Calorimeter and Muon System

Lepton Identification

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On Behalf of the LHCb Collaboration

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The LHCb experiment

- LHCb is dedicated to the Study of CP violation in the B meson system

- recent reoptimisation
  - VELO, RICH1, Tracking
  - Less material before Calorimeter (\(\sim 70\%X_0\))
LHCb Calorimeters

Requirements:
- Identification of hadrons, electrons, $\gamma$, $\pi^0$
- Energy/Position measurement
- L0 Trigger input: → see talk by O. Callot
  - High sensitivity
  - Fast response (40MHz)

Scintillator Pad Detector (SPD)
Scintillator Pad Detector (SPD)

Preshower (PRS) → L0
- $\gamma$ / MIP separation (SPD)
- Electron, $\gamma$ / $\pi$ (PRS)
- Charged Multiplicity (SPD)

ECAL → L0
- Et of electron, $\gamma$
- $\pi^0$ offline reconstruction

HCAL → L0
- Et of hadrons
- Particle ID
**SPD / PRS**

- **Scintillating detector**
  - 2.5 $X_0$ lead converter sandwiched between two scintillator planes (pads)

- **3 zones: granularity depends on the occupancy**
  - Cell size: 40.4 / 60.6 / 121.2 mm
  - ~ 6000 channels
  - Notice: 3 same zones for ECAL (HCAL: 2 zones)
  - Projective Calorimeters

- **L0:**
  - ECAL finds local Et maxima
  - SPD/PRS determines electromagnetic nature of energy deposit

- **Signal read with MAPMT**

- **Dynamic range: 0 – 100 Mips**
  - 10 bits (PRS) + 1 bit (SPD)
ECAL

- **Shashlik technology**
  - Radiation resistance
  - Fast response
  - 66 layers of 2mm Pb / 4mm scintillator
    - $25 \chi_0$, $1.1 \lambda_I$
  - WLS fibres transport signal to PMT

- **ECAL front-end/L0 electronics**
  - Installed on top of sub-detectors (200rad/y)
  - Low noise front-end integrator
  - Et range: 0 - 10GeV (12 bits)

- 90% of the modules delivered to CERN
- **Longitudinal tiles**
  - Iron and scintillator tiles
    - 6mm master, 4mm spacer / 3mm scintillator
    - $5.6 \, \lambda$$_i$
  - 2 zones (1468 channels)
  - Signal propagates with WLS fibres to PMT

- Same front-end electronics as ECAL

- 30% of the modules already delivered
ECAL-HCAL Electronics

- **Scintillator + WLS fibre**: fast system
  - Try to measure every bunch crossing: no pileup effect (residue after 25 ns: < 1%)

- **Digital electronics based on Actel anti-fuse technology**
  - FPGA configuration insensitive to Single Event Effects
  - Protection by Parity code and Triple Voting

- **All components have been tested in proton and ion beams**
Energy Resolution of series modules (test beam measurements)

\[
\frac{\sigma(E)}{E} = \frac{9.4\%}{\sqrt{E}} \oplus 0.83\% \oplus \frac{0.145\, GeV}{E}
\]

\[
\frac{\sigma(E)}{E} = 0.75 \frac{\sqrt{E}}{E} \oplus 0.1
\]
Calorimeter Performances: $\pi^0$ reconstruction

- $\pi^0$ reconstruction efficiency
  - Resolved $\pi^0$ (2 clusters)

$\pi^0$ reconstruction

$$\pi^0 \rightarrow \gamma \gamma$$
$$\pi^0 \rightarrow \gamma (e^+e^-)$$
$$\pi^0 \rightarrow (e^+e^-)(e^+e^-)$$

$\sigma \sim 9 \text{ MeV}/c^2$

$\pi^0$ efficiency inside detector acceptance $\sim 50\%$

Merged $\pi^0$ (1 cluster)

$\sigma \sim 14 \text{ MeV}/c^2$

Conversions

$\sigma \sim 14 \text{ MeV}/c^2$
Muon System

- **Requirements**
  - Muon triggering (L0)
    - Fast measurement / Bunch crossing id.
    - High efficiency (down to $p=5\text{GeV/c}$)
    - $Pt$ resolution $\sim 20\%$
  - Muon offline identification
    - Tagging + reconstruction
      - $\varepsilon>90\%$, mid-id$<1.5\%$

- **Layout**
  - 5 stations: 1x(2 layers)+ 4x(4 layers)
  - Projective geometry

- **Granularity**: Stations divided in 4 regions
  - X-dim: L0 $Pt$ resolution
  - Y-dim: background rejection
  - Logical pads from logical channels

- **435m$^2$ – 1380 chambers – 26k channels**
MWPC

- Wire/cathode reading
- 2mm wire pitch $\varepsilon = 99\%$ (20ns-2 gaps)
- Time resolution: 4ns

- M1 radiation length: $0.15X_0$
  (Nomex Honeycomb)

- Central Part M1 (0.6m$^2$): Triple-Gem?
Muon system electronics

- Muon electronics Architecture
  - Physical Channels: 120k
  - Logical pads: 26k
    - Made from
      - strip crossing
      - physical pads
  - L0 / L1 / DAQ

- MWPC pre-series production started
- Several sites are ready (tooling and clean room) for production
- Electronic Architecture has been reviewed and approved
  - Final version of most chips has been received
Lepton identification: Tracking

- Tracking performance

\[ \varepsilon = 94\% \quad \text{for} \quad P > 10\text{GeV} \]

\[ R_{\text{Ghost}} \approx 3\% \quad \text{for} \quad P_{\text{cut}} = 0.3\text{GeV} \]
Electron Identification (I)

- Require impact of a track near a calorimeter cluster
- Build 4 parameters:
  - Distance + $P_{\text{track}} - E_{\text{cluster}}$ matching

![Graphs and diagrams showing electron and hadron distributions,以及距离和能量匹配的计算结果。]
Electron Identification (II) : combined analysis

- Combine Calo + Rich + Muon

- $\eta$ = 0

- $\pi \rightarrow e$

- $\epsilon(e) = 95\% - \epsilon(\pi \rightarrow e) = 0.7\%$

- $J/\psi \rightarrow e^+ e^-$

- $B_s^0 \rightarrow J/\psi \phi$

- $\sigma \approx 60 \text{ MeV}$
Muon Identification (I)

- **Definition of Fields of Interest around track extrapolation**
- **Require hits in # stations in FOI**

<table>
<thead>
<tr>
<th>Momentum (GeV)</th>
<th>Muon Stations</th>
</tr>
</thead>
<tbody>
<tr>
<td>$3 &lt; P &lt; 6$</td>
<td>M2 + M3</td>
</tr>
<tr>
<td>$6 &lt; P &lt; 10$</td>
<td>M2 + M3 + ( M4 or M5 )</td>
</tr>
<tr>
<td>$P &gt; 10$</td>
<td>M2 + M3 + M4 + M5</td>
</tr>
</tbody>
</table>

- $\epsilon(\mu) = 94.3\% - \epsilon(\pi \rightarrow \mu) = 2.9\%$

Estimator to further reject pions
Muon Identification (II)

- Combine Muon+Rich+Calo
  - Further improves selection wrt FOI only

- $J/\Psi \rightarrow \mu^+ \mu^-$ ($B_s^0 \rightarrow J/\Psi \Phi$)
  - $\epsilon(\mu) = 93\% - \epsilon(\pi \rightarrow \mu) = 1\%$

- $\sigma \sim 15 \text{ MeV}$
Conclusion

- **Calorimeter**
  - Complementary systems
  - SPD / PRS / ECAL / HCAL
  - L0
  - Fast / sensitive / efficient / robust

- **Muon system**
  - Simple (all MWPC) / robust
  - L0
  - Logical channel: no geometrical ambiguity

- **Lepton Identification ($B_s^0 \to J/\Psi \Phi$)**
  - Electrons: $\varepsilon(e) = 95\% - \varepsilon(\pi \to e) = 0.7\%$
  - Muons: $\varepsilon(\mu) = 93\% - \varepsilon(\pi \to \mu) = 1\%$

- **LHCb will be ready for data taking in 2007 at LHC start-up**
  - Detector production is on schedule
  - Detector installation starts at the end of next year (magnet installation ongoing)
**The LHCb experiment**

- **LHCb** is dedicated to the Study of CP violation in the B meson system

- **LHCb**
  - Mostly single interactions (PileUp Veto)
    - \( L_{\text{nom.}} = 2 \times 10^{32}\text{cm}^{-2}\text{s}^{-1} \)
    - 12 mrad < \( \theta \) < 300 mrad
    - Efficient trigger (L0~1MHz, L1~40kHz)
    - Recent Re-optimisation
      - VELO, RICH1, Tracking
      - Less material before Calorimeter

- pp collisions at \( \sqrt{s} = 14 \text{ TeV} \)
- Forward \( \bar{b}b \) production correlated
- \( \sigma_{\text{total}} \sim 100 \text{ mb} \rightarrow \text{Int. Rate} : 2 \times 10^7 \text{Hz} \)
  - \( \sigma_{\bar{b}b} \sim 500 \text{ \( \mu \)b}, \sigma_{\text{inel}} \sim 80 \text{ mb} \)
  - S/B\sim1%
- \( 10^{12} \bar{b}b \) pairs per year

- Luminosity [cm\(^{-2}\)s\(^{-1}\)]

- Probability

- \( \theta \) [rad]

- S/B ~ 1%
Lepton identification: Tracking

- Tracking performance

  - Efficiency

  ![Efficiency Graph](image)

  - Ghost Rate

  ![Ghost Rate Graph](image)

  - $\varepsilon = 94\% - P > 10\text{GeV}$

  - $R_{\text{Ghost}} \sim 3\% - P_{\text{cut}} = 0.3\text{GeV}$
Lepton Identification Robustness

- **Electrons (Calo effects)**
  - Coherent / incoherent noise increase
    - +50 up to +100%
  - Dead channels
    - 1% (PRS/SPD) – 0.2% (ECAL/HCAL)
  - Channel gain error
    - +50%
  - No re-tuning (nominal reference histo)

  - $\varepsilon(e)$ loss of 2.5%
  - $\varepsilon(\pi \rightarrow e) = 0.7\% \rightarrow 1\%$

- **Electrons (ex. of track multi. Effect)**
  - Increase track multiplicity by x2

  - $\varepsilon(e)$ unaffected
  - $\varepsilon(\pi \rightarrow e) = 0.7\% \rightarrow 1\%$

- **Muons (Muon system effects)**
  - Increase low energy background by x5
  - No re-tuning

    - $\varepsilon(\mu) = 94\%$ unaffected
    - $\varepsilon(\pi \rightarrow \mu) = 2.9\% \rightarrow 11.7\%$

  - After algorithm re-tuning

    - $\varepsilon(\mu)$ loss of 7%
    - $\varepsilon(\pi \rightarrow \mu)$ back to 2.9%