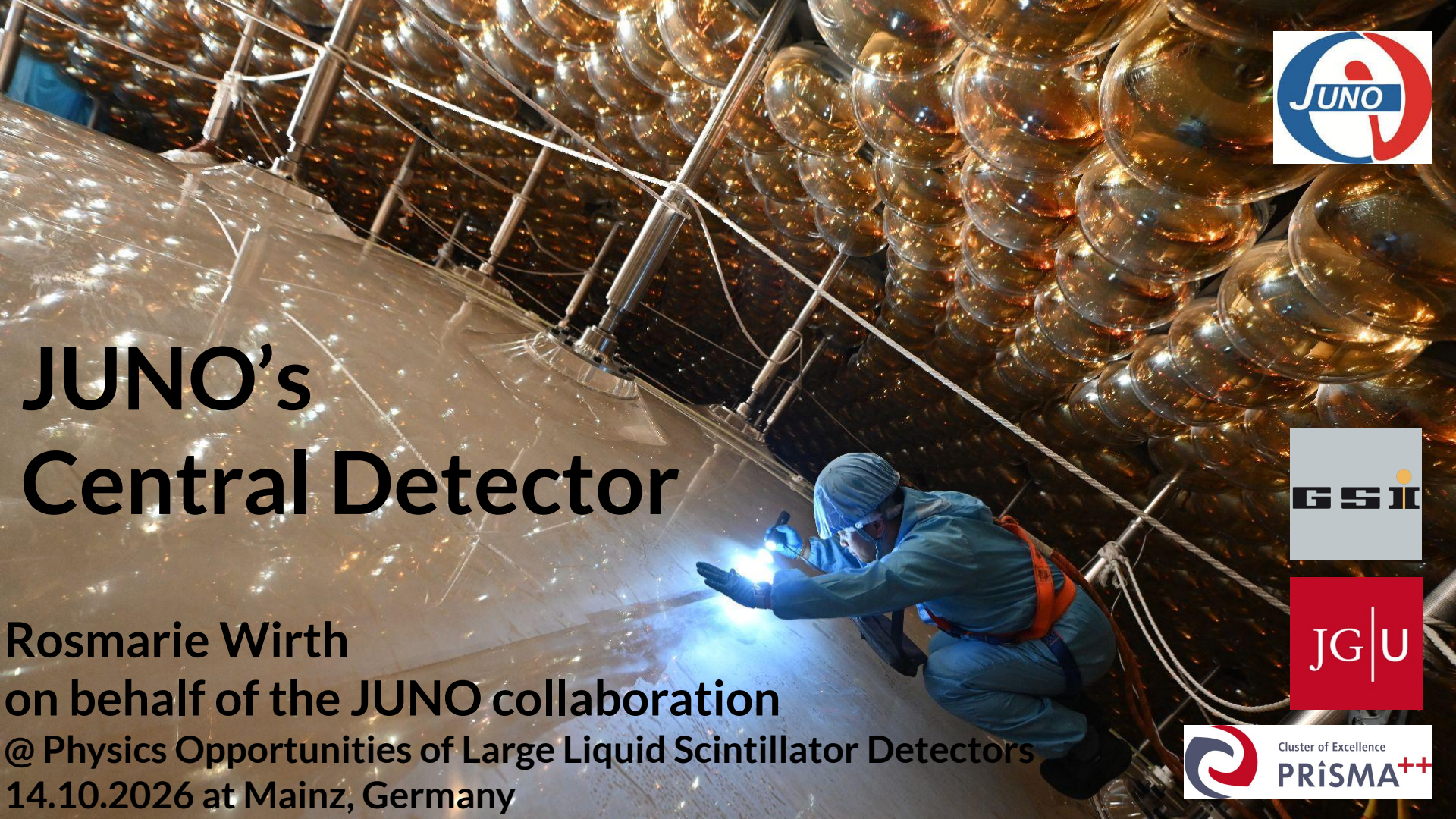




JUNO's Central Detector

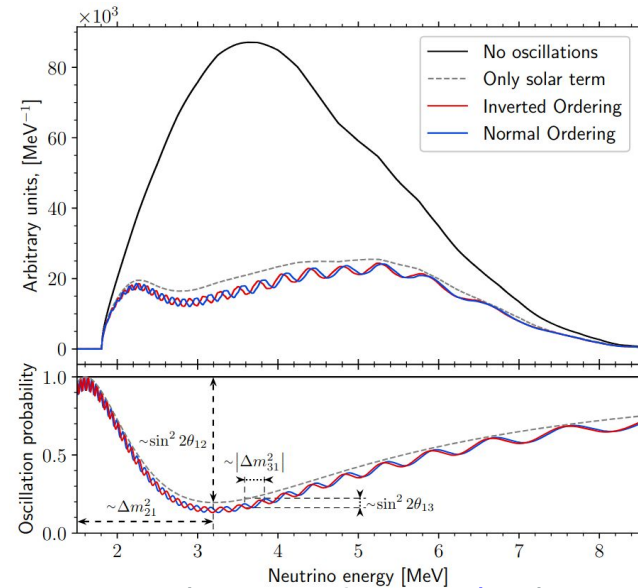
Rosmarie Wirth
on behalf of the JUNO collaboration
@ Physics Opportunities of Large Liquid Scintillator Detectors
14.10.2026 at Mainz, Germany

JUNO in a nutshell

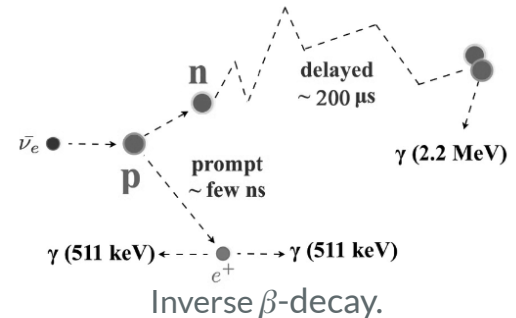
JUNO is a large liquid scintillator (LS) detector and aims to determine the neutrino mass ordering (NMO) by observing the reactor electron anti-neutrino oscillation spectrum at 52.5 km baseline.

- Located in southern China,
- 20 kton spherical liquid scintillator detector,
- Designed energy resolution of 3 % at 1 MeV,
- Reactor $\bar{\nu}_e$ detection via inverse β -decay,

Latest results with world leading precision [arXiv 2609.37895](#) on 207.2 days of data.



Expected spectrum for **normal** and **inverted** ordering.

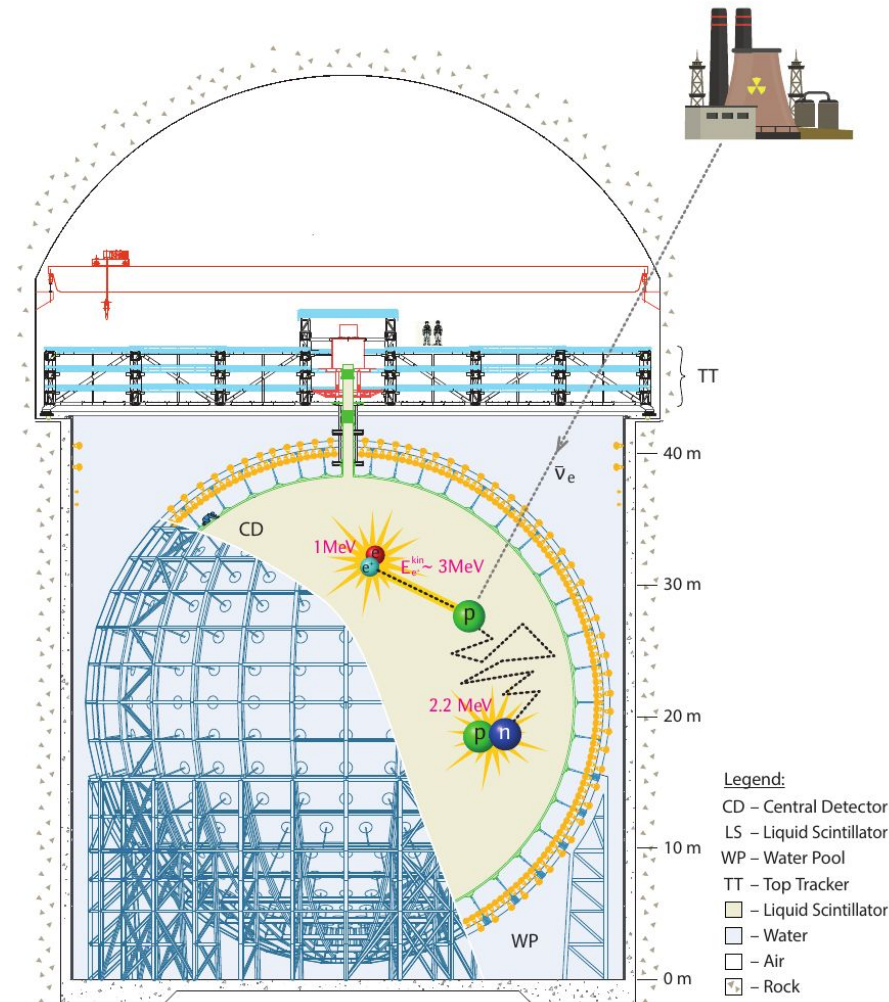


The JUNO experiment

20 kT Central Detector (CD) covered here, presentation on calibration by Davide next.

Further experiment characteristics :

- 650 m overburden to reduce muon induced backgrounds,
- 35 kt water pool as active muon veto instrumented with 2400 20" PMTs,
- Top Tracker (TT) for additional muon veto and track reconstruction,
- TAO (Taishan anti-neutrino observatory) as a reference detector at 30 m baseline.
- OSIRIS (Online Scintillator Internal Radioactivity Investigation System) used for LS quality checks during filling.

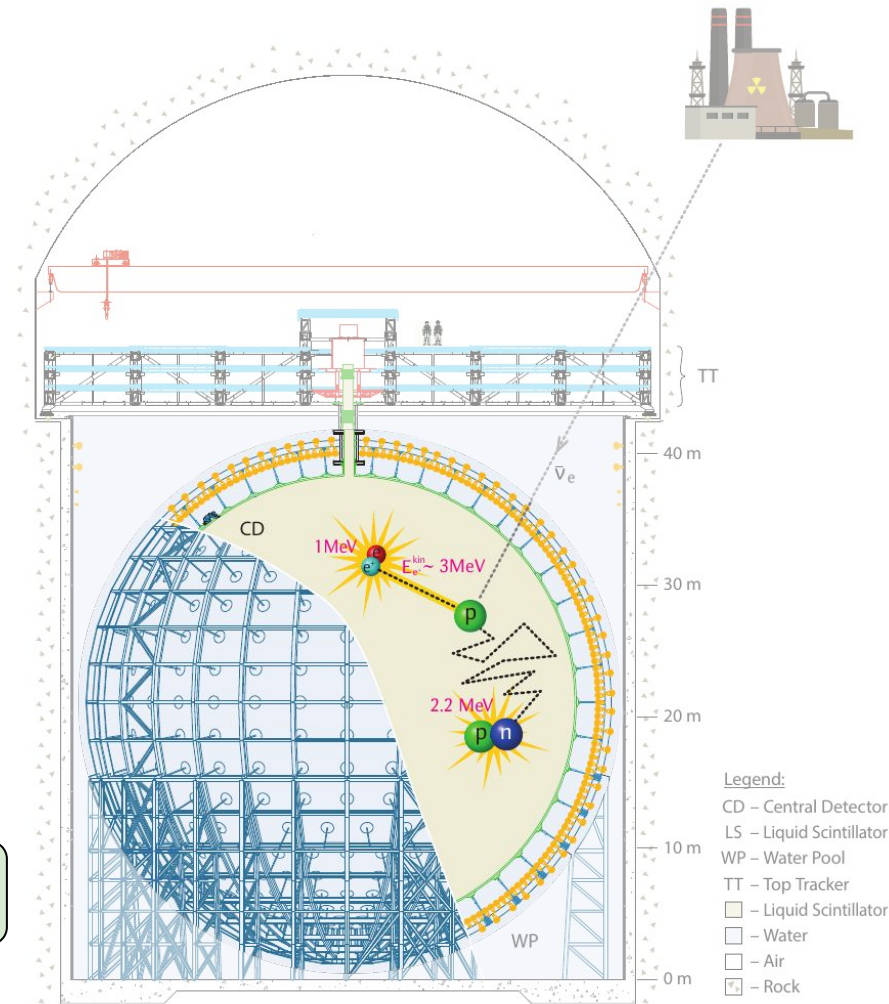


JUNO's Central Detector

Requirements for physics goals:

- Large Volume for high statistics, 20 kT LS with 35.4 m diameter,
- high energy resolution (3 % @1 MeV),
- maximal possible optical coverage,
- high light transmittance >20 m,
- lowest possible radioactive background.

How was JUNO's central detector design chosen?



CD Design choices and construction



Vessel: Acrylic sphere or balloon?

Balloon vessels used in Borexino and KamLAND.

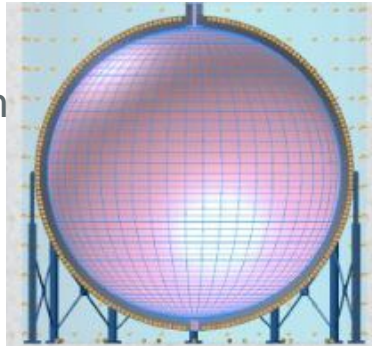
- Balloon is cheap, but steel tank and buffer LS increase overall costs.

- Nylon prototype was studied with 0.127 mm thickness and 6 m radius.

- During production and packaging, the nylon balloon prototype develops many irreversible crease-related damages. It ruptured during test under a pressure of 1200 Pa.



Balloon prototype



Balloon support structure

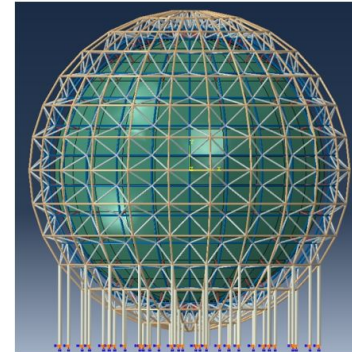
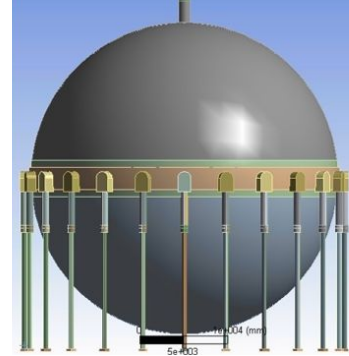
Acrylic vessel used in SNO+ and Daya Bay.

- Fully compatible with LS and pure water, while highly transparent @ [380, 700] nm.

- Low radioactivity for PMMA (Polymethyl methacrylate) with < 1 ppt U/Th/K.

- Mechanically strong.

*Eur. Phys. J. Plus 139,
1128 (2024)*



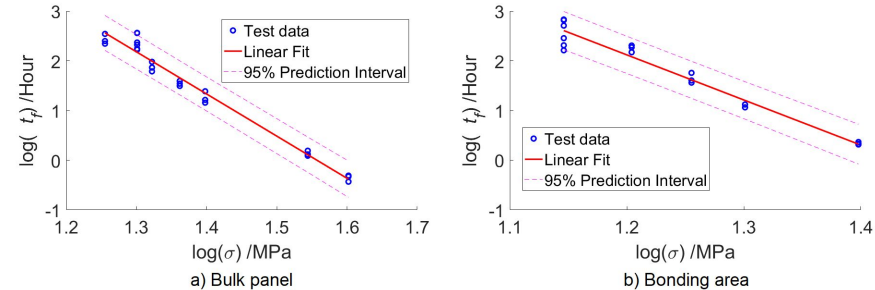
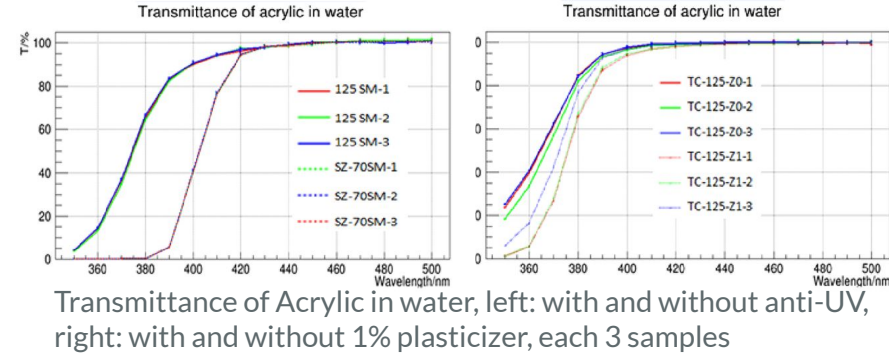
Acrylic vessel with different support structures

Acrylic was chosen over a balloon vessel.

Acrylic formulation

- Low radioactive contamination of acrylic
 $^{238}\text{U} < 0.6$ ppt and $^{232}\text{Th} < 0.7$ ppt
- No anti-UV and No plasticizer
 → Required material studies
- High transmittance of $>96\%$ @420 nm, with 120 mm thickness
- Panels produced flat and thermoformed
- Long term performance:
 - **Creep:** better w/o plasticizer, but crisper
 - **Creep:** Test soaking in water and LS with 20°C
 → Creeping time is 104 years at 3.5 MPa stress

*Radiat Detect Technol
 Methods 5, (2021).
 J. High Energy Phys.
 2021(11), 102.*



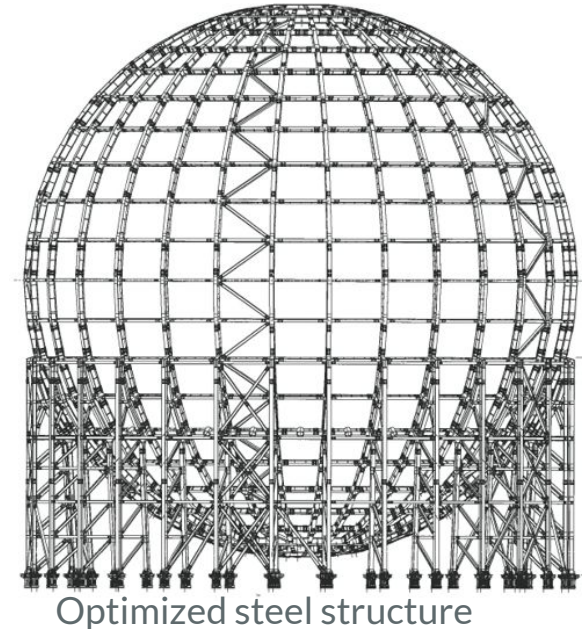
Logarithmic plots on stress and fracture time for left: panel, right: bonding area

How to support the acrylic vessel?

A stainless steel structure of ~900 t was chosen to support the acrylic vessel, PMTs, front-end electronics and anti-geomagnetic field coils and optical shielding.

- A quadrilateral frame with 23 latitudinal and 30 longitudinal zones and five in-plane zig-zag supports was chosen.
- The Acrylic vessel is supported by connecting bars attaching the acrylic nodes to the steel structure.
- Radioactive background requirements:

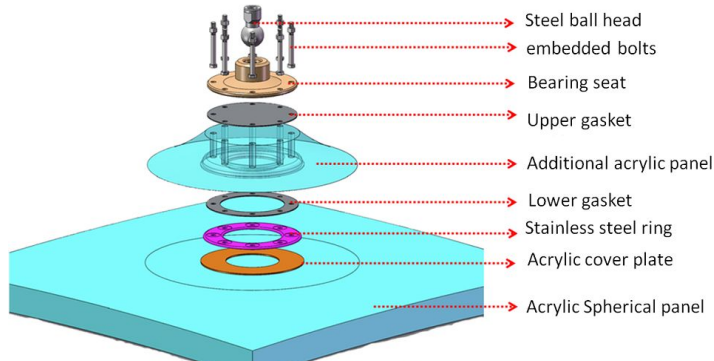
Components	Mass (T)	^{238}U (ppb)	^{232}Th (ppb)	^{40}K (ppb)	^{60}Co (mBq/kg)	Singles in FV (Hz)	Upper limit (Hz)
Structure member	583.79	1	3	0.2	20	0.02	0.1
SS node	23.6	0.2	0.6	0.02	1.5	0.9	1.5
Connecting bar	67.18	0.2	0.6	0.02	1.5	0.2	0.5
Welding material	13.35	200	100	10	50	0.02	0.05



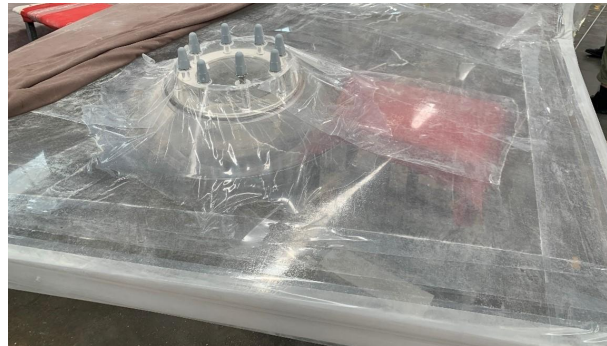
Acrylic vessel - Assembly

Acrylic vessel produced in 263 panels + 2 chimneys and assembled in place.

- Acrylic nodes attach acrylic panels over connecting bars to steel frame.
- Connecting bars /w 4 fiber grating (FBG) + 1 temperature sensor.
- 590 bars, /w 220 include springs to adjust stiffness & control internal force.
- Stress on the acrylic vessel is designed to be < 3.5 MPa and was/is closely monitored during construction, filling and operation.



Acrylic node detailed schematics



Acrylic panel with node

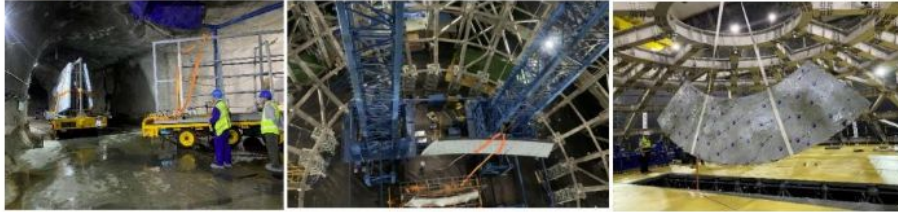


Connecting bar

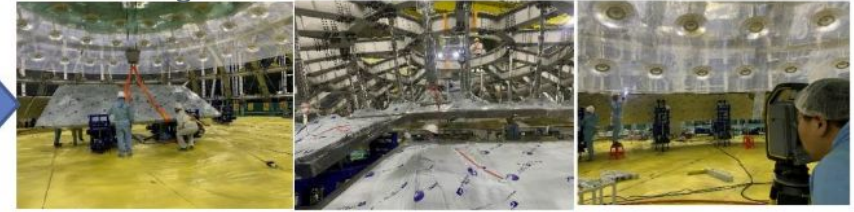
JUNO acrylic vessel assembly

Eur. Phys. J. Plus 139.
1128 (2024)

Transport



Positioning



Bonding



Connecting bars installation



Sanding, polishing, cleaning

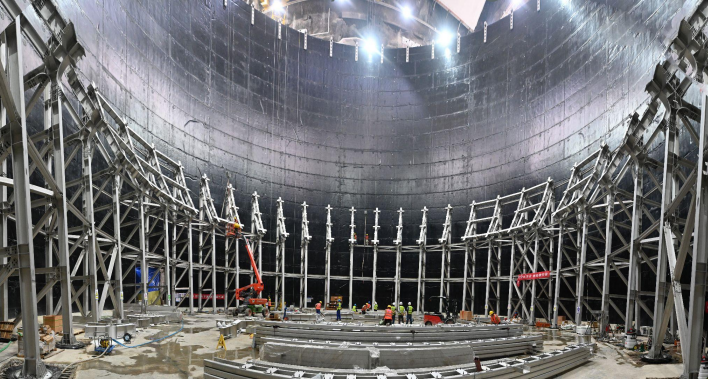


Lower Platform



JUNO construction

Steel structure assembly bottom legs



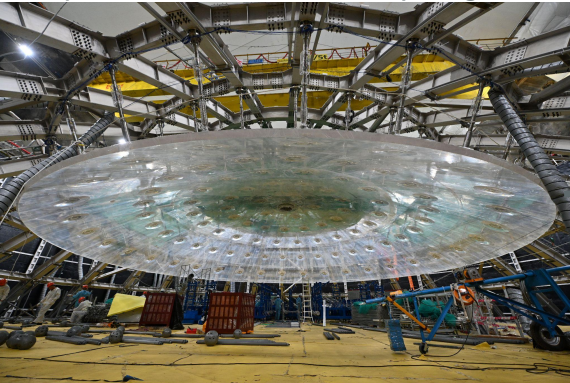
Steel structure with lifting platform



Completed steel structure



Acrylic vessel installation top rings



Acrylic vessel installation until equator



Acrylic vessel completed



PMT instrumentation

Double calorimetry: large PMTs (LPMTs) & small PMTs (sPMTs)

- LPMT distances of ~ 3 mm for high optical coverage
- All PMTs characterized individually before installation, two types of Large PMTs chosen:

	LPMT (20-inch)		SPMT (3-inch)
	Hamamatsu	NNVT	HZC
Quantity	5000	15012	25600
Charge Collection	Dynode	MCP	Dynode
Photon Efficiency	28.5%	30.1%	25%
Dynamic range	[0, 100] PEs		[0, 2] PEs
Coverage	75%		3%
Reference	Eur.Phys.J.C 82 (2022) 12, 1168		NIM.A 1005 (2021) 165347

- More about PMT calibration next talk by Davide



Installed LPMTs and sPMTs



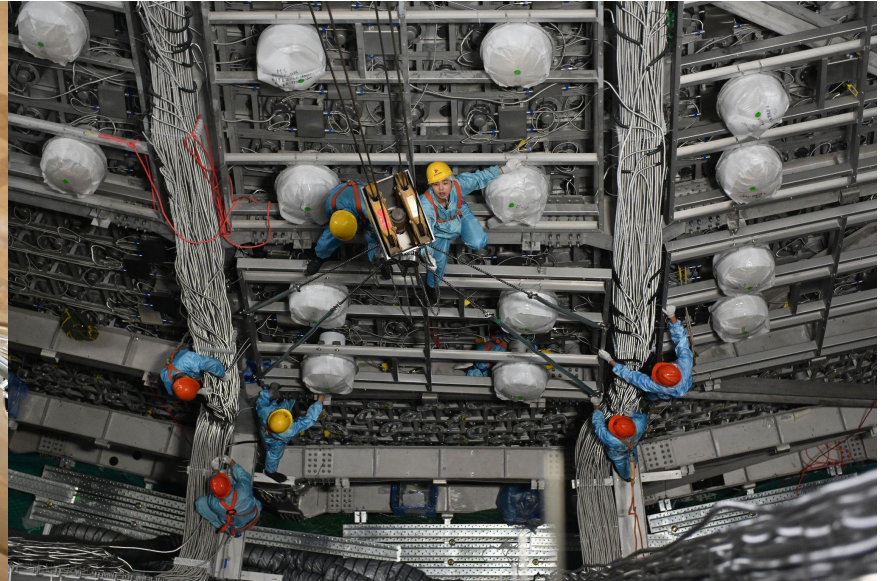
PMT Implosion protection, Acrylic & stainless steel cover (JINST 18 (2023), P02013)

PMT installation

PMT modules installed after acrylic panels and connected from the outside.



Installing the PMTs after acrylic panels



Electronics connected from the outside

Liquid scintillator tuning

JUNO's liquid scintillator composition was optimized using LS tests in Daya Bay, simulations and lab measurements, maximizing the light yield.

LAB: linear alkylbenzene

high transparency, good light yield

PPO: 2,5-diphenyloxazole

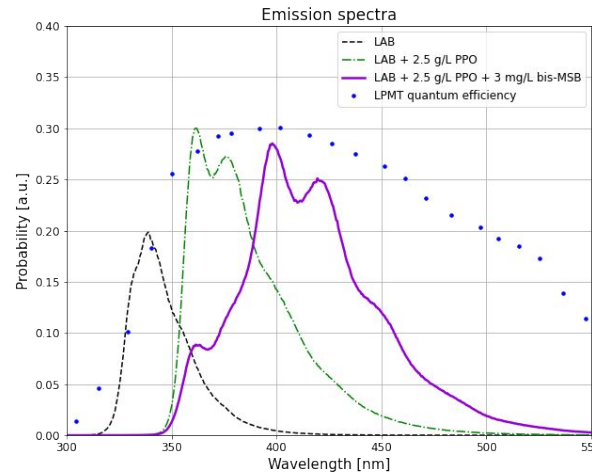
primary wavelength shifter

bis-MSB: 1,4-bis(2-methylstyryl)benzene

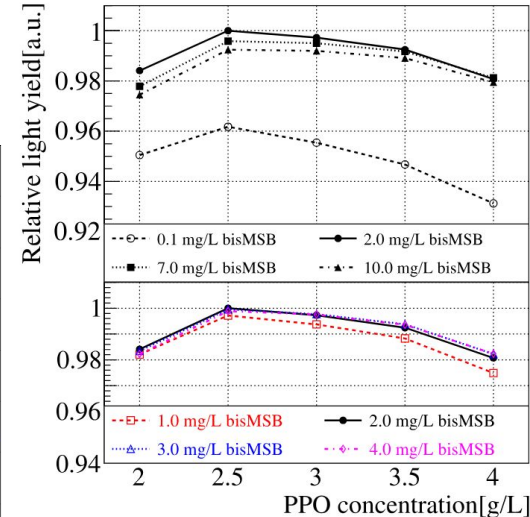
secondary wavelength shifter

BHT: 2,6-ditert-butyl-4-methylphenol

anti-oxidant - prevents aging



Measured emission spectrum of JUNO LS with MCP-LPMTs quantum efficiency [2025 JINST 20 P05009](#)



Simulated observed light yields with different recipes normalized to 2.5 g/L PPO + 2 mg/L bis-MSB, based on Daya Bay LS tests. Top: bis-MSB coarse, bottom: bis-MSB fine tuning

Final recipe: LAB + 2.5 g/L PPO + 3 mg/L bis-MSB + 0.005 % BHT

JUNO LS production and filling

Radiat Detect Technol
Methods (2026). 00708



5000 m³ tank LAB tank



Aluminium stripping to remove particles



Distillation removes radioactive residues



Mixing adds PPO and bis-MSB



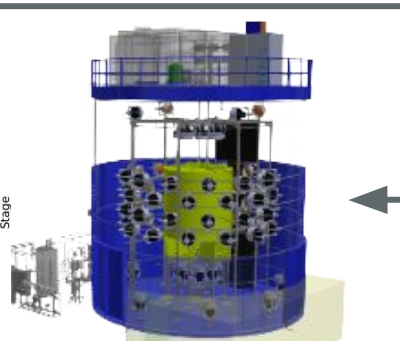
1800 m SS pipes to underground



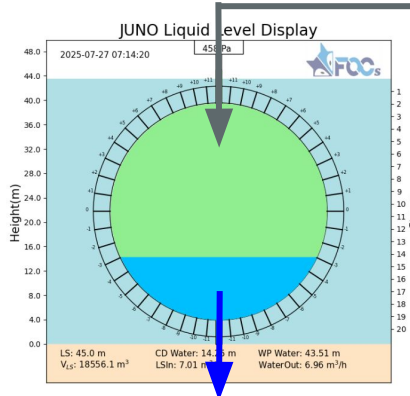
Water extraction removes radioactive residues



Gas stripping removes Rn and O₂



OSIRIS monitoring LS



Liquid scintillator filling

LS filling is the final step of detector construction, keeping structural integrity and purity of the LS is crucial.

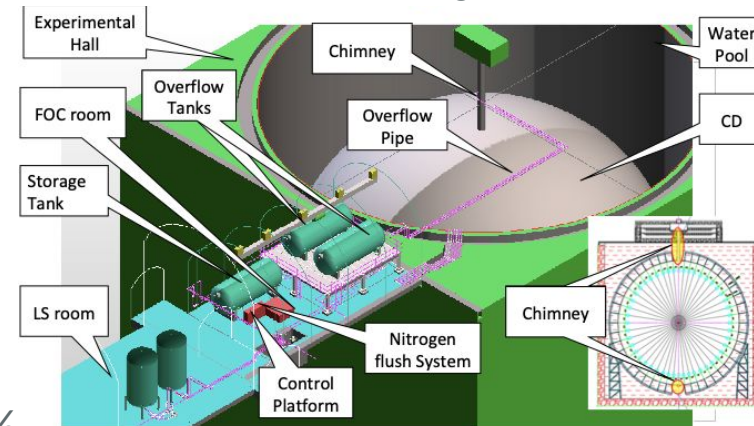
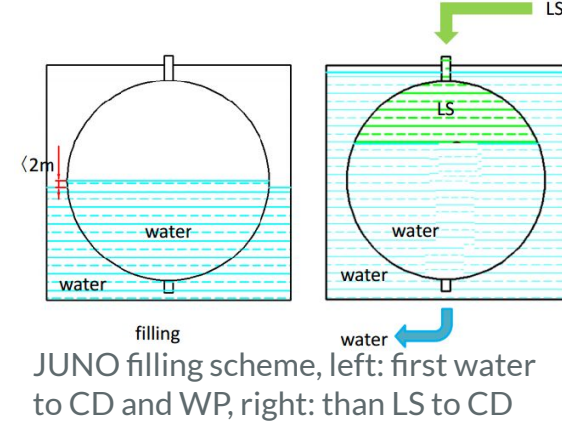
- LS pollution by radon from underground air, must be strictly avoided. All valves/fittings require 10^{-6} mbar·L/s for helium.
- All inner surfaces washed and rinsed with ultrapure water.

FOC (filling, overflowing and circulating) system:

- Keep LS pressure stable for detector safety,
- designed for temperature range 21.0 ± 1.4 °C,
- LS thermal volume coefficient 8.8×10^{-4} °C⁻¹,
- one storage and two overflow tanks each 50 m³,
- overflow tanks can passively absorb or refill LS.

During LS filling: level control ± 2 cm, flow regulation $\pm 0.5\%$.

[*Eur. Phys. J. Plus* 139, 1128 \(2024\)](#)
[arXiv:2512.14033 \(2025\)](#)



Drawing of JUNO's FOC system with CD.

Liquid scintillator specs

Chin. Phys. C. 50
(2026) 043001

Liquid scintillator: LAB + 2.5 g/L PPO + 3 mg/L bis-MSB + 0.005 % BHT

Measured light yield: 1785 PE/MeV for neutrons @ Detector Center

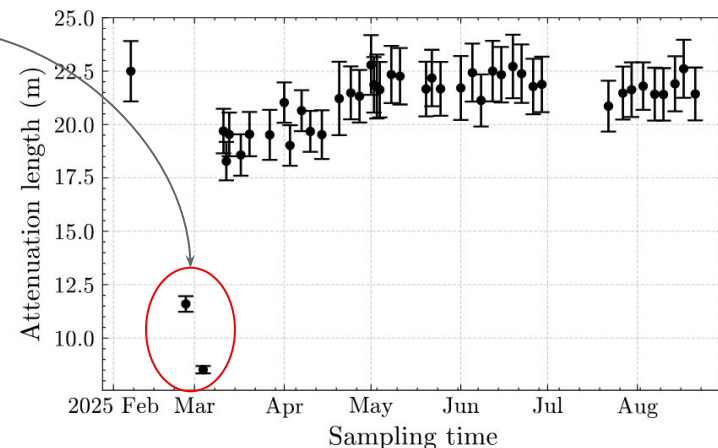
Attenuation length: the average attenuation length reached 20.6 m at @ 430 nm,
~500 m³ of low quality LS due to yellowish PPO

Radio purity: at $r < 16.5$ m fiducial volume

²⁸³U contamination $(7.5 \pm 0.9) \times 10^{-17}$ g/g

²³²Th contamination $(8.2 \pm 0.7) \times 10^{-17}$ g/g

Radio purity one magnitude better than
required for NMO analysis.

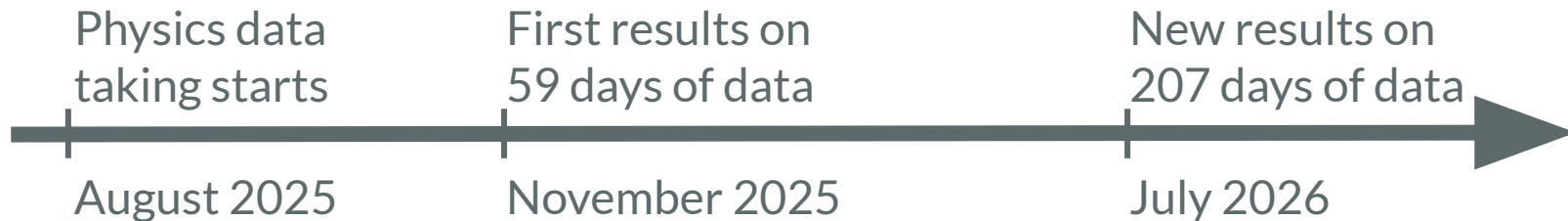


LS attenuation length measurement during the
6 month filling process

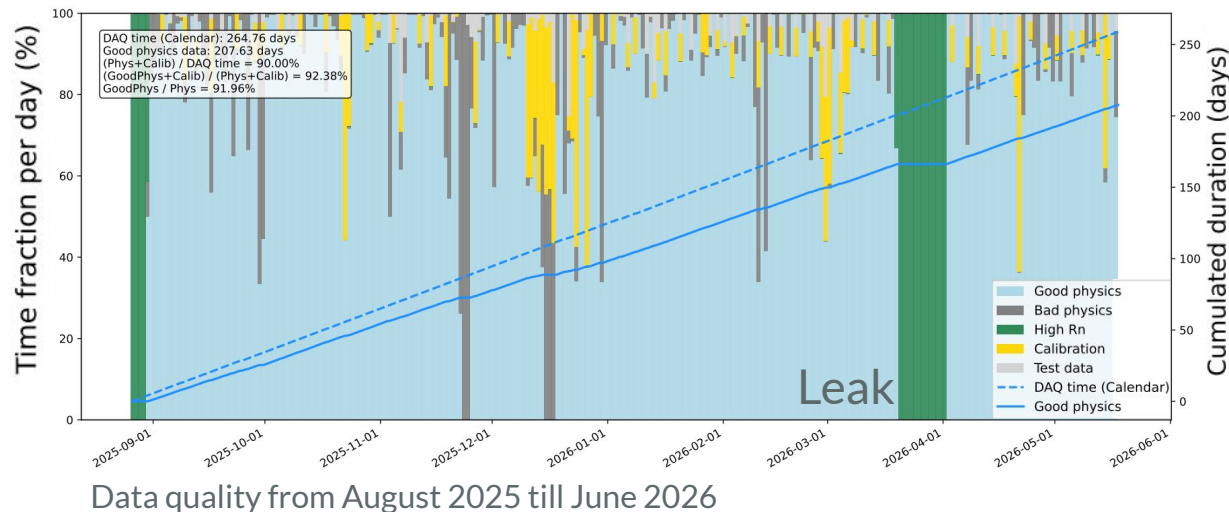
Detector operation and data taking



JUNO operation



Since the start of physics data taking JUNO steadily took data with short interruptions by calibration campaigns and service works.



Leaks in the acrylic sphere

Unfortunately we have experienced cracks, which have been repaired quickly!

1st LS leak LS to water in March 2025 and 2nd leak water to LS in March 2026

Clearance between PMTs and acrylic vessel allowed experienced divers to access the leaks. Both leaks could be repaired quickly within 1 week and two days using special underwater epoxy and tape.



JUNO first crack close to the top chimney,

JUNO's Central Detector - Rosmarie Wirth



Diver applying glue to close the first crack,



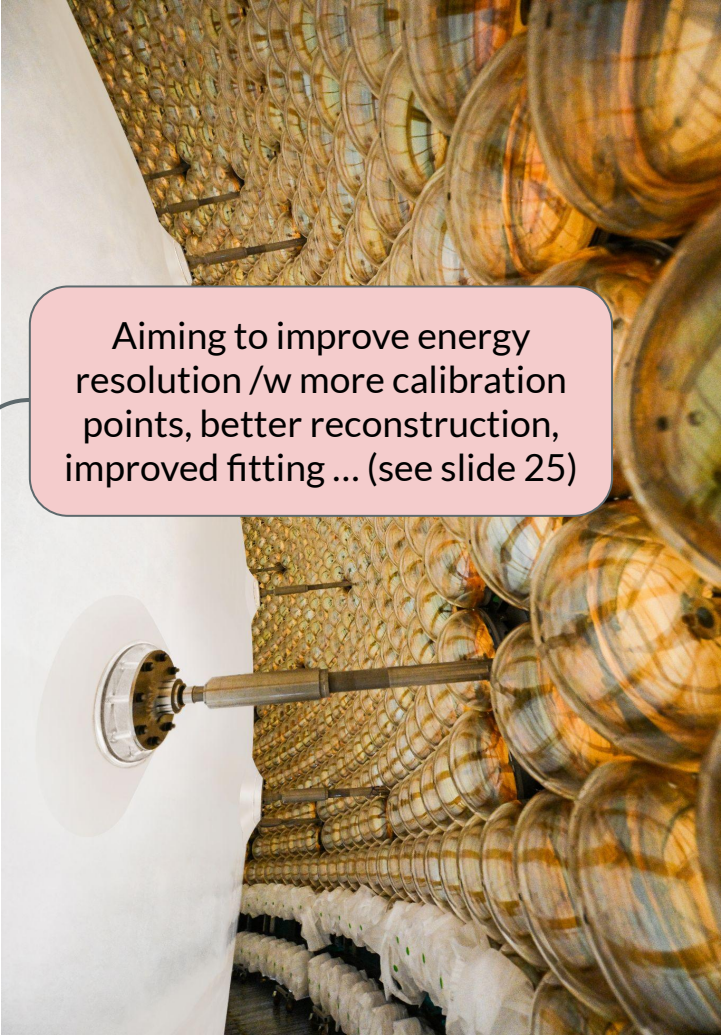
2nd crack with epoxy and divers hand

Summary

JUNO's design decisions were motivated and detector construction shown. Archived characteristics:

- 20 kT LS with 35.4 m diameter, ✓
- High energy resolution (3 % @1 MeV),
→ Bit worse: ^{68}Ge with ~3.5 % @ 2×0.511 MeV
- Maximal possible optical coverage,
→ Optical coverage of 75 % by LPMs ✓
- High light transmittance >20 m,
→ Average attenuation length 20.6 m ✓
- Lowest possible radioactive background
→ Limits for NMO analysis met. ✓

Thank you for your attention.



Aiming to improve energy resolution /w more calibration points, better reconstruction, improved fitting ... (see slide 25)

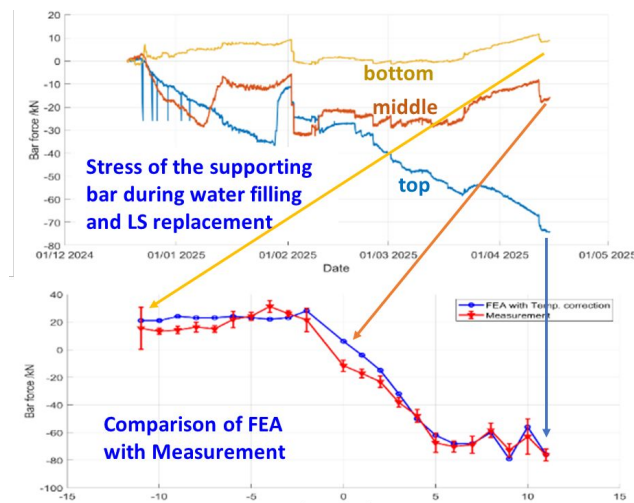
Back up



Leaks in the acrylic sphere

As shown by Yifang Wang
at Neutrino 2026

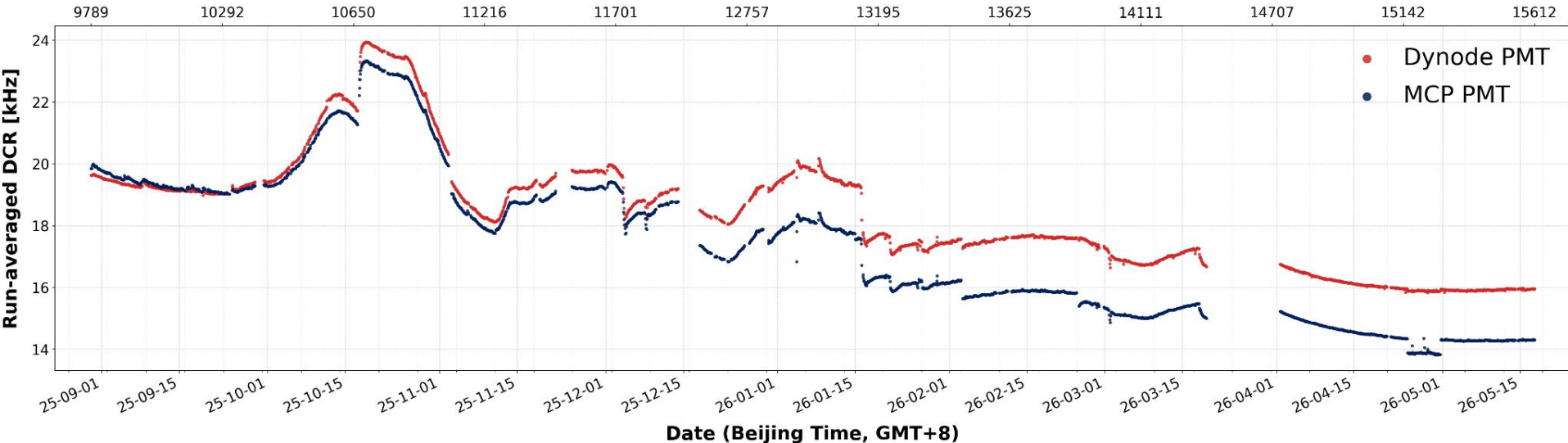
- Main structure is safe, stress within expectations
- However, a LS leak to water happened on March 21, 2025:
 - ⇒ Abnormal trigger rate observed and confirmed by under water robot
 - ⇒ Leak was stopped within 1 week using epoxy and tape by divers
 - ⇒ Further repair by epoxy and acrylic plate to reduce the stress (pulling open the crack) by 50%
- Another leak of water to LS happened on March 19, 2026:
 - ⇒ Experienced divers were called to stop the leak within 2 days
 - ⇒ Further repair in the following two days
 - ⇒ A total of $\sim 1\text{Bq }^{222}\text{Rn}$ went into LS, 13 days of data excluded
 - ⇒ No other increase of radioactive backgrounds in LS



JUNO LPMTs in operation

2026 Neutrino
Conference

- 17612 LPMTs installed for CD and 2400 in WP
- ~26 dead PMTs + electronics, ~1.2/month (status July 2026)
- ~600 PMTs were switched off due to high DCR or flashing (status July 2026)
- Dark count rate (DCR) decreases steadily, trends from WP temp. and HV changes

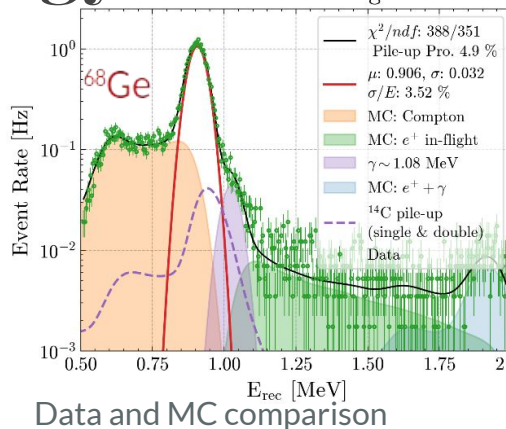


Light Yield and Energy Resolution

As shown by Yifang Wang
at Neutrino 2026

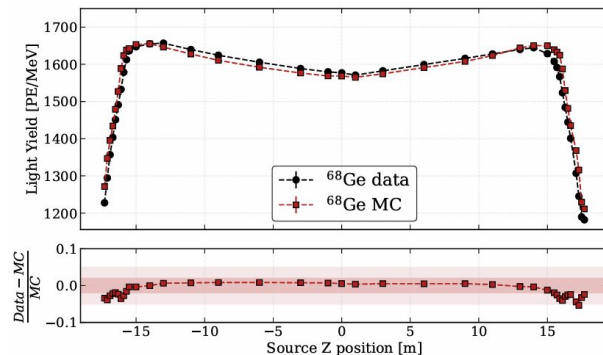
Light yield the detector center:

- ~ 1600 PE/MeV for ^{68}Ge
- ~ 1785 PE/MeV for neutrons,
- in good agreement with MC

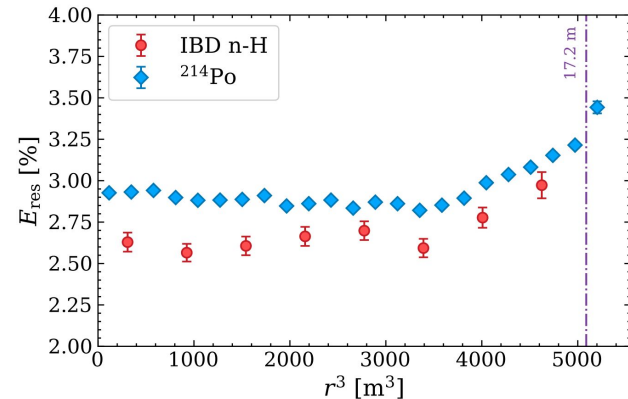


Energy resolution:

- Energy resolution for ^{68}Ge is $\sim 3.5\%$ @ 20511 MeV at the center, slightly worse than the expected 3.1%
 - Better MC for $\check{C}$ process, optical boundaries, δ electrons, ...
 - Possible improvements: ML to remove ^{14}C , more calibration, better reconstruction and fitting methods, ...
- Energy resolution for alpha from ^{214}Po is $\sim 2.9\%$ @ 0.93MeV



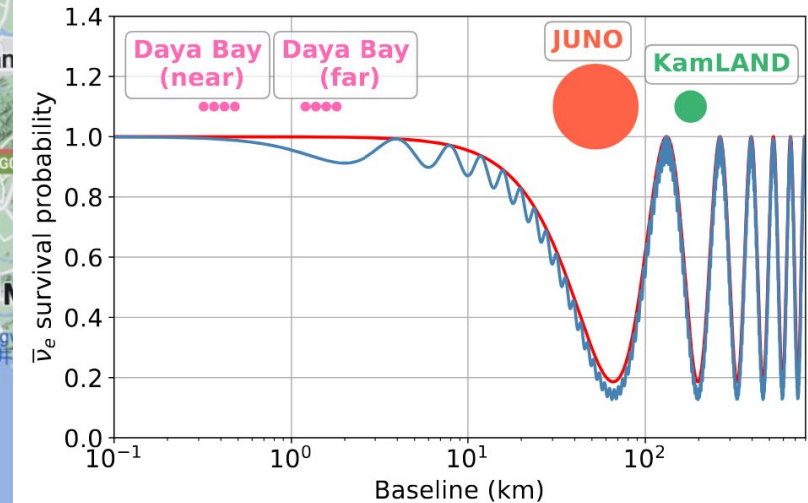
Light yield of ^{68}Ge along Z axis



Energy resolution for ^{214}Po , IBD n-H over r^3

JUNO's location

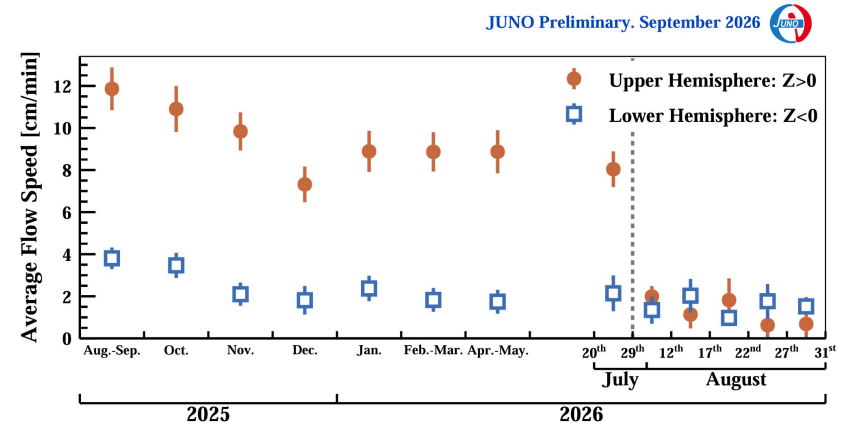
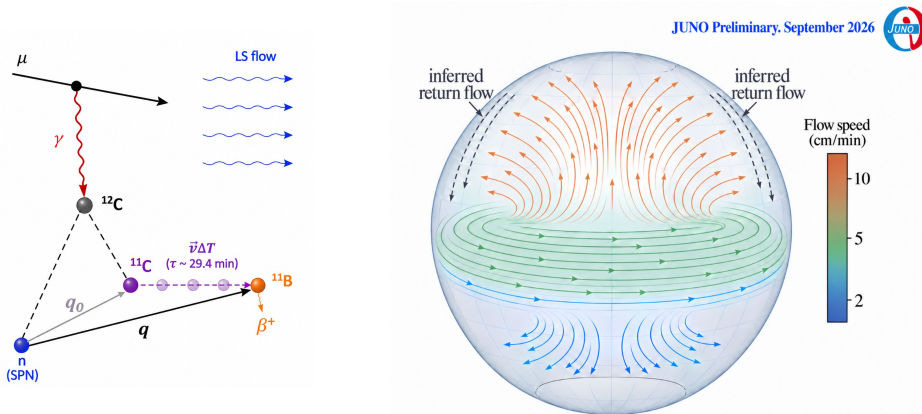
*Nature volume 654,
pages 343–348 (2026)*



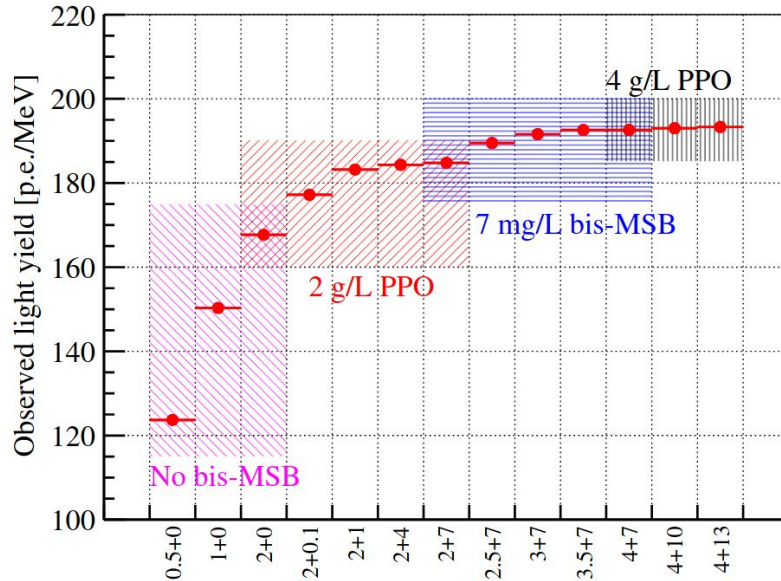
Survival probability P_{ee} of 4 MeV reactor electron anti-neutrinos against baseline. Red: slow solar oscillation, blue total P_{ee} JUNO near solar oscillation maximum

Measurement of LS flow

- LS flow velocity was measured using cosmogenic ^{11}C and spallation neutron.
- After adjusting the water-temperature in July 2026, the flow speed in the upper hemisphere dropped sharply.
- Higher LS flow in top hemisphere implies elevated U/Th signals mostly from radon emanated from upper chimney.



LS mixture tuning

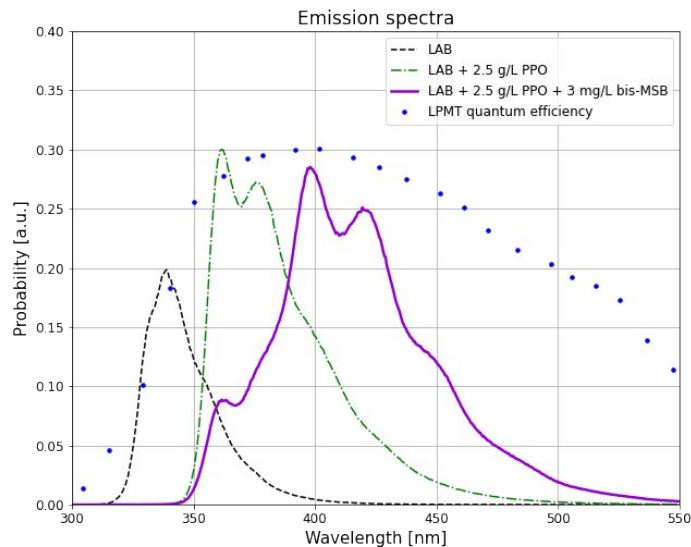


13 LS compositions have been tested at one Daya Bay anti-neutrino detector measuring the Observed light yield for a ^{60}Co calibration source at 2.505 MeV.

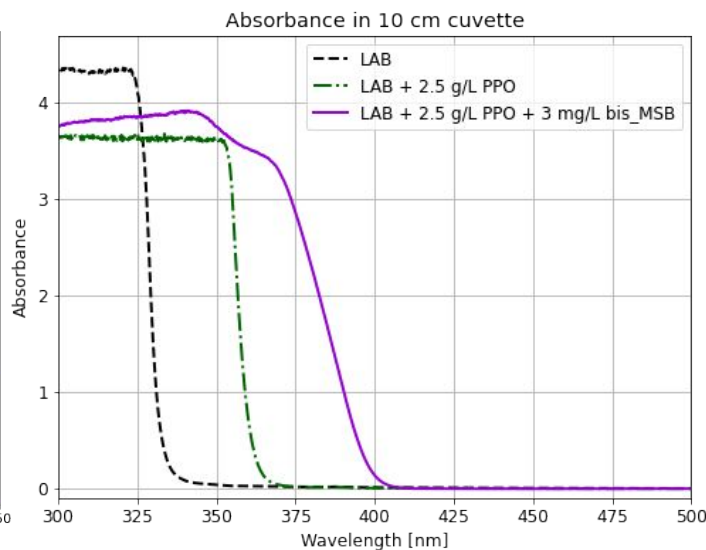
The LS mixture was changed gradually adding PPO and bis-MSB with at least 3 days of self-circulation.

JUNO LS characterizations

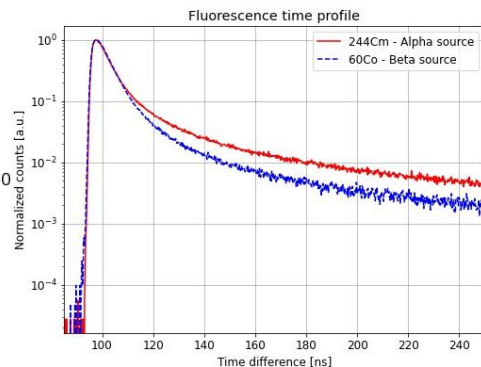
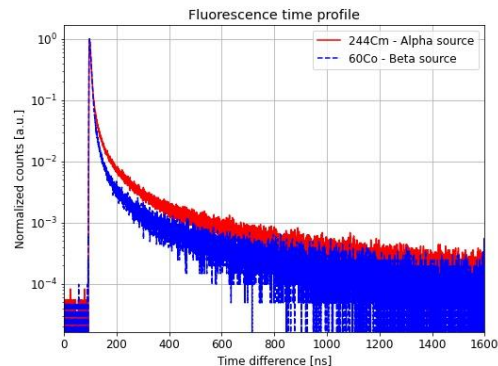
2025 JINST 20 P05009



Measured emission spectrum of JUNO LS with MCP-LPMTs quantum efficiency



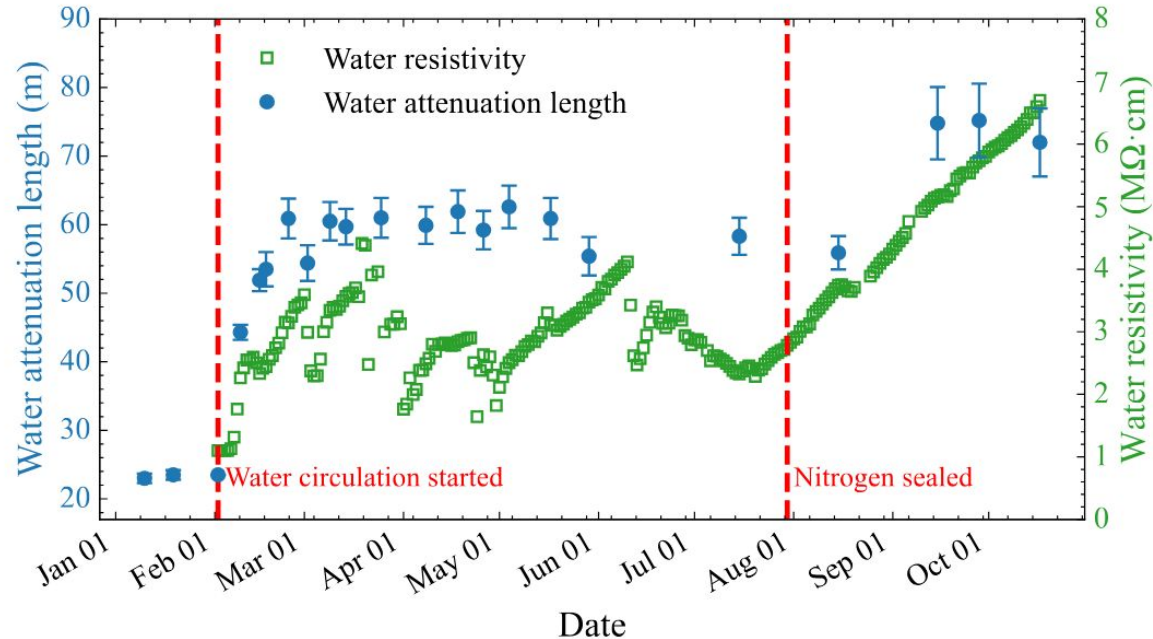
LS absorbance from lab measurement



Fluorescence time profile, top: full range, bottom: zoom

Water attenuation length in Water Pool

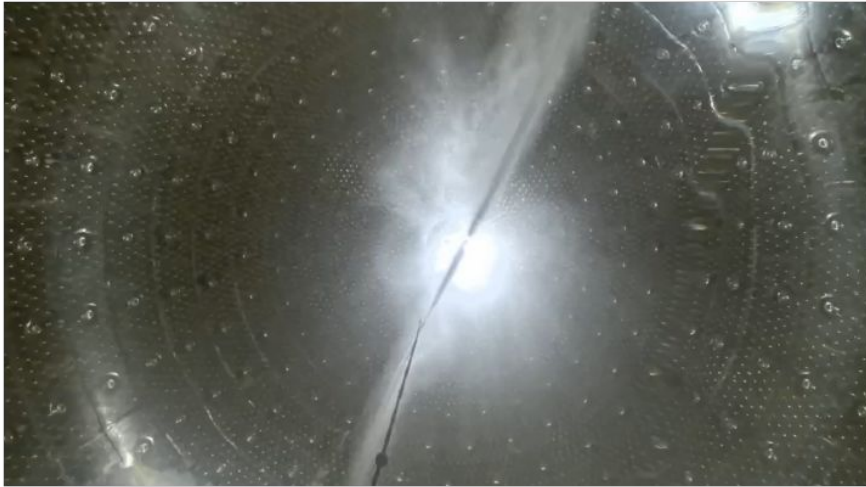
Chin. Phys. C. 50
(2026) 043001



Water attenuation length and water resistivity for 2025. First increase after circulation started; second with nitrogen sealing of the water pool.

CD Surface protection and cleaning

Pure water was used to remove dust and protective paper before the water filling.



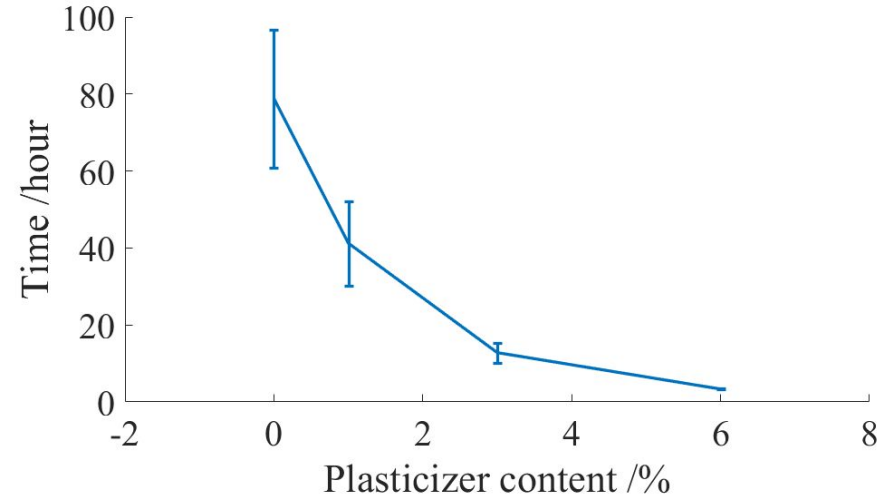
Cleaning the CD inside with pure water to remove protective film.



Protective soluble paper film to protect acrylic from Rn decay daughters.

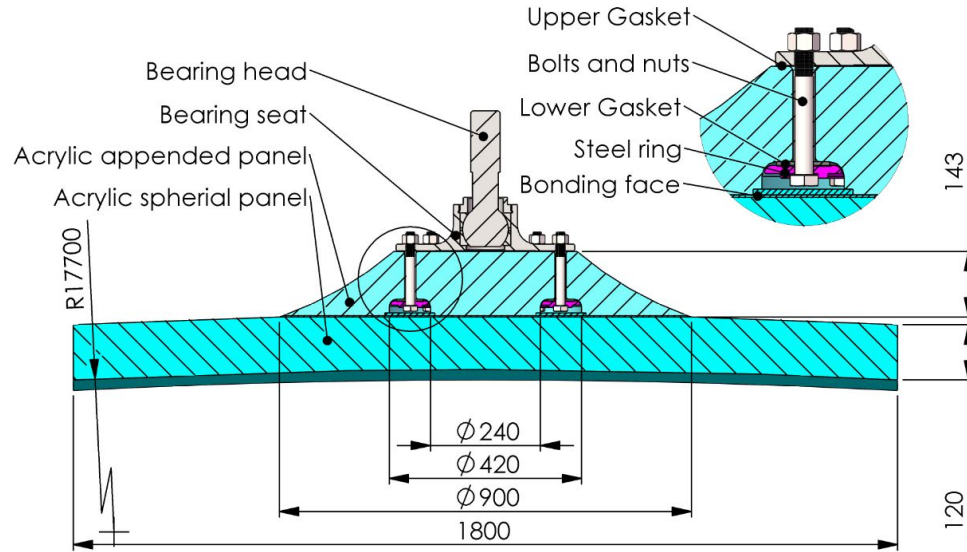
Acrylic Vessel - No Plasticizer

- 0% plasticizer in JUNO's acrylic
- Creep performances improve when the plasticizer content is lower
- A customized creep machine was designed and used for the creep tests
- tensile strength of 120 mm one-time cast panel can reach (70 ± 4) MPa



Creep fracture time over plasticizer content in %.

Acrylic Nodes and Acrylic assembly

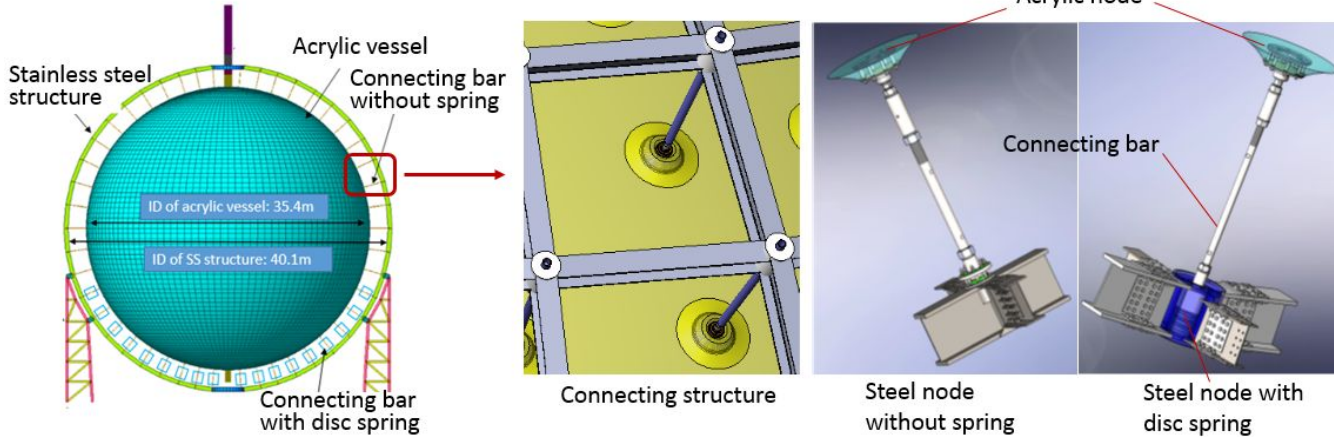


Technical drawing of acrylic node



Test fitting of north pole acrylics

Connecting bars



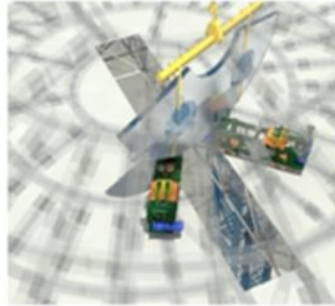
220 /w spring on the bottom 370 /wo spring on the top hemisphere to adjust the axial stiffness and control the internal force.

Connecting bars include 4 fiber grating (FBG) and 1 temperature sensors.

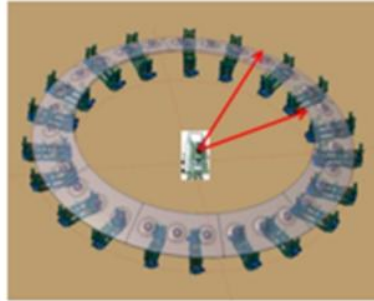


Acrylic assembly

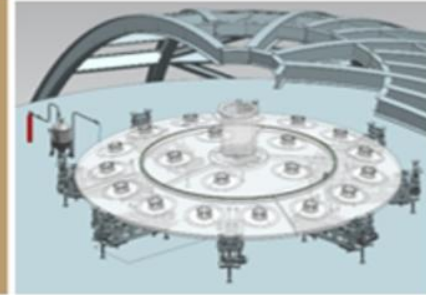
*Eur. Phys. J. Plus 139,
1128 (2024)*



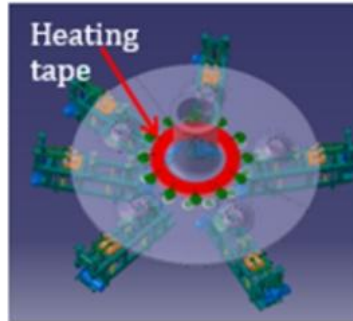
Lifting panel &
fixture on platform



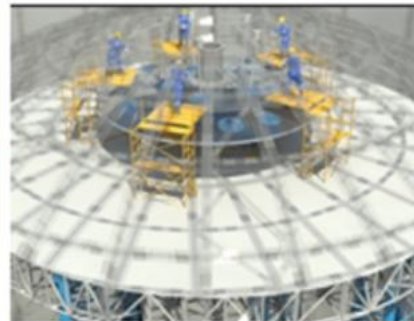
Locating & survey



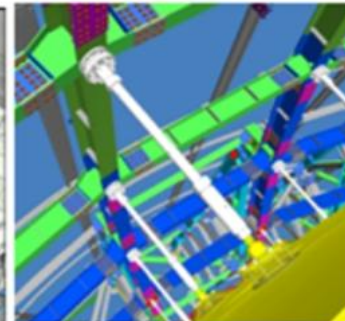
Bonding circle &
vertical lines



Annealing



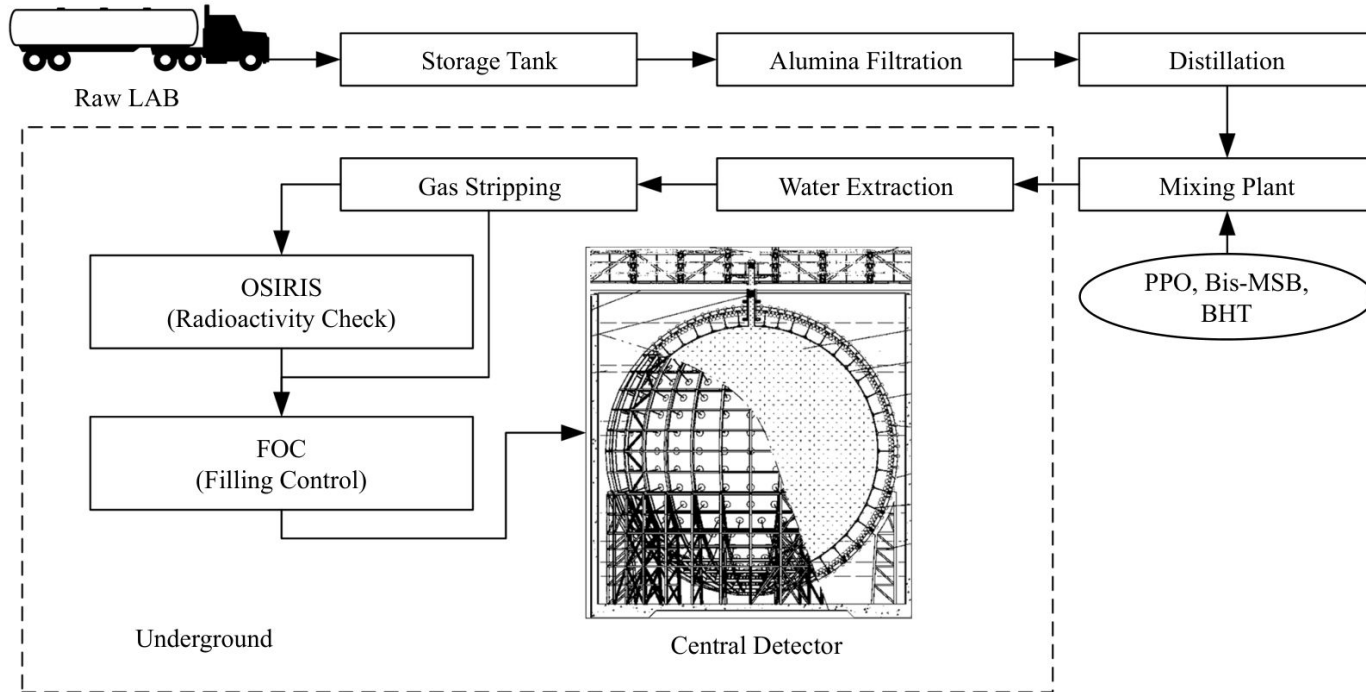
Sanding & polishing



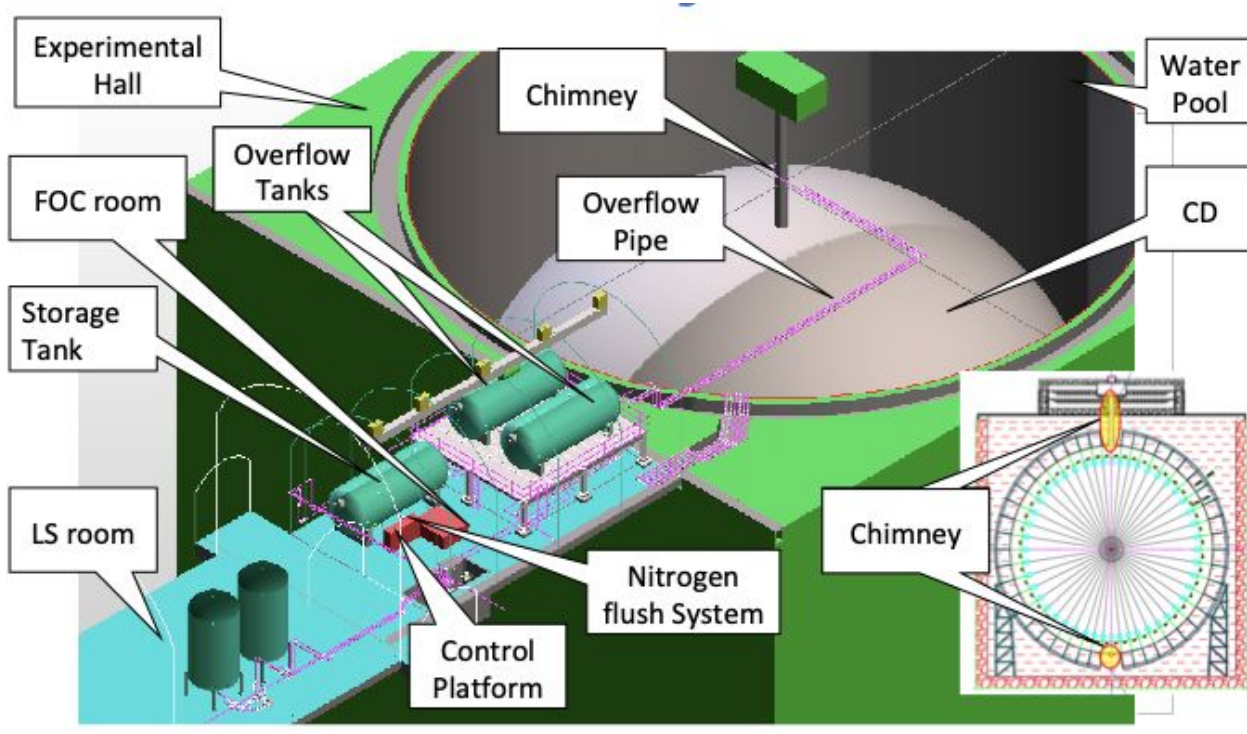
Installing
connecting bar

JUNO LS filling chain schematic

*Radiat Detect Technol
Methods (2026). 00708*



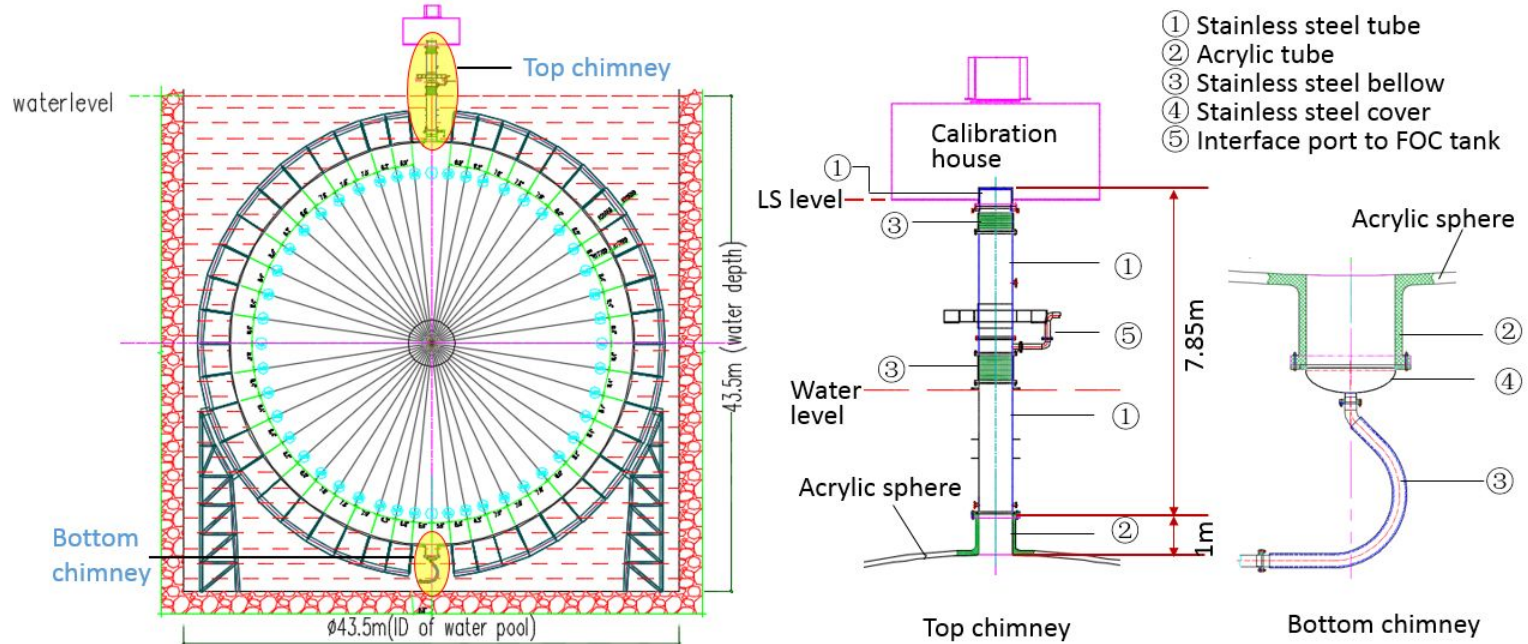
FOC system - large picture



FOC (filling, overflowing, and circulating) system

JUNO chimneys

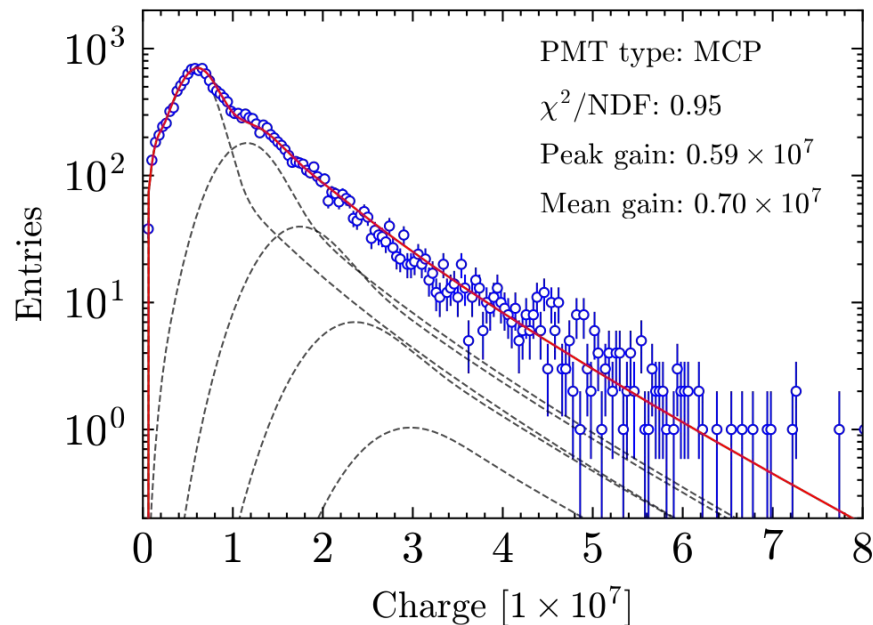
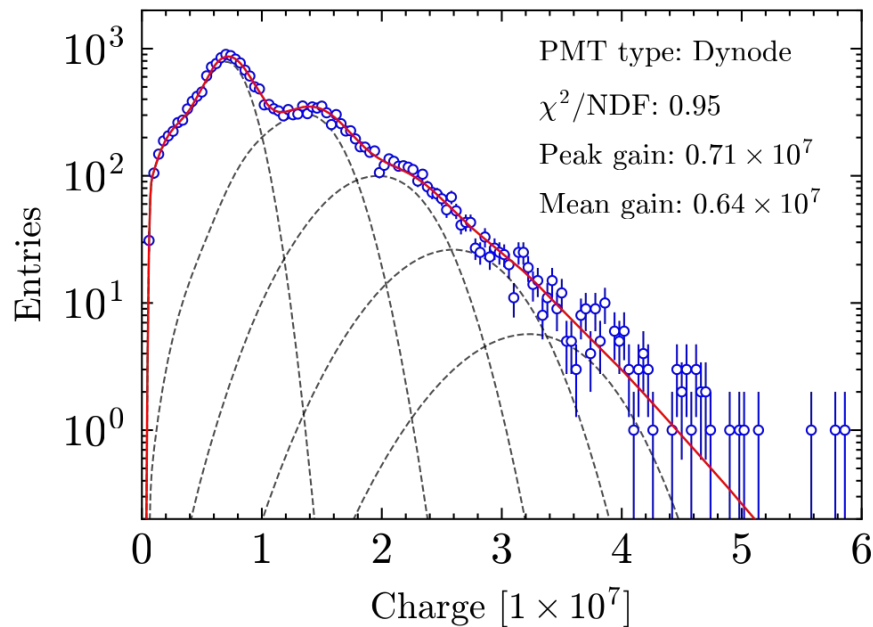
*Eur. Phys. J. Plus 139,
1128 (2024)*



JUNO's chimney design as schematic drawing.

JUNO LPMTs gain

Chin. Phys. C. 50
(2026) 043001



JUNO LPMTs charge spectra - Dynode and MCP from laser calibration.