Muons at CalDet

MINOS Collaboration Meeting

October 2001

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- Event Selection
- Muon Energy Spectra and Fits
- Other investigations:

  green/clear comparison

  cosmic muons

  stability of MIP values

  dE/dx(E_{beam})

Introdction

- Objective is to produce a set of numbers corresponding to energy deposited by a muon for each strip (and each side) for detector calibration
- From test-beam runs, muons are selected and energy deposits are histogrammed for each channel
- Muon energy spectra are fitted to give a value corresponding to peak of Landau for each strip
- From using these selection and fitting techniques other investigations are also possible:

  Difference between green/clear fibre readout cables

  Stability of MIP Values

  Cosmic muon energy deposits

  dE/dx as a function of beam energy

Data Used

- 2 GeV runs used to obtain a set of MIP numbers for calibration
- 1.0, 1.6 and 2 GeV runs used to investigate dE/dx as a function of muon energy
- A single cosmic run was also analysed

Event Selection in Beam Data

Look at each event in turn and apply the following selection criteria:

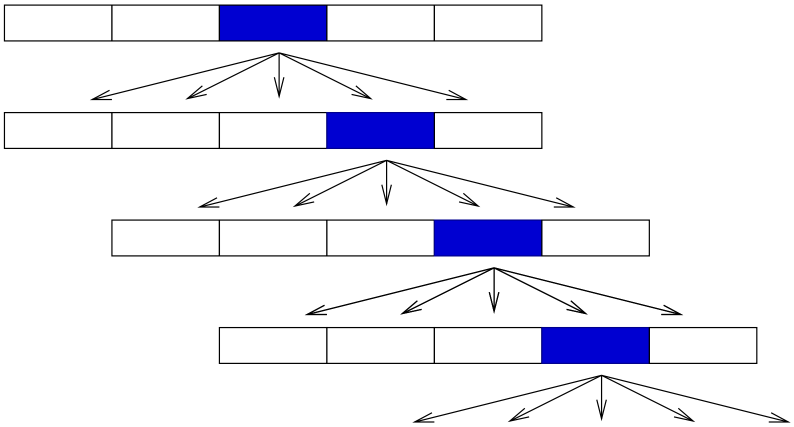
Cuts:

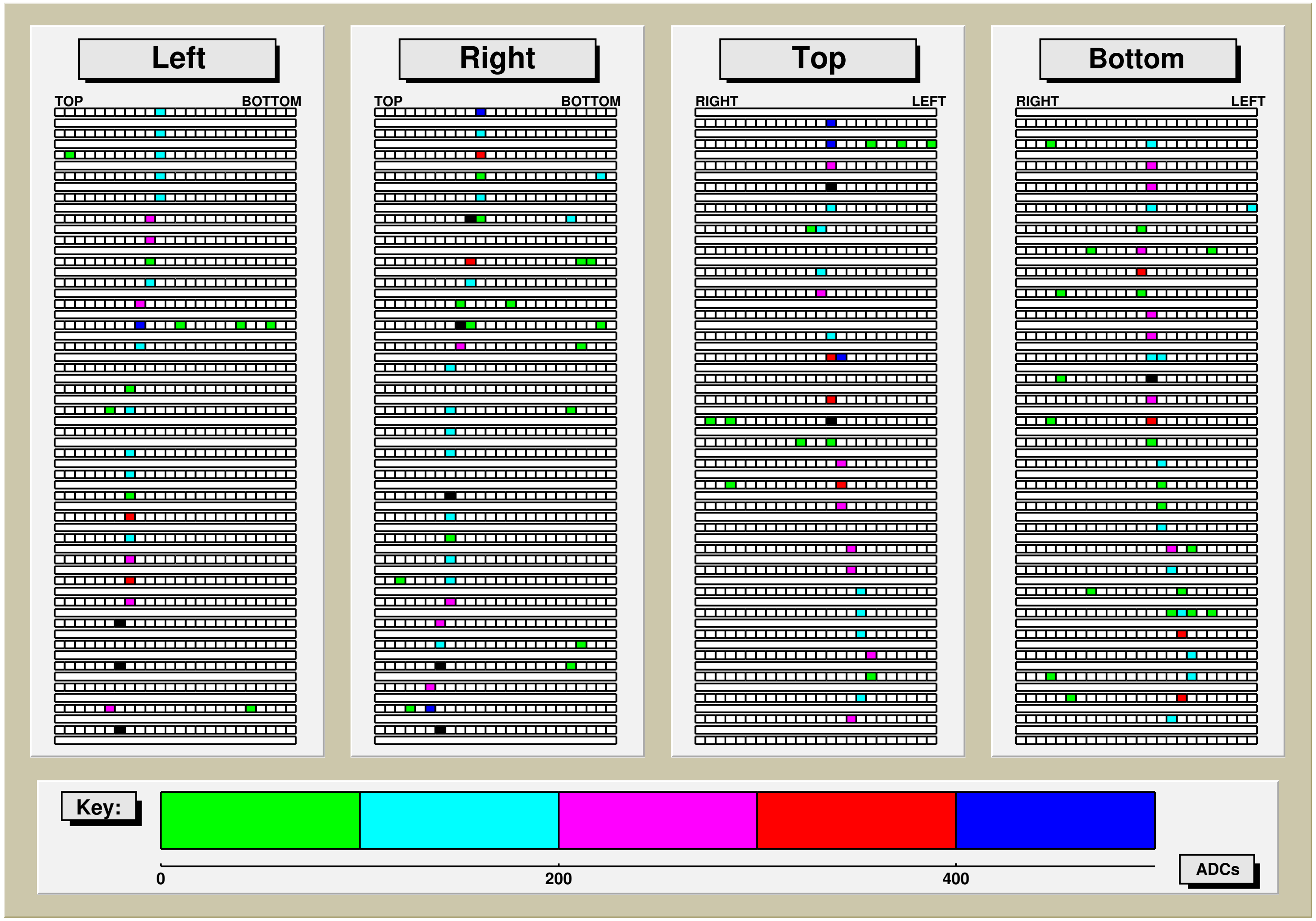
- Total number of hits in an event >= 16
- Number of hits in a "track" >= 4 (in both orientations => minimum track length = 8 planes)
- Along the path of a track, no more than 2 hit strips in 5, per plane
- Angle of track must be < 10 degrees in all 4 views wrt beamline
- Only hits in a track seen on both sides are accepted

To find a "track":

Find a hit in strip n, look for another hit in the next plane (of same orientation) within n+/-m strips, etc...

Stop tracking if more than 2 hits are seen in a block of n+/-m strips or if 2 hits within a block occur in 2 consecutive planes

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Key:
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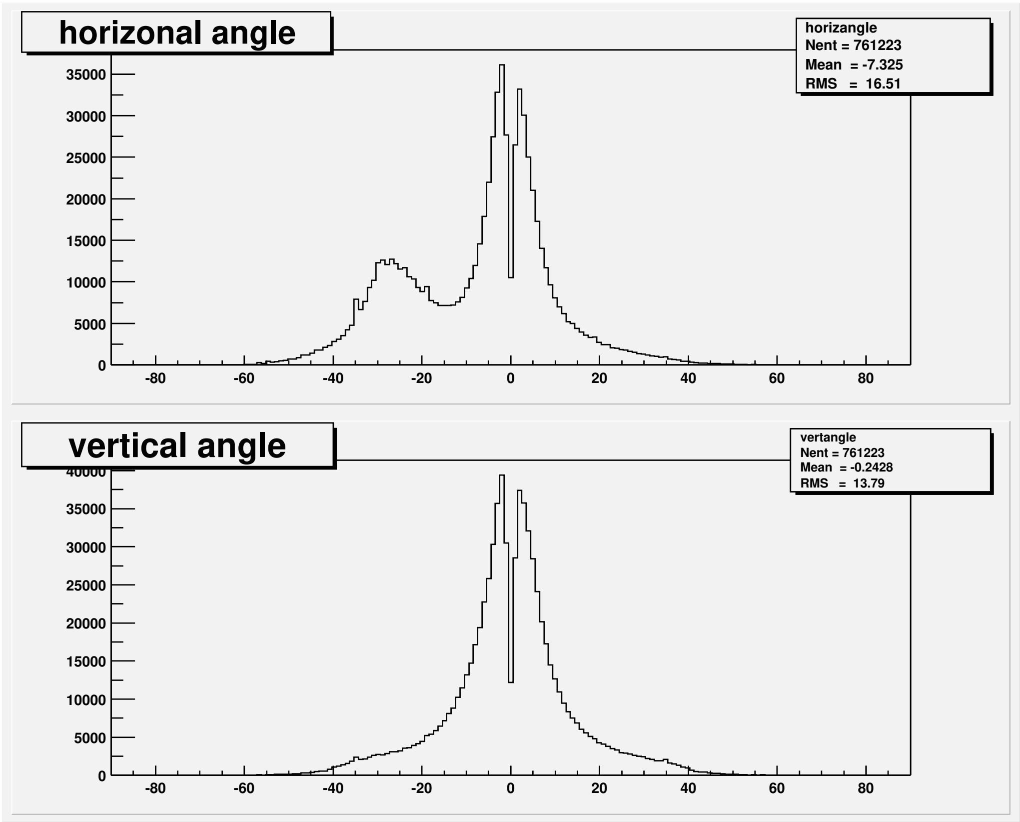
200
400
ADCs

Cut	Approx. No. of events	% of total	% of previous
None	3,700,000	100	100
>=16 hits	3,250,000	87.8	87.8
4 Hit Track (even planes)	1,114,000	30.1	34.3
4 Hit Track (odd planes)	1,215,000	32.8	37.4
Track in both even and odd	761,000	20.6	65.3
<10 degrees	350,000	9.5	46.0

Table 1: Selection Statistics from a 2 GByte Beam Run. Typically $\sim$ 9-10% of events pass all cuts.

Angles of Muon Events from Beam

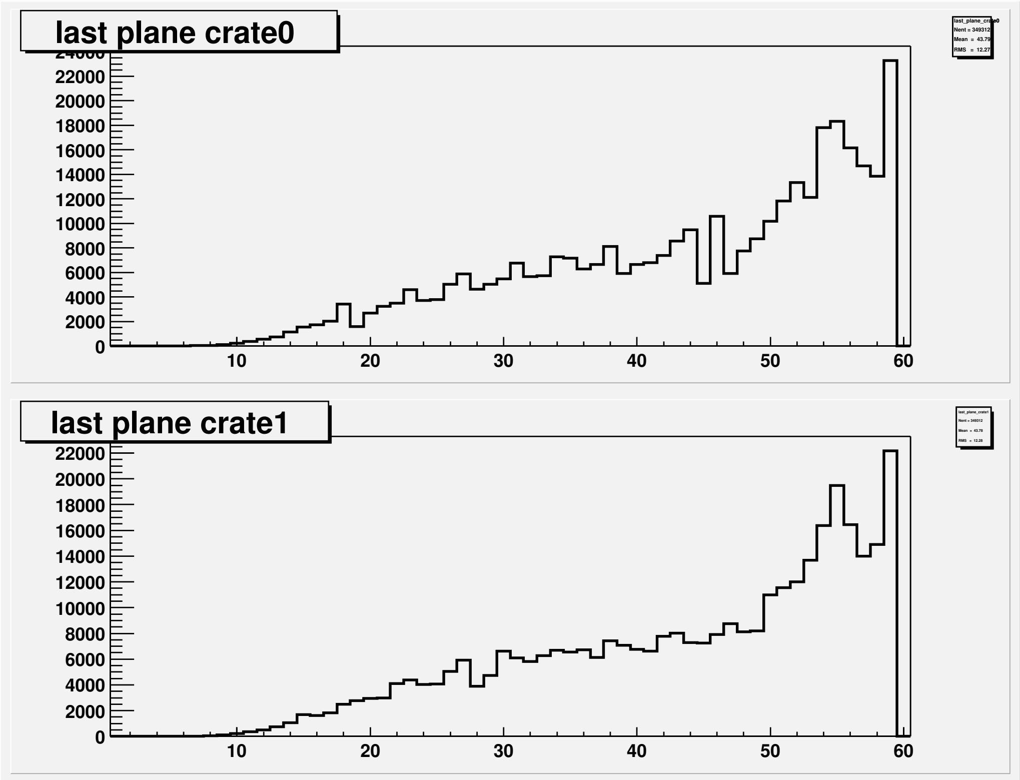


Peaks around 0 as expected in both horizontal and vertical angle.

Secondary peak in horizontal angle corresponding to muons from PS

Last Plane Hit/Track Length

Looking at the last plane hit in each selected event:



Stopping distance for 2 GeV muons peaks at $\sim$ plane 55

Fitting Function

- Energy deposition in thin strips of material follows a Landau distribution $\longrightarrow$ assume the parameters of the Landau can be used to characterise the shapes of the MIP histograms
- Histograms are too wide to be fit using a Landau alone $\Rightarrow$ need to convolute Landau with another function to simulate extra width (esp. due to PMT)
- MIP energy deposits are small $\longrightarrow$ low light levels at the photocathode $\Rightarrow$ convolute with a Poisson distribution
- We require:

$$L \otimes P = \int L(\lambda, \mu, \sigma).P(n, \lambda)d\lambda$$

  Where:
  L(x,μ,σ) is the Landau distribution with mean μ and width σ and
  P(x,λ) is the continuous Poisson distribution with mean λ

- Difficult to calculate!

Fitting Function

Instead:

- Use the ROOT adapted CERNLIB routine for Landau
- Simulate integral with summation:

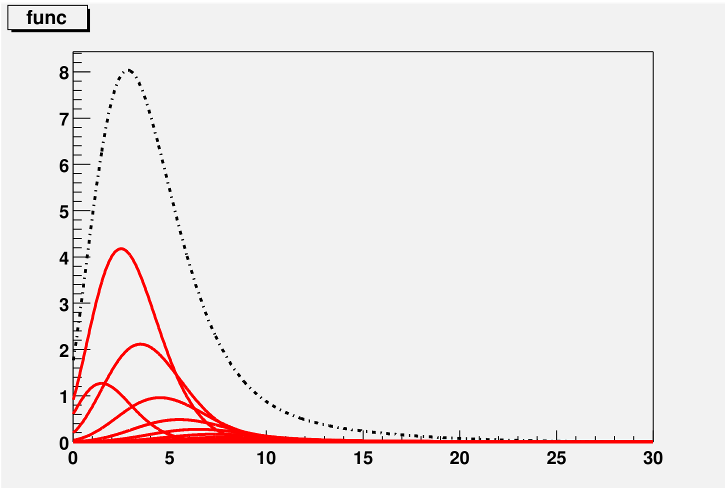
$$L \otimes P \approx N \sum_{\lambda=1}^{20} L(\lambda.s, \mu, \sigma).P(n, \lambda.s)$$

Where the basic units used are NPEs and s is a scale factor which depends on the range of the histogram

- Therefore need 3 fit parameters: μ and σ in NPEs from Landau, and a normalisation constant, N

Example with:

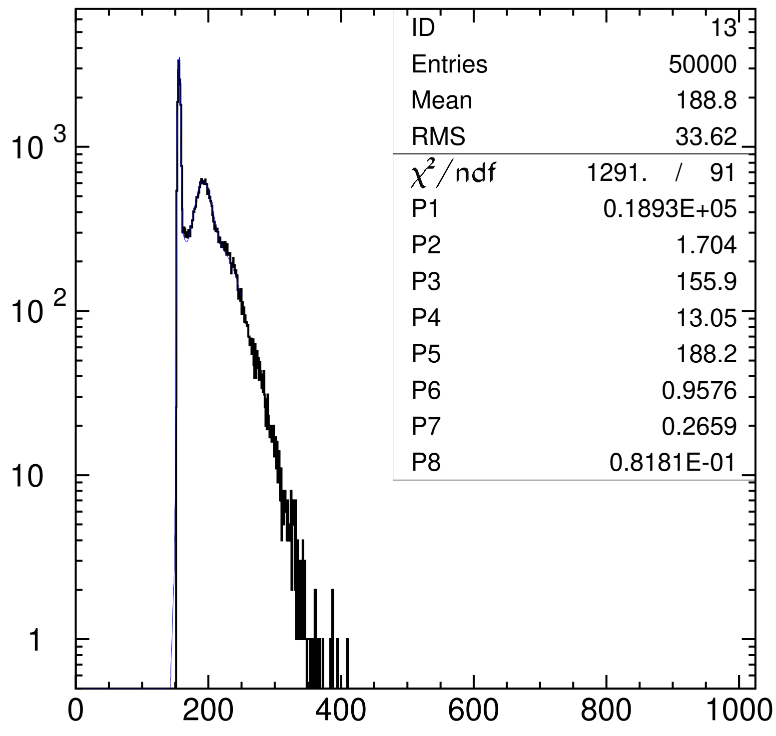
$\mu = 3$
$\sigma = 0.5$
$N = 100$
$s = 20$



Converting to NPEs

The fitting function needs a value for the gain. This is obtained either:

- From fits to low light level distributions (Ryan Nichol)

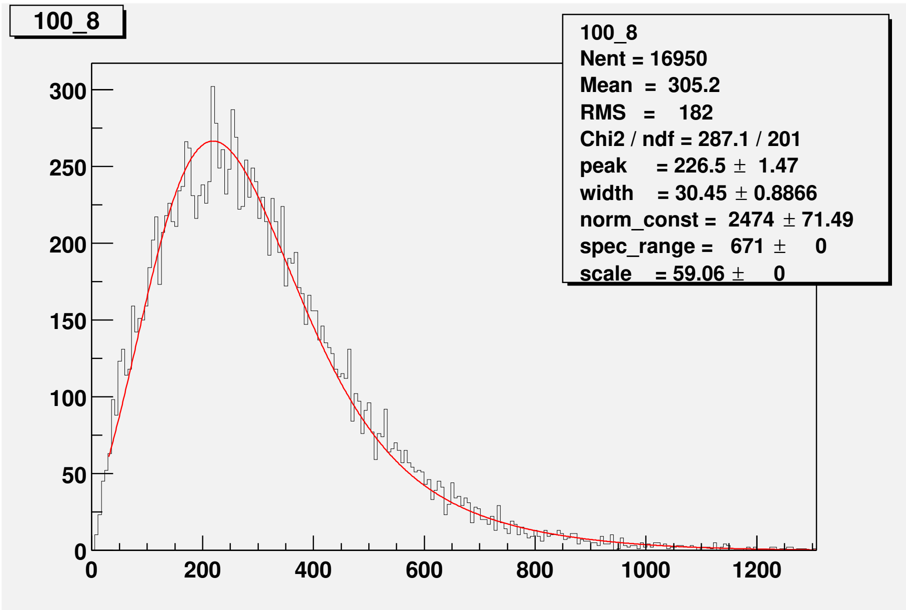


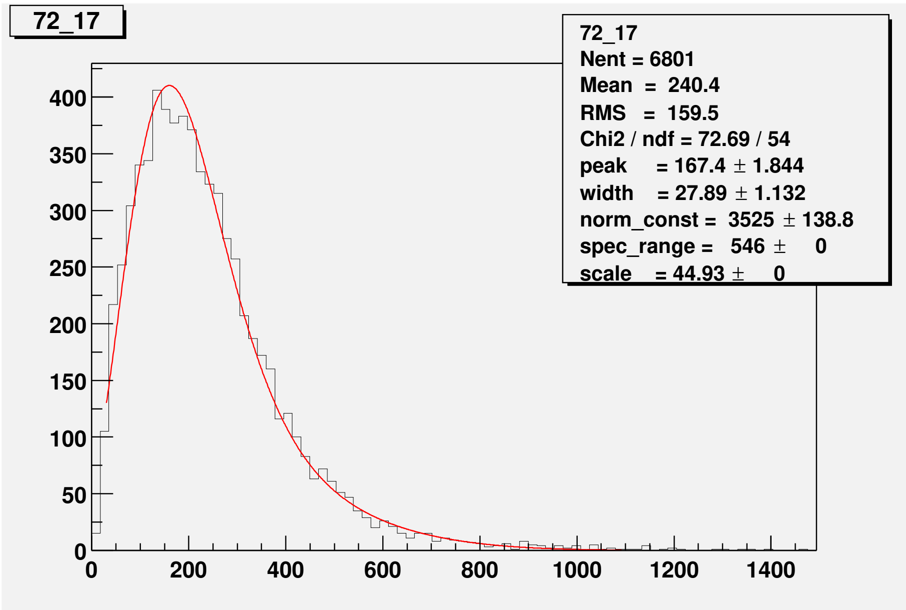
- Or from high light level LI distributions using mean/sigma method (Leo Jenner)

Fit using both sets of values and use fit with best chi2/ndf value

Examples of Fits

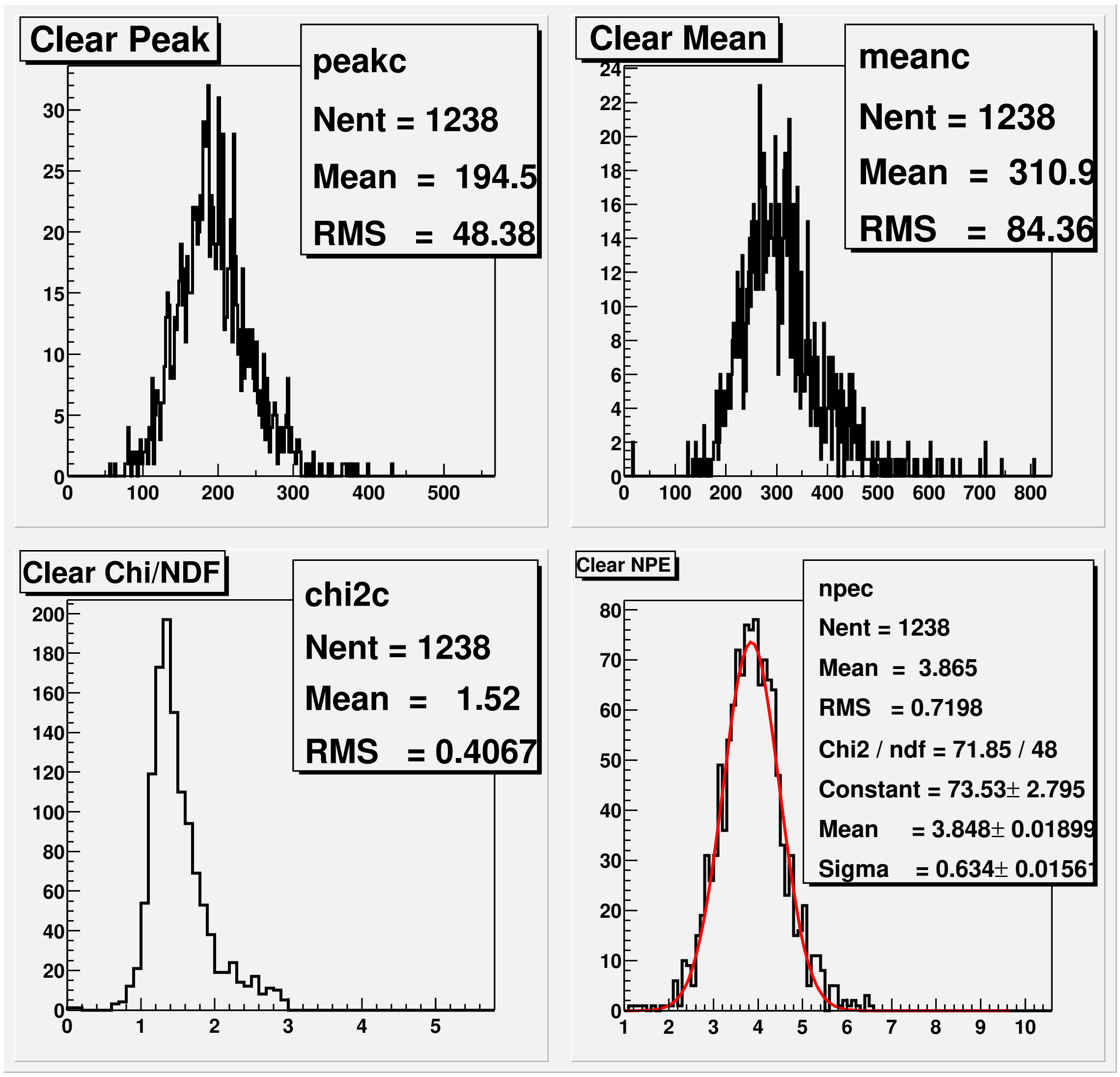
Histograms are rebinned and fit using the function above. Examples:





Fit Summaries

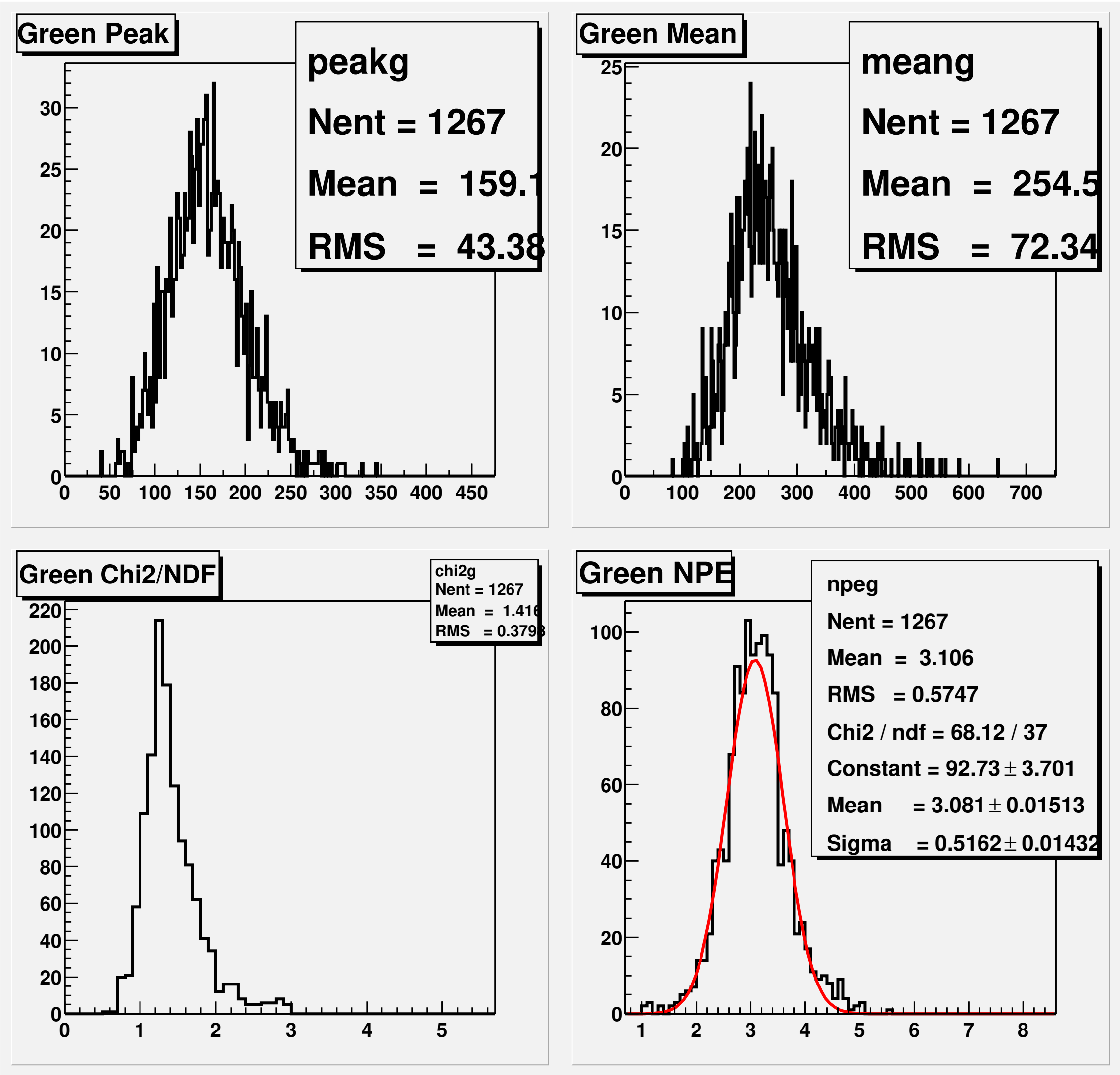
For Clear Fibre Readout:



Mean MIP value = 3.85 +/- 0.02

Fit Summaries

For Green Fibre Readout:

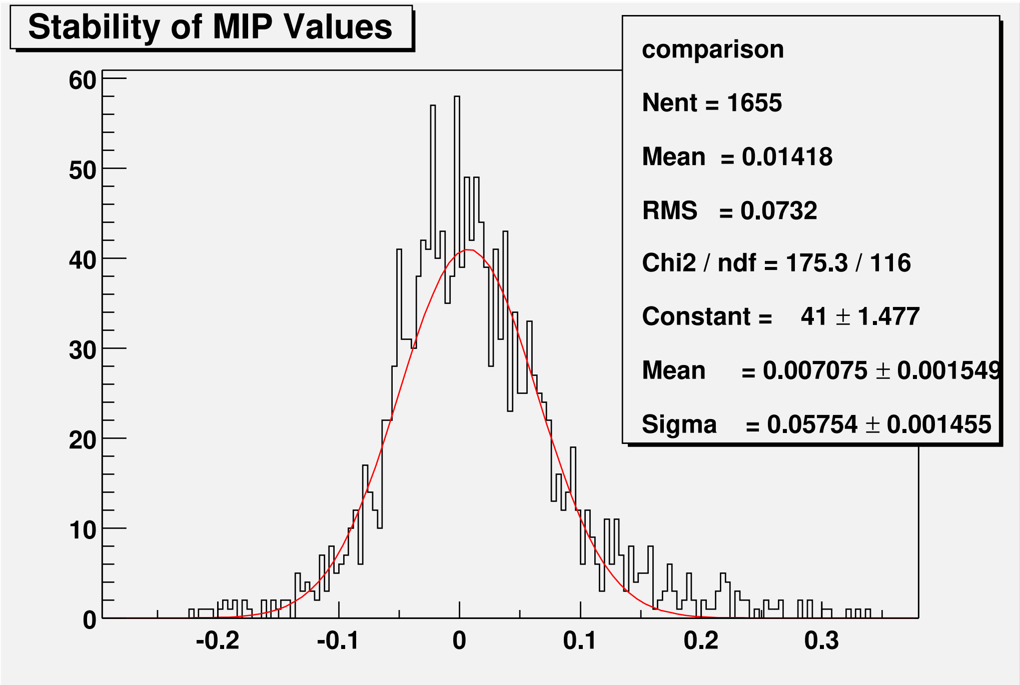


Mean MIP value = 3.08 +/- 0.02

Stability of MIP Values Over Time

Comparing two runs collected a month apart

Look at fractional difference in peak positions for all (possible) channels:



Peak is at zero, width $\sim$6%

Green/Clear Comparison

Green Fibre: Mean MIP value = 3.08 +/- 0.02

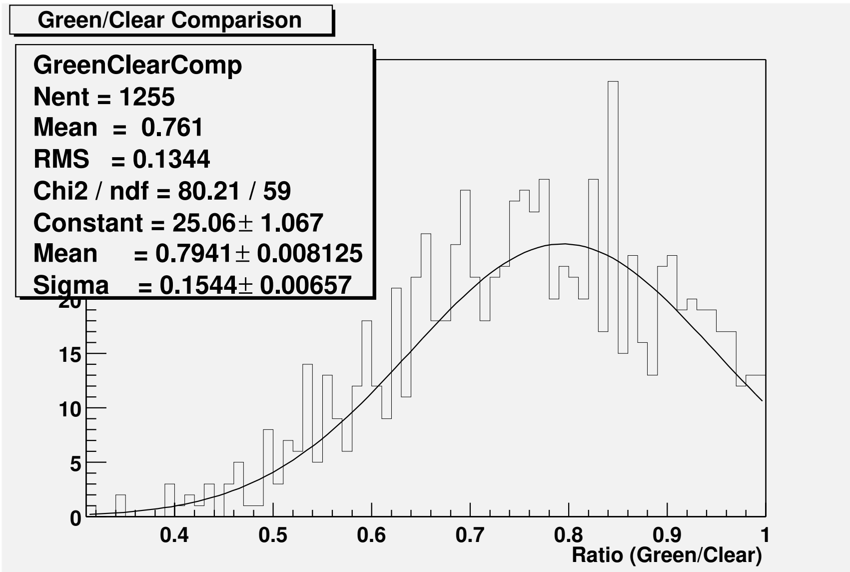
Clear Fibre: Mean MIP value = 3.85 +/- 0.02

Assuming the only difference between the two values is the difference in fibre attenuation length, the ratio (green/clear) should be: exp(-4/6)/exp(-6/11) $\approx$ 0.89

(assuming green attenuation length = 6m and clear attenuation length = 11m)

From means: 3.08/3.85 = 0.80 +/- 0.01

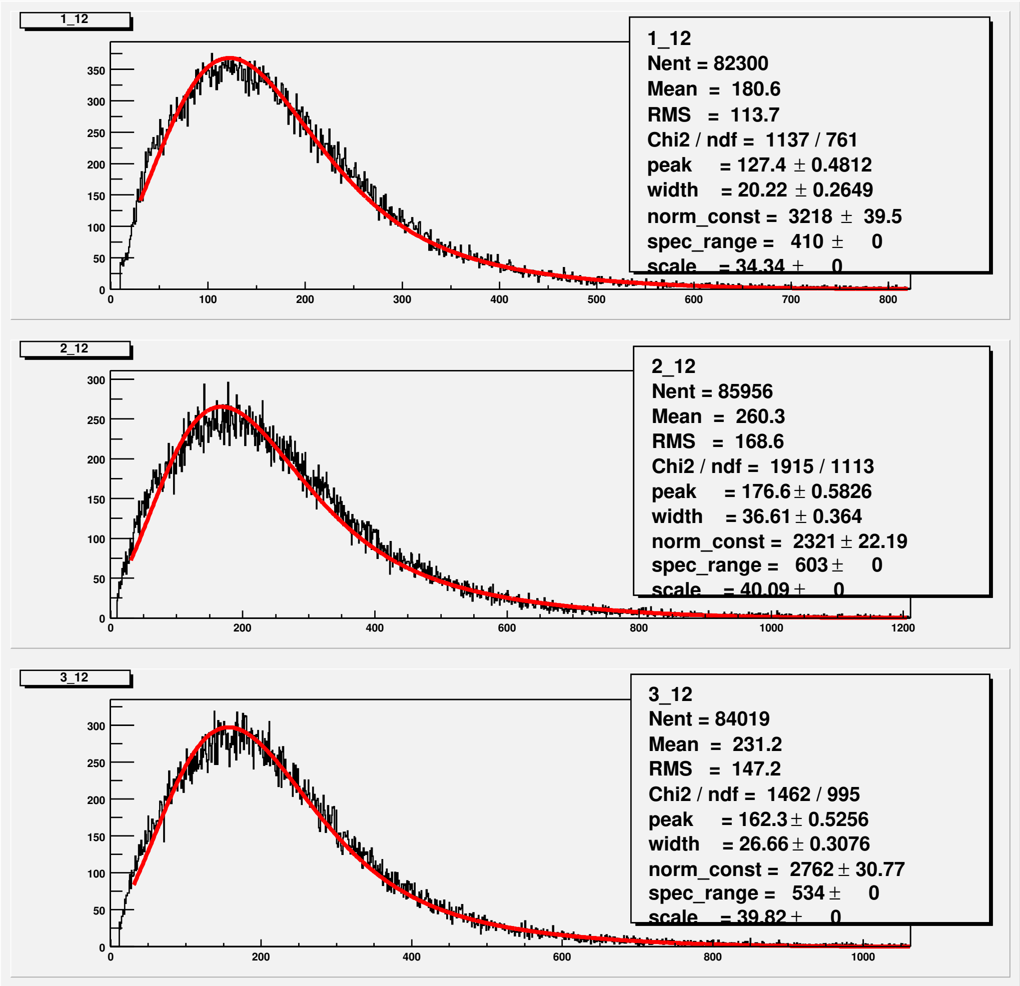
From histogram of ratios by strip: 0.79 +/- 0.01



Given a clear attenuation length of 11m, this value predicts 5.2m for green fibre

Energy Spectra - Fine Structure

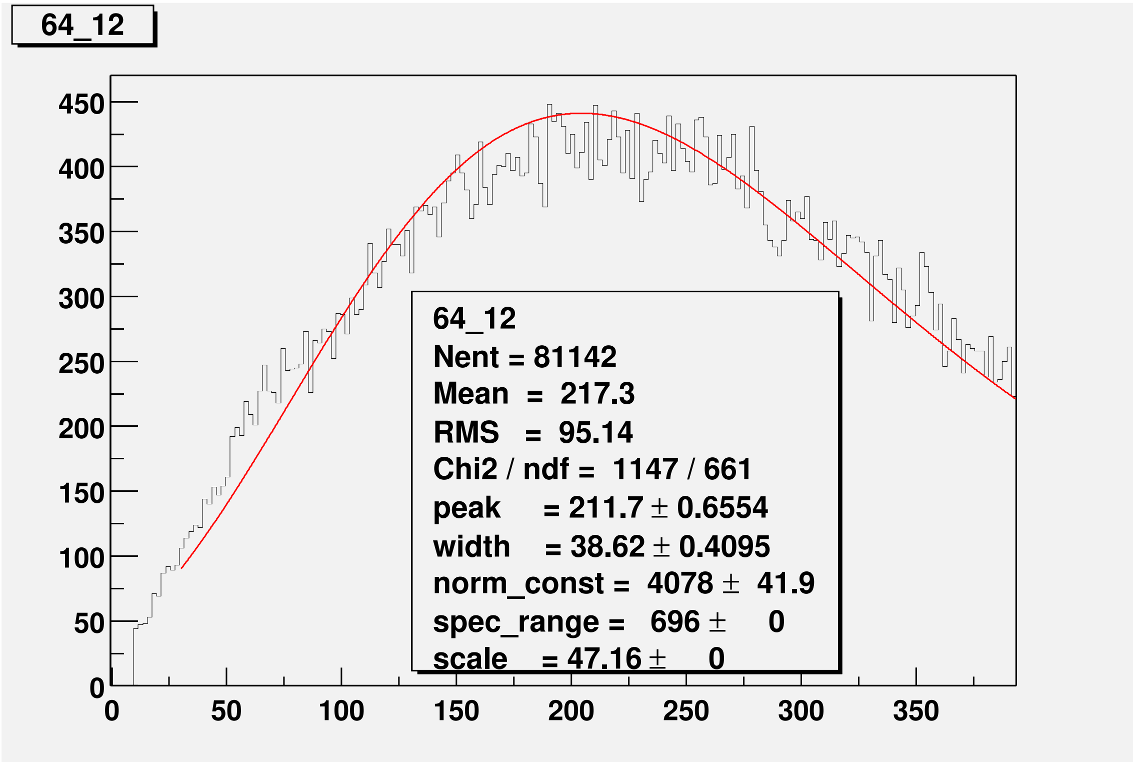
The spectra with the highest numbers of entries exhibit structure not modelled by my fit:



First time there have been enough statistics to see this feature.

Some work is needed to understand the structure and to modify the fit.

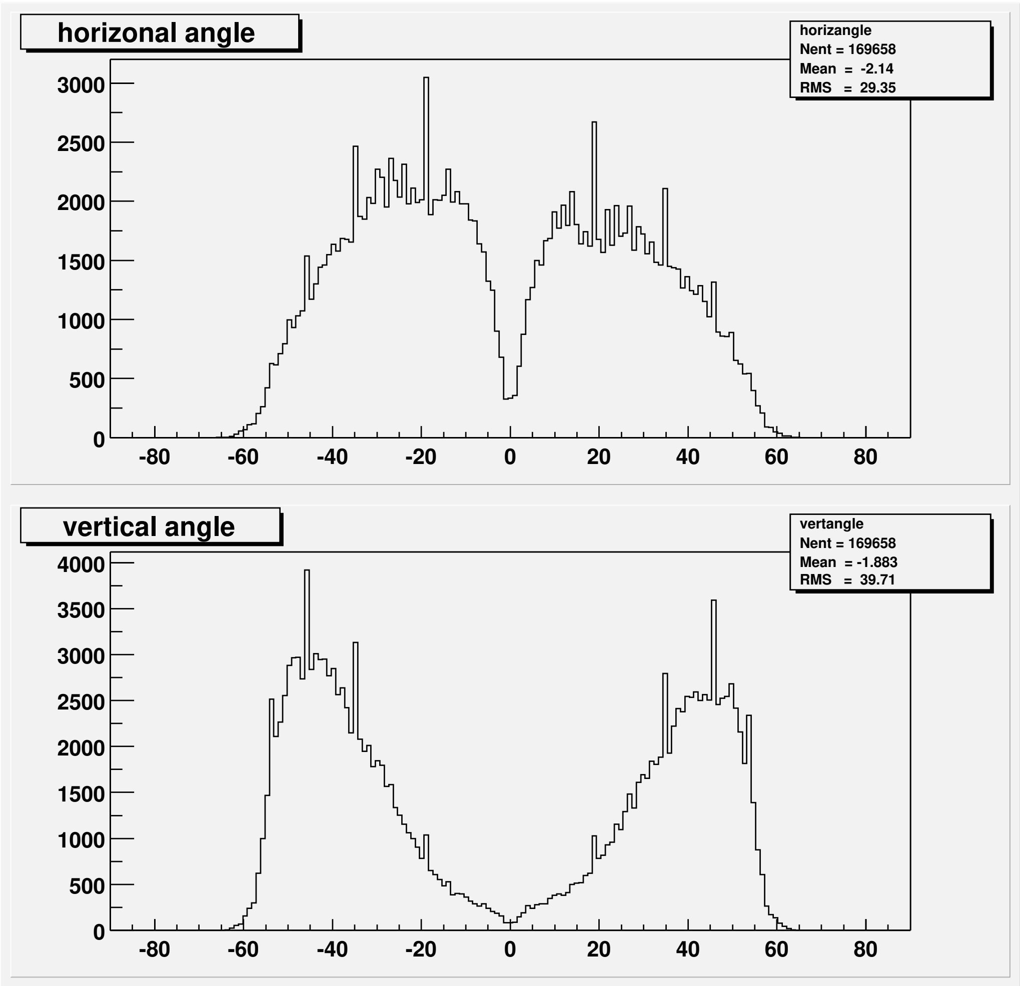
Energy Spectra - Fine Structure



Cosmic Runs

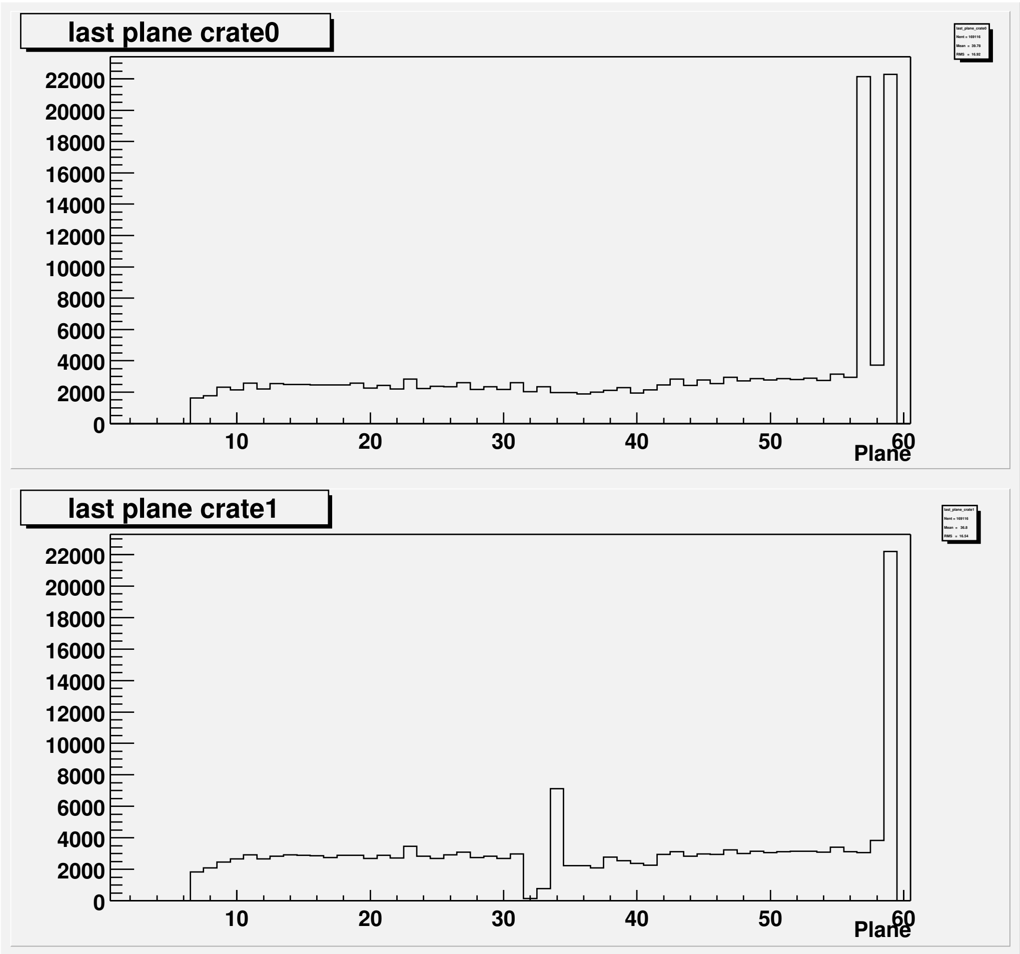
- Using same event selection but with a higher angular acceptance
- Correct energy deposits for different paths through scintillator
- Fit spectra using same fitting function

Angular Distribution of Cosmic Events



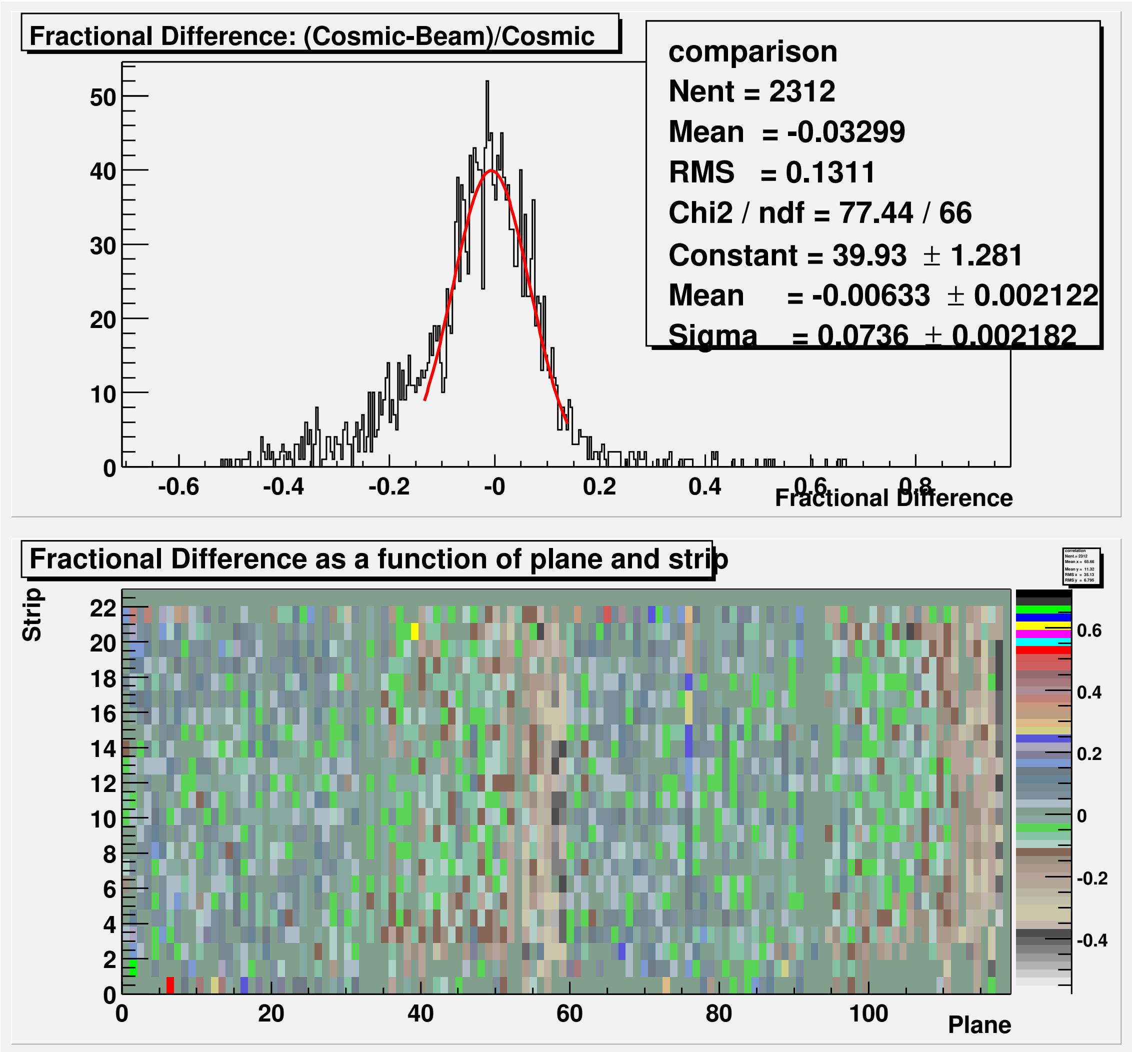
Cosmic Runs

Last Plane Hit in Cosmic Events



Cosmic Runs

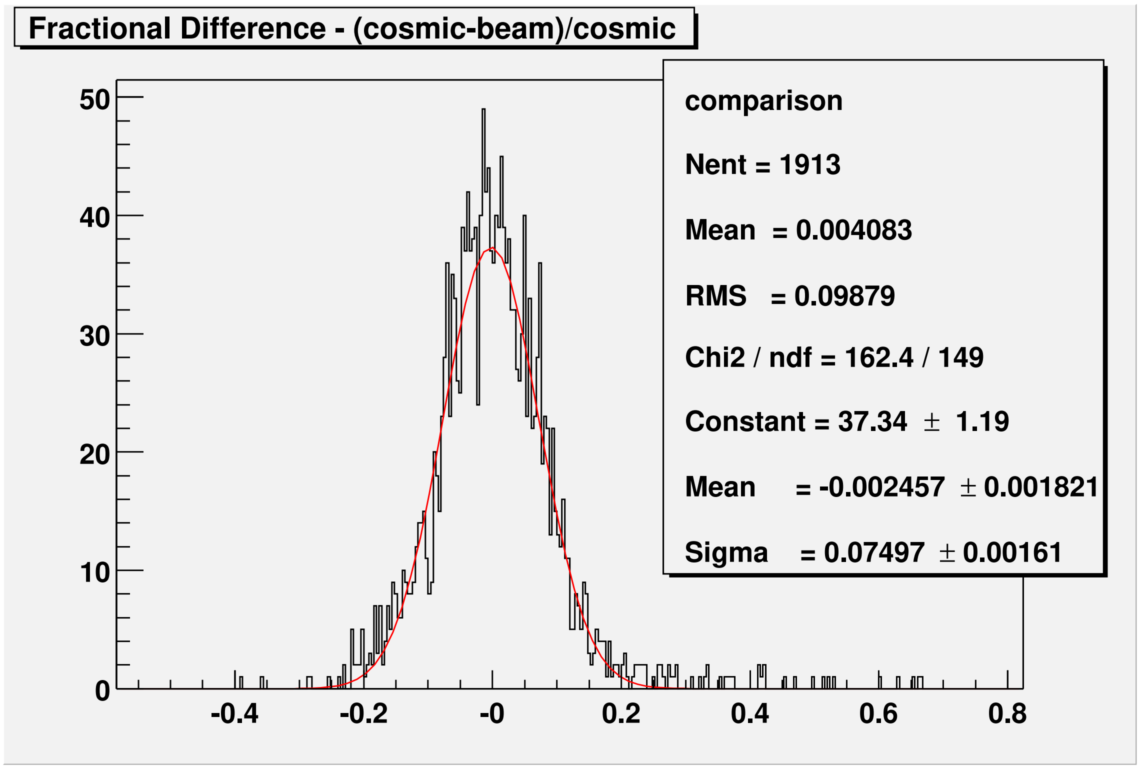
Beam/Cosmic Comparison



Cosmic Runs

Beam/Cosmic Comparison

Look only at planes 1-50:



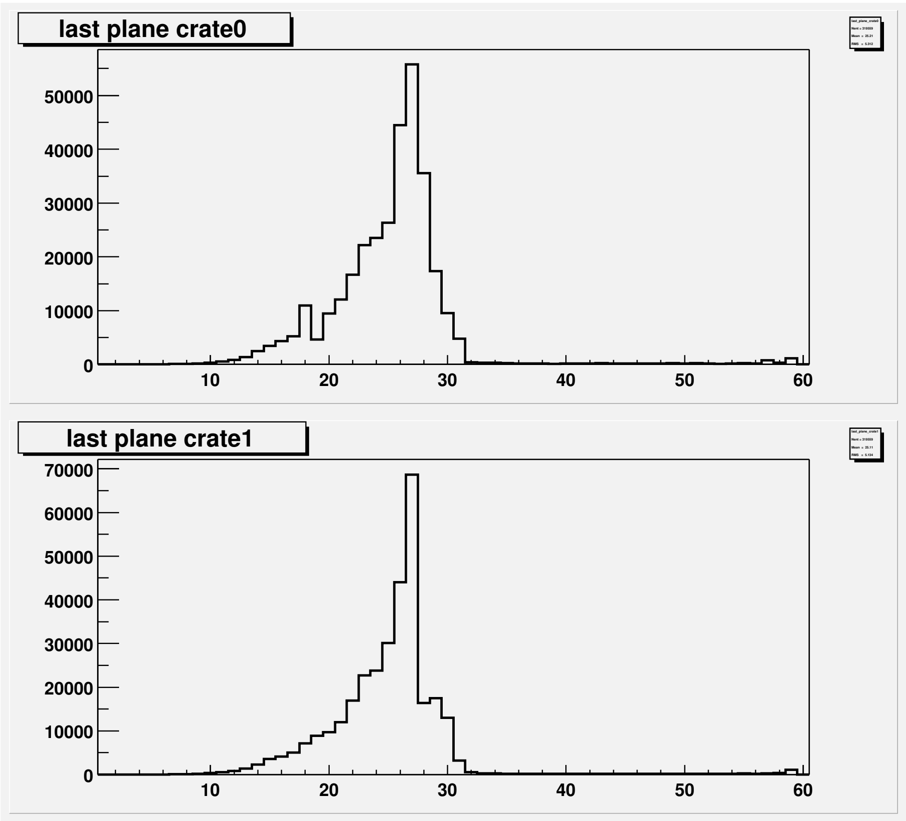
Beam and Cosmic Energy Deposits agree to within ∼7.5%

Energy Loss

Stopping Muons

- To understand energy loss as a function of muon energy, look at three runs for beam energies 1, 1.6 and 2 GeV
- Know that the most energetic muons in a run have the beam energy. Need to select these muons for this measurement
- Look at stopping muons: histogram last plane hit in all muon events for each run

For 1 Gev Run:



Energy Loss

- Muons with maximum beam energy correspond to those in the peak
- Select only muons stopping in peak plane (+/- 1 plane) then fill and fit energy spectra as before
- Look at strips in the front planes of detector to find energy loss

Stopping Plane:

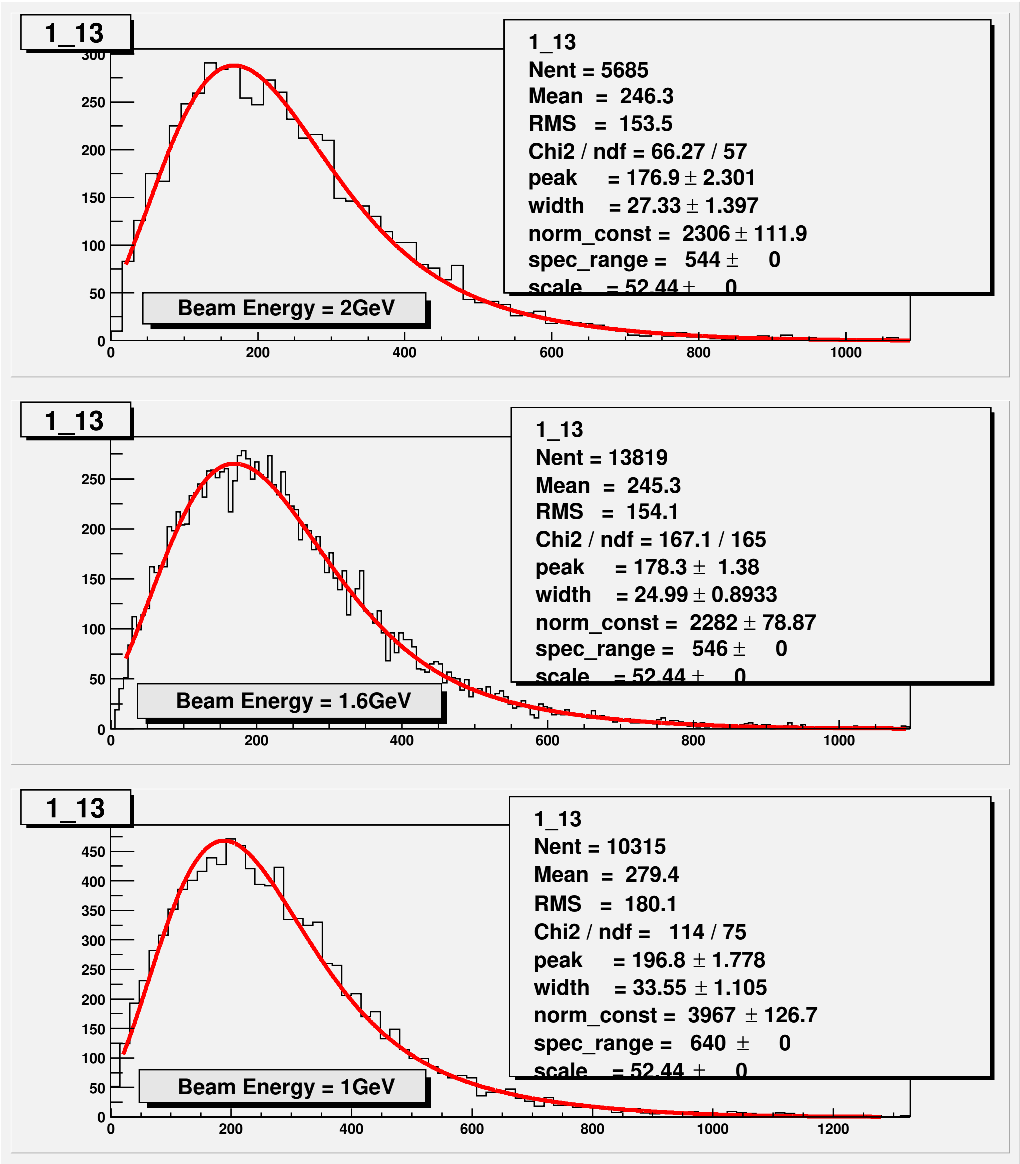
1 GeV : plane 27

1.6 Gev : plane 43

2 GeV : plane 55

Energy Loss

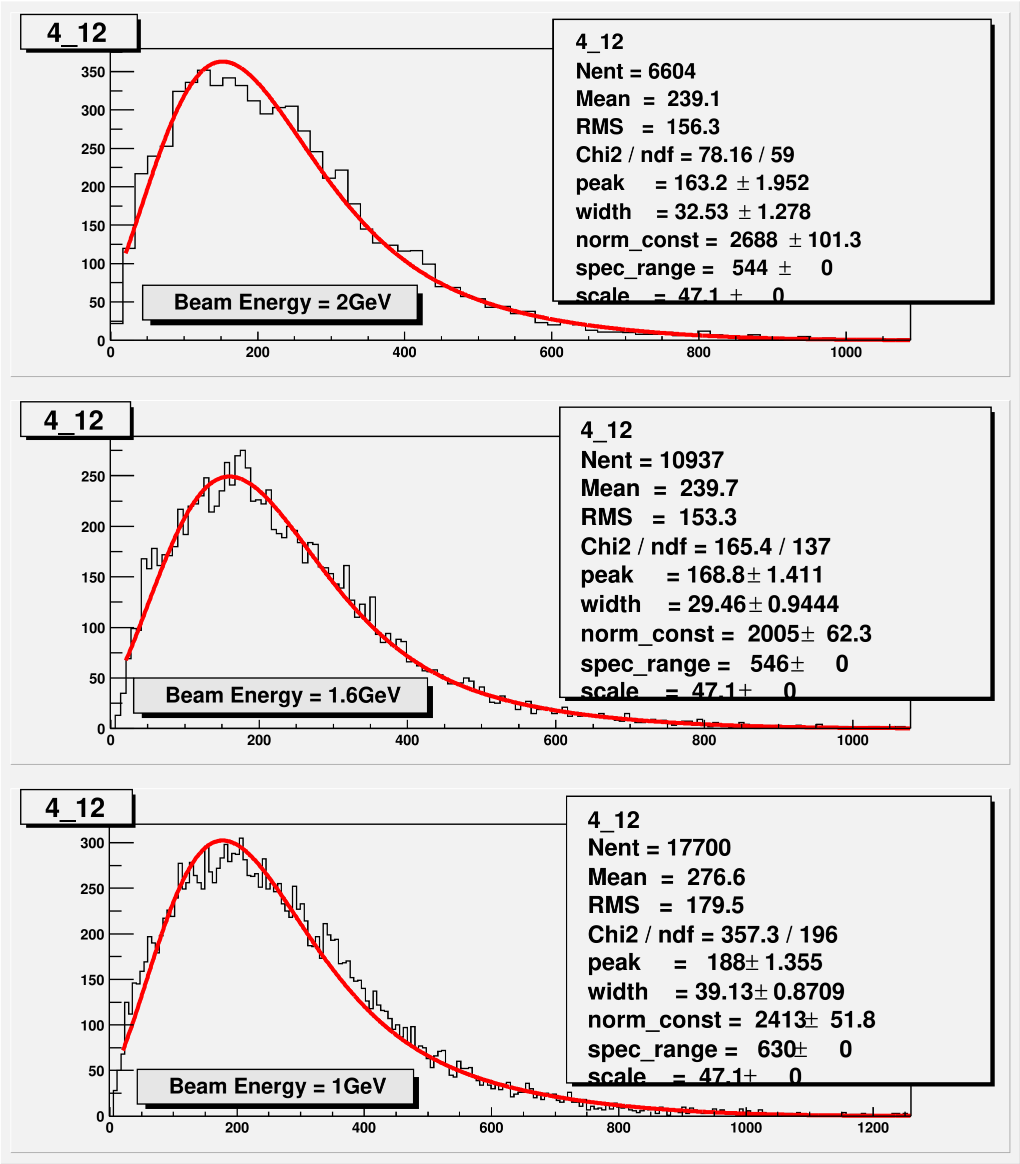
Look at a single strip in plane 1:



Energy Deposited by 1 GeV muon is greater than that for 1.6 and 2 GeV

Energy Loss

Look at a different strip in plane 4:

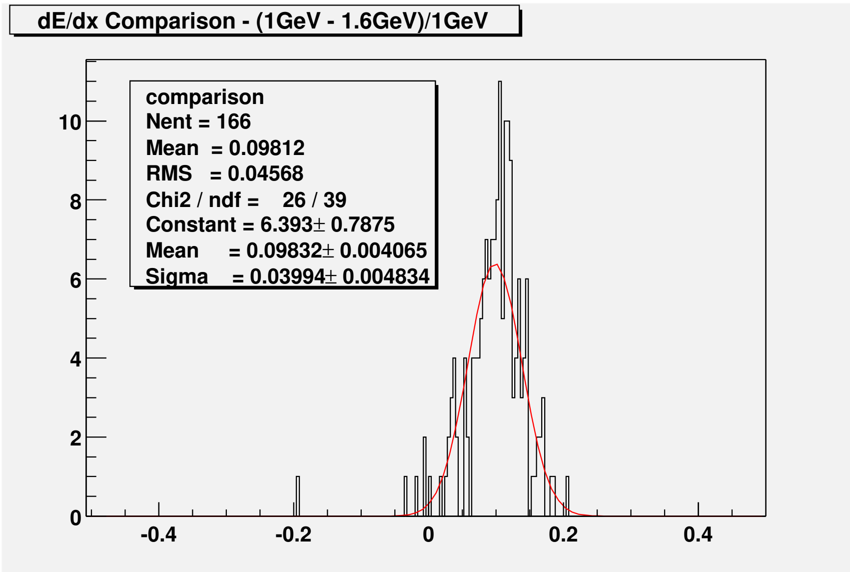


Same pattern

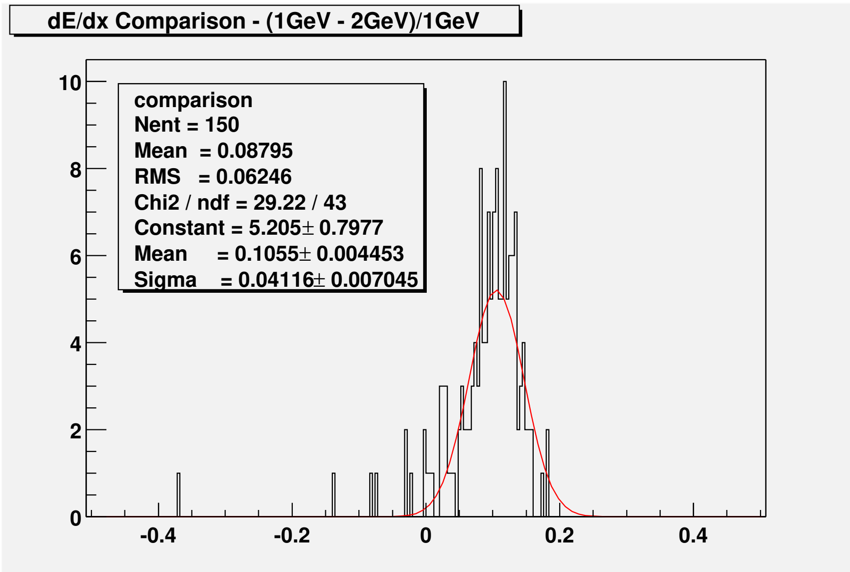
Energy Loss

Compare energy deposits from all possible strips in first 15 planes:

Fractional difference between 1 and 1.6 GeV energy deposits



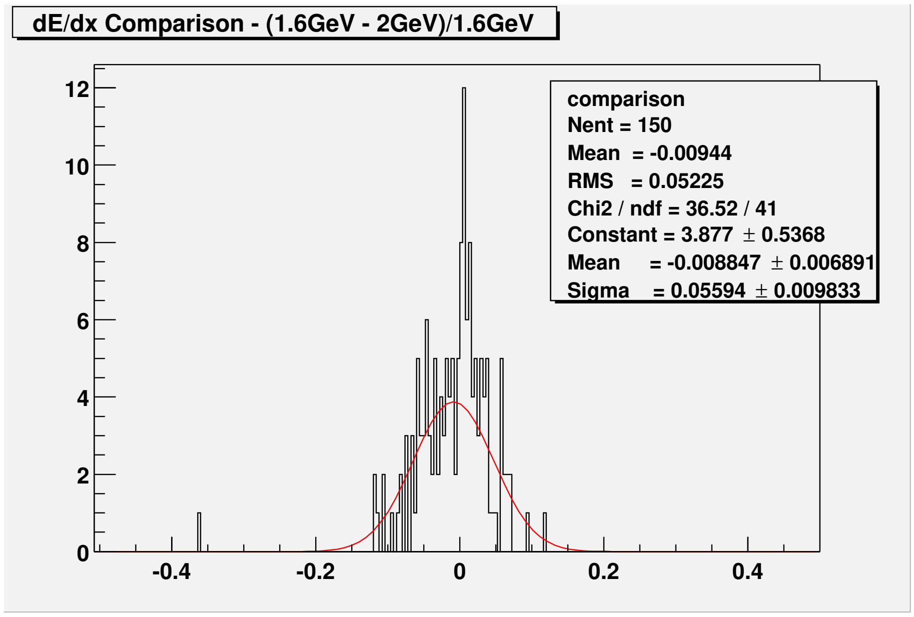
Fractional difference between 1 and 2 GeV energy deposits



Energy Loss

The muons from the 1 GeV beam deposit ∼10% more energy than the muons from the higher energy beams

Can also look at the fractional difference in muon dE/dx between the 1.6 and 2 GeV beam:



Appear to be the same to within ∼5%

Summary

- At 2 GeV, mean MIP values are

  for clear: 3.85 pes

  for green: 3.08 pes

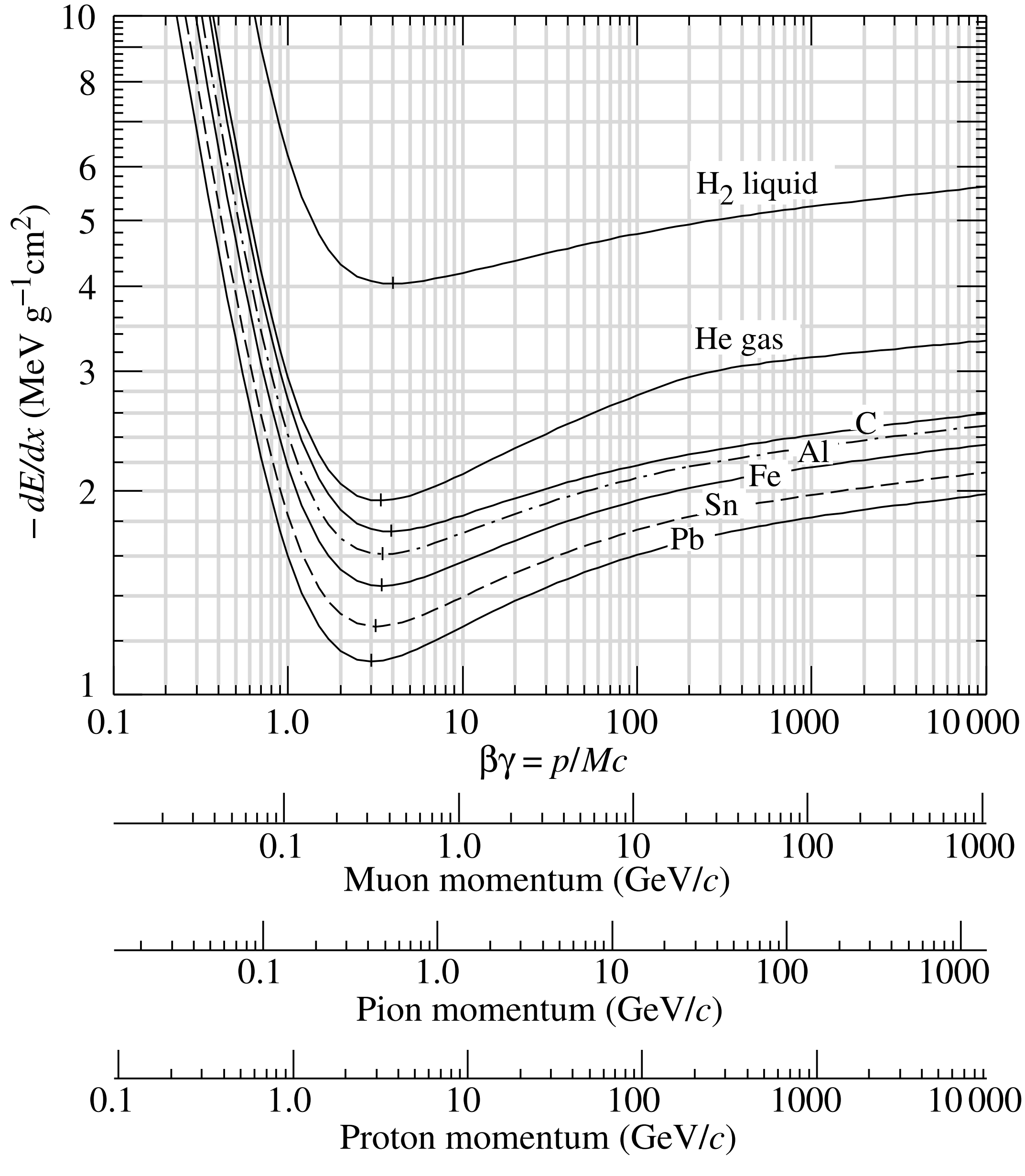
- Fine structure in muon energy spectra needs to be understood

- MIP values are stable to $\sim$6% over the period of a month

- Corrected MIP values for cosmics agree with 2 GeV measurements to $\sim$7%

- Looking at stopping muons, maximum energy muons from 1 GeV beam deposit $\sim$10% more energy than muons from both 1.6 and 2 GeV beam

Just in case



H2 liquid
He gas
C
Al
Fe
Sn
Pb
−dE/dx (MeV g−1cm2)
βγ = p/Mc
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1.0
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100
1000
10 000
1
2
3
4
5
6
8
10
Muon momentum (GeV/c)
Pion momentum (GeV/c)
Proton momentum (GeV/c)