# Status of the JUNO Detector

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# Jiangmen Underground Neutrino Observatory

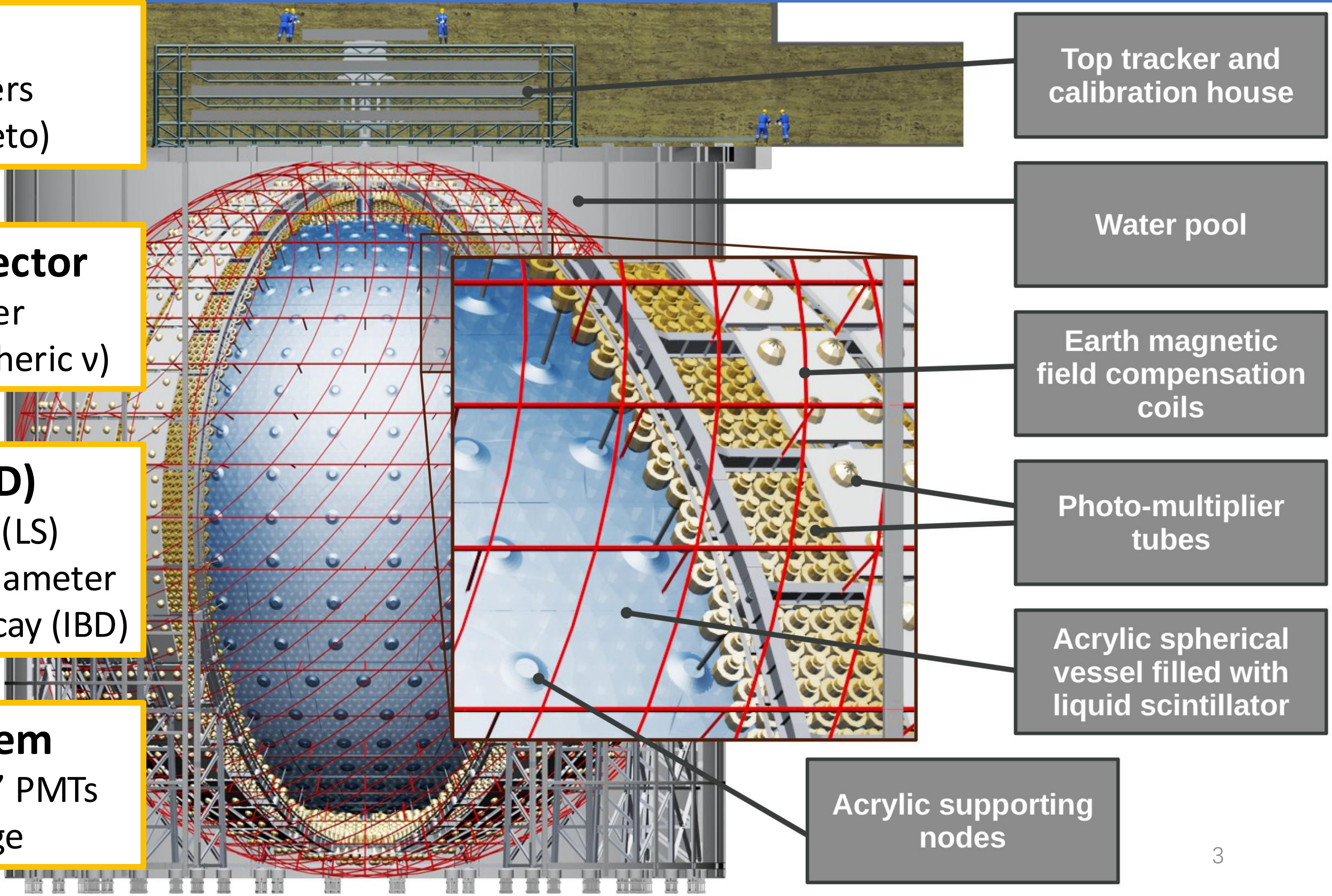
# A Multi-purpose Underground Liquid Scintillator Experiment

**Top Tracker**
3 plastic scintillator layers
Precise muon tagging (veto)

**Water Cherenkov Detector**
35 kton ultra-pure water
>2500 PMTs (veto & atmospheric ν)

**Central Detector (CD)**
20 kton liquid scintillator (LS)
Acrylic sphere with 35.4 m diameter
Detect ν's via inverse beta decay (IBD)

**Light Detection System**
17596 20'' PMTs + 25600 3'' PMTs
78% geometric coverage



# Key Design Features of JUNO

- Primary goal: to determine **Neutrino Mass Ordering** (NMO)

- Requirements:
  - High statistics (~$10^5$ IBD events in 6 years)
  - Excellent energy resolution (3% at 1 MeV)
  - Well controlled energy response systematics
  - Low background, both internal & external

- How?
  - Huge LS mass with high light yield & transparency
  - High PMT coverage and efficiency
  - Good PMT performance
  - Complementary calibration systems

| Characteristics | KamLAND | JUNO (goal) | Relative Gain |
|---|---|---|---|
| **Energy Resolution** | **6% @ 1 MeV** | **3% @ 1 MeV** | **2** |
| **Light Yield** | **250 p.e. / MeV** | **>1200 p.e. / MeV** | **~5** |
| Geometric coverage | 34% | ~78% | ~2 |
| PPO content | 1.5 g/L PPO | 2.5 g/L PPO | ~1.5 |
| Attenuation length / D | 15/16 m | 20/35 m | ~0.8 |
| PMT QExCE | 20%x60% ~ 12% | ~30% | ~2 |

← use **KamLAND** as a reference

← **target** (Energy Resolution, Light Yield)

← **> 40000 PMTs** (Geometric coverage)

← **optimized LS** (PPO content, Attenuation length / D)

← **more efficient PMTs** (PMT QExCE)

# Liquid Scintillator Production

- Four purification plants designed to reach a radio-purity of **$10^{-17}$** g/g (U/Th) and **20 m** attenuation length at 430 nm

5000 $m^3$ LAB tank

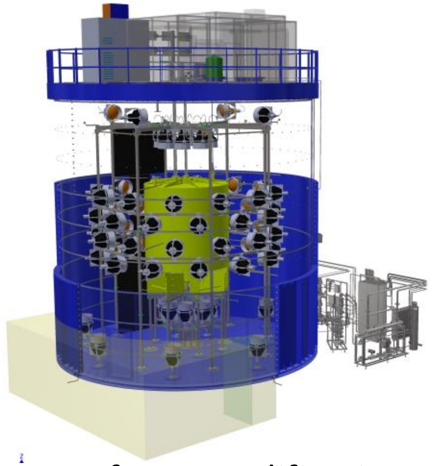
$Al_2O_3$ to remove particles

Distillation to remove radioactive impurities

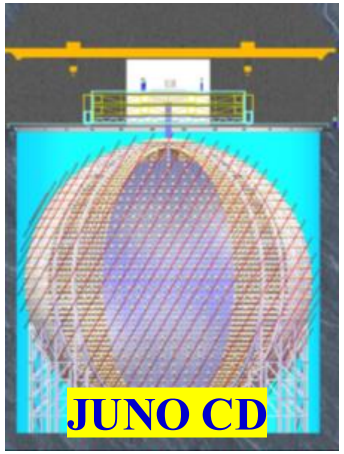
Add 2.5 g/L PPO and 3 mg/L bis-MSB

Water extraction to remove radioactive impurities

Gas stripping to remove Rn and $O_2$



OSIRIS for LS qualification



# Calibration System in JUNO

■ Multiple calibration campaigns →

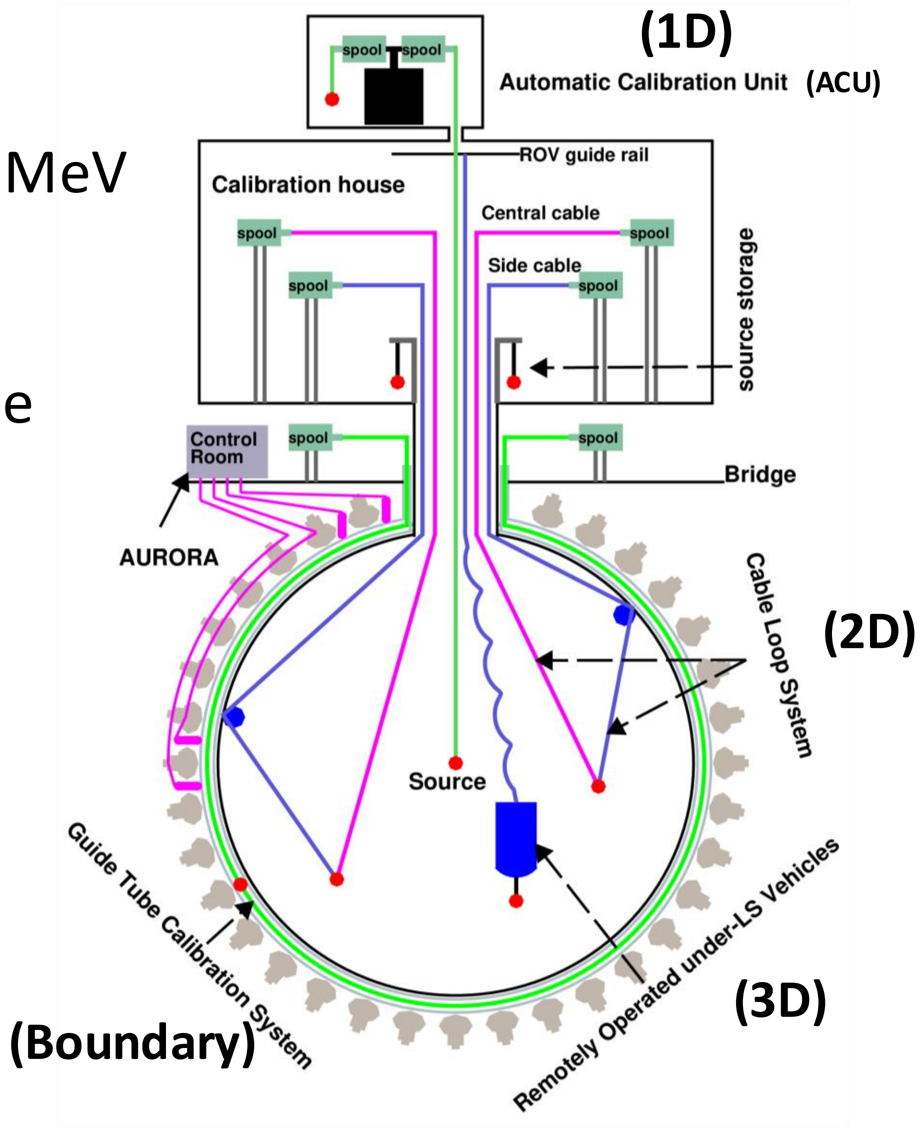
- Determination of $e^+$ energy non-linearity at <1%
- Optimization of $e^+$ energy resolution at <3% level at 1 MeV

➢ ACU works well so far, in LS filling

- $^{137}$Cs, $^{54}$Mn, $^{60}$Co, $^{68}$Ge, $^{241}$Am-Be, $^{241}$Am-$^{13}$C used
- 4 rounds of calibration along z-axis have been done

| Sources/Processes | Type | Radiation |
|---|---|---|
| $^{137}$Cs | $\gamma$ | 0.662 MeV |
| $^{54}$Mn | $\gamma$ | 0.835 MeV |
| $^{60}$Co | $\gamma$ | 1.173 + 1.333 MeV |
| $^{40}$K | $\gamma$ | 1.461 MeV |
| $^{68}$Ge | $e^+$ | annihilation 0.511 + 0.511 MeV |
| $^{241}$Am-Be | n, $\gamma$ | neutron + 4.43 MeV ($^{12}$C*) |
| $^{241}$Am-$^{13}$C | n, $\gamma$ | neutron + 6.13 MeV ($^{16}$O*) |
| (n,$\gamma$)p | $\gamma$ | 2.22 MeV |
| (n,$\gamma$)$^{12}$C | $\gamma$ | 4.94 MeV or 3.68 + 1.26 MeV |

Radioactive sources + laser sources + natural radioactive isotopes



# A Long Journey

Tunnel Digging

Inspection of bonding lines

Project Start

2013

2015

Start of civil construction

Beginning of detector installation

2022

Early Time of Detector Installation

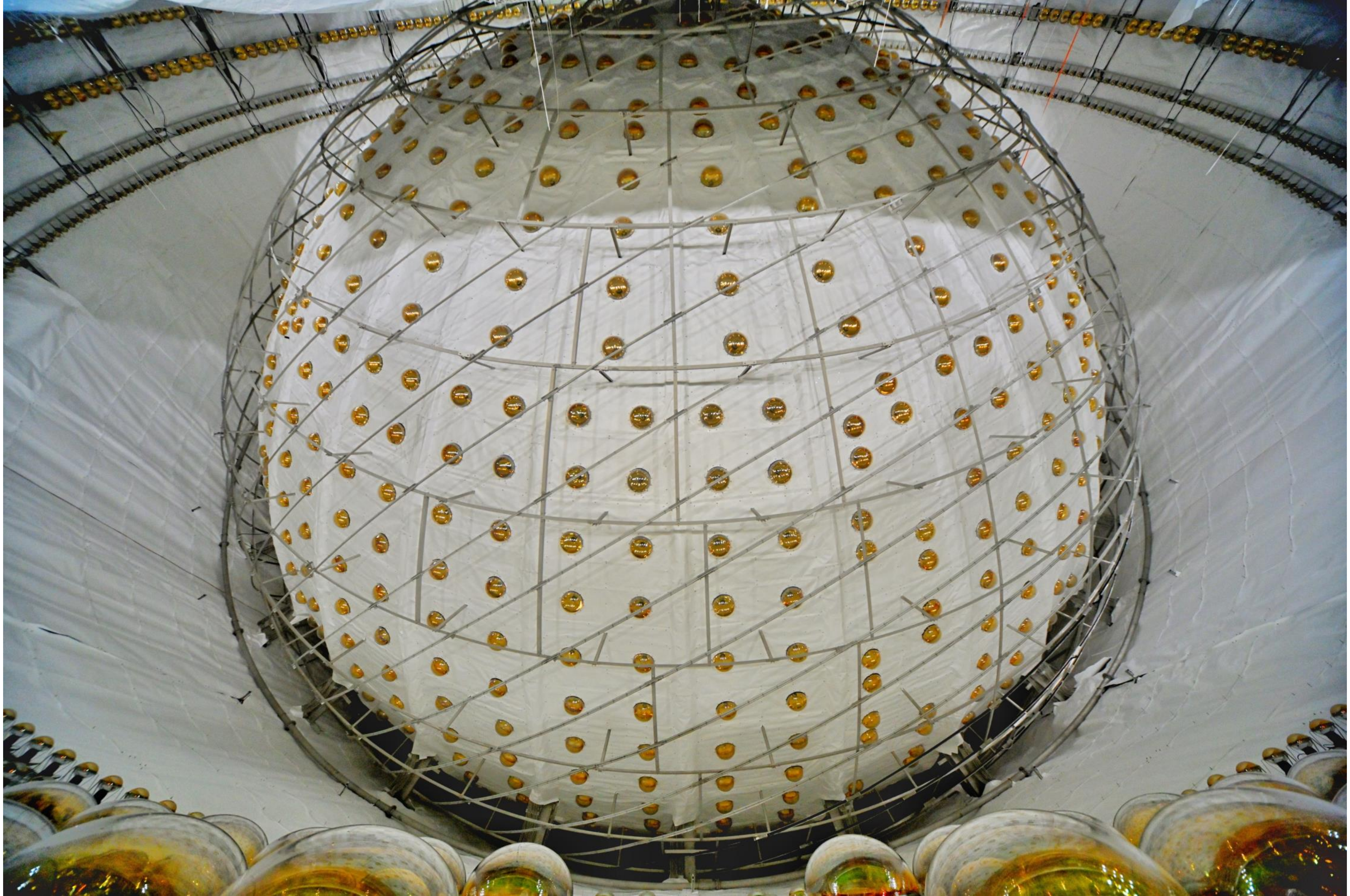
2024 Dec 1

End of detector installation

Cleaning & installation of extra PMTs

2024 Dec 17

Completion of acrylic vessel installation

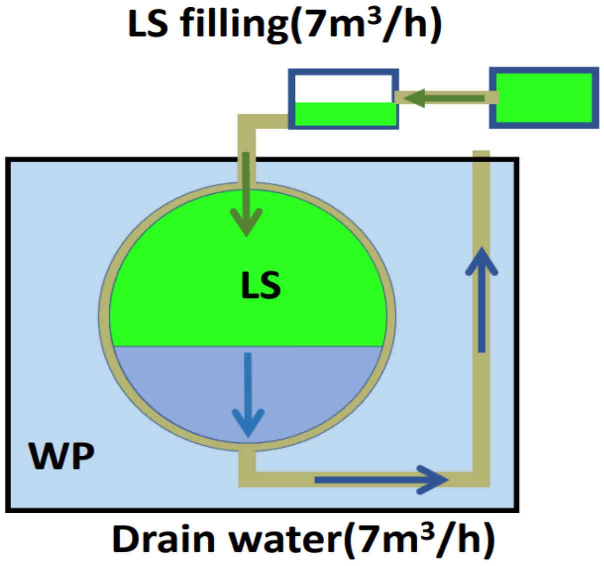


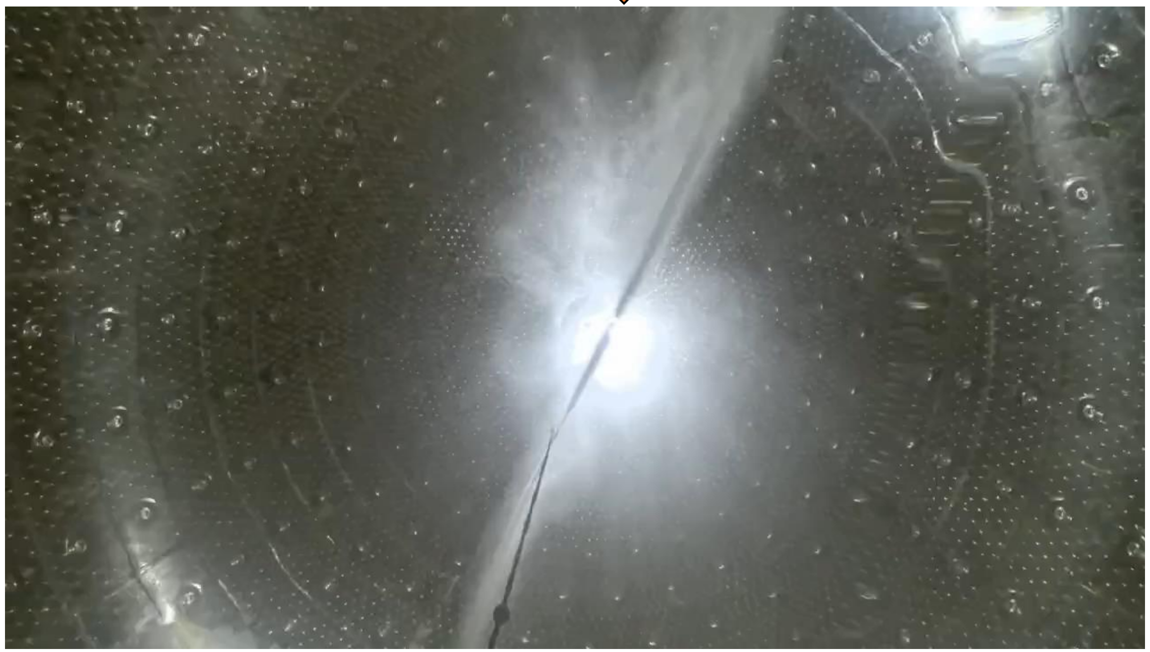
# Final Cleaning & Filling Scheme

Reduce Rn, dust to class <1000

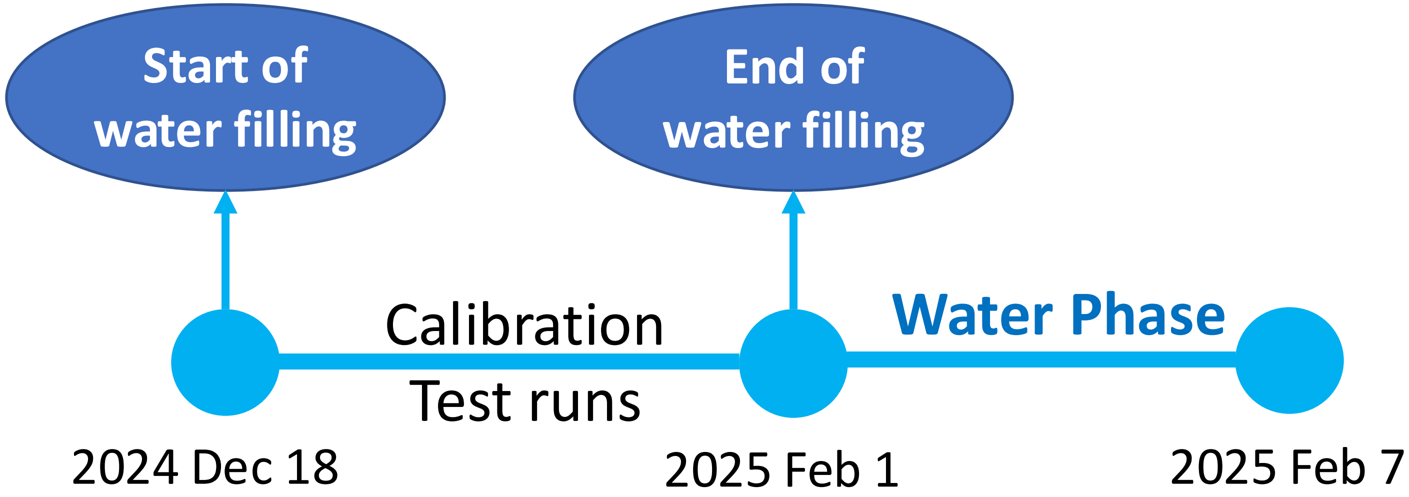
Complete CD construction → days settlement with proper moisture → Remove the protective film and wash the acrylic surface by the high pressure water spray → Fill CD and VETO by high purity water → replacing water in CD by LS

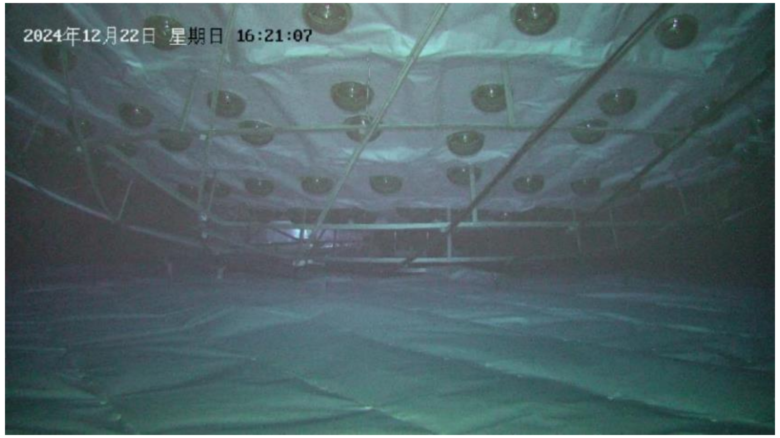
Water for CD: U/Th$<10^{-15}$ g/g, $^{226}$Ra$<0.1$ mBq/m$^3$
Water for VETO: U/Th$<10^{-14}$ g/g



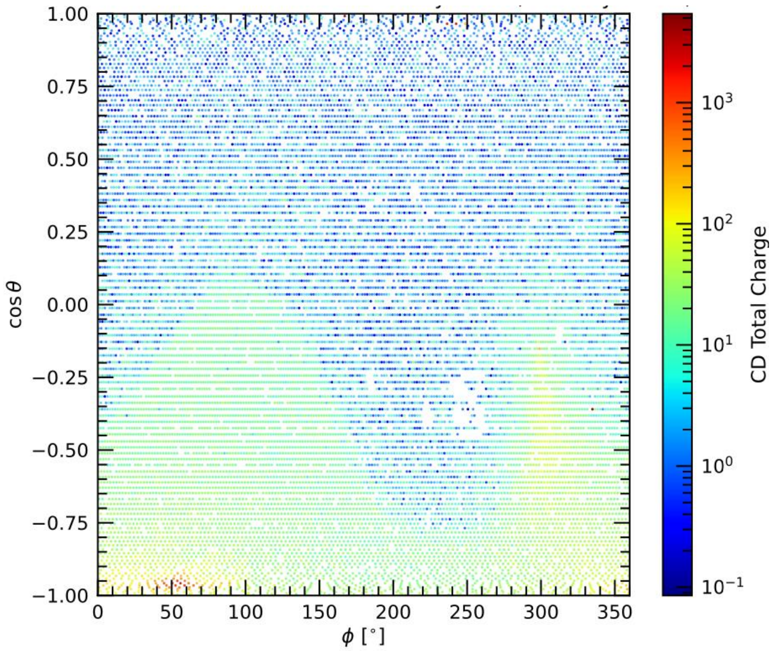



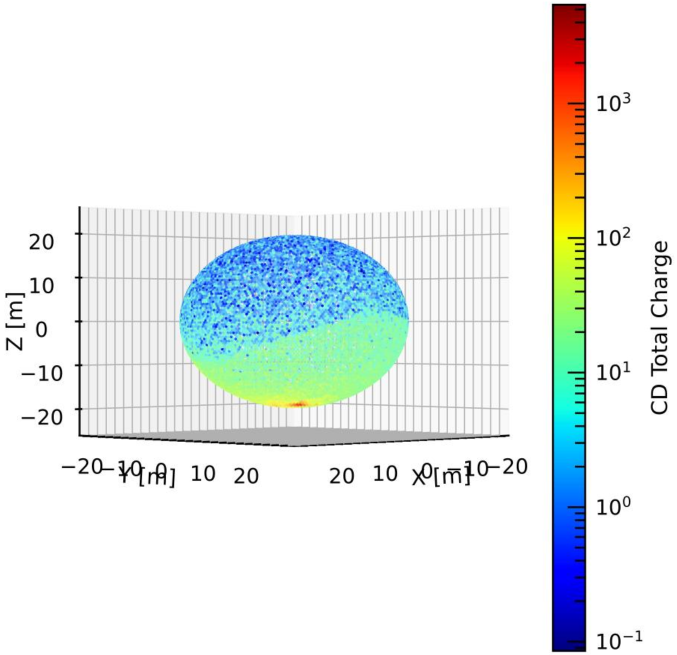
# Water Filling Phase



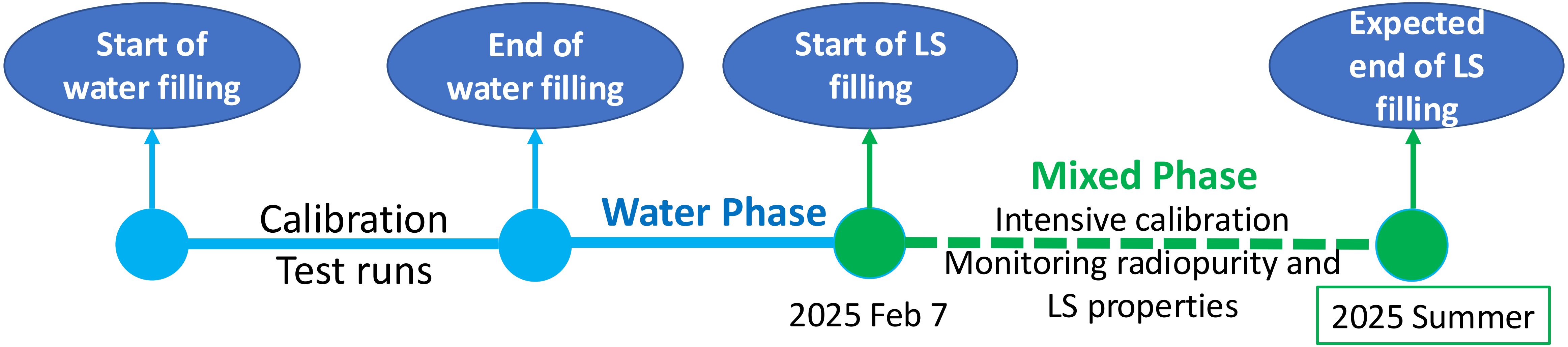



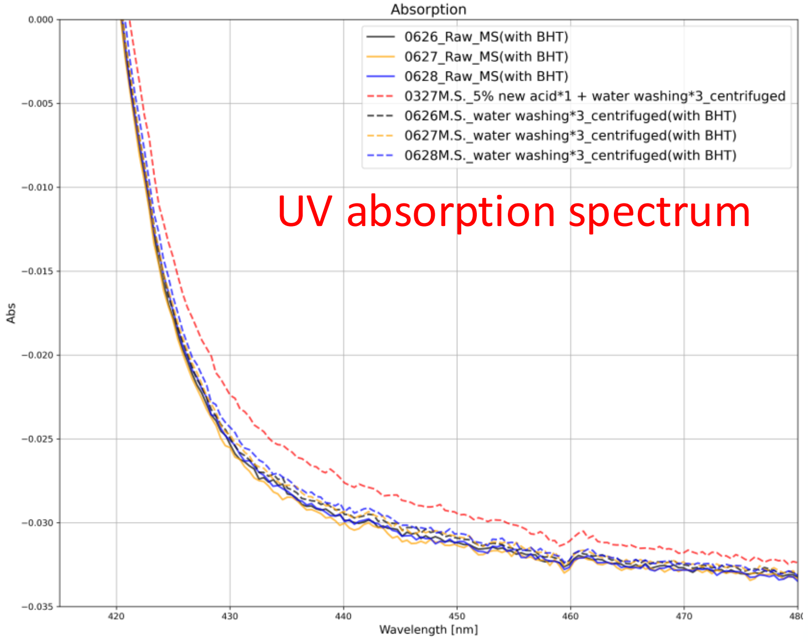

- Highlights:
  - Calibration of 20’’ PMTs (gain, time delays) with laser data
  - Small failure rate of 20’’ PMT: ~20/20k (0.1% loss during installation/due to high dark rate)
  - Calibration sources work as expected (Am-Be and Am-C) and used to probe low-energy threshold
  - Observe first muon events



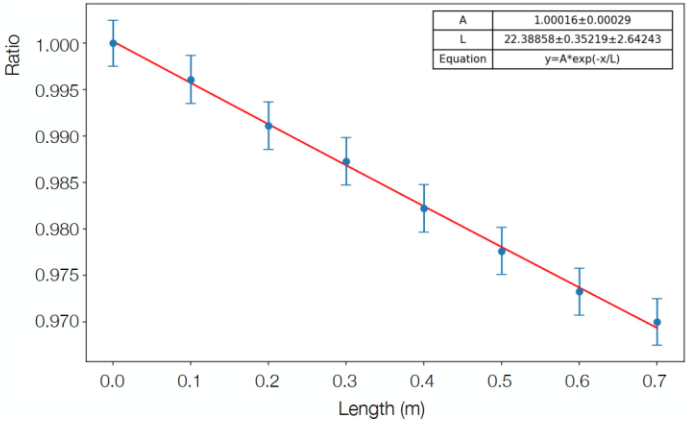



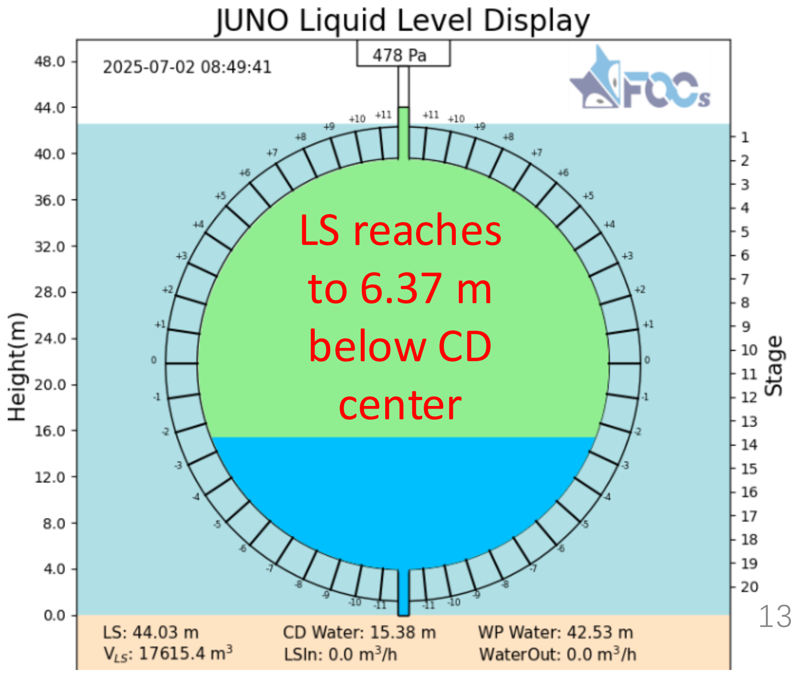
# Current Phase: Liquid Scintillator Filling



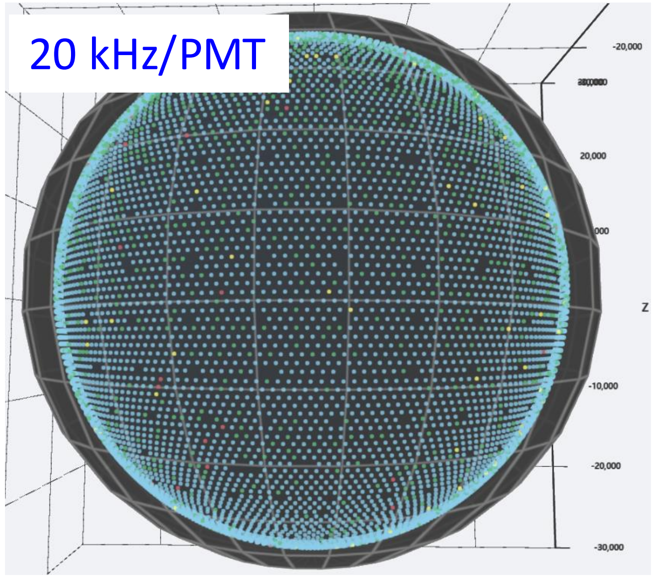

Attenuation Length ~ 22.4 m



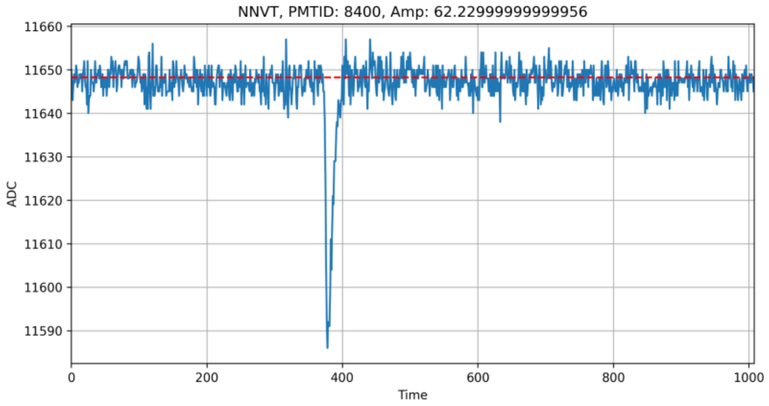
# Status of Detector Performance: PMT & LS

Dark rate of 20” PMTs in CD




Total PMTs installed: 17596
Unstable or Flashing: <1%
Gain stable within 1%

Waveform of a typical PMT



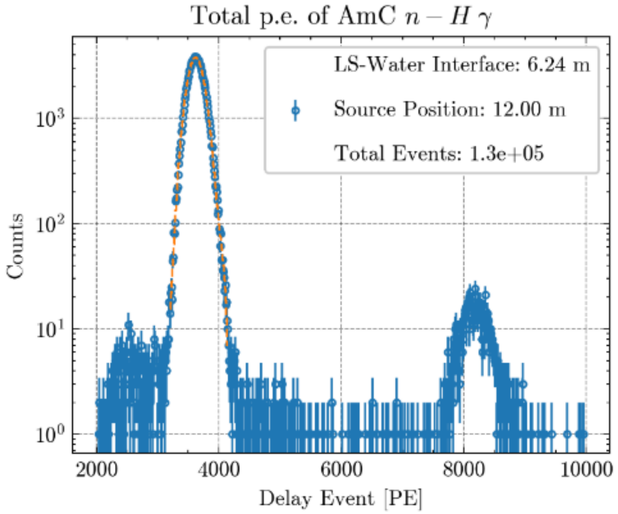

Good grounding and low noise:
RMS ~2.8 ADC ch. ➔ ~0.055 PE
Current PMT threshold: 0.2 PE/ch.
Trigger: ~ 300 PMTs/225ns
➔ ~150 keV
(Under adjustment)

Performance of LS in CD

- $^{222}$Rn in fresh LS: < 1mBq/m$^3$
- Current Rn level: < 0.1mBq/m$^3$
- U/Th: <$10^{-16}$ g/g

from AmBe calibration

- Attenuation length: ~20m
- Light yield: ~ 1600/MeV




All in agreement with the design and expectations

# Summary

- JUNO will be the largest liquid scintillator experiment with unprecedented precision

- The construction of the detector is completed

- Water filling phase is finished

- Currently under liquid scintillator filling phase
  - Taking commissioning data: good performance so far
  - **Expect physics data-taking in beginning of summer 2025**

See Mariangela's talk tomorrow
for more on JUNO physics

# Thank you!

# Merci!


# 谢谢！

~750 collaborators from 72 institutions in 17 countries/regions

# Backup1: JUNO-TAO

- Taishan Anti-neutrino Observatory (TAO)
  - A satellite detector of JUNO
  - Independent and precise measurement of reactor neutrino spectrum
  - 2.8 kton Gd-dopped LS
  - ~44 m from nuclear core
  - Resolution 1.5% at 1 MeV
  - 94% optic coverage with SiPMs

- Status
  - ➢ Installation finished, under filling phase
  - ➢ Plan to start data-taking before summer