RICH detectors with aerogel

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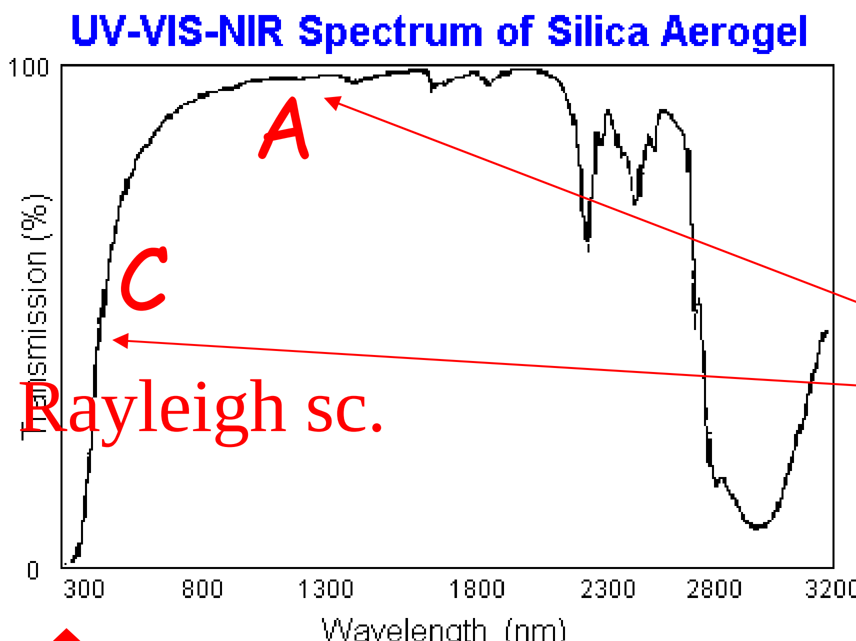
- Optical properties of aerogel → radiator of RICH
- contributions to $\delta\theta_c$ from aerogel in a RICH
- performance of the aerogel focalized RICH of HERMES
- HERMES RICH long-term performance stability
- performance of the aerogel focalized RICH-1 of LHCb
- BELLE: aerogel radiator in a proximity focus RICH

Aerogel RICH story: optical property improvemets vs time

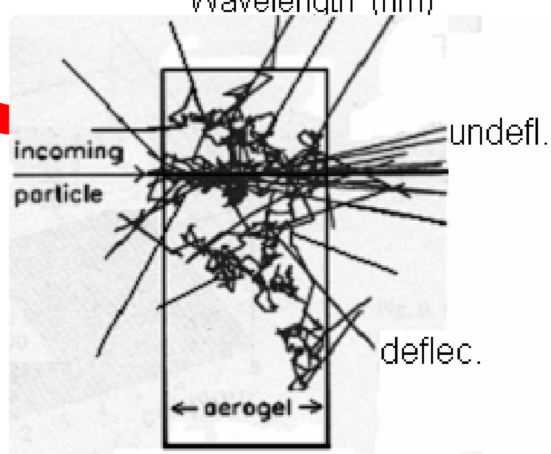


T up to 2 μm:
Hunt formula

$$T = A \cdot \exp(-Ct/\lambda^4)$$

Absorption

Clarity



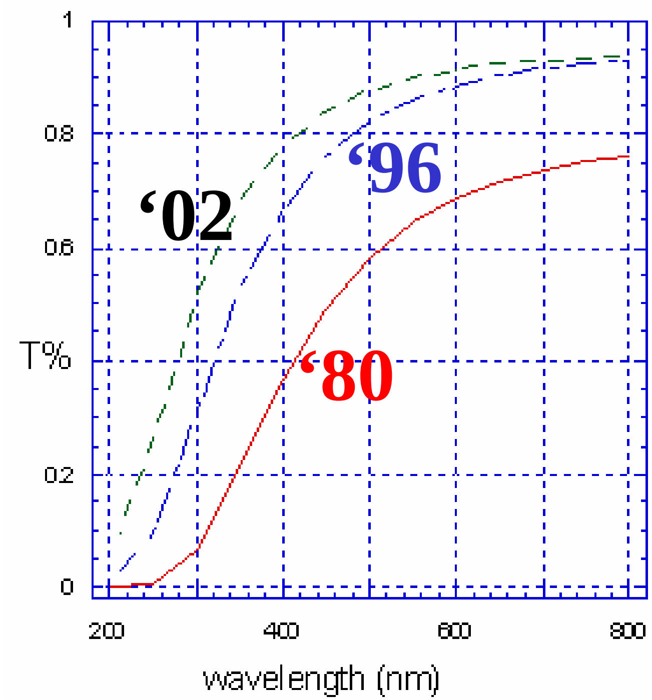
Airglass ('80s):

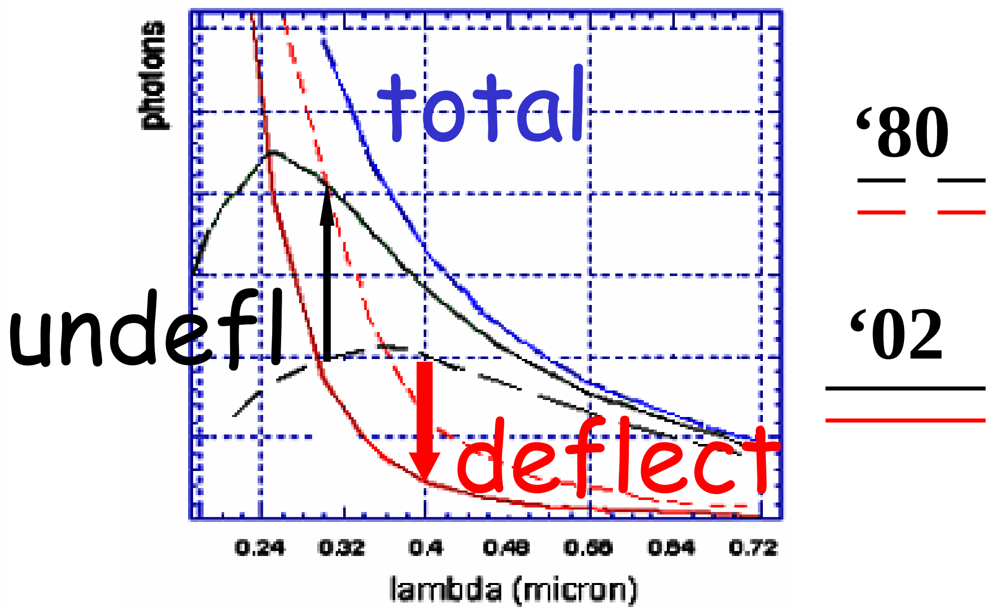
A=0.8 (opaque,absorbing)

C=0.02 $\mu m^4/cm$ (diffusing)

→Aerogel in Cher. counters

improve of transmittance: n=1.03, t=1cm

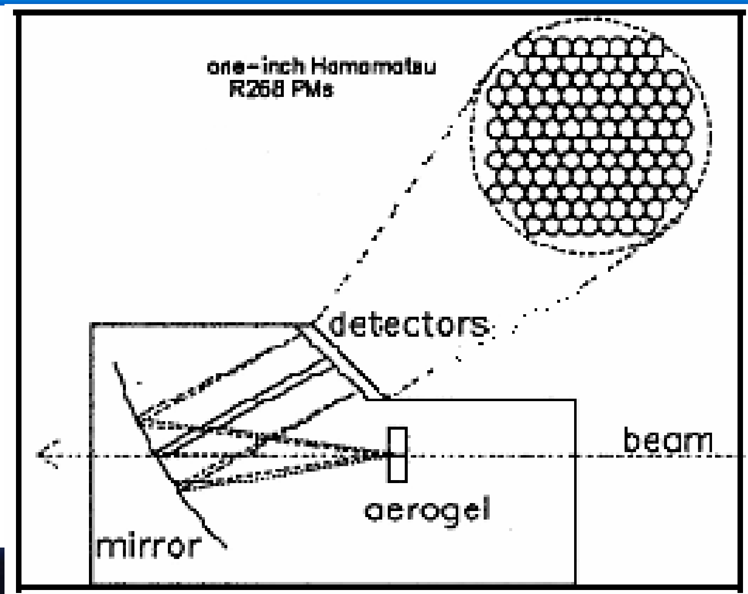


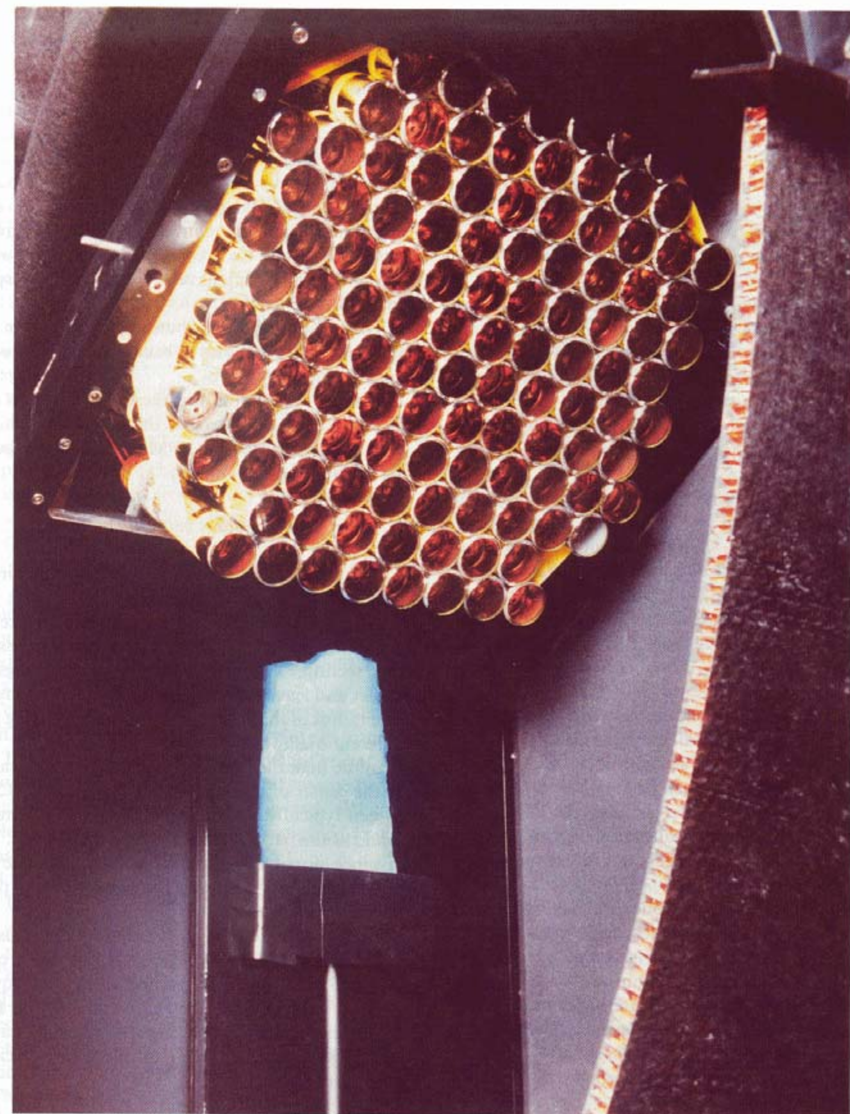


year	A	C	producer	Λ(0.4μm)
'07			Novosibirsk	5 cm
'02	0.96	0.005	Novosibirsk	4 cm
'96	0.95	0.01	Matsushita	2.3 cm
'80	0.8	0.02	Airglass	1 cm

Λ attenuation length

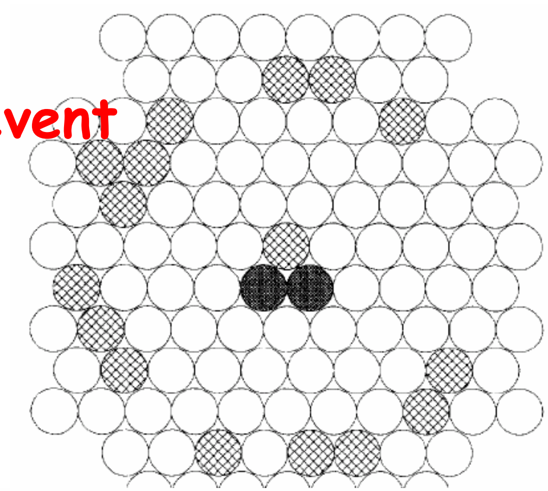
'95 T.Ypsilantis, J.Seguinot, NIMA368(1995)
'96: first focalized RICH with aerogel at CERN
CERN-Bari-Milan-Rome- coll. @ PS-T9 beam



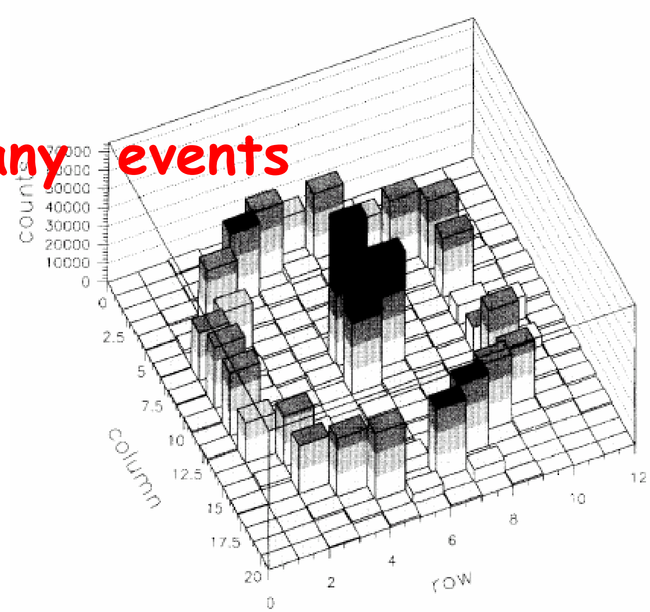


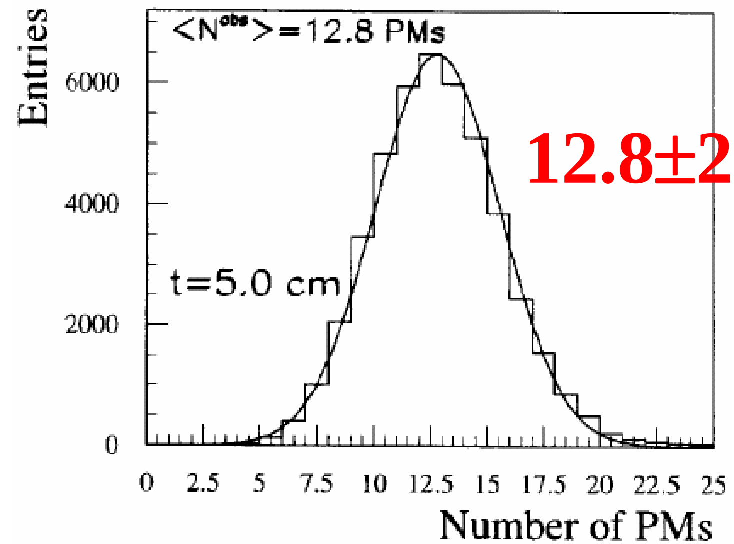
'96: 5cm of Matsushita aerogel, π^- 10GeV/c

one event

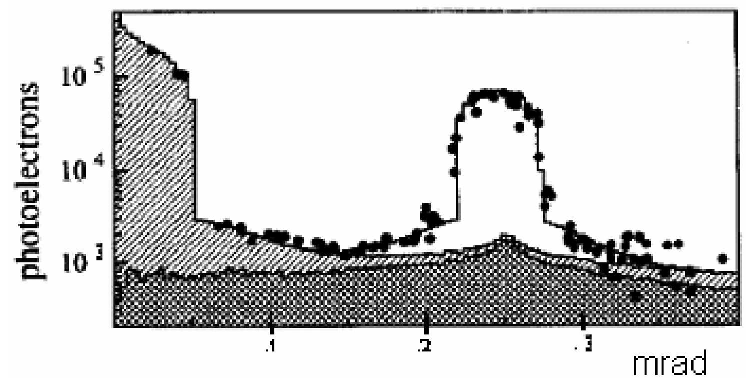


many events





12.8±2.7 PMs



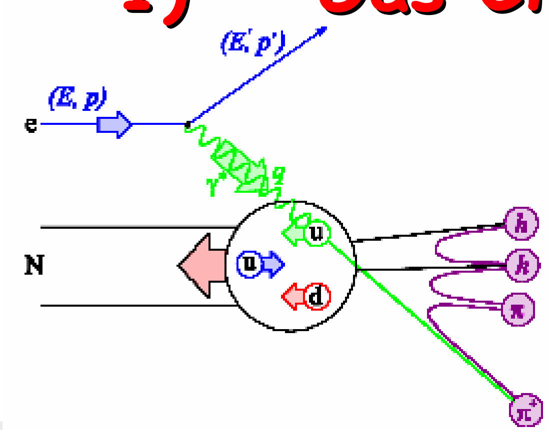
$\delta\theta/\theta$ = 8% / pe

$\delta\theta/\theta$ = 2.3% / ring

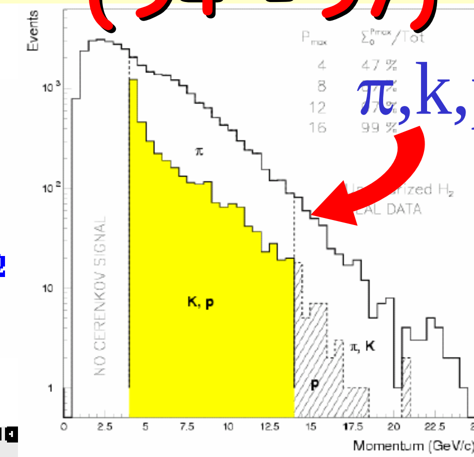
R. De Leo et al., Nucl. Instr. and Meth. **A 401** (1997) 187.

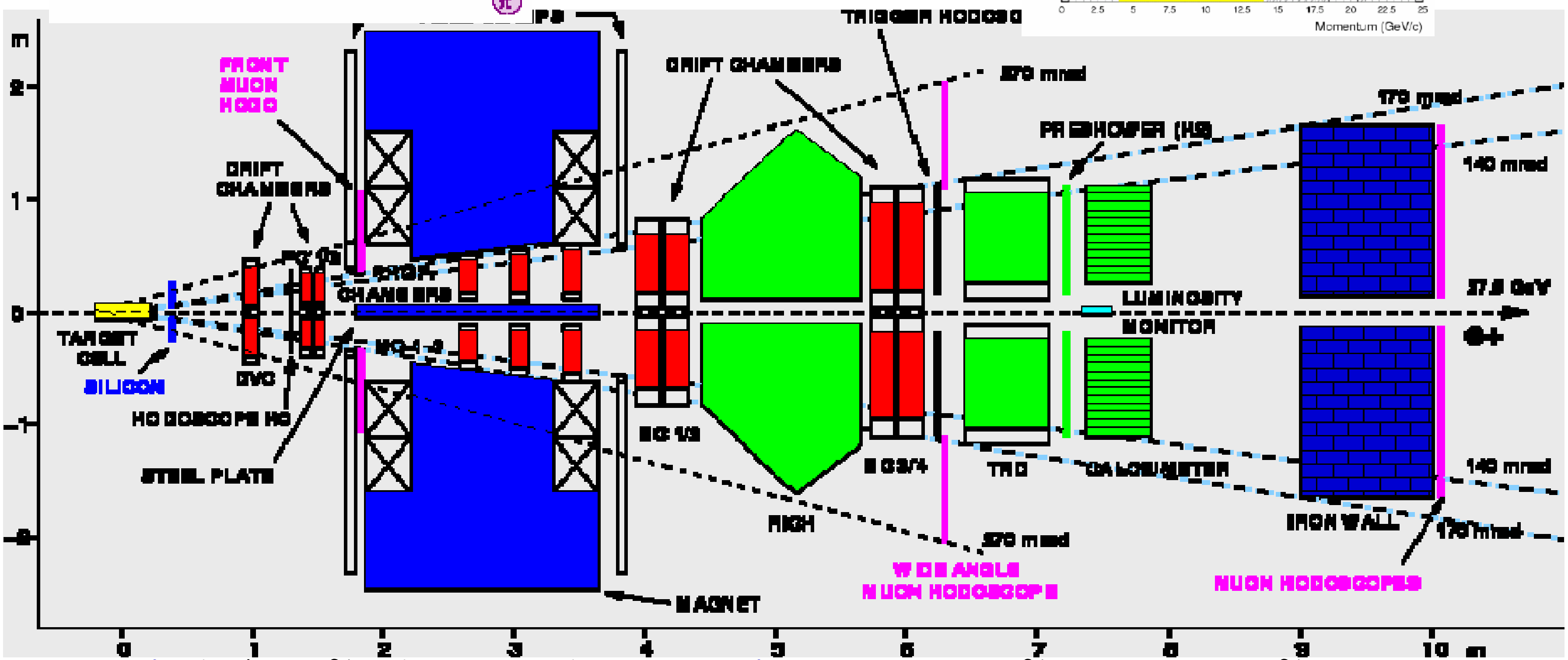
HERMES 27.5 GeV e^{+-} long.pol on p,d,3He- long.trans.pol

1) Gas Cherenkov: DIS ('94 -'97)



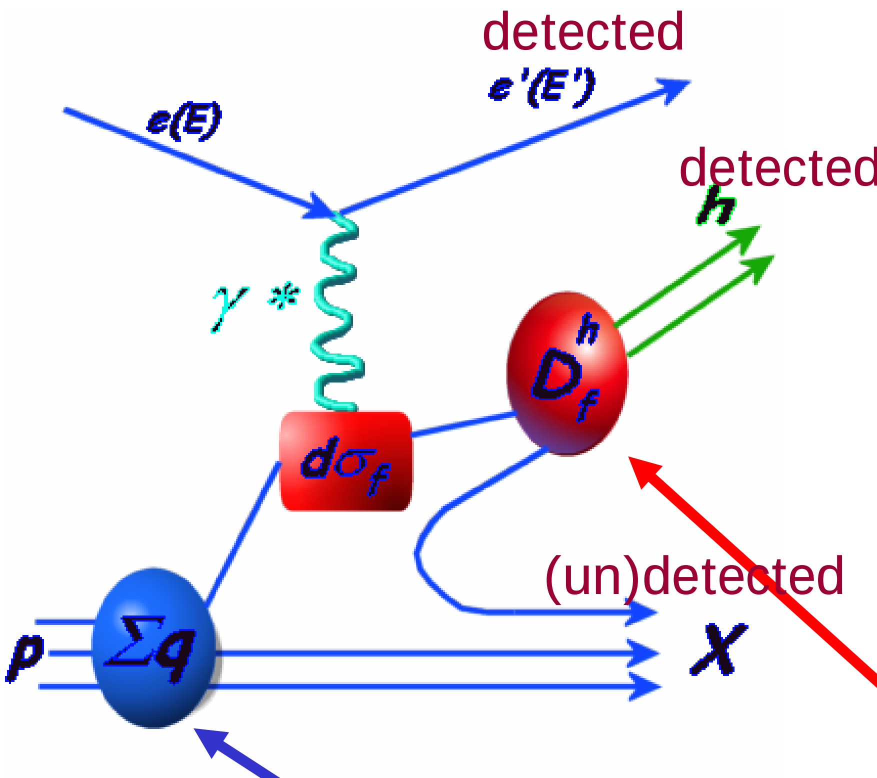
Typical Kinematics:
$E_{e^+} = 27.5 GeV$
$x > 0.02,\ W^2 > 10 GeV^2$
$1.0 GeV^2 < Q^2 < 15 GeV^2$
$\nu < 24 GeV$





•resol. dp/p~2%, dq<1 mrad PID: leptons e~98%, contam. <1%

2) RICH: SemiInclusiveDIS ('98 - '07)



$$\sigma\,(ep \rightarrow e'\,h\,X)$$

probability that struck quark of flavour *f* fragments into hadron of type *h* with energy fraction z

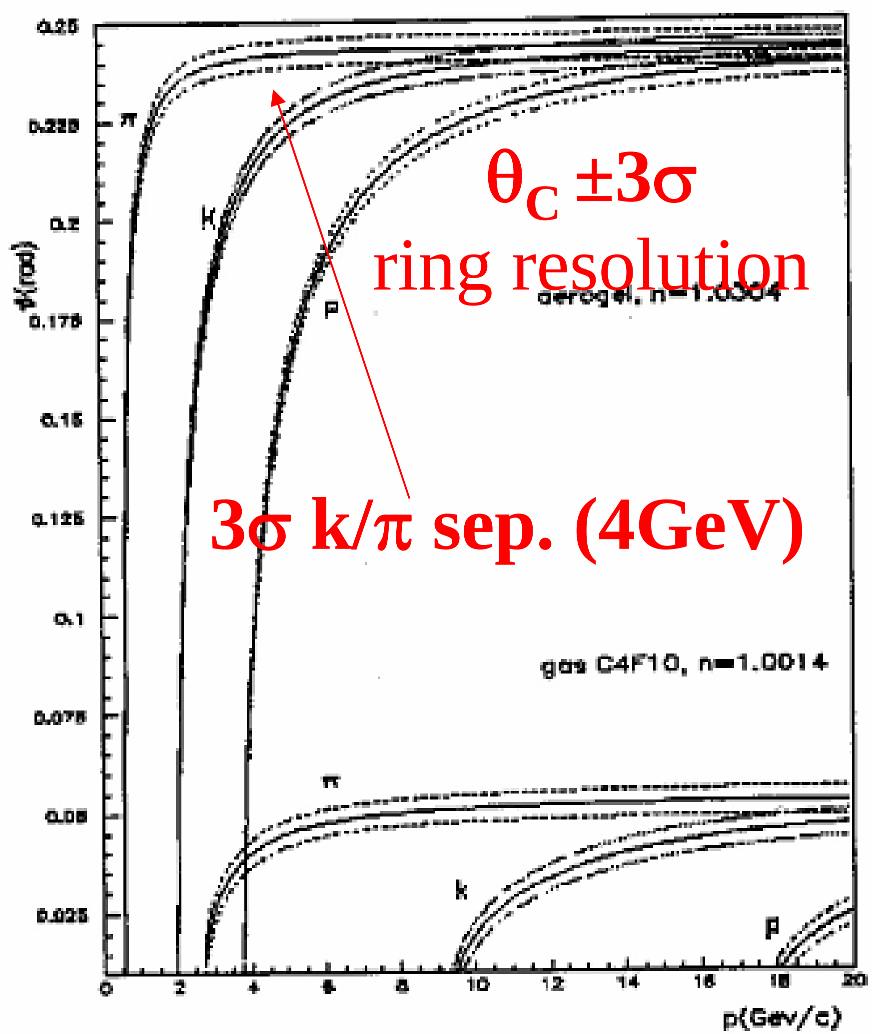
distribution function

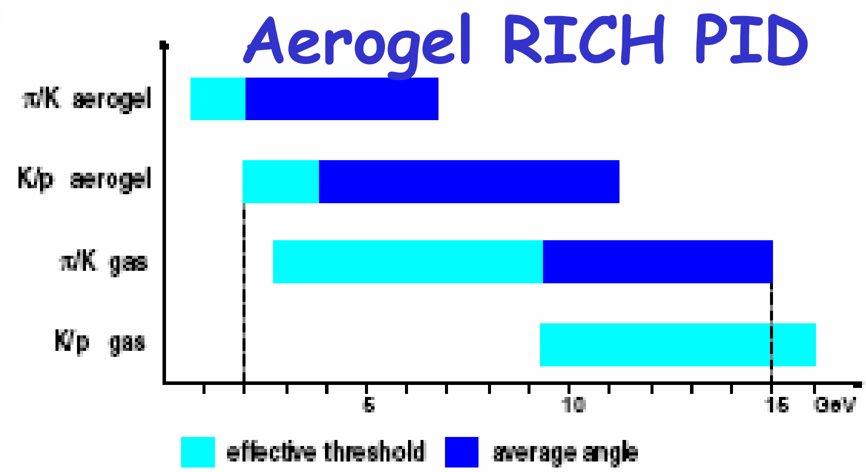
fragmentation function

$z = E_h/\nu$

$$d\sigma^{h}(z) \propto \sum_{f} q_f(x) \otimes d\sigma_f \otimes D_f^{q\rightarrow h}(z)$$

'97: the HERMES dual radiator RICH proposal





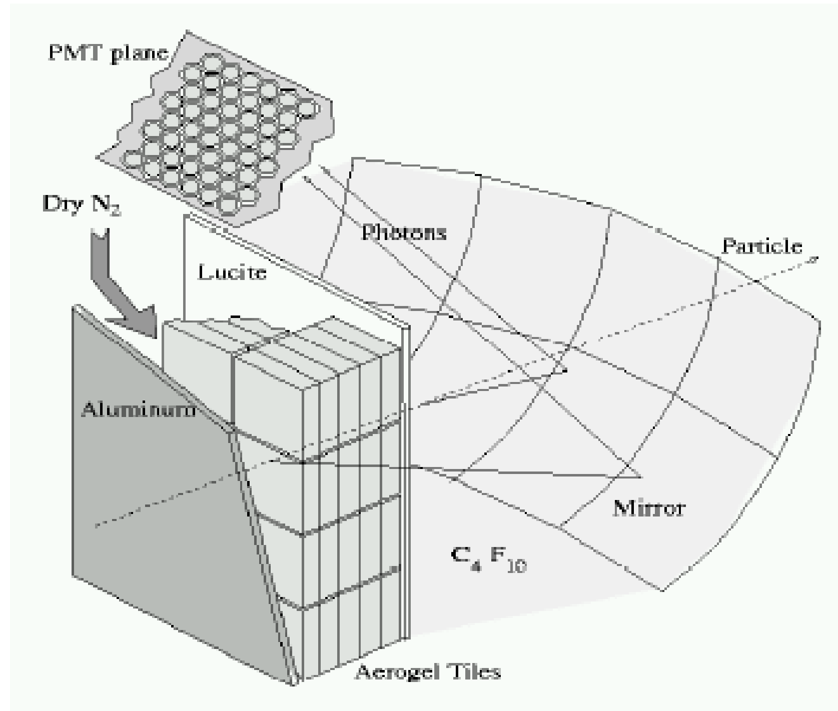
- focalized R = 2.2 m
- n(aerogel)=1.03, θ_C=242 mrad
- n(C_4F_{10})= 1.00137
- Npe (aerogel) = 10
- $\delta\theta/\theta$(/ring) =1.2 % (4.1% / pe)
- $\delta\theta$(/ring) = 3 mrad
- $\theta_C^{\pi}-\theta_C^{k}$(4GeV,n =1.03) = 9 mrad

Designing a RICH

Aerogel wall

11x11x1 cc

- Array of 425 tiles/half
- Stacks of 5 tiles
- Black tedlar foil around edges
- Lucite end window
- Dry N_2 atmosphere



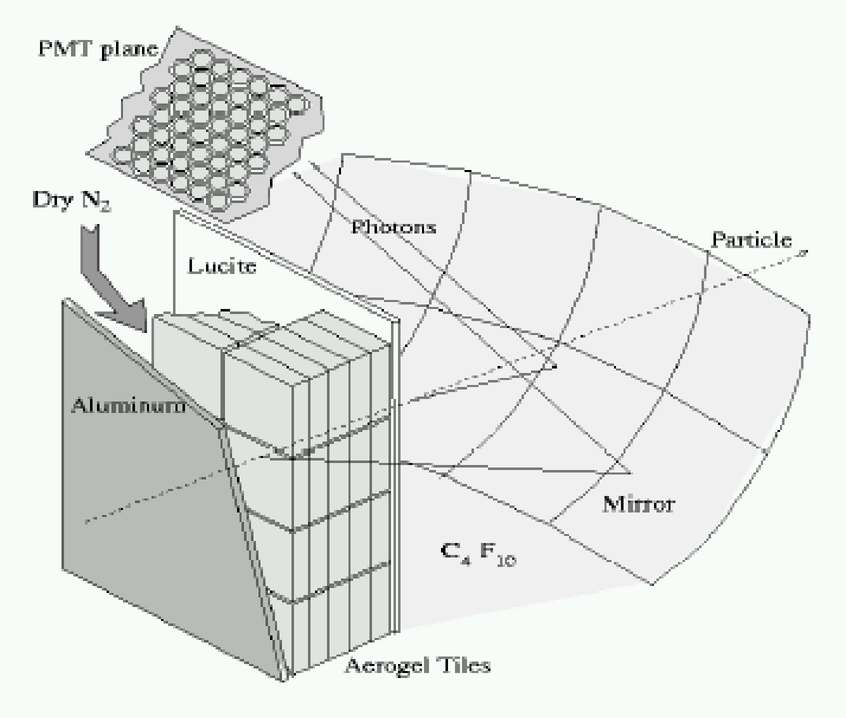
Dry N_2 flow in aerogel!

Hydrophobic aerogel from Matsushita !

Designing a RICH

Mirror array

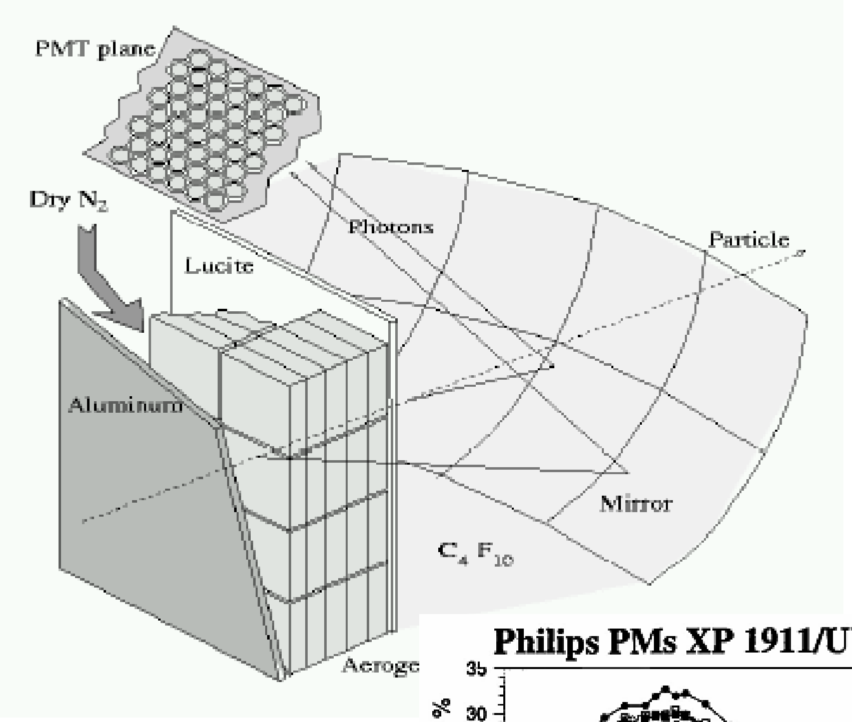
- Spherical array
- 4×2 mirror segments
- Focal length = 110 cm
- Graphite fibre composite

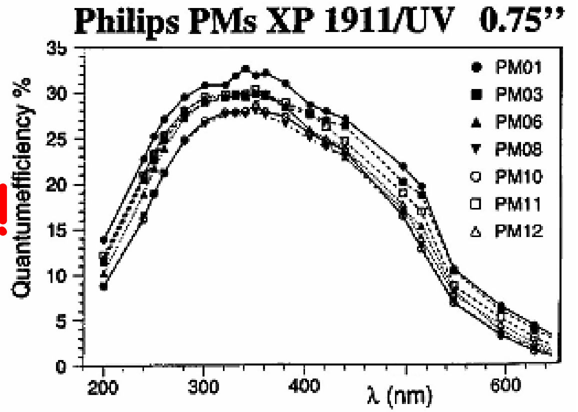


Designing a RICH

Photon detector

- Based on SELEX design
- 1934 PMTs/half in hexagonal close-pack
- Philips XP1911/UV green enhanced
- Soft steel matrix for magnetic shielding





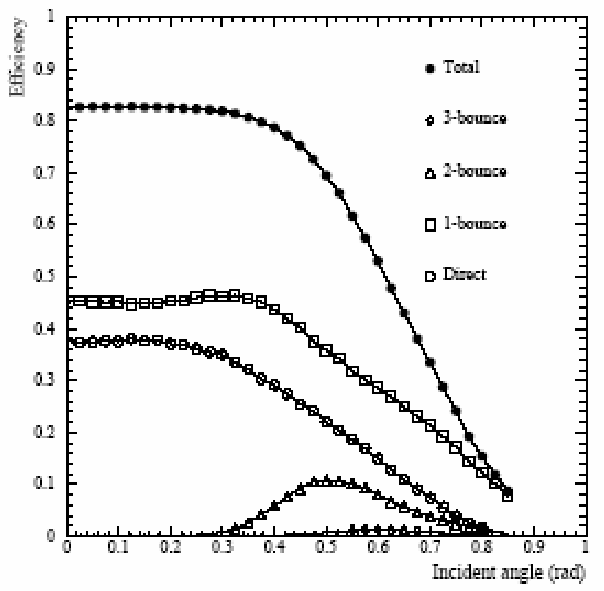
0.75" PMT → dominant pixel contrib.!

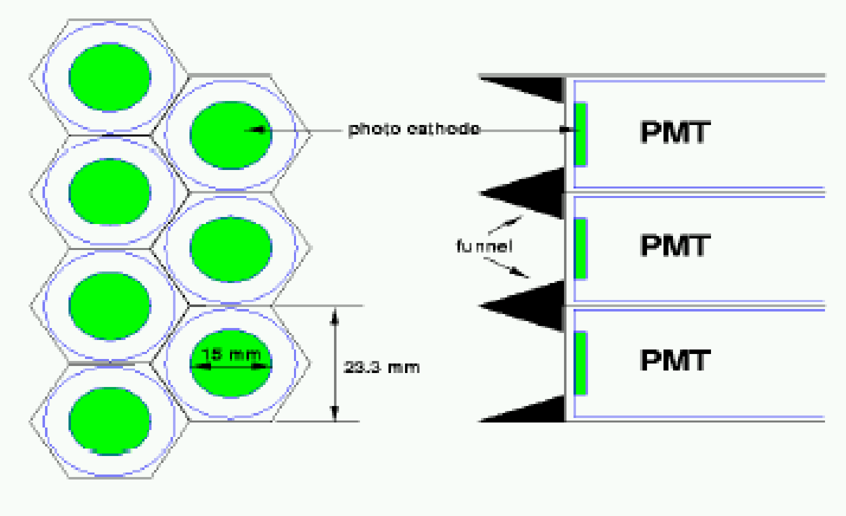
hermes

Photon detector

Photon detector

- Light collecting funnels to cover 92% of focal plane



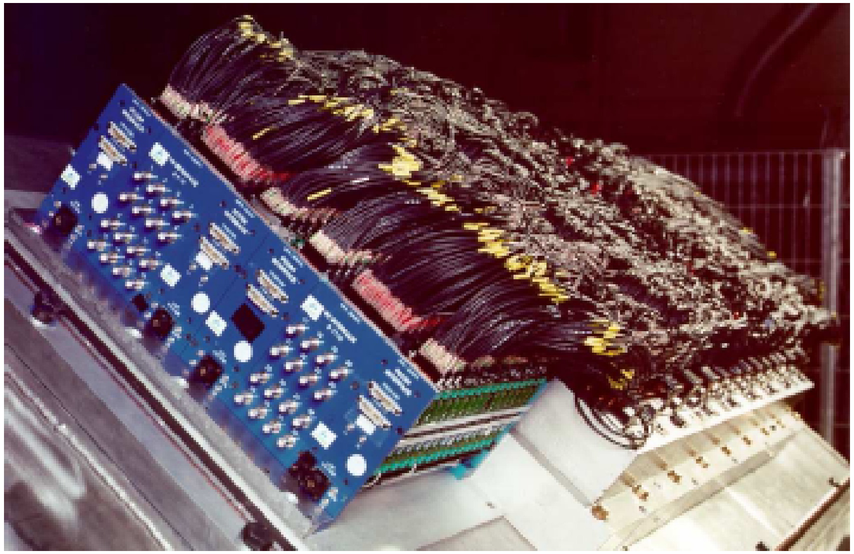


funnels:
pixel contrib.even larger!

Photon detector

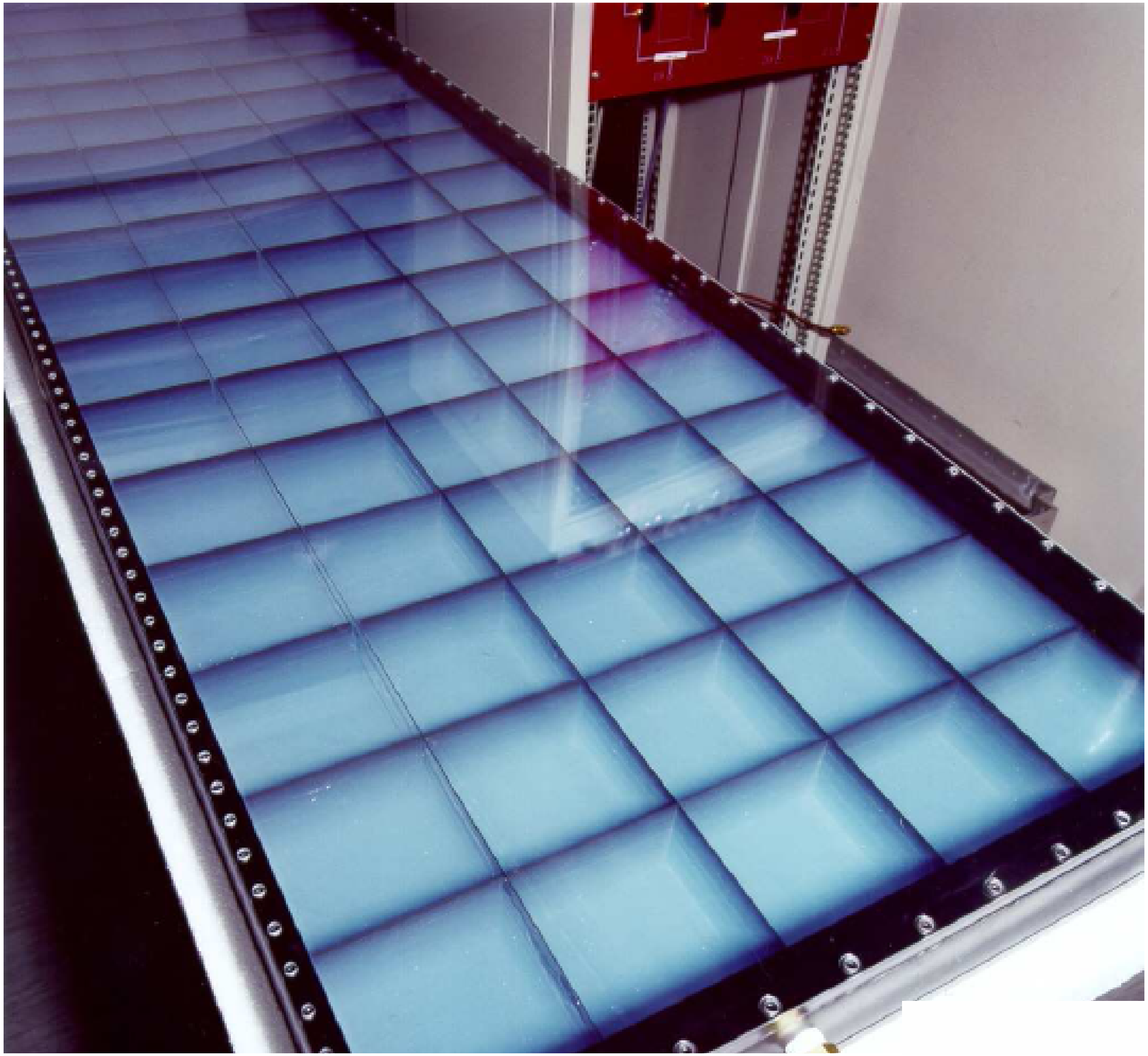
Read-out system

- PCOS4 system
  Like MCs
- Digital read-out
- Threshold = 0.1 p.e.



PMT's: fired-not fired!

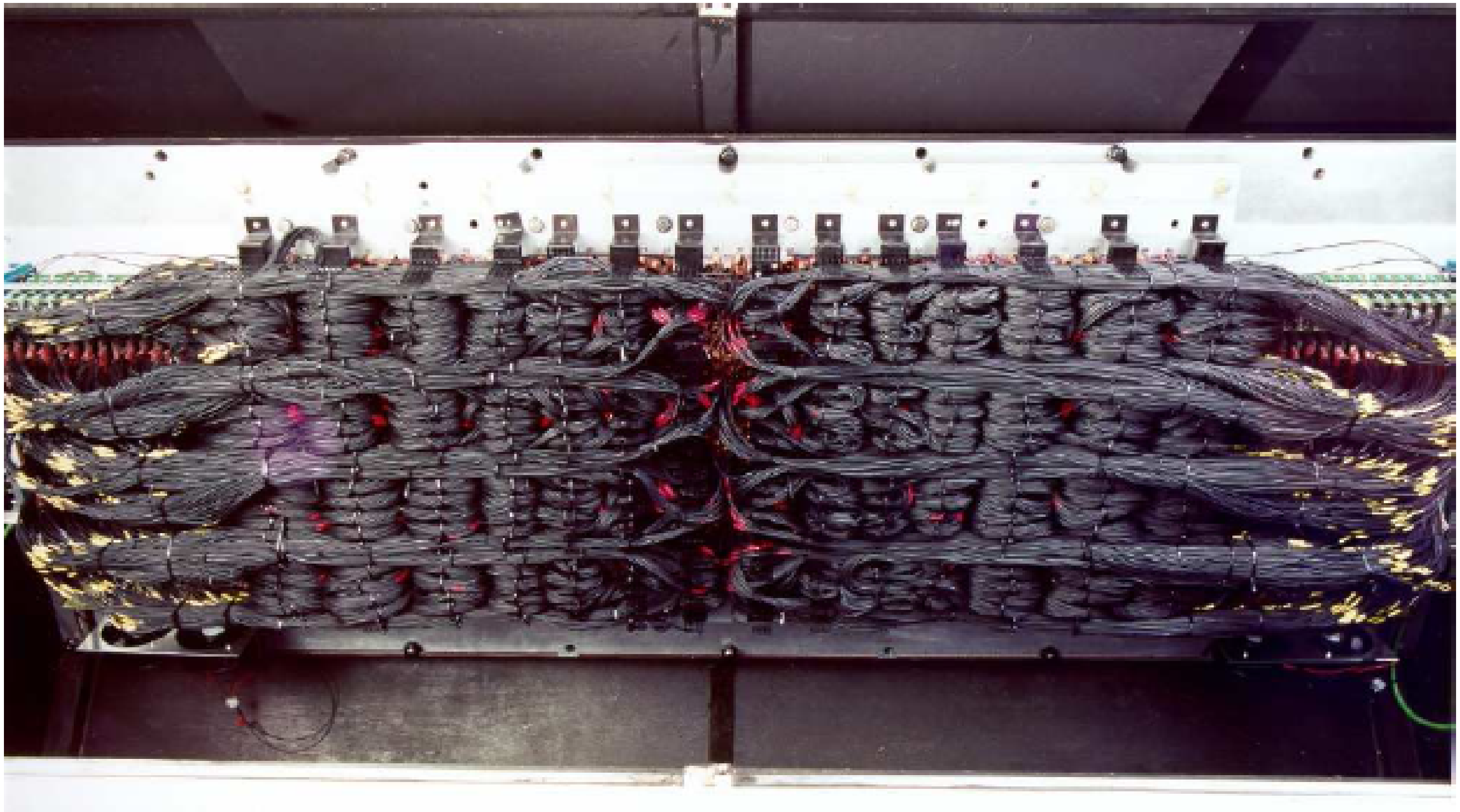
Building a RICH



Building a RICH

Building a RICH

Building a RICH



12 km of cables

Building a RICH

hermes

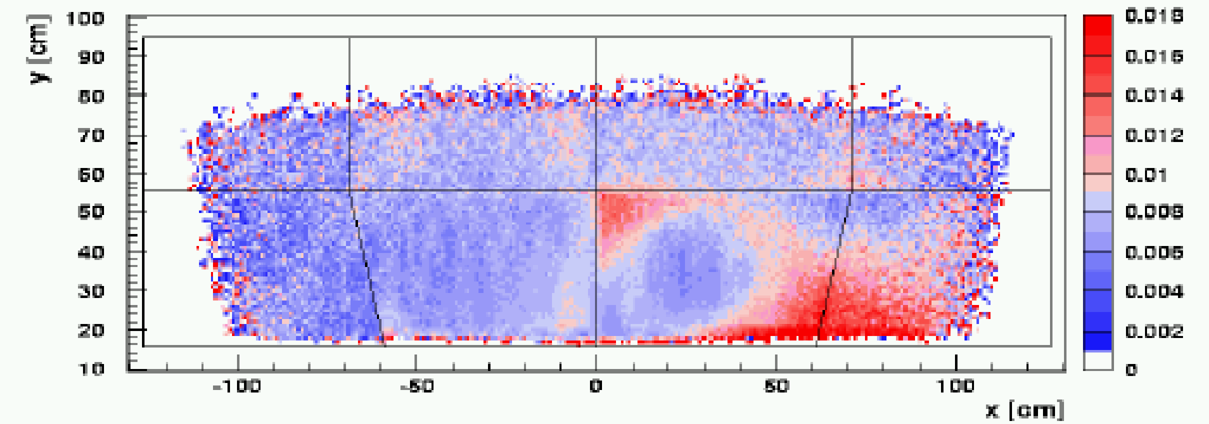
Building a RICH

Timelines

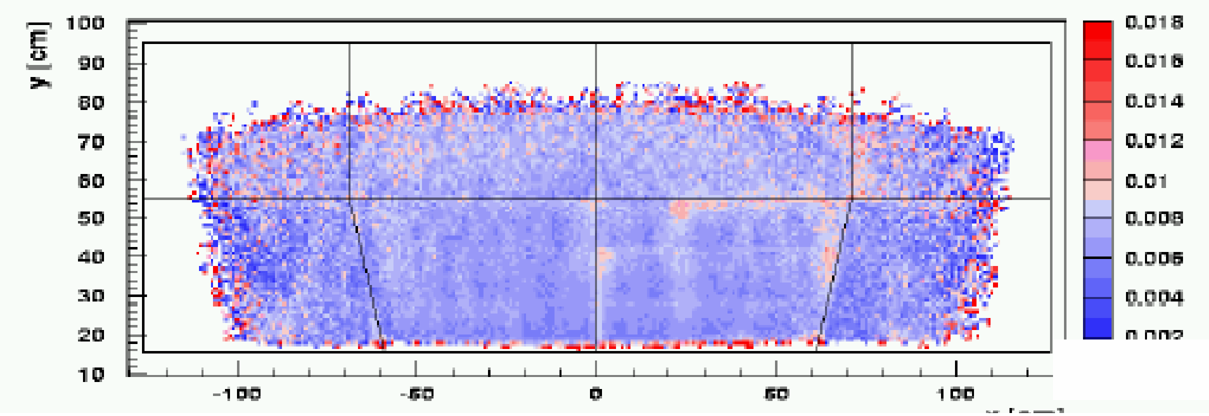
- November 96: original discussions
- December 96: first HERMES RICH-meeting
- March 97: proposal accepted by HERMES
- Spring-summer 97:
- Autumn 97: test aerogel-PMT prototype @ CERN
- March 98: test PMTs
- Easter 98: start assembly
- May 98: install 2 RICH-detectors
- August 98: first rings

Recognizing rings

- Difficult alignment procedure
  - aerogel tiles
  - mirror position, tilt, segments
  - focal plane



mirrors not Aligned

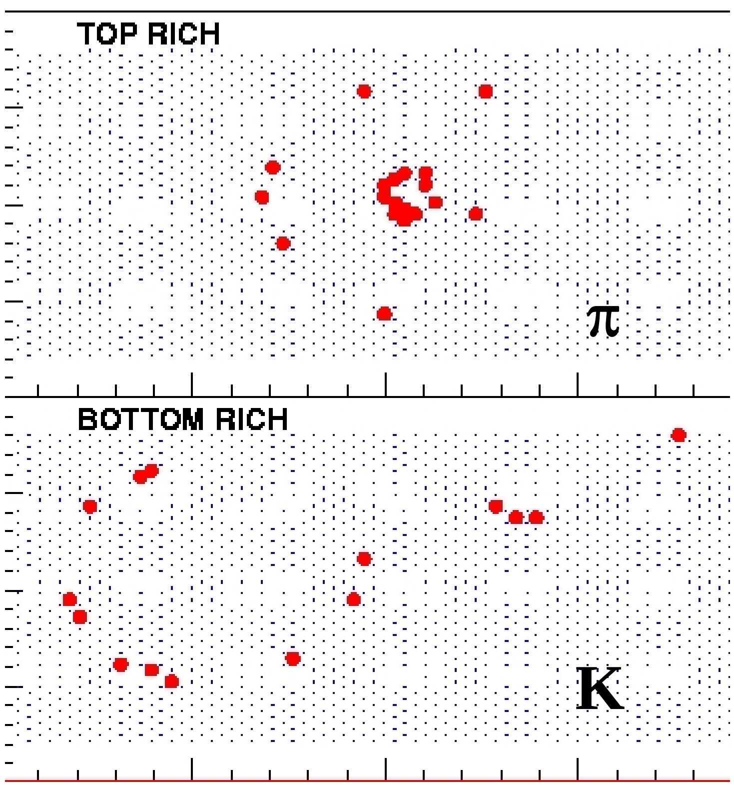


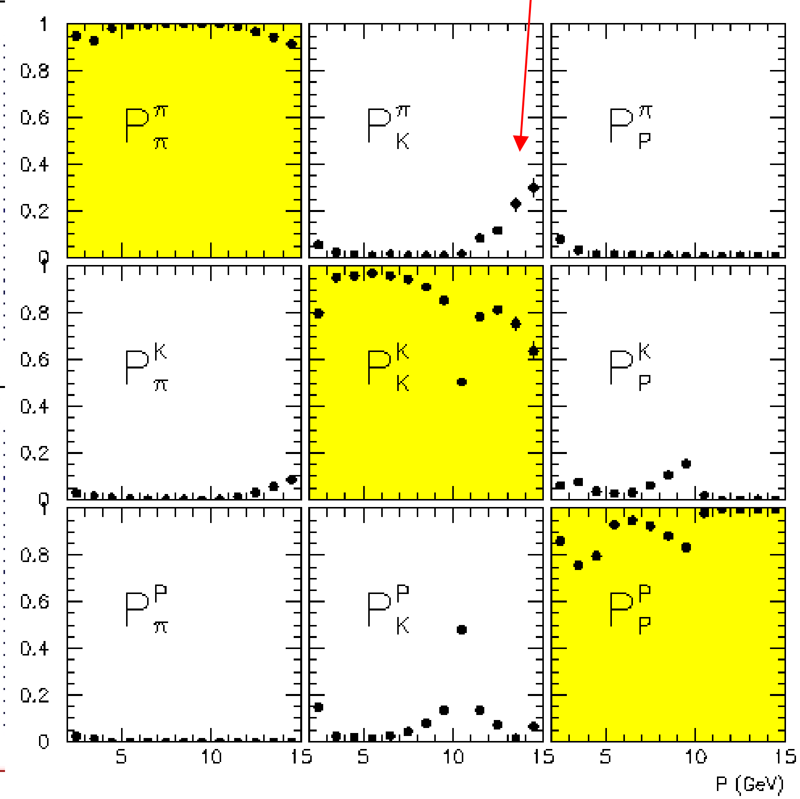
mirrors aligned

Recognizing rings

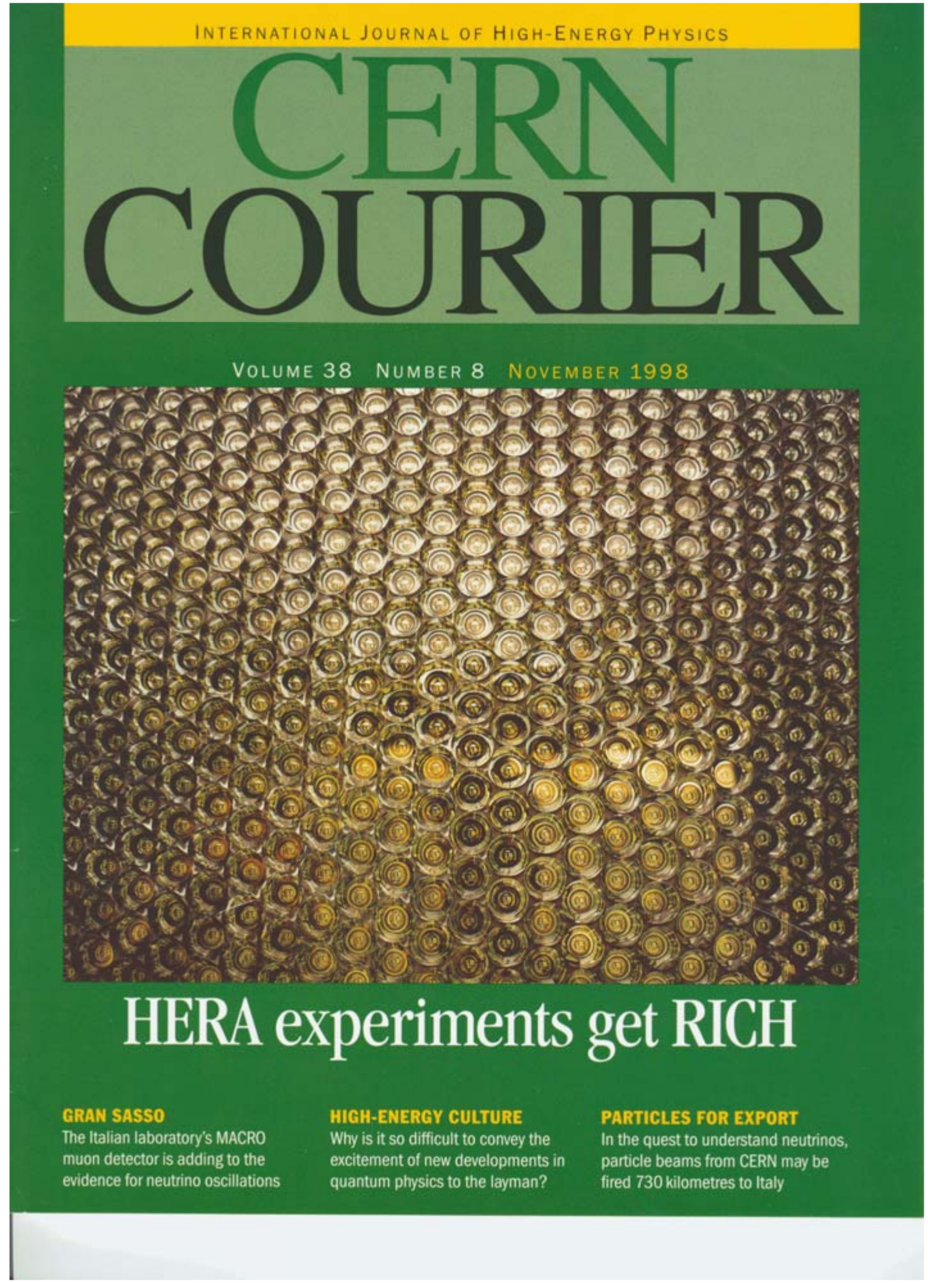
- Difficult alignment procedure
  - aerogel tiles
  - mirror position, tilt, segments
  - focal plane
- Reconstruction of Čerenkov angles: IRT, DRT

k misidentified as π





nov. '98


INTERNATIONAL JOURNAL OF HIGH-ENERGY PHYSICS

CERN COURIER

VOLUME 38 NUMBER 8 NOVEMBER 1998

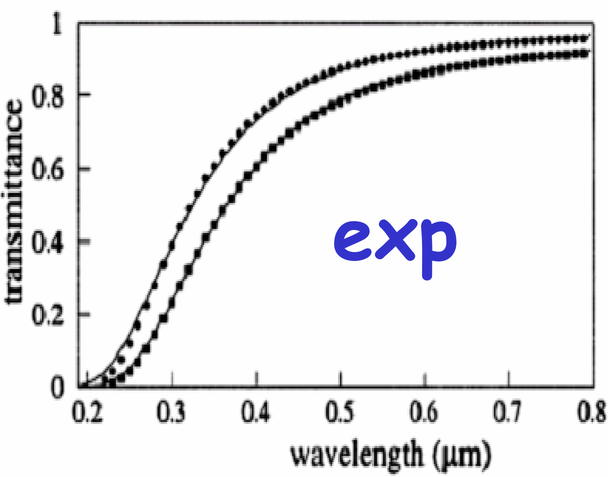
HERA experiments get RICH

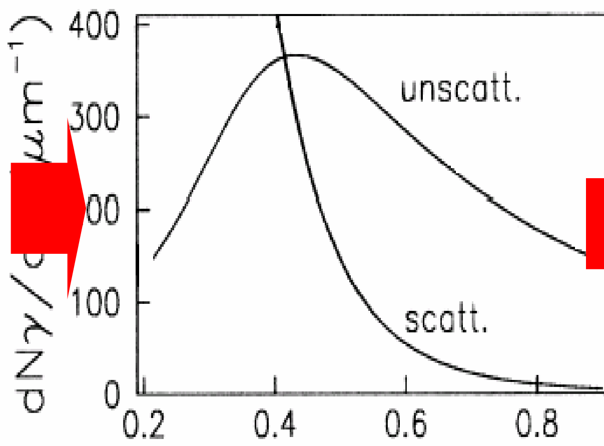
GRAN SASSO
The Italian laboratory's MACRO muon detector is adding to the evidence for neutrino oscillations

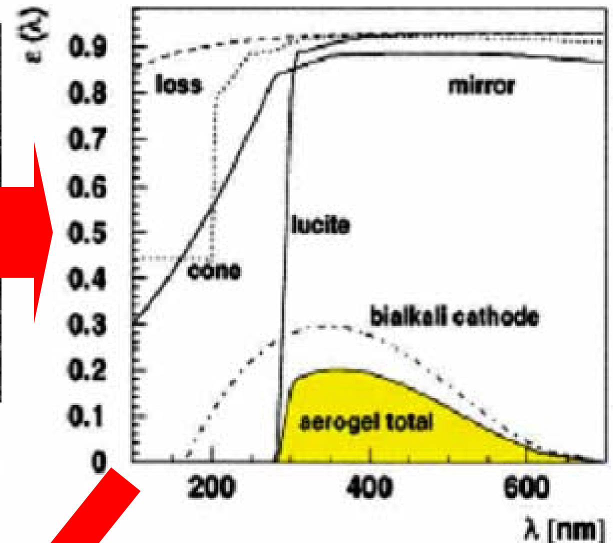
HIGH-ENERGY CULTURE
Why is it so difficult to convey the excitement of new developments in quantum physics to the layman?

PARTICLES FOR EXPORT
In the quest to understand neutrinos, particle beams from CERN may be fired 730 kilometres to Italy

T → Cher. γ's → photoelectrons

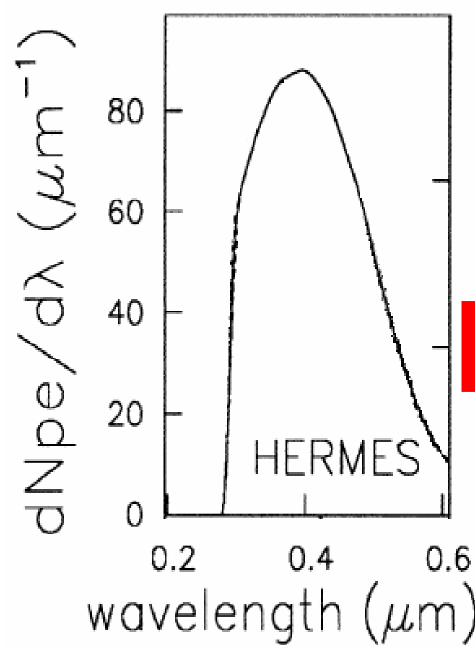






Hunt par	Av.value	σ (%)
A	0.964	2.4
Ct (μm^4)	0.0094	8.3

Λ(400 nm) = 2.3cm



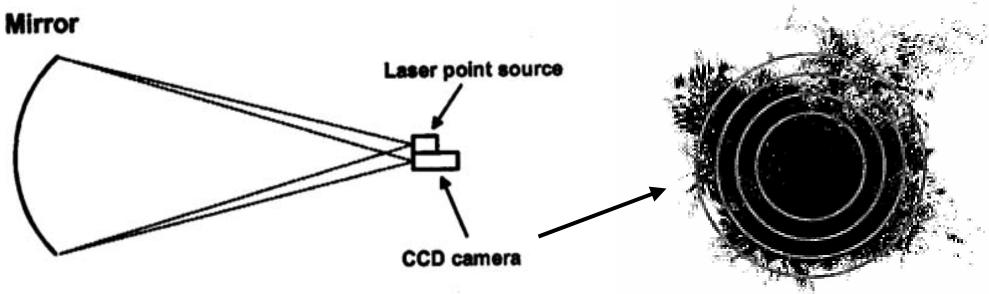
Npe (calc.)
12±2

geometrical contributions to $\delta\theta_c$

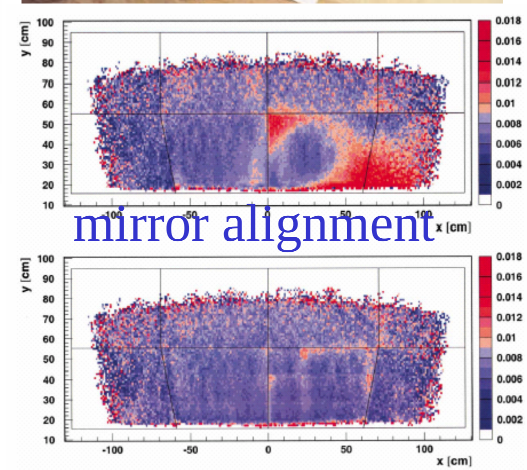
1) pixel $\left(\frac{\delta\theta}{\theta}\right)_{pixel} = \left(\frac{D}{4R}\right) = 2.30$ % /pe

2) focal plane

a) $(\vartheta\theta/\theta)_{\mathbf{opt.aber.}} = (d/R)^2 = 0.5\%$

b) 

$\vartheta\theta = \sigma/2R(\vartheta\theta/\theta)_{\mathbf{surf.imp.}} = 0.3\ \%$



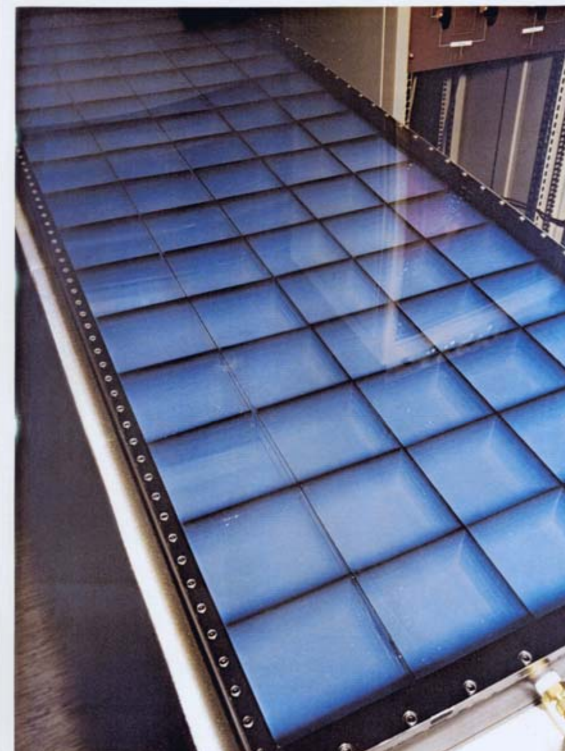
a)+b) $(\vartheta\theta/\theta)_{mirror} = 0.6\ \%\ /\ pe$

3) point emiss. $(\vartheta\theta/\theta)_{point} = 0.7\ \%\ /\ pe$

aerogel opt. properties contrib.s to $\delta\theta_c$

- 1) n dispersion in the different tiles
- 2) chromatic dispersion $n(\lambda)$
- 3) forward scattering
- 4) tile surface irregularities

aerogel Selected 850 tiles over 1200
11x11x1 cc from Matsushita
2 planes, 5 rows, 17 columns, 5 layers



one aerogel radiator

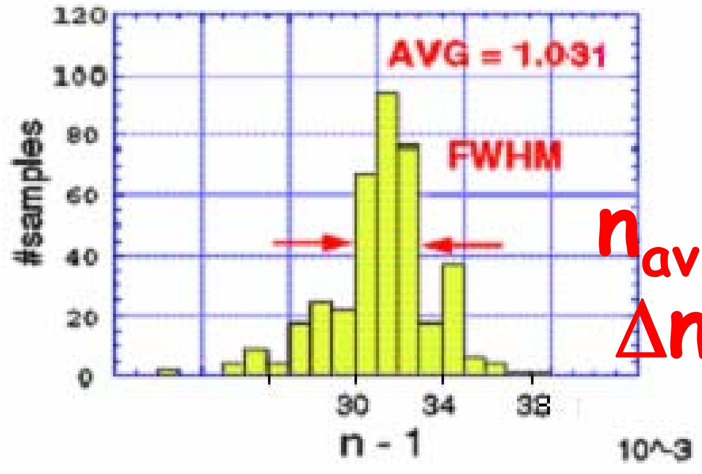
Optical characterization of n=1.3 aerogel of the HERMES RICH
E.Aschenauer et al., Nucl. Instr. and Meth. A440 (2000) 338

1) n dispersion (633 nm)

minim.deflec.

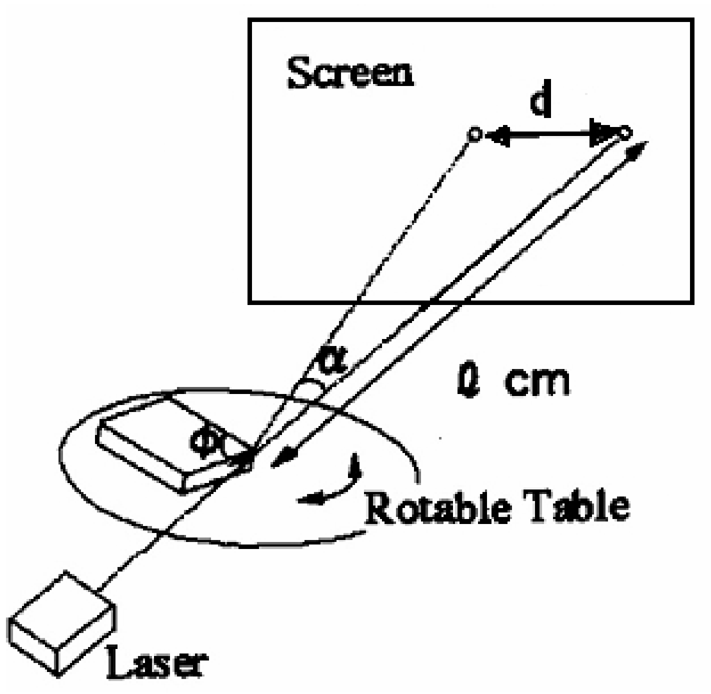
l = 4m → high precision

$\delta n/n = 10^{-4}$



$n_{av}=1.0304$

$\Delta n \approx 3*10^{-4}$



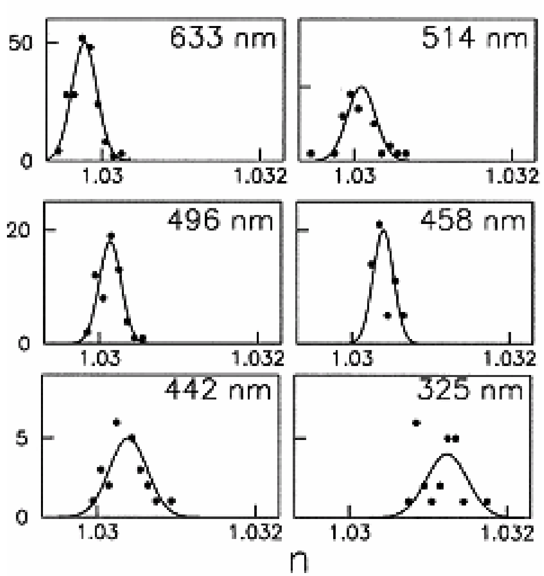
$\delta n/(n-1)$ = 1.5 %

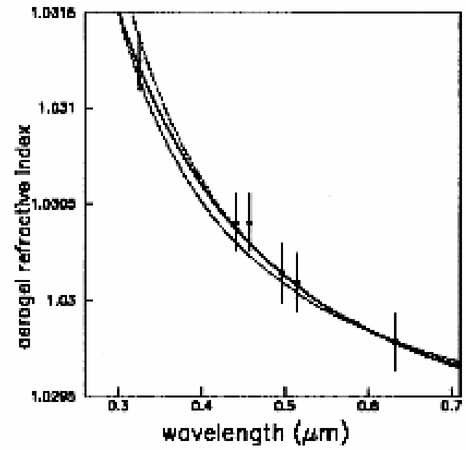
reduced to 1.0 %

by sorting similar-n tiles

$$\left(\frac{\delta\theta}{\theta}\right)_n = \frac{1}{2}\frac{\delta n}{n-1} = 0.5\% \ \ /\text{pe}$$

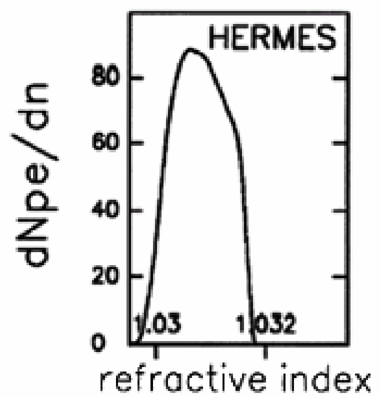
2) chromatic dispers.: n (λ) meas.





$$n = C + C'/\lambda^x \qquad x = 1.2 \pm 0.2.$$

$$n_{\mathrm{aerogel}}(\lambda) = A n_{\mathrm{SiO_2}}(\lambda) + (1 - A) n_{\mathrm{air}}(\lambda)$$

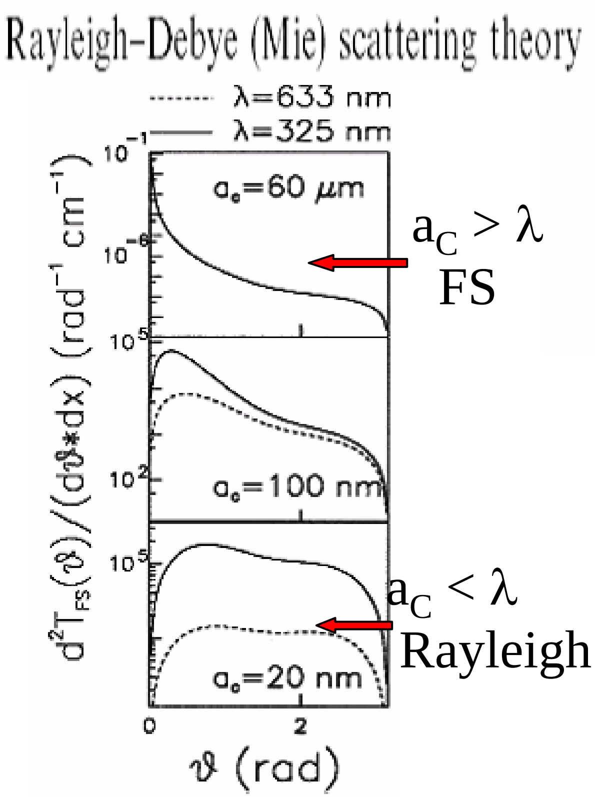


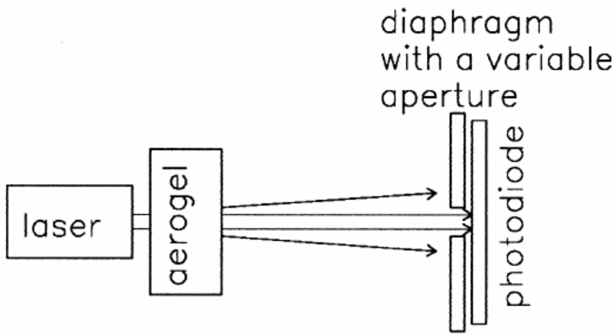
$$n_{\mathrm{aver}} \pm \sigma_n = 1.0312 \pm 0.0008$$

$$\left(\frac{\delta\theta}{\theta}\right)_{\mathrm{chromatic}} = \frac{1}{2}\left(\frac{\sigma_n}{n_{\mathrm{aver}} - 1}\right) = 1.3\ \%\ \ /\ \mathrm{pe}$$

3) forward scattering

- due to large inhomogeneities (a_C) of ε, mostly on the surfaces
- responsible of fuzzy vision of objects through aerogel
- influence $dNpe/d\vartheta$ not Npe
- forward peaked ($\neq$ Rayleigh isotropic)
- dep. on pH of solvent used in gel



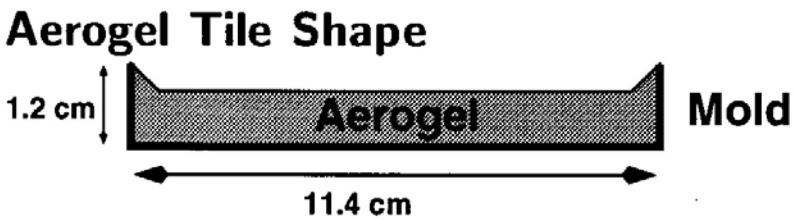


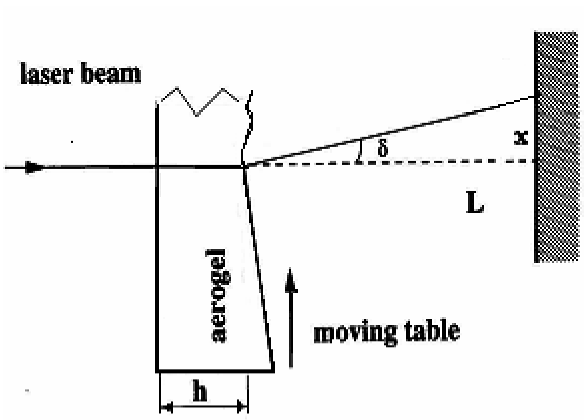
5 cm of aerogel:

23% of Cher.ph. are FS @1.55 mrad → $\delta\theta_{FS}$

$$\left(\frac{\delta\theta}{\theta}\right)_{FS} = \left(\frac{\delta\,\theta_{FS}}{\theta_C}\right) = 0.4\ \%\ /pe$$

4) surface irregularities

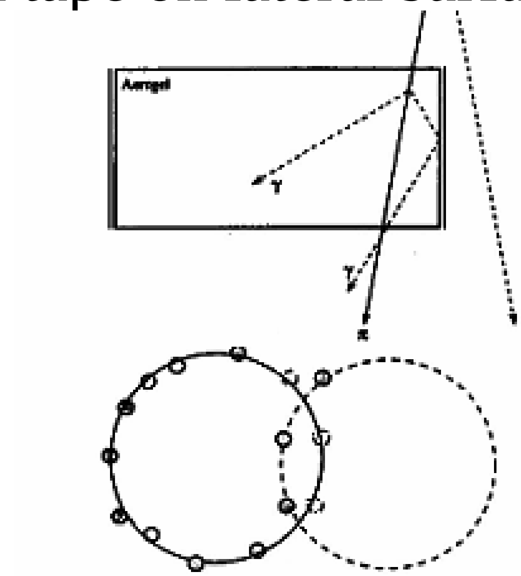


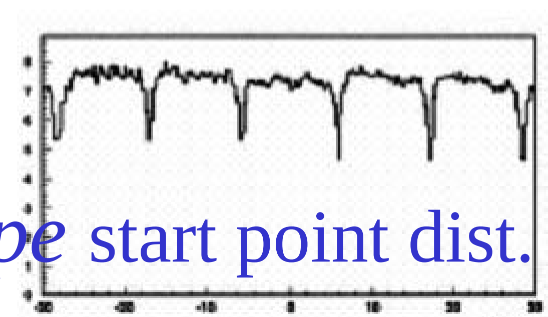


$$\left(\frac{\delta\theta}{\theta}\right)_{\text{surf.}} = \frac{\delta\theta_S}{\theta_C} = 0.4\ \%\ /\ \text{pe}$$

avoid internal reflections

black tape on lateral surfaces



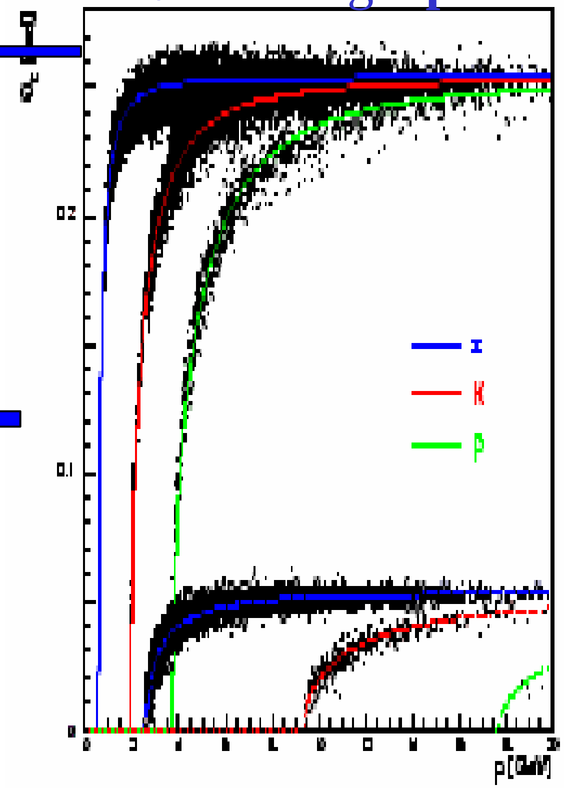


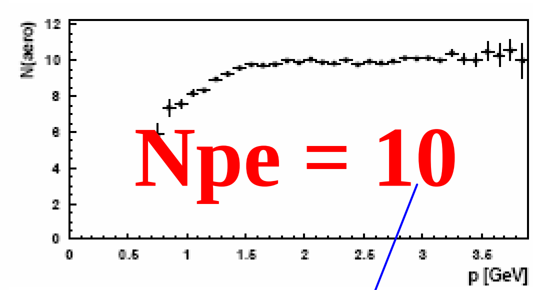
pe start point dist.

exp.- calc. angle resolution (%)

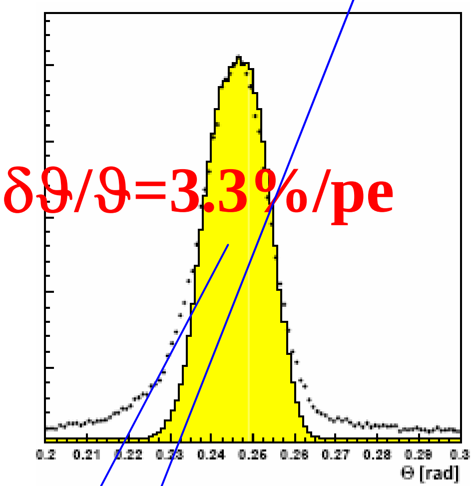
	HERMES
• Pixel	2.3
• Mirror	0.6
• Point emiss.	0.7
• n disp.	0.5
• Chromatic	1.3
• Forw.Scatt.	0.4
• Surface	0.4
• Total (calc.)/pe	2.9
• Total (exp.)/pe	3.3
• Npe (exp.)	10

θc for single **pe**





Npe = 10



δϑ/ϑ=3.3%/pe

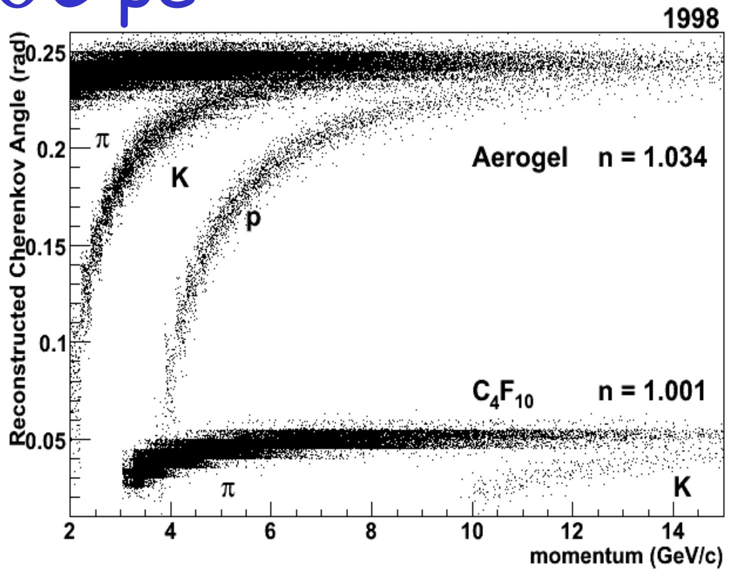
δϑ/ϑ = 1.1% /ring

Npe=10: 3.3σ k/π sep. (4GeV)

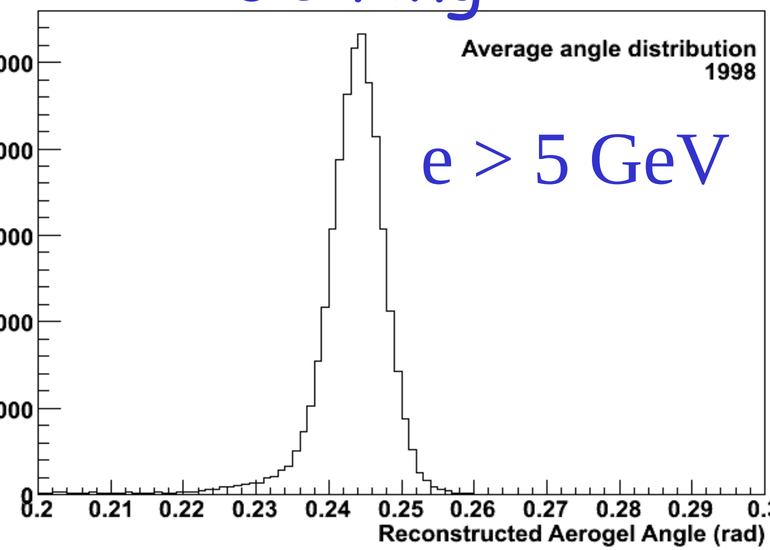
Npe=6: 2.5σ k/π sep. (4GeV)

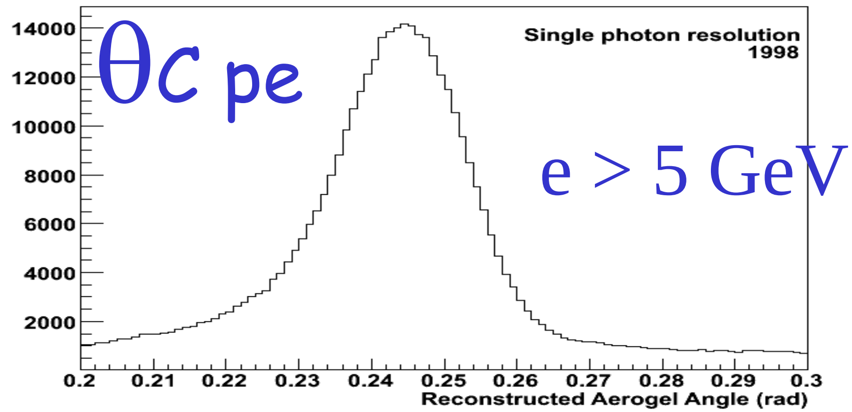
RICH stability 1998

θ_C pe



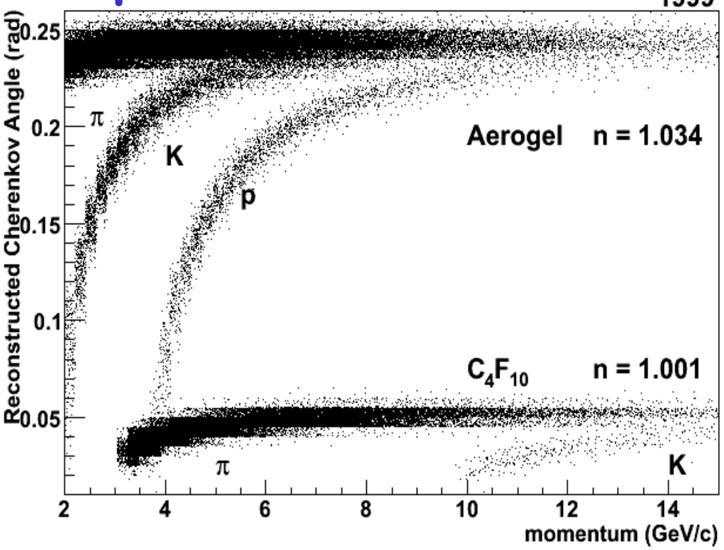
θ_C ring



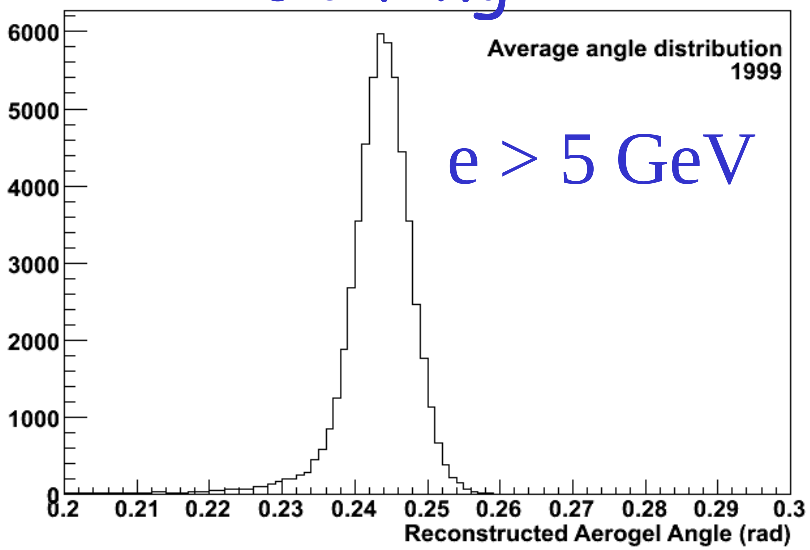


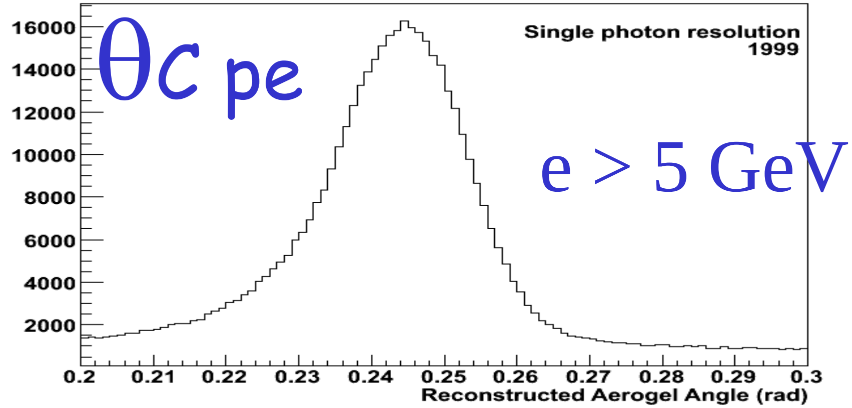
RICH stability 1999

θc pe



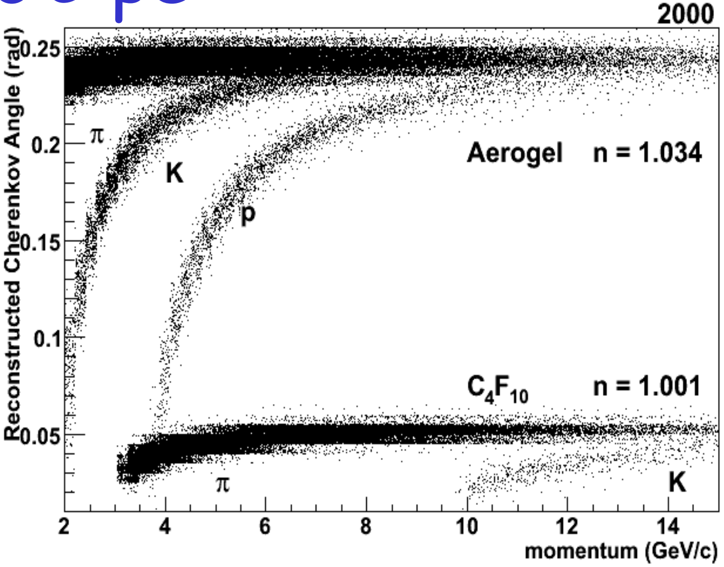
θc ring



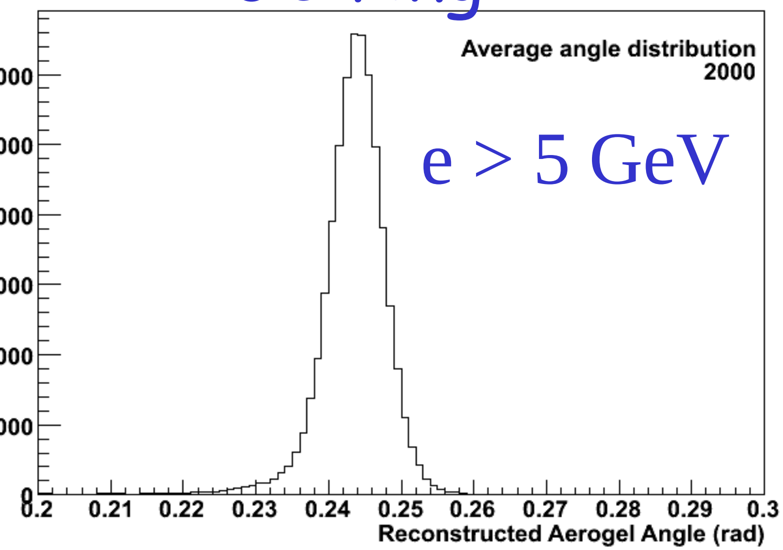


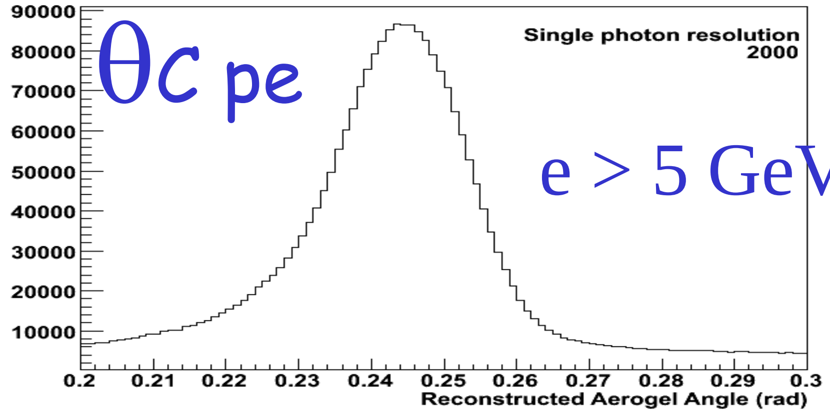
RICH stability 2000

θ_c pe



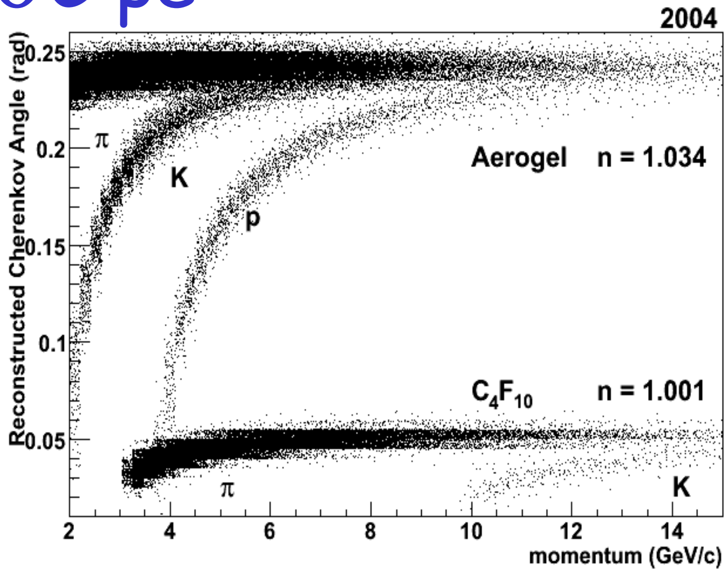
θ_c ring



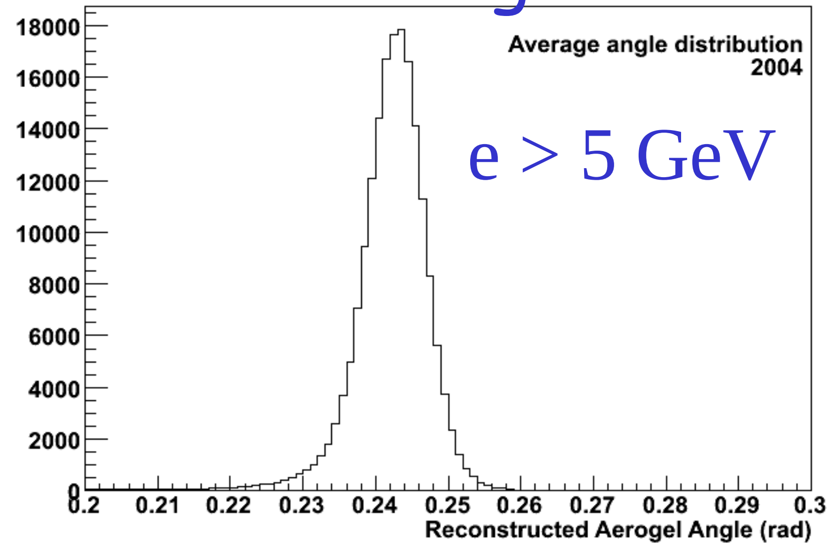


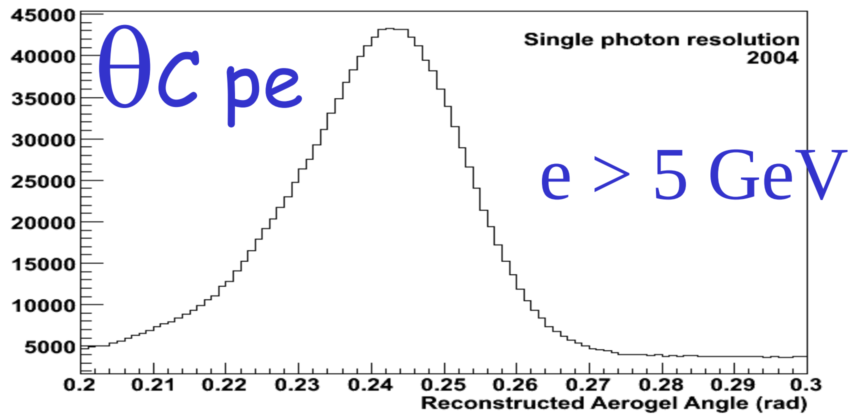
RICH stability 2004

θc pe



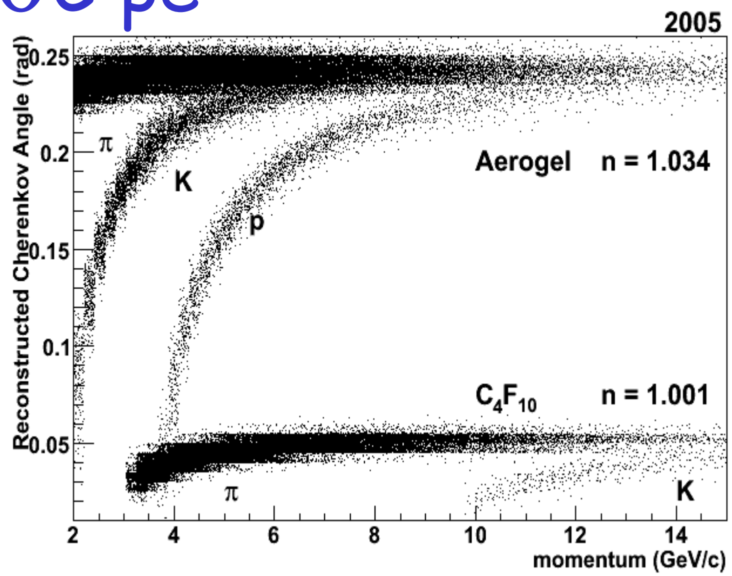
θc ring



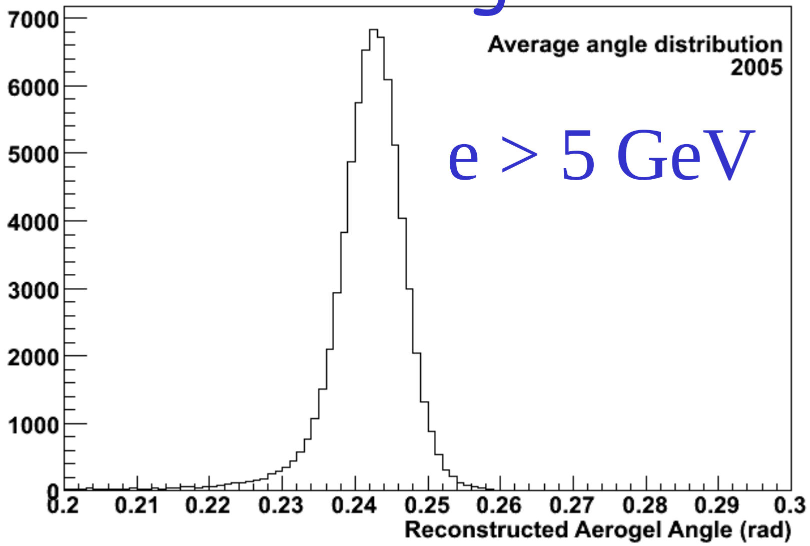


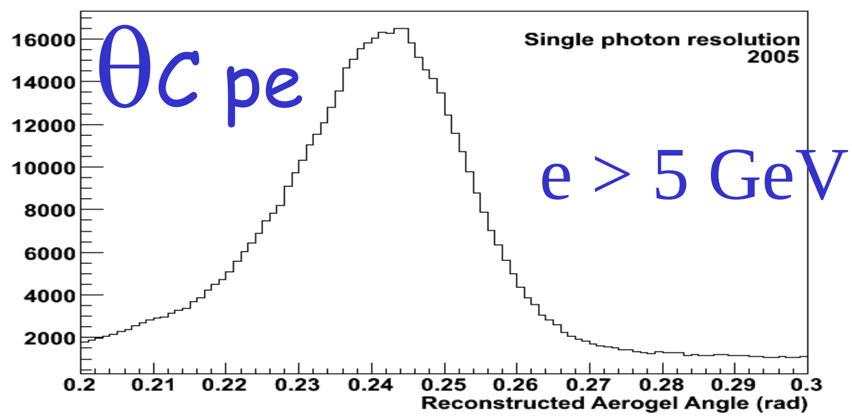
RICH stability 2005

θ_c pe

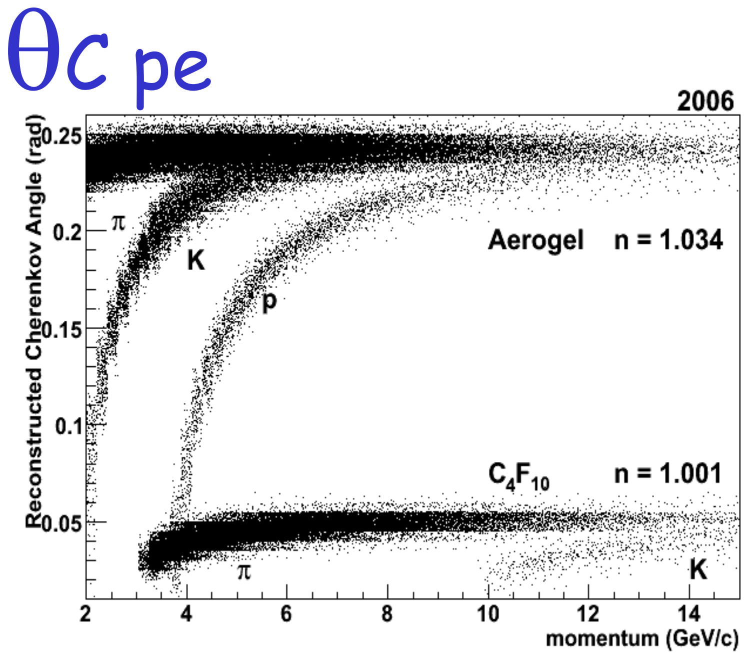


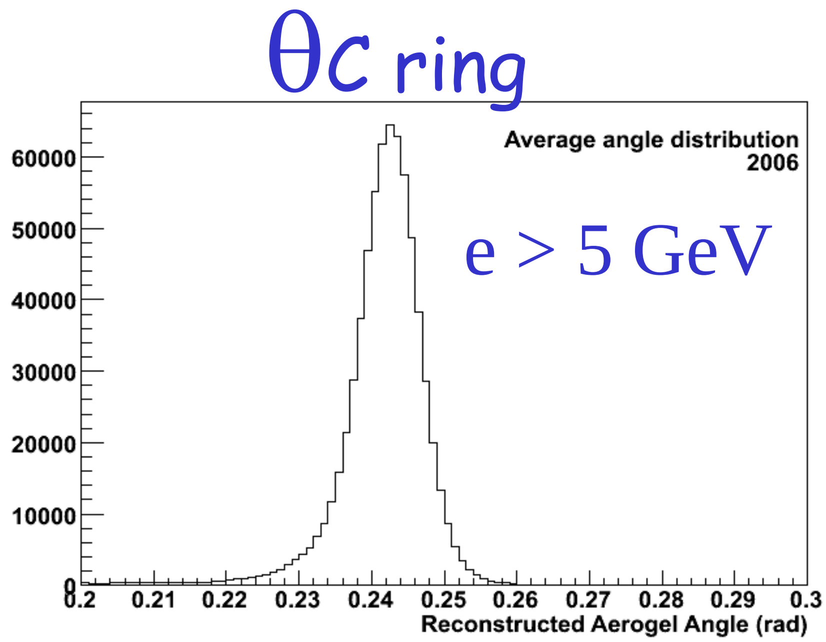
θ_c ring

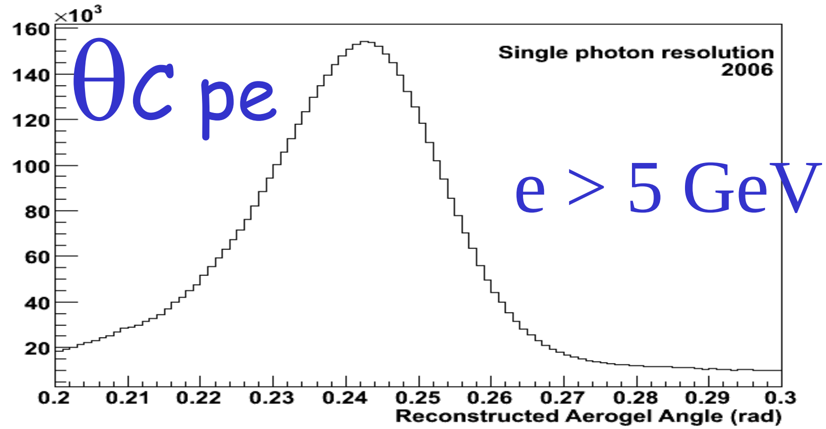




RICH stability 2006

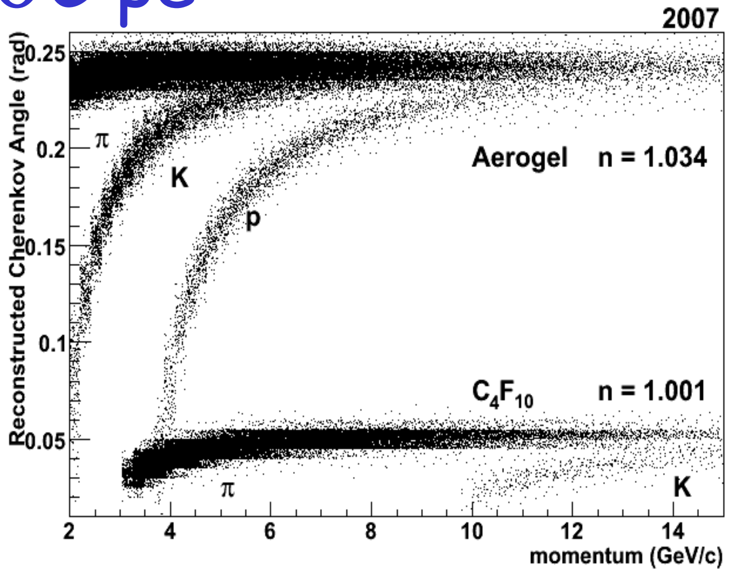




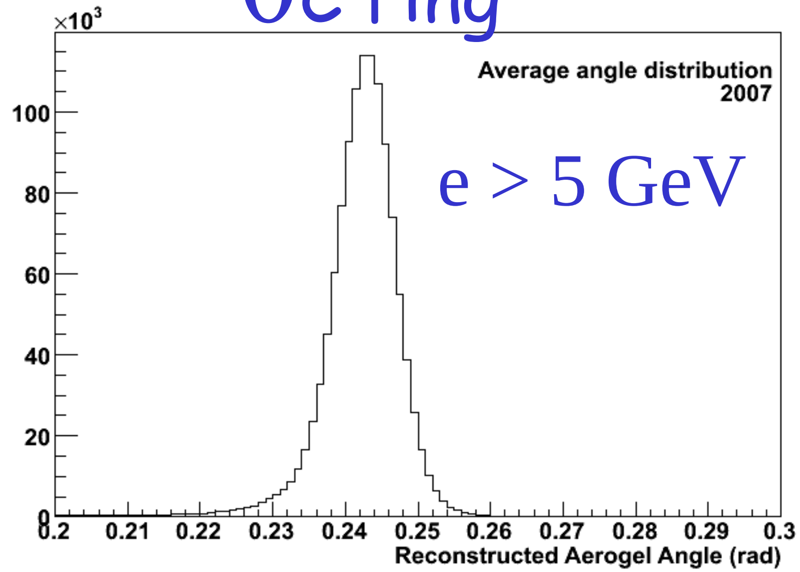


RICH stability 2007

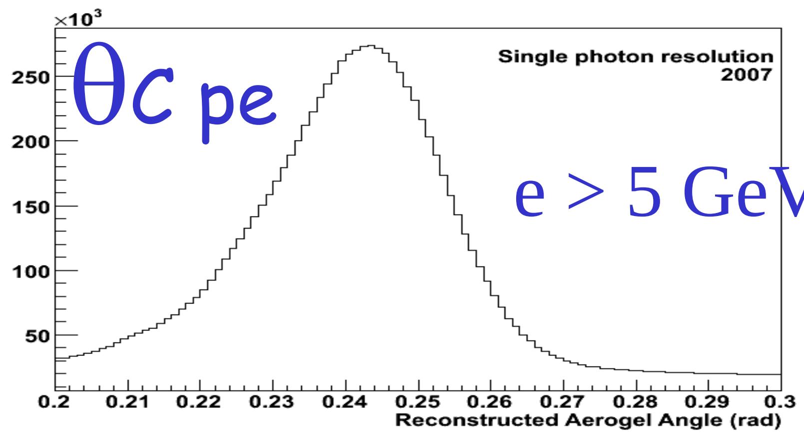
θc pe



θc ring



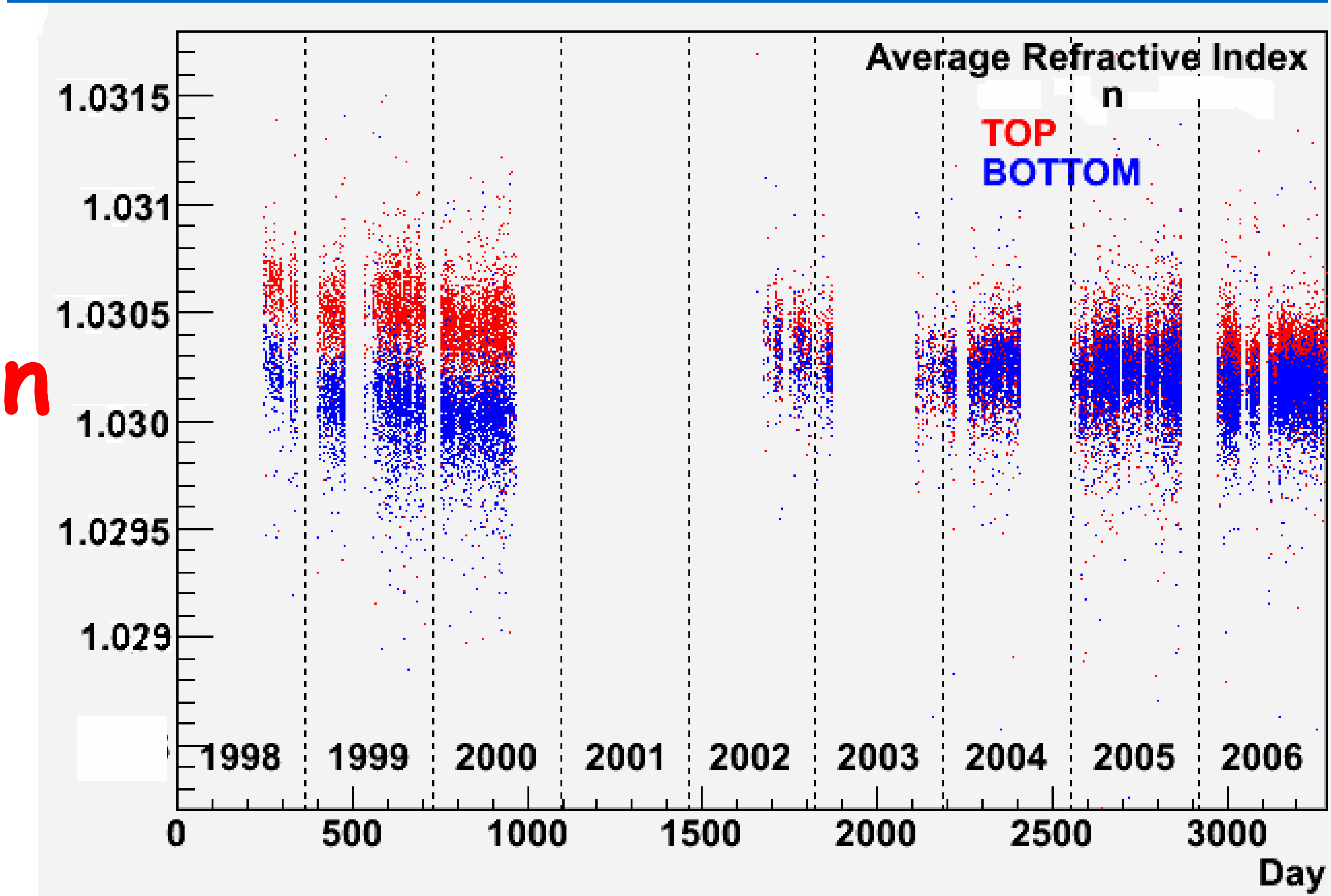
e > 5 GeV



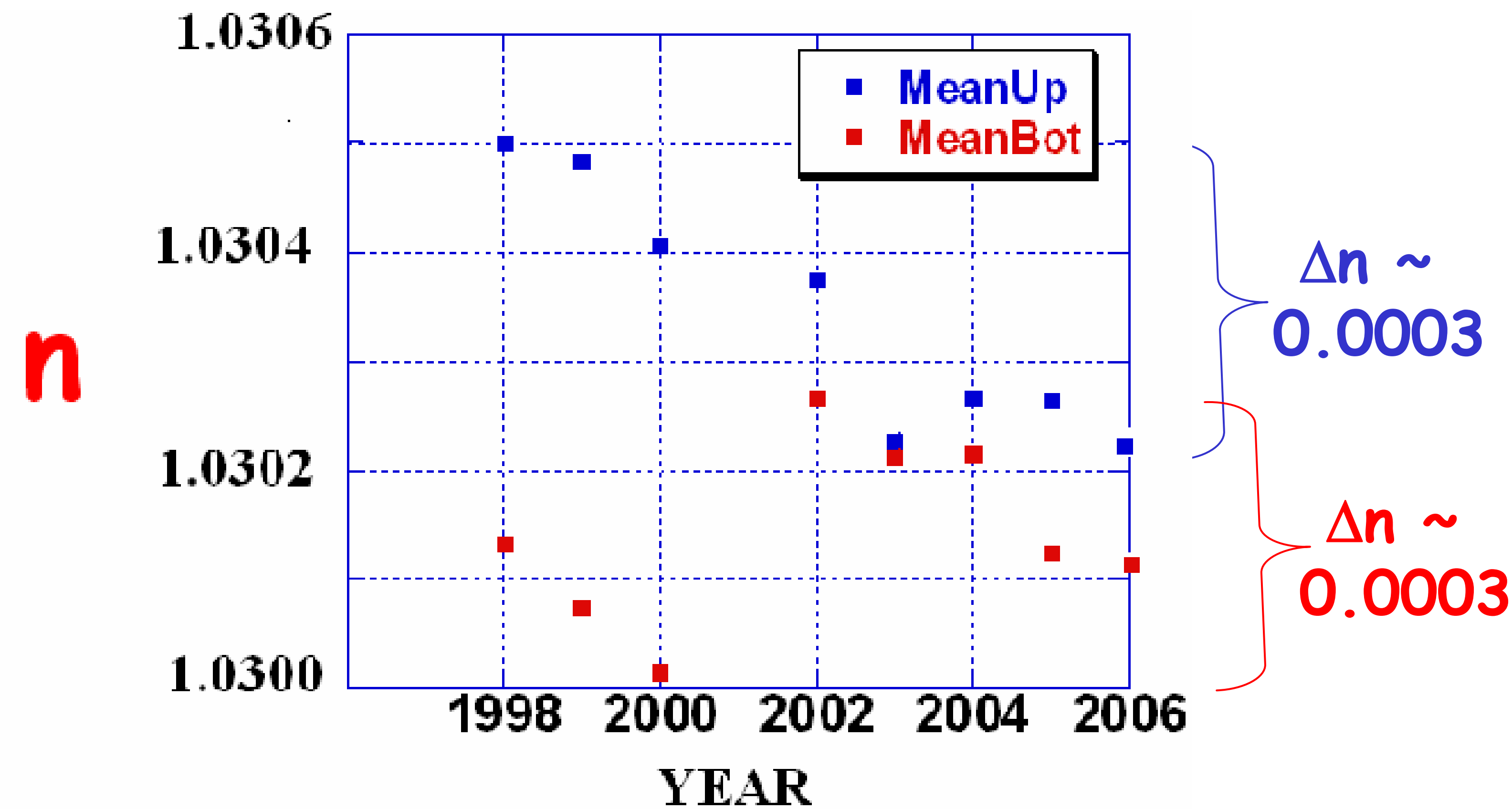
θc pe

e > 5 GeV

θ_C ring → n (e^+>5GeV) plot vs day



average n (e^+>5GeV)

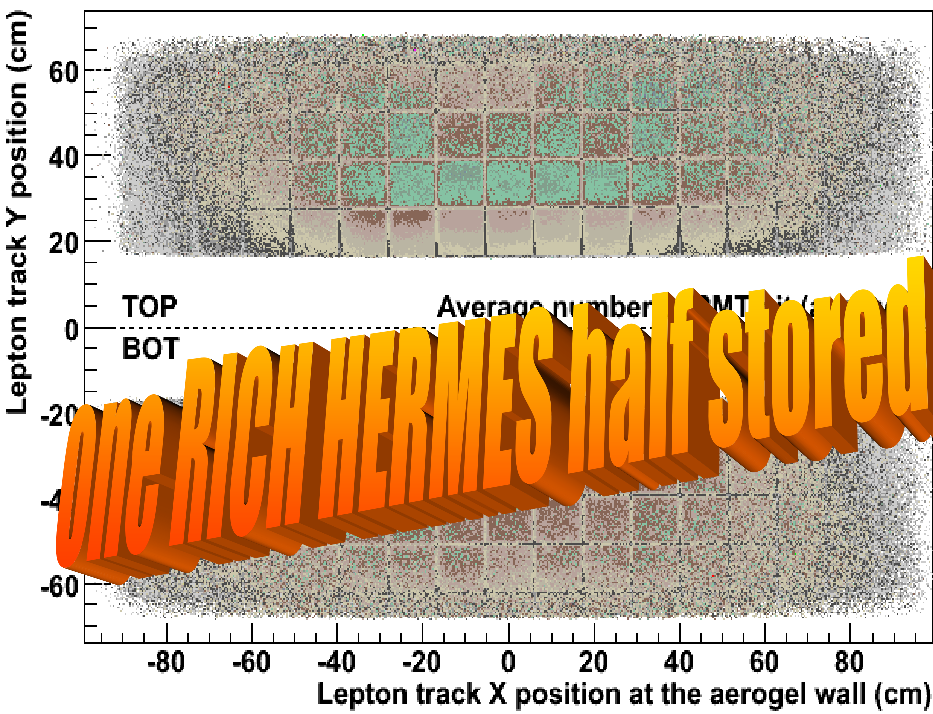


Δn ≈ 3 *10^{-4} in 10 years!

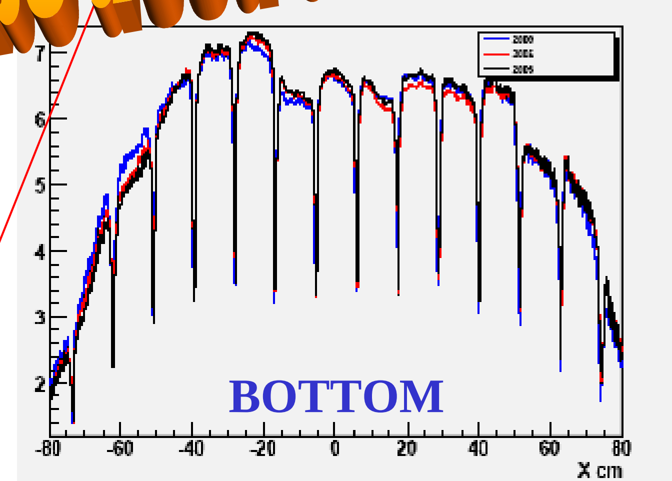
Δn ≈ 1*10^{-4} in the last 5 years!

pe reconst.starting point distribution

e > 5 GeV

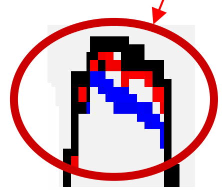


N_{pe}



one RICH HERMES half stored to be used at Jlab !

a real stable aerogel RICH !

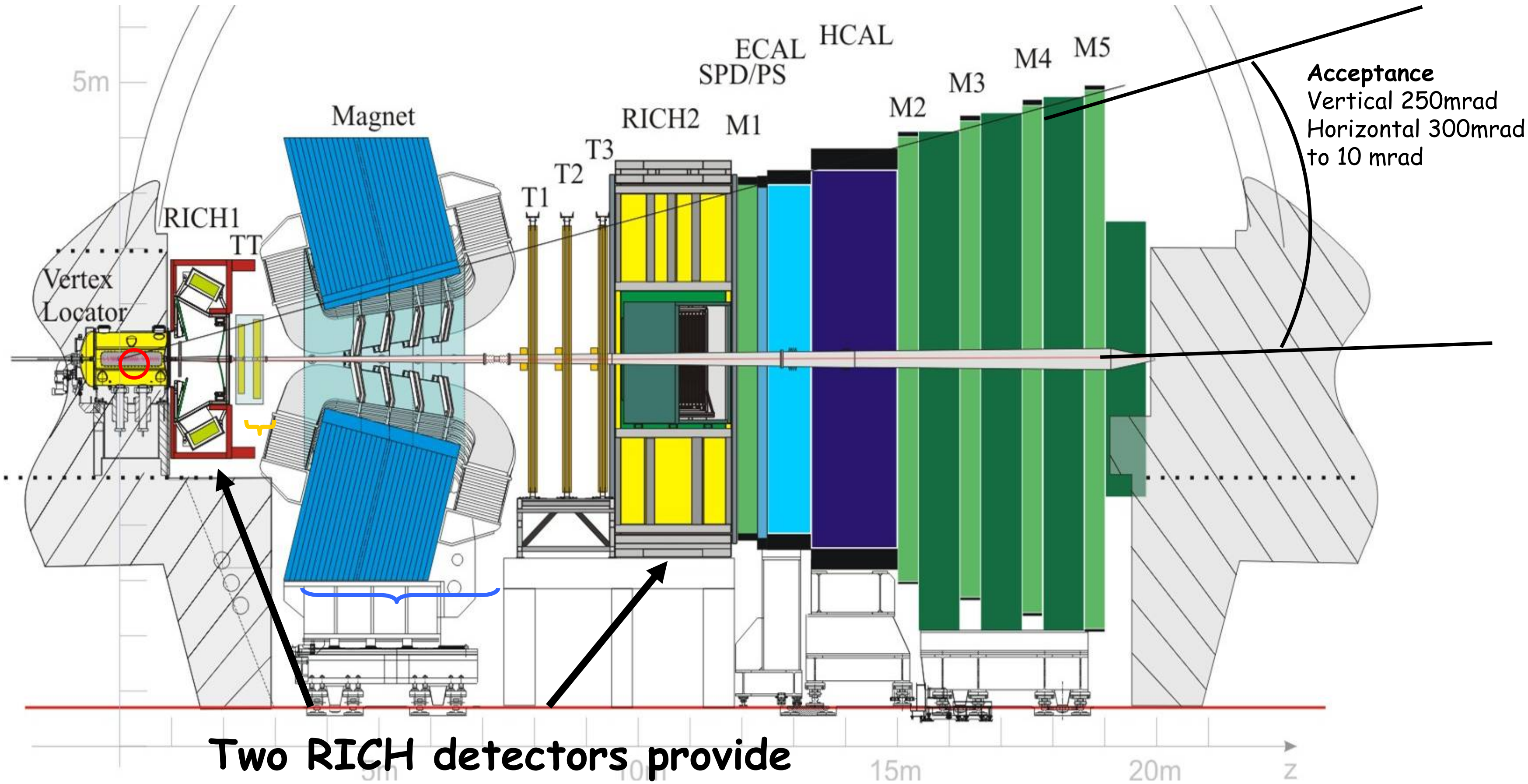


$\Delta N_{pe} < 0.2$

in 10 years!

The LHCb detector

Forward spectrometer (running in pp collider mode).
A dedicated B-physics experiment at the LHC

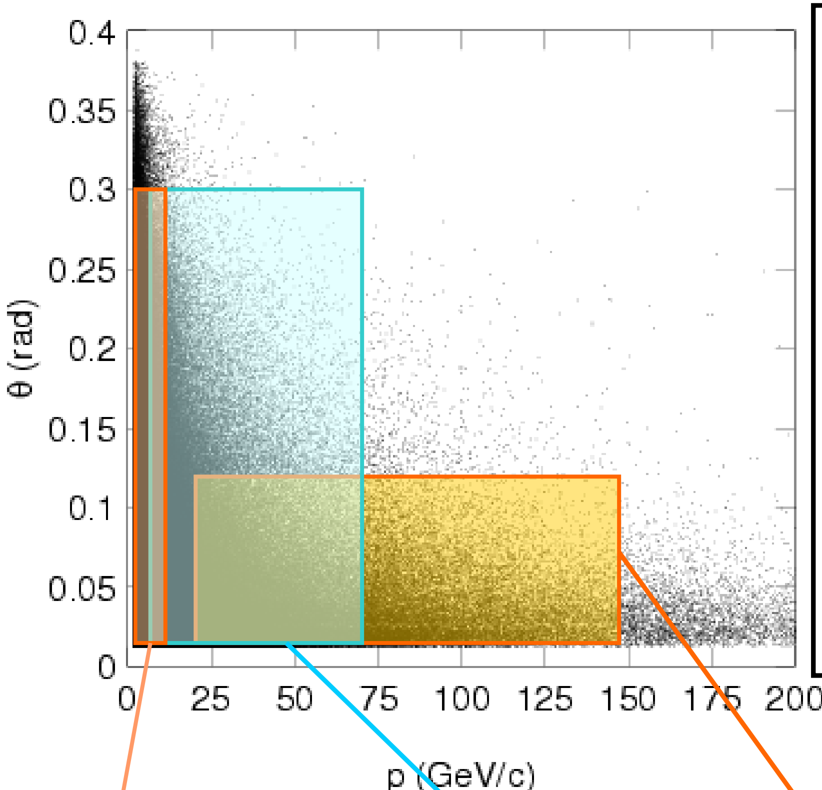


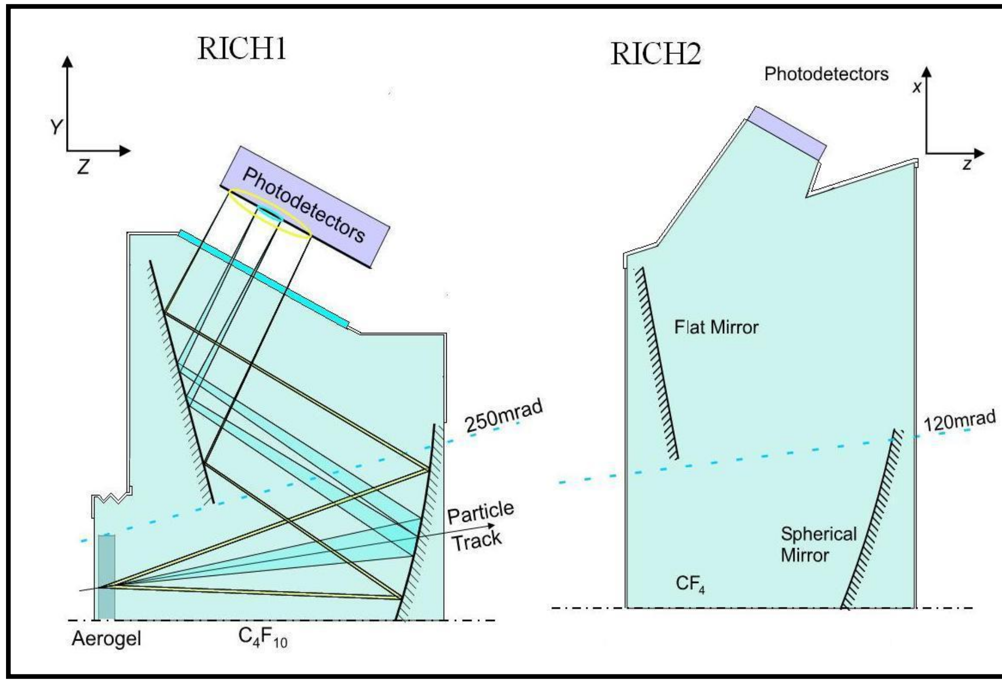
Two RICH detectors provide
p/K/p identification

K/π separation 2-150 GeV/c

The RICH Radiators

Neville HARNEW, RICH2007 15-20 October, Trieste





Silica Aerogel
n=1.03
1-10 GeV/c

C_4F_{10} gas
n=1.0014
Up to ~70 GeV/c

CF_4 gas
n=1.0005
Beyond ~100 GeV/c

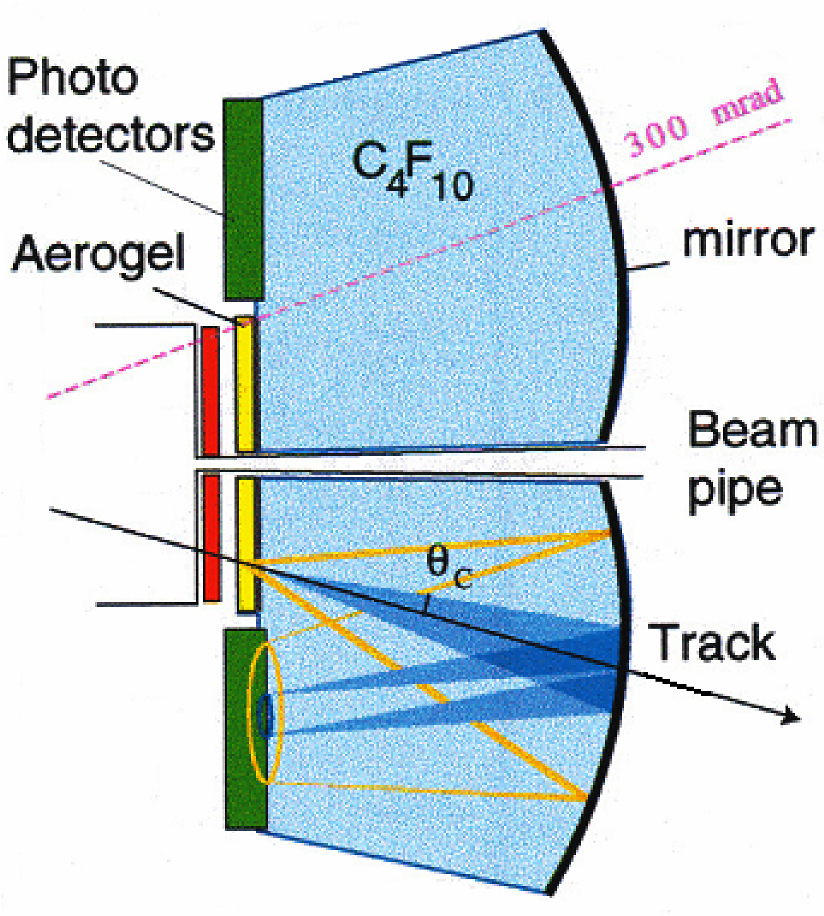
RICH1:
25→250 mrad vertical
25→300 mrad horizontal

RICH2:
15→100 mrad vertical,
15→120 mrad horizontal

Expected photon yields – for isolated saturated particles

Aerogel	C_4F_{10}	CF_4
5.3	24.0	18.4

RICH-1 LHCb



BINP-Novosibirsk:

20x20x4 cm^3

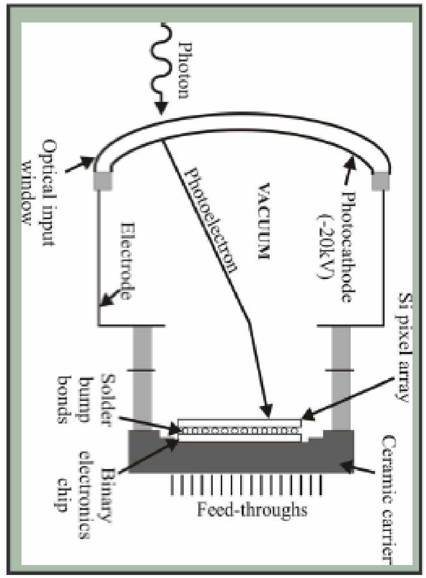
n=1.03 **hygroscopic**

A=0.96 *C*=0.005 (t=4 cm)

Λ (400 nm) = 4 cm

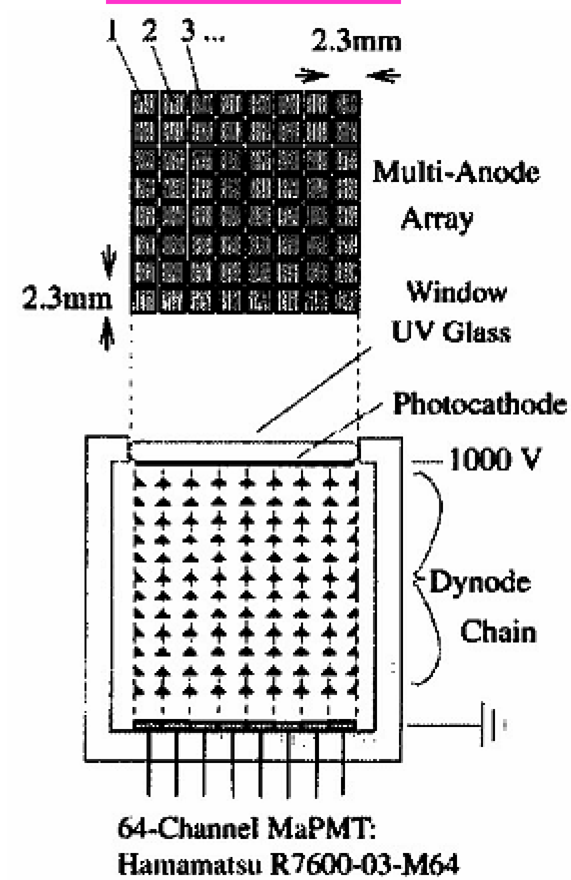
The PhotoDetectors

HPD



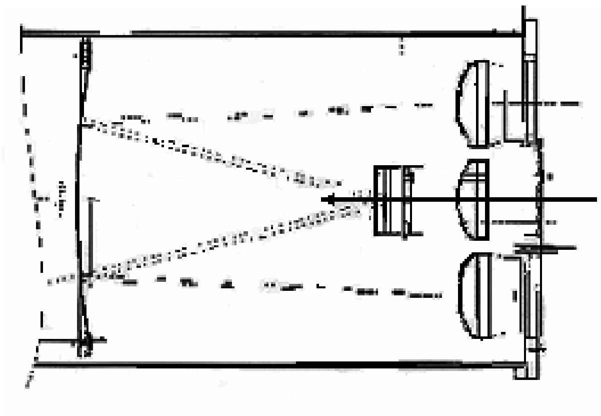
- Bialkali Photocath. D=110 mm, QE(320nm)>20%
- Overall D=125 mm   82% active area
- voltage -16 KV
- Electron optics: cross-focussed
- demagnification 2.3
- Anode: Si pixel :1 mm x 1 mm (320x32 matrix)
  2048 pixels, size at photocath. 2.5 x 2.5 mm^2

MaPMT



pixels, size 2.3 x 2.3 mm^2

4 HPD & AEROGEL from Novosibirsk: test beam
C.Matteuzzi, INFN Milano



N_{pe} yield

	No filter	Filter D263 (0.3 mm)
4 cm DATA MC	9.7 11.5	6.3 7.4
8 cm DATA MC	12.2 14.7	9.4 10.1

t=4 cm Npe ~10

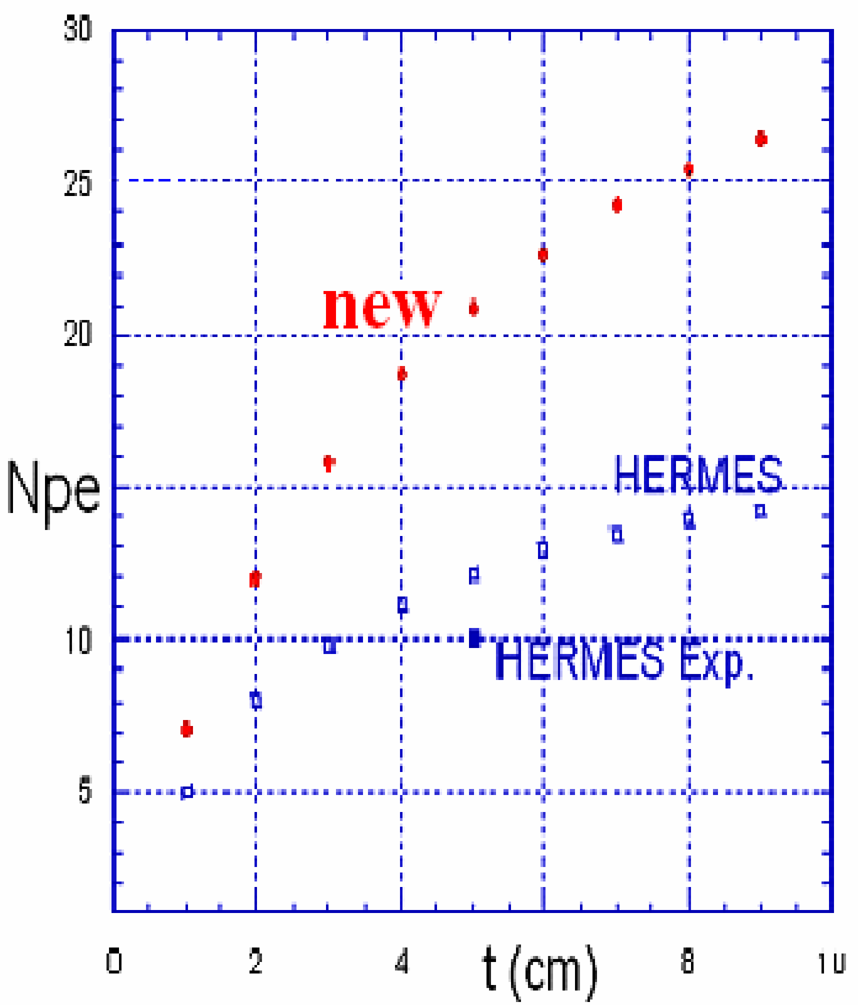
Angular resolution

$\delta\vartheta/\vartheta = 2.0\ \%\ /\ pe$

$\delta\vartheta/\vartheta =$ **0.67** % / ring

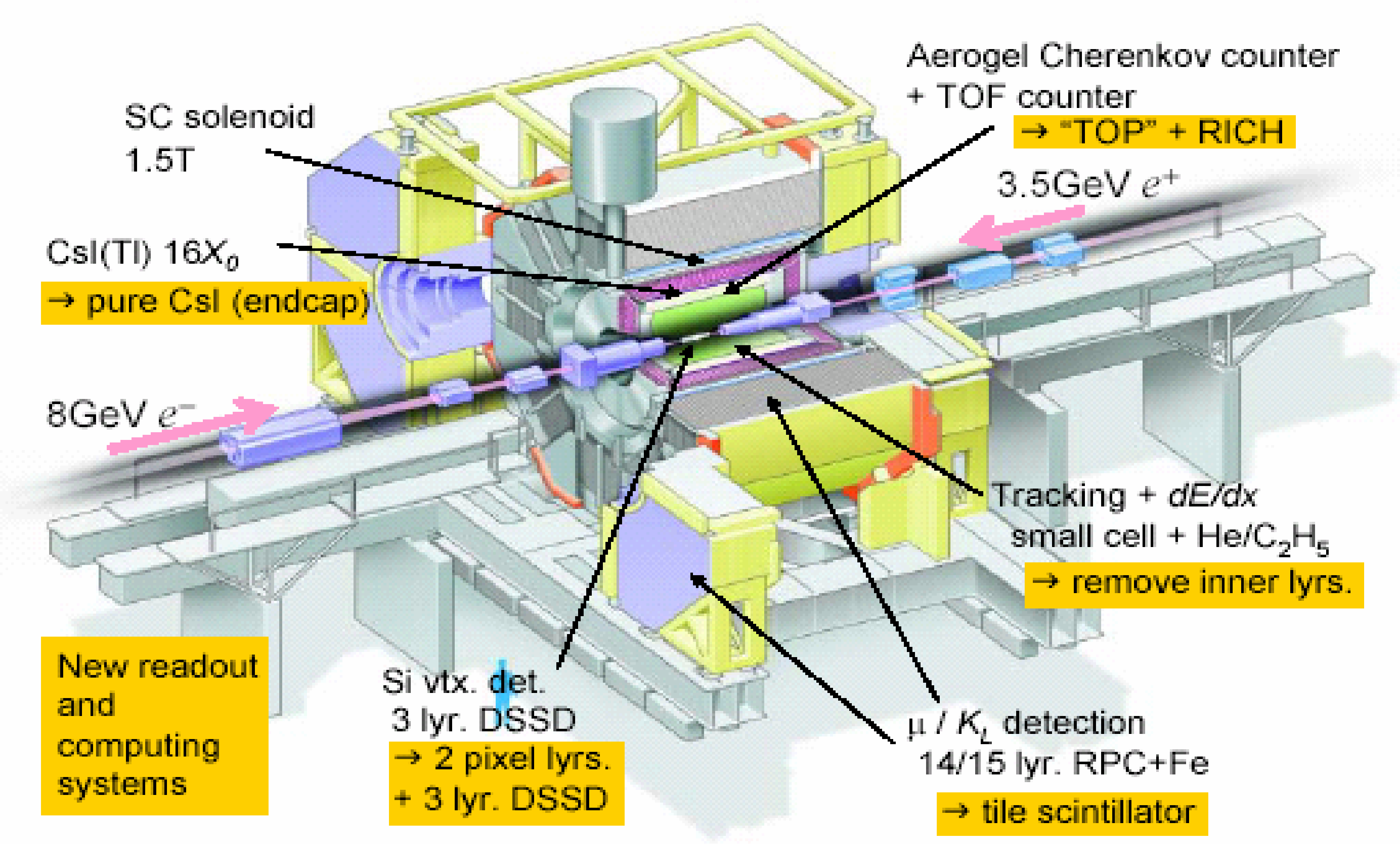
δϑ/ϑ(/pe)(%) and Npe for HERMES with old (t=5cm Λ=2.3 cm) and new (t=4cm Λ=4cm) n=1.03 aerogel old (1") and new ($2.5x2.5mm^2$) pixel size

	old	new
• Pixel	2.3 ←	0.3
• Mirror	0.6	0.5
• Point emiss.	0.7	0.6
• n disp.	0.5	0.5
• Chromatic	1.3	1.4 ←
• Forw.Scatt.	0.4	0.4
• Surface	0.4	0.4
• Total (calc.)/pe	2.9	1.8
• Total (exp.)/pe	3.3	(2.0)
• Npe (calc.)	12	18
• Npe (exp.)	10	**(15)**
• Total /ring	1.1	**(0.55)**



6σ k/π sep. (4 GeV)

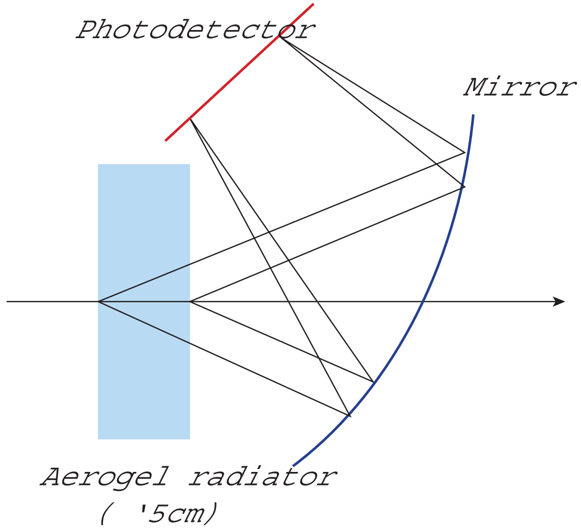
BELLE upgrade (KEK $L=10^{34} \rightarrow \approx 2*10^{35}$)

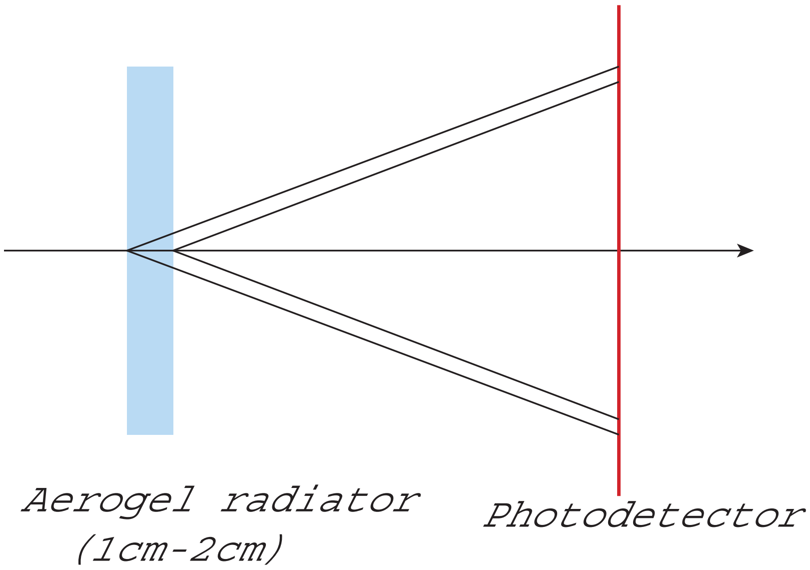


BELLE Aerogel RICH R&D

Chiba-KEK-Nagoya-Ljubljana coll.

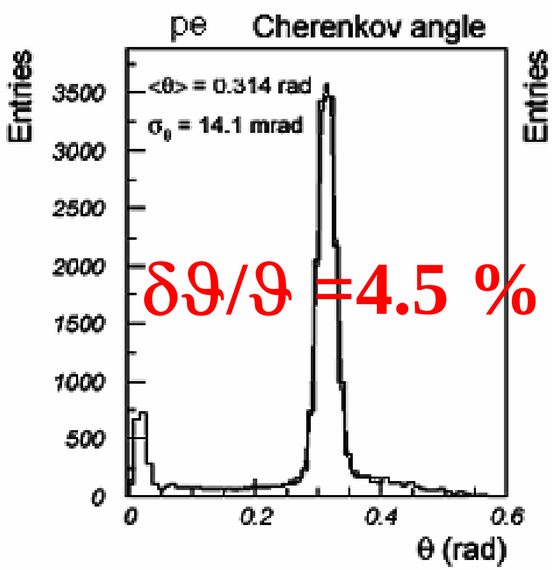
- focusing — proximity focus

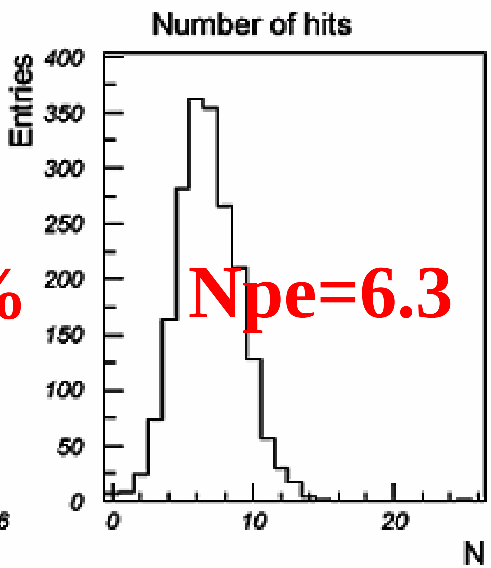




’02 beam test results

- New aerogel from Matsushita & Chiba-U.
- Λ(400nm)= 3 cm, n= 1.05, t= 2 cm
- H8500-M64 PMT flat panel, 6x6 mm2 pixel,
- very clean rings observed !
- $\delta\vartheta/\vartheta$ =4.5 %/pe, Npe = 6.3, $\delta\vartheta$(/ring) = 5.6 mrad
- θ_π-θ_k (4GeV, n=1.05) = 23 mrad $\rightarrow$ 4 σ sep. possible
- $\delta\vartheta/\vartheta$(/pe) accounted by point-emiss. & pixel contr.s



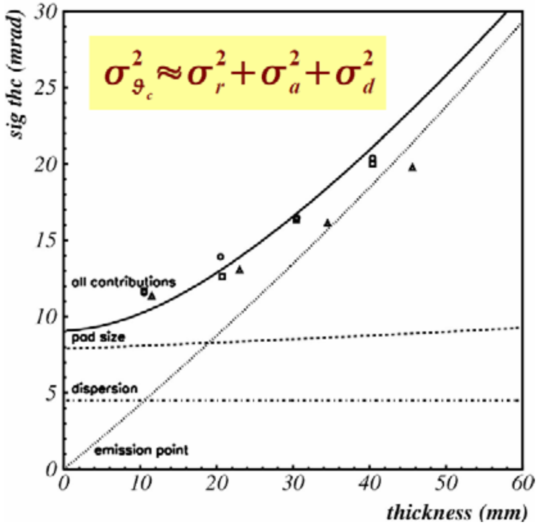


$\delta\vartheta/\vartheta$ =1.8 %/ring

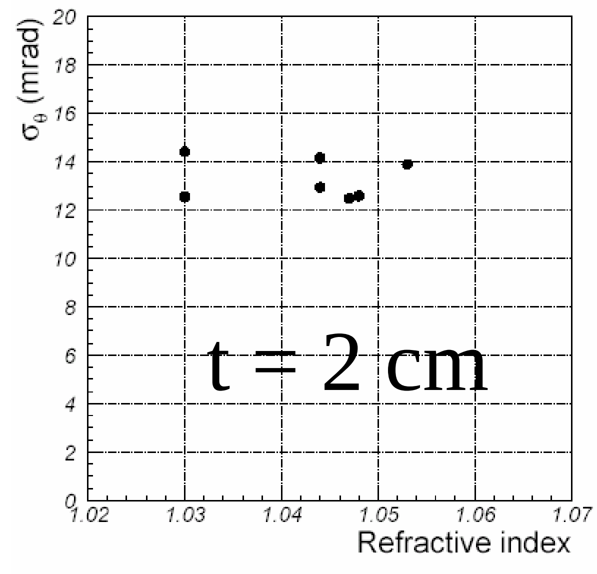
NIM A521(2004) 367

Toru Iijima, RICH2007 @ Trieste

σ/pe vs t



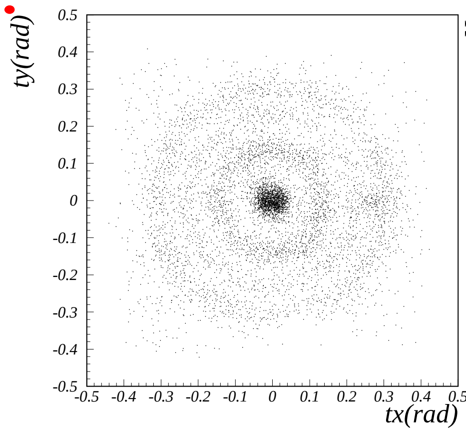
σ/pe vs n

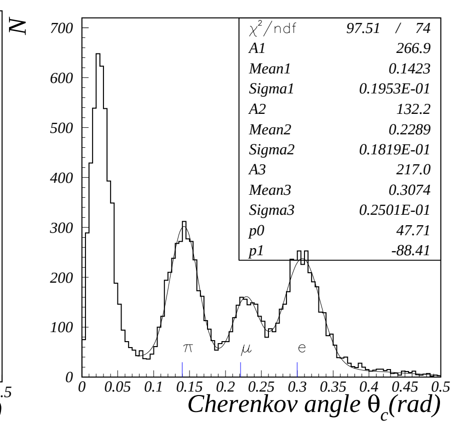


t < 2cm: pixel

t > 2cm: point.em.

- e^-, μ^-, π^- at 0.5 GeV

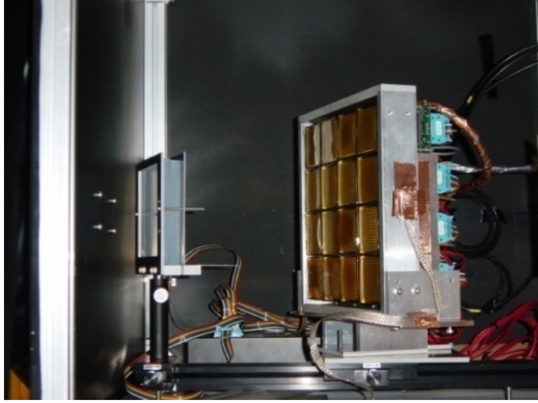




RICH with Multilayer Radiators

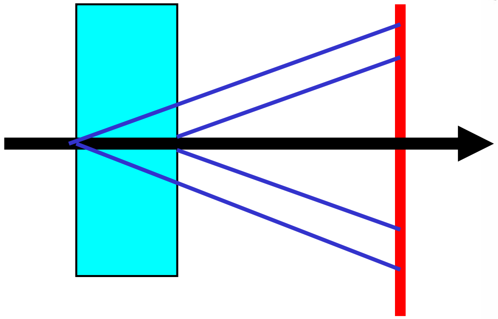
NIM A548(2005)383

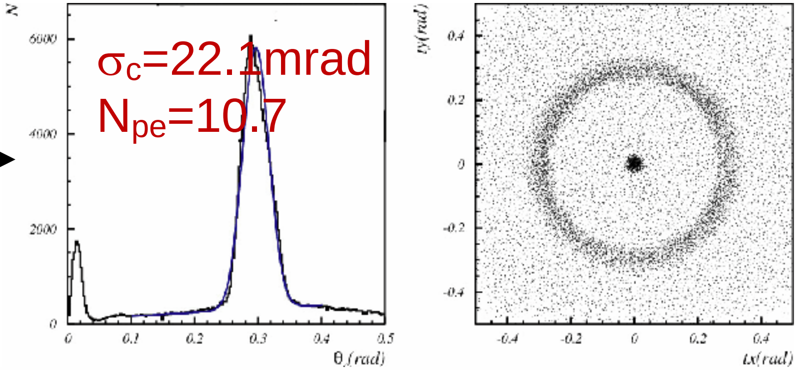
- Demonstration of principle
  - 4×4 array of H8500 (85% effective area)



Conventional

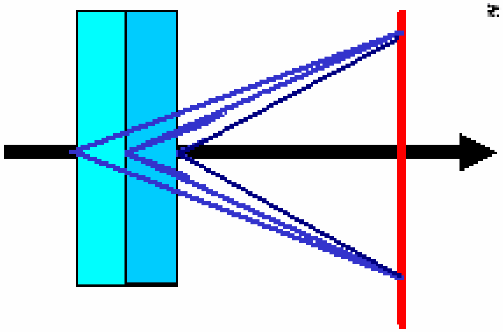
4cm thick aerogel
n=1.047

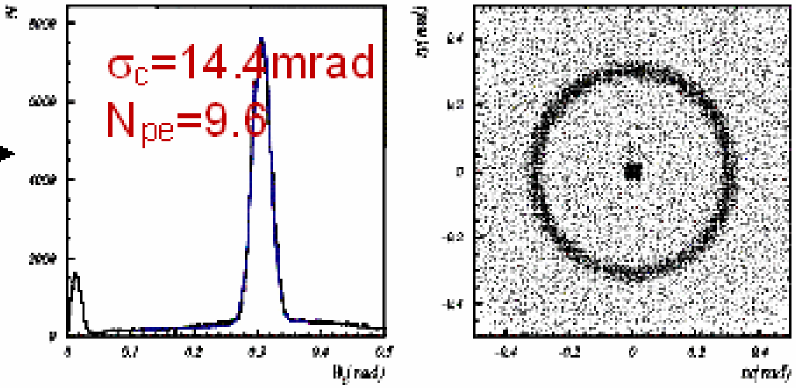




Multiple Radiator

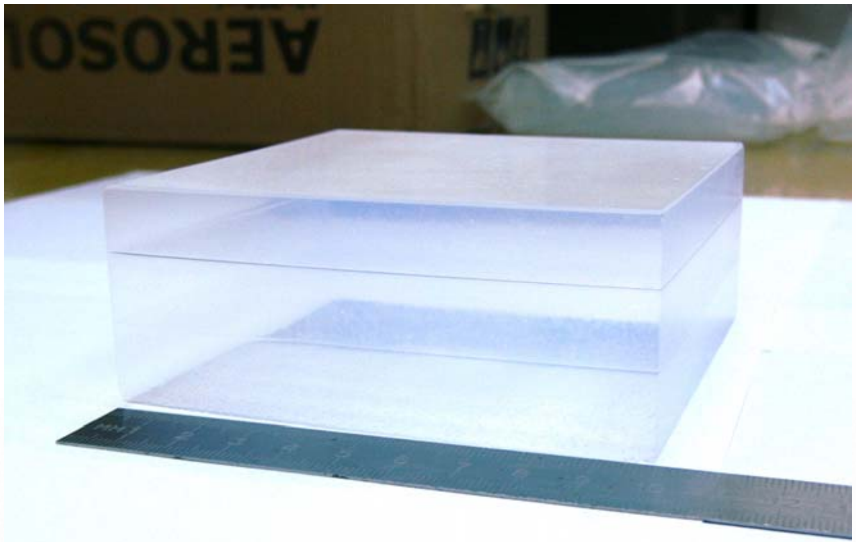
2 layers of 2cm thick
n_1=1.047, n_2=1.057

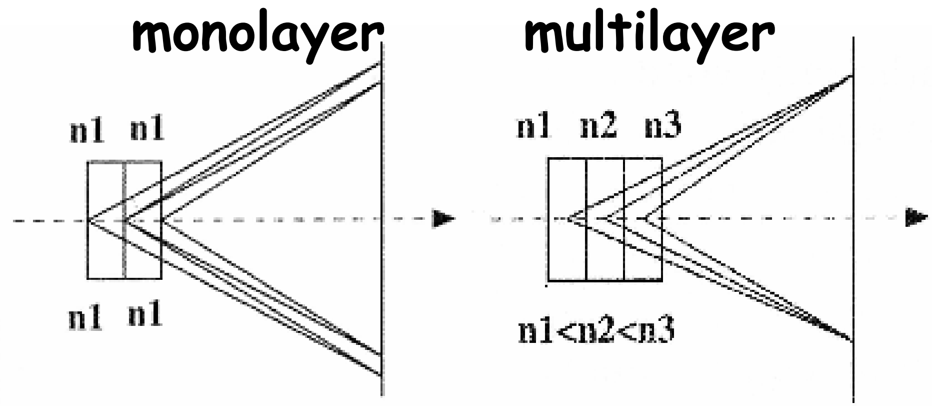


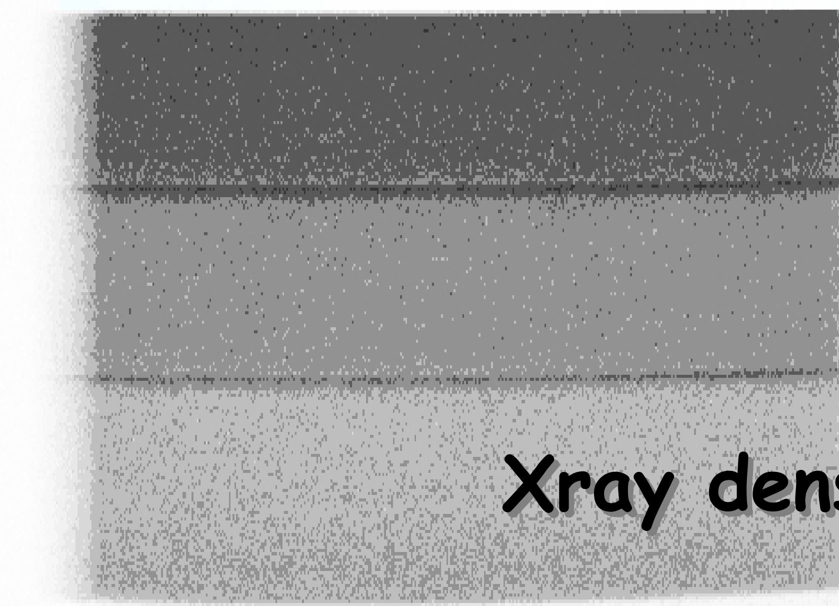


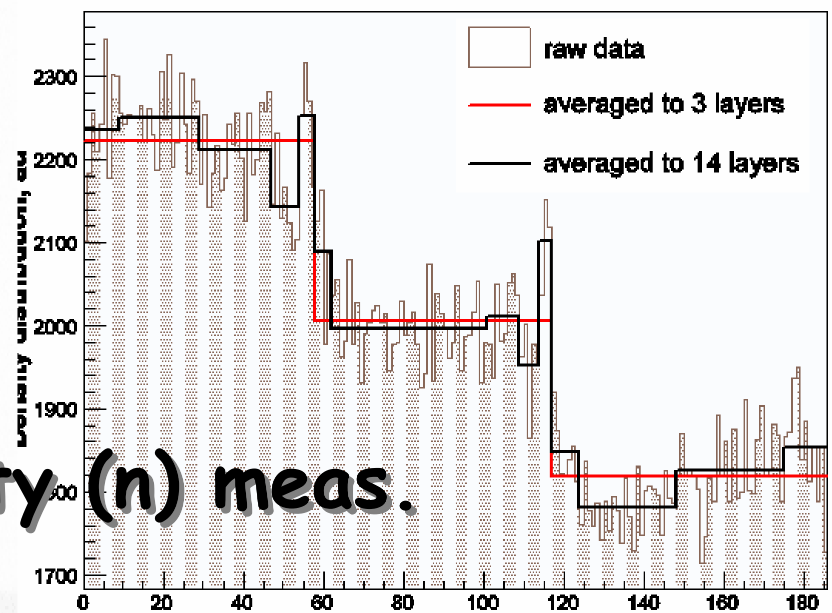
π/K separation with focusing configuration ~ 4.8σ @4GeV/c

n multilayer aerogel









Xray density (n) meas.

aerogel RICH summary

aeroRICH	CERN-test	HERMES	HER(new)	BELLE	BELLE
year	‘96	‘98	‘02	’04	‘07
type	foc.	foc.	foc.	prox.	prox-2lay.s
n	1.03	1.031	1.03	1.05	1.047-1.057
Λ (cm)	2.3	2.3	4	4.5	5 ↑
t (cm)	5	5	4	2	2 ↓
δθ/θ (%)(/pe)	8	3.3	(2.0)	4.5	4.6
Npe	12.8	10	(15)	6.3	10
δθ/θ (%)(/ring)	2.3	1.1	(0.55)	1.9	1.5 ↓