The 20-inch PMT system for the JUNO experiment

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Outline

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- The JUNO detector
- Overview of 20” PMT system
- 20” PMT Sensors
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- Test results of photon detection efficiency
- PMT high voltage divider
- PMT Potting
- PMT protection
- PMT installation
- Summary
the JUNO experiment

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

- ~53km from the Yangjiang and Taishan NPP
- ~700m under ground

<table>
<thead>
<tr>
<th>NPP</th>
<th>Daya Bay</th>
<th>Huizhou</th>
<th>Lufeng</th>
<th>Yangjiang</th>
<th>Taishan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status</td>
<td>Operational</td>
<td>Planned</td>
<td>Planned</td>
<td>Under construction</td>
<td>Under construction</td>
</tr>
<tr>
<td>Power</td>
<td>17.4 GW</td>
<td>17.4 GW</td>
<td>17.4 GW</td>
<td>17.4 GW</td>
<td>18.4 GW</td>
</tr>
</tbody>
</table>

~ by 2020: 26.6 GW
the JUNO detector

- **Target:** 3%/E(MeV) energy resolution, largest liquid scintillator detector in the world
  - the central detector: 20kton liquid scintillator, **18000 20” PMTs** + 25000 3” PMTs;
  - the VETO detector: a top tracker of plastic scintillator walls + a water Cherenkov detector of 35kton ultra-pure water and **2000 20” PMTs**;
  - the calibration system: four complementary calibration methods

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**Central detector**

- **Mechanical structure**
  - Acrylic sphere
  - Stainless-steel truss

- **PMT**
  - 18,000 20” PMTs
  - 25,000 3” PMTs

- **Liquid scintillator**
  - 20 kton LS

**Calibration system**

- ACU, ROV, etc.

**VETO detector**

- Top Tracker
  - 62 Plastic scintillator walls

- Water Cherenkov
  - 35 kt high-purity water
  - 2000 20” PMTs

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- Acrylic sphere: Φ35.4m
- Stainless-steel struss: Φ40.1m
- Water pool: Φ43.5m
Overview of the 20” PMT system

- PMT sensors: totally 20000 20” PMTs
- PMT testing: acceptance test, parameter characterization
- PMT voltage divider: PMT high voltage supply and operating parameter optimization
- PMT potting: waterproof sealing of divider, pin and cable;
- PMT protection: prevent implosion chain reaction
- PMT integration/installation
20” PMT Sensors

- 15000 MCP-PMTs are from NNVT (North Night Vision of Technology CO., LTD, China).
- 5000 dynode-PMTs are from Hamamatsu company.

- the JUNO specifications

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>unit</th>
<th>MCP-PMT (NNVT) Typical value, limit</th>
<th>R12860 (Hamamatsu) Typical value, limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection Efficiency (QE*CE)</td>
<td>%</td>
<td>27%, &gt;24%</td>
<td>27%, &gt;24%</td>
</tr>
<tr>
<td>P/V of SPE</td>
<td></td>
<td>3.5, &gt; 2.8</td>
<td>3, &gt; 2.5</td>
</tr>
<tr>
<td>TTS on the top point</td>
<td>ns</td>
<td>~12, &lt; 15</td>
<td>2.7, &lt; 3.5</td>
</tr>
<tr>
<td>Rise time/ Fall time</td>
<td>ns</td>
<td>R<del>3, F</del>12</td>
<td>R<del>5,F</del>9</td>
</tr>
<tr>
<td>Anode Dark Count</td>
<td>Hz</td>
<td>20K, &lt; 30K</td>
<td>10K, &lt; 50K</td>
</tr>
<tr>
<td>After Pulse Rate</td>
<td>%</td>
<td>1, &lt;2</td>
<td>10, &lt; 15</td>
</tr>
<tr>
<td>Radioactivity of glass</td>
<td>ppb</td>
<td>238U:50 232Th:50 40K: 20</td>
<td>238U:400 232Th:400 40K: 40</td>
</tr>
</tbody>
</table>
Acceptance and testing of 20” PMT

- A test and storage warehouse of 4500m² has been prepared near to JUNO site.
- JUNO has received about 10000 PMTs: 6K from NNVT + 4K from Hamamatsu
- Visual inspection and performance test are ongoing:

  7k finished for visual inspection, and 5k finished for performance test

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**Storage of received PMTs**

**PMT visual inspection**

**Batch test of 72 PMTs in two container systems**

**photocathode scanning test**
Test results on photon detection efficiency (PDE)

- For the early delivered PMTs (batch #1 to #17)

  - PDE in average, 30.1% in average, 35% for the highest

  - Averaged PDE: 27.9%
    - NNVT: 27.5%
    - Hamamatsu: 28.3%

- For the newly delivered NNVT PMTs (Batch #18, 253 pieces)

  - PDE is largely improved: 30.1% in average, 35% for the highest

  - Data from NNVT (all 253 PMTs): 30.1%

  - Confirmed by JUNO testing (100 PMTs sampled): ~32%

Refers to the talks “characterization of the 20-inch PMT for the JUNO Central detector” and “The R&D, mass production of the 20 inch PMT for neutrino detector” for more information.
High voltage divider

- The final design finished, mass production is under preparation

  - 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: <1%
  - Smooth signal shape: Rise/Falling time: 3ns/12ns
  - Reliability: failure rate <0.1%/6 year

Flasher rate is significantly reduced by improvement on soldering

- Original flasher rate: 0.1@1500v to 1Hz@3000v
- After improvement: 10^{-4}Hz @ 3000V

see poster D_71 for more information
PMT potting

• The final design is finished with multiple waterproof layers;
  - stainless-steel shell acts as a pressure-resistant container;
  - epoxy/Polyurethane is used for structural adhesion between shell and glass;
  - Butyl tape is for the first layer of water sealing;

• 200 prototypes have been produced and tested;
  - 100 samples each for MCP PMT and Hamamatsu PMT
  - temperature cycling test
  - Long-term water-tight test (half a year up to now)
  - Accelerated aging test
  - No leaking observed so far

• Start potting of the real PMTs from Jan. 2019
PMT implosion Protection (1)

- **Requirement**
  - Prevent chain reaction triggered by one PMT implosion;

- **Study with naked PMT**

  - **Design of protective cover:**
    - Acrylic + stainless steel
    - 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;

see also poster # D_79 for more information
PMT implosion Protection (2)

- **Protective cover prototyping**
  - totally produced more than 60 acrylic covers and stainless-steel covers;
  - done by injection molding for the acrylic and by stamping for the stainless-steel;

- **Implosion test with multiple PMTS**
  - tested many times with 2 PMTs, 3 PMTs, ..., 7 PMTs with different cover thickness;
  - 9 ~11mm non-uniformly thick acrylic cover and 2mm thick stainless-steel cover is the current choice;
1. JUNO requirement on PMT Coverage:
   > 75%
   → distance between PMT covers: 3 mm;
   • Diameter of PMT: 508mm;
   • Thickness of cover: 9mm
   • gap between cover and PMT: 2mm
   -> Clearance between PMT covers: 3mm
   -> PMT center to center: 533mm;
   → lose 0.25% coverage if increasing distance by 1mm;

2. A possible layout reaches 17510 PMTs, coverage is 75.1% - a demo. was constructed

3. Final installation of PMT on the JUNO detector is under design - bidding of the installation company was finished
Summary

- 20000 20” PMTs will be used for the JUNO experiment;
- About 10000 20” PMTs have been delivered:
  - 6000 MCP PMTs (NNVT) and 4000 dynode PMTs (Hamamatsu);
- Photon detection efficiency of the delivered PMTs is about 27.9%;
- Newly produced NNVT PMTs has improved the PDE from 27.5% to 30.1%, reaching 35% for the highest;
- PMT high voltage divider, potting and protection has finished the final design and prototyping, mass production is under preparation (need ~2 years for production);
- PMT integration is required to reach 75% optical coverage;
- PMT related work is scheduled to be finished in 2020;