LHCb calorimeter from trigger to physics

CERN

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On behalf of the LHCb collaboration

LHC tunnel

Calor04
Perugia

Goal : (in)validate the SM attacking the $\cancel{CP}$ in B system

10^5 $b\bar{b}$ pair produced every second at LHCb

→ reconstruct a large variety of (rare) B decay modes
including decays with **prompt** γ , π^0 , ...

Main points :

- Precise vertex location
- **Particle Identification**
Kaon, pion, muon, **electron**, ...
- **Fast** and flexible **trigger** system

Scintillator Pad Detector & Preshower

- 2.5 X0 Pb converter between two scintillator planes.
- One-to-One correspondence with Ecal pads.

Shashlik Electromagnetic calorimeter

- Pb/Scintillator : 5952 readout channels.
- Granularity varies transversally from ~ 1 to $3 R_M$
- Testbeam resolution : $\sigma/E \sim 10\%/\sqrt{E} \oplus 1\%$

Hadronic calorimeter

- Fe/Scintillator : 1488 readout channels.
- Granularity varies transversally 13x13 cm & 26x26 cm
- Resolution : $\sigma/E \sim 80\%/\sqrt{E} \oplus 10\%$

→ see dedicated talks in this conf.

Calorimeter system at Level-0 trigger

- Measure energy and identify γ /e/h using **SPD/PS/Ecal/Hcal** in coincidence.
- Spd & Prs validate the charged and EM nature of incoming particle, respectively.

→ **Used at the fast Level-0 trigger**

- 40 MHz hardware trigger.
- Identify high $P_{\perp}$ particles that could sign a B decay.
- Use Calorimeter and Muon sub-systems.
- 10 MHz visible interactions → 1 MHz

Strategy of Level-0 calorimeter trigger

- Form all 2x2 pads clusters in Ecal and Hcal
- Identify **electron, photon, π^0 and hadron** with highest E_+
- Spd hits multiplicity
→ pile-up/busy events
- Total Hcal energy
→ halo-muons event

→ Level-0 Decision Unit

- LODU also receives highest P_+ muon candidates and Pile-Up detector info.

Level-0 performance

• LODU thresholds tuned to maximize the offline selected yield of some typical B decay modes ($\pi\pi$, $J/\psi(\mu\mu)K_s$, $J/\psi(ee)K_s$, $K^*\gamma$, ...)

- Hadronic trigger : 700 kHz ; Threshold : 3.6 GeV/c
- Electromagnetic trigger (e, γ, π^0) : 300 kHz ; Threshold : 2.5-4.5 GeV/c
- Muonic trigger : 160 kHz ; Threshold : 1.1 GeV/c

Typical overlap with offline selection

Hadronic decays ~ 50%
Radiative decays ~ 70%
Di-muons channels ~ 90%

Overlap	EM	hadronic	Muonic	Level-0
$B_d \rightarrow K^*\gamma$	68%	32%	8%	73%
$B_d \rightarrow \pi^+\pi^-\pi^0$	66%	39%	8%	77%
$B_d \rightarrow J/\psi(ee)K_s$	37%	22%	7%	48%
$B_d \rightarrow \pi^+\pi^-$	14%	48%	7%	54%
$B_d \rightarrow J/\psi(\mu\mu)K_s$	8%	20%	87%	90%

40 MHz data

Level-0

Custom electronics, full. synchronous, latency = 4 μ s

- High P_{T} particles from **Calo** & Muon system

1 MHz

Level-1

L1Buffer (FIFO), average latency <1 ms

- Tracks with large P_{T} and large IP
- Use Velo, Trigger Tracker and **Level-0** trigger
- **IP criteria relaxed if γ or $e^{\pm}$ is found at Level-0**
- **Matching tracks with Level-0 Calo clusters**

40 kHz

HLT

Common L1/HLT CPU farm, flexibility, scalability

- Under developpement
- L1 validation with full tracking. $\epsilon > 95\%$
- In / Exclusive reconstruction using full detector
- Maximal overlap with offline selection ($\sim 100\%$)
- **Fast Calo reconstruction under study**
- Goal : **FAST** > **EFFICIENT** > **PRECISE**

200 Hz

Offline

storage

- Goal : **PRECISE** > **EFFICIENT** > **FAST**

Ecal offline strategy

Clusterisation : cellular automaton procedure

→ Clusters growing iteratively around local maxima

Several hypotheses are made about the cluster origin :

Evaluate energy & position according to each hypothesis

Ecal offline strategy

Use energy-weighted moments of cluster up to order 2 :

- **0th moment order : cluster energy** $\varepsilon = \sum \varepsilon_i$
→ Corrected from Prs leakage, module frame dead material ...
- **1st order moment : cluster barycenter** $(x_b, y_b) = (\sum x_i \varepsilon_i, \sum y_i \varepsilon_i) / \varepsilon$
→ Corrected from S-shape, angular effects, shower penetration depth, ...
- **2nd order moment : cluster spread** $S_{xy} = \begin{pmatrix} \sum x_i^2 \varepsilon_i & \sum x_i y_i \varepsilon_i \\ \sum x_i y_i \varepsilon_i & \sum y_i^2 \varepsilon_i \end{pmatrix} / \varepsilon$
→ Used to match the cluster position with an eventual impact extrapolated from reconstructed tracks.
→ Decide whether the cluster is 'neutral' → **photon reconstruction**
or 'charged' → **electron identification**

Electron identification

Calorimeter estimators for electron Id. :

- Track-Cluster position/energy matching χ_e^2 contains E/p $\longrightarrow$
- Preshower deposit E_{Prs}
- Hcal deposit along extrapolated track E_{Hcal}
- Bremstrahlung photon χ_{brem}^2

no material in magnet region $\rightarrow$ linear extrapolation

E_e corrected from Bremstrahlung energy : $E_e = E_1 + E_2$

Electron identification

Combined electron Id.

Calorimeter estimators are combined with Rich estimator to provide a $\Delta\text{Log-likelihood}$ for electron hypothesis versus the hadron hypothesis.

$\Delta\text{Log}\mathcal{L}_{e/h}$

- Average efficiency $\varepsilon = 95\%$
- Misidentification rate 0.7%

- $J/\psi \rightarrow e^+e^- : \sigma_M \sim 60 \text{ MeV}/c^2$

$$\sigma(J/\psi \rightarrow \mu^+\mu^-) \sim 15 \text{ MeV}/c^2$$

Low P_T background from real (secondary) electrons or ghost tracks.

$$B_d \rightarrow J/\psi(ee)K_s \quad (\text{Br} = 2.0 \cdot 10^{-5})$$

$26 \cdot 10^3$ selected evts/year - B/S ~ 1

$$B_s \rightarrow J/\psi(ee)\phi \quad (\text{Br} = 3.1 \cdot 10^{-5})$$

$20 \cdot 10^3$ selected evts/year - B/S ~ 1

- Flavour tagging of semi-leptonic B decay

Photon reconstruction

- Material before Calo system : 70% X0
→ 44% of photons converts before Calo
- Conversion after magnet can be seen as a single cluster.
→ Identified using SPd hit (Eff~ 90%)

- Tracking system may reconstruct conversions before magnet.

$$\frac{\sigma_E}{E} = \frac{11.0\%}{\sqrt{E}} \oplus 1.45\% \oplus \frac{172 \text{ MeV}}{E}$$

Radiative B decays

$$B_d \rightarrow K^* \gamma \quad (\text{Br} = 2.9 \cdot 10^{-5})$$

$35 \cdot 10^3$ selected evts/year - $B/S < 0.7$

$$B_s \rightarrow \phi \gamma \quad (\text{Br} = 4.3 \cdot 10^{-5})$$

$9 \cdot 10^3$ selected evts/year - $B/S < 2.4$

$$\sigma(M_B) \sim 65 \text{ MeV}/c^2$$

Photon pair from neutral pion decay

- Ave. multiplicity : ~ 10 reconstructed π^0 s/event
- Mass resolution : $\sigma = 10 \text{ MeV}/c^2$

Reconstruction efficiency decreases at high E_+
→ distance between the two photons becomes of the order of the Ecal pad size.

$E_+(\pi^0) (\text{GeV}/c)$

High P_+ π^0 s are seen as single Ecal clusters

Merged photons from prompt π^0

- Built 2 virtual interleaved sub-clusters from the original Ecal cluster.
- Share the pad energy between sub-clusters according to the expected transversal shape of photon showers.

Iterative procedure

- Reconstruct each sub-cluster as coming from a photon.

Merged photons from prompt π^0

Mass resolution $\sigma = 15 \text{ MeV}/c^2$

- Energy and angular resolutions consistent with resolved case.
- Large purity due to high E_{T}
- Low multiplicity (less than 1/event)

**'merged' π^0
important for physics**

Efficiency to reconstruct π^0 in $B_d \rightarrow \pi^+\pi^-\pi^0$ events

$$\varepsilon = 53\%$$

(33% from resolved + 20% from merged)

Most of the inefficiency due to
photon conversion before magnet

$$B_d \rightarrow \pi^+\pi^-\pi^0 \quad (\text{Br} = 2.0 \cdot 10^{-5})$$

• $12 \cdot 10^3$ selected evts/year - $B/S < 1$
• $\sim 60\%$ with merged $\pi^0 \rightarrow \gamma\gamma$

$$B_u \rightarrow \rho^+\rho^0 \quad (\text{Br} = 2.0 \cdot 10^{-5})$$

• $19 \cdot 10^3$ selected evts/year - $B/S < 1$
• $\sim 30\%$ with merged $\pi^0 \rightarrow \gamma\gamma$

Transverse momentum (GeV/c)

SPD/PS/ECAL/HCAL
complementary
system

$e/\gamma/h$ separation

participates to the
fast & flexible
trigger system
for LHCb

Reconstruction of
prompt γ , π^0 , η , ...
gives access to
the study of B
decay. Important
feature to the
complete physics
program of LHCb.

Algorithms/Selection
under development
→ performance
will improve.

Production ongoing.
Ready to take data in 2007