JUNO 20″ PMTs and Preliminary Performance Results

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(on behalf of JUNO Collaboration)

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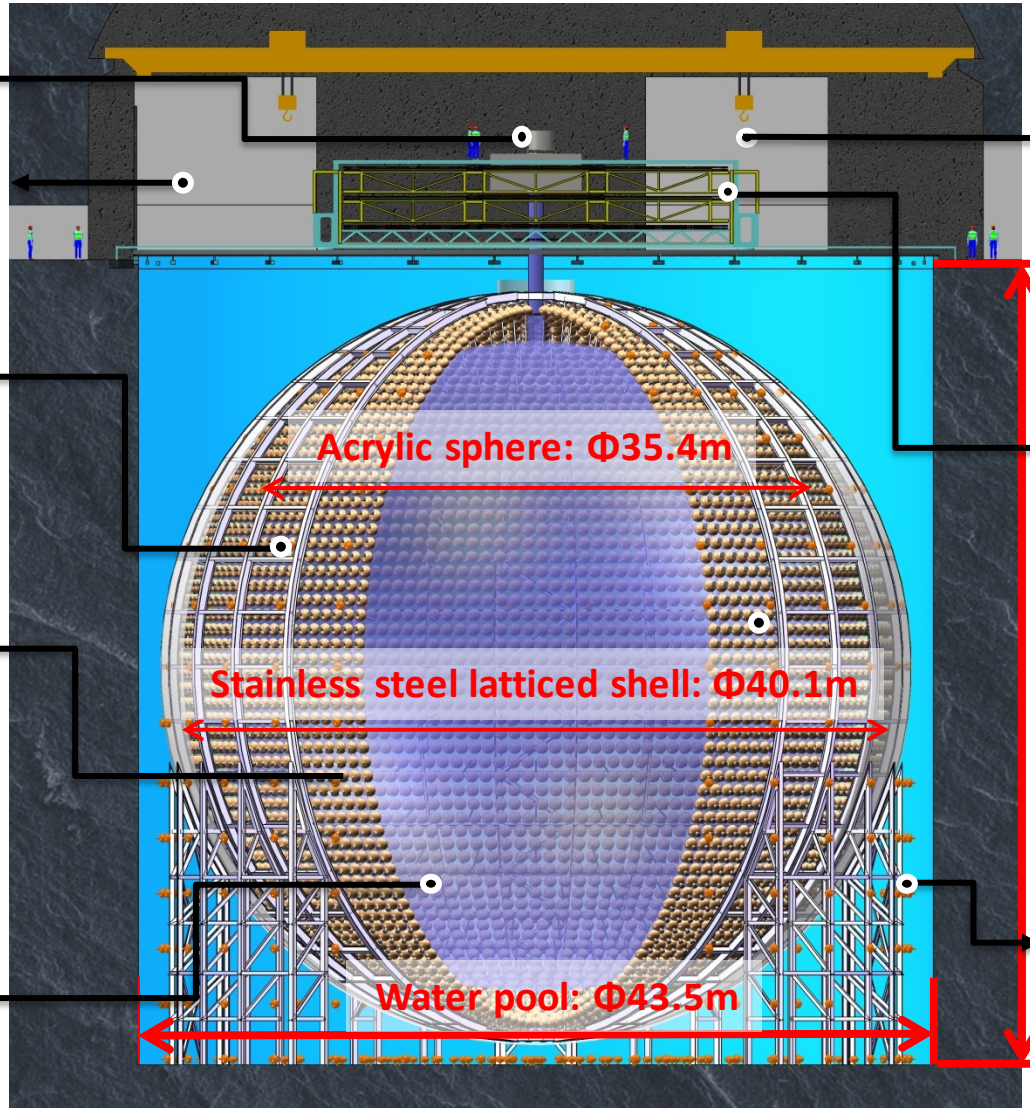
The JUNO Detector System



Calibration room

Pure water room

Central detector
Acrylic sphere
Stainless-steel truss

CD PMT
~18,000 20" PMTs
+ ~25,000 3" PMTs

Liquid scintillator
20 kton

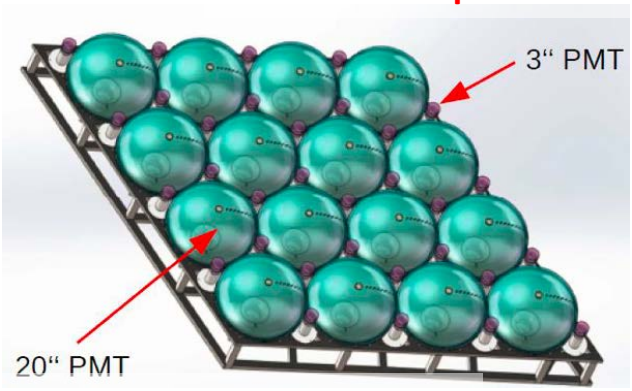
LS Filling room

Top Tracker

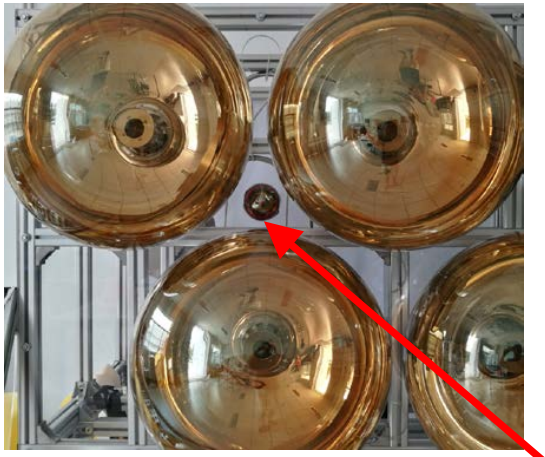
Water Cherenkov
35 kton pure water
2,000 20" veto PMTs

The PMT Array of the JUNO Central Detector

3” PMTs: ~2% photo-coverage



20” PMTs: ~75% photo-coverage



A Demo for the PMT module

SPMT system

- **Cross-check the LPMT system. Energy measurement via “photon-counting”.**
- **Extend the dynamic range of detecting muons. Better muon tracking**

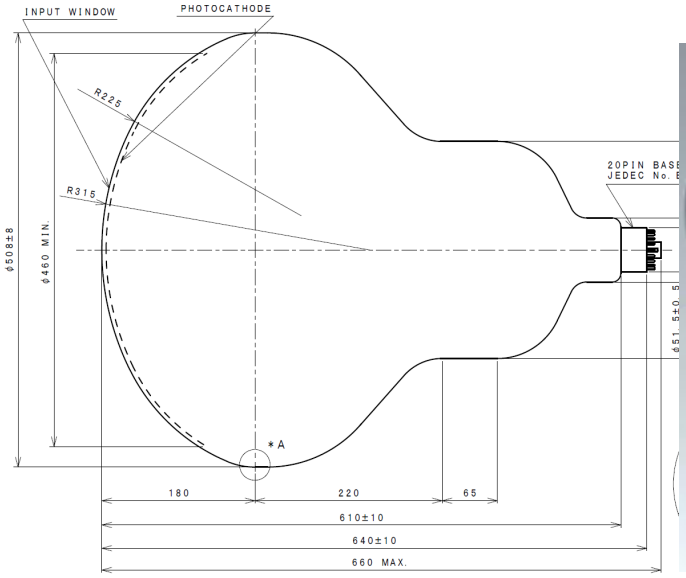
20” MCP-PMT
15,000

20” Dynode-PMT
5,000

3.1” PMT, 25,000

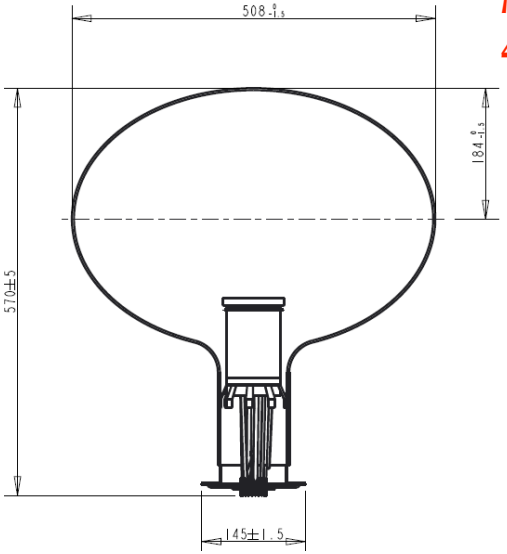
Three Types of JUNO PMTs

- **20″ PMTs**
  - Hamamatsu PMTs, R12860-50, 5K
    - Used in Central Detector (assumption)
  - MCP-PMTs by NNVT, 15K
    - Used in both Central Detector and the water Cherenkov veto detector
  - Electronics are housed with the PMT
- 3″ PMTs
  - Not covered in this talk



Unit : mm

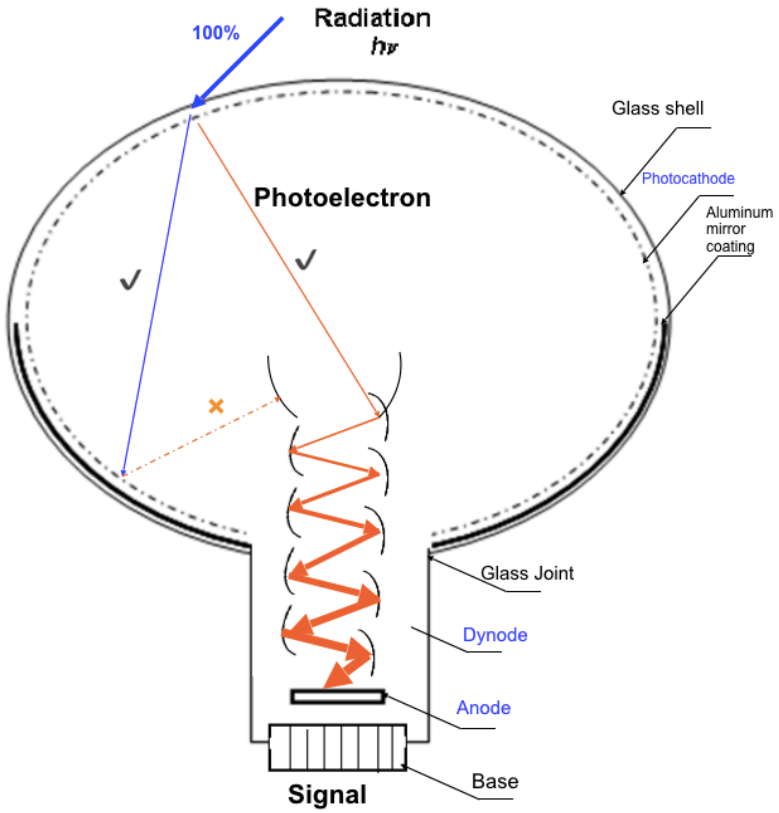
MCP-PMT photocathode 4mm taller

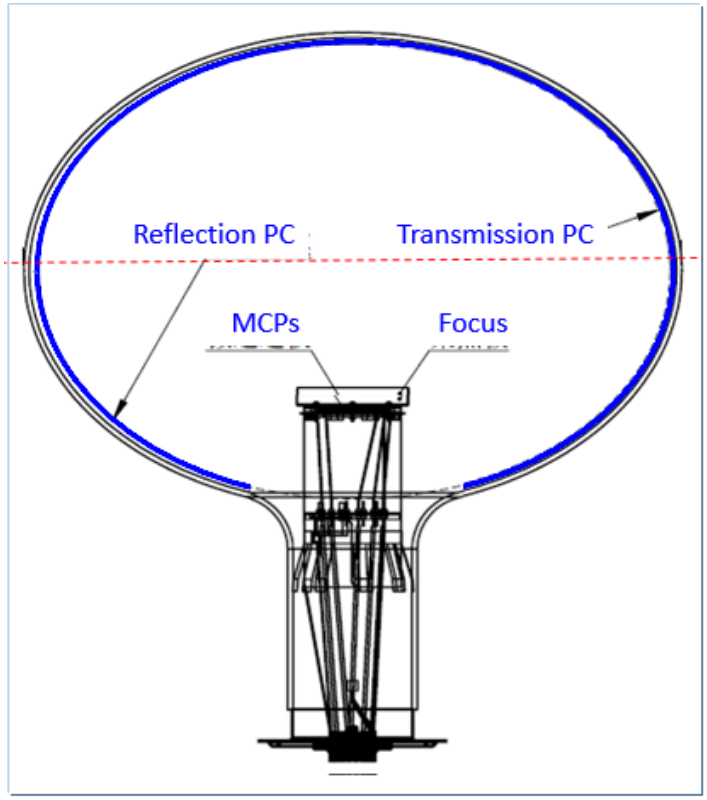


Photograph of MCP-PMT

Why MCP-PMTs Could Do Better?

Photon Detection Efficiency : PDE = $QE_{Trans+Ref}$ * CE





Dynode:(PDE)= QE_{Trans} * CE

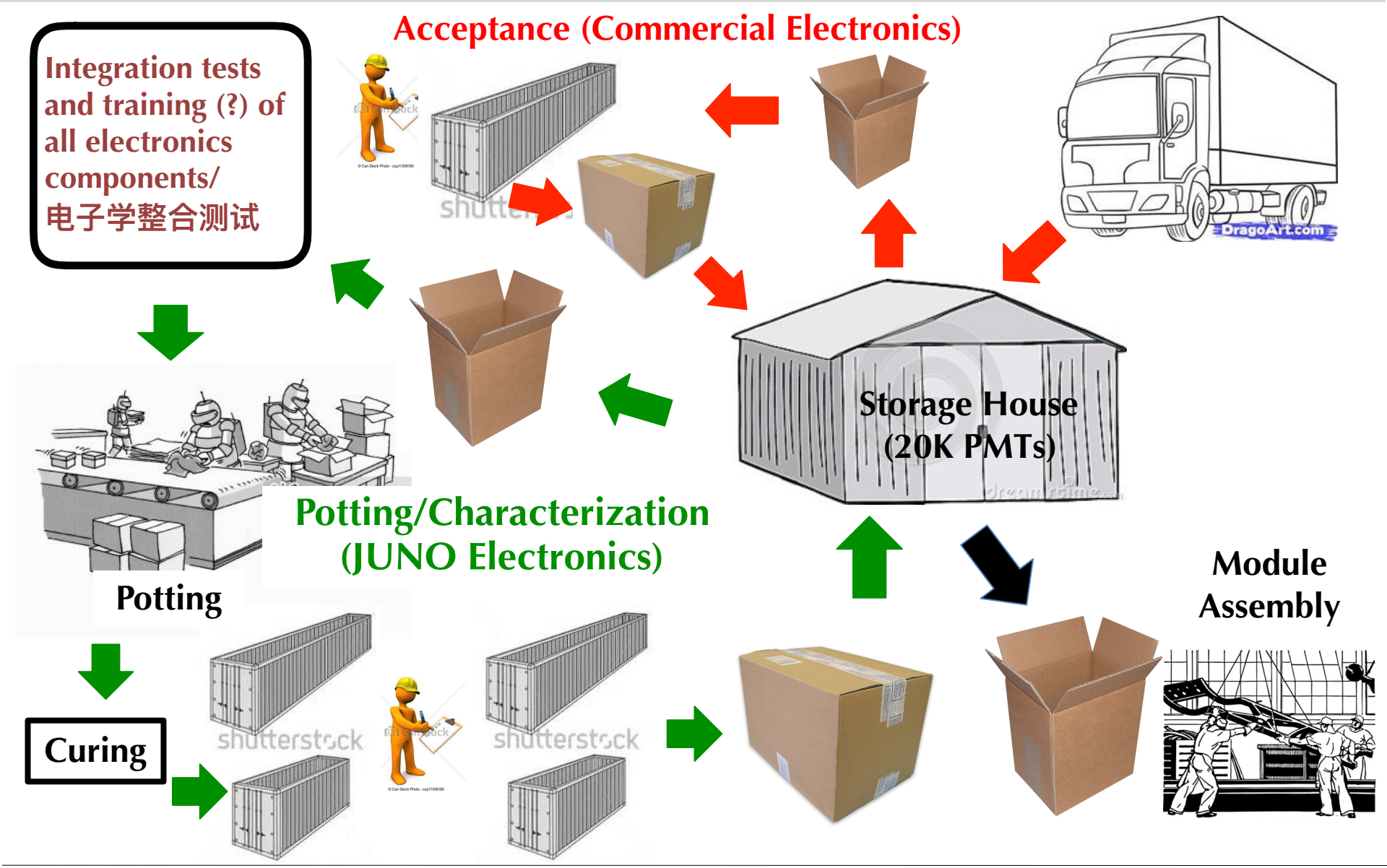
= 20% * 70% = 14% (2009)

= 30% * 90% = 27% (2015)

MCP :(PDE)= QE_{Trans} * CE

= 27% * 100% = 27% (2016)

PMT Work Flow and Logistics

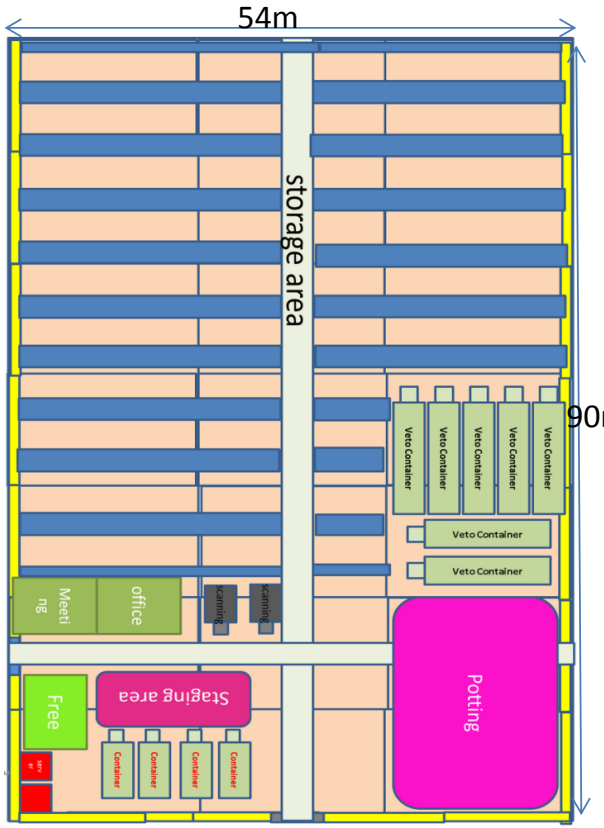


The PMT Testing and Characterization Site

- The JUNO Pan-Asia PMT PMT potting & characterization station has been built in Zhongshan city, Guangdong Province, with great support from the host company.
- PMTs delivery since May 2017. First take visual check (bubbles, weight, scratches/damages, etc), then do performance test

The PMT Testing&Characterization Lab Layout

- A test and storage warehouse of 4500m^2 has been prepared near to JUNO site.
- JUNO has received about 10k PMTs: 6K from NNVT + 4K from Hamamatsu
- Visual inspection and performance test are ongoing:
  7k finished for visual inspection, and 5k finished for performance test

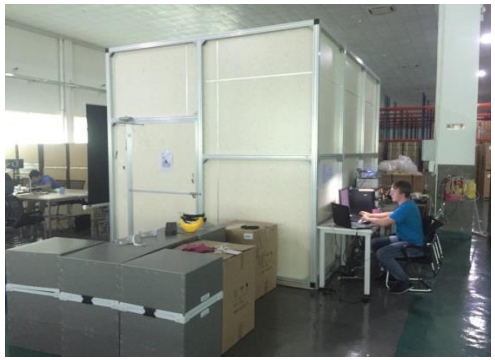


the test and potting station

Storage of received PMTs

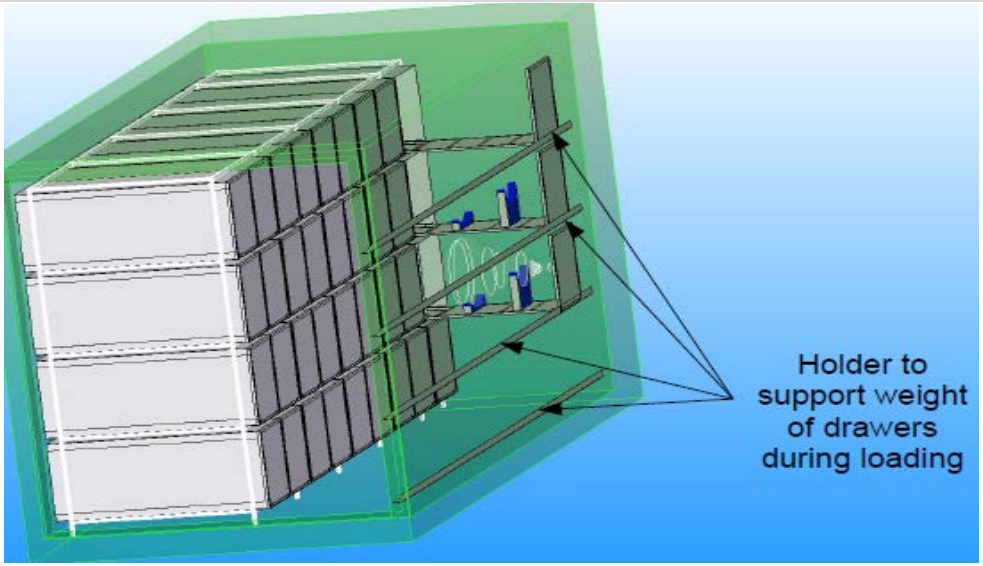
PMT visual inspection

Batch test of 72 PMTs
in two containers



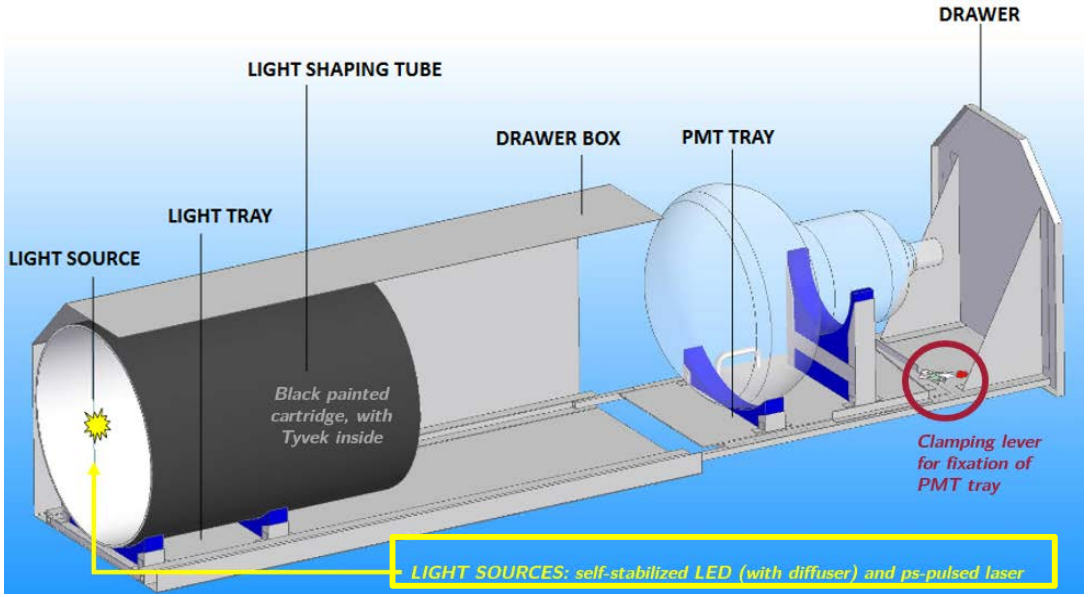
scanning test of PMT
within a dark room

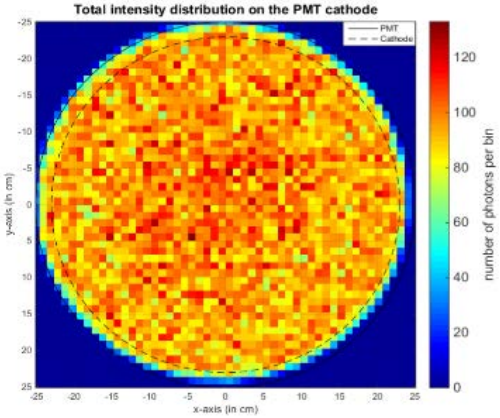
The Container Mass Testing System



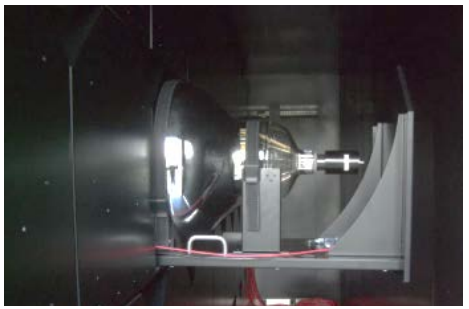
Every PMT will be tested in this system at least 2 times: **acceptance test** with naked PMT after delivery, **full characterization test** after potting of the PMTs

Shielding against Earth Magnetic Field with soft- iron/aluminum layers, reduced to ~ 5 μT (≤ 10% of EMF)





Uniform light field on PMT surface (simulation)



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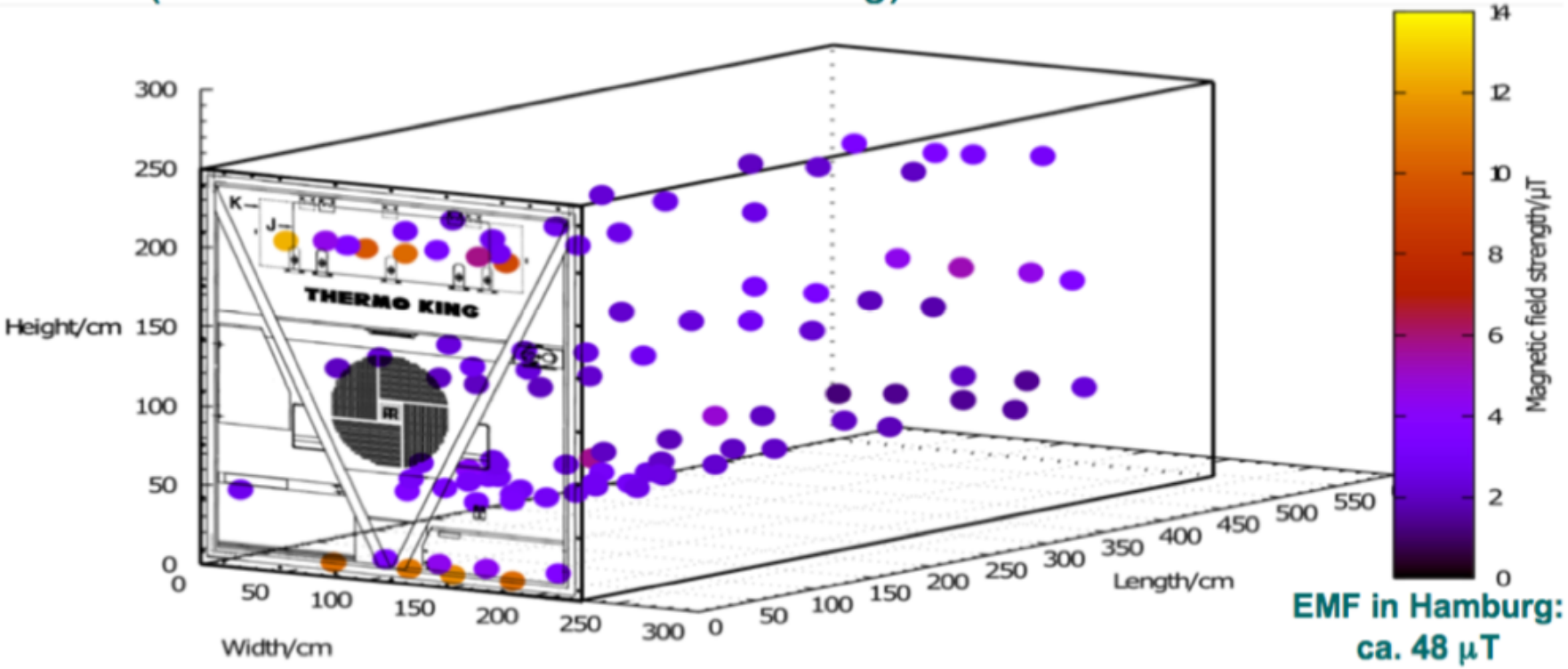
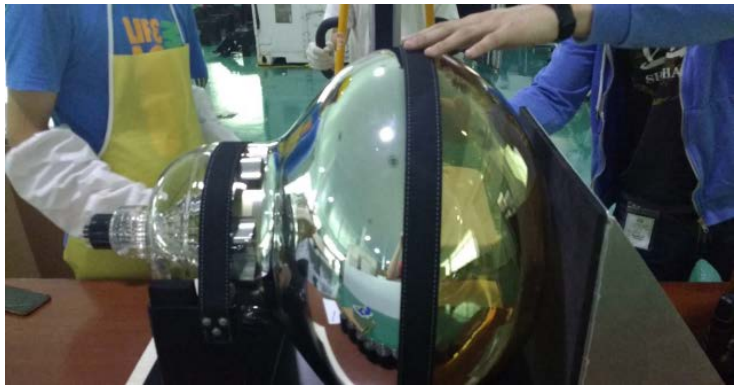
Container Magnetic Field Shielding

- Multi-layer soft Si-iron, aluminum
- Installation completed in August 2016
- Shielding factor better than 10

  (one box needed additional shielding)



PMT Mass Testing Operation and Parameters

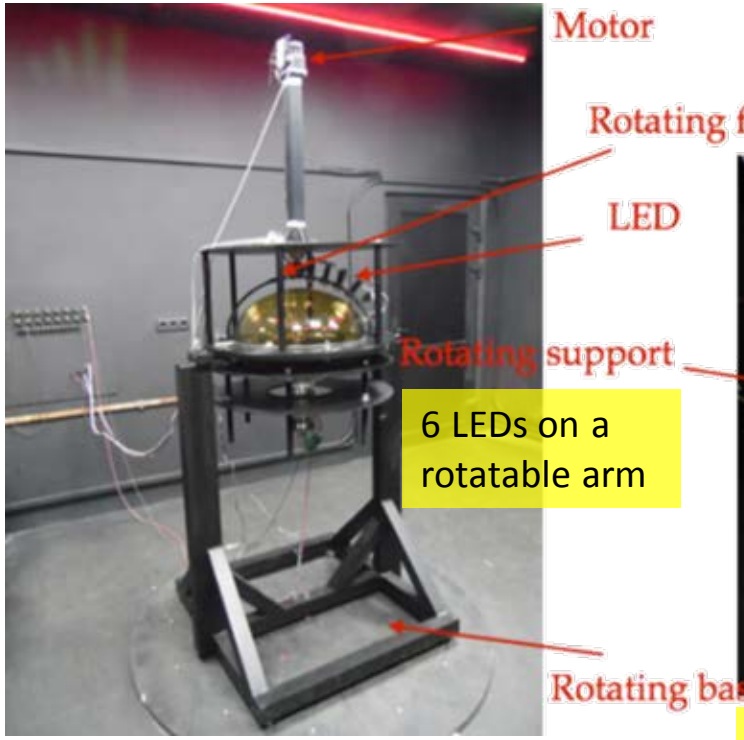


Cover most parameters and all tubes be measured

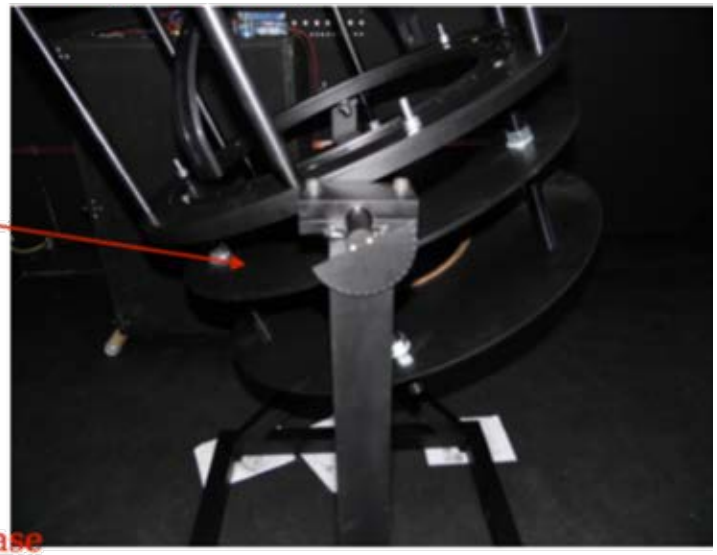
✓ Detection efficiency @ 420nm	(av. 27%, > 24%)
✓ TTS of Single Photon Events	(< 12ns)
✓ Rise time / fall time	(< 8ns / < 16 ns)
✓ HV applied to reach gain of 10^7	
✓ Dark Rate	(< 50 kHz)
✓ P/V ratio	(> 2.5)
✓ Pre- and after-pulse ratio	(< 5% / < 10%)

PMT Photocathode Uniformity Evaluation

- Batch test of ~ 5% of all delivered PMTs to check for photocathode uniformity, and cross-checks of suspicious PMTs (PDE ~ 24%) from the container tests. Two stations in total



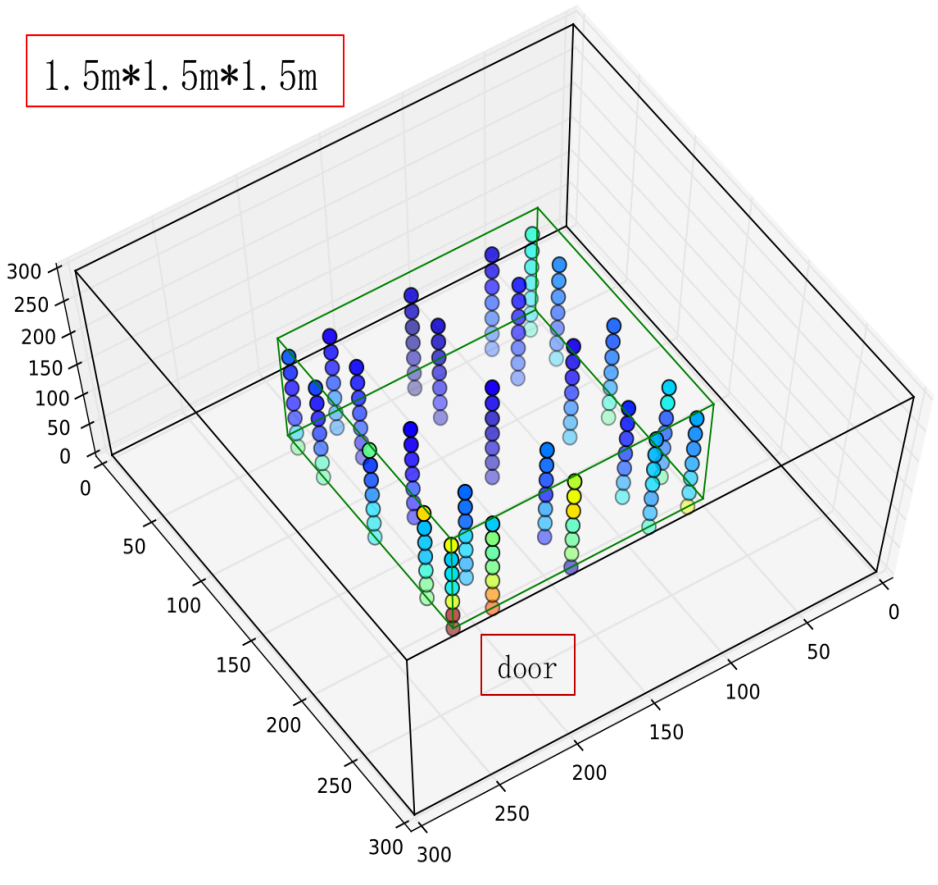
6 LEDs on a rotatable arm

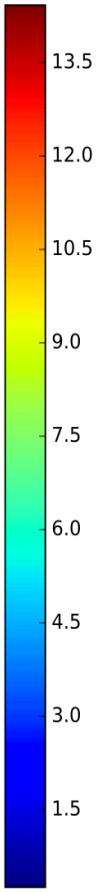


LEDs: self-stabilized with monitored light intensity, periodical calibration with reference PMT

The dark room is surrounded with EMF compensation coils, the residual field at PMT position is ~ 2 μT

Earth Magnetic Field Compensation





Colorbar:

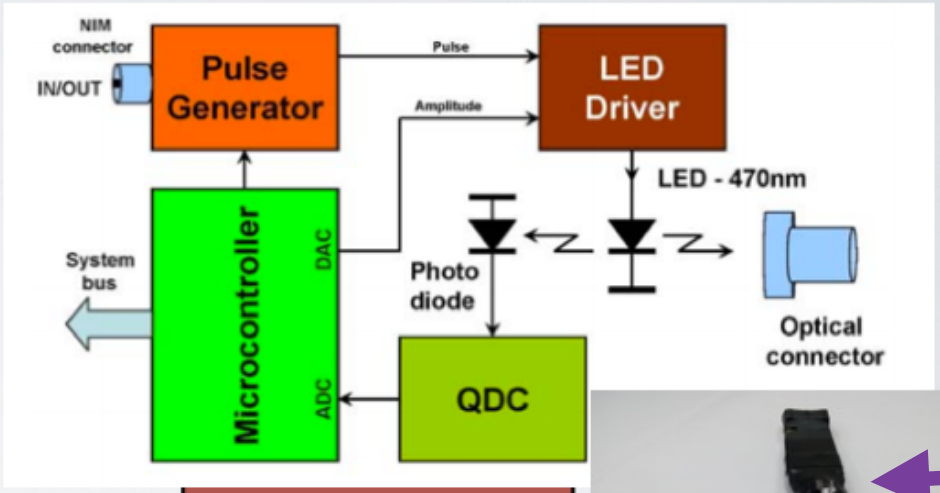
$$values = \frac{with\ compenstation}{without\ compensation} \times 100$$

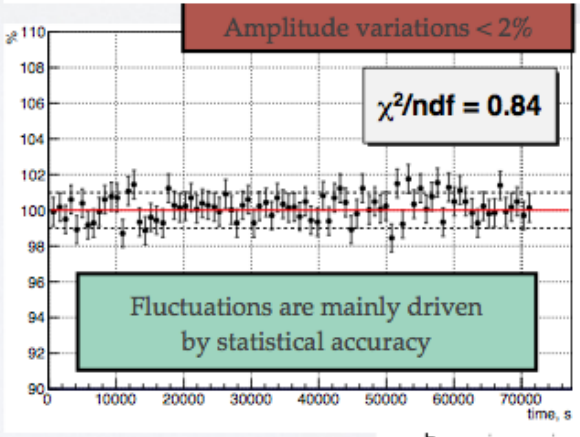
1m*1m*1m: ⩽5%

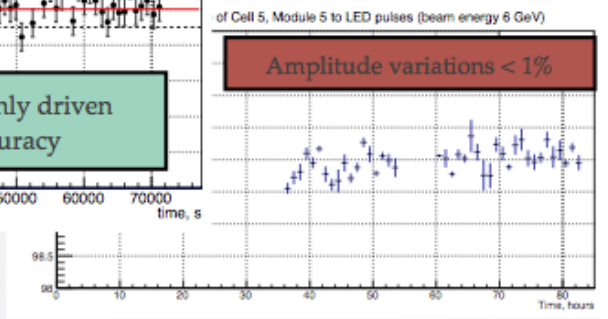
1.5m*1.5m*1.5m: ⩽10%

The Specially Made LED Light Source

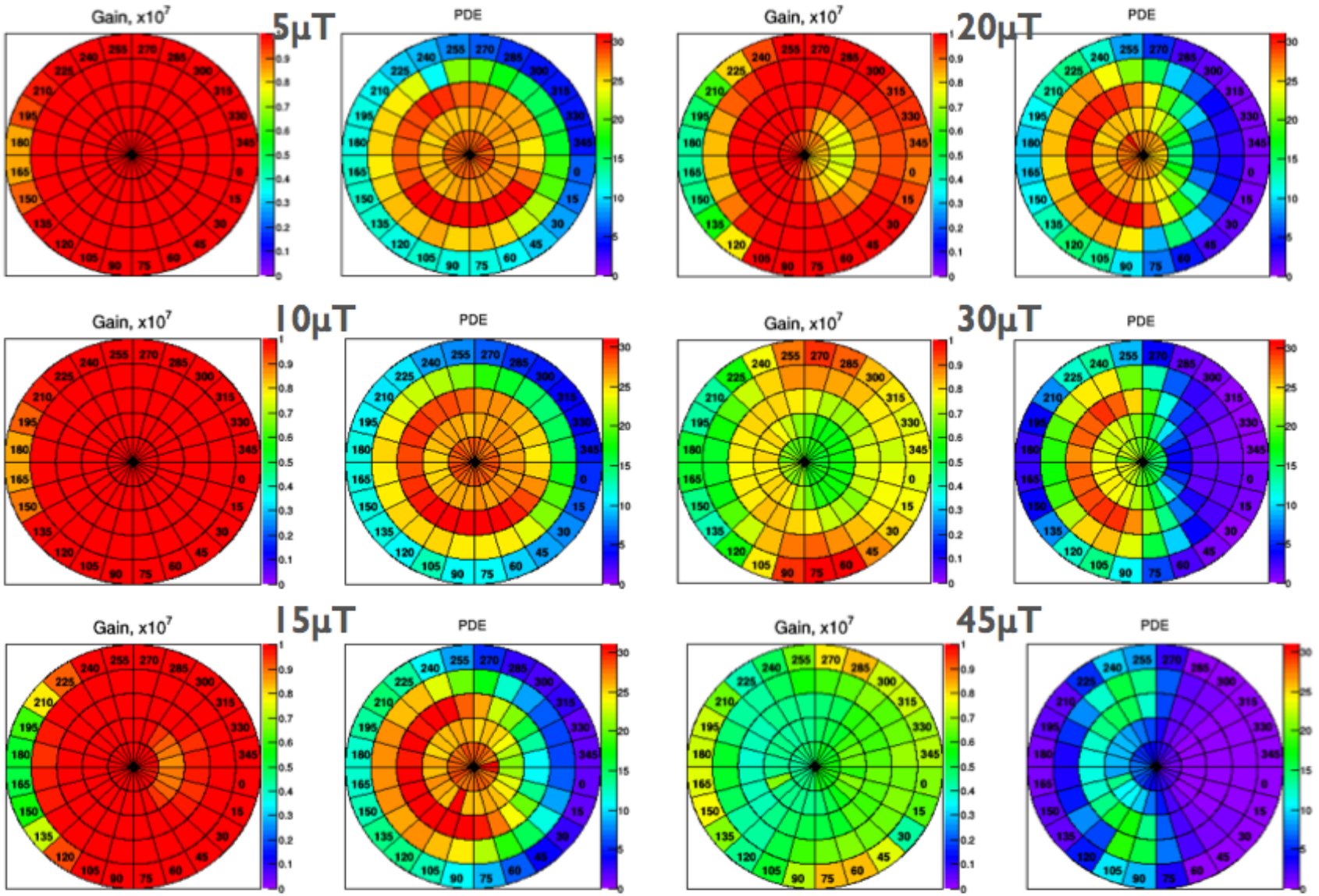
- Stability provided by PIN-photodiode <2%
- PIN->ADC->DAC feedback inside
- Digital control: 12-bit ajustable amplitude, int/ext - trigger, feedback on/off
- LED wavelength range 420-430 nm (each is calibrated)



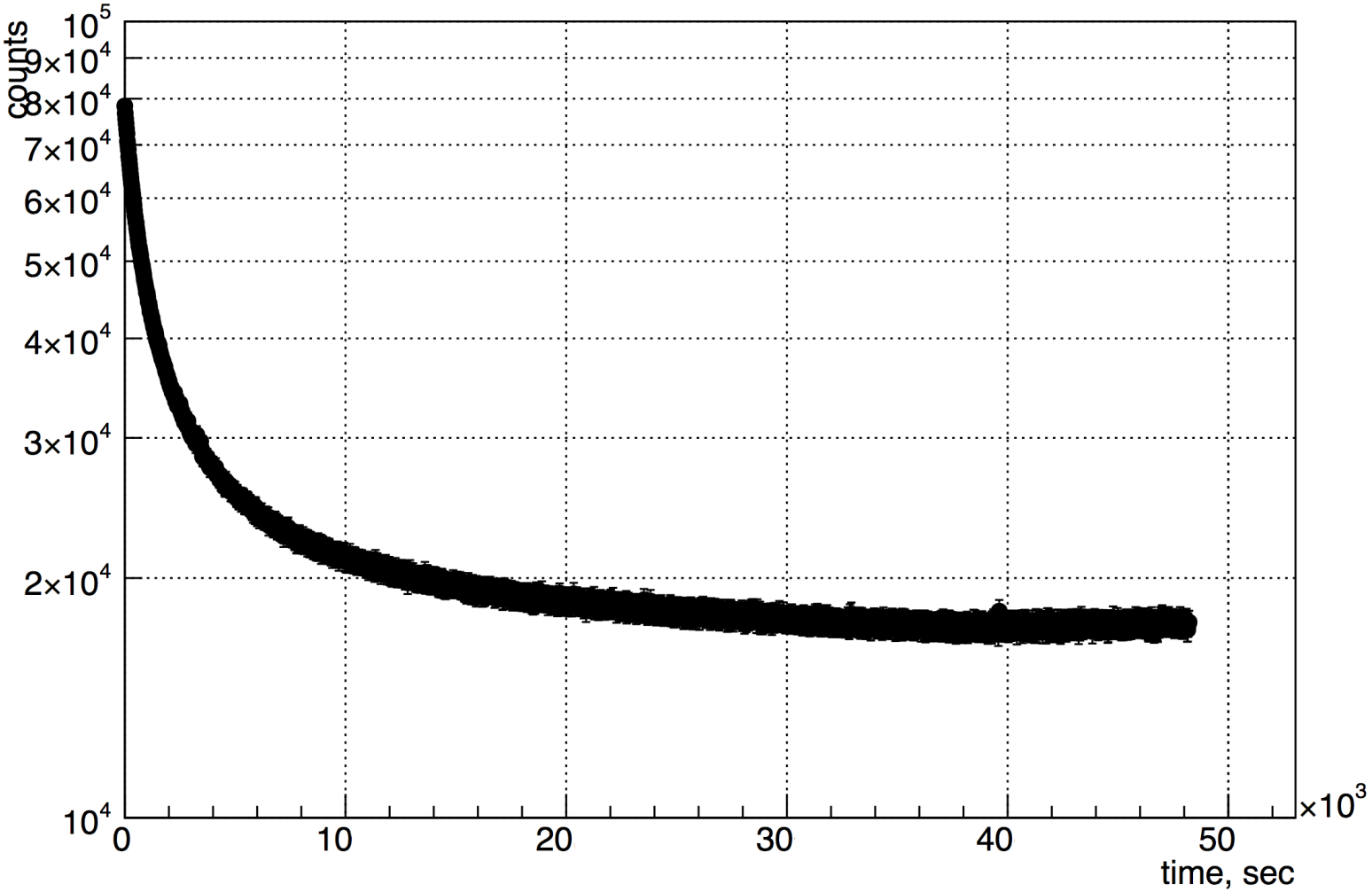




PMTs Sensitive to Earth Magnetic Field



PMTs Need to "Cooled" Down Overnight



Dark Noise Counts Evolution wrt Time

Quality Control Steps for Bare PMTs

The Current Status of 20″ PMTs

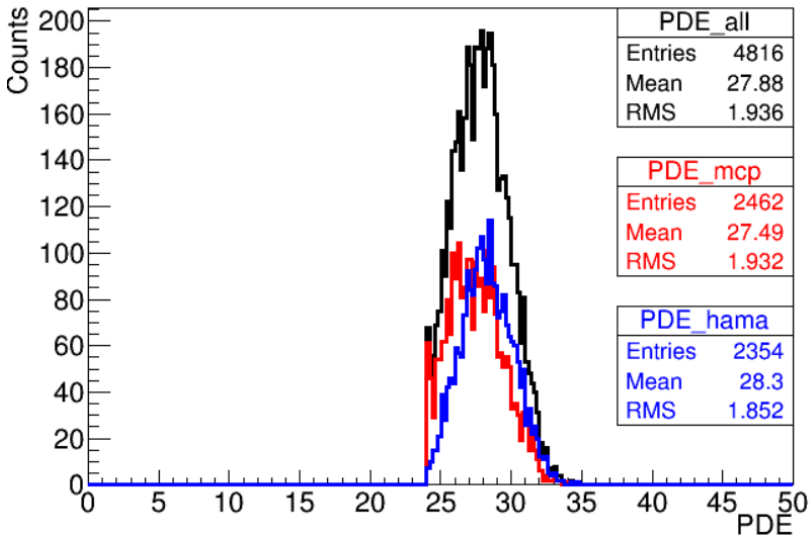
- Totally received 10048 tubes (till to 26th June, 2018)
  - MCP-PMT from NNVT: 6048 tubes
  - From Hamamatsu: 4000 tubes
- Each working day
  - Visual check: ~60 tubes
  - Container testing: ~60 tubes
  - Scan station: 2~4 tubes

Container #1:
Finished mass 221 (7735 tests)
Container #2:
Finished mass 34 (1224 tests)
Scan station: finished ~730 tests

PMT Performance

Early delivered PMTs
(batch #1 to #17)

Averaged PDE: 27.9%
-- NNVT: 27.5%
-- Hamamatsu: 28.3%

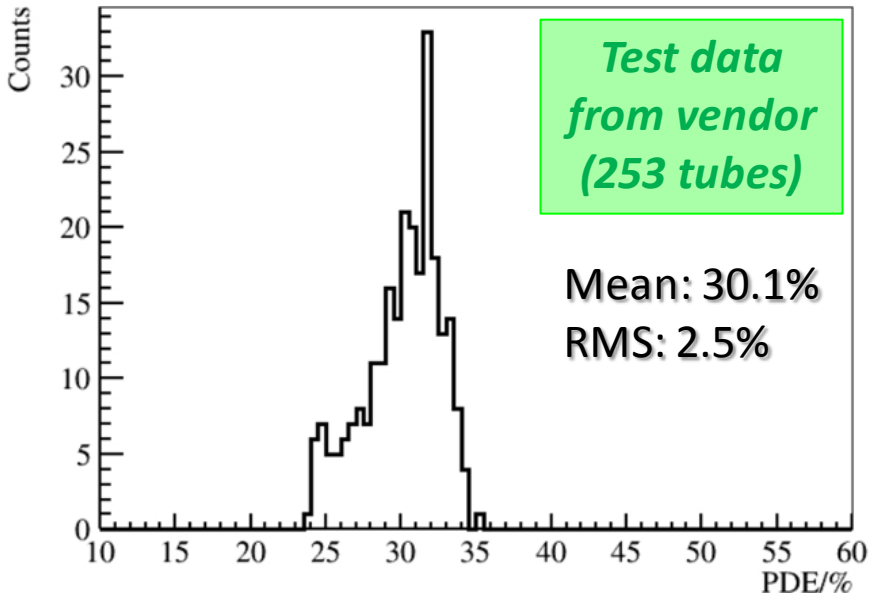


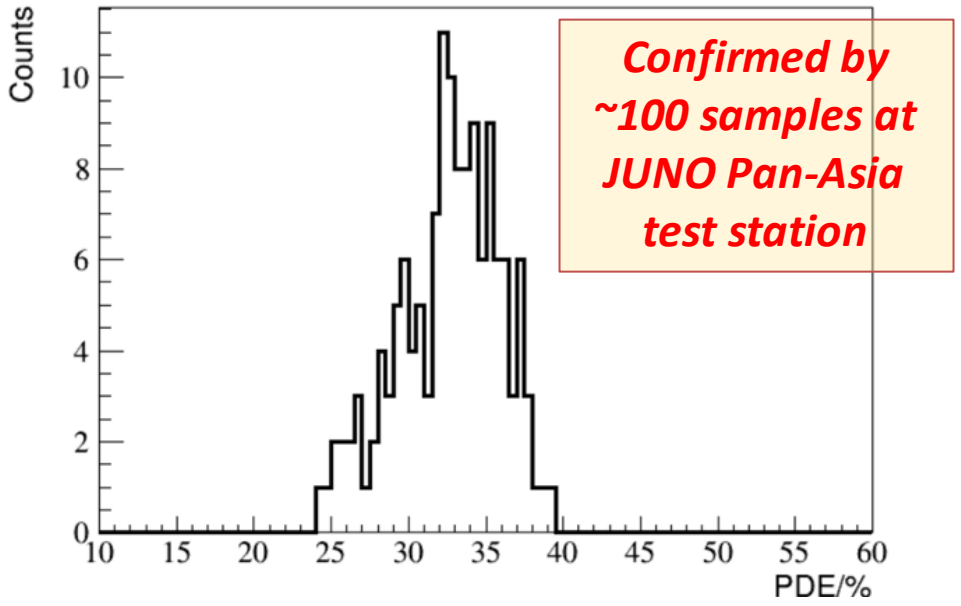
Preliminary

Quantity	NNVT MCP-PMT Mean (RMS)	Hamamatsu PMT Mean (RMS)
S/N	7.4%	7.6%
Amplitude (mV)	7.7 (1.1)	6.5 (0.4)
charge Resolution (%)	32.2 (2.7)	27.7 (2.6)
P/V	4.5 (1.5), all >2.5	3.9 (0.7), all >2.5
Rise time (ns)	4.5 (0.6)	6.8 (0.6)
Dark count rate (kHz)	41	17
DE Uniformity	7%	17%

High-DE PMTs Newly Manufactured by NNVT

- The MCP-PMT producer (North Night Vision Technology Co. LTD) has kept improving the QE with new technologies
- The average QE of the most recent batch (18th) reached ~30%, with similar dark noise. It's expected that the rest batches are all high QE tubes.





Summary

- The JUNO Experiment is primarily aimed at resolving the neutrino mass hierarchy problem —— an unprecedented massive LS detector with an unprecedented energy resolution
  - ➡ One key factor: to collect enough photoelectrons with high photocathode coverage and high detection efficiency
- The JUNO detector system needs ~20k 20″ PMTs: 5k conventional dynode PMTs and 15k MCP-type PMTs. Both types are being used for the first time at this (large) scale
- JUNO collaboration has developed a dedicated quality control and performance characterization system
  - ➡ Two systems have been developed
  - ➡ Elaborated testing procedures have been implemented
- Our preliminary results show that both types of PMTs are exceeding the requirements by the JUNO experiment


感谢所有的为现场运行付出汗水的同事！
Thanks to all the hard-working colleagues!