Dealing with Longitudinally Segmented Calorimeters (and some other ideas)

Olga Lobban, Texas Tech University
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Longitudinally Segmented Calorimeter Calorimeter which is divided into parts along the direction of incoming particles. Typically, calorimeters have two longitudinal sections, the electromagnetic and the hadronic section. As seen by incoming particles, the electromagnetic section is in front of the hadronic section.

Longitudinally Segmented Calorimeters: Why?

- The calorimeter properties needed to optimize the response and resolution of a calorimeter are **different for electromagnetic and hadronic showers**.
  - Electromagnetic showers require:
    - **large sampling fraction**
    - **large sampling frequency**
    - **small lateral granularity**
  - Hadronic showers require:
    - **small sampling fraction**
    - **large lateral granularity is acceptable**
- **Particle identification:**
  - Electrons usually deposit most of their energy in the electromagnetic section, whereas pions deposit energy in both the electromagnetic and hadronic sections.
  - Discriminate between electrons (photons) and hadrons by using the ratio of signal in the hadronic section with the signal in the electromagnetic section.

Problems with a Longitudinally Segmented Calorimeter

CALIBRATING IT!!!

Calibrating it?

- **Determining the overall energy scale (the constants which convert ADC counts to GeV) for each section of the calorimeter.**

- Electrons deposit all of their energy in the electromagnetic section of the calorimeter, determining the energy scale, A, for the electromagnetic section is easy:
  - Use a testbeam of electrons sent into the electromagnetic section.

$$\mathbf{A} = \frac{\textbf{signal from em section}}{\textbf{energy deposited in em section}}$$

- Pions deposit their energy in **BOTH** sections of the calorimeter $\rightarrow$ determining the calibration constant for the hadronic section is **NOT** trivial

Plug Upgrade Calorimeter at CDF

- The Plug Upgrade Calorimeter consists of two longitudinal segments, an **electromagnetic section** and a **hadronic section**, each with a different composition.

- **Electromagnetic section**
  - Pb/scintillator sampling calorimeter
  - $\sim 1\lambda_0$ in depth.

- **Hadronic section**
  - Fe/scintillator sampling calorimeter
  - $\sim 7\lambda_0$ in depth.

- The Plug Calorimeter is a noncompensating calorimeter.
  - em section: $e/h = 1.43$
  - had section: $e/h = 1.36$

- We developed a method to calibrate the hadronic section which avoids some pitfalls of a commonly used method.

"mip" Method

- Send a beam of pions into the electromagnetic section of the calorimeter (with the hadronic section directly behind the electromagnetic section).
- Choose pions which are "mip-like" in the electromagnetic section.
- With that specific set of pions, the energy scale, B for the hadronic section is,

$$\mathbf{B} = \frac{\textbf{signal from had section}}{\textbf{energy deposited in had section}}$$

- Reconstructed energy,

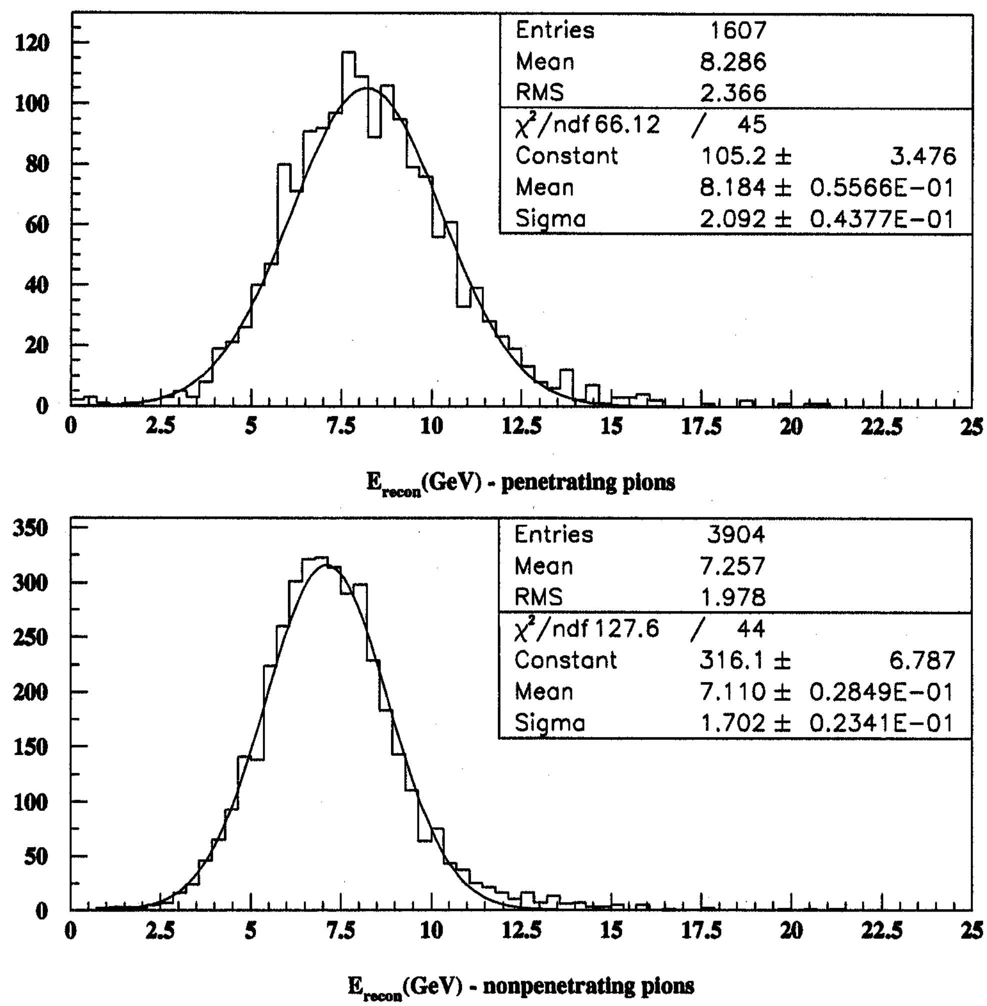
$$\mathbf{E}_{\text{recon}} = \frac{\textbf{em signal}}{\mathbf{A}} + \frac{\textbf{had signal}}{\mathbf{B}}$$

Consequences of "mip" Method

- **The reconstructed energy of pions depends on the starting point of pion showers.**
  - The Plug is **noncompensating. Its response to hadronic energy deposition is smaller than its response to electromagnetic energy deposition.**
  - If penetrating pions are used to set the energy scale for the hadronic section, then it is only for this particular sample of pions that the energy will be reconstructed correctly.
  - Most pions begin showering in the em section of the calorimeter (the energy scale of the electromagnetic section is determined with electrons.)
  - The "mip" method gives a larger weight to the signal in the had section, compared to the signal in the em section.
  - Pions which begin showering in the em section do not "fully benefit" from the boosting of the hadronic section's signal.

Consequences of “mip” Method

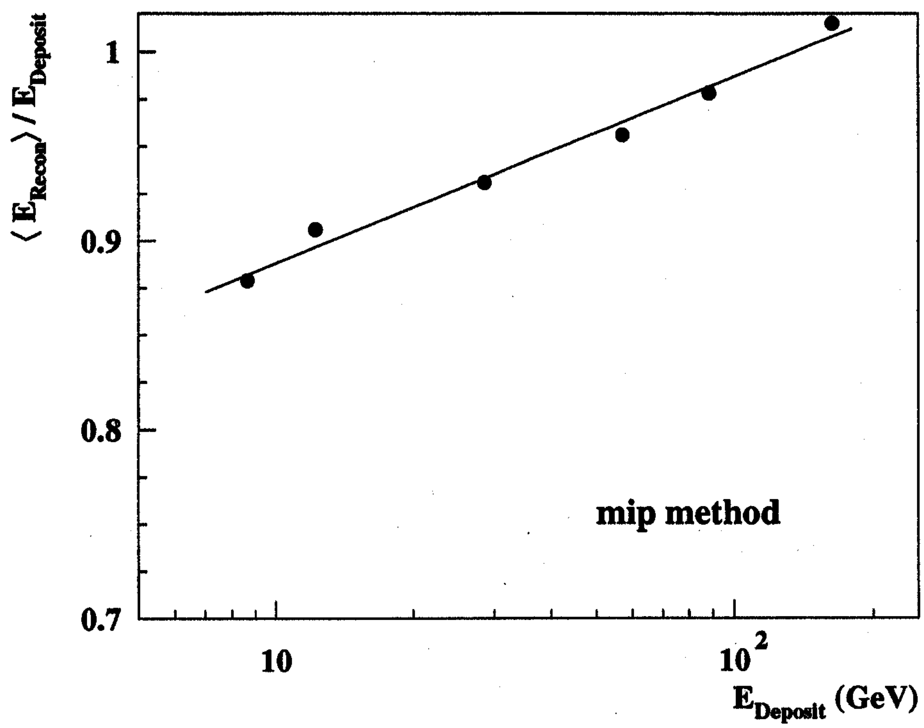
- Pions which start showering in the electromagnetic section will be reconstructed with an energy smaller than the actual energy deposited in the calorimeter.



Consequences of "mip" Method

- **An artificial increase in pion signal nonlinearity.**
  - For hadron showers, the fraction of electromagnetic energy from the π_0 content of the shower increases as a function of energy.
  - This rising f_{em} causes an intrinsic nonlinearity in all noncompensating calorimeters (they respond differently to electromagnetic energy than they do to hadronic energy).
  - With the "mip" method, one sees a **larger** nonlinearity than the intrinsic nonlinearity of the calorimeter.
  - The "mip" method boosts the signal from the hadronic section with respect to the signal from the electromagnetic section.
  - As the energy of the pion shower increases,an increasing fraction of the energy (which is boosted by the "mip" method) is deposited in the hadronic section of the calorimeter.

Consequences of "mip" Method



"mip = non-mip" Method

- Send a beam of pions into the electromagnetic section of the calorimeter (with the hadronic section directly behind it).

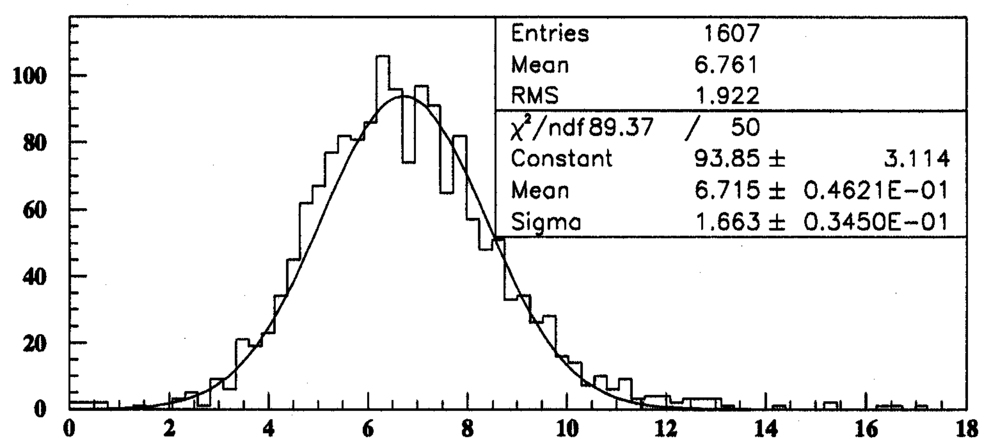
- **Choose the energy scale of the hadronic section such that the reconstructed energy for penetrating and nonpenetrating pions is equal.**

- By using the "mip=non-mip" method, one can avoid the (undesirable) consequences of the "mip" method.

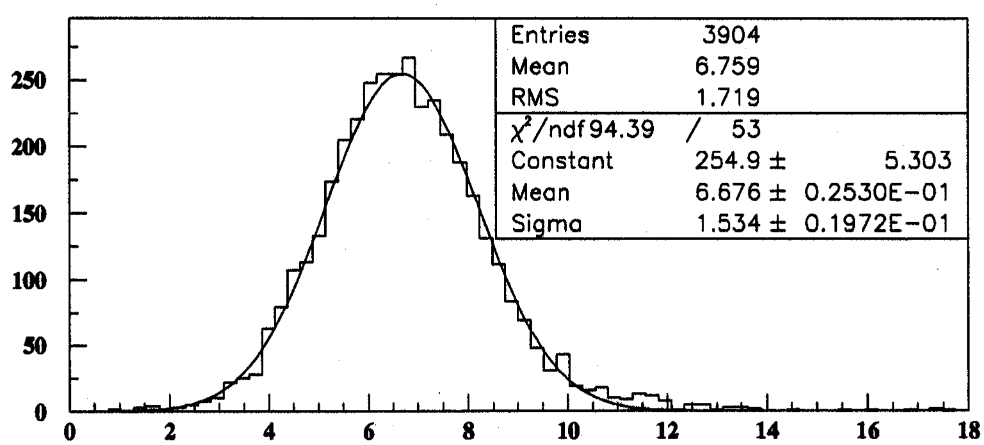
$$E_{recon} = \frac{\text{em signal}}{A} + \frac{\text{had signal}}{B}$$

"mip = non-mip" Method

- The energy scale of the hadronic section for the "mip=non-mip" method was chosen **such that** the difference between the reconstructed energy of early and late (miplike in the em section) showering pions was eliminated.



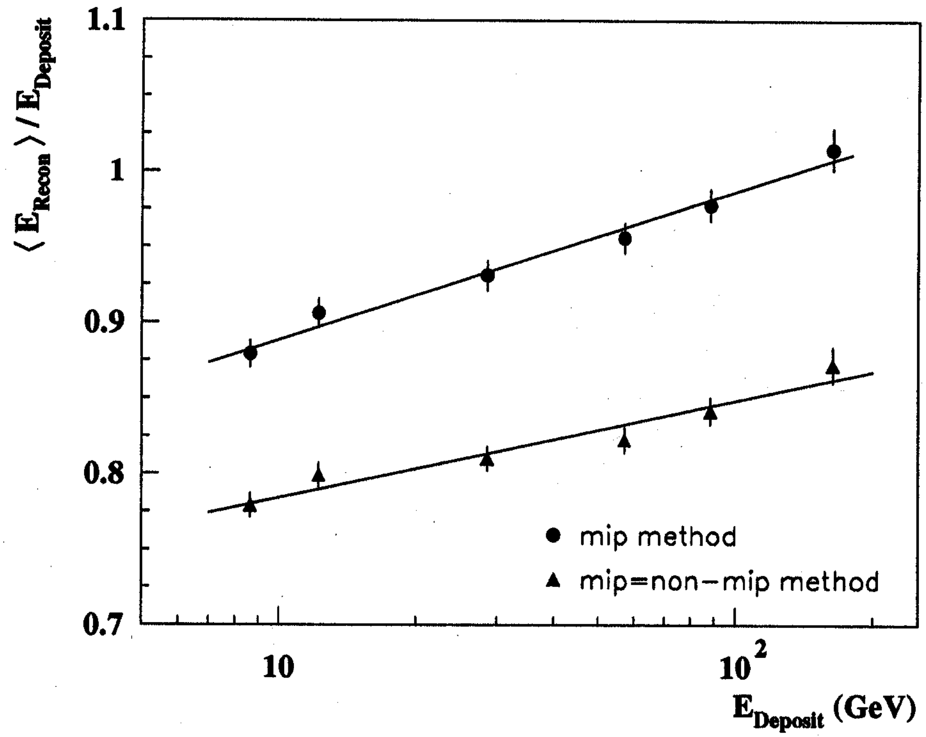
E_{recon}(GeV) - penetrating pions



E_{recon}(GeV) - nonpenetrating pions

"mip = non-mip" Method

- By using the "mip=non-mip" method, the nonlinearity of the calorimeter's response to pions is less severe.
- The slope of the line for the "mip" method is 30% larger than the slope of the line for the "mip=non-mip" method.



Final Energy Reconstruction

- Regardless of which method is used to set the energy scale of the hadronic section, the value of the reconstructed energy does not equal the value of the deposited energy.

- An energy dependent correction must be applied (in an iterative way). The energy dependent correction factor is simply the inverse of the $\langle E_{\text{recon}} \rangle / E_{\text{deposit}}$ curves.

- The curves are fit with a function of the form

$$E_{\text{deposit}} / \langle E_{\text{recon}} \rangle = p_1 + p_2 \ln E_{\text{deposit}}$$

- In order to reconstruct the final pion energy, simply perform the iteration

$$E_{n+1} = (p_1 + p_2 \ln E_n) \cdot \langle E_{\underset{1}{\text{[redacted]}}} \rangle$$

  where $E_1 = \langle E_{\text{recon}} \rangle$

- If this procecure is applied to a sample of pions which includes early and late showering pions in the same ratio as was the case for the sample of pions used to make the correction factor curves, then this procedure works for both methods.

Final Energy Reconstruction

- If one applies this procedure to a sample of pions which includes early and late showering pions in a **different** ratio than the sample used to make the correction factor curves, then this procedure **only** yields the correct energies for the "mip=non-mip" method.

E_{deposit}	E_{final} - "mip=non-mip"	
	penetrating	nonpenetrating
8.6	8.7±0.1	8.6±0.1
12.2	12.3±0.1	12.3±0.1

E_{deposit}	E_{final} - "mip"	
	penetrating	nonpenetrating
8.6	9.3±0.1	8.2±0.1
12.2	13.2±0.1	11.9±0.1

What is important for the experiment?

- With traditional techniques:
  - If it is important to optimize electromagnetic resolution, then a **large sampling fraction** is required.
  - If it is important to optimize hadronic resolution, then a **small sampling fraction** is required.
- **These two goals exactly conflict with each other!**
- In the past, the electromagnetic energy resolution has generally been given priority.
- If an electromagnetic calorimeter has a high sampling fraction, and thus a large e/h value, then it makes sense to build a hadronic calorimeter with a similarly large e/h value.

If hadronic response and resolution is a priority...

- One should choose a **compensating** and **longitudinally unsegmented** calorimeter.
  - It should be compensating in order to eliminate fluctuations in the electromagnetic component of hadron showers (also important for jets)
  - It should be unsegmented because calibrating longitudinal segments is a **tricky business.**

If hadronic response and resolution is a priority...

...here's why the calorimeter does NOT have to be segmented.

- The traditional reasons for segmenting a calorimeter
  - **particle id**
  - **separately optimize electromagnetic and hadronic response**
- There are several ways to perform **particle identification** (electron/hadron separation) without longitudinal segmentation.
  - **Time structure** of signals. Electron signals are faster than hadronic signals.
  - Differences in the **lateral profiles** of electromagnetic and hadronic showers. Electrons have very different lateral profiles than hadrons.
  - A **thin preshower detector** upstream of the calorimeter.

If hadronic response and resolution is a priority...

- **Separately optimizing each section.**
  - Optimizing both the electromagnetic and hadronic response will result in a poor hadronic performance.

why?

  - The performance of the hadronic section of the calorimeter depends strongly on the e/h value of the electromagnetic section.
  - Optimizing the electromagnetic section's performance implies a large e/h value.
  - Putting an electromagnetic section with a large e/h value in front of a hadronic section, has severe consequences for the hadronic response.
- Essentially, if you want excellent electromagnetic performance **AND** excellent hadronic performance, it cannot be done with current technology...

UNLESS WE EXPLORE...

A Very Nifty Idea: Dual Readout Calorimetry

- Equip a calorimeter with **scintillating fibers** and **quartz fibers**.
- **Quartz fibers**
  - Relativistic charged particles produce Cerenkov light in the quartz fibers.
  - For all practical purposes, the quartz fibers see only the em component of hadronic showers ($e/h = 5$).
- **Scintillating fibers**
  - produce light for every charged particle that crosses them.
- From the **Scintillating fibers**, we measure how much energy was deposited in the calorimeter.
- From the **Quartz fibers**, we measure what fraction of the energy deposited came from the π_0 component of the shower.
- The signal from the quartz fibers would provide a way to **event by event** determine the em fraction, f_{em}, of hadronic showers.

Have Your Cake and Eat it, Too!!!

With dual readout calorimetry,

- Achieve essential advantages of compensation.
  - Eliminate dominating source of fluctuations in non-compensating calorimeter (fluctuations in f_{em}).
  - Eliminate signal nonlinearity.

- With this technique, the sampling fraction could be as large as needed for optimizing the calorimeter's resolution for electromagnetic showers, and the hadronic resolution **WOULD NOT** suffer!