Electromagnetic Calorimeter for the LHCb experiment
What I will talk about

- Design and production of calorimeter modules
- Performance studies
- Quality control and pre-calibration of modules
- Monitoring system prototype
- (Radiation resistance)

What I will not talk about

- Calorimeter electronics
- MC simulation
- Trigger and Physics with Calorimeter

Frederic Machefert @ Electronics & DAQ session
Patrick Robbe @ Simulation & Data Analysis session
Olivier Deschamps @ Simulation & Data Analysis session
- Shashlik type technology
- 3 regions with different cell size
- 3.3 k modules, 6.0 k electronics channels

Integration of ECAL modules into the detector wall
E/M calorimeter: module design

Pb/Sc stack
OUTER MODULE

R/O part

MIDDLE MODULE

INNER MODULE

Z = 12520 mm
E/M calorimeter: module design

PMT R7899-20

R/O part

Space for cabling

Base: Cockcroft-Walton multiplier

Cable turn area
### E/M calorimeter: module design

- Volume ratio Pb:Sc = 2:4 (mm)
- Pb/Sc: 66 layers => 416 mm, 25 $X_0$, 1.1 $\lambda$ depth
- $R_M = 3.5$ cm

<table>
<thead>
<tr>
<th></th>
<th>Inner section</th>
<th>Middle section</th>
<th>Outer section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner size</td>
<td>65 cm x 65 cm</td>
<td>194 cm x 145 cm</td>
<td>388 cm x 242 cm</td>
</tr>
<tr>
<td>Outer size</td>
<td>194 cm x 145 cm</td>
<td>388 cm x 242 cm</td>
<td>776 cm x 630 cm</td>
</tr>
<tr>
<td>Cell size</td>
<td>4.04 cm x 4.04 cm</td>
<td>6.06 cm x 6.06 cm</td>
<td>12.12 cm x 12.12 cm</td>
</tr>
<tr>
<td># of modules</td>
<td>176</td>
<td>448</td>
<td>2688</td>
</tr>
<tr>
<td># of cells per module</td>
<td>9</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td># of cells (channels)</td>
<td>1472</td>
<td>1792</td>
<td>2688</td>
</tr>
<tr>
<td># of fibers per cell</td>
<td>16</td>
<td>36</td>
<td>64</td>
</tr>
<tr>
<td>Fiber density</td>
<td>0.98 cm$^{-2}$</td>
<td>0.98 cm$^{-2}$</td>
<td>0.44 cm$^{-2}$</td>
</tr>
</tbody>
</table>
Modules production: fiber loops preparation

Kuraray WLS fibers: Y11(250)MS
Modules production: fiber loops preparation
Modules production: fiber loops preparation

- Fiber bending down to loop radii ~10mm
- In total 140 K loops produced
- Production rate up to 1.5 K /day
- Loop-to-loop spread: r.m.s. < 1.6%
Modules production: tiles production

- Tiles are produced with injection moulding technique under high pressure
- Chemical treatment of tile edges
- Light reflection from tile edges ~90%
- In total 450 K tiles produced
- Production rate up to 800 tiles with treated edges /day
- Tile-to-tile spread: r.m.s.<2.5%
Modules production: stack assembly

- Plastic matrix
- Steel pressing matrix
- Steel stretching tape
- Tong
- Flanch of tong
In total 3.6 K modules produced
Assembly rate up to 10 outer modules /day
Module-to-module spread: r.m.s. < 6%
All the ECAL modules have been produced.
QC and pre-calibration of ECAL modules

- Pre-calibrate modules to better than 10% (with cosmic particles and/or with e-beam)

- Pre-calibrate several modules to the best possible value and distribute them uniformly over detector surface => better convergence of calibration with particles

- Calibrate modules with particles in the detector

in Vladimir

- Data taking time ~20 min for outer cell

- $\sigma/A$~25%; precision in peak position ~3%

- Module-to-module spread: r.m.s.<6%
QC and pre-calibration of ECAL modules

- Set-up designed for ~30 module cells
- Event rate: 5/hour (inner cell); 400/hour (outer cell)

- Data taking time ~20 h (inner)
- Inner cells: \( \sigma/A \approx 8\% \); precision in peak position < 1% with veto from neighbouring cells to select ~vertical tracks
QC and pre-calibration of ECAL modules

Peak position is determined to a precision of ~1%

offs-line veto

central cell

corner cell

Inner module

&~50 h data taking

Peak position is determined to a precision of ~1%

offs-line veto

central cell

corner cell

Inner module

~50 h data taking

Peak position is determined to a precision of ~1%

offs-line veto

central cell

corner cell

Inner module

~50 h data taking

Peak position is determined to a precision of ~1%

offs-line veto

central cell

corner cell

Inner module

~50 h data taking

Peak position is determined to a precision of ~1%

offs-line veto

central cell

corner cell

Inner module

~50 h data taking

Peak position is determined to a precision of ~1%

offs-line veto

central cell

corner cell

Inner module

~50 h data taking

Peak position is determined to a precision of ~1%

offs-line veto

central cell

corner cell

Inner module

~50 h data taking

Peak position is determined to a precision of ~1%

offs-line veto

central cell

corner cell

Inner module

~50 h data taking

Peak position is determined to a precision of ~1%

offs-line veto

central cell

corner cell

Inner module

~50 h data taking

Peak position is determined to a precision of ~1%

offs-line veto

central cell

corner cell

Inner module

~50 h data taking

Peak position is determined to a precision of ~1%

offs-line veto

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corner cell

Inner module

~50 h data taking

Peak position is determined to a precision of ~1%

offs-line veto

central cell

corner cell

Inner module

~50 h data taking

Peak position is determined to a precision of ~1%
**Module performance**

**Uniformity**

Transversal scan of ECAL module with **50 GeV e⁻ beam**

- **P1**: $861.3 \pm 0.6755E-01$
- **P2**: $0.4617E-02 \pm 0.3120E-03$
- **P3**: $0.3911E-02 \pm 0.7667E-04$
- **P4**: $1.719 \pm 0.4521E-01$

**Uniformity parameters**

- $A^{\text{global}} = (0.46 \pm 0.03\%)$
- $A^{\text{local}} = (0.39 \pm 0.01\%)$

- $\pm 1.3\%$ for perpendicular e-beam
- $\pm 0.6\%$ for e-beam at 200 mrad

**Energy resolution**

ECAL module energy resolution: e⁻ beam

- $\chi^2/\text{ndf} = 7.668 / 3$
- $P1: 0.9368E-01 \pm 0.1760E-02$
- $P2: 0.8332E-02 \pm 0.2494E-03$
- $P3: 0.1454 \pm 0.1306E-01$

- $(9.4\pm0.2\%) \oplus (0.83 \pm 0.02\%) \oplus ((145 \pm 13) \text{ MeV})/E$

**Required energy resolution:**

$\frac{\sigma_E}{\sqrt{E}} \leq 10\% \oplus 1\%$
Module performance

Energy resolution: constant term

Contribution from the lateral non-uniformity

Errors quoted are the errors of the fit!

<table>
<thead>
<tr>
<th>$\chi^2/\text{ndf}$</th>
<th>6.378 / 1</th>
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</thead>
<tbody>
<tr>
<td>P1</td>
<td>0.9412E-01 ± 0.5835E-03</td>
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<tr>
<td>P2</td>
<td>0.8387E-02 ± 0.9144E-04</td>
</tr>
<tr>
<td>P3</td>
<td>0.1200 ± 0.000</td>
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</table>

<table>
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<tr>
<th>$\chi^2/\text{ndf}$</th>
<th>0.3680 / 1</th>
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</thead>
<tbody>
<tr>
<td>P1</td>
<td>0.9385E-01 ± 0.1759E-02</td>
</tr>
<tr>
<td>P2</td>
<td>0.6478E-02 ± 0.3538E-03</td>
</tr>
<tr>
<td>P3</td>
<td>0.1200 ± 0.000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$\chi^2/\text{ndf}$</th>
<th>0.2167 / 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>0.9013E-01 ± 0.3570E-02</td>
</tr>
<tr>
<td>P2</td>
<td>0.5676E-02 ± 0.7850E-03</td>
</tr>
<tr>
<td>P3</td>
<td>0.1200 ± 0.000</td>
</tr>
</tbody>
</table>

$\sigma_E/E = (9.4 \pm 0.1)\% \oplus (0.84 \pm 0.01)\% \oplus (0.12 \text{ GeV})/E$

$\Delta x, \Delta y \approx (\pm 15 \text{ mm}, \pm 30 \text{ mm})$

$\sigma_E/E = (9.4 \pm 0.2)\% \oplus (0.65 \pm 0.04)\% \oplus (0.12 \text{ GeV})/E$

$\Delta x, \Delta y \approx (\pm 1 \text{ mm}, \pm 30 \text{ mm})$

Ave.

$\sigma_E/E = (9.0 \pm 0.4)\% \oplus (0.57 \pm 0.08)\% \oplus (0.12 \text{ GeV})/E$

$\Delta x, \Delta y \approx (\pm 1 \text{ mm}, \pm 1 \text{ mm})$

~Half of the constant term value comes from lateral non-uniformity of response
Monitoring system

Basic requirements:
- Control of time and temperature stability;
- Small pulse duration and dispersion of amplitude;
- Adjustable pulse rate and amount of light;
- Emulate e/m particles in full “physics” region;
- Gain control to better than 1% accuracy;
- Control only electronics chain: supply LED light directly to the PMT;
- Use empty bunches for monitoring system job.

In total
- 512 LDs/LEDs/splitters/fiber bundles
- 64 PIN-diodes
Monitoring system: the method

Correction of time- and temperature-instability with the monitoring system prototype

LED signal seen by PIN-diode

LED signal seen by PMT

Signal from 50 GeV electrons seen by PMT

Corrected signal from electrons

Initial effect of ~4% is corrected to better than 0.5%.

Corrected electron signal, RUNs 3263 - 3311

Test beam data

22 hours
Physics with ECAL ⇒ see talk by Olivier Deschamps

\[ \gamma / \pi^0 \text{ reconstruction} \]

\[ J/\Psi \rightarrow e^+ e^- \]

\[ \pi^0 \text{ reconstruction} \]

\[ \pi^0 \rightarrow \gamma \gamma \]

\[ \pi^0 \rightarrow \gamma (e^+ e^-) \]

\[ B^0 \rightarrow K^* \gamma \]

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

\[ B_s^0 \rightarrow \phi \pi^0 \]

\[ N / 50 \text{ MeV/c}^2 \]

\[ M(K\pi\gamma), \text{[GeV/c}^2] \]

\[ M(KK\gamma), \text{[GeV/c}^2] \]

\[ \text{Invariant mass (MeV/c}^2) \]

\[ \text{Entries} \]

\[ e^+ e^- \text{ mass (GeV/c}^2) \]