Design of an Efficient, High-Throughput Photomultiplier Tube Testing Facility for the IceCube Upgrade

Lasse Halve[1] and Johannes Werthebach[2] for the IceCube Collaboration

technische universität dortmund

III. Physikalisches Institut B

RWTH AACHEN UNIVERSITY

IceCube Upgrade

Introduction

IceCube measures Cherenkov light produced by charged particles created in neutrino interactions in and nearby the detector [1]. Photomultiplier Tubes (PMT) in Digital Optical Modules (DOM) are used for the detection. In the IceCube Upgrade [2]:

- With the IceCube Upgrade, seven new cable-strings equipped with novel instruments will be deployed in the center of the existing IceCube detector
- More than 300 multi-PMT digital optical modules (mDOM) [3] with 24 3-inch PMT [4] each will be constructed
- In total, more than 10,000 PMTs need to be tested and pre-calibrated

Testing System Requirements

General requirements:

- Throughput of a few hundred PMTs per week
- Testing at low temperatures (-20°C) [5]
- Adaptability to future IceCube Gen2 [6] PMT testing

Testing of the PMTs includes:

- Calibration of required high voltage
- Relative photo-detection efficiency
- Charge response linearity
- Darkpulse rate
- Timing resolution
- Pre-, Late-, and Afterpulse probabilities

Lightsource System

- Developed custom light source systems:
  - Fast LEDs (sub-nanosecond)
  - Multiple wavelengths and intensities
- LEDs mounted in selection apparatus driven by stepper motor
- LEDs driven by nano-second pulsers [7]
- Light couples into optical fiber routed inside cooling room
- Integrating PTFE sphere [8] used for distribution to PMTs

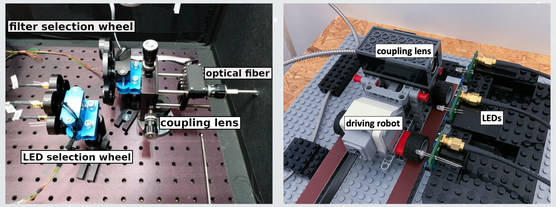

Figure 4: Light source systems in Aachen and Dortmund

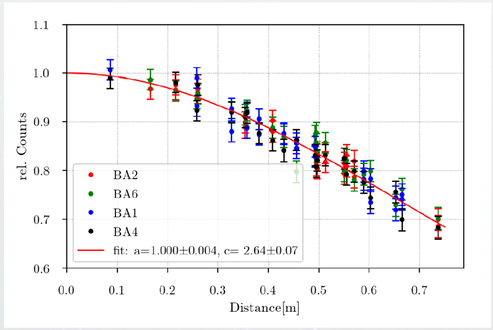

Figure 5: Relative light yield as a function of distance to the PMT rack center. From [9].

- Relative light yield in each rack position is measured
- Critical correction in determination of the relative photo-detection efficiencies of the PMTs

Test Results

Several PMTs have undergone testing with a reduced set of measurements:

- Fully automated measurements of SPE spectra
- Extraction of gain and other characteristics in automated analyses
- Calibration of target high voltage

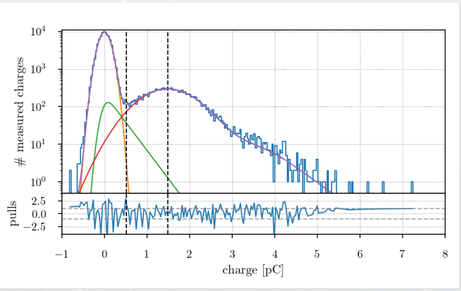

Figure 6: Example of a recorded SPE spectrum

Only a single defective PMT out of the first 320 was rejected because of a faulty solder joint.

Mechanical Design and Implementation

Two sites are hosting PMT Testing facilities:
- RWTH Aachen University
- TU Dortmund University

Testing is carried out in dark, temperature controlled rooms, that have been vetted for light-, and air-tightness.

PMTs are attached to a rack inside the rooms, mounted on eight slide-in bars with twelve PMTs each. In total, 96 PMTs can be tested simultaneously.

Figure 3: Cooling rooms at the test facilities in Aachen and Dortmund

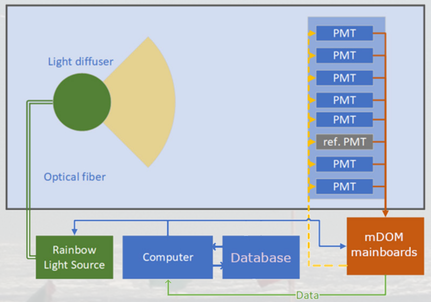

Figure 1: Design schematic of the test facilities

The multi-rack design is modular and enables:
- Un-/Mounting of PMTs outside the cooling room during testing
- Fast turnaround times between measurements

PMTs are controlled with mDOM mainboards:
- Control the high voltage for each PMT
- Read out waveforms from the PMTs
- Read scaler rates for each PMT

Figure 2: PMTs on a slide-in bar

Summary and Outlook

- More than 10,000 PMTs need to be tested for the new mDOMs in the IceCube Upgrade.
- We have presented a design of a testing facility that is implemented at two sites in Germany capable of testing a few hundred PMTs per week
- A modular mounting setup reduces the time between testing cycles
- Testing procedures and analyses are fully automated
- The test facility can easily be adapted such that it can be used for future IceCube Gen2 testing
- Near future: Each PMT integrated into an mDOM will be tested

References

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[1] Lasse Halve, RWTH Aachen University
lasse.halve@icecube.wisc.edu
[2] Johannes Werthebach, TU Dortmund University
jwerthebach@icecube.wisc.edu