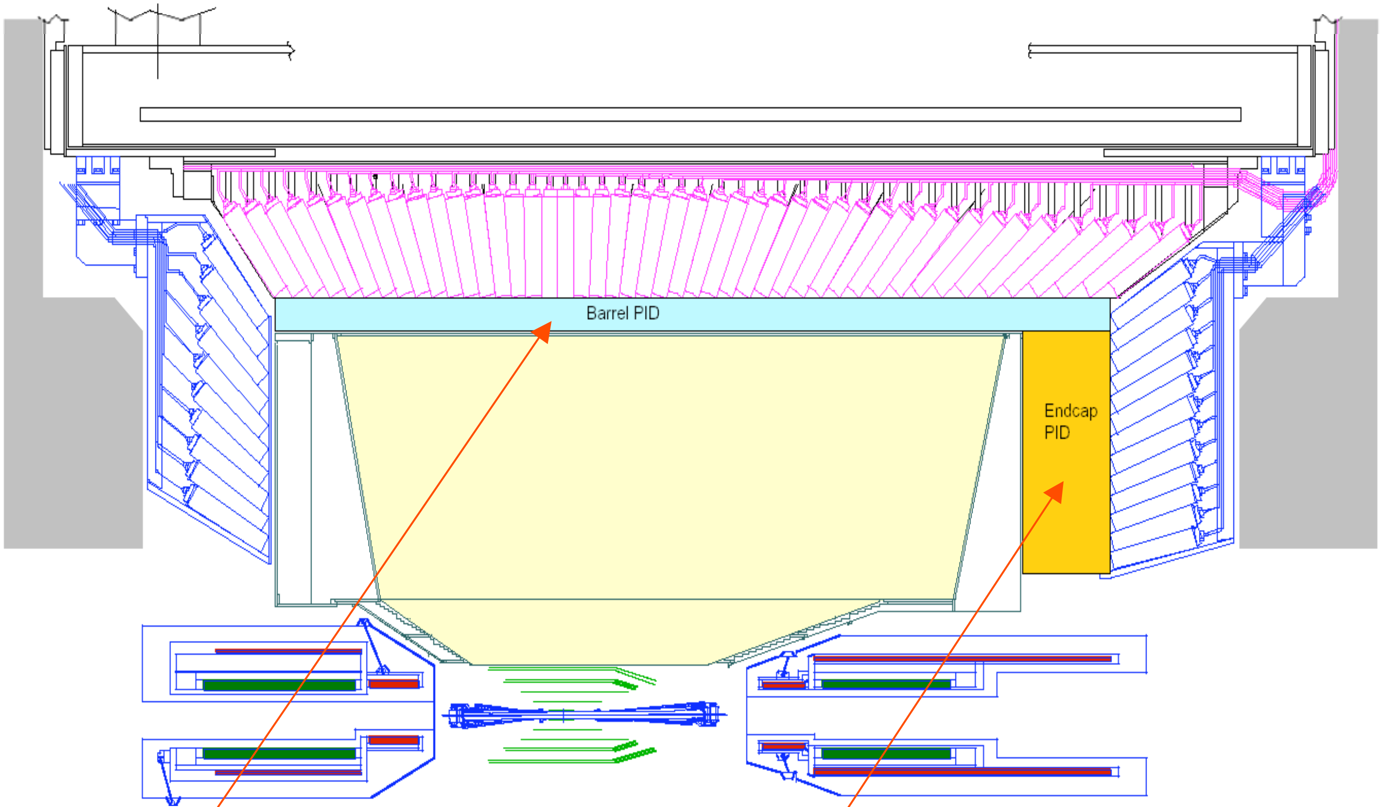
Aerogel RICH and TOP: status report

Peter Križan

University of Ljubljana and J. Stefan Institute

Super B factory workshop, Frascati, March 16-18, 2006

Belle upgrade – side view

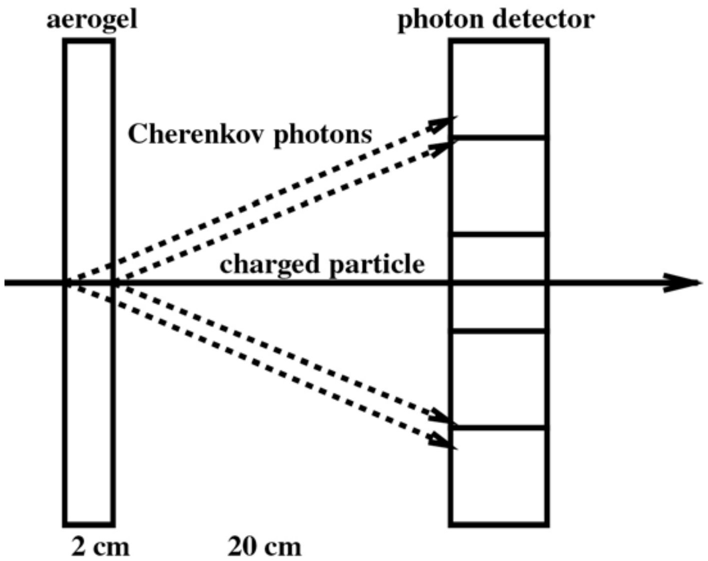


Two new particle ID devices, both RICHes:

Barrel: Time-Of-Propagation (TOP) or focusing DIRC

Endcap: proximity focusing RICH

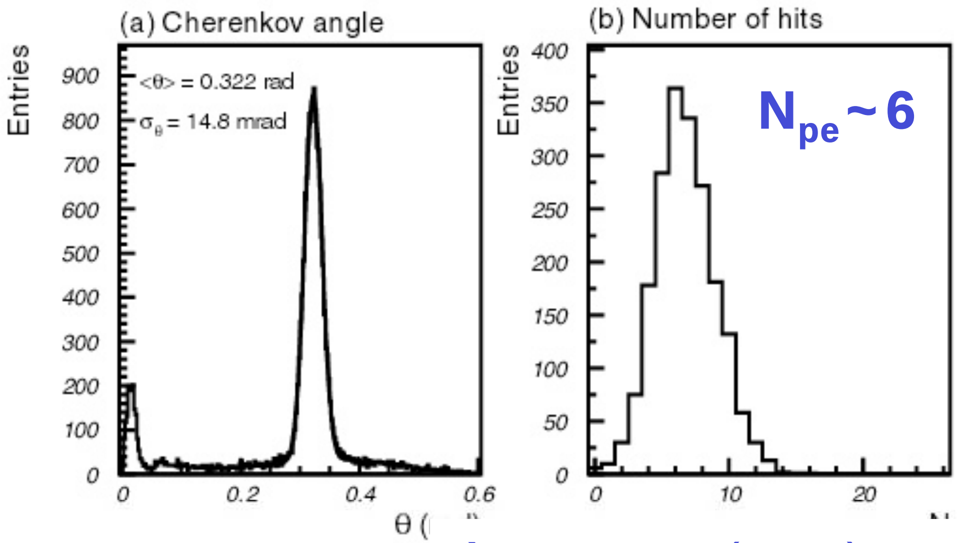
Endcap: Proximity focusing RICH



K/p separation at 4 GeV/c:
$q_c(p)$– $q_c(K)$ ~ 23 mrad

measured: s_0 ~ 13-14 mrad

→ 6s separation with N_{pe}~10



→NIM A521 (2004)367

Beam test results with 2cm thick aerogel tiles: >4s K/p separation

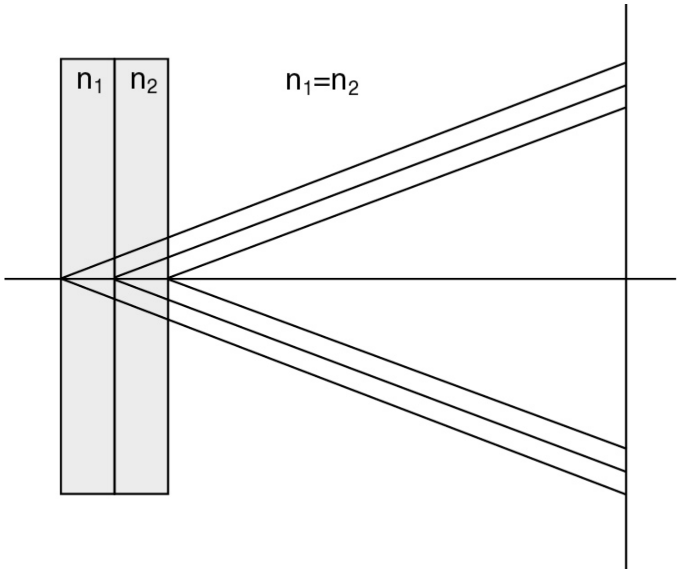
→need more photons

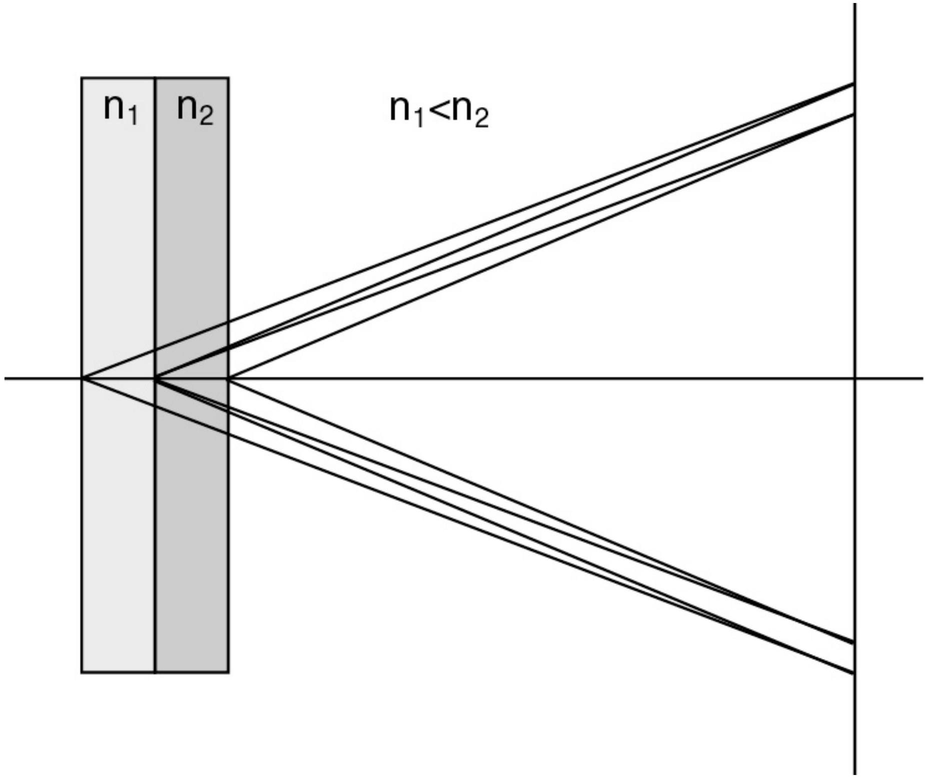
Radiator with multiple refractive indices

How to increase the number of photons without degrading the resolution?

→ stack two tiles with different refractive indices: "focusing" configuration

normal

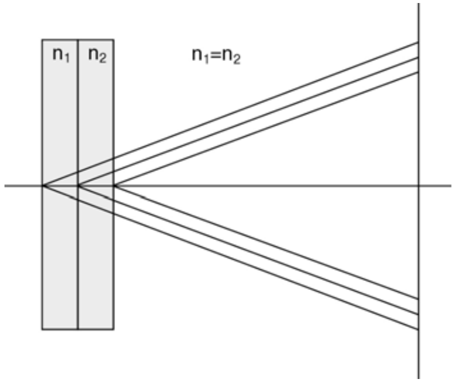


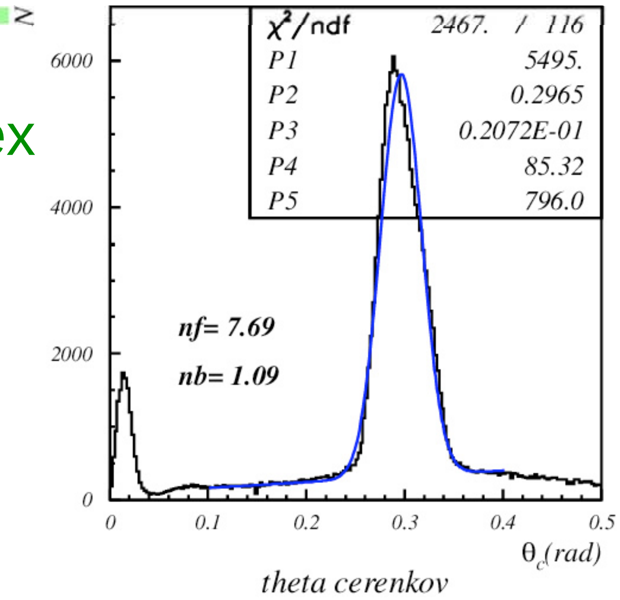


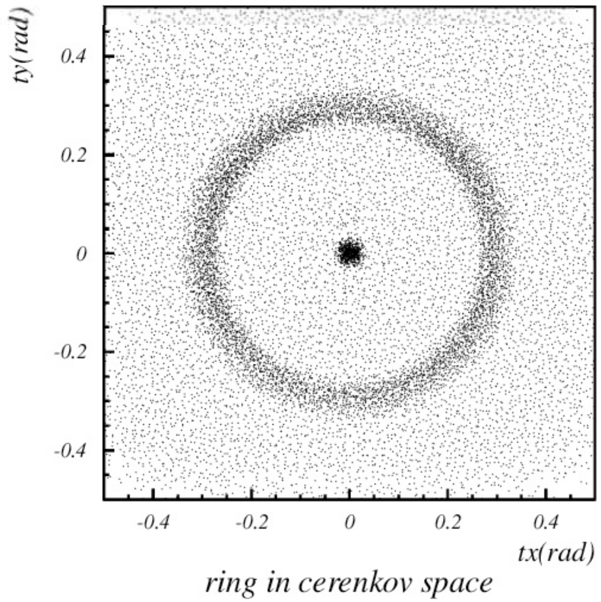
NIM A548 (2005) 383

Focusing configuration – data, 2004

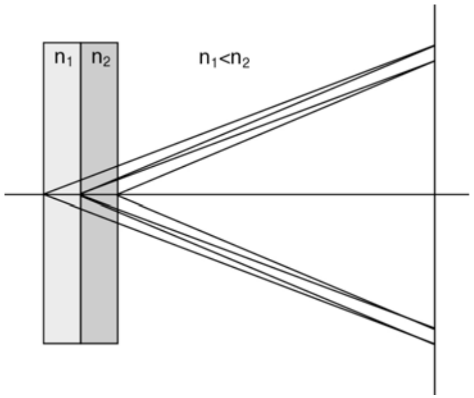
4cm aerogel single index

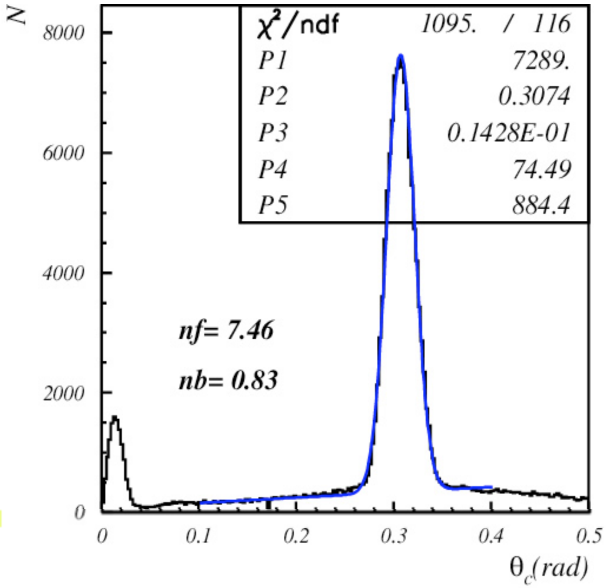


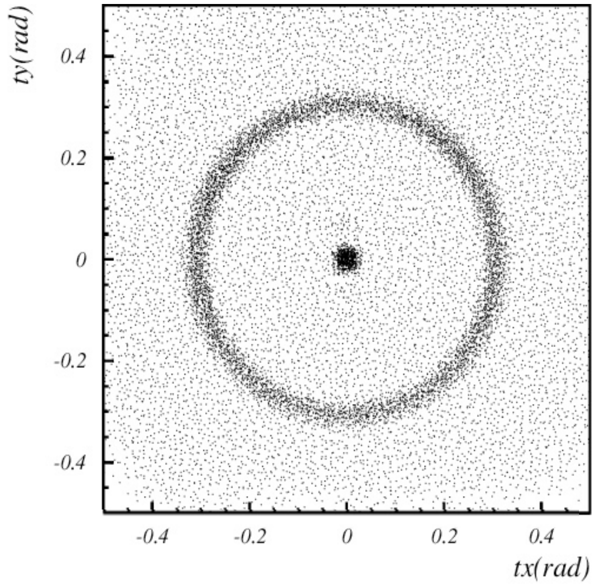




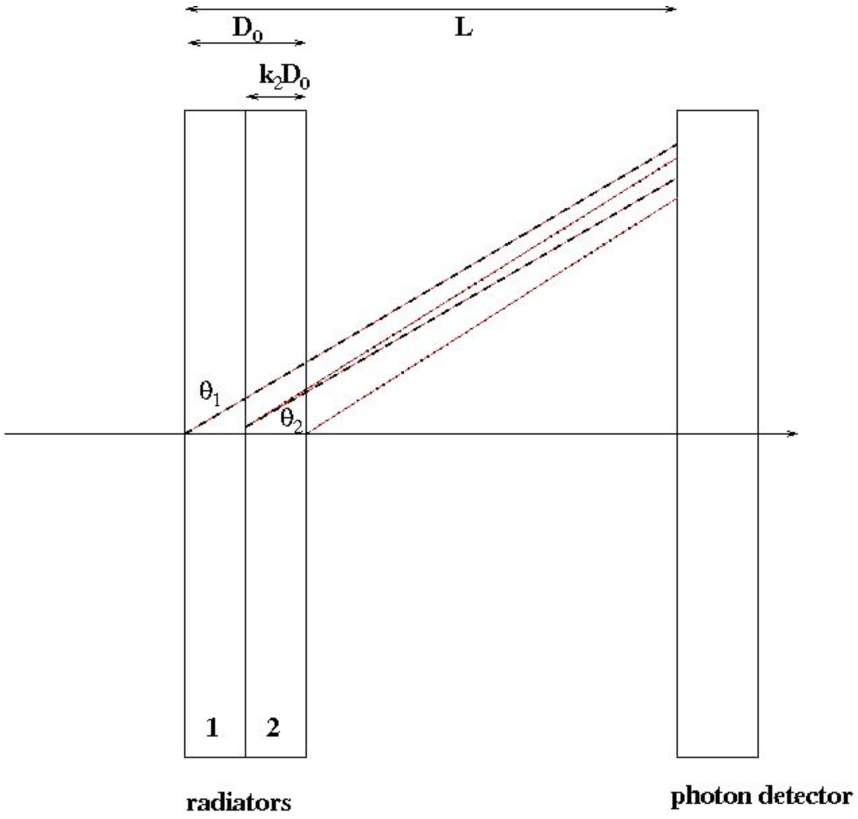
2+2cm aerogel







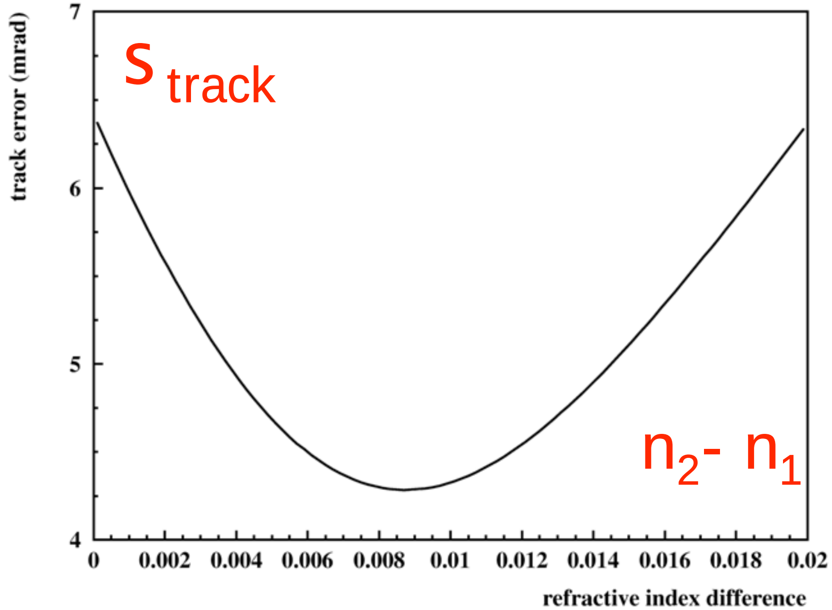
Multiple radiator: Optimisation of radiator parameters



Minimized: error per track

$$\sigma_{track} = \frac{1}{\sqrt{N_{\det}}}\sqrt{\sigma_{emp}^{2} + \sigma_{\det}^{2} + \sigma_{rest}^{2}}$$

vary parameters $n_2 - n_1$, D_0, D_2/D_1

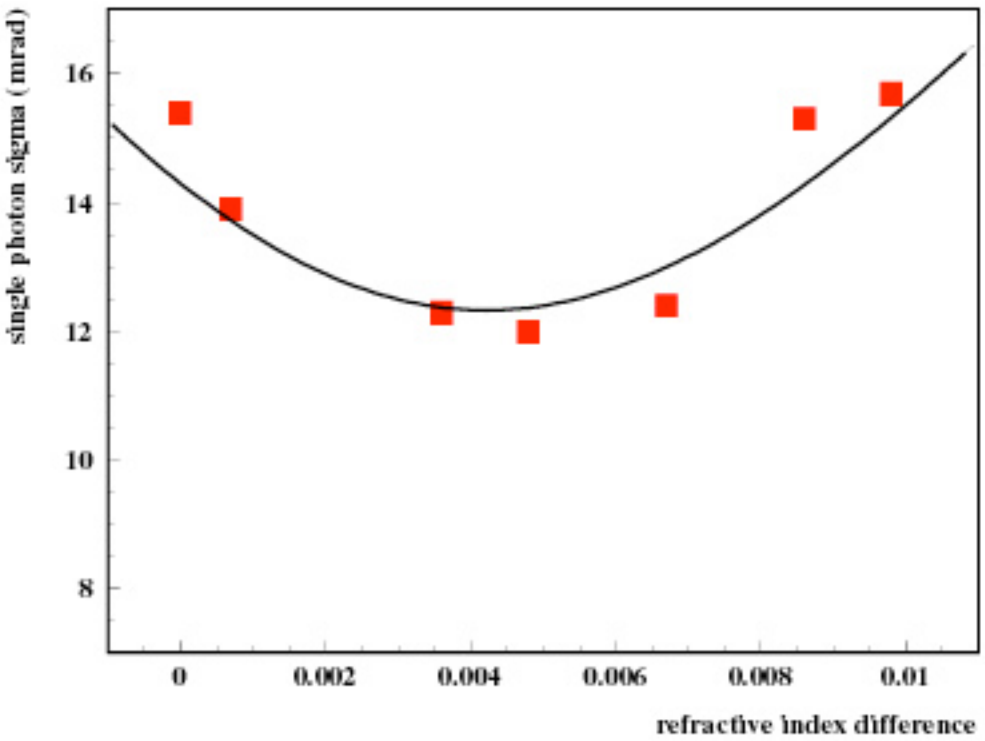


→robust design, little influence from variation in $n_2 - n_1$ and D_2/D_1

→physics/0603022

Comparison with the data

Single photon sigma vs $n_2 - n_1$



$n_2 - n_1$

Data: december 2005 beam test

Curve: expectation

Multiple radiators: optimized

Number of layers	one	two	three	four
Thickness (cm)	1.9	3.2	4.4	5.6
Single photon s_0	12.8	12.5	12.6	12.8
N_p	5.7	9.0	11.9	14.7
s_{track}	5.4	4.2	3.7	3.3

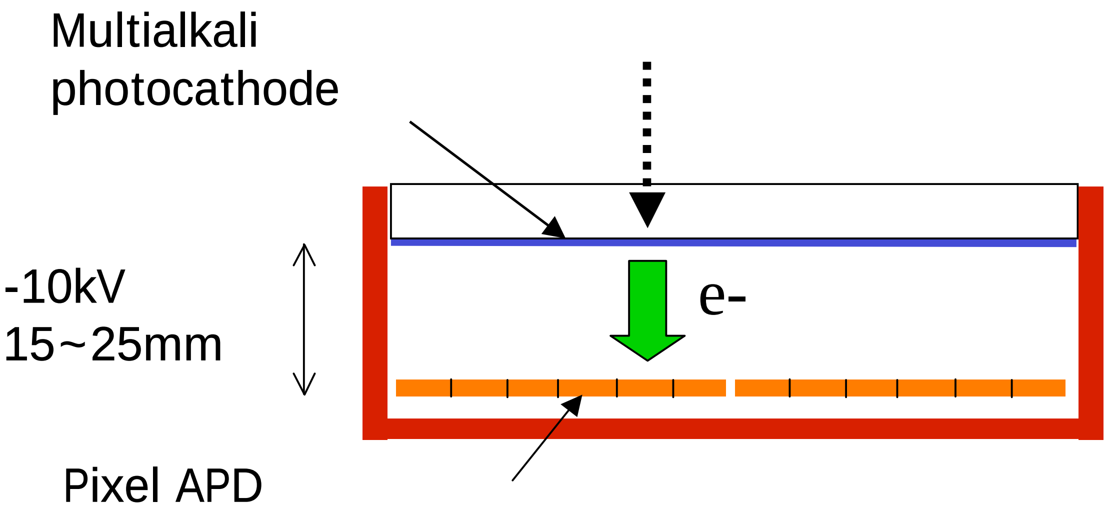
→ The improvement in **s_{track}** comes from the increase in the number of photons.

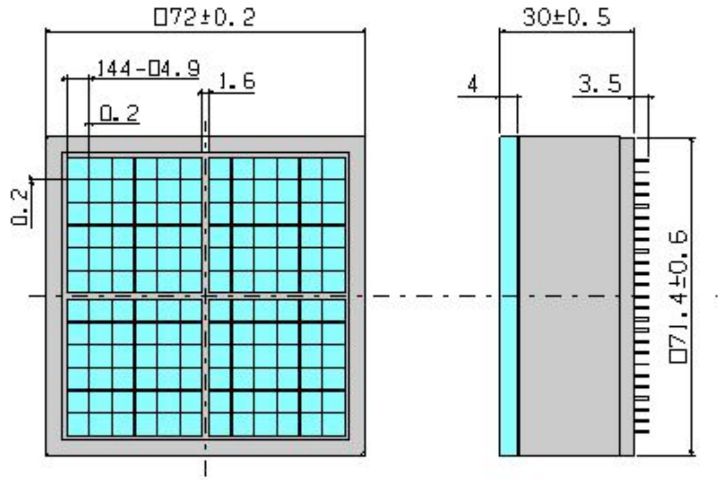
Photon detectors for the aerogel RICH requirements and candidates

Need: Operation in a high magnetic field (1.5T)
Pad size ~5-6mm

Candidates:

- MCP PMT (Burle 85011)
- large active area HAPD of the proximity focusing type





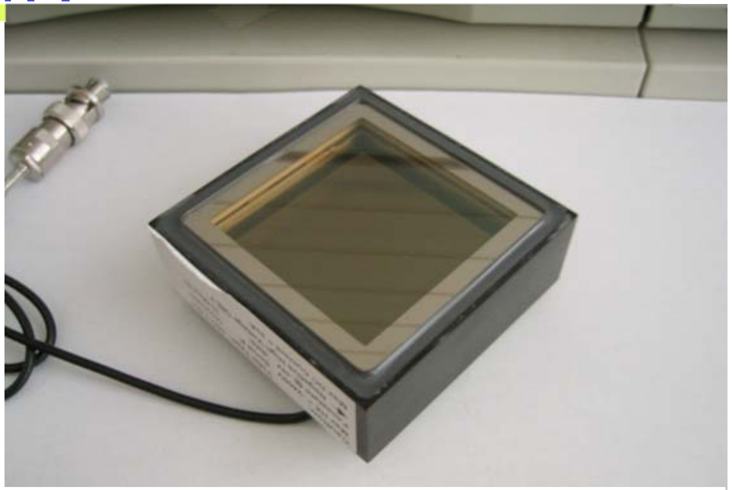
HAPD R&D project in collaboration with HPK.

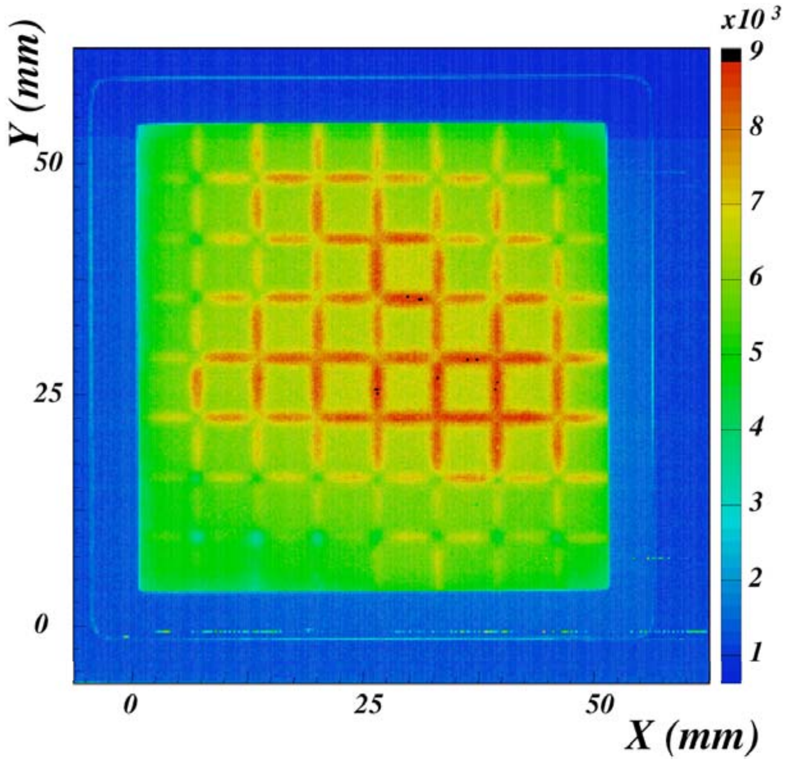
Problems: sealing the tube at the window-ceramic box interface, photocathode activation changes the properties of APD.

Photon detector R&D: Burle MCP-PMT

BURLE 85011 MCP-PMT:

- multi-anode PMT with 2 MCPs
- 25 μm pores
- bialkali photocathode
- gain ~ 0.6 x 10^6
- collection efficiency ~ 60%
- box dimensions ~ 71mm square
- 64(8x8) anode pads
- pitch ~ 6.45mm, gap ~ 0.5mm
- active area fraction ~ 52%





count rates - all channels: charge sharing at pad boundaries

→Proc. IEEE NSS 2004

Burle MCP PMT beam test

Resolution and number of photons (clusters)

- s_J ~13 mrad (single cluster)
- number of clusters per track N ~ 4.5
- s_J ~ 6 mrad (per track)

-> ~ **4 s p/K separation at 4 GeV/c**

Open questions

Operation in high magnetic field:

- the present tube with 25mm pores only works up to 0.8T, for 1.5T need ~10mm
- 10mm version with 4 channels available since June, tests done (J. Va'vra)

Number of photons per ring: too small. Possible improvements:

- bare tubes (52%->63%)
- increase active area fraction (bare tube 63%->85%)
- increase the photo-electron collection efficiency

(from 60% at present up to 70%)

-> Extrapolation from the present data 4.5 ->8.5 clusters per ring

s_J: 6 mrad -> 4.5 mrad (per track)

-> >5 s p/K separation at 4 GeV/c

Aging of MCP-PMTs ?

TOP counter R&D status

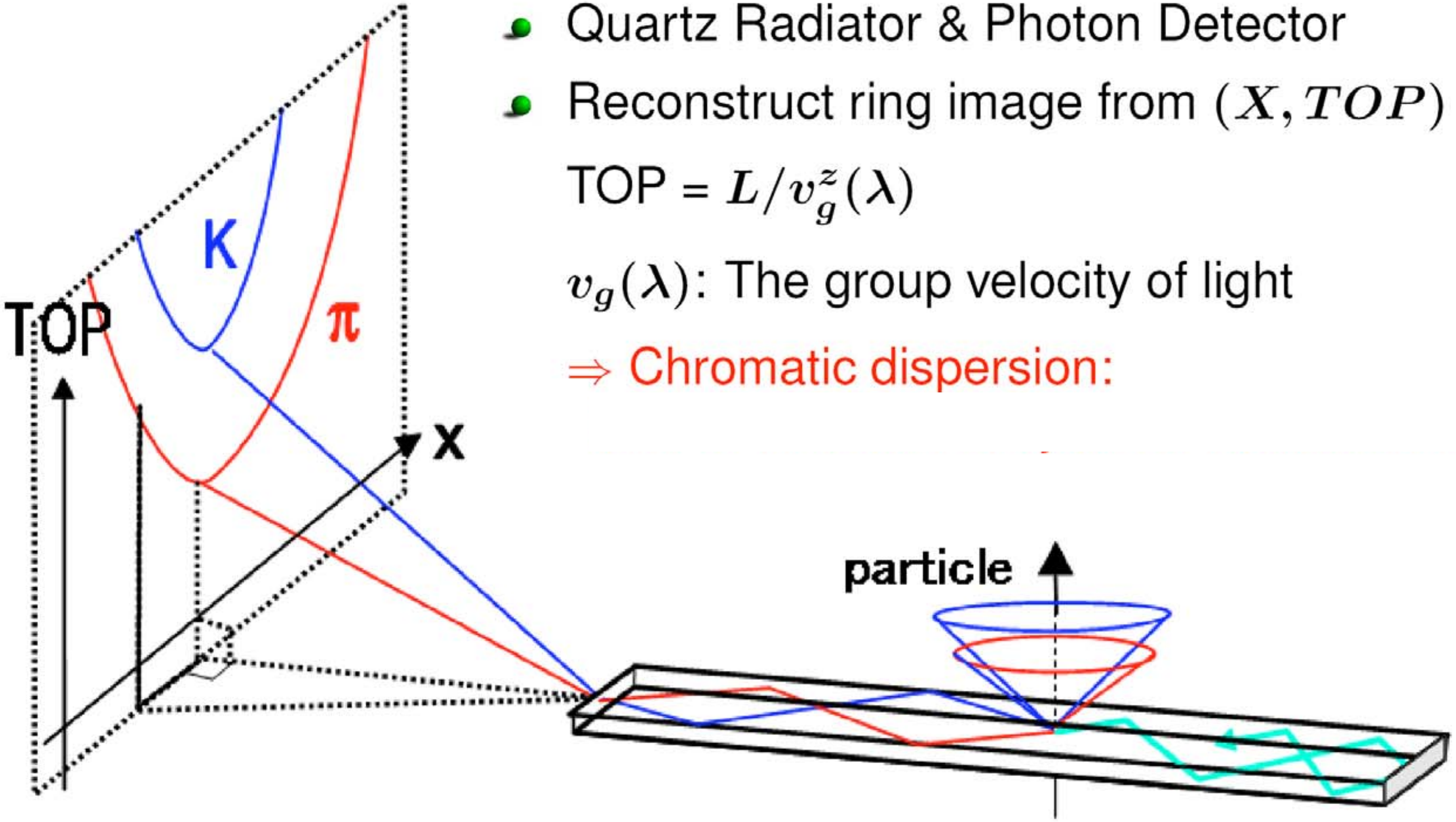
- Ring Imaging Cherenkov counter
  with precise measurement of the Time Of Propagation (and TOF)

  - Quartz Radiator & Photon Detector
  - Reconstruct ring image from (X, TOP)

    TOP = $L/v_g^z(\lambda)$

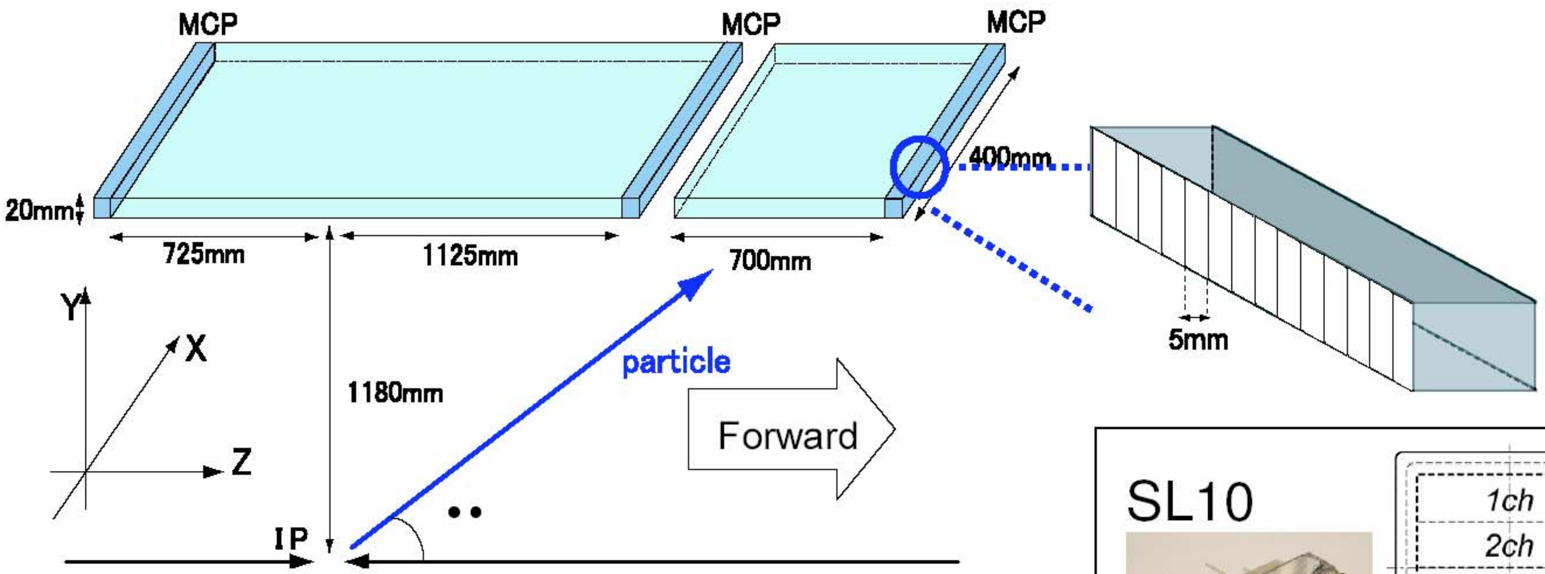
    $v_g(\lambda)$: The group velocity of light

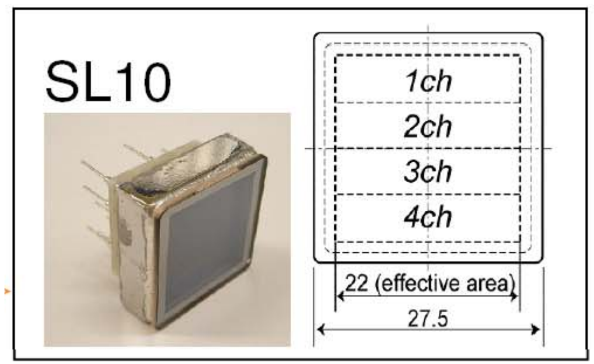
    $\Rightarrow$ Chromatic dispersion:



TOP baseline design

- Radiator: Quartz bar of 255cm^L $\times$ 40cm^w $\times$ 2cm^T $\times$ 18 units in ϕ segmented at $\theta = 46^\circ$ to reduce chromatic dispersion error
- Photon detector: Multi-anode MCP-PMT at three readout planes SL10 (R&D w/ HPK) : 5mm pitch linear array, $\sigma_{TTS} \sim 30$ ps.





Photon detectors for TOP counter

Tests on the bench: amplification and time resolution in high magnetic field.

3 MCP-PMTs studied: Burle (25 mm pores), BINP (6mm pores), Hamamatsu SL10 (6 and 10mm pores)

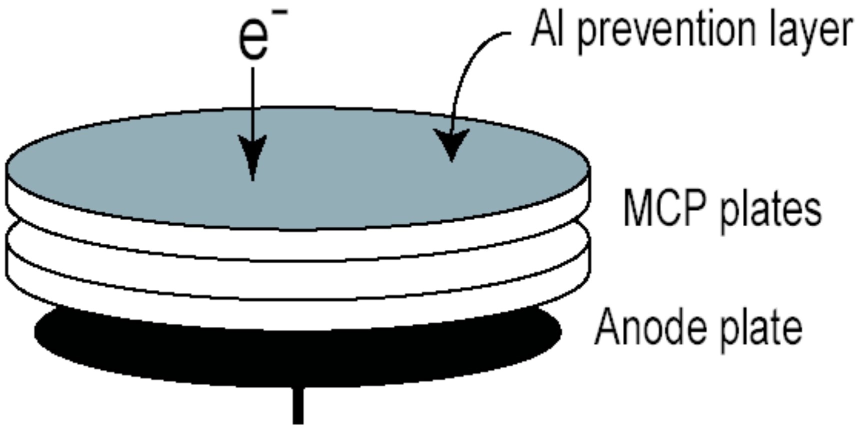
All: good time resolution at B=0, 25mm pore tube does not work at 1.5T

→ NIM A528 (2004) 763

SL10: cross-talk problem solved by segmenting the electrodes at the MCP

MCP ageing

Study tubes with and without protective Al foil (stops feedback ions to reach the photocathode, but reduces the photo-electron collection efficiency by 60%) from two producers, Hamamatsu and BINP, with bi-alkali phocathodes.

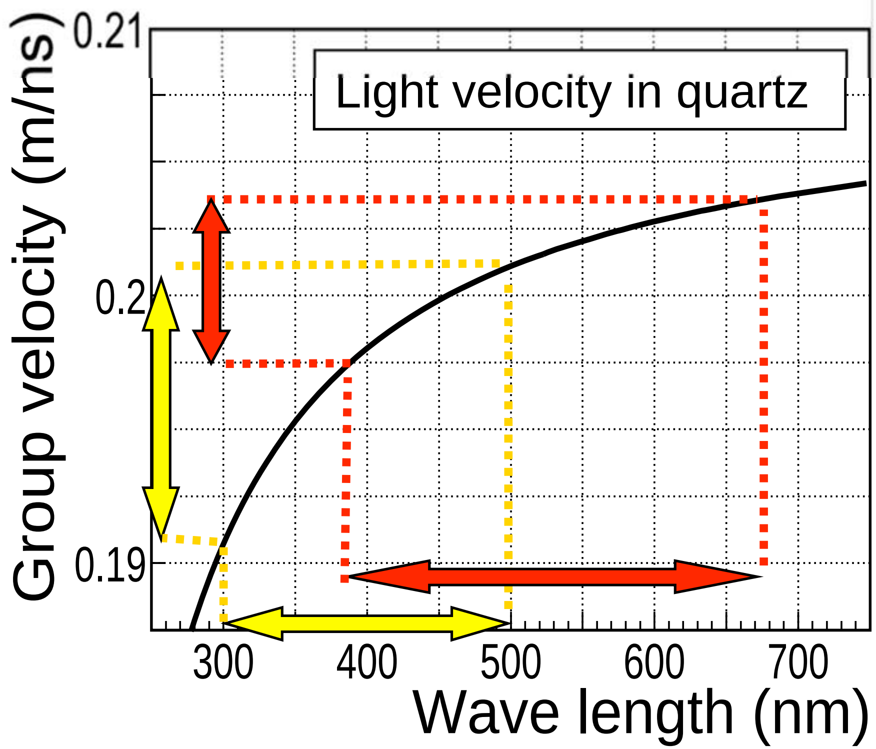


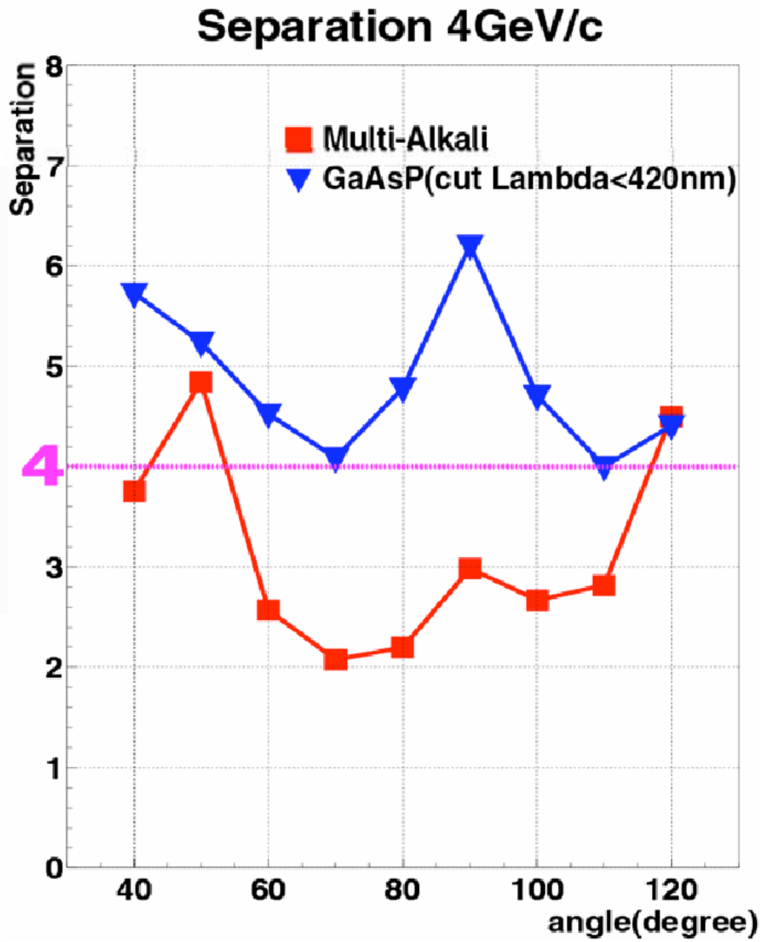
→Al foil is needed

TOP counter MC

Expected performance with:

bi-alkali photocathode: <4s p/K separation at 4GeV/c (← chromatic dispersion)



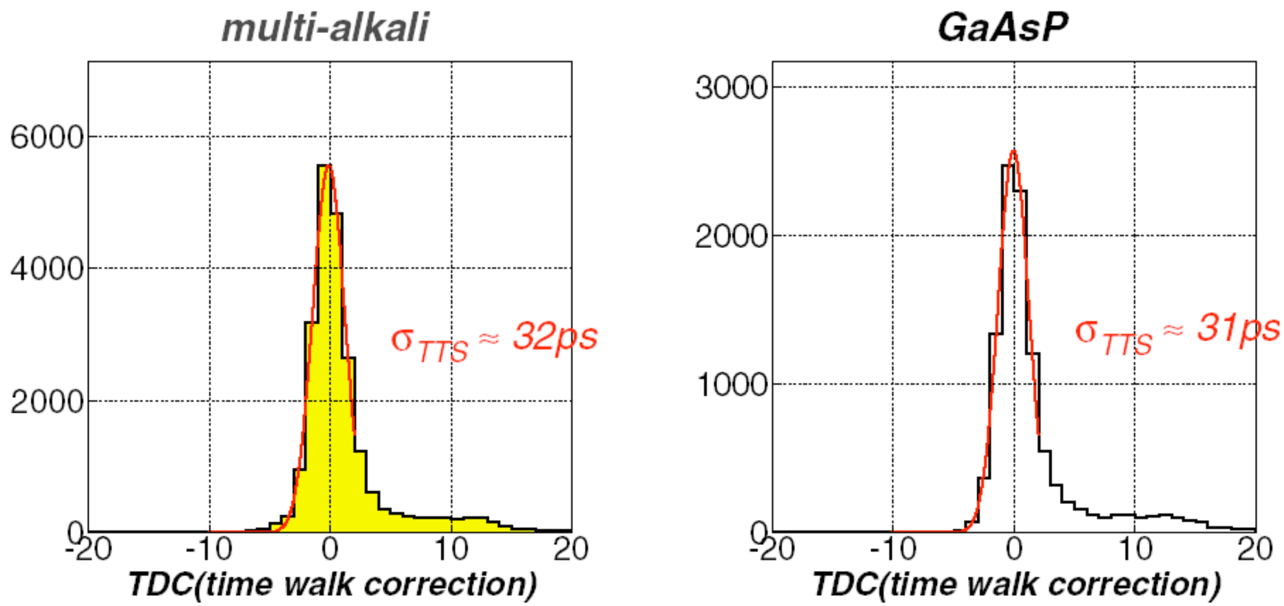


with GaAsP photocathode: >4s p/K separation at 4GeV/c

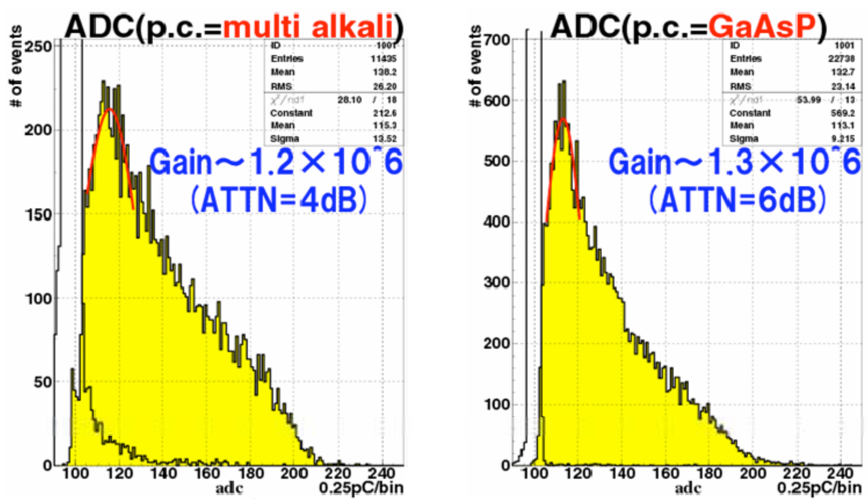
GaAsP vs bialkali: Timing and pulse height spectra

TTS of MCP-PMt with GaAs/GaAsP may be worse due to the thickness of photo-cathode (1micron instead of 10nm).
→OK

TDC: $\sigma_{TTS} \sim$ 30ps



ADC: Gain $\sim 1.0 \times 10^6$

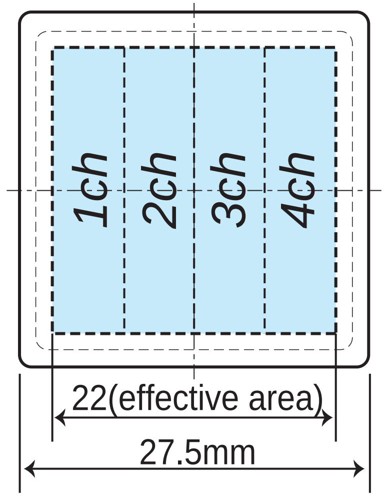


Pulse height spectra: OK

GaAsP MCP-PMT with pads

- Square-shape MCP-PMT with GaAsP photo-cathode
- First prototype
  - 2 MCP layers
    - f 10mm hole
  - 4ch anodes
  - Slightly larger structure
    - Less active area

Target structure



•Enough gain to detect single photo-electron

•Good time resolution (TTS=42ps) for single p.e.

–Slightly worse than single anode MCP-PMT (TTS=32ps)

•Next: check the performance in detail, increase active area frac., ageing

Summary

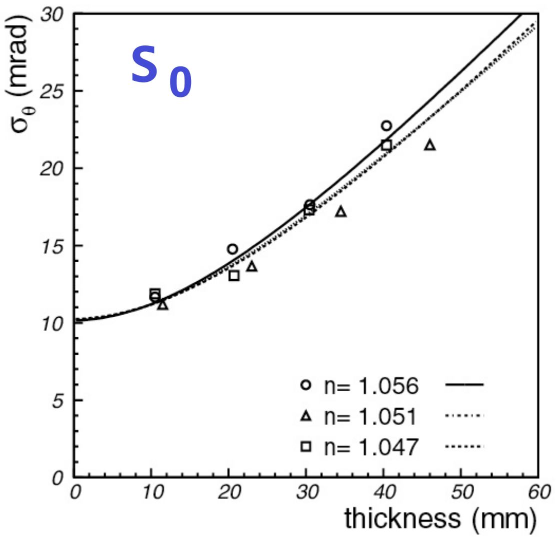
- Aerogel RICH: proof of principle OK, new ways found how to increase the number of photons (focusing radiator); photon detectors for 1.5T under development/study; progress in aerogel production methods (water jet cutting)
- TOP: MC study: reduce cromatic error; MCP PMT operation at 1.5T OK; MCP PMT with GaAsP tested, similar time resolution; ageing tests →need Al foil

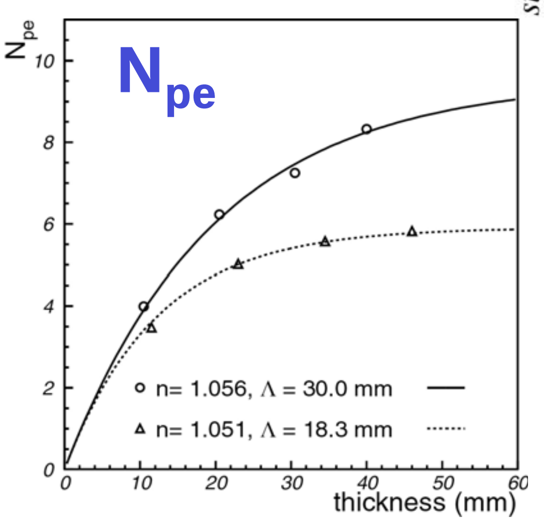
Backup slides

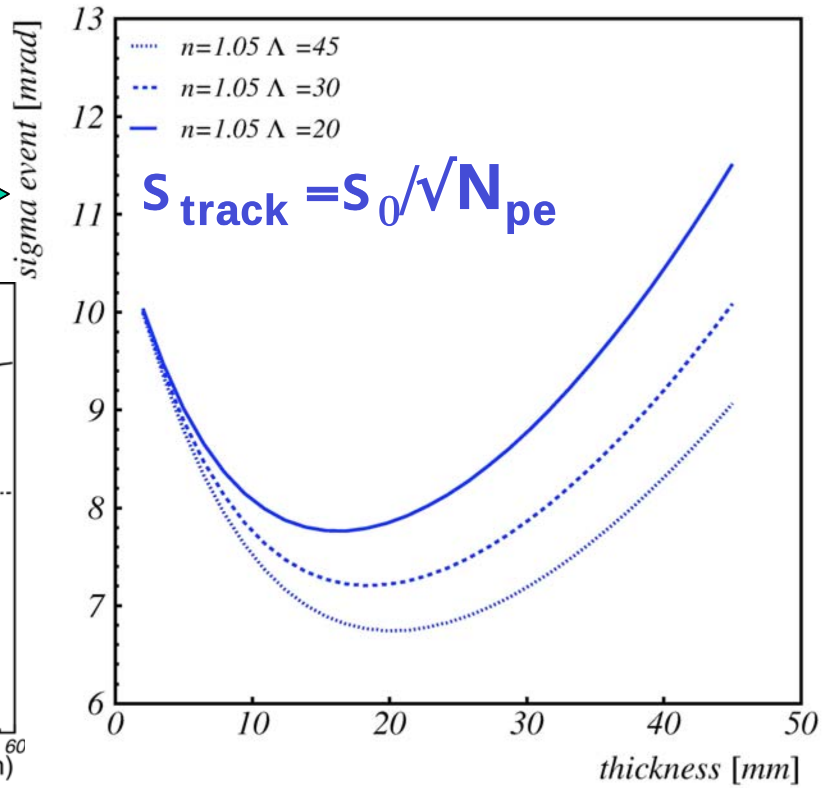
How to increase the number of photons?

What is the optimal radiator thickness?

Use beam test data on s_0 and N_{pe}



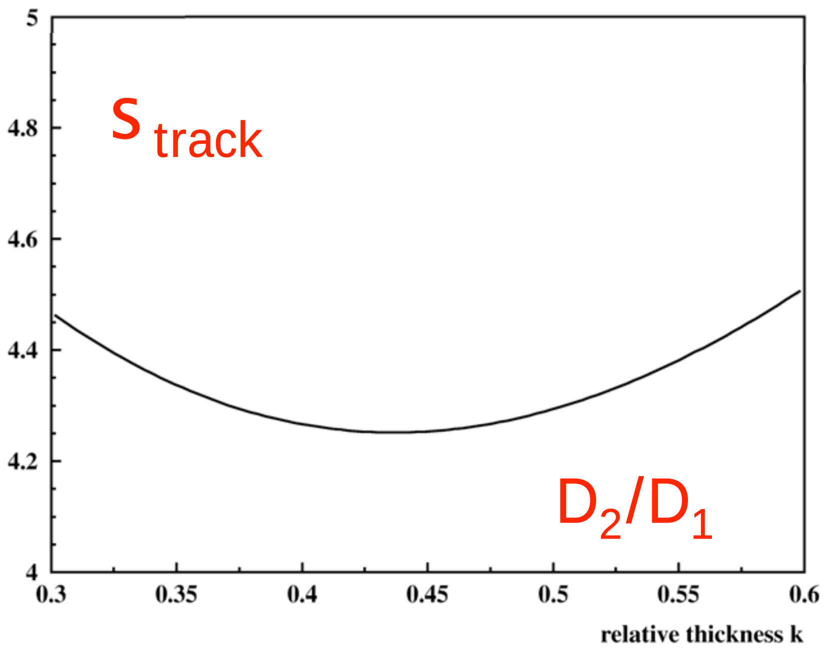




Minimize the error per track: $s_{track}=s_0/\sqrt{N_{pe}}$

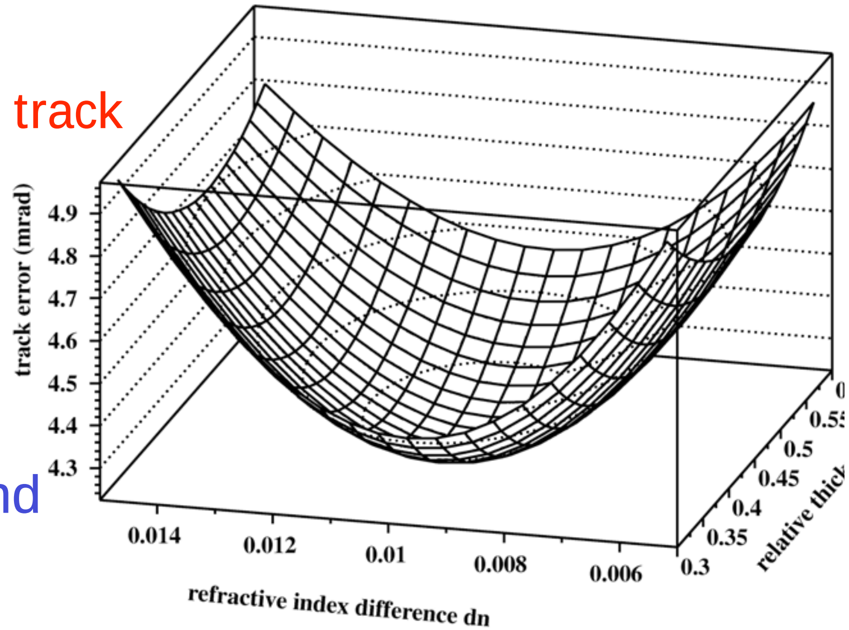
→ Optimum is close to 2 cm

→NIM A521 (2004)367; NIM A553 (2005) 5



← Minimize track error vs. relative radiator thickness D_2/D_1

at fixed total thickness D_0=4cm and refractive index difference dn=0.009



Minimize track error vs. →

relative radiator thickness D_2/D_1 and refractive index difference n_2- n_1

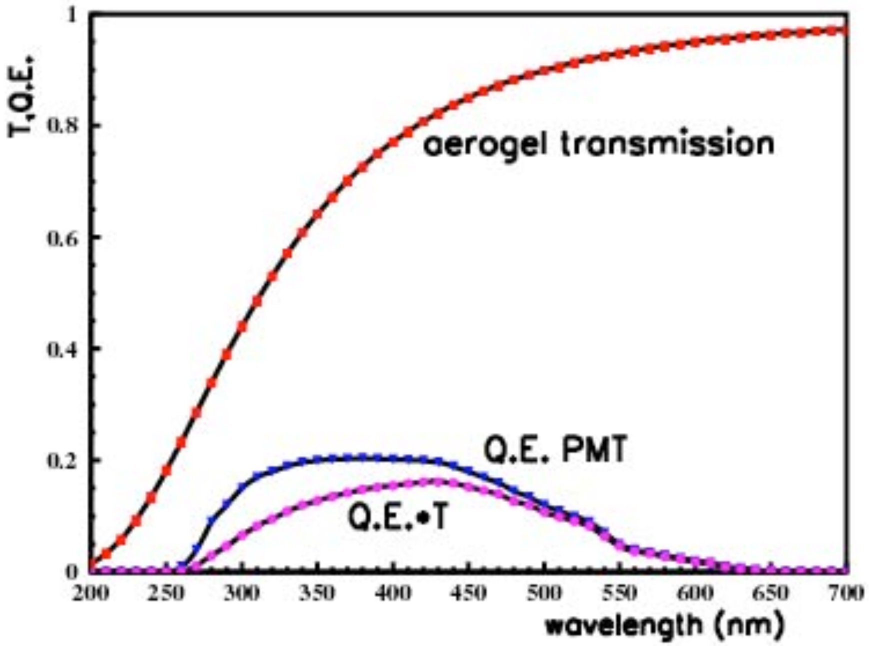
at fixed total thickness D_0=4cm

→robust design, little influence from variation in n_2- n_1 and k

Photon detectors for the aerogel RICH requirements and candidates

Needs:

- Operation in high magnetic field (1.5T)
- High efficiency at l >350nm
- Pad size ~5-6mm

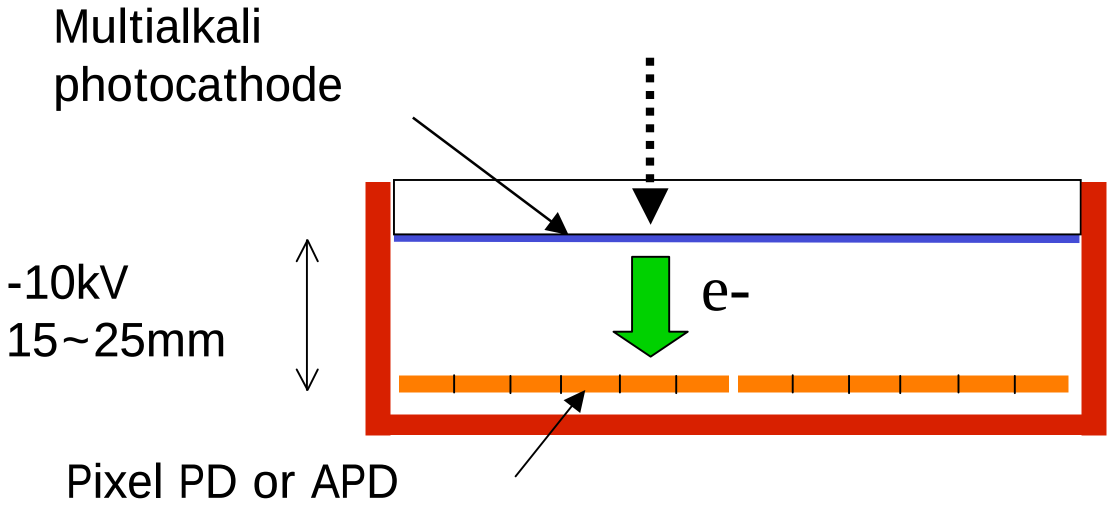


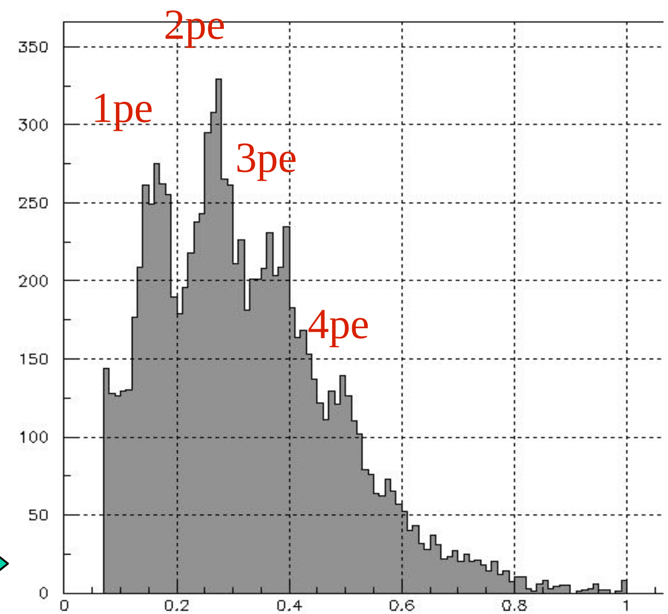
Candidates:

- large area HPD of the proximity focusing type
- MCP PMT (Burle 85011)

Development and testing of photon detectors for 1.5 T

Candidate: large area HPD of the proximity focusing type



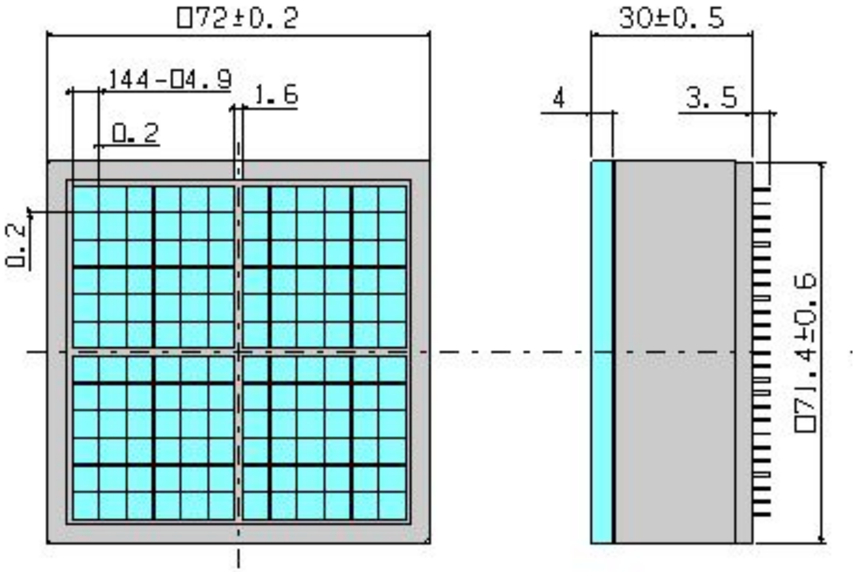


R&D project in collaboration with HPK

Tests with single channel and 3x3 channel devices look very promising.

HPD development

59mm x 59mm active area (65%),
12x12 channels



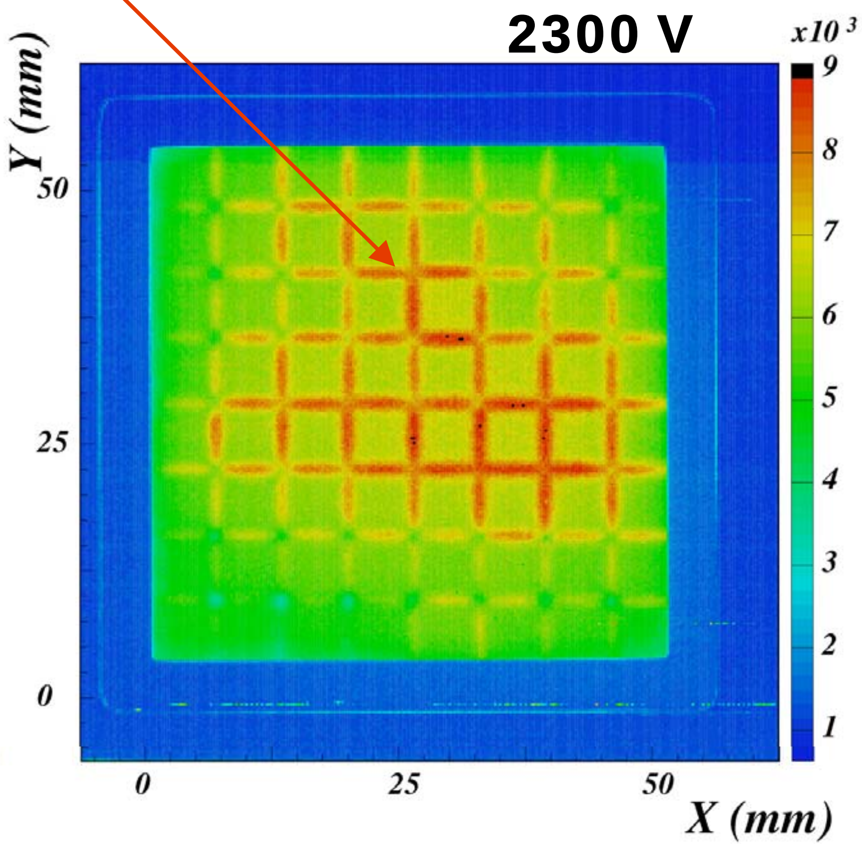
Ceramic HPD box

Photon detector R&D – Burle MCP-PMT bench tests

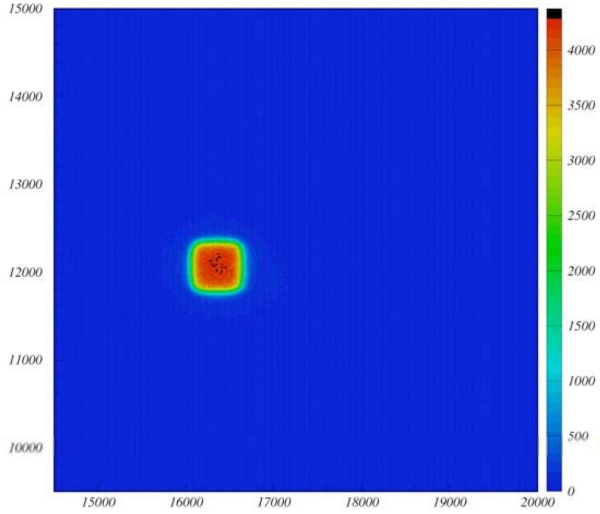
Proc. IEEE NSS 2004

Study uniformity of the sensitivity over the surface

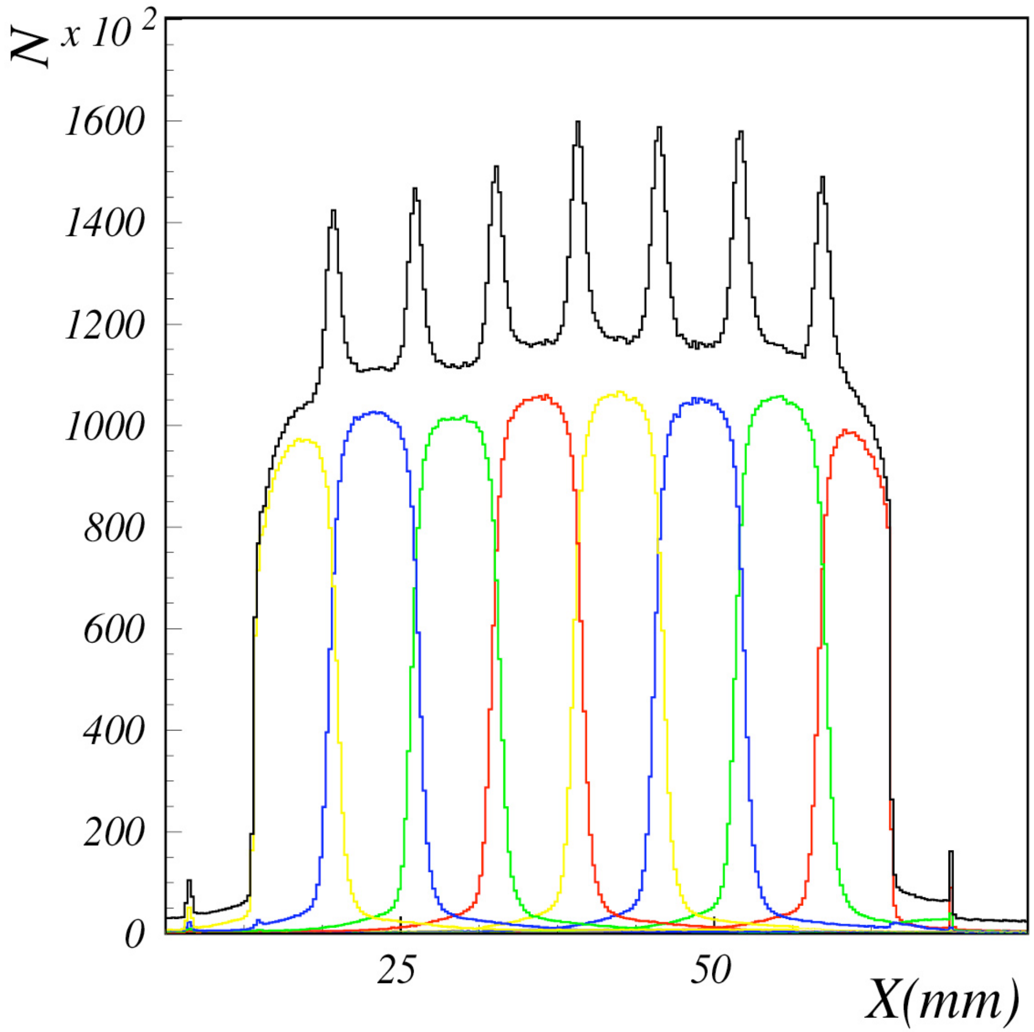
count rates - all channels: charge sharing at pad boundaries



single channel response:
- uniform over pad area
- extends beyond pad area (charge sharing)



Burle MCP-PMT bench tests



charge sharing at pad boundaries

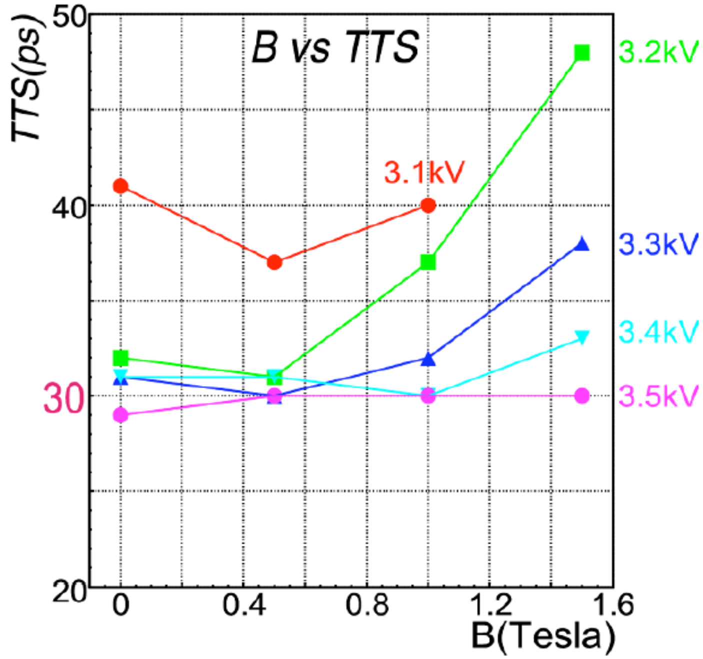
- slice of the counting rate distribution including the central areas of 8 pads (single channels - colored, all channels - black)

Proc. IEEE NSS 2004

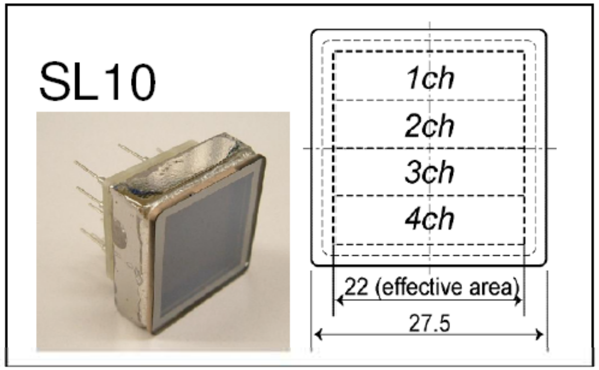
Rectanglular PMT: SL10

- 4ch linear array MCP-PMT

Photo cathode	mutli-alkali
MCP ch ϕ	10 μm
# of MCP	2 stage
# pixel/size	1$\times$4 / 5mm$\times$22mm
Geometrical C.E.	50%
Eff. area(2cm^{T})	77%
Gain (HV)	2$\times$ 10^6 ($-$3.5 kV)
σ_{TTS}(HV, B)	$\sim$30ps ($-$3.5 kV, 1.5T)

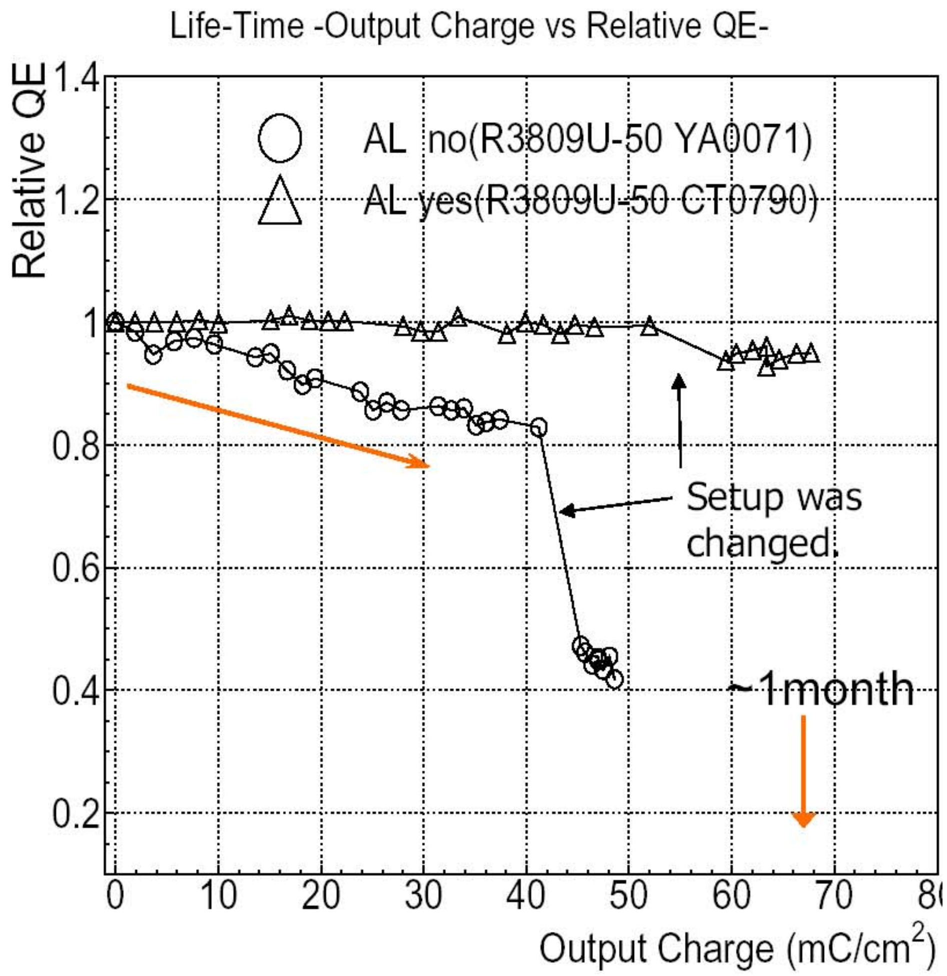


- Gain $> 10^6$, $\sigma_{TTS} \sim$ 30ps in B =1.5 T : Confirmed

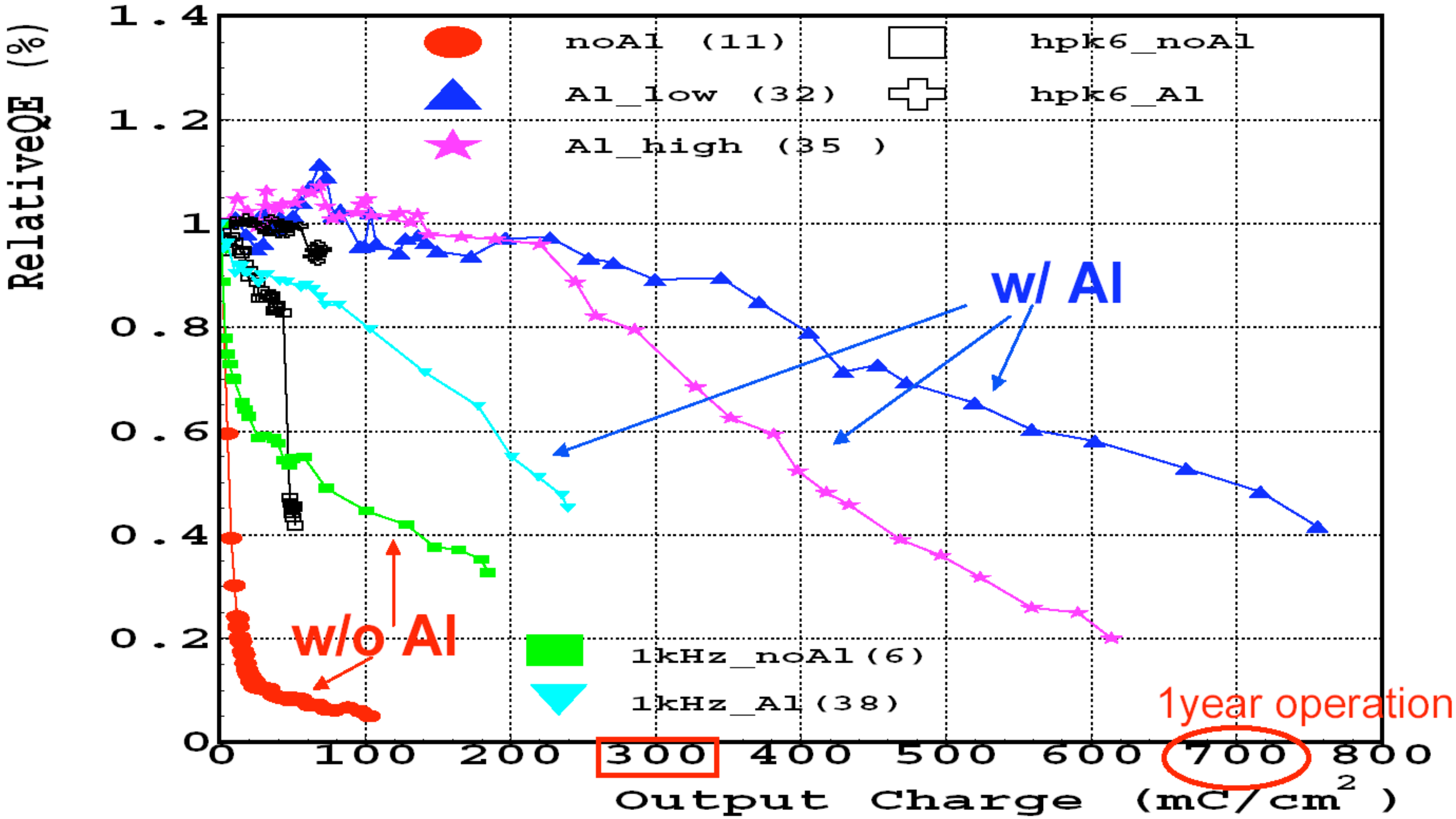


Lifetime: Q.E. of HPK

- Measurement Q.E. lifetime
- $\sim$ 700 mC/cm^2 output for one year operation. (BG rate $\times$20)
- Rapid efficiency drop for PMT w/o Al layer
  $\Rightarrow$ Need Al layer



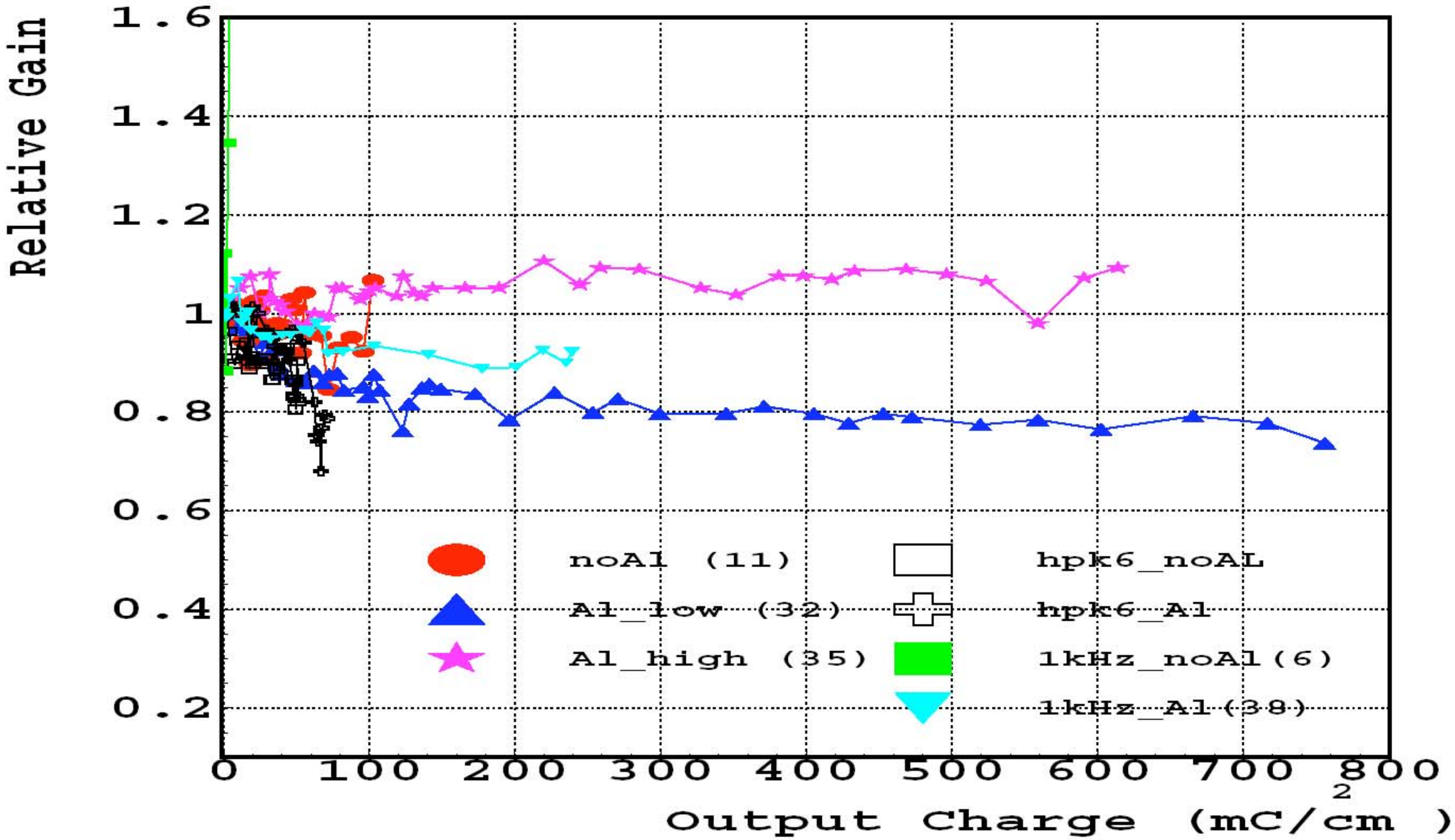
Lifetime: Q.E. of BINP



- Need Al-layer, too.
- Lifetime ~ 300mC/cm^2 even w/ Al layer

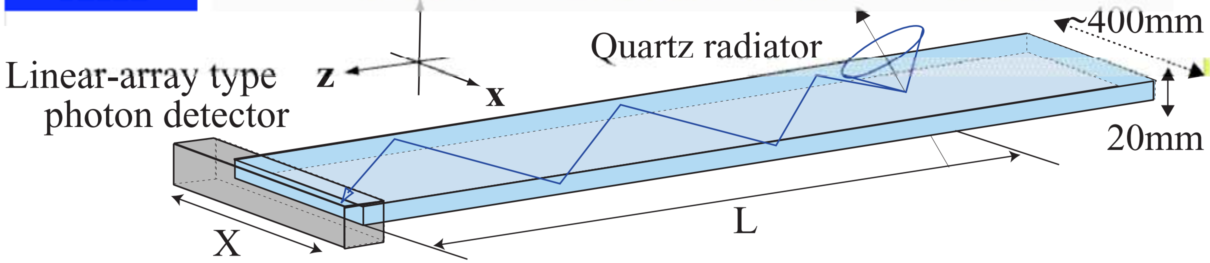
  ⇒ Need effort (Vacuum level)

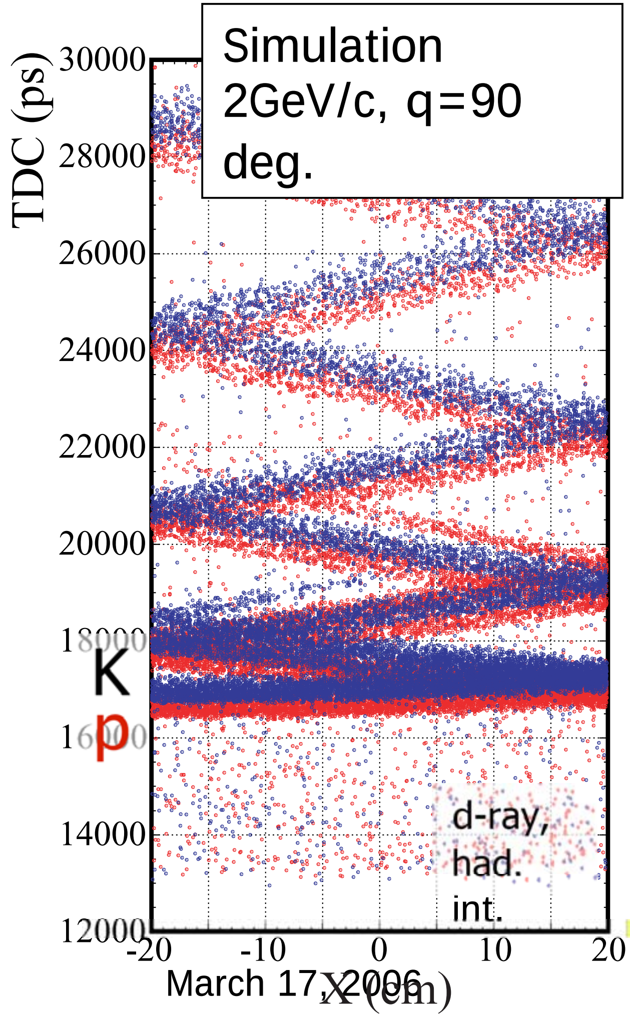
Lifetime: Gain

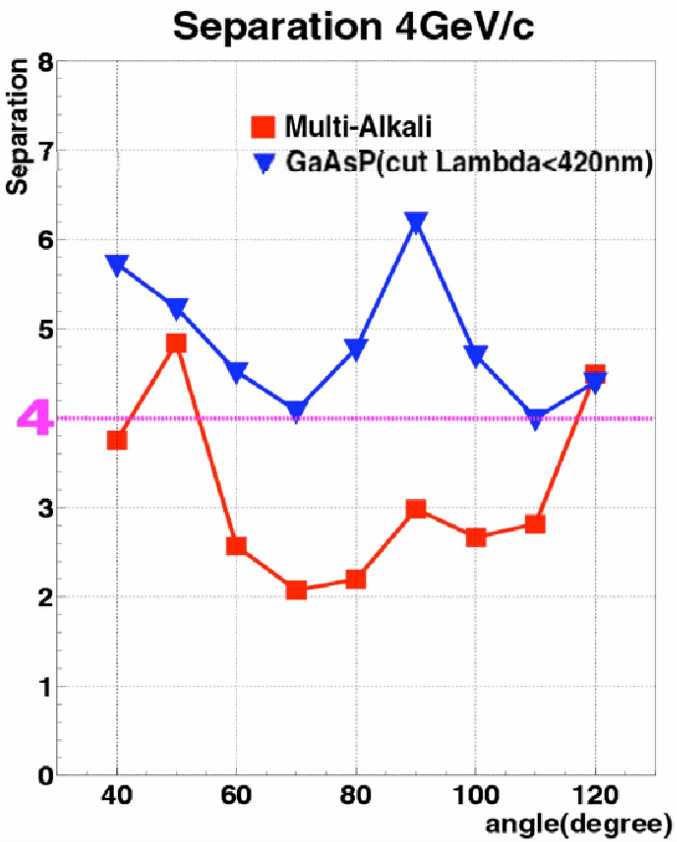


- Gain is almost stable ($> 80\%@700\text{mC/cm}^2$)
- If gain drops, we can raise high voltage up to recover it.

TOP counter MC







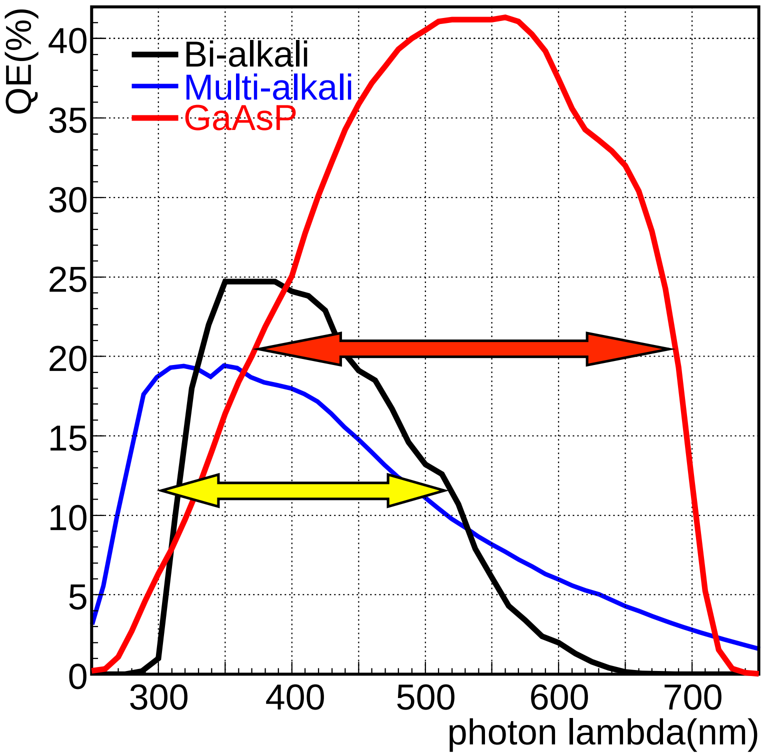
Expected performance with:

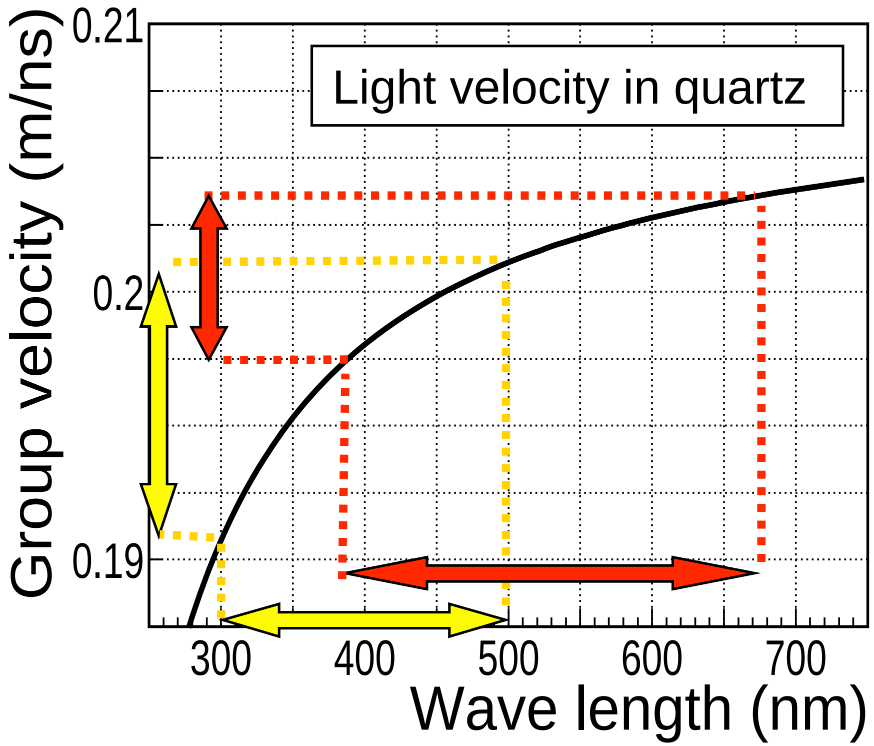
bi-alkali photocathode: <4s p/K separation at 4GeV/c (← chromatic dispersion)

with GaAsP photocathode: >4s p/K separation at 4GeV/c

GaAsP photo-cathode

- High quantum efficiency
- Sensitive at longer wavelengths

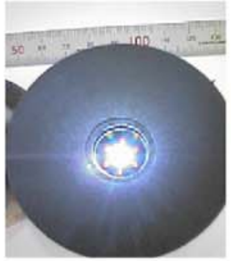




MCP-PMT Performance

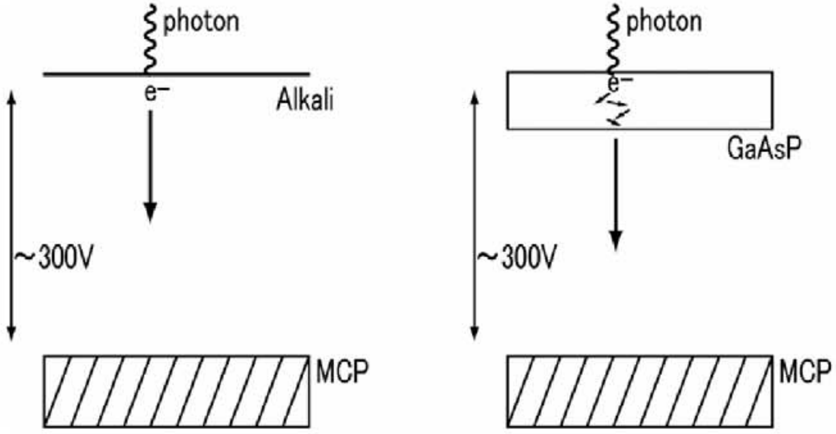
TTS of MCP-PMT w/ GaAs/GaAsP may be worse due to the thickness of photo-cathode. $\Longrightarrow$ should be checked

- multi(bi)-alkali(HPK/BINP) $\sim$ 100 Å




- GaAsP (HPK) $\sim$ μm

- GaAs (BINP) $\sim$ μm: Just delivered

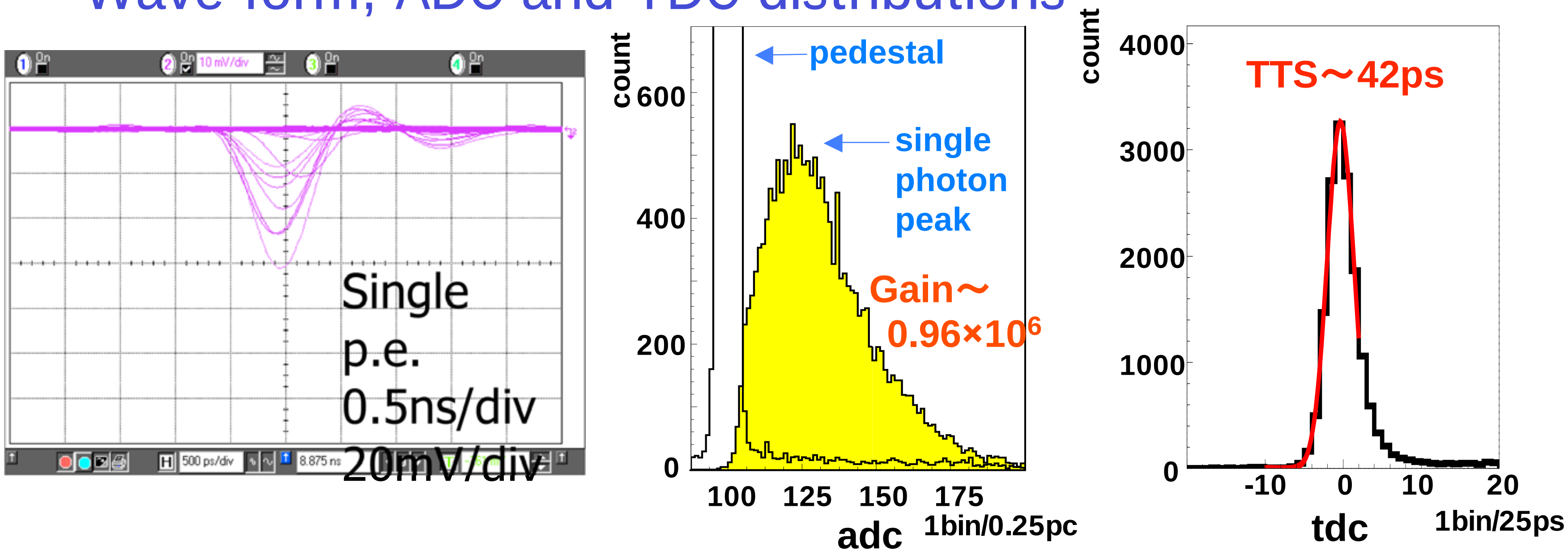


Measured MCP-PMT

	HPK	BINP
photo-cathode	multi-alkali GaAsP	multi-alkali (GaAs)
MCP ch ϕ	6μm	
# of MCP	2stage	
anode	single	

GaAsP MCP-PMT performance

- Wave form, ADC and TDC distributions



- Enough gain to detect single photo-electron
- Good time resolution (TTS=42ps) for single p.e.
  - Slightly worse than single anode MCP-PMT (TTS=32ps)
- Next
  - Check the performance in detail
  - Develop with the target structure

Cross-talk

- Time resolution becomse worse due to cross talk of neighbor signals.
- To reduce cross talk, divide electrodes on MCP.
- S/N is improved from ~ 5 to ~ 10.