Analysis of electromagnetic showers in CALICE Analog Hadron Calorimeter prototype (AHCAL)

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Analysis of electromagnetic showers in CALICE AHCAL prototype

A schematic layout of the International Linear Collider (ILC)

The Large Detector Concept

A Higgs decay event (simulation)
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AHCAL prototype at CERN testbeam

HCAL layer with 216 tiles (3x3, 6x6, 12x12 cm)

3x3 scintillator tile with WLS fiber and SiPM

Silicon Photo Multiplier (SiPM)
size ~ 1mm, 1156 pixels

A SiPM's single photo-electron peaks

A pixel saturation effect
Electromagnetic shower in a hadron calorimeter is a useful tool:

- high density of energy losses  =>  to study the saturation effects and to validate calibrations
- EM shower develops completely in calorimeter volume  =>  to check reconstruction of energy and energy resolution
- well understood physics (~2% level of uncertainty )  =>  to validate MC digitization
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CALICE tile AHCAL prototype at CERN 2007 test beam facility

- 38 layers (30 with high granularity at central region)
- each layer has 2cm of absorber (steel) and 0.5cm of active scintillator layer
- length: 114.57 cm, hadronic: 5 $\lambda_0$, e/m: 43.7 $X_0$

Positron runs collected:
- Energy: 10 - 50 GeV
- Position of beam: 0, +6cm, -6cm
- Angles: 0,10,20,30 degrees

AHCAL prototype:

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the very first results from e+ data analysis..

- 4 data samples have been analyzed: large variations in the reconstructed energies expected to be consistent
- residual to linearity is about 4% at 40 GeV and 7% at 50 GeV – too big!
- large variations in the energy resolution curves is a hint to problems in the calibration procedure which can be improved

Further investigations are needed!
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..a lot of work was done to improve the energy reconstruction..

Improvement of calibration

Longitudinal energy profile of muons

- remove “bad” tiles
- new MIP calibration
- new saturation correction

improved profile is in agreement with expectations

+ temperature correction of SiPM response has been applied for all tiles
All corrections have been applied - improvement of linearity

Better consistency between data samples

Max. deviation from linearity of ~ 4%!

40 and 50 GeV still need more accurate analysis
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Improvement of energy resolution after all corrections have been applied

- removing “bad” tiles from analysis
- more accurate calibration
- temperature correction for SiPM

can really improve the data!

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Longitudinal profile study..

An electromagnetic shower's energy profile:

\[ \frac{dE}{dt} = p_1 \cdot t^{p_2} \cdot e^{-p_3 \cdot t} \]

where \( E \) – energy deposited, \( t \) – depth in calorimeter

The maximum depth of an e/m shower in calorimeter for e+(e-):

\[ t_{\text{max}} = \left[ \ln\left(\frac{E}{e_c}\right) - 0.5 \right] X_0 \]

\( E \) – particle energy
\( e_c \) – critical energy (\( \approx 33.6 \text{ MeV} \))

Calculated: \( t_{\text{max}} \approx 5.2 X_0 \)  
From data: \( t_{\text{max}} \approx 5.3 X_0 \)

Quite good agreement!

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Analysis of electromagnetic showers in CALICE AHCAL prototype data (all correction applied) (black) and fully digitized MC (red)

The idea is:
- study a “tower” of 3x3 tiles around the beam impact point
- compare the data and MC in:
  the central tile: high signal, big saturation
  the peripheral zone: low signal, small saturation
- study the calibration quality for single tiles

We can also study an individual tile response (we have a highly granular calorimeter!)

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data (before corrections) (black) and MC (red)

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data (all correction included) (black) and MC (red)

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Not a big effect.. as expected
An agreement is fine

Significantly better after applying the corrections!
Summary & Outlook

- Electromagnetic showers in Analog Hadron Calorimeter is a very good tool for validating the calibration procedure.

- An expected 2% level of uncertainties in reconstructed energies of positrons is achieved after an accurate and precision calibration and corrections.

- The linearity of the calorimeter response for positrons is less then 4% (residuals to the linear fits) in 10 – 50 GeV range.

- Monte Carlo study shows quite good agreement with a data in integral scale.
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Backup slides
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Deep Analysis - ON!
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Monte Carlo simulation..

CALICE Mokka based GEANT4 framework simulation:

- detailed CERN'2007 test beam setup geometry

- high granularity layers (1x1cm tiles) with “ganging” after the simulation to AHCAL prototype tile pattern (3x3, 6x6, 12x12 cm tiles)

- digitization (conversion energies to MIP, MIP to SiPM pixel, add the pixel statistics, add saturation, conversion back to ADC counts, x-talk (~10% per tile) included)

- all calibration and saturation are from testbeam condition DataBase!

- using the same processors of CALICE Marlin to analysis