JUNO 20-inch PMT Testing Systems and Progress

presented by

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MOTIVATION FOR PMT TESTING: ENERGY RESOLUTION

High optical coverage (>75%) of the central detector volume (20 kt LSc = neutrino target)

⇒ (mainly) consists of ~ 17600 20-inch PMTs
⇒ additional ~ 2400 20-inch PMTs used in the water pool (active Cherenkov veto)
⇒ two PMT types in use in JUNO:

- 5000 dynode PMTs
  - type Hamamatsu R12860
- 15000 MCP-PMTs
  - type NNVT N6201

20'000 20-inch PMTs in total

Main design goal:

\[ \sigma(E) = 3\% / \sqrt{E} \]

Impeccable performing PMTs
(high photon detection efficiency, low noise level, good timing/charge resolution, ...)

⇒ list of individual PMT performance requirements

<table>
<thead>
<tr>
<th>Parameter</th>
<th>unit</th>
<th>tube type</th>
<th>Min.</th>
<th>typical</th>
<th>Max.</th>
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<tbody>
<tr>
<td>PDE @ 420 nm</td>
<td>%</td>
<td>both</td>
<td>24.0</td>
<td>27.0</td>
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<tr>
<td>P/V ratio of SPE</td>
<td></td>
<td>Hamamatsu</td>
<td>2.5</td>
<td>3.0</td>
<td>-</td>
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<tr>
<td></td>
<td></td>
<td>NNVT</td>
<td>2.5</td>
<td>3.5</td>
<td>-</td>
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<tr>
<td>DCR @ 0.25 PE</td>
<td>kHz</td>
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<td>20</td>
<td>50</td>
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<td></td>
<td></td>
<td>NNVT</td>
<td>-</td>
<td>-</td>
<td>100</td>
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<tr>
<td>Rise Time</td>
<td>ns</td>
<td>Hamamatsu</td>
<td>-</td>
<td>8.5</td>
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<tr>
<td>Fall Time</td>
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<td>-</td>
<td>12.0</td>
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<td>Supply HV (@ G = 10^7)</td>
<td>V</td>
<td>Hamamatsu</td>
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<td>-</td>
<td>12.0</td>
<td>15.0</td>
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<tr>
<td>PPR</td>
<td>%</td>
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<td>0.8</td>
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<tr>
<td>APR</td>
<td>%</td>
<td>Hamamatsu</td>
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<td>10</td>
<td>15</td>
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<td>NNVT</td>
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<td>-</td>
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<td>QE Non-Uniformity</td>
<td>%</td>
<td>both</td>
<td>5</td>
<td>15</td>
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<td>Non-Linearity &lt; 10%</td>
<td>% PE</td>
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<td>1000</td>
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<td>Spectral Response</td>
<td>nm</td>
<td>both</td>
<td>-</td>
<td>300-600</td>
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<tr>
<td>Res.</td>
<td>(2πθ)</td>
<td>Hamamatsu</td>
<td>-</td>
<td>400</td>
<td>-</td>
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<td></td>
<td></td>
<td>NNVT</td>
<td>-</td>
<td>-</td>
<td>50</td>
</tr>
<tr>
<td>Radioactivity</td>
<td>(2πθ)</td>
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<td>400</td>
<td>-</td>
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<tr>
<td></td>
<td>ppb</td>
<td>NNVT</td>
<td>-</td>
<td>-</td>
<td>50</td>
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<tr>
<td>of glass</td>
<td>(%)</td>
<td>Hamamatsu</td>
<td>-</td>
<td>40</td>
<td>-</td>
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<tr>
<td></td>
<td></td>
<td>NNVT</td>
<td>-</td>
<td>-</td>
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</table>

compare also talk of Hans Steiger:
JUNO Detector Design and Status (Feb. 22 18:10, FID #229)
(1) PMT MASS TESTING CONTAINER SYSTEM

Two identical testing systems set up in commercial shipping (reefer) containers, capable for testing large numbers of 20-inch PMTs

- **36 drawer boxes** = channels for PMT testing per container
- **Climate control unit + improved magnetic shielding** of the container interior (down to 10% EMF)
- Every channel is equipped with **two light sources @ 420 nm**:
  - (1) self-stabilized LED (provided by JINR Dubna)
  - (2) picosecond Laser system
- **Homogeneous illumination** of the whole PMT photocathode at very low light intensities ($\mu \sim 0.05 - 2$ p.e.)
- Fully equipped with **commercial data taking electronics**
- PMT characterization supervised by **fully automated data acquisition software** based on LabView
  - sequence of individual measurements
  - tailored to 24h cycle and optimized to PMTs

**Paper to be published in the next few weeks**
(2) PMT PHOTOCATHODE SCANNING STATION

Two identical scanning stations operated in separate dark rooms, capable to perform detailed tests of a representative PMT sub-sample

- 7 self-stabilized LEDs @ 420 nm at different zenith angles mounted on a rotatable arch
  - individual measurements for each area surface element with very low light intensities (μ ~ 1.5 p.e.)
  - enables photocathode uniformity measurements / scans of the whole PMT photocathode with high spatial resolution

- Can also act as complementary system for cross-checking results from the PMT mass testing in the containers

- Active magnetic field suppression (by Helmholtz coils in the walls)
  - enables scans and surveys for influence of magnetic fields on the PMT performance (i.e. PDE)

- Automated data acquisition and analysis

- Additional setup with LED operated at higher light intensity (μ ~ 100 p.e.) optimized for afterpulse measurements

For more information see: arXiv:1705.05012
PMT TESTING STATUS AND RESULTS

- 75 containers x months and 84 scanning stations x months in total
- > 22,000 PMT delivered + tested with the containers
  → 19,950 PMTs accepted by Jan. 2021
  → Ham: <PDE> ~ 28.1 % ; <DCR> ~ 15.3 kHz
  → NNVT: <PDE> ~ 28.9 % ; <DCR> ~ 49.0 kHz
- Potting of PMTs ongoing
  → ~ 14,500 PMT potted, of which 4,800 PMTs have been tested a second time
  → 1,200 PMTs additionally tested together with final JUNO readout electronics
- > 3,100 PMTs scanned within the scanning stations
  → 600 PMTs randomly sampled (PDE uniformity)
  → only 2-3% with non-uniformity ≥15%
  → 150 PMTs tested for after-pulse contributions
- Very good agreement of PMT testing results between container system and scanning station
- PMT performance + testing result paper in preparation
Thank you.

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CONTAINER SYSTEM DETAILS

- Capable to characterize all 20,000 20-inch PMTs with good precision (e.g. $\Delta$PDE < 1%, S/N > 10)
- Stable and comparable conditions for all PMT tests
- PMT testing must fit to the JUNO schedule

ADVANTAGES OF REEFER CONTAINERS:

- Multi-channel system
- Very good light tightness
- Stable environmental conditions thanks to climate control units installed to the containers
- Good shielding against electromagnetic noise and stable magnetic fields (such as the EMF)
- High flexibility and versatility

Main light source:
- Self-stabilized LED (420 nm) by HV Sys
- Collimator (aluminum, 1.2 mm hole), equipped with neutral density filter for light attenuation
- Optical fiber connected to ps-Laser (420 nm)
- PTFE diffuser
CONTAINER SYSTEM DETAILS II

- Two containers equipped with **commercial data taking electronics** covering all 36 channels per container
- Controlled and monitored via PC (onsite and remotely)

- **Fully automated data acquisition software** (DAQ)
  - based on LabView
  - sequence of individual measurements, performing a full PMT characterization
  - remote operation during the Covid19 pandemic
MORE (exemplary) PMT RESULTS ACQUIRED BY THE CONTAINER SYSTEM
TESTING PROCEDURE AND PMT CLASSIFICATION CRITERIA

- **Testing procedures**
  - Unpacking
  - Visual Inspection
  - Preparation of PMTs
  - Loading + Testing
  - Scanning Station Tests

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Mass Test

- The 1st time
  - Retest
  - Can not meet the requirements

Container

- Apart from PDE and DCR
  - Qualified
  - After Retesting
    - After Retesting
    - The 1st time
  - <23%
    - 23%~25%
      - PDE
        - accept
        - reject
      - DCR
        - accept

Scanning Station

Need more checking

compare also *J. Phys. Conf. Ser. 1468 (2020) 1, 012197*
PERFORMANCE SURVEY FOR THE PMT CONTAINER SYSTEM

Several studies were made to proof the capability of the container system and estimate its accuracy and systematics:

- Analysis of reference PMT* data from 200 consecutive runs of both containers
  - very good stability over time for (almost) all parameters observed
  - only negligible systematic effects between different channels
  - accuracy / result reproducibility within the aimed specifications (e.g. \( \Delta(PDE) < 1\% \), \( \Delta(RT, TTS) \ll 1 \text{ ns} \), \( \Delta(HV) < 5 \text{ V} \), ...)

- Cross-check of results between two containers using \(~ 250\) PMTs, showing consiting results between both containers

- Remaining differences / systematic effects between containers quantified and under control

- Additional surveys about noise level, light tightness, jitters, ... performed

*) reference PMTs = up to 5 PMTs per container which are characterized together with the untested PMTs in each container run, with main purpose to monitor the system for stability over time and reproducibility of testing results
MAGNETIC SENSITIVITY OF PMTS

Hamamatsu PMTs

PDE vs MF

\[ \text{PDE vs MF} \]

\[ \sigma_{\text{PDE}} \text{ vs MF} \]

NNVT PMTs

PDE vs MF

\[ \text{PDE vs MF} \]

\[ \sigma_{\text{PDE}} \text{ vs MF} \]
SCANNING STATION CALIBRATION