

Installation and commissioning of the JUNO 3-inch PMT system

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Outline

- SPMT system design, production and test
- Installation situation
- Commissioning status
 - Water phase
 - LS-water phase
- Summary

SPMT system introduction

2016-2017

• System design

2018-2020

• PMT production

2020-2022

• PMT instrumentation

2021-2022

• Electronics production

2022-2023

• Electronics integration

2023-2024

• Installation

2025

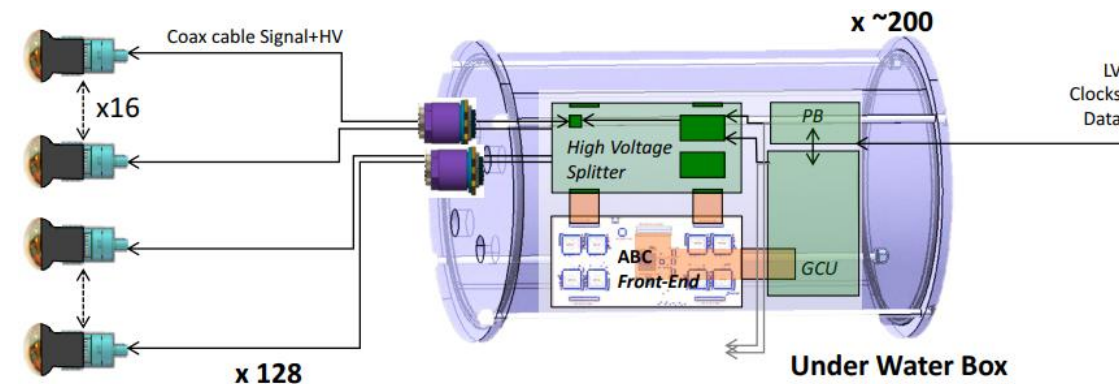
• Commissioning

- **25600** 3-inch PMTs (**small PMT**, or **sPMT**) and frontend electronics: **all underwater**
- The primary goal is measuring **the charge non-linearity of 20-inch PMTs (Large PMT, or LPMT)**
- Other physics potentials: measurement of oscillation parameters ($\sin^2 2\theta_{12}, \Delta m^2_{21}$), searching for **proton decay**, ...

[CPC 46 \(2022\) 123001](#), [CPC 47 \(2023\) 113002](#)



LPMTs and surrounding sPMTs

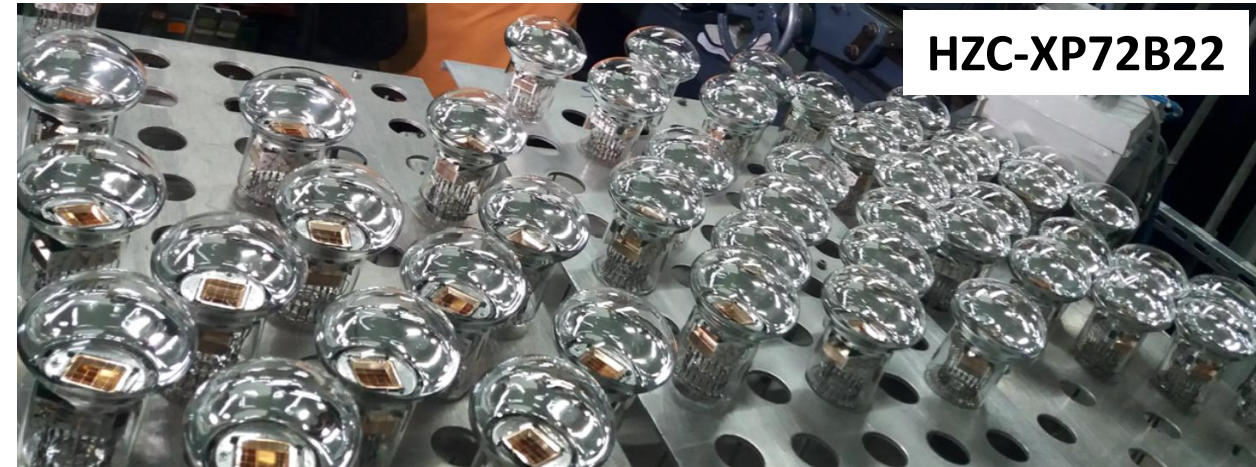


Electronics with 128 3-inch PMTs

SPMT system production and test

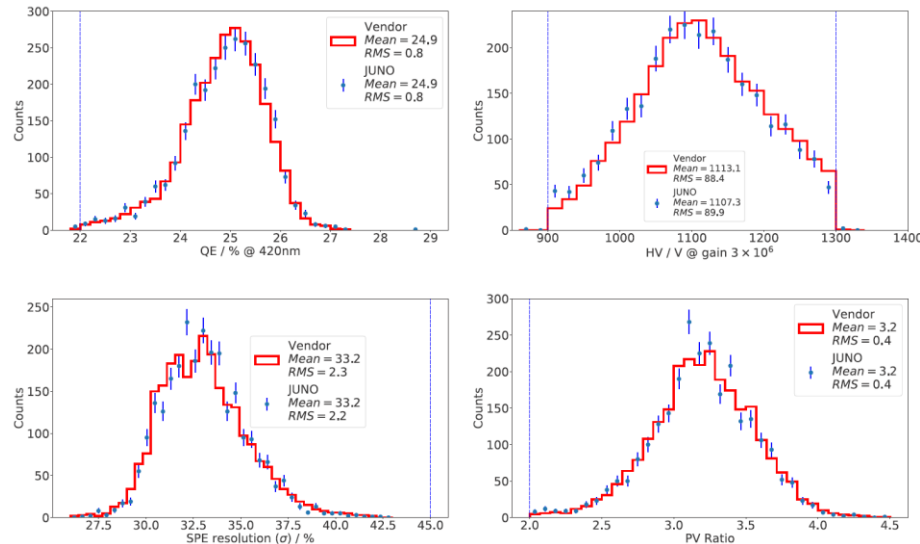
SPMT production and test

- Totally **26000** 3-inch PMTs produced by Hainan Zhangchuang (HZC)
- Performance tests and study for 2 years, meeting the requirement of JUNO
- The **largest** sample of 3-inch PMTs ever produced and studied in detail



NIM, A 1005 (2021) 165347

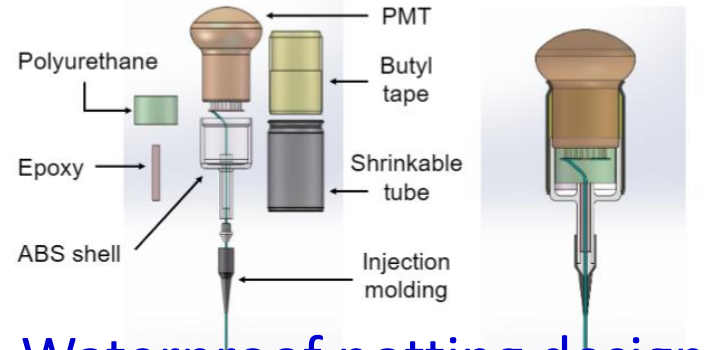
3-inch PMTs mass production



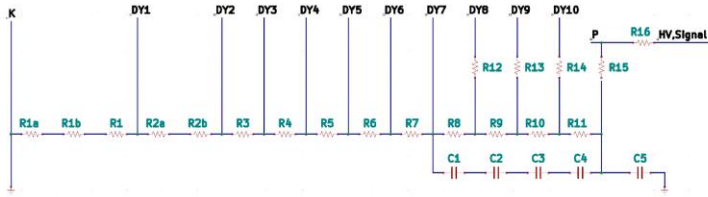
Parameters	Class	Requirement		Test fraction		Tolerance of diff.	Results (mean)	Rejection number
		(limit)	(mean)	HZC	JUNO			
Φ (glass bulb)	A	(78, 82) mm	–	100%	10%	–	OK	0
QE@420 nm	A	>22%	>24%	100%	10%	<5%	24.9%	1
High Voltage	A	(900,1300) V	–	100%	10%	<3%	1113 V	1
SPE resolution	A	<45%	<35%	100%	10%	<15%	33.2%	0
PV ratio	A	> 2	> 3	100%	10%	–	3.2	0
DCR@0.25 PE	A	<1.8 kHz	<1.0 kHz	100%	10%	–	512 Hz	1
DCR@3.0 PE	A	<30 Hz	–	100%	10%	–	7.2 Hz	1
TTS (σ)	B	<2.1 ns	–	–	3%	–	1.6 ns	0
Pre-pulse	B	<5%	<4.5%	–	3%	–	0.5%	0
After-pulse	B	<15%	<10%	–	3%	–	3.9%	11
QE non-uniformity	B	<11%	–	–	3%	–	5%	0
Φ (eff. cathode)	B	>74 mm	–	–	3%	–	77.2 mm	0
QE@320 nm	C	>5%	–	–	1%	–	10.2%	0
QE@550 nm	C	>5%	–	–	1%	–	8.6%	0
Aging	D	>200 nA years	–	–	3 PMTs	–	OK	0

All 26000 3-inch PMTs test results summary

sPMT integration



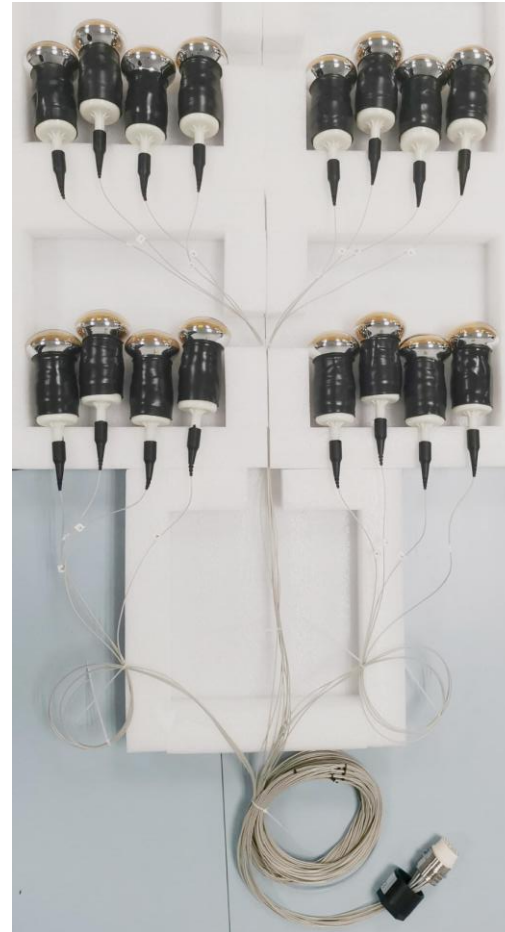
Waterproof potting design



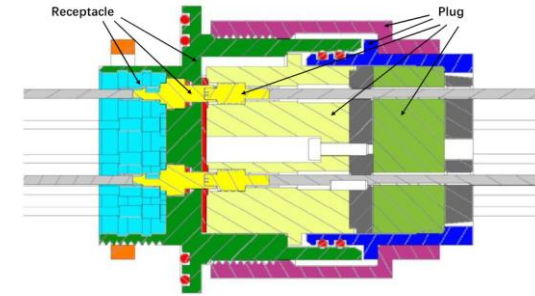
(b) HV splitter



(c)



A group of 16 PMTs

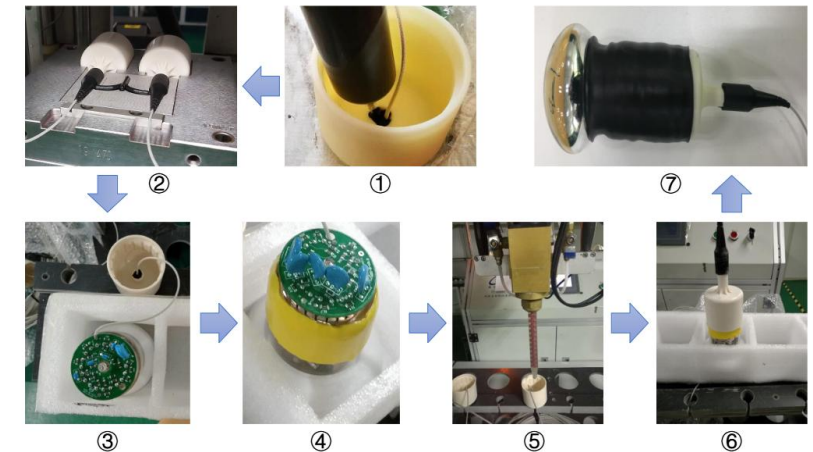


(a)



(b)

Cable and HV connector

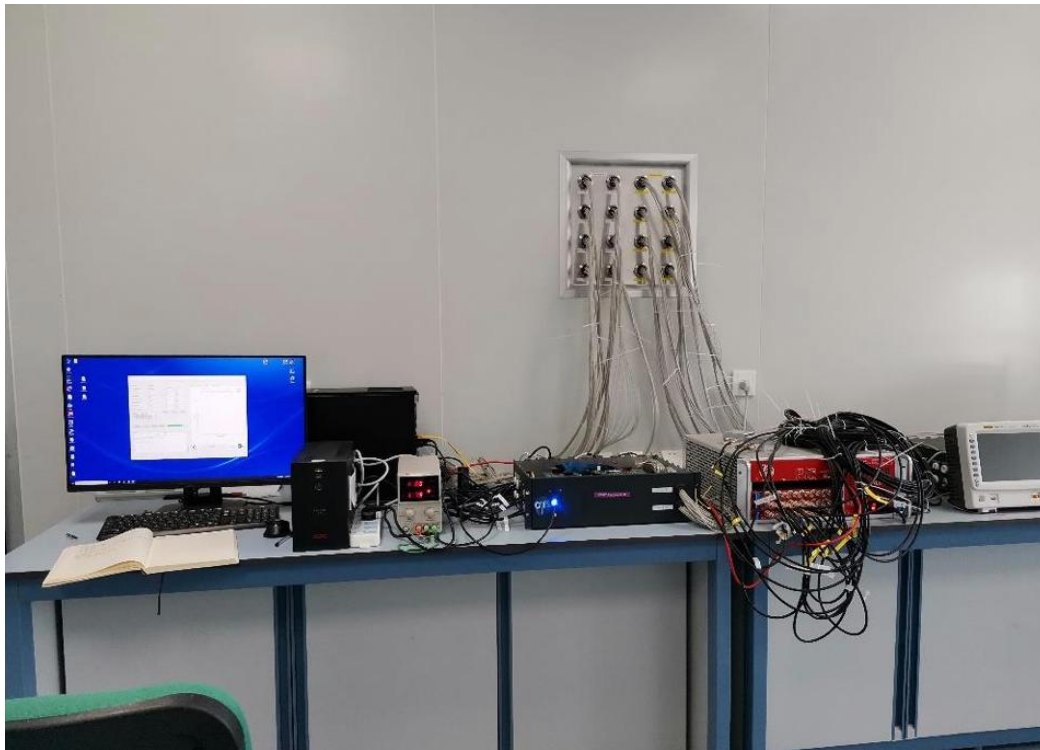


Integration procedure

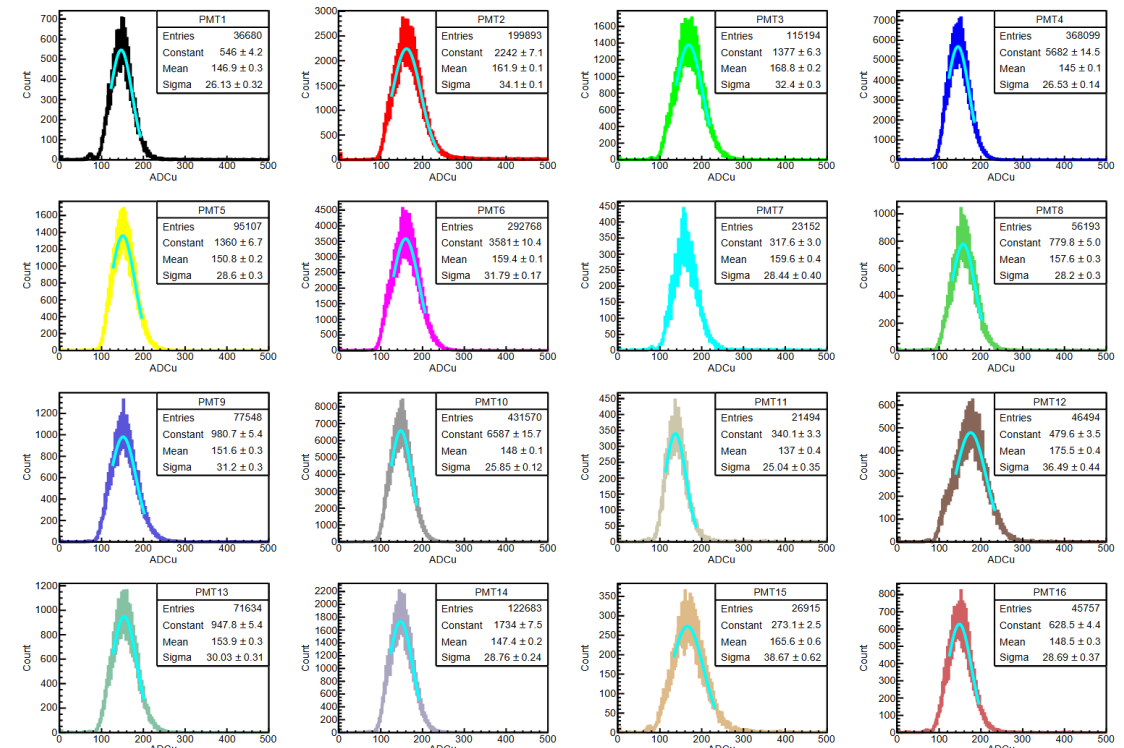
- sPMT integration with HV splitter, cable, connector and waterproofing
- HV tests for all sPMTs and 13% for water pressure test

Acceptance tests after integration

- PMT functional tests including gain, single photon electron, dark noise, 99.3% qualified.
- The rest were replaced due to high DCRs, deviations from the target gain, poor charge resolution, or electrical short circuits.

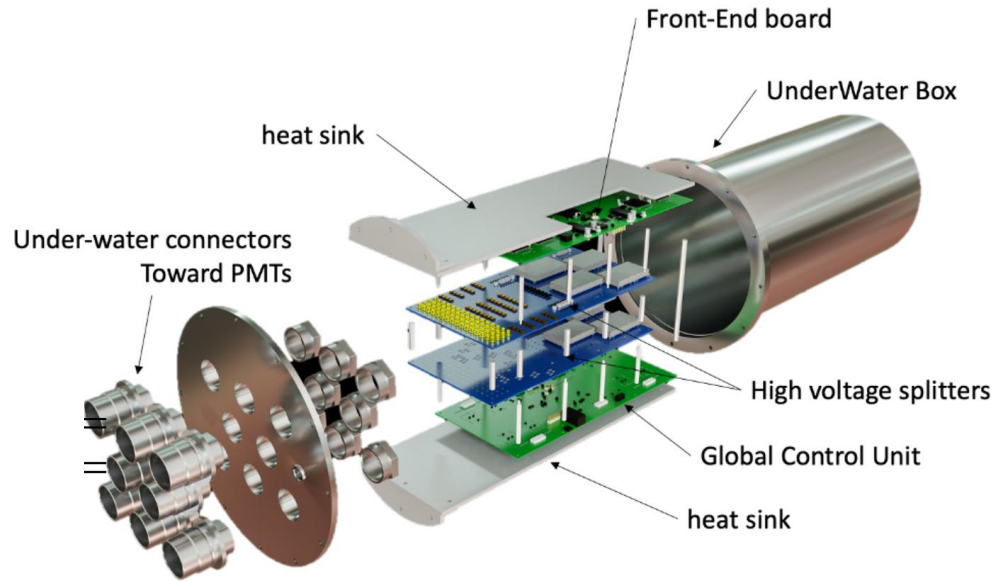


PMT front-end integration test system
using **early version of JUNO electronics**

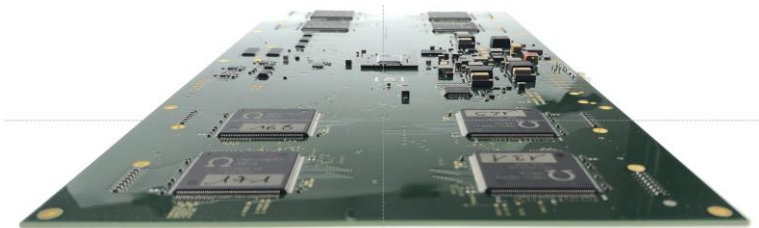


PMT single photoelectron spectrum

Component of electronics

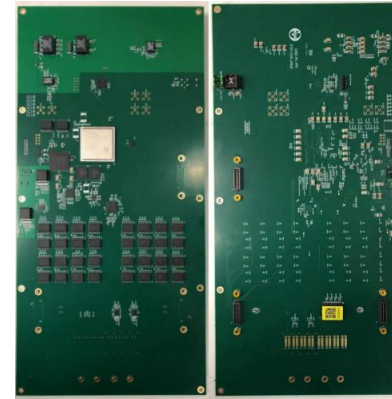


Electronics overview



Front-End board: 8 CATROCs for signal digitization (France)

128 channels contained in an underwater stainless-steel box



Global Control Unit: control and transfer data to DAQ



Heat dissipation and mechanical structure



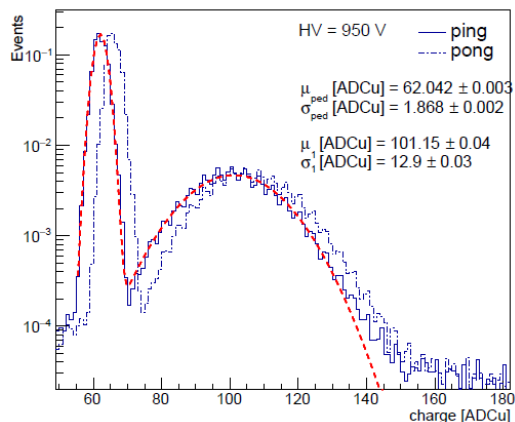
Underwater Box (Chile, US)



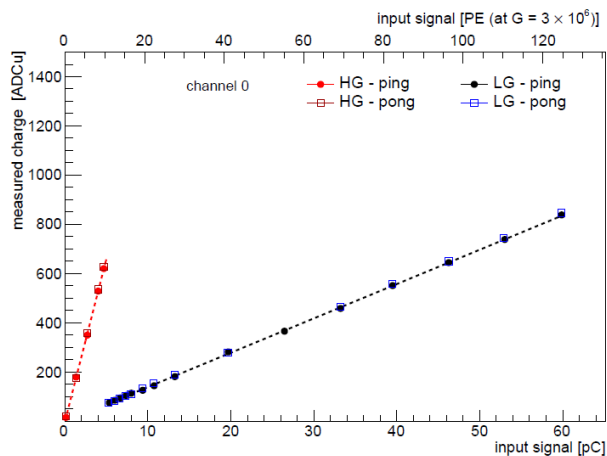
HV splitter: supply high voltage and split signal (Chile, Russian)

Electronics performance

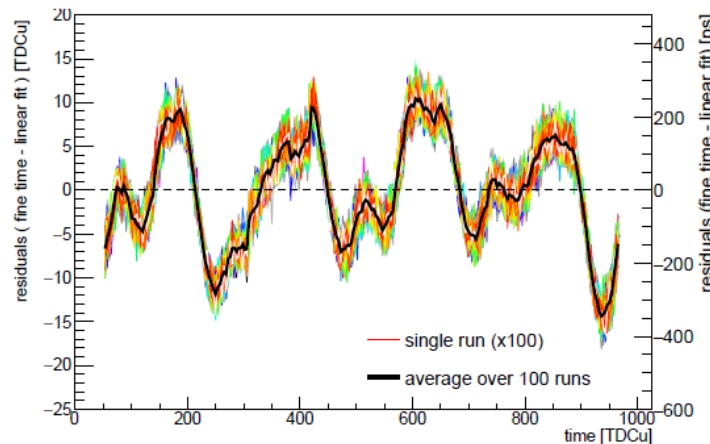
- CATIROC: an integrated chip designed by the Omega laboratory ([2021 JINST 16 P05010](#))
- Noise: **0.015 pC (0.03 PE)**, at 3×10^6 gain
- Time resolution: **< 150 ps**



SPE spectrum



Charge measuring range

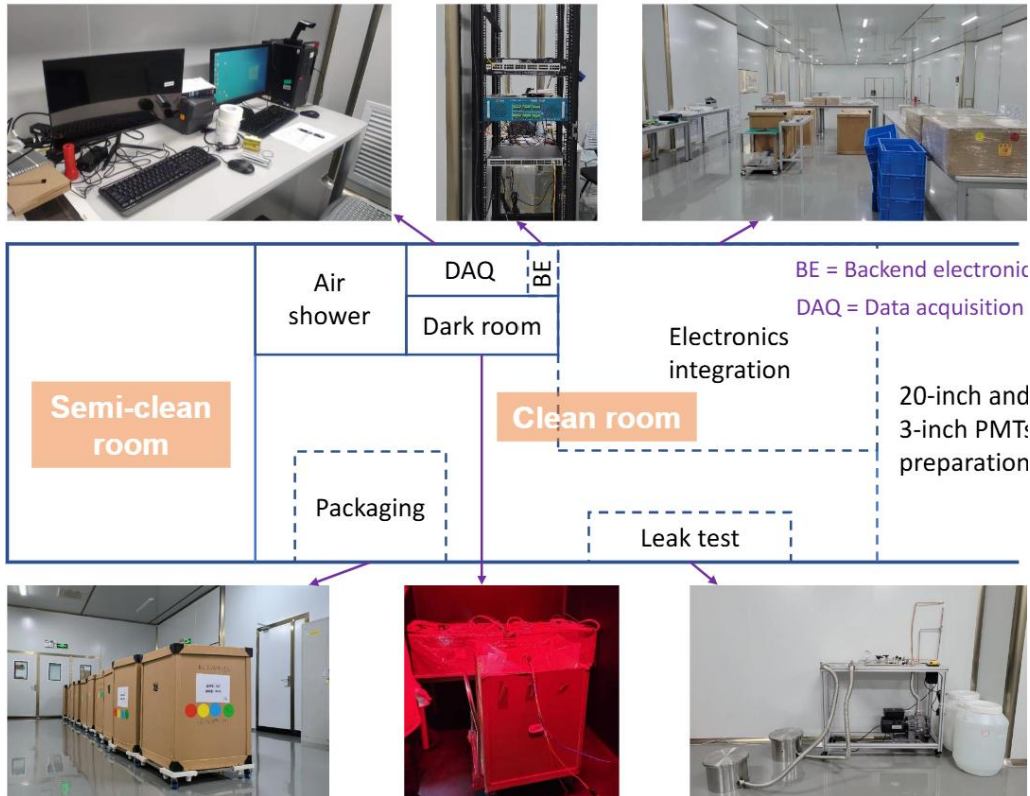


Time measurement

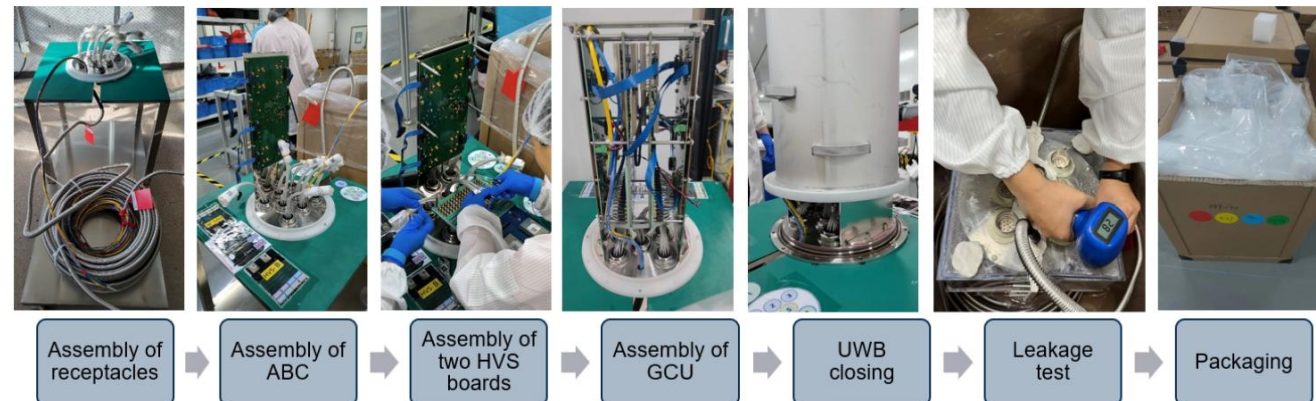
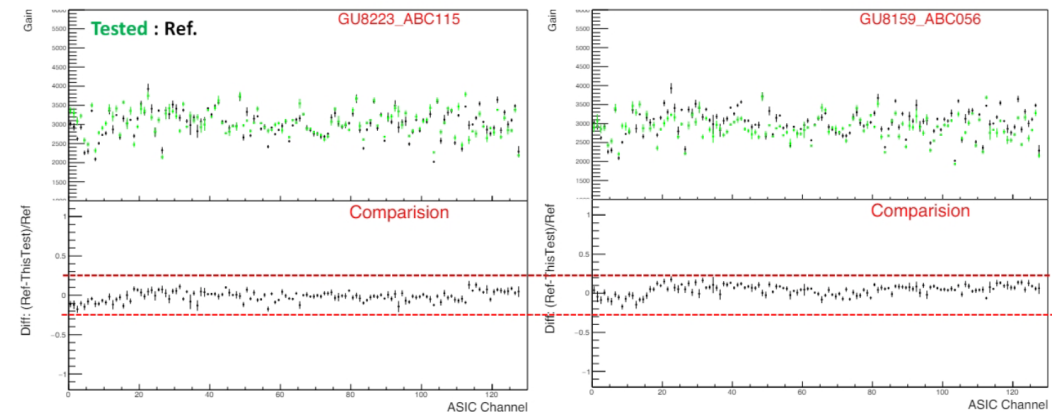
Configurations	
SSH RC	50
PA gain	20
Discr. thr	900 DACu
HG/LG thr	720 DACu
SSH Peak time	26 ns
$\sigma_{\text{charge,HG}}$	2 ADCu (0.015 pC)
$\sigma_{\text{charge,LG}}$	1 ADCu (0.74 pC)
Calibration fit	
intercept (p0)	[ADCu]
HG	66.9 ± 0.3
LG	68.6 ± 0.1
LSB (1/p1)	[fC/ADCu]
HG	7.9 ± 0.4
LG	73.6 ± 0.1
residuals	< 4 ADCu
variations within channels	< 5%

Electronics integration

- 200+4 spares sets (26,112 channels) of electronics assembled at JUNO
- Functional test for all channels with PMTs
- Leakage tests for all integrated underwater boxes with a customized SF₆ gas-based system, *arXiv:2505.24142*



Electronics integration lab



Electronics assembling procedure

SPMT installation and commissioning

sPMT installation overview

- SPMT installation over 2 years and was finished on Dec.5, 2025
- Preparation work in the surface assemble building
 - Cleaning, cable arrangement, PMT sampling test, electronics test...
- Installation for 25,587 PMTs and 200 electronics underwater boxes
 - Installation speed: Average 101 PMTs/working day. 1 or 2 group of workers (3-6 workers).



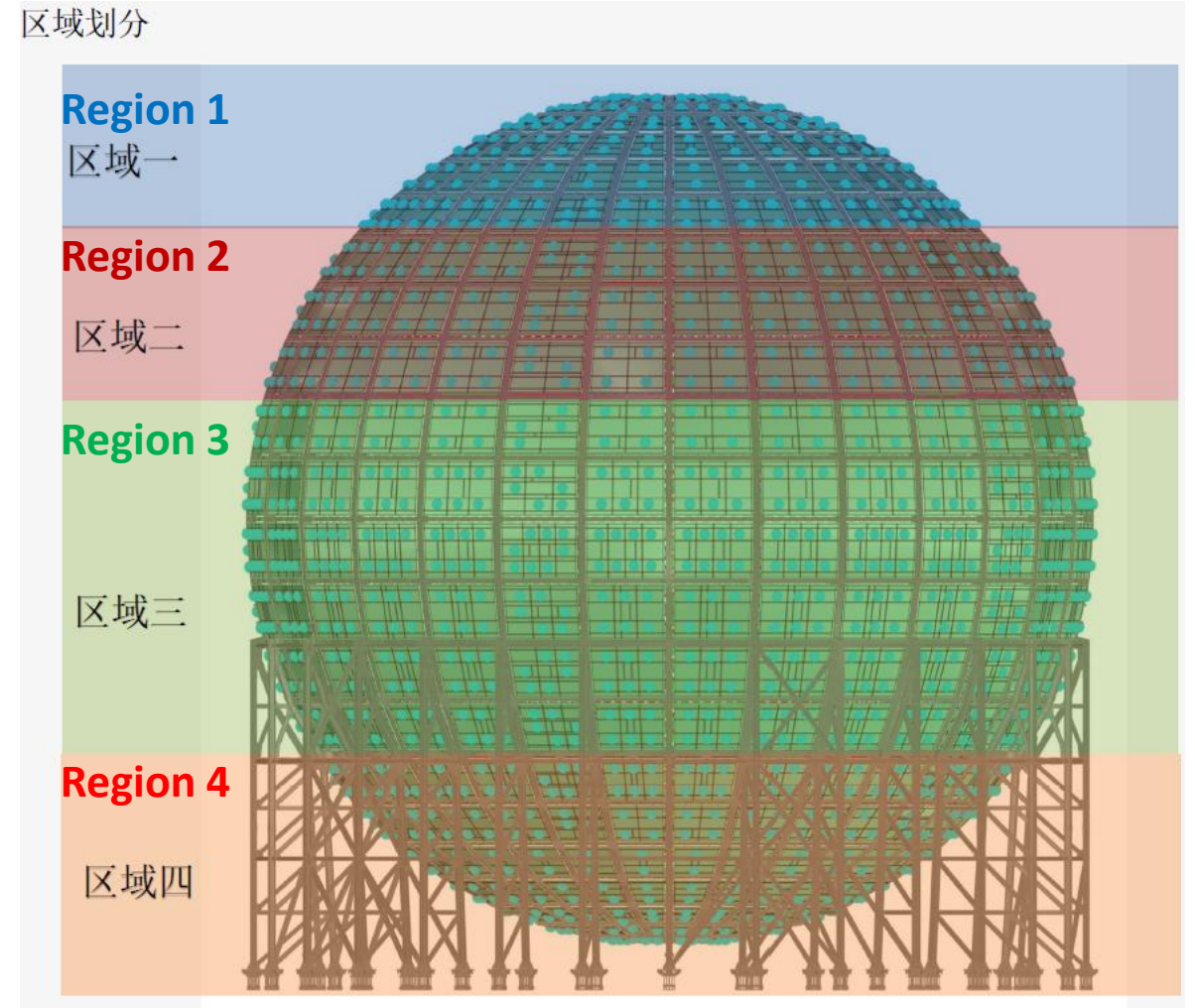
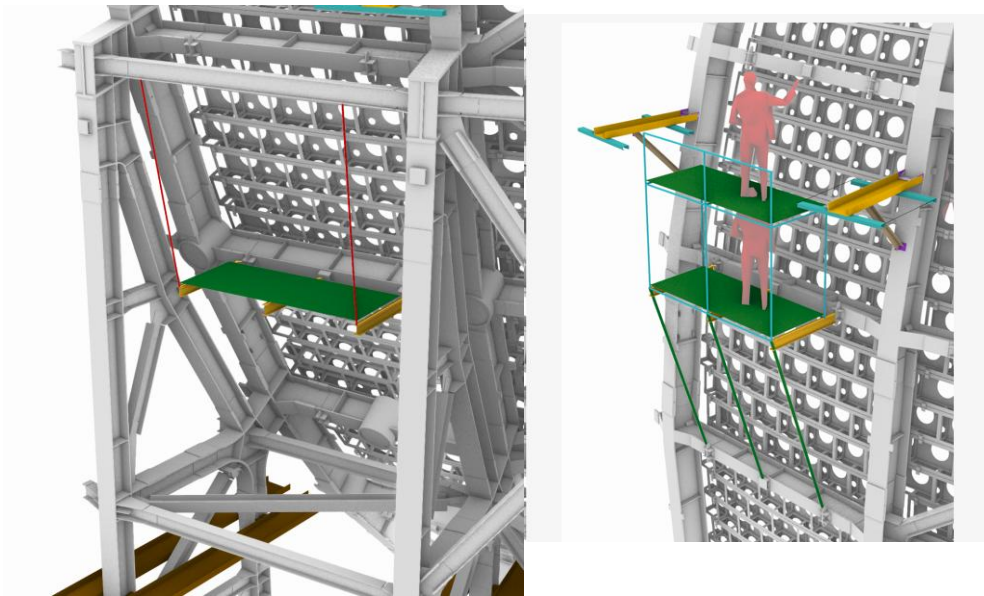
SPMT installation



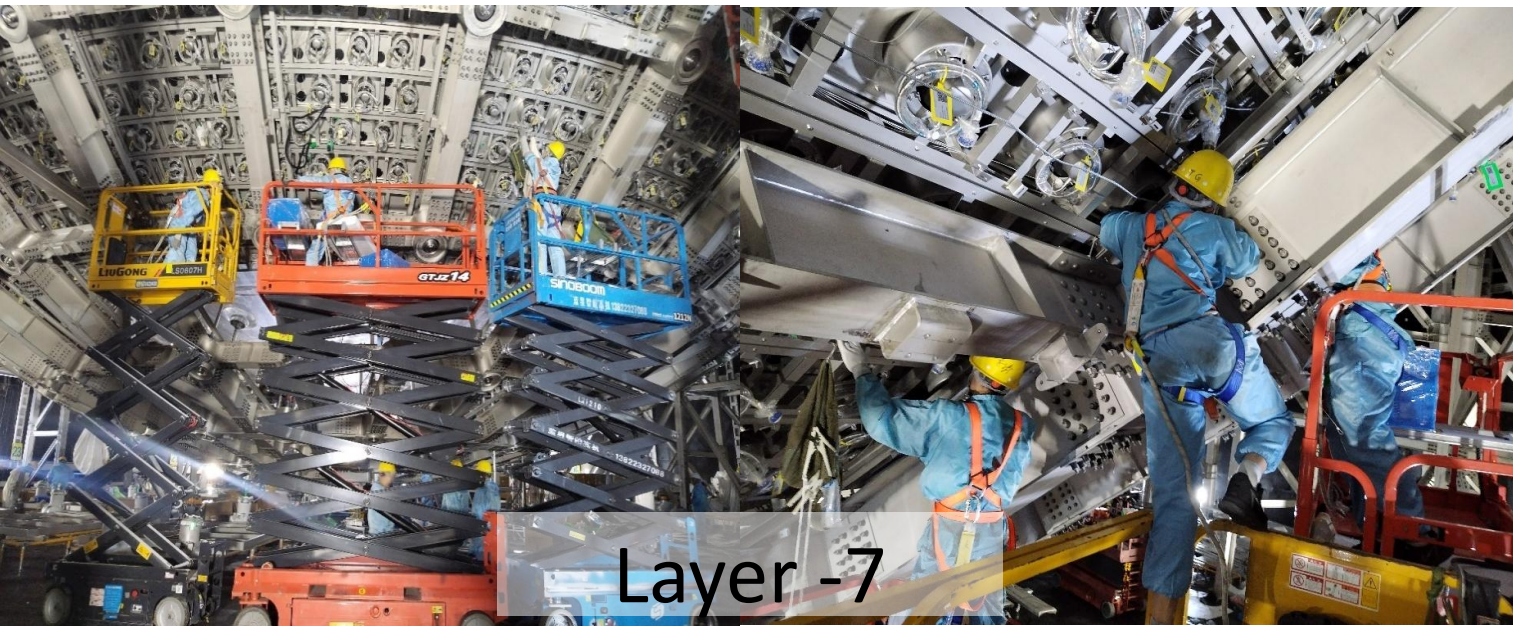
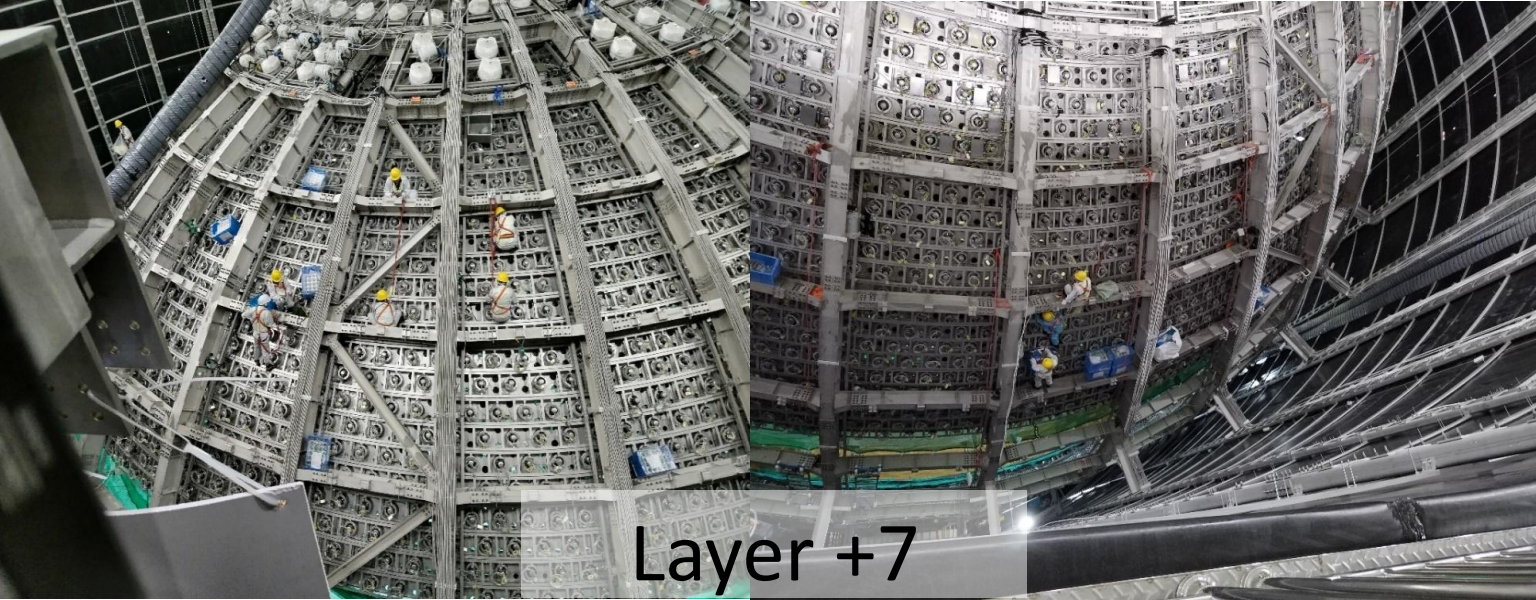
Electronics lifting and installation

Different regions require different strategies

- Region 1 and 2: people directly stand in the windows to install.
- Region 3: Outside platform
- Region 4: Scissors lift

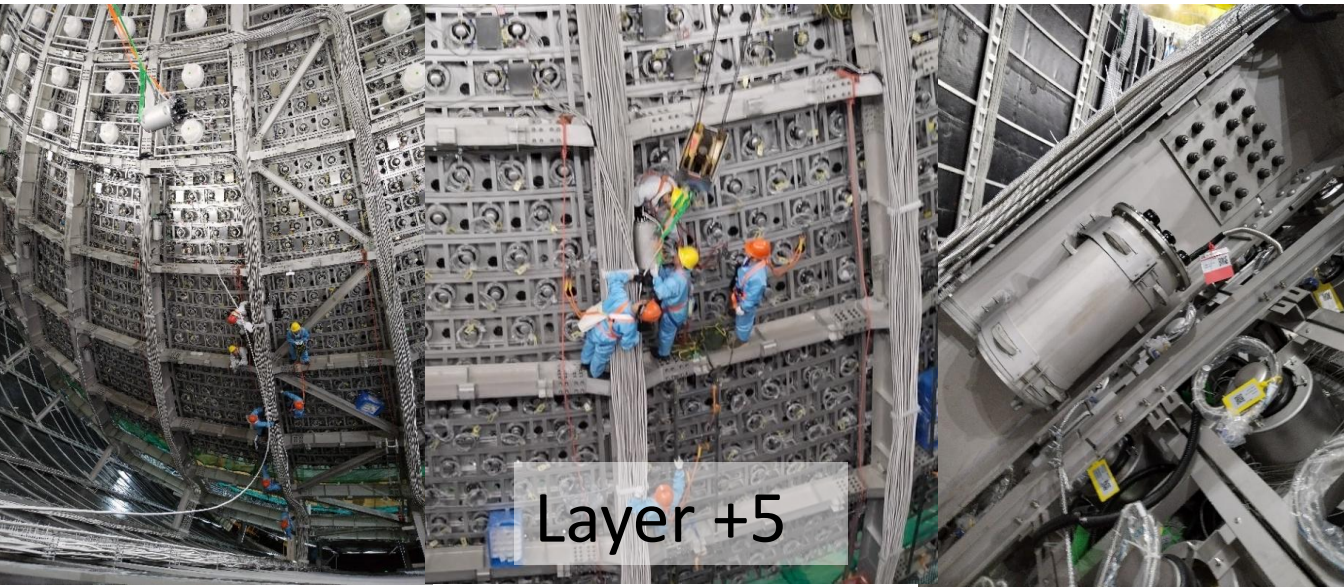


PMT installation

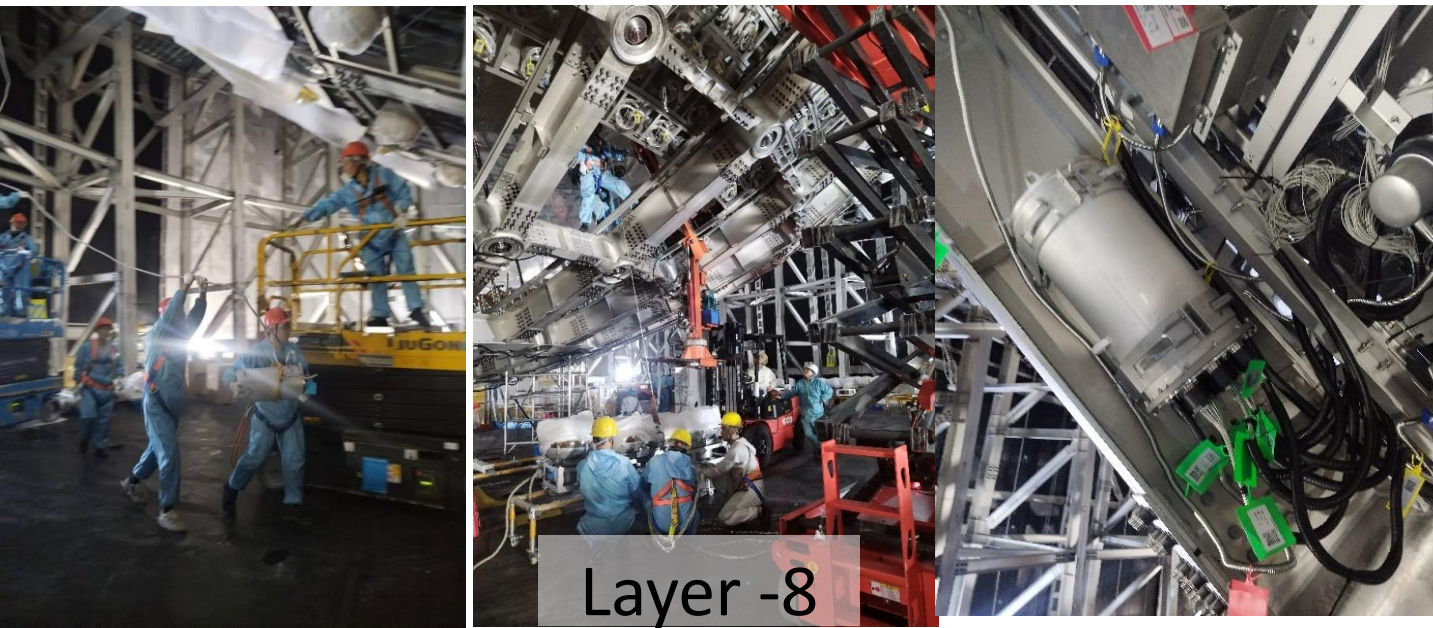


- 25k sPMTs installed one by one on the stainless steel truss
- Checking after installation
 - Check cable in each window
 - Check safety and cleanness

Underwater electronics installation



- Supervise on the side
- Tests after the installation
 - Air vacuum leakage test
 - Pedestal test
 - Connect to PMTs
 - The overall installation checking include label and screw ...
 - Pedestal test again
 - Light-off test
 - Check and repair the suspicious PMTs or cables



Installation quality assurance



Install support



Install PMT



Install Light Barrier

Module
MID: GJ-N57-06(3/6)
PID: N-057-020.5-U
CID: 12



QR code on installation
position

SPMT
MID: GJ-N57-06(3/6)
PID: N-57-020.5-U
CID: 12 Type: L



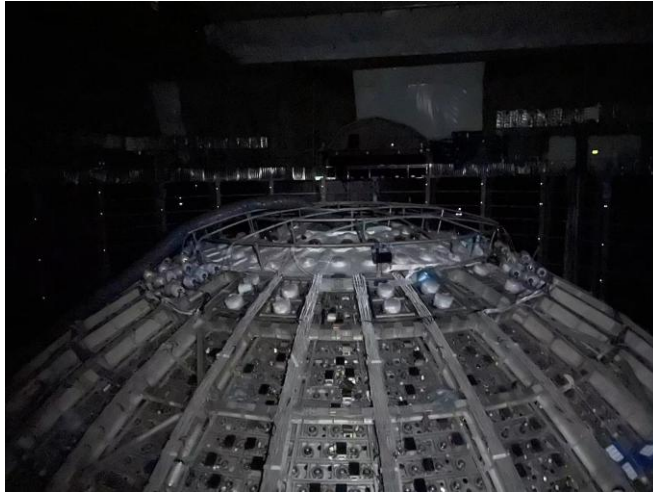
QR code on PMT

- Developed a WeChat app to scan QR code to ensure the installation position for each PMT and electronics box
- On-site supervision and visual inspection

Installation quality control: lights-off tests



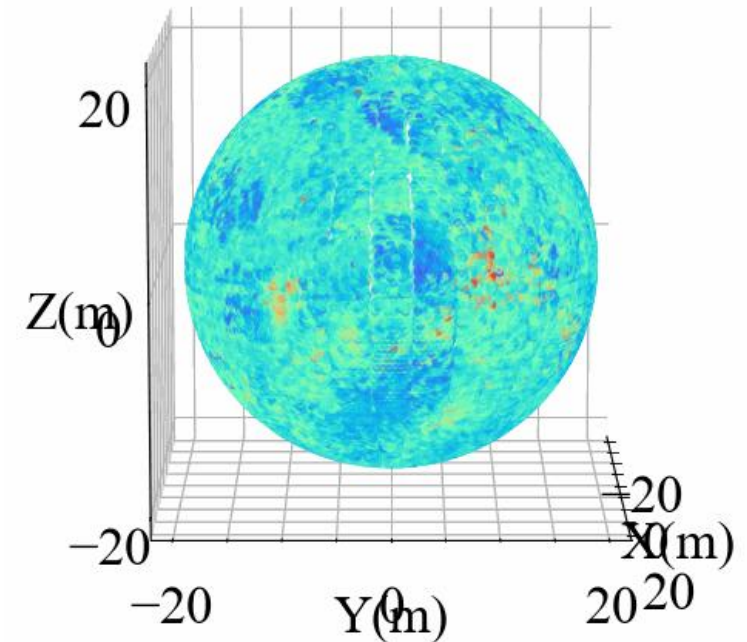
Operate in
electronics room



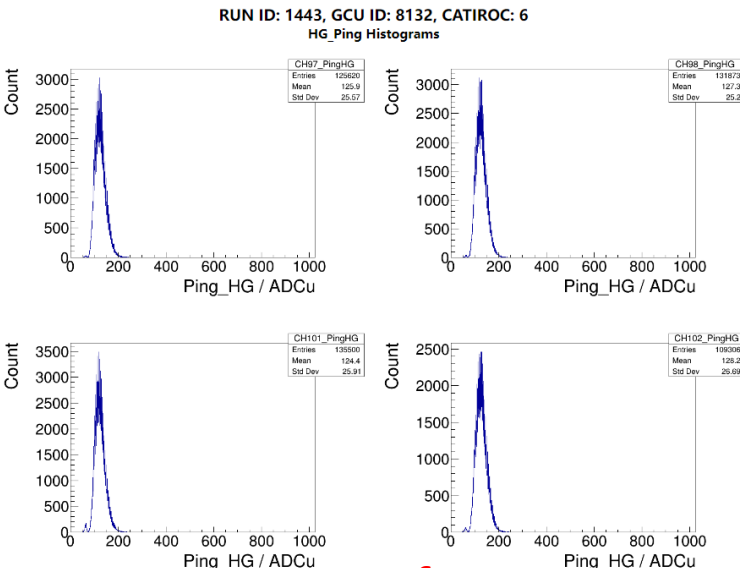
JUNO detector with lights off

- 10 times of lights-off tests during installation
- Replaced and repaired problematic channels

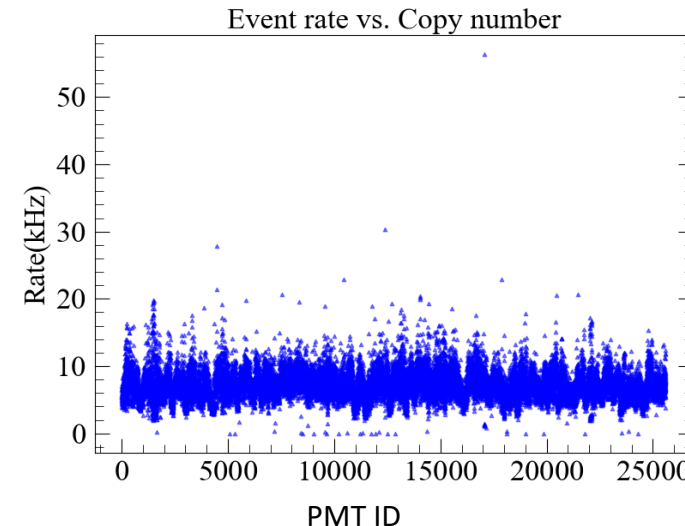
Event rate vs. location



PMT: Hit map



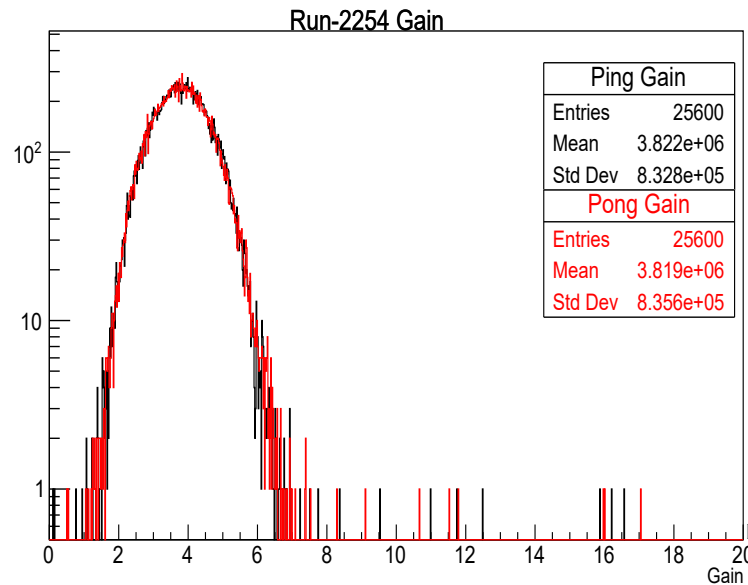
SPE spectrum of 4 SPMTs



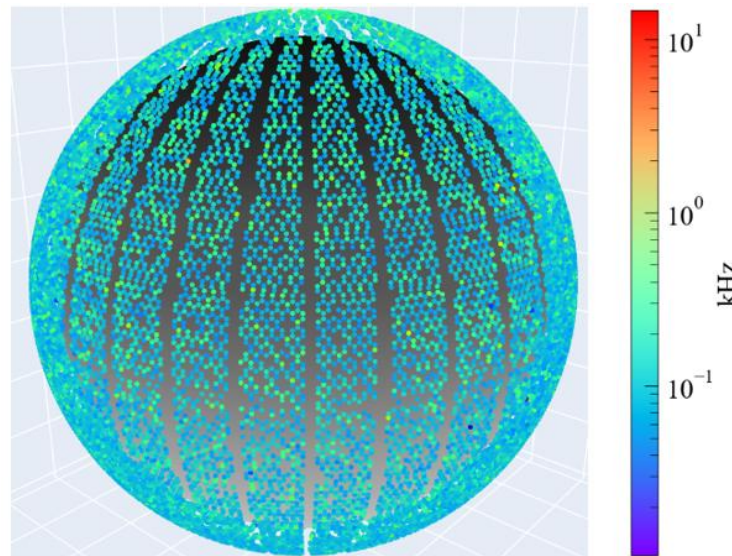
The average DCR is ~7kHz

Water phase performance

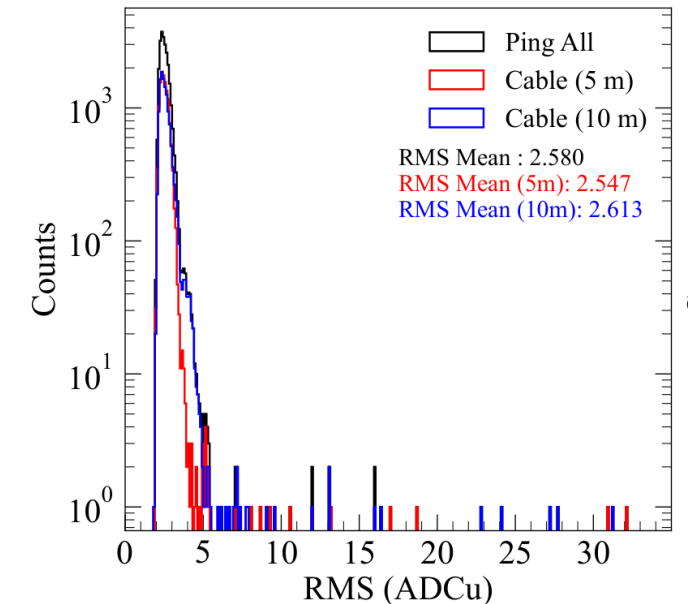
- 44 days of water filling from Dec.18th, 2024 to Feb.1st, 2025
- PMT dark count rate reduced to 530 Hz due to the covering of the detector



Average gain: 3.8×10^6



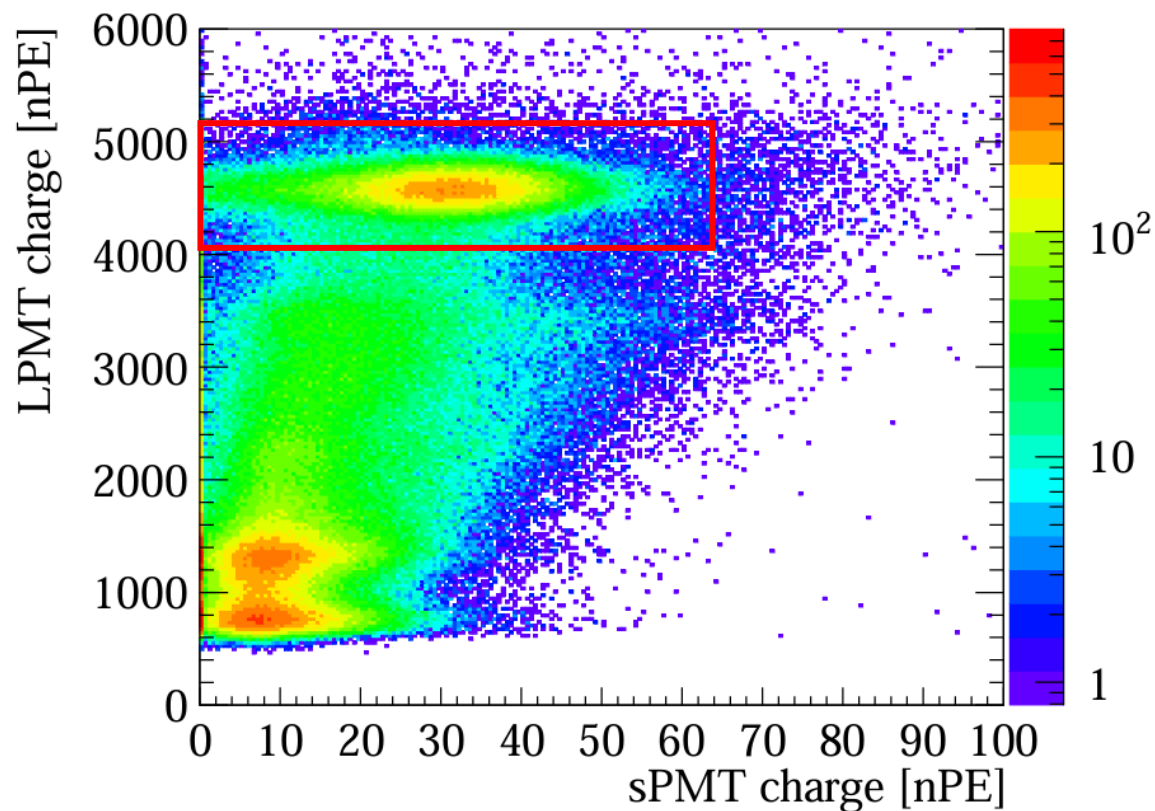
Average hit rate: 530 Hz



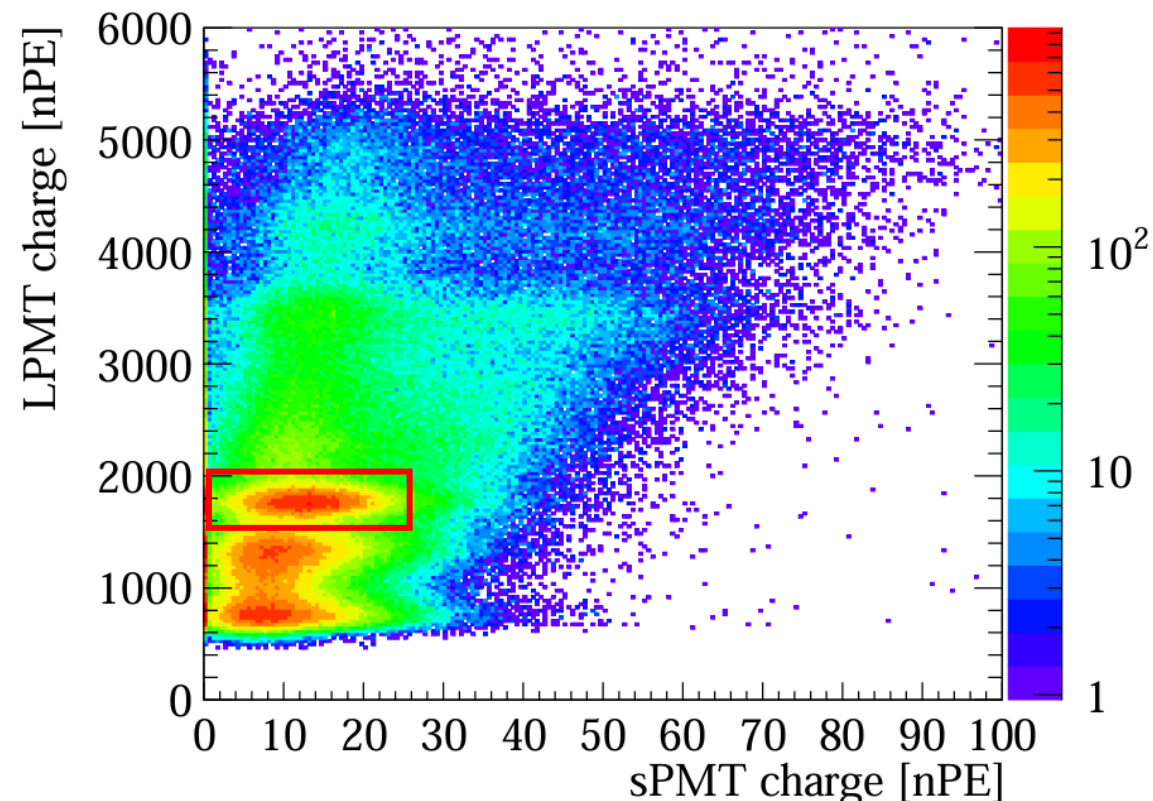
RMS ~ 2.6 ADCu (about 0.05 PE) for electronics noise

Calibration source performance

^{60}Co (1.333+1.173MeV γ)



^{54}Mn (0.835MeV γ)



- The sPMT system can observe the calibration source clearly
- More challenge and excitement are waiting for us!

Summary

- After a decade of hard work, sPMT system construction completed
 - ~25k 3-inch PMTs with HV divider, frontend cable, connectors and waterproofing
 - 200 electronics with signal digitizer, control, HV supply and underwater mechanics
- Detector commissioning ongoing. Physics data taken coming soon.

