Aerogel RICH & TOP counter for super KEKB

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Nagoya University

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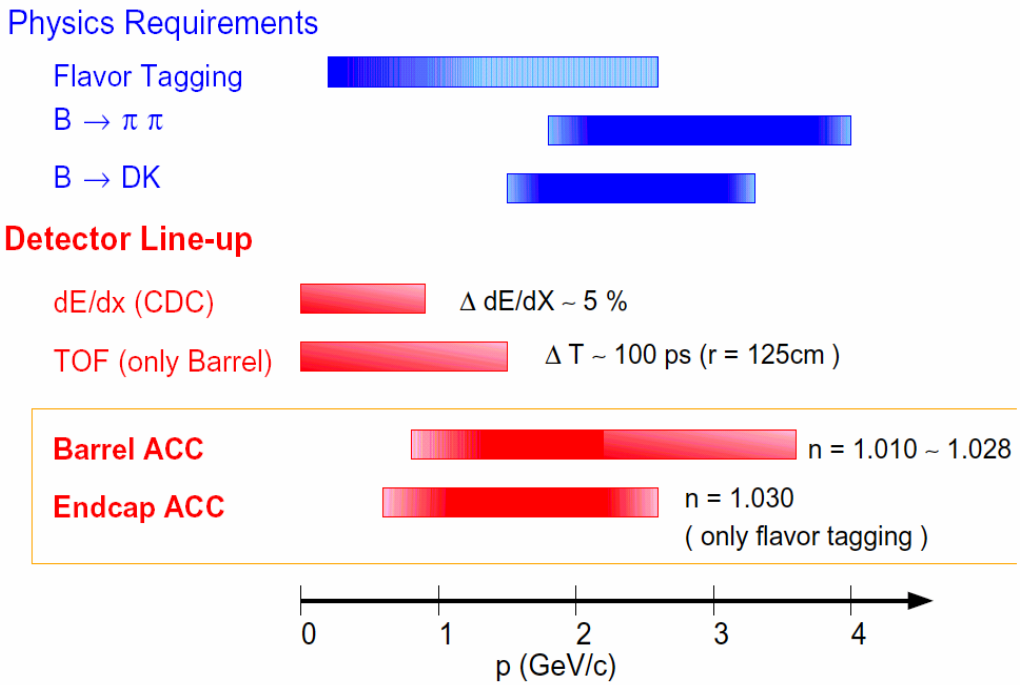
The 3rd SuperB workshop at SLAC

Introduction

Current BELLE performance



We cannot PID at high momentum region in the forward endcap

Present endcap-ACC is used only for flavor tagging

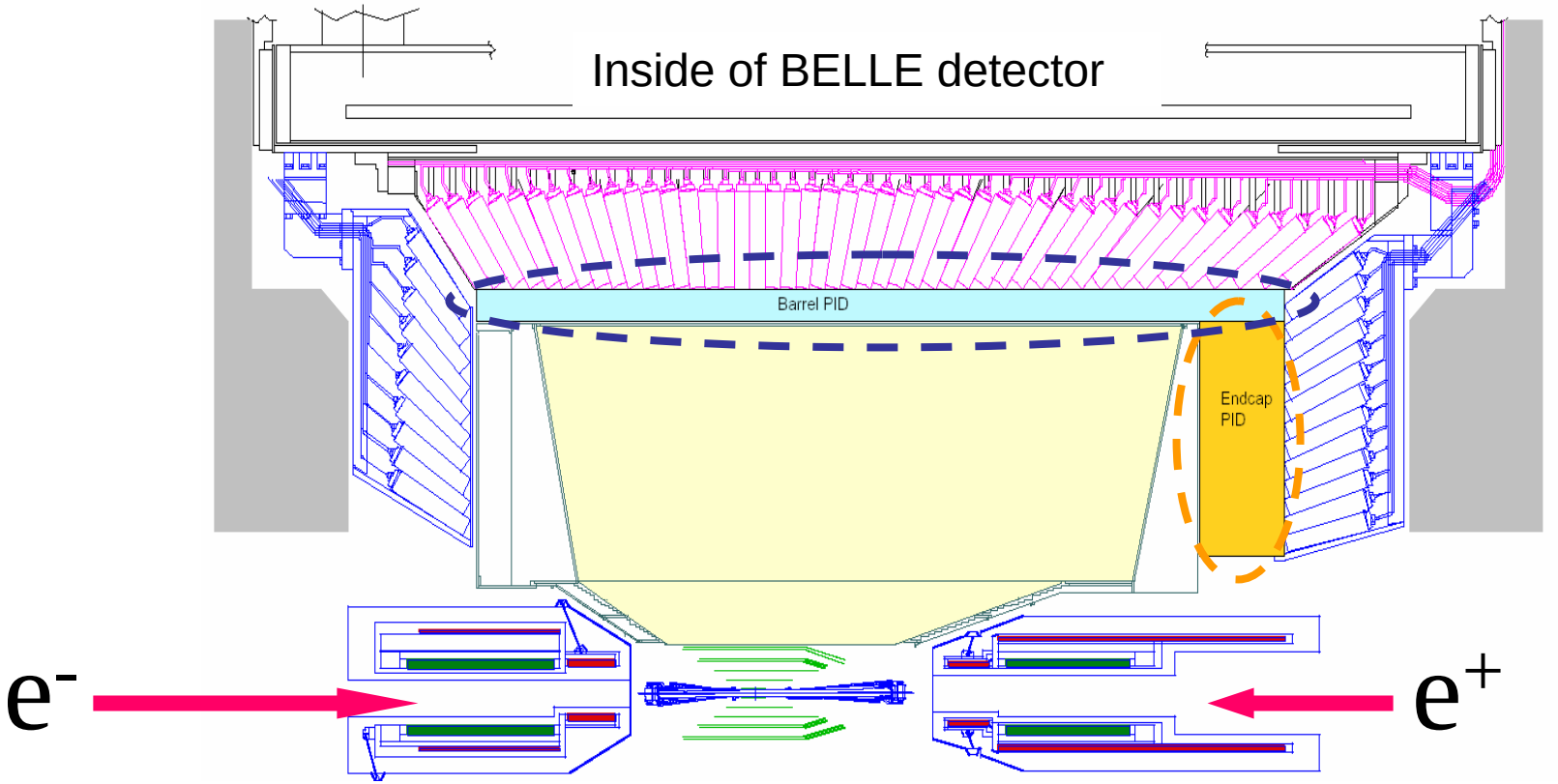
Further Improvement on π/K separation with the start of super KEKB

PID Target:

π/K separation > 4σ @4GeV/c

Upgrading BELLE Detector

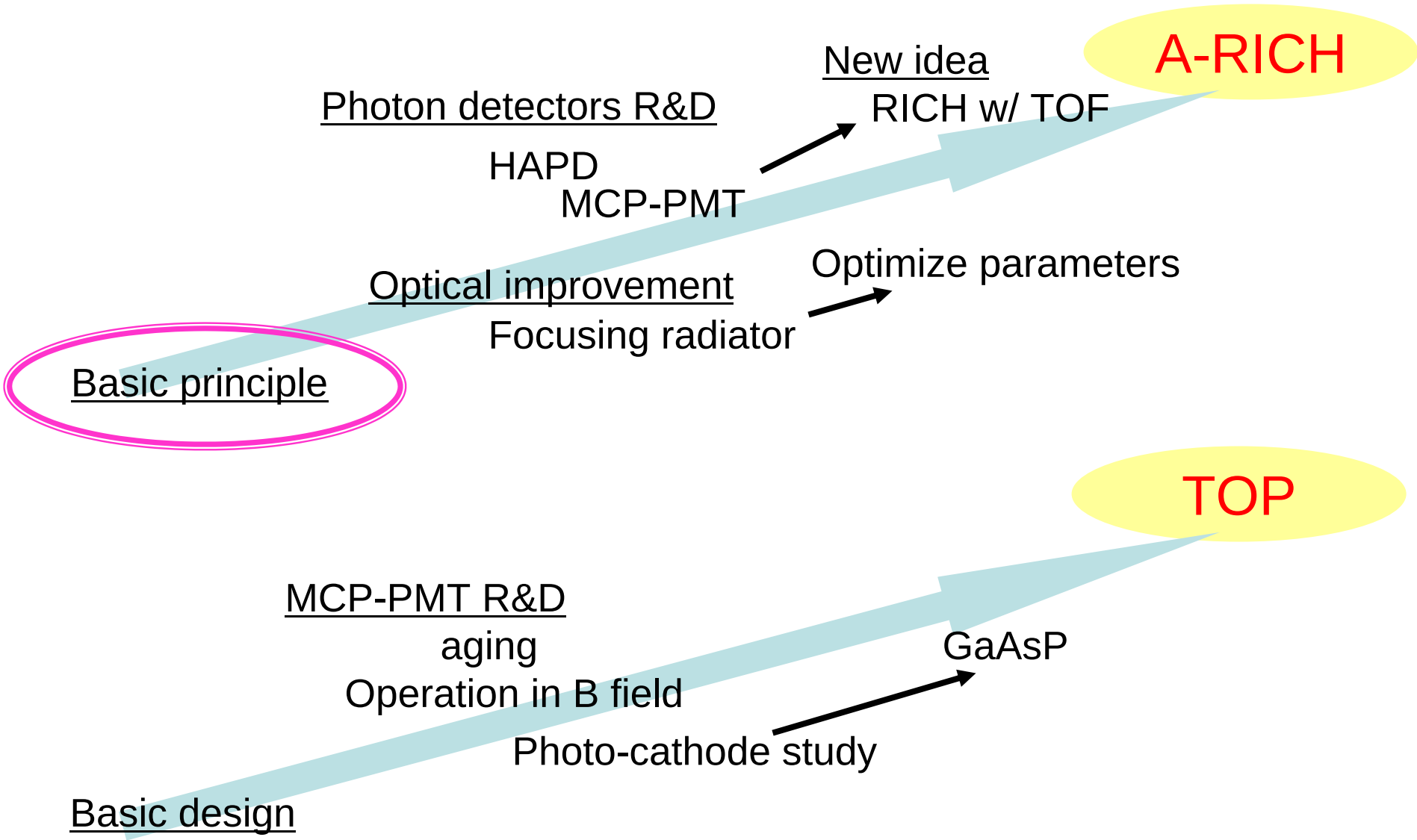
Two new particle ID devices, both RICHes



Endcap: **Proximity Focusing Aerogel RICH(A-RICH)**

Barrel: **Time of Propagation Counter(TOP)**

Outline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Optical improvement
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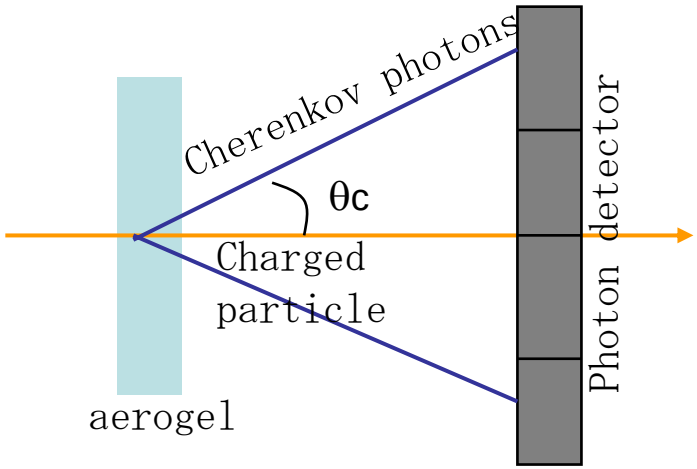
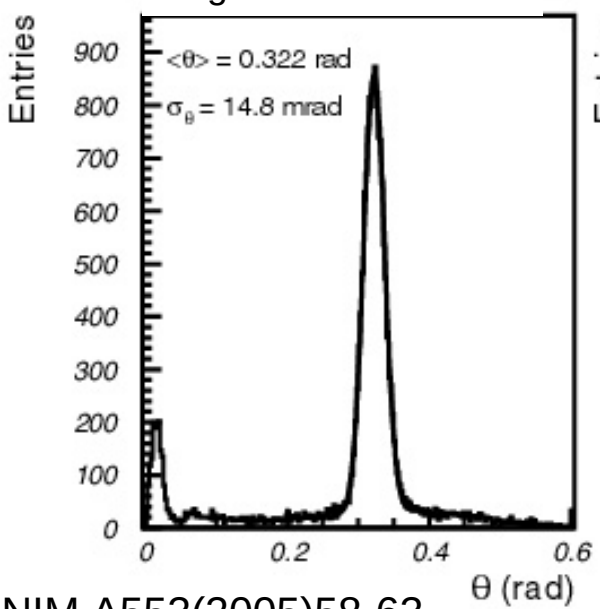
Endcap: Proximity Focusing A-RICH



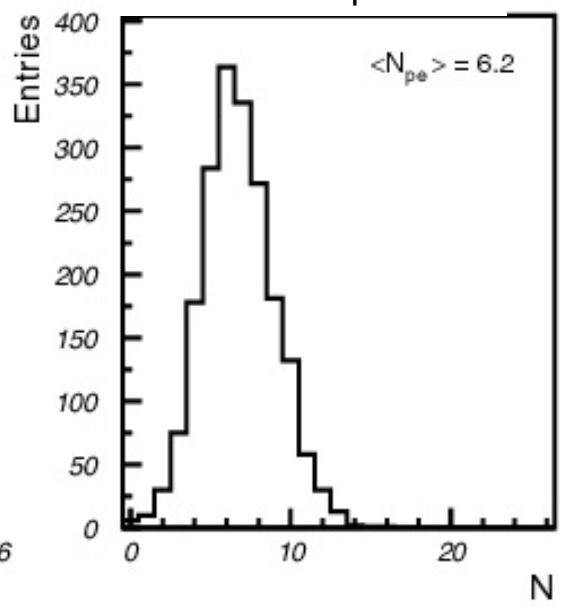
- PID by Cherenkov ring image emitted from aerogel radiator
- Cherenkov angle π/K (4GeV/c, n=1.05)

$$\theta_c^{\pi} - \theta_c^{K} \cong 23 mrad$$

Angle distribution



# of detected photons



NIM A553(2005)58-63

Typical beam test results

π-, 4GeV/c, 2cm thick aerogel

π/K separation ~ 4.0σ

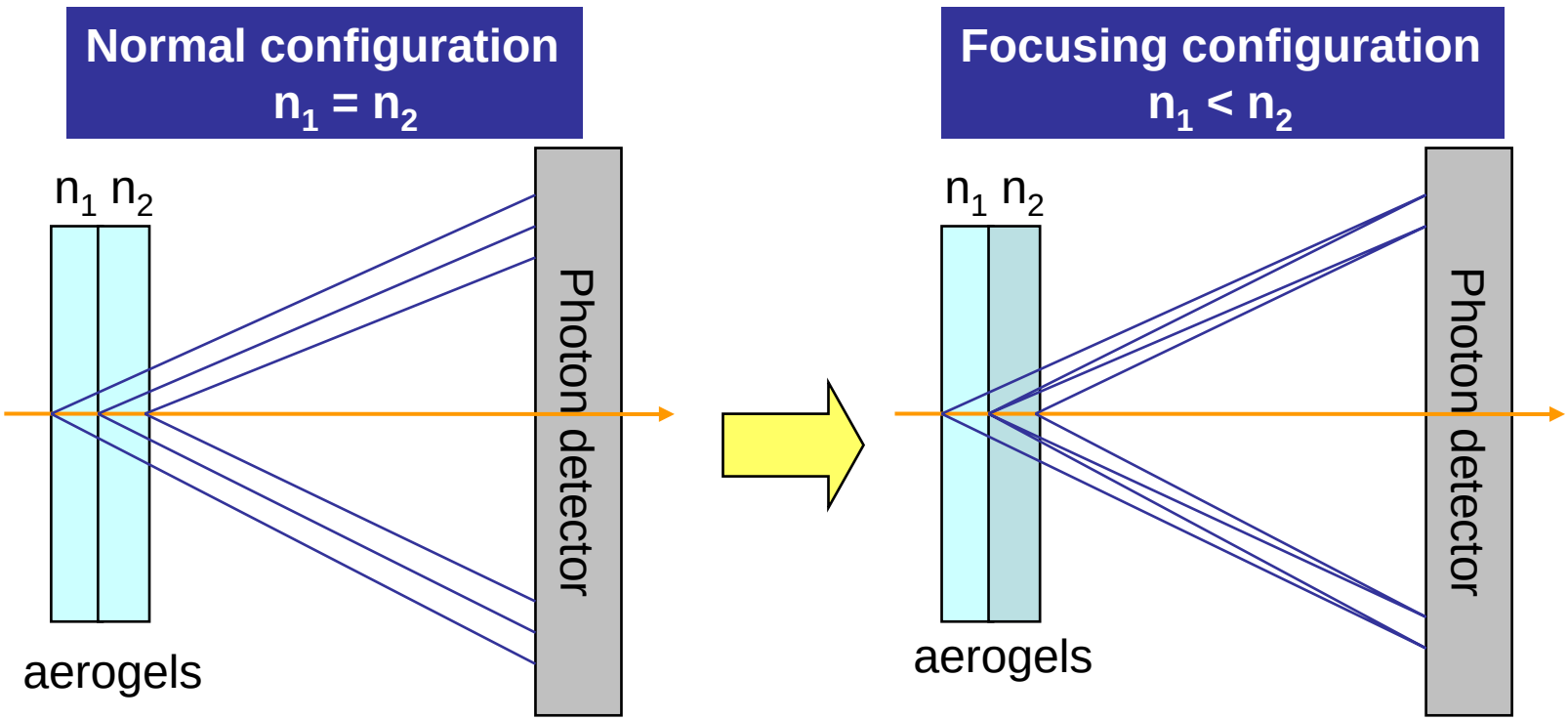
It seems to reach our target, but

Can we improve the separation over 4σ?

Focusing configuration

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

Use radiator with gradually increasing refractive index in down stream direction

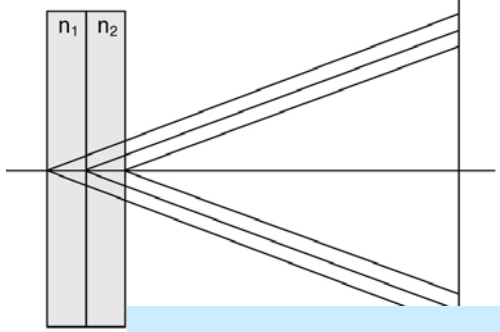


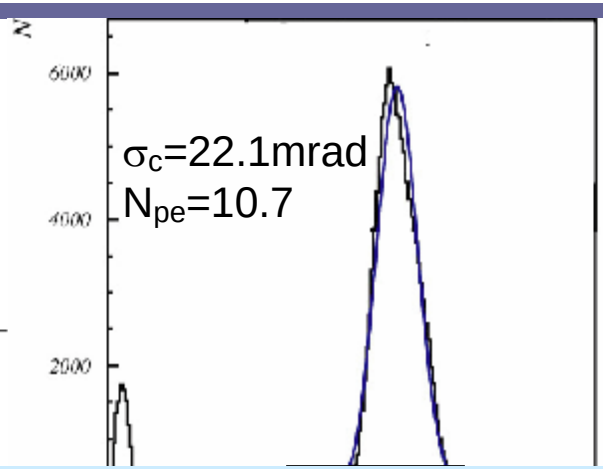
Results of focusing configuration

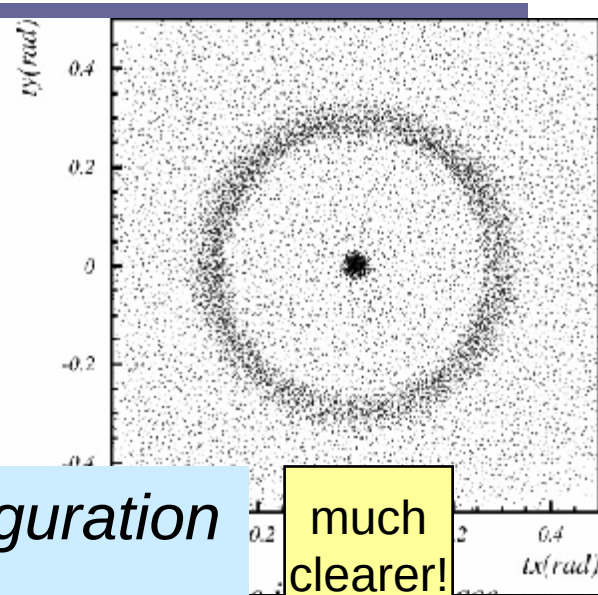
A-RICH

4cm thick aerogel
n=1.047

normal





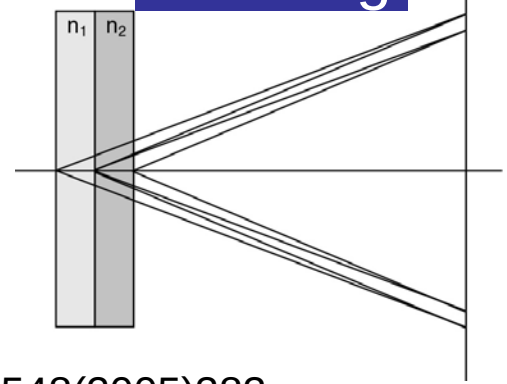


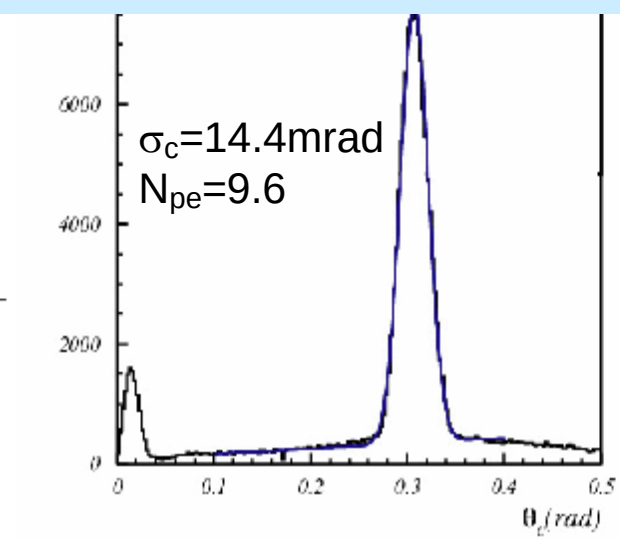
π/K separation with focusing configuration

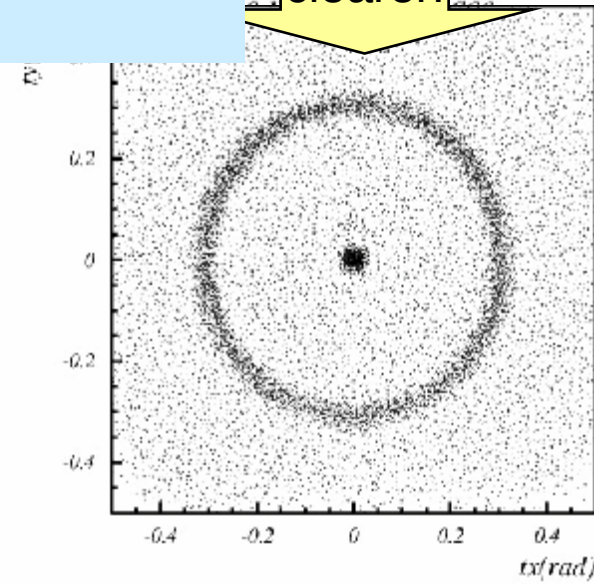
~ 4.8σ @4GeV/c

2 layers of 2
n_1=1.047, n_2=1.057

focusing







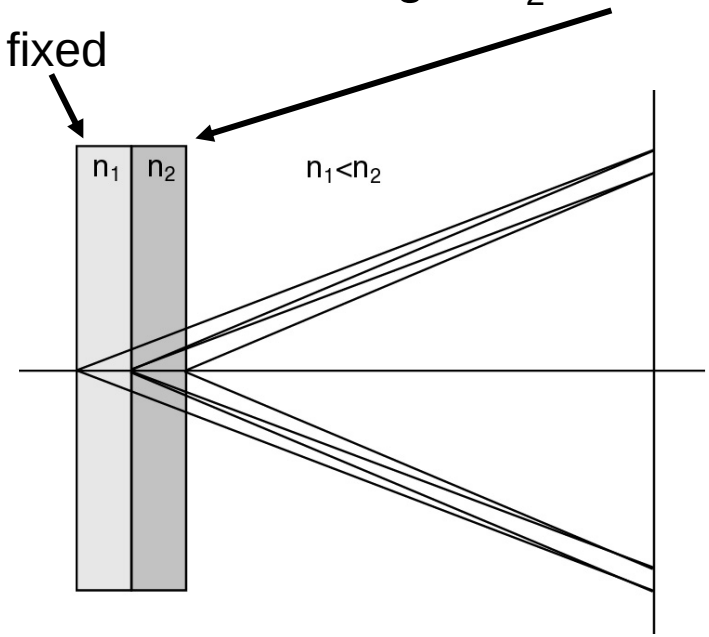
NIM A548(2005)383

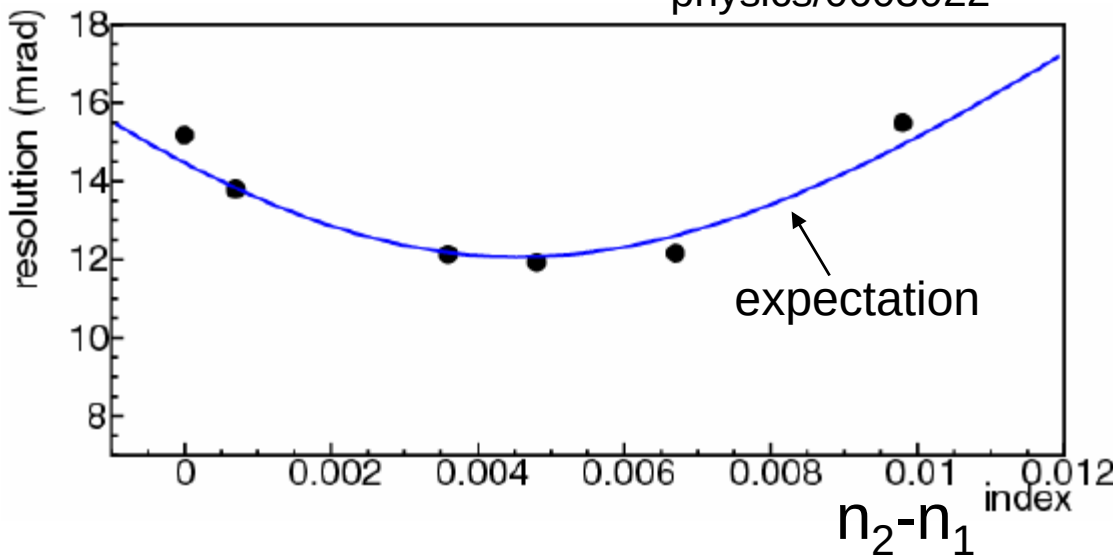
Optimization of dual radiator indices

A-RICH

Upstream aerogel: n_1=1.045
Downstream aerogel: n_2 is changed

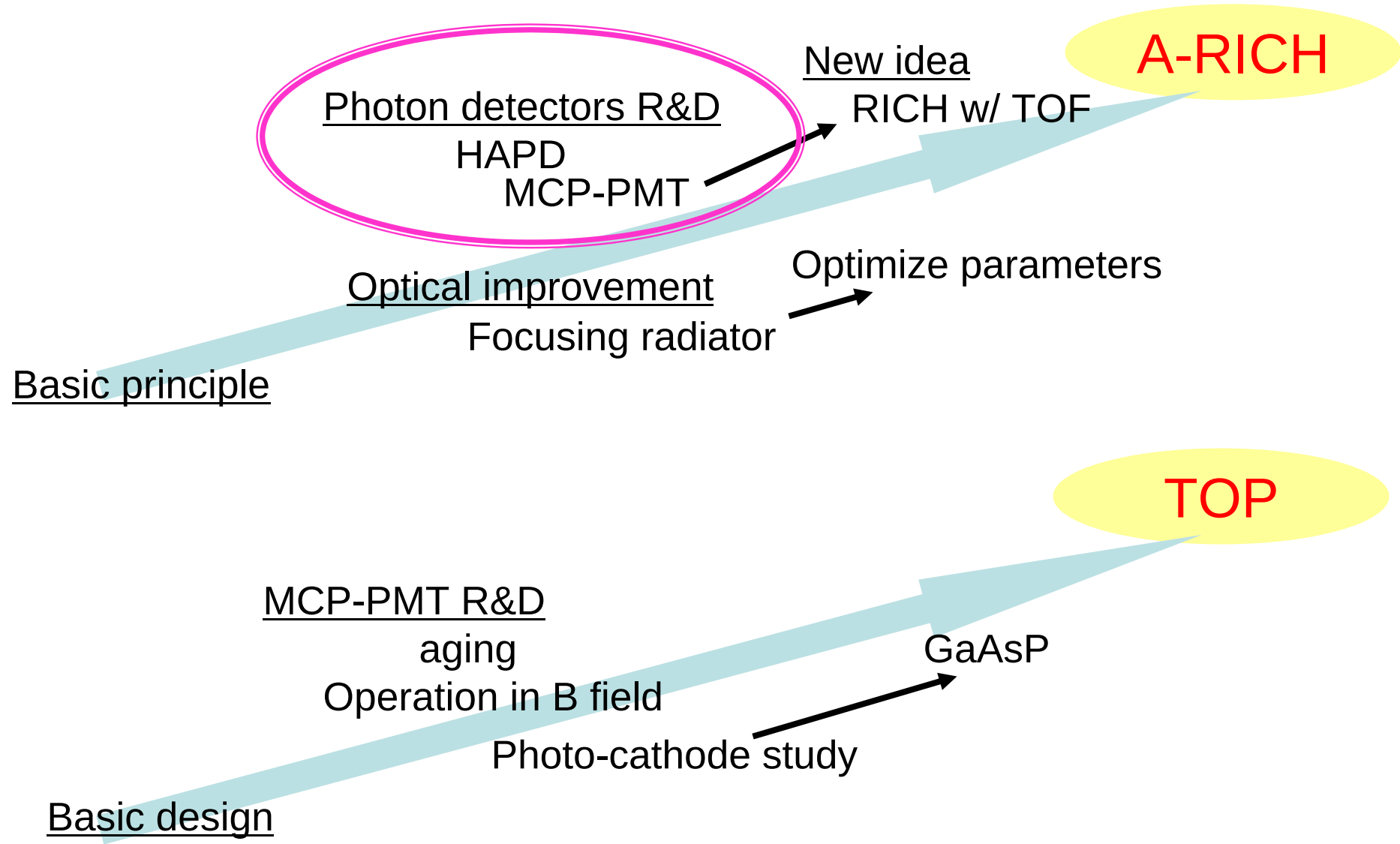
Data points: Dec. 2005 beam test
physics/0603022





- Measured resolution is in good agreement with expectation
- Wide minimum region allows some tolerances(~0.003) in aerogel production

Outline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HAPD
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Photon Detectors for A-RICH

- Requirements
  - Working in B=1.5T
  - Pixel size ~5-6mm
  - Good sensitivity to single photon
  - Large effective area

- Candidates
  - HAPD with large effective area
  - MCP-PMT

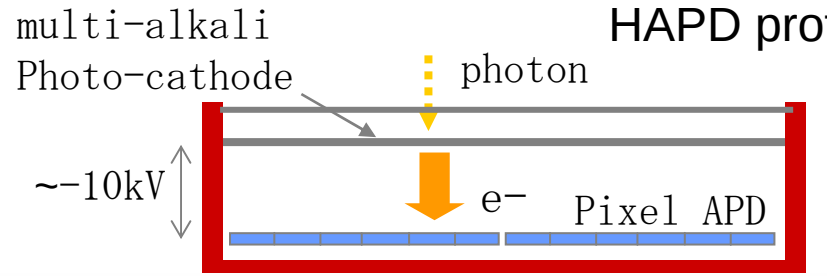
Photon Detectors for A-RICH; HAPD

demerits

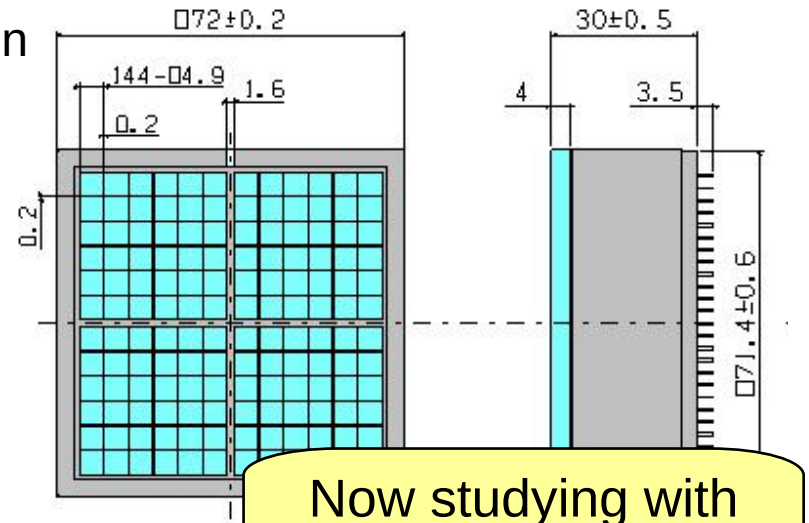
- Low gain (~10^4)
- High noise rate

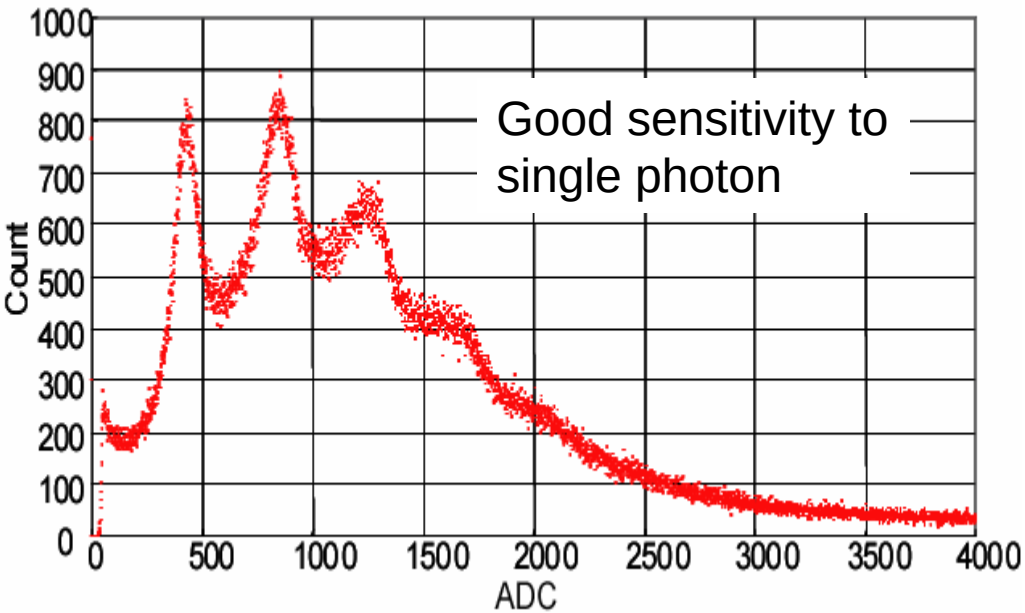
merits

- High efficiency
- High energy resolution



HAPD prototype design





Now studying with HPK!

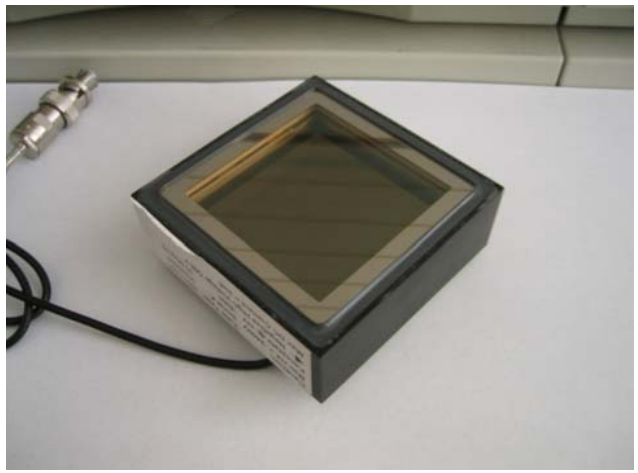
Problems

- difficulties of sealing
- activation of photocathode changes the properties of APD

Photon Detectors for A-RICH; MCP-PMT

BURLE 85011 MCP-PMT

photo-cathode	Bi-alkali
MCP	25μm pores, 2 MCPs
gain	~ 0.6×10^6
collection efficiency	~ 60%
dimensions	~ 71mm square
# of channels	8×8
pitch	~ 6.45mm
active area	~52%



<u>demerit</u>

- active area

<u>merits</u>

- High gain
- Good time resolution

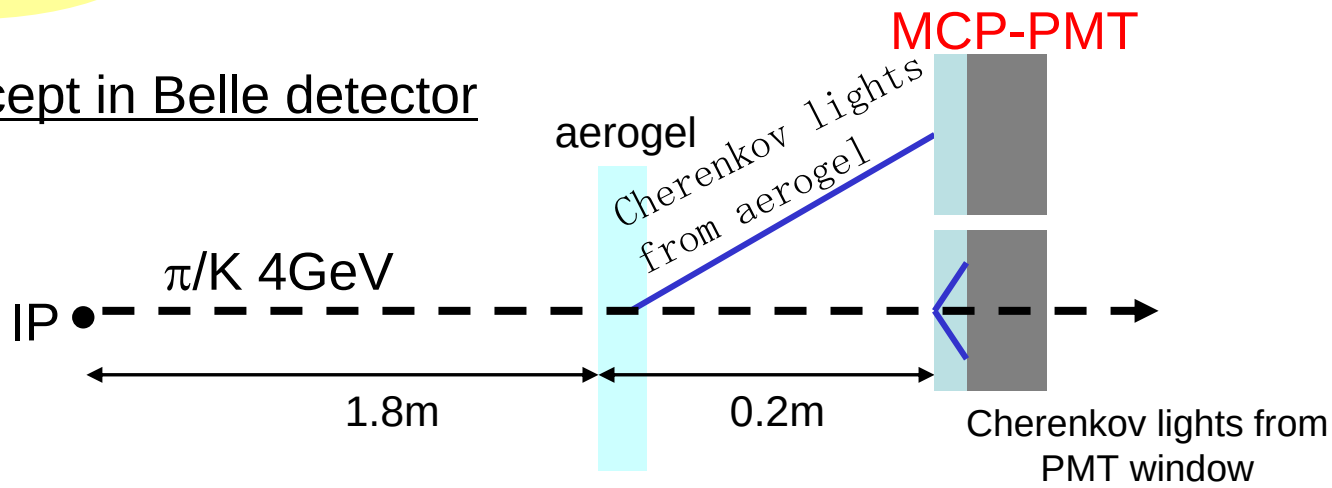
TTS~50psec(single p.e.)

Can we use this merit?

A-RICH with TOF using MCP-PMT

New idea!

Fast photon detector enables A-RICH to have TOF info.



Cherenkov photons emitted in the radiator { Aerogel, PMT glass window }

→ $\Delta TOF_{ring}(\pi/K)$ ~37psec

→ $\Delta TOF_{window}(\pi/K)$ ~47psec

@4GeV/c

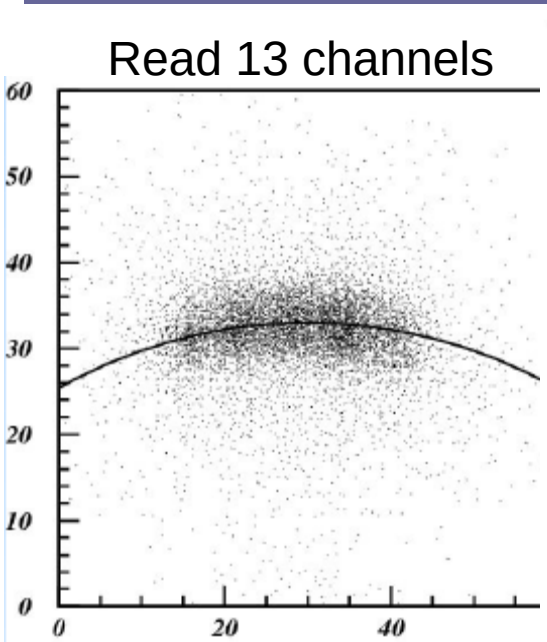
TTS of BURLE MCP-PMT can reach 19 psec for multi photons

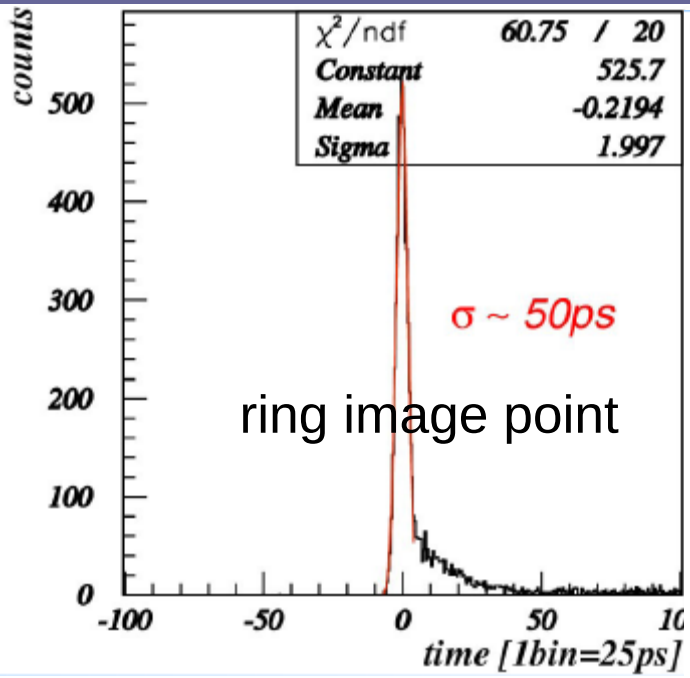
S_{TOF} (π/K) > 2.4 σ for multi photons?

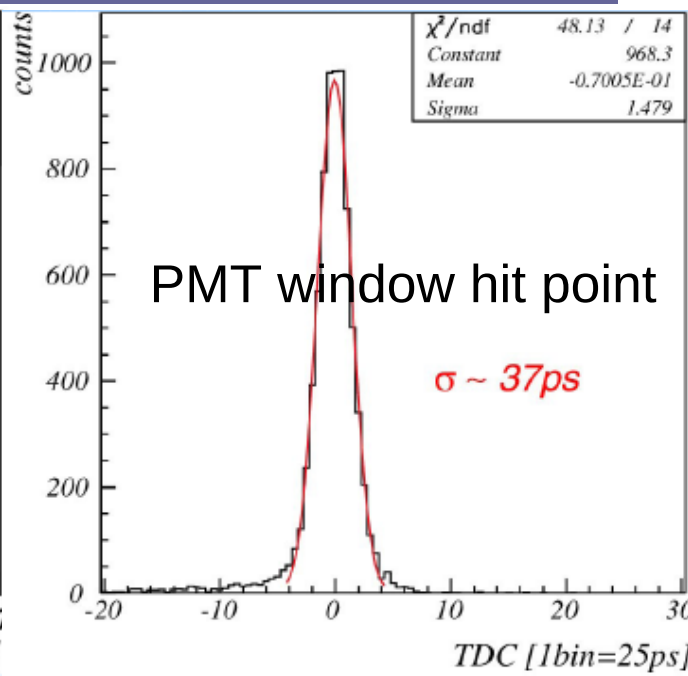
PID can extend lower momentum region

→ $\Delta TOF(\pi/k)$ is bigger

A-RICH with TOF Beam test results





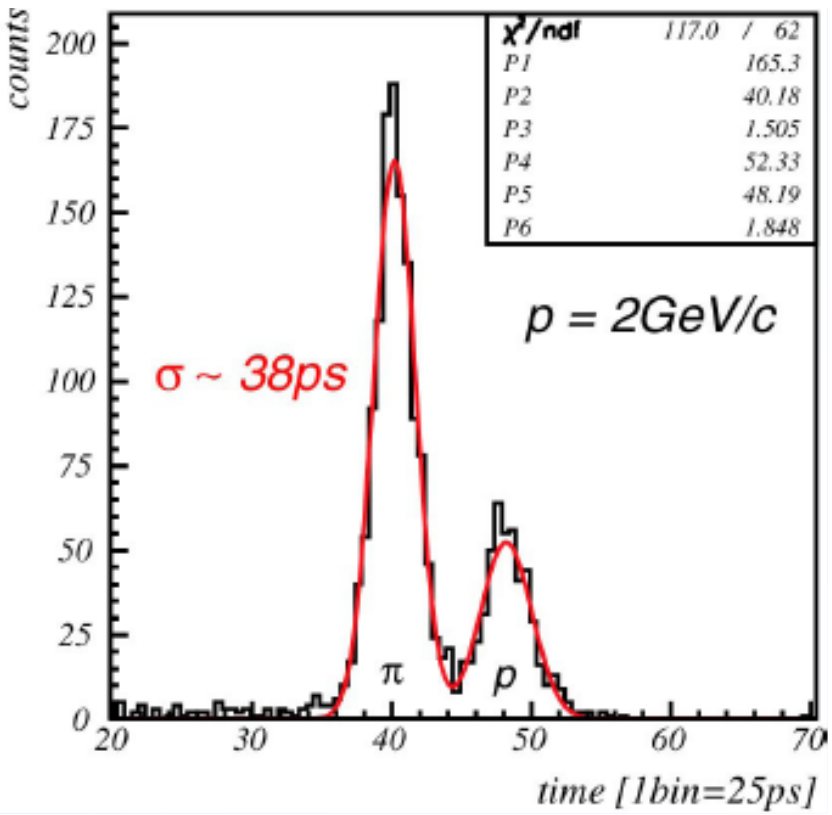


- TTS(ring image point) **~50psec**
  - Time resolution per one track (N_{pe}~10) ~20psec
- TTS(PMT window hit point) **~37psec**

Consistent to expectations

π/K separation with MCP-PMT
S_{TOF} ~ 2.2σ @4GeV/c

A-RICH with TOF PID at low momentum



TOF test with pions and protons at 2GeV/c

Photons from PMT window

π/p are well separated

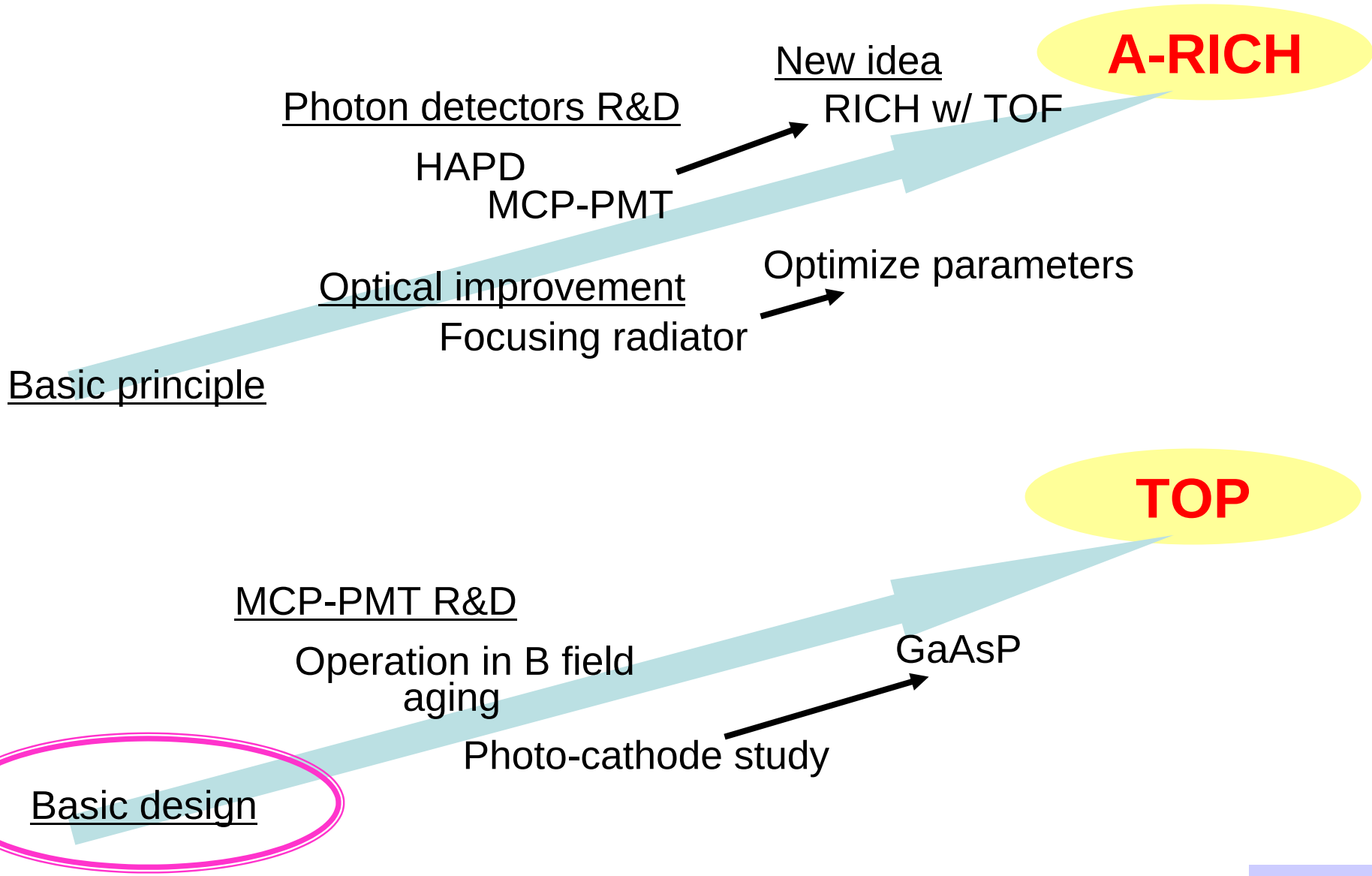
Even in distance between start counter and MCP-PMT is 65cm, instead of 2.0m in Belle

A-RICH with TOF using MCP-PMT looks very promising

At this test, π/p separation with MCP-PMT

$S_{TOF} \sim 4.8\sigma$ @2GeV/c

Outline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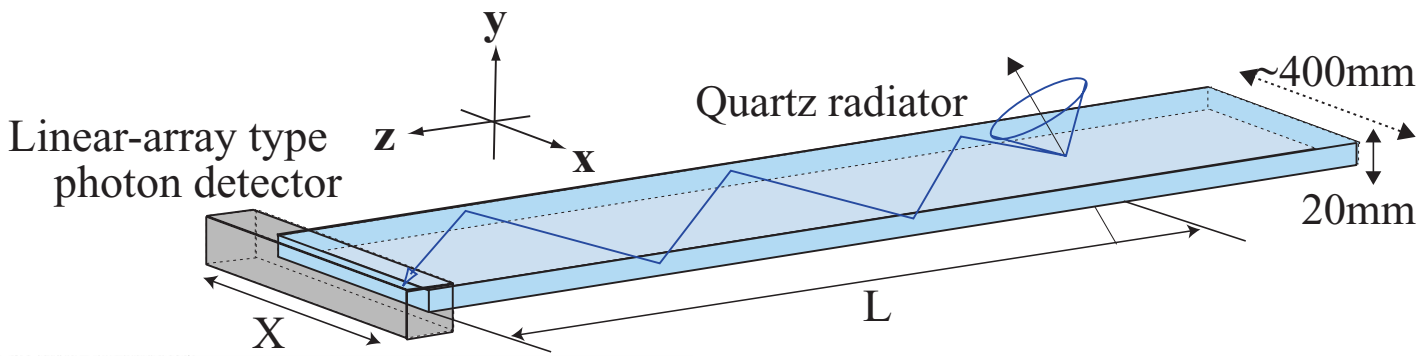
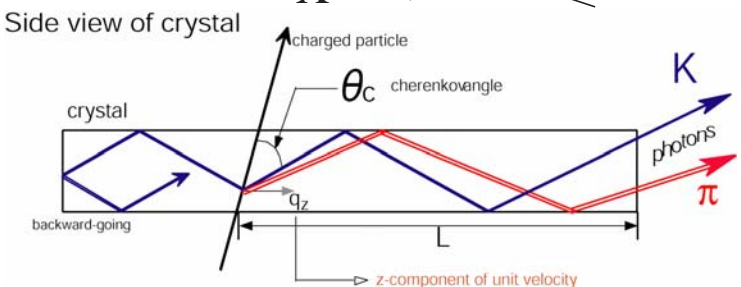
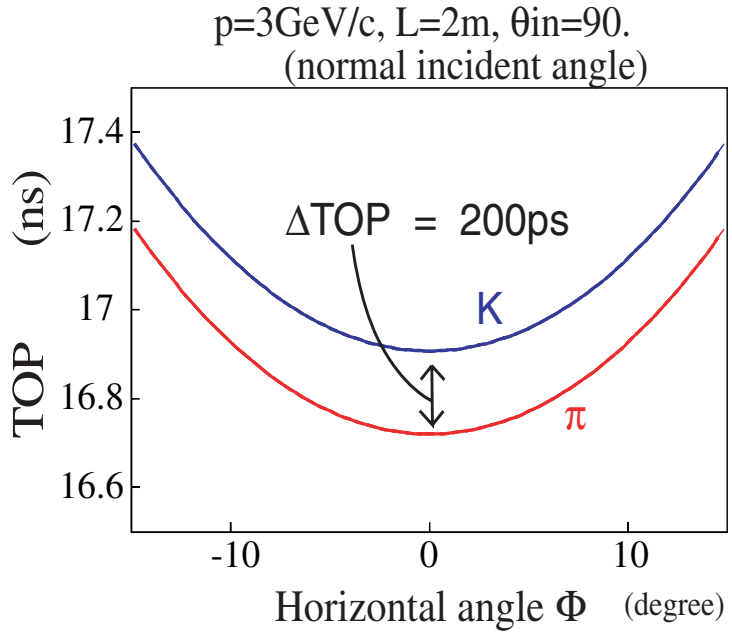
Barrel: TOP counter

Cherenkov ring imaging is used as timing information





$$cos\theta_c = \frac{1}{n(\lambda)\beta}$$



Difference of path length

→ Difference of time of propagation (TOP)

(+ TOF from IP)

With precise time resolution (σ~40ps)

Photon Detector for TOP; MCP-PMT

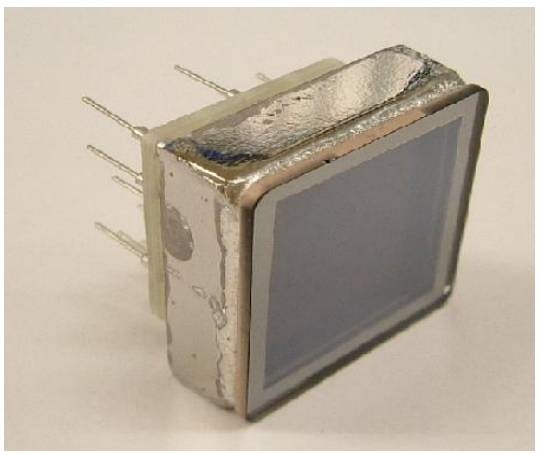
TOP

- Requirements:
  - Good sensitivity to single photon
  - TTS~30ps (single photon)
  - working in 1.5T

- 3 MCP-PMTs studied:
  - BURLE (25μm pores)
  - BINP (6μm pores)
  - HPK (6 and 10μm pores)

B=0T: all samples have good TTS(~30ps)
B=1.5T: BINP and HPK samples have high gain(~10^6) and good TTS(~30ps)

→ NIM A528 (2004) 763



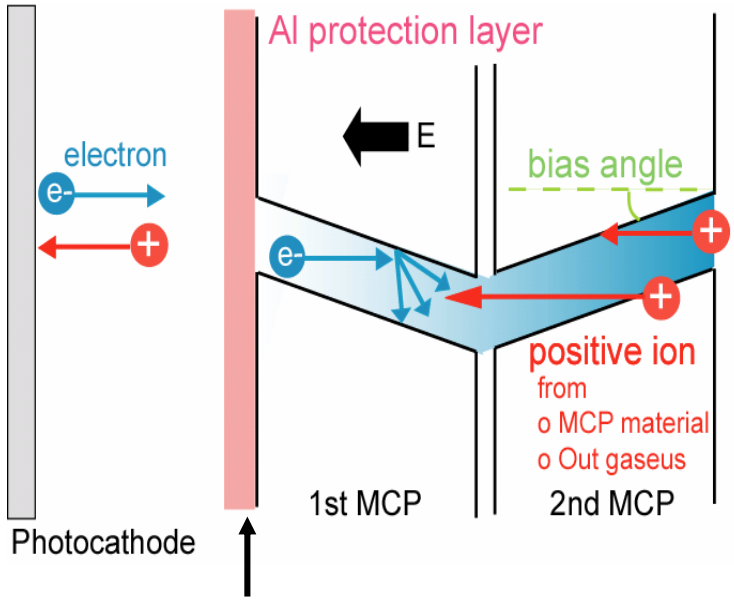
These samples were round shaped (1ch.)

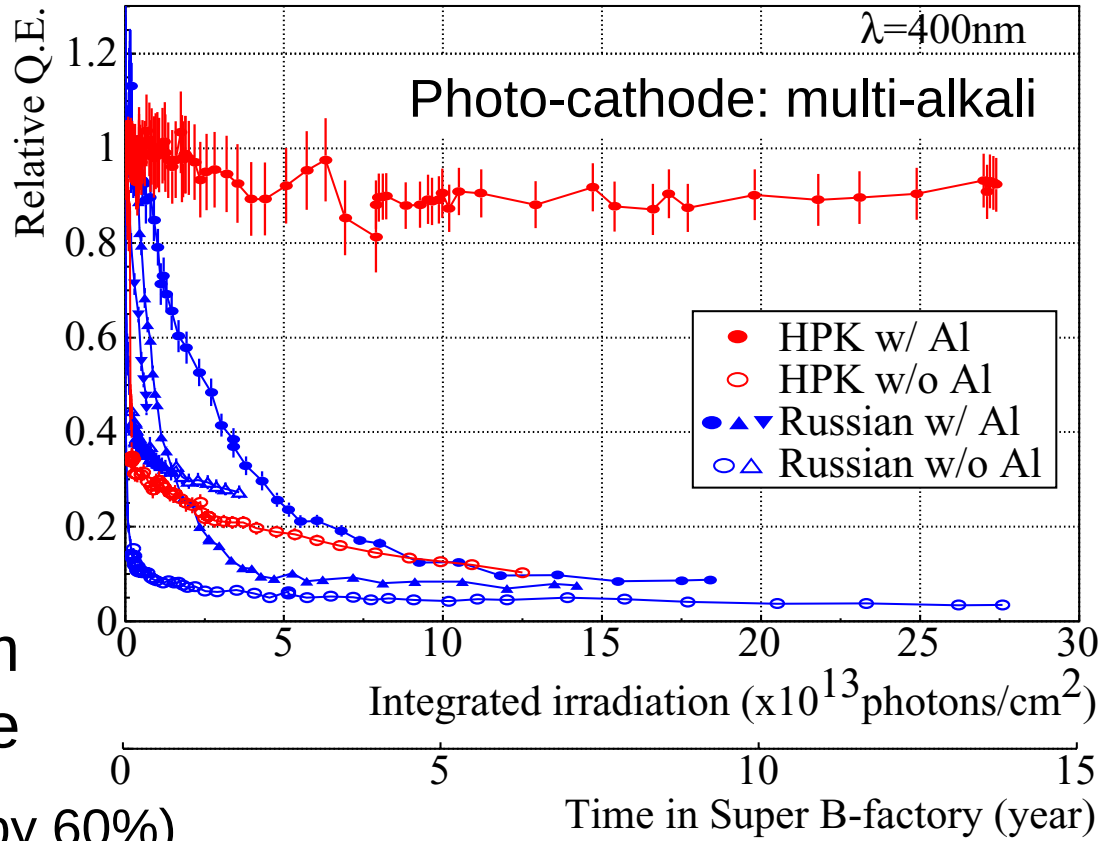
We've developed square shaped (4ch.)

MCP-PMT aging

TOP

Study of tubes w/ and w/o Al layer





Prevent feedback ions from reaching the photo-cathode

(It reduces collection efficiency by 60%)

HPK w/ Al survives over 13 years of operation!
Al layer is necessary

MCP-PMT with GaAsP

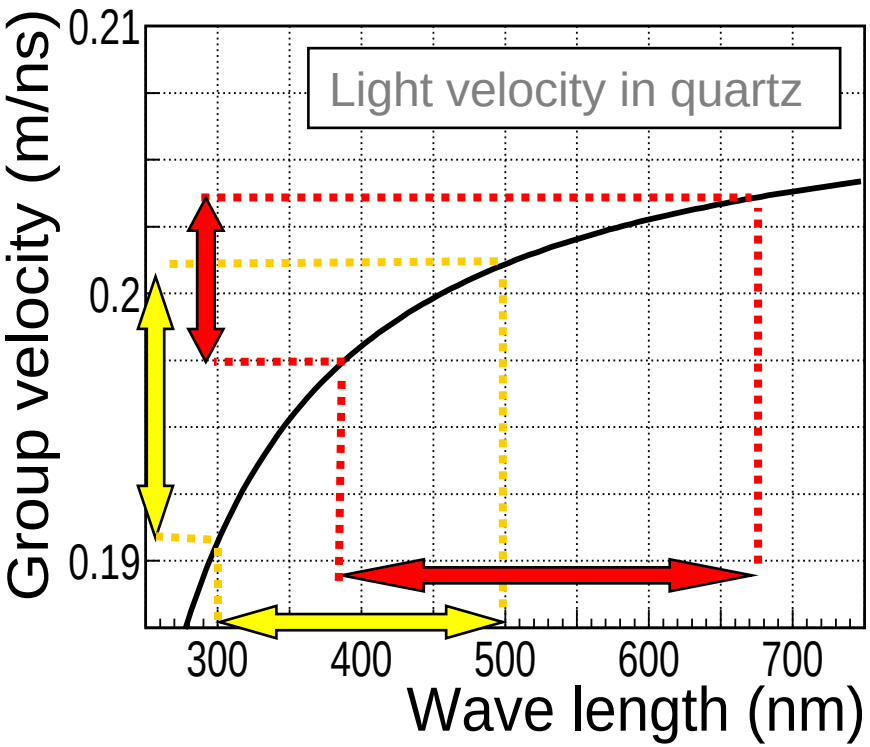
TOP

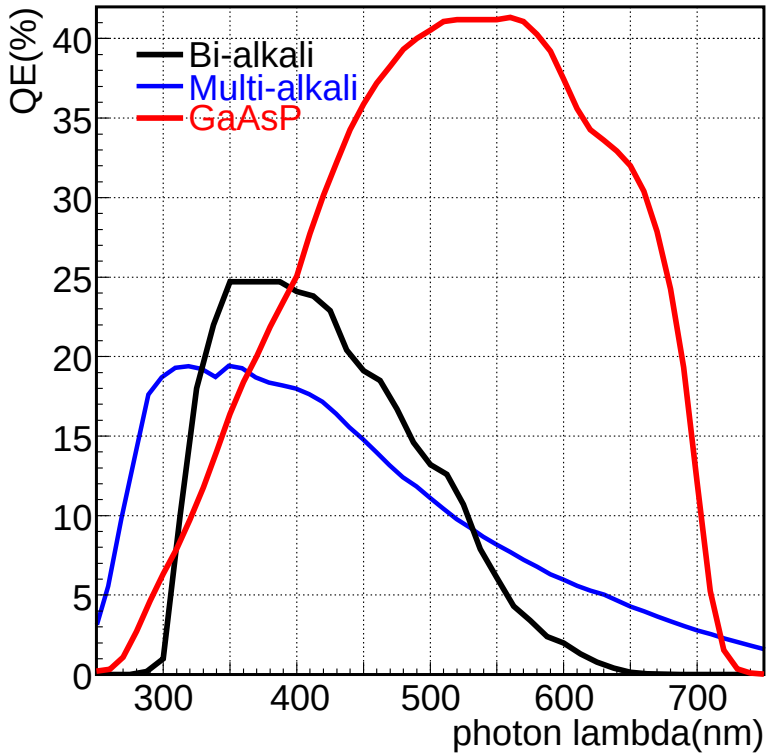
Expected performance

bialkali photo-cathode:

π/K separation at 4GeV/c < 4σ

→ chromatic dispersion





GaAsP photo-cathode:

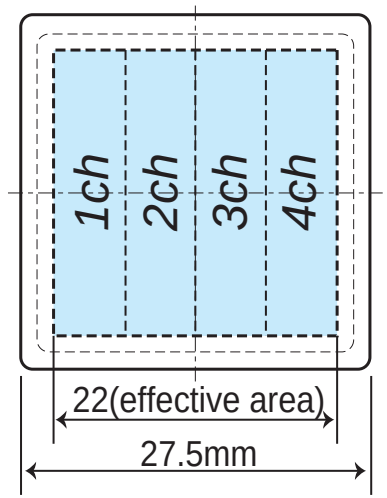
- Higher Q.E.
- At longer wavelength

  →less dispersion

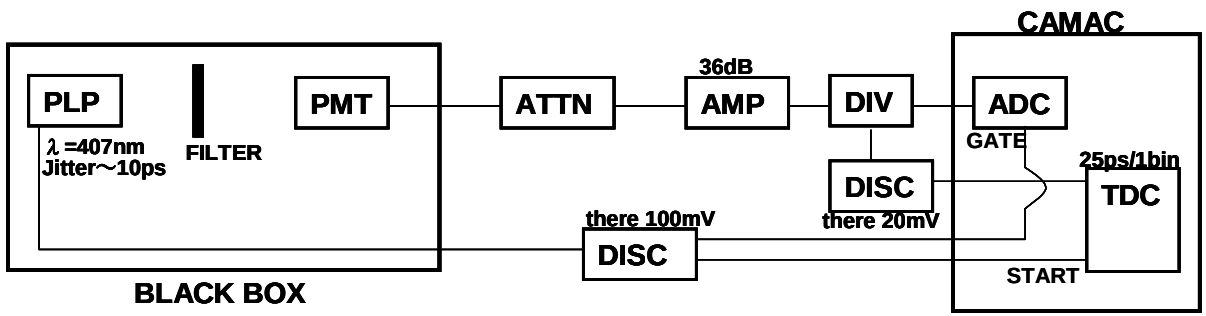
π/K separation > 4σ @4GeV/c

GaAsP MCP-PMT development

- Square-shape MCP-PMT with GaAsP photo-cathode is under development with HPK
- First prototype
  - The same type as previous tubes

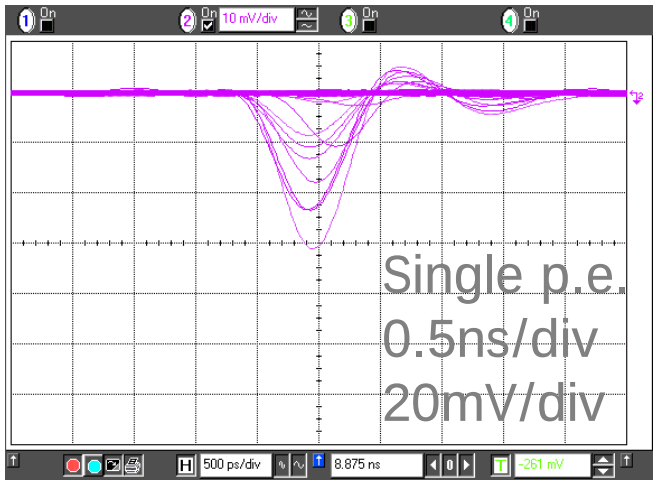


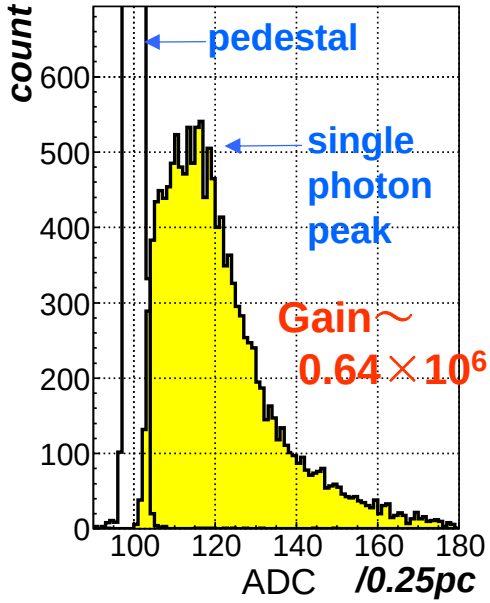
- Performance test
  - Gain
  - Time resolution

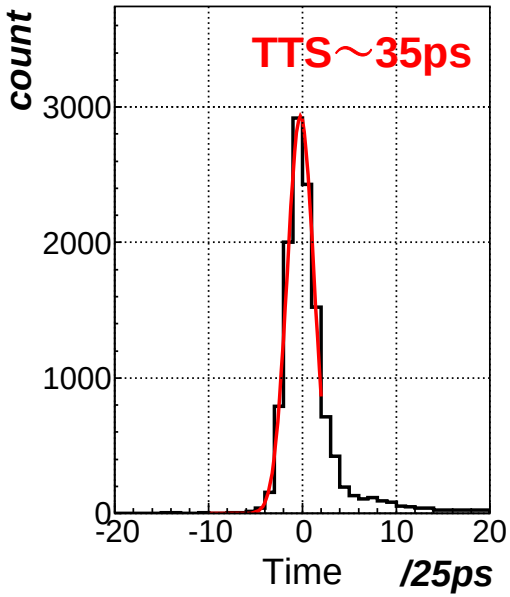


GaAsP MCP-PMT performance

- Wave form, ADC and TDC distributions







- Enough gain(~10^6) to detect single p.e.
- Good time resolution (TTS~35ps) for single p.e.
- Next
  - Check the performance in detail
  - Life time of GaAsP photo-cathode tube

Summary

We are studying new types of RICH for super KEKB

Aerogel RICH counter for endcap

- Test the focusing configurations
  - We studied about optimal parameters
- More studies: RICH with TOF (using MCP-PMT)
  - Extend PID ability into low momentum region

TOP counter for barrel

- M ps)
- A
- M
  - It will reduce the effect of chromatic dispersion

Both RICHes(A-RICH, TOP) look very promising

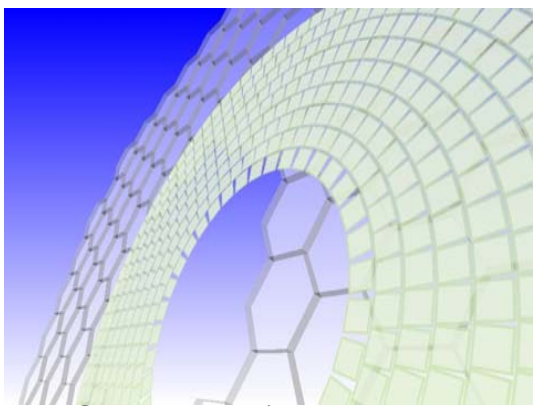
π/K separation can be over 4σ @4GeV/c

But there is still a lot of work to be done!

Tasks for practical use

A-RICH

- Photon detectors
  - Develop HAPD & MCP-PMT in parallel
- Readout system
  - ASIC
- Mechanical design
  - Line up of photon detectors and radiators

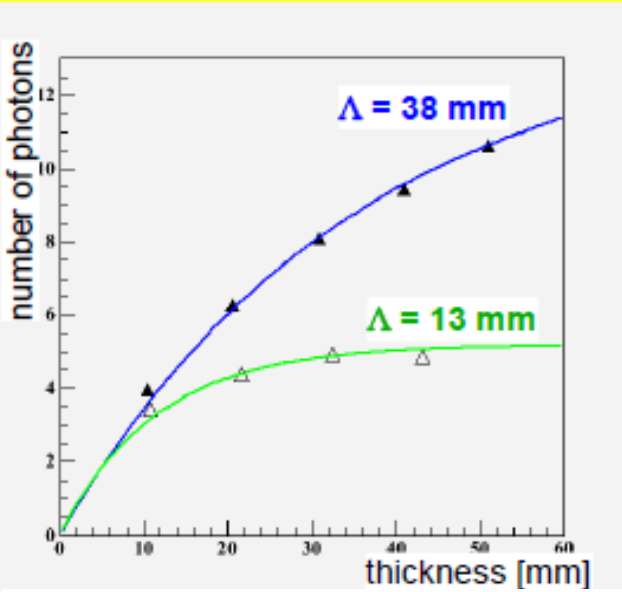


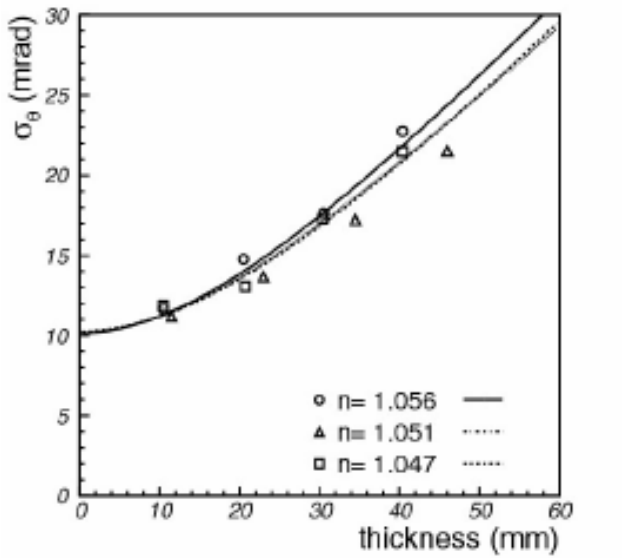
TOP

- MCP-PMT
  - Make practical tube
  - Aging of tube with GaAsP
- Readout system
  - TAC
- Test of prototype
  - Line up of photon detectors and radiators

Backup

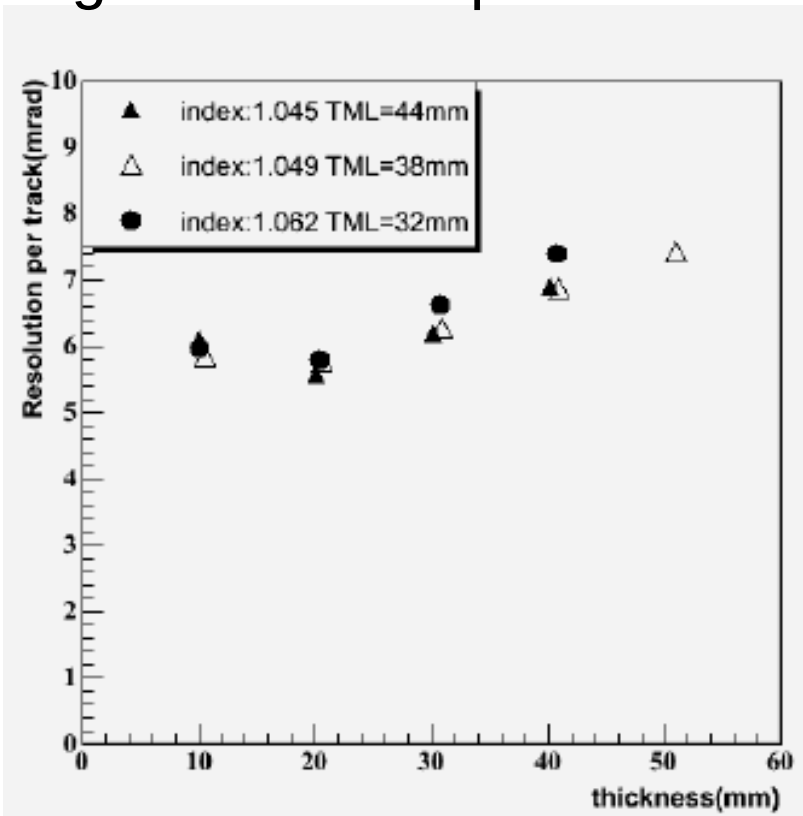
Optimal aerogel thickness





Cherenkov angle resolution per track

$$\sigma_{track} = \frac{\sigma_{\theta c}}{\sqrt{N_{pe}}}$$

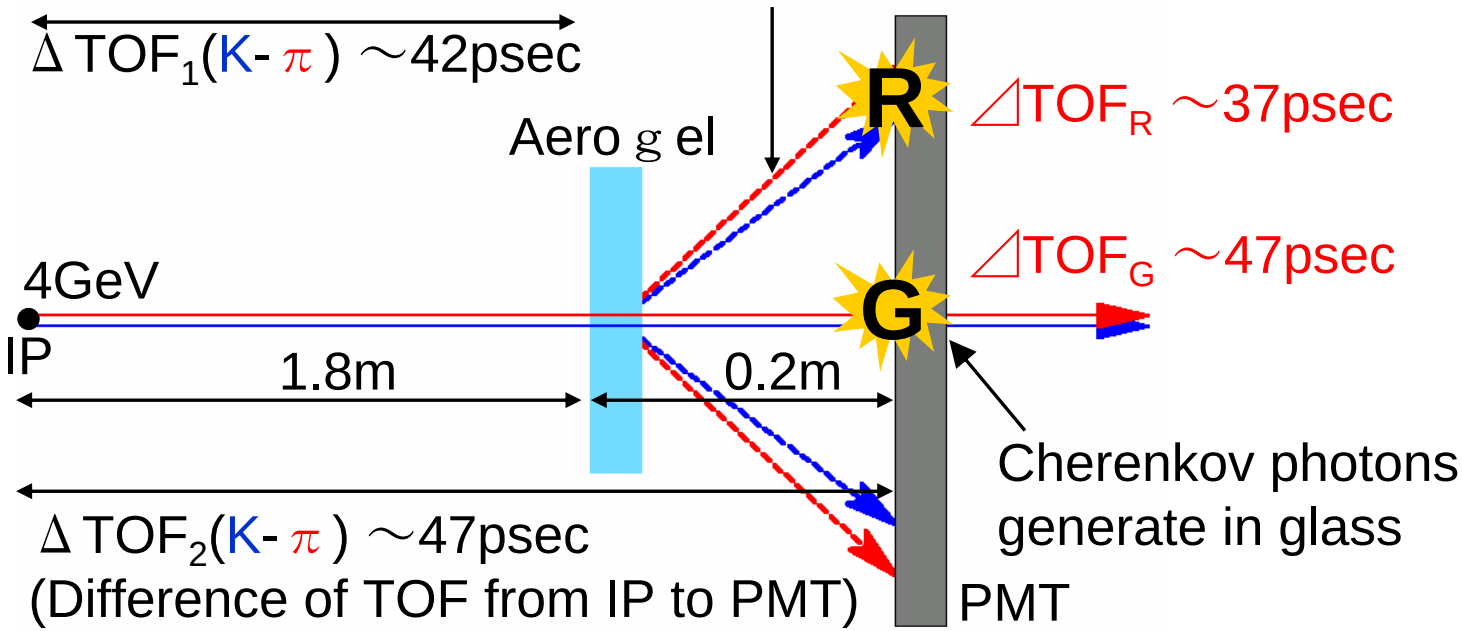


The best resolution ~ 5.5mrad at 2cm thick aerogel

RICH with TOF

RICH with TOF

ΔTOP(K-π) ~-5psec
(Difference of TOP from emission point of Cherenkov light to PMT)



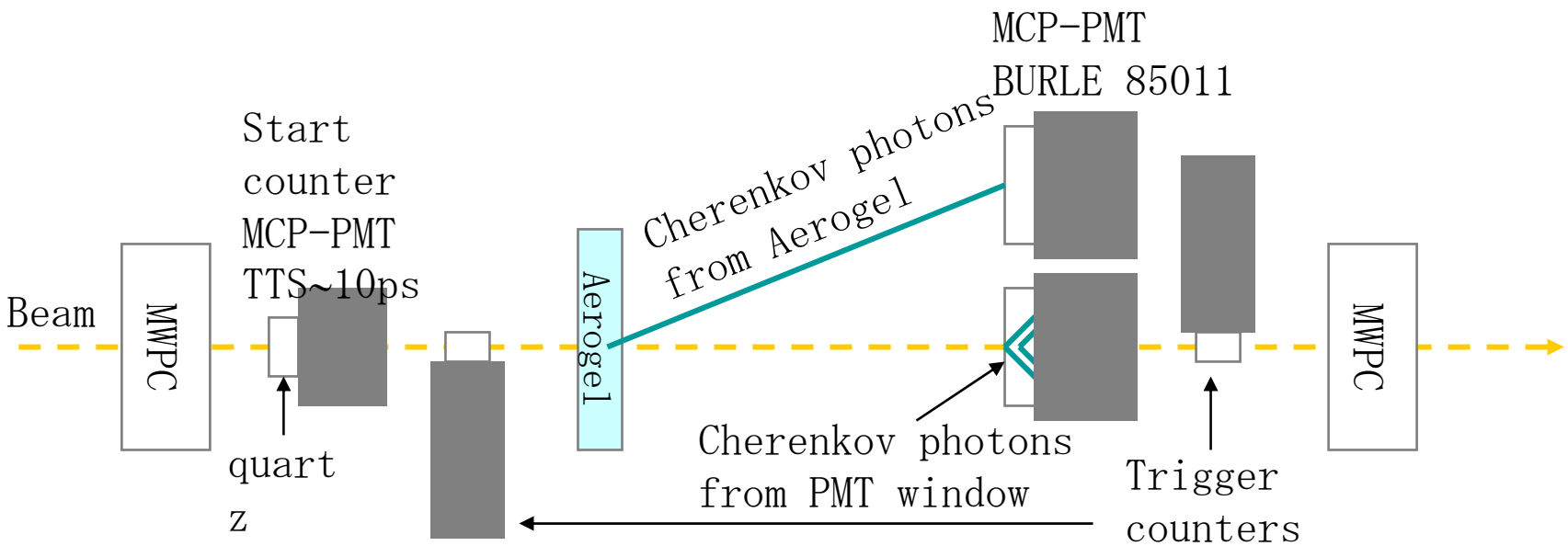
Time resolution of 10 psec has been achieved with HPK MCP-PMT @ Nagoya university.

Time resolution of BURLE MCP-PMT can reach 19 psec for multi photons.

More than 2.4 σ for multi photons?

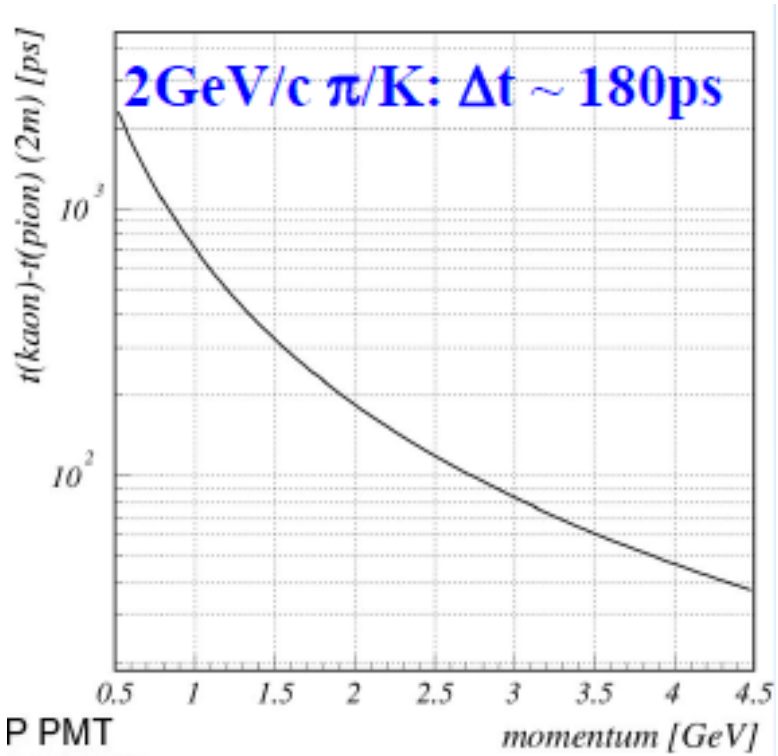
A-RICH with TOF using MCP-PMT

Setup of beam test

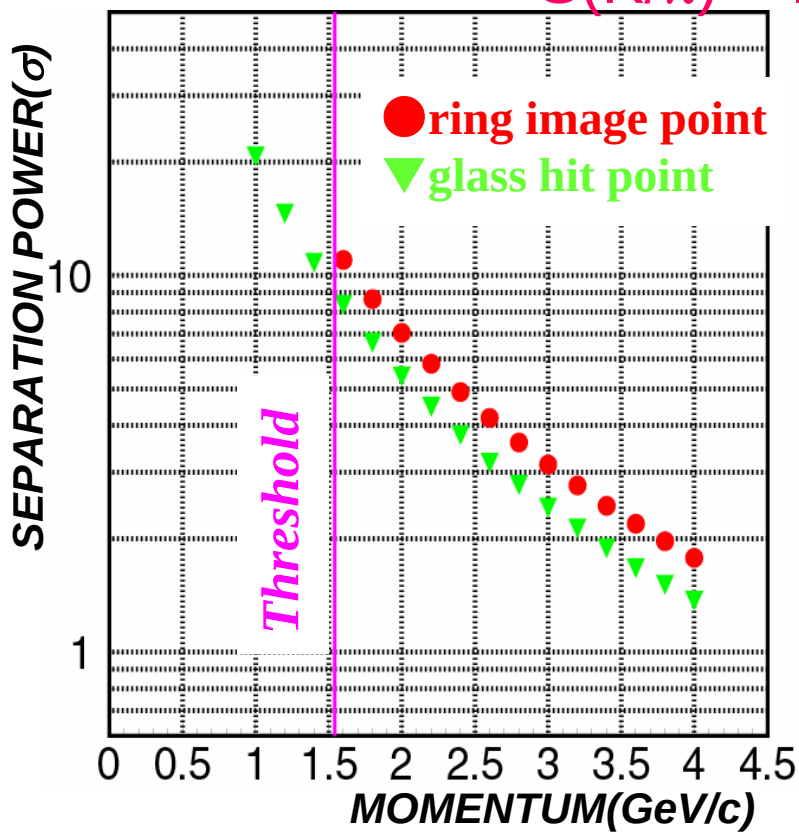


K/π separation by TOF

- Good performance in lower momentum region
- Enable PID under threshold P_c of aerogel



S(K/π) > 10σ



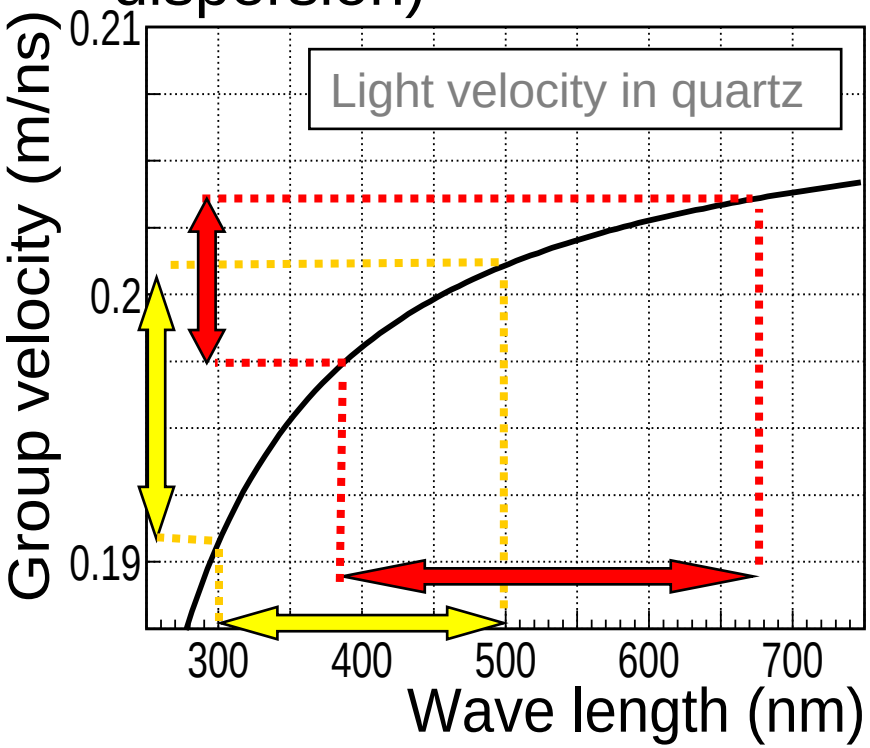
TOP counter MC

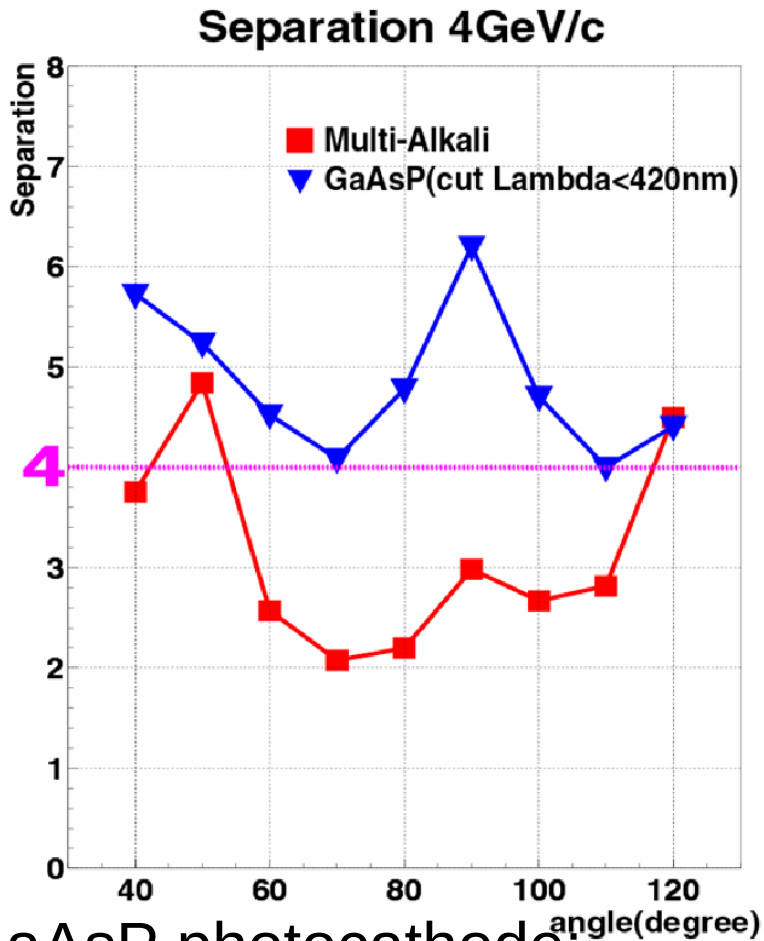
Expected performance

bi-alkali photocathode:

π/K separation at 4GeV/c < 4σ

(because of chromatic dispersion)



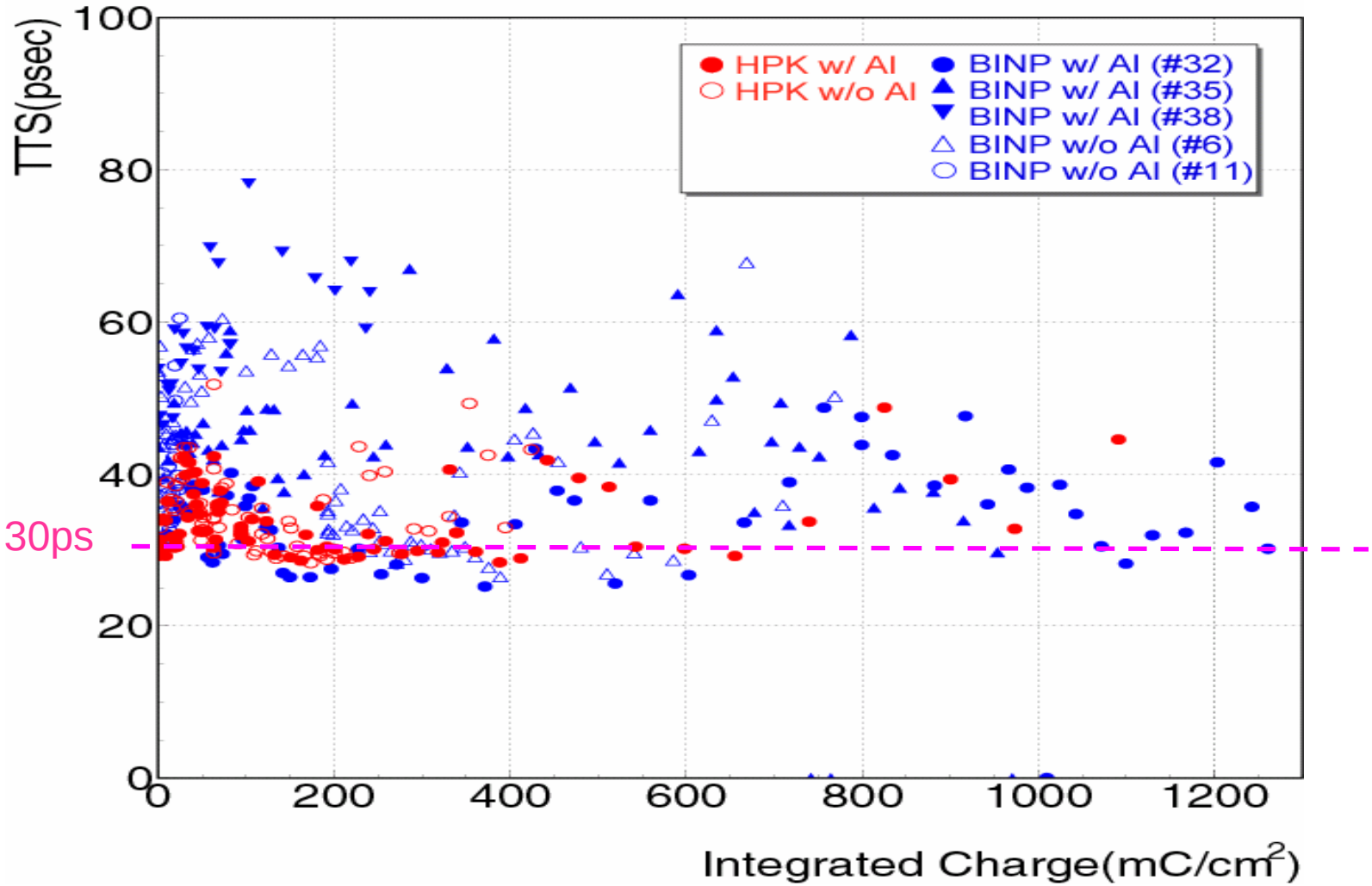


GaAsP photocathode:

π/K separation at 4GeV/c > 4s

less dispersion

TTS

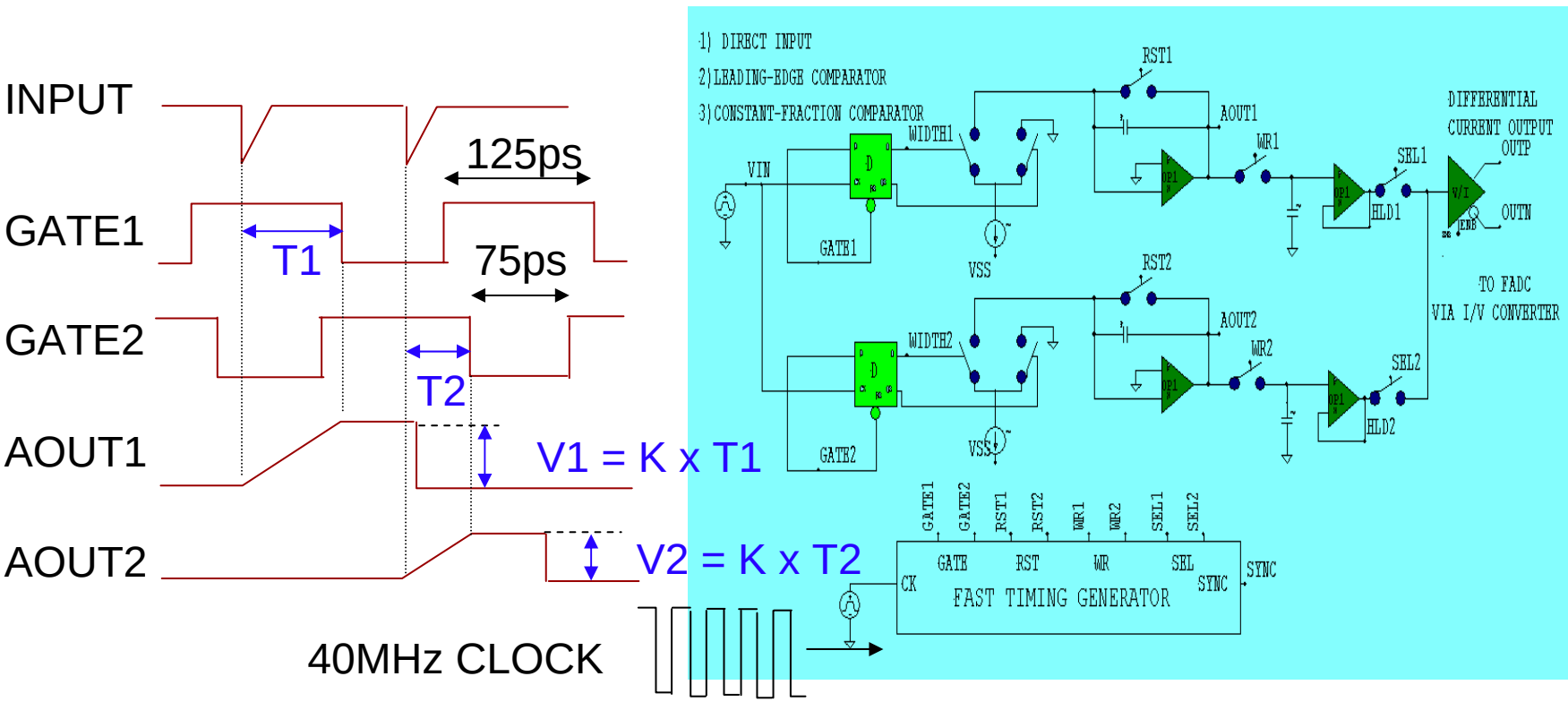

TTS(psec)
100
80
60
40
20
0
0
200
400
600
800
1000
1200
Integrated Charge(mC/cm²)
HPK w/ Al
HPK w/o Al
BINP w/ Al (#32)
BINP w/ Al (#35)
BINP w/ Al (#38)
BINP w/o Al (#6)
BINP w/o Al (#11)
30ps

Cross-talk of MCP-PMT

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

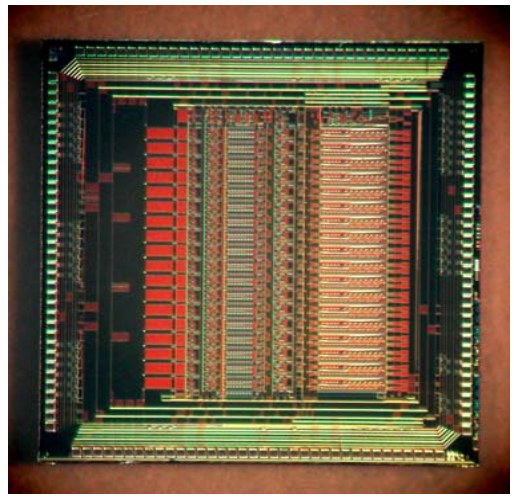
R&D of Readout ASIC for TOP

- Time-to-Analog Converter → Time resolution <~20ps
- Double overlap gates → Less dead time (~100ns)
- 0.35μ CMOS process
- 2nd batch TAC-IC was submitted to VDEC (U. Tokyo)



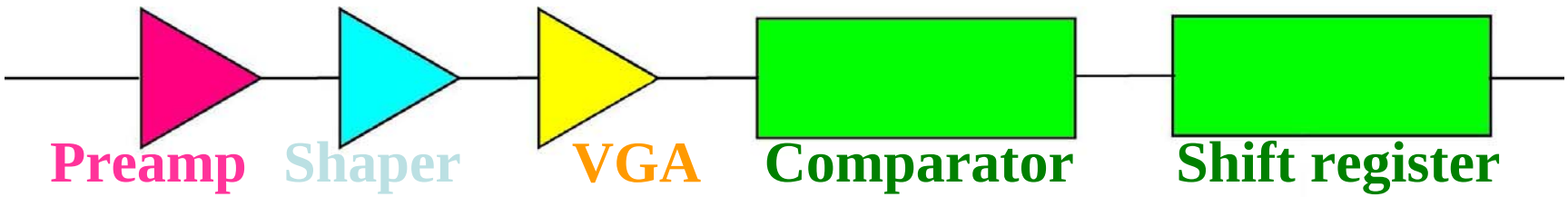
Readout Electronics

- Aerogel RICH readout
  - Total ~ 100k channels!
  - Readout scheme → pipeline
    - ✓ Only record hit information
- Basic parameters for the ASIC
  - CMOS-FET
  - Gain=10V/pc
  - Shaping time=0.15μsec
  - VGA=1.25~20
  - 18 channels/chip
  - Power consumption : 5mW/channel

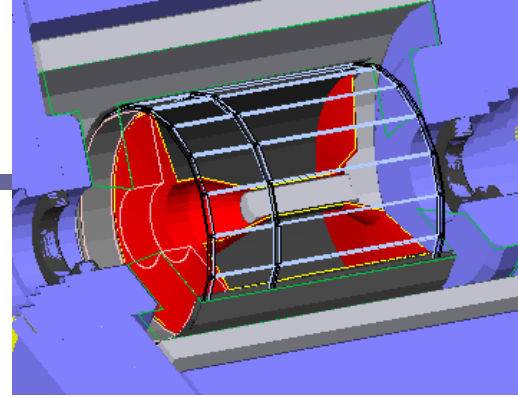


□4.93[mm]

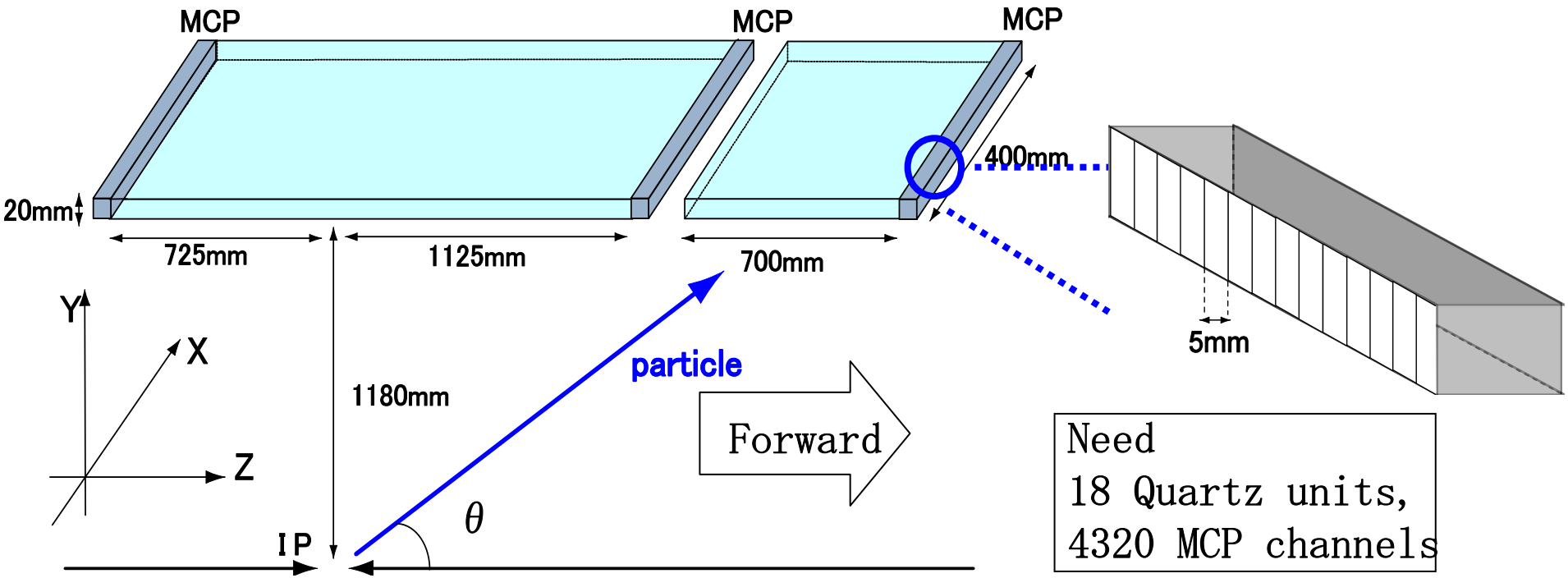
3rd batch was submitted to VDEC (More protection to noise was done)



Design



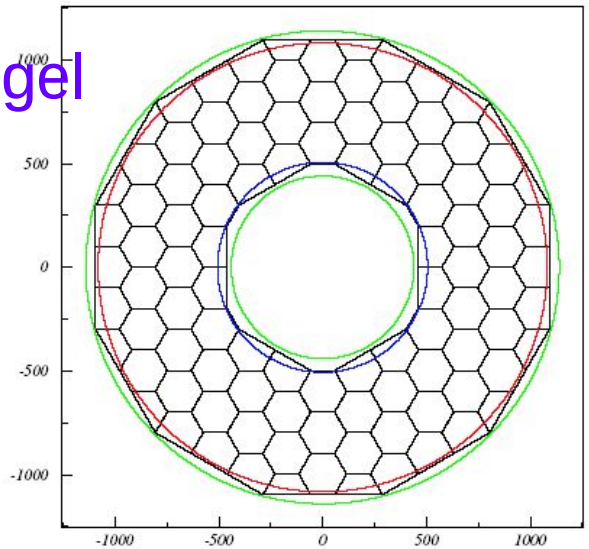
- Quartz: 255cm^{L} x 40cm^{W} x 2cm^{T}
  - cut at θ=46deg. to reduce chromatic error
- Multi-anode MCP-PMT
  - Linear array (5mm pitch), Good time resolution (<~40ps)
  - Three readout plane



Need
18 Quartz units,
4320 MCP channels

Mechanical design

Aerogel



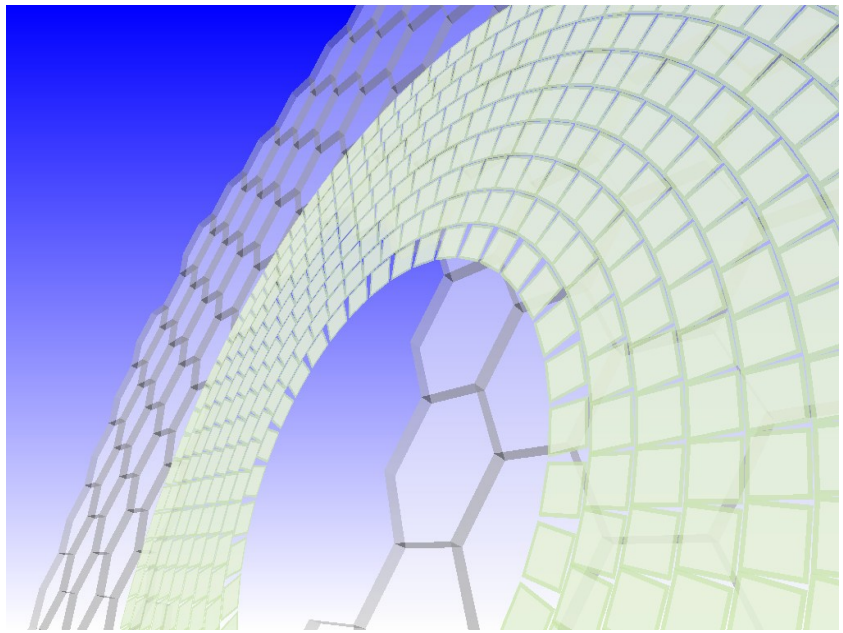
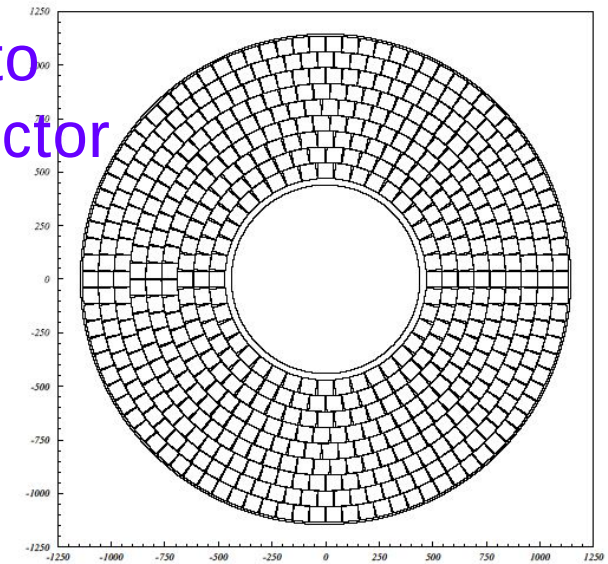


Photo detector



- Aerogel radiator
  - Hexagonal tiling to minimize aerogel boundary
  - side length, 125 mm
- Photo detector
  - Total PD : 564, 6 sectors
  - Cover 89.0% of area

Collaborator

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R.Pestotnik, T.Seki, T.Sumiyoshi, M.Tabata,
Y.Unno