Performance of the LHCb RICH detectors

On behalf of the LHCb-RICH Collaboration

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Outline

- Two RICH detectors in LHCb:
 - Design features of the RICH system
 - Components of RICH1 and RICH2
- HPDs (Hybrid Photon Detectors):
 - Description
 - Characterization
- Results from Commissioning :
 - Monitoring magnetic field distortions
 - Time alignment of readout
- Performance from Simulations:
 - Photoelectron yields,
 - Cherenkov angle resolutions
 - PID performance

The LHCb Experiment at the LHC

- Optimized to study the decays of B-Hadrons
- Probe physics beyond the standard model
- Precision measurements of CKM angles

- Forward Spectrometer
- Acceptance : from 10 mrad to 250 mrad (vertical) , 300 mrad (horizontal)

- **Particle identification at LHCb: π / K separation in 1-100 GeV/c**
Two RICH detectors: RICH1, RICH2

LHCb-RICH

- Several test beam studies over 10 years
- Latest test beam results :
Presentation (N56-3) by
H.Skottowe at this conference.

RICH1

Silica Aerogel
n=1.03 , L=5cm
1-10 GeV/c

C₄F₁₀ gas
n=1.0014 , L~85cm
Up to ~60 GeV/c

RICH2

CF₄ gas
n=1.0005 , L ~ 200 cm
Up to ~100 GeV/c

RICH1 Detector

Photon detector plane 14 by 7 Array of Hybrid Photon Detectors (HPDs)

Upper Magnetic Shielding Protects HPDs from B field, supports upper HPDs

Glass Planar Mirrors

Quartz Window

Spherical Mirrors
Lightweight carbon fibre mirrors 1.4% radiation length.

Beryllium beampipe
(defines RICH1 inner acceptance)

4 m

1.175m

Gas Enclosure
supports mirrors and aerogel, contains C_4F_{10}

Aerogel Tiles

Entrance Window sealed to LHCb-Vertex Detector
Exit Window made of Carbon fibre and PMMI foam.

RICH1 Detector

Aerogel Tiles

Aerogel in RICH1:

- 16 tiles made at Novosibirsk
- Tile size up to 20cm*20cm*5cm .
- Rayleigh Scattering:
Non-scattered Transmission = $A \exp -(Ct/\lambda^4)$
where typically $A=0.93$
 $C= 0.0059 \mu\text{m}^4 \text{cm}^{-1}$
 $t=5\text{cm}$, λ = wavelength
- Prototype Aerogel tests: NIMA 553(2005) p 356
Also N30-218: D.L.Perego

RICH1-HPD Array

Spherical Mirrors

- Mirrors : Size 640mm X 835 mm , made from Carbon Fiber Reinforced Polymer by CMA (USA) .
Coating: Al (80nm)+ MgF₂ (160nm) by SESO(France)
(NIMA 595 (2008) p. 197)

Mirror D₀
~ 1.2 mm

RICH2 Detector

- Signals from HPD sent via a 100 m optical cable to LHCb-DAQ

HPD Column in RICH2

- Mirrors installed within an alignment precision of 0.3 mrad

Hybrid Photon Detectors

- Photodetectors: Pixel HPDs
Developed in collaboration with industry.
(Photonics-DEP: main partner)
- Prototype developments: NIMA 530(2004) p. 82,
NIMA 449(2000) p.48

- 484 HPDs covering 3.3 m^2 with $> 64\%$ active area fraction.
- Typical Threshold = 970 e^- , Noise = 130 e^- , Signal = 5000 e^-
- All the HPDs characterized using dedicated test stations :
(NIMA 595 (2008) p 142)
- Dark Counts: below 5 KHz/cm^2 (specification: max 20 KHz/cm^2)
- **98% of HPDs produced well within specifications for LHCb.**
- Vacuum Quality: Look for signs of IFB (Ion Feed Back):
Typical rate of IFB hits = 0.04% (specification: max 1%).

Recently, some HPDs from early production batches seem to have developed a larger rate; they are replaced with new tubes and the old tubes are being investigated in detail.

RICH Commissioning: Magnetic Field Distortions

- Magnetic fields distort the photoelectron trajectory : image distortions and loss of signal
- Overall shielding + individual shielding around HPDs : avoid loss of signal.

RICH1: max field ~ 600 Gauss $\rightarrow$ below 24 Gauss

OK for HPD operation.

RICH2: max field ~ 150 Gauss $\rightarrow$ below 6 Gauss

- Monitoring and correcting for image distortions in situ:

- RICH2:
- Send a pattern from a projector into the HPD array
 - Measure the image with/without the Field
 - Parametrize rotation of the image and correct for it

Max. effect of magnetic field

- Position resolutions after corrections : $\sigma_x = 0.76$ mm, $\sigma_y = 0.73$ mm
= Resolutions from HPD pixel size alone.

RICH1: A similar distortion monitoring system using an array of LEDs is being commissioned.

RICH Commissioning: Time Alignment

- RICH readout system fully integrated to LHCb online system
- LHC beam dump → Muons → LHCb : used for time alignment of RICH with LHCb trigger
- Events Display: Integrated over a few events

RICH2 : Muon hits

Typical Delay time scan between laser pulse and HPD readout

RICH1: Muon hits

Performance From Simulations

- Full simulation: PYTHIA→EVTGEN→GEANT4→Digitization
Pattern recognition and PID: Global Likelihood method (TNS: vol 52, No.5 (2005), p 1665)
(NIMA 433(1999) P 257).

➤ Current yields from fully contained isolated saturated tracks:

Aerogel	C ₄ F ₁₀	CF ₄
7.7	37	24

➤ Single photoelectron Cherenkov angle resolutions in mrad (Data Challenge 2006)

	Aero-gel	C ₄ F ₁₀	CF ₄
Chromatic	2.4	0.9	0.5
Emission Pt.	0.4	0.8	0.4
Pixel	0.5	0.5	0.2
PSF	0.5	0.5	0.2
Overall	2.5	1.4	0.7
RICH+Tracking	2.6	1.6	0.8

Kaon Identification Performance

- The yields include the backgrounds from various reflections and backscattering within the HPD which contribute ~15% to the yield.

RICH Calibration

- MC free calibration : Select events from real data in the channel
 $D^{*+} \rightarrow D^0 \pi^+$, $D^0 \rightarrow K^+ \pi^-$
Selection of events mainly from the
narrow mass difference (145.4 MeV) between D^* and D^0
- Calibrate the results of RICH PID performance for the pions and kaons selected,
in bins of P and Pt of the corresponding tracks.
- Dedicated trigger to provide 10^7 events
in one year of data.
- Other possibilities :
Select $\Lambda \rightarrow \rho \pi$ and $K_s \rightarrow \pi^+ \pi^-$
from the data for calibration.

Summary

- The two RICH detectors are successfully installed in LHCb
- These detectors are read out as part of the LHCb data acquisition system and they are being commissioned with LHC beams.
- Using fully simulated data the performance of the detectors are evaluated and procedures for alignment and calibration are developed.
- We are eagerly waiting for LHC collisions to get real data and to see Cherenkov rings !

Spare Slides

Spare Slides

Optical Configuration of RICH1 and RICH2

RICH2 HPD column

Directions of bb production

RICH Readout configuration

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RICH2: Pixel resolution after Field corrections.

RICH1- Photo

RICH2 HPD array

Pixel chip

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Hits integrated on RICH2 HPD array
using photons from a pulsed laser

Pattern from a Projector into RIC H2

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Effect of Magnetic field
Inside RICH2 HPD