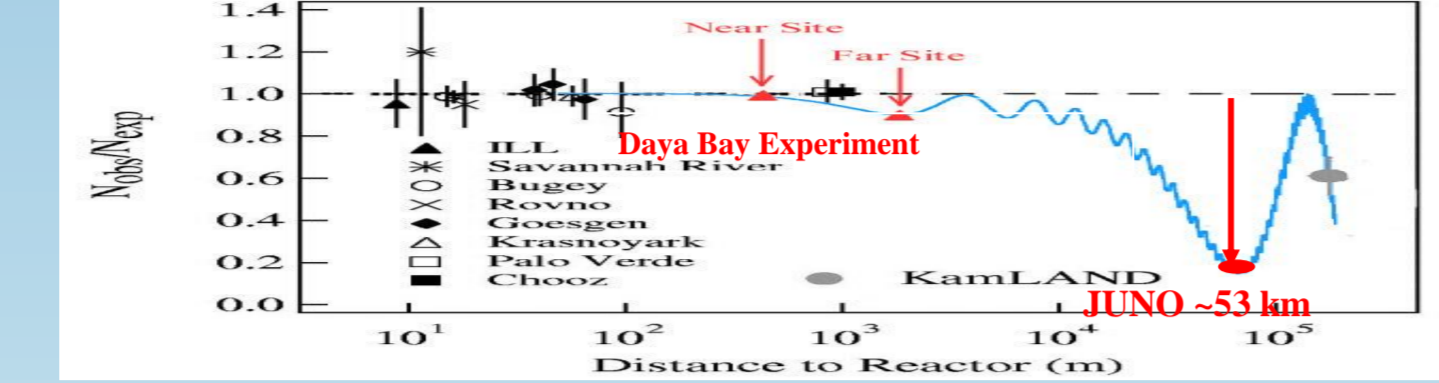


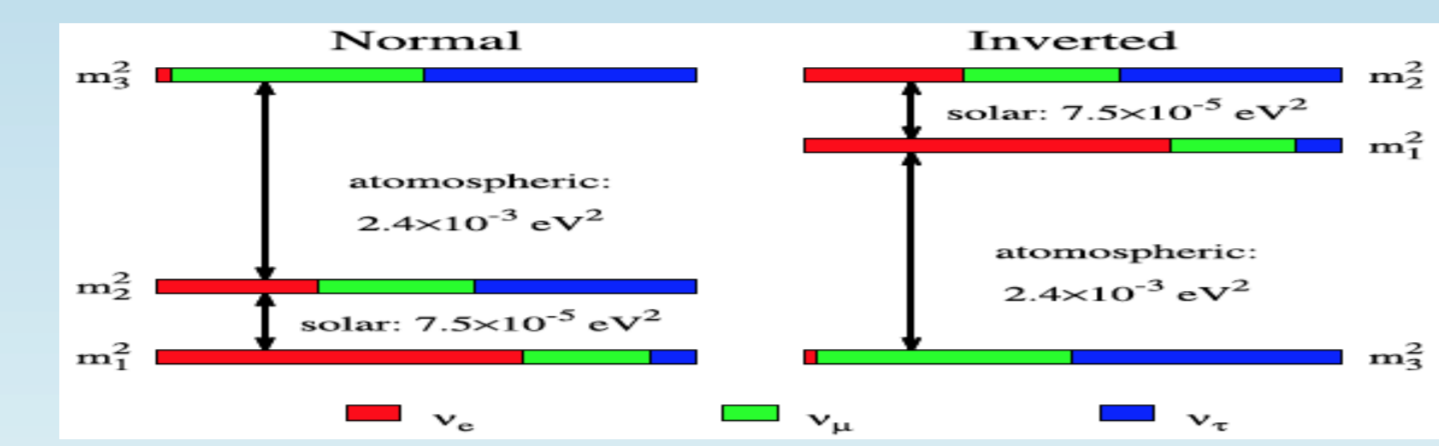
1. the JUNO experiment

The Jiangmen Underground Neutrino Observatory (JUNO) is a multipurpose neutrino experiment. It is located 700m underground in Jiangmen, Guangdong province. The JUNO experiment is 53km away from both Yangjiang and Taishan nuclear power plants, which will reach 26.6GW in 2020.



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

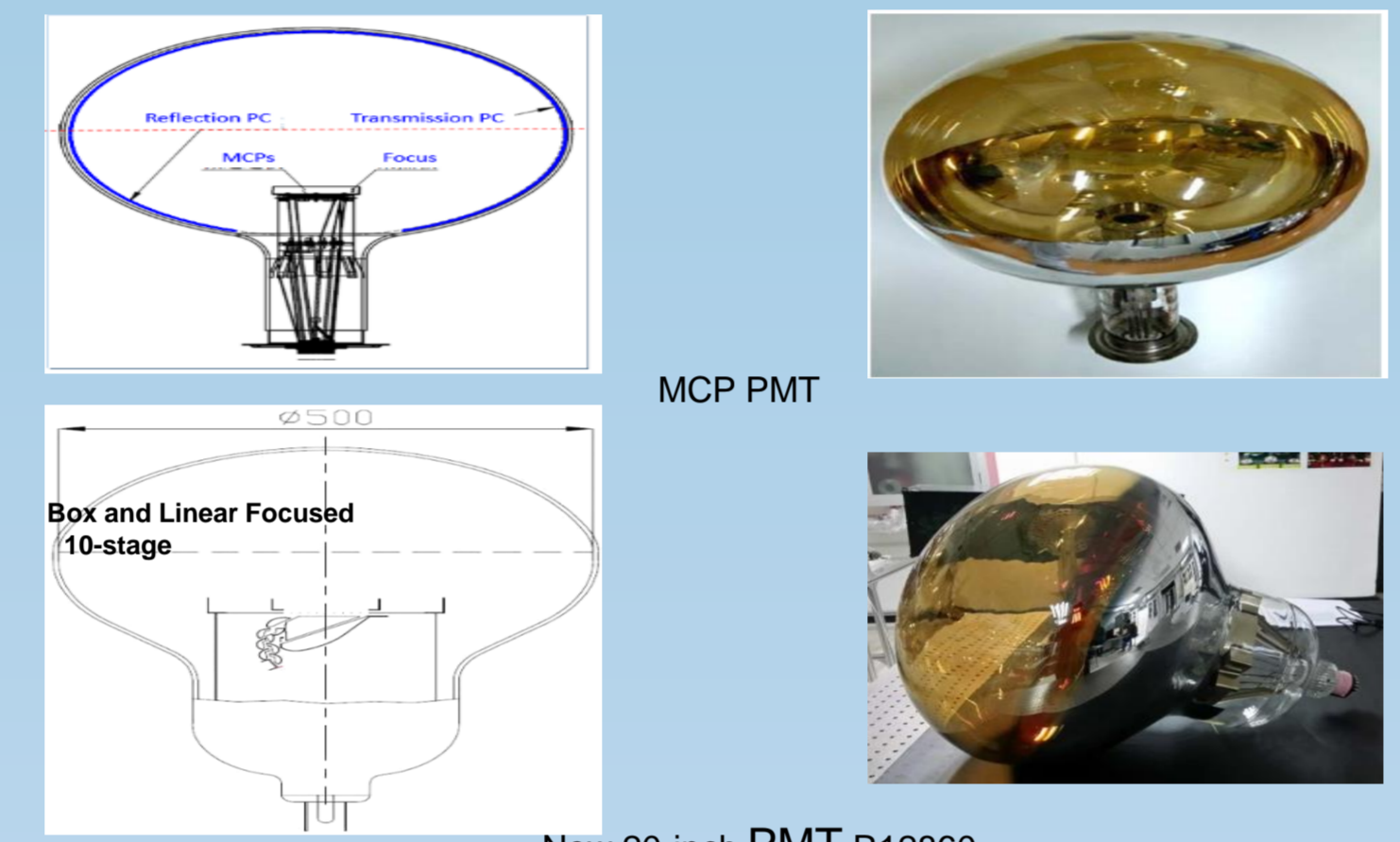


3. the 20-inch PMTs

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

- 15000 are MCP PMTs produced by NNVT
 - High QE: transmission photocathode at top hemisphere + reflection photocathode at the bottom
 - High CE: less shadowing effect
 - Low radioactivity glass shell
 - 5000 are dynode PMTs from Hamamatsu with Box & Line dynode structure
- JUNO specifications:

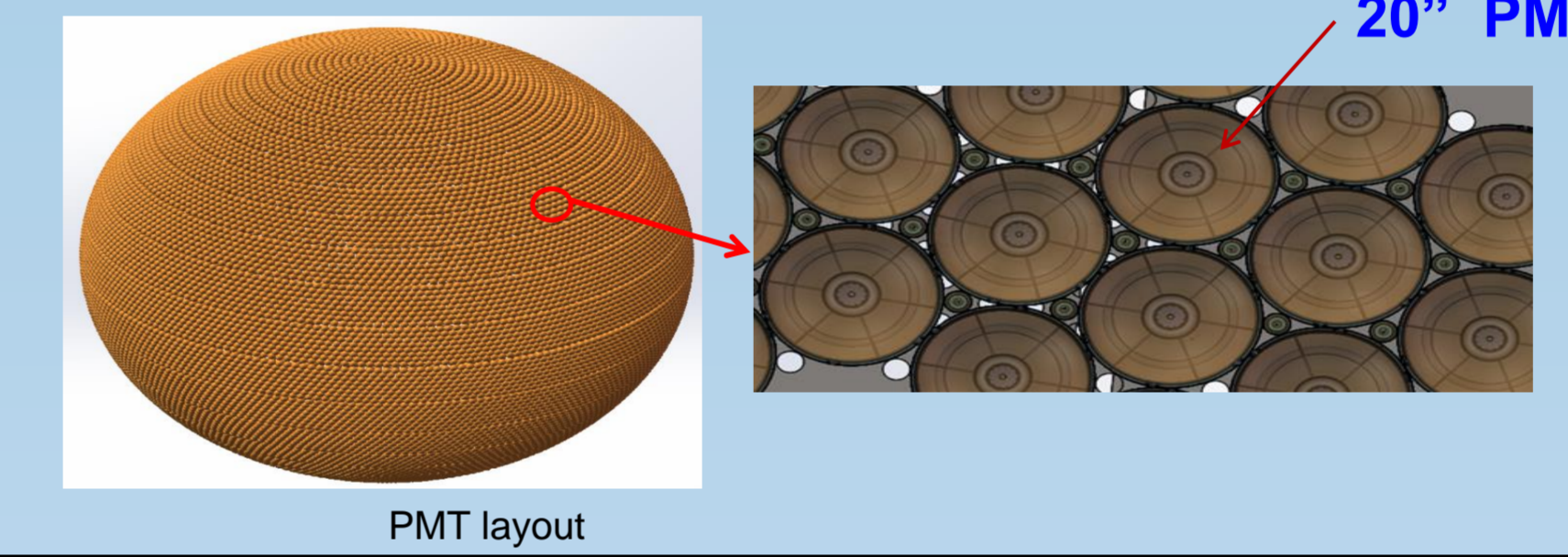
Parameters	unit	MCP-PMT (NNVT)	R12860 (Hamamatsu)
Detection Efficiency (QE*CE)@420nm	%	27, >24	27, >24
HV@10 ⁷ Gain	V	2500, <2800	2000, <2500
PV		3.5, > 2.8	3, > 2.5
TTS (FWHM)	ns	12, < 15	2.7, < 3.5
Rise time/ Fall time	ns	1.7 / 12	5 / 9
Dark noise rate	KHz	20, <100	10, <50
Pre pulse / After Pulse	%	0.5/1.0 (count)	1.5 / 15 (charge)
Non-linearity(0-1000pe)	%		10
Radioactivity of glass	ppb	²³⁸ U:50 ²³² Th:50 ⁴⁰ K: 20	²³⁸ U:400 ²³² Th:400 ⁴⁰ K: 40



4. Overview of the 20-inch PMT instrumentation

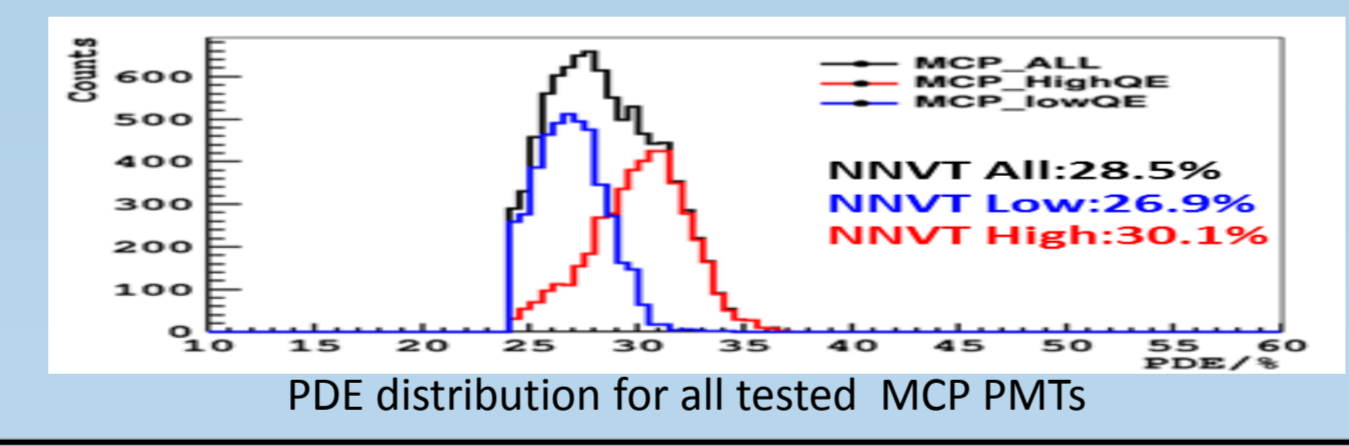
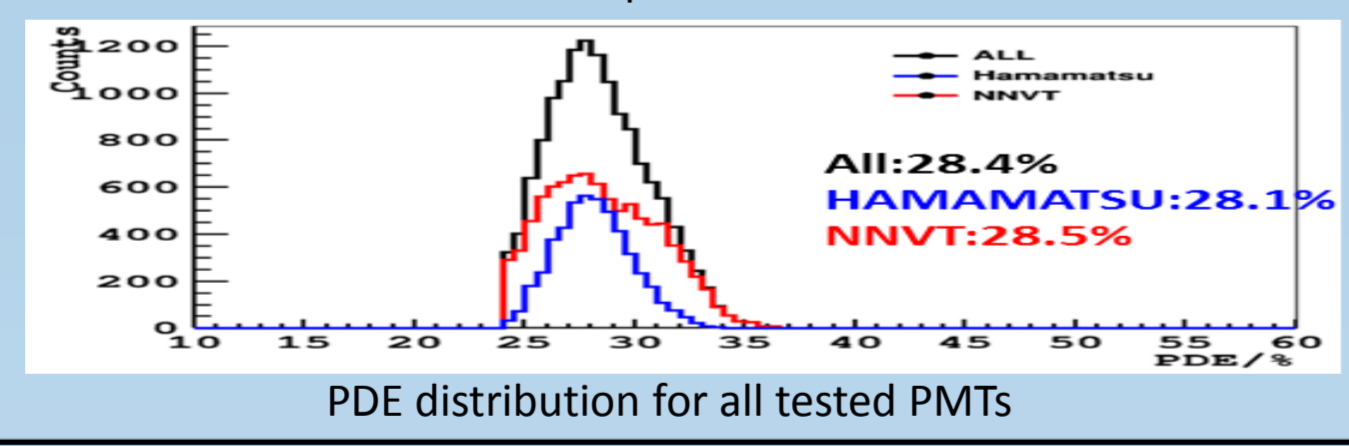
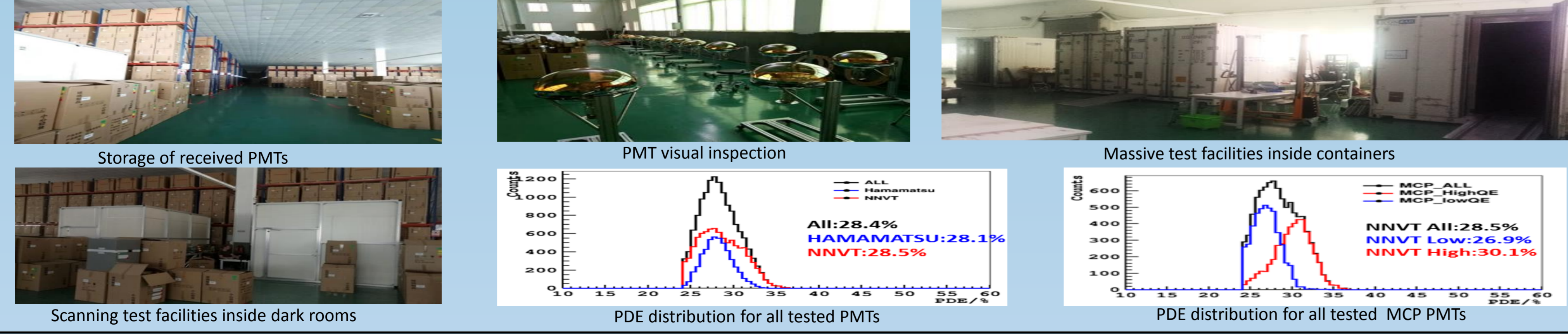
The goal of PMT instrumentation is to instrument all 20" PMT, including PMT testing, high voltage divider, waterproof potting, implosion protection and assembly.

- **PMT testing:** including acceptance test and performance characterization. The test facilities can test 72 PMTs per day.
- **High voltage divider:** each PMT need to be equipped with a high voltage divider.
- **Waterproof potting:** keep the PMT external electrodes and the high voltage divider isolated from water, with a failure rate controlled being 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 mentioned above into a PMT assembly.



5. Acceptance and testing of 20-inch PMT

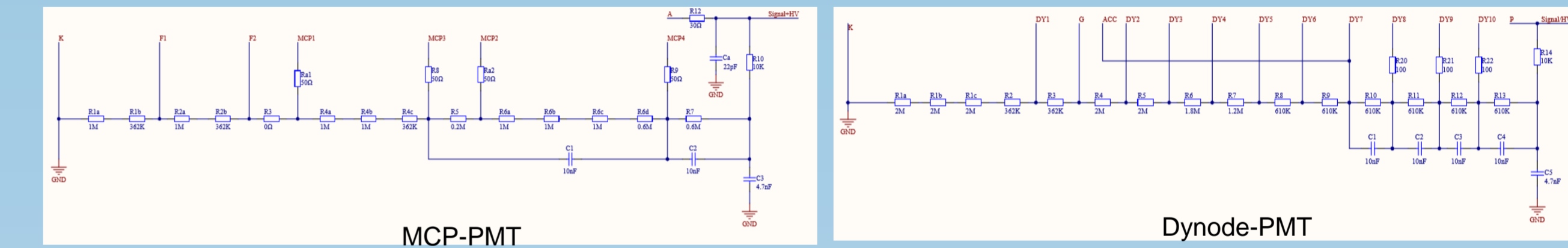
- JUNO has received about 19000 PMTs (~14000 MCP PMTs and 5000 dynode PMTs) by now, a warehouse near to JUNO site with 4500 m² area is used to store these PMTs;
- Test facilities are equipped in standard containers and customized dark rooms in the warehouse;
- Over 17000 PMTs have been tested for both visual quality and performance;
- The photon detection efficiency (PDE) for all PMTs is 28.4% in average, with MCP PMT is 28.5% and Dynode PMT is 28.1%, respectively.
- The PDE for MCP PMT is increasing, with the PDE reaching 30.1% for lately received PMTs.



6. High Voltage Divider

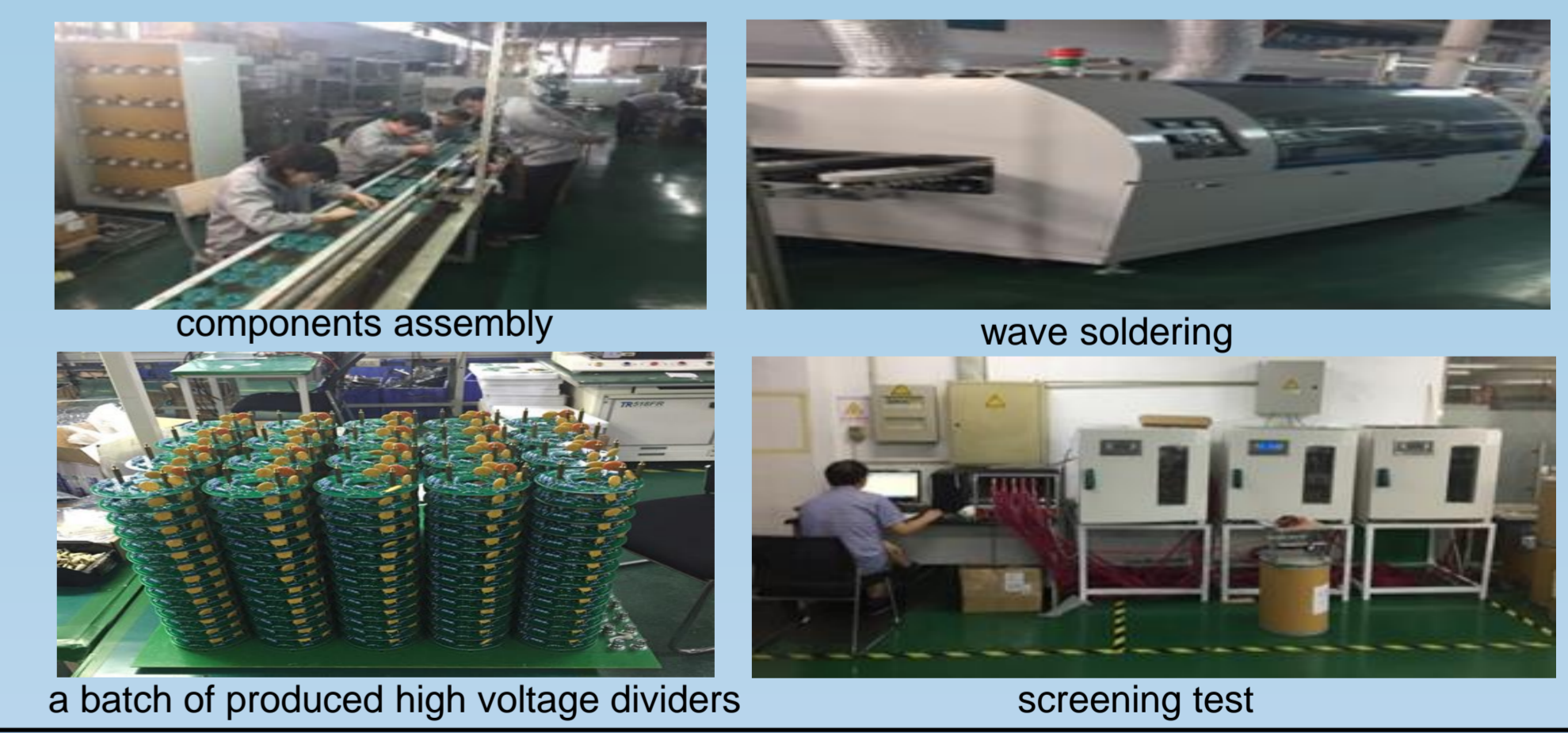
JUNO requirements and design:

- Two types: for MCP PMT and dynode PMT
- **operating current & HV:**
 - less than 300μA@3000V
 - gain at 10⁷ and positive HV
- **Dynamic range & Linearity**
 - full dynamic range: 4000 p.e.
 - non-linearity: < 10% for 1000p.e.;
- **Overshoot & ringing:** less than 1%
- Proper distribution ratio of voltage and total resistance, to get the best performance of a PMT;
- **Reliability:** failure rate < 0.1% for the first 6 years



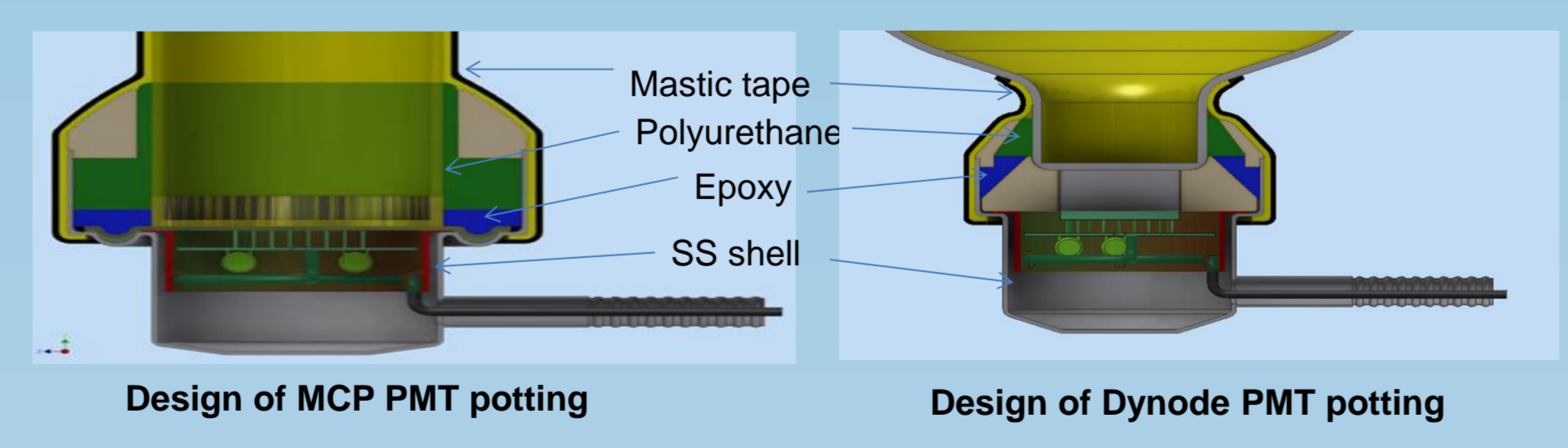
Current status:

- mass production is ongoing, components are soldered to PCBs by wave soldering, 16000 dividers have been produced;
- two-week screening test at 80°C is performed to select early failure products;



7. Waterproof Potting

- **The potting is designed as 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;

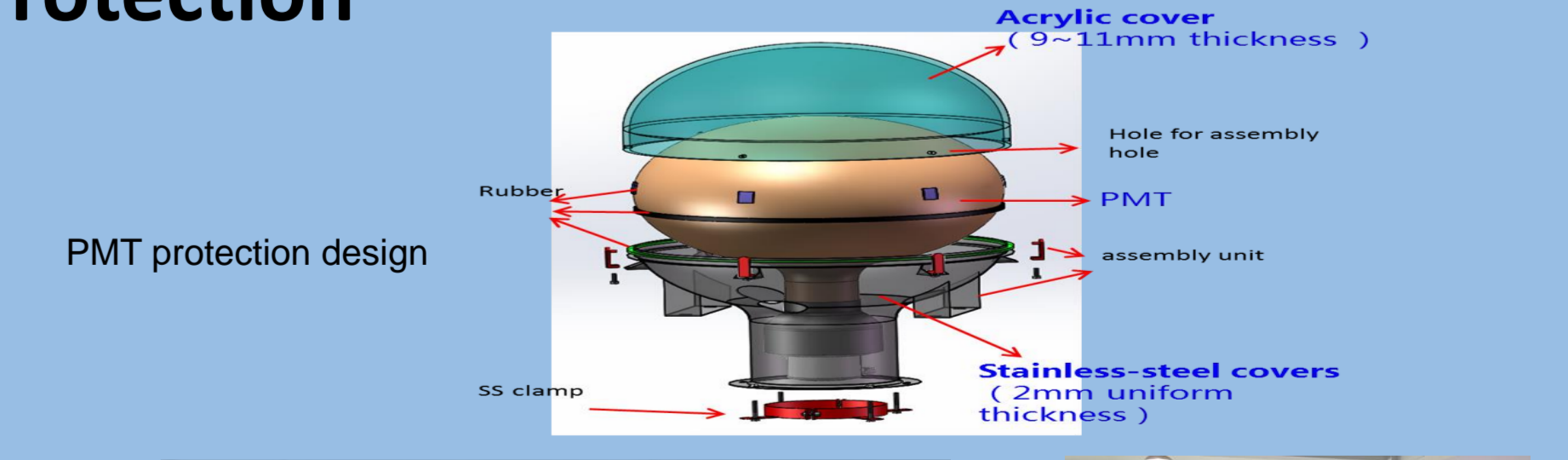


- **JUNO potting has officially started**
 - A Potting Laboratory with 650m² area is built in the PMT warehouse;
 - Potting was started in July of 2019, with 40 – 50 PMTs potted per day;
 - So far about 7000 PMTs have been potted, no leaks found after leakage test done by pressurized water or gas.



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 is fabricated by injection moulding**
 - a pair of moulds have been machined and polished;
 - pilot production have been finished with covers produced successfully;
 - light transparency of the covers reach 91% in air, only 1% loss due to absorption by acrylic;



- **The stainless-steel cover is fabricated by stamping technology**
 - moulds have been machined and trialed, samples are produced successfully

