CALICE SiW Ecal
- Results and Plans -

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Ecal Prototype - CALICE Collaboration

- W as absorber material
- Signal extraction by “Silicon Wafers”
- Extreme high granularity 1x1 cm² cell size
- Detector is optimized for particle separation

The ECAL prototype

Note the density

Structure 1
Structure 2
Structure 3

Metal inserts (interface)

Detector slab

ACTIVE ZONE (18x18 cm²)

360mm

200mm

3 structures W-CFi (1,2,3 x 1.4mm)
15 « detector slabs »
Dimension 200x360x360 mm

Silicon wafers with 6x6 pads (10x10 mm²)
CALICE Testbeam Data Taking

Large scale testbeam effort by CALICE Collaboration

Testbeam Setup at CERN 2007

Slabs slit into alveolas

Data taking 2006 2/3 equipped Ecal
Data taking 2007 (nearly) fully equipped Ecal
Data taking 2008 fully equipped Ecal

Today: Analysis of 2006 Data

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Calibration – Uniformity of Response

Calibration with wide spread μ-beam

18 Mio. Events
Uniform response of all cells
only 1.4‰ dead cells

Differences in Response can attributed to different
- Manufacturers
- Production series

Experience to deal with different manufacturers and production series
Essential for final detector
~3000m² of Silicon needed
Stability

Comparison between calibration constants achieved in situ and on a dedicated testbench

Calibration once achieved can be transported

Important for taking testbeam data at different locations
Ecal Correction of Energy Deposition - Acceptance

Dips in energy measurement by inter wafer gaps (needed for isolation)

Need to take geometrical acceptance into account in analysis

Absolute calibration by comparing $E_{\text{dep}}$ on MIP level with beam energy
Correction of Energy Deposition I – Acceptance Correction

Restoring homogeneous response with correction function

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

Energy loss due to acceptance limits not fully recovered

Important issue for future R&D

Requires close collaboration between CALICE and SiWafer Suppliers
Correction of Energy Deposition II – Sampling Fraction

Sampling Fraction increases with calorimeter depth

Naive Weighting: \( E_{\text{rec}} = \sum_i w_i E_i \) with
- \( w_i = 1 \) for \( i = 0,9 \)
- \( w_i = 2 \) for \( i = 10,19 \)
- \( w_i = 3 \) for \( i = 20,29 \)

Accounting for varying amount of supplementary material

Naive Weighting:
\[
\tilde{\eta} = \frac{w_{i}^{'} - w_{i}}{E_{\text{beam}}} = (7.2 \pm 0.2 \pm 1.7) \%
\]

\( w_{i}^{'} = w_{i} + \tilde{\eta} \) for odd layers
\( w_{i}^{'} = w_{i} \) for even layers
Linearity of Response

Overview

- Highly linear response over large energy range
- Linearity well reproduced by MC
  \[ \text{MIP/GeV} \sim 266.5 \ [1/\text{GeV}] \]
- Offset O(1MIP)
- Linearity O(1%)
- Residuals from low energetic signals in cells
  Might be reflection of guard ring effect
Energy Resolution

Example 20 GeV e- beam:

Gaussian like Calorimeter Response

Resolution curve shows typical $\sqrt{E}$ dependency

$$\frac{\Delta E_{\text{meas.}}}{E_{\text{meas.}}} = \left[ \frac{16.7 \pm 0.1 \text{ (stat.)} \pm 0.4 \text{ (syst.)}}{\sqrt{E \text{[GeV]}}} \right] %$$

- Resolution well describes by MC
- Actual number not overwhelming for electromagnetic calorimeters but

Design emphasises spatial granularity over energy resolution

Calorimeter for Particle Flow
Longitudinal Shower Development

Logarithmical Grow of Shower Maximum as expected by Theory
Position Resolution

Essential for good Particle Separation

Double Particle Event in SiW Ecal

Particle Distance ~5cm

Tracks in Calorimeter by energy weighted cell positions

Reference by Tracking Chamber

Better than 2mm towards higher energies

Worse resolution in y due to overlap of passive areas
EUDET Prototype

- **Logical continuation** to the physical prototype study which validated the main concepts: alveolar structure, slabs, gluing of wafers, integration
- Techno. Proto: study and validation of most of technological solutions which could be used for the final detector (moulding process, cooling system, wide size structures,...)
- Taking into account industrialization aspect of process
- First cost estimation of one module

<table>
<thead>
<tr>
<th>System</th>
<th>Details</th>
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<tbody>
<tr>
<td>Short detector</td>
<td><img src="image1.jpg" alt="Image" /></td>
</tr>
<tr>
<td>Slabs (x14)</td>
<td>- 3 structures: 24 $X_0$</td>
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<tr>
<td></td>
<td>(10×1,4mm + 10×2,8mm + 10×4,2mm)</td>
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<tr>
<td></td>
<td>- Sizes: 380×380×200 mm³</td>
</tr>
<tr>
<td></td>
<td>- Thickness of slabs: 8.3 mm (W=1,4mm)</td>
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<tr>
<td></td>
<td>- VFE outside detector</td>
</tr>
<tr>
<td></td>
<td>- Number of channels: 9720 (10×10 mm²)</td>
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<tr>
<td></td>
<td>- Weight: ~ 200 Kg</td>
</tr>
<tr>
<td>Long detector</td>
<td><img src="image2.jpg" alt="Image" /></td>
</tr>
<tr>
<td>Slab (1)</td>
<td>- 1 structure: ~ 23 $X_0$</td>
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<tr>
<td></td>
<td>(20×2,1mm + 9×4,2mm)</td>
</tr>
<tr>
<td></td>
<td>- Sizes: 1560×545×186 mm³</td>
</tr>
<tr>
<td></td>
<td>- Thickness of slabs: 6 mm (W=2,1mm)</td>
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<tr>
<td></td>
<td>- VFE inside detector</td>
</tr>
<tr>
<td></td>
<td>- Number of channels: 45360 (5×5 mm²)</td>
</tr>
<tr>
<td></td>
<td>- Weight: ~ 700 Kg</td>
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</table>
The groups working on the EUDET Electromagnetic Calorimeter

- What we call “EUDET Module” is in fact the next SiW Ecal CALICE Prototype

- Financial support by EU
Module EUDET – Current Design (final – developed 2008)

Composite Part with metallic inserts (15 mm thick)

- Thickness: 1 mm
- Heat shield: 100+400 µm (copper)
- PCB: 1200 µm
- Glue: 100 µm
- Wafer: 325 µm
- Kapton® film HV: 100 µm
- Thickness of W: 2100/4200 µm (± 80 µm)

- Gaps (slab integration): 500 µm
- Heat Shield: 400 µm? Validation with the demonstrateur
- PCB: ~1200 µm
- Thickness of SiWafer: 325 µm
Alveolar Structures with (~) ILC Dimensions

Rails for mechanical integration with Hcal

Metrology

Planarity 0,59 mm

Planarity 0,65 mm
Thermal Layer – Developing the Techniques for Layer Construction

Proof-of-principle to build long layers

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Silicon Sensors

Looking forward to ILD/SiD

We are facing a real show stopper !!!!
The cost issue

The cost estimate of a financially viable ECAL for ILD assumes this input:

A cost at the level 2 € / cm²
Now we are at the level of 10 to 20 €/cm²
About 2500 m² of sensors needed for SiW ECAL of ILD = 300 000 sensors
(actual design)

What could we do / rely on?
- Savings due to the change on scale?
- Create a *competition* between manufacturers?
  - specific production...
  - financial weight of our orders
- Do things ourselves?
  - manpower, equipment
- Optimize financial impact being opportunistic?
  - order when markets are low
  - share production among various small batches
- Optimize the yield?
- Deal with consumer devices manufacturers?
  - eg. OnSemi

It's time to act!!!!
Top Priority in R&D in coming years!!!
- SiW Tungsten Ecal with up to 9400 cells operated successfully during testbeam campaigns 2006 (and 2007 and 2008)
  Today: Selected Results from 2006 campaign

- Stable operation
  uniform response to MIPs, robust calibration
  only 1.4‰ dead cells

- Energy resolution and Linearity well described by MC
  Linearity $O(1\%)$
  Resolution $(16.5%/\sqrt{E} \pm 1\%)$

- Promising results for Shower development and Spatial Resolution

- Technological Prototype (EUDET Module) on its way

- The whole SiW Ecal project depends on the price of the SiW Wafers

Backup ...
The CALICC Collaboration

Calorimeter R&D for the ILC

~293 physicists/engineers from 51 Institutes and 13 Countries from 4 Continents

- Integrated R&D effort
- Benefit/Accelerate Detector Development due to *common* approach

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Intermediate task:

Build prototype calorimeters to
- Establish the technology
- Collect hadronic showers data with unprecedented granularity to
  - tune clustering algorithms
  - validate existing MC models
Silicon sensors: Matrices

- **4” High resistive wafer**: 5 KΩcm
- **Thickness**: 525 microns ± 3 %
- **Tile side**: 62.0 ± 0.0 - 0.1 mm
- **1 set of guard rings per matrix**
- **In Silicon**: ~80 e-h pairs / micron ~ 42000 e^- /MiP
- **Capacitance**: ~21 pF (one pixel)
- **Leakage current @ 200 V**: < 300 nA (Full matrix)
- **Full depletion bias**: ~150 V
- **Nominal operating bias**: 200 V
- **Break down voltage**: > 300 V

**Important point**: manufacturing must be as simple as possible to be near of what could be the real production for full scale detector in order to:
- Keep lower price (a minimum of step during processing)
- Low rate of rejected processed wafer
- Good reliability and large robustness

Wafers passivation Compatible with a thermal cooking at 40° for 12H, while gluing the pads for electrical contact with the glue we use (conductive glue with silver).
Front-end PCB

6 active wafers
Made of 36 silicon PIN diodes
216 channels per board
Each diode a 1 cm² square

2 calibration switches chips
6 calibration channels per chip
18 diodes per calibration channel

12 FLC_PHY3 front-end chip
18 channels per chip
13 bit dynamic range

Line buffers
To DAQ part
Differential

30 layers with varying thickness

Courtesy of J.C. Vanel LLR