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

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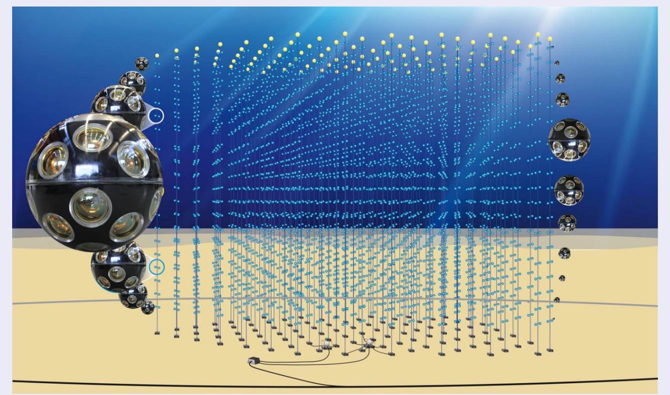
KM3NeT/ORCA overview [1, T1245]



- KM3NeT detector located in Mediterranean sea
  - Water Cherenkov detector arrays
- ORCA: "low-energy" array for oscillation studies
  - Detect atmospheric neutrinos in GeV energy range
  - NMO obtained from Earth matter effects
- Neutrino sample divided in 3 PID classes
  - Track-like (ν_μ CC) to Shower-like (ν_e CC + ν NC)
- Detector being installed gradually until 2025

ORCA systematics

Table: Baseline and optimistic scenarios for the treatment of systematics considered in the ORCA analysis.

Parameter	Baseline scenario	Optimistic scenario
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	7% prior
Flux $\nu_\mu/\bar{\nu}_\mu$ skew	5% prior	5% prior
Flux $\nu_e/\bar{\nu}_\mu$ skew	2% prior	2% prior
Flux spectral index	free	free
NC normalization	10% prior	10% prior

Combined analysis

- Systematic errors from JUNO and ORCA not correlated
  - Different neutrino sources and energy
  - Different detection medium and methods
  - ⇒ Only oscillation parameters "shared" between JUNO and ORCA
- However, not all oscillation parameters are shared...
  - δ_{CP} and θ_{23} → no impact on JUNO
    - ⋆ In ORCA, fit done twice, each time with θ_{23} starting in a different octant
  - Δm^2_{21} and θ_{12} → negligible impact on ORCA
    - ⋆ Parameters also precisely determined by JUNO
  - Δm^2_{31} and θ_{13} → both JUNO and ORCA sensitive to them
    - ⋆ However, worse precision on θ_{13} than from current experiments
  - ⇒ Prior added on θ_{13} from Ref. [3]
- Perform grid scan on Δm^2_{31} and θ_{13}
  - In each point, compute separately χ^2 from JUNO and ORCA
  - Asimov data set used to compute χ^2
  - χ^2 separately profiled over systematic errors and other oscillation parameters

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

- Central value of oscillation parameters from best-fit of Ref. [3]

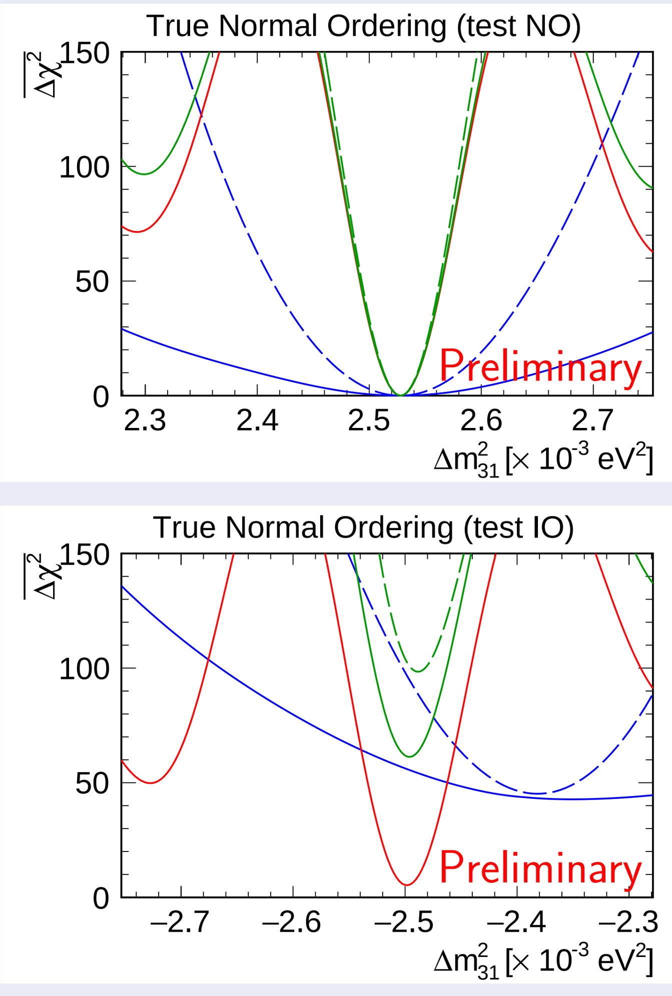
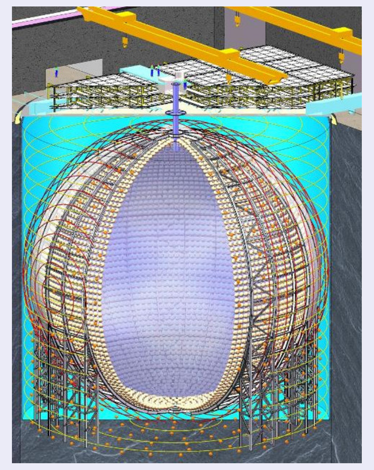


Figure: $\overline{\Delta\chi^2}$ profile for only JUNO (red), only ORCA (blue), and the combination of JUNO and ORCA (green) for 6 years of data taking assuming baseline (solid) or optimistic (dashed) systematics.

JUNO overview [2, T1209]

- JUNO detector located in south east of China
- At 53 km from Yangjiang and Taishan Nuclear Power Plants (NPP)
  - Detect reactor $\bar{\nu}_e$ at few MeV energy range via IBD
  - NMO from fast oscillations, not relying in matter effects
- JUNO energy resolution: $3\%/\sqrt{E/\text{MeV}}$
  - Energy resolution critical for NMO determination
- Data taking to start in 2022



JUNO in this study

- JUNO modeling following Ref. [2]
  - Syst. error on reactor spectrum, detector response
  - Backgrounds rate, shape, and uncertainties
  - Detector mass, distance and power of NPPs
- Only 2 reactor cores @ Taishan considered
  - Ref. [2] considered 4 cores @ Taishan
  - 2 cores @ Taisahn already build
  - However, plan for adding last 2 cores uncertain
- Nominal $3\%/\sqrt{E/\text{MeV}}$ energy resolution assumed
  - From JUNO studies, nominal resolution achievable
  - Impact of significantly worse resolution studied

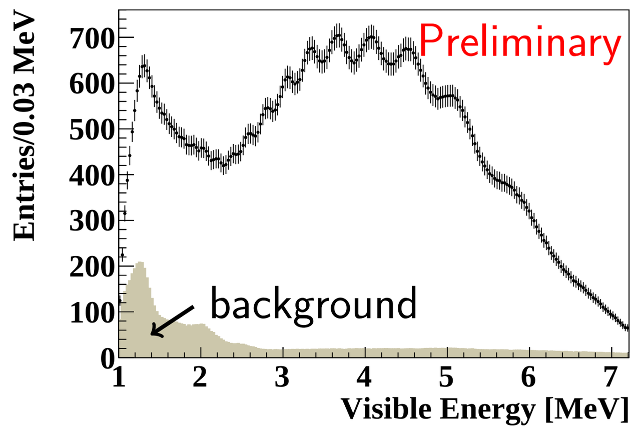


Figure: Expected event distribution for 6 years of data with JUNO. True NO and oscillation parameters from Ref. [3] are assumed.

Results

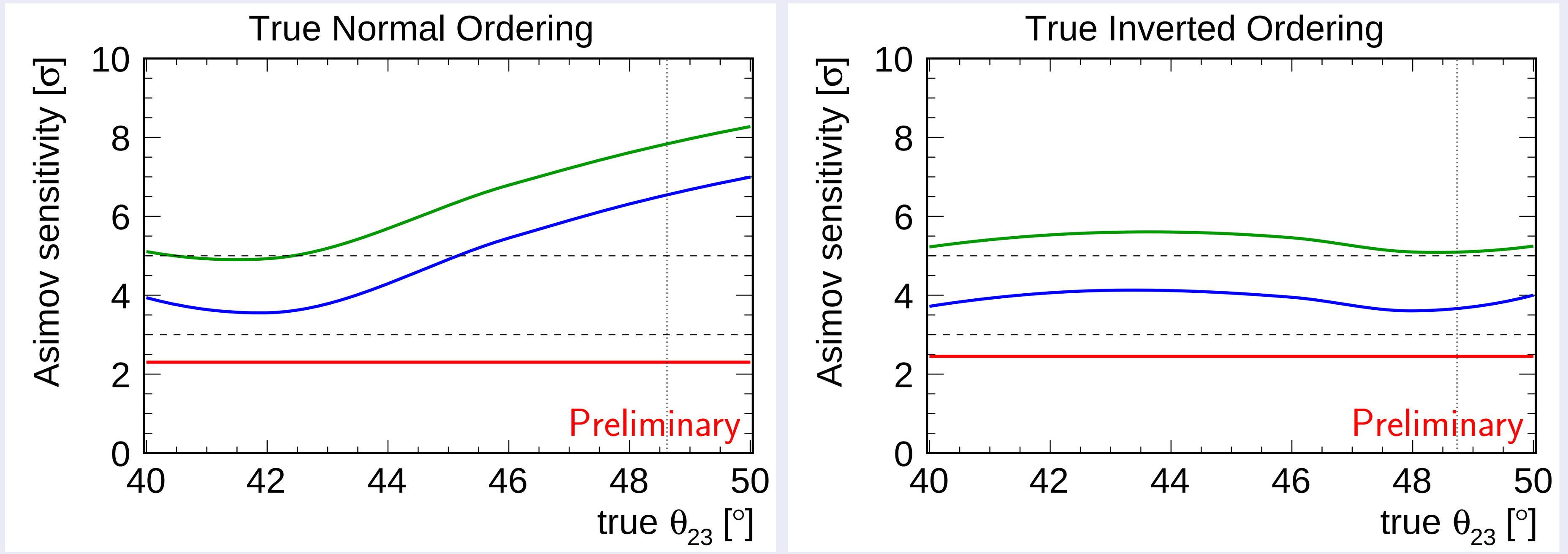


Figure: NMO sensitivity as a function of the true θ_{23} value for 6 years of data taking for only JUNO (red), only ORCA (blue), and the combination of JUNO and ORCA (green). The vertical lines indicate the global best-fit values used in this analysis (from Ref. [3]).

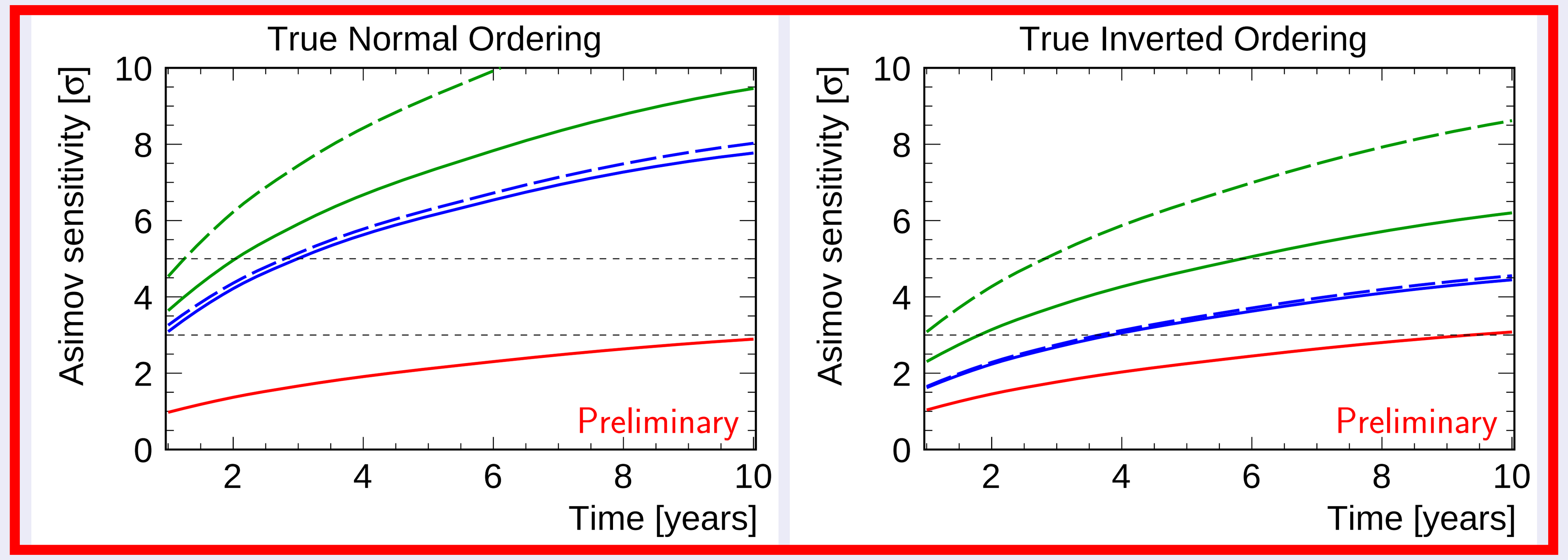


Figure: NMO sensitivity as a function of time for only JUNO (red), only ORCA (blue), and the combination of JUNO and ORCA (green), assuming baseline (solid) or optimistic (dashed) systematics.

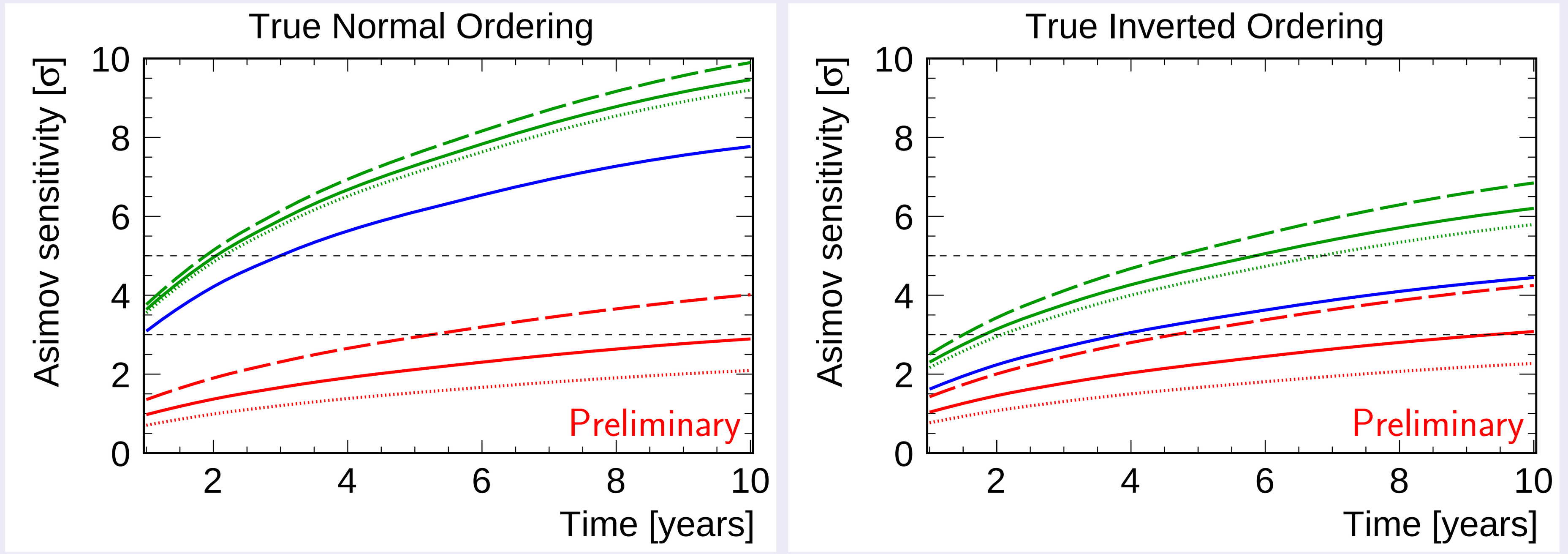


Figure: NMO sensitivity as a function of time for only JUNO (red), only ORCA (blue), and the combination of JUNO and ORCA (green), considering a better (dashed) and worse (dotted) energy resolution for JUNO than the nominal one (solid) by $\pm 0.5\%/\sqrt{E/\text{MeV}}$.

Conclusions

- Combination power relies on tension between best-fit of Δm^2_{31} in "wrong ordering" between JUNO and ORCA
- Systematic errors impacting combined analysis different from stand-alone analyses
- Result robust regarding JUNO energy resolution
- However, non negligible impact from treatment of ORCA energy scale systematics
- For NO with current best fit, 5σ NMO determination reached in only 2 years
- **NMO determination @5σ with 6 years of data for any oscillation parameter**

References

[1] S. Adrian-Martinez *et al.* [KM3NeT Collaboration], J. Phys. G **43** (2016) no.8, 084001 [1601.07459].
[2] F. An *et al.* [JUNO Collaboration], J. Phys. G **43** (2016) no.3, 030401 [1507.05613].
[3] I. Esteban *et al.* JHEP **01** (2019), 106 [1811.05487].

Related presentations @ICRC

[T1209] J. P. A. M. de André *et al.* [JUNO Collaboration] "JUNO Physics Prospects"
[T1245] M. Perrin-Terrin *et al.* [KM3NeT Collaboration] "Sensitivity of the KM3NeT/ORCA detector to the neutrino mass ordering and beyond"