

Status of JUNO

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International Conference on Fundamental Physics from Quanta to Cosmos

Beijing

Oct. 25th, 2026

Neutrinos: Portal to New Physics

- **Many important questions in neutrino physics**
  - ⇨ Nature of neutrino mass, Majorana or Dirac, CP violation in lepton sector, etc.
- **Neutrino oscillations: a sensitive probe to study neutrino mass**

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \begin{pmatrix} \cos\theta_{13} & 0 & e^{-i\delta}\sin\theta_{13} \\ 0 & 1 & 0 \\ -e^{i\delta}\sin\theta_{13} & 0 & \cos\theta_{13} \end{pmatrix} \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} e^{-i\delta_1} & 0 & 0 \\ 0 & e^{-i\delta_2} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$\theta_{23}\sim 45^\circ$ by atmospheric neutrinos (1998)	$\theta_{13}\sim 9^\circ$ by reactor and accelerator neutrinos (2012)	$\theta_{12}\sim 34^\circ$ by solar neutrinos (2001)	neutrino-less double beta decay

Neutrinos: Portal to New Physics

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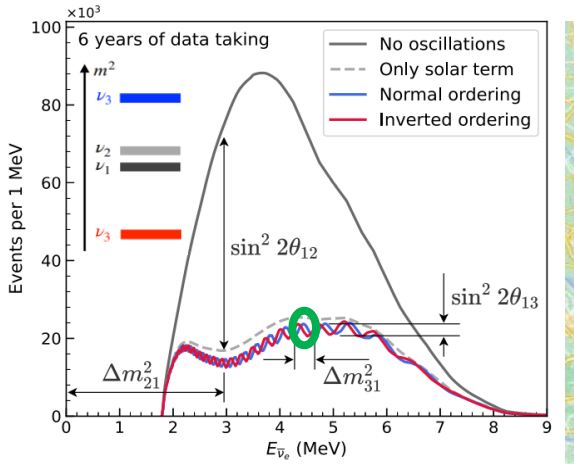
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- **Determine the neutrino mass ordering (NMO) is essential to**
  - ⇨ Reduce the difficulty to determine δ_{CP} using the matter effect in long baseline experiments
  - ⇨ Narrow down solutions for neutrinoless double beta decay results
  - ⇨ Create synergy and narrow down models for astro-particle physics and cosmology

Jiangmen Underground Neutrino Observatory

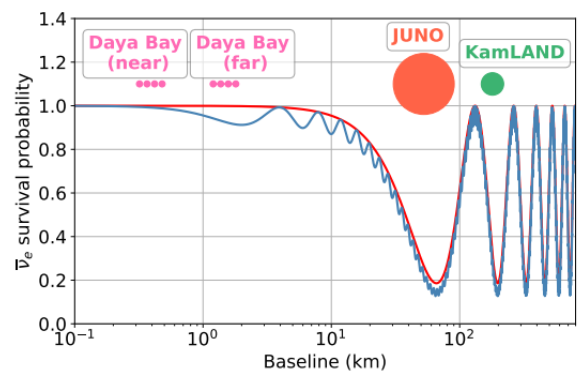
JUNO studies how reactor $\bar{\nu}_e$'s oscillate (disappear) into other flavors

$$P_{\bar{\nu}_e \to \bar{\nu}_e}(L,E) = 1 - \sin^2 2\theta_{12}\cos^4\theta_{13}\sin^2\frac{\Delta m^2_{21}L}{4E} - \sin^2 2\theta_{13}\left(\cos^2\theta_{12}\sin^2\frac{\Delta m^2_{31}L}{4E} + \sin^2\theta_{12}\sin^2\frac{\Delta m^2_{32}L}{4E}\right)$$









JUNO collaboration

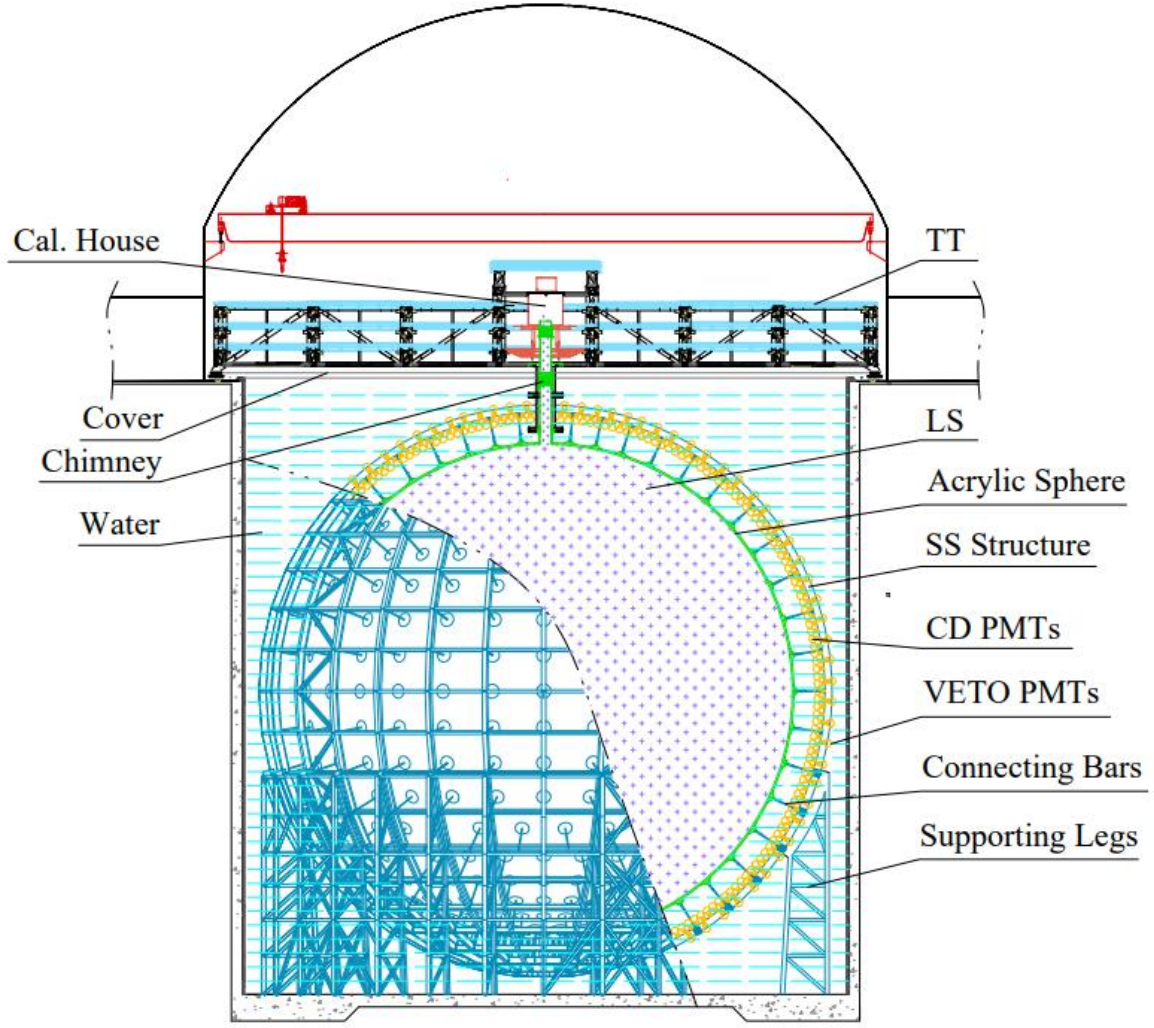
= 70 institutes，> 700 participants

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	UCI
China	NCEPU	Germany	JGUMainz	USA	UMD-G
China	NJU	Germany	RWTH-AC		
China	RNCG	Germany	TUM		

JUNO detector

- **Determination of NMO required 20kt LS and 3% energy resolution @1 MeV**
- **Technical achievements**
  - ⇨ A huge acrylic sphere with D=35.4m
  - ⇨ High efficiency 20-inch MCP-PMTs (30%)
  - ⇨ Very transparent LS (L_{att}~20.6m)
  - ⇨ 75% PMT coverage by 17,596 20-inch PMTs with only 3 mm clearance

	KamLAND	JUNO design	Ratio
Photon Statistics	**250 p.e./MeV**	**1200 p.e./MeV**	**5**
PMT coverage	**34%**	**75%**	**2.2**
LS transparency	**~12 m**	**> 20 m**	**~0.9**
Light yield (anthracene)	**30%**	**45%**	**~1.5**
Detection Eff.(QE×CE)	**~15%**	**30%**	**~ 2**



CDR, arXiv:1508.07166; CD: *Eur.Phys.J.Plus* 139 12, 1128; PMT: Eur.Phys.J.C 82 12, 1168; LS: NIMA 988 164823, etc.

In two years..

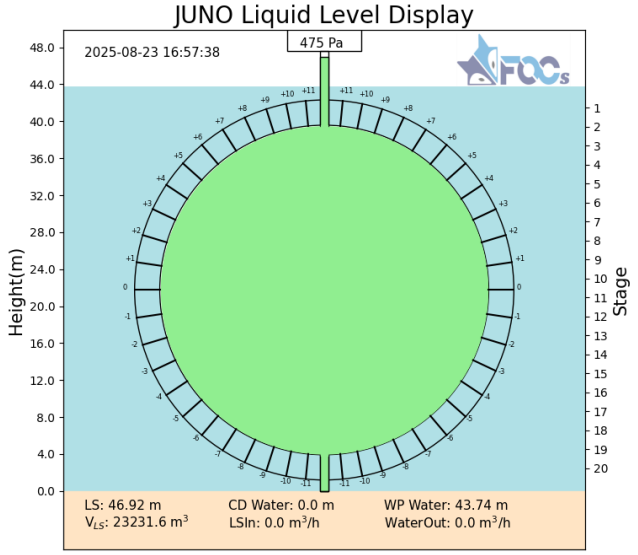
Detector assembly done, Dec. 2024



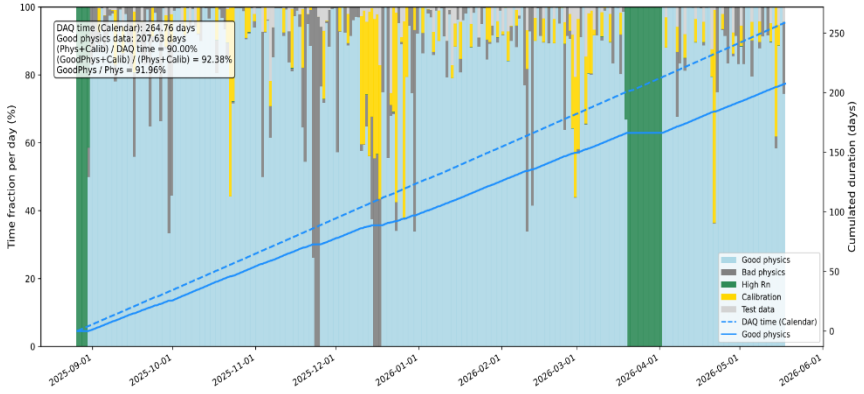
Water filling started Dec. 2024



LS filling finished Aug. 2025

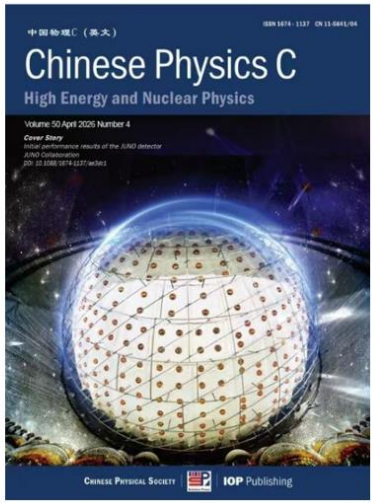


Stable operation since Aug. 26

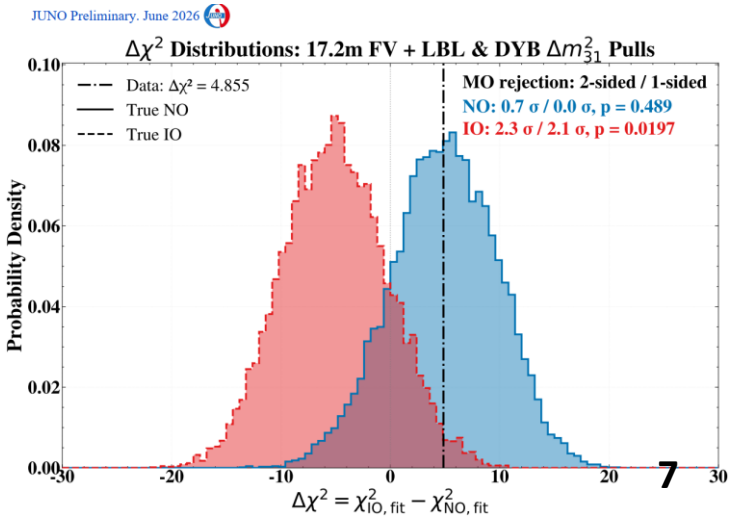


First result released in Nov. 2025

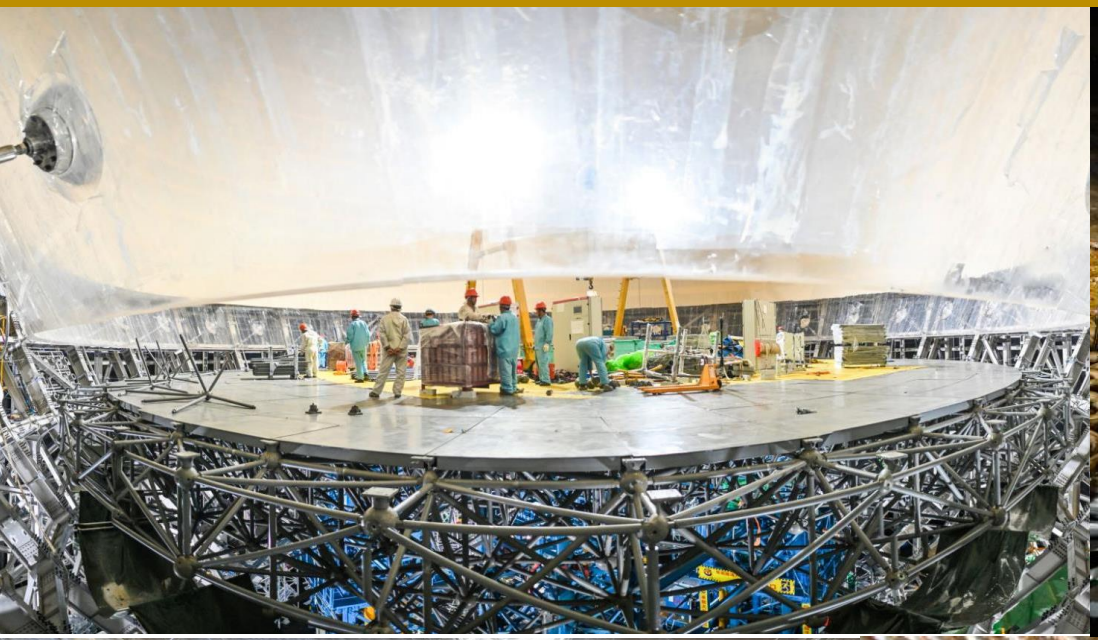




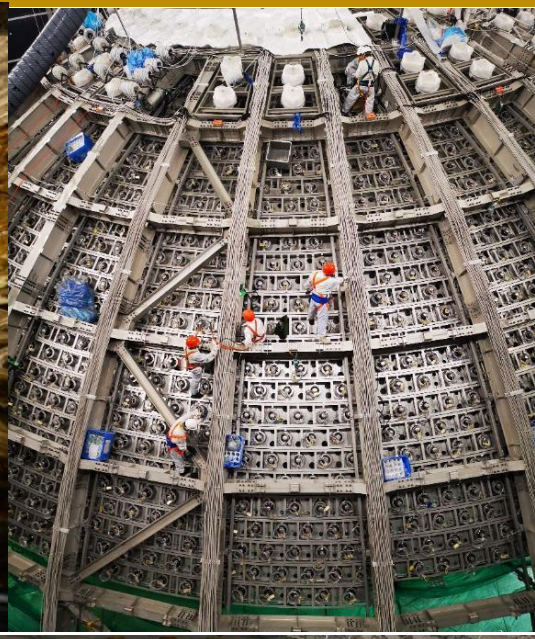
NO favored June 2026



Detector Construction

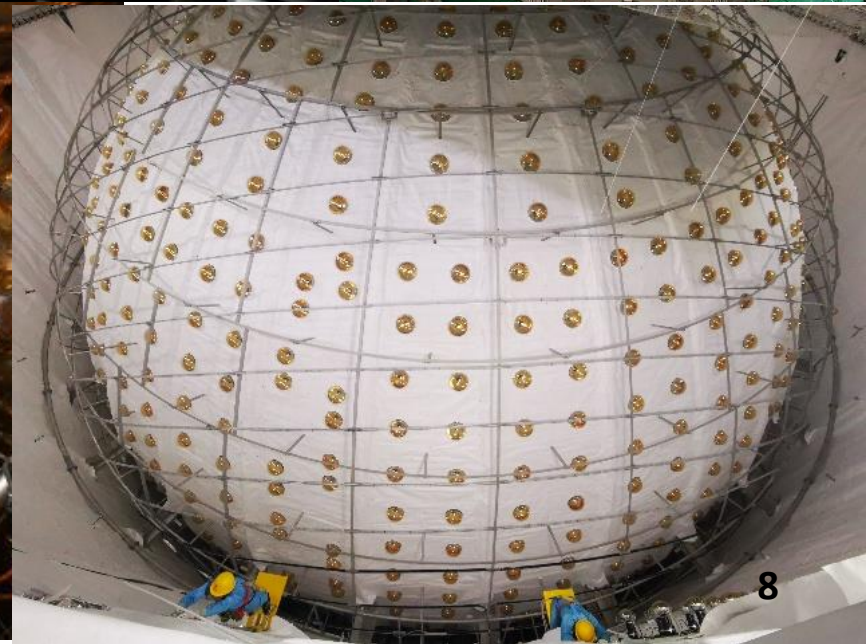












Liquid filling

Four purification plants to achieve target radio-purity <10^{-15} g/g U/Th and 20 m attenuation length



5000 m^3 LAB tank



1) Al_2O_3 for optical



2) Distillation for radiopurity



Mixing PPO and bis-MSB

SS pipes to underground



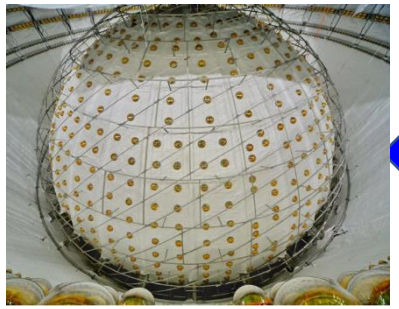
3) Water extraction to remove radioactive impurities



4) Gas stripping to remove Rn and O_2



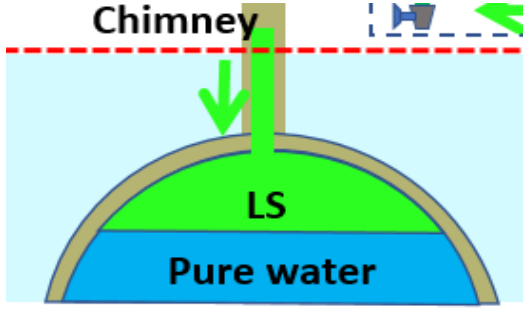
CD FOC system



JUNO detector

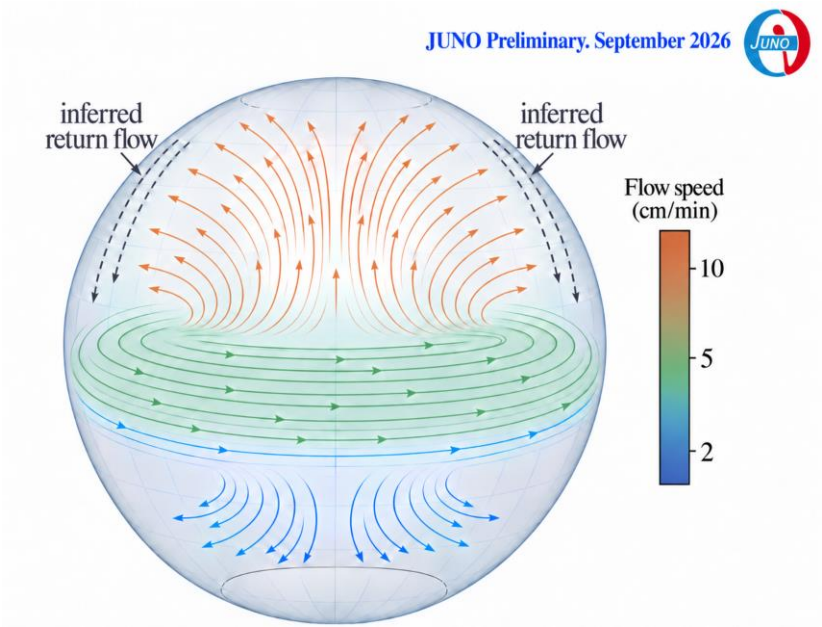
Filling strategies:

- Leakage (single component < 10^{-6} mbar·L/s)
- Cleaning vessel before filling
- Clean environment
- Water/LS filling



A clean detector

- JUNO is too large to recirculate for cleaning, unlike Borexino, KamLAND, SNO+,…
- Low background control is critical
  - ⇨ Simulation for background budget, careful screening and radiopurity control of raw materials, production handling, etc.
  - ⇨ Leak check of all joints, cleaning and washing of all inner surfaces, acrylic surface protection, online ^{222}Rn monitor during filling, etc.
- Interestingly, most of ^{238}U and ^{232}Th came from Radon pollution from top chimney

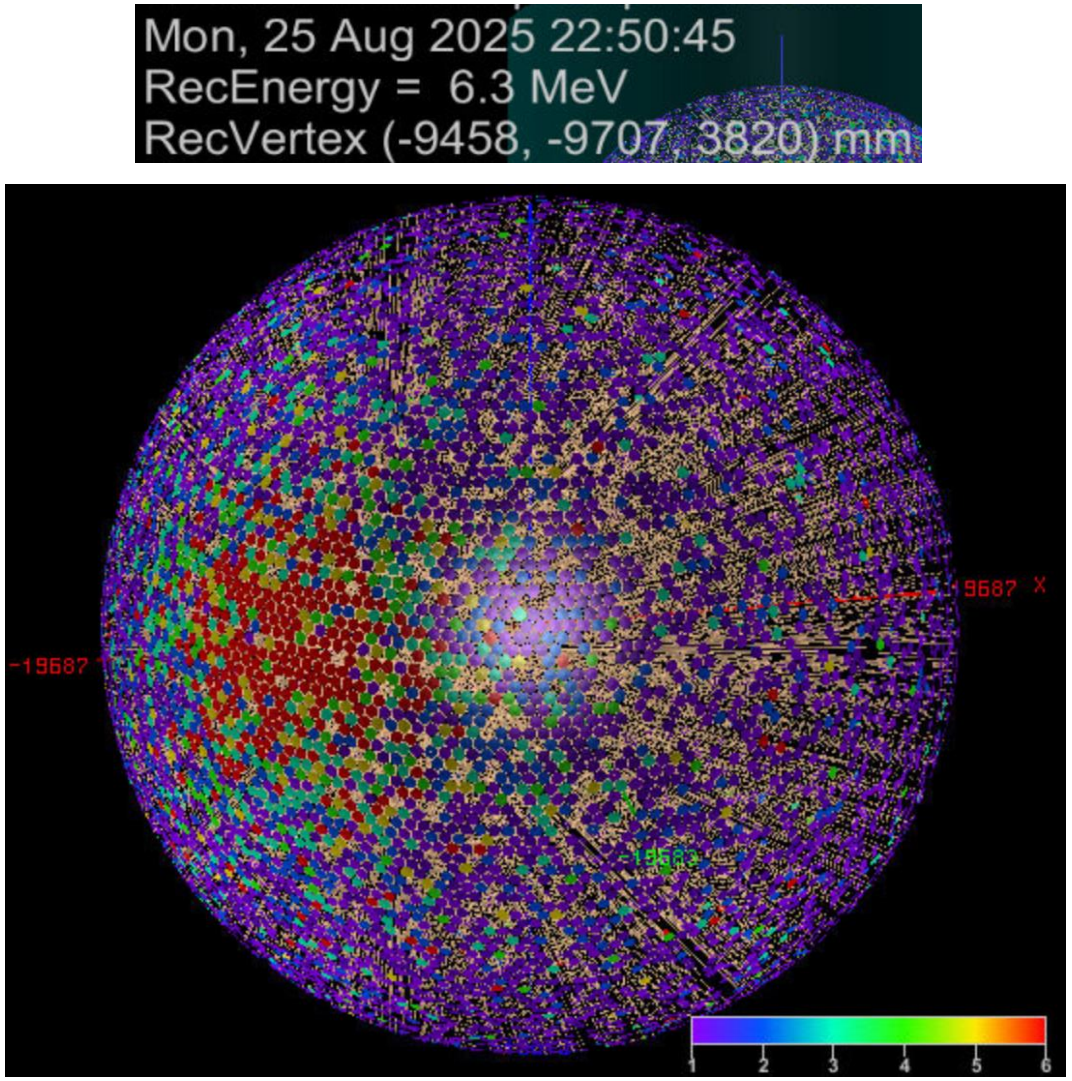


Reduce water temperature by 0.5°
Speed of LS flow reduced by 5 times
^{238}U/^{232}Th pollution reduced by 2-5 times

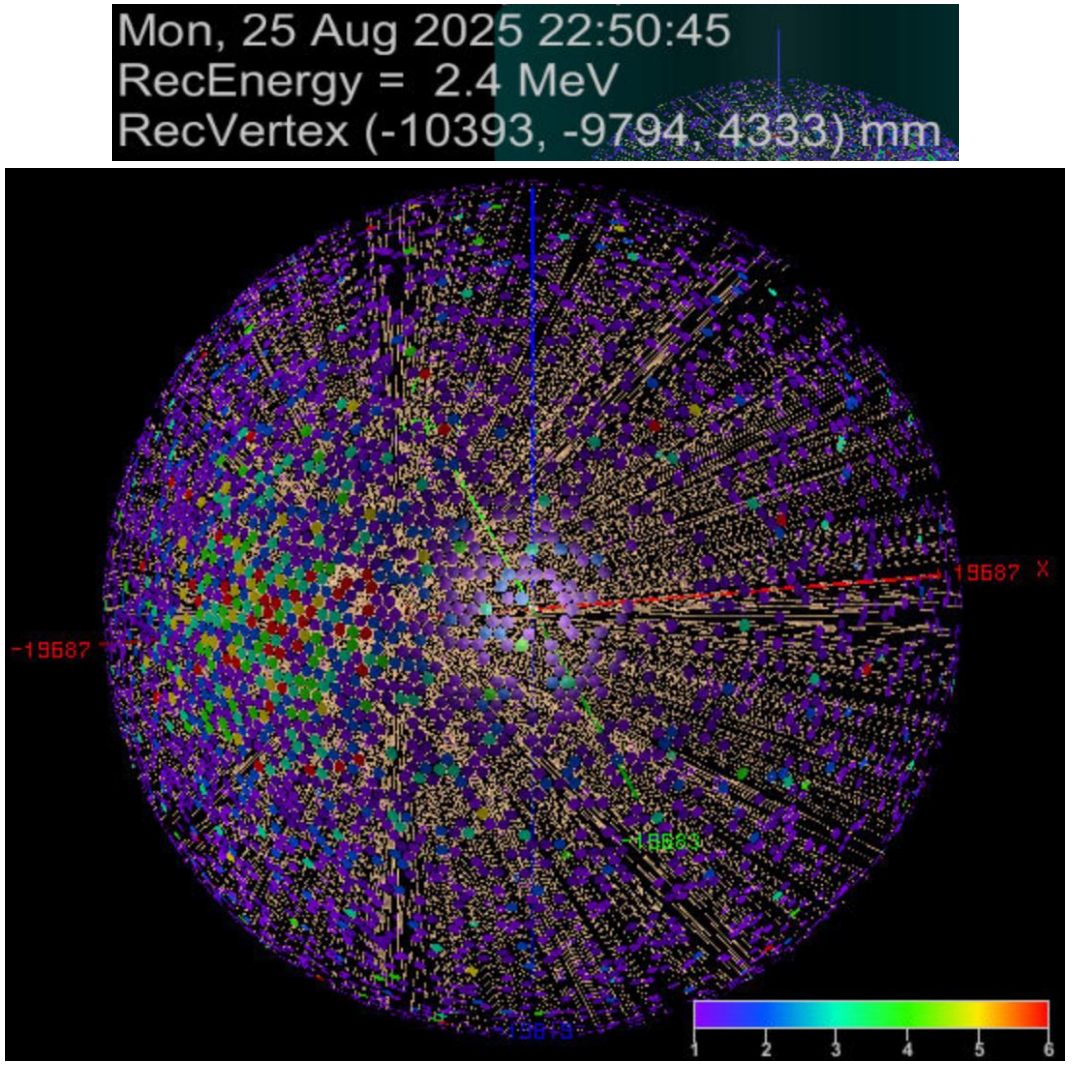
	^{238}U [10^{-17} g/g]	^{232}Th [10^{-17} g/g]
2026-06	8.2±0.6	7.8±0.5
2026-09	3.6±0.1	1.4±0.1

Current purity level fulfilled physics requirements

Golden Reactor Neutrino Event in JUNO



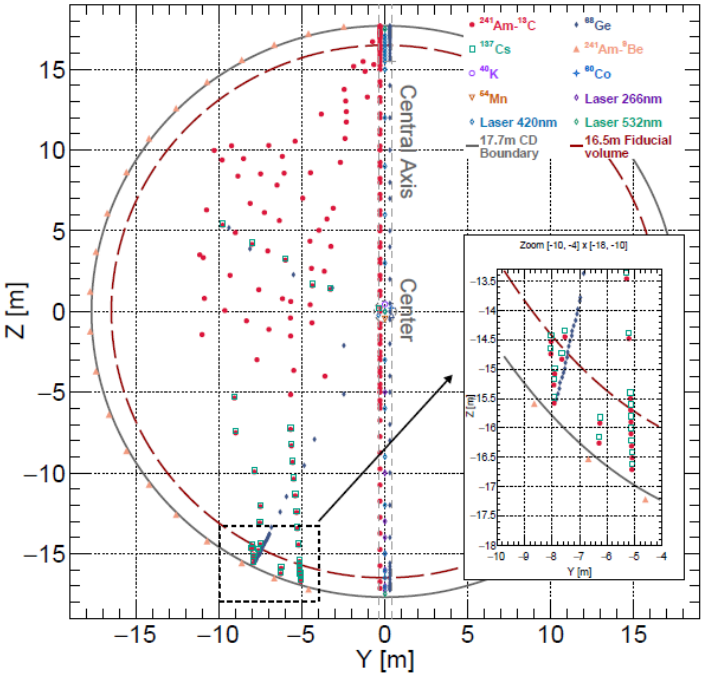
Prompt e+ signal

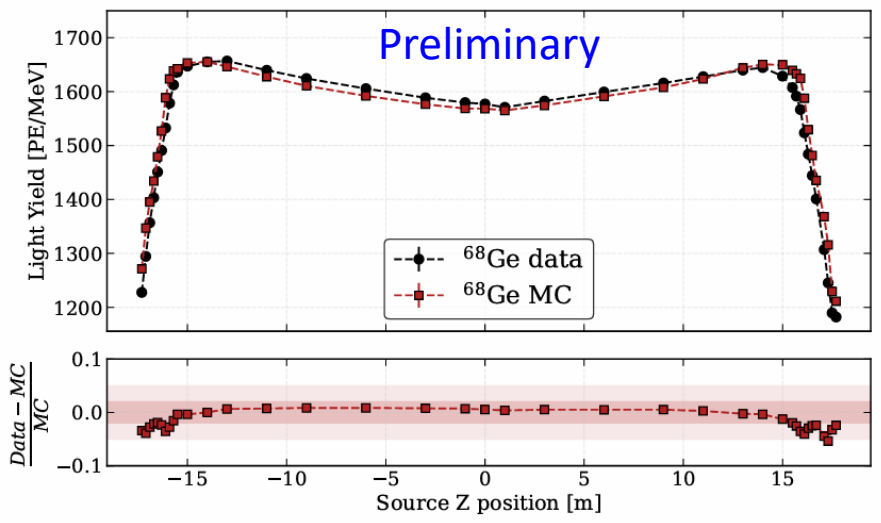


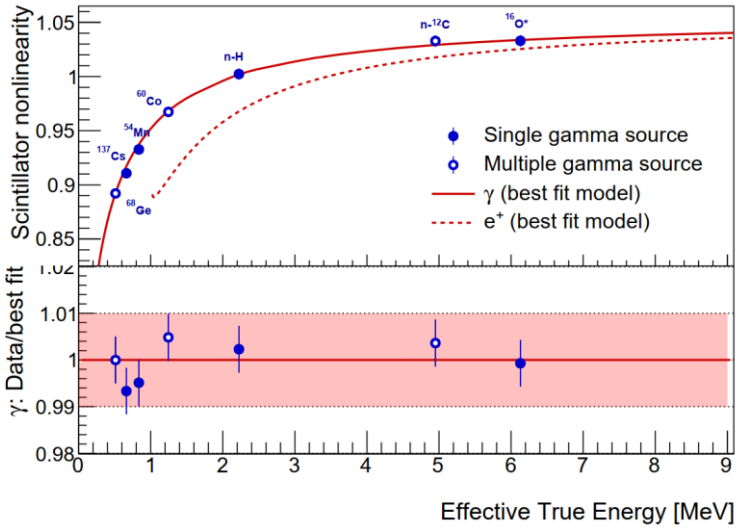
Delay neutron signal

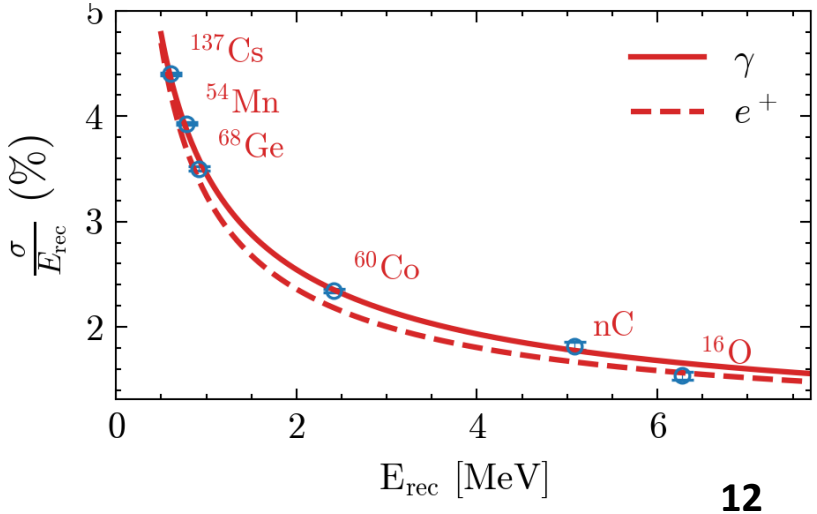
Energy response

- Light yield is more than 1,600 p.e./MeV from ^{68}Ge
- Comprehensive calibration and reconstruction efforts
  - ⇨ Residual spatial non-uniformity and time instability RMS ~0.3%
  - ⇨ Precision of energy nonlinearity calibration < 1%, RMS ~0.4%
- Energy resolution for ^{68}Ge is ~3.5% @ 2× 0.511 MeV at the center, slightly worse than the expected 3.1%
  - ⇨ Energy resolution for alpha from ^{214}Po is ~2.9% @0.93MeV
  - ⇨ Better MC; more calibration; ML to remove ^{14}C; better recon., etc.



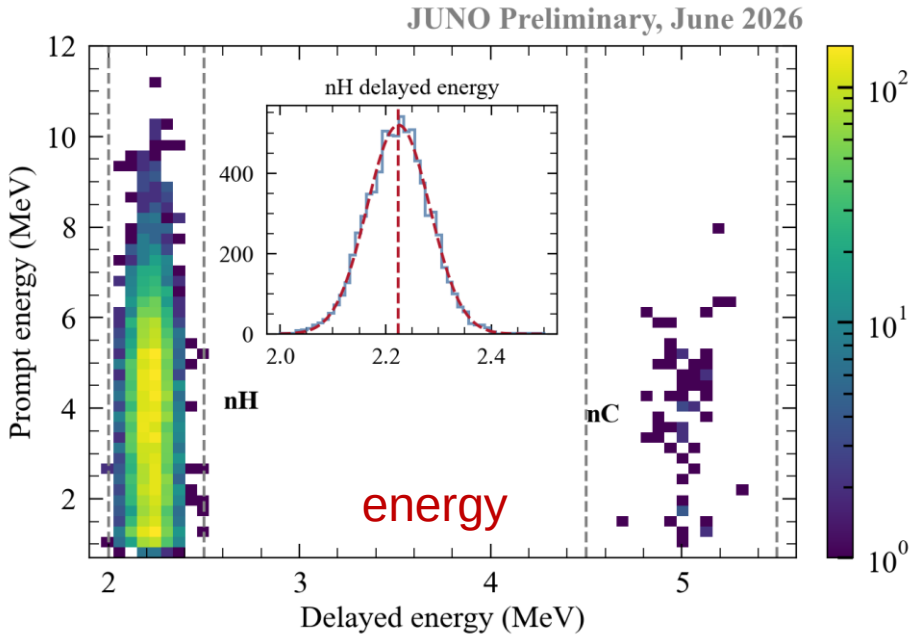


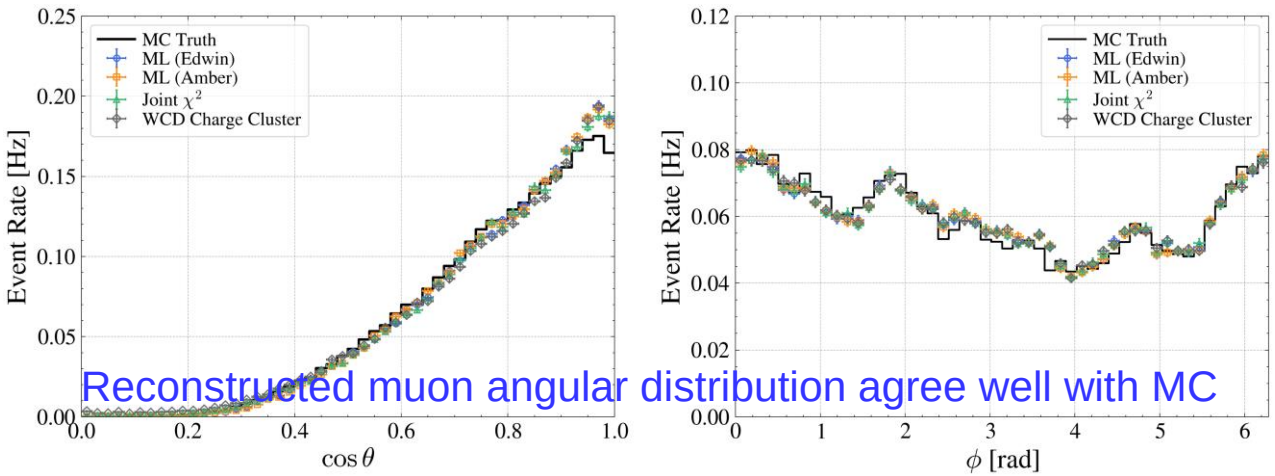




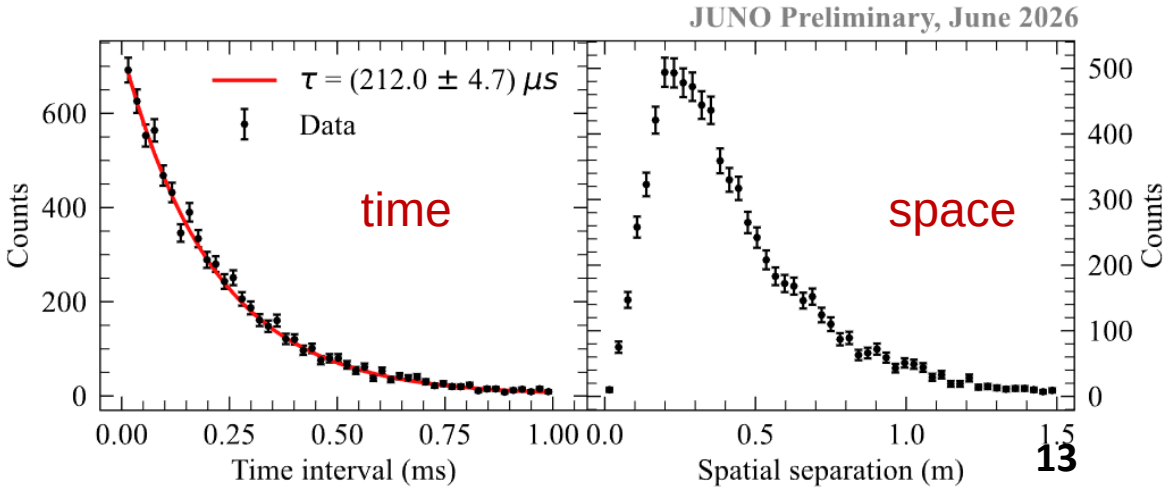
Background well understood

- Neutrino events selected by the coincidence in time, space with distinctive energy features between prompt and delayed
- B:S ~ 1:9 , largest background ^{9}Li ~1.4/day
  - ⇨ Reduced from 80/day by well reconstructed muon tracks with ML method using training data from the Top Track detector
- IBD efficiency 74%, improvement expected
- Measured **reactor neutrino** event rate consistent with **expectation**

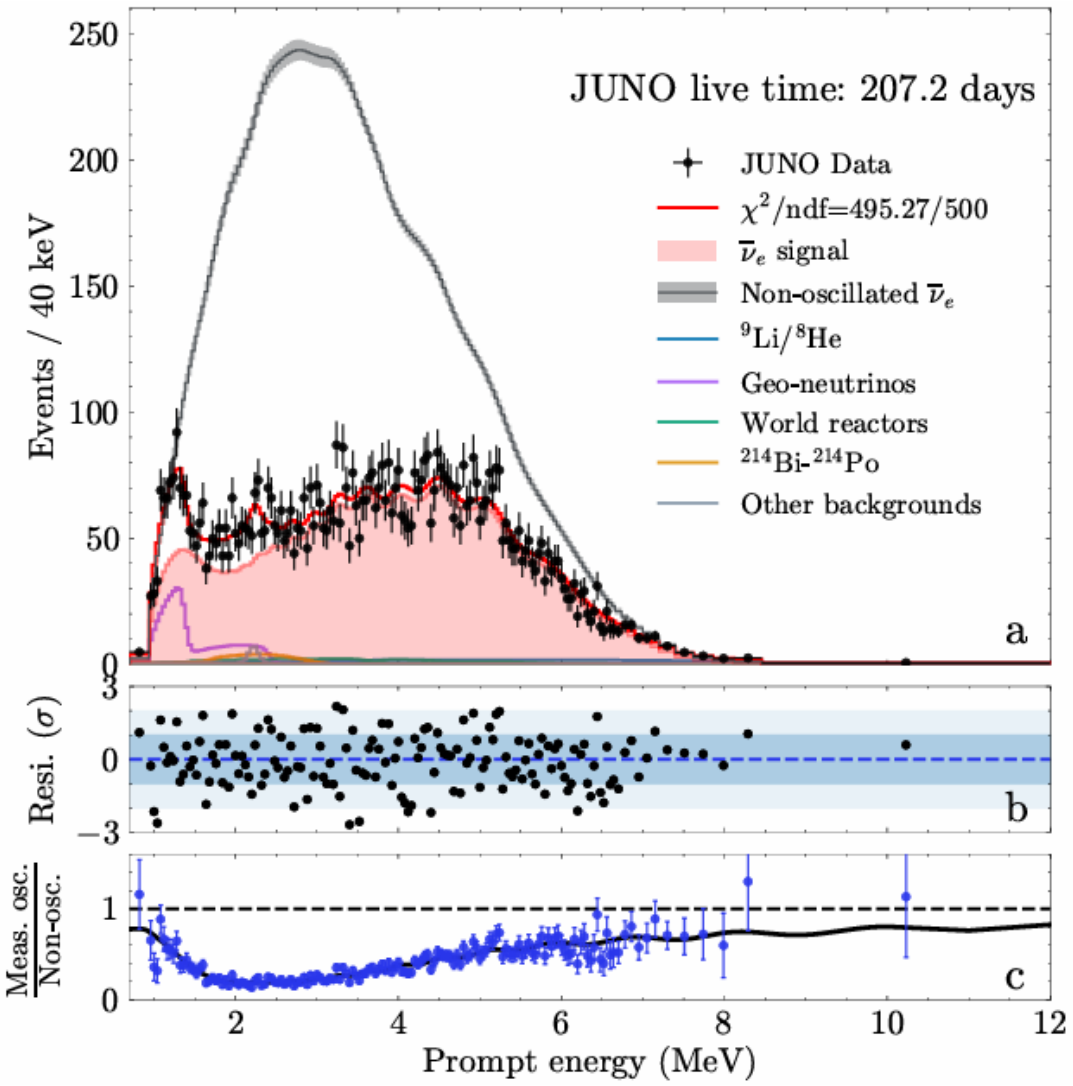




Reconstructed muon angular distribution agree well with MC



Measured Reactor Neutrino Spectrum

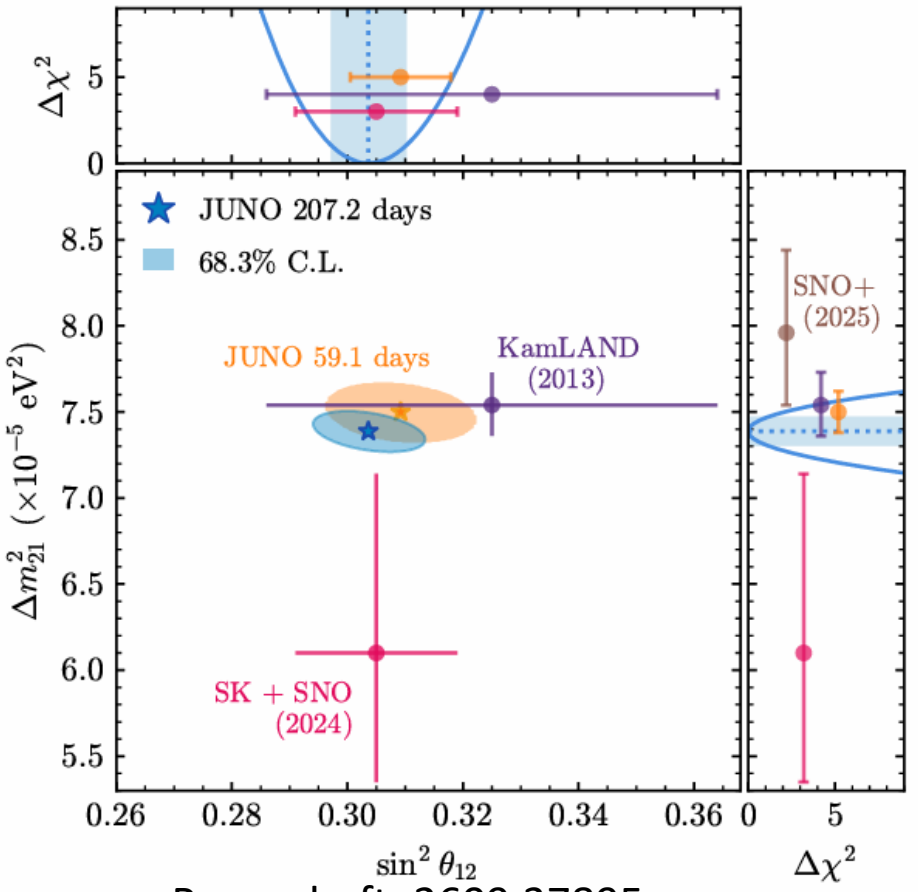


Antineutrinos ($\overline{\nu}_e$) Candidates Summary		
DAQ live time (days)	207.2	
$\overline{\nu}_e$ candidates	8294	
Selection Efficiencies (%)	ε	$\sigma_{\rm rel}$
Fiducial volume	87.12%	0.96%
PMT flasher rejection	$> 99.9\%$	Negligible
μ veto	93.67%	0.02%
Multiplicity cut	95.94%	negligible
Prompt-delayed coinc.	95.50%	0.32%
Correlated discriminator	98.99%	0.15%
Total efficiency ($\varepsilon_{\rm tot}$)	74.01%	1.02%
$\overline{\nu}_e$ signal (cpd)		
w/o $\varepsilon_{\rm tot}$ corrected	36.02 ± 0.62	
w/ $\varepsilon_{\rm tot}$ 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

Fitting constrained by the near detector spectra from TAO (arXiv: 2610.23331) **and Daya Bay** (PRL 130 16, 161802)

Solar oscillation parameters

- Fitting constrained by the near detector spectra from TAO and DYB
  - ⇨ Geo-neutrino rate left free in the fitting
- Even though the statistics uncertainty is dominant, systematic errors become important:
  - ⇨ Improving ^{214}Bi background and detection eff.



Paper draft: 2609.37895

$\sin^2\theta_{12}$	Precision (%)	stat.+1 syst.
Stat-Only	1.2995	
Power	0.1368	
Spent nuclear fuel	0.0415	
Non-equilibrium	0.0631	
Fission fraction	0.1059	
Fission energy	0.0398	
Detection efficiency	0.5755	
Matter density	0.0673	
Detector response covariance	0.4081	
Reactor spectrum	0.3961	
Bkg rate	1.0781	
Bkg shape	0.2081	
AllSyst	1.6112	
Total	2.0700	

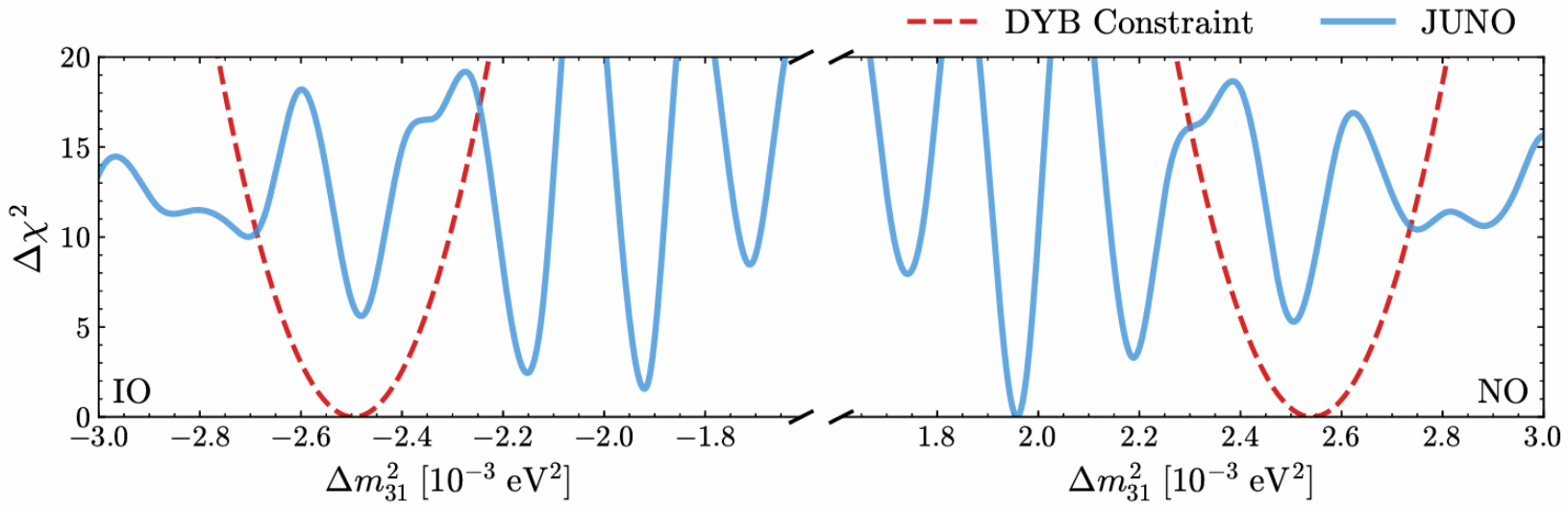
0.0 0.5 1.0 1.5 2.0

Δm^2_{21}	Precision (%)	stat.+1 syst.
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	

0.00 0.25 0.50 0.75 1.00

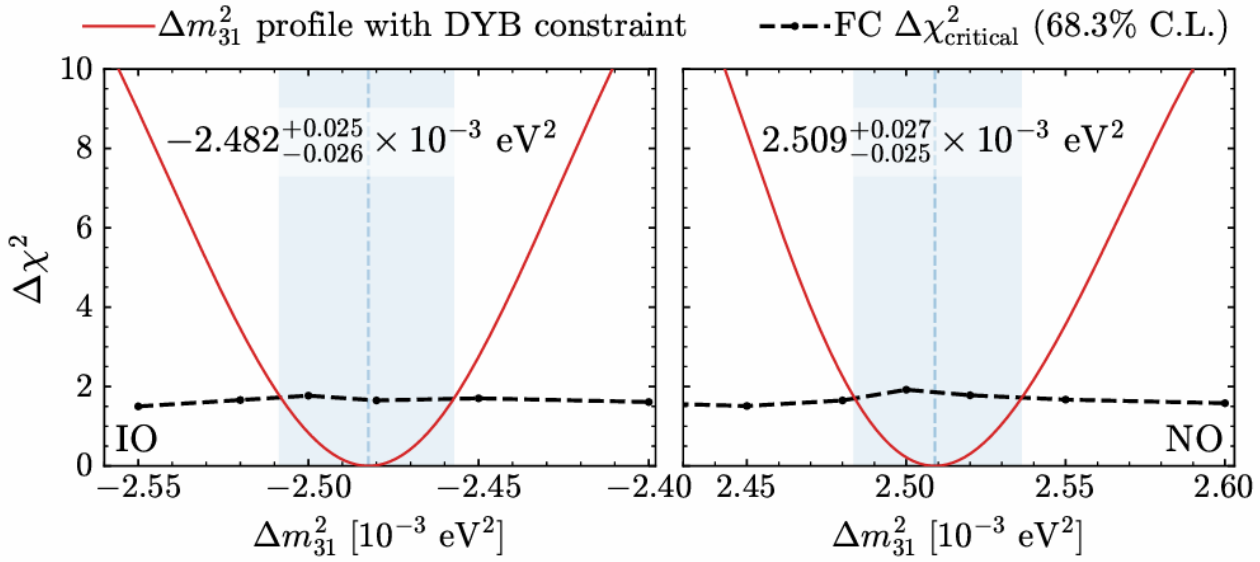
1% precision Δm^2_{31}

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



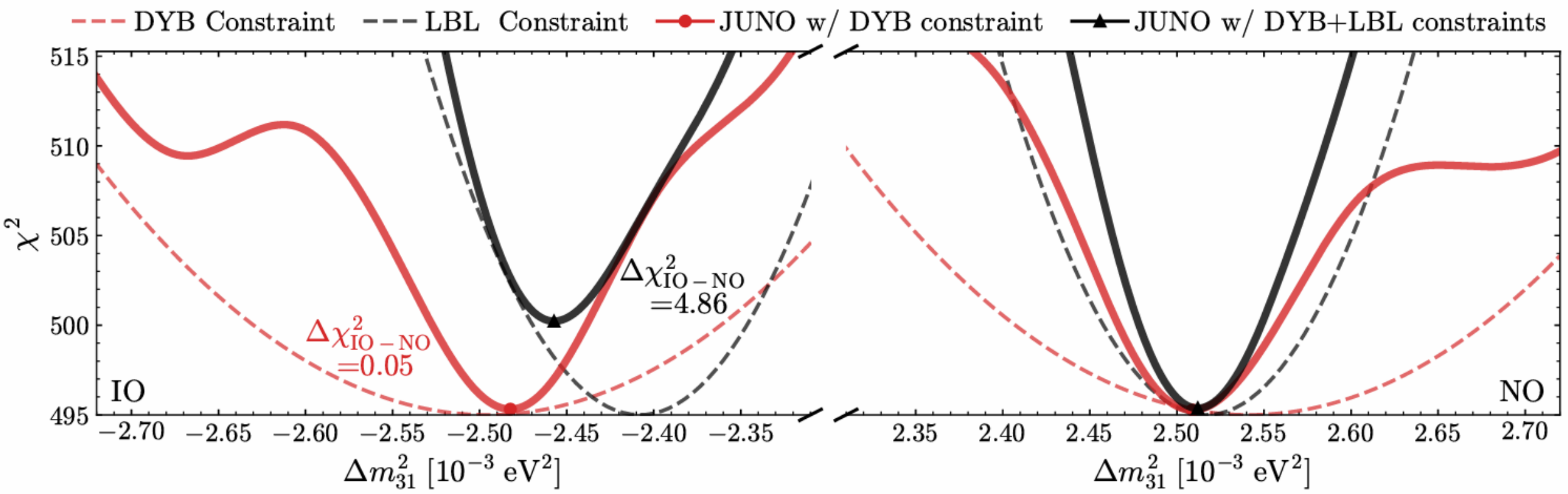
The final minimum for each mass ordering is obtained by using the Δm^2_{31} constraint from the Daya Bay result (PRL 130 16, 161802)

Feldman-Cousins (FC) method is used to determine the 1σ range of Δm^2_{31}: ~1% precision achieved



Adding constraints from NuFit-LBL

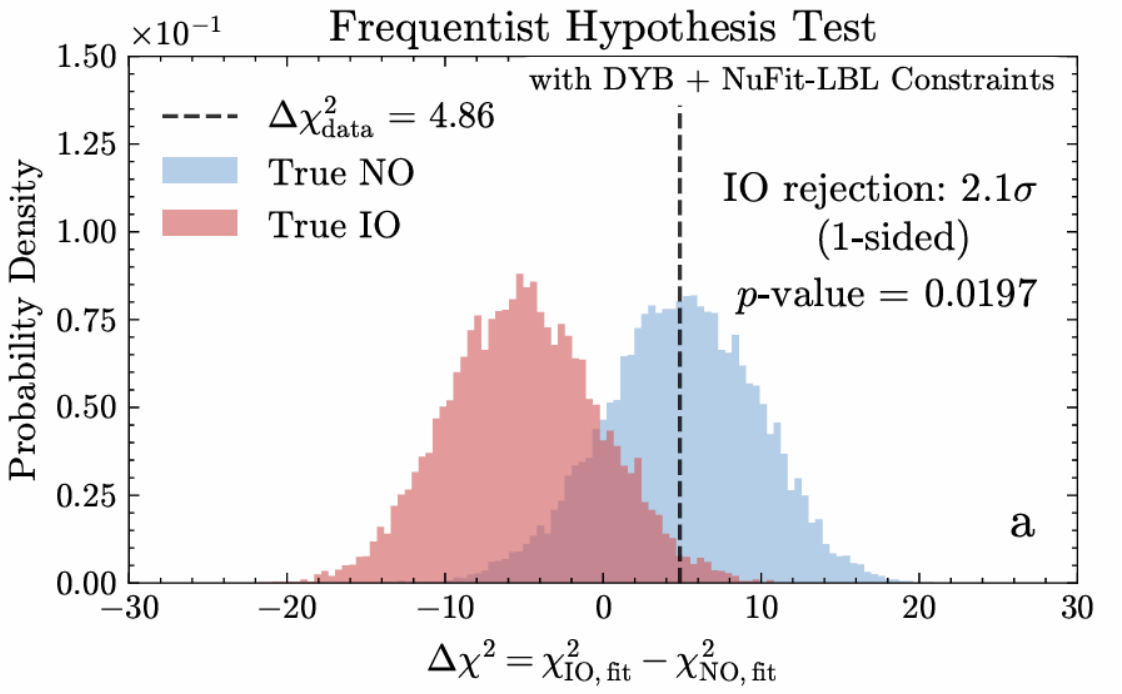
- Δm^2_{31} from reactor and accelerator neutrinos should align at the right mass ordering[1]
- Adopt the NuFit-LBL results from [2]: normal mass ordering is favored at $\Delta\chi^2 = 4.86$



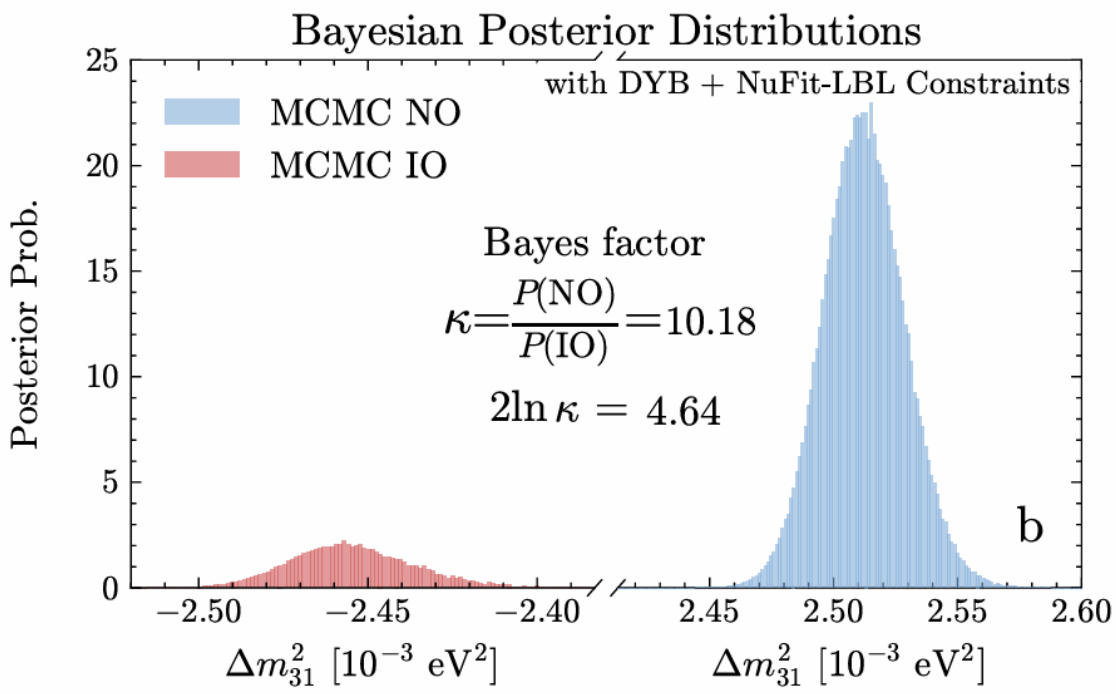
[1] H. Nunokawa, S. Parke and R.Z. Funchal, Phys. Rev. D 72 (2005) 013009; Y. F. Li et al., Phys. Rev. D 88, 013008 (2013)
[2] NuFIT 6.0 (JHEP 12 (2024) 216 [arXiv:2410.05380]), www.nu-fit.org and M. Maltoni private communication

Significance on mass ordering

- Frequentist approach using FC method to convert $\Delta\chi^2$ to significance
- Scanned over δ_{CP}
- Normal Ordering is favored at 2.1σ/2.3σ (1-sided / 2-sided)

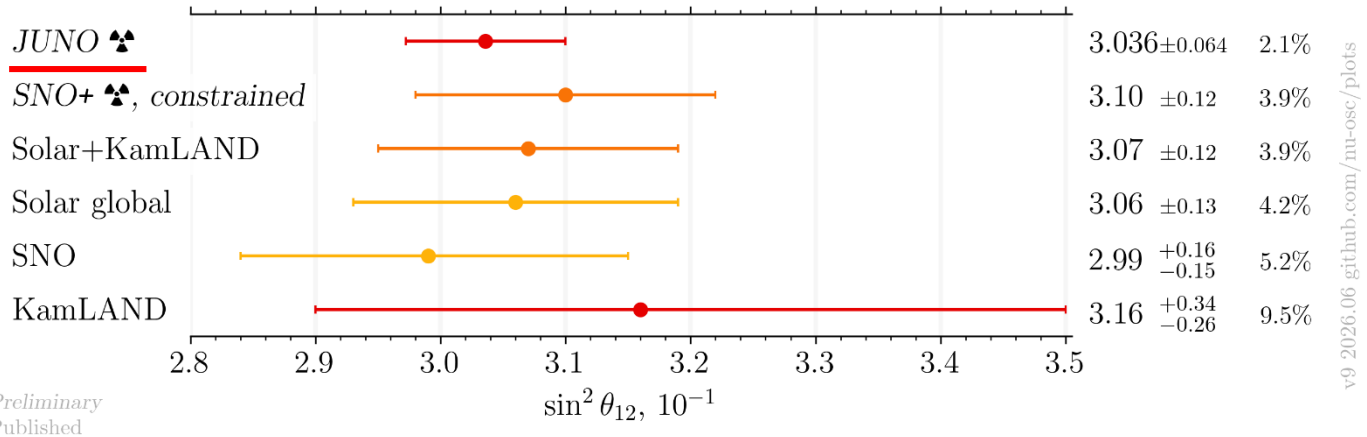


- Bayesian approach using Markov Chain Monte Carlo(MCMC) method
- Normal Ordering is favored with a Bayes factor of 10.18 ➔ $2\ln\kappa = 4.64$

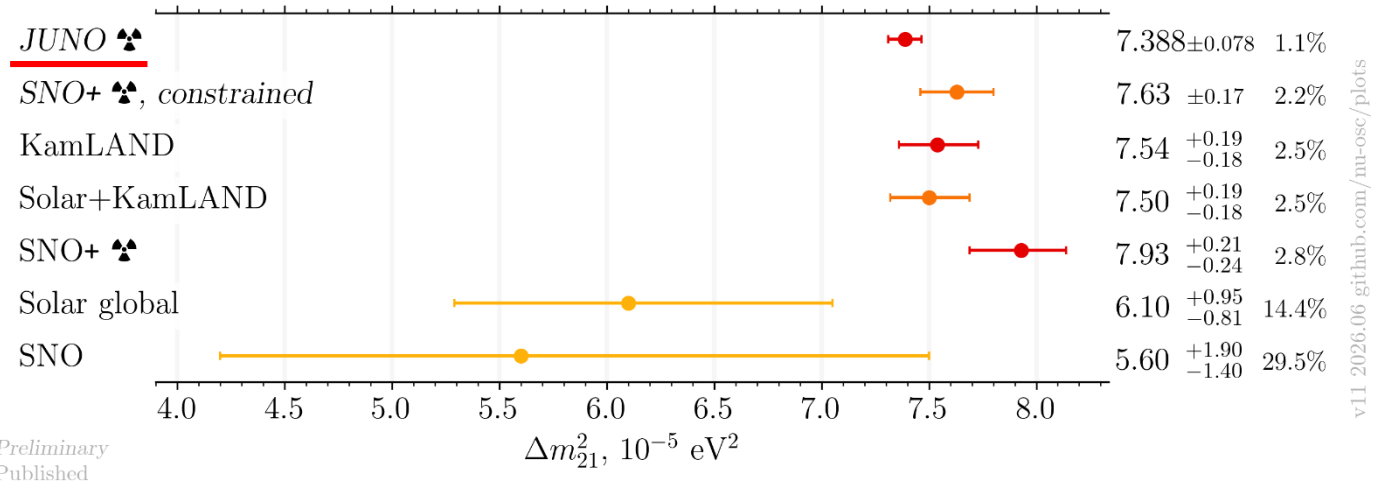


Current Results of Oscillation Parameters

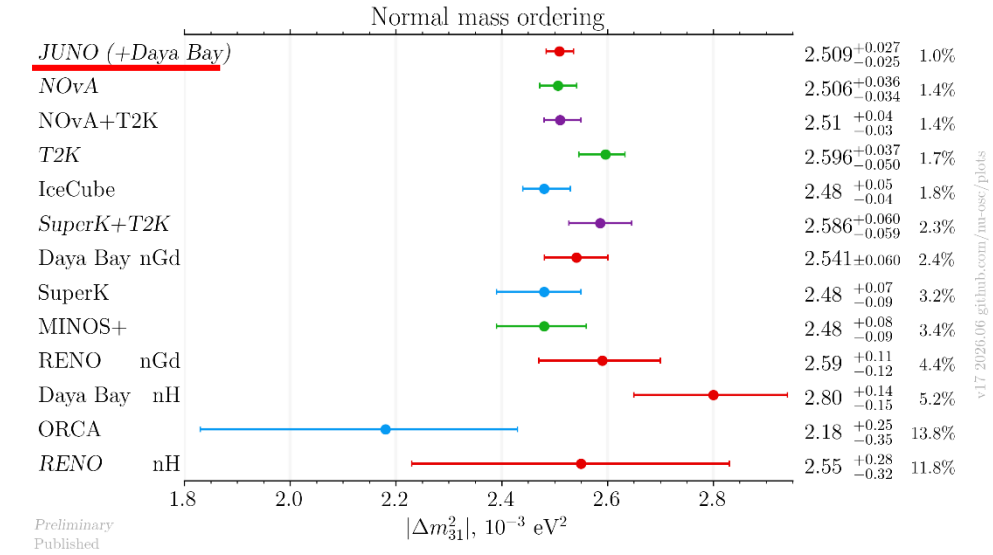
$\sin^2 2\theta_{12}$

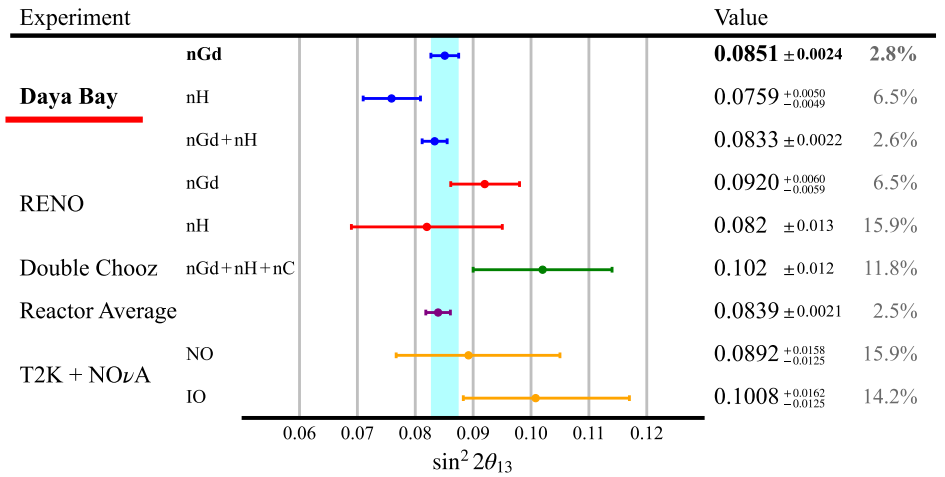


Δm^2_{21}



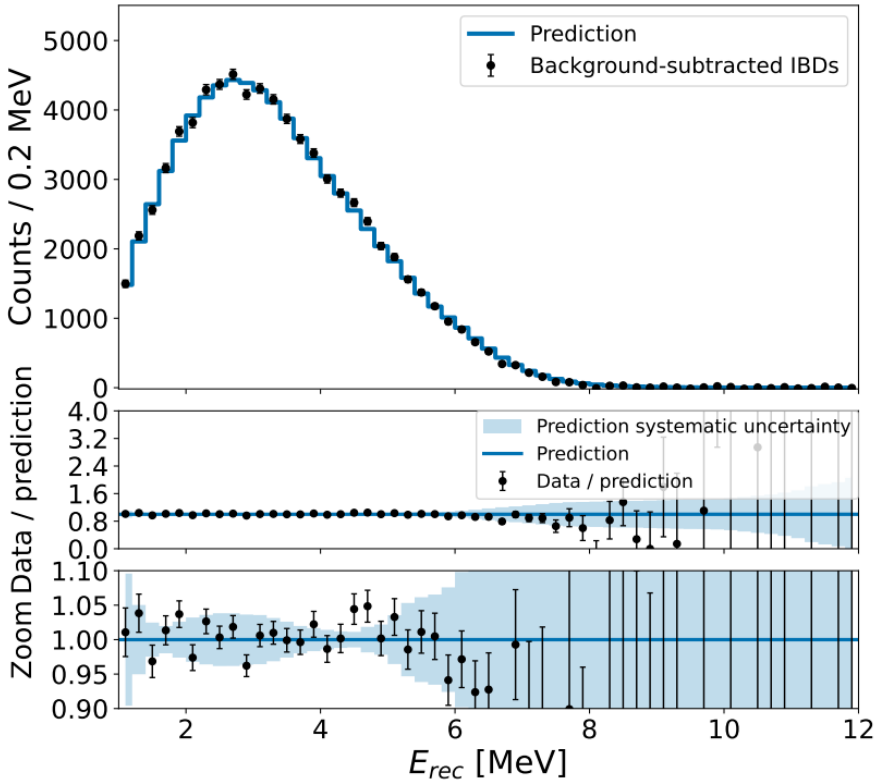
Δm^2_{31}

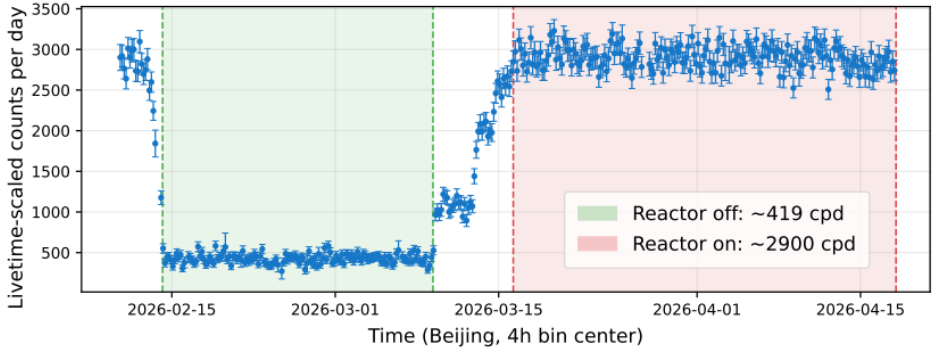




JUNO-TAO

- An innovative apparatus with Gd-loaded LS @-50^{o}C + SiPM
  - ⇨ 43.4m from Taishan-1 reactor core(4.6 GW)
  - ⇨ 10 m^2 SiPM (>94% coverage) w/ PDE > 50%
  - ⇨ Reduce the SiPM dark rate by 10^3 to 50 Hz/mm^2
  - ⇨ Model-independent reference spectrum for JUNO, benchmark for nuclear database, etc.
- Operation started in Feb. 2026
  - ⇨ Stable Gd-LS and SiPM running at -50 ^{o}C
  - ⇨ 2500 IBD/day with a S:B = 6:1
  - ⇨ Light yield ~4000 p.e./MeV, energy resolution 2.8% for ^{68}Ge, better than 3.5% of JUNO ^{68}Ge
- First measurement of reactor ν spectrum at better than 3%@1MeV energy resolution
  - ⇨ Good data/prediction agreement
  - ⇨ Used as high-resolution constraints by JUNO

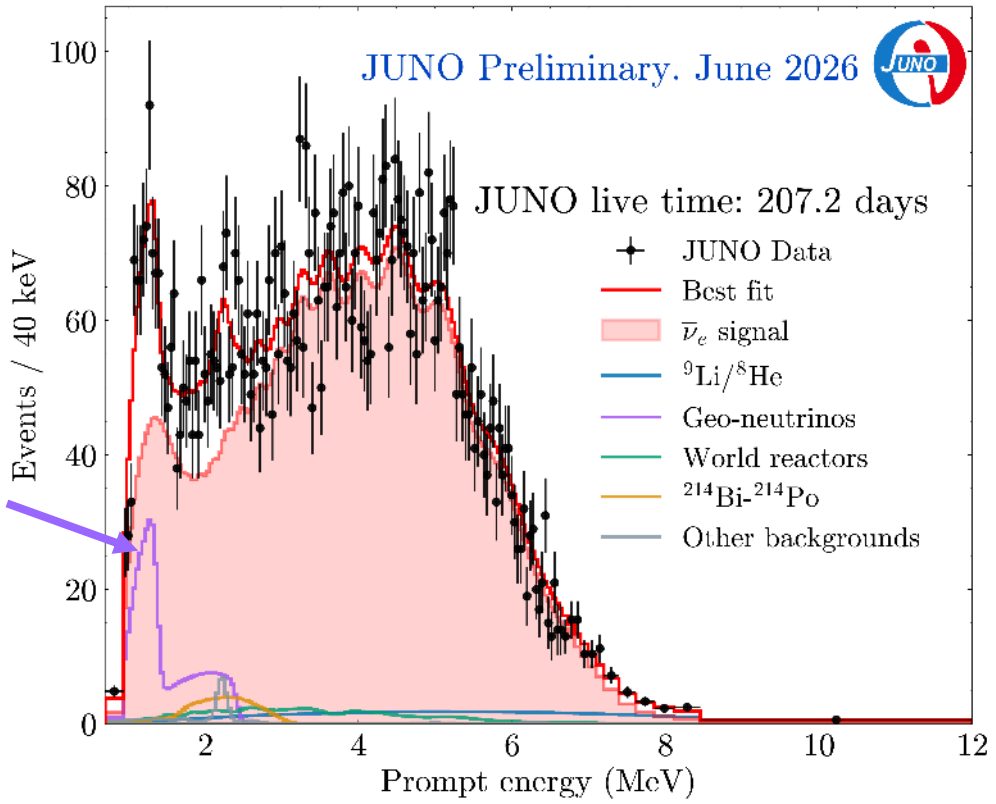


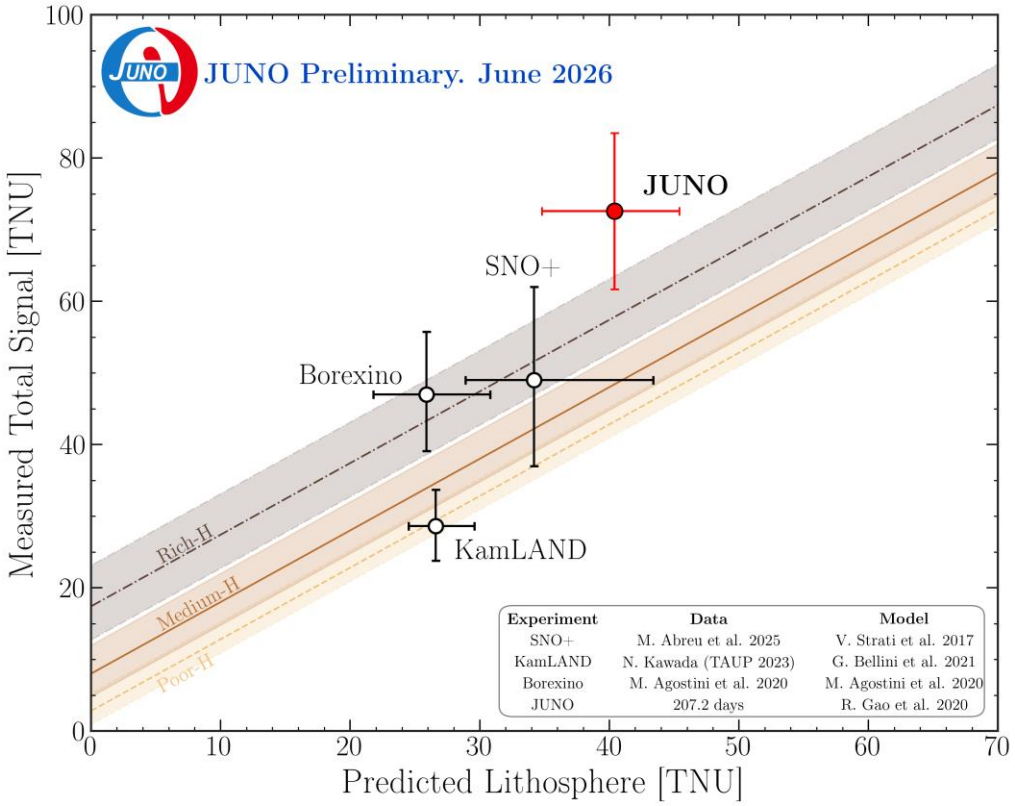


Results on Geo-neutrinos

- Fits are performed without constraint on geo-neutrino flux, but with 3.4±10% U/Th ratio
  - ⇨ Constraining the geo-nu flux doesn't change oscillation results
- Clear geo-nu signals at 1-3 MeV, giving a flux of 73 ± 11 TNU
  - ⇨ Largest geo-neutrino samples so far, and most precise measurement
- JUNO result is higher than expectation from existing models, but not statistically significant
- Need more JUNO data and more refined geological model predictions

geo-ν





Summary and prospects

- 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 keep improving
- First measurement on Δm^2_{31} achieved a precision of ~1%
- With external constraint, **Normal Mass Ordering** is favored at ~2.1σ
- First geo-neutrino results yield a flux of 73 ± 11 TNU
- Other promising new results not covered in this talk:
  - ⇨ First atmospheric neutrino events in JUNO
  - ⇨ First limit on the DSNB neutrino flux in JUNO
  - ⇨ Smooth running of supernova neutrino alert system
  - ⇨ Solar neutrino background modelling


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Thanks!