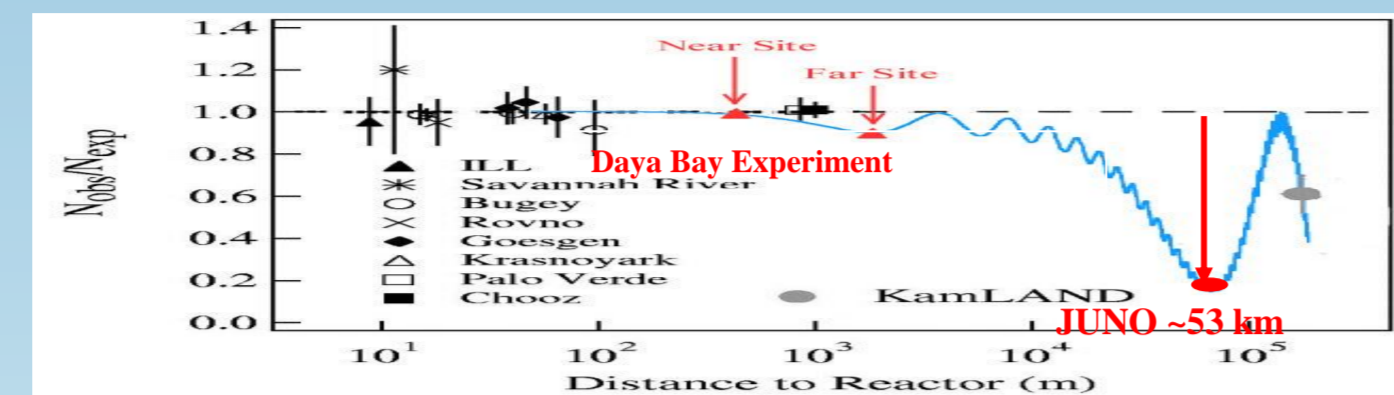




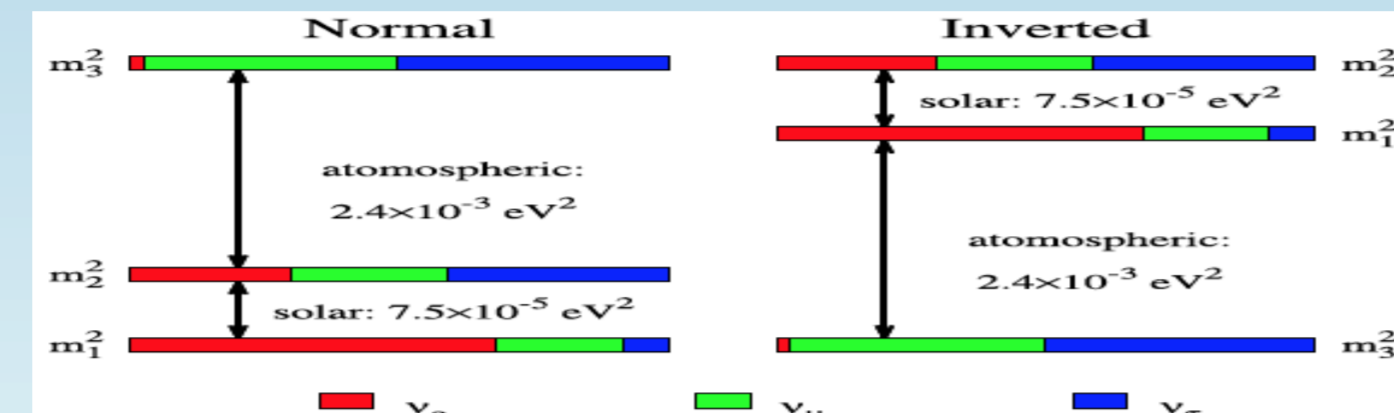
1. the JUNO experiment

The Jiangmen Underground Neutrino Observatory (JUNO) is a multipurpose neutrino experiment. It is located at 700m underground in Jiangmen, Guangdong province. The JUNO experiment is 53 km from Yangjiang and Taishan nuclear power plants.



There are rich physics in JUNO listed below. The main goal is determination of the neutrino mass ordering by measuring the reactor antineutrinos from the above nuclear power plants.

- Mass ordering
- Oscillation parameters
- Supernova neutrinos
- Geo-neutrinos
- Solar neutrinos
- Sterile neutrinos



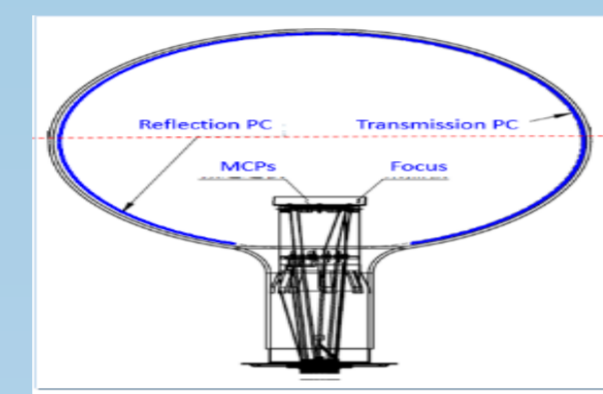
3. the 20-inch PMT Specifications

There are totally 20000 20-inch PMTs in JUNO, in which:

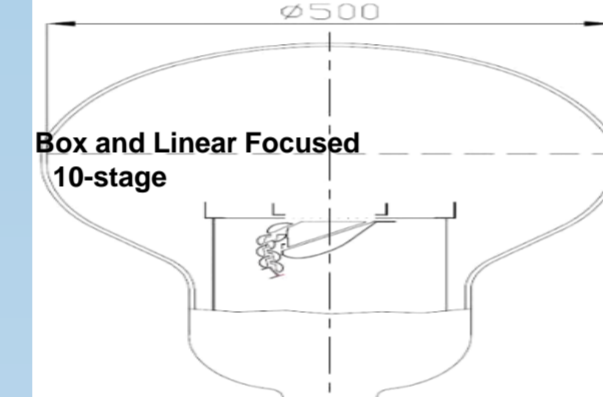
- 15000 MCP PMTs of GDB-6201 type produced by NNVIT in China
- 5000 dynode PMTs of R12860-50 type with Box & Line dynode structure from Hamamatsu in Japan

The JUNO specifications of the 20-inch PMTs:

Parameters	unit	MCP-PMT	Dynode PMT
Photon Detection Efficiency @420nm	%	> 24 (27 in avg.)	> 24 (27 in avg.)
HV@10 ⁷ Gain	V	< 2800	< 2500
P/V		> 2.8	> 2.5
TTS (FWHM)	ns	< 15	< 3.5
Rise time/ Fall time	ns	< 1.7 / < 12	< 5 / < 9
Dark noise rate	KHz	50 (24%PDE≤27%) 60 (27%PDE≤28%) 80 (28%PDE≤29%) 100 (29%PDE)	<50
Pre pulse / After Pulse (charge ratio)	%	< 1 / < 15	< 1.5 / < 15
QE uniformity	%	<10	<15
SPE resolution	%	<40	<40



MCP PMT

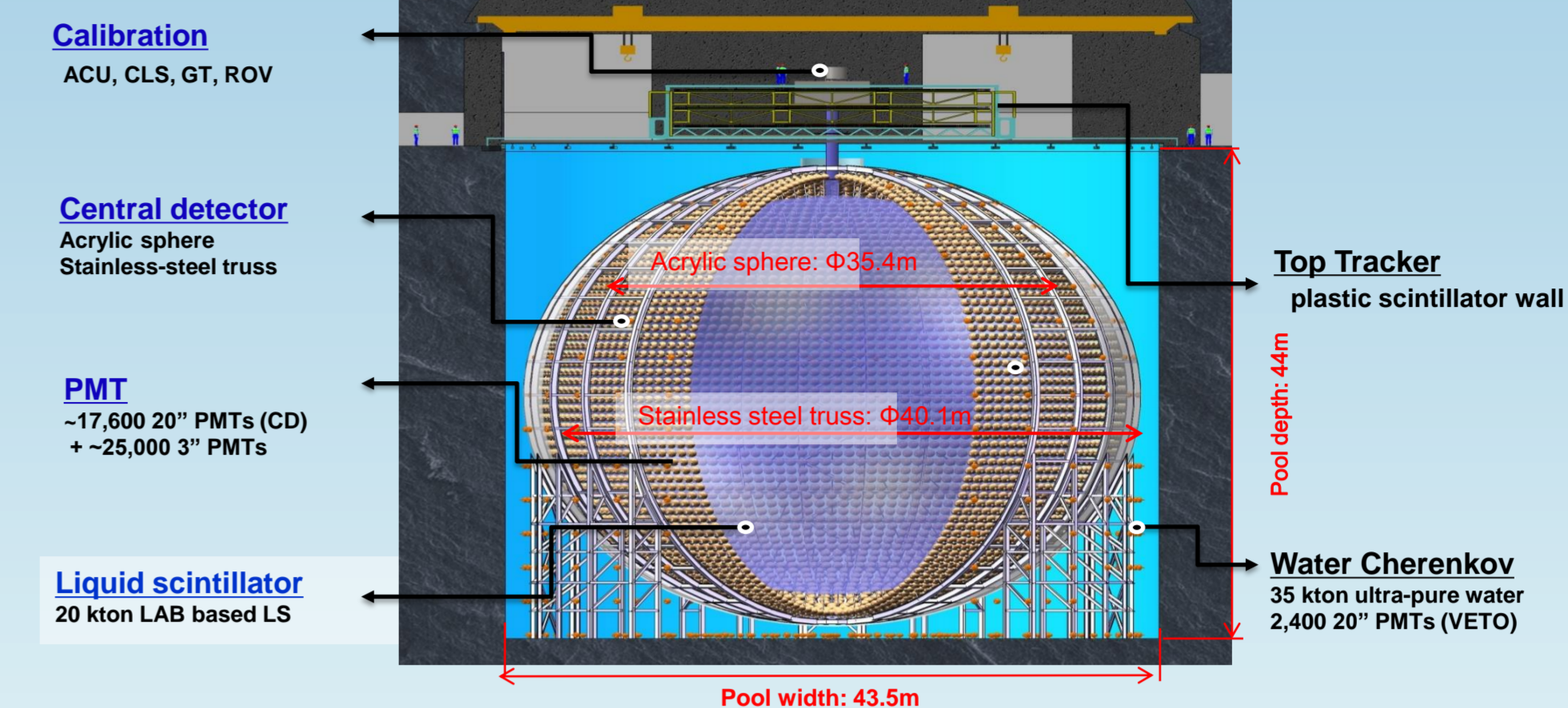


New 20-inch PMT R12860



2. Overview of the JUNO Detector

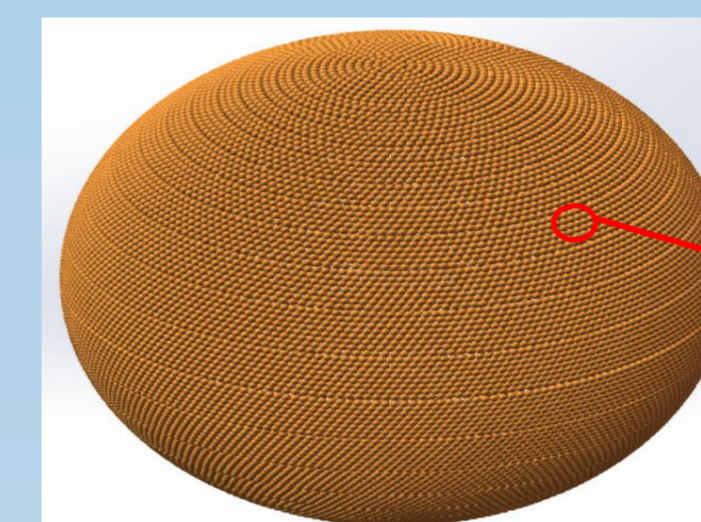
The JUNO detector consists of a central detector and a VETO detector. To reach the 3%/√E(MeV) energy resolution, the central detector consists of a large acrylic vessel of 35.4 m in diameter and a stainless-steel truss of 40.1 m in diameter, which hold 20-kton liquid scintillator, 20000 20-inch PMTs and 25000 3-inch PMTs. The VETO detector is divided into a top tracker and a water Cherenkov detector.



4. Overview of the 20-inch PMT instrumentation

The goal of PMT instrumentation is to instrument all 20-inch PMTs for the experiment, including testing & characterization, high voltage divider, waterproof potting, implosion protection and assembly.

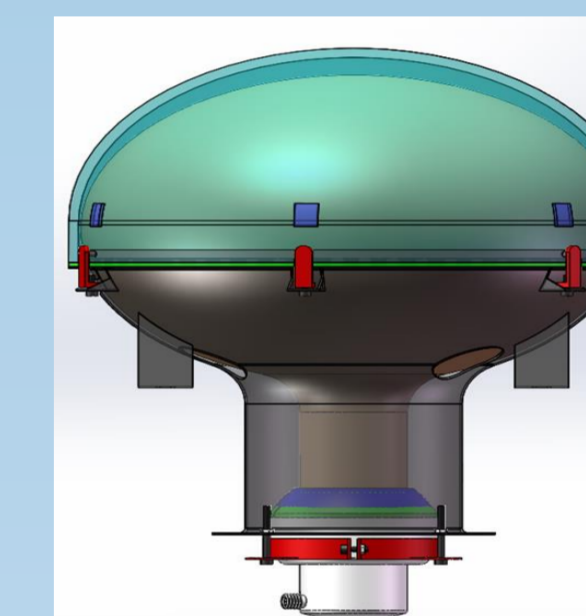
- **PMT testing:** including acceptance test and characterization. Every PMT will be tested and characterized. The unqualified will be rejected
- **High voltage divider:** a divider is needed for a PMT to distribute the high voltage and send out the signal.
- **Waterproof potting:** keep the PMT electrode pins and the divider isolated from water, with a failure rate less than 0.5% for the first 6 years.
- **Implosion protection:** protect PMTs from chain implosion in case a PMT is imploded by whatever reason.
- **Assembly:** integrate the different parts of PMT mentioned above into an assembly.



PMT layout



20" PMT



PMT assembly

5. Testing of 20-inch PMTs

- JUNO has received all 20000 PMTs (15000 MCP PMTs and 5000 dynode PMTs) now.
- Test facilities are equipped in commercial containers and custom-made dark rooms in the PMT testing & potting workshop near JUNO site.
- A visual inspection is performed before testing, to check the defects such as cracks, bubbles, scratches etc.
- All PMTs have been tested now, the photon detection efficiency (PDE) in average is 28.7% for all PMTs, 28.9% for MCP PMTs and 28.1% for dynode PMTs. A aging of the light (LEDs) used for the test is found , and the real PDE can be further higher after a correction of the aging.



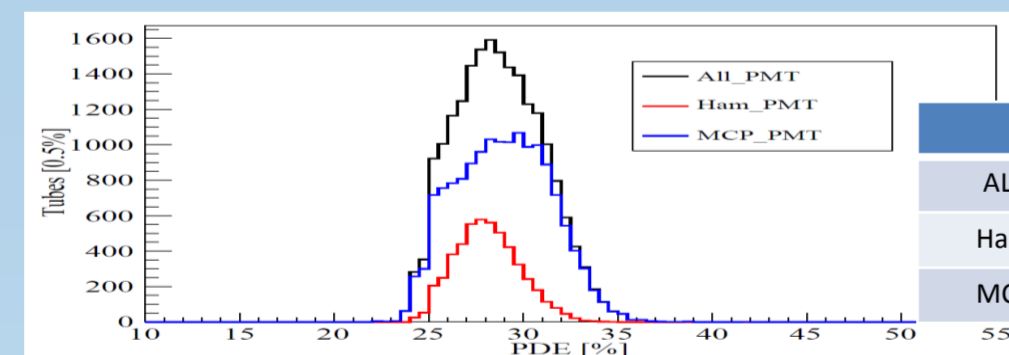
Storage of received PMTs



PMT visual inspection

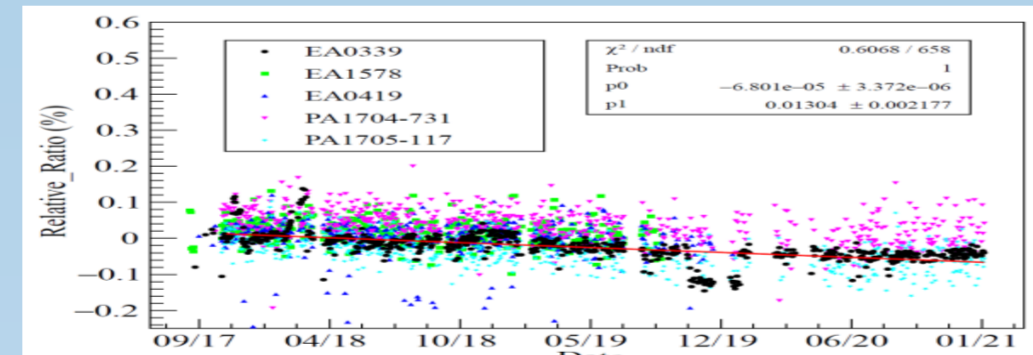


Massive test facilities inside containers



PDE distribution for all tested PMTs

PMT	PDE [%]
ALL_PMT	28.7
Ham_PMT	28.1
MCP_PMT	28.9

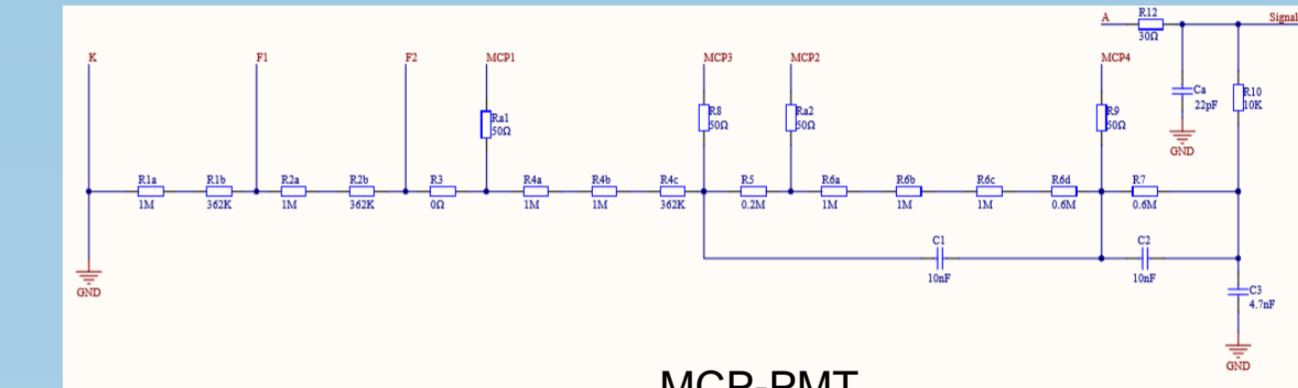


A trend of aging is found by the monitoring PMTs

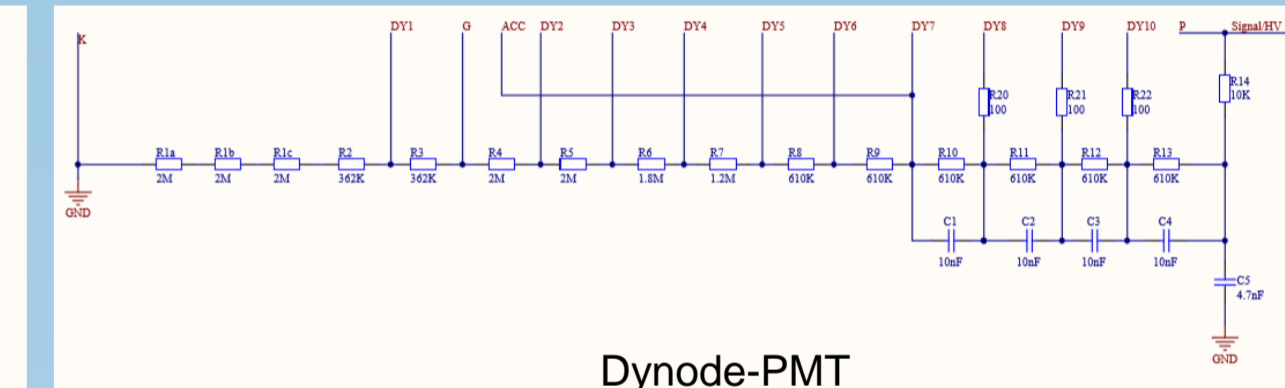
6. High Voltage Divider

JUNO requirements and design specifications

- Different dividers for MCP PMT and dynode PMT
- **Working current &HV:**
 - less than 300μA each divider
 - positive HV less than 3000 V
- **Dynamic range & Linearity**
 - full dynamic range: 4000 p.e.
 - non-linearity: < 10% for 1000p.e.;
- **Overshoot & ringing:** less than 1%
- Voltage ratio is optimized and reached the best performance of PMT;
- **Reliability:** failure rate < 0.1% for the first 6 years



MCP-PMT



Dynode-PMT



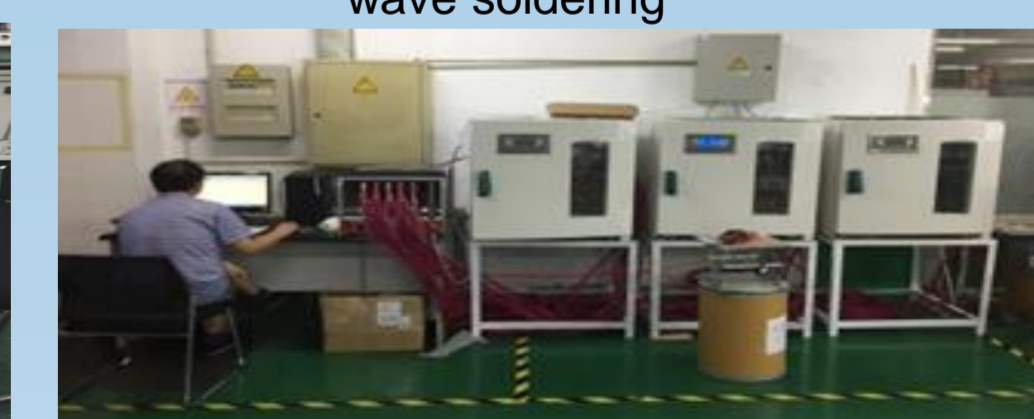
components assembly



wave soldering



a batch of produced high voltage dividers



screening test

Current status:

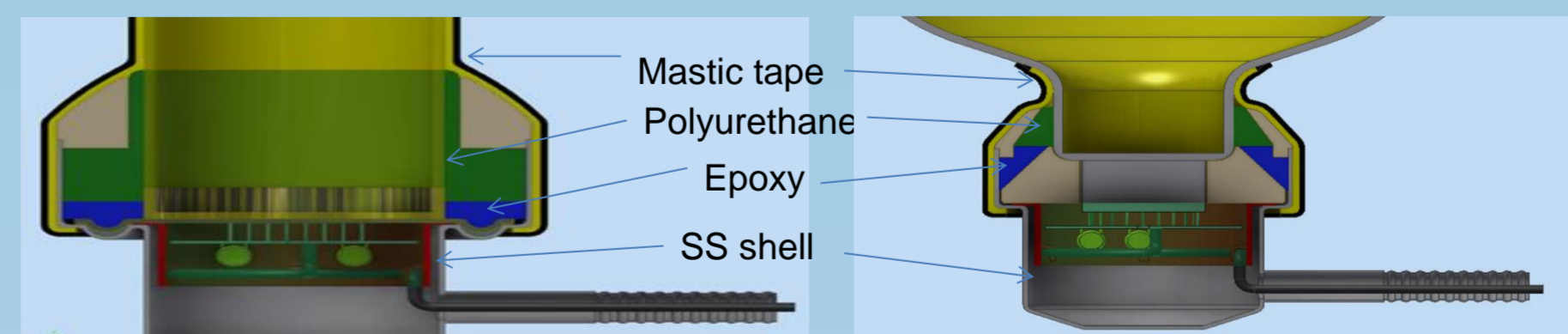
- Mass production is finished now, all 20000 dividers have been produced and delivered to PMT testing & potting workshop.
- All dividers are experienced a two-week test at 80°C for a early failure screening.

7. Waterproof Potting

- **The potting is designed with multiple waterproof layers;**
 - **stainless-steel shell** acts as a pressure-resistant house;
 - **epoxy** is for structural adhesion between shell and glass;
 - **polyurethane** is used as a filling sealant;
 - **mastic tape** is used as the outmost layer of sealing;

JUNO potting is approaching the end.

- A Potting Laboratory with 650m² area is built in the PMT workshop;
- Potting was started in July of 2019, with 40 – 50 PMTs potted per day;
- So far 18000 PMTs have been potted, no leaks found by a leakage test using pressurized water and SF₆ gas.
- Will be finished in 2~3 months.



Design of MCP PMT potting

Design of Dynode PMT potting



Potting workshop



Potted PMTs

8. PMT implosion Protection

Final design of the PMT implosion protection has been finished

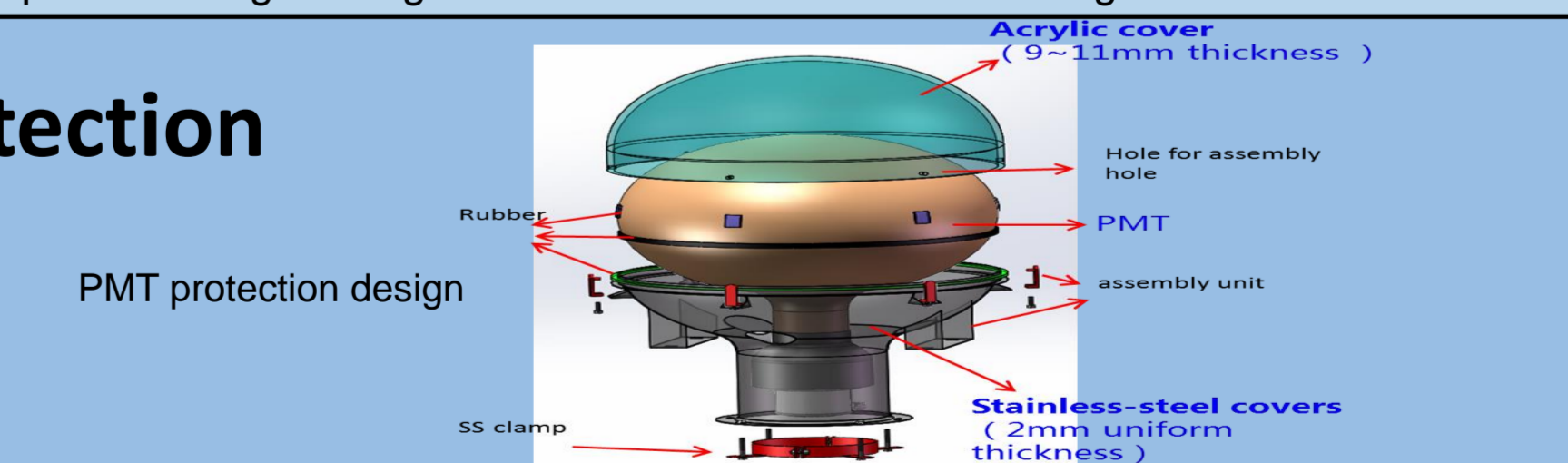
- top cover: **acrylic**, 9~11mm thickness varying from equator to top;
- bottom cover: **stainless-steel**, 2mm thickness uniformly;
- connection parts and assembly;

The acrylic cover has started for mass production

- So far about 6000 covers been produced;
- good yield rate larger than 90%;
- light transparency of the covers reach 91.5% in air and 98% in water;

The stainless-steel cover will start production very soon

- all production steps are tested and prototyped,
- production will be soon in a month



the injection machine



the produced acrylic covers in storage



A n acrylic cover



A stainless-steel cover