Characterization of KM3NeT photomultipliers in the Hellenic Open University

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Outline

- The KM3NeT telescope
- The KM3NeT optical modules
- PMT characterization
  - Calibration setup
  - Gain slope and single pe characteristics
  - Peak-to-Valley
  - Transit Time Spread
  - Dark current rate
  - After pulses fraction and multiplicity
- Summary and outlook
The KM3NeT Telescope

Optical Module (OM): pressure resistant sphere containing photomultipliers

Detection Unit (DU): mechanical structure holding OMs, environmental sensors, electronics,...

DU is the building block of the telescope

KM3NeT in numbers
- ~12200 DOMs
- ~620 DU
- ~20 DOM/DU
- ~40m DOM spacing
- ~1 km DU height
- ~100 DU distance
- ~4 km³ volume

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KM3NeT Optical Modules

- 31 3'' PMTs (~30% max QE) inside a 17'' glass sphere with 31 bases (total ~6.5W)
- Cooling shield and stem
- Full prototypes under testing

- Single vs multi-photon hit separation
- Large (1260 cm$^2$) photocade area per OM
PMT Characterization

PMTs under testing (Nikhef, ECAP Erlangen, INFN Catania)
- 200 Hamamatsu R12199 PMTs (E. Leonora talk)
- 94 ETL PMTs
- 7 HZC PMTs (O. Kalekin talk)

Tested for
- Quantum efficiency
- Gain slope
- Dark current rate
- Transit Time Spread (TTS)
- After pulse fraction
- Peak-to-valley ratio
- Effective area

KM3NeT specifications for PMTs:
- QE @ 470nm > 20%
- HV for 5x10^6 gain 1000-1400V
- TTS <2ns sigma
- Dark current rate <1kHz
- Peak-to-valley ratio >3
HOU PMT Calibration Setup

- Dark box hosting the PMT under calibration
- PMT power base provided by Erlangen
- HLMP-LB11-FJ000 LED (blue - 470nm) inside the dark box powered by a ~3V pulse with adjustable width
- NIM Pocket Pulser Model 417 (10kHz)
- NIM electronics: discriminator and NIM/TTL
- External high voltage power supply for the PMTs
HOU PMT Calibration Setup

- 5GS/s high sampling rate oscilloscope (Tektronix 5052B) with LAN connectivity
- Custom software for data acquisition (LabVIEW and C++)
- Acquisition rate 350Hz if the full pulse waveforms are saved, >1kHz otherwise
- PMT stays in darkness without supply voltage for ~3h
- PMT powered with the typical voltage for ~1h before measurements begin
Gain slope & single pe characteristics

Setup

- PMT in spe conditions by narrowing the LED pulse width
- Oscilloscope triggered by the LED power pulse
- Around 100000 pulses acquired for each PMT voltage supply in the range 1000-1400V with 50V step
- Procedure may be repeated for higher light level
Gain slope & single pe characteristics

Results

Data Analysis
→ Binary data converted to V=f(t)
→ Check data quality
→ Correct dc offset (if any) due to temperature changes
→ Noise reduction
→ Charge and pulse height distributions

PMT charge distributions:
- spe mean charge
- spe mean pulse height
for every PMT high voltage supply
Charge Distributions (single pe level)

→ Gaussian distribution for the noise
→ Exponential distribution for the dark current
→ Polya functions used for the signal

\[
P(x) = \frac{(a \cdot x / M)^a}{x \cdot \Gamma(a)} \cdot e^{-a \cdot x / M} \\
\bar{x} = M \\
\sigma_x = \frac{M}{\sqrt{a}}
\]
→ Gaussian distribution for the noise
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\[ P(x) = \frac{(a \cdot x / M)^a}{x \cdot \Gamma(a)} \cdot e^{-a \cdot x / M} \]
\[ \bar{x} = M \]
\[ \sigma_x = \frac{M}{\sqrt{a}} \]
Using the charge distributions for each number of photoelectrons, we can estimate the number of events for 0, 1, 2, ... photoelectrons

→ the mean number of photoelectrons is estimated assuming poissonian statistics and fitting the discrete distribution
Gain slope & single pe characteristics

Results

Gain as a function of supplied voltage

\[ G_V = A \cdot V^{kn} \]

But

\[ G_V = \frac{Q_V^{N_{pe}}}{N_{pe} \cdot e} \]

\[ \log Q_V^{N_{pe}} = \log (N_{pe} \cdot e \cdot A) + kn \cdot \log V \]

Slope is calculated at every light level employed

Calculation of the operational voltage for a specific gain of 5 \( \cdot 10^6 \)

\[ G_V = G_{V_0} \cdot \left( \frac{V}{V_0} \right)^{kn} \]
Peak-to-Valley measurements

Peak-to Valley preliminary results for ZB6160

<table>
<thead>
<tr>
<th>High Voltage (V)</th>
<th>Peak-to-valley</th>
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</thead>
<tbody>
<tr>
<td>1100</td>
<td>3.3±0.1</td>
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<tr>
<td>1200</td>
<td>3.5±0.1</td>
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<tr>
<td>1300</td>
<td>3.6±0.2</td>
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<tr>
<td>1400</td>
<td>3.4±0.1</td>
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</table>
Transit Time Spread (TTS) measurements

Sheffield Pulser for the LED with a ~0.5ns light output width
- PMT at spe conditions
- Acquisition of 100000 waveforms
- Distribution of the arrival time of the pulse (measured at a threshold equal to 1/3 of the spe mean pulse height)

ZB6277  FWHM = 3.55ns  TTS = 1.4ns

J. E. McMillan, Using the Sheffield Pulser, Sheffield, 2001

O. Kalekin, DE. Leonora, D. Samtleben, Test Report, 200 Hamamatsu PMTs of type R12199-02, 1-4-2013
Dark current measurements

- PMT signal input to the CAEN Mod. N844 Low Threshold Discriminator
- PMT voltage set for a gain of $5 \cdot 10^6$
- Discriminator threshold set to 1/3 of the average pulse height
- Discriminator output fed to ORTEC 871 TIMER AND COUNTER and the dark current rate is measured

ZB6277 ~2.5kHz
ZB6160 ~1.4kHz

Measured at a room temperature of ~25°C
After pulses

Work for after pulses fraction is underway
- Same setup as for gain slope
- 10μs or 100μs window recorded
- Pulses registered if higher than 1/3 of the mean pulse height
- Time distribution of the pulses following the main pulse
- Multiplicity of after pulses is also measured
Summary and Outlook

HOU 3"

PMT Calibration
spe characteristics, gain slope, TTS, peak-to-valley
- Acquisition of ~100000 pulses at 8-10 power supply values up to 1400V (around 1h)

Dark current rate measurements at various room temperatures measured instantly

After pulses fraction and multiplicity
- 3-4M waveforms (around 1h)

Outlook
- Automation of the measurements and analysis procedures
- Development of the first DOM construction center of the KM3NeT-Gr