Experimentelle Methoden der Teilchenphysik

Sommersemester 2011/2012

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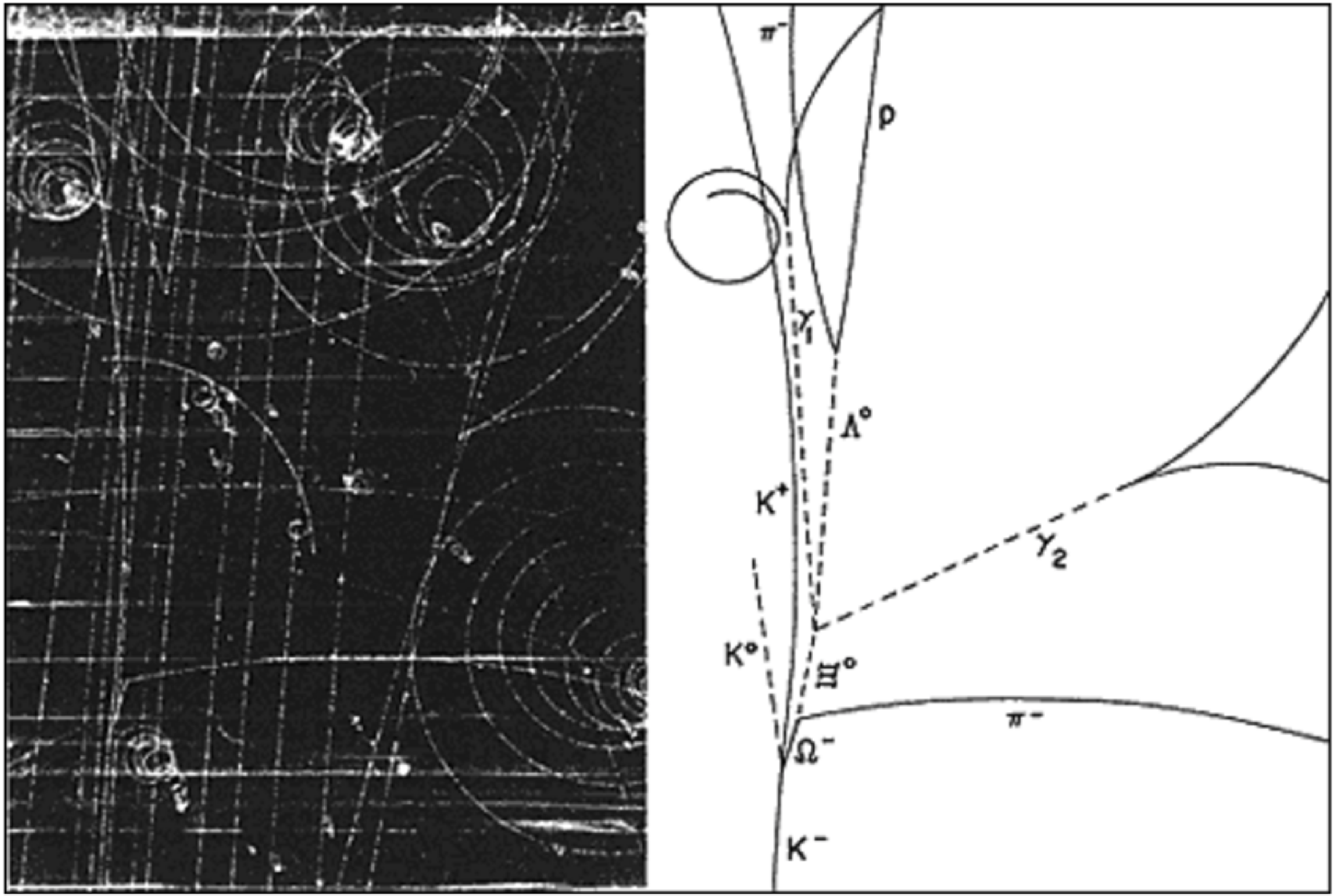
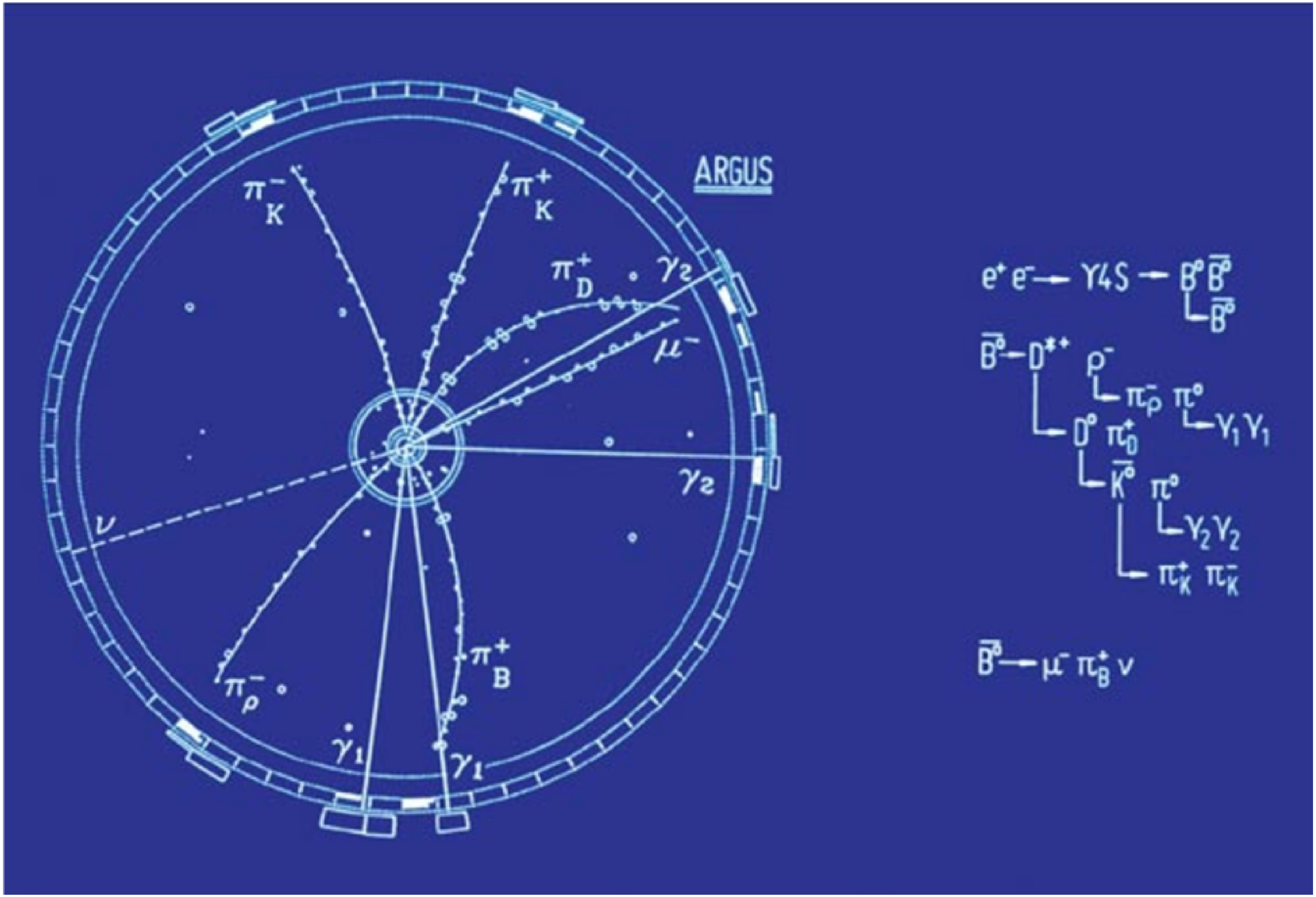
Kapitel 8: Teilchenidentifikation

http://terascale.physik.uni-freiburg.de/lehre/Sommersemester%202012

Entdeckung der Mischung im B-Systems



Entdeckung der Mischung im B-Systems



Identifikation über Laufzeitunterschiede

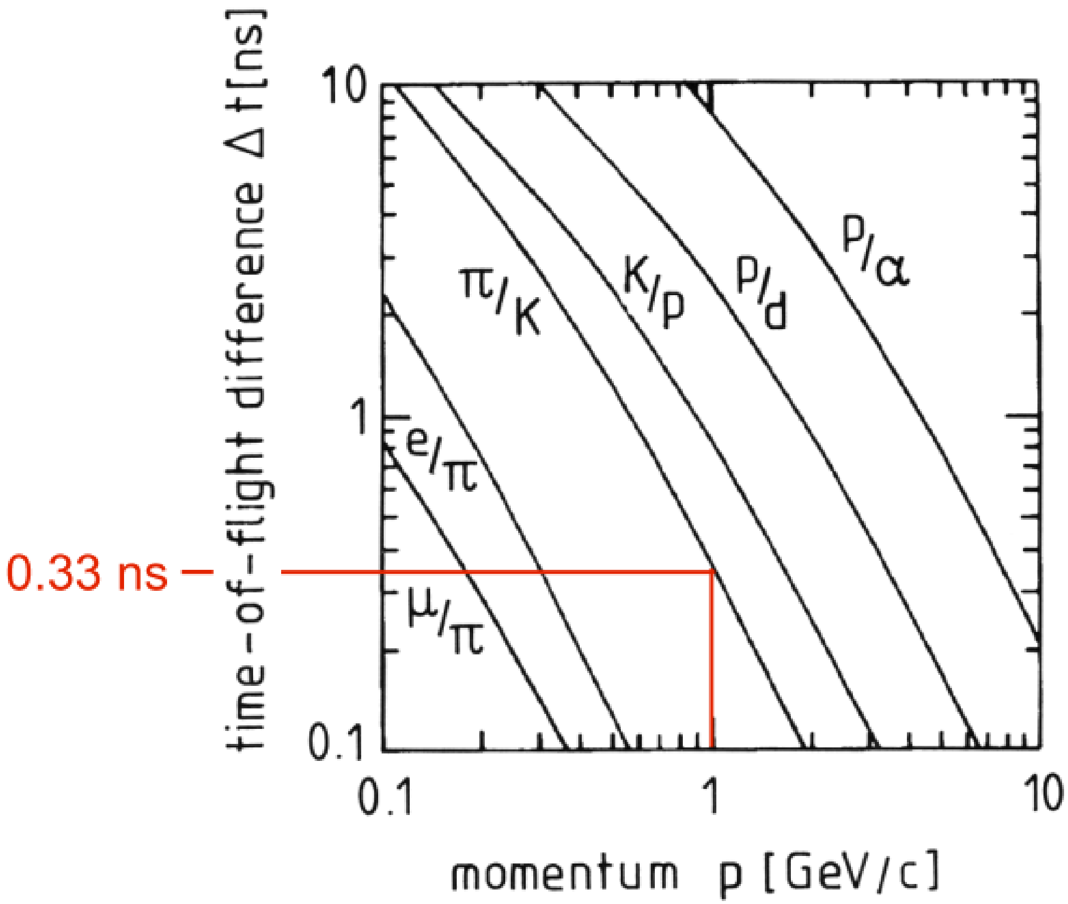
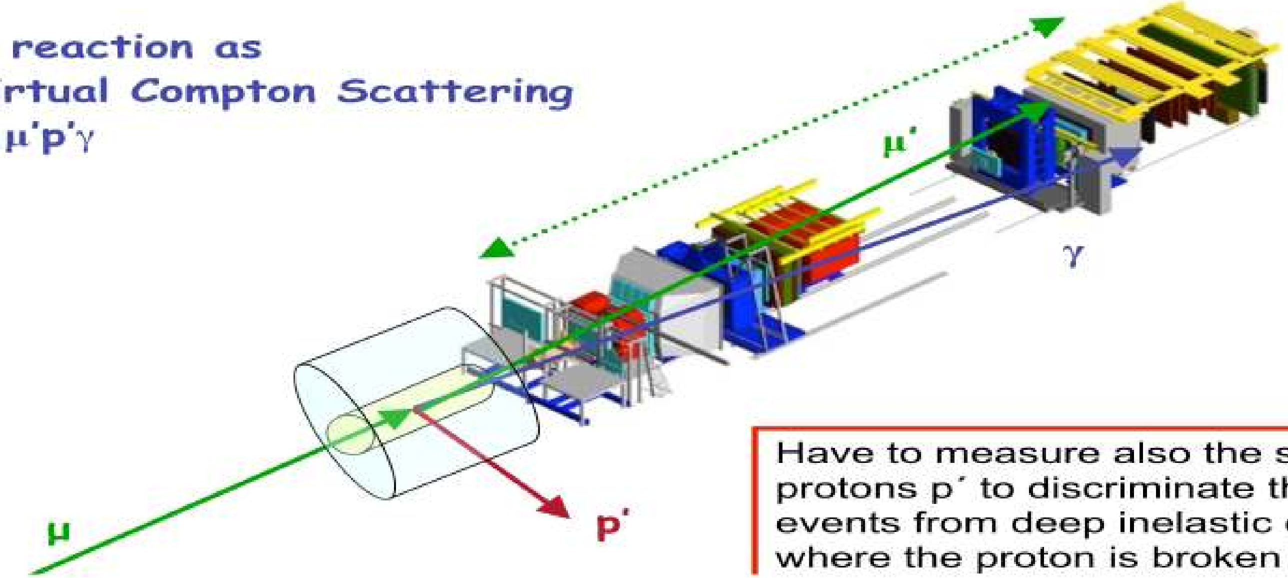


Fig. 6.6. Time-of-flight differences for different pairs of particles for a flight distance of 1 m (after [1]).

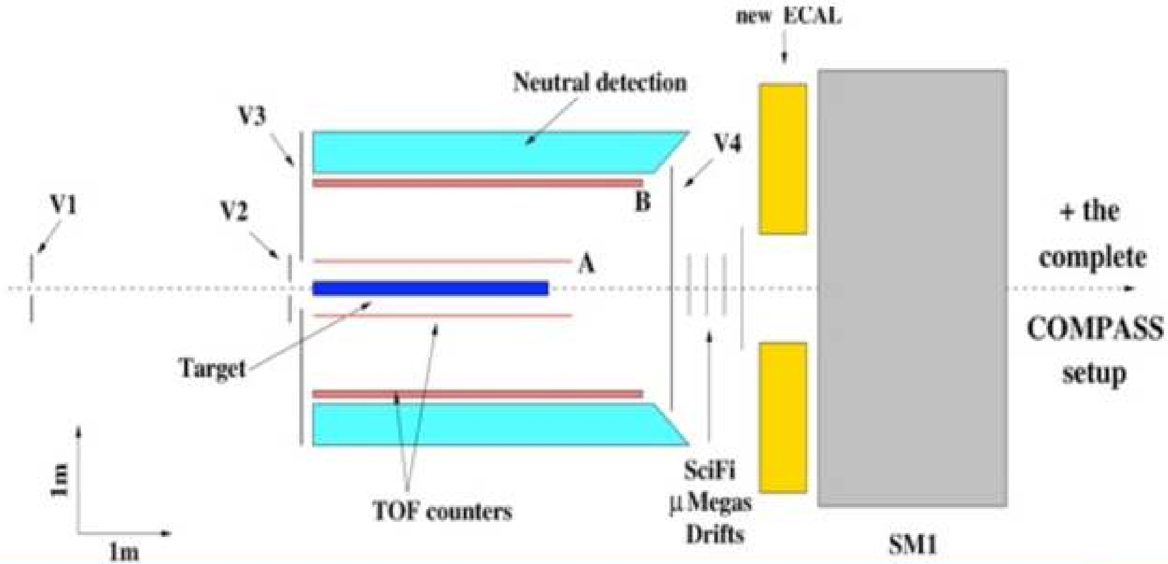
Fulgzeitzähler

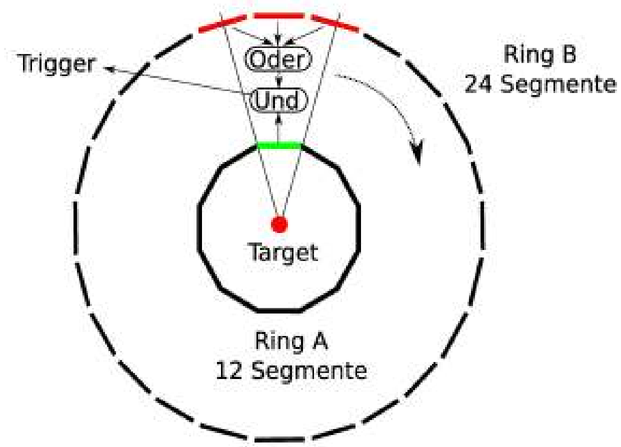
Example: The CAMERA detector of the COMPASS experiment

Exclusive reaction as
Deeply Virtual Compton Scattering
$\mu p \rightarrow \mu' p' \gamma$



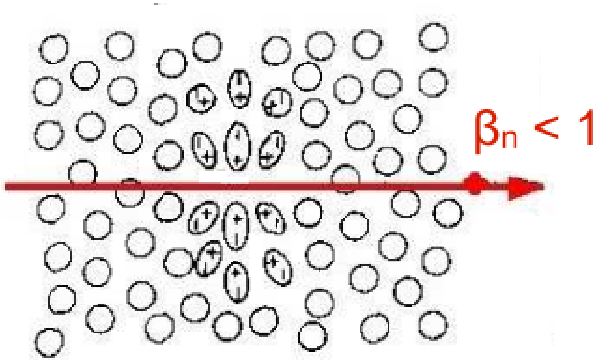
Have to measure also the slow protons p´ to discriminate these events from deep inelastic events where the proton is broken up!

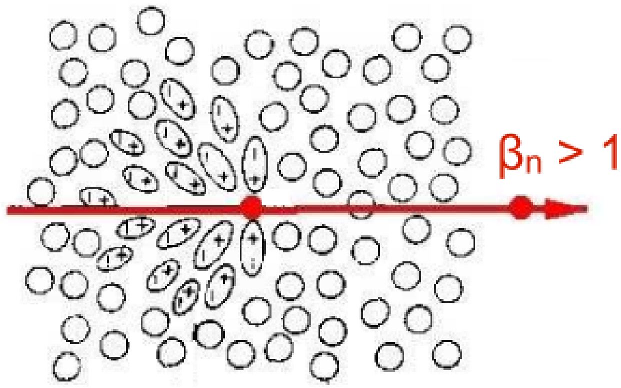




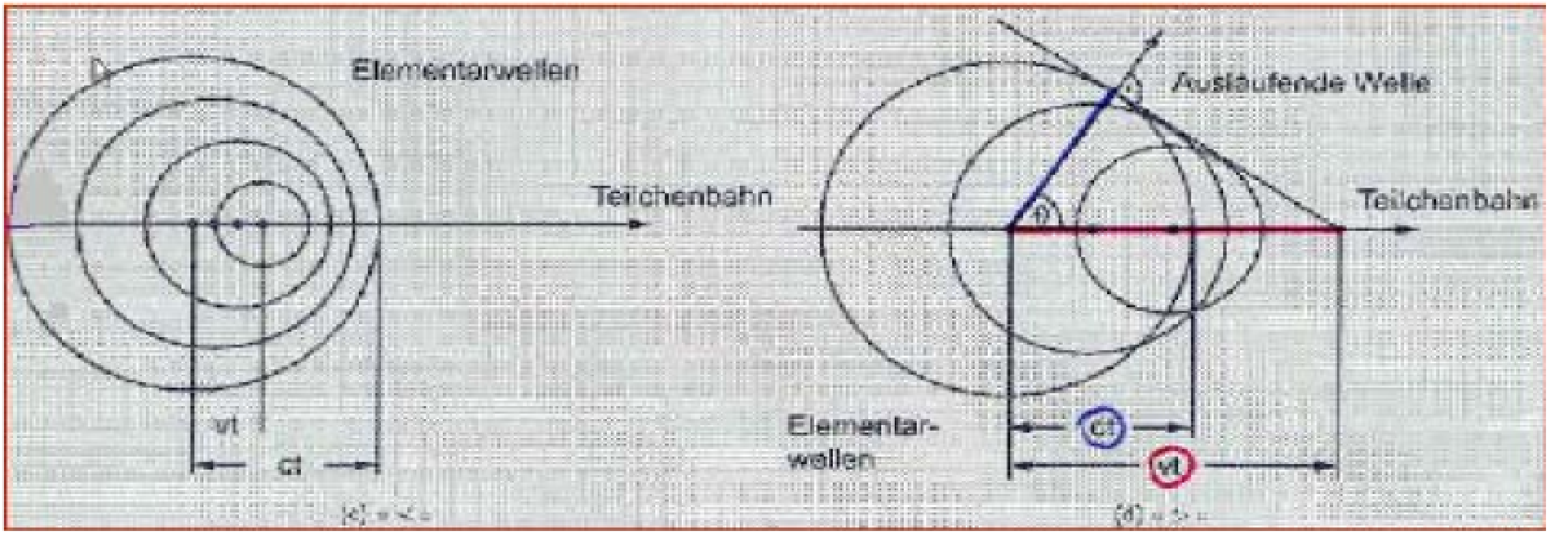
Cerenkov-Effekt

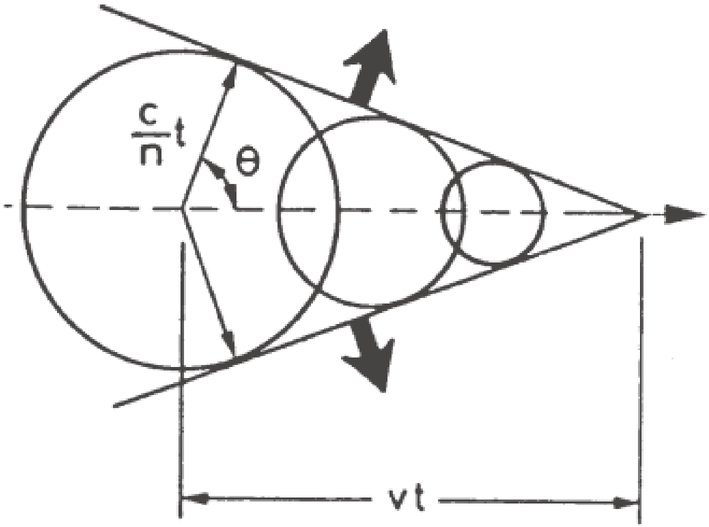
- A moving particle in a medium polarizes the medium
- As long as $\beta_n = v/c_n = n \cdot v/c < 1$ the polarization is symmetric $\Rightarrow$ no resulting dipole moment
- For $\beta_n = v/c_n > 1$ (particle faster as polarization buildup) $\Rightarrow$ dipole moment, at each place changing time $\Rightarrow$ electromagnetic radiation

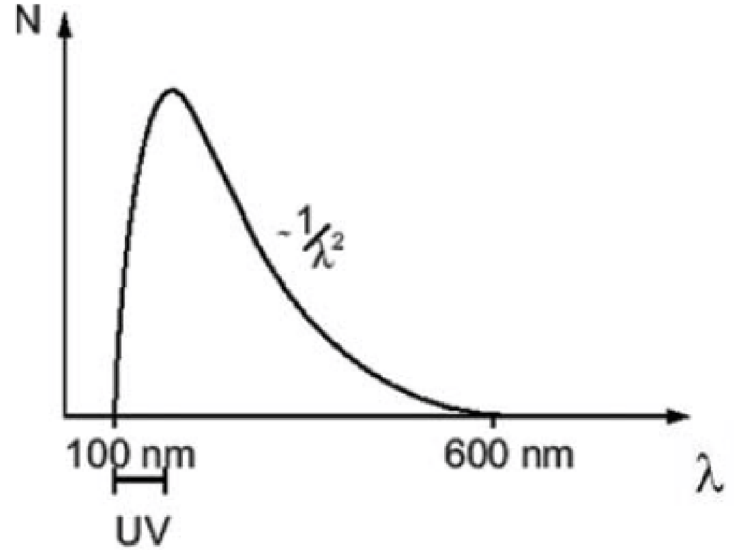




Cerenkovwinkel und Emissionsspektrum



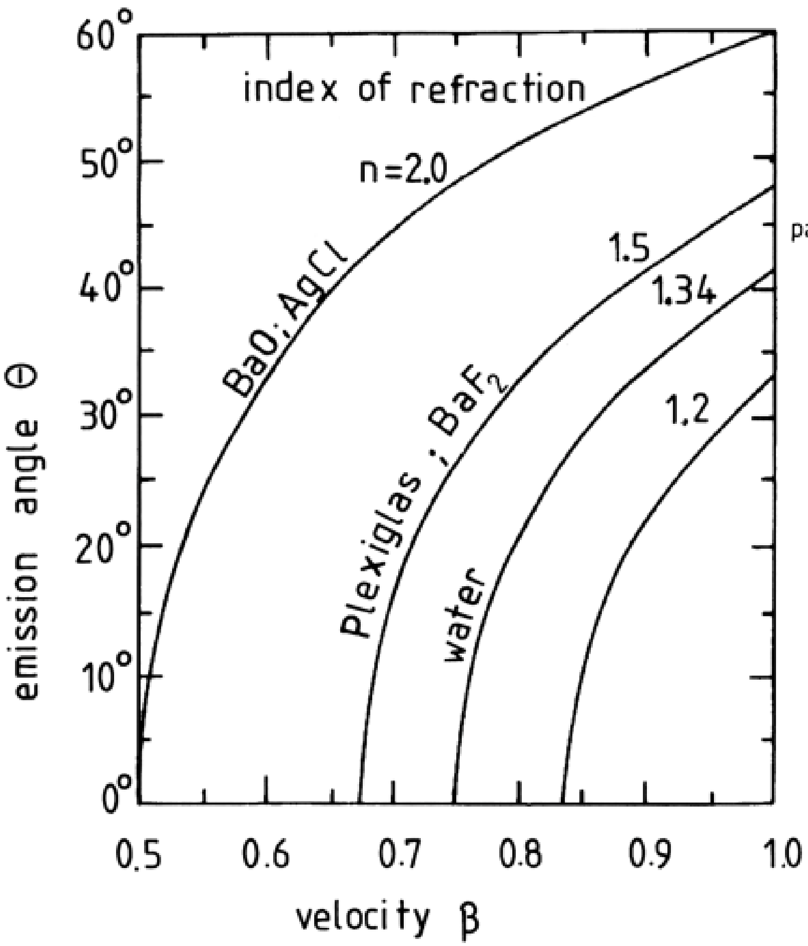


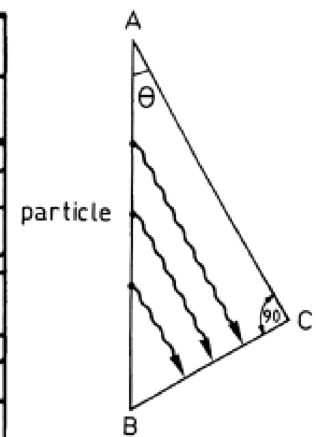


Cerenkovwinkel für unterschiedliche Materialien

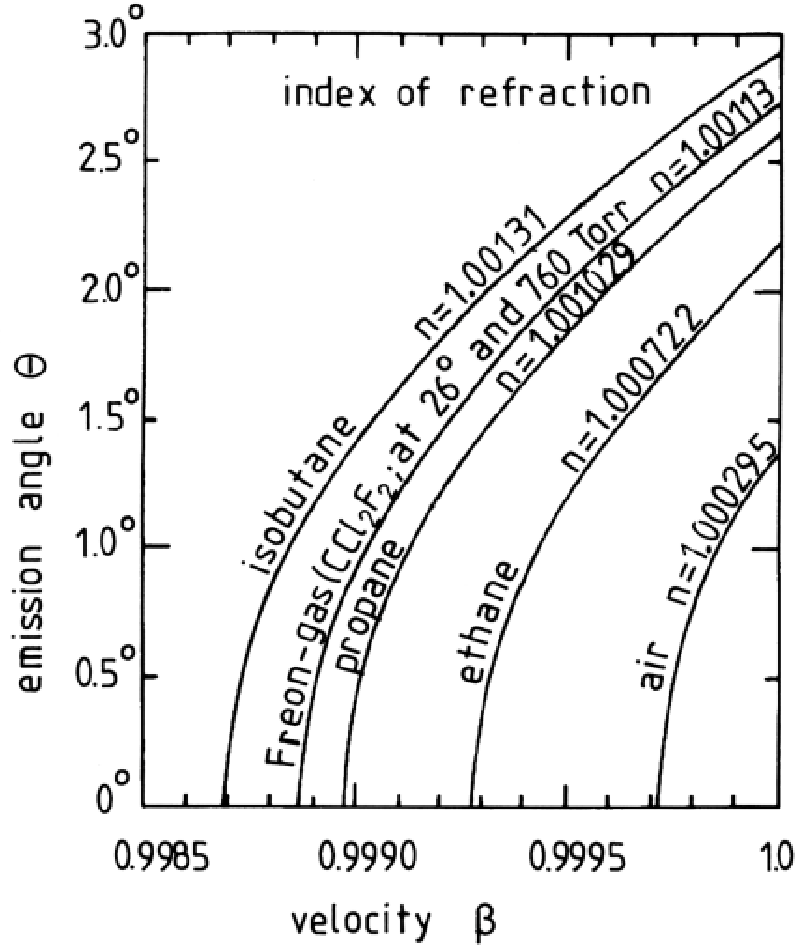
$$\cos\Theta_c = \frac{1}{\beta \cdot n}$$

Solids/Liquids





Gases



Particle discrimination at p = 10 GeV/c:

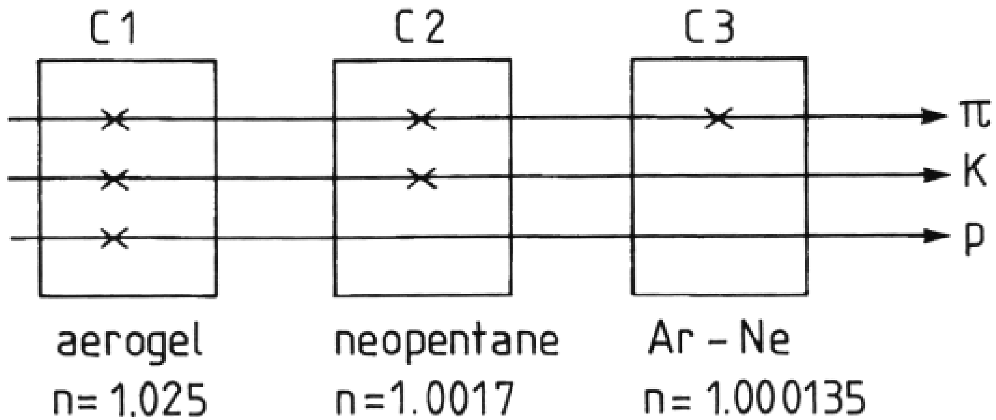


Fig. 6.12. Principle of particle identification by threshold Cherenkov counters (x represents production of Cherenkov photons).

$$\beta = v\,\frac{1}{c} = \frac{p}{m}\frac{c}{c^2} = \frac{(pc)}{E} = \frac{(pc)}{\sqrt{(pc)^2 + (m_0c^2)^2}}$$

	m_0 [GeV]	β	β · n for C1	β · n for C2	β · n for C3
π	0,140	0,99990	1,02490	1,00160	1,00004
K	0,494	0,99878	1,02375	1,00048	0,99892
p	0,938	0,99563	1,02052	0,99732	0,99576

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

$$L = \frac{N_0 p^2}{490 \cdot c^2 \left(m_2^2 - m_1^2\right) \cdot q} \text{ [cm]}$$

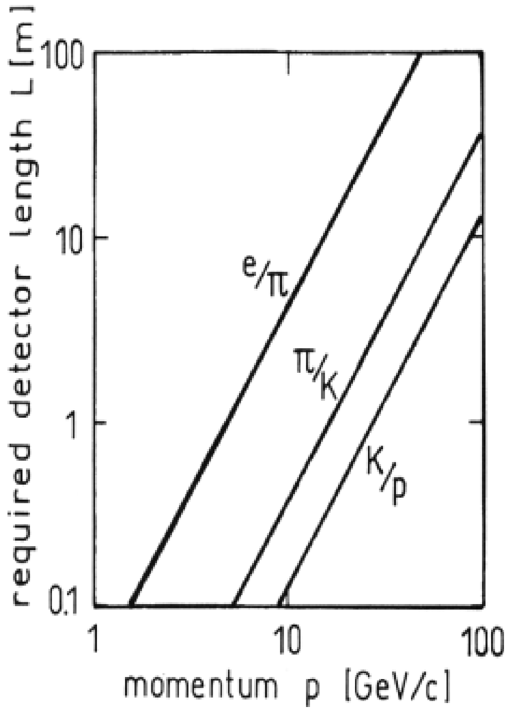


Fig. 6.11. Required detector length for the separation of particle pairs with a threshold Cherenkov counter versus the momentum ($N_0 = 10$, $q = 0.25$) [1, 449].

European Muon Collaboration (CERN 1975-1985) Threshold Cherenkov counter

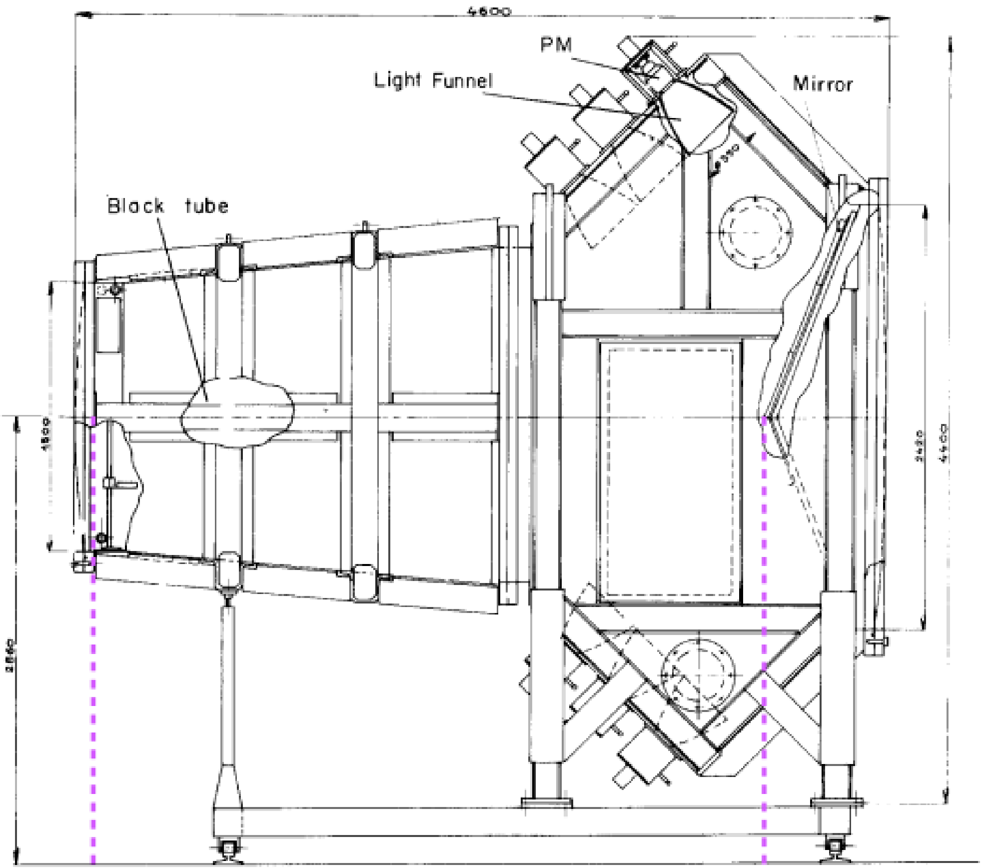


Fig. 1. Side view of the Cherenkov counter. The beam comes from the left.

4m ← length needed to get enough photons!

6(vert.) x 13 (hor.) mirrors on 78 PMs

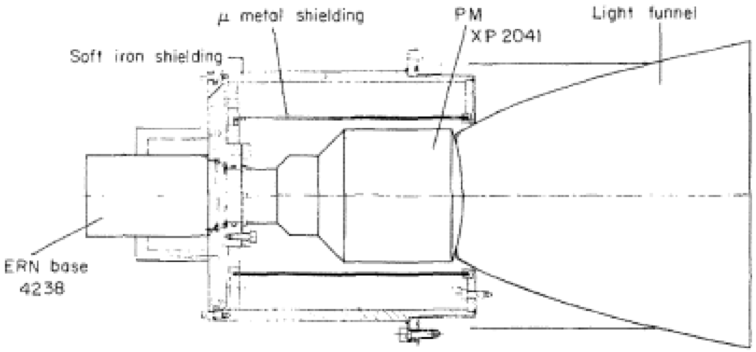


Fig. 2. Photomultiplier housing, showing the light funnel and the magnetic shielding.

Two operation modes:

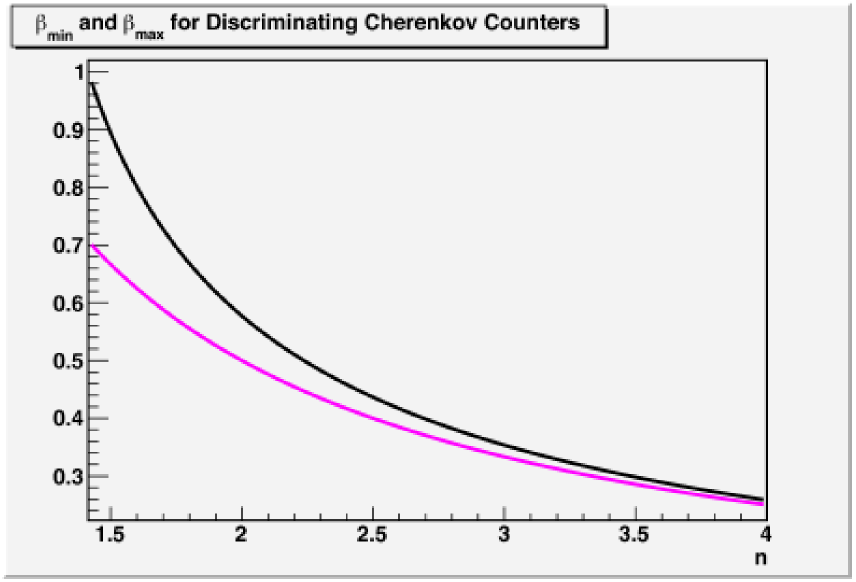
- N_2 (n - 1 = 3 $\cdot 10^{-4}$):
  → π/K separation 6 - 22 GeV/c
- Ne (n - 1 = 0.7$\cdot 10^{-4}$):
  → π/K separation 20 - 70 GeV/c

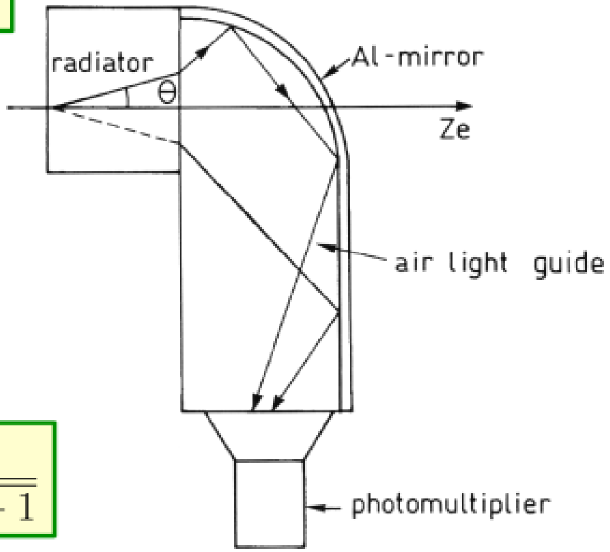
From equation for the the Čerenkov angle: $\cos\Theta_c = \frac{1}{\beta_{\min}\cdot n} = 1 \quad\rightarrow\quad \boxed{\beta_{\min} = \frac{1}{n}}$

From refraction (Snell´s law): $\frac{\sin\Theta_c}{\sin 90^\circ} = \frac{1}{n} \quad\rightarrow\quad 1-\cos^2\Theta_c = \frac{1}{n^2} \quad\rightarrow\quad 1-\frac{1}{\beta^2_{\max}\cdot n^2} = \frac{1}{n^2}$

$$\rightarrow\quad \beta^2_{\max}\left(1-\frac{1}{n^2}\right) = \frac{1}{n^2} \quad\rightarrow\quad \beta^2_{\max} = \frac{1}{n^2-1}$$

$$\rightarrow\quad \boxed{\beta_{\max} = \frac{1}{\sqrt{n^2-1}}}$$





Then the PM will only see a signal if $\boxed{\frac{1}{n} < \beta < \frac{1}{\sqrt{n^2-1}}}$

Differentieller Cerenkovzähler (1)

A different method for a **differential** Čerenkov detector:

- Focus the parallel Čerenkov radiation and select Θ_C^{min} and Θ_C^{max} by a suitable diaphragm
- can be further improved by chromaticity corrections: „Differential Isochronous Self-collimating Counter" = DISC
- has been used in the construction of the CERN „CEDAR = Čerenkov Differential Counters with Achromatic Ring focus"

Some specifications for CEDAR counters

	CEDAR-W	CEDAR-N
Momentum range	15-150 GeV/c	30-340 GeV/c
Velocity resolution* $\Delta\beta/\beta$	5×10^{-6}	10^{-6}
Radiator gas	nitrogen	helium
Working pressure	1.6^{-8} bars	10^{-14} bars
Cerenkov angle	30.8 mrad	25.8 mrad
Pressure control accuracy	10^{-3}	3×10^{-4}
Temperature uniformity	0.3°C	0.1°C
Overall length	6.2 m	6.2 m

*) These values correspond to the π/K difference at top momentum

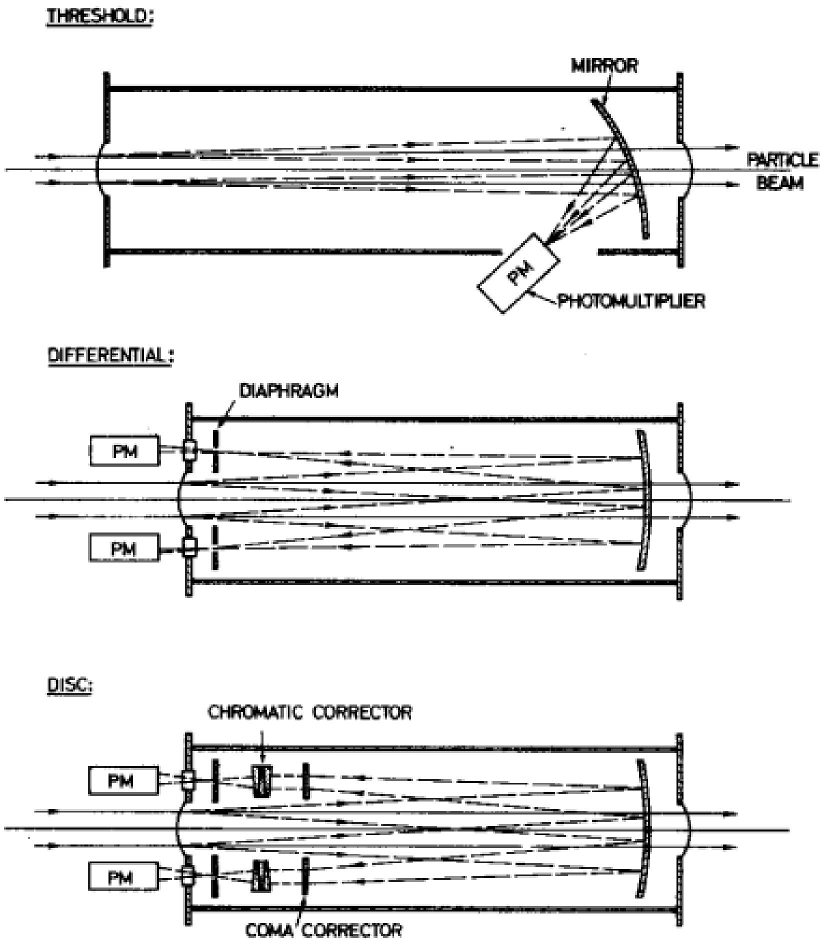
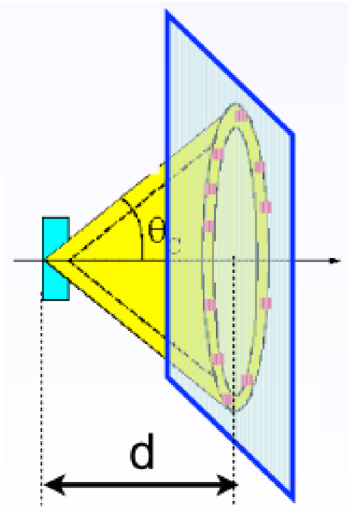


Fig. 1. A schematic drawing of the main items in a threshold, a differential and a DISC type of Cherenkov counter. These instruments are used to identify high-energy charged particles.

Ring Imaging Čerenkov counter (RICH)



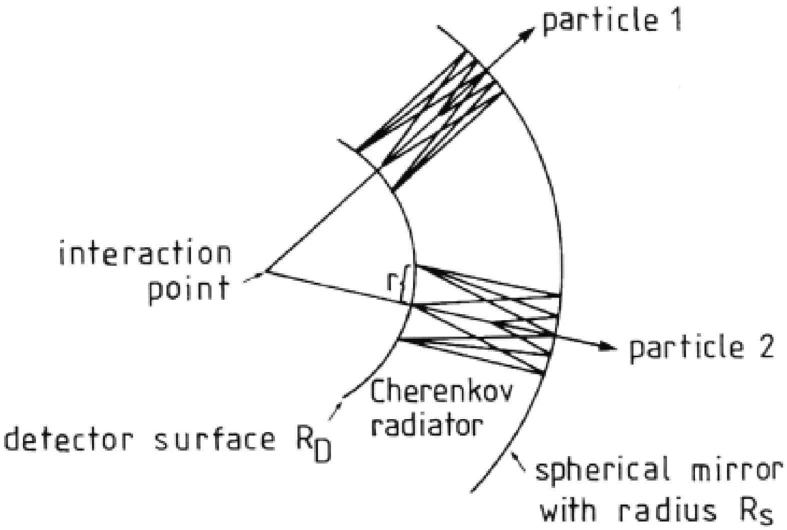


Fig. 6.14. Working principle of a RICH counter [450].

Thin radiator ⇒ Δr small ≈ 0

Radius of Čerenkov ring r:

$r = \tan \Theta_c \cdot d$

Thick radiator ⇒ need focusing

Focus of spherical mirror: $f = R_S/2$

⇒ parallel Čerenkov light is **focused** at $R_D = R_S/2$

Radius of Čerenkov ring r:

$$r = f \cdot \Theta_c = \frac{R_S}{2} \cdot \Theta_c$$

from which:

$$\cos \Theta_c = \frac{1}{n\beta} \quad \rightarrow \quad \beta = \frac{1}{n \cos\left(\frac{2r}{R_S}\right)}$$

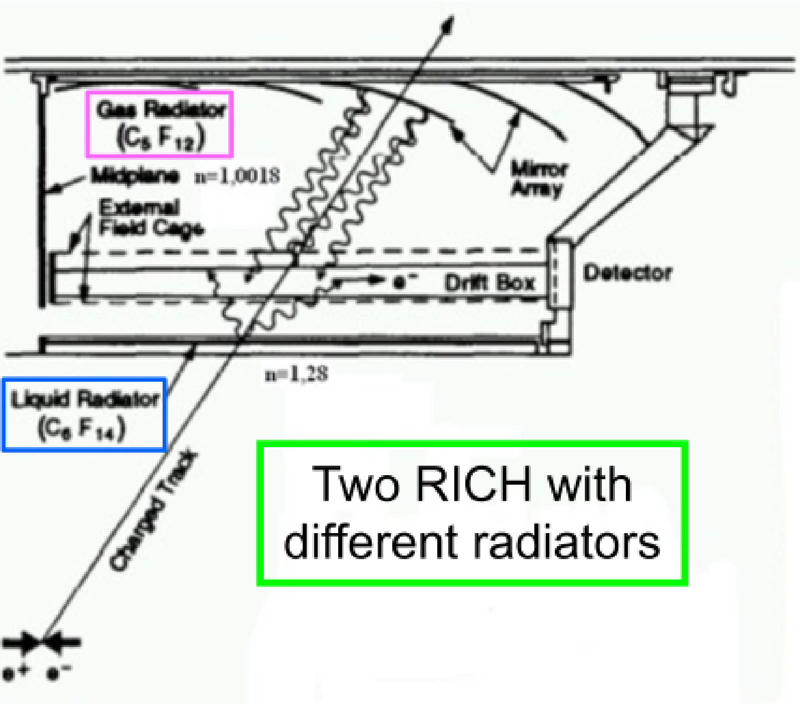
Ring Imaging Čerenkov counter (RICH)

$$\cos\Theta_c = \frac{1}{n\beta} \quad \rightarrow \quad \beta = \frac{1}{n\cos\left(\frac{2r}{R_S}\right)}$$

$$\Theta_c = \arccos\left(\frac{1}{n\beta}\right) = \arccos\left(\frac{1}{n}\cdot\frac{E}{p}\right)$$

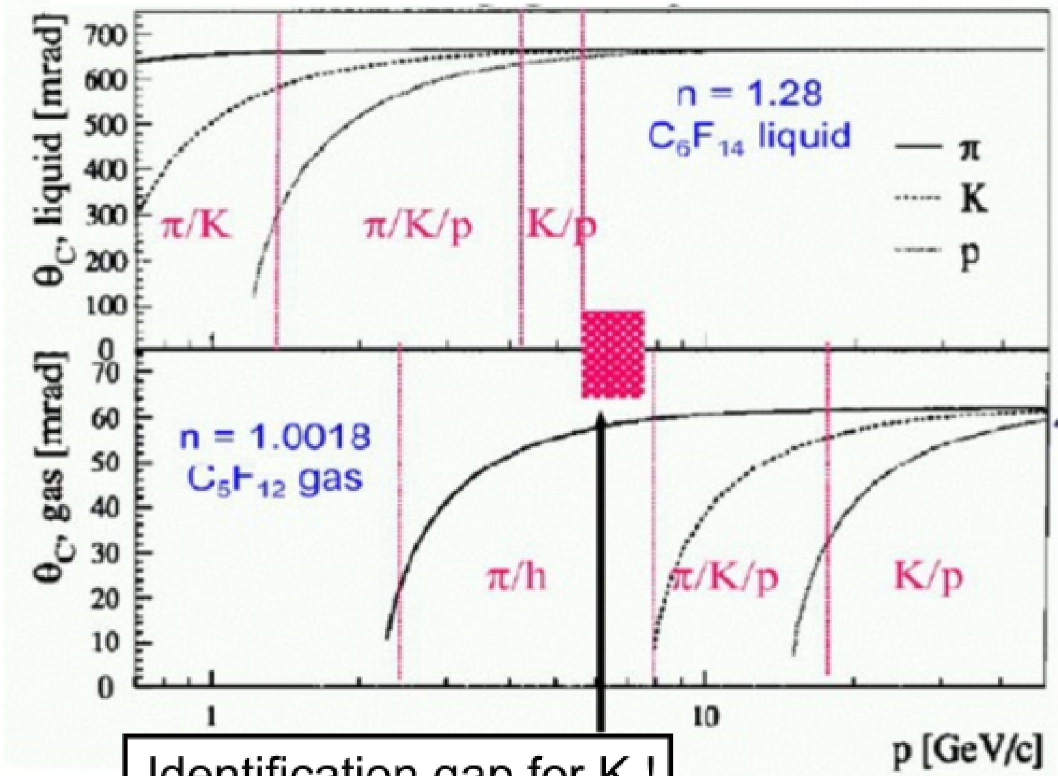
$$\Theta_c = \arccos\left(\frac{1}{n}\cdot\frac{\sqrt{p^2+m^2}}{p}\right)$$

DELPHI (LEP)



Two RICH with different radiators

Čerenkov angle versus momentum:

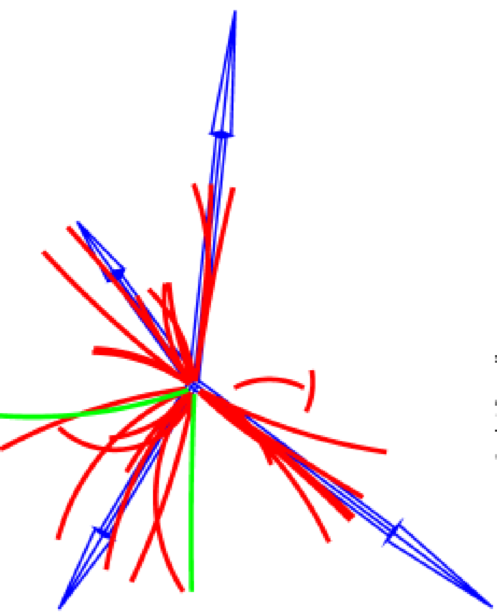


Identification gap for K !

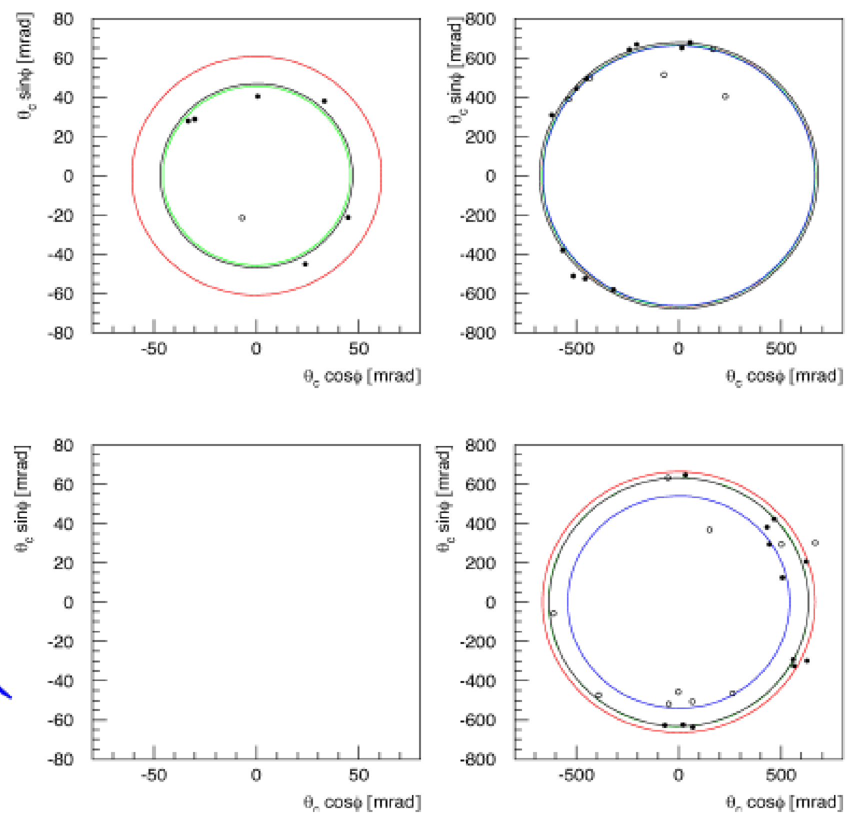
All ring imaging Čerenkov counters need a **large area photon detector!**

The biggest problem of the RICH is the **number of photons!**

Example: DELPHI RICH at 161 GeV beam energy



4 Jet Event



Kaon 11.8 GeV/c

Gas Radiator: Ring Identification
Liquid Radiator: Ambigous

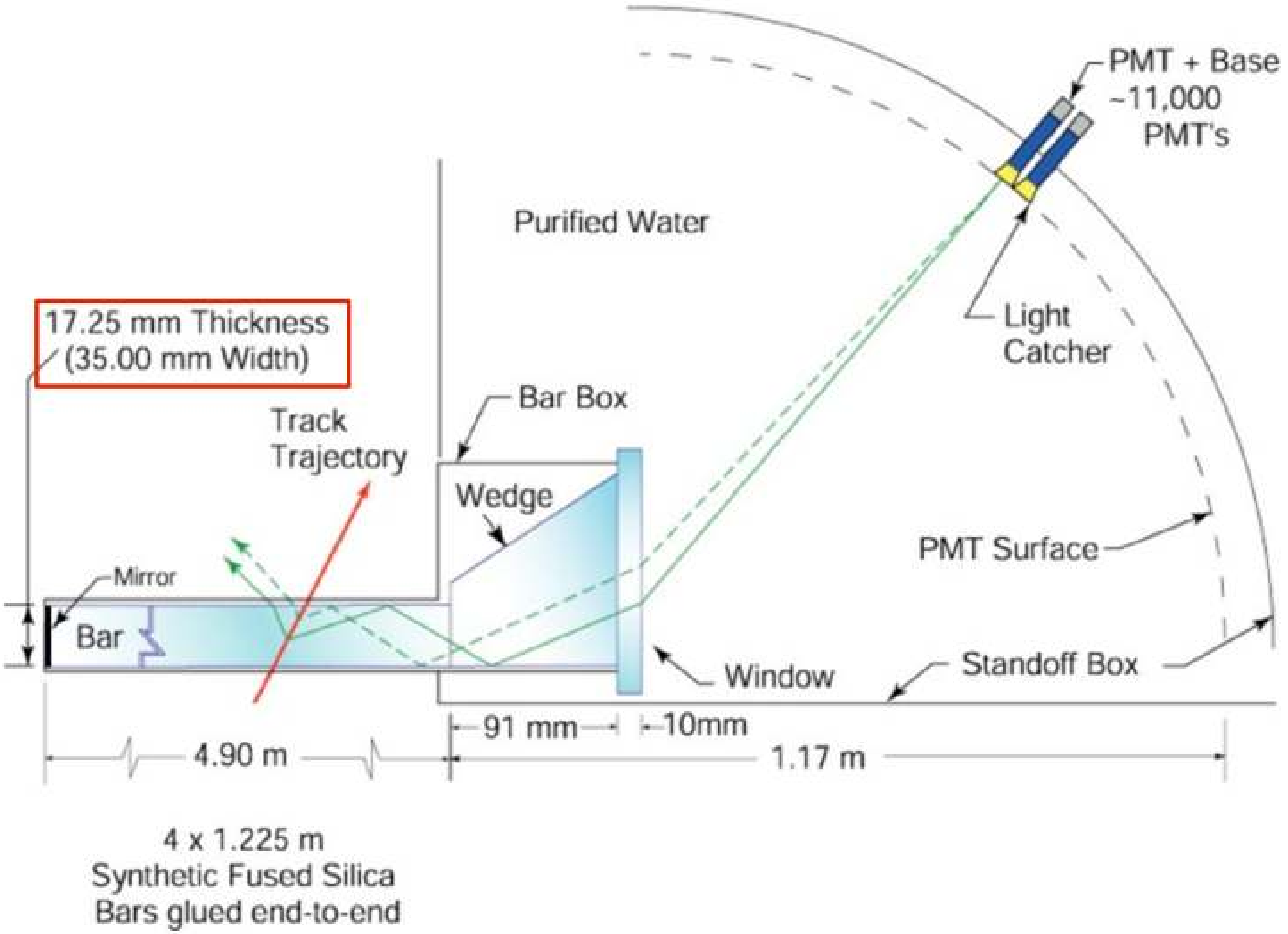
Kaon 2.2 GeV/c

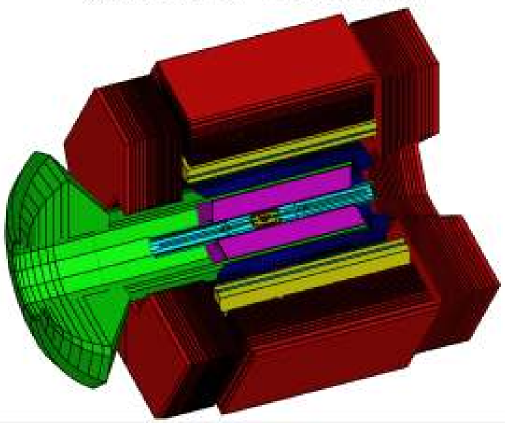
Gas Radiator: Veto Identification
Liquid Radiator: Ring Identification

DIRC-Beispiel: BABAR

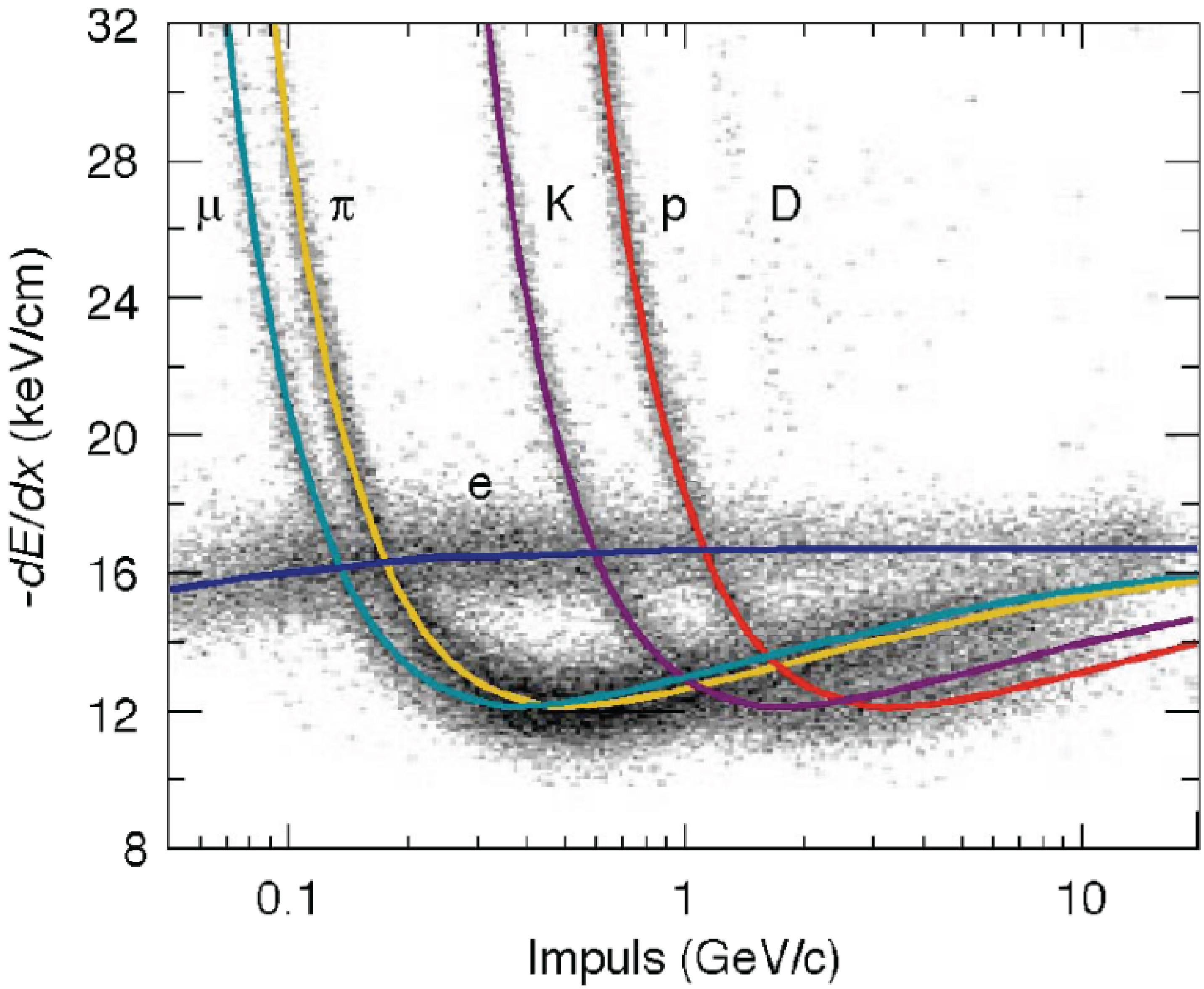
Detection of Internally Reflected Cherenkov light (DIRC)

- Invented by the **BABAR** experiment at SLAC
- Principle: use Čerenkov medium as a light guide
- Advantages :
  - small size of detection volume
  - photon detector outside of core detector volume

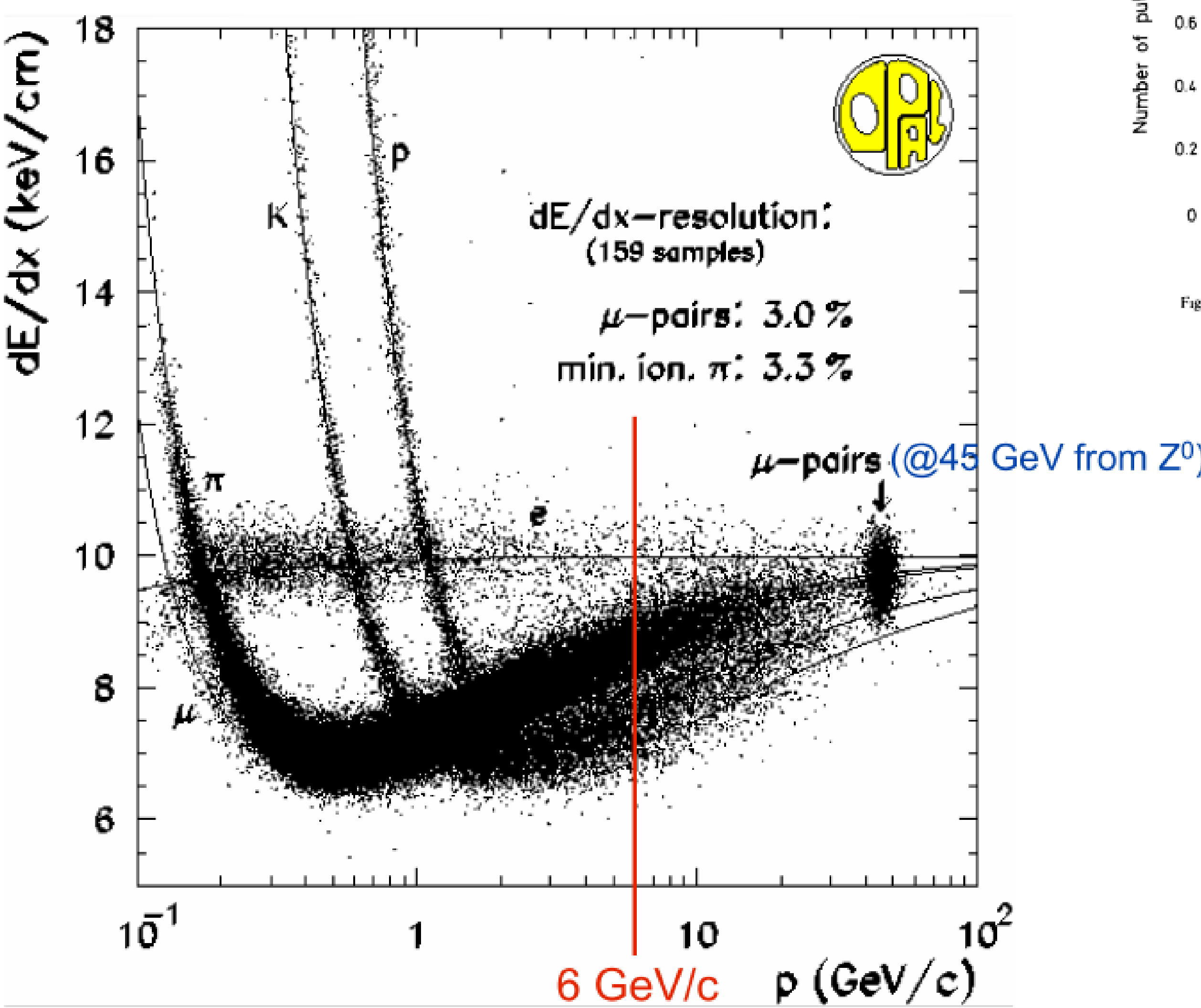




Identifikation über spez. Energieverlust



OPAL Jet drift chamber performance



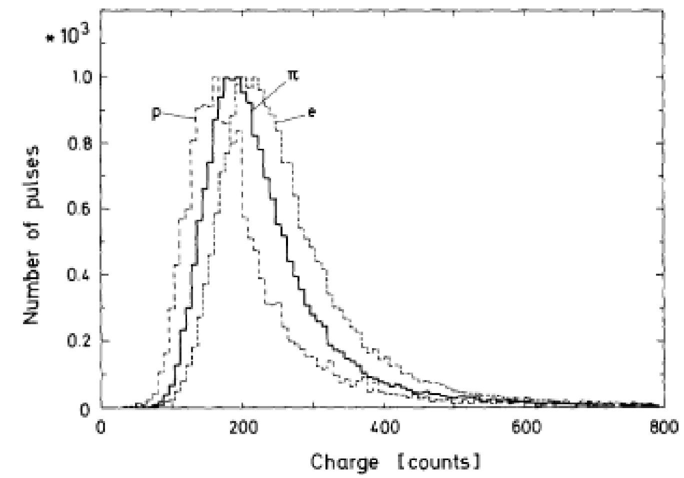


Fig. 3. Measured charge distributions for protons, pions and electrons at 6 GeV/c

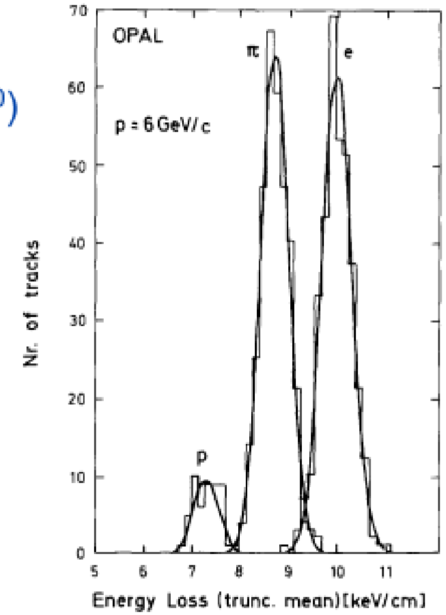
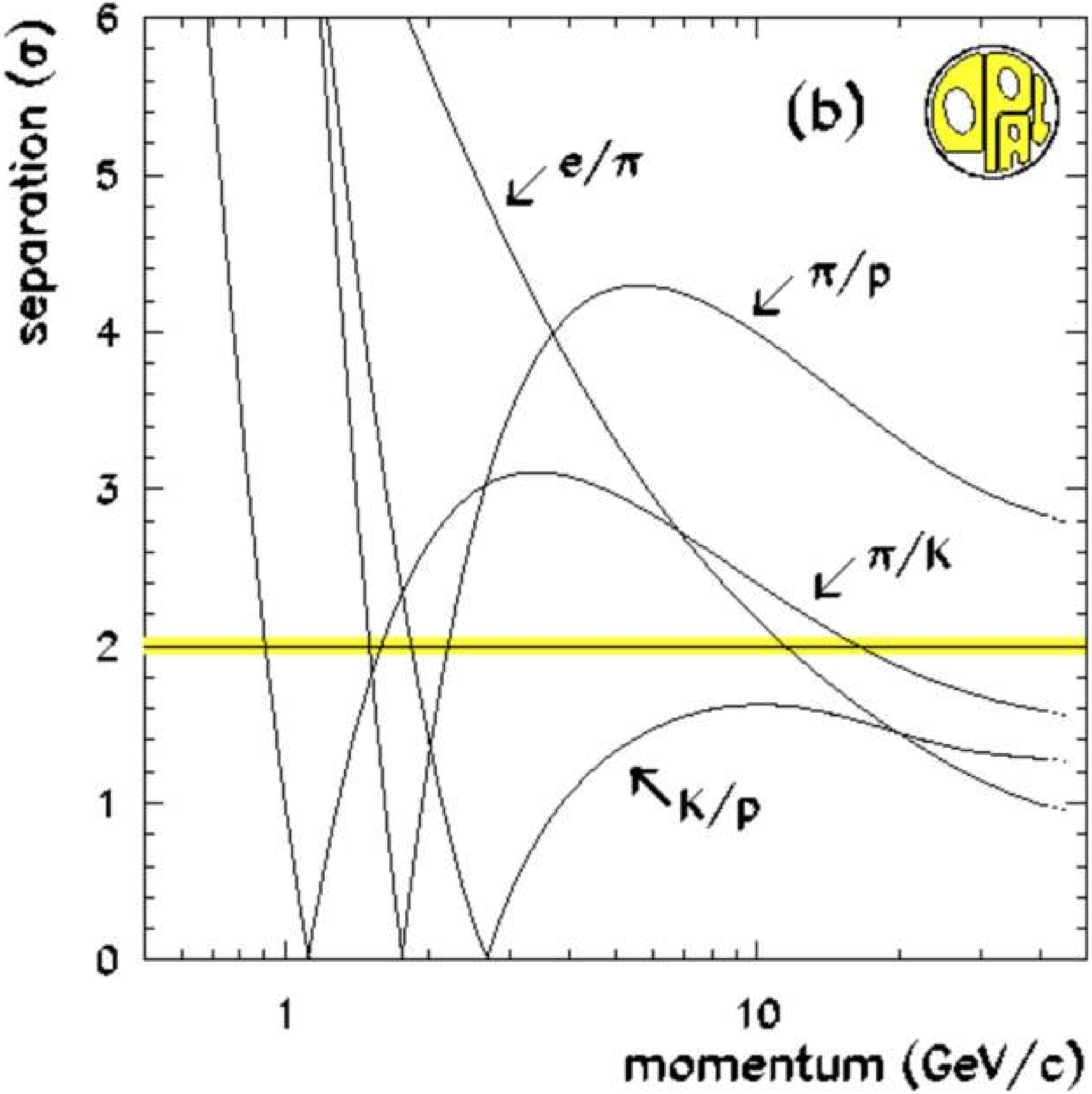
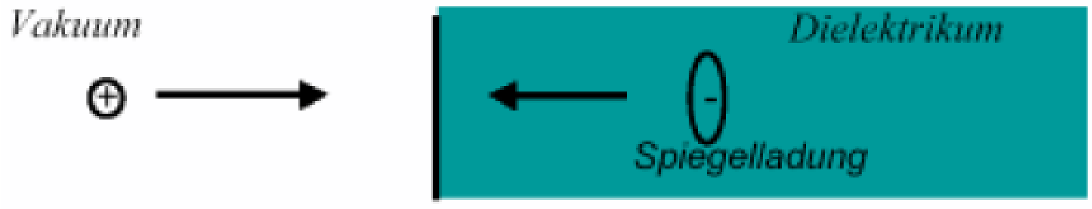


Fig. 12. Measured truncated mean of protons, pions and electrons at 6 GeV/c.

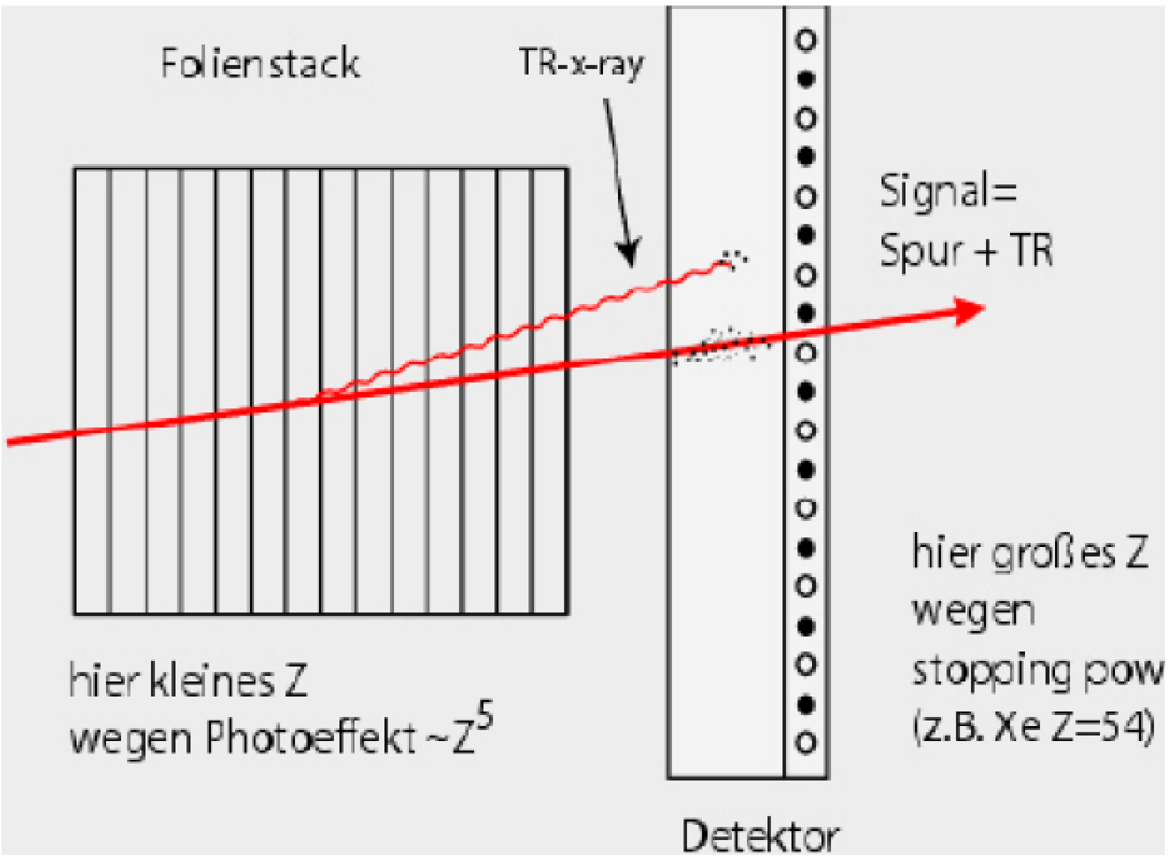
Identifikation über spez. Energieverlust



Übergangsstrahlungsdetektor

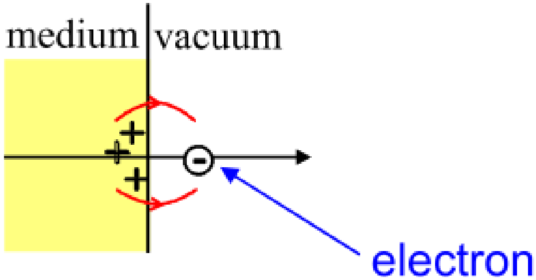


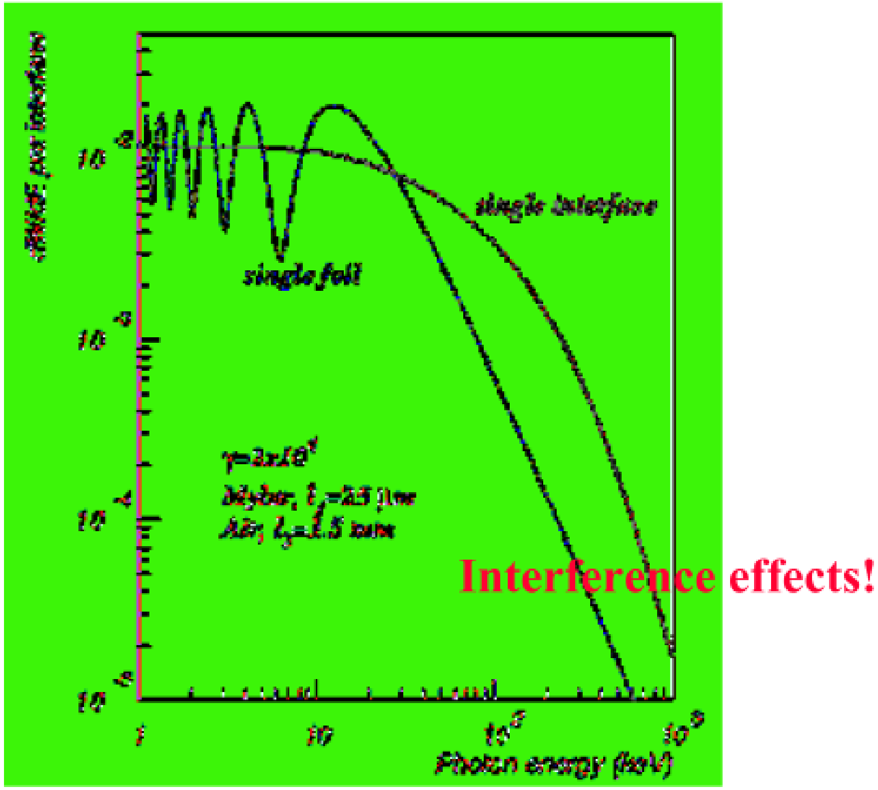
$$\theta = \frac{1}{\gamma_{Teilchen}}$$



Übergangsstrahlung

- Electron polarizes the medium temporarily at the boundary (also for $\beta < 1/n$!)
- Changing dipole moment („plasma oscillations") leads to radiation





<u>Characteristics:</u>

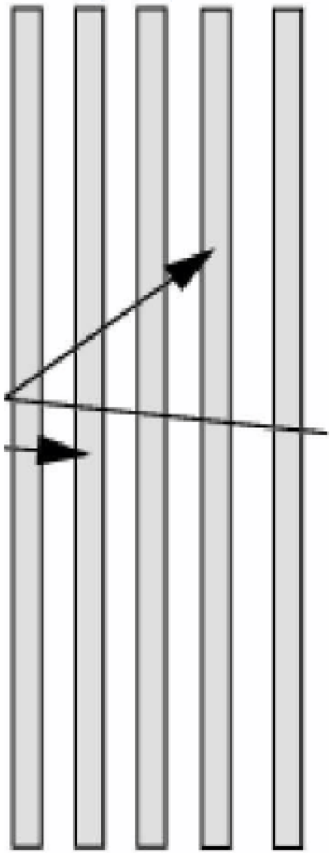
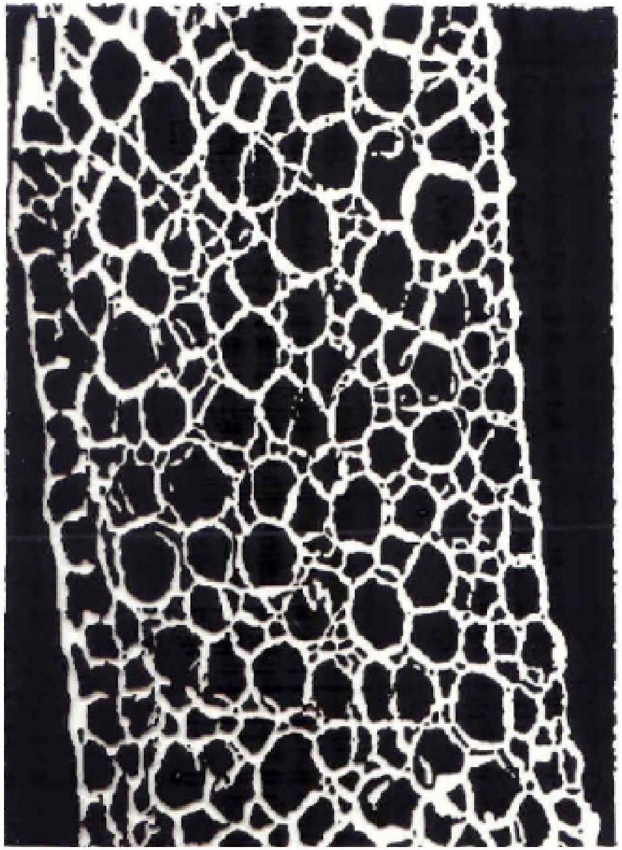
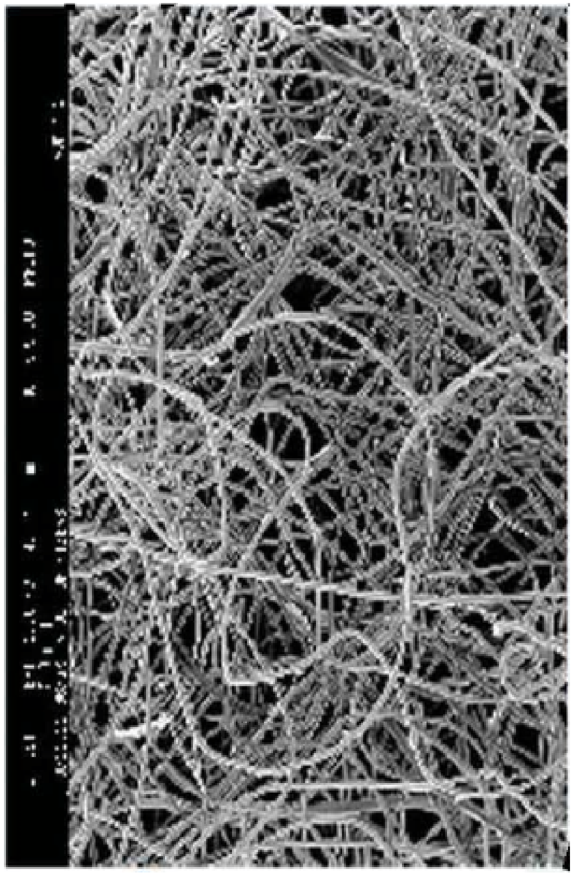
Forward emission: $\Theta \lesssim 1/\gamma$

Radiation energy per passage: $W = \frac{1}{3}\alpha\hbar\omega_P\gamma \propto \gamma$

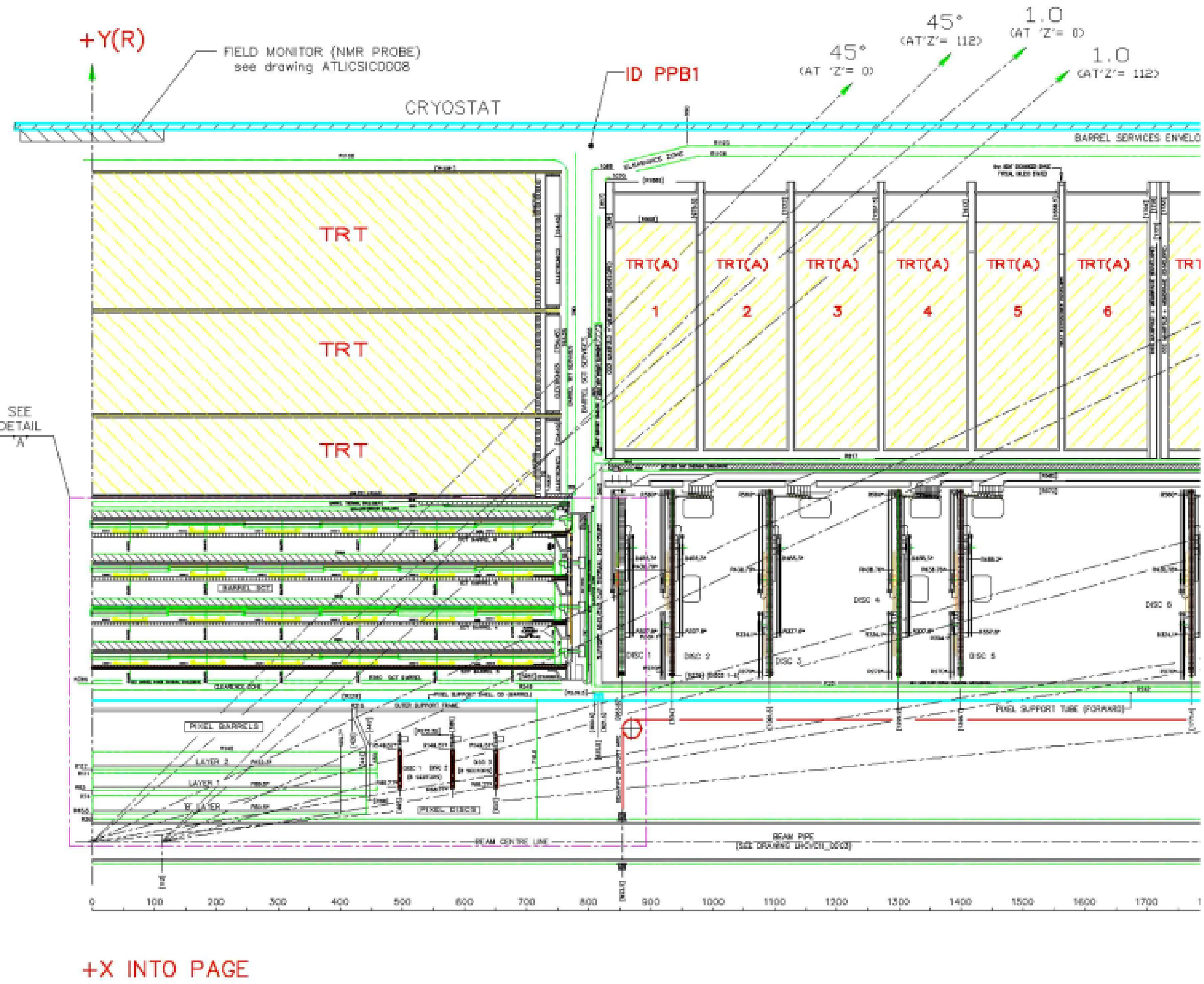
with: $\omega_P = \sqrt{\frac{4\pi\alpha n_e}{m_e}} = 28.8\sqrt{\rho\frac{Z}{A}}\ \mathrm{eV}$

Small number of photons: $N_\gamma \approx \frac{W}{\hbar\omega} \approx \alpha = \frac{1}{137}$

$\Rightarrow$ need $\gamma \gtrsim 10^4$ and multiple foils

Foils	Foam	Fibers
		

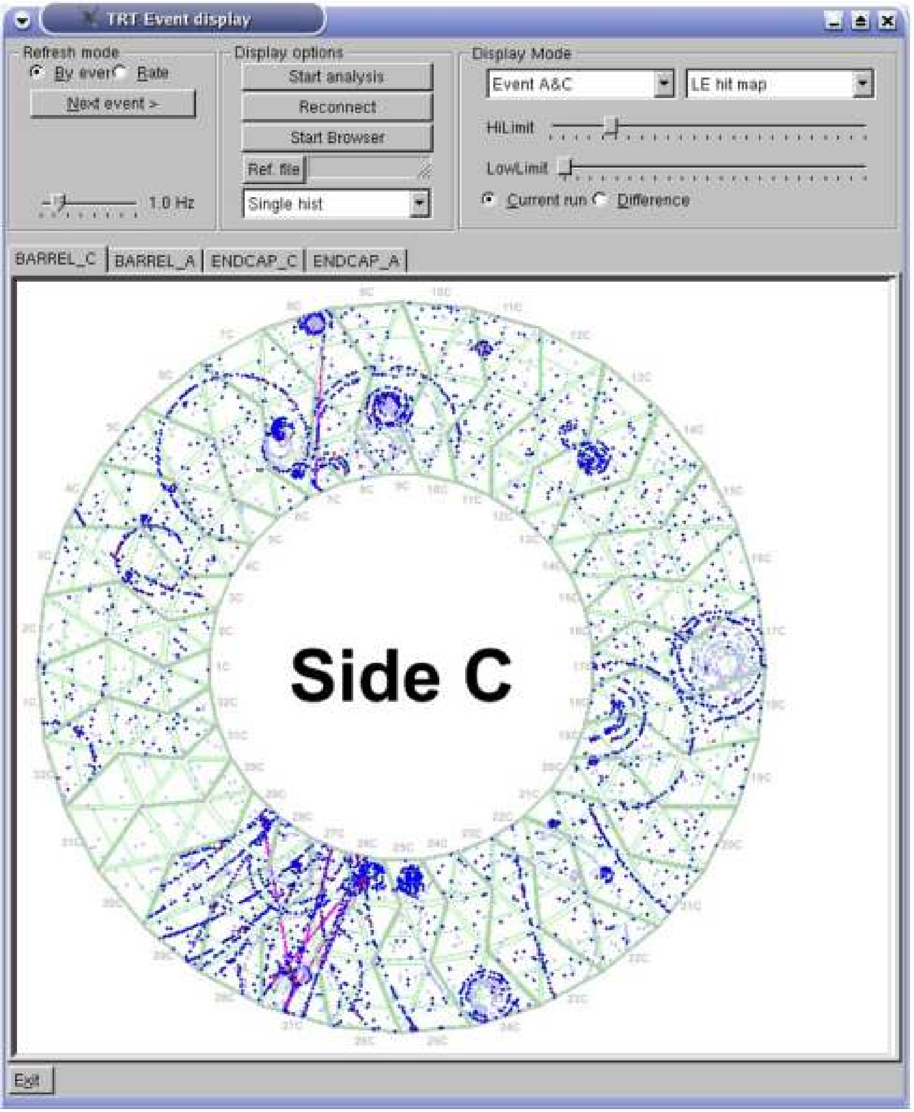
ATLAS Übergangstrahlungsdetektor

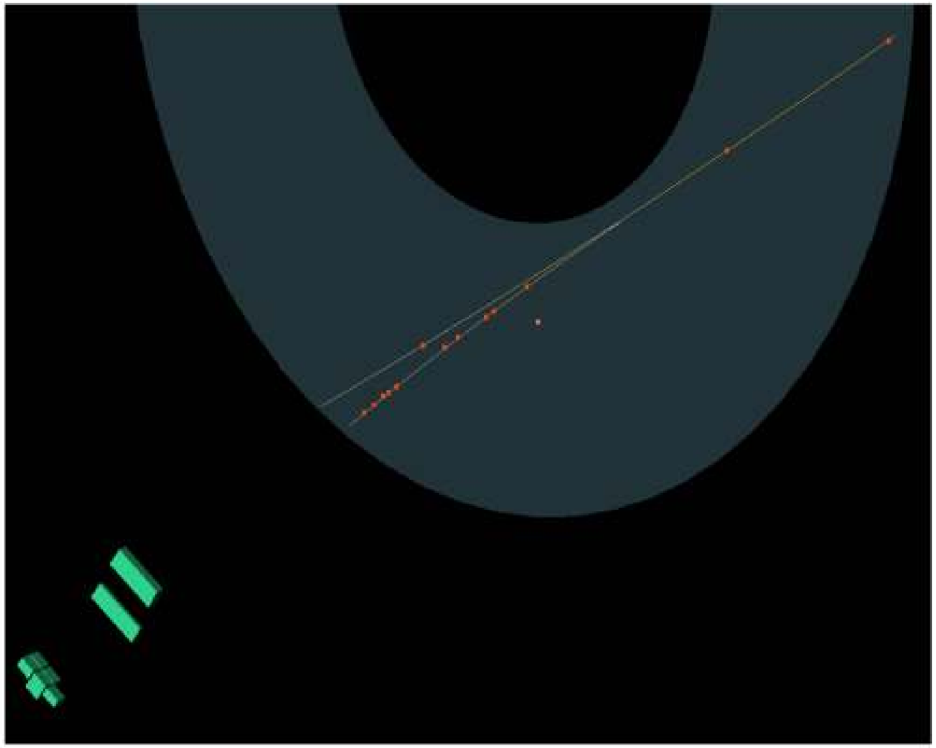


TRT = Transition Radiation Tracker

Combination of tracker and transition radiation detector

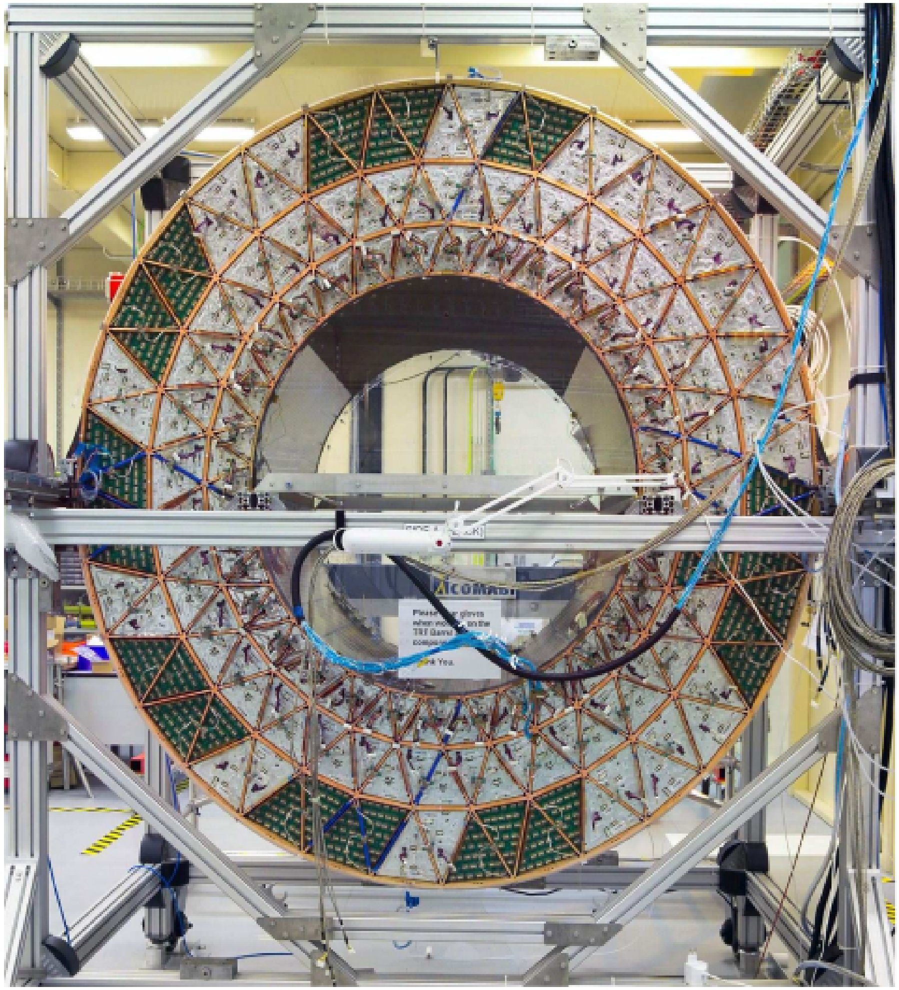
Spuren im ATLAs TRT

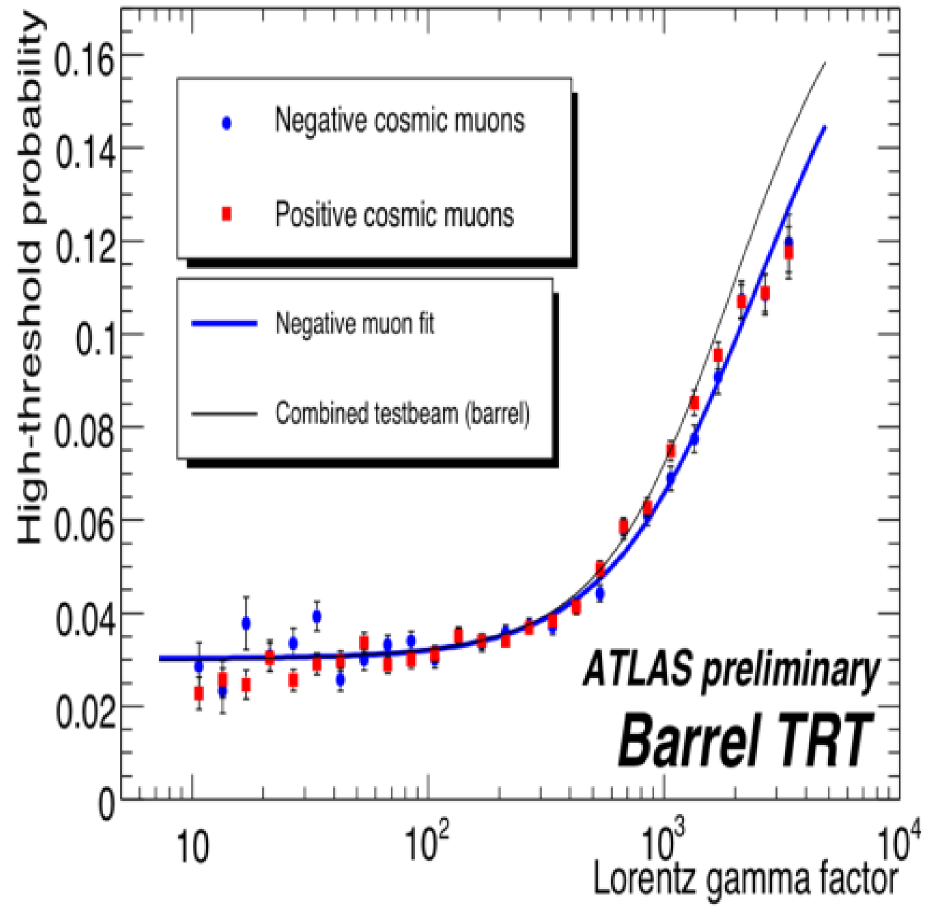




Two tracks are seen in the TRT. Red dots give high energy hits (high threshold) in the TRT (sign for transition radiation). One track (electron) has 10 red dots. Transition radiation detector works!

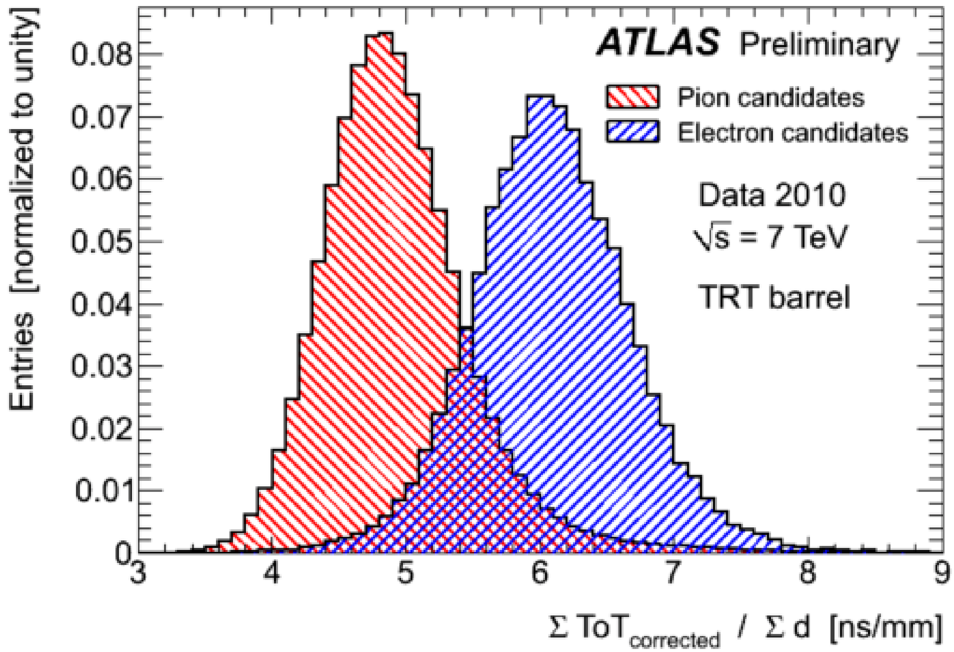
ATLAS TRT

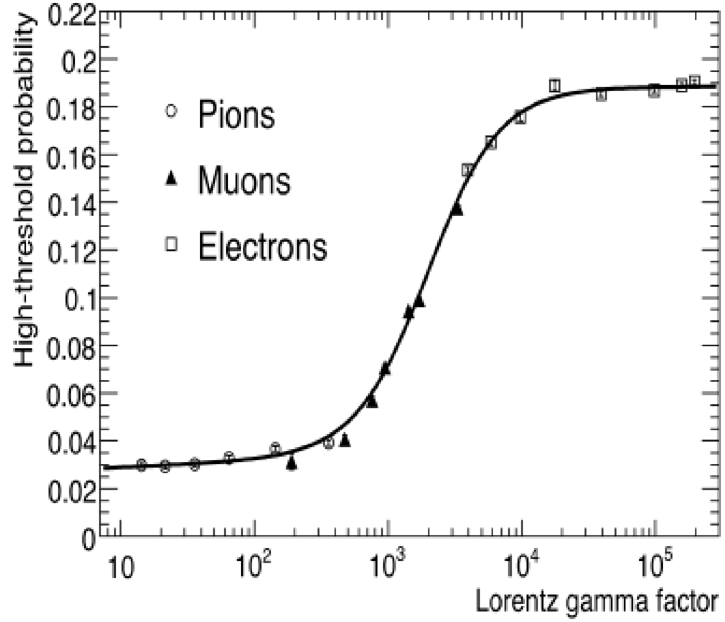


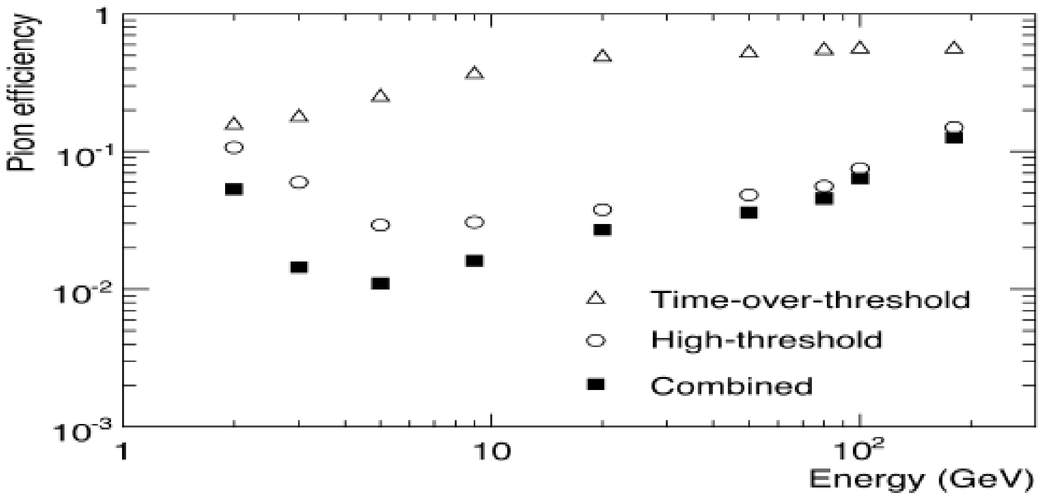


High-threshold probability
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Negative cosmic muons
Positive cosmic muons
Negative muon fit
Combined testbeam (barrel)
ATLAS preliminary
Barrel TRT
10
10^2
10^3
10^4
Lorentz gamma factor

Eletron-/Pion-Trennung in ATLAS



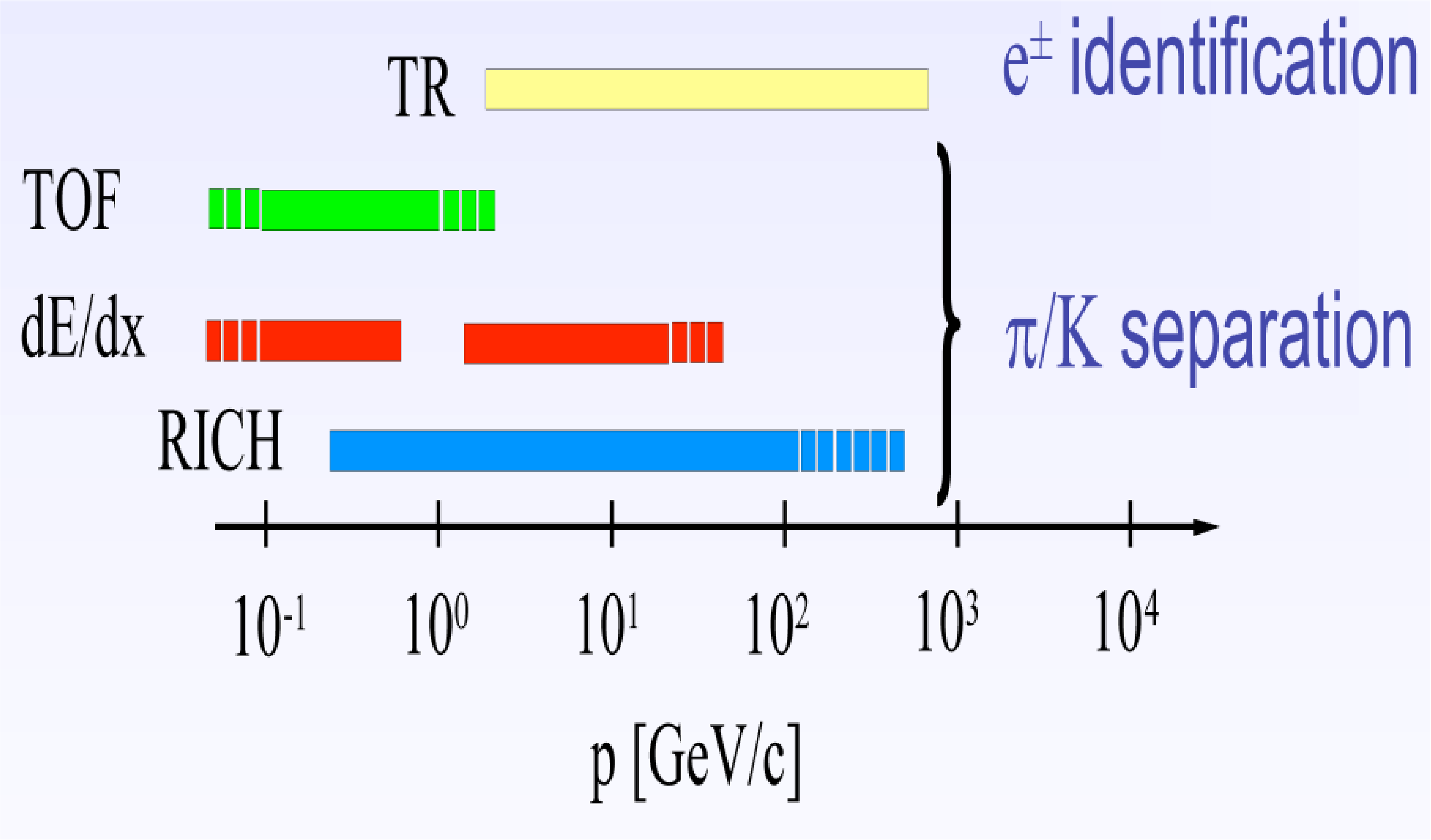




für Elektron-Nachweis-

wahrscheinlichkeit von 90%

Teilchenidentifikation Überblick



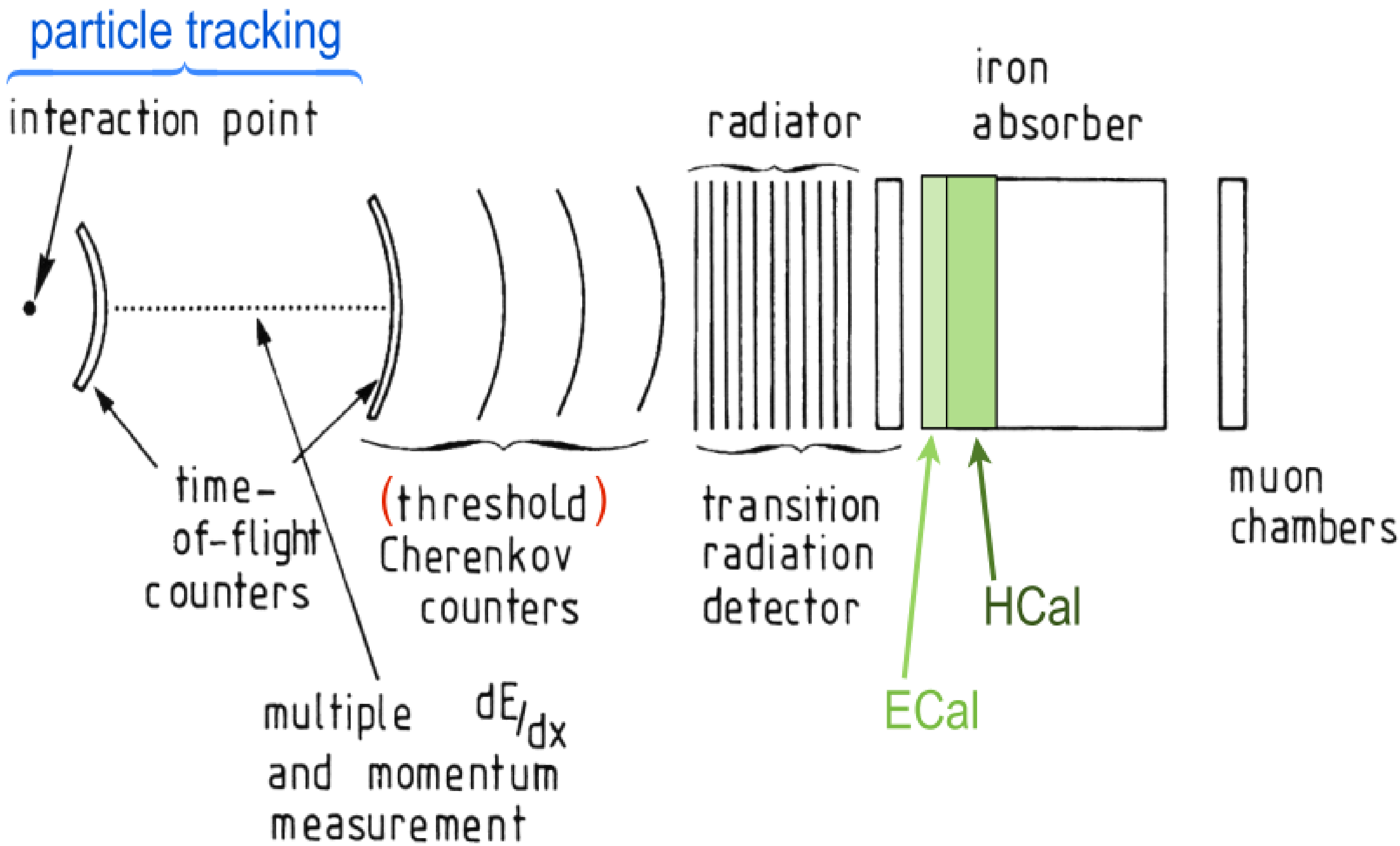
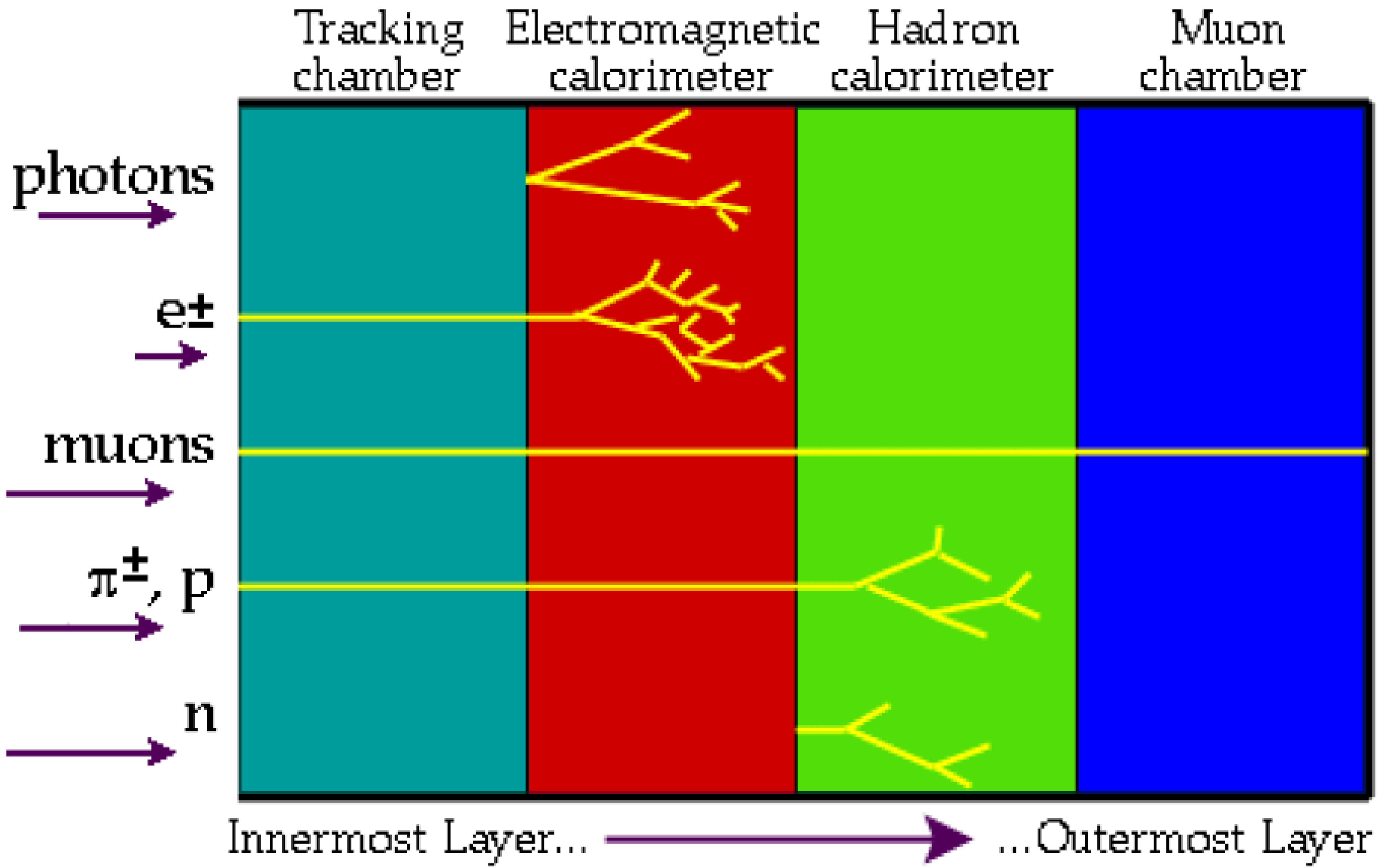


Fig. 6.35. Sketch of a detector specialized in particle identification.

Teilchenidentifikation durch Subdetektoren



Teilchenidentifikation durch Subdetektoren