Characterization of improved photocathode in large hemispherical photomultiplier

D. Dornic¹, B. Genolini¹, C. Moussant², T. Nguyen Trung¹, J. Pouthas¹

(1) IPN Orsay, IN2P3-CNRS, Université Paris-Sud, France
(2) Photonis, France

dornic@ipno.in2p3.fr
• **Improved photocathode** on large hemispherical photomultiplier (PMT) for astroparticle and neutrino experiments.

• A **new bi-alkali photocathode process** has been developed by Photonis

• The process has been tested on some samples of Photonis **XP1805**
PMT produced for the Pierre Auger Observatory (~5000 pieces in the surface detector)

- Hemispherical, 9 inches (230mm)
  Sk (blue) ~9.6 µA/ImF
  QE(350nm) ~26%

- 8 stages: linear focused
  + foil first dynode
  Gain: $10^6$, P/V ~1.5

- Dark count rate (0.3 pe) ~1kHz
  After-pulse (100ns-16µs) ~0.1%
- Anode current linear within 5% up to : 50 mA
Photocathode characterization

- Photocathode sensitivity
- Spectral response - quantum efficiency
- Relative detection efficiency
- Photocathode uniformity
**Photocathode sensitivity**

**Blue measurement (Corning Blue filter)**

- **Standard (~800 PMTs)**
  - Sk CB: 9.32 µA/lmF
  - Sk White: 68.37 µA/lm

- **Improved (~25 PMTs)**
  - Sk CB: 11.35 µA/lmF
  - Sk White: 118.00 µA/lm

- Increase of Sk CB: ~19%
- Increase of Sk White: ~42%

**White measurement**

- **Standard (~800 PMTs)**
  - Sk CB: 9.32 µA/lmF
  - Sk White: 68.37 µA/lm

- **Improved (~25 PMTs)**
  - Sk CB: 11.35 µA/lmF
  - Sk White: 118.00 µA/lm

Increase of Sk CB: ~19%
Increase of Sk White: ~42%
- Quantum efficiency (400 nm)
  - Standard: \(~26\%\)
  - Improved: \(~32\%\) \(+\ 19\%\)

- Quantum efficiency (600 nm)
  - Standard: \(~1.6\%\)
  - Improved: \(~6.3\%\) \(+\ 75\%\)

- Extension of the spectral sensitivity in the red region

\[ QE(\%) = 124 \frac{S_{k,\lambda}(\mu A/W)}{\lambda(nm)} \]
Relative detection efficiency (RDE)

Injected light level: 1pe (low yield down to few % of non zero pulses)

Quasi parallel light source

**Light source:** Source $^{241}$Am + fast plastic scintillator (BC422)

- very stable, homogeneous and noiseless

**Trigger:** fast PMT (XP2020) directly coupled to the scintillator
Relative detection efficiency (RDE)

- **RDE**: charge histogram analysis
- **Digital threshold** (clean cut, reproductive) at **different levels** (to be less affected by the SER shape) at a **given gain**
- Measurement with a $\Phi=100\text{mm}$ **diaphragm** placed in the center of the photocathode

$$RDE(Th, G) = 100 \left( \frac{N_{pe}(Th, G) - N_{background}(Th, G)}{N_{source}} \right)$$

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Relative detection efficiency (RDE)

- ~16% difference of the RDE between standard and improved PMT
- Dispersion between standard PMTs and between improved PMTs can be due to photocathode and collection homogeneity, slight gain mismatch

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Photocathode Uniformity

Example of uniformity curve for a PMT with improved process

Green: photocathode uniformity
Red: anode uniformity

The new process conserves a good photocathode uniformity
What about the other PMT characteristics?

✓ Dazzling effect
✓ Dark count rate
✓ Temperature dependance of the dark count rate
✓ Afterpulse
**Dazzling effect**: noise rate decay time after exposure

The decay time is higher in the new process (1 to 1.5 day)

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**Dark count rate**

*\( T=15^\circ C, \ Th=0.3 \text{ pe} \)*

<table>
<thead>
<tr>
<th>PMT number</th>
<th>Standard</th>
<th>Improved process</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5348</td>
<td>5368</td>
</tr>
<tr>
<td></td>
<td>5371</td>
<td>5372</td>
</tr>
<tr>
<td>Dark count rate (kHz)</td>
<td>0.9</td>
<td>0.9</td>
</tr>
</tbody>
</table>

**The dark count is higher in the new process**

<10 kHz (general specification for the physics experiments)
Dark count rate vs temperature

- Same noise level at low temperature
- Increase of the sensitivity with temperature

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Afterpulse (100ns-15µs)

Injection light with a LED of 10pe
100 ns dead time (to avoid latepulse)
Threshold: 0.3 pe

Acquisition: digital oscilloscope
- Band width: 300 MHz
- Sampling rate: 500 MSPS
- Time window: 15 µs
- Rate: 300 Acq/s

\[ \tau_{af}(\%) = 100 \frac{N_{2nd \, pulses} - N_{background}}{N_{10 \, pe}} \]

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Afterpulse (100ns-15µs)

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<td>0.19</td>
<td>0.09</td>
</tr>
</tbody>
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- Same afterpulse characteristics (time and amplitude)
- But: the afterpulse rate is slightly higher in the new process but remains very low
Conclusion

• **Photocathode characteristics:**
  - Quantum efficiency (400 nm): +19%
  - Extension of the sensitivity in the red region

• **Secondary effects:**
  - Dazzling increased
  - Dark count rate: higher
  - Increase of the temperature sensitivity
  - Afterpulse: slightly higher