Cherenkov Detectors
LHCb RICH

MASTER SEMINAR

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Cherenkov Effect

- Named after a Russian Physicist
- Discovered that charged particles moving through a medium under“some” conditions emanate a glow (i.e photons)
- Analogous to a sonic boom
- The theoretical interpretation assumes that the atoms of the medium become polarised in the region along the charged particle track. owing to the transient nature of this phenomenon, polarised atoms relax back to equilibrium by emitting a short em pulse.

$$cos\Theta = c/(\eta \times v)$$

Θ → emission angle of Cherenkov photon

v → velocity of charged particle

η → Refractive Index of the medium

Cherenkov Effect

- The Idea to discriminate particles by differentiating between different values of emission angle was conceived by A. Roberts in 1960 and proved to be an extremely powerful method for identifying particles as Ypsilantis and Seguinot practically demonstrated in 1977 by imagining Cherenkov photons.

So we have, $$cos\Theta = c/(\eta \times v)$$

and $$m = p\sqrt{\eta^2 cos^2\Theta - 1}$$

m → mass of the unknown particle (e.g. Kaon, Pion)

p → known momentum of the particle (known via curvature of trajectory calculations)

η → Refractive Index of the radiator

Cherenkov Detector Highlights

In Summary :

- Energy loss for Cherenkov radiation is of the order of KeV/cm
- The amount of Cherenkov Radiation is proportional to the square of the particle charge and it is independent of the particle mass
- Consequently most of the photons are emitted in the UV region
- Equal number of photons per unit path per unit frequency interval.

$$d^2E/dxd\omega = (z^2e^2\omega/c^2)(1 - 1/\beta^2\eta^2\omega)$$

E → Energy of the particle

ω → Radiation frequency

Historical Overview

- Indeed as early as 1919 M. Curie observed a faint blue light coming from concentrated solution of radium in water.
- In early days distilled water was used as radiator and photo-graphic emulsions or the researchers eyes as a photodetector.
- A major breakthrough in this technique was provided in the 1940s by the availability of photomultipliers capable of detecting feeble light with high efficiency and fast response.
- Cherenkov detectors played a fundamental role in important high energy physics achievements for example in the discovery of antiproton.

Particle Identification with Cherenkov Detector

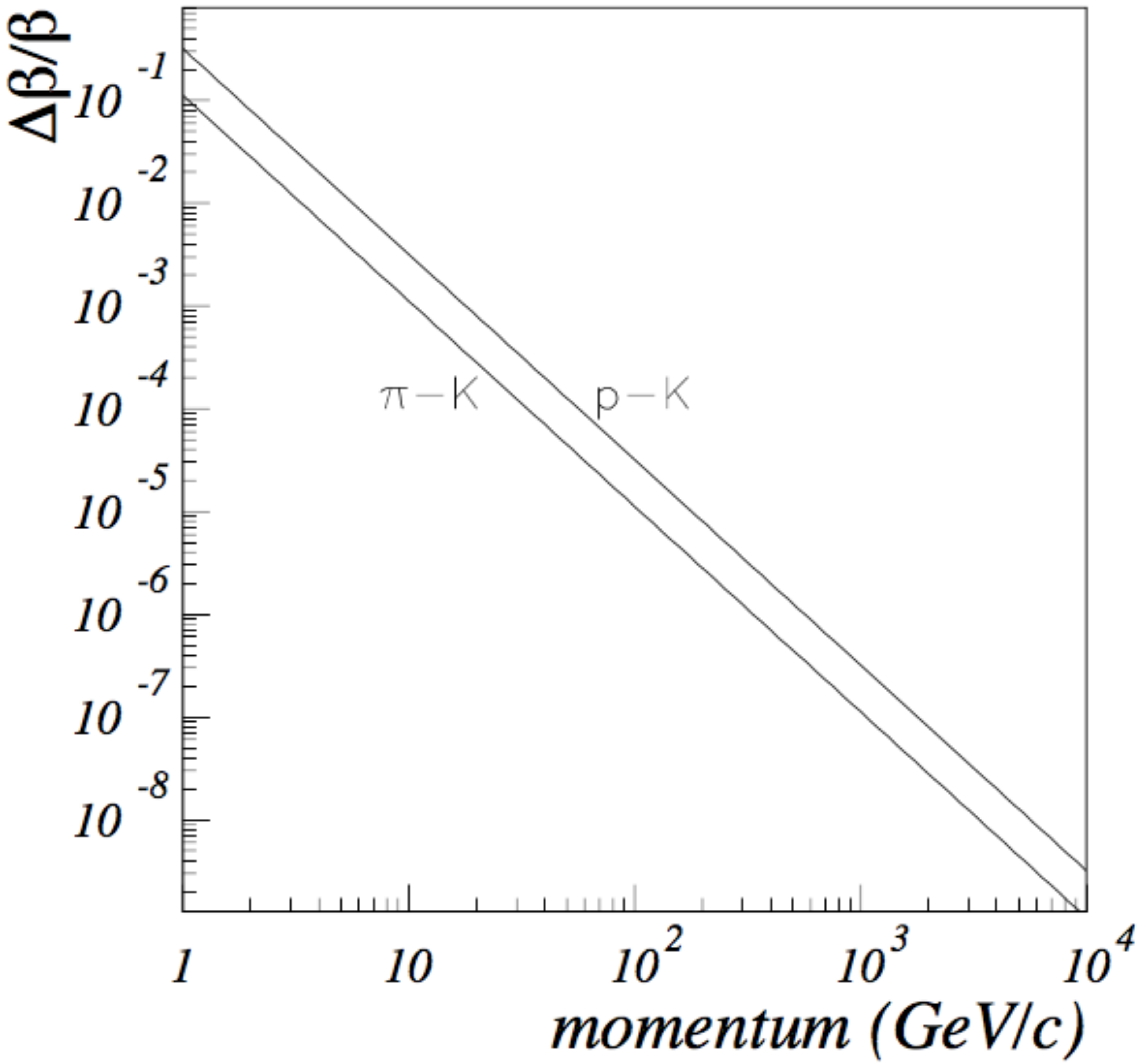


Figure 1: Resolution in velocity required to separate two particle species as a function of their momentum.

Threshold Cherenkov Detector

- By plotting the Cherenkov angle as a function of the particle velocity, one realises that the greatest sensitivity is provided by measuring the angle close to the threshold where $d\Theta/d\beta$ is large
- However the drawback is that the few photons emitted near the emission threshold cause the measurement of the cherenkov angle to be affected by a large statistical error.

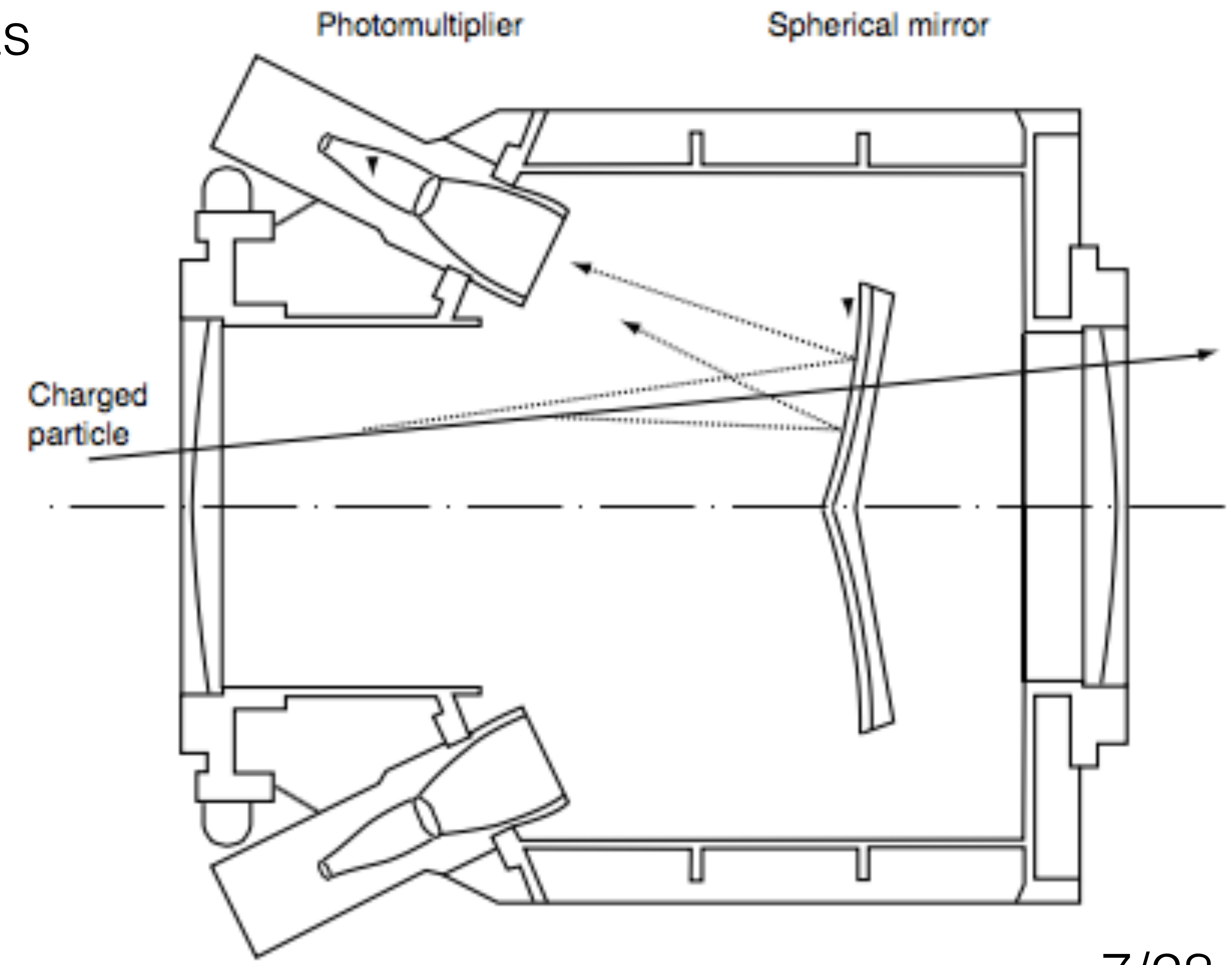


Figure 1a : Schematic layout of a Threshold Cherenkov detector

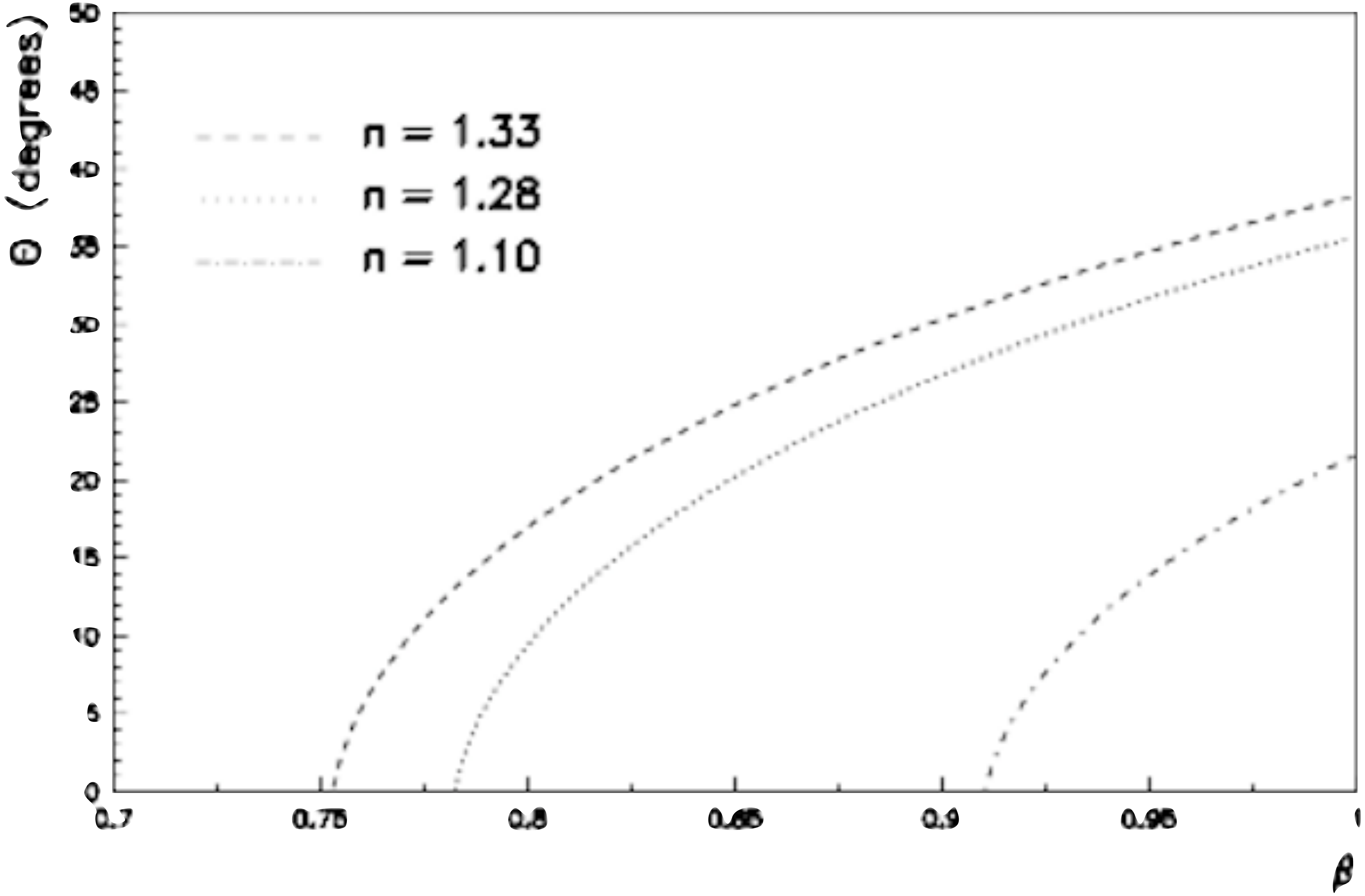


Figure 2: Variation of Cherenkov angle with particle velocity for three different refractive indices: n=1.33 (water), n=1.28 (liquid perfluorohexane) and n=1.1 (aerogel). Emission Angle changes rapidly close to the velocity threshold, its variation flattens as particle velicity increases.

Threshold Imaging Cherenkov (TIC)

- A modern version of threshold Cherenkov detector was proposed in 1995 for performing the hadron identification in the 3-8 GeV/c momentum range.

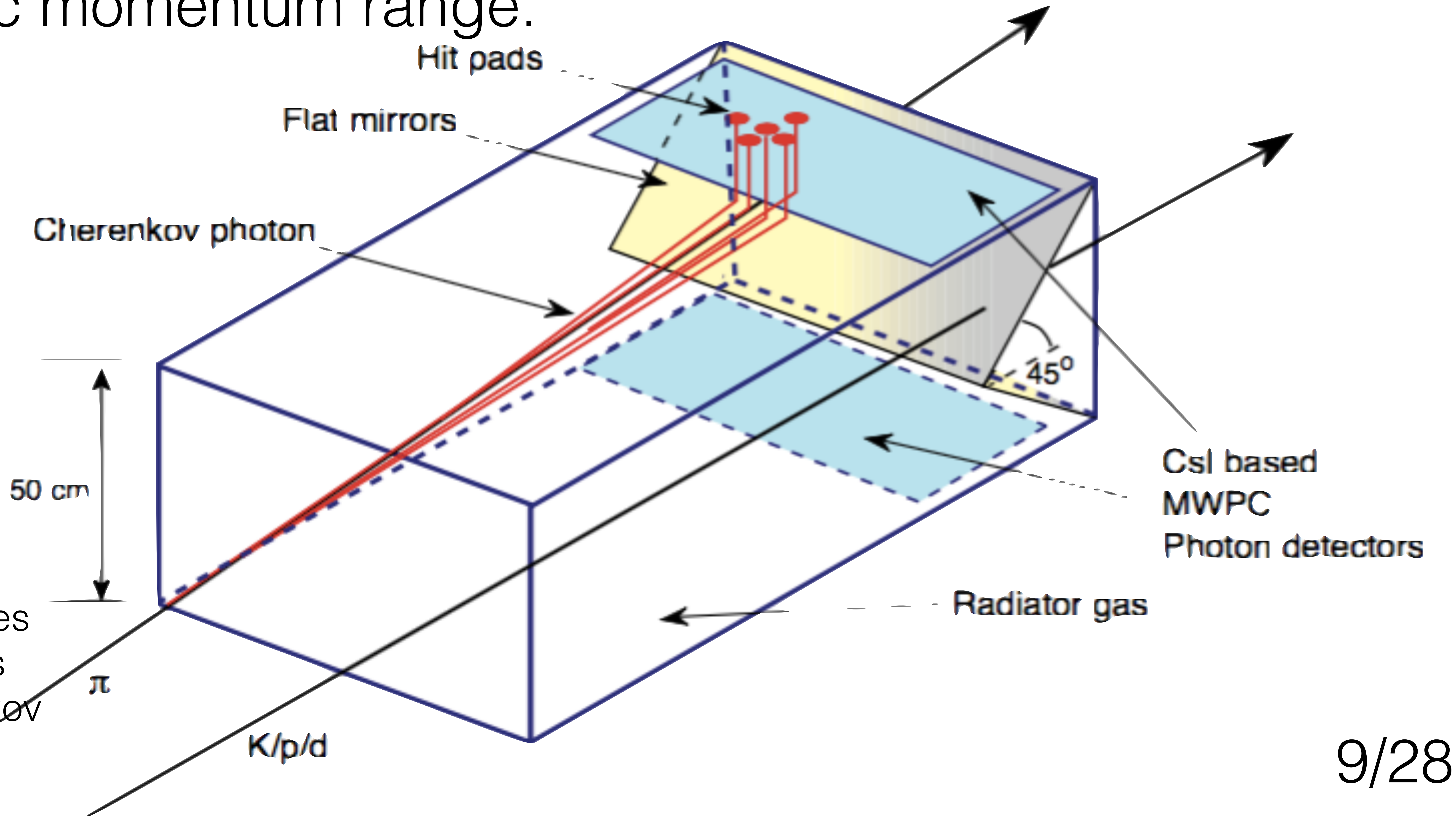


Figure 3: schematic of a TIC detector. Two particles are traversing the gas radiator, one of them emits Cherenkov photons since it is above the Cherenkov threshold

DISC
{Differential Isosynchronous Self collimating Detector}

- A significant step in the application of Cherenkov radiation to PID took place at the beginning of 1970s namely DISC detector.
- By taking into account the formidable accuracy achieved in the past $\triangle\beta/\beta = 10^{-7}$ is still so far the most precise device ever built for measuring the speed of particles.

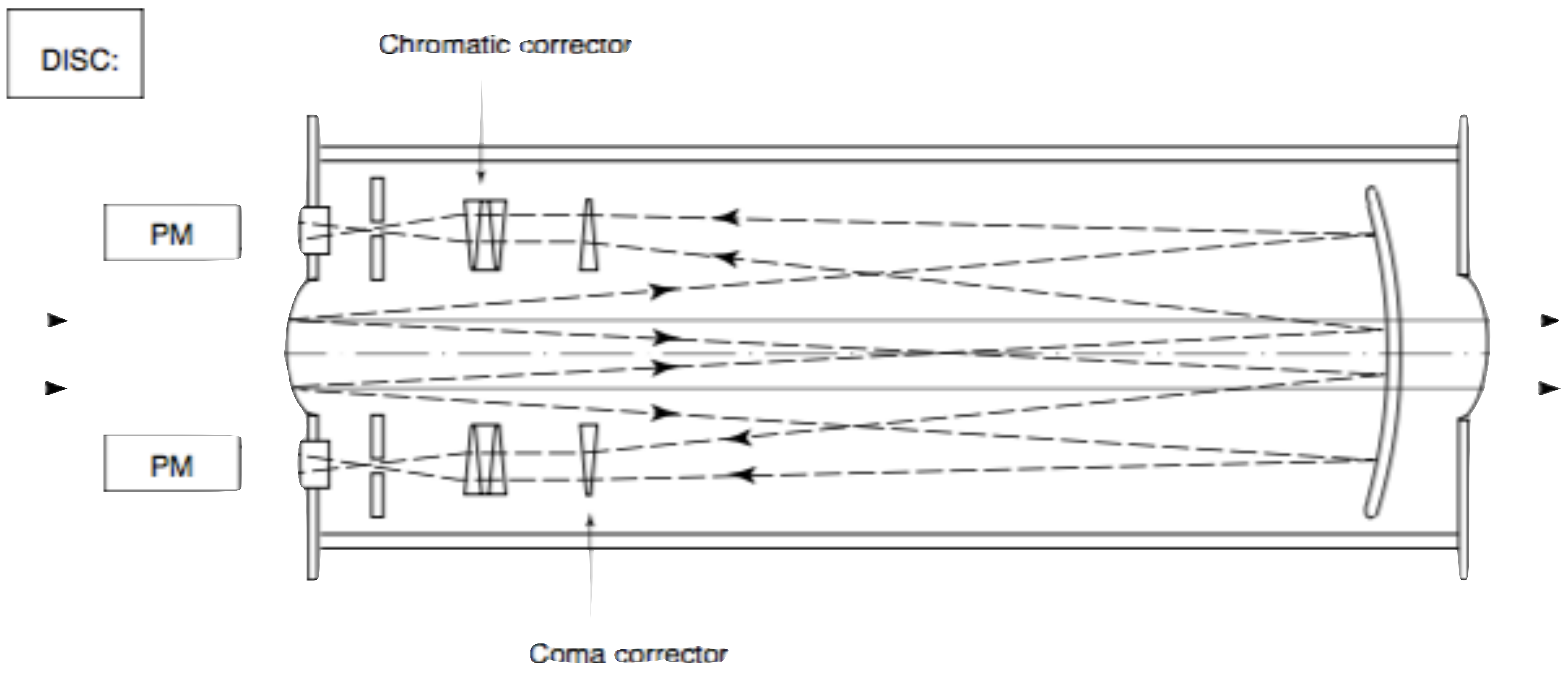


Figure 4 : Schematic layout of a DISC

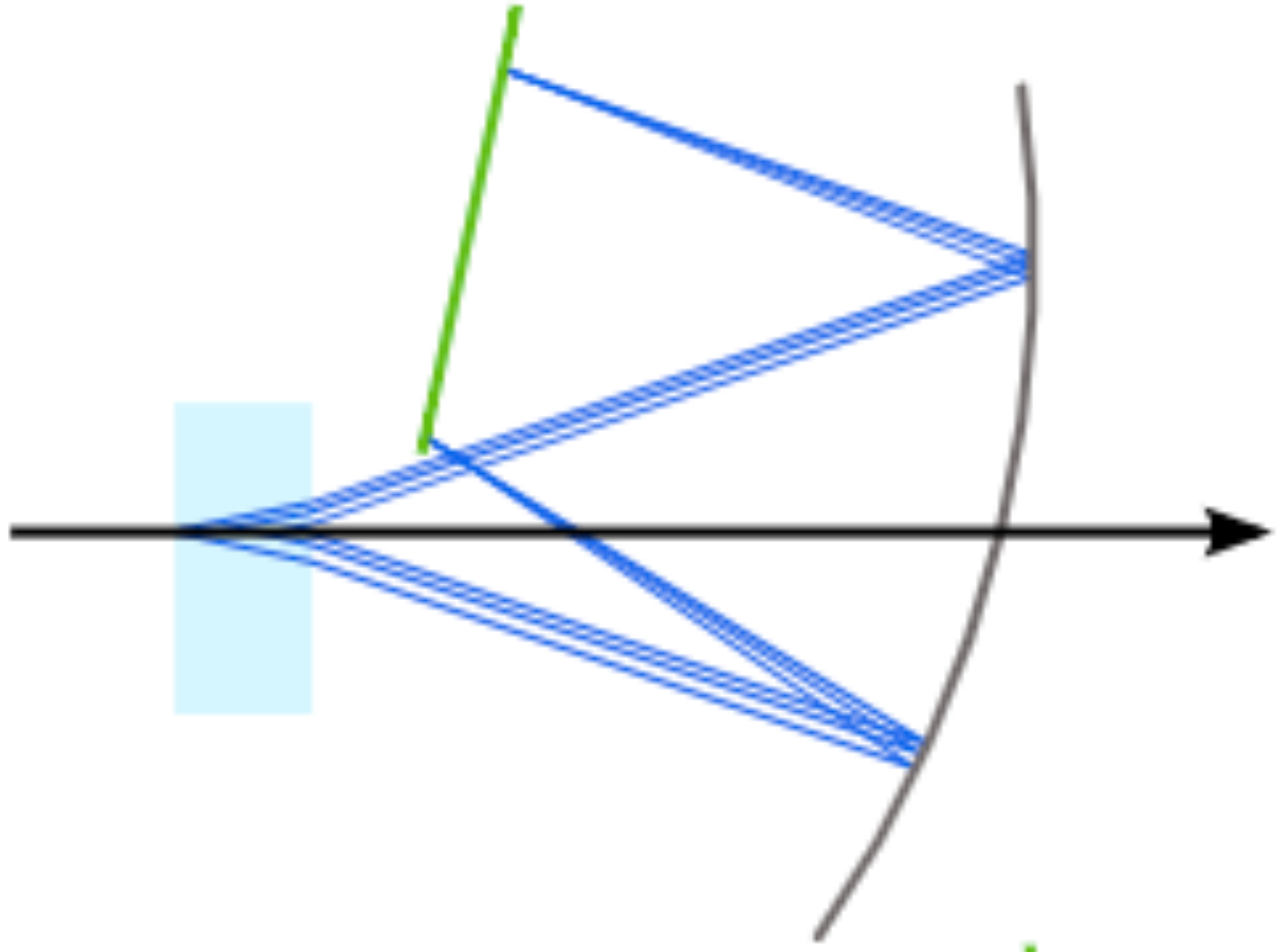
RICH Detector

{Ring Imaging CHerenkov}

- RICH detector consists of two basic elements arranged in a focusing or in a proximity focusing geometry
- A transparent dielectric medium called a radiator, whose refractive index is appropriate for the range of particle momentum being specifically studied and a photon detector.
- The latter provides information on the position of the photoelectron initiated by the conversion of the Cherenkov photons in a suitable photosensitive volume, or a conversion layer.
- The resolution of the Cherenkov rings is determined by the ratio of the radiator thickness and photodetector distance.

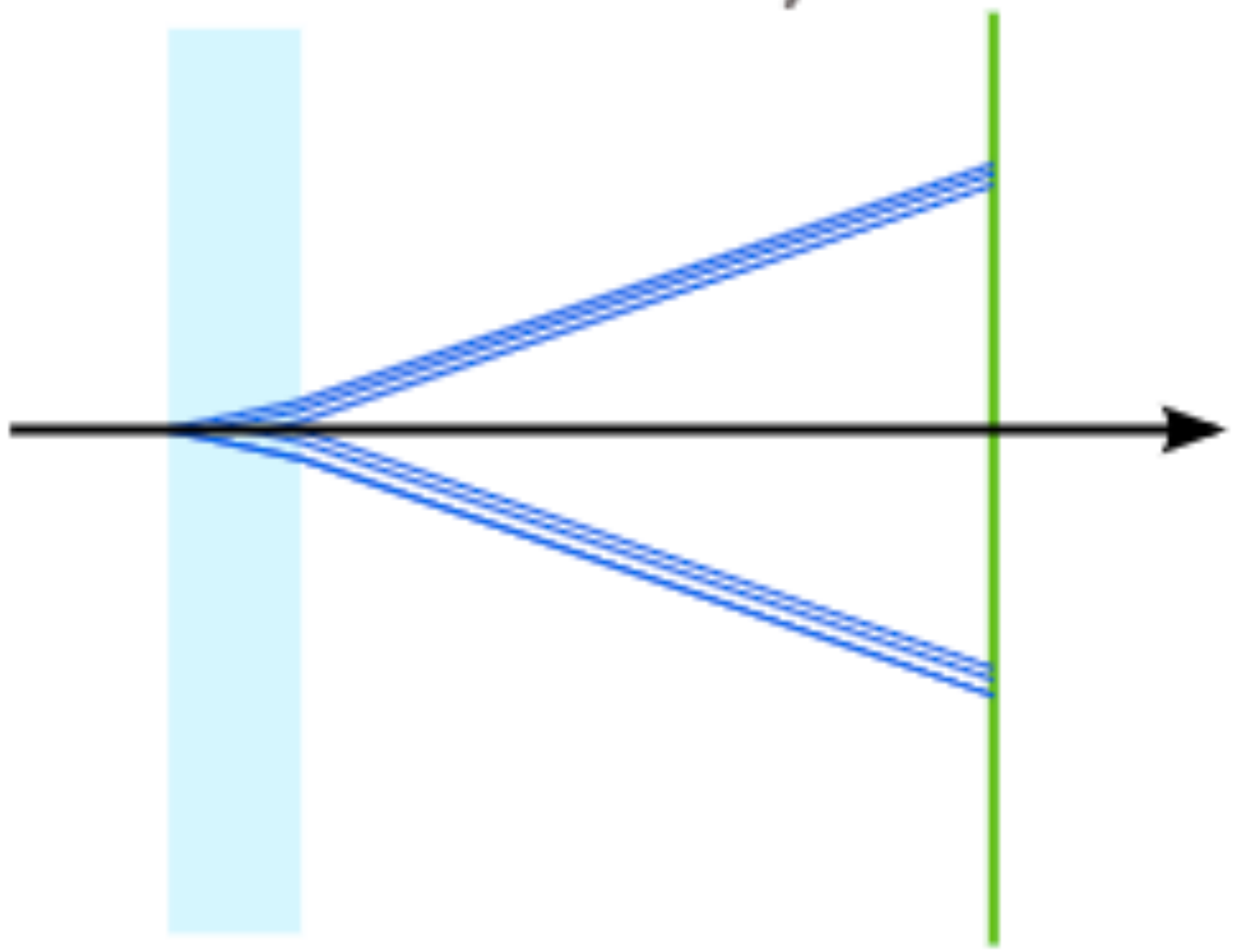
RICH Types

Focusing RICH Detectors



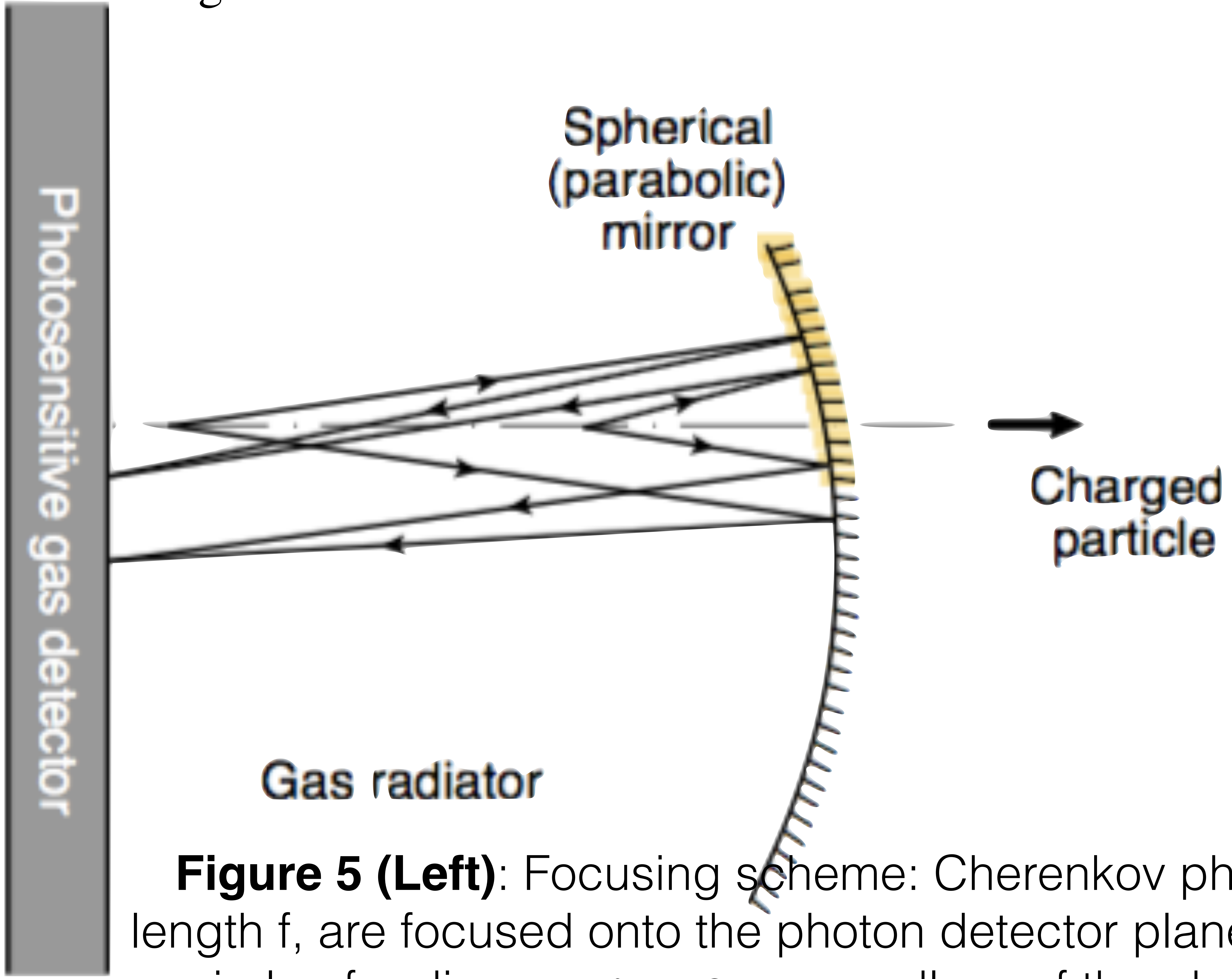
- The detector volume b/w radiator and photodetector.
- suitable for low RI radiators.
- As a result 'Large Radiator length' required to compensate

Proximity Focusing Rich Detectors



- More compact design with a thin radiator volume.
- Quite compact designs are possible. In this configuration, the resolving power is worse than that of gaseous radiators, but it enables good PID in a momentum range where gaseous radiators are insensitive.

Figure 3 (Right) : Proximity-focusing scheme: The detector volume, placed between the radiator and the photodetector, is known as the 'proximity gap' and is necessary to enlarge the Cherenkov cone to a more convenient size for the imaging



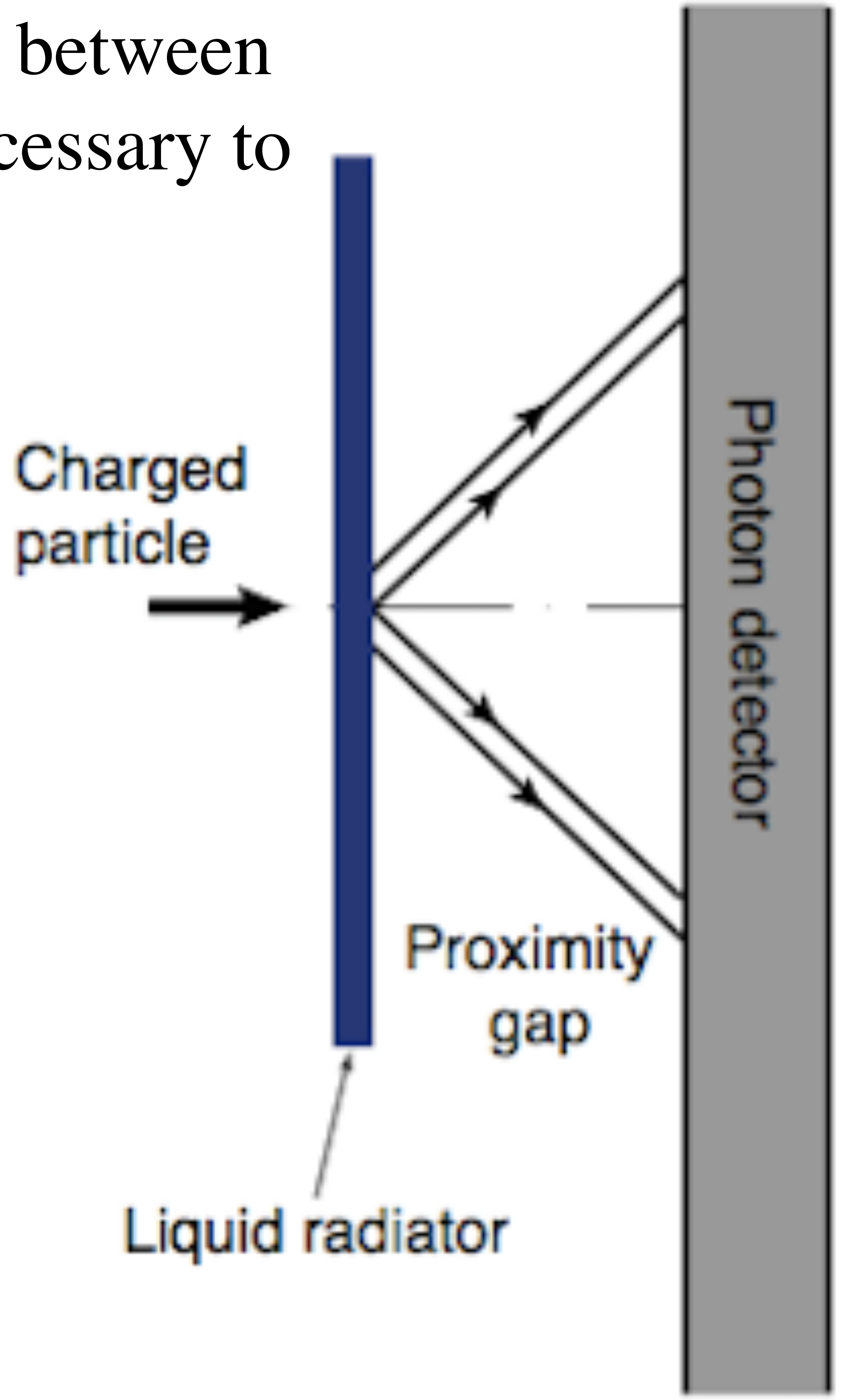


Figure 5 (Left): Focusing scheme: Cherenkov photons, collected by a mirror of focal length f, are focused onto the photon detector plane of the mirror. The resulting pattern is a circle of radius $r = f \tan \Theta c$ regardless of the photon emission point along the particle track.

Detector Component

Photon Detector :

- The basic task of the photon detector is to convert Cherenkov photons into detectable electrical signal by means of a material with single photon sensitivity defined by Quantum efficiency, QE
- Besides the above mentioned characteristics the photon detector employed in RICH must have :

1. fast response
2. low noise
3. long term stability
4. low cost in order to cover large surfaces.

- Photon Detectors can be divided into two classes :

1.gaseous detector

2.vacuum based detector

Gaseous Detector

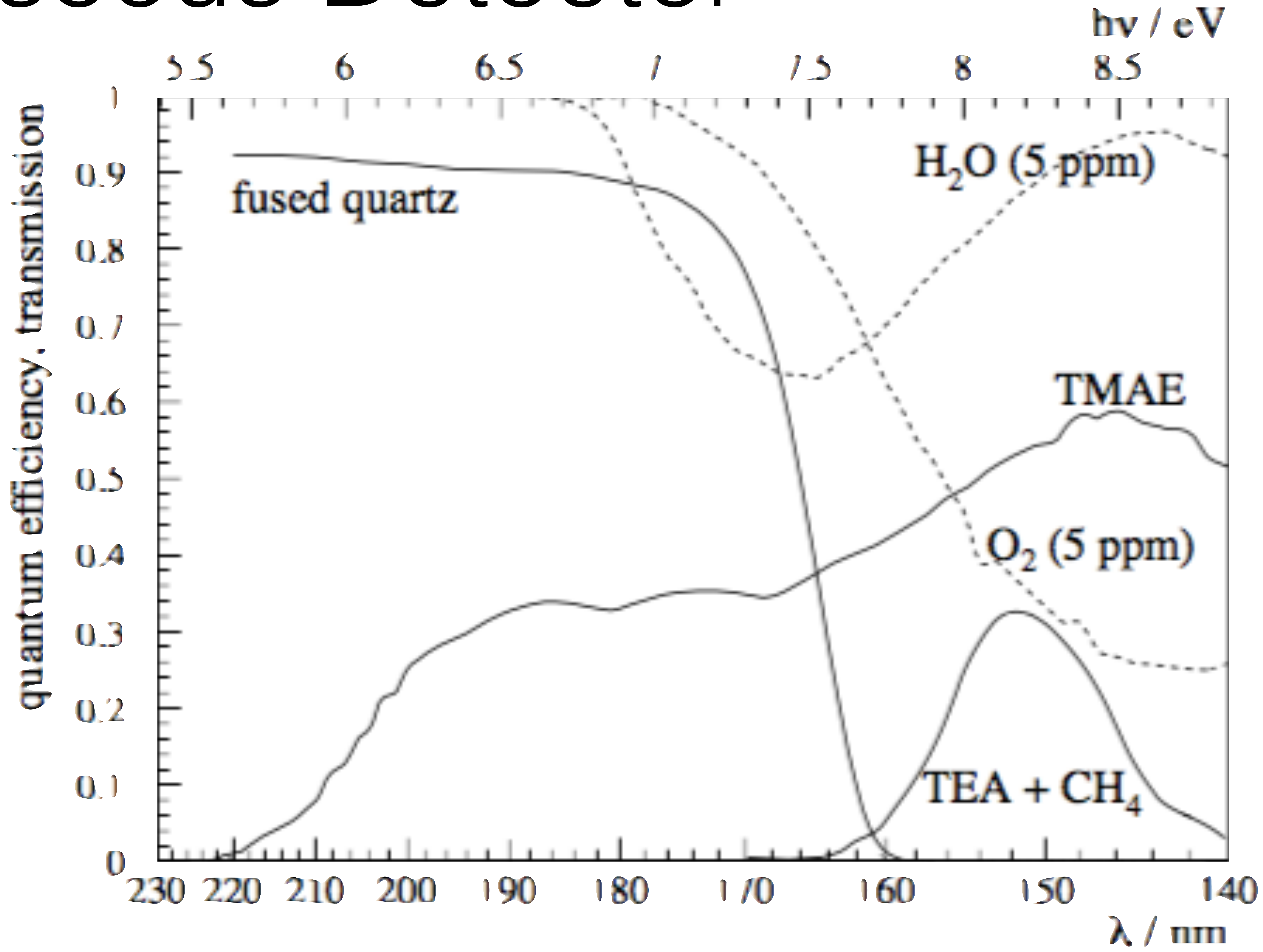


Figure 6 : TEA and TMAE quantum efficiency as a function of wavelength

Gaseous Detector

- In the recent years, considerable effort has been made in the use of CsI, deposited onto the cathode plane of a gaseous detector is a valid alternative to TMAE.
- The main advantages include:

1. Improved Cherenkov angle resolution
2. No parallax error

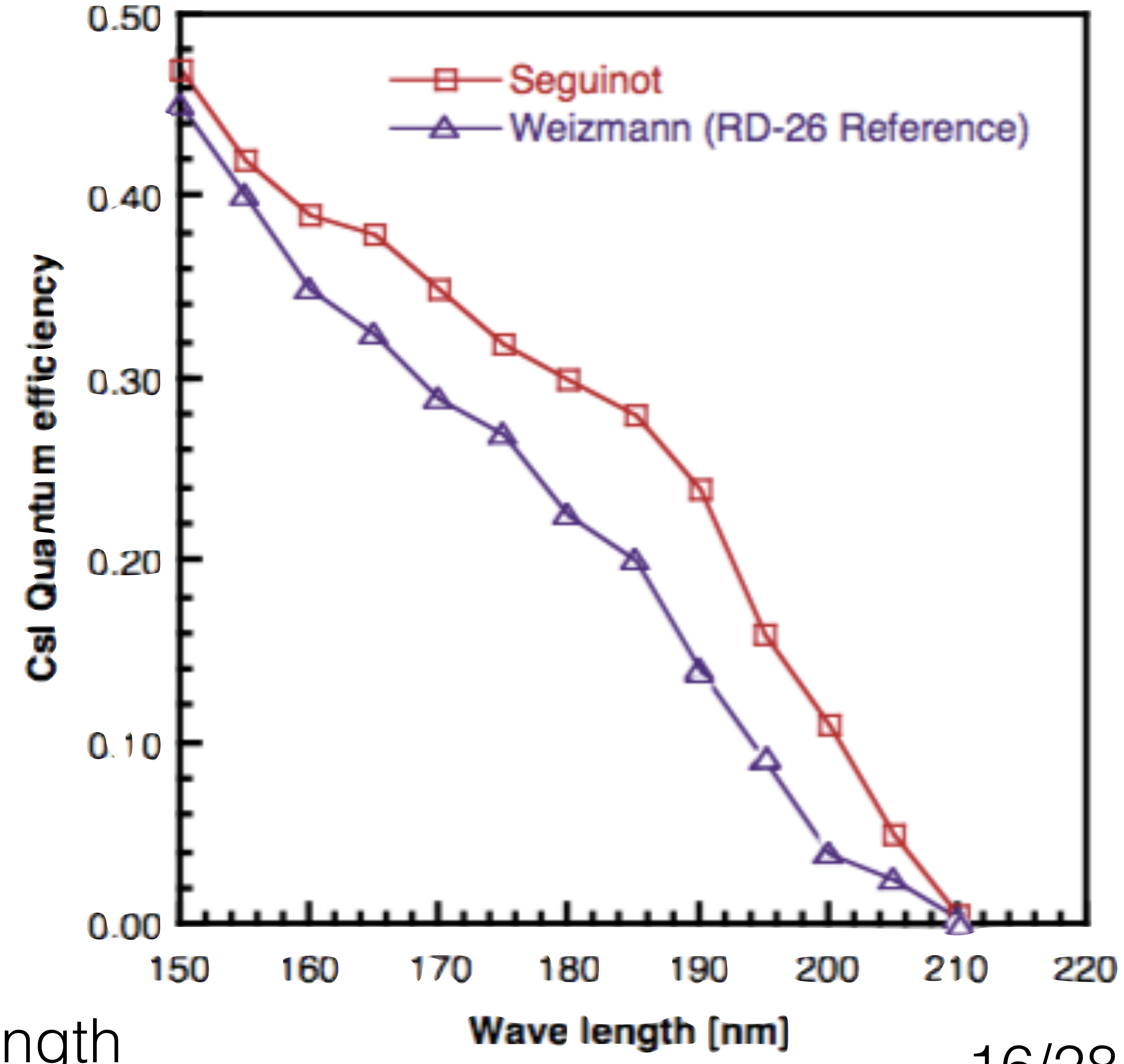


Figure 7 : QE of CsI as a function of wavelength

Photomultiplier
{PMT}

- Electron tube device which convert light into measurable electric current.
- Consists of a photosensitive cathode
- Followed by an electron multiplier section
- Finally an anode from which the amplified signal is taken.

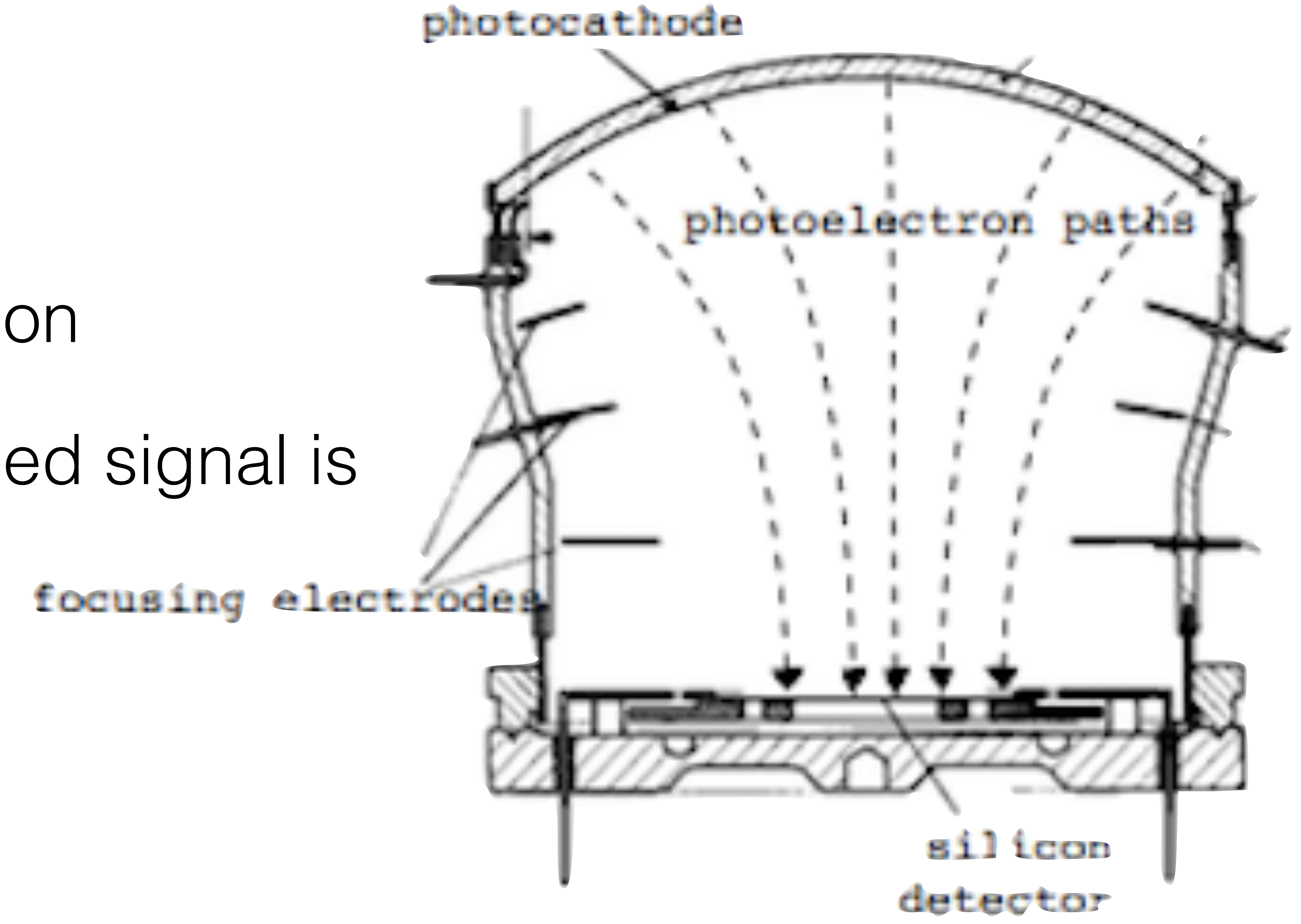


Figure 8 : HPD with electrostatic focusing

LHCb RICH

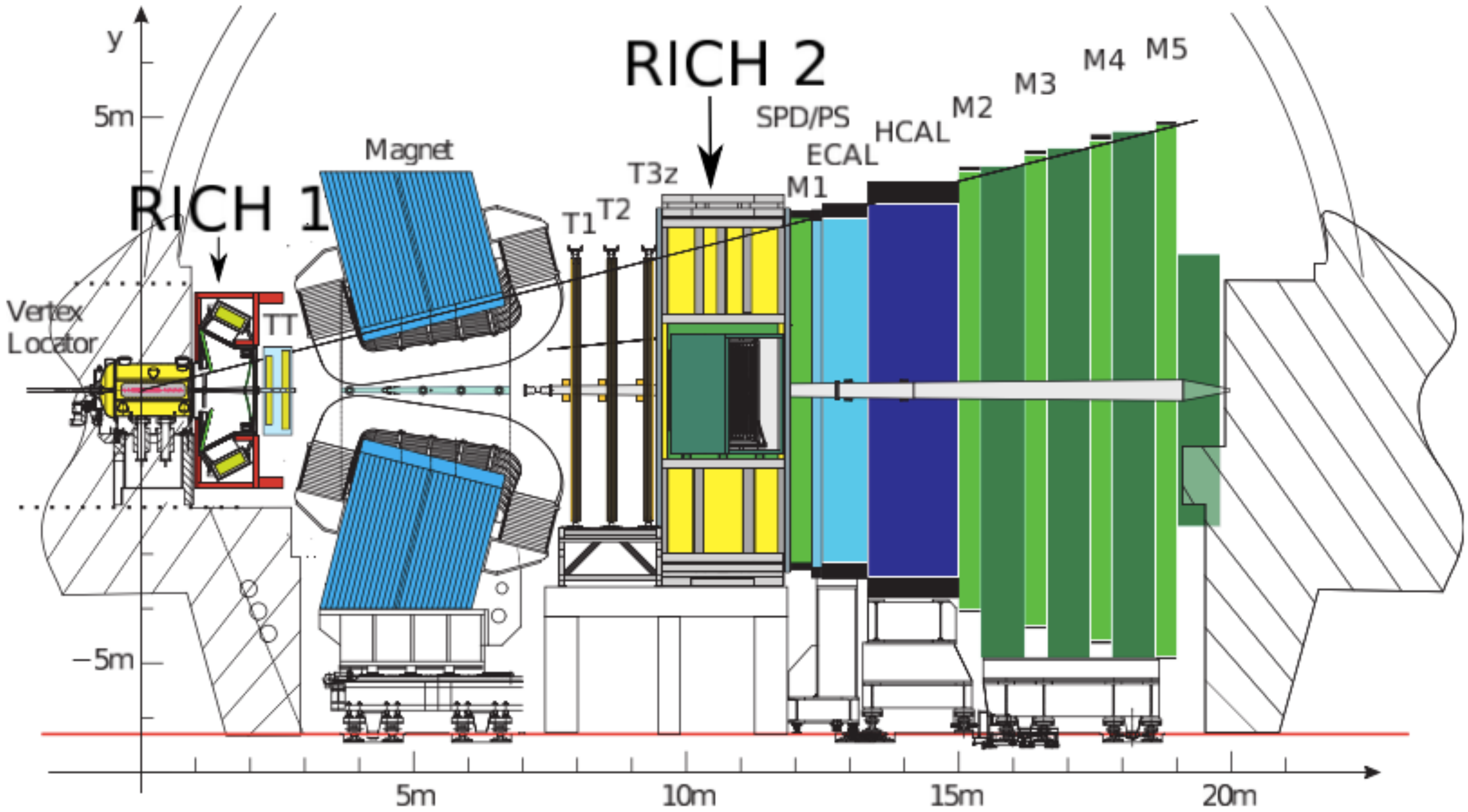


Figure 9 : Side view of the LHCb spectrometer, with the two RICH detectors indicated

RICH1

- Primary role of RICH is the identification of charged hadrons(pions, kaons, protons)
- There is a strong correlation between momentum and polar angle, with the high momentum particles produced predominantly at low polar angles.
- As a result the RICH system has two detectors : RICH 1 & RICH 2.
- RICH 1 :
  - Covers the low and intermediate momentum region 2-40 GeV/c
  - C4F10 fluorocarbon gas at room temp. is used as radiator with refractive index 1.0014 at 0 deg C along with aerogel.
  - 196 HPD's are installed.
  - the photodetector planes are separated from radiator gas volume by quartz window.

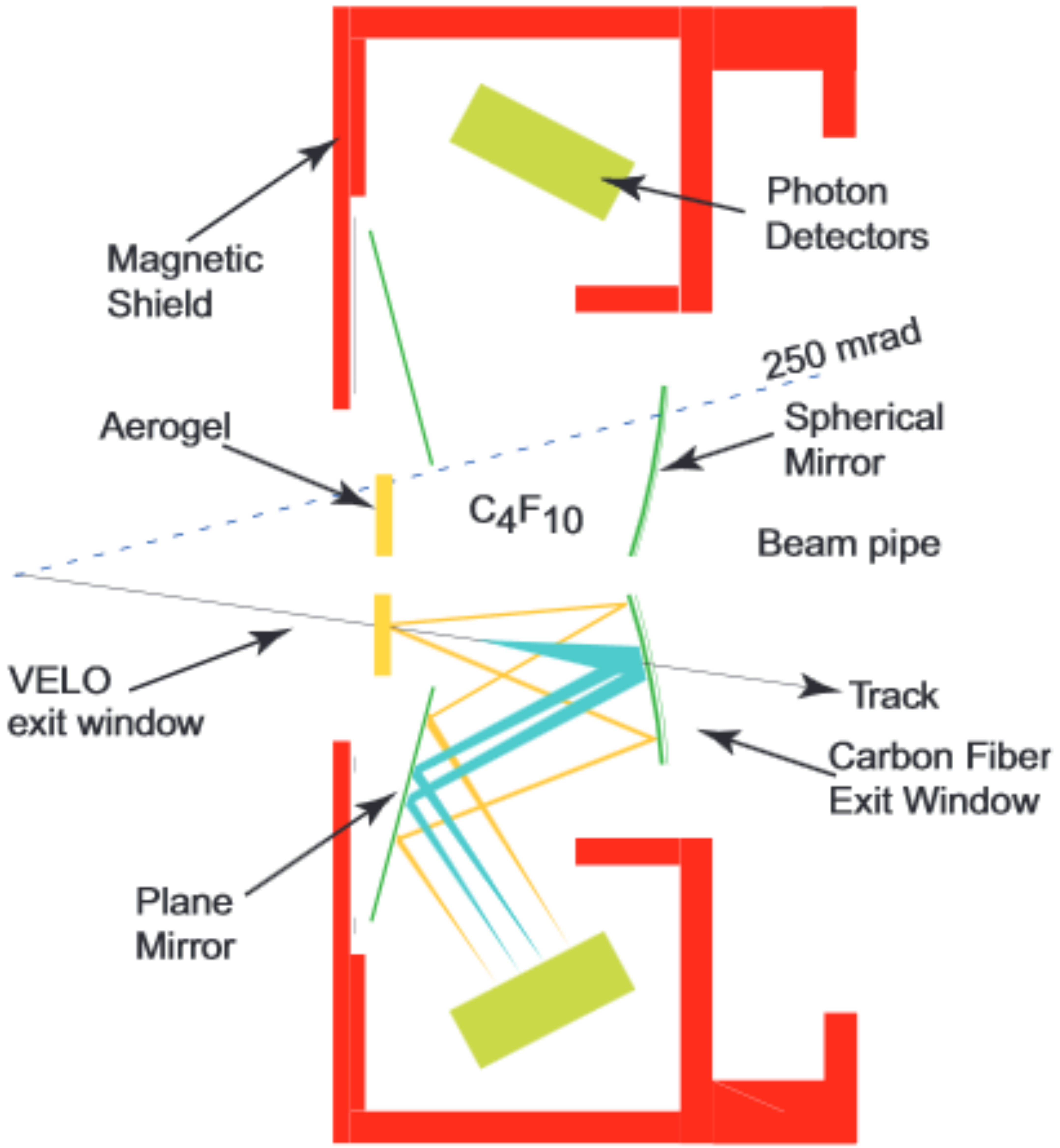


Figure 10 : Schematic layout of RICH 1

RICH 2

- Covers the high momentum region 15-100 GeV/c, over the angular range of 15-120 mrad.
- CF_4 Fluorocarbon gas at room temp. and pressure is used as a radiator with refractive index 1.0005 at 0 deg C
- About 5% CO_2 has been added to CF_4 in order to quench scintillation in this gas.
- A total of 288 HPD's are installed.
- Side Note : Whilst RICH detectors are primarily used for hadron identification, it is worth nothing that a distinct muon band can also be observed.

Magnetic Distortion

- Inside an HPD, photoelectrons travel upto 14 cm from the photocathode to the silicon anode. This device is therefore sensitive to stray magnetic fields from the LHCb spectrometer magnet.

- All HPD's in RICH 1 and RICH 2 experience some residual fringe field.

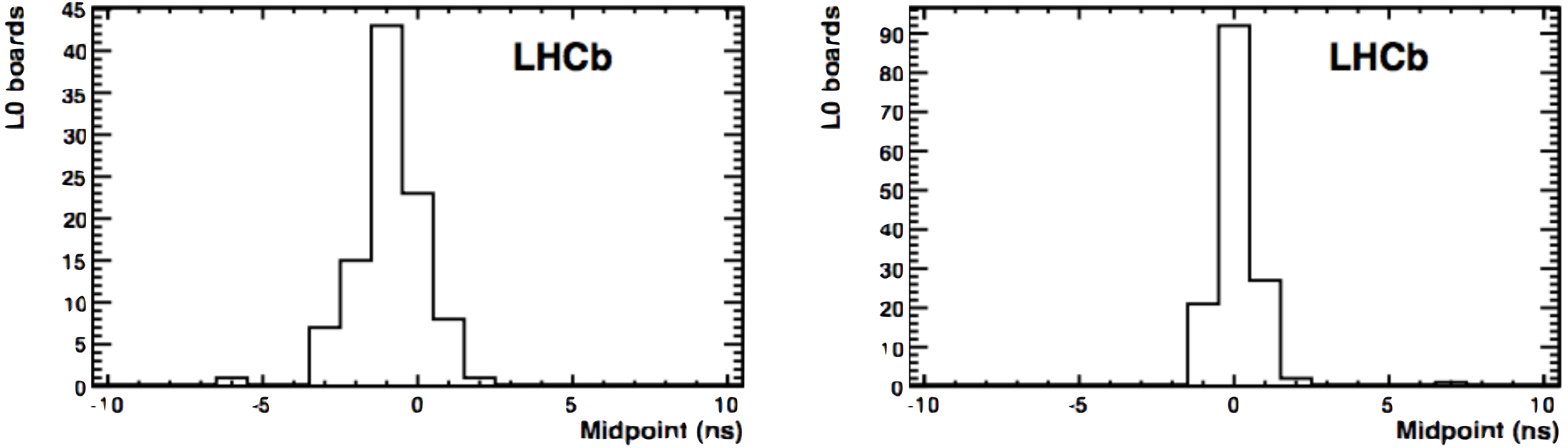


Figure 11 : The RMS deviations of the HPDs are approximately 1ns, RICH1 (left) RICH2 (Right)

Particle Identification

- In order to determine the particle species for each track, the Cherenkov angle information must be combined with the track momentum measured by the tracking system.

- Since the most abundant particles in the p-p collisions are pions, the likelihood minimisation procedure starts by assuming all particles are pions {in essence we are doing Hypothesis Testing}.

- Then for each track in turn, the likelihood is recomputed changing the mass hypothesis to electron, muon, pion, kaon and proton, whilst leaving all other hypothesis unchanged.

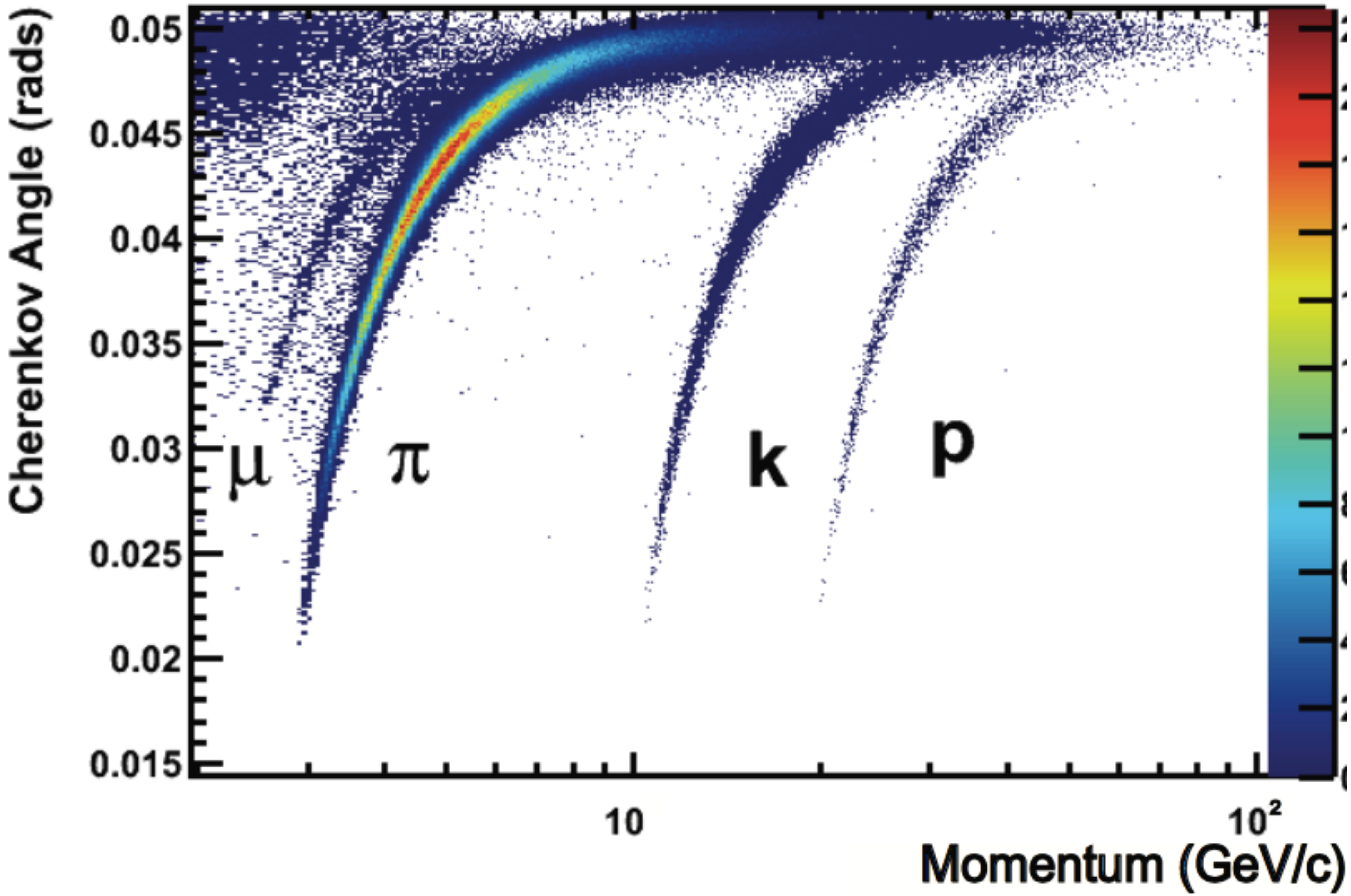


Figure 12 : Reconstructed Cherenkov angle as a function of track momentum in the C4F10 radiator

Particle Identification

with RICH Detectors

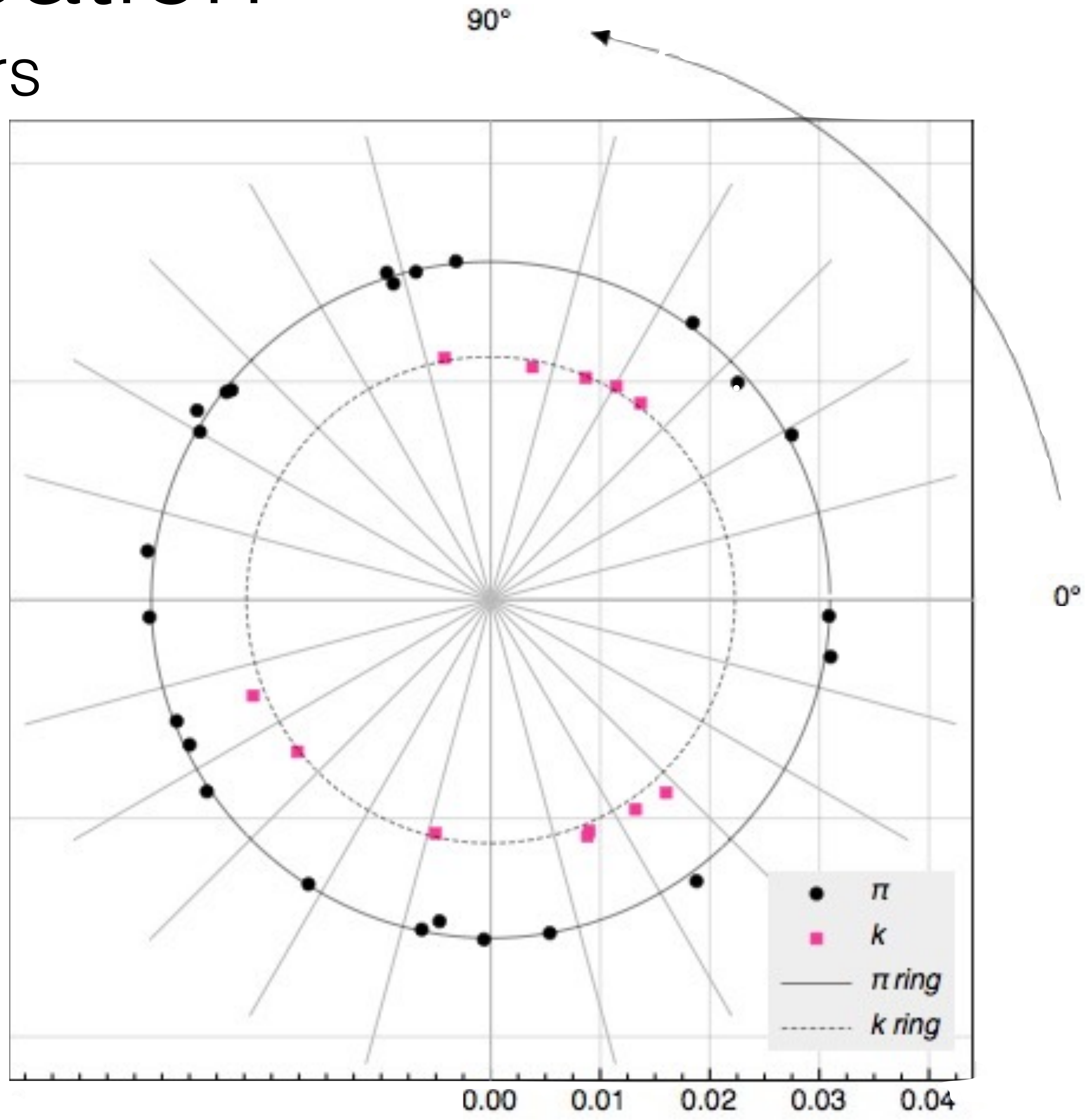


Figure 13 : Cherenkov photons emitted by 22 GeV/c pion and kaons

Performance

- RICH PID both during and after data taking, is particularly important for analysis.
- It enables comparison with expectations and provides a benchmark against which to compare effectiveness
- RICH devices have been able to identify particles in a vast momentum range1-100 GeV/c

Performance as a function of event multiplicity

- The result demonstrate, as expected, some degradation in PID performance with the increased interaction multiplicity.
- The kaon/pion separation is extremely robust right upto the highest interaction multiplicities and thus gives the confidence that the current RICH system is suitable for operation at the higher luminosities foreseen in the future.

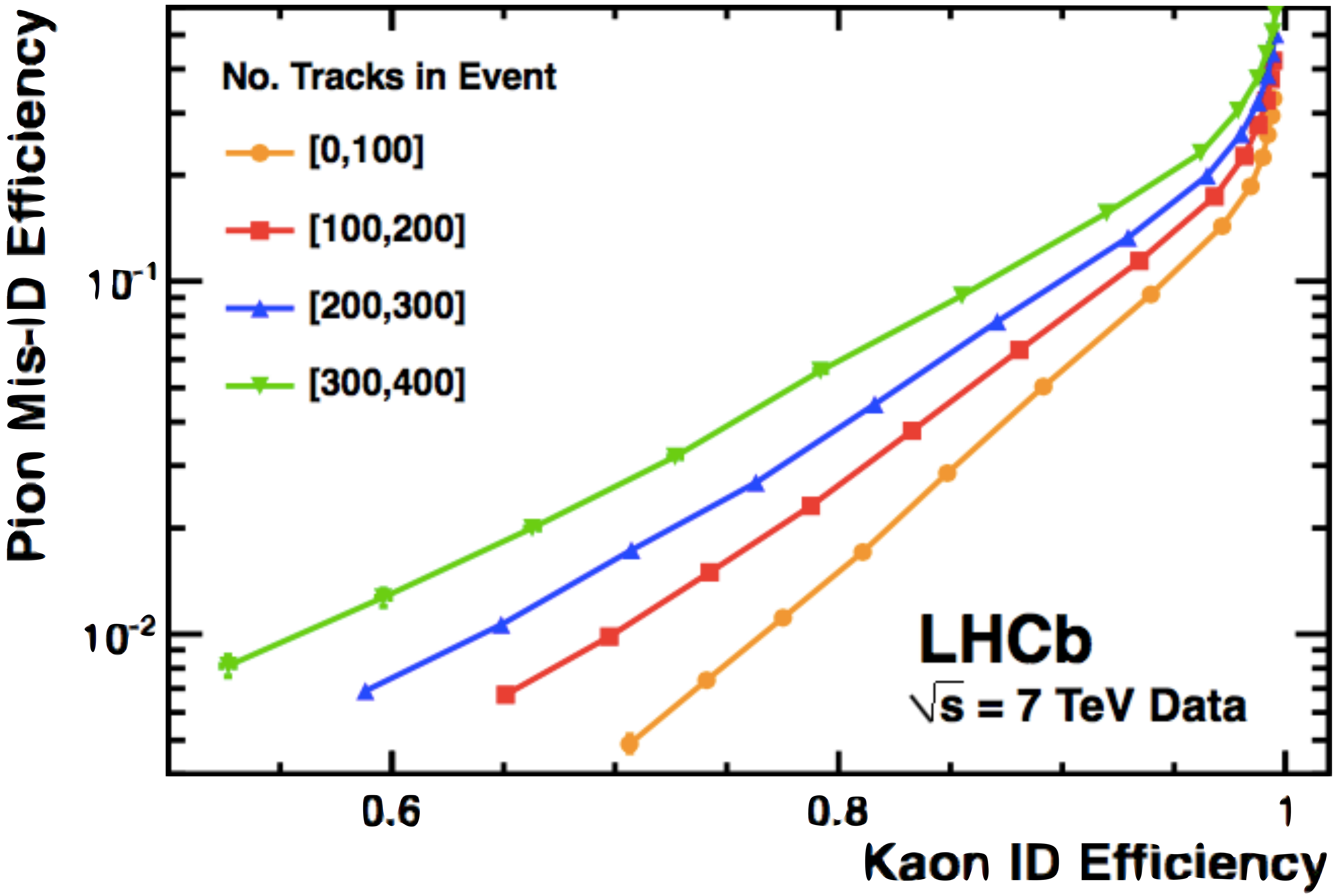


Figure 14 : Kaon identification efficiency and pion misidentification rate measured on data as a function of track momentum.

Conclusion

- A phenomena discovered by a Russian scientist Cherenkov in 1934 has become in recent years the basic ingredient of the RICH devices, being able to identify particles in the vast momentum range 1-100 GeV/c.
- Despite their complexity and high manpower costs, the outstanding physics results that have been achieved from the first generation of large RICH devices largely compensate the efforts made and justify the construction of new devices for the future experiments.

THANKYOU