Jet Energy Resolution in Dual-Fiber Readout Calorimeter

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ALCPG Meeting
Fermilab
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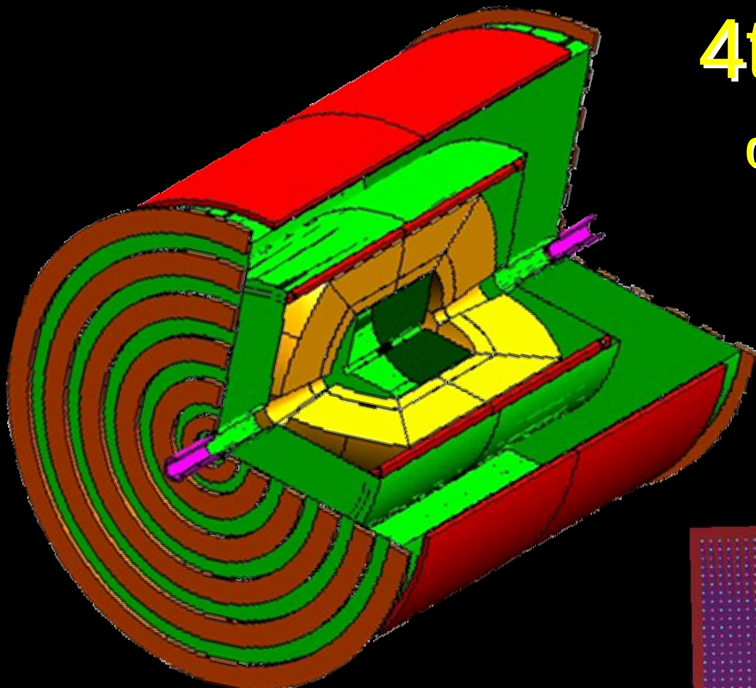
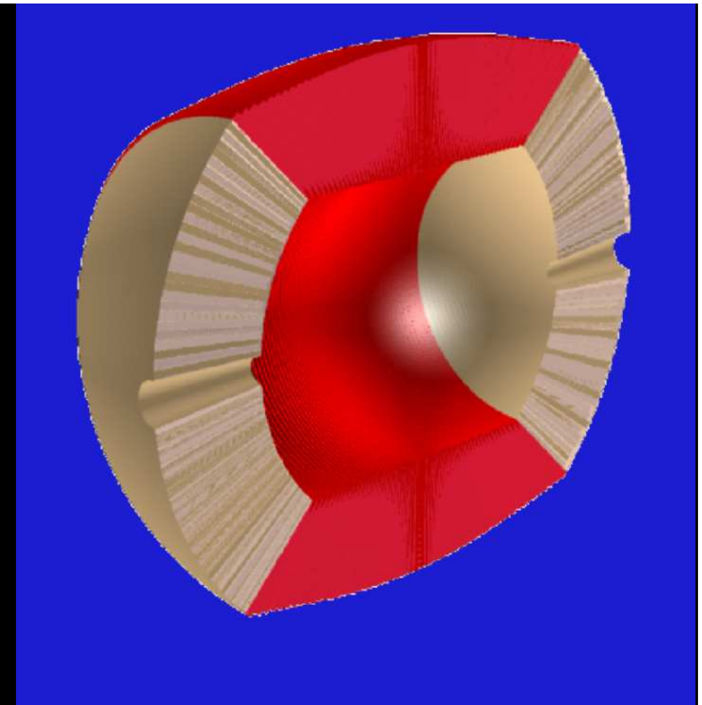
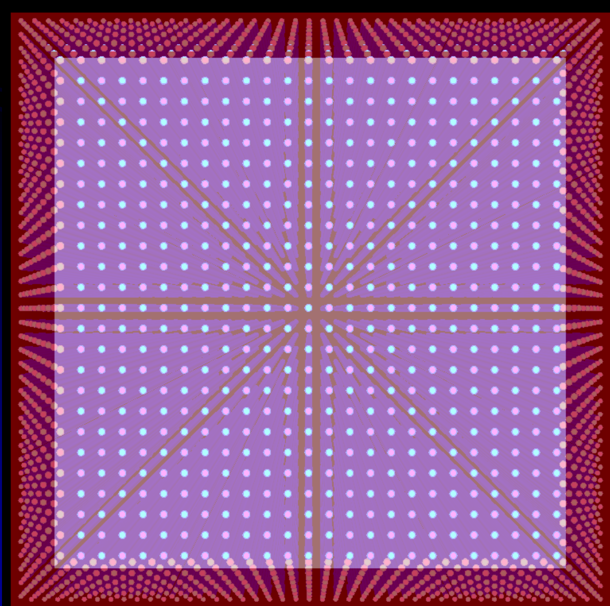
4th Concept

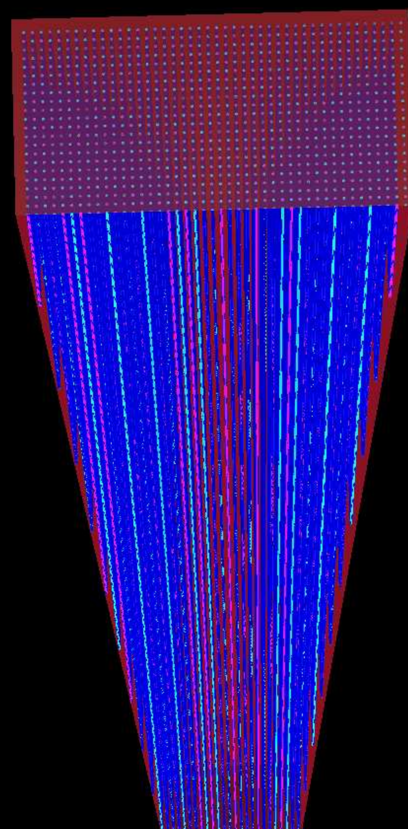
detector for ILC

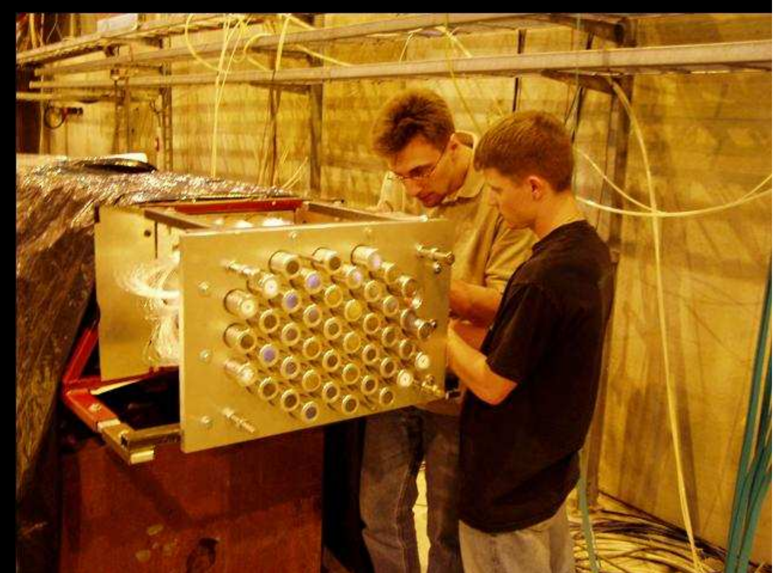




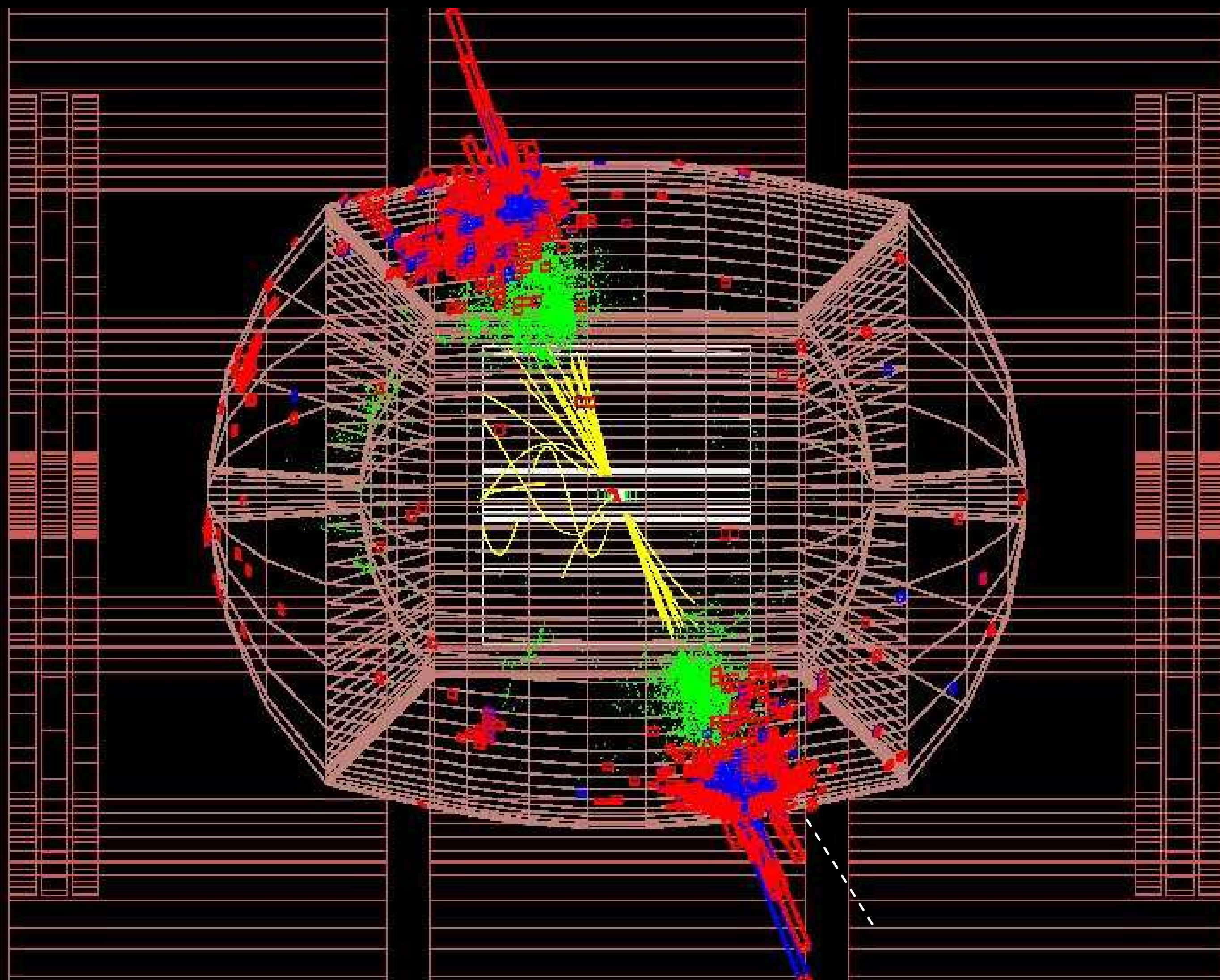
Dual Readout
calorimeter







500 GeV Di-Jet event display



A Strategy of Jet Reconstruction with Compensating Calorimeters

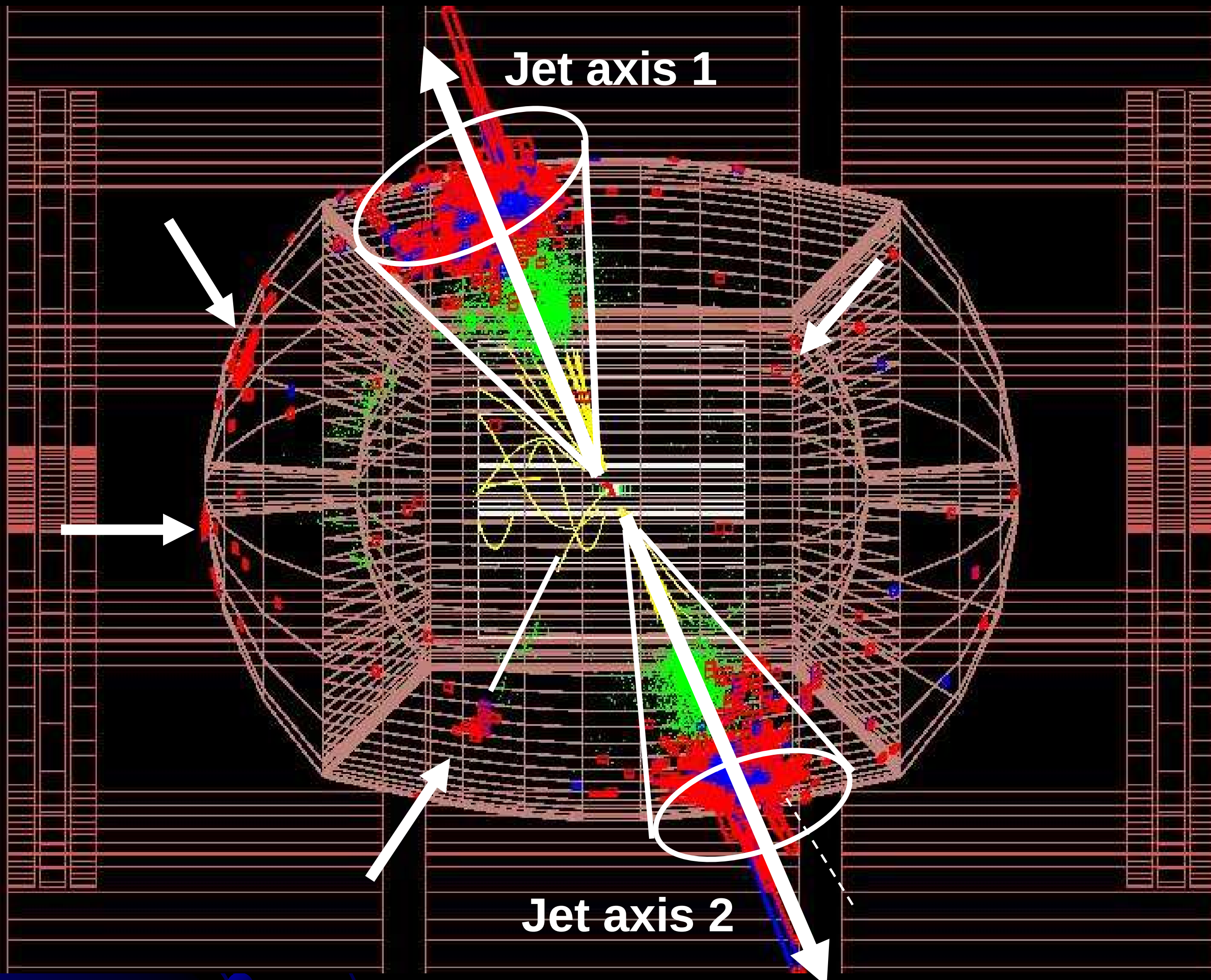
- Assume the jet made of 2 non-overlapping regions
  - Core: region of the calorimeter with overlapping showers
  - Outliers: hit cells separated from the core
- Measure the Core energy

  using information from the calorimeter
- Reconstruct Outliers individually

  using tracking and/or calorimetry

  for charged or neutral particle

Jet Reconstruction Strategy



Plans for Jet Studies

- Use Compensating Calorimetry for ILC

  and Durham jet finder algorithm

  - Study performance

    of the calorimeter and jet algorithm

Present study

- Improve Resolution

  with proper treatment of "outliers"

  - Delicate interplay among tracking,

    calorimetry, and muon detector

In progress

A Starting Point for this Strategy

- use compensating calorimeter

  to reduce ***fluctuation***

  which dominate calorimeter resolution

1. Fluctuation in the em shower fraction, f_{em}

   (fluctuations in the π^0 content of the cascade)

2. Fluctuation in the visible energy

   (fluctuations in the nuclear binding energy losses)

2 examples of Compensating Calorimeters

based on Dual Readout

- Sampling Fiber Calorimeter (HCAL)

  + crystals (ECAL)

  in 4^{th} Concept Detector for ILC

Used in the present studies

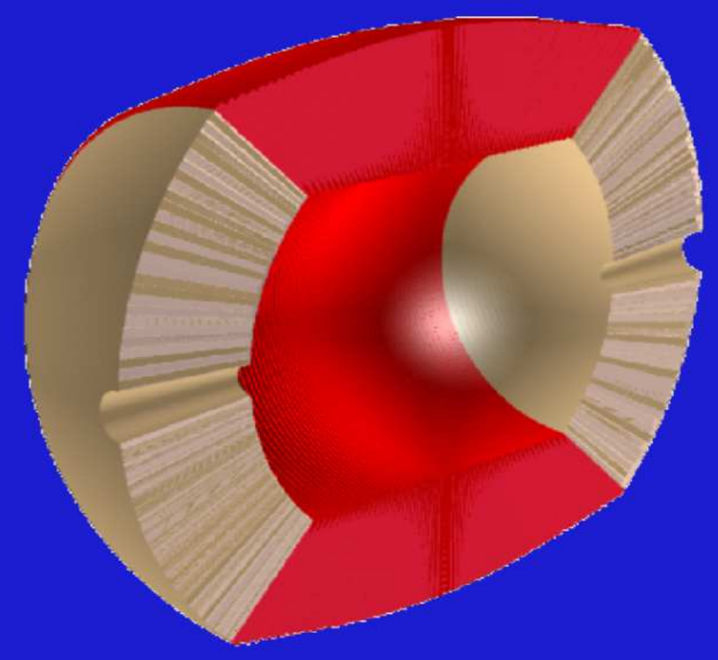
- Total absorption segmented crystals (HCAL & ECAL)

Dual-Readout: Measure every shower twice –using Scintillation light and Cerenkov light.

Dual Readout Fiber Hadronic Calorimeter

4th Concept Hadronic Calorimeter (first version*)

- Cu + scintillating fibers + Ĉerenkov fibers
- ~1.5° aperture angle
- ~ 10 λ_{int} depth
- Azimuth coverage down to 3.8°
- Barrel: 13924 cells
- Endcaps: 3164 x 2 cells

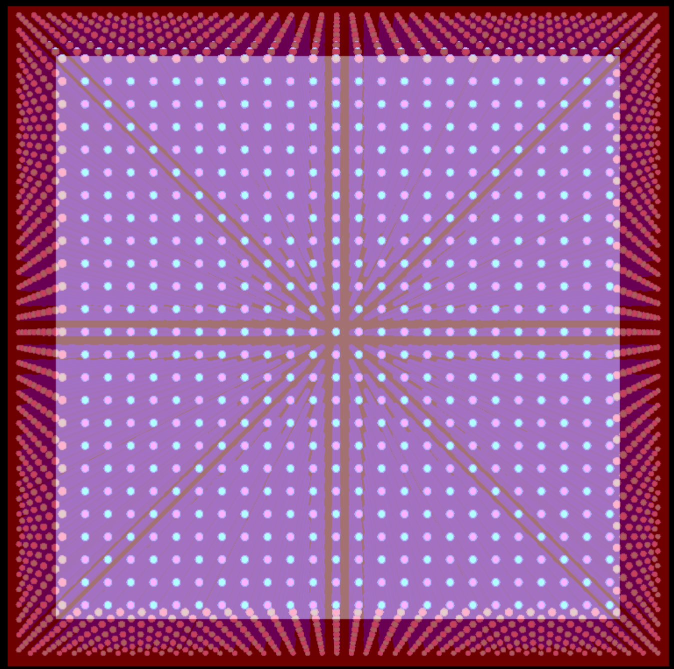


Fully projective geometry

***In the present studies**

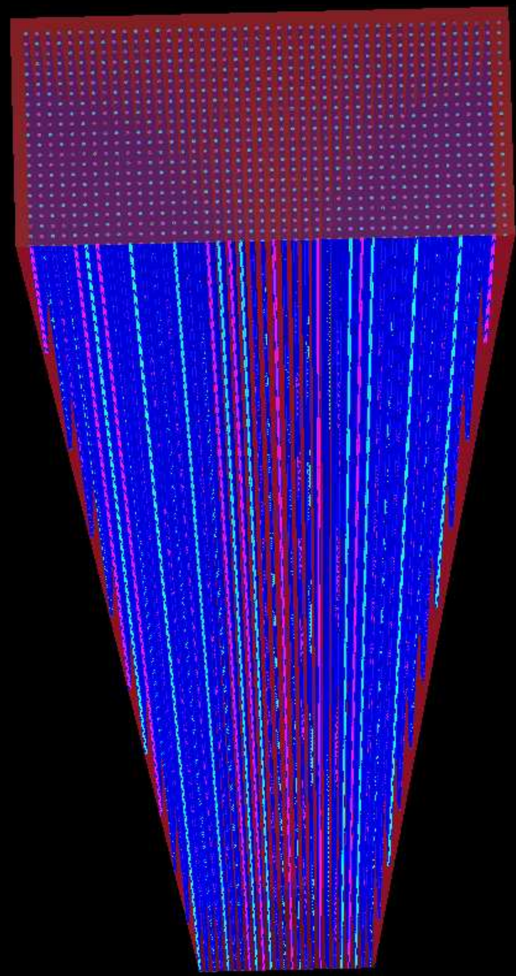
4th Concept Hadronic Calorimeter Cells

Bottom view of single cell



Prospective view of clipped cell

Top cell size:~ 8.8 × 8.8 cm²



Bottom cell size: ~ 4.8 × 4.8 cm²

0.3 mm radius

Plastic/Quartz fibers

Cell length: 150 cm

Number of fibers inside each cell: ~1980

equally subdivided between Scintillating and Cerenkov

Fiber stepping ~2 mm

See C. Gatto's talk on Thursday (Calorimetry)

Simulation

- ILCroot framework
- Pandora-Pythia to generate
  1. $e^+e^- \rightarrow qq$ (q=uds) @ 60, 100, 140, 200, 300, 500 GeV
  2. $e^+e^- \rightarrow Z \rightarrow qq$ (q=uds) @ 91 GeV
- Fluka to track particles in the detectors
- Full Digitization/Clusterization for VXD, central tracker, and HCAL
- Full pattern recognition
  - Clusterization = collection of nearby "digits"
  - Unfolding of overlapping showers through Minuit fit to shower shape
- Fast rec-points (gaussian smearing of hits) for Muon detector

See C. Gatto's talk on Monday (Tracking)

Simulation Reconstruction Analysis in ILCroot Framework

- CERN architecture (based on Alice's Aliroot)
- Uses ROOT as infrastructure
  – All ROOT tools (I/O, graphics, PROOF, data structure, etc)
  – Extremely large community of users/developers
- Six MDCs: robustness, reliability, portability
- Single framework generation, simulation, reconstruction, analysis
- Available from Fermilab

  ilc.fnal.gov/detector/rd/physics/detsim/ilcroot.shtml

  www.fisica.unile.it/~danieleb/IlcRoot

Calibration

Energy of HCAL calibrated in 2 steps:

1. Calibrate with single 40 GeV e^-

   → raw E_C and E_S

2. Calibrate with single 40 GeV π^-

   → η_C and η_S

Reconstructed Energy

Once HCAL calibrated, Calorimeter Energy:

$$E_{HCAL} = \frac{\eta_S \cdot E_S \cdot (\eta_C - 1) - \eta_C \cdot E_C \cdot (\eta_S - 1)}{\eta_C - \eta_S}$$

$$\eta_c = \left(\frac{e}{h}\right)_C \qquad \eta_S = \left(\frac{e}{h}\right)_S$$

Calorimeter performance

- Total Reconstructed Energy
- Energy Response
- Total Energy Resolution

Jet Reconstruction Performance for di-jet events

- Jet Reconstructed Energy
- Jet Energy Resolution

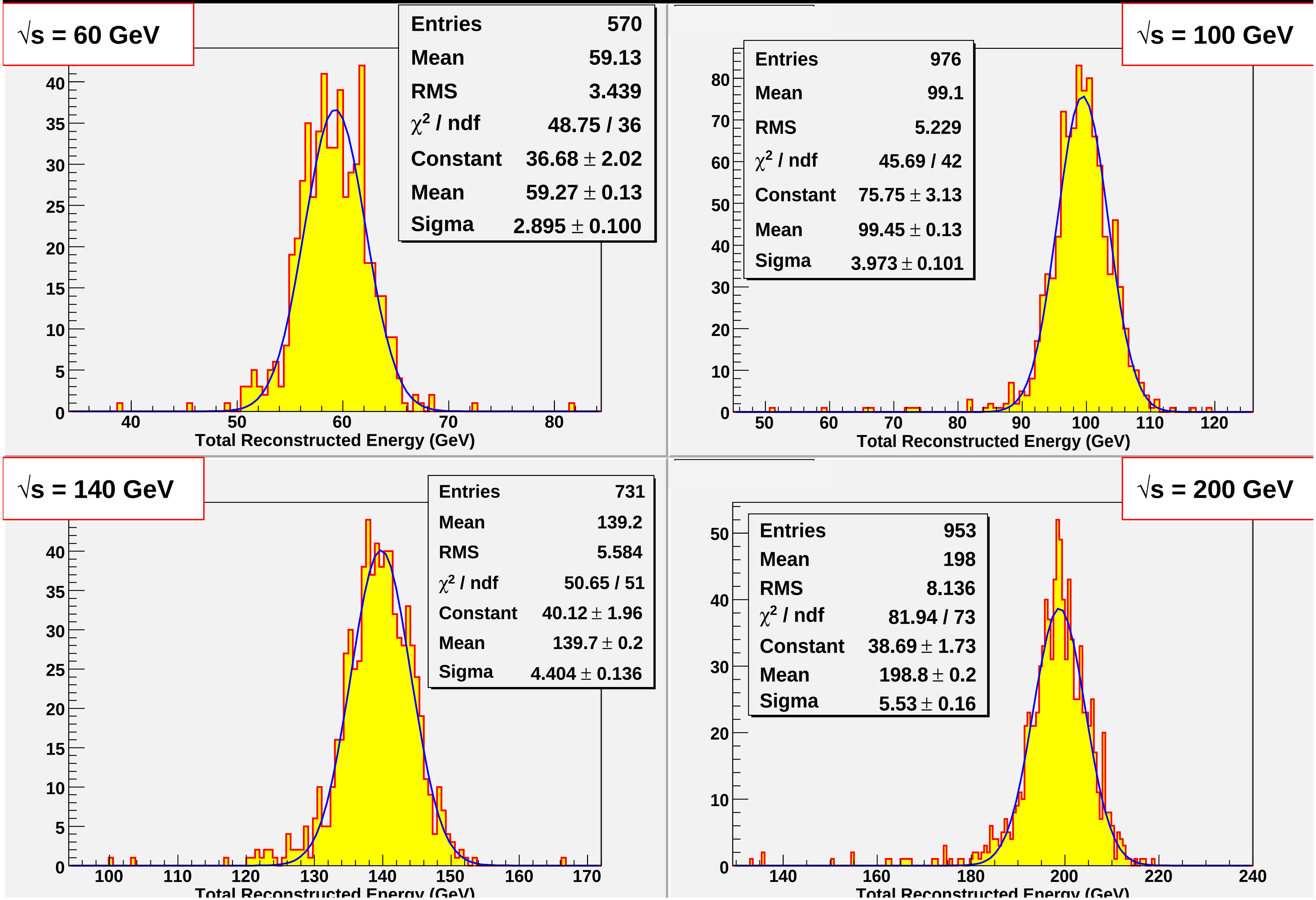
Jet Reconstruction Performance at Z Pole (91 GeV)

- Number of jets found
- Z Mass

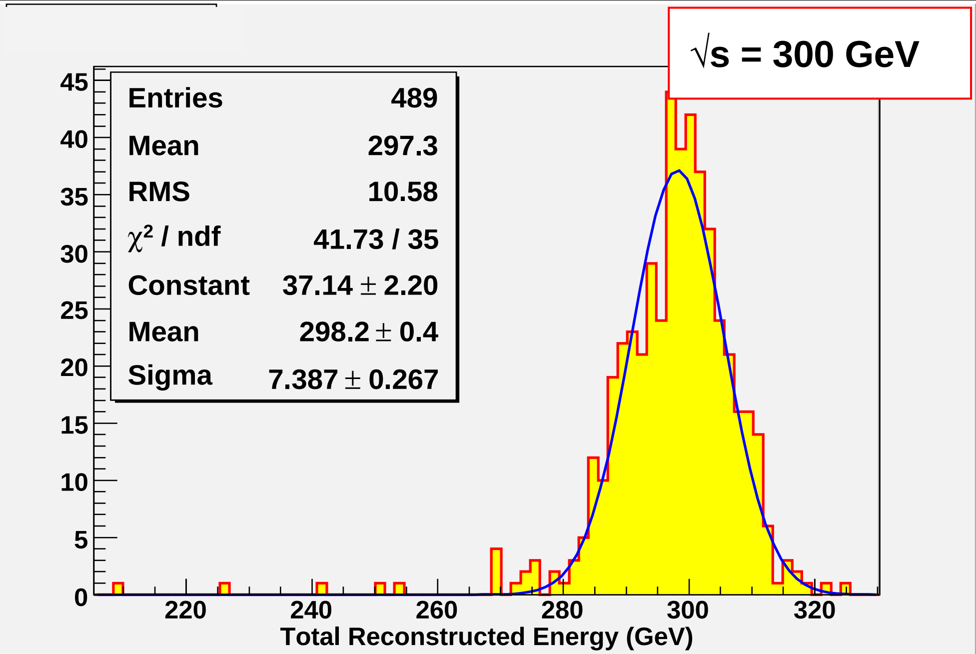
Calorimeter Performance

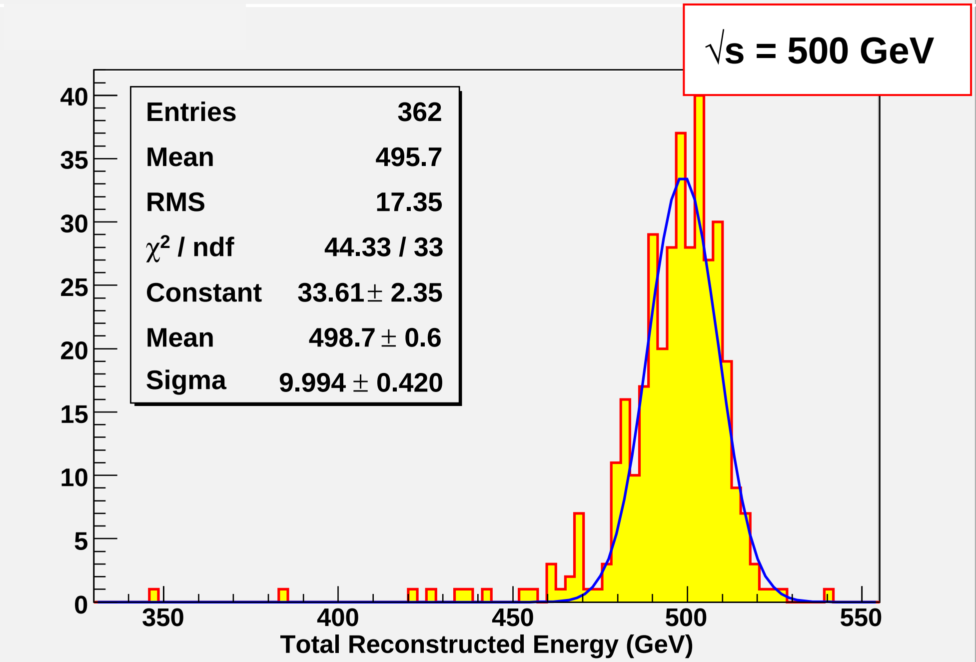
- Total reconstructed energy
- Energy response
- Energy resolution

$e^+e^- \to qq$ (q=uds) @ 60, 100, 140, 200, 300, 500 GeV



$e^+e^- \rightarrow qq$ (q=uds) @ 60, 100, 140, 200, 300, 500 GeV

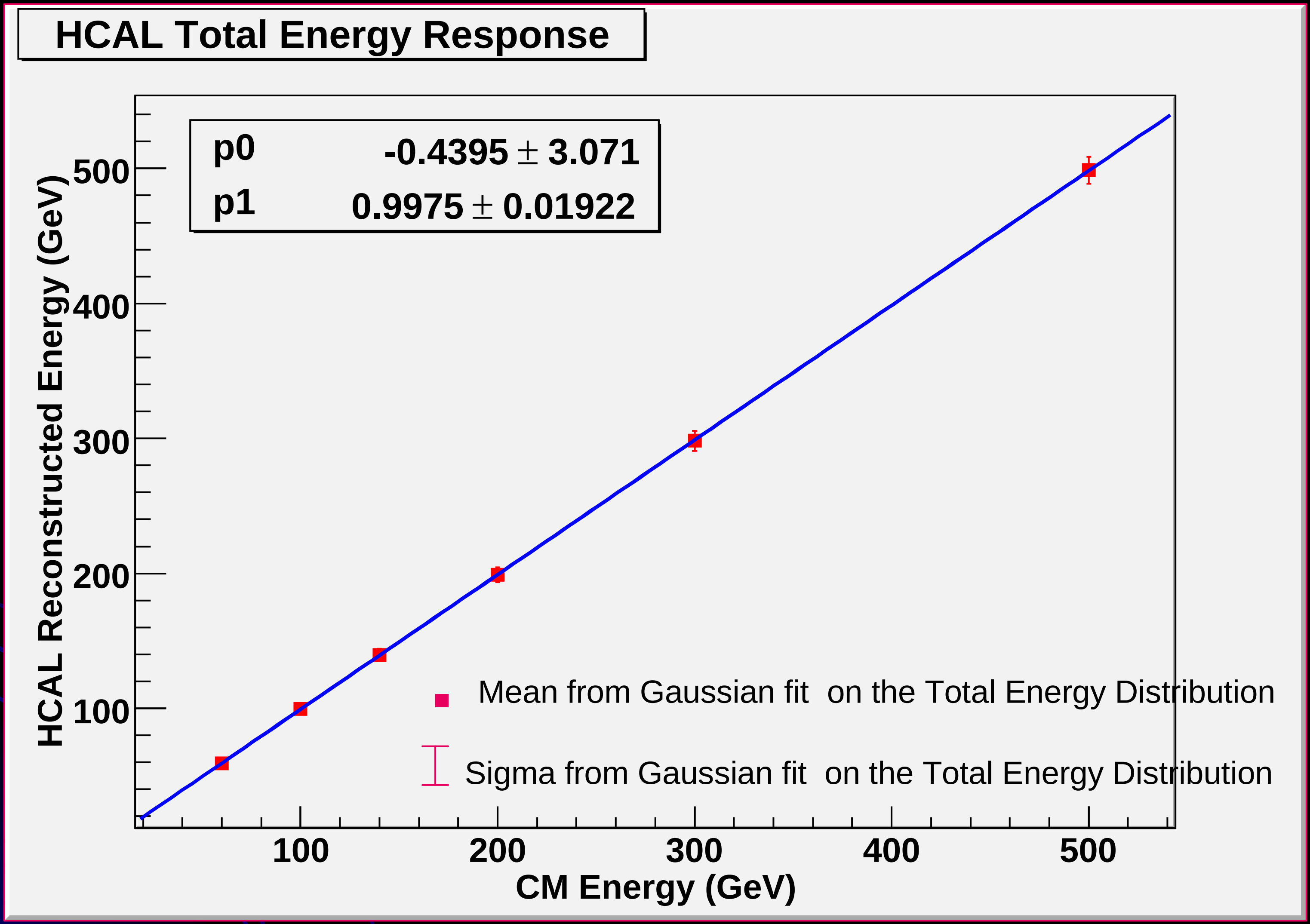




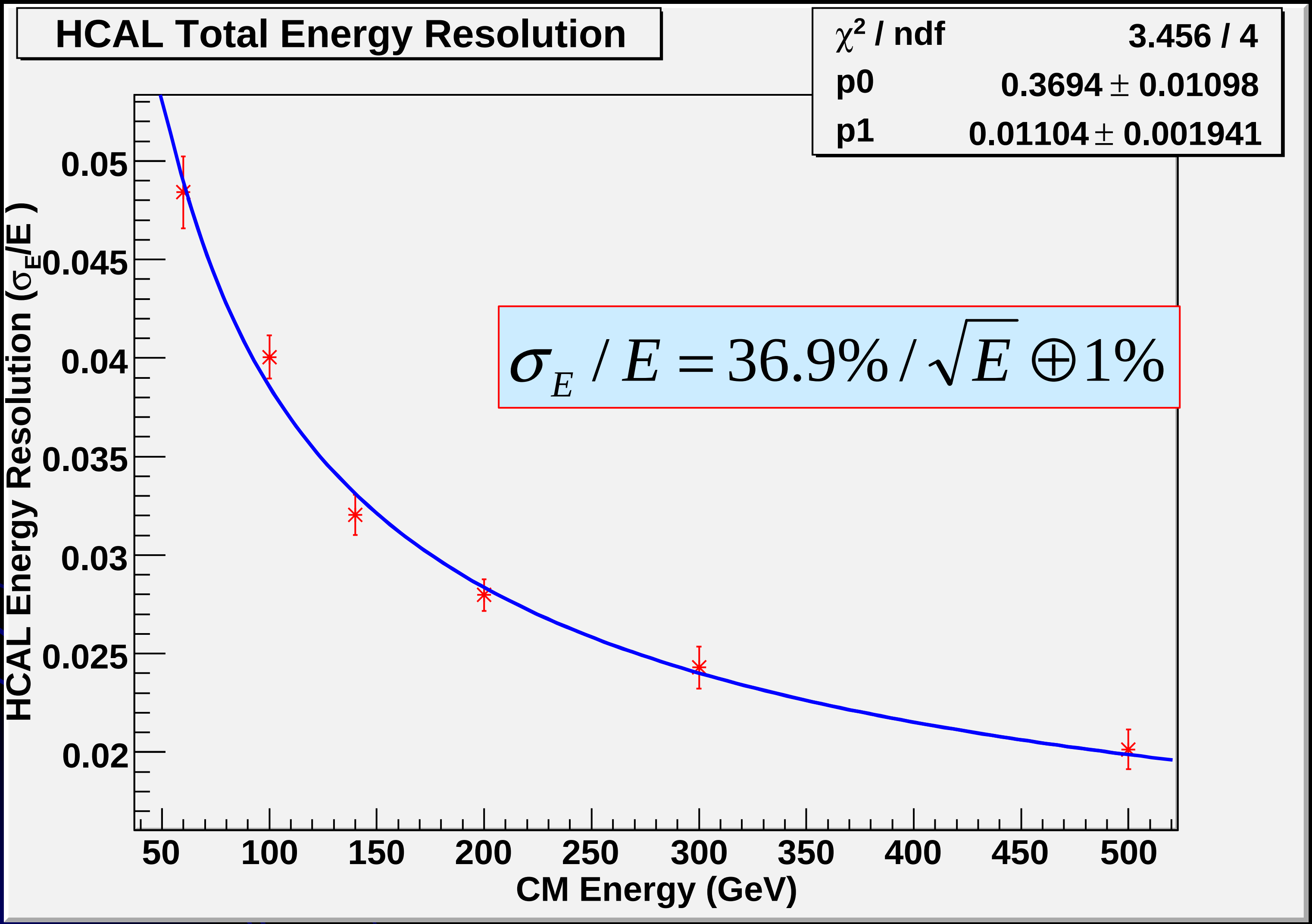
(rms_{90} : rms of central 90% of events)

	σ	rms_{90}
E_{CM}(GeV)	$\sigma/E = \alpha/\sqrt{E}$	$\sigma/E = \alpha/\sqrt{E}$
60	37.5 %	32.1 %
100	40.1 %	34.0 %
140	37.9 %	32.7 %
200	39.6 %	34.9 %
300	42.1 %	36.7 %
500	45.0 %	40.6 %

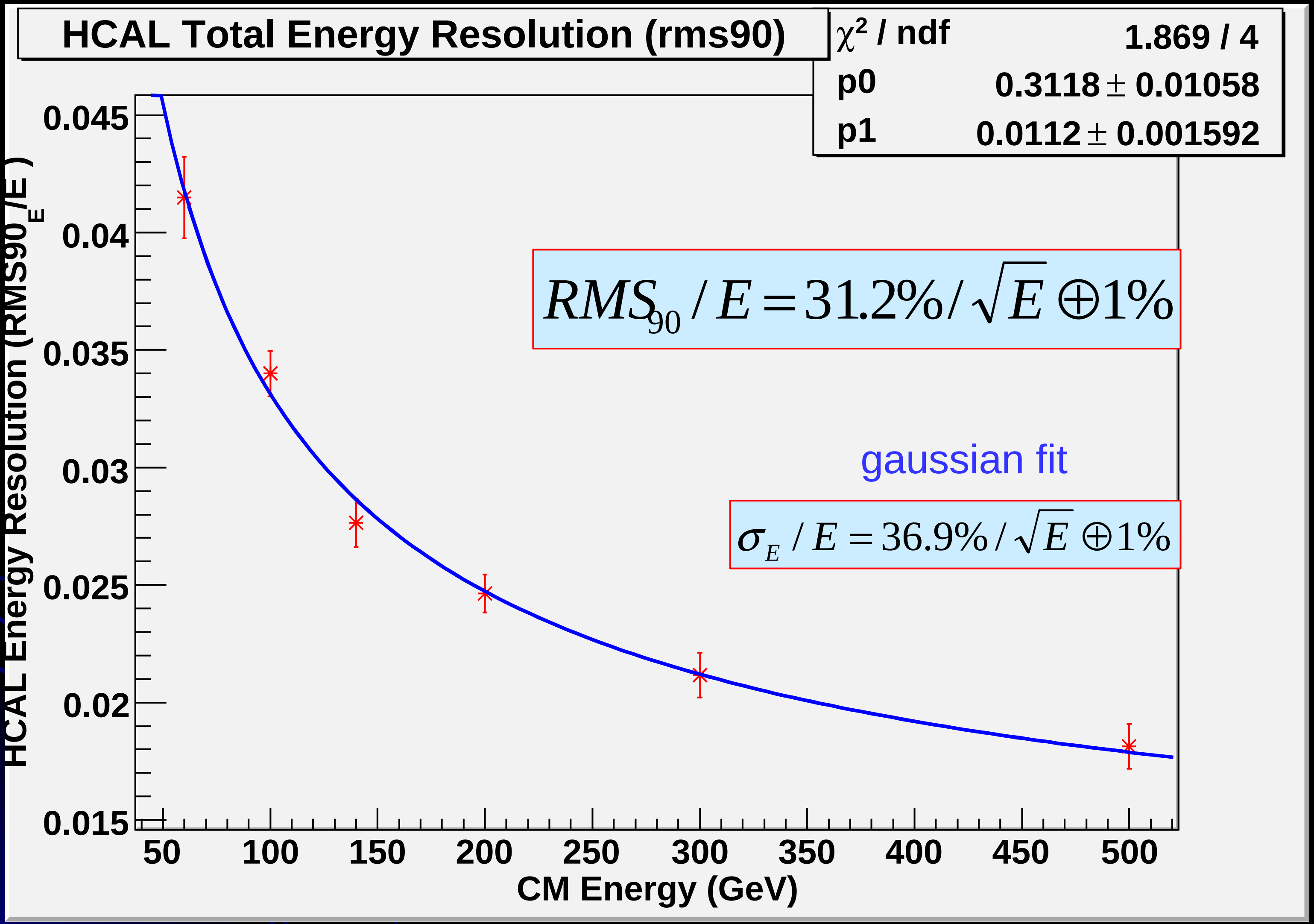
Energy Response



Total Energy Resolution (Gaussian fit)



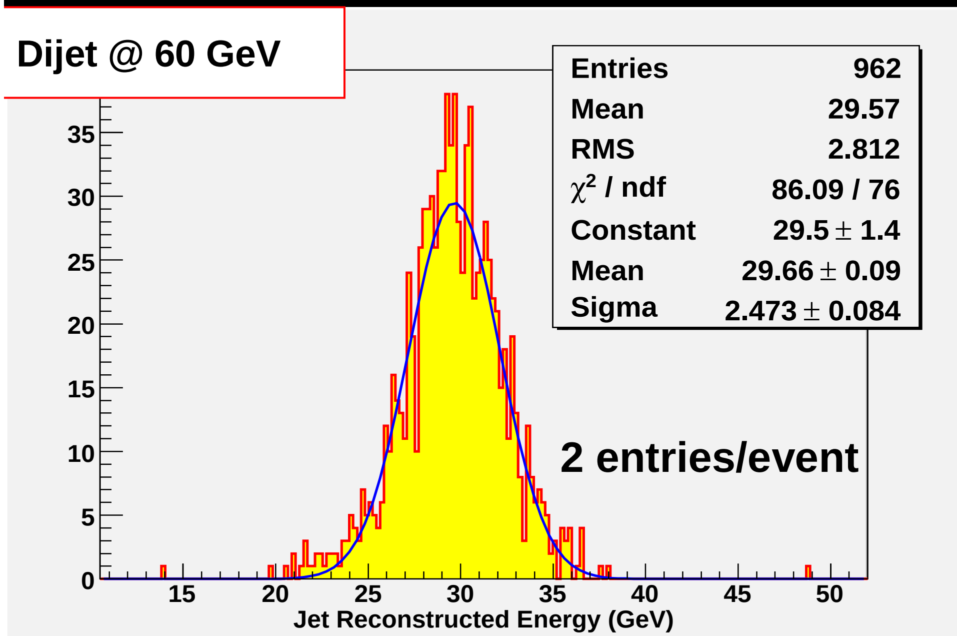
Total Energy Resolution (rms$_{90}$)

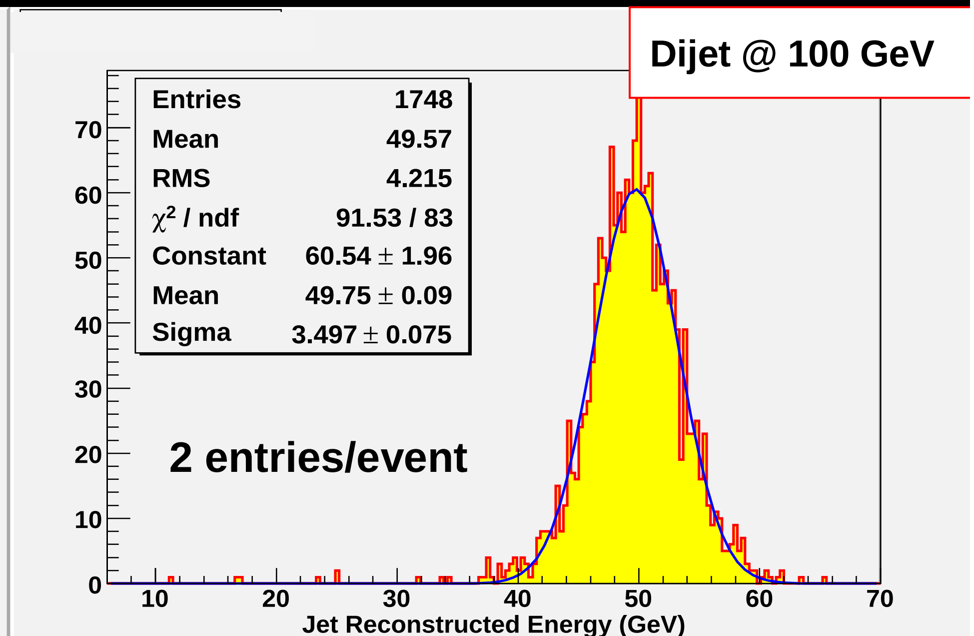


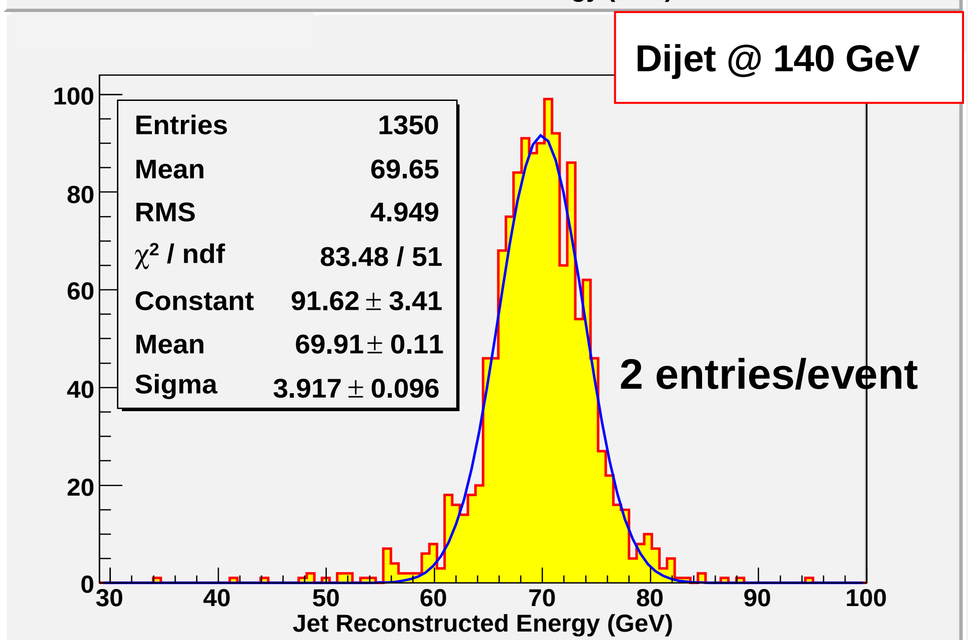
Jets Reconstruction Performance for di-jet events

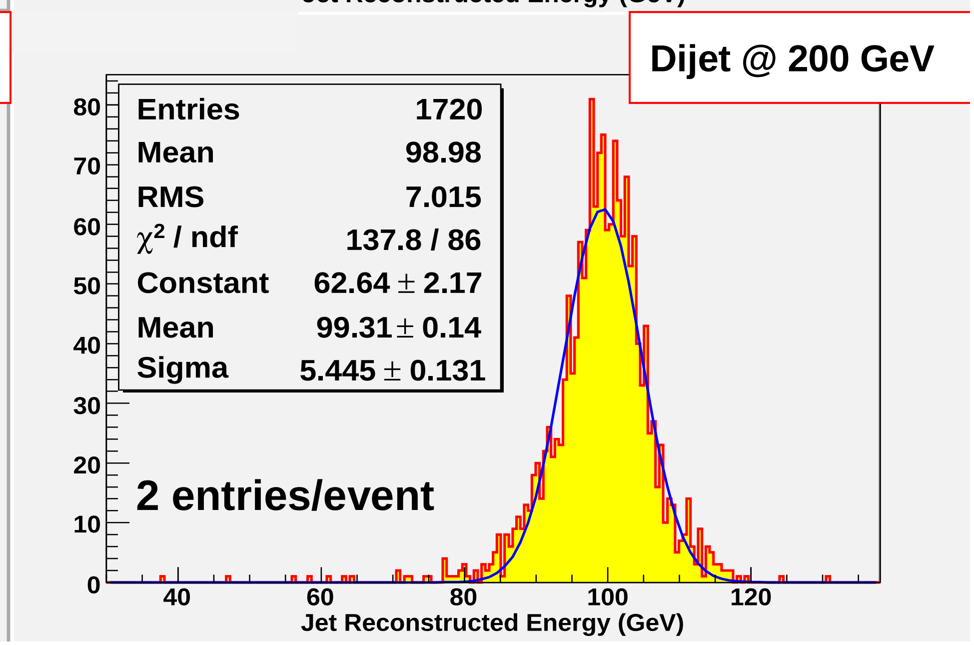
- Jet Energy reconstruction
- Energy Resolution

Di-jet events $e^+e^- \rightarrow qq$ (q=uds) @ 60, 100, 140, 200, 300, 500 GeV

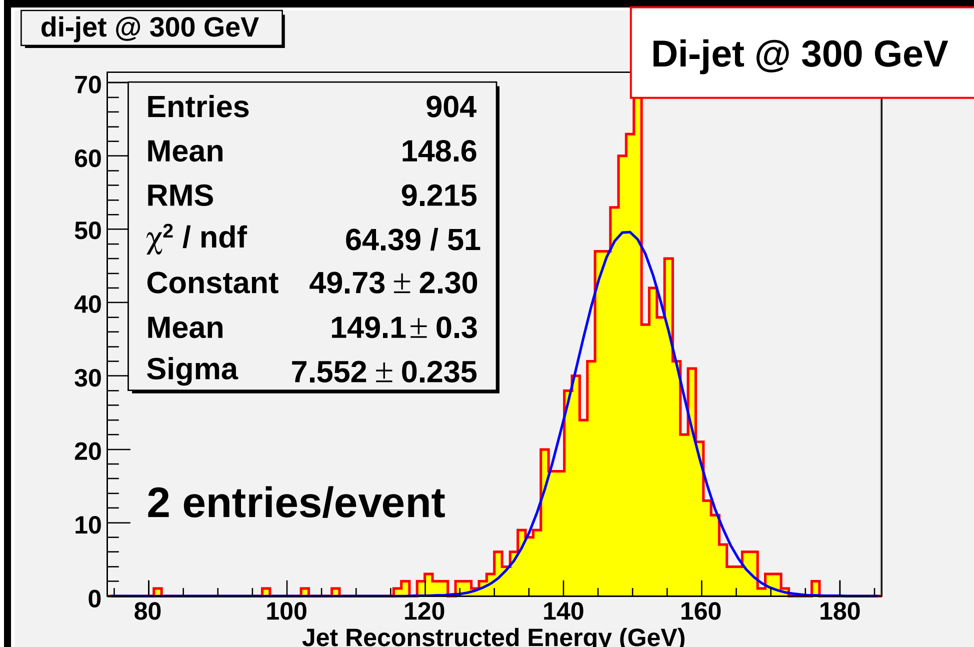


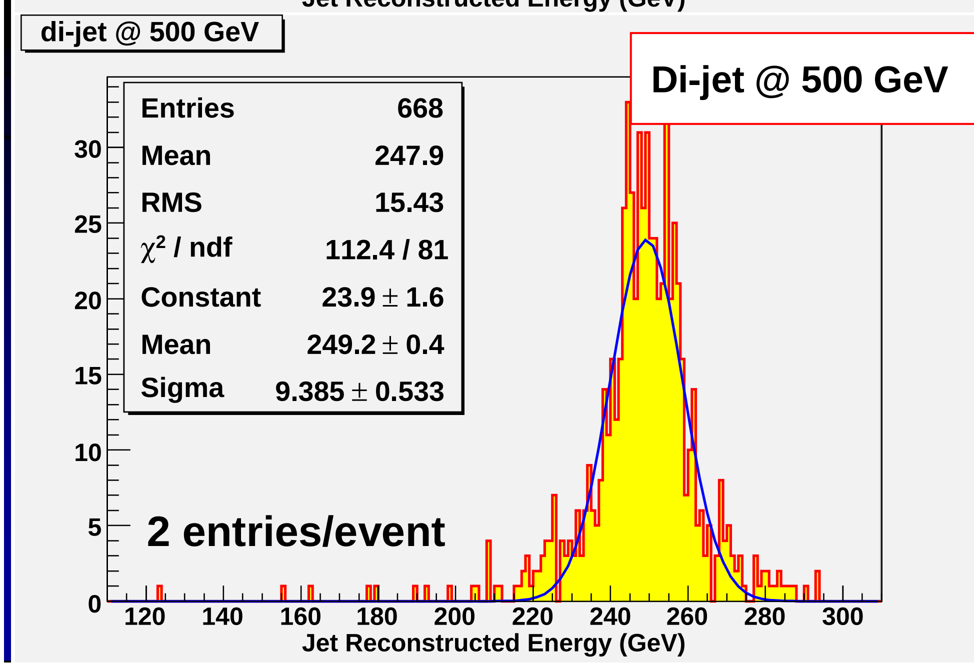






Di-jet events $e^+e^- \to q\bar{q}$ (q=uds) @ 60, 100, 140, 200, 300, 500 GeV

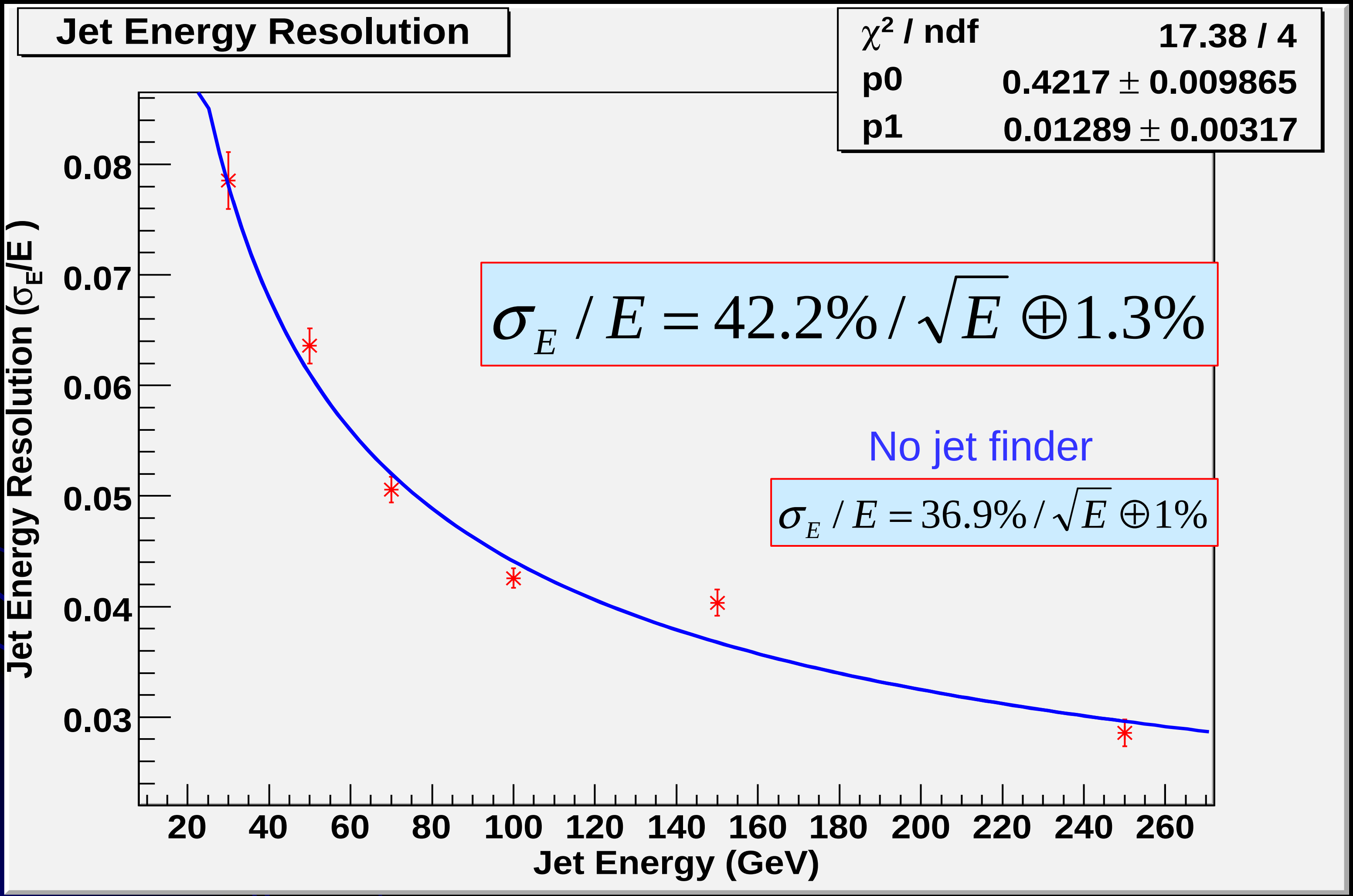




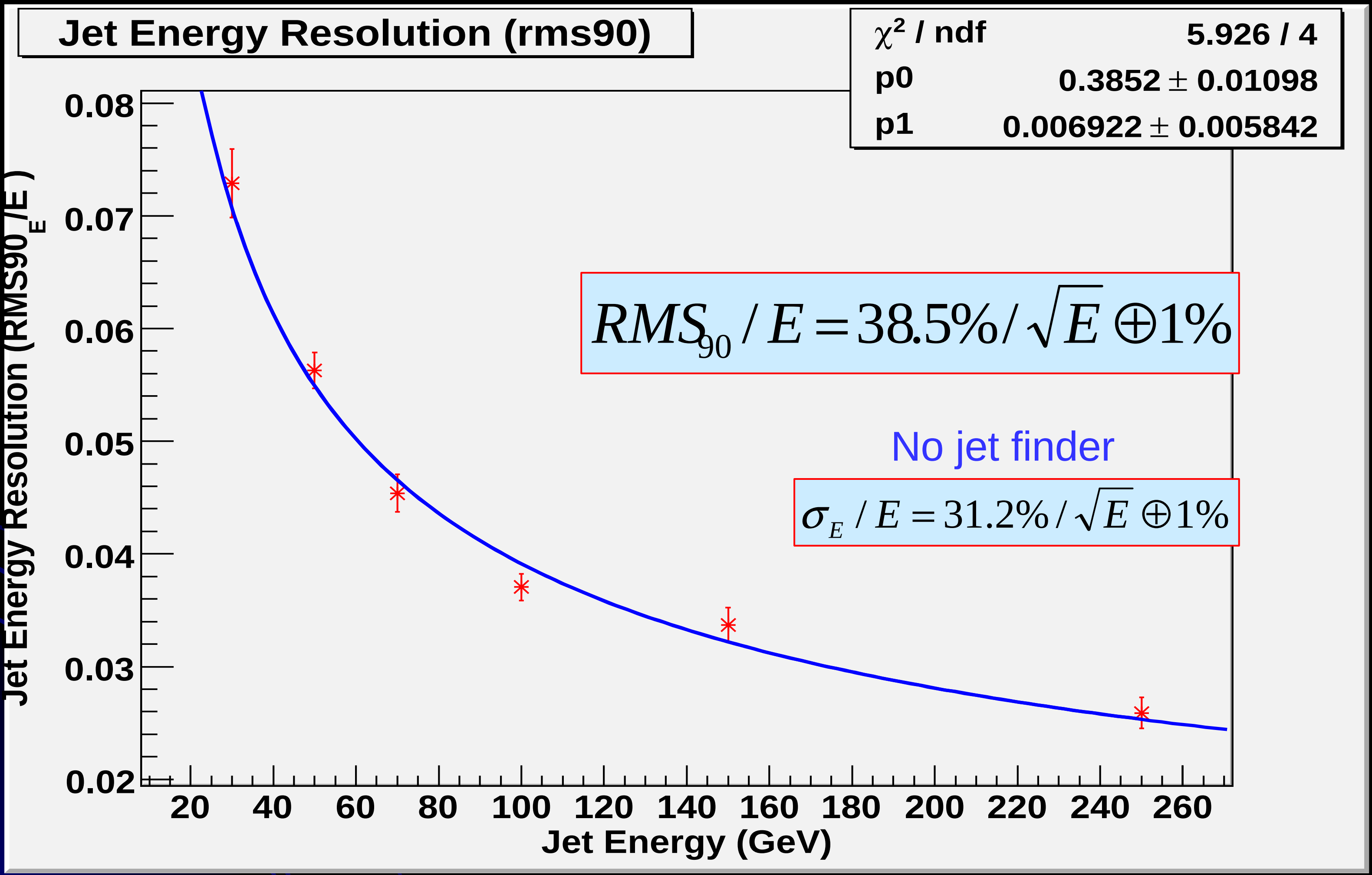
(**rms90** : rms of central 90% of events)

	σ	rms_{90}
E_{jet}(GeV)	$\sigma/E = \alpha/\sqrt{E}$	$\sigma/E = \alpha/\sqrt{E}$
30	43.0 %	39.9 %
50	45.0 %	39.8 %
70	42.3 %	38.0 %
100	42.6 %	37.1 %
150	49.4 %	41.3 %
250	45.2 %	41.0 %

Jet Energy Resolution (gaussian fit)



Jet Energy Resolution (rms$_{90}$)



Jet Reconstruction Performance at Z Pole (91 GeV)

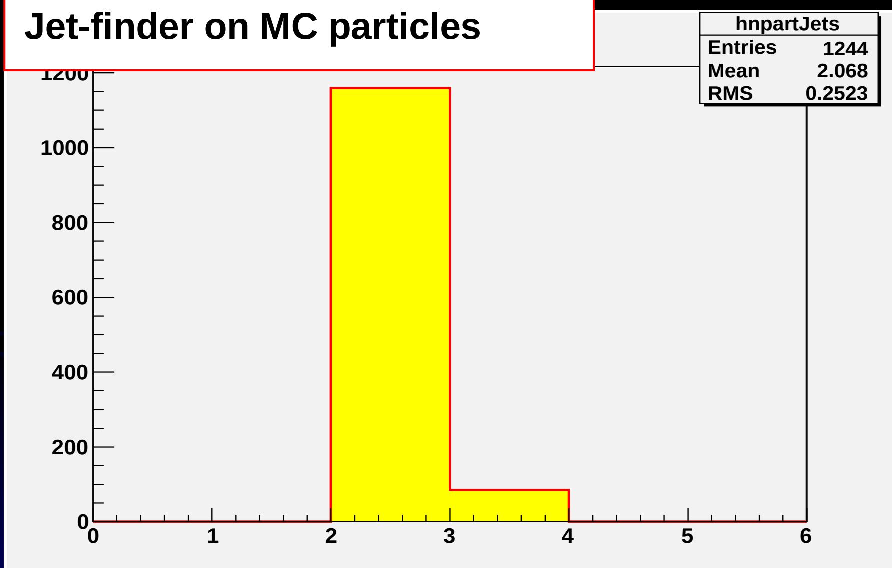
- Number of jets found with Durham (Ycut = 0.07)
- Z Mass Resolution

Number of Jets found

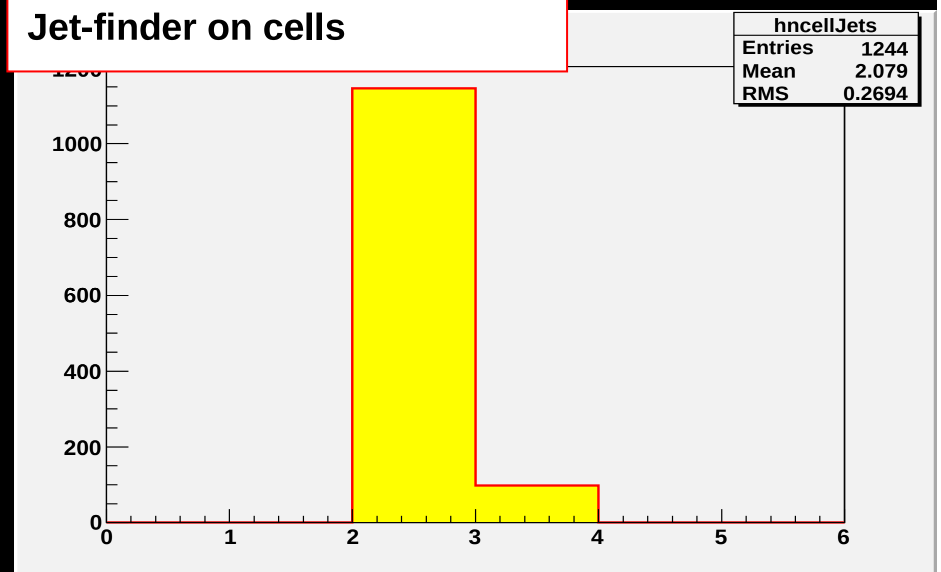
Durham

YCut = 0.07

Jet-finder on MC particles

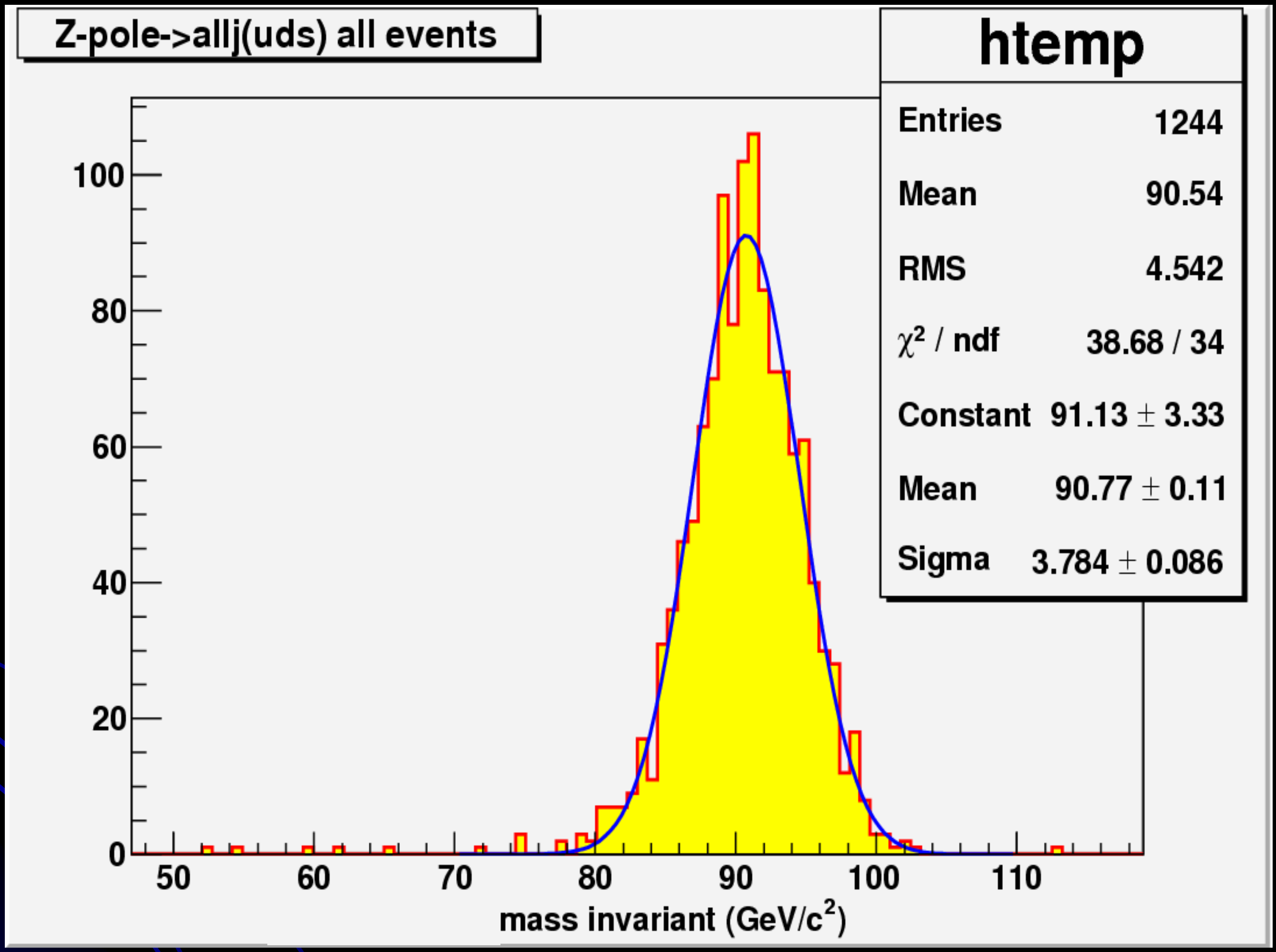


Jet-finder on cells



Z_o Mass (with Gaussian fit)

39.7 %/sqrt(E)

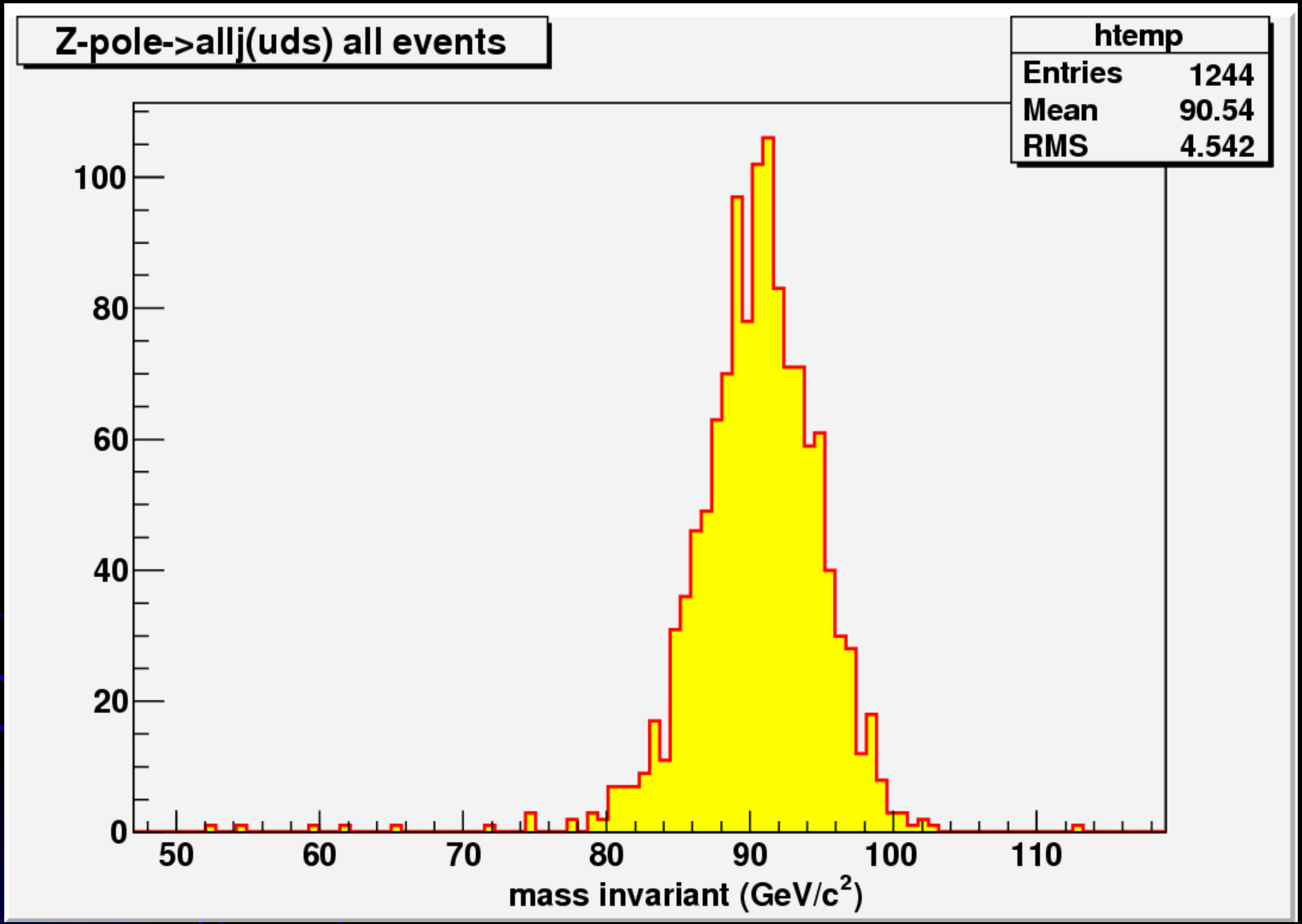


All events, no cuts

Z_o Mass (with RMS_{90})

(rms_{90}: rms of central 90% of events)

32.8 %/sqrt(E)



All events, no cuts

Summary

- Resolution with a fiber Hadronic Calorimeter

  Total reconstructed Energy (clustering based on Calorimeter alone)

  $\sigma_E/E = 36.9\%/\sqrt{E}\ (\sigma)\quad 31.2\ \%/\sqrt{E}\ (rms_{90})$

  Jet reconstructed Energy (Calorimeter + Jet Finder)

  $\sigma_E/E = 42.2\%/\sqrt{E}\ (\sigma)\quad 38.5\%/\sqrt{E}\ (rms_{90})$

All the detectors

are in the simulation:

VXD,DCH,HCAL,MUD

- Improving Resolution :

  Optimize Performance of the Calorimeter

  e.g. measure neutrons to correct visible energy

  (nuclear binding energy losses)

  Use information from Tracking and Calorimetry

  * low transverse momenta tracks, decaying tracks (kinks, V0's), γ's

  * Leftover muons leaving the calorimeter

Backup slides

Total Absorption Dual Readout Calorimeter

Courtesy of Adam Para

- Uniform, integrated (EM+HAD) calorimeter
- High density (~8g/cm3) ←→ 6-7 λ in a typical ILC calorimeter gap
- Linear response to hadrons and electrons (e/h=1)
- Excellent single particle and jet energy resolution
- Excellent electron/photon energy resolution
- Decoupled energy and spatial measurements of EM showers: three silicon pixel layers
- Total absorption calorimeter: minimal reliance on Monte Carlo modeling
- Longitudinal segmentation

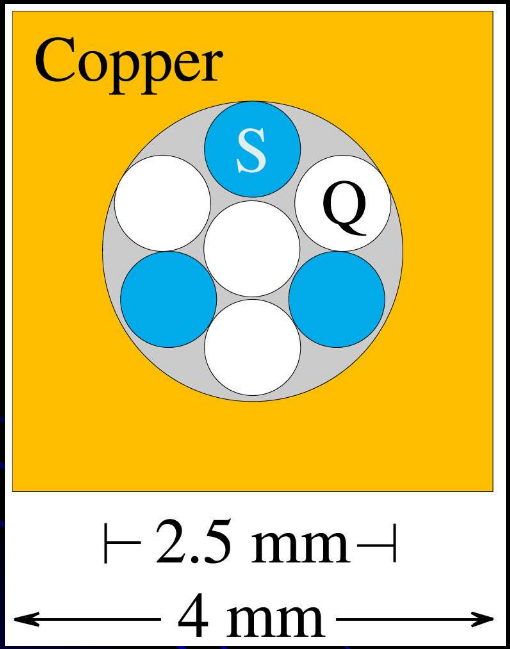
Possible Calorimeter Design

- Heavy crystals ($PbWO_4$, PbF_2 doped with scintillator) or scintillating glass transparent to Cherenkov
- Crystal sizes of the order of 2.5×5×5 cm in the EM 'section' to 10×5×5 cm in the HAD section
- All crystals read-out via silicon photodetectors (hermeticity)
- Crystals glued into full-depth towers

Courtesy of Adam Para

Dual REAdout Module (DREAM)

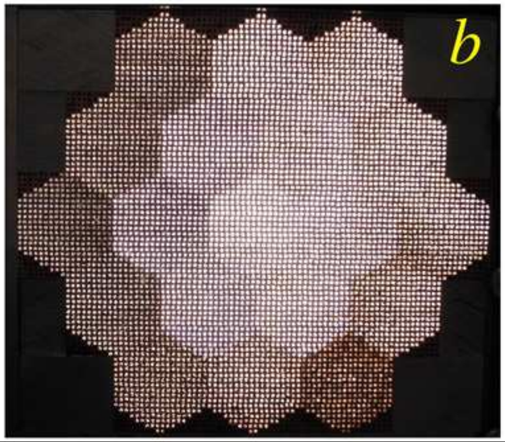
http://www.phys.ttu.edu/dream/



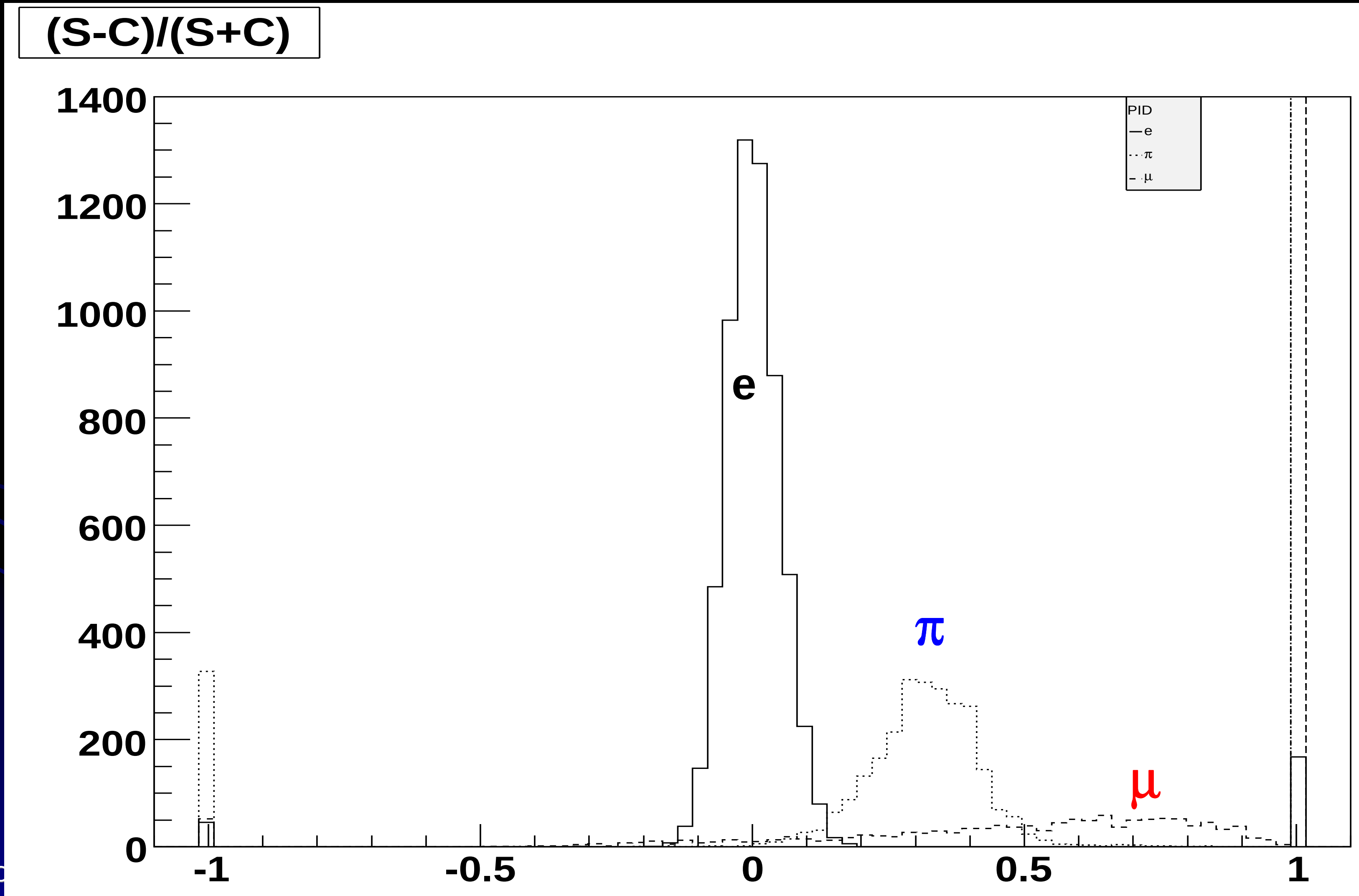
Unit cell

Back end of 2-meter deep module

Physical channel structure



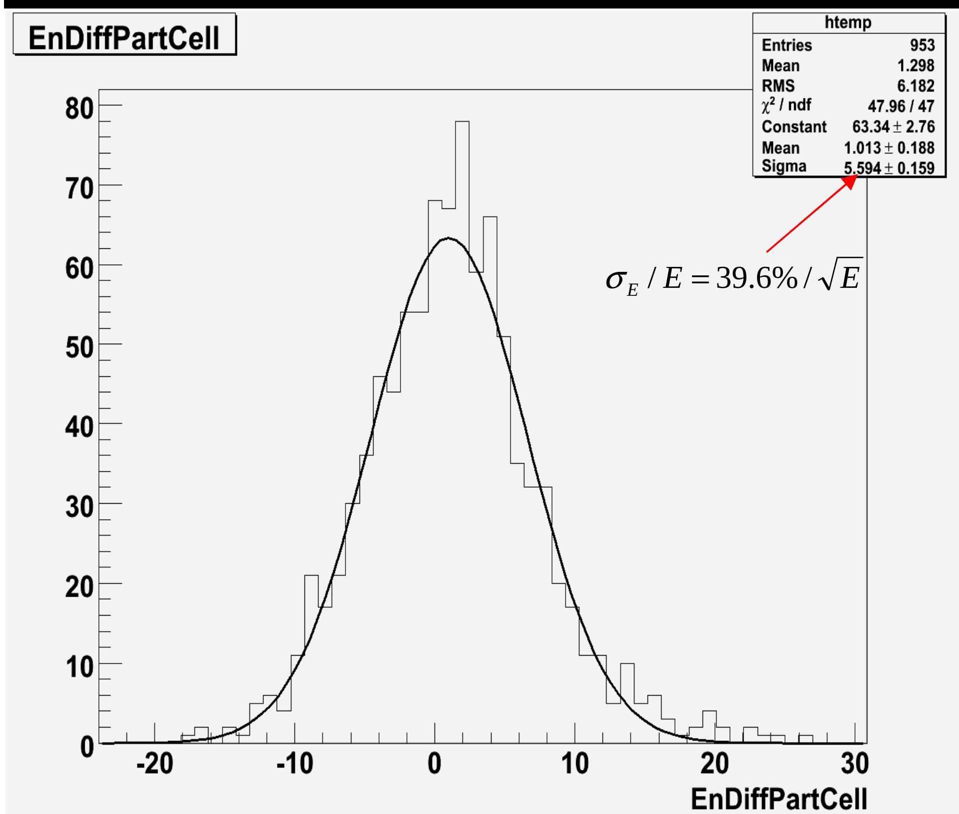
Pid Identification



ALC

E_{CM}=200 GeV

- Calorimetric Energy only



- Calorimetric Energy + Muon Spctrometer