Breakthrough in the Lifetime of Microchannel-Plate Photomultipliers

Fred Uhlig, Alexander Britting, Wolfgang Eyrich, Albert Lehmann

supported by
Outline

- Motivation
- Properties of MCP-PMTs and lifetime constraints
- Setup of lifetime measurements under PANDA conditions
- Results of the latest measurements for various devices concerning:
  - Darkcount rate
  - Gain
  - Quantum Efficiency measurements
  - QE surface scan
- Comparison with previous measurements
- Summary and outlook
The PANDA-Detector

π/K separation up to 4GeV/c

Focal planes of both DIRC detectors are inside magnetic field

Disc-DIRC >5C/cm²

Barrel-DIRC 5C/cm²

PID requirements for PANDA: π/K separation up to 4GeV/c
## Photosensor requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>PMTs</th>
<th>MCP-PMTs</th>
<th>SiPMs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnetic field resistance up to 2T (Disc DIRC)</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Gain &gt; $5 \times 10^5$ (single photons)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Time resolution: $\sigma &lt; 100$ps</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>High geometrical efficiency</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>High photon rates 200kHz/cm² (Barrel), &gt;200 kHz/cm² (Disc)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Radiation hardness</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>Darkcount rate</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>Lifetime: &gt;5C/cm² for 10 year PANDA operation (50% duty, Gain = $10^6$) at high luminosity ($2 \times 10^{32}$ cm$^{-2}$ s$^{-1}$)</td>
<td>✓</td>
<td>?</td>
<td>?</td>
</tr>
</tbody>
</table>
Lifetime of MCP-PMTs (~ 4 years ago)

- QE @ 400nm drops to 50% of starting value within 50 – 200mC/cm²
- Corresponding PANDA-Barrel time $\leq 0.4$ years
- Lifetime of standard MCP-PMTs is not sufficient for usage under PANDA conditions!
- No other models available ~ 3 - 4 years ago
Aging of photo cathode

- Photocathodes of older MCPs are more damaged due to impact of (heavy) ions:
  - Chemical reactions, Adsorption
  - Cluster/lattice/surface defects

- Possible solutions:
  - Make cathode more "robust"
  - Reduce flux of (heavy) ions

Afterpulsing measurements

No lifetime enhancements

ALD coated

relative counts (XP 85012 - 9000413)

Counts/trigger

10^3
10^4
10^5
10^6

0 0.1 0.2 0.3 0.4 0.5 0.6 time [s]

Counts/trigger

10^6
10^3
10^4
10^5

0 0.1 0.2 0.3 0.4 0.5 0.6 time [s]
Methods to increase lifetime

- Improved vacuum (PHOTONIS, BINP #1359, #3548)
- New photo cathode, Cs/Sb -vapor (BINP #1359, #3548)
  → Problem: higher darkcount rate
- Protection layer:
  - In front of first MCP layer (old Ham. MCP-PMTs, BINP #82)
    → Problem: reduction of collection efficiency
  - Between MCP layers
    (Ham. R10754X-01-M16)
- Treatment of MCP surfaces:
  - Electron scrubbing (PHOTONIS, BINP #1359, #3548)
<table>
<thead>
<tr>
<th></th>
<th>BINP</th>
<th>PHOTONIS</th>
<th>Hamamatsu</th>
<th>Hamamatsu</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1359 / 3548</td>
<td>XP85112/A1-HGL</td>
<td>R10754X-01-M16</td>
<td>R10754X-01-M16M</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1223 / 1332</td>
<td>JT0117</td>
<td>KT0001 / KT0002</td>
</tr>
<tr>
<td>Pore size (µm)</td>
<td>7</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Number of pixels</td>
<td>1</td>
<td>8x8</td>
<td>4x4</td>
<td>4x4</td>
</tr>
<tr>
<td>Active area (mm²)</td>
<td>$9^2\pi$</td>
<td>53x53</td>
<td>22x22</td>
<td>22x22</td>
</tr>
<tr>
<td>Geom. Efficiency (%)</td>
<td>36</td>
<td>81</td>
<td>61</td>
<td>61</td>
</tr>
<tr>
<td>Photo cathode</td>
<td>Multi-alkali</td>
<td>Bi-alkali</td>
<td>Multi-alkali</td>
<td>Multi-alkali</td>
</tr>
<tr>
<td>Peak Q.E.</td>
<td>495</td>
<td>390</td>
<td>375</td>
<td>375</td>
</tr>
<tr>
<td>comments</td>
<td>$Na_2KSB(Cs) + Cs_3Sb$ cathode</td>
<td>ALD</td>
<td>Prot. layer between 1. and 2. MCP</td>
<td>ALD</td>
</tr>
</tbody>
</table>

Quantum Efficiency of various MCP-PMTs

Fred Uhlig
NDIP 2014
Simultaneous measurements of several different MCP-PMTs under similar conditions as at the PANDA-DIRCs

Constant illumination (1 MHz single photons) of all MCPs within same lightspot → permanent monitoring to calculate collected anode charge

Every 7-14 days: Measurement of Gain, darkcount and QE

QE is measured separately using a Xenon arc lamp with monochromator (Δλ = 1nm, 250-700nm)

QE surface scans are done every 2-4 months with PiLas (372nm, Ø ~1mm)
Dark count rate

**New cath.** BINP 1359/3548

![Graph showing dark count rate vs anode charge for BINP 1359 and BINP 3548.]

**PHOTONIS XP85112/A1-HGL**

![Graph showing dark count rate vs anode charge for PHOTONIS XP85112/A1-HGL with different marker styles for different pixels.]

**Hamamatsu R10754X-01-M16**

![Graph showing dark count rate vs anode charge for Hamamatsu R10754X-01-M16 with different marker styles for different pixels.]

**Hamamatsu R10754X-07-M16M**

![Graph showing dark count rate vs anode charge for Hamamatsu R10754X-07-M16M with different marker styles for different pixels.]

Protection layer
Gain

New cath.

BINP 1359/3548

\[
\text{Gain} \times 10^3
\]

- BINP 1359
- BINP 3548

\[
\text{anode charge [mC/cm}^2\text{]}
\]

PHOTONIS XP85112/A1-HGL

- 1332 - Pix 57 (cov.)
- 1332 - Pix 43
- 1223 - Pix 17 (cov.)
- 1223 - Pix 23

Hamamatsu R10754X-01-M16

\[
\text{Gain} \times 10^3
\]

- Pixel 2
- Pixel 10
- Pixel 11
- Pixel 15

Protection layer

Hamamatsu R10754X-07-M16M

\[
\text{Gain} \times 10^3
\]

- Pixel 1
- Pixel 3
- Pixel 11
- Pixel 16

ALD
Spectral Quantum Efficiency

New cath.

**BINP 3548**

- **300 nm**
- **400 nm**
- **450 nm**
- **500 nm**
- **600 nm**

**PHOTONIS XP85112/A1-HGL -1223**

- **300 nm**
- **400 nm**
- **450 nm**
- **500 nm**
- **600 nm**

**Hamamatsu R10754X-01-M16**

- **300 nm**
- **400 nm**
- **450 nm**
- **500 nm**
- **600 nm**

**Hamamatsu R10754X-07-M16M**

- **300 nm**
- **400 nm**
- **450 nm**
- **500 nm**
- **600 nm**
Relative QE

\[
\text{rel. QE} := \frac{QE(\lambda)}{QE_{Q=0}(\lambda)} / \frac{QE(\lambda_0)}{QE_{Q=0}(\lambda_0)}; \lambda_0 = 350\text{nm}
\]

**new cath. BINP 3548**

**PHOTONIS XP85112/A1-HGL**

**Hamamatsu R10754X-01-M16**

**Hamamatsu R10754X-07-M16M**
**QE surface scan**

**protection layer**

**Hamamatsu R10754X-01-M16**

Laser spot size: ~1mm, 372nm

Aging starts at corners (M16) or rim (BINP 3548)

**new cath.**

**BINP 3548**

**Laser spot size:** ~1mm, 372nm

**Aging starts at corners (M16) or rim (BINP 3548)**
- red area is **not** illuminated
- aging starts at the edge after 6C/cm²
- difference between covered (right) and illuminated (left) area clearly visible at >7C/cm²
Comparison with older MCP-PMTs

- Aging of XP85112/A1-HGL – 1223 has started after 6C/cm²
- XP85112/A1-D – 9001332 has collected over 4C/cm² with no degradation
- Ham. ALD coated MCP-PMT shows no aging effects (2.6C/cm²)
- Performance of BINP 3548 acceptable
- ALD is most promising technique
Summary and Outlook

- Requirements: $5 \text{C/cm}^2$ (50% duty cycle, 10 years), Disc-DIRC even more

- Lifetime of MCP-PMTs has substantially increased:
  - ALD coated devices show best performance
  - Surface scans show that aging starts at the corners/edges
  - XP85112/A1-HGL - 1223 has passed $\sim 7 \text{C/cm}^2$, first aging effects visible at $\sim 6.0 \text{C/cm}^2$
    $\rightarrow$ currently checked with other devices (1332, 1393)

- Future improvements:
  - ALD + new cathode?
  - Change MCP material (leadglas $\rightarrow$ borosilicateglas)
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Int. Collect. Charge (Jun. 25th) [mC/cm²]</td>
<td>3615 / 5587</td>
<td>7062 / 4076 / 1026</td>
<td>2085</td>
<td>2633</td>
</tr>
<tr>
<td>Max applied current per anode [nA]</td>
<td>315 / 346</td>
<td>56 / 59 / 59</td>
<td>45.3</td>
<td>71.4 / 40.3</td>
</tr>
<tr>
<td>Specified max. DC anode cur. [nA]</td>
<td>1000</td>
<td>47 (64 Chans.) 94 (32 Chans.)</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Max Diff. Charge [mC/cm²/d]</td>
<td>10.7 / 11.7</td>
<td>13.5 / 13.6 / 13.6</td>
<td>14.1</td>
<td>19.3 / 10.9</td>
</tr>
<tr>
<td>Anode area per pixel (cm²)</td>
<td>2.54</td>
<td>0.36</td>
<td>0.32</td>
<td>0.32</td>
</tr>
<tr>
<td>Measured Channels</td>
<td>1</td>
<td>8 + 2 (unexposed) + MCP-Out / 7 chans 1393</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Illuminated area</td>
<td>100%</td>
<td>50% / 100% (1393)</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Applied voltage (V) using voltage divider</td>
<td>3100 (+100)</td>
<td>2050 / 2000 2100 / 2050 illum.</td>
<td>3300</td>
<td>2400 / 2600</td>
</tr>
</tbody>
</table>
Assumptions:
- PANDA high luminosity mode: \(2 \times 10^{32} \text{cm}^{-2} \text{s}^{-1}\)
  \(\rightarrow\) p-pbar reaction rate: 20MHz
- QE of XP85112
- 1 year of 100% duty cycle!

results:
- Int. Charge is radial dependent
- \(\frac{1}{\text{cm}^{2} \cdot \text{a}}\) at focal plane
- Assuming 50% duty cycle and 10 years operation time  \(\rightarrow\)
  5C/cm² needed!
Magnetic field performance

- Lamor radi of electrons determine maximum magnetic field $\rightarrow 10\mu$m or less required for 2T
- Gain decreases almost instantly, if B-field is parallel to mcp channels
- Gain drops faster for larger tilt angles > 20°
Illumination setup

- LED-Lightspot is expanded on all MCPs
- Trigger rate: 272kHz – 1MHz
- Scaler: event reduction for monitoring
- TDC used for crosstalk and pedestal supression
- Stability of LED is measured with photodiode
Goal: Determine mass/kind of backscattered ions and estimate their amount

Absolute time can be calculated by time difference of primary and after pulse

Classical approach for estimating m/q
Microchannel-Plate PMTs

- Typical pore sizes: 6 – 25µm
- Very fast signals:
  - Rise time: 0.5 – 1.5ns
  - TTS < 50ps
- Gain > $10^6$ with 2 MCP stages
- Low dark count rate
- Usable in B-fields of up to 2T → Standard PMTs not usable in PANDA

Problems:
- Price
- Aging → QE drops!