RICH detectors for LHCb

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On behalf of the LHCb RICH collaboration

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Outline of the talk

• The LHCb experiment
• RICH1 & RICH2
• The Hybrid Photon Detector (HPD)
• The aerogel radiator
• Commissioning and performance
• Summary
b-Physics at the LHC

forward event

pp interaction
(trajectory vertex)

secondary vertices

B^- \sim \text{10 mm}

b-hadron

particle identification

\nu

leptons

\nu

\pi^+

\pi^-

K^-

\pi^+

\pi^+
The LHCb experiment

Two Ring Imaging Cherenkov detectors provide $p/K/\pi$ identification
The experimental site
Cherenkov radiators

All charged tracks in b-events

Silica Aerogel
n=1.03
1-10 GeV/c

C\textsubscript{4}F\textsubscript{10} gas
n=1.0014
Up to ~70 GeV/c

CF\textsubscript{4} gas
n=1.0005
Beyond ~100 GeV/c

**RICH1:**
25→250 mrad vertical
25→ 300 mrad horizontal

**RICH2:**
15→100 mrad vertical,
15→ 120 mrad horizontal

θ\textsubscript{c} max
242 mrad

0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
25
50
75
100
125
150
175
200
p (GeV/c)

θ (rad)

θ\textsubscript{c} (mrad)

Momentum (GeV/c)

0
1
10
100
0
50
100
150
200
250
e
μ
π
p
K
C\textsubscript{4}F\textsubscript{10} gas
CF\textsubscript{4} gas
Aerogel

53 mrad
32 mrad

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RICH layout

Aerogel

Spherical Mirror

C_{4}F_{10}

Beam pipe

Track

Photon Detectors

250 mrad

VF10 exit window

Plane Mirror

56 glass spherical mirrors

Support structure

40 glass flat mirrors

Central Tube

288 HPDs and magnetic shielding

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Photon detectors requirements

**Hits in the photon detectors for one event** (full LHCb simulation)

- **Total area:** 3.3 m²
- **Active area fraction:** 63%
- **Single photon sensitivity:** 200 - 600 nm
- **Quantum efficiency:** >20%
- **Good granularity:** 2.5 x 2.5 mm²
- **# of channels:** 500k
- **LHCb DAQ rate:** 40MHz
- **Rad. tolerant:** 3 kRad/year
Pixel Hybrid Photon Detectors

- Pixel HPDs developed in collaboration with industry (Photonis-DEP lead partner)
- Vacuum tube with silicon pixel readout (Quartz window with S20 photocathode)
- 75 mm active diameter
- 484 HPDs to meet the requirements
- Factor 5 demagnification @ 20kV
- Encapsulated electronics:
  - 8192 pixels logically OR-ed in groups of 8 to form a matrix of 32 x 32
  - binary output of 1024 channels
Magnetic distortions

Residual distortions monitored and corrected for by projecting patterns on the HPDs in situ
HPD qualification

- Two Photon Detector Test Facilities (PDTFs) have qualified all 550 HPDs produced by Photonis/DEP.
- 98% of tubes have passed the selection criteria.
- Excellent response, QE, dark counts, ion feedback.

The development and serial production of very high quantum efficiency photocathodes for the HPD has been an outstanding technological success.
RICH1 schematics

- Photon detector plane 14 by 7 Hybrid Photon Detectors (HPDs)
- Upper Magnetic Shielding
- Spherical Mirrors
  Lightweight carbon fibre mirrors 1.5% radiation length
- Glass Planar Mirrors
- Aerogel goes here
- Gas Enclosure
  supports mirrors and aerogel, contains C₄F₁₀
- Beryllium beampipe
  (defines RICH1 inner acceptance)
- RICH1 Exit Window
  Carbon fibre & PMMI foam
  Sealed direct to the beampipe.
RICH1 installation

Beryllium beampipe, seal to VELO and flat mirrors

Upper HPD box

98 HPDs

Carbon Fibre Mirrors
RICH2

HPD column module

HPD modules inserted here
RICH2 Commissioning

Routine operation with high voltage and full integration into LHCb Control system and Data acquisition system.

Ready for collisions!

HPD array from inside RICH2

RICH2 HPD planes, pulsed laser

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Silica aerogel

Hygroscopic, produced by Boreskov Institute of Catalysis Novisibirsk

• 30 litres produced for LHCb
• 200x200x50 mm tiles – the largest ever
• Exceptional clarity
  \[ C \sim 0.005 \, \mu m^4 cm^{-1} \]
  \[ \frac{l}{l_0} = A \exp \left(-\frac{Ct}{\lambda^4}\right) \]
  for thickness t in cm

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Aerogel for LHCb

Successfully tested against:

• humidity: loss of transparency recovered by baking at 500 °C

• radiation: neutron, proton and γ up to several LHCb lifetimes

• exposure to C₄F₁₀ : tolerable slight modification of optical parameters

Performance of the aerogel as radiator for the RICH of LHCb has been confirmed by several tests on charged particle beams over the years
Refractive index characterisation

Homogeneity measured with laser and charged particle beam:

$$\sigma(n-1)/(n-1) \sim 0.76\%$$

(contribution to $\sigma_\theta \sim 0.8$ mrad)

Refractive index measured over wide wavelength range
Aerogel mechanics

Carbon fiber box with wings to stop photons radiated upstream of aerogel D263 glass filter to kill scattered photons and improve resolution
Trial installation successful, aerogel goes in as last component in spring
Performance of the RICH system has been verified in a 80 GeV/c charged particle beam at CERN SPS. C₄F₁₀ ~1m radiator length.

- Realistic 25 ns beam structure
- Final RICH hardware and DAQ
- Full simulation results for photon yield and θ_c resolution have been validated

Pixel map of a C₄F₁₀ ring focussed on 4 HPDs integrated over ~50k events
Particle ID performance

- **Ring finding**
  - The algorithm uses tracks, and performs a global likelihood fit to particle hypotheses across both RICH detectors.

- **π – K separation**
  - Excellent efficiency and low mis-ID rate

### Kaon identification performance

<table>
<thead>
<tr>
<th></th>
<th>Aerogel</th>
<th>C₄F₁₀</th>
<th>CF₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>photon yield isolated tracks</td>
<td>5.3</td>
<td>24.0</td>
<td>18.4</td>
</tr>
<tr>
<td>single p.e. resolution (mrad)</td>
<td>2.6</td>
<td>1.5</td>
<td>0.7</td>
</tr>
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\[ K \to K, \text{Pr} : 97.29 \pm 0.06 \% \]
\[ \pi \to K, \text{Pr} : 5.15 \pm 0.02 \% \]

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Summary and prospects

• LHCb RICH project in good shape

• RICH2 fully equipped, commissioning is already at an advanced stage

• RICH1 is almost completed, commissioning will benefit from RICH2 experience

• Excellent quality and highly performing HPDs

• The RICH system will contribute to physics results starting from LHC day one.