Photocathode aging in microchannel plate PMT

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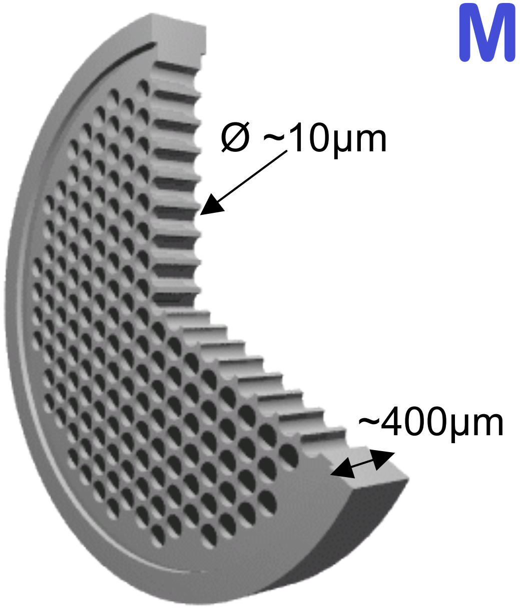
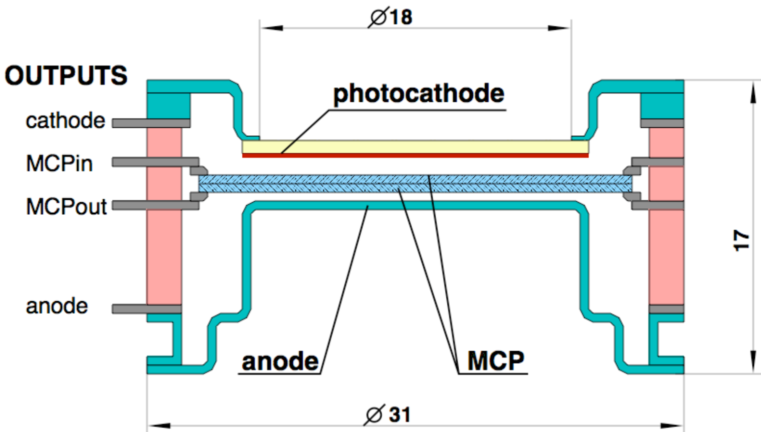
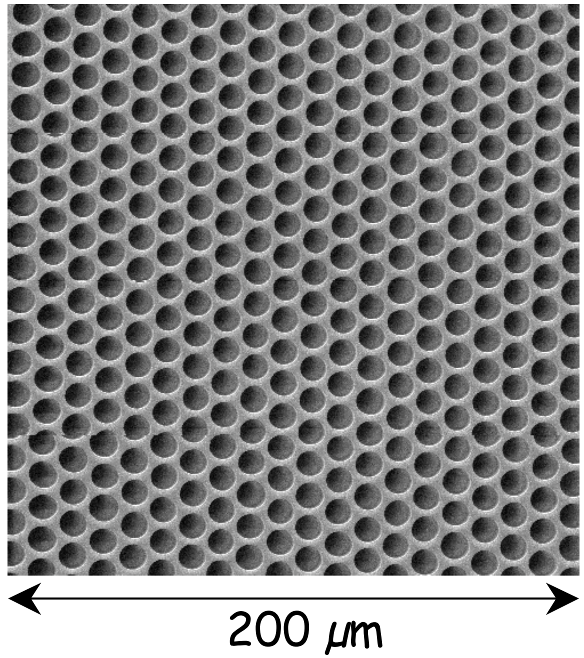
Outline:

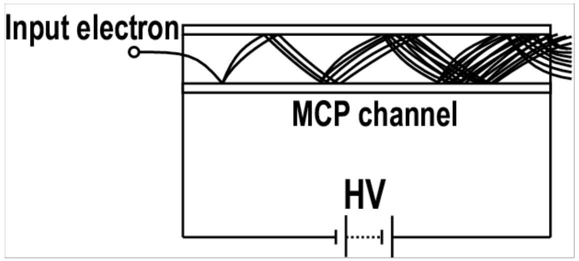
- MCP PMT and its application in HEP
- Study of the photocathode aging
- Lifetime of the best sample
- Summary

Microchannel plate PMT



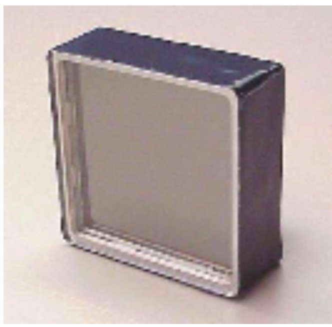






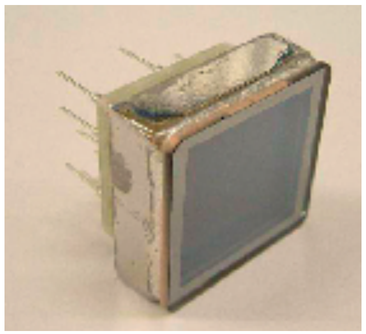
- Immunity to magnetic field
- Excellent time resolution
- Good space resolution
- Limited counting rate capability
- Short lifetime

Photonis



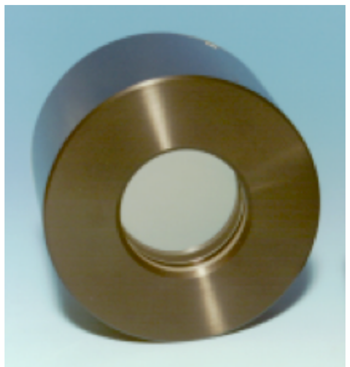
5x5 cm

Hamamatsu



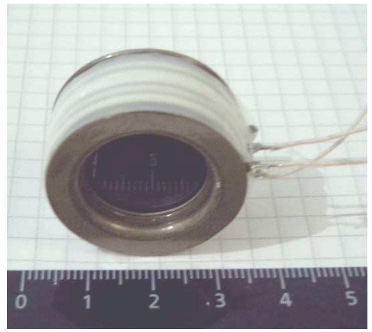
2x2 cm

Photek

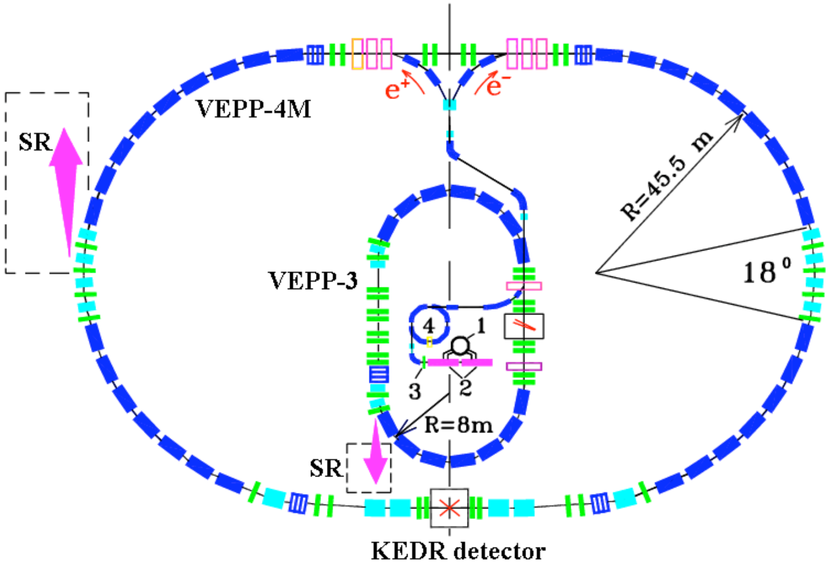


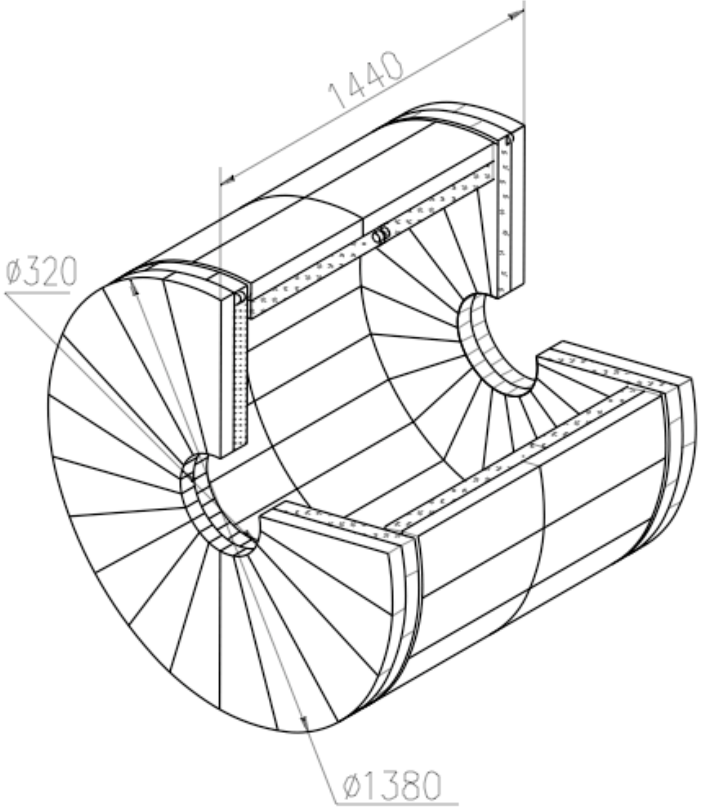
Ø 10-40 mm

Ekran FEP



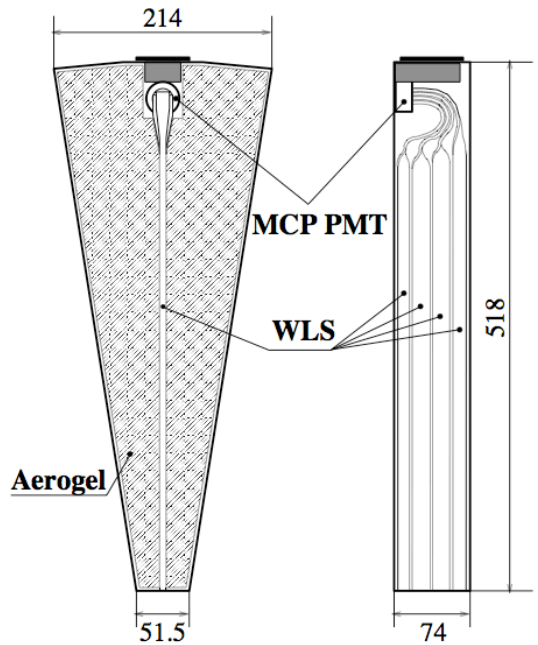
Ø 18 mm





ASHIPH counters for KEDR

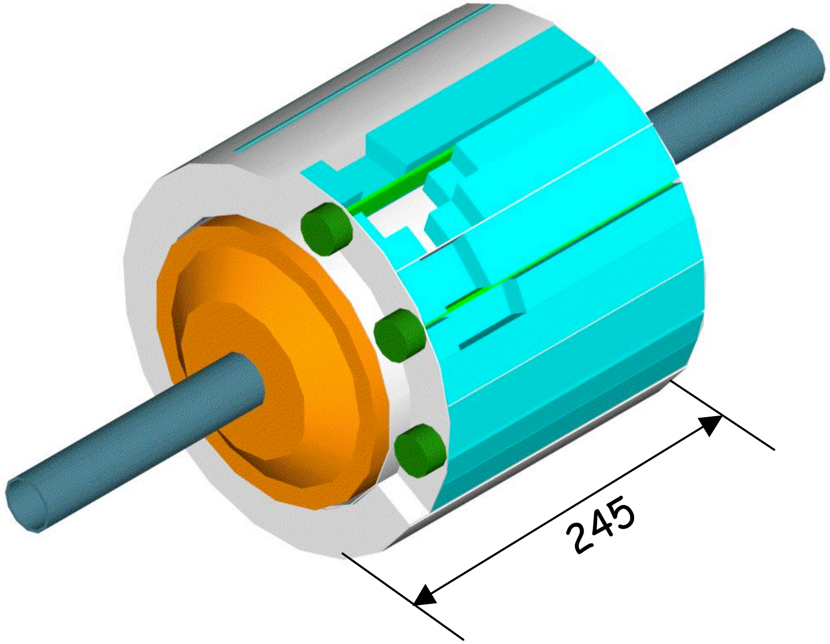
- π/K separation in momenta range 0.6 ÷ 1.5 GeV/c
- Aerogel n=1.05 (1000 litres)
- 160 MCP PMT
- Magnetic field up to 1.5 T



80 counters have been working since 2003

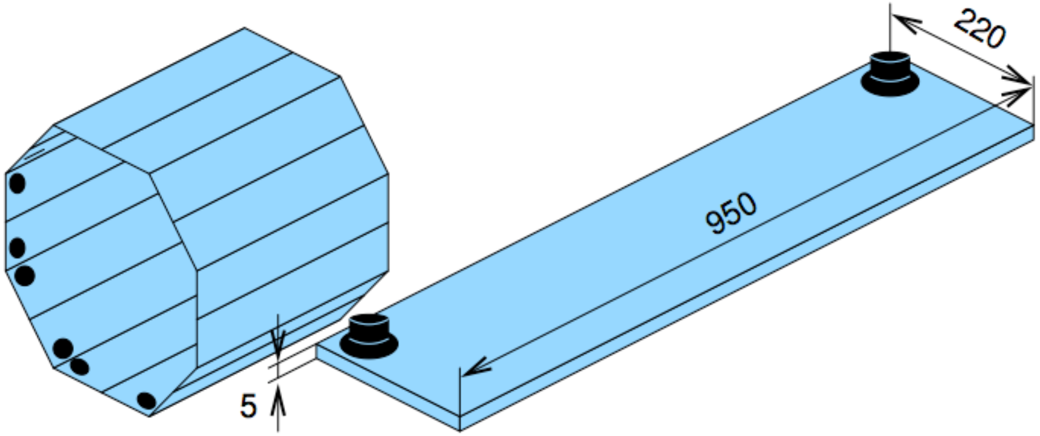
ASHIPH counters for SND

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



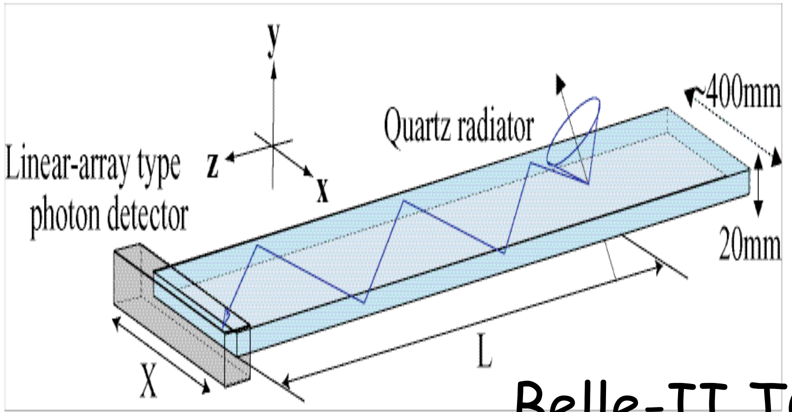
TOF counters for CMD-3

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



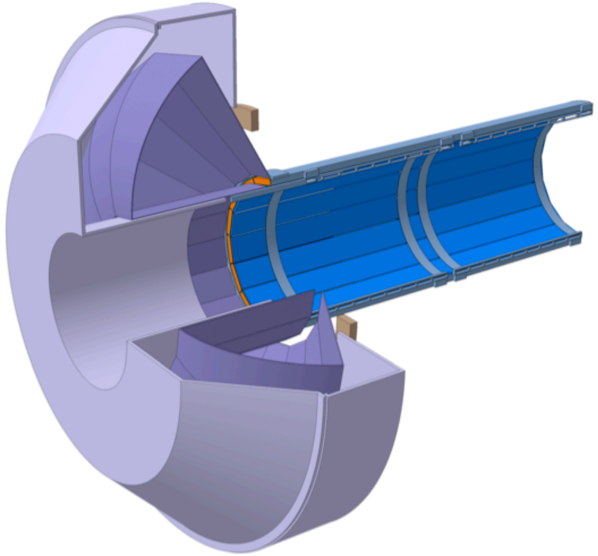
SND and CMD-3 are working at VEPP-2000 e^+e^- collider in BINP

Future MCP PMT applications



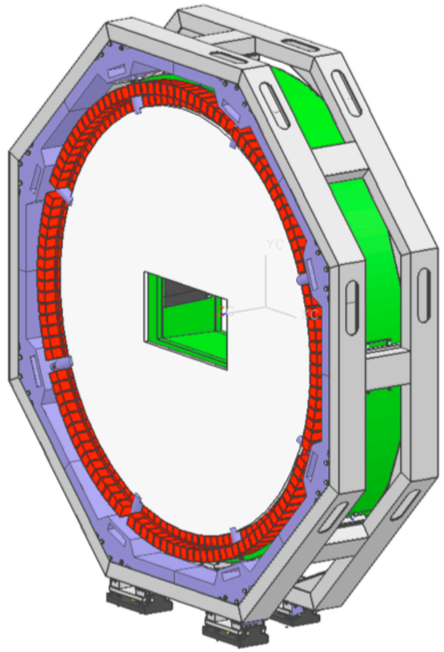
Belle-II TOP

I_{OUT} = 0.15 C/cm^2/year



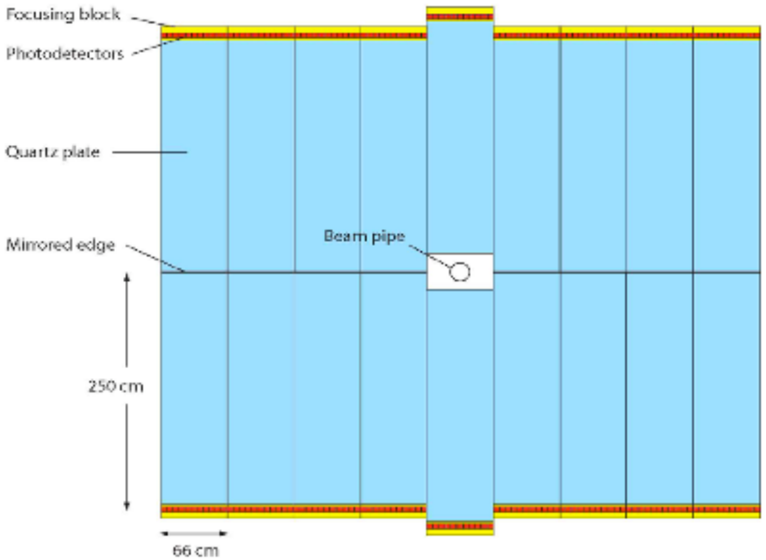
PANDA DIRC

$I_{OUT} \leq$ 1 C/cm^2/year



PANDA Disk DIRC

$I_{OUT} \leq$ 5 C/cm^2/year

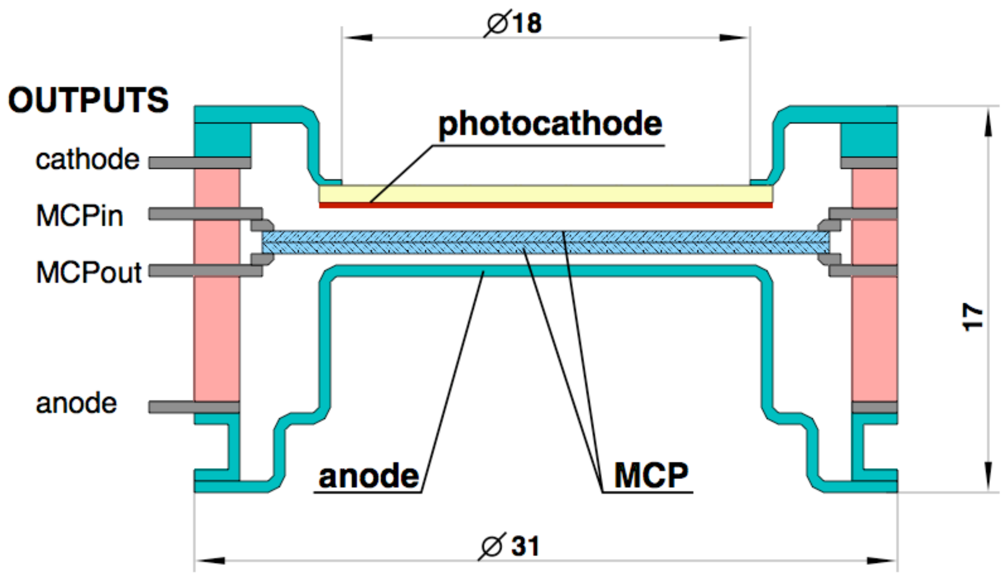


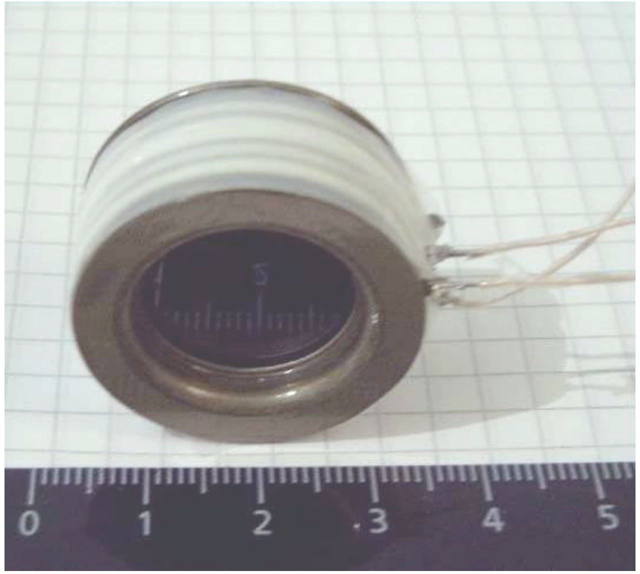
LHCb TORCH

$I_{OUT} \sim$ 5 C/cm^2/year

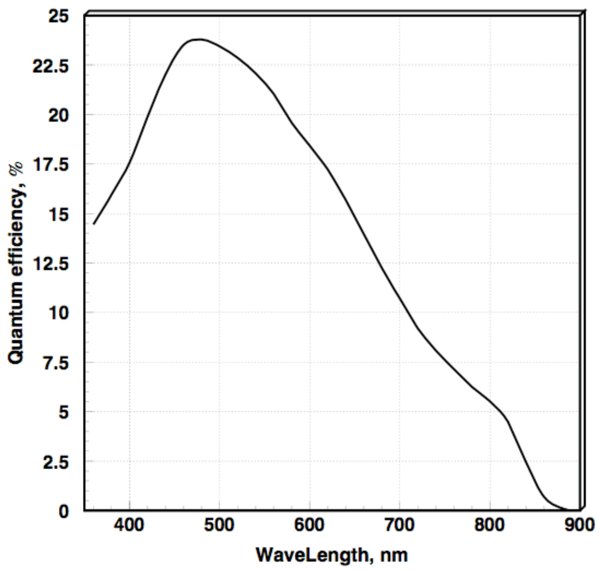
- DIRC-like TOF for SuperB
- QUARTIC for AFP
- GasTOF for HPS
- . . . . .

MCP PMT under investigation



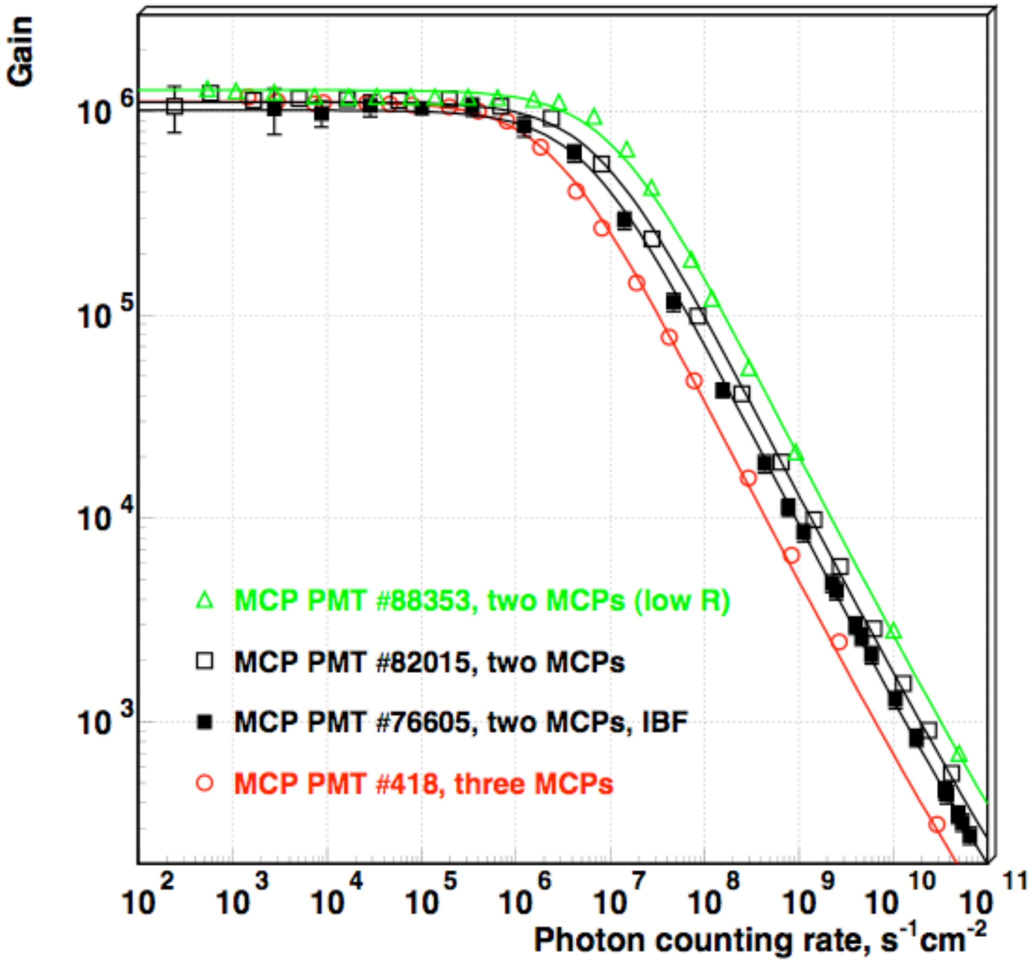


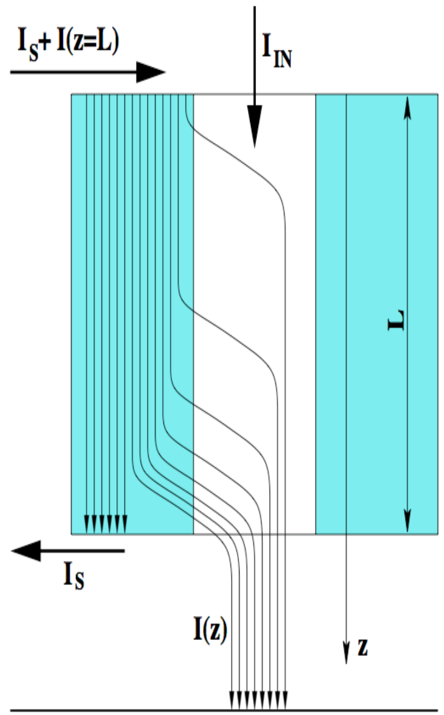
Manufacturer: "Ekran FEP" (Novosibirsk)
Borosilicate glass window
Alkali-antimonide photocathode
Maximum QE at λ=500nm
Two MCPs with channel diameter of 7 μm
Channel bias angle 13°
Single anode



Gain decrease at high counting rate

A.B.Berkin and V.V.Vasilyev,
Technical Physics, 2008, Vol. 53, No. 2, p.272





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

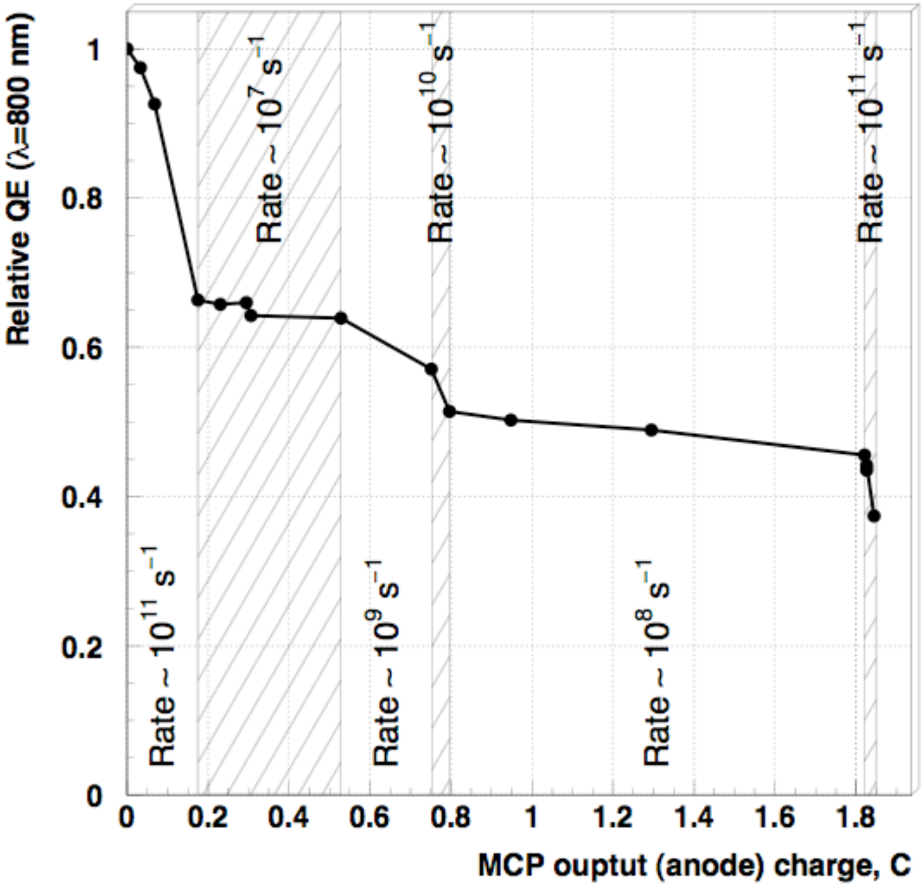
where

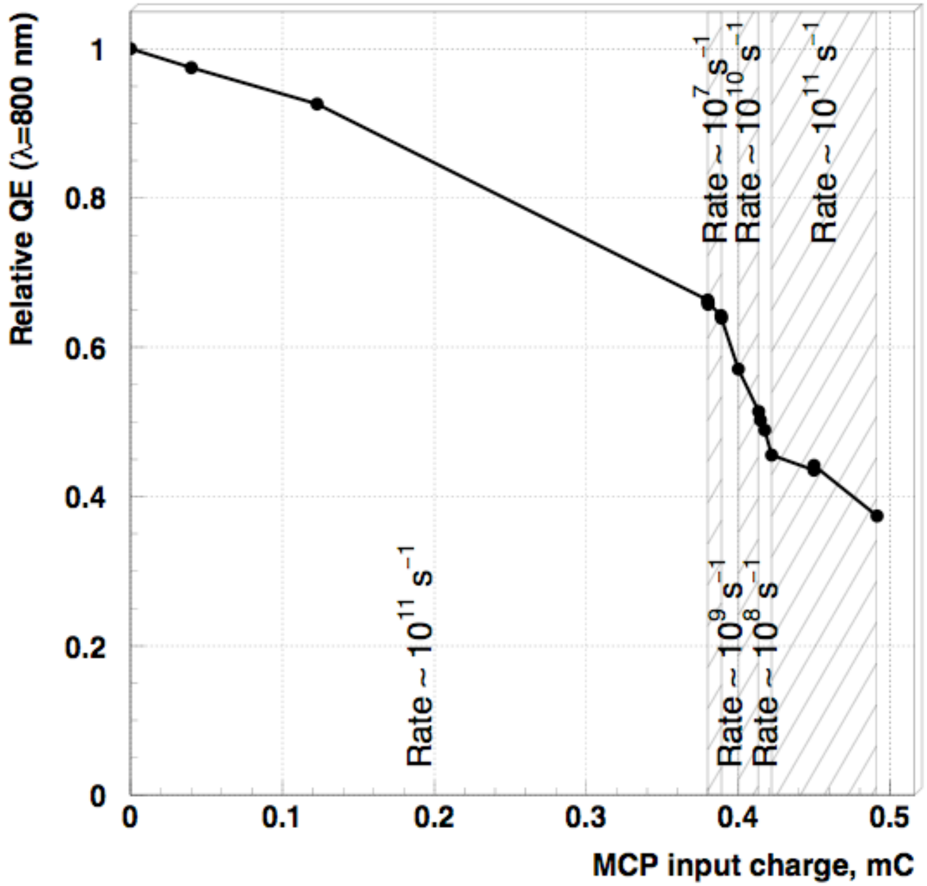
$F = \ln(G_0) + \ln(1+I_{in}/I_s) - \ln(1+I_{in}/I_s \cdot G_0)$

$\alpha = \ln(G_0)/L$

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

QE degradation at different counting rates

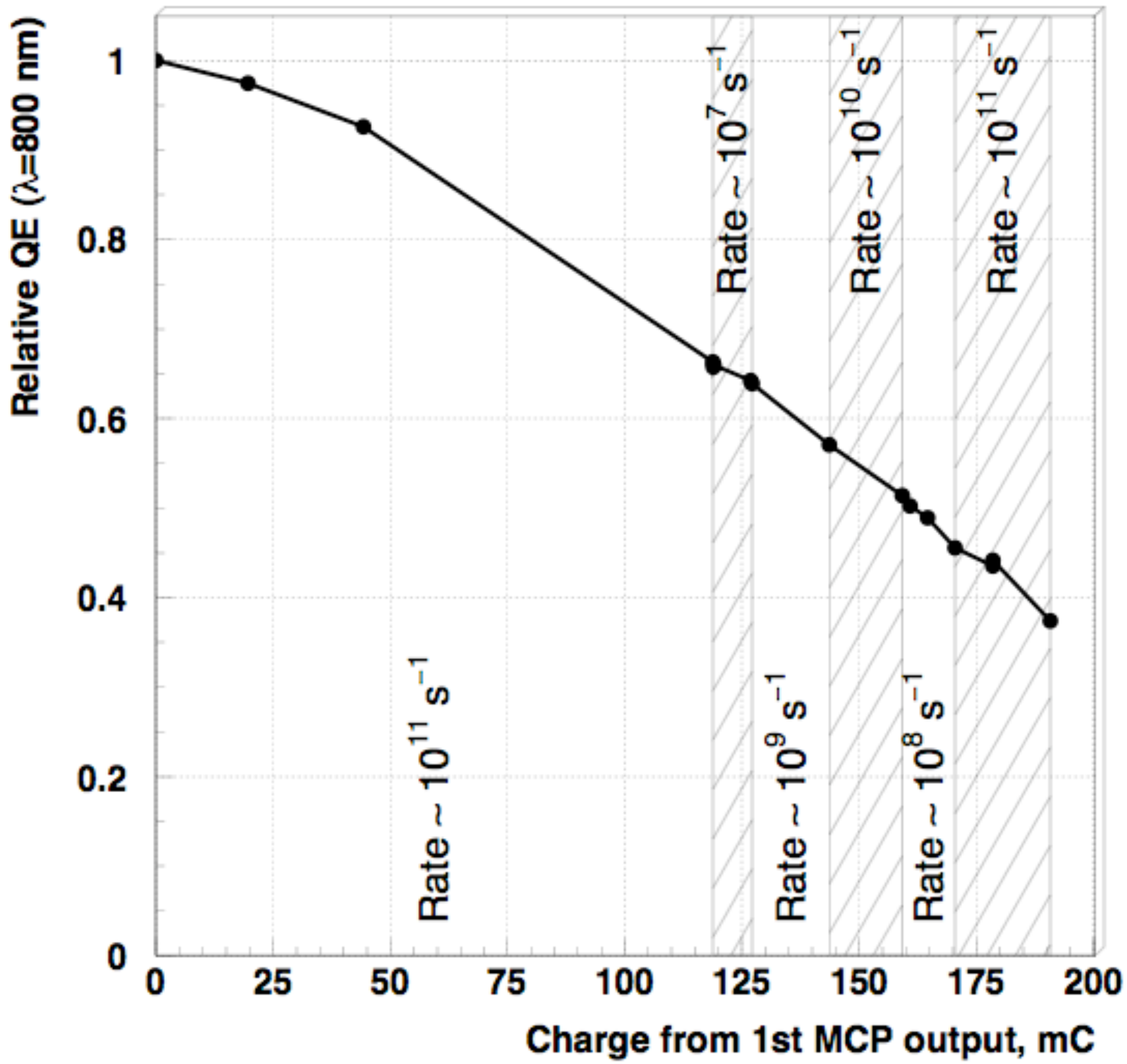


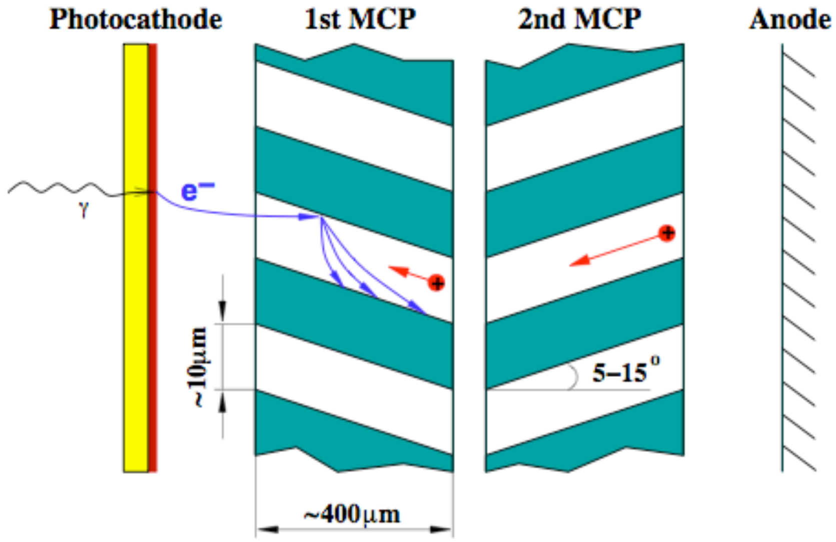


The higher counting rate the faster QE degradation per unit of anode charge

The higher counting rate the slower QE degradation per unit of cathode charge

QE degradation vs. charge from 1st MCP



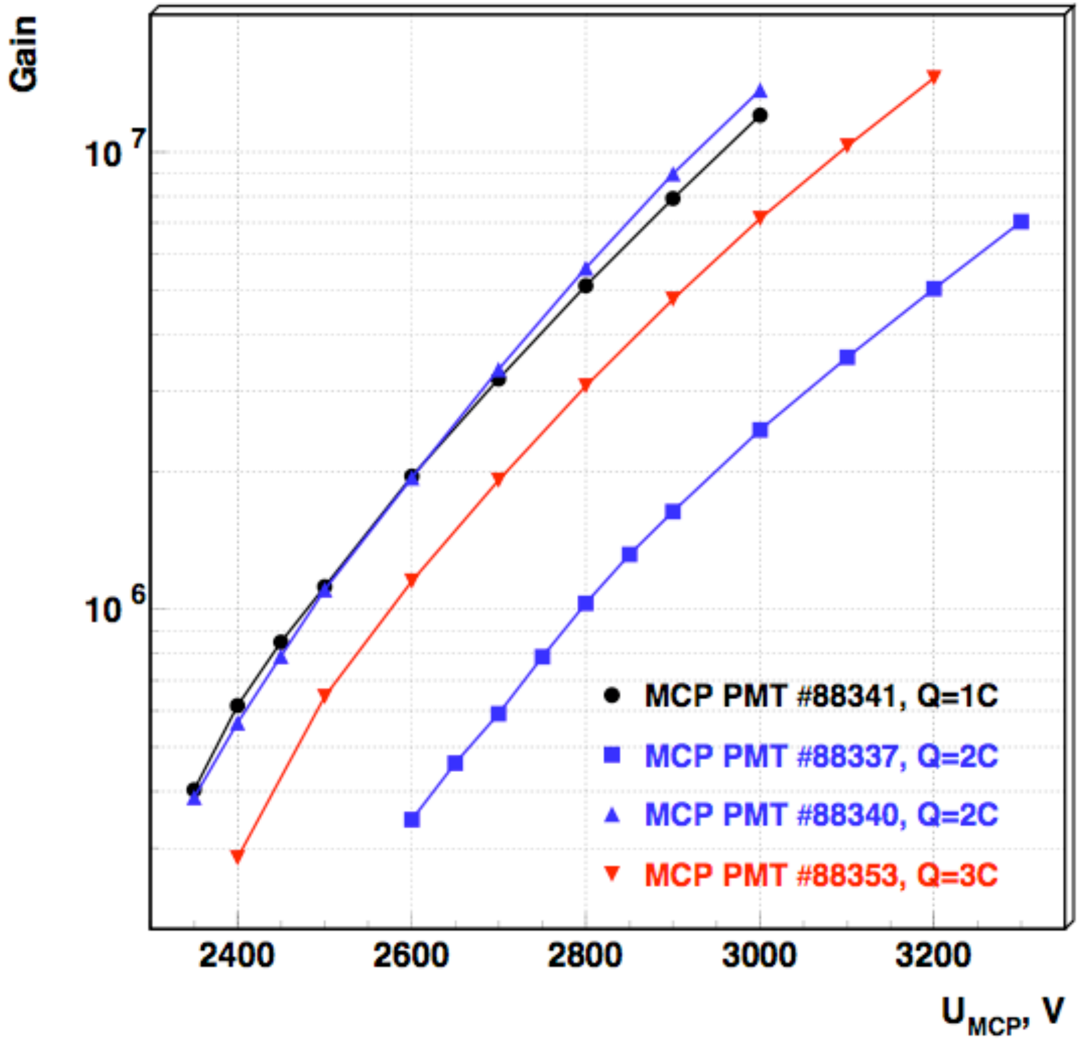


There is no correlation between QE degradation rate and photon counting rate.

Enhancement of MCP degassing: gain

Two stage of MCP degassing:
1. Heating
2. Electron scrubbing

+ Photocathode lifetime increase
- Gain degradation

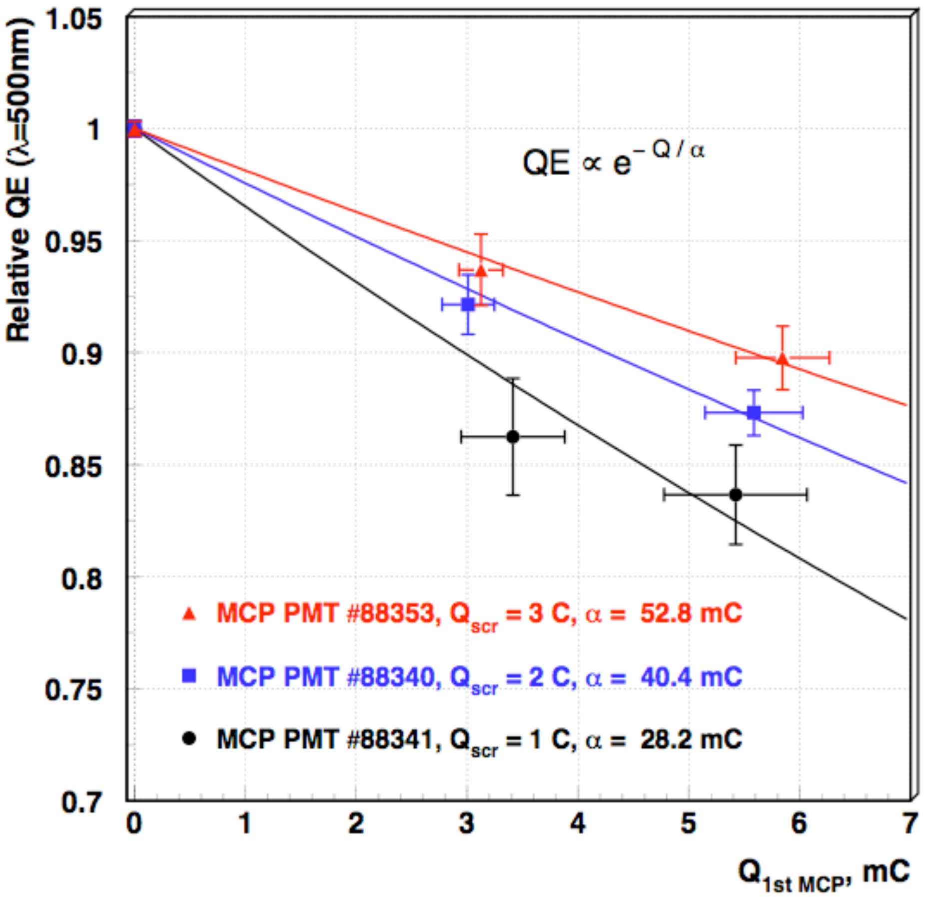


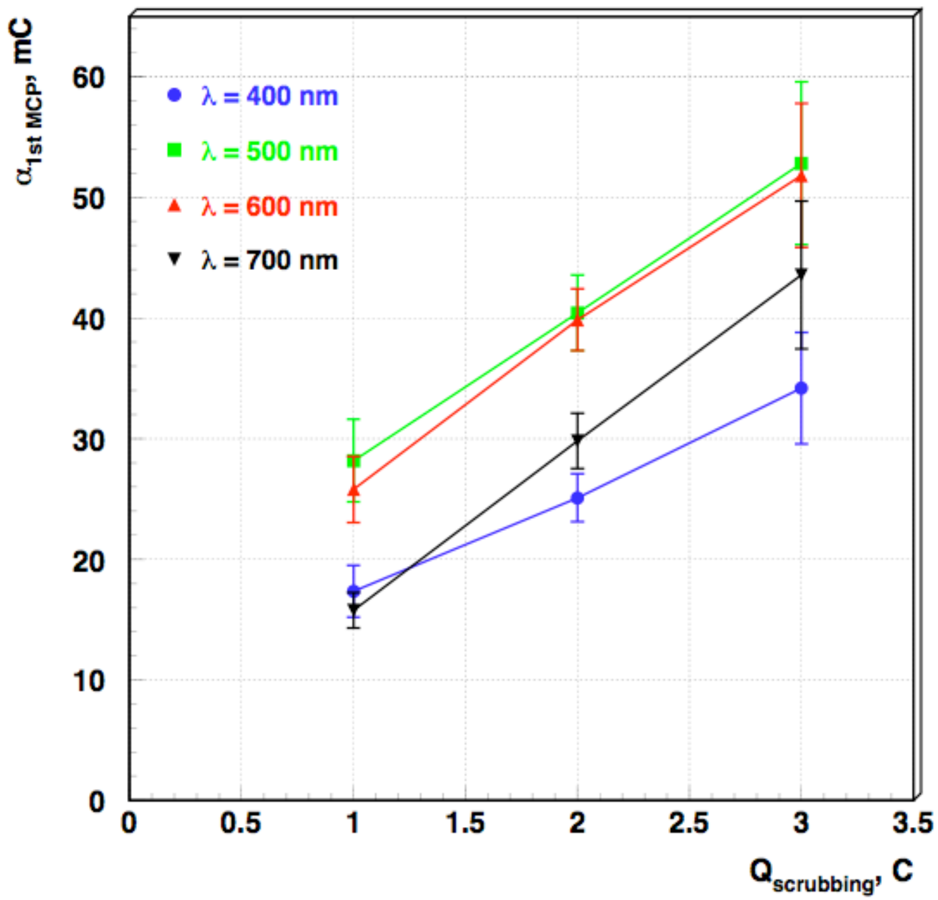
Duration of electron scrubbing has been increased in 2 and 3 times

↓

MCP gain is not affected (large spread of initial MCP quality)

Enhancement of MCP degassing: aging



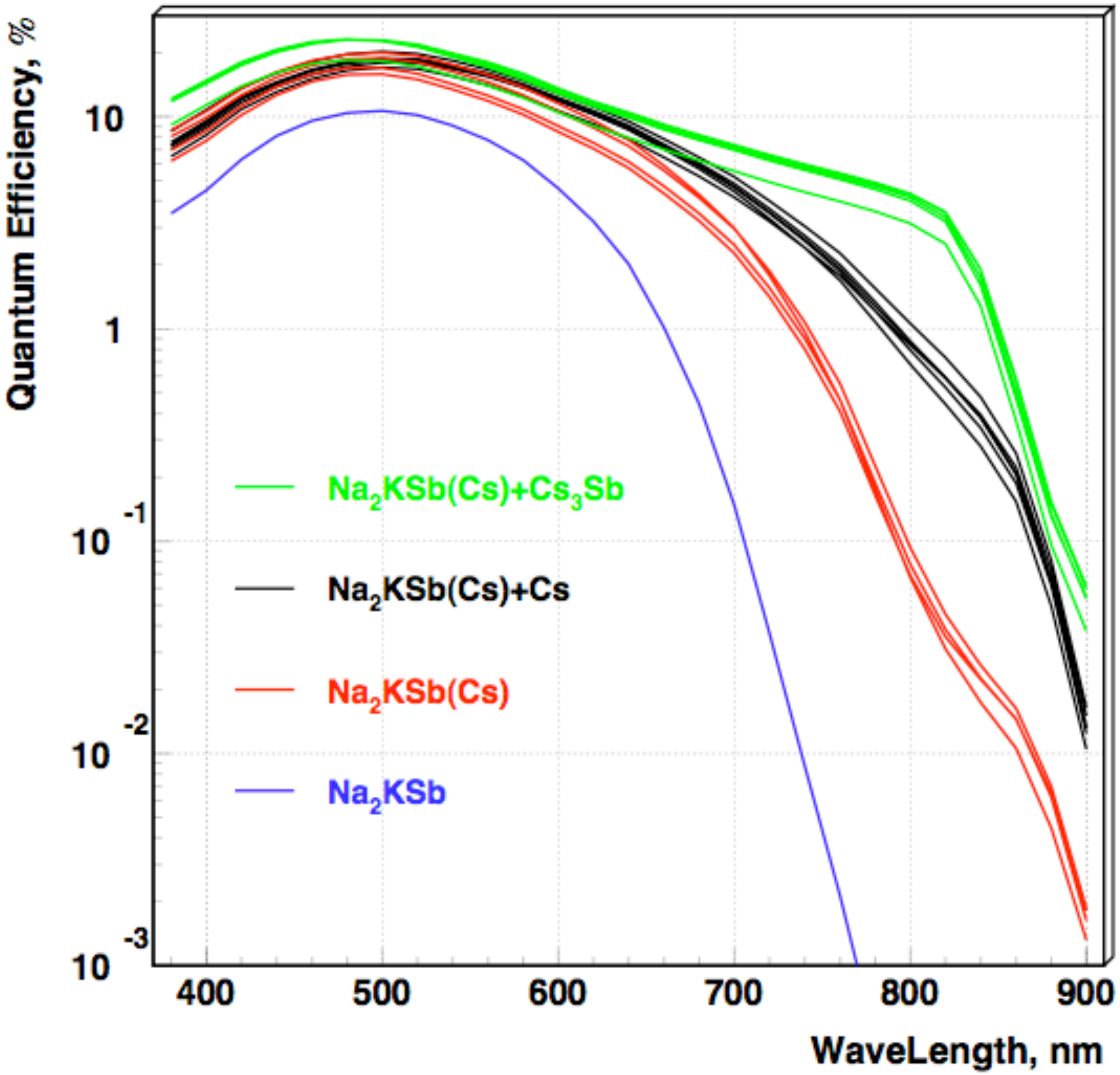


Three times better electon scrubbing

↓

Two times slower QE degradation

Photocathodes: spectral response



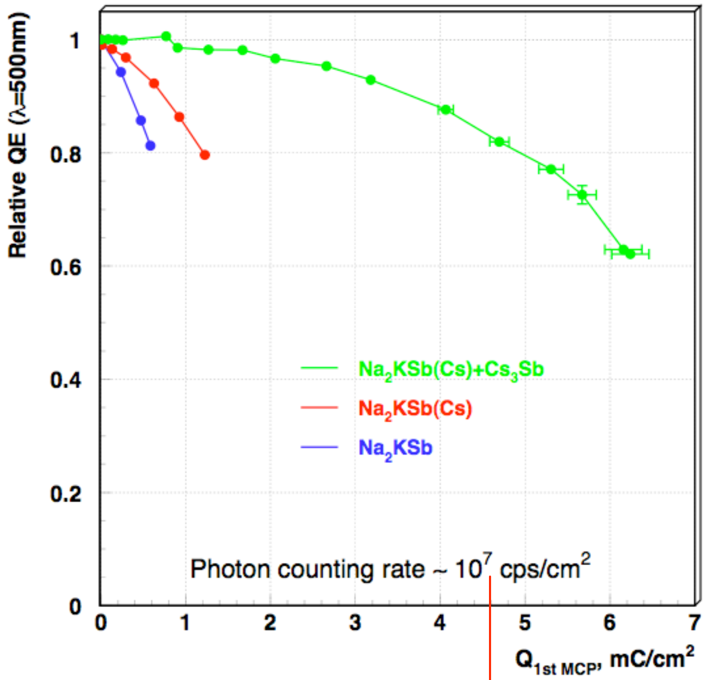
Na_2KSb :
Dark rate < 0.5 kcps/cm^2

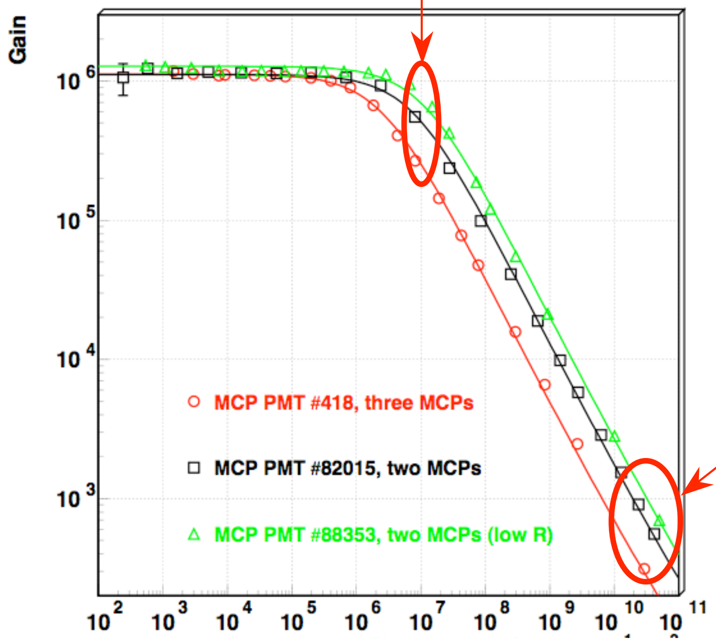
$Na_2KSb(Cs)$:
Dark rate ~ 0.5 kcps/cm^2

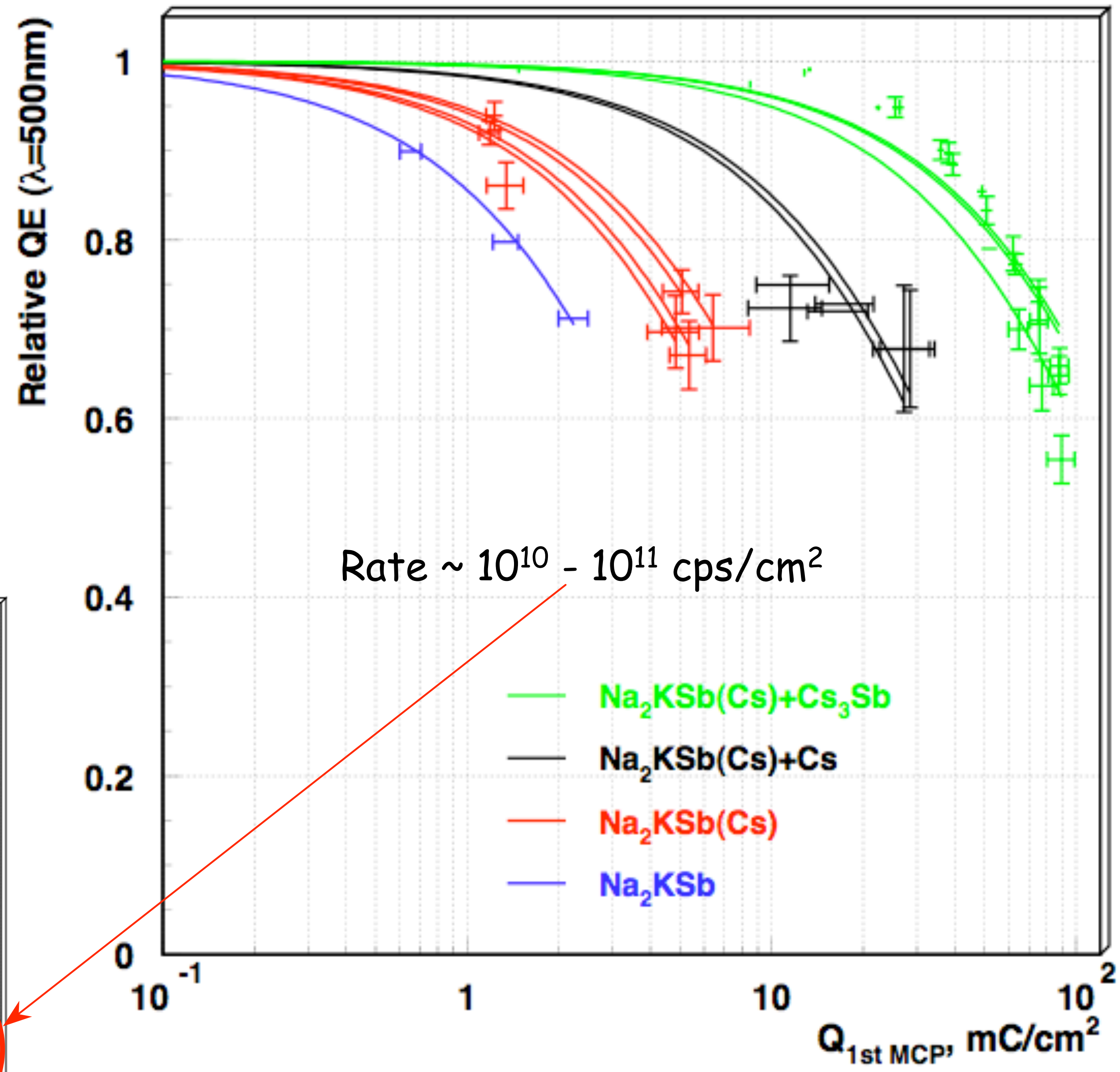
$Na_2KSb(Cs) + Cs$:
Dark rate ~ 5 kcps/cm^2

$Na_2KSb(Cs) + Cs_3Sb$:
Dark rate ~ 50-100 kcps/cm^2

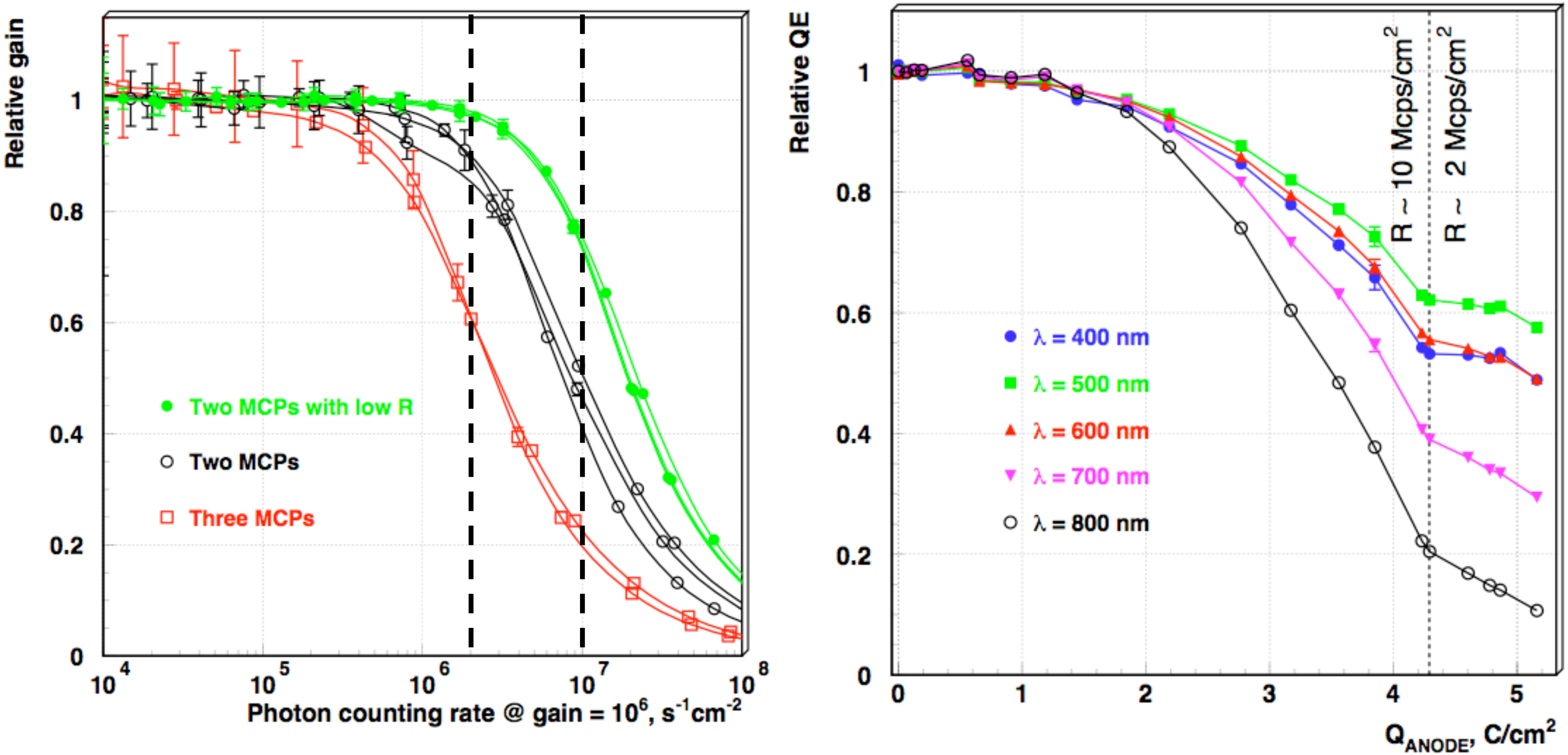
Photocathodes: aging comparison







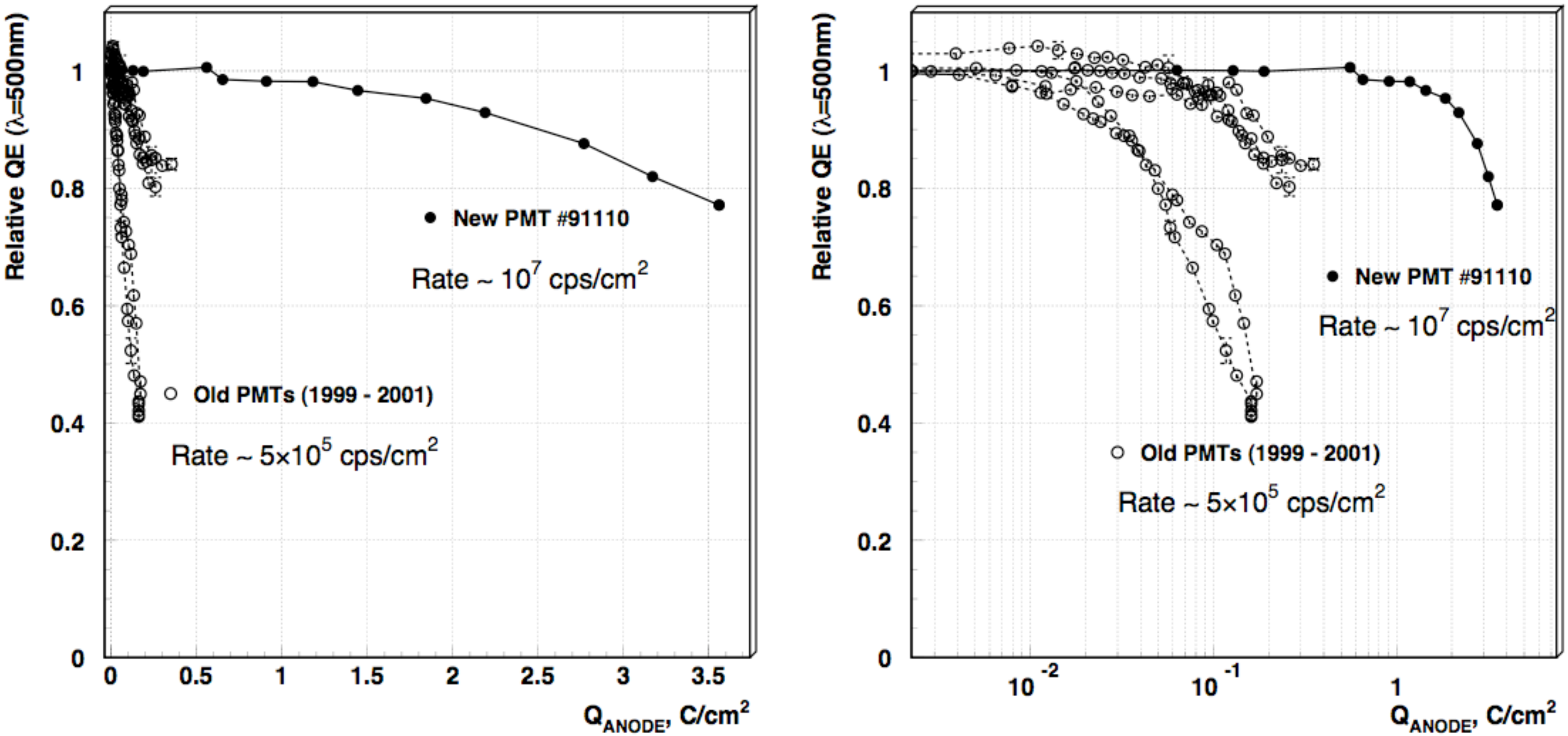
Best sample: photocathode lifetime



At Rate ~ 10 Mcps/cm² LifeTime (-20% @ QE_{MAX}) = 3.3 C/cm²

and much higher at 2 Mcps/cm² !

Best sample: comparison with old tubes



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

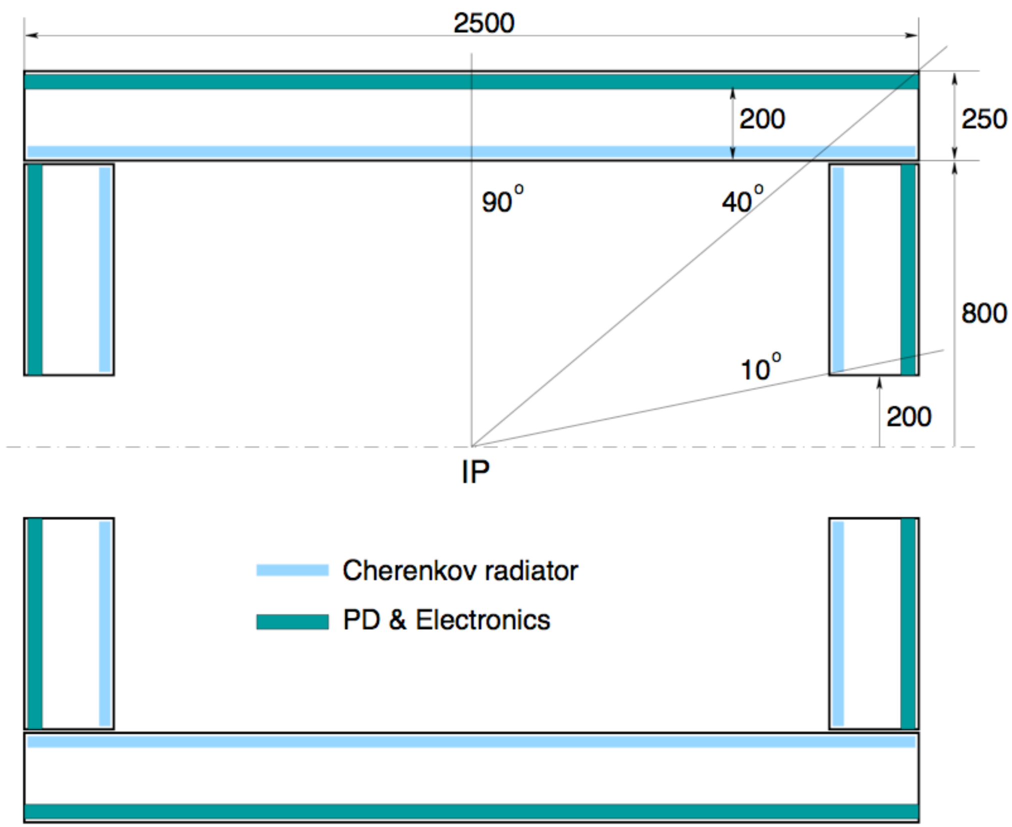
Summary

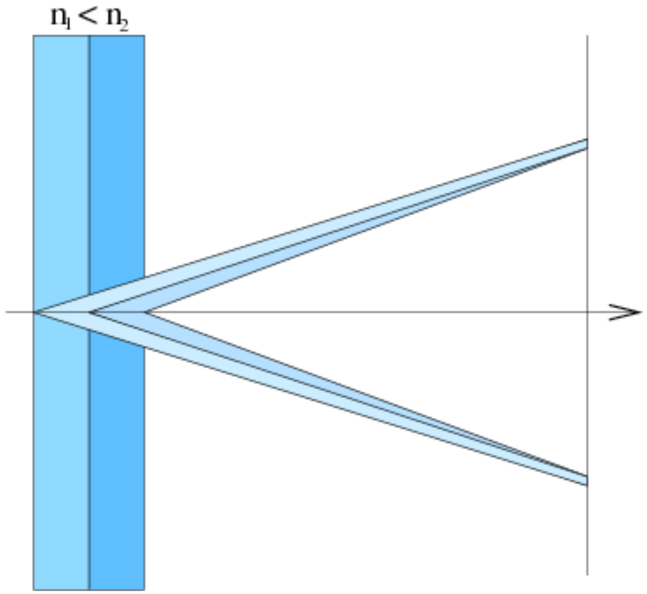
- QE degradation is proportional to the charge extracted from the 1st MCP (at high counting rate).
- Enhancement of MCP electron scrubbing did not affect MCP gain and decreased the photocathode aging rate.
- Optimization of the photocathode formation process can decrease aging rate by order of magnitude.
- The photocathode lifetime of the best MCP PMT sample is more than 3.3 C/cm^2 of accumulated anode charge.

Thank you!

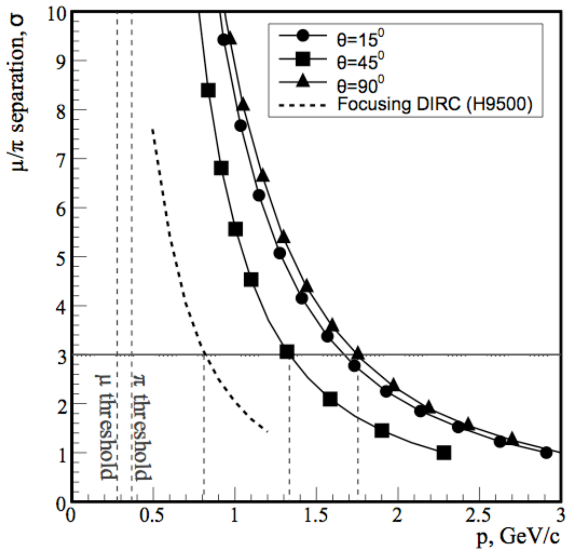
FARICH for Super cτ

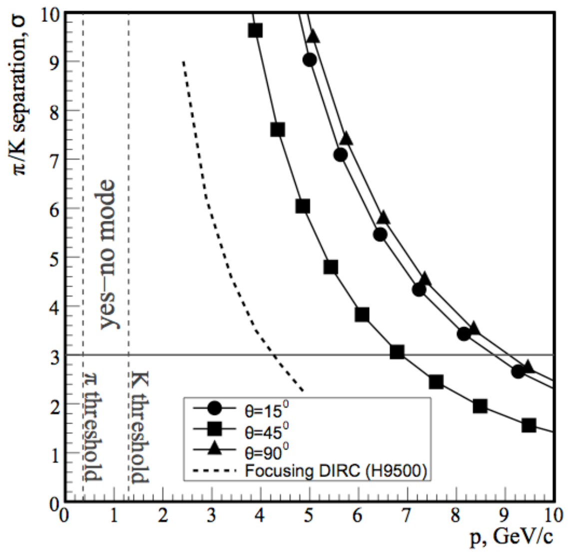
(E_{CM} = 2–5 GeV, L = 10^{35} cm^{-2}s^{-1})



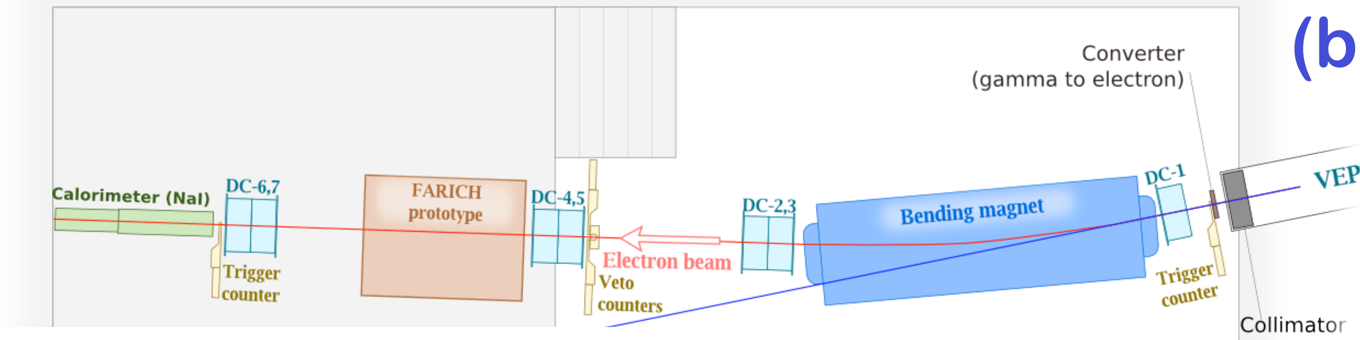


- μ/π and π/K separation
- Four-layer aerogel n_{max}=1.07
- Total area of photodetectors is 21 m², ~10⁶ channels
- Magnetic field of 1 T
- MCP PMT is possible photodetector for endcaps

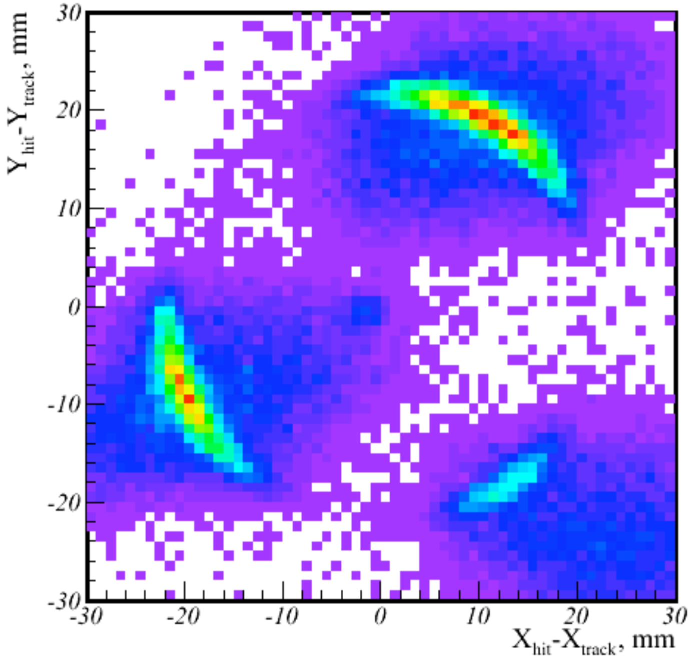


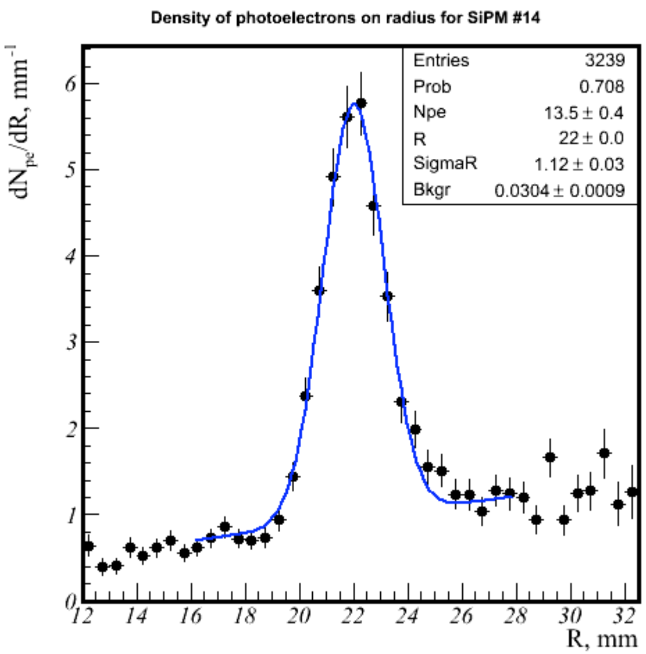


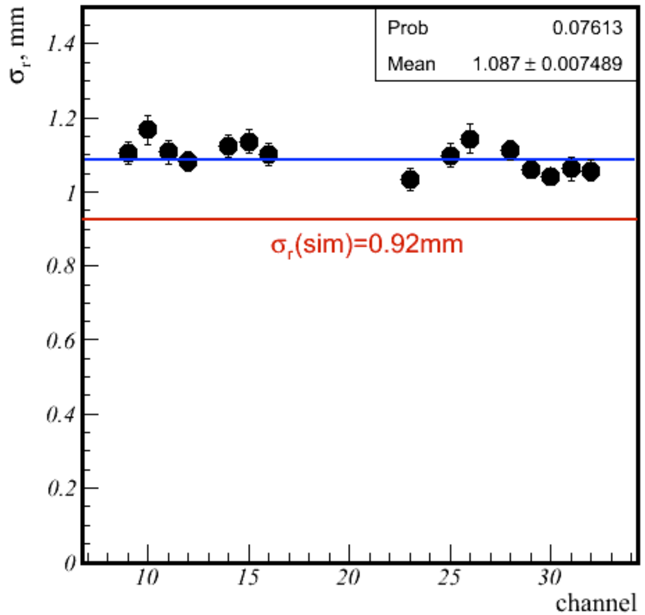
FARICH for Super cτ (beam test results)



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

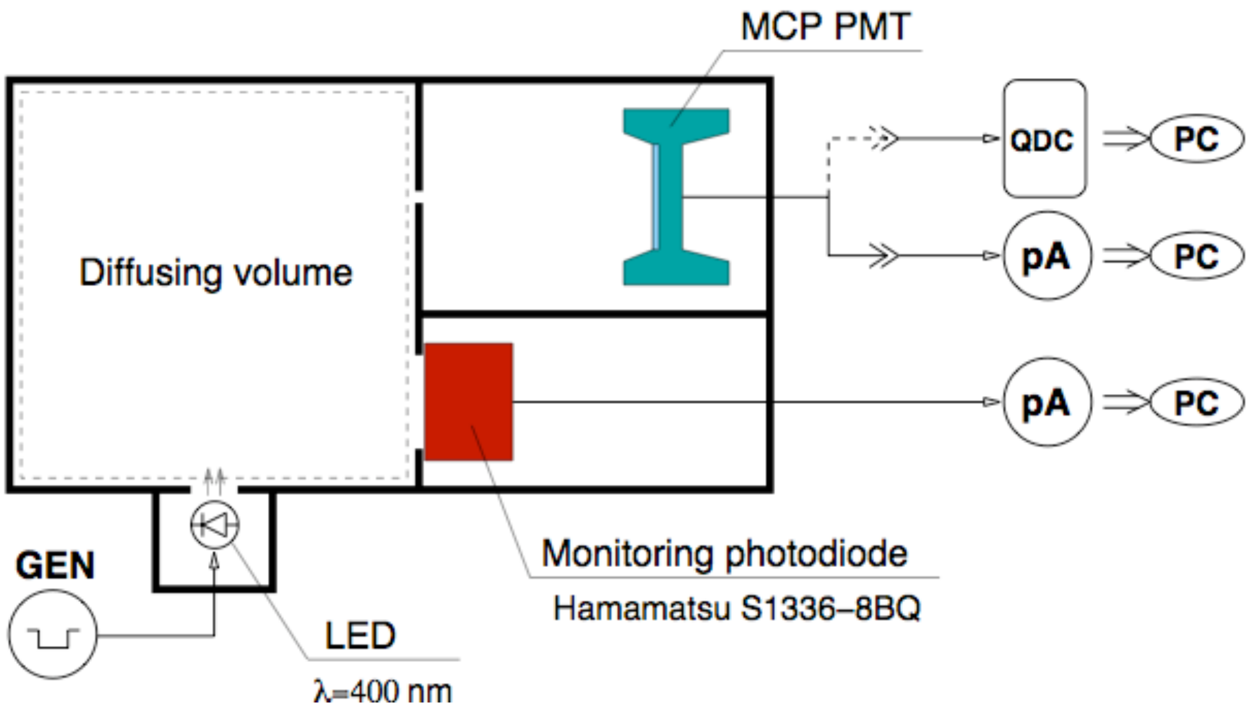


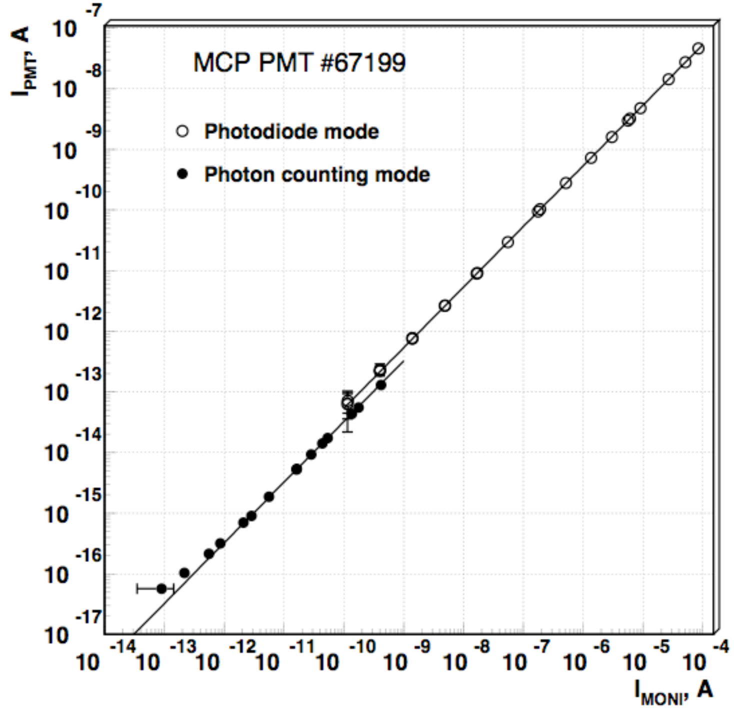




Good agreement with MC simulation!

Experimental setup





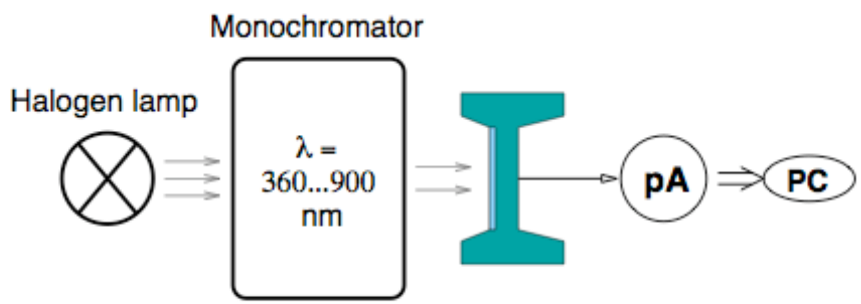
Low light intensity (photon counting mode):

$K = R_{PMT}/I_{MONI}$

High light intensity (direct current mode):

$R_{PMT} = I_{MONI}\,K$

QE measurement:



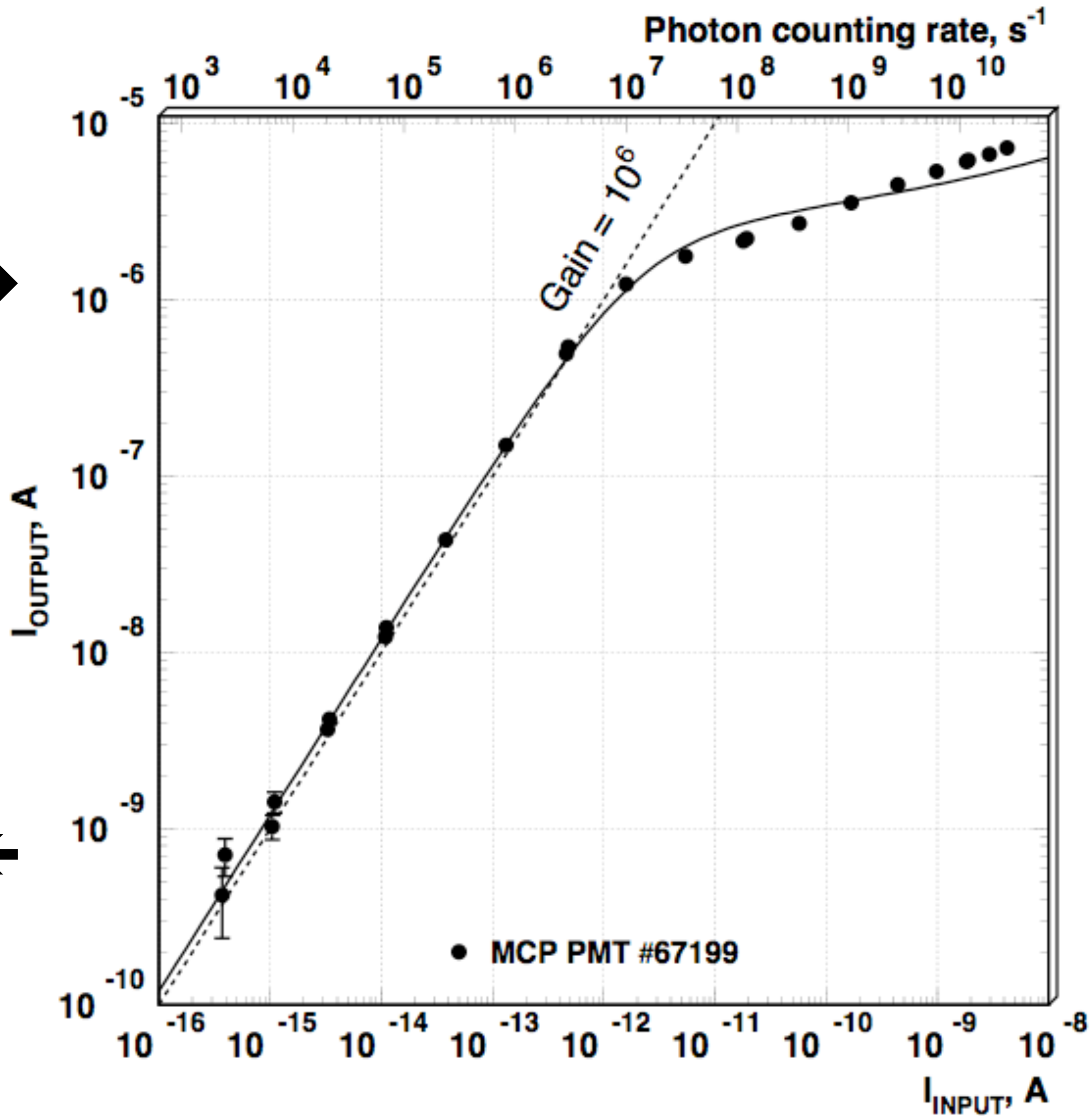
Reference PD: Hamamatsu S1227-1010BQ

Calculation of 1st MCP current

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

$I(z=L) = f(I_{in}, G_0, I_s)$
G_0 and I_s - free parameters

➔

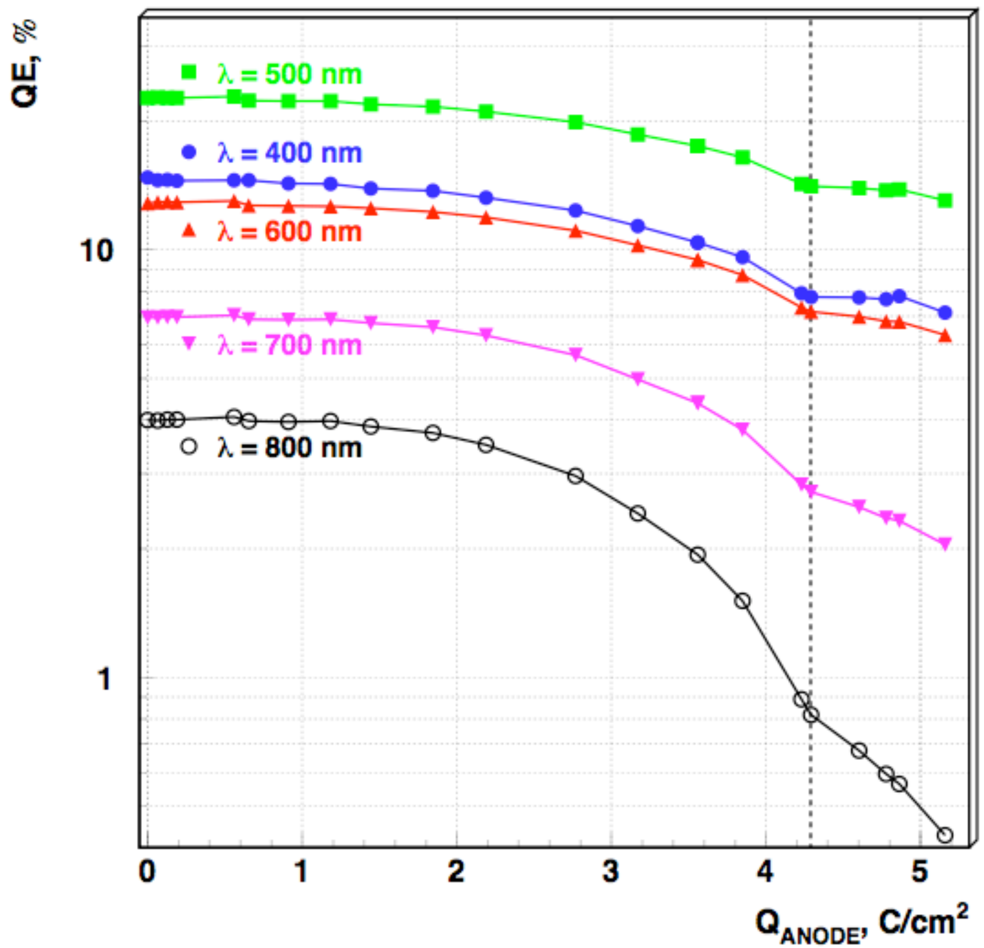


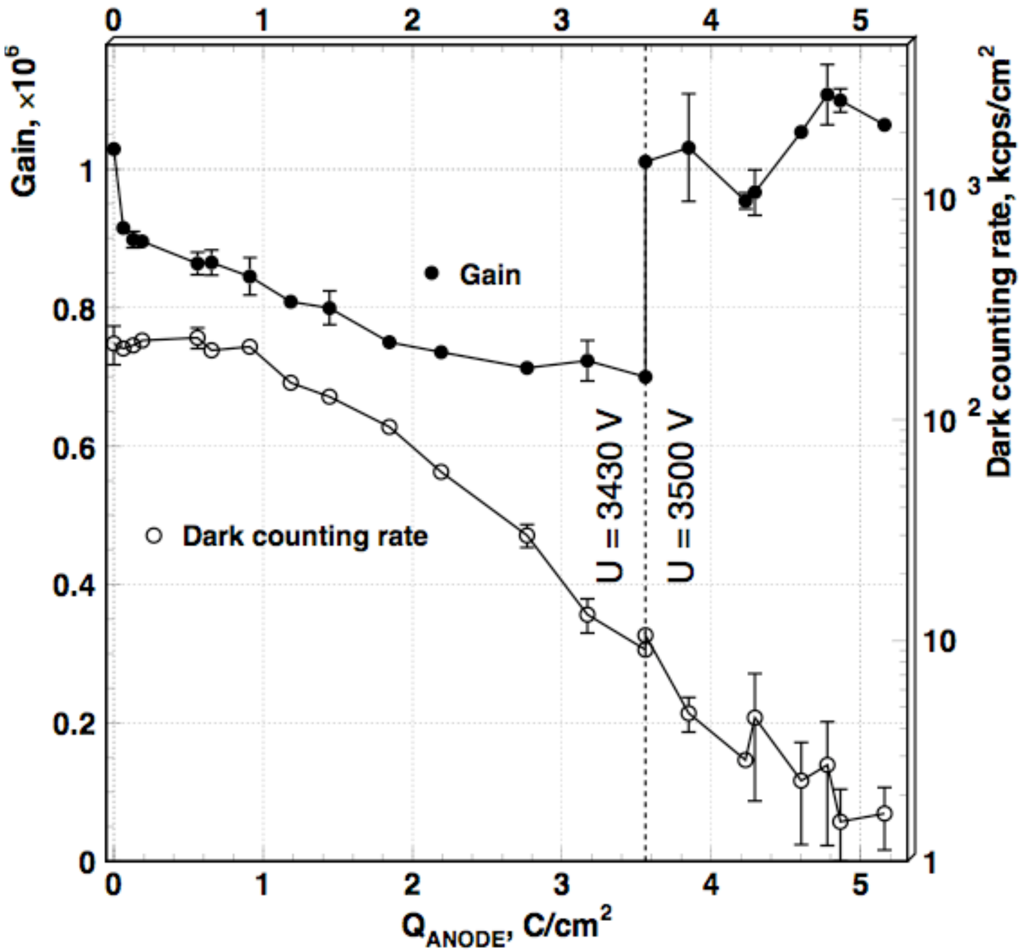
🡐

Calculation of the current extracted from 1st MCP :

$I(z=L/2)$ using G_0 and I_s obtained from approximation

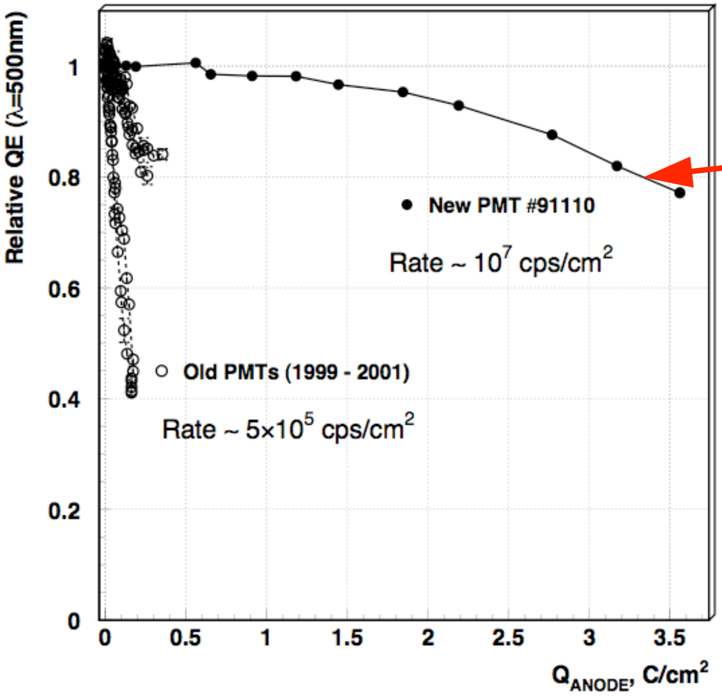
MCP PMT #91110: lifetime





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

MCP PMT lifetime comparison



Novosibirsk : 3.0 C/cm^2 (R ~ 1×10^7 $s^{-1}cm^{-2}$)

Hamamatsu : 2.5 C/cm^2 (R ~ 5×10^5 $s^{-1}cm^{-2}$)

Photonis : 0.1 C/cm^2 (R ~ 2×10^5 $s^{-1}cm^{-2}$)

($G_0 \sim 10^6$)