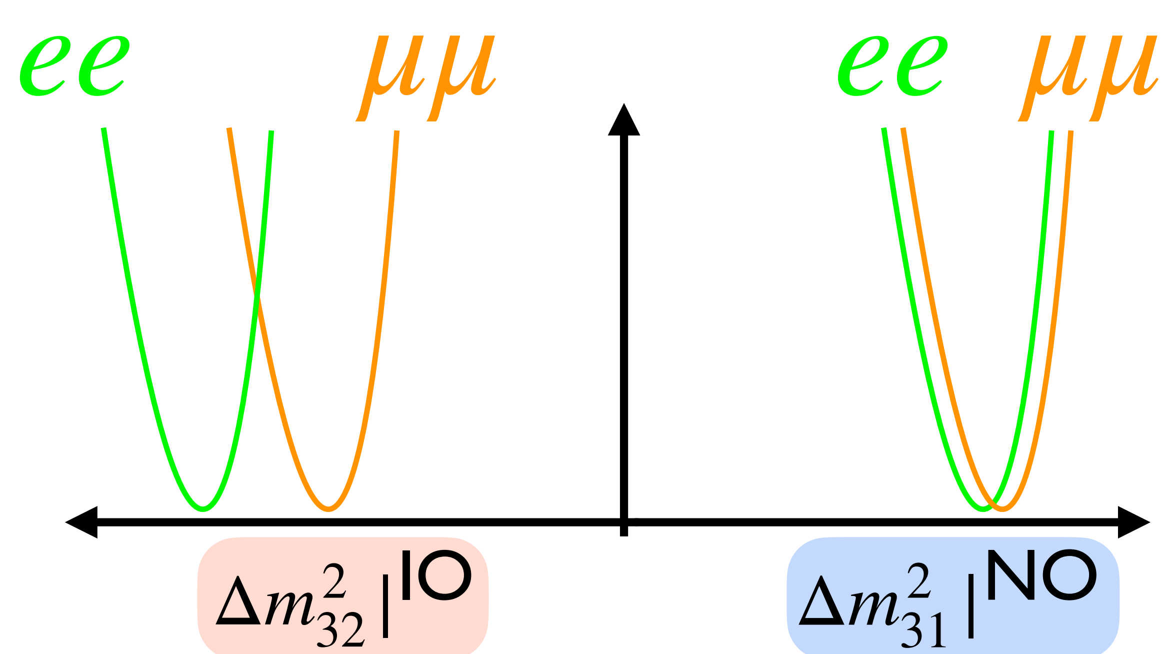
S. Parke

Significant with current precision

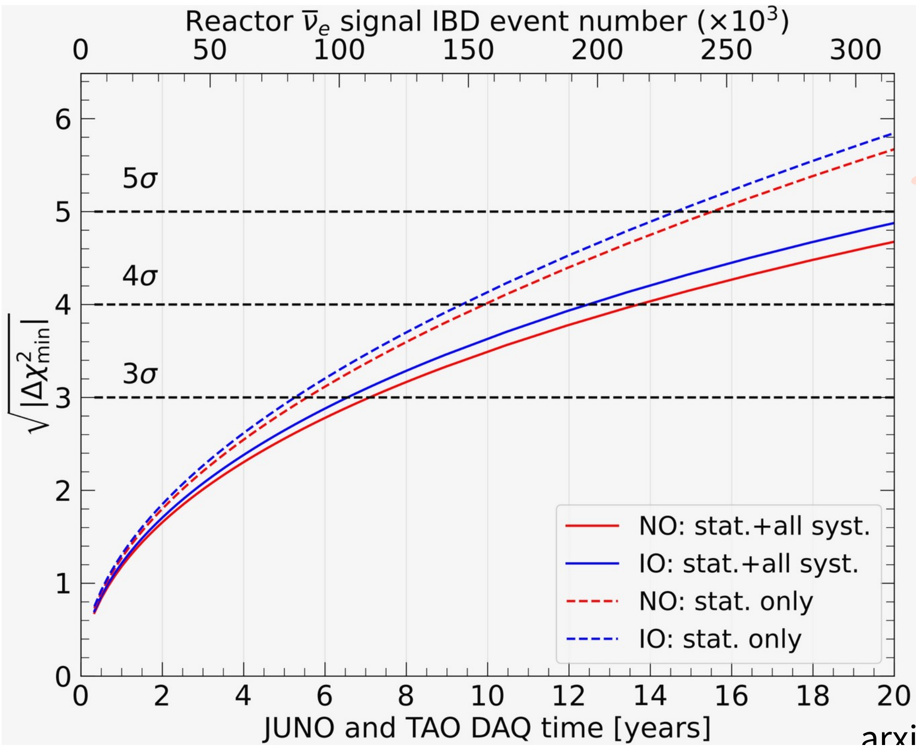
If Nature is IO, [blue] ≃ [yellow]

If Nature is NO, [red] ≃ [yellow]



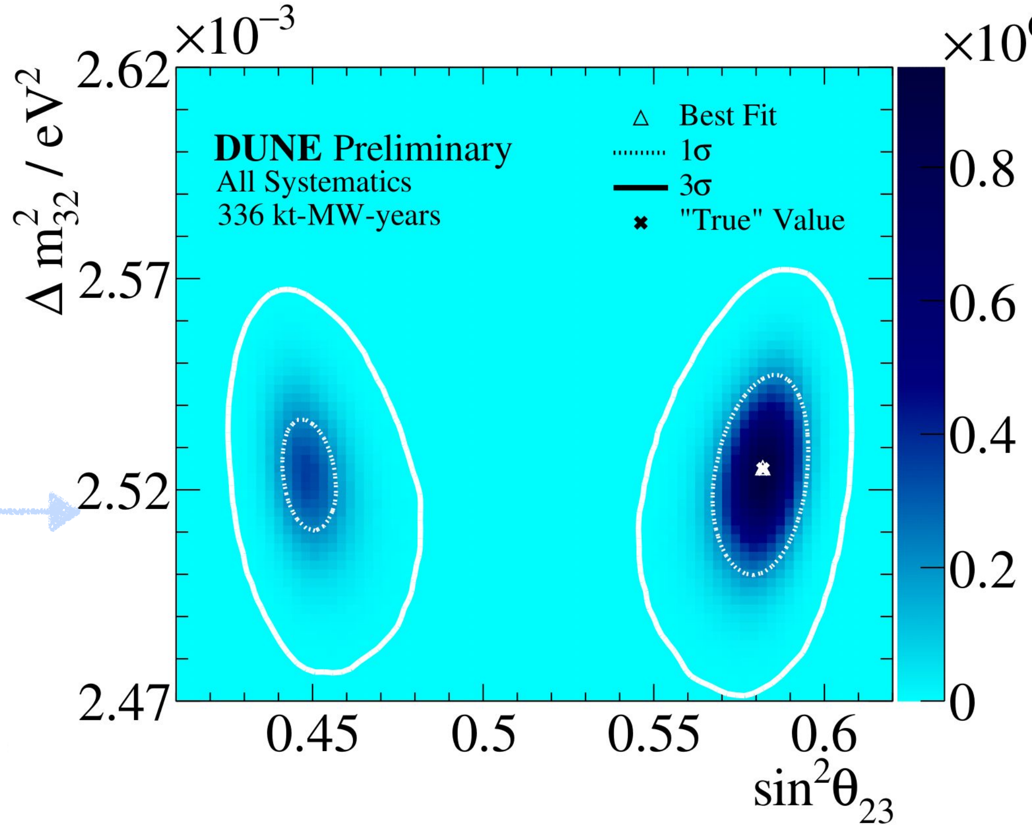


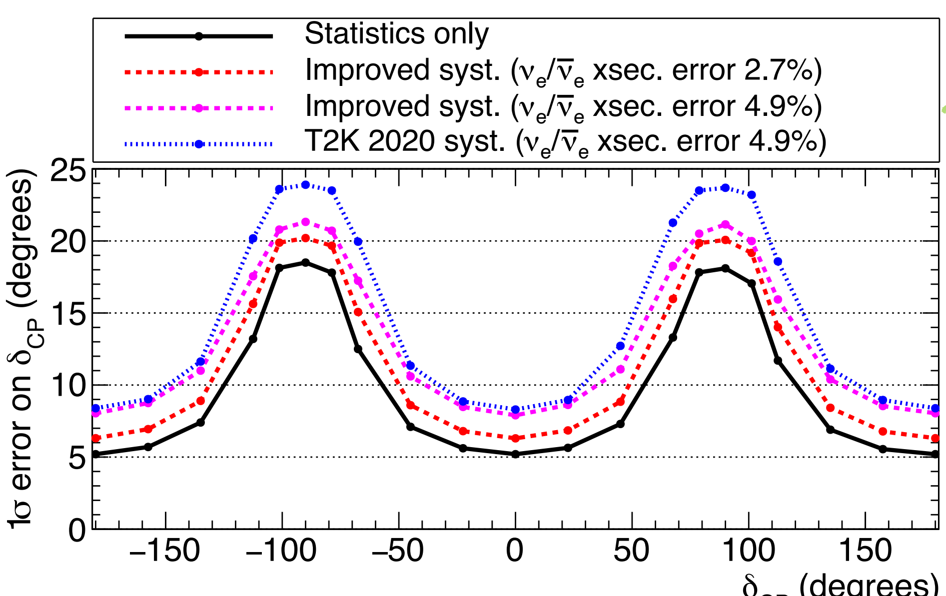
Current Prospect for Future



JUNO:
S. Kumaran

DUNE:
L. Warsame





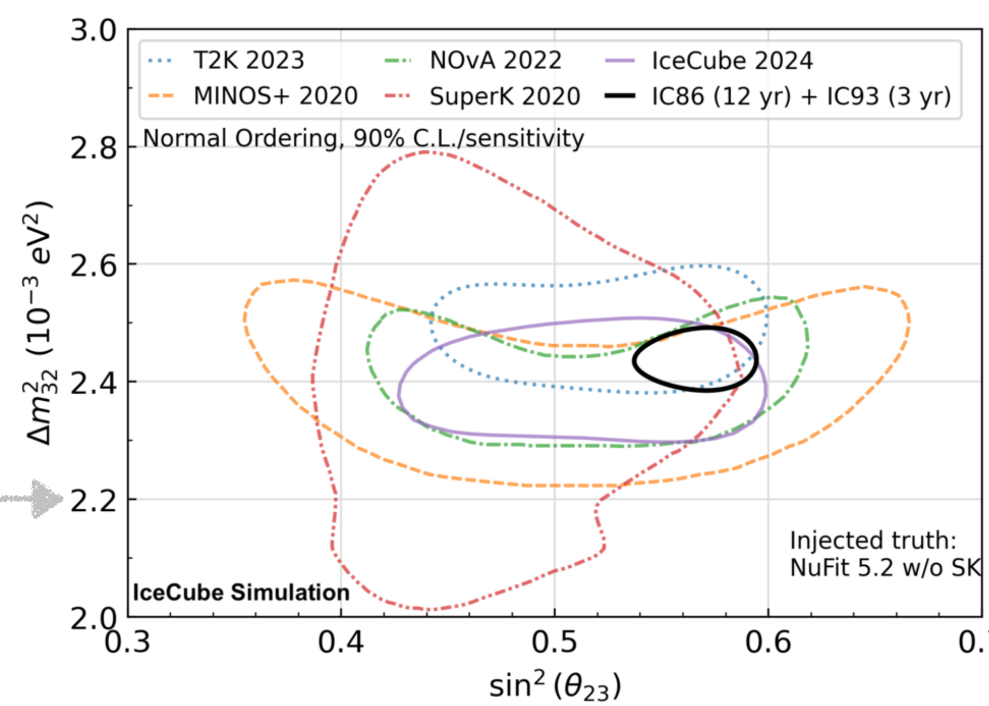
Hyper-K preliminary

True normal ordering (known), HK 10 Years (2.7×10^{22} POT 1:3 ν:$\bar{\nu}$)

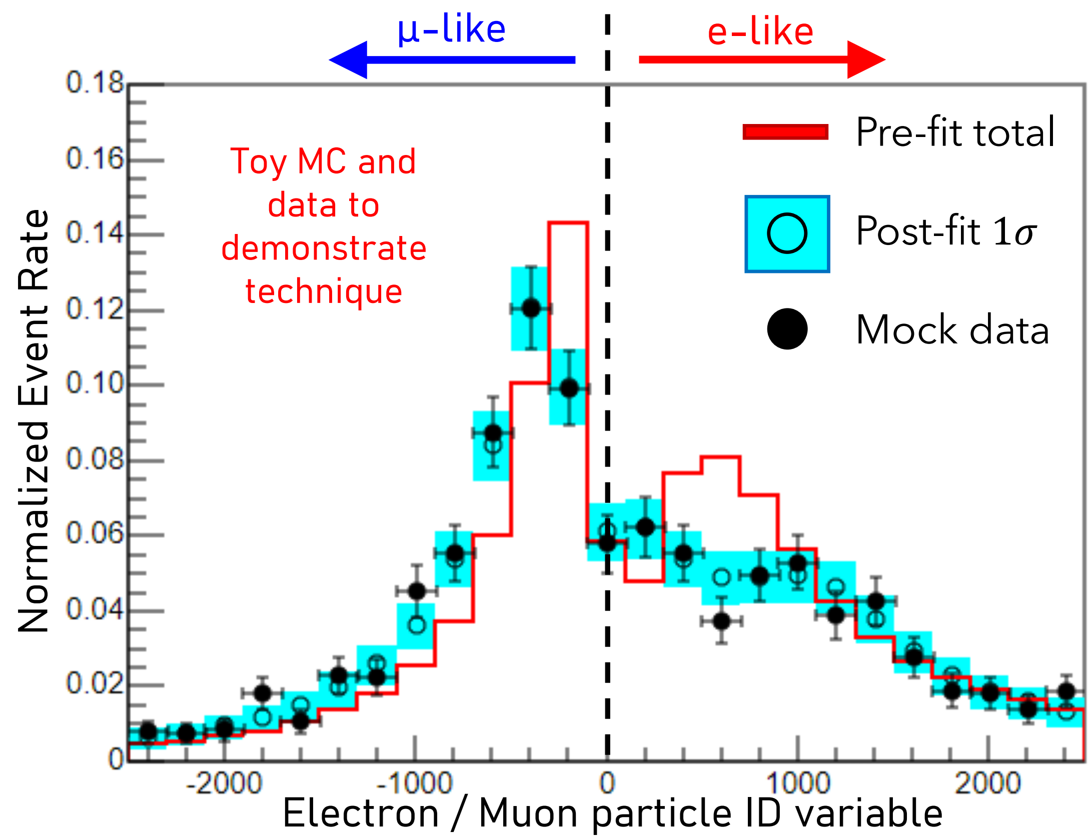
$\sin^2\theta_{13}$=0.0218±0.0007, $\sin^2\theta_{23}$=0.528, Δm^2_{32}=2.509×10^{-3}eV^2/c^4

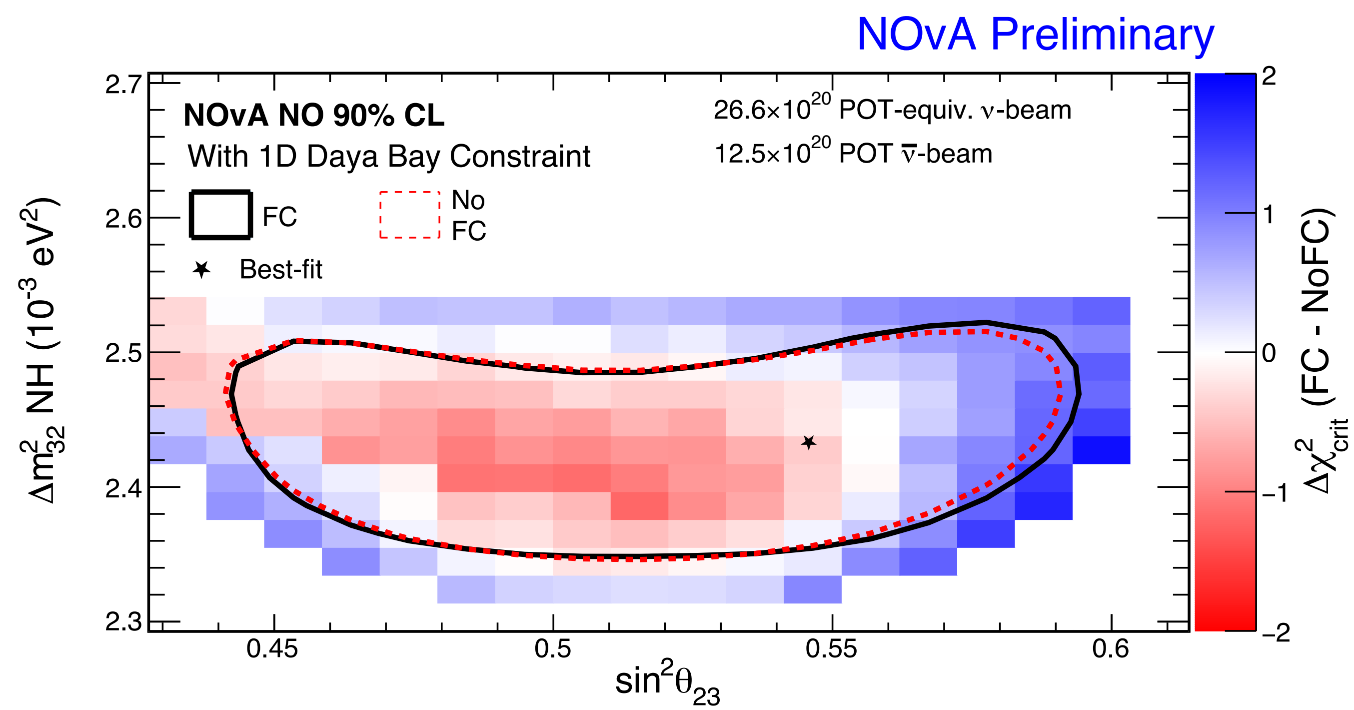
HyperK:
T. Dealtry

IceCube
upgrade:
J. Peterson



Improving ID & Sensitivity

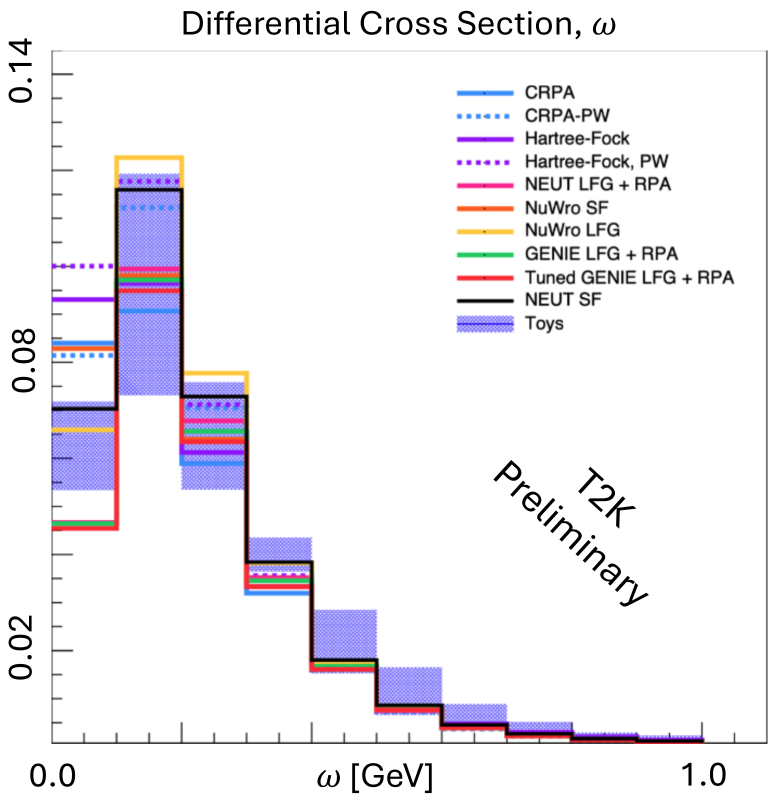




M. Reh: Use atmospheric νs at SuperK to constrain e-μ identification at T2K

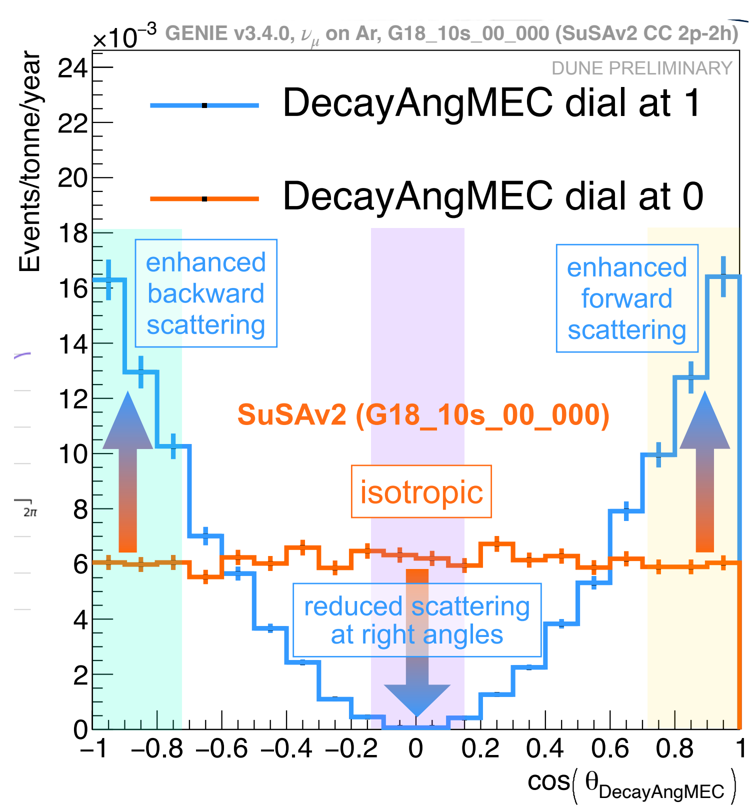
A. Dye: Feldman-Cousins method to correctly measure mass ordering at NOvA

Systematics on ν Interaction

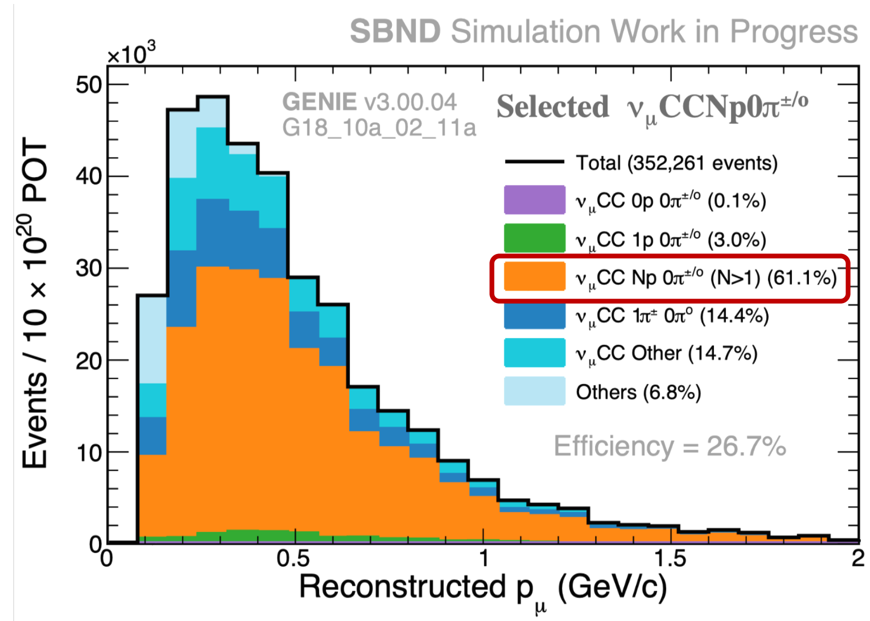


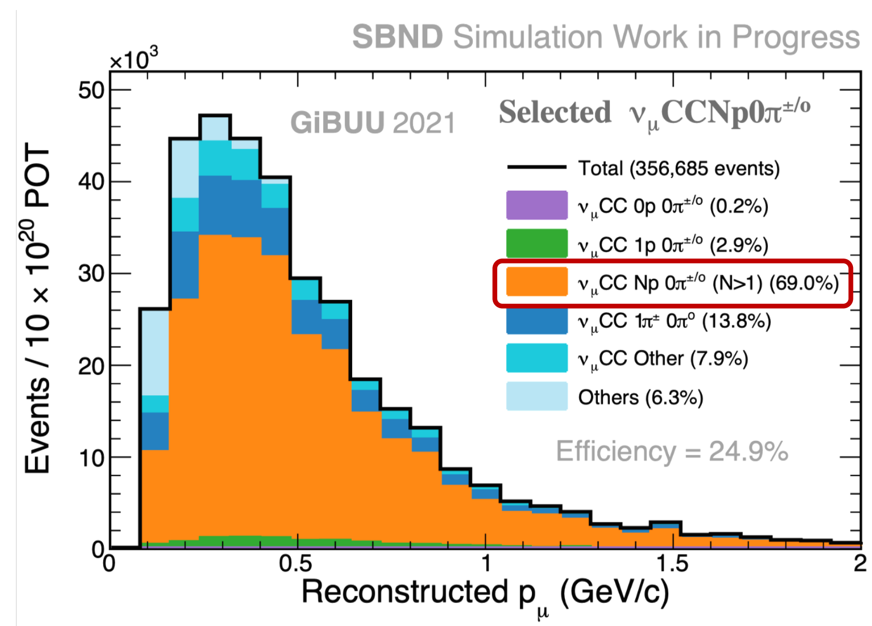
E. Miller: T2K near detector upgrade and systematics improvement

L. Bathe-Peters: MEC 2p2h systematics in LAr



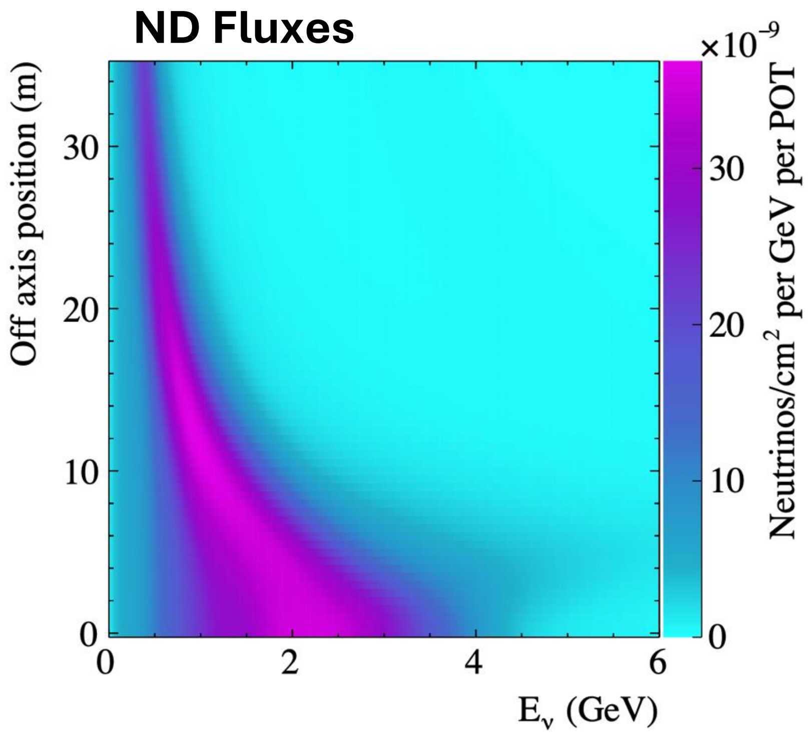
S. Yadav: Exclusive processes

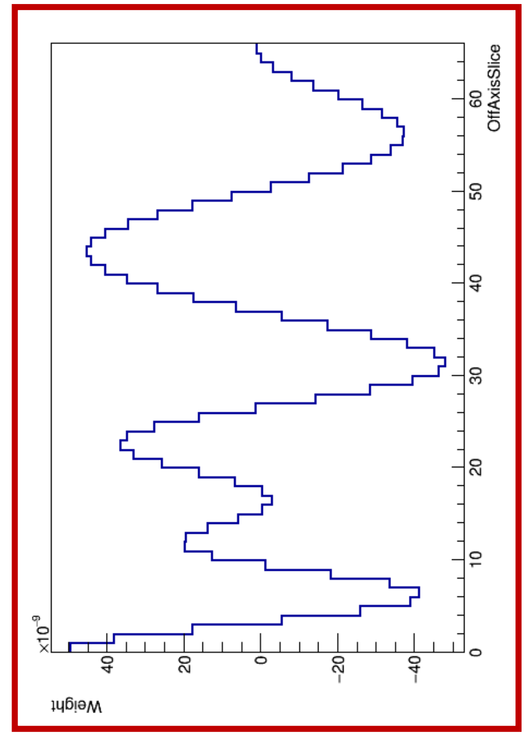




PRISM

DUNE: C. Hasnip





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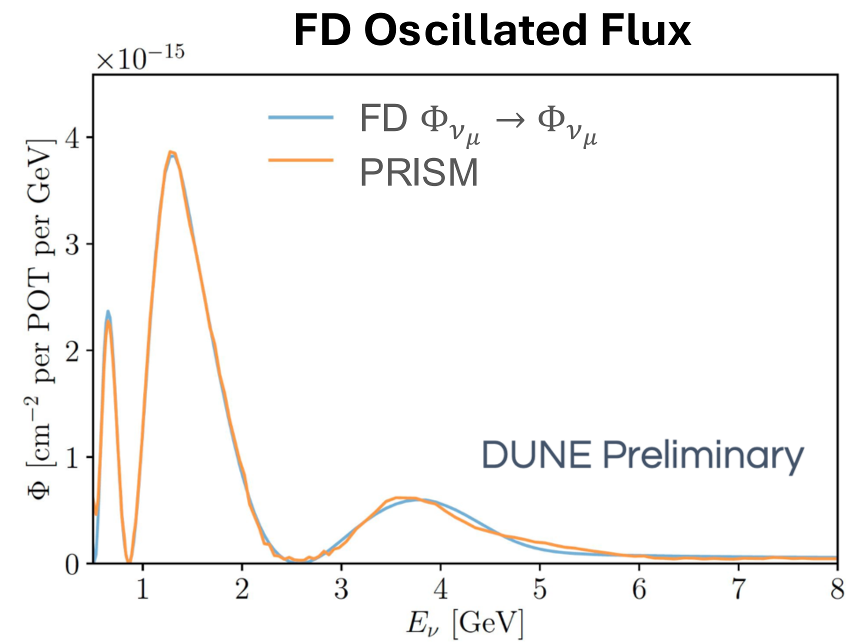
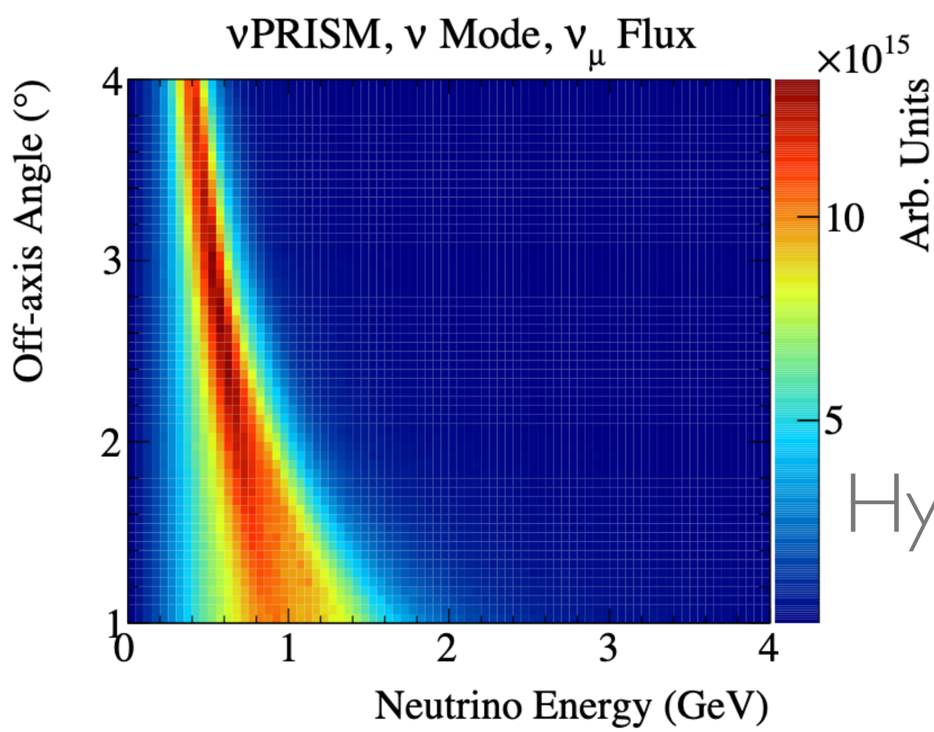
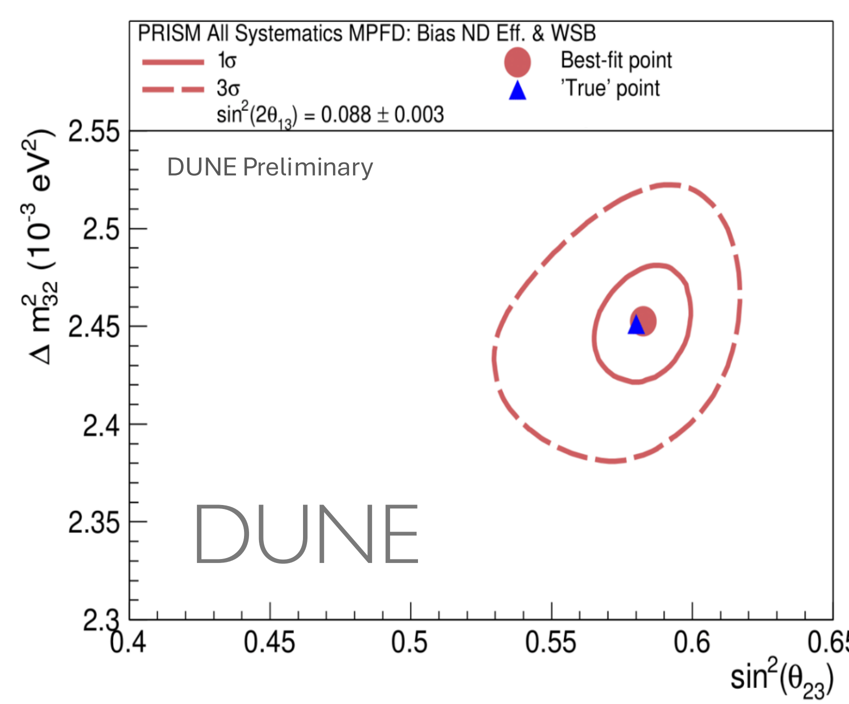


arXiv:2103.13910 [physics.ins-det]



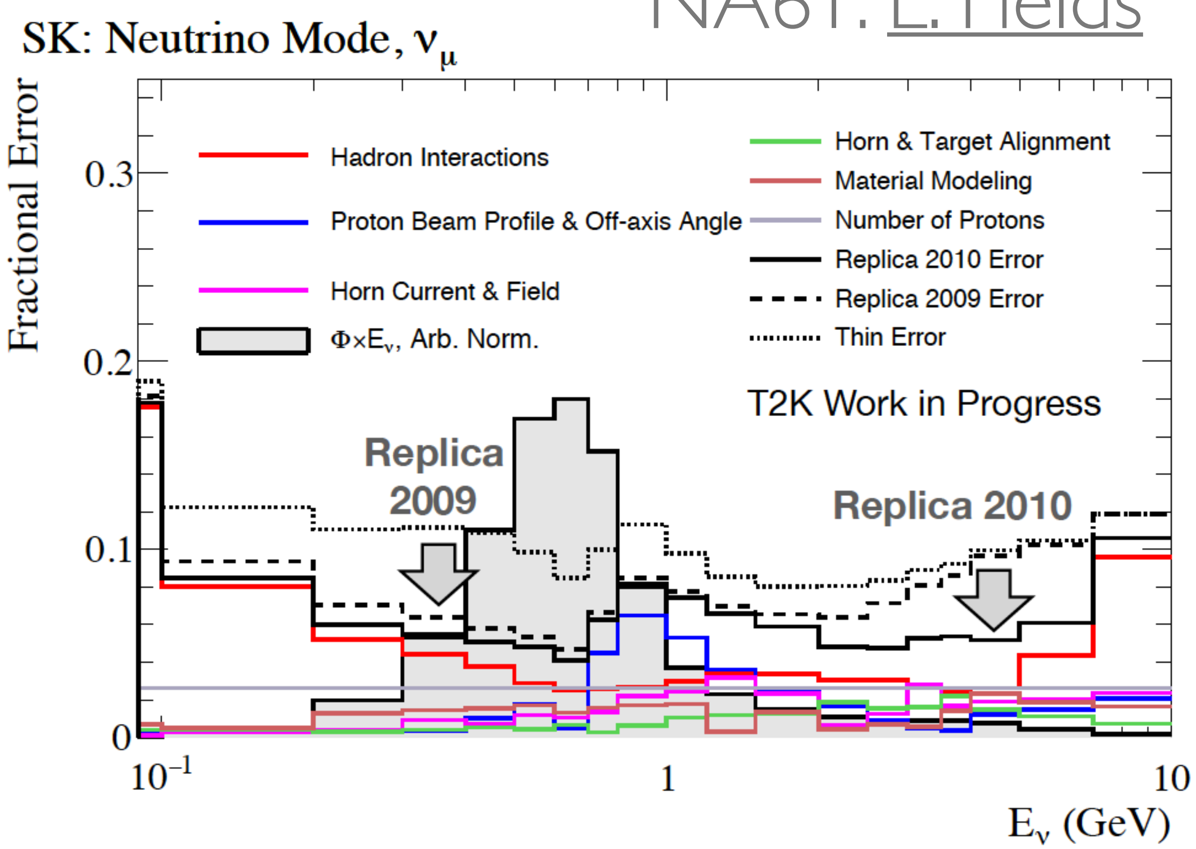
HyperK IWCD: T. Dealtry



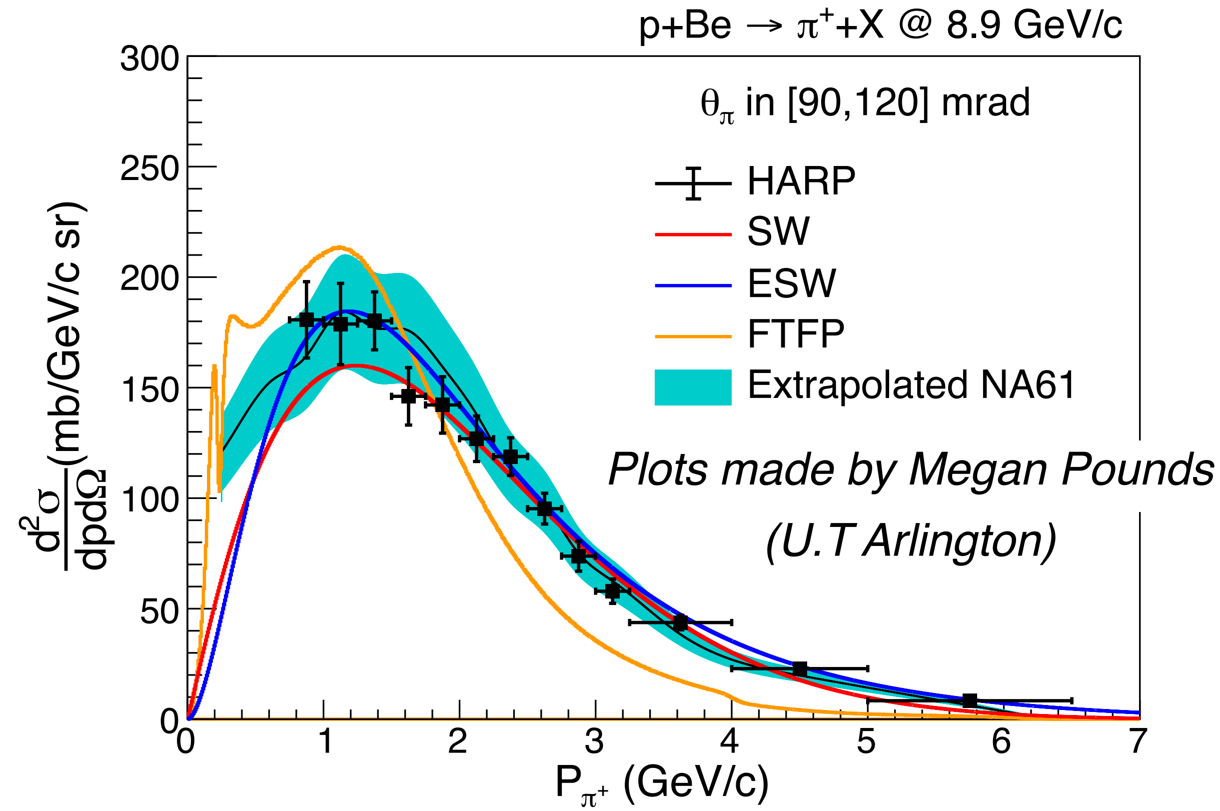
DUNE

Hadron Production Data

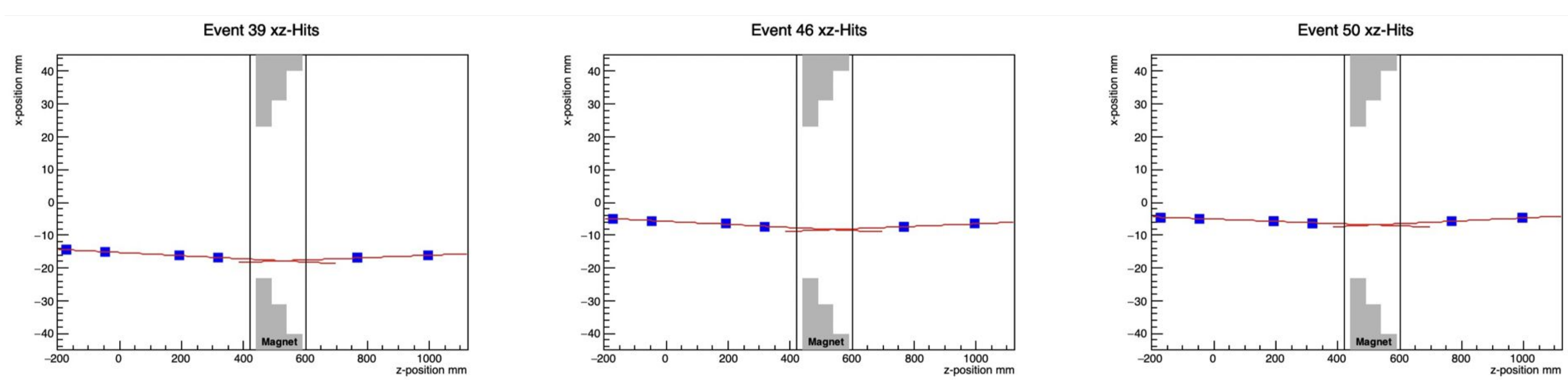
NA61: L. Fields



Challenges and improvements: L. Aliaga

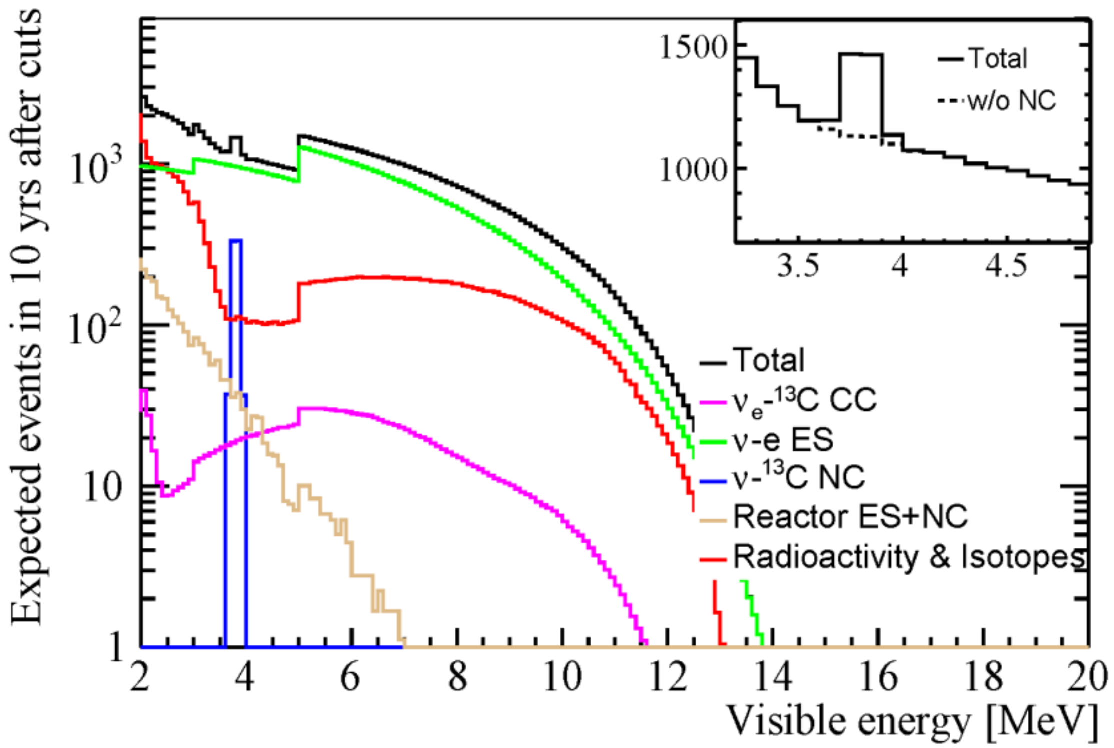


EMPHATIC: R. Chirco Complementary to NA61



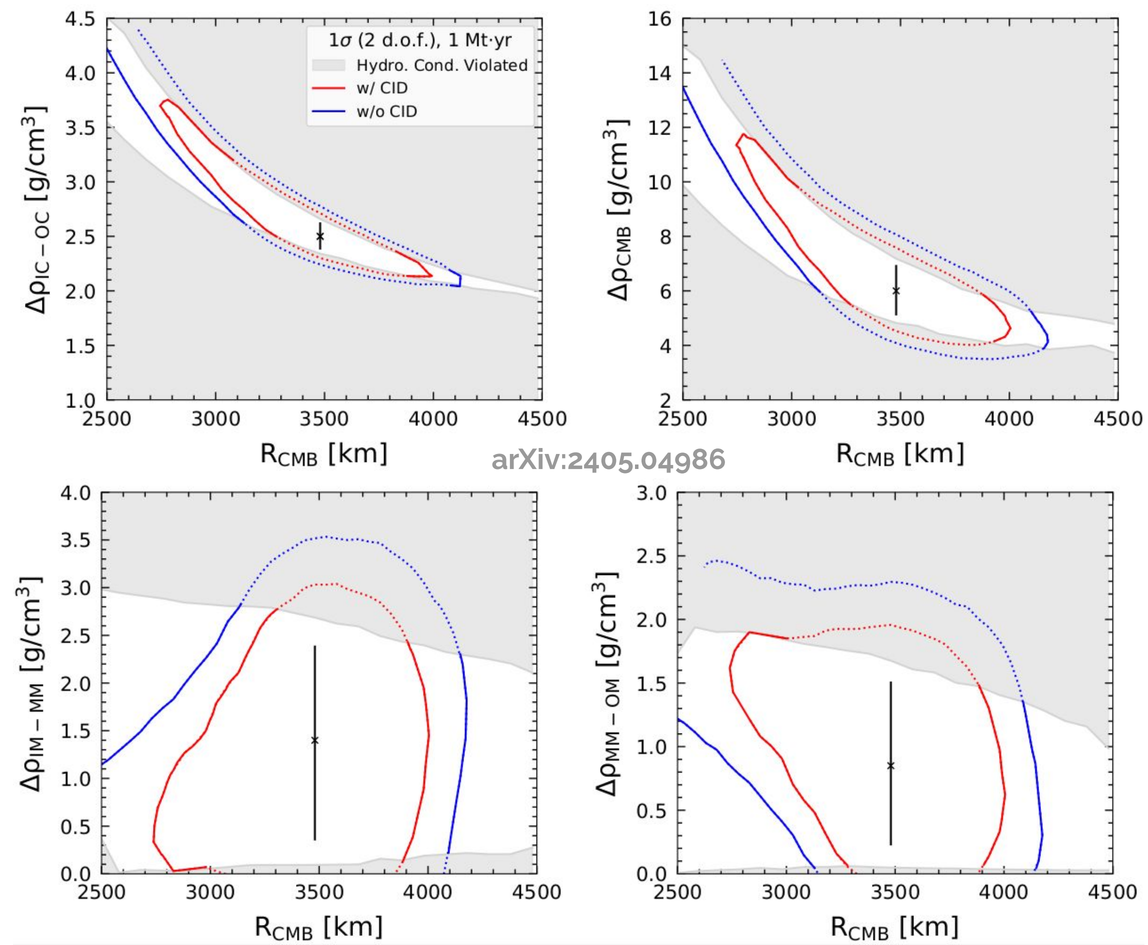
ν Probes

JUNO: I. Morton-Blake
Solar neutrino



With 10 years, expect to reach:
Φ_{8B}: 5%, θ_{12}: 8%, Δm^2_{12}: 20%
And geo-ν, supernova ν, atmospheric ν, etc.

Earth tomography using 50-kton magnetized iron calorimeter at INO: A.K. Padhyay

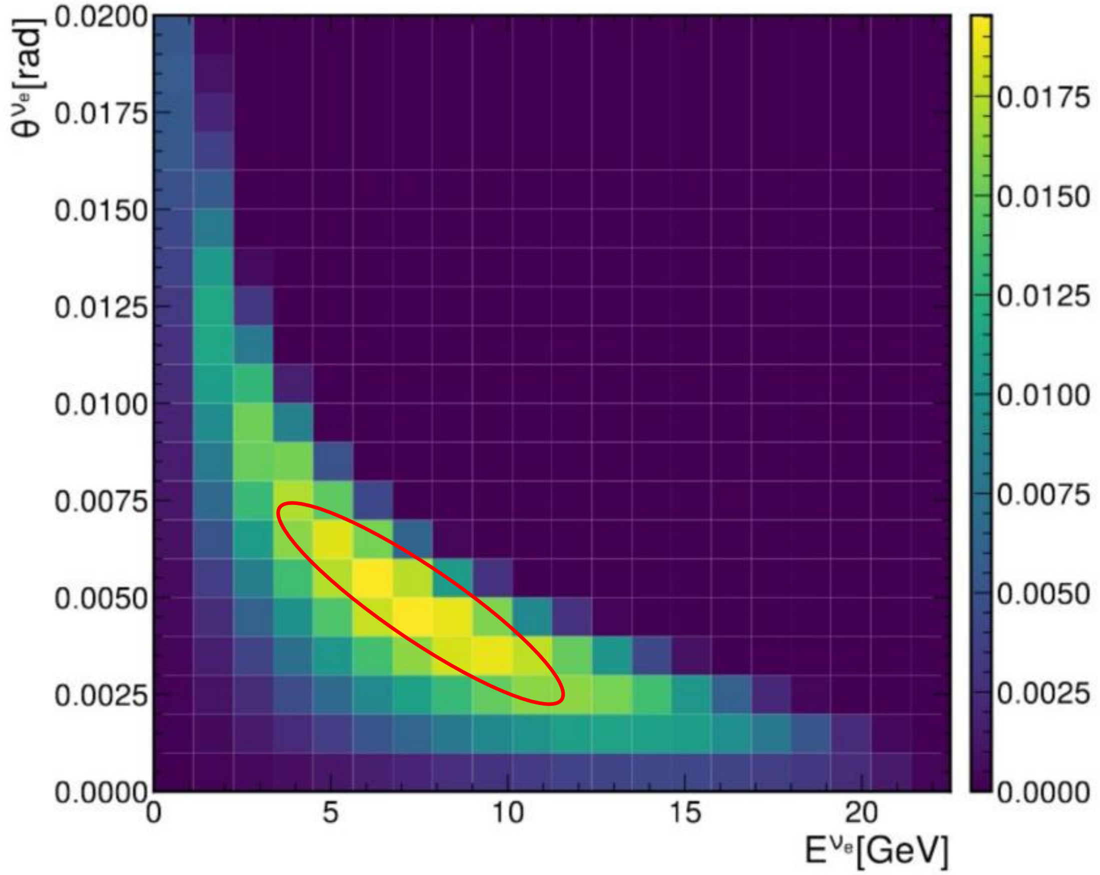


Assume normal mass ordering

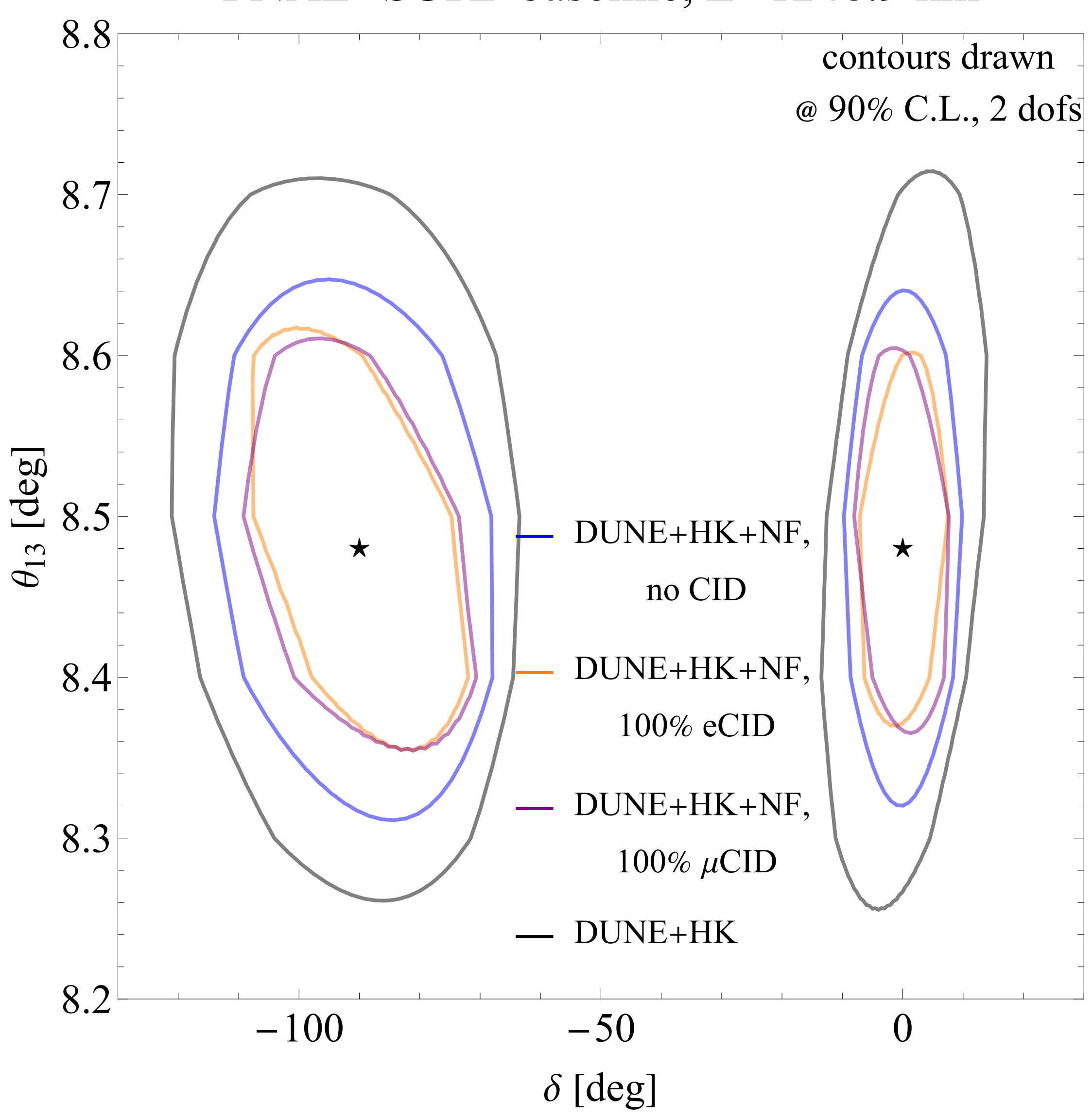
New Accelerators

A. Ruzi: $e^+e^- \rightarrow \mu^+\mu^-$

$$\mu^+ \rightarrow \nu_e, \bar{\nu}_\mu$$
$$\mu^- \rightarrow \nu_\mu, \bar{\nu}_e$$

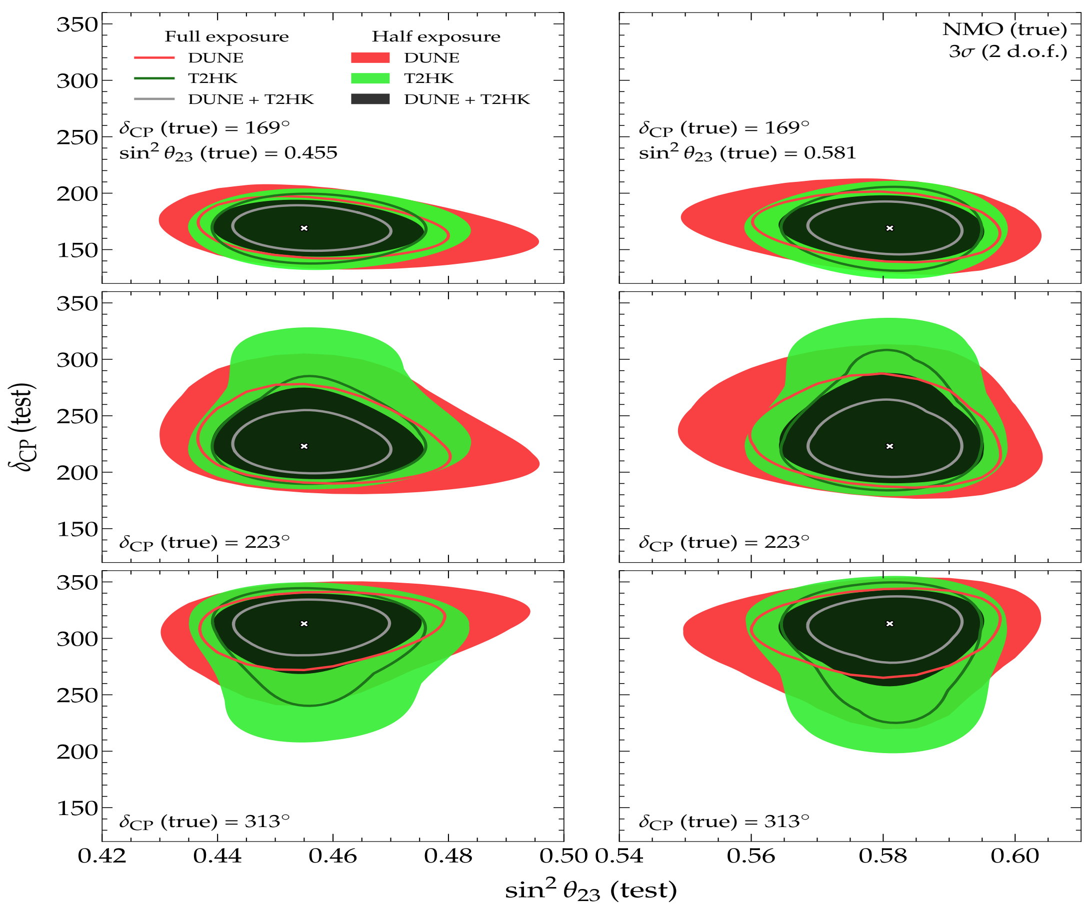


J. Gehrlein: ν factory

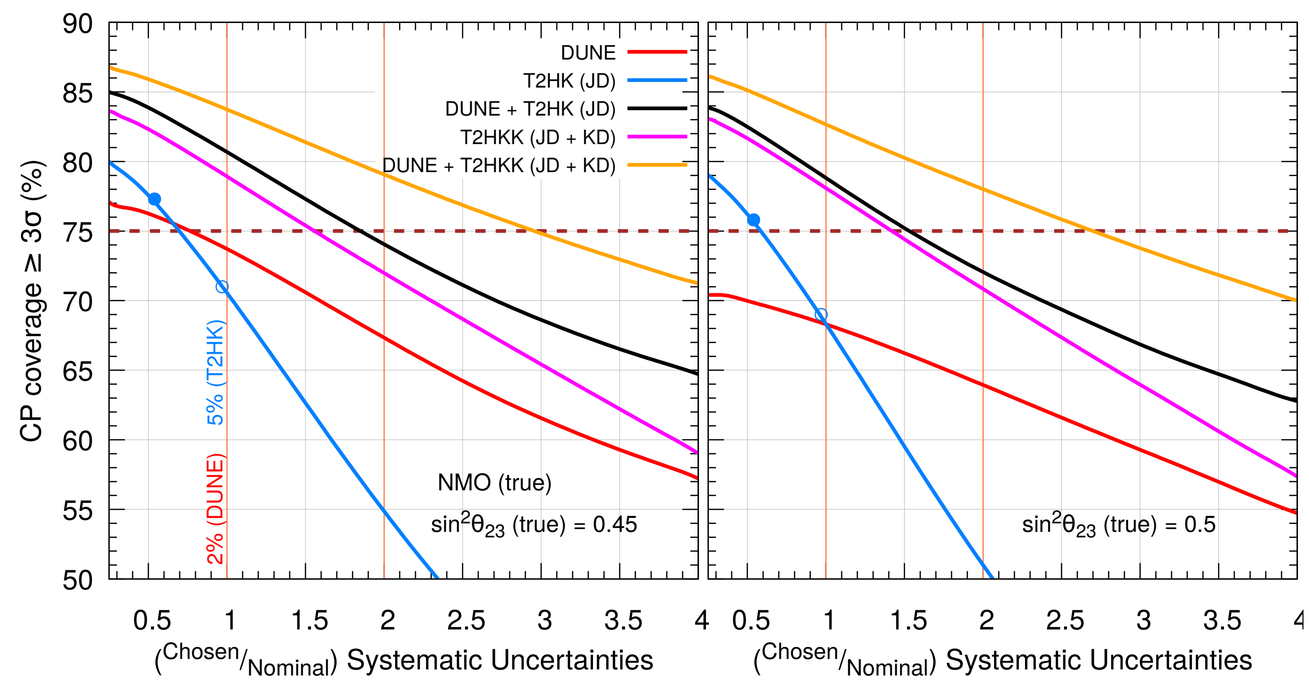


Complementarity

Oscillation parameter measurements: R. Kundu



CP violation measurements: M. Singh



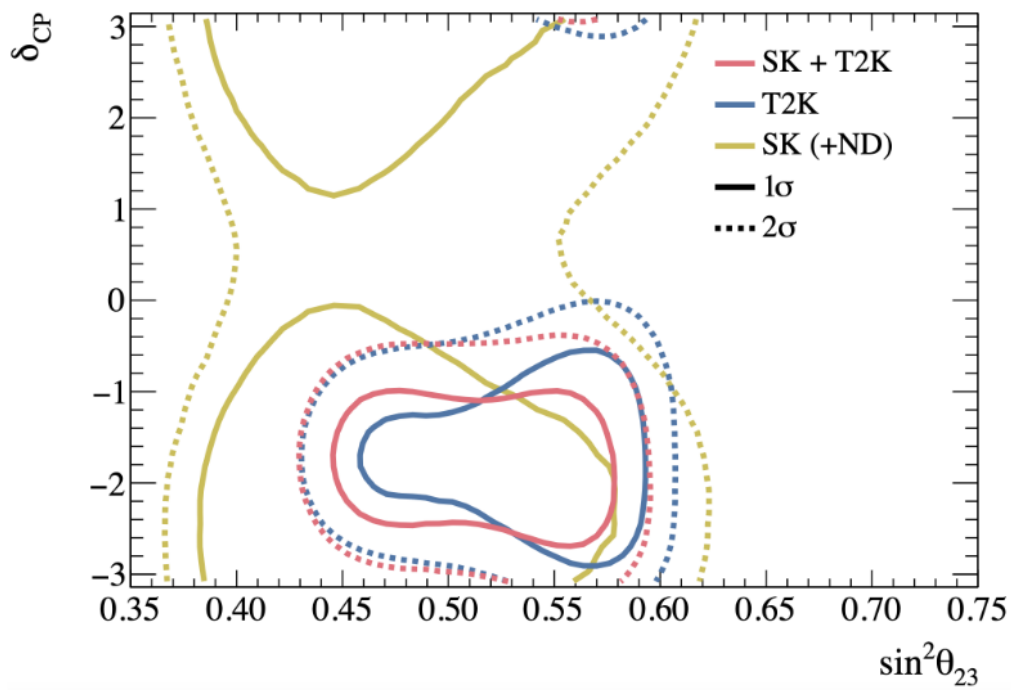
Multi-experiment analyses are necessary!

Combining data from multi-experiments required: beam + atmospherics + reactor

Workshop: Understand the procedure and get prepared early

Hosted by M. Scott

Multi-Experiment Analyses



- Discussed
  - T2K+NOvA
  - T2K+SK
  - CMS+ATLAS (Higgs)
- JUNO, DUNE, HyperK, IceCube upgrade

- Comparison of tuned event rate prediction (constrained by near detectors) necessary
  - Top priority: inter-operability of neutrino event generators - shared nuHEPMC event format
  - PRISM techniques, common flux & geometry interfaces
- Common inputs, e.g. hadron production, lepton/meson scattering data
  - Systematic uncertainties are sub-leading now, but not in the future

Summary of Summary

- Discussed the current results and the prospect of the future experiments
- Discussed how to improve the measurements
  - Hadron production
  - Constraints & control samples
  - Other probes & new accelerators
- Multi-experiment analyses are necessary!
  - Need to get prepared early
- Mark stepping down, thank you!

Extras

Imperial College London

Sunday 15th September

NuFACT 2024 Satellite Workshop:

Multi-experiment oscillation analysis

Mark Scott
m.scott09@imperial.ac.uk

Imperial College London

Overview

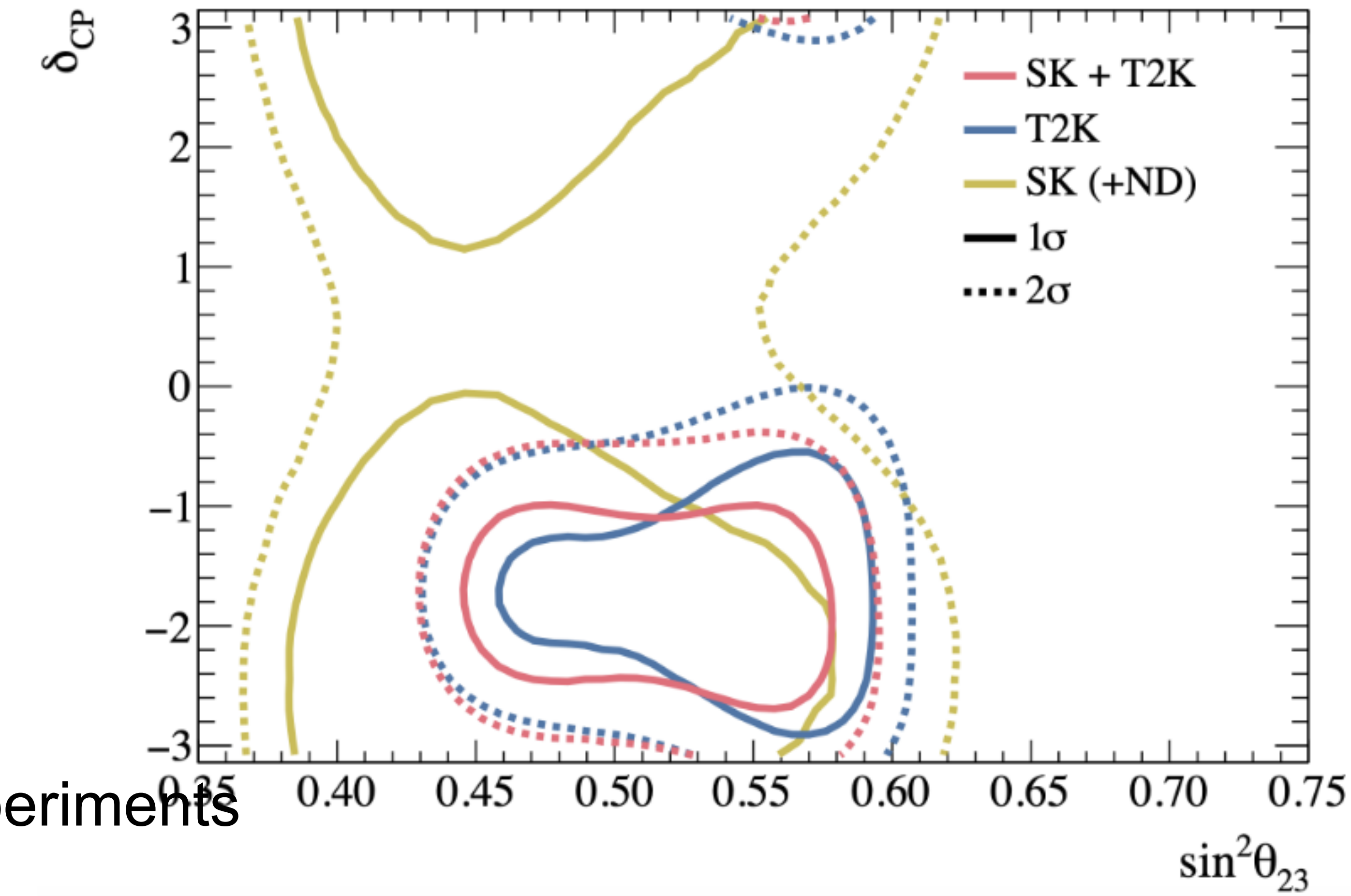
- Next generation of experiments aim for precision neutrino physics
  - Direct searches for new physics, unitarity of PMNS
  - These searches **require** combining data from multiple experiments
  - Need reactor and atmospheric, not just beam

- **(Updated) Goals for workshop:**
  - Start (hopefully regular) discussion between experiments to make combinations easier
  - Get ideas for ways to work together in future
  - **Understand what steps we can take now to allow combined analyses in the future**

Multi-experiment analyses take a long time to perform (4+ years) so must start discussing earlier rather than later

Ongoing multi-experiment analyses

- Heard details from
  - T2K + NOvA
  - T2K + SK
  - CMS + ATLAS Higgs combinations
- Discussed physics but also sociological side



- Also heard from next generation of experiments
  - JUNO, DUNE, Hyper-K, IceCube-Upgrade
  - **Clear interest in the community!**

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Takeaways from workshop

- Comparison of tuned event rate predictions (after near detector constraint) between experiments necessary for robustness
  - Benefit from PRISM technique (IWCD and DUNE-PRISM)
  - Sharing of near detector data could be less sensitive than oscillation data
  - **Requires inter-operability of neutrino event generators – shared nuHEPMC event format a necessary first step**
  - Common flux and geometry interfaces also beneficial

- Common inputs, such as hadron production data, lepton and meson scattering experiments
  - **Uncertainties are sub-leading now, but not in the future**
  - Multi-experiment analysis may be useful to motivate these experiments
  - Should consider how these will impact individual neutrino experiments