Aerogel RICH

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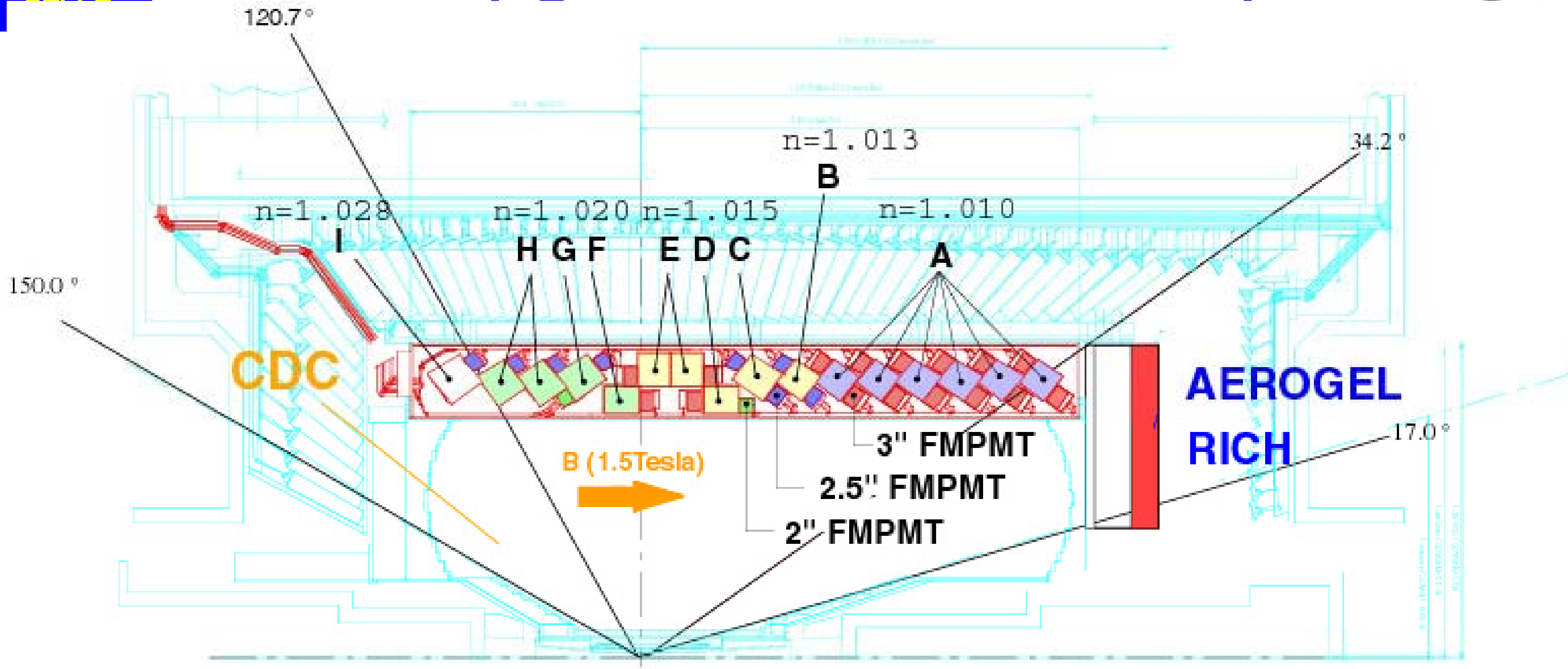
PID upgrade in the endcap



improve K/π separation in the forward (high mom.) region for few-body decays of B's

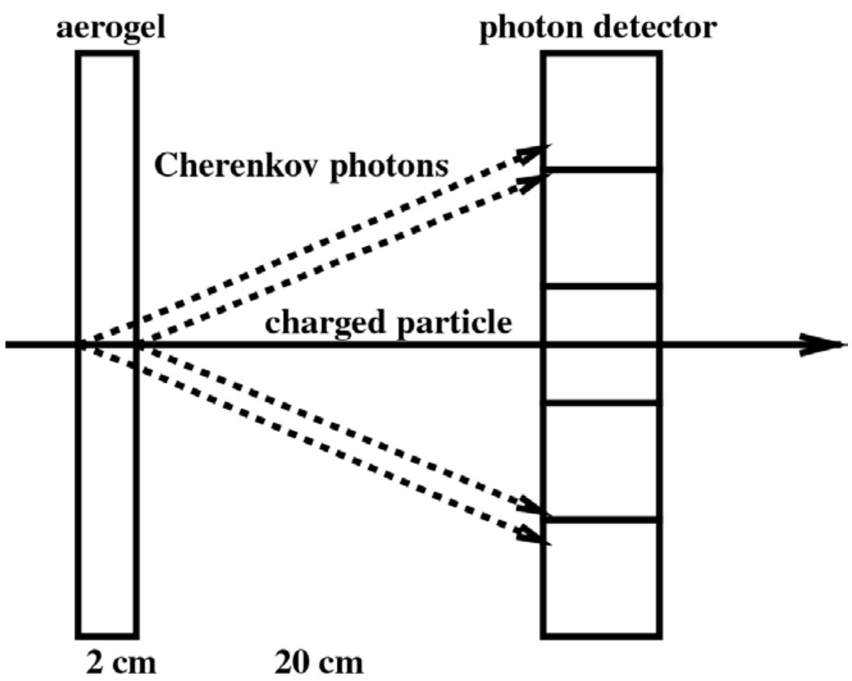
good K/π separation for b -> dγ , b -> sγ

improve purity in fully reconstructed B decays

low momentum (<1GeV/c) e/μ/π separation (B ->Kll)

keep high the efficiency for tagging kaons

Proximity focusing RICH in the forward region



K/π separation at 4 GeV/c

$\theta_c(\pi)$ ~ 308 mrad (n = 1.05)

$\theta_c(\pi) - \theta_c(K)$ ~ 23 mrad

$d\theta_c(\text{meas.}) = \sigma_0$ ~ 13 mrad

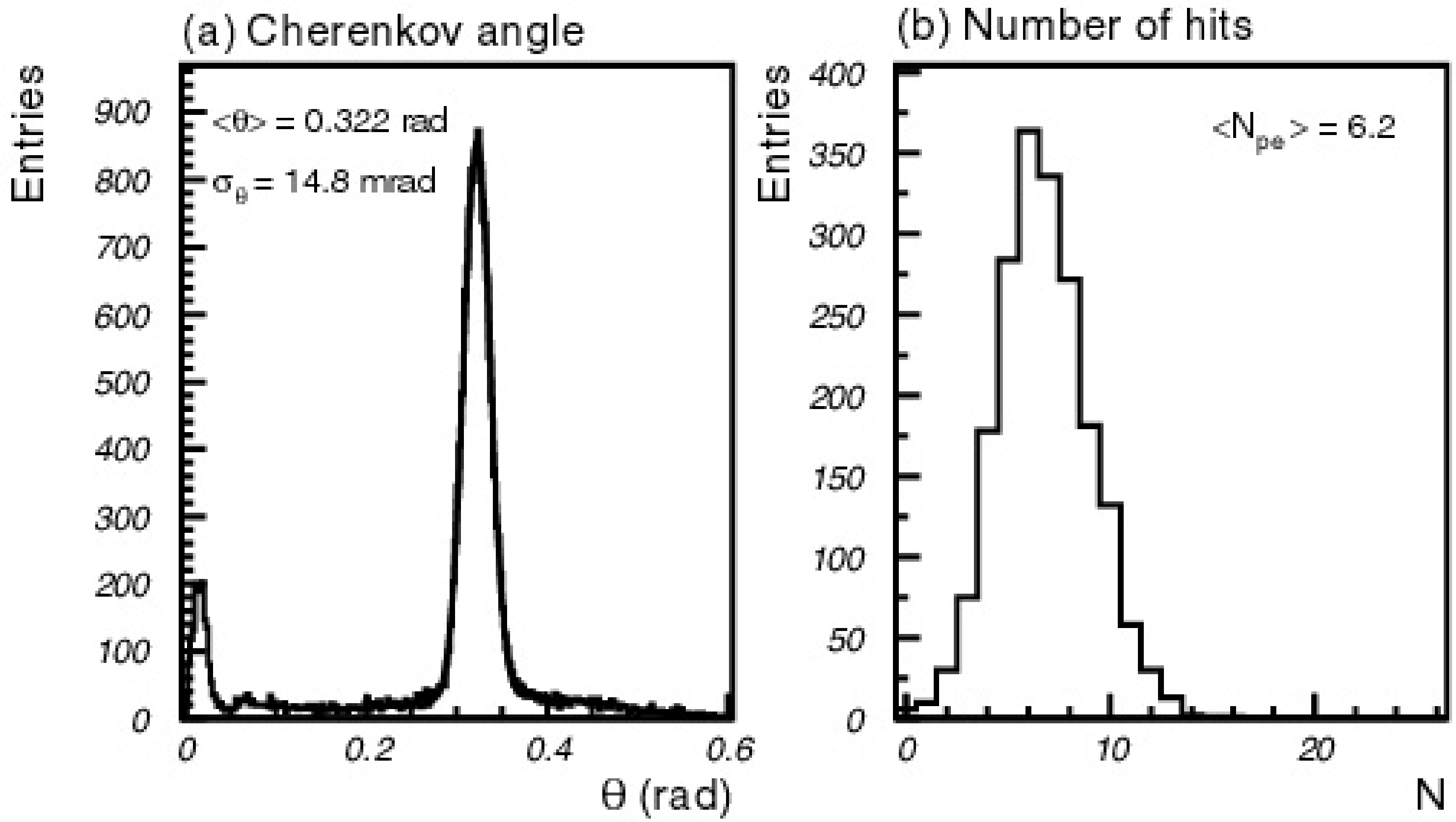
With 20mm thick aerogel and 6mm PMT pad size

→ 6σ separation with N_{pe}~10

Beam test: Cherenkov angle resolution and number of photons

Beam test results with 2cm thick aerogel tiles:

>4σ K/π separation

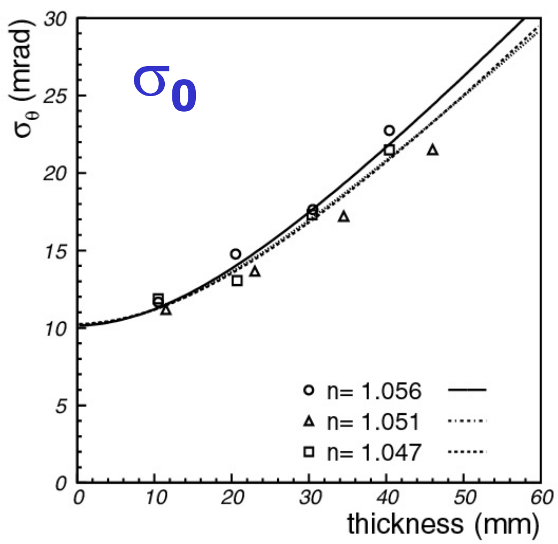


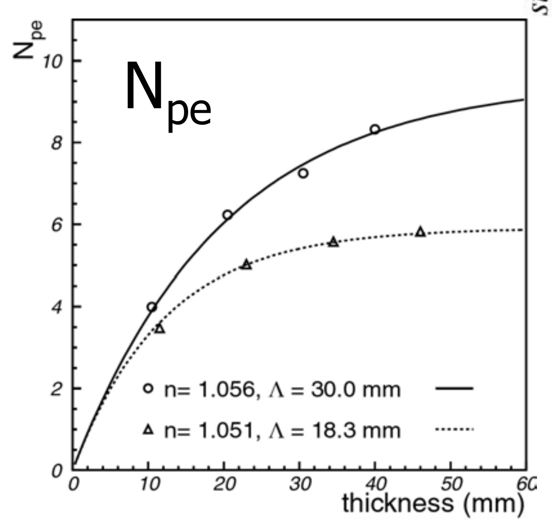
-> Number of photons has to be increased.

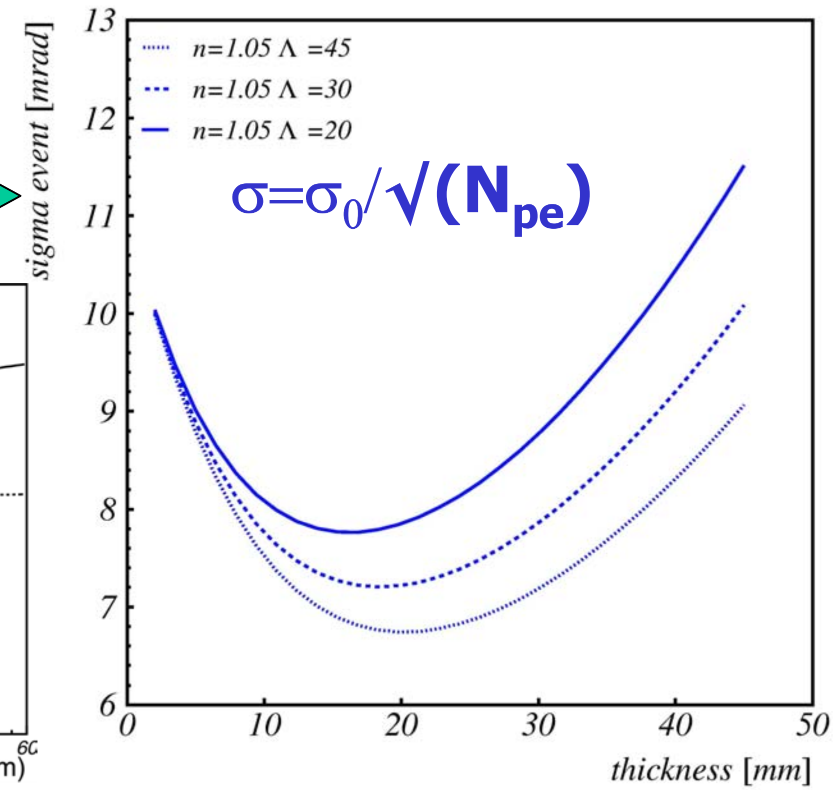
How to increase the number of photons?

What is the optimal radiator thickness?

Use beam test data on σ_0 and N_{pe}



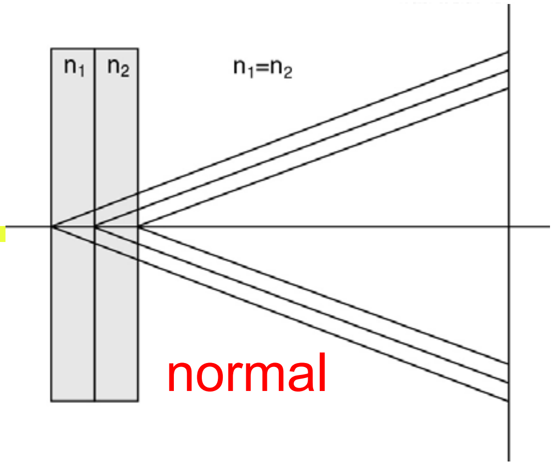




Minimize the error per track: $\sigma=\sigma_0/\sqrt{(N_{pe})}$

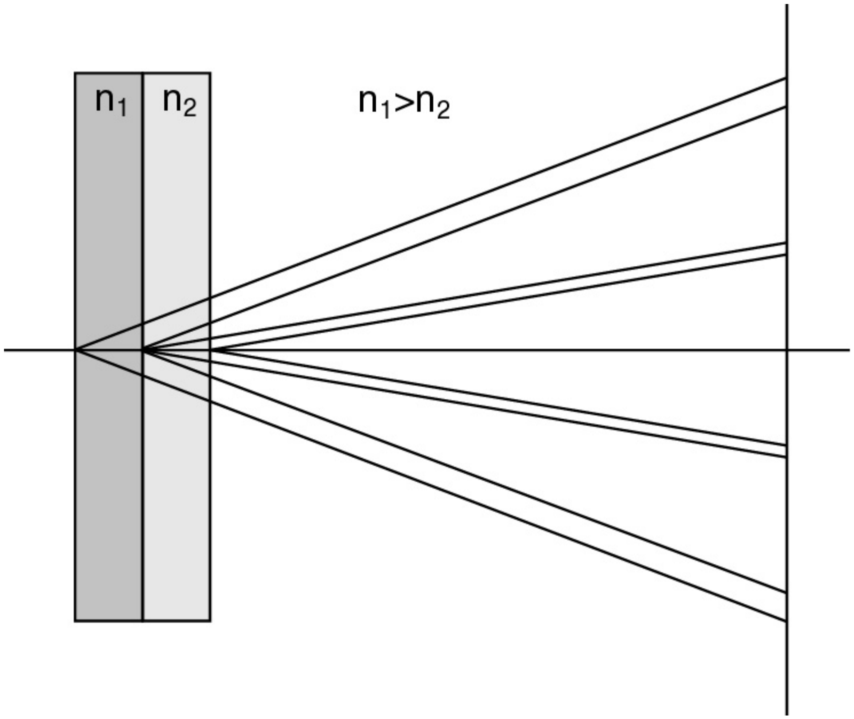
→ Optimum is close to 2 cm

Radiator with multiple refractive indices

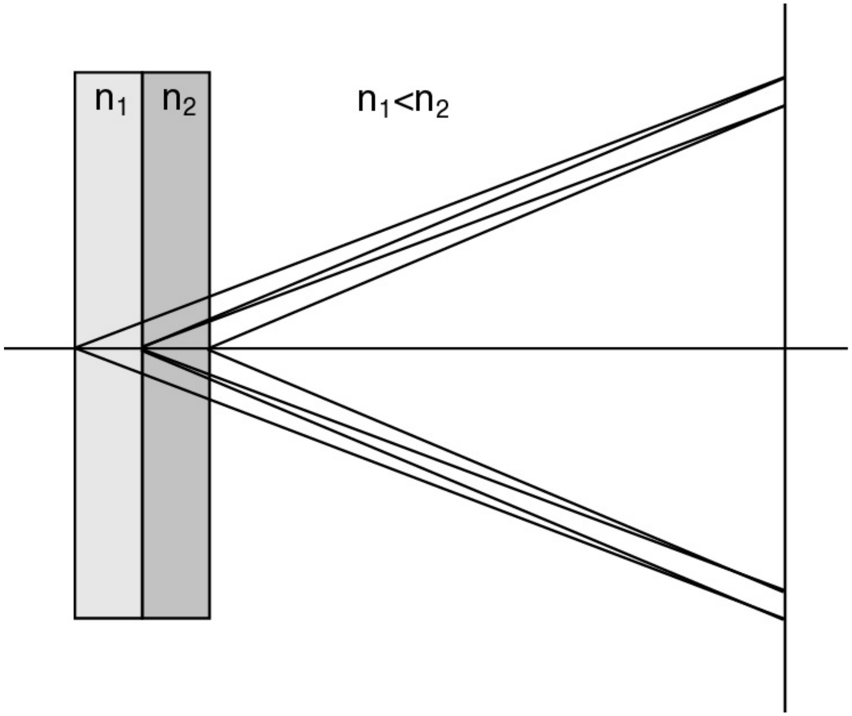


How to increase the number of photons without degrading the resolution?

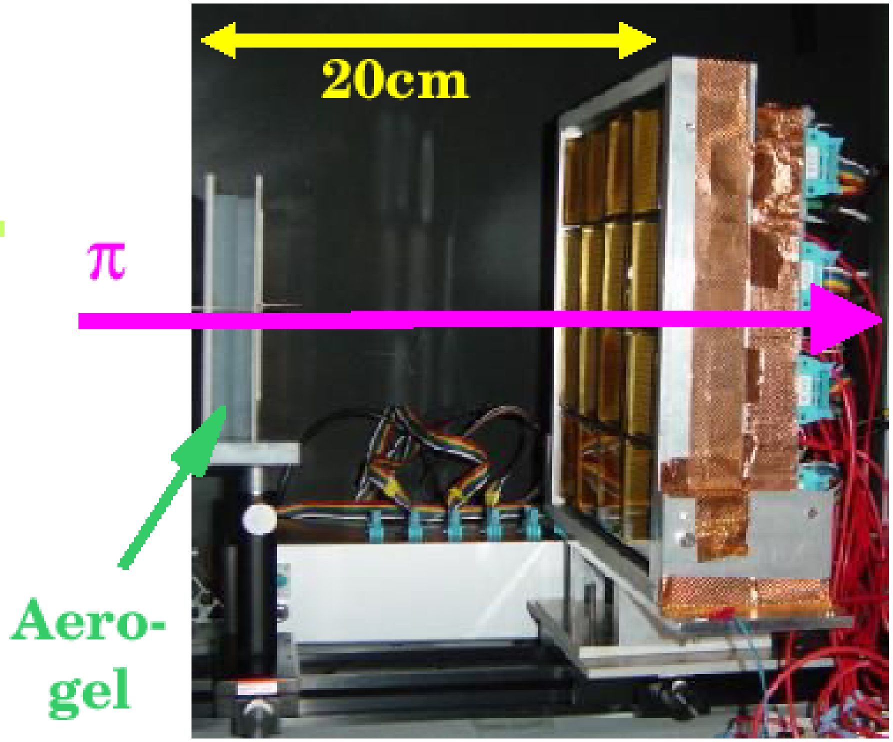
- measure two separate rings
"defocusing" configuration

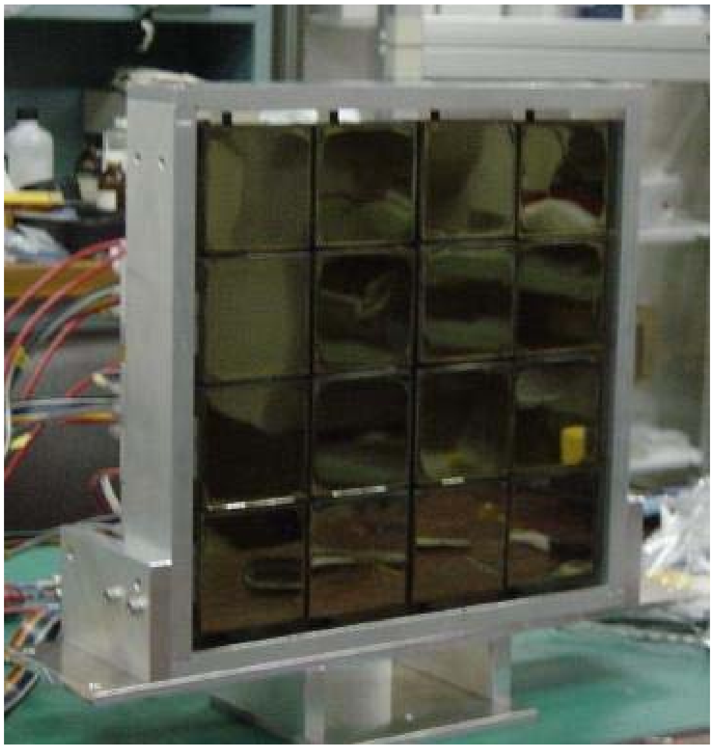


- measure overlaping rings
"focusing" configuration



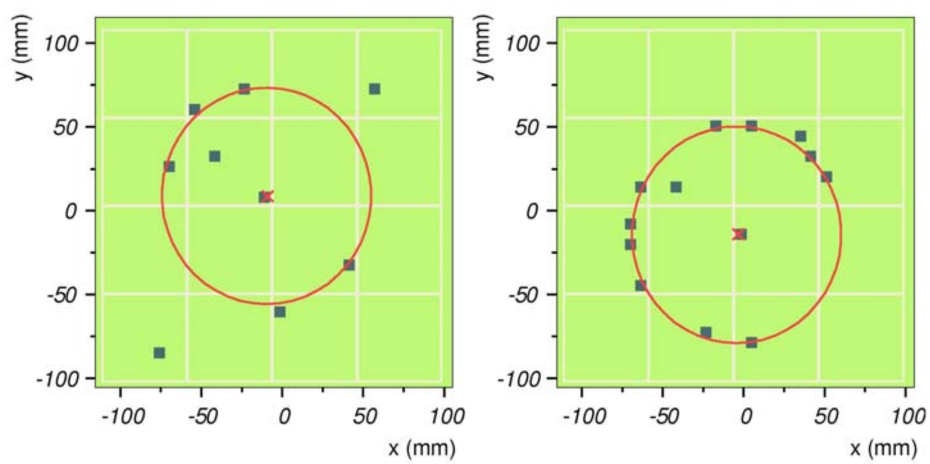
Beam tests





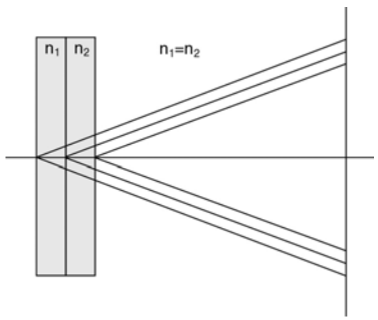
Photon detector: array of 16 H8500 PMTs

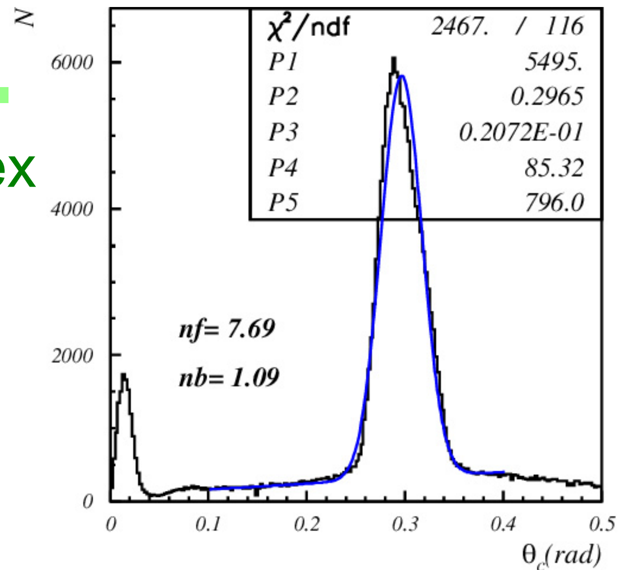
Clear rings, little background



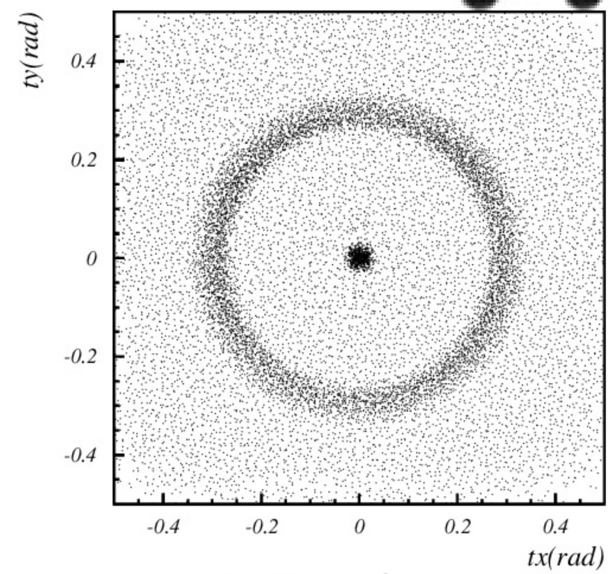
FOCUSING CONFIGURATION - data

4cm aerogel single index



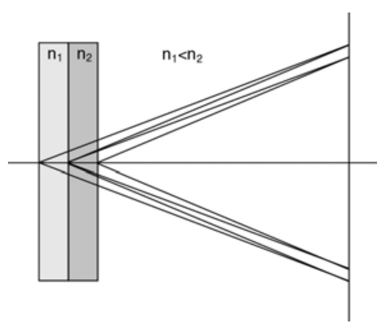


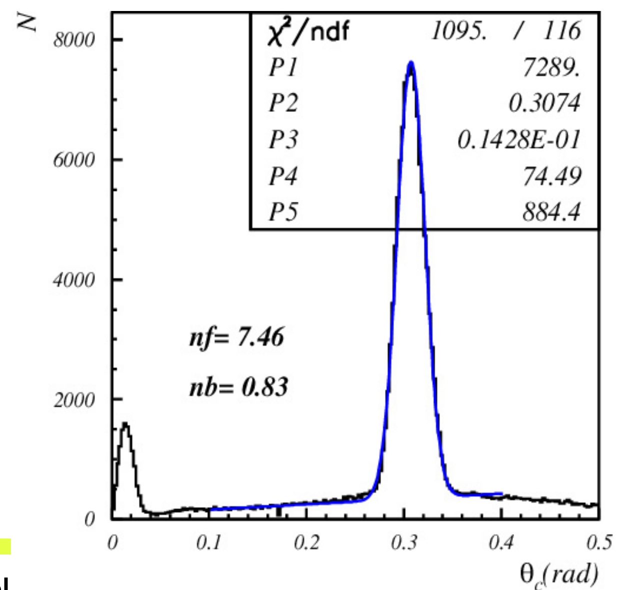
theta cerenkov

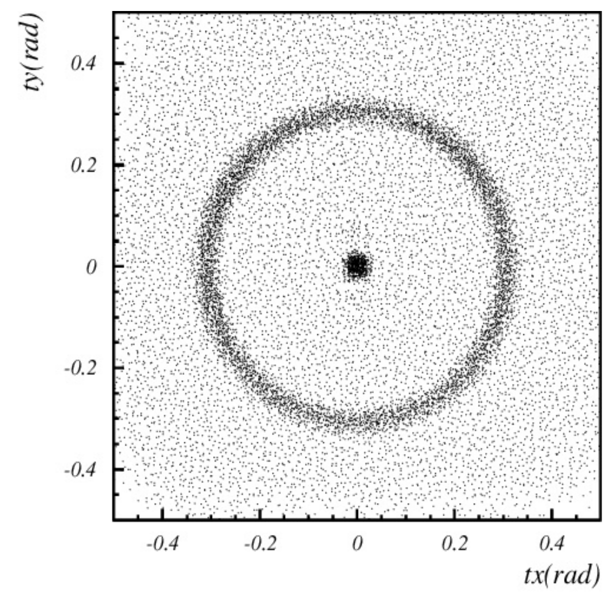


ring in cerenkov space

2+2cm aerogel

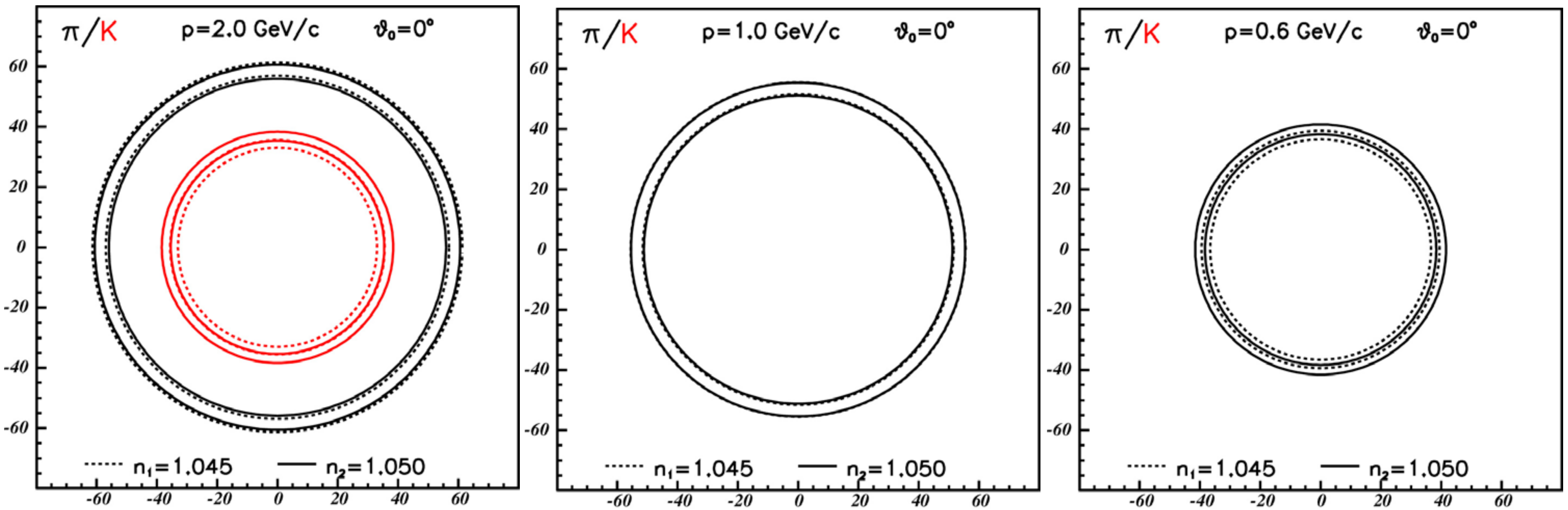






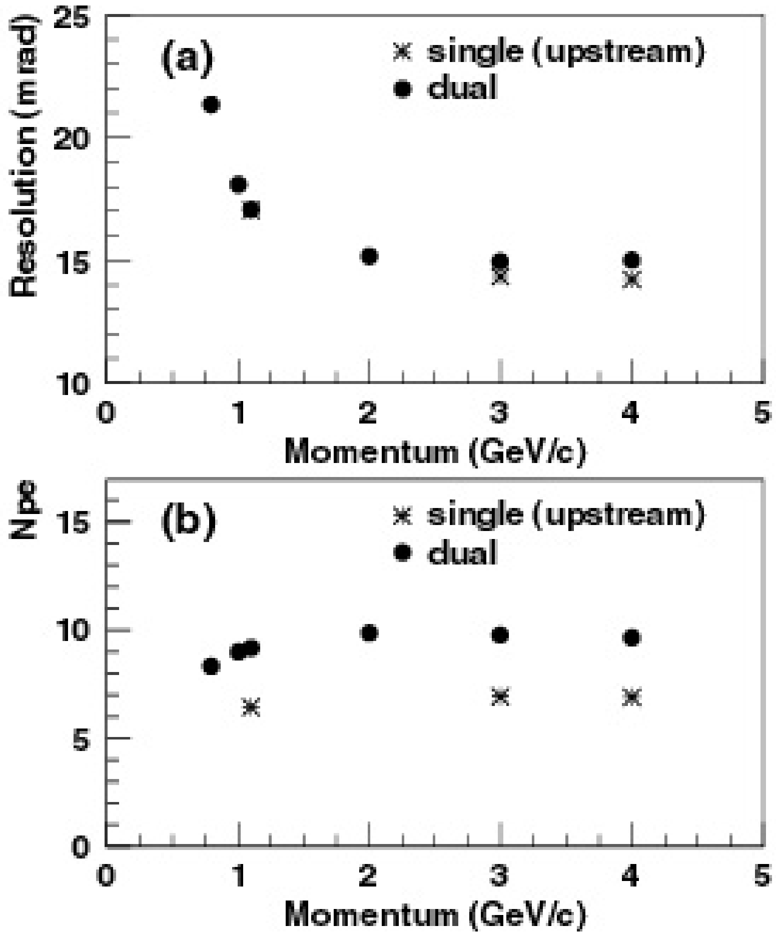
FOCUSING CONFIGURATION - low momentum

- overlapping of rings for low momentum tracks



Good overlapping down to 0.6 GeV/c

FOCUSING CONFIGURATION – momentum scan

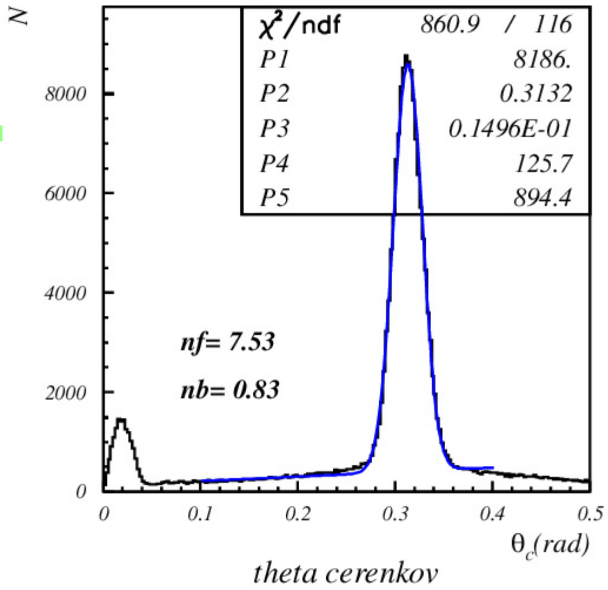


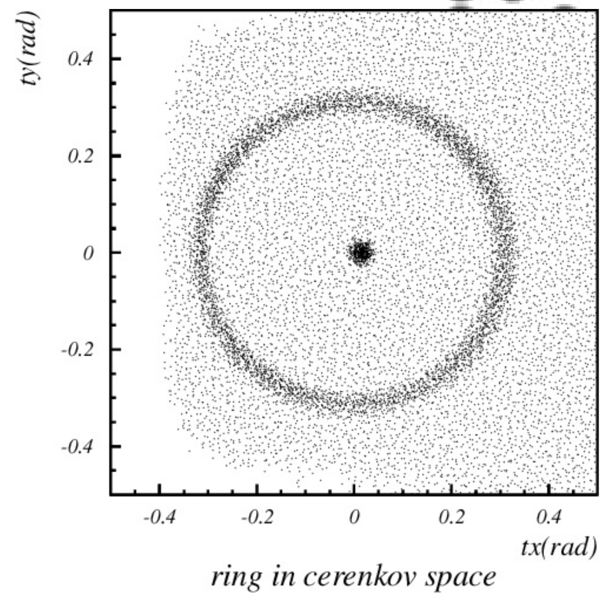
- single photon resolution: dual radiator ~same as single (of half the thickness) for the full momentum range

- number of detected hits: dual radiator has a clear advantage

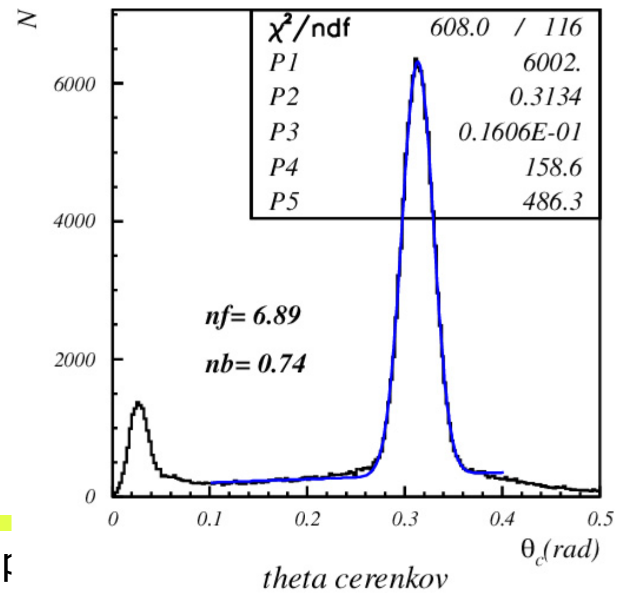
FOCUSING CONFIGURATION - inclined tracks

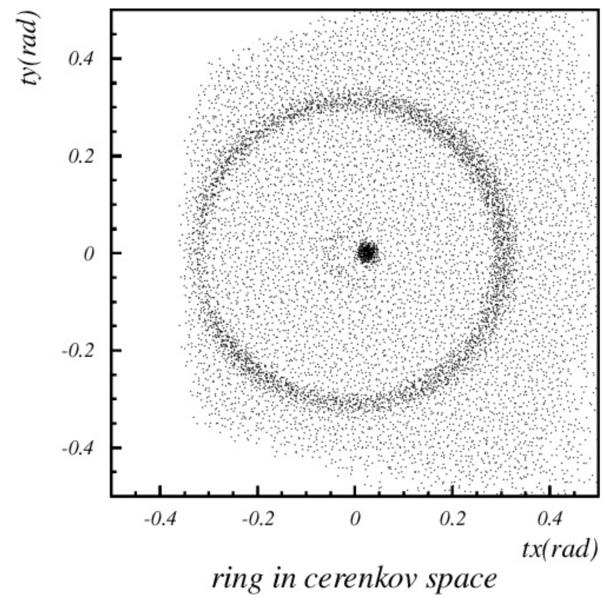
- 2+2cm aerogel
- angle 20°





- 2+2cm aerogel
- angle 30°



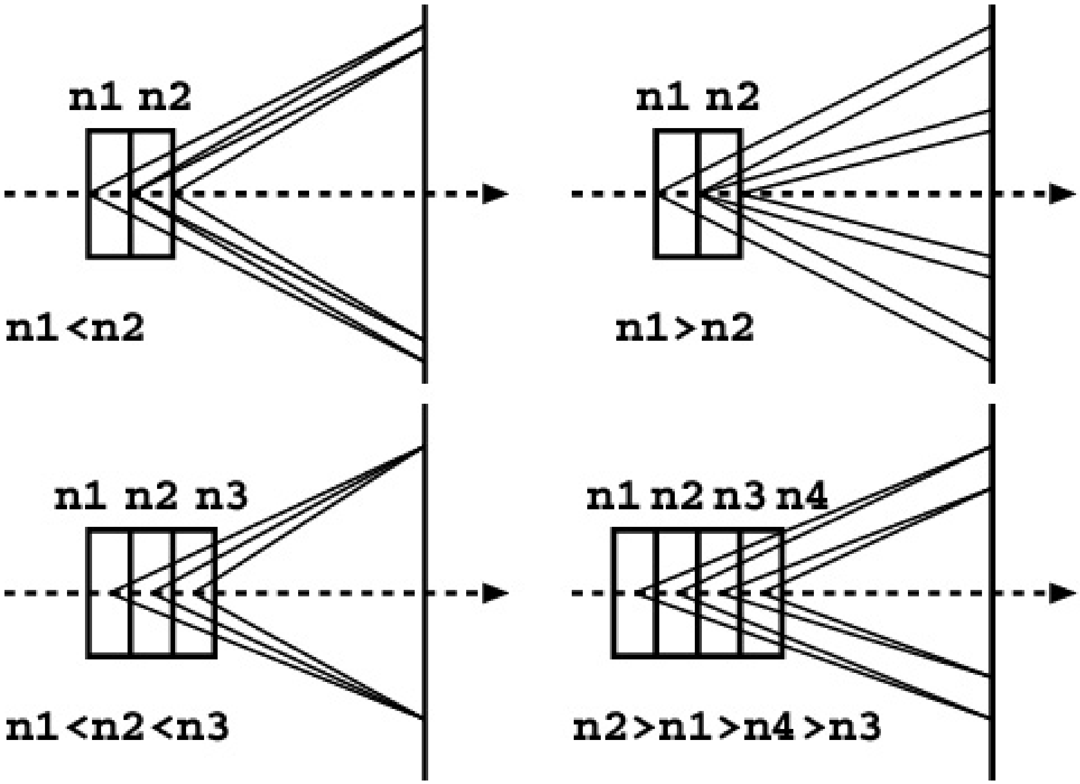


Works as well!

MULTILAYER EXTENSIONS

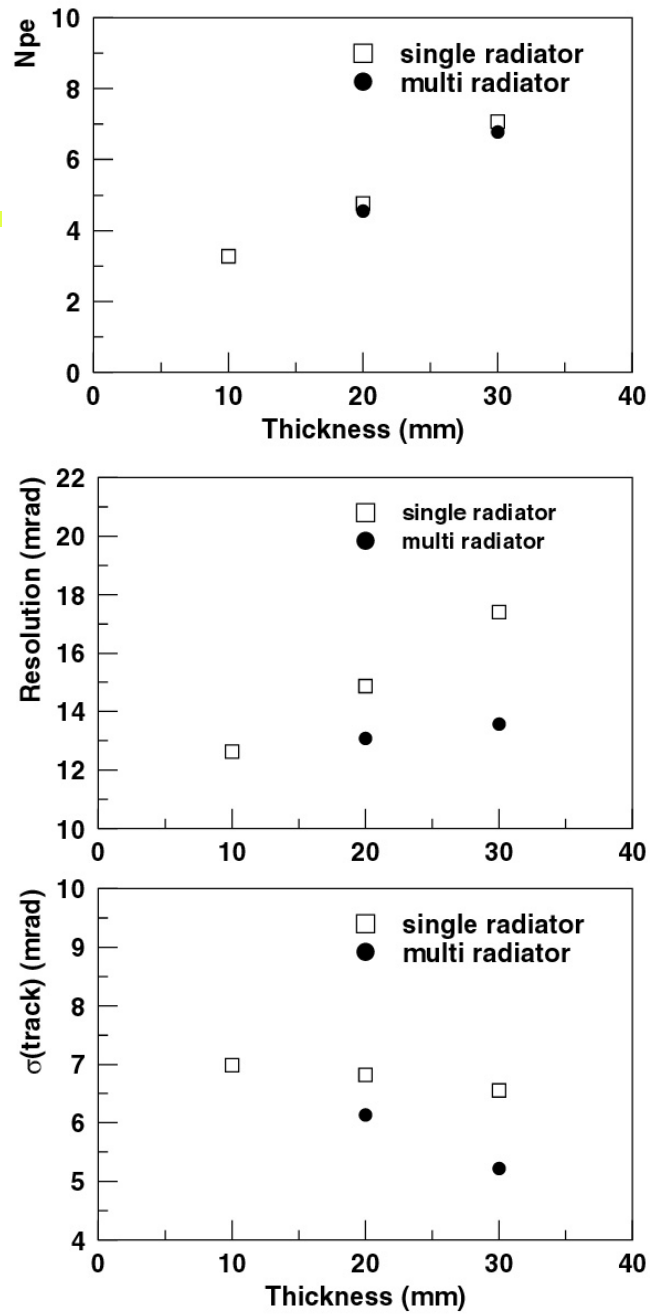
focusing

defocusing

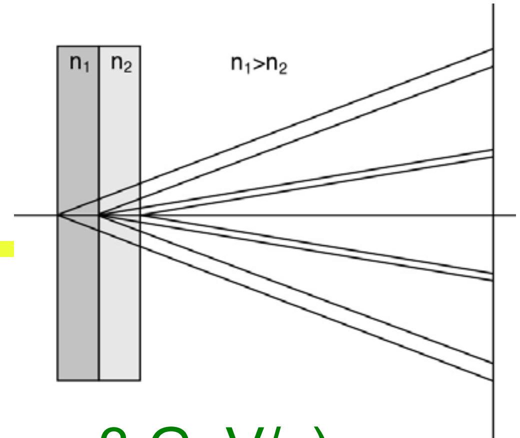


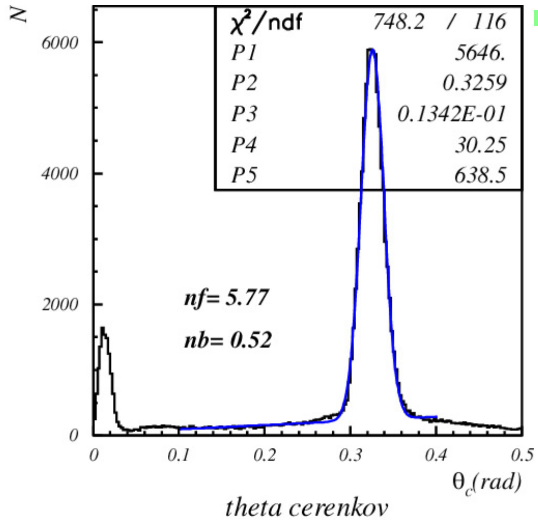
focusing

focusing-defocusing

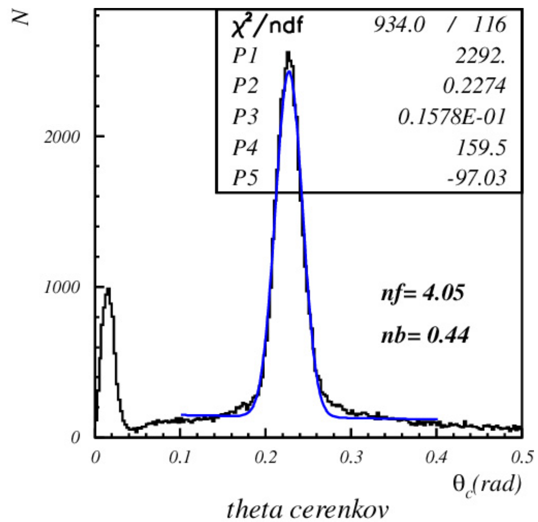


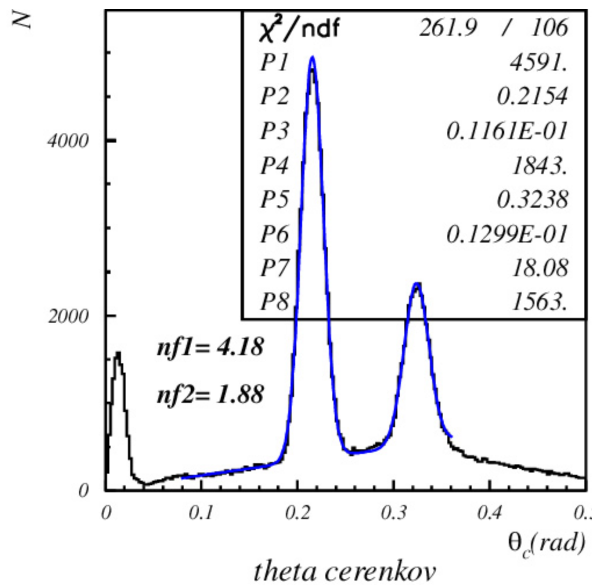
Defocusing configuration, data

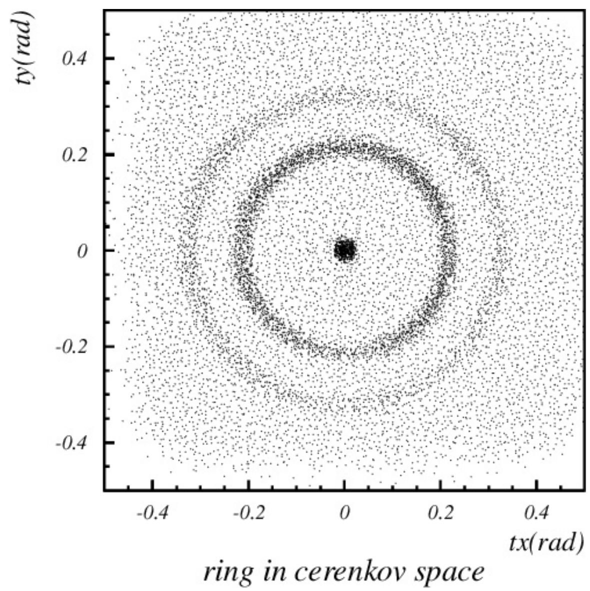




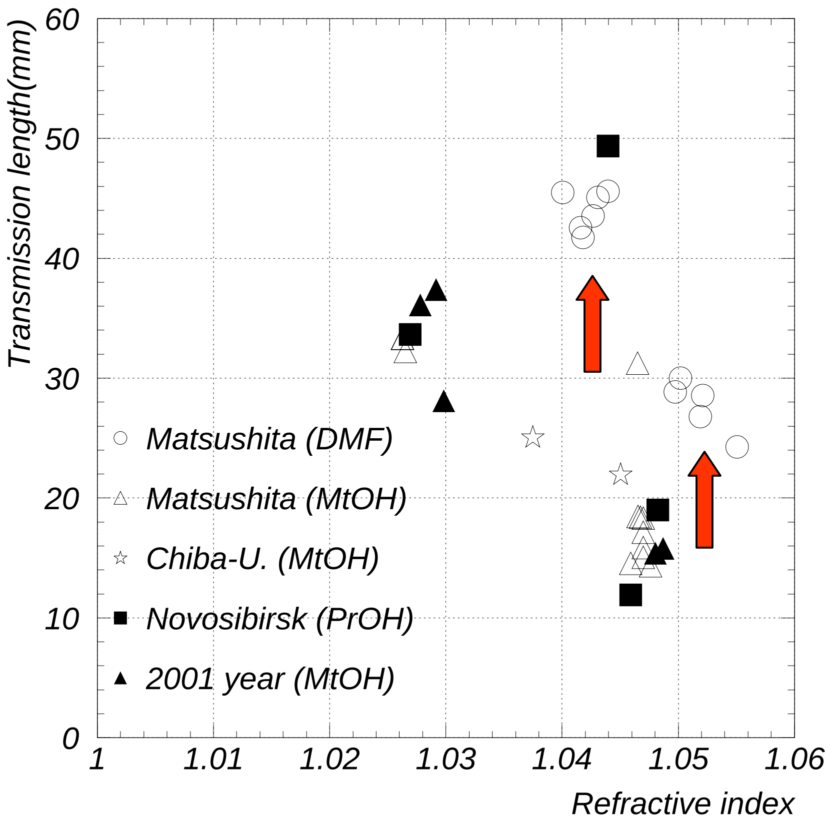
- two well separated rings (pions, 3 GeV/c)
- decrease of n_1 peak due to absorption







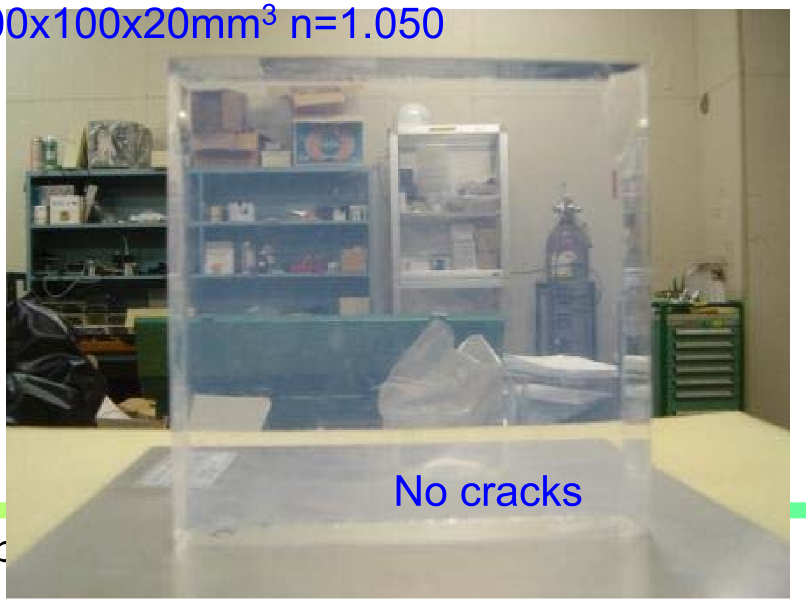
Aerogel production R&D



Transmission length vs refractive index

- Reported last year: better optical quality for n~1.05 hydrophobic aerogel
- a new solvent (Di-Methyl-Formamide instead of Methyl-alcohol)
- precursor (Methyl-silicate-51) from a different supplier
- -> considerable improvement

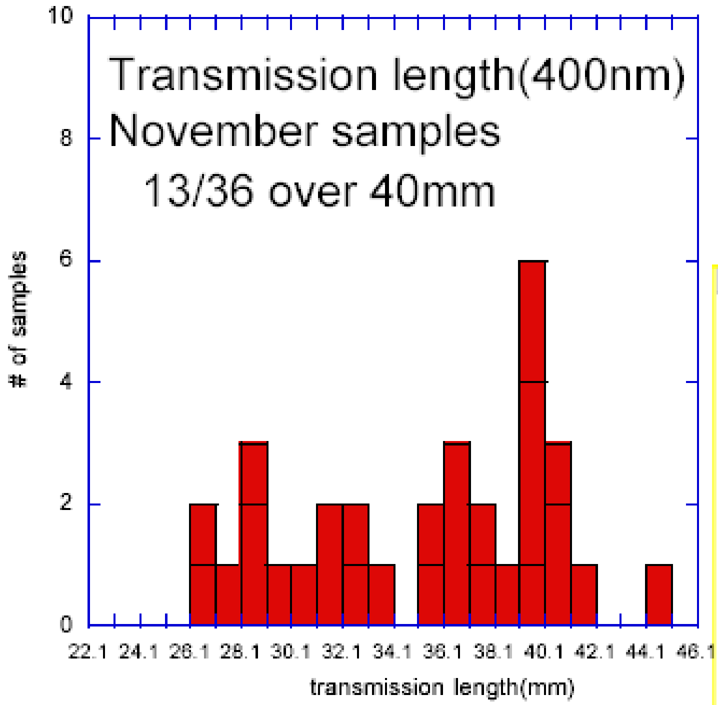
$100x100x20mm^3$ n=1.050

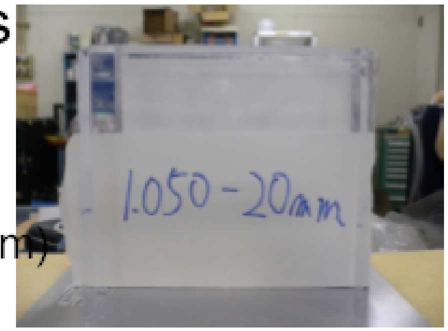


No cracks

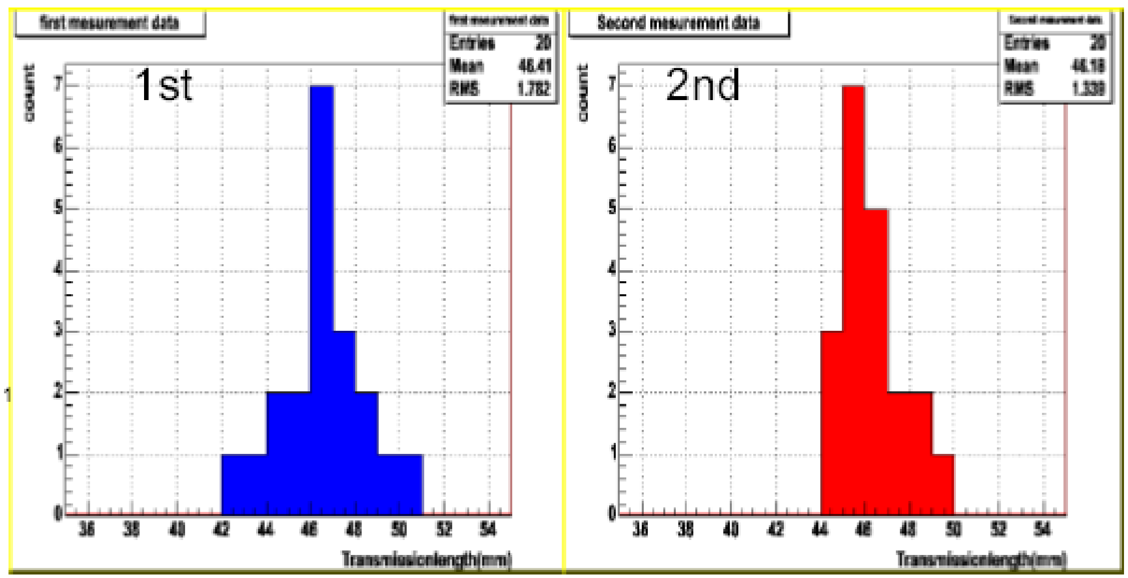
Aerogel production R&D

- Further optimization for n = 1.050 samples





Transmission length(400nm)
March samples

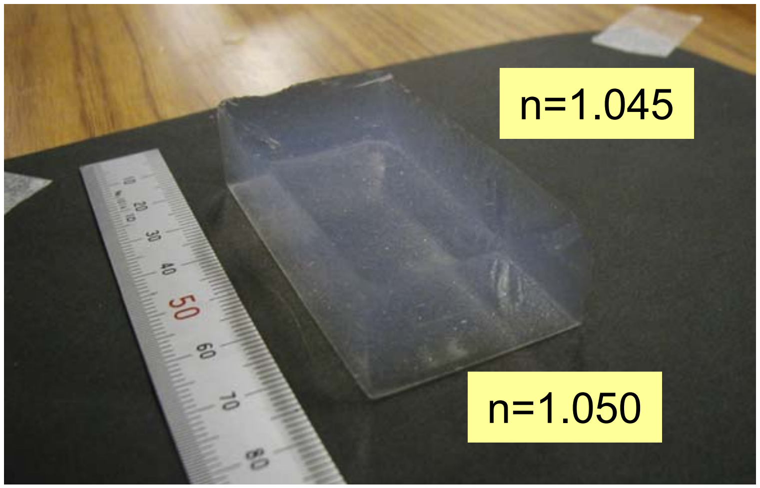


Av:46.4+-1.8mm

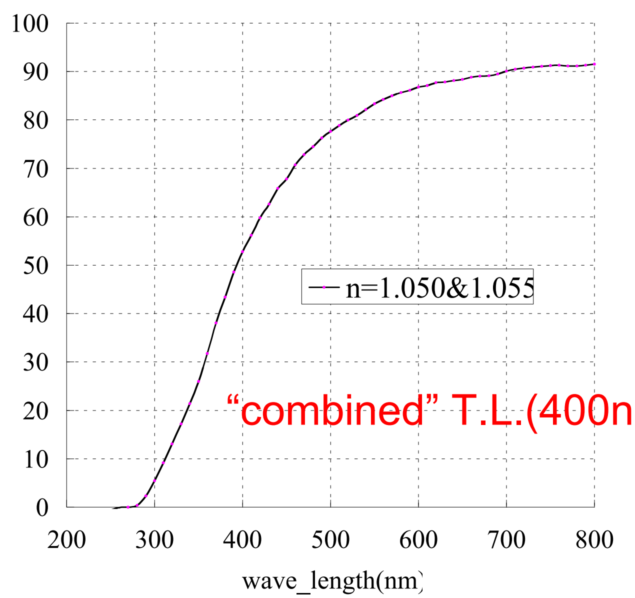
Av:46.2+-1.4mm

All samples better than 40mm

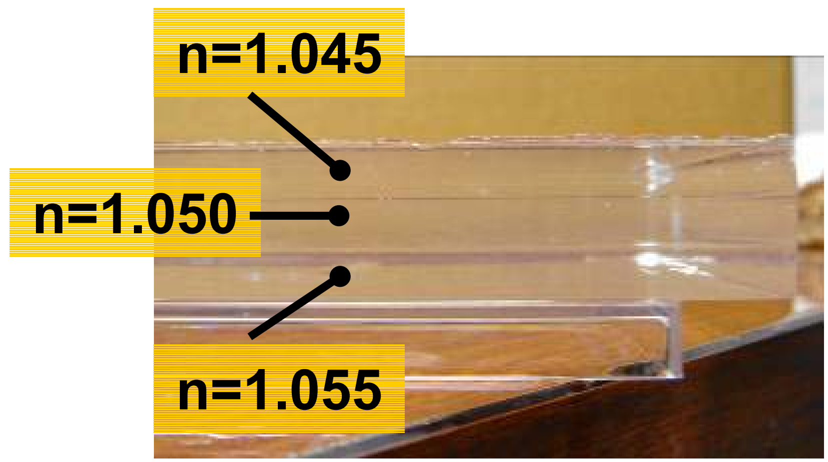
Aerogel production: multilayer samples



- 2 (or more) layers with different n
- layers attached directly at molecular level
- easy to handle
- Insensitive to possible surface effect

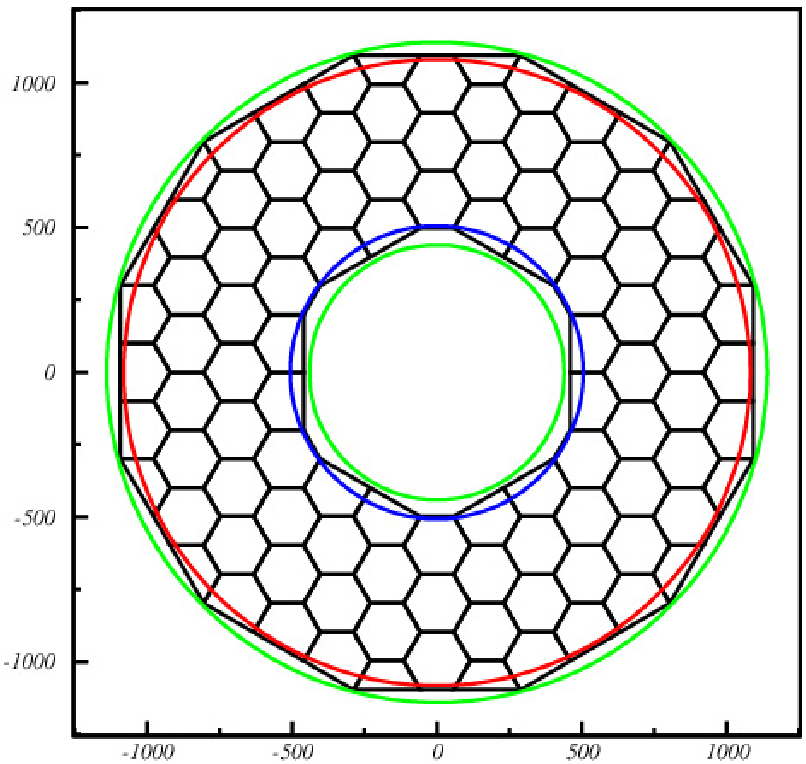


"combined" T.L.(400nm)=41.1mm



Tiling of the radiator

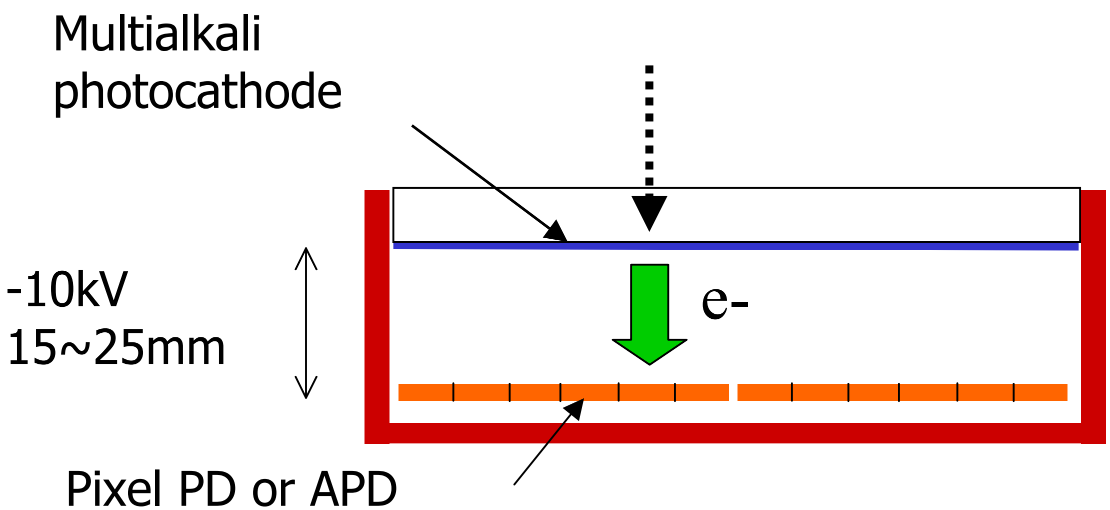
Minimize photon yield losses at the aerogel tile boundary: hexagonal tiling scheme



- Cut into hexagonal shape from a square block
- Machining device: use “water-jet” thanks to hydrophobic nature

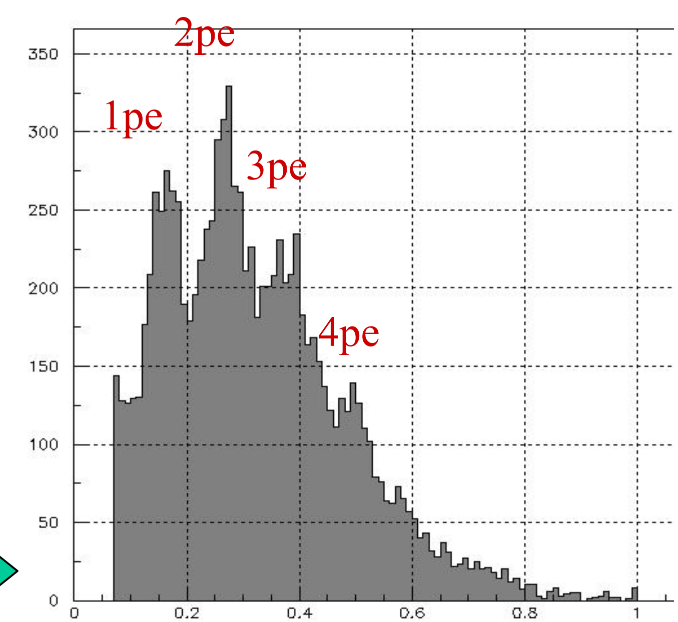
Development and testing of photon detectors for 1.5 T

- Baseline: large area HPD of the proximity focusing type
- Backup: MCP-PMT



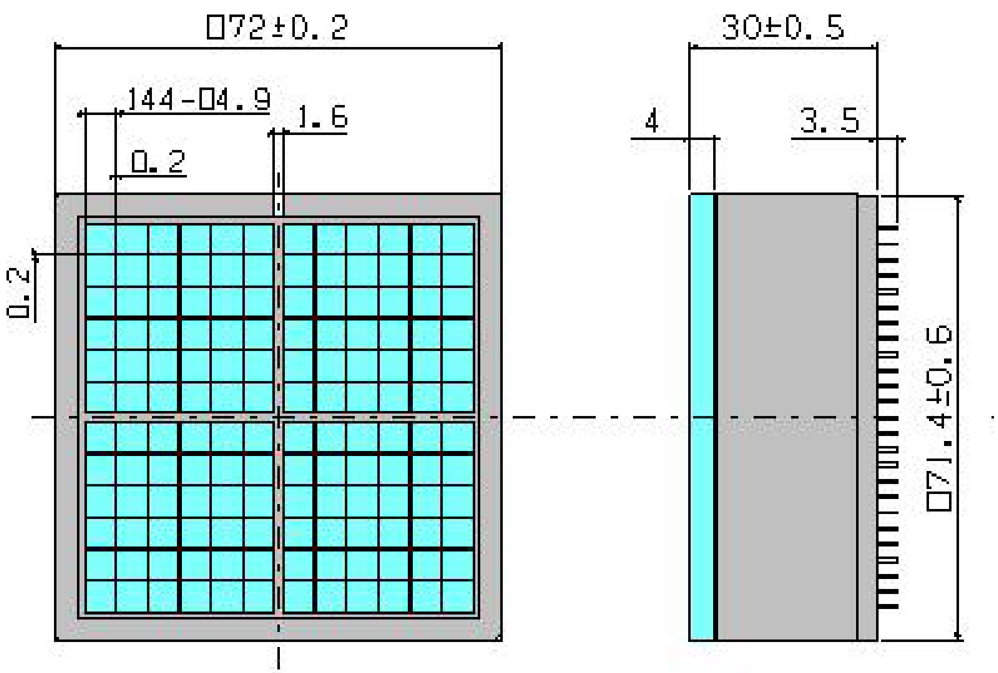
R&D project in collaboration with HPK

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



HPD development

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



Ceramic HPD box

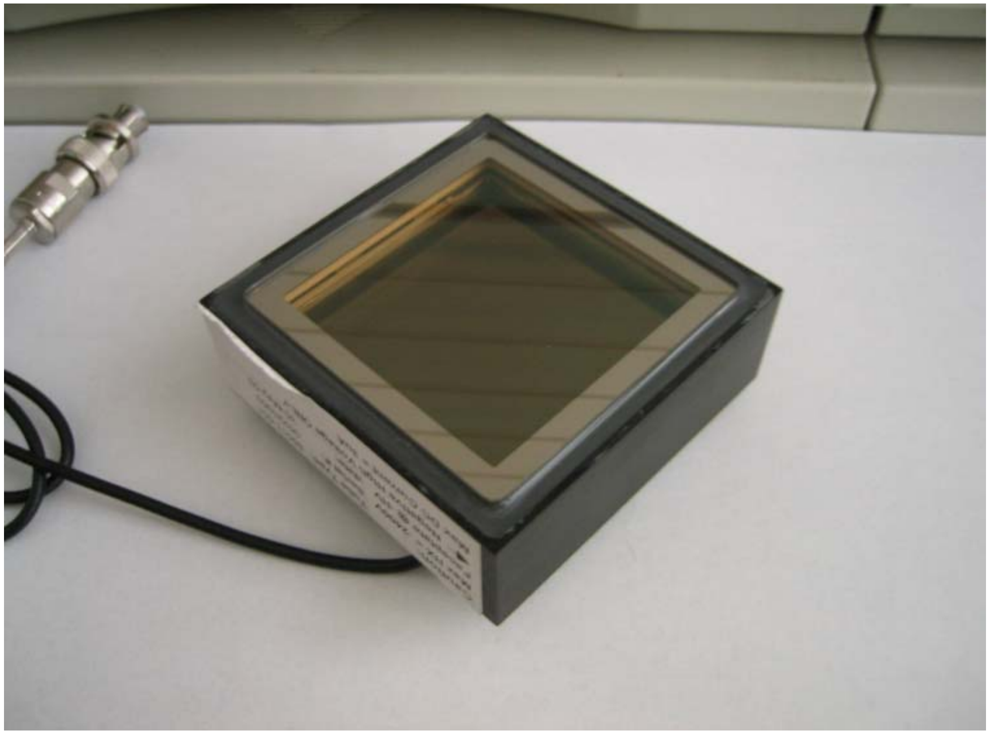
First tests carried out. Problems with sealing the tube at the window-ceramic box interface.

Waiting for the next batch in September.

Photon detector R&D – backup option: 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%

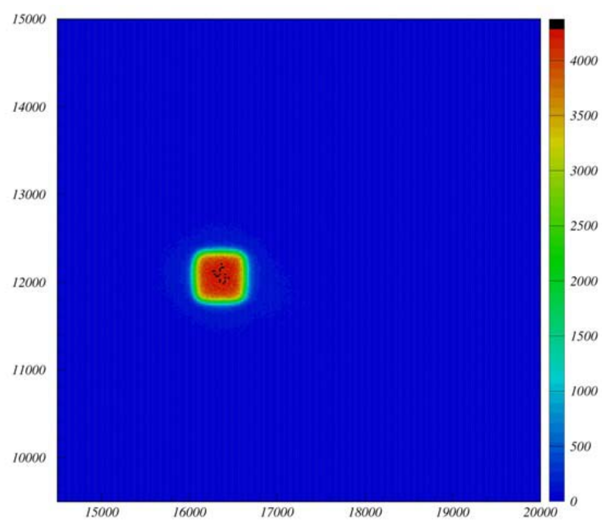


Photon detector R&D – Burle MCP-PMT bench tests

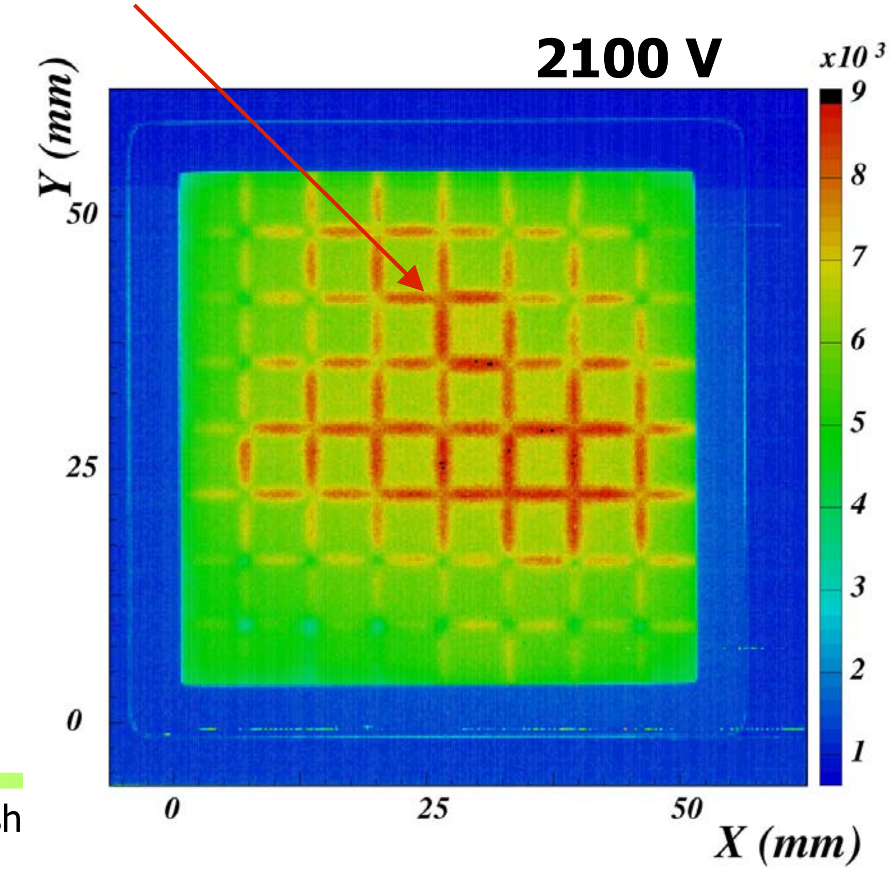
Study uniformity of the sensitivity over the surface

single channel response:

- uniform over pad area
- extends beyond pad area (charge sharing)

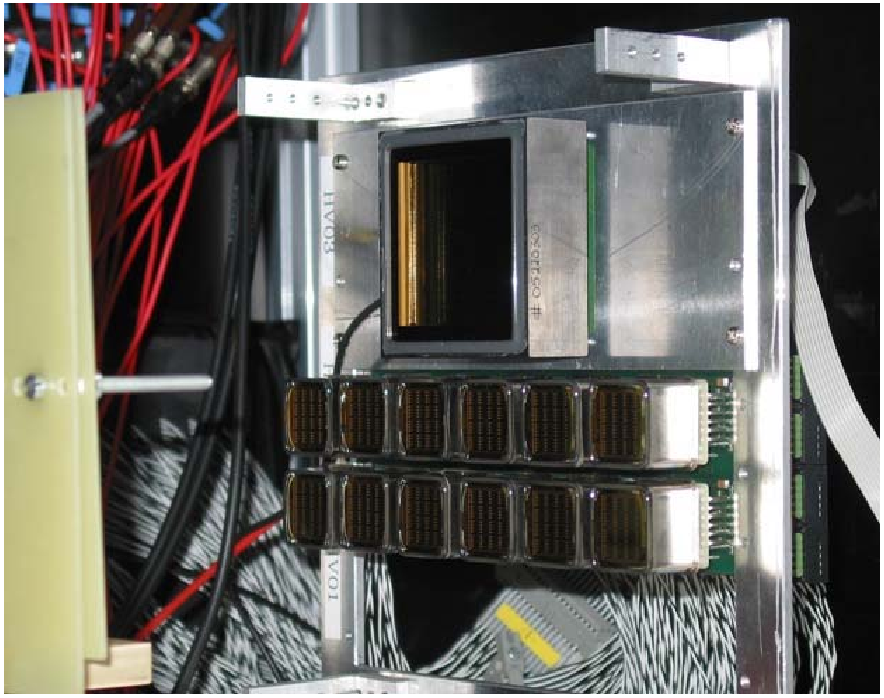


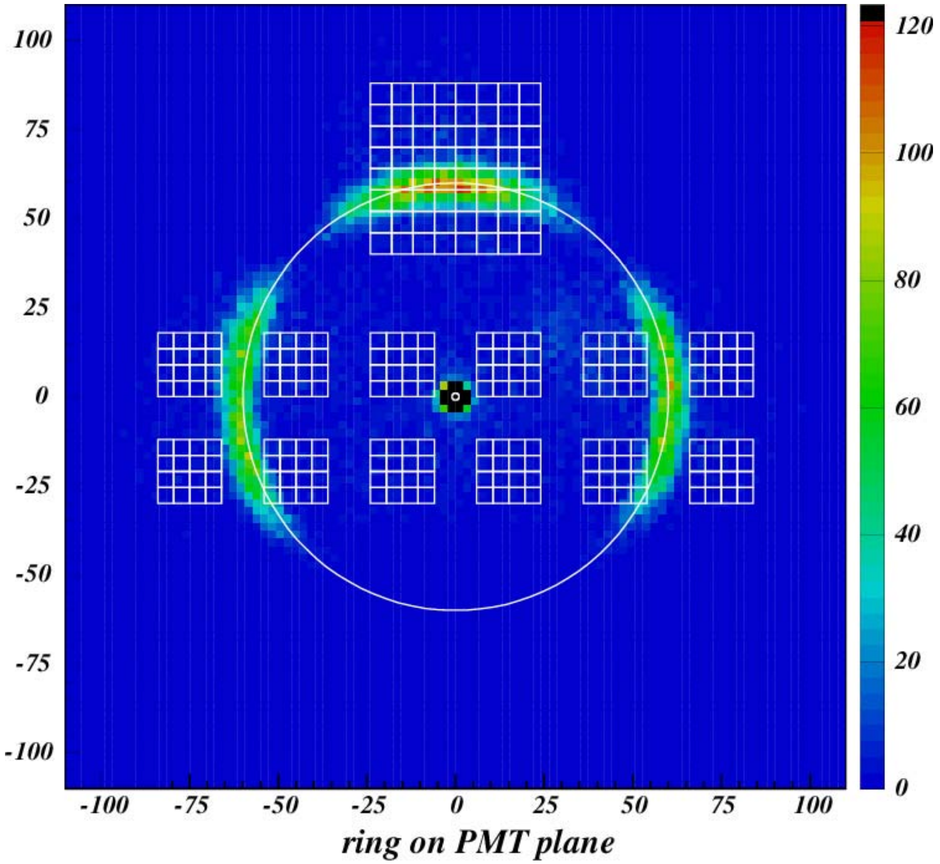
count rates - all channels: charge sharing at pad boundaries



Burle MCP PMT beam test

- **BURLE MCP-PMT** mounted together with an array of 12(6x2) **Hamamatsu R5900-M16 PMTs** at 30mm pitch (reference counter)





Burle MCP PMT beam test 2

Resolution and number of photons (clusters)

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

-> ~ 4 σ π/K separation at 4 GeV/c

Open questions

Operation in high magnetic field:

- the present tube with 25μm pores only works up to 0.8T, for 1.5T need ~10μm

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 hits per ring

σ_ϑ: 6 mrad -> 4.5 mrad (per track)

-> >5 σ π/K separation at 4 GeV/c

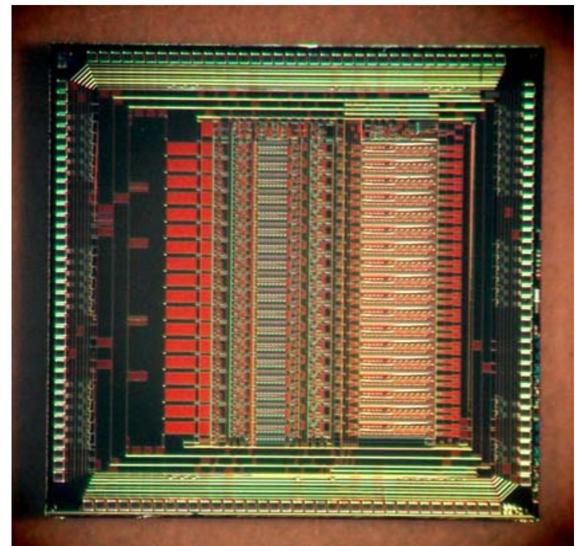
Aging of MCP-PMTs ?

Read-out electronics: ASIC under development

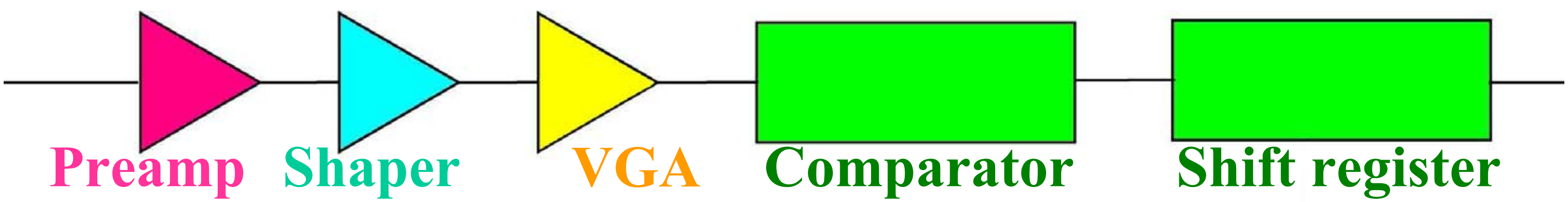
Need high density front-end electronics.
Need high gain with very low noise amplifiers.
Deadtimeless readout scheme-> Pipeline.

Develop an ASIC for the front-end electronics

- Gain : 5 [V/pC]
- Shaping time : 0.15 [μ s]
- S/N : 8 (@2000[e])
- Readout : pipeline with shift register
- Package : 18 channels/chip



□4.93[mm]



Read-out electronics

ASIC controled and read-out by a control board (for tests: can also be done with standard VME modules+level adapters)

Detailed evaluation of the system is under way.

Preparation of the read-out of an array of 3x3 HAPDs in a beam test.

Backup options use chips from Ideas: a VA/TA based system developed by the K2K group at KEK and VA64TAP+LS64

Summary

- Proof of principle shown already last time.
- More photons: employ radiators with multiple refractive indices. Idea successfully tested in beam tests.
- Aerogel production: transmission length improved, new cutting methods tested, multiple layer samples.
- R&D issues: development and testing of a multichannel photon detector for high mag. fields
- mass production of large aerogel tiles
- readout electronics

Back-up slides

Read-out electronics

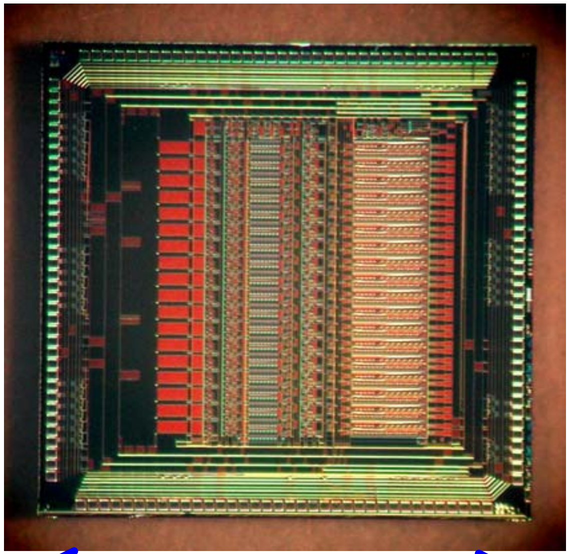
- Total number of readout channels for the full detector amounts to 86k.
- Detector characteristics
  - Leakage current: 10 or 25 ［nA］
  - Detector capacitance: 10 or 70 ［pＦ/pixel］
  - signal: 2000 or 20000 [electron/photon]

- Need high density front-end electronics.
- Need high gain with very low noise amplifiers.
- Deadtimeless readout scheme-> Pipeline.

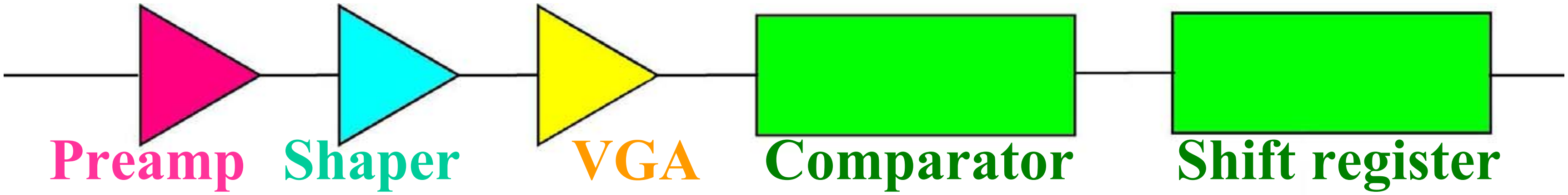
Develop an ASIC for the front-end electronics

Read-out electronics: ASIC under development

- Basic parameters for the ASIC (Rohm CMOS 0.35 μ m)
  - Gain : 5 [V/pC]
  - Shaping time : 0.15 [μ s]
  - VGA : 1-16
  - S/N : 8 (@2000[e])
  - Readout : pipeline with shift register
  - Package : 18 channels/chip
  - Control : LVDS
  - Power consumption : 5 m W/channel
- Detailed evaluation is under way.



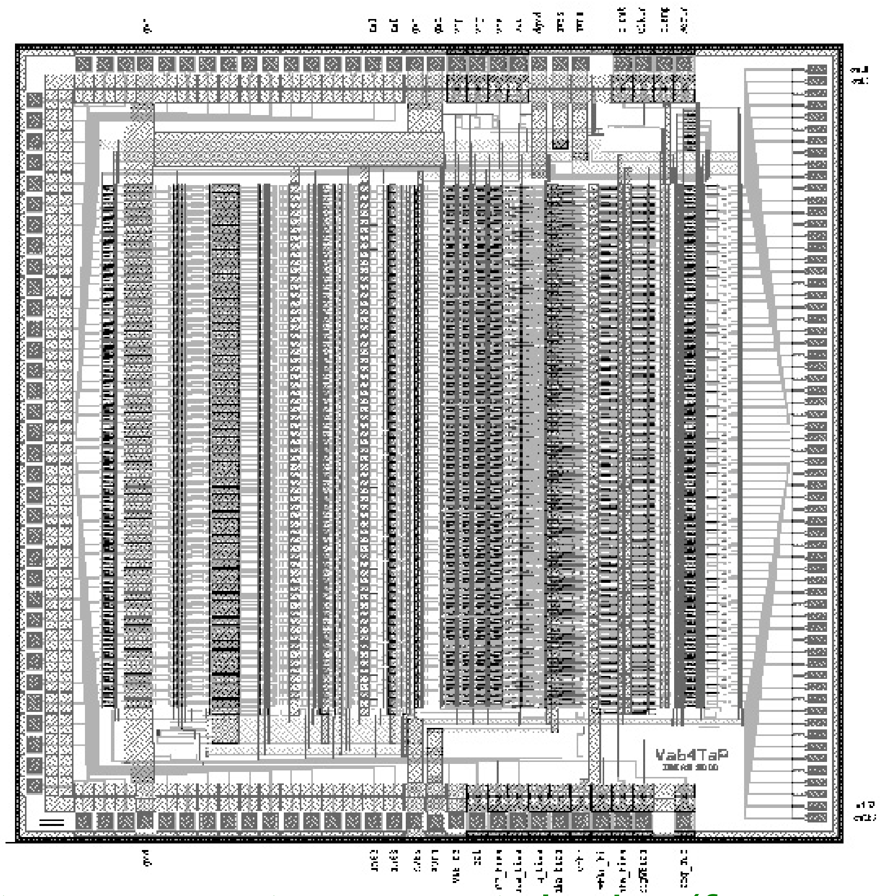
□4.93[mm]



VA64TAP: backup read-out electronics

VA64TAP is a low-power, low-noise ASIC with 64 channels, each with:

- preamplifier (ENC ~ 500 @ 10 pF)
- amplifier (can be switched off)
- fast CR-RC shaper (75 ns)
- discriminator with 4-bit trim-DAC
- threshold uniformity: +-200e-
- threshold nominal value: 3000e-
- power: 2.3 mW/ch.
- parallel output
- die size: 5.5mm x 5.4mm

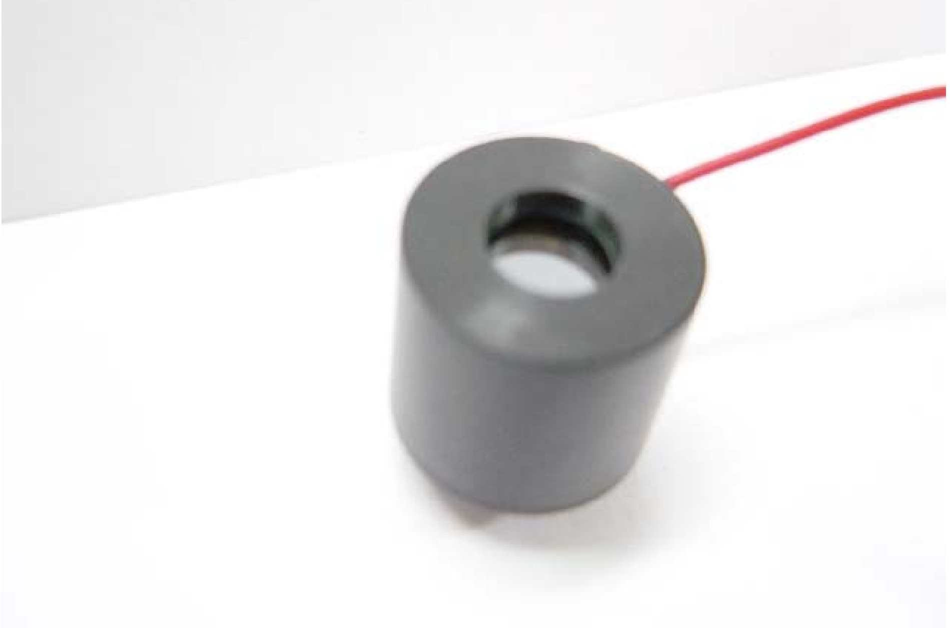


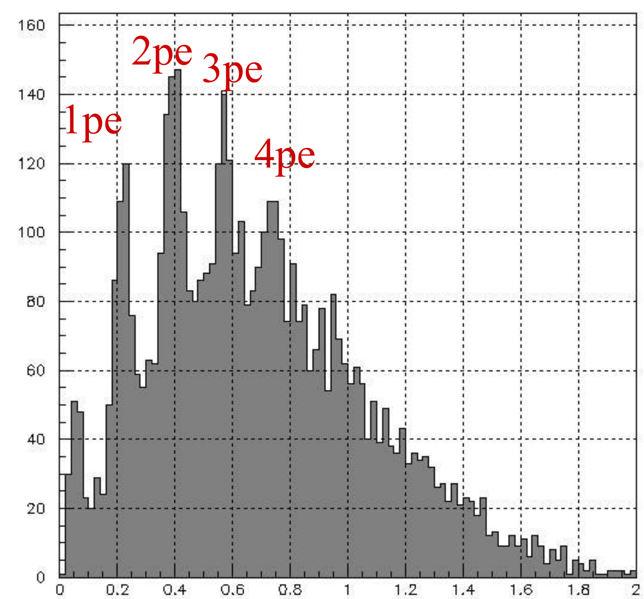
Auxiliary chip LS64: logic level adapter, converts current logic (from VA64TAP) into CMOS logic (0V, 2.5V - 5V).

Same lateral dimensions, direct channel to channel bonding to VA64TAP

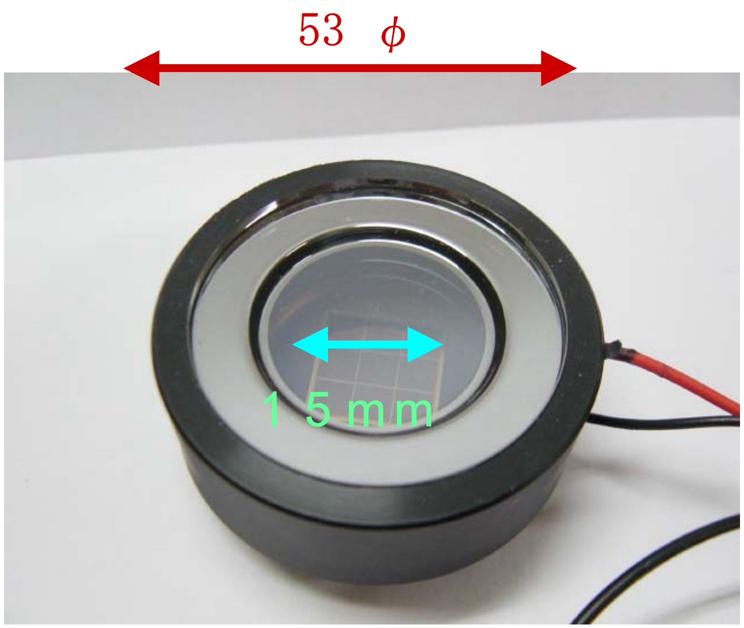
Prototype Test
- single-channel HPD -

Leak current : 4 [nA]
Detector capacitance : 20 [pF]
Gain (8kV) : 1500 [electron/photon]
Bias voltage : 80 [V]

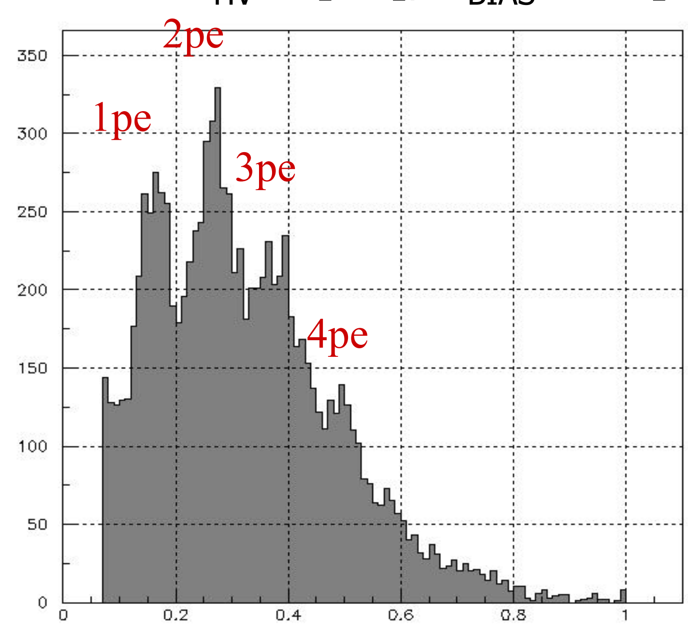




Prototype Test
- 3×3multi-channel HAPD -



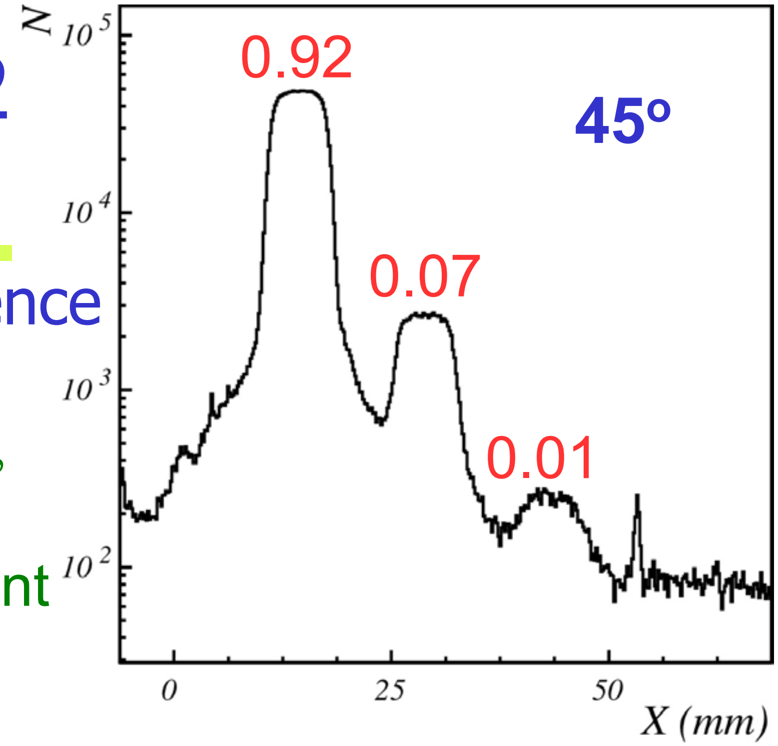
- Diode : □5 [mm/ch]
- Gain : 26000 [electron/photon]
- C_d : 73 [pF]
- I_L : 14 [nA] (average/ch)
- Condition: V_{HV}=8[KV], V_{BIAS}=320[V]



Gain of the HAPD is higher than for the HPD, but the noise level is also higher due to its large detector capacitance.

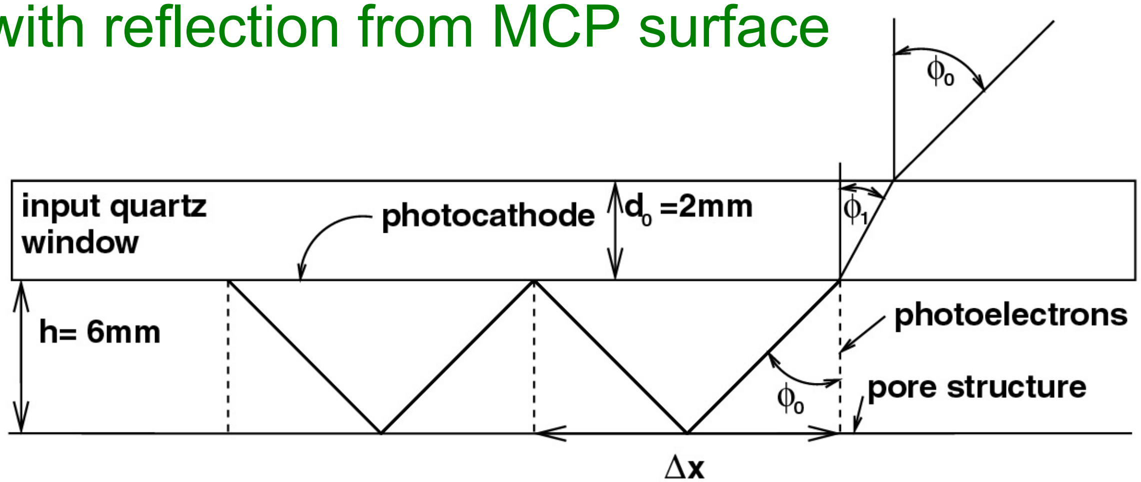
The HPD shows a better single photon response.

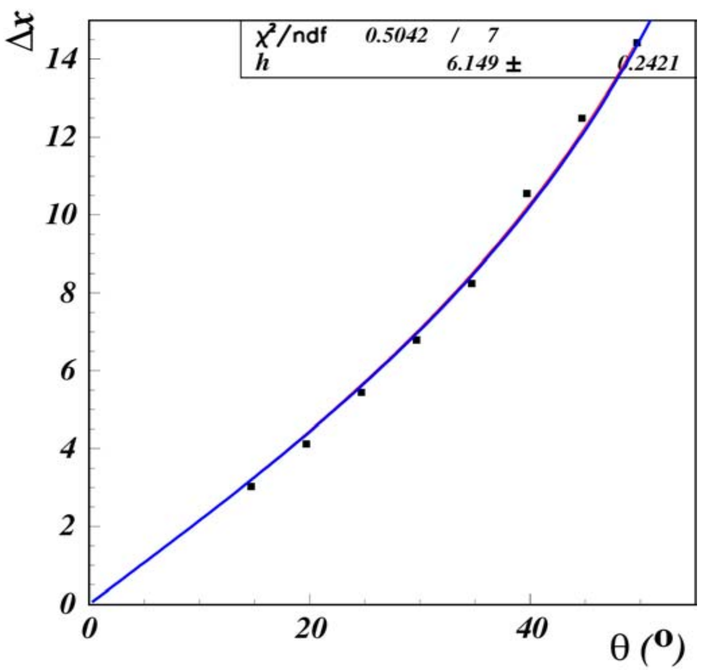
MCP-PMT bench tests 2



Satelite images for finite angles of incidence

- relative intensities of main peak, first and second reflections are 0.92, 0.07 and 0.01, respectively
- displacement of secondary image consistent with reflection from MCP surface

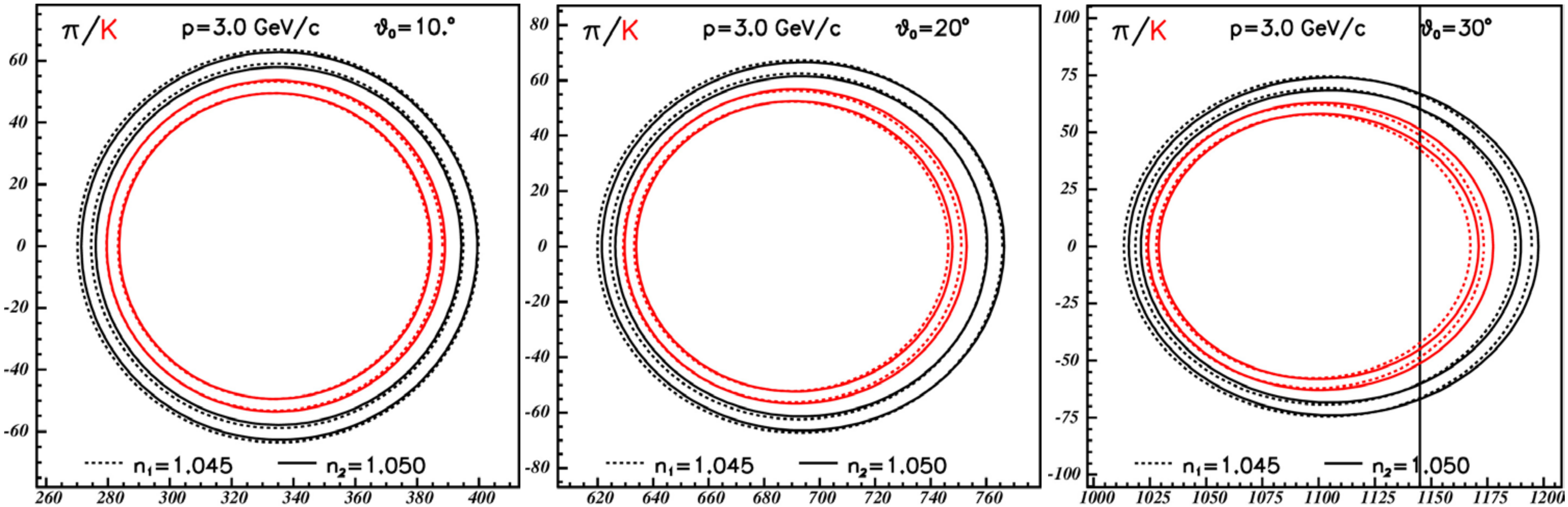




- impact on spatial resolution (+10% @18°)
- impact on timing resolution $\Delta t \sim 40$ps

FOCUSING CONFIGURATION - different incidence angles

- overlapping of rings for inclined tracks
- expected range ~ 17°-34°



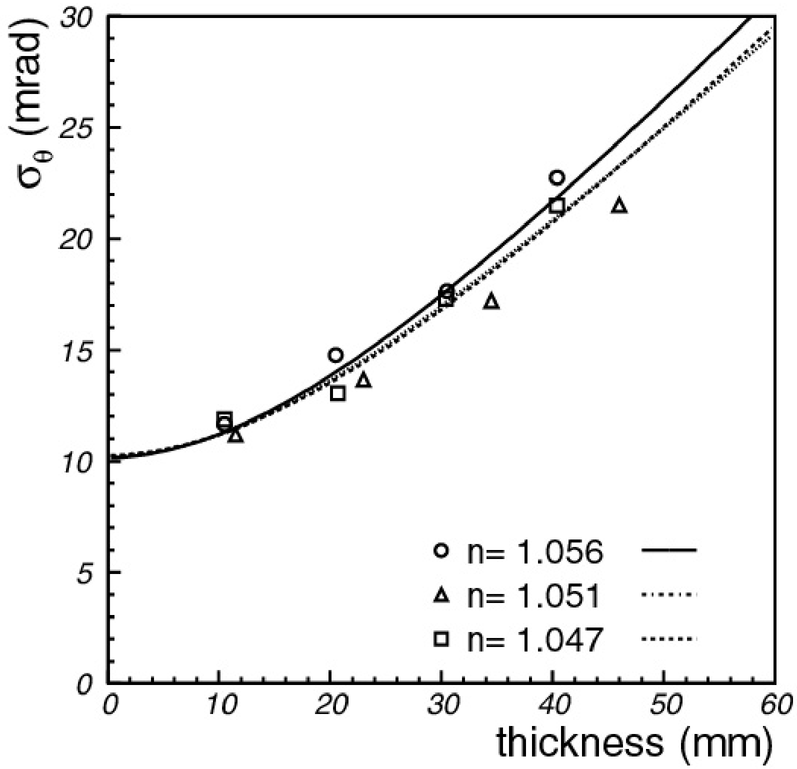
Good overlapping up to 30°

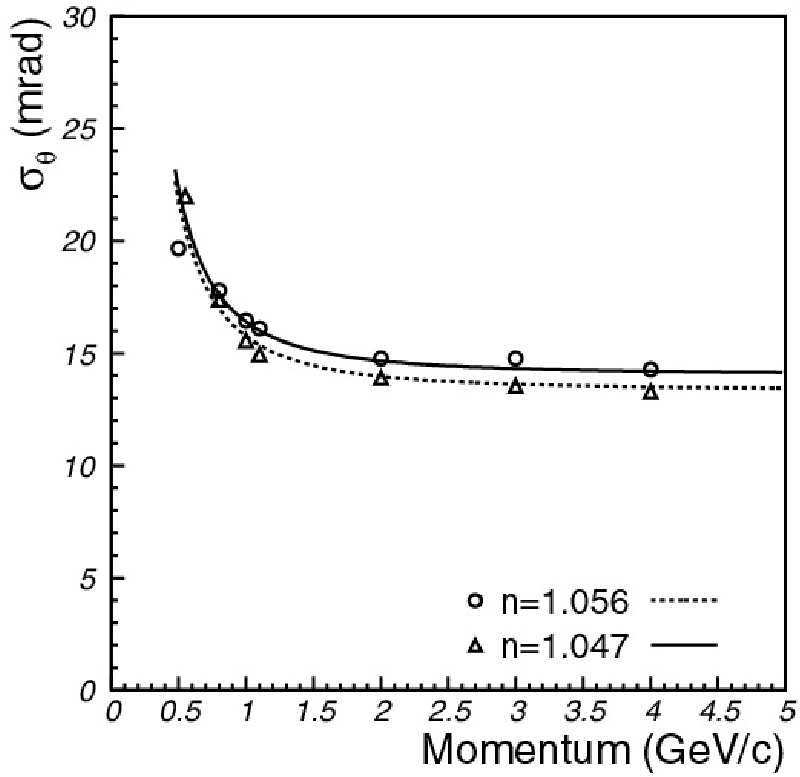
Resolution for single photons

In agreement with expectations (+ 6-8 mrad)

Typically around 13 mrad (for 2cm thick aerogel)

Shown as a function of thickness, momentum

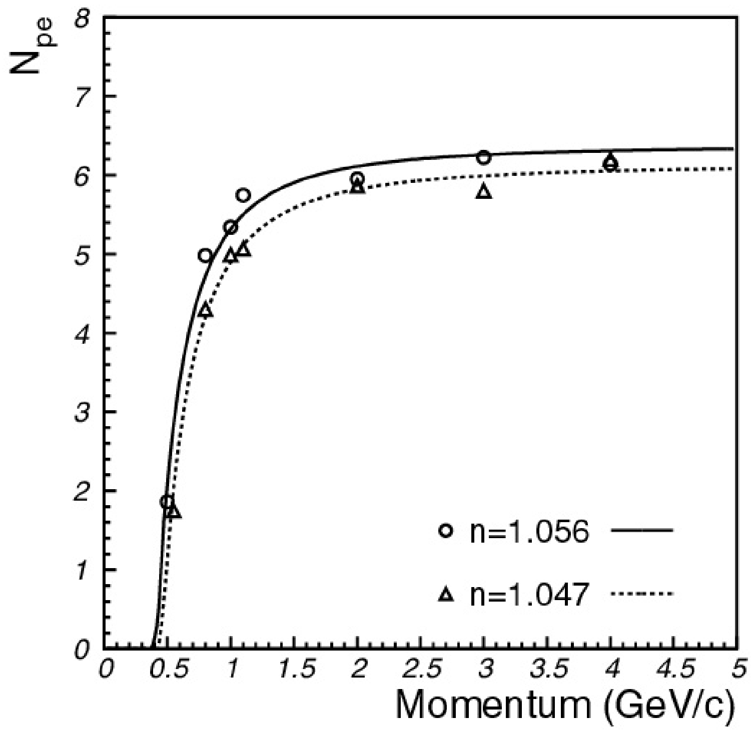


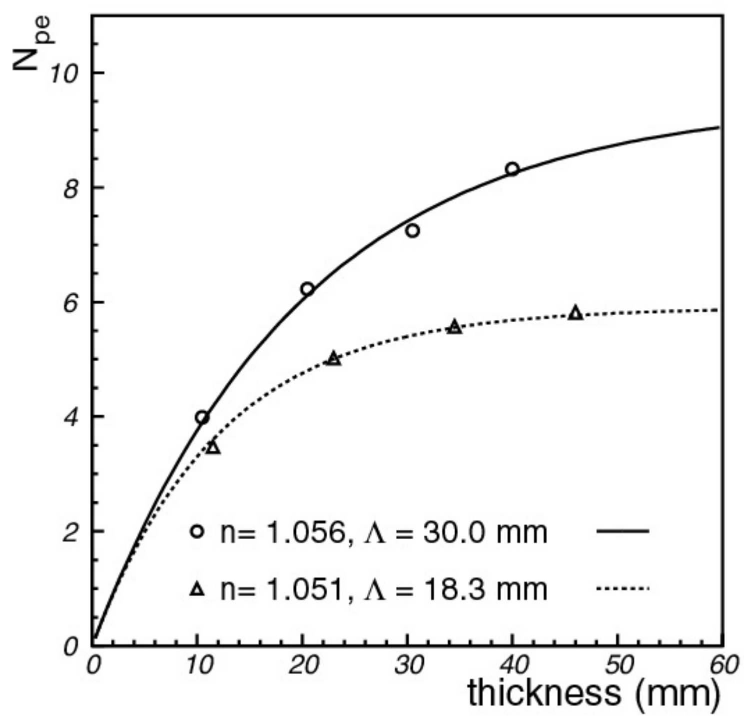


Photon detector: array of 16 H8500 PMTs

Number of photons

Shown as a function of momentum, thickness

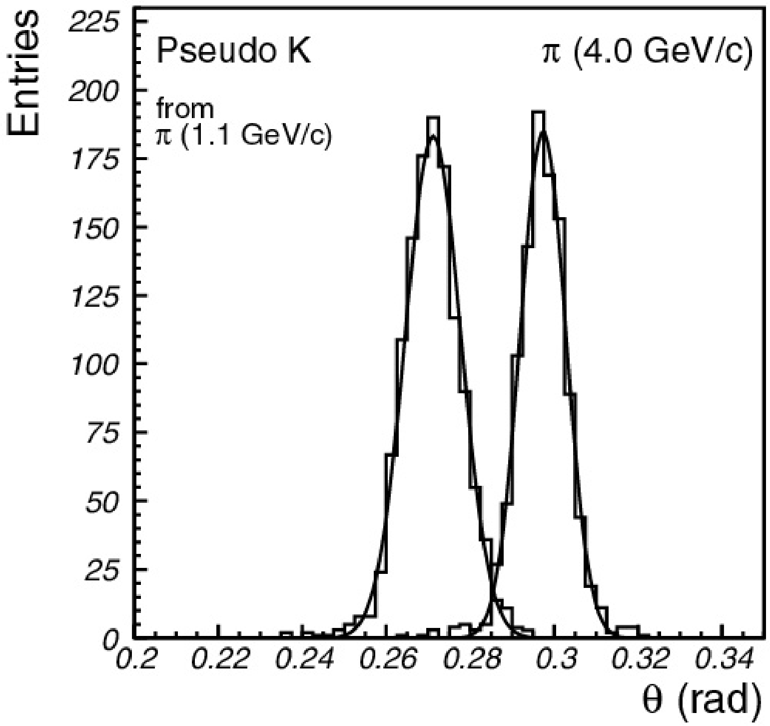




Again: in reasonable agreement with expectations

Photon detector: array of 16 H8500 PMTs

PID capability on test beam data



From typical values (single photon resolution 13mrad and 6 detected photons) we can estimate the Cherenkov resolution per track: 5.3mrad;

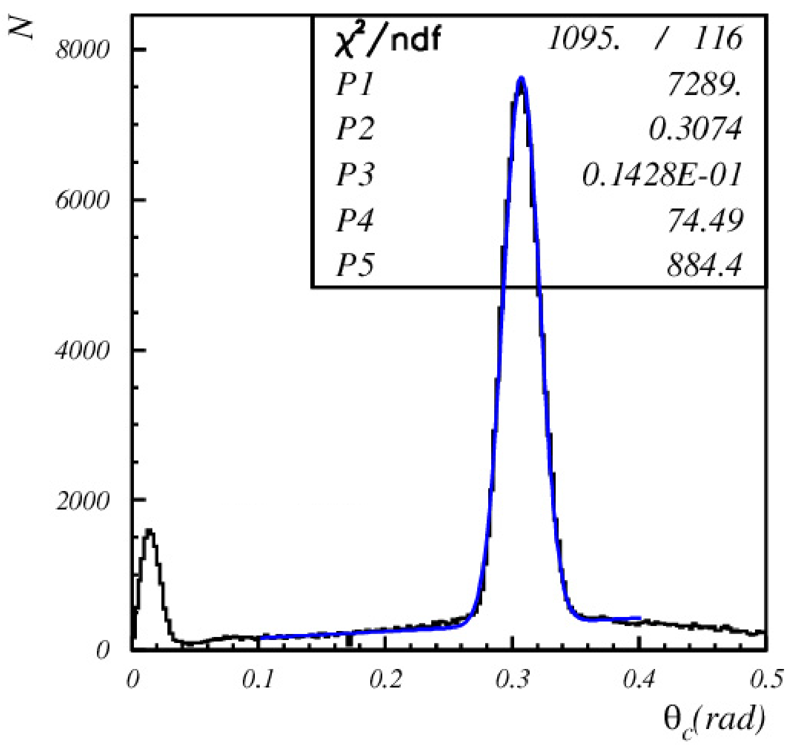
-> 4.3sigma p/K separation a 4GeV/c.

Illustration of PID performance: Cherenkov angle distribution for pions at 4GeV/c and 'kaons' (pions at 1.1GeV/c with the same Cherenkov angle as kaons at 4GeV/c). Details: NIM paper

Photon detector: array of 16 H8500 PMTs

Resolution studies

Cherenkov angle distribution



Radiator: thickness 20.5mm

σ_θ is obtained by fitting the θ distribution Gaussian + background

σ_θ (data)=14.3mrad

$$\sigma_\theta(\mathrm{calc}) = \sqrt{\sigma_{\mathrm{emp}}{}^2 + \sigma_{\mathrm{pix}}{}^2}$$

σ(calc)	11.8 mrad
σ_{pix}	7.8 mrad
σ_{emp}	8.8 mrad

$$\sigma_\theta = \sqrt{\sigma_{\mathrm{emp}}{}^2 + \sigma_{\mathrm{pix}}{}^2 + \sigma_{\mathrm{rest}}{}^2}$$

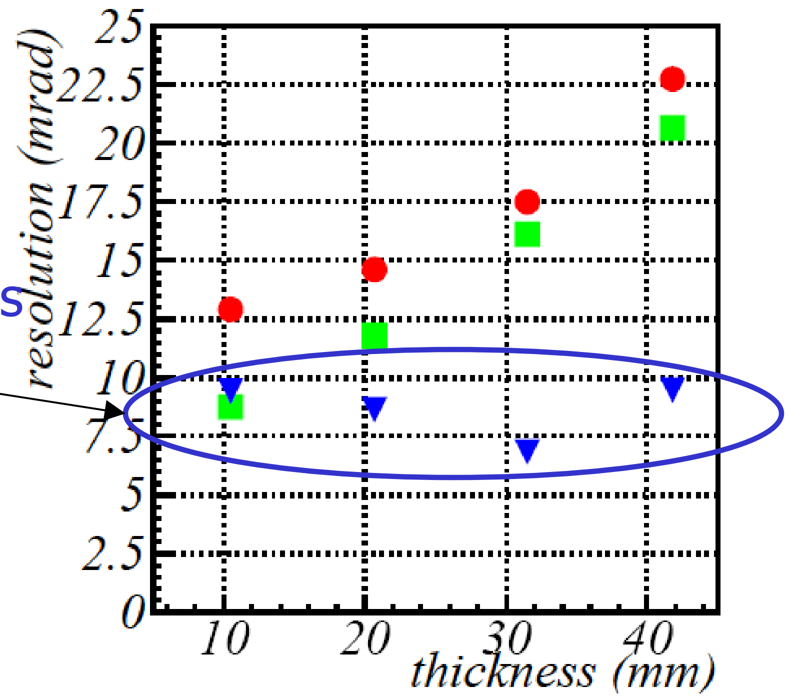
What is 'rest'?

Resolution studies 2

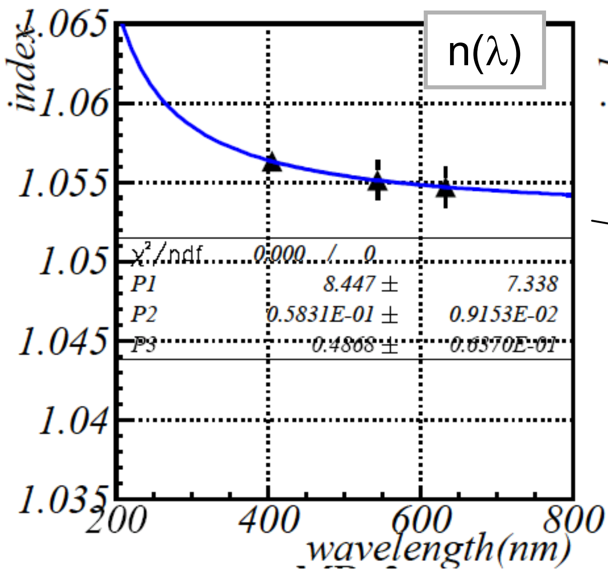
- σ_θ (data) : Data(n=1.046)
- σ_{calc} : Calculated value $(\sigma_{pix}^2 + \sigma_{emp}^2)^{1/2}$
- σ_{rest} : $(\sigma_{data}^2 - \sigma_{calc}^2)^{1/2}$

Rest component σ_{rest}=7~8 mrad
does not depend on radiator thickness

Cherenkov angle resolution



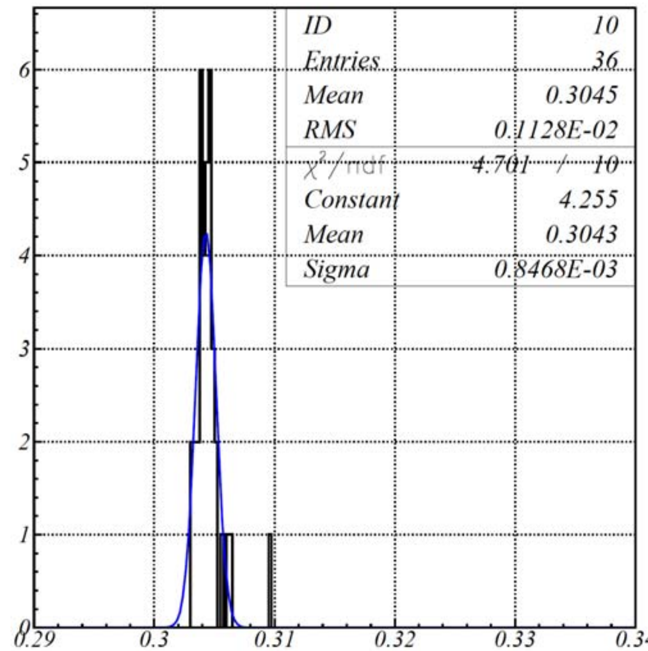
Refractive index



Chromatic error? 2-3 mrad (depends on the sample)

Resolution studies 3

Non-uniformity of the radiator? Group tracks according to the impact position in 5mmx5mm regions, plot Cherenkov angle distribution for each of them:

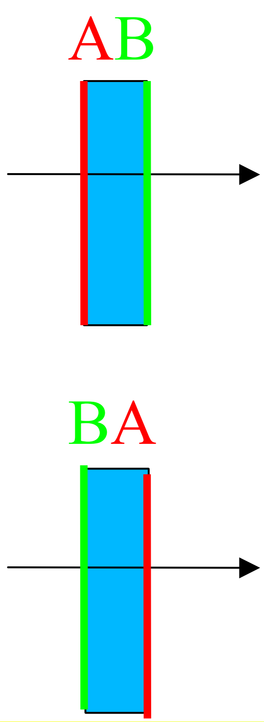


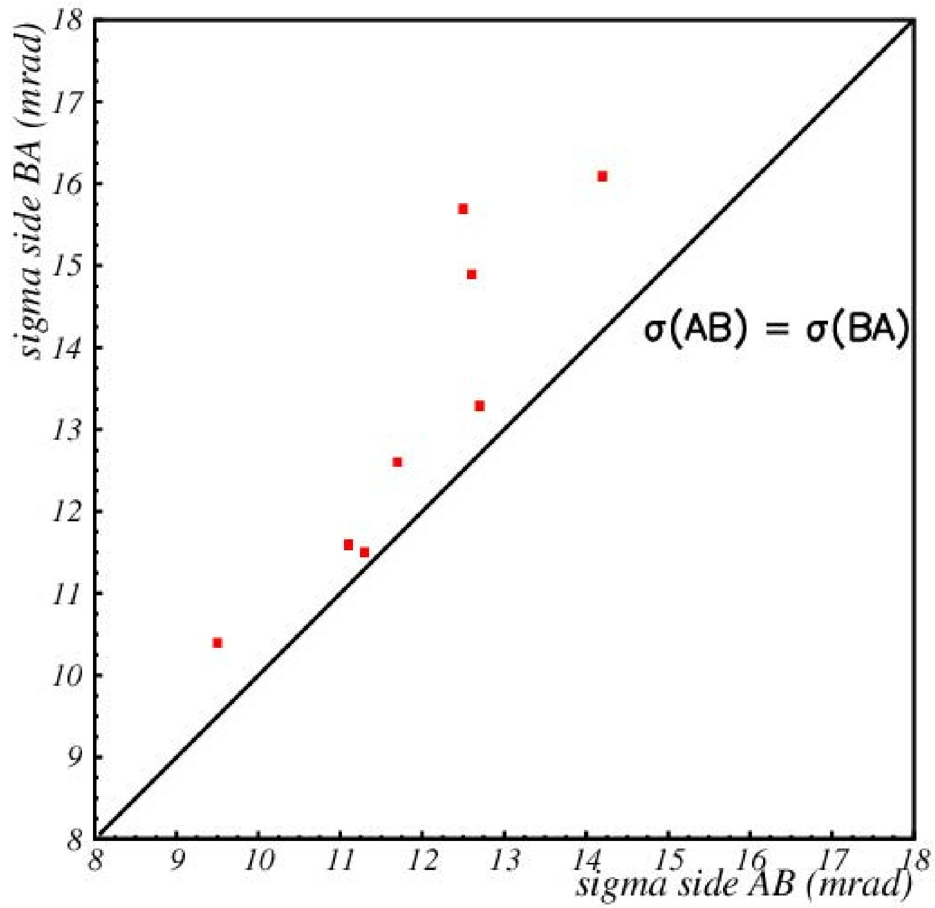
Cherenkov angle variation due to non-uniformity of aerogel: 1 mrad

Resolution studies 4

Does it depend on the orientation of the sample?

Measure the Cherenkov angle and sigma for both orientations of the aerogel tile
→some samples have large difference in sigma for AB and BA cases

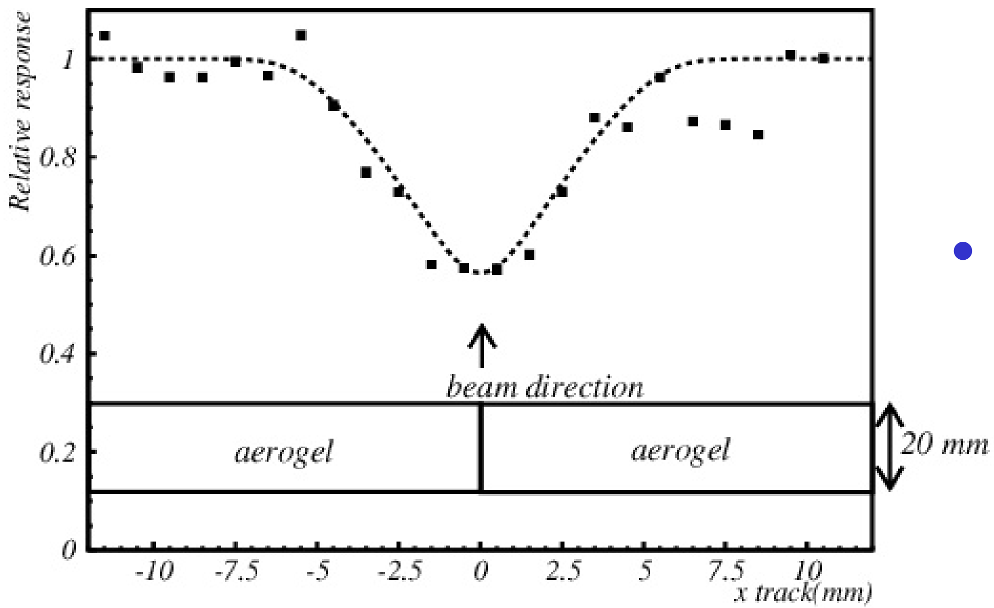




Is it focusing/defocusing? →under study

Yield losses at tile boundaries

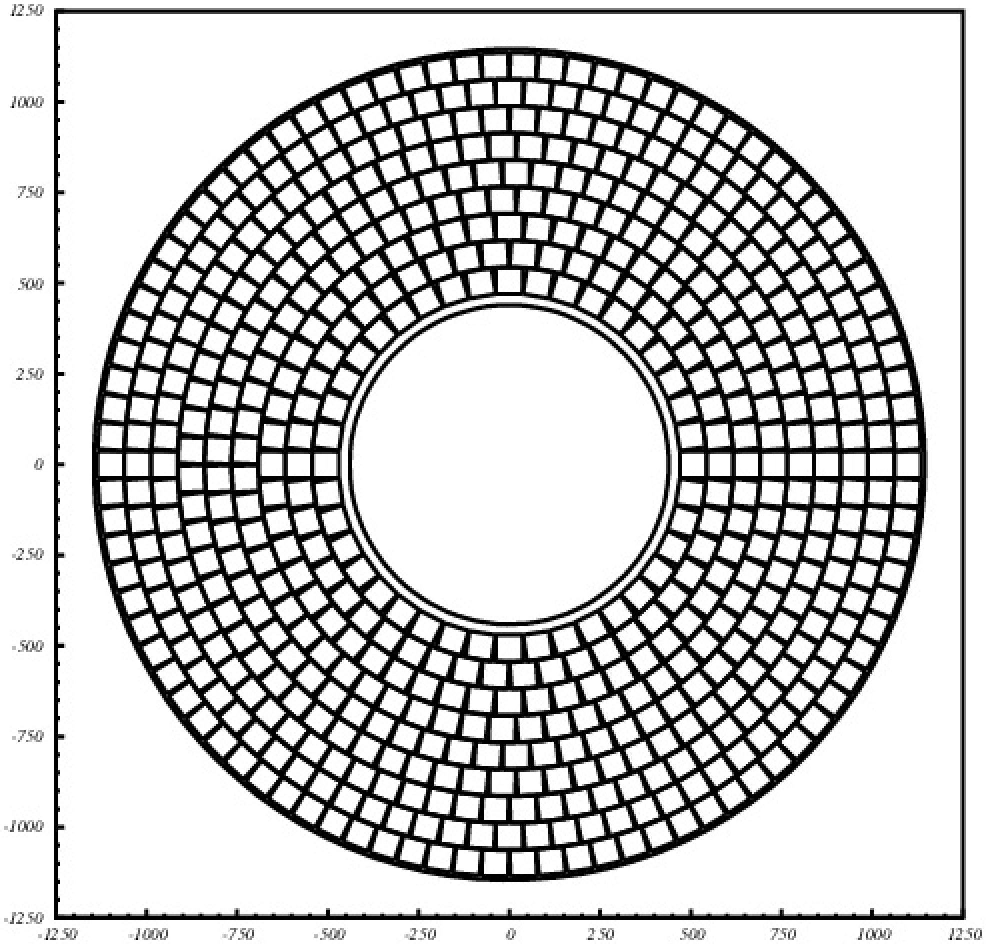
How to design radiator tiles: check losses at the tile boundary.



- Scan with the beam across the tile boundary. As expected, the yield is affected over a few mm in the vicinity of the boundary.
- A simple model (all photons hitting the boundary get lost) accounts for most of the dependence

→ Reduce the fraction of tracks close to tile boundaries and corners.

Photon detector tiling



- 92% of the surface covered by HPDs
- minimal distance between modules: 0.5~mm
- max. distance (few mm) allows for feeding in the HV supply cable (has to come to the front side of the HPD)
- six equal sectors