The PMT Mass Testing Systems for JUNO

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on behalf of the JUNO PMT Instrumentation Group

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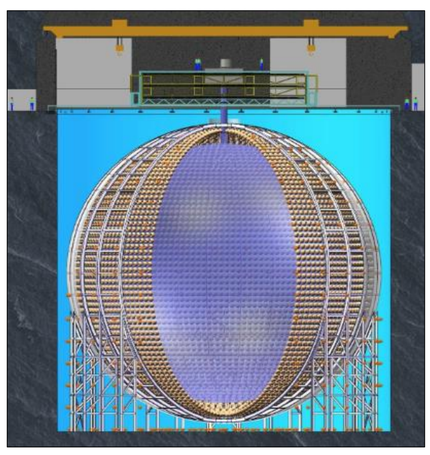
THE JUNO EXPERIMENT

The JUNO Experiment is a neutrino oscillation experiment currently under construction in China, primary aiming to measure the neutrino mass hierarchy with $>3\sigma$ after 6 years. Therefore it's using 20 kt LSc with high light yield as target, surrounded by roughly 18'000 20" PMTs and 25'000 3" PMTs. The target is embedded into an active muon Čerenkov veto using 2'000 20" PMT, so that in total **20'000 20" PMTs** are mounted inside the experiment. With this design, an energy resolution of $3\%/\sqrt{E_{vis}}$ is feasible and major design goal of JUNO.

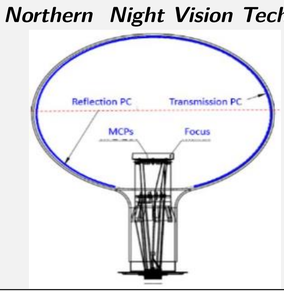
For achieving this ambitious energy resolution, it is crucial to check all the PMTs to hit certain quality criteria (high PDE, good resolution, low dark rate, good uniformity) before mounting them into the JUNO experiment.



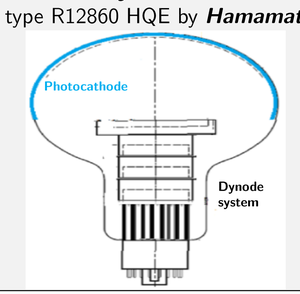
LARGE PMTs OF JUNO

Two types of 20" PMTs are used in JUNO:

15'000 MCP-PMTs,
by ***Northern Night Vision Technology***



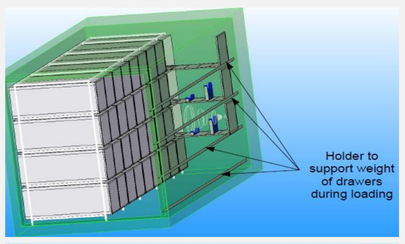
5'000 dynode PMTs
type R12860 HQE by ***Hamamatsu***



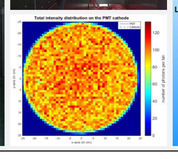
TWO INDEPENDENT SYSTEMS FOR MASS TESTING OF 20" PMTS

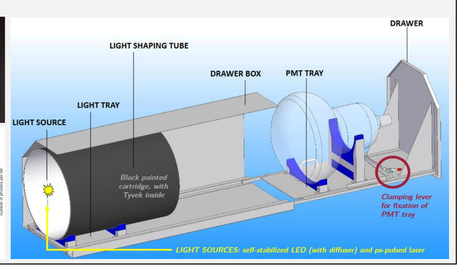
PMT MASS TESTING FACILITY IN COMMERCIAL SHIPPING CONTAINERS

Every PMT will be tested in this system at least 2 times: ***acceptance test*** *with naked PMT after delivery,* ***full characterization test*** *after potting of the PMTs*



- In total 4 shipping containers equipped with a drawer system containing **36** boxes (PMT channels) per container
- **2 independent light sources** for each channel:
  (1) self-stabilized LEDs with 2 mm PTFE diffuser
  (2) ps-Laser System with fibers in each box
- Light shaping tube for well-defined, nearly homogeneous light field on PMT surface (investigated by simulations)
- Shielding against Earth Magnetic Field with soft-iron/aluminum layers, reduced to ~**5 µT** (≤ 10% of EMF)
- Climate control unit and temperature monitoring system
- Fully automated DAQ software based on **LabView**

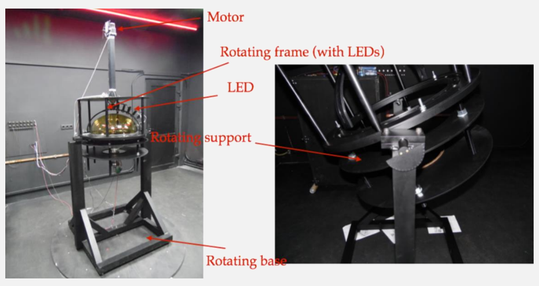


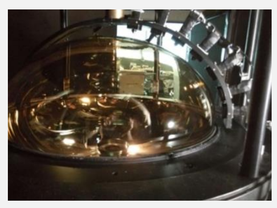


PMT SCANNING STATION FOR PHOTOCATHODE UNIFORMITY SCANS

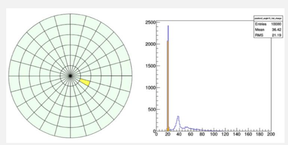
Batch test of ~ ***5%*** *of all delivered PMTs to check for* ***photocathode uniformity****, and* ***cross-checks*** *of suspicious PMTs (PDE ~ 24%) from the container tests*

- 2 stations equipped with 6 **LEDs** at certain angular positions on a rotatable arm
- LEDs are self-stabilized with monitored light intensity (same as used in containers), periodical calibration with reference PMT
- System can hold **one 20" PMT** to scan over **whole PMT photocathode** in order to get angular-resolved distribution of PDE and gain
- Located in a dark room with surrounding electric coils to reduce EMF inside, residual magnetic field at PMT position is ~**2 µT**
- Fully automated data taking, producing graphical results (photocathode map)

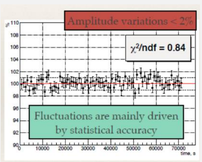




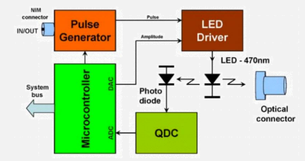
Self-stabilized LED (by HV-Sys)



Scanning Station Analysis Method

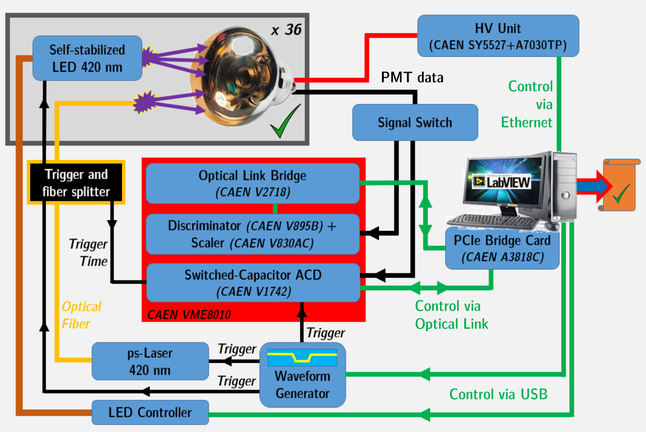


LED source stability measured by 20" Hamamatsu 12860 HQE PMT in a single point



(http://hvsys.ru/images/data/news/10_small_1368803142.pdf)

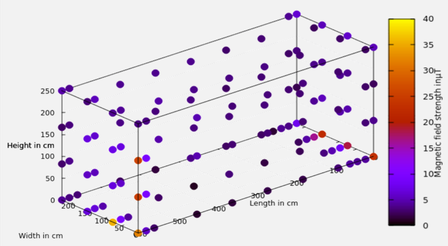
ELECTRONICS SCHEME AND DAQ WORKFLOW (CONTAINER)



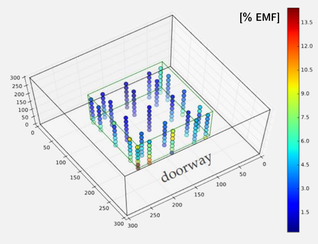
- [1] Read-in of PMT data; Some initial checks
- [2] Cool-down time (≤12h); Dark count monitoring during cool-down
- [3] Gain/HV measurement with 7 different HVs; Fit spectra to find best HV for 10^7 gain
- [4] Set new HV; Dark count measurement with final HV
- [5] LED measurements with different light intensities; Laser measurements with different light intensities
- [6] Final dark count measurement; Save all the data and end DAQ

MAGNETIC FIELD COMPENSATION

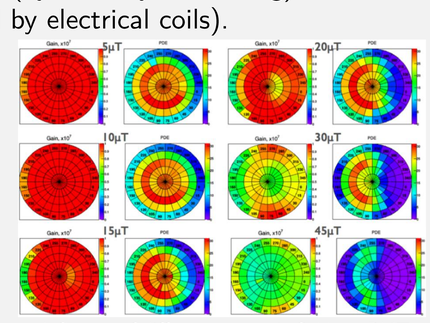
The Earth Magnetic field has to be reduced to a level of 10% to guarantee no bad influences on the measurements. This is achieved passively for the container (by multilayer shielding) and actively for the scanning station (compensation field produced by electrical coils).



Residual magnetic field inside the container, ~ ***5 µT****. Weak spots are strengthened with additional FINEMED layers around boxes*



Residual magnetic field inside the dark room of scanning station, ~ ***2 µT*** *at PMT position (center)*



Influence of different magnetic fields to PMT performance (EMF ~ 50 µT)

MILESTONES

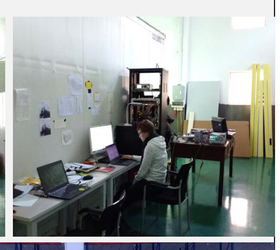
- **Container #1** commissioned in June/July 2017, running since September 2017 (first few months with reduced measurement program)
- **Container #2** commissioned in March 2018, calibration phase until May 2018, start running in normal mass testing mode now
- **Scanning Station #1** commissioned in June 2017, running since July 2017
- **Scanning Station #2** commissioned in and running since January 2018

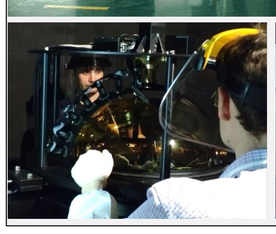
9000 PMTs delivered PMTs *(May 2018)*

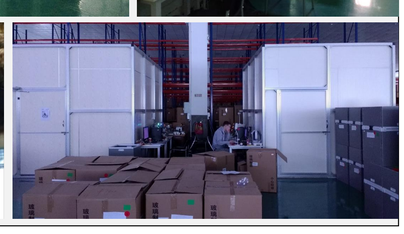
→ ~ **5000 PMTs** already tested with container system,

→ ~ **600 PMT** scanned by Scanning Stations

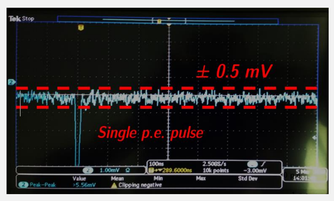
- **Containers #3 and #4** under preparation, will be shipped to China in late Summer 2018





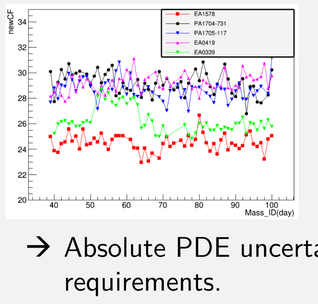


EXEMPLARY DATA



Low noise levels of **±0.5 mV,** Noise-to-Signal-ratio of ~**7 %**

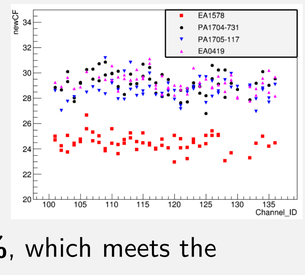
5 Reference PMTs per container to monitor system's stability and repeatability of measurement (measured with each PMT batch, at 1 fixed and 4 rotating position inside container)



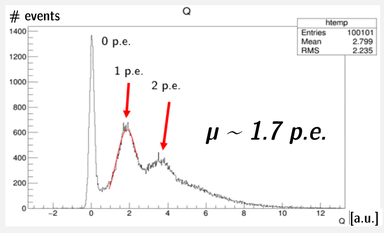
Data of Reference PMTs in Container #1.

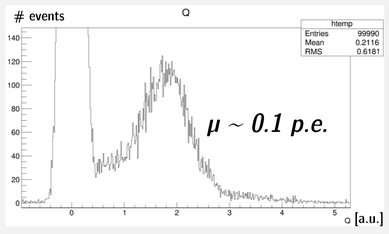
Left: Stability of results over time.

Right: Stabilty of results over channel.



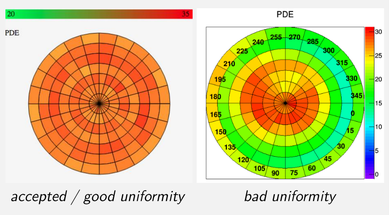
→ Absolute PDE uncertainty of ~**1 %**, which meets the requirements.





Single photoelectron spectrum of PMT EA1885: Measurements performed at different light (LED) intensities.

Scanning station: Single photo-electron spectrum for each surface element. Colored plots are showing good and bad photocathode uniformity.



accepted / good uniformity *bad uniformity*

PMT PARAMETERS TO TEST

- ✓ **Detection efficiency @420nm**
- ✓ **TTS of Single Photon Events**
- ✓ **Rise Time / Fall Time**
- ✓ **HV to reach gain of 10^7**
- ✓ **Dark Count Rate**
- ✓ **P/V Ratio**
- ✓ **Pre- and After-pulse Ratio**
- ✓ **High Uniformity of PDE**

TESTING PROCEDURE

- ✓ Visual checks of PMT glass and photocathode (after delivery)
- ✓ Unbox the PMTs and prepare them for testing
- ✓ Loading the container with PMTs
- ✓ Automated data taking (~ 20 h)
- ✓ Unloading the container
- ✓ Analyze data to check PMT performance
- ✓ Accept/reject PMT with clear results
- ✓ Cross-check PMTs with edgy results in the scanning station
- ✓ Save all raw data for further analysis

→ **Direct data analysis to decide about acceptance, rejection or cross-check by scanning station!**

→ Already rejected several hundred bad PMTs after testing!

ACKNOWLEDGEMENTS

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