“aerogel as radiator of RICHs”

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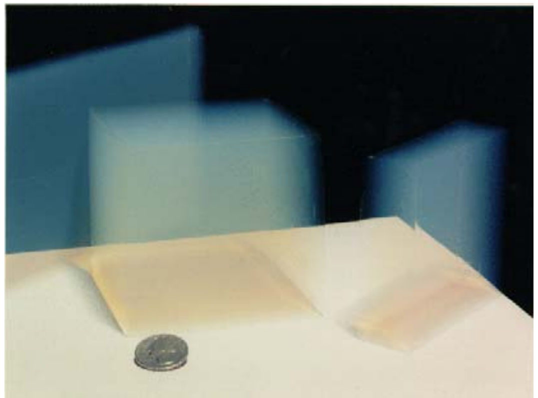
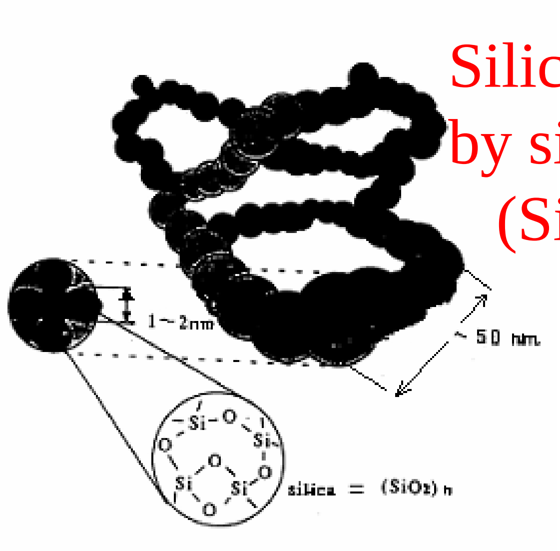
- Optical properties of aerogel
- Aerogel: radiator of Cherenkov counters & focalized RICH
- contributions to $\delta\theta_C$ from aerogel in a focalized RICH
- performance of the aerogel focalized RICH of HERMES
- performance of the aerogel focalized RICH-1 of LHCb
- BELLE: aerogel radiator in a proximity focus RICH

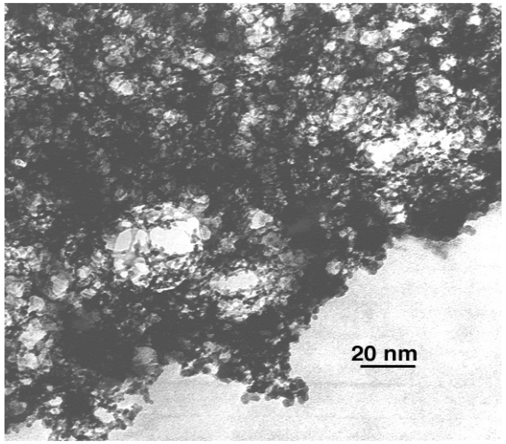
aerogel: nicknames, structure



- "A little bit of almost nothing"
  (the lightest solid, ρ: 3-350 mg/cc)
- "Frozen smoke" (much akin to air, up to 99.5%)
- "Holy grail" (Fortune Magazine: aerogel is used in >800 different applications)



Silica colloids linked by siloxan bonds (Si- O-Si)



trasm. elect. micrograph
<d>=20 nm micropores

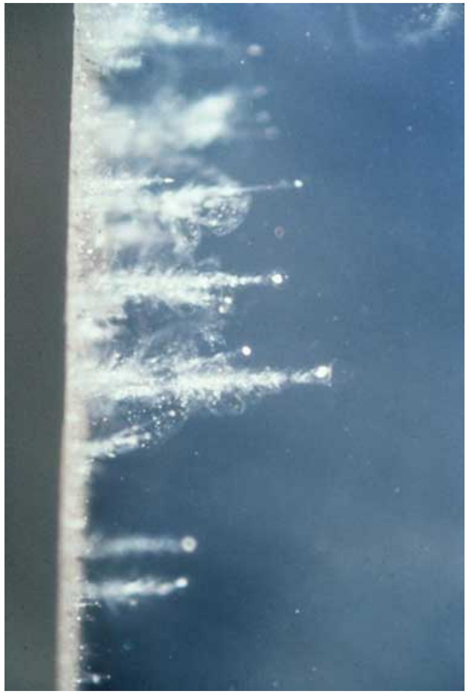
a bit of history

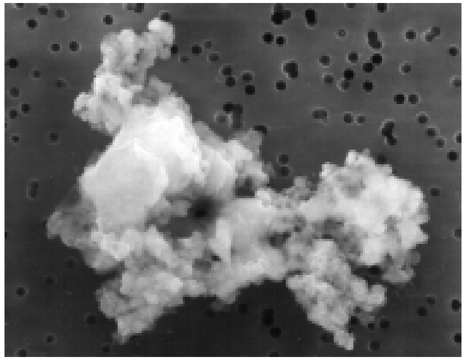
- 1931: S.Kistler: aerogel has the same solid structure of the wet-gel
  supercritical drying to avoid shrinkage due to surface tension
- Late ‘70s: S.Teichner (Lyon) sol-gel 1-step method hydrolyzing toxic TMOS in a methanol solution (alcogel) (240 C, 100 Atm)
- Early ‘80s: 1700 liters of aerogel used at DESY, TASSO exp.
- ‘83: A.Hunt (Berkeley): TMOS replaced by TEOS
  alcohol replaced by liquid CO_2 (31 C, 100 Atm)
- ‘85: J.Fricke: 1st Symp. on aerogels in Wurzburg
- ‘91: L.Hrubesh (LLNL): 2-step method

  1st step: a condensed silica oil is prepared from TEOS with a non-alcohol solvent (precursor)

  2nd step: precursor is processed to gel

aerogel in space

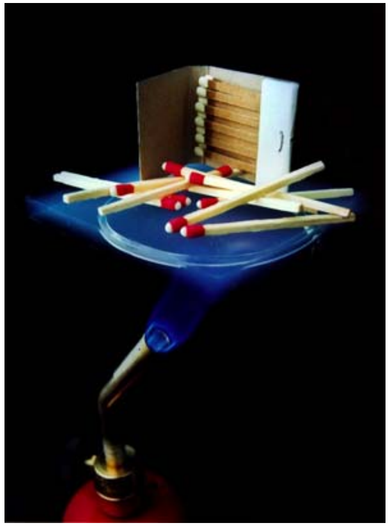


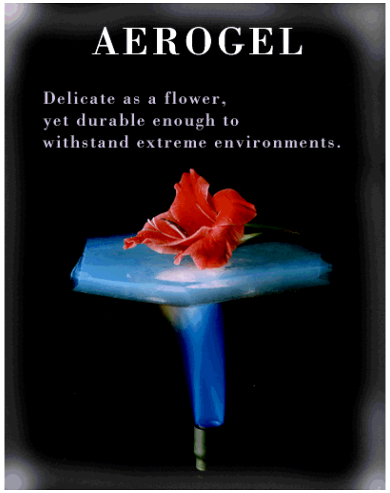


10 micron cosmic dust

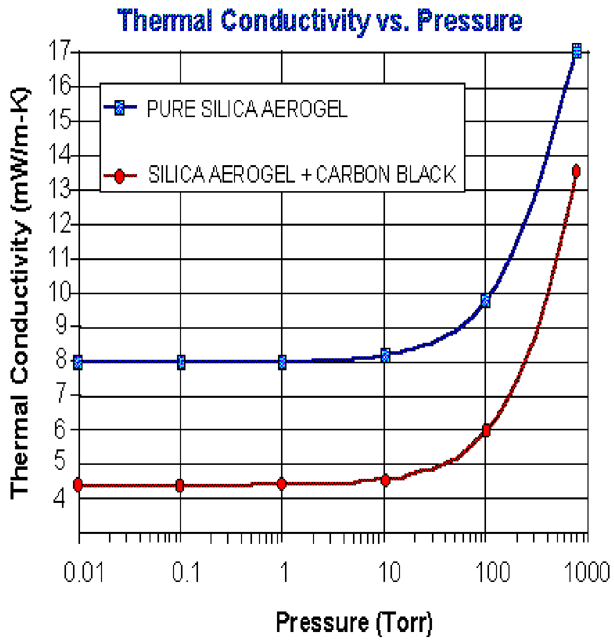
cosmic dust or meteoroids
softly captured
(impact damage minimized)

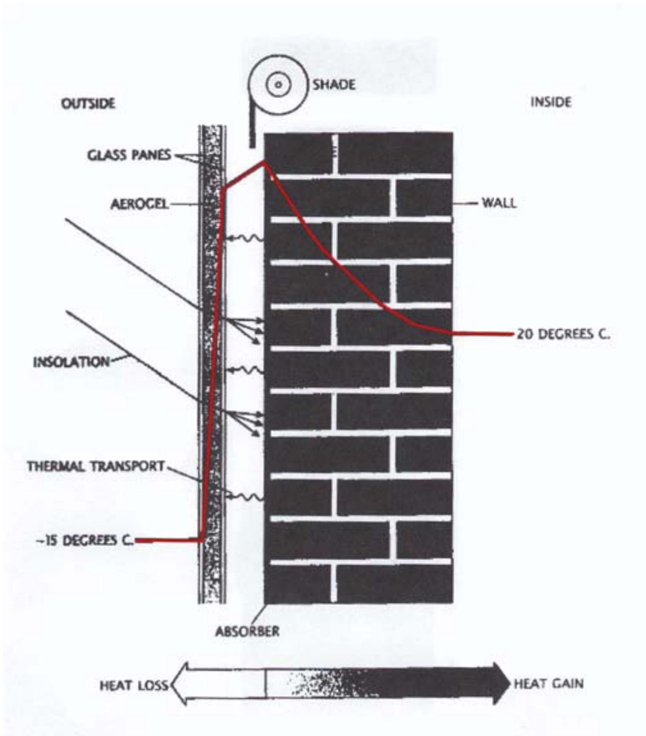
thermal properties



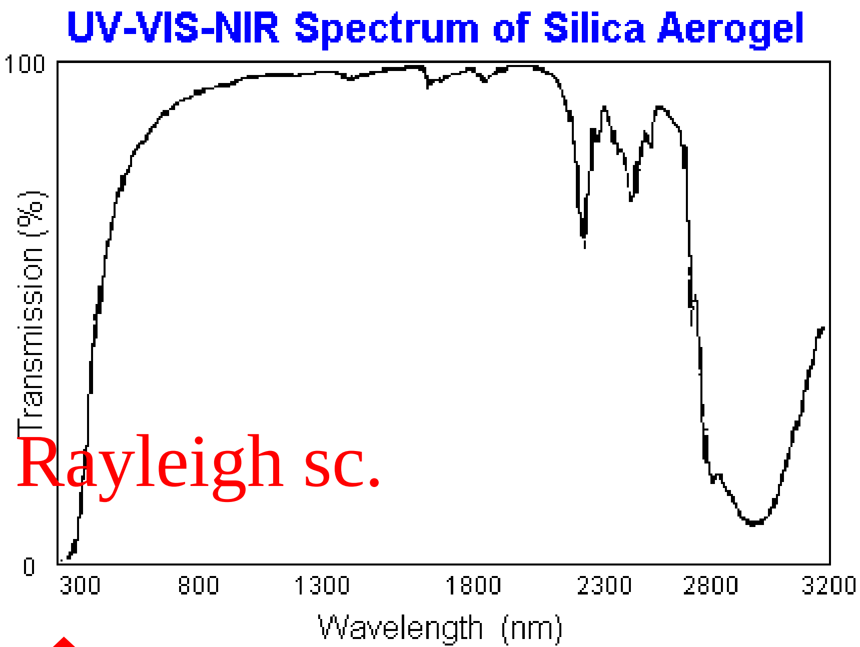


thermal conductivity ~ 0.017 W/m K



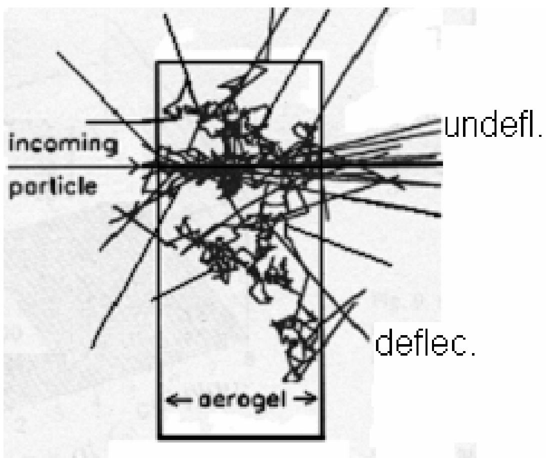


optical properties



Rayleigh sc.

T up to 2 μm:
Hunt formula
$T = A * \exp(-Ct/\lambda^4)$

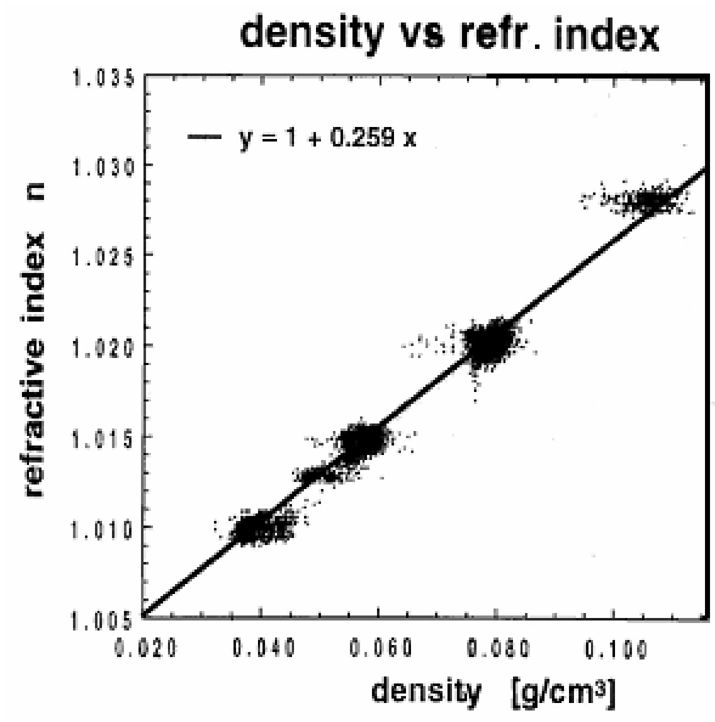


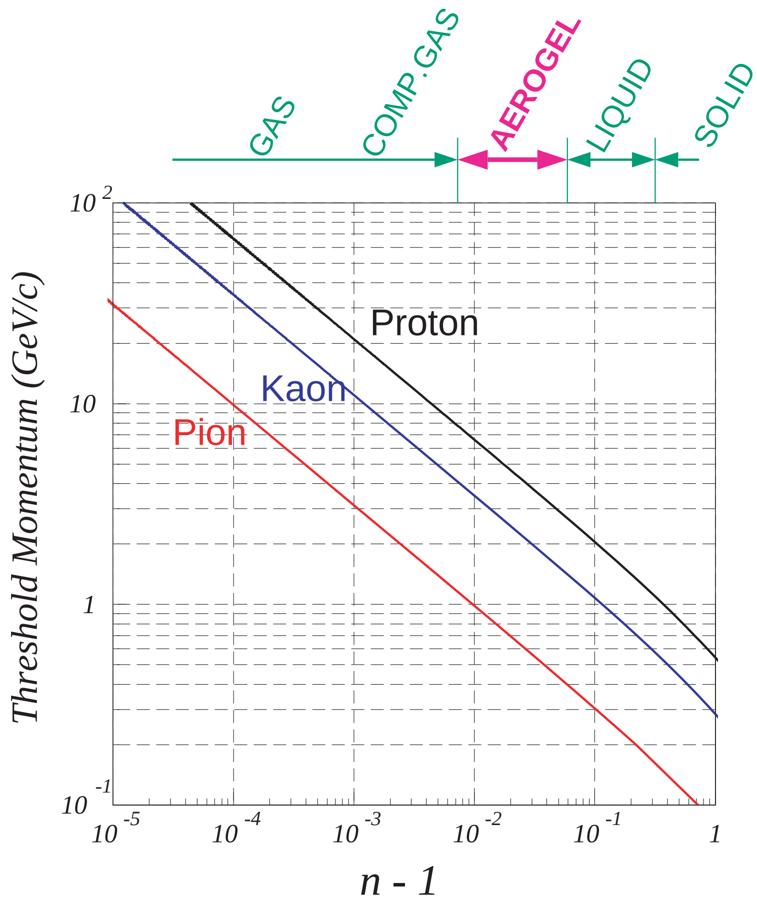
Airglass ('80s):
A=0.8 (opaque)
C=0.02 μm⁴/cm (diffusing)
→Aerogel in Cher. counters

aerogel refractive index controlled by alcohol volume

$n=1+0.26*\rho$

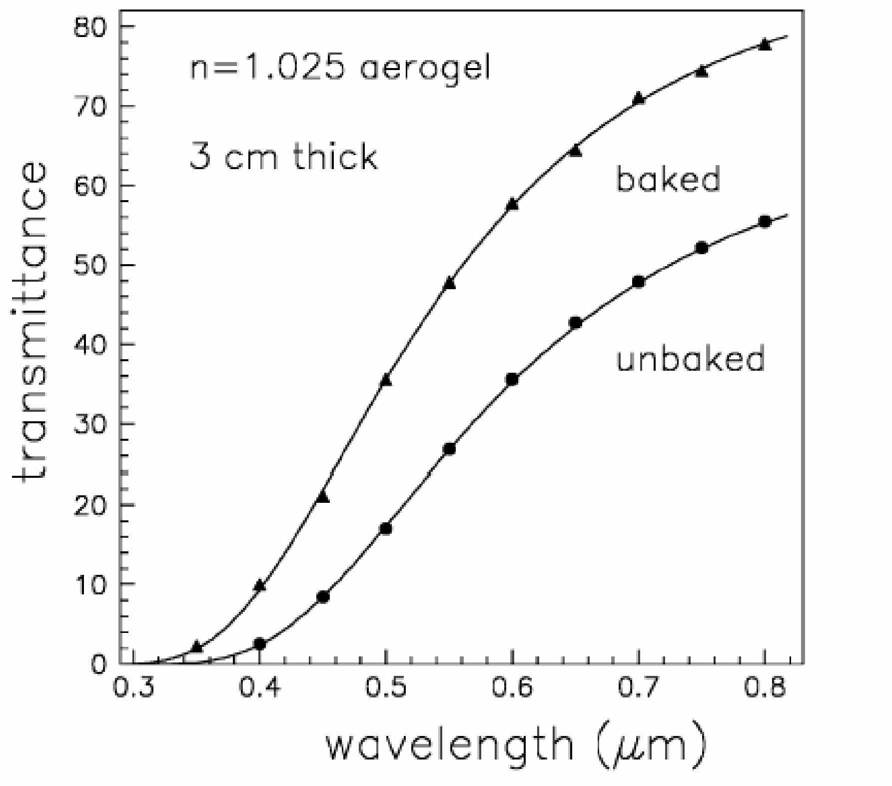
n: 1.008-1.08



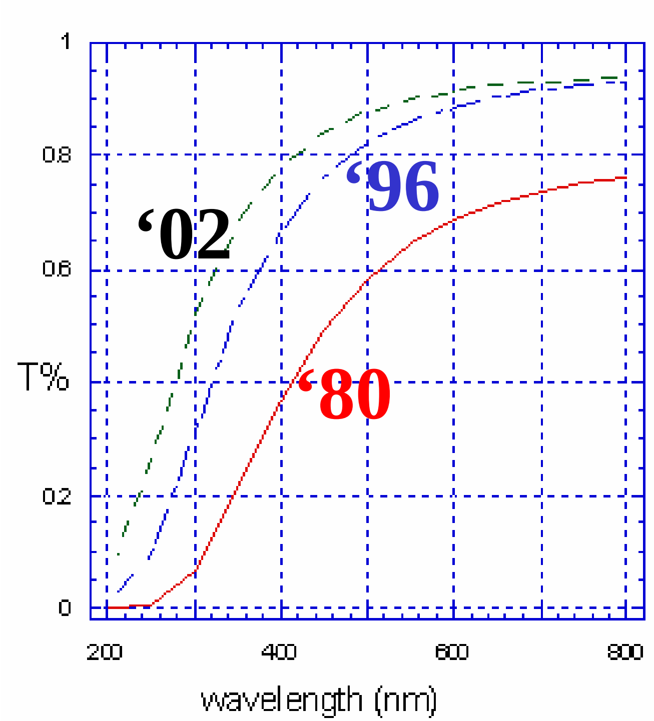


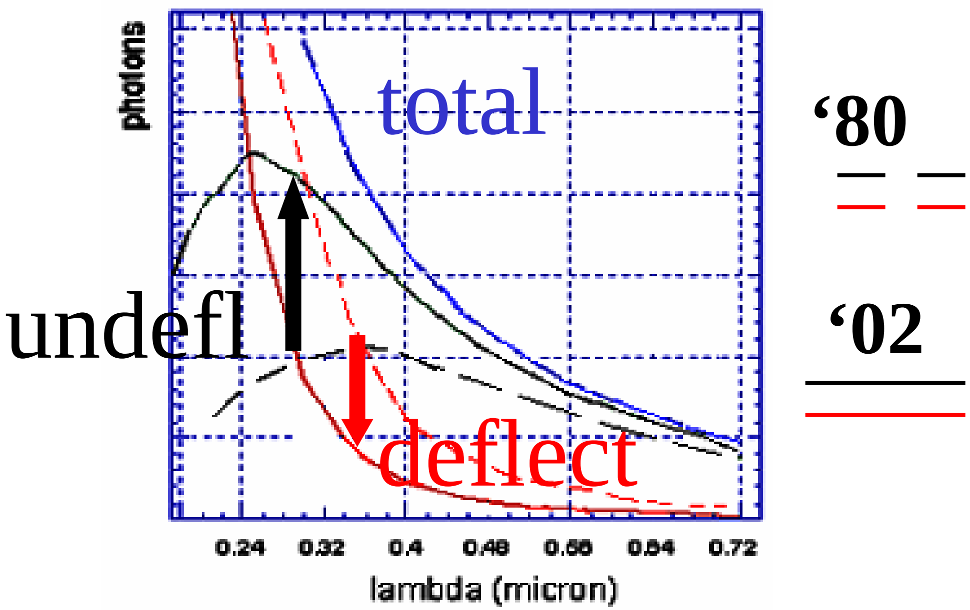
hygroscopic aerogel (Airglass)

12 h at 500 ºC baking, 3% of tile weight (water) removed



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



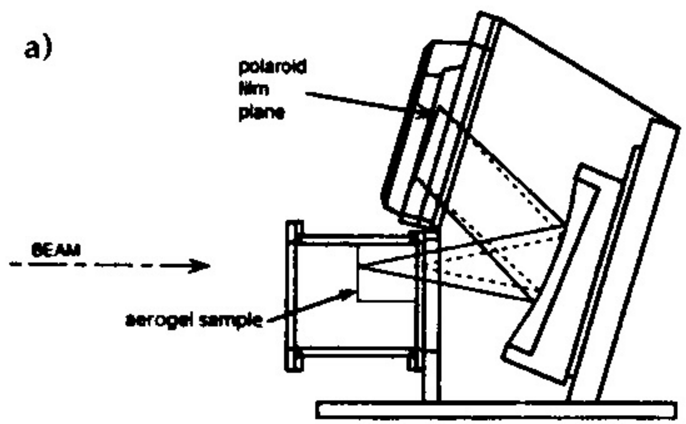


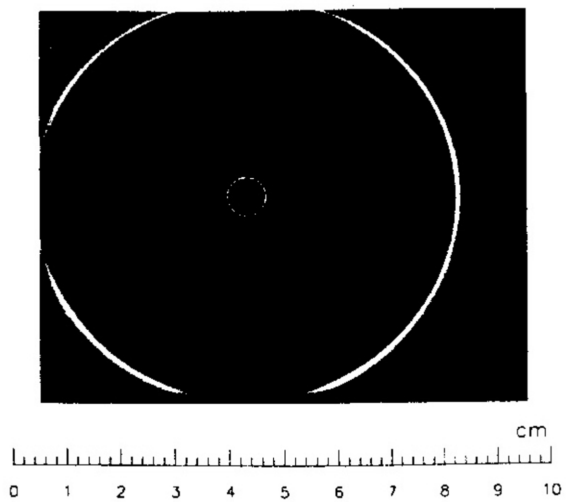
year	A C	producer	Λ(0.4μm)
'02	0.96 0.005	Novosibirsk	4 cm
'96	0.95 0.01	Matsushita	2.3 cm
'80	0.8 0.02	Airglass	1 cm

aerogel as focalized RICH radiator

- V.I.Voboriov & al., (1990) 350 MeV e^- at Novosibirsk
- D.Fields, H.v.Hecke & al.NIMA349(1994)

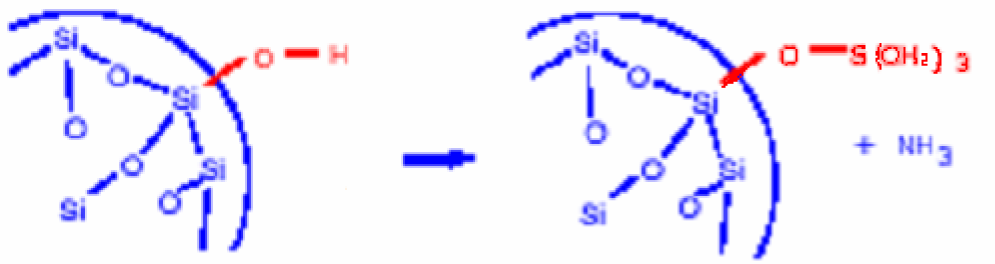
  450 GeV protons at CERN (NA44 exp.)





’96 KEK & Matsushita Co.

- new development for BELLE at KEKb
- new 1 step: precursor methylsilicate 51
- high opt. quality: $\Lambda(400\ \mathrm{nm}) = 2.3\ \mathrm{cm}$
- long term stability
- rad. hardness: No deterioration of T & n
  up to 10 MRad @ Nat’l Tsing Hua Univ.
- surface treatment: hydrophobic

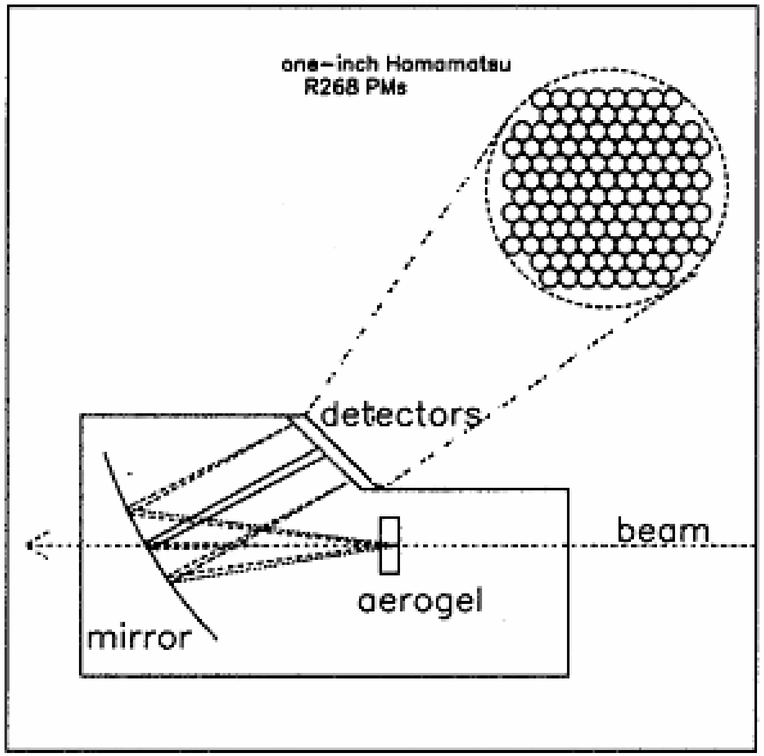


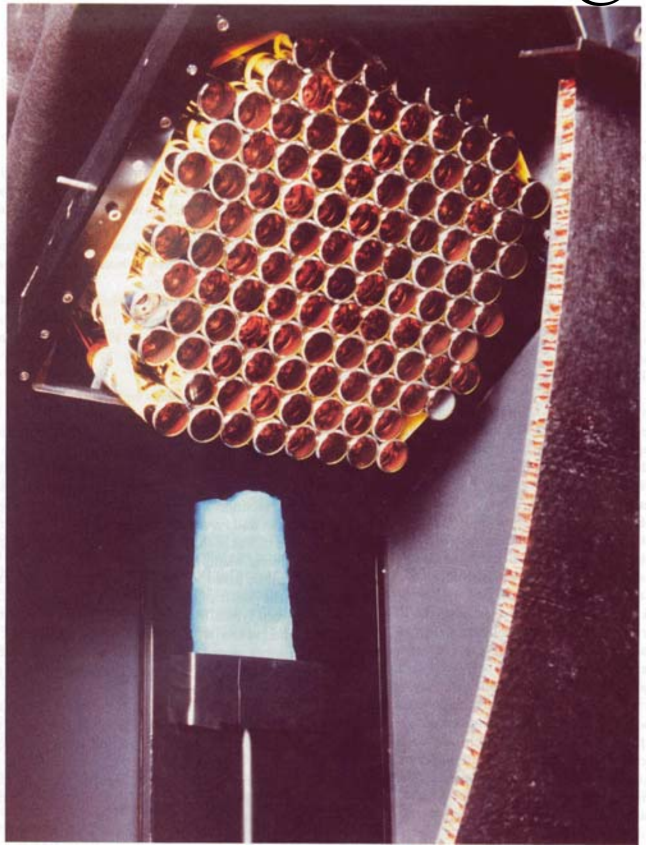
OH on the surface replaced by TMS (trimethylsilil)

focalized RICH with aerogel

- T.Ypsilantis & J.Seguinot, NIMA368(1995)
- T.Ypsilantis, J.Seguinot & al., NIMA401(1997),

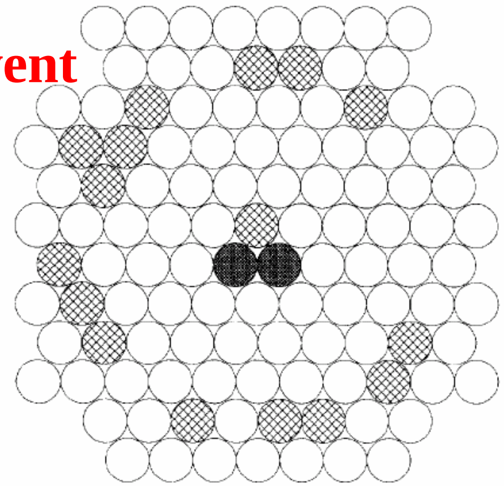
(CERN-Bari-Milan-Rome-Coll.de France coll. @ PS-T9



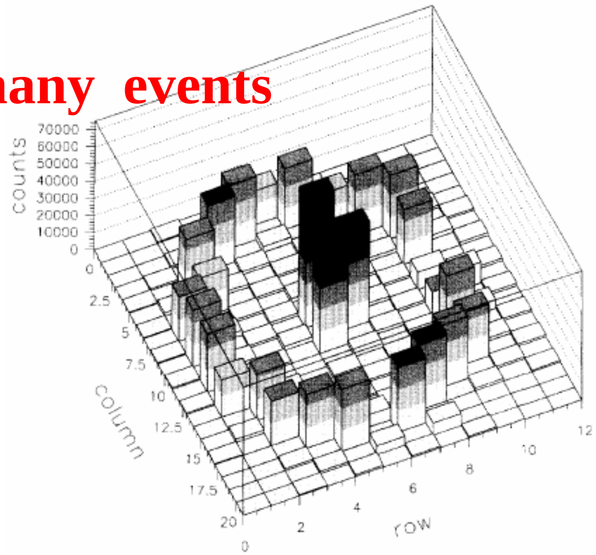


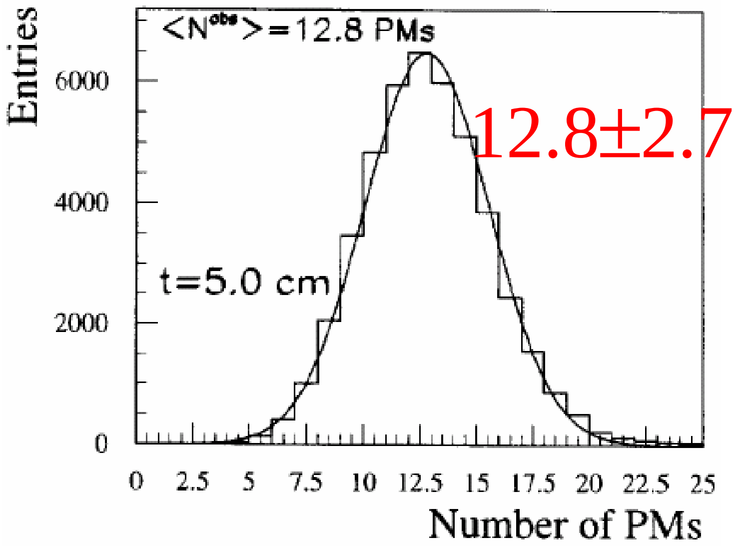
5 cm of KEK aerogel, π^- 10 GeV/c

one event

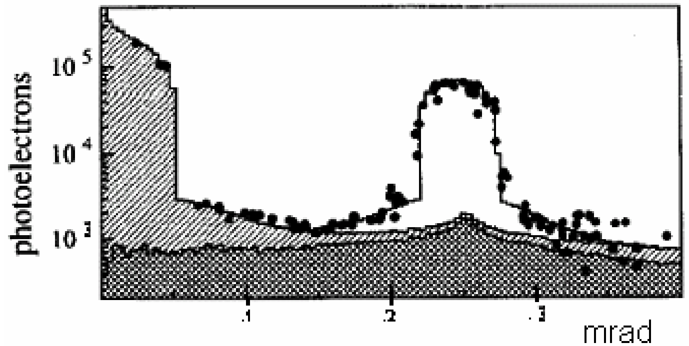


many events





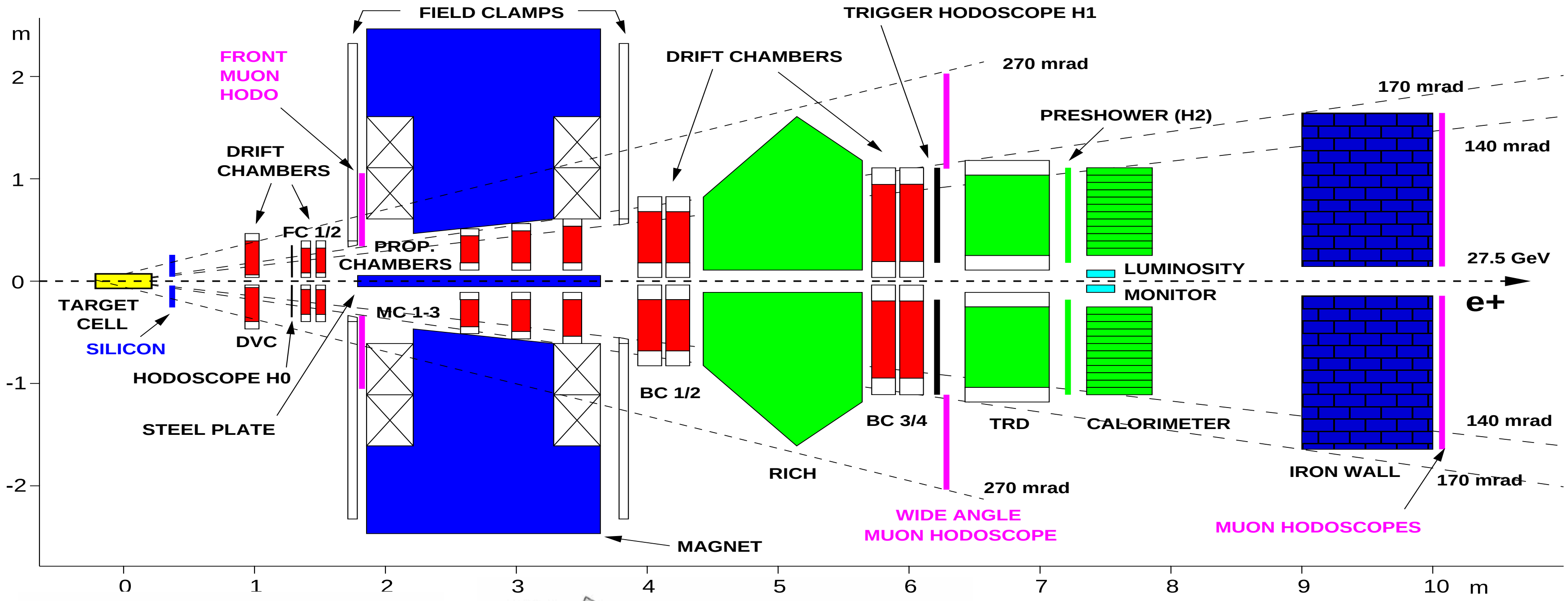
12.8±2.7 PMs



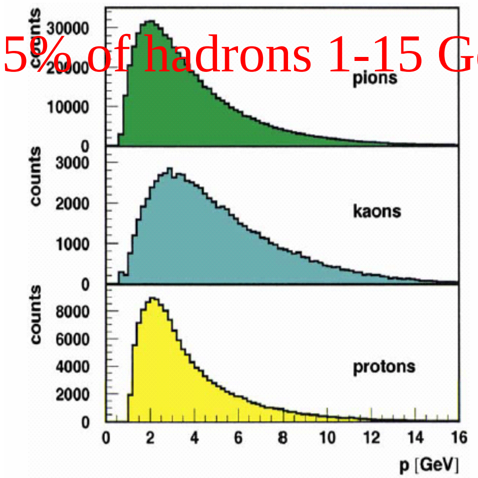
$\delta\theta/\theta$ = 8% / pe

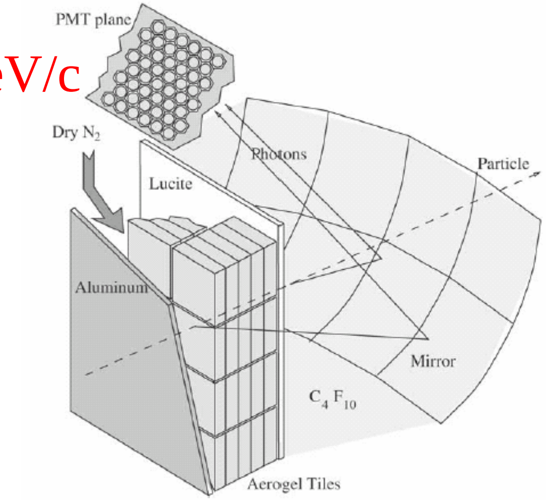
$\delta\theta/\theta$ = 2.3% / ring

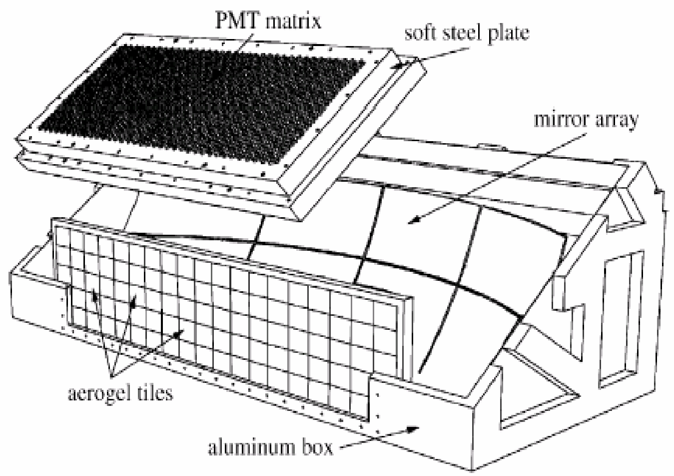
HERMES DIS 27.5 GeV e on p



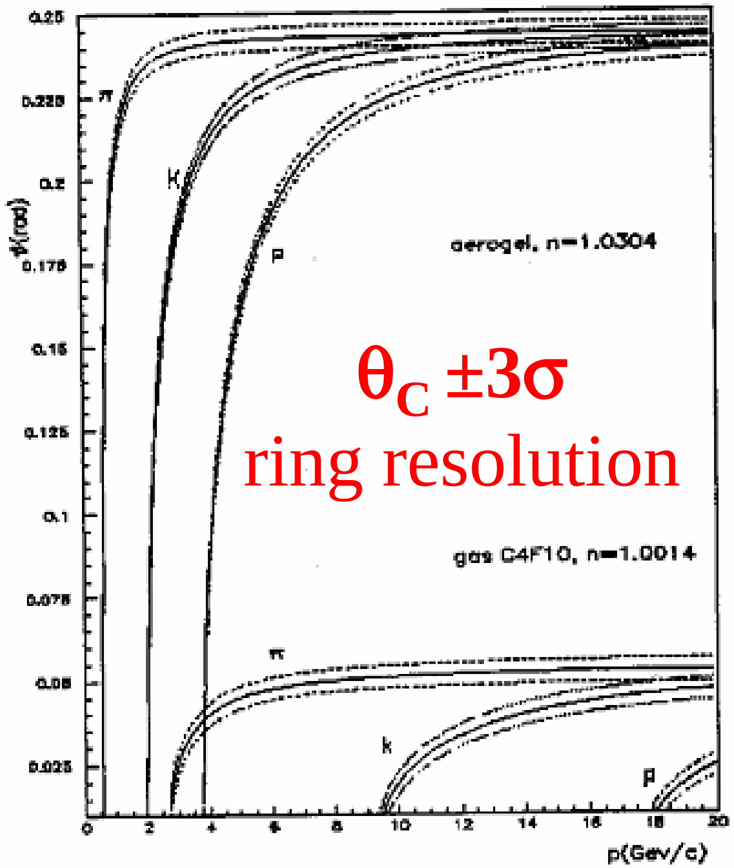
95% of hadrons 1-15 GeV/c

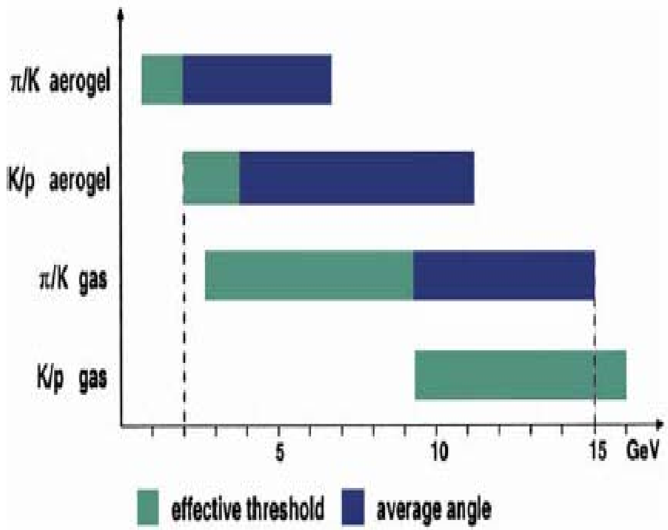






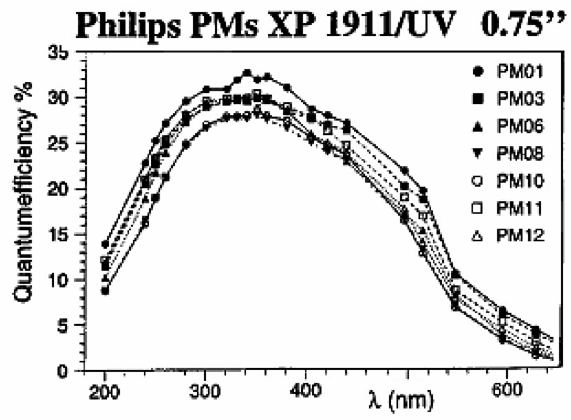
HERMES dual radiator RICH

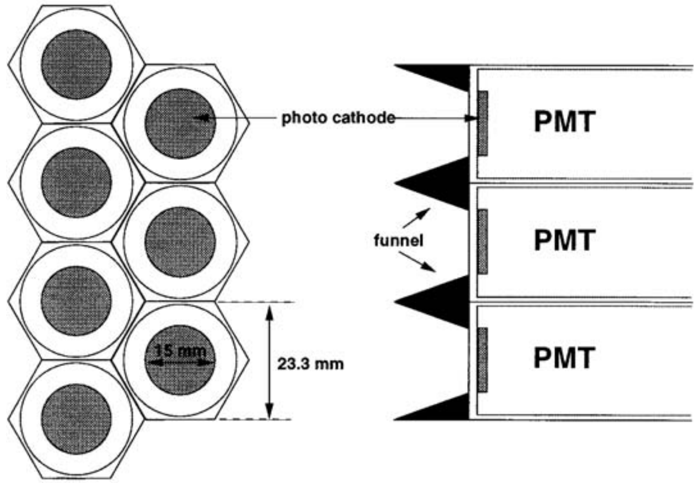


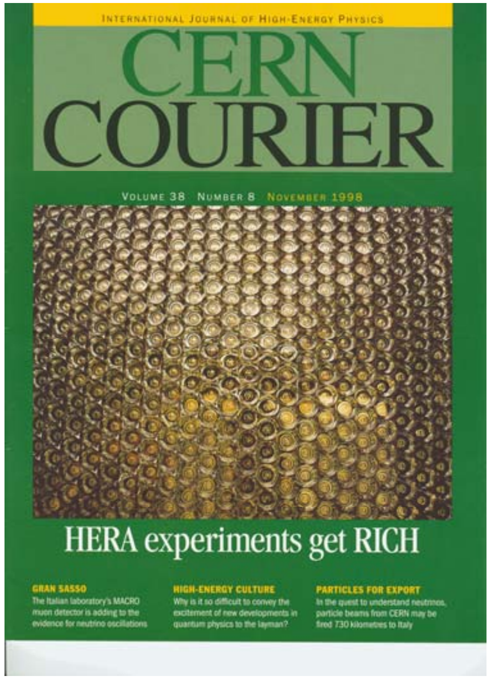


- focalized R = 2.2 m
- n(aerogel)=1.03, θ_C=242 mrad
- $n(C_4F_{10})$= 1.00137
- Npe (aerogel) = 12
- $\delta\theta/\theta$(/ring) =1.2 % (4.1% / pe)
- $\delta\theta$(/ring) = 3 mrad
- $\theta_C^{\pi}-\theta_C^{k}$(7GeV,n =1.03) = 9 mrad

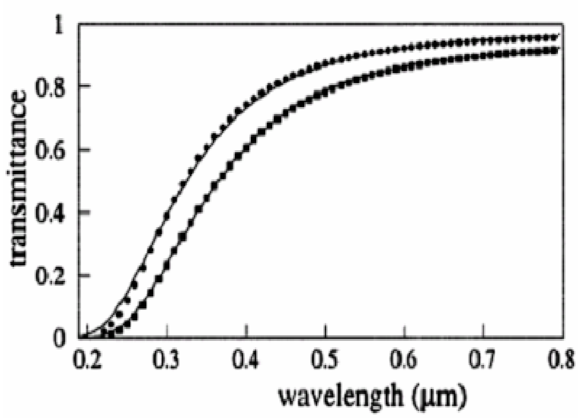
2*1934 3/4"PMTs 1"Al mylar funnels

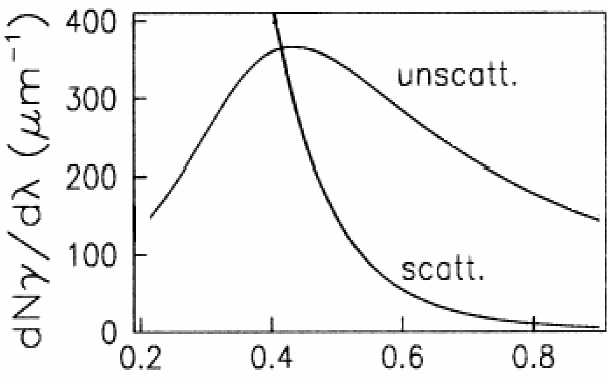


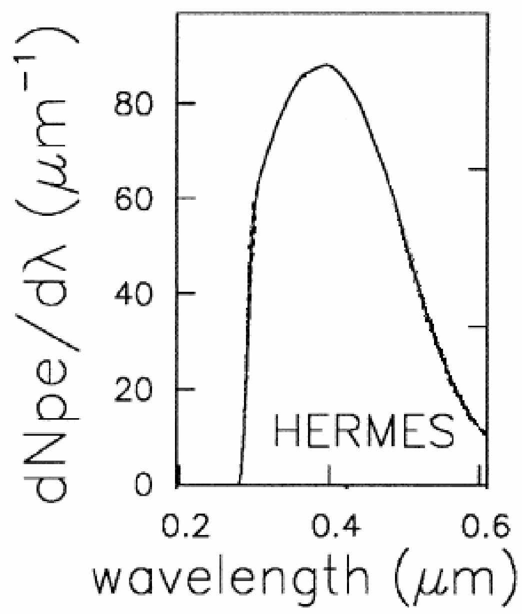




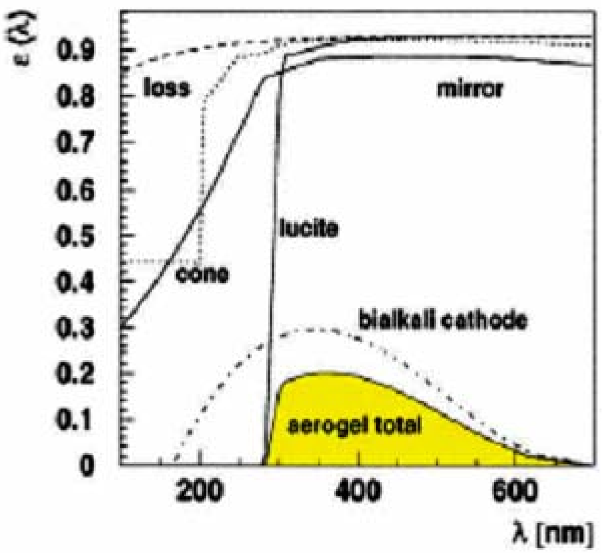
T → Cher. γ's → photoelectrons







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



Λ (400 nm) = 2.3 cm

Npe (calc.)
12±2

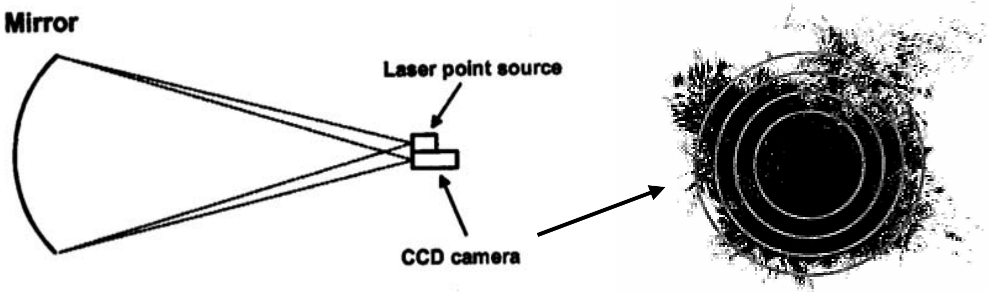
geometrical contributions to $\delta\theta_c$

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

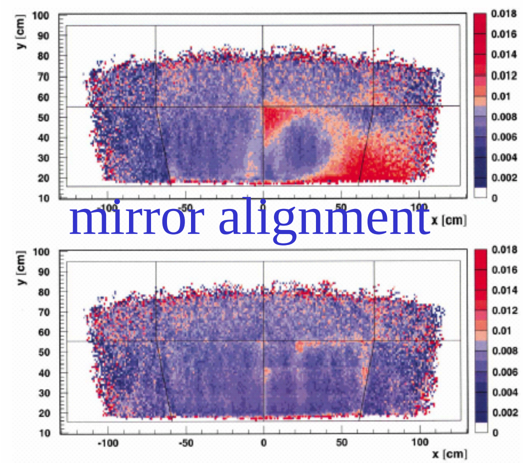
2) focal plane

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

b)



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



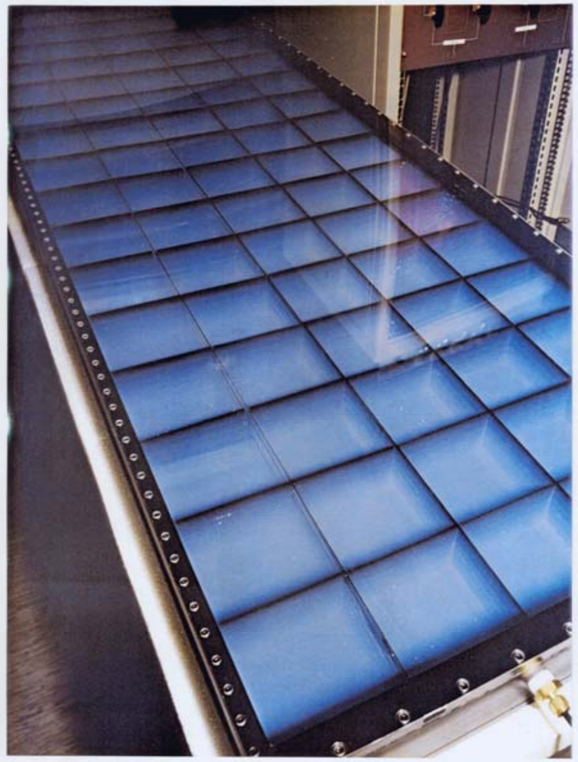
a)+b) $(\vartheta\theta/\theta)_{\mathrm{mirror}} = 0.6$ % / pe

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

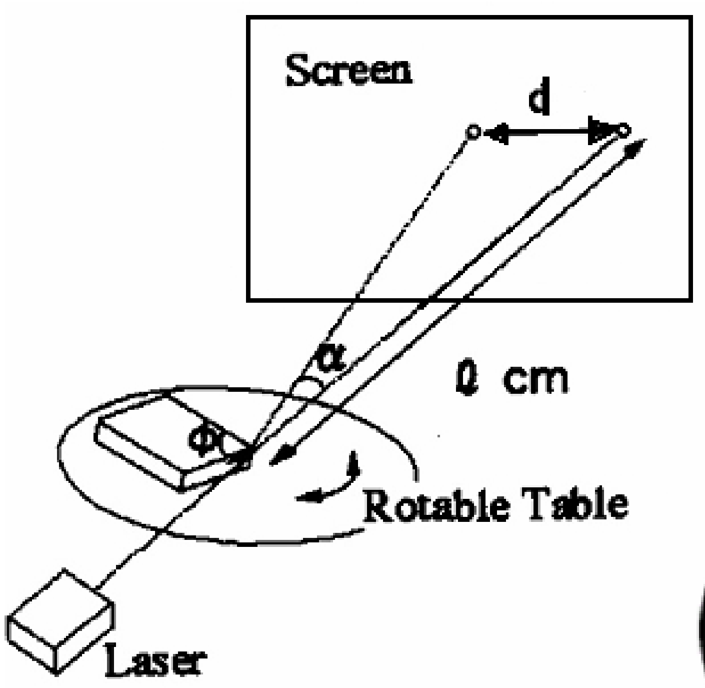


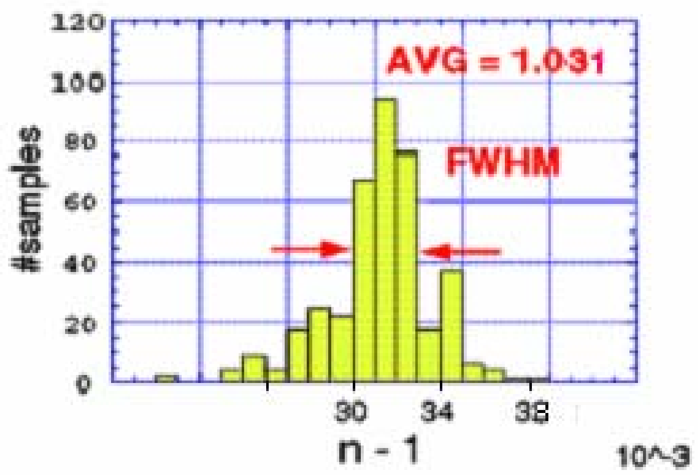
one aerogel radiator

1) n dispersion

minim.deflec.

l = 4m → δn/n=10^{-4}

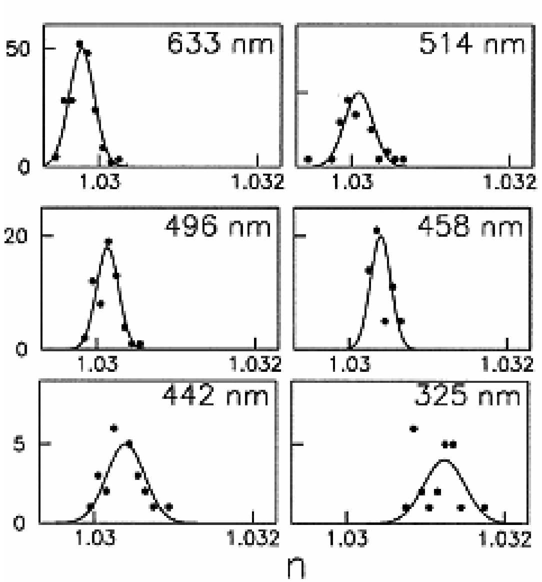


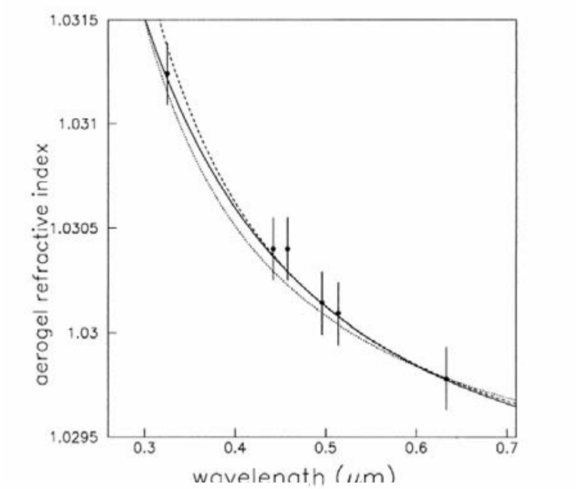


δn/(n-1) = 1.5 %
reduced to 1.0 %
by sorting similar-n tiles

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

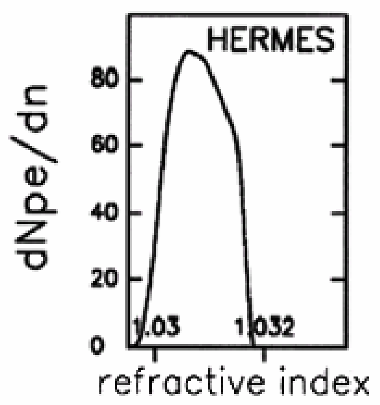
2) chromatic dispers.: n (λ) meas.





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

$n_{\text{aerogel}}(\lambda) = A n_{\text{SiO}_2}(\lambda) + (1 - A) n_{\text{air}}(\lambda)$



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

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

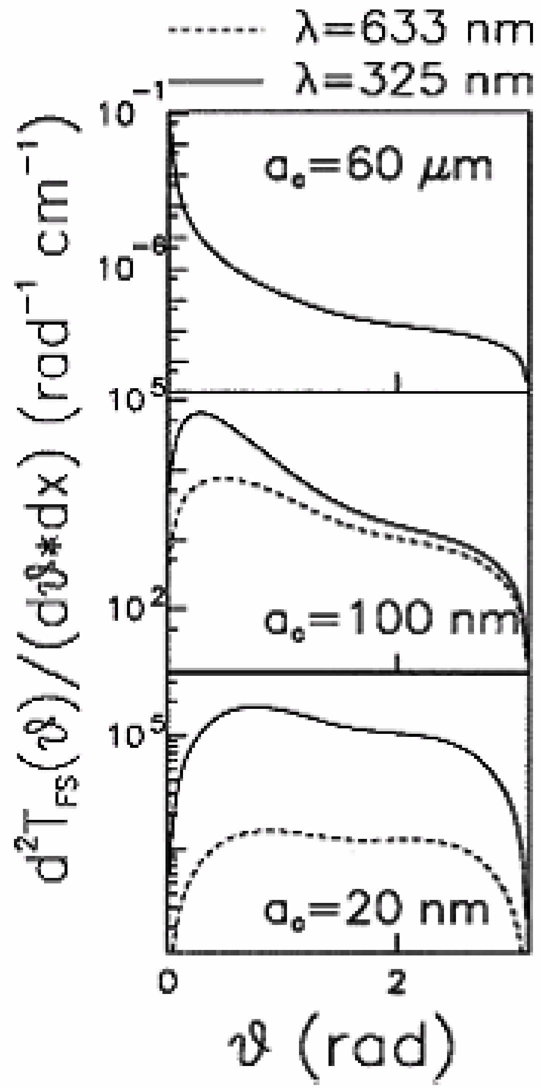
3) forward scattering

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

Rayleigh-Debye (Mie) scattering theory

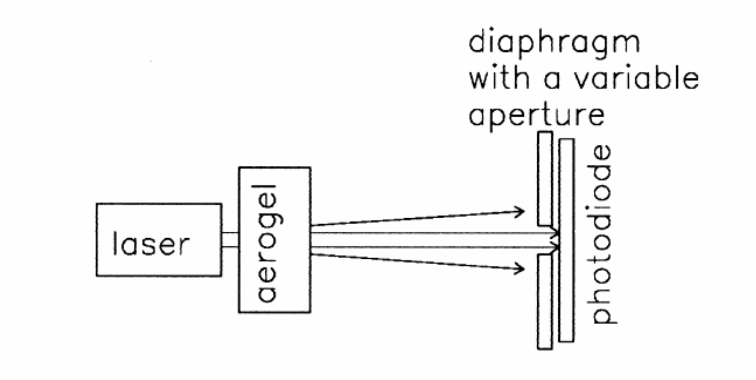
$$\frac{d^2 T_{FS}}{d\theta\, dx} = \frac{(1+\cos^2\theta)}{\lambda^4}(\sin\theta)\, wf.$$



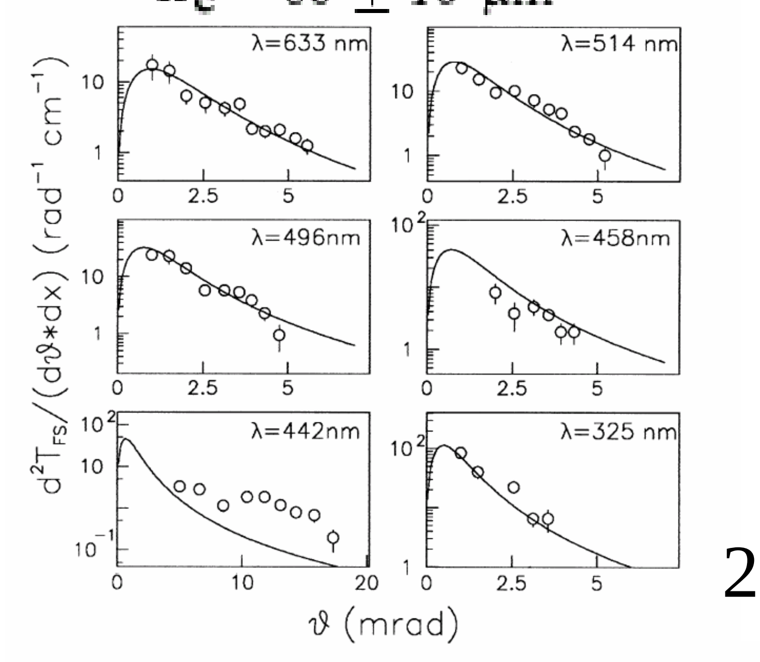
$w \propto a_C$ (inhomog.)

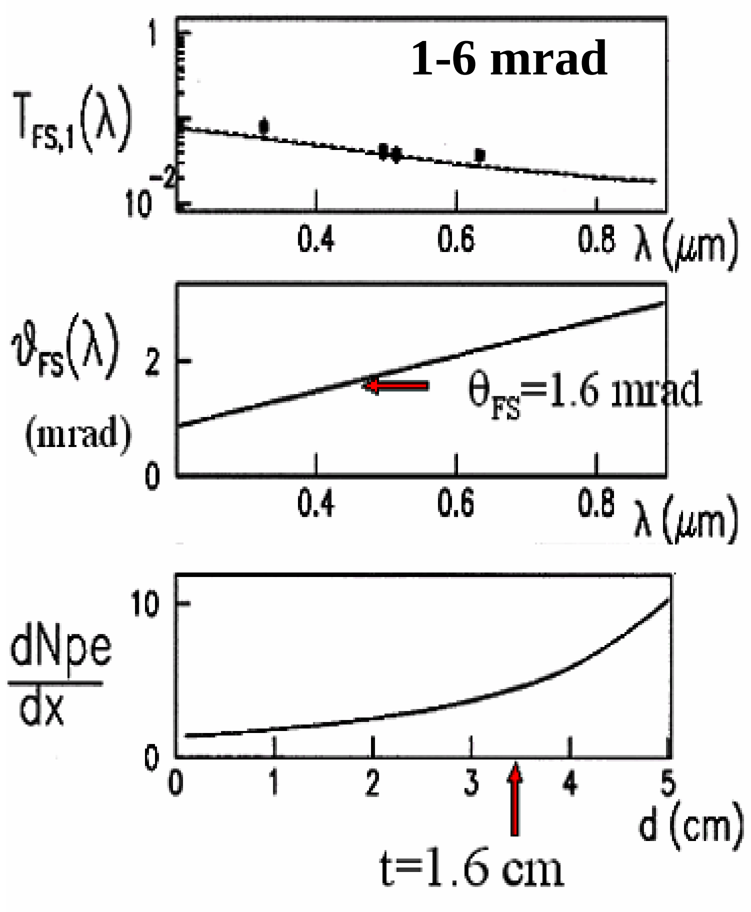
$a_C > \lambda$ FS

$a_C < \lambda$ Rayleigh



$a_c = 60 \pm 10\ \mu\text{m}$

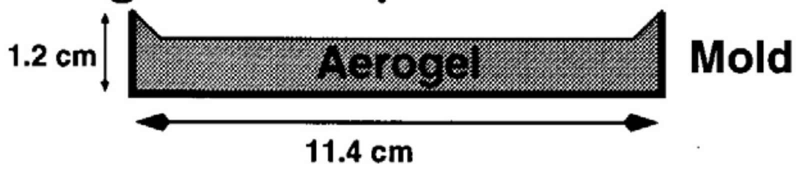


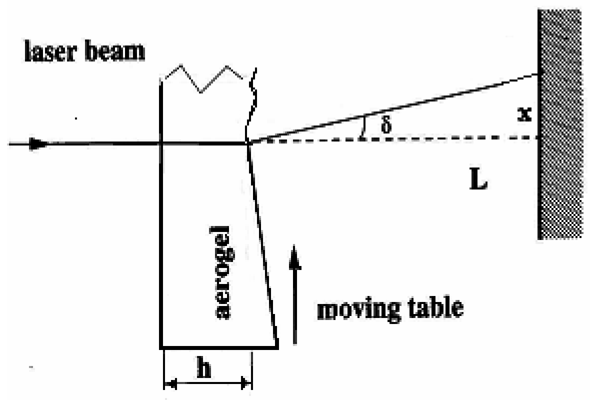


23% of Cher.ph. are FS → $\delta\theta_{FS}$

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

4) surface irregularities

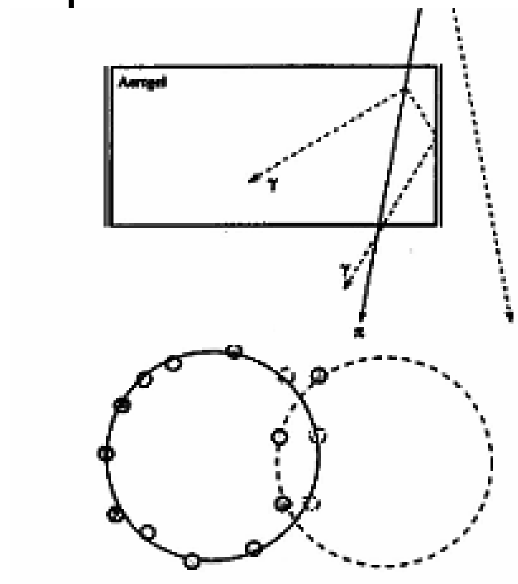


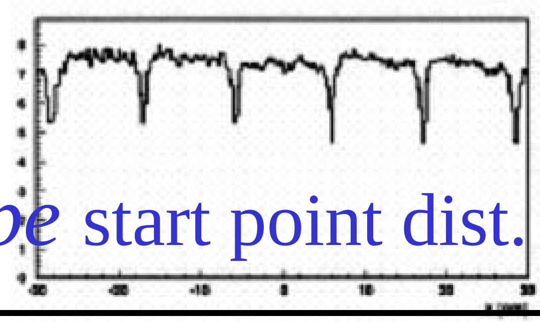


$$\left(\frac{\delta\theta}{\theta}\right)_{surf.} = \frac{\delta\theta_S}{\theta_C} = 0.4\ \% \ / \ pe$$

avoid internal reflections

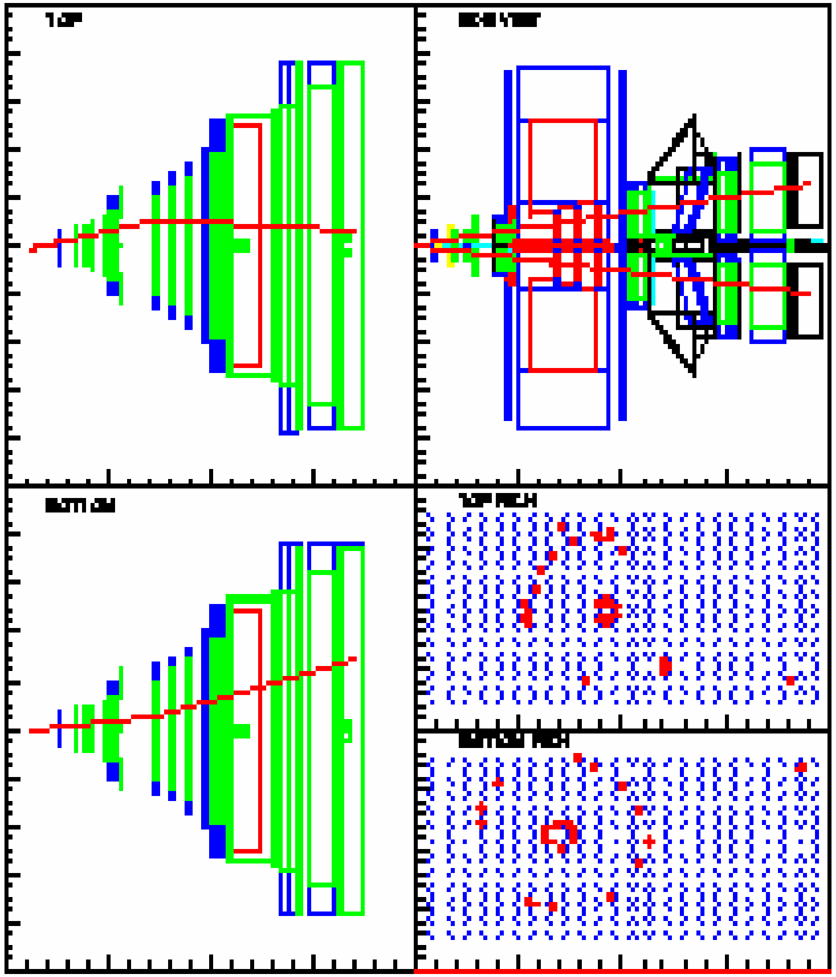
black tape on lateral surfaces

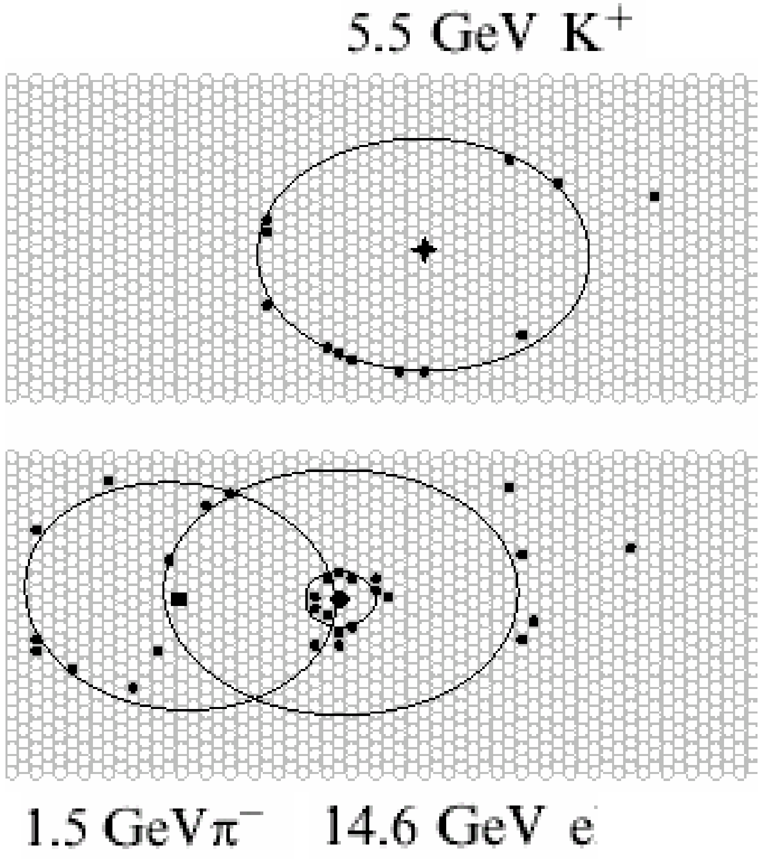




pe start point dist.

on-line display



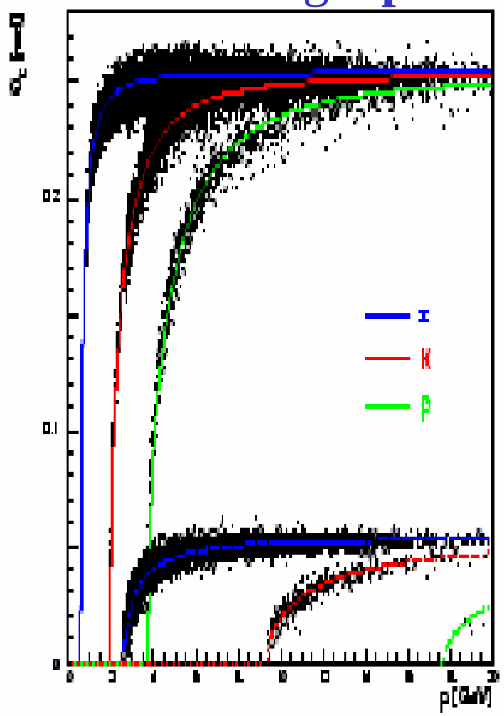


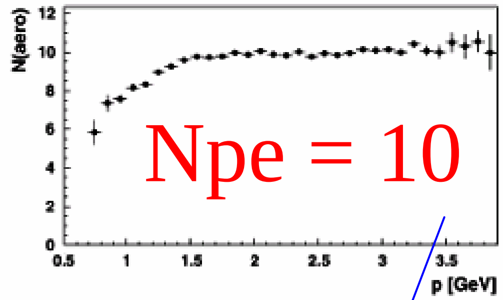
exp.-calc. angle resolution (%)

HERMES

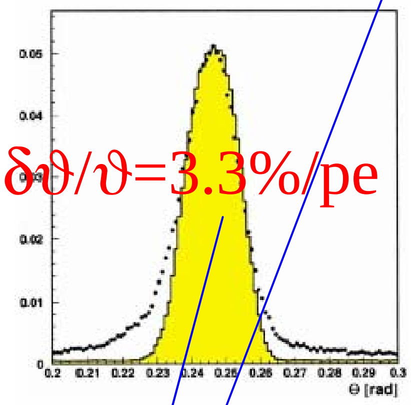
- Pixel 2.3 ←
- Mirror 0.6
- Point emiss. 0.7
- n disp. 0.5
- Chromatic 1.3
- Forw.Scatt. 0.4
- Surface 0.4
- Total (calc.)/pe 2.9
- Total (exp.)/pe 3.3
- Npe (exp.) 10

θc for single **pe**





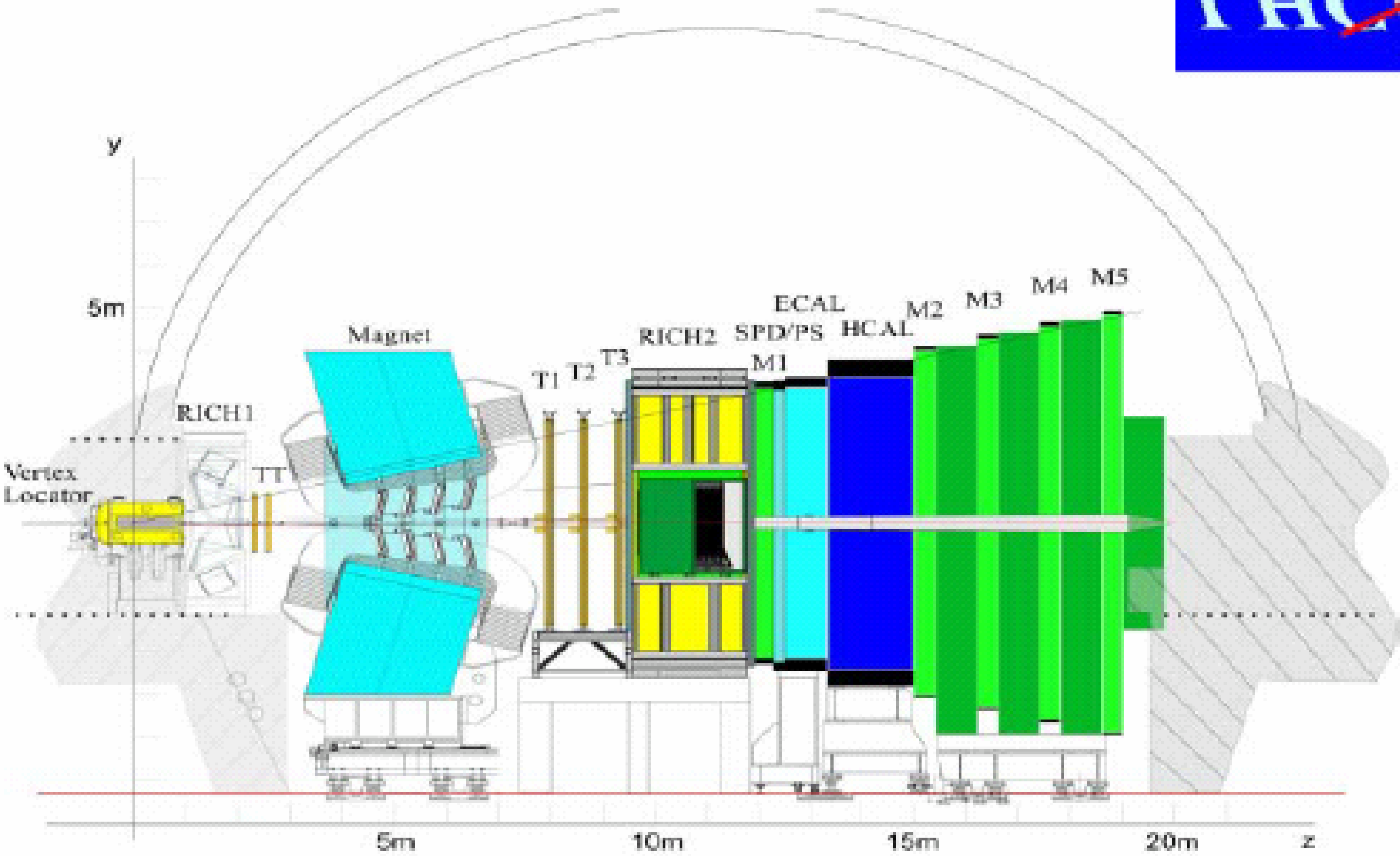
Npe = 10



$\delta\vartheta/\vartheta$=3.3%/pe

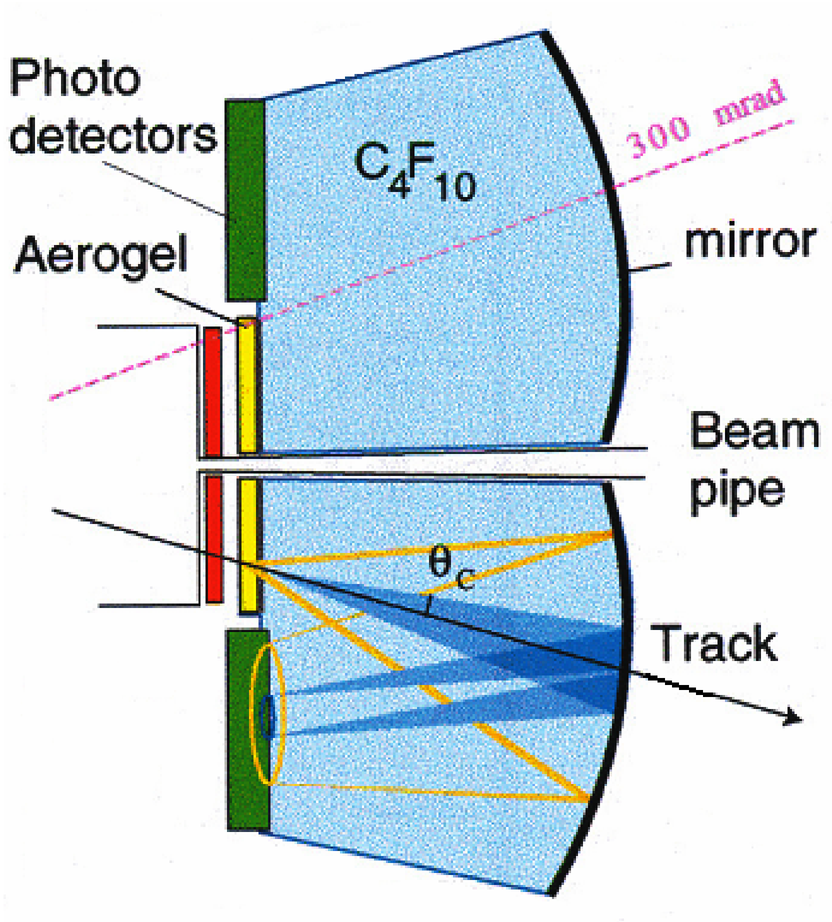
$\delta\vartheta/\vartheta$ = 1.1% /ring

The LHCb detector



K/π separation 2-150 GeV/c

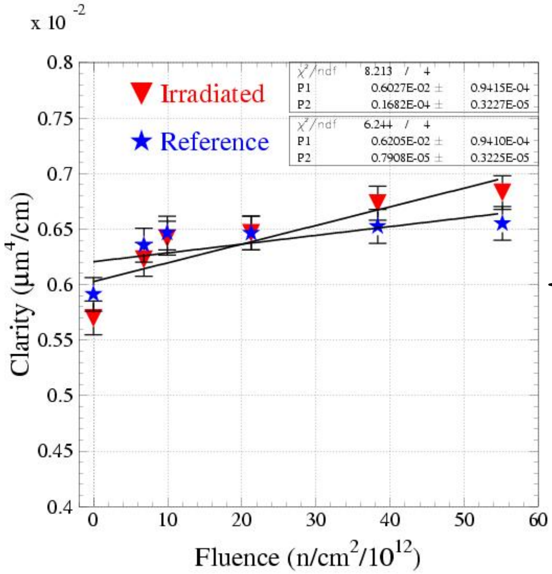
RICH-1 LHCb



BINP-Novosibirsk:
20x20x4 cm^3
n=1.03 hygroscopic
A=0.96 C=0.005 (t=1 cm)
Λ (400 nm) = 4 cm

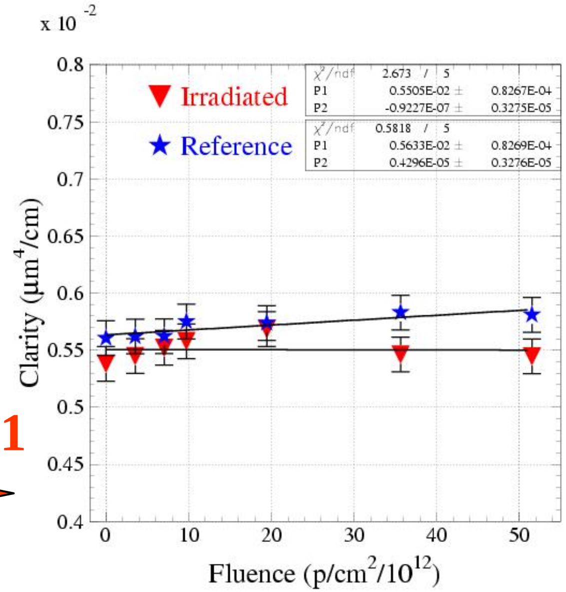
Clarity measurements

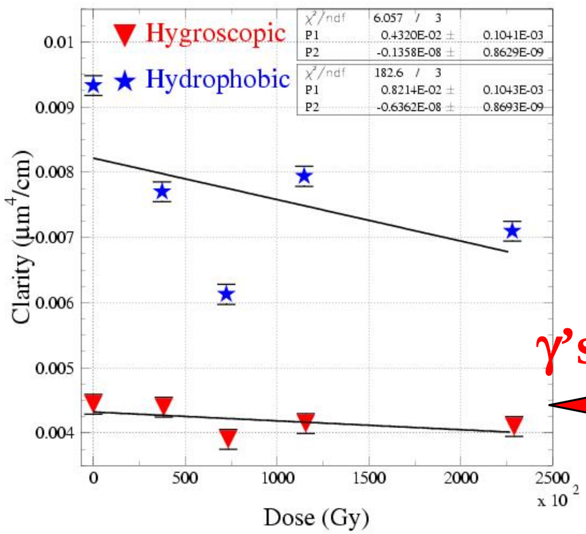
Sezione di Milano
C.Matteuzzi



neutrons from IRRAD-2

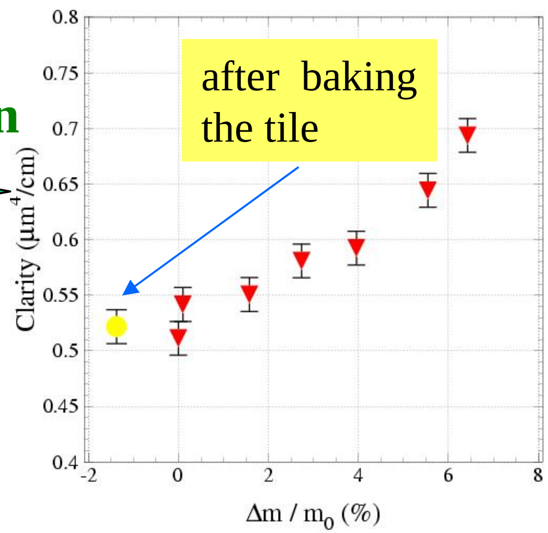
protons from IRRAD-1





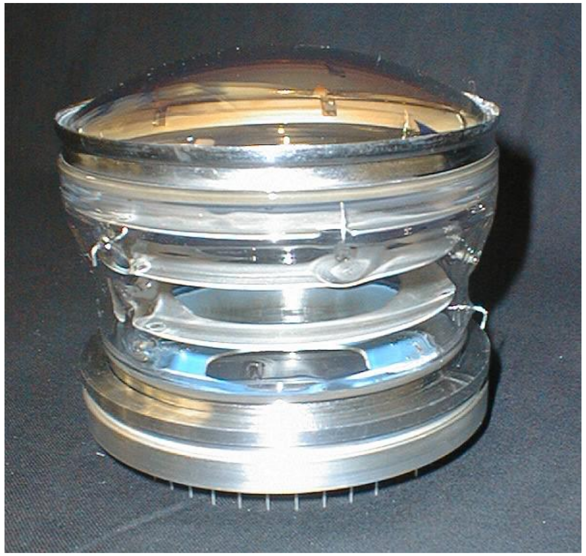
humidity absorption

γ's from ^{60}Co



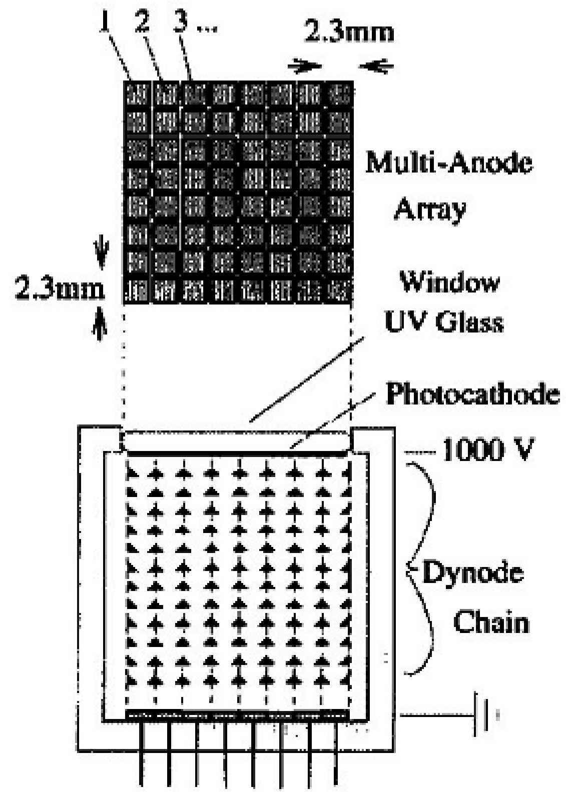
The PhotoDetectors

HPD



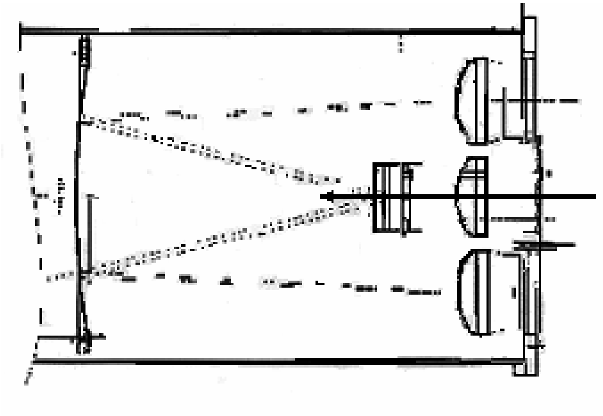
- Bialkali Photocath. D=110 mm, QE(320nm)>20%
- Overall D=125 mm   82% active area
- voltage -16 KV
- Electron optics: cross-focussed
- demagnification 2.3
- Anode: Si pixel :1 mm x 1 mm (320x32 matrix)
  2048 pixels, size at photocath. 2.5 x 2.5 mm^2

MaPMT

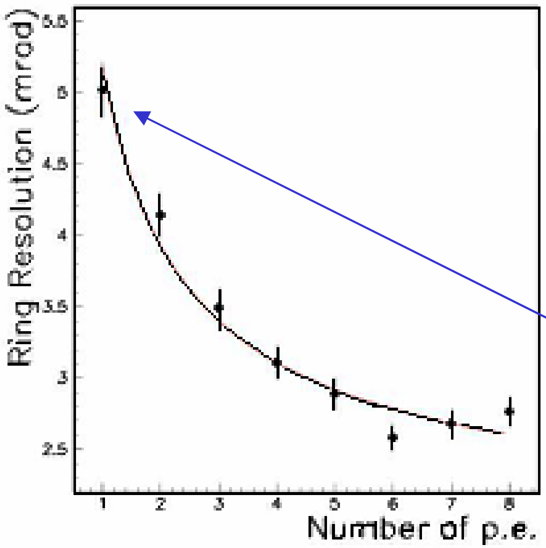


64-Channel MaPMT:
Hamamatsu R7600-03-M64

4 HPD & AEROGEL from Novosibirsk: test beam



Angular resolution



N_{pe} yield

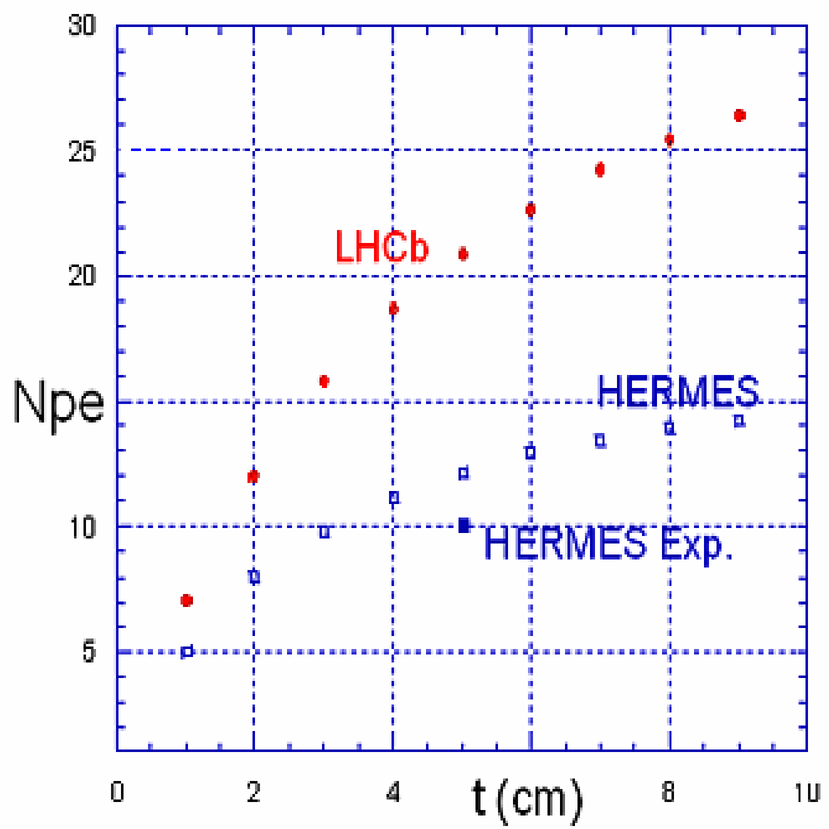
	No filter	Filter D263 (0.3 mm)
4 cm DATA MC	9.7 11.5	6.3 7.4
8 cm DATA MC	12.2 14.7	9.4 10.1

t=4 cm Npe ~10

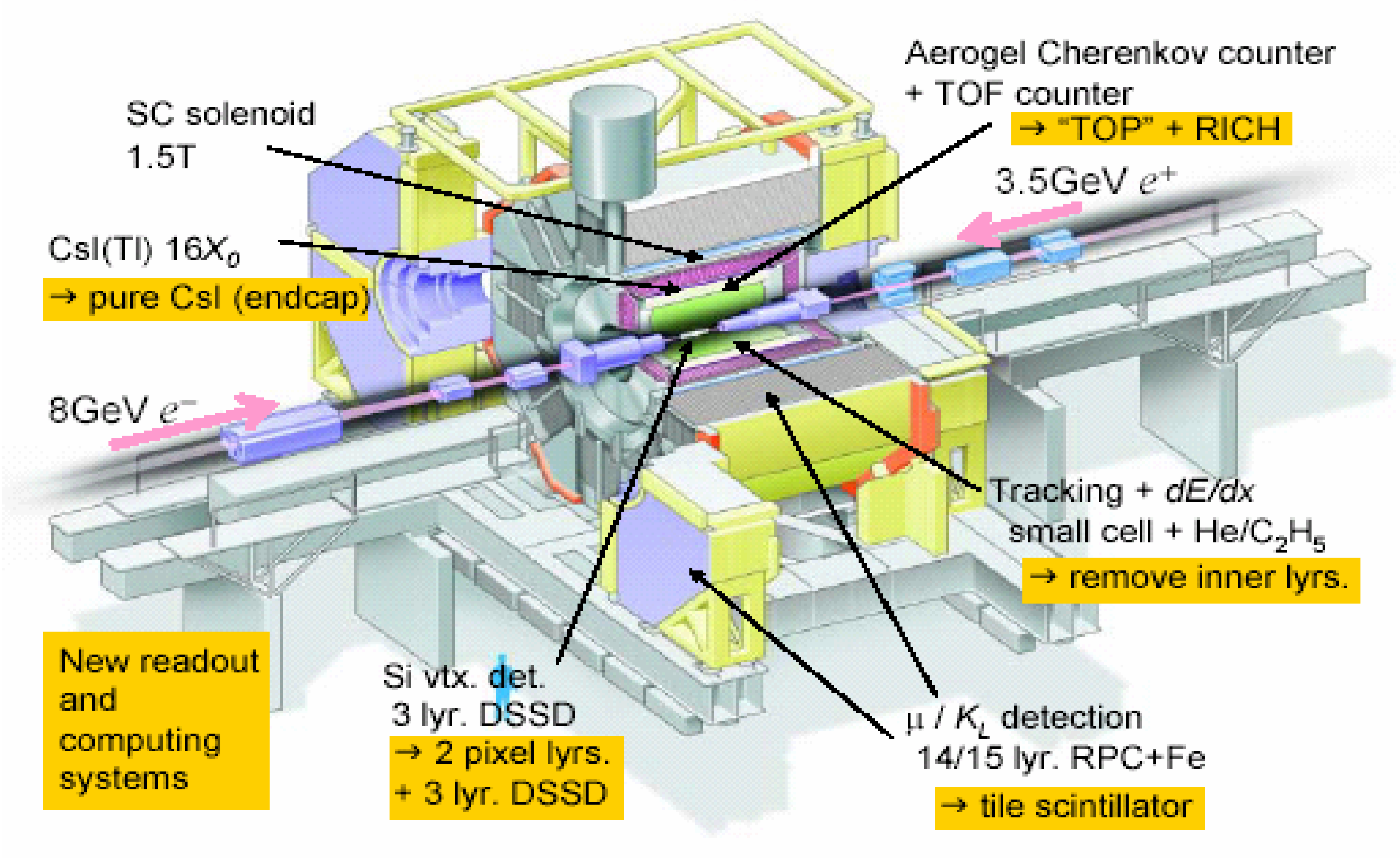
$\delta\vartheta/\vartheta = 2.0\ \% / \text{pe}$

LHCb RICH-1 **δϑ/ϑ(/pe)(%)** and Npe from HERMES

	HERMES	LHCb
• 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	10



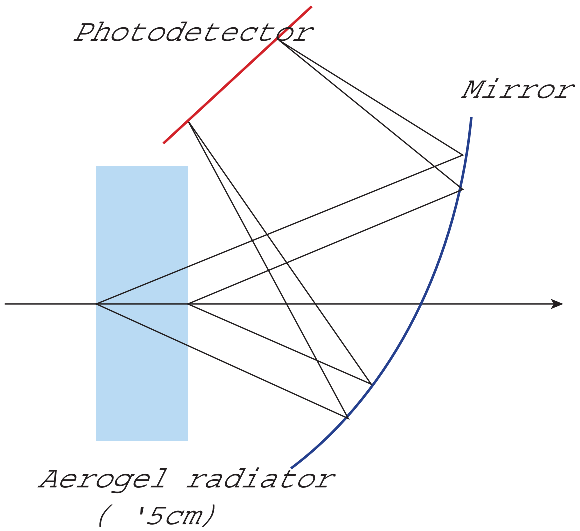
BELLE upgrade (KEK $L=10^{34} \rightarrow \approx 2*10^{35}$)

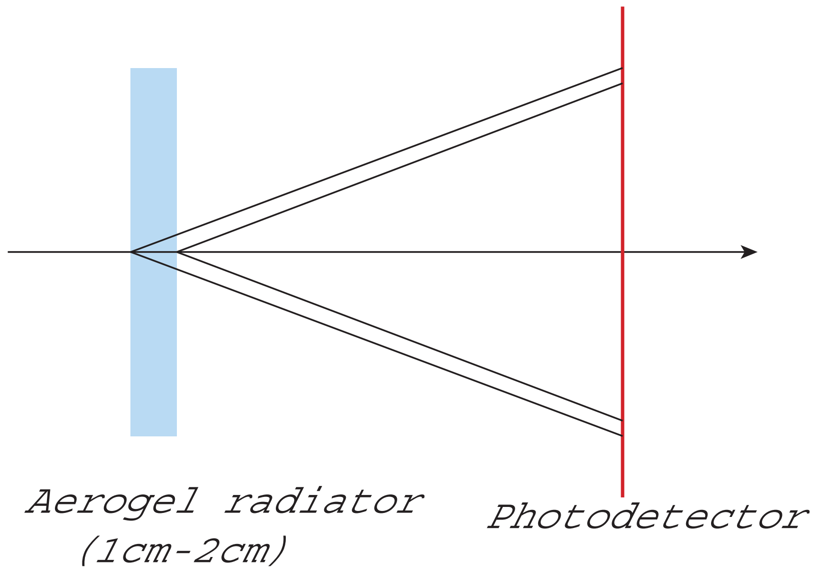


BELLE Aerogel RICH R&D

Chiba-KEK-Nagoya-Ljubljana coll.

- focusing — proximity focus



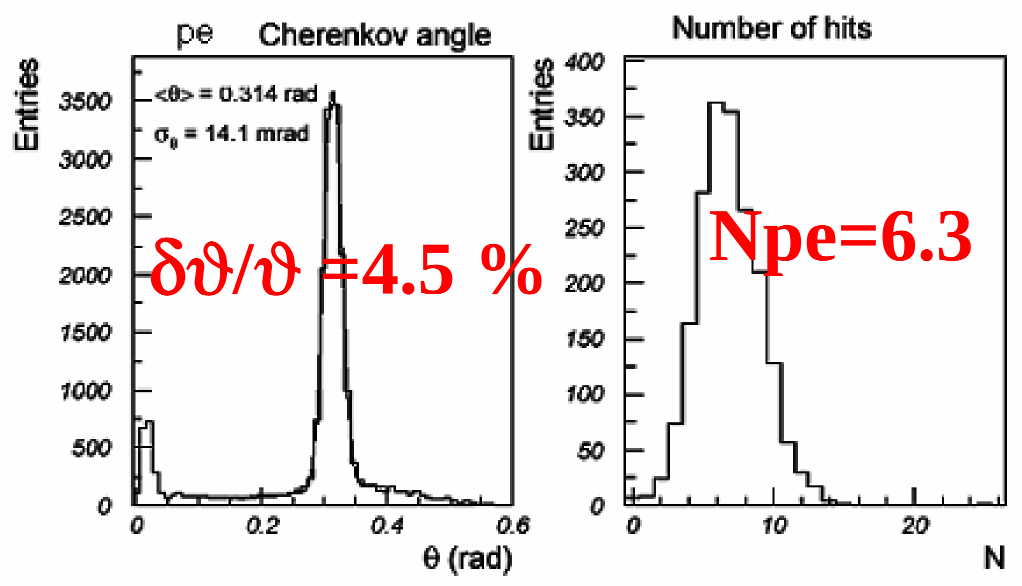


’02 beam test at π2 KEK-PS

- New aerogel from Matsushita & Chiba-U.
- Precursor: same Methylsilicate-51 but new supplier
- Solvent: di-methyl-formadide (DMF) instead of Methyl-alcohol
- Λ(400nm)= 3 cm, n= 1.05, t= 2 cm
- H8500-M64 PMT flat panel, 6x6 mm^2 pixel, 84% cov.area, QE(400nm)=25%, sensit. to 1.5T

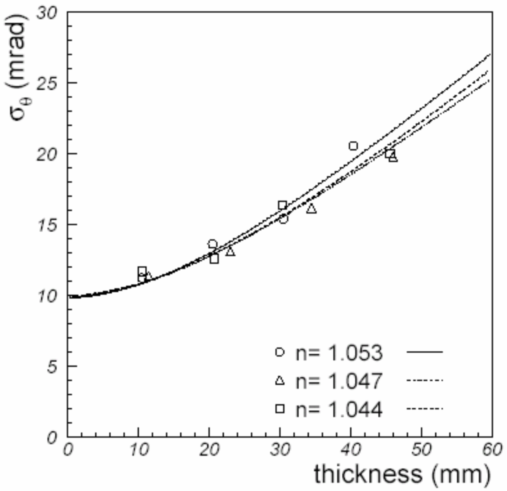
’02 beam test results

- very clean rings observed !
- $\delta\vartheta/\vartheta$ =4.5 %/pe, Npe = 6.3, $\delta\vartheta$(/ring) = 5.6 mrad
- $\theta_\pi - \theta_k$ (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

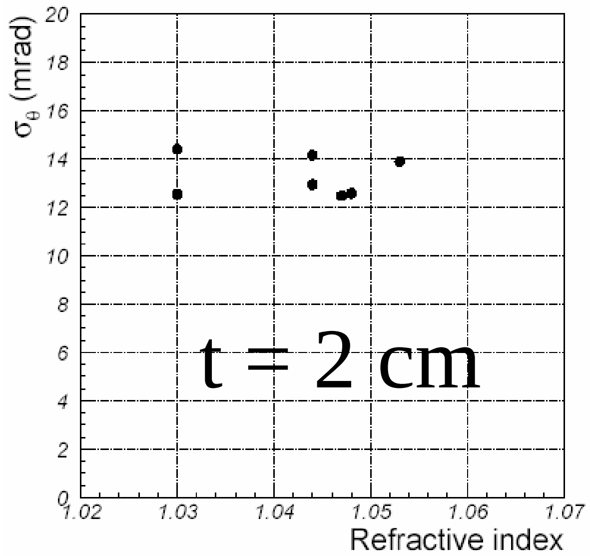
σ(/pe) vs t



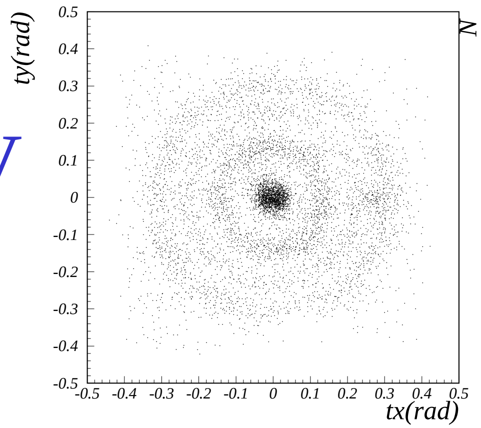
$$\sigma_{emp} = d \sin\theta_c \cos\theta_c / L\sqrt{12}$$

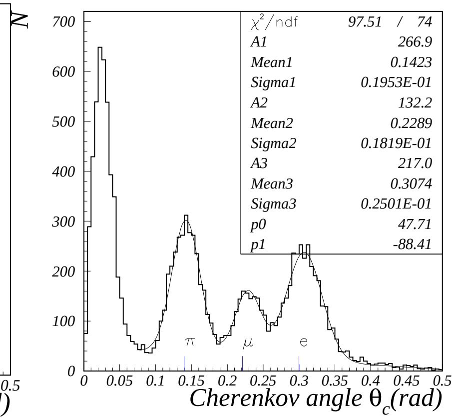
$$\sigma_{pix} = a \cos^2\theta_c / L\sqrt{12}$$

σ(/pe) vs n

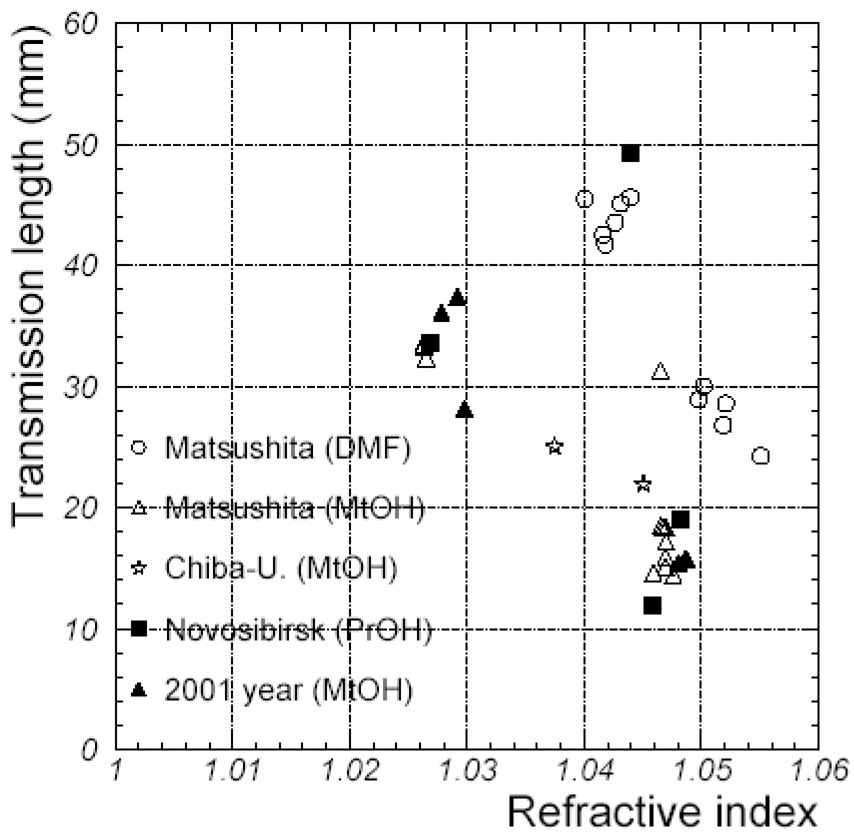


- e^-, μ^-, π^- at 0.5 GeV





Λ vs n in new Matsushita aerogel



aerogel RICH summary

aeroRICH	CERN-test	HERMES	LHCb	BELLE
year	‘97	‘99	‘ 02	‘02
type	foc.	foc.	foc.	prox.
n	1.03	1.031	1.03	1.5
Λ (cm)	2.3	2.3	4	4.5
t (cm)	5	5	4	2
$\delta\theta/\theta$ (%)(/pe)	8	3.3	2.0	4.5
Npe	12.8	10	10	6.3
$\delta\theta/\theta$ (%)(/ring)	2.3	1.1	0.6	1.8