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Applications

Analysis of Test-Beam Data from a Prototype LHCb RICH Detector

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(on behalf of the LHCb RICH Group)

LHCb Experimental Goals

- Precision Measurements of CP Violation and rare b decays
- Large Samples of b decays at LHC
 - $N_{bb} = 10^{12}$ / year with Luminosity $2 \cdot 10^{32} \text{ cm}^{-2}\text{s}^{-1}$ for 10^7s
 - b production predominately at small polar angle

➡ LHCb optimized as single forward arm spectrometer

Example decays

- Many pure hadronic final states

➡ Particle identification (π/K) essential

- Employ two RICH detectors

➡ This talk: beam test of a RICH prototype

- Test of photon detector in beam conditions
- Integration of readout electronics
- Mechanics, power, cooling, insulation...

LHCb Experiment

- Dedicated B physics Experiment at the LHC

- Acceptance :
 - 15-300mrad (bending)
 - 15-250mrad (non-bending)

- Particle ID
 - RICH detectors
 - Calorimeters
 - Muon Detectors

RICH System Overview

RICH1:

5cm aerogel $n = 1.03$, 2-11 GeV
4 m³ C₄F₁₀ $n = 1.0014$, 10-60 GeV

RICH2:

100 m³ CF₄ $n = 1.0005$, 17-100 GeV

Photon Detector : The LHCb Pixel HPD

Require :

- Cover total area $\sim 2.8 \text{ m}^2$
- Single photon sensitivity
- Granularity $\sim 2.5\text{mm} \times 2.5\text{mm}$
- Visible and near-UV sensitivity
- 25ns time resolution

Solution : The LHCb Pixel Hybrid Photon Detector

Electron optics: Cross-focussed, demagnification ~ 5

Anode: 16 16mm^2 Si pixel detector, bump-bonded to 40MHz binary readout chip

Pixel cell: $62.5\mu\text{m} \times 500\mu\text{m}$: 256 x 32 matrix

Effective pixel size at photocathode:
 $2.5\text{mm} \times 2.5\text{mm}$: 1024 channels

- HPD developed in close collaboration with industry
- Extensive programme of lab measurements → device is well understood, operates as expected in the lab
- Beam-tests of first six pre-production HPDs before launching production of ~550 !
- Integration Issues :

from:

One single HPD

to:

One HPD column

in :

One RICH detector

- Need to ensure that the HPD and other elements of the RICH detector will work in situ i.e. test :

- Complete readout electronics chain
- Mechanics
- Power
- Cooling, insulation

Establish these elements work as in the lab using a standard candle

The Prototype RICH Detector

- A prototype RICH detector was constructed

- Beam tests at CERN-PS T9 facility :

- 10 GeV negative pions and electrons
- Equip 3 columns with first six pre-production HPDs
- N₂ radiator- optics such that electron ring encompassed on single HPD
- C₄F₁₀ radiator – rings cover up to four HPDs
- Measure HPD detection efficiency with prototype on- and off-detector electronics operating together in beam conditions

Test beam Set-up

Column
Mechanics

Quartz
Window

Mirror

Detector Housing

Radiator vessel

Beam Pipe

Thin Al foil

RICH Readout Electronics

1. Pixel chip, encapsulated in HPD

- Binary data multiplexed out at 40 MHz

2. Level-0 Board

- Drives the pixel chip
- Distributes clocks, triggers via TTC
 - Controls DC power levels for pixel chip
 - Gbit optical links (in LHCb 100 m to counting room)
 - Controlled using JTAG interface

- During the test beam the pixel chip and L0 board were able to drive out the data at the full LHCb speed of 40 MHz
- 1.6Gbit optical link also used successfully

3. Data Acquisition

- Writes the L0 data to disk
 - Data from the L0 1.6 Gbit optical link is received by a custom receiver
 - Triggered L0 events were transferred to receiver card immediately, buffered there until the end of the PS spill
 - Then copied to PC through PCI interface

Cherenkov Rings

- Cherenkov rings observed from pion and electron beams with both :

- N_2 radiator – rings on one HPD at a time

Ring radii are in-line with expectations:

$$\pi \quad 13.9 \pm 0.2 \text{ pixels}$$

$$e \quad 16.7 \pm 0.2 \text{ pixels}$$

(plots integrated over ~30k events)

- C_4F_{10} radiator – rings spread on up to four HPDs

(integrated plot shown)

- As can be seen from plots, noise is at very low level $<0.1\%$

Calculating the p.e. yields

- N_2 data, 10 GeV pion beam – count number of photoelectrons (p.e.) in rings

- Several effects change $N_{\text{p.e.}}$ distribution :

- Charge Sharing

(single p.e. $\rightarrow$ 2 pixel hits)

$\rightarrow$ 2.5% effect

- Double hits

(two p.e. $\rightarrow$ 1 pixel hit)

$\rightarrow$ 3% effect

- Asynchronous nature of set-up

- Beam trigger and chip clock not coincident (as they will be in LHCb)

$\rightarrow$ timing inefficiency

$\rightarrow$ additional efficiency factor ~ 0.7

- Good fit to $N_{\text{p.e.}}$ with Poisson + these effects

- Taking the detection efficiencies measured in lab (~85%) find a good agreement between data and expectation :

HPD	$\mu(\text{fit})$	$\mu(\text{theory})$	Ratio
1	7.8	6.0	1.3
2	11.5	11.2	1.0
3	8.8	8.9	1.0
4	9.7	10.7	0.9
5	10.1	10.0	1.0
6	8.5	11.4	0.8

Known timing problem
with L0 board

Under investigation

- Largest contribution to the error in $\mu(\text{theory})$ from integration of measured QE of each tube, error at 10% level
- Detection efficiencies confirmed, performance as expected

Cherenkov Angle Resolution

- N_2 data, 10 GeV pion beam
- Width of Cherenkov angle distribution compared between **DATA** and GEANT4 based **Monte Carlo** :
 - $\sigma_{\text{DATA}} = 1.1$ mrad
 - $\sigma_{\text{MC}} = 1.0$ mrad
- No. of effects reproduced in simulation :

Chromatic	0.4
Pixel	0.8
Emission point	0.3
Beam divergence	0.2
Charge Sharing	0.3
Total	1.0

→ in test-beam set-up are dominated by pixelisation

- Remaining difference under investigation

Conclusions

- The first six pre-production HPD's tested in lab conditions
- Now also tested in beam conditions :
 - Electron and pion Cherenkov rings observed- radii and photoelectron yields in line with expectations
 - Successfully integrated **pre-production HPD** together with other RICH elements
 - First meeting of **readout electronics chain** on-detector: binary chip and L0 board together and operated at 40 MHz, 1.6Gbit r/o through optical fibres
 - **Final mechanics** and **HPD Mounting scheme** used successfully
 - Pre-production HPD performance verified. Production of ~550 such devices now ongoing – now have 21 HPDs completed

Forming uncorrelated events

- Size of charge sharing (single p.e. $\rightarrow$ 2 pixel hits) and double hits (two p.e. $\rightarrow$ 1 pixel hit) **determined from the data**
- Take an event in the data with n hits then form a new event with n hits taken from n different events
 - no contribution from charge sharing
 - difference between no. of vertically and horizontally adjacent hits in the data and in the uncorrelated events $\rightarrow$ amount of charge sharing
 - can count no. of times have two hits in same pixel $\rightarrow$ amount of double hits
- Confirm charge sharing result from runs taken with an LED light source- very low occupancy $\rightarrow$ can just count no. adjacent hits (limited statistics)

Cooling Scheme

- Complete column of HPDs will output 220W
- Use cooling plates attached to HPD aluminum column to remove this heat
- Thermal mat between copper skin and electronics components
- Cooling system: closed circuit circulation of water/ C_6F_{14}

Model for Δt p.e.
arrival and pixel
passing threshold

Good match with
delay scan data