Hadronic Showers in a Highly Granular Imaging Calorimeter

Alexander Kaplan - University of Heidelberg
The AHCAL Prototype

- **CALICE**: calorimeters for precision measurements at future lepton collider, optimized for Particle Flow - aim is a jet energy resolution of:
  \[ \frac{\sigma_E}{E} \approx 3 \text{ – } 4\% \]

**Analogue Hadronic Calorimeter Prototype:**
- highly granular scintillator-steel sandwich
- 3x3 cm² cell size, 7608 Channels, SiPM readout
The Test Beam Program

Studies shown base on 2007 CERN data

2006 & 2007: $e^\pm$, $\mu$ and hadron beams 8-180 GeV acquired at CERN SPS H6 test beam

2008 & 2009: extending low energy range from 8 down to 1 GeV at FNAL MTBF

2010 & 2011: active AHCAL layers moved back to CERN: tungsten absorber
Monte Carlo Simulation

- **Simulation**: necessary for design of real detector, hadronic shower simulation still in development, **validation necessary**!
- **Mokka**: Geant 4 application able to simulate full ILD detector as well as test beam setup
- Geant 4 simulation is organized in **physics lists combining several physics models valid at different energy ranges**. Many physics list tested - here only four presented.
- All Events have been simulated with **Geant 4.9.3**. For simulations with the **experimental CHIPS** physics list the **patched version Geant 4.9.3.p01** was used.

### Physics Lists:

- **QGSP_BERT**
  - Models applied for $\pi$ at different energies:
  - BERT
  - LEP
  - QGSP

- **FTF_BIC**
  - Models applied at different energies:
  - BIC
  - FTF

- **LHEP**
  - Models applied for $\pi$ at different energies:
  - LEP
  - HEP

- **CHIPS**
  - Models applied for $\pi$ at different energies:
  - CHIPS (patched version Geant 4.9.3.p01)
First thing to look at to validate calibration and simulations: **Calorimeter Response**

For **QGSP_BERT**, **FTF_BIC** and **LHEP** the transition between models is visible.

**CHIPS** looks promising - **no transition and no energy dependence.**

Overestimation of deposited energy is expected due to incorrect simulation of low energy neutrons.

Energy points presented:

**Energy Scale**

- **systematics**
- **data**
- **FTF_BIC**
- **QGSP_BERT**
- **CHIPS**
- **LHEP**

---

B.Lutz, Ph.D. Thesis

CALICE preliminary

\[
E_{\text{MC}} / E_{\text{data}}
\]

\[
E_{\text{MC}}
\]

\[
E_{\text{data}}
\]
First hadronic Interaction

- High granularity allows to find position of first hadronic interaction
- Primary Track Finder by M.Chadeeva: agreement of +/-1 layer for 74% of all events
- Allows shower profiles relative to first interaction point
Nuclear Interaction length

Distribution of first interaction point: exponential behavior
Fitting an exponential (binned-likelihood) allows to extract interaction length for pions
This is a test of the cross sections implemented in Geant4
FTF_BIC agrees with DATA, for QGSP_BERT transition region is visible - agreement above 20 GeV
LHEP & CHIPS have both different lambda (expected due to different cross sections)
Longitudinal profiles

- Profiles relative to first hard interaction point
- Simulation allows to disentangle deposited energy into contributions by electrons, positrons, protons and mesons
Mean Shower Depth

\[ \langle z \rangle = \frac{\sum_i z_i E_i}{\sum_i E_i} \]

- Fritiof and QGS models predict too small shower depth
- CHIPS shower center of gravity deeper than in data
Mean Shower Radius

\[
\langle r \rangle = \frac{\sum_i r_i E_i}{\sum E_i}
\]

- All models predict too small mean shower radius
- CHIPS model fits best to data
Track segments

- **Track multiplicity** influenced by shower topology: **number of secondaries created**
- Number of tracks provided by LHEP & QGS_BIC is far too low
- Other lists quite close to each other, from which QGSP is closest to data, FTF_BIC furthest away
Pandora PFA Performance

- Use Pandora PFA with test beam data mapped to ILD geometry
- Overlay two pion showers, assume one to be neutral and the other to be charged
- Investigate PFA performance varying the distance and energy of the two showers

Energy: 10 GeV neutral, 10 GeV charged

Oleg Markin, ITEP Moscow
Pandora PFA Performance

- Use Pandora PFA with test beam data mapped to ILD geometry
- Overlay two pion showers, assume one to be neutral and the other to be charged
- Investigate PFA performance varying the distance and energy of the two showers

Energy: 10 GeV neutral, 30 GeV charged

Oleg Markin, ITEP Moscow

Energy: 10 GeV neutral, 30 GeV charged
Pandora PFA Performance

- Use Pandora PFA with test beam data mapped to ILD geometry
- Overlay two pion showers, assume one to be neutral and the other to be charged
- Investigate PFA performance varying the distance and energy of the two showers

Oleg Markin, ITEP Moscow
Outlook: EM Fraction

- **EM component** = Energy from $\pi^0$ and $\eta$ decaying into $\gamma$ → available in MC
- **Simulations show different EM fraction** → validation against DATA interesting
- **Deep Analysis**: clustering algorithm initially developed by V. Morgunov can be tuned to find EM-like clustering → would be also applicable for DATA
- **Not ready yet**: cluster identification still energy and physics lists dependent has to be improved further.
Summary

• The CALICE collaboration built a **highly granular analogue hadron calorimeter**

• It allows **precise measurements of hadron showers** as well as **validation of MC models** on a very precise level

• **Imaging calorimeter:**
  - measure track multiplicity
  - determine first interaction point
  - PFA validation with test beam data
  - possibly measure EM component in data (in progress)

• **Conclusion on physics lists:**
  - LHEP: outdated, shown for reference since it is still used as stop gap
  - String + Cascade models: give reasonable description, but room for improvement
  - CHIPS model: promising, but still experimental - patched version 4.9.3.p01 tested
ADDITIONAL SLIDES
Resolution without any compensation: $\approx 52\% / \sqrt{(E)}$

High granularity allows software compensation approach - several methods studied

Basic idea is, that **EM-components of shower are denser**
→ use an event-wise weighting of hits to energy density
→ typically achieve a relative improvement of 10-20%

Geant4 physics lists model this reasonable well, but not perfectly