Particle Identification of the LHCb detector

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on behalf of the LHCb collaboration

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The LHCb experiment: introduction

- precision measurements of CP violation and rare phenomena in B meson decays
  ⇒ Standard Model consistency?, new physics?

- Experimental requirements:
  - Efficient trigger (see talk by Mitesh Patel)
  - Vertex identification
  - High track reconstruction efficiency
  - Control of systematics
  - Particle identification
    1. π/K separation ⇒ RICH
    2. lepton id ⇒ muon + calo

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RICH detectors for hadron identification

RICH1
Z ~ 1.0 – 2.2 m
aerogel:2→~10 GeV/c
C₄F₁₀ :10→~60 GeV/c

RICH2
Z ~ 9.5 – 11.9 m
CF₄ :16→~100 GeV/c

efficient pion/kaon separation up to ~100 Gev/c

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Lepton identification: muons and electrons

- B → J/ψ K_s ⇒ access to angle β
- Rare decays B → μμ

Info used in 1st level trigger

HCAL
- Fe + scintillator tiles
- 1468 cells, 5.6 λ/σ
- σ/E ~ 75% / √E

ECAL
- Shashlik type
- 66 layers 2mm Pb/4mm scintillator
- 25 X_0
- σ/E ~ 10% / √E
Goal: $\pi/K$ separation in $\sim 1$-100 GeV/c range

(a) $B \rightarrow \pi\pi$ decay

(b) tagging kaons

Polar angle versus momentum

$B_d^0 \rightarrow \pi\pi$

RICH1
25-300 mrad

RICH2
15-120 mrad

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RICH detector specifications

RICH system divided into 2 detectors with 3 radiators

RICH1

RICH2

θ_c (mrad)

Momentum (GeV/c)

Aerogel

C4F10

CF4
**RICH1: low momentum tracks**

Aerogel

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**Aerogel Support Structure**

- Thickness 5 cm
- $n = 1.030 \pm 0.001$

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**Be Mirrors**

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RICH2: high momentum tracks (CF4)

- 300 mrad
- 120 mrad
- CF$_4$ gas
- Beam pipe
- Spherical mirror
- Flat mirror
- Photodetector housing

- X
- Z
- 10 11 12 m

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56 spherical mirrors on two planes

-> installed and aligned with precision $\sigma_0 \leq 50 \, \mu\text{rad}$
Photon Detectors

Requirements:
- 2.5x2.5 mm² granularity => \( \sigma(\theta_{CH}) = 0.6 \) mrad (RICH1)
- Coverage of 2.6 m²
- Single photon sensitive \( \lambda \) 200 – 600 nm
- Read-out speed 40 MHz

Hybrid Photon Detector (HPD)
- S20 multi-alkali photocathode
- Cross-focusing electron optics (\( \sim 20kV \), demagnification factor of 5)
- Photo-electrons focused on anode assembly (16x16 mm²), fully encapsulated in the vacuum enclosure

Mu-metal shielding
Simulated $|B|$ field distribution in RICH1

Most important effects from axial fields $\rightarrow$ RICH1

Effect = PARAMETRISABLE $\rightarrow$
RICH simulation and pattern recognition

✓ Simulation in Geant4

get rings out multitude of hits!
RICH simulation and pattern recognition

<table>
<thead>
<tr>
<th></th>
<th>RICH1</th>
<th>RICH2</th>
</tr>
</thead>
<tbody>
<tr>
<td>L (cm)</td>
<td>5</td>
<td>85</td>
</tr>
<tr>
<td>n</td>
<td>1.03</td>
<td>1.0014</td>
</tr>
<tr>
<td>N_{pe}</td>
<td>7</td>
<td>31</td>
</tr>
<tr>
<td>σ_{tot}θ (mrad)</td>
<td>2.19</td>
<td>1.29</td>
</tr>
<tr>
<td>Chromatic</td>
<td>2.07</td>
<td>0.80</td>
</tr>
<tr>
<td>Emission Point</td>
<td>0.34</td>
<td>0.80</td>
</tr>
<tr>
<td>Pixel Size</td>
<td>0.57</td>
<td>0.57</td>
</tr>
<tr>
<td>σ_{tot}θ (mrad)</td>
<td>2.60</td>
<td>1.60</td>
</tr>
</tbody>
</table>

- Pattern recognition approaches:
  - Track based (local/global)
  - Other algorithms (ring fitting)

- Difference in log-Likelihood under different hypotheses → significance of π/K separation for true pions
**RICH hadron ID performance**

**Heavy PID**

- **Kaon identification** eff ~88%
- **Kaon misidentification** ~12%

**Light PID**

- **Pion identification** ~ 97%
- **Pion misidentification** ~ 3%
Time dependant asymmetries in $B_s \rightarrow D_s K$ with CP asymmetry in $B^0_s \rightarrow J/\psi \phi$

$\Rightarrow \gamma$ with $\sigma(\gamma) = 15^0$ per year

• Very little theoretical uncertainties
• Insensitive to new physics
• $\sim 5400$ evts per year expected

**RICH hadron ID performance: $B_s \rightarrow D_s K$**

- **BUT!**

- **contamination $\sim 90\%$**
**RICH hadron ID performance: \( B_s \rightarrow h^+h^- \)**

- B\( \rightarrow \pi\pi \) measurement precision 2-5\(^0\) per year
- Combination of B\( \rightarrow \pi\pi \) and B \( \rightarrow KK \)
  - \( \rightarrow \gamma \) measurement precision 5\(^0\) per year
  - \( \rightarrow \) sensitive to new physics
- Yields: 26k \( B^0 \rightarrow \pi^+\pi^- \) and 37k \( B_s \rightarrow KK \)

\[ B^0 \rightarrow \pi^+\pi^- \]

\[ B_s \rightarrow K^+K^- \]

**With RICH**

Purity = 84\%, \( \varepsilon \) = 79\%

**No RICH**

Purity = 13\%

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Muon identification

✓ Search of hits in muon stations compatible with reconstructed track extrapolations

Further reduction of bkg with other algorithms and multivariable analysis

=> μ eff ~ 90%, π eff 0.8%
✓ Provide global PID with DLL

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Electron identification

Difference in log likelihood for (DLL): signal (e) and bkg hypothesis based on 4 variables

Corrected cluster energy – position matching

Energy deposition in preshower

Bremsstrahlung correction

Energy deposition along extrapolated track in HCAL

χ²_e

χ²_brem

e+/e- h/μ

e+/e- h/μ

e+/e- h/μ

E_{ps}(MeV)

E_1

E_2
Electron identification performance

**B^0 \rightarrow J/\psi K_{S}^0 \ J/\psi \rightarrow e^+e^-**

- Eff 95%

**B^0 \rightarrow J/\psi K_{S}^0 \ J/\psi \rightarrow e^+e^-**

- Eff 81%

**π misid 0.7%**

Combined with RICH $B_S \rightarrow J/\psi \phi \ J/\psi \rightarrow e^+e^-$

- $e_{\text{eff}} 78%$
- $\pi_{\text{misid}} 1%$

**Tail from Bremsstrahlung**

Bkg rejected with $p_T$ cut, mainly coming from secondary electrons and ghosts

**Performance**

- $e_{\text{eff}} 78%$
- $\pi_{\text{misid}} 1%$
Conclusions

Particle identification is essential for the LHCb physics program!

- **Hadron identification**
  - $3\sigma$ $\pi$-K separation from 1-100 GeV/c provided by 2 RICH detectors
  - RICH2 construction almost complete, RICH1 construction underway
  - photon detector understood and being produced
  - Installation expected to be completed by October 2006

- **Electron identification**
  - ECAL installed, HCAL underway

- **Muon identification**
  - Muon project well advanced (480 chambers produced = 1/3 of the total)

- **Combined PID improves performance**
Dipole Magnet

ECAL

Muon filters

½ HCAL

RICH1 magnetic shielding

Installation progress in point 8

Eager for first collisions in 2007!