The 20 inch PMT system for the JUNO experiment

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Outline

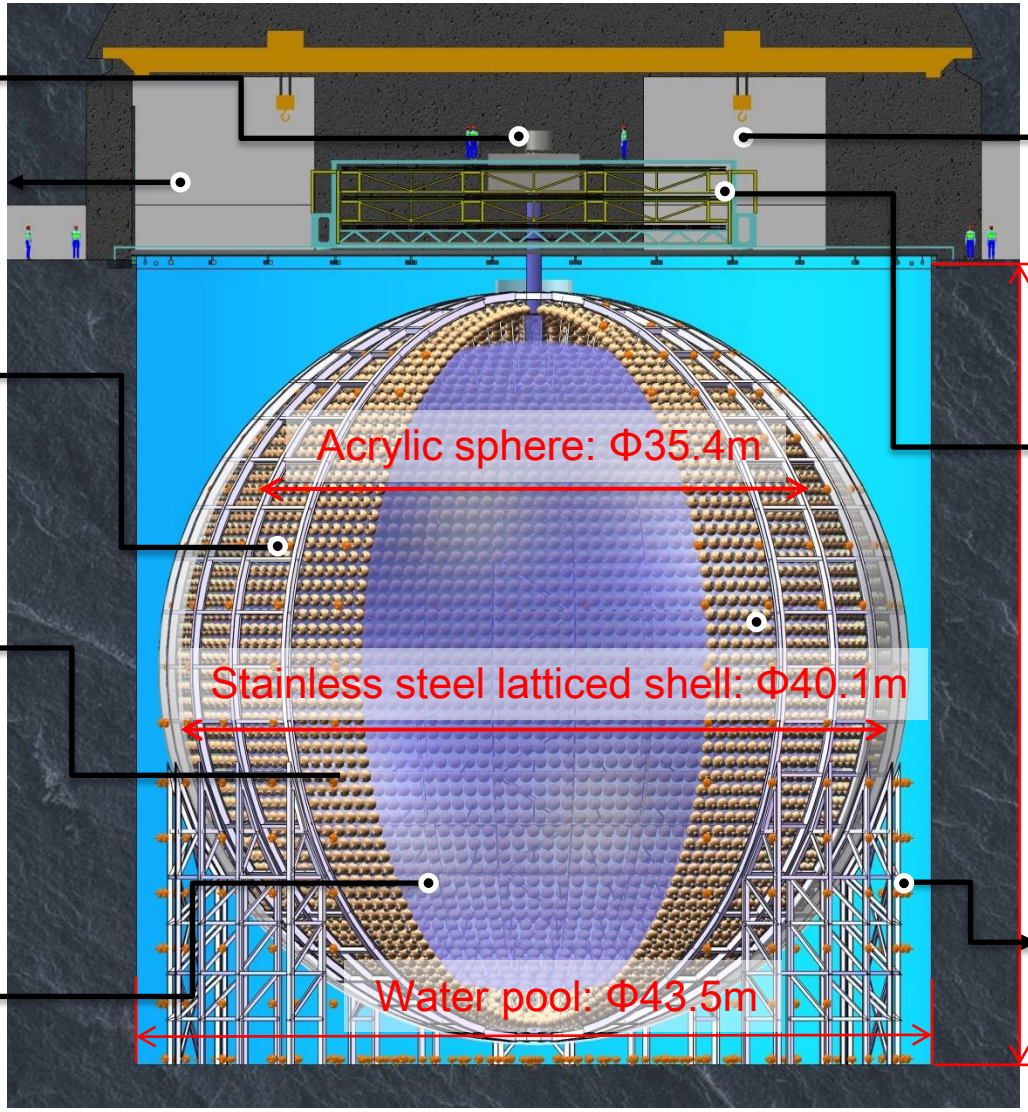
- JUNO introduction
- JUNO detector
- Overview of 20” PMT system
- 20” PMT Specifications
- PMT testing facilities;
- PMT Base
- PMT Potting;
- PMT implosion protection;
- PMT mechanicals
  - assembly structure;
  - coverage and layout;
  - module design;

Location of the JUNO experiment

JUNO (Jiangmen Underground Neutrino Observatory) is located in Jiangmeng city, Guangdong province in South China:

- about 53km to the Yangjiang and Taishan NPP;
- ~700m depth under ground

JUNO detector



Calibration room

Pure water room

LS Filling room

Central detector
Acrylic sphere
Stainless-steel truss

Top Tracker

CD PMT
~18,000 20” PMTs
+ ~25,000 3” PMTs:

Liquid scintillator
20 kton

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

Overview of the 20” PMT system

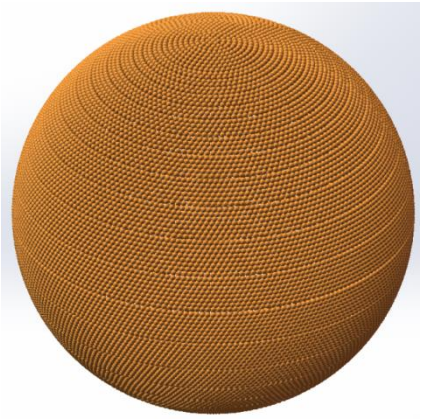
- Totally 20000 20” PMTs for JUNO

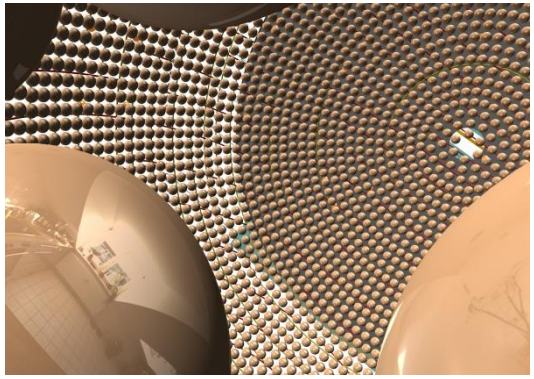
  - 15000 MCP-PMTs from of NNVT (North Night Vision of Technology CO., LTD),

  -5000 dynode-PMTs from HAMAMATSU PHOTONICS

MCP-PMT

Dynode-PMT





- The system covers:

  acceptance test/characterization ;
  base design;
  waterproofing/potting;
  earth magnetic field shielding;
  implosion protection;
  mechanical assembly;
  modularization & installation;

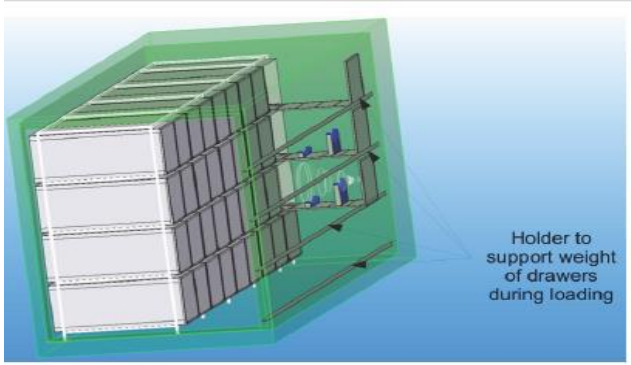
20” PMT specifications

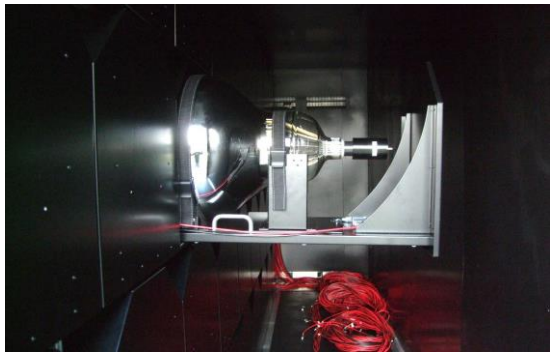
- The main specifications of PMT:

Parameter list	Averaged value (lower limit)	
	MCP PMT	Dynode PMT
PDE (QE*CE) @420nm	27% (>24%)	27% (>24%)
Non-uniformity of PDE	8% (< 10%)	5% (<15%): within ±70°; 20%(<30%): within ±80°;
Gain	10^7	10^7
HV	2500 V (<2800V) @Gain=10^7	2000V (<2500V) @Gain=10^7
P/V	3.5 (>2.8)	3 (>2.5)
TTS(FWHM)	12ns (<15ns)	2.7ns (<3.5ns)
Rise/Fall time	1.7ns / 12ns	5ns / 9ns
Dark rate	20kHz (<30kHz)	10kHz (<50kHz)
Ratio of Pre-pulse, After pulse	0.5% (<1%) , 1% (<2%)	0.8% (1.5%) , 10% (<15%)
Non-linearity @ Gain=10^7, 0-1000pe	< 10%	< 10%
Radioactivity level (ppb)	^{238}U:50, ^{232}Th:50, ^{40}K:20	^{238}U:400, ^{232}Th:400, ^{40}K:40
Water pressure	8 atm.	8 atm.

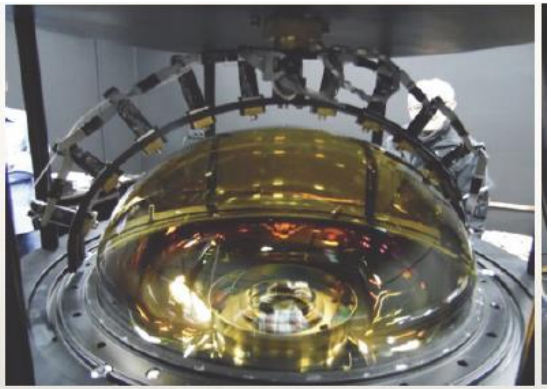
PMT testing facilities

- Four test facilities will be equipped in commercial container
  - each container can test 36 PMTs in parallel;
  - separated LEDs located in each testing drawer box;
  - homogeneous light field produced by the light shaping tube;
  - earth magnetic field shielded to less than 10%;
  - commercial electronics used for the first two containers and JUNO electronics for the rest;





- Three scanning stations are designed for Photoncathode non-uniformity measurement and detailed study
  - automatically scanning the PDE non-uniformity of the photo-cathode;
  - 14 stabilized LEDs for PDE scanning of about 3-5% of the total PMTs;
  - detailed study can be performed by the scanning station;

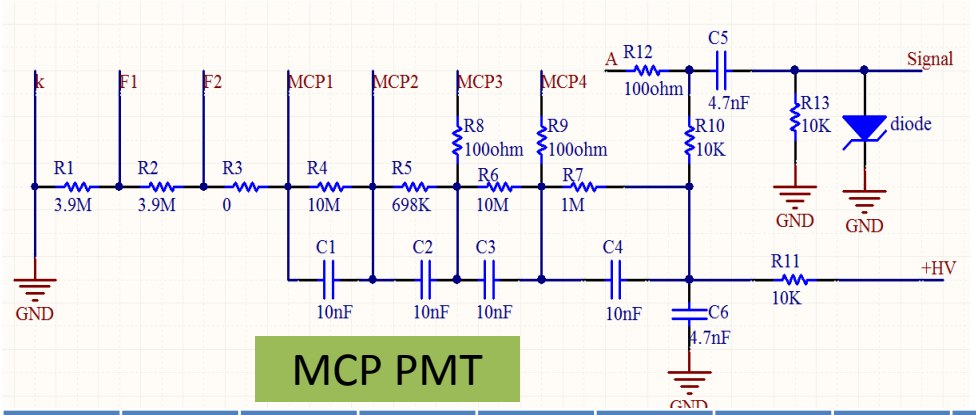


PMT Base

- Two types:
  MCP PMT and dynode PMT
- DC current &HV:
  <300μA@3000V, Gain 10^7,

Positive HV;

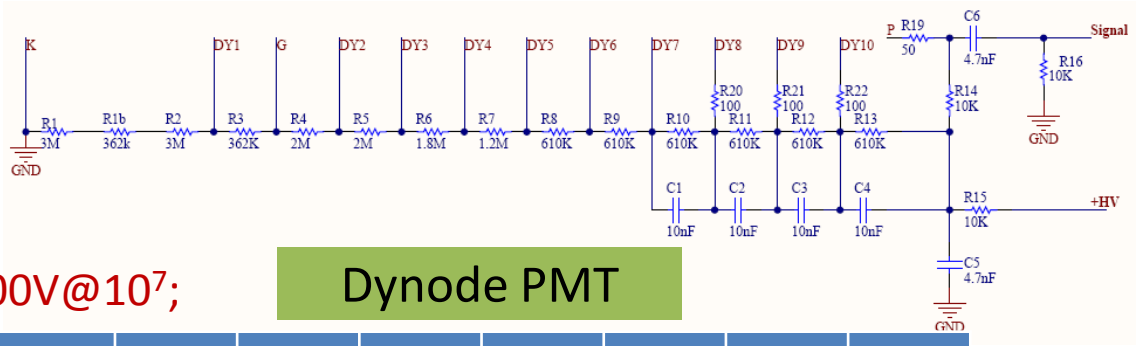
- Dynamic range & Linearity
  full dynamic range: 4000 p.e
  non-linearity: < 10% for 1000 p.e;
- Overvoltage protection/clamping:
  < 8V @ 50 Ω load
- Overshoot and ringing minimization:
  about 1% with 50Ω load
- Reliability:
  failure rate < 0.1%/ 6 year
- Production for PMT acceptance test:
  100 pcs for MCP, 50 for Dynode;



MCP PMT

Electr-odes	K	F1	F2	MCP1	MCP2	MCP3	MCP4	A
Resistance (ohm)	3.9M	3.9M	0	10M	698k	10M	1M	

total resistance: 30Mohm
HV: ~ 2000V@10^7;



Dynode PMT

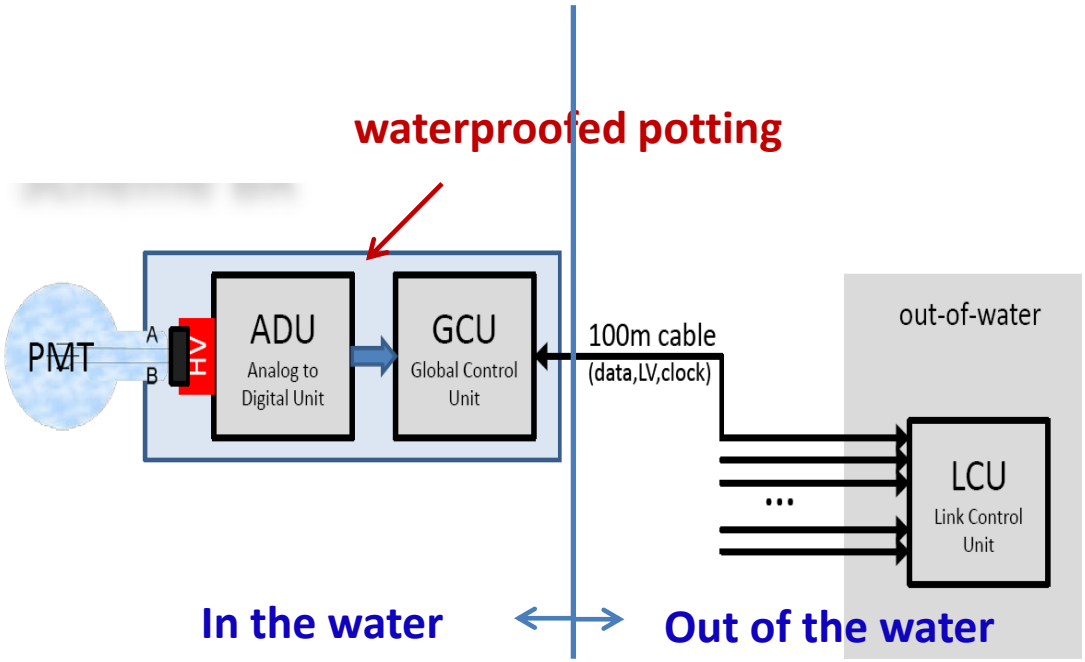
total resistance: 18Mohm; HV: ~ 1700V@10^7;

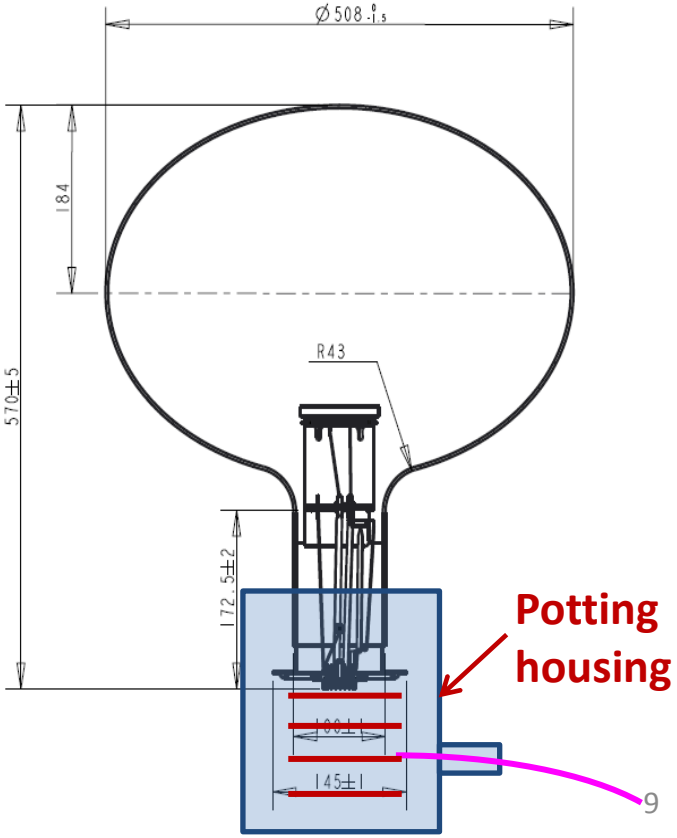
Electr-odes	K	DY1	G	DY2	DY3	DY4	DY5	DY6	DY7	DY8	DY9	DY10	P
Resistance (Ohm)	6.4M	0.4M	2M	2.4M	1.8M	1.2M	0.6M	0.6M	0.6M	0.6M	0.6M	0.6M	

See poster from Fengjiao Luo for more details

PMT Potting (1)

- Base, HV unit, and the readout electronics (ADU, GCU) will be integrated to PMT, as the BX option;
- Waterproofed potting is needed for those integrated components, with failure rate aimed to 0.5% for first 6 years and 5% for 20 years;
- About 15W heat from the electronics need dissipate into the water;
- the working temperature of the electronics keeps less than 40 ℃;





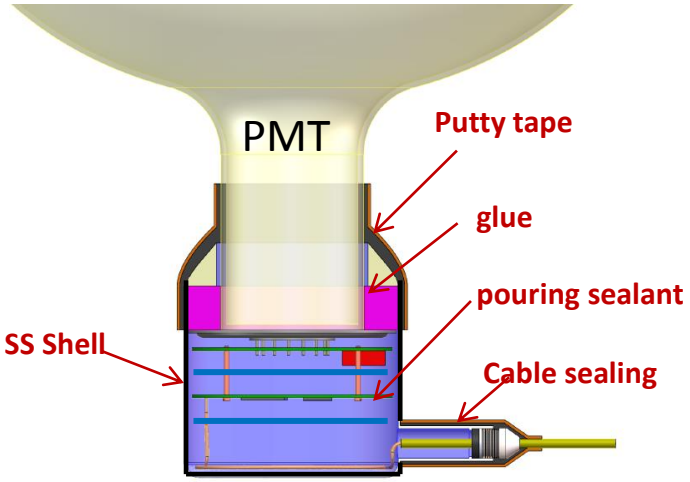
PMT Potting (2)

- Preliminary design

-with multiple waterproof layers: putty + glue + pouring sealant;

- a stainless-steel shell is for the housing, and heat dissipation;

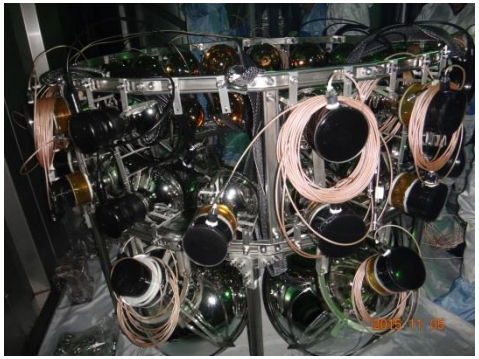
- cable is sealed by glue and O-ring



- Prototyping and testing

- 40 PMTs were potted for JUNO prototype;

- many samples were potted for waterproof test, heat conducting test, thermal cycle test and aging test;



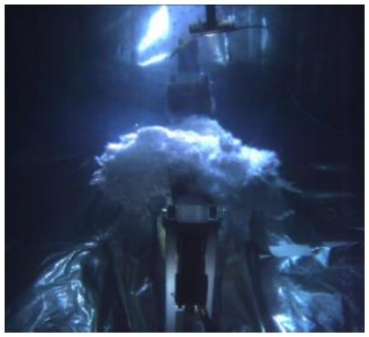
PMT implosion Protection (1)

- Requirement

  - Prevent chain reaction triggered by one PMT implosion;

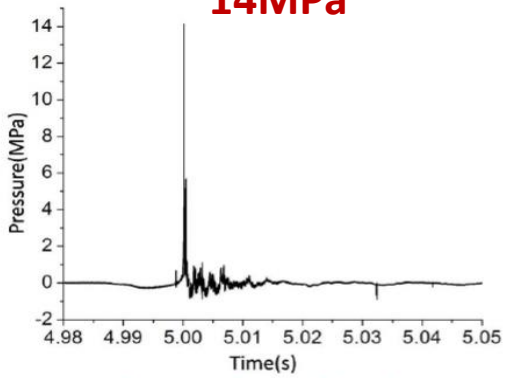
- Study with naked PMT

PMT start break

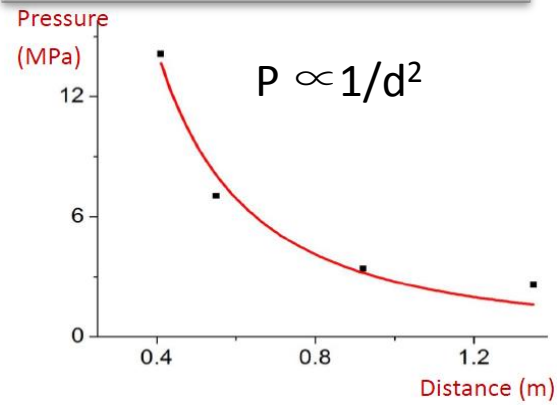


shockwave initiated

14MPa

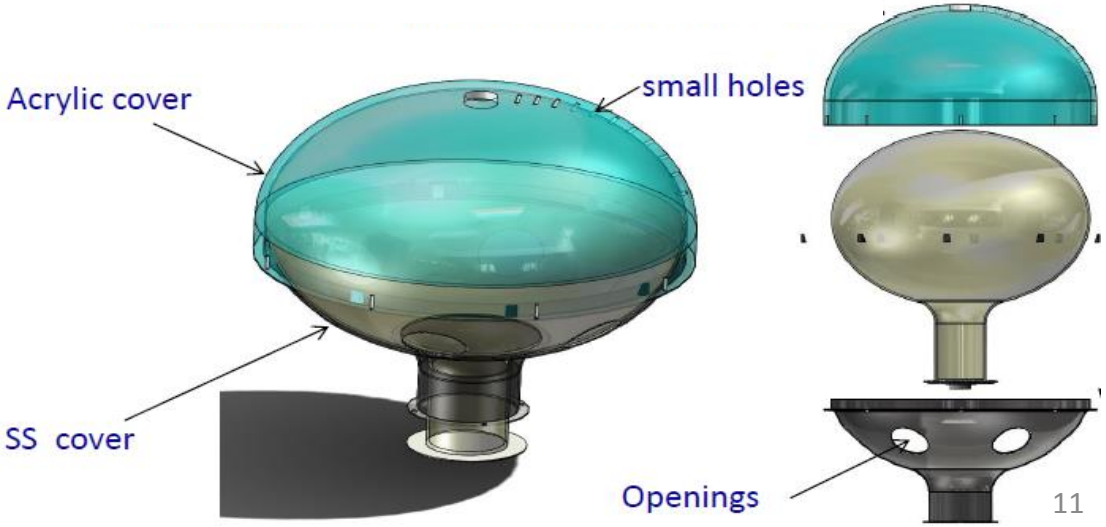


the wave form of shockwave



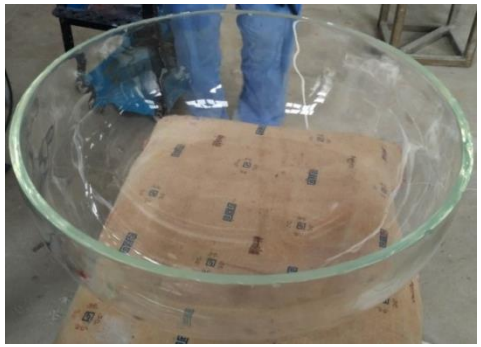
- Requirements on Protective cover

  - good light transparency, least possible light blocking;
  - thinnest possible, minimize the impact on PMT coverage;
  - compatible with pure water and low radioactivity;
  - strong support from bottom cover;

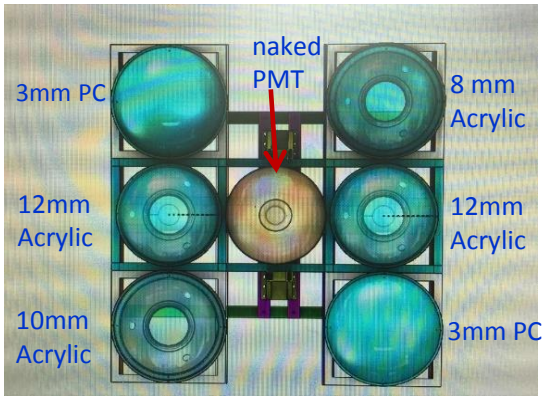


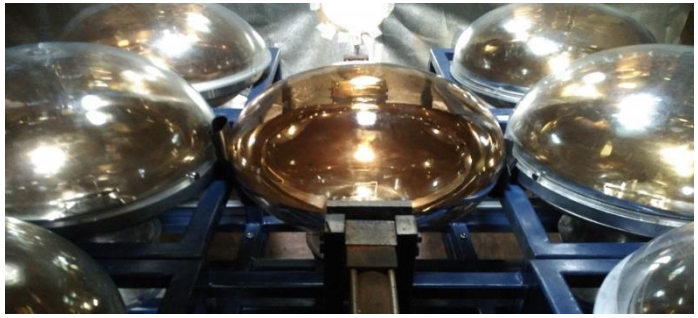
PMT implosion Protection (2)

- Protective cover prototyping
  - totally produced > 30 acrylic samples
  - done by different manufacturing techniques
  - also produced the PC(polycarbonate) and PETG (Polyethylene terephthalate) samples for test

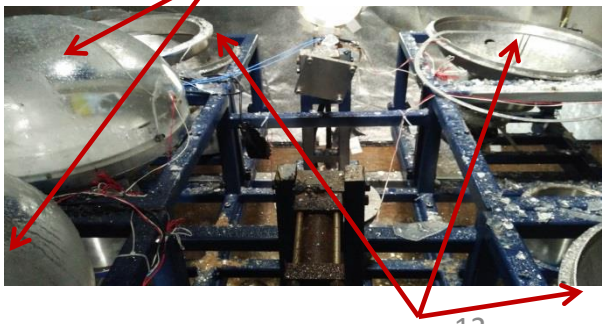


- Implosion test with multiple PMTS
  - tried many times with 2 PMTs, 3 PMTs, …, 7 PMTs for the largest number;
  - with different configurations on cover thickness, different materials;





10mm and 12mm thick acrylic covers are survived;



others are broken

PMT implosion Protection (3)

- Conclusions from protection tests

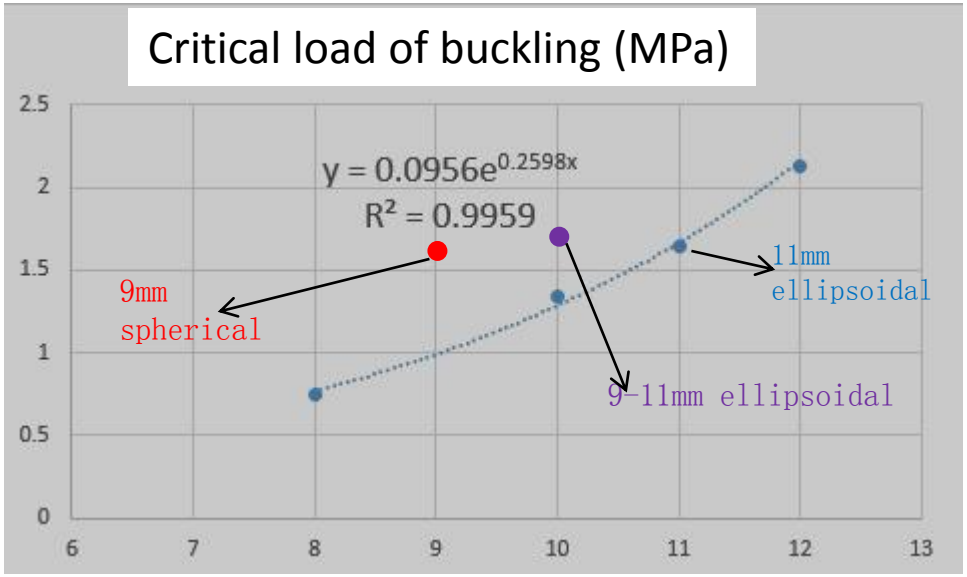
- 7-8 mm thickness is the threshold of acrylic cover;
- acrylic cover with a minimum thickness about 9mm were always survived;
- the broken of cover is caused by buckling under a step pressure from 0 to 5atm.;
- PC and PETG were not working for a thin thickness , and block significant amount of light if the thickness larger than 3mm;

- Conclusions from simulation

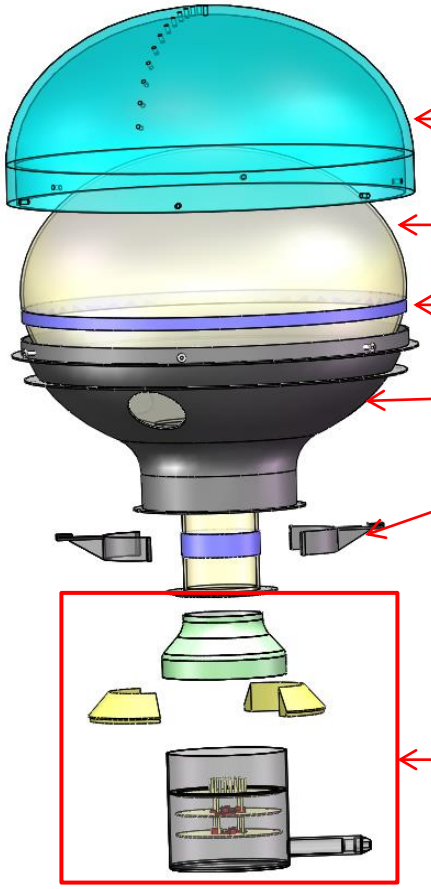
- Three different designs to reach a safety factor of 3 (1.5MPa step pressure):

1) Ellipsoidal cover of 11mm thick;
2) Ellipsoidal cover with thickness from 9- 11mm;
3) Spherical cover of 9mm thick;

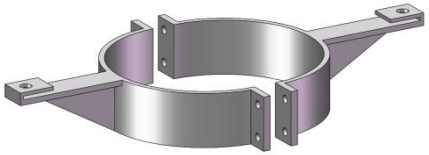
We will choose 2) or 3) for final design due to the impact to PMT coverage;



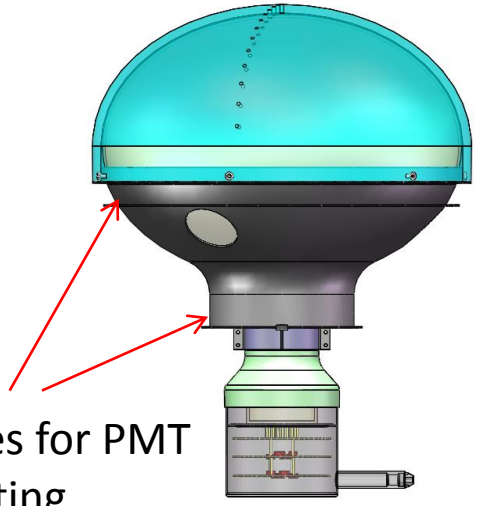
PMT assembly structure



1. Top cover : 9mm acrylic
2. PMT
3. Rubber ring between cover and PMT
4. Bottom cover : 2mm stainless-steel
5. Clamps (Two half with reinforcing rib)



6. Potting structure



Flanges for PMT mounting

- Top cover and bottom cover connected by screws;
- Rubber ring between cover and PMT for buffering;
- Two flanges on bottom covers for mounting PMT to module

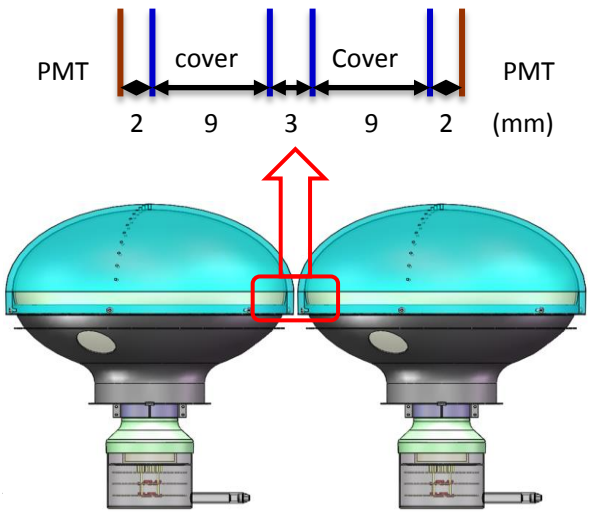
PMT coverage and layout

1. JUNO requirement on PMT Coverage:
   > 75%

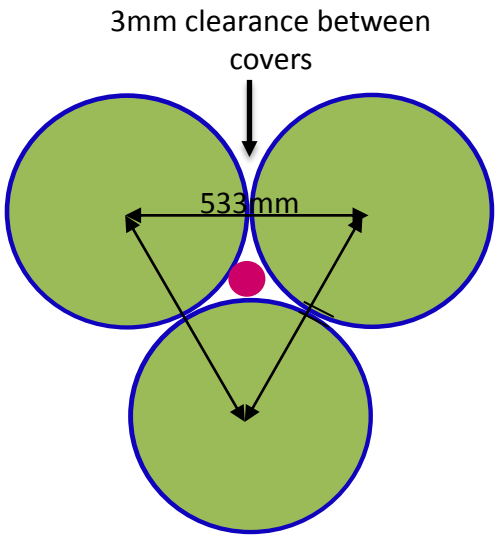
→ distance between PMTs: 25mm;

→ lose 0.25% if increasing distance by 1mm;

- Diameter of PMT: 508mm;
- Thickness of cover: 9mm
- gap between cover and PMT: 2mm
  -> Clearance between PMT covers: 3mm
  ->PMT center to center: 533mm;



distance between PMT glass shell: 25mm;

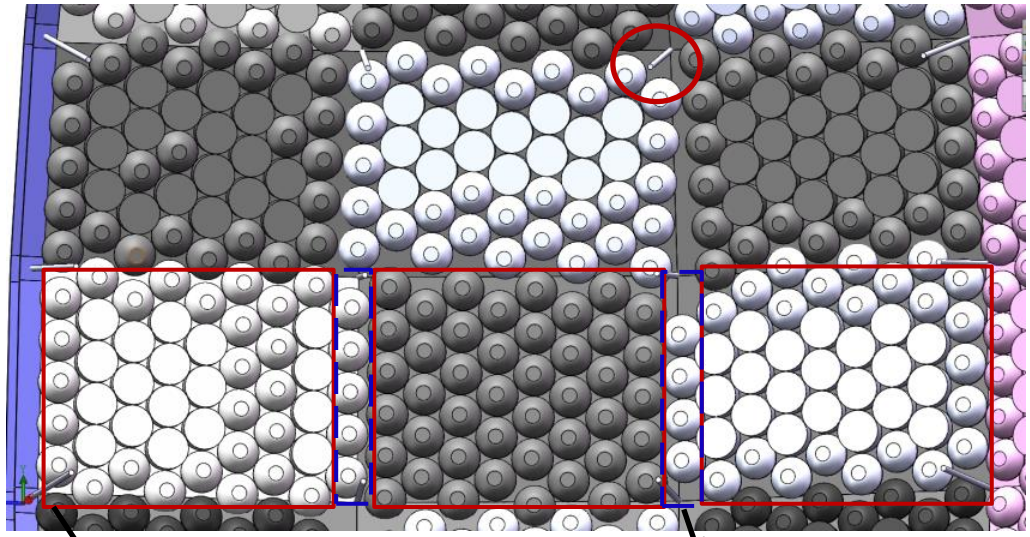


distance between PMT center 533mm;

2. A possible layout from PMT installation:

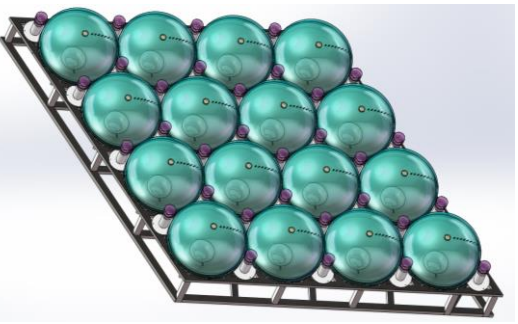
- with one largest possible module in the windows of truss, and smallest possible modules in the back of truss;
- layout optimized to minimize the interference from supporting bars;

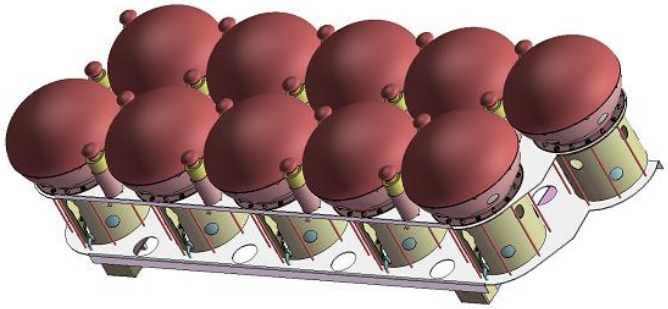
-> reach 17510 PMTs , coverage is 75.1%

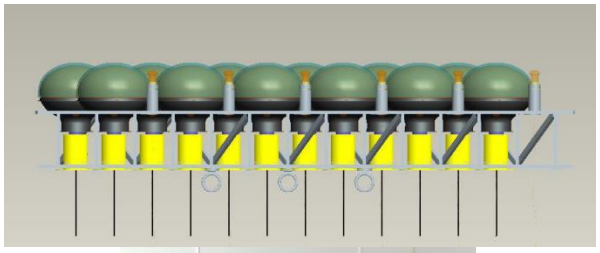


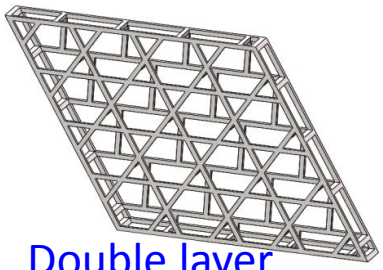
PMT module design

- PMT will be pre-assembled to module before final installation on detector;
  - minimize the work on steel truss where space is very limited;
  - reduce the overall time by doing work in parallel;
- The module design:
  - different module size: 10, 16 or more PMTs;
  - a few options under consideration for supporting structure:
    - double layer unistrut frame: light, but less precision;
    - double layer stiffened plates: high precision but
    - unistrut frame (back)+ stiffened plate (front);

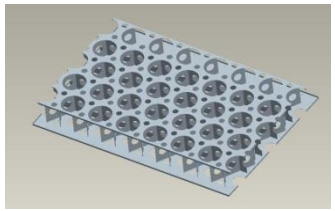








Double layer
Unistrut frame



double layer
stiffened plate

unistrut frame + stiffened plate

Summary

- The JUNO 20” system covers a full list of the PMT instrumentation task;

- 20k PMTs with a high PDE of 27% required, acceptance test and characterization needed and first testing facilities available;

- two different bases for MCP PMT and dynode PMT, small batch produced for PMT testing;

- preliminary design of potting completed with multiple waterproof layers, under varieties of tests;

- implosion protection with an acrylic and stainless steel cover, successful in the implosion tests, 9mm for the minimum thickness to reach a safety factor of 3;

- assembly structure with the PMT, protective covers , potting structure , integrated and inter-connected;

- optical coverage required larger than 75% which can be achieved by proper layout of PMTs;

- modularization of PMT for final installation considered, with some preliminary designs and prototype finished;

Thanks!