Hadronic Energy Reconstruction in CALICE Calorimeter Prototypes

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Outline

• The CALICE test beam setup

• The Analog Hadron Calorimeter
  • Detector Layout
  • Calibration

• Energy Reconstruction & Shower Weighting
  • Reconstruction Technique
  • HCAL contained Showers
  • CALICE Combined Analysis

• Summary
The CALICE Program

- Extensive test beam campaign
  - DESY: 2006
  - FNAL: 2008, ...

- Wide variety of beam energies and particle species
  - 2 GeV to 80 GeV
  - muons, $e^\pm$, $\pi^\pm$, unseparated hadrons
CALICE Calorimeter Setup

- 40 GeV negative pions

Si-W ECAL
1x1 cm² lateral segmentation
30 layers, ~ 0.9 λ, 30 X₀
~ 10 k channels

Analog HCAL
3x3 - 12x12 cm² lateral segmentation
38 layers, ~ 4.5 λ
~ 8 k channels

Tail Catcher / Muon Tracker
5 x 100 cm² Scintillator Strips
16 layers
~ 300 channels
The CALICE Analog HCAL

• Iron absorber structure:
  • 38 layers
  • 2 cm total absorber thickness per layer (1.1 $X_0$, 0.12 $\lambda$)
  ▸ total $\sim$ 4.5 $\lambda$

• Active layers: Scintillator tiles
  • high granularity in the layer center:
    100 3x3 cm$^2$ tiles, then 6x6 cm$^2$ and 12 x12 cm$^2$
  • light collection via wls fiber, read out with SiPM
Analog HCAL: Calibration

- Auto-calibration of SiPM gain: Individual photons can be resolved
- Low-intensity LED light coupled into each detector cell
- High gain setting of front-end electronics
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- MIP-Calibration with Muons
  - Complete detector illuminated with high energy muons
  - Equalization of response of all cells by matching the MPV position
Energy Reconstruction

- Analog information available for each cell in each of the three detectors
  - Reconstructed energy is the sum of all cell energies, each with a suitable weight

- In total 6 different sampling structures in the calorimeter setup
  - 3 different W plate thicknesses in the ECAL: 1.4, 2.8 and 4.2 mm, 10 layers each
  - uniform sampling in the HCAL: 20 mm Fe absorber per layer
  - 2 different samplings in the TCMT: 19 mm Fe absorber for the first 8 layers, then 102 mm Fe absorber

Intercalibration factors including the conversion from the MIP to the GeV scale were determined with data using a minimization technique
- For the ECAL, these do not correspond to the ratio of absorber thickness (shower development is folded in!)
Shower Weighting

- In a non-compensating calorimeter (CALICE HCAL: $e/\pi \sim 1.2$):
  - fluctuations in the em fraction of the events deteriorates energy resolution
  - change of em fraction with energy leads to non-linear response

- Improved resolution by identification of the shower components

- Electromagnetic showers tend to be denser than purely hadronic ones:
  - clear correlation between reconstructed energy and energy in high density shower regions

- Apply weights to energy deposits according to the local energy density in the shower to correct for difference in detector response
Hadronic Energy Resolution: Optimization with Weighting

Simple approach: Weight calorimeter cells according to their energy content
- Apply higher weights to cells with low energy density

Technicalities:
- Subdivision into 10 energy density bins for HCAL (6 bins for TCMT and ECAL)
- Weights are determined with a minimization technique from data
- Weights are energy dependent!
- Parametrization used, no prior knowledge of beam energy necessary to apply weights
Resolution for Showers contained in HCAL

2 ways to reconstruct the energy:

- One conversion factor per detector, no density dependent weighting

- Density dependent weighting using an energy dependent parametrization of the weights, the weights are selected event by event using the first energy estimate obtained with one factor per detector: prior knowledge of beam energy not necessary!
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stochastic term w/o weighting: 62.4%, with parametrized weighting 48.8%
HCAL: Improvements in Linearity

- Density dependent weighting improves the linearity of the detector response!

- No temperature correction to data applied: significant spread from run to run at the same energy due to temperature variations
Expansion to the Full Setup

- Two reconstruction methods:
  - No weighting: one calibration factor (MIP to GeV) per subdetector (ECAL, HCAL, TCMT)
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Complete CALICE Setup: Resolution

• Expansion to the complete setup: ECAL, HCAL, TCMT
  • separate weights in each of the detectors

• Same technique as for HCAL
  only study
  • Significant improvement of resolution with weighting technique (~ 20%)
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stochastic term w/o weighting: 61.3%, with parametrized weighting 49.2%
Linearity of Energy Response: Combined Setup

- Energy reconstructed with single conversion factors and with parametrized density dependent weighting
- Noise rejection: Isolated noise hits (and isolated neutrons) rejected in the analysis

![Graph showing linearity of detector response](image)
Linearity of Energy Response: Combined Setup

- Energy reconstructed with single conversion factors and with parametrized density dependent weighting
- Noise rejection: Isolated noise hits (and isolated neutrons) rejected in the analysis
  - Weighting of cells according to their energy content improves linearity of the detector: better than 4% from 8 to 80 GeV
  - Cell-by-cell temperature correction not yet included: leads to a run-to-run spread at a given energy
Summary and Outlook

• CALICE tests imaging calorimeters for future high energy lepton colliders

• The high granularity can be used for software compensation:
  • First successful tests with weighting based on the energy of each cell:
    20% improvement in energy resolution, both for showers contained in the HCAL
    and for the complete CALICE setup

• Future steps:
  • Combination with clustering algorithms
  • Evaluation of neural networks