PID at Super-KEKB/Belle
&
Aerogel-RICH R&D

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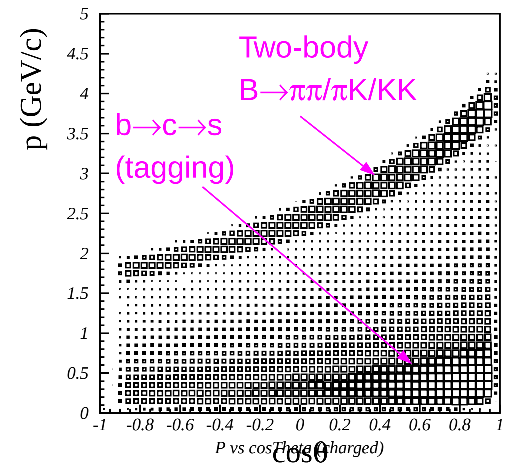
January 30, 2002

2nd Workshop on Higher Luminosity B-Factory

Physics Requirement

- Importance of K/π separation remains unchanged also at the Super-Belle.
  - Flavor tagging (p<2 GeV/c)
    - For any CPV measurement in neutral B.
  - Two-body decays (1.5<p<4GeV/c)
    - B→ππ/Kπ, B→ρπ(πππ) / Kππ
    - B→DK/Dπ
    - Others: η'π/η'K etc.

Kaon Momentum Distribution



- Increased demand at the Super KEKB/Belle
  - b→dγ/b→sγ (required reduction ~50?)

Good separation in inclusive measurements (multiple tracks)

  - Full reconstruction tag (efficiency/purity)
  - How about τ / charm ?

Large impact of improved PID

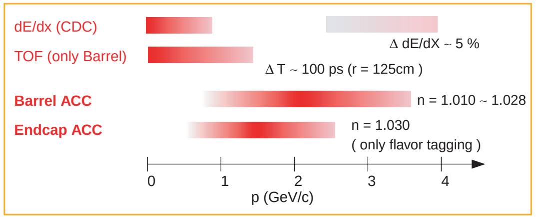
- ++ low momentum e/μ–π separation (< 1 GeV/c)
  + low momentum e/μ–π separation (< 1 GeV/c)
  - B→K(*)ll (b →sll) (especially in μ channel)

Good K/π < 5 GeV/c ⇒ good μ/π < 1 GeV/c

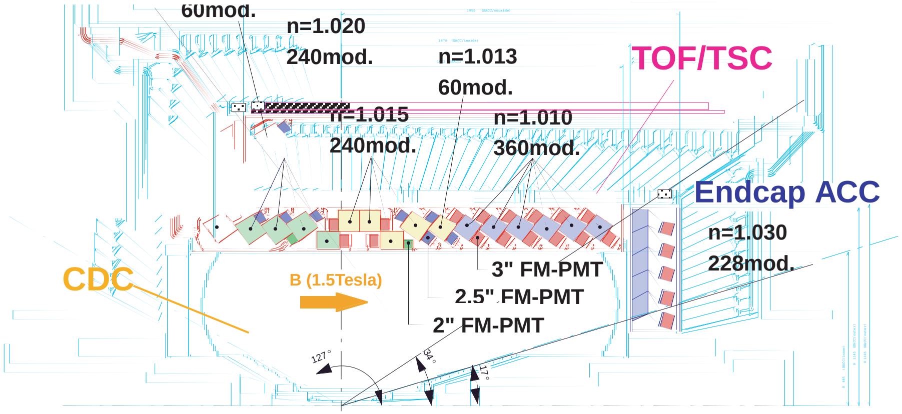
Present Belle-PID

Combination of dE/dx + ToF + ACC

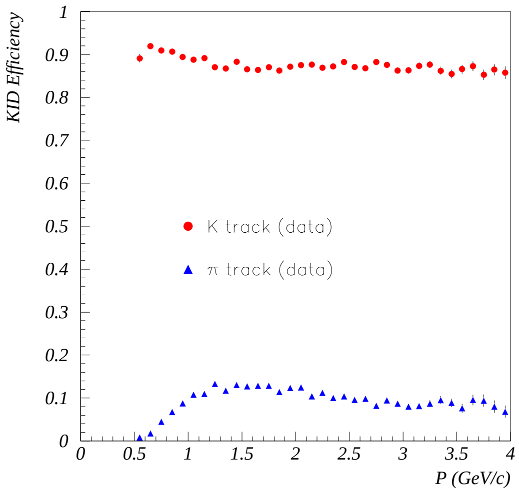
- Performance
  - eff.=88%/fake=8.5%.



- Concerns:
  - Background immunity
    - TOF dead time: O(10%)
  - Material thickness
  - Radiation hardness
  - "Particle ID Holes"
    - EACC works only for tagging
    - e/μ-π separation at low momentum

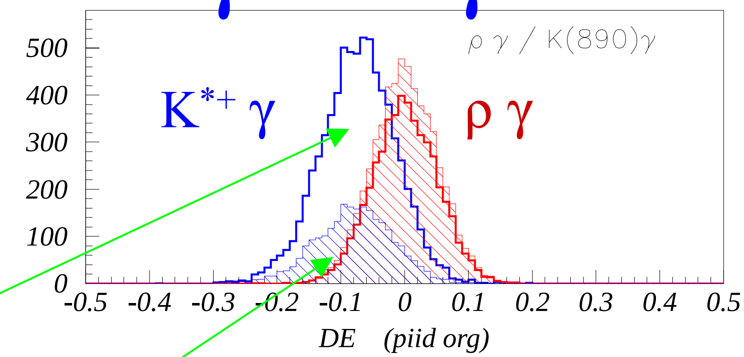


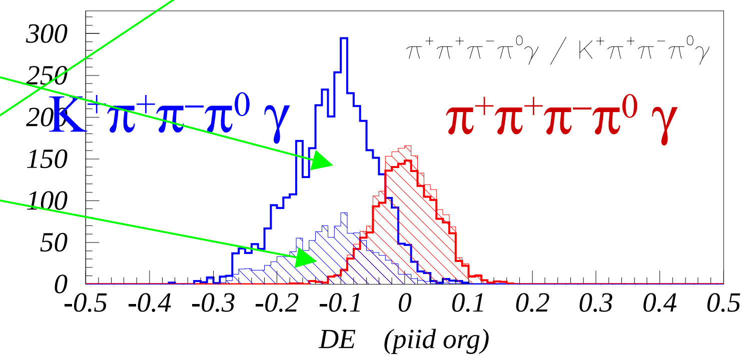
⇒Points of improvement @ upgrade



K/π-ID Impact in b→dγ/b→sγ

- $B^+ \to \rho\gamma / K^{*+}\gamma$ ($\pi^+\pi^-\gamma / K^+\pi^-\gamma$)
- $B^0 \to \pi^+\pi^+\pi^-\pi^0\gamma / K^+\pi^+\pi^-\pi^0\gamma$
- Conditions:
  - Br(sγ) = 20 × Br(dγ)
  - Present eff/fake from data (open histograms)
  - Improved eff/fake = 0.975/0.025
    ~ 4σ separation of two Gaussian (hatched histograms)





	Present	0.95/0.05	0.975/0.025	0.99/0.01
dγ/sγ (2chg)	0.64	1.3 (1.1)	2.3 (1.8)	4.6 (2.6)
dγ/sγ (3chg)	0.45	0.90 (0.78)	1.7 (1.2)	4.2 (1.9)

(): Endcap as it is.

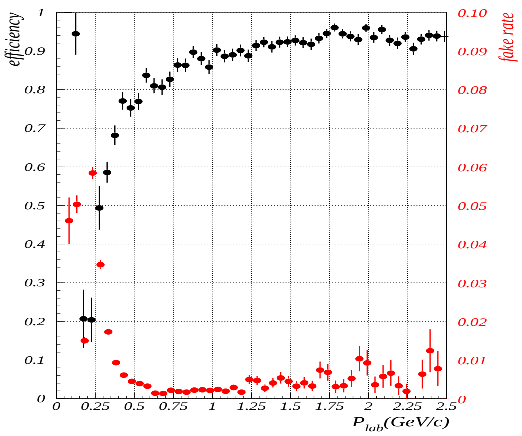
PID w/ good eff/fake and hermeticity is important

Low momentum e/μ–π ID

- Present Belle EID/MUID @ p< 1GeV/c
  - Only weak e-π separation
  - Almost no μ–π separation

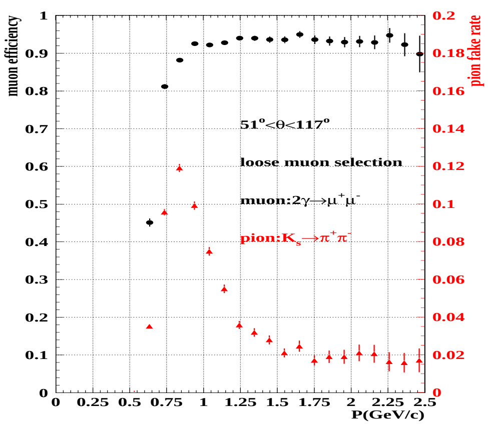
EID : Combination of

CsI E/p
CsI shower shape
track-cluster matching
dE/dx、ACC



Muon ID : Combination of

Range
Matching to track extrapolation of KLM hits

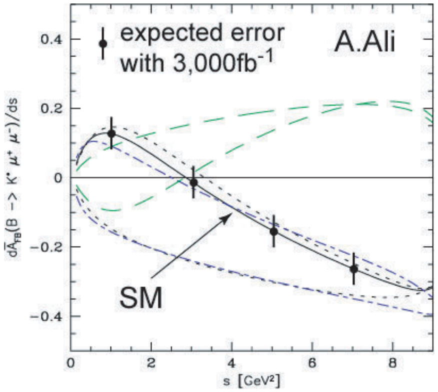


Cherenkov detector having good K/π separation < 5GeV/c will cure e/π and μ/π separation < 1GeV/c.

Lepton/π-ID Impact in b→sll

- Forward-backward asymmetry (AFB)
  - Need to measure AFB as a function of Mll
    May flip sign below and above 1.5GeV

  However,
  - In Kμμ channel, Mll<1.5GeV is difficult
    because (almost) no μ/π separation.

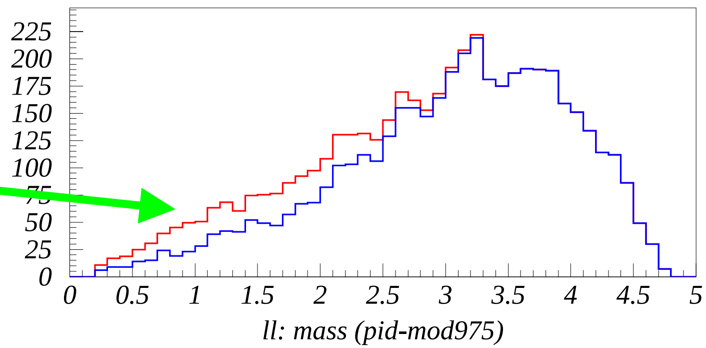


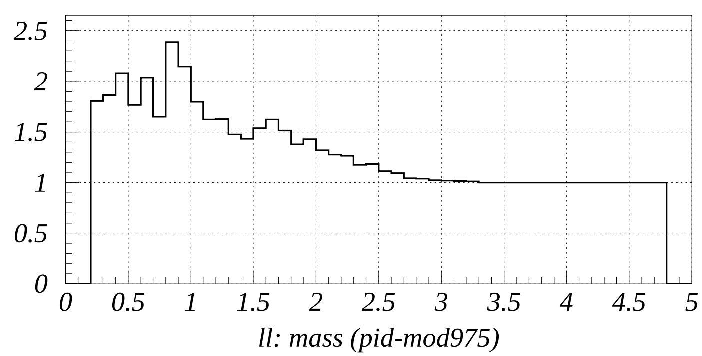
- Present MUID

  + 97.5% @ p<1GeV/c by Cherenkov

  ⇒ ×2 events in Mll < 1 GeV

  ⇒ ×1.5 events in 1 < Mll < 2 GeV





A good Cherenkov detector will give significantly earlier finding of AFB and test of the sign flip.

PID Upgrade Options (I)

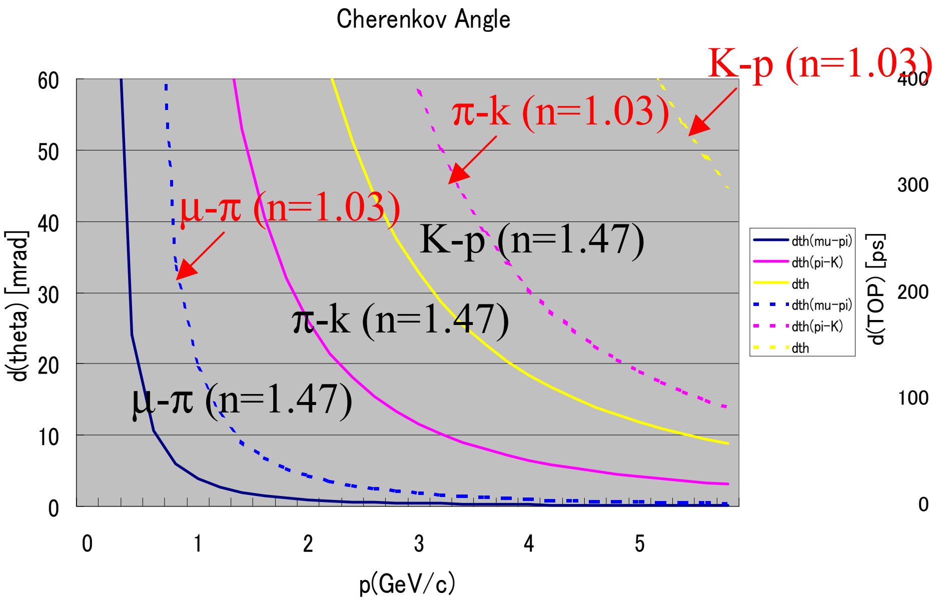
Two R&D's for Ring Imaging Devices

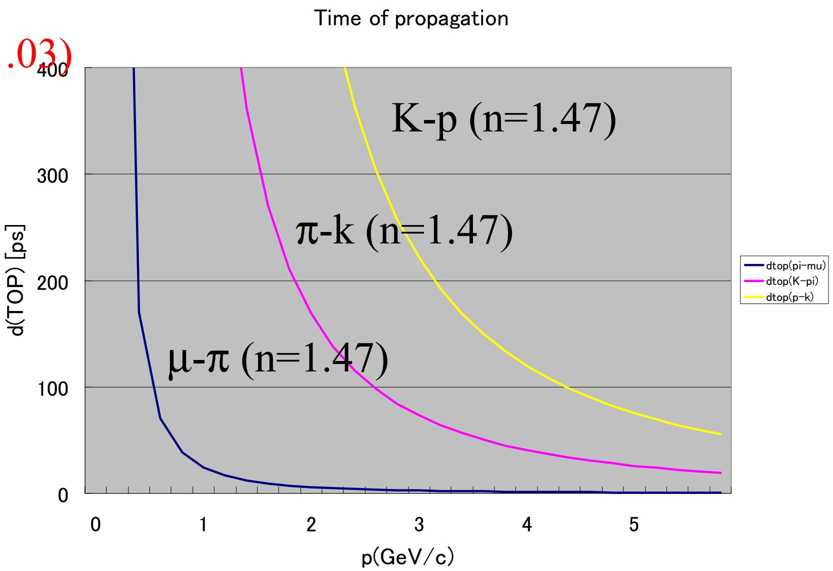
- *TOP counter (Nagoya)*

    Propagation time: $T = L/(c/n)/\sin\theta_c$

- *Proximity-Focusing Aerogel RICH (KEK-Chiba-Slovenia)*

    Cherenkov angle: $\cos\theta_c = 1/n\beta$





Note: π-k separation at 5GeV/c ≒ μ-π separation at 1 GeV/c

PID Upgrade Options (II)

TOP counter

- Measure for each Cherenkov photon:
  - Time-Of-Propagation with <100ps TTS
  - Horizontal emission angle
- High resolution TOF (in a sense)
  - No decay constant in light emission
  - Time measurement for all detected photons

⇒R&D for TOP include all aspects of conventional TOF.

Aerogel-RICH

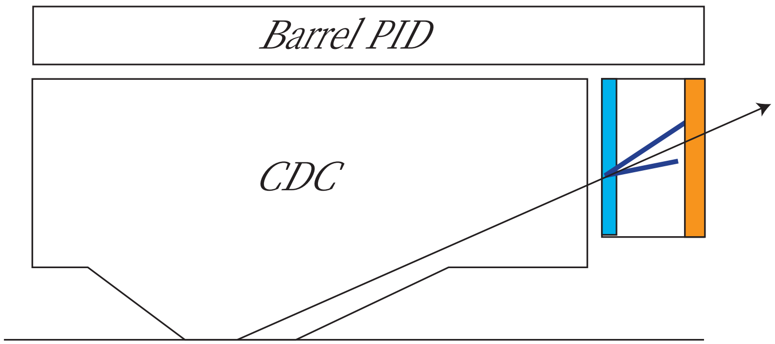
- Utilize the high quality aerogel developed for Belle-ACC
- Large $\Delta\theta c$ than solid(liquid) radiators

  ⇔Light yield is the key issue because of low n.
- Proximity focusing to suit the limited space.

Both requires photodetection (in visible light region) with position sensitivity and high magnetic field immunity.

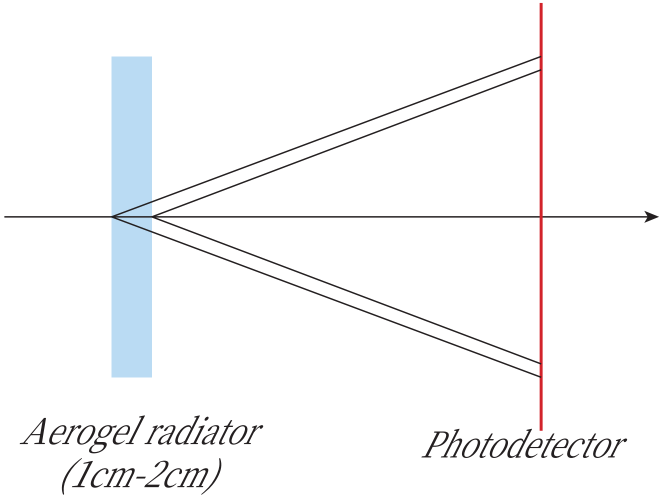
Concept of Aerogel-RICH

- High optical quality of the Belle aerogels
  ⇒RICH w/ aerogel + visible light photodetection
  (New trend!)



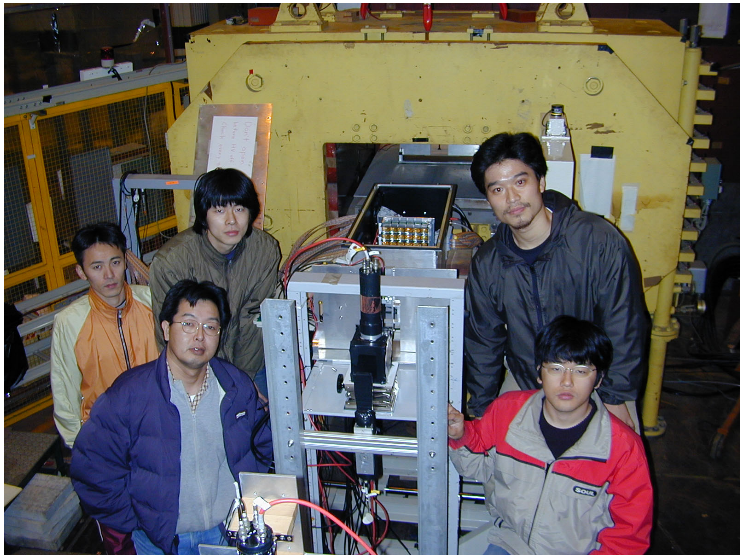
- Proximity focusing scheme
  - Suitable for Belle geometry
  - Aerogel must be thin enough not to deteriorate the angle resolution
  - Light yield is the key issue

- Considered for endcap upgrade
  - Photodetection is difficult for barrel (because of the field direction)
  - Must cover down to 0.8 GeV/c for tagging (dE/dx limit)



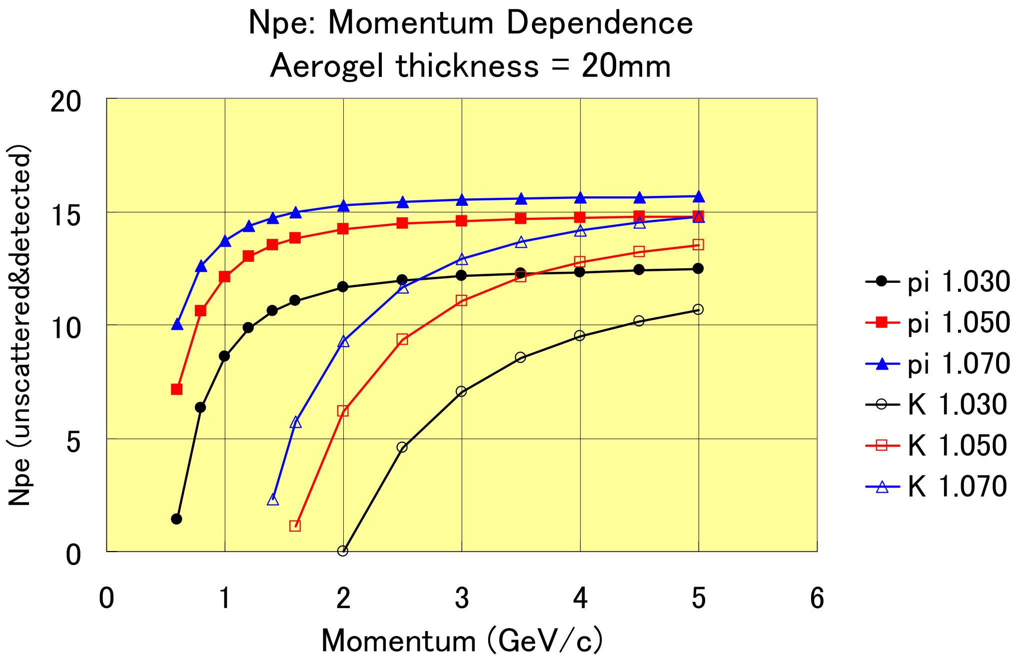
Aerogel RICH: R&D status

- Simulation study by M.Iwamoto (Chiba-U) & T.Iijima
- Cosmic ray tests @ J Stefan Institute: June-Oct, 2001
- First beam test @ KEK-PS (π2): Nov. 25 – Dec.3, 2001
  - Silica aerogel radiator: n=1.029/1.050 (2cm thick)
  - 6×6 Multi-anode PMT array (Hamamatsu R5900-M16)
    - 36% photocathod coverage: □18mm / 30mm pitch
    - lens-based light collection system (HERAB spec.)



Aerogel-RICH: Simulation(I)

- Simulated Npe for unscattered photons.
  - Normal incidence
  - Assume 100% geometrical acceptance for photodetection

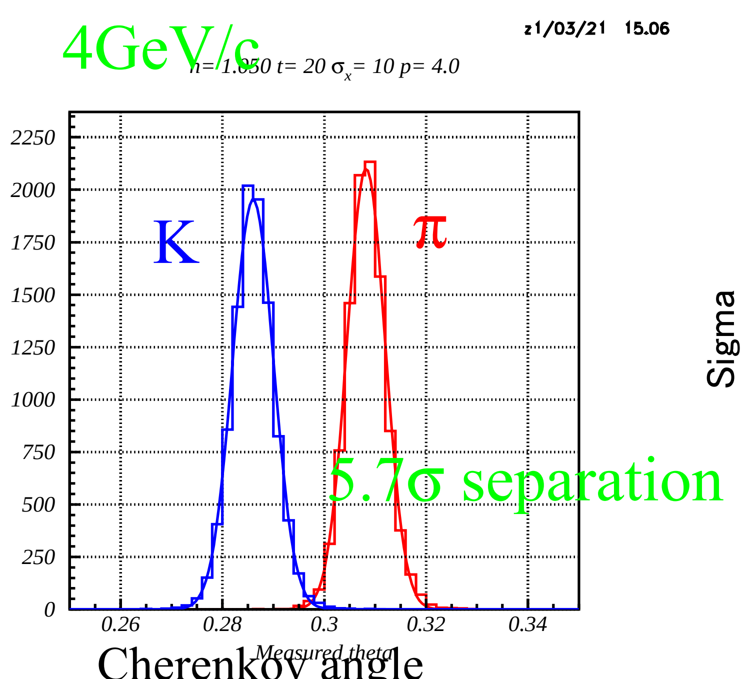


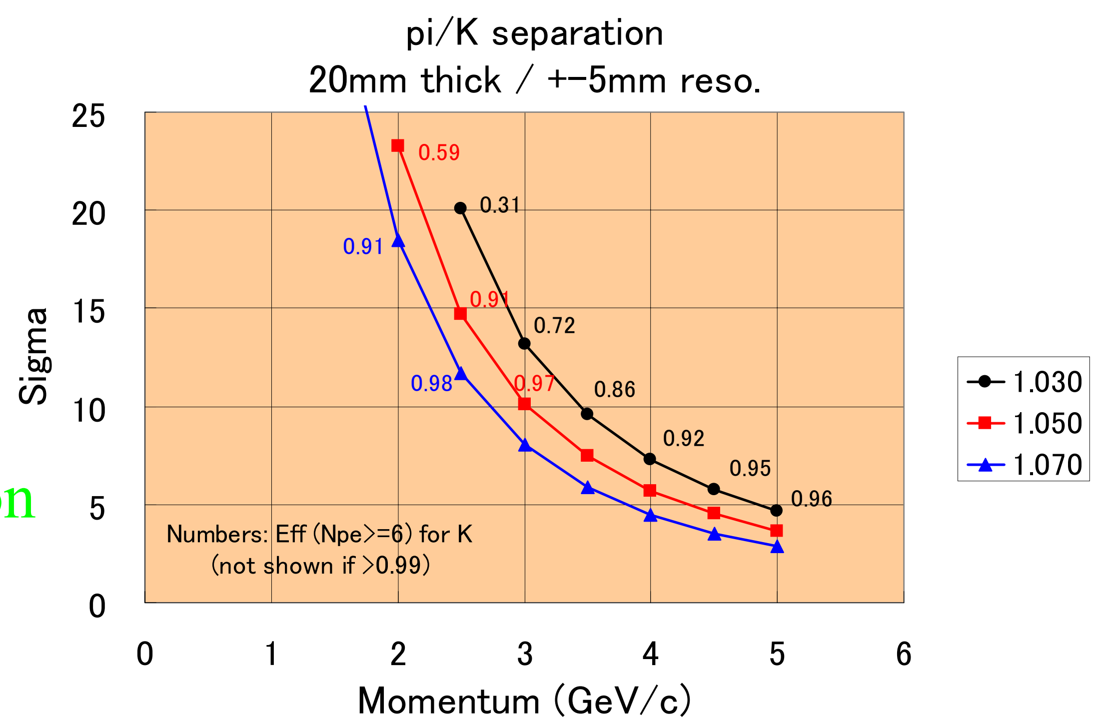
- Higher n is preferred to have enough light yield for pions at 0.8 GeV/c.
  ⇔Lower n gives better separation at high momentum (next slide).

Aerogel-RICH: Simulation (II)

- Simulation indicates:
  - Npe>12 possible for light velocity particles
  - N=1.030 gives better separation, but light yield at around threshold (p~0.8GeV/c) may be critical. ⇒Optimal n ~1.05
  - Separation @ 4GeV/c > 5σ possible even with 10mm read-out pad.

    ⇒Need verification with experiment.

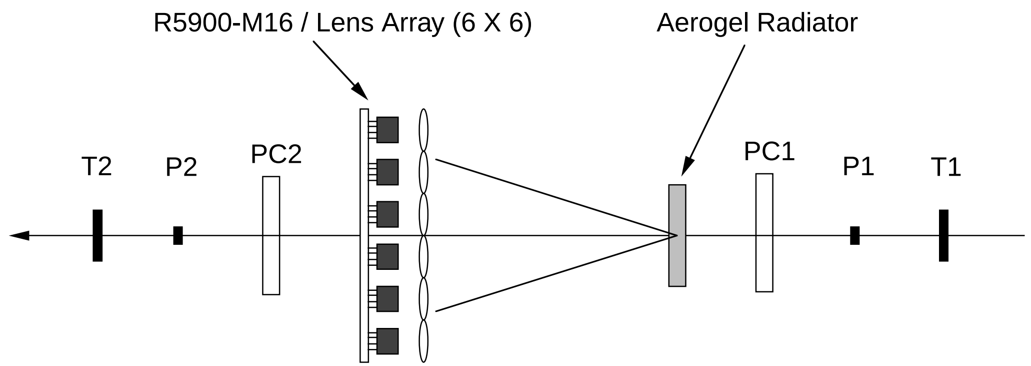




1st Beam Test Setup

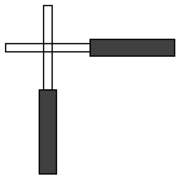
AEROGEL RICH BEAM TEST LAYOUT

2001.09.01
Toru Iijima



Positioning scint.

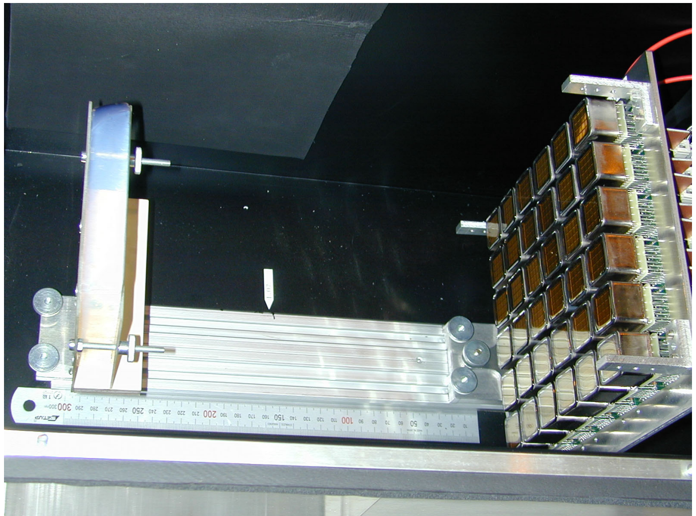
5mm X 5mm X 10cm scint.

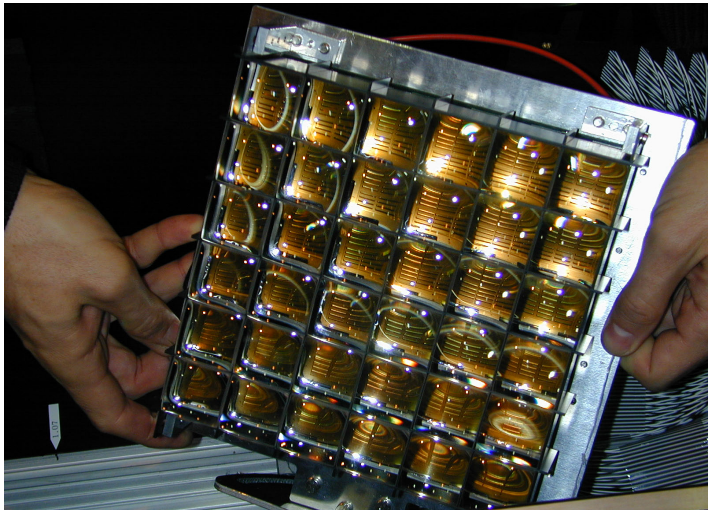


T1,T2: Trigger scint. (about 5cmX5cm)

P1, P2: Positioning scint.

PC: IJS MWPC (option?)

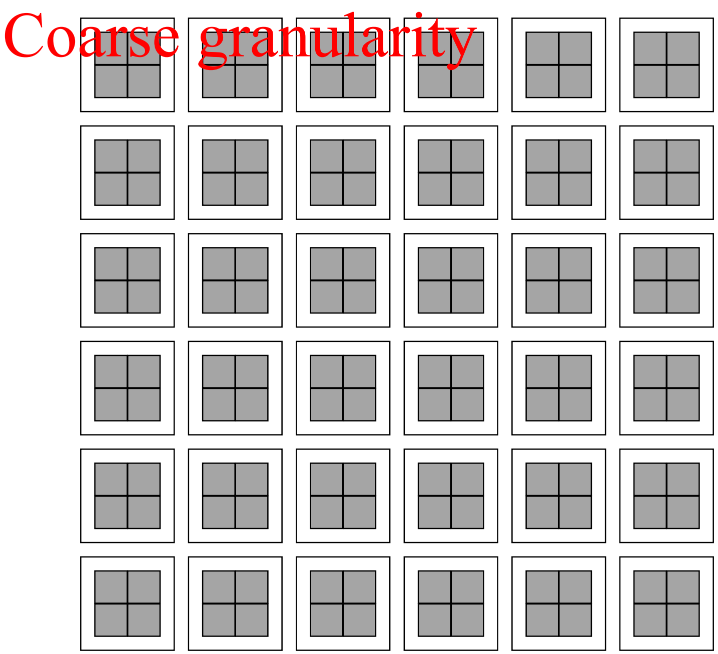


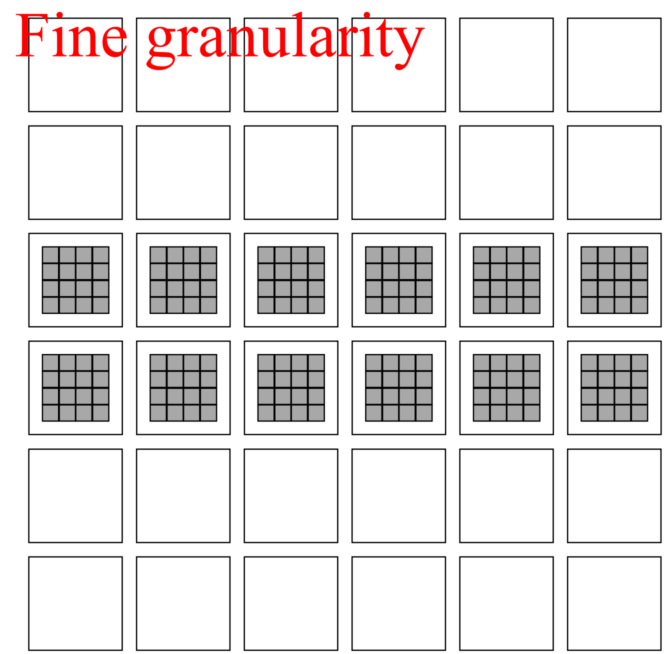


Multi-anode PMT configuration

Two readout configurations:

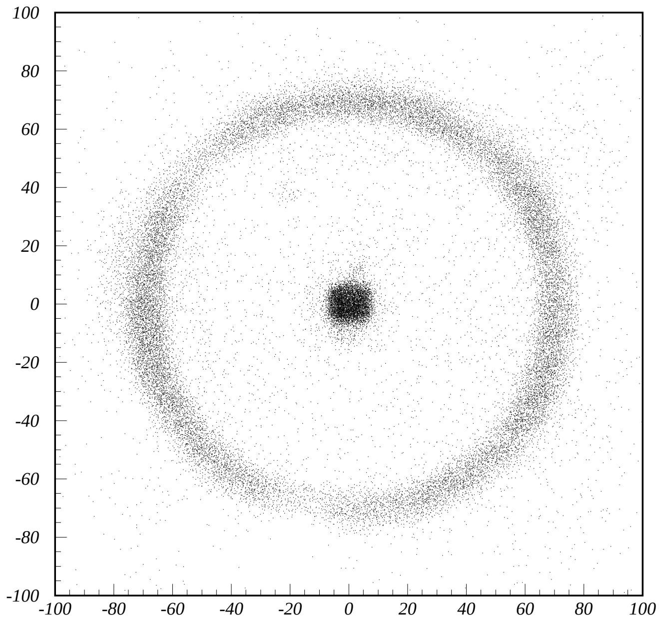
- Coarse granularity:
  - every 4 pads grouped together (144ch)
  - Light yield measurement
- Fine granularity:
  - only 1/3 sector connected to TDC (192ch)
  - Angular reso. measurement



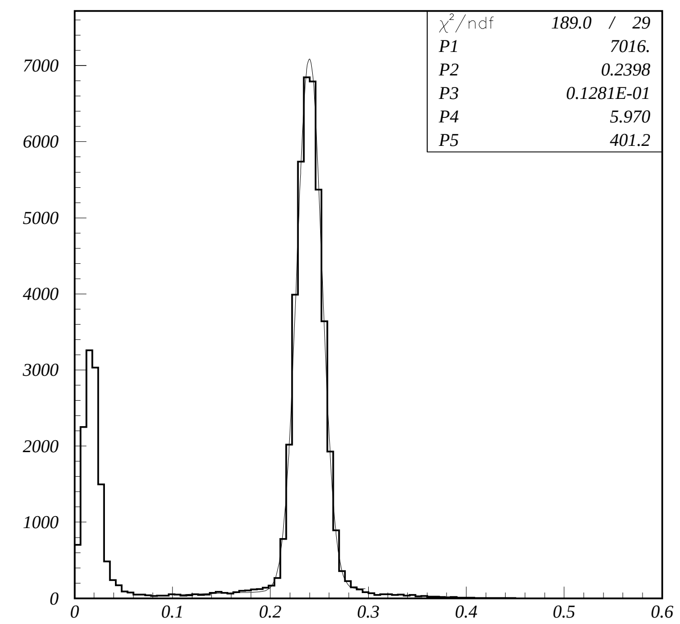


Observed Ring Image (I)

- Coarse granularity, 3GeV/c pion
- n=1.029 (2cm thick)

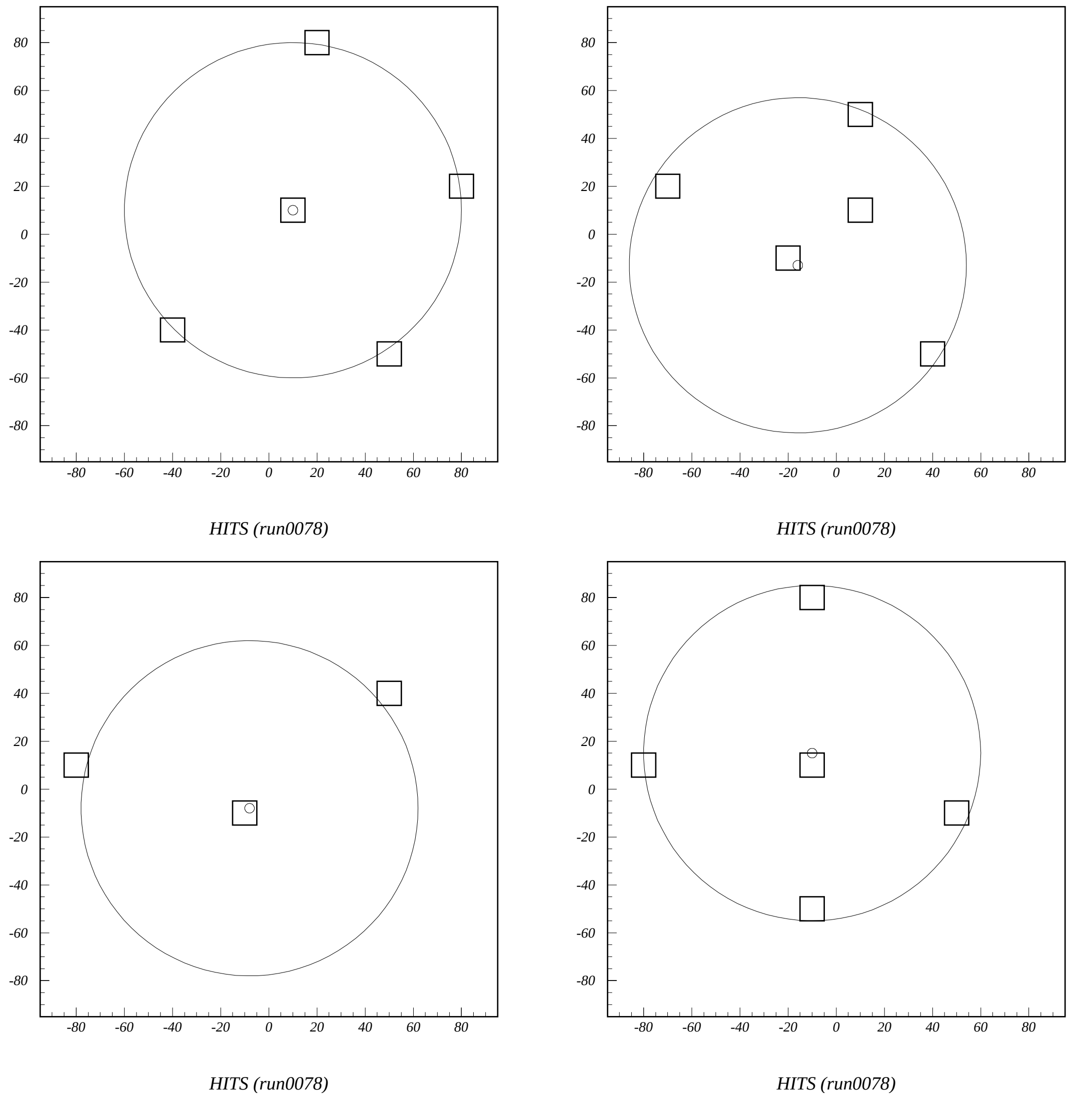


RING (run0074)



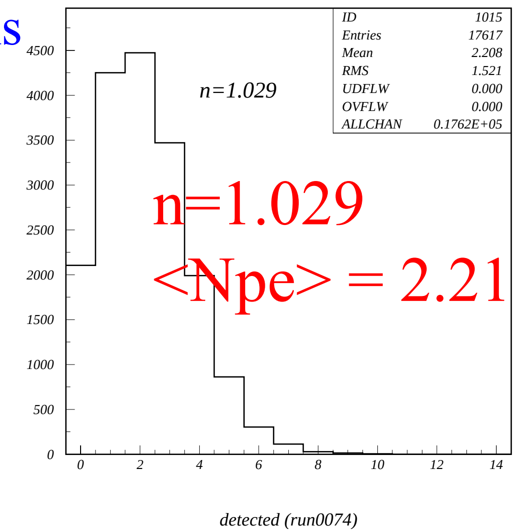
CHERENKOV ANG. (run0074)

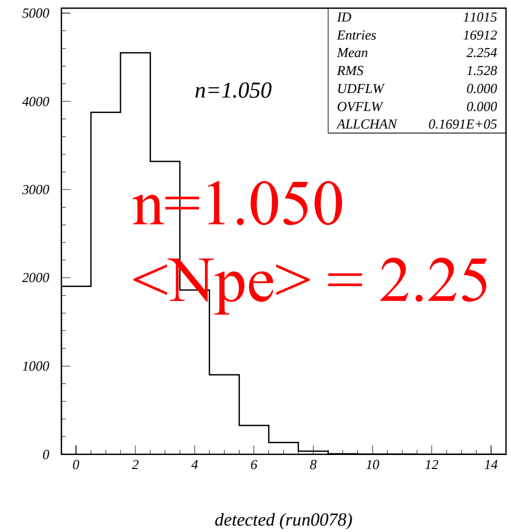
Event Display



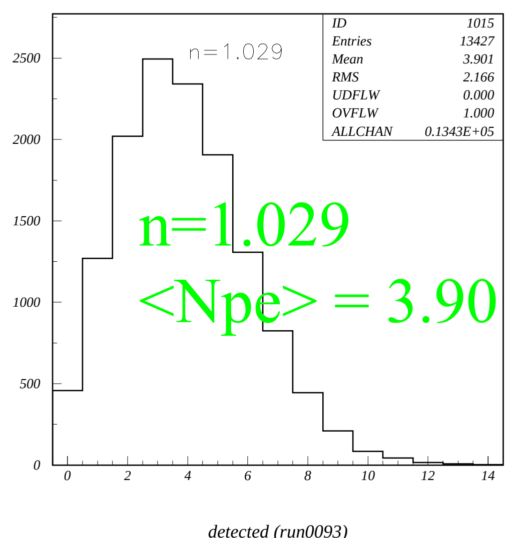
Detected Npe / event

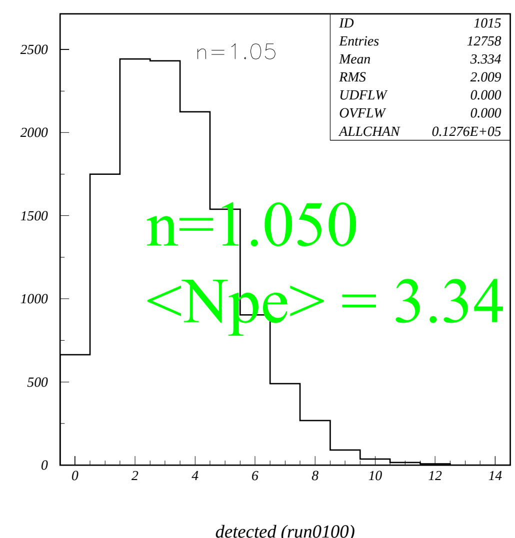
- Coarse granularity, 3GeV/c pions
  - Without lens





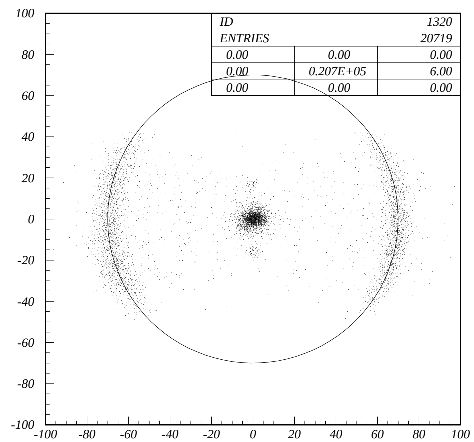
  - With lens



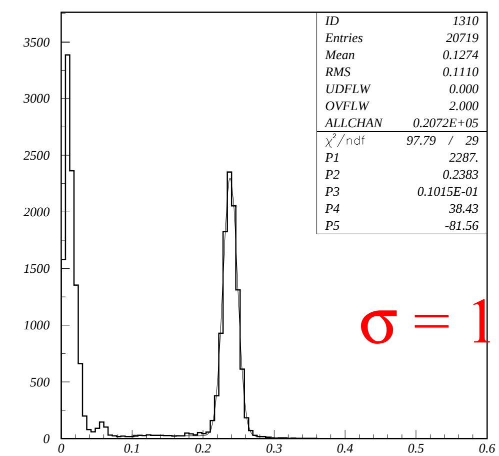


Observed Ring Image (II)

- Fine granularity, 3GeV/c pion
  - n=1.029, 2cm think



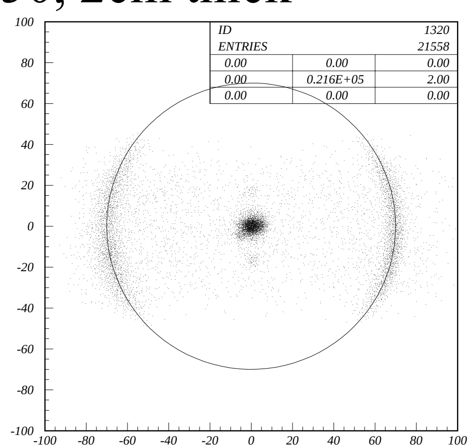
RING (run0129)



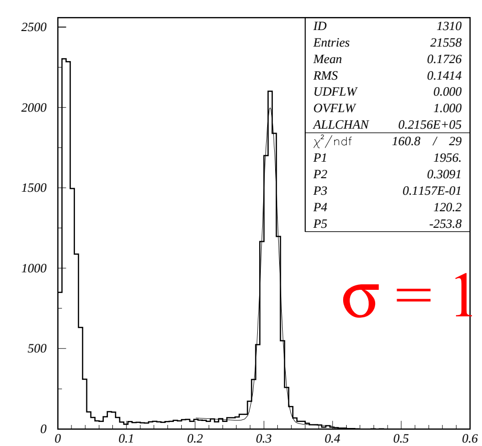
CHERENKOV ANG. (run0129)

σ = 10.2mrad

  - n=1.050, 2cm thick



RING (run0140)

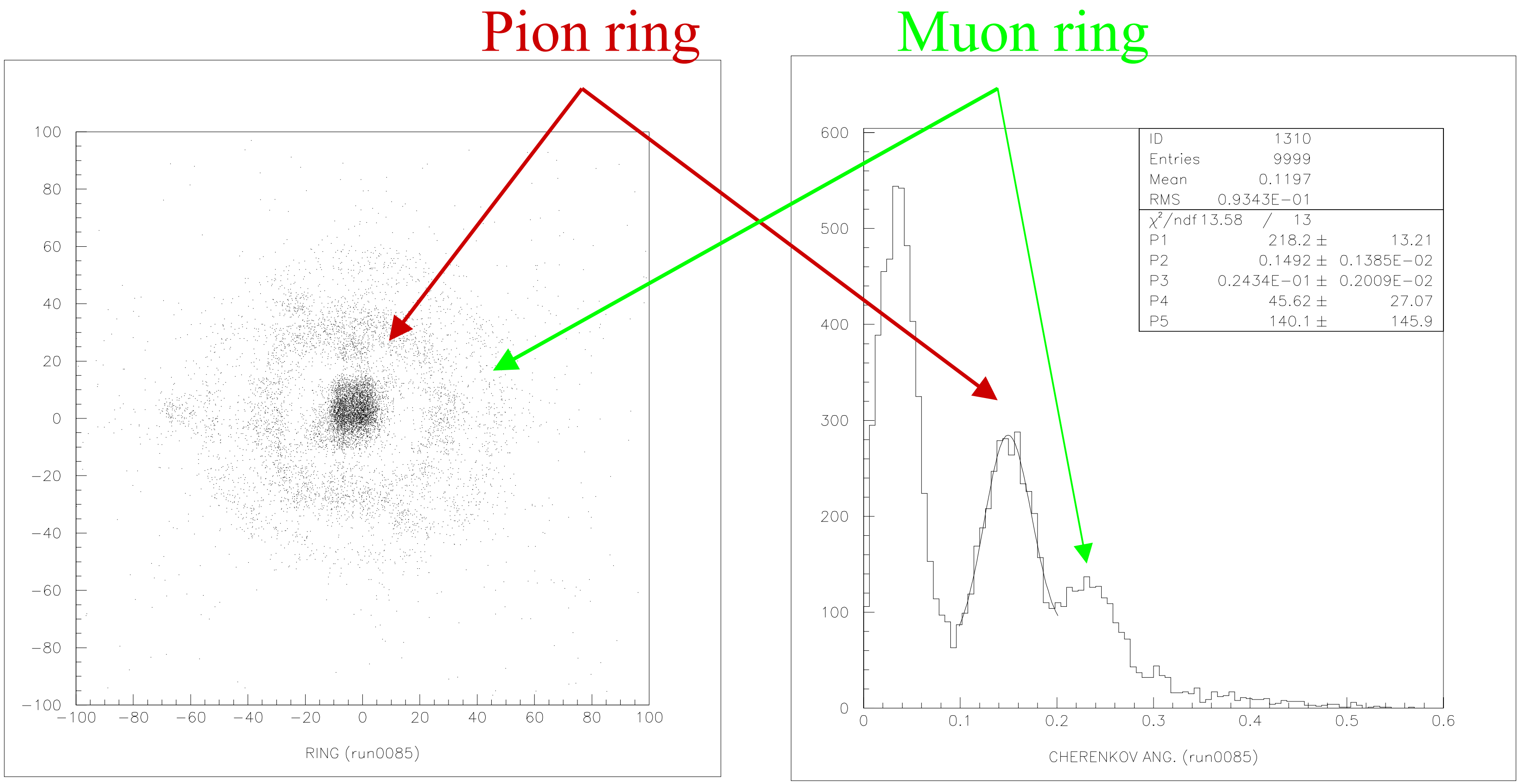


CHERENKOV ANG. (run0140)

σ = 11.6mrad

Identification of μ/π

- Data @ P = 0.5 GeV/c



1st Beam Test Results (Preliminary)

- Light yield (Npe) / angular reso. ($\delta\theta c$) w/ 3GeV/c pion
  - Numbers in ( ) show MC expectation

index	Npe		$\delta\theta c$ (mrad)	
	w/o lens	w/ lens	coarse	fine
1.029	2.21 (3.78)	3.90	12.8 (10.6)	10.2
1.050	2.25 (4.06)	3.34	15.9 (14.6)	11.6

- Present guess for lower Npe than MC: data/exp ~ 0.55
  - Photocathode QE (25%)
  - Dynode correction efficiency (100%)
  - Counting efficiency above threshold (100%)

  (): MC assumption

Each factor could yield factor of ~0.8

⇒Pad-by-pad calibration for single p.e. efficiency is underway.

R&D Targets

- Improvement of high index aerogels
  - The present production method (know-how) is not optimized for n>1.05
  - N=1.05 sample from Novosibirsk showed 80% increase in Npe at the beam test.

⇒ There is large potential to improve Npe ×2

- Photodetection
  - Good effective area ratio (36% → > 70%):

⇒ Flat pannel PMT ×2

  - Good single photoelectron detection
    - QE
    - S/N (Peak-valley)
    - Magnetic field immunity

⇒ Hybrid PD/APD ×1.5

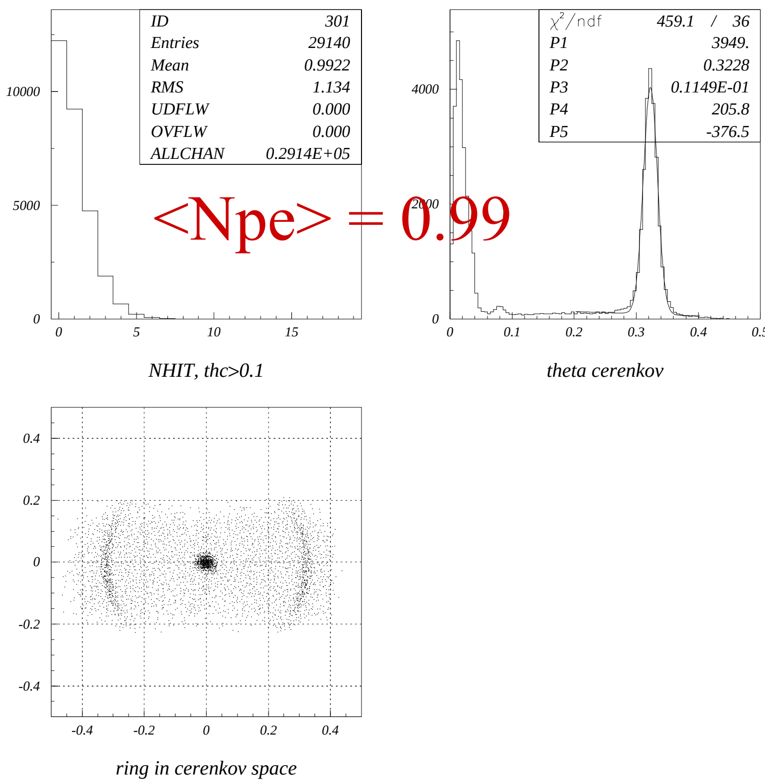
- More ideas
  - Dual-radiator option
  - Optics to increase area (light guide etc.)

“Good” Aerogel Data

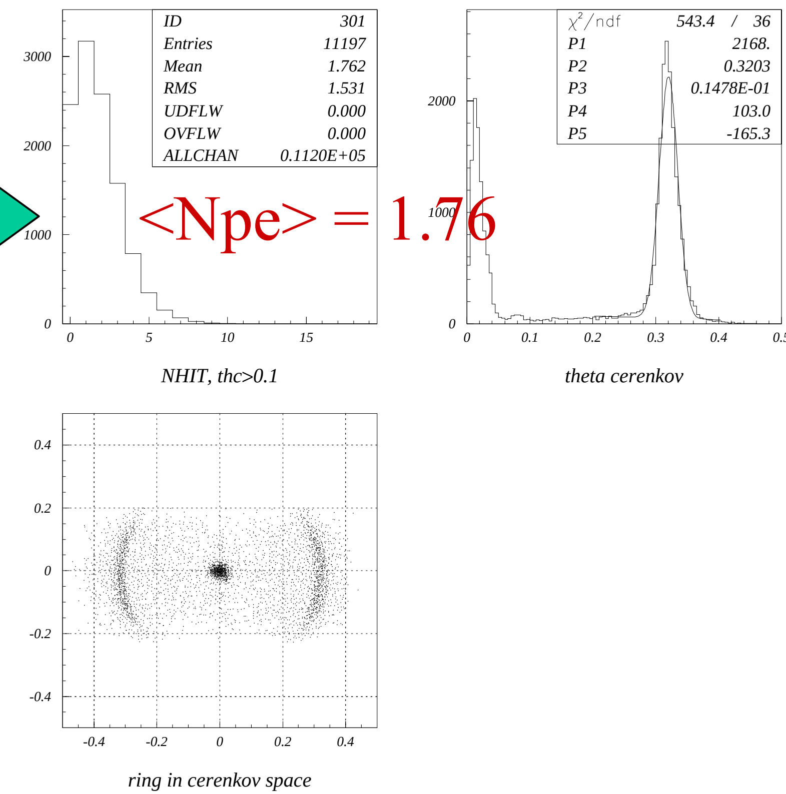
- 80% increase in Npe with n=1.05 sample from Novosibirsk.

KEK-1.05
λscat(400nm) ~ 15mm

Novosibirsk-1.05
λscat(400nm) ~ 48mm

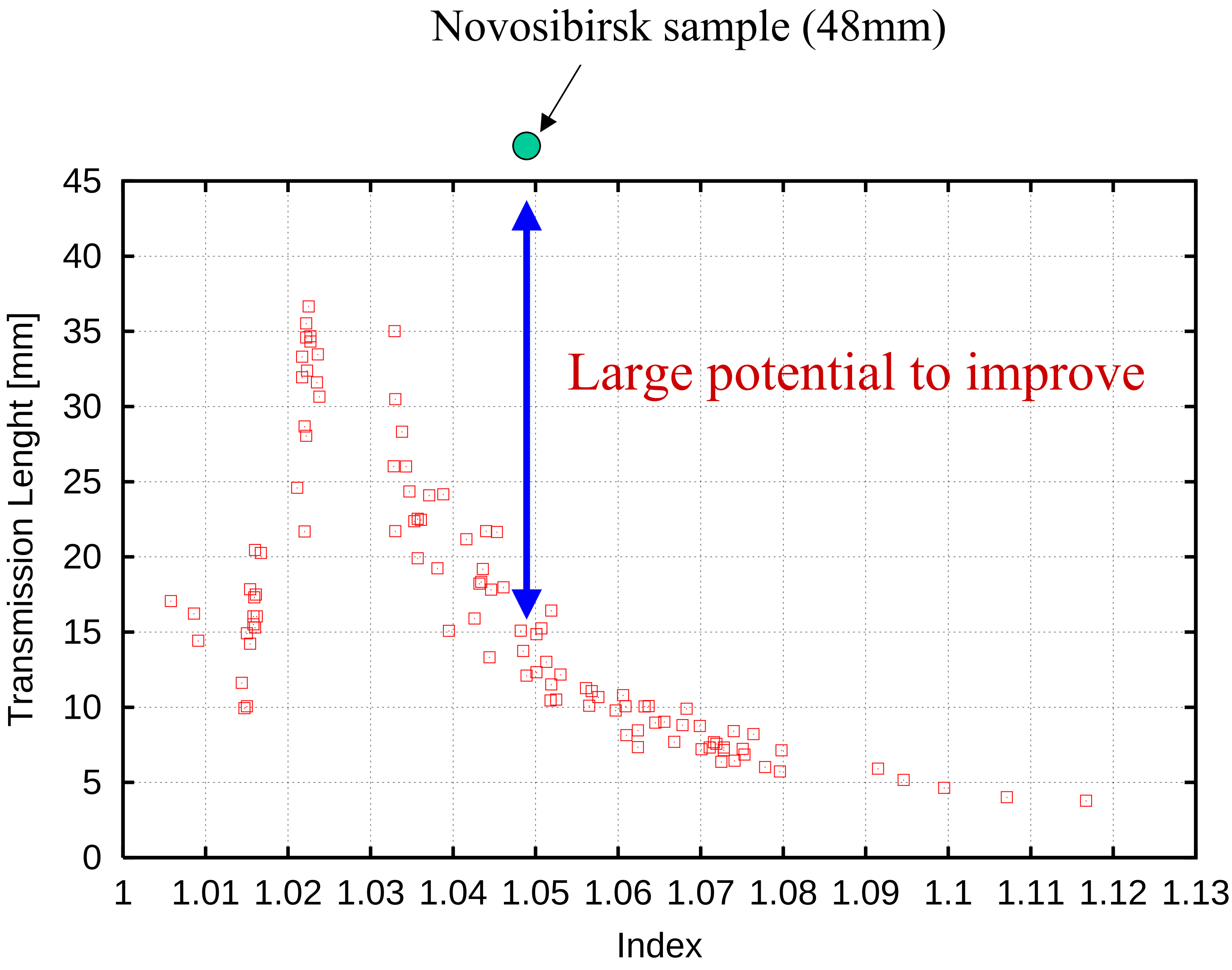


<Npe> = 0.99



<Npe> = 1.76

Transmission of KEK samples



Aerogel R&D

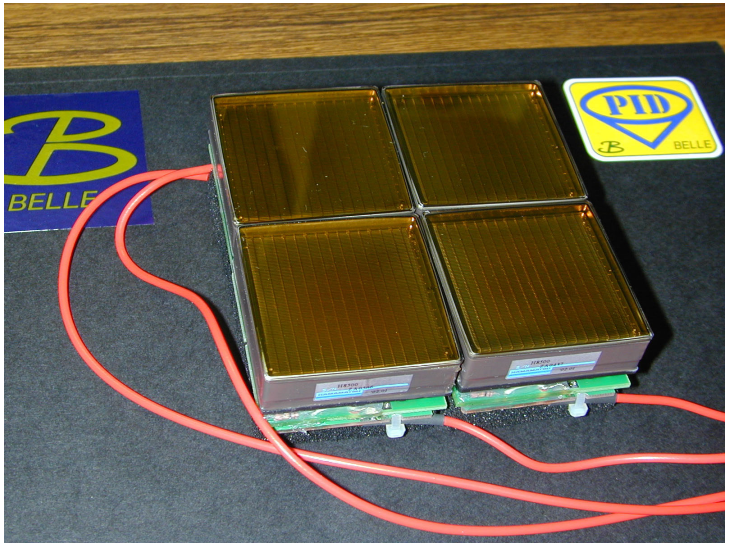
- Need revisit production method of aerogels.
  - KEK: Semi two-step method with precursor.
    - Hydrophobic
    - Not optimized for high index (~1.05)
  - Novosibirsk: ???
    - Hydrophilic

  ⇒Will start R&D soon
- Some practical issues:
  - Surface flatness / cracks
  - Image distortion @ boundary of tiles.

  ⇒Trial to make large tiles
- Necessary volume = ~ 80 litters (~2000 litters for the present ACC)
  - Large mass production is not necessary.
  - Probably, more choices for the production methods.

Flat Panel PMT for R&D

- Newly developed 8 × 8 multi-anode PMT by HPK.
- Effective area = □49mm for □51.7mm package (90% coverage)
- Single p.e. peak is observable.



- Cannot be used in 1.5Tesla field, but very useful for 1st year R&D's.
  - Further performance studies and better understanding of the detector behavior.
    - Incident angle dependence
    - Effects of tile boundaries, etc.
  - Optimization of design
    - Radiator index, thickness
    - Anode pad size, etc.

- Will soon build 5 × 5 array and make a test counter for these subjects.
  - 8 pcs. Already at hand.
  - Read-out electronics with preamp / analog memory / flash ADC

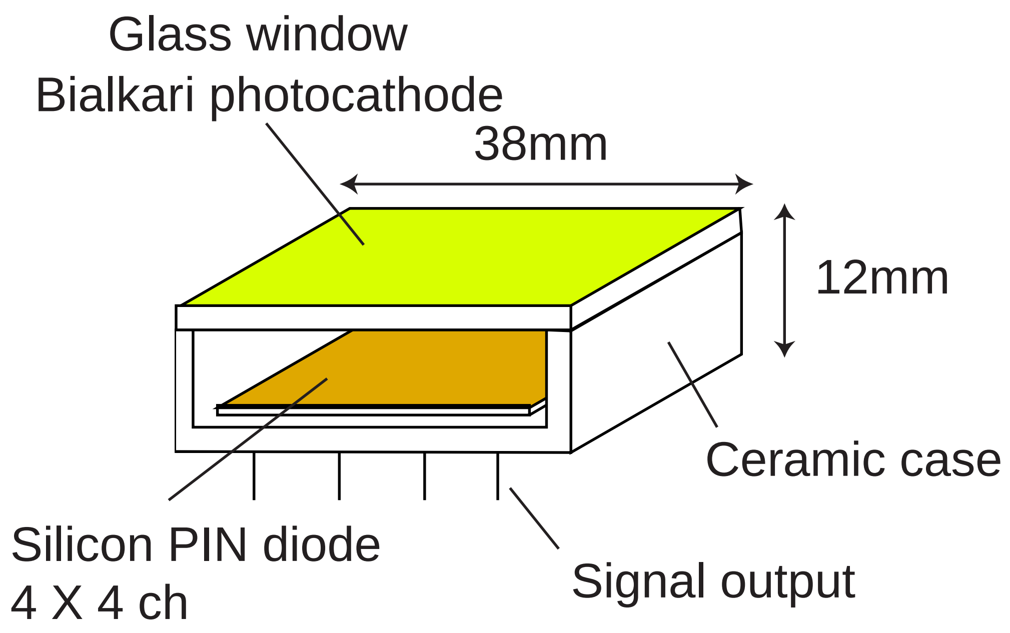
New Photodetector Development

- Need position sensitive photodetector (for visible light region) with good effective area and magnetic field immunity.
- Possible options;
  - Hybrid (A)PD (HPD/HAPD)
    - Good single p.e. sensitivity
    - Lower cost than finemesh ?
    - Two-year R&D project
  - Multi-anode finemesh PMT
    - Basic technology at hand

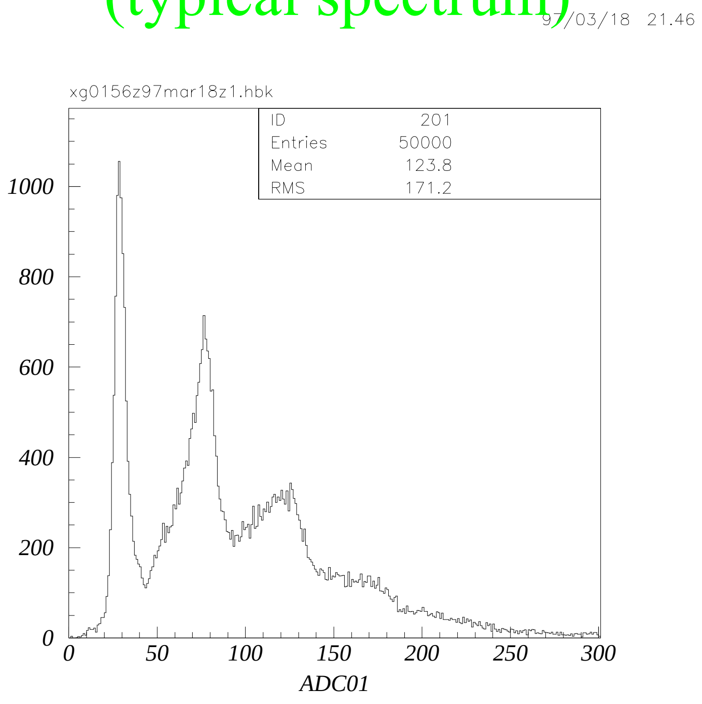
Flat panel HPD

- Compact HAPD array at hand can used for initial R&D's.
- Also need studies on light guide to reduce dead area.
  - Lens system (like @ HERA-B RICH)
  - Fish tail plastic/air light guide

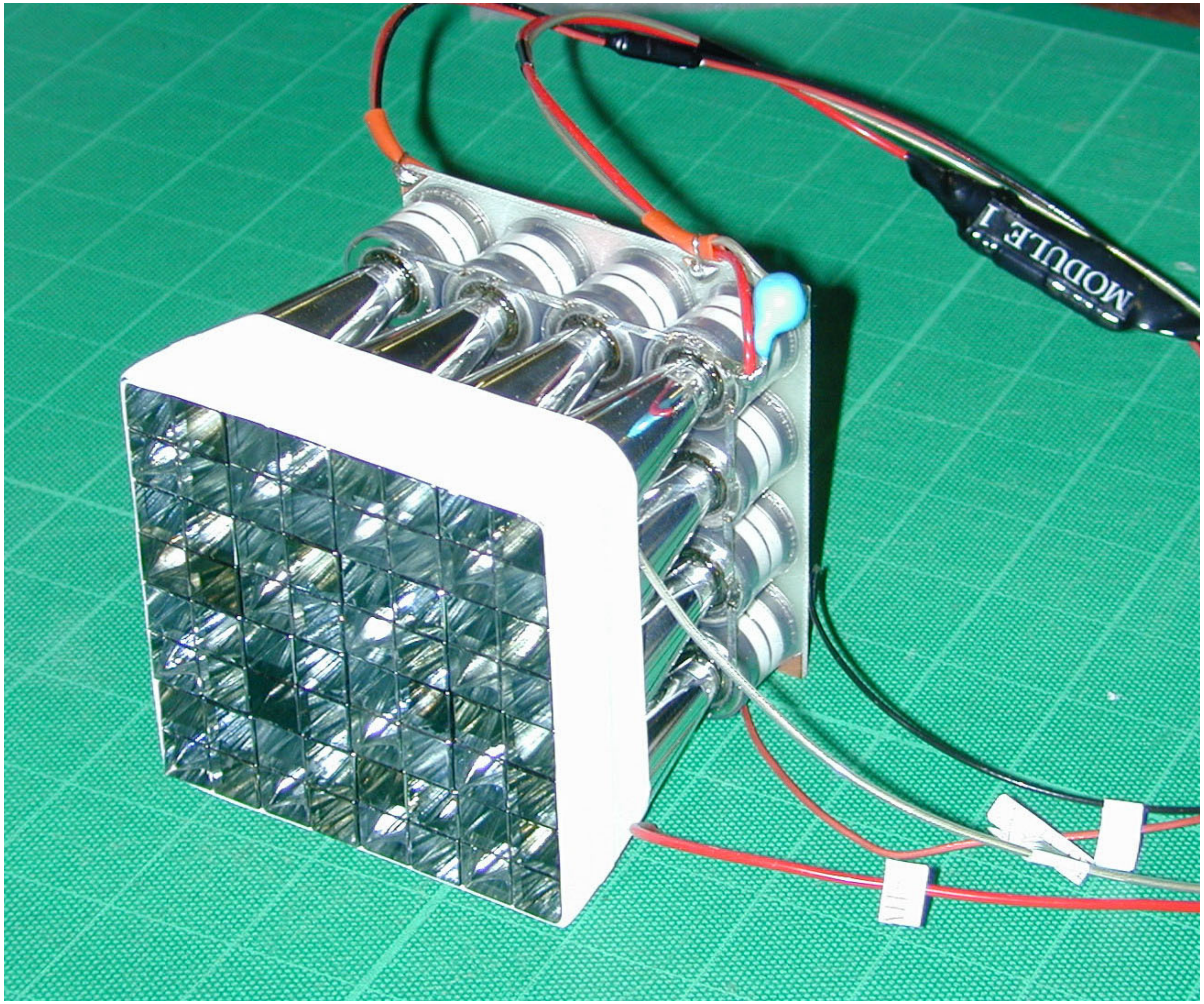
‘Flat panel HPD’



Photon counting w/ hybrid PD
(typical spectrum)

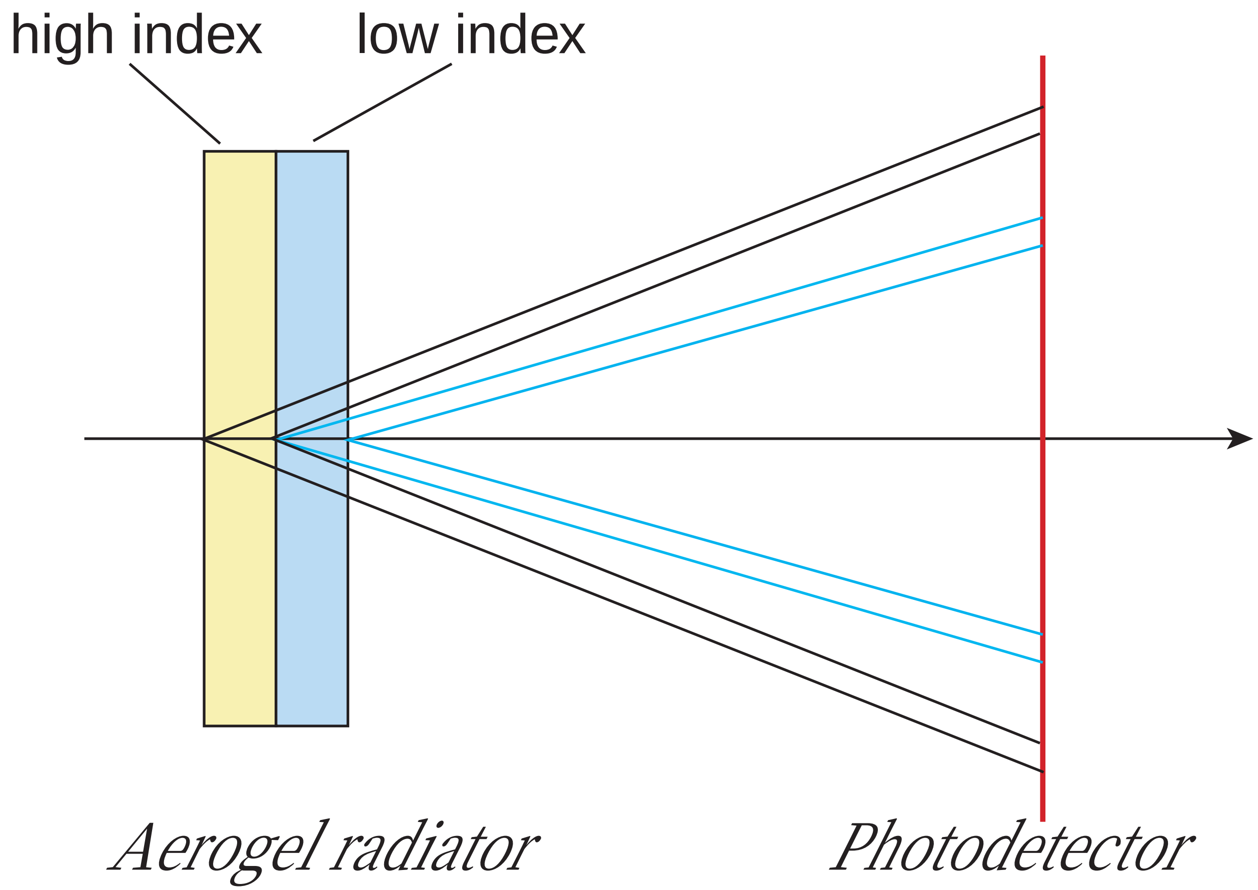


Small HAPD Array



Dual Radiator Scheme

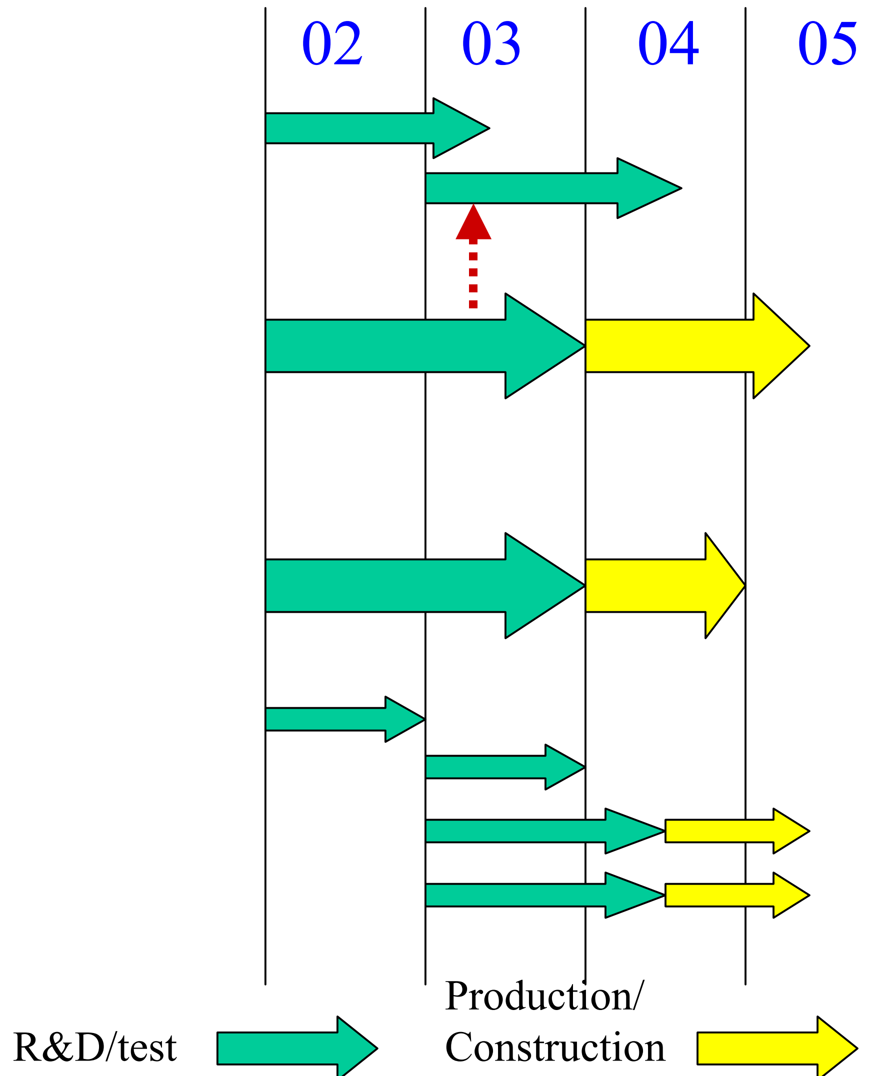
- Interesting option, if aerogel transmission is improved.
- Light yield can be increased without deteriorating the angular resolution.
- Need study effectiveness with simulation



List of R&D items / Time Table

- Continue R&D to prove the performance and decide by FY03/end

- Test
  - Test counter w/ flat panel PMT
  - Prototype w/ new photodetector
- New photodetector development
  - Flat panel HPD
  - Multi-anode finemesh PMT
  - Light guide
- Aerogel
  - Production method
  - Surface,size, edge sharpness etc.
- Software development
  - Detector simulator (GEANT-based)
  - Reconstruction
- Read-out electronics
- Mechanical structure



Summary

For PID upgrade, we should aim at

- Ring Imaging Cherenkov detectors which can separate K/π up to 5GeV/c.

  This will give also l-π separation in the low momentum region, that is crucial for important urements, such as B-> Kll decays.

- PID hermeticity is essential to purify events for inclusive measurements, for which Super-Belle has advantage over hadron machine B factories.

Aerogel-RICH R&D

- Intensive R&D works are in progress. The 1st beam test has been done.

Important R&D items:

- Improvement of aerogel quality
- Development of new position sensitive photodetector, having
  - large effective area / package
  - single p.e. sensitivity

Let's build a new good PID with our original idea !
You are welcome to join !

Present PID Concern: Radiation Hardness

Present: 20rad@CsI (endcap)→$O(10^{3\sim4})$rad/10years ?

- Aerogel radiator
  - Have been tested upto 10Mrad. No change was seen.
- PMT borosilicate glass window
  - According to HPK text book, ~20% drop at λ=400nm @ 10^5 rad (Need further check.)
- Plastic scintillator (TOF)
  - Effect @ O(10K)rad?
- Gain drift due to current stress
  - If we see some effects, proper calibration will cure the problem

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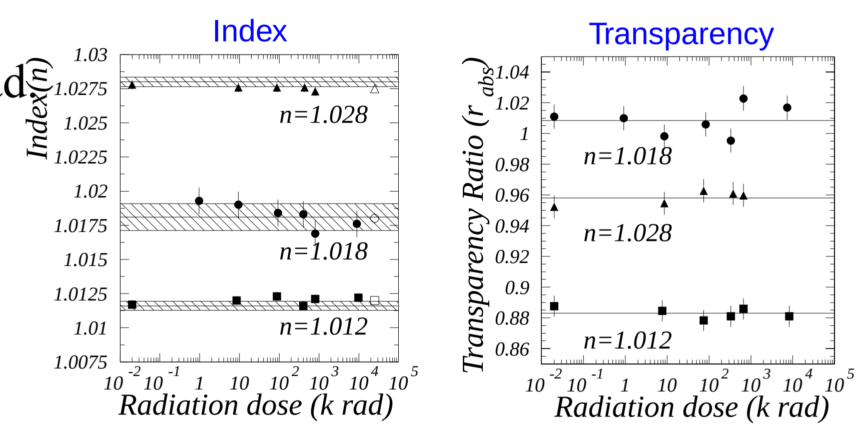

*rabs = relative to un-dosed reference sample

Irradiation facility @ Nat'l Tsing Hua Univ. Co γ-ray (1320 Ci)

Present PID Concern: Background Immunity

- Detector dead time
  - PMT signal duration ~100ns

→Dead time fraction = 10^{-7} ×N(Hz)

	TOF	BACC	EACC
Present rate	30kHz	1kHz	5kHz
Dead time	0.3%	0.01%	0.05%
×10	3.0%	0.1%	0.5%
×100	30%	1.0%	5.0%

- Electronics add more dead time (⇒M.Tanaka @ 1st wrokshop).
- Note: ACC is an ON/OFF device, and these become intrinsic inefficiency for kaon ID or rejection.

⇒*At least, TOF has to be replaced.*

R&D Cost (unit: yen)

- New photodetector development
  - Flat pannel HPD 25M
  - Finemesh multi-anode 5M
- Aerogel improvement 2.5M
- Test bench with flat panel PMT 5M
- Read-out electronics 5M
- Beam test & misc. 2.5M