



# 3-inch PMTs and electronics system in JUNO

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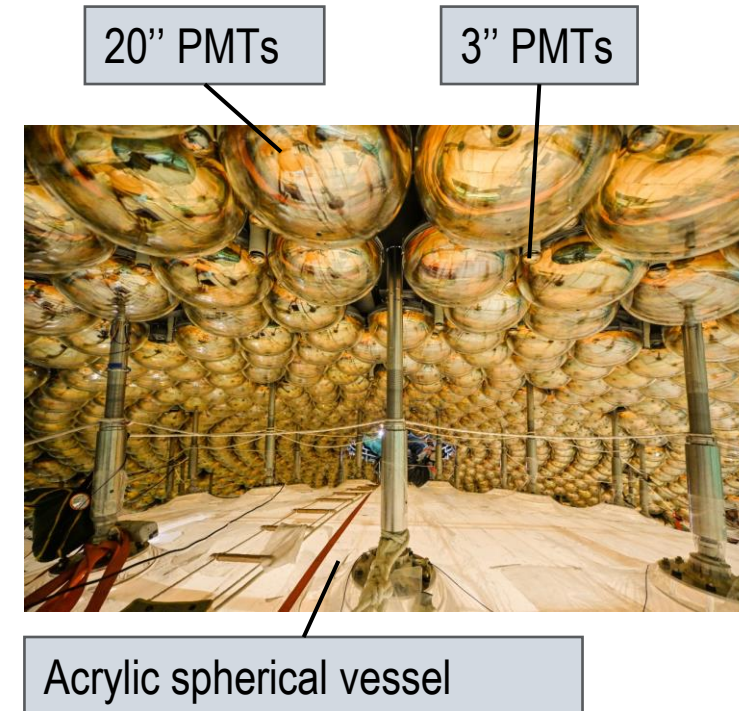
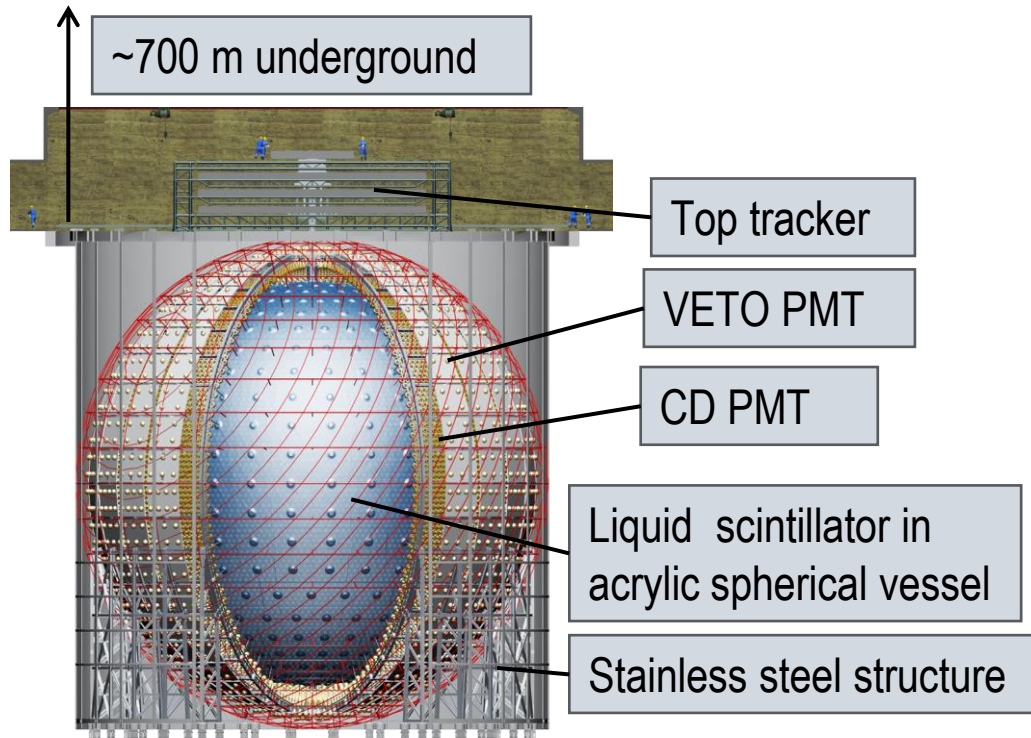
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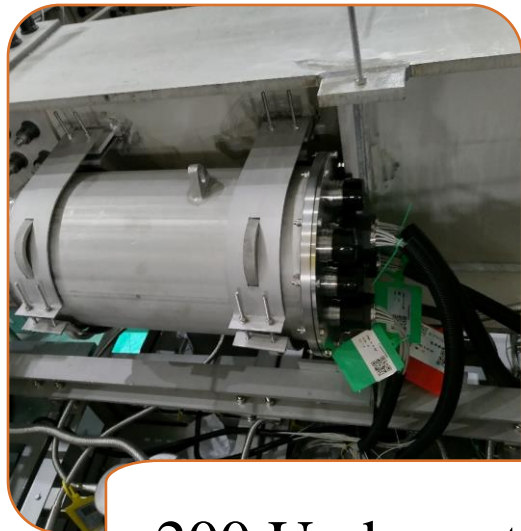
August 2023



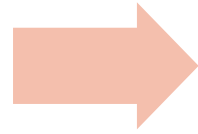
# JUNO detector



- **Main physics goal of JUNO is to determine neutrino mass ordering and make a sub-percent measurement of three oscillation parameters.**
- **The Central Detector (CD) consists of a 20 kt Liquid Scintillator (LS) target.**
- **25,600 3-inch “small” and 17,612 20-inch “large” photomultiplier tubes (SPMTs and LPMTs, respectively) detect the light produced by neutrino interactions in the CD.**



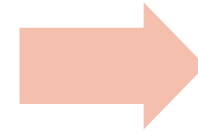
200 Underwater boxes (UWBs)



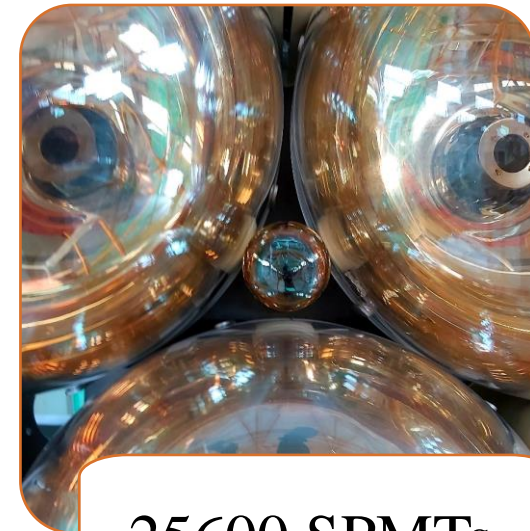
× 8 groups  
(128 PMTs)  
per UWB



1600 groups

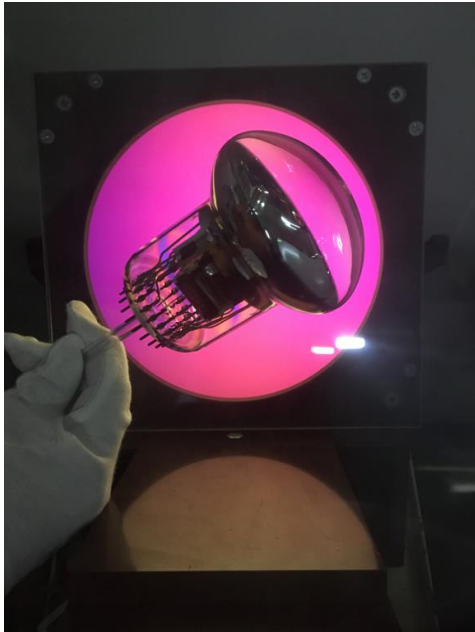
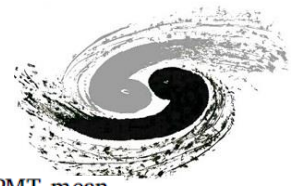


× 16  
PMTs per  
group



25600 SPMTs

- **Calibrating charge non-linearity of LPMTs and their electronics.**
- **Aid for high-energy and high-rate events: muon, supernova neutrino.**
- **Semi-Independent measurement:  $\theta_{12}, \Delta m_{21}^2$**



Summary of the 3-inch PMTs acceptance criteria and test results for different parameters. Results for class A parameters were from 26,000 PMT mean value of vendor data after acceptance measurement introduced in Section 4.2, and other results were from acceptance measurement only. Unless specified, all of the parameters were measured at  $3 \times 10^6$  gain.

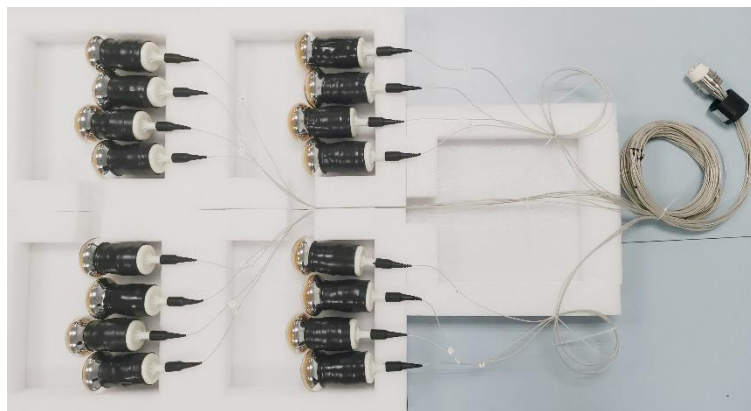
Parameters	Class	Requirement		Test fraction		Tolerance of diff.	Results (mean)	Rejection number
		(limit)	(mean)	HZC	JUNO			
$\Phi$ (glass bulb)	A	(78, 82) mm	–	100%	10%	–	OK	0
QE@420 nm	A	>22%	>24%	100%	10%	<5%	24.9%	1
High Voltage	A	(900,1300) V	–	100%	10%	<3%	1113 V	1
SPE resolution	A	<45%	<35%	100%	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 ( $\sigma$ )	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
$\Phi$ (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

- **26,000 XP72B22 3-inch PMTs were produced and characterized at Hainan Zhanchuang Photonics Technology Co., Ltd (HZC) under JUNO’s supervision.**
- **15 parameters have been characterized.**
- **Only 15 PMTs were found to be unqualified and thus rejected.**

Cao C , Xu J , He M ,et al.Mass production and characterization of 3-inch PMTs for the JUNO experiment[J]. 2021.DOI:10.1016/j.nima.2021.165347.



- **Integration** of PMTs with HV dividers, frontend cable and connector with water proofing
- Supply **same HV** to **16 PMTs** through a multi-channel connector
- Partnership with industry was key to completing this process.



Production and test of bare PMT  
*@HZC*

Plug and Receptacle  
*@Axon*

Cable sealing  
*@Pan Asia*

Potting and Leakage test  
*@HZC*

Acceptance Testing  
*@Guangxi University*

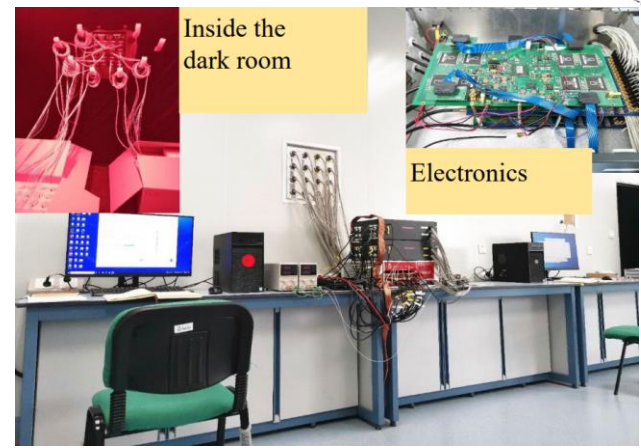




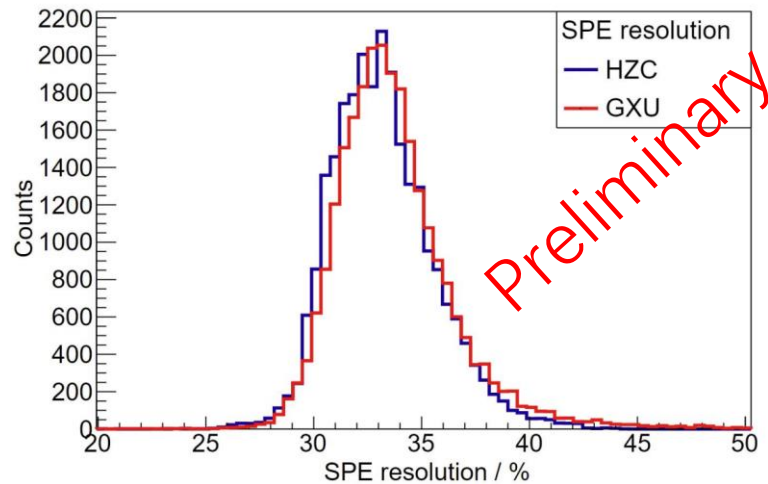
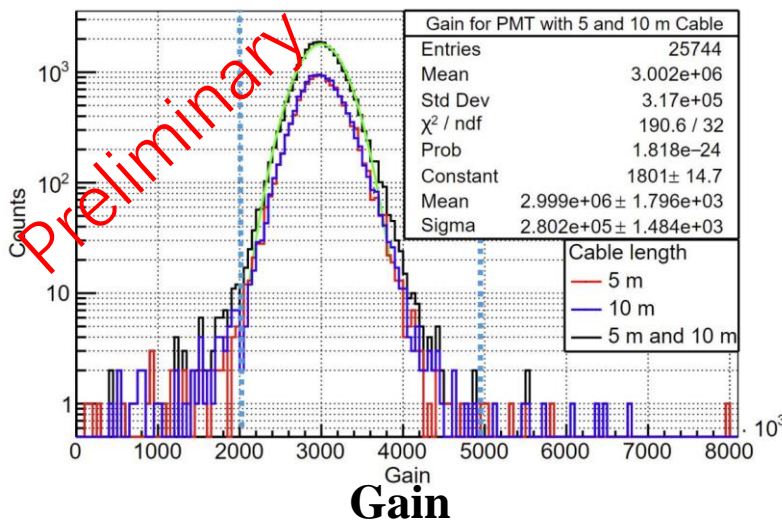
# Acceptance tests of water proofing potting PMTs



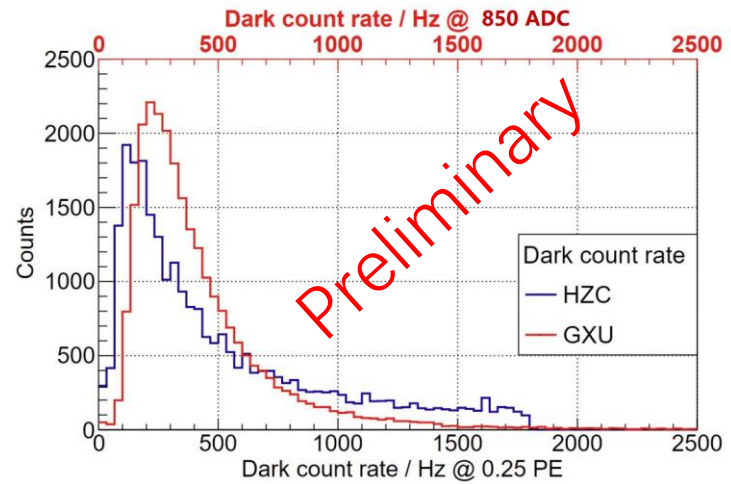
- Acceptance of SPMTs after waterproofing was finished in Guangxi University (GXU).
- Unqualified ratio < 0.7%
- Gain spread ~ 10%, mean SPE resolution ~33%, mean dark rate ~400 Hz



Test station at GXU



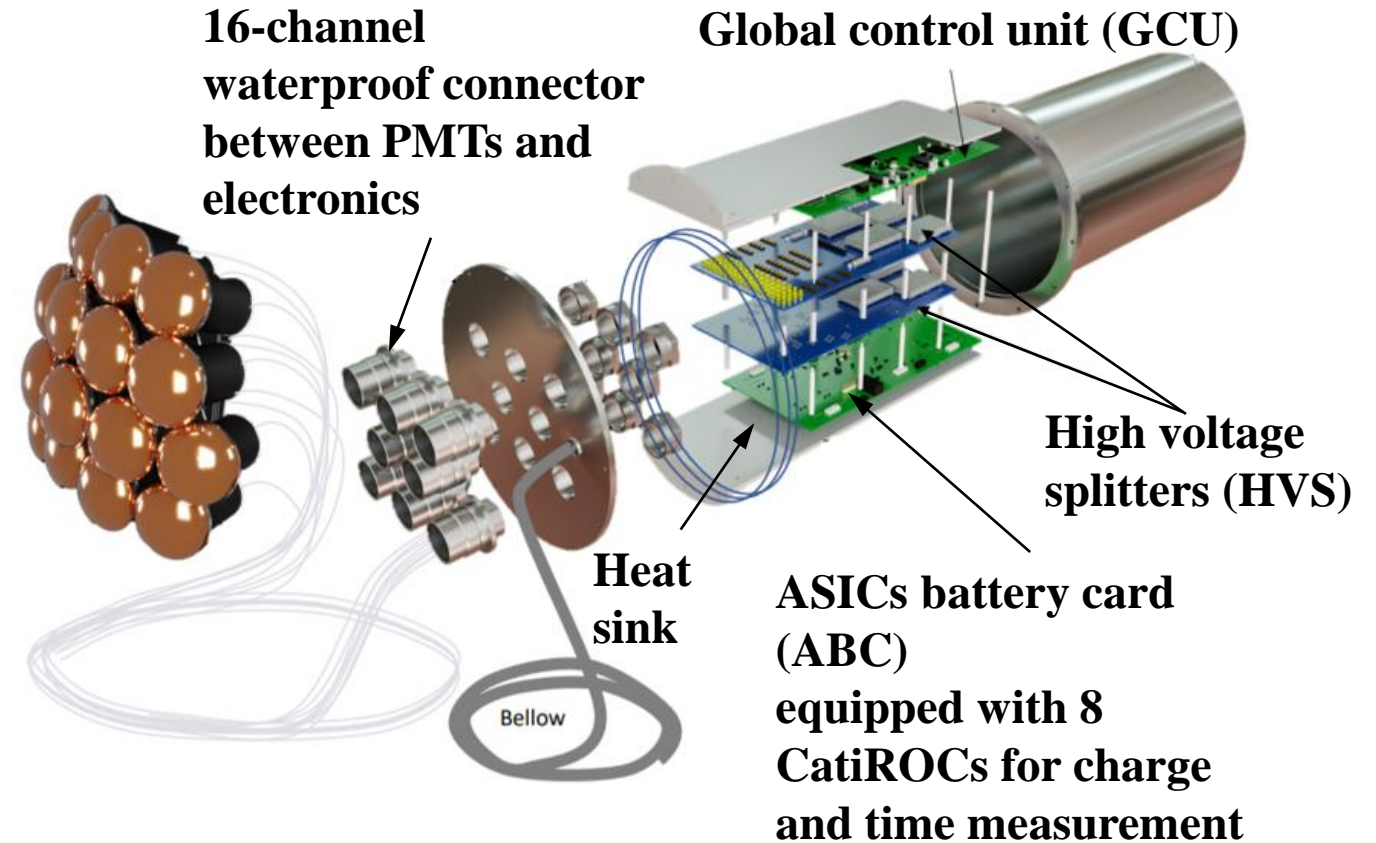
Single photon electron (SPE) resolution



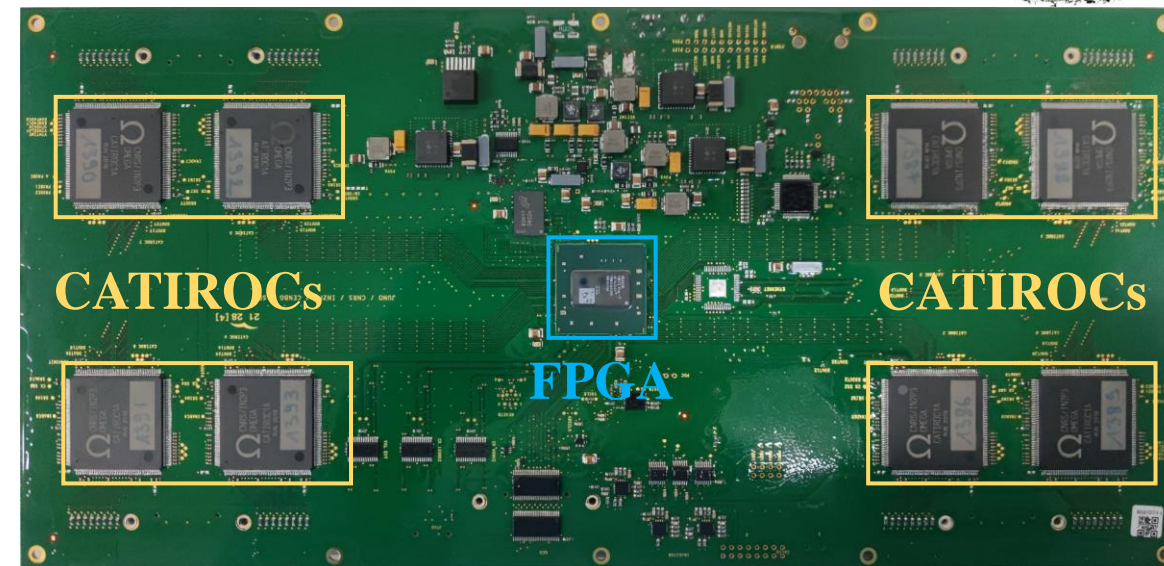
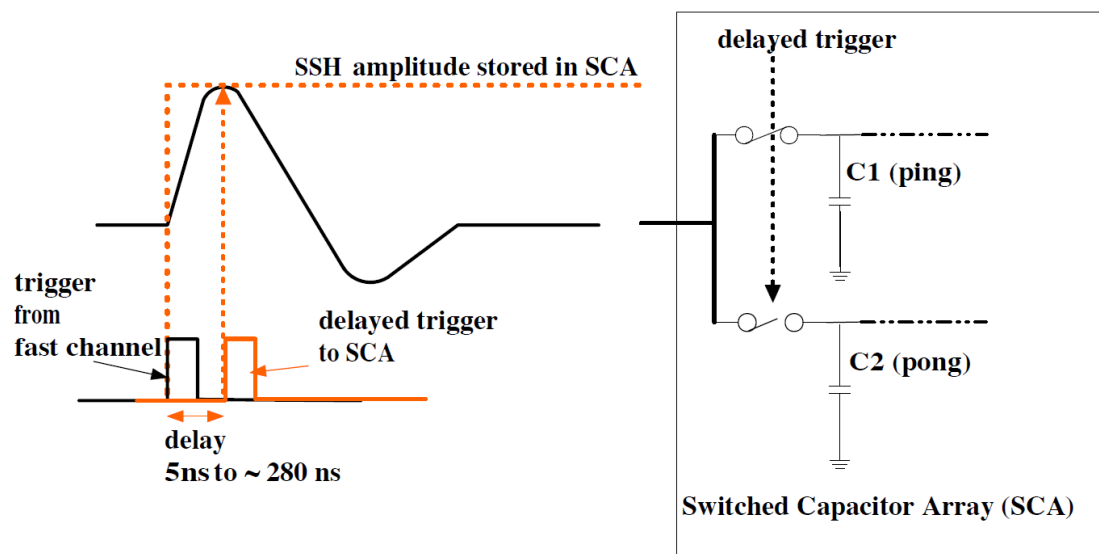
Dark count rate



- The whole system will be installed underwater at a maximum depth of ~40 m.
- Each group of 16 PMTs shares the same HV and threshold.



Conforti S , Settimo M , Santos C ,et al.CATIROC: an integrated chip for neutrino experiments using photomultiplier tubes[J]. 2020.DOI:10.48550/arXiv.2012.01565.



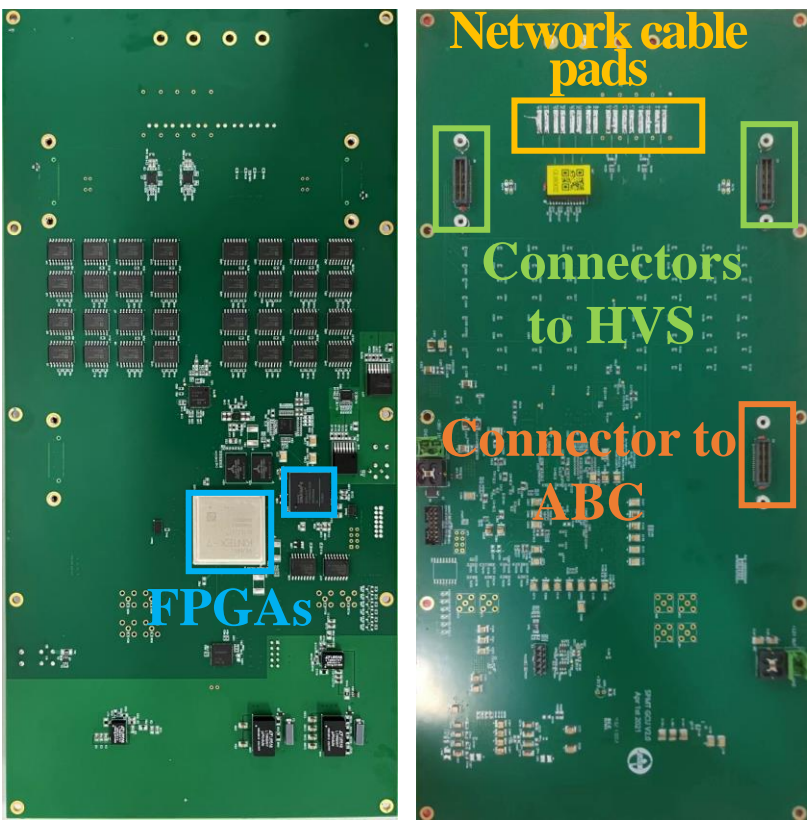
Charge measurement method of CATIROC

ABC board

- **8 CATIROCs on one ASICs Battery Card (ABC) for 8 groups of PMTs**
- **CATIROC is an ASIC to analyze signals from PMTs and output time and charge data.**
- **The dynamic range using both the low and high gain regimes is from 0 to ~120 PE.**
- **Noise of high gain is about 2 ADCu, which correspond to 0.015 pC and 0.03 p.e. for a gain of  $3 \times 10^6$**

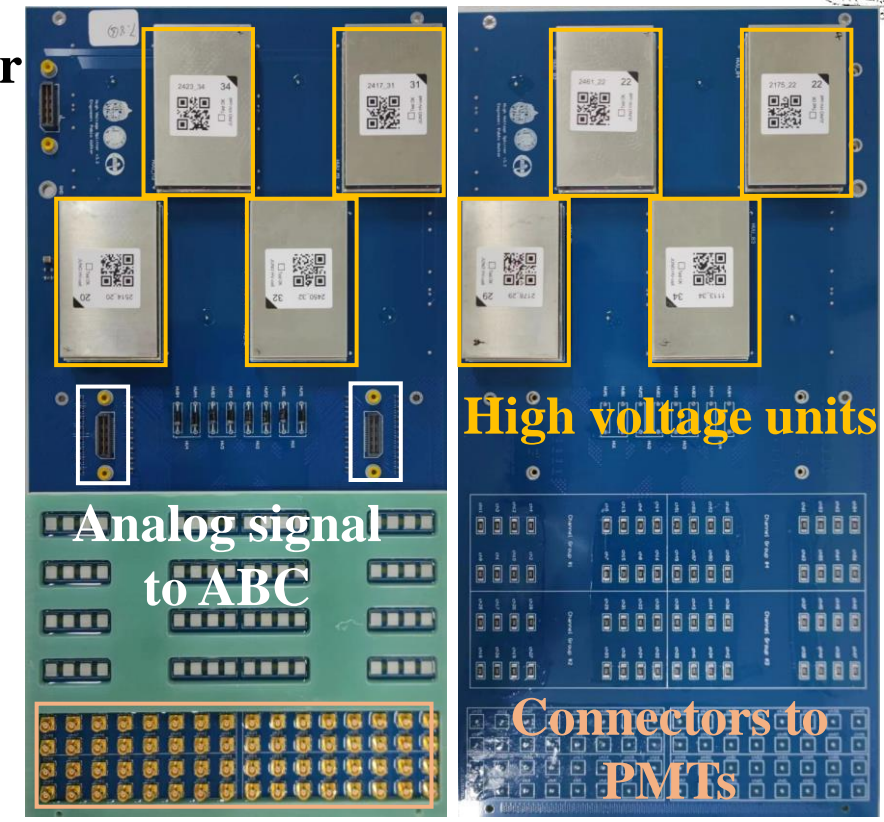


# HVS and GCU



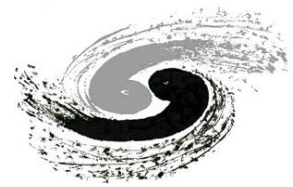
GCU board

Connector to GCU

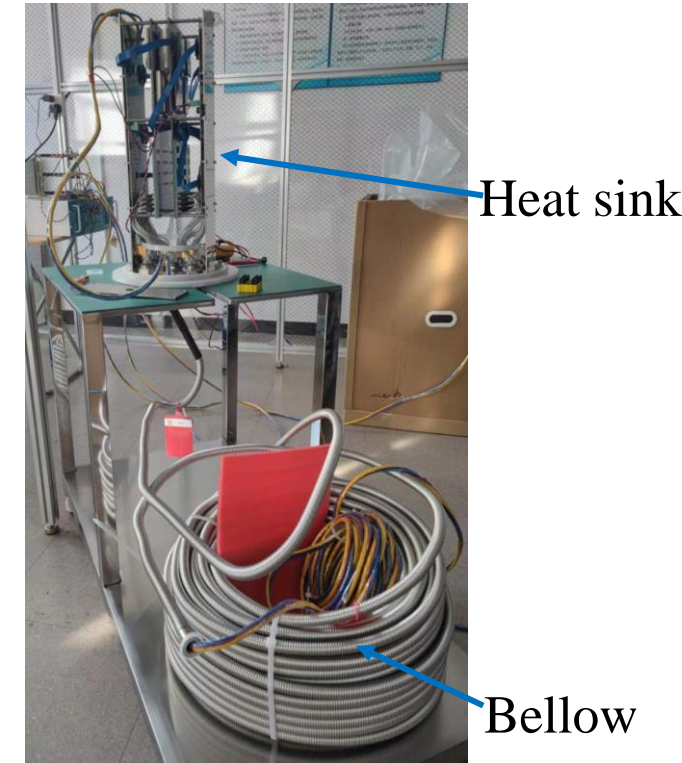
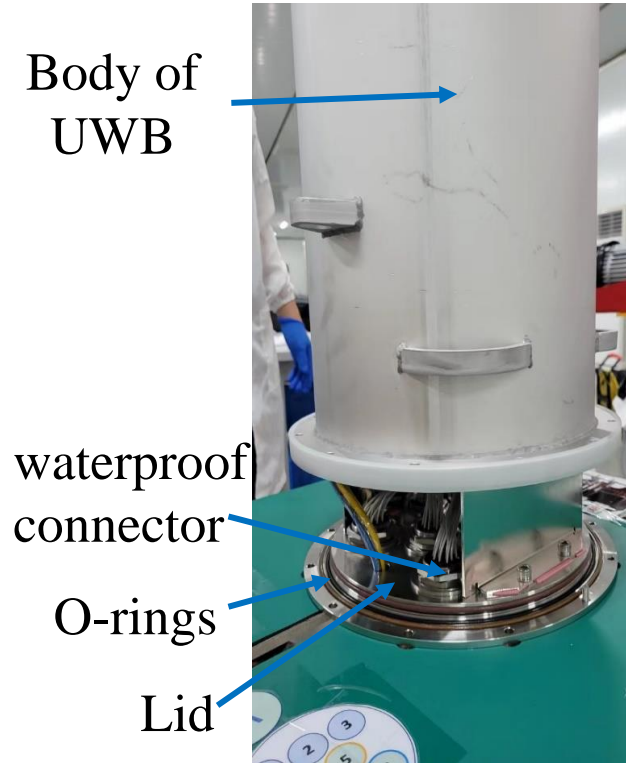


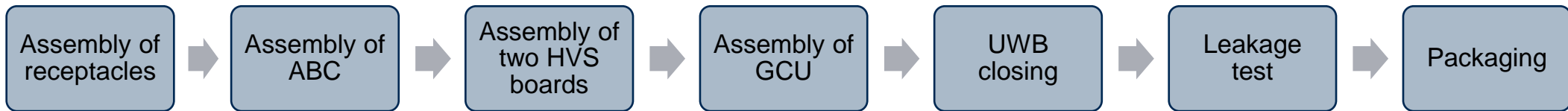
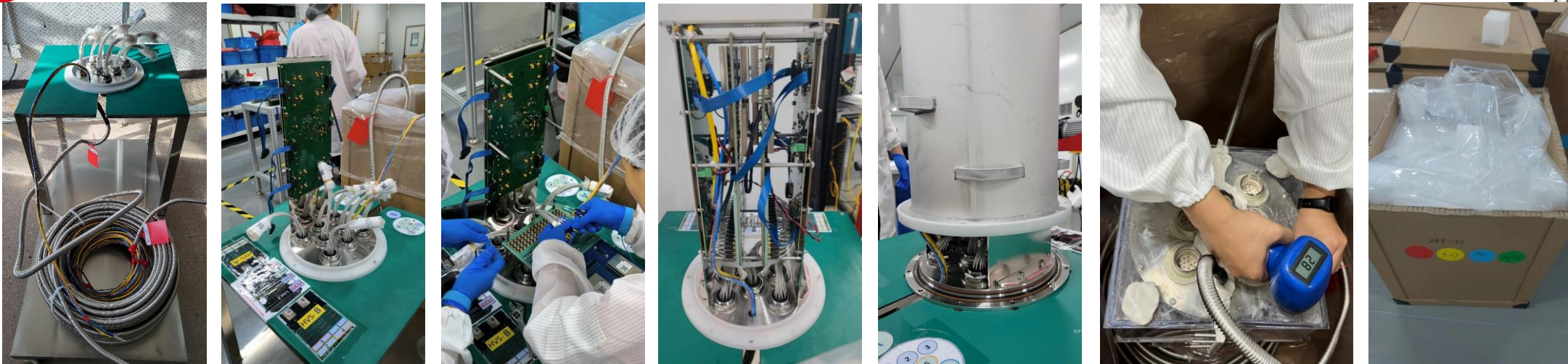
HVS board

- **High Voltage splitter (HVS):** supply high voltage and split signal
- **Global Control Unit (GCU):** control and transfer data to DAQ



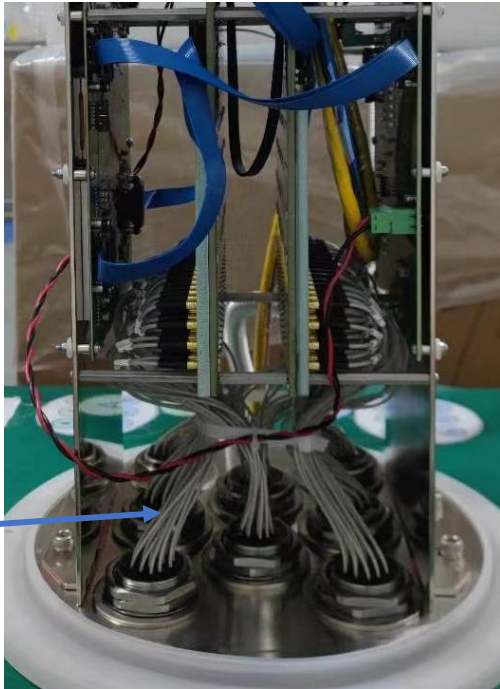
- **Network and power cables run inside bellows to electronic rooms in the surface.**
- **Heat sink to support electronic boards and dissipate heat through the front lid.**
- **UWB sealed with 3 redundant O-rings.**
- **Custom-made Axon waterproof connectors between HVS and SPMTs.**





## SPMT electronics integration procedure

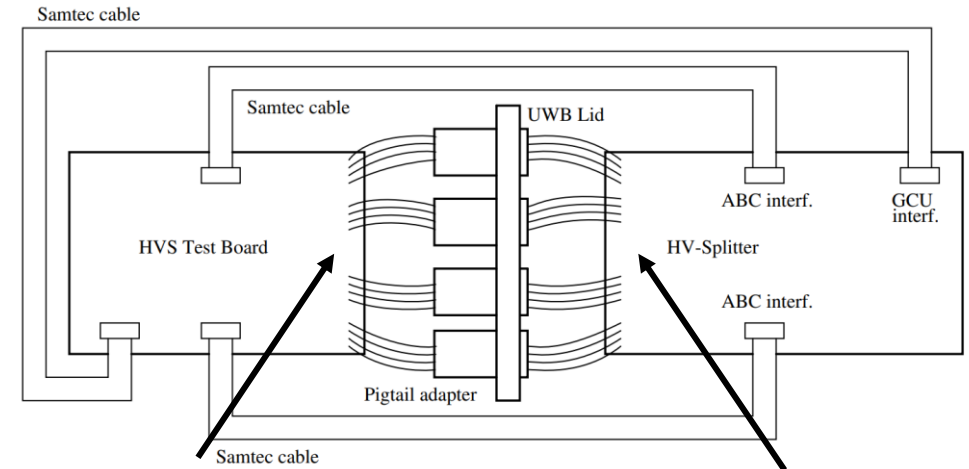
- **204 sets of electronics have been integrated at JUNO site.**
- **Mass integration starts in September 2022 and ends in April 2023.**
- **2 ~ 4 workers worked together with 2 ~ 4 JUNO collaborators.**
- **2 electronics per day at first → 3 ~ 4 electronics per day.**



128 PMT cables



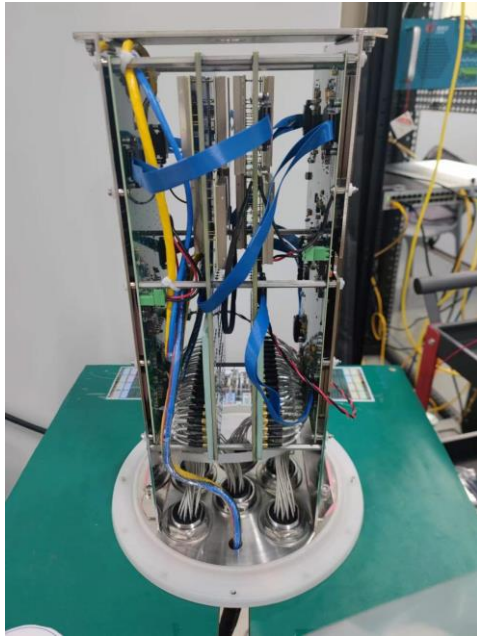
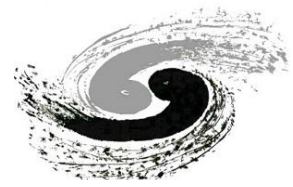
HVS test board system



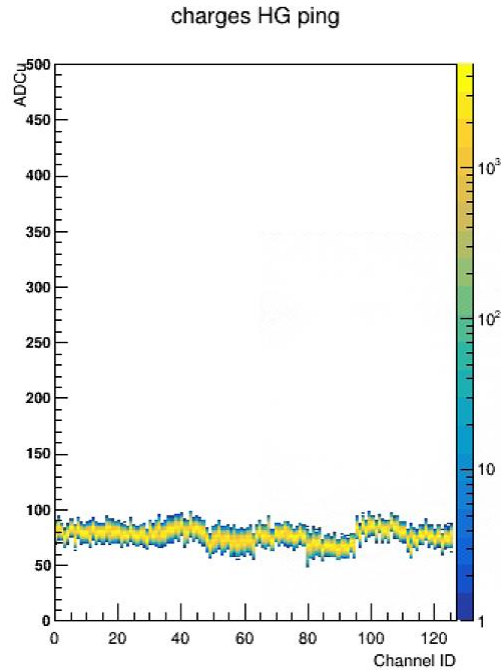
Standard connecting map on test board

Real connections on HVS

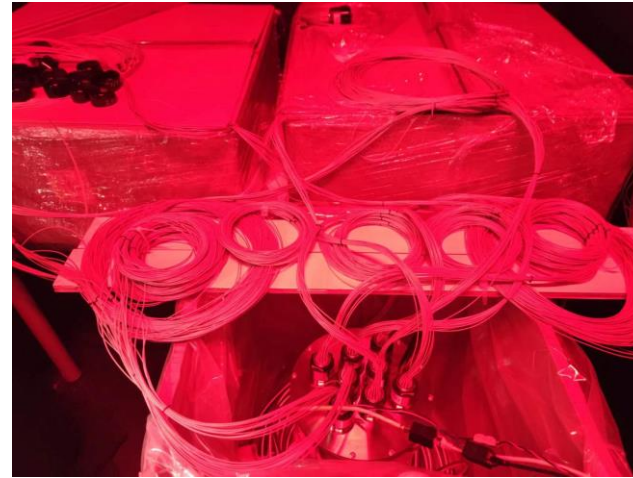
- Use series of known pulses to ensure correctness of 128 cable connections
- Make sure HVS is working.



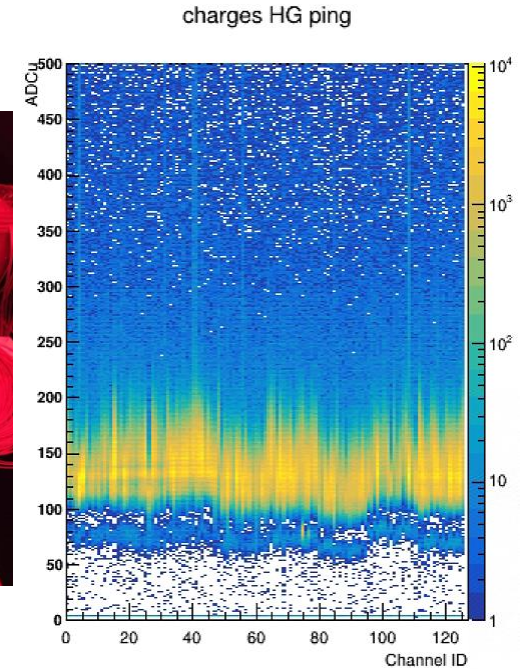
Pedestal test before closing UWB



Pedestal of one set of electronics

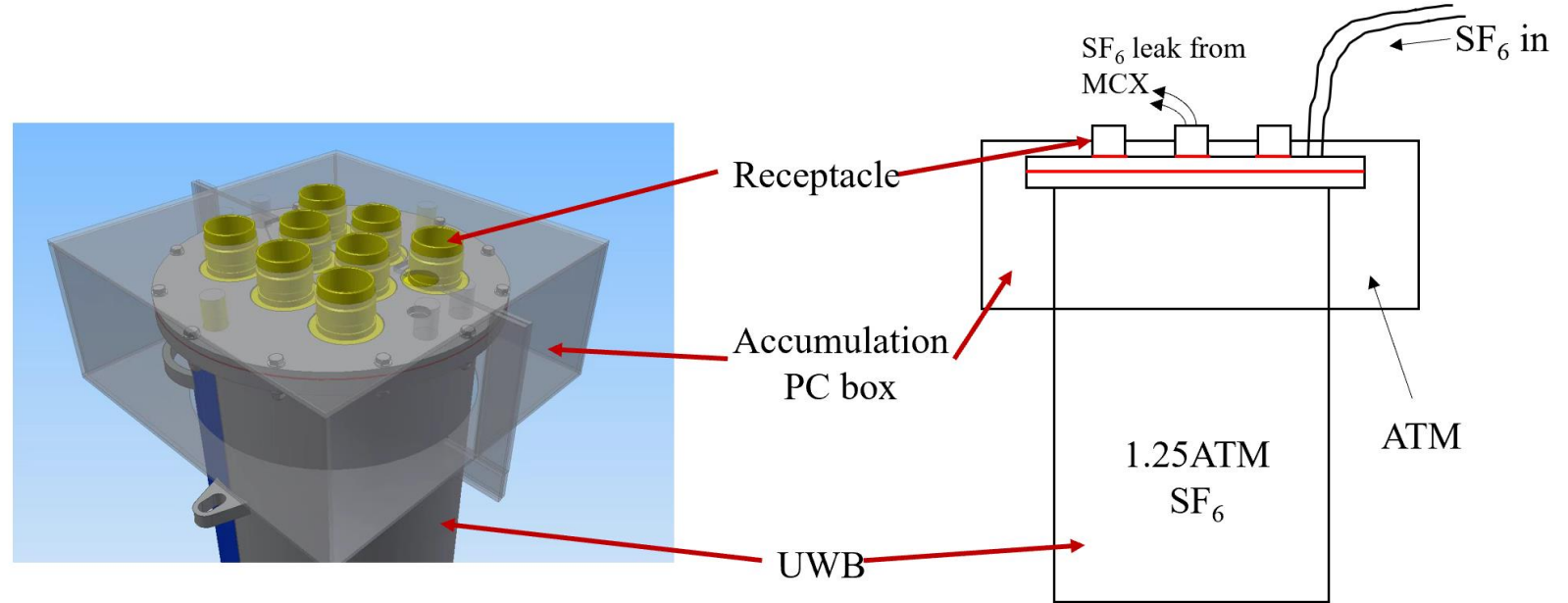


Test with SPMTs in dark room



SPE signals read by one set of electronics

- **RMS of pedestal is about 0.04 p.e. consistent with result tested with single ABC.**
- **All electronics finished integration and passed tests!**



**Leakage test system**

- **A SF6 based leakage test system was designed for UWB.**
- **Sensitivity is  $\sim 10^{-8} \text{ Pa} \cdot \text{m}^3 / \text{s}$**
- **Leaky receptacles were identified and sealed with epoxy.**

# PMT installation



Install support



Install PMT



Install Light Barrier

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



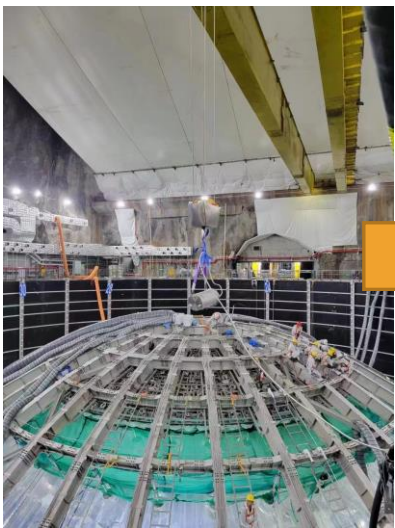
QR code on installation position

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



QR code on PMT

- Starts in November 2022
- One group of 3 workers can install 60 ~ 80 PMTs per day on the stainless steel truss.
- **9265/25600 (~36%)** PMTs were installed
- QR codes to make sure correct installation position.



Hoist UWB



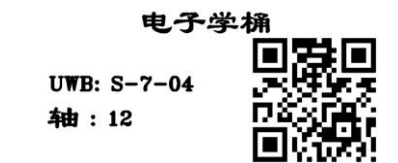
Install UWB



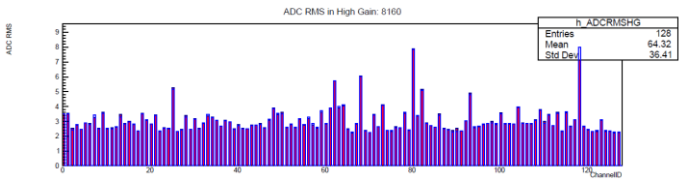
Connect SPMTs to UWB



QR code on installation position



QR code on UWB



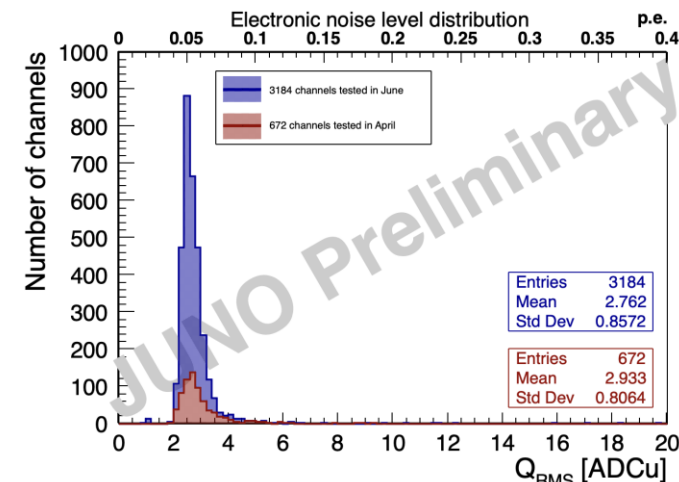
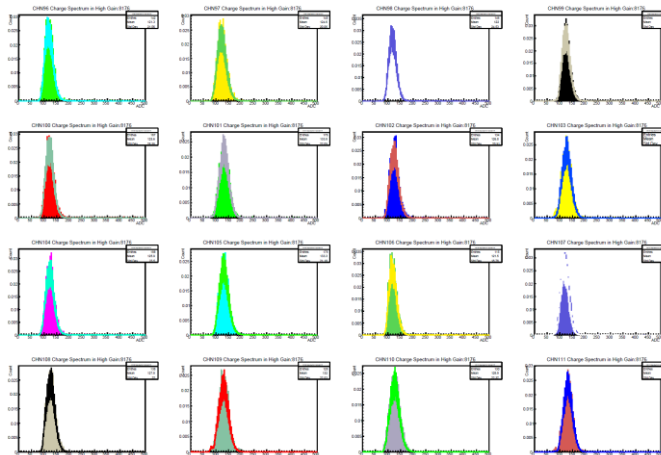
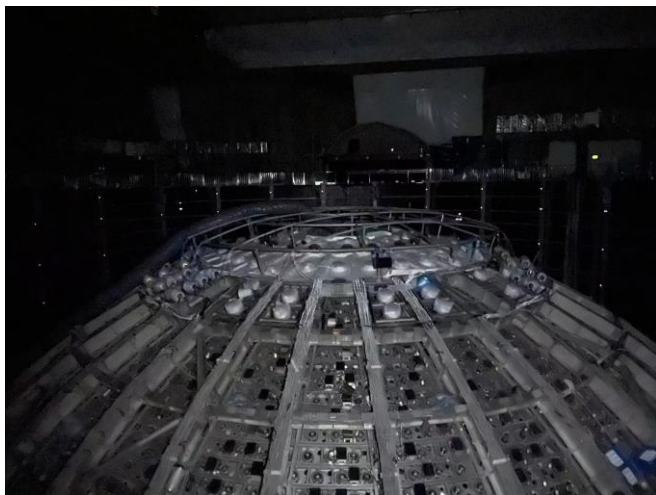
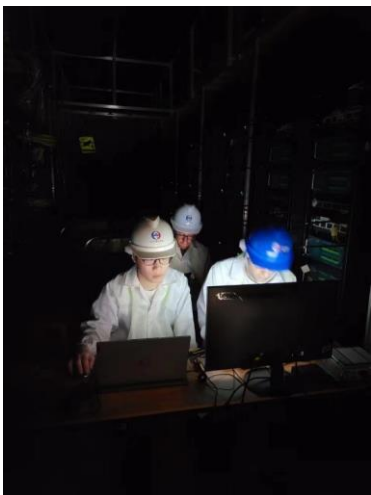
Pedestal test after installation



Leakage test after installation

- Starts in March 2023.
- 26 UWBs per day if only the SPMT UWBs are installed.
- **56/200 (~28%)** UWBs were installed.





Operate in electronics room

JUNO detector with lights off

Charge spectra of one group of 16 SPMTs

Noise on detector

- 30 UWBs with 3184 PMTs were tested during three dedicated lights-off tests.
- Electronics noise of SPMT is **2.8 ADC** counts, **~5% of SPE**  
→ Much lower than the trigger threshold of 1/3 p.e.
- Problematic cables (~1/1000) were identified and repaired.



- **26k 3-inch PMTs and electronics were produced and integrated.**
- **1/3 PMTs and 1/4 electronics have been installed in the detector.**
- **PMTs and electronics are connected through 16-channel underwater connectors.**
- **Three times lights-off tests have been conducted with ~0.1% problematic channels identified and repaired.**
- **Installation of PMTs and electronics to be completed by early 2024.**



**Thank you!**