Calibration of the Scintillator HCAL of ILD

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(on behalf of the CALICE collaboration)

Overview

1. Introduction
2. Precision of AHCAL Calibration
3. Test beam exercise
4. MIP Stubs at ILD
5. Summary
Introduction

ILD detector

March 2009 Letter of Intent

International Detector Advisory Group (IDAG)

Calorimeter CALIBRATION:

- how?
- how do you monitor it?
- how much data?
- which precision?

AHCAL answers
From measured amplitude to energy in MIPs:

\[ E_{\text{MIP}} = \frac{A}{A_{\text{MIP}}} \cdot f_{\text{resp}} \left( \frac{A}{A_{\text{pixel}}} \right) \]

where

- \( A \) - measured amplitude in ADC counts
- \( A_{\text{MIP}} \) - cell by cell MIP scale
  - predicted by simulation and verified with test beam data
  - Estimated time to acquire sufficient statistics for entire ILD detector: about 2 months \( \rightarrow \) too long (but we can use MIP stubs, see later)
- \( f_{\text{resp}} \) - SiPM response function (non-linear), measured apriori on test bench
- \( A_{\text{pixel}} \) - amplitude of a single fired photo-sensor pixel (from LED-induced signals)
Idea

- Use ILD simulations of single hadrons and of jets
- Induce deliberately mis-calibrations due to temperature fluctuations, statistical precision of calibration factors, etc
- Check the effects on energy resolution

Method

- Consider mis-calibrations of the AHCAL energy scale with a random factor following a Gaussian distribution with mean at zero
- Rerun complete ILD reconstruction (including Pandora PFA algorithm)
Single Hadron Resolution

- Shoot $K^0_L$ in ILD detector and reconstruct energy sum in ECAL+HCAL
- Effects of coherent fluctuations (i.e. due to TEMPERATURE):

- HCAL inside coil $\rightarrow$ expect T variations only from endcaps (via cable paths), if any. Worse realistic case: $< 1^\circ$ T variation
- For $\sim 4%/K$ variation of SiPM response $\Rightarrow \sim 8%$ worse single particle resolution at 100 GeV, if no T corrections applied
Jet Energy Resolution

- Use $Z^0 \rightarrow uds$ samples at $\sqrt{s} = 91$ GeV and at 500 GeV
- Run complete ILD reconstruction chain (including Pandora PFA algorithm)
- 4 scenarios studied in the Munich group:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
<th>Impact</th>
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<tbody>
<tr>
<td>i)</td>
<td>Temperature/voltage fluctuations</td>
<td>Global shift for all cells, on event-by-event basis</td>
</tr>
<tr>
<td>ii)</td>
<td>Imperfect intercalibration of individual modules</td>
<td>Uncorrelated layer-wise shifts</td>
</tr>
<tr>
<td>iii)</td>
<td>Imperfect intercalibration of individual cells</td>
<td>Uncorrelated cell-wise shifts</td>
</tr>
<tr>
<td>iv)</td>
<td>Imperfect calibration of detector energy scale</td>
<td>Global shift for all cells, constant for all events</td>
</tr>
</tbody>
</table>
AHCAL Calibration: How much precision?

Jet Energy Resolution - continued

- Worst case i: 5% RMS $\Rightarrow$ 10% worse dijet energy resolution (can be recalibrated in situ with LED system or MIP stub in hadronic)
- Cases ii, iii: no significant effect
- Case iv: large effect, but also shifted reconstructed dijet invariant mass
AHCAL Calibration: Will it work?

Exercise with test beam data:
- transport calibration to different temperature/high voltage
- study energy resolution
- can we find MIP tracks?

**CERN data**
"collider mode"
(reference)

**FNAL data**
"test beam mode"

2 methods to transport MIP calibration from FNAL to CERN conditions:

1) **T/U calibration** (instantaneous, but non-local):

\[ A(T_1, U_1) = A(T_2, U_2) + \frac{dA}{dT}(T_1 - T_2) + \frac{dA}{dU}(U_1 - U_2) \]

2) **Gain correction** (local, but non-instantaneous):

\[ A(T_1, U_1) = A(T_2, U_2) + \frac{dA}{dG}(G(T_1, U_1) - G(T_2, U_2)) \]
Transport of the MIP Calibration

- Comparison between **T/U calibrated** FNAL and reference CERN sample

**Before T/U correction:**
- Black: before transport
- Red: $U_{CERN} = U_{FNAL}$

- Entries 7255
- Mean $-0.1478$
- RMS 0.1389

**After T/U correction:**
- Black: after transport
- Red: $U_{CERN} = U_{FNAL}$

- Entries 7284
- Mean 0.05652
- RMS 0.1212
- Constant 11.5 $\pm$ 718.5
- Mean 0.00101 $\pm$ 0.04216
- Sigma 0.0009 $\pm$ 0.0785

- Remaining 4% **offset** consistent with different muon beam energies (32 GeV at FNAL, 80 GeV at CERN)

- Results: shift = 4.2%, spread = 7.8%
Comparison between G calibrated FNAL and reference CERN sample

**Relative difference**
- Black: all channels
- Red: $U_{CERN} = U_{FNAL}$

**Correlation**

- Results: shift = 2.9%, spread = 7.7%
- Both methods are equivalent in terms of precision and consistent with each other
In Situ MIP Calibration

- Collect all MIP stubs in pion runs to obtain **layer by layer correction factors** to the MIP calibration after transportation.

Method: look for isolated hits which form MIP tracks in hadron events.

- Fit amplitude of all tracks in a layer → get most probable value of energy loss ⇒ correction factors.

![Diagram showing identified track and amplitude distribution](image)

- Landau + Gauss fit: \( \text{MPV} = 0.9938 \pm 0.0175 \)

CALICE Preliminary
In Situ MIP Calibration - continued

CERN

CERN: layerwise Lan−Gau fit on cells with > 1000 entries

Average shift: 1%

![CERN Graph]

FNAL - G correction

FNAL_G: layerwise Lan−Gau fit on cells with > 1000 entries

Average shift: 2.2%

Layers 13, 22: bad transport coefficients, corrected with in-situ calibration

![FNAL Graph]
Impact on Hadronic Response

- Residual from linearity of reconstructed hadron showers fully contained in the AHCAL ($8 \text{ GeV} < E < 80 \text{ GeV}$)

**BEFORE** layer by layer in situ calibration from MIP stub

**AFTER** layer by layer correction

- Hadron energies with FNAL T/U and G coeff. are in agreement, but $\sim 5\%$ higher than CERN reference

- Clear agreement between different calibration methods
Even at $Z^0$ resonance, no channel by channel calibration within realistic running times $\rightarrow$ look for MIP stubs in jets and define a MIP correction layer by layer

1000 identified tracks per layer $\rightarrow$ calibration precision of 3-4%

Required luminosity per electronic module (HBU) at $Z^0$ pole:
Luminosity requirement for in situ calibration with MIP stubs from jets:

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<tr>
<th></th>
<th>Luminosity at 91 GeV</th>
<th>Lumi. at 500 GeV</th>
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<tbody>
<tr>
<td>layer-module to 3% to layer 20</td>
<td>1 pb⁻¹</td>
<td>1.8 fb⁻¹</td>
</tr>
<tr>
<td>layer-module to 3% to layer 48</td>
<td>10 pb⁻¹</td>
<td>20 fb⁻¹</td>
</tr>
<tr>
<td>HBU to 3% to layer 20</td>
<td>20 pb⁻¹</td>
<td>36 fb⁻¹</td>
</tr>
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For endcaps: muons from the beam halo might be used for calibration (rates between 10 Hz/m² and 10 kHz/m² at full energy)
What level of precision is required?

- Worse case scenario: uncorrected temperature variation during data taking
- Simulated as event by event coherent shifts with RMS=5%
- Effect on single particle energy resolution: max 10% worsening
- Effect on di-jet energy resolution: max 10% (5%) worse at 500 (91) GeV

How do you monitor and maintain it?

- Inter-calibration for calorimeter cells can be obtained during test beam runs and transported to the operation condition of 'collider run'
- ~ 6% uncertainty with both tested transport methods
- Calibration offsets layer by layer measured using MIP stubs
- No impact on hadron energy resolution from calibration transport
If operation at the $Z^0$ pole is your strategy, how much data is required?

- A cell by cell MIP calibration is not necessary in situ
- Average values for individual module layers with 3% accuracy from a data set corresponding to $10 \, \text{pb}^{-1}$ at the $Z^0$ pole, or to $20 \, \text{fb}^{-1}$ at 500 GeV
BACK-UP SLIDES
When applying test beam based calibrations to collider data, need to monitor possible time-dependent variations due to:

- changed operating conditions (voltage, etc)
- ageing effects
- mechanical de-adjustments during handling

**Monitoring methods**

- LED system
- in-situ MIP calibration using track segments and hadron showers (see later)
- slow control reading of bias voltages and temperature