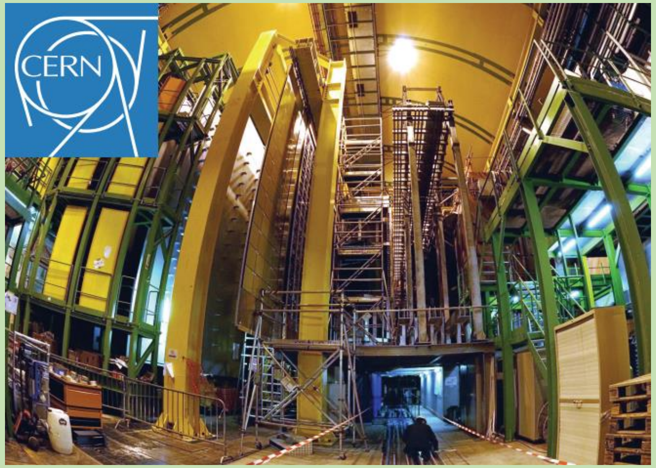
LHCb-RICH detectors and their gas radiators

CERN: Mini-Workshop on gas transport parameters
for present and future generation of experiments



On behalf of LHCb-RICH group

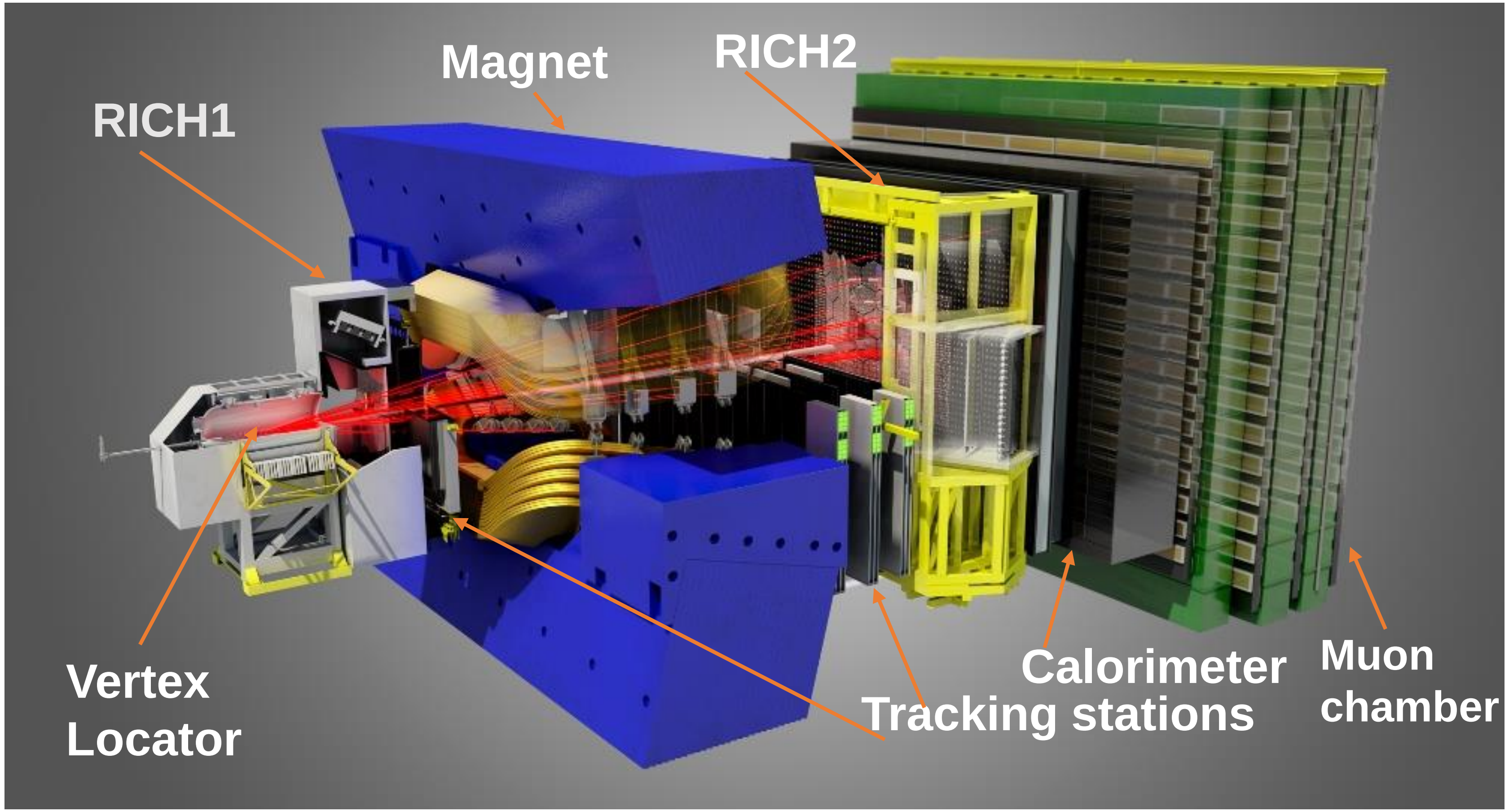
S.Easo
22-04-2021

Science and Technology Facilities Council

Outline

- ➢ LHCb experiment
  - *Synopsis of particle identification in LHCb*
- ➢ Design features of the current RICH system
  - Unique in covering the momentum range 2-100 GeV/c for hadrons
- ➢ Properties of the current gas radiators
  - Gas system successfully operated for many years
- ➢ Performance of the RICH system
- ➢ Issues regarding radiators for future LHCb upgrades and ideas for alternative gases
  - *Discussed in the second talk from LHCb later today*
- ➢ Summary

The LHCb Experiment



2 < η < 5, Forward spectrometer.

Overall acceptance ~ 10→300 mrad

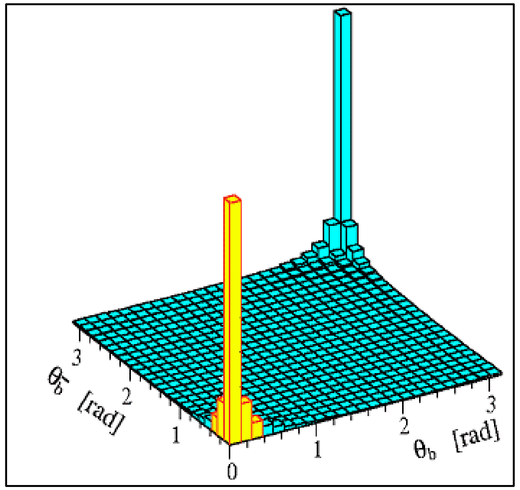
Momentum range : 2-100 GeV/c

From 2015:

- pp : $\sqrt{s}$ = 13 TeV
- RICH1:
  C_4F_{10} < ~ 60 GeV/c,
  Photodetectors: Top + Bottom
- RICH2:
  CF_4: < ~ 100 GeV/c
  Photodetectors: Left+ Right

Before 2015:

- pp : $\sqrt{s}$ = 8 TeV, Aerogel < 10 GeV/c



Polar angles of b and $\bar{b}$ hadrons from p-p collisions in LHC

Features of the RICH system

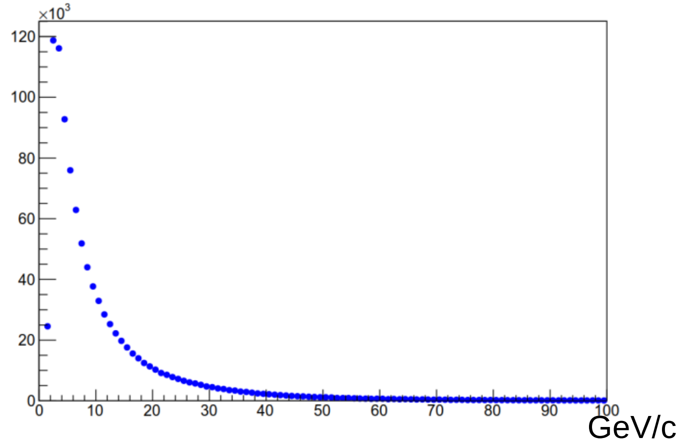
- **Momentum coverage: 2- 100 GeV/c**
  - Upper limit defined from typical physics channels:

    Examples: Momenta of π^+ in $B_s^0 \to D_s^- \pi^+$ and π^+ in $B^0 \to \pi^+ \pi^-$

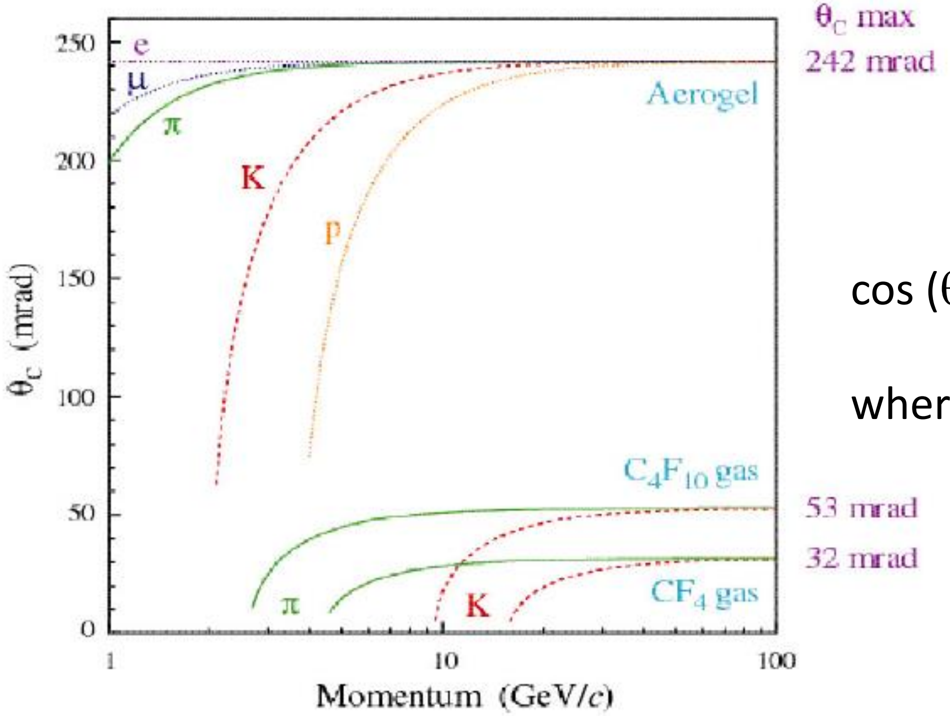
  - Lower limit also defined from typical physics channels:

    Large fraction tracks in low momenta.
    kaons used for flavour tagging in b→c→s transitions, have low momenta.

Particle momentum



- **Radiators to cover different momentum ranges**
  - Aerogel was removed in LS1.
  - Hence using only 'veto mode' for momenta below 10 GeV/c



$\cos(\theta) = 1/(n\,\beta)$

where $\beta = \frac{1}{\sqrt{1+(m/p)^2}}$

- **The data from RICH is an an essential part of the physics programme of LHCb**

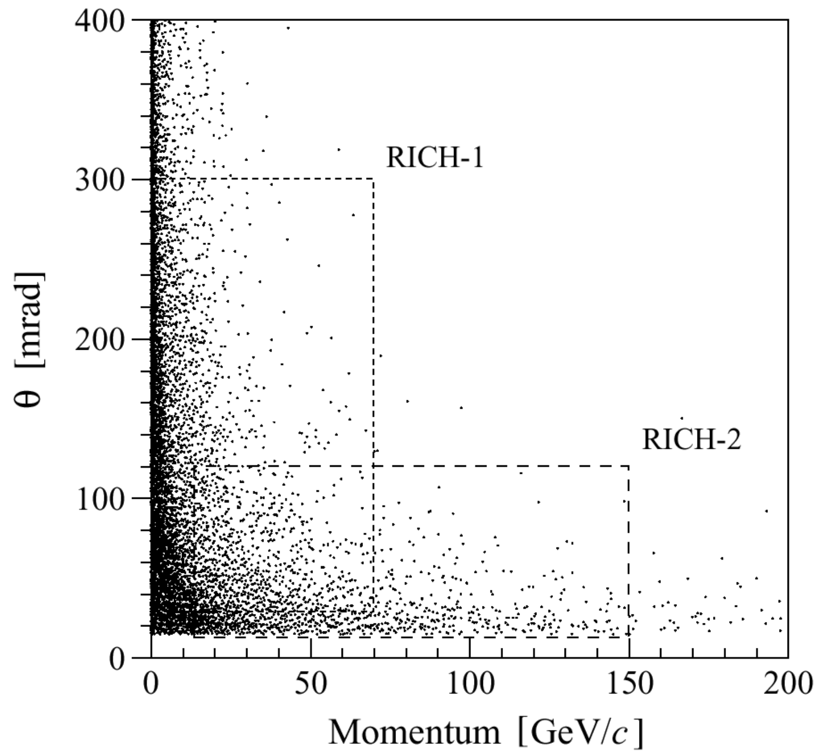
LHCb-RICH Design features

RICH1: C_4F_{10} L ~ 107 cm p: < 60 GeV/c
n ~ 1.0014 (nominal at 400 nm)

- **Upstream of LHCb Magnet**
- **Acceptance: 25→250 mrad (vertical)**
  300 mrad (horizontal)
- **Gas vessel: 4 m^3**

RICH2: CF_4 L ~ 196 cm p: < 100 GeV/c
n ~ 1.0005 (nominal at 400 nm)

- **Downstream of LHCb Magnet**
- **Acceptance: 15→100 mrad (vertical)**
  120 mrad (horizontal)
- **Gas vessel : 100 m^3**



Charged tracks : polar angle vs momentum

$$(n-1) \propto \frac{P}{T}$$

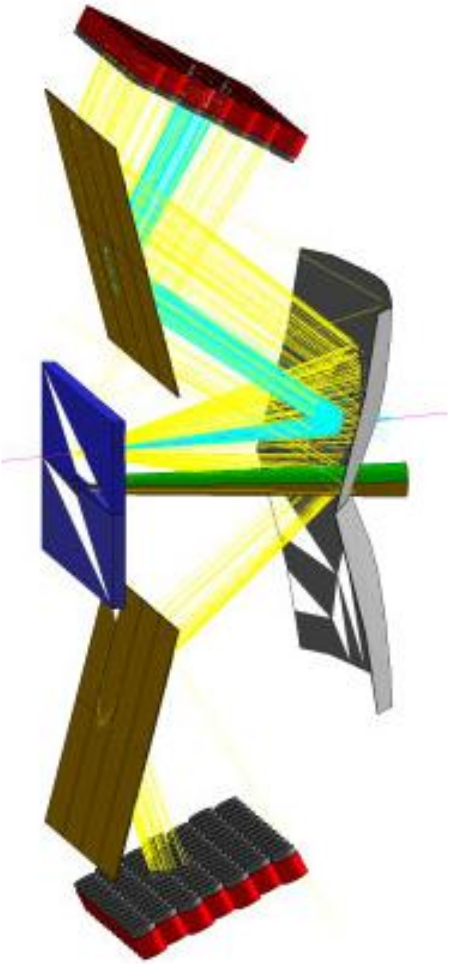
- ❖ However the two RICH detectors are kept at ambient temperature(T) and pressure (P).
- ❖ This avoids potential damage to the mirror systems and the thin quartz windows. It also helps to reduce variation of P and T within the gas vessels.
- ❖ P and T are constantly monitored and n recalculated in online, using Sellmeier formulae.

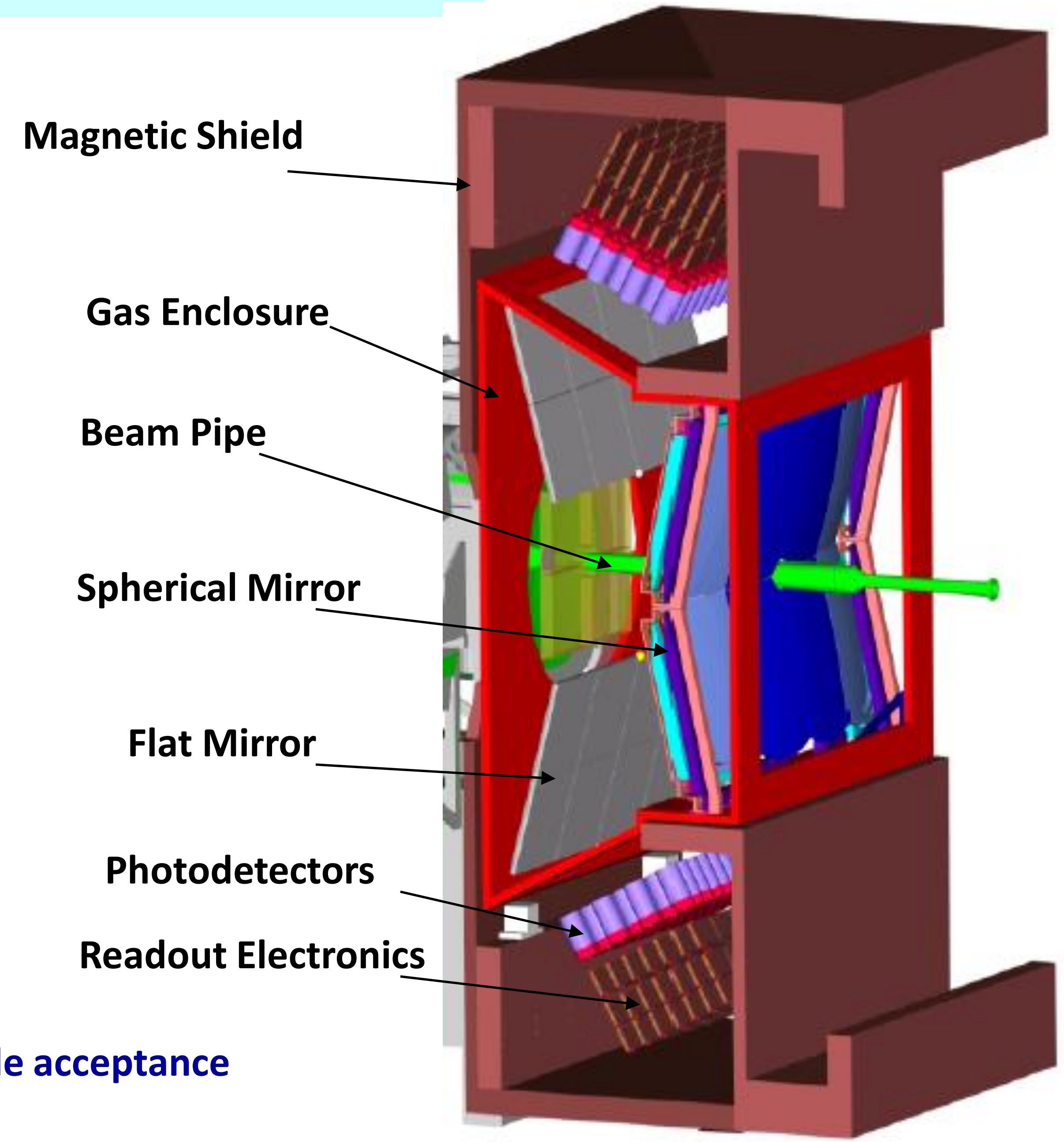
Number of photons produced $\propto L\left(1-\frac{1}{(n\beta)^2}\right)$

- ❖ Length (L) of RICH2 is larger than that of RICH1.

LHCb- RICH1 SCHEMATIC

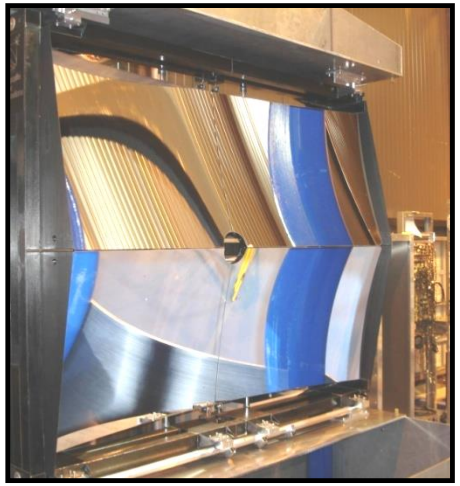
RICH1 OPTICS



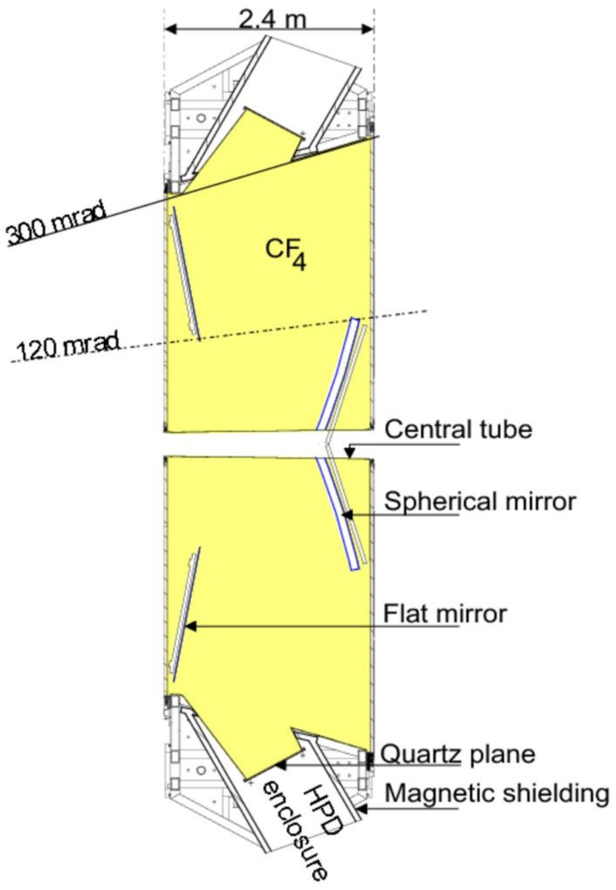


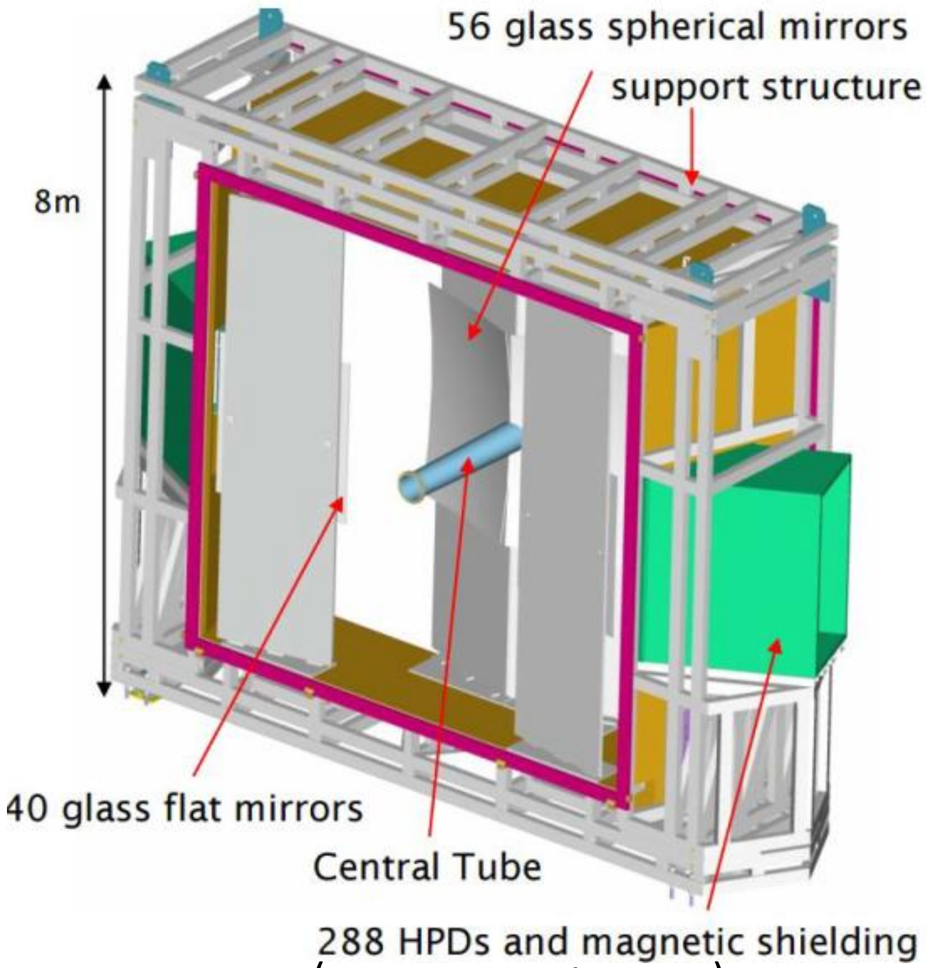
- Spherical Mirror tilted
  to keep photodetectors outside acceptance
  (tilt ~ 0.3 rad)

RICH1 in pictures



LHCb- RICH2 SCHEMATIC





(1152 MaPMTs in RUN3)

RICH2 in pictures

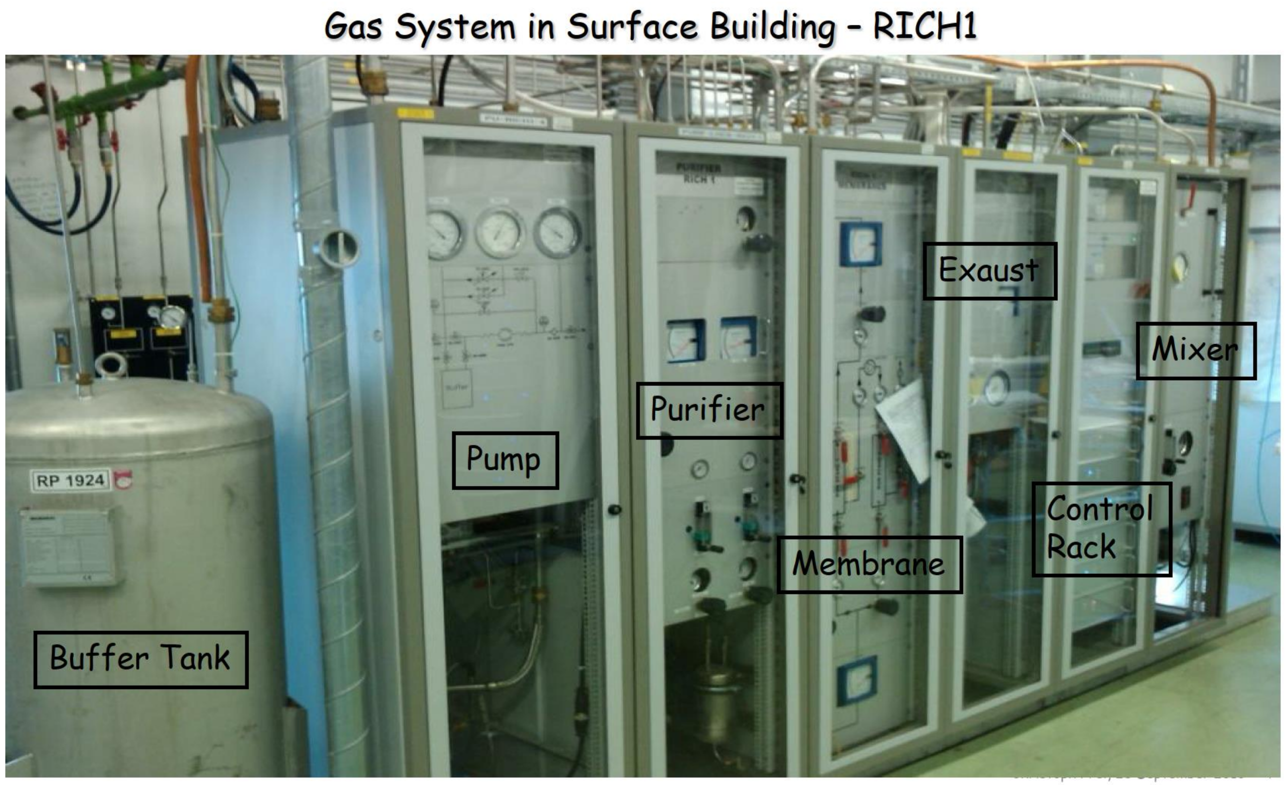
Properties of the current gas radiators

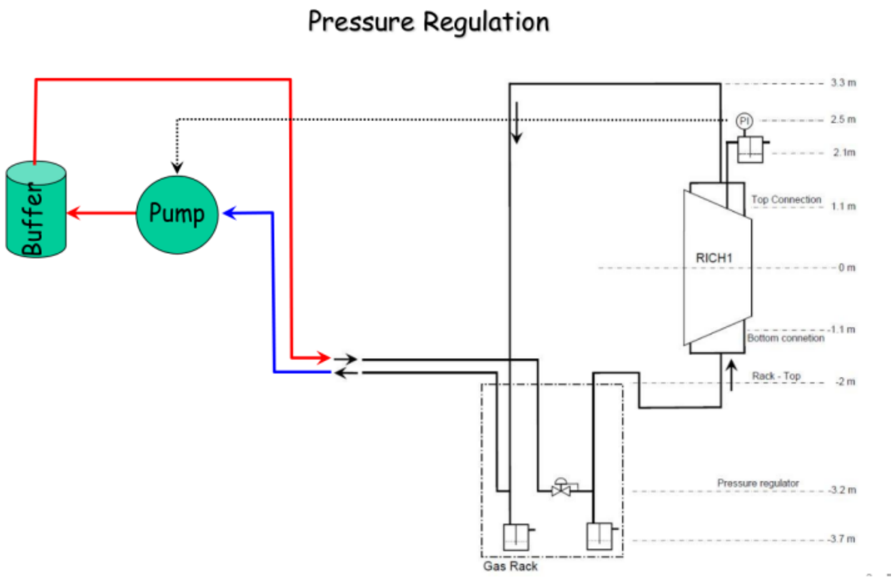
- The current choice of the two gas radiators is based on results from extensive searches of different gases.
- They were used in test beam studies, before using them in the LHCb-RICH system

	RICH1	RICH2
Gas	C_4F_{10}	CF_4
Volume	$\sim$4 m^3	$\sim$100 m^3
Flow	$\sim$0.5 m^3/h	$\sim$5 m^3/h
O2 impurity	0.4 % / $<$ 0.02%	0.1 % / $<$ 0.02%
N2 impurity	2 % / $<$ 1%	0.5 % / $<$ 1%
H2O impurity	$<$ 0.02%	$<$ 0.02%
Density	10 kg/m^3	3.5 kg/m^3
Boiling point	-1.9°C	-128°C
Price	$\sim$1000 CHF/m^3	$\sim$300 CHF/m^3

- Important to keep impurities down
- Impurities can change refractive index.
  They may also produce photons from scintillation and ionization.

Gas system in pictures

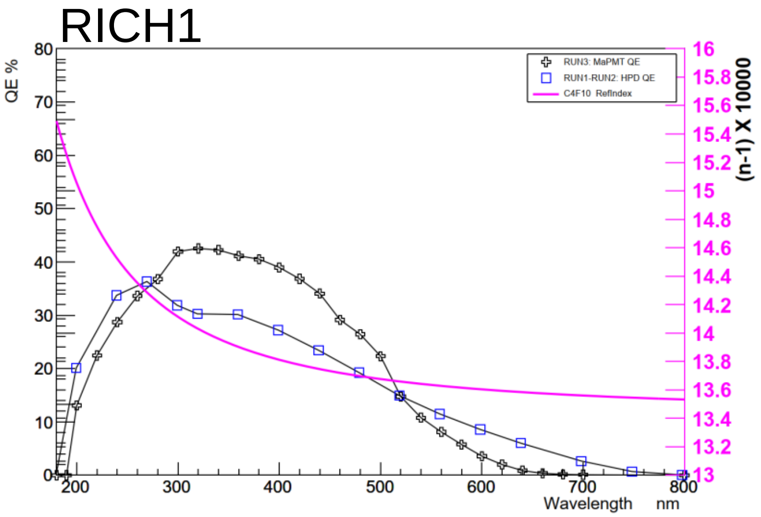


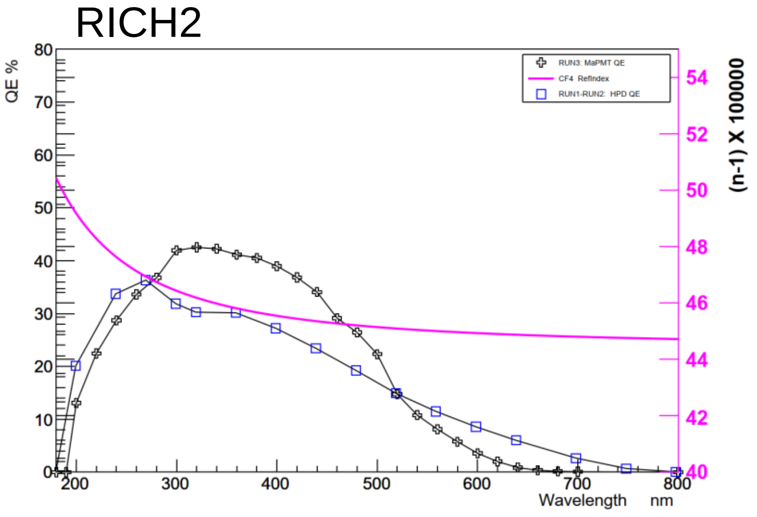


LHCb contact for the gas system: Christoph.Frei@cern.ch

Properties of the current gas radiators

	RICH1 C_4F_{10}	RICH2 CF_4	
L	107	196	cm
θ_c^{max}	53	32	mrad
π_{Th}	2.6	4.4	GeV/c
K_{Th}	9.3	15.6	GeV/c





Nominal single photon resolution (in mrad)	RICH1-old HPD, C_4F_{10}	RICH1-RUN3 MaPMT, C_4F_{10}	RICH2-old HPD, CF_4	RICH2-RUN3 MaPMT, CF_4
Chromatic	0.84	0.52	0.48	0.34
Overall (RICH)	1.60	0.80	0.65	0.50
Yield	**32**	**63**	**24**	**34**

- Two of the requirements for new radiators:
  - The chromatic error should not worsen than the current level
  - The yield should be at least as good as the current level
- This would imply that distributions of n for the new radiators need to be similar to or better than those shown here.

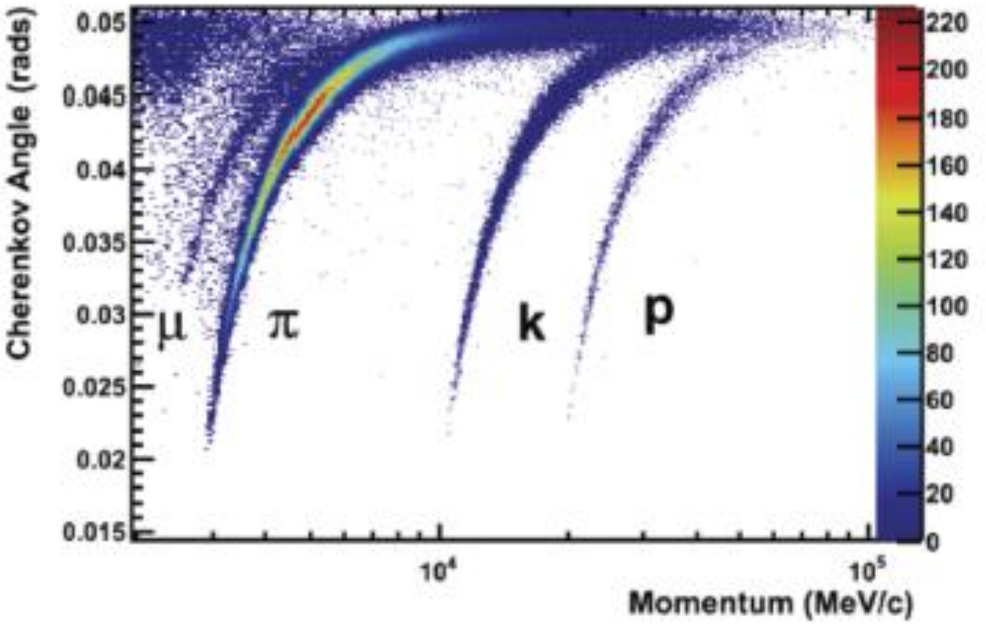
Full table with all other components of the resolutions in backup page

- *Yield : Number of photon hits detected per charged track.*
- *RICH1 radiator length and optics upgraded for RUN3.*
- *RICH2 : From R-Type MaPMTs*
- *Chromatic error: From the variation of n with wavelength.*

Properties of the gas radiators

- CF_4 scintillation:
  - A few percent of CO_2 is added to CF_4 so that the scintillation photons are mostly quenched.
    Ref: Nucl.Inst.Meth. A 791 (2015) 27-31 ("Quenching the scintillation in CF4 Cherenkov gas radiator")

- C_4F_{10} : Particle separation from isolated Cherenkov rings in real data



Eur.Phys. J.C (2013) 73:2431

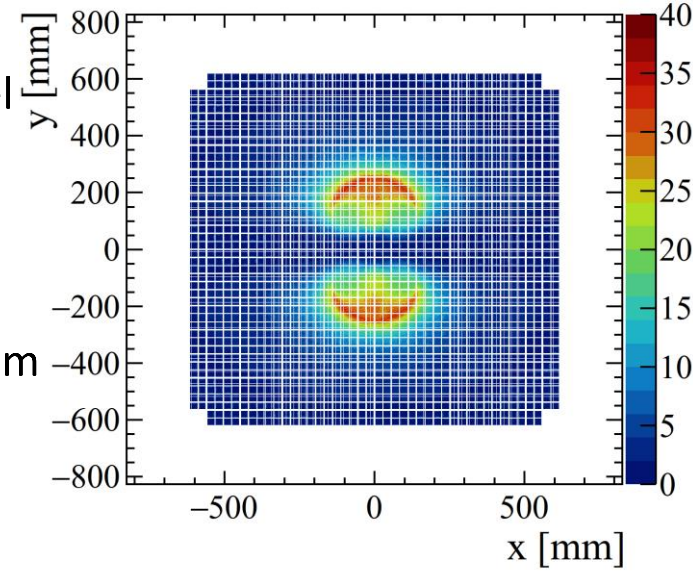
- Other gases : They were expected to perform worse than the two gases used, especially in the low wavelength region. When there was potential shortfall in the supply of C_4F_{10}, investigations were done regarding the use of C_3F_8 as a substitute. However this option was later abandoned.

Data from the RICH detectors

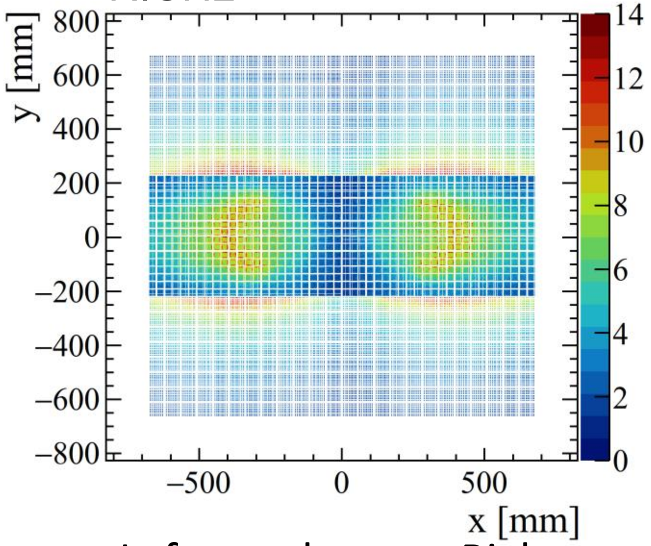
RICH1

Top panel

Bottom panel

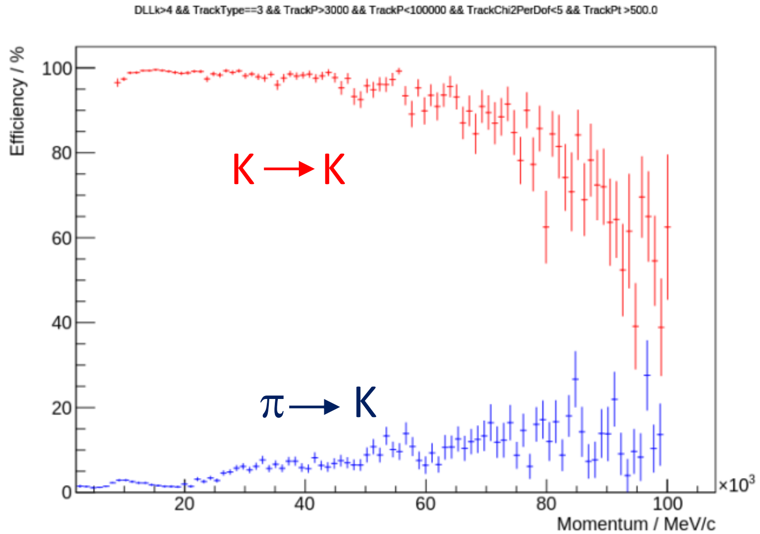


RICH2



Left panel Right panel

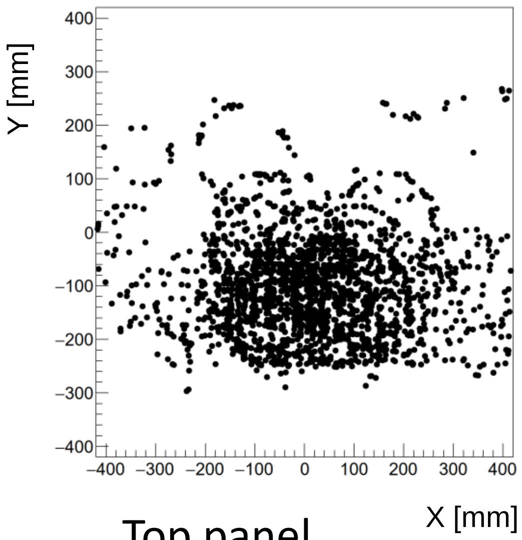
Typical performance



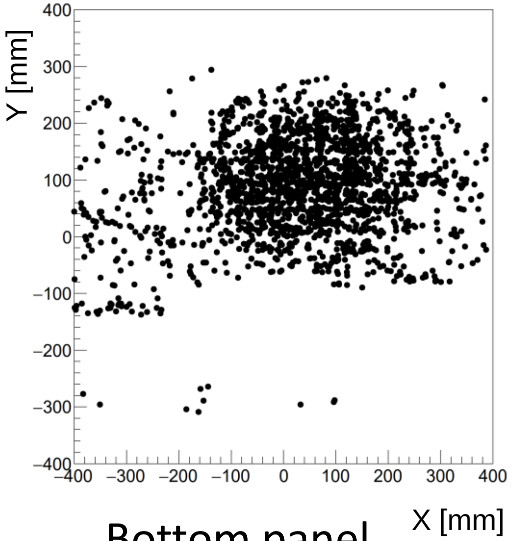
kaon identification efficiency

pion misidentification probability

RICH1 : Single Event



Top panel

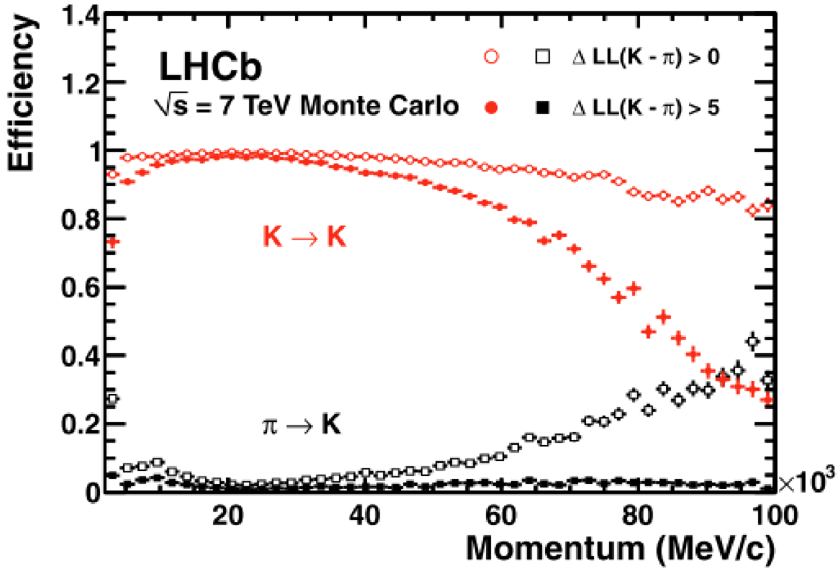


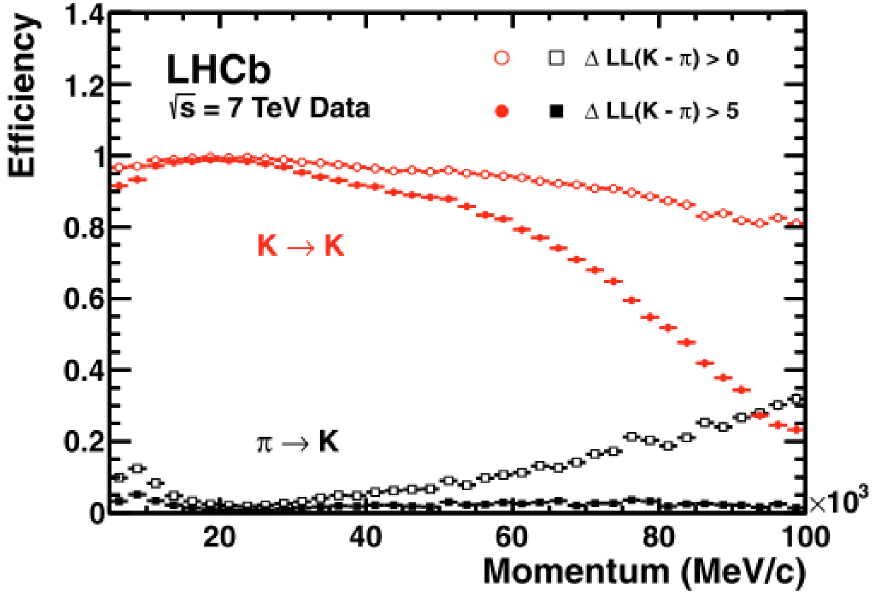
Bottom panel

- Occupancy quoted in percentage, in the detector planes
- These use RUN3 configuration
- Reconstruction uses a log-likelihood algorithm for particle identification

Ref: "*Overview of LHCb RICH Upgrade*",
S.Easo, Nucl.Inst.Meth. A 876 (2017) 160-163

Examples of RICH performance from earlier data





Detector performance from RUN1: *Eur.Phys. J.C (2013) 73:2431, M.Adinolfi et.al.* *“Performance of the LHCb RICH detector at the LHC”*

Summary

- Data from the RICH system is used in most of the physics analysis results from LHCb
- The two gas radiators cover the momentum range required for LHCb.
- The gas system worked successfully for the past two RUNs and is expected to be used for RUN3.
- New gases would need to perform at least as good as the current system, in terms of the chromatic error contributions and photon yields.

BACKUP PAGES

LHCb-RICH: Nominal resolutions

Nominal single photon resolution (in mrad)	RICH1-old HPD, C_4F_{10}	RICH1-RUN3 MaPMT, C_4F_{10}	RICH2-old HPD, CF_4	RICH2-RUN3 MaPMT, CF_4
Chromatic	0.84	0.52	0.48	0.34
Pixel	0.60, PSF=0.86	0.50	0.19 PSF=0.29	0.22
Emission point	0.76	0.36	0.27	0.32
Overall Overall/$\sqrt{N}$ $\oplus$ Track	1.60 0.49	0.80 0.36	0.65 0.42	0.50 0.36
Yield (N)	**32**	**63**	**24**	**34**

RICH2 R-type MaPMTs used here