First Physics Results from JUNO

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On behalf of the JUNO Collaboration

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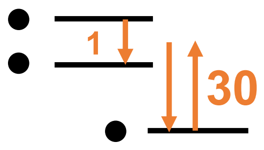
Neutrino Mass and Mixing

$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = \begin{pmatrix}1 & 0 & 0\\ 0 & \cos\theta_{23} & \sin\theta_{23}\\ 0 & -\sin\theta_{23} & \cos\theta_{23}\end{pmatrix}\begin{pmatrix}\cos\theta_{13} & 0 & \sin\theta_{13}e^{-i\delta_{CP}}\\ 0 & 1 & 0\\ -\sin\theta_{13}e^{i\delta_{CP}} & 0 & \cos\theta_{13}\end{pmatrix}\begin{pmatrix}\cos\theta_{12} & \sin\theta_{12} & 0\\ -\sin\theta_{12} & \cos\theta_{12} & 0\\ 0 & 0 & 1\end{pmatrix}\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$



$\theta_{13} \neq 0 \rightarrow \delta_{CP}$ can be observed

Open questions

- ❑ Neutrino *mass* structure
  - ❖ Mass gaps (Δm^2_{21}, $|\Delta m^2_{32}|$) and ordering (sgn Δm^2_{32})?
- ❑ Neutrino *flavour* structure
  - ❖ Mixing angles (θ_{12}, θ_{23} , θ_{13}) and CP-phase (δ_{CP})?

🙅 Not accessible through oscillation measurements:

- ❑ Absolute mass
- ❑ Dirac/Majorana nature

θ_{12}: mixing between ν_1 and ν_2

θ_{23}: mixing between ν_μ and ν_τ

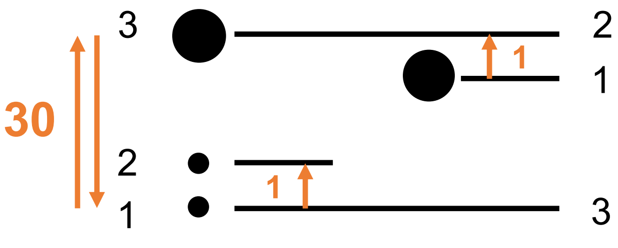
θ_{13}: if 0, effective 2 flavour mixing

- ➢ No CPV!

$$\begin{pmatrix}\nu_e\\ \nu_{\mu'}\\ \nu_{\tau'}\end{pmatrix} = \begin{pmatrix}\cos\theta_{12} & \sin\theta_{12} & 0\\ -\sin\theta_{12} & \cos\theta_{12} & 0\\ 0 & 0 & 1\end{pmatrix}\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$

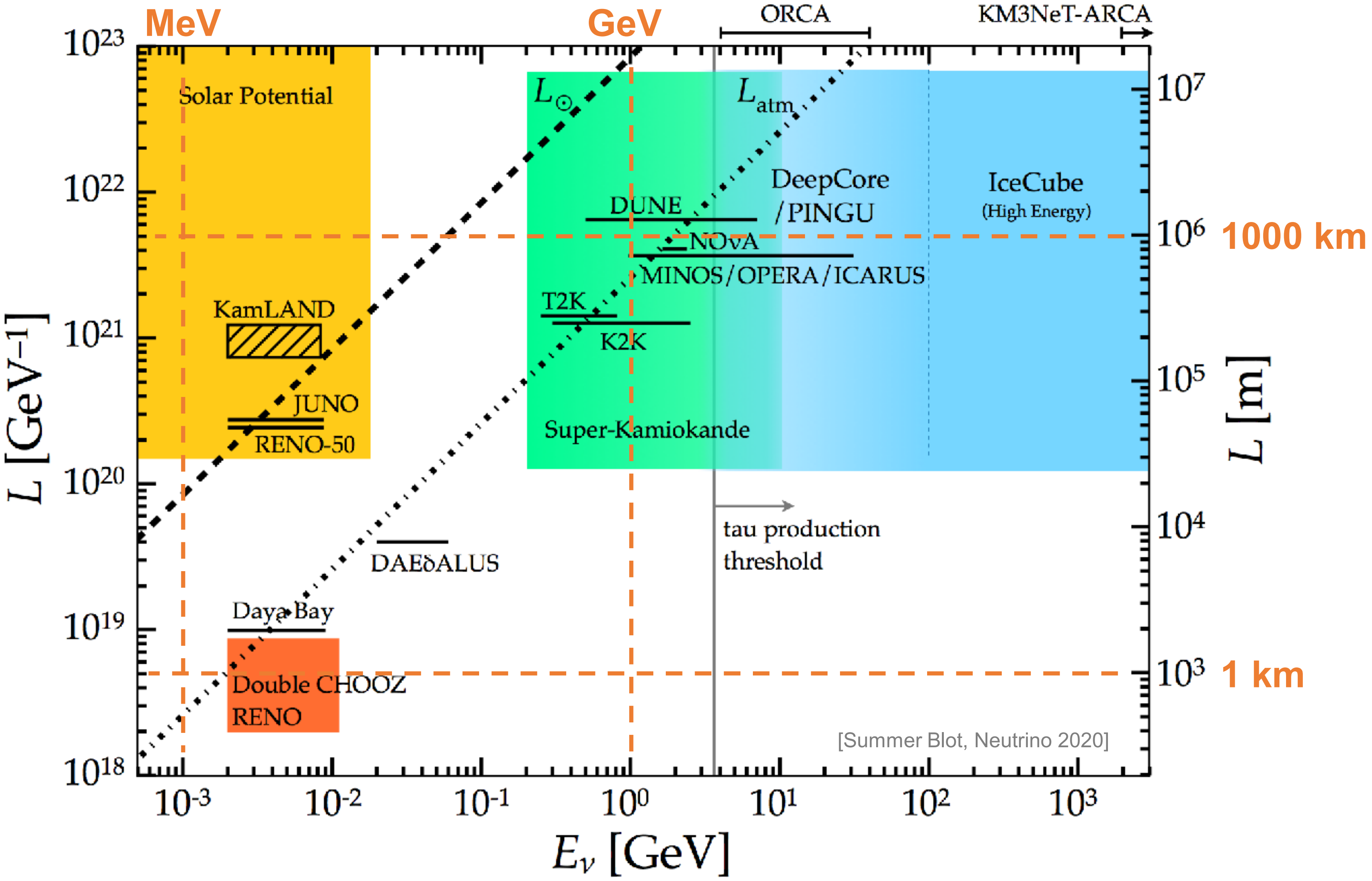
Neutrino Oscillation Experiments

Only two Δm^2



Normal Inverted

Oscillation Phase ~ $\Delta m^2 L/E$



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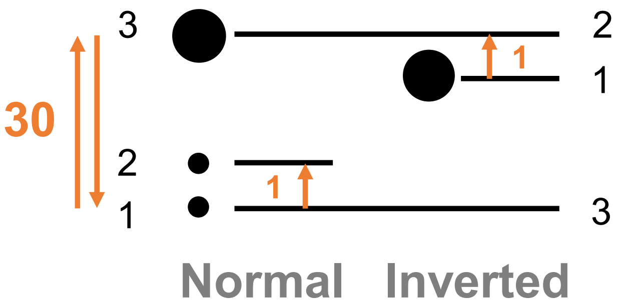

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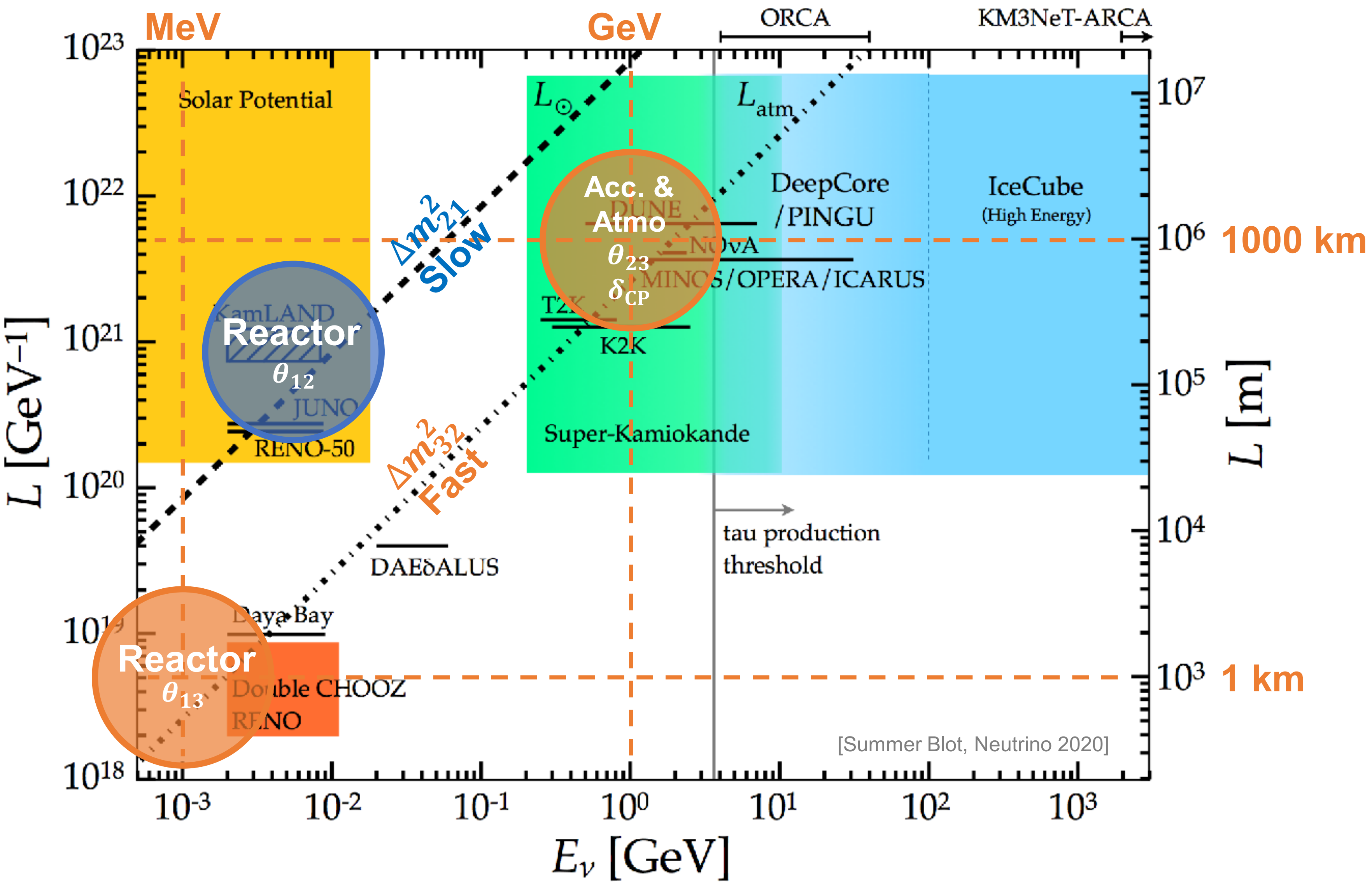
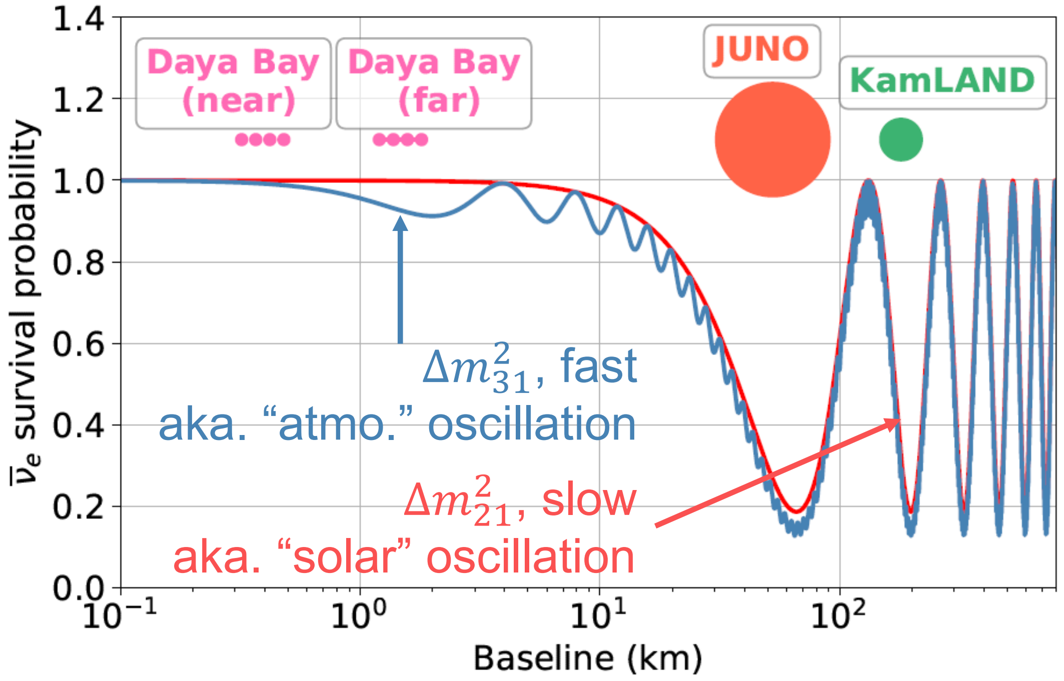
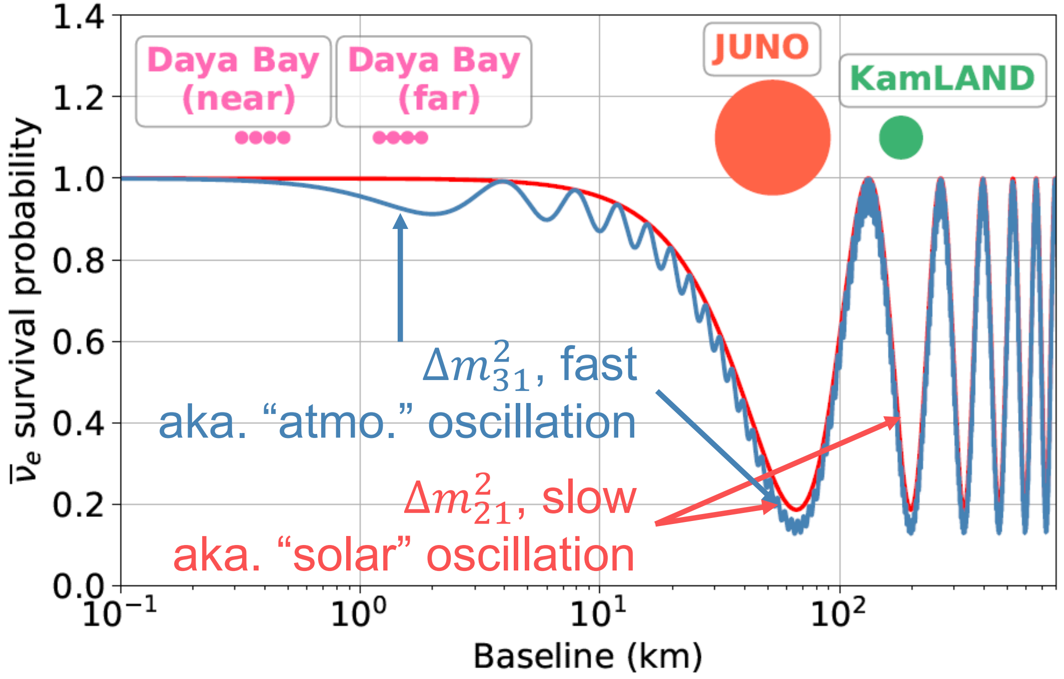


Neutrino Oscillation at JUNO

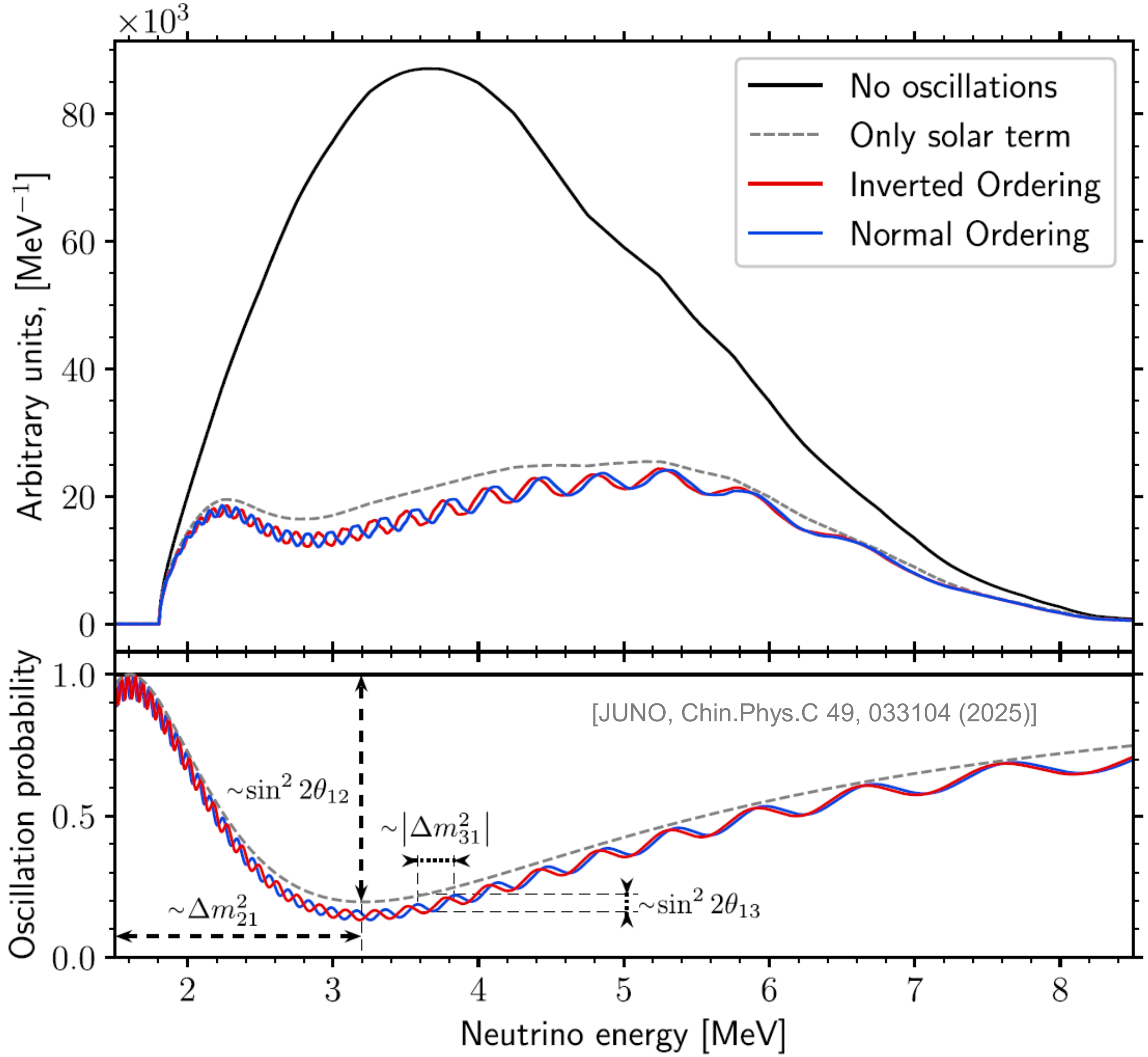


Neutrino Oscillation at JUNO



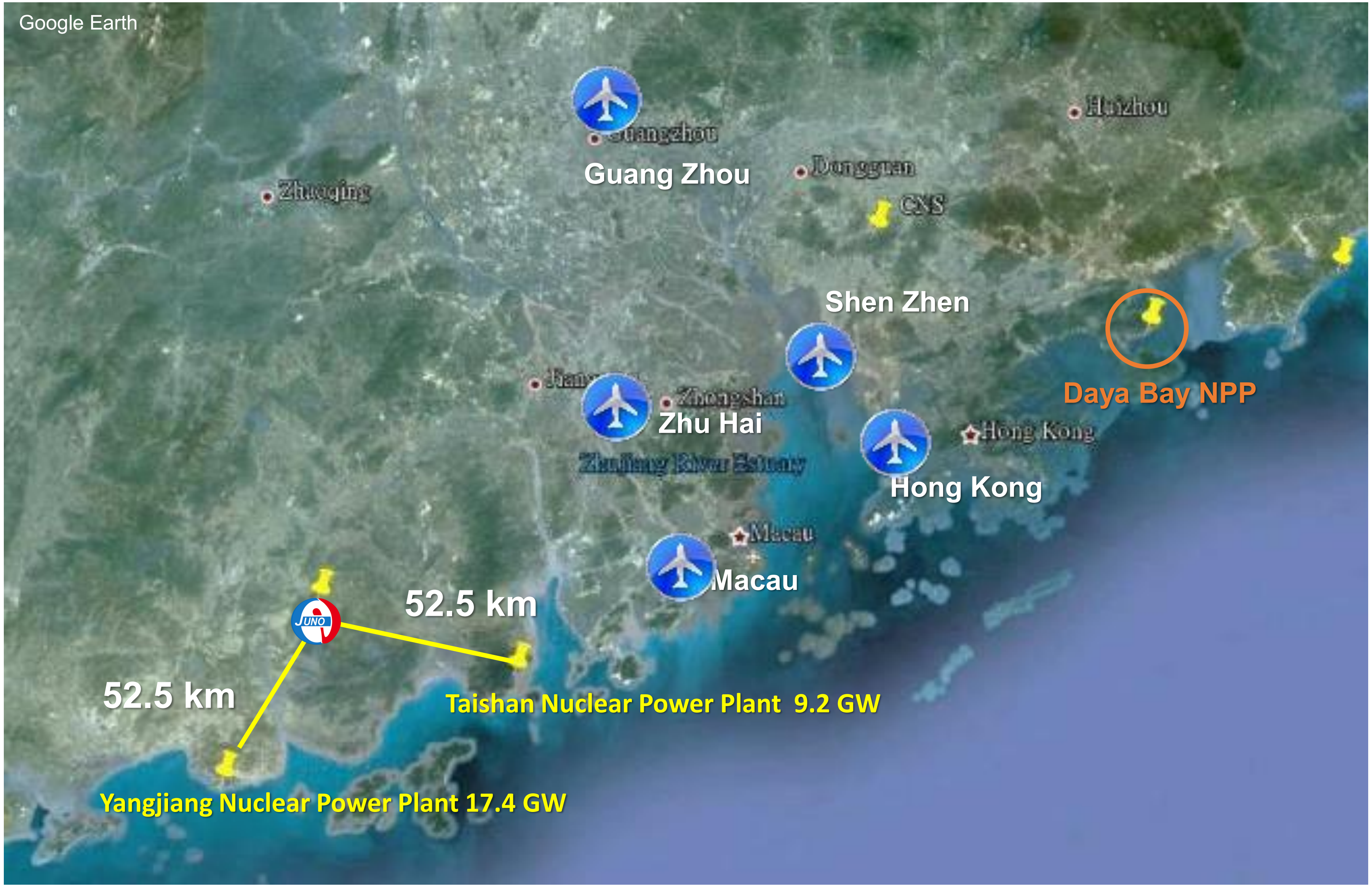
$$
\begin{aligned}
P_{ee}(L/E) &= 1 - P_{21} - P_{31} - P_{32} \\
P_{21} &= \cos^4(\theta_{13}) \sin^2(2\theta_{12}) \sin^2(\Delta_{21}) \\
P_{31} &= \cos^2(\theta_{12}) \sin^2(2\theta_{13}) \sin^2(\Delta_{31}) \\
P_{32} &= \sin^2(\theta_{12}) \sin^2(2\theta_{13}) \sin^2(\Delta_{32})
\end{aligned}
$$

S. Petcov and Piai, Phys. Lett. B 553, 94-106 (2002)
J. Learned et al., PRD 78(2008)071302
L. Zhan, Y. Wang et al., PRD 78(2008)111103



JUNO's main goal: Neutrino Mass Ordering

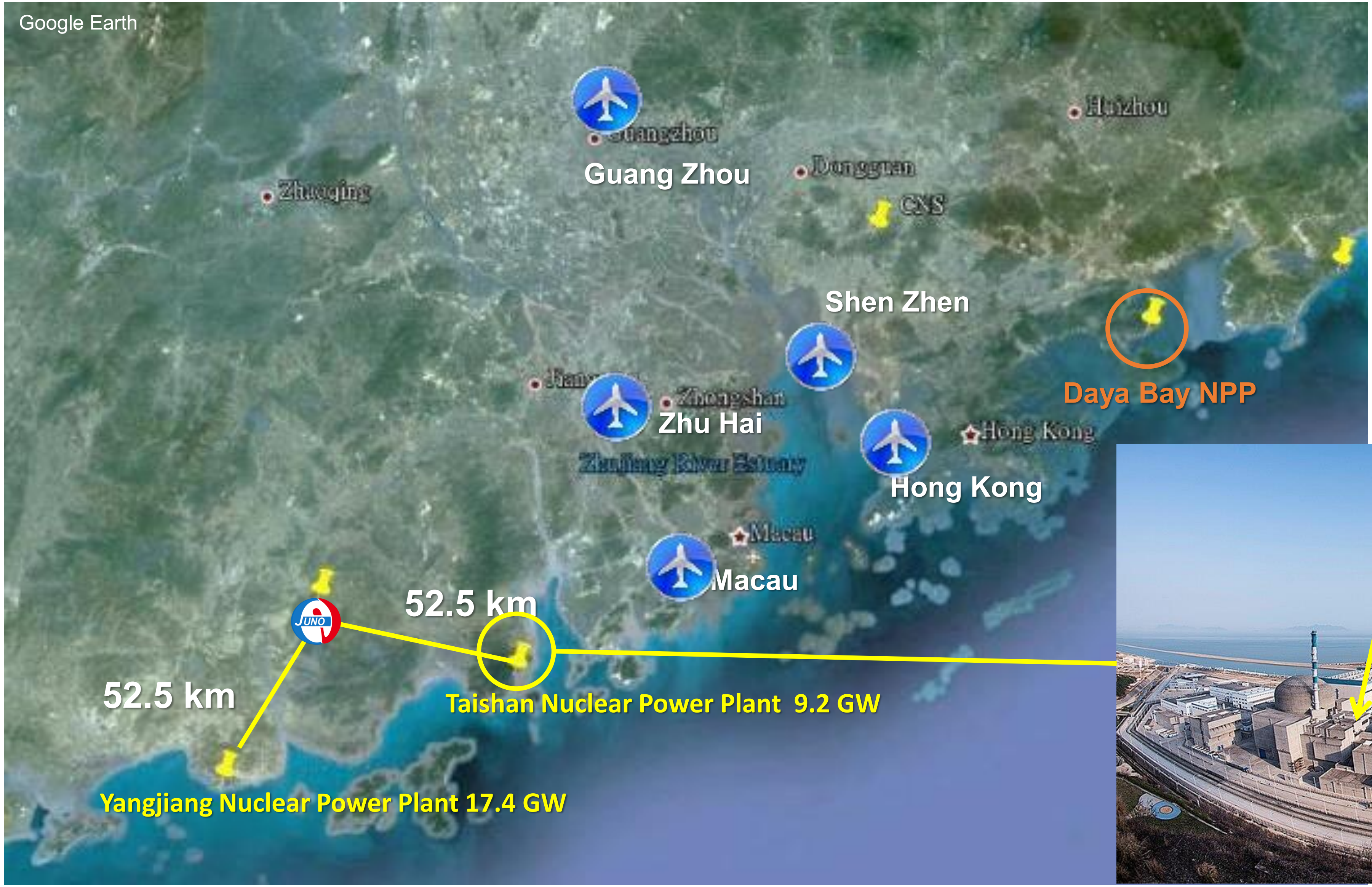
JUNO's Location



JUNO: Jiangmen Underground Neutrino Observatory

- ❑ Data taking since Nov. 2025

JUNO's Location



JUNO-TAO: Taishan Antineutrino Observatory

- Satellite experiment of JUNO
- Data taking since Feb. 2026

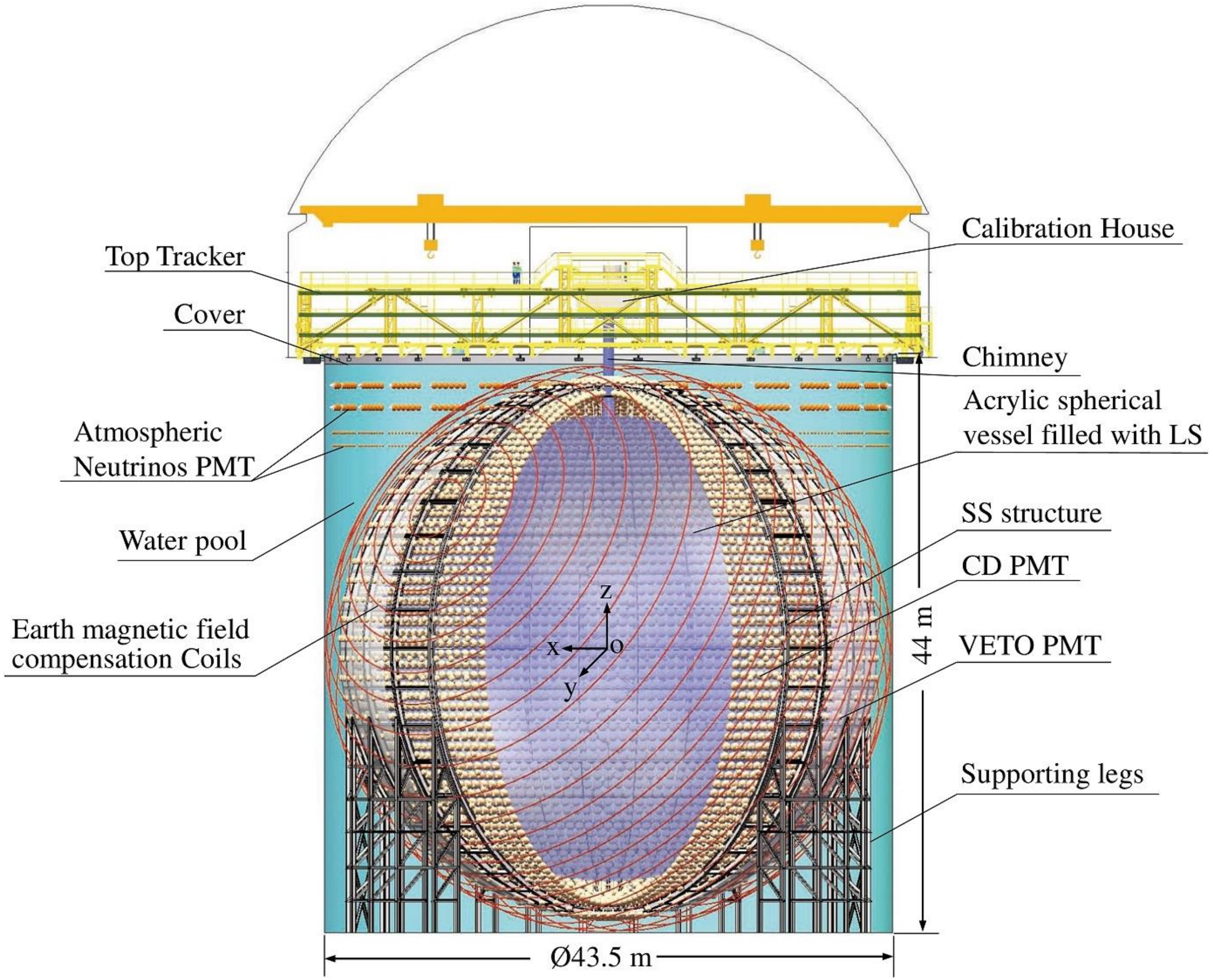
JUNO Project and Collaboration

- Project firstly approved in China in 2013 and later in other countries. Civil construction started in 2015
- Collaboration mostly established in 2014, now >700 collaborators from 70 institutions in 16 countries/regions

Country	Institute	Country	Institute	Country	Institute
Armenia	YerPhI	China	SDU	Italy	INFN-CT
Belgium	ULB	China	SJTU	Italy	INFN-FE
Chile	SAPHIR	China	SUSTech	Italy	INFN-LNF
Chile	UNAB	China	SYSU	Italy	INFN-MI
China	BISEE	China	THU	Italy	INFN-MIB
China	CDUT	China	UCAS	Italy	INFN-PD
China	CNPRI	China	WHU	Italy	INFN-PG
China	CUGB	China	WuYiU	Italy	INFN-Roma3
China	DGUT	China	XJTU	Pakistan	PINSTECH (PAEC)
China	ECUT	China	XMU	Russia	JINR
China	GXU	China	ZZU	Slovakia	FMFI-UK
China	HIT	Czech	Charles U.	Taiwan-China	NCTU
China	HunanU	Finland	JyU	Taiwan-China	NKNU
China	IGGCAS	France	CPPM	Taiwan-China	NTU
China	IHEG-CAGS	France	IJCLab	Taiwan-China	NTUT
China	IHEP	France	IPHC	Thailand	CHULA
China	IMP	France	LP2iB	Thailand	NARIT
China	JNU	France	Subatech	Thailand	SUT
China	JXNU	Germany	EKUT	U.K.	U. Liverpool
China	KNRC	Germany	GSI	U.K.	U. Warwick
China	Nankai U.	Germany	U. Hamburg	USA	UC-Irvine
China	NCEPU	Germany	JGUMainz	USA	UMD-G
China	NJU	Germany	RWTH-AC		
China	RNCG	Germany	TUM		

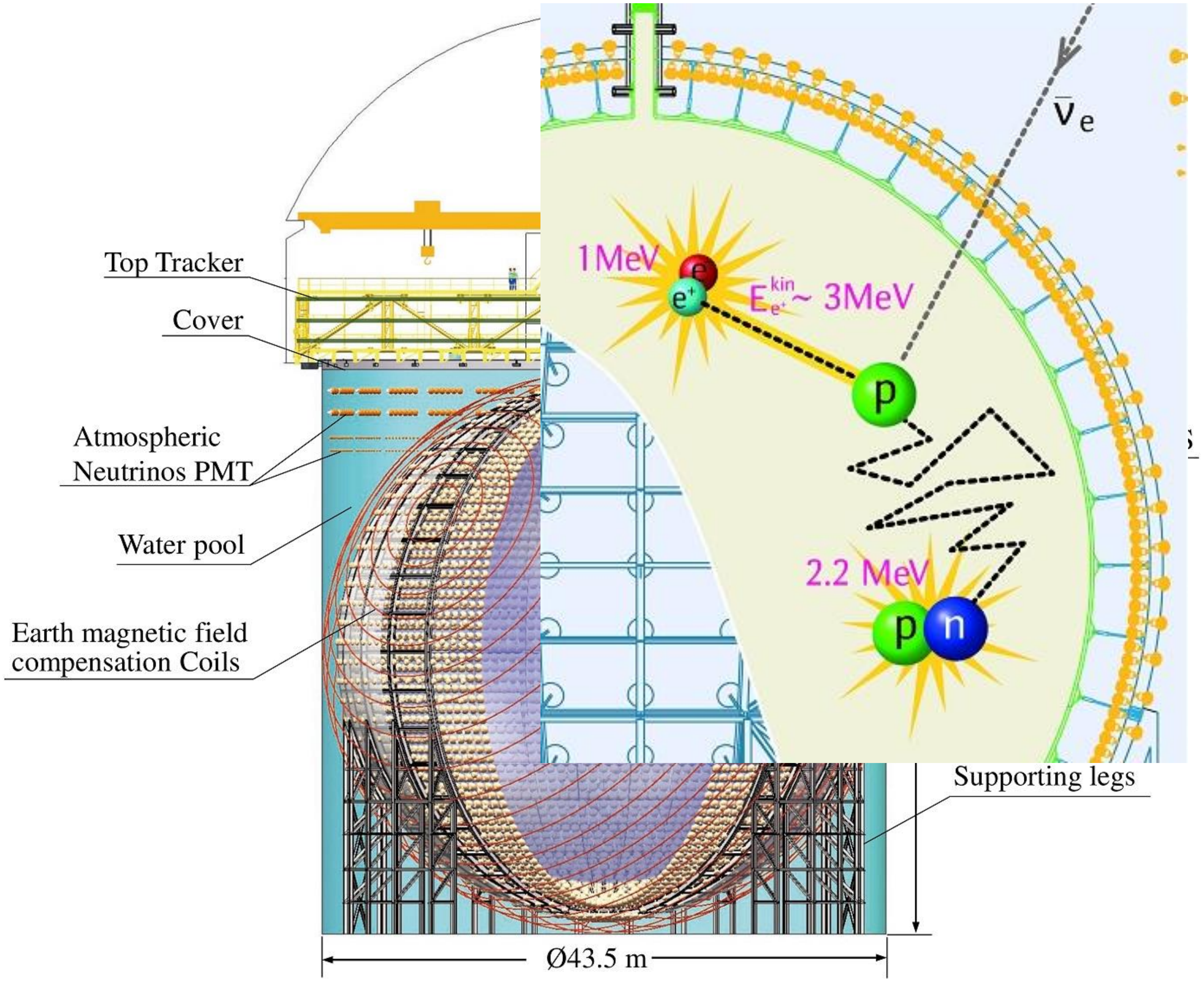
+Observers: USTC, Peking Uni., Jilin Uni., Beijing Normal Uni., CIAE (China), PUC, UEL (Brazil)

The JUNO Detector



- ❑ Ø43.5 m, H 44 m Water Pool/WP
  - ❖ 35 kt water—Water Cher' Detector/WCD
  - ---------------------------- Tyvek ----------------------------
  - ❖ 5 kt water buffer between WCD and AV
- ❑ Stainless Steel Structure/SSS
  - ❖ WCD PMTs viewing outwards
  - ➢ 2,404 20'' veto PMTs (Micro-Channel Plate/MCP)
  - ---------------------------- Tyvek ----------------------------
  - ❖ CD PMTs viewing inwards
  - ➢ 17,596 20'' large PMTs: 4939 dynode + MCP (w/ ×2 photon detection efficiency)
  - ➢ 25,587 3'' small PMTs (higher dynamic range, calibration for large PMTs; a problem due to the connections: add N_2 into water)
    - ✓ 75%+3% geometrical coverage ← SSS mechanical precision ~3 mm
- ❑ **Ø35.4 m Acrylic Vessel/AV**
  - ❖ **20 kt liquid scintillator—Central Detector/CD**
    - ➢ Fluorescence emission peak 430 nm (violet-blue)

The JUNO Detector



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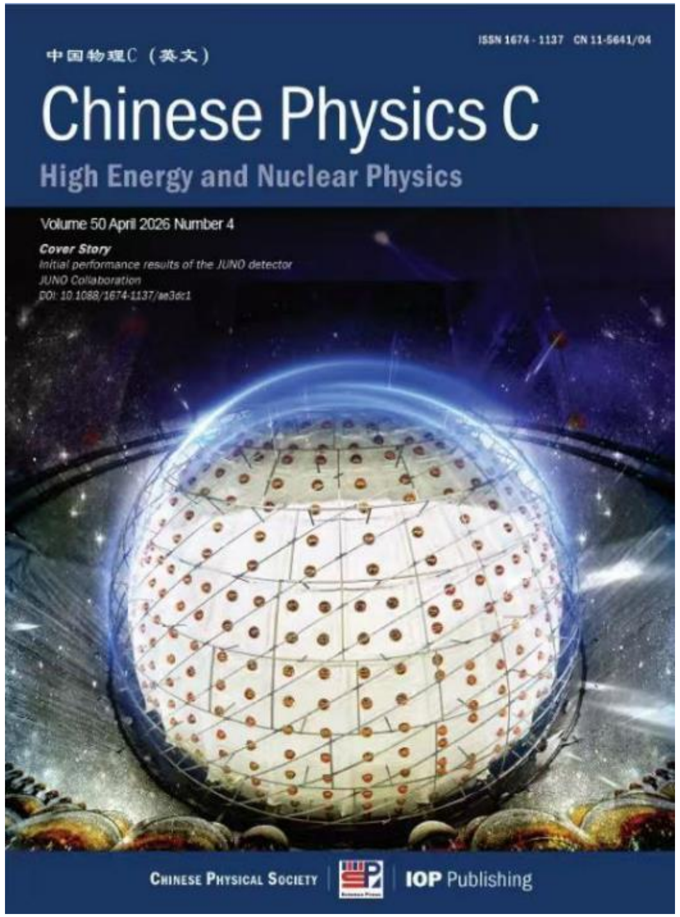
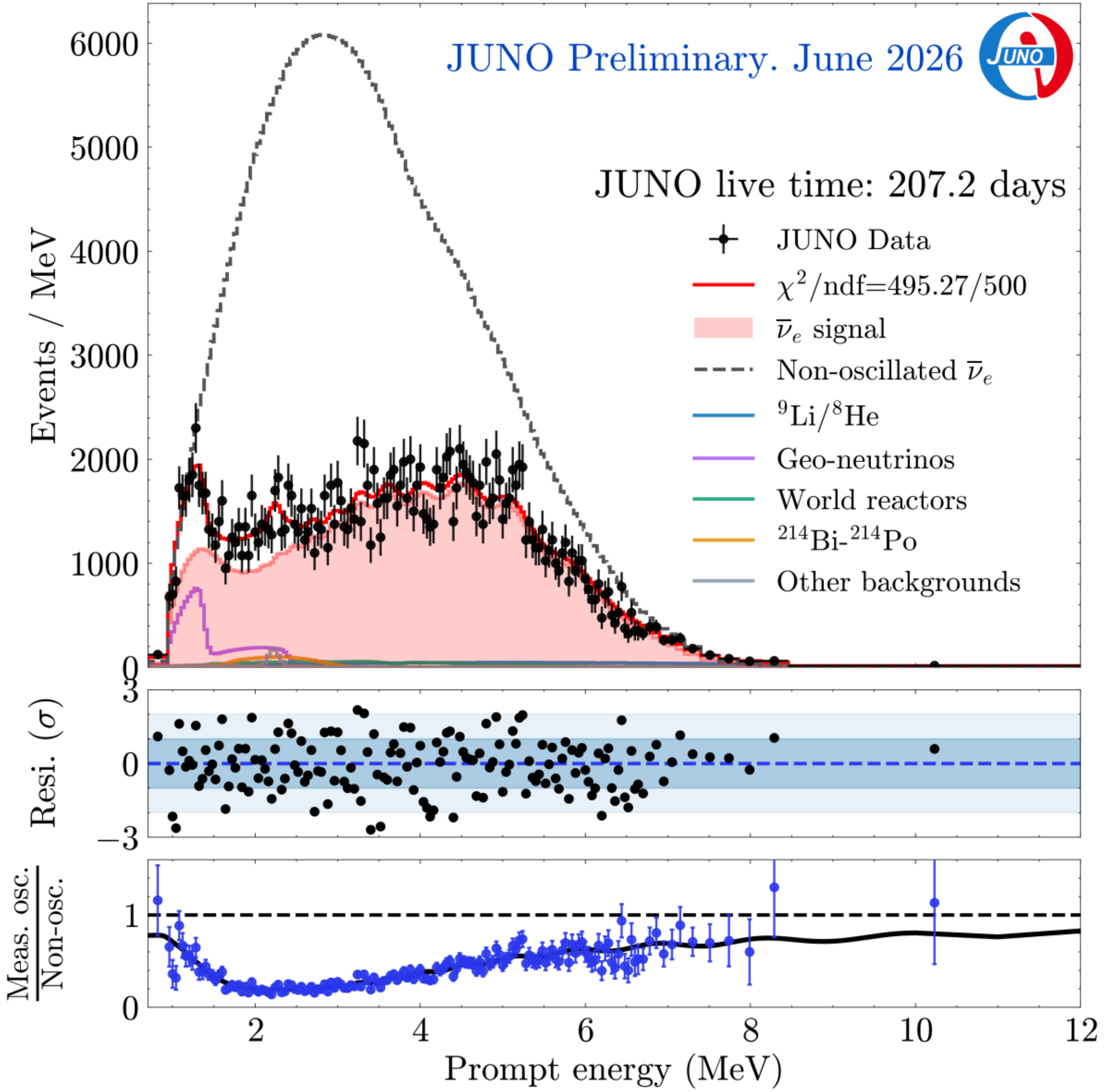
First results using 59 days of data recently published



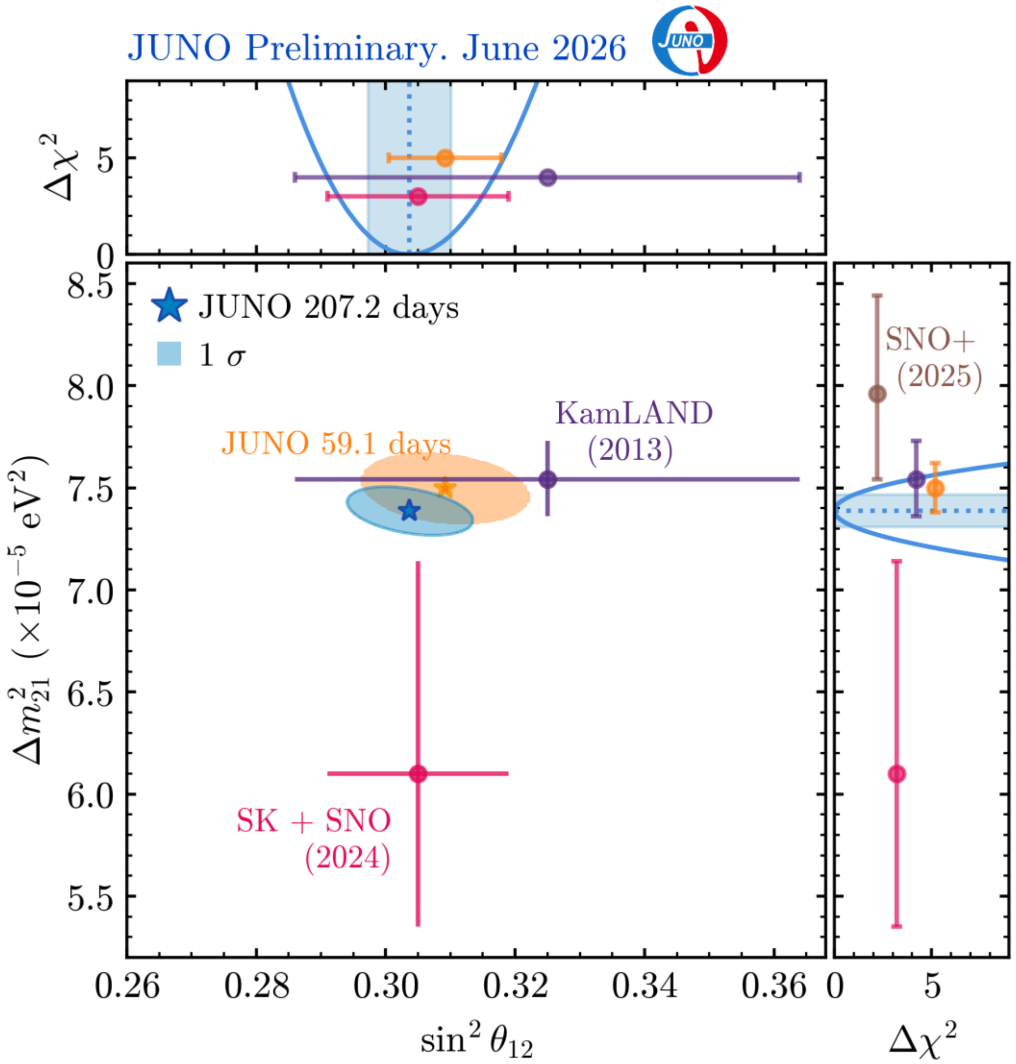
New results released yesterday in Neutrino 2026 with 207 days of data

Reactor $\bar{\nu}_e$ Energy Spectrum at JUNO



- ❑ Fitting constrained by the near detector spectra from TAO and Daya Bay (PRL 130 16, 161802)
- ❑ Consistent results from three independent analyses

JUNO's New Results of Solar Mixing Parameters



Δm^2_{21}	7.388±0.078 (1.60% → **1.06%**)
$\sin^2\theta_{12}$	0.3036±0.0064 (2.8%→**2.1%**)

- ❑ Even though the statistical uncertainty is dominant, systematic errors become important:
  - ➢ ^{214}Bi background and detection eff. can be improved

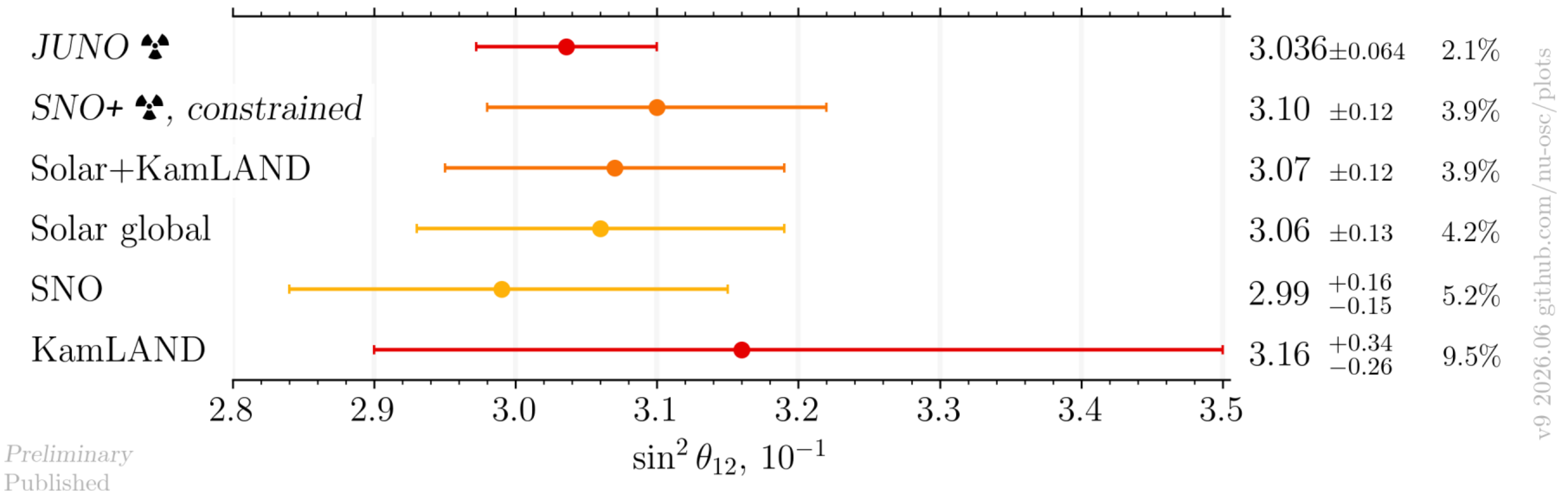
Δm^2_{21}	Precision (%)
Stat-Only	0.8741
Power	0.0729
Spent nuclear fuel	0.0261
Non-equilibrium	0.0384
Fission fraction	0.1069
Fission energy	0.0194
Detection efficiency	0.2775
Matter density	0.0125
Detector response covariance	0.1531
Reactor spectrum	0.2794
Bkg rate	0.3585
Bkg shape	0.1043
AllSyst	0.6090
Total	1.0653

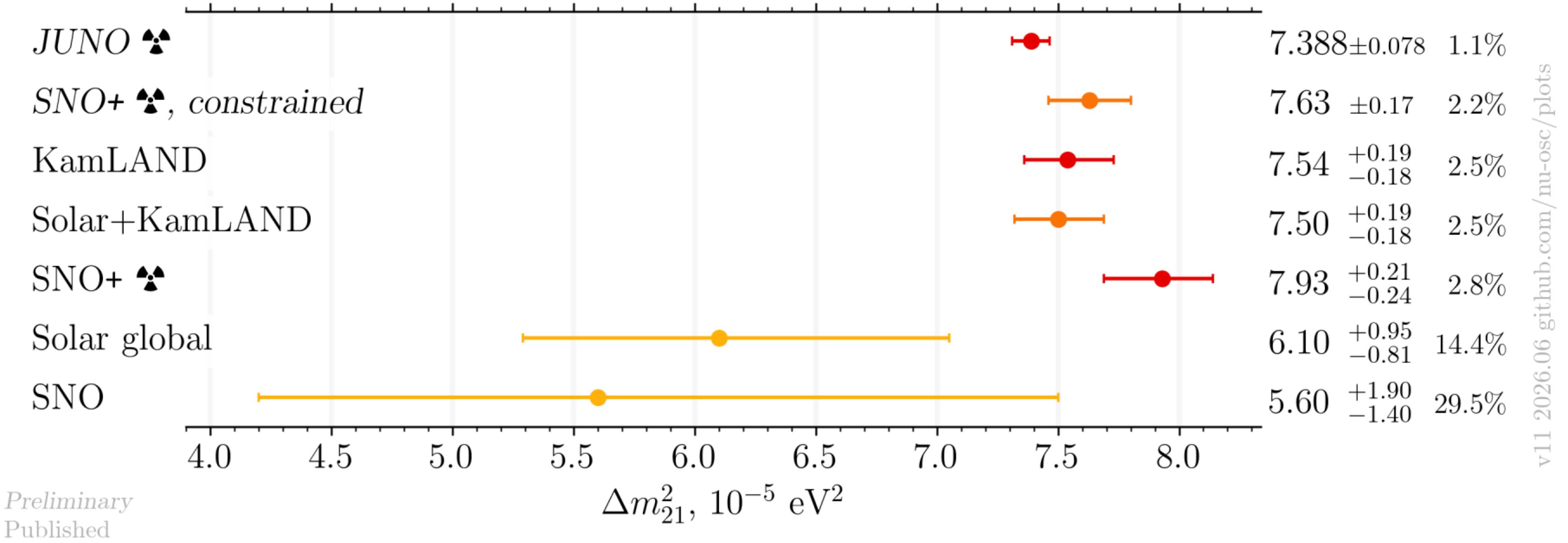
stat.+1 syst.

Bkg rate decomposition	Precision (%)
Bi214 rate	0.3410
Li9 rate	0.1041
DoubleN rate	0.0288
AlphaN rate	0.0248
WorldRea rate	0.0197
Atm rate	0.0160
Fn rate	0.0065
Acc rate	0.0026

Stat-Only: JUNO+TAO+DYB; Free GeoNu rate; JUNO 207.2 d, TAO 31.3 d

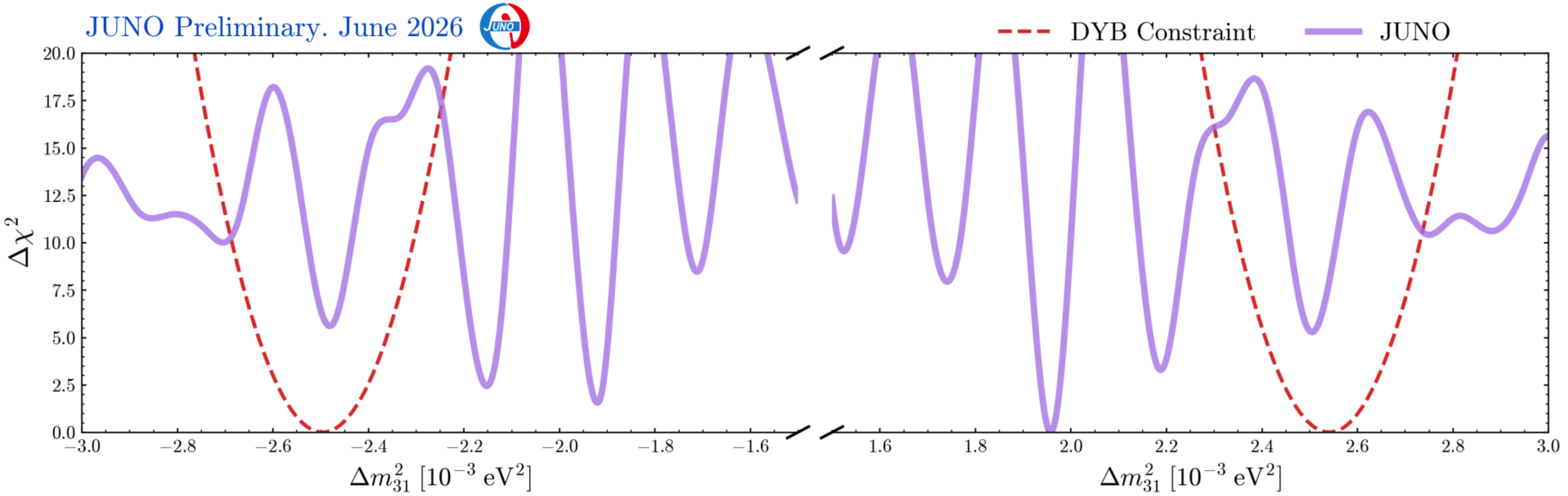
JUNO's New Results of Solar Mixing Parameters



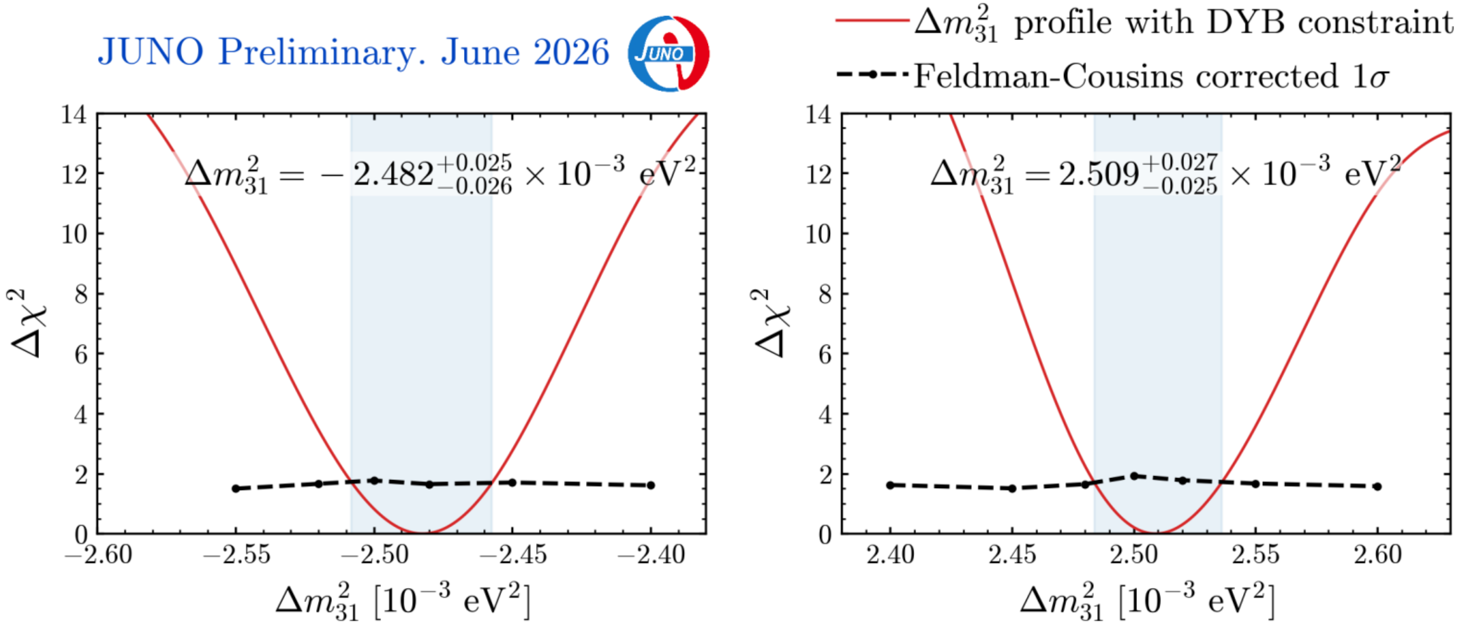


JUNO First Measurement of Δm^2_{31}

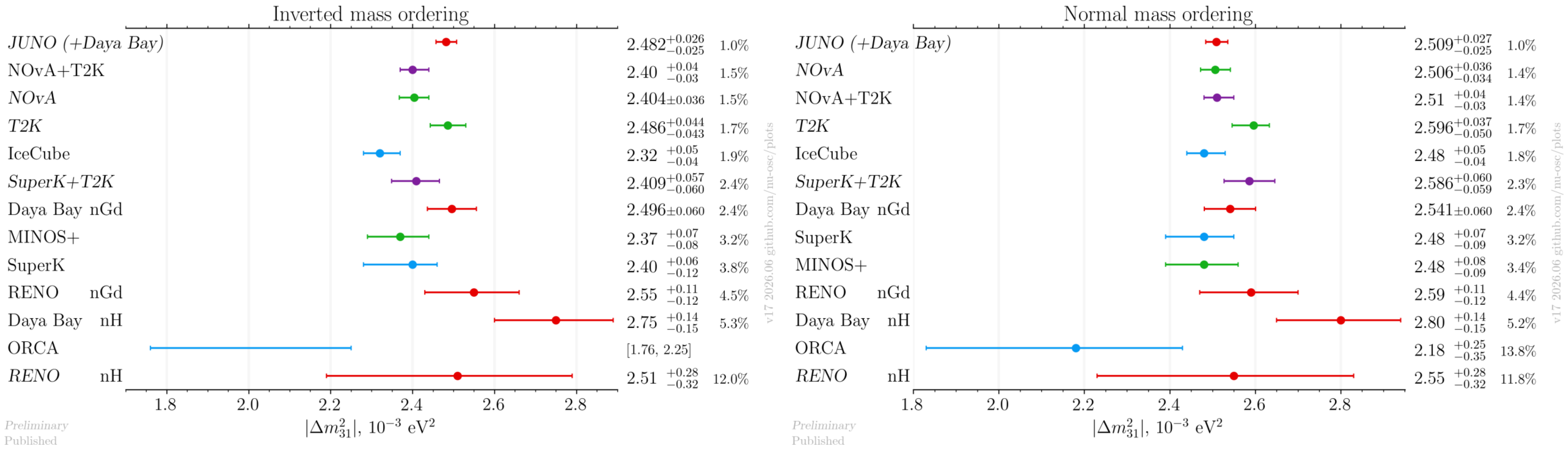
- Due to statistical fluctuations, JUNO-only profiles of Δm^2_{31} have multiple minima



- The final minimum for each mass ordering is obtained by using the Δm^2_{31} constraint from the Daya Bay result (PRL 130 16, 161802)
- Feldman-Cousins (FC) method is used to determine the 1σ range of Δm^2_{31}: ~1% precision achieved



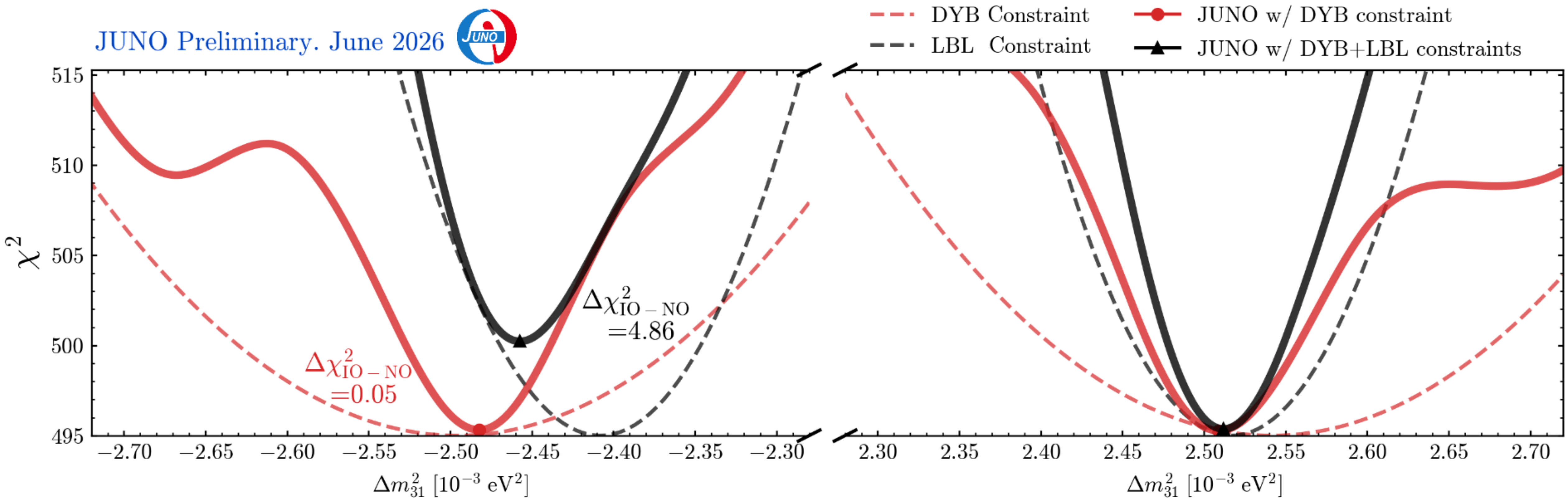
JUNO First Measurement of Δm^2_{31}



- Results from JUNO have smallest uncertainties

JUNO First Measurement of Δm^2_{31}

- ❑ Δm^2_{31} from reactor and accelerator neutrinos should align at the right mass ordering [1]
- ❑ Adopt the NuFit-LBL results from [2]: normal mass ordering is favored at **$\Delta\chi^2$ = 4.86**

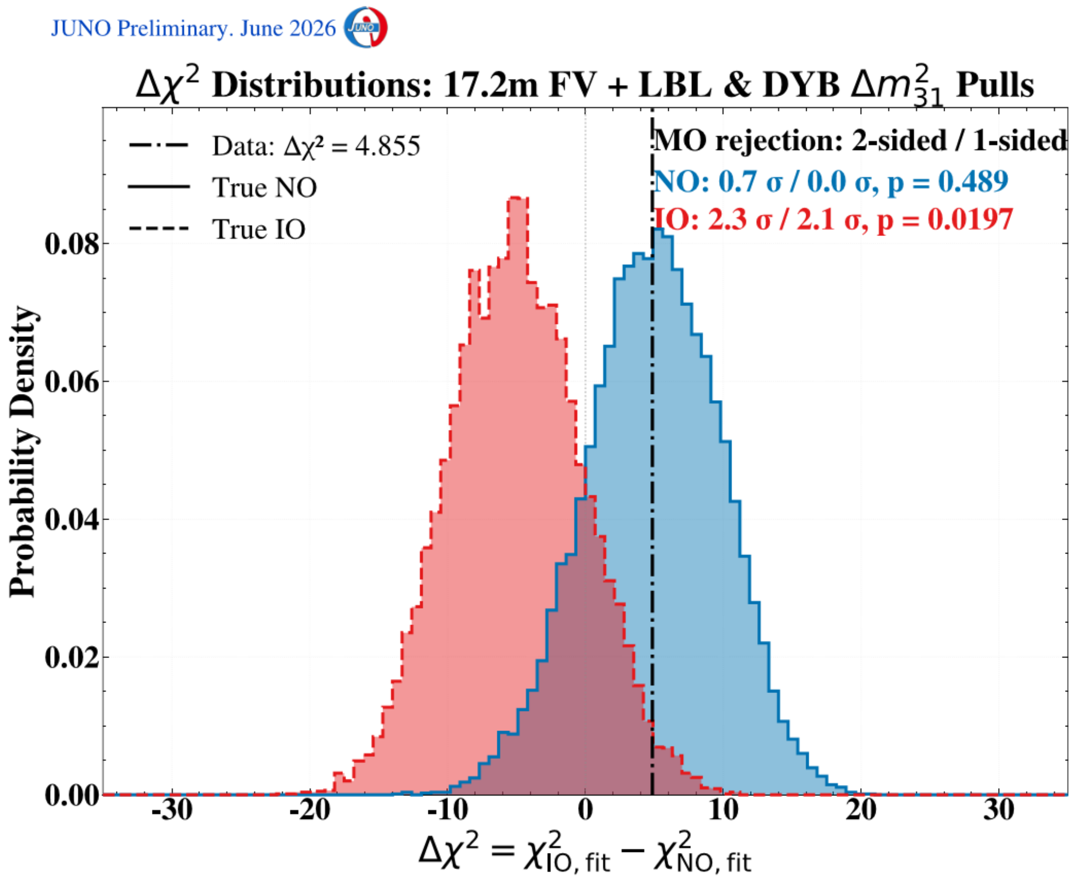


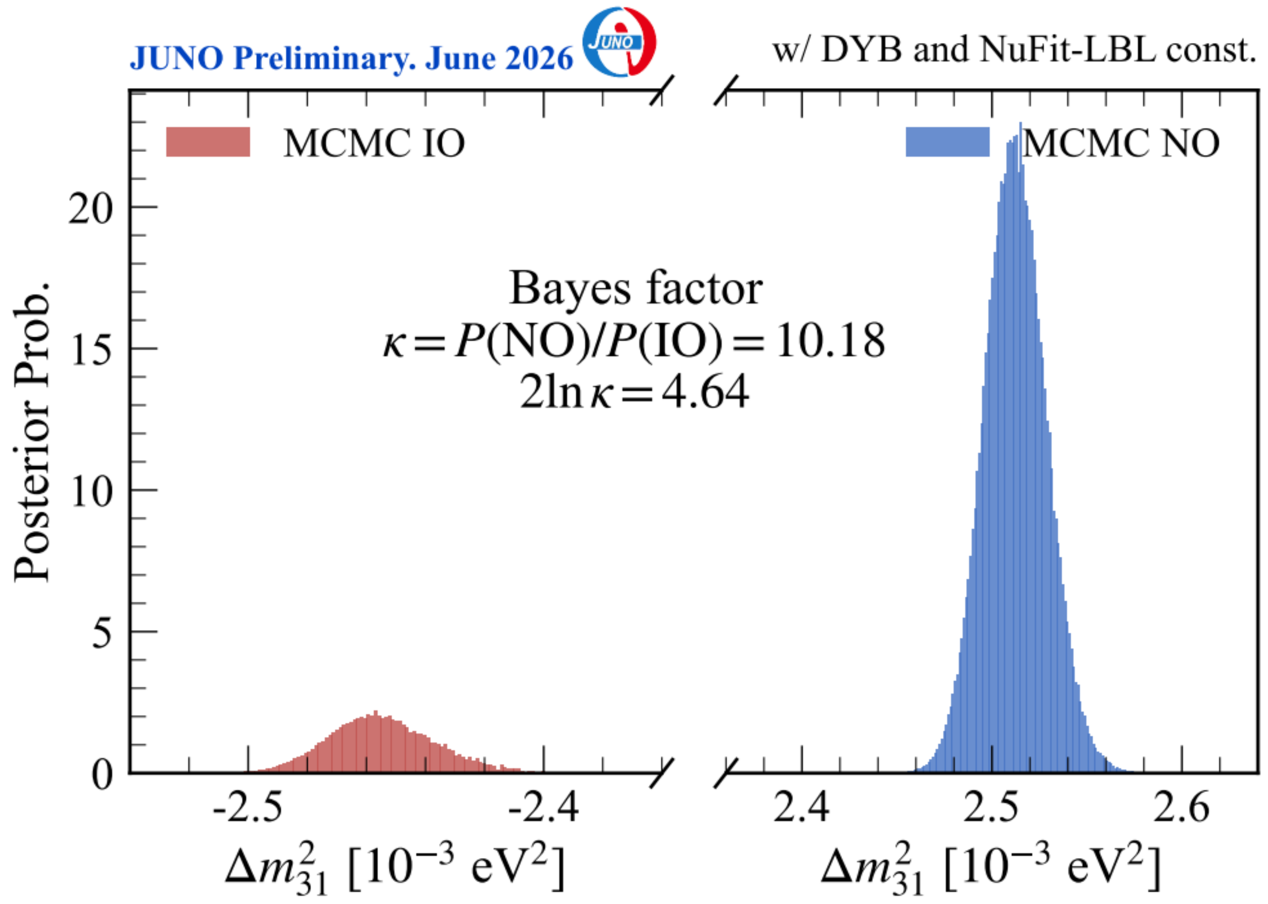
[1] H. Nunokawa, S. Parke and R.Z. Funchal, Phys. Rev. D 72 (2005) 013009; Y. F. Li et al., Phys. Rev. D 88, 013008 (2013)
[2] NuFIT 6.0 (JHEP 12 (2024) 216 [arXiv:2410.05380]), www.nu-fit.org and M. Maltoni private communication

JUNO's Neutrino Mass Ordering Significance

- Frequentist approach using pseudo exp. to convert $\Delta\chi^2$ to significance
- Influence of δ_{CP} considered (scanned)
- Normal Ordering is favored at **2.3σ**

- Bayesian approach using Markov Chain Monte Carlo (MCMC) method
- Normal Ordering is favored with a Bayes factor of **10.18**
  ➔ 2ln κ= 4.64, consistent with the frequentist $\Delta\chi^2$





Summary

- ❑ The JUNO detector and TAO are successfully built and operating smoothly
- ❑ Initial performance shows that the detector works well as designed
- ❑ Precision of solar oscillation parameters further improved by a factor of 1.3-1.5
- ❑ First measurement on Δm^2_{31} achieved a precision of ~1%
- ❑ With external constraint, **Normal Mass Ordering** is favored at ~2.3σ

Photo credit: LIU Yuexiang@IHEP

BACKUP