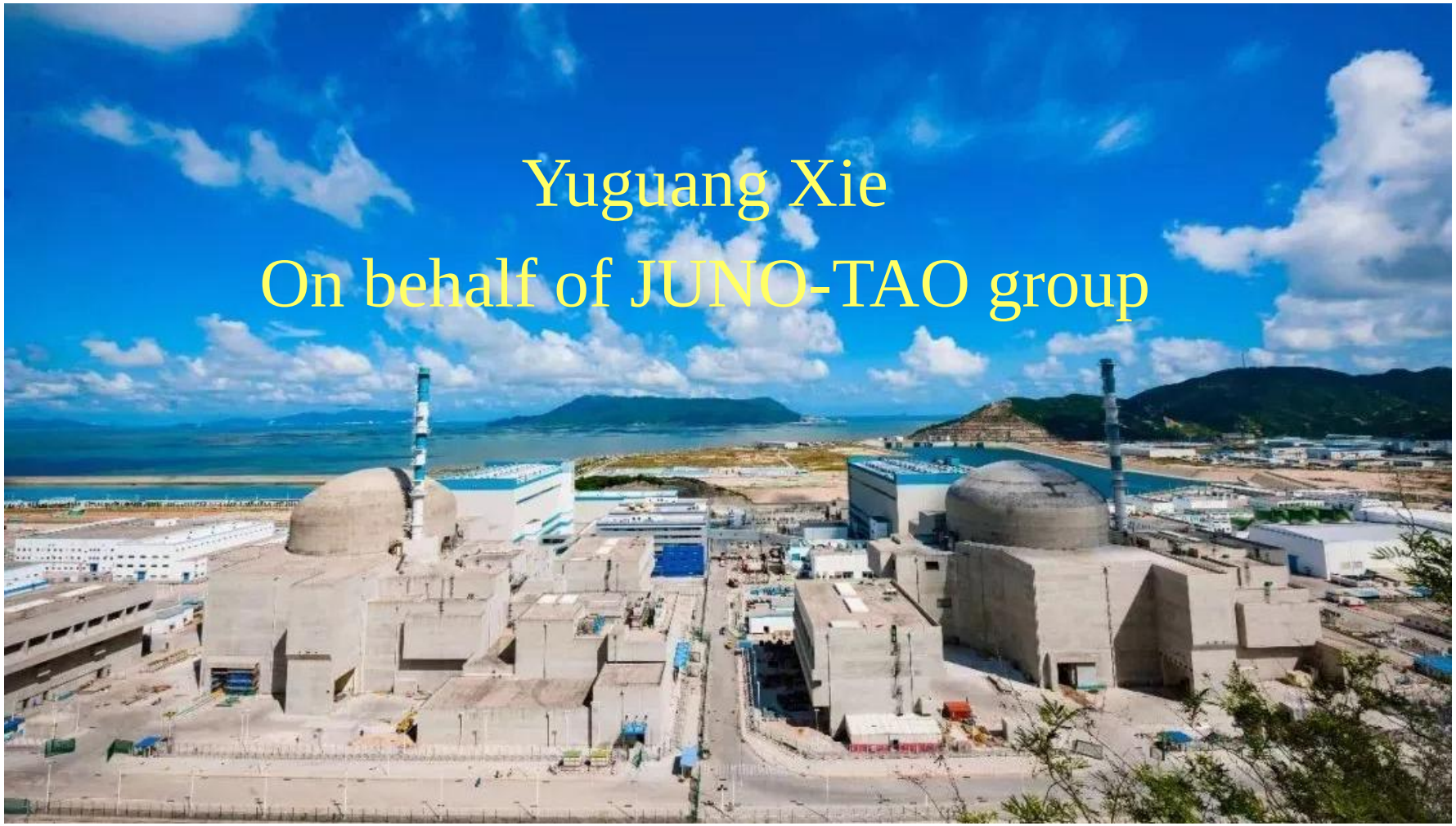
Status of the JUNO-TAO Detector

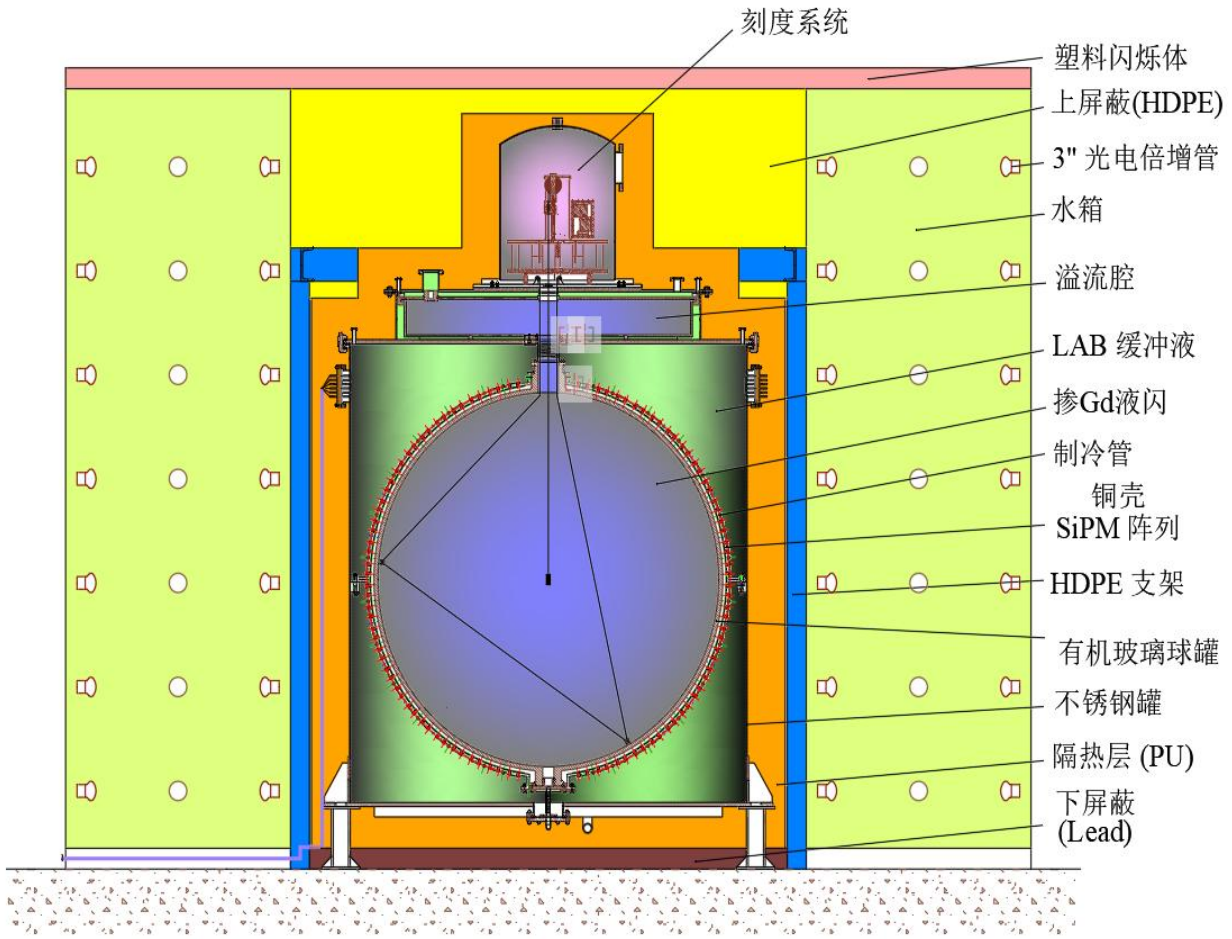


Yuguang Xie

On behalf of JUNO-TAO group

Outline

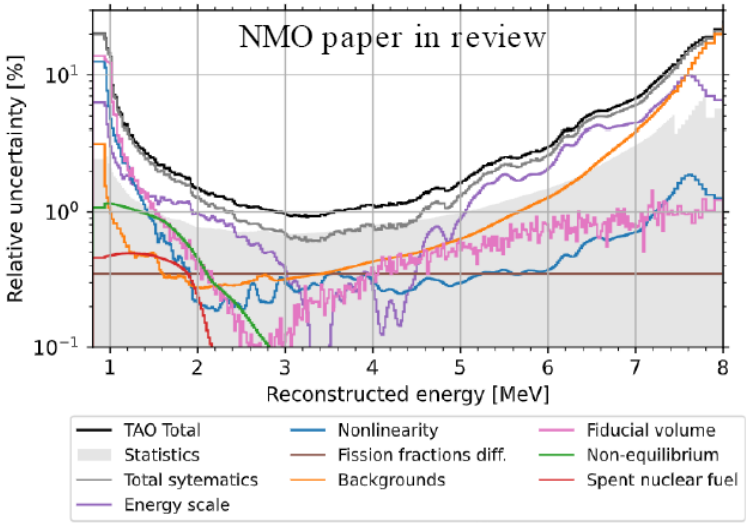
- TAO's goals
- TAO Detector
- LS production
- SiPM & Electronics
- 1:1 experiment
- Taishan laboratory
- Summary

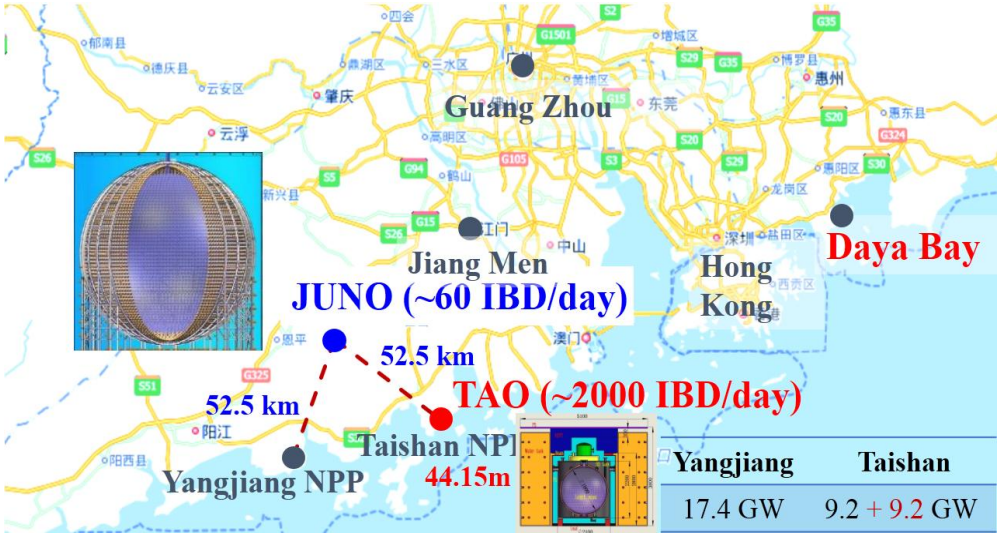


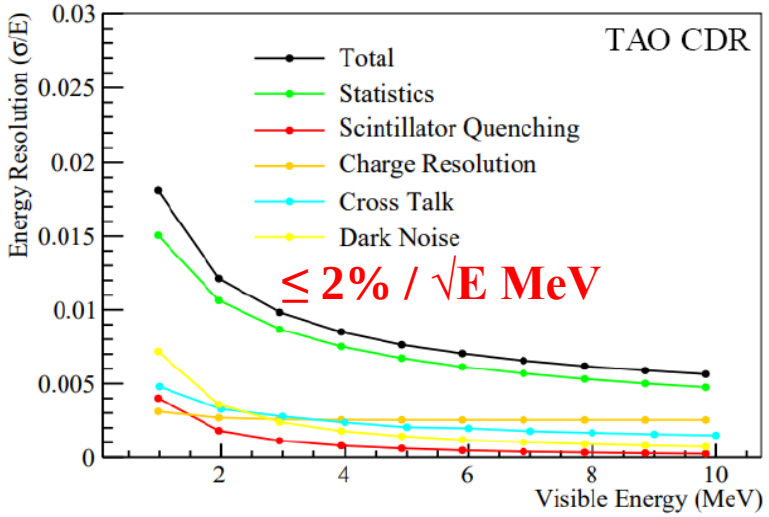
I. TAO's goals

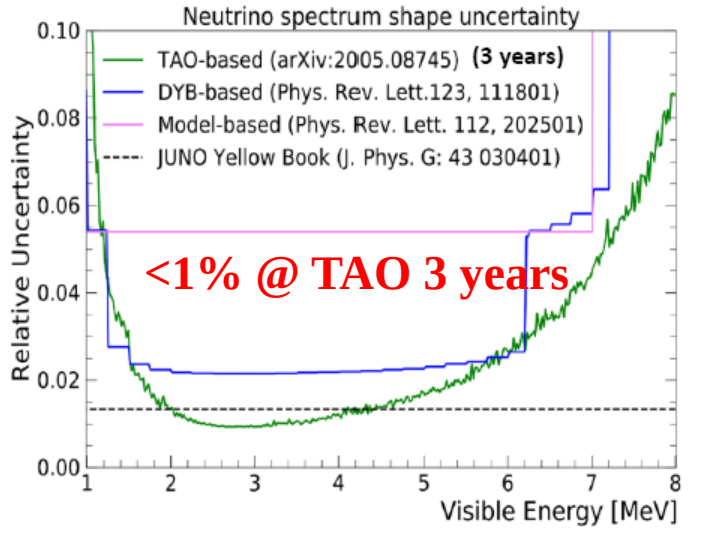
Taishan Antineutrino Observatory (TAO or JUNO-TAO) is a ton-level, high energy resolution liquid scintillator (LS) detector running at -50℃.

- A satellite detector of JUNO. To reactor core: JUNO: 52.5km; TAO: 44.15m
- Measure reactor neutrino spectrum w/ sub-percent E resolution.
- Physics goals:
  1. Model-independent reference spectrum for JUNO
  2. A new benchmark for investigation of the nuclear database
  3. Spectrum fine structure observation, shape anomaly study
  4. Reactor monitoring: status/fuel
  5. New physics: sterile neutrino









II. TAO Detector

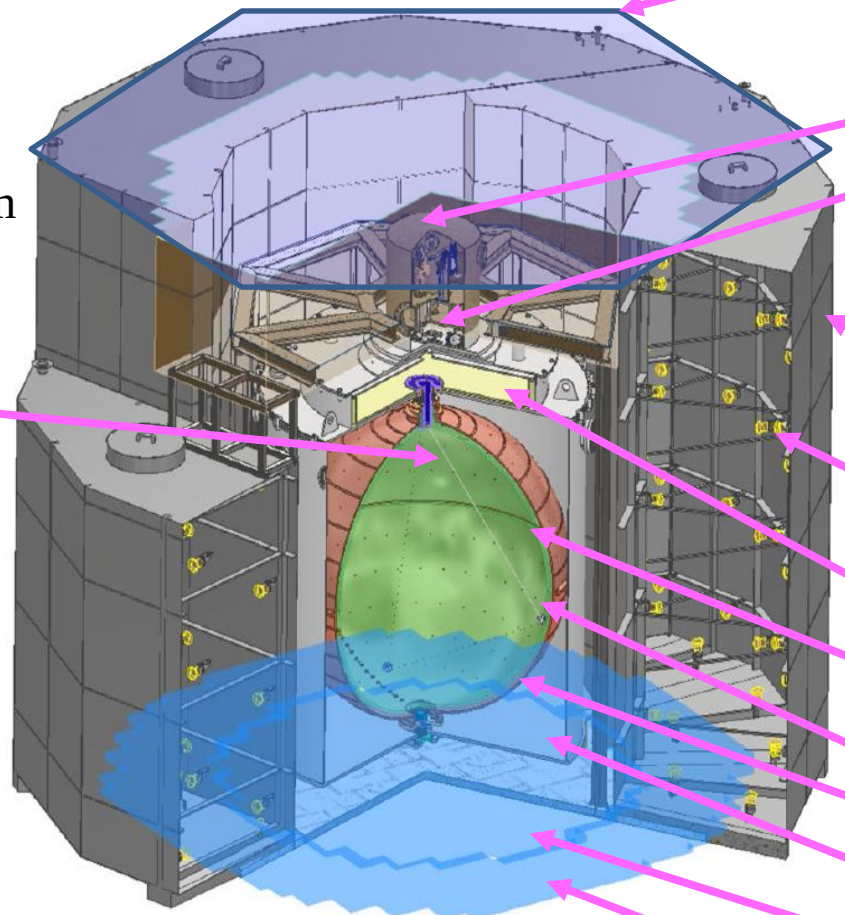
Scheme: full coverage high PDE SiPMs, Low-temperature new recipe LS

Highlights:

- Energy resolution <2%@ √E MeV
- SiPM PDE >50% (~4000 p.e./MeV)
- SiPM coverage: 94% of ~4π, ~10m^2
- SiPM DCR: <100 Hz/mm^2 @-50℃
- Dewatering Low-temperature LS : <10ppm

◆ Central detector

- **Acrylic sphere** 1.8m (ID), 20mm-thick with 2.8 t Low-T Gd-LS
- **Copper shell** 1.886m (ID), 12mm-thick with 4024 pieces of 50*50mm^2 SiPM tiles
- **SS tank** 2.09m(ID), 10mm-thick with 3.2 t LAB/Gd-LAB
- **Cryogenic system** with 4.5kW cooling power and 150mm-thick melamine foam full covering keeping -50℃ running condition



◆ Top Veto Tracker (TVT)

4-Layer PS, 160 strips
2 m×20 cm×2 cm/strip

Top Shield(HDPE)

◆ ACU & CLS

6 types of exemption sources

◆ Water Tank

3 irregular water tanks
~300 3" PMT

Overflow Tank
Cu Shell
SiPM Array
Acrylic Vessel
SS Tank
Insulation (MF) Bottom
Shield(Lead)

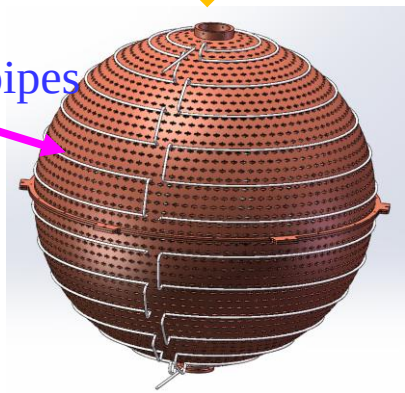
1. Central Detector (CD)

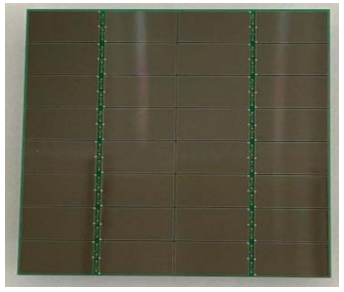
- **Acrylic Sphere (AS) :** 1.8m (ID), 20mm-thick, 93% transparency as JUNO AV
- **Copper shell(CS) :** 1.886m (ID), 12mm-thick, Oxygen-free copper, Ultra-low radioactivity and best thermal conductivity, SiPMs and AS support
- **SS tank:** 2.09m(ID), 10mm-thick, U:<0.11, Ra:1.89, Th: <0.07, K-40:0.25 Bq/kg
- **Cryogenic system:** 4.5kW cooling power, SiPM & FEB heat power: ~ 2kW, heat leakage: 0.5kW, cooling pipes on CS and SS tank

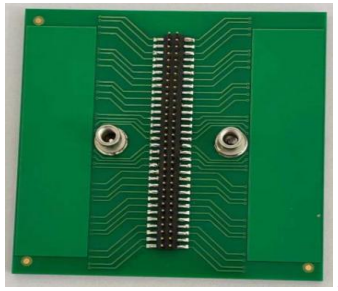
150mm-thick melamine foam full covering

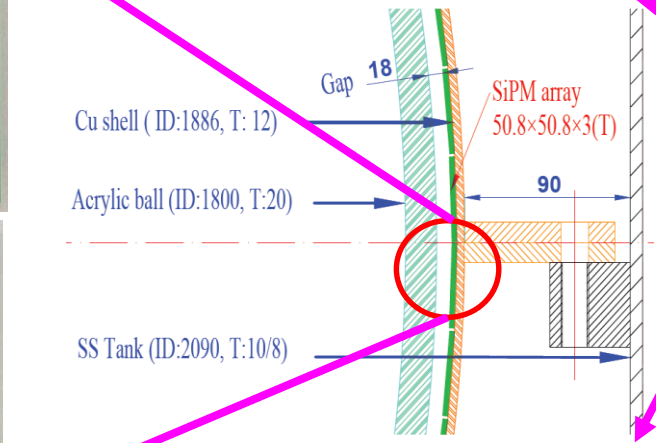
keeping -50±0.5℃ running condition inside tank

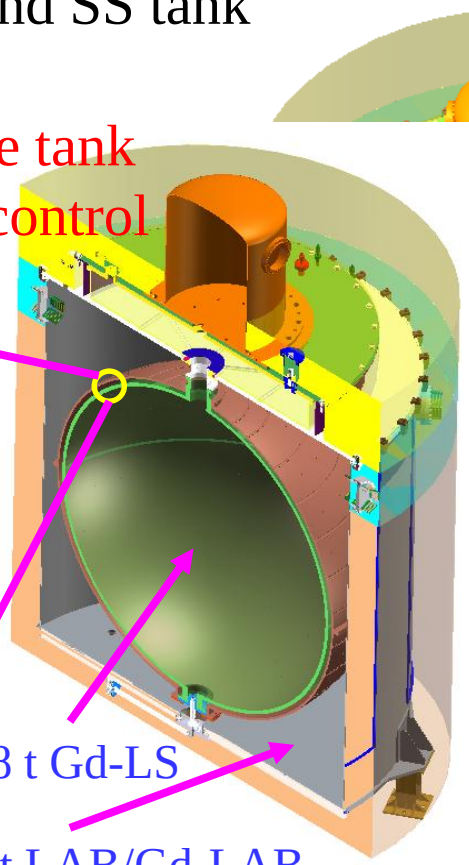
All materials used in CD passed radioactivity control

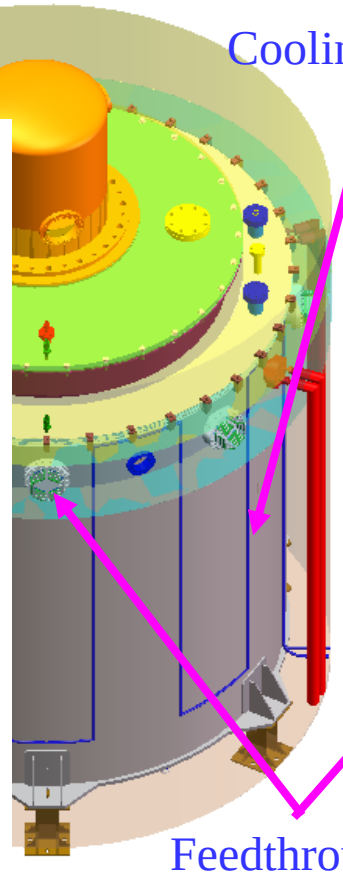












Total 4024 SiPM tiles

Gaps : 0.4~1.0 mm

2.8 t Gd-LS

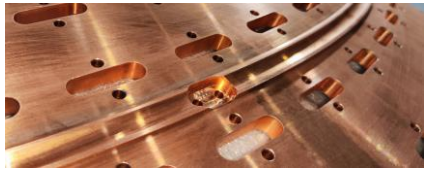
3.2 t LAB/Gd-LAB

Feedthroughs

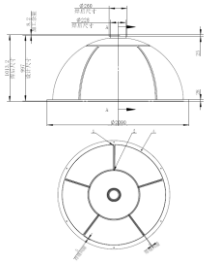
◆ Copper shell production (welding is very challenging)

- Started from March 2021, up-semi CS done in Feb. 2023, down-semi CS done in May 2023. Welding patent granted.
- Precision: Inner diameter(1886)<0.5mm, thickness(12)<0.2mm, flatness(1910)<0.08mm; hole diameter(5.3)<0.05mm, angle(4π)<0.01° , position(4π)<0.04mm. Tile models mounting easy, gaps reasonable.

SS tank inner surfaces, CS all surfaces, accessories contacting with liquid, all were coated with PTFE(25~50um) for LAB/LS compatibility requirement.



Cutting → Molding →Welding → Machining



Dividing(8 parts)

Molding

Assembly & welding

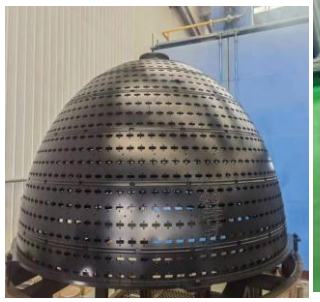
Welding done

Turning and milling

Machining done

Degreasing

Sandblasting

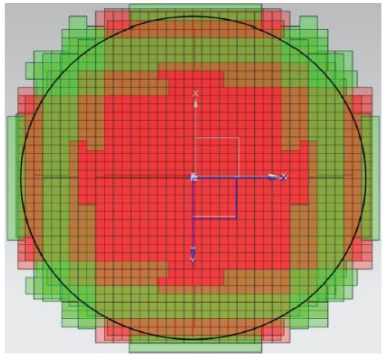


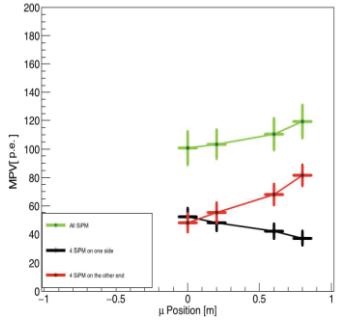
PTFE coating done

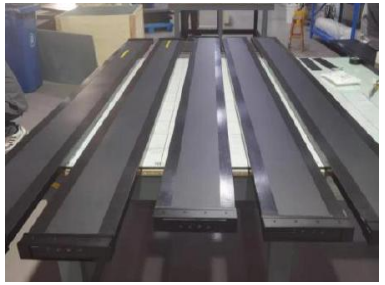
2. Muon Veto system

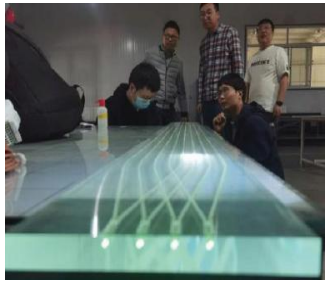
◆ Top Veto Tracker (TVT) by Sun Yat-sen University

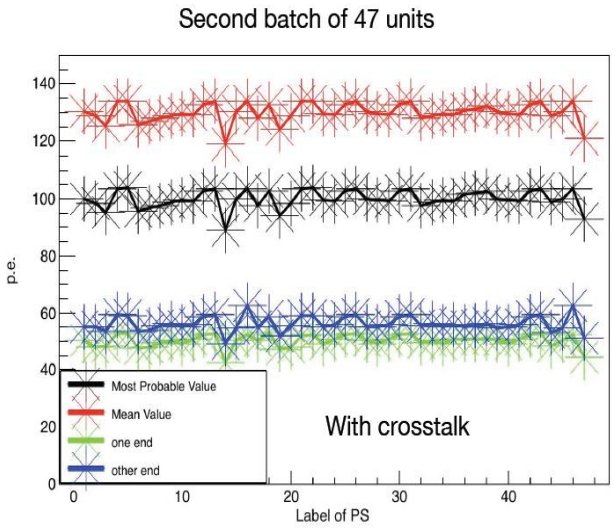
- Plastic scintillator + SiPM + WS-fiber
- >99% μ tagging efficiency @ 64 p.e.
- 4-Layer PS, 160 strips, 2 m×20 cm×2 cm/strip
  2.4m attenuation length, 9000 ph/MeV, 40 and 47 p.e.
- 4 Sensl J-40035 SiPMs one end, total 1320 pieces
  optical grease coupling(5 p.e. up)
- 57 PS produced and accepted, test system verified.
- Production done in Oct., test done in Dec.











◆ Water Tank (WT)

- 3 irregular water tanks
- ~300 3 “ PMT from Daya Bay
- Water quality monitored for ~5 months, no big change, no cycling needed.
- Water tank prototype test ongoing.
- Production in Oct., installation in Dec. 2023.

◆ Readout

- WT: JUNO SPMT electroics(Catiroc)+GCU+TDAQ
- TVT: SiPM+FEB+GU+TDAQ

3. Calibration system (Eur. Phys. J. C 82 (2022) 12, 1112)

- Automated Calibration Unit (ACU, update from Daya Bay's), on Z-axis

To calibrate non-linearity between kinetic energy and released photons in LS

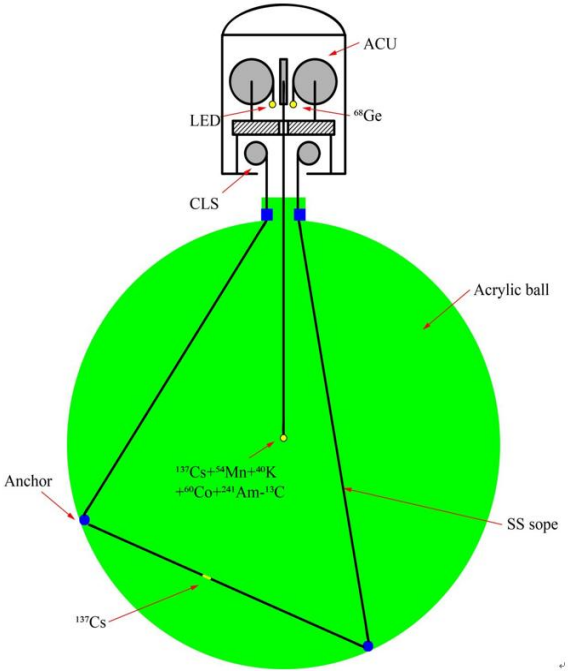
  - ^{68}Ge (e+), ^{137}Cs + ^{54}Mn + ^{40}K + ^{60}Co + AmC (γ), most are exempted sources
  - UV-LED（265nm, wavelength adjustable, for 1:1 experiment, by MSU & JINR）

- Cable Loop System (CLS, refer to JUNO CLS), off Z-axis

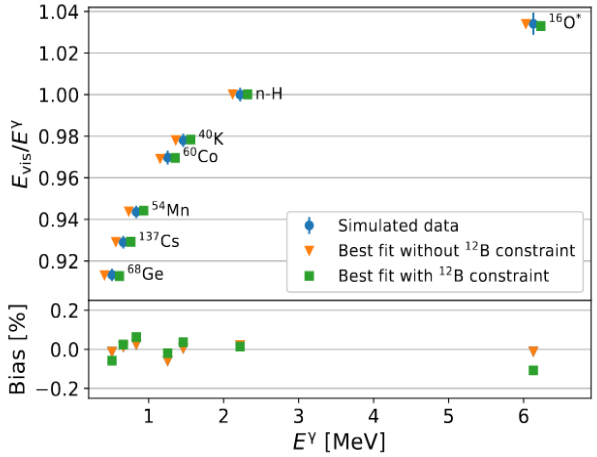
To calibrate non-uniformity at different positions in LS

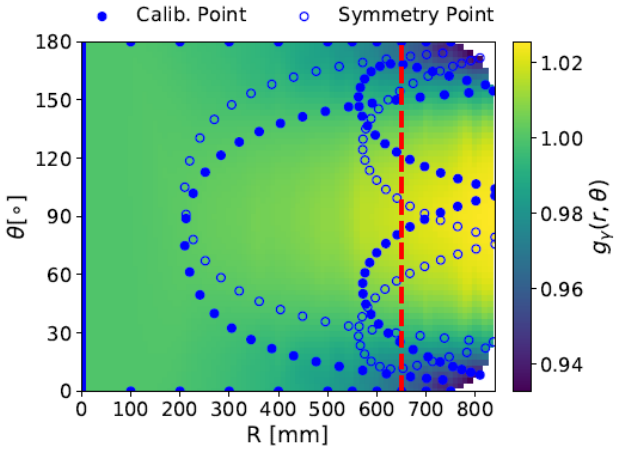
  - ^{137}Cs (γ)

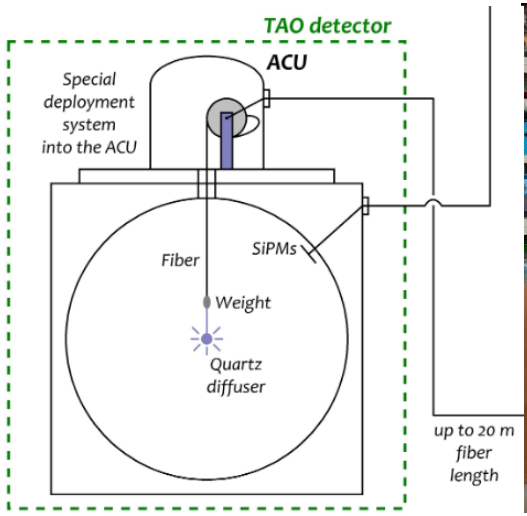
- E non-linearity < 0.6%, non uniformity < 0.2%.
- Sources are in production, ready in Oct. 2023.
- ACU, CLS and LED system were integrated and tested.
- Sources movement and PLC control system were optimized in low temperature.

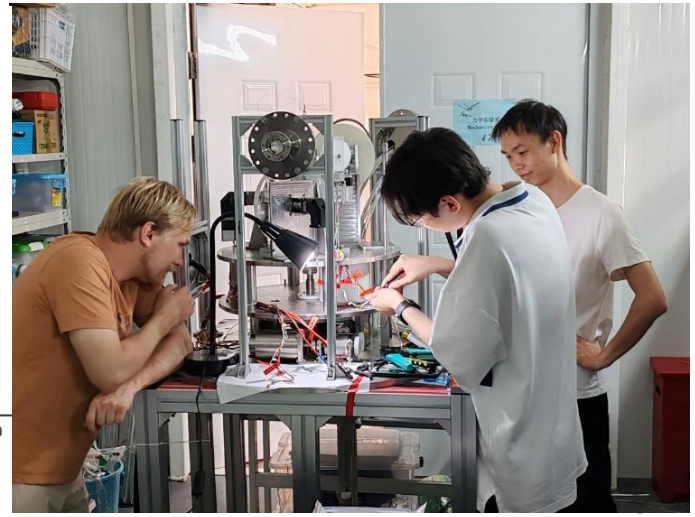


Source	Type	Radiation	Activity [Bq]
^{137}Cs	γ	0.662 MeV	50
^{54}Mn	γ	0.835 MeV	50
^{60}Co	γ	1.173 MeV + 1.333 MeV	10
^{40}K	γ	1.461 MeV	10
^{68}Ge	e^+	annihilation 0.511 MeV + 0.511 MeV	500
^{241}Am-^{13}C	n,γ	neutron + 6.13 MeV (^{16}O*)	2 (neutron)
$n(p,\gamma)d$	γ	2.22 MeV	2 (neutron)





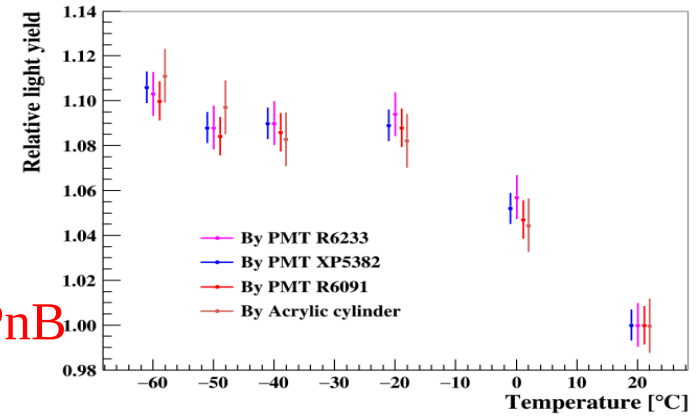


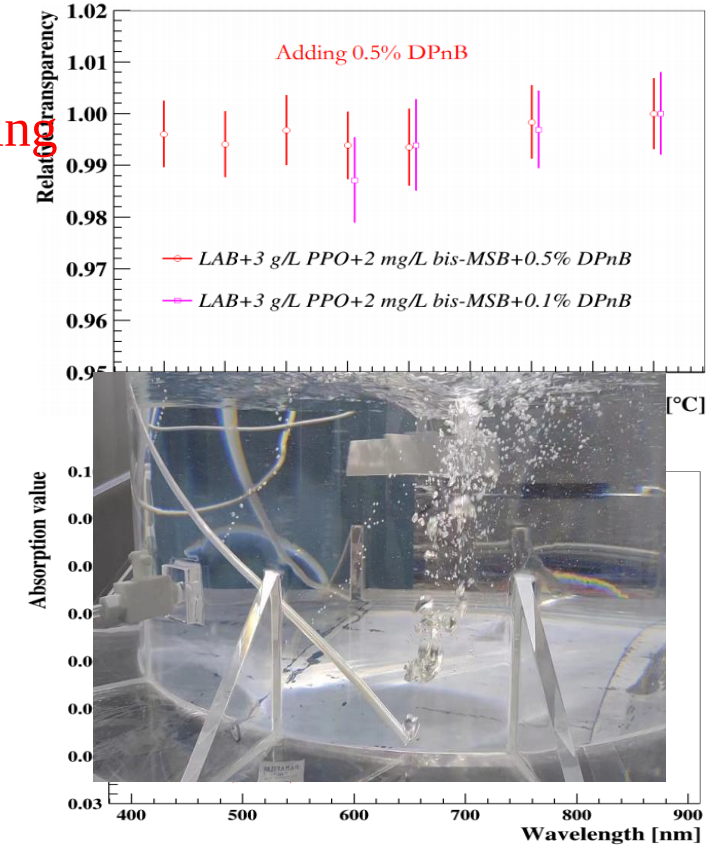


III. LS production

1. Low temperature LS (DOI: 10.1016/j.nima.2021.165459)

- High light yield & flash point & transparency
- Low water content and good stability at -50℃, new recipe needed!
- Final LS Recipe: LAB + 3 g/L PPO + 2 mg/L bis-MSB + 0.1%Gd + 0.5%DPnB
- DPnB co-solvent helps all solutes to dissolve at low T.
- N2 bubbling reduces water content from ~100 to < 10 ppm level.
- Massive material compatibility tests were done, some verifications are ongoing.
- TAO-LS precision chariacterization was also studied (by Hans Steiger et.al.)



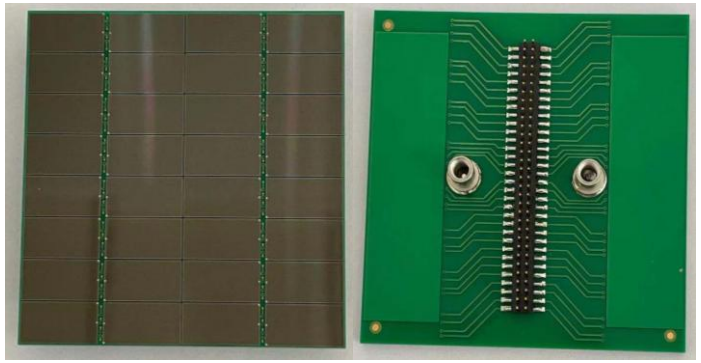


2. Mass production

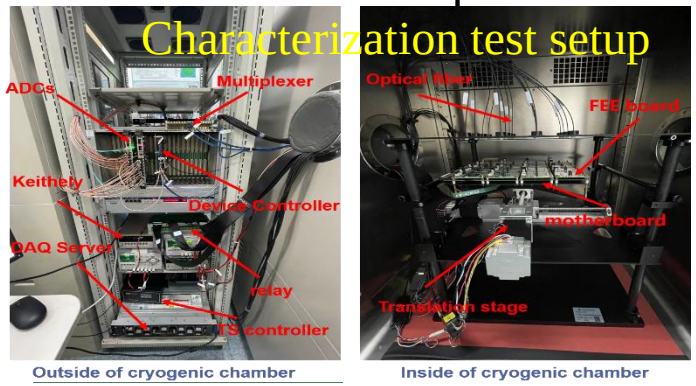
- For LAB: No Gd doped in 1:1 prototype, 3.5t ready.
- For LS: Add PPO/bis-MSB/DPnB/LAB (for dilution), circulation, finished.
- Nitrogen bubbling (15L/min for ~5h, ongoing) before filling in mid of this September.

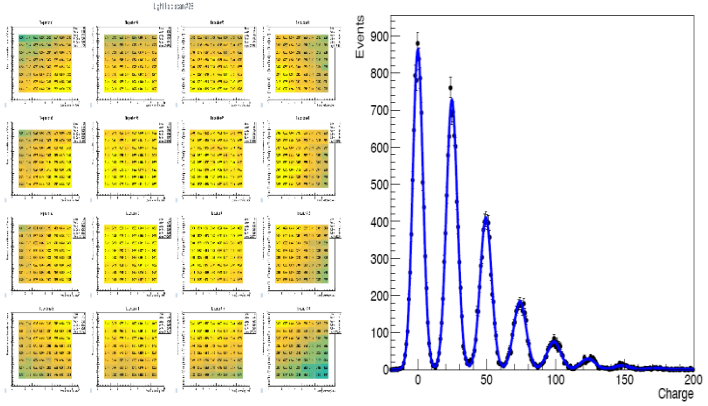
IV. SiPM & Electronics

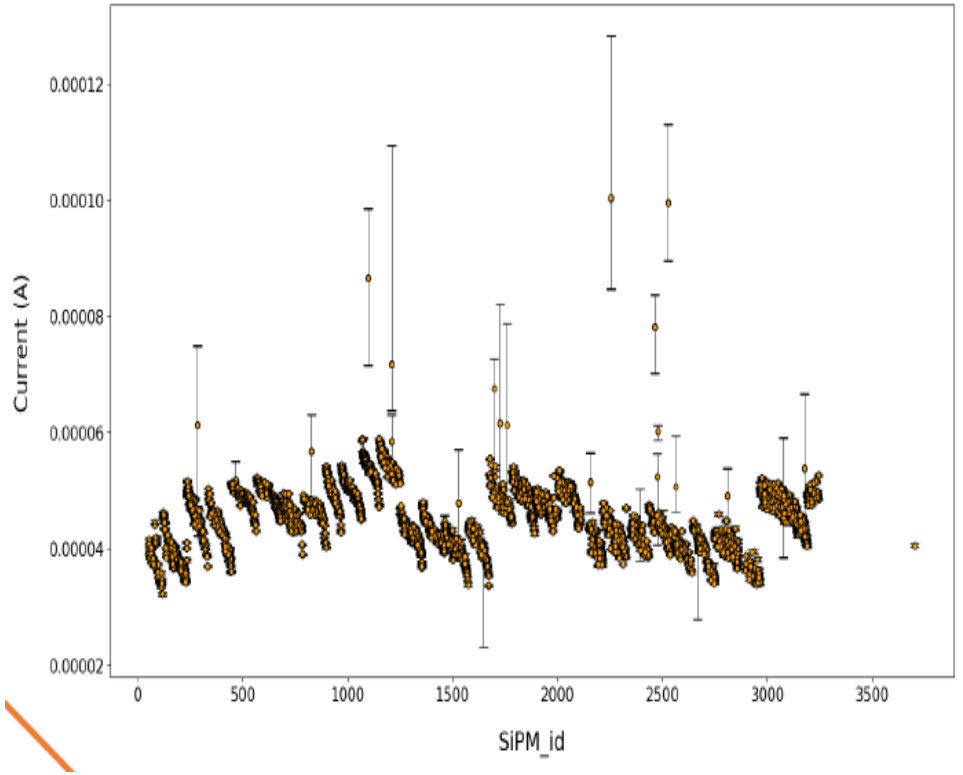
1. SiPMs and mass testing



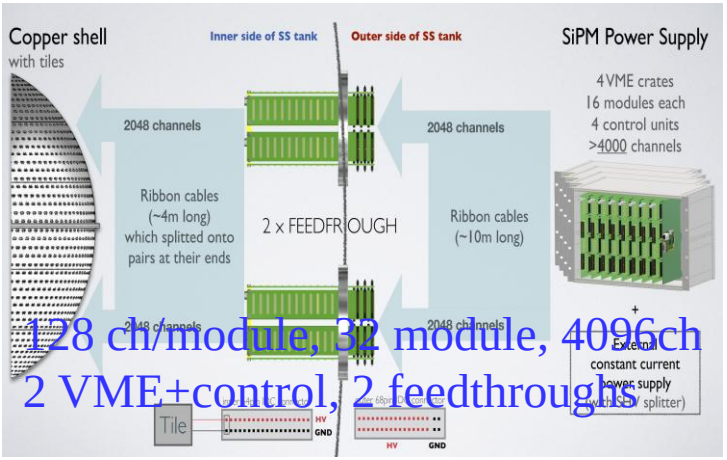
- SiPM tile: Hamamatsu s16080, 16ch/tile, 4100 pieces arrived, ~3000 tested
- Visual test, burn-in test and characterization test in -50℃ for all SiPMs.
- Characterization test data analysis is still ongoing.
- ~0.3% surface defect/tile; ~0.6% abnormal current in burn-in test;
  ~0.7% abnormal performance in characterization test.







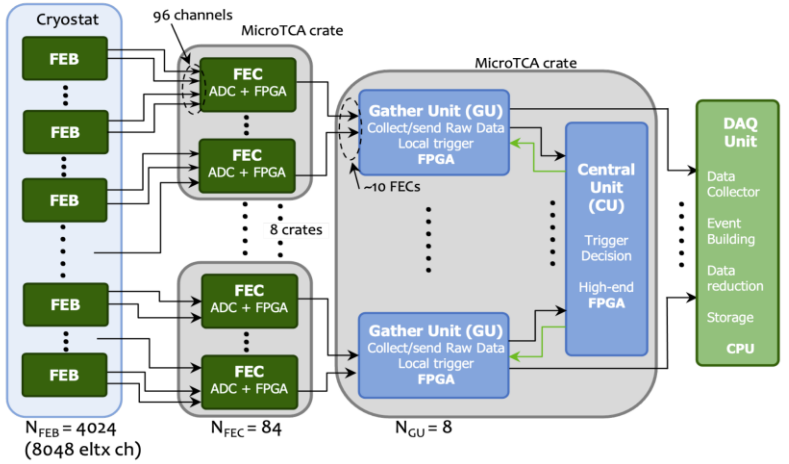
- SiPM power (by DUBNA JINR)

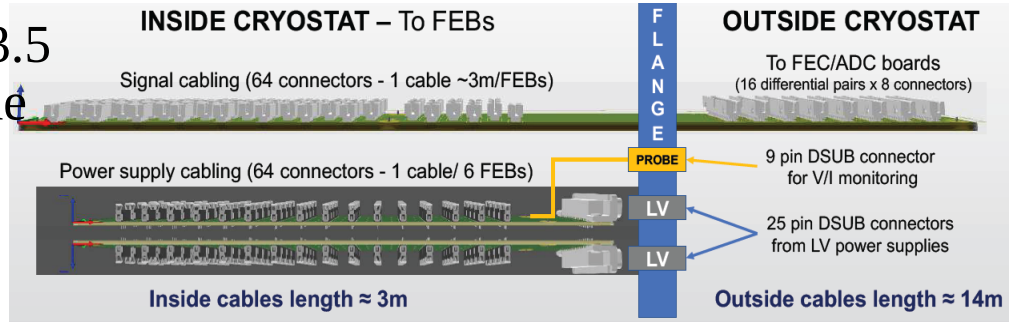


128 ch/module, 32 module, 4096ch
2 VME+control, 2 feedthroughs

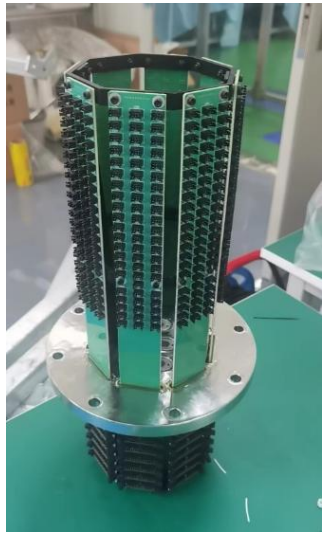
2. SiPM electronics(by INFN, IHEP and USTC)

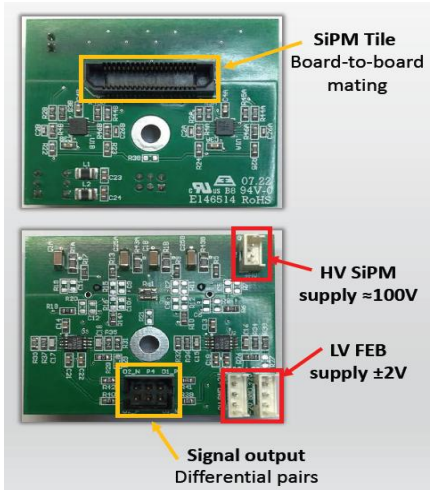
- Final scheme: SiPM+FEB+FEC+(GU+CU)+TDAQ (for CD)
- 2chs/tile, 8048chs total, noise<0.1 p.e.; time resolution<1ns.
- ADC: 250MHz/12bit, 2Vpp input, DR:1 – 180 p.e./ch
- Data rate: FEC→TDAQ: ~70 Gbps, TDAQ→Disk: ~100 Mbps
- 100 FEBs passed test and ready for 1:1 experiment, protected with epoxy glue.
- Cables: analog readout inside tank with differential pairs, 1.5 ~ 3.5 m five types of length, protected with PTFE for each tile. Outside length ~14m.
- Joint commissioning will start soon.

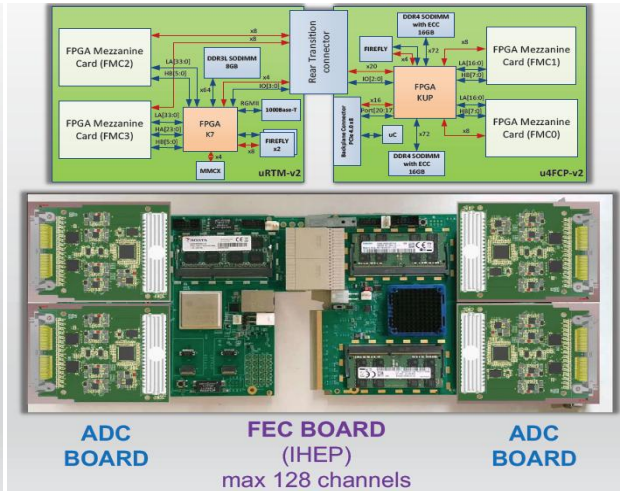




FEB with low radioactivity Aramid PCB (<0.25Bq/kg)







TDAQ details in Xiaolu's talk in A3 session this afternoon.

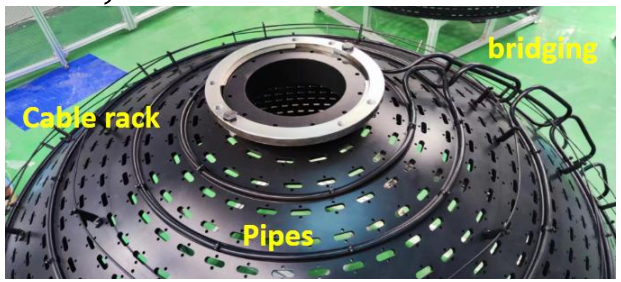
VI. 1:1 experiment

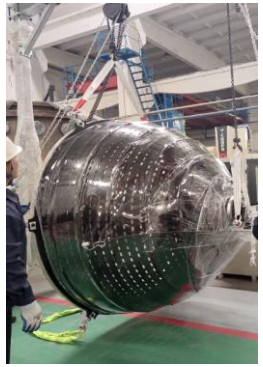
1. Purpose

- Test key installation procedures with a part of condition limitations in Taishan, avoid big issues and save time on site, very important! (Such as CS rotation, SiPM assembly, Cabling, tools)
- Test performance of cryogenic system, real SiPM tiles (~100), LS, calibration system, etc..

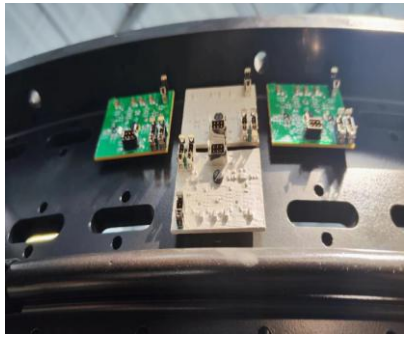
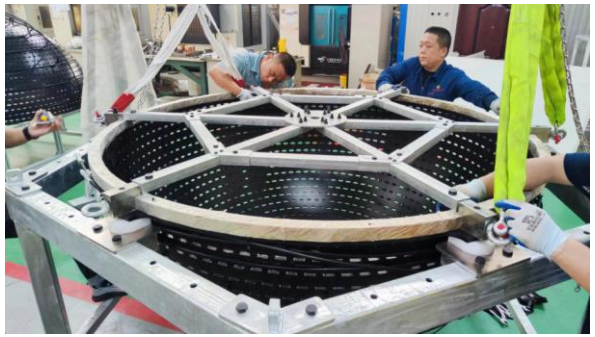
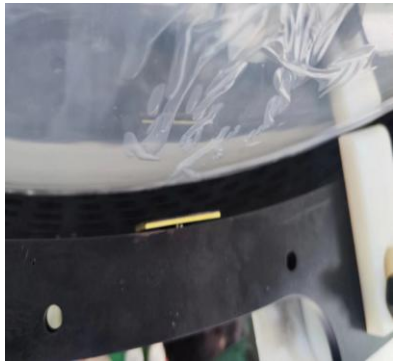
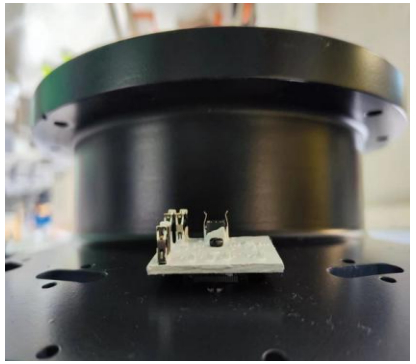
2. Progress

- All key installation steps and tools verified.
- SiPM tiles assembly procedure optimized, in 10k class clean shed.

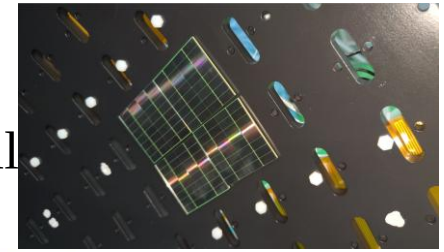


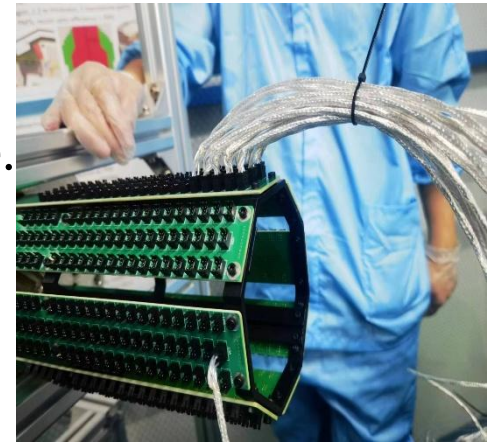



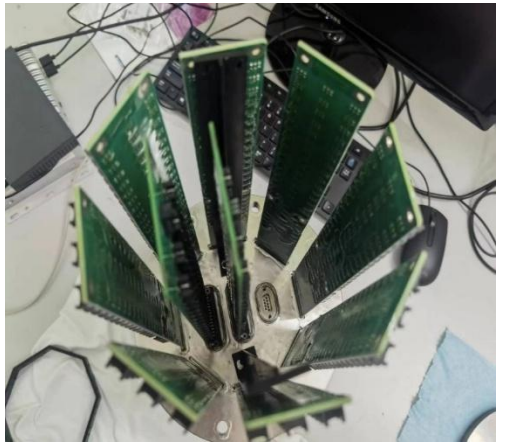


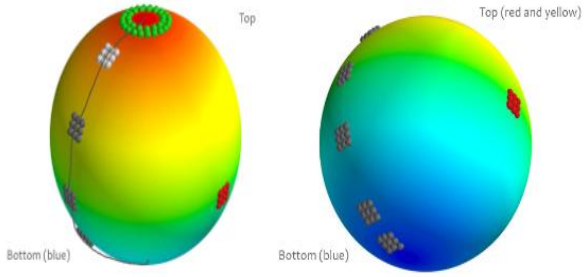





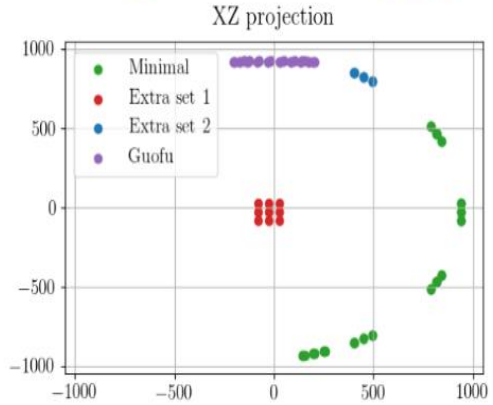
- All parts (including tools) were clean with Alconix detergent or alcohol or pure water flushing.
- ~ 100 real SiPM tiles and FEBs had been mounted on CS.
- 1900 pieces heating films had covered most of CS surfaces.
- Feedthroughs leakage check passed.
- Issues found in SiPM cabling: different length scheme is mustbe.
- CS and acrylic sphere assembly ongoing.
- Commissioning planned in Sept. 20th.
- Acrylic sphere, CS, SiPMs and SS tank will be reused in Taishan

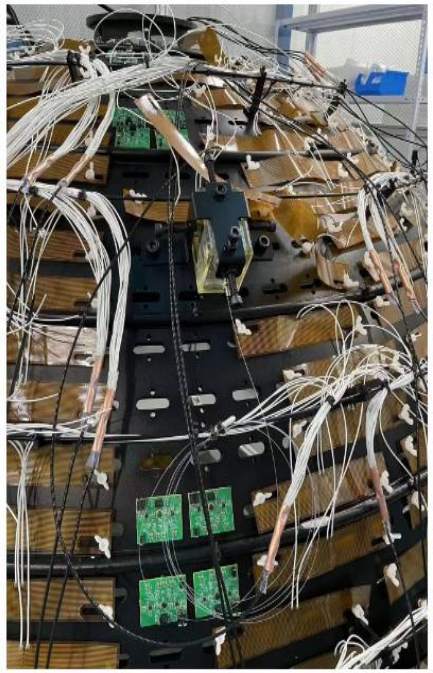


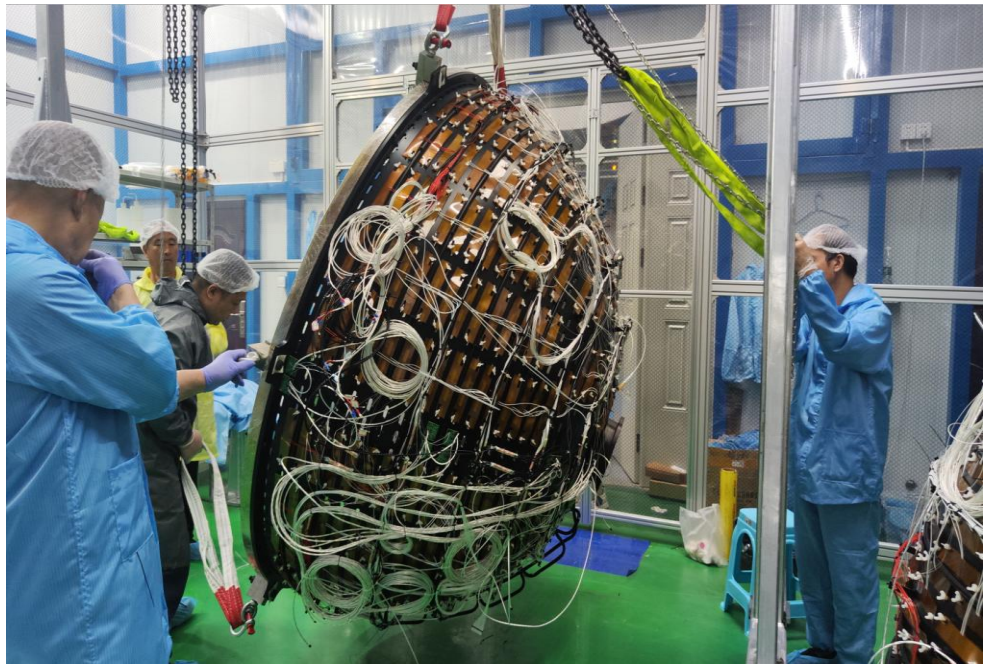




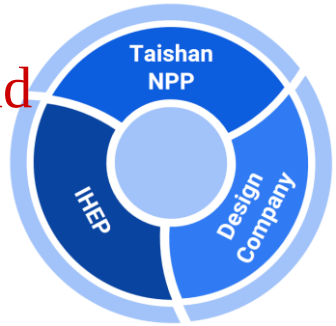








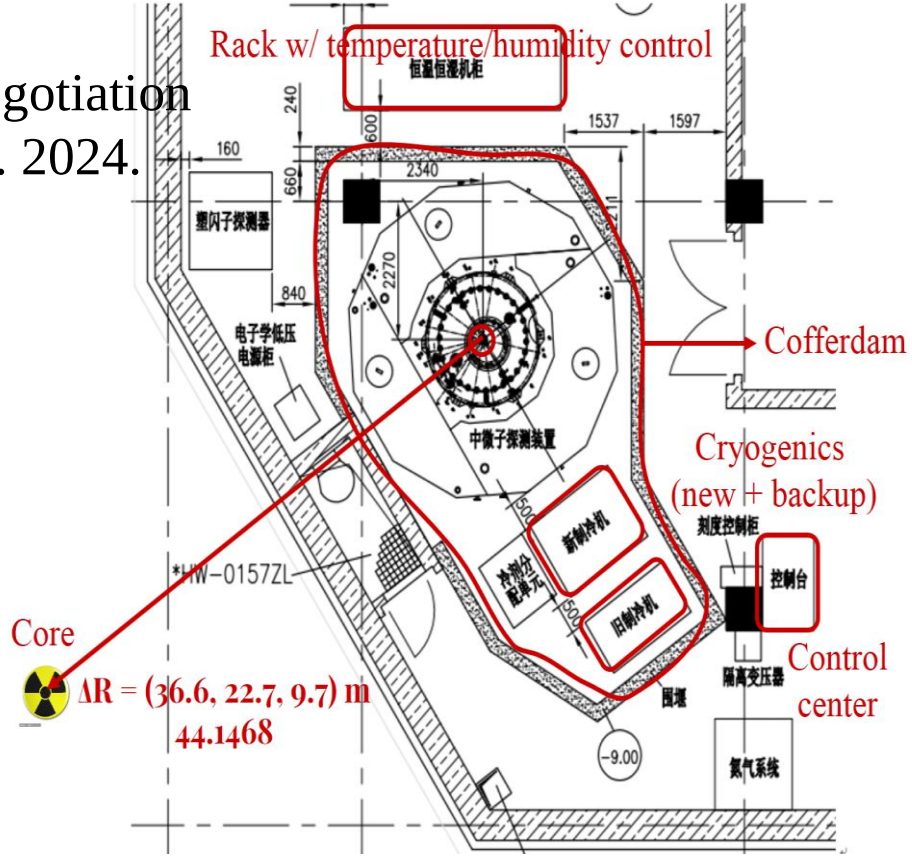
VI. Taishan laboratory



- Project application and approval is precondition for TAO success. It is complicated and time consuming. Key issues: safety concern, nuclear-level engineering standard.

- ✓ Core determined: #1, distance: △R(36.6, 22.7, 9.7)=44.15m
- ✓ All site conditions and limitations were checked for transportation and assembly onsite (with installation company).
- ✓ Hall layout scheme mostly fixed.
- ✓ Inspection / maintenance / contingency plan and responsibility: in negotiation
- ✓ FDR in review, lab construction will start in Feb.2024, ready in May. 2024. Early onsite work may start in March 2024.

Lab layout



VII. Summary and outlook

- TAO is an attractive and challenging near core neutrino experiment.
- Many subsystems in a good shape, and reach ready status by the end of 2023.
- TAO will be online in 2024.

Thank you!