Calibration of the Scintillator HCAL of ILD

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(on behalf of the CALICE collaboration)

Overview

Introduction

ILD detector

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Letter of Intent

International Detector Advisory Group (IDAG)

Calorimeter CALIBRATION:

how?

how do you monitor it?

how much data?

which precision?

AHCAL answers

AHCAL Calibration: How?

- From measured amplitude to energy in MIPs:

$$E\,[\mathrm{MIP}] = \frac{A}{A_{MIP}} \cdot f_{resp}\left(\frac{A}{A_{pixel}}\right)$$

where

- A - measured amplitude in ADC counts
- A_{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_{resp} - SiPM response function (non-linear), measured apriori on test bench
- A_{pixel} - amplitude of a single fired photo-sensor pixel (from LED-induced signals)

AHCAL Calibration: How Much Precision?

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

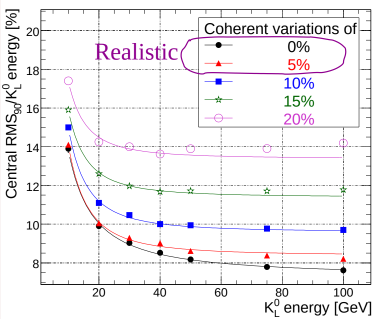
Method

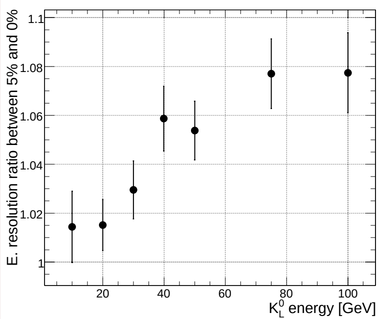
- Consider mis-calibrations of the AHCAL energy scale with a random factor following a Gaussian distribution with mean at zero
- Rerun complete ILD reconstruction (including Pandora PFA algorithm)

AHCAL Calibration: How Much Precision?

Single Hadron Resolution

- Shoot K_L^0 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

AHCAL Calibration: How Much Precision?

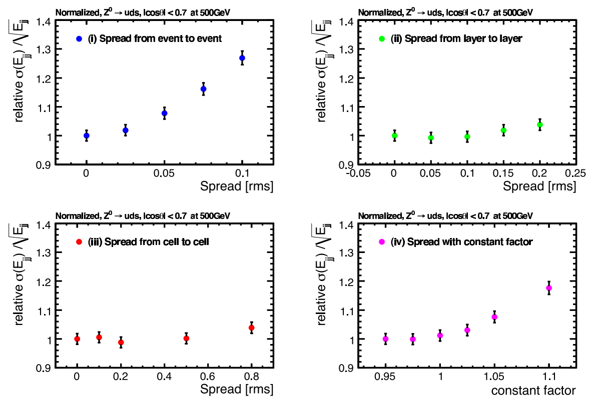
Jet Energy Resolution

- 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:

i)	Temperature/voltage fluctuations	$\Rightarrow$	global shift for all cells, on event-by-event basis
ii)	Imperfect **intercalibration** of individual **modules**	$\Rightarrow$	uncorrelated layer-wise shifts
iii)	Imperfect **intercalibration** of individual **cells**	$\Rightarrow$	uncorrelated cell-wise shifts
iv)	Imperfect calibration of detector energy scale	$\Rightarrow$	global shift for all cells, constant for all events

AHCAL Calibration: How much precision?

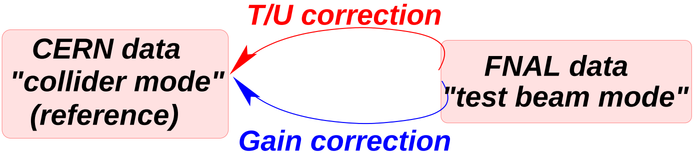
Jet Energy Resolution - continued



- 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?



- 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):

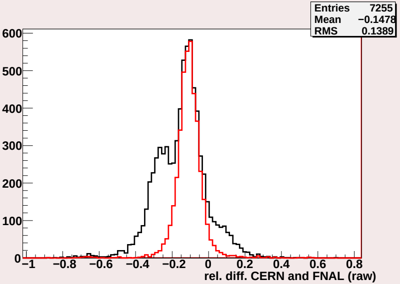
$$A(T_1,\ U_1) = A(T_2,\ U_2) + \frac{dA}{dG}\left(G(T_1,\ U_1) - G(T_2, U_2)\right)$$

Transport of the MIP Calibration

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

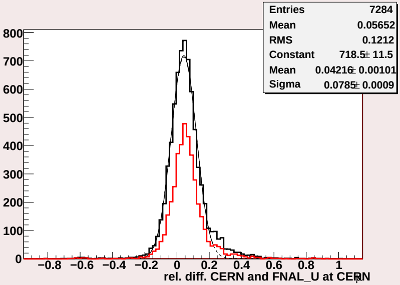
Before T/U correction:

- Black: before transport
- Red: $U_{CERN} = U_{FNAL}$



After T/U correction:

- Black: after transport
- Red: $U_{CERN} = U_{FNAL}$



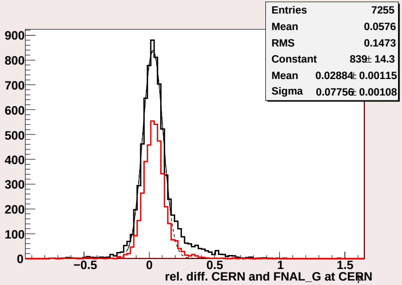
- Remaining 4% **offset** consistent with different muon beam energies (32 GeV at FNAL, 80 GeV at CERN)
- Results: shift = 4.2% , spread = 7.8%

Transport of the MIP calibration - continued

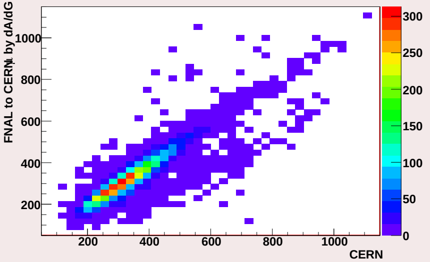
- Comparison between **G calibrated** FNAL and reference CERN sample

Relative difference

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



Correlation

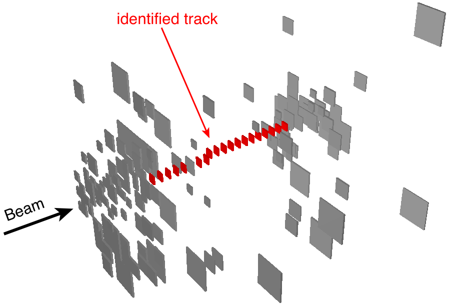


- Results: shift = 2.9% , spread = 7.7%
- Both methods are equivalent in terms of precision and consistent with each other

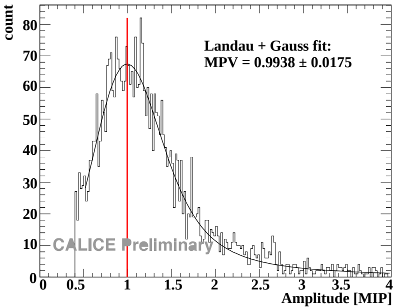
In Situ MIP Calibration

- 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

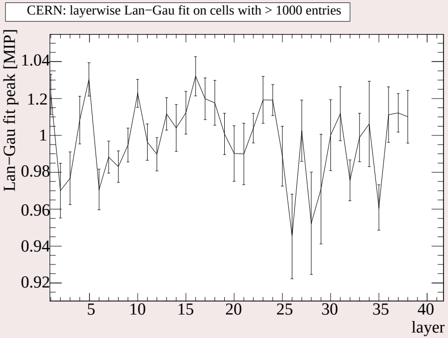


- Fit amplitude of all tracks in a layer $\rightarrow$ get most probable value of energy loss $\Rightarrow$ correction factors



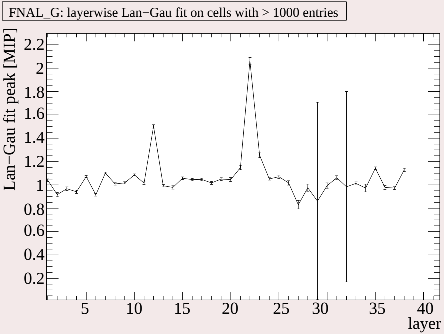
In Situ MIP Calibration - continued

CERN



- Average shift: 1%

FNAL - G correction

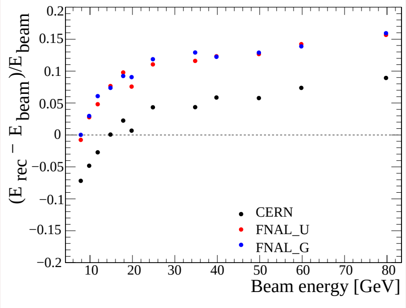


- Average shift: 2.2%
- Layers 13, 22: bad transport coefficients, corrected with in-situ calibration

Impact on Hadronic Response

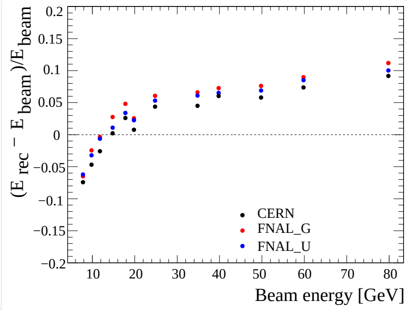
- Residual from linearity of reconstructed hadron showers fully contained in the AHCAL ($8\ \mathrm{GeV} < E < 80\ \mathrm{GeV}$)

BEFORE layer by layer in situ calibration from MIP stub



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

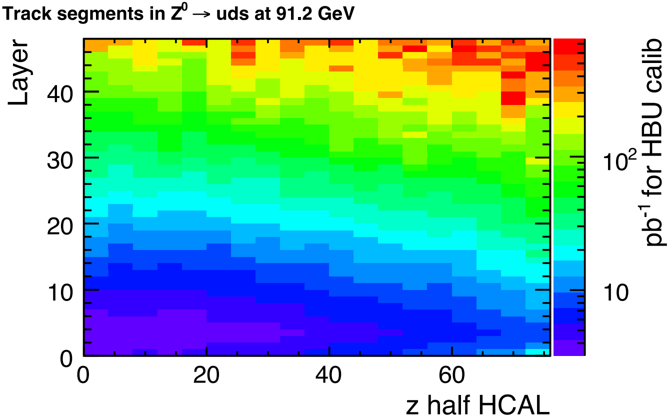
AFTER layer by layer correction



- Clear agreement between different calibration methods

MIP Stubs at ILD

- 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:



MIP Stubs at ILD - continued

- Luminosity requirement for in situ calibration with MIP stubs from jets:

	Luminosity at 91 GeV	Lumi. at 500 GeV
layer-module to 3% to layer 20	1 pb^{-1}	1.8 fb^{-1}
layer-module to 3% to layer 48	10 pb^{-1}	20 fb^{-1}
HBU to 3% to layer 20	20 pb^{-1}	36 fb^{-1}

- For endcaps: muons from the beam halo might be used for calibration (rates between 10 Hz/m^2 and 10 kHz/m^2 at full energy)

The Answers in Summary

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'
- $\sim$ 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

The Answers in Summary - continued

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 pb^{-1} at the Z^0 pole, or to 20 fb^{-1} at 500 GeV

BACK-UP SLIDES

AHCAL Calibration: Monitoring

- 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