Performance of the PMT Mass Testing System for the JUNO Experiment

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on behalf of the JUNO PMT Instrumentation Group

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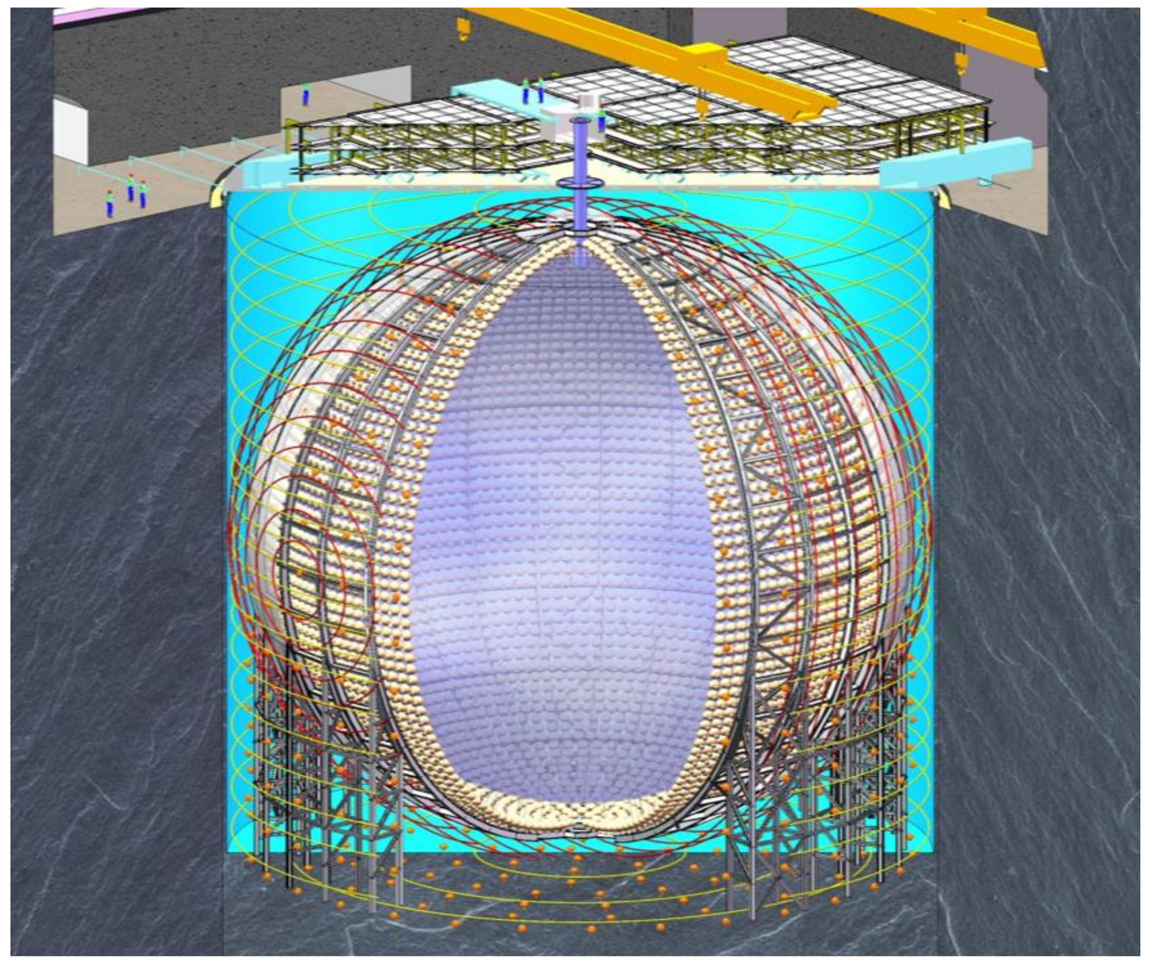
THE JUNO EXPERIMENT

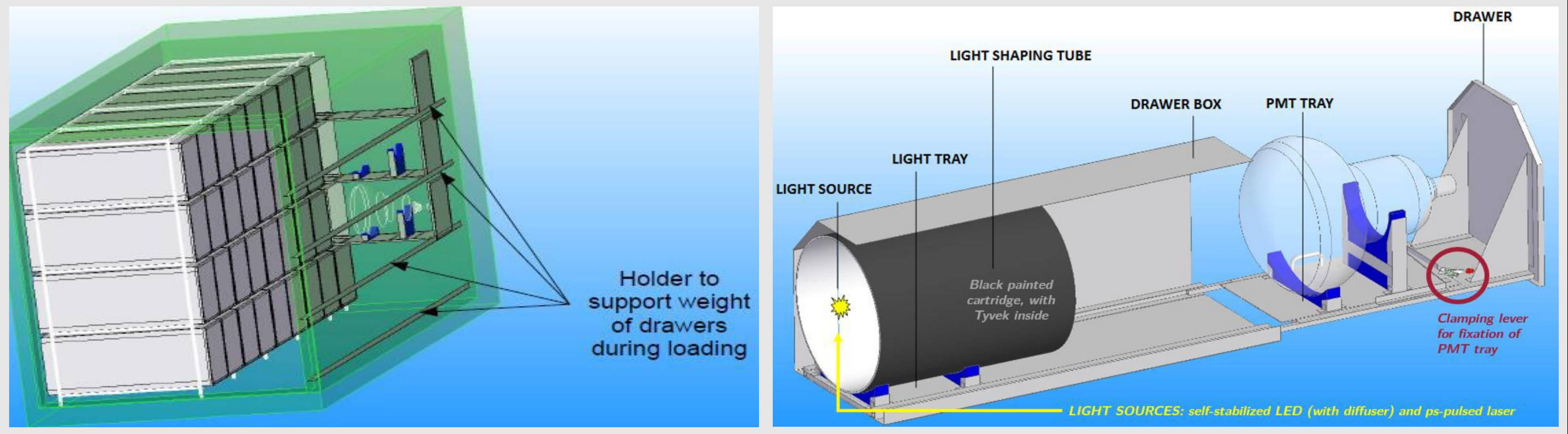
The JUNO experiment is a multi-purpose neutrino observatory currently under construction in Jiangmen, China. Its main goal is the measurement of the neutrino mass hierarchy with a significance of **>3σ** after 6 years of measurements. To achieve this result, an energy resolution of **3%/$\sqrt{E_{vis}[MeV]}$** was defined as a primary design goal for JUNO. Therefore the detector is using 20kt of liquid scintillator surrounded by roughly 18000 20'' PMTs and 25000 3'' PMTs. The Čerenkov veto is using additional 2000 20'' PMTs, which leads to a total of **20000 20'' PMTs** mounted inside the detector. Those 20'' PMTs used in JUNO are of two types: Dynode (produced by Hamamatsu Photonics K.K.) and Micro-Channel-Plate (produced by North Night Vision Technologies Co Ltd (NNVT)). Since the performance and characteristics of the PMTs are crucial for achieving such an ambitious energy resolution, a PMT mass testing setup was developed.



PMT MASS TESTING FACILITY IN COMMERCIAL SHIPPING CONTAINERS

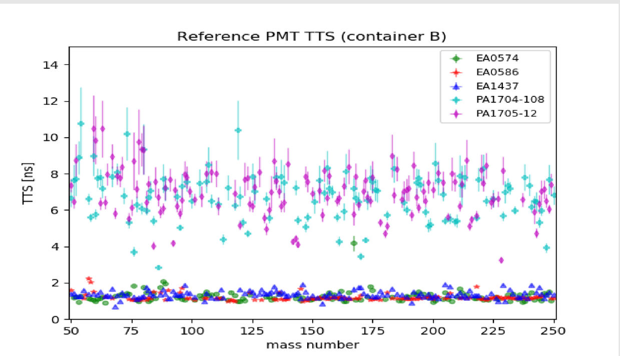
To achieve the ambitious goal of an energy resolution of 3%, each PMT needs to be tested for its characteristics and performance. For this purpose, a multichannel PMT testing system inside of commercial shipping containers was developed and set up, with following main features:

- 4 standard shipping containers equipped with a drawer system providing 36 or 32 measurement channels (two containers with each configuration)
- Two containers are equipped with commercial DAQ electronics, one is used for accelerated aging tests, one will be equipped with final JUNO electronics
- 2 independent light sources for each channel:
  (1) self-stabilized LEDs
  (2) ps-Laser system with fibers in each box
- Light shaping tube to guarantee a well defined, homogenous light field
- Shielding against Earths Magnetic Field (EMF) to ~10% of the EMF
- Climate control with temperature monitoring system
- Fully automated, LabVIEW based DAQ software

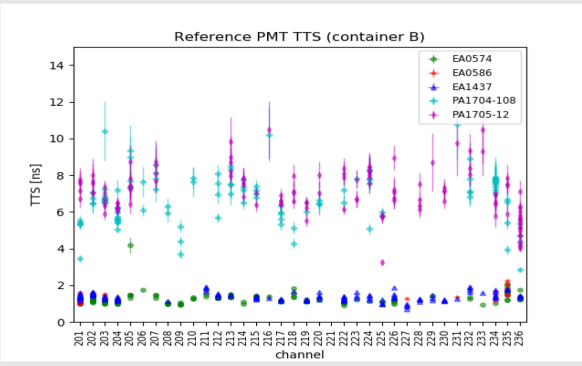


TIME TRANSIT SPREAD (TTS)

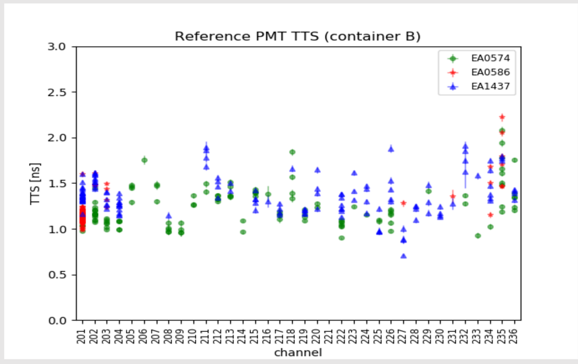
The TTS is relevant for the timing resolution of the detector.
Due to differences in the principles of operation, the MCP-type PMTs feature a higher TTS than the dynode-type. A focus to the dynode-type PMTs (right) of container B shows stable results over the repeated measurement with residual fluctuations due to systematic uncertainties in the sub-ns regime only.



TTS stability over time, mass number indicates the measurement run.



TTS of the reference tubes per channel.

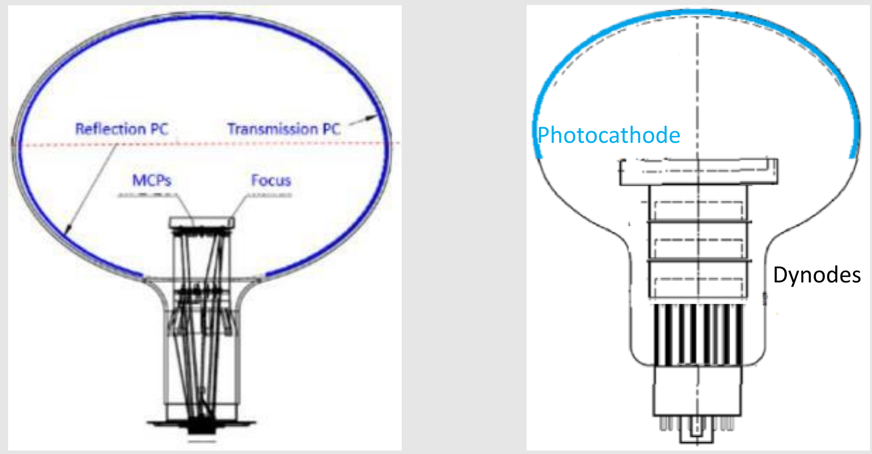


TTS of the reference tubes per channel, Hamamatsu only.

THE 20'' PMTs OF JUNO

The types of PMTs used in JUNO:

MCP-type: (by NNVT) | Dynode-type: (by Hamamatsu)

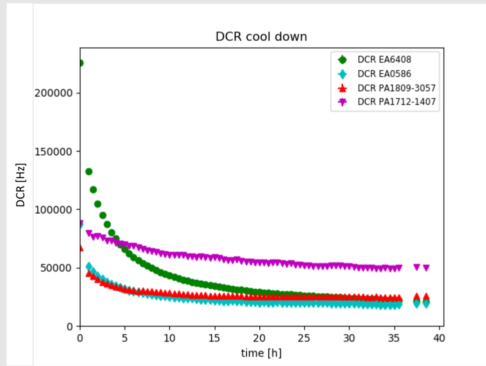


THE REFERENCE PMTs

In both containers equipped with commercial electronics, five PMTs with well-known performance (three dynode and two MCP), are serving as reference PMTs, staying in the containers in all runs. The reference tubes are used to calibrate each drawer in relation to those PMTs and allow to monitor the containers' performance over time and channel wise. Four PMTs are circulating in a random pattern, with an additional PMT always staying in a fixed channel.

DARK COUNT RATE (DCR)

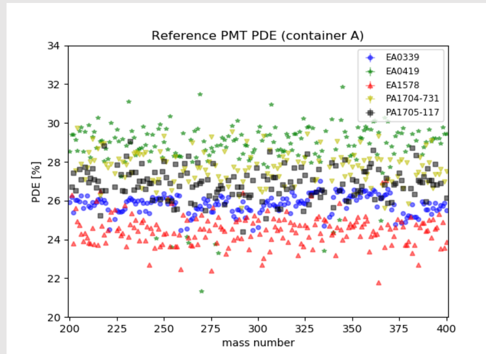
The DCR is a key property of the PMT. Prior to the actual measurement, a waiting time of at least 12h between closure of the container and start of the characterization measurement is needed to reduce DCR induced noise.
Since this parameter depends on a prior illumination, the "cool-down" of a PMT is monitored by the DAQ.



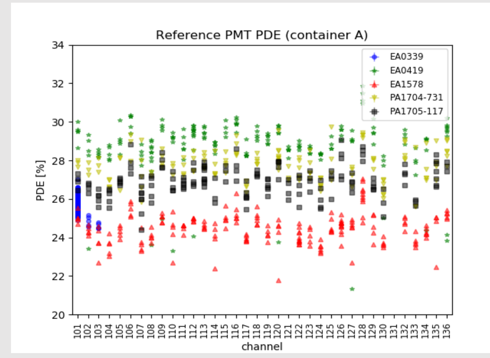
DCR development during cooldown phase. For characterization, the DCR after 20 hours is used.

PHOTO DETECTION EFFICIENCY (PDE)

The light intensity of each drawer box has been calibrated individually during commissioning w.r.t. well-known references (a small set of PMTs with well-known PDE), enabling a relative PDE measurement in the container tests. The PDE is measured using a light intensity producing roughly 1 p.e. per trigger event.

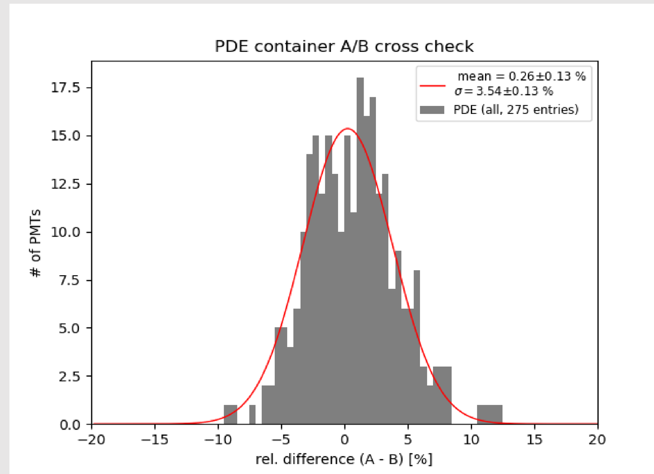


PDE stability of reference tubes over time, mass number indicated the name of the measurement run.



PDE of the reference tubes per channel.

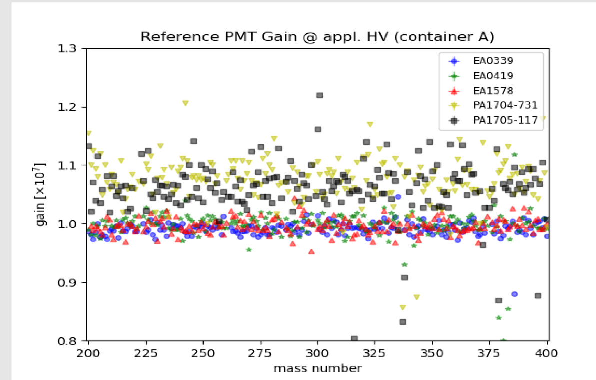
As a crosscheck, some PMTs were tested in both, container A and container B. Further, a relative difference referenced to the average can be calculated. The resulting sigma of 3.5% leads to a relative resolution of ≈2.5% in the PDE. The resulting plot can be seen on the left, a good consistency is clearly visible.



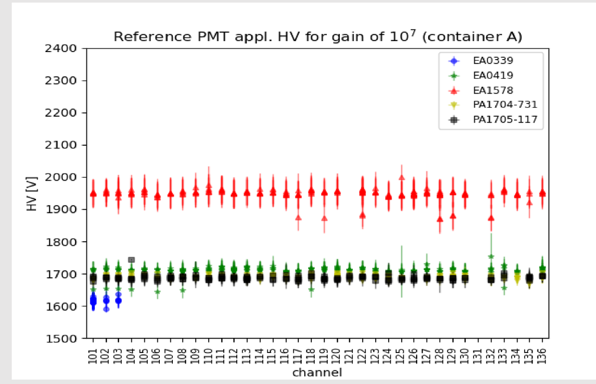
Cross check of the PDE value between PMTs tested in both, container A and container B. Fitted was a standard Gaussian.

GAIN

At the beginning of each run the container measures the gain at different HV settings, starting with the value suggested by the vendors. The data taken by this runs then is analyzed and used to select an operation voltage leading to a fixed gain of 1E7.



Calculated gain of the reference PMTs before correction



Applied voltage of the reverence PMTs for the gain of 1e7. The stable values are clearly visible.

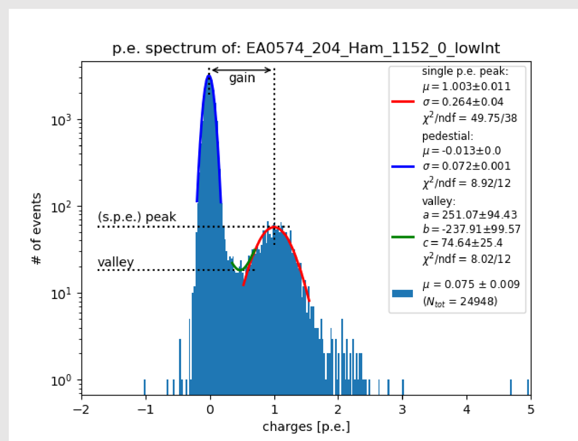
As can be seen above, the calculated HV for a gain of 1e7 shows a stable behavior. Considering this, a gain of 1e7 for all PMTs and tests, can be assumed.

PEAK TO VALLEY RATIO & SIGNAL TO NOISE RATIO

The peak to valley ratio (P/V) and signal to noise ratio (S/N) are parameters, that are derived from the charge histogram of a PMT.

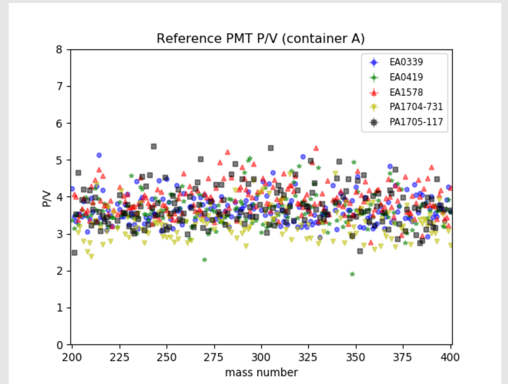
$$S/N = \frac{\sigma_{ped}}{mean_{sig} - meanpe_{d}}$$

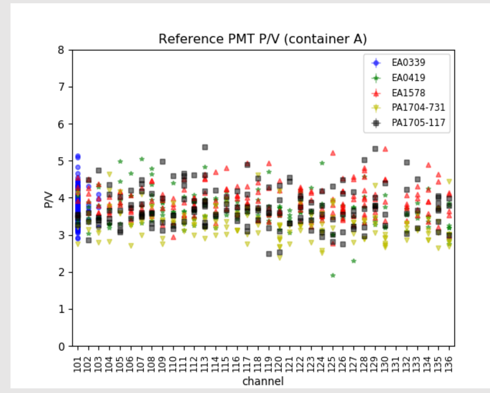
$$P/V = \frac{N_{peak}}{N_{valley}}$$



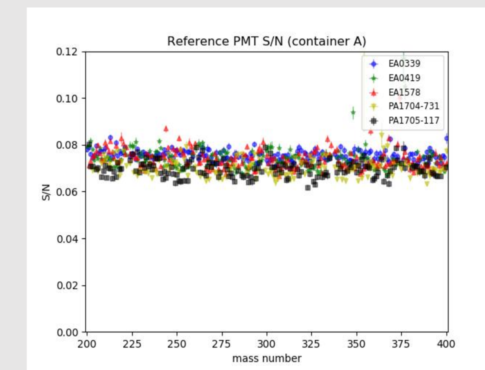
Exemplary charge histogram of a reference PMT at low light intensity, logarithmic scale. (Fits for signal, pedestal and valley are marked)

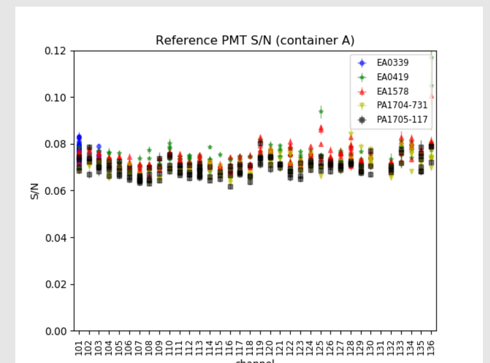
A comparison of the spread of the P/V (top) and the S/N (bottom) shows differences in variations of the parameters:





Whilst the S/N shows a stable behavior, with some systematical differences per channel. So with this system, a S/N below 10% and a P/V>2.5 is achievable.





ACKNOWLEDGEMENTS

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