JUNO-TAO Status and Prospect

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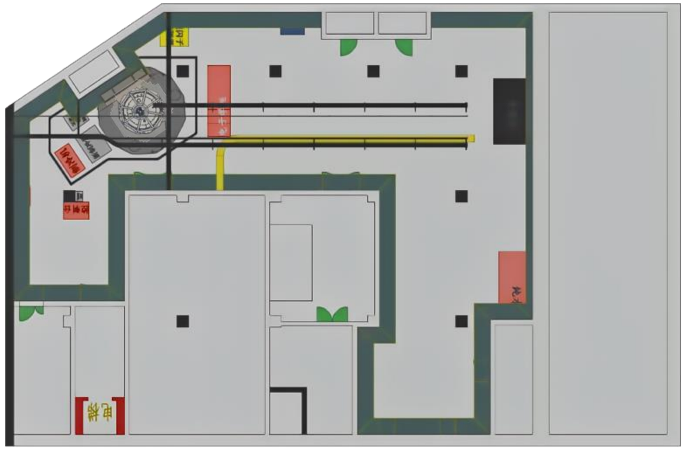
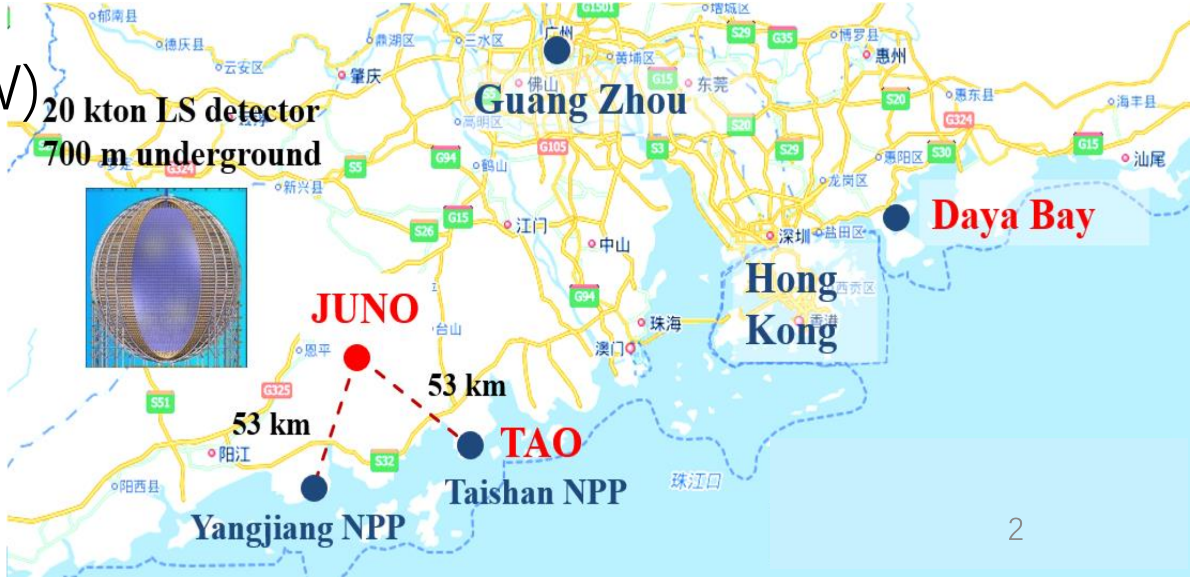
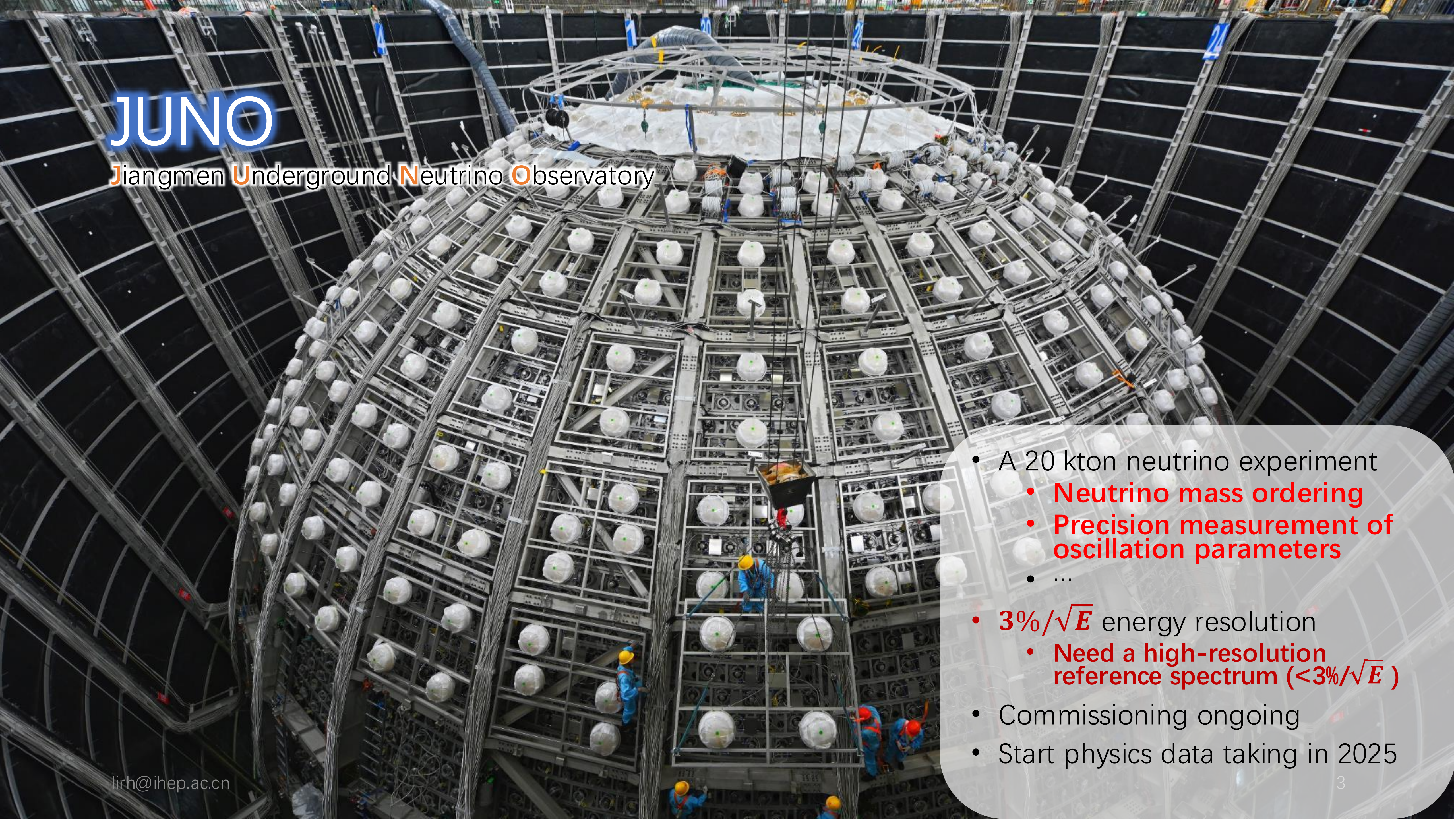
3rd IAEA TM Meeting

JUNO-TAO

- TAO: **T**aishan **A**ntineutrino **O**bservatory
- A satellite experiment of **JUNO**
- Measure reactor neutrino w/ **sub-percent E resolution**
- Short-baseline reactor antineutrino experiment
- Location:
  - 44 m from Taishan NPP core (4.6 GW)
  - -9.6 m







JUNO

Jiangmen Underground Neutrino Observatory

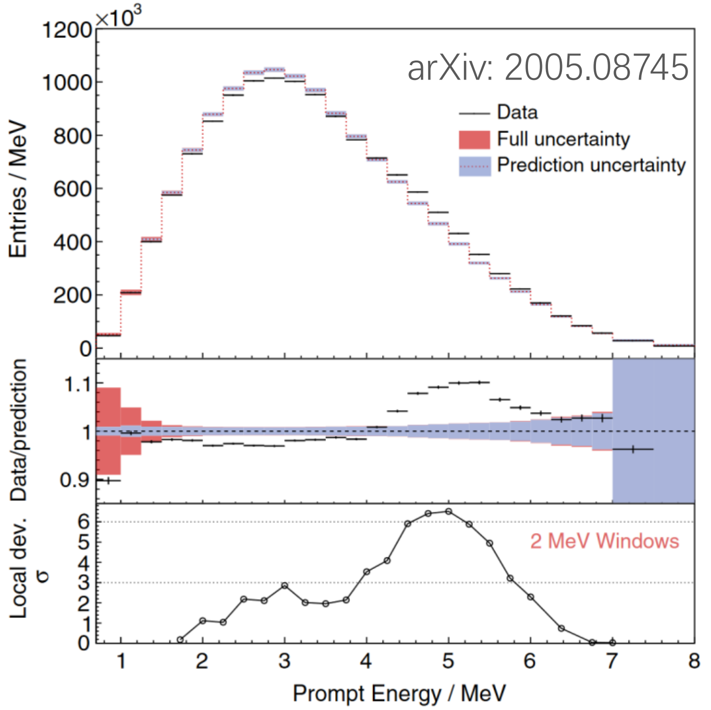
- A 20 kton neutrino experiment
  - **Neutrino mass ordering**
  - **Precision measurement of oscillation parameters**
  - …
- $\mathbf{3\%/\sqrt{E}}$ energy resolution
  - **Need a high-resolution reference spectrum (<3%/$\sqrt{E}$)**
- Commissioning ongoing
- Start physics data taking in 2025

Reference Spectrum

- Summation method
  - 10% ~ 20% energy dependent uncertainty
- Conversion method
  - Huber-Mueller model
- Daya Bay
  - Energy resolution $8\%/\sqrt{E}$

5 MeV bump

No fine structures



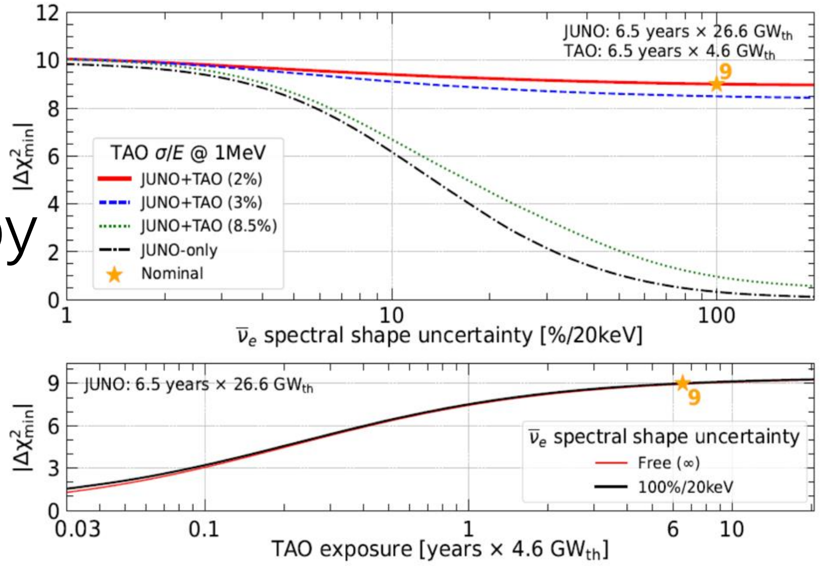
We need a more precise spectrum!

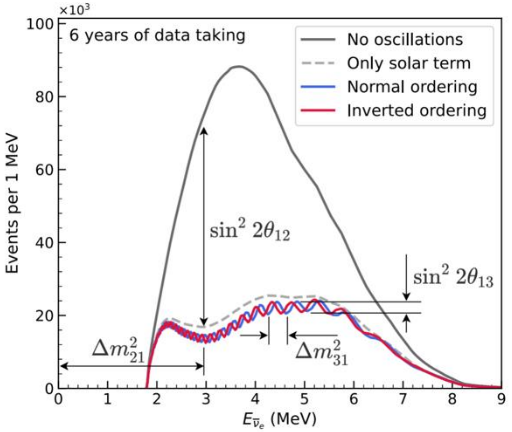
TAO Motivation

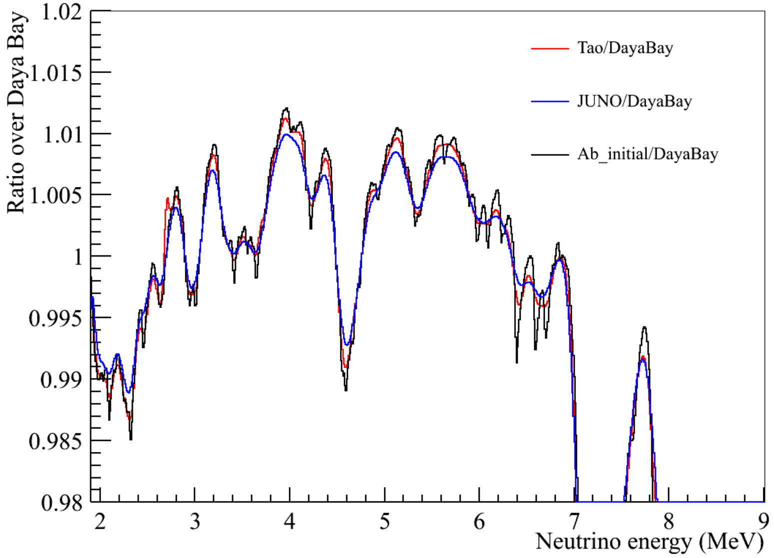
1. Provide a reference spectrum for JUNO

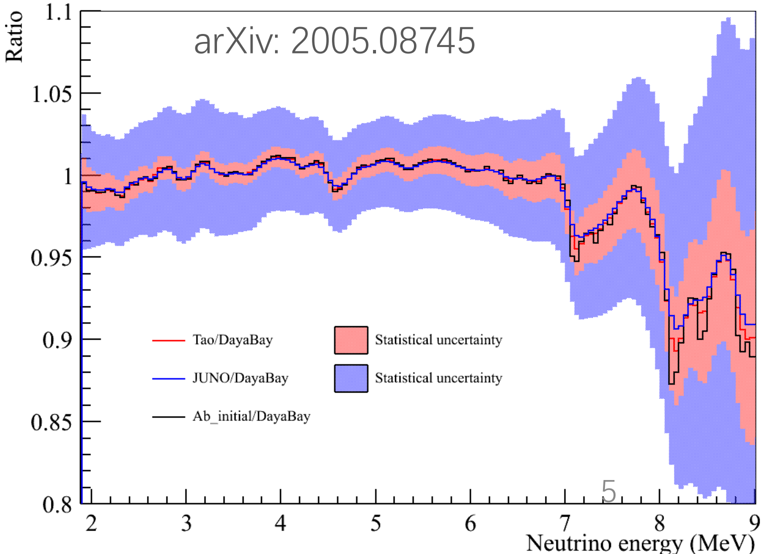
- TAO can help to remove the model dependence by measuring fine structures in neutrino energy spectrum
- The energy resolution of TAO must be equal or better than $3\%/\sqrt{E}$

arXiv: 2405.18008





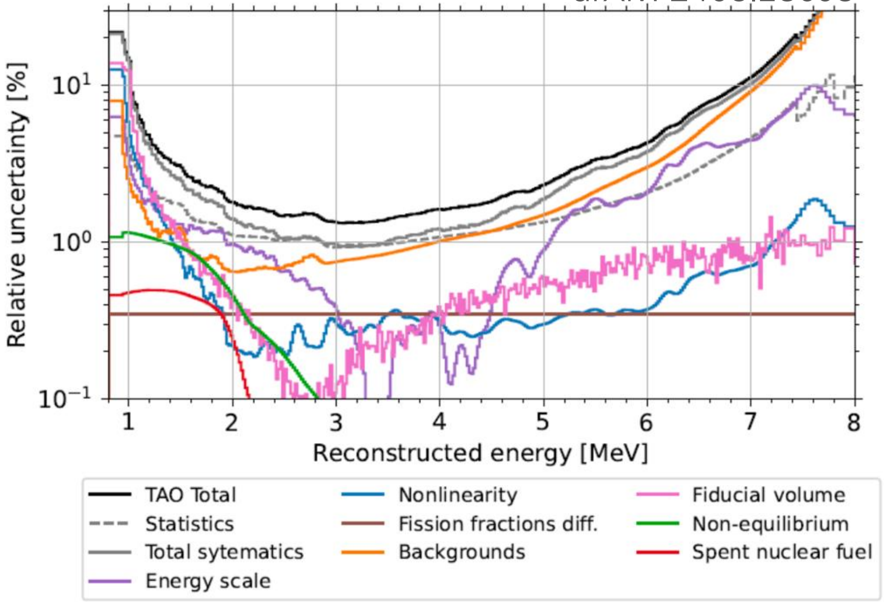




TAO Motivation

2. Provide a benchmark spectrum for nuclear database
   - $<2\%/\sqrt{E}$
   - Reactor spectral shape precision ~ 1% in 2-5 MeV
3. Measuring isotopic neutrino spectra, reactor monitoring & sterile neutrino

arXiv: 2405.18008

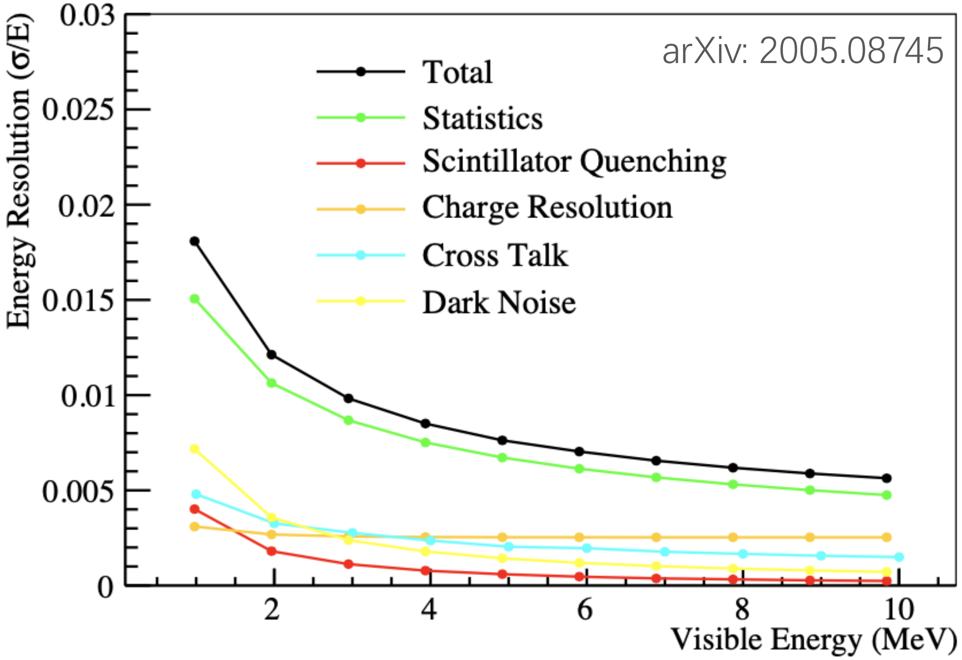


Energy Resolution

To get higher energy resolution → Use SiPM → High dark count rate! (~100k Hz/mm^2) → Cool down to -50 °C → Liquid Scintillator untransparent → New LS recipe → **Done!**

	SiPM	Hamamatsu PMT	NNVT PMT	HZC SPMT (3 inch)
PDE	48.8%	28.1%	30.1%	25%

From latest mass testing

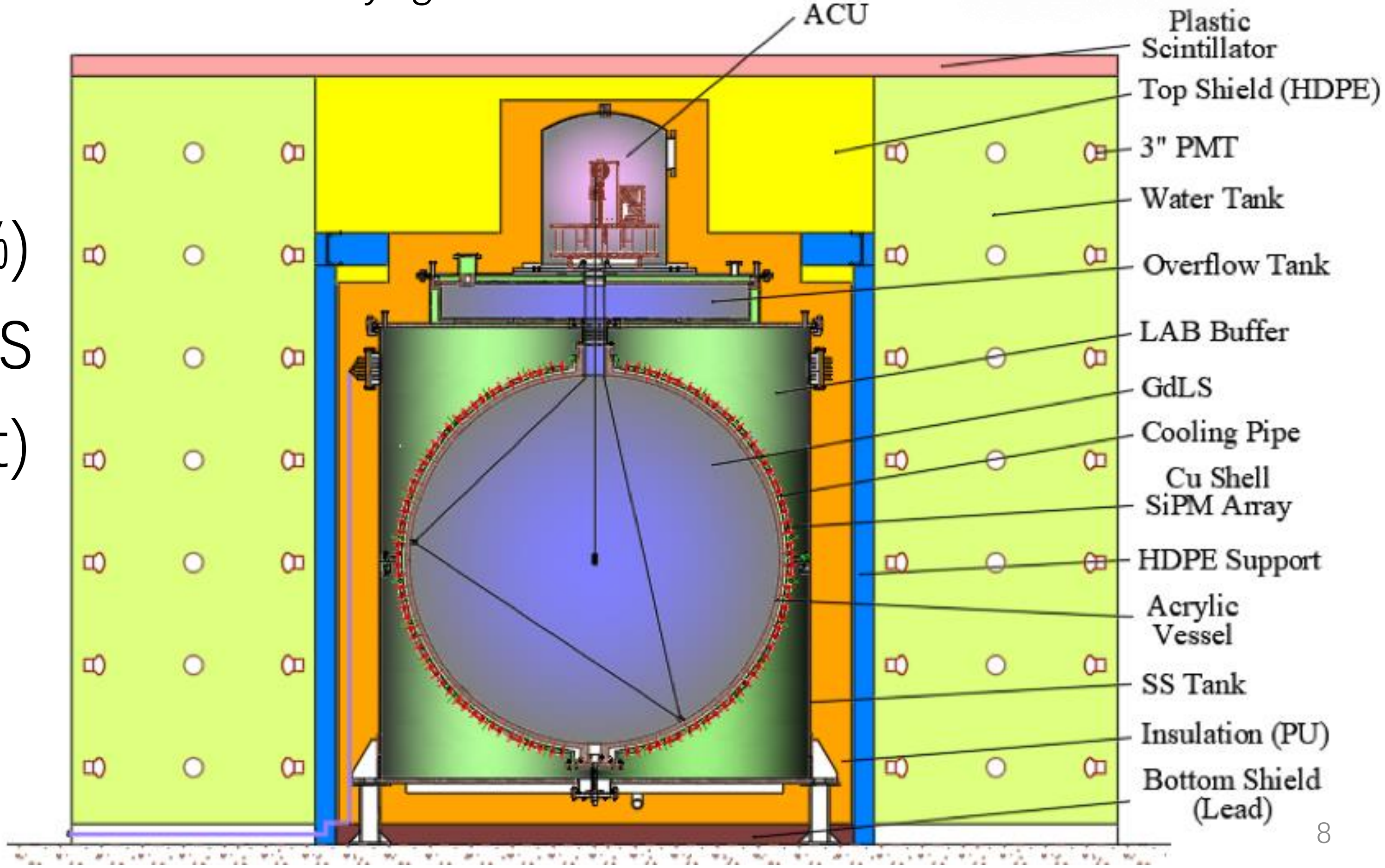


TAO Detector

Inner → Outside

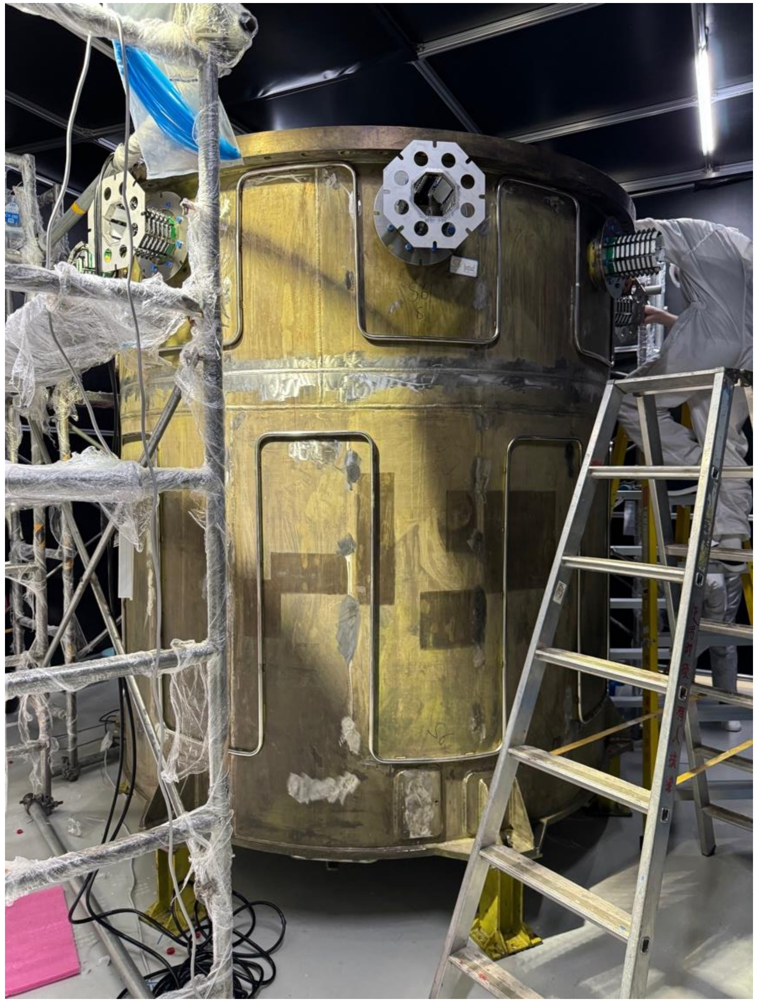
Gd-LS ⇨ acrylic vessel ⇨ SiPM & support ⇨ LAB buffer ⇨ cryogenic vessel ⇨ water & HDPE shield ⇨ TVT

- -9.6 m underground
- ~ 10 m^2 SiPM coverage (95%)
- 1.8 m diameter, 2.8 ton GdLS (1 ton w/ fiducial volume cut)
- Operate at -50°C
- 1000 IBD/day w/ FV
- 4500 p.e/MeV



Since 2023 IAEA TM Meeting

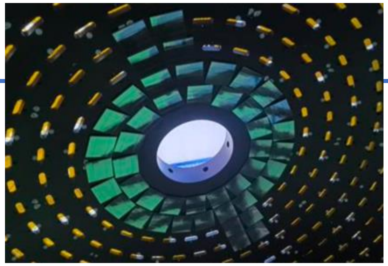
- Detailed testing
  - SiPM mass test
  - Calibration system test
  - Data taking chain test
- 1:1 Prototype finished
- Production of every part almost done
- Assembling on going, started in Sept. 2024

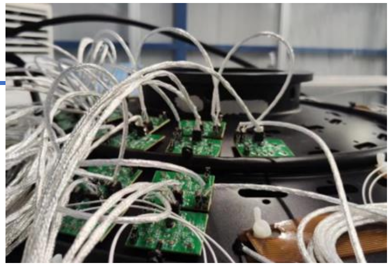


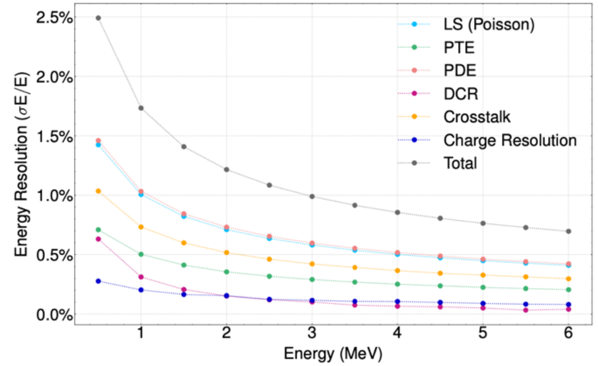
arXiv:2406.12912

SiPM

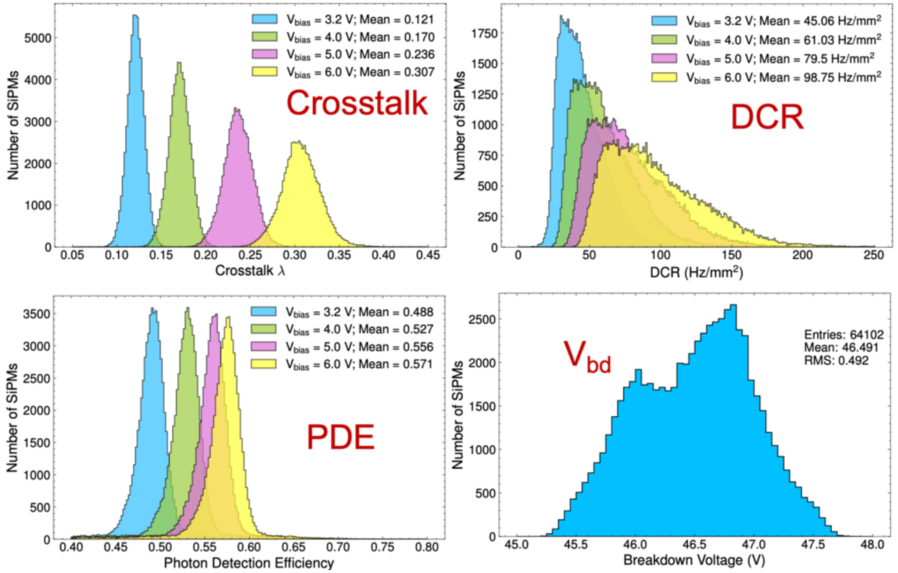
- Tile 50.8 x 50.8 mm^2, 4024 tiles from **HPK**
- Supported & cooled by **copper shell**
- Work at **-50°C**, dark noise 100k➜45 Hz/mm^2
- Mass testing finished
  - **10 m^2 SiPM tested**







Parameters	Value	Measured	Unit
Photon Detection Efficiency	Min: 0.44, Typical: 0.47	0.488	-
Dark Count Rate	Max: 41.7, Typical: 13.9	45.06	Hz / mm^2
Crosstalk Probability	Max: 0.15, Typical: 0.12	0.121	-
After-pulsing Probability	Max: 0.08, Typical: 0.04	< 0.001	-
Pixel Gain	Min: 1×10^6, Typical: 4×10^6	$> 1\times10^6$	-
Dark Current Deviance	Max: 95, Typical: 40	-	%
Operating Voltage Range	Min: 6, Typical: 6.5	> 6.5	Volt



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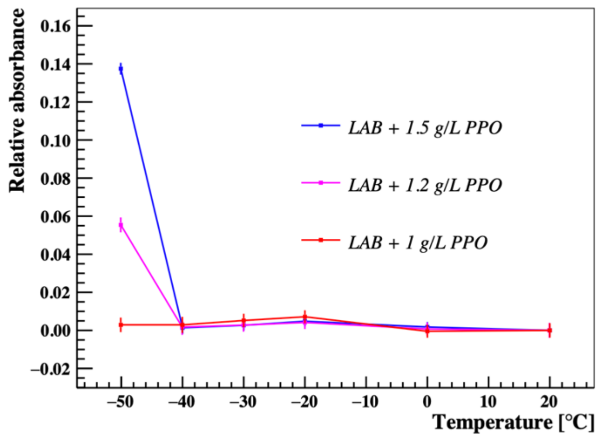
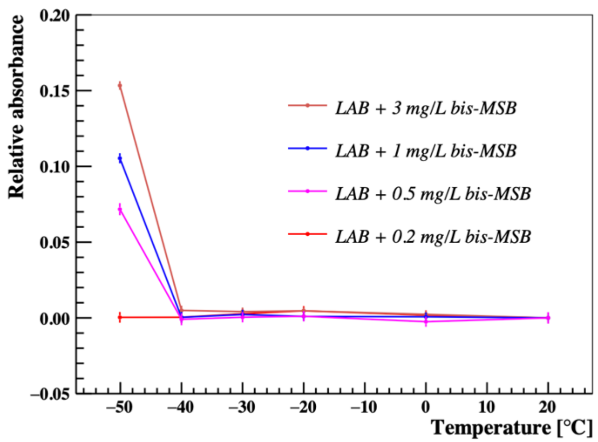
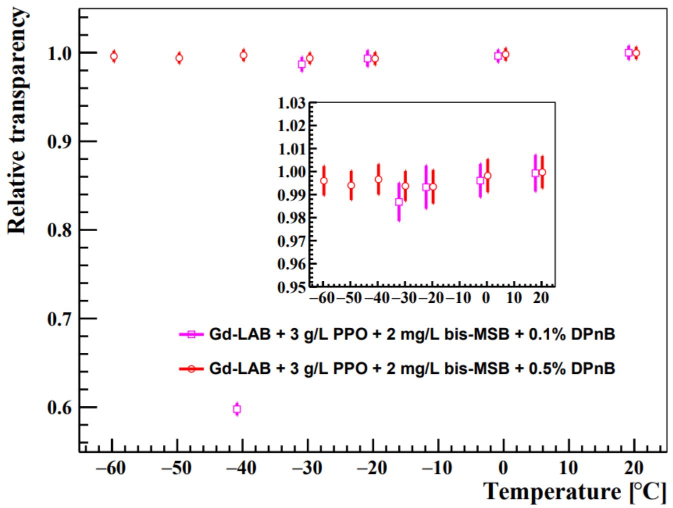
GdLS & LAB Buffer

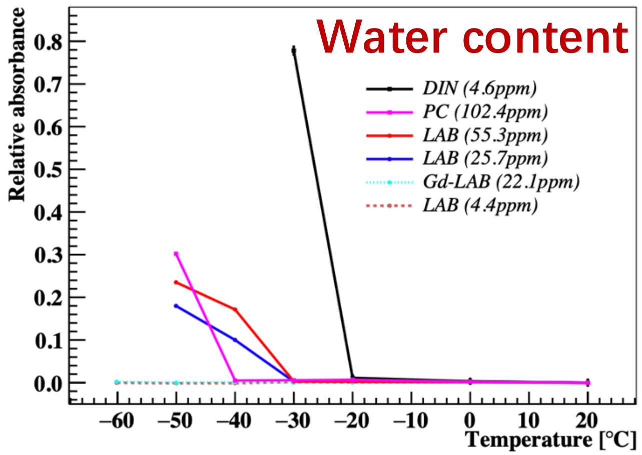
- GdLS recipe: Gd-LAB + 3 g/L PPO + 2 mg/L bis-MSB + **0.5% DPnB**
- Good stability at -50°C
  - **Water content:**
    - LAB <8 ppm (~ 40 ppm for LAB in the air)
    - GdLS <22 ppm (~80 ppm for GdLS in the air)
  - **Cosolvent**: Ethanol ➜ DPnB (less volatile & higher flash point)

DOI: 10.1016/j.nima.2021.165459
Nucl.Instrum.Meth.A 1009 (2021) 165459



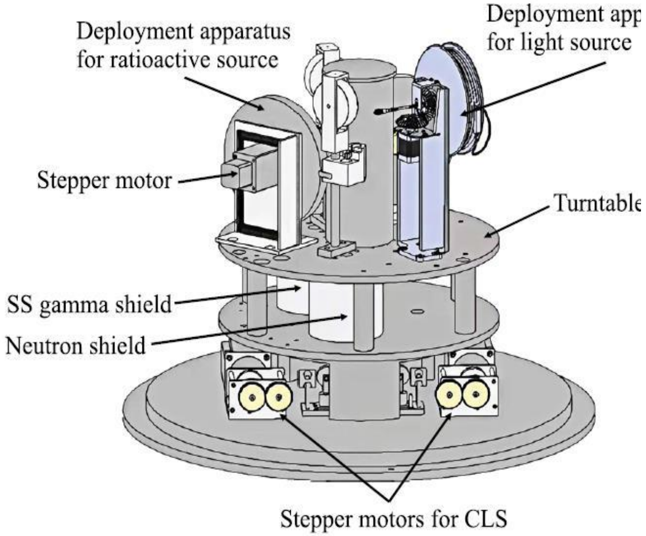


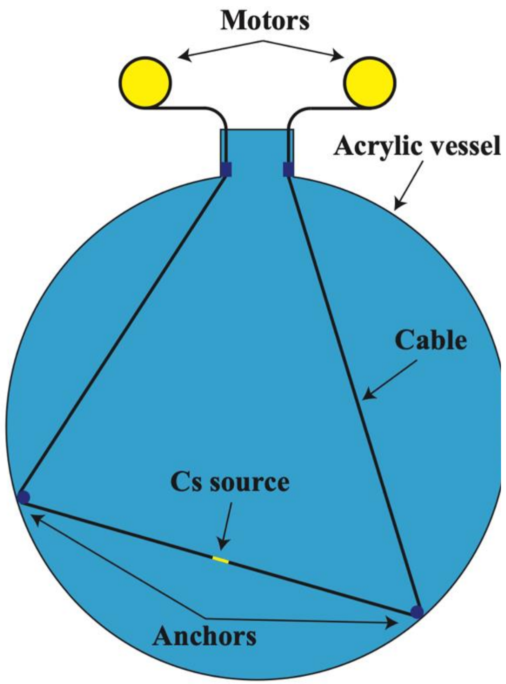


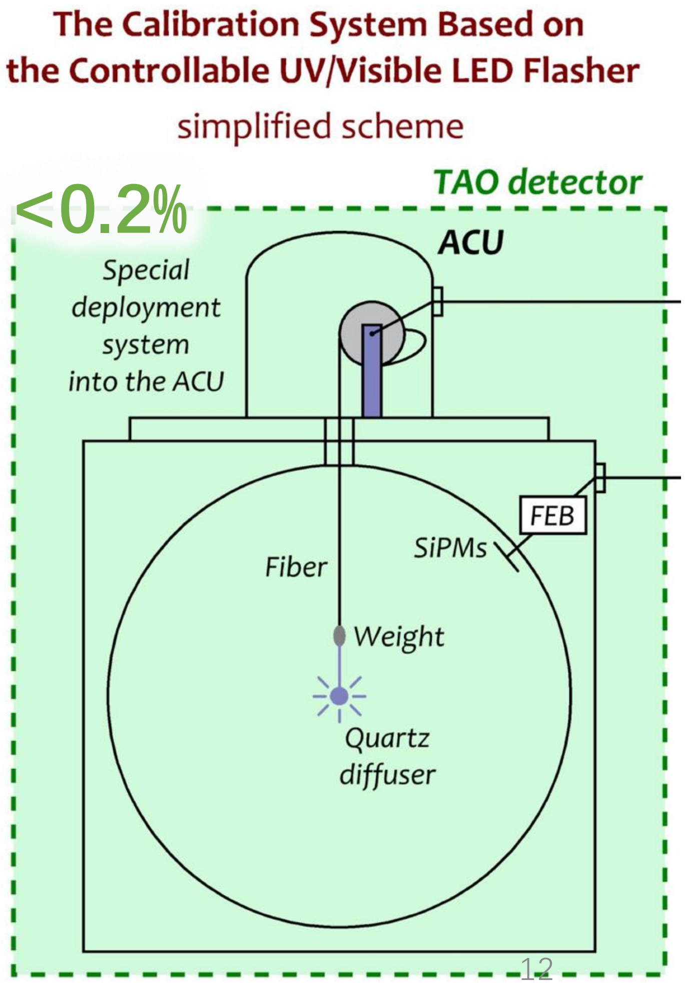


Calibration

- Calibrate the detector response with multiple sources (energies) at deployed positions frequently
- ACU recycled from Daya Bay
- Physics non-linearity **<0.6%** , residual non-uniformity is **<0.2%**
- Installed and tested at 1:1 prototype







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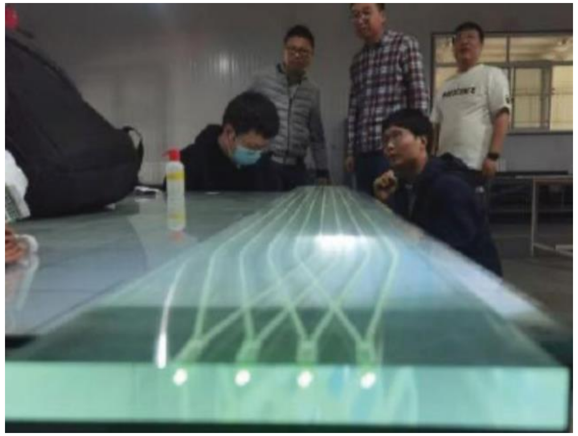
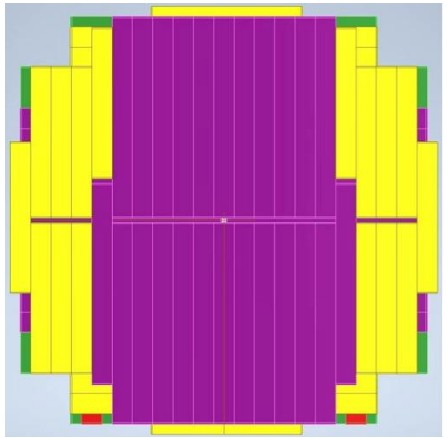
Doi: 10.1140/epjc/s10052-022-11069-3
Eur.Phys.J.C 82 (2022) 12, 1112

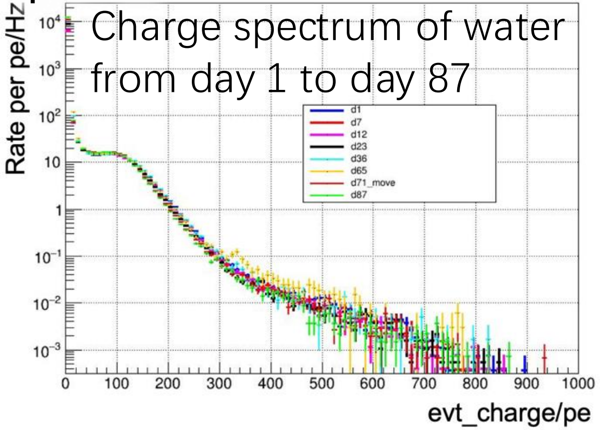
Muon Veto

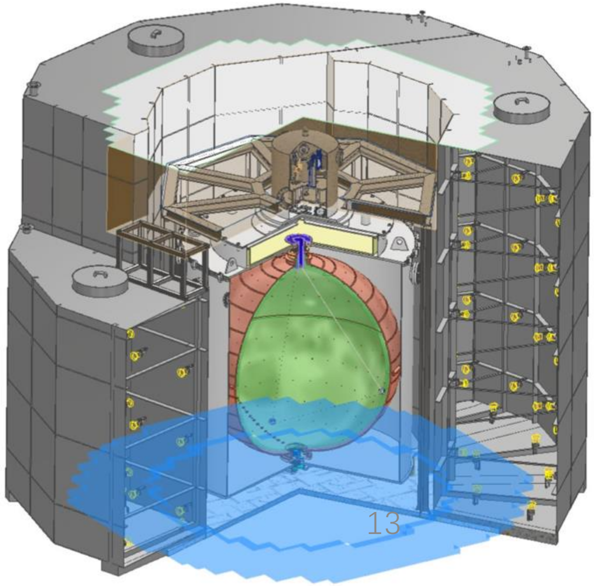
DOI: 10.1088/1748-0221/17/09/P09024
JINST 17 (2022) 09, P09024
DOI: 10.1007/s41365-023-01263-7
NUCL SCI TECH 34, 99 (2023)





- **Top veto tracker**
  - 4 layers with each 2 cm thickness, 1 mm gap between strips
  - Muon veto efficiency ~ 99% (3/4)
  - Data taking chain successful
- **Water tank**
  - Dodecagon, 1.2 m thickness, 3 standalone parts
  - 70-ton water & Tyvek applied
  - 300 3” PMTs, muon veto efficiency > 99%
  - Pure water stability confirmed (87 days)

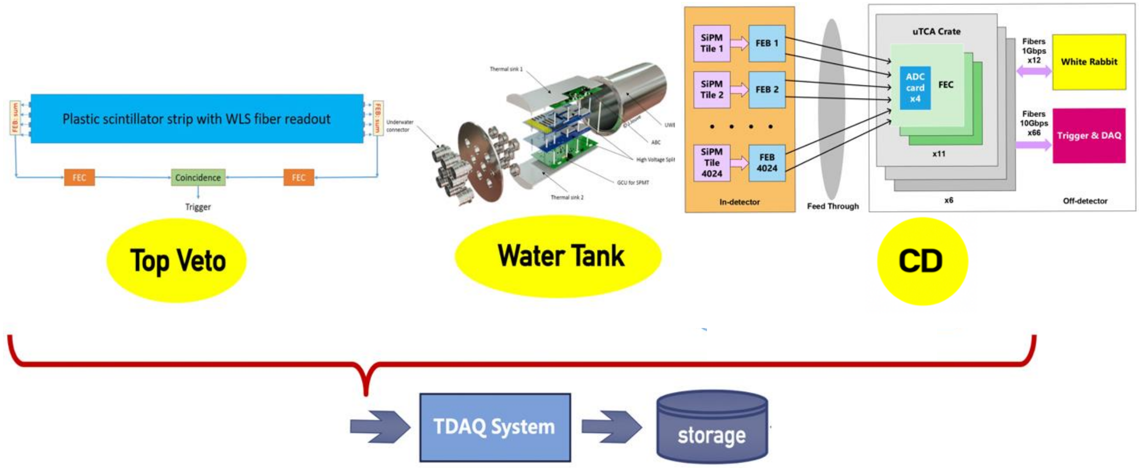


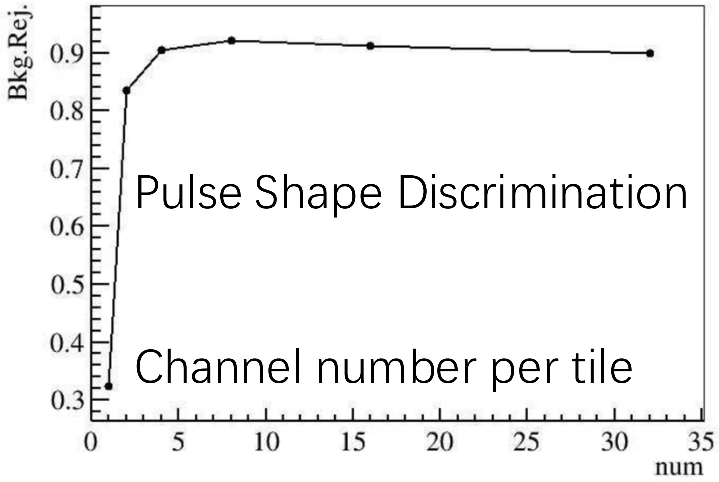


Electronics & TDAQ

- Electronics of central detector (CD)
  - FEB based on discrete components
  - **~ 8000 channels for ~4000 SiPM tiles**
  - Waveform digitized by ADC
  - FPGA calculates Q/T, sent to TDAQ
- Electronics of veto detectors
  - Same strategy with CD for TVT
  - Same 3'' PMTs electronics in JUNO

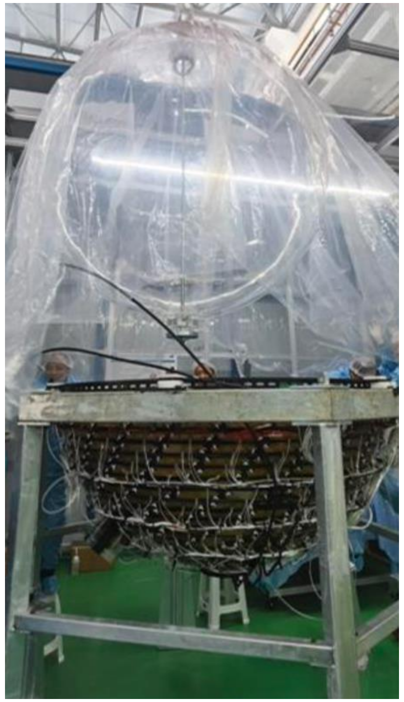
Data Stream	Interface	DAQ Data input	Data Merge	SW Trigger	Compression	Storage
CD	SiTCP	~Gbps	Y	N	Y	<80Mbps
WT	IPbus/TCP	~105Mbps	Y	Y	Y	<10Mbps
TPS	SiTCP	~40Mbps	Y	Y	N	<1Mbps
SUM						<100Mbps*





1:1 Prototype

- Assembling finished in **Dec. 2023** in IHEP
- Running stably at -50°C, uniformity OK
- ~100 SiPMs installed
- Data taken with Co 60, LED & cosmic muon
- Disassembled in summer, 2024

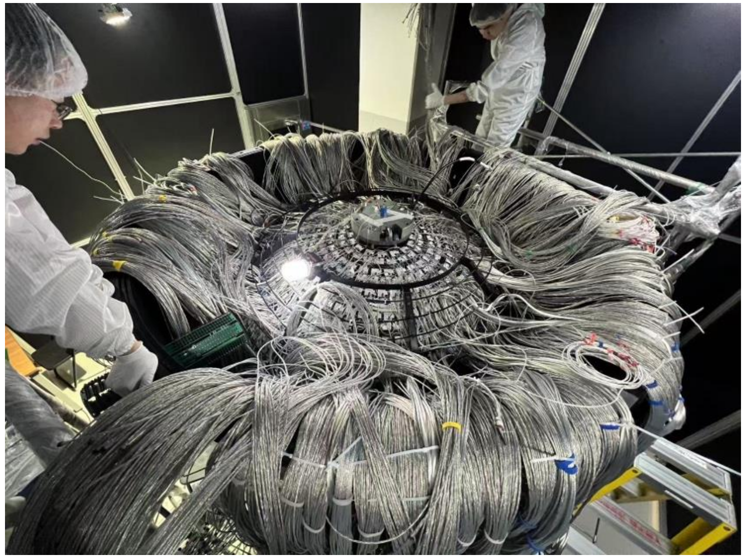


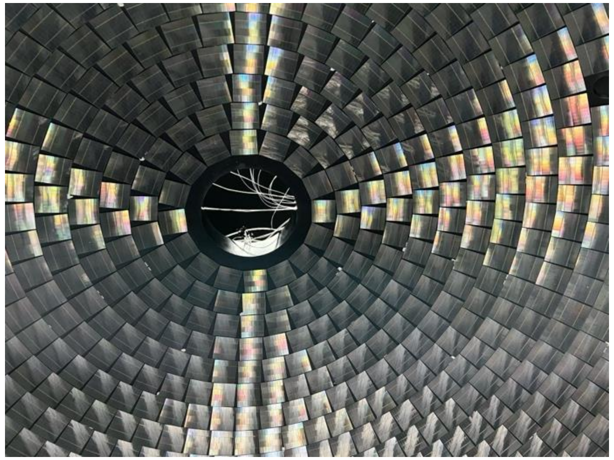
Assembling in Taishan

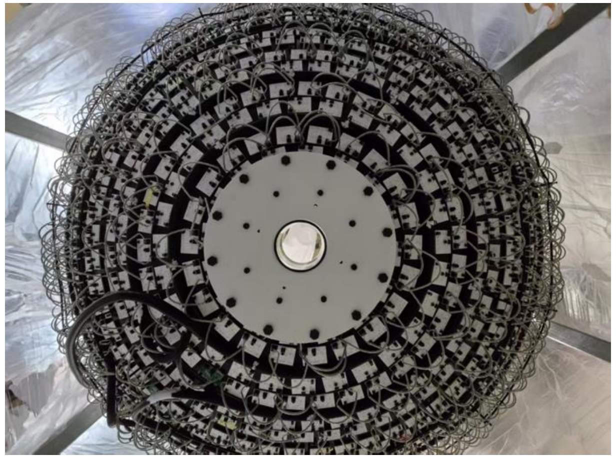
- Started from Sept. 2024
- Acrylic vessel, copper shell, SiPMs, stainless steel tank, cabling finished, some detailed check ongoing
- Will start liquid scintillator filling in late April

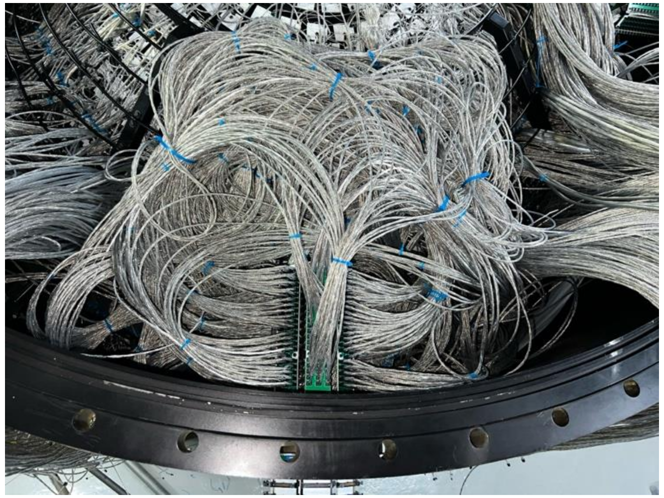


Assembling in Taishan









Summary

- TAO will measure reactor antineutrino spectrum with sub-percent E resolution
- 1:1 prototype is successful, disassembling finished
- Assembling in Taishan NPP started **in 2024**
- **Commissioning data taking shall start in May 2025**

Thank you!