The 20-inch PMT Instrumentation for the JUNO experiment

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on behalf of the JUNO Collaboration

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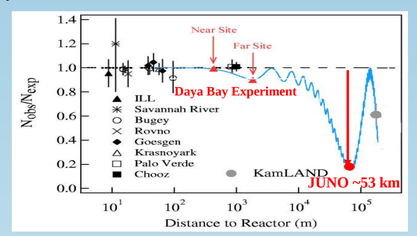
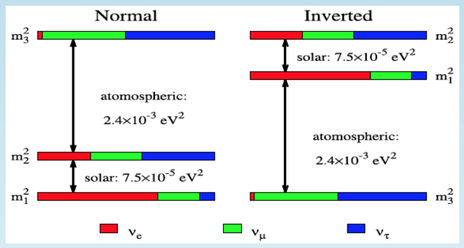
1. the JUNO experiment

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



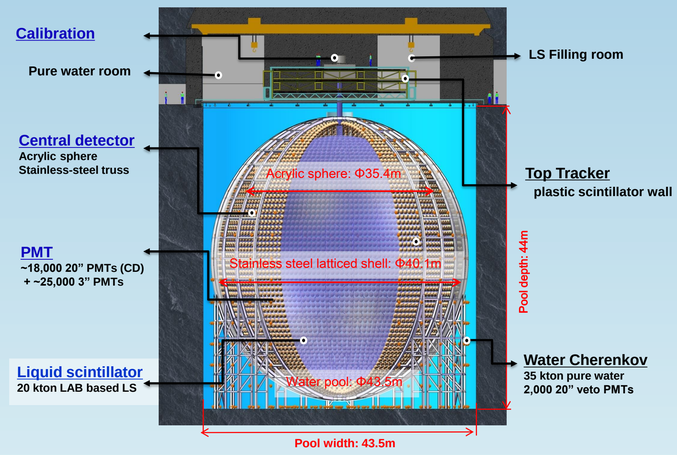
There are rich physics listed below for JUNO. The main scientific goal is determination of the neutrino mass hierarchy (MH) by detecting the reactor antineutrinos from those nuclear power plants.

- Mass hierarchy
- Precision measurement of mixing parameters
- Supernova neutrinos
- Geo-neutrinos
- Solar neutrinos
- Sterile neutrinos
- Atmospheric neutrinos
- Exotic searches



2. Overview of the JUNO Detector

The JUNO detector consists of central detector, liquid scintillator (LS), PMT system, VETO detector and calibration system. To reach 3%/√E(MeV) energy resolution, the central detector will build a large acrylic vessel and a stainless-steel truss which hold 20kt liquid scintillator, 20000 20-inch PMTs and 25000 3-inch PMTs. The VETO detector will divide into a top tracker and a water Cherenkov detector. The calibration system will provide different methods for JUNO calibration.



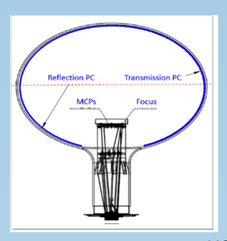
3. the 20-inch PMT sensors

JUNO 20-inch PMT system includes totally 20000 PMTs, in which:

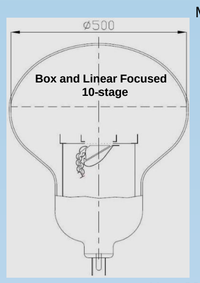
- 15000 PMTs are the MCP PMT produced by Chinese team (IHEP + NNVT)
  - Higher QE: transmissive photocathode at top + reflective photocathode at bottom
  - High CE: less shadowing effect
  - Low radioactivity glass shell
- The rest 5000 20" PMTs are the dynode PMT from Hamamatsu

JUNO PMT specifications:

Characteristics	unit	MCP-PMT (NNVT)	R12860 (Hamamatsu)
Detection Efficiency (QE*CE)	%	27%, > 24%	27%, > 24%
P/V of SPE		3.5, > 2.8	3, > 2.5
TTS	ns	~12, < 15	2.7, < 3.5
Rise time/ Fall time	ns	R~3, F~12	R~5,F~9
Anode Dark Count	Hz	20K, < 30K	10K, < 50K
After Pulse Rate	%	1, <2	10, < 15
Radioactivity of glass	ppb	238U:50 232Th:50 40K: 20	238U:400 232Th:400 40K: 40



MCP PMT

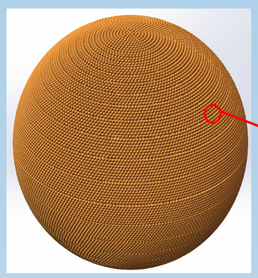


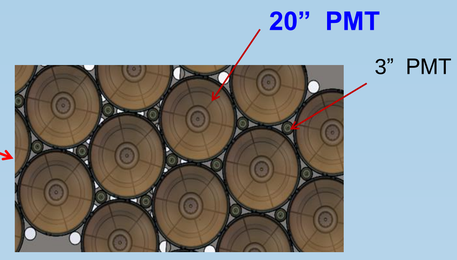
New 20-inch PMT R12860

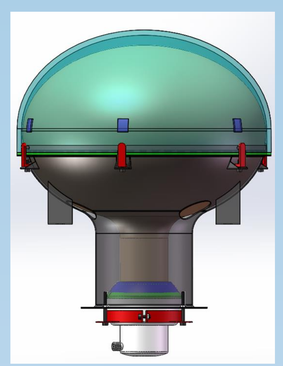
4. the 20-inch PMT instrumentation

The goal of PMT instrumentation is to instrument the 20000 20" PMT into the JUNO detector, including mass testing, base production, waterproof potting, implosion protection and installation.

- Mass testing: for the acceptance test and performance characterization. Two of the four test facilities were built and running, it can test 72 PMTs per day.
- Waterproof potting: to make the PMT and its base water tight with a target failure rate <0.5% for the first 6 years. Designed as multiple waterproof layers.
- Implosion protection: to protect the PMT from chain implosion. Designed as acrylic + stainless-steel protective covers. prototypes produced and many implosion tests done;
- Installation: install the single PMT to module, and then install the module to JUNO detector. Designed to achieve 75% optical coverage, only 3 mm clearance between the adjacent PMTs.

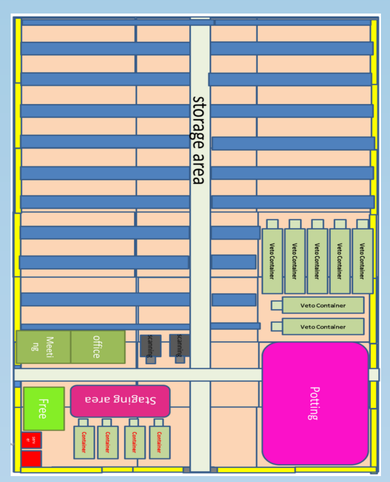






5. Acceptance and testing of 20-inch PMT

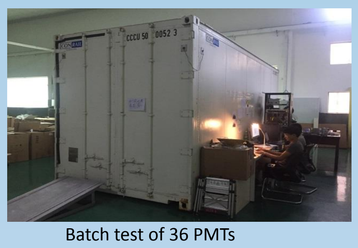
- JUNO has received about 9000 PMTs (~5500 MCP PMTs and 3500 Hamamatsu PMTs);
- A test, potting and storage station of 4500m^2 has been prepared near to JUNO site;
- Performance test and visual inspection has started;
- The average d DE(detection efficiency) of both MCP PMTs and dynode PMTs is larger than 27%;
- Visual inspection shows MCP-PMT has better glass quality than dynode PMT.



the test and potting station

Storage of received PMTs

PMT visual inspection



Batch test of 36 PMTs within a container

scanning test of PMT within a dark room

6. PMT High Voltage Divider

JUNO requirements:

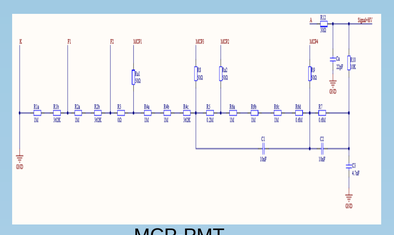
- Two types: MCP PMT and dynode PMT
- DC current &HV:
  <300μA@3000V, Gain 10^7, Positive HV,
- Dynamic range & Linearity
  - full dynamic range: 4000 p.e
  - non-linearity: < 10% for 1000 p.e;
- Overshoot and ringing:
  about 1% with 50Ω load
- Reliability: failure rate < 0.1%/ 6 year

MCP-PMT signal optimization:

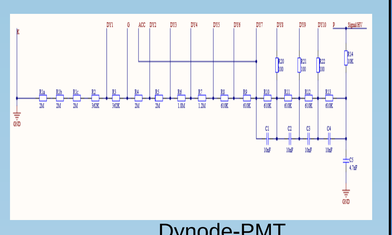
- Slower rise time : ~4 ns;
- Smoother falling edge;
- Larger SPE amplitude

Test of Flasher:

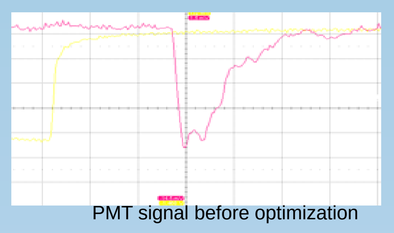
- original lasher rate : 0.1~1Hz, mainly due to that the soldering point is not smooth;
- after improvement of the soldering: Flasher rate down to 0.0001Hz



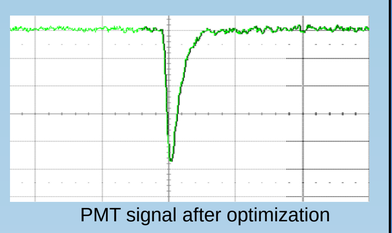
MCP-PMT



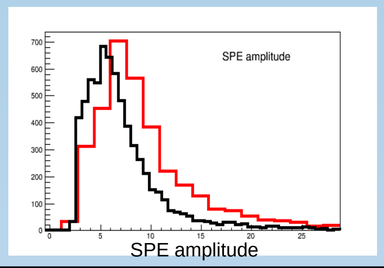
Dynode-PMT



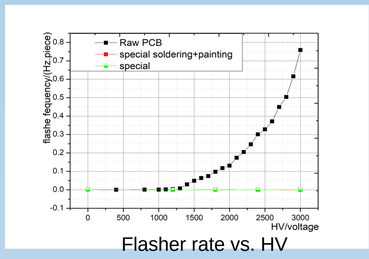
PMT signal before optimization



PMT signal after optimization



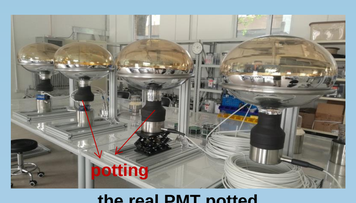
SPE amplitude



Flasher rate vs. HV

7. Waterproof Potting

- **The final design is done with multiple waterproof layers;**
  - stainless-steel shell acts as a pressure-resistant container;
  - epoxy is used for structural adhesion between shell and glass;
  - mastic tape is for the first layer of water sealing;
- **200 prototypes have been manufactured and tested;**
  - 100 samples each for MCP PMT and Hamamatsu PMT;
  - More than 10 temperature cycles;
  - Long term water-tight test;
  - Accelerated aging test;
  - Vacuum test;
- **On-site potting workshop is under preparation**
  - start potting from Jan. 2019;
  - 50~60 PMTs per day;



the real PMT potted

200 potting samples

temperature cycling

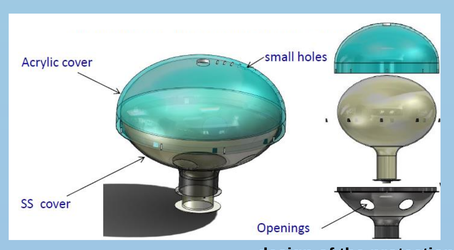
Water-tight test

accelerated aging test

vacuum test

8. PMT implosion Protection

- **Final design of the PMT implosion protection:**
  - top cover: acrylic, 9~11mm thick from equator to top;
  - bottom cover: stainless-steel, 2mm thick uniformly;
- **Many implosion tests have been done with different configurations:**
  - 3 PMTs, 5 PMTs and 7 PMTs;
  - test performed in the pressurized water tank;
  - shock wave triggered by the bare PMT in the center;
  - strength of the shock wave measured by pressure sensor;
  - video recorded by high-speed camera;
- **Prototypes of the acrylic and stainless steel cover are produced:**
  - acrylic cover made by injection molding;
  - stainless steel cover made by stamping;



design of the protection

Implosion test

Prototypes of the bottom cover