Recent Progress in Čerenkov Counters

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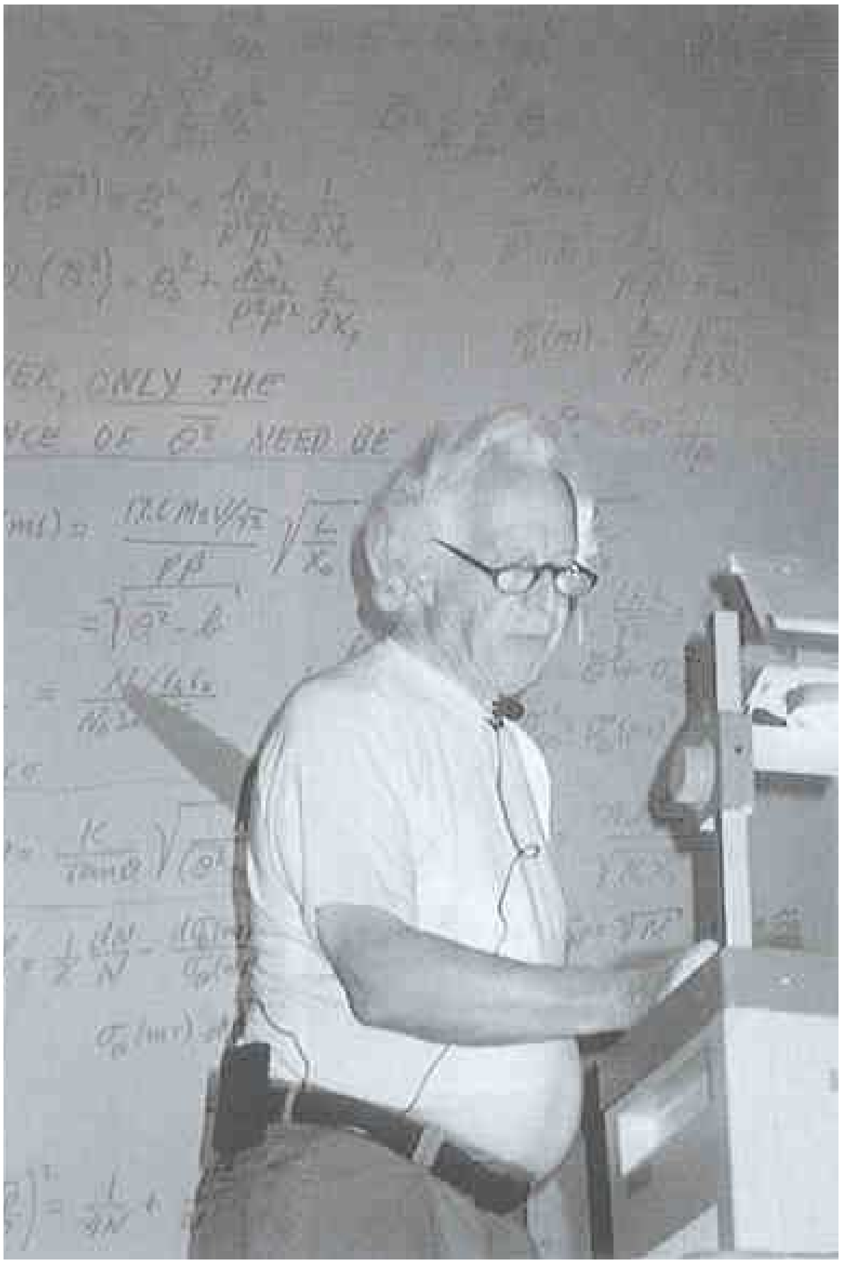
- Introduction: Čerenkov counters
- Long term experience
- Recent developments
- Relevance for other research fields
- Conclusions

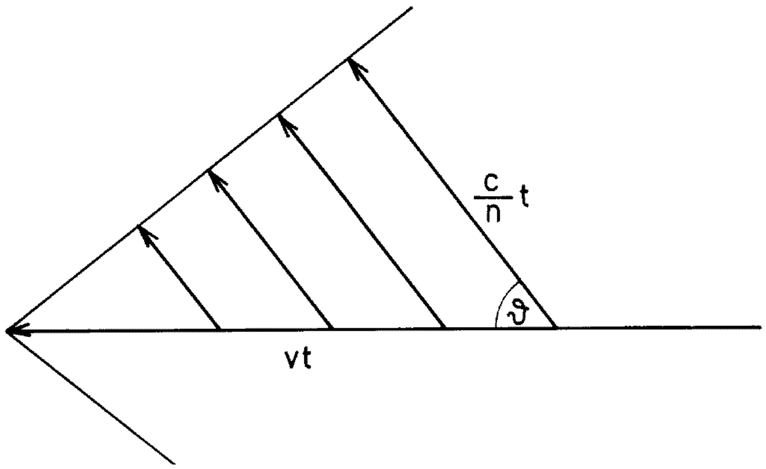
Tom Ypsilantis

The *spiritus agens* of the field is gone.



Čerenkov counters

A charged track with velocity $v = \beta c$ above the speed of light c/n in a medium with the index of refraction $n = \sqrt{\epsilon}$ emits polarized light at a characteristic (Čerenkov) angle,
$\cos\vartheta = \frac{c/n}{v} = \frac{1}{\beta n}$



Two cases:

1) $\beta < \beta_t = \frac{1}{n}$: below threshold no Čerenkov light is emitted.

2) $\beta > \beta_t$: the number of Čerenkov photons emitted over unit photon energy E in a radiator of length L amounts to

$\frac{dN}{dE} = n_e L \frac{d\sigma}{dE} = L \frac{\alpha}{\hbar c} \sin\vartheta^2$

where $\frac{\alpha}{\hbar c} = 370 \mathrm{eV}^{-1}\mathrm{cm}^{-1}$

Number of detected photons

Example: in 1 cm of water ($n = 1.33$) a track with $\beta = 1$ emits $N = 320$ photons in the spectral range of visible light ($\Delta E \approx 2\ \mathrm{eV}$).

If Čerenkov photons were detected with an average detection efficiency of $\epsilon = 0.1$ over this interval, $N = 32$ photons would be measured.

In general: number of detected photons amounts to

$N = N_0 L \sin\vartheta^2$

where N_0 is the figure of merit,

$N_0 = \frac{\alpha}{\hbar c} \int Q \cdot T \cdot R \, dE$

and $Q \cdot T \cdot R$ is the product of photon detection efficiency, transmission of the radiator and windows and reflectivity of mirrors employed.

Typically: $N_0 = 50 - 100/\mathrm{cm}$

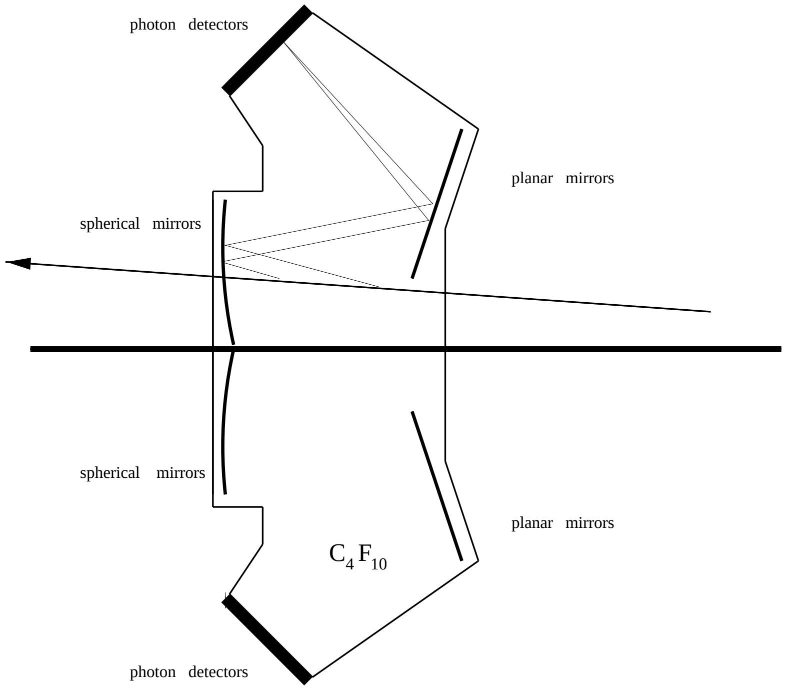
RICH Building Blocks

Need 10 - 20 detected photons and a good angular resolution: how do we get there?

→ Very carefully design, build and run a RICH counter

RICH Building Blocks

- Radiators
- Mirrors, windows
- Photon detectors (single photons)
- Light collectors
- Auxiliary systems



Types of Čer. counters

Threshold counters

→ count photons to separate particles below and above threshold

Ring Imaging (RICH or CRID)

→ measure Čerenkov angle

→ count photons

Long term experience

Long term running experience, in particular from DELPHI and SLD ring imaging Čerenkov counters:

- We have learned how to build a very sensitive detector, and operate it over many years
- RICH counters proved to be a reliable tool for particle identification, of particular importance for b physics

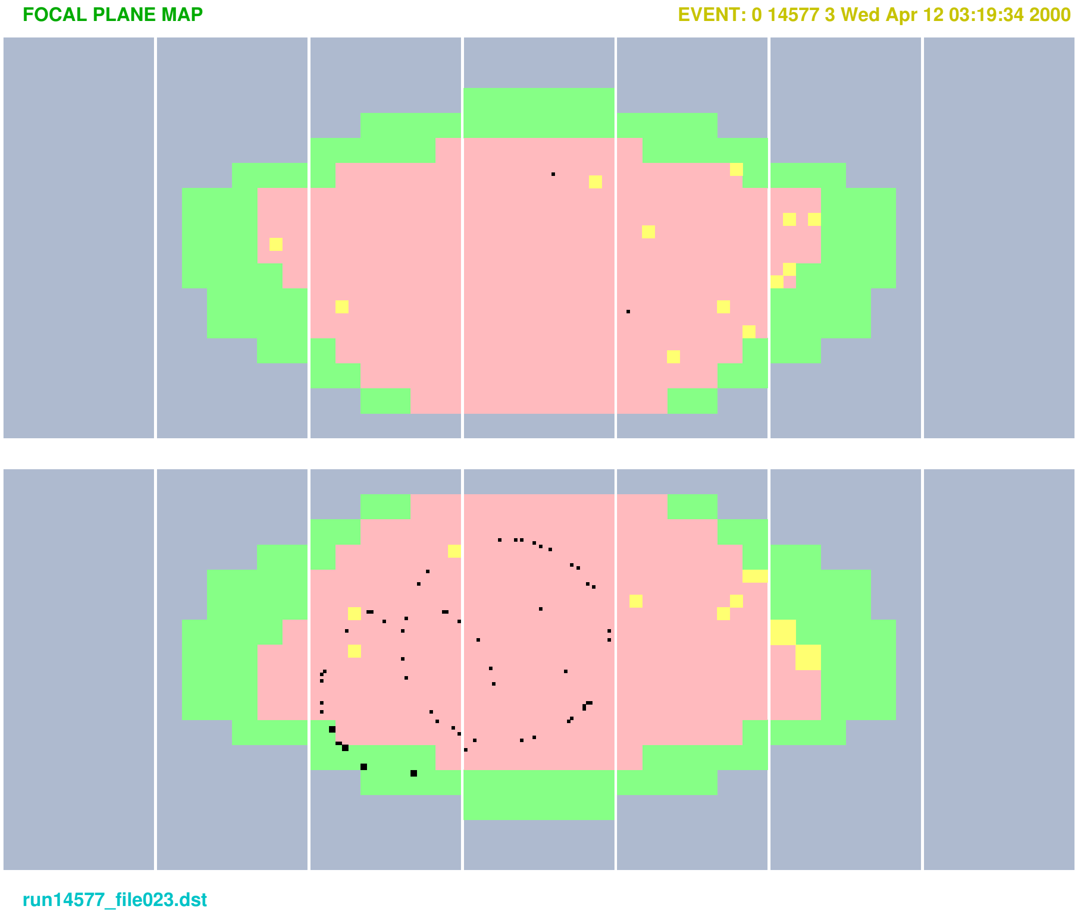
Recent developments

- Photon detector in action: MAPMT for HERA-B
- Photon detector reborn: TEA for CLEO III RICH
- Photon detector mature: CsI for ALICE, HADES, Compass
- New photon detector: HPD for LHCb
- New light concentrators: lenses
- New technique: DIRC at BaBar
- New radiator: aerogel for Belle, HERMES, LHCb
- Systems with several radiators: HERMES, LHCb
- High track densities: HERA-B RICH

Photon detector in action:

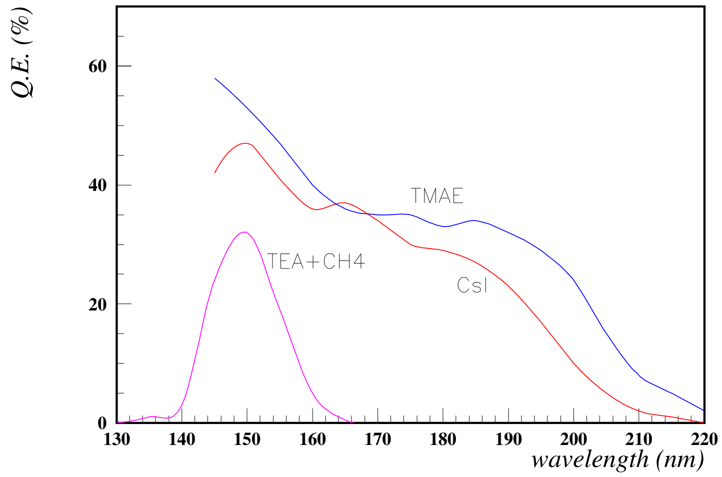
Multianode PMTs in HERA-B

- Clear rings, no noise

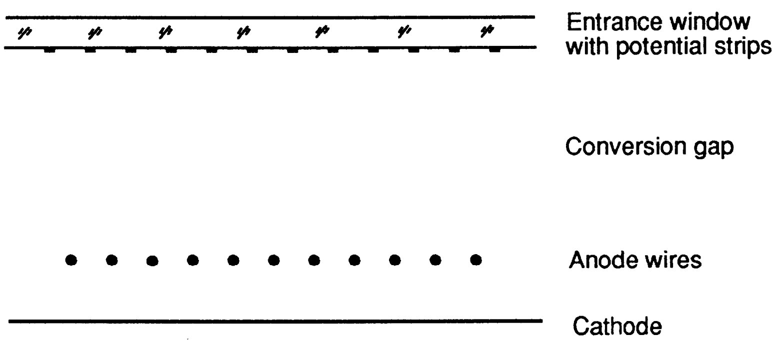


HERA-B background event

Photon detector reborn: TEA for CLEO III RICH

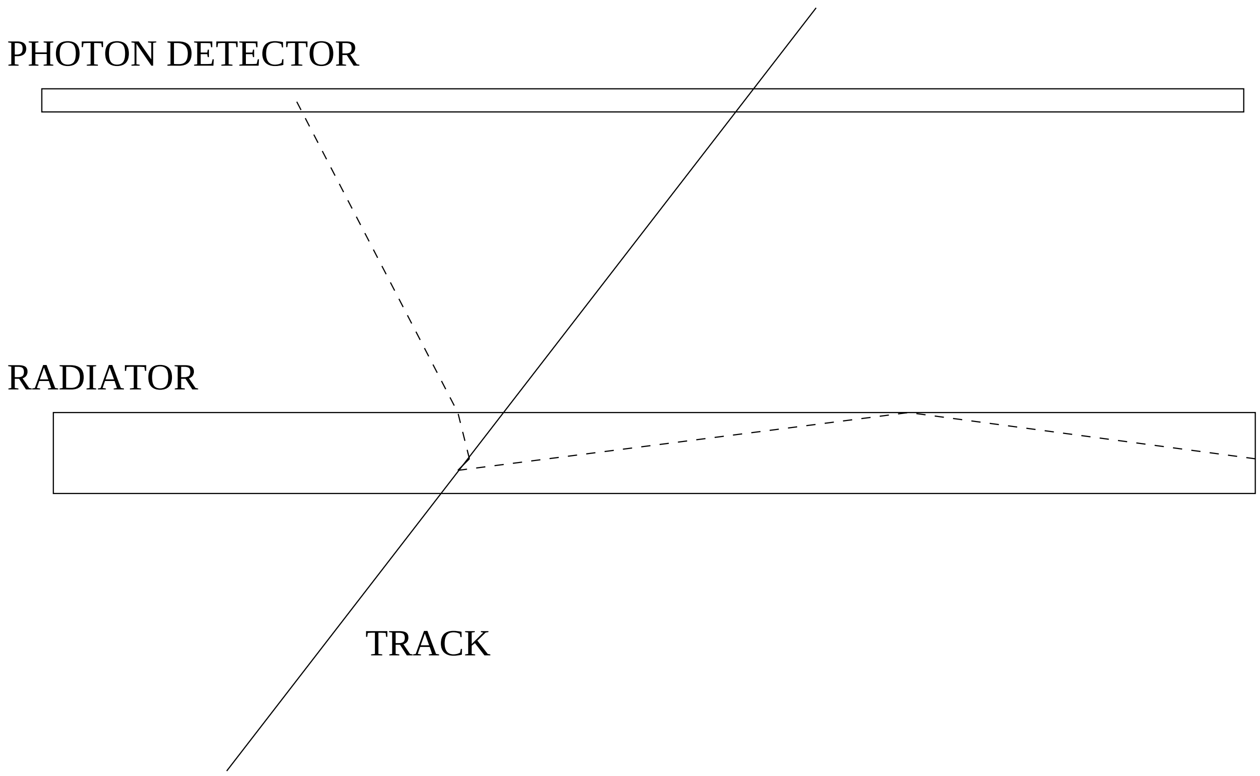


- TEA: Tri Etil Amine: a low vapour pressure photo-sensitive additive to chamber gas with an absorption length of 0.61mm.



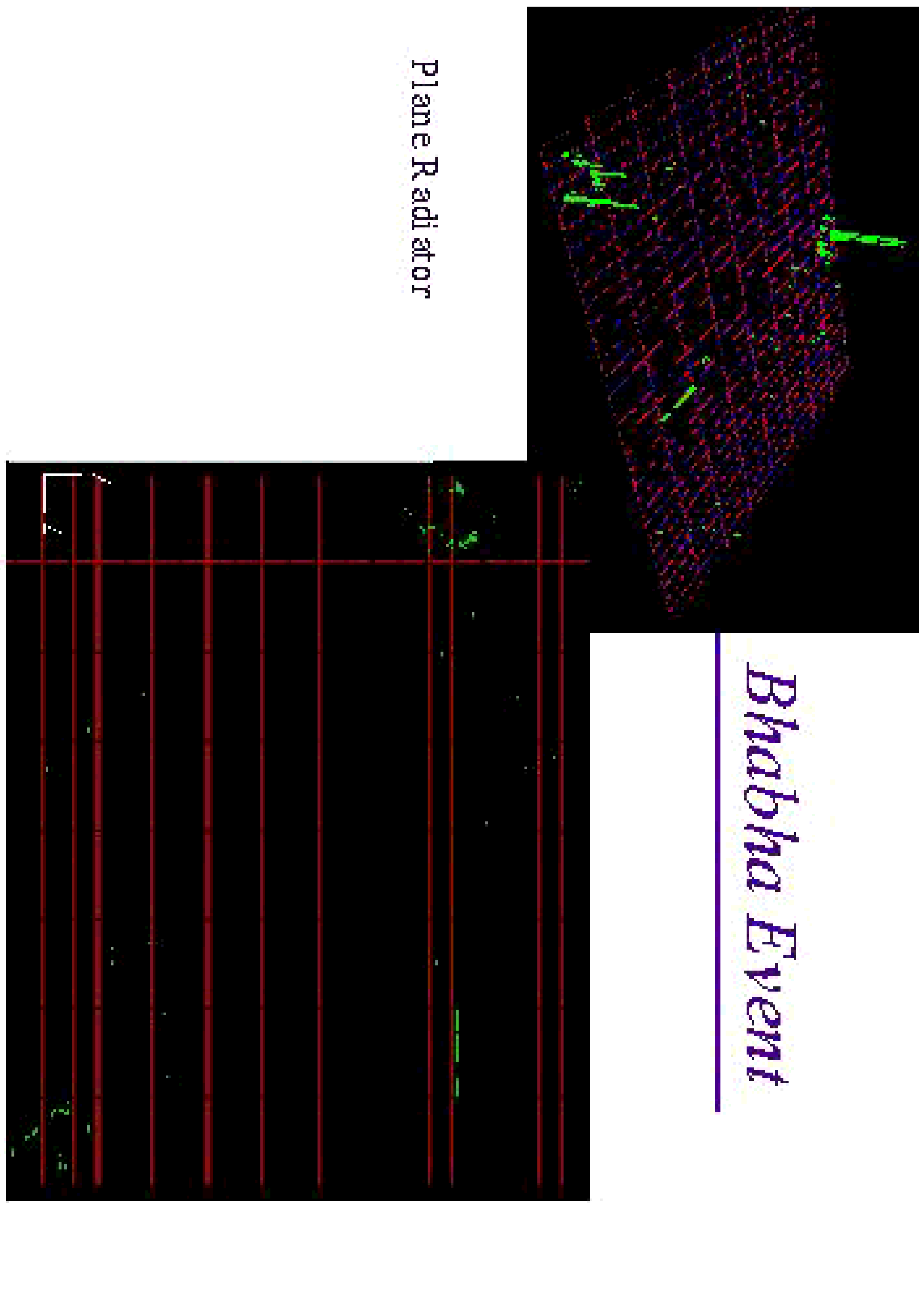
- Photoelectrons are detected in a thin multiwire chamber with pad read-out.

- First used in the pioneering RICH experiment E605.
- Examples: proximity focusing RICH counters
  College de France prototype, CLEO III RICH



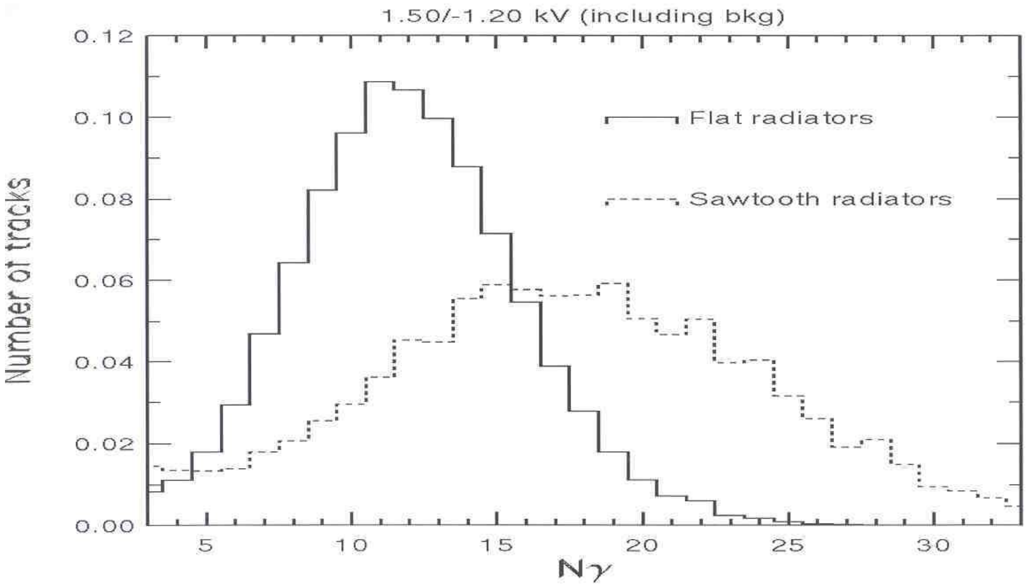
Proximity focusing RICH - principle

CLEO III RICH

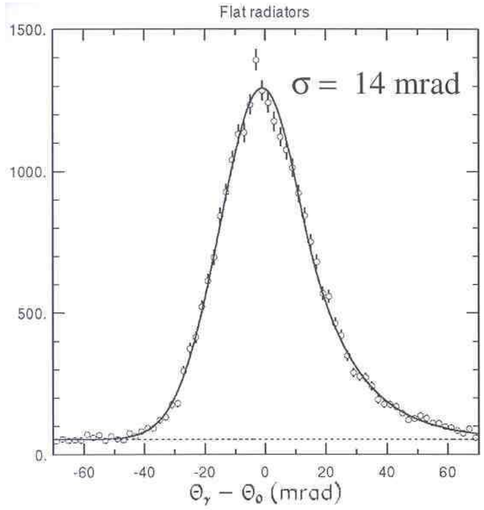


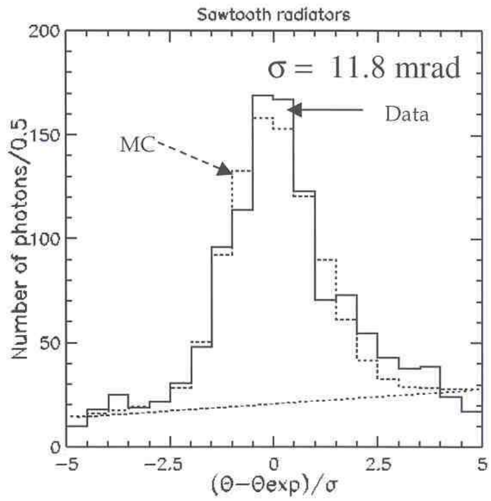
CLEO III RICH

Number of detected photons



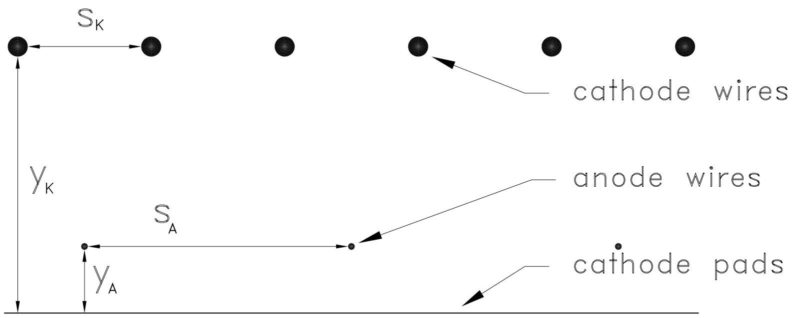
Resolution





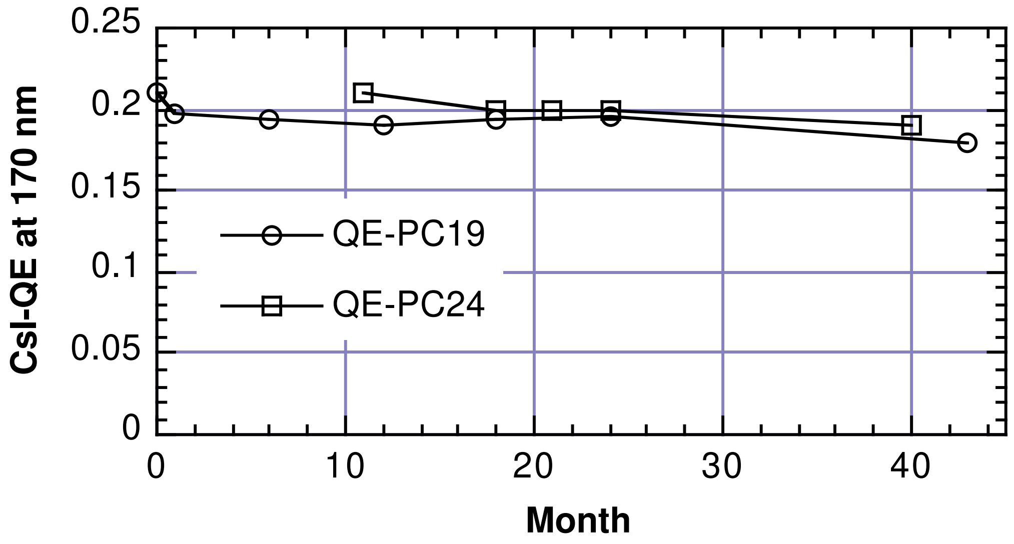
Photon detector mature: CsI

- A multiwire chamber with cathode pad read-out.
- A solid CsI layer, 100nm - 1μm thick, is evaporated on the cathode with pads (or on the entrance window).



- Needs a high purity chamber gas, usually methane with a water and oxygen content of order ppm, careful handling of the evaporated cathode.
- A lot of R+D (influence of substrate, conditioning, thickness, evaporation procedure, transfer to the chamber) was needed to make the technique mature.

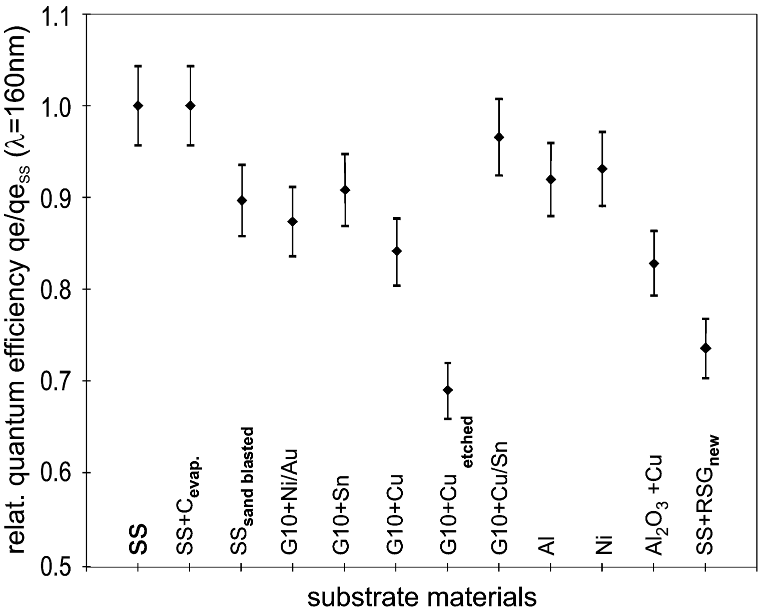
- Stability in the chamber (ALICE)



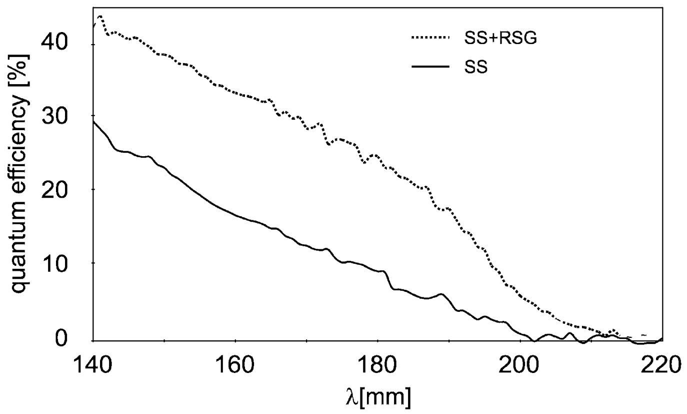
- Ageing under ion bombardment and high rate instabilities make it less suitable for high track density experiments (HERA-B)

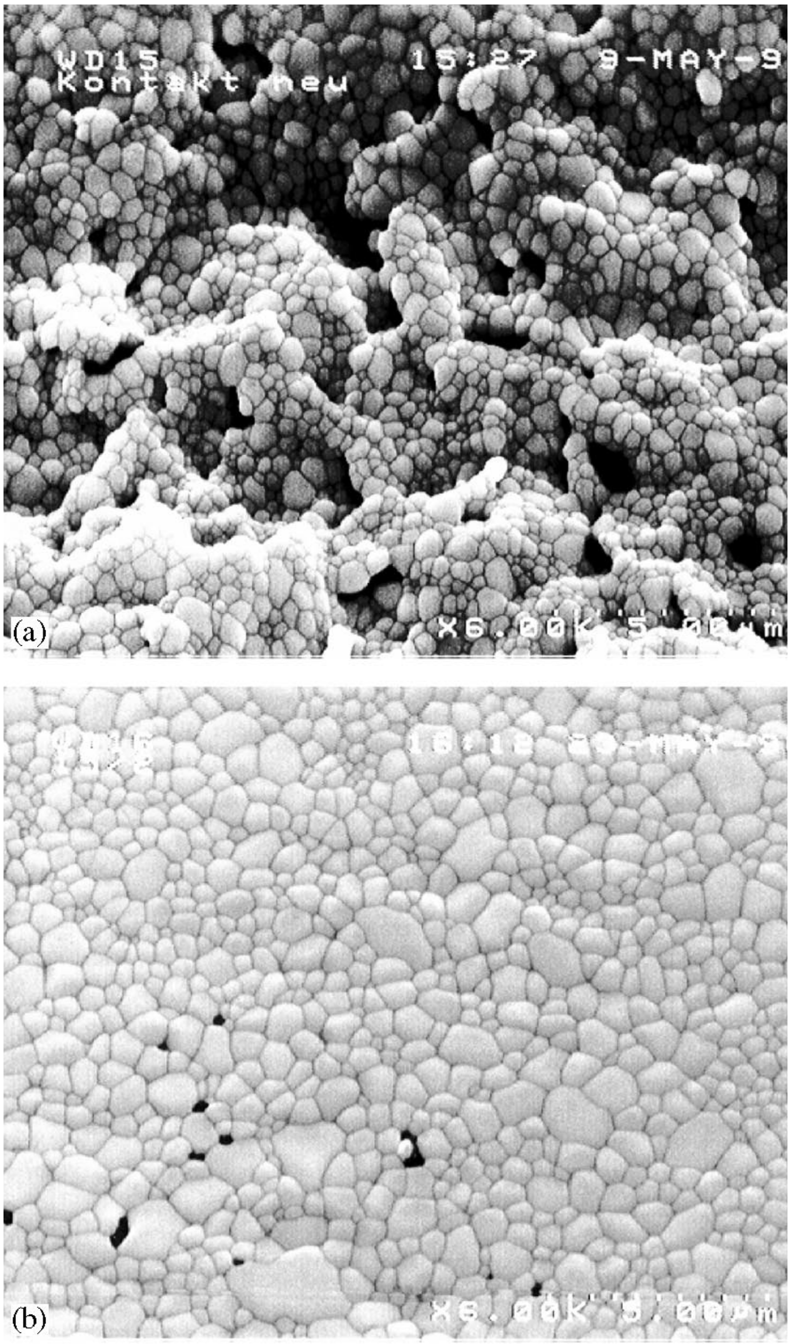
CsI photocathodes

Influence of substrate (HADES)



Conditioning helps for some substrates (HADES)

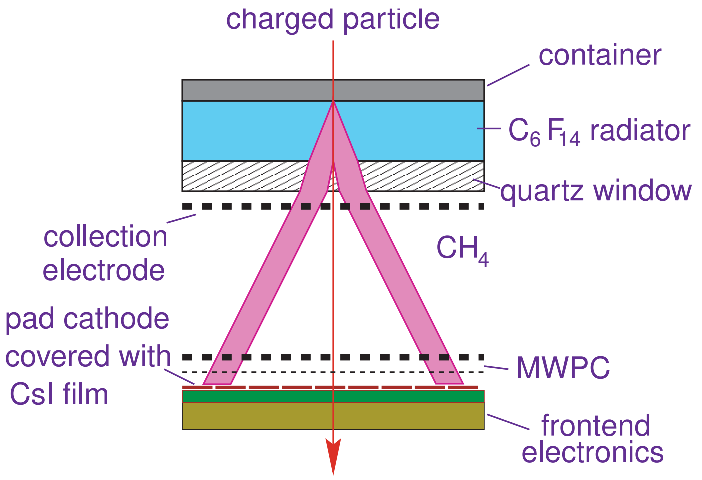




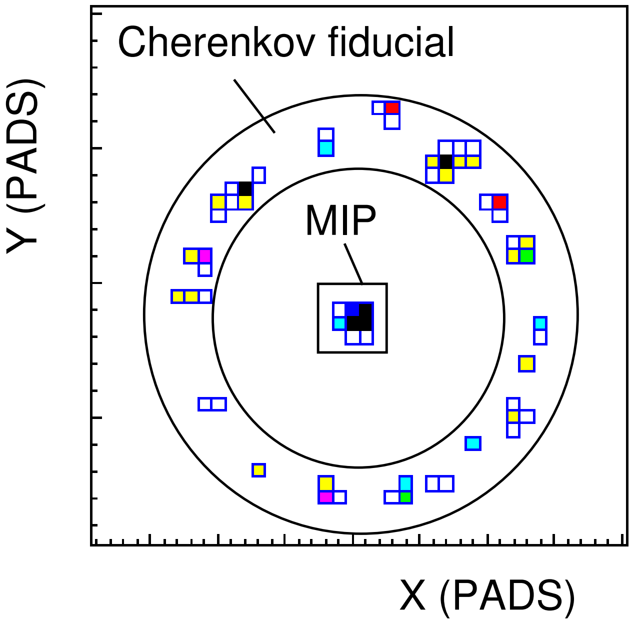
CsI film for two different substrates. The upper one has a better quantum efficiency

RICH with CsI

RICH with CsI as photo-sensitive substance will be used in HADES, COMPASS, ALICE, was considered for HERA-B.



ALICE RICH principle, beam test event

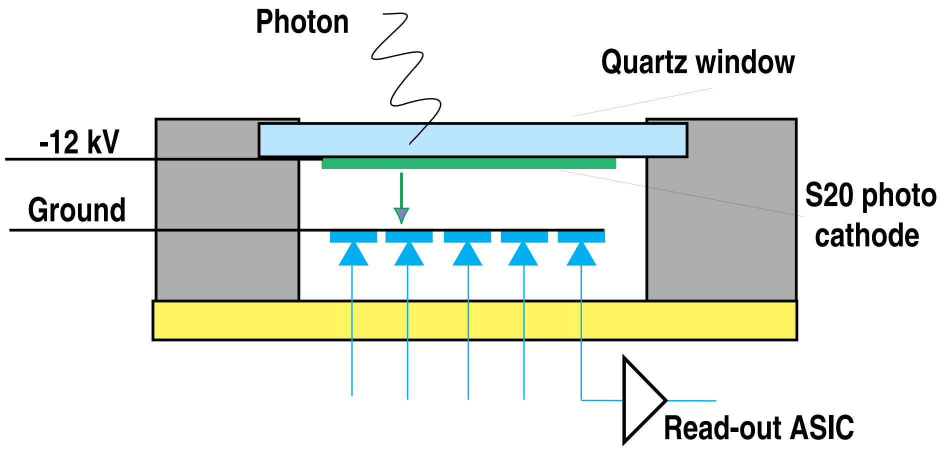


New photon detector:

HPD for LHCb

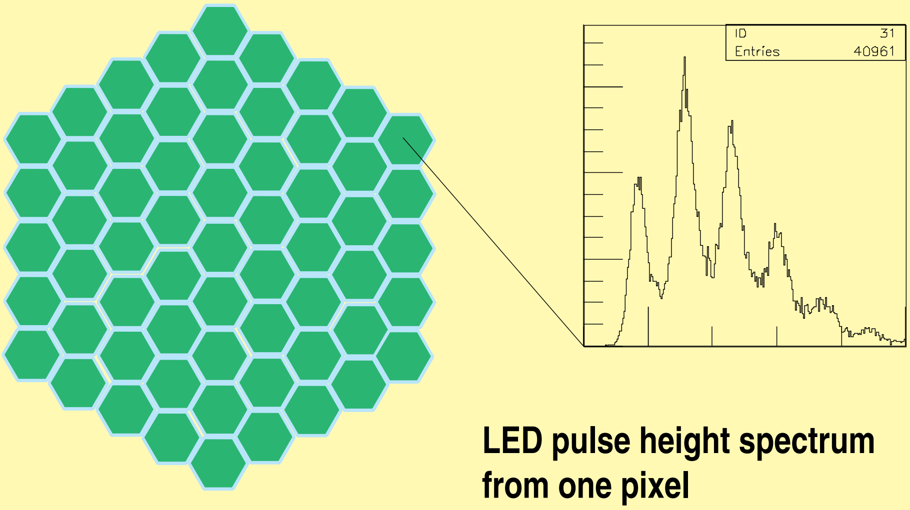
Hybrid PhotoDiode:

61 pixel Diodes : 2 x 2 mm^2
DEP (NL) + LHCb development



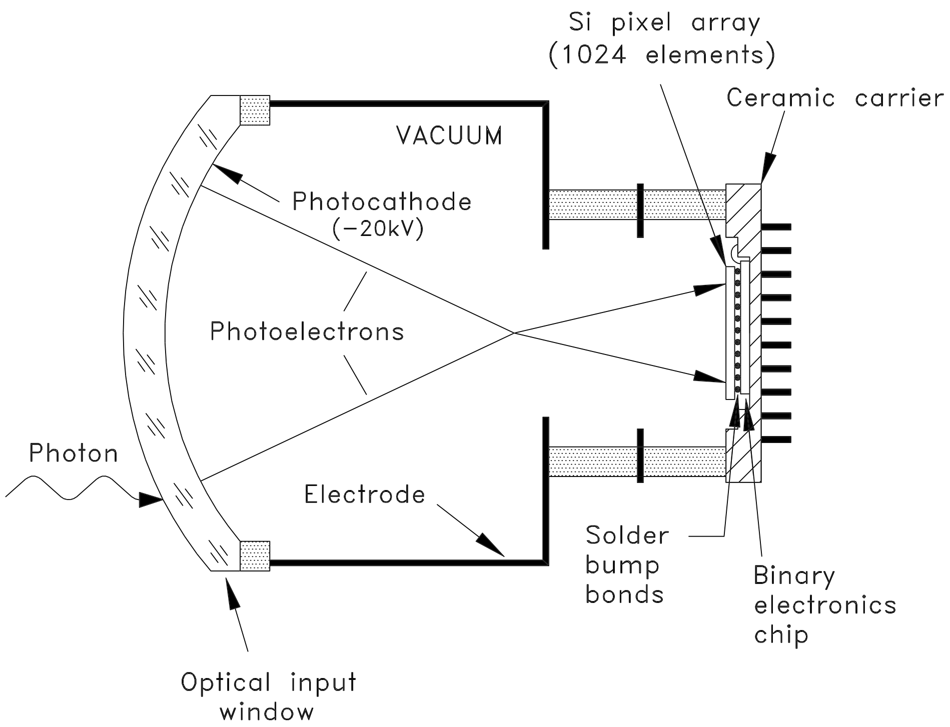
Silicon Pixel pattern

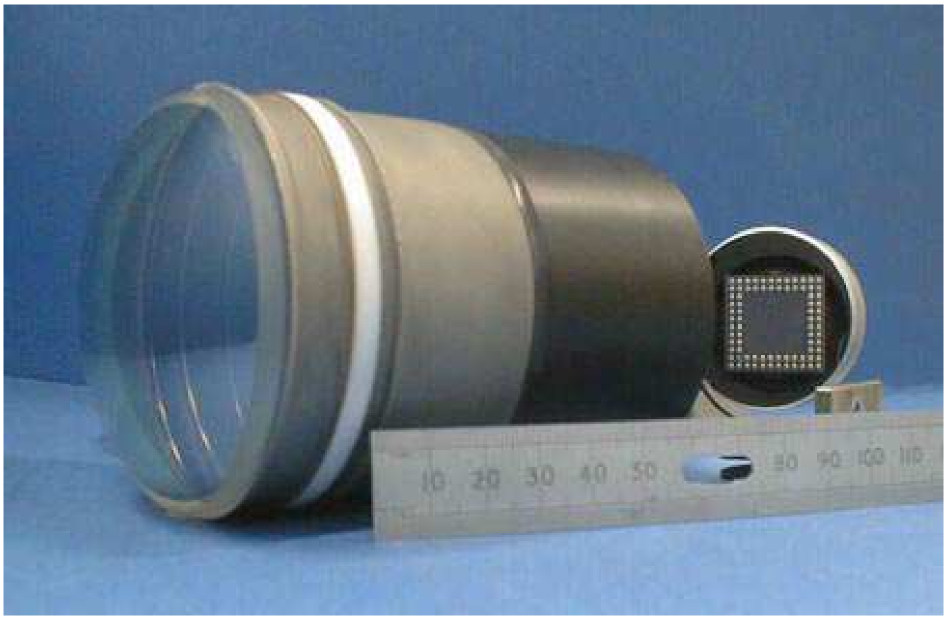
Single-photon sensitivity



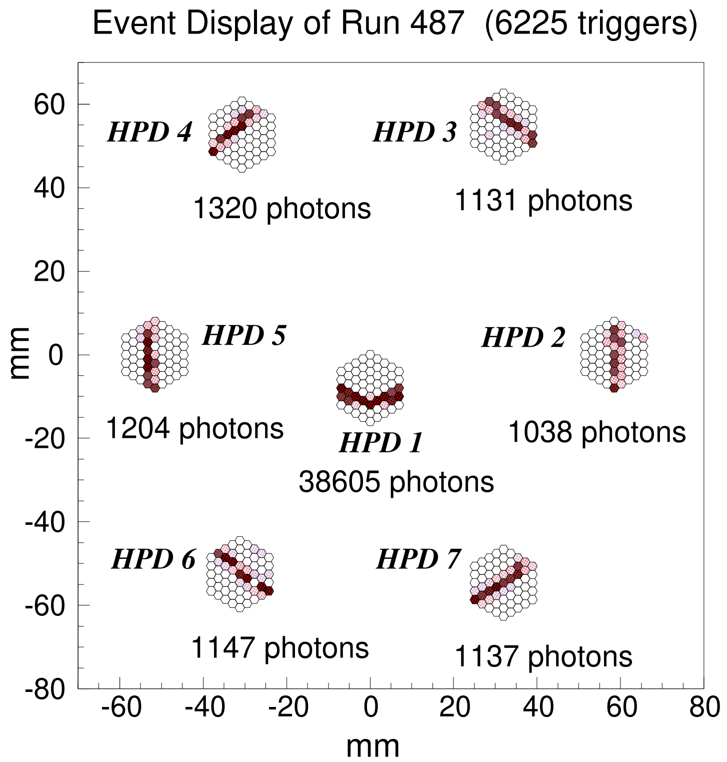
LED pulse height spectrum from one pixel

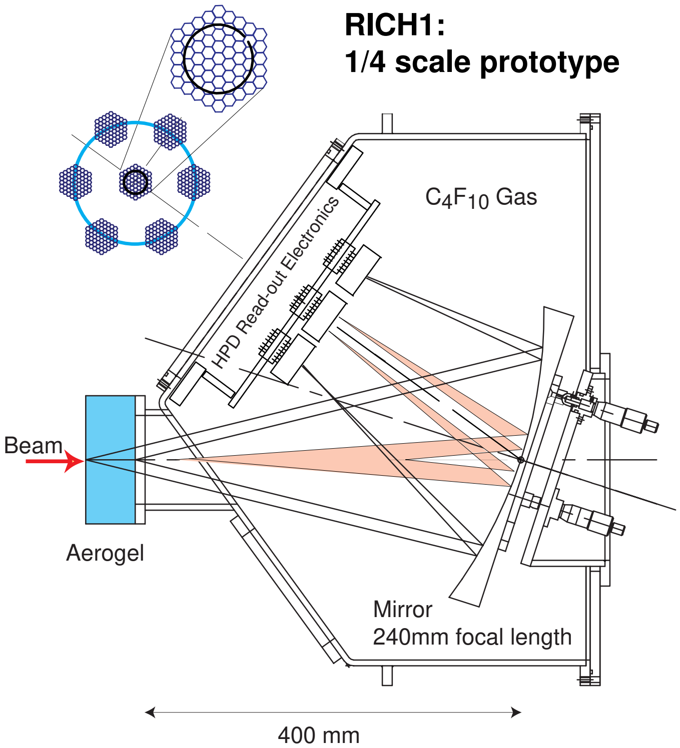
HPD for LHCb


Si pixel array
(1024 elements)
Ceramic carrier
VACUUM
Photocathode
(−20kV)
Photoelectrons
Photon
Electrode
Solder
bump
bonds
Binary
electronics
chip
Optical input
window



HPD beam tests





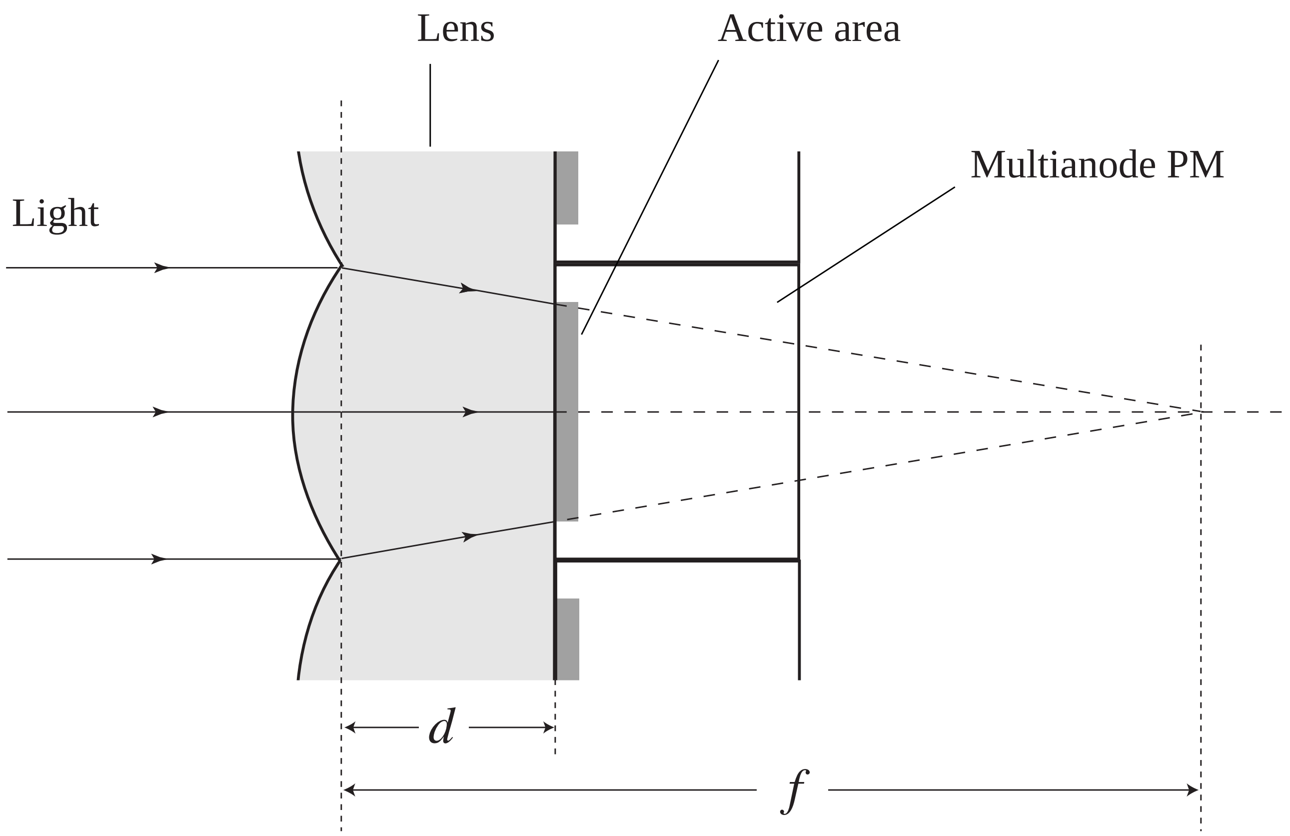
New light concentrators:

systems of lenses

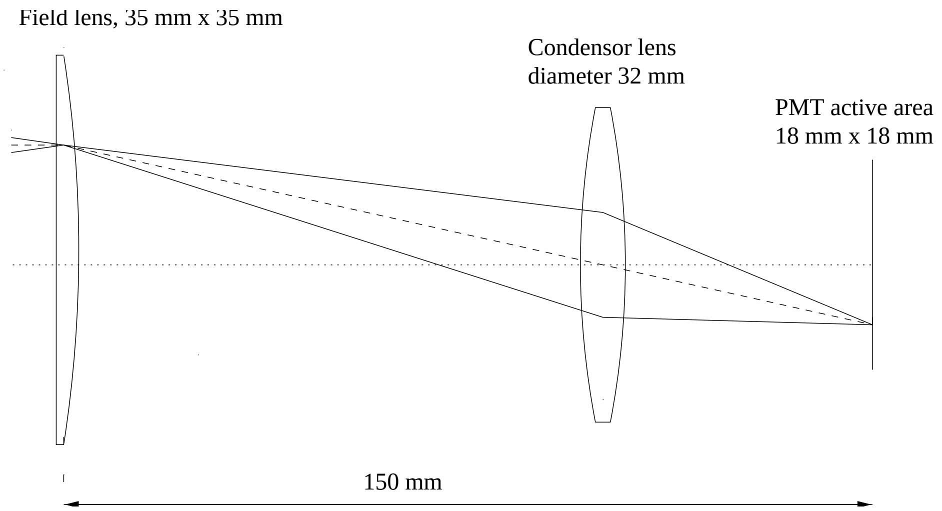
Optical systems for light collection and demagnification:

→ reduce dead area, adapt pad size

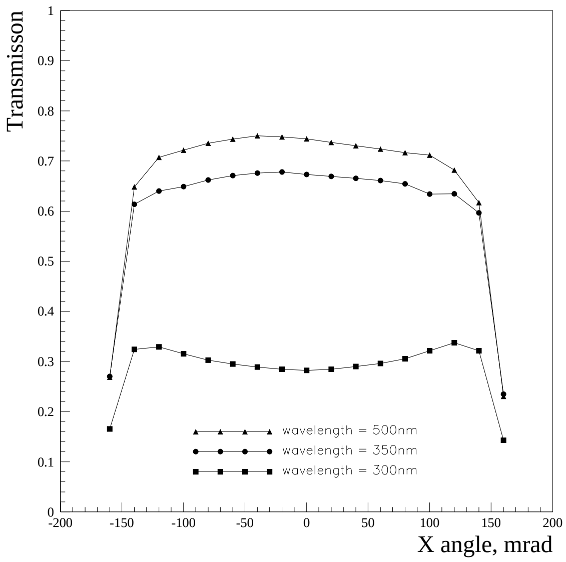
- LHCb: quartz lens + PMT

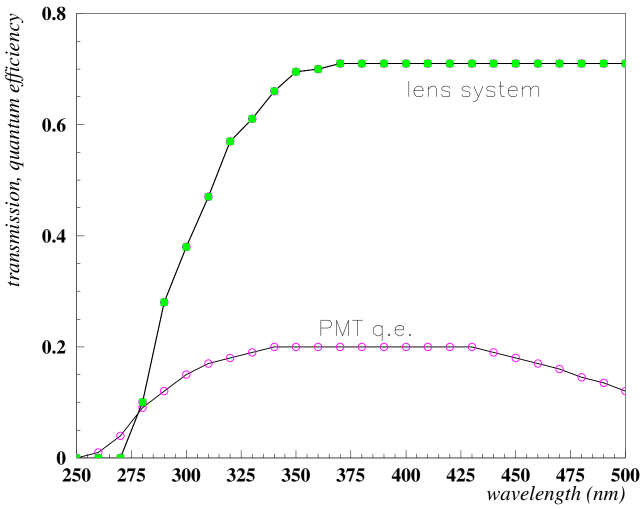


- HERA-B: two UVT plexi-glass lens system



→ angular acceptance, material transmission

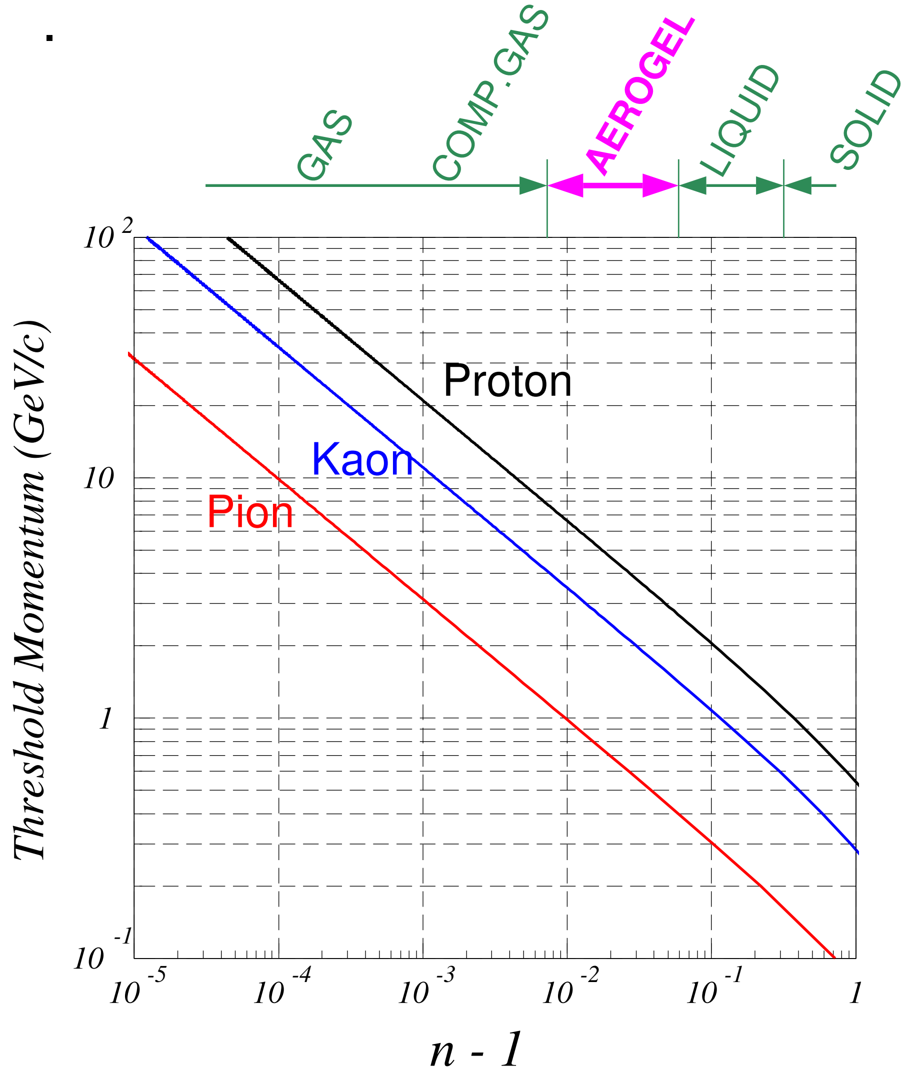




- Flat acceptance for incident angles below 120 mrad

New radiator: aerogel for Belle, HERMES, LHCb

Aerogel fills the gap between gases and liquids/solids.

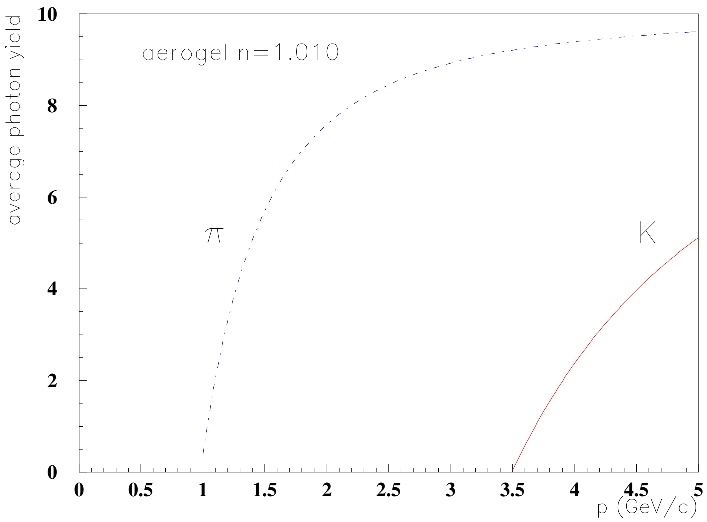


New: better transmission, hydrophobic

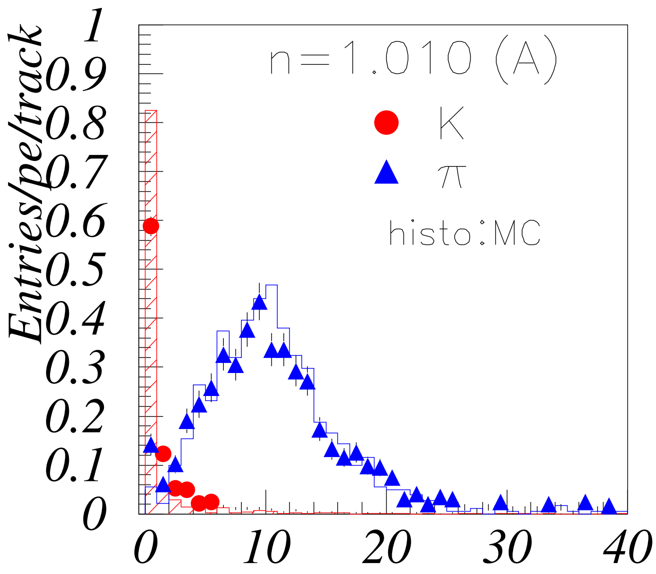
Aerogel for threshold Č.

Belle: separation of K (below) vs. π (above thr.): properly choosing n for a given kinematic region

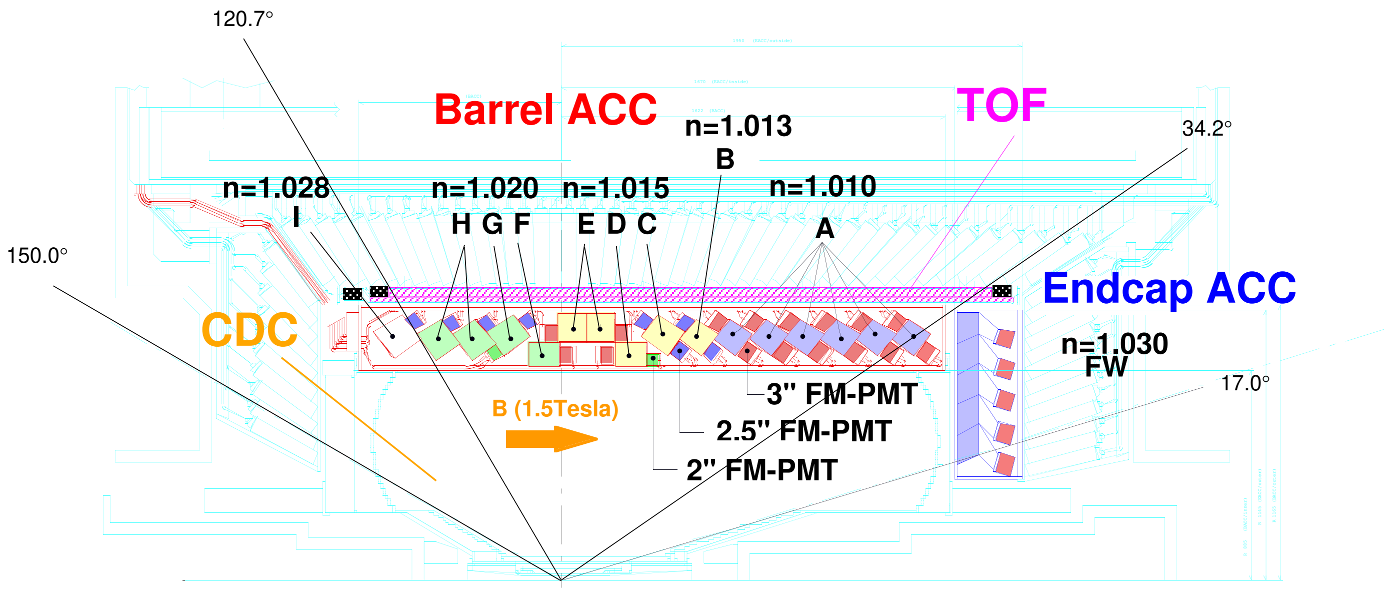
expected average yield vs p

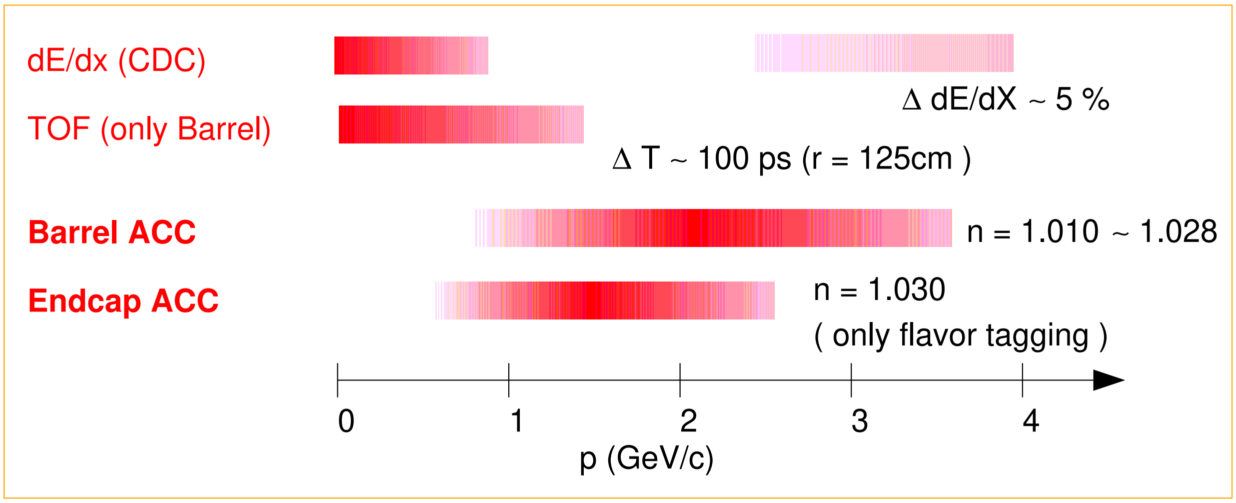


measured for 2 GeV/c< p <3.5 GeV/c

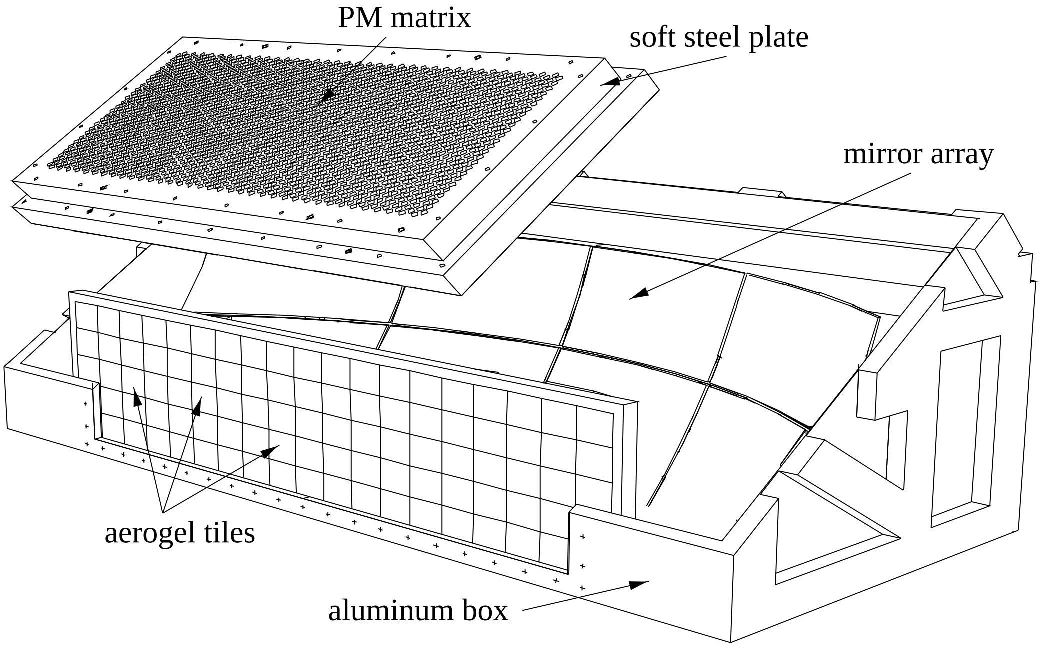


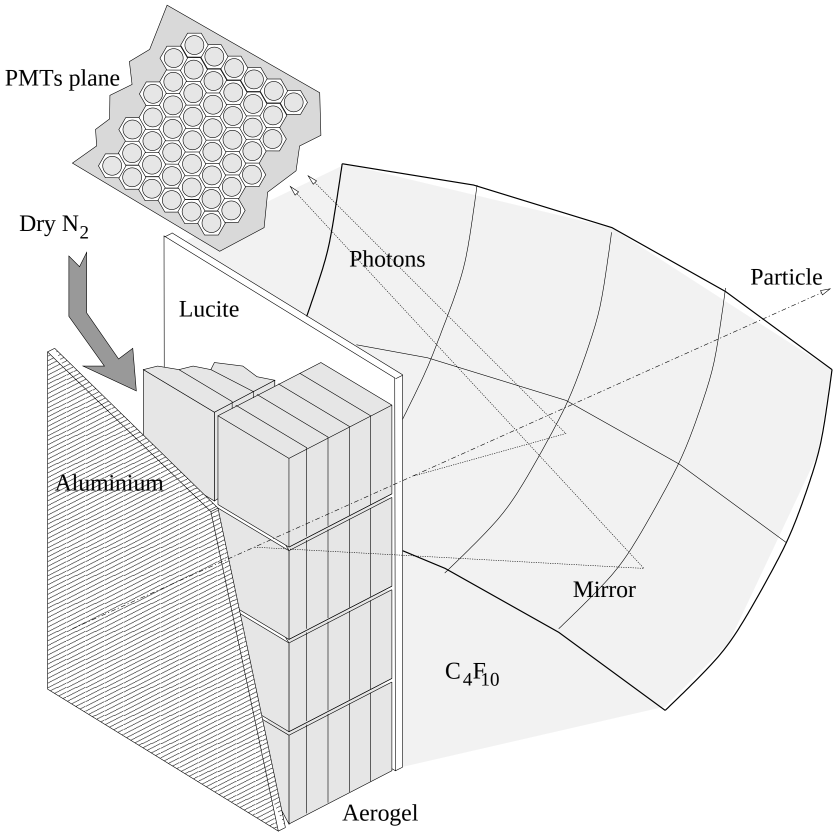
Aerogel for Belle



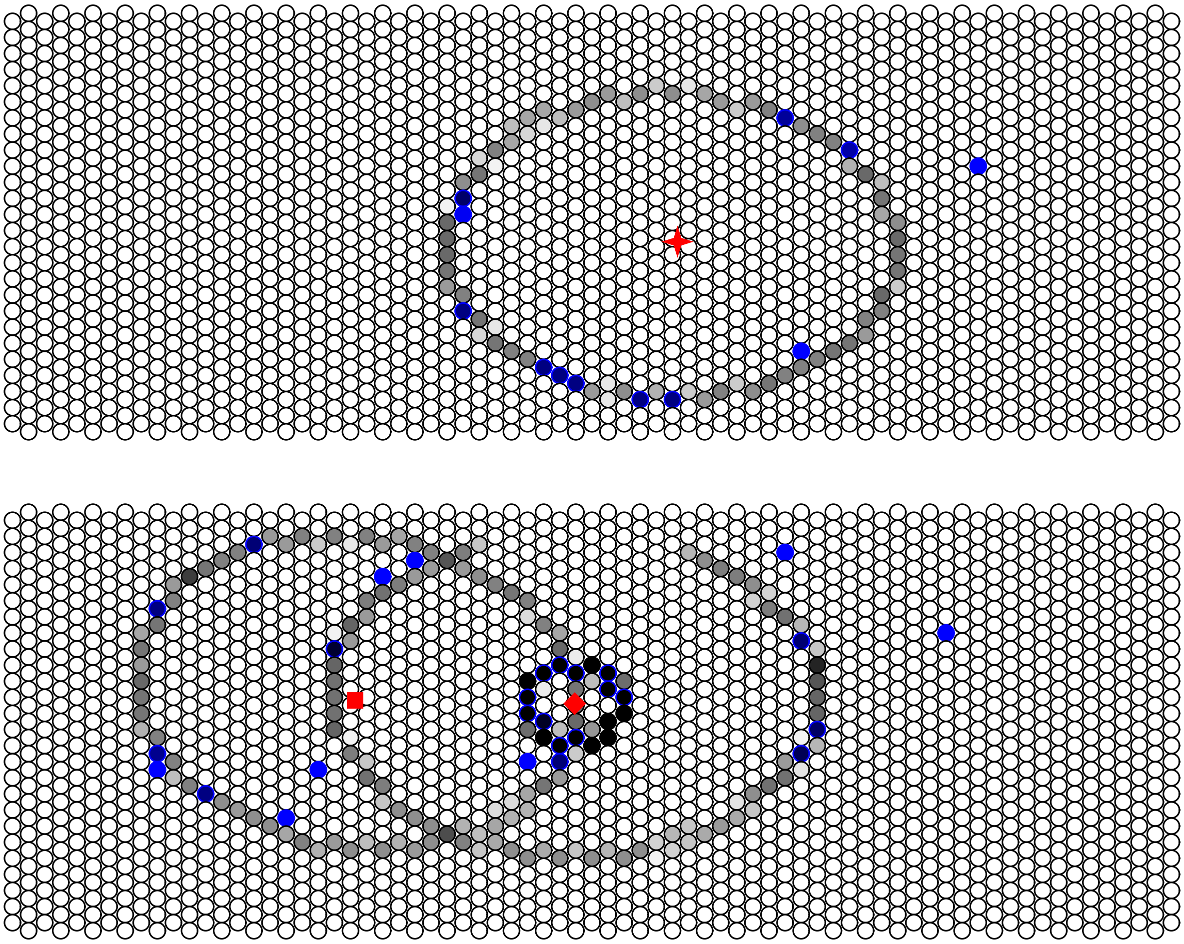


Aerogel for Hermes RICH





HERMES rings from aerogel

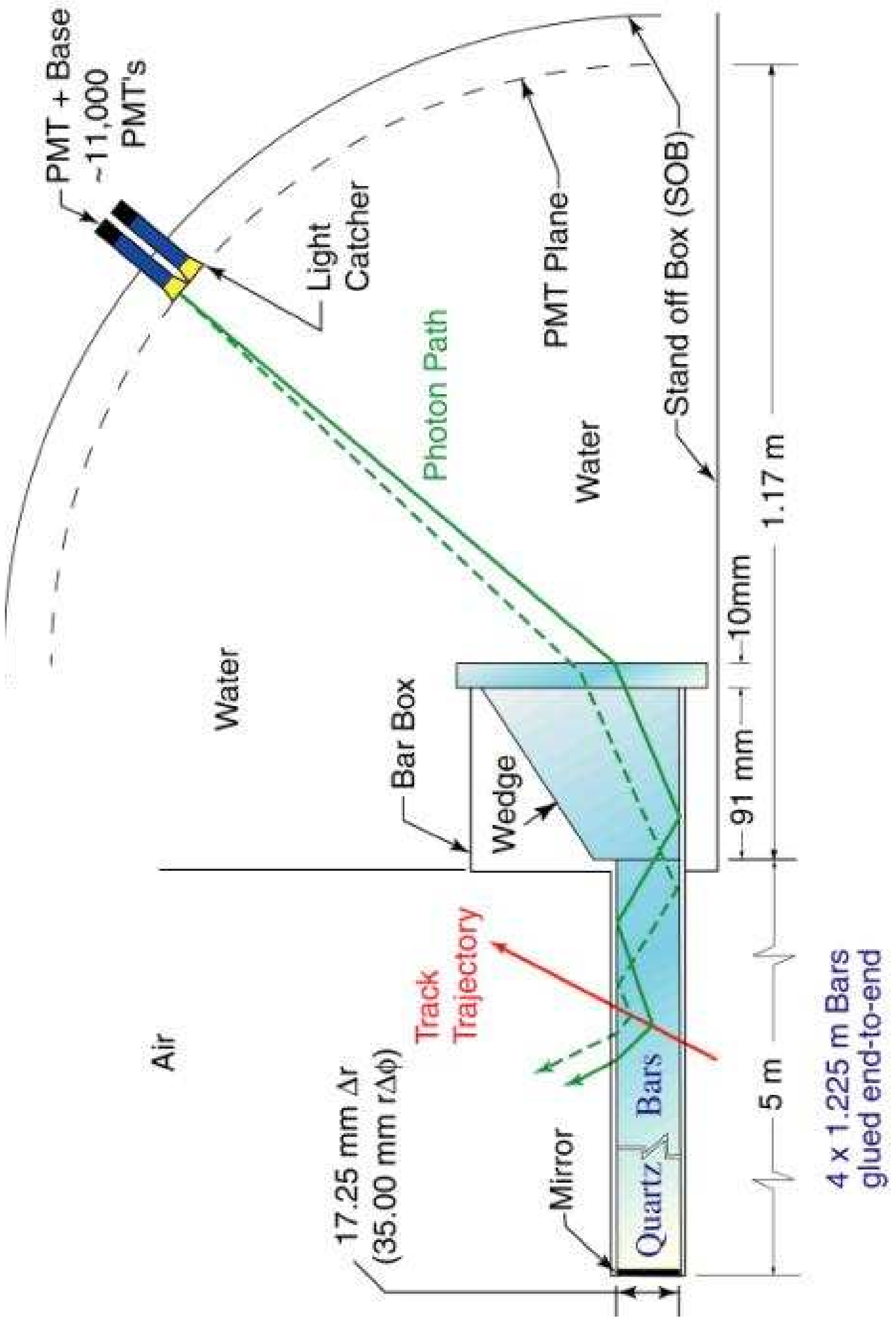


Run: 3360 Event: 20097411 Time: Mon Nov 23 05:39:09 1998 Number of tracks: 3

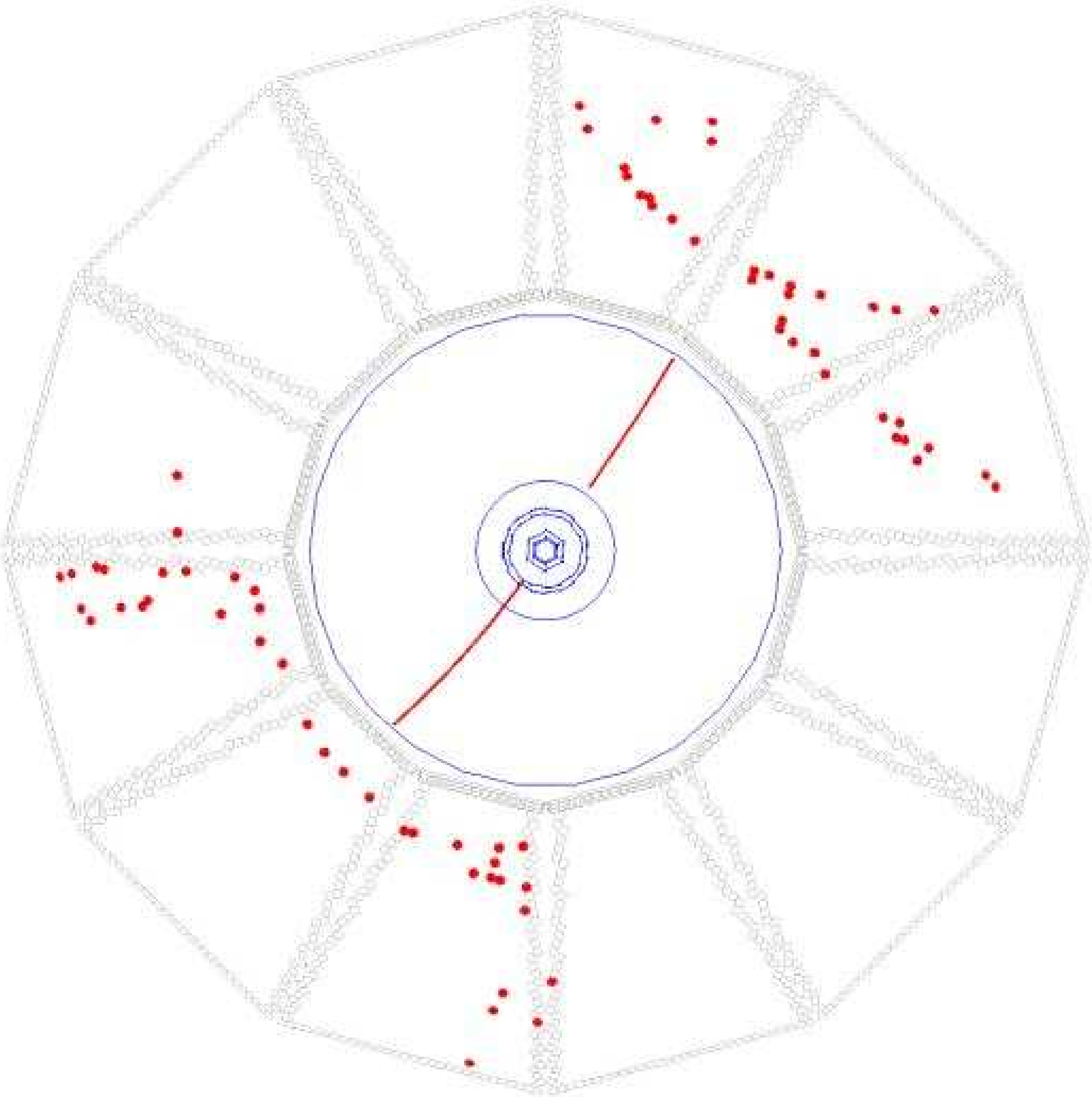
Particle	1	2	3
Momentum(GeV/c)	5.54	1.52	14.61
Type(est)	Kaon+	Pion-	Electron
Position	Top	Bottom	Bottom

No hits — 1 or more hits

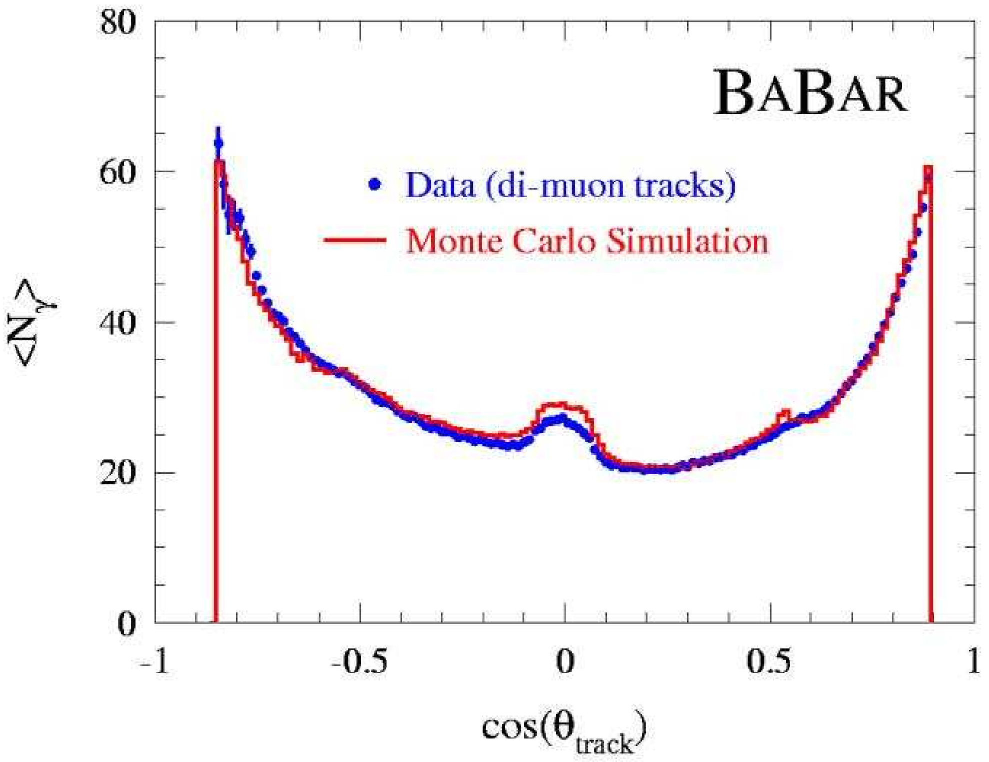
New technique: DIRC

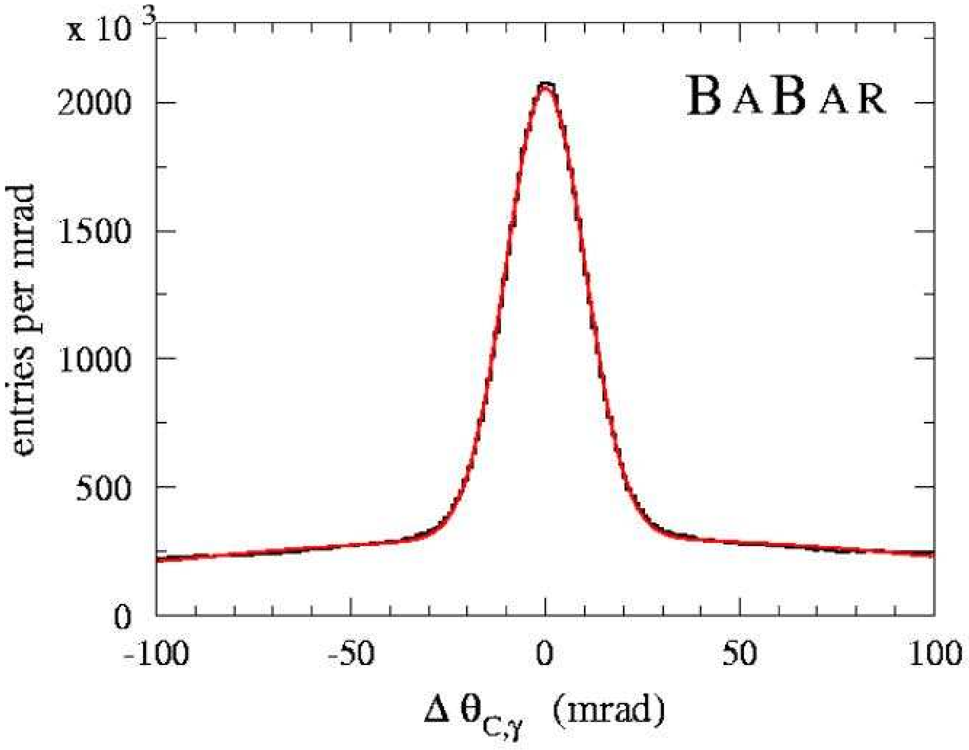


DIRC event

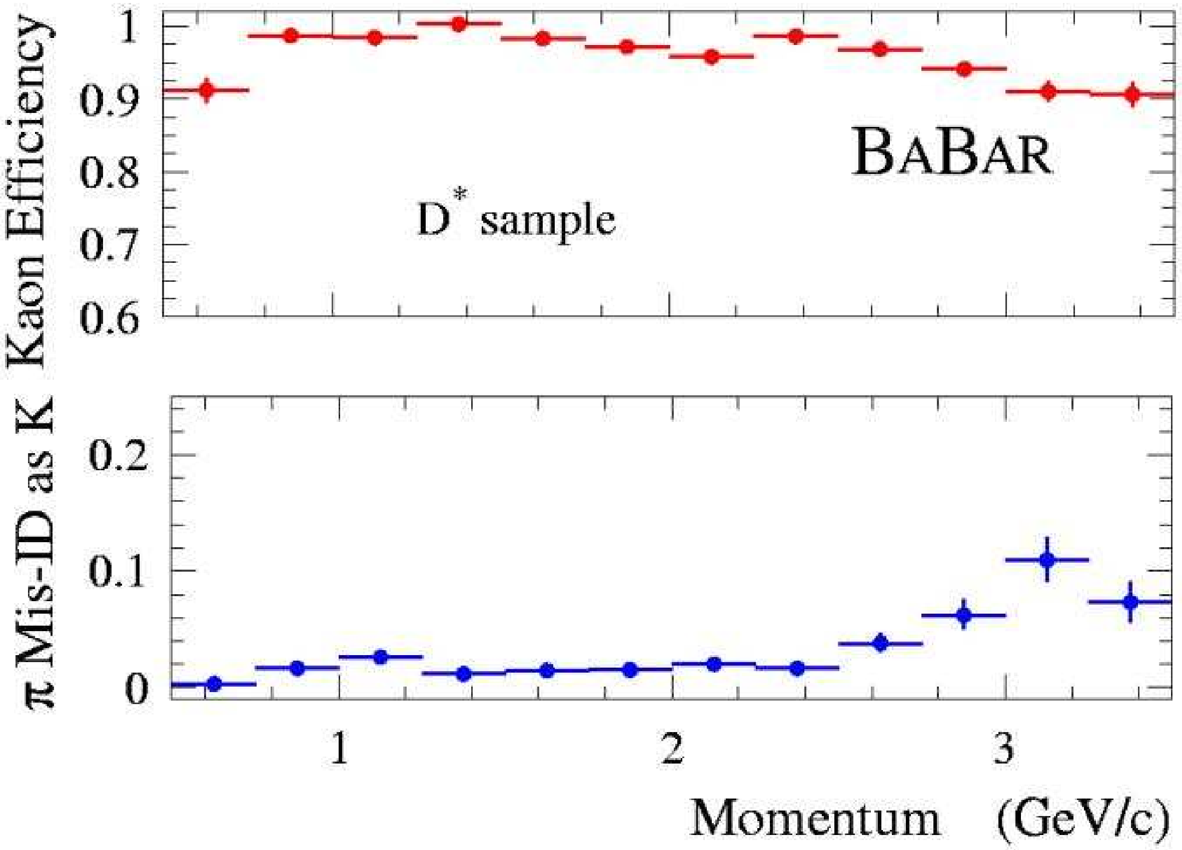


DIRC performance





DIRC PID


Kaon Efficiency
1
0.9
0.8
0.7
0.6
BABAR
D* sample
π Mis-ID as K
0.2
0.1
0
1
2
3
Momentum (GeV/c)

RICHes with several radiators

Why more than one radiator?

The kinematic region covered by the RICH, $p_{min} \rightarrow p_{max}$, depends on:

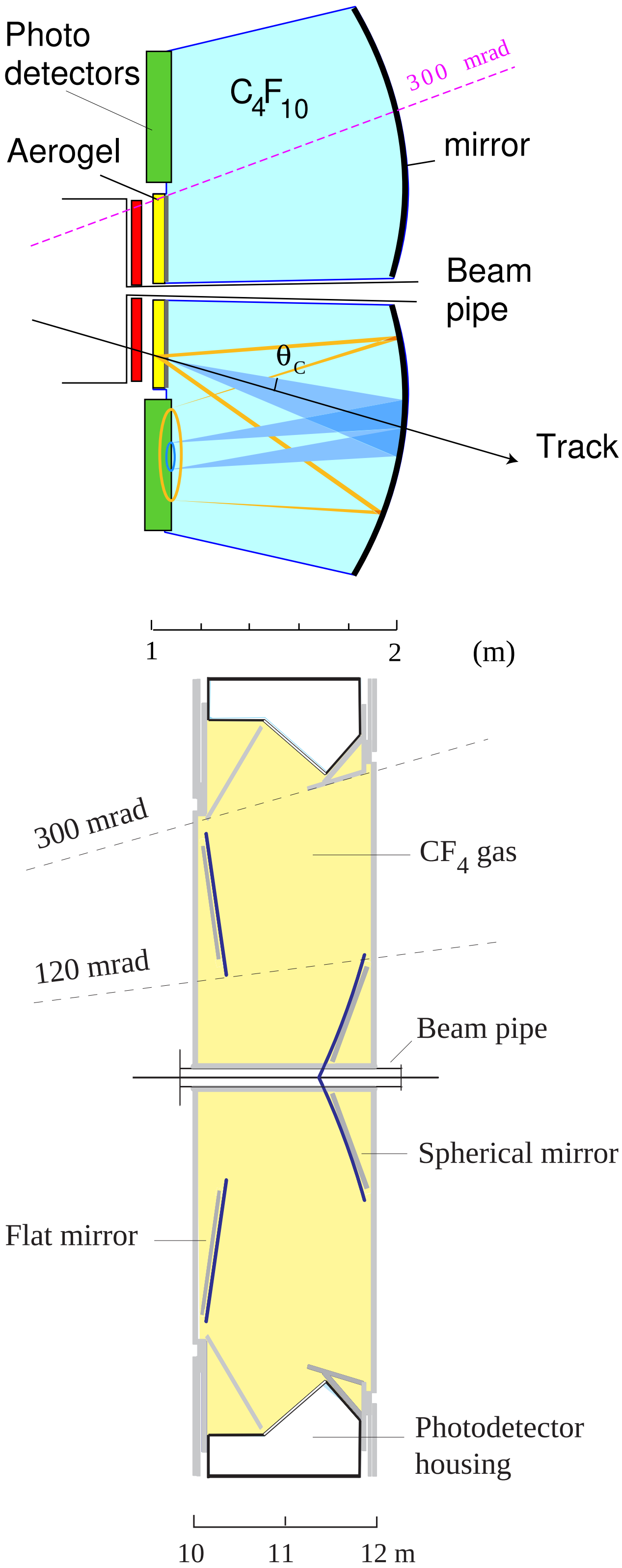
- the threshold momentum for the lighter of the two particles we want to separate $p_t = \beta_t \gamma_t mc$, $\beta_t = 1/n$. Typically $p_{min} = \sqrt{2} p_t$.
- the resolution in Čerenkov angle (ultimately given by the dispersion), which set a momentum limit p_{max} for a separation between two particle species.

A general property:

$$\frac{p_{max}}{p_{min}} \approx 4 - 7$$

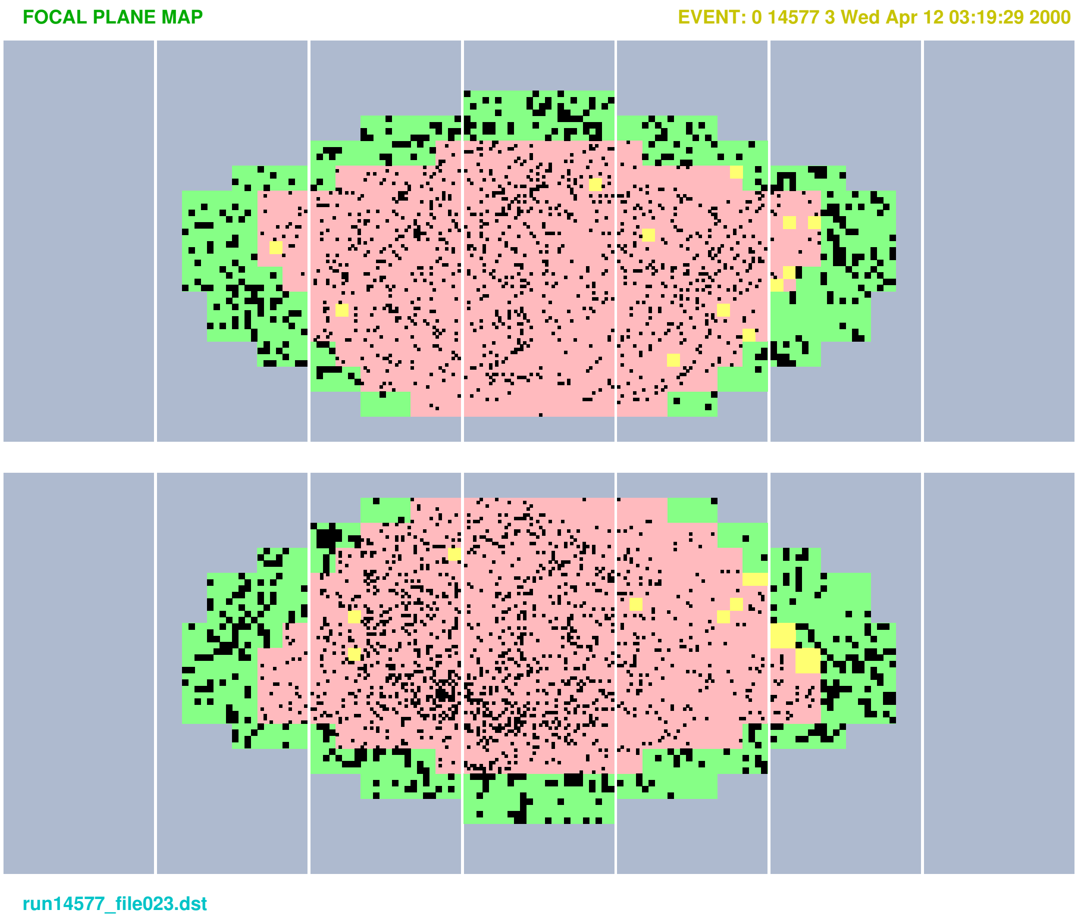
For a larger kinematic region we need two or more radiators.

RICHes for LHCb



RICH at high track densities

- HERA-B: Typical event



- Typical rates: 1MHz in the hottest part
- In operation since summer 1998
- No degradation of performance has been observed

HERA-B Performance

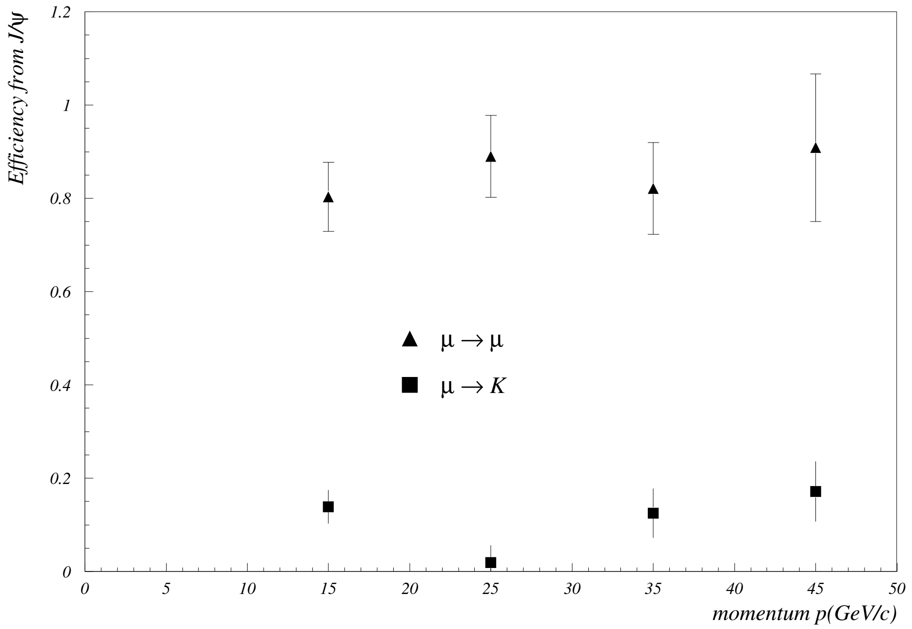
- RICH parameters:

  $N_0 = 43cm^{-1}$

  Number of photons = 32 per saturated ring

  Resolution = 0.7 mrad (M16), 1.0 mrad (M4)

- $\rightarrow$ in very good agreement with expectations



- Preliminary results of particle identification are promissing, tracking system still not perfectly aligned.

Relevance for other fields

- Medical applications

  Experience with photon detectors

- Environmental physics

  Monitoring of pure β emitters (^{90}Sr)

Conclusions