Response of the CALICE Si-W ECAL prototype to electrons

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Summary

- Introduction
- Electron selection
- Uniformity of the response of the ECAL
- Performance (resolution, linearity)
- Longitudinal and transverse shower development
- Conclusion and outlook
ECAL Prototype

A high granularity calorimeter optimized for Particle Flow for ILC physics

- **Absorber**: tungsten
- **Active element**: silicon
- **High sampling**: 30 layers
- **High granularity**: 1x1 cm$^2$ cells
- **Compact**: ~ 20 cm depth for 24 X0
- **Channels**: 6471 (2006)
Test Beam campaign of CALICE at CERN

- Validate the Si-W technology
- Characterisation of the prototype
  - Response in energy (resolution, linearity)
  - Spatial resolution
  - Response uniformity

Si-W ECAL

HCAL Tail Catcher

Beam (e⁻ or π)

AIM
Event selection

- \[ E_{\text{raw}} = \sum_{i=0}^{9} E_i + 2 \sum_{i=10}^{19} E_i + 3 \sum_{i=20}^{29} E_i \]

- **Energy window**: \(125 < E_{\text{RAW}} / E_{\text{beam}} < 375\): \(\mu\) and \(\pi\) rejection
- **Cut on Čerenkov counter**: \(\pi\) rejection
- **Beam halo rejection**

![Graph showing event selection criteria with peaks for \(\pi\), \(\mu\), and electron]
Control of the uniformity response
Control of the uniformity response

Reconstructed energy ~ 2mm

zoom into a wafers slab

CALICE 2006 data

Y (mm)

X (mm)

GeV

Reconstructed energy

~ 2mm
Measurement of the energy gaps

Simple and robust model

\[ f(\tilde{x}, \tilde{y}) = \left( 1 - a_x e^{\frac{-(\tilde{x} - x_{gap})^2}{2\sigma_x^2}} \right) \left( 1 - a_y e^{\frac{-(\tilde{y} - y_{gap})^2}{2\sigma_y^2}} \right) \]

Function of the shower barycenter only
→ works both for photons and electrons

Mean effect observed on electrons in the energy range 10-30GeV
Correction of the energy gaps

**CALICE 2006 data**

- **raw data**
- **corrected data**

**CALICE 2006 data**

- **raw data**
- **corrected data**

20 GeV electrons
Correction of the energy gaps

Correction for the energy loss in the inter-wafer gap improves the shape of energy distribution.

[Graph showing energy distribution with labeled '20 GeV electrons']
Energy reconstruction

- **Event/event cut on barycenter to inter-wafer gap distance**
  - Distance $>4\sigma$

- **Event/event cut on barycenter to ECAL border distance**
  - Cut corresponding to 97% containment
  - No leakage

- **The beam energy**:
  Uncertainty on the beam energy is modelled by

\[
\frac{\Delta E}{E} = \frac{0.12}{E} \oplus 0.1\% \rightarrow \text{determined by the observed momentum spread}
\]
Used data – CERN 2006

Data sample used to characterise the prototype

<table>
<thead>
<tr>
<th>Energy (GeV)</th>
<th>particle</th>
<th>date</th>
<th>statistics (kevts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>$e^-, e^+$</td>
<td>Oct</td>
<td>10.6</td>
</tr>
<tr>
<td>10</td>
<td>$e^-, e^+$</td>
<td>Aug, Oct</td>
<td>55.9</td>
</tr>
<tr>
<td>12</td>
<td>$e^-, e^+$</td>
<td>Oct</td>
<td>32.1</td>
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<tr>
<td>15</td>
<td>$e^-, e^+$</td>
<td>Aug, Oct</td>
<td>60.4</td>
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<tr>
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<td>Aug, Oct</td>
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<tr>
<td>30</td>
<td>$e^-, e^+$</td>
<td>Aug, Oct</td>
<td>43</td>
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<tr>
<td>40</td>
<td>$e^-$</td>
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<tr>
<td>45</td>
<td>$e^-$</td>
<td>Aug</td>
<td>129.3</td>
</tr>
</tbody>
</table>

Sample size after the full selection
Reconstructed energy

Mean and width extracted using a Gaussian fit \([-1\sigma, +2\sigma]\)

- $\chi^2 / \text{ndf} = 17.47 / 19$
- Constant = $758.9 \pm 9.2$
- Mean = $7916 \pm 4.4$
- Sigma = $258.8 \pm 4.1$

30 GeV electrons
Linearity of the response

- The prototype is linear at 1% level
- \( E_{\text{meas}} = \frac{E_{\text{raw}} - \alpha}{\beta} \)
  - \( \alpha = -97 \) MIP
  - \( \beta = 266 \) MIP/GeV
Energy resolution

Beam spread subtracted from $\Delta E / E$

\[
\begin{array}{|c|c|}
\hline
\chi^2 / \text{ ndf} & 28.48 / 33 \\
\text{stochastic} & 16.69 \pm 0.1253 \\
\text{constant} & 1.089 \pm 0.06493 \\
\hline
\end{array}
\]
Illustration of the spatial resolution

~5 cm
Spatial resolution

- Linear fit:
  \[ \chi^2 = \sum_{i,j} (x_{\text{meas}} - x_{\text{th}})_i W_{ij} (x_{\text{meas}} - x_{\text{th}})_j \]
  \[ x_{\text{th}} = P_{0x} + P_{1x} \times z \]
  \[ x_{\text{meas}} = \frac{\sum_i E_i x_i}{\sum_i E_i} \]
  \( i \) = hits in layer L.

- Error matrices extracted from the simulation (per energy)
  - \( x \) and \( y \) uncorrelated
  - two error matrices \( W_{ij} \)
  - two independent fits

- Minimize \( \chi^2 \) with respect of \( p_{0x}, p_{1x} \)
Spatial resolution

Position Resolution

Calice Preliminary

Angular Resolution

Calice Preliminary
Longitudinal shower development

CALICE preliminary

20 GeV electrons

function: \( c \times t^\alpha \times \exp(-\beta \times t) \)
Longitudinal shower development

20 GeV electrons

CALICE preliminary
Longitudinal shower development

**CALICE preliminary**

- **Shower max. [layers weighted by \( W \) thickness]**
- **Beam energy [GeV]**

- Red circles: DESY runs
- Blue circles: CERN runs
Radial development of the shower

center
$e^{-} 3 \text{ GeV}$

- 90% containment
- 95% containment

Radius (mm)

center

- 90% containment
- 95% containment

energy (GeV)
Conclusion and outlook

- The Si-W ECAL prototype operated successfully in 2006 at CERN and DESY
- The characterisation of the ECAL was performed with 6471 operating cells (99.86% operating cells)
- The study of the 2007 data with an up scaled version of the ECAL (up to 9400 channels) is ongoing
- More data are being taken at Fermilab (2008)