Neutrino Physics at TAO

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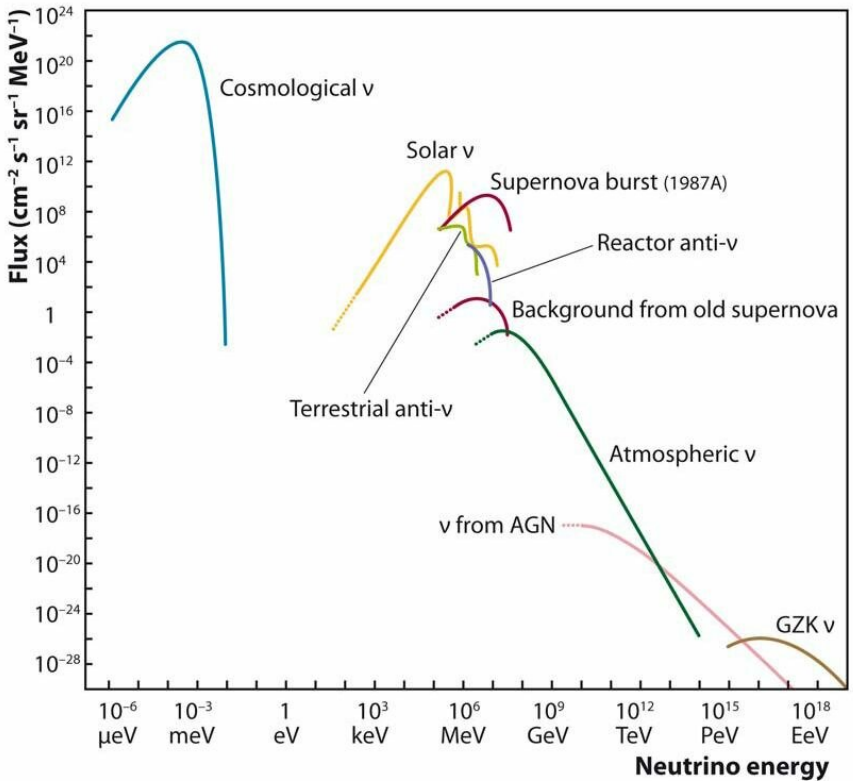
Why Study Neutrinos?

- **Most abundant** **massive** particles in universe.
- **Physics** beyond the Standard Model (BSM).
- Key to **matter-antimatter asymmetry**.
- Crucial for **mass ordering determination**.
- Reactor neutrinos provide **pure flavor source**.



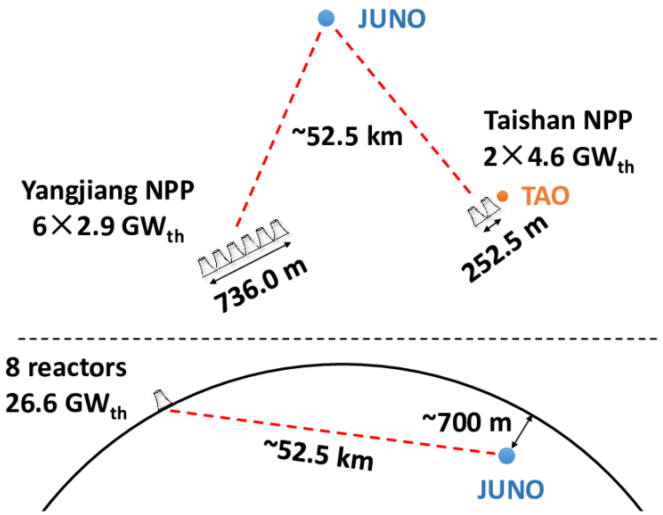
J Mimouni, 2015 J. Phys.: Conf. Ser. **593** 012003.

JUNO Experiment

JUNO (**J**iangmen **U**nderground **N**eutrino **O**bservatory)

JUNO experiment in a nutshell

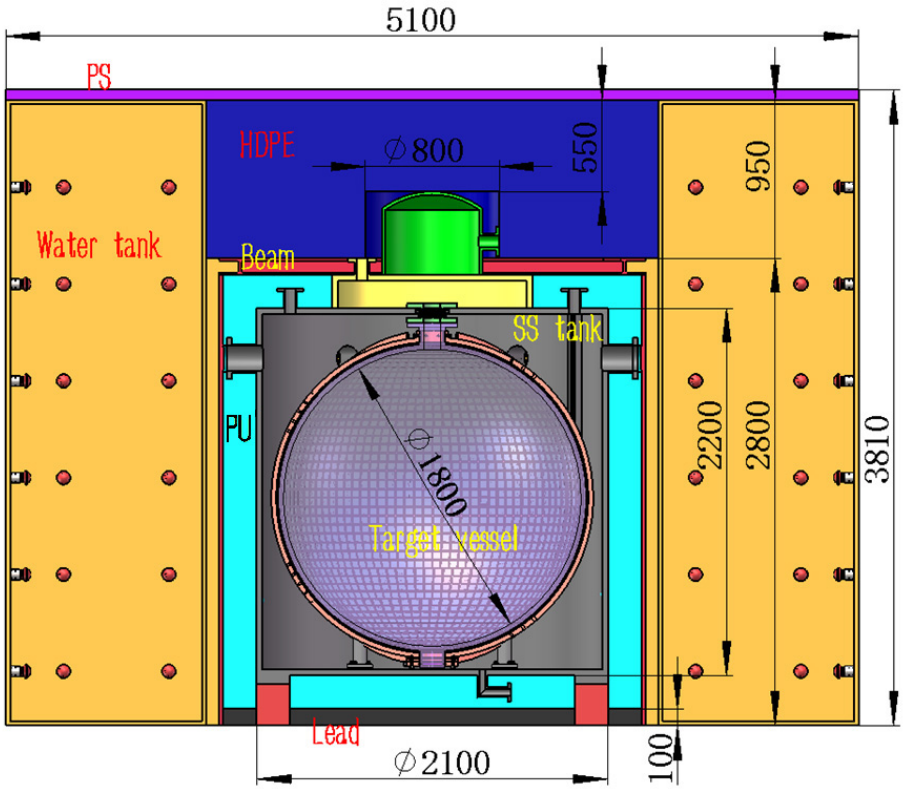
- **Characteristics**: 3% energy resolution at 1 MeV, $\sim$ 20,000 (20-inch) PMTs.
- **Far detector**: $L \simeq 52.5$ km, 20 kton liquid scintillator.
- **Physics**: Neutrino mass ordering (NMO). Precision measurements $\{\theta_{12}, \Delta m^2_{21}, \Delta m^2_{31}\}$. Solar neutrinos. Atmospheric neutrinos. Geo-neutrinos. BSM.



https://arxiv.org/abs/2204.13249

TAO Detector

TAO (**T**aishan **A**ntineutrino **O**bservatory), satellite experiment of JUNO



Main Characteristics

- **Mass and type**: 2.8 ton Gd-doped spherical liquid scintillator (LS).
- **Central detector**: Acrylic vessel 1.8 m diameter.
- **Technology**: 4024 Silicon Photomultipliers (SiPMs).
- **Baseline**: $\sim$44 m from reactor core.
- **Energy resolution**: $< 2\%$ at 1 MeV.

World-leading energy resolution!

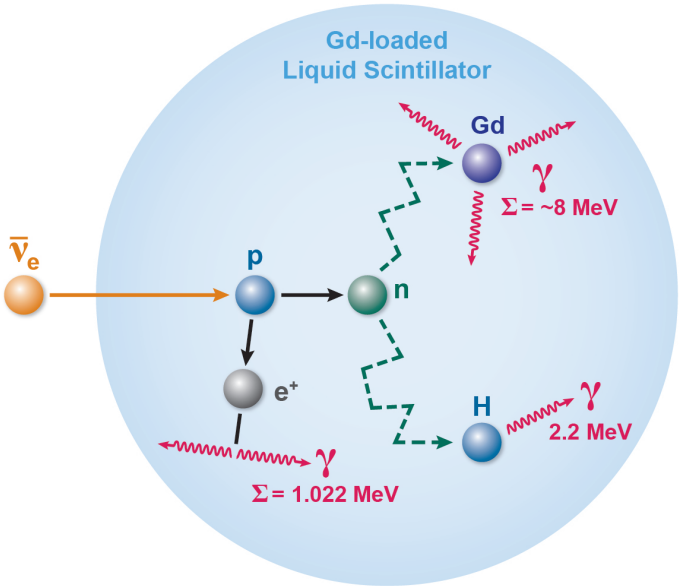
https://arxiv.org/abs/2005.08745

Detection Principle

Inverse Beta Decay (IBD)

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

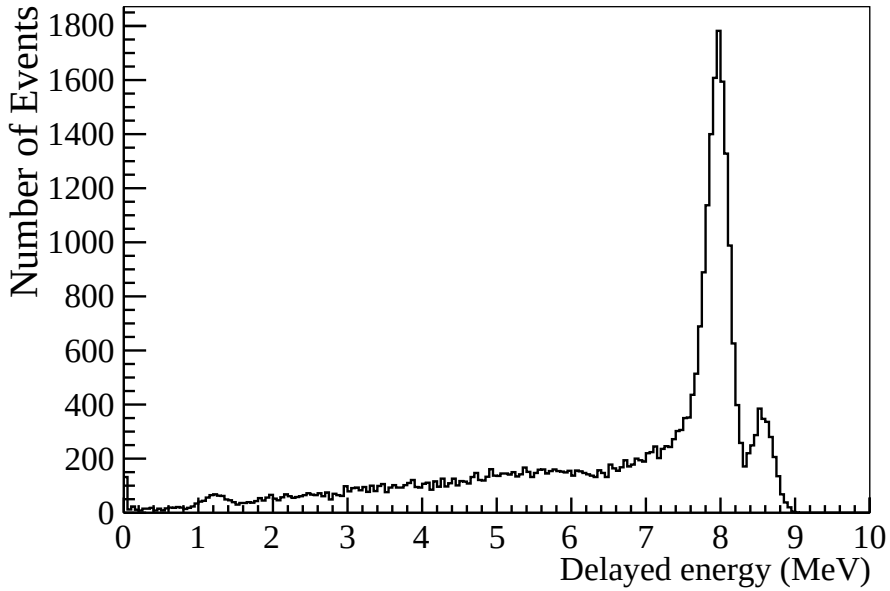
Prompt Signal



e^+ annihilation $\rightarrow$ two γ-rays:

$E_{\text{prompt}} \simeq E_{\nu_e} - 0.784$ MeV

Delayed Signal

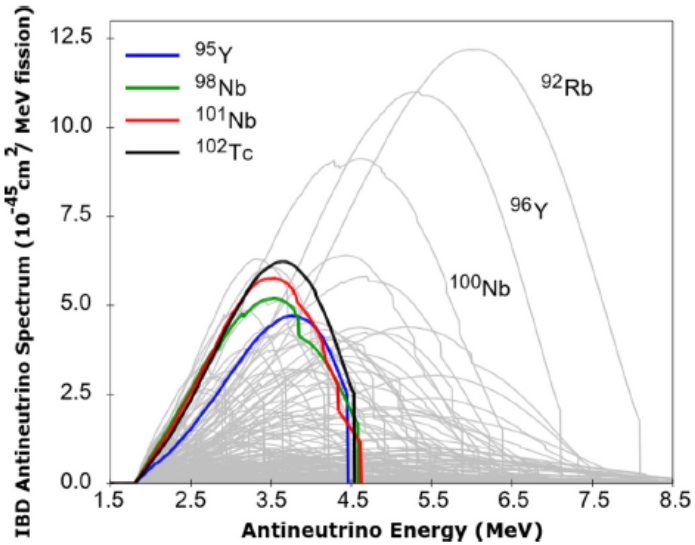


n capture on Gd $\rightarrow$ γ-rays ($\sim$30 μs)

X. Qian, J. Peng, Rep. Prog. Phys. **82** 036201 (2019).

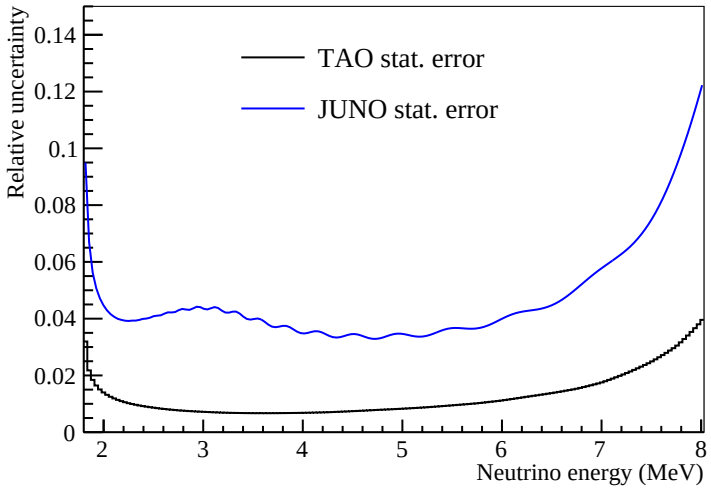
Physics Goals

Fine structure measurement



- Test nuclear databases.
- Improvement of neutrino flux models.

Reference spectrum for JUNO



- TAO bin-to-bin (b2b) propagated to JUNO.
- $\sigma_{\mathrm{b2b}}^{\mathrm{TAO}} \lesssim 1.0\%$.

Exotic Physics

- Sterile neutrino

Expected signal and backgrounds at TAO

Neutrino flux

$$\Phi(E_\nu) = \frac{W_{\rm th}}{\sum_i f_i \langle e_i \rangle} \sum_i f_i s_i(E_\nu).$$

IBD signal

$$S \propto \frac{\mathcal{N}}{4\pi L^2} \int dE_\nu \; \sigma_{\rm IBD}(E_\nu) \; \Phi(E_\nu).$$

Table: Expected signal and background event rates at TAO.

IBD signal	2000 events/day
Muon rate	70 Hz/m^2
Singles from radioactivity	$<$ 100 Hz
Fast neutron background after veto	$<$ 200 events/day
Accidental background rate	$<$ 190 events/day
^{8}He/^{9}Li background rate	$\sim$ 54 events/day

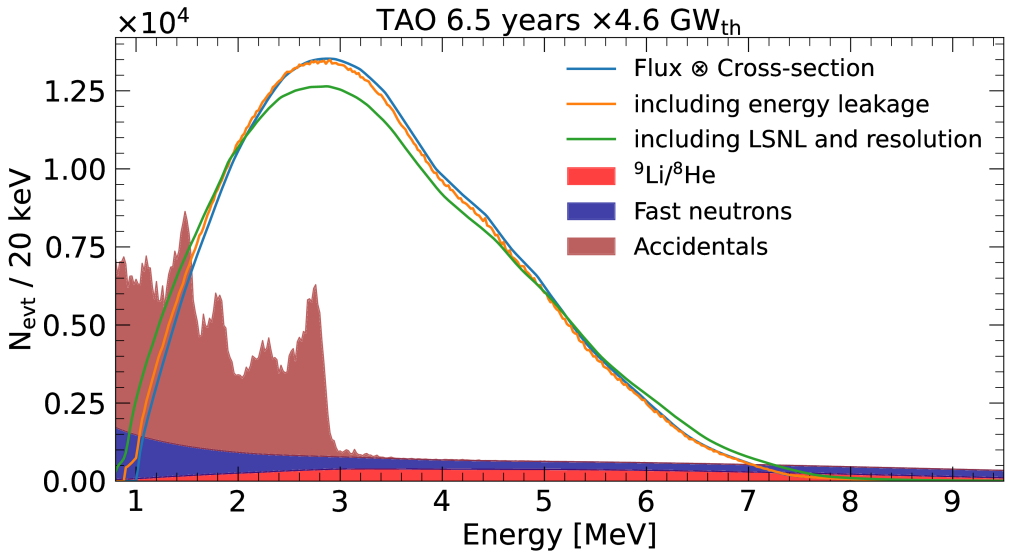
TAO CDR: https://arxiv.org/abs/2005.08745

Expected $\bar{\nu}_e$ spectrum at TAO

Energy spectra of IBD signal and backgrounds in TAO from both reactor cores at Taishan.

- **Detector effects:** Leakage, LSNL and Energy resolution.
- **TAO Baseline:** 44 m (both reactor cores).
- **Time-exposure:** 6.5 years.
- **Bin size:** 20 keV.

Expected signal and backgrounds at TAO



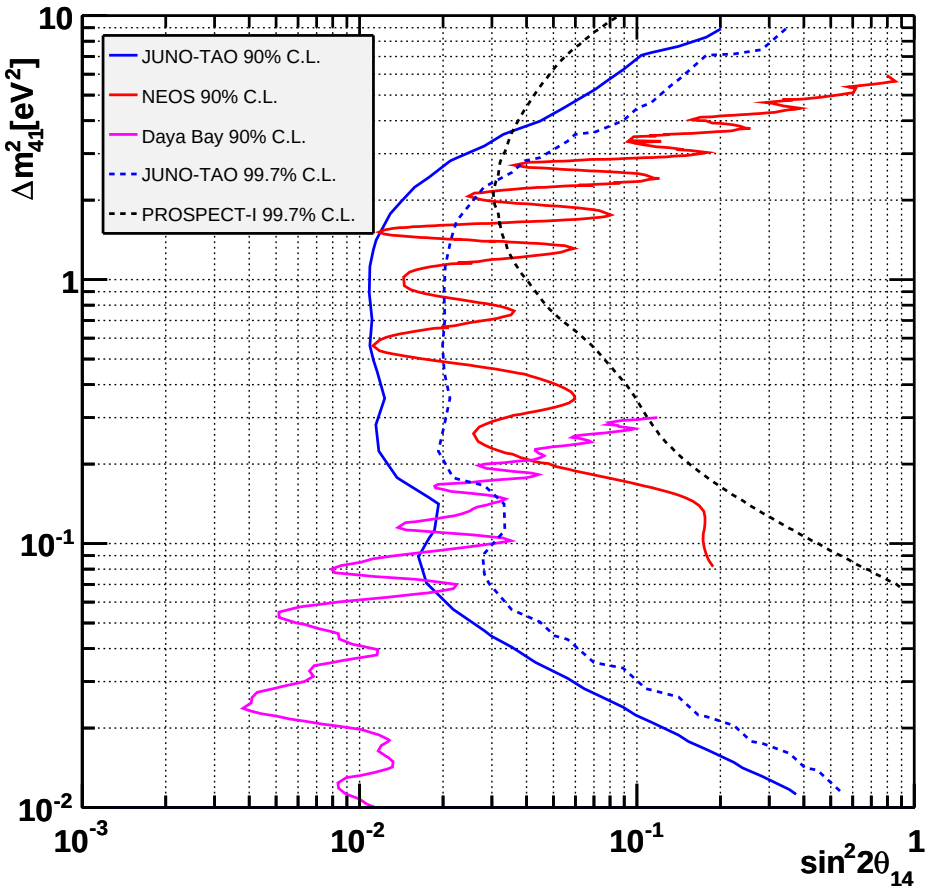
https://arxiv.org/abs/2405.18008

Sterile Neutrino

Motivation: LSND and MiniBooNE anomalies, reactor anti-neutrino anomaly (RAA $\lesssim 2\sigma$).

- $P_{ee} \simeq \sin^2 2\theta_{14} \sin^2\left(\frac{\Delta m^2_{41} L}{4E_\nu}\right)$.
- **Data suggest:** $\Delta m^2_{41} \sim 1$ eV^2 and $\theta_{i4} \sim [10^{-2} - 10^{-1}]$.
- **TAO Baseline:** 30 m (update to 44 m baseline in progress).
- **Time-exposure:** 3 years.
- **Bin size:** 50 keV.

TAO sensitivity to sterile neutrino



Other physics potential

TAO sensitivity to electromagnetic properties of neutrinos (work in progress).

- Weak mixing angle ($\sin^2\theta_W$) sensitivity.
- Neutrino charge radius $\langle r^2_{\nu_e} \rangle$.
- Effective neutrino magnetic moment (μ_{ν_e}).

Official results expected next year!

TAO Current Status

- **Electronics & TDAQ commissioning:** $\simeq 10^3$ channels (ongoing).
- **Liquid scintillator filling:** finishing.
- **Water tank:** commissioning ongoing.
- **Top veto tracker:** installation and commissioning ongoing.
- **Remaining hardware installation:** earlier next month.

TAO Current Status

- **Central detector:** mostly completed.
- **Veto detector:** completed, finishing installation.
- **Electronics:** commissioning ongoing.
- **Lab renovation:** almost completed.

Expected data taking next month!

Summary

Main Advances at TAO.

- **World-leading energy resolution**: $<2\%$ at 1 MeV.
- **Critical role** in JUNO's mass ordering determination.
- **Precise measurement** of neutrino energy spectrum.
- **Search for** sterile neutrino.
- **Pathfinder** for next-generation experiments.

Exciting results arriving soon–stay tuned!

Acknowledgments

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JUNO website: https://juno.ihep.cas.cn/

BACK UP (Silicon Photomultiplier Technology)

Advantages over PMTs

- **Higher photon detection efficiency** ($\gtrsim 50\%$).
- **Compact size** and low voltage operation.
- **Excellent timing resolution** ($\lesssim 1$ ns).
- **High gain** SS tank to operate at -50°C to reduce SiPM dark noise.