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IUPAP
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JUNO

中國科學院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

The 3-inch PMT system and its progress at JUNO

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Institute of High Energy Physics, Chinese Academy of Sciences

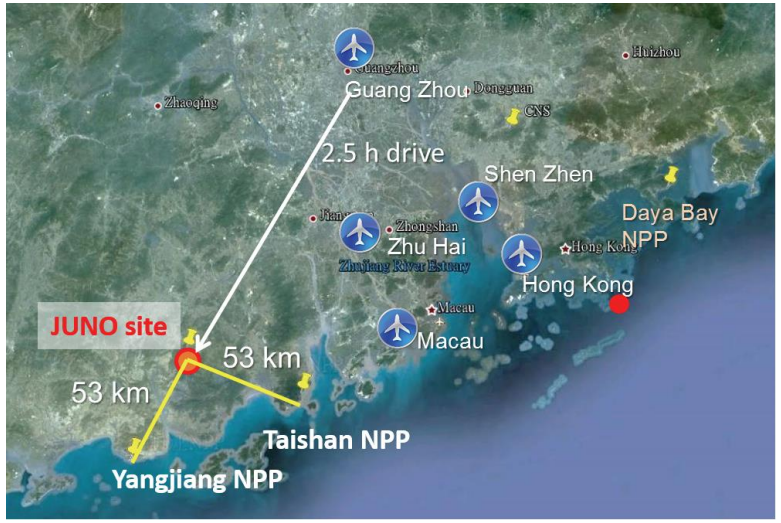
2023/9/3

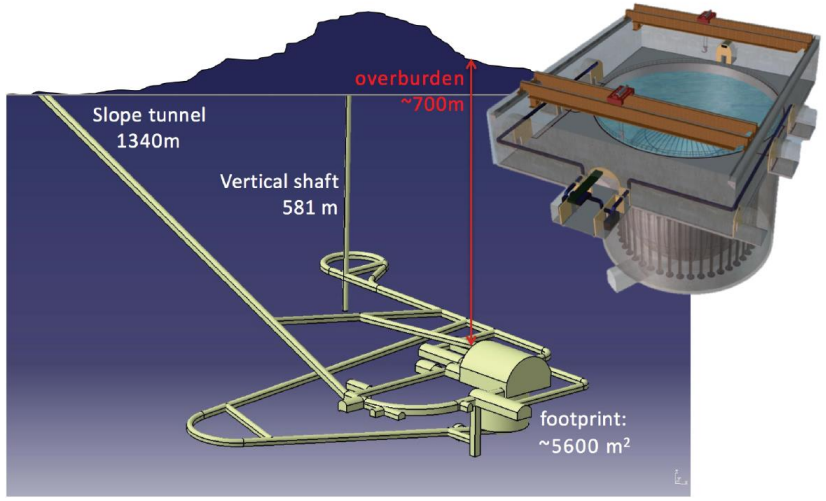
Outline

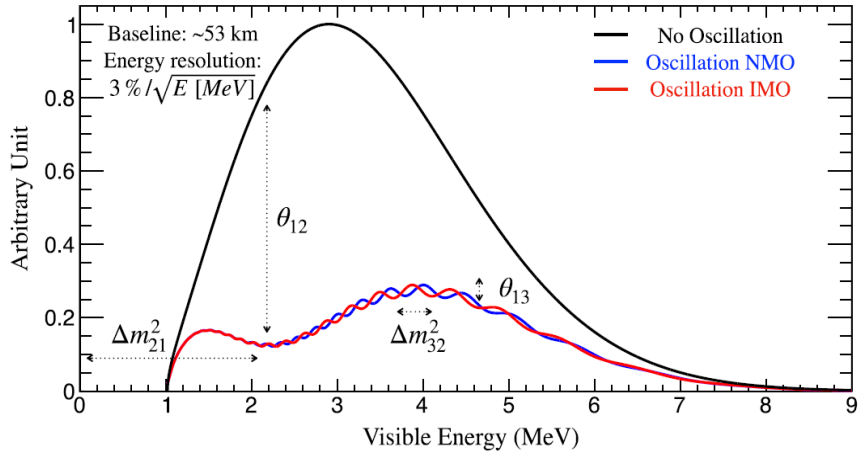
- **JUNO experiment introduction**
- **3-inch PMT (SPMT) system introduction**
- **Each part of SPMT system**
  - **PMTs**
  - **Instrumentation**
  - **Electronics**
  - **Installation**
- **Summary**

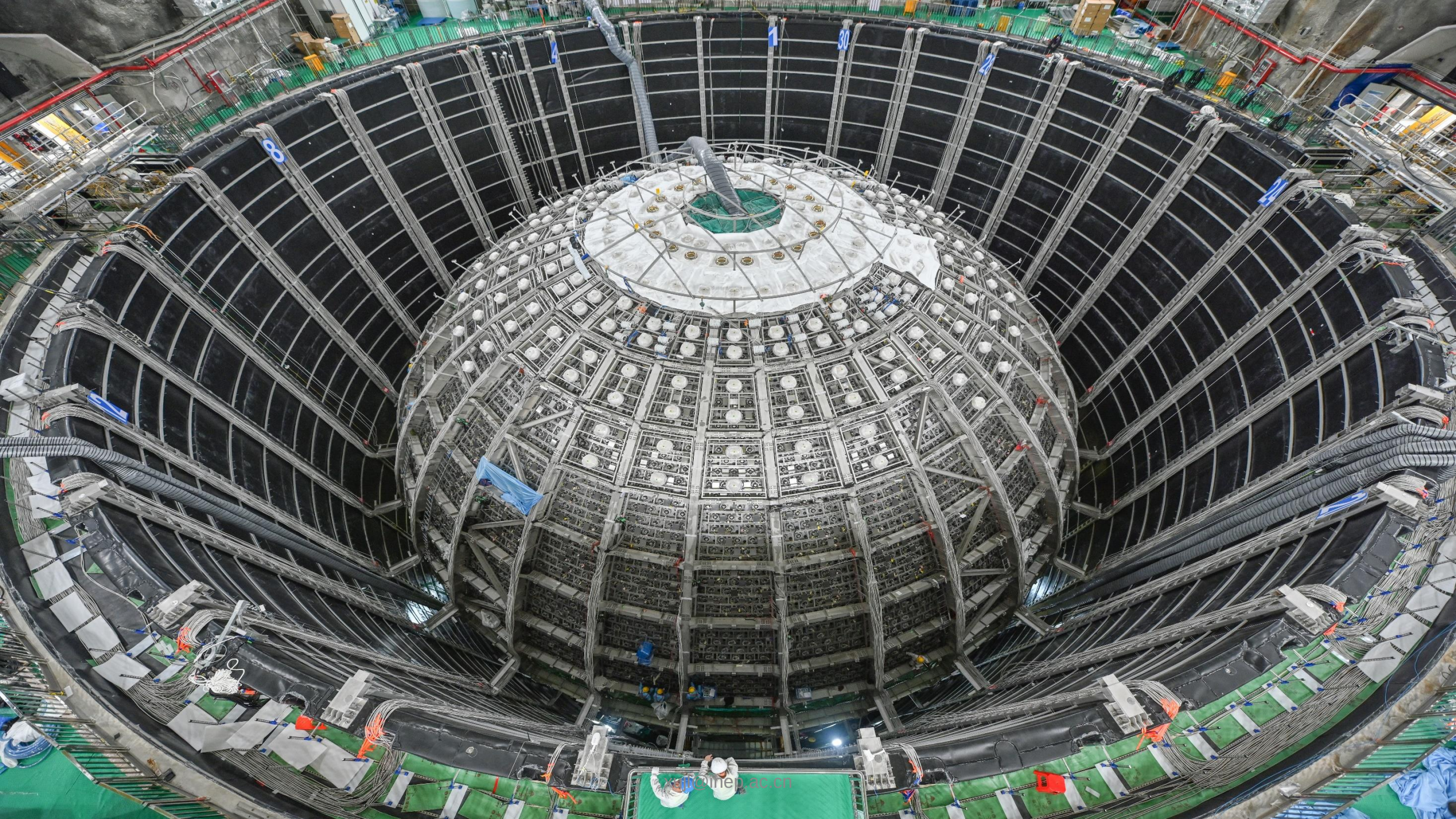
Jiangmen Underground Neutrino Observatory

- **Under construction in underground 700 m in southern of China,**
- **20 kton liquid scintillator (LS), aimed to reach 3% @ 1 MeV energy resolution.**
- **Physics goals:**
  - **Main:** Determine neutrino mass ordering by reactor antineutrino.
  - **Multipurpose:**
    - Measure solar neutrino oscillation with highest precision (<1%).
    - Detect many neutrinos include Supernova neutrino, Geo-neutrino, solar neutrino,…
- **Detector requirement: high transparency LS, high coverage of PMTs and low backgrounds.**
- **The most challenging design in the reactor neutrino experiments throughout the world.**








1
30
2
4
8

JUNO detector

Calibration room

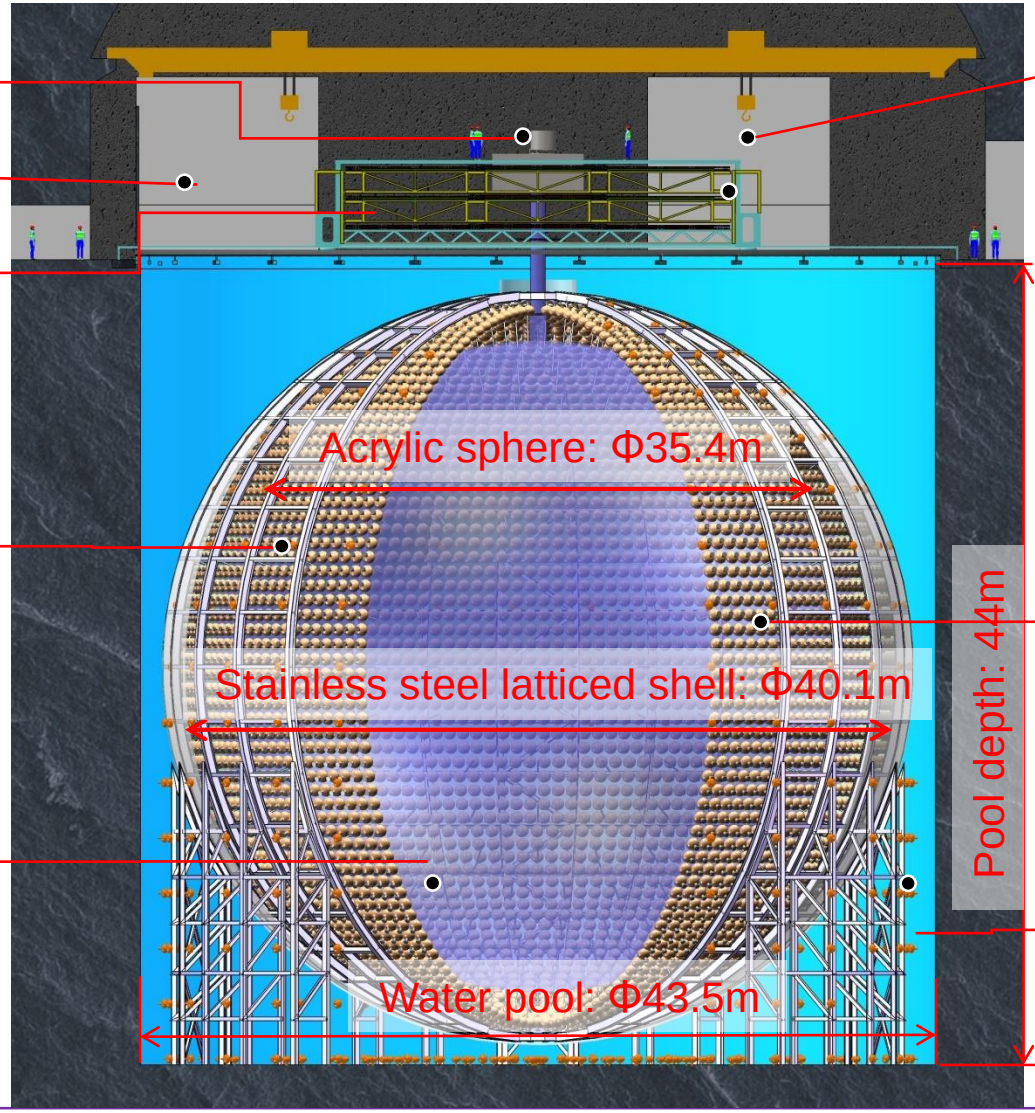
Pure water room

Top Tracker

Central detector
SS latticed shell
Acrylic sphere

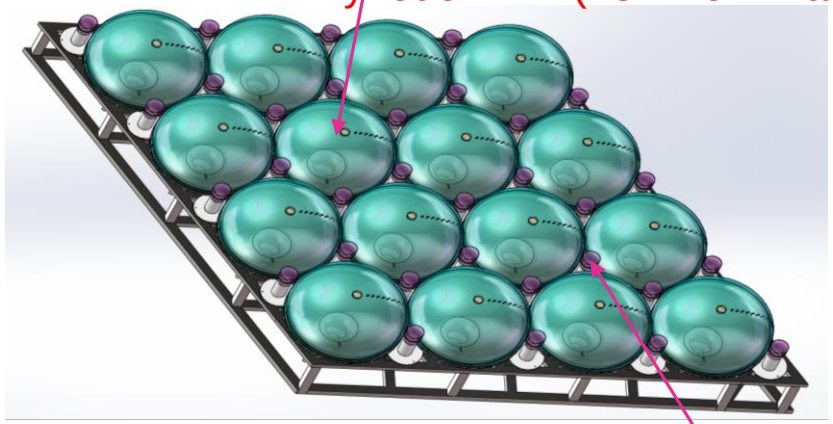
LS
20 kton

700m underground



LS Filling room

20” PMT (~18K)
MCP-PMT (~13K from NNVT)
Dynode PMT (~5K from Hamamatsu)



PMT
~17,612 20” PMTs +
~25,600 3” PMTs:
coverage >75%

3” PMT(~25.6K)
Dynode PMT from HZC Photonics

Water Cherenkov
35 kton pure water
2,400 20” veto PMTs

Science news in Aug. 23, 2023

JOURNALS | COVID-19 Science

HOME > NEWS > ALL NEWS > CHINA'S NEW UNDERGROUND LAB COULD ANSWER LONG-STANDIN...

NEWS | ASIA/PACIFIC

China's new underground lab could answer long-standing neutrino mystery

Physicists hope to pin down relati
change "flavors" on the fly

23 AUG 2023 · 2:55 PM · BY DENNIS NORMILE

SCIENCE science.org

NEWS | IN DEPTH

And industrial partners boosted the sensitivity of the 43,000 photomultiplier tubes arrayed around the sphere that detect the pulses. In a first, smaller tubes sit between larger tubes, enhancing the sensors.

A version of this story appeared in Science, Vol 381, Issue 6660.

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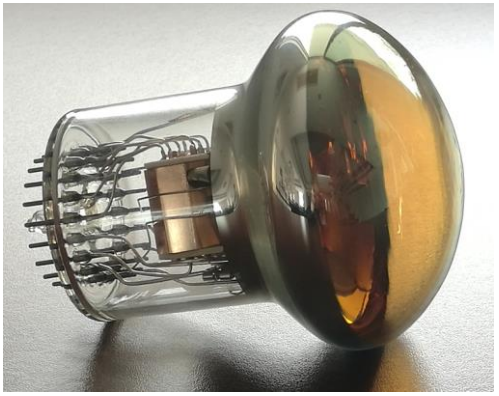
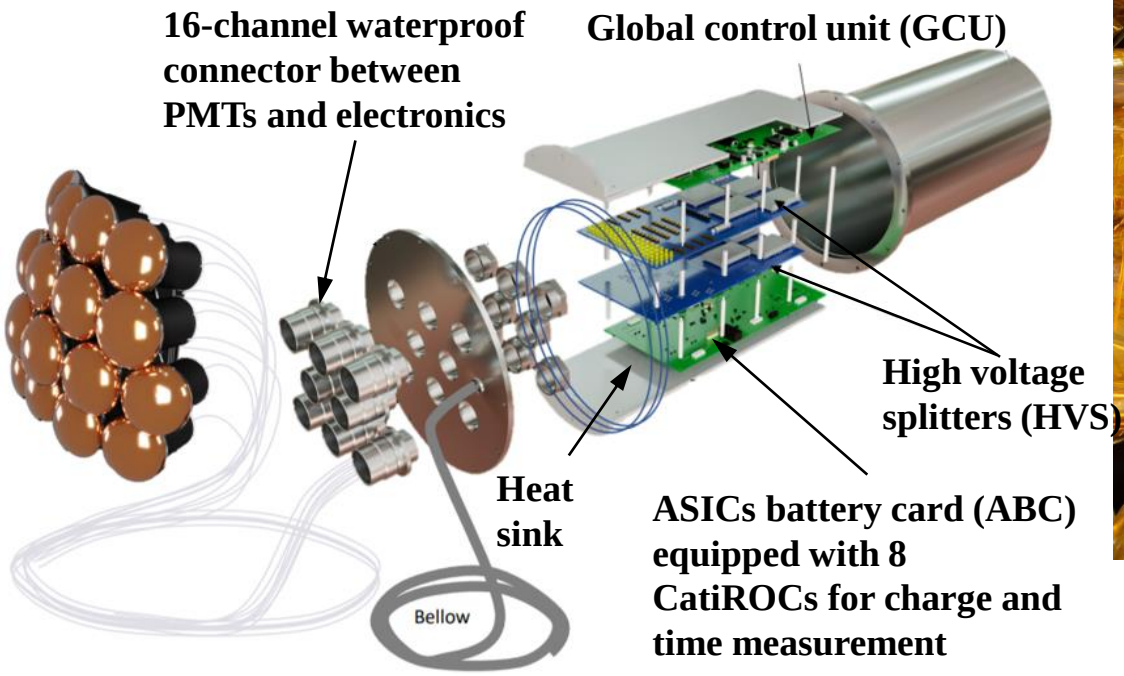
KAIPING, CHINA—Some 700 meters beneath a hill here in the rural

SPMT system





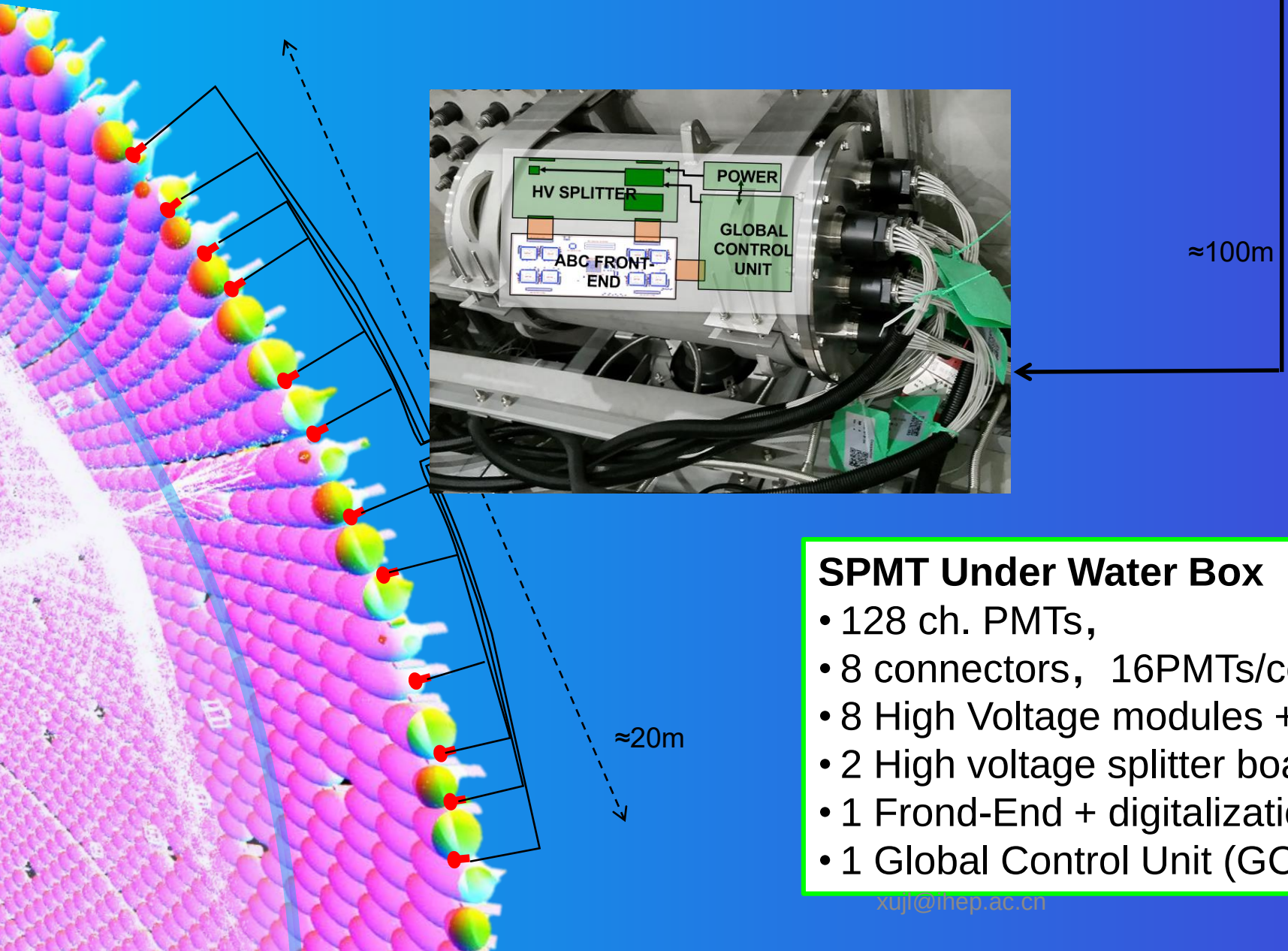
- Calibrating charge non-linearity of LPMTs and their electronics.
- Aid for high-energy and high-rate events: muon, supernova neutrino.
- Semi-Independent measurement: $\boldsymbol{\theta_{12}}, \Delta\boldsymbol{m^2_{21}}$

SPMT system

MAIN DAQ

SURFACE

Power Supply
Clock
Data



- **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.**

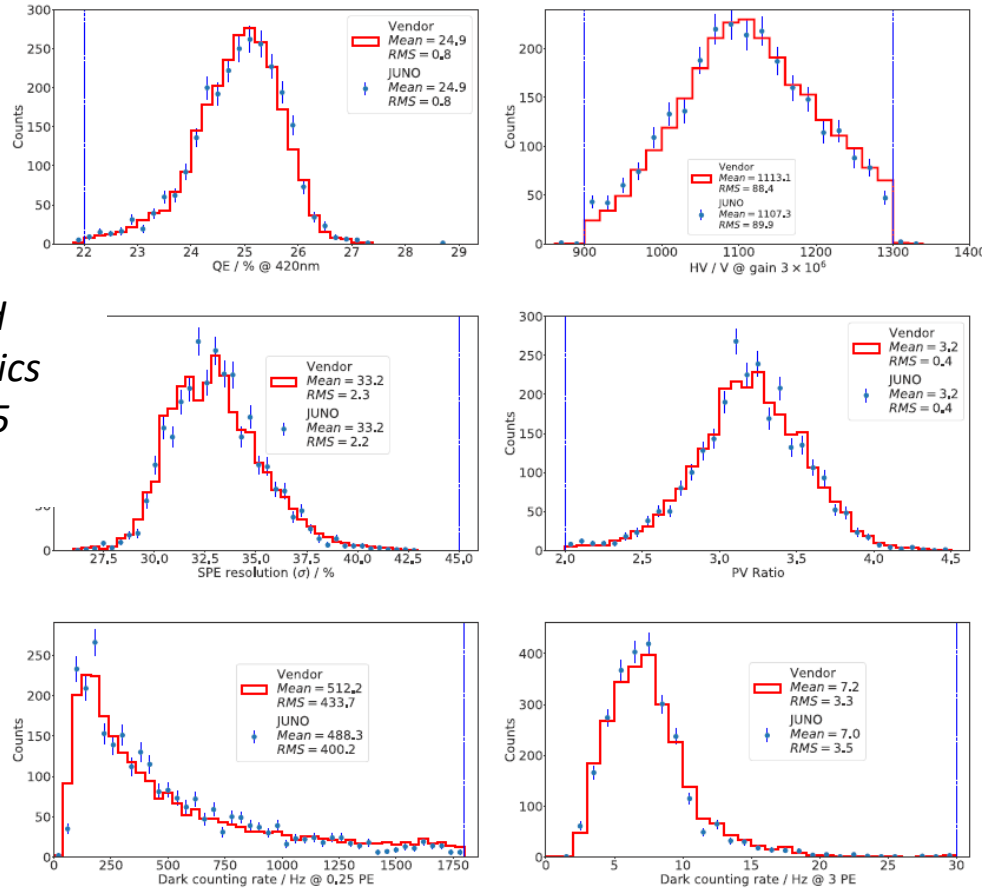
SPMT Under Water Box

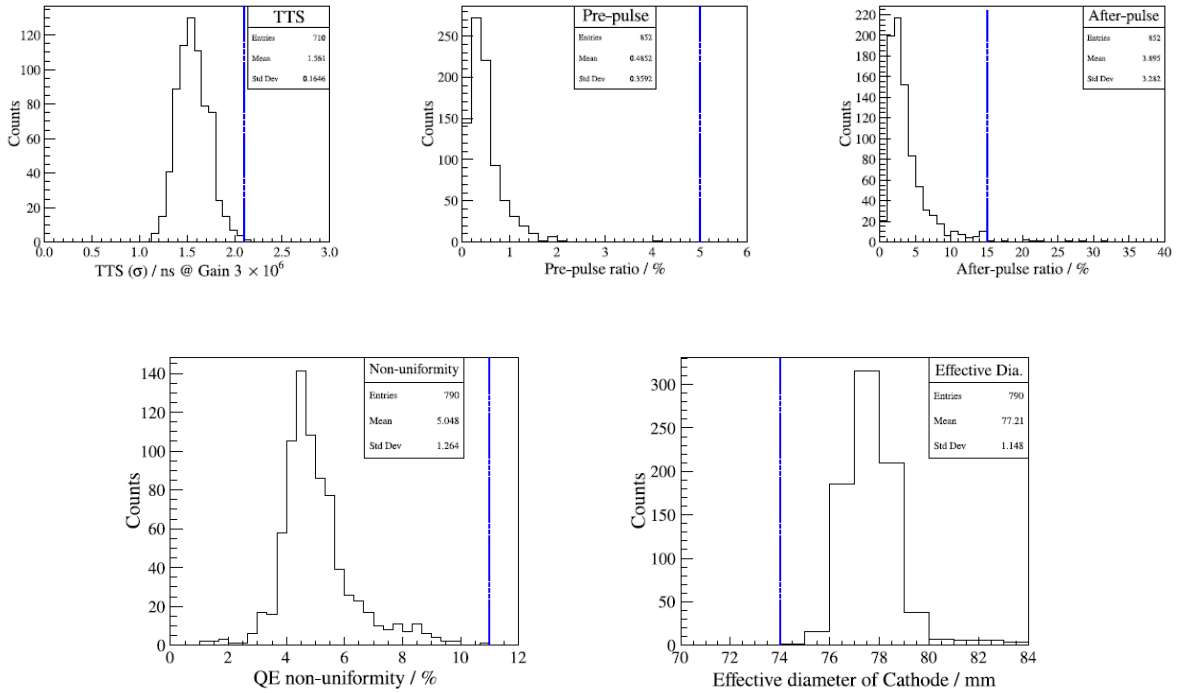
- 128 ch. PMTs,
- 8 connectors, 16PMTs/connector
- 8 High Voltage modules + 8 spares
- 2 High voltage splitter boards
- 1 Frond-End + digitalization Electronics (ABC)
- 1 Global Control Unit (GCU)

3-inch PMT production

- Mass production and water-proof potting finished
  - Hainan Zhanchuang Photonics Technology Co. (HZC)
- ~1-10% sampling test to confirm the parameters meet JUNO requirements.

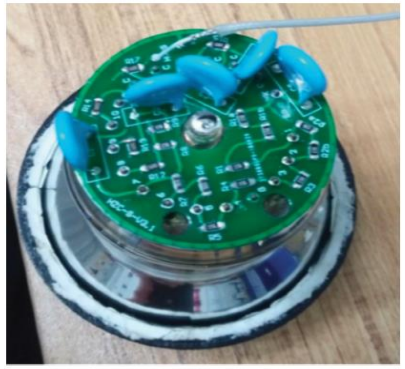
Nuclear Inst. and Methods in Physics Research, A 1005 (2021) 165347

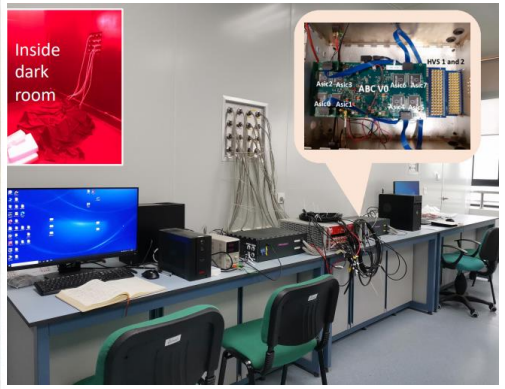




PMT instrumentation

Cable and plug production (Axon) → Cable sealing (Pan Asia & Dongguan) → PMT soldering (HZC) → PMT potting (HZC) → PMT testing (GXU) → JUNO onsite





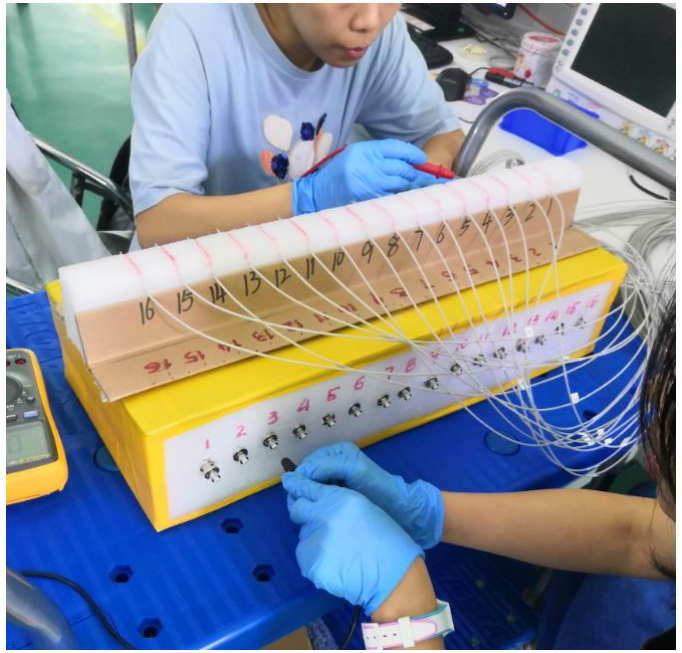
- Had inspection at each step to have a good quality control.
  - visual check
  - HV test, water-proofing test, signal test.
  - Finished production and testing.

Cable and Connector

- Custom-made for JUNO by AXON
- Everything goes well:
  - Electrical performance, water proofing, Long term stability, radiopurity,…
- Finished mass production

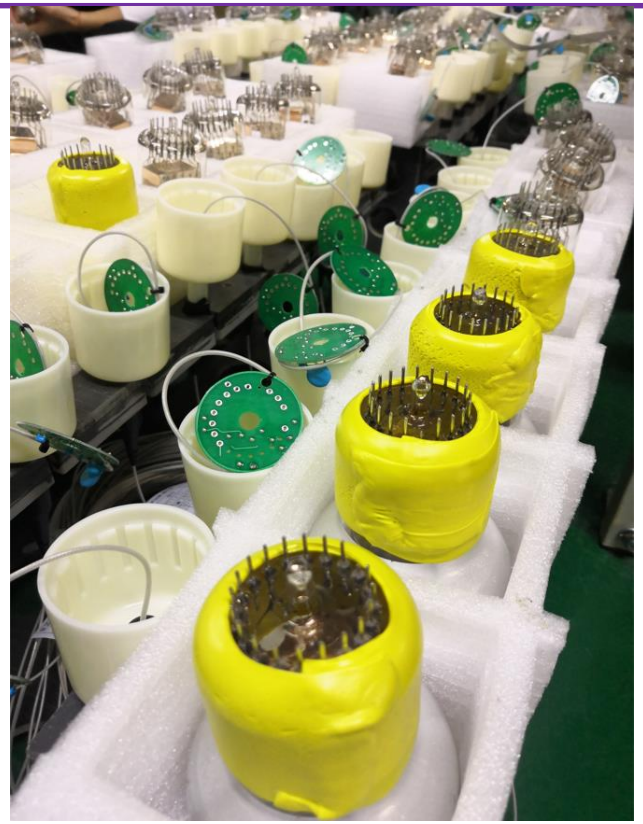
Cable production

Cable and connector pressure



Cable electrical test

PMT potting and water pressure test



Bare pmt potting

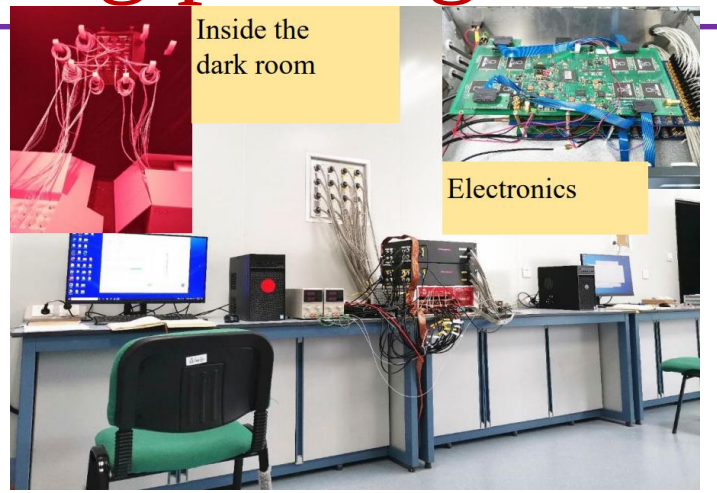
Water pressure test in tank

Drying after pressure

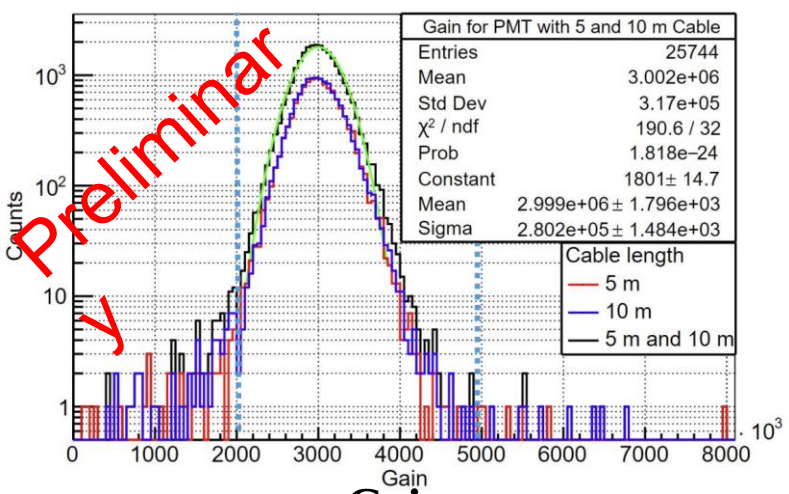
- 10% PMTs was selected to do water tank pressure test.

Acceptance tests after water-proofing potting

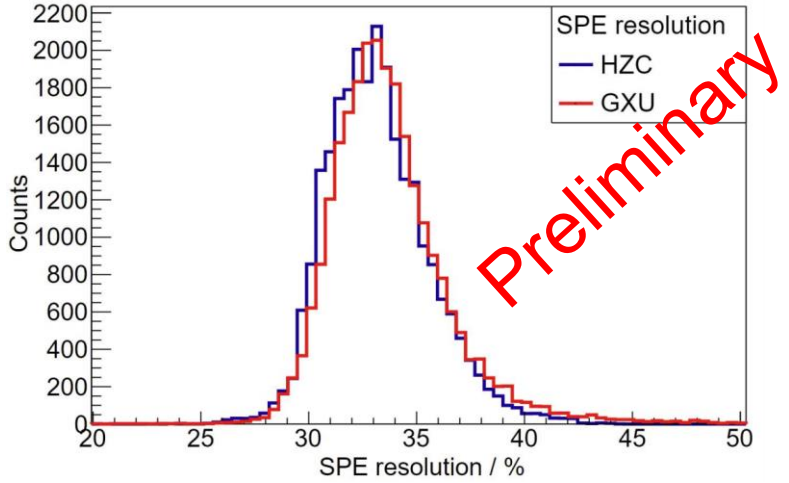
- **Acceptance test finished in Guangxi University (GXU).**
- **Unqualified ratio < 0.7%**
- **Gain spread ~ 10%, mean SPE resolution ~33%, mean dark rate ~400 Hz**



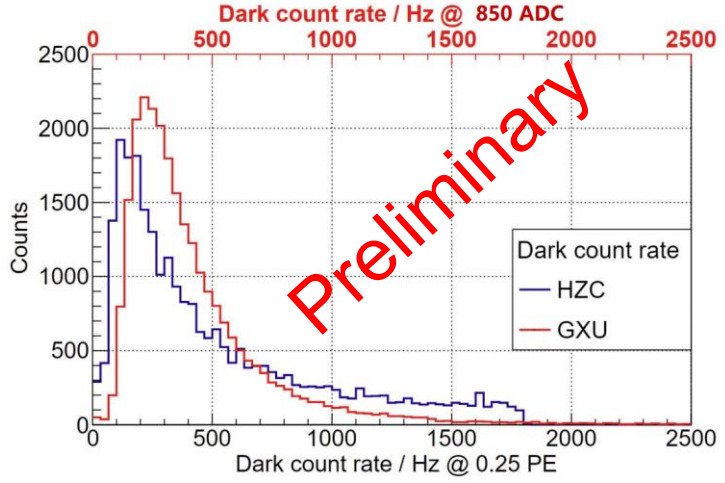
Test station at GXU



Gain

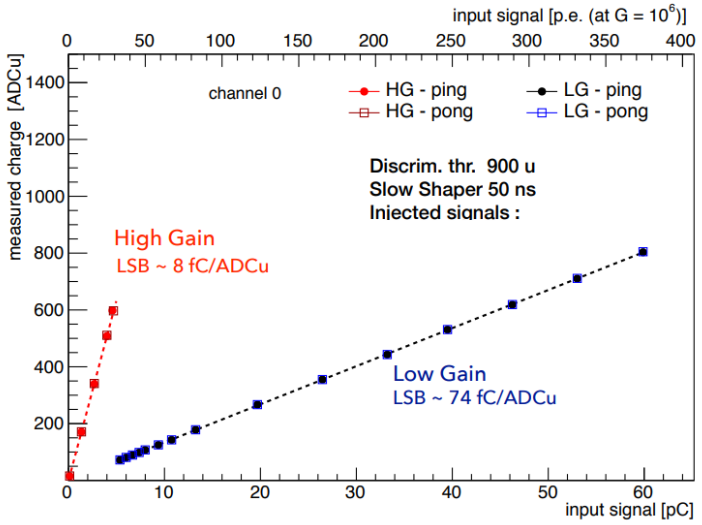


Single photon electron (SPE) resolution



Dark count rate

CATIROC and ABC

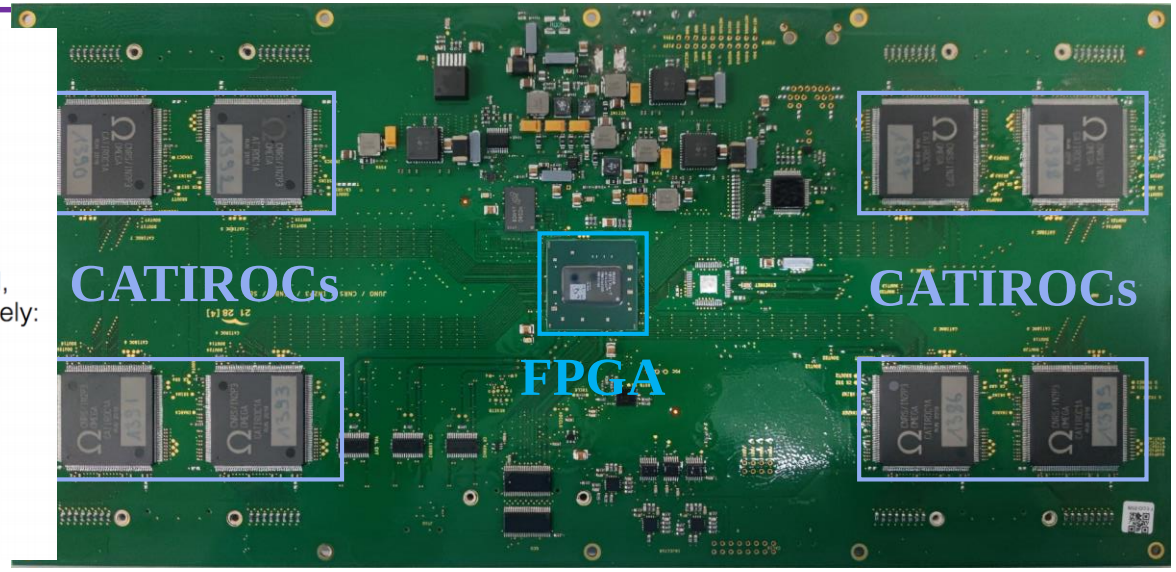


Range of operation :
160 fC - 70 pC
(1 - 400 p.e. @ G = 10^6)

Saturation:
~ 7 pC (HG), ~70 (LG)

Calibration for each channel,
ping/pong and HG/LG separately:
HG: ~ 8 fC/ADCu
LG: ~ 70 fC/ADCu

Charge resolution:
2 ADCu (HG) ~ **0.1 p.e.**
1 ADCu (LG) ~ 1 p.e.



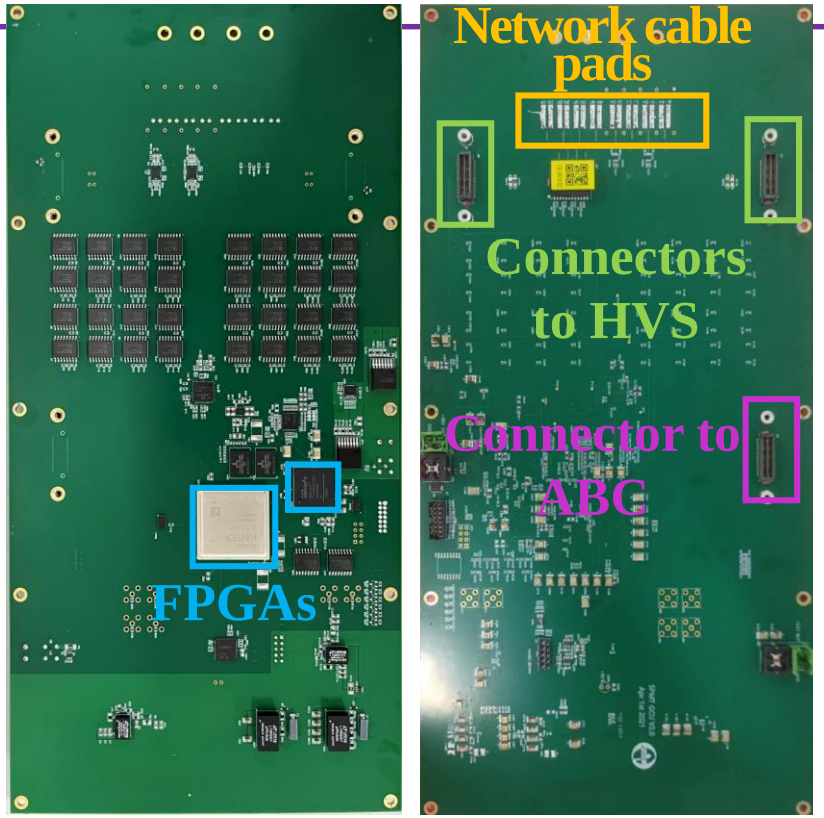
Charge measurement method of CATIROC

ABC board

Conforti S , Settimo M,et al., 2021 JINST 16 P05010.

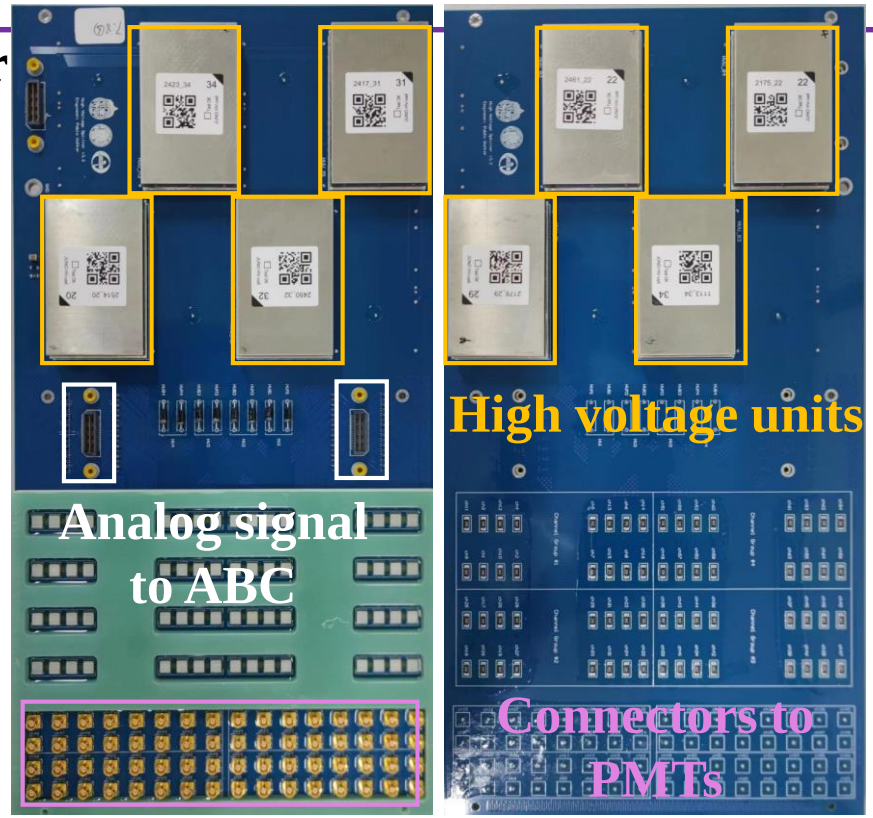
- **8 CATIROCs on one ASICs Battery Card (ABC) for 8 groups of PMTs**
- **CATIROC is an ASIC to analyze signals from PMTs and output time and charge data.**
- **The dynamic range using both the low and high gain regimes is from 0 to ~120 PE.**
- **Noise of high gain is about 2 ADCu, which correspond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

HVS and GCU



GCU board

Connector to GCU

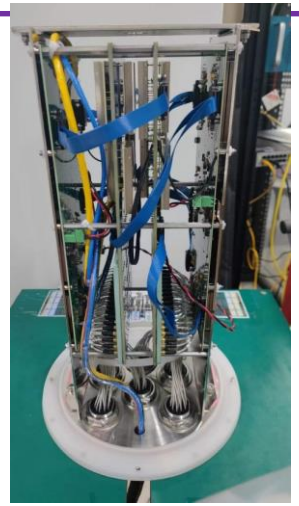
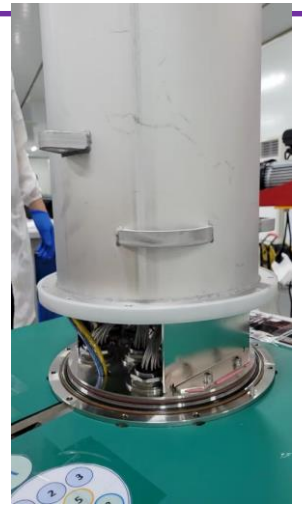


HVS board

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

Electronics integration



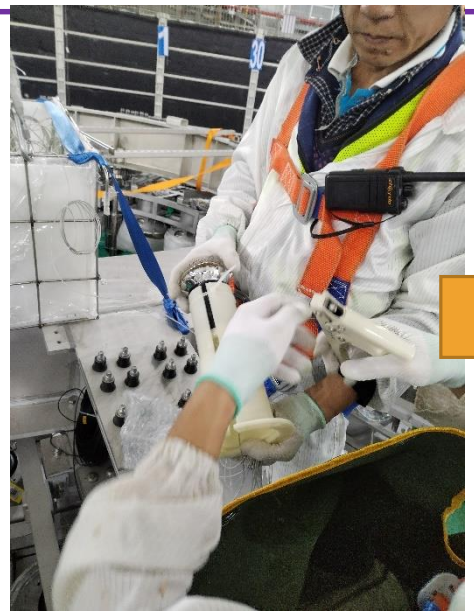




Assembly of receptacles → Assembly of ABC → Assembly of two HVS boards → Assembly of GCU → UWB closing → Leakage test → Packaging

SPMT electronics integration procedure

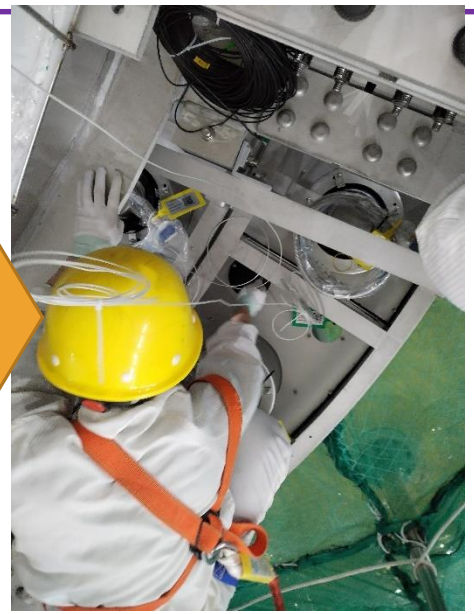
- **200+4 spare sets of electronics have been integrated in clean room at JUNO site.**
- **Mass integration finished (2022.9-2023.4)**
- **Visual inspect and Electrical test at each step, finally SF6 pressure for leakage test and total signal function test by PMT dark noise.**

PMT installation

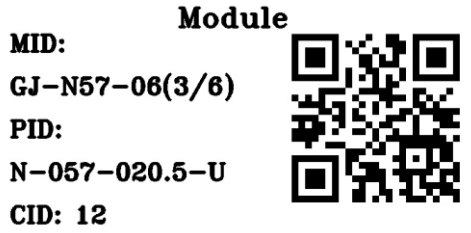


Install support

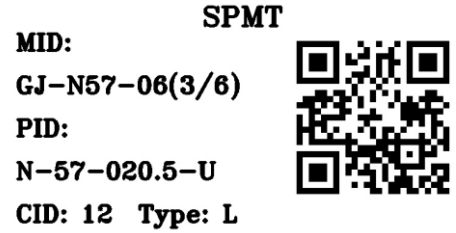
Install PMT



Install Light Barrier



QR code on installation position



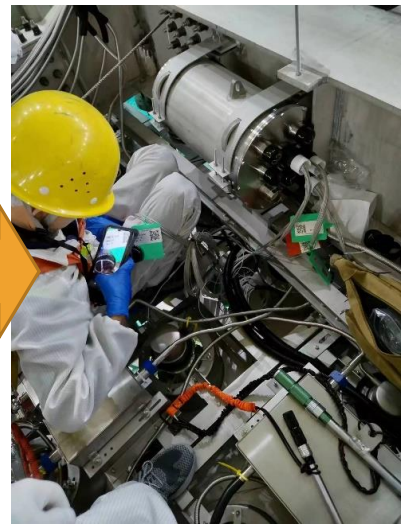
QR code on PMT

- Starts in Nov. 2022
- 60-80 PMTs/day were installed by one group of 3 workers.
- 9280/25600 (~36%) PMTs were installed
- QR codes to make sure correct installation position.

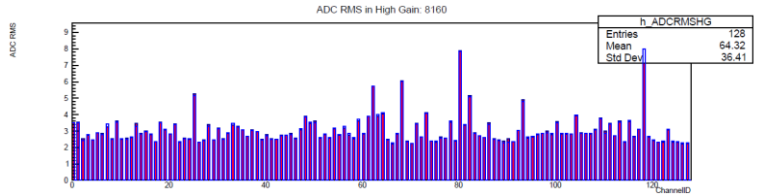
Electronics installation

Hoist UWB+arrange bellows

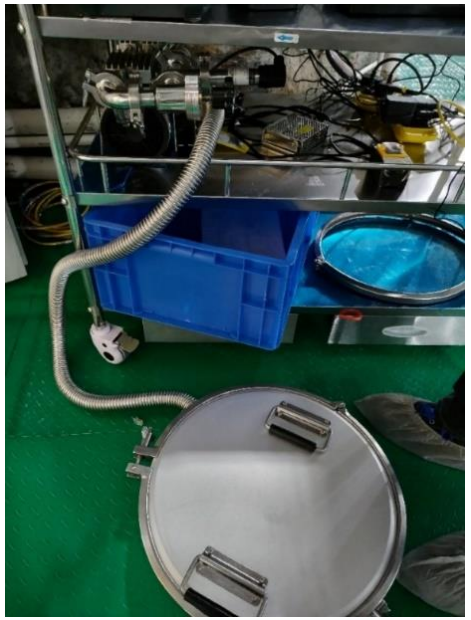
Install UWB



Connect SPMTs to UWB



Pedestal test after installation

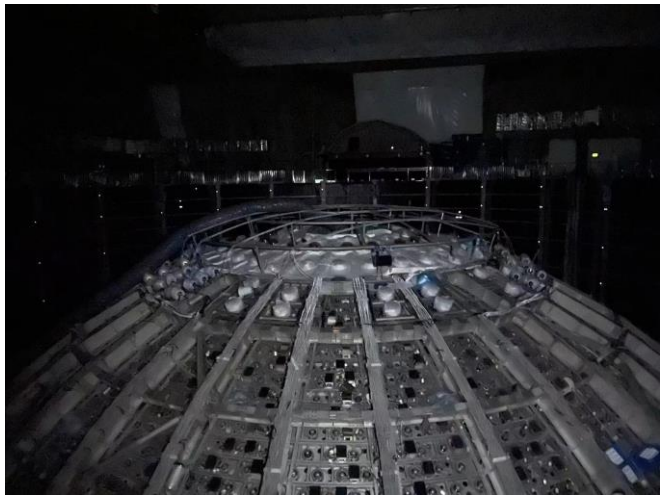


Air negative pressure test

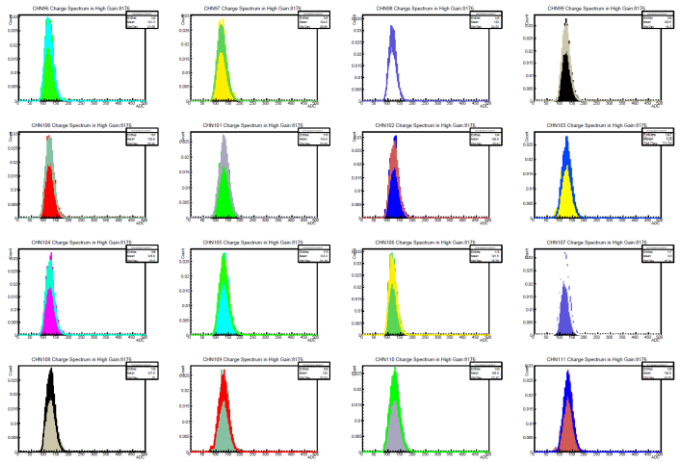
- Starts in March 2023.
- Installation speed is ~25-30 UWBs/day by 9 workers.
- Currently 56/200 (~28%) UWBs were installed.
- After installation, all the UWBs were passed the pedestal and air pressure tests.

Lights-off tests

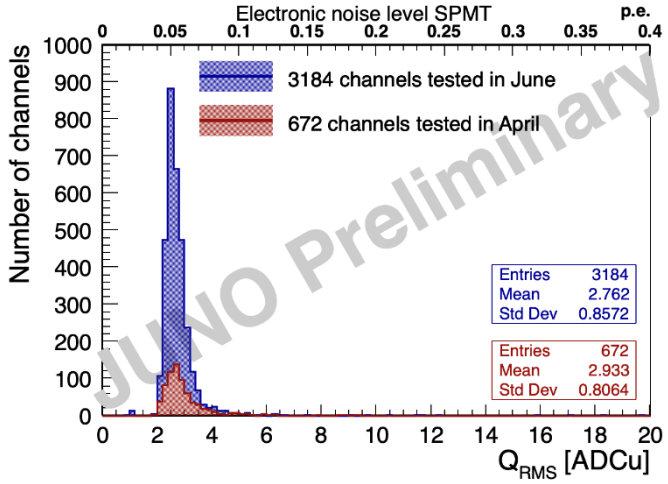
Operate in electronics room



JUNO detector with lights off



Charge spectra of one group of 16 SPMTs



Noise on detector

- **Turn off all lights in experimental hall, to test check pmt status and the whole chain.**
- **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**

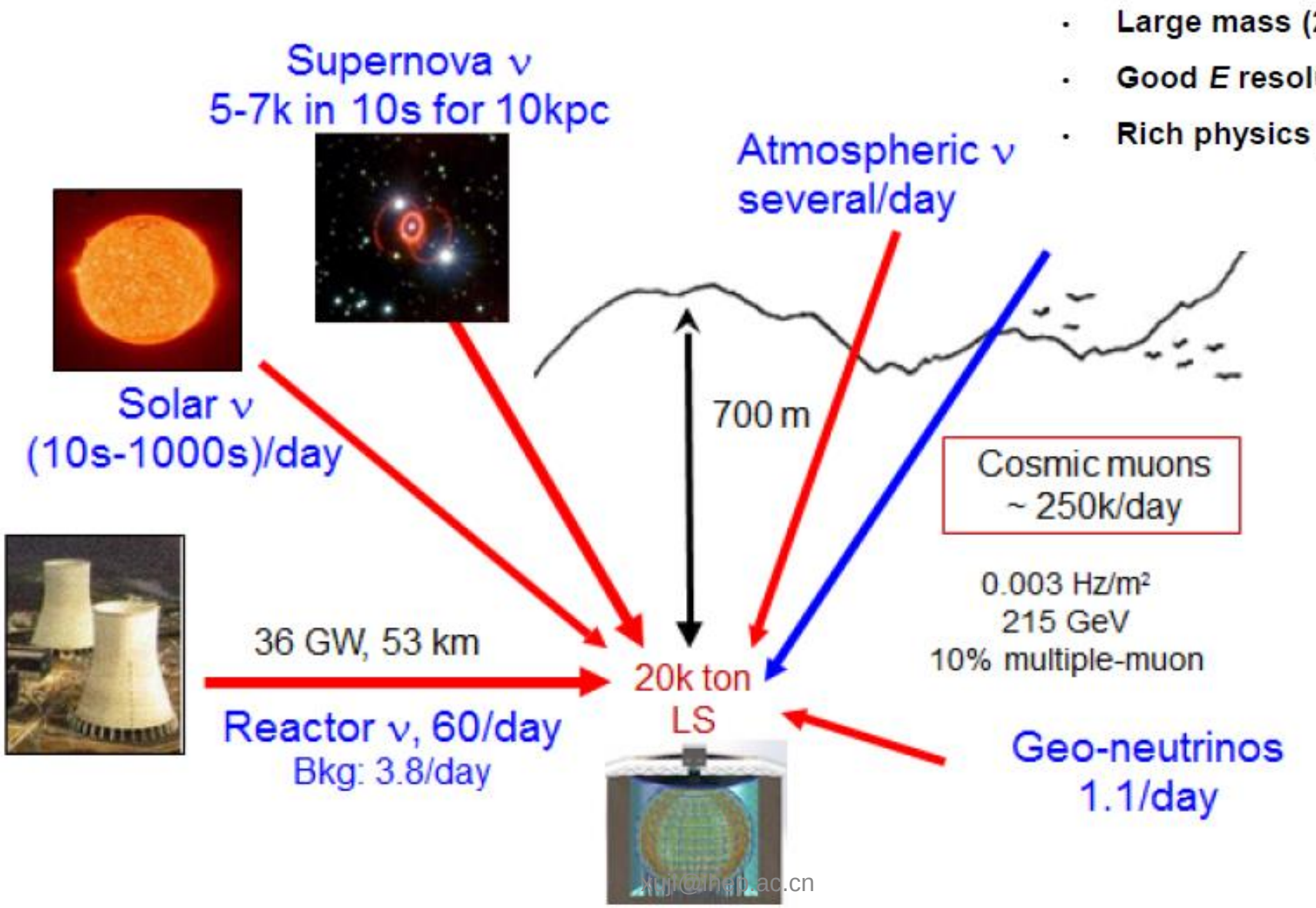
  → Much lower than the trigger threshold of 1/3 p.e.
- **Problematic cables (~1/1000) were identified and repaired.**

Summary

- **~26k channels of 3-inch PMTs and electronics were produced and integrated.**
- **Currently ~1/3 PMTs and ~1/4 electronics have been installed.**
- **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.**

- Thanks!

Back up



- Large mass (20 kt)
- Good *E* resolution (3%)
- Rich physics potentials

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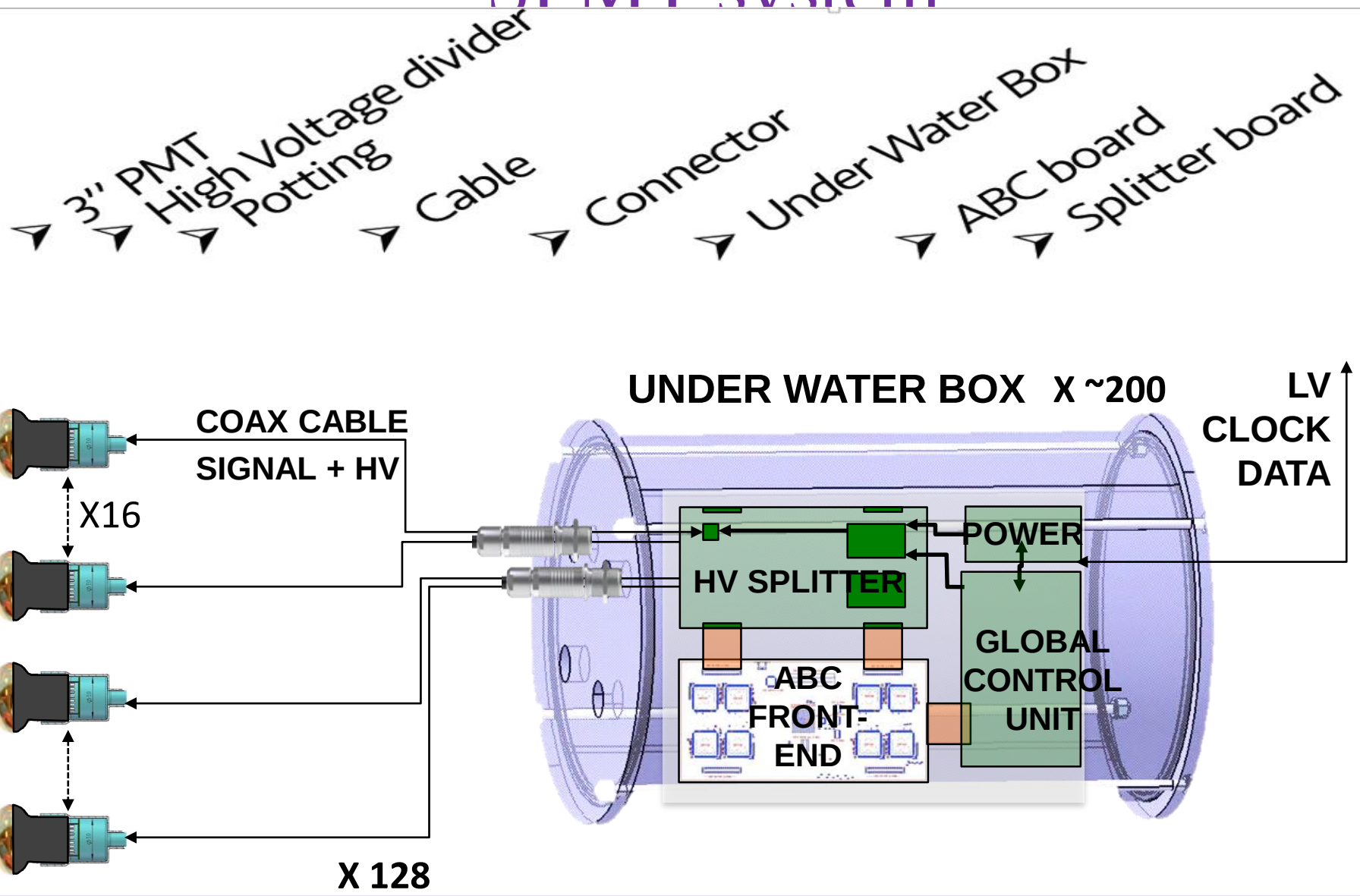
SPMT system


3" PMT
High Voltage divider
Potting
Cable
Connector
Under Water Box
ABC board
Splitter board
UNDER WATER BOX X ~200
LV
CLOCK
DATA
COAX CABLE
SIGNAL + HV
X16
HV SPLITTER
POWER
GLOBAL
CONTROL
UNIT
ABC
FRONT-
END
X 128