JUNO-TAO Status and Prospect

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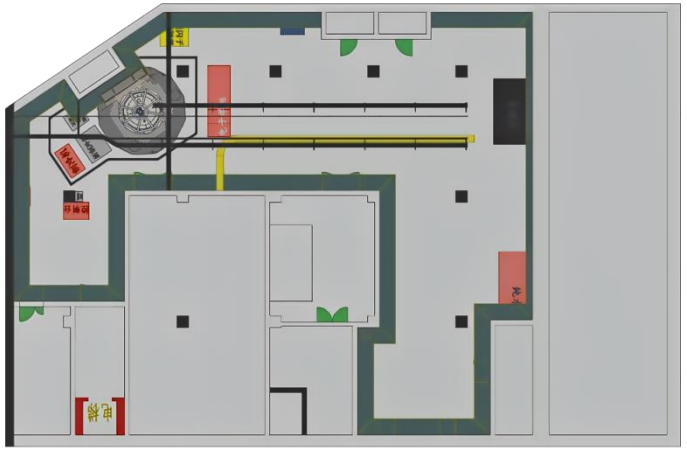
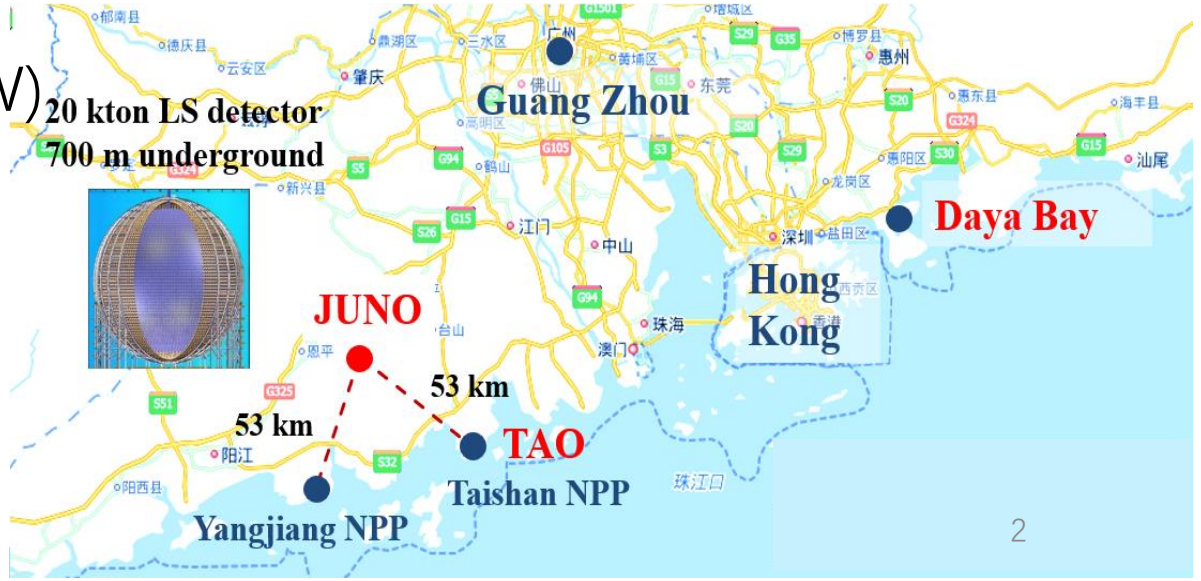
JUNO-TAO

- TAO: **T**aishan **A**ntineutrino **O**bservatory
- A satellite experiment of **JUNO**
- Measure reactor neutrino w/ **<2% @ 1 MeV E resolution**
- Short-baseline reactor antineutrino experiment
- Location:
  - 44 m from Taishan NPP core (4.6 GW)
  - ~9.6 m



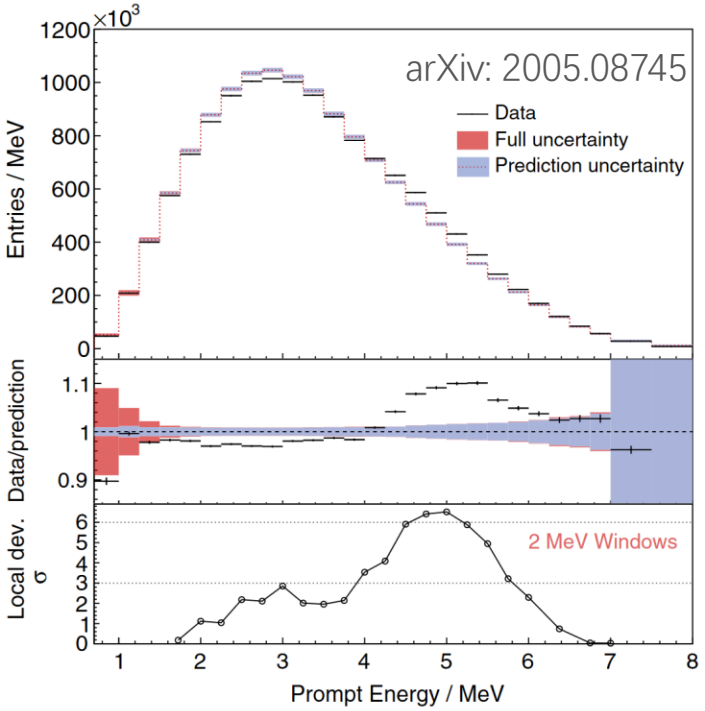


Reference Spectrum of JUNO (3% @ 1 MeV)

- Summation method
  - 10% ~ 20% energy dependent uncertainty
- Conversion method
  - Huber-Mueller model, uncertainty ~5%
- Daya Bay
  - Energy resolution 8%, uncertainty ~2%

5 MeV bump problem

No fine structures



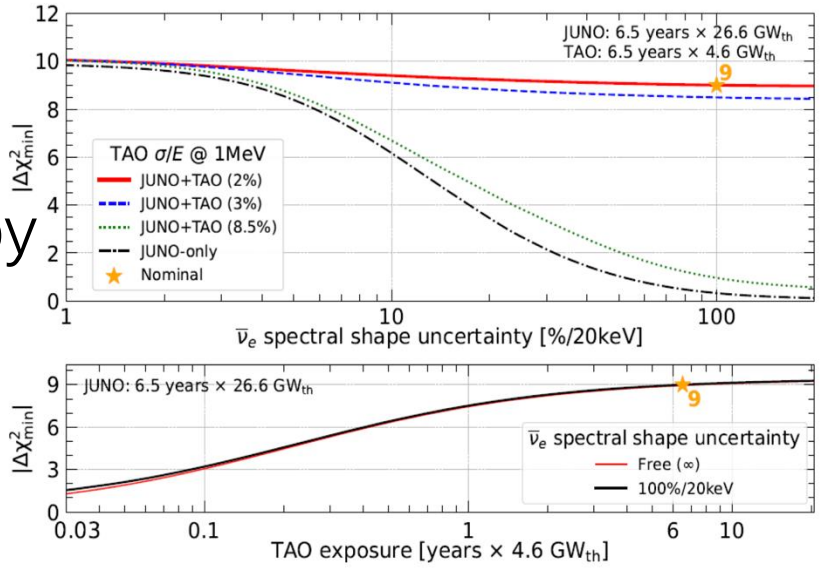
We need a more precise spectrum!

TAO Motivation

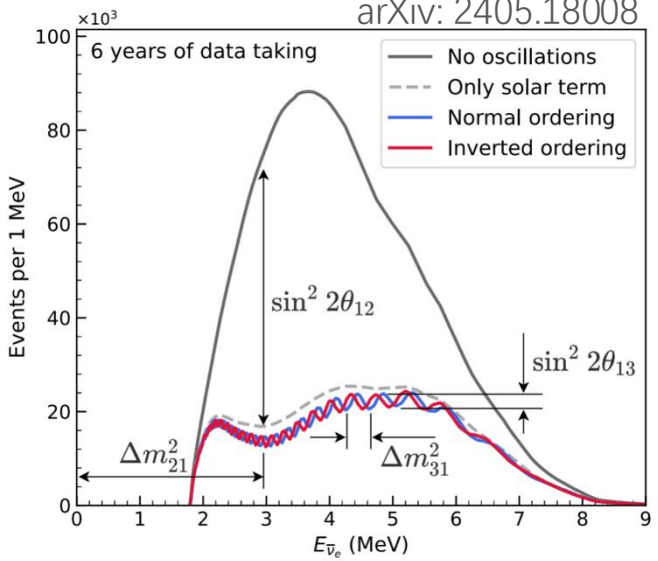
1. Provide a reference spectrum for JUNO

- 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% @ 1 MeV

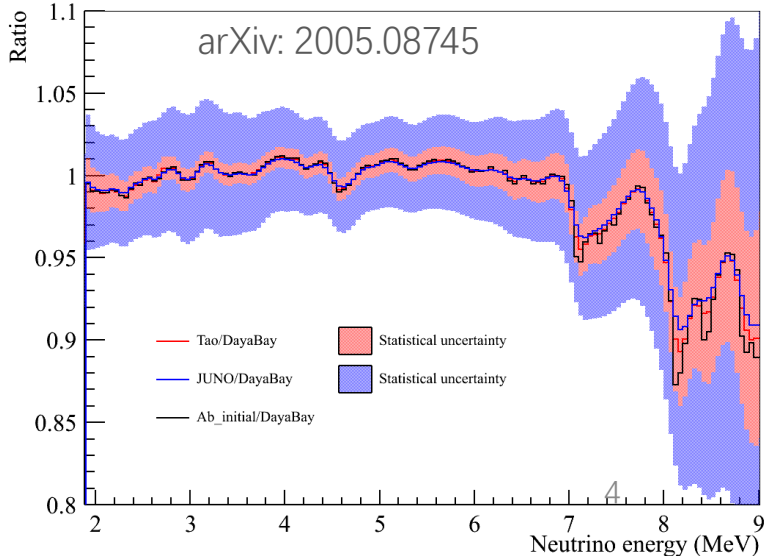
arXiv: 2405.18008



arXiv: 2405.18008



arXiv: 2005.08745

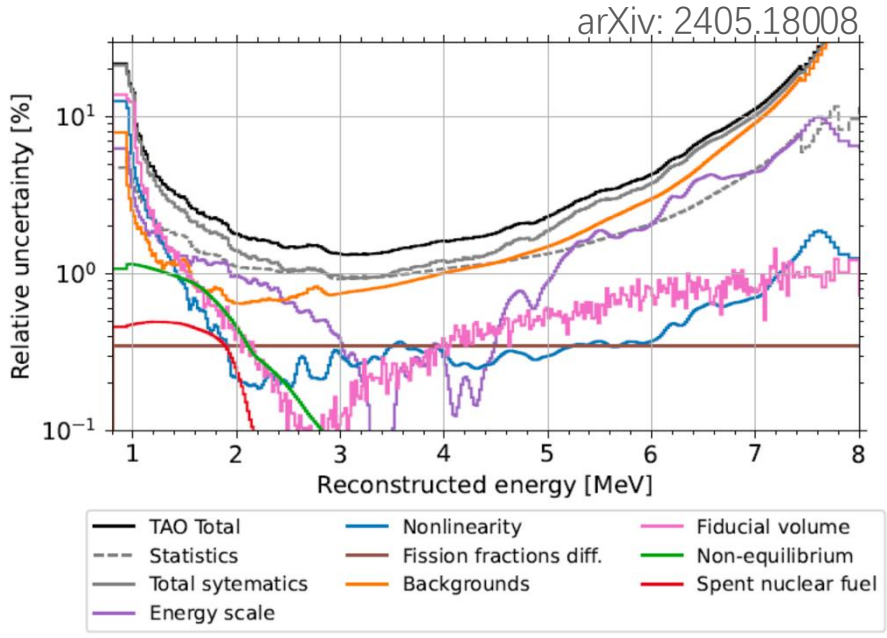


TAO Motivation

2. Provide a benchmark spectrum for nuclear database

- **<2% @ 1 MeV**
- Reactor spectral shape precision ~ 1% in 2-5 MeV

3. Measuring isotopic neutrino spectra, reactor monitoring & sterile neutrino



Energy Resolution

To get higher energy resolution

Use SiPM

High light yield, but high DCR of SiPM (~100k Hz/mm^2)

Cool down to -50 °C

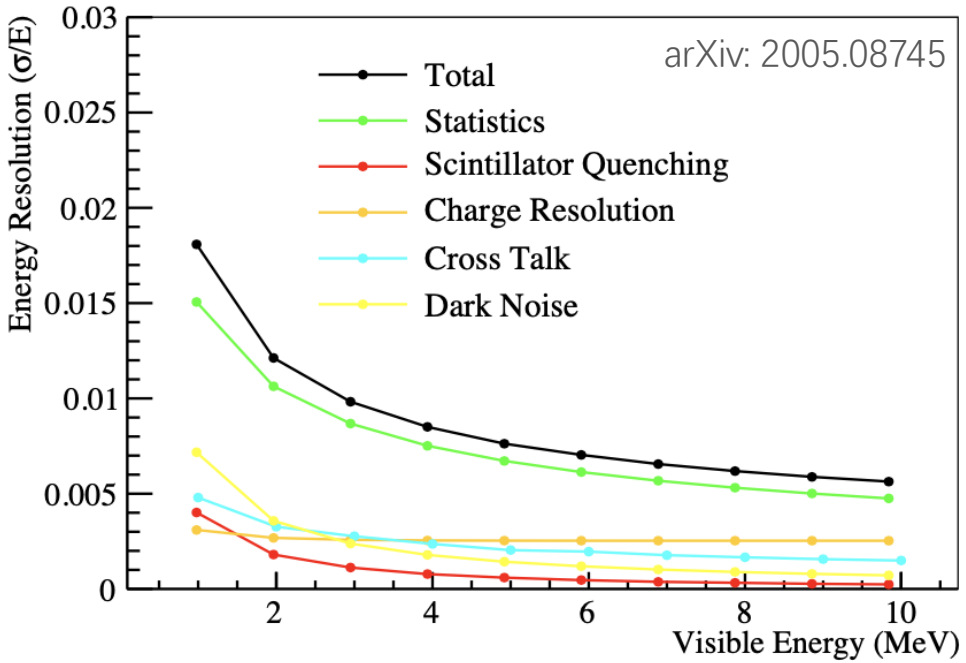
Light yield further enhanced, but LS becomes cloudy

New LS Recipe for low temperature

Done!

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

From latest mass testing

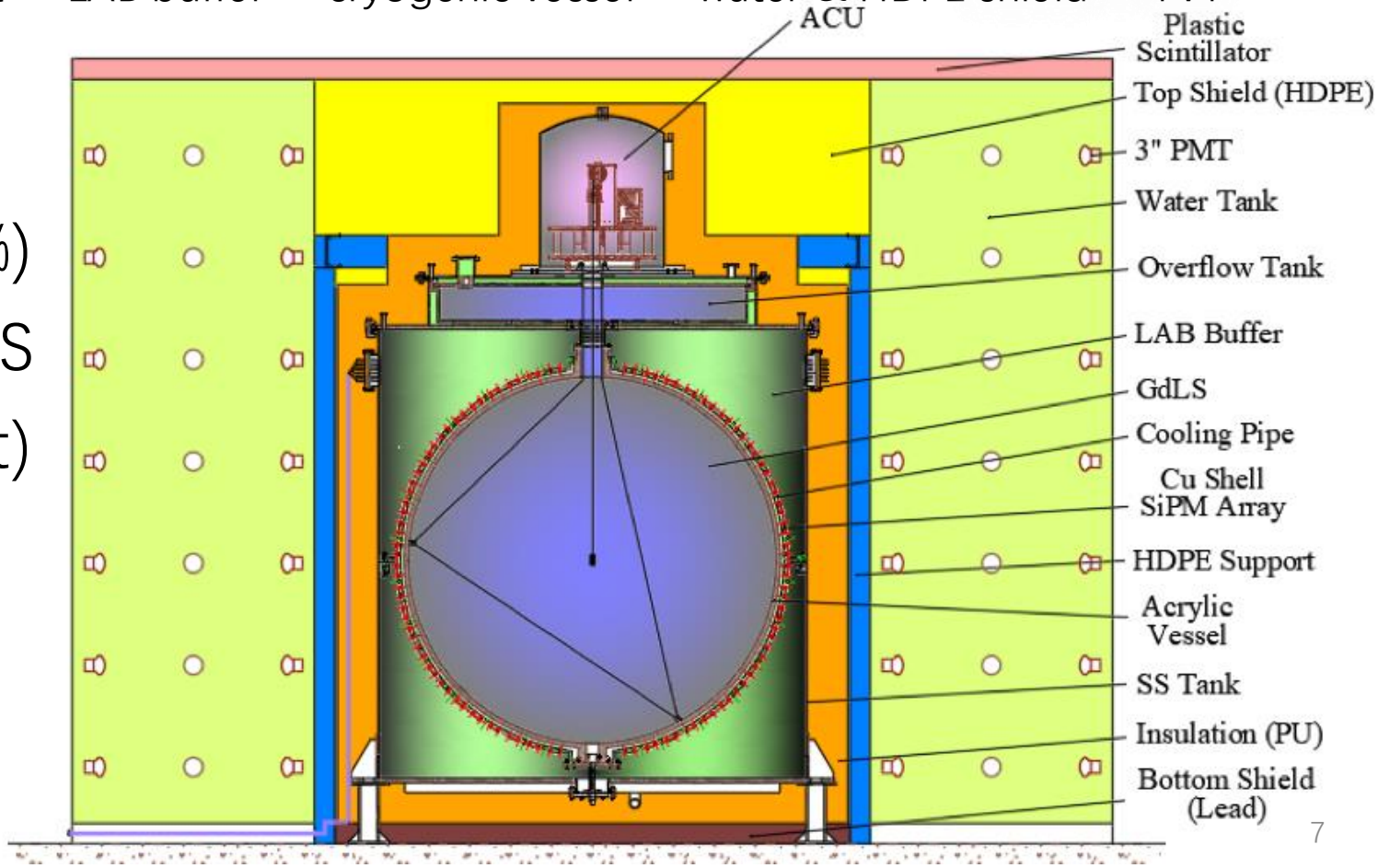


TAO Detector

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



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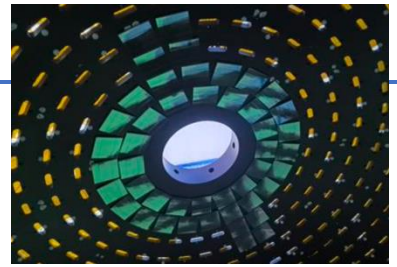
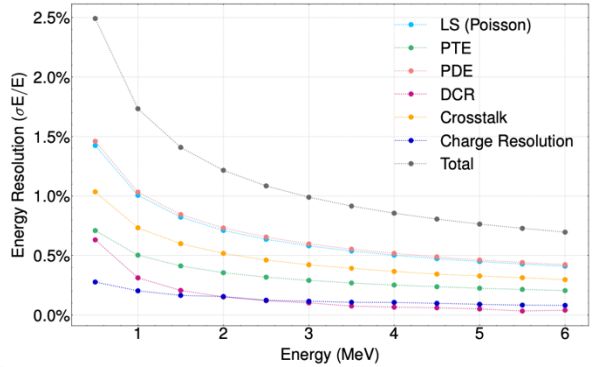
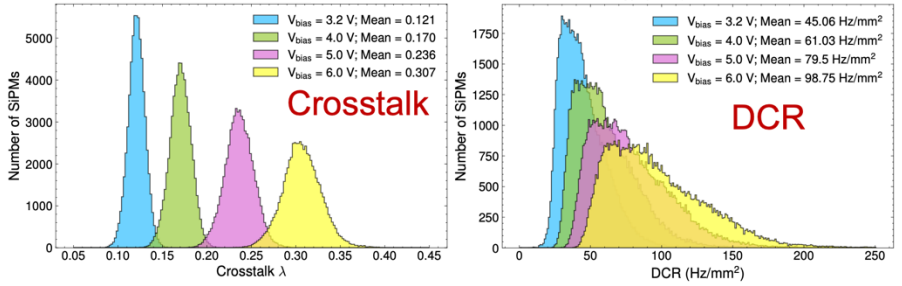
SiPM



- Tile 50.7 x 50.7 mm^2, 4024 tiles from **HPK**
- Supported & cooled by **copper shell**
- Work at **-50°C**, dark noise 100 k➔45 Hz/mm^2
- Mass testing finished
  - **10 m^2 SiPM tested**



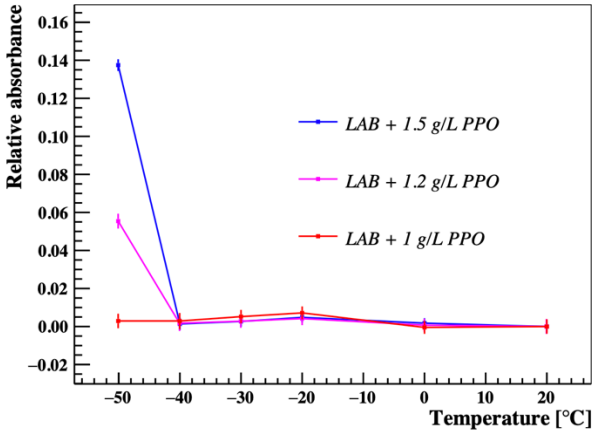


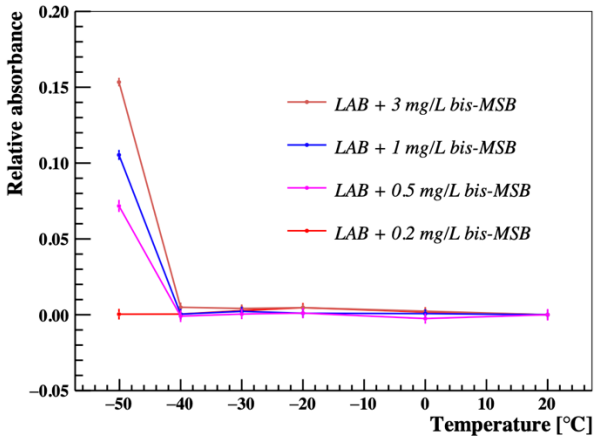
Parameters	Value	Measured	Unit
Photon Detection Efficiency	Min: 0.44, Typical: 0.47	0.488	-
Dark Count Rate	Max: 41.7, Typical: 13.9	45.06	Hz / mm^2
Crosstalk Probability	Max: 0.15, Typical: 0.12	0.121	-
After-pulsing Probability	Max: 0.08, Typical: 0.04	< 0.001	-
Pixel Gain	Min: 1×10^6, Typical: 4×10^6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

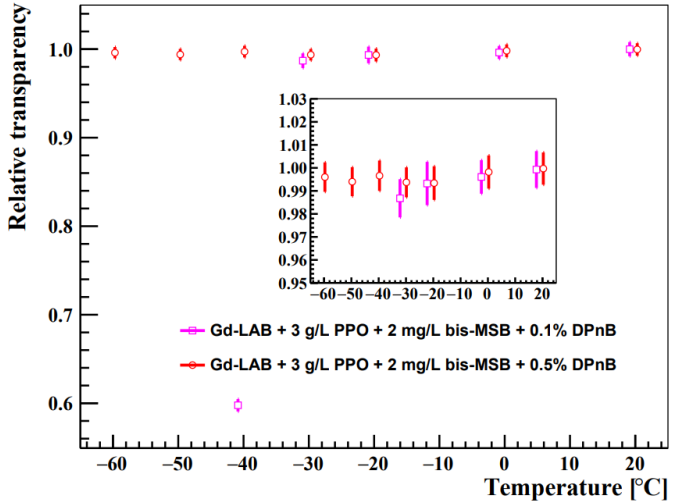
GdLS & LAB Buffer

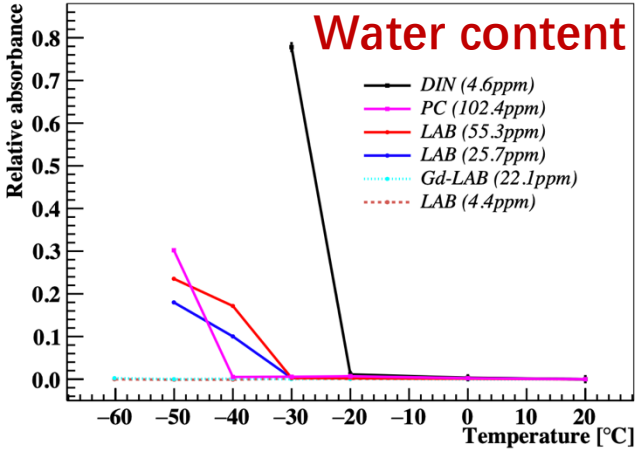
- GdLS recipe: Gd-LAB + 3 g/L PPO + 2 mg/L bis-MSB + **0.5% DPnB**
- Good stability at -50°C
  - **Water content:**
    - LAB <8 ppm (~ 40 ppm for LAB in the air)
    - GdLS <22 ppm (~80 ppm for GdLS in the air)
  - **Cosolvent**: Ethanol ➜ DPnB (less volatile & higher flash point)

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



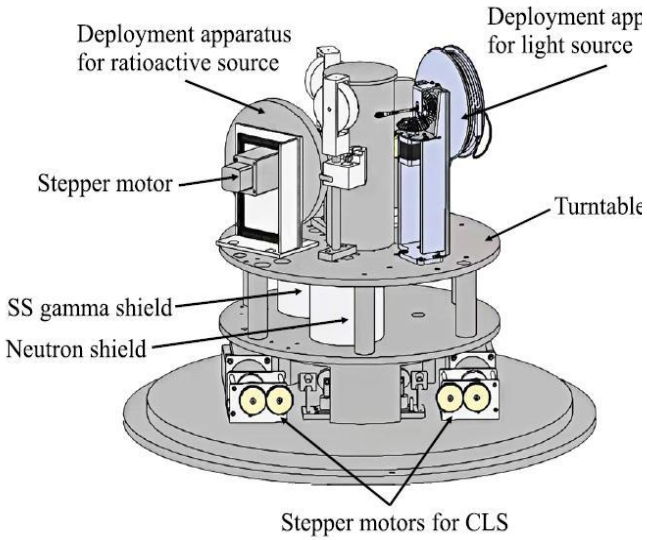


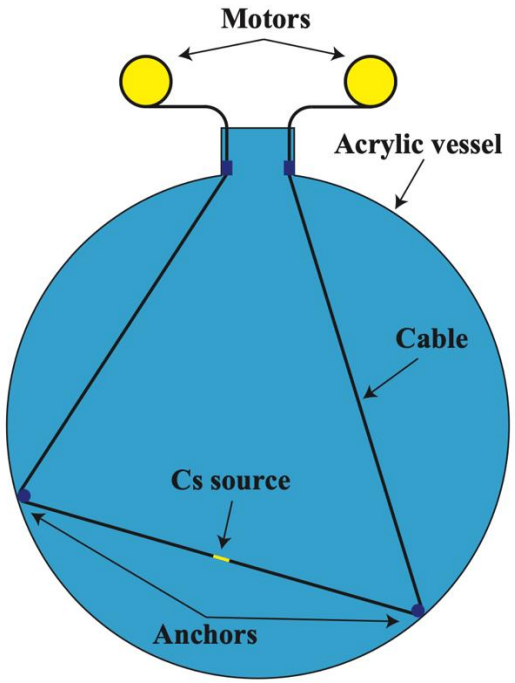




Calibration

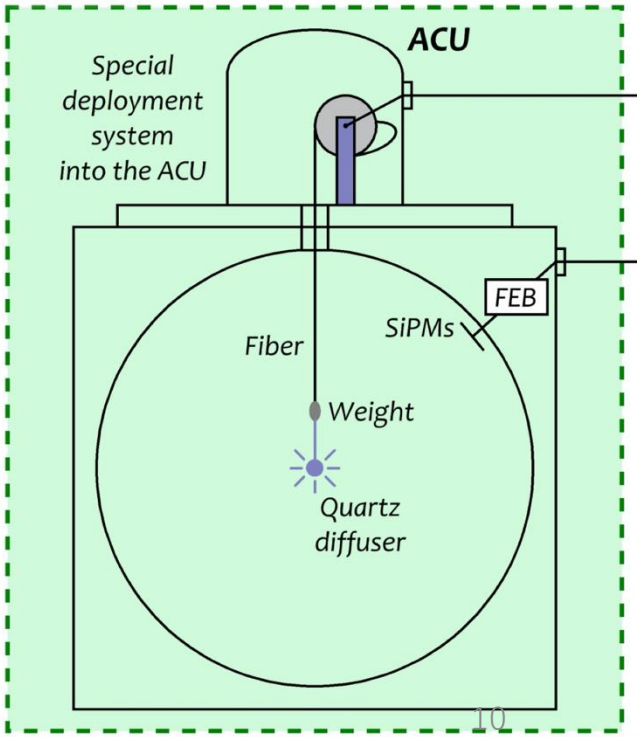
- Calibrate the detector response with multiple sources (energies) at deployed positions
- ACU recycled from Daya Bay
- Physics non-linearity **<0.6%** , residual non-uniformity is **<0.2%**
- Installed and tested at 1:1 prototype





The Calibration System Based on the Controllable UV/Visible LED Flasher

simplified scheme



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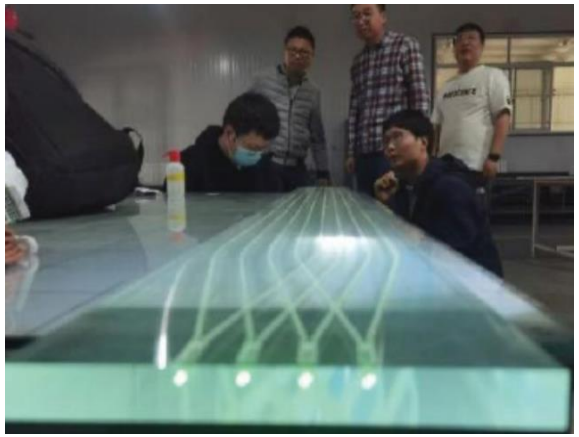
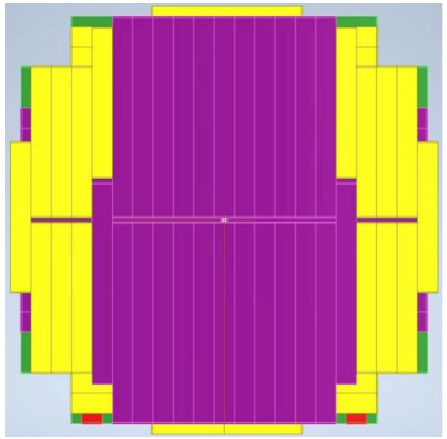
Doi: 10.1140/epjc/s10052-022-11069-3
Eur.Phys.J.C 82 (2022) 12, 1112

Muon Veto

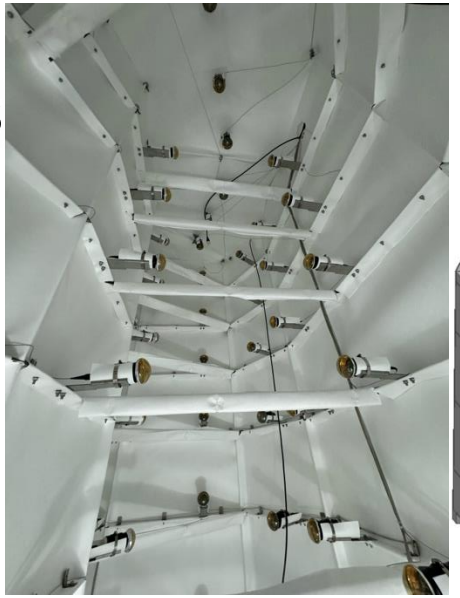
DOI: 10.1088/1748-0221/17/09/P09024
JINST 17 (2022) 09, P09024
DOI: 10.1007/s41365-023-01263-7
NUCL SCI TECH 34, 99 (2023)

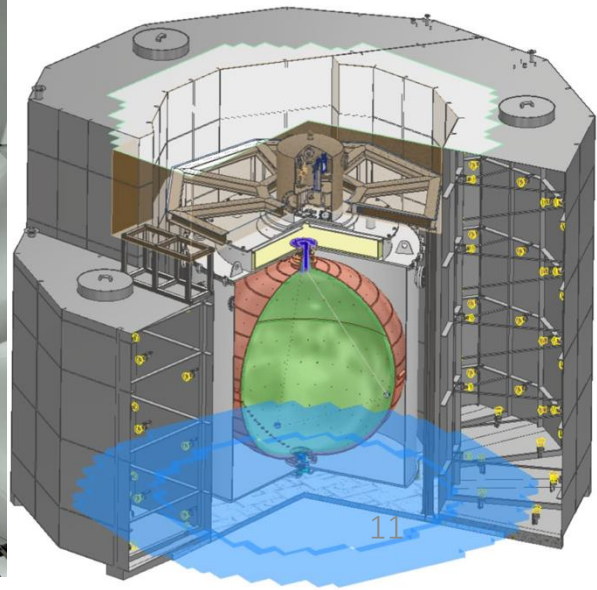
- **Top veto tracker**
  - 4 layers with each 2 cm thickness, 1 mm gap between strips
  - Muon veto efficiency ~ 99% (3/4)
  - Data taking chain successful





- **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)

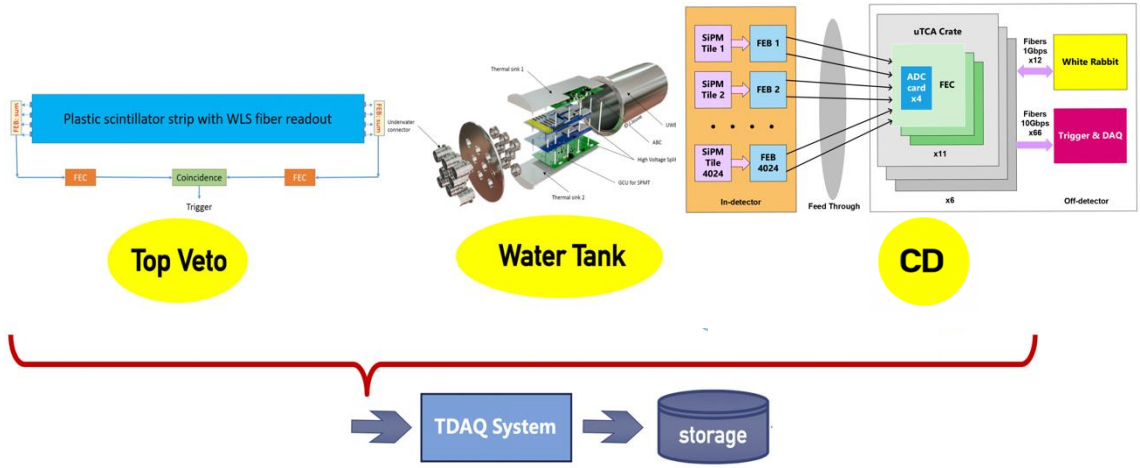




Electronics & TDAQ

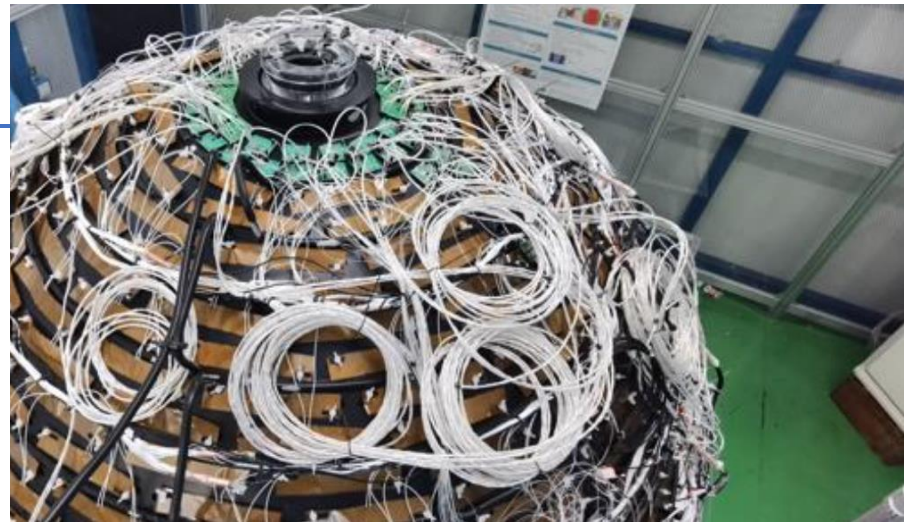
- Electronics of central detector (CD)
  - FEB based on discrete components
  - **~8000 channels for ~4000 SiPM tiles**
  - Waveform digitized by ADC
  - FPGA calculates Q/T, sent to TDAQ
- Electronics of veto detectors
  - Same strategy with CD for TVT
    - Software trigger & hardware trigger
  - Same 3” PMTs electronics in JUNO
    - Software trigger

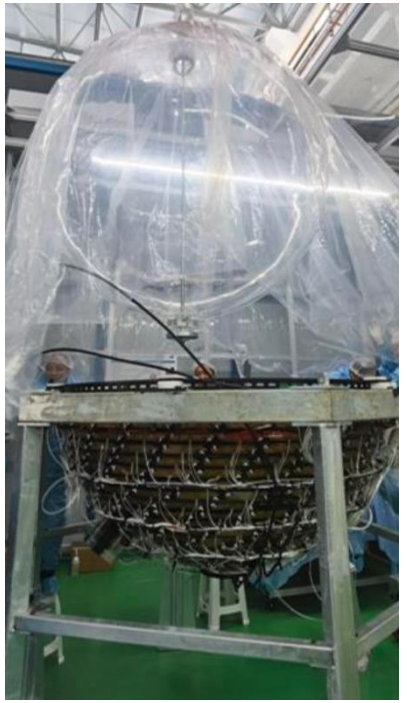
Data Stream	Interface	DAQ Data input	Data Merge	SW Trigger	Compression	Storage
CD	SiTCP	~Gbps	Y	N	Y	<80Mbps
WT	IPbus/TCP	~105Mbps	Y	Y	Y	<10Mbps
TPS	SiTCP	~40Mbps	Y	Y	N	<1Mbps
SUM						<100Mbps*



1:1 Prototype

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





Assembling in Taishan

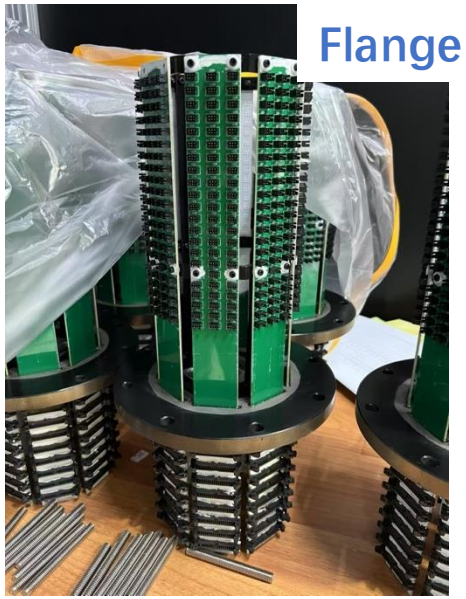
- Started from Sept. 2024
- CD (Acrylic vessel, copper shell, SiPMs, stainless steel tank, cabling) assembling finished
- Water tank assembling finished, TVT assembling ongoing
  - Cabling & further test ongoing
- Liquid scintillator filling ongoing

Acrylic Vessel

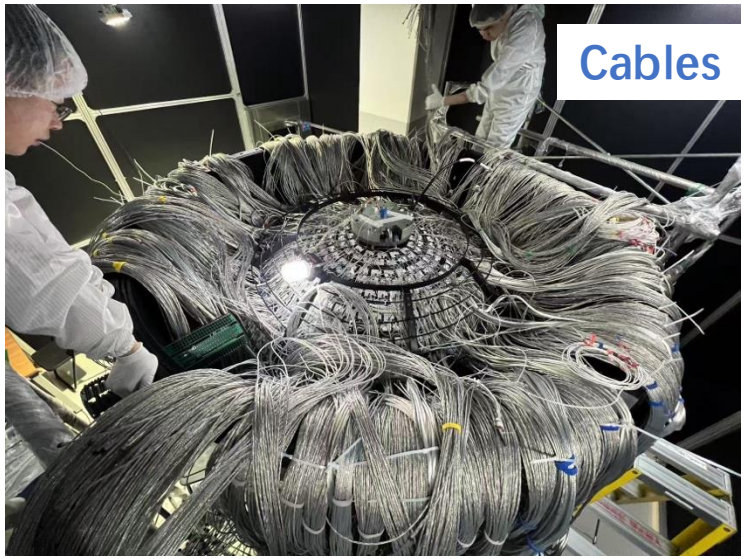
Assembling in Taishan

Copper shell

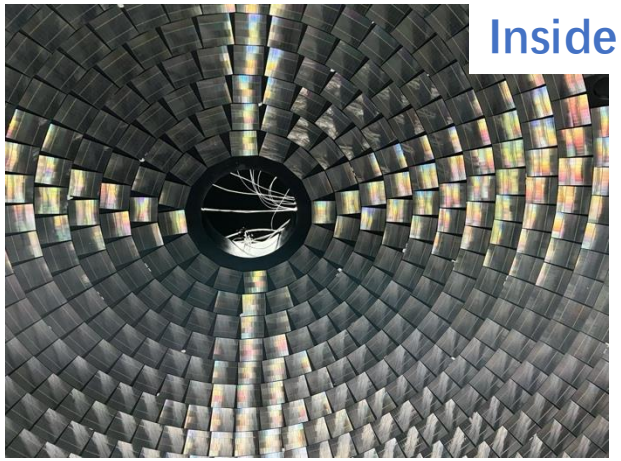
FEB



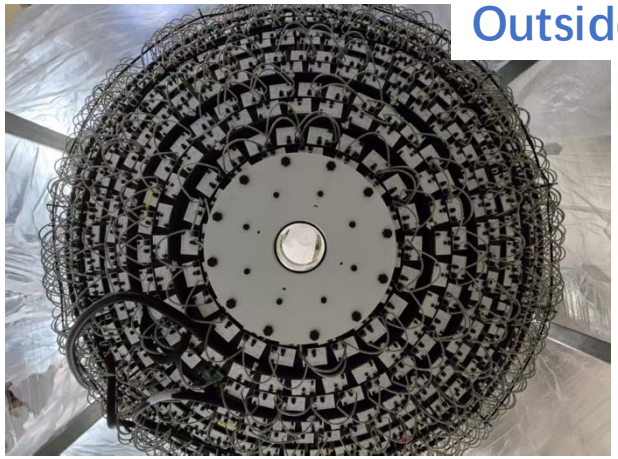
Flange



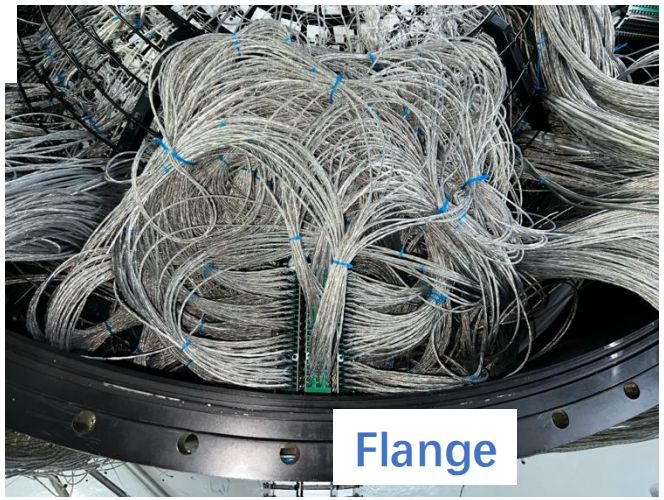
Cables



Inside



Outside



Flange

Assembling in Taishan

Placement of stainless steel tank

Assembling of ACU

Assembling of thermal insulation (Melamine foam)

Assembling in Taishan

Placement of water tank
Dry run ongoing

Placement of TVT

Assembling of TVT

Liquid scintillator filling

Summary

- TAO will measure reactor antineutrino spectrum with **<2% @ 1 MeV** E resolution
- Assembling in Taishan NPP started **in 2024, almost completed**
- **Commissioning will start next month**

Thank you!