Neutrino mass ordering determination through a combined JUNO and KM3NeT/ORCA analysis

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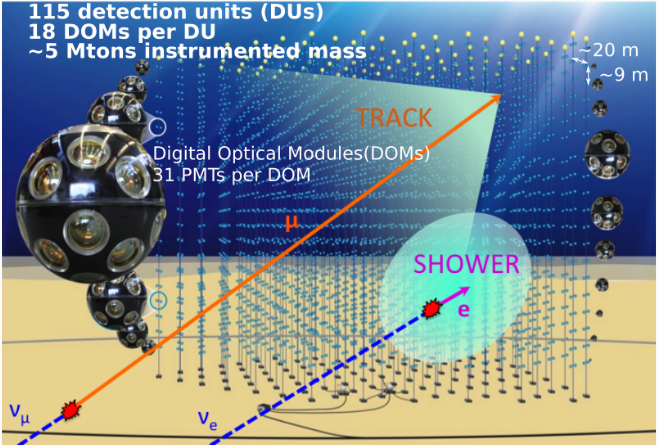
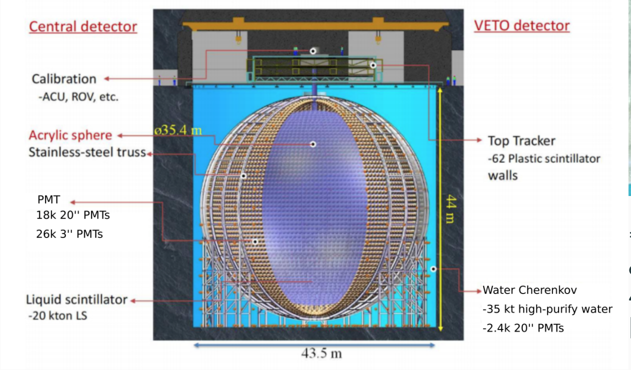
KM3NeT/ORCA

- **ORCA**: Oscillation Research with Cosmics in the Abyss.
- Study of **atmospheric neutrino oscillations above 1 GeV**.
- **Matter effect** allows **the determination of the NMO**.



JUNO

- **JUNO**: The Jiangmen Underground Neutrino Observatory.
- **Reactor neutrinos** at **medium baseline**(53 km).
- **Determine NMO** by **interference effects** between fast oscillations in $\overline{\nu}_e$ **spectrum**.
- The **Yangjiang NPP** is already fully operational, with **6 reactors** and The **Taishan NPP** has already **2 reactors** in operation.



*Model following F. An et al., J. Phys. G 43 (2016) no.3, 030401 [arXiv:1507.05613].

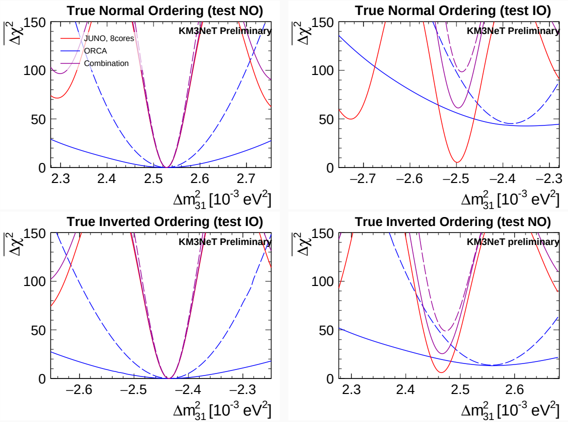
Combination strategy

- $\Delta\chi^2$ minimization of Asimov dataset.
- Combination on Δm^2_{31} and θ_{13} using a scanned grid:

$$\chi^2(\Delta m^2_{31}, \theta_{13}) = \chi^2_{\mathrm{JUNO}}(\Delta m^2_{31}, \theta_{13}) + \chi^2_{\mathrm{ORCA}}(\Delta m^2_{31}, \theta_{13}) + \frac{\left(\sin^2\theta_{13} - \sin^2\theta_{13}^{GF}\right)^2}{\sigma_{\sin^2\theta_{13}^{GF}}}$$

Osc parameters	JUNO	ORCA
θ_{13}	scan in grid	
Δm^2_{31}	scan in grid	
θ_{23}	$\times$	fitted
θ_{12}	fitted	fixed
Δm^2_{21}	fixed	
δ_{CP}	$\times$	fitted

Synergy effect, 6 years data taking



2 systematic approaches for ORCA:

- Dashed - Optimistic approach: with similar systematic set in Ref [1] 10.1103/PhysRevD.101.032006
- Solid - Conservative approach: with detector energy scale systematic leading to worse precision on Δm^2_{31}.

True NMO	JUNO (8 cores)	ORCA	Simple Sum	Combination
NO	2.3 σ	6.5 σ	6.9 σ	7.8 σ
IO	2.4 σ	3.6 σ	4.3 σ	5.1 σ

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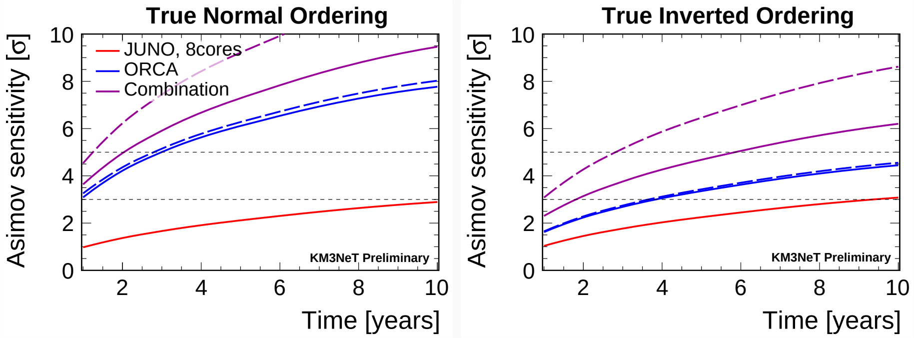
[1] Combined sensitivity to the neutrino mass ordering with JUNO, the IceCube Upgrade, and PINGU. 10.1103/PhysRevD.101.032006

Sensitivity in time

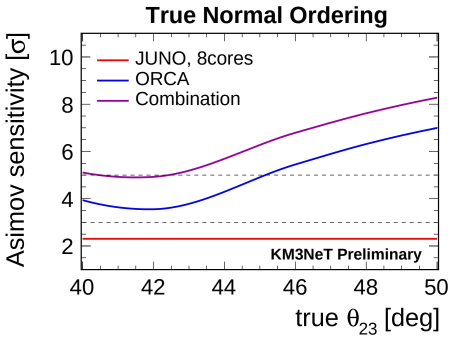


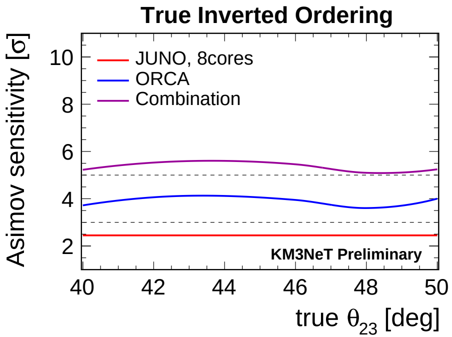
Dashed: Optimistic, Solid: Conservative

With the combined analysis

- Time needed to reach 5σ is reduced by at least one year compared to ORCA alone.
- A 5σ significance can be obtained within 2/6 years in case of true NO/IO, respectively, and independently of the systematic approach.

θ_{23} dependence, 6 years data taking





- θ_{23} dependence driven by ORCA sensitivity
- The combination ensures 5σ after 6 years regardless of the true value of θ_{23} and the true NMO.

Conclusion

- **The tension in the best fit values of Δm^2_{31} boosts the NMO sensitivity in a joint fit** between JUNO and KM3NeT/ORCA.
- 5σ can be reached after **6 years of combination** of JUNO and ORCA.
- **Detector energy scale for ORCA** can have strong impact on the combination.

Thank you for your listening!

Back up

Systematics

Table 1: Systematics parameters in ORCA analysis

Parameter	ORCA standard systematic	PINGU-like systematic
PID-class norm. factors	free	×
Effective area scale	×	10% prior
Detector energy scale	5% prior	×
Flux energy scale	×	10% prior
Flux $\nu_e/\bar{\nu}_e$ skew	7% prior	
Flux $\nu_\mu/\bar{\nu}_\mu$ skew	5% prior	
Flux $\nu_e/\bar{\nu}_\mu$ skew	2% prior	
Flux E-tilt	free	
NC norm	10% prior	

Systematics

Table 2: Systematic parameters in JUNO analysis

Error source	Value
Correlated reactor error	2.0%
Uncorrelated reactor error	0.8%
Reactor spectrum	1.0%
Detector response	1.0%

Background rate and shape, together with all the associated uncertainties were taken from Ref. [[2]]

[2] J. Phys. G 43 (2016) 030401

Impact of JUNO energy resolution

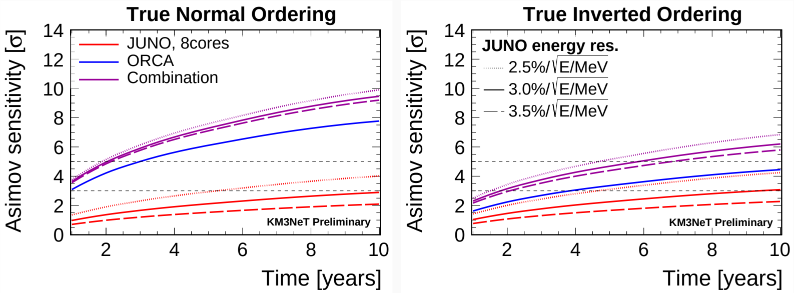


Figure 1: NMO sensitivity as a function of time, considering a better (dotted) and worse (dashed) energy resolution for JUNO than the nominal one (solid) by $\pm 0.5\%/\sqrt{E/\mathrm{MeV}}$.

Nominal number of reactors for JUNO

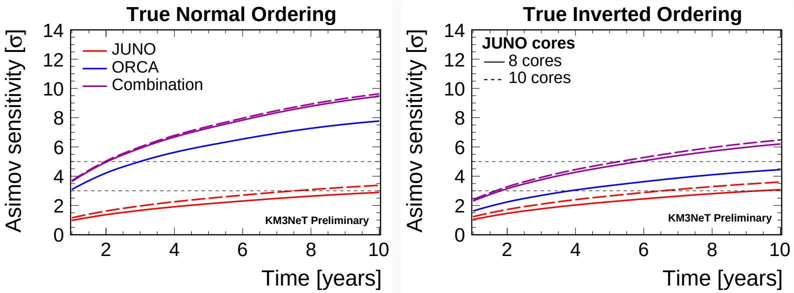


Figure 2: NMO sensitivity as a function of time, considering 2 (solid) or 4 (dashed) Taishan NPP reactors, corresponding respectively to 8 or 10 reactor cores at 53 km from JUNO.

Δm^2_{31} dependence

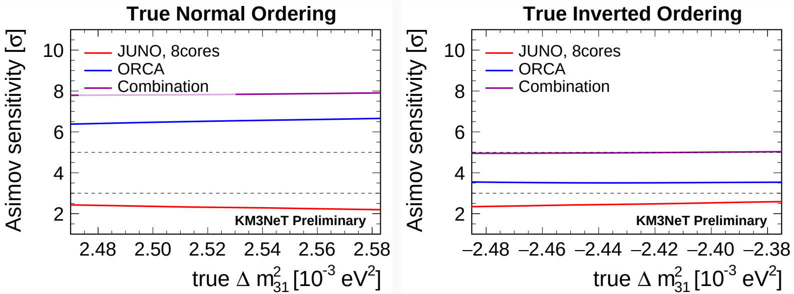


Figure 3: NMO sensitivity as a function of the true Δm^2_{31} value for 6 years of data.