# The RICH detector of the LHCb experiment


Clara Matteuzzi

INFN and Universita' di Milano-Bicocca

*On behalf of the LHCb RICH groups*


- **Description of the detector**
- **Operation**
- **Performance**

# The LHCb experiment

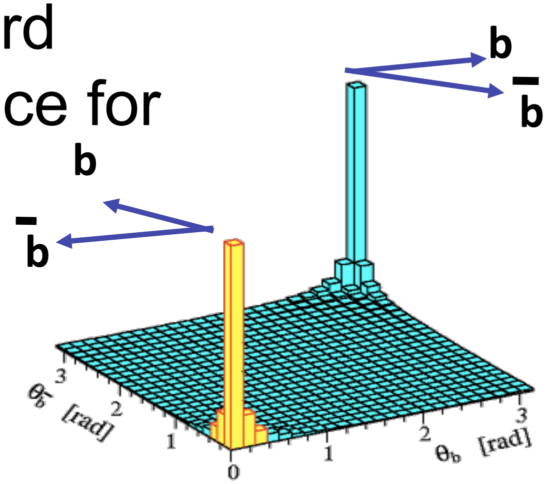
- Main physics measurements planned: *b* and *c* physics
  (rare decays, CP asymmetries,...)

- Momentum range of particles: B hadrons produced with <p> ≈ 70 GeV
  ⇨ decay products from few to 100 GeV

- Hadron machine environment (LHC)
  high particle density in the final state
  running now at 7 TeV , at 14 TeV in 2 years

# The LHCb experiment

- The LHCb detector is a single arm forward spectrometer, maximizing the acceptance for $b\bar{b}$ events
  - Coverage in η between 1.9 and 4.9




- LHCb “nominal” running conditions at $\sqrt{s}$=14 TeV:
  Luminosity $2 \cdot 10^{32}$ cm$^{-2}$s$^{-1}$ with β* = 10 m
  < 1 pp interactions per bunch crossing

**Present running conditions are :**

Energy $\sqrt{s}$ = 7 TeV,
Luminosity should reach close to nominal ***L*** ~$10^{32}$
reached on the 14th october 2010 1.01x$10^{32}$ !!
with 248 bunches per beam and with
β* = 3.5 m ⇒ ~ 2.0 pp visible interactions per crossing

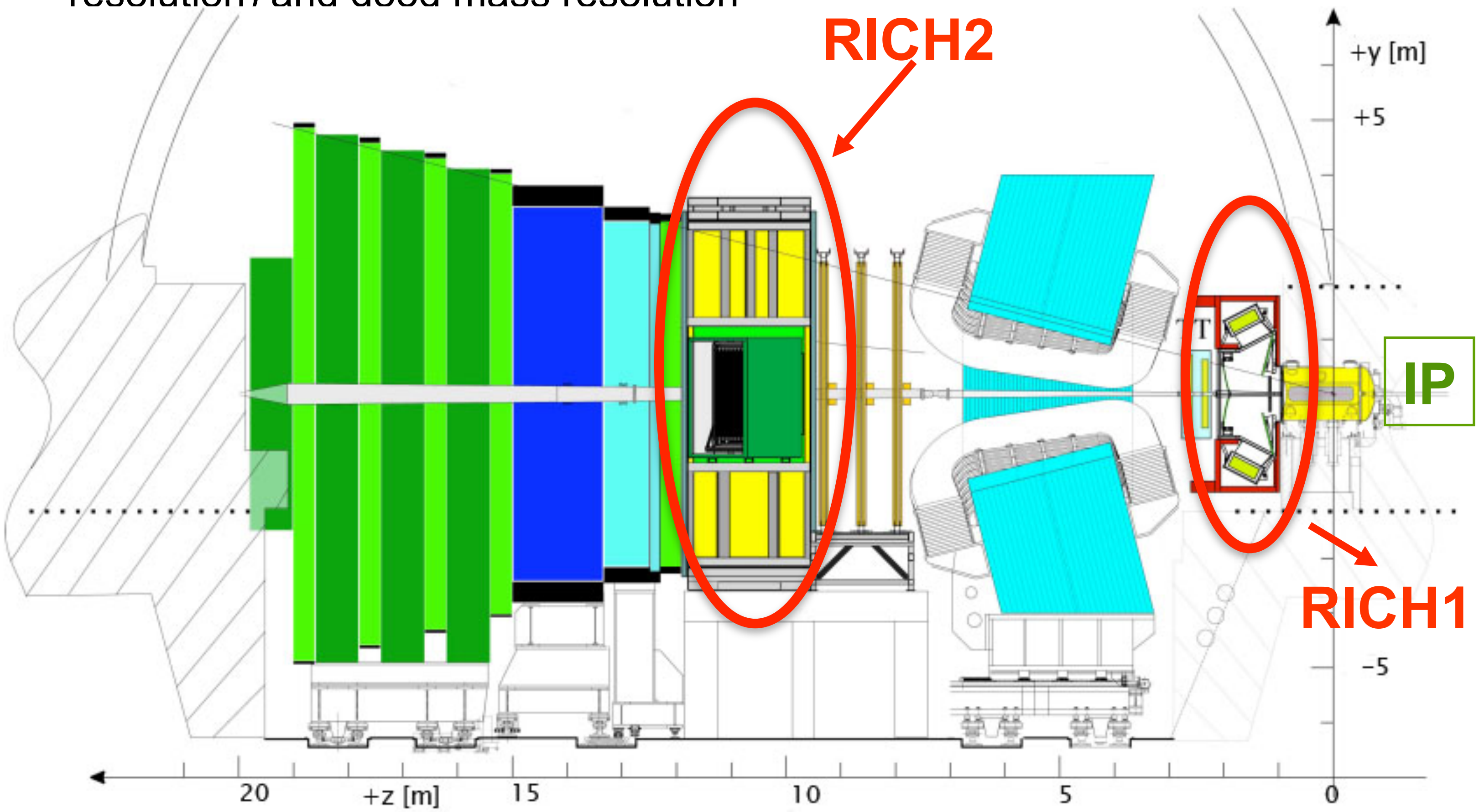
# The LHCb experiment

The most important features:

- Efficient trigger for B decay topologies
- **Excellent particle identification**
- Precison vertexing (good decay time resolution) and good mass resolution

Acceptance:

300 mrad horizontal
250 mrad vertical



# The RICH of LHCb

**Physics aims:**

separate K /$\pi$/p in the range 2-100 GeV/c to :

- reconstruct rare (and less rare) B and D decays

  *(ex. $B \to KK$ , $K\pi$ , $\pi\pi$, $B \to D_s K$ and $D_s \pi$, ...)*

- and to tag flavour : identify K

  from b fragmentation *(SSK, $B_s$)*

  from b $\longrightarrow$ c $\longrightarrow$ s *(OSK,* $B^0$ and $B_s$*)*

Must reject pion better than at the percent level

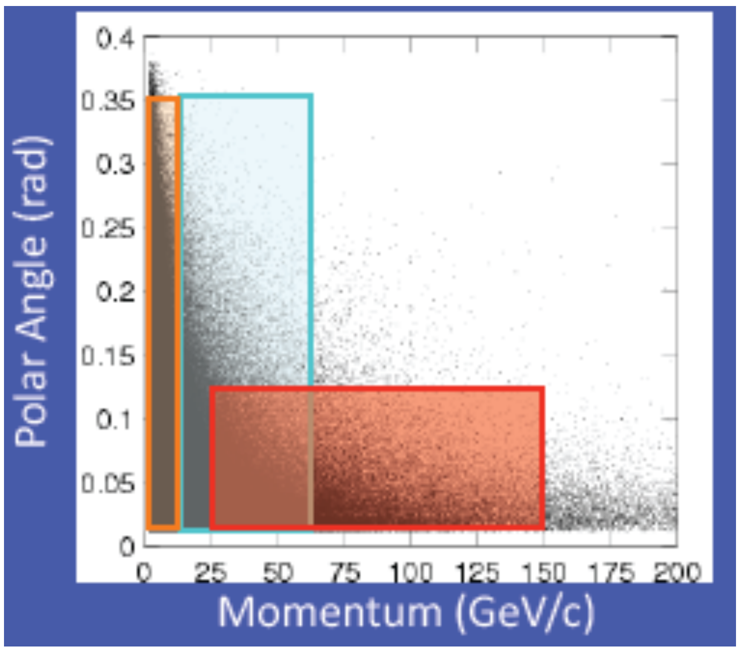
**Geometry:**

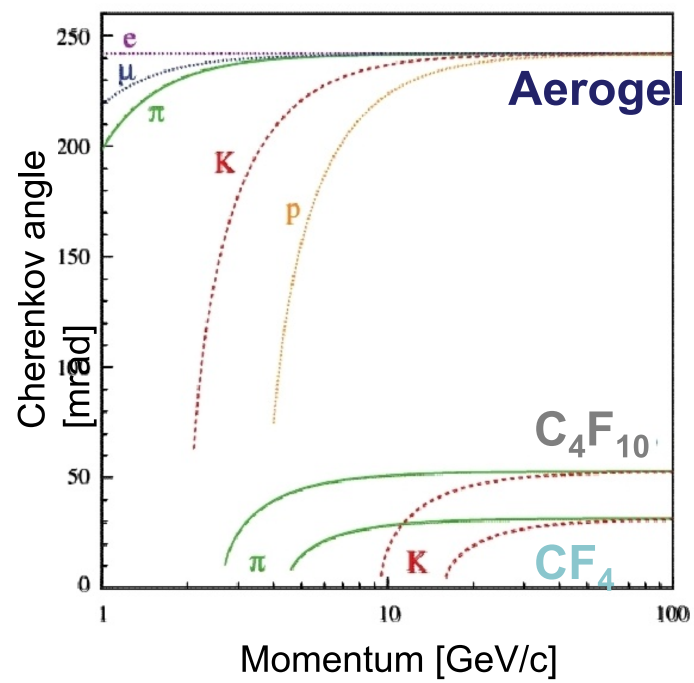
focussed, 2 RICHes with 3 different radiators

# The RICH of LHCb: *the radiators*

Radiators: 5 cm aerogel n = 1.030 @ 400 nm
95 cm $C_4F_{10}$ n=1.0014 @ 400 nm } RICH-1

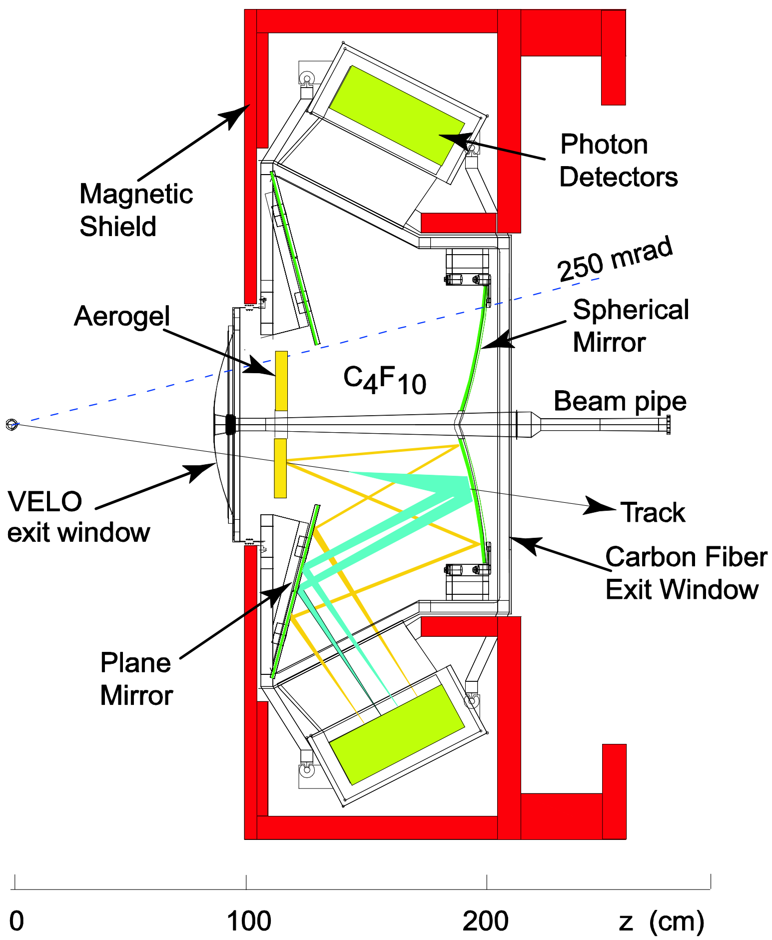
180 cm $CF_4$ n=1.0005 @ 400 nm RICH-2

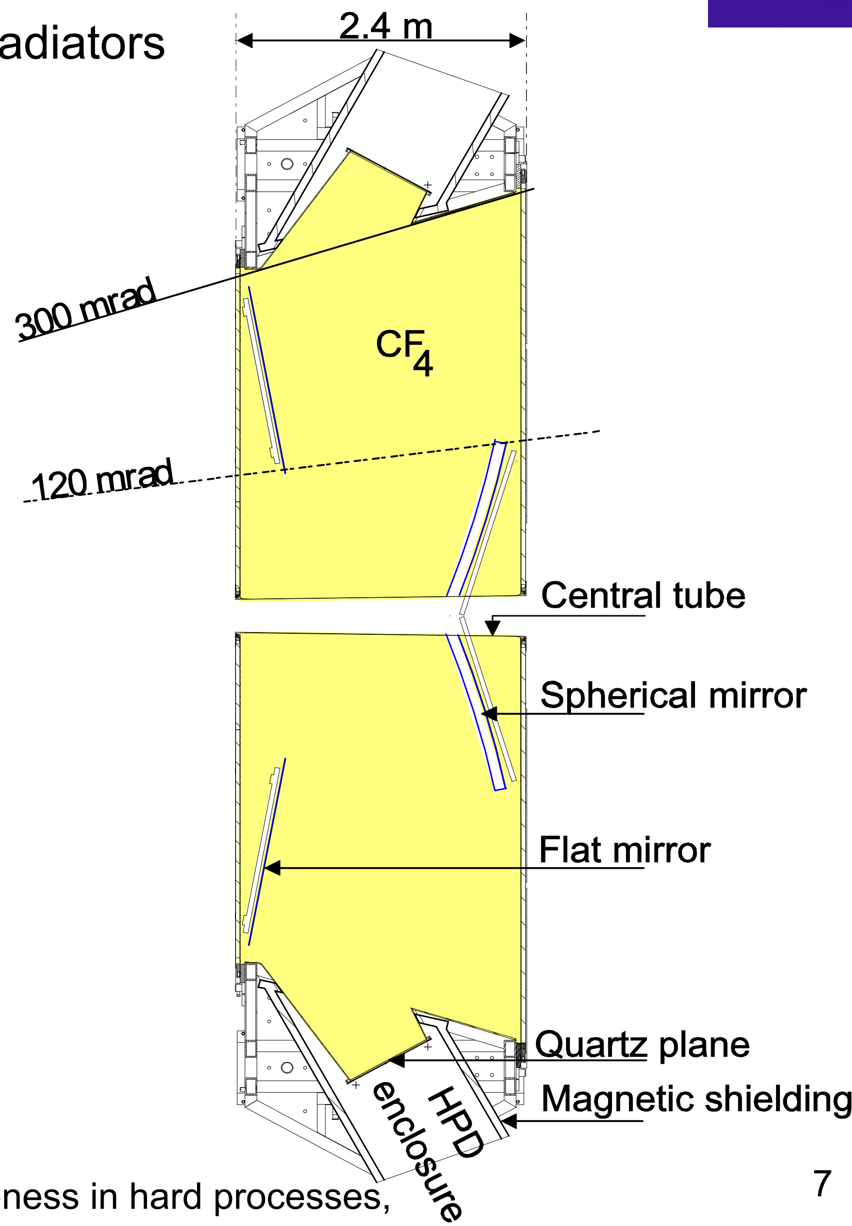


# The RICH of LHCb : *the vessels*

The solution of LHCb: 2 RICHes with 3 radiators



# The RICH of LHCb

## Focussed geometry

Mirrors :

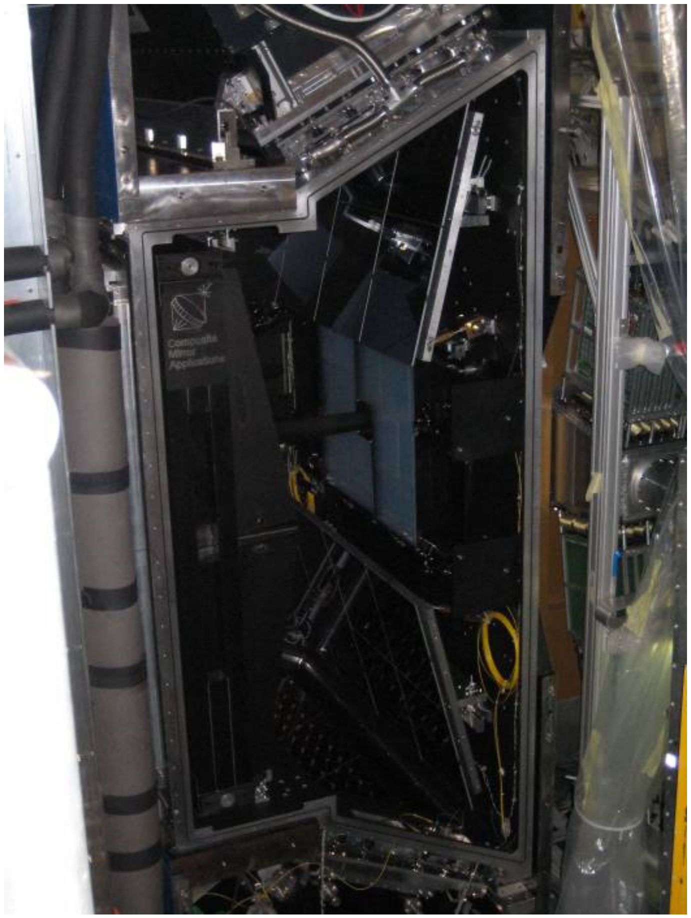
**RICH-1:** 4 spherical (f= 135 cm) in Carbon fiber
16 plane *(R> 600m) outside the spectrometer acceptance*

**RICH-2:** 52 spherical (f= 430 cm ) in glass
40 plane *(R= 80 m) ) outside the spectrometer acceptance*

# The RICH of LHCb : *the vessels*

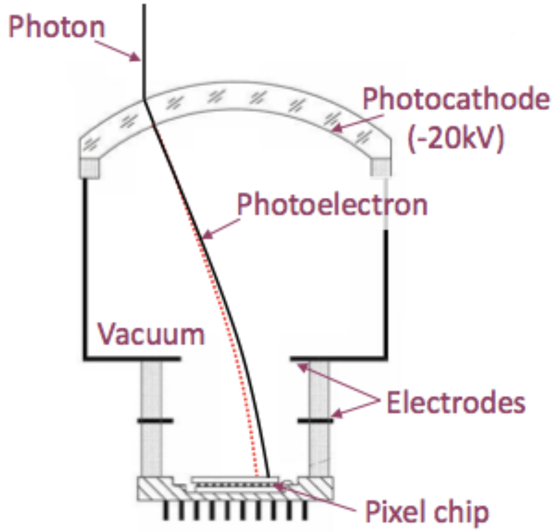
**RICH-2 vessel**

**RICH-1 vessel**



# The RICH of LHCb: *the photodetectors*

- Hybrid Photon Detectors (HPD) developed in collaboration with DEP-Photonis Combines vacuum technology with silicon pixel readout




➡ **484 HPDs**

**196 in RICH1 and 288 in RICH2**

➡ **Total area covered of 3.3 m$^2$**

➡ **Operate at -18 kV**

➡ **Cross focusing electrodes**

➡ **Sensitive to magnetic field**

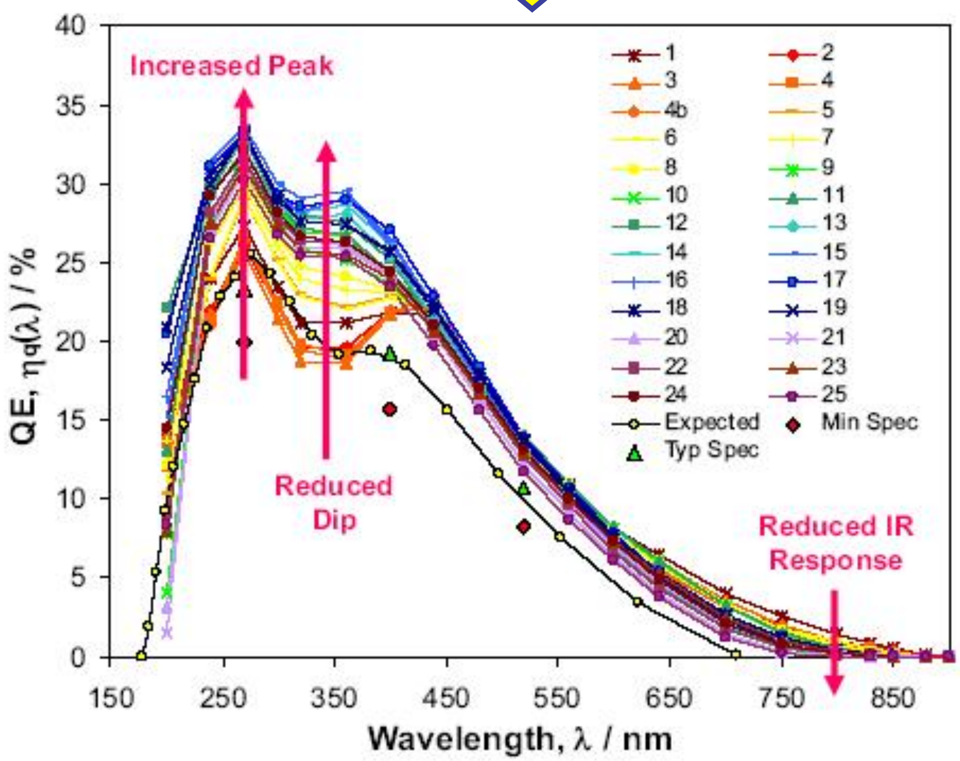
➡ **Anodes:**

- 256 x 32 pixel Si sensors
  8-fold binary OR → effective
  32x32 array sensor (500 x 500 $\mu$m)
- Bump-bonded to binary readout chip

# The RICH of LHCb: *the photodetectors*

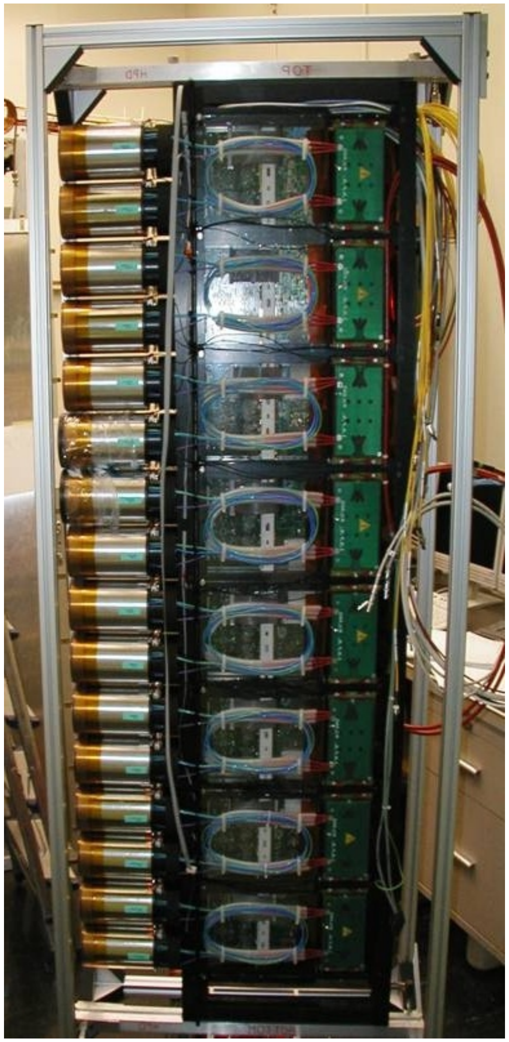
- **Multialkali photocathode (S20)**
- **with 2.5 x 2.5 mm$^2$ granularity**
  demagnification factor =5 @ 20kV
- **200-600 nm wavelength**

Quantum efficiency



# The RICH of LHCb: *the photodetectors*

The assembly :



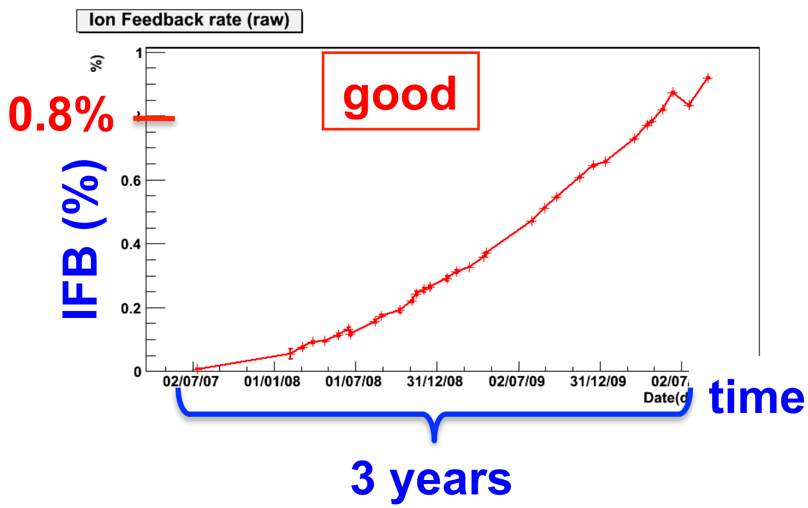
# The RICH of LHCb: *the photodetectors*

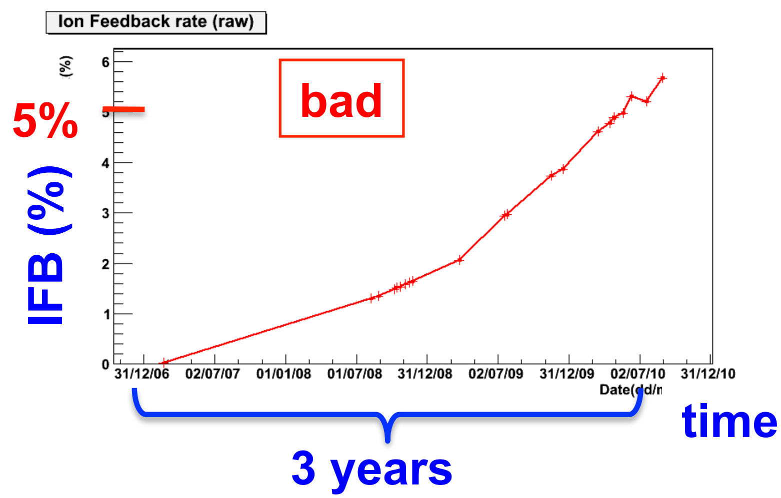
**~18% of HPDs have experienced vacuum problems** *(Ion FeedBack, IFB)*

→ *ions originated by $e^-$ ionising residual gas atoms*

*Signature of IFB → large cluster size: >5 pixels*

Most HPDs show a linear increase of IFB with time with low slope. Noisy tubes have a higher slope and eventually start to glow (*) . Defined IFB rate > 5% as threshold above which an HPD is considered at risk.




~13 HPD replacements/year expected

*(*)glowing: When the process ion-electron emission becomes self-sustained*
*→ light emission seen by photocathode and externally*

# Monitoring and control

Get a complete picture of operation

Detect any issue as early as possible

# The RICH of LHCb: *monitoring and control*

Needs to control the different contributions to the Cherenkov angle resolution:

**Radiators:**

Composition of gas radiators: measured by chromotography to calibrate n-1

- Typical RICH1 : 98% $C_4F_{10}$ , 0.8% $CO_2$, 1% $N_2$, 0.2% $O_2$
- Typical RICH2 : 98% $CF_4$ , 1.8% $N_2$ , 0.2% $O_2$

Monitoring with hydrostatic pressure difference top - bottom

Control P and T continuously for correcting automatically the density $\rho_{gas}$

**Spatial precision:**

*dedicated runs when no collisions to:*

Monitor ageing of HPDs (IFB runs)

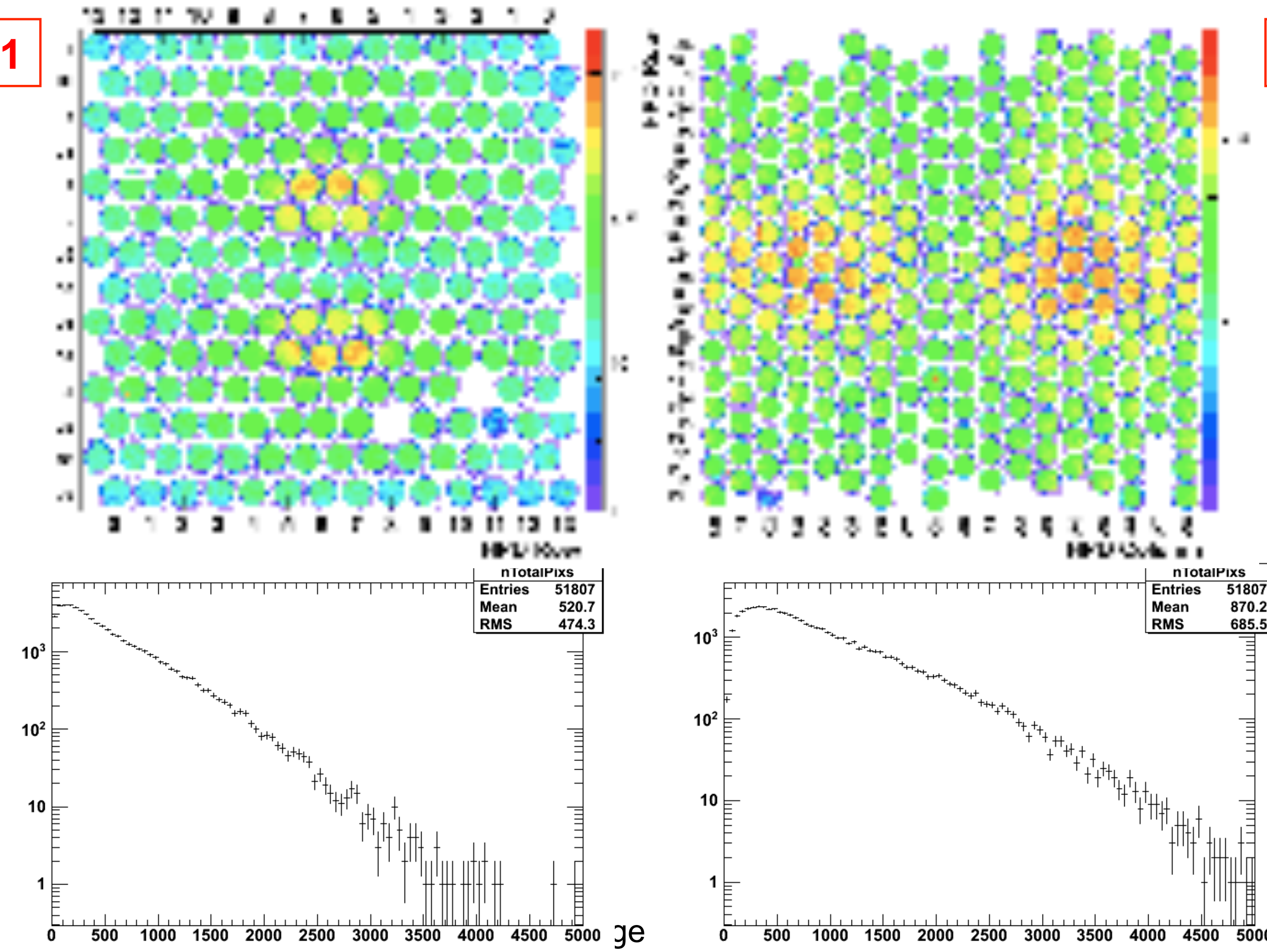
Corrections for magnetic distorsion which induce a shift+rotation in HPD image *(dedicated magnetic distorsion monitoring systems in RICH1/2)*

# The RICH of LHCb: *monitoring and control*

## RICH Operation fully automated

RICH1

RICH2



# The RICH of LHCb: *monitoring and control*

## Monitoring:

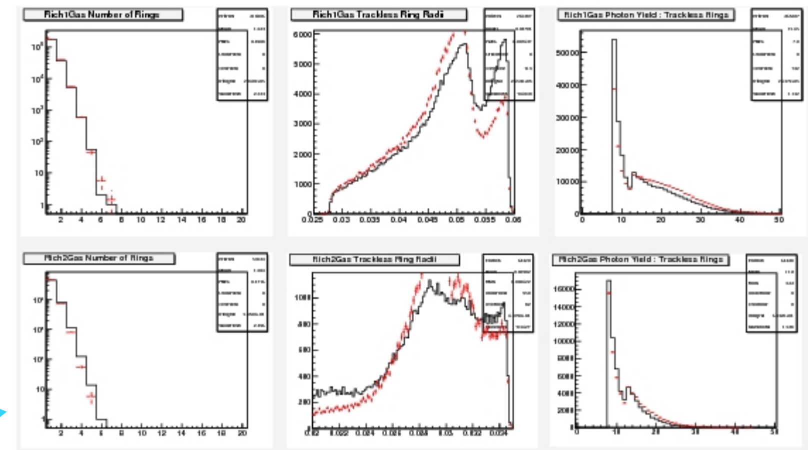
**HV stability**

**# hits**

**Disable misbehaving HPDs**

**Trackless rings**

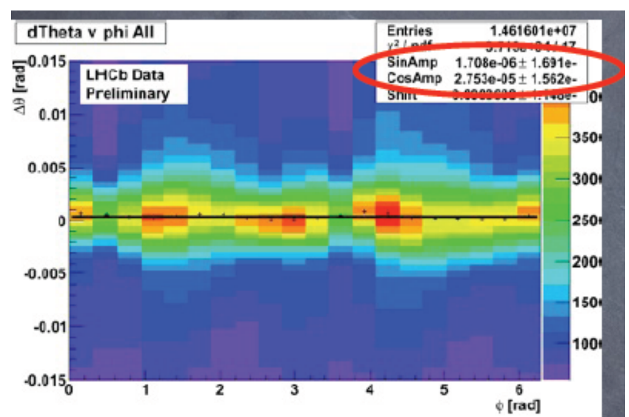
radii sensitive to T and P



**Online reconstruction** ***(tracks available)***

Cherenkov angle, global alignment

**Alignment**

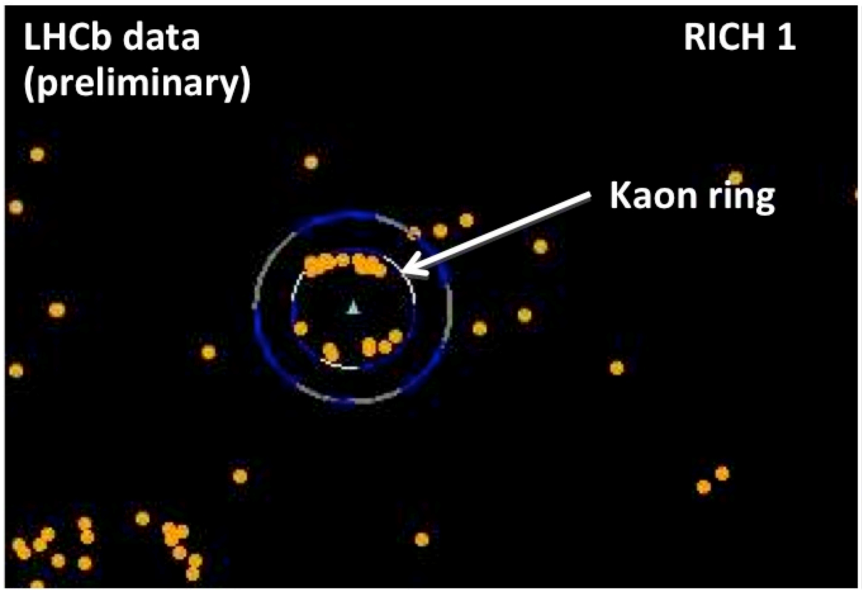


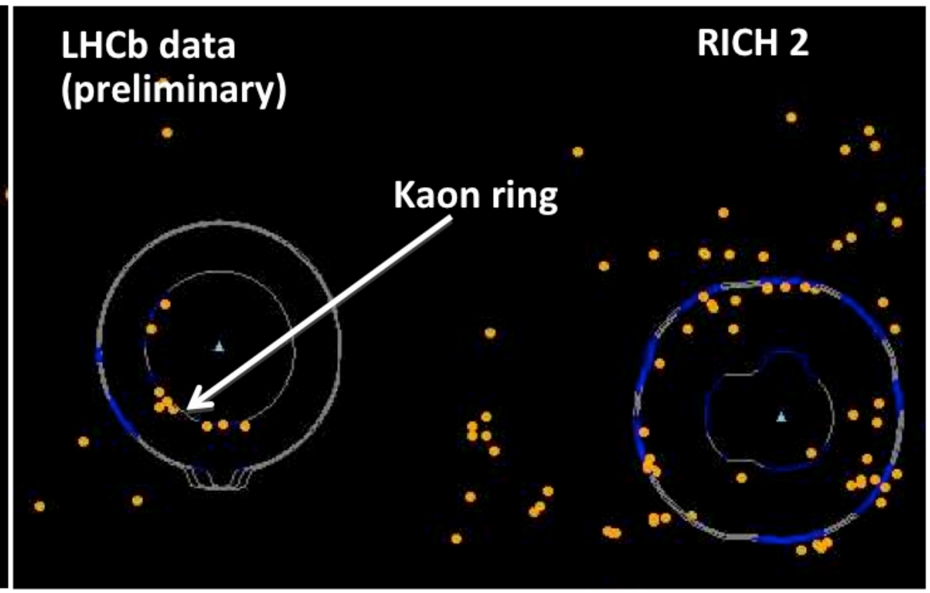

**DAQ integrity**

**Data Quality**

# The RICH of LHCb: *the very first data at 450 GeV*

**RICH-1** **RICH-2**



# The RICH of LHCb: the performance

# The RICH of LHCb : *the resolution*

Needs a resolution In the range of O(1 mrad) , sub mrad in RICH2

**Units : mrad**

| | RICH-1 | | RICH-2 |
|---|---|---|---|
| | Aerogel | $C_4F_{10}$ | $CF_4$ |
| Emission | 0.4 | 0.8 | 0.2 |
| Chromatic | 2.1 | 0.9 | 0.5 |
| HPD | 0.5 | 0.6 | 0.2 |
| Track | 0.4 | 0.4 | 0.4 |
| Total | 2.6 | 1.5 | 0.7 |

Expected $N_{pe}$ ≈ 6.5 30 22

# The RICH of LHCb: *the resolution*

**The full RICH alignment and calibration is very complex**

- Shift/rotation of HPD panels
- Individual mirror alignment
- Individual HPD shift / rotation
  *(including photodetector chip)*
- Individual aerogel tile calibration (16 tiles)
- Magnetic distorsion corrections
  *(more important in RICH1 than in RICH2)*

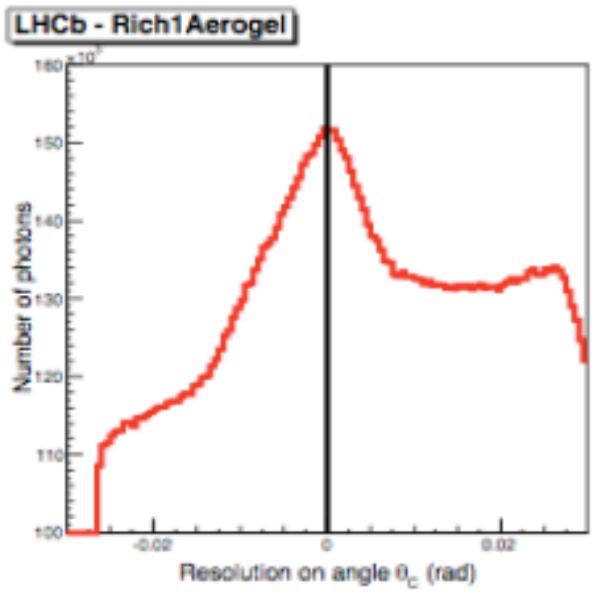
**Tracking:**

- $\sigma(\theta_C)$ relies on track information also for alignment.

# The RICH of LHCb : *the resolution*

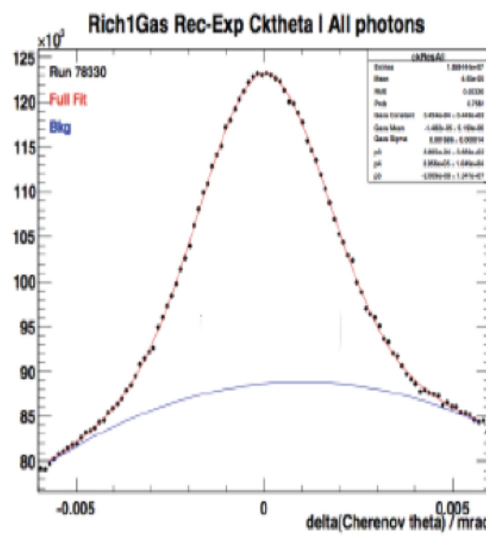
After several millions of pp collision events :

**RICH1 aerogel**



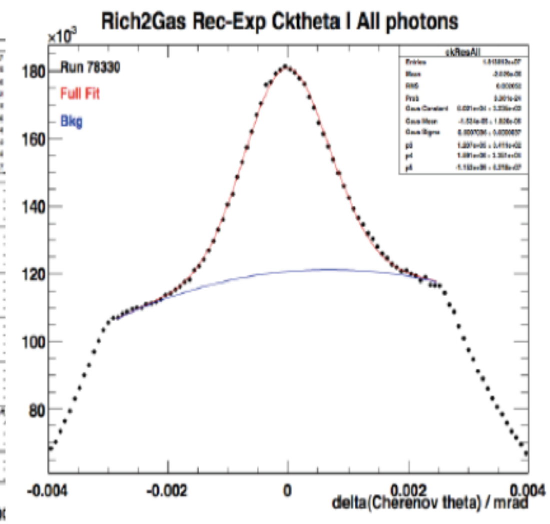

$\sigma_{FWHM}$ =3.5-4 mrad
MC: 2.6 mrad

**RICH1 $C_4F_{10}$**




$\sigma$ =1.69 mrad
MC: 1.57 mrad

**RICH2 $CF_4$**




$\sigma$ =0.73 mrad
MC: 0.67 mrad

# The RICH of LHCb : *the PID calibration*

Use high purity samples of $\pi$, K, and p selected without using the RICH information

*Decay modes used (or to be used):*

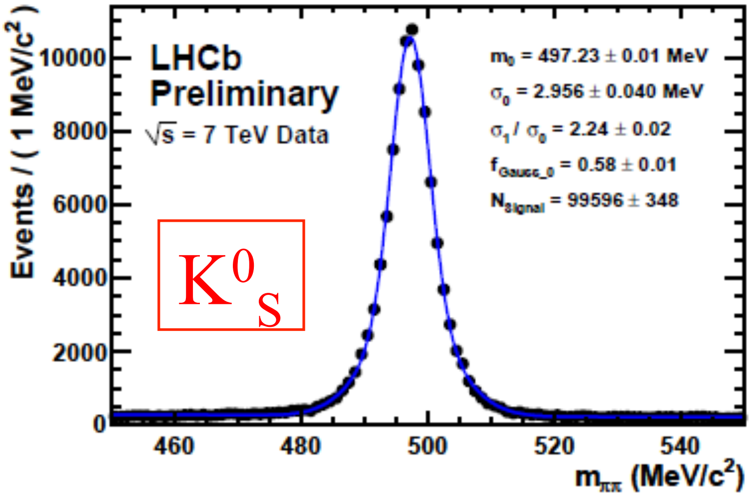
**V0 decays**

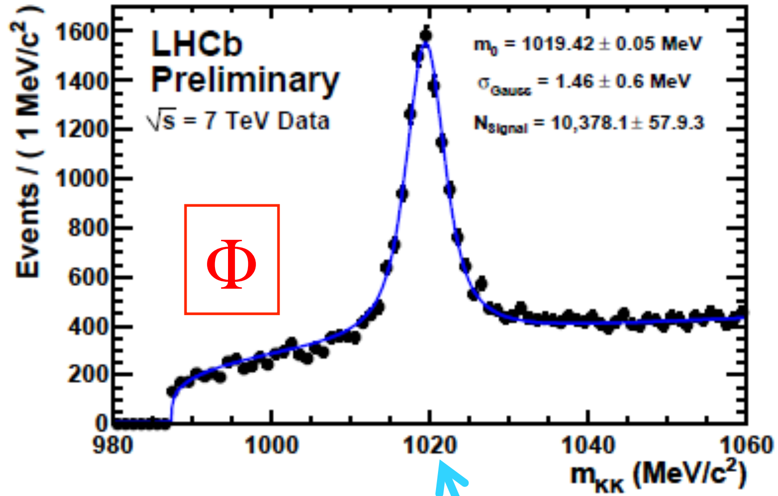
$$K_S^0 \to \pi^- \pi^+$$
$$\Lambda^0 \to p\pi^-$$

**Resonances**

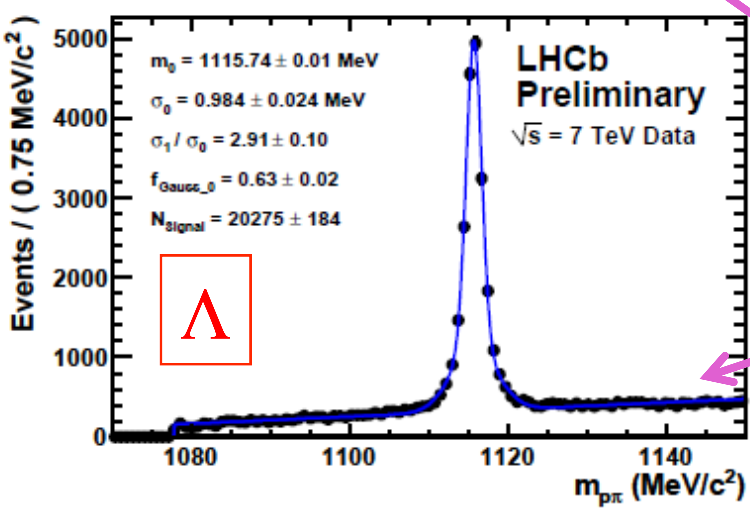
$$\phi(1020) \to K^+ K^-$$
$$D^{*+} \to D^0(K^- \pi^+)\pi^+$$
$$D_s^+ \to \phi(K^+ K^-)\pi^+$$

# The RICH of LHCb: *calibration*




More background in a K sample…
(use of tag-and-probe method)



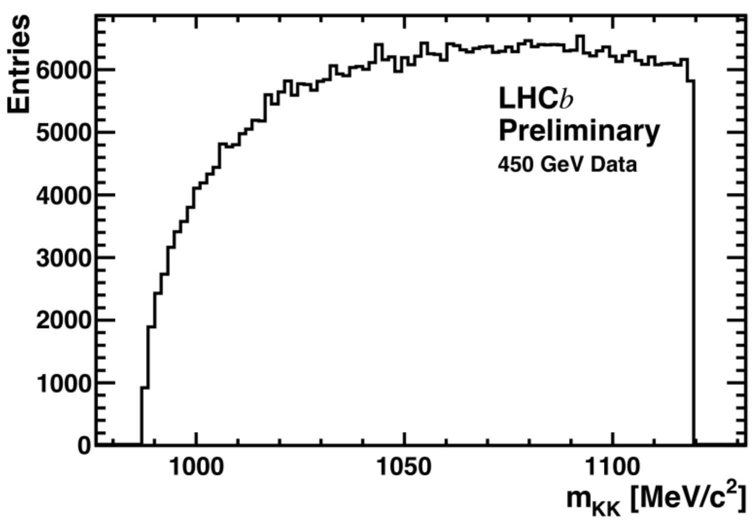

Very clean samples of $\pi$ and $p$

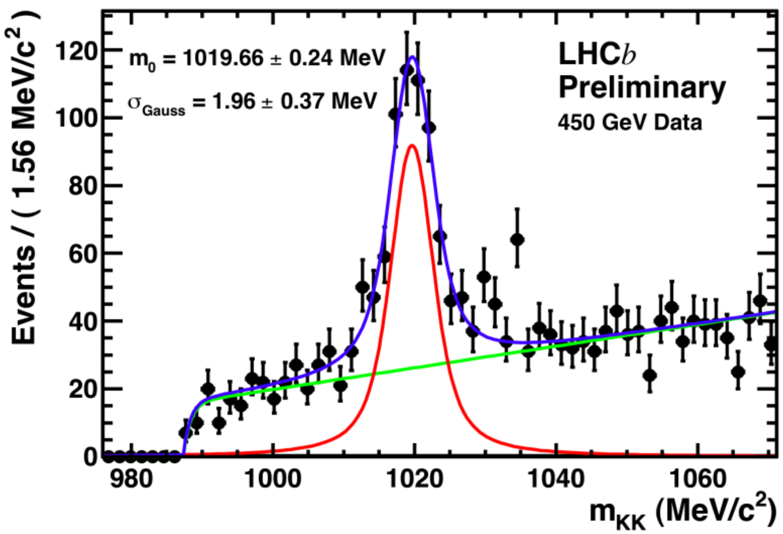
## What did the RICH of LHCb see in the very first data?

### Observation of $\phi \rightarrow K^+K^-$

**Only tracking**

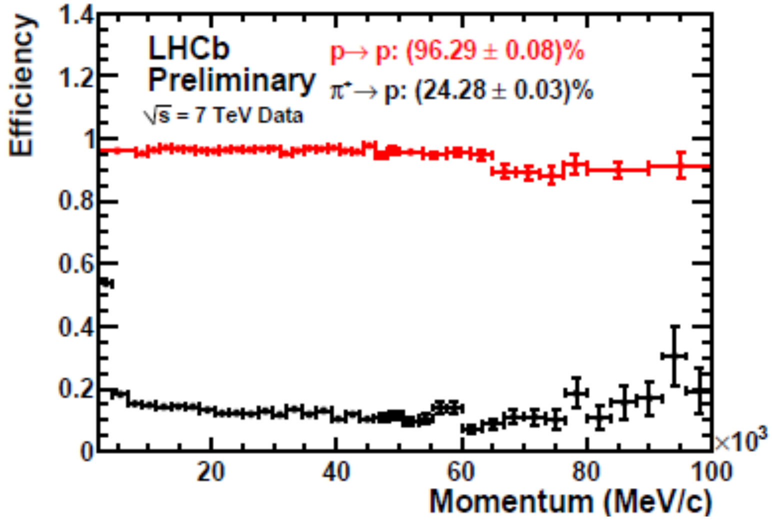
**With RICH**



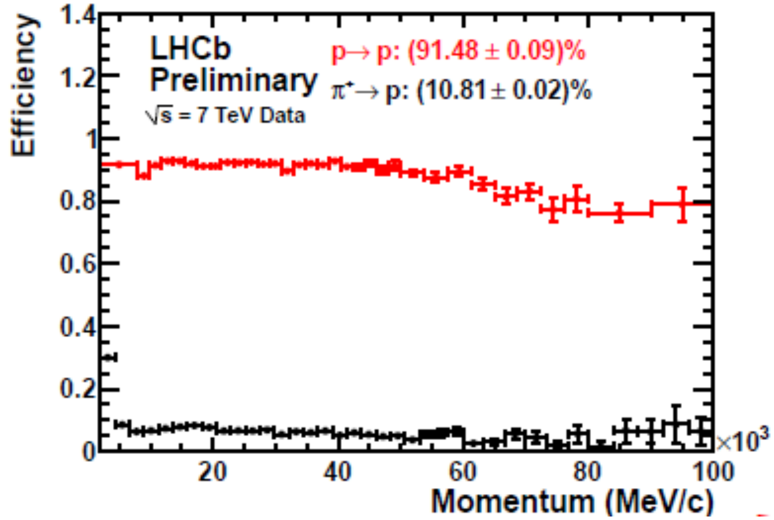



# The RICH of LHCb: *proton identification*

$\Delta \log \mathcal{L}(p-\pi) > 0$



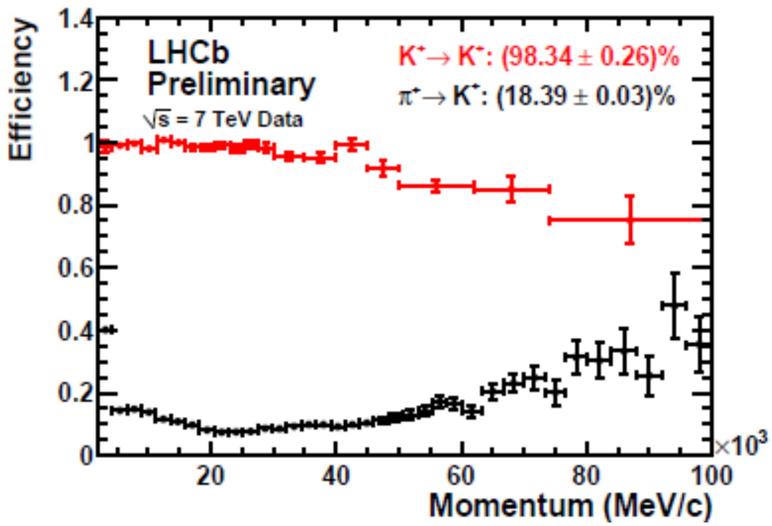

$\Delta \log \mathcal{L}(p-\pi) > 5$



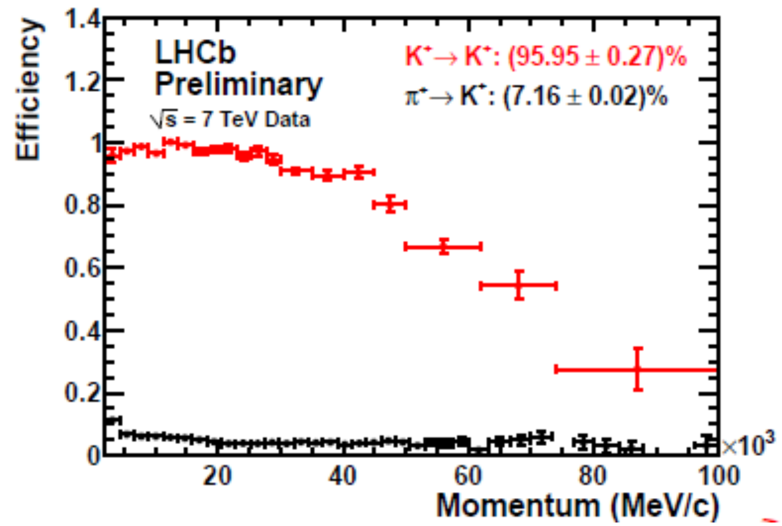
# The RICH of LHCb: *kaon identification*

*Based on july 2010 calibration*

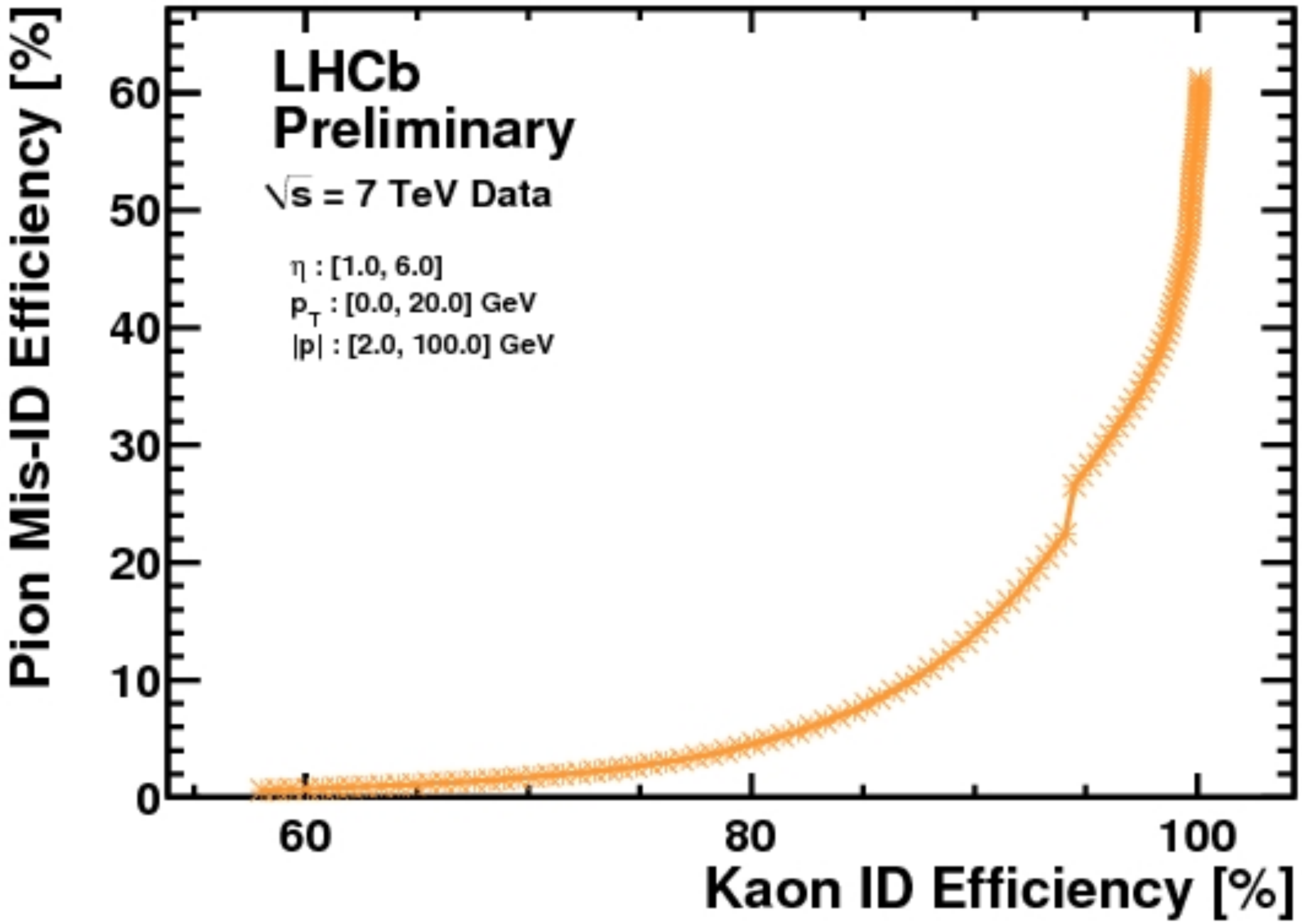
$\Delta \log \mathcal{L}(K-\pi) > 0$




$\Delta \log \mathcal{L}(K-\pi) > 5$

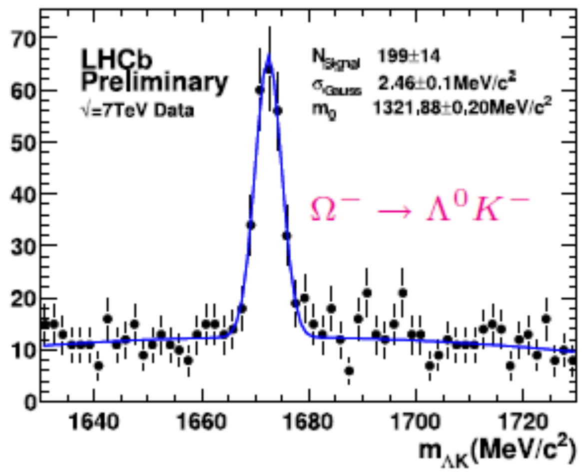


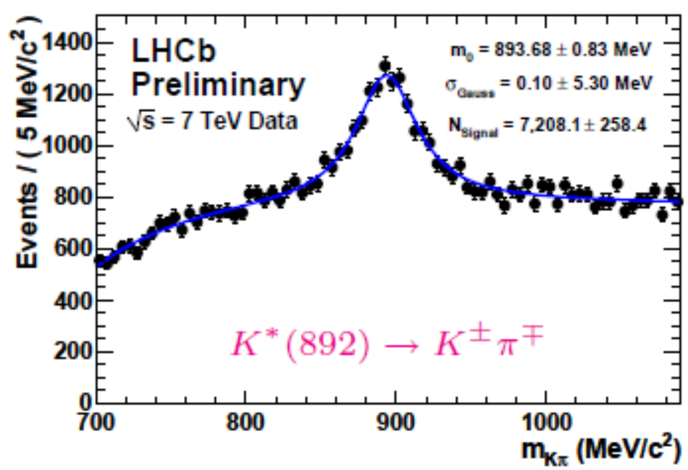
# The RICH of LHCb: *kaon identification*

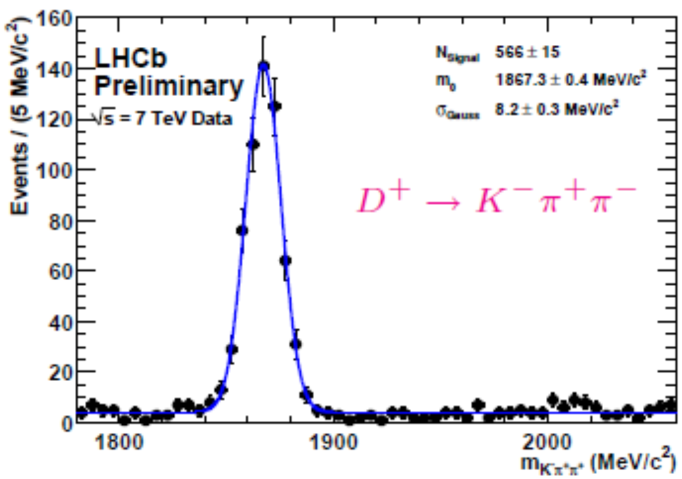


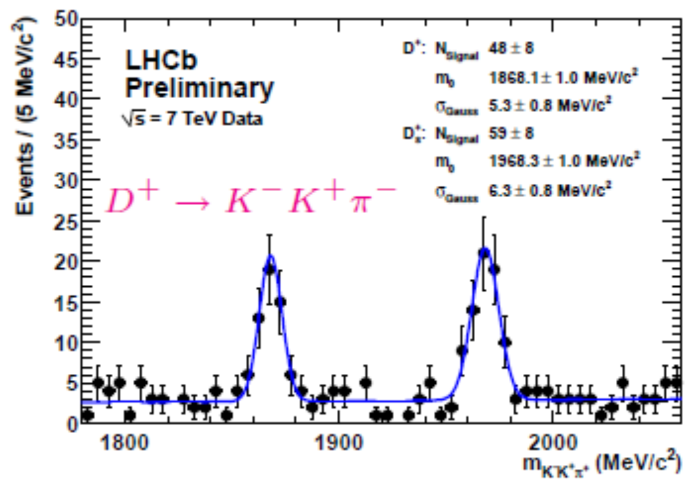
# The RICH of LHCb: *the performance*

Many channels can be seen thanks to the RICH:



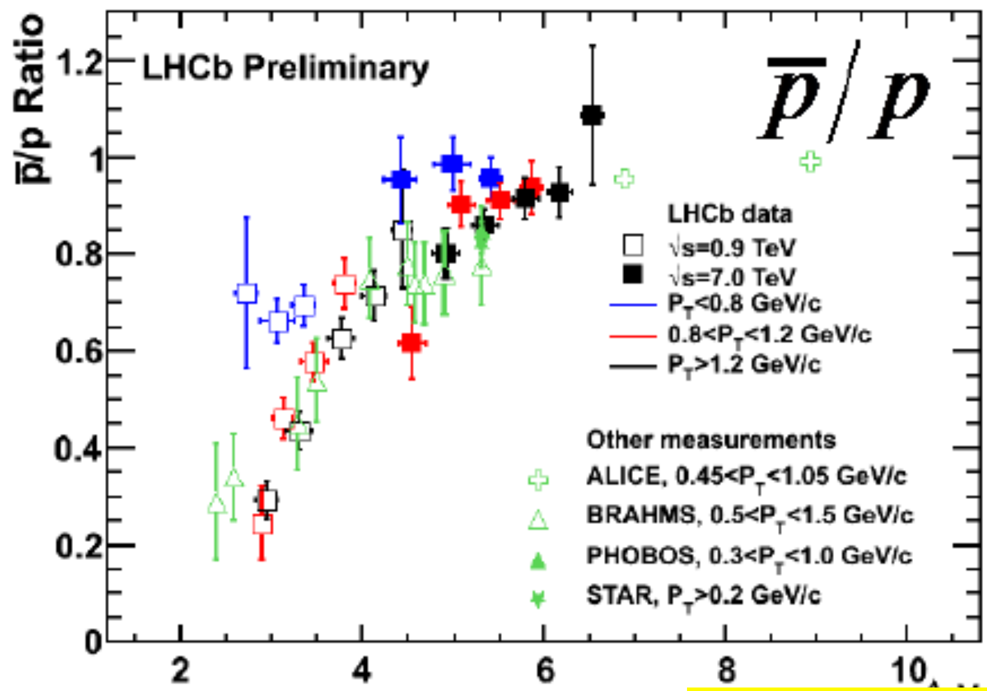



# The RICH of LHCb: *the performance*

Analysis of proton and antiproton production ratio possible with the RICH:




**$\Delta y$ = y(beam) –y(p)**

With:

*y(beam)*: 6.6 : $\sqrt{s}$ = 0.9 TeV

8.3 : $\sqrt{s}$ = 7 TeV

*(Presented at ICHEP2010)*

# Conclusions

- The RICH of LHCb is demonstrating to be the powerful tool to produce the physics it was designed for

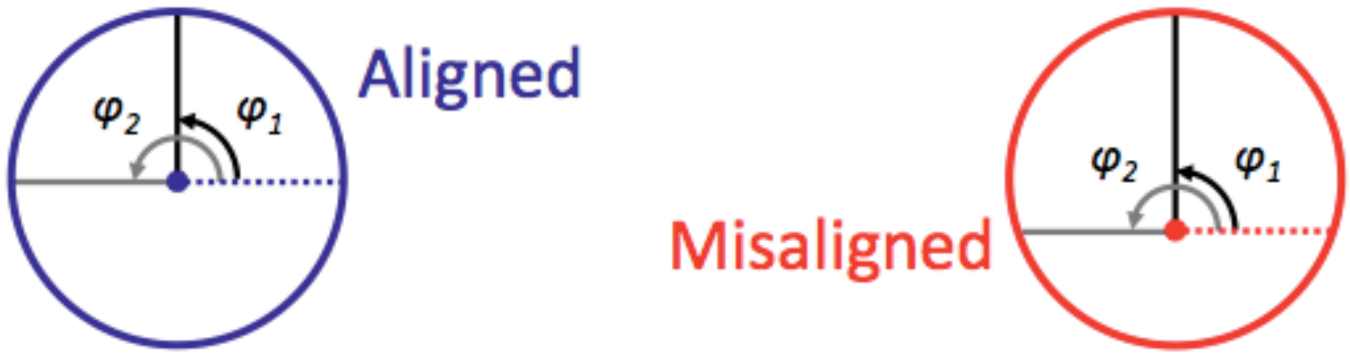
- The RICH of LHCb is operating very smoothly and stably at LHC since the startup of the machine

- The RICH of LHCb is approaching the level of performance expected by the simulation after only few months of operation
  ⇒ continuous calibration and alignment iterations

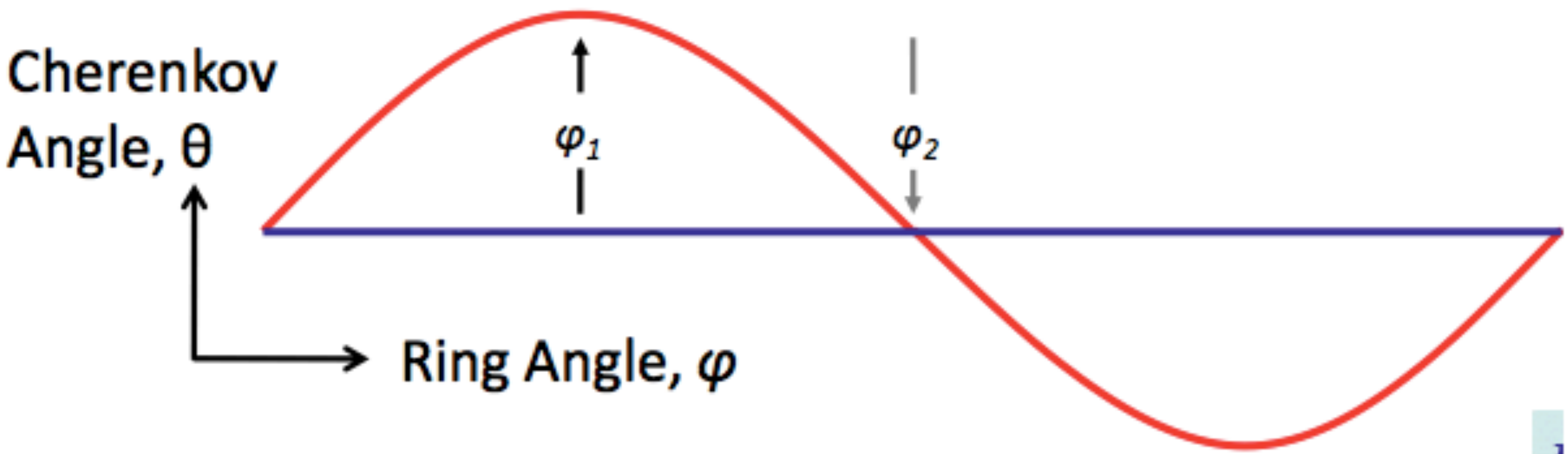
- BUT: it is a sophisticated tool and needs an important effort to keep under control the different components of the Čerenkov angle resolution, and an important effort in term of software tools for the treatment of the detector data in order to perform as expected

# Backup slides

Misalignment is observed relative to tracking:




Seen as a distribution **Δθ = Asin*φ* + Bcos*φ***:



# The RICH of LHCb: *the Δlog $\mathcal{L}$ distributions*