Simulation of the LHCb electromagnetic calorimeter response with GEANT4

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Simulation of the LHCb Electromagnetic Calorimeter response with GEANT4

Patrick Robbe (LAL Orsay) for the LHCb Calorimeter Group, 1 April 2004
• Principles and setup of the LHCb ECAL Simulation

• Specific LHCb ECAL Implementations

• Comparison with test beam data
The LHCb Detector

Precision $B$ physics experiment at LHC
The LHCb Electromagnetic Calorimeter (ECAL)

- **Lead – Scintillator shashlik detector**
  - Light collected by WLS fibers
  - Readout by PMT at the back of the detector
- Provides **fast information for trigger** (high $p_T$ $\gamma$, $e$, $\pi^0$)
- **Reconstruction** of $B$ hadrons with neutral final states ($B^0 \rightarrow K^{*0}\gamma$, $B^0 \rightarrow \pi^+\pi^-\pi^0$, ...)
- **Identification** of $e^\pm$ (for reconstruction, tagging, ...)


ECAL Simulation with GEANT4

- Simulation of detector response is based on GEANT4 and ECAL simulation is integrated into the entire LHCb simulation software.

- **General framework:**
  - **Primary particles** (produced by Pythia for the p-p collisions, EvtGen for B decays and from background) are given to GEANT4 for processing.
  - GEANT4 is set up with:
    - specific LHCb geometry and material description
    - specific actions to simulate ECAL behaviour

- **Execution speed** is an issue
Geometry Setup

Outer ECAL: 2688 cells
(12 cm × 12 cm)

Middle ECAL: 1792 cells
(6 cm × 6 cm)

Inner ECAL: 1584 cells
(4 cm × 4 cm)
• **Stack:**

  - 66 times...

• **Lead Tile:**

  - **Detailed and optimized** geometry (for example, no fiber in Scintillator, but they are the same material)

  - **Active** material is **Scintillator Tile**
Timing (1)

- Specific ECAL implementation
- Share each energy deposition in *two consecutive 25 ns time bins*, according to test beam measurements.
- Simulates signal integration by electronics chain.
- \( t_0 \) = time of arrival of photons at the \( z \) position of the maximum of the shower \( ie 11 \) cm after ECAL front surface.
Timing (2)

Total energy vs. Time Slot (1 ns bin)

Photons

Total energy vs. Time Slot (1 ns bin)

Pions

Geant4
Non Uniformities – Muon Test Beam

Scan with muons perpendicular to ECAL cell

- Fiber positions
- Cell Center
- ± 3% amplitude

Slice in a fiber row

Slice between 2 fiber rows
Non Uniformities – Simulation

• 3 different components:
  ▪ **Local Non Uniformity:**
    - \( A \times (1 - \cos 2\pi(x-x_0)/d) \times (1 - \cos 2\pi(y-y_0)/d) \)
    - \((x_0, y_0)\) = center of the cell
    - \(d\) = distance between fibers
  ▪ **Global Non Uniformity:**
    - \( B \times (x-x_0+L/2)^2 \times (y-y_0+L/2)^2 \)
    - \(L\) = cell size
  ▪ **Reflection on the edges** of the tile (for one side):
    - \( C \times \exp(-|x-x_0+L/2|/D) \)
Non Uniformities – Muon Simulation

Scan with muons perpendicular to ECAL cell

Cell Edge  Cell Center

± 3 % amplitude

Slice in a fiber row

Slice between 2 fiber rows
Non Uniformities – Electron Test Beam

Scan with 50 GeV electrons perpendicular to ECAL cell

Cell Edge

<table>
<thead>
<tr>
<th>Cell Center</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\chi^2$/ndf</td>
</tr>
<tr>
<td>P1</td>
</tr>
<tr>
<td>P2</td>
</tr>
<tr>
<td>P3</td>
</tr>
<tr>
<td>P4</td>
</tr>
</tbody>
</table>

± 0.7 % amplitude

Preliminary results
Non Uniformities – Electron Simulation

Scan with 50 GeV electrons perpendicular to ECAL cell

- Preliminary results
- Parameters that reproduce muon test beam data do not reproduce electron test beam data (factor 2 between them)
- This will be studied in more details (including other cell size of ECAL) with test beam this summer

± 0.8 % amplitude
Resolution – Test Beam

Electrons perpendicular to the module

**Middle Module**

<table>
<thead>
<tr>
<th>Resolution</th>
<th>Test Beam</th>
</tr>
</thead>
<tbody>
<tr>
<td>E(GeV)</td>
<td>3.057 / 4</td>
</tr>
<tr>
<td>P1</td>
<td>0.7799</td>
</tr>
<tr>
<td>P2</td>
<td>7.810</td>
</tr>
<tr>
<td>P3</td>
<td>21.000</td>
</tr>
</tbody>
</table>

**Outer Module**

<table>
<thead>
<tr>
<th>Energy resolution, %</th>
<th>E(GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>0.936E-01</td>
</tr>
<tr>
<td>P2</td>
<td>0.833E-02</td>
</tr>
<tr>
<td>P3</td>
<td>0.1454</td>
</tr>
</tbody>
</table>

\[
\sigma_{E/E} = (9.4 \pm 0.4)\%/E^{0.5} \oplus (0.83 \pm 0.02)\%
\]

**Graph**

- \(\sigma_{E/E} = (7.8 \pm 0.3)\%/E^{0.5} \oplus (0.78 \pm 0.05)\%\)
Resolution – Simulation

Electrons perpendicular to one Outer Module

Linearity

\[ E_{\text{vis}} = a E + b \]
\[ a = 0.133 \pm 0.001 \]
\[ b = 4.0 \pm 2.3 \text{ MeV} \]

Resolution

\[ \frac{\sigma}{E} = \frac{\sigma}{\sqrt{E}} \oplus b \]
\[ a = 9.8 \pm 0.4 \% \]
\[ b = 1.0 \pm 0.1 \% \]

Active / Total = 7.5 ± 0.1

\[ \frac{\sigma}{E} = (9.8 \pm 0.4 \%) / E^{0.5} \oplus (1.0 \pm 0.1 \%) \]
Conclusions

• LHCb simulation software contains a realistic simulation of ECAL detector.

• **Timing and non uniformities** are taken into account in the simulation.

• For non uniformities, **more detailed studies** with new test beam data will be performed in the near future.