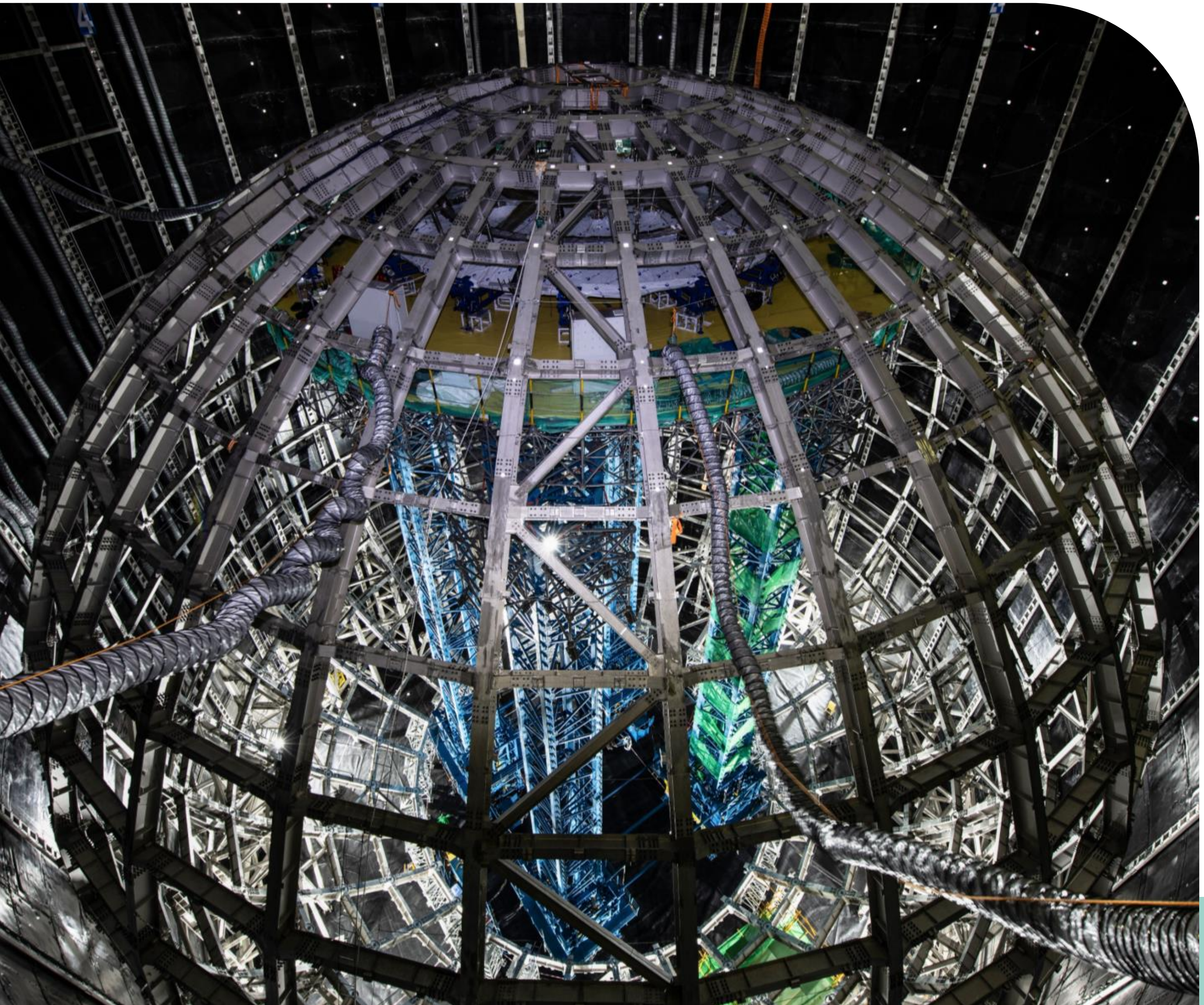
Detector design and current status of JUNO experiment



Claudio Lombardo[ab] on behalf of the JUNO Collaboration

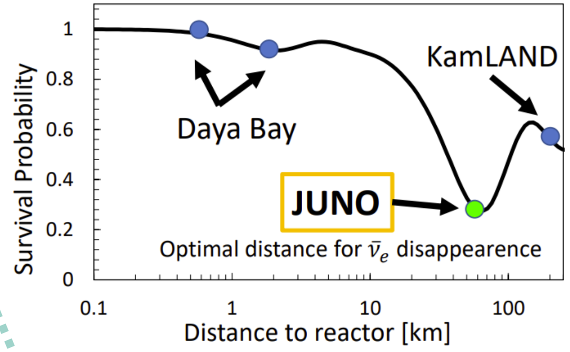
[a] University of Catania, department of Physics and Astrophysic "E.Majorana"

[b] INFN - Catania

EPS-HEP Universität Hamburg 21-25 August 2023

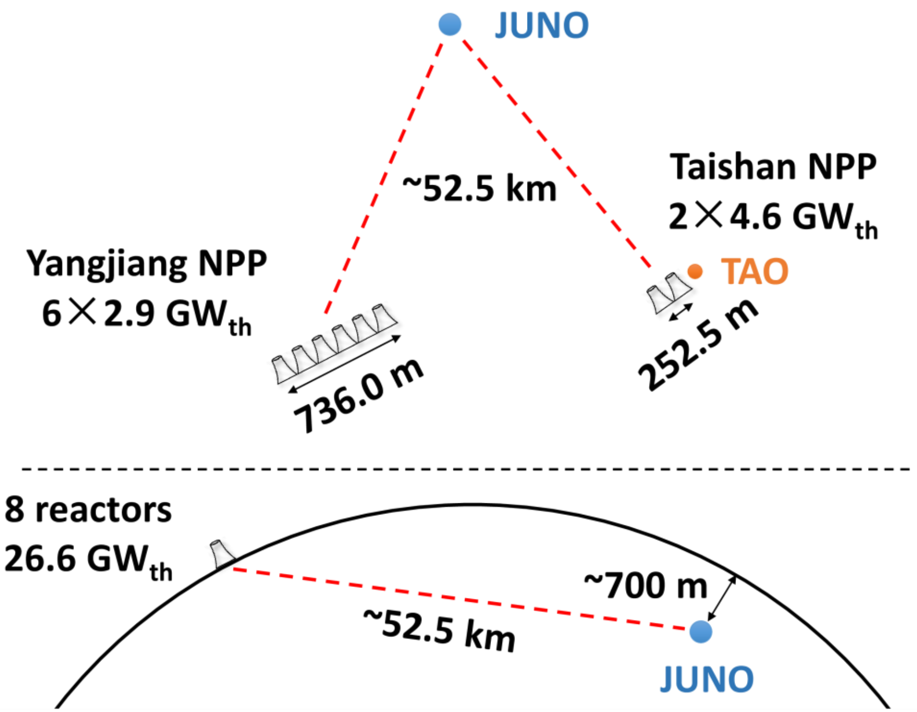
JUNO site


Guang Zhou
Shen Zhen
Hong Kong
JUNO
53 km
53 km
JUNO-TAO
Taishan NPP
Yangjiang NPP
珠江口


Survival Probability
1
0.8
0.6
0.4
0.2
0
Daya Bay
KamLAND
JUNO
Optimal distance for $\bar{\nu}_e$ disappearence
0.1
1
10
100
Distance to reactor [km]

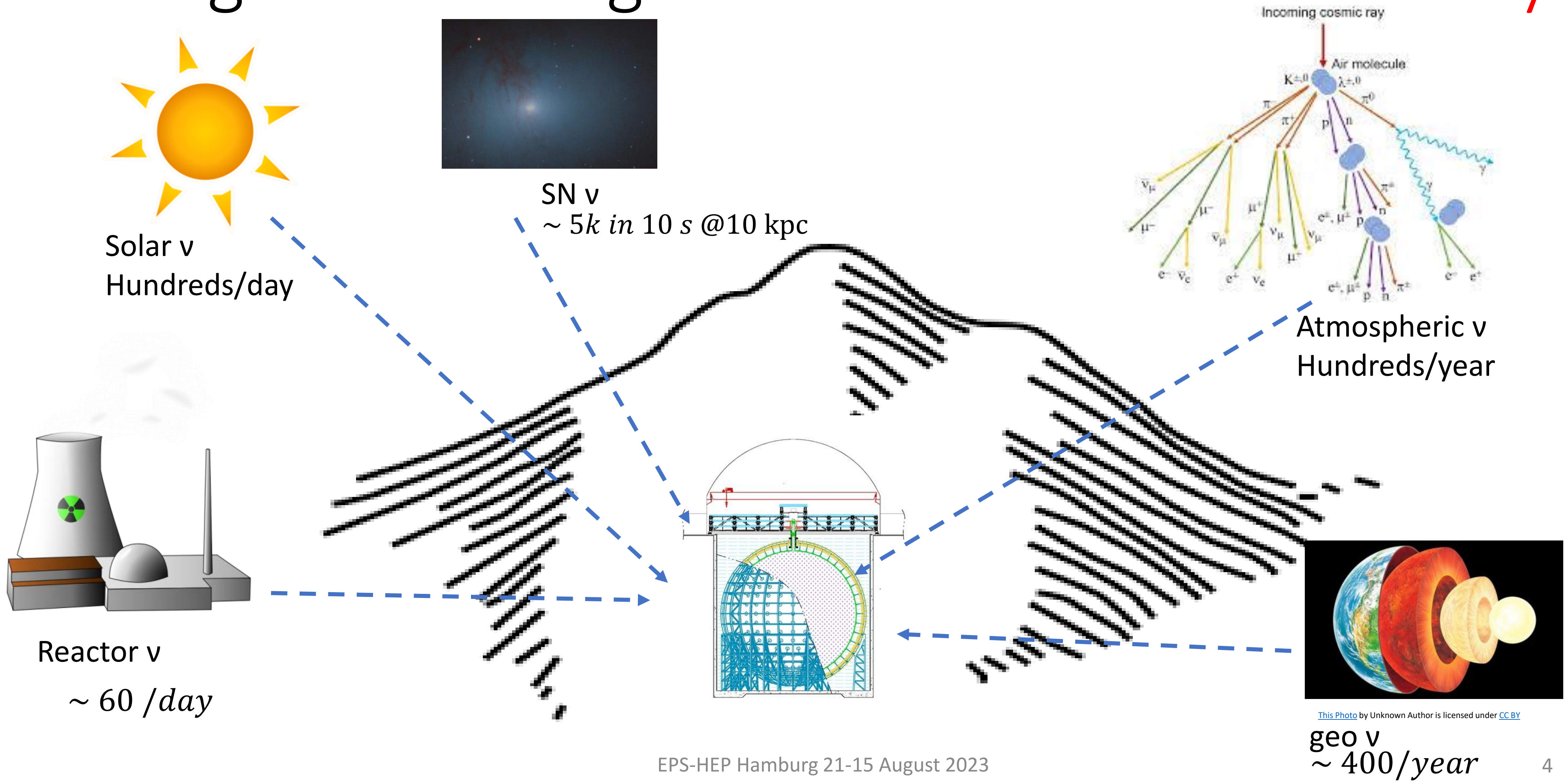

Russia
Kazakhstan
Mongolia
Kyrgyztan
Taj.
Pakis.
Nep.
B.
Ban.
India
Myanmar
Laos
Viet.
Thai.
N.K.
S.K.
Japan
Beijing
Shanghai
Harbin
Shenyang
Urumqi
Lhasa
Chengdu
Chongqing
Wuhan
Xian
Kunming
Taipei
500 km
300 mi

JUNO site

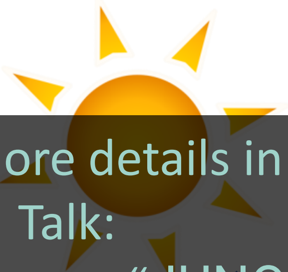

JUNO
~52.5 km
Taishan NPP
2×4.6 GW$_{th}$
Yangjiang NPP
6×2.9 GW$_{th}$
TAO
736.0 m
252.5 m
8 reactors
26.6 GW$_{th}$
~700 m
~52.5 km
JUNO

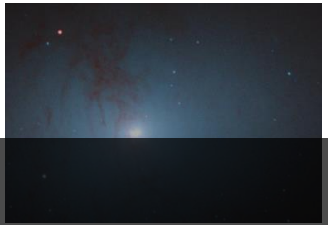

Vertical tunnel:
563 m
Overburden
~650 m
(1800 m.w.e.)
Slope tunnel: 1265 m
@ slope of 42%

Jiangmen Underground Neutrino Observatory



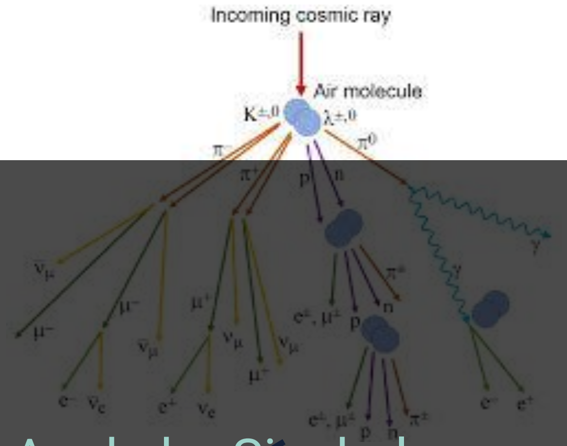
Jiangmen Underground Neutrino Observatory





SN ν

$\sim 5k\ in\ 10\ s$ @10 kpc



Solar ν

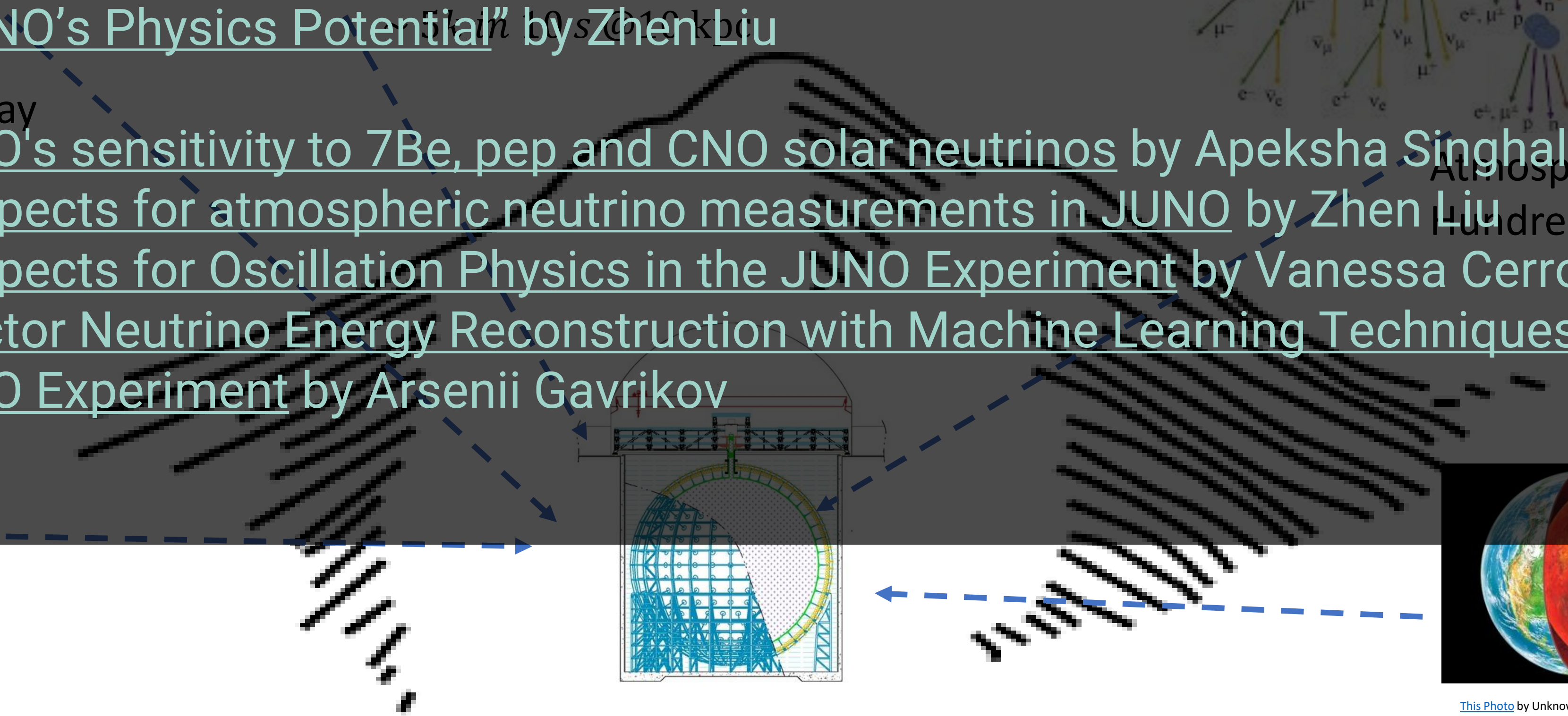
Hundreds/day

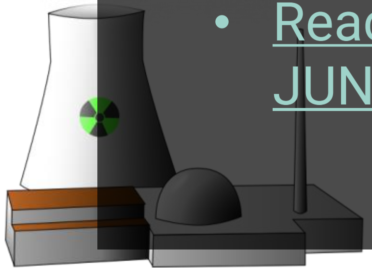
Atmospheric ν

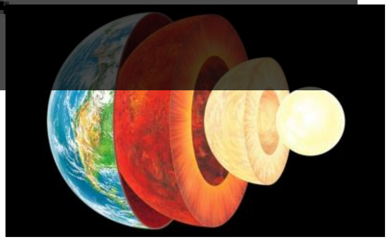
Hundreds/year

More details in:

- Talk:
  - “JUNO’s Physics Potential” by Zhen Liu
- Poster:
  - JUNO's sensitivity to 7Be, pep and CNO solar neutrinos by Apeksha Singhal
  - Prospects for atmospheric neutrino measurements in JUNO by Zhen Liu
  - Prospects for Oscillation Physics in the JUNO Experiment by Vanessa Cerrone
  - Reactor Neutrino Energy Reconstruction with Machine Learning Techniques for the JUNO Experiment by Arsenii Gavrikov







Reactor ν

$\sim 60\ /day$

geo ν

$\sim 400/year$

JUNO DETECTOR

JUNO: Detector

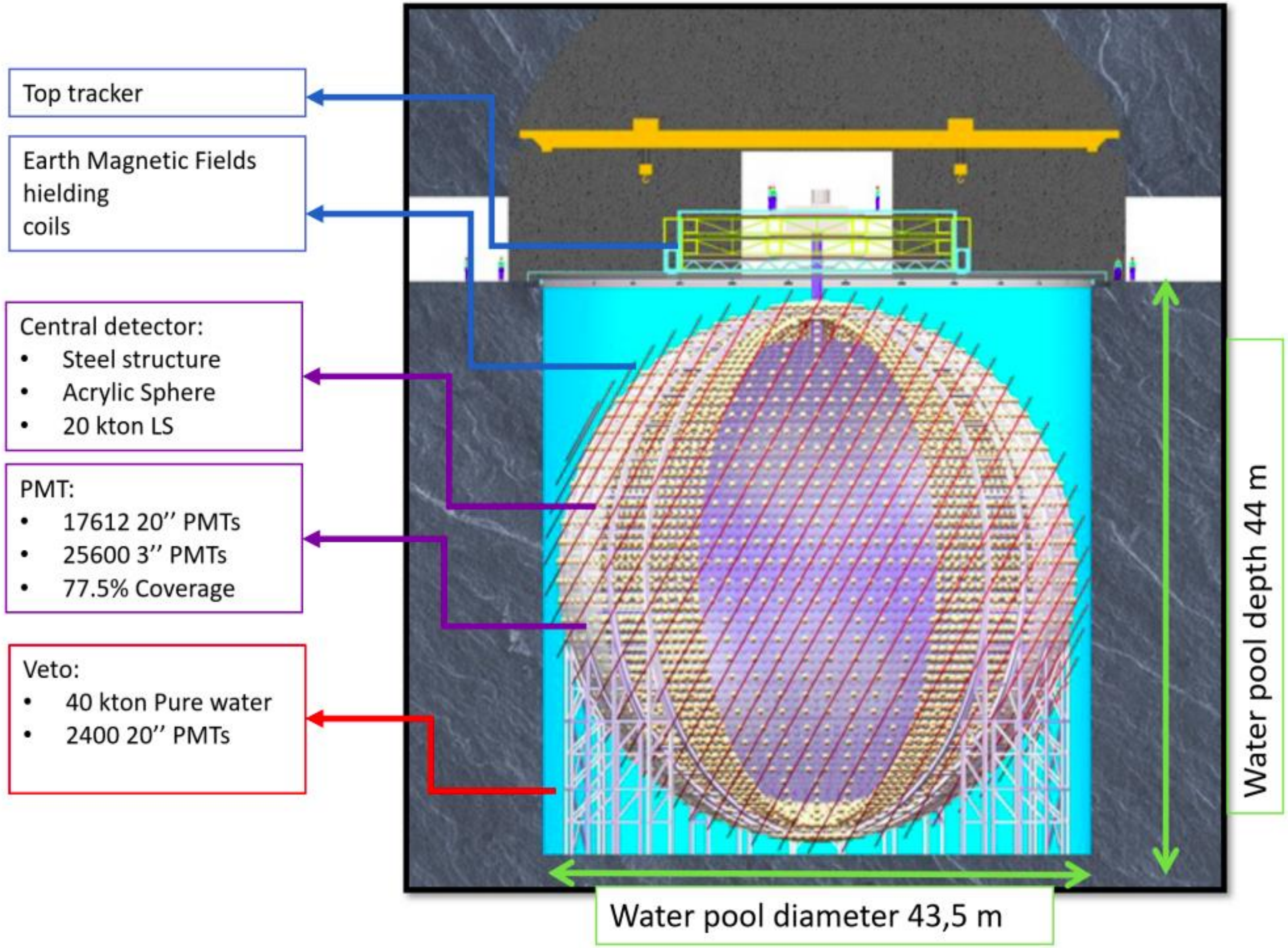
- **20 kt** of liquid scintillator based on LAB inside a 35.4 m acrylic vessel

- Surrounded by a water Cherenkov tank and a top muon tracker as veto
- **17612 20-inch PMTs + 25600 3-inch PMTs for dual calorimetry**
- Primary goals: precise measurement of reactor neutrino oscillation parameters and Neutrino Mass Ordering (NMO) determination

Requirements:

- High statistics ($\sim 10^5$events in 6 yr)
- Energy resolution: $\sim 3\%$**@1MeV**
- Energy scale uncertainty < **1%**

arXiv:2104.02565
JUNO physics and detector, Progress in Particle and Nuclear Physics 123, 103927 (2022)



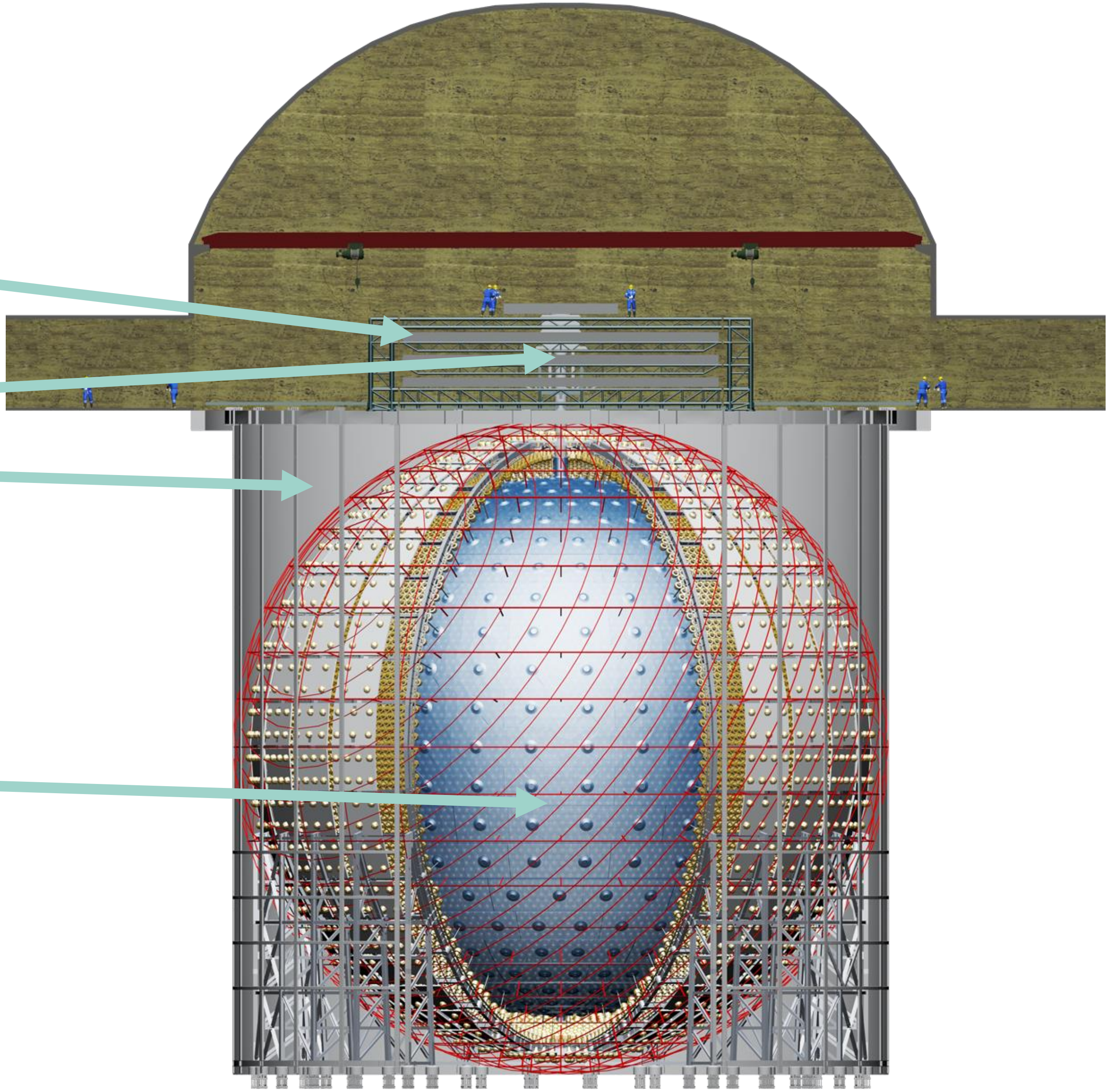
JUNO: Detector

Top Tracker (TT)
- Precise μ tracker
- 3 layers of plastic scintillator
- ~ 60% of area above WCD

Calibration House

Water Cherenkov Detector
- 35 kton ultra-pure water
- 2.4k 20” PMTs
- High μ detection efficiency
- Protects CD from external radioactivity & neutrons from cosmic-rays

Central Detector
- Acrylic sphere with 20 kton liquid scint
- 17.6k 20” PMTs + 25.6k 3” PMTs
- 3% energy resolution @ 1 MeV



arXiv:2104.02565
JUNO physics and detector, Progress in Particle and Nuclear Physics 123, 103927 (2022)

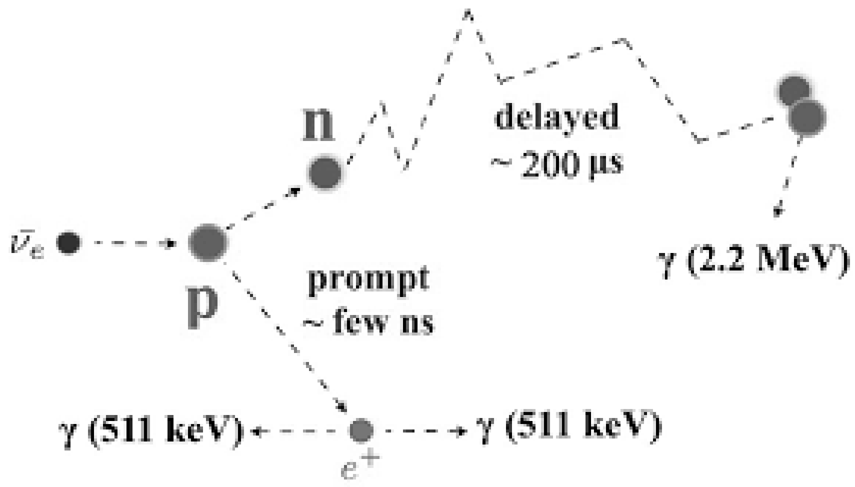
JUNO: neutrino detection

(Anti-)neutrinos are observed mainly via:

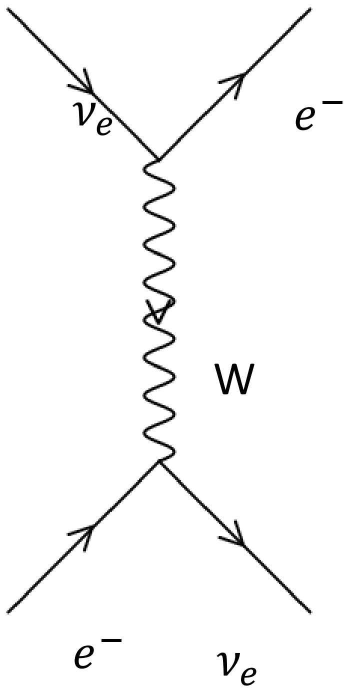
- **Inverse Beta Decay (IBD)** via the positron signal (1) and the following neutron capture (2):

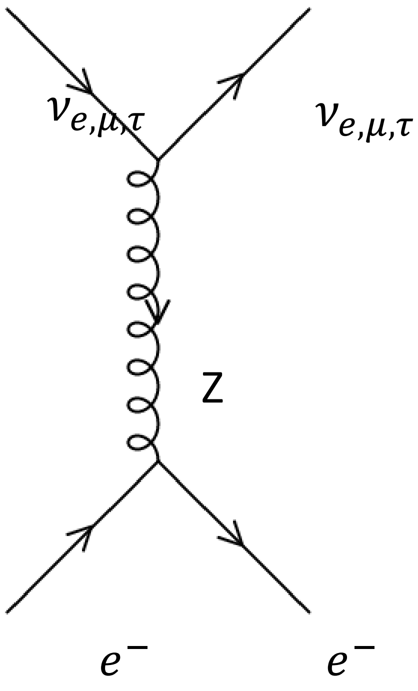
$$\overline{\nu}_e + p \rightarrow e^+ + n \qquad (1)$$

$$n + p \rightarrow d + \gamma \qquad (2)$$



- **Elastic scattering (ES)** on e^- **,** CC and NC interactions:





Acrylic Vessel

About half acrylic sphere was finished!

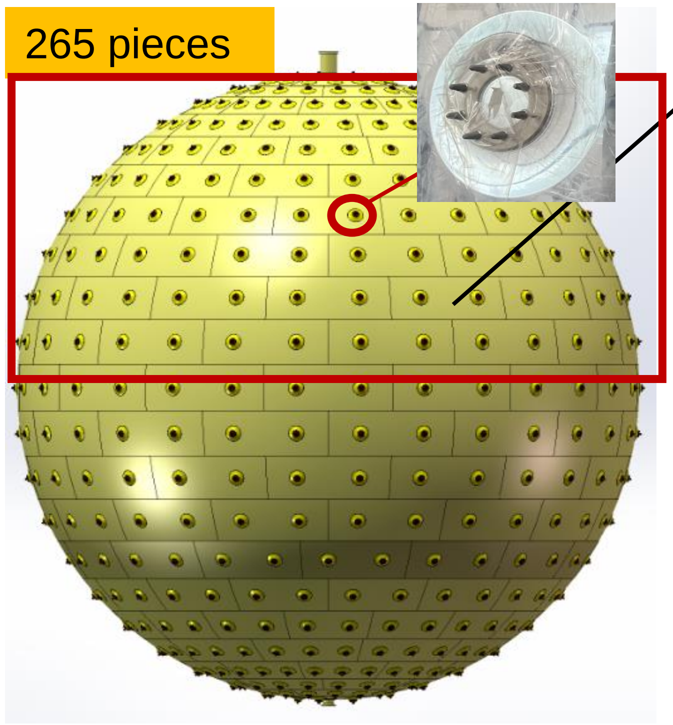
LS container:

Inner diameter: 35.40±0.04 m

Thickness: 124±4 mm

Light transparency > 96% @ LS

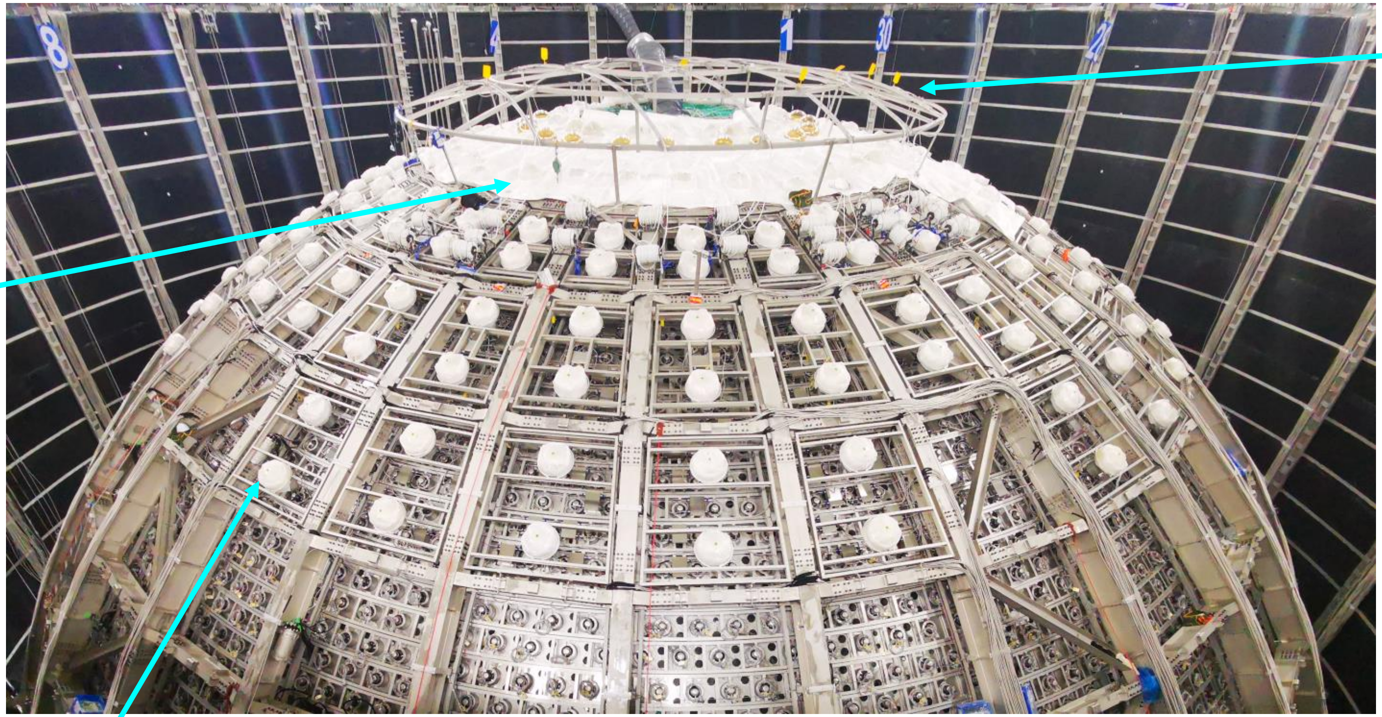
Radiopurity: U/Th/K < 1 ppt



Water Cherenkov Detector

Earth magnetic shielding coils installation: 6 coils installed (32 coils in total)

Tyvek reflective film installation started



200 veto PMTs installed(~10% of PMT)

Water system almost ready for commissioning

35 kton of ultrapure water serving as passive shield and water Cherenkov detector.

- 2400 20-inch MCP PMTs, detection efficiency of cosmic muons larger than 99.5%
- Keep the temperature uniformity 21℃±1℃
- Quality: ^{222}Rn < 10 mBq/m^3, attenuation length 30~40 m

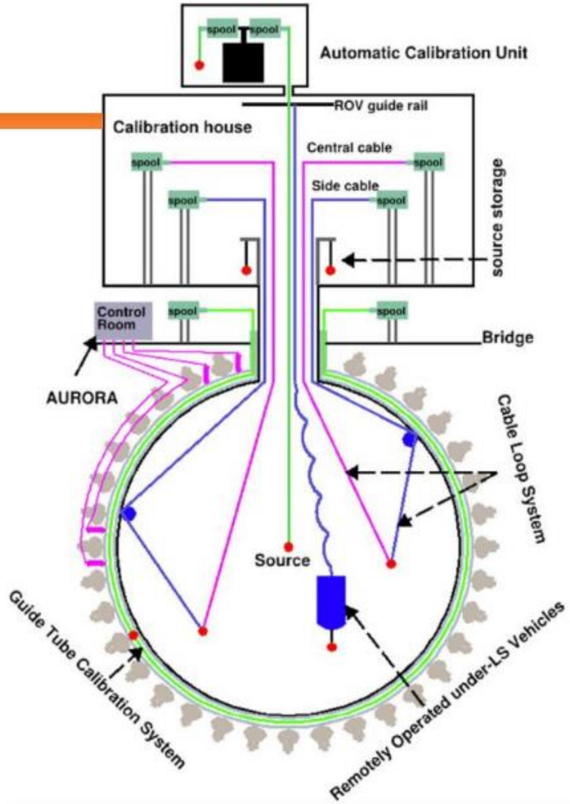
650 m rock overburden (1800 m.w.e.) → R_μ = 4 Hz in LS, $<E_\mu>$ = 207 GeV

JUNO: Calibration system

Crucial to understand detector response non-uniformity and achieve: <1% energy scale uncertainty + 3% at 1MeV energy resolution

Four complementary sub-systems: 1D, 2D and 3D scan with multiple calibration sources

Cable system finished prototype test

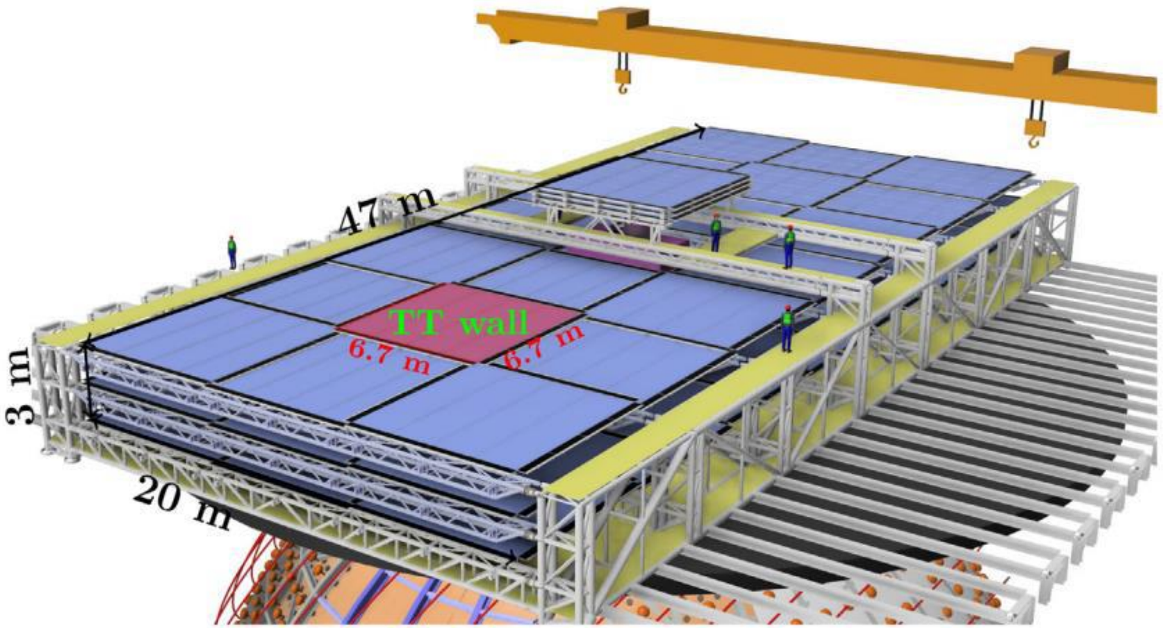


Angel, Abusleme, et al. "Calibration strategy of the JUNO experiment." *Journal of High Energy Physics* 2021.3 (2021).

JUNO: Top tracker

Plastic scintillator from the OPERA experiment
- About 60% coverage on the top**, three layers** to reduce accidental coincidence
- All scintillator panels arrived on site in 2019
- Provide control muon samples to validate the track reconstruction and study cosmogenic backgrounds
- The Top Tracker support bridge is ready for production.

More info on the poster: The Top Tracker of the JUNO Experiment by Deshan Sandanayak

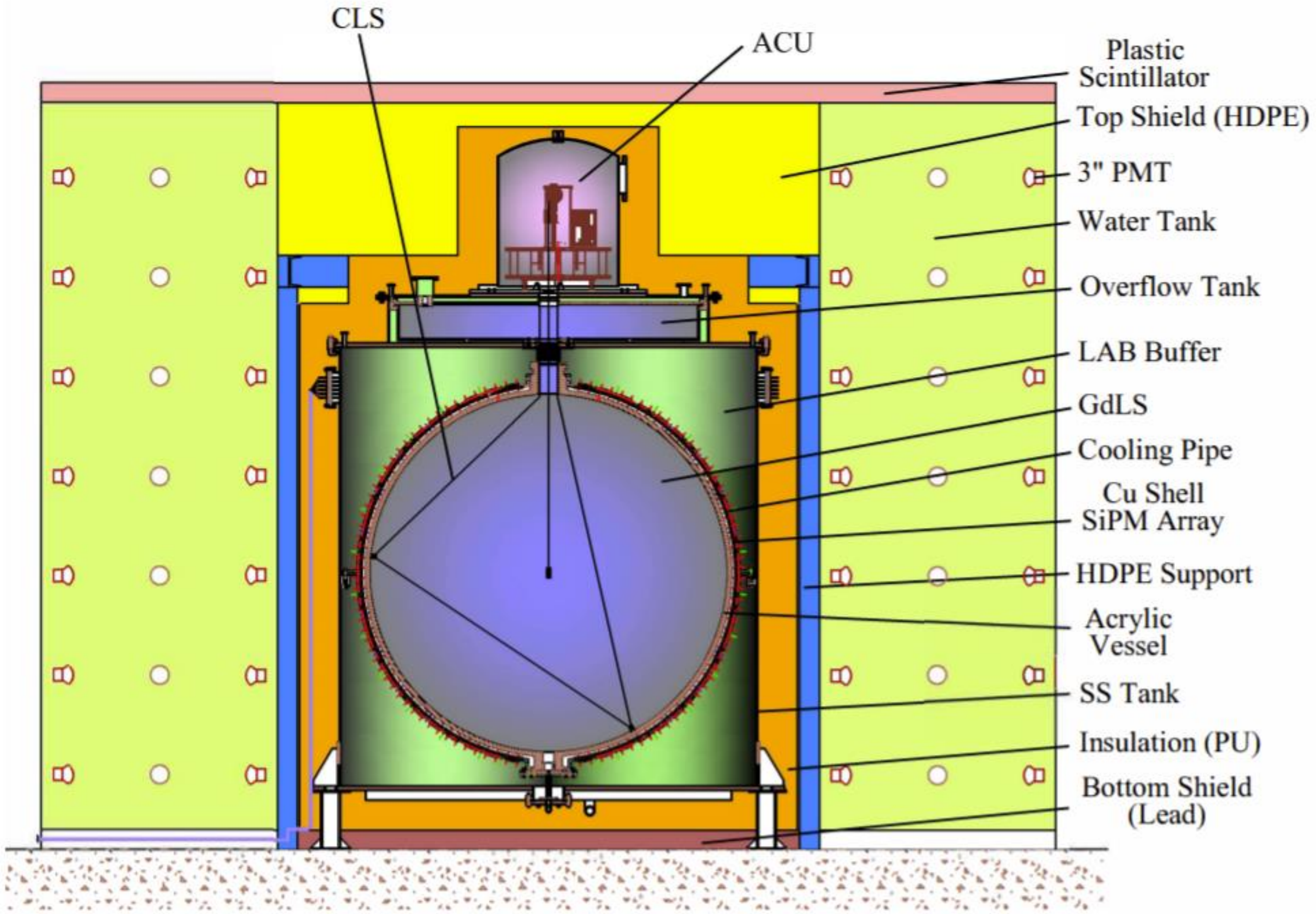


arXiv:2303.05172

JUNO: Taishan Antineutrino Observatory

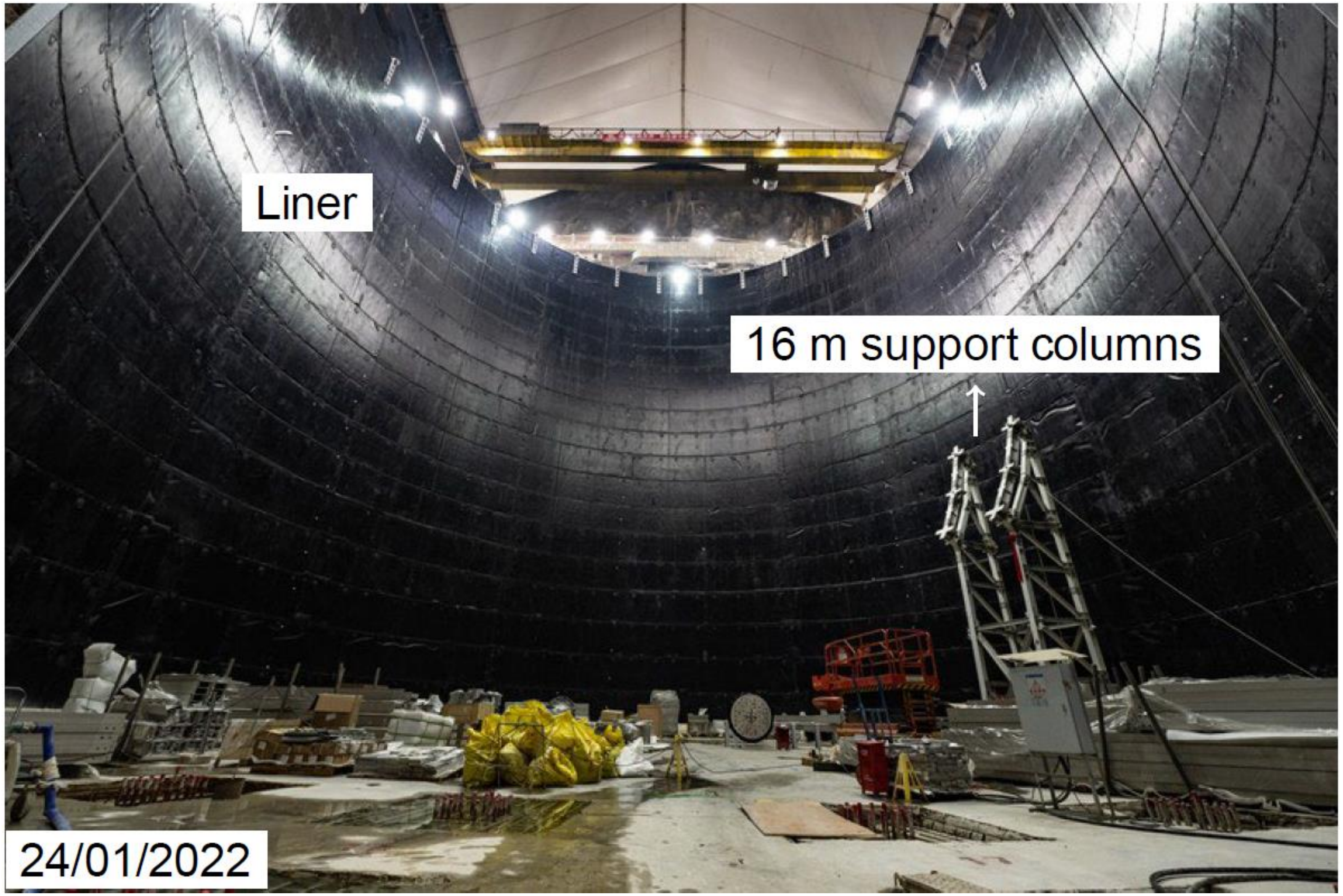
- 2.8 ton of Liquid Scintillator doped with Gadolinium (GdLS) in a spherical vessel with 1.8 m diameter
- Expected 4000 IBD/Day (2000 with 1-ton fiducial volume)
- $\sim 10\ m^2$ of SiPMs (more than 4000 4 x 8 SiPMs arrays)
- Operate at -50 °C to reduce SiPM dark noise
- From the center to the outside: GdLS → Acrilic vessel → SiPMs and support → LAB Buffer → Criogenic system → water and HDPE shield → muon veto
- High energy resolution : $\sim 1.5\%$@1MeV
- Prototype under construction in China
- More info on the poster: JUNO-TAO design, prototype and its impact for JUNO physics by Claudio Lombardo (me)

arXiv:2005.08745



Current Status

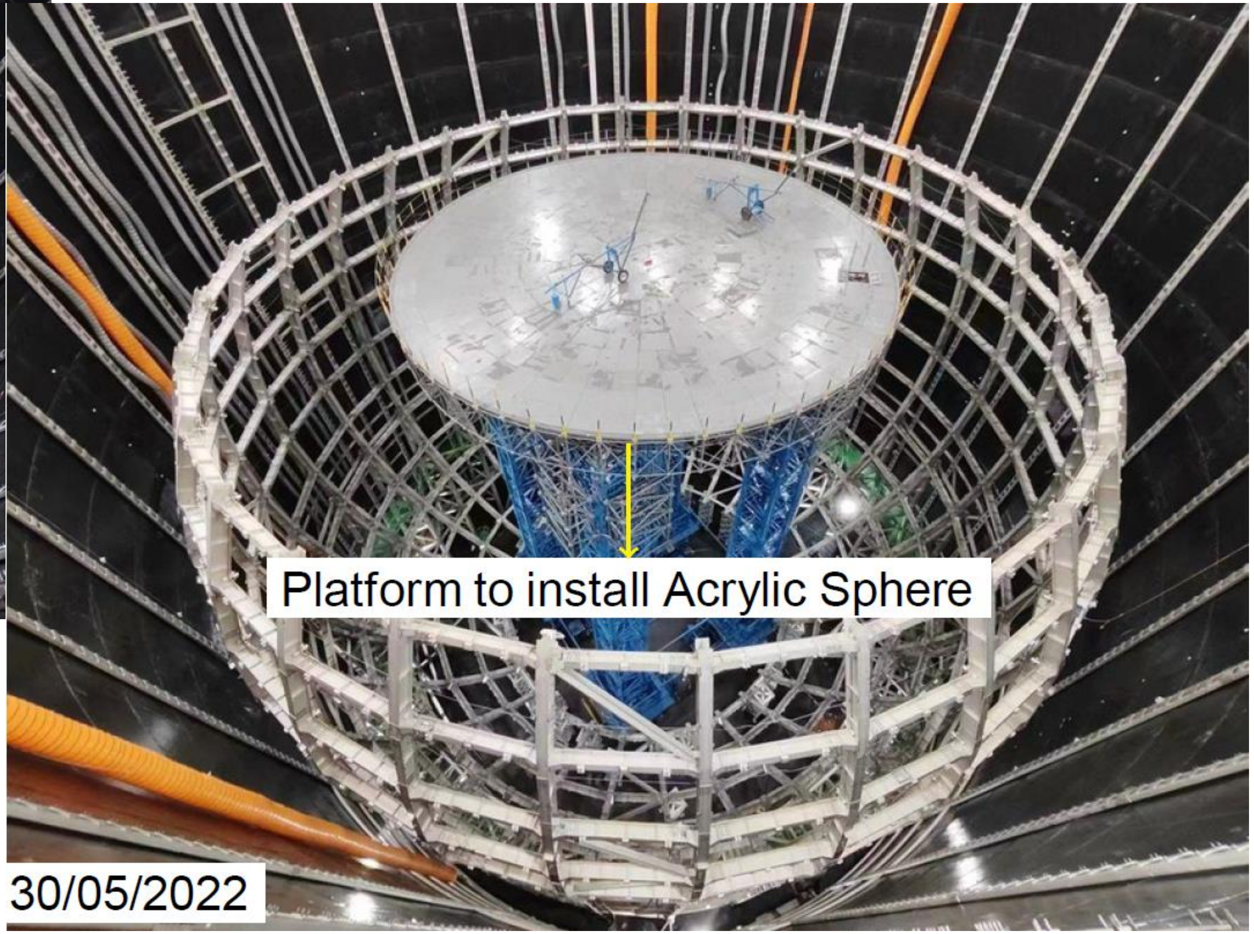
JUNO: Status



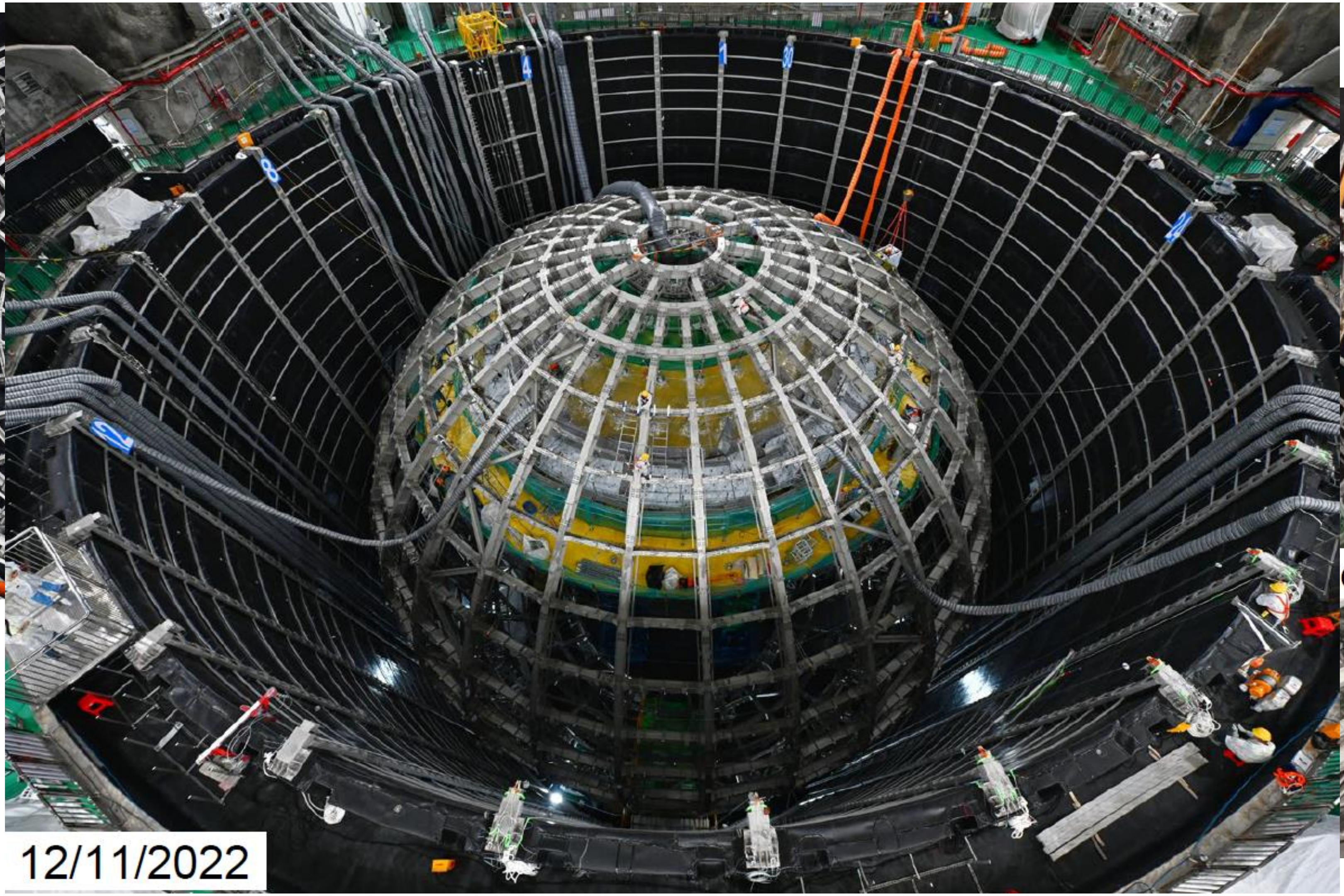
After the deployment of the liner on the wall of the experimental pool (radon stopping) the installation of the detector started in January 2022

JUNO: Status

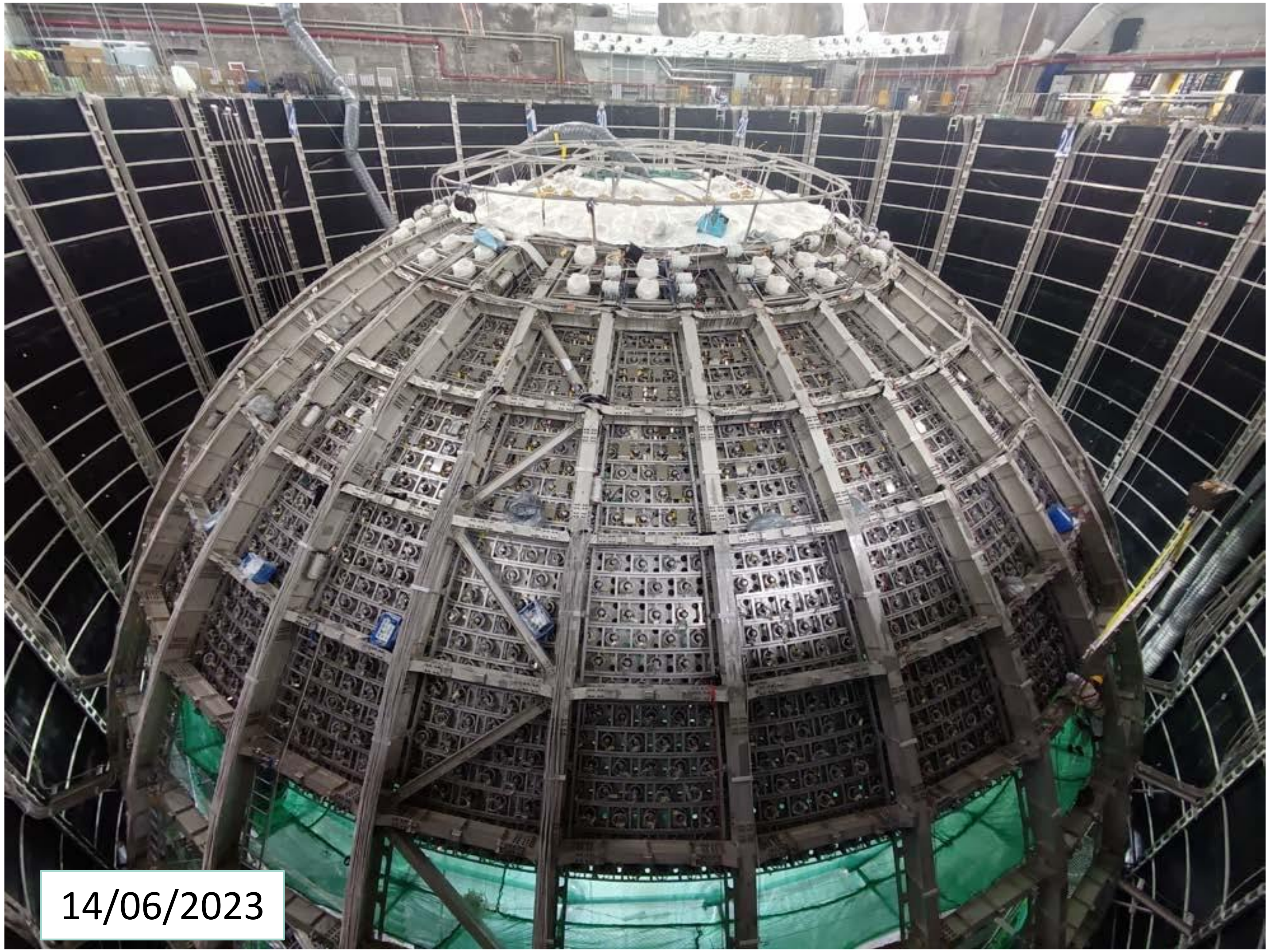
JUNO: Status



JUNO: Status

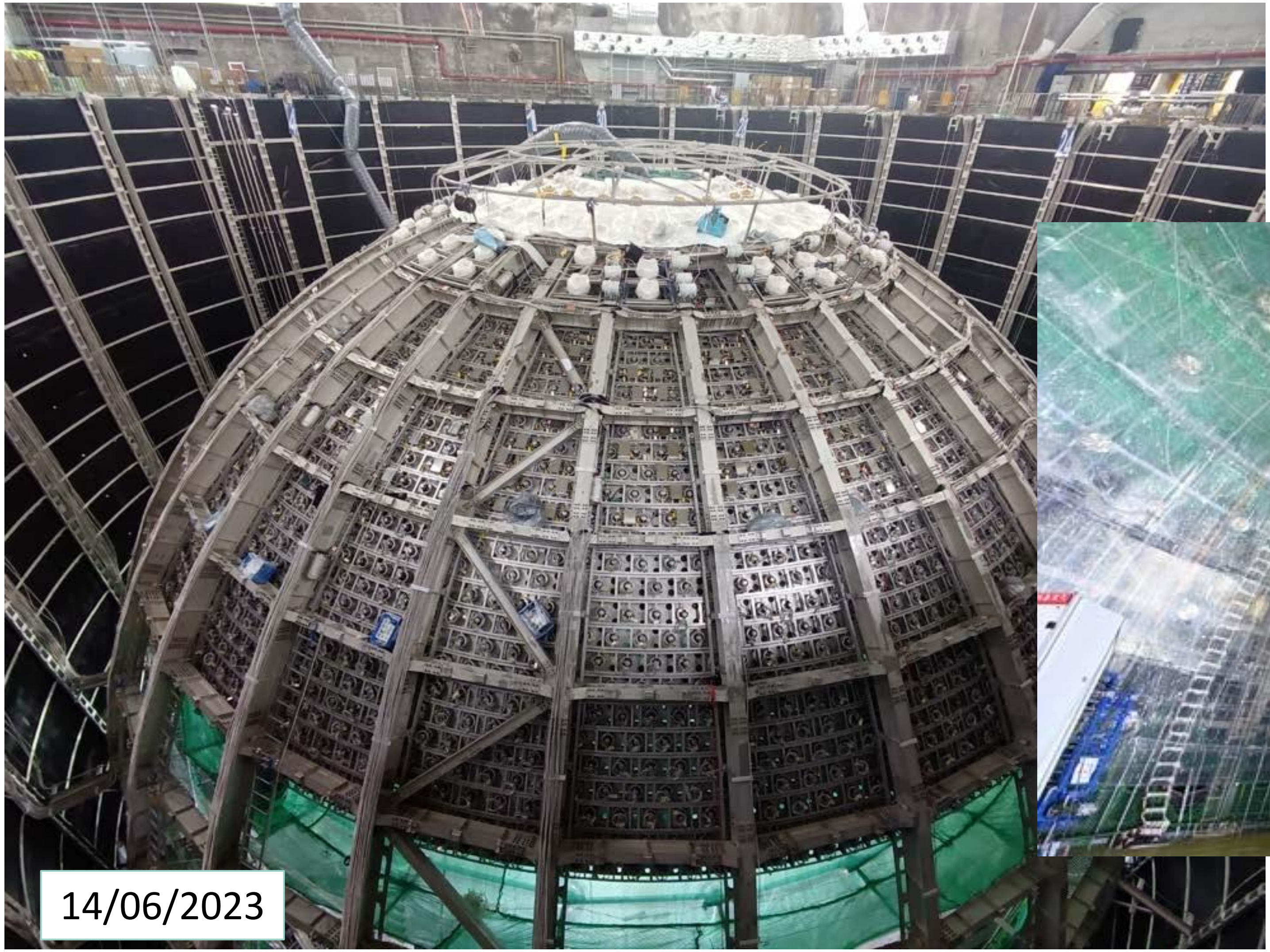


JUNO: Status


14/06/2023

Acrylic vessel installation → on going
PMT installation → started
Electronics installation → started

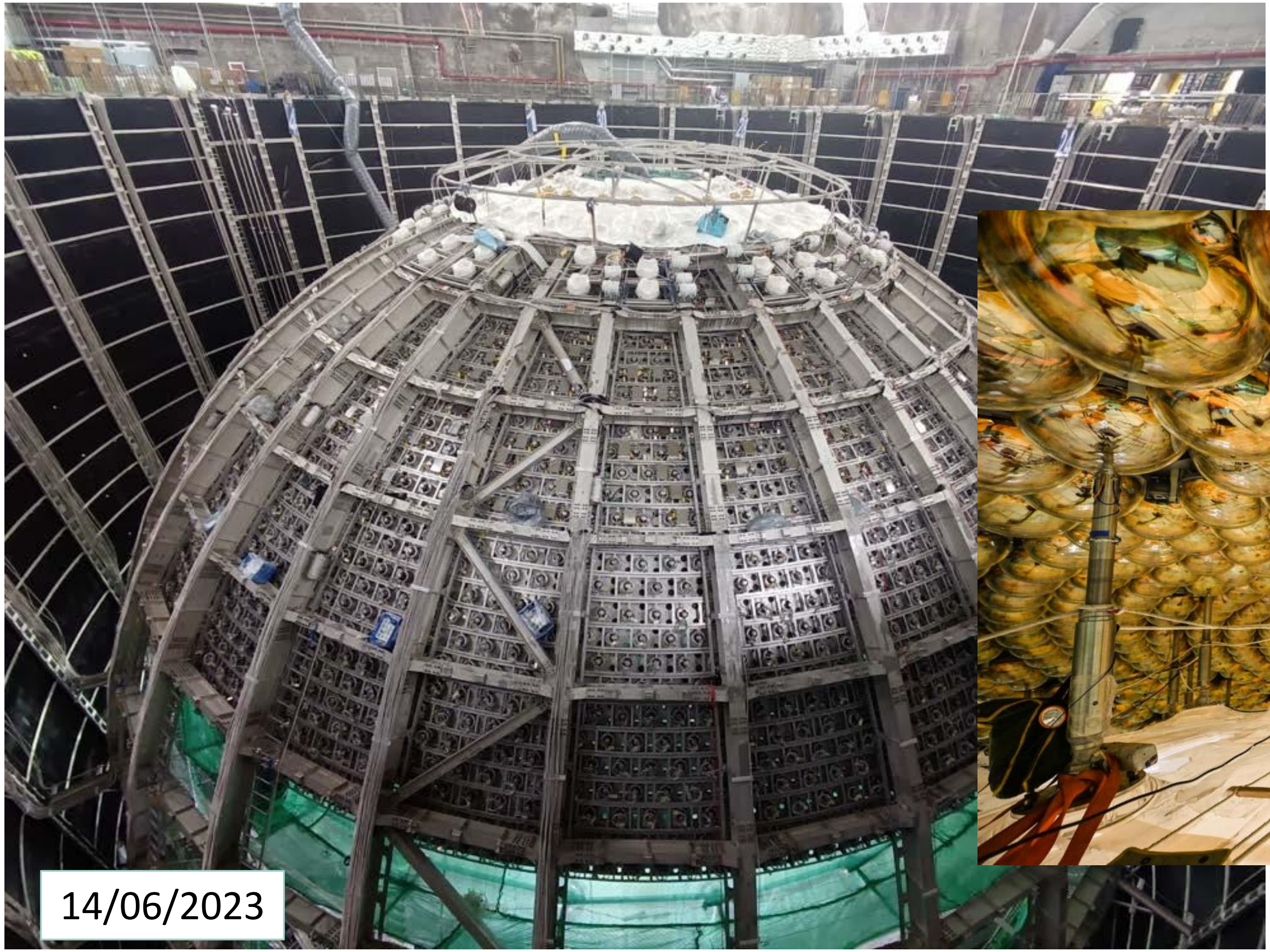
JUNO: Status



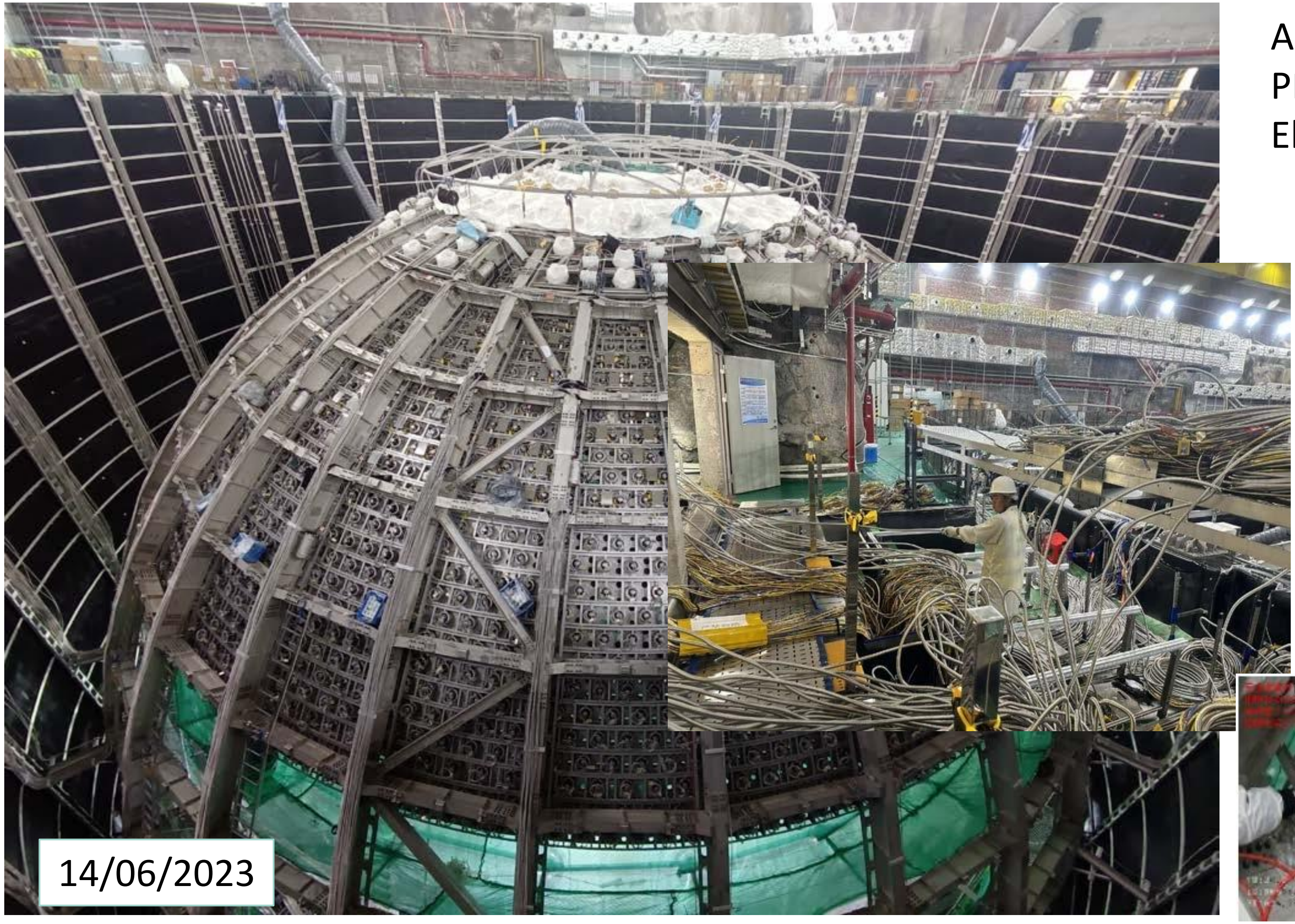
Acrylic vessel installation → on going
PMT installation → started
Electronics installation → started

JUNO: Status

Acrylic vessel installation → on going
PMT installation → started
Electronics installation → started



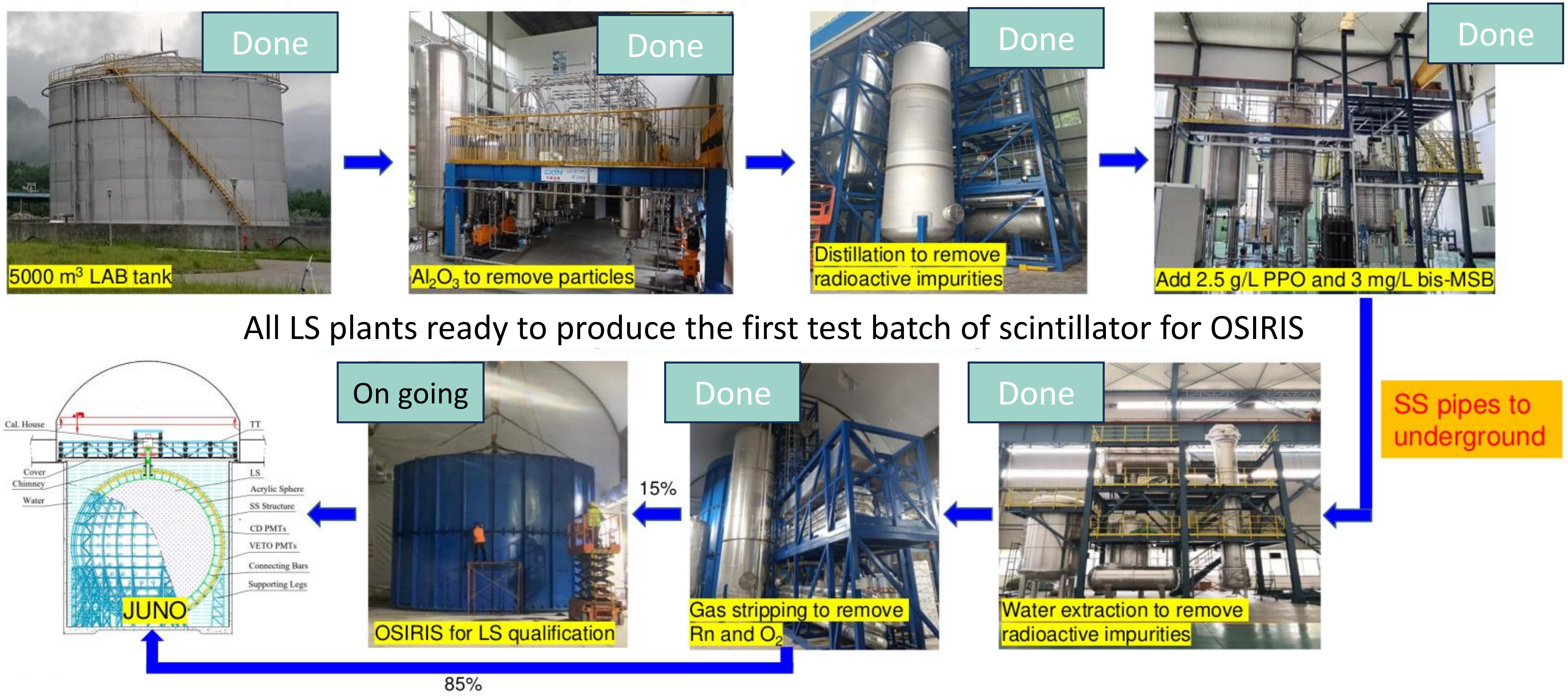
JUNO: Status



Acrylic vessel installation → on going
PMT installation → started
Electronics installation → started

JUNO: Status (OSIRIS)

Four purification plants to achieve target radio-purity 10^{-17} g/g U/Th and 20 m attenuation length at 430 nm.

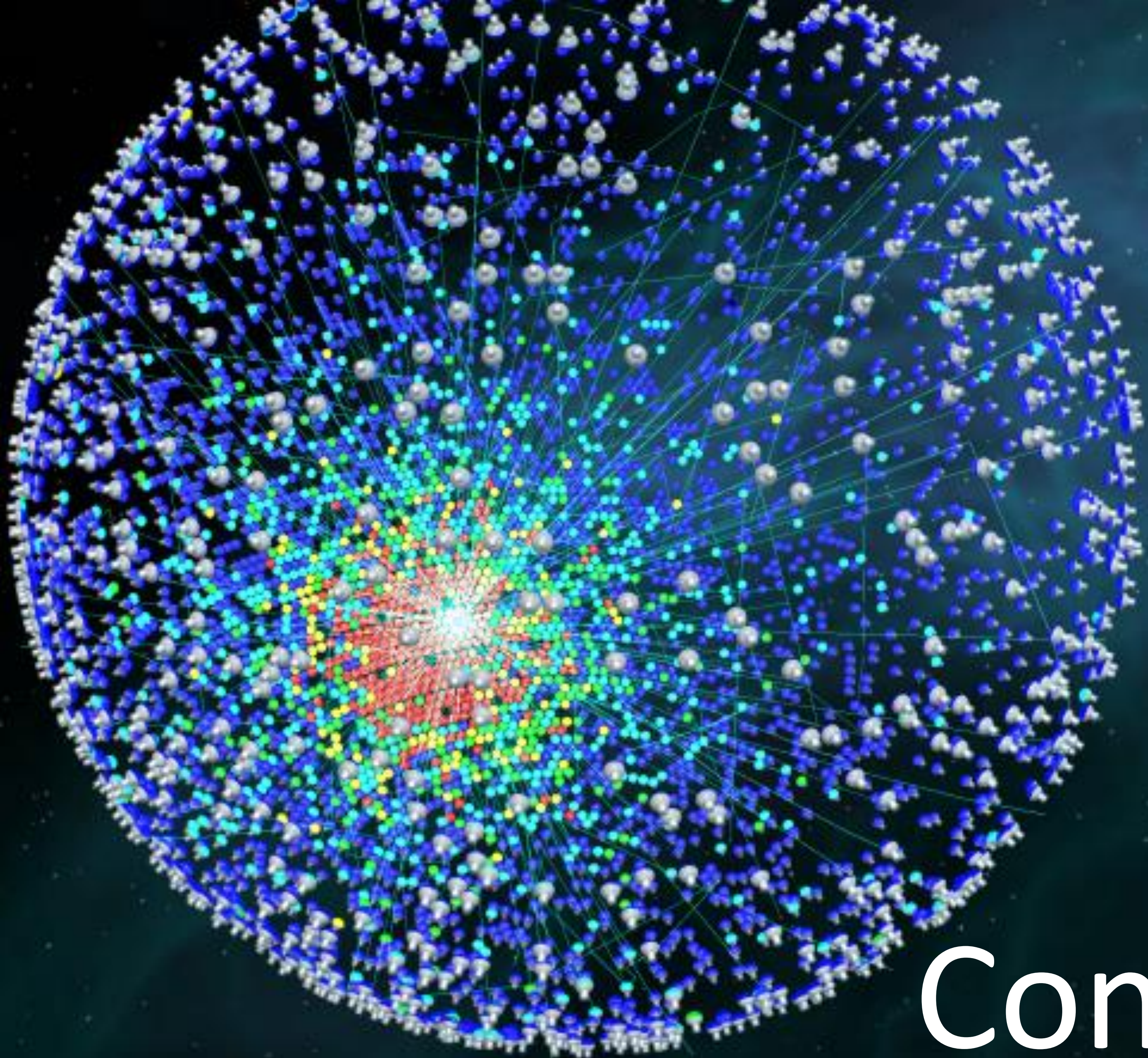


All LS plants ready to produce the first test batch of scintillator for OSIRIS

Abusleme A et al., Optimization of the JUNO liquid scintillator composition using a Daya Bay antineutrino detector, NIM A 988 (2021) 164823

Abusleme, A et al. The design and sensitivity of JUNO's scintillator radiopurity pre-detector OSIRIS. Eur. Phys. J. C 81, 973 (2021).

Conclusion



Conclusion

JUNO will have unique properties: large target mass & good energy resolution

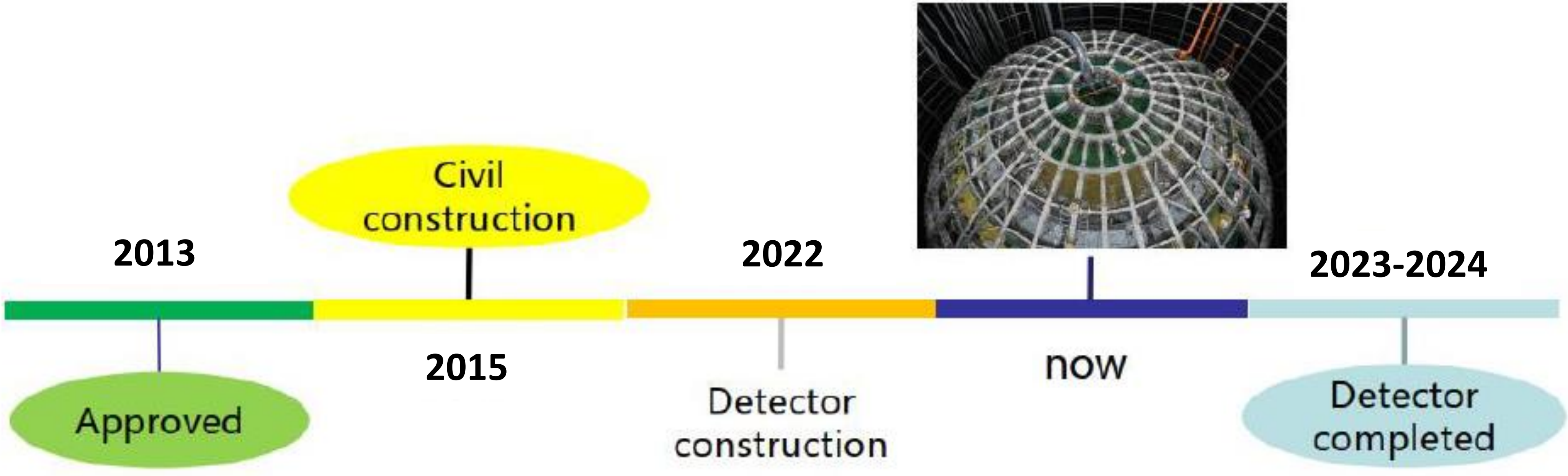
- Very large photo-coverage & high LS light yield and transparency
- JUNO-TAO for reference reactor spectrum
- Multipronged strategy towards 3% energy resolution including calibration
- Huge effort for challenging radiopurity targets

Conclusion

Installation of the different parts of JUNO is ongoing

- Civil construction (cave, lab, civil buildings) finished
- Water pool finished
- Stainless structure finished
- Acrylic sphere ongoing
- PMTs and electronics ongoing
- Liquid Scintillator production plants and OSIRIS almost finished
- TAO prototype under construction at IHEP(Beijing)

Conclusion


2013
Approved
Civil construction
2015
2022
Detector construction
now
2023-2024
Detector completed

Thanks for your attention

Back up

Huge effort for radiopurity control

Radiopurity of materials

Singles (R < 17.2 m, E > 0.7 MeV)	Design [Hz]	Change [Hz]	Comment
LS	2.20	0	
Acrylic	3.61	-3.2	10 ppt -> 1 ppt
Metal in node	0.087	+1.0	Copper -> SS
PMT glass	0.33	+2.47	Schott -> NNVT/Ham
Rock	0.98	-0.85	3.2 m -> 4 m
Radon in water	1.31	-1.25	200 mBq/m³ -> 10 mBq/m³
Other	0	+0.52	Add PMT readout, calibration sys
Total	8.5	-1.3	

The Kr value takes into account the release from acrylic and the analysis approach to cope with it for solar ^{7}Be

LS for solar neutrinos:

U/Th$<10^{-17}$ g/g, $^{40}K<10^{-18}$ g/g,
$^{85}Kr<50$ μBq/m^3,
$^{226}Ra<5\times10^{-24}$ g/g (0.1 μBq/m^3),
$^{210}Pb<10^{-24}$ g/g ($^{222}Rn<5$ mBq/m^3)

Crucial the initial purification recirculation much more difficult than Borexino, KamLAND, SNO+,…

Radiopurity control of raw material:

- ✓ Careful material screening
- ✓ Meticulous Monte Carlo Simulation
- ✓ Accurate detector production handling

Better than spec. by 15%

Good enough for MH from reactor ν's

10^{-15} g/g for U and Th already demonstrated by the Daya Bay test

Radiopurity control for LS:

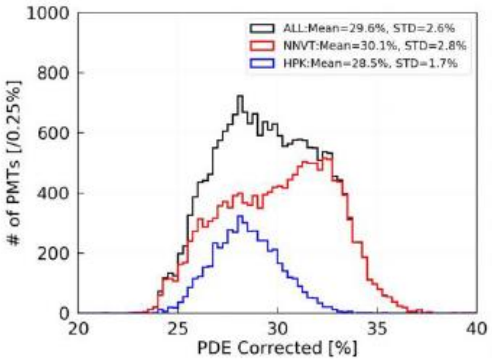
- Leak check(single component < 10^{-6} mbar·L/s) of all joints to reduce 222Rn and 85Kr
- Cleaning of all pipes, vessels to remove dust (check water cleanness)
- Clean room environment during installation
- Surface treatment of the acrylic vessel (Rn daughters)
- LS filling strategy

Photomultiplier Tubes

- **17612 (CD) + 2400 (Veto) 20” PMT**
  - 5k Hamamatsu (HPK) PMTs, 15k NNVT PMTs
  - worst NNVT PMTs used in Veto
- 25600 3” PMT for CDs
- All PMTs produced & tested & waterproofed
- PMT installation and Electronics assembly ongoing

Clearance between PMTs: 3 mm → **Assembly precision: < 1 mm**

Photon Detection Efficiency

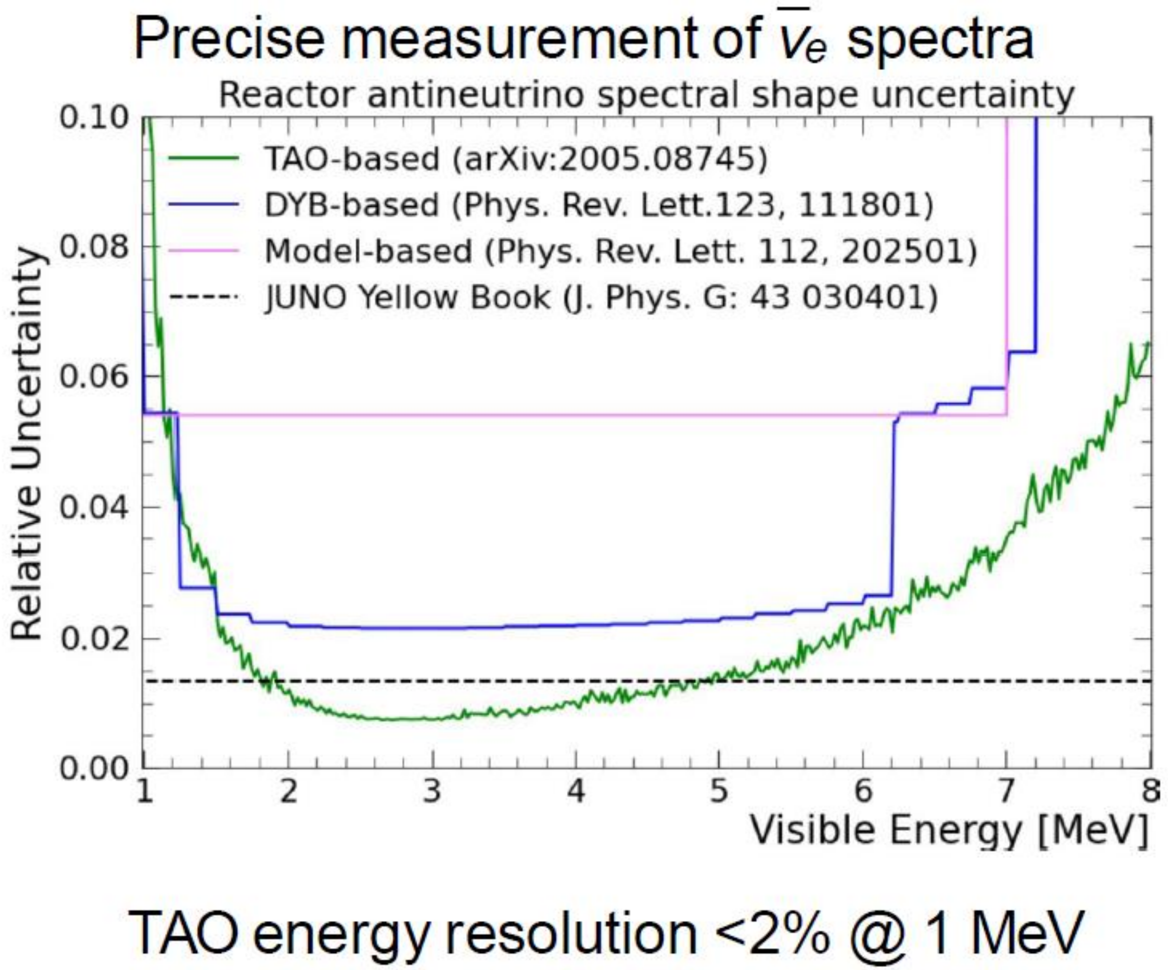


17612 (CD) + 2400 (Veto) 20-inch PMTs

25600 3-inch PMTs

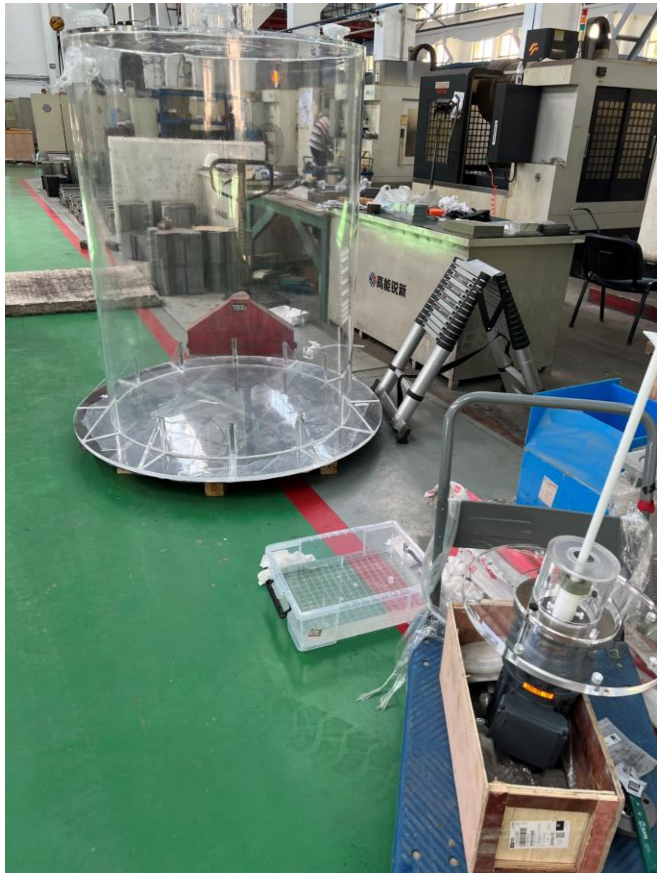
PMT installed in detector

TAO goal


Precise measurement of $\overline{\nu}_e$ spectra
Reactor antineutrino spectral shape uncertainty
TAO-based (arXiv:2005.08745)
DYB-based (Phys. Rev. Lett.123, 111801)
Model-based (Phys. Rev. Lett. 112, 202501)
JUNO Yellow Book (J. Phys. G: 43 030401)
Relative Uncertainty
0.10
0.08
0.06
0.04
0.02
0.00
1
2
3
4
5
6
7
8
Visible Energy [MeV]
TAO energy resolution <2% @ 1 MeV

JUNO: Status TAO

North hemisphere inside the clean room, picture taken during SiPMs installation



(part of the)Tools to produce GdLS for the prototype

Electronics produced → to be shipped to China

SiPMs under testing

Prototype ready this **autumn**

Pictures taken in July