Photodetector for Aerogel RICH

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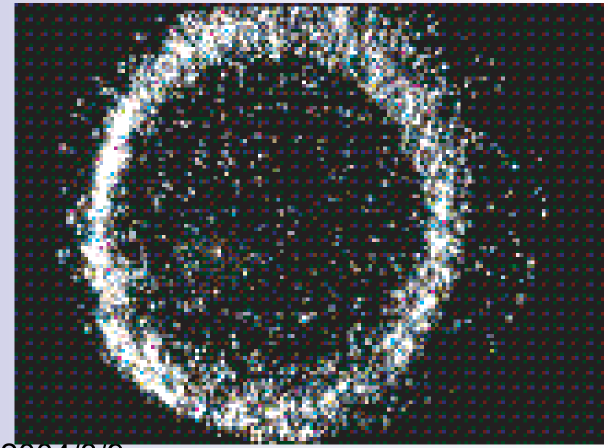

特定領域科研費「質量起源」研究会

March 9, 2004

Collaborators

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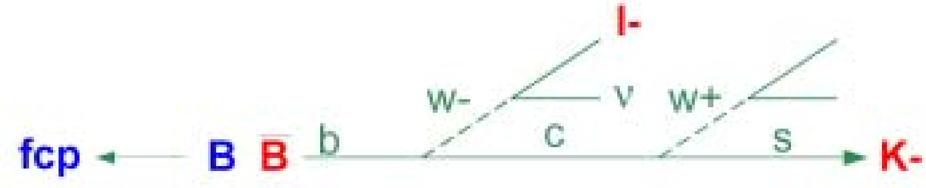
Talk Outline

“Frozen smoke”…

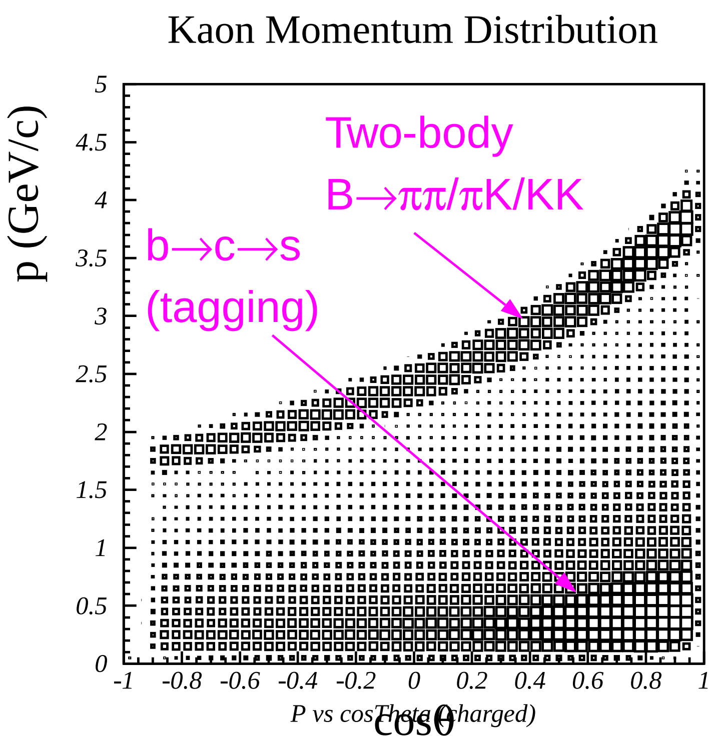
The lightest material in solid form

- Introduction
  - Particle ID in Belle
  - Why Aerogel-RICH ?
- Requirement for Photodetector
- Results w/ Flat Pannel PMT
- Development of Hybrid Photodetector (HPD/HAPD)
- Remarks
- Summary

Particle ID in Belle



- Physics Targets
  - Flavor tagging
  - B→$\pi\pi$/ Kπ/ KK, B→DK/ Dπ
  - Low momentum μ/π at Super-B
    - A_{FB} in B→Kll



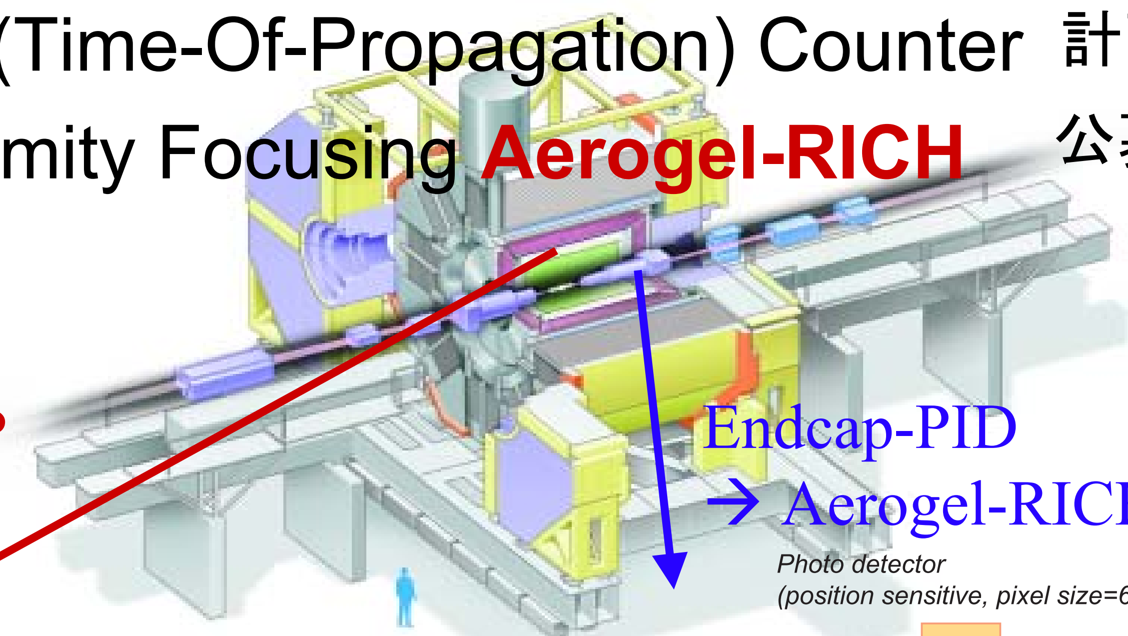
- Present PID
  - dE/dx + TOF + ACC(threshold)
  - Eff.(K→K) ~90% / fake(π→K) ~10%
  - Lack of high momentum PID in the forward endcap
  - (almost) no μ/π for P_T<1.0GeV/c

- Upgrade target = K/π separation for 0.7~4 GeV/c @ >4σ
  (similar μ/π separation for P< 1GeV/c)

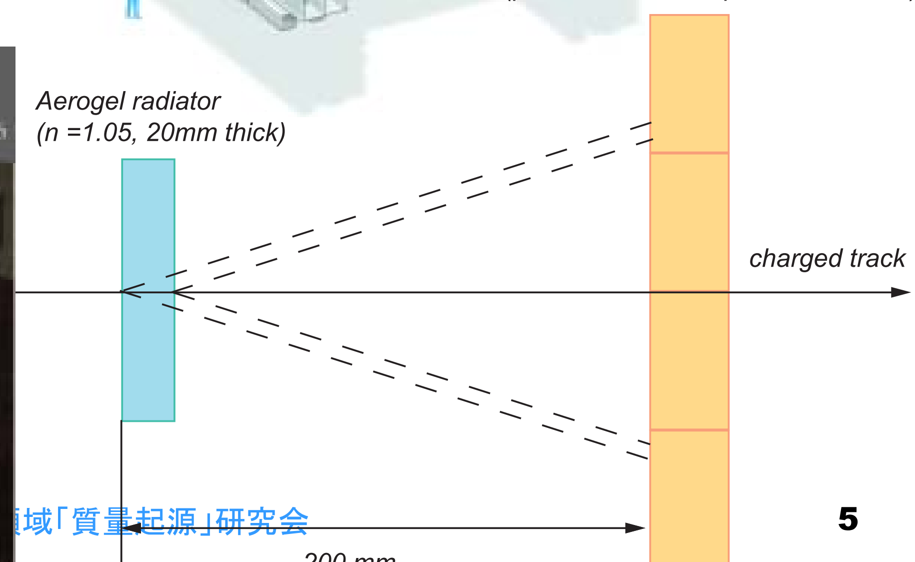
Possible Upgrade Plan

- Barrel→ **TOP** (Time-Of-Propagation) Counter 計画
- Endcap→ Proximity Focusing **Aerogel-RICH** 公募

Barrel PID → TOP



Endcap-PID
→ Aerogel-RICH



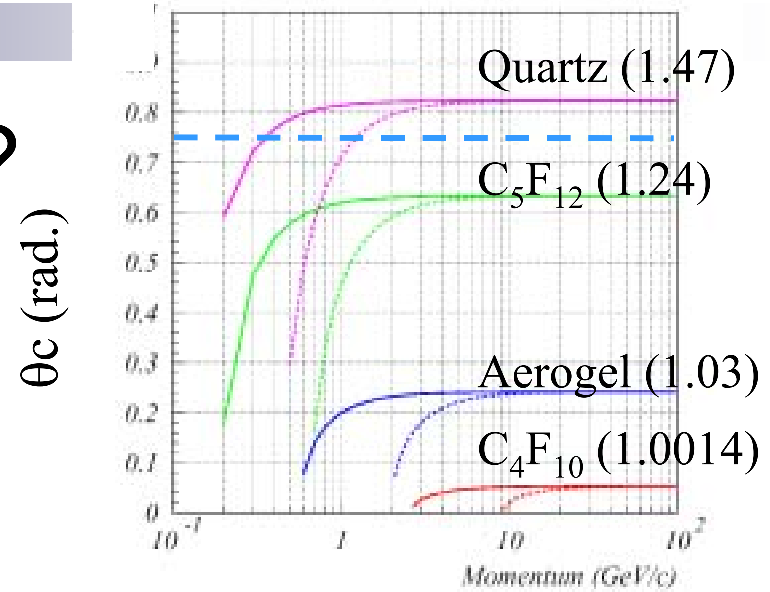
Why Aerogel for RICH?

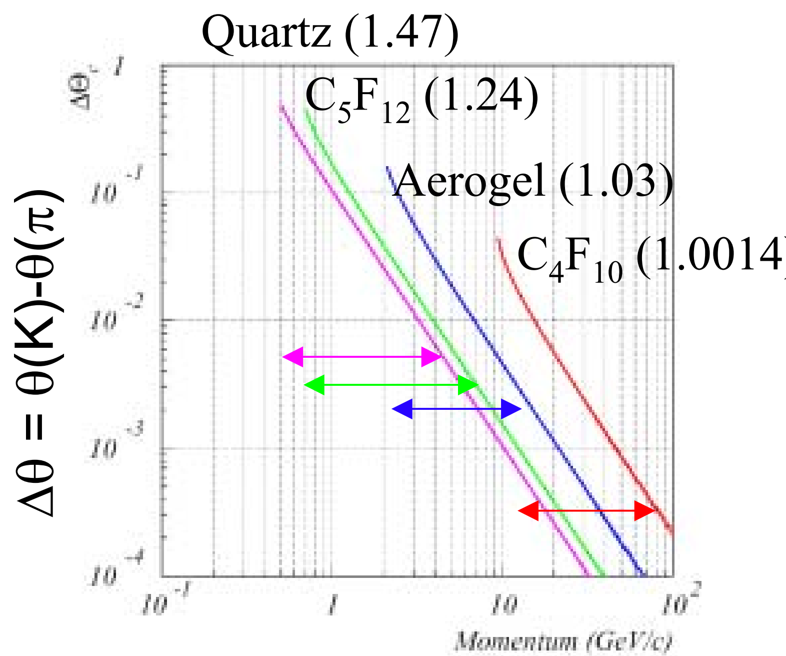
- Less material $\rho \sim 0.1\text{-}0.2\ g/cm^3$
- Compact ring ↔ background
- Large $\Delta\theta_c$ ↔ small chromatic error

Separation power $$S = \frac{\Delta\theta_c}{\sigma_0}\sqrt{N_{pe}}$$

Single photon resolution
- Optics (emission point, mirror, …)
- Pixel size in photodetection
- **Chromatic dispersion**
  - Quartz ~5mr
  - C_5F_{12} (liq.) ~3mr
  - Aerogel ~2mr (※)

※ NIM A457(2001)52





⇨ **Aerogel fills the gap also in RICH application (new trend)**

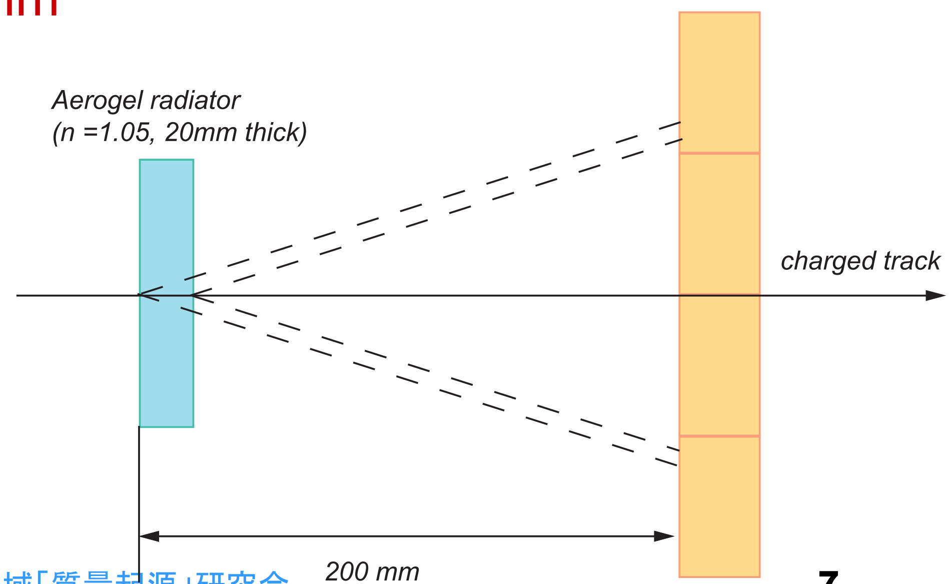
Proximity Focusing Aerogel RICH

- For Belle upgrade in the forward endcap
- $>4\sigma$ K/π for $0.7 < p < 4.5$ GeV/c
- Proximity focusing w/ n =1.05, 2cm.
  - No mirror complex
    → suitable for collider geometry
  - Thin radiator
    → light yield enough ?
- Photodetection in B=1.5T w/ $5\times5mm^2$ granularity. ⇨ HPD (baseline)

- The major R&D items
  - Photodetection in 1.5T
  - Aerogel improvement

Design values

Npe	~7.5
σ_0	11mr
σ(pix)	6.4mr
σ(em)	8.6mr
σ(chr)	2.0mr



Photodetection for Aerogel RICH

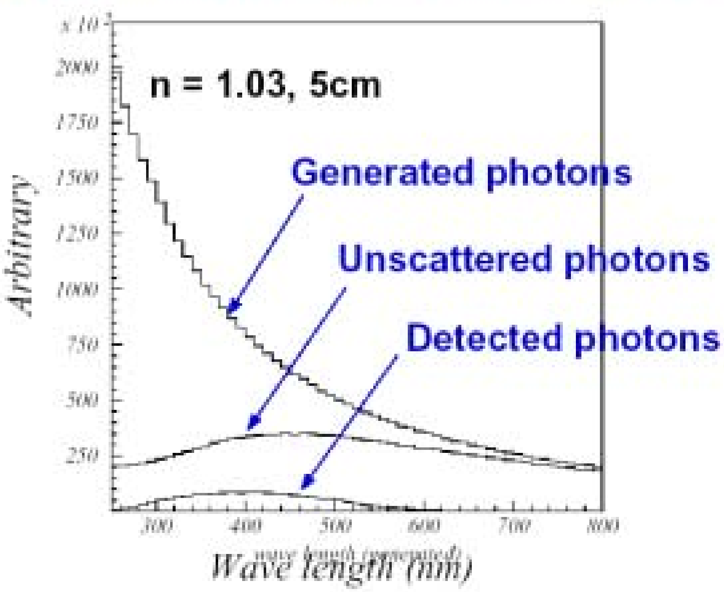
- Rayleigh scattering dominates in aerogel $T = A \cdot e^{-CL/\lambda^4}$

→ Short wave length suppressed.

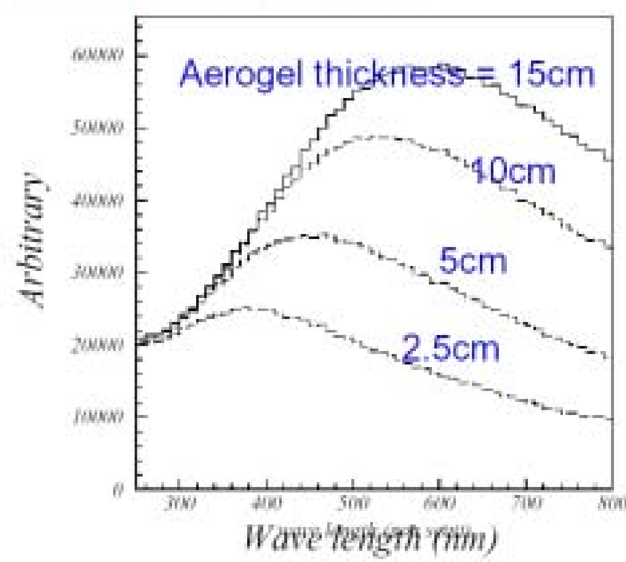
→ Detection in visible wavelength region

→ Vacuum based device w/ bialkali/multialkali photocathode.

- Expected photon spectrum @ each step



- Unscattered photon spectrum for various thickness



Photodetector Requirements

Single photon counting in visible λ region with good

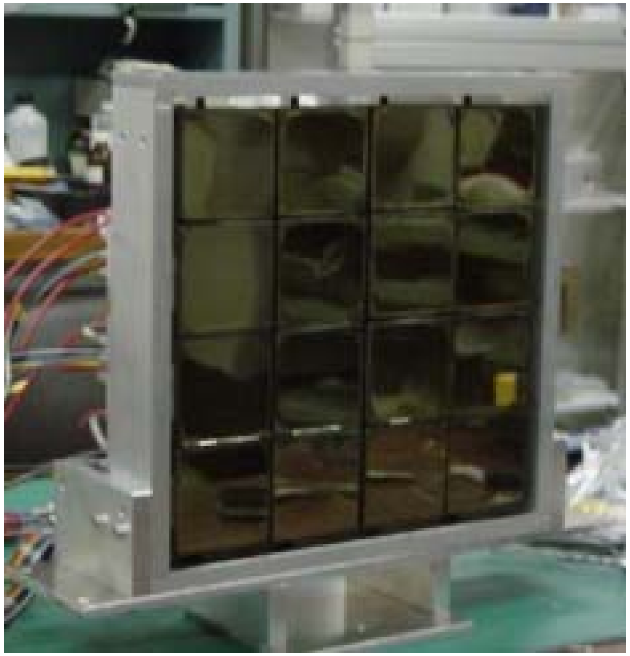
- Position sensitivity ~5mm
- Q.E. x C.E. >20%
- Magnetic field immunity 1.5 T
- Effective area >70%

++ ASIC development to readout many channels. O(10^5)

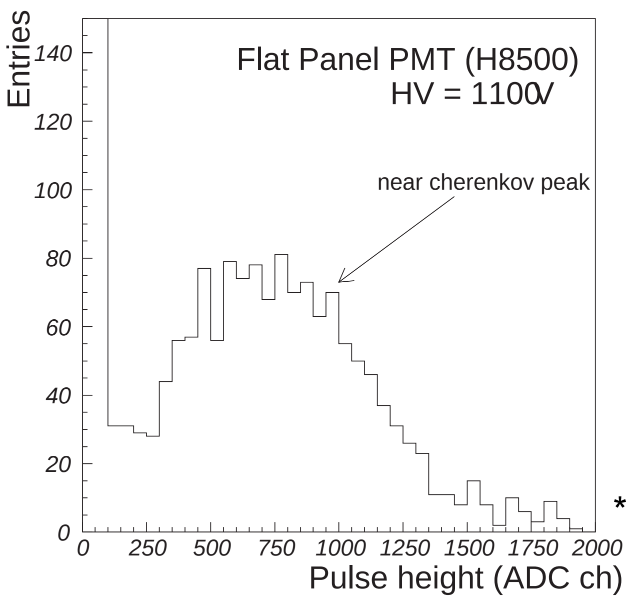
- Hybrid photodetector (HPD) Ideal (probably)
- MCP(micro-channel-plate) PMT C.E.<60%
- Flat Panel PMT don't work in 1.5T

No device on market satisfy the requirement

Flat Panel PMT (HPK H8500)



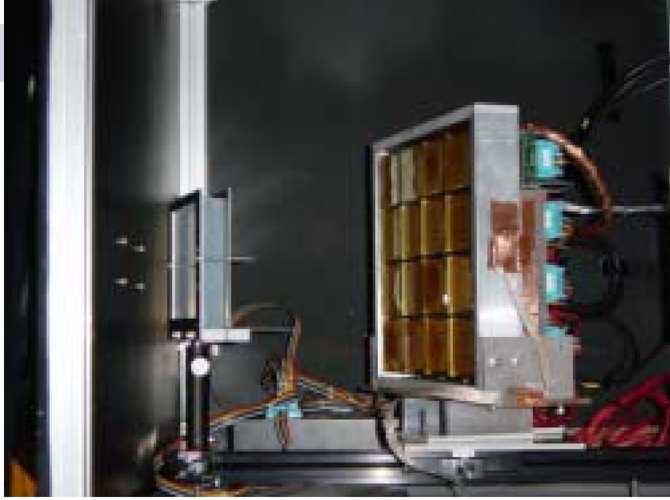
- Large effective area, 84%
  - 64ch (pixel size = 6mmx6mm)
  - aligned with 52.5 mm pitch
- Response for Cherenkov photon



* for the best PMT

- Still under developing…
  →Large variation among 16 PMTs
  - Q.E. : 16~25% (@400nm)
  - Gain : 1~6 x 10^6

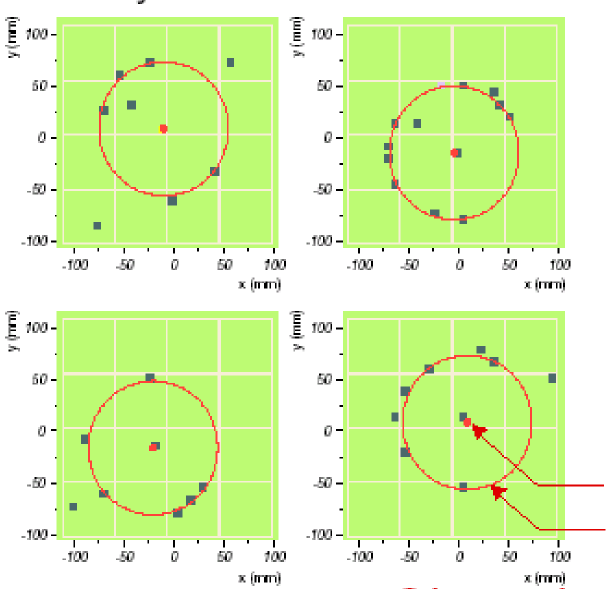
Beam Test w/ Flat Panel PMT



- Demonstration of principle
  - 4×4 array of H8500 (85% effective area)
- σ_0 ~14mr
- Npe ~ 6
  - ~9 if normalized to the best PMT sensitivity

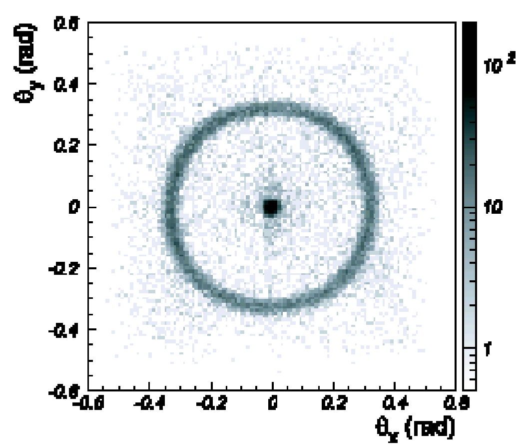
➡ 4σ K/π at 4GeV/c

Event-by-event hit record



Data taken w/ 3GeV/c pions

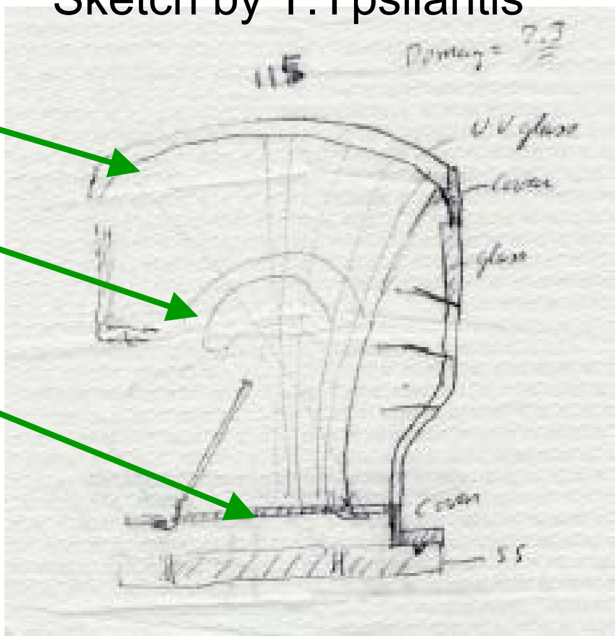
Accumulated hit record



Clear ring images are observed !

Hybrid Photodetector (HPD)

pad-HPD (CERN/LHCb)
Sketch by T.Ypsilantis



- Marriage of vacuum photocathod and silicon device technologies.
- Photoelectrons are accelerated w/ 10-20KV, bombarded on Si and lose its whole energy.
- Create electron-hole pair per 3.6eV loss.

  ⇨ Gain = 3000-5000 / pe

- No multiplicative process

  Much less gain fluctuation for each photoelectron. ⇔ Conventional PMT

- Geometry: Electrostatic / proximity focusing

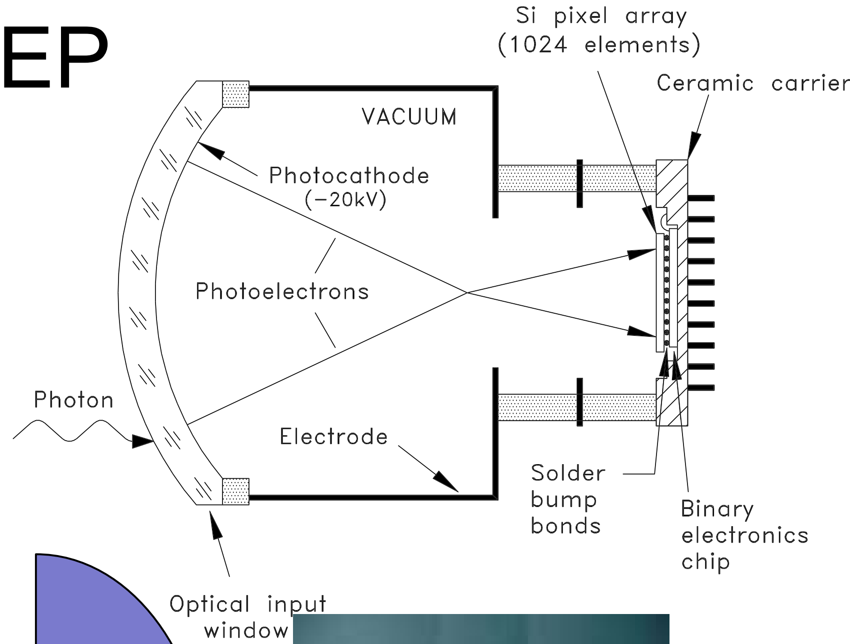
  ↳ Operate in B field

- Sensor: PD / APD

  ↳ Additional 10-100 gains

M.Matthias et al,
IEEE2003 NSS-MIC Conf.

cf) Pixel HPD @ LHCb+DEP

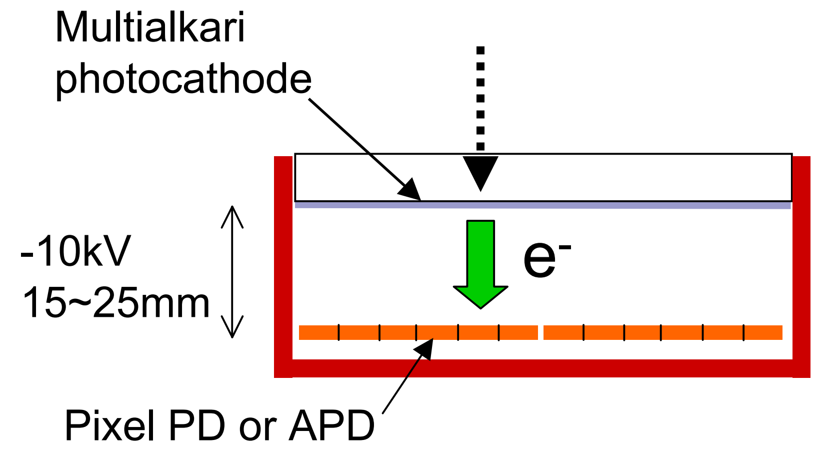


- 80mm ϕ photocathod window
  to cover 70% of 2.6m^2 total area
- Electron optics
  - 20KV→ 5000 e$^-$ / photon
  - Cross focusing (x5 demagnification)
- 8192 pixels (62.5μmx500μm)
  →1024 super-pixel (0.5mmx0.5mm)
- LHCBPIX1 chip bump-bonded in vacuum

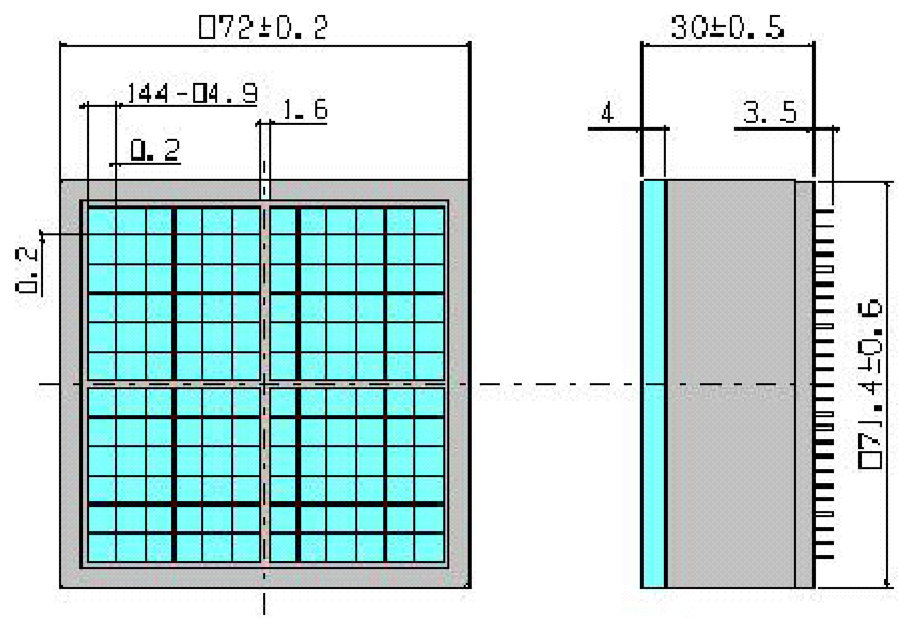
Cannot be used in B field.

Our New Development
12x12 HPD

- Proximity geometry for use in strong B filed
- Large effective area
- Consider both PD/APD options

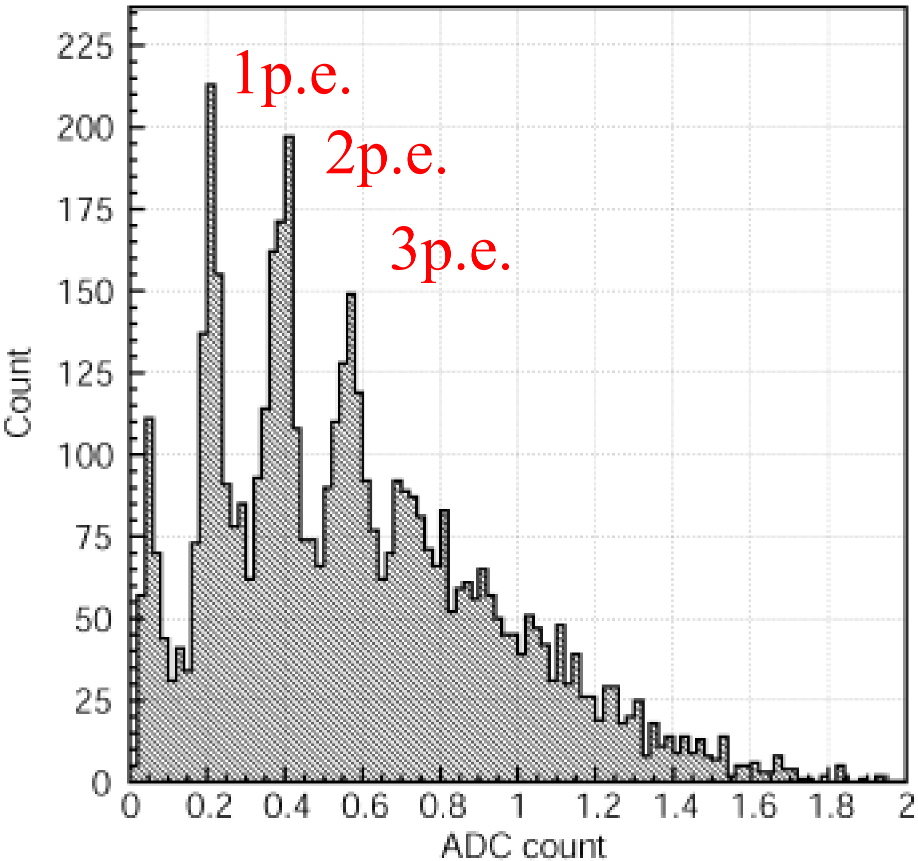


Package	72x72mm^2	
Number of pixels	12x12 (6x6/chip)	
Pixel size	5x5mm^2	
Effective area	64%	
	PD	APD
Gain	2000	20000
Cd	10pF	80pF
I (leak)	10nA	30nA

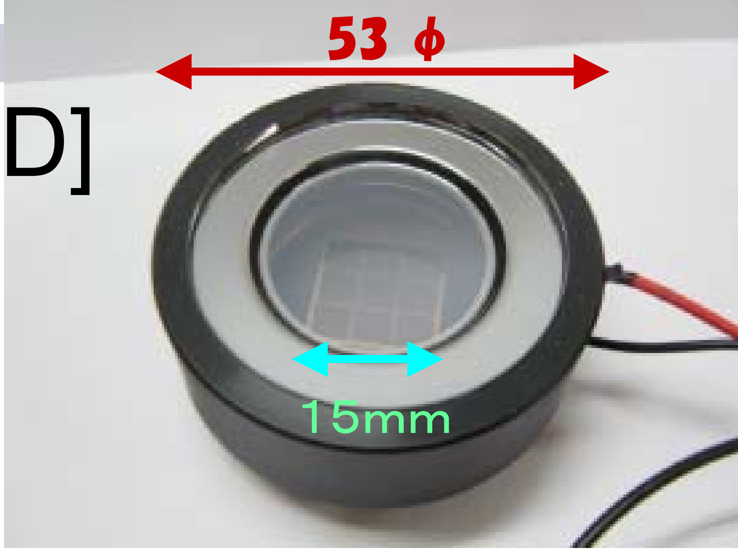


Ptototype Test [Single Channel HPD]

- TO-8 type (sensitive area = ϕ8mm)
- V_{HV} = -8KV
- V_{BIAS} = -80V
- Gain = 1500 e/photon

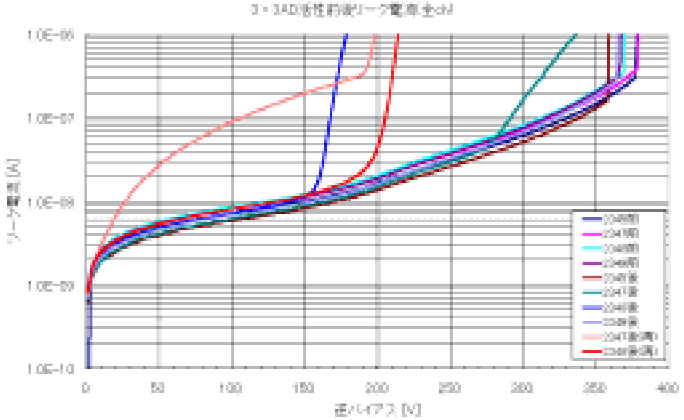


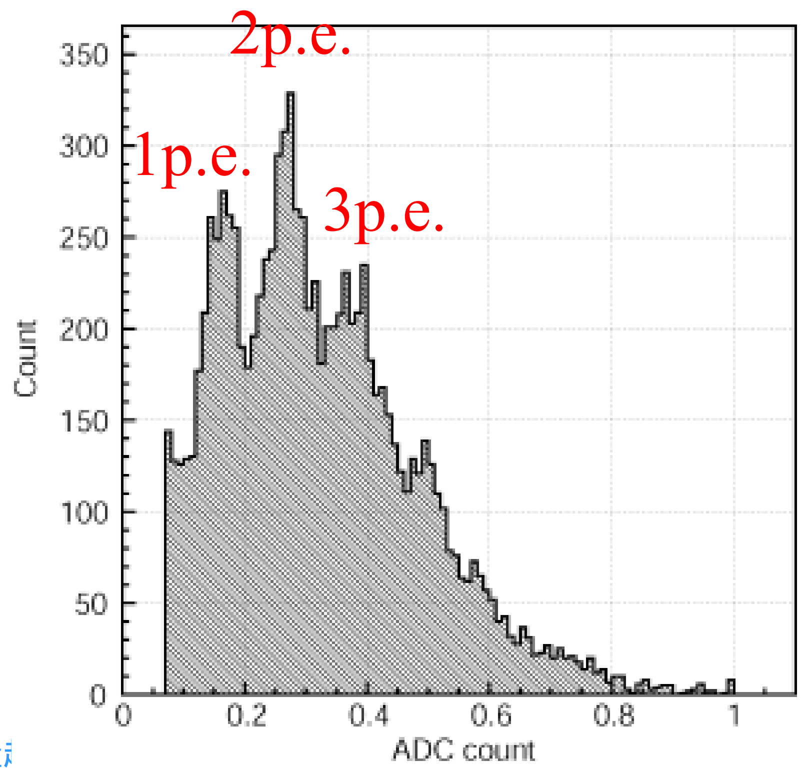
Prototype Test [3x3 HAPD]



- Diode= □5mm/ch
- VHV = -8KV
- VBIAS = 320V
- Gain = 26000 e/photon
- Cd = 73pF / I_L = 14nA
- Surface irradiation type

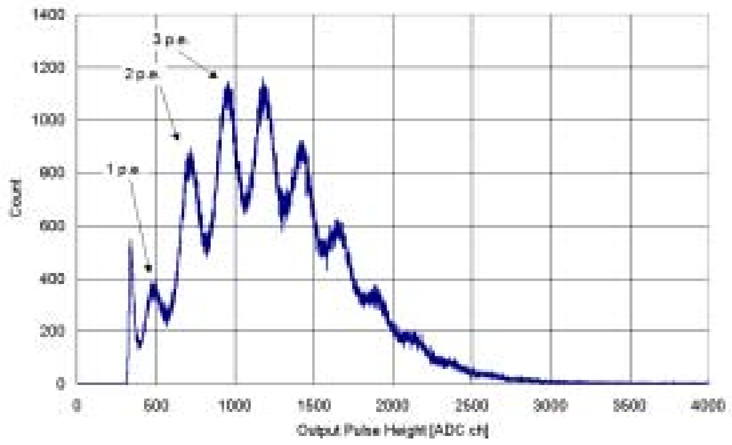
- Larger noise than HPD
- Low yield of APD?



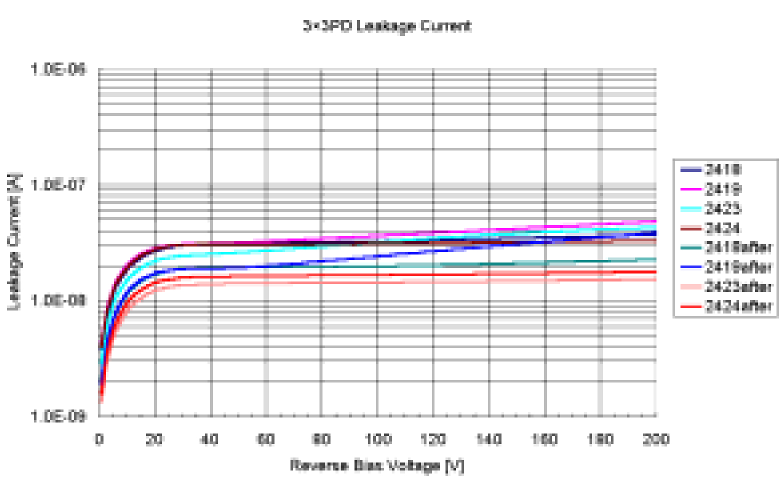


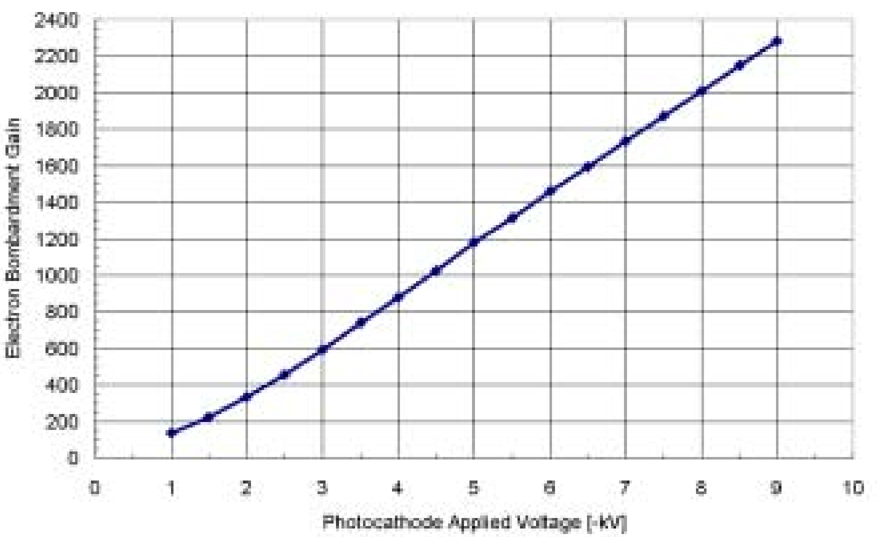
Prototype Test [3 x 3 HPD]

- Photon counting test in progress



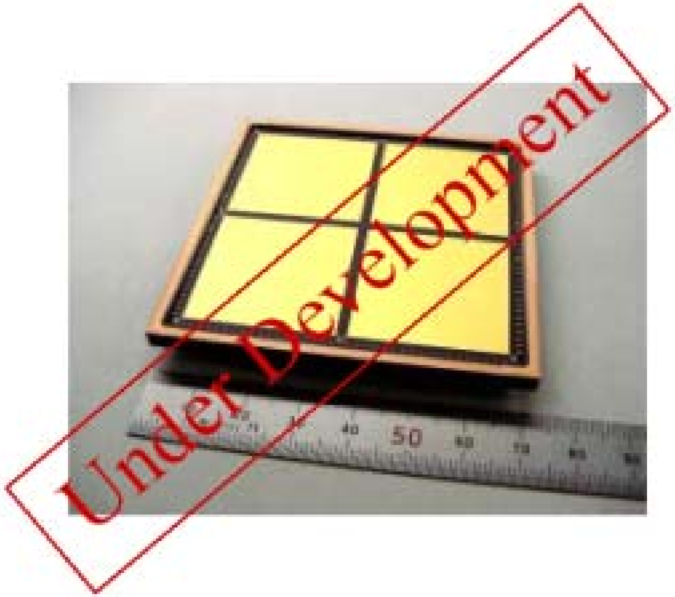
- Back irradiation type
- No serious problem in production
- EB gain = 2100 @ 8KV



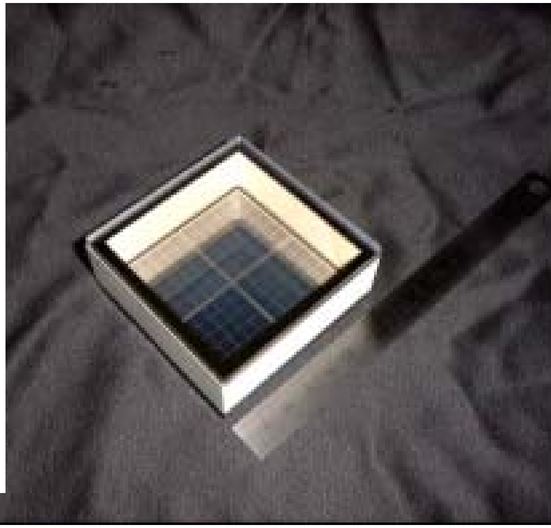


Status of 12x12 H(A)PD

- The bulb part is made of ceramic.
- Vacuum leak test is underway.
- 4x(6x6) HPD/HAPD installed in the ceramic case by a transfer technology.
- The 1st prototype coming soon.



No photocathode
In this sample



Development of Readout ASIC

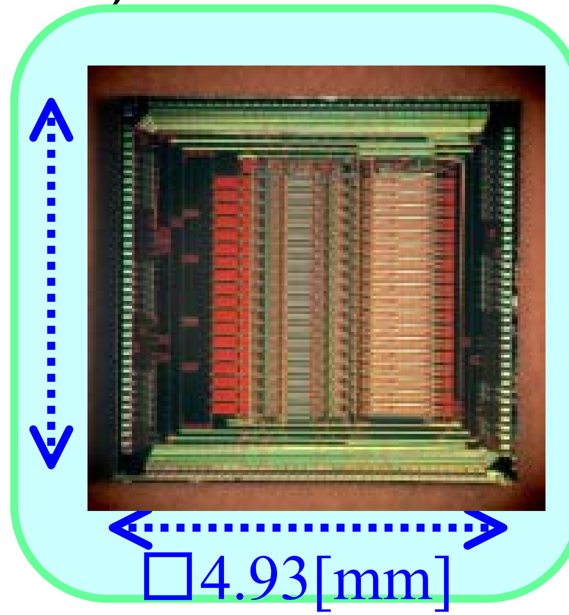
- Total #channel in the real system = 120K
- Photodetector characteristics
  - Gain ~ 2000 (HPD) / 20000(HAPD)
  - Cd ~ 10pF(HPD) / 70pF(HAPD)
  - Leak I ~ 10nA(HPD) / 30nA (HAPD)
- Small space

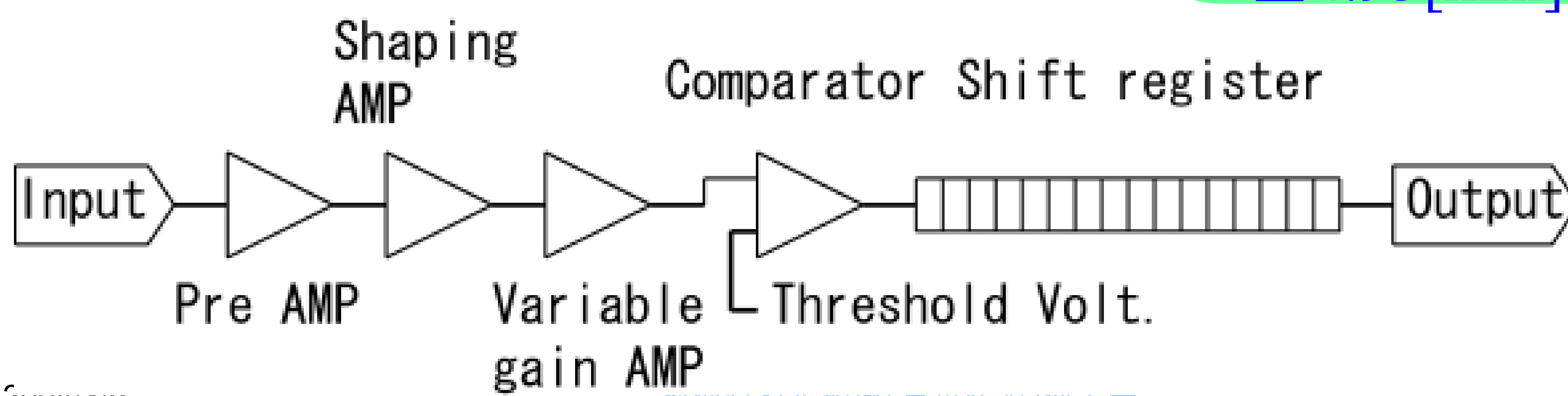
- Need
  - High density front-end electronics
  - High gain w/ low noise amplifiers
  - Deadtime less readout scheme (pipeline)

- ASIC development

ASIC for HPD/HAPD Readout

- Basic parameters (Rohm 0.35μm CMOS)
  - Gain = 5V/pC
  - Shaping time = 0.15μs
  - VGA = 1~16
  - Pipeline readout w/ shift register
  - 18 channels/chip
  - 5mW/channel
- 1st trial at VDEC





Remark: New Optics in Aerogel RICH ? Preliminary

- Is there any way to increase L and hence improve Npe without diminishing σ(emission) ?

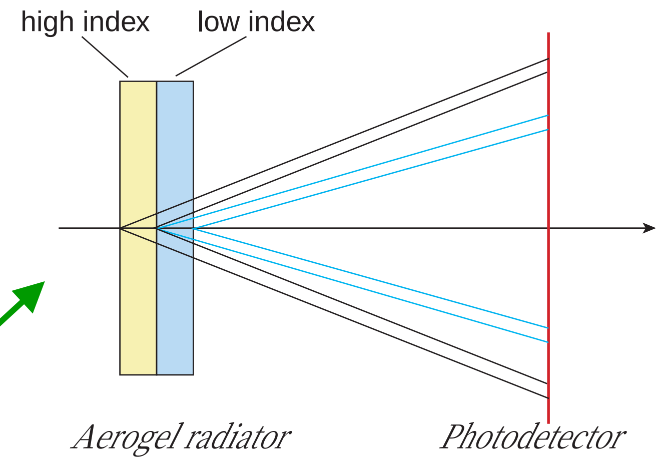
Yes, probably

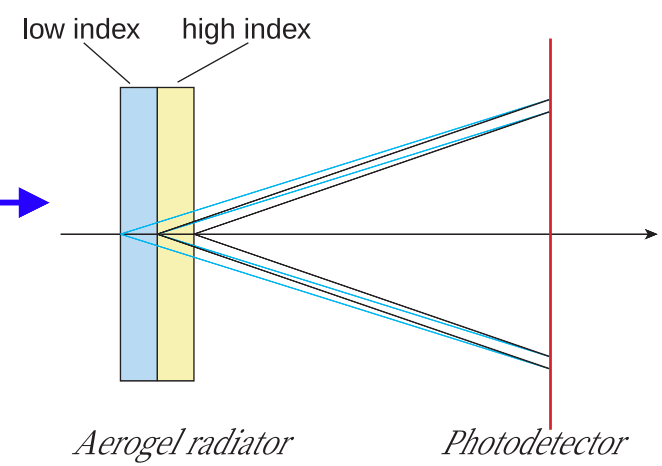
- Aerogel features;

  Index controllable at mixture

  → θc can be chosen at will.

- Idea: stack (more than) 2 aerogel with different indices.
  - **n1>n2 → completely separated rings (velocity measured twice).**
  - **n1<n2 → focusing to compensate the increased thickness.**



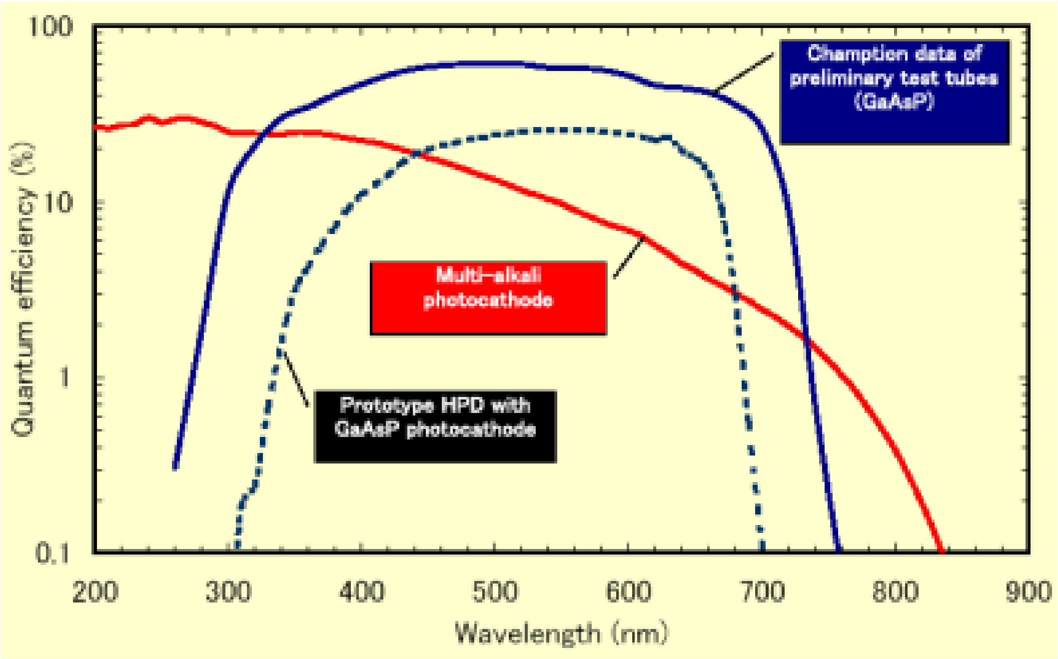


Dual Aerogel RICH !?
Studies are in progress.

Remark: GaAsP Photocathode?

- Sensitive in longer wavelength (<700nm)
  - Lead to less chromatic error
  - Aerogel is more transparent
- QE as high as 40% (or more) at peak

→ compensate N_{pe} loss due to $1/\lambda^2$ dependence.



M.Suyama et al, IEEE2003 NSS-MIC Conf.

Dream in future ?

Summary
開発の歴史

あと、もうちょっと！です。

エアロジェルの改良

特定

基盤

奨励

2003

- HPD

B=1.5T

2002

- Flat Panel Npe~7

Large effective area

2001

- R5900 **Npe~2**

1997

- IIT

Backup Slides

Limitation of RICH

Investigation by P.Glassel [NIM A433(1999)17]

- Pmin limited by the decrease in N/N_{max}
- Chromatic error dominates @ P_{max}
- P_{max}/P_{min} = 4~7
  Need two/three radiators to cover wide region.
- Aerogel fill the gap also in RICH application.

Table 3
Examples for chromatic aberration limits

Radiator	LiF	C_6F_{14}	C_5F_{12}	N_2	He
L	1 cm	1 cm	0.5 m	2 m	10 m
γ_t	1.35	1.62	16	41	120
Bandwidth (eV)	6–7.7	6–7.3	5.5–7.7	5.5–7.7	5.5–10
$\sigma_n = \Delta n/\sqrt{18}$	0.009	0.0028	30×10^{-6}	12×10^{-6}	5×10^{-6}
σ_{θ_c} (mrad)	5.4	2.8	0.45	0.40	0.13
σ_{θ_c} (mrad)	1.8	0.9	0.14	0.13	0.042
Chromatic/msc	5	5	10	30	60
3σ separ. $K\pi$					
p_{max} (GeV/c)	4	7	50	100	330
p_{min} (GeV/c)	0.6	0.88	11	28	83

Chromatic Error in Aerogel

R.De Leo et al., NIM A457 (2001) 52

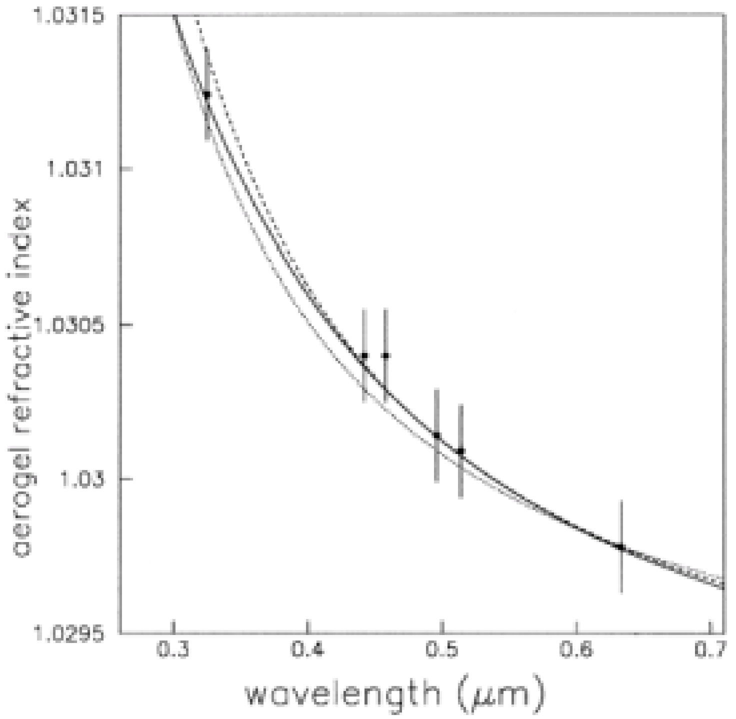
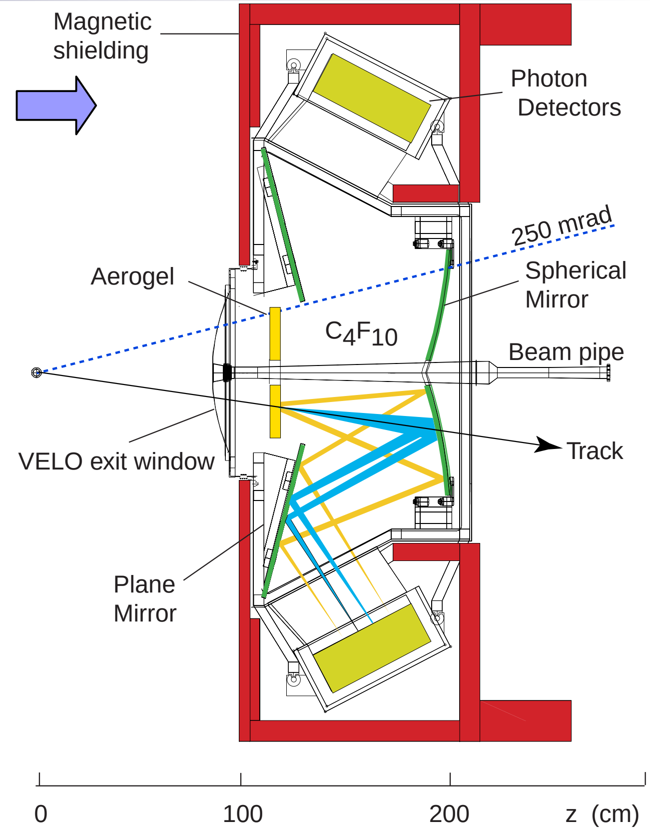


Fig. 2. The refractive index of one Matsushita aerogel tile measured at six wavelengths. The solid, dashed, and dotted lines are fits to the experimental data based on Eqs. 3, 4, and 7, respectively, with calculated values normalized to the experimental value of the refractive index of aerogel at 633 nm.

cf) LHCb RICH

RICH1 →

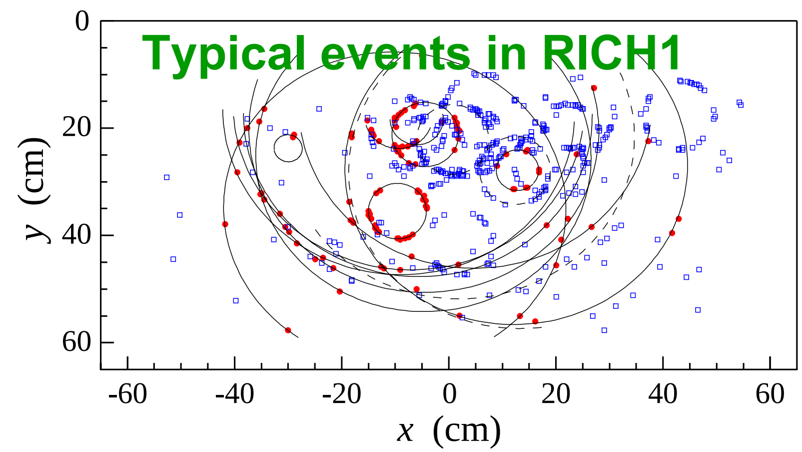


- Three radiators to cover 1~100 GeV/c
- RICH1: Aerogel(n=1.03) 5cm 1-10 GeV/c
  C_4F_{10} (n=1.0014) 80cm 10-60 GeV/c
- RICH2: CF_4 (n=1.0005) 2m -100 GeV/c
- Photodetection by HPD array
  - 2.5×2.5mm granularity, total area = 2.6m^2

Design values

	Aerogel	C_4F_{10}	CF_4
Npe	~7	~31	~23
σ_0	2.0mr	1.3mr	0.6mr
σ(pix)	0.6mr	0.6mr	0.2mr
σ(opt)	0.3mr	0.7mr	0.3mr
σ(chr)	1.6mr	0.8mr	0.4mr

→ 10σ K/π for 10-40 GeV/c
3σ K/π for 30-90 GeV/c



Improved Aerogel by Matsuhita/KEK

- Optimization for n=1.05
  - n=1.01~1.03 range was optimized in the Belle construction, but not for n=1.05

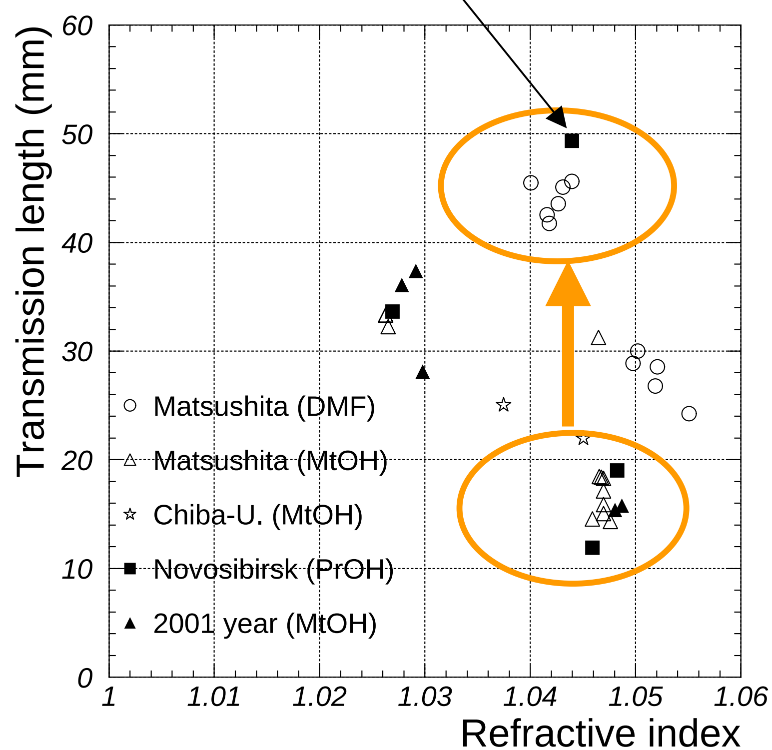
  →Cooperative research with Matsushita Co. Ltd.
- Improvement in transmission length, Λ(@400nm)

  15mm → 45 mm [n=1.05]

Solvent	methyl alcohol →di-methyl-formamide(DMF)
Precurser	Methyl-silicate-51 from different company

Studies are still in progress…

*Novosibirsk's one : hydrophilic



Test w/ Flat Panel PMT

π/K separation

- Measured N_{pe} ~6, σ_θ ~13 mrad give naïve resolution per track: $\sigma_\theta/\mathrm{sqrt}(N_{pe})$ ~ 5.3 mrad

  *contribution from bkg. is small

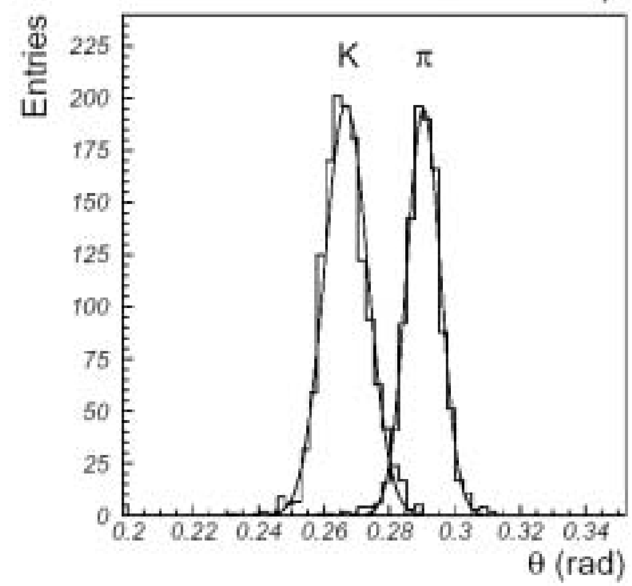
  - π/K sep. @4 GeV/c → ~ 4σ
- N_{pe} is strongly affected by performance* of PMT
  - Normalized N_{pe} with the best PMT →~9

    → better separation is expected in near future

*Q.E and threshold cuts to the pulse height distribution

Cherenkov angle/track for π/(pseudo)K (@ 4 GeV/c)

*Pseudo K →π (1.1 GeV/c)



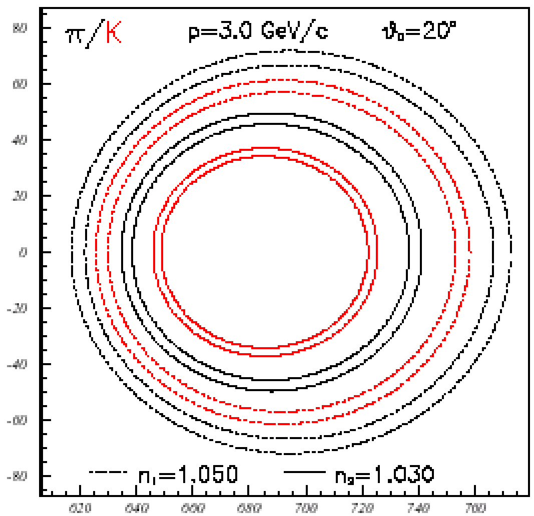
NB. pseudo K has some effect from multiple scattering

Dual Aerogel RICH

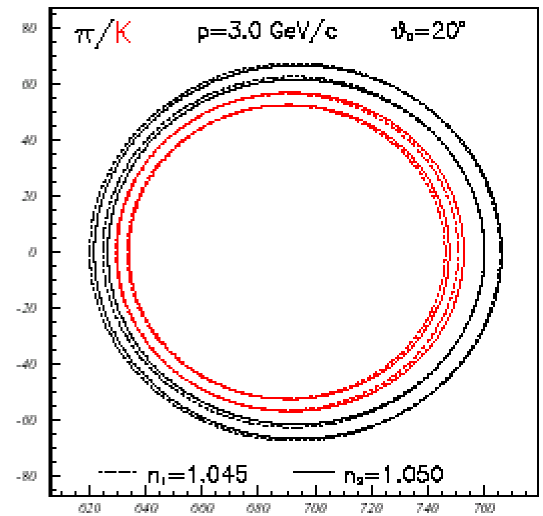
Pion and kaon rings for the two dual radiator shemes

Pion and kaon rings for the two dual radiator shemes

n1>n2



n1<n2

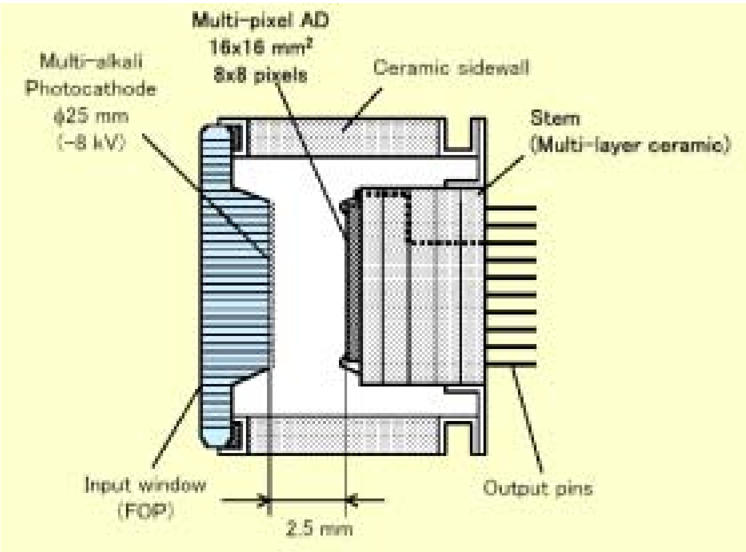


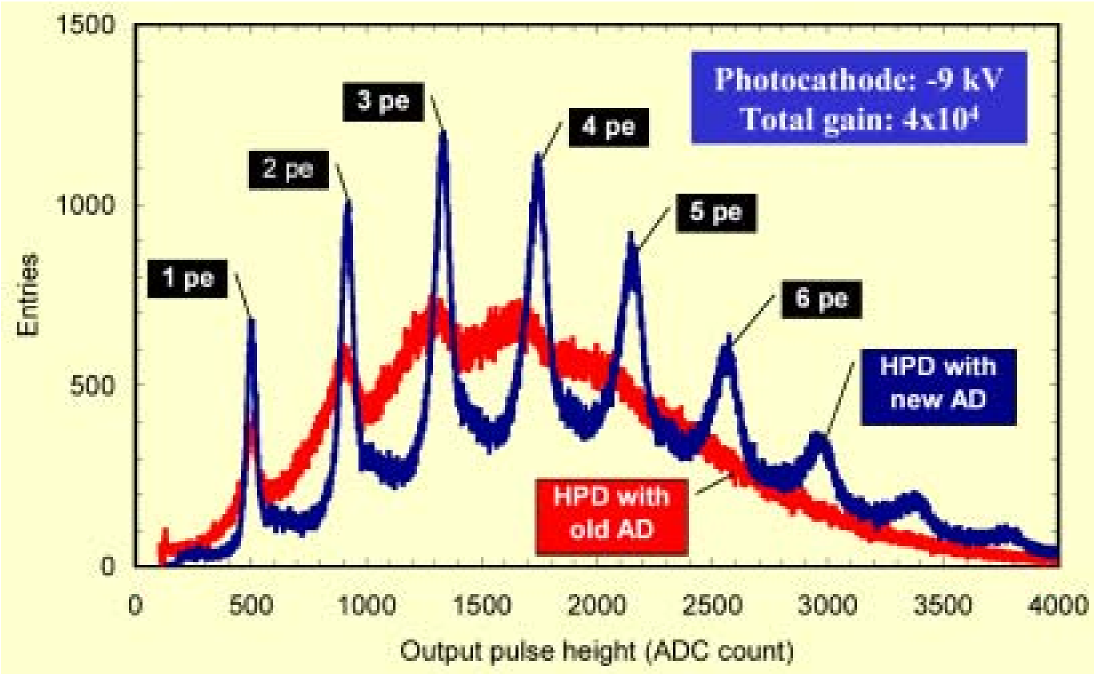
$p=3GeV/c, \theta_i=20^o$

M.Suyama et al,
IEEE2003 NSS-MIC Conf.

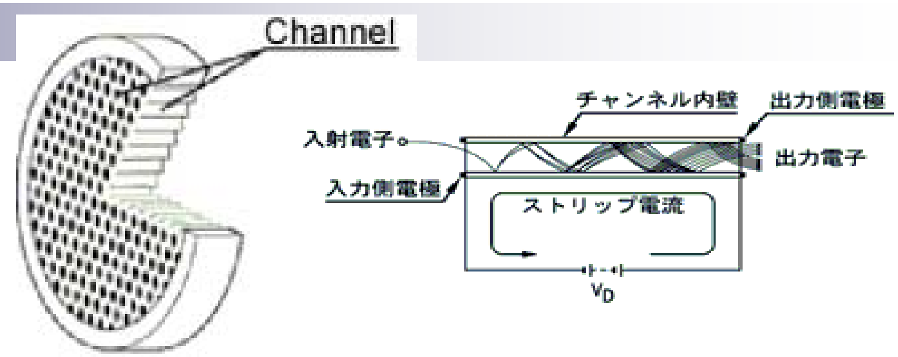
Proximity Focusing HPD R&D by KEK+HPK

- Proximity focused structure for operation in strong B field.
- Acceleration voltage = 8KV
- Avalanche diode
  - 8x8 pixels
  - 2x2 mm2/pixel
- Total gain = 4×10^4





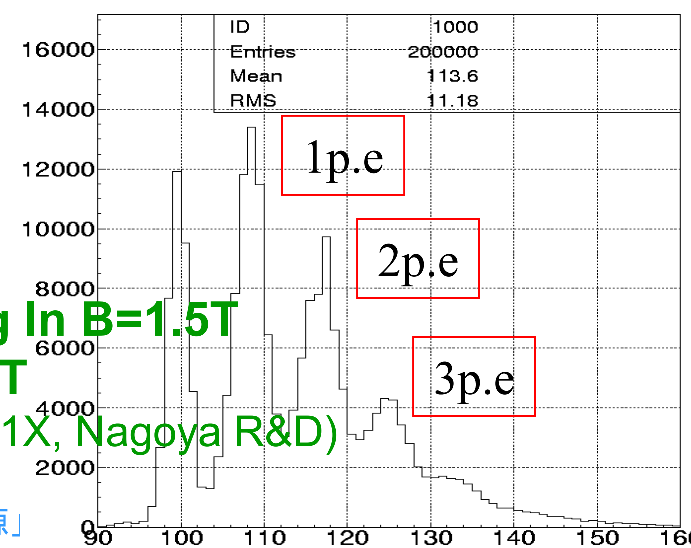
MCP-PMT



- Electron amplification in micro channel (ϕ ~10μm)
  - Fast/small transit time spread
  - Gain saturation
  - B field immunity
- Geometrical apperture ~ 60%

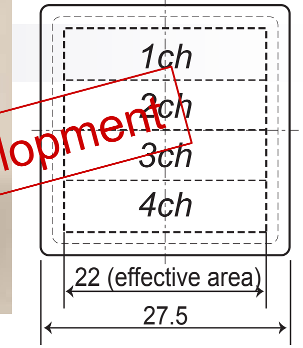
  ※ without Al film at MCP-in
- Gain ~O(10^6) w/ 2-3 stages

- R&D in progress for
  - Focusing DIRC (SLAC)
  - TOP (Belle/ Nagoya)



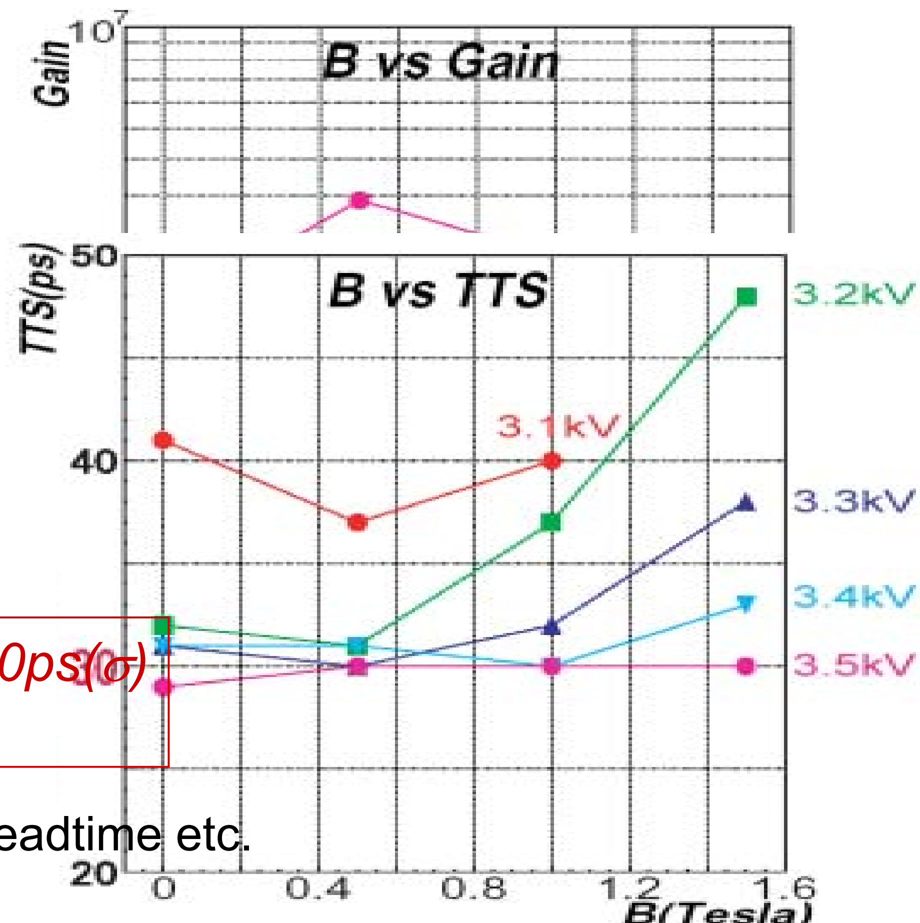
Photon counting In B=1.5T
w/ 6μm MCP-PMT
(HPK R3809-U50-11X, Nagoya R&D)

HPK MCP-PMT R&D at Nagoya



- 1x4 linear-anode MCP-PMT newly developed for TOP readout.

#MCP stage	2
Gain (HV)	$2x10^6$ (-3.5KV)
MCP hole dia.	10μm
Geometrical collection eff.	50%
#pixel /size	1x4 / 5mmx22mm
Effective area/ Total area	64%



Confirmed gain > 10^6 and TTS = 30ps(σ)
In B=1.5T magnetic field.

※ Remaining issues: cross talk, life, deadtime etc.

Test of 1st batch sample

- Linearity (left)
- Channel-by-channel offset variation