

Participation of the Institute of Physics (IOP), Bhubaneswar, in the DUNE Project

Part 2: MC, Reconstruction, Sensitivity Studies with Beam and Atmospheric Neutrinos



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Introducing Institute of Physics (IOP), Bhubaneswar, India



Institute of Physics (IOP), Bhubaneswar is an autonomous national institute established in 1974 to conduct world-class basic science research in Physics. It is funded by the Department of Atomic Energy, Government of India

Last year, we celebrated the Golden Jubilee of our Institute

Long Experience of Working on Long-baseline & Atmospheric Neutrinos

- Our neutrino group at the Institute of Physics (IOP) has been actively involved in the physics studies of the DUNE project since its inception
- During my PhD, I worked on the novel CERN-INO Magic Baseline Beta-beam proposal. During my postdoctoral research, I worked extensively on long-baseline neutrinos with Patrick Huber (Virginia Tech) and Pilar Hernandez (IFIC, Valencia)
- We have contributed significantly towards the India-based Neutrino Observatory (INO) and IceCube projects
- Several PhD students completed their theses on DUNE and are currently doing postdoctoral studies

Recent Invited Talks on Long-baseline Neutrinos

- Invited talk on “BSM Searches in Neutrino Experiments” at the Neutrino 2020 Conference, Fermilab, Chicago, USA, 24th June 2020
- Invited talk on “Complementarity among Next-generation Long-baseline Experiments” at the Snowmass Summer Meeting, University of Washington, Seattle, USA, 19th July 2022
- Invited talk on “Unprecedented Precision on Neutrino Oscillation Parameters using Synergy between DUNE and T2HK” at the WIN 2023 conference, Sun Yat-sen University Zhuhai Campus, Zhuhai, China, 7th July 2023

**12 publications on DUNE from
our group over the last 10 years**

1 PRL, 7 JHEP, 3 EPJC, 1 PLB

Improved precision on 2-3 oscillation parameters using the synergy between DUNE and T2HK

Sanjib Kumar Agarwalla, Ritam Kundu, Masoom Singh

JHEP 10 (2024) 243

A plethora of long-range neutrino interactions probed by DUNE and T2HK

Sanjib Kumar Agarwalla, Mauricio Bustamante, Masoom Singh, Pragyanprasu Swain

JHEP 09 (2024) 055

Flavor-dependent long-range neutrino interactions in DUNE & T2HK: alone they constrain, together they discover

Masoom Singh, Mauricio Bustamante, Sanjib Kumar Agarwalla

JHEP 08 (2023) 101

Constraining Lorentz Invariance Violation with Next-Generation Long-Baseline Experiments

Sanjib Kumar Agarwalla, Sudipta Das, Sadashiv Sahoo, Pragyanprasu Swain

JHEP 07 (2023) 216

Enhancing Sensitivity to Leptonic CP Violation using Complementarity among DUNE, T2HK, and T2HKK

Sanjib Kumar Agarwalla, Sudipta Das, Alessio Giarnetti, Davide Meloni, Masoom Singh

Eur.Phys.J.C 83 (2023) 8, 694

Model-Independent Constraints on Non-Unitary Neutrino Mixing from High-Precision Long-Baseline Experiments

Sanjib Kumar Agarwalla, Sudipta Das, Alessio Giarnetti, Davide Meloni

JHEP 07 (2022) 121

A close look on 2-3 mixing angle with DUNE in light of current neutrino oscillation data

Sanjib Kumar Agarwalla, Ritam Kundu, Suprabh Prakash, Masoom Singh

JHEP 03 (2022) 206

Can Lorentz Invariance Violation affect the Sensitivity of Deep Underground Neutrino Experiment?

Sanjib Kumar Agarwalla, Mehedi Masud

Eur. Phys. J. C (2020) 80: 716

Addressing Neutrino Mixing Schemes with DUNE and T2HK

Sanjib Kumar Agarwalla, Sabya Sachi Chatterjee, S. T. Petcov, A. V. Titov

Eur. Phys. J. C (2018) 78: 286

Octant of θ_{23} in danger with a light sterile neutrino

Sanjib Kumar Agarwalla, Sabya Sachi Chatterjee, Antonio Palazzo

Phys.Rev.Lett. 118 (2017) no.3, 031804

Degeneracy between θ_{23} octant and neutrino non-standard interactions at DUNE

Sanjib Kumar Agarwalla, Sabya Sachi Chatterjee, Antonio Palazzo

Phys.Lett. B762 (2016) 64-71

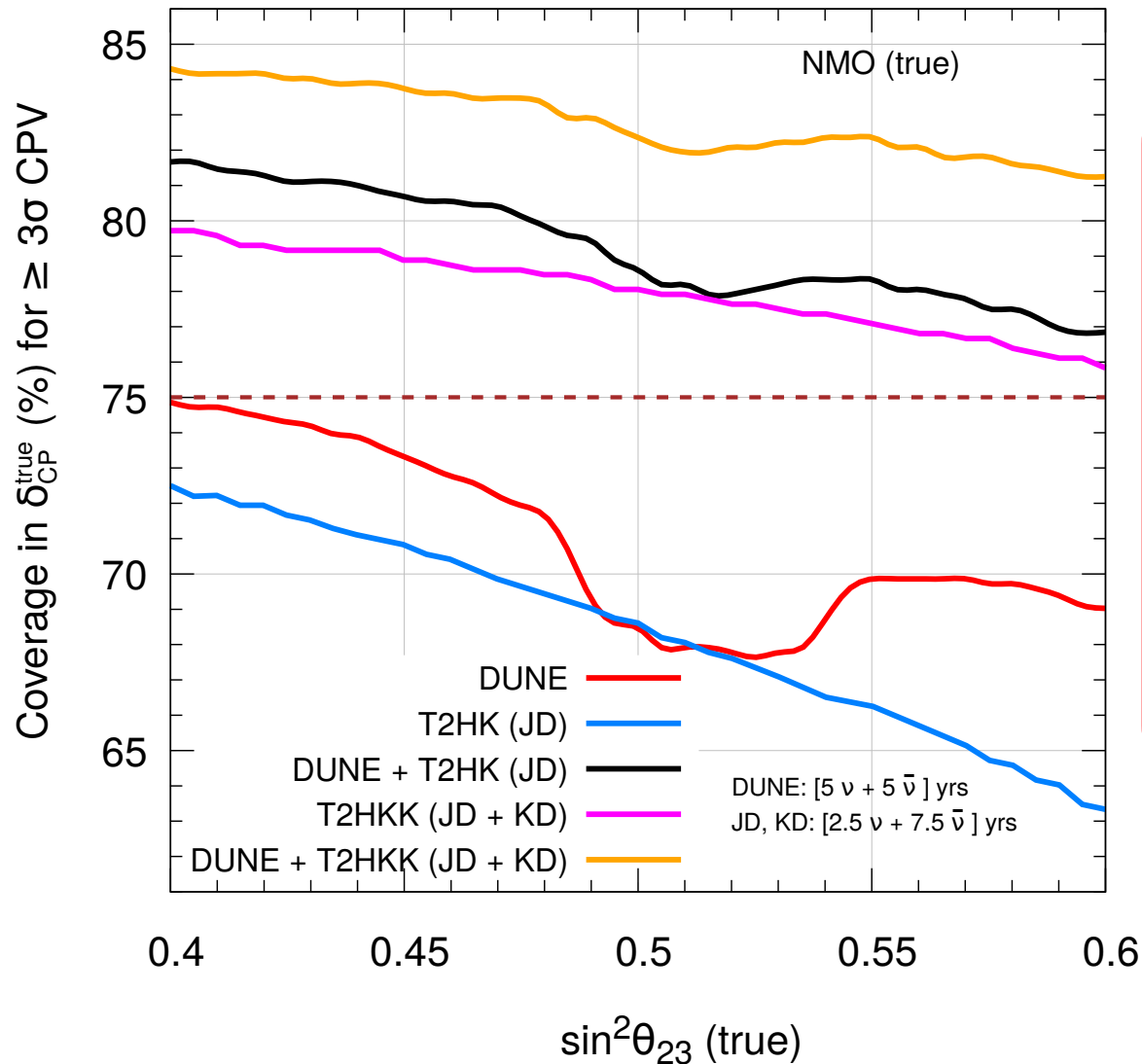
Physics Reach of DUNE with a Light Sterile Neutrino

Sanjib Kumar Agarwalla, Sabya Sachi Chatterjee, Antonio Palazzo

JHEP 1609 (2016) 016

Some Highlights

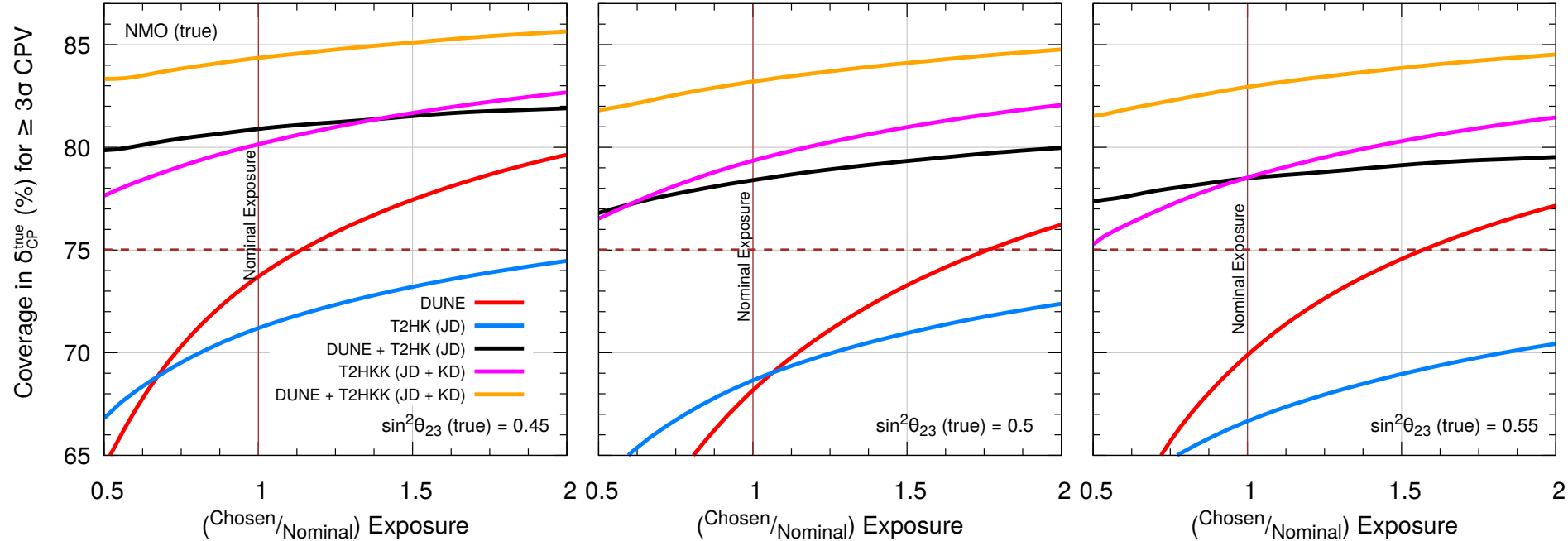
CP Coverage for Leptonic CP Violation at $\geq 3\sigma$ as a function of θ_{23}



Agarwalla, Das, Giarnetti, Meloni, Singh, Eur.Phys.J.C 83 (2023) 8, 694

CP Coverage for Leptonic CPV at $\geq 3\sigma$ as a function of Exposure

Agarwalla, Das, Giarnetti, Meloni, Singh, Eur.Phys.J.C 83 (2023) 8, 694

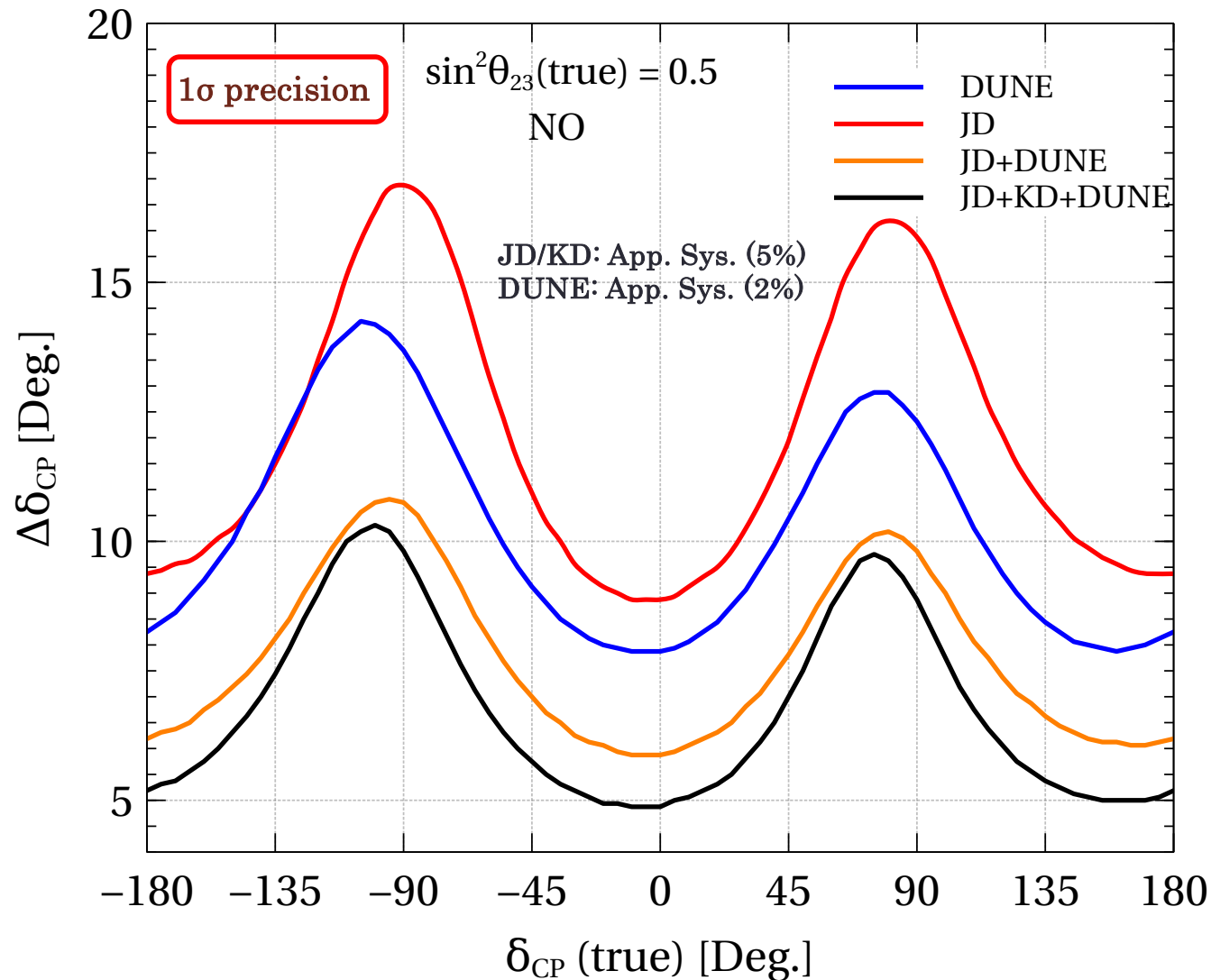


DUNE & T2HK individually cannot achieve leptonic CPV at $\geq 3\sigma$ for at least 75% choices of δ_{CP} with their nominal exposures & systematic uncertainties

DUNE + T2HK can attain the same for all values of θ_{23} with only half of their nominal exposures

DUNE + T2HKK can further enhance the CP coverage to more than 80% with only half of their nominal exposures

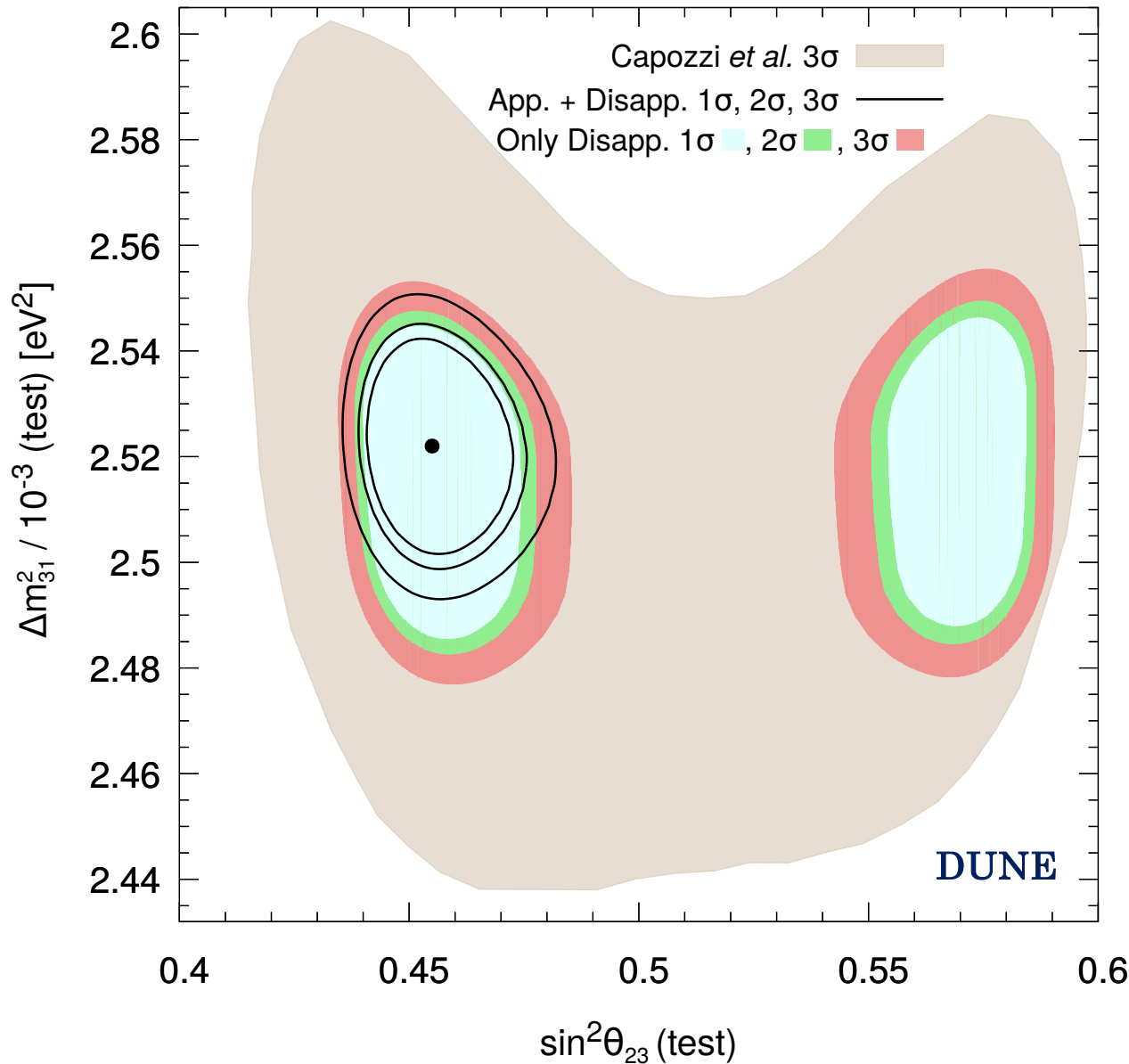
High-Precision Measurement of Dirac CP Phase



DUNE + T2HK (JD) can measure any value of δ_{CP} with a 1σ precision $\lesssim 10^\circ$

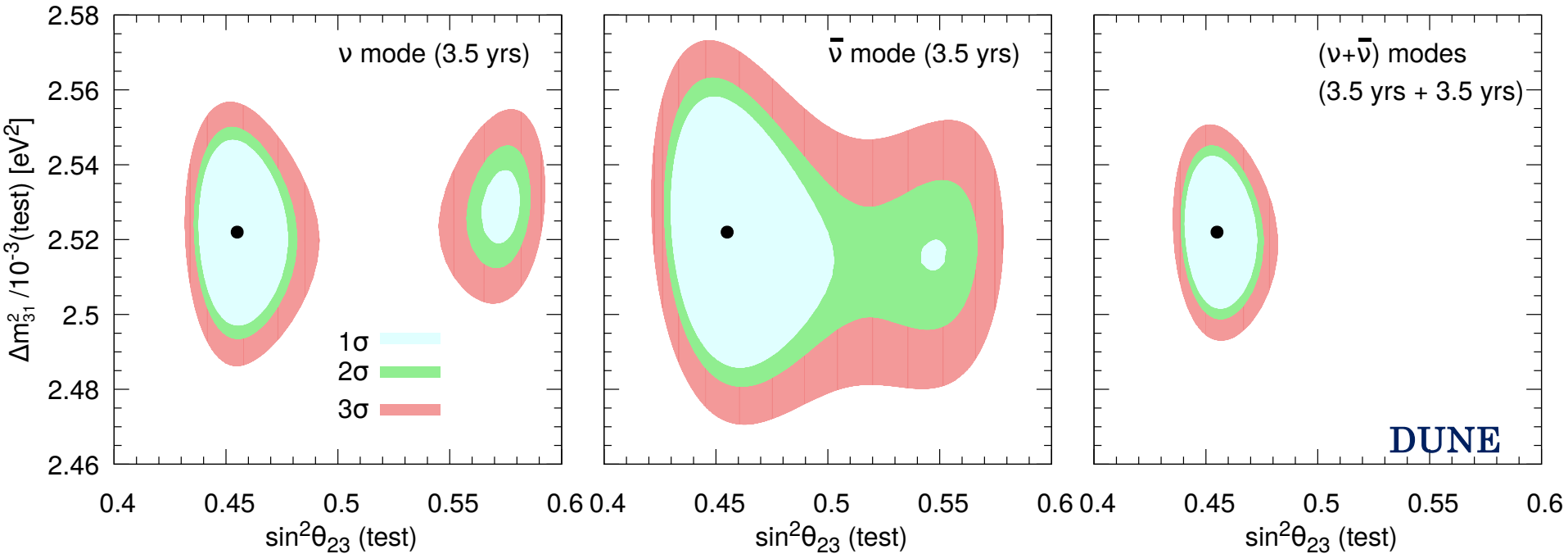
Agarwalla, Das, Giarnetti, Meloni, in preparation

Precision Measurement of Atmospheric Oscillation Parameters



Contributions from
both appearance
and disappearance
channels are
important

Precision Measurement of Atmospheric Oscillation Parameters



Contributions from both neutrino and antineutrino modes are crucial

Agarwalla, Kundu, Prakash, Singh, JHEP 03 (2022) 206

Precision Measurement of Atmospheric Oscillation Parameters

This work: Sens. (3σ , 2 d.o.f.)

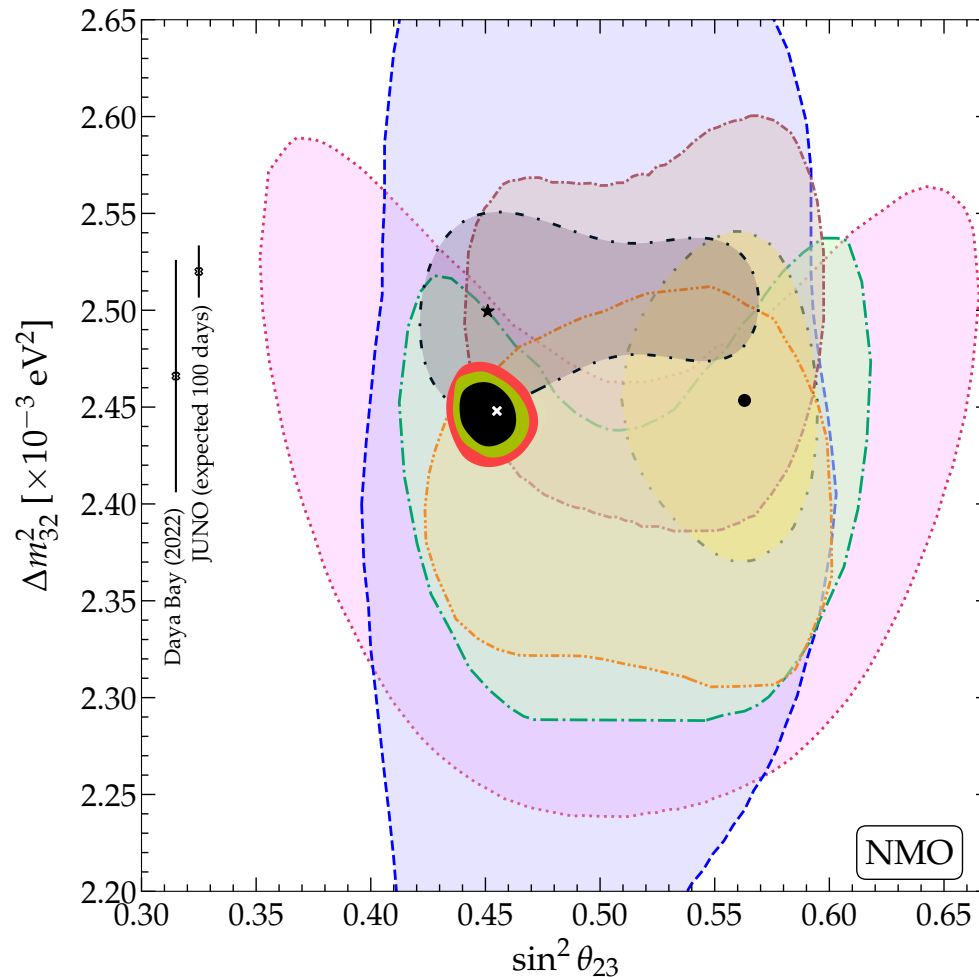
- DUNE [5 yr + 5 yr]
- T2HK [2.5 yr + 7.5 yr]
- DUNE + T2HK

Near future Sens. (90% C.L.)

- IC86 (12 yr) + IC93 (3 yr)
- ORCA sens. (3 yr)

Measurements (90% C.L.)

- MINOS+ (2020)
- Super-K (2023)
- DeepCore (2024)
- NOvA (2022)
- T2K (2023)



Agarwalla, Kundu, Singh, JHEP 10 (2024) 243

Octant of θ_{23} in Danger with a Light Sterile Neutrino

Sanjib Kumar Agarwalla,^{1,2,*} Sabya Sachi Chatterjee,^{1,2,†} and Antonio Palazzo^{3,4,‡}

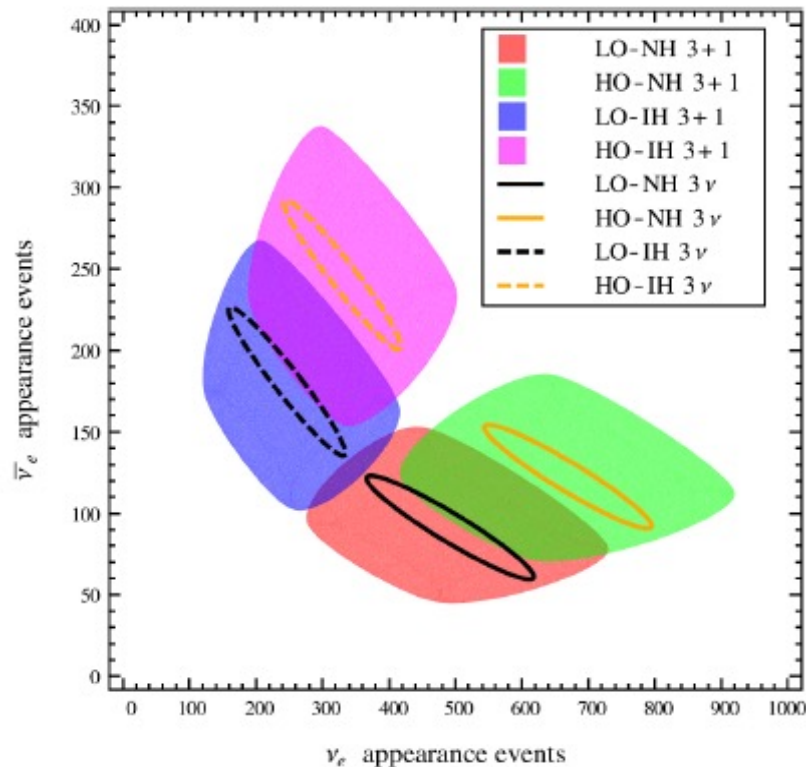
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⁴*Istituto Nazionale di Fisica Nucleare, Sezione di Bari, Via Orabona 4, 70126 Bari, Italy*

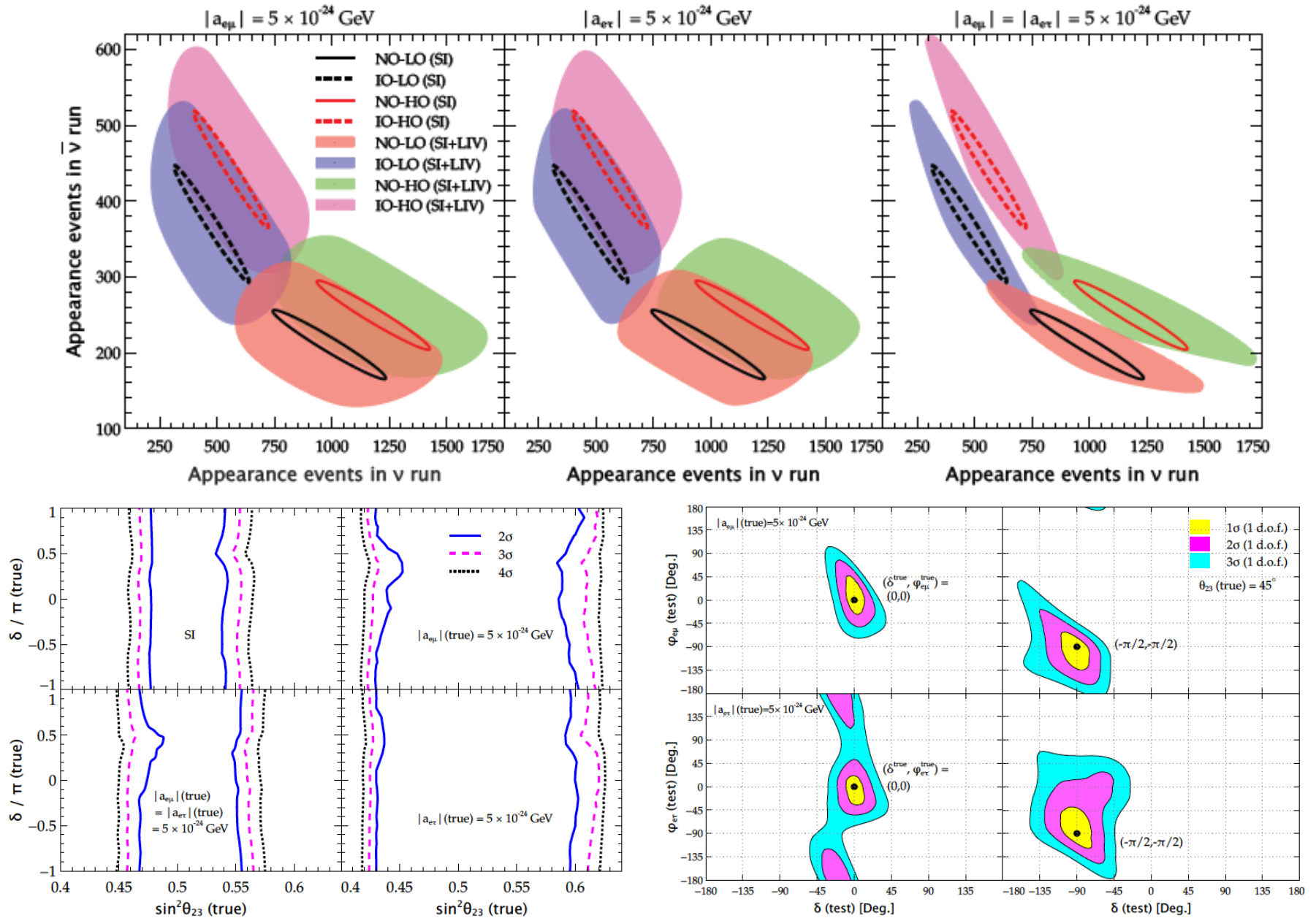
(Received 23 May 2016; revised manuscript received 5 December 2016; published 20 January 2017)



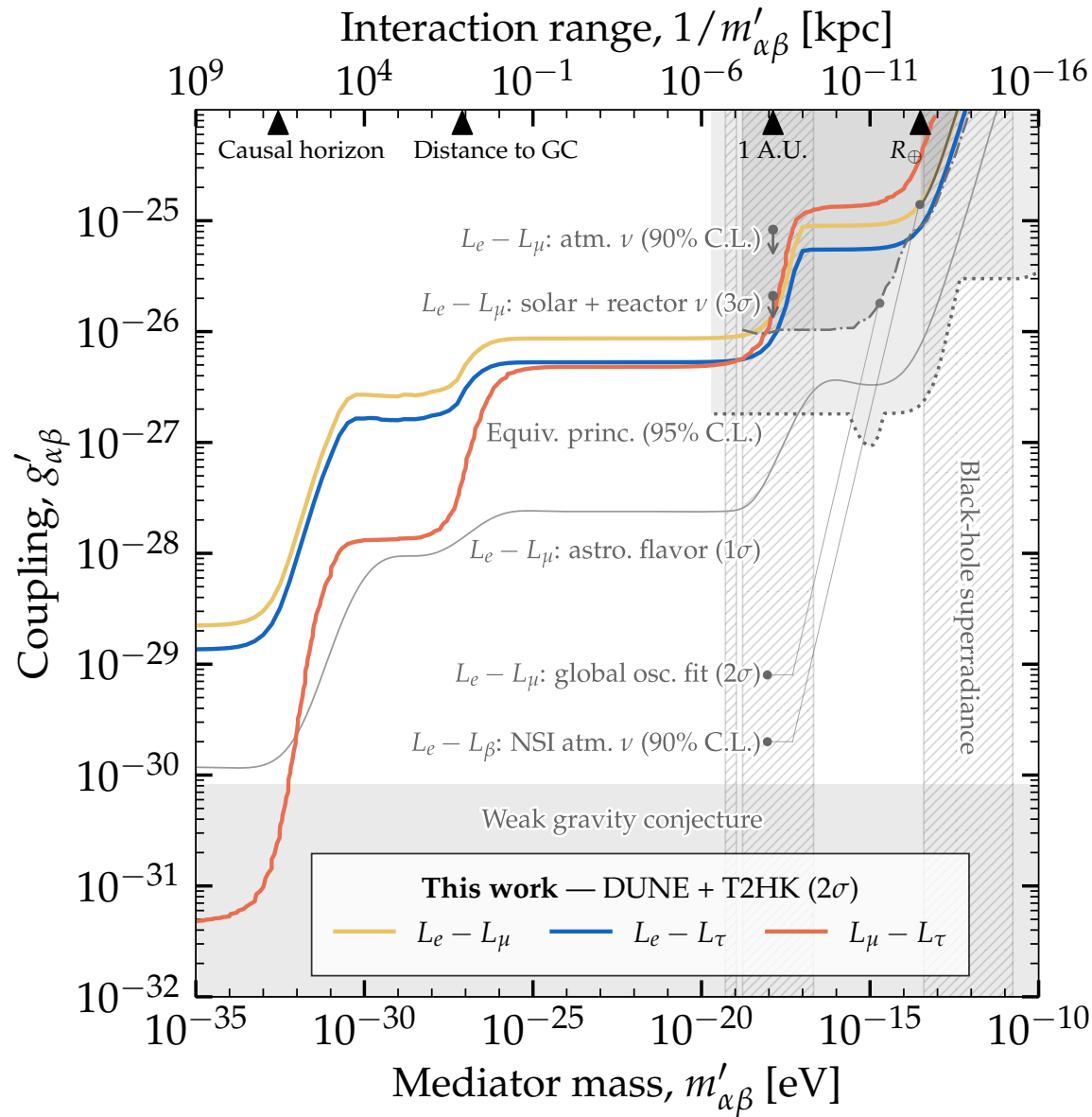
$$\sin^2 \theta_{23} = 0.42 \text{ (LO) and } 0.58 \text{ (HO)}$$

- Three-flavor ellipses due to variation in δ_{13} in $[-\pi \text{ to } \pi]$
- Four-flavor blobs due to variation in δ_{13} and δ_{14} in $[-\pi \text{ to } \pi]$
- Due to new CP phases, sensitivity towards octant lost in DUNE

Can LIV affect the Sensitivity of DUNE?



Long-Range Neutrino Interactions at DUNE and T2HK



Singh, Bustamante, Agarwalla, JHEP 08 (2023) 101

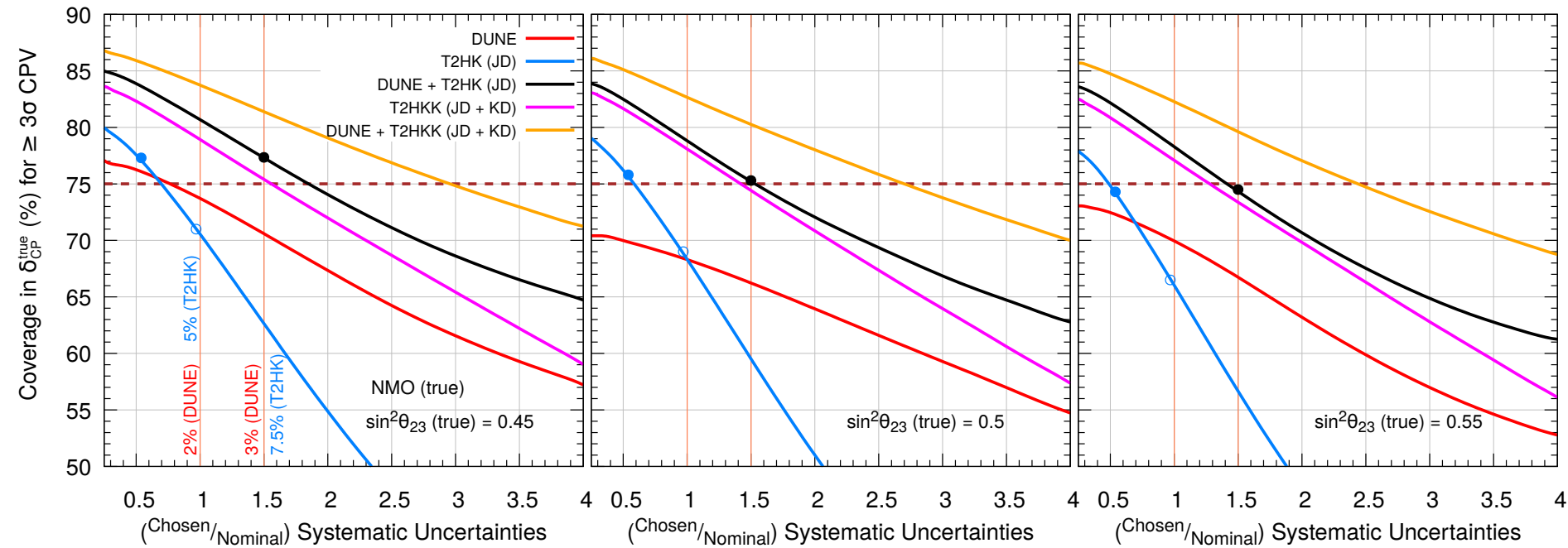
We propose the following work based on our expertise and future research interests as a member of DUNE. To facilitate this, we request access to DUNE resources.

- **Monte Carlo (MC) Production for DUNE:** We plan to contribute to the MC production to enhance the MC statistics by generating additional simulated data sets for DUNE. We aim to incorporate advancements from the ProtoDUNE to ensure accurate and up-to-date modelling of the LArTPC detector response.
- **Event Reconstruction for DUNE:** We aim to participate in DUNE's event reconstruction efforts by contributing to the development and improvement of algorithms based on machine learning techniques.
- **Preliminary Sensitivity Studies:** Using the new MC simulations and event reconstructions, we plan to make more accurate forecasts of DUNE's sensitivity to several interesting physics studies, involving beam and atmospheric neutrinos.

We are excited about the opportunity to contribute to the DUNE project and look forward to collaborating with the larger team in both scientific and technical roles.

Thank You!

CP Coverage for Leptonic CPV at $\geq 3\sigma$ as a function of Systematics

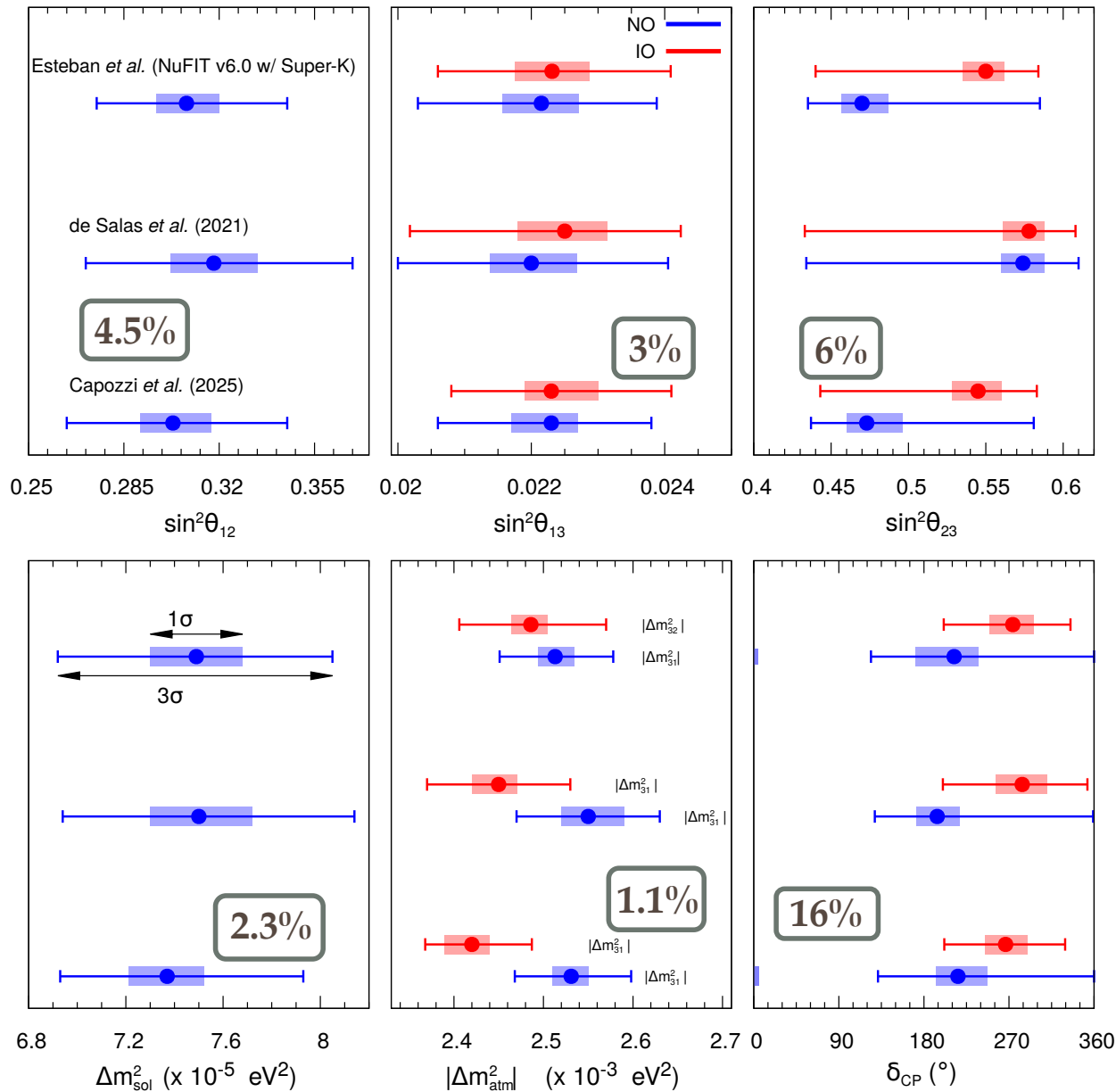


Complementarity between DUNE & T2HK may allow us to achieve 75% CP coverage for $\geq 3\sigma$ leptonic CP violation, even in a pessimistic scenario where the systematic uncertainties are 1.5 times larger than the nominal ones

Agarwalla, Das, Giarnetti, Meloni, Singh, Eur.Phys.J.C 83 (2023) 8, 694

Remarkable Precision on Neutrino Oscillation Parameters

Robust three-flavor neutrino oscillation paradigm



Huge boost to search for BSM physics at ν expts

Ultimate Bounds on Long-Range Interactions

Cosmological electrons ($10^{79} e$)

Sun ($10^{57} e$)

Moon ($10^{49} e$)

Earth ($10^{51} e$)

Milky Way ($10^{67} e$)

Not to scale

Huge Electron repositories in the local and distant Universe

Oscillations sensitive to long-ranged flavored interactions between neutrino and electron. Use flavor composition of TeV-PeV astrophysical neutrinos at IceCube

Bustamante, Agarwalla PRL 122, 061103 (2019)

Under the L_e-L_μ or L_e-L_τ symmetry, an electron sources a Yukawa potential —

$$V \sim \frac{g'_{e\beta}{}^2}{r} e^{-m'_{e\beta} r}$$

Z' coupling $\rightarrow g'_{e\beta}{}^2$

Z' mass $\rightarrow m'_{e\beta}$

Distance to neutrino $\rightarrow r$

A neutrino “feels” all the electrons within the interaction range $\sim (1/m')$

$g_{\text{gravity}} \sim 10^{-19}$

