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

Precise 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, ...)
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
Outer ECAL: 2688 cells (12 cm × 12 cm)

Middle ECAL: 1792 cells (6 cm × 6 cm)

Inner ECAL: 1584 cells (4 cm × 4 cm)
ECAL Outer Module

- 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
• 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)** for photons and pions. The left plot shows data for photons, while the right plot shows data for pions. Both plots use a logarithmic scale for the y-axis.

- The data is labeled as "Geant4."
Non Uniformities – Muon Test Beam

Scan with muons perpendicular to ECAL cell

- Fiber positions
- Cell Center
- Slice in a fiber row
- Slice between 2 fiber rows

± 3 % amplitude
3 different components:

- **Local Non Uniformity:**
  \[ A \times (1-\cos 2\pi(x-x_0)/d) \times (1-\cos 2\pi(y-y_0)/d) \]
  - \((x_0, y_0) = \text{center of the cell}\)
  - \(d = \text{distance between fibers}\)

- **Global Non Uniformity:**
  \[ B \times (x-x_0+L/2)^2 \times (y-y_0+L/2)^2 \]
  - \(L = \text{cell size}\)

- **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

Cell Center

\[ \chi^2/\text{ndf} = 802.9 -41 \]

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>P1</td>
<td>861.3 ±</td>
<td>0.6755E-01</td>
</tr>
<tr>
<td>P2</td>
<td>0.4617E-02 ±</td>
<td>0.3120E-03</td>
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<tr>
<td>P3</td>
<td>0.3911E-02 ±</td>
<td>0.7667E-04</td>
</tr>
<tr>
<td>P4</td>
<td>1.719 ±</td>
<td>0.4521E-01</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
Resolution – Test Beam

Electrons perpendicular to the module

Middle Module

Outer Module

\[ \sigma_{E/E} = (7.8 \pm 0.3)/E^{0.5} \oplus (0.78 \pm 0.05)\% \]

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

Electrons perpendicular to one Outer Module

Linearity

Resolution

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

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

Active / Total = 7.5 ± 0.1

\[ \sigma_{E/E} = (9.8 \pm 0.4 \%) / E^{0.5} \oplus (1.0 \pm 0.1 \%) \]
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.