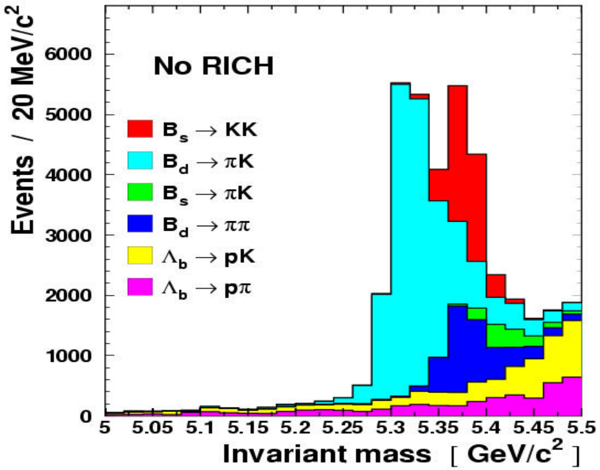
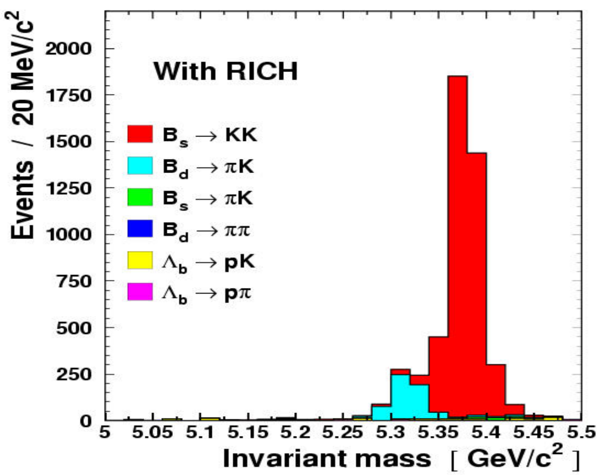
# Status of the LHCb RICH and hadron particle identification

M. Adinolfi
University of Oxford
On behalf of the LHCb collaboration

(with many thanks to all the people whose presentations have been hacked)

# Precision CP Measurements require a RICH



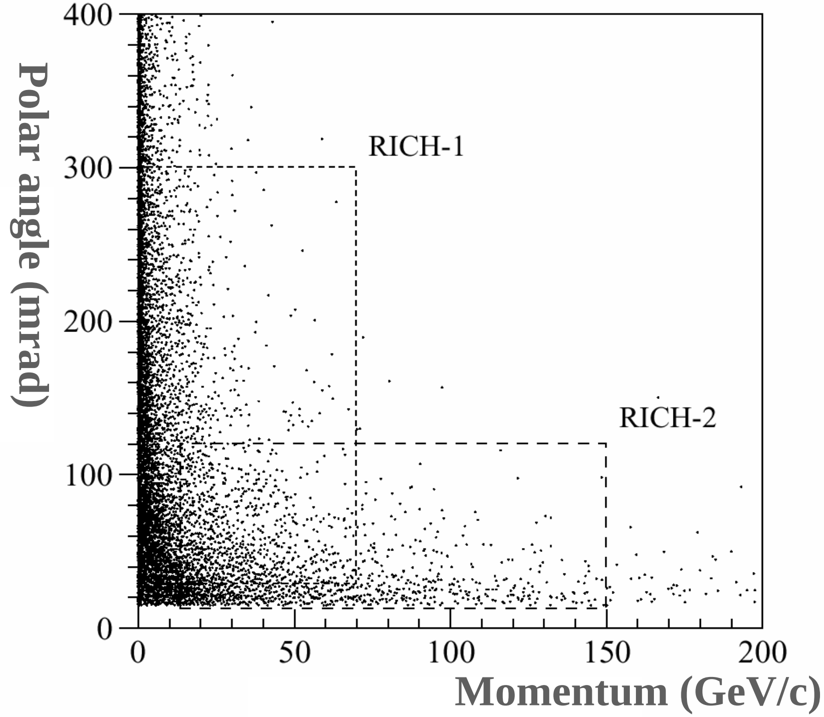

- Large sample of beauty events ~$10^{12}$/year at LHC start-up.
- Many hadronic final states e.g.: $B \to \pi^+ \pi^-$, $B_s \to K^+ K^-$. $B_s \to \pi K$.
- Flavour tagging, e.g.: kaons from b $\to$ c $\to$ s decays.

➡ Particle identification is essential.

Lepton identification will be discussed in the next talk.

LHCb Physics performance presented on Saturday

# Requirements for the LHCb RICH

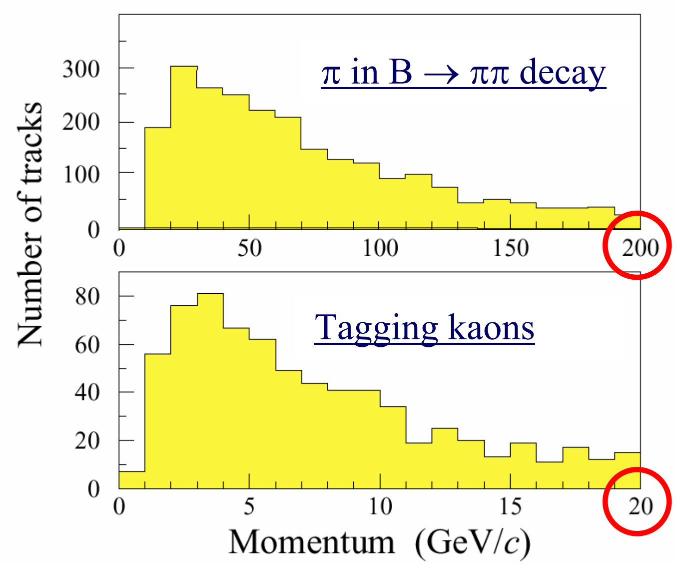



- Strong correlation between track momentum and polar angle.
- Physics requires identification of both low and high momentum hadrons.
  - Upper limit: π in B → ππ decay
  - Lower limit from tagging kaons.

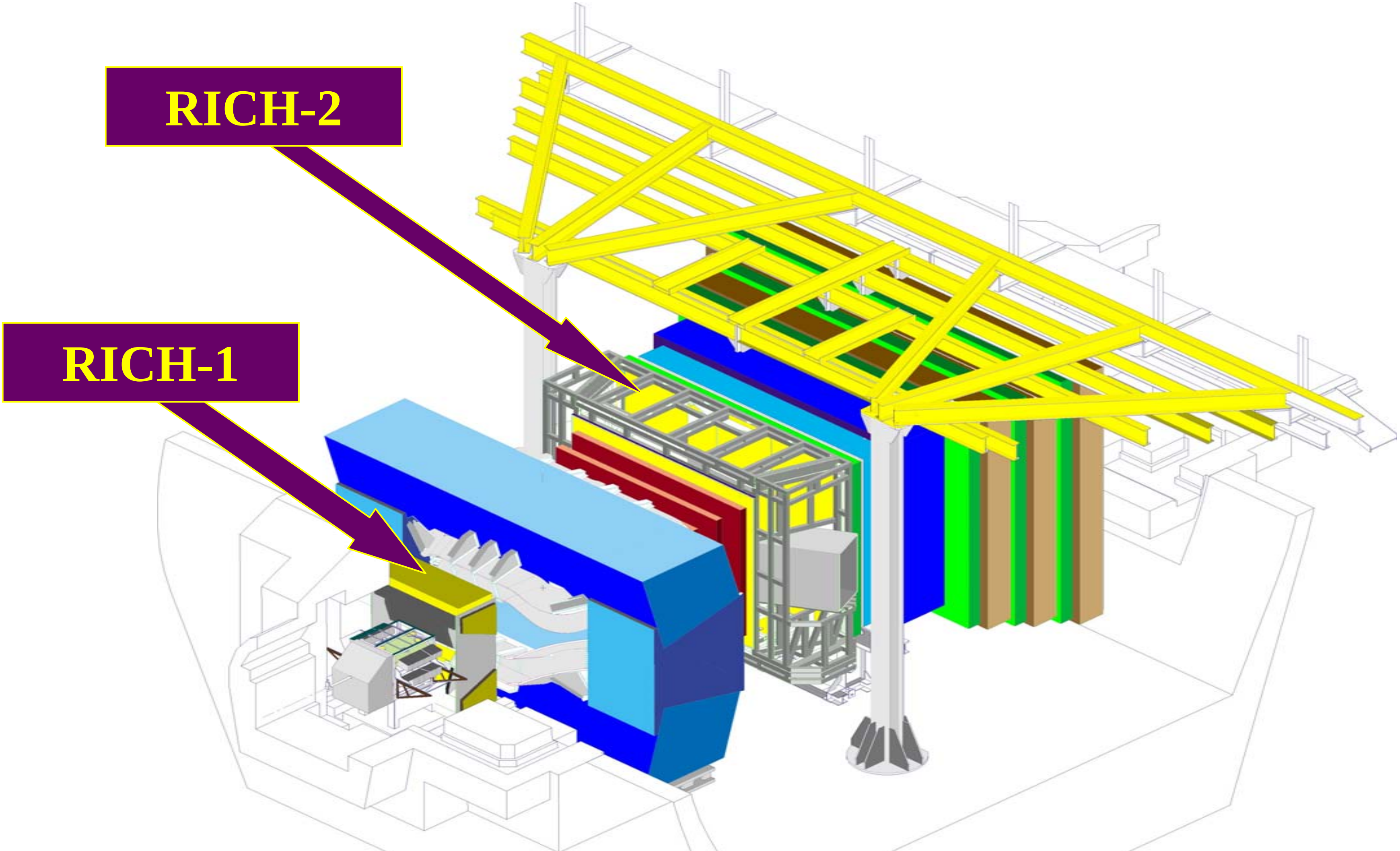
2 different RICH detectors are used:

RICH-1: Low momentum (2-60 GeV/c) particles, 25-300 mrad acceptance, upstream of magnet.

RICH-2: High momentum (20–100 GeV/c) particles, 15-120 mrad acceptance, downstream of magnet.



# The LHCb RICH Detectors



# Further Requirements for RICH-1

More constraints have been imposed on the RICH-1 during the re-optimization of LHCb, including:

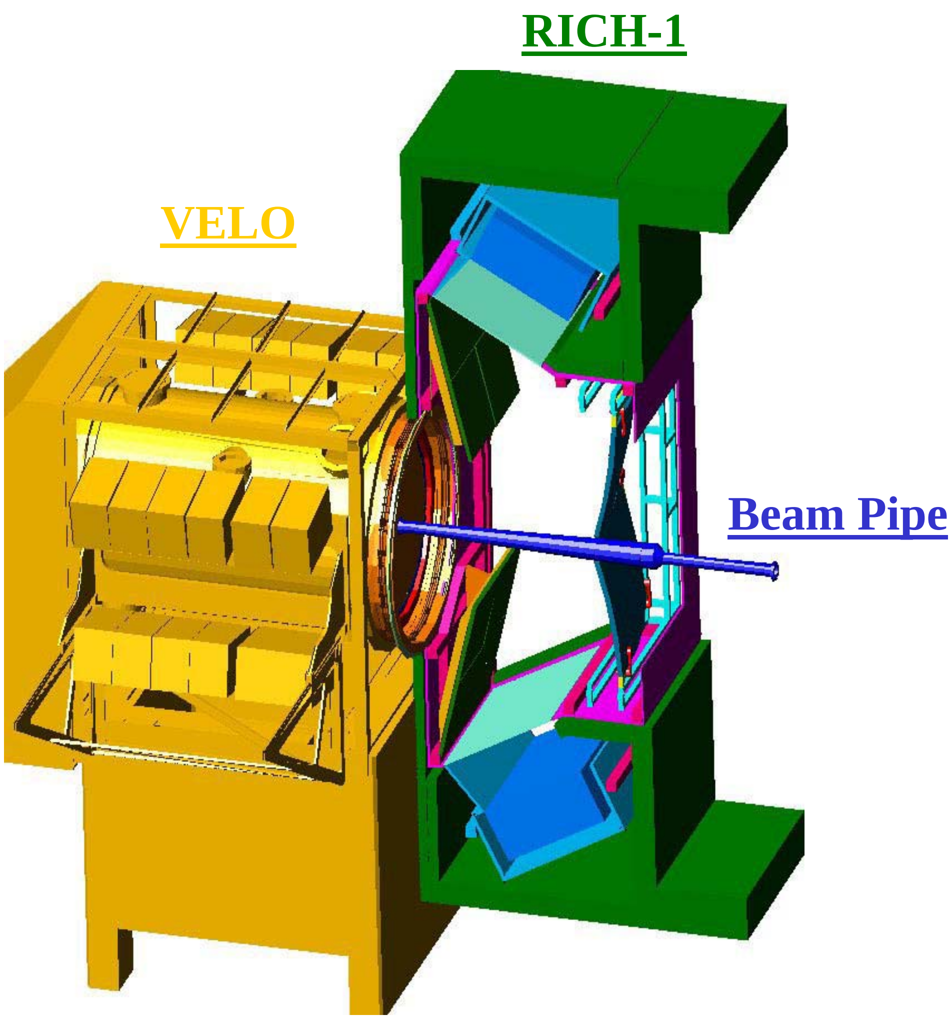
- Reduce the material within the spectrometer acceptance.
  - Gas vessel directly sealed to the VELO;
  - Light mirrors;
  - Mirror support outside acceptance;

**$X_0$ reduced from 14% to 7.3%**

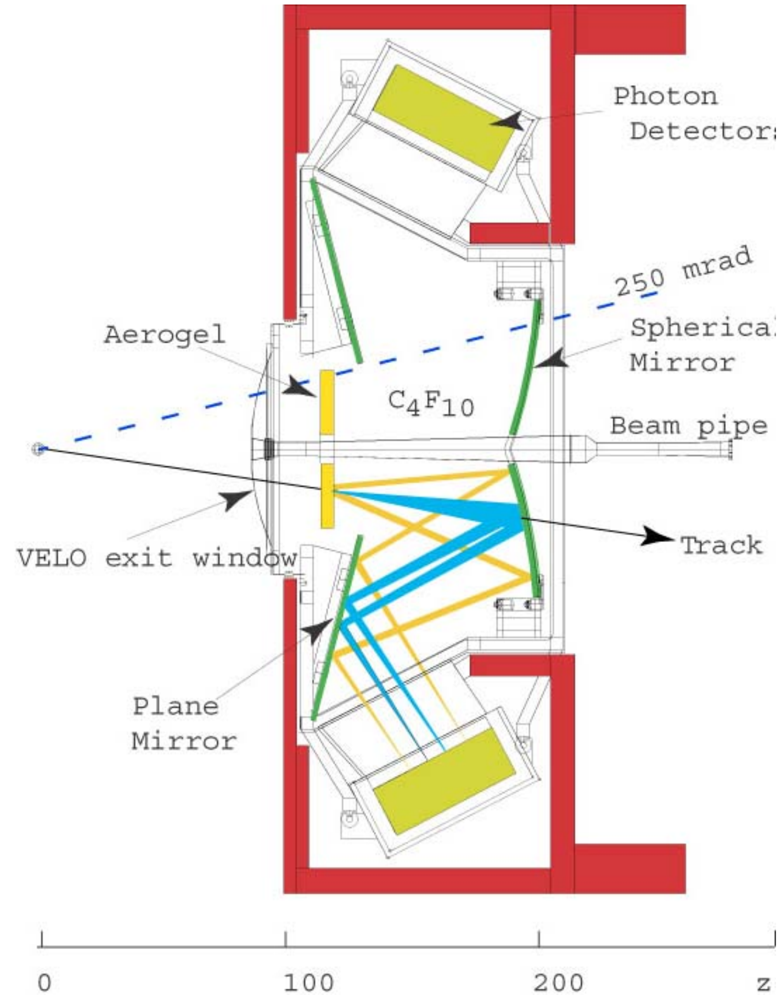
- Compatibility with the increased magnetic field (∫B ~ 0.15 Tm) in the RICH-1 region.
  - Iron shield designed to increase B field in the gas vessel:

**Vertical RICH**

# RICH-1



RICH-1
VELO
Beam Pipe

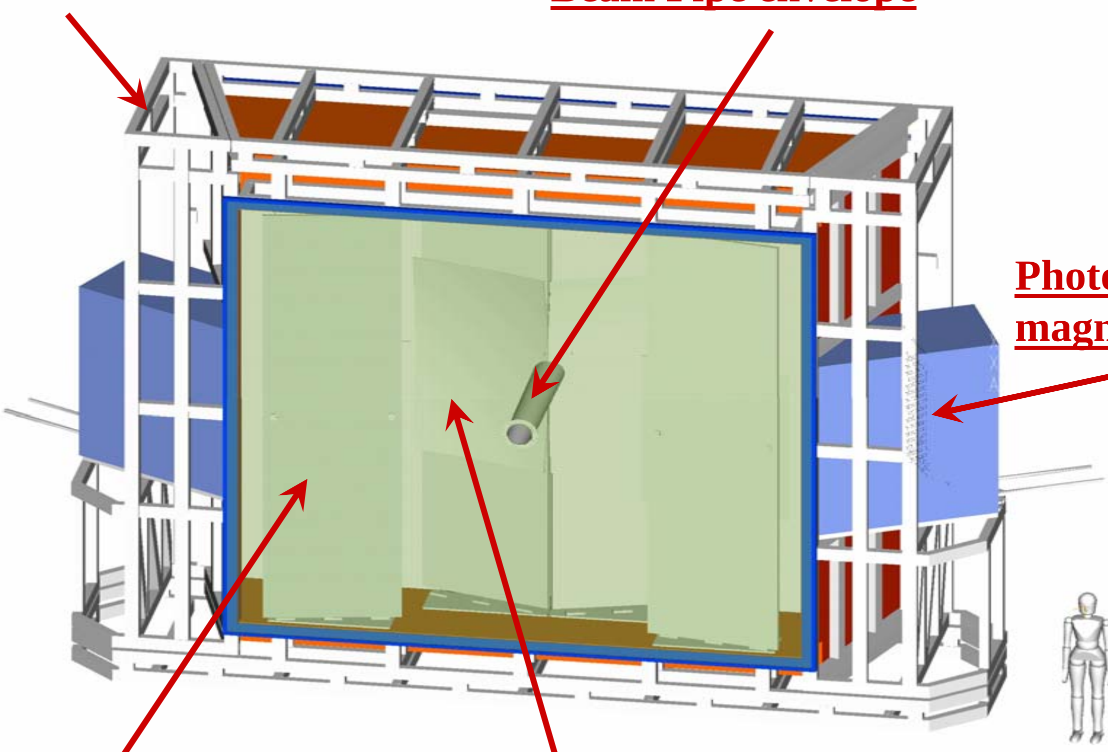



Photon
Detector
250 mrad
Aerogel
Spherica
Mirror
$C_4F_{10}$
Beam pipe
VELO exit window
Track
Plane
Mirror
0
100
200
z

# RICH-2

Support Frame

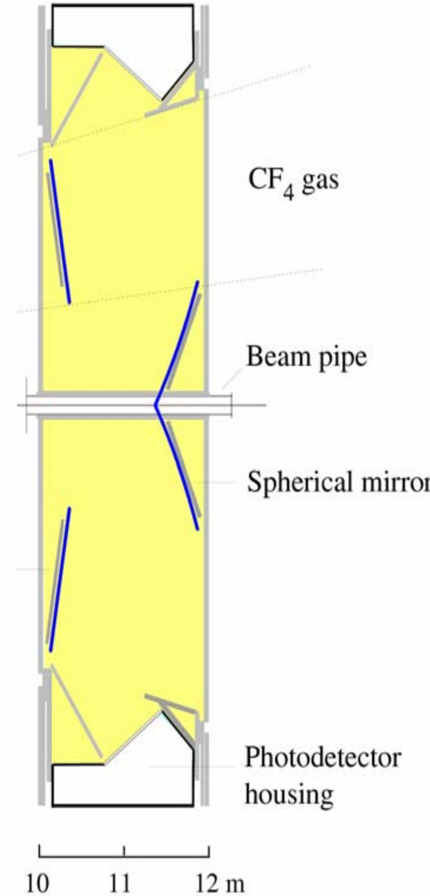
Beam Pipe envelope



Photodetector magnetic shield

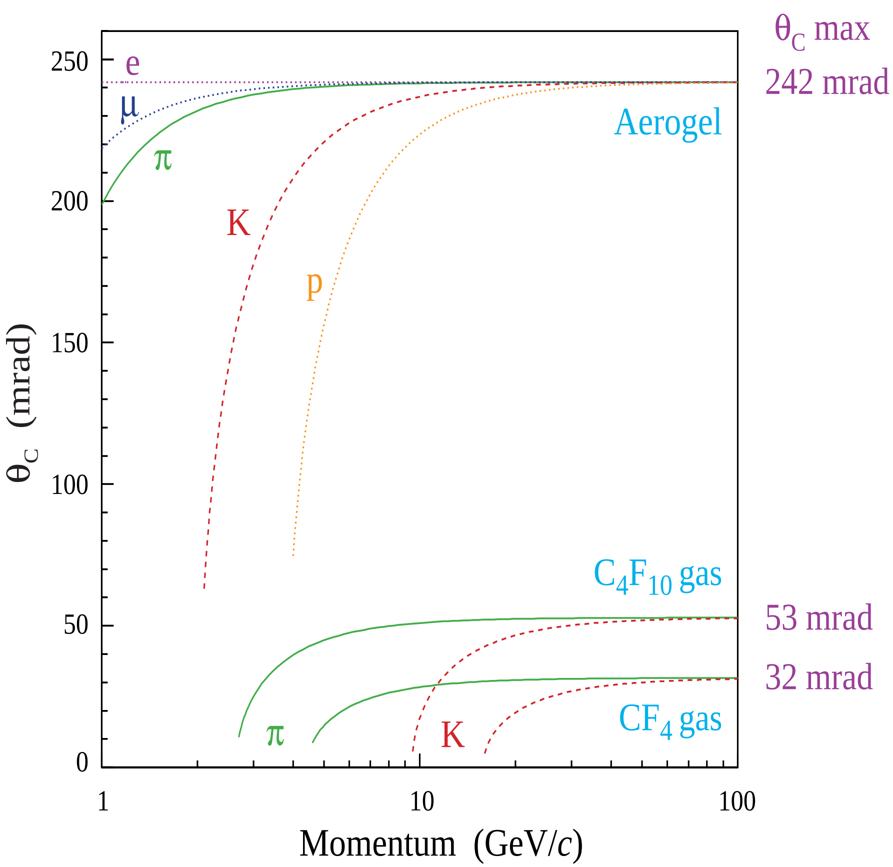
Flat mirrors

Spherical mirrors



# RICH-2 panel prototype

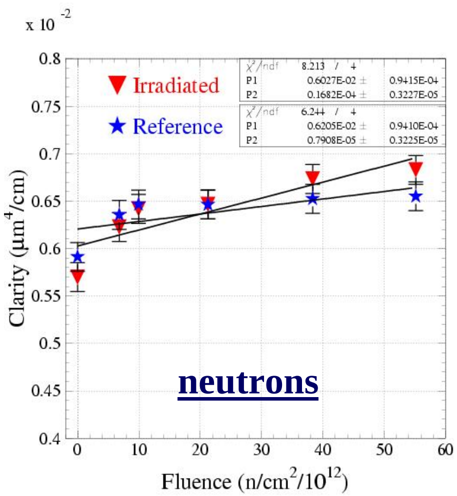
# Radiators

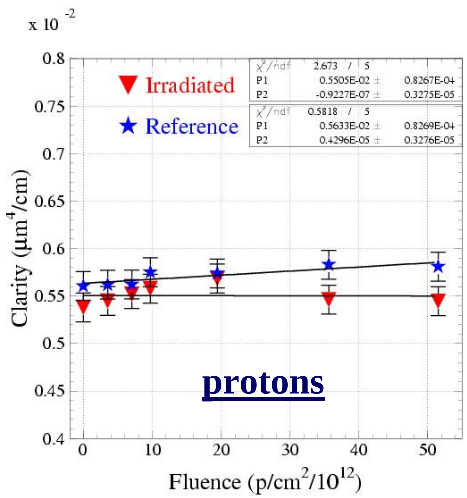


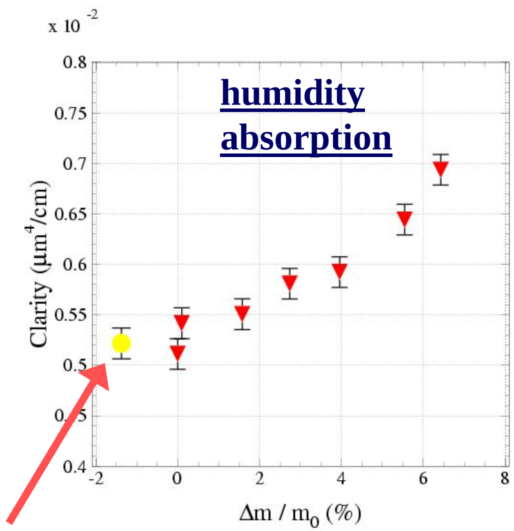

3 different radiators are needed to cover the whole momentum spectrum.

| | Aerogel | $C_4F_{10}$ | $CF_4$ |
|---|---|---|---|
| Length (mm) | 50 | 850 | 1670 |
| n | 1.03 | 1.0014 | 1.0005 |
| $\theta_c$ (mrad) | 242 | 53 | 32 |
| π (GeV/c) | 0.6 | 2.6 | 4.4 |
| K (GeV/c) | 2.0 | 9.3 | 15.6 |

# Aerogel




ter bake-out

- ➢ Silica aerogel produced at Boreskov Institute of Catalysis, Novosibirsk.
- ➢ Transmission is described by

$$T = A \exp(-CL/\lambda^4)$$

C = clarity coefficient.

- ➢ 40 mm thick tiles tested at CERN PS beam. Photoelectron yield: 9.7±1.0 (6.3±0.7 with filter).
- ➢ Samples tested with C=0.0072 μm$^4$/cm and C=0.0064 μm$^4$/cm. C=0.008 μm$^4$/cm used in the simulation.
- ➢ Radiation hardness verified with n, p and γ sources .
- ➢ Humidity absorption changes C. Baking out restores tiles to initial conditions. Hydrophobic samples being tested

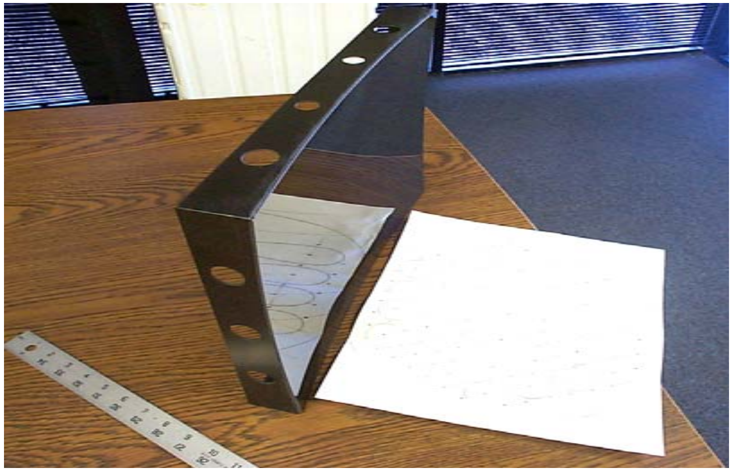
# Mirrors

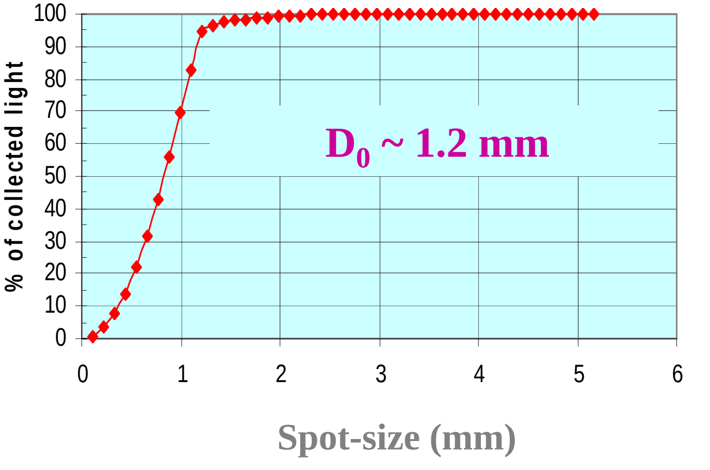
RICH-2 and RICH-1 flat mirrors: 6 mm thick glass, coated by 900 nm Al+$MgF_2$ or $SiO_2$.

RICH-1 spherical mirrors require lightweight solution, 2 prototypes under study:

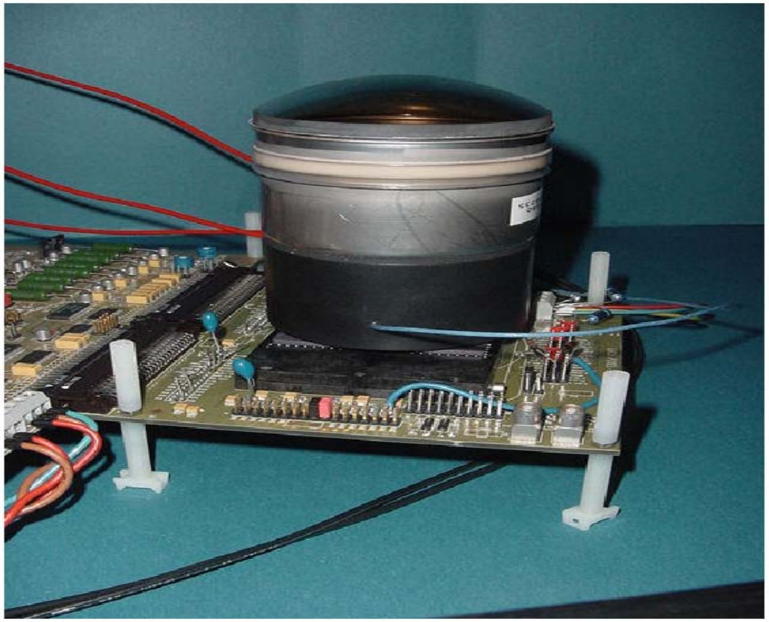
- ¼ - scale carbon-fibre/epoxy composite (from CMA).
  - Optical qualities within specifications.
  - Already successfully used by NASA and by Hermes (DESY) in a $C_4F_{10}$ environment.
  - HERMES resolution lower than LHCb thus a sample is undergoing long-term tests in $C_4F_{10}$
- ¼-scale Be 3 mm thick with 0.3 mm glass coating
  - Optical qualities within specifications (better than carbon-fibre mirror).
  - Higher cost than carbon-fibre

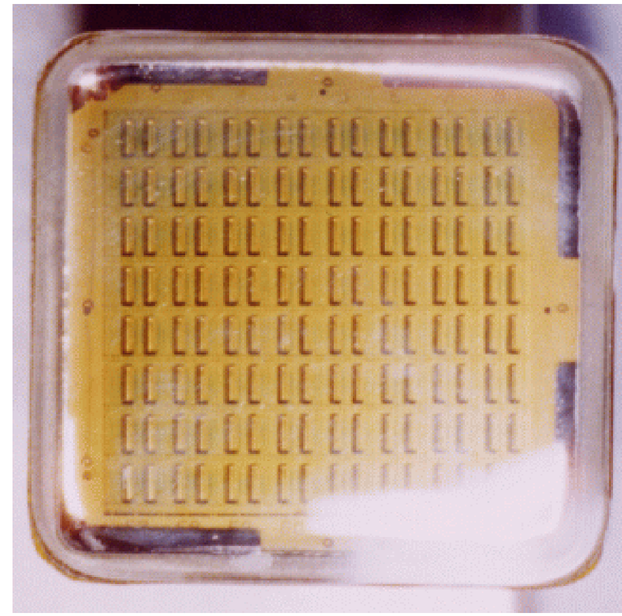
## Carbon-fibre/epoxy mirror





# Photodetectors





- Hybrid Photon Detector
- Granularity 2.5 × 2.5 mm$^2$.
- 83% active area.
- Quantum efficiency > 20%.
- Silicon pixel detector bump-bonded to readout chip developed at CERN

- Hamamatsu M64 multi-anode PMT.
- Active area 38%, increased to 85% with a quartz lens.
- Effective pixel size 3×3 mm$^2$.
- Quantum efficiency 22% (380 nm)
- Read-out via the LHCb Beetle chip

# RICH Performance

RICH response simulated with the LHCb GEANT-3 based program.

- Cherenkov process described with in-house code verified against test-beam data.
- Transmissions, reflectivities and HPD QE set to nominal values.
- Background include:
  - •Rings from secondary particles
  - •Photons from Rayleigh scattering
  - •Charged particles striking the HPD windows.
  - •Late arriving photo-electrons from previous beam crossings.
- Only tracks found and reconstructed by the tracking algorithm considered in the Cherenkov angle calculations.

New

New

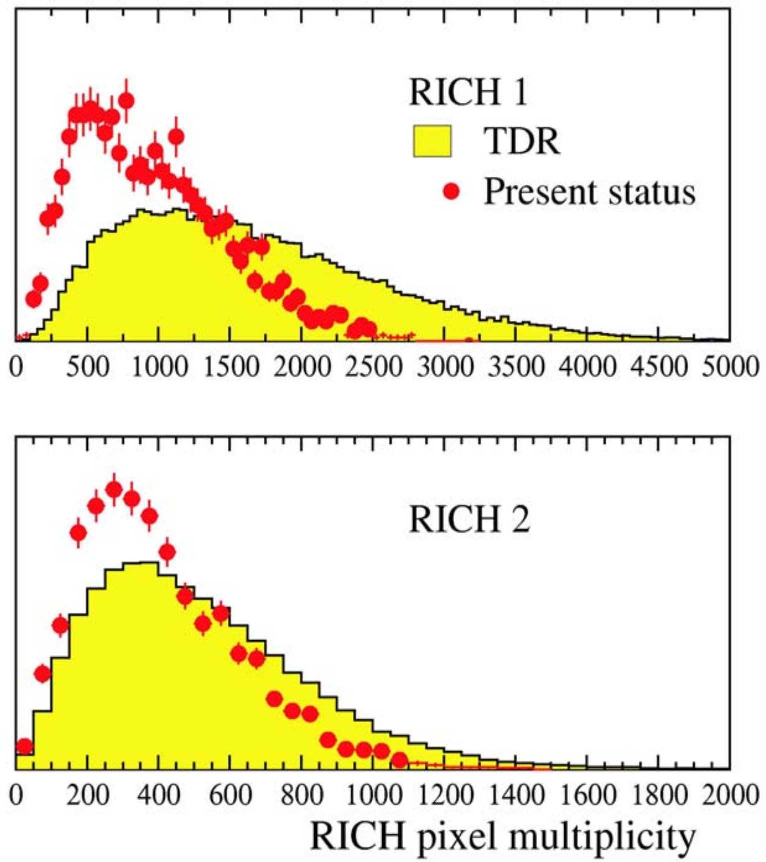
## Photoelectron yield

| Radiator | Npe | Npe (TDR) | $\sigma(\theta_C)$ mrad |
|---|---|---|---|
| Aerogel | 6.8 | 6.6 | 1.89 |
| $C_4F_{10}$ | 30.3 | 32.7 | 1.27 |
| $CF_4$ | 23.2 | 18.4 | 0.59 |

## RMS widths (mrad) to Cherenkov angle

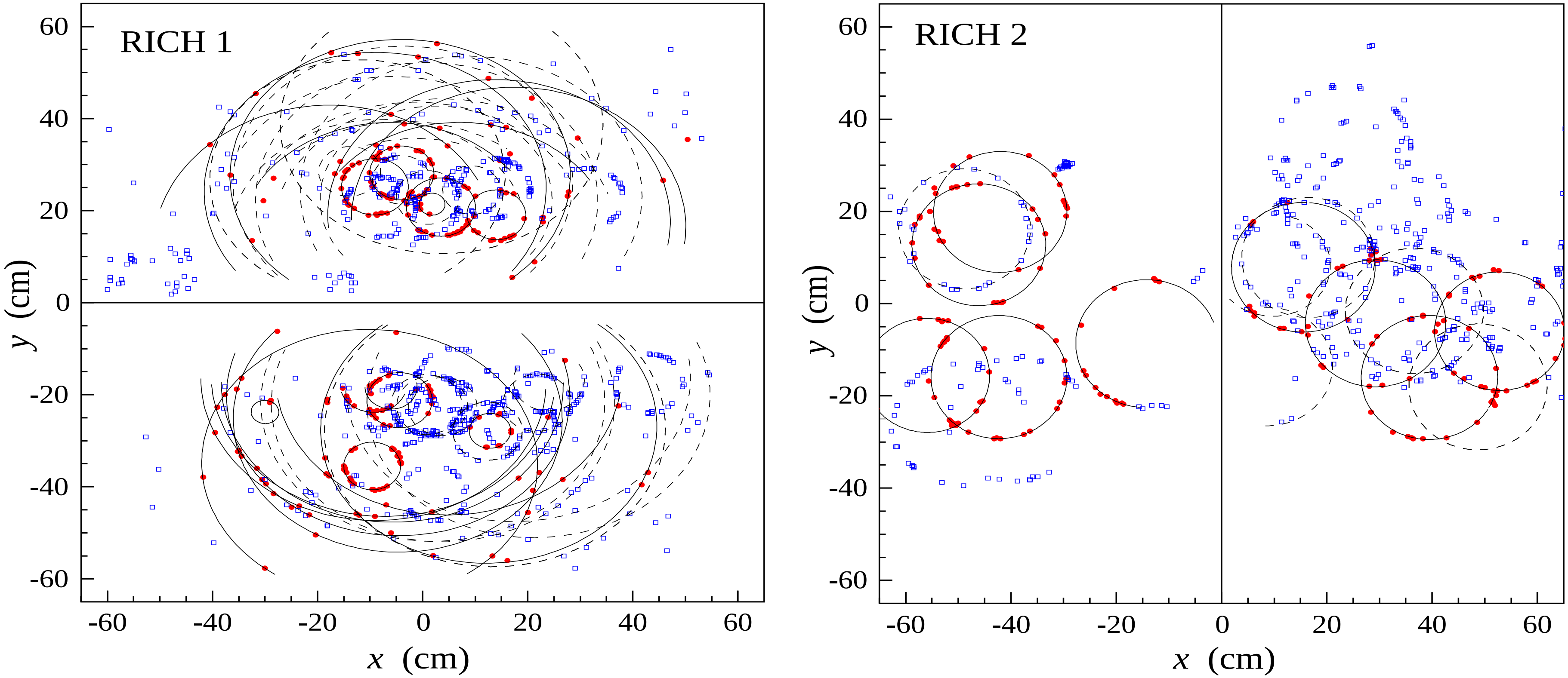
| Contribution | Aerogel | $C_4F_{10}$ | $CF_4$ |
|---|---|---|---|
| Emission | 0.29 | 0.69 | 0.28 |
| Chromatic | 1.61 | 0.81 | 0.36 |
| Pixel | 0.62 | 0.62 | 0.17 |
| Tracking | 0.52 | 0.40 | 0.23 |
| Total | 1.89 | 1.27 | 0.59 |

# RICH Performance (2)




- The beam pipe is now made of Be-Al alloy. This, and the low mass of the new design, results in a significant reduction in hits from secondary particles in RICH-2
- In RICH-2 the total pixel multiplicity does not change as much because of the increase in the radiator length.

# A typical B Event



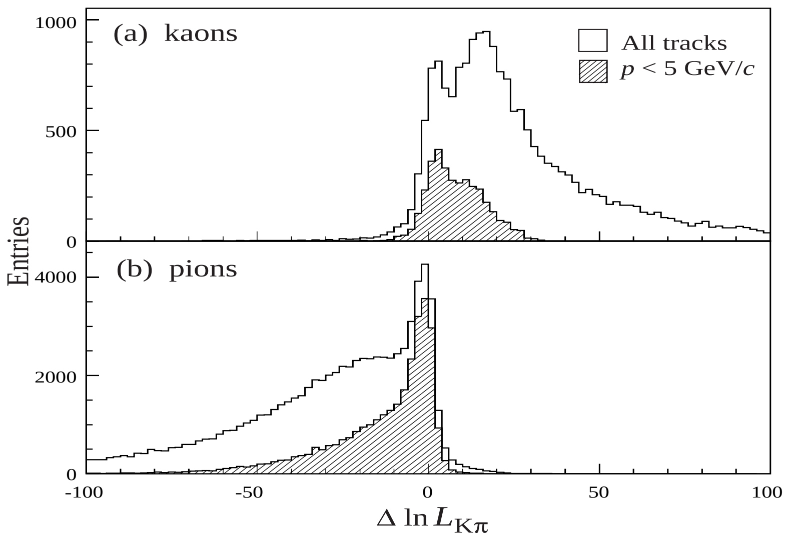

Superimposed are the rings from "long" tracks (solid) and other tracks (dashed) – See previous presentation.

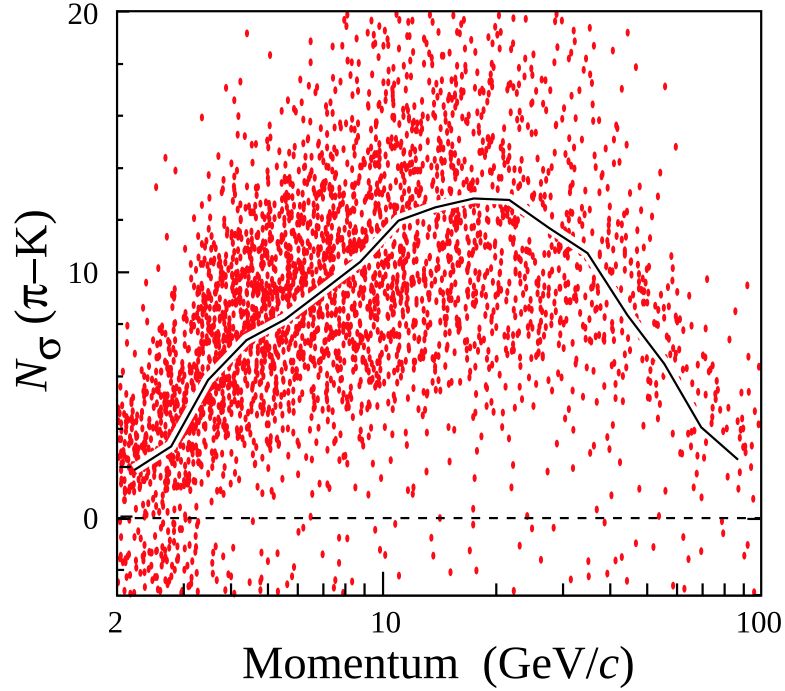
# Particle Id Performance: pions

Using "long" tracks from $B^0_s \rightarrow D^-_s K^+$ events, the ratio of the likelihood between assuming the $\pi$ and the K hypothesis is calculated:

$\Delta \ln L_{K\pi} = \ln L(K) - \ln L(\pi)$

This can be converted in the significance of the $\pi$-K separation $N_\sigma^2 = 2|\Delta \ln L_{\pi K}|$

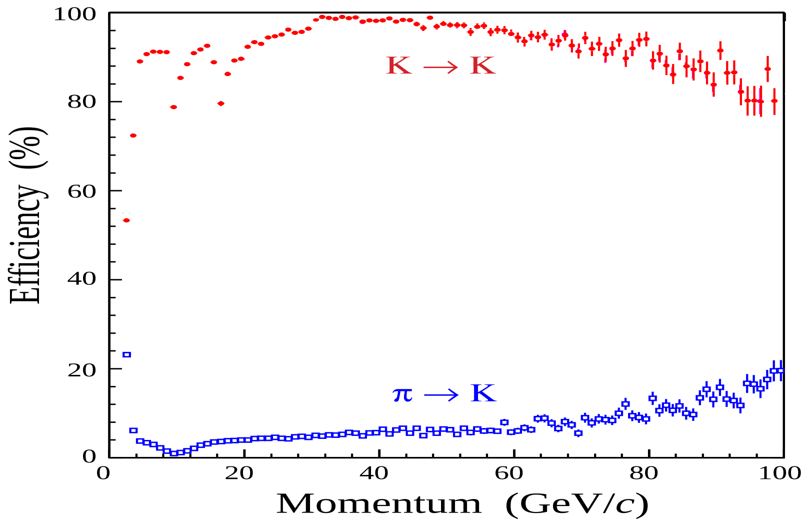


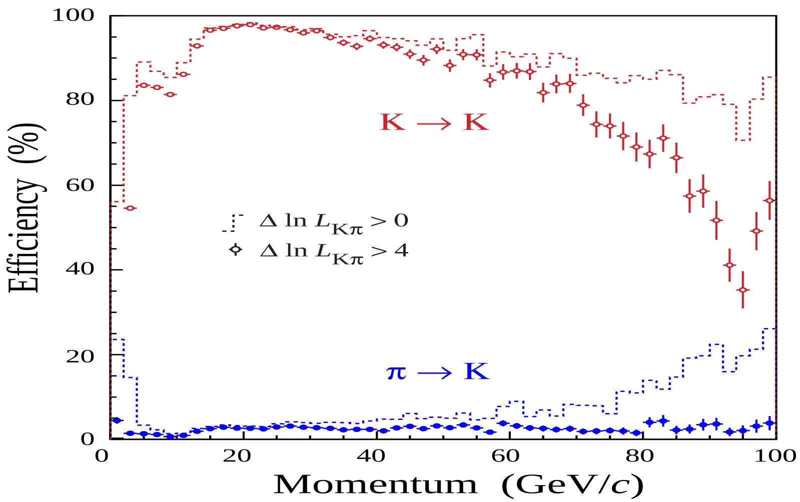




**3σ or better separation in the 3-80 GeV/c region.**

Each track in a $B \rightarrow \pi\pi$ sample and the average are shown.

# Particle Id Performance: kaons




Defining a track as a kaon if the maximum log-likelihood is for a K or a p hypothesis, otherwise a π:

Efficiency ε(K→K) = 91%,

Mistag ε(π→K) = 5.6%

By changing the cut on $\Delta \ln L_{\pi K}$ it possible to reduce the misidentification rate at the cost of a reduction in efficiency.

| $\Delta \ln L_{\pi K}$ | ε(K) | ε(π→K) |
|---|---|---|
| > 0 | 91 | 5.6 |
| > 2 | 88 | 2.9 |
| > 4 | 85 | 1.7 |
| > 8 | 79 | 0.8 |

# Conclusions

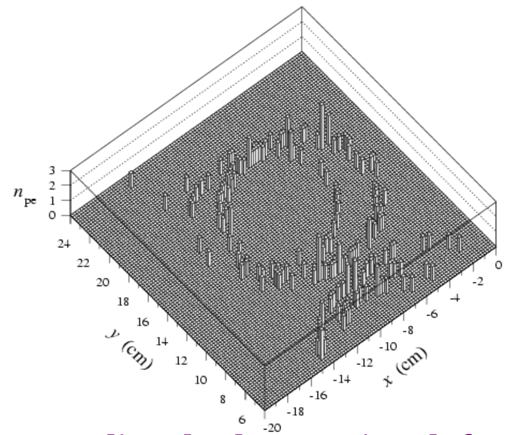
- LHCb will use a RICH detector to identify hadrons produced in the B mesons decays, in a momentum range between 2 GeV/c and 100 GeV/c.
- The RICH design has been re-optimised to reduce the overall material in the detector and to take into account the needs of the Level-1 trigger.
- The new design provides the required particle identification performance.
- The Kaon identification efficiency is of 88% in the required momentum range with a pion misidentification of 3%.
- No significant degradation in performance is observed when simulating significantly worse detector behaviour.
- The RICH is currently on schedule for the first data at the LHC in 2007

# Extra slides

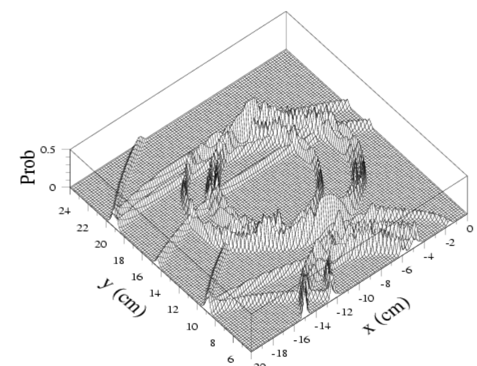
# RICH Pattern Recognition

- The pattern recognition algorithm treats all reconstructed tracks in the event simultaneously – "global" approach.
- For a given set of track mass hypotheses the probability that a photon signal would be seen in each pixel is calculated.
- Background effects, both from tracks and independent from tacks, are included.
- The sums of the contributions from all sources can be compared to the observed photons and a likelihood calculated.
- Starting from the case where every particle is assumed to be a π, the likelihood is recalculated assuming that each particle is in turn a e, μ, K, p with the other track hypotheses unchanged.
- The change of hypothesis that gives the largest maximum is selected and the procedure is iterated until no increase in the likelihood is found.

**Observed photon signal**




**Predicted photon signal for a given track hypothesis**



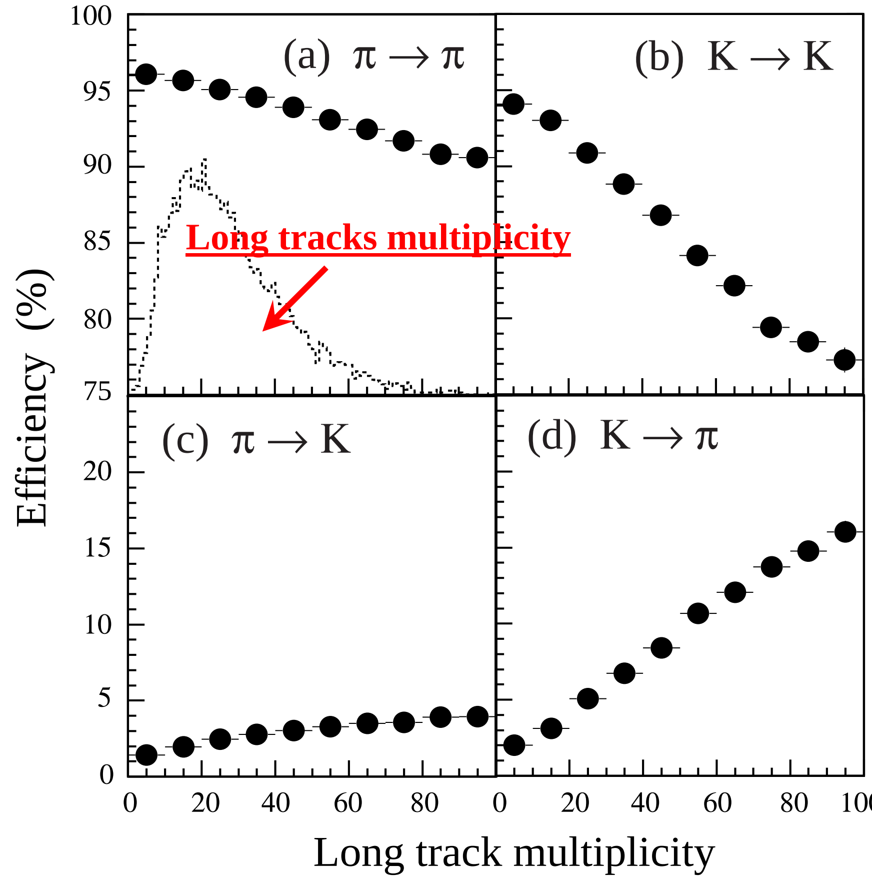
# Particle Id Robustness

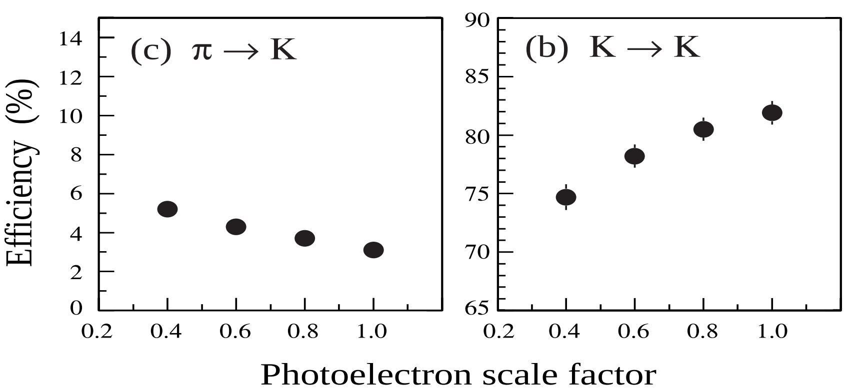
- Particle Id Efficiency as function of track multiplicity:

π efficiency drops by 5%, K efficiency by 16% over a 1-100 tracks range.

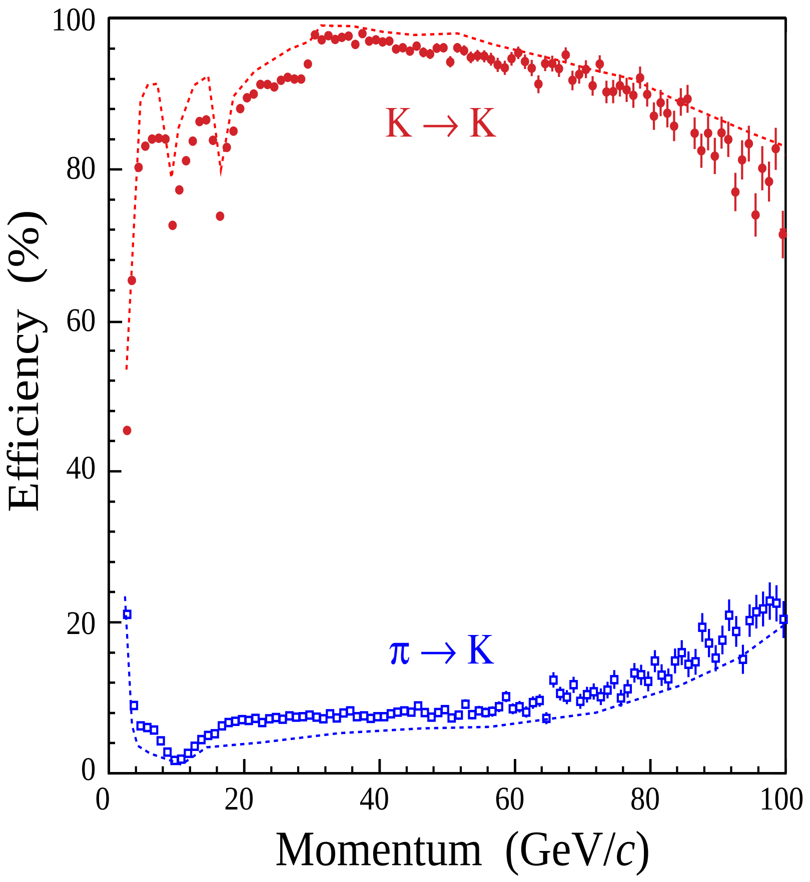
- Non nominal performance of mirrors and photodetectors simulated by scaling the number of photoelectrons

Effect is relevant only at low momentum.



# Particle Id Robustness (2)

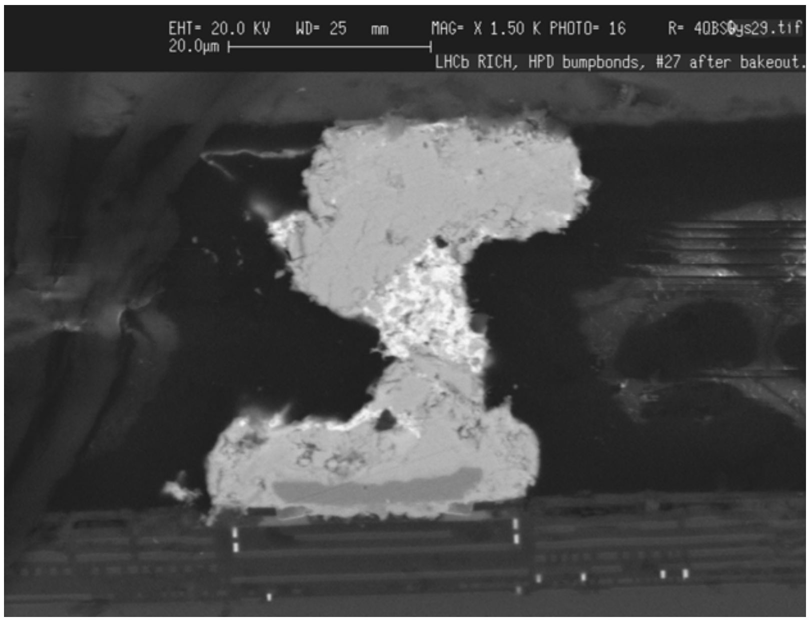



Global effects eventually due to a degraded LHCb performance have been studied in a special MonteCarlo simulation where the generator parameter were set to a more "pessimistic" value.

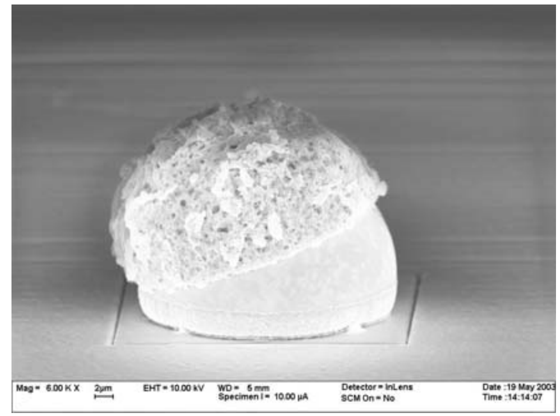
- 20% decrease efficiency in all photodetectors.
- Random noise at a rate of 0.3% per pixel.
- Smearing of the emission point error in RICH-1 to 1.2 mrad.

No dramatic effect observed.

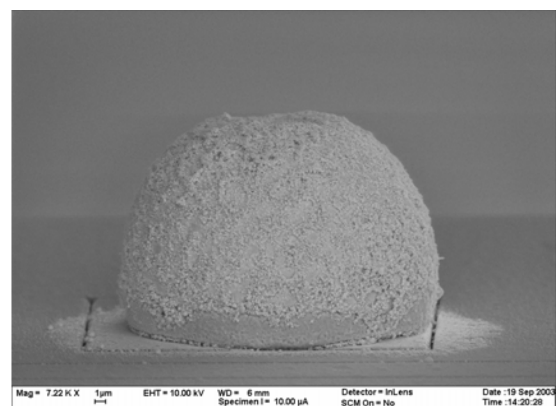
# Status of the Bump Bonding




**September 2002**



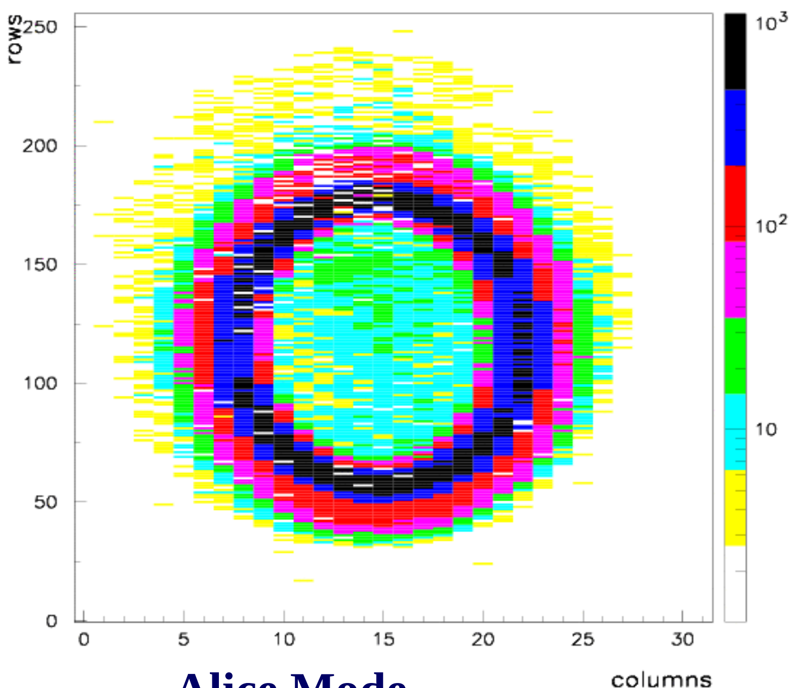

**May 2003**



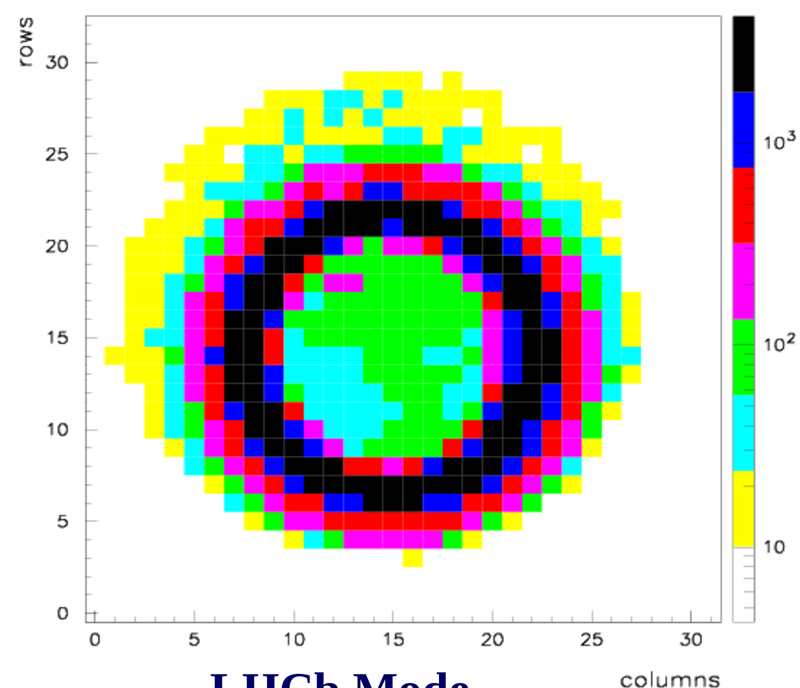

**Current**

# HPD results

- In LHCb 8 vertical pixels are OR'ed together.
- Missing pixels cause some efficiency loss but no channel loss

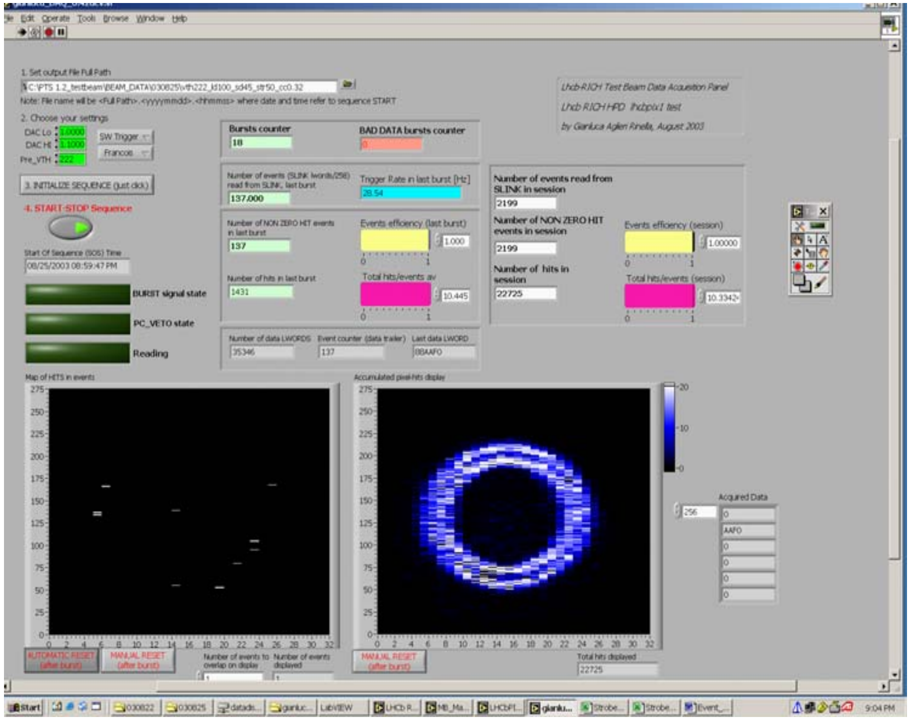


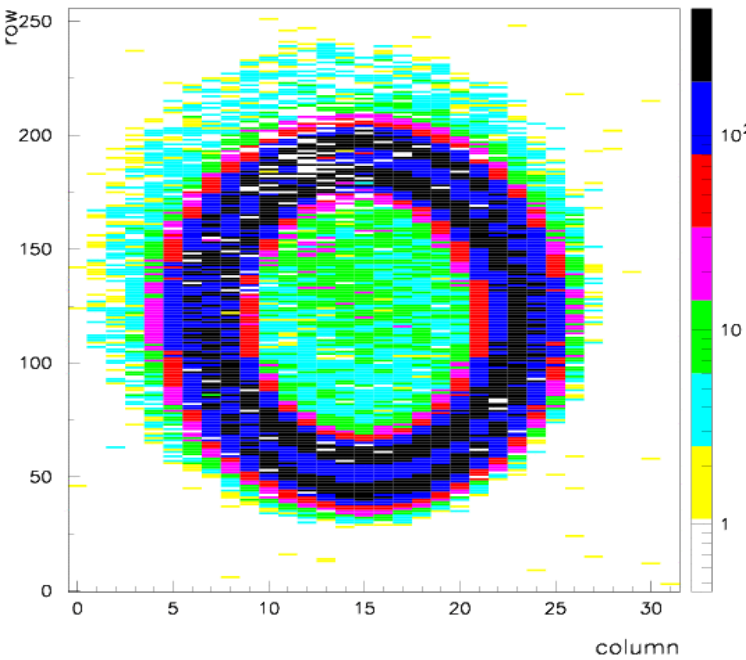

**Alice Mode**




**LHCb Mode**

# HPD Cherenkov rings






- PS T9 test beam area.
- Trigger selects mostly pions, with electrons contamination.
- Radiator is air.