# A Simulation Study of the Totally Active Dual Readout (CCAL02) Detector

Final Presentation

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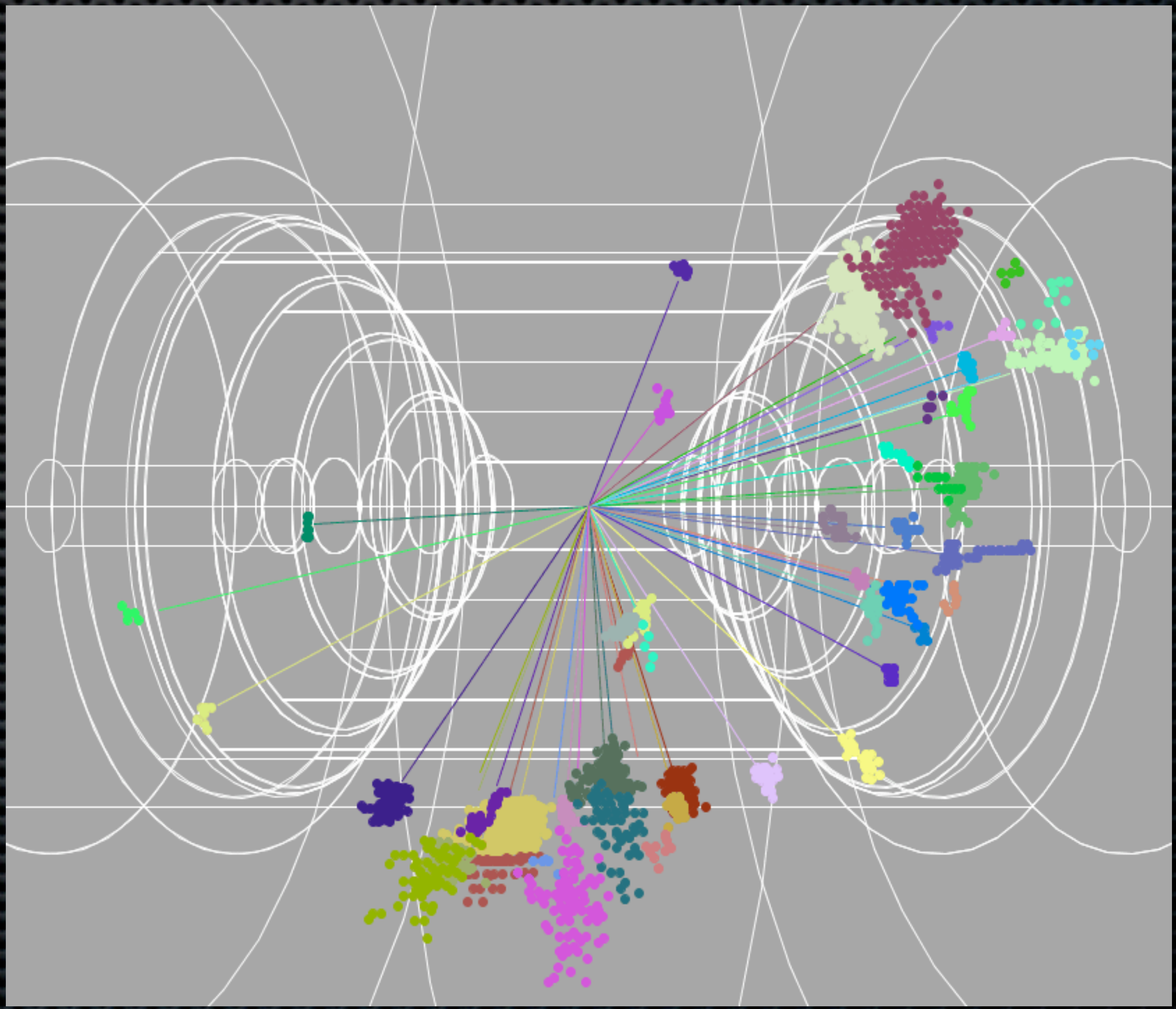
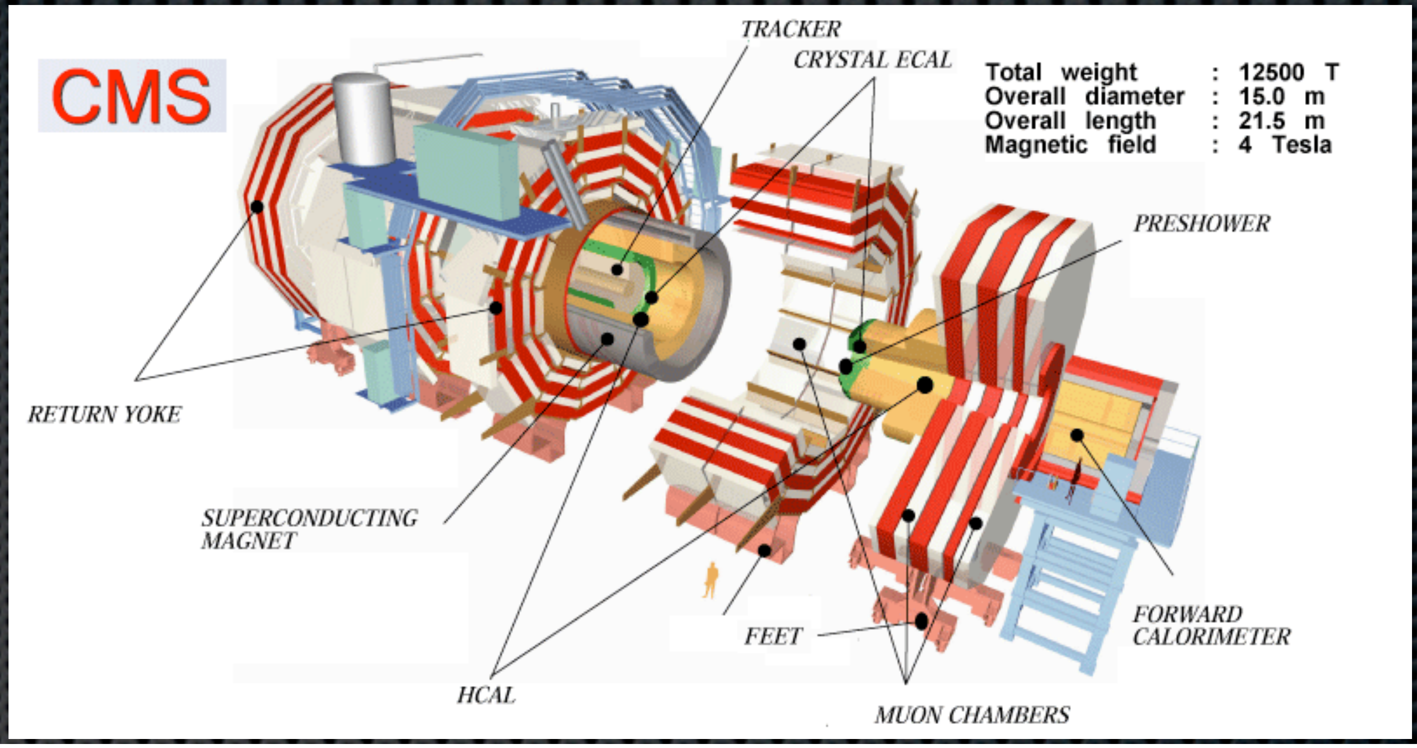


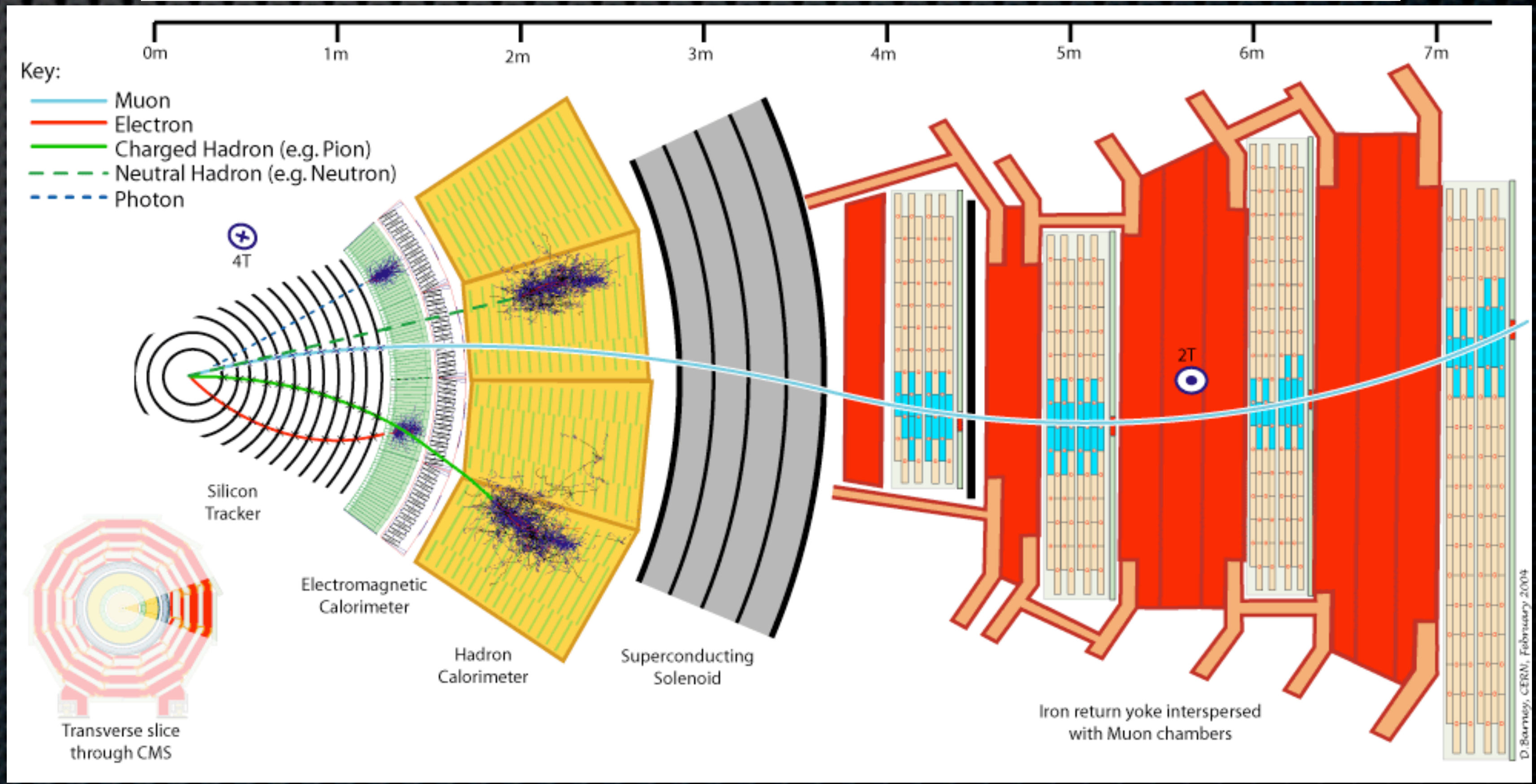
# Why do we need the Dual Readout Calorimeter??

- Dual Readout calorimeter will be a high precision calorimeter.
- Future colliders such as the International Linear Collider (ILC) will require very precise energy measurements.
- One reason for this is to distinguish WW and ZZ production from e+ e- collisions.
- To do this detectors must be able to measure jet energy about a factor of two better than the best achieved so far.
- The jet energy resolution must be roughly 5GeV for 100-150GeV jets.

# Brief overview of the physics and functionality of particle detectors.




- Calorimeters are instruments used to measure energy deposition of traversing particles.
- Electromagnetic Calorimeter
  - Electromagnetic showers
- Hadron Calorimeter
  - Hadron showers

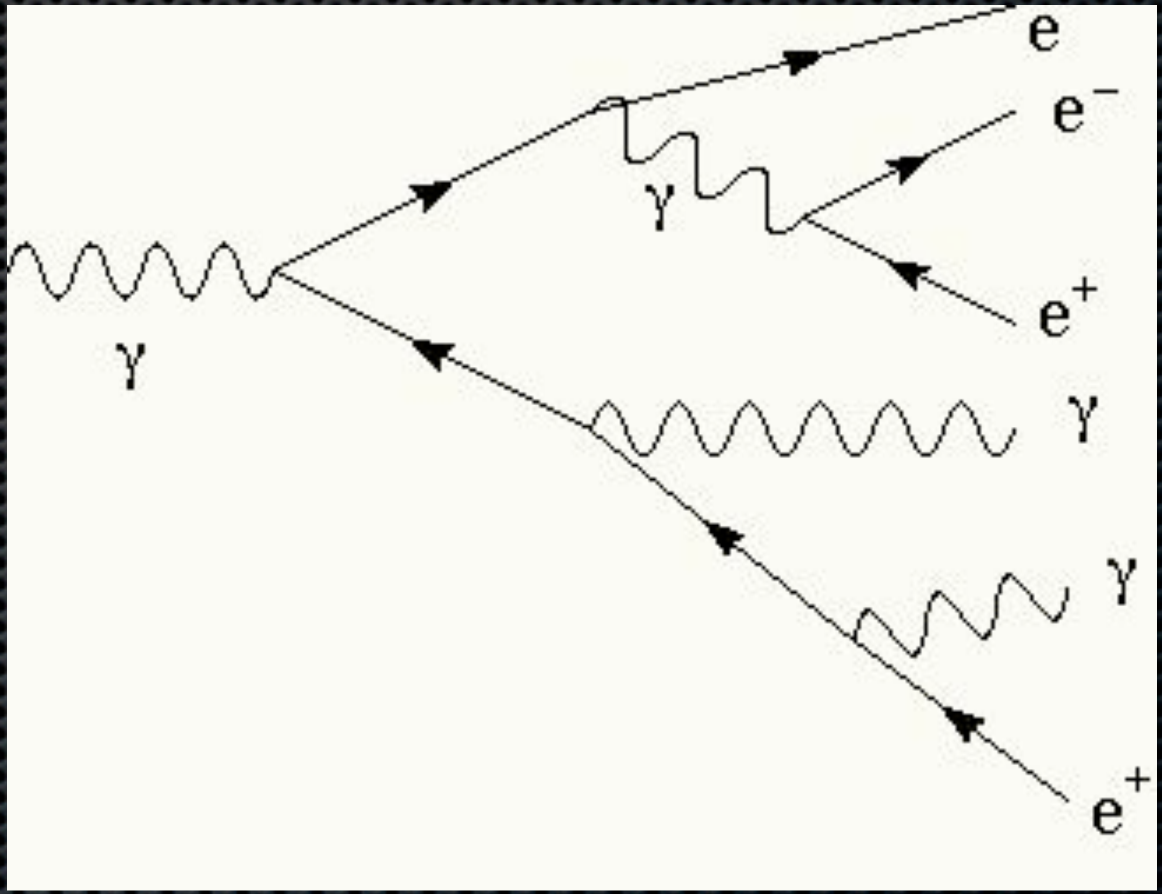


# Electromagnetic Showers

Happens when an electron, positron or photon with high enough energy enters a medium.

## Two main processes

- Pair Production (energetic photon producing electron-positron pair)
- Bremsstrahlung radiation (photon emitted from a deflected positron or electron.)




EM showers are characterized by their radiation lengths X0

In the end, we measure SCINTILLATION light. This is a precise measure of the energy deposited by the EM shower.

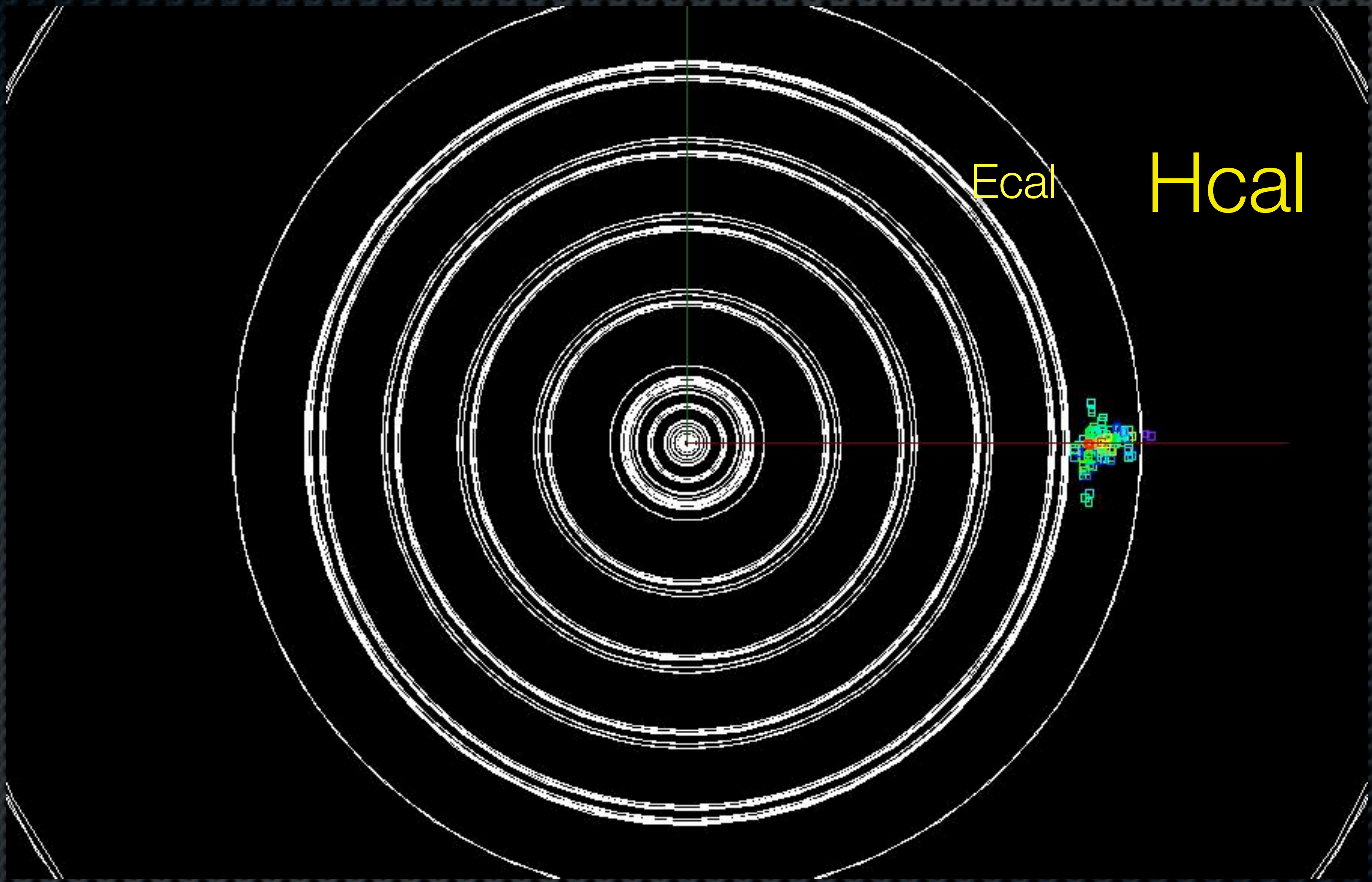
# Hadron Showers

Occurs when an energetic hadron like a pion, nucleon or atomic nuclei enters a medium. Like Electromagnetic showers but much more complicated.

- Involves dozens of different processes... many of which involve nuclear interactions. Characterized by interaction length $l_0$.
- Some of these nuclear interactions are invisible to the calorimeter. This makes energy measurement for hadrons very difficult.
- As a result Hadron Calorimeters have much worse energy resolution than Electromagnetic calorimeters.
- Other contributing factor: leakage (large interaction length)

Simulated examples of different types of showers

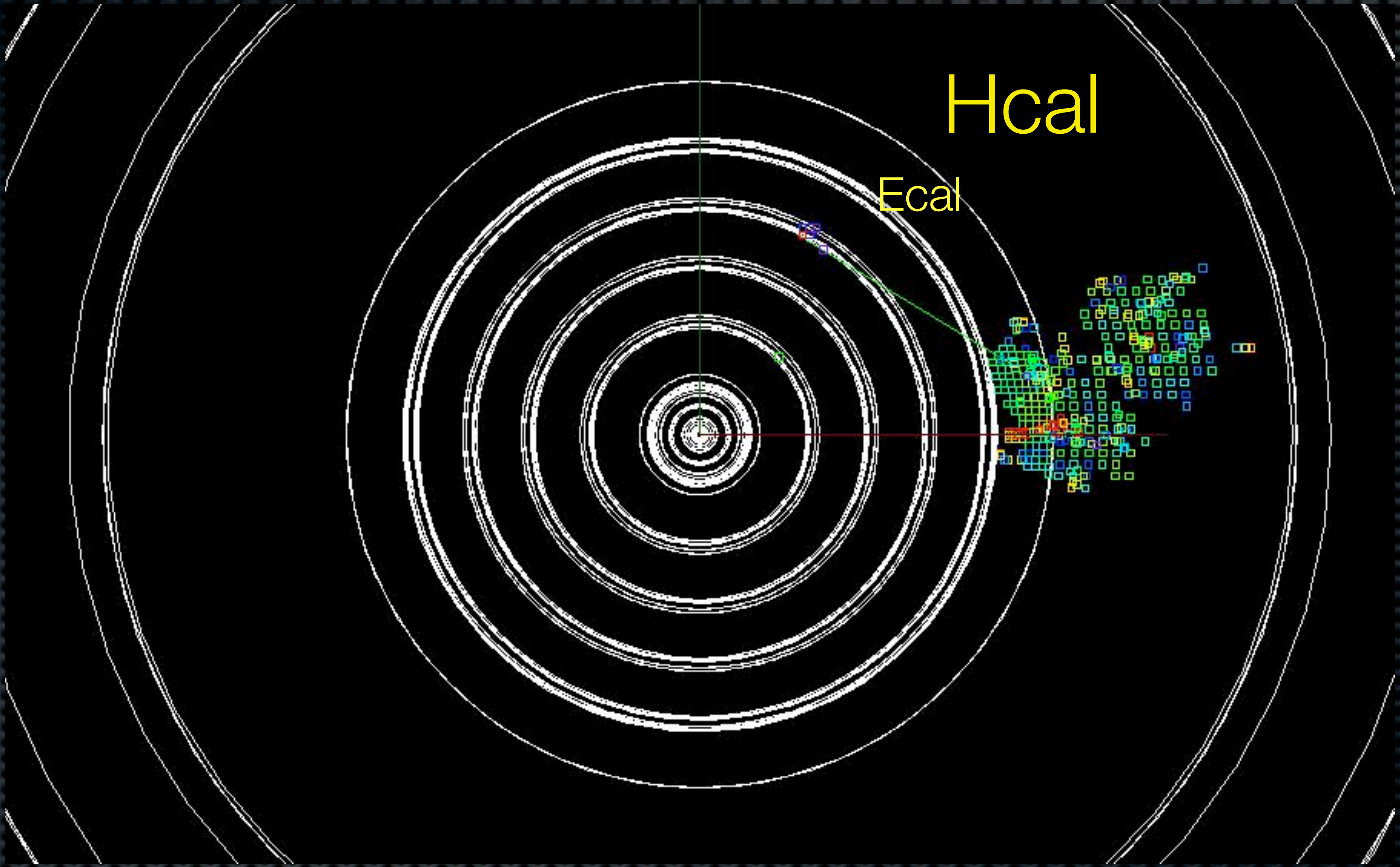
## EM Shower: 1 GeV Electron




Energy deposition well-defined and usually contained within calorimeter

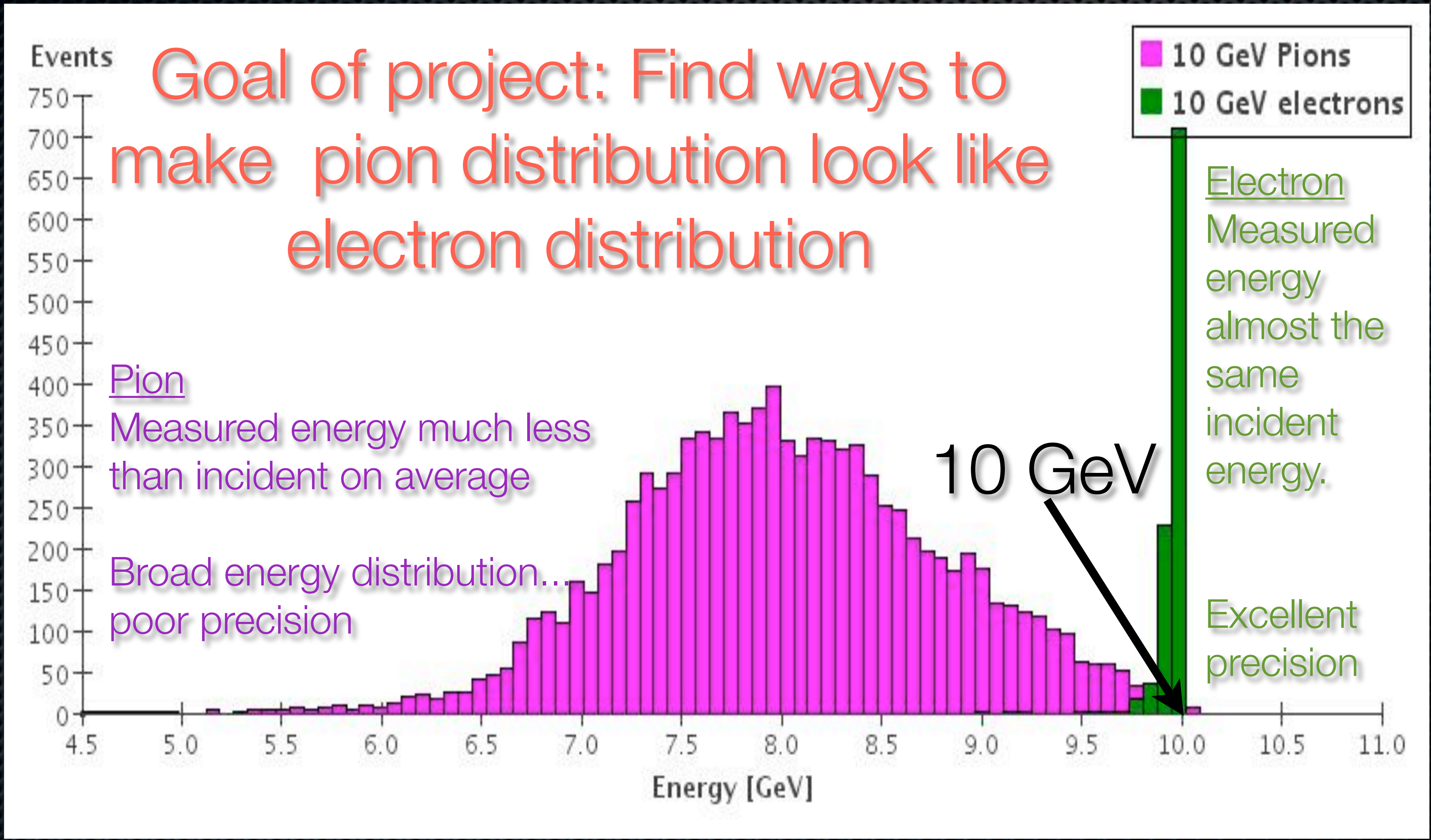
Simulated examples of different types of showers

## Hadron Shower: 1 GeV Pion




Energy deposition is very diffuse and not always contained within detector.

# Comparison of Energy deposited by EM shower and Hadronic Shower for 10 GeV electrons and 10 GeV Pions



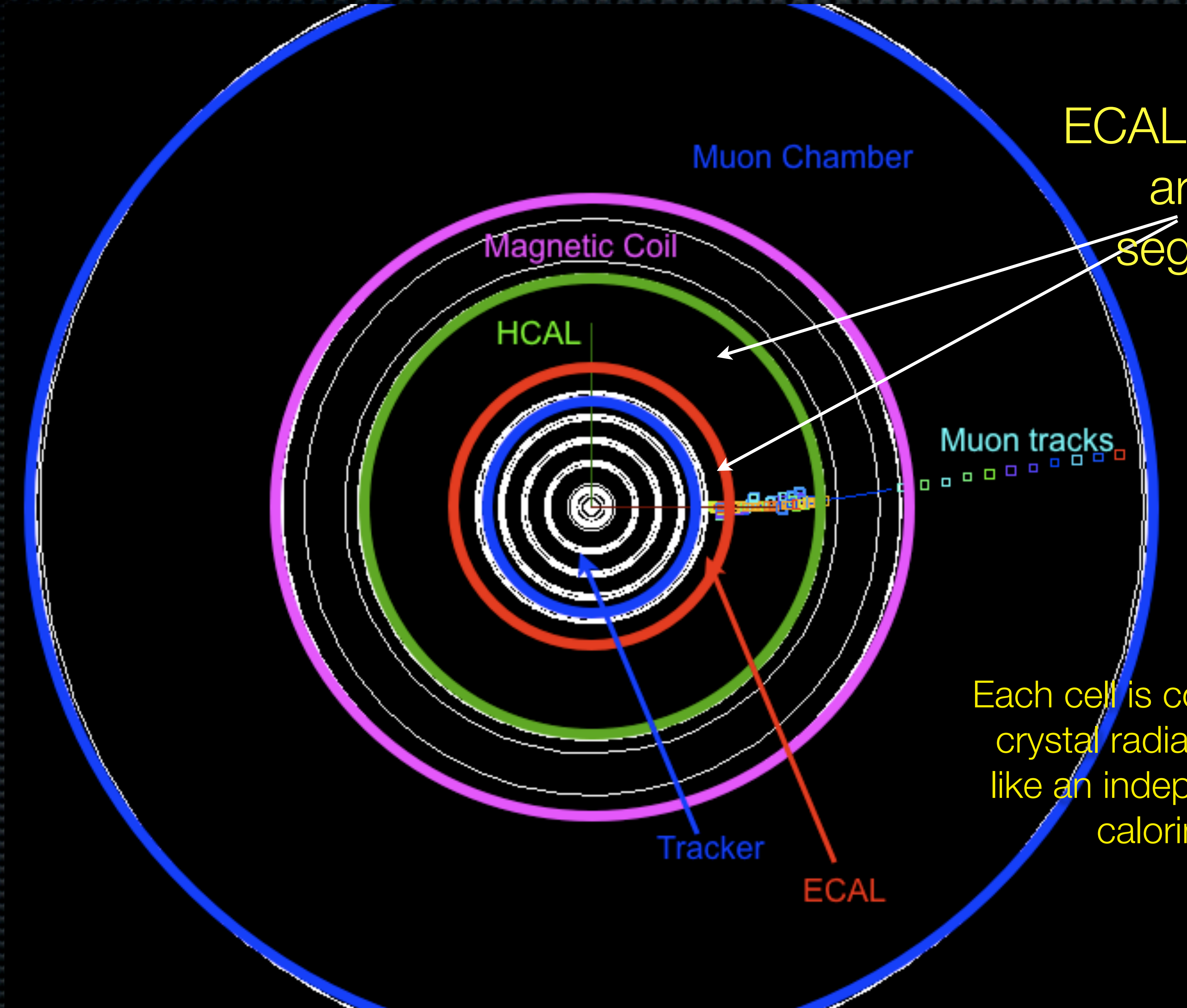
# Principle behind the Dual Readout Calorimeter

- Dual readout refers to the calorimeter's to read out both Scintillation light and Cerenkov light.
  - Cerenkov light is emitted when a charged particle is traveling through a medium faster than the speed of light in that medium.
  - What charged particles? Very likely e- and e+ from EM shower.
  - Cerenkov light is a precise measure of the electromagnetic portion of a particle shower.
- Using both readouts its is possible to account for the energy lost to nuclear interactions in the case of hadronic showers. (will show this)

# Simulation environment

- Simulation was done using an extended version of the American Linear Collider Physics Group (ALCPG) software suite.
- ALCPG suite consists of
  - Simulator for the Linear Collider (SLIC). Built on Geant4 and simulates the passage of particles through matter. Uses various physics lists to define physical processes.
  - lcsim.org package. Used for reconstruction and analysis.
  - Java Analysis Studio (JAS3). General purpose analysis software built entirely on the a java platform

# Cross-sectional Diagram of CCAL02 detector




ECAL and HCAL are finely segmented.

Each cell is composed of a crystal radiator and acts like an independent sub-calorimeter.

# Detector dimensions

TABLE I. Table showing detector configuration.

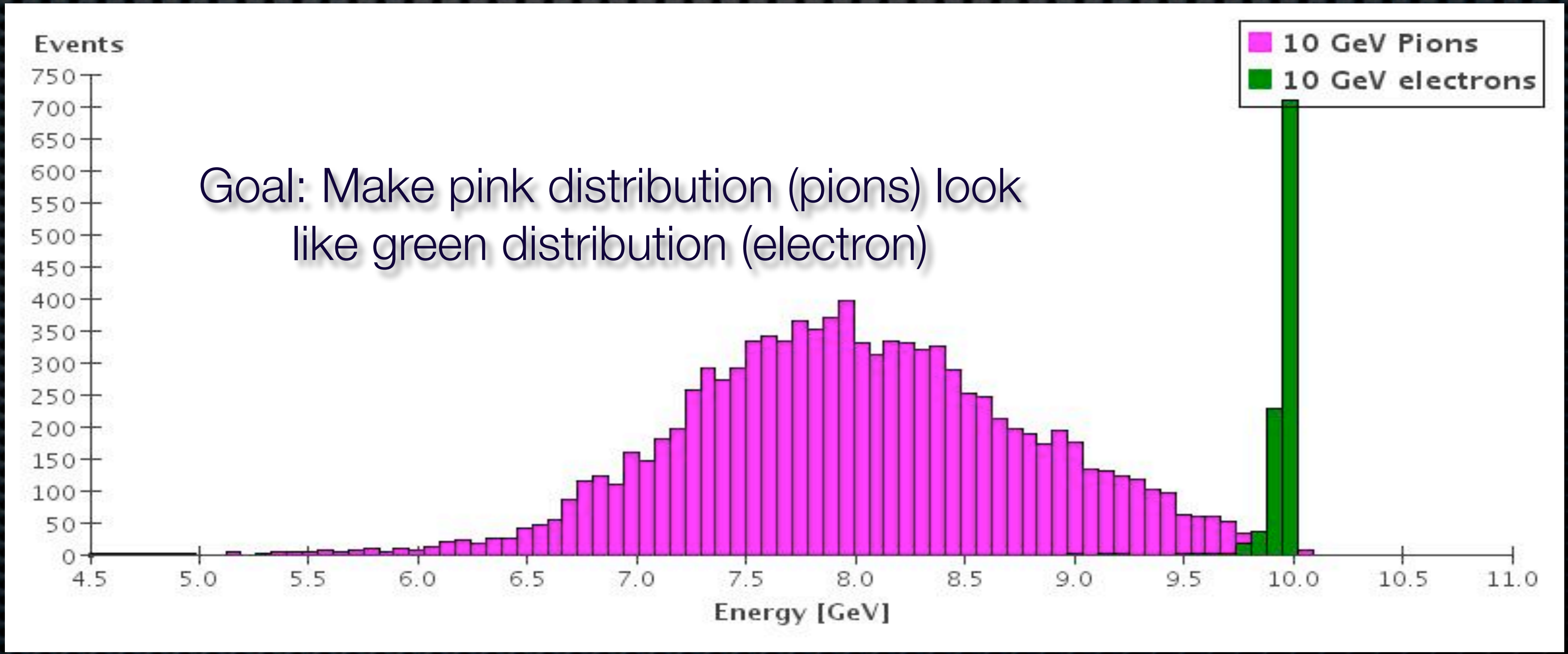
| *Name* | *layers* | *Length* (cm) | *Depth* (cm) | *Seg.* (cm) |
|---|---|---|---|---|
| Ecal Barrel | 8 | 3 | 24 | 3 x 3 |
| Hcal Barrel | 17 | 6 | 102 | 5 x 5 |
| Total Barrel | 25 | | 126 | |
| Ecal Endcap | 8 | 3 | 24 | 3 x 3 |
| Hcal Endcap | 17 | 6 | 102 | 5 x 5 |
| Total Endcap | 25 | | 126 | |

TABLE II. Table showing material properties of calorimeter crystals.

| *Material* | *Density* ($g/cm^3$) | *Rad.Length* (cm) | *IALength* (cm) |
|---|---|---|---|
| *BGO* | 7.13 | 1.12 | 21.88 |
| $PBWO_4$ | 8.3 | 0.9 | 18 |

# Dual Readout Correction Process

1. Getting scale factors by electron calibration.
2. Obtaining dual readout correction function for pions.
3. Applying correction function to pion energy response.

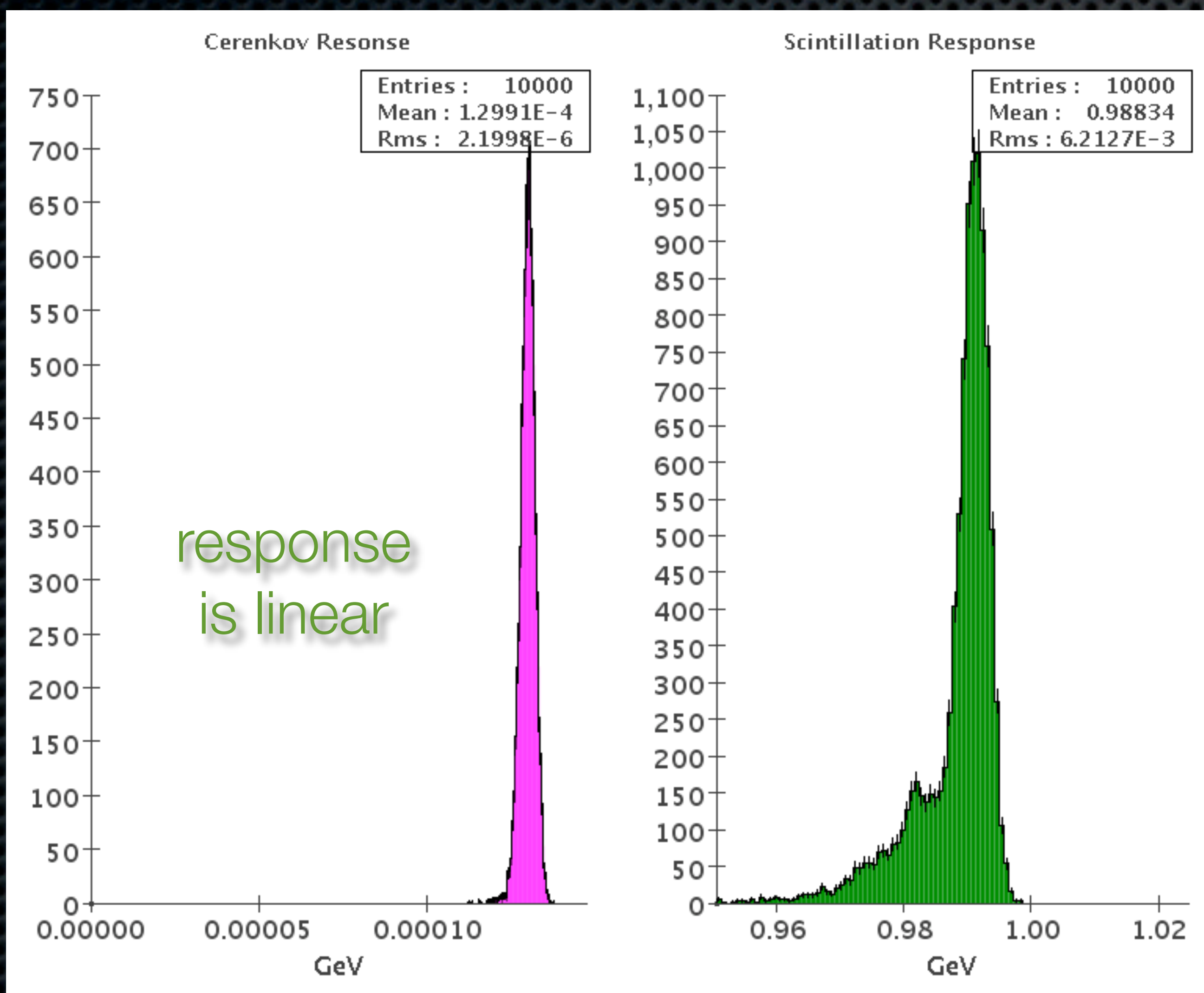


# Dual Readout Correction Process

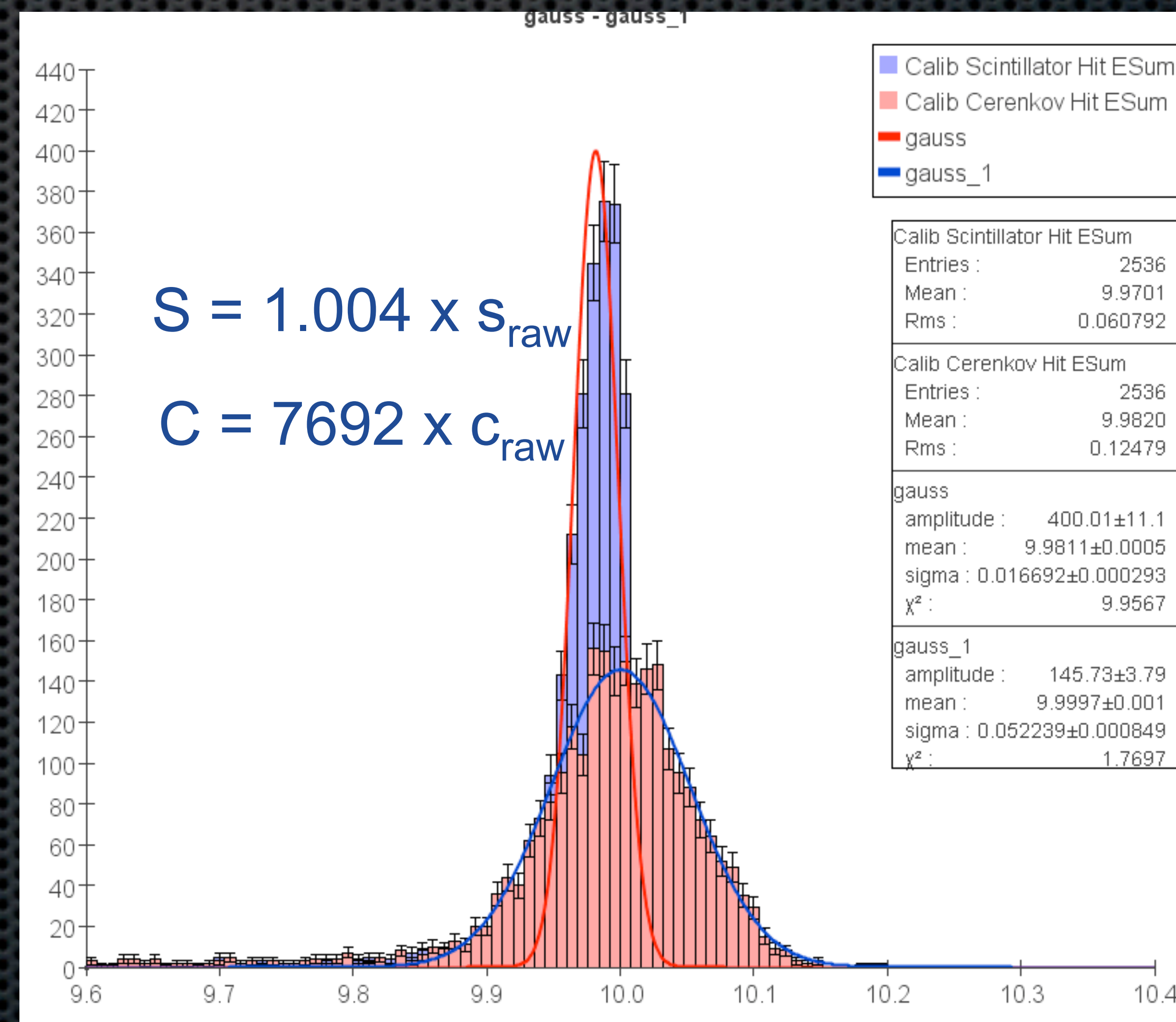
## 1. Electron Calibration

Cerenkov light is a <u>precise</u> measure of the EM shower!

Plot showing the Cerenkov response and scintillation response for 1 GeV electron simulated for 10000 events




Plot shows the scaled Scintillation response overlaid with the scaled Cerenkov response for 10 GeV.




Note difference in x-scale

$C_{mean} = 9.97$ GeV

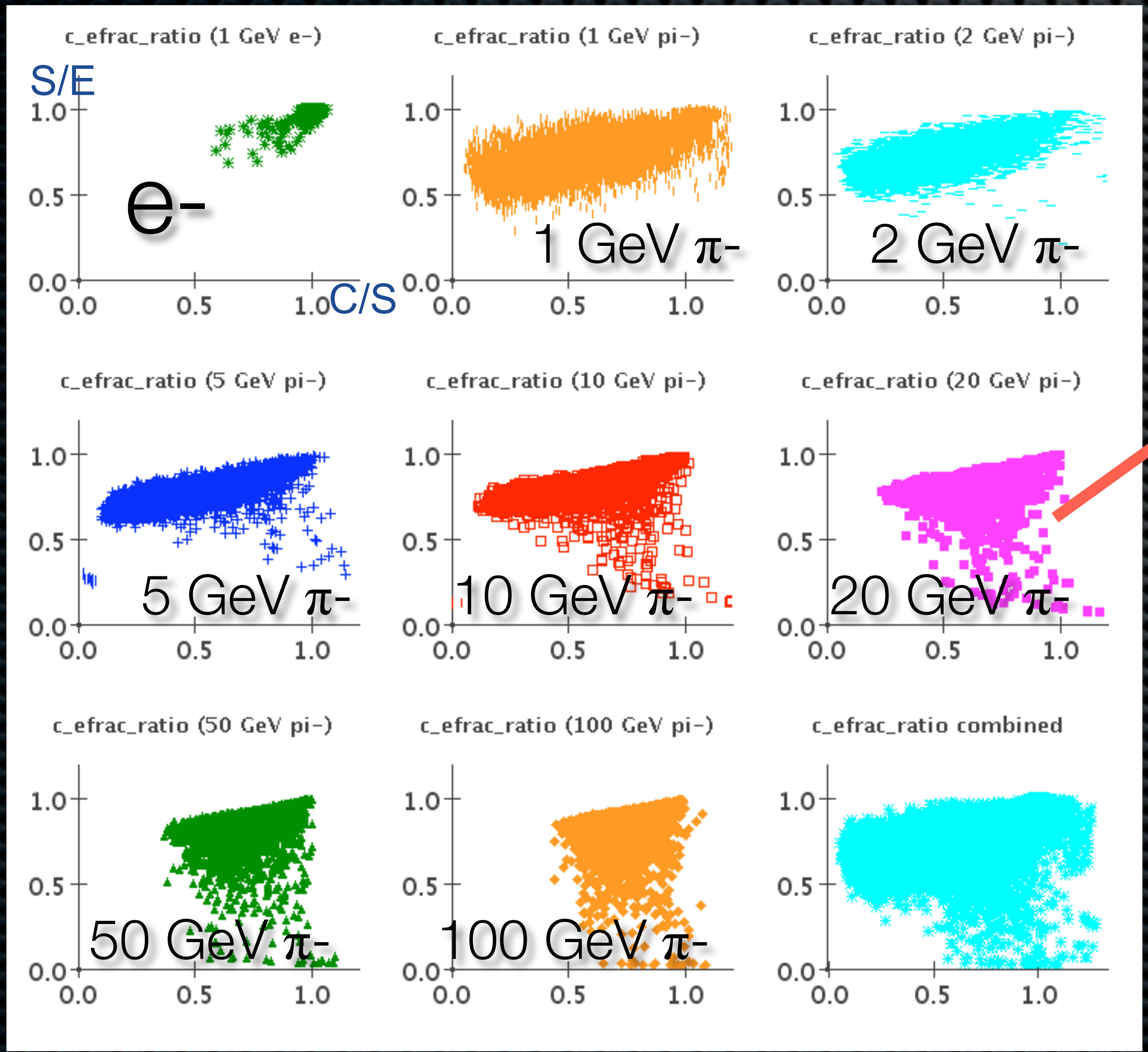
$S_{mean} = 9.98$ GeV

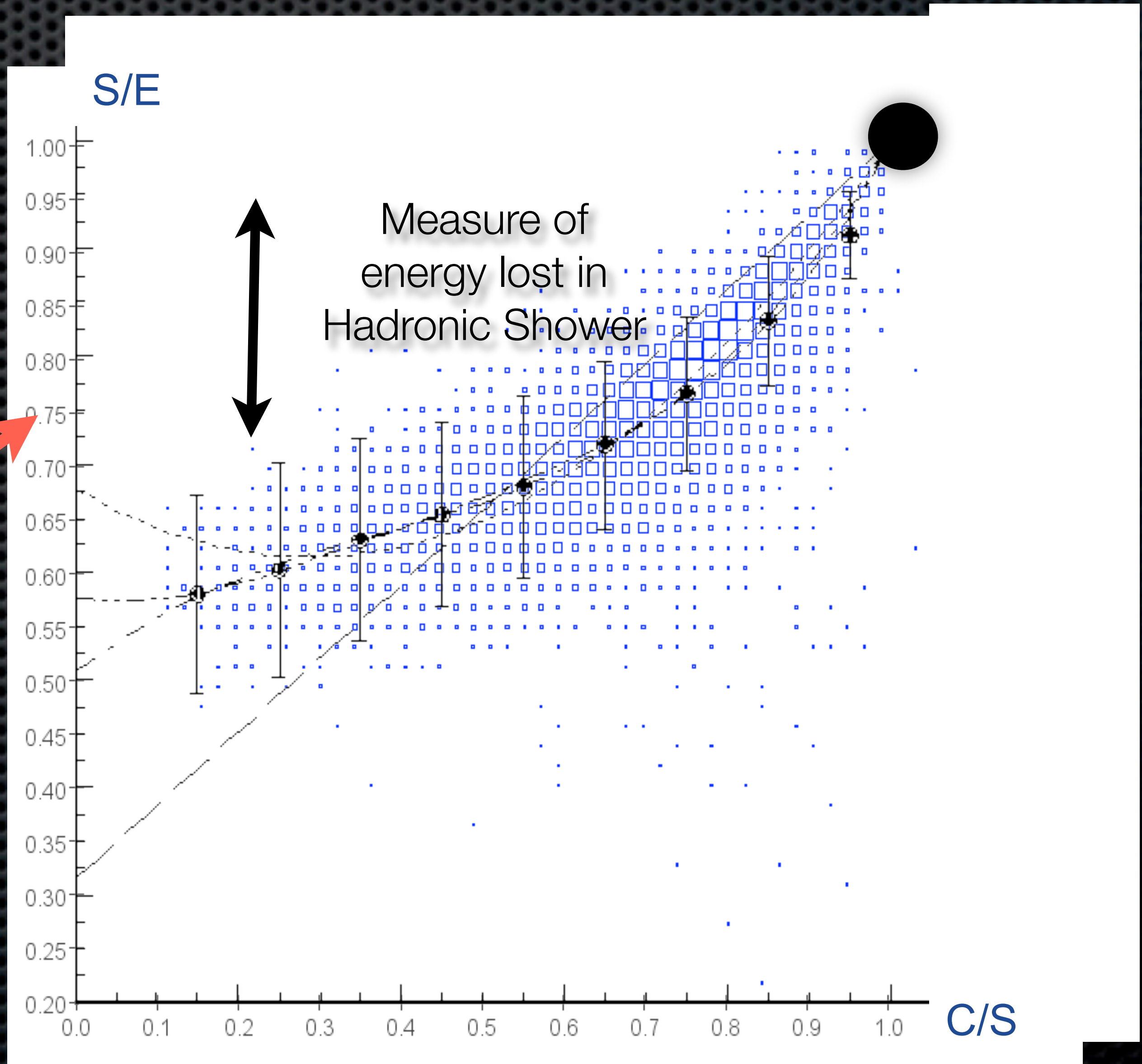
# Dual Readout Correction Process

## 2. Obtaining the Dual Readout Correction function

Plot showing Fraction (S/E) vs. Ratio (C/S) for various energies

S - scaled scintillation response
E - energy of incident particle
C - scaled Cerenkov response



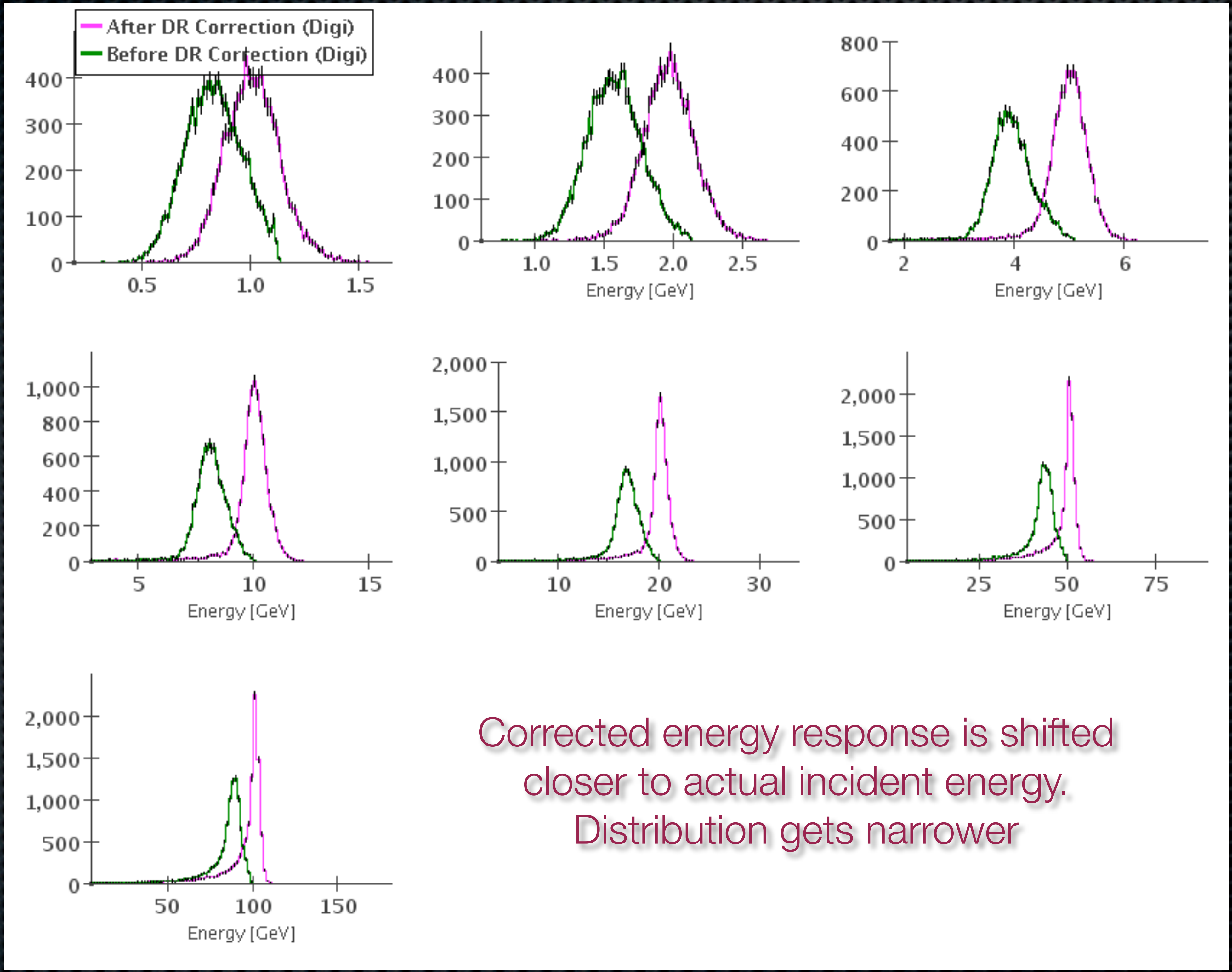




P1 = .315 + .684(C/S)
P2 = .677 - .439(C/S) + .762(C/S)$^2$
P3 = .506 + .608(C/S) - 1.050(C/S)$^2$ - .935(C/S)$^3$
P4 = .577 - .149(C/S) + 1.464(C/S)$^2$ - 2.302(C/S)$^3$ + 1.410(C/S)$^4$

# Dual Readout Correction Process

## 3. Applying correction function to scintillation response

Plot showing scintillation response before and after correction



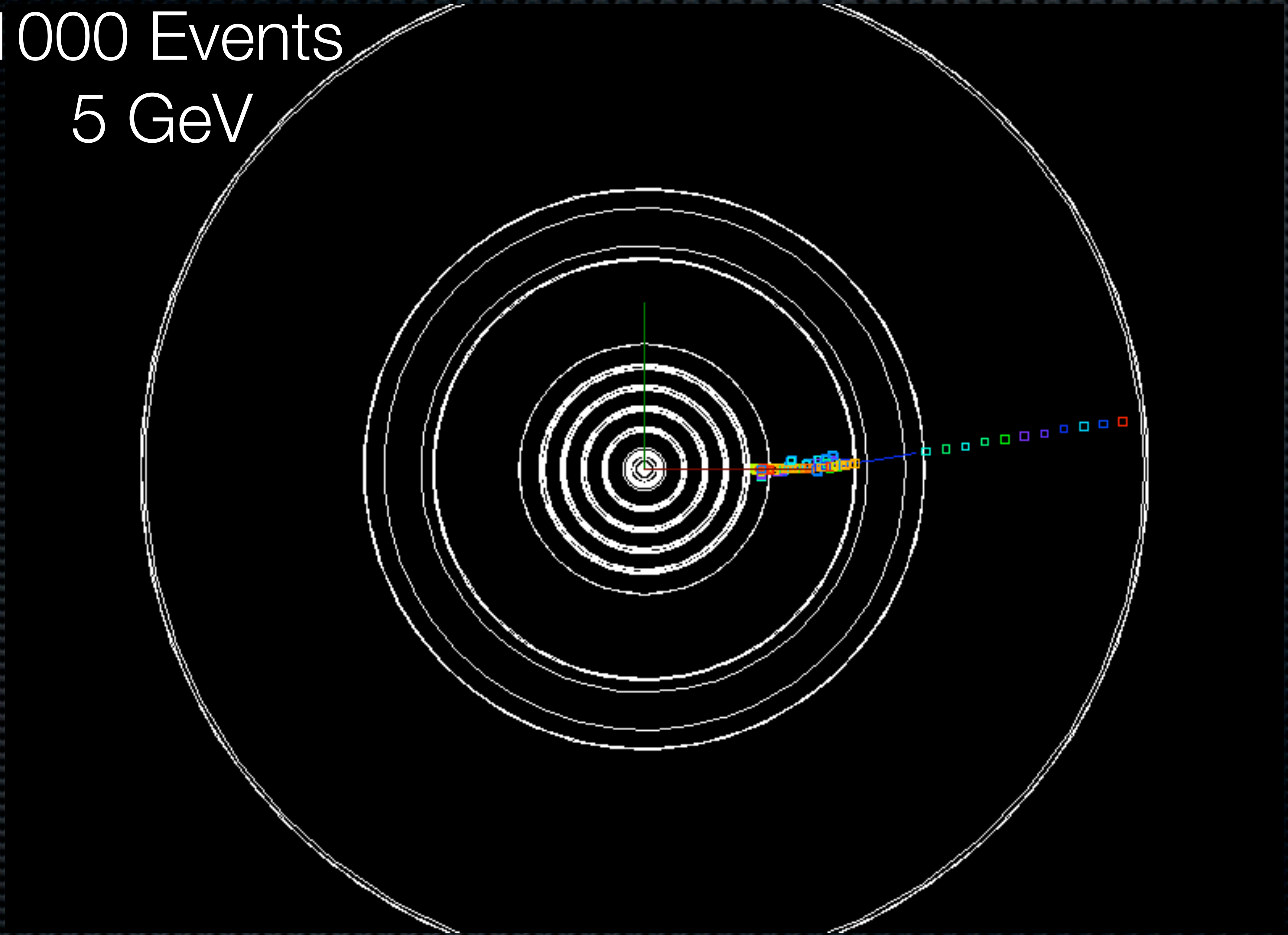

Corrected energy response is shifted closer to actual incident energy.
Distribution gets narrower

# Factors that affect energy resolution

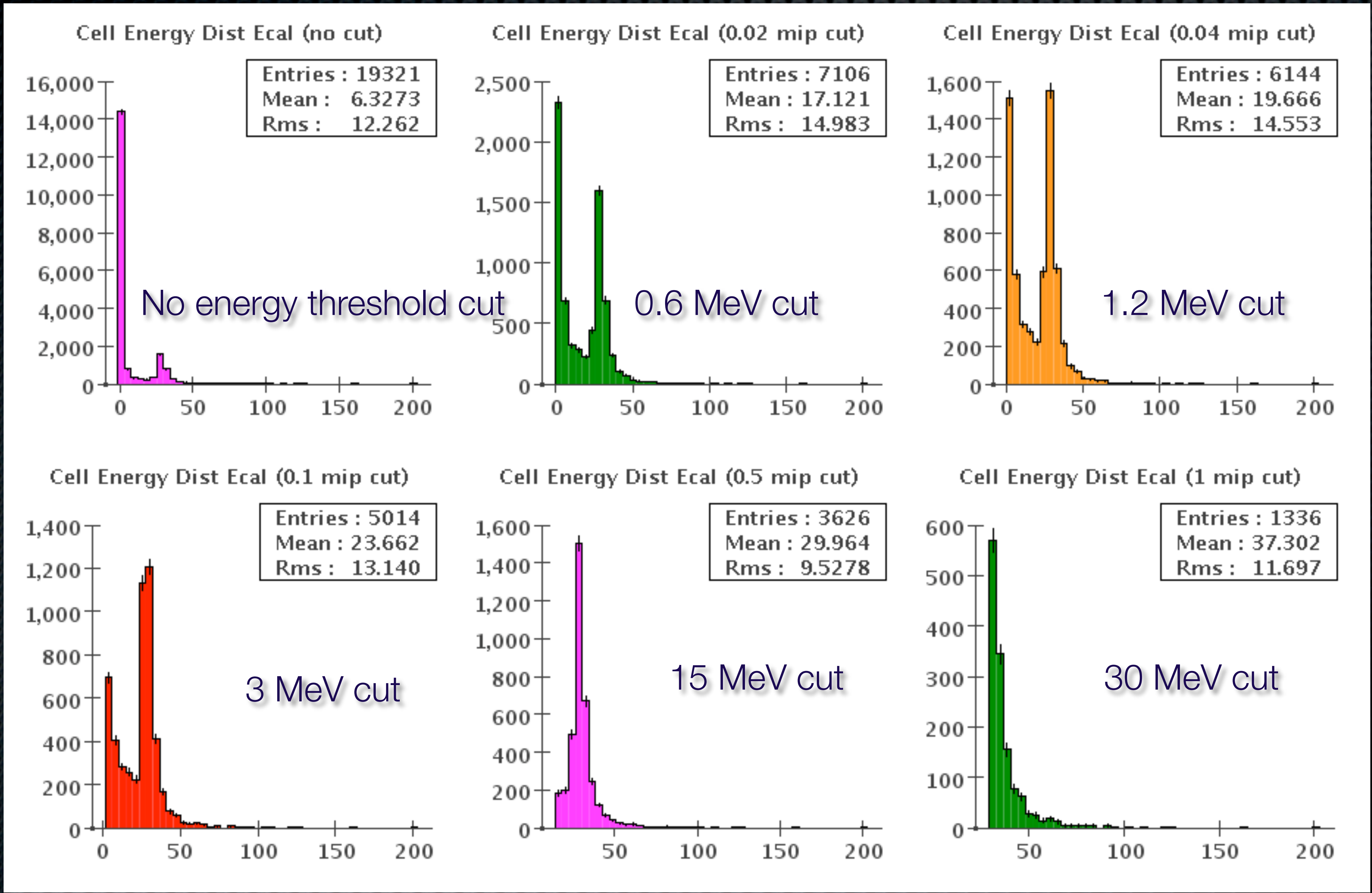
- noise
- losses in Hadron shower due to nuclear interaction
- threshold cuts
- geometric segmentation
- leakage
- quality of correction function
- photon statistics (absorption in crystals, detector efficiency)

# Muon Simulation: Segmentation effects

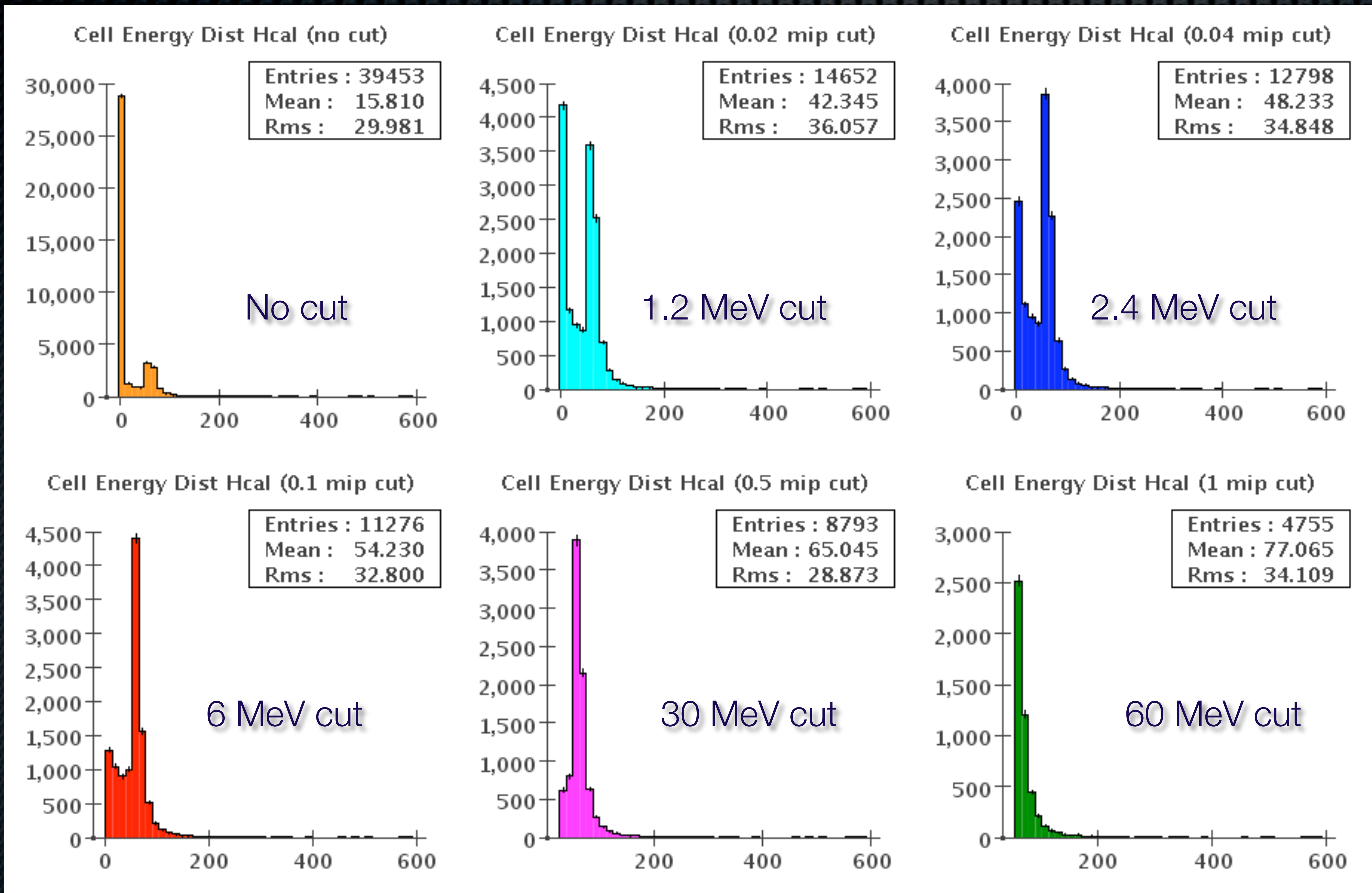
1000 Events
5 GeV



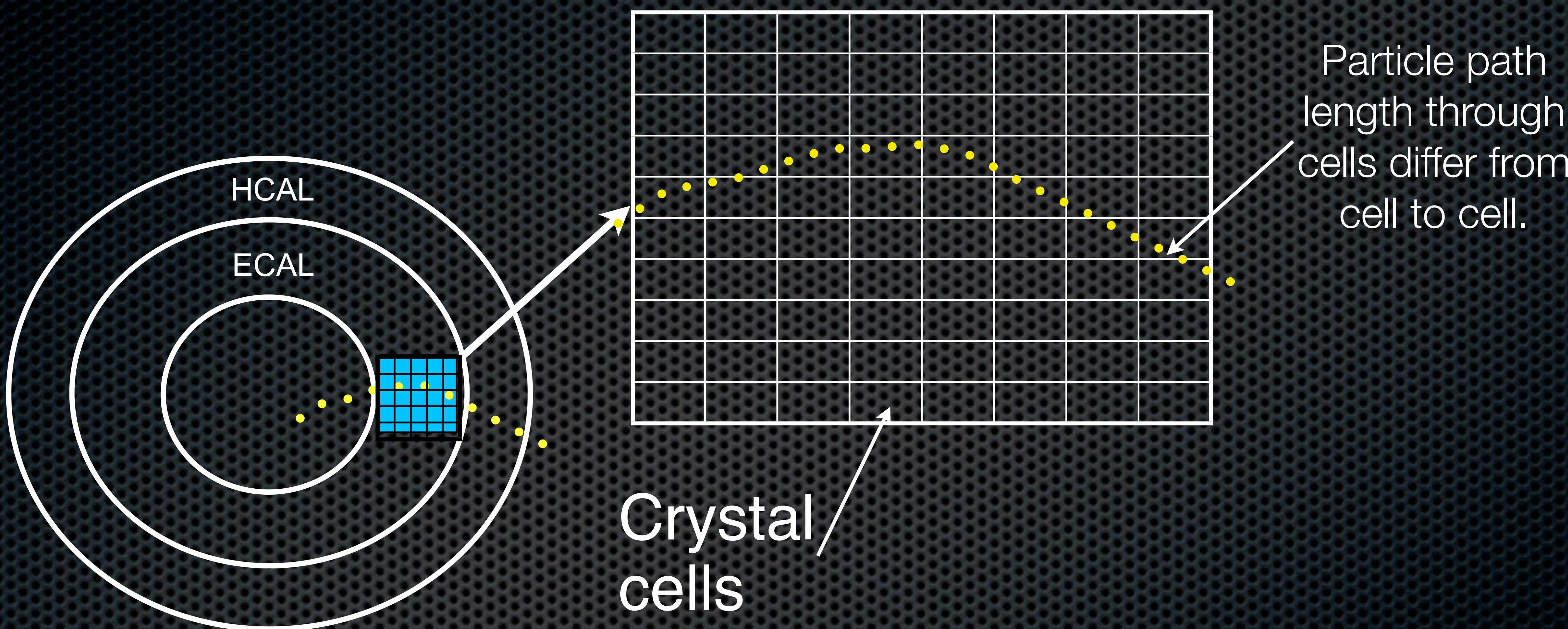
# Muon Energy Dist. per cell Ecal (MeV)



# Muon Energy Dist. per cell Hcal (MeV)

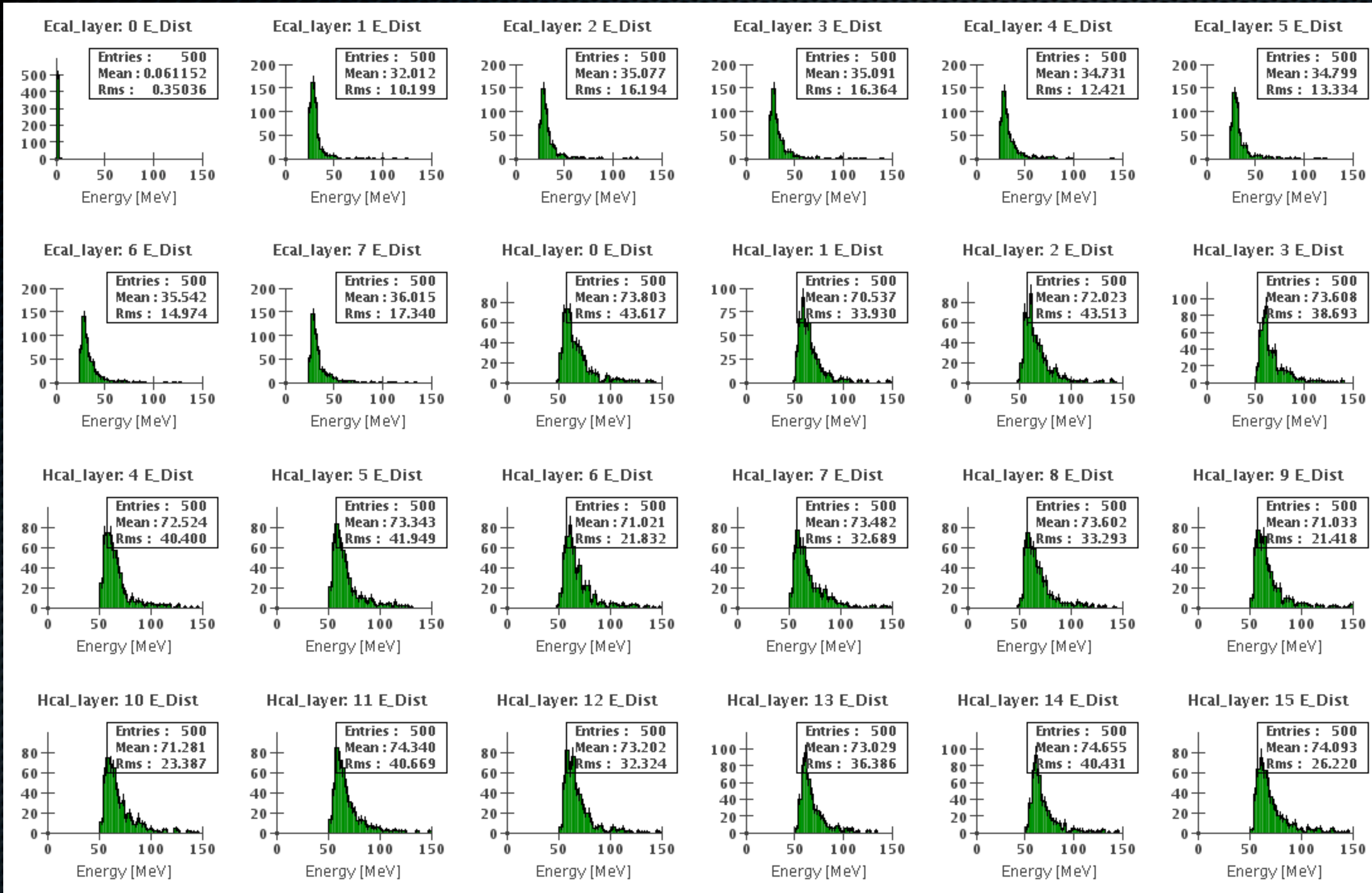


# Segmentation effects

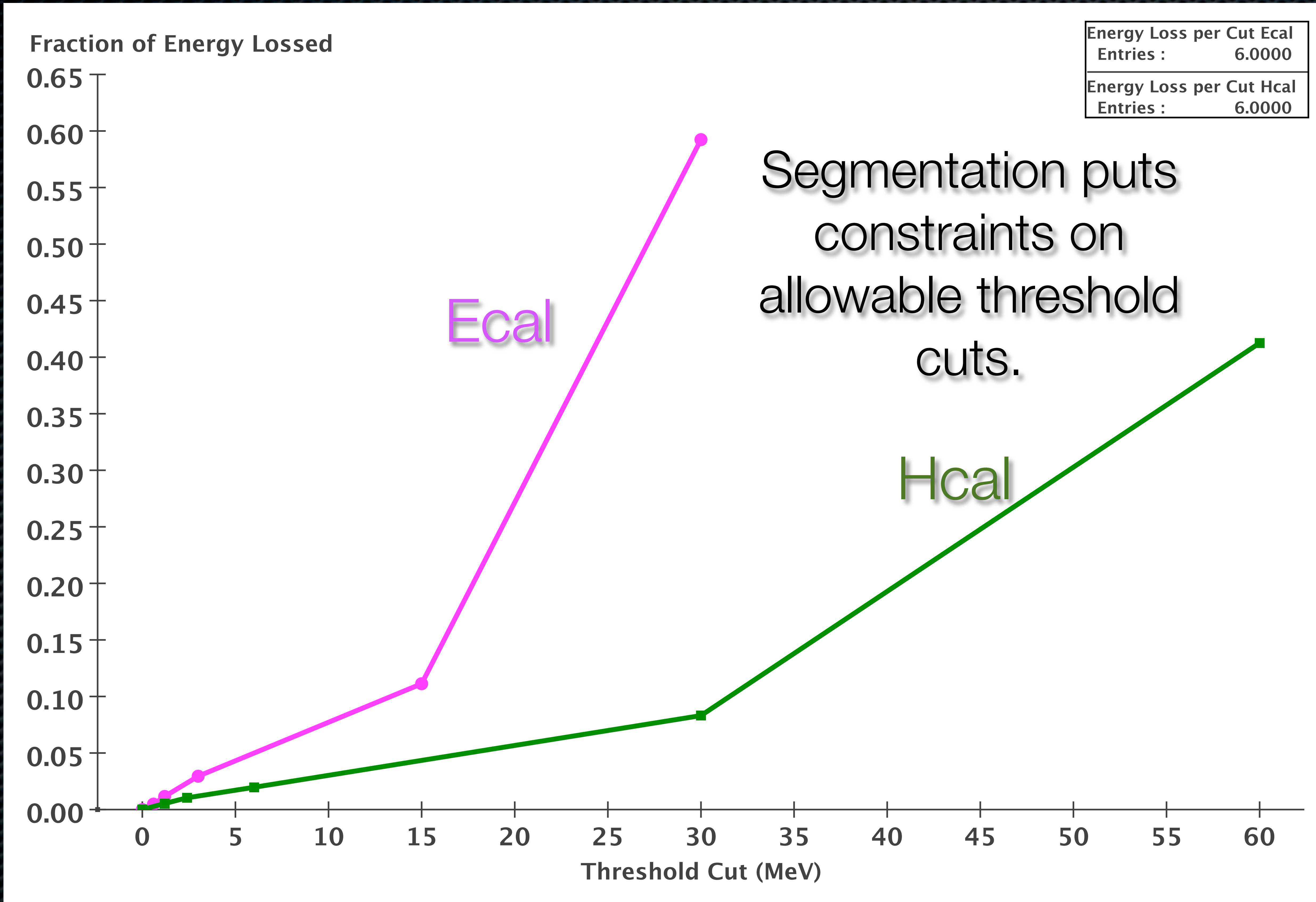



The spikes near zero in the cell energy distribution represent the instances where particles barely passes through a cell and deposits a very small amount of energy

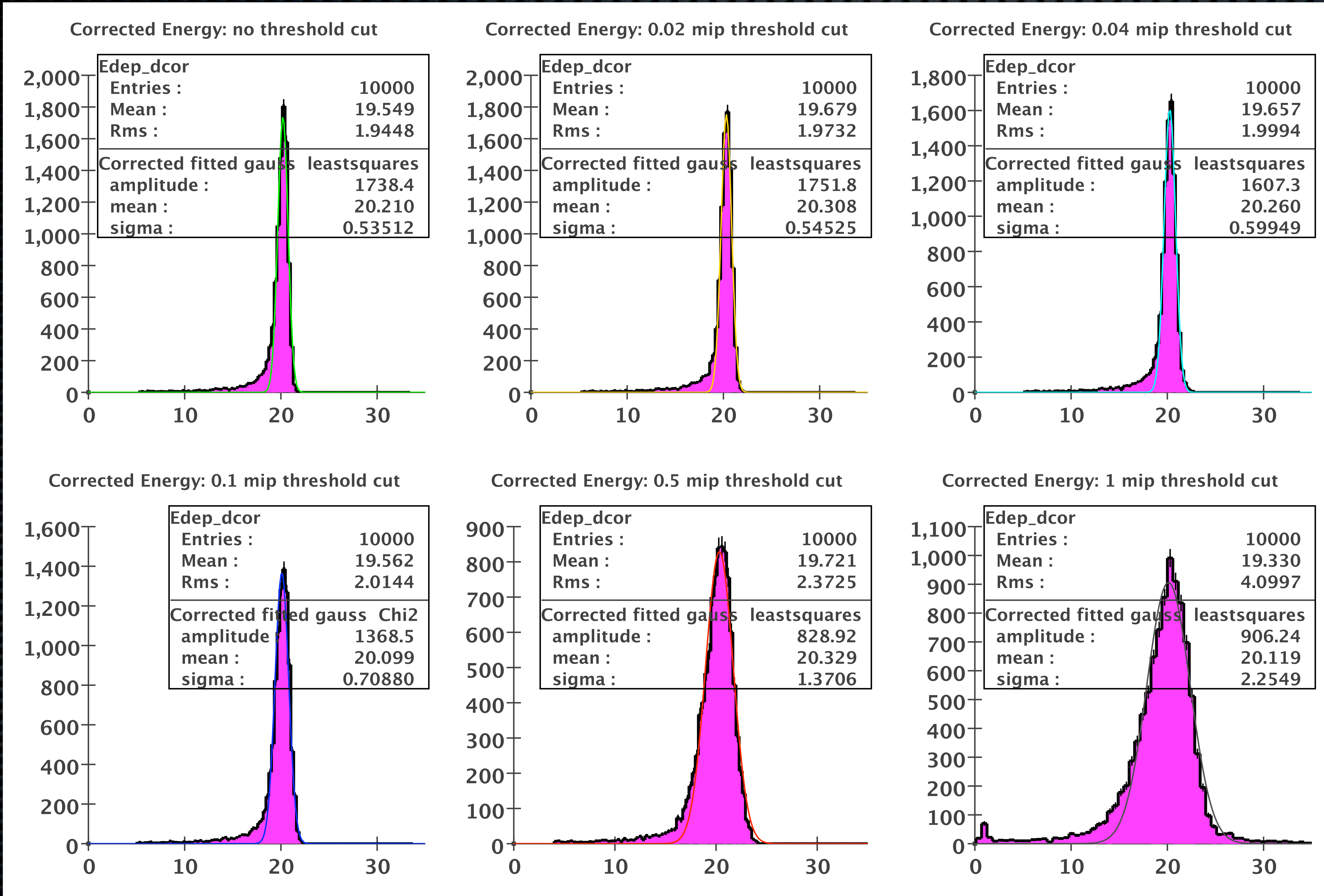
# Energy distribution per layer



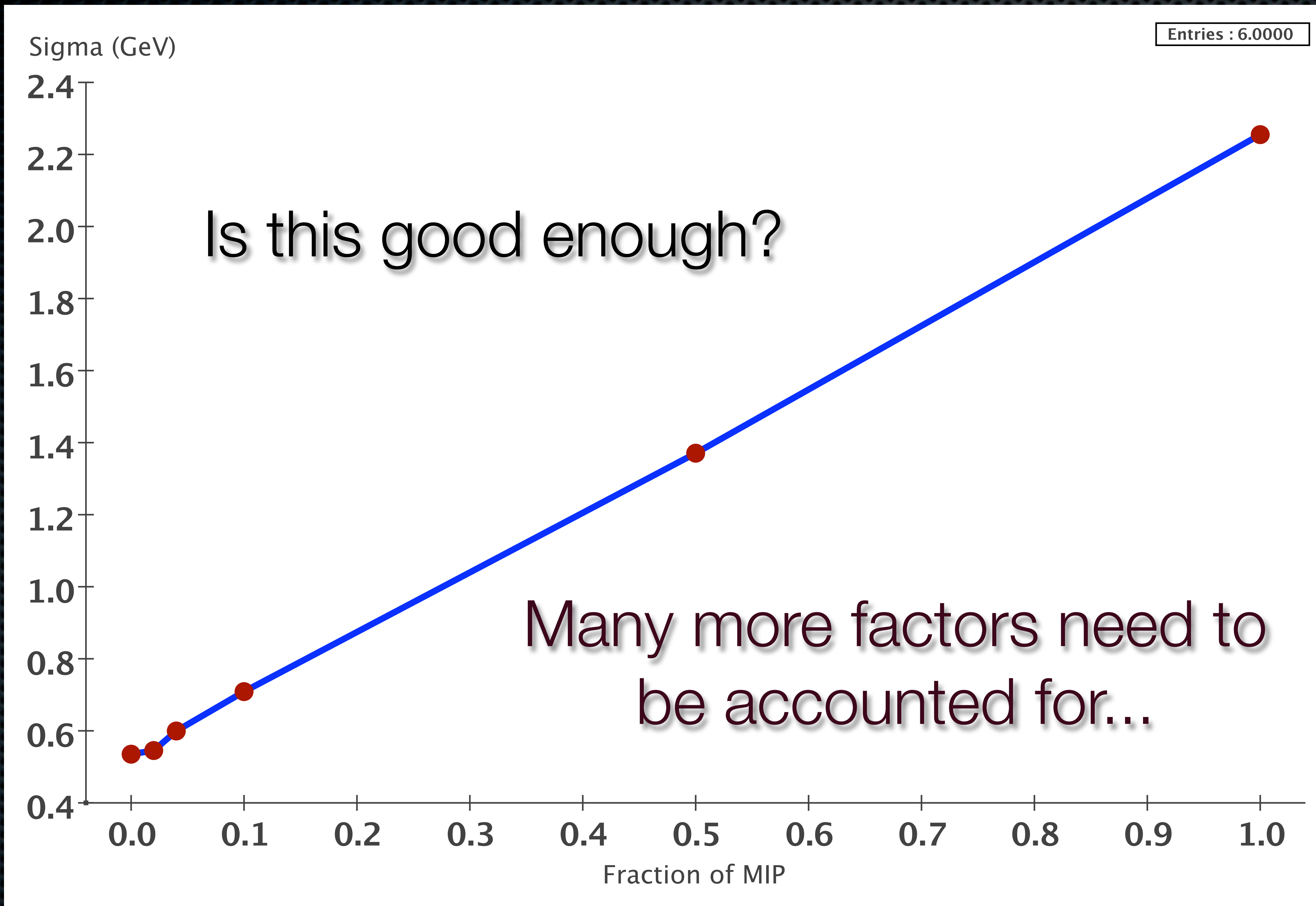
# Fraction of Energy Lossed per cell per cut



# Corrected Pion Energy (20 GeV)



# Sigma per cut



# End.

## Acknowledgments

- Hans Wenzel (Advisor)
- Dual Readout Calorimetry Group
- SIST Committee

# Modified Correction function