

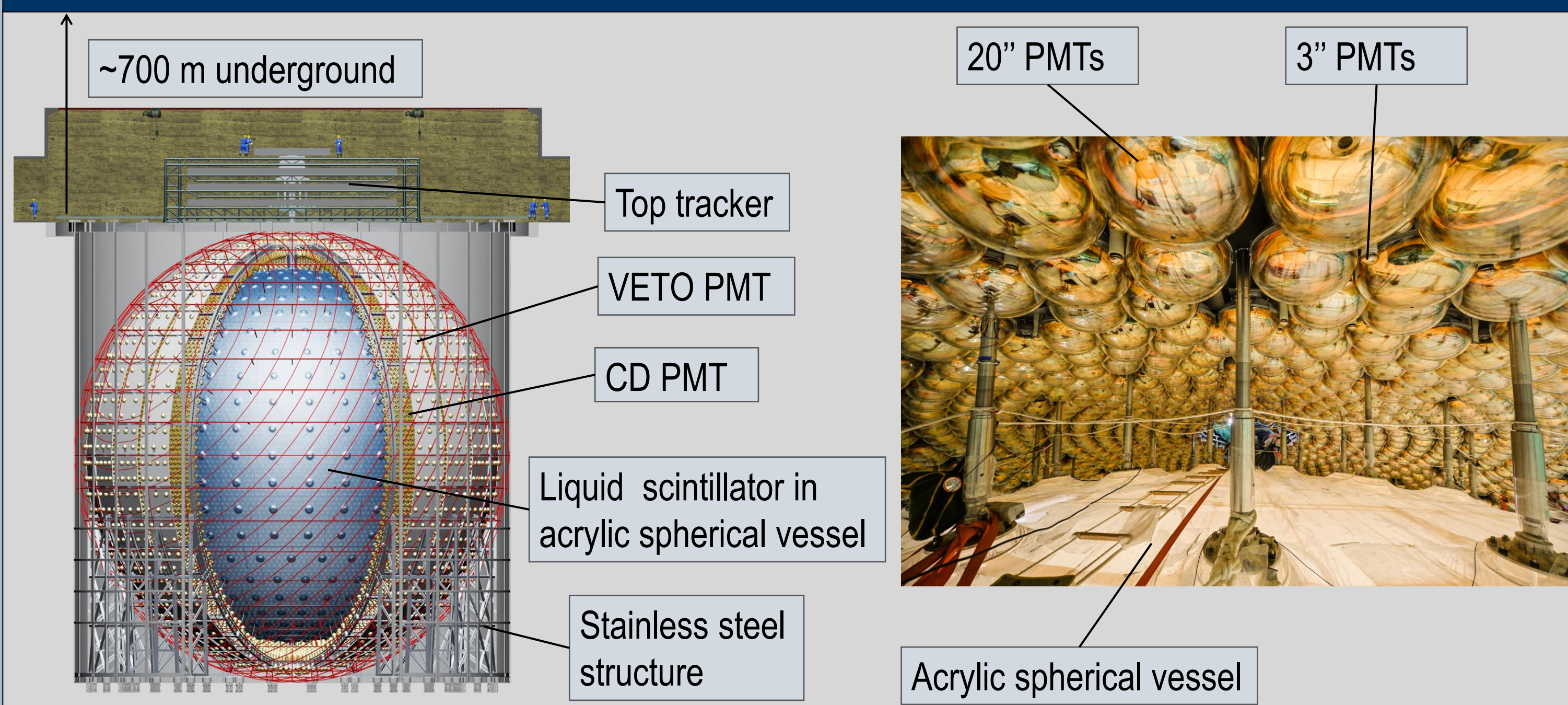


# Status of the small PMT system in JUNO

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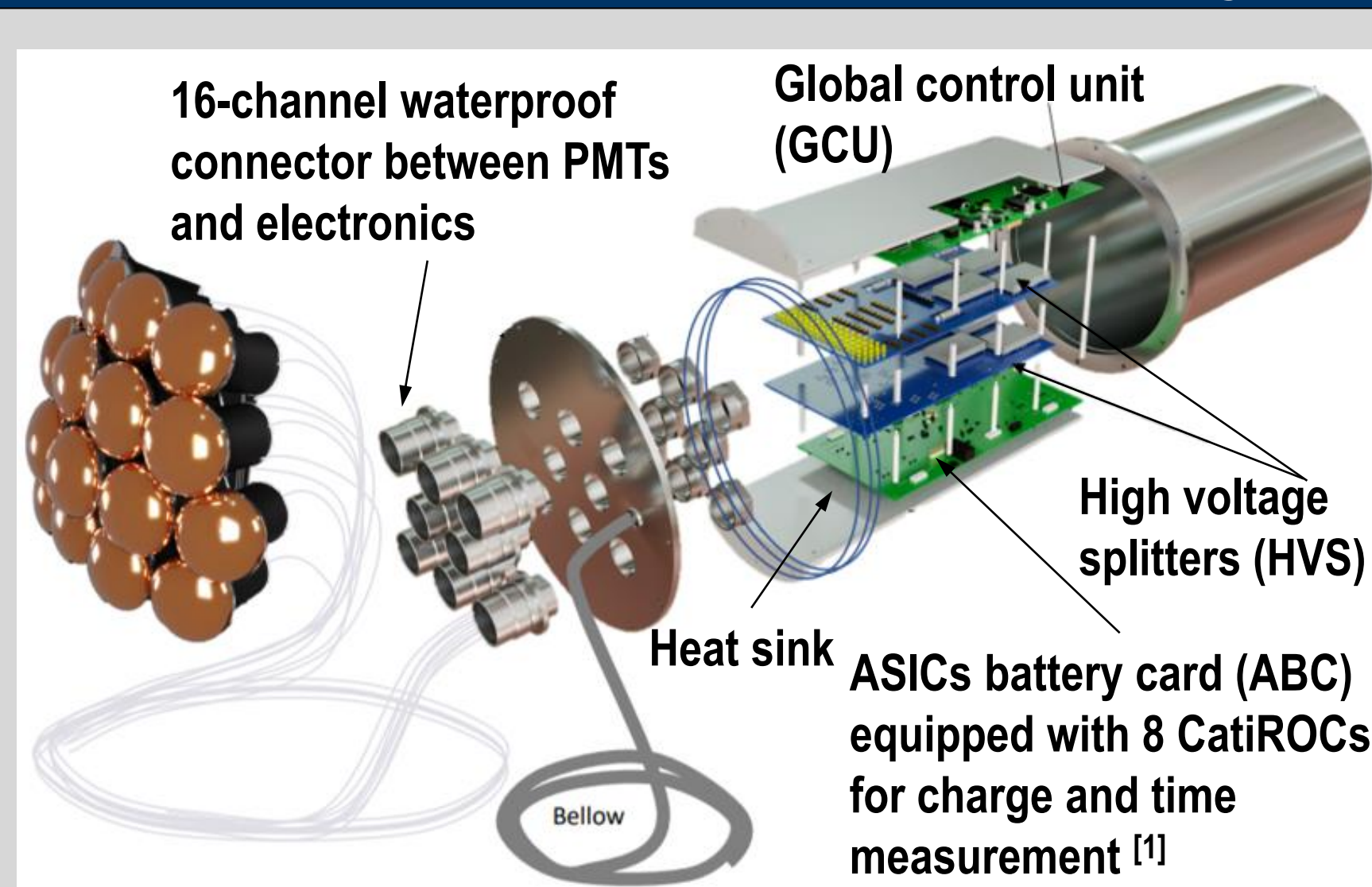


## JUNO detector



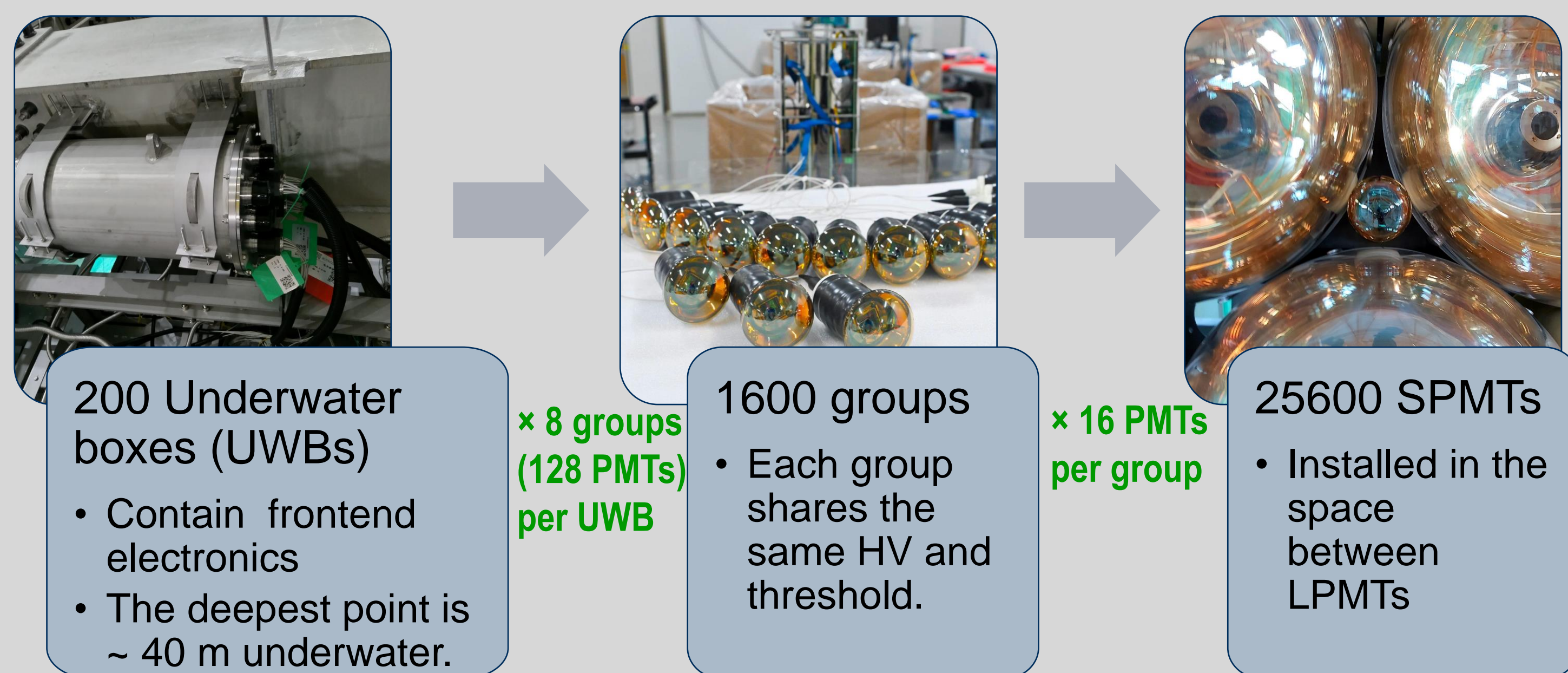
- Main physics goal of JUNO is to determine neutrino mass ordering and make a sub-percent measurement of three oscillation parameters.
- The Central Detector (CD) includes a 20 kt Liquid Scintillator (LS) target.
- 25,600 3-inch “small” and 17,612 20-inch “large” photomultiplier tubes (SPMTs and LPMTs,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

## SPMT system



### Why SPMT?

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



200 Underwater boxes (UWBs)  
 • Contain frontend electronics  
 • The deepest point is ~ 40 m underwater.

× 8 groups (128 PMTs) per UWB

1600 groups  
 • Each group shares the same HV and threshold.

× 16 PMTs per group

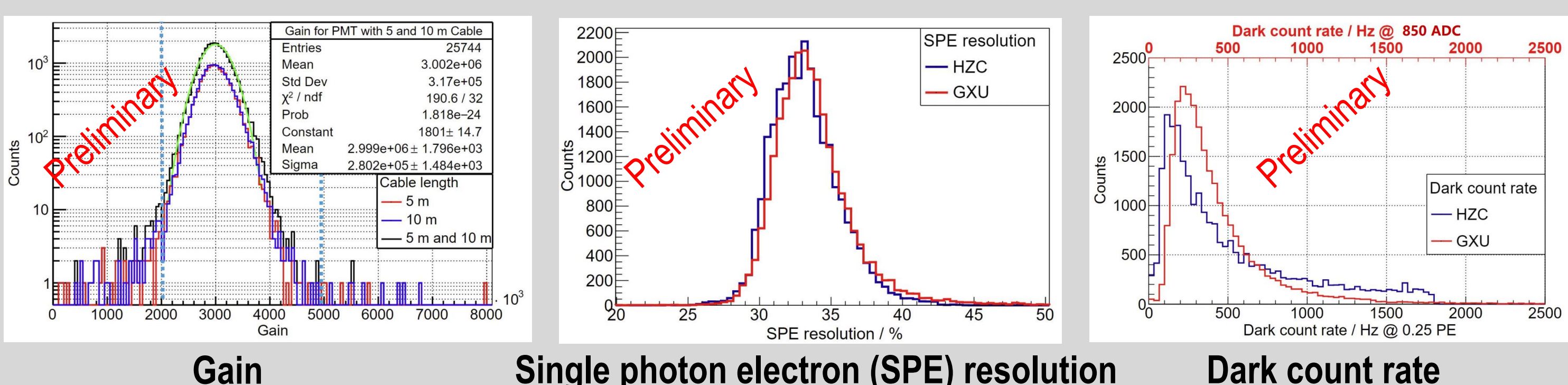
25600 SPMTs  
 • Installed in the space between LPMTs

## PMT performance

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

Summary of the 3-inch PMTs acceptance criteria and test results for different parameters.<sup>[2]</sup>

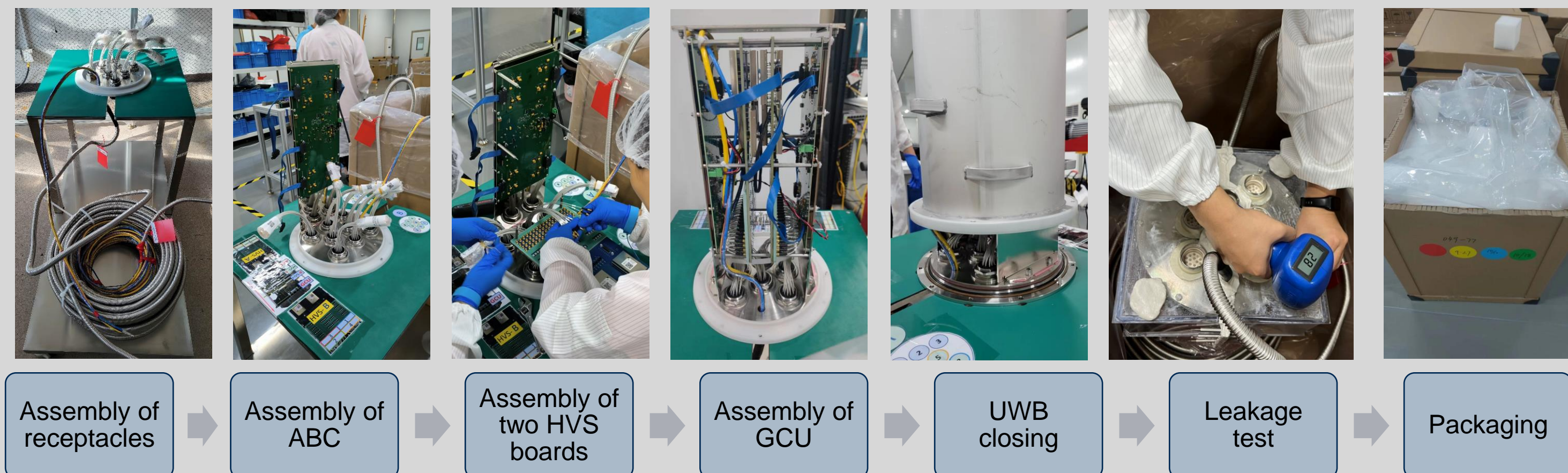
- Bare PMTs were produced and characterized in Hainan Zhanchuang



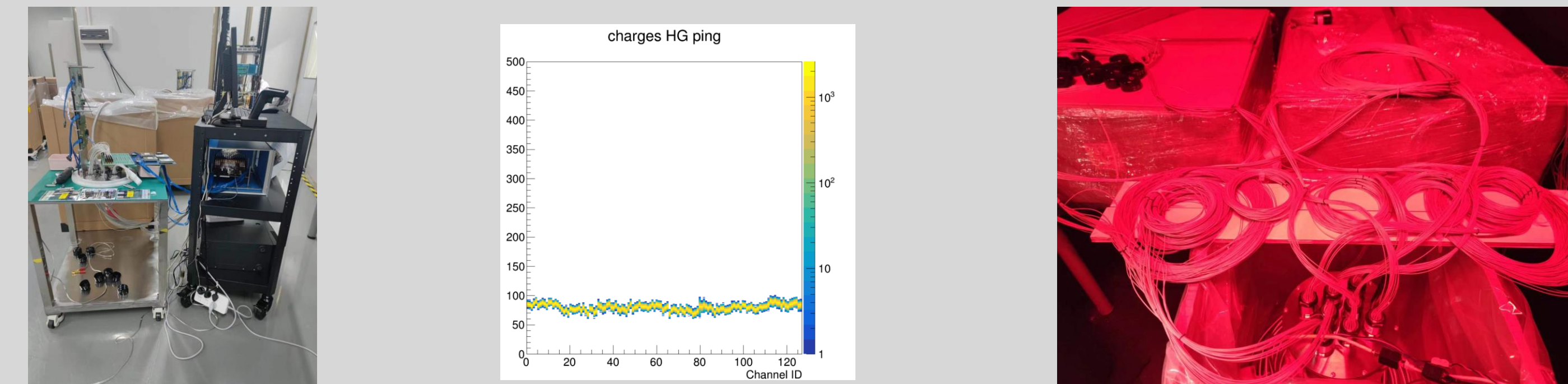
- Acceptance of SPMTs after waterproofing done in Guangxi University

## Electronics integration

### Integration procedure



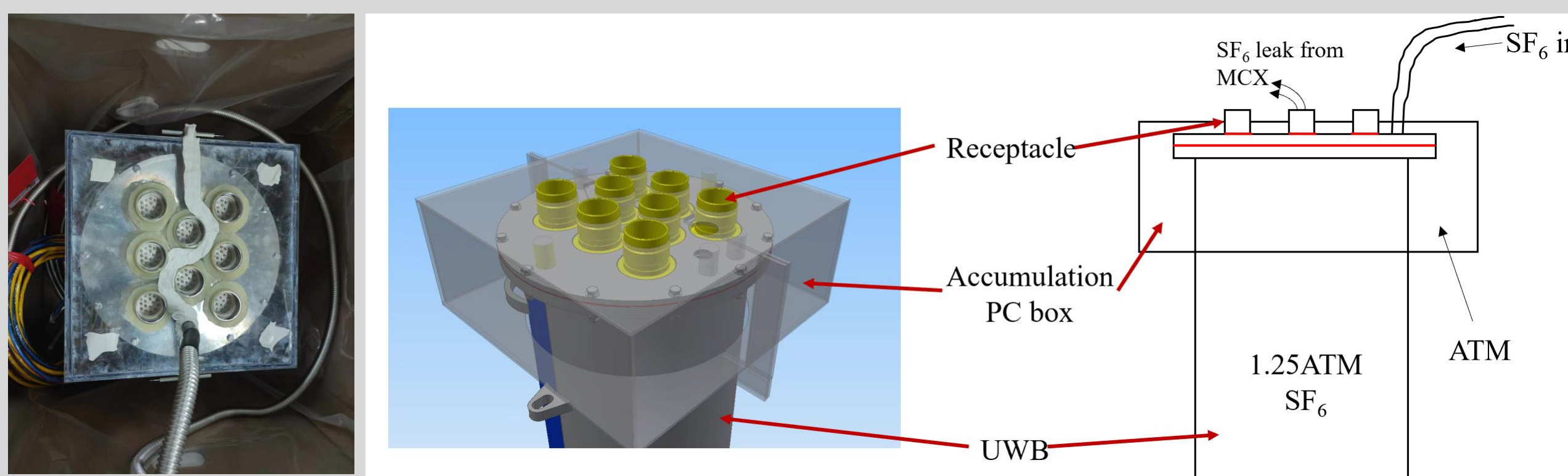
### Tests during integration



a. Check cables with HV test board

b. Pedestal test before closing UWB

c. Test with SPMTs in dark room



d. Leakage test system

- A SF<sub>6</sub> based leakage test system was designed for UWB.
- Sensitivity is ~ 10<sup>-8</sup> Pa · m<sup>3</sup> / s

**All electronics finished integration and passed tests!**

## Installation

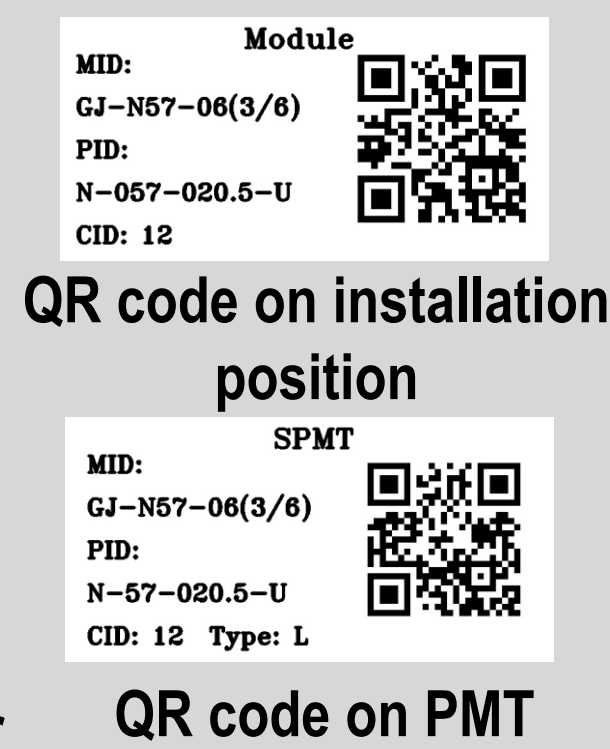
### PMT installation



Install support

Install PMT

Install Light Barrier

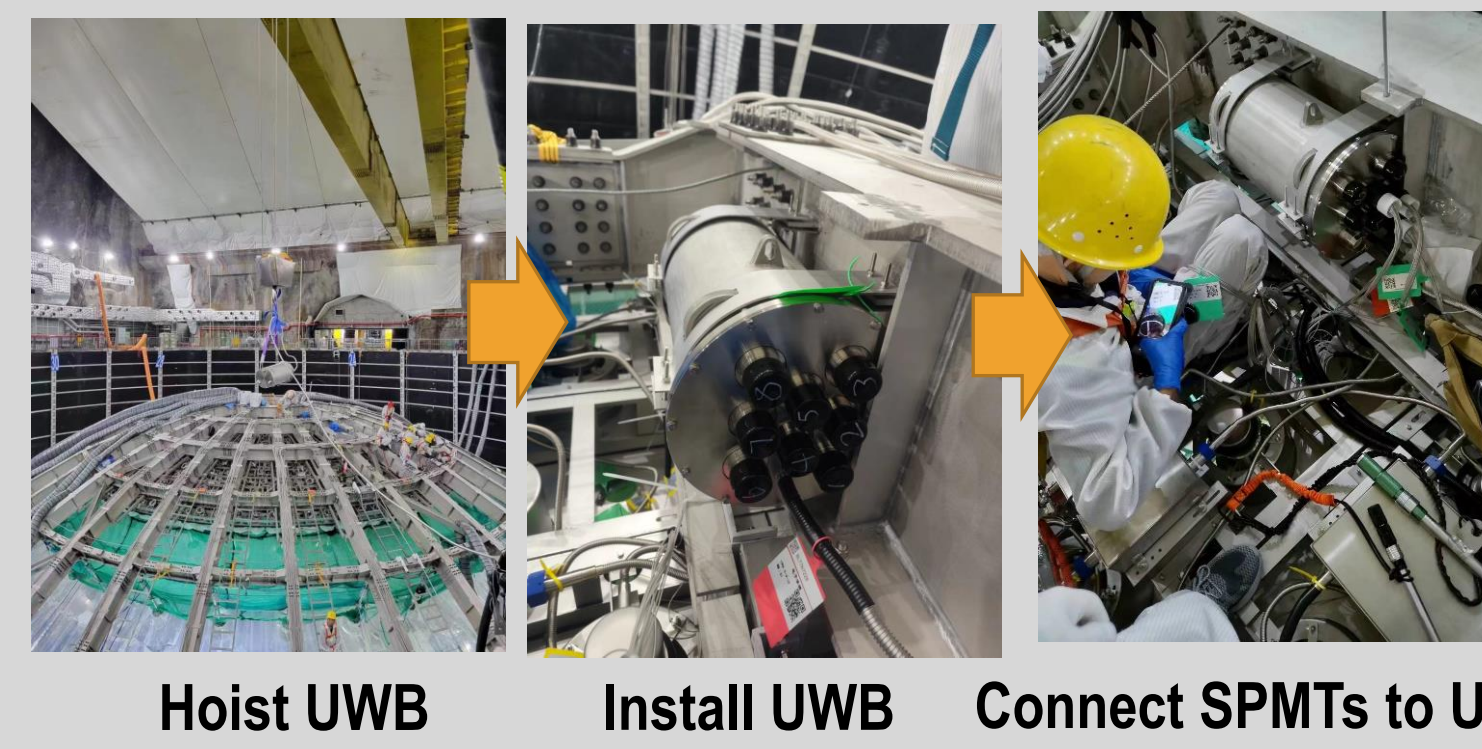


QR code on installation position

QR code on PMT

- 3600/25600 (~14%) PMTs were installed
- QR codes to make sure correct installation position.

### Electronics installation



Hoist UWB

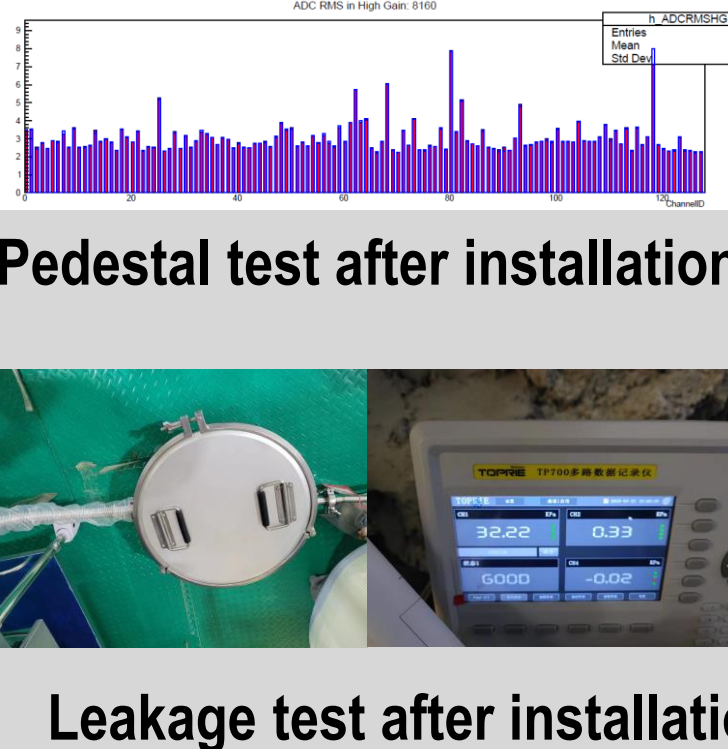
Install UWB

Connect SPMTs to UWB



QR code on installation position

QR code on UWB



Pedestal test after installation

Leakage test after installation

- 30/200 (~15%) UWBs were installed.

## Lights-off test



Operate in electronics room

JUNO detector with lights off

Charge spectra of one group of 16 SPMTs

- To validate installed SPMTs and UWBs.
- 3 times light-off tests already done.
- Take pedestal and SPE data with light off.
- Problematic channels (<1/1000) were identified and resolved.

## Perspective

PMT installation is going to be finished this year and the commissioning with liquid scintillator will start in 2024.

## References

- [1] 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.
- [2] 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.