Neutrino mass ordering determination through combined analysis with JUNO and KM3NeT/ORCA [1]

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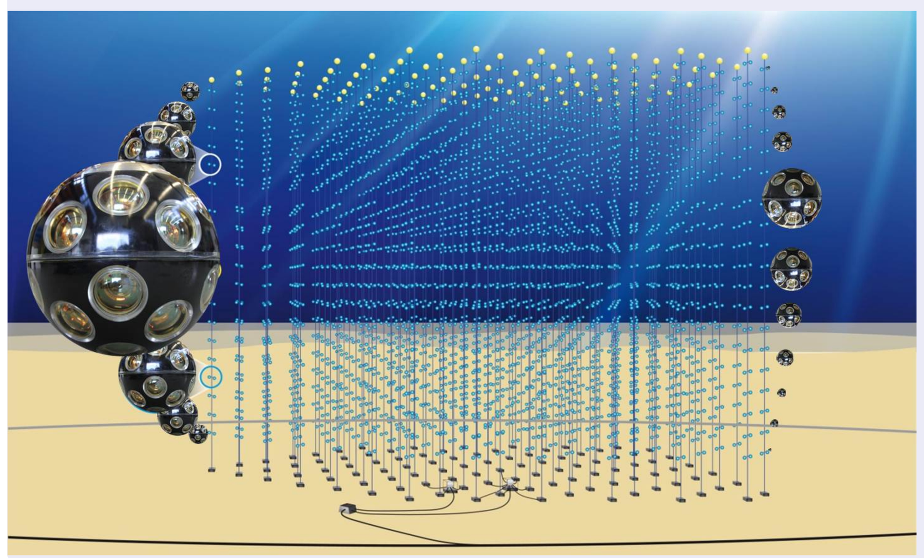
KM3NeT/ORCA overview [2, KM3Net talk]



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

ORCA systematics

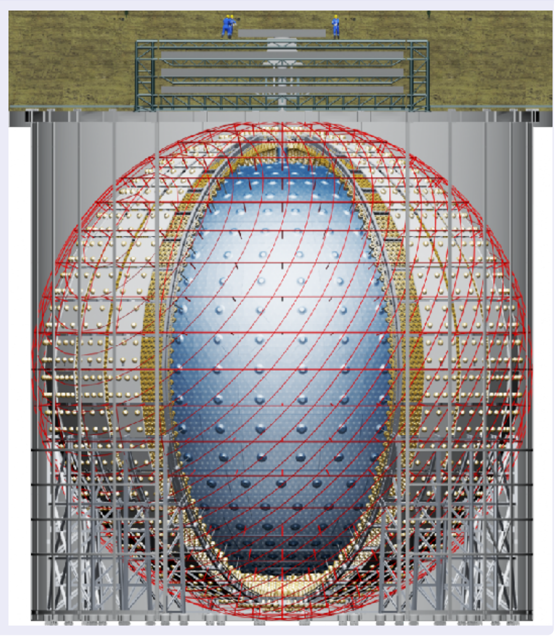
Table: Baseline and optimistic scenarios for the treatment of systematics considered in the ORCA analysis.

Parameter	Baseline scenario	Optimistic scenario
Flux spectral index	free	free
Flux $\nu_e/\bar{\nu}_e$ ratio	7% prior	7% prior
Flux $\nu_\mu/\bar{\nu}_\mu$ ratio	5% prior	5% prior
Flux $(\nu_e+\bar{\nu}_e)/(\nu_\mu+\bar{\nu}_\mu)$ ratio	2% prior	2% prior
NC normalization	10% prior	10% prior
Detector energy scale	5% prior	×
PID-class norm. factors	free	×
Effective area scale	×	10% prior
Flux energy scale	×	10% prior

- Baseline scenario corresponds to systematics used in other KM3NeT/ORCA papers
- Optimistic scenario matches best parameters from Ref. [6]

JUNO overview [3, 4]

- JUNO detector located in south east of China
- 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
  - Update to JUNO NMO study presented at Neutrino 2022 [5]
    - This work still uses previous JUNO performance values!
- JUNO energy resolution: $3\%/\sqrt{E/\mathrm{MeV}}$
  - Energy resolution critical for NMO determination
- Data taking to start in 2023



JUNO in this study

- JUNO modeling following Ref. [3]
  - 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. [3] considered 4 cores @ Taishan
  - 2 cores @ Taisahn already build
  - However, plan for adding last 2 cores uncertain
- Nominal $3\%/\sqrt{E/\mathrm{MeV}}$ energy resolution assumed
  - From JUNO studies, nominal resolution achievable
  - Impact of significantly worse resolution studied

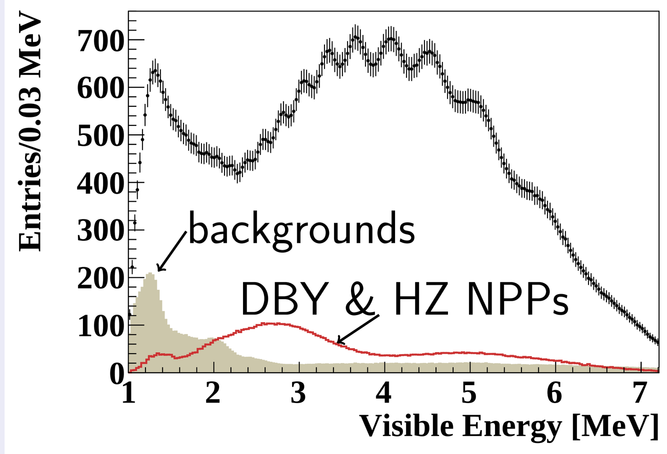


Figure: Expected event distribution for 6 years of data with JUNO. True NO and oscillation parameters from Ref. [7] are assumed.

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
  - Δm^2_{21} and θ_{12} → negligible impact on ORCA
  - 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. [7]
- Perform grid scan on Δm^2_{31} and θ_{13}
  - Asimov data set used to compute χ^2
  - In each point, compute separately χ^2 from JUNO and ORCA
  - χ^2 separately profiled over systematic errors and other oscillation parameters

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

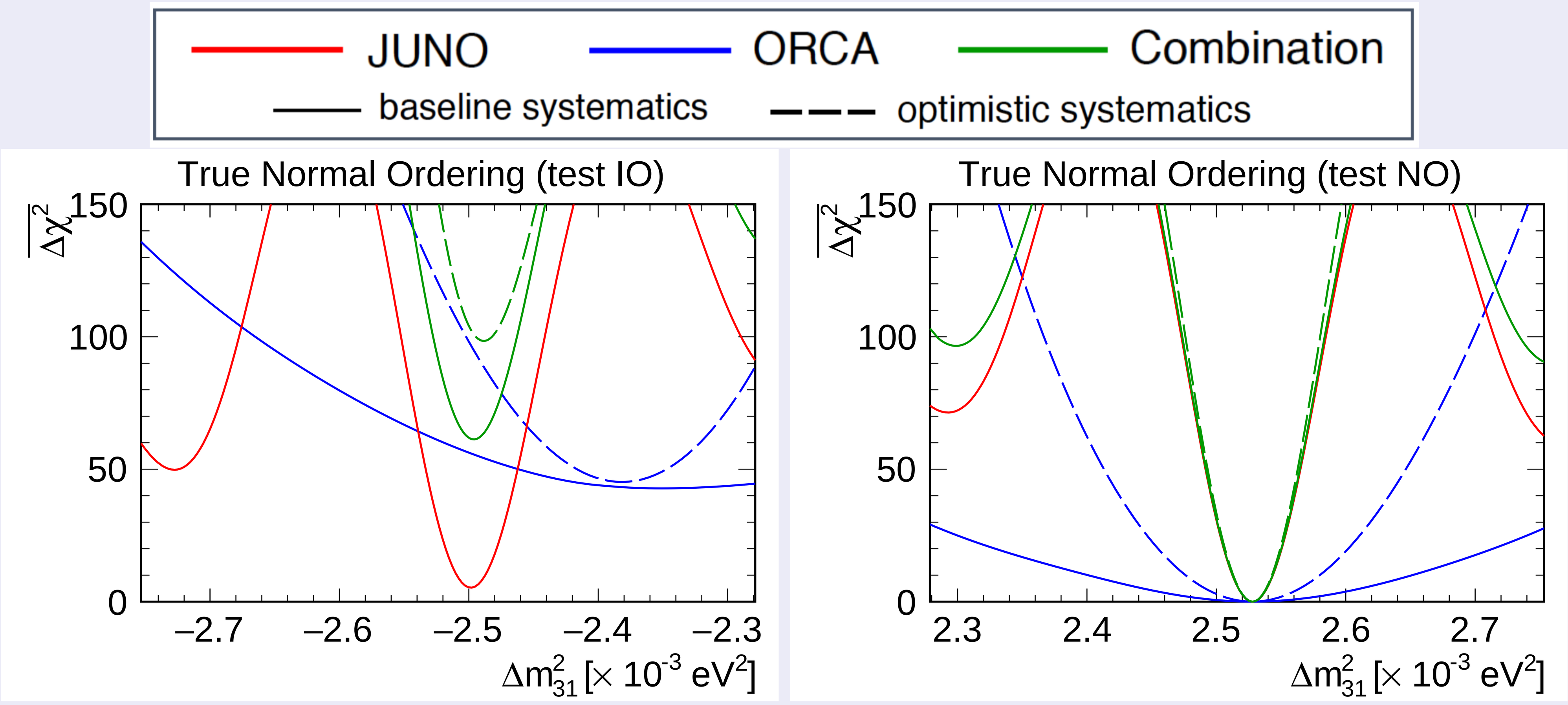


Figure: $\overline{\Delta\chi^2}$ profile for 6 years of data taking.

Results

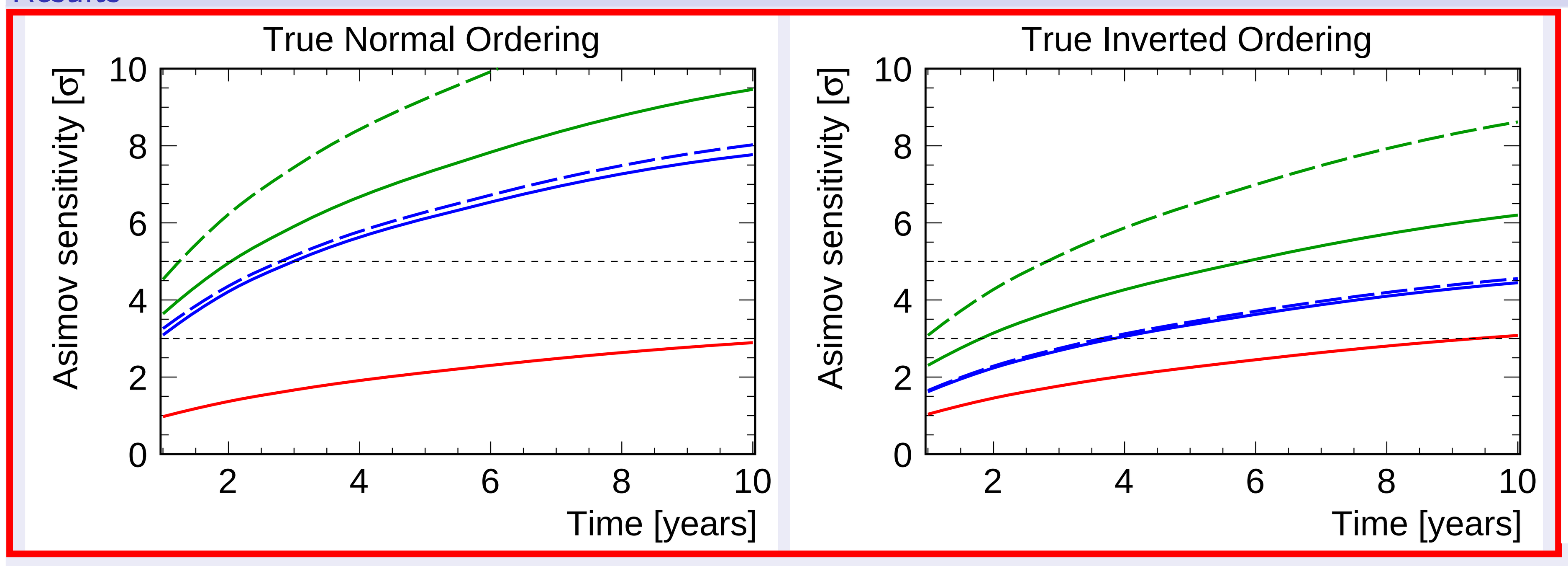


Figure: NMO sensitivity as a function of time.

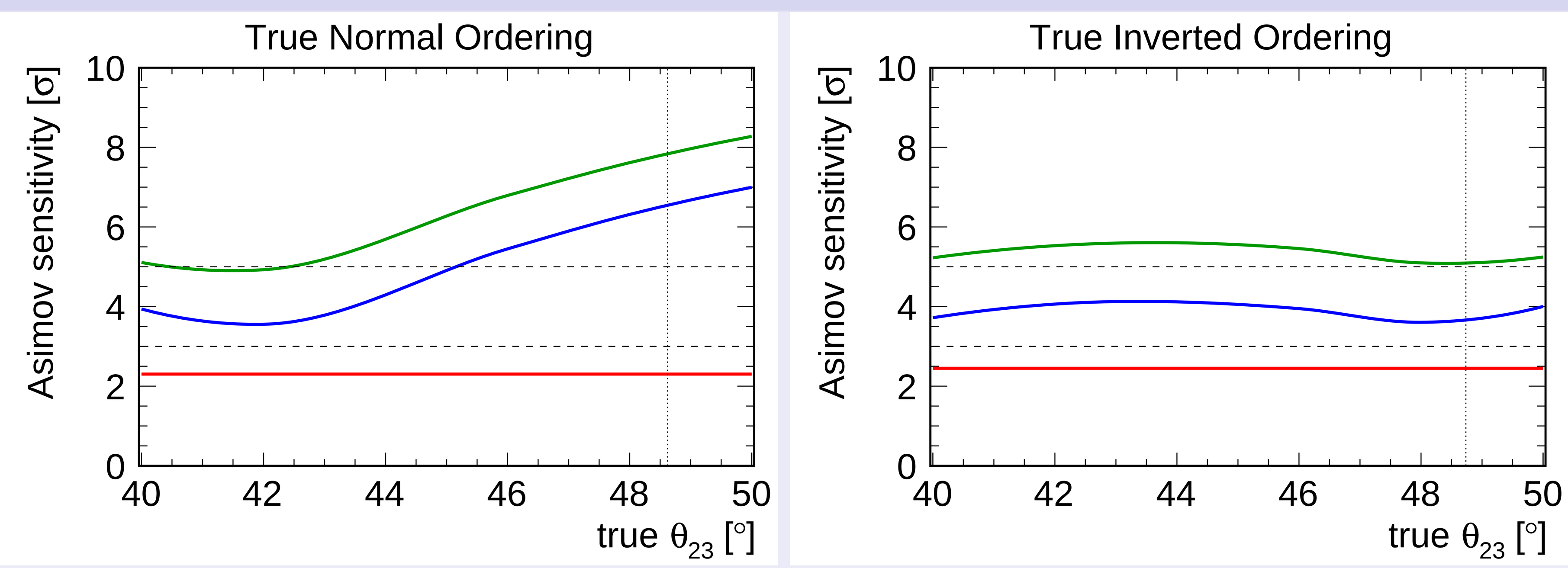


Figure: NMO sensitivity as a function of the true θ_{23} value for 6 years of data taking Vertical lines from Ref. [7].

Conclusions

- Combination power relies on tension between best-fit of Δm^2_{31} in "wrong ordering" between JUNO and ORCA
- Different systematic errors impact in combined analysis
- For current NO best fit, reach 5σ NMO determination in 2 years
- **NMO determination @5σ with 6 years of data for any oscillation parameter**

Dependency on JUNO energy resolution and number of NPPs @ 53 km for JUNO

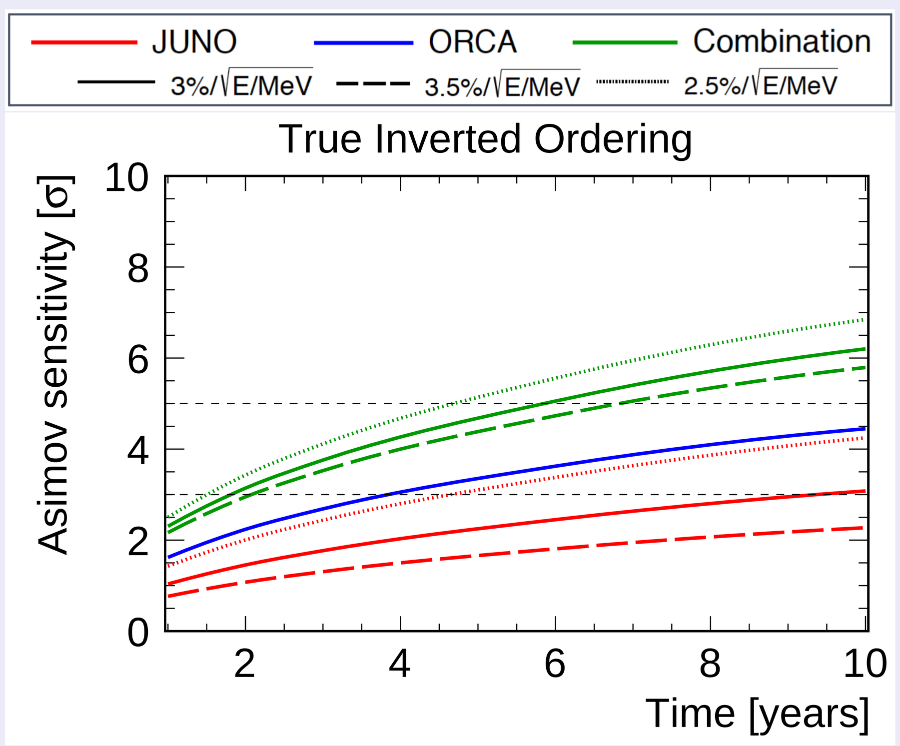


Figure: NMO sensitivity as a function of time with different energy resolution for JUNO.

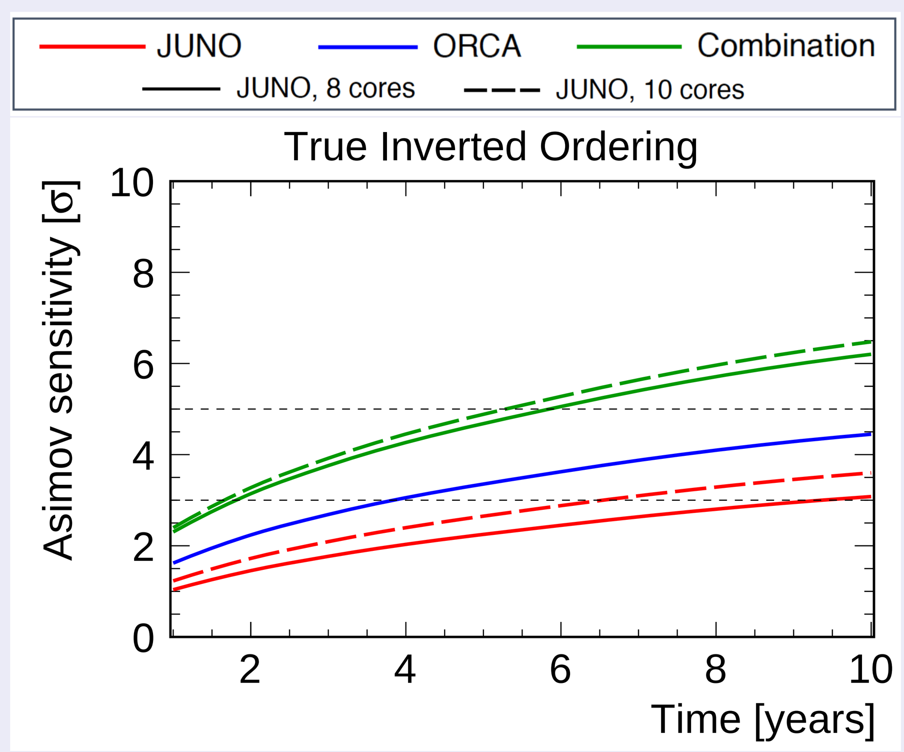


Figure: NMO sensitivity as a function of time with different number of NPP at 53 km from JUNO.

References

[1] S. Aiello *et al.* [KM3NeT and JUNO members], JHEP **03** (2022), 055 [2108.06293].
[2] S. Adrian-Martinez *et al.* [KM3NeT Collaboration], J. Phys. G **43** (2016) no.8, 084001 [1601.07459].
[3] F. An *et al.* [JUNO Collaboration], J. Phys. G **43** (2016) no.3, 030401 [1507.05613].
[4] A. Abusleme *et al.* [JUNO], Prog. Part. Nucl. Phys. **123** (2022), 103927 [2104.02565].
[5] J. Zhang *et al.* [JUNO], Neutrino 2022, DOI: 10.5281/zenodo.6775075.
[6] M. G. Aartsen *et al.* [IceCube-Gen2], Phys. Rev. D **101** (2020) no.3, 032006 [1911.06745].
[7] I. Esteban *et al.* JHEP **01** (2019), 106 [1811.05487].

Related presentation @RICH

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