Photocathode aging in microchannel plate PMT

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Outline:

- MCP PMT and its application in HEP
- Study of the photocathode aging
- Lifetime of the best sample
- Summary
Microchannel plate PMT

- Immunity to magnetic field
- Excellent time resolution
- Good space resolution
- Limited counting rate capability
- Short lifetime

Input electron

MCP channel

HV

\[ \varnothing \sim 10 \mu m \]
\[ \sim 400 \mu m \]

\[ \varnothing \sim 18 \mu m \]

\[ \varnothing \sim 31 \mu m \]

\[ 200 \mu m \]

Photonis

Hamamatsu

Photek

Ekran FEP

5x5 cm

2x2 cm

\[ \varnothing 10-40 \text{ mm} \]

\[ \varnothing 18 \text{ mm} \]

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ASHIPH counters for KEDR

- $\pi/K$ separation in momenta range 0.6 ÷ 1.5 GeV/c
- Aerogel $n=1.05$ (1000 litres)
- 160 MCP PMT
- Magnetic field up to 1.5 T

80 counters have been working since 2003
ASHIPH counters for SND

- π/K separation in momenta range $300 \div 870$ MeV/c
- Aerogel $n=1.13$
- 9 MCP PMT
- No magnetic field

TOF counters for CMD-3

- Antineutron identification
- BC-408 scintillator (16 bars)
- 32 MCP PMT

SND and CMD-3 are working at VEPP-2000 $e^+e^-$ collider in BINP
Future MCP PMT applications

**Belle-II TOP**

\[ I_{OUT} = 0.15 \text{ C/cm}^2/\text{year} \]

**LHCb TORCH**

\[ I_{OUT} \sim 5 \text{ C/cm}^2/\text{year} \]

**PANDA DIRC**

\[ I_{OUT} \leq 1 \text{ C/cm}^2/\text{year} \]

**PANDA Disk DIRC**

\[ I_{OUT} \leq 5 \text{ C/cm}^2/\text{year} \]

- DIRC-like TOF for SuperB
- QUARTIC for AFP
- GasTOF for HPS
MCP PMT under investigation

Manufacturer: “Ekran FEP” (Novosibirsk)
Borosilicate glass window
Alkali-antimonide photocathode
Maximum QE at $\lambda=500$nm
Two MCPs with channel diameter of 7 $\mu$m
Channel bias angle 13°
Single anode
Gain decrease at high counting rate


\[ I(z) = I_{in} e^{\alpha z} \ln(G_0) / F \cdot (1 + I_{in}/I_s \cdot e^{\alpha z}) \]

\[ G = G_0 \cdot \ln(G_0) / F / (1 + I_{in}/I_s \cdot e^{\alpha z}) \]

where

\[ F = \ln(G_0) + \ln(1 + I_{in}/I_s) - \ln(1 + I_{in}/I_s \cdot G_0) \]

\[ \alpha = \ln(G_0)/L \]
QE degradation at different counting rates

The higher counting rate the faster QE degradation per unit of anode charge

The higher counting rate the slower QE degradation per unit of cathode charge
There is no correlation between QE degradation rate and photon counting rate.
Two stages of MCP degassing:
1. Heating
2. Electron scrubbing

+ Photocathode lifetime increase
- Gain degradation

Duration of electron scrubbing has been increased in 2 and 3 times

\[ \text{MCP gain is not affected} \]

(large spread of initial MCP quality)
Enhancement of MCP degassing: aging

Three times better electron scrubbing

Two times slower QE degradation
**Photocathodes: spectral response**

- **$\text{Na}_2\text{KSB}$**: Dark rate $< 0.5$ kcps/cm$^2$
- **$\text{Na}_2\text{KSB(Cs)}$**: Dark rate $\sim 0.5$ kcps/cm$^2$
- **$\text{Na}_2\text{KSB(Cs)} + \text{Cs}$**: Dark rate $\sim 5$ kcps/cm$^2$
- **$\text{Na}_2\text{KSB(Cs)} + \text{Cs}_3\text{Sb}$**: Dark rate $\sim 50$-100 kcps/cm$^2$
Photocathodes: aging comparison

Rate $\sim 10^{10} - 10^{11}$ cps/cm$^2$
Best sample: photocathode lifetime

At Rate $\sim 10$ Mcps/cm$^2$ LifeTime ($\sim$20% @ $Q_{E_{\text{MAX}}}$) = 3.3 C/cm$^2$

and much higher at 2 Mcps/cm$^2$!
Best sample: comparison with old tubes

Lifetime improved by one order of magnitude (at least)!
Summary

- QE degradation is proportional to the charge extracted from the 1st MCP (at high counting rate).
- Enhancement of MCP electron scrubbing did not affect MCP gain and decreased the photocathode aging rate.
- Optimization of the photocathode formation process can decrease aging rate by order of magnitude.
- The photocathode lifetime of the best MCP PMT sample is more than 3.3 C/cm² of accumulated anode charge.
Thank you!
FARICH for Super cτ

\((E_{\text{CM}} = 2–5 \text{ GeV}, L = 10^{35} \text{ cm}^{-2}\text{s}^{-1})\)

- \(\mu/\pi\) and \(\pi/K\) separation
- Four-layer aerogel \(n_{\text{max}}=1.07\)
- Total area of photodetectors is 21 m\(^2\), \(\sim 10^6\) channels
- Magnetic field of 1 T
- MCP PMT is possible photodetector for endcaps
FARICH for Super $\tau$ (beam test results)

- $e^-$-beam $E = 1.35 \text{ GeV}$
- 4-layer aerogel, $t=31\text{mm}$
- 32 SiPM (CPTA, Moscow)
- CAEN TDC V1190B

Good agreement with MC simulation!

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**Experimental setup**

Low light intensity (photon counting mode):
\[ K = \frac{R_{\text{PMT}}}{I_{\text{MONI}}} \]

High light intensity (direct current mode):
\[ R_{\text{PMT}} = I_{\text{MONI}} K \]

**QE measurement:**

Reference PD: Hamamatsu S1227-1010BQ
Calculation of 1st MCP current

Approximation of dependence $I_{\text{OUTPUT}}(I_{\text{INPUT}})$:

$$I(z=L) = f(I_{\text{in}}, G_0, I_s)$$

$G_0$ and $I_s$ - free parameters

Calculation of the current extracted from 1st MCP:

$I(z=L/2)$ using $G_0$ and $I_s$ obtained from approximation
MCP PMT #91110: lifetime

Lifetime measurements at "low" counting rate: $2 \cdot 10^6 - 10^7 \text{s}^{-1}\text{cm}^{-2}$
MCP PMT lifetime comparison

Novosibirsk: 3.0 C/cm² (R ~ 1x10⁷ s⁻¹cm⁻²)

Hamamatsu: 2.5 C/cm² (R ~ 5x10⁵ s⁻¹cm⁻²)

Photonis: 0.1 C/cm² (R ~ 2x10⁵ s⁻¹cm⁻²)

(G₀ ~ 10⁶)