A proximity focusing RICH with multiple refractive index aerogel radiator

Peter Križan

University of Ljubljana and J. Stefan Institute

For Belle Aerogel RICH R&D group

Contents

Introduction, motivation and requirements

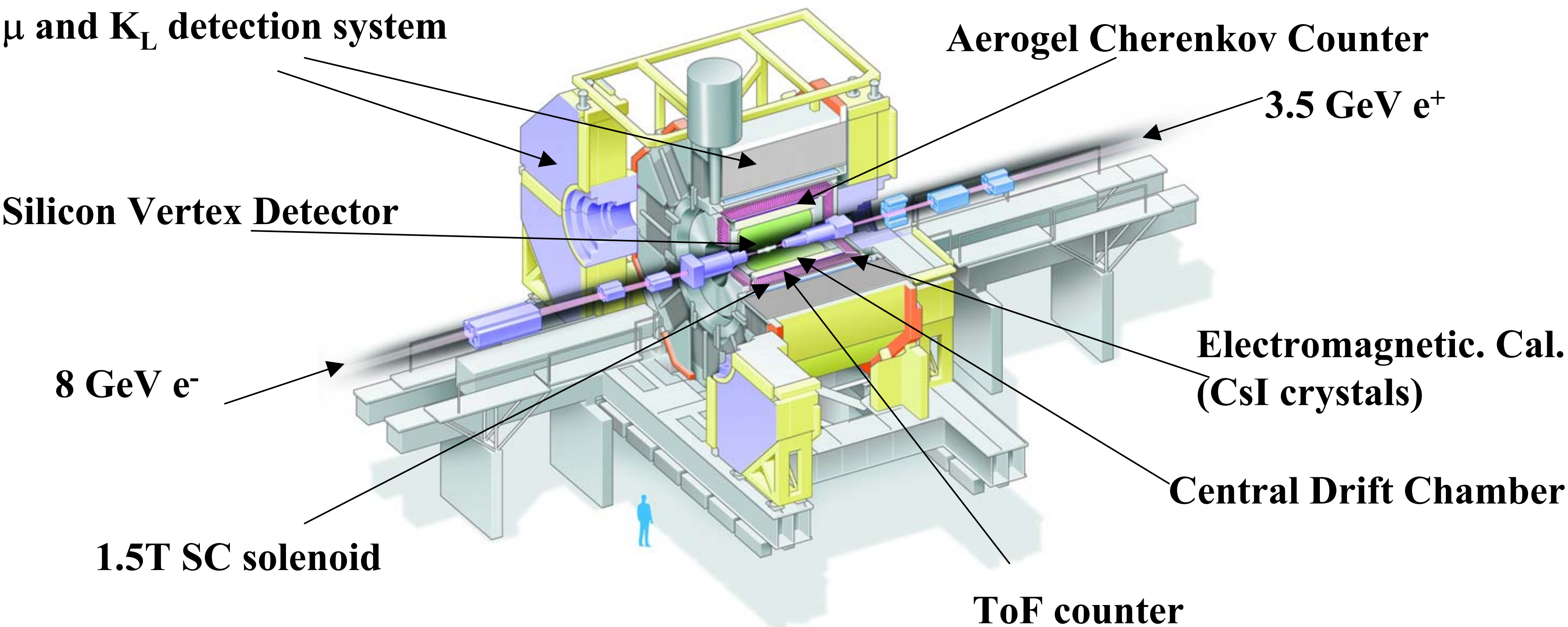
Radiator with multiple refractive indices

Beam test results

Further radiator optimisation

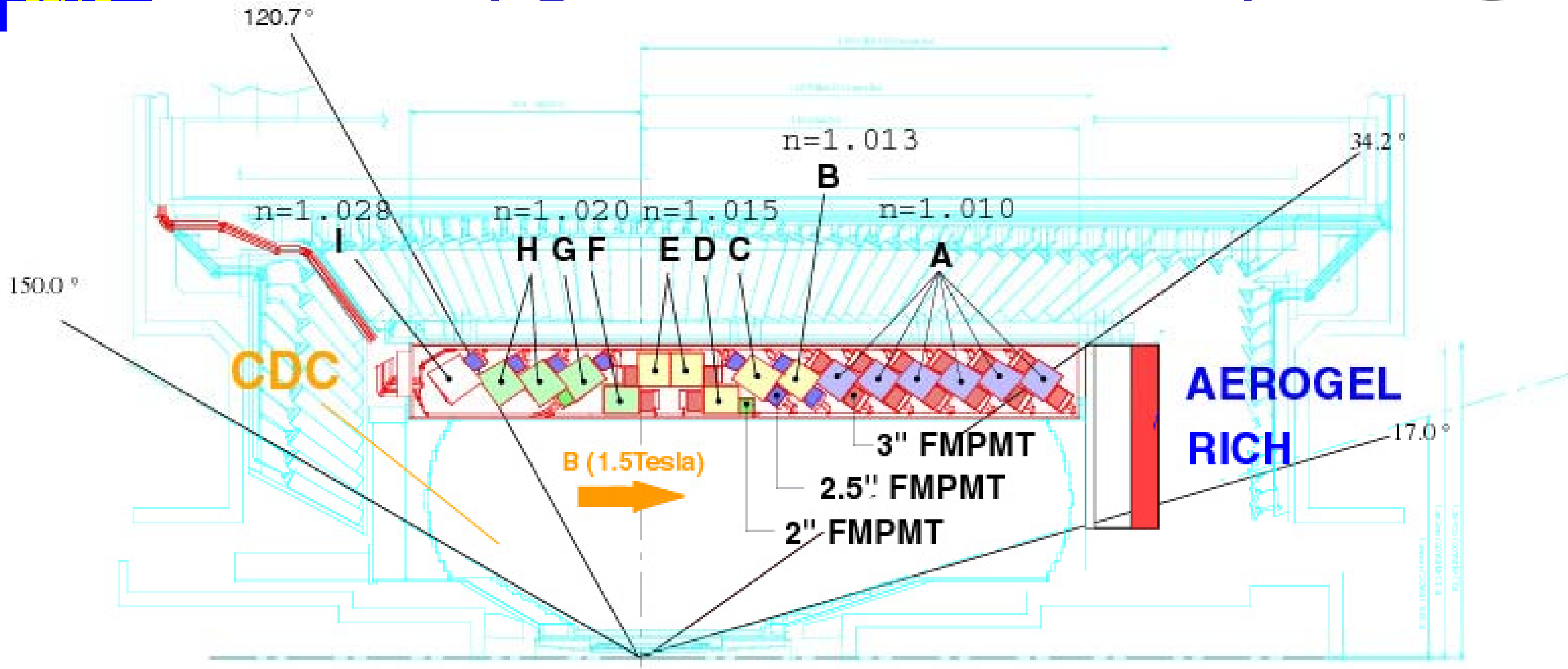
R&D issues

Belle spectrometer at KEK-B



Accumulated data sample ≅ 500 M BB-pairs

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)

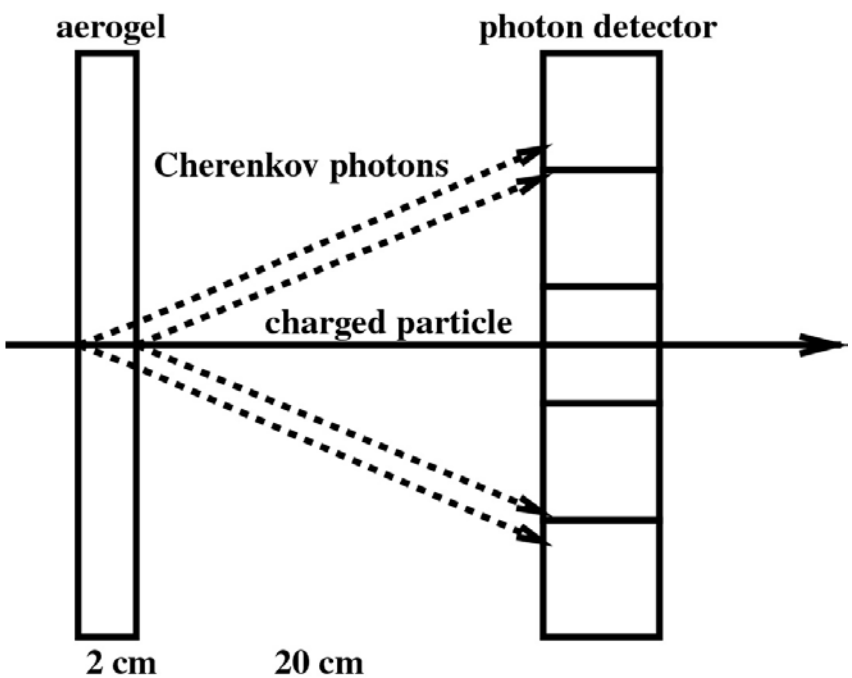
keep high the efficiency for tagging kaons

BELLE Aerogel RICH group

Adachi, S. Fratina, T. Fukushima, A. Gorišek, T. Iijima, H. Kawai, M. Konishi, S. Korpar, Y. Kozakai, P. Križan, T. Matsumoto, S. Nishida, S. Ogawa, S. Ohtake, R. Pestotnik, S. Saitoh, T. Seki, A. Stanovnik, T. Sumiyoshi, Y. Uchida, Y. Unno, S. Yamamoto

Chiba University, Japan
Toho University, Funabashi, Japan
High Energy Accelerator Research Organization (KEK), Japan
J. Stefan Institute, Ljubljana, Slovenia
University of Ljubljana, Slovenia
Nagoya University, Nagoya, Japan
Tokyo Metropolitan University

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

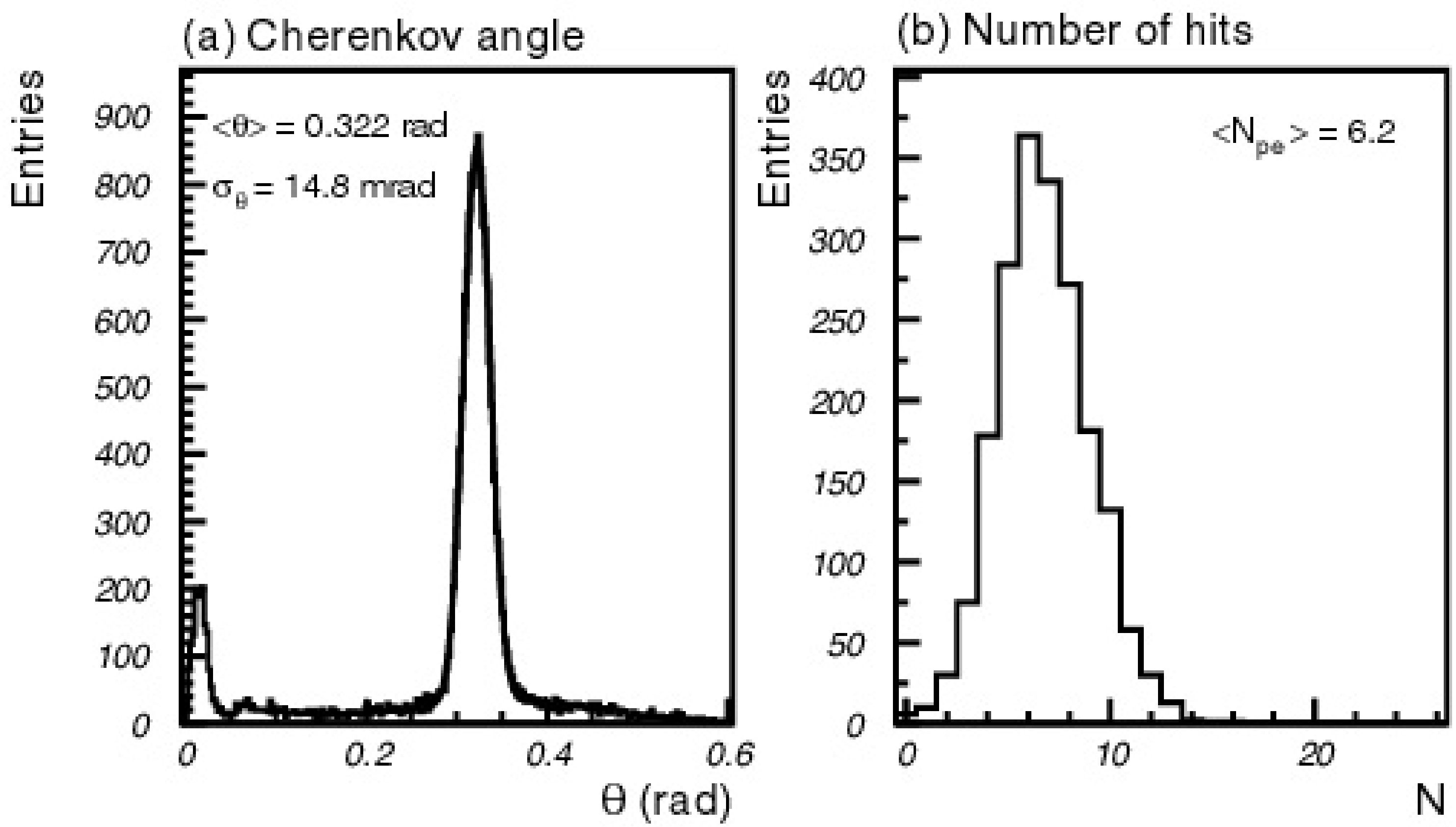
$d\theta_c$(meas.) = σ_0 ~ 13 mrad
With 20mm thick aerogel and 6mm PMT pad size

→ 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

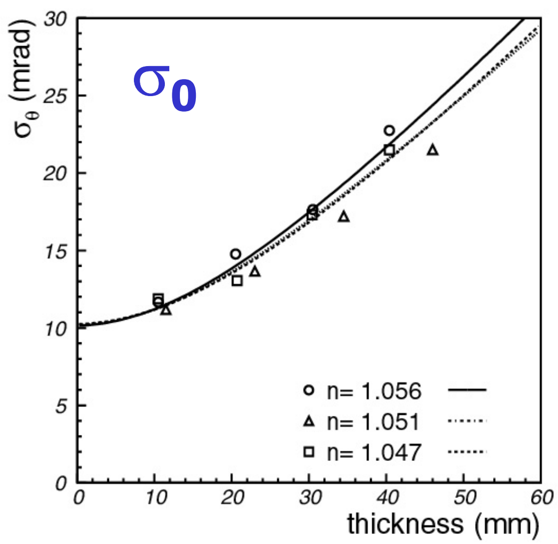


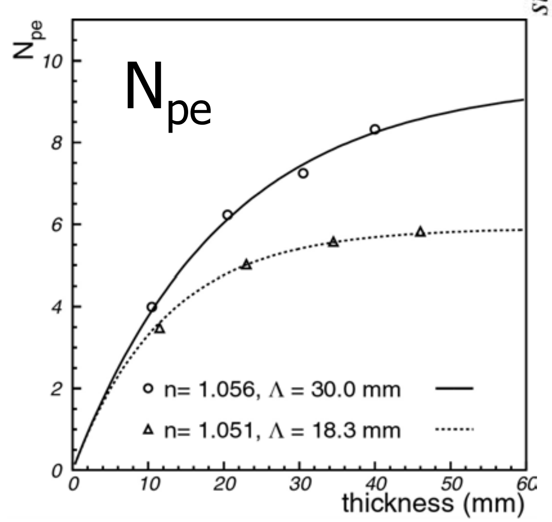
-> Number of photons has to be increased.

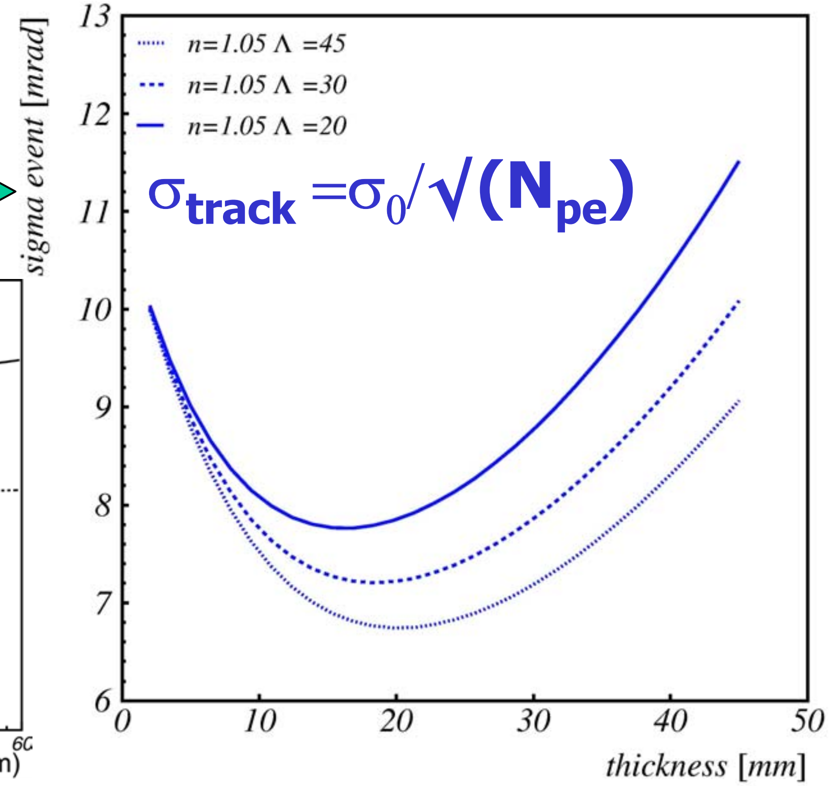
How to increase the number of photons?

What is the optimal radiator thickness?

Use beam test data on σ_0 and N_{pe}



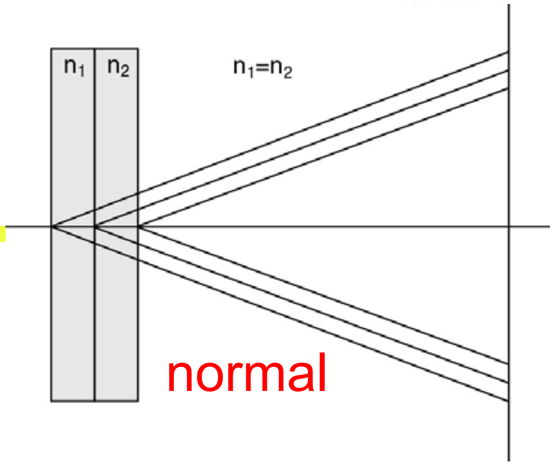




Minimize the error per track: $\sigma_{track} = \sigma_0/\sqrt{(N_{pe})}$

Optimum is close to 2 cm

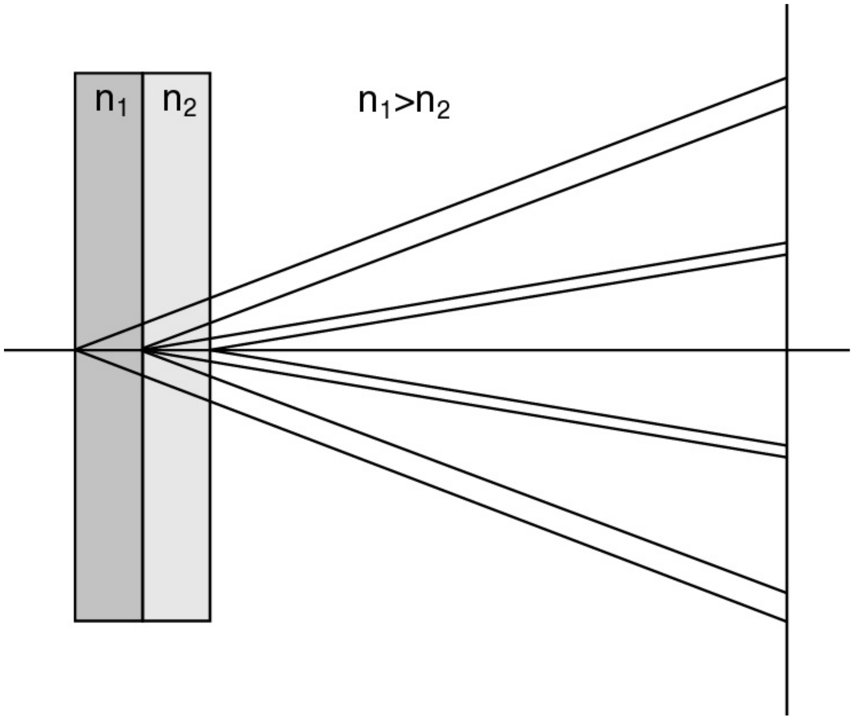
Radiator with multiple refractive indices



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

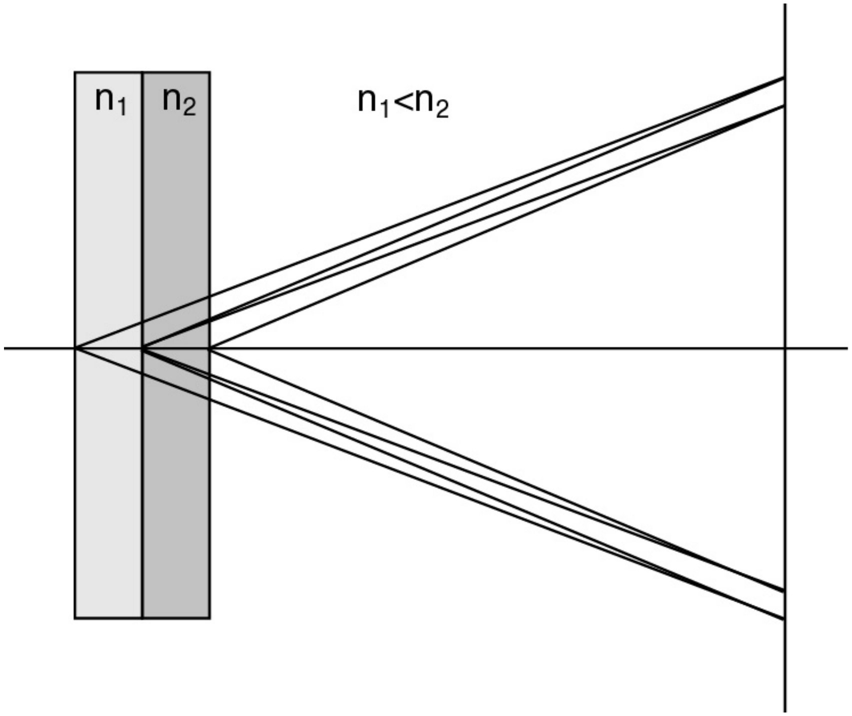
- measure two separate rings

"defocusing" configuration

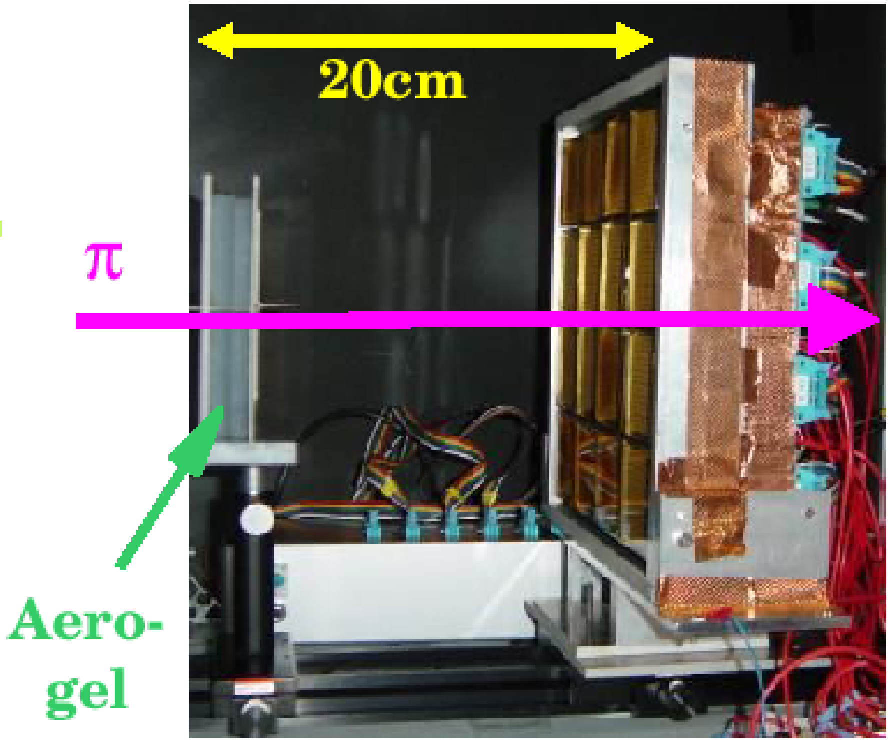


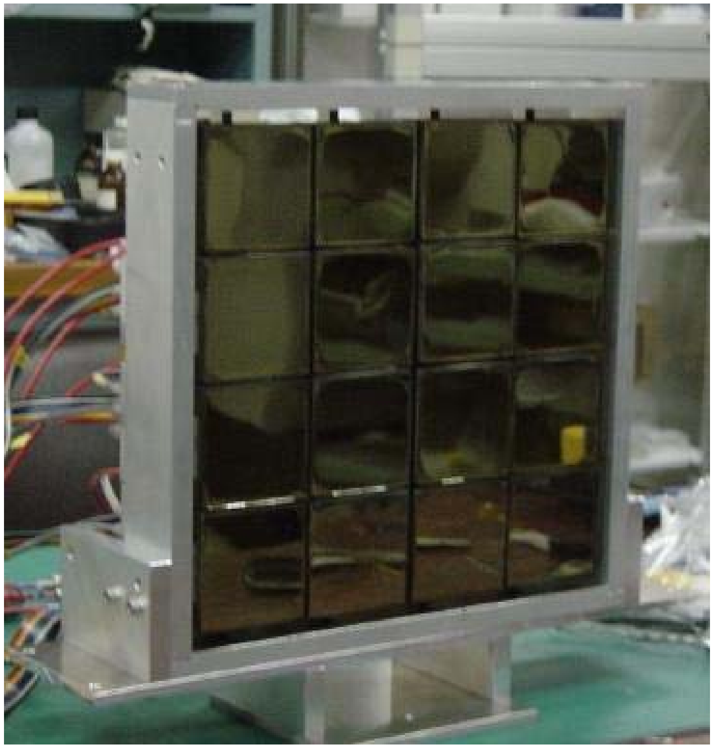
- measure overlaping rings

"focusing" configuration



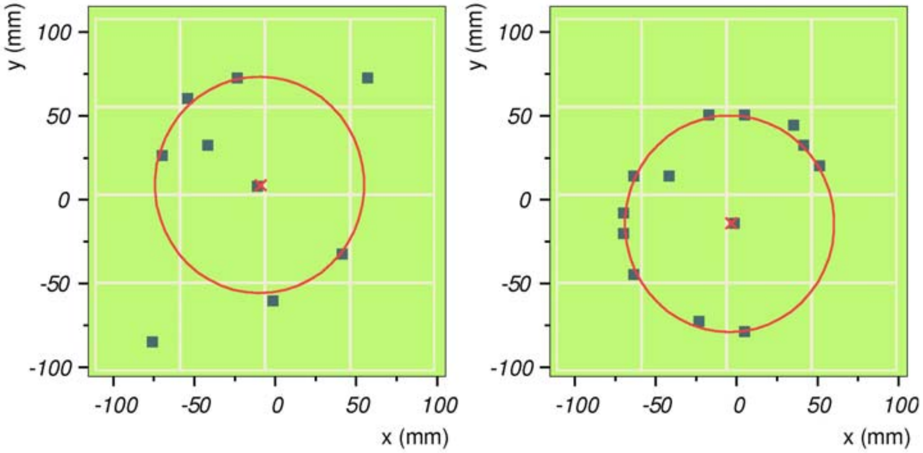
Beam tests





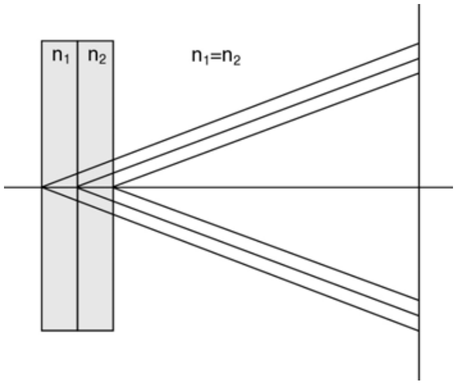
Photon detector: array of 16 H8500 PMTs

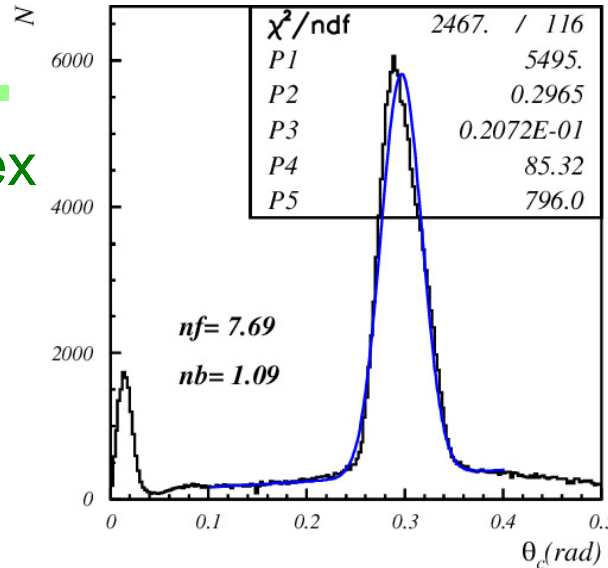
Clear rings, little background



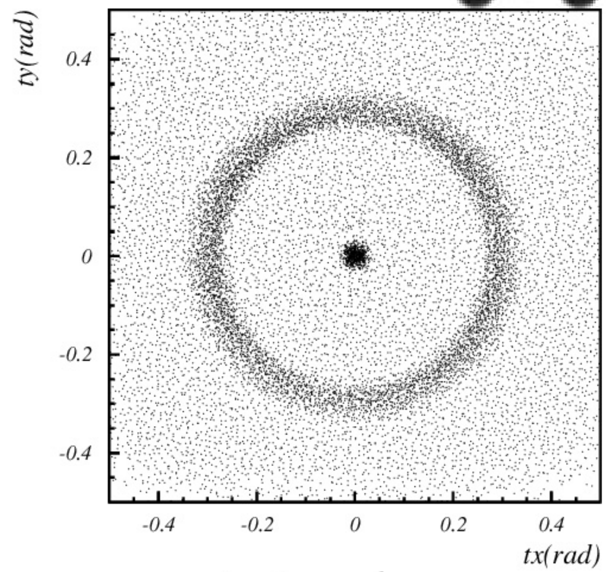
Focusing configuration – data

4cm aerogel single index



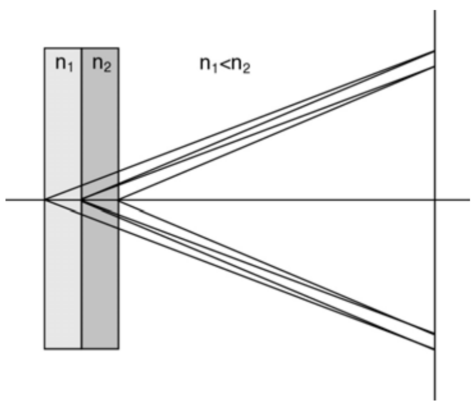


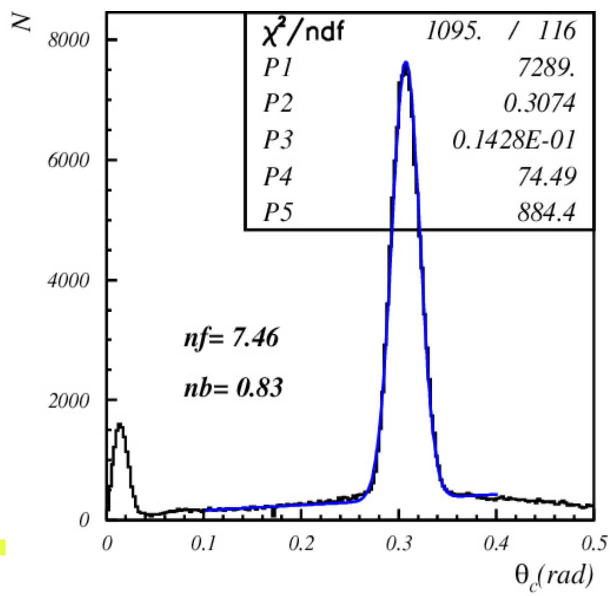
theta cerenkov

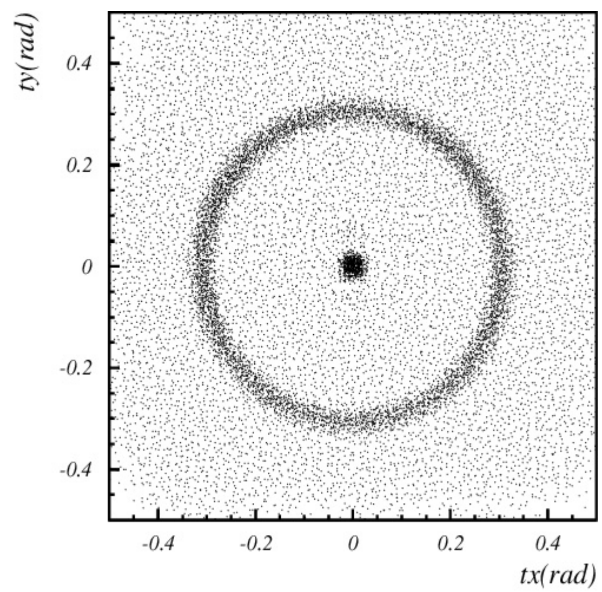


ring in cerenkov space

2+2cm aerogel

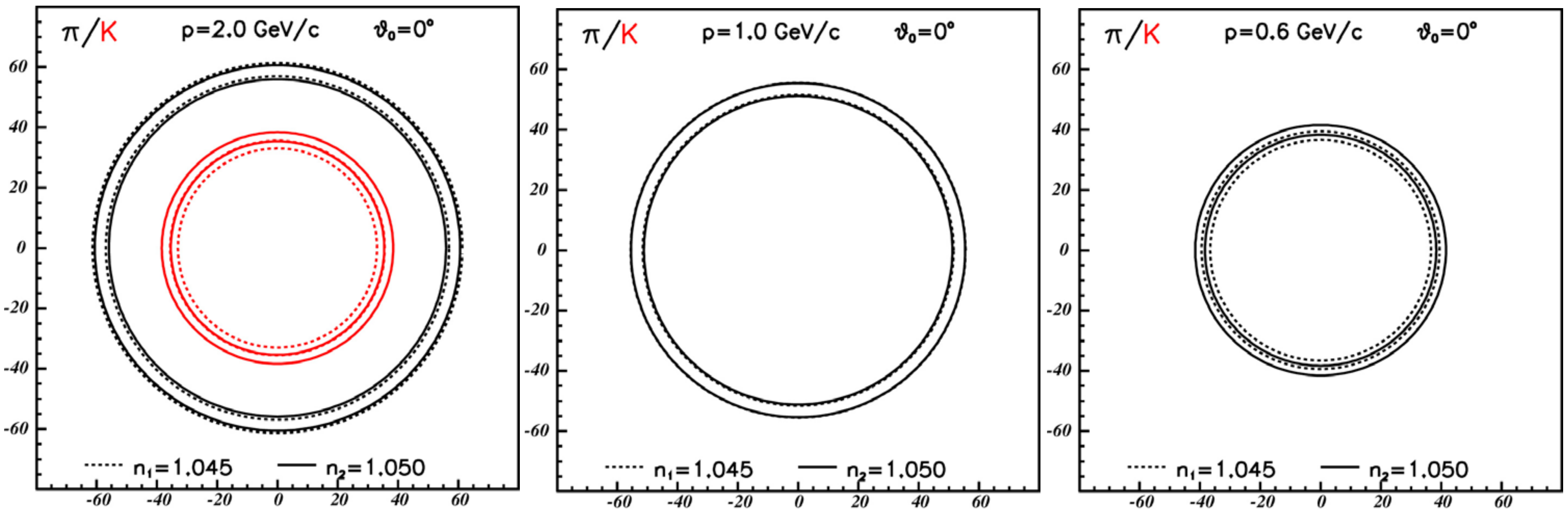






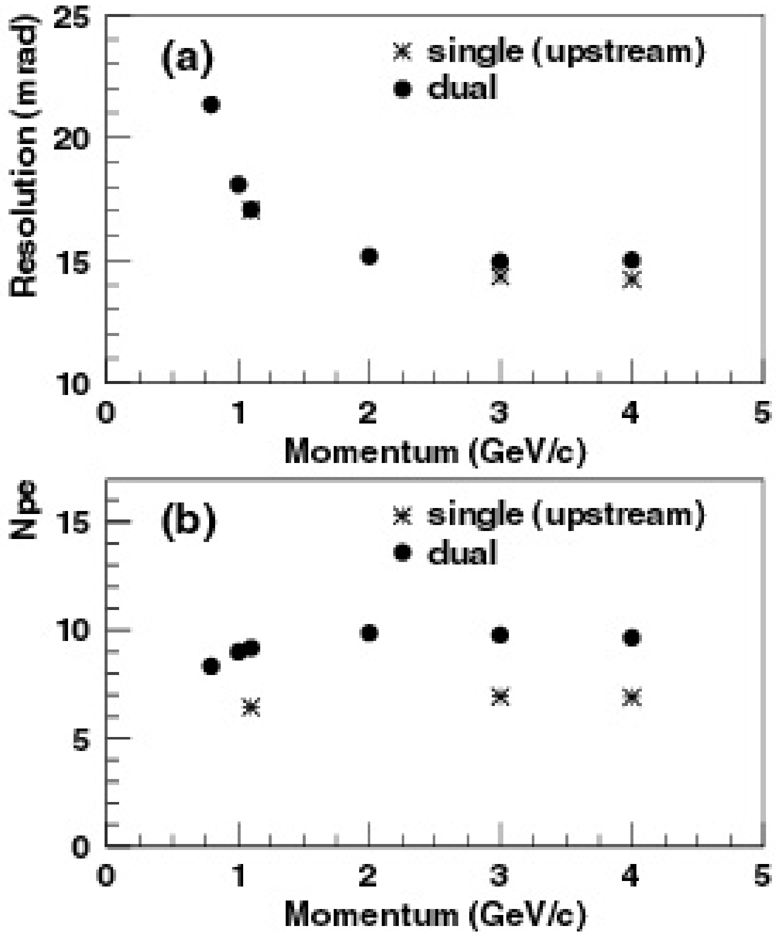
Focusing configuration – low momentum

- Matching of indices: done for high momentum tracks (4GeV/c)
- How is the overlapping of rings at lower momenta?



Good overlapping down to 0.6 GeV/c

Focusing configuration – momentum scan



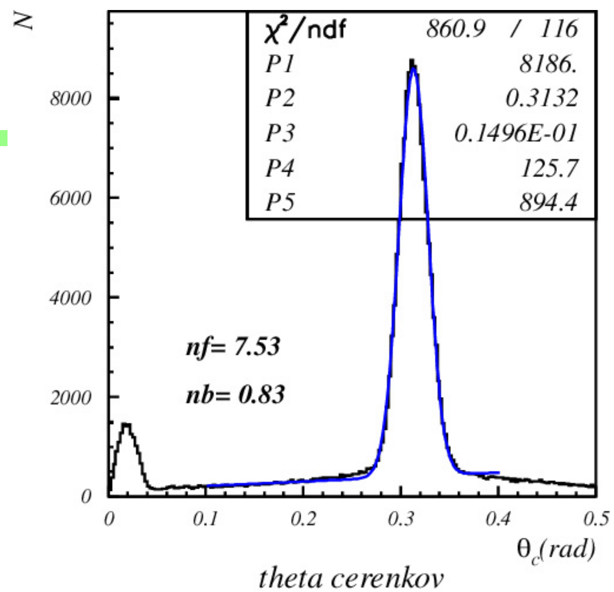
- single photon resolution: dual radiator ~same as single (of half the thickness) for the full momentum range

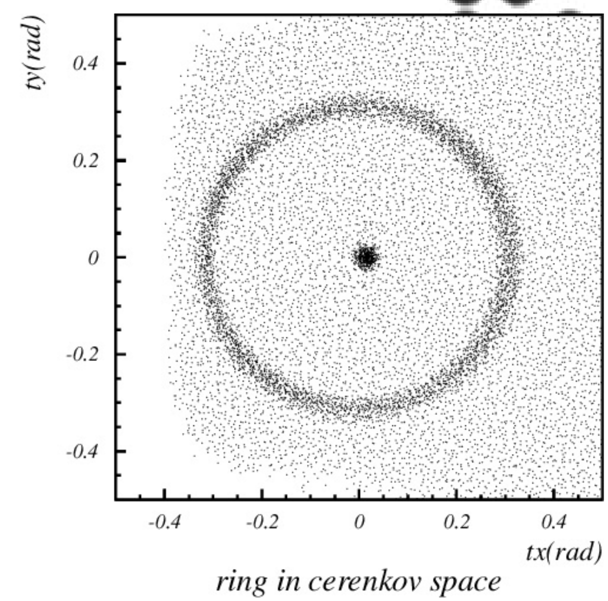
- number of detected hits: dual radiator has a clear advantage

Overlapp optimized at 4GeV/c-> OK at low momenta as well

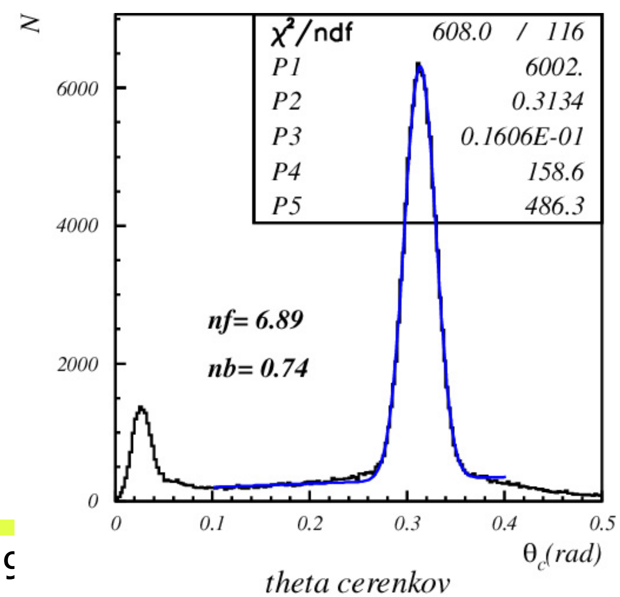
Focusing configuration - inclined tracks

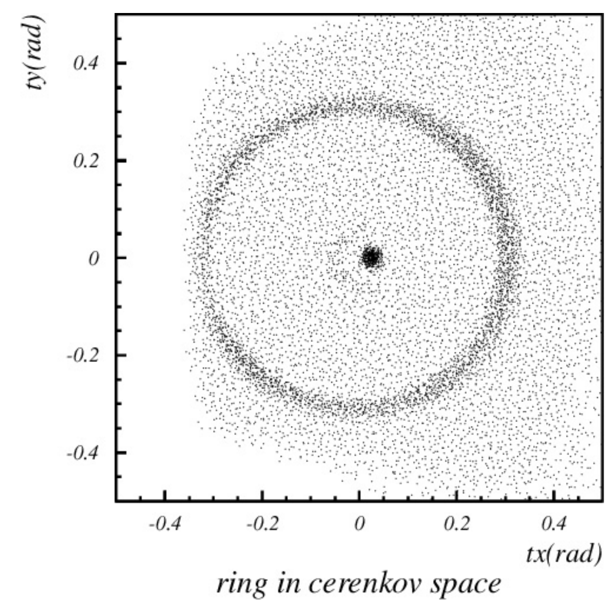
- 2+2cm aerogel
- angle 20º





- 2+2cm aerogel
- angle 30º



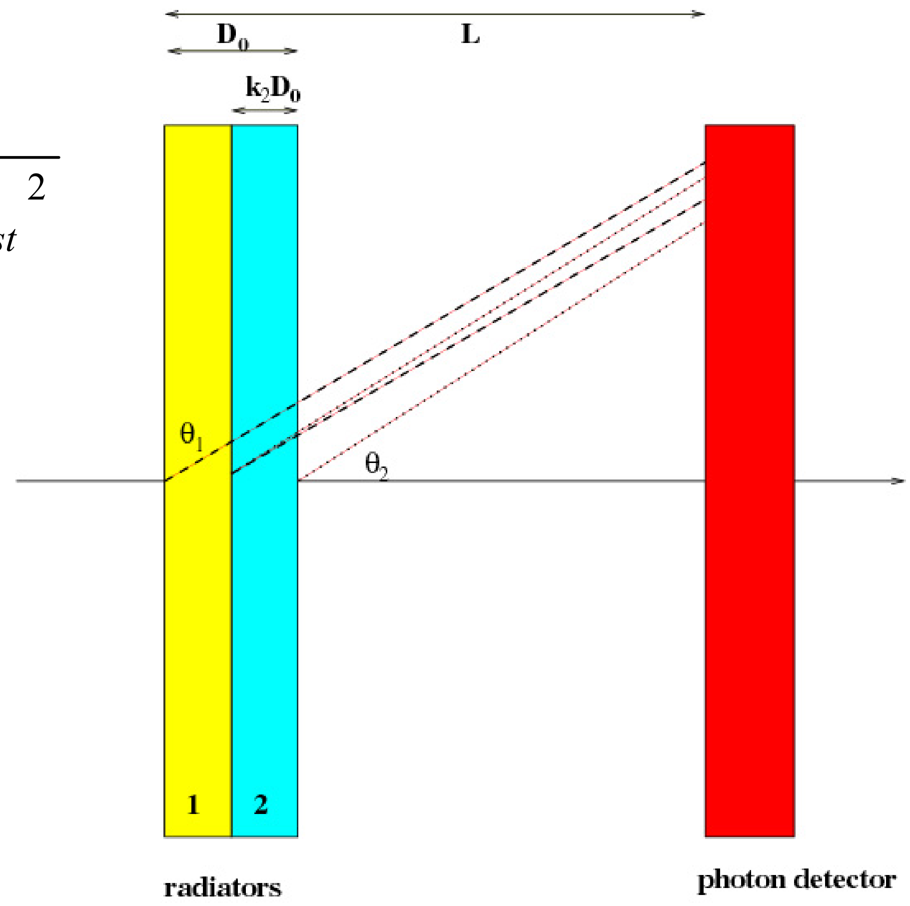


Works as well!

Optimisation of the dual radiator configuration

Mimimize:

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

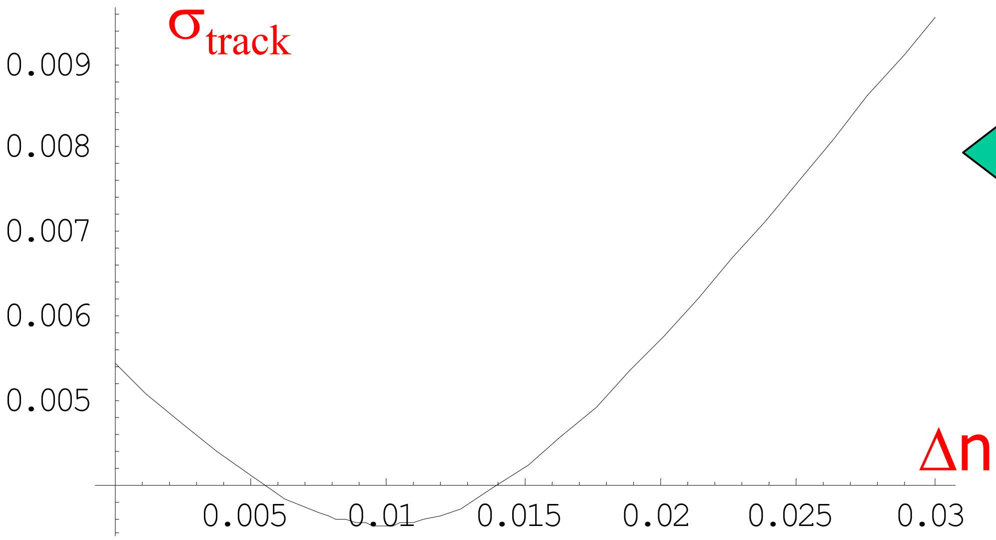


Input data:

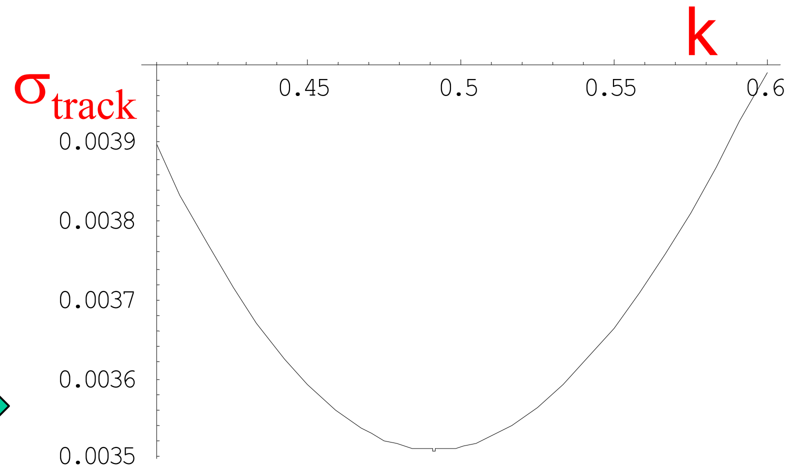
- total length L is fixed (20 cm)
- attenuation length: 4 cm
- Cherenkov angle = 0.3,
- pad size 6 mm, σ_{rest}=6 mrad

Optimisation of the dual radiator configuration

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

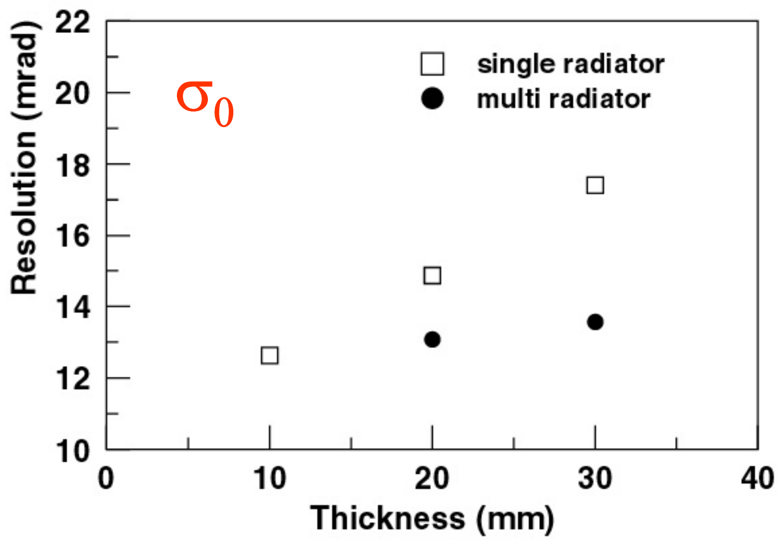


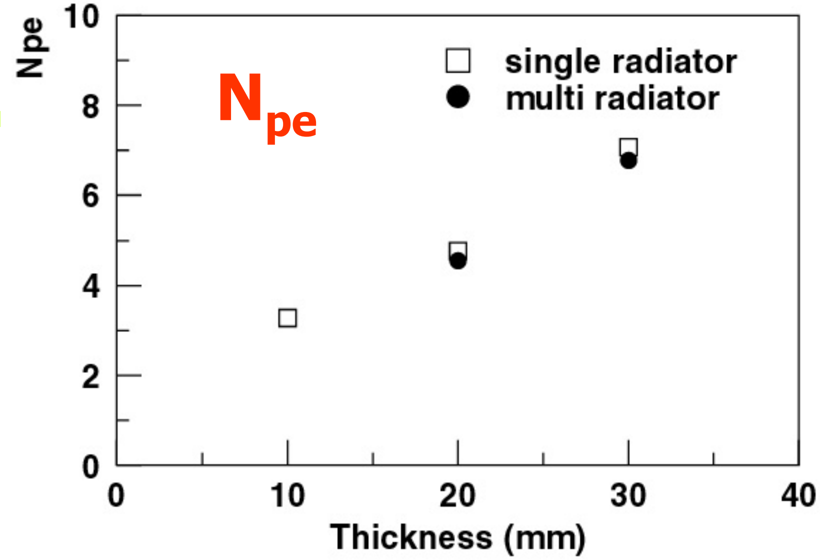
Vary difference in refractive index Δn

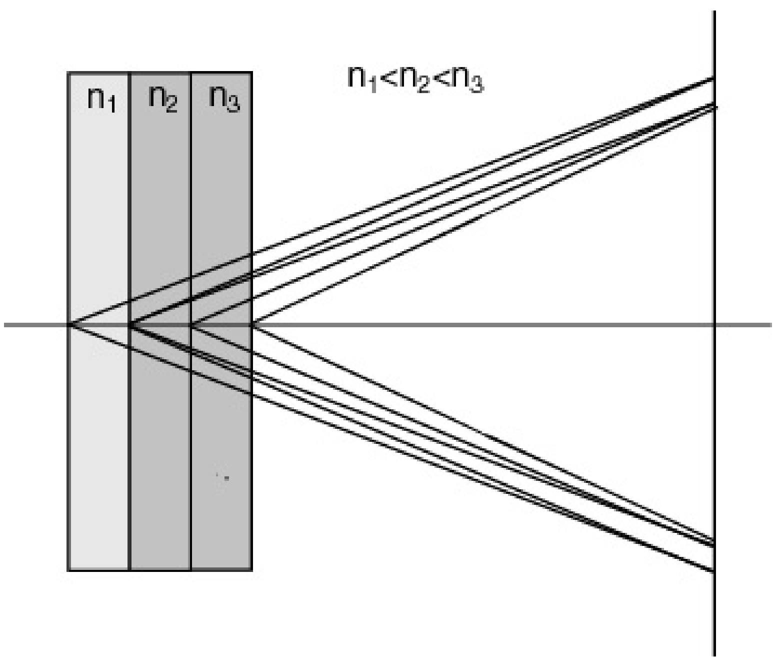


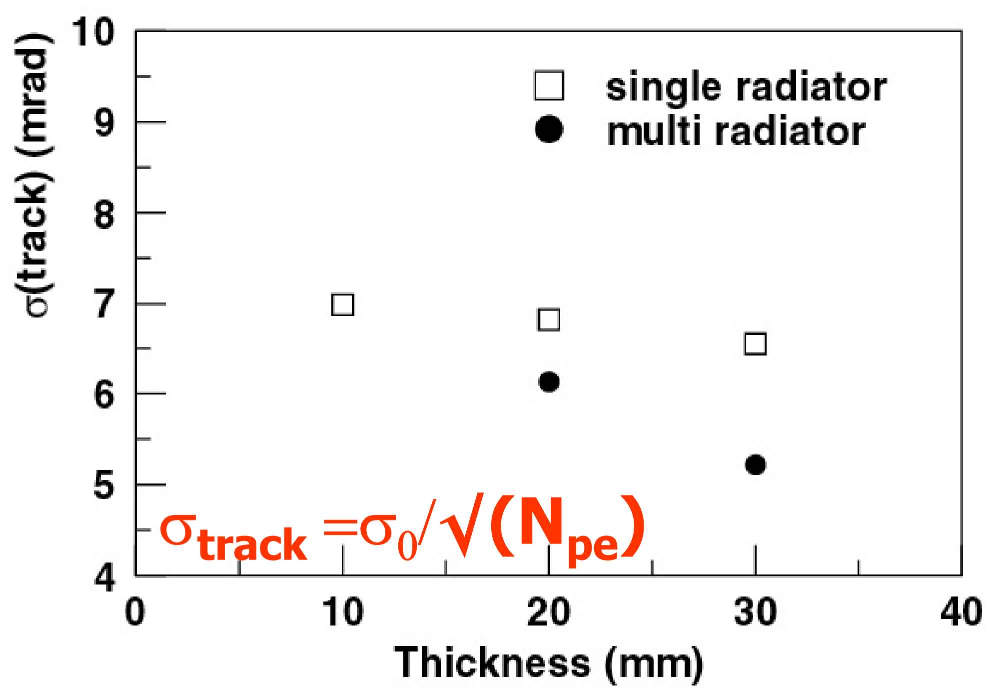
Only a very weak dependence on k, relative rad. thickness (k=0.5 - same thickness)

Multilayer extensions









Extension to many layers – expectations

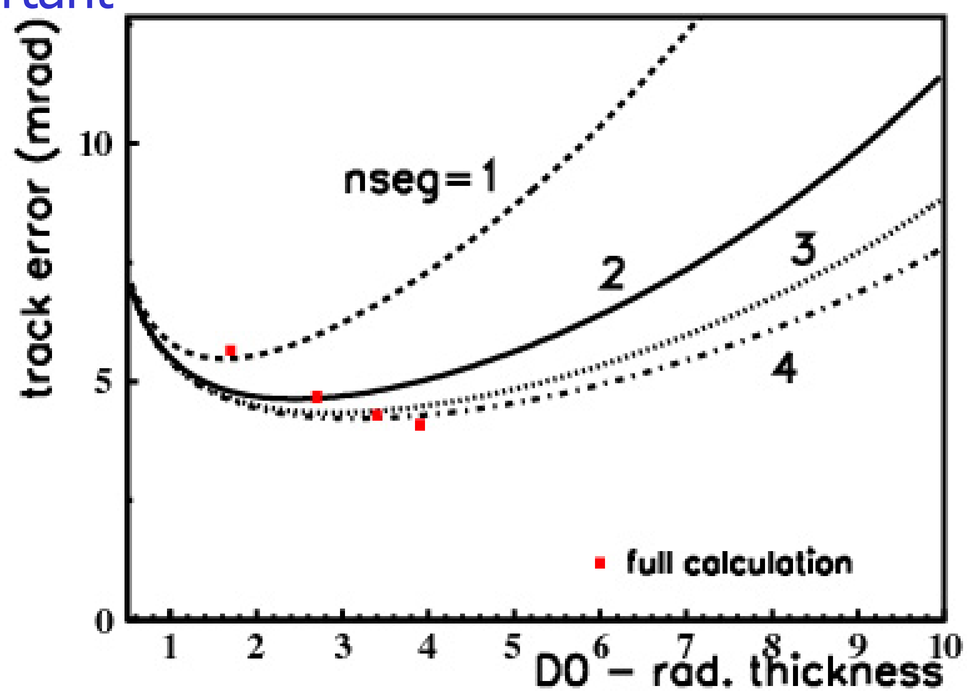
1 -> 2 layers: a big jump in resolution per track

2 -> 3, 4: small steps

But: more radiator layers -> shallower optimal thickness minimum

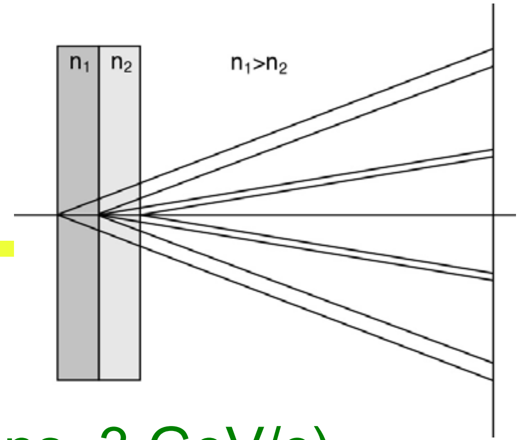
-> of particular importance in the vicinity of threshold, where the number of photons is more important

$$\sigma_{\mathbf{track}} = \sigma_0 / \sqrt{(\mathbf{N_{pe}})}$$

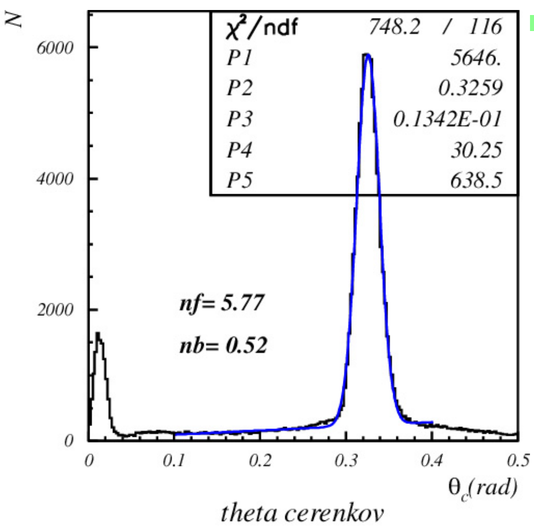


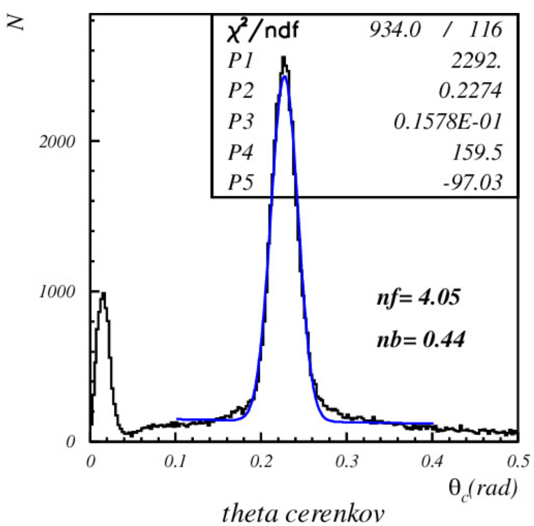
Curves: simple model. Points: full calculation

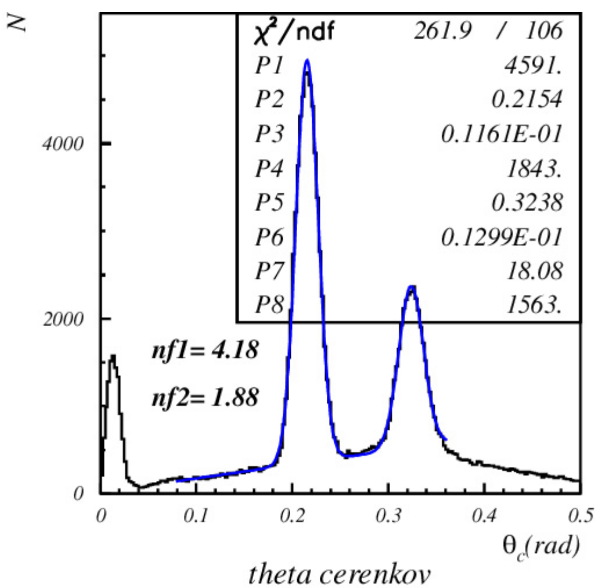
Defocusing configuration, data

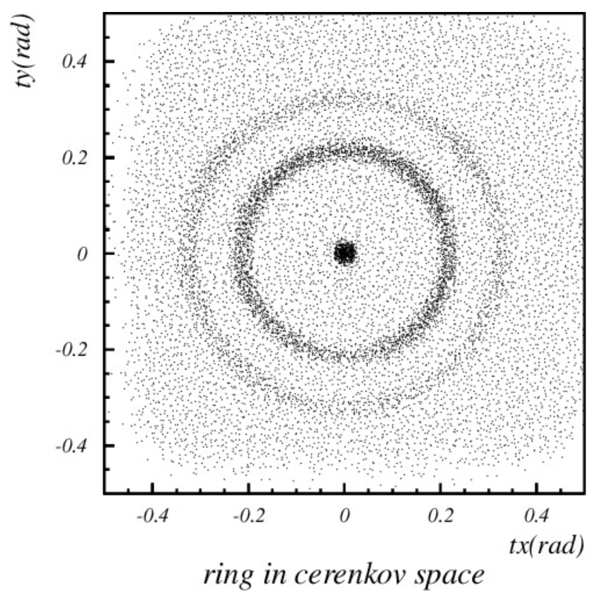


- two well separated rings (pions, 3 GeV/c)
- decrease of n_1 peak due to absorption

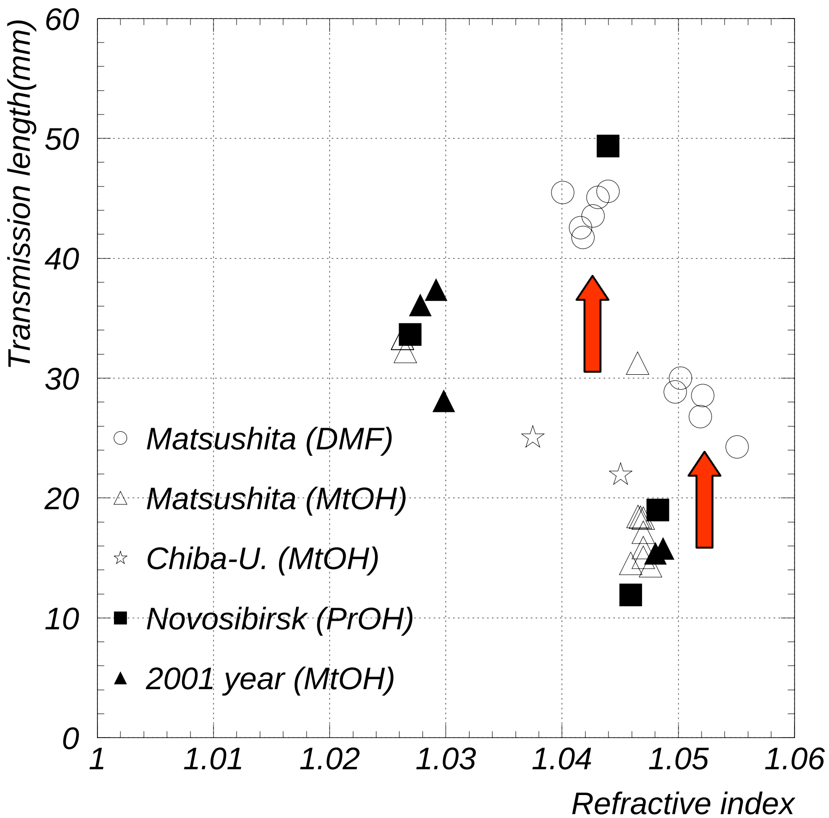








Aerogel production R&D

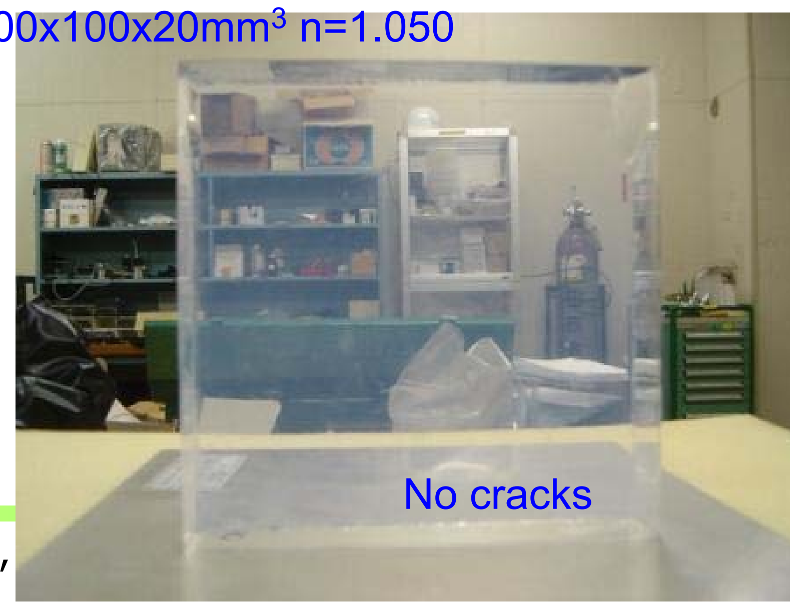


Transmission length vs refractive index

Going to thicker radiators: advantage only if aerogels have a high transmission length -> R+D

Improved optical quality for n~1.05 hydrophobic aerogel with a new solvent and precursor

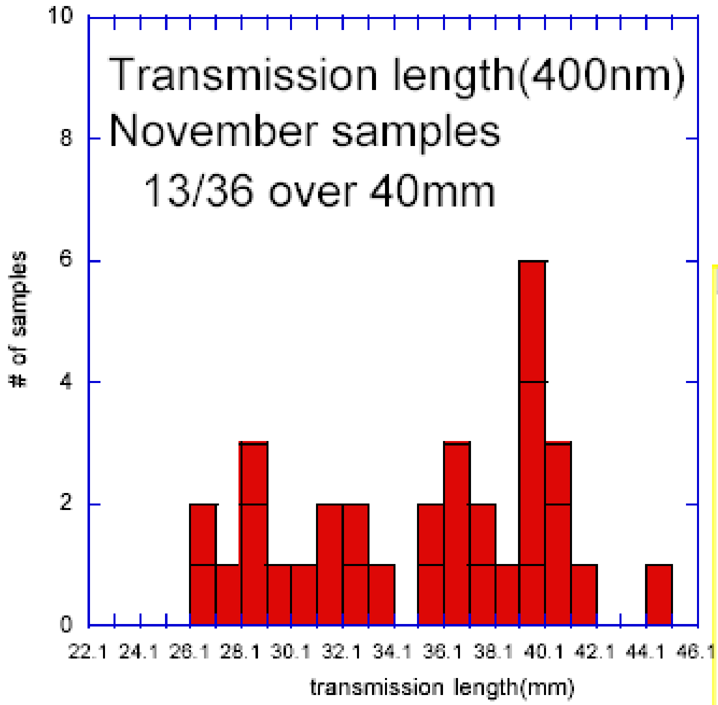
$100 \times 100 \times 20 mm^3$ n=1.050

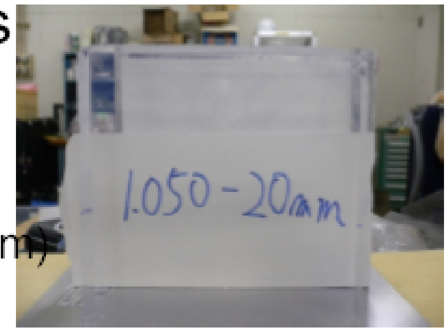


No cracks

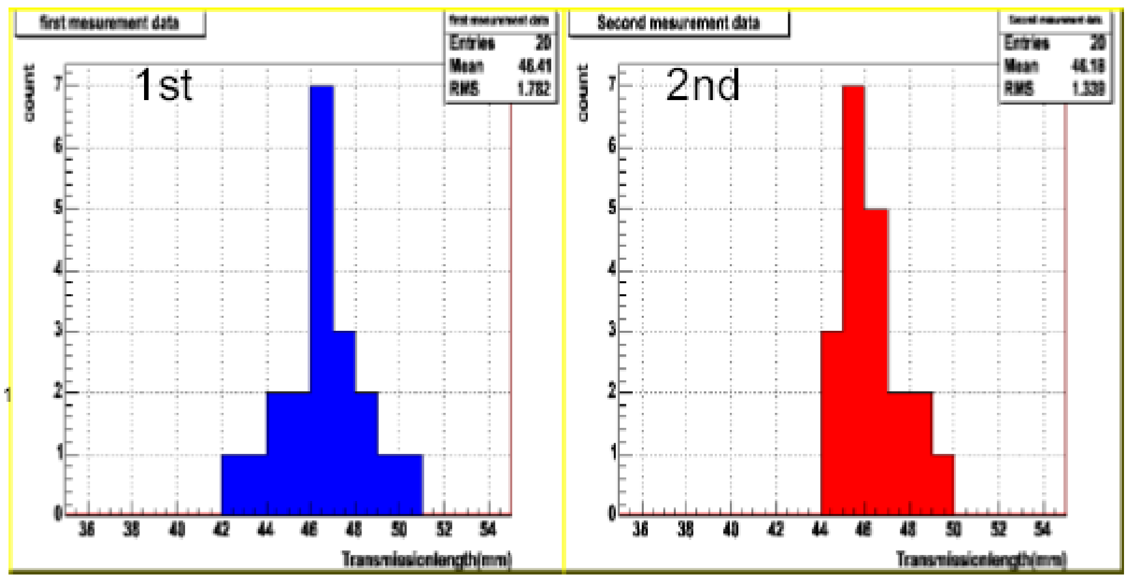
Aerogel production R&D

- Further optimization for n = 1.050 samples





Transmission length(400nm)
March samples

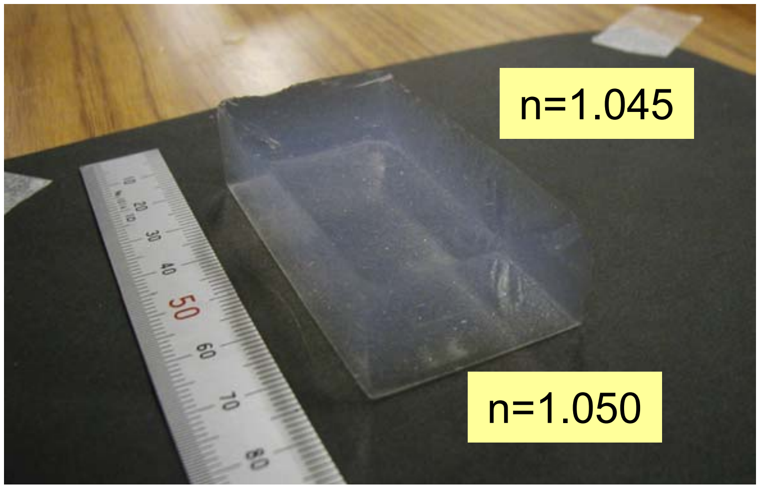


Av:46.4+-1.8mm

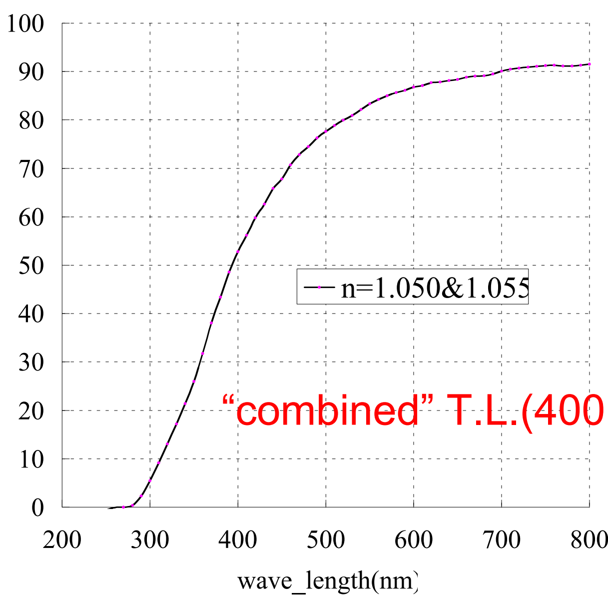
Av:46.2+-1.4mm

All samples better than 40mm

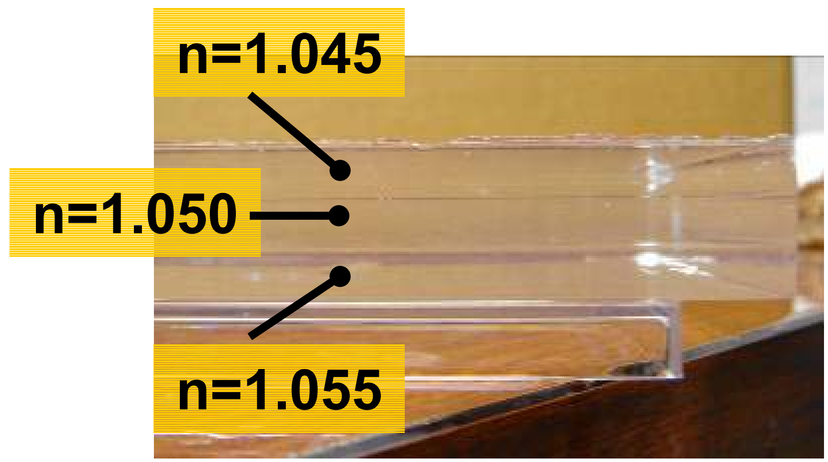
Aerogel production: multilayer samples



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

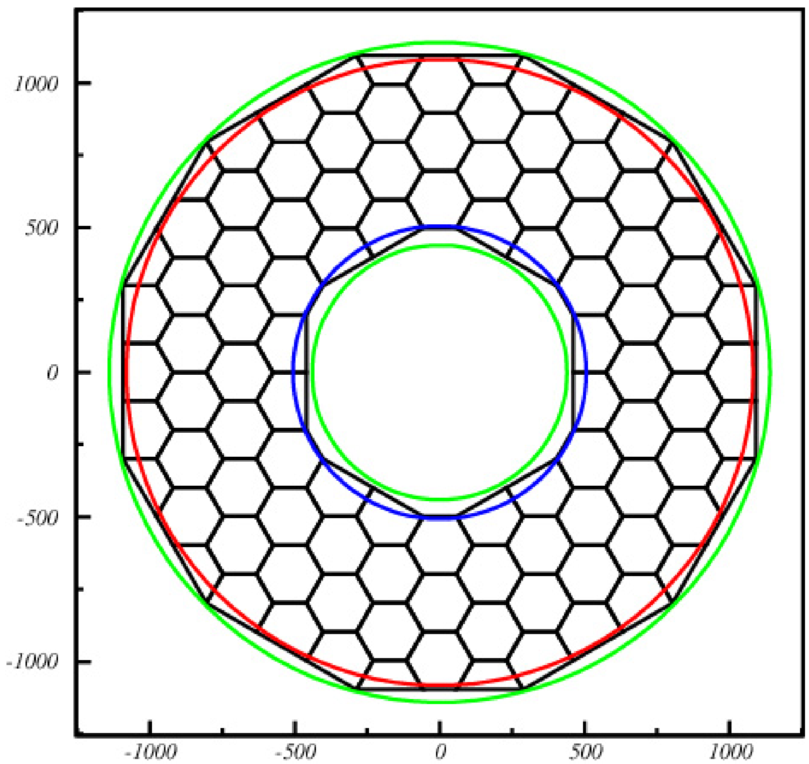


"combined" T.L.(400nm)=41.1mm



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

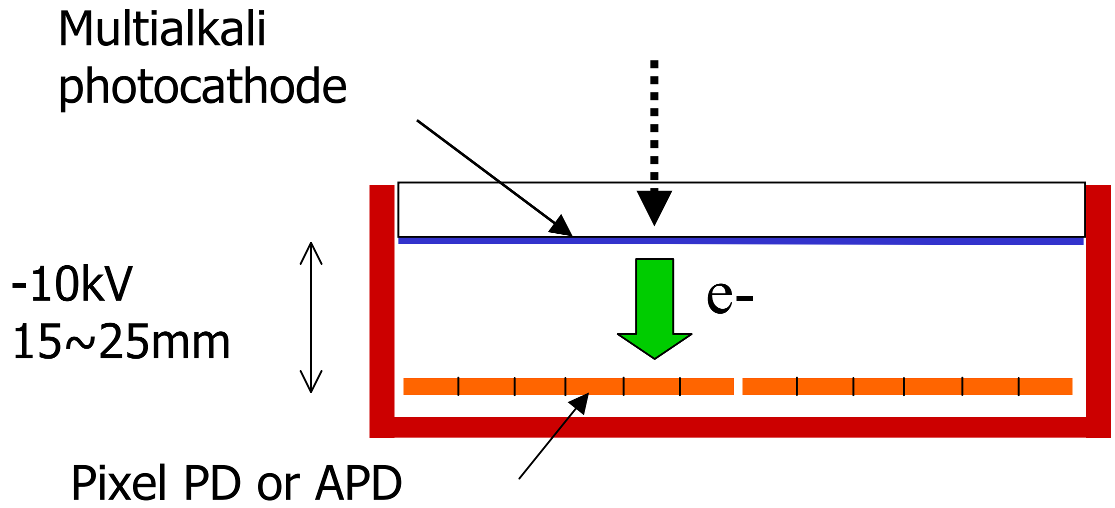
Summary

- Proximity focusing RICH with aerogel as radiator is by now a well proven experimental technique.
- Increase the number of Cherenkov 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

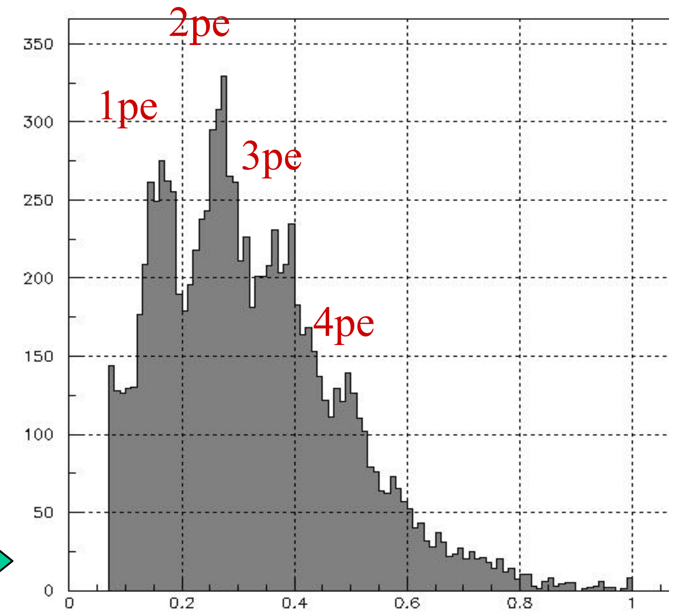
Development and testing of photon detectors for 1.5 T

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



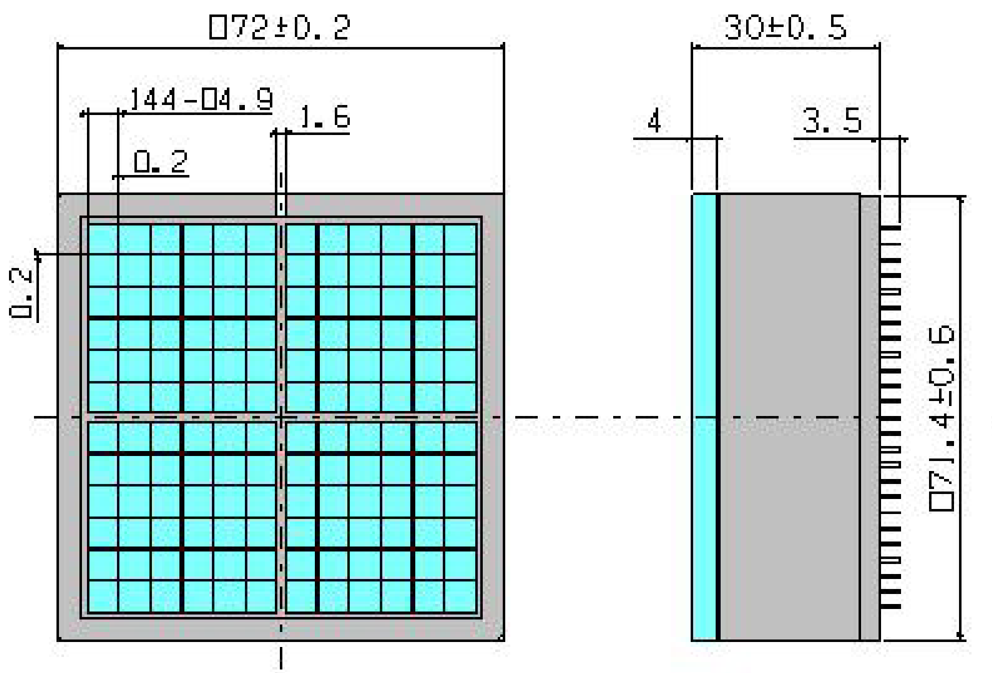
R&D project in collaboration with HPK

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



HPD development

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



Ceramic HPD box

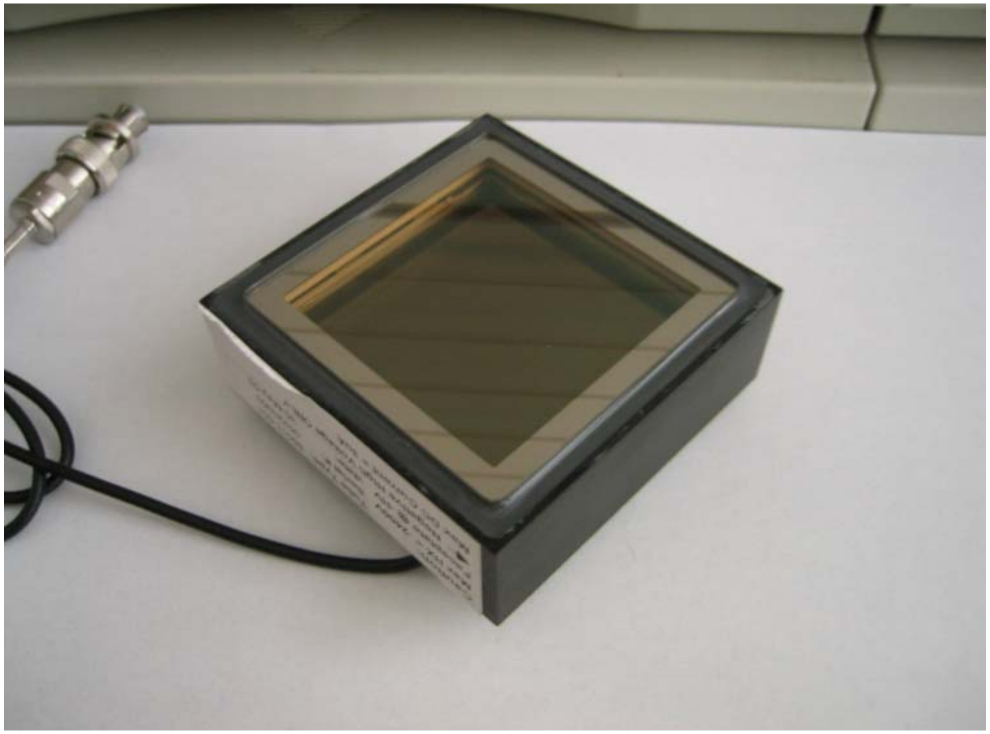
First tests carried out. Problems with sealing the tube at the window-ceramic box interface.

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%

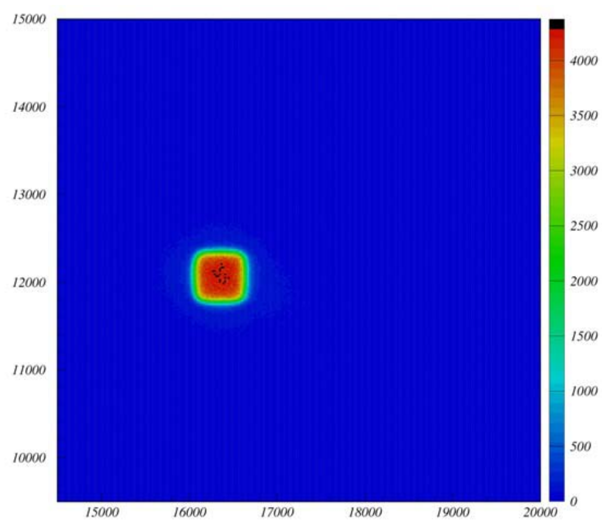


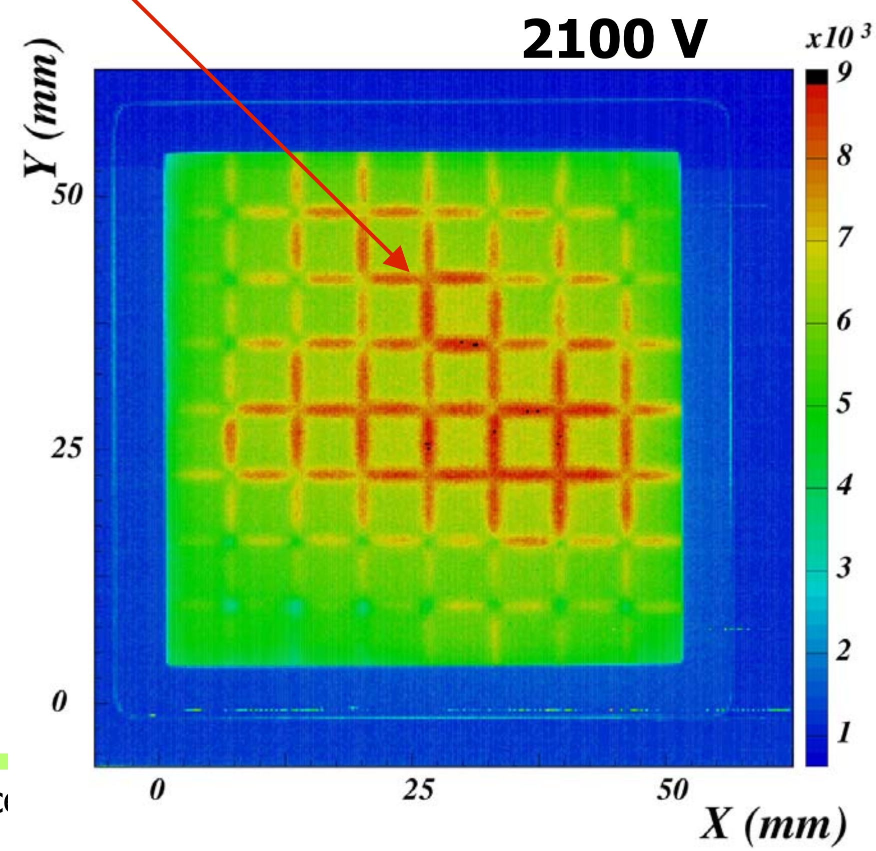
Photon detector R&D – Burle MCP-PMT bench tests

Study uniformity of the sensitivity over the surface

count rates - all channels: charge sharing at pad boundaries

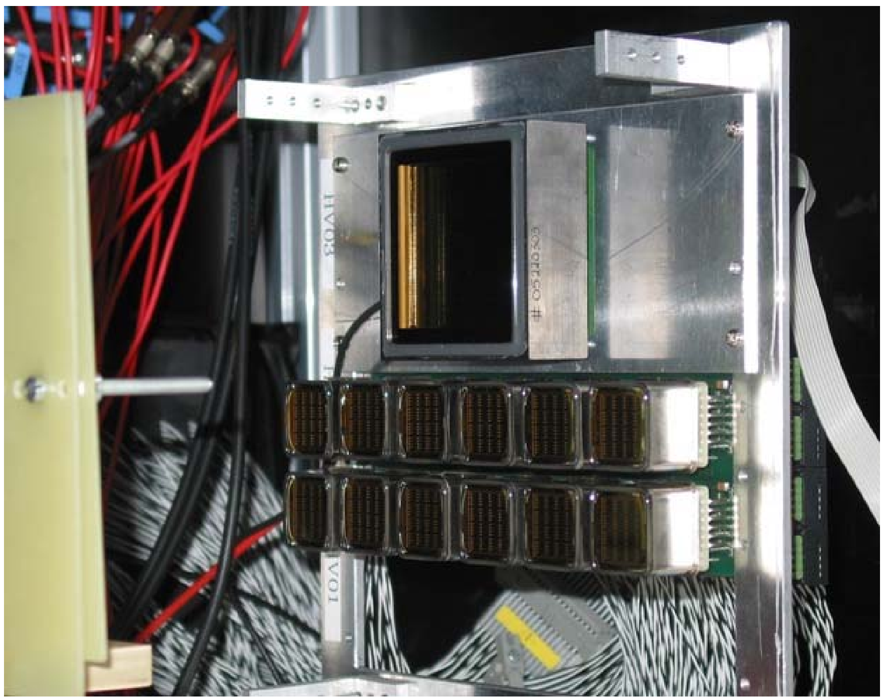
single channel response:
- uniform over pad area
- extends beyond pad area (charge sharing)

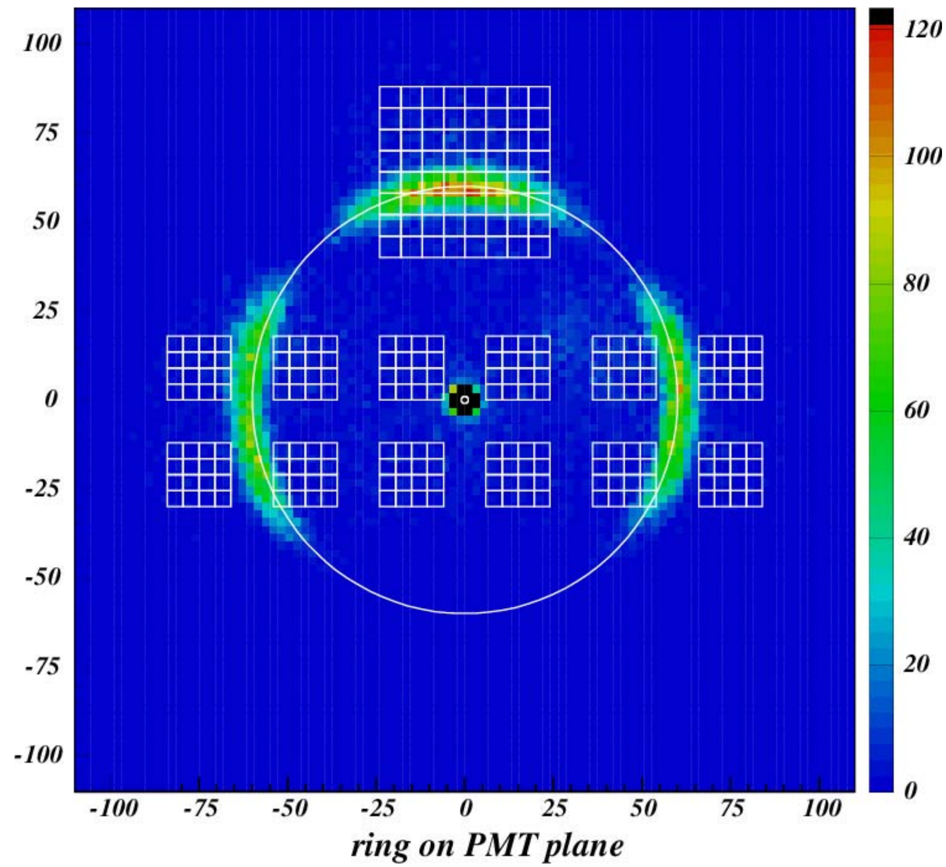




Burle MCP PMT beam test

- **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

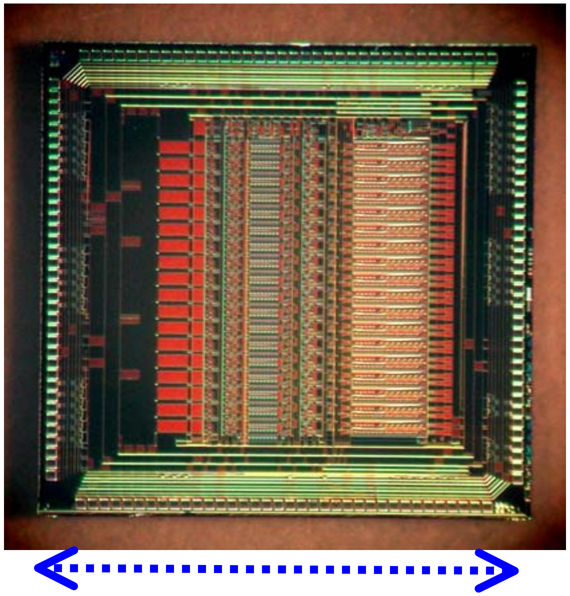
Aging of MCP-PMTs ?

Read-out electronics: ASIC under development

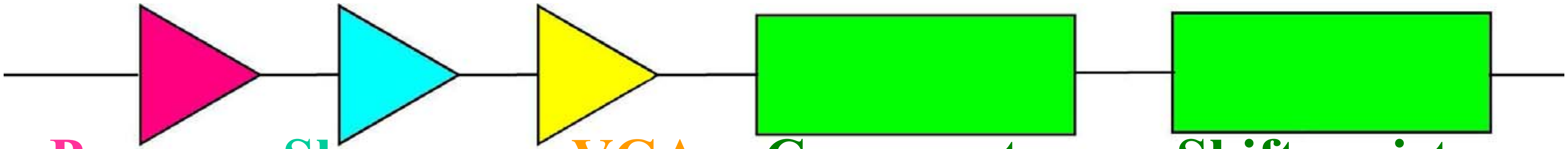
Need high density front-end electronics.
Need high gain with very low noise amplifiers.
Deadtimeless readout scheme-> Pipeline.

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

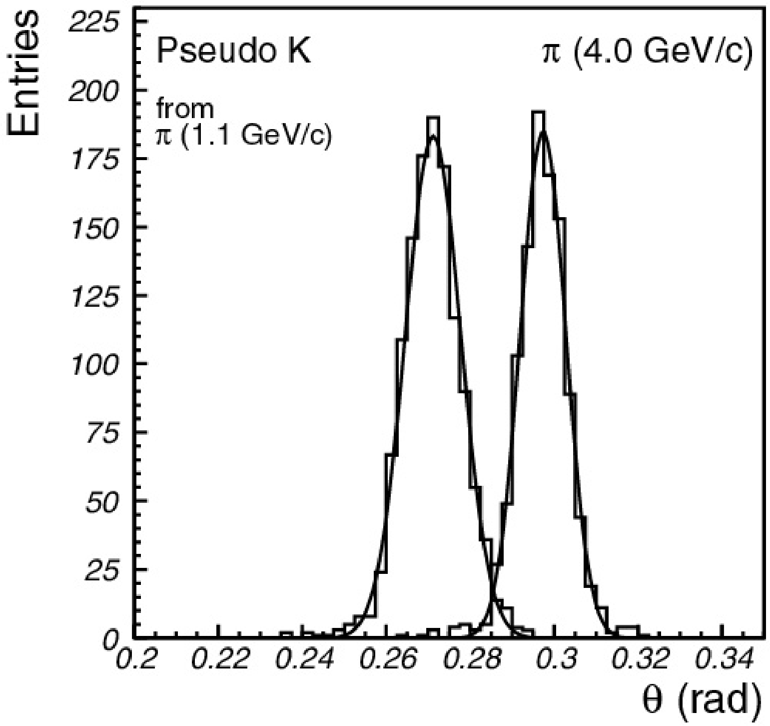
ASIC controled and read-out by a control board (for tests: can also be done with standard VME modules+level adapters)

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

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;

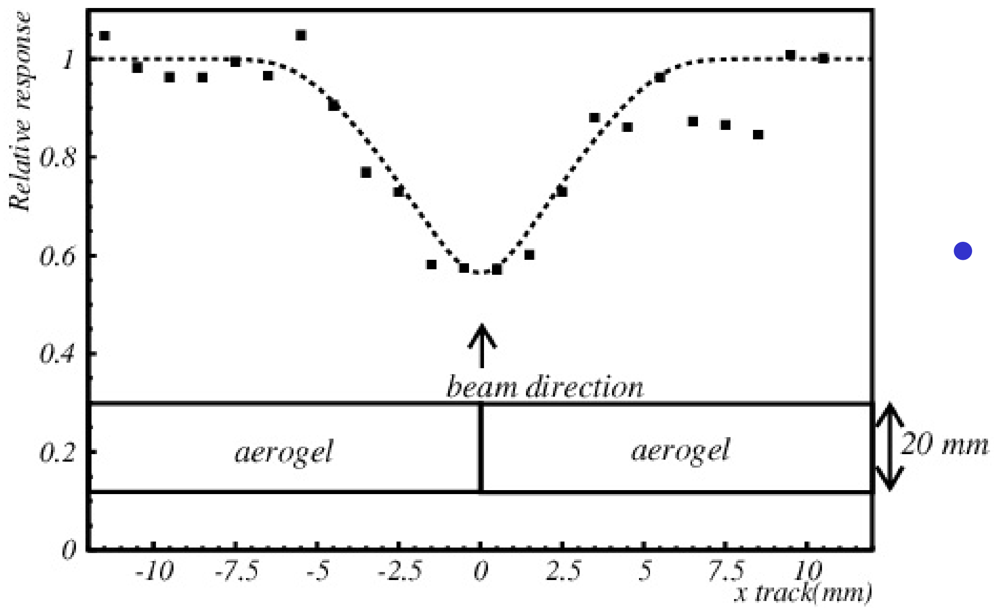
-> 4.3sigma p/K separation a 4GeV/c.

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

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.