Noise and spurious pulses for Cherenkov light detection with 10-inch and 3-inch photomultipliers

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Summary

- PMT 10 inch and PMT 3 inch in single photoelectron condition
  - Charge and Time distribution for pre and delayed pulses (spe)
  - Charge and Time distribution for afterpulses AP (type 1, type 2 and multiple AP2)

- PMT 3 inch
  - Variation of transit time spread (TTS) and of fractions of spurious pulses in different conditions of response of PMT (from spe to 3 pe and 5 pe)
Spurious pulses not correlated with main pulse:

Pre-pulses: due to the direct photoelectron emission on the first dynode from the photons which passed the photocathode without interaction. The arrival time of pulse will be anticipated in confront of the main pulse.

Delayed: The primary photoelectron is reflected from the first dynode without a secondary electron emission, it turns towards the photocathode, makes a loop and only after it creates a cascade of electrons in the dynodes. The arrival time of the hit will be delayed in confront of the main pulse (delay 10ns-100ns).

Spurious pulses time-correlated with the main PMT response:

After pulses (type 1, type 2, multiple after pulses): noise pulses that appear following the main PMT response to a detected light event. (100ns-16µs after Main pulse)
R7081 10-inch by Hamamatsu

Gain = $5 \times 10^7$
Laser PicoQuant wavelength 410nm
10kHz (external trigger)
Large Area PMT Mushroom shape
Bialkali photocathode
Active base by ISEG

Charge distribution of dark pulses

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10-inch Spurios Pulses (spe)

Both pre and delayed pulses have a charge distribution mainly of 1 spe

Pre-pulses < 0.1%

Delayed pulses ~ 5%
Measurements Setup for After pulses

Oscilloscope LeCroy
Trigger : Laser and PMT Main signal coincidence
Acquisition for 20µs
5.0 GS/s
Offline analysis

Spurious pulses taken in single photoelectron conditions
10-inch After pulses (spe)

Type 1: (10 ns - 100 ns) : due to luminous reaction on the electrodes.

Type 2: AP (100 ns - 16µs) : due to the ionization of the residual gas in the PMT.

- 2 peaks (ion contributions)

- CH$_4^+$
- Cs$^+$

~2% AP1

AP1 mainly of 1 pe.

~9% AP2

AP2 mean value about 1.5 pe
10-inch After pulses (spe)

Charge Vs Arrival Time for After pulses:
AP1 are mainly of spe
AP2 have more high charged events

Charge distribution of AP2 in different time ranges.
In black there is the peak corresponding to $CH_4^+$ while in gray there is the $Cs^+$ peak. High charged AP2 are due mainly to $CH_4^+$

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10 inch Multiple After pulses (spe)

Multiple AP2 events are present in PMTs. For only one AP2 the mean charge is about 1.2 pe but charge per pulse increases up to 3 pe with the increasing of number of AP2.

<table>
<thead>
<tr>
<th>Nº AP2</th>
<th>Fraction (%)</th>
<th>Mean Charge (pe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.27</td>
<td>1.2</td>
</tr>
<tr>
<td>2</td>
<td>2.59</td>
<td>1.3</td>
</tr>
<tr>
<td>3</td>
<td>0.87</td>
<td>1.9</td>
</tr>
<tr>
<td>4</td>
<td>0.46</td>
<td>2.9</td>
</tr>
<tr>
<td>5</td>
<td>0.21</td>
<td>2.5</td>
</tr>
<tr>
<td>6</td>
<td>0.15</td>
<td>2.5</td>
</tr>
<tr>
<td>7</td>
<td>0.10</td>
<td>2.6</td>
</tr>
<tr>
<td>8</td>
<td>0.08</td>
<td>2.6</td>
</tr>
<tr>
<td>9</td>
<td>0.03</td>
<td>2.3</td>
</tr>
<tr>
<td>10</td>
<td>0.05</td>
<td>2.3</td>
</tr>
<tr>
<td>11</td>
<td>0.03</td>
<td>2.9</td>
</tr>
</tbody>
</table>
R12199-02 PMT 3-inch by Hamamatsu

- Gain = $5 \times 10^6$
- Laser PicoQuant wavelength 410nm, 10kHz (ext-trigger)
- Mushroom shape
- Bialkali photocathode
- Passive base made by Erlangen group

3-inch PMTs into a multiPMT optical module

- Dark current with glass for two different PMTs for effects of glass see E.Leonora’s presentation
3 inch characterization in spe conditions

Peak to valley ratio:
Fit expo+gaus

Charge Spectrum spe

Single photoelectron=0.8 pC

TTS ~ 4ns

Time distribution

<table>
<thead>
<tr>
<th>htime</th>
<th>Entries</th>
<th>Mean</th>
<th>RMS</th>
<th>Constant</th>
<th>Mean</th>
<th>Sigma</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>23441</td>
<td>98.07</td>
<td>5.603</td>
<td>4014</td>
<td>97.62</td>
<td>2.208</td>
</tr>
</tbody>
</table>
3-inch main properties

Set of 20 PMTs by HAMAMATSU 3-inch R12199-02 tested in INFN-Catania laboratory

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3 inch Characterization (1, 3, 5 pe)

Mean charge PMT response of 1, 3 and 5 pe

<table>
<thead>
<tr>
<th>conditions</th>
<th>TTS FWHM (ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 pe</td>
<td>4,0</td>
</tr>
<tr>
<td>3 pe</td>
<td>3,0</td>
</tr>
<tr>
<td>5 pe</td>
<td>2,8</td>
</tr>
</tbody>
</table>

Changing PMT conditions from 1 to 5 pe TTS is reduced.
3 inch Spurious Pulses: Pre-Pulses and delayed (1, 3, 5 pe)

Pre-pulses and delayed fractions became lower at conditions of 3 pe and 5 pe.
Pre pulses (very low statistic!) and delayed pulses increase in charge from 1 pe to 5 pe.

<table>
<thead>
<tr>
<th>conditions</th>
<th>Pre-pulses</th>
<th>delayed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 pe</td>
<td>0.3 %</td>
<td>6.40 %</td>
</tr>
<tr>
<td>3 pe</td>
<td>0.01 %</td>
<td>1.14 %</td>
</tr>
<tr>
<td>5 pe</td>
<td>0.002 %</td>
<td>0.47 %</td>
</tr>
</tbody>
</table>
3 inch After pulses type 1 (spe)

AP1 = 0,11 %

Fraction of AP1 lower than that of 10inch

Behaviour of AP1 looks very similar to 10-inch PMT.
Two peaks like 10-inch at ~1μs and ~3μs for the two ions Cs\(^+\) and CH\(_4\)^+ (time difference with 10-inch due to the geometry).

Higher mean charge for AP2 than AP1.

Time-Charge correlation has a behaviour similar to that of 10-inch with an higher charge component for the CH\(_4\)^+ peak.
3 inch Multiple Afterpulse (spe)

Differently to 10-inch PMT, in 3 inch PMT multiple AP2 have a charge mainly of spe.
Multiple AP2 show lower fractions in confront of 10-inch PMT.

<table>
<thead>
<tr>
<th>Number of AP type 2</th>
<th>Events (%)</th>
<th>Mean Charge (pe)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.81%</td>
<td>1.20</td>
</tr>
<tr>
<td>2</td>
<td>0.25%</td>
<td>1.21</td>
</tr>
<tr>
<td>3</td>
<td>0.07%</td>
<td>1.18</td>
</tr>
<tr>
<td>4</td>
<td>0.025%</td>
<td>1.22</td>
</tr>
</tbody>
</table>
Conclusions

<table>
<thead>
<tr>
<th>10 inch (spe conditions)</th>
<th>3 inch (spe conditions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TTS (FWHM) ~ 3 ns</td>
<td>TTS (FWHM) ~ 4 ns (in 3 pe and 5 pe conditions it becomes lower)</td>
</tr>
<tr>
<td>Pre-pulses and delayed are of spe charge</td>
<td>Pre-pulses and delayed are of spe charge (in 3 pe and 5 pe, fractions are lower and charge increases)</td>
</tr>
<tr>
<td>AP1 mainly of spe, temporal peak at around 30 ns</td>
<td>AP1 mainly of spe, temporal peak at about 20 ns</td>
</tr>
<tr>
<td>AP2 mainly of 1,5 pe, temporal peaks at around 2(\mu)s and 8(\mu)s (Cs and (CH_4^+)). First peak with an higher charge contribution in confront of the second</td>
<td>AP2 mainly of 1,6 pe, temporal peaks at around 1(\mu)s and 3(\mu)s (Cs and (CH_4^+)). First peak with an higher charge contribution in confront of the second</td>
</tr>
<tr>
<td>Single AP2 with mean charge of 1,2 pe</td>
<td>Single AP2 have a mean charge mainly of 1,2 pe</td>
</tr>
<tr>
<td>Multiple AP2 (&gt;1) with a mean charge &gt;1,5 pe</td>
<td>Multiple AP2 (&gt;1) with a lower statistic than 10-inch and mean charge of about 1,2 pe</td>
</tr>
</tbody>
</table>
Thank you for your attention