Recent Neutrino Oscillation Results from JUNO

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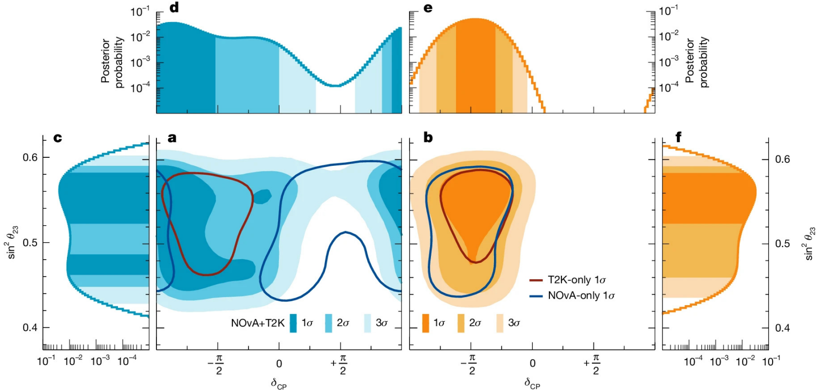
on behalf of the JUNO collaboration

Tsinghua University, Center for High Energy Physics

2026-05-26 NPN 2026 @ Mito

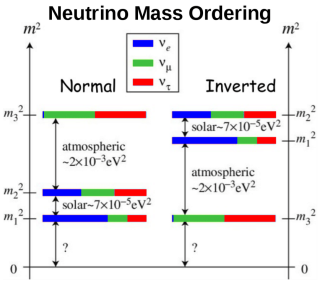
The Global Context



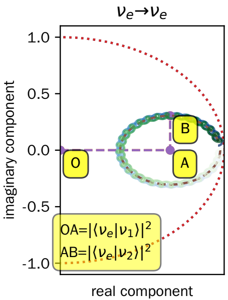
Nature 646, 818–824 (2025).

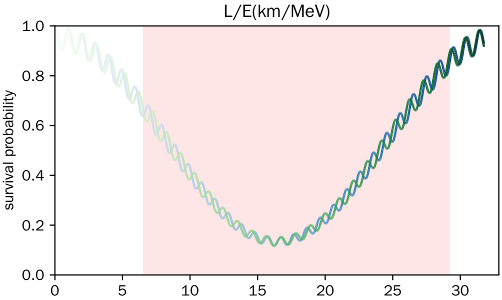
- T2K and NOνA combined fit shows favor of inverted ordering.
- JUNO is committed to provide the independent & orthogonal NMO input.
  - $\rightarrow$ Synergy with accelerator ν facilities

ν Mass Ordering (NMO): Sign of Δm^2_{31}

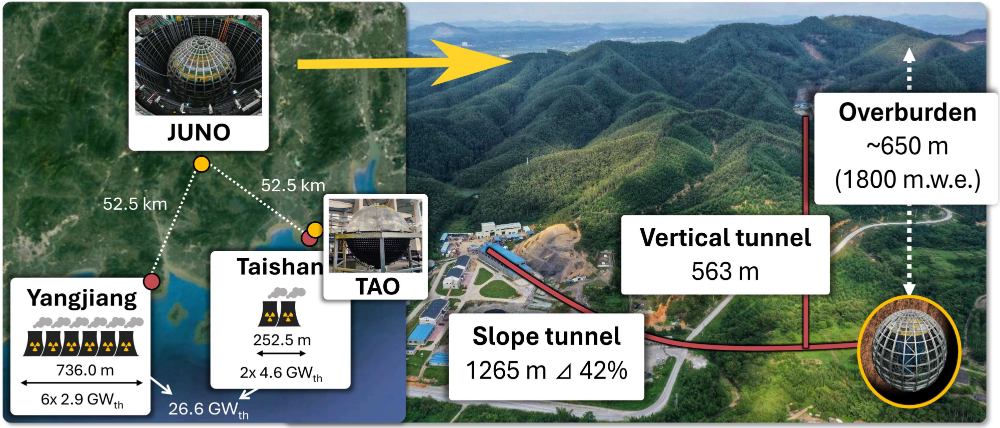


- $\Delta m^2_{21} = m^2_2 - m^2_1 = 7.5 \times 10^{-5}\,\mathrm{eV}^2$
- $\Delta m^2_{31} = m^2_3 - m^2_1 = 2.4 \times 10^{-3}\,\mathrm{eV}^2$
- normal order: $m^2_3 > m^2_1$;
  - inverted order: $m^2_3 < m^2_1$
- imprints subtle difference on energy spectra.





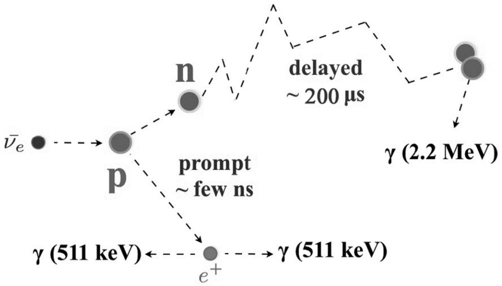
Jiangmen Underground Neutrino Observatory

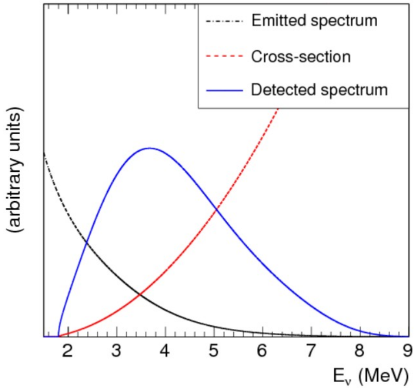


- 52.5 km captures the first minimal of ν_{12} oscillations.

$\bar{\nu}$ Detection with Inverse Beta Decay (IBD)

$$\bar{\nu}_\mathrm{e} + \mathrm{p} \longrightarrow \mathrm{e}^+ + \mathrm{n}$$

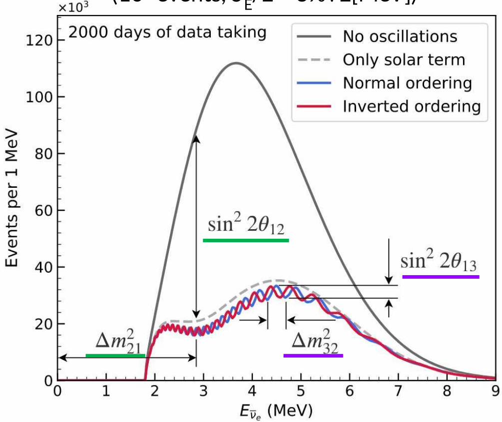


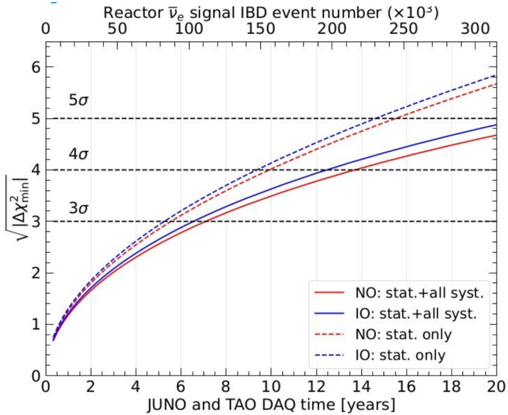


e^+/γ scintillation light are collected by photomultipliers.

Sensitivity to ν Mass Ordering

Exemplary spectrum, 6y
(10^5 events, $\sigma_E/E = 3\%\sqrt{E[\text{MeV}]}$)

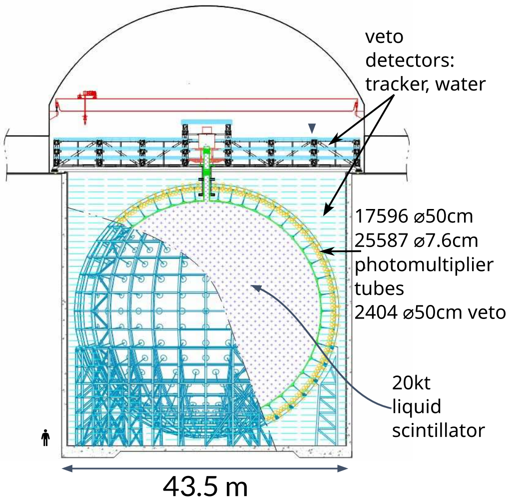




$\Delta\chi^2$ is the χ^2 difference between correct and wrong hypothesis.

3σ determination in 6.5 years. Chin. Phys. C 49 033104

A Liquid Scintillator Detector



Large Exposure

- proven technology to scale up.
- world's largest by $20\times$.

Measurement of ν Energy

- bright liquid scintillator.
- maximize the coverage of photomultiplier tubes.
- > 1700 photo-electrons/MeV.

Control of Backgrounds

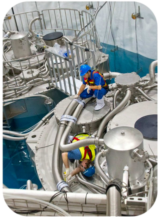
- effective impurity removal: filtration, distillation, absorption.
- active shield of water and μ tracker.

20 kton LS Target Providing High Statistics

Proximity to 8 nuclear reactors and **unprecedented size**

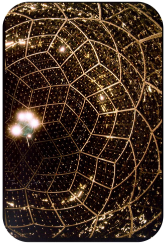
evolution of LS detectors

Reines & Cowan 300 L

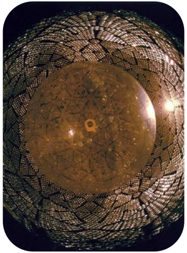


Daya Bay 8 x 20 t

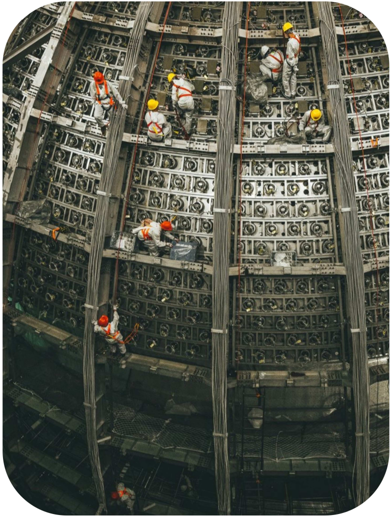
Borexino 300 t



KamLAND 1,000 t



SNO+ 780 t

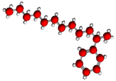


JUNO 20,000 t

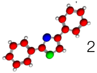
High Energy Resolution with Dense PMT Array

	KamLAND	JUNO
PE yield per MeV	250	>1700
Resolution @ 1MeV	6%–7%	$\sim 3\%$
Photocoverage/%	34	78
PMT QE $\times$ CE/%	12	30
Relative light yield	1	1.5

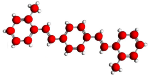
Bright Liquid Scintillator



Solvent: LAB
Linear Alkyl-Benzene
88% C + 12% H

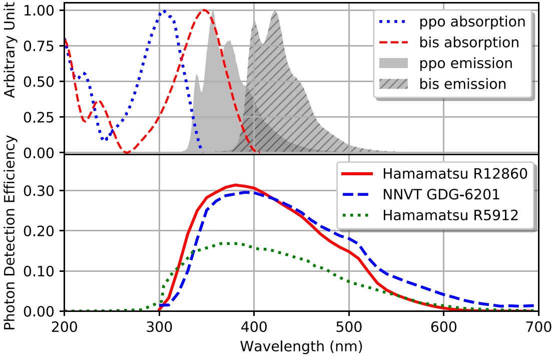


Fluor:
2.5 g/L PPO



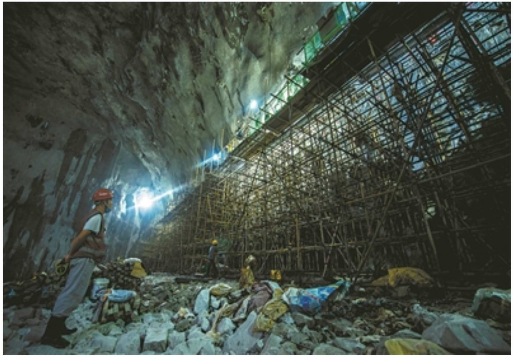
Wavelength shifter:
3mg/L bis-MSB

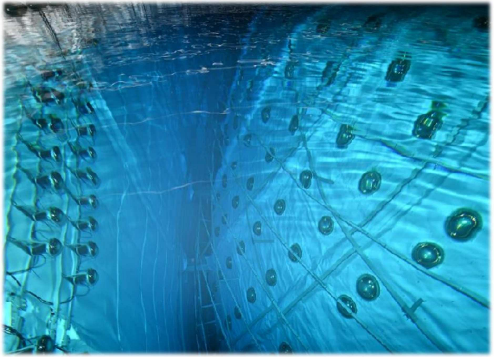
- Carefully designed liquid scintillation cocktail.
- Efficienct transmission of ionization energy to scintillation photons.



NIM A 967, 163860 (2020), JINST 20, P05009 (2025).

Decade-Long Endeavor



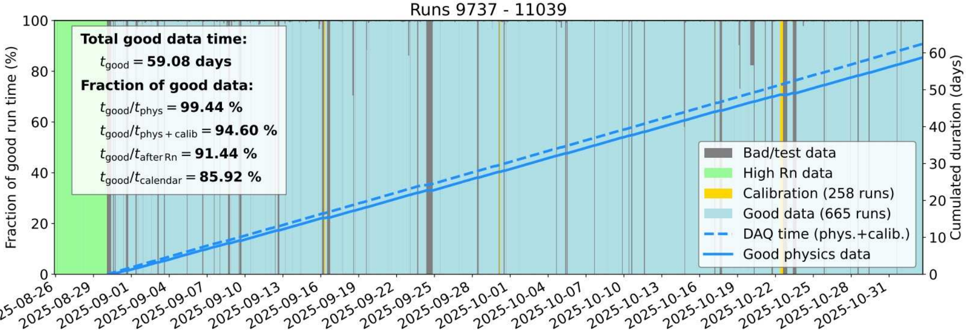


12-years from civil excavation to sub-percent precision physics.

- total LS $23\,231.6\,\mathrm{m}^3$; total water $41\,225.1\,\mathrm{m}^3$.

Stable Operation

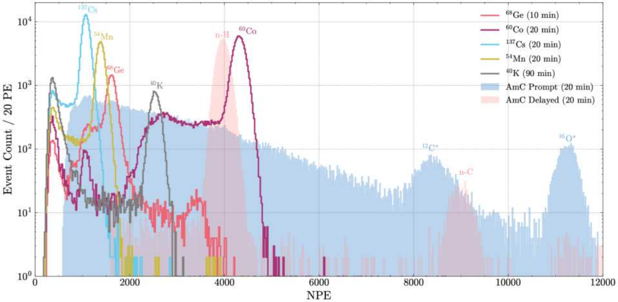
- Data taking $> 98\,\%$.
  - Calibration twice a week with laser and AmC source[1].
- Physics data $> 92\,\%$ duty factor.

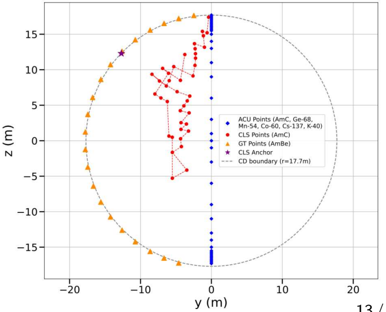


[1] Detector maintenance performed during calibration source moving.

Calibration Chin. Phys. C 50, 043001 (2026)

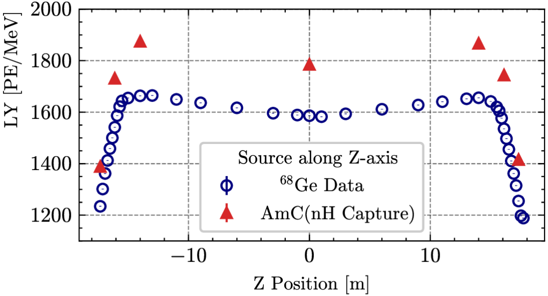
- Extensive calibration at the beginning of data taking of Aug. 2025
- Multiple calibration sources covering wide energies and positions.
- Natural radioactivity and cosmogenic sources complements
  - ^{210}Po, ^{214}Bi-^{214}Po, ^{12}B, ^{11}C.

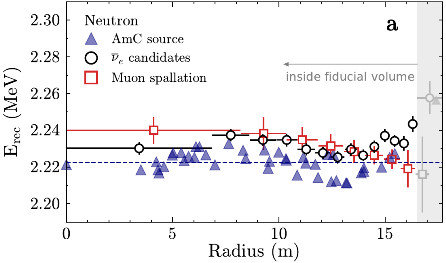


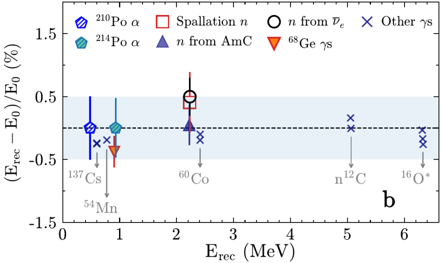


PE Yield and Residual Non-Uniformity

- Analytic/ML tools driving the energy resolution limit.
- Energy non-uniformity within $\pm 0.5\,\%$ for $r < 16.5\,\mathrm{m}$



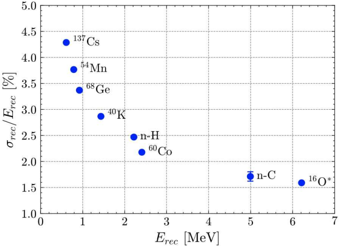


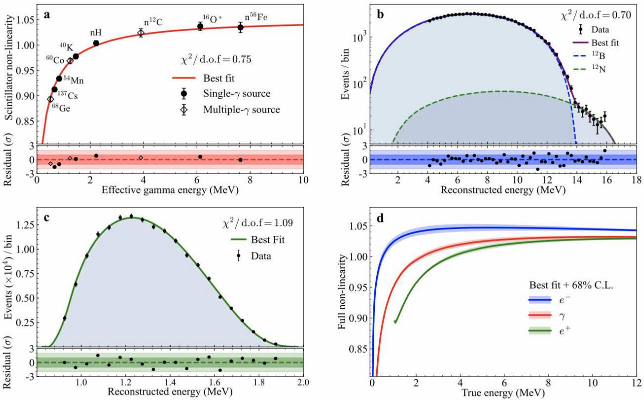


Chin. Phys. C 50, 043001 (2026); arXiv:2511.14593

Energy Resolution and Non-Linearity

- Energy non-linearity calibrated to $< 1\,\%$.
- Energy resolution is approaching the design level.

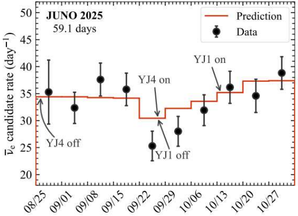


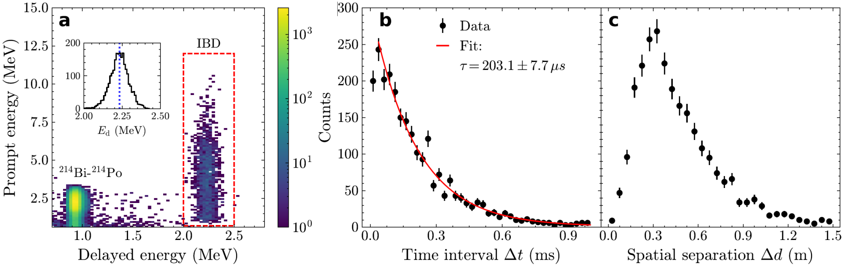


Chin. Phys. C 50, 043001 (2026); arXiv:2511.14593

The Reactor $\bar{\nu}_e$ Sample

- Final IBD coincidence selection is by tempo-spatial and energy criteria.
- Signal efficiency $\sim 70\,\%$, fiducial volume $R < 16.5\,\text{m}$ dominant.

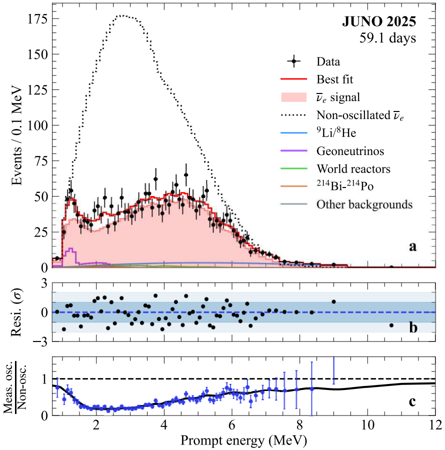




arXiv:2511.14593

The Reactor $\bar{\nu}_e$ Spectrum

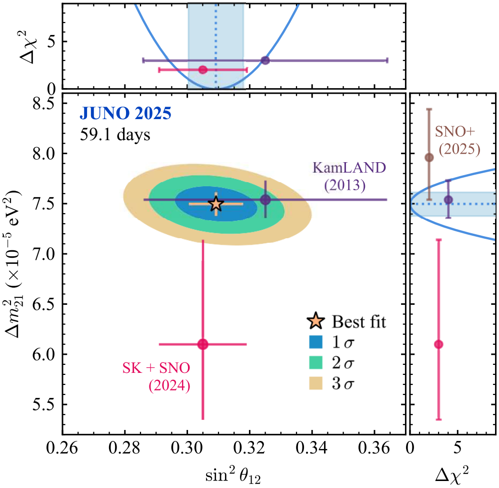
- Show the breathtaking data vs. un-oscillated prediction plot.
- The visible oscillation patterns.

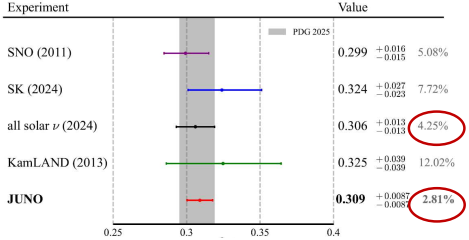


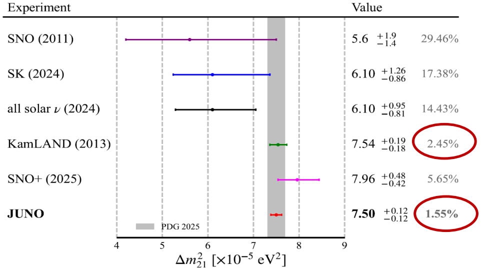
arXiv:2511.14593

Antineutrinos ($\bar{\nu}_e$) Candidates Summary		
DAQ live time (days)	59.1	
$\bar{\nu}_e$ candidates	2379	
Selection Efficiencies (%)	ε	σ_{rel}
Fiducial volume	80.6	1.6
PMT flasher rejection	>99.9	negligible
μ veto	93.6	negligible
Multiplicity	97.4	negligible
Prompt-delayed coinc.	95.1	0.13
Total efficiency ($\varepsilon_{\mathrm{tot}}$)	69.9	1.6
$\bar{\nu}_e$ signal (cpd[1])		
w/o $\varepsilon_{\mathrm{tot}}$ corrected	33.5 ± 1.7	
w/ $\varepsilon_{\mathrm{tot}}$ corrected	47.9 ± 2.6	
Non-oscillated $\bar{\nu}_e$	150.9 ± 2.7	
Backgrounds (cpd)	Pre-fit	Best-fit
^{9}Li/^{8}He	4.3 ± 1.4	3.9 ± 0.6
Geoneutrinos	1.2 ± 0.5	1.4 ± 0.4
World reactors	0.88 ± 0.09	0.88 ± 0.09
^{214}Bi-^{214}Po	0.18 ± 0.10	0.20 ± 0.10
^{13}C(α, n)^{16}O	0.04 ± 0.02	0.04 ± 0.02
Fast neutrons	0.02 ± 0.02	0.02 ± 0.02
Double neutrons	0.05 ± 0.05	0.07 ± 0.05
Atmospheric neutrinos	0.08 ± 0.04	0.07 ± 0.04
Accidentals ($\times 10^{-2}$)	4.9 ± 0.3	4.9 ± 0.3

Results of $\sin^2\theta_{12}$ and Δm^2_{21}







Unprecedented precision achieved by JUNO. arXiv:2511.14593

Summary and Prospect

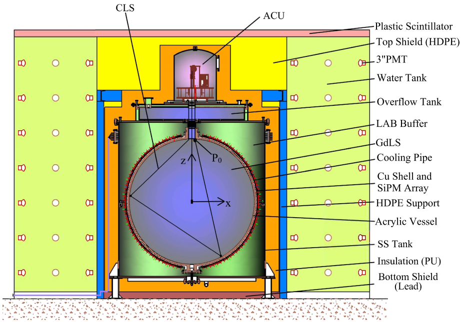
- JUNO is fully operational and delivering sub-percent precision on Δm^2_{21}.

Impact on the 3-flavor ν oscillation paradigm

- JUNO's precision tightly constrains the parameter space.
  - Powerful input to test leptonic flavor models.
- Setting the stage for the mass ordering measurement.

JUNO-TAO

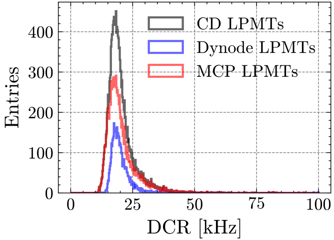
- JUNO-TAO as the ultimate reference for reactor spectrum.
- TAO started data-taking in Feb. 2026.

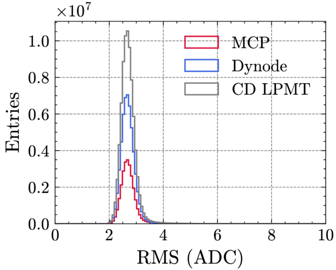


PMT electronics stability

- Large PMTs (LPMTs):
  - Lost 0.1% LPMTs during installation in the Central Detector (CD)
  - Approximately 2-3% of large PMTs flashing at any one time
  - 20.6 kHz and 22.7 kHz of Dark Count Rate (DCR) for dynode and MPC-PMTs, respectively
- Electronics:
  - Low noise levels (mean pedestal RMS of 2.6 ADC counts roughly 0.05 PE)
  - PMT Threshold at 0.2-0.3 PE
- Trigger:
  - Threshold at 200 keV

arXiv:2511.14590

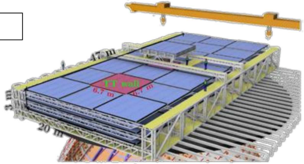


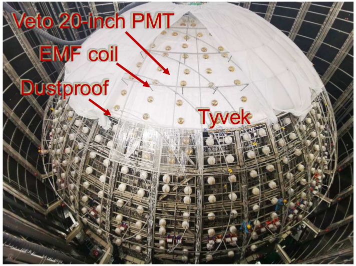


Veto

- Water Cherenkov + Top tracker
- Water Cherenkov detector
  - 35 kton water to shield backgrounds from the rock
  - Instrumented w/ 2400 20-inch PMTs on SS structure
  - Water pool lining: 5mm HDPE (black) to keep the clean water and to stop Rn from the rock, covered w/ tyvek
  - 100 ton/h pure water system
    Requirement: U/Th/K<10^{-14} g/g and Rn<10 mBq/m^3, attenuation length>40 m, temperature controlled to (21±1) °C
- Top tracker
  - Refurbished OPERA scintillators
  - 3 layers, ~60% coverage on the top
  - $\Delta\theta \sim 0.2°$, $\Delta D \sim 20$ cm
- Earth Magnetic Field compensation coil

NIMA 1057 (2023) 168680





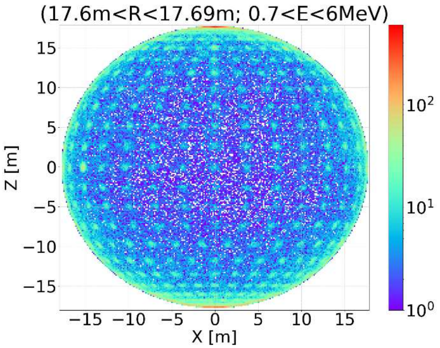
Clean detector

Measured radioactivity in LS and water better than specification

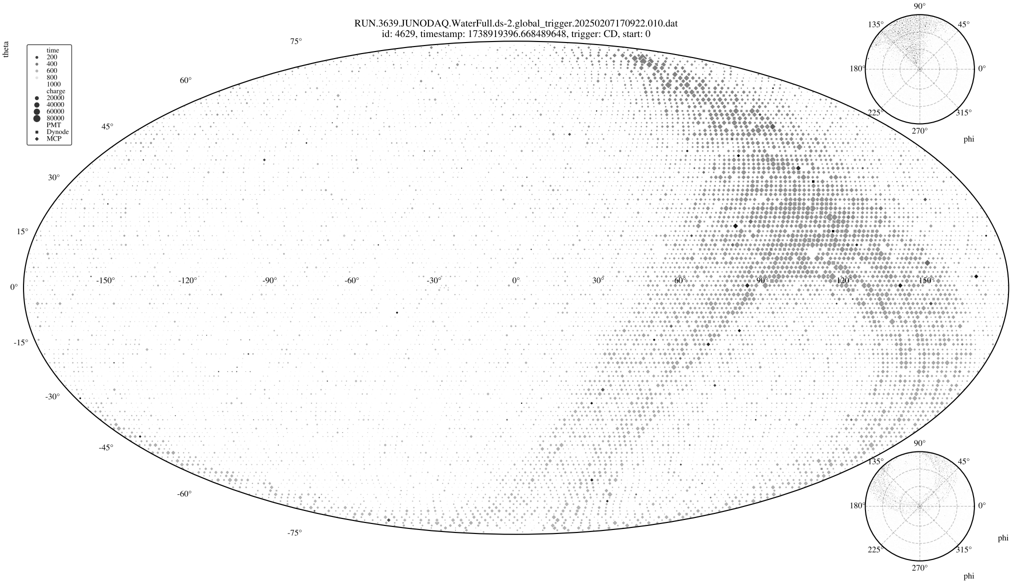
- Radiopurity control of raw material, cleaning of inner surface, ^{222}Rn control

Central Detector	Specification	Measure
Singles Rate (Hz)	< 7.2 Hz	< 7 Hz
^{238}U/^{232}Th ($\times 10^{-15}$ g/g)	< 1	< 0.1
^{210}Po ($\times 10^{4}$ cpd/kt)	< 8	< 5

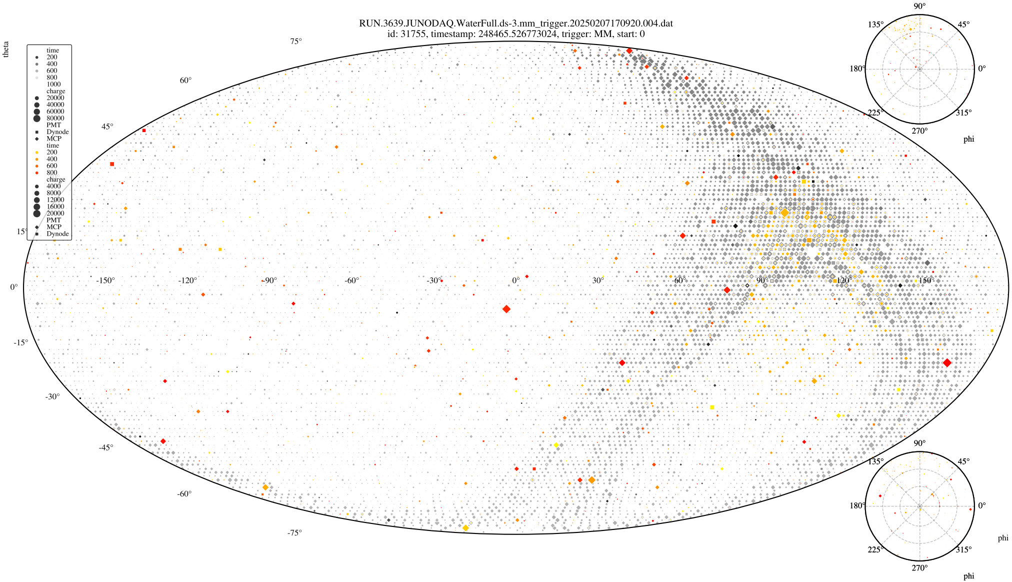
Muon Veto Detector	Specification	Measure
^{222}Rn (mBq/m^3)	< 10	<10
^{226}Ra (mBq/m^3)	< 1	< 0.01
U/Th ($\times 10^{-15}$ g/g)	<10	<0.4



Water phase: stopping muon



Water phase: michel electron



Oscillation Fit Statistical and Systematic Breakdown

Daya Bay Data

Data from nearby nuclear power plants

Huber-Mueller Model

Reactor Unoscillated Flux

Oscillation Parameters ($\sin^2\theta_{12}$, Δm^2_{21} **free**)

Matter effects (small)

Distances to reactors

Oscillation Effects

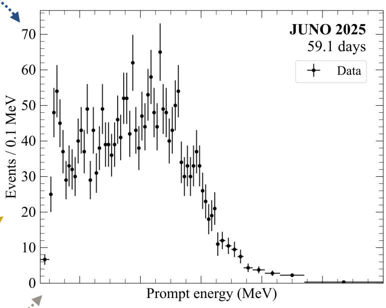
Energy Non-linearity

Energy Resolution

Detector Response

Backgrounds

The oscillation parameters are extracted through a fit of the oscillated energy spectrum



TAO data will be available for future analyses