the number of photons becomes, after angular integration,

$$\frac{dN}{d\lambda} = \frac{2\pi\alpha}{\lambda^2} L \sin^2 \theta_c \tag{5.7}$$

The number of photons emitted in the wavelength interval from λ_1 to λ_2 is then

$$N = 2\pi\alpha L \int_{\lambda_2}^{\lambda_1} \sin^2 \theta_c / \lambda^2 \, d\lambda \tag{5.8}$$

For a counter equipped with a photocathode sensitive in the visible region, $\lambda_1 = 400$ nm and $\lambda_2 = 700$ nm, such that we have

$$\frac{N}{L} = 490 \sin^2 \theta_c \quad \text{photons/cm}$$

If the sensitivity is expanded into the ultraviolet region, the yield of photons can be increased by a factor of two to three. One way of achieving this goal

Fig. 5.6. Cherenkov angle θ_c as a function of the reduced particle velocity $\beta = v/c$ for a series of refractive indices n.

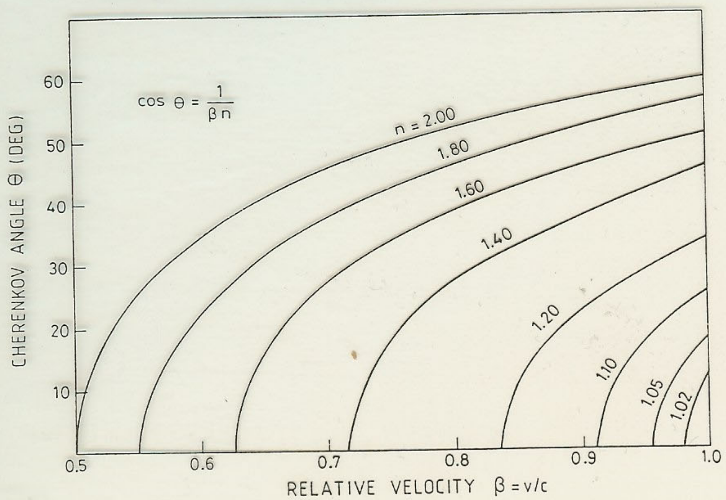


Table 6.2. *Compilation of Cherenkov radiators [1, 34, 35, 122]. The index of refraction for gases is for 0 °C and 1 atm (STP). Solid sodium is transparent for wavelengths below 2000 Å [447, 448]*

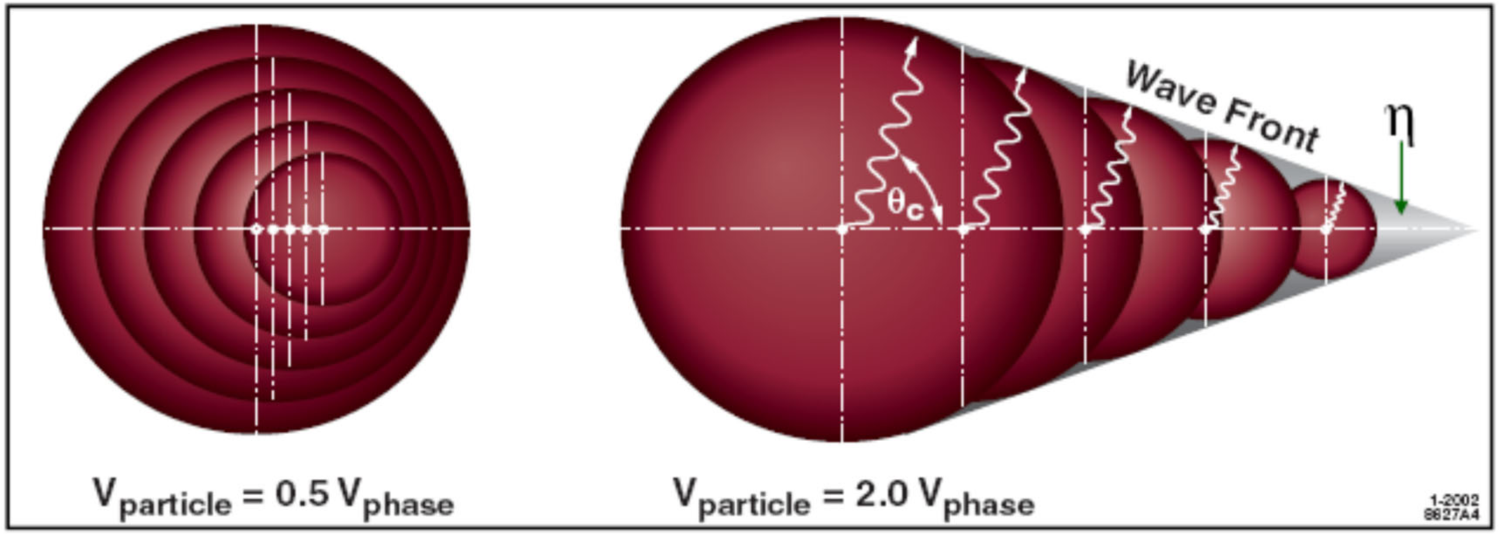
material	$n-1$	β-threshold	γ-threshold
solid sodium	3.22	0.24	1.029
lead sulfite	2.91	0.26	1.034
diamond	1.42	0.41	1.10
zinc sulfide (ZnS(Ag))	1.37	0.42	1.10
silver chloride	1.07	0.48	1.14
flint glass (SFS1)	0.92	0.52	1.17
lead fluoride	0.80	0.55	1.20
Clerici solution	0.69	0.59	1.24
lead glass	0.67	0.60	1.25
thallium formate solution	0.59	0.63	1.29
scintillator	0.58	0.63	1.29
Plexiglas (lucite)	0.48	0.66	1.33
boron silicate glass (Pyrex)	0.47	0.68	1.36
water	0.33	0.75	1.52
silica aerogel	0.025 - 0.075	0.93 - 0.976	4.5 - 2.7
pentane (STP)	$1.7 \cdot 10^{-3}$	0.9983	17.2
CO_2 (STP)	$4.3 \cdot 10^{-4}$	0.9996	34.1
air (STP)	$2.93 \cdot 10^{-4}$	0.9997	41.2
H_2 (STP)	$1.4 \cdot 10^{-4}$	0.99986	59.8
He (STP)	$3.3 \cdot 10^{-5}$	0.99997	123

supposed to be precisely at threshold and does not radiate. Under these circumstances one has:

$$\beta_2 = \frac{1}{n} \tag{6.26}$$

or

$$\gamma_2 = \frac{1}{\sqrt{1-\frac{1}{n^2}}} \,. \tag{6.27}$$



Basic Cherenkov Equations-I

Cherenkov radiation of wavelength λ emitted at polar angle (θ_c), uniformly in azimuthal angle (φ_c), with respect to the particle path,

$$\cos\theta_c = \frac{1}{\beta\, n(\lambda)}$$

The number of photo-electrons N_{pe} is always "too small".

$$N_{pe} = 370\,L \int \varepsilon \sin^2\theta_c dE = L\,N_0 \sin^2\theta_c$$

For z=1

Usually N_o ranges between ~ 20 and 100

Depends on velocity and n!

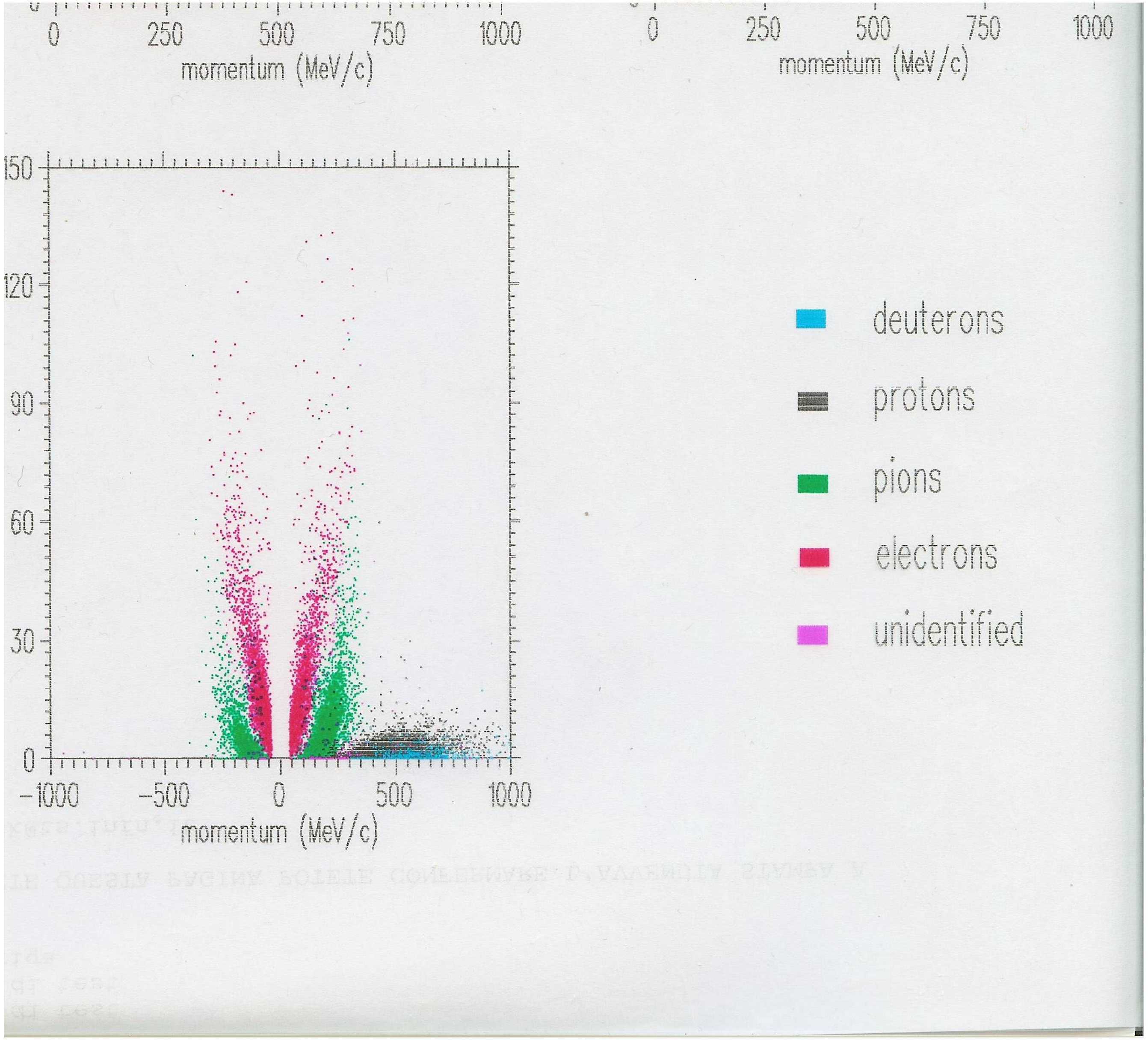
E.g., for No = 50, β = 1;

		n	N_{pe}/cm
Solid	SiO_2	1.47	27
Liquid	H_2O	1.34	22
Gas	C_5F_{12}	1.0017	0.17
Gas	He	0.00004	0.004

Shortcut to Rich07overv.lnk

Shortcut to review.lnk

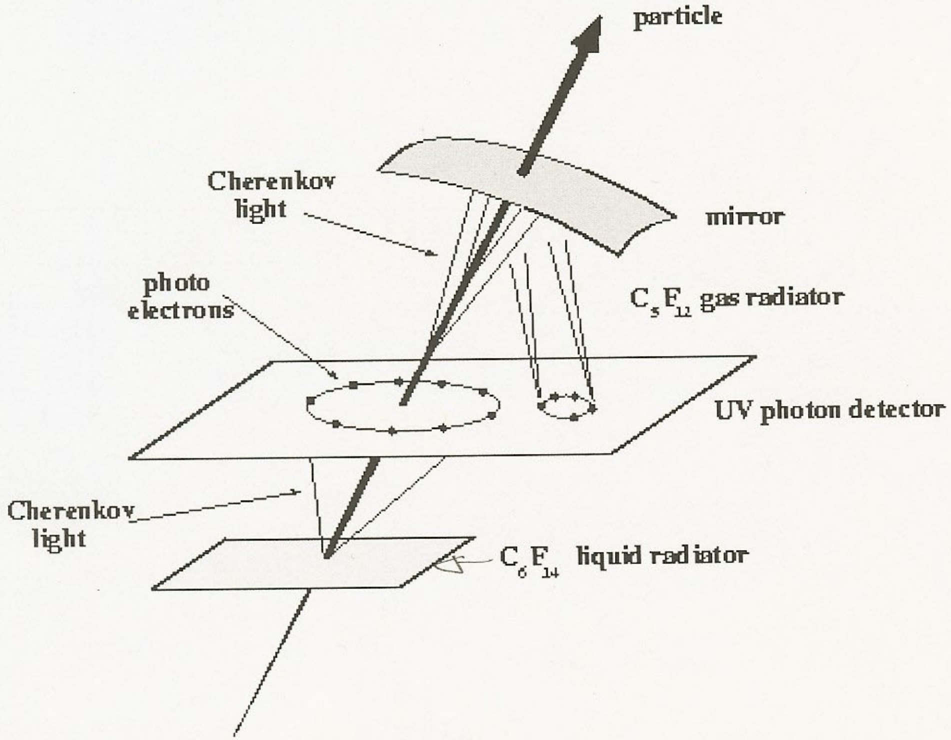
Cherenkov effect + multiplication (electrons)



particle velocity β. Particles pass through a radiator, the radiated photons may be directly collected by (or are focused by a mirror onto) a position-sensitive photon detector. Respectively, these are called *direct focusing* or *mirror-focused* RICH detectors. For direct focusing radiators have to be kept thin (e.g. a liquid radiator), to avoid broadening the ring or filling it; however, [Fabjan95b] report a use of a similar setup as a threshold counter. The Cherenkov radiation emitted at angle δ is focused onto a ring of radius r at the detector surface, and β can be determined by a measurement of r. For photon detection one uses thin photosensitive (an admixture of e.g. triethylamine to the detector gas) proportional or drift chambers, see [Barrelet91].

A detailed treatment of errors in Cherenkov detectors can be found in [Ypsilantis94]. An outlook for the future use is given in [Treille96].

For the various currently successful ways of building practical RICH detectors, see [Ekelof96] or [Ypsilantis94], and literature given there. An example is the combined RICH with liquid radiator (unfocused) and gas radiator (mirror-focused) of the DELPHI experiment at LEP (see [Abreu96], [Aarnio91]):



A combined tracking cum RICH project, including even identification of particles by energy loss,

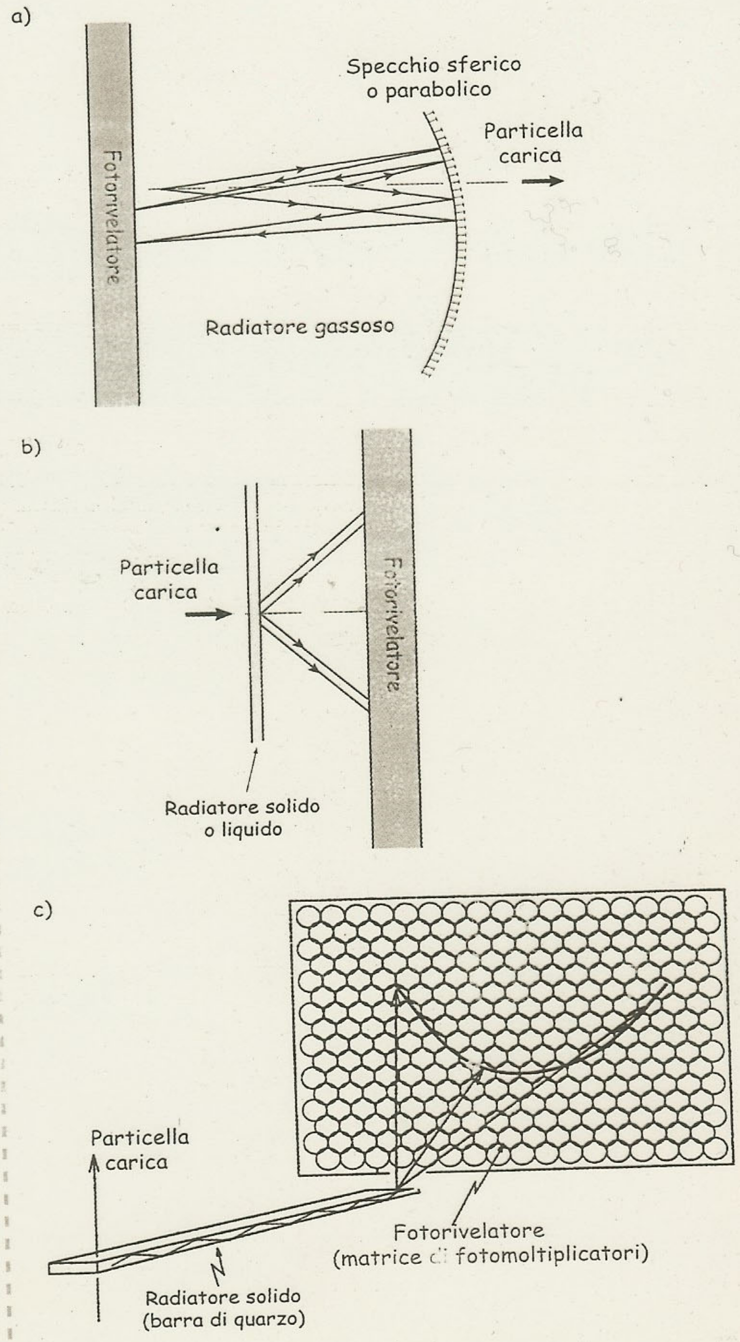
Fig. 2
Principio di funzionamento dei 3 tipi di rivelatori RICH che vengono impiegati in esperimenti di fisica nucleare o subnucleare:

a) RICH con radiatore gassoso e focalizzazione dell'immagine anulare ottenuta con specchi sferici o parabolici;

b) RICH con radiatore solido o liquido "sottile" (nella direzione di attraversamento delle particelle): l'immagine di tipo anulare è dovuta allo spessore ridotto del radiatore ed alla distanza fra questo ed il fotorivelatore;

c) DIRC: la luce intrappolata pe riflessione all'interno di una lunga barra di quarzo, fuoriesce all'estremità conservando l'informazione relativa all'angolo Cerenkov

[2] La tecnica sviluppata per la rivelazione dei neutrini è stata premiata con il premio Nobel per la fisica 2002 (vedi in questo numero *I premi Nobel per la fisica 2002*, a pg. 22).



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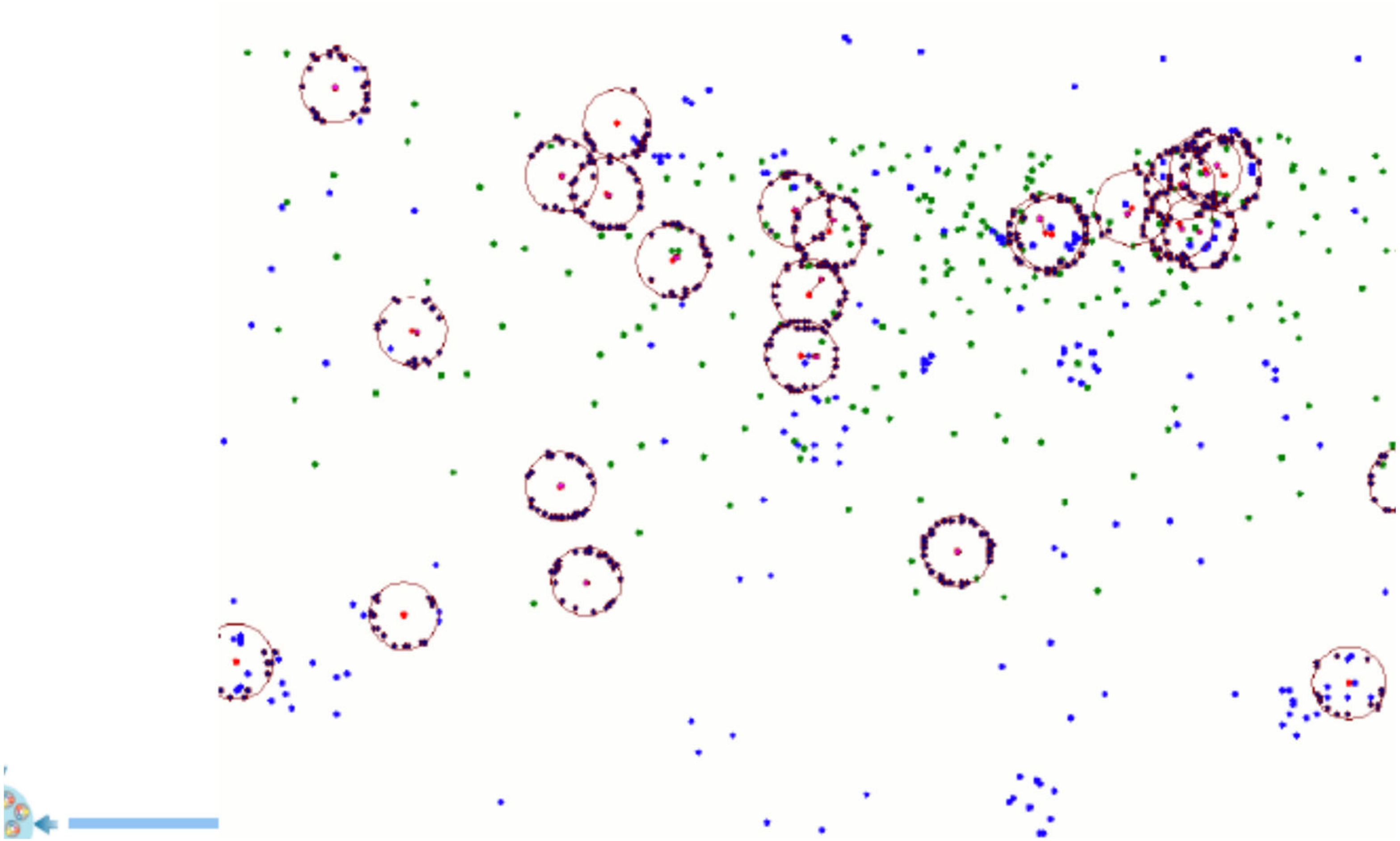
Development of a RICH detector for electron identification in CBM (FAIR/GSI)

UrQMD simulation of central Au+Au collisions, 25 AGeV

event display of inner fraction of RICH detector:



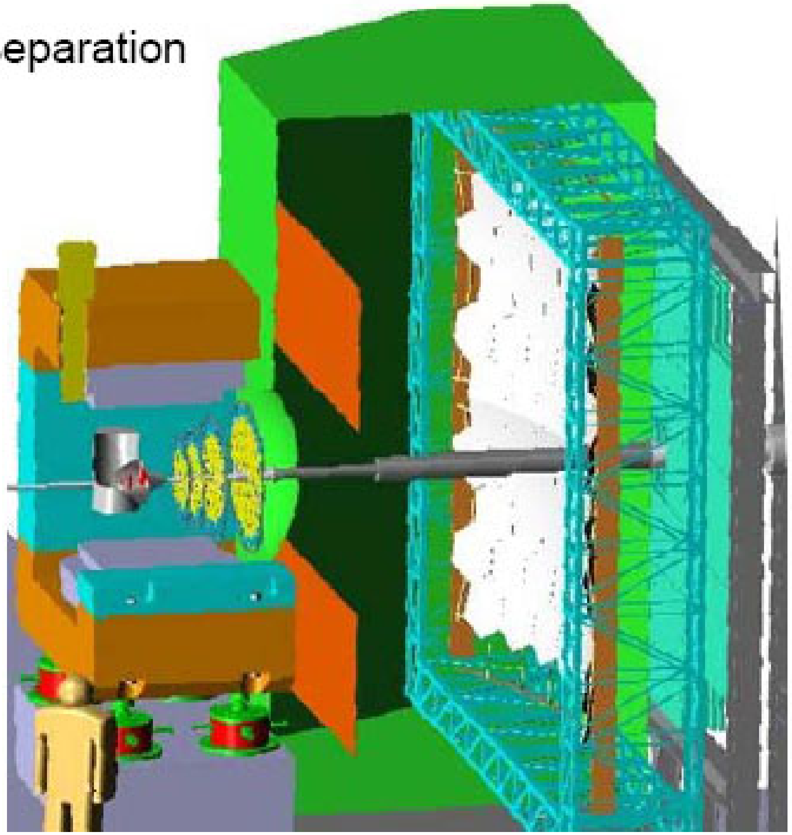
RICH concept (II)

concept

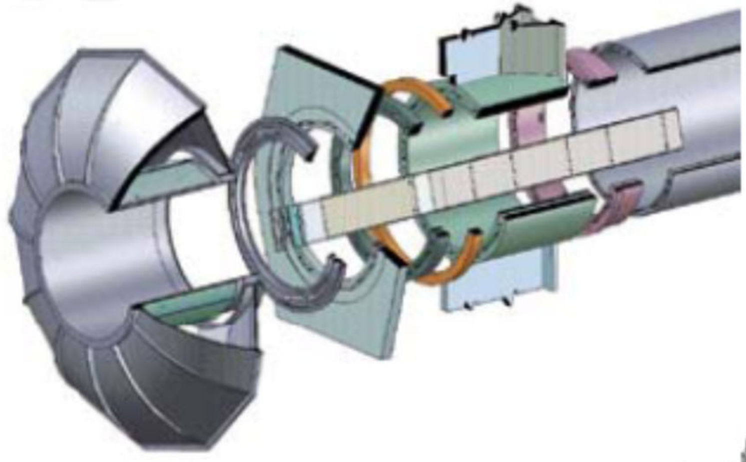
- gaseous RICH detector
- rather high Cherenkov threshold for pions (4.5-6 GeV/c)
  → N_2 radiator (γ_{th}=41, $p_{\pi,th}$=5.6 GeV/c)
- glass mirrors (4-6 mm, R=4.5m) with vertikal separation
  → focus to upper & lower part of CBM
  → photodetector shielded by magnet yoke
- photodetector plane: PMTs
  → MAPMTs
  (e.g. Hamamatsu H8500 with UV windows)
- no further windows

→ Cherenkov photons with $\lambda \geq 200$ nm

→ 2.5 m radiator length (22 hits/ring)

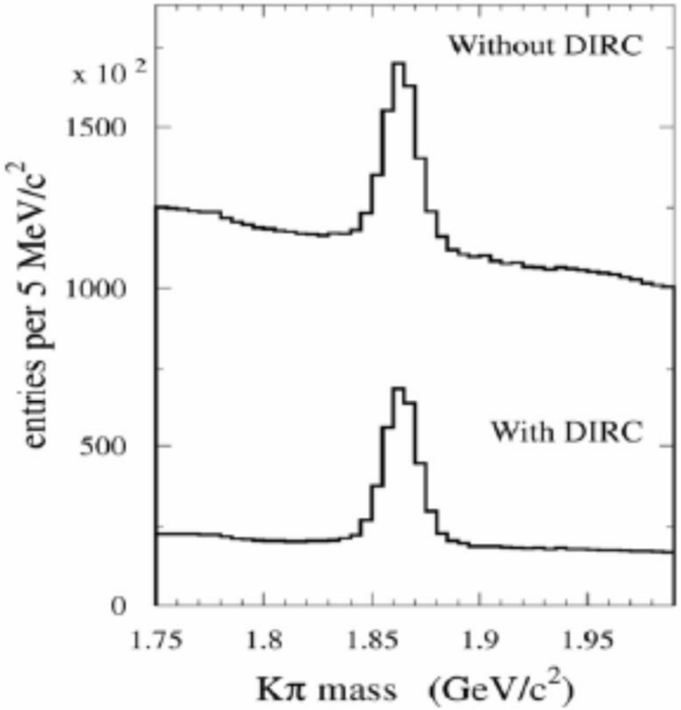


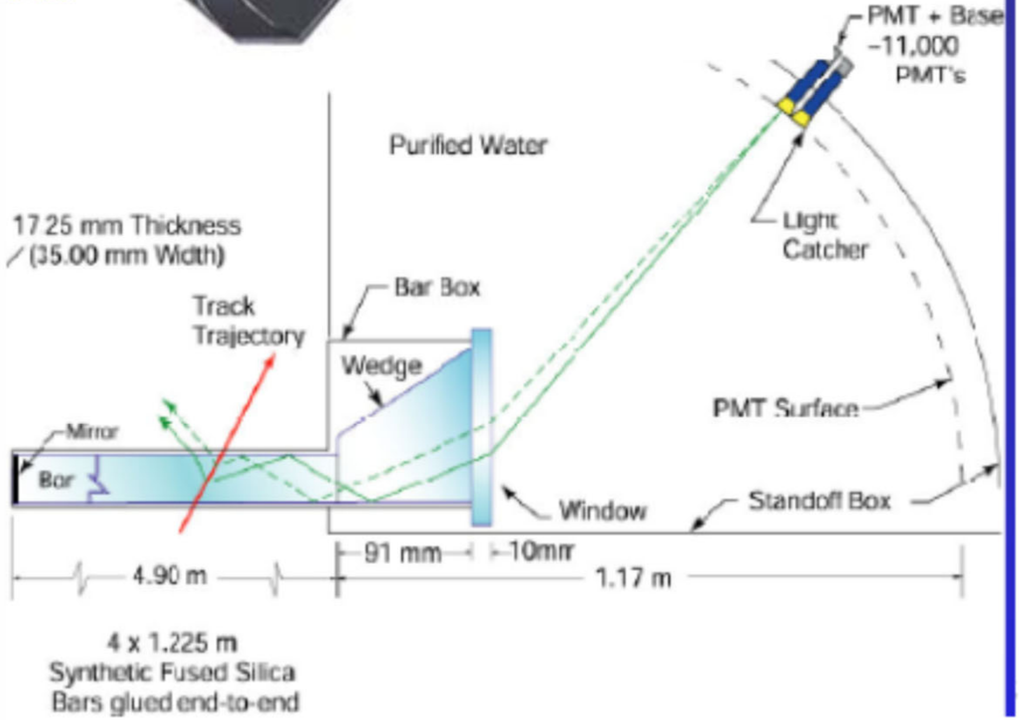
Flavour physics – BABAR DIRC

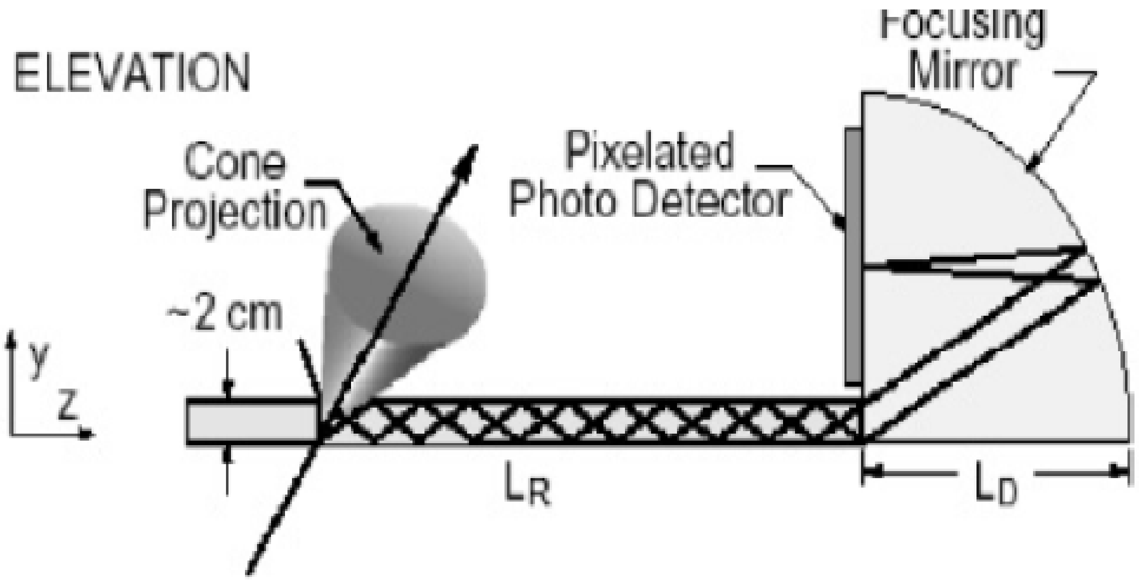


11,000 PMTs: 29mm diameter
π / K separation: 0.5 - 4 GeV/c

N_photons detected > 30 / track
σ_θ < 10 mrad
x 6 reduction in $D^0 \rightarrow K\pi$ backgroun






ELEVATION
Focusing
Mirror
Cone
Projection
Pixelated
Photo Detector
~2 cm
y
z
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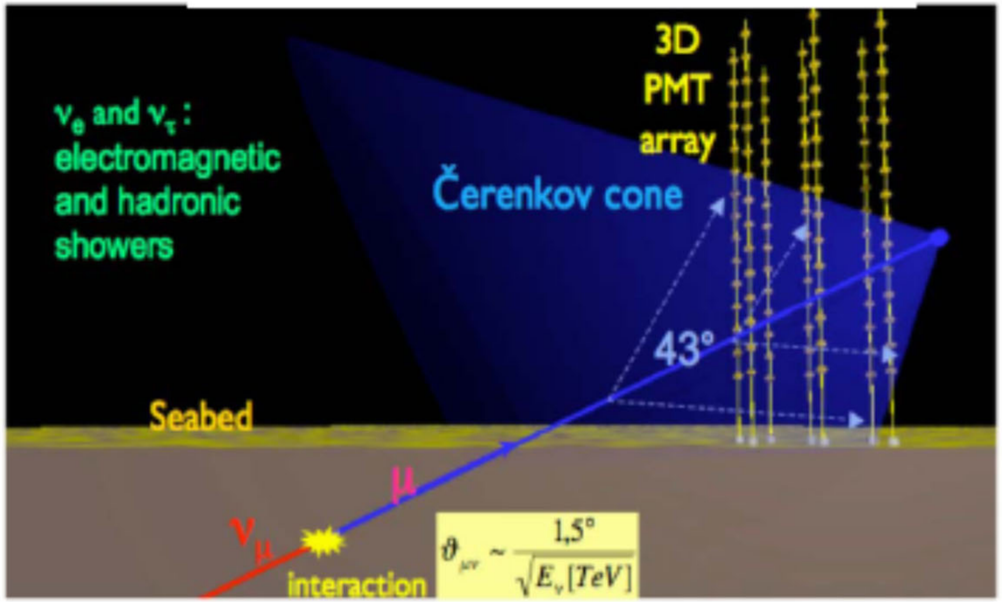
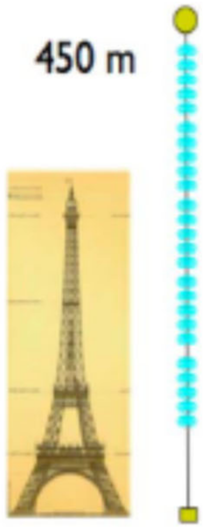
L_D

Neutrino Astronomy ... how ?

Neutrinos can be detected using the visible Cherenkov radiation produced as the high-energy charged lepton (final state of CC interactions) propagates through a transparent medium with superluminal velocity.

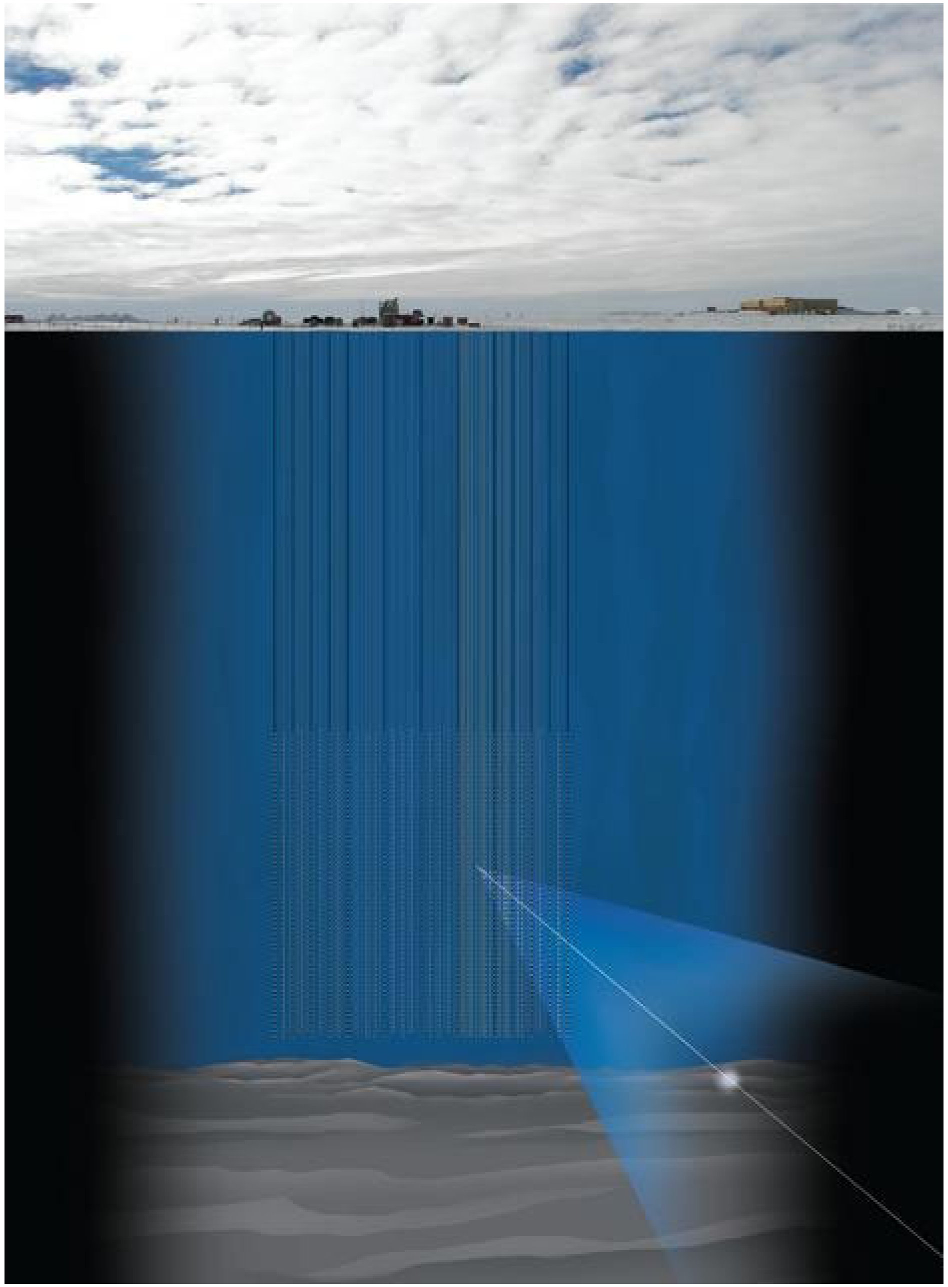




Due to low fluxes expected, cubic-kilometer scale detector are required to perform HE neutrino astronomy (E ~100GeV -10 PeV)→prototype structures currently taking data.

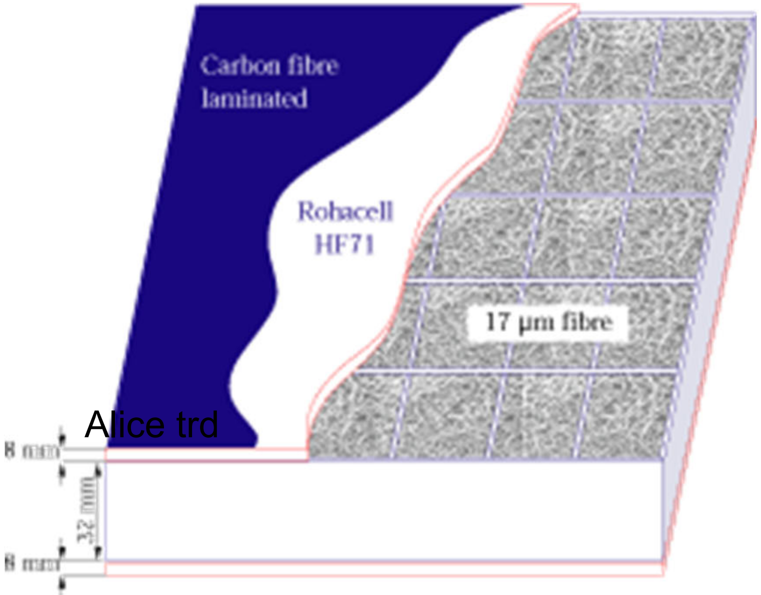
Ice cube
Pictorial event

Selecting events coming from 'below'
(using the earth as a filter/shield)



Transition radiation detectors: the radiator

La radiazione di transizione è emessa quando una particella carica attraversa un mezzo con un indice di rifrazione discontinuo, e.g. alla superfice di separazione fra il vuoto ed un dielettrico.



Energia emessa proporzionale a γ

The radiator is optimized to provide the best compromise between transition radiation yield, radiation thickness and mechanical stability. The final radiator consists of polypropylene fibre mats of 3.2 cm total thickness, sandwiched between two Rohacell foam sheets of 0.8 cm thickness each. The foam is reinforced by carbon fibre sheets with a thickness of 0.1 mm laminated onto the outer surface. The measured radiator performance, with a pion rejection factor of 100 at an electron efficiency of 90%, is as required.