JUNO and JUNO-TAO Detectors

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on behalf of JUNO Collaboration

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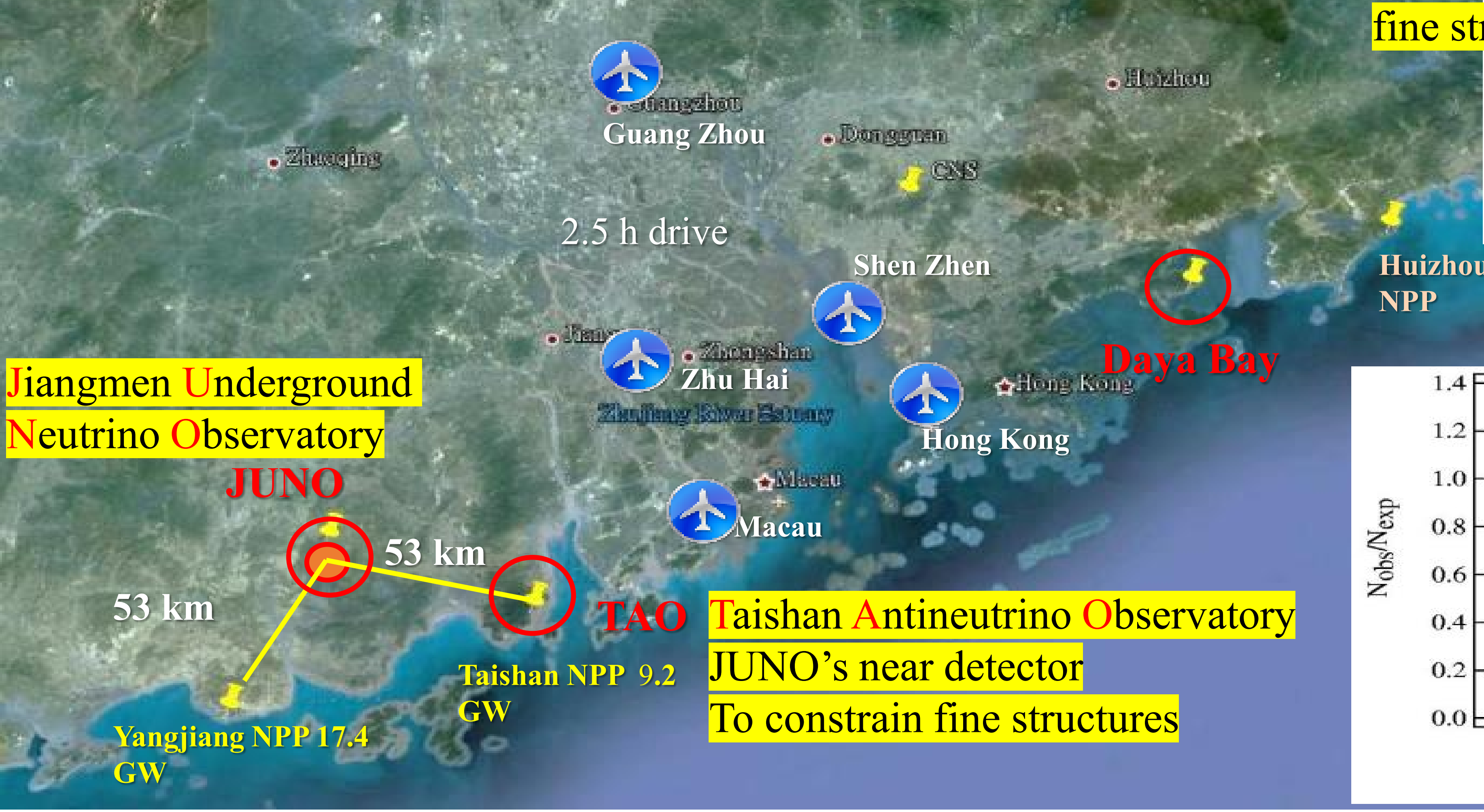
Before "Before We Begin…"

Before We Begin…

- JUNO Detector, focusing on the parts NOT covered by other talks in this session
- JUNO-TAO (or simply TAO) Detector, focusing on major features
- Less technical pages, more photos

Location/Relationship of JUNO and TAO

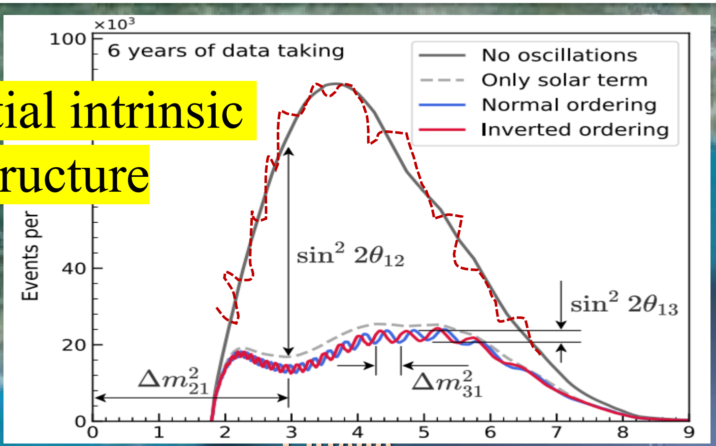
* Yangjiang and Taishan Reactor Group: one of the most powerful
* Taishan Nuclear Reactor: highest single-core power

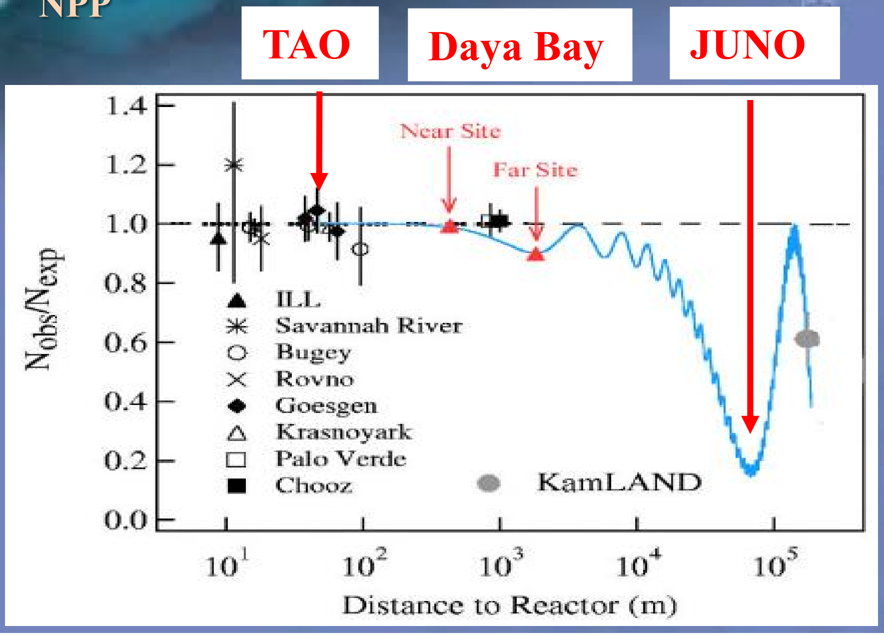


Jiangmen Underground Neutrino Observatory

Taishan Antineutrino Observatory
JUNO's near detector
To constrain fine structures

Potential intrinsic fine structure

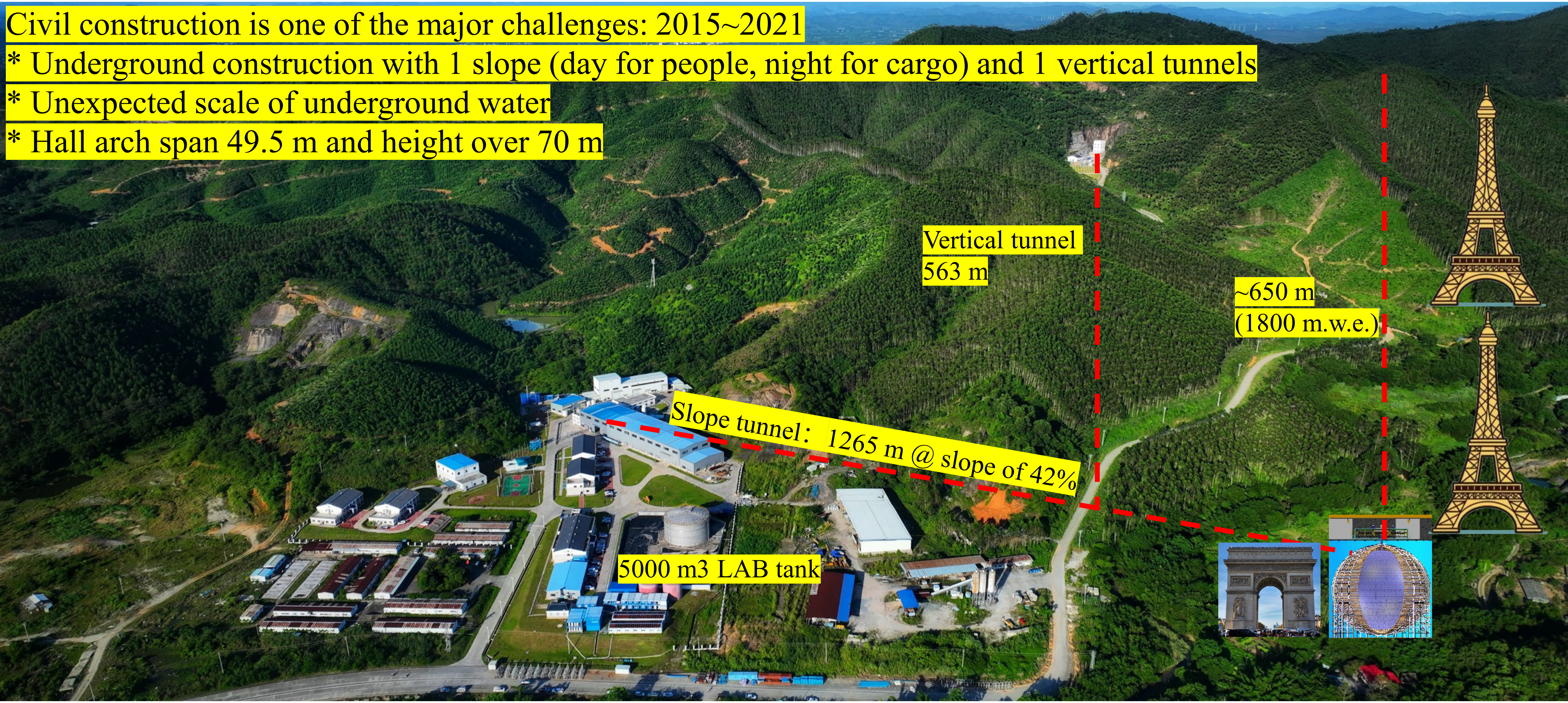




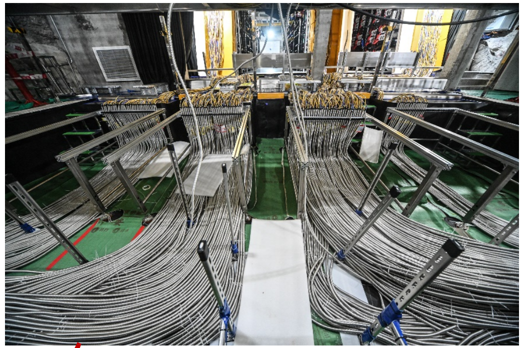
JUNO Site: Jinji Village, Dashi Mountain

Civil construction is one of the major challenges: 2015~2021

* Underground construction with 1 slope (day for people, night for cargo) and 1 vertical tunnels
* Unexpected scale of underground water
* Hall arch span 49.5 m and height over 70 m

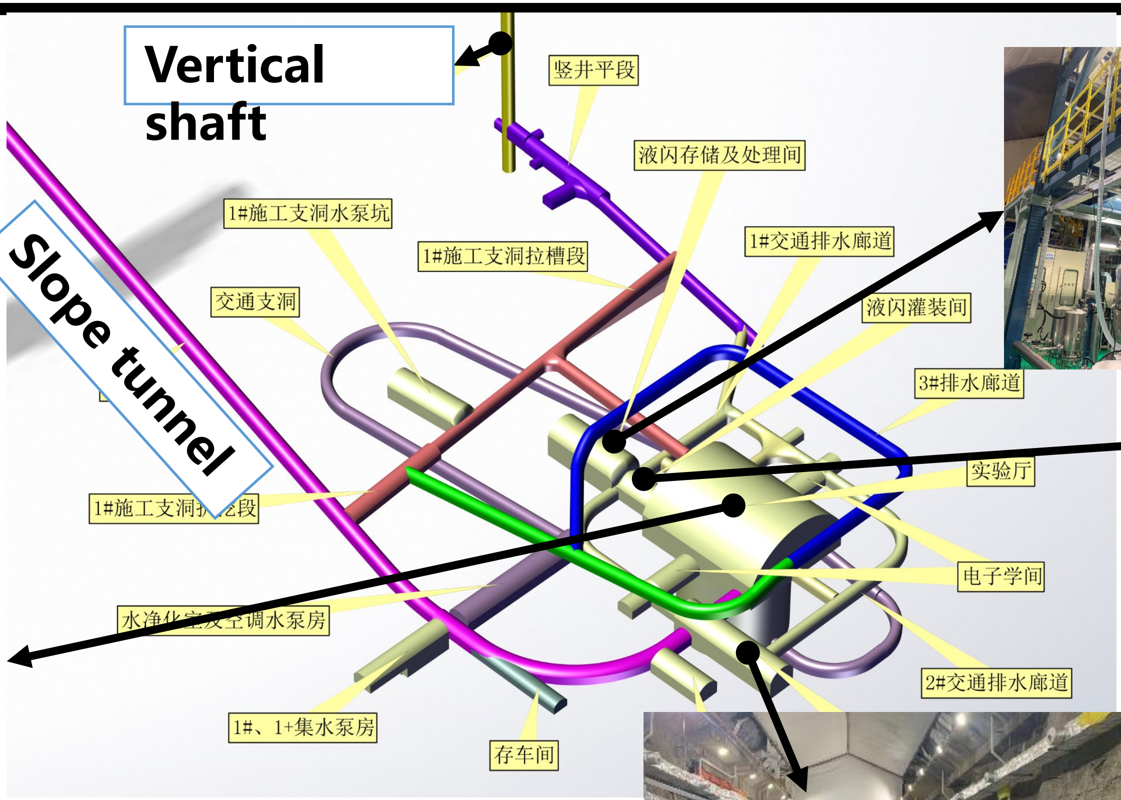


JUNO Underground Lab



Electronics rooms

Experimental Hall

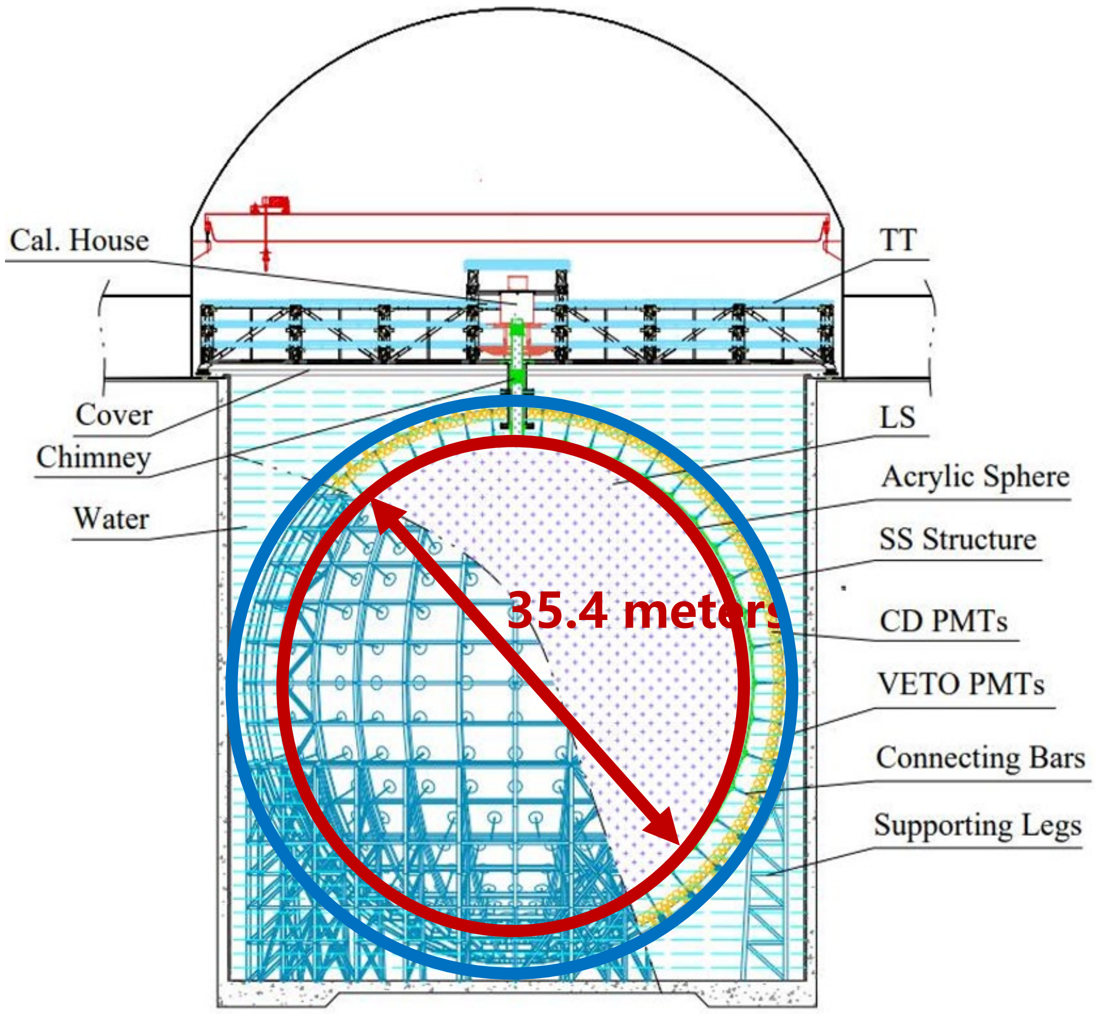


Liquid Scintillator hall

Filling Overflow Circulating room

Underground installation room

JUNO Detector Overview



Key requirements

- **Target mass of 20,000t** liquid scintillator → biggest
- **Energy resolution < 3%@ 1MeV** → 1200 PE / MeV

Central Detector

- Stainless Steel structure (Finished in June 2022)
- Acrylic Sphere with 35.4m diameter (Done in Oct. 2024)
- 17612 20" PMTs + 25,600 3" PMTs (Installed in Dec. 2024)
  - 3" PMTs → Loic Labit's talk later
- 20,000t liquid scintillator (Filling finished on Aug. 22, 2025)

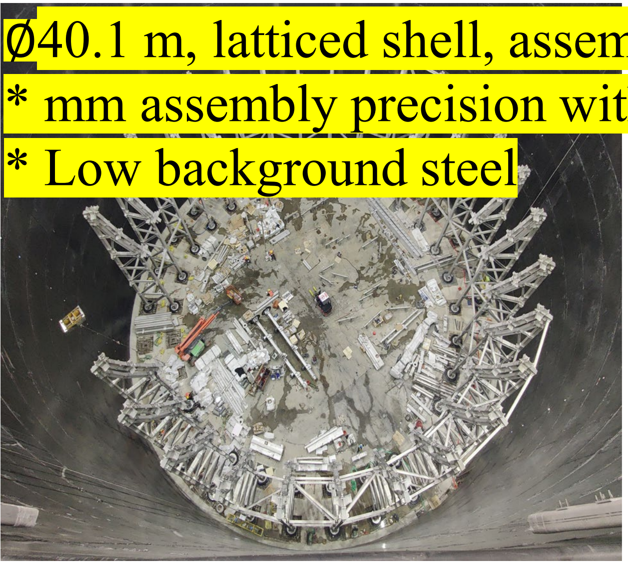
Veto Detector

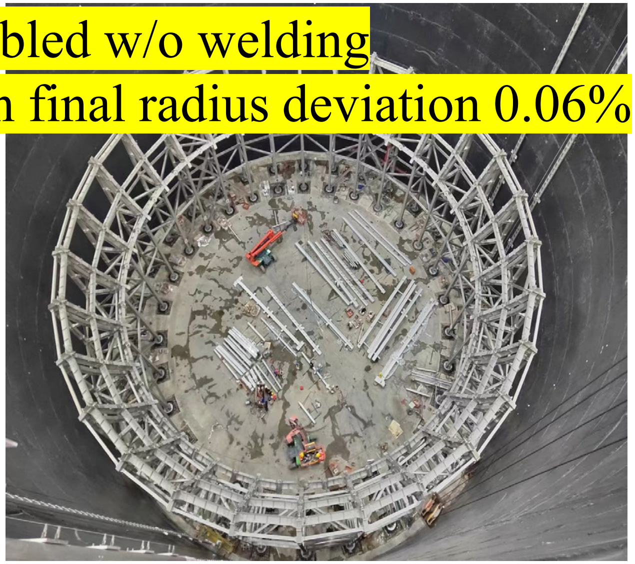
- Top tracker (João Pedro Athayde Marcondes de André's talk later)
- Water pool (2400 20" PMTs)

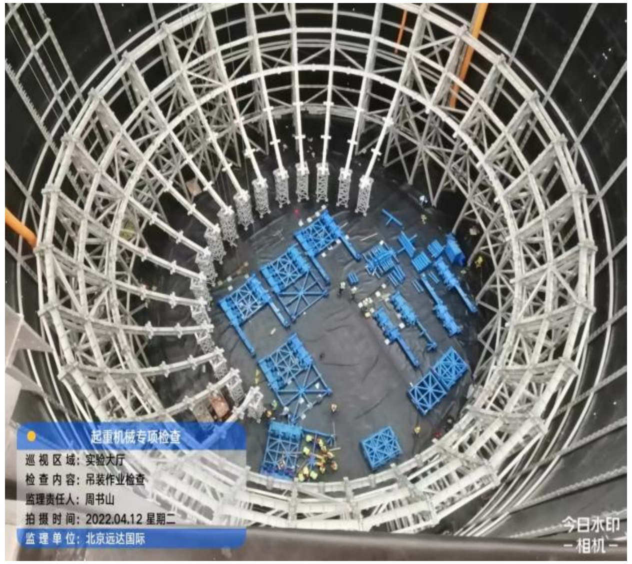
Stainless Steel Structure Assembly

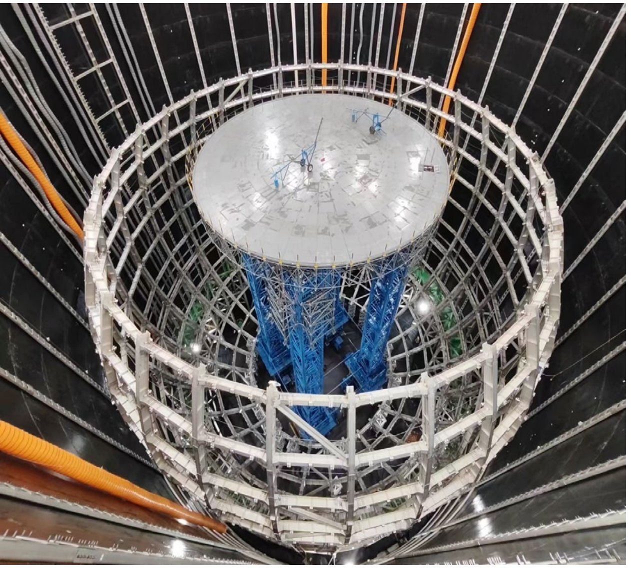
Ø40.1 m, latticed shell, assembled w/o welding

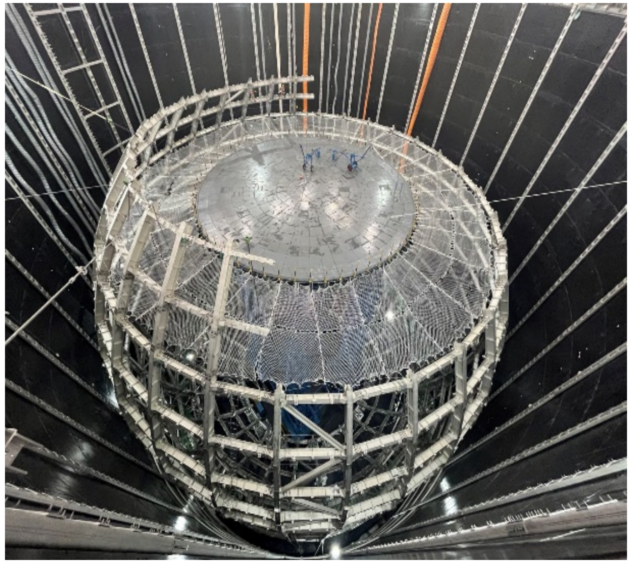
* mm assembly precision with final radius deviation 0.06%
* Low background steel

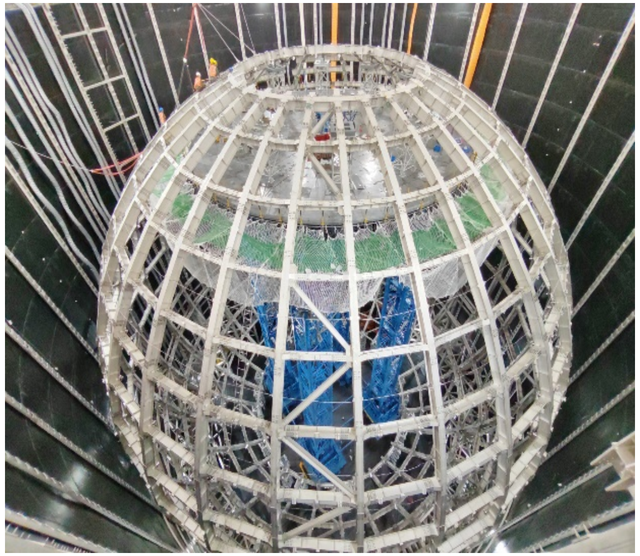






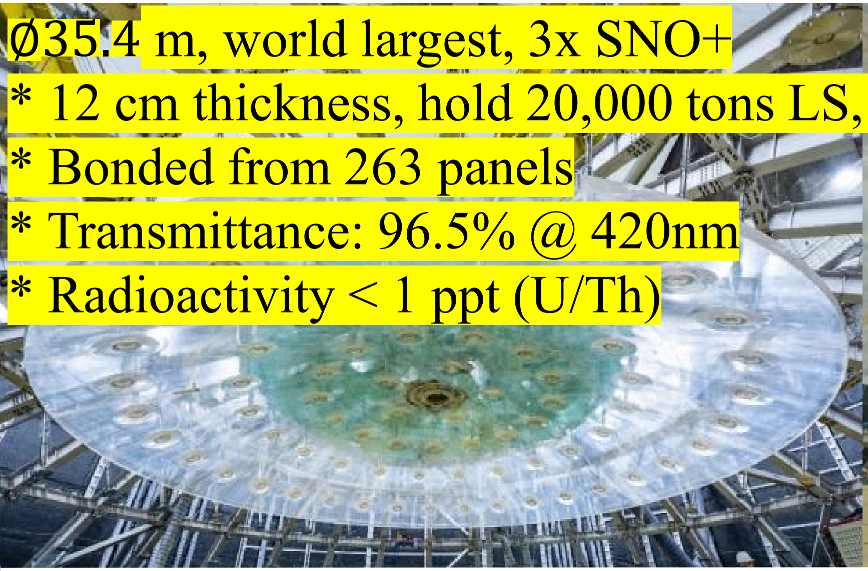


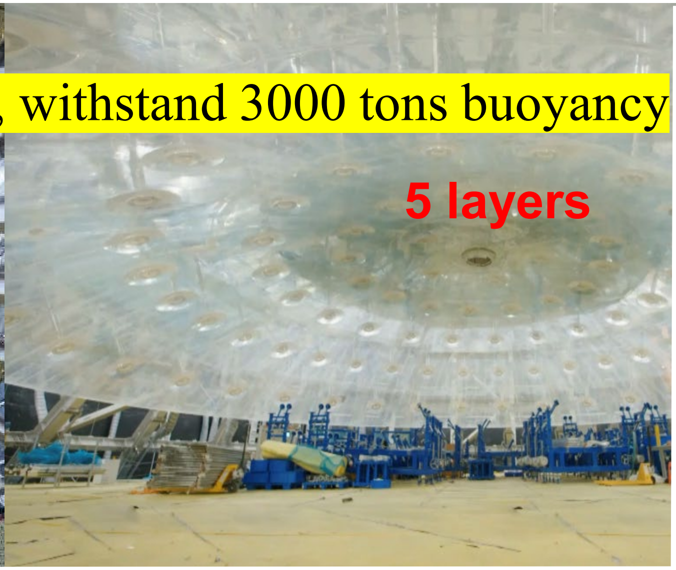




Acrylic Sphere Assembly

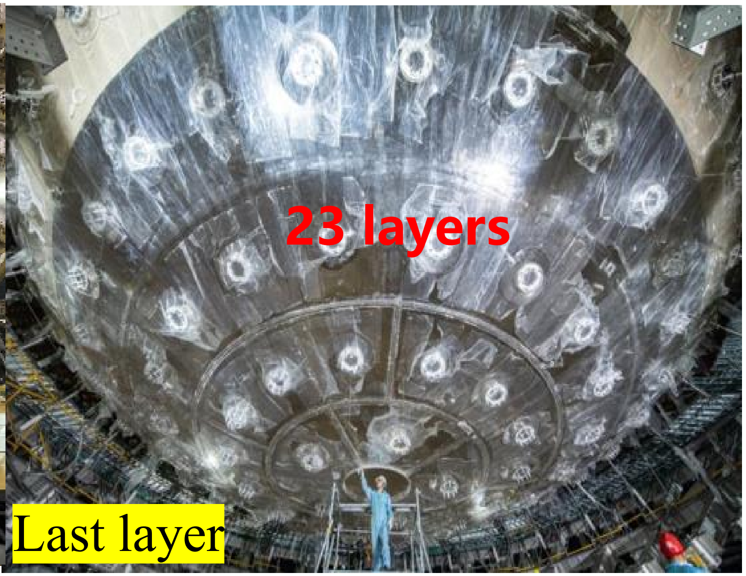
Ø35.4 m, world largest, 3x SNO+
* 12 cm thickness, hold 20,000 tons LS, withstand 3000 tons buoyancy
* Bonded from 263 panels
* Transmittance: 96.5% @ 420nm
* Radioactivity < 1 ppt (U/Th)



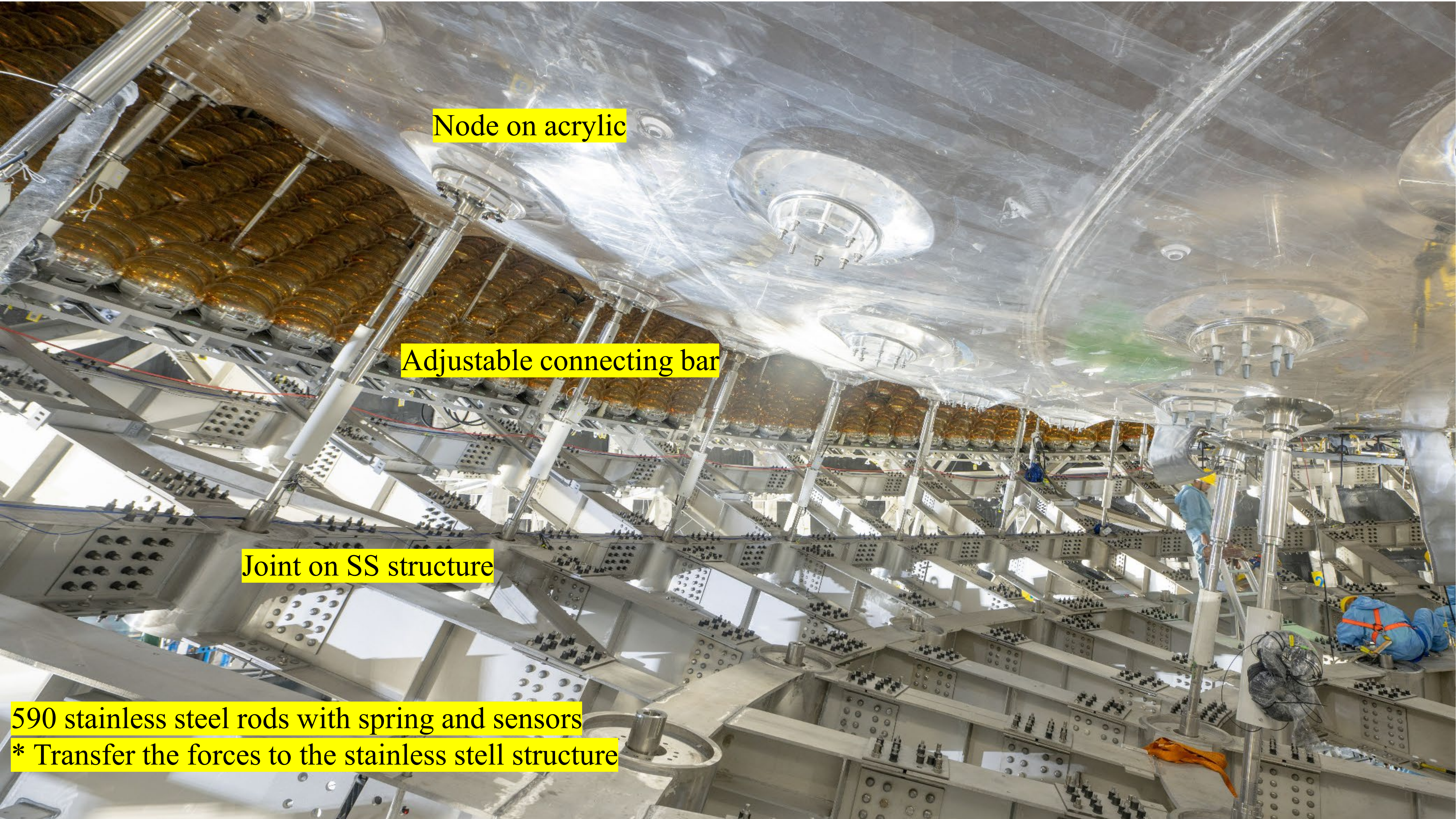


Liftable Platform for top-down assembly

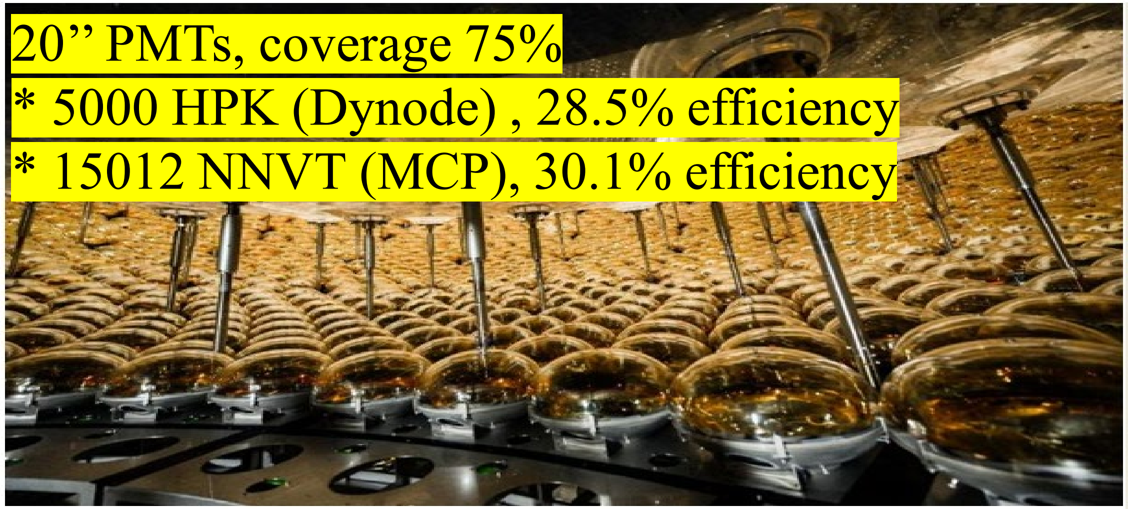
Acrylic Panel

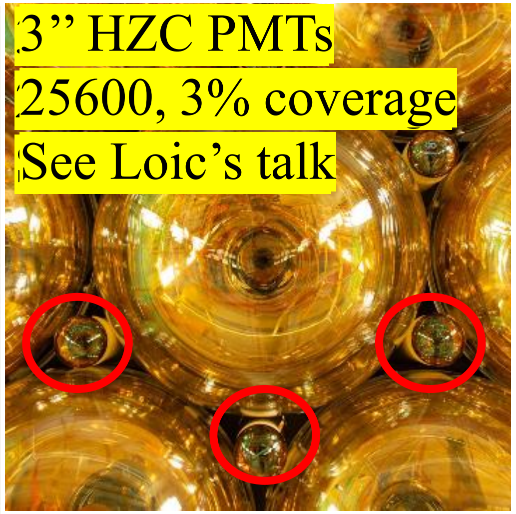


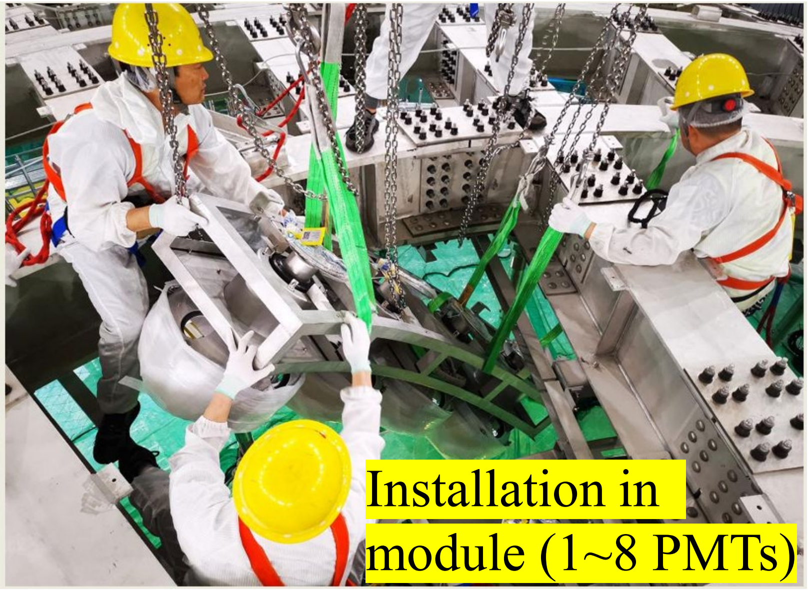
Last layer

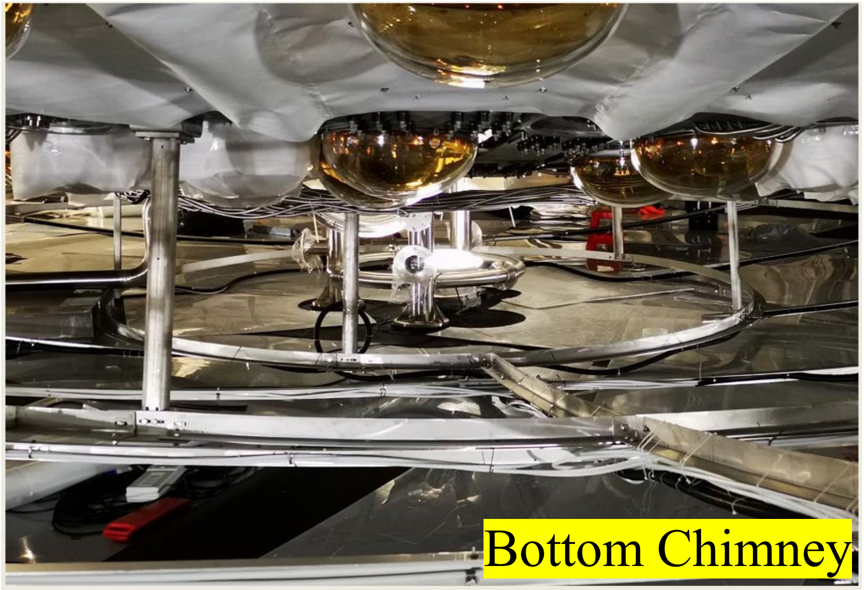

Node on acrylic
Adjustable connecting bar
Joint on SS structure
590 stainless steel rods with spring and sensors
* Transfer the forces to the stainless stell structure

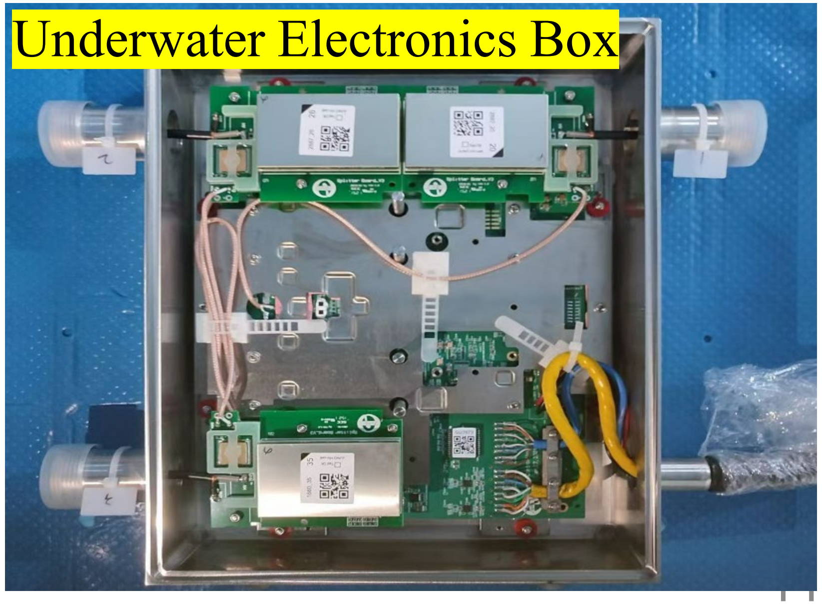
PMT Installation



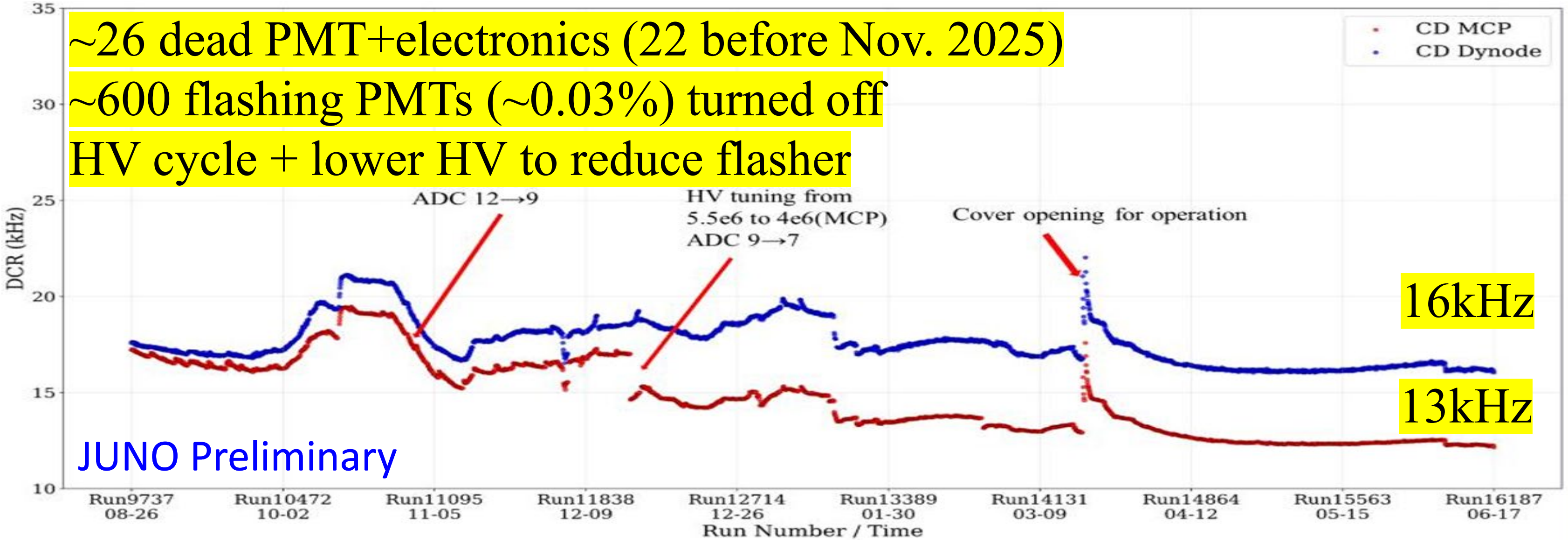


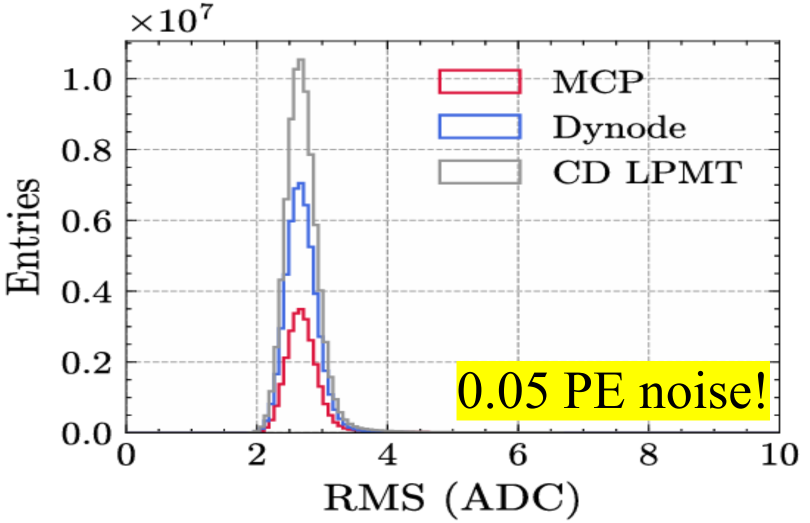


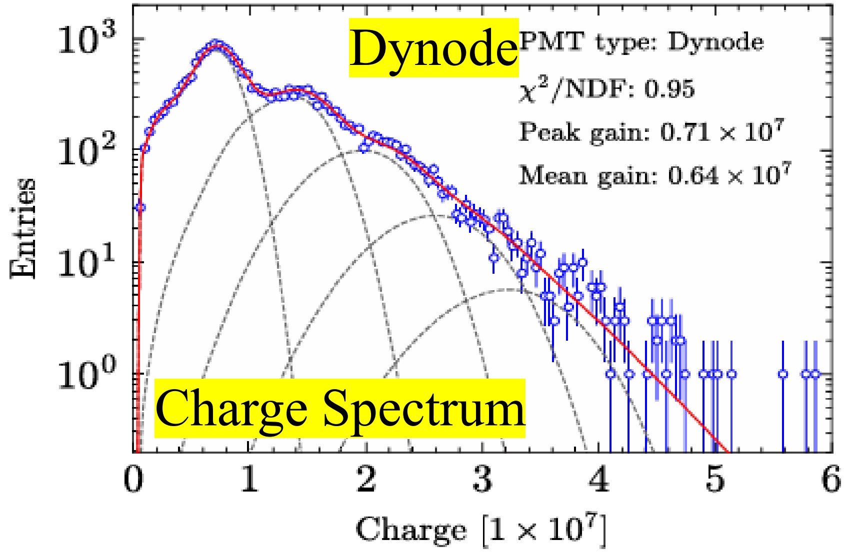


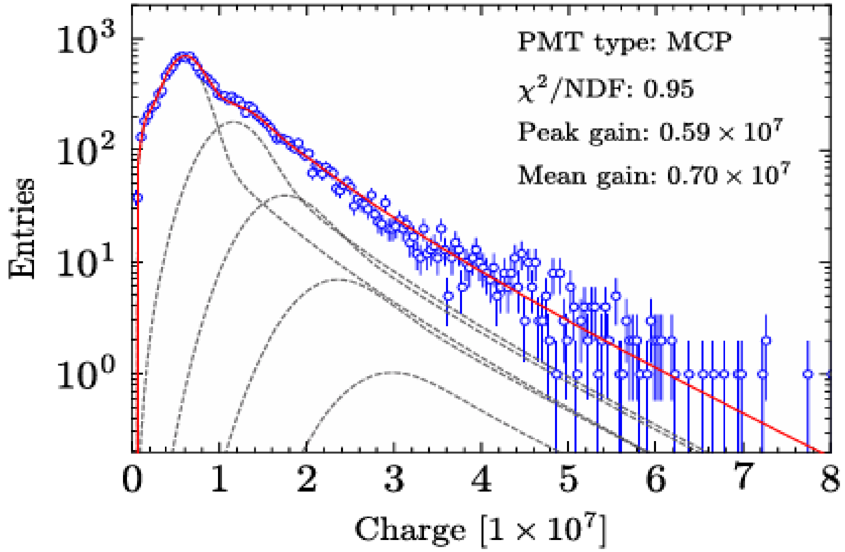


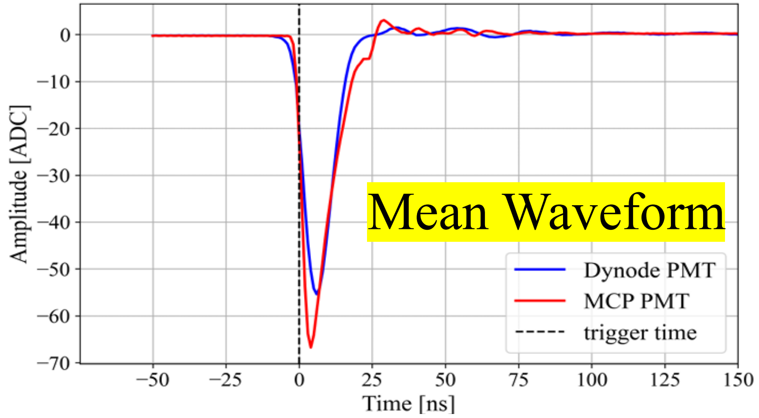
PMT+Electronics Performance











Parameter	Installation Test		Pan-Asia Test	
	MCP PMT	Dynode PMT	MCP PMT	Dynode PMT
rise-time (ns)	4.0	6.6	3.6	6.2
fall-time (ns)	13.9	9.4	15.3	9.6
FWHM (ns)	11.1	11.8	9.9	9.6

Liquid Scintillator Production and Performance

- LAB + 2.5 g/L PPO + 3 mg/L bis-MSB + 50mg/kg BHT
  - High light yield (1200PE/MeV required, **1785 PE/MeV with neutron**), long attenuation length (>20m required, **20.6m @430nm**), low background (U/Th < 1 ppq required, **~0.1 ppq measured**)

5000 m^3 LAB storage tank

1) Al_2O_3 for optical transparency

2) Distillation for radiopurity

Mixing LAB with PPO and bis-MSB

1800 m SS pipes to underground

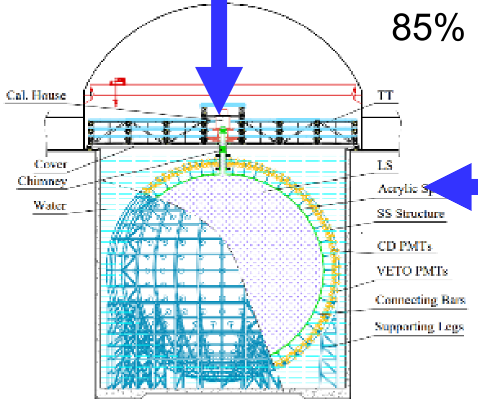
3) Water extraction to remove radioactive impurities

4) Gas stripping to remove Rn and O_2

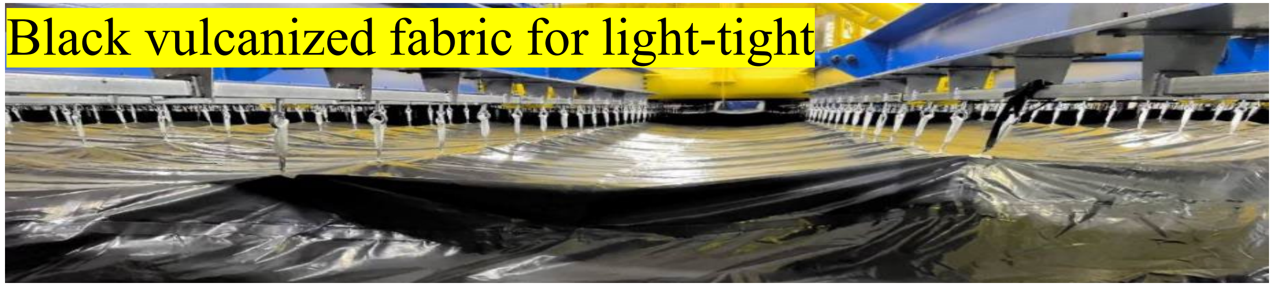
15%

Monitoring pre-detector (OSIRIS)

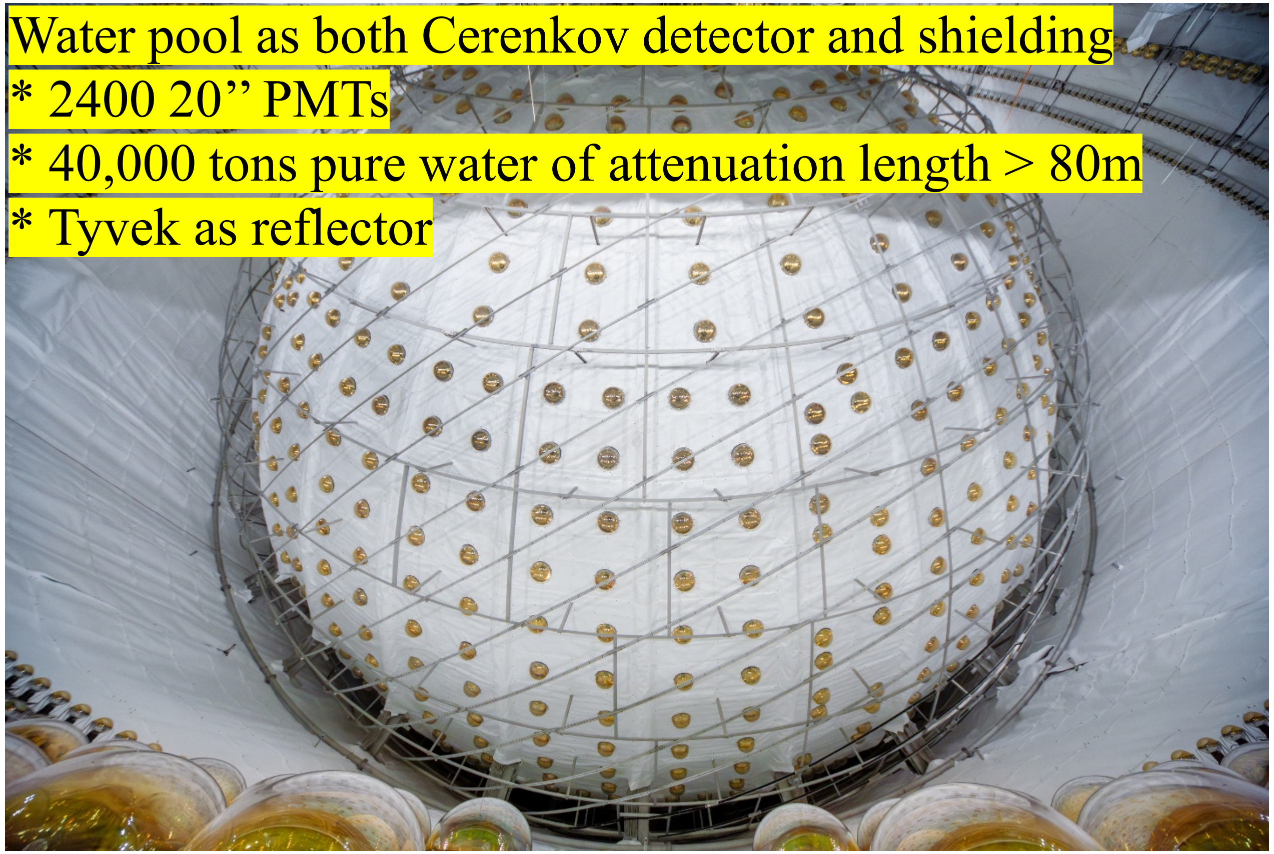
85%



Veto Detector



Black vulcanized fabric for light-tight



Water pool as both Cerenkov detector and shielding

* 2400 20” PMTs

* 40,000 tons pure water of attenuation length > 80m

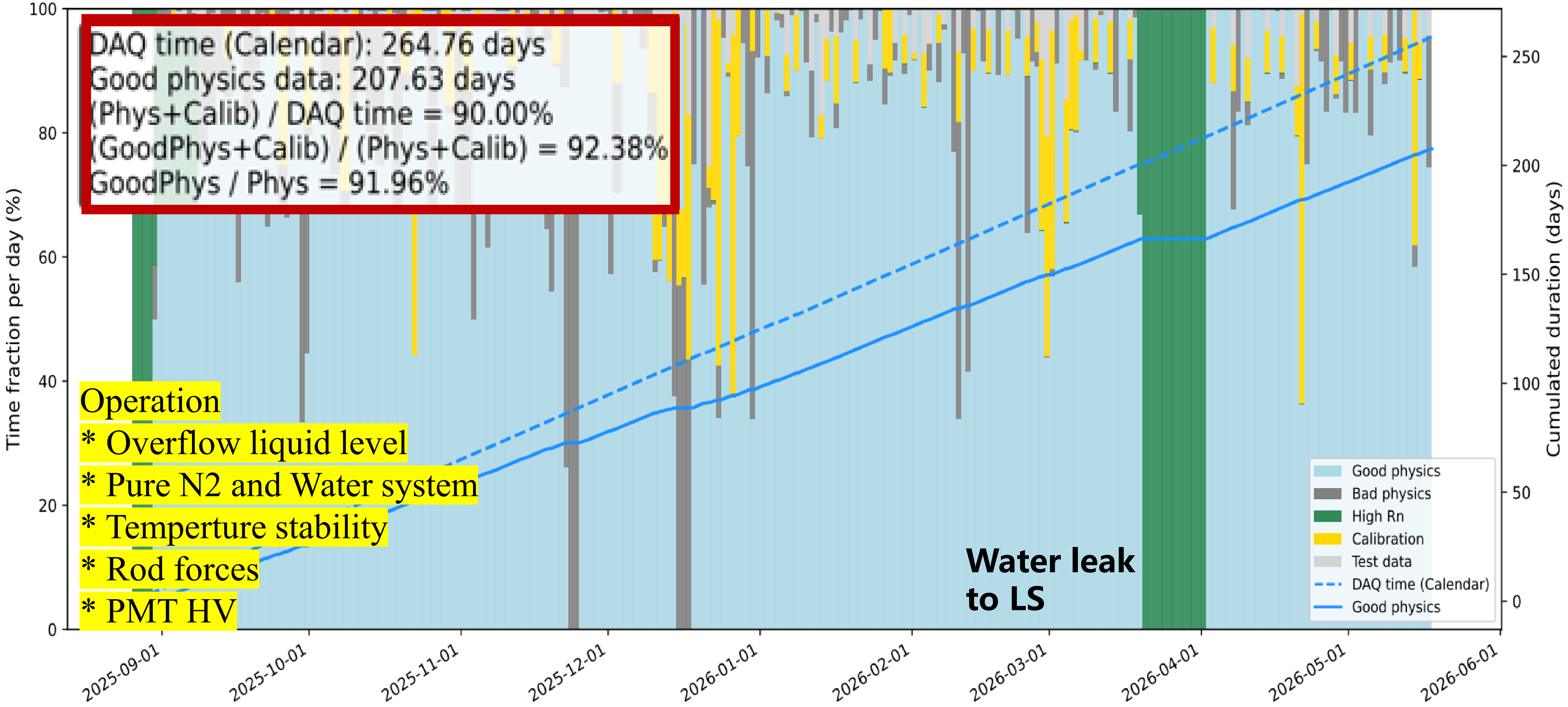
* Tyvek as reflector

Top Tracker

(João Pedro Athayde Marcondes de André’s talk)

Bottom of the pool

Detector in Stable Data-taking



TAO Site: Taishan NPP, Core #1

Ultra strict engineering management for civil work in Nuclear Island

TS1: world 1st EPR (3rd generation) in operation (China-French joint venture)

TAO Detector Design

Key requirements

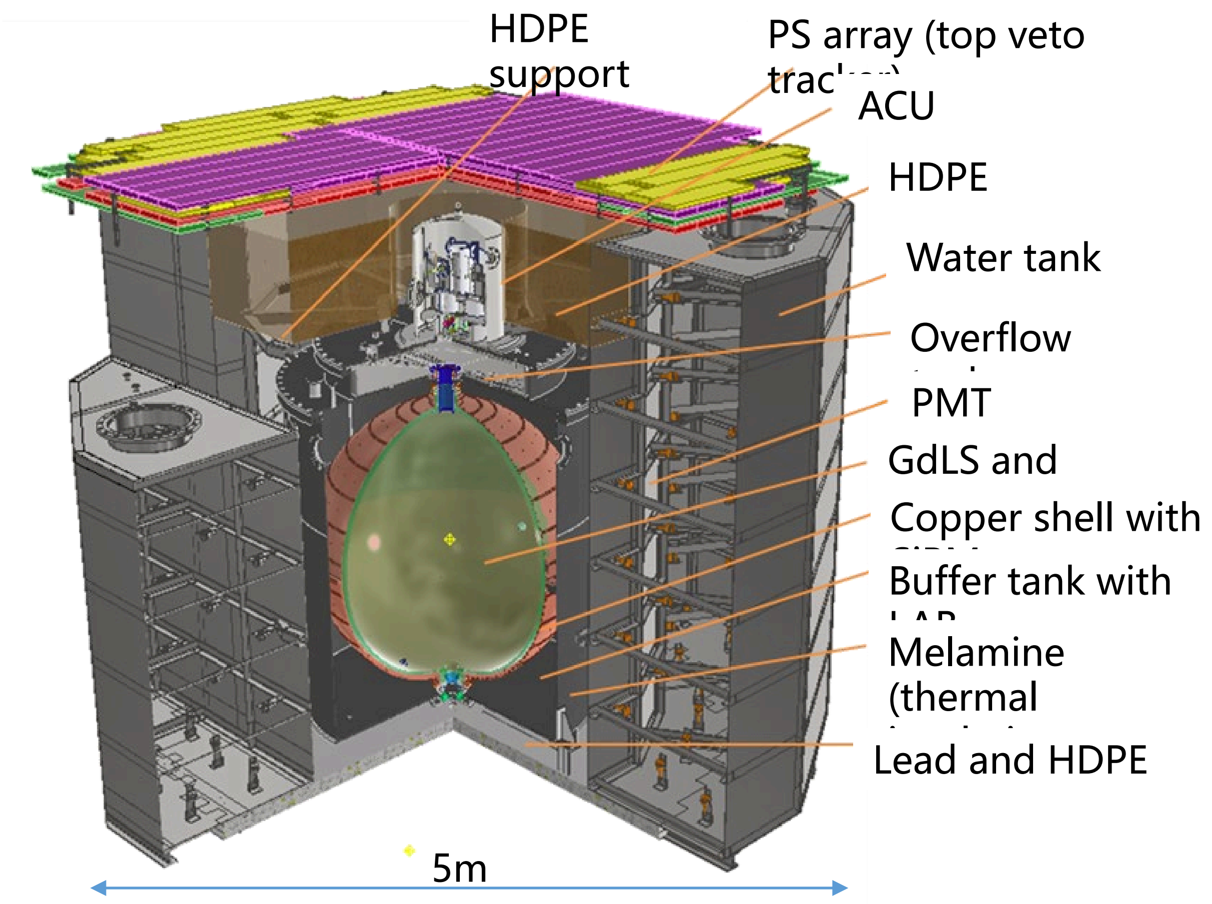
- Energy resolution: <3%@ 1MeV (JUNO mass ordering measurement), aim for 2%@ 1MeV (own goal)

Central detector

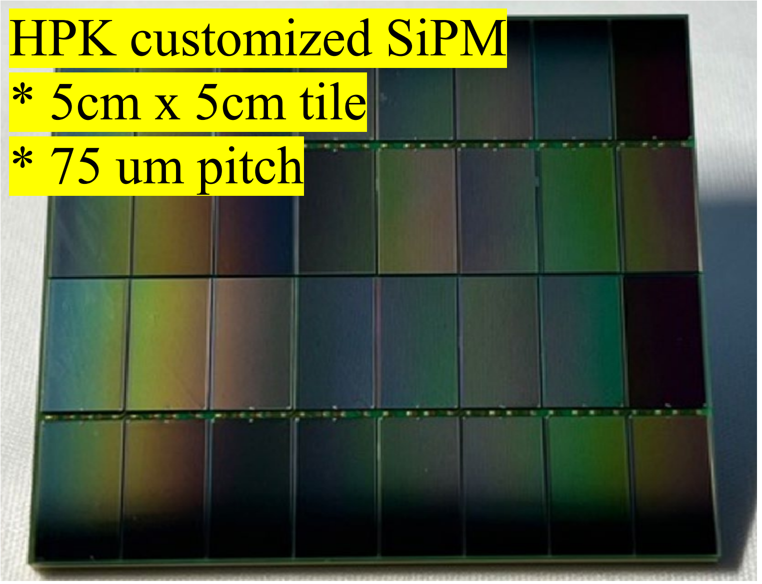
- **2.8 t low temperature LS** (Gd doped)
- **10 m^2 SiPM** (replace PMT)
- Acrylic sphere (Ø 1.8m, 2 cm thick)
- Copper shell (vs JUNO SS lattice)
- Buffer tank filled with LAB
- Running at -50℃ → suppress SiPM DCR

Veto detectors

- 4 layers of plastic scintillator (PS) strips
- 3 water Cerenkov detectors



SiPM Assembly and Cabling



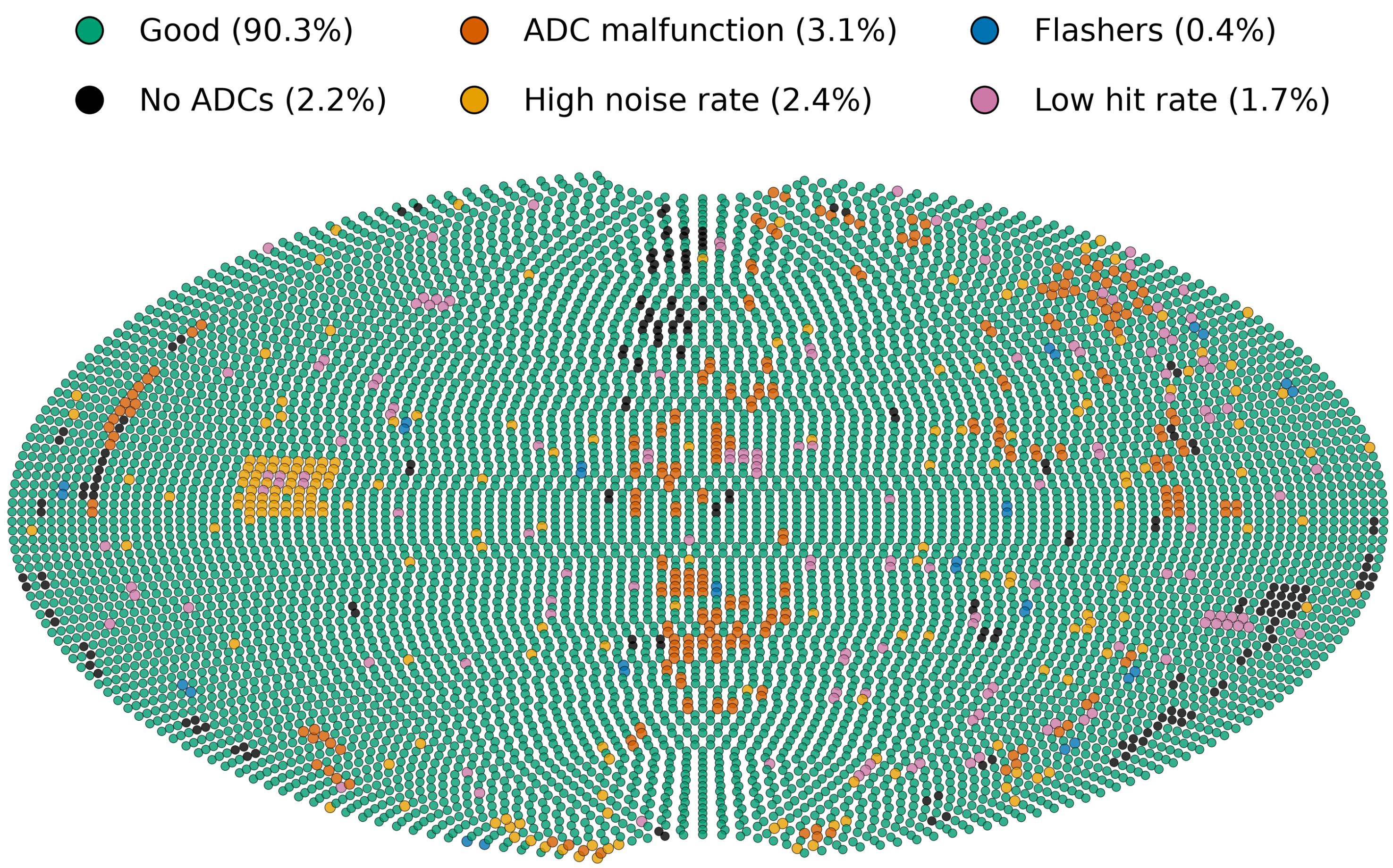
SiPM+Electronics Performance

After assembly

- 100% good on copper shell
- 99% good with cables

After commissioning

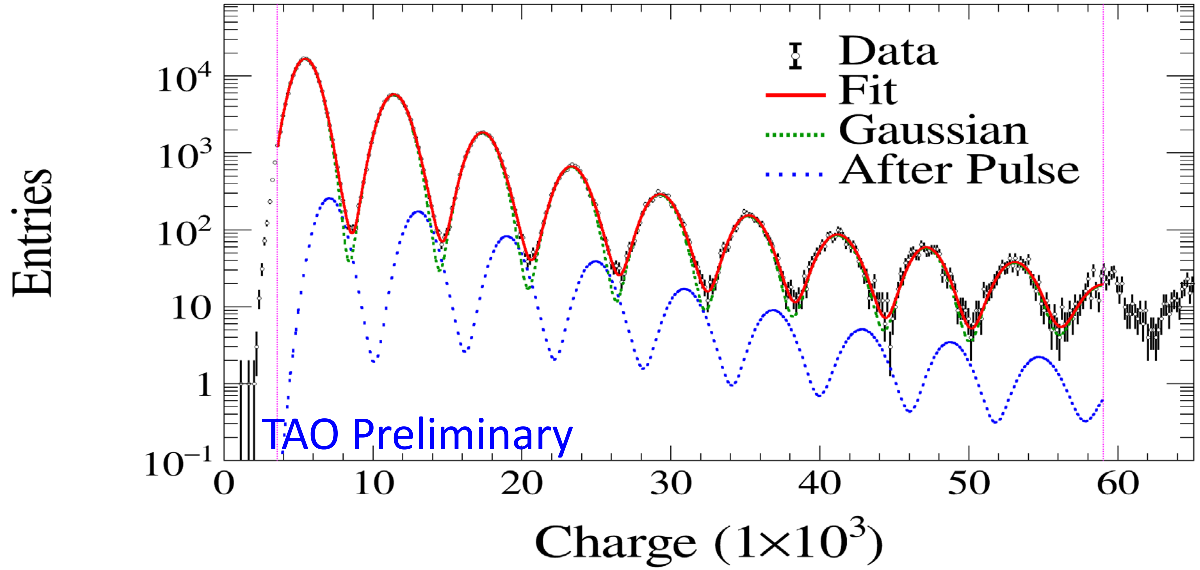
- 90% good channel
- For the rest 10%
  - 5.3% ADC missing/broken
    → will be completed/replaced
  - 2.4 % noisy channels
    → addressing noise issue
  - Low hit rate: 1.7%
  - Flasher: 0.4%

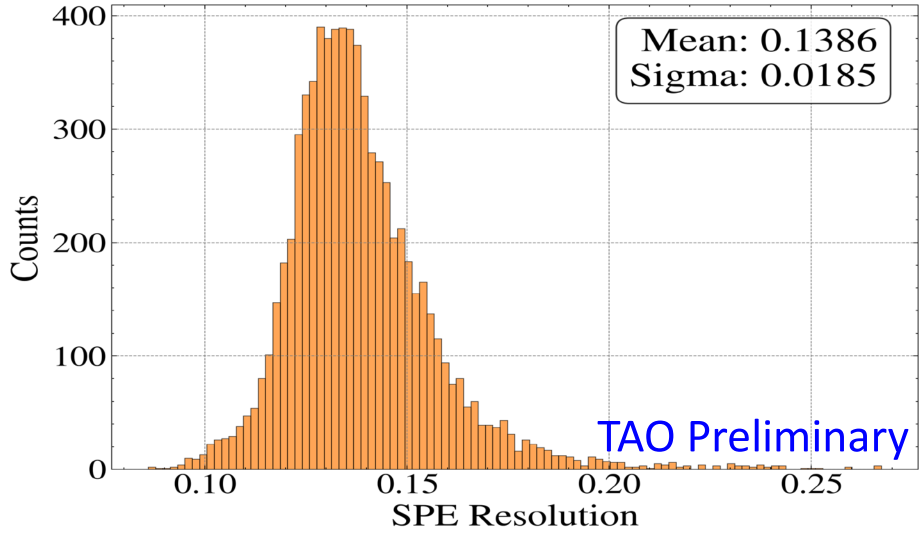


4024 SiPMs, 8048 channels in total

SiPM+Electronics Performance

- **SiPM over voltage V_{ov}:** 3.5 V (Ge-68 energy resolution scan)
- **Gain:** 6000 ± 130 LSB, uniformity ~2%, stability: ~0.1%
- **Single photo-electron (SPE) resolution**: ~14% (15% in CDR)
- **DCR**: ~50 Hz/mm^2 (100 Hz/mm^2 in CDR)
- **PDE**: ~50% (SiPM QA/QC), uniformity ~5%
- **Cross-talk**: ~25% (preliminary)
- **After-pulse**: < 5% (SiPM QA/QC)
- **Baseline fluctuation**: 0.13 PE
- **Timing precision**: ~1 ns

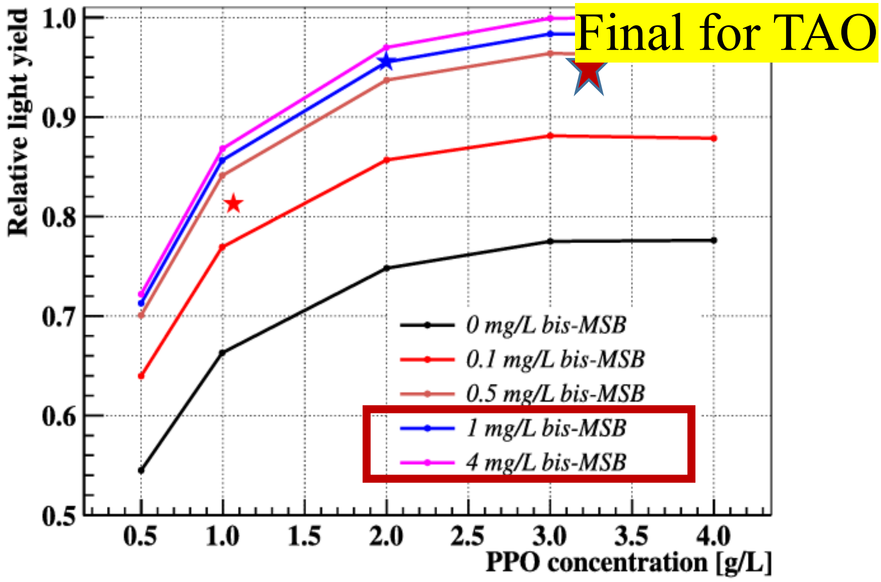




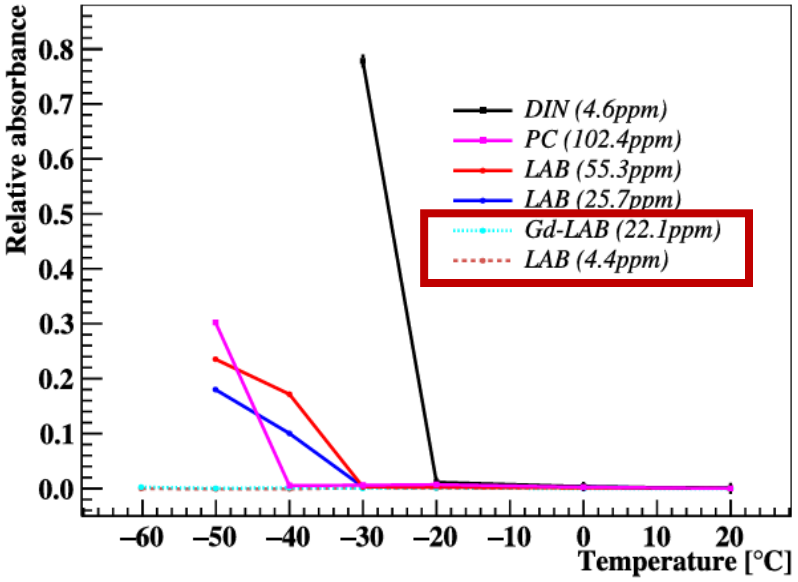
Low Temperature Liquid Scintillator

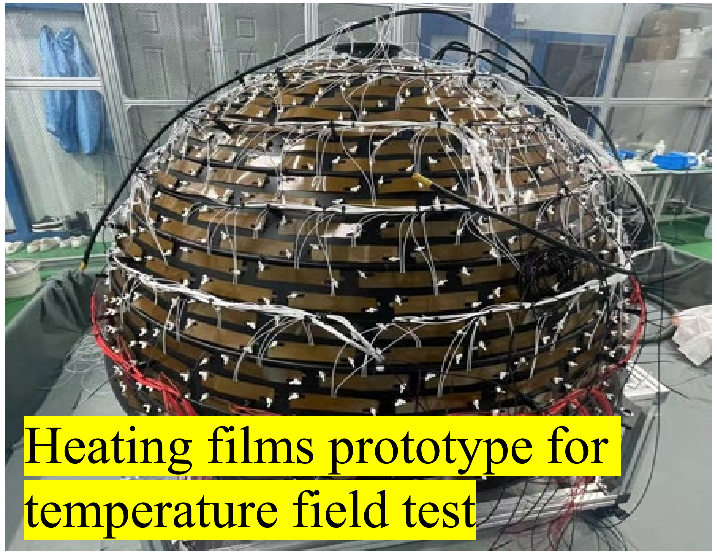
- LAB + 3 g/L PPO + 2 mg/L bis-MSB + **0.5% DPnB (co-solvent) + 0.1% Gd**
  - R&D reveals key requirements: co-solvent, water purging
  - Engineering: 1) uniform low-temperature field → thick copper shell as temperature stabilizer (detector running @-48 ± 0.5℃); 2) water purging of the LS and detector with N2

Co-solvent maximize fluor concentration



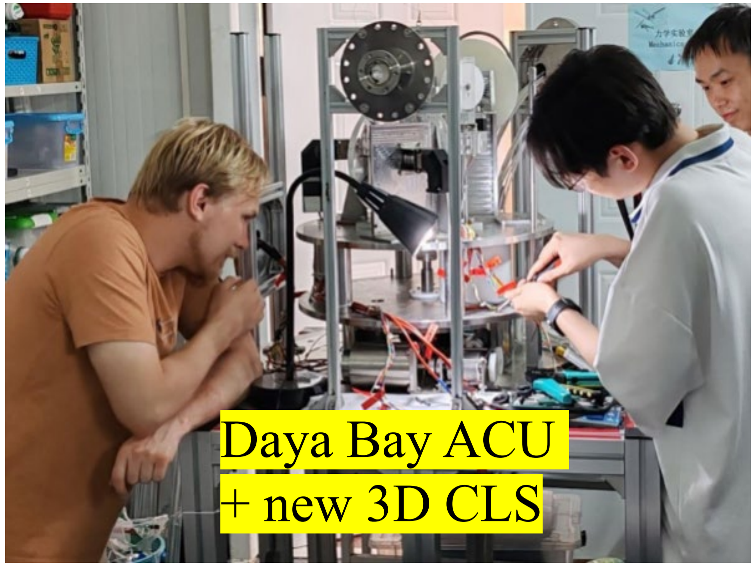
Water influences transparency

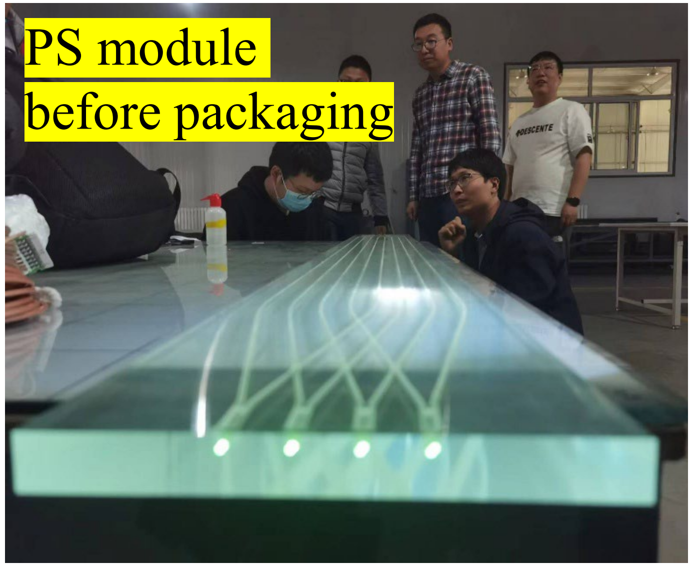


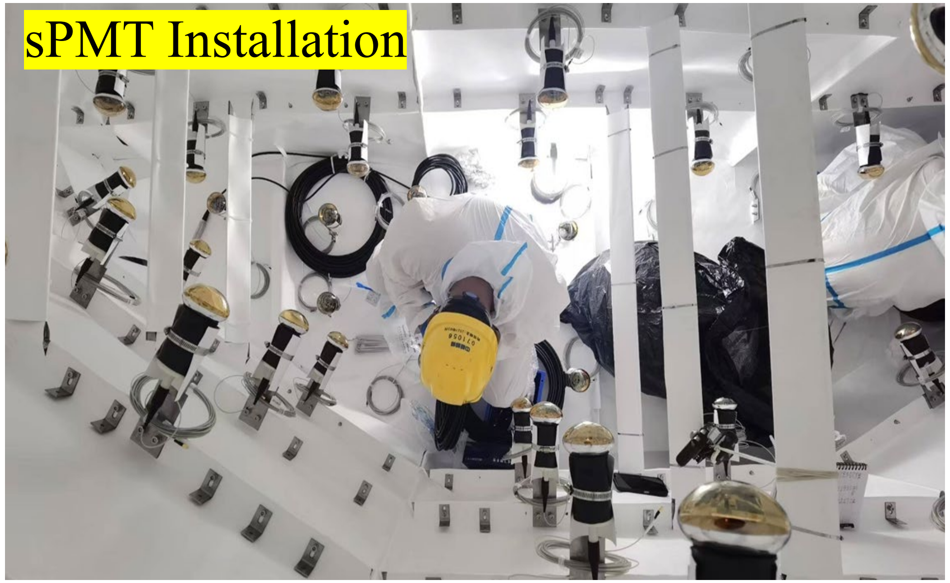


Heating films prototype for temperature field test

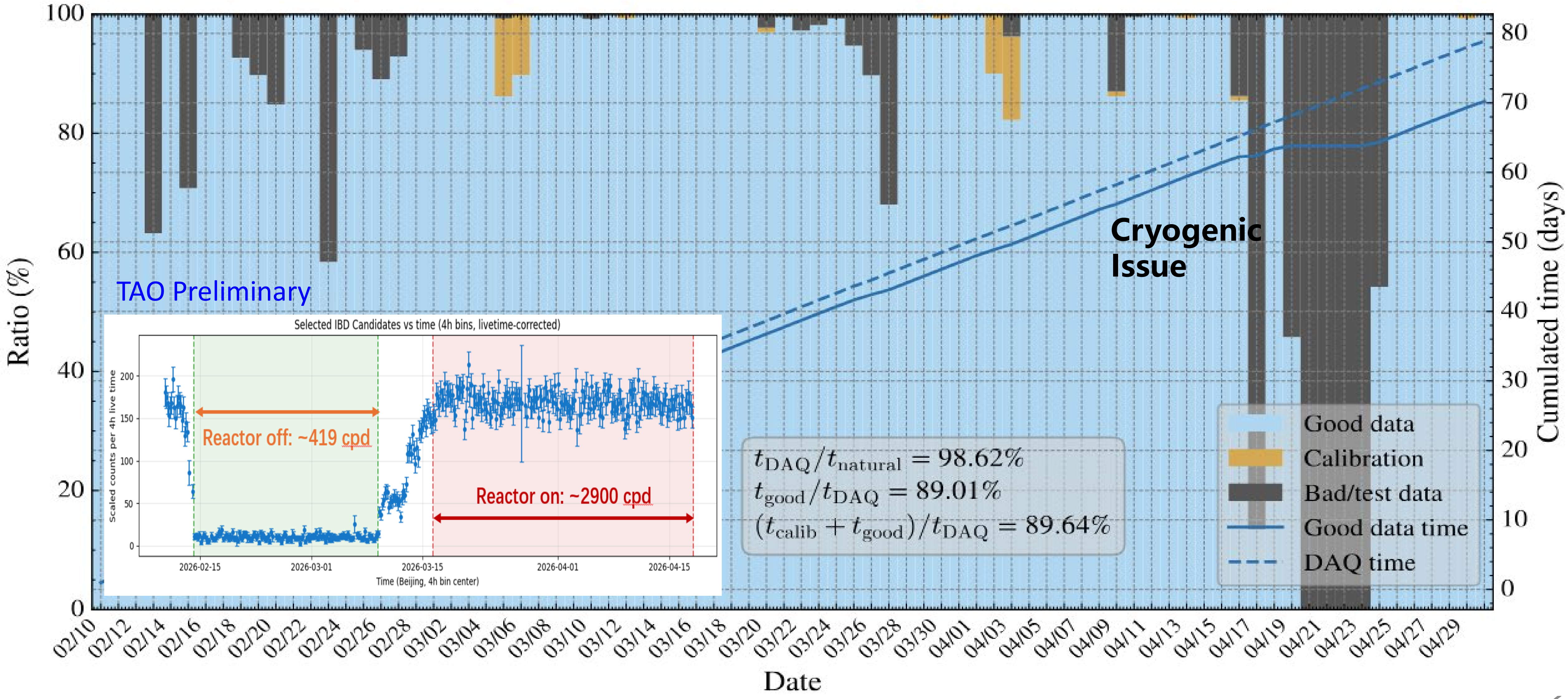
Calibration and Veto Systems





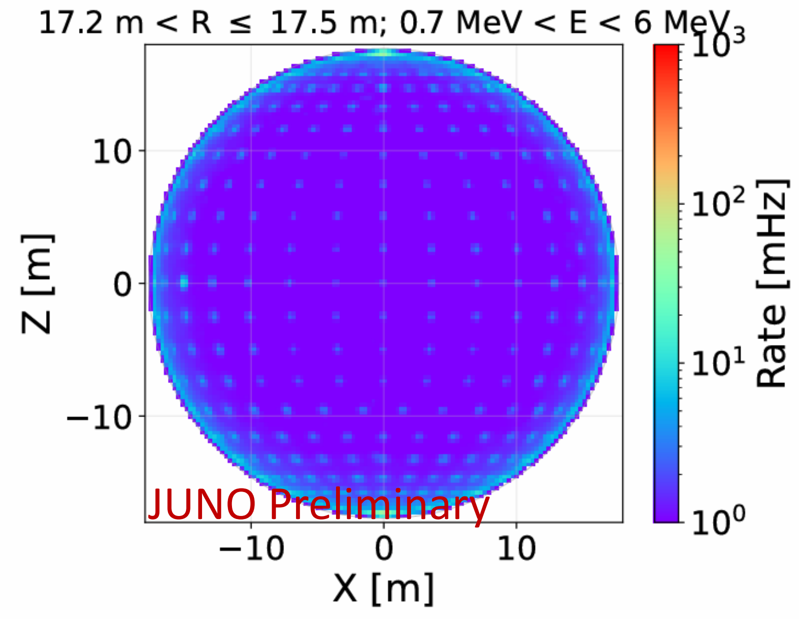


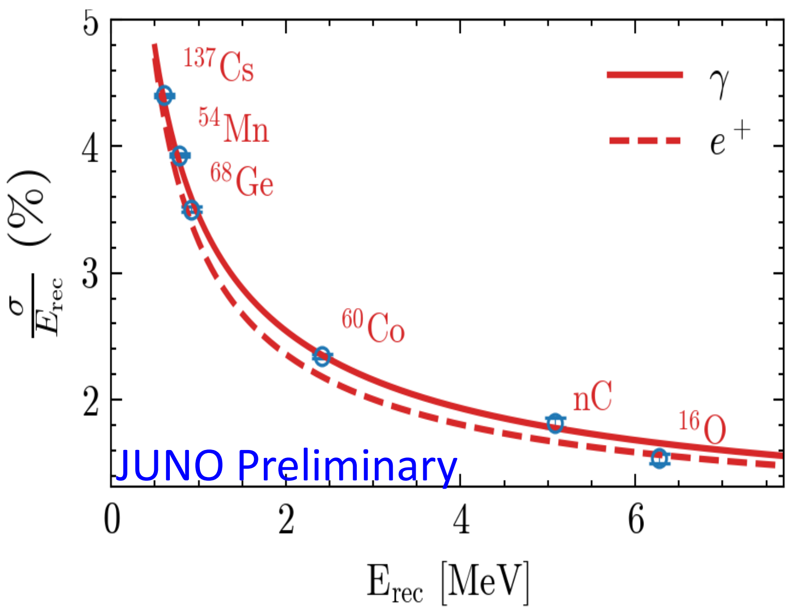
Detector in Stable Data-taking

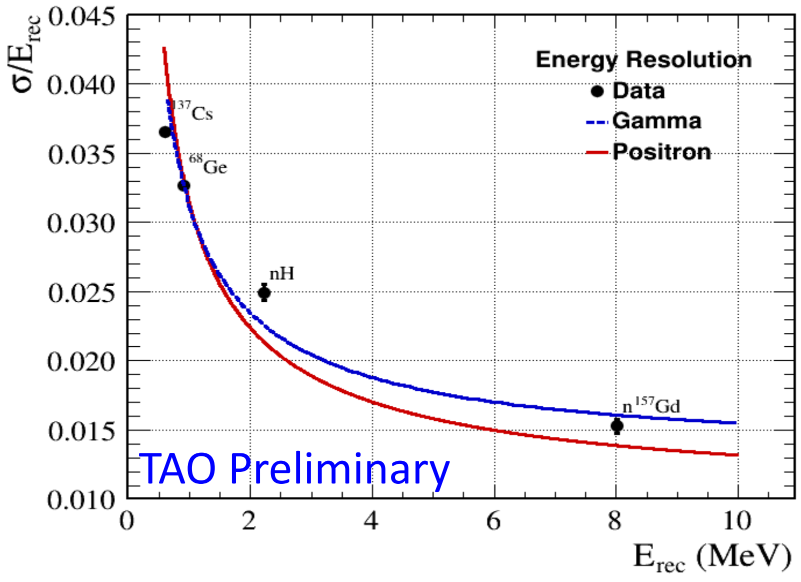


JUNO/TAO Key Performance

- ☐ JUNO / TAO energy resolution, 3.5% / 2.8%@Ge-68 (~1MeV) (design 3% / 2%)
  - Further improvements ongoing
- ☐ JUNO low background: **detector is cleaner than design**
  - Dominating radioactivity is from PMT glass and SS node







Summary and Outlook

- JUNO and its satellite TAO detectors have cutting-edge and innovative design
- Both detectors are constructed and in stable data-taking
- Tremendous efforts to make JUNO a precise and clean detector, giving its large scale
- TAO is relatively small but with similar level of complexity, hard assembly
- Next chapter: operate the detectors safely and stably, further improve the detector performance (in particular the energy resolution)


Thanks!
江门中微子实验

Merci!