Overview of LHCb RICH Detector Development

*On Behalf of
LHCb-RICH Group*

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S. Easo

Rutherford-Appleton Laboratory, U.K.

OUTLINE

- LHCb and its Particle Identification
- Design and Main Features of LHCb-RICH
- Components of RICH1 and RICH2:
  - Radiators: Aerogel, C_4F_{10} gas, CF_4 gas.
  - Mirrors: Beryllium, Glass Type.
- RICH Photodetectors: HPD, Readout System
- RICH Performance : LHCb Detector Simulations
- Summary

LHCb EXPERIMENT

- Precision measurements of CP violation in B Meson System
- Search for Signals of 'New Physics' beyond Standard Model
- Large samples of events with B_d and B_s Mesons
- At the beginning of LHC $2 \cdot 10^9$ $b\bar{b}$ events per year after trigger selection
- Most of the b-hadrons produced at small polar angles
- Single forward arm spectrometer with open geometry
- From the CP Asymmetries in the final states of B meson decays, measure CKM Angles.

Examples:

γ from $B_d^0 \rightarrow \pi^+ \pi^-$, $B_s^0 \rightarrow K^+ K^-$

γ from $B_s^0 \rightarrow D_s^+ K^-$

THE LHCb EXPERIMENT

Magnet already installed

PARTICLE IDENTIFICATION IN LHCb

Particle Identification using RICH is an essential part of LHCb.

- Identification of Kaons to tag the flavour of b hadrons where $b \rightarrow c \rightarrow s$
- Momentum Range: 2 → 100 GeV/c :
  - Upper limit from the π in $B_d \rightarrow \pi^+ \pi^-$
  - Lower limit from the tagging Kaons

LHCb-RICH SPECIFICATIONS

RICH1: Aerogel $L=5\text{cm}$ $p: 2 \rightarrow 10 \text{ GeV}/c$
 $n=1.03$ (nominal at 540 nm)
 C_4F_{10} $L=85 \text{ cm}$ $p: < 70 \text{ GeV}/c$
 $n=1.0014$ (nominal at 400 nm)

Upstream of LHCb Magnet

Acceptance: $25 \rightarrow 250 \text{ mrad}$ (vertical)
 300 mrad (horizontal)

Gas vessel: $2 \times 3 \times 1 \text{ m}^3$

RICH2: CF_4 $L=196 \text{ cm}$ $p: < 100 \text{ GeV}/c$
 $n=1.0005$ (nominal at 400 nm)

Downstream of LHCb Magnet

Acceptance: $15 \rightarrow 100 \text{ mrad}$ (vertical)
 120 mrad (horizontal)

Gas vessel : 100 m^3

53 mrad
 32 mrad

RICH1 SCHEMATIC

RICH1 OPTICS

Magnetic Shield

Gas Enclosure

Beam Pipe

Spherical Mirror

Flat Mirror

Photodetectors

Readout Electronics

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

COMPONENTS OF RICH1

▪ Gas Enclosure:

- Aerogel and Mirrors attached to this box
- Non-magnetic, to minimize distortions from the field on the optical configuration
- Made of 30 mm thick Aluminium alloy

▪ Exit window:

- Low mass material
- PMI (polymethacrylimide) foam between carbon fibre epoxy

Radiators:

- C_4F_{10} : Results with prototypes in testbeam already published
- Concern over availability of C_4F_{10} :
Backup Option: 50:50 mixture of C_5F_{12} and C_3F_8

▪ Silica Aerogel:

- fragile linked network of SiO_2 nanocrystals
- hygroscopic
- nominal $n=1.03$ at 540 nm
- Loss of signal from Rayleigh Scattering

Ref. Talk by C. Matteuzzi

RICH1 MIRRORS

- **Spherical Mirror inside LHCb acceptance**
- **Requirements:**
  - Minimum material with sufficient rigidity
  - $D_0 < 2.5$ mm (size of circle at focal plane with 95 % image intensity from a point source)
  - Reflectivity > 90 % in 200-700 nm
- **Selected 3 mm thick Beryllium + < 0.3 mm glass coated with $\text{Al}+\text{SiO}_2+\text{HfO}_2$: 0.8 % X_0 .**
  - RoC = 2700 mm
  - 8 segments : 410 X 600 mm and 385 X 600 mm
  - $D_0 = 0.41$ mm for prototype, FEA: negligible distortions

Be Prototype

Be mirror array seen from rear

- **Flat Mirror outside LHCb acceptance:**
  - 16 segments : 370 X 387 mm
  - 6 mm thick Simax (Borosilicate) glass or equivalent

RICH2 SCHEMATIC

RICH2 Optics Top View

- Plane Mirrors to reduce the length of RICH2
- Spherical mirror tilted to keep photodetectors outside acceptance.(tilt=0.39 rad)

RICH2 COMPONENTS

HPD Array

Structure (Al Alloy)

Central Tube Around
Beam Pipe
(Carbon fibre epoxy)

Mirror Support Frame

Photon Funnel

Spherical Mirror: RoC=8600 mm

- 42 Hexagons + 14 Half Hexagons

- size of a hexagonal segment= 510 mm

Flat mirror: 20 Rectangular segments

- size of a segment= 410 X 380 mm²

All mirrors made of Simax (Borosilicate) glass

Al + SiO₂ + HfO₂ coating for the required reflectivity

Production of the mirrors is underway

RICH2 STRUCTURE ASSEMBLY

**Entrance Window
(PMI foam between two
carbon fibre epoxy Skins)**

- **Final verifications of the structure in progress at CERN**
- **Mirrors and Shielding to be Mounted**
- **Scheduled to be transported to LHCb cavern in summer, 2005**

- **At installation time, alignment of mirrors using a laser based system, to well below one mrad**
- **Monitor changes in Mirror alignment of a set of mirrors using a dedicated laser system inside the gas vessel**
- **Final alignment using data**

Photon Detectors and Readout System

- Active area fraction (>73 %), Granularity of $2.5 \times 2.5 \text{ mm}^2$, Sensitive in $200 \rightarrow 600 \text{ nm}$, 40 MHz readout and tolerant well beyond 3 K Rad/year

Pixel HPD

- **Pixel Chip:**
  - $16 \times 16 \text{ mm}^2$
  - 13 million transistors
  - $0.25 \mu\text{m}$ CMOS technology
  - Analogue input $\rightarrow$ Binary Output
  - Data collected in testbeams with HPD+Pixel Chip

Overall Readout System

- 198 + 288 HPDs to cover 2.6 m^2 in RICH1 + RICH2
- *Ref. Talk by N. Kanaya on tests using HPDs*

RICH SOFTWARE AND PERFORMANCE

- Detector Simulation and performance evaluation has been an integral part of RICH detector development
- Using an OO Framework (GAUDI) in C++, a complete software chain implemented for all LHCb detectors, including the RICH

- This facilitates detailed simulations of the Detectors
- **RICH Reconstruction:** Reconstruct Cherenkov Angle from Hits → Global Log likelihood method.
- **RICH in Trigger:** useful for channels like $B_s \rightarrow D_s^+ D_s^- \rightarrow K^+ K^- \pi^+ K^+ K^- \pi^-$
Offline Pattern Recognition ~ 1s /event on 1GHz PC
Online: A possible algorithm:
Fast 'likelihood method' in the Hit space
No Angle reconstruction; tests show ~ 10 ms/event
Ref. Talk by N. Neufeld

RICH PERFORMANCE

- Used in RICH Simulation in 2004 (DC04)
Not the very final engineering design
- Yield: Mean Number of hits per saturated track (Beta ~1).

Aerogel	C4F10	CF4
6.8	31.0	23.0

Cherenkov Angle Resolutions

Components and Overall (mrad)	Aerogel	C ₄ F ₁₀	CF ₄
Chromatic	2.07	0.80	0.47
Emission Point	0.34	0.80	0.33
Pixel Size	0.57	0.57	0.16
Overall RICH	2.19	1.29	0.60
Overall RICH+Tracks	2.60	1.60	0.61

- All these are compatible with testbeam results

Example: For RICH2 prototype, testbeam results compared to simulations in:

NIMA 456(2001) 233-247

RICH EVENT DISPLAY

Red: From particles from Primary and Secondary Vertex

Blue: From secondaries and background processes (sometimes with no reconstructed track)

RICH PATTERN RECOGNITION

Difference in the log-likelihood between K and π hypothesis in $B_s^0 \rightarrow D_s^+ K^-$ events.

In general, $\Delta \ln L_{K\pi}$ is positive for kaons and negative for pions.

$B_s^0 \rightarrow D_s^+ K^-$

(signal)

$B_s^0 \rightarrow D_s^- \pi^+$

(background)

After using cut on difference in log-likelihood, background at 10% level

RICH PERFORMANCE

- After Particle Identification,
Efficiency (in %) of pion and kaon identification and
Probability (in %) of misidentifying pion and kaon for different momenta

Particle Momentum (Gev/c)→

Particle Momentum (Gev/c)→

- Best measured tracks in Minimum Bias events used for this

SUMMARY AND PLANS

- **RICH is an essential component of LHCb**
- **HPDs are now being produced for the RICH detectors**
- **Engineering Designs of both RICH detectors are accomplished**
- **RICH2 construction almost complete and RICH1 construction underway**
- **Installation expected to be completed by October 2006**
- **Detailed simulation using GEANT4 done and expected performance verified**