

NuFact 2019

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Double Calorimetry System in JUNO

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On behalf of the JUNO collaboration

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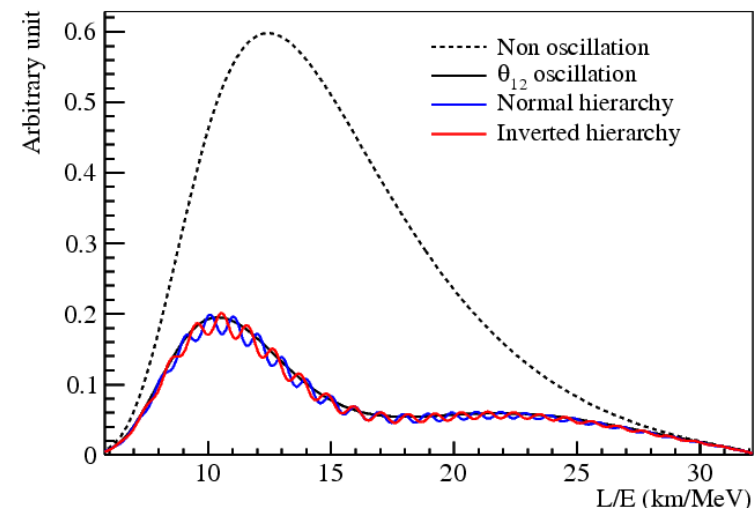
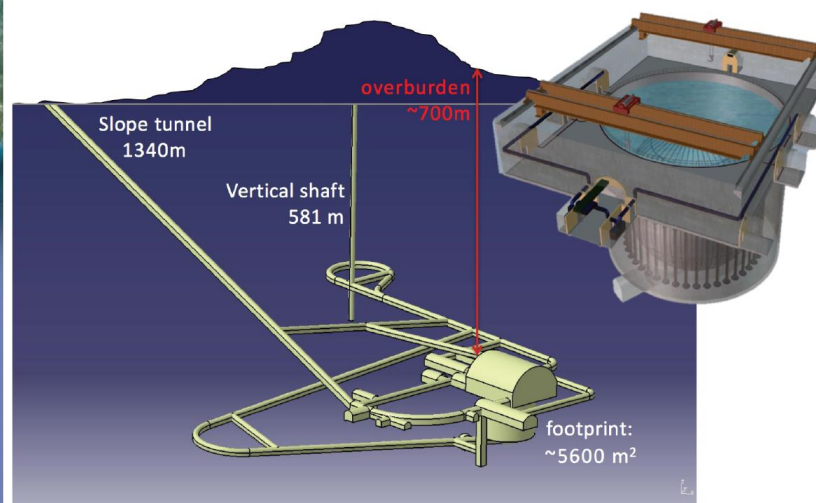
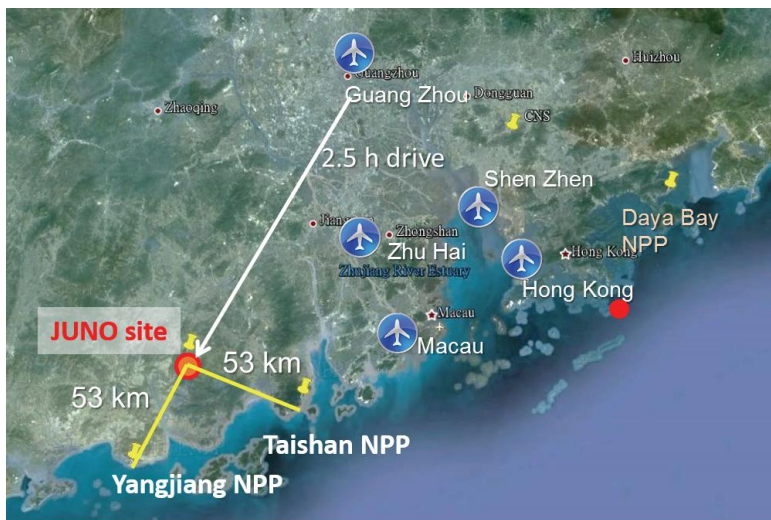
Outline

- **JUNO introduction**
- **Double calorimetry system**
- **20-inch PMT (LPMT) system**
- **3-inch PMT (SPMT) system**
- **Summary**

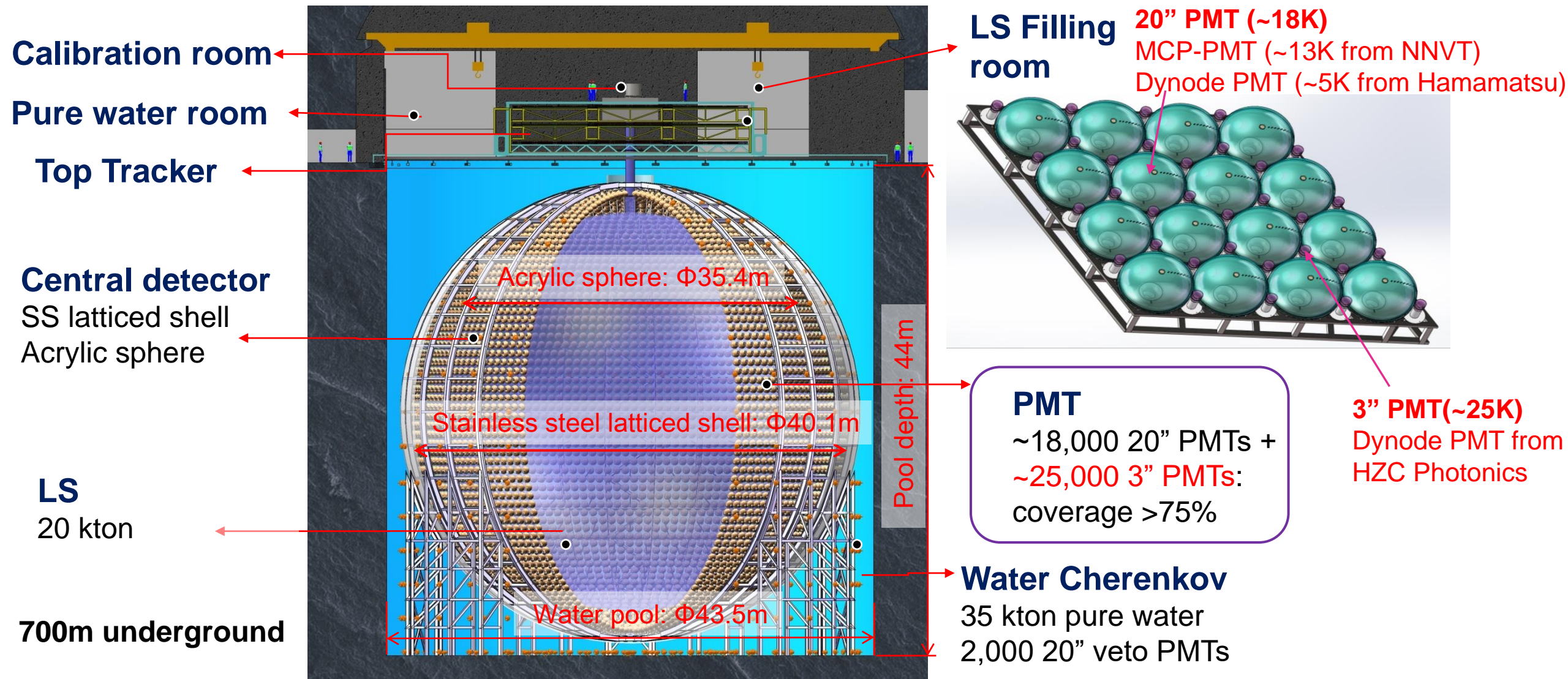
Jiangmen Underground Neutrino Observatory



- 20 kton liquid scintillator (LS), 3% @ 1 MeV energy resolution, under construction in southern of China.
- **Physics goals:**
 - **Main:** Determine neutrino mass hierarchy by reactor antineutrinos.
 - **Multipurpose:**
 - Measure solar neutrino oscillation with highest precision (<1%).
 - Many neutrinos: Supernova, Geo-, solar,...
- **Detector requirement: high transparency LS, high (75%) coverage of PMTs and low backgrounds.**
- **The most challenging design in the reactor neutrino experiments throughout the world.**

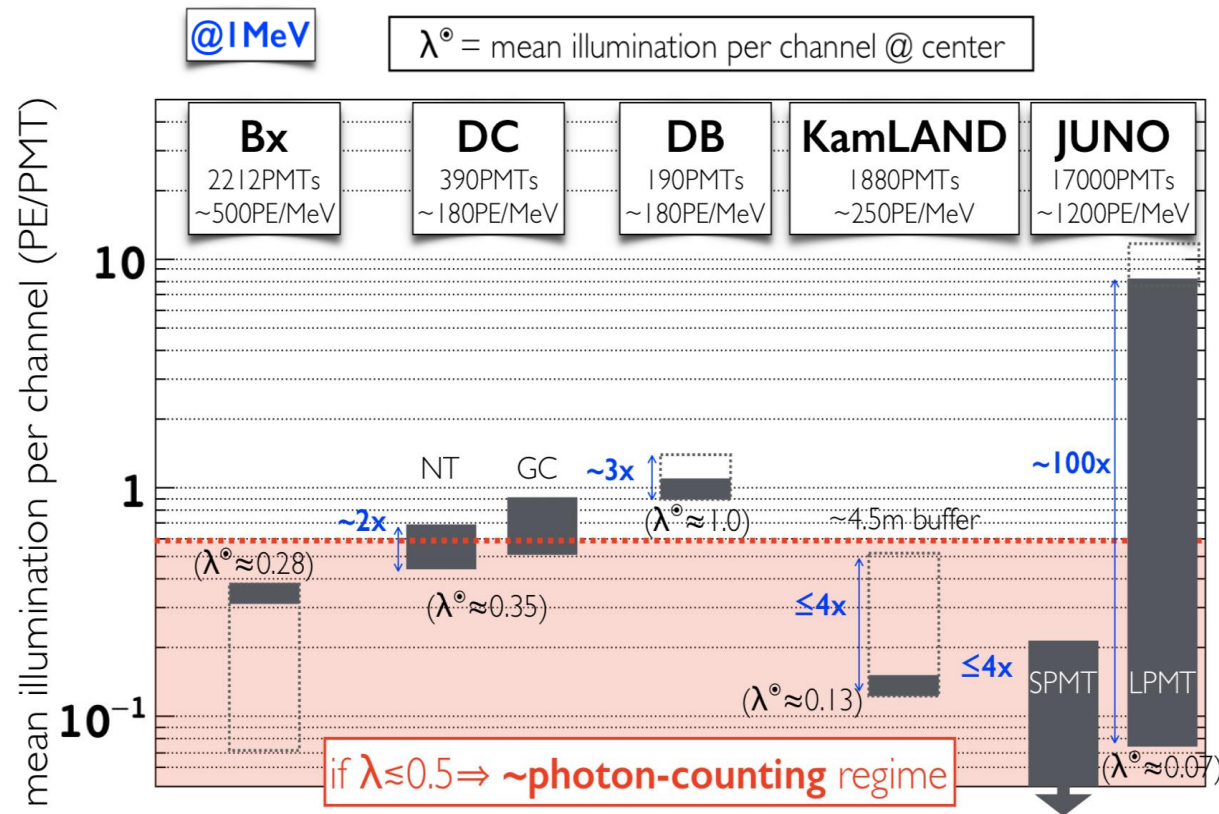


JUNO detector



Double Calorimetry

- Large-PMT (LPMT): measure energy via “charge integration”, increase photon statistics → stochastic effect
- Small-PMT (SPMT): measure energy via “photon counting”, control systematics → non-stochastic effect



$$\frac{\sigma(E)}{E} = \sqrt{\left[\frac{a}{\sqrt{E}} \right]^2 + [b(E)]^2}$$

Stochastic term $\sim 1200 \text{ p.e./MeV}$
 (~ Light yield, Transparency
 Photo-coverage, QE...)

Non stochastic terms
 (~ control of systematics)

- **Two independent systems, same IBD detection make double calorimetry**
 - Improve the energy scale precision, in particular, the coupling of nonlinearity and non-uniformity
 - Little extra light (3-4%) allows for a little more room for non-stochastic systematics in calorimetry
- **Enhanced Physics Capabilities**
 - Solar parameters measurements with *partly independent* systematics
 - Help reconstruction for high energy physics: muon, atmospheric ν ...
 - Help detection of supernova neutrino

LPMT + SPMT system

MAIN DAQ

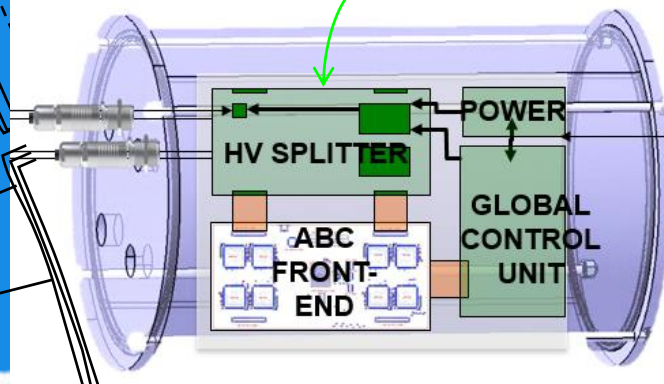
SURFACE

MAIN DAQ

SPMT Under Water Box

- 128 ch. Photomultipliers
- High Voltage
- Decoupling HV/Signal
- Frond-End + digitalization Electronics
- Global Control Unit (GCU)

UNDER WATER BOX X ~200

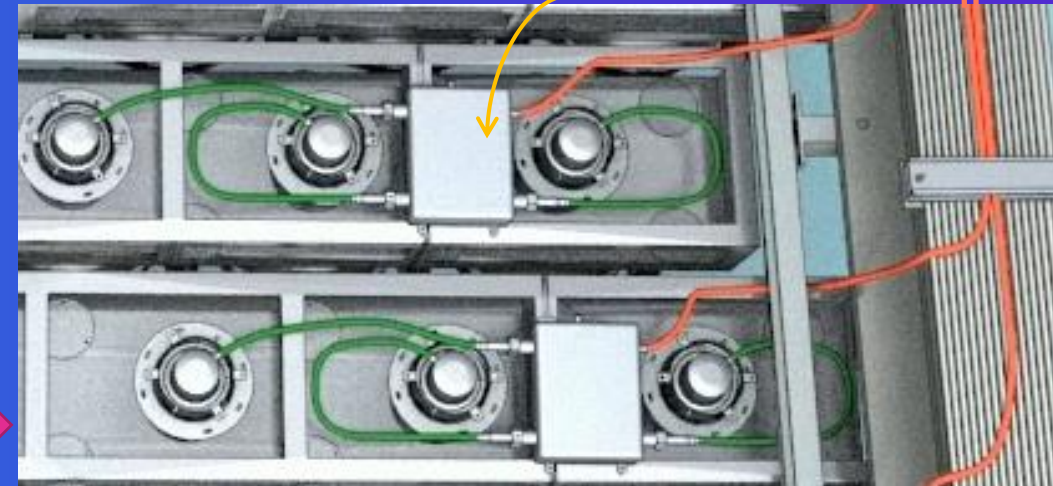


≈100m

LPMT Under Water Box

- 3 ch. Photomultipliers
- High Voltage
- Decoupling HV/Signal
- Frond-End + digitalization Electronics
- Global Control Unit

LPMT

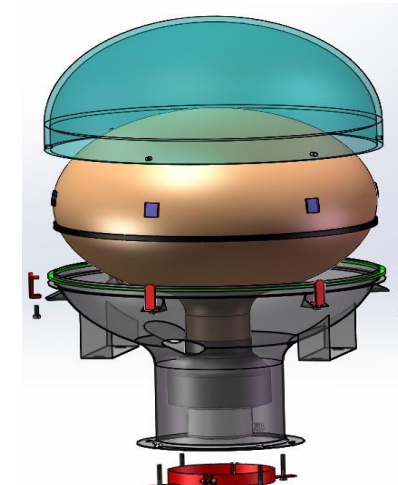


≈20m

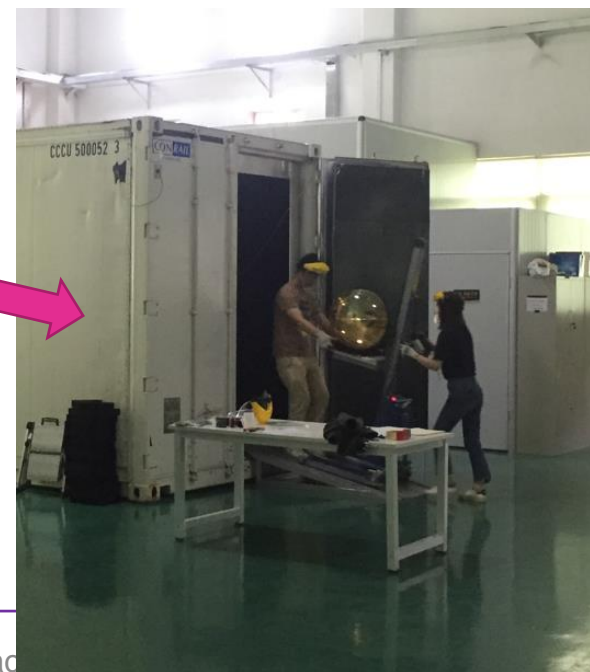
Zoom in



LPMT and Protection



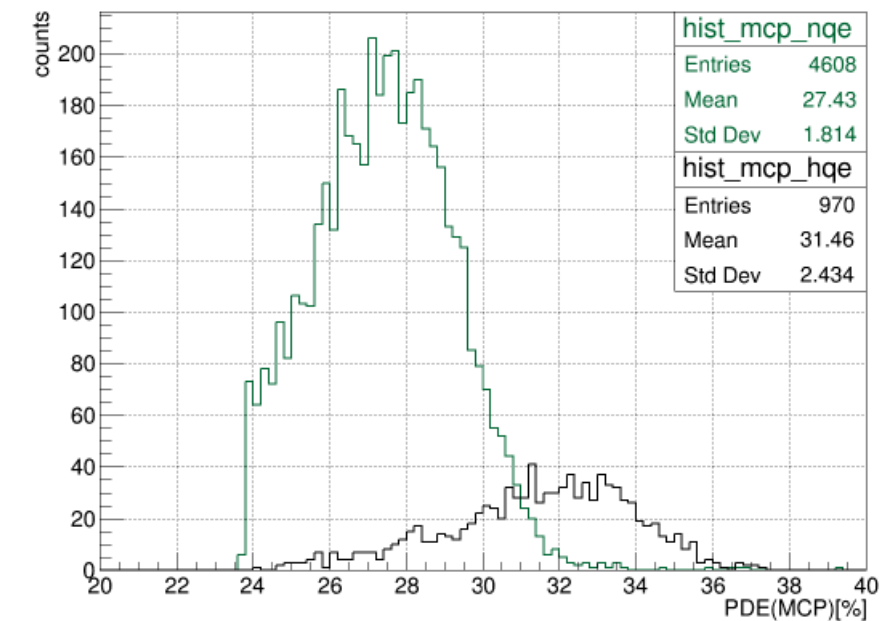
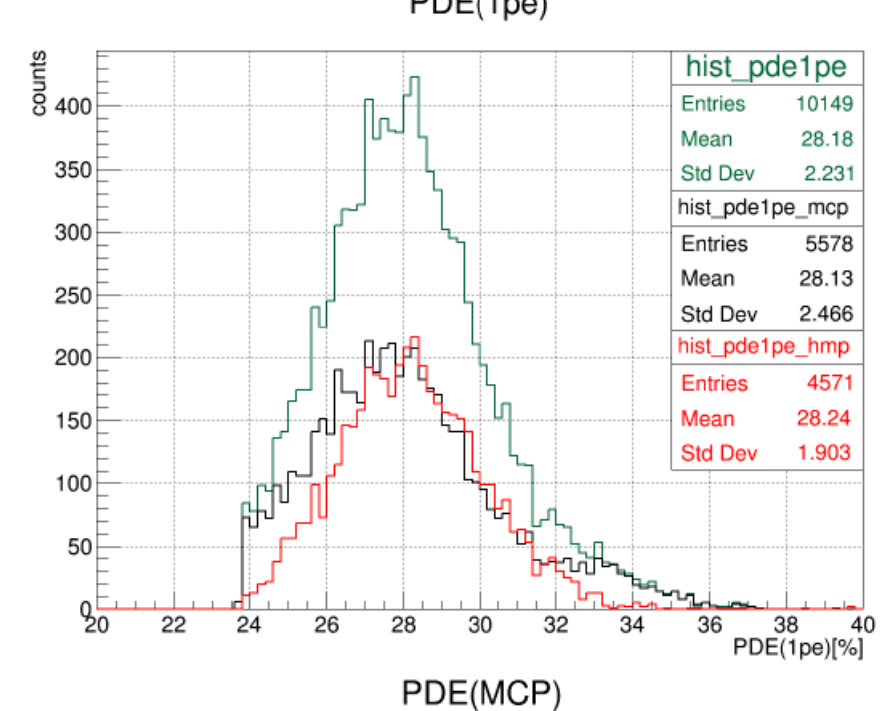
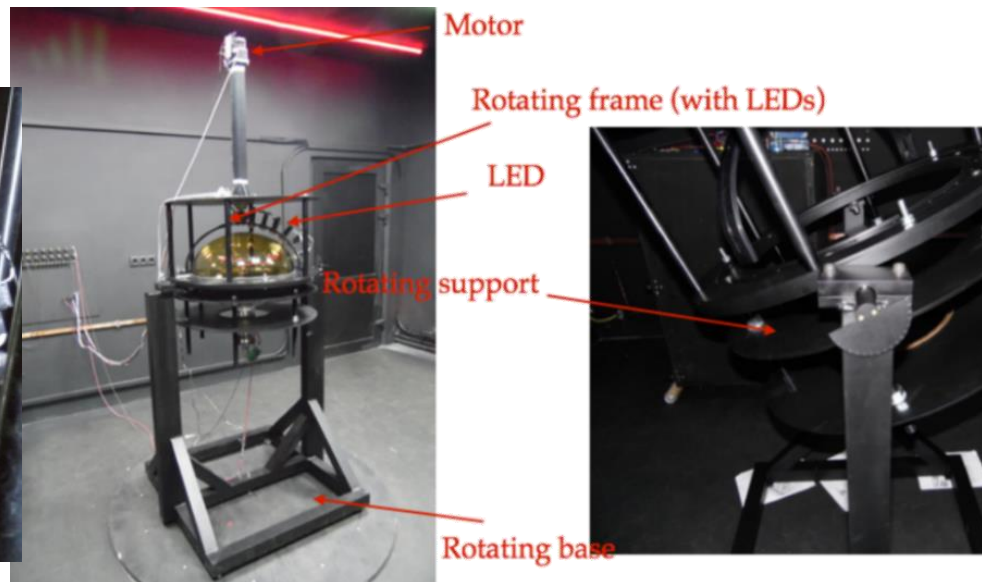
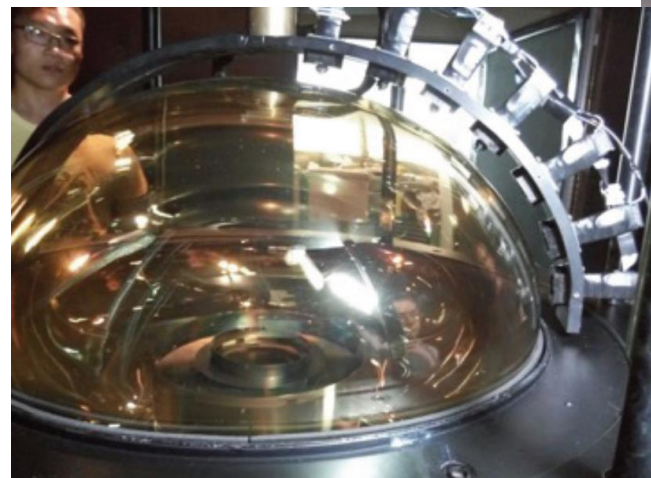
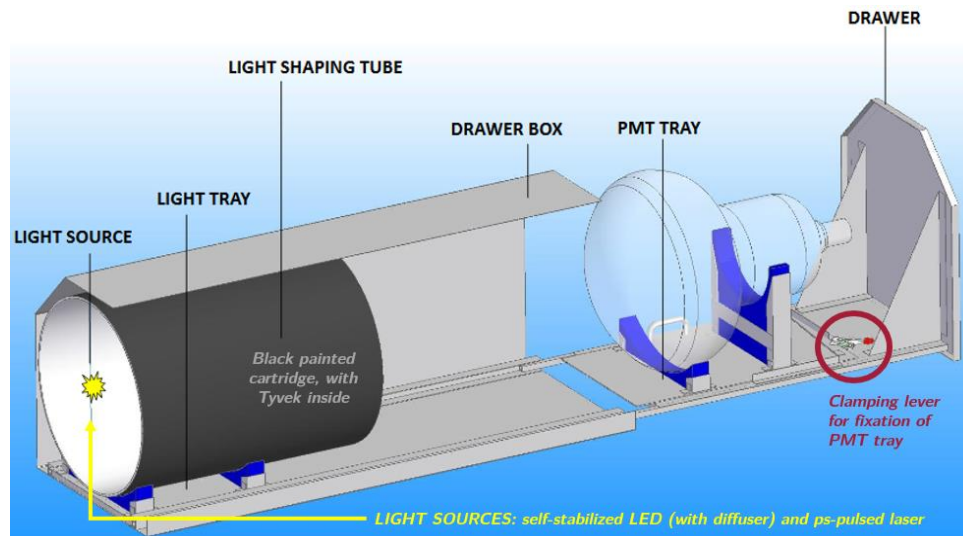
Container



Visual
check



LPMT Characterization

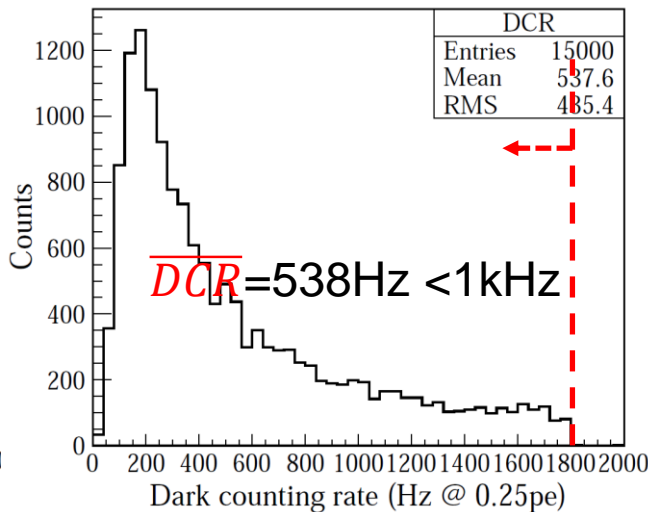
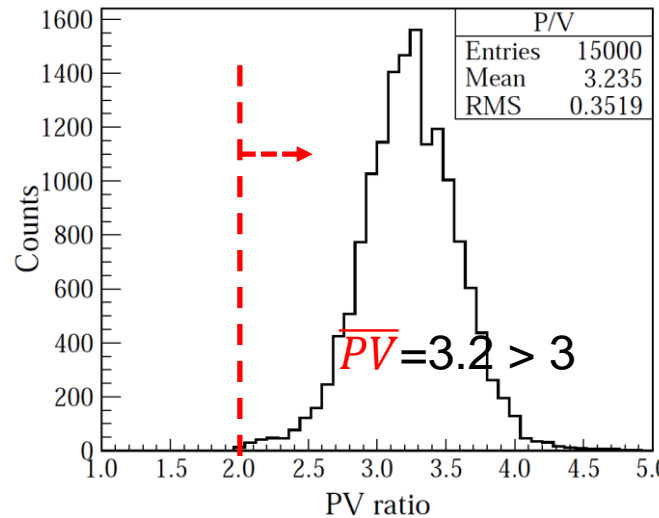
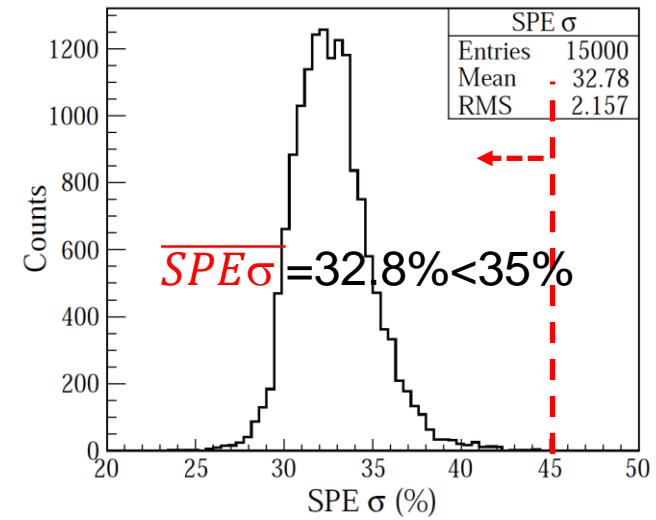
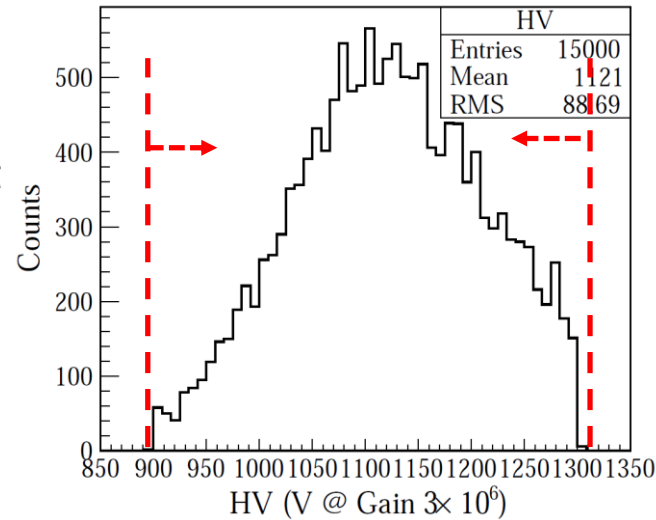
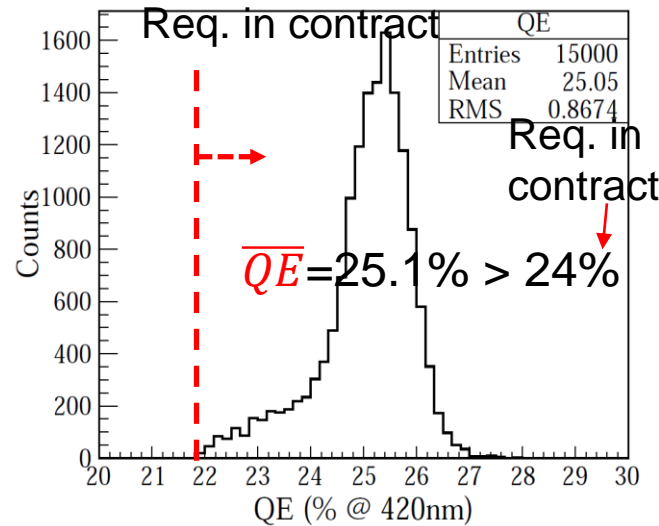




- Custom-made for JUNO
 - Good SPE resolution (32.8%) help for “photon-counting” mode.
 - Re-design the SPMT shape to obtain a better timing ($\sigma \sim 2.1\text{ns}$) — JUNO model.
- Hainan Zhanchuang Photonics Technology Co. (HZC)
- Sampling test to confirm the parameters meet JUNO requirements.
 - 10% sampling test for main parameters like SPE resolution, QE, HV @ Gain 3×10^6 , P/V, DCR.
 - 3% sampling test for TTS, pre/after pulse, QE non-uniformity and so on
 - 1% sampling test for Spectral response range.



SPMT Characterization



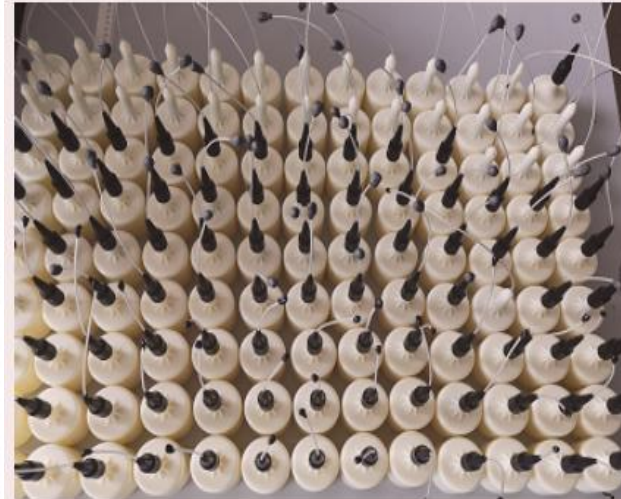
- ~19,000 out of 26,000 were already produced.
- ~1000 pcs / month.
- 15,000 PMT already accepted, the largest number of PMT gathered.
- Acceptance rate > 99%.

Bare SPMT Testing Summary

Parameters	Sampling data req.	Mean
1. Diameter Of Glass Bulb (mm)	78<Dia. <82	✓
2. QEXCE @420nm (%)	>22 (Mean>24)	25.1
3. HV@3X10 ⁶ gain	900-1300	1121
4. SPE resolution (%)	<45 (Mean<35)	32.8
5. P-V Ratio	>2 (Mean>3)	3.2
6. Dark Rate@0.25PE (Hz)	<1.8k (Mean<1k)	538
7. Dark Rate@3PE (Hz)	<30	7.2
8. SPE TTS (FWHM) (ns)	<5	4.9
9. Pre pulse ratio (10-90ns)	<5 (Mean<4.5)	0.4
10 .After pulse ratio (50ns -20μs)	<15 (Mean<10)	4.8
11. QE non-uniformity (%)	<11	5.2
12. Effective Dia. Of cathode (mm)	>74 (Mean>76)	77.1
13. Spectral response range (%)	QE320>5	13.4
	QE550>5	8.8

PMT Divider and Potting

- Divider: Under mass production, 6,000+.
- PMT Potting:
 - Potting technology has been developed successfully and delivered to HZC - company will do the mass potting.
 - Will start mass production soon.



Cable sealing samples



Helium leak detection

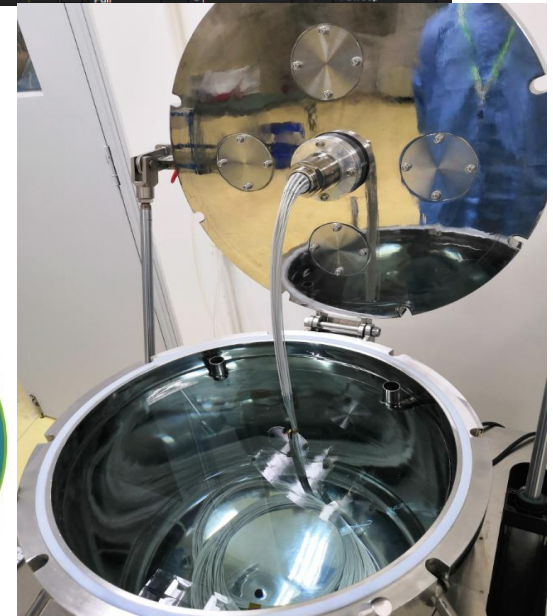
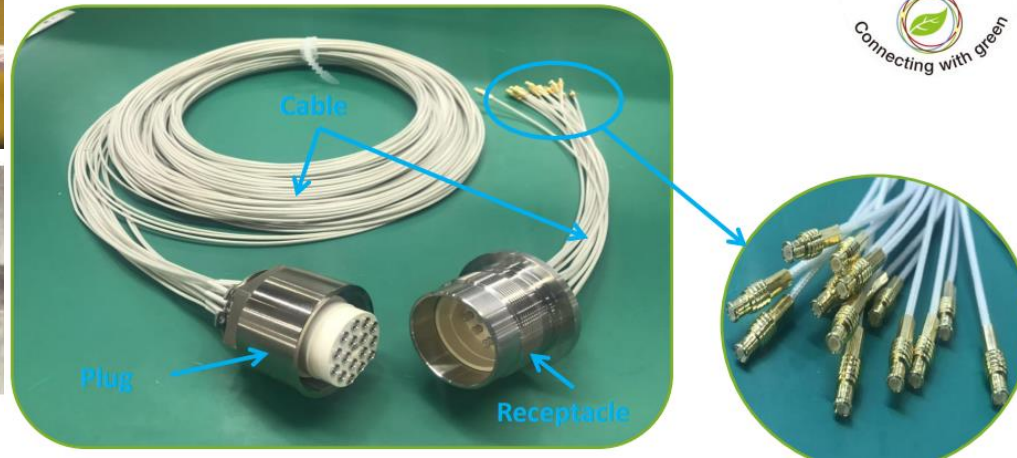
Cable and Connector

- Custom-made for JUNO by AXON
 - The cable with this protection against water spread if cable broken.
 - 16-cable connector, easy for installation and good water proofing.
- Everything goes well:
 - Electrical performance, water proofing, Long term stability, radiopurity, PMT signals with pmt-divider-potting-cable-connector Chain,...
- Will start mass production soon.

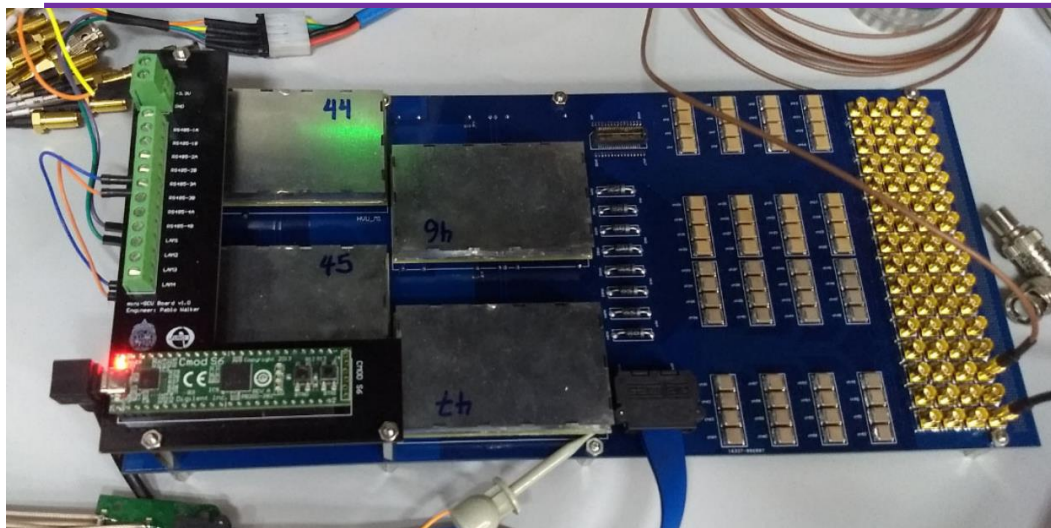


Water ingress \approx 4-5 cm

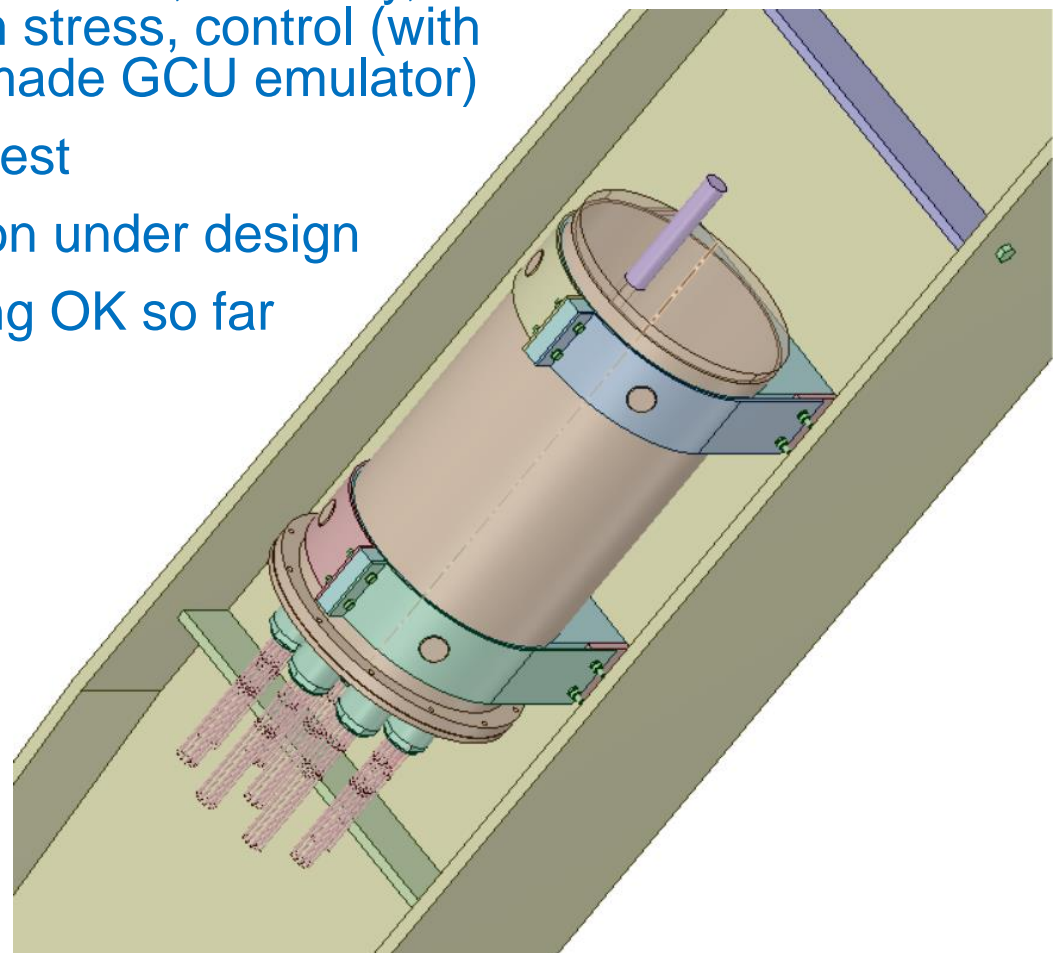
Axon product: Cable and Connector



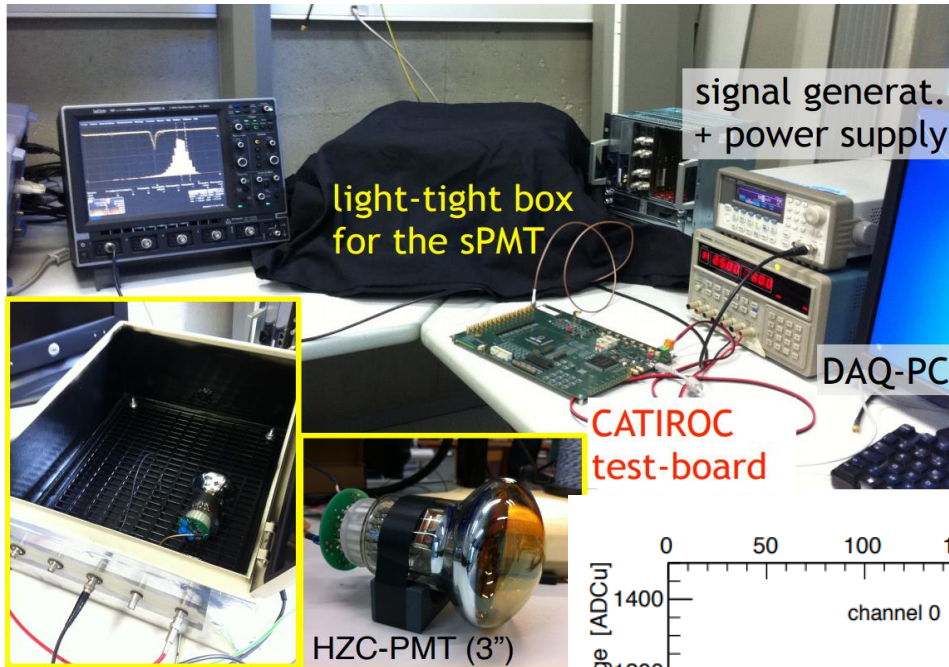
HV splitter and UWB



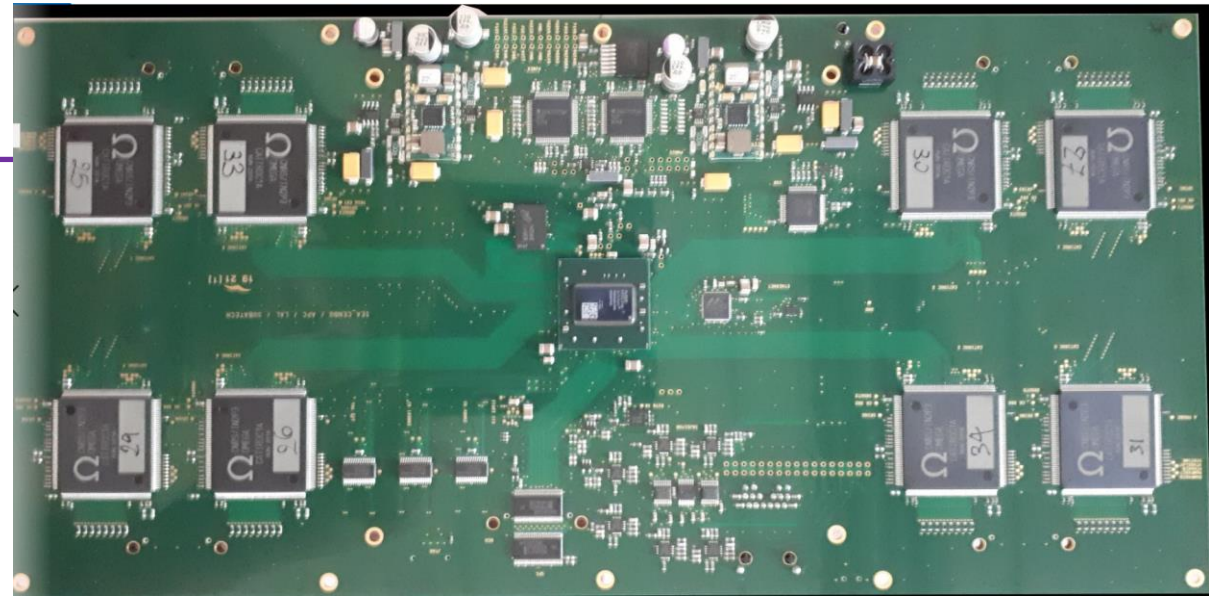
- Characterization, reliability, long-term stress, control (with custom-made GCU emulator)
- Mockup test
- Installation under design
- Everything OK so far



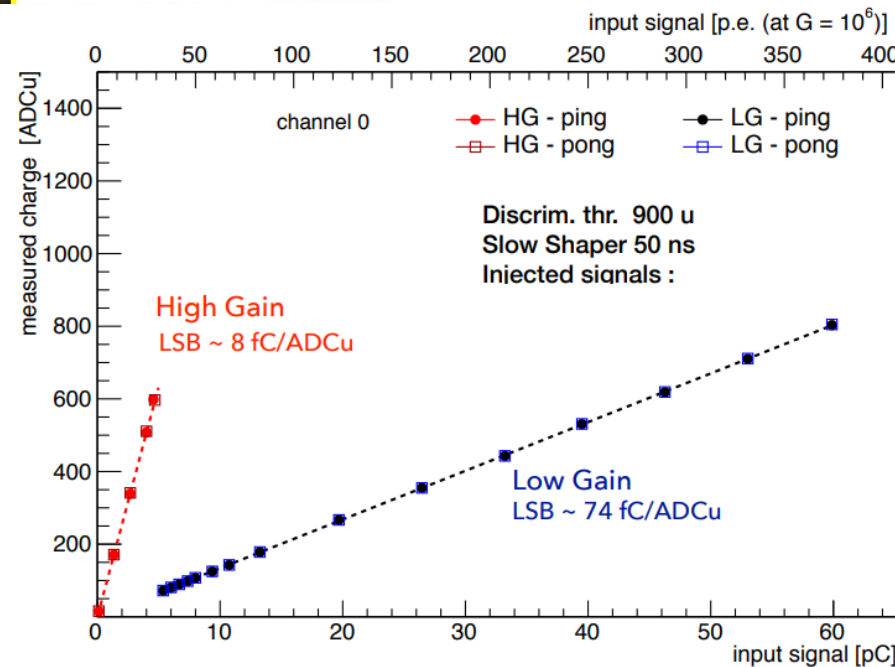
Electronics



- Now 3,000 CatiROCs produced and delivered.



ASIC Battery Card (ABC) with 8 × CatiROC



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

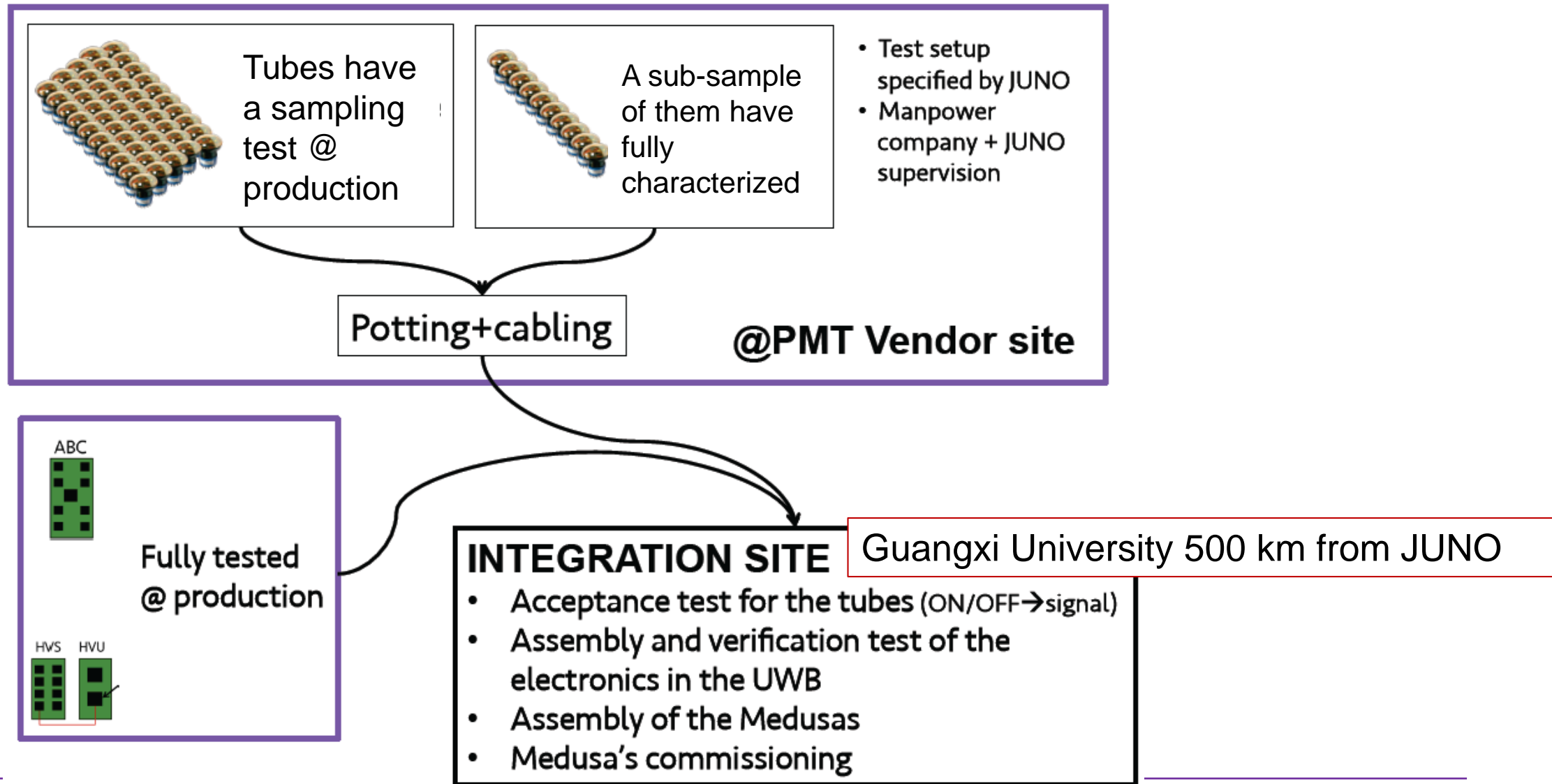
Charge resolution:

2 ADCu (HG) ~ 0.1 p.e.

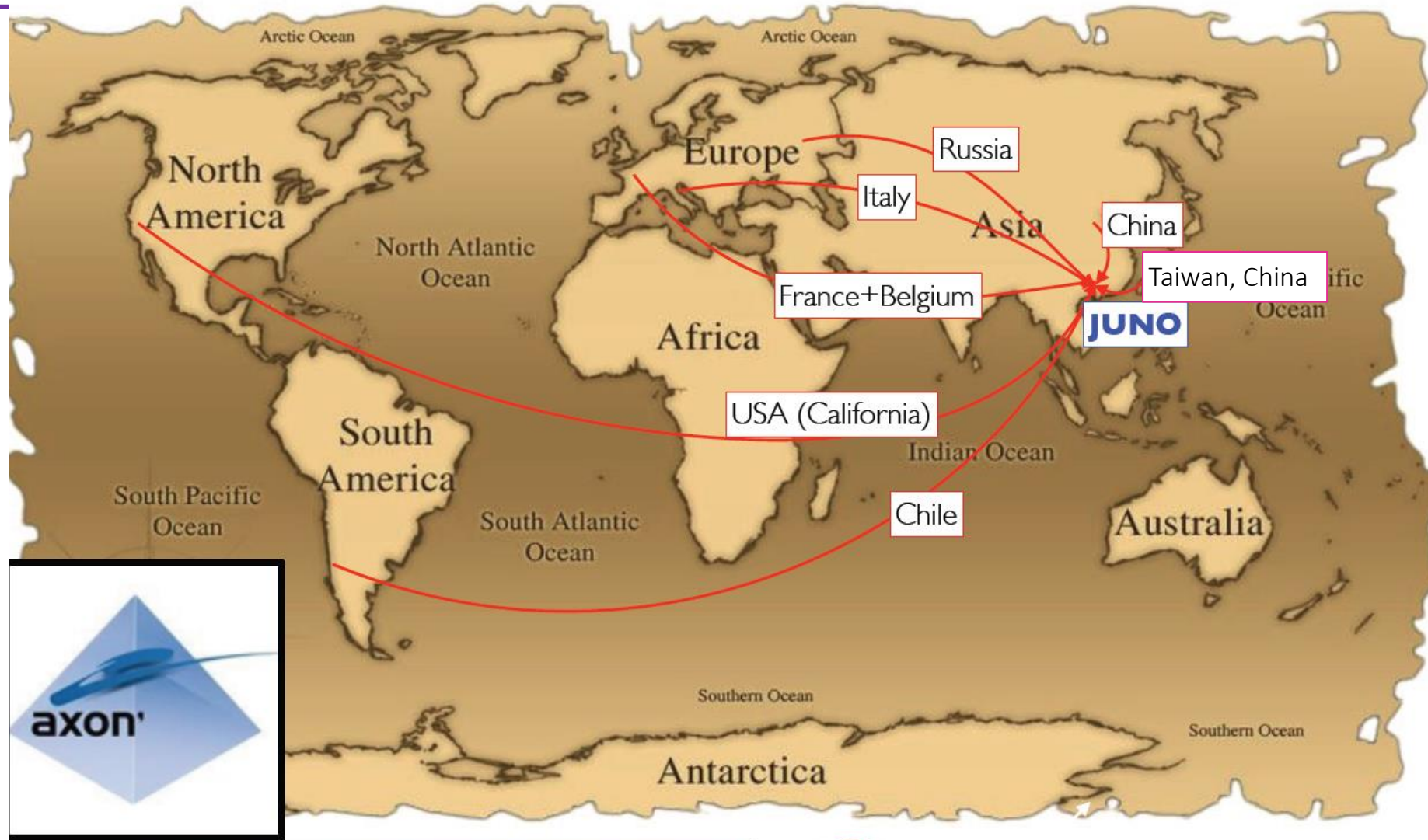
1 ADCu (LG) ~ 1 p.e.

Also with good time resolution 0.1 ns

Mass testing and integration



World-wide integration ...



Summary

- SPMT as an independent PMT system with LPMT makes **double calorimetry system**.
- Not only can test the same IBD signals, but also can give **some corrections and helps** to LPMTs, aiming to reach $3\%/ \sqrt{E}$ and 1% energy scale and **enhanced physics capabilities**.
- **~15,000 LPMTs accepted**:
 - ~5,000 Hamamatsu dynode PMTs, ~10,000 NNVT MCP PMTs.
 - Others for LPMT are going well.
- **SPMTs system is in good progress**:
 - **~15,000 PMTs** were accepted.
 - **Divider, potting, cable, splitter, ABC, UWB** are also going well.

- BACKUP

3-inch PMT data sheet



Photomultiplier

10-stage
80mm (3.1"), Round tube

Application

✓ High energy physics

Features

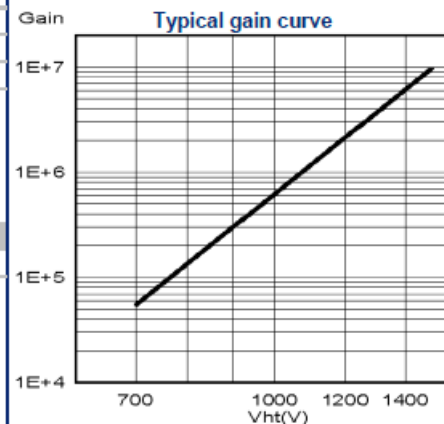
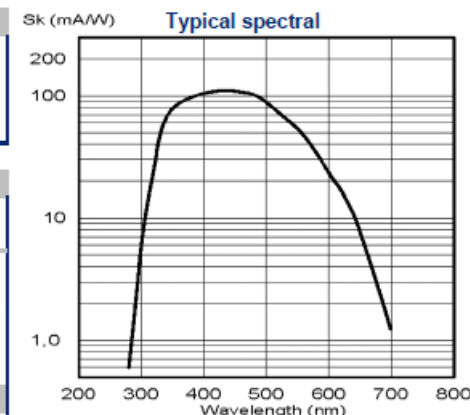
✓ High Quantum Efficiency
✓ Low profile

XP72B22

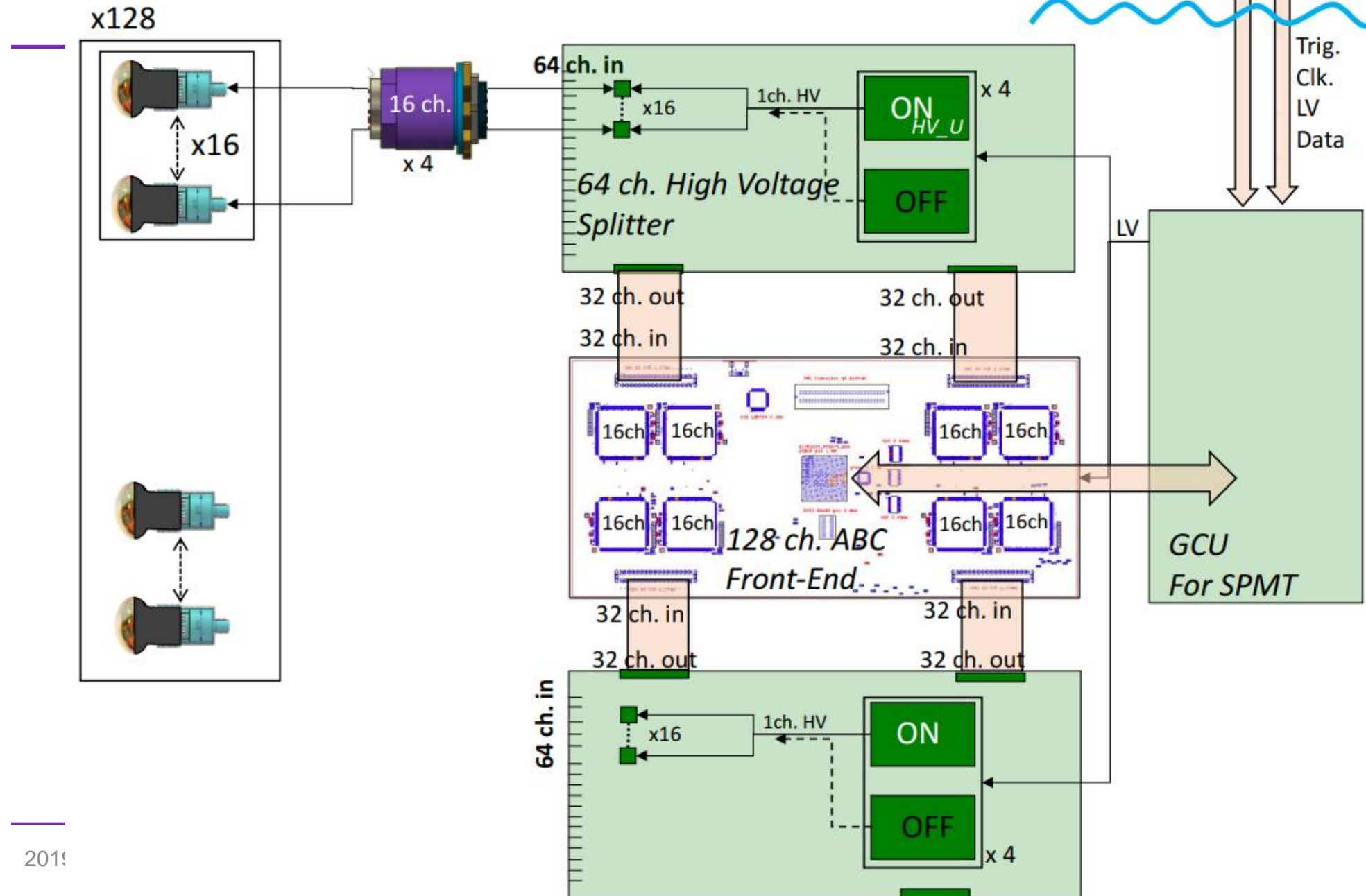


Description	
Window material	Borosilicate low K
Photocathode	Bi-alkali
Refr. Index at 420nm	1.54
Multiplier structure	Box and Linear focused

Photocathode characteristics	Min	Typ	Max	Unit
Spectral range:		290-700		nm
Maximum sensitivity at		404		nm
Sensitivity:				
Luminous		110		μA/lm
Blue *	10	12		μA/lmF
Quantum Efficiency, at 404 nm	22	25		%
Quantum Efficiency, at 470 nm	18	20		%
Characteristics with voltage divider A	Min	Typ	Max	Unit
Gain slope (vs supp. Volt., log/log)		6.8		
For an anode blue sensitivity of		50		A/lmF
Supply voltage *	900	1150	1300	V
Gain		3x10 ⁶		
Anode dark current *		10	30	nA
Noise		1000	2000	Hz
Mean anode sensitivity deviation				
Long term (16h)		1		%
After change of count rate		1		%
Vs temperature between 0 and +40°C at 420 nm		-0.3		%/K
For a supply voltage of : 1000V	Min	Typ	Max	Unit
Linearity (2%) of anode current up to		30		mA
Anode pulse:				
Rise time		3.5		ns
Duration at half height		5		ns
Transit time		49		ns
Center to edge difference (C.E.D)		1		ns
Time resolution at 511 keV with LSO		1.3		ns







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

