Overview and Latest Physics Results in JUNO

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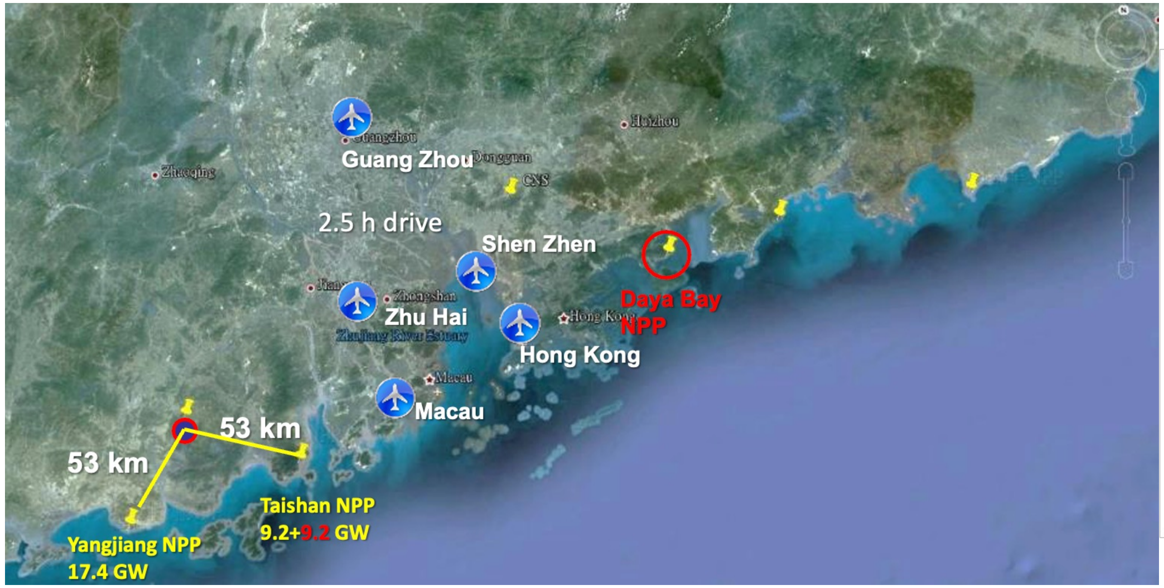
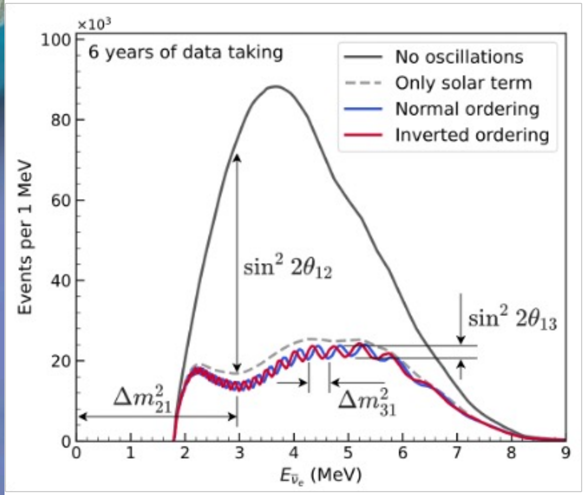
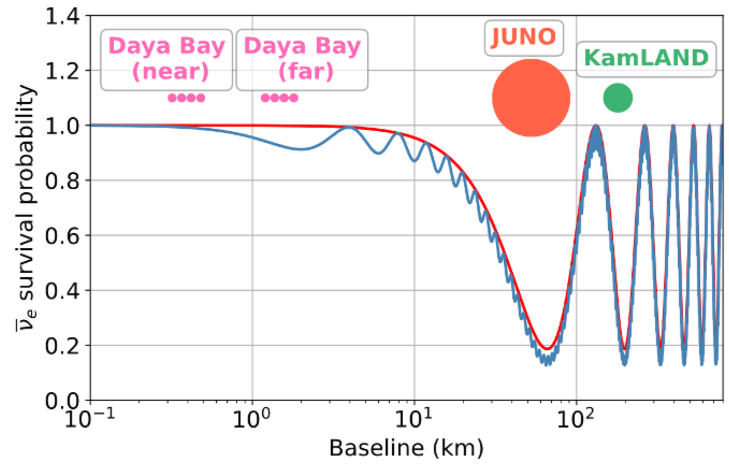
TeV Particle Astrophysics
TeVPA 2026
Tendo
Japan
August 30 - September 4, 2026

JUNO Location & Primary Goal





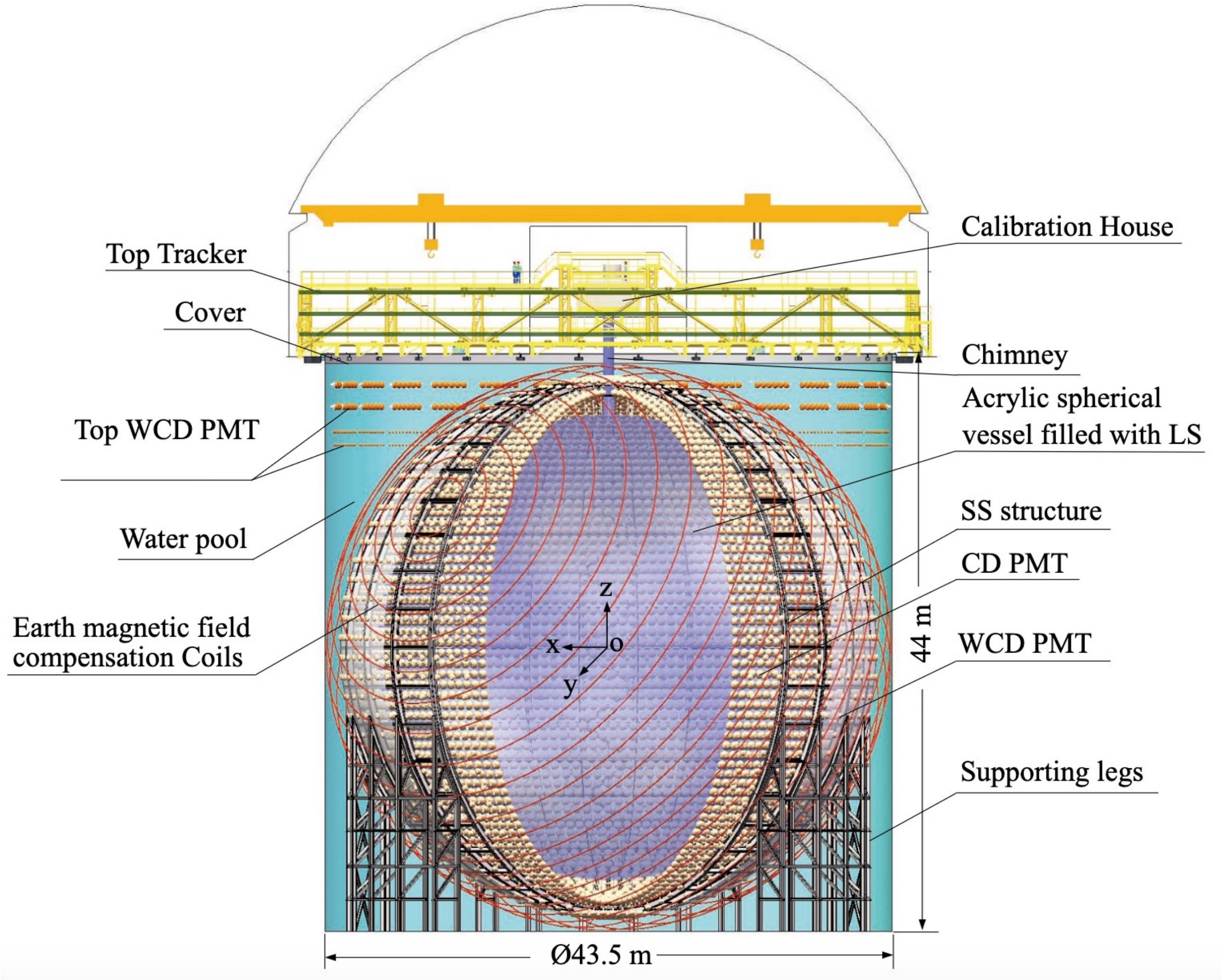


Primary physics goal: Use reactor neutrinos to determine the mass ordering

- Independent of matter effects & CP phase

- Located in Jiangmen, Guangdong — **650 m** rock overburden
- **52.5 km** from the Yangjiang & Taishan reactor
- Equidistant from both ⇒ effectively increases the neutrino flux
- Sits at the first solar oscillation maximum ⇒ maximal spectral distortion

The JUNO Detector



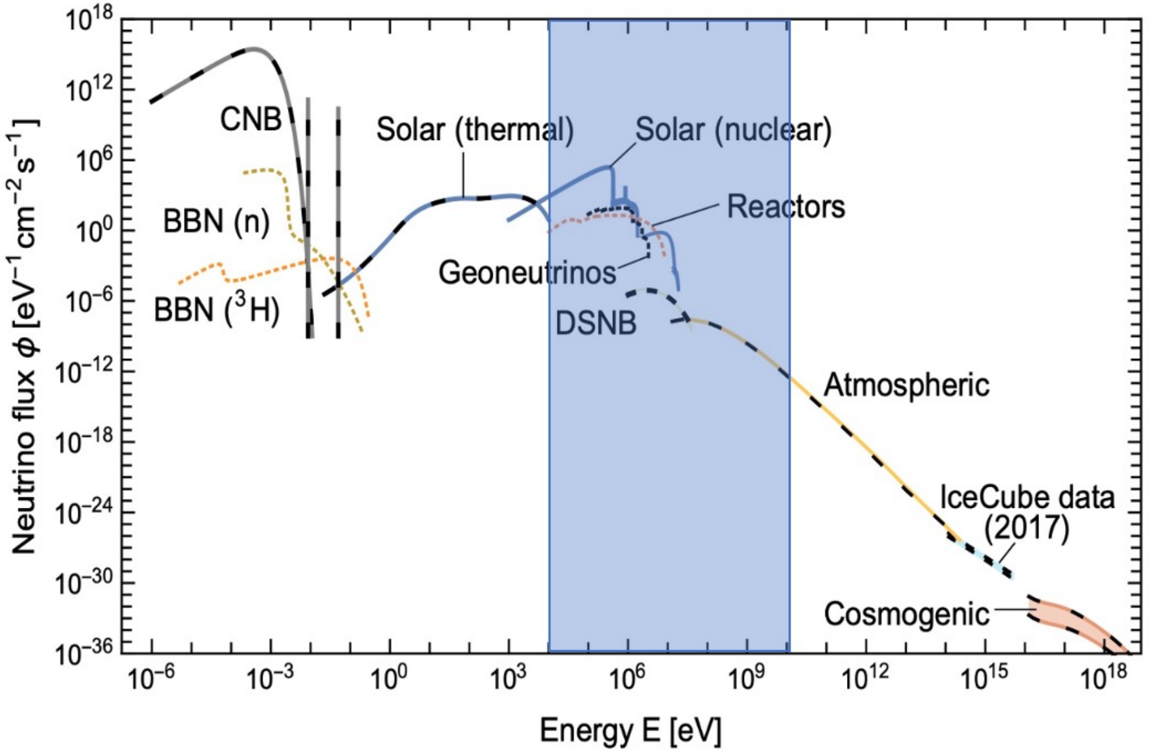
VETO System

- Top Tracker — plastic scintillator
- Water Pool: Ø43.5 m, H 44 m
- Earth magnetic-field shielding coils

Central Detector

- Stainless-steel structure · 35.4 m Ø acrylic sphere
- 20 kton LAB-based liquid scintillator
- 17,612 × 20″ PMT + 25,600 × 3″ PMT
- ⇒ 78% photocathode coverage

Neutrino Sources



JUNO — Key Capabilities

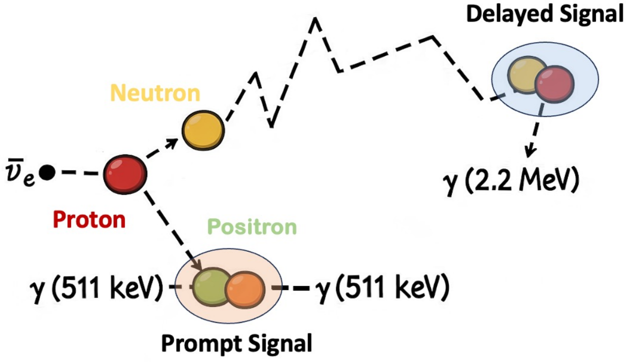
- **20 kton** liquid-scintillator detector
- Excellent energy resolution
- Wide energy range
- Low background levels

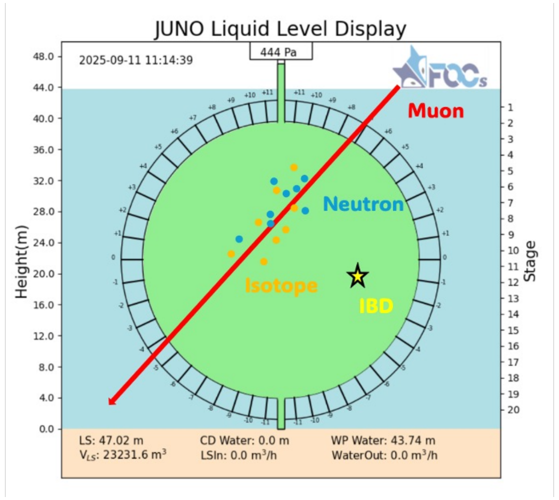
Beyond its primary physics goals, JUNO is a truly **multi-purpose detector**

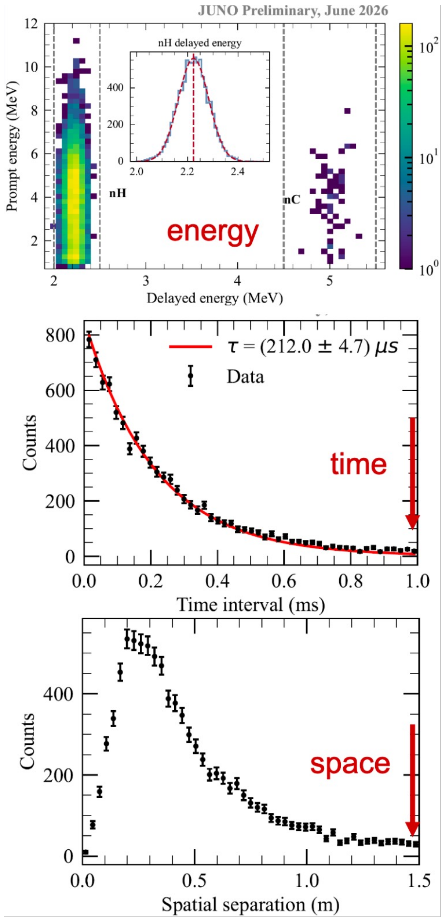
IBD Event Selection

Muon (μ) and spallation neutron (*spn*) identification	
μ	$Q > 3 \times 10^4$ pe (CD), or $Q > 700$ pe (WP)
spn	$Q \in (3, 30) \times 10^3$ pe, $\Delta T_{spn-\mu} \in (0.02,\ 2)$ ms
IBD selection criteria	
PMT flasher removal	Using hit multiplicity and timing info
Prompt E	$0.7 < E_p < 12.0$ MeV
Delayed E	$2.0 < E_d < 2.5$ MeV (n capture on H) $4.5 < E_d < 5.5$ MeV (n capture on ^{12}C)
Coincidence	$5 < \Delta T_{p-d} < 1000\ \mu$s, $\Delta R_{p-d} < 1.5$ m
Fiducial volume	$r_p < 17.2$ m, $\lvert z_p \rvert < 15.5$ m
Muon veto	$\Delta T_{d-\mu} > 5$ ms (CD), $\Delta T_{d-\mu} > 2$ ms (WP) $\Delta R_{d-spn} > 4$ m or $\Delta T_{d-spn} > 1.2$ s $\frac{\Delta R_{d-\mu}}{2.5\ \text{m}} + \frac{\Delta T_{d-\mu}}{0.5\ \text{s}} > 1$
Multiplicity	No additional event with $E > 0.7$ MeV (inside the FV) nor $2.0 < E < 6.0$ MeV (outside the FV) occurred within $(t_d - 2,\ t_d + 1)$ ms
L.L.R.	Likelihood-ratio selection

Improved selections

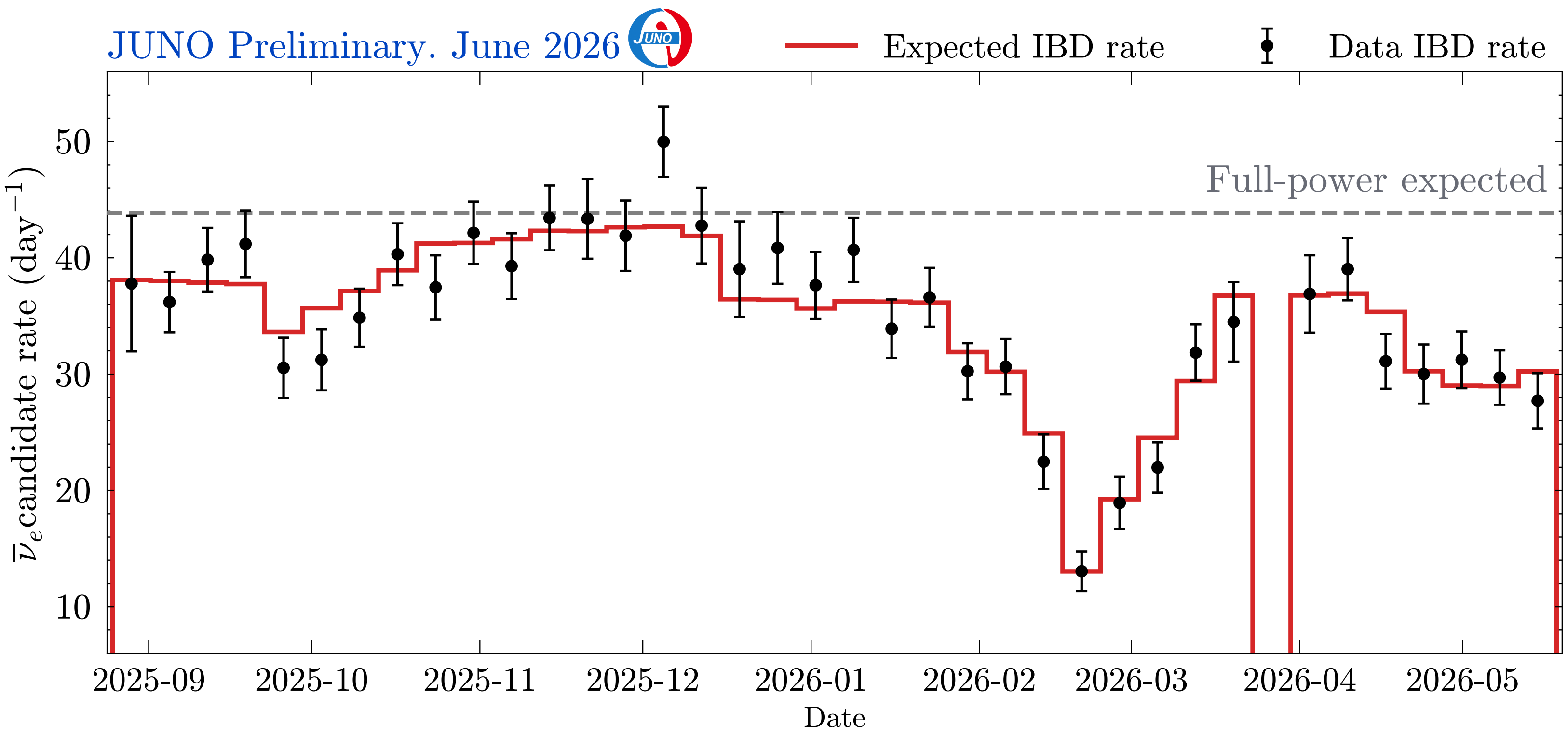




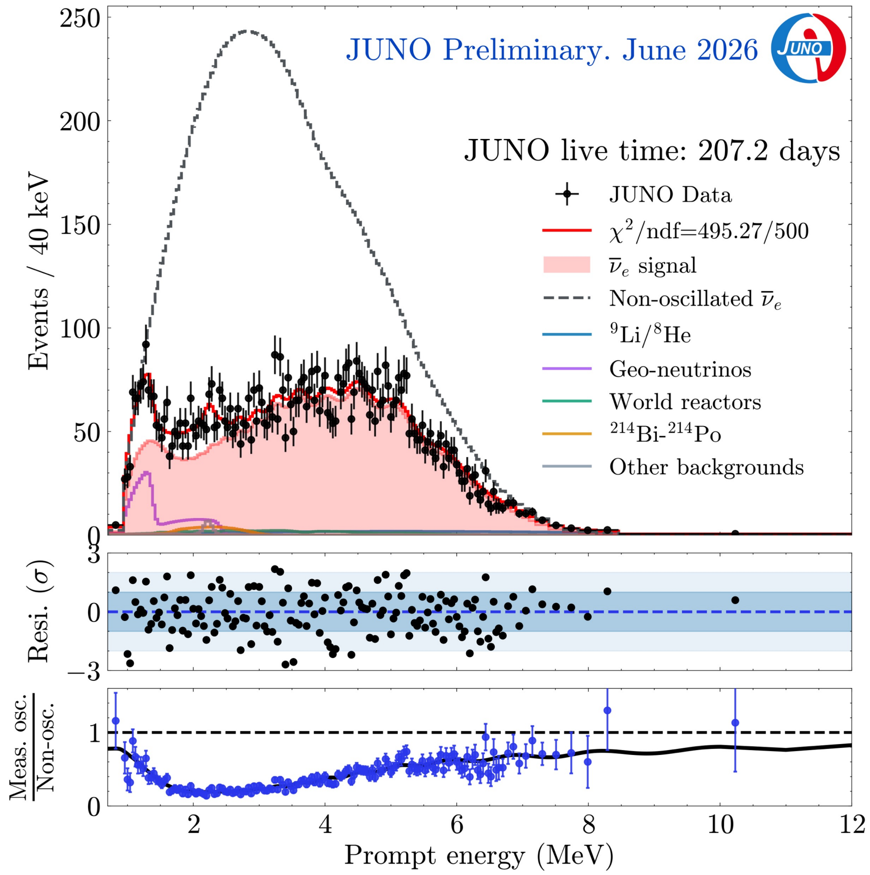


Reactor Neutrino Event Rate

- Measured reactor neutrino event rate consistent with expectation
- Total live time is 207.2 days



Neutrino Measurement in JUNO

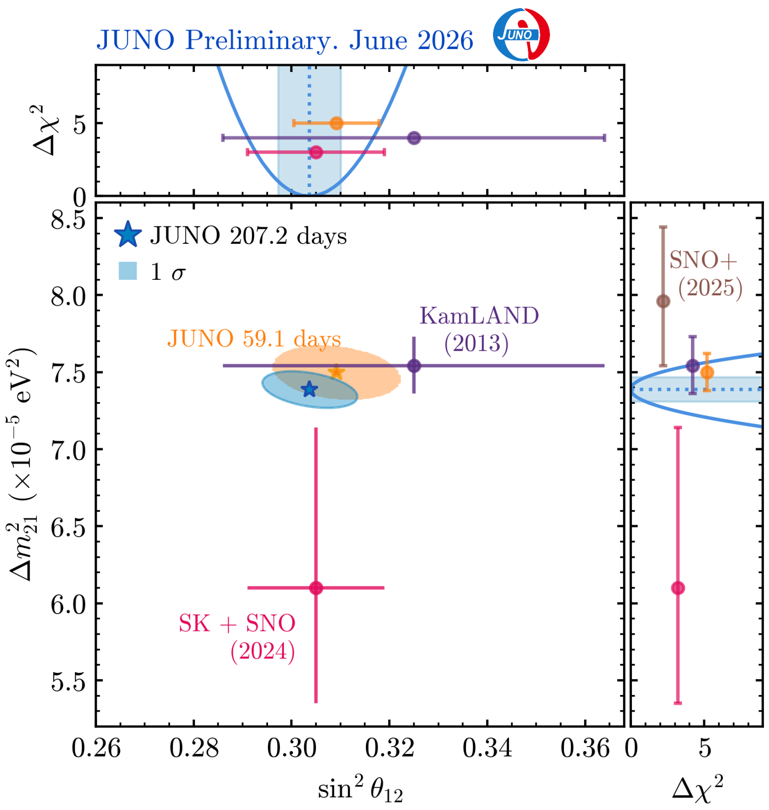


Reactor flux constrained by

- TAO satellite detector
- Daya Bay near-detector data (PRL 130, 161802)

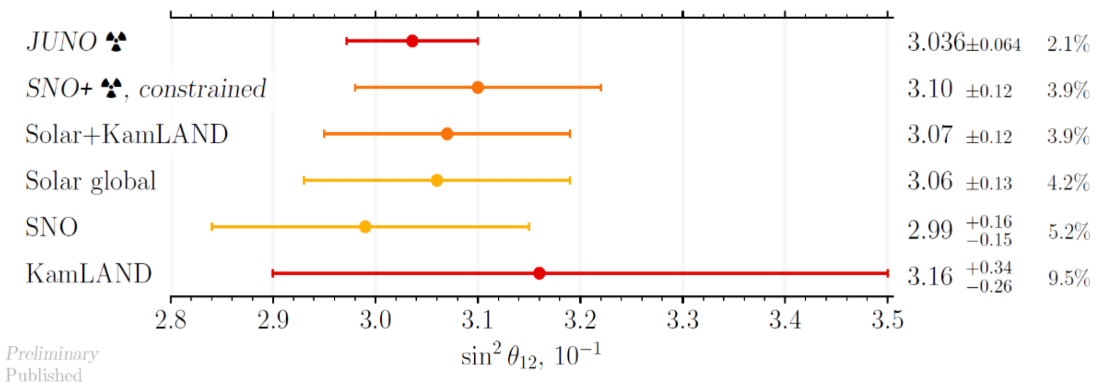
Antineutrinos ($\overline{\nu}_e$) Candidates Summary		
DAQ live time (days)	207.2	
$\overline{\nu}_e$ candidates	8294	
Selection Efficiencies (%)	ε	σ_{rel}
Fiducial volume	87.12%	0.96%
PMT flasher rejection	> 99.9%	Negligible
μ veto	93.67%	0.02%
Multiplicity cut	95.94%	negligible
Prompt-delayed coinc.	95.50%	0.32%
Correlated discriminator	98.99%	0.15%
Total efficiency (ε_{tot})	74.01%	1.02%
$\overline{\nu}_e$ signal (cpd)		
w/o ε_{tot} corrected	36.02 ± 0.62	
w/ ε_{tot} corrected	48.67 ± 1.08	
Backgrounds (cpd)	Pre-fit	Best-fit
^{9}Li/^{8}He	1.05 ± 0.27	1.41 ± 0.26
Geoneutrinos	Free	2.12
World reactors	0.92 ± 0.09	0.92 ± 0.09
^{214}Bi-^{214}Po	0.42 ± 0.31	0.57 ± 0.34
^{13}C(α, n)^{16}O	0.05 ± 0.02	0.05 ± 0.02
Fast neutrons	0.02 ± 0.02	0.02 ± 0.02
Double neutrons	0.10 ± 0.10	0.13 ± 0.10
Atmospheric neutrinos	0.09 ± 0.04	0.11 ± 0.05
Accidentals	0.07 ± 0.01	0.07 ± 0.01

New Results of Solar Oscillation Parameters

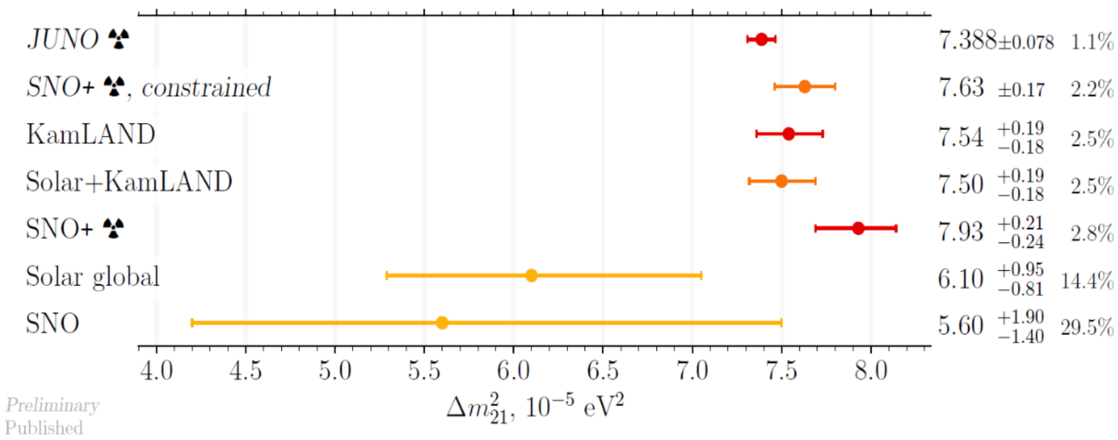


Parameter	JUNO best-fit	Precision (59.1 → 207.2 days)
Δm^2_{21}	7.388 ± 0.078	1.60% → **1.06%**
$\sin^2\theta_{12}$	0.3036 ± 0.0064	2.8% → **2.1%**

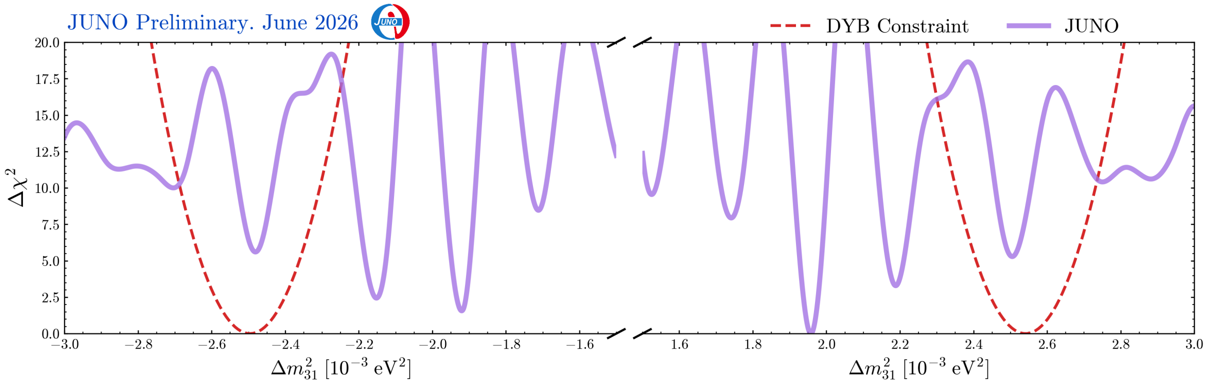
$\sin^2 2\theta_{12}$

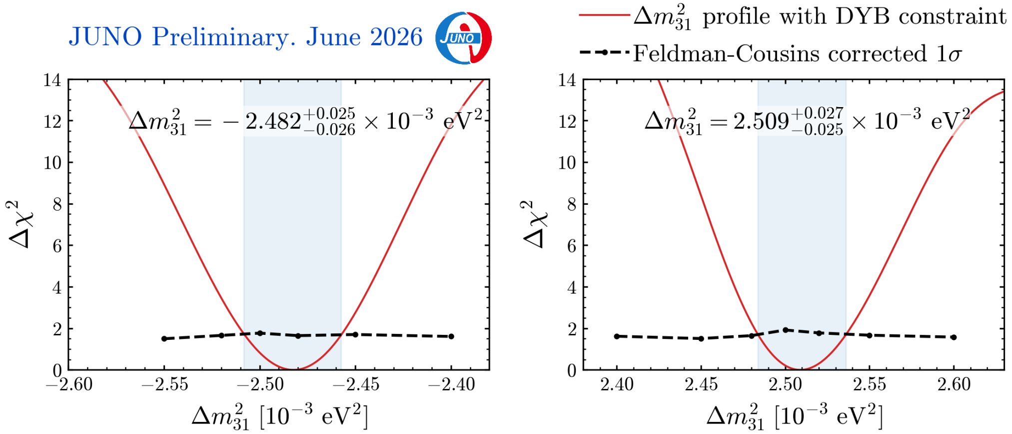


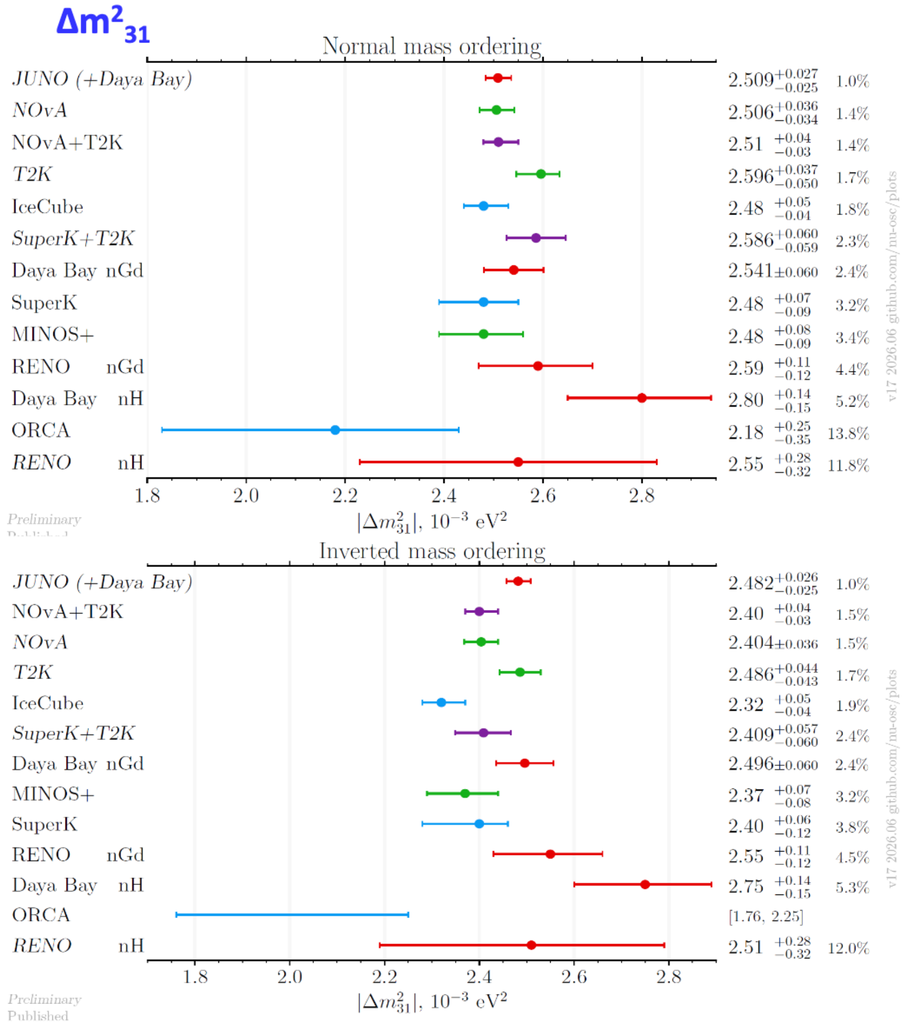
Δm^2_{21}



First Result of Δm^2_{31}



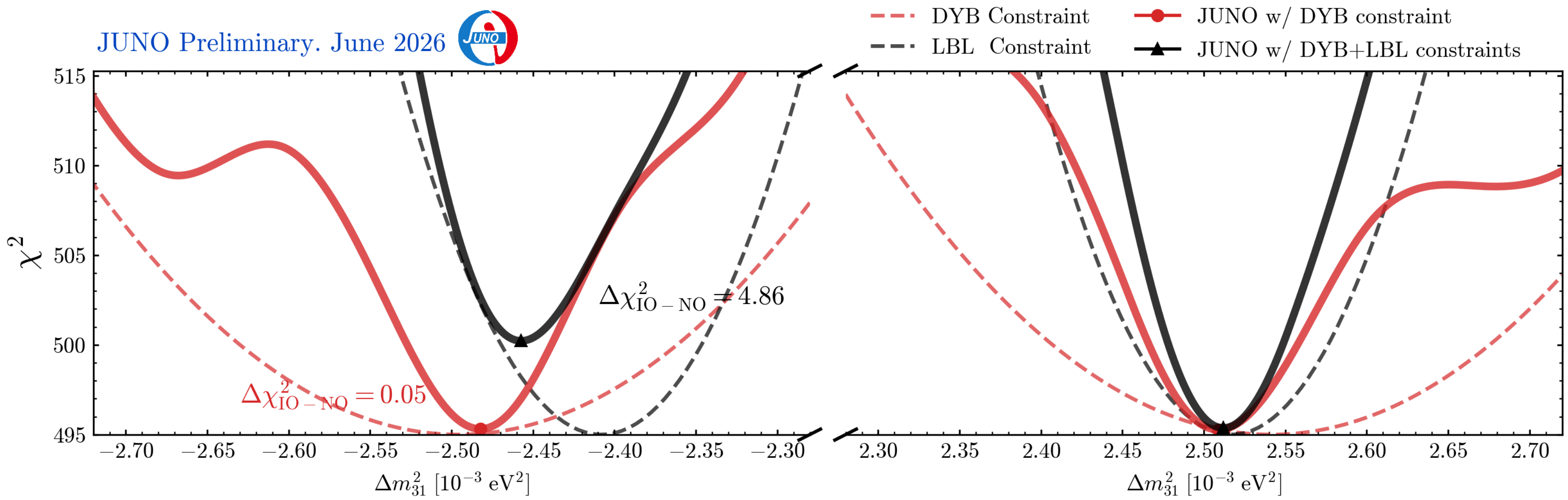




- The final minimum for each mass ordering is obtained by using the Δm^2_{31} constraint from the Daya Bay result (PRL 130 16, 161802)
- Feldman-Cousins (FC) method gives 1σ range of Δm^2_{31} ~1% precision

Adding Constraint from NuFit-LBL

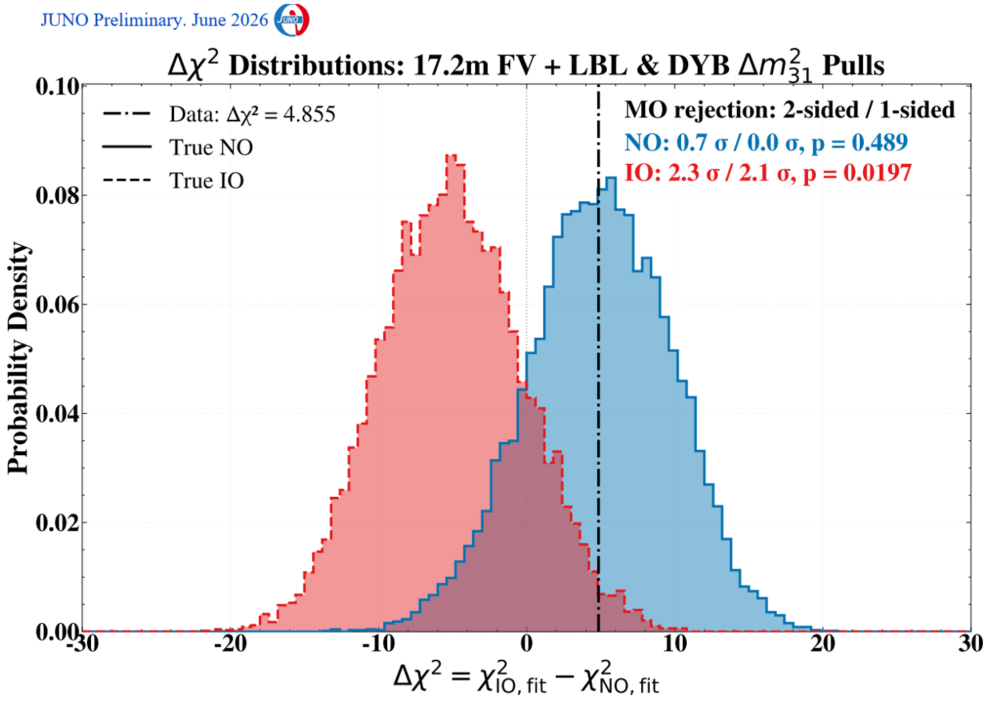
- Δm^2_{31} from reactor and accelerator neutrinos should align at the right mass ordering[1]
- Adopt the NuFit-LBL results from [2]: normal mass ordering is favored at $\Delta\chi^2 = 4.86$



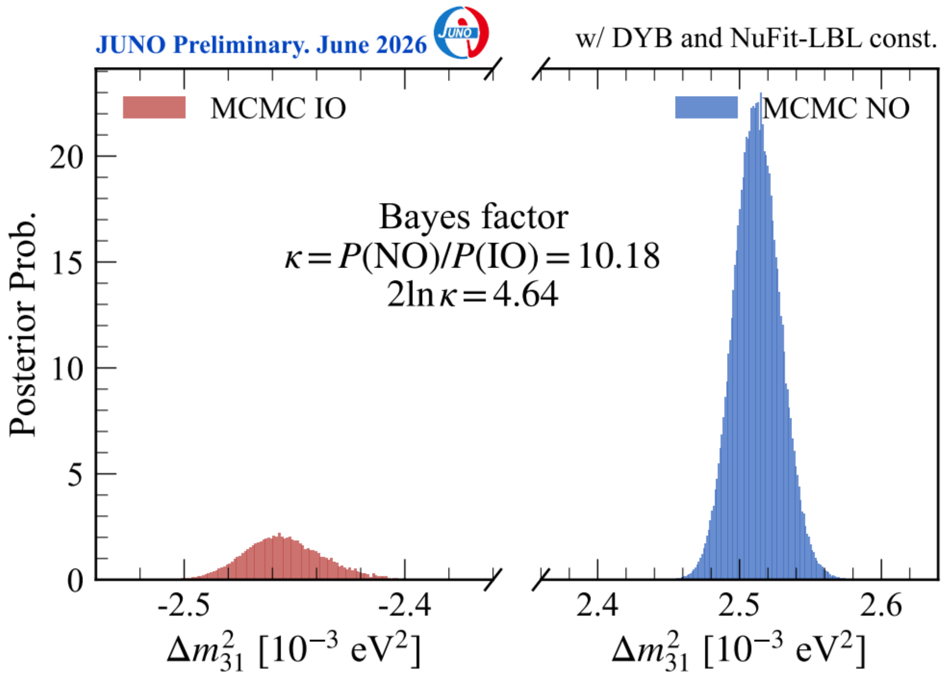
[1] H. Nunokawa, S. Parke and R.Z. Funchal, Phys. Rev. D 72 (2005) 013009; Y. F. Li et al., Phys. Rev. D 88, 013008 (2013)
[2] NuFIT 6.0 (JHEP 12 (2024) 216 [arXiv:2410.05380]), www.nu-fit.org and M. Maltoni private communication

Neutrino Mass Ordering Significance

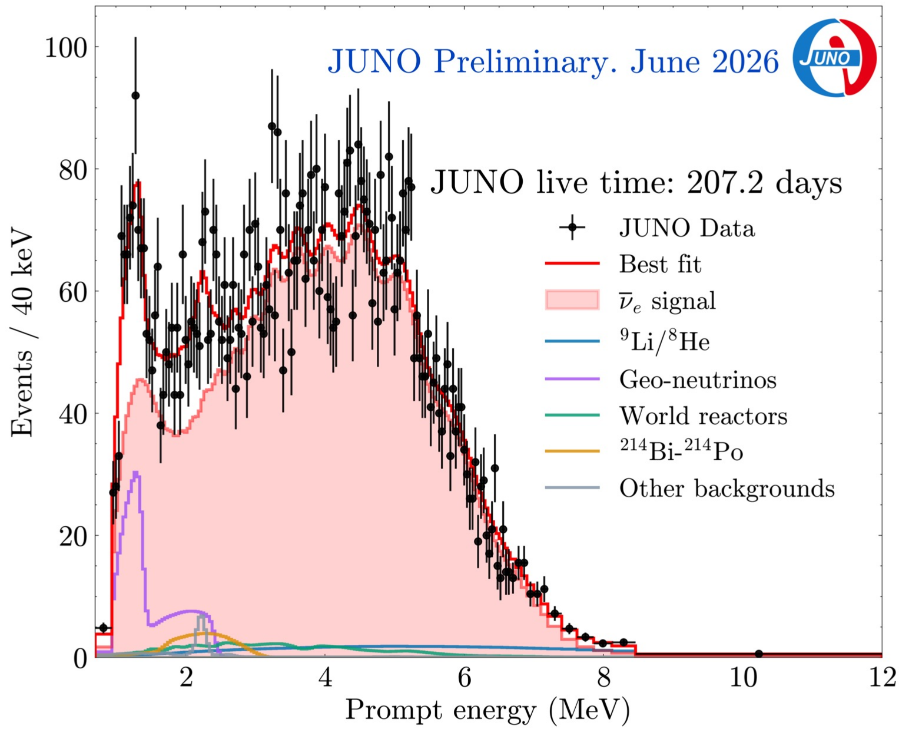
- Frequentist approach using pseudo exp. to convert $\Delta\chi^2$ to significance
- Influence of δ_{CP} considered (scanned)
- Normal Ordering is favored at 2.1 (2.3) σ



- Bayesian approach using Markov Chain Monte Carlo(MCMC) method
- Normal Ordering is favored with a Bayes factor of **10.18** ➔ 2ln κ= 4.64

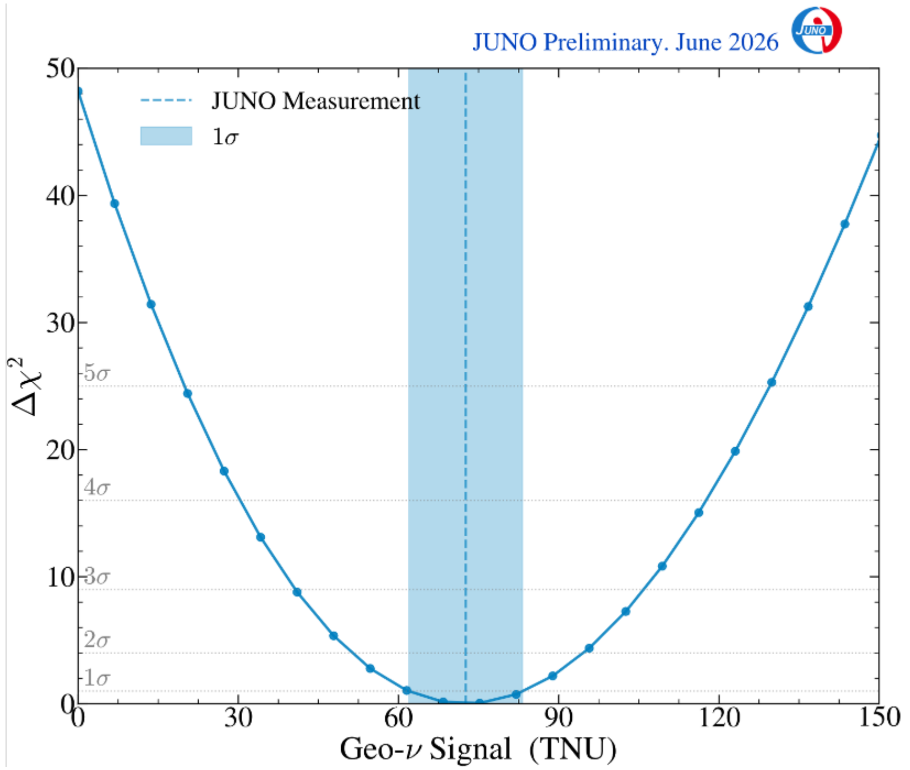


Geoneutrino Measurement in JUNO



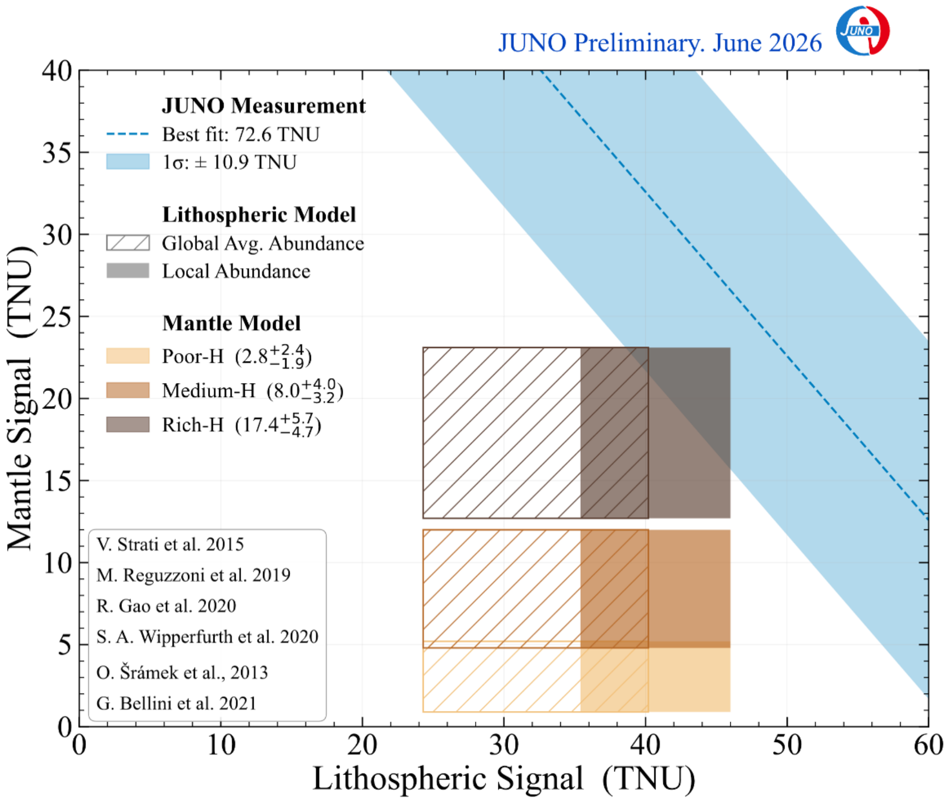
Best fit: 73 ± 11 TNU (~15% precision)
440 ± 66 geoneutrino events from 207.2 days

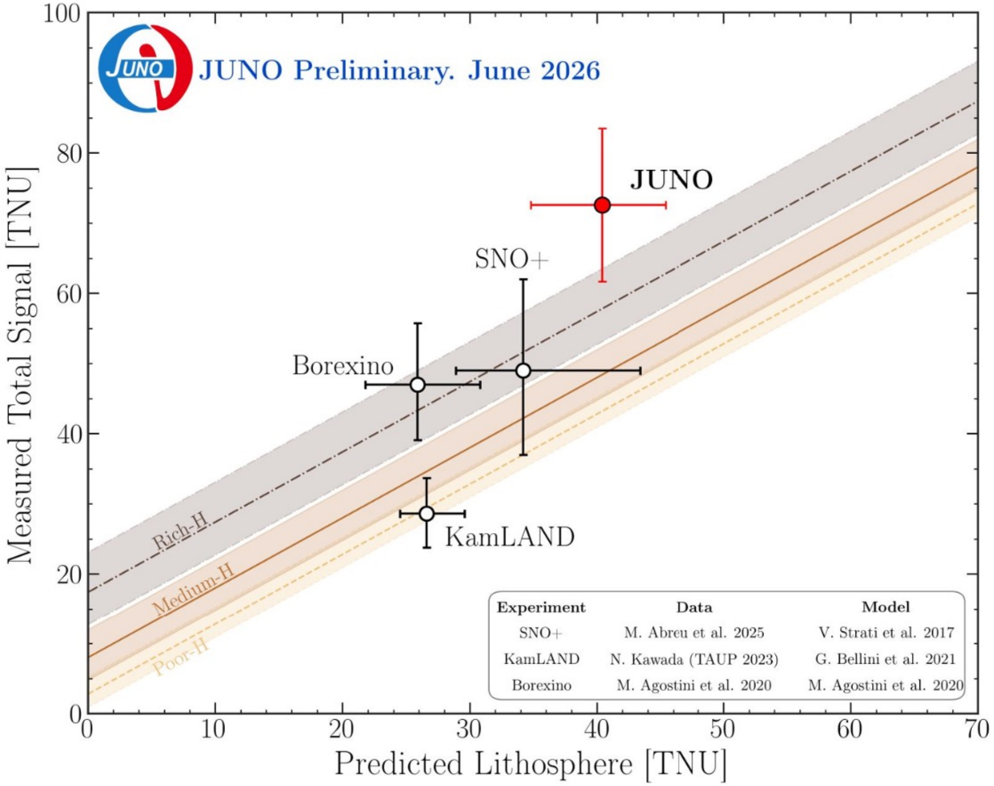
- Fit without geo flux constraint
- Th/U signal ratio fixed to chondritic 0.29 (±10%)



1 terrestrial neutrino unit (TNU) corresponds to one IBD event over 1 year exposure of 10^{32} free target protons at 100% detection efficiency

Comparing Measurements with Models

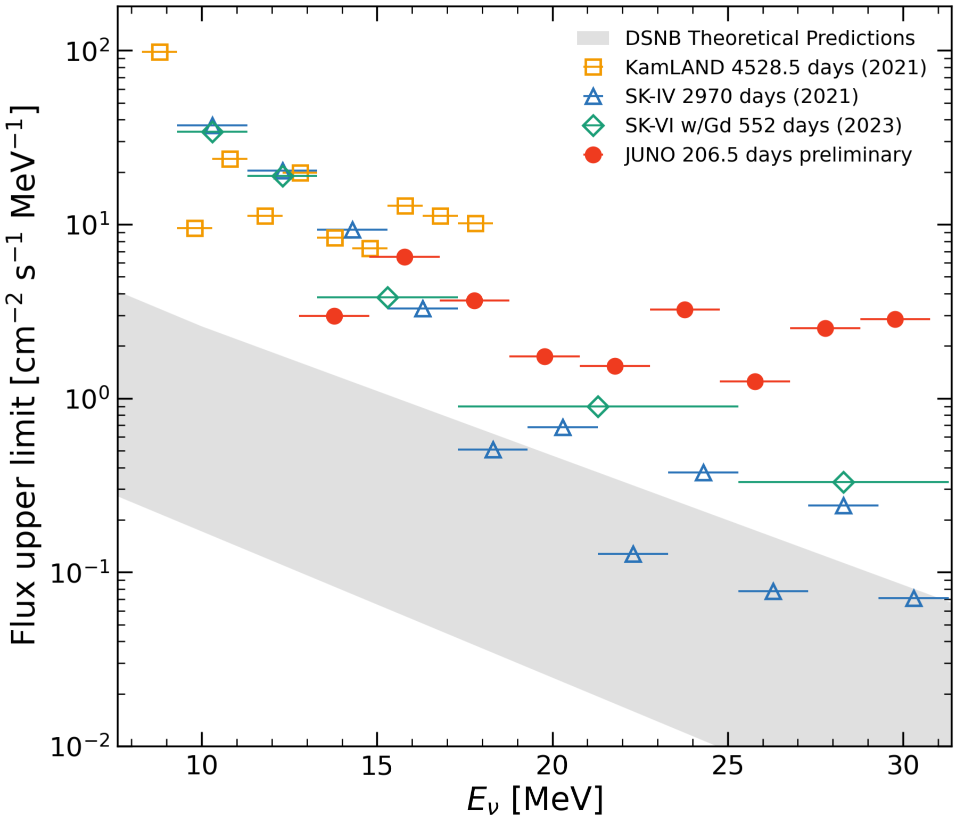




- JUNO result is higher than expectation from most existing models, but not statistically significant
- Need more JUNO data and more refined geological model predictions

Diffuse Supernova Neutrino Background

- DSNB: The accumulated neutrino signal from all core-collapse supernovae throughout cosmic history
- 19 DSNB candidate events were observed in 12–30 MeV
  - Consistent with the predicted background of 21.3 ± 10.5 events
  - A competitive upper limit on the DSNB flux was obtained
- A preliminary pulse-shape-discrimination (PSD) study suggests that most of these candidate events likely originate from atmospheric neutrino interactions



Summary

- JUNO and TAO built and running smoothly, performance close to design
- Precision of solar oscillation parameters further improved by **a factor of 1.3–1.5**

  First measurement on $|\Delta m^2_{31}|$ achieved a precision of **~1%**

  With external constraint, **Normal Mass Ordering** is favored at **~2.1 (2.3) σ**
- Geo-ν flux 73 ± 11 TNU
- First DSNB limit

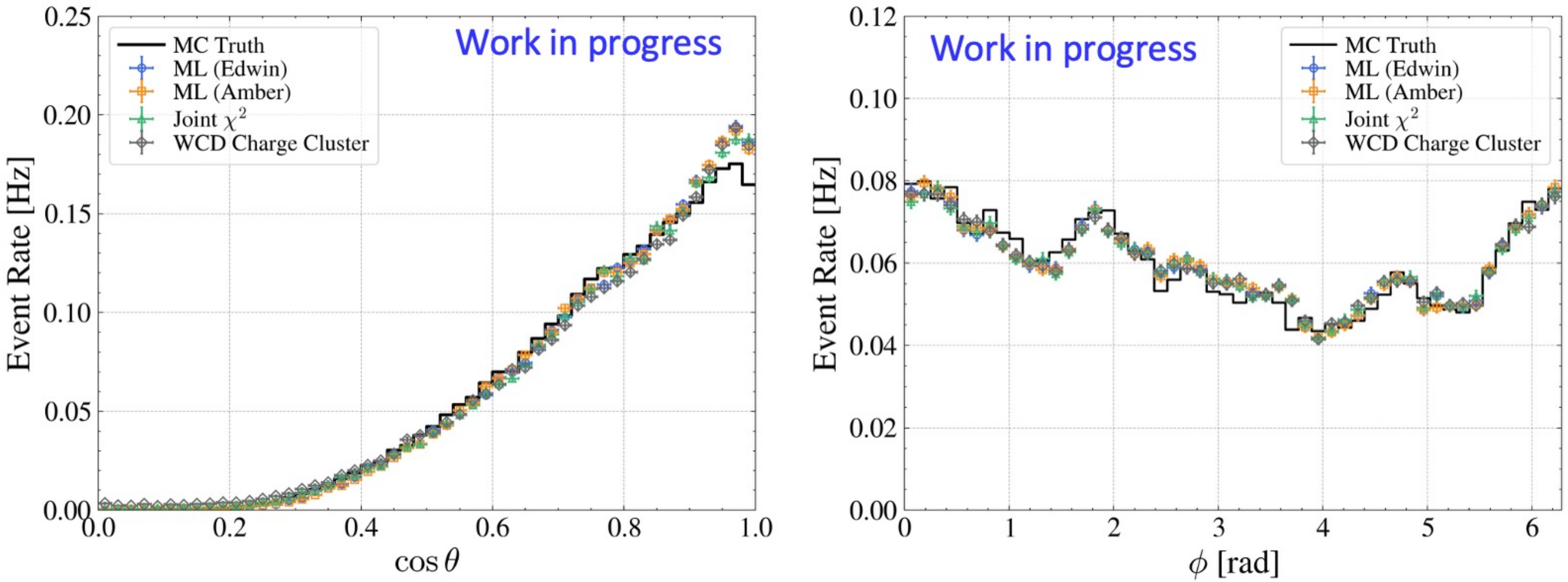
Backup

Experiments	KamLAND	Borexino	SNO+	JUNO
Target Mass [tons]	1,000	300	780	**20,000**
Number of PMTs	~1,900	~2,200	~10,000	**17,612 + 25,600**
PMT Coverage	~34%	~30%	~50%	**78%**
Light Collection [p.e./MeV]	~250	~450	~520	**> 1,600**
Energy Resolution	$6\%/\sqrt{E}$	$5\%/\sqrt{E}$	$5\%/\sqrt{E}$	$3\%/\sqrt{E}$
Geo ν Events	183	53	35	**440**
Geo ν Measurement Time	5227 live days (2002–2020)	3263 live days (2007–2019)	685 live days (2022–2025)	**207 live days (2025–2026)**

> JUNO's **20 kton target** + $3\%/\sqrt{E}$ energy resolution make it the world's most sensitive geoneutrino detector.

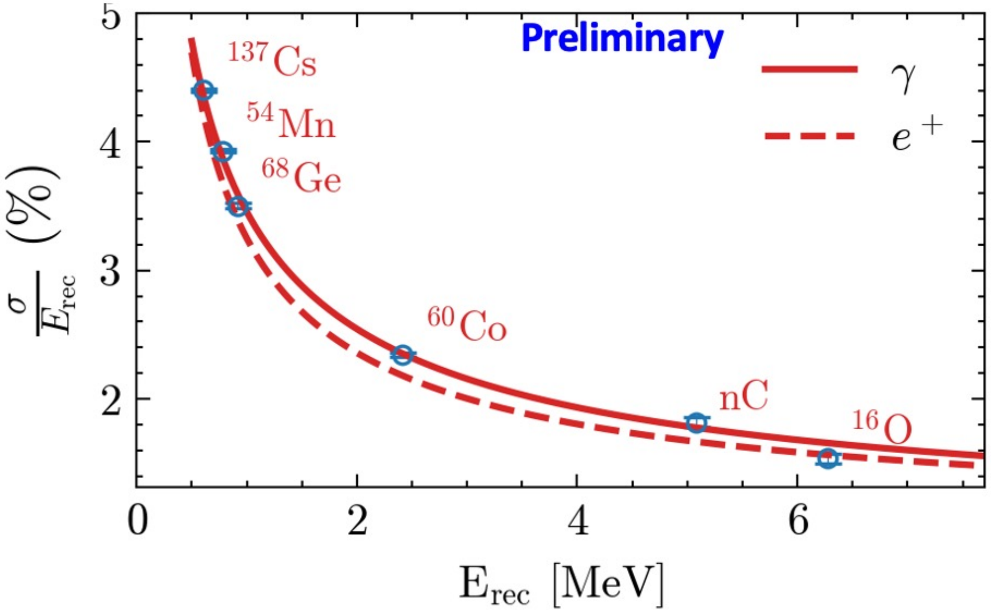
440 (207 days in JUNO) > 183 + 53 + 35 (Over years) !

Backup

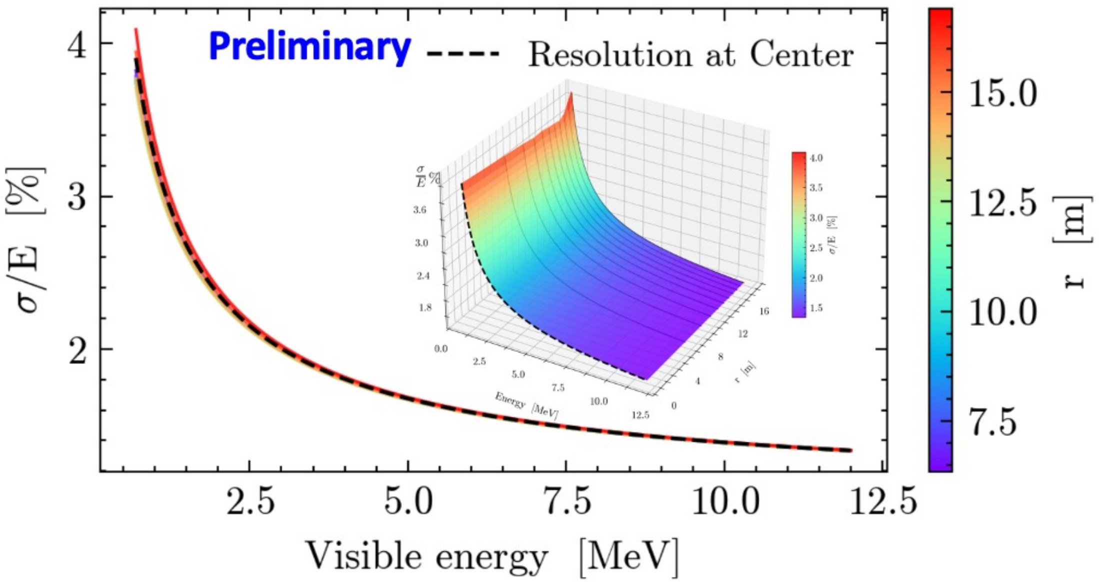


Work in progress
MC Truth
ML (Edwin)
ML (Amber)
Joint χ^2
WCD Charge Cluster
Event Rate [Hz]
$\cos\theta$
Work in progress
Event Rate [Hz]
ϕ [rad]

Backup



Preliminary
^{137}Cs
^{54}Mn
^{68}Ge
^{60}Co
nC
^{16}O
γ
e^+
$\frac{\sigma}{E_{rec}}$ (%)
E$_{rec}$ [MeV]



Preliminary
Resolution at Center
σ/E [%]
Visible energy [MeV]
r [m]