# Earlier Resolution of Neutrino Mass Ordering?

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On behalf of co-authors of arXiv:2008.11280 [hep-ph]

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## 1. Introduction

Neutrino Mass Ordering (MO): a fundamental open question in neutrino physics.

Normal ($m_{\nu_1} < m_{\nu_2} < m_{\nu_3}$) or Inverted ($m_{\nu_3} < m_{\nu_1} < m_{\nu_2}$) ?

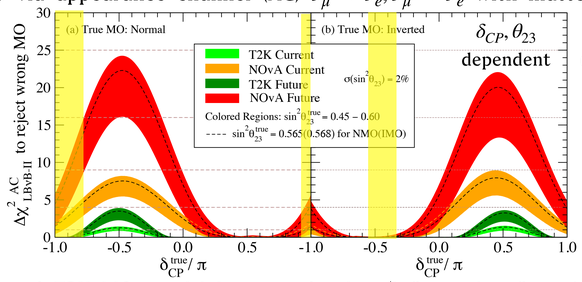
Normal MO is favored at $\sim 3\sigma$ in current global analysis [1,2,3].

Eventually, $\geq 5\sigma$ MO answer is requisite.

In our arXiv:2008.11280 study, we demonstrate that the combined sensitivity of JUNO with NOvA and T2K experiments has the potential to yield the first fully resolved ($\geq 5\sigma$) measurement of neutrino MO.

## 2. NOvA and T2K

On-going long baseline neutrino beam (LBν̄B) experiments MO via appearance channel (AC) $\nu_\mu \to \nu_e, \bar{\nu}_\mu \to \bar{\nu}_e$ with matter effects.




$\delta_{CP}, \theta_{23}$ dependent

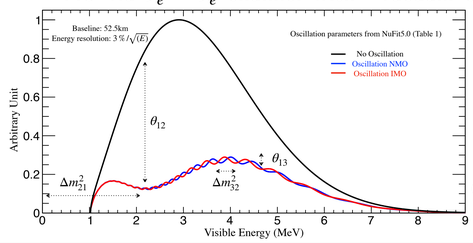
Can not reach $5\sigma$ for current favored $\delta_{CP}$ .

NOvA and T2K synergy not shown

NOvA and T2K MO sensitivity reproduction (information from Neutrino2020) and expectation ( $\sim 3$ times more statistics).

## 3. JUNO

Upcoming medium baseline reactor neutrino experiment MO via $\bar{\nu}_e \to \bar{\nu}_e$ channel with ~vacuum oscillation.

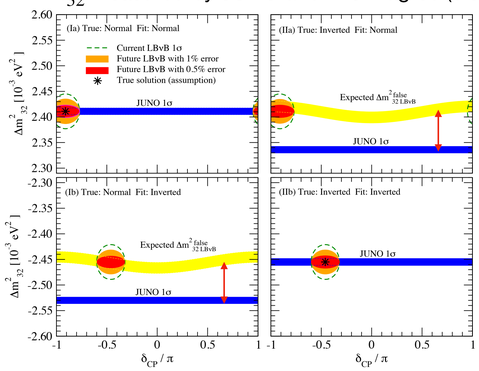



JUNO intrinsic MO sensitivity $\sim 3\sigma$ [4]. Can not reach $5\sigma$.

CP phase independent

## 4. MO boosting synergy between JUNO and LBνB

$\Delta m^2_{32}$ measured by JUNO and LBν̄B agree (disagree) for true (false) MO.




Disagreement of $\Delta m^2_{32}$ for false MO is the origin of the boosting.

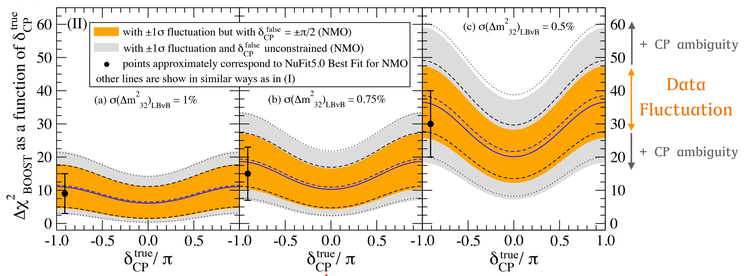
$$\Delta\chi^2_{BOOST} \sim \left( \frac{\Delta m^2_{32\ JUNO}{}^{false} - \Delta m^2_{32\ LBνB}{}^{false}}{\sigma(\Delta m^2_{32})_{LBνB}} \right)^2$$

$\Delta m^2_{32\ LBνB}$ is from the $\nu_\mu \to \nu_\mu, \bar{\nu}_\mu \to \bar{\nu}_\mu$ disappearance channel (DC).

Schematic illustration of the origin of the boosting

## 5. Boosting MO sensitivity

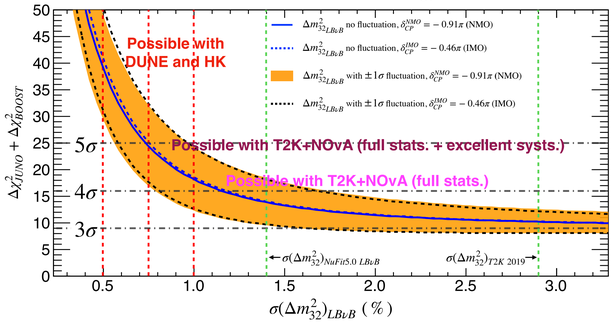
$\Delta\chi^2_{BOOST}$ as a function of CP phase for $\sigma(\Delta m^2_{32})_{LBνB} = 1\,\%, 0.75\,\%, 0.5\,\%$




Achievable with NOvA and T2K nominal expected exposures.

## 6. Boosted JUNO MO sensitivity

JUNO + $\Delta m^2_{32\ LBνB}$ information as a function of $\sigma(\Delta m^2_{32})_{LBνB}$ for current favored $\delta_{CP}$

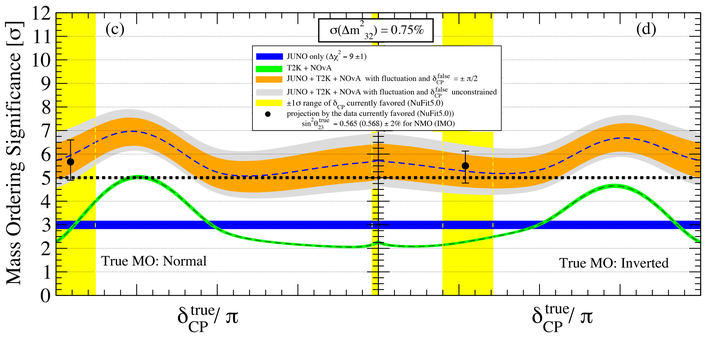



Remain as vacuum oscillation MO measurement

## 7. Combined MO sensitivity of JUNO, T2K and NOvA

JUNO + T2K & NOvA appearance channel and disappearance channel

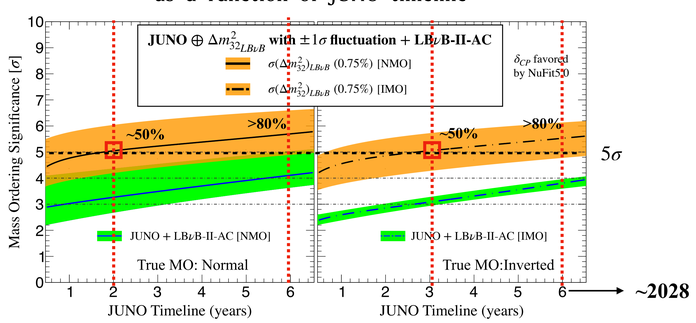
$(\sigma(\Delta m^2_{32})_{LBνB} = 0.75\,\%)$




$5\sigma$ median sensitivity can be achieved in full $\delta_{CP}$.

## 8. Estimated timeline of combined MO sensitivity

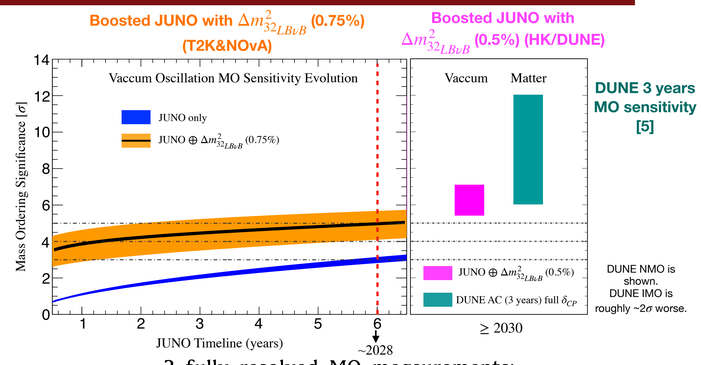
JUNO + T2K + NOvA with $\sigma(\Delta m^2_{32})_{LBνB} = 0.75\,\%$ and currently favored $\delta_{CP}$ as a function of JUNO timeline




NOvA and T2K data are expected to be available by 2026.

Atmospheric data will accelerate the $5\sigma$ MO determination.

## 9. Vacuum oscillation MO vs Matter effect MO




DUNE 3 years MO sensitivity [5]

DUNE NMO is shown. DUNE IMO is roughly ~2σ worse.

2 fully resolved MO measurements:

Vacuum oscillation by JUNO+Boosting vs Matter effect by DUNE.

Discrepancy may imply new physics.

## 10. Conclusions

- The combined sensitivity of JUNO, NOvA and T2K has the potential to yield the first resolved (≥5 σ ) MO measurement.
- JUNO + LBνB disappearance channel information ($\Delta m^2_{32\ LBνB}$) has the potential to achieve ≥5 σ vacuum driven MO measurement.
- It would be important for the comparison between two fully resolved MO measurements: vacuum oscillation (JUNO+$\Delta m^2_{32\ LBνB}$) and matter effects (DUNE). This comparison serves as cross-check. If discrepancy appears, it may imply new physics.

References

[1]: Ivan Esteban et al. The fate of hints: updated global analysis of three-flavor neutrino oscillations, JHEP 09 (2020) 178

[2]: Francesco Capozzi et al. Addendum to: Global constraints on absolute neutrino masses and their ordering, Phys. Rev. D 101, 116013 (2020)

[3]: P. F. de Salas et al. 2020 Global reassessment of the neutrino oscillation picture, J. High Energ. Phys. 2021, 71 (2021)

[4]: JUNO collaboration, Neutrino Physics with JUNO. J. Phys. G, 43(3):030401, 2016.

[5]: DUNE collaboration, Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume II DUNE Physics. ArXiv:2002.03005 [hep-ex]. 2 2020

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