Status of 20-inch PMT Instrumentation for the JUNO experiment
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On behalf of JUNO collaboration

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

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-ton 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.

3. the 20-inch PMT Specifications

There are totally 20000 20-inch PMTs in JUNO, in which:
- 15000 MCP PMTs of Goo-621 type produced by NIMT in China
- 5000 dynode PMTs of R12865-50 type with Box & Line dynode structure from Hamamatsu in Japan

The JUNO specifications of the 20-inch PMTs:

- Photon Detection Efficiency @420nm
- Voltage ratio is optimized and reached the best performance of PMT;

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.

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.

6. High Voltage Divider

JUNO requirements and design specifications
- Different dividers for MCP PMT and dynode PMT
- Working current MHz:
  - less than 300μA each divider
  - positive HV less than 3000 V
- Dynamic range & Linearity:
  - full dynamic range: 4000 p.e.
  - non-linearity: < 10% for 1000 p.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

Current status:
- Basic 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;
  - 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.

8. PMT Implosion Protection

- Final design of the PMT implosion protection has been finished
  - top cover: acrylic, 3.23mm 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 have 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