Study of T11 Beam Specifications and Rate of Muon Energy Loss in the Calibration Detector

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First Year Talk

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Preview

- **Neutrino Oscillations:** There is now strong evidence that neutrinos oscillate from one flavour to another and therefore that they have mass.
- **MINOS:** The Near and Far Detectors sample the neutrino beam and look for changes.
- **Calibration:** At CalDet we use a beam of protons, pions, electrons and muons to calibrate the detectors.
- **Monte Carlo:** We compare Monte Carlo simulations to the real data to make sure we understand everything.
- **de/dx:** We need to look at the rate that muons lose energy as they travel through the detector as part of the calibration process.
- **MC to Data Comparison:**Whilst looking at muon de/dx we discovered that the data was not consistent with the beam specifications.
- **Results:** The muons' energies were about 3.8% higher than expected. The spread of momenta of the muons was 5% around the specified energy and not 1.5%

Neutrino Oscillations

- Too few ν_μ 's from the atmosphere
- Not enough ν_e 's arriving at the earth from the sun
- Super Kamiokande $\longrightarrow$ neutrinos change from one flavour to another
- Quarks: their weak and mass eigenstates are not the same
- Hence oscillating neutrinos are massive
- Not allowed in the Standard Model
- Neutrino mass and weak eigenstates $\longrightarrow$ 3 x 3 matix
- Two flavour approximation:

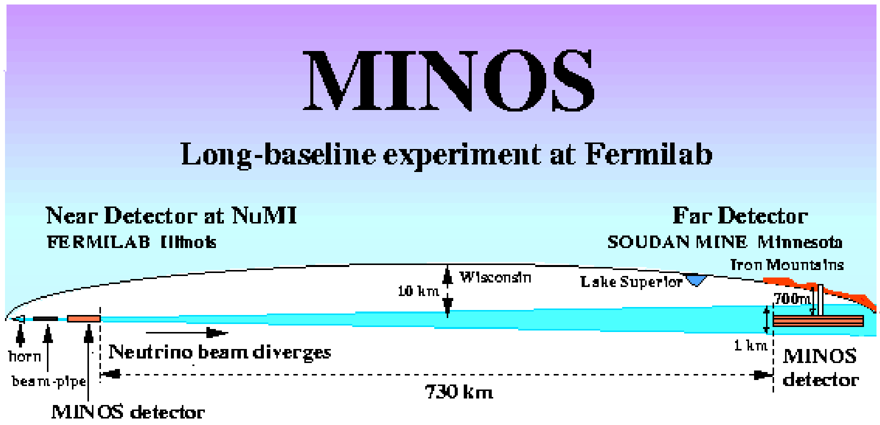
$$\begin{bmatrix} \nu_\alpha \\ \nu_\beta \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} \nu_1 \\ \nu_2 \end{bmatrix}$$

- This gives the transition probability equation for flavour α to flavour β:

$$P_{\alpha\beta} = sin^2 2\theta sin^2(1.27\Delta m^2 L/E_\nu)$$

  where θ is the neutrino mixing angle, $\Delta m^2 =$ m_1^2 - m_2^2 of mass eigenstate 1 and 2, L is the path length in km and E is the neutrino energy in GeV
- Over 10 billion neutrinos go through your thumbnail every second - we should try to find out about them!

MINOS



- MINOS stands for the Main Injector Neutrino Oscillation Search
- Beam of mainly ν_μ from Fermilab, Illinois to Soudan mine, Minnesota
- The beam is sampled by the 'Near' Detector at Fermilab...

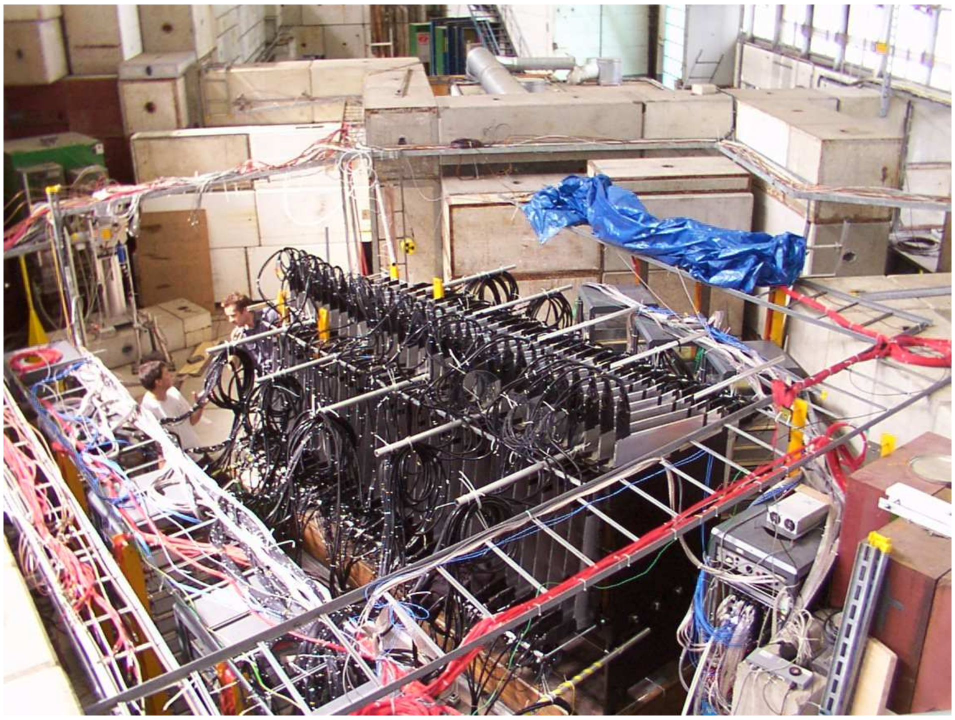
MINOS

- ...and the 'Far' Detector at Soudan

- We look for differences in the neutrino event characteristics and rate
- Long tracks seen in the detectors are likely to be muons
- Fewer long tracks in Far Detector: $\nu_\mu \rightarrow \nu_\tau$
- B-field bends muon tracks $\rightarrow$ better momentum resolution

Calibration

- Near/Far Detector uses iron+scintillator planes
- Planes are calibrated using cosmic muons $\longrightarrow$ MEU



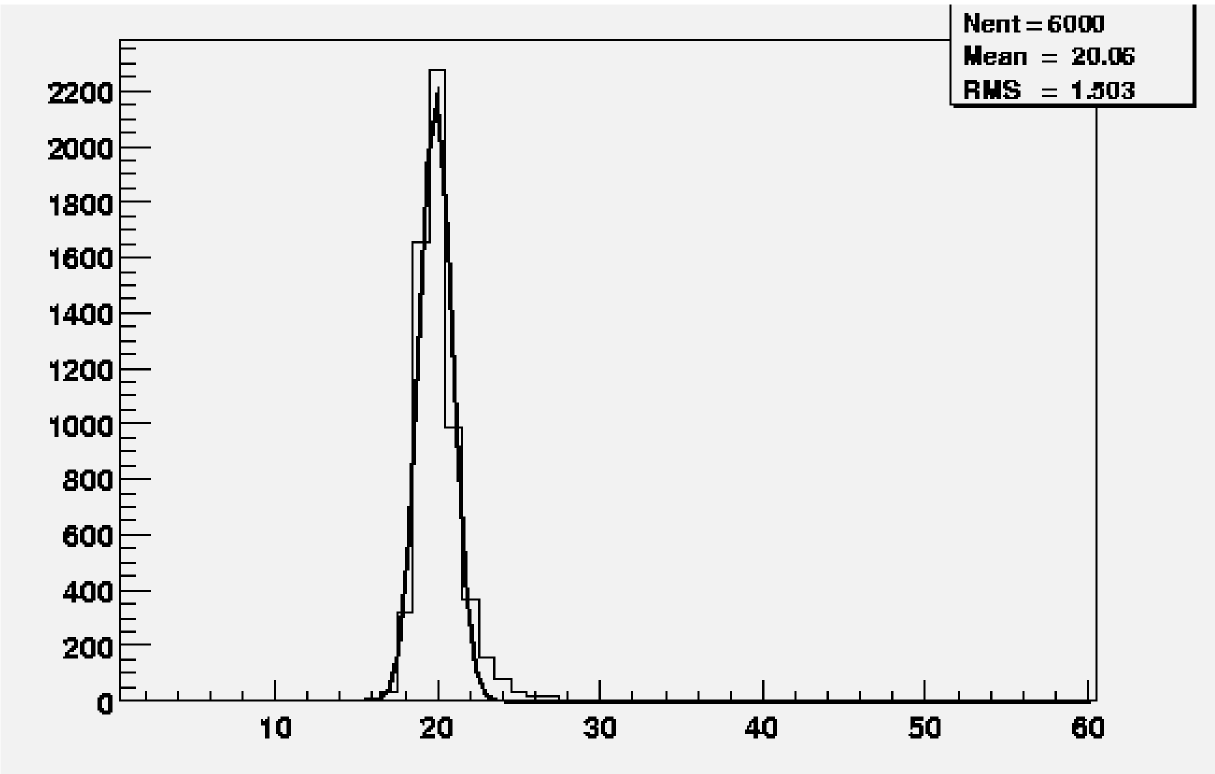
- Calibration Detector placed in beam of particles of known energy
- MEU $\longrightarrow$ Visible Energy
- Cerenkov detector and TOF help identify different particles

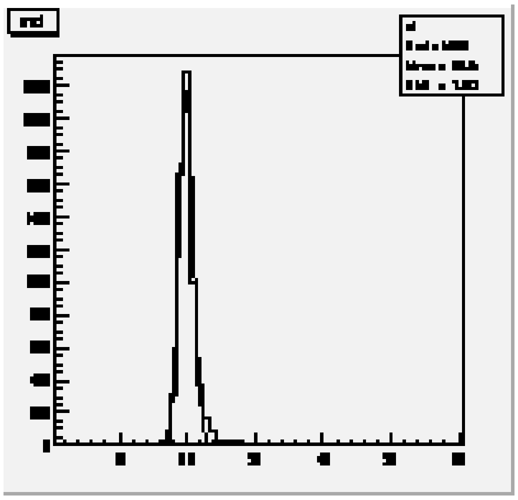
Monte Carlo

- Use Monte Carlo to simulate particle interactions in CalDet
- Helps with particle identification
- Make sure everything's working OK
- Code running on Geant 3.21 incorporates:
  - Rayleigh Scattering, Pair Production, Bremsstrahlung etc
  - WLS Light Trapping efficiency, Birk's saturation
  - Double ended clear/green readout, attenuation, PMT
- 6000 muons at 0.8, 1, 1.4, 1.6, 2 GeV generated

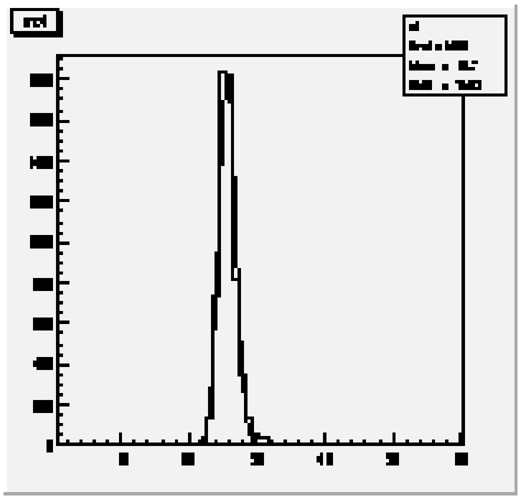
de/dx

- Muons tracked through detector
- LPH extracted
- Gaussian fitted

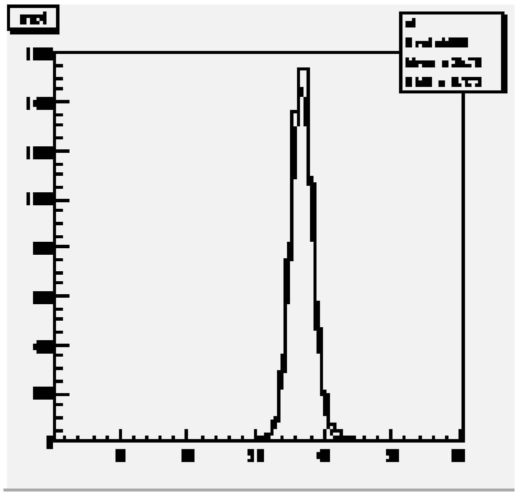




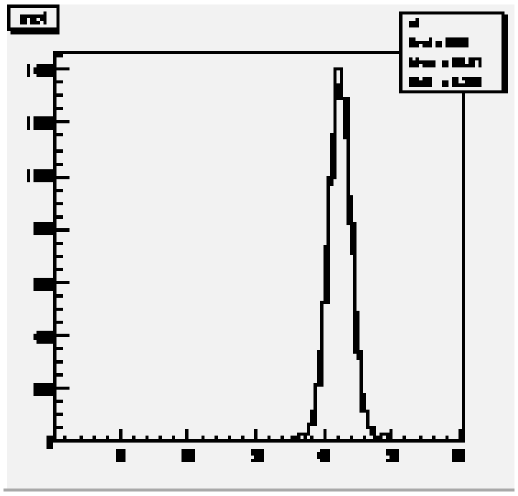
0.8 GeV



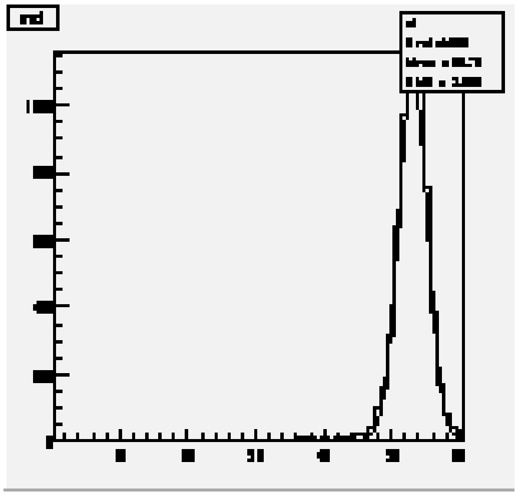
1 GeV



1.4 GeV

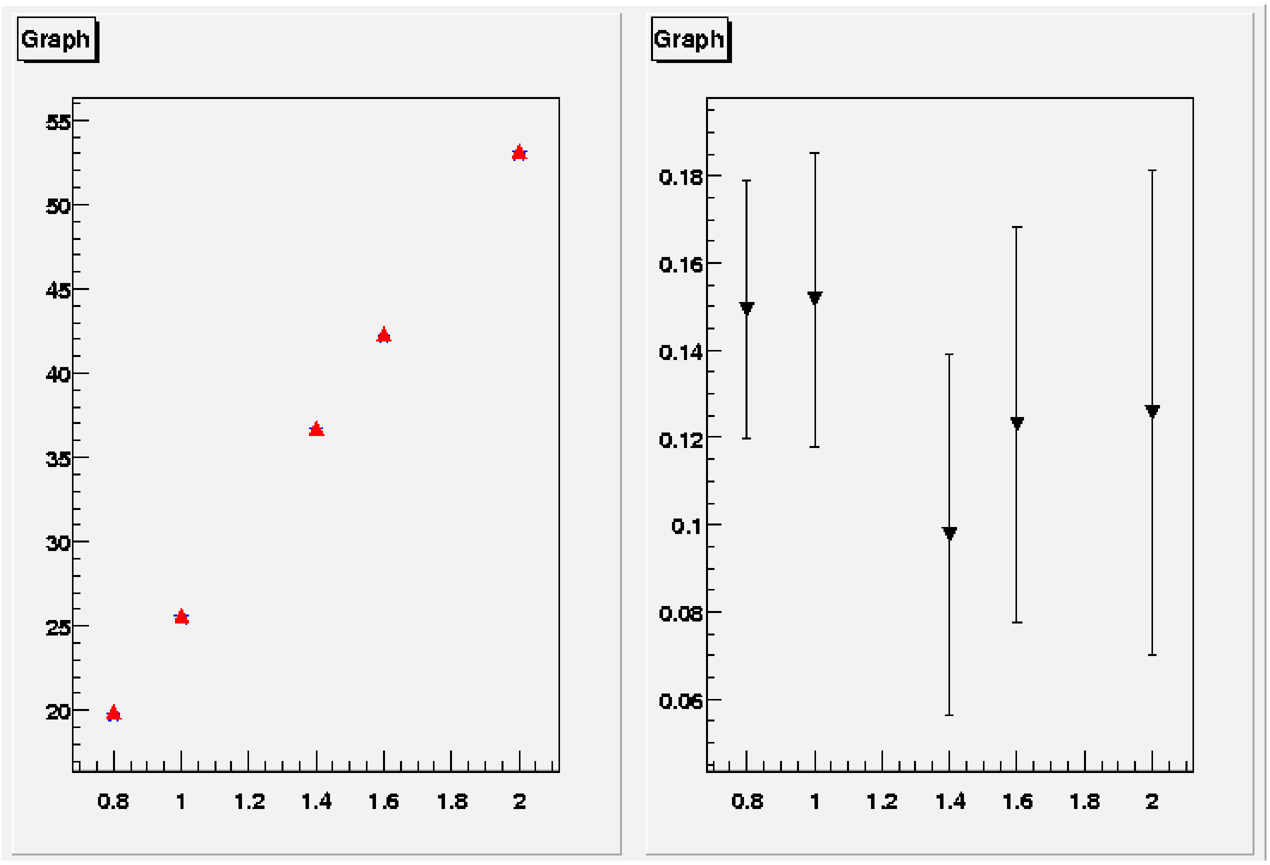


1.6 GeV



de/dx

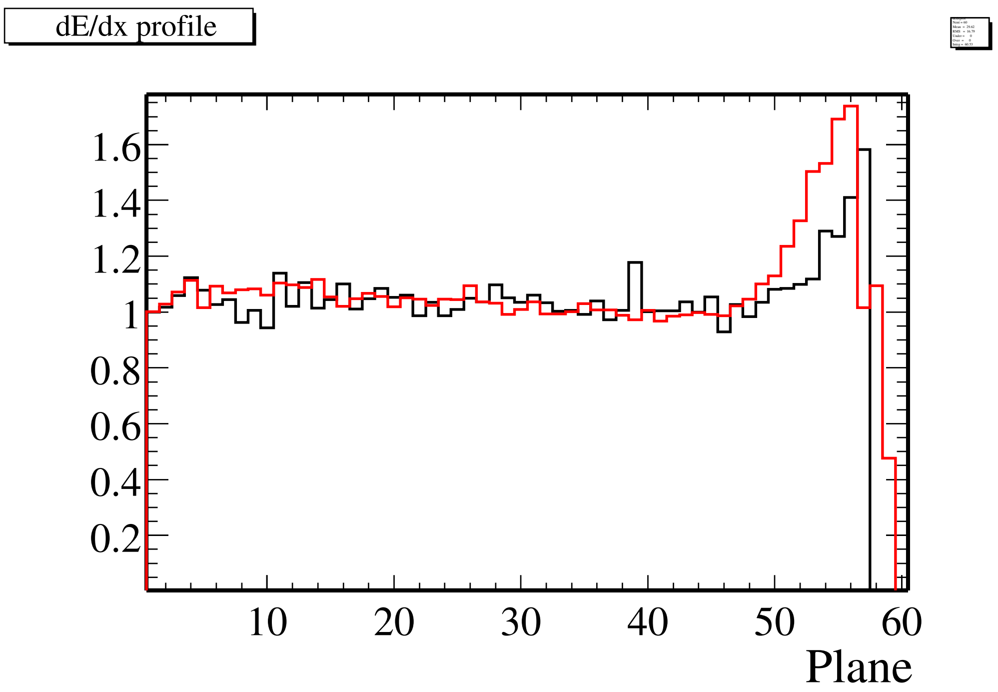
- The means of all 5 energies are plotted
- +ve and -ve muons overlaid



- Differences on right $\longrightarrow$ -ve go 0.75% further

de/dx

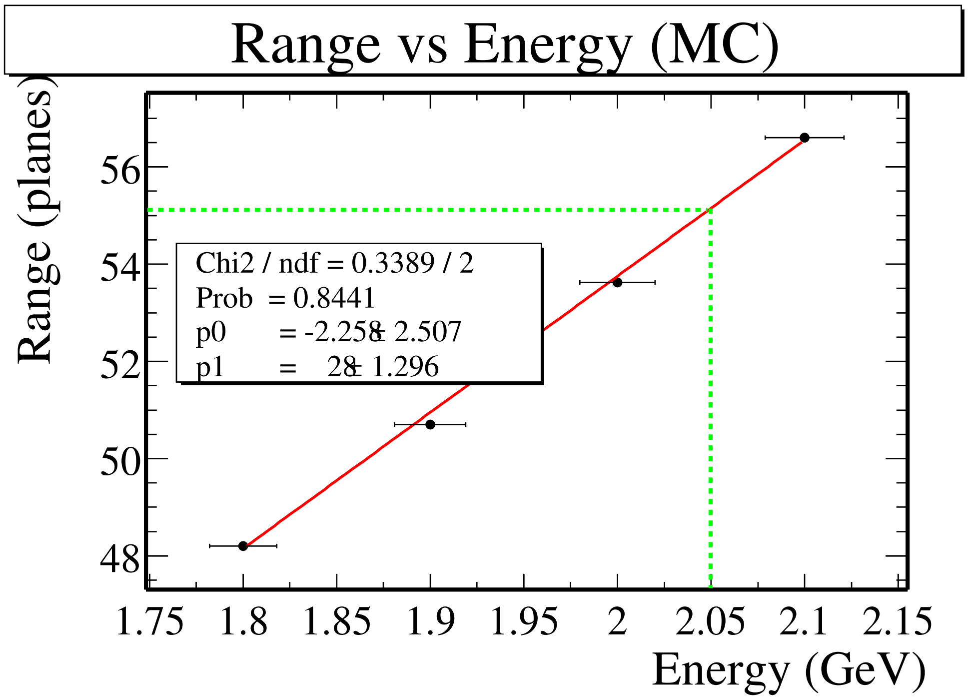
- Energy deposited in each plane as muons travel through the detector
- Special cuts to select muons from real data
  - 16 hits anywhere in detector
  - Green and Clear hit
  - $<$ 10 degrees
  - $<$ 3 consecutive hits
- Monte Carlo is red, real data in black



- Real data - only muons stopping in 54,55,56 used
- **Peaks do not coincide!**

MC to Data Comparison

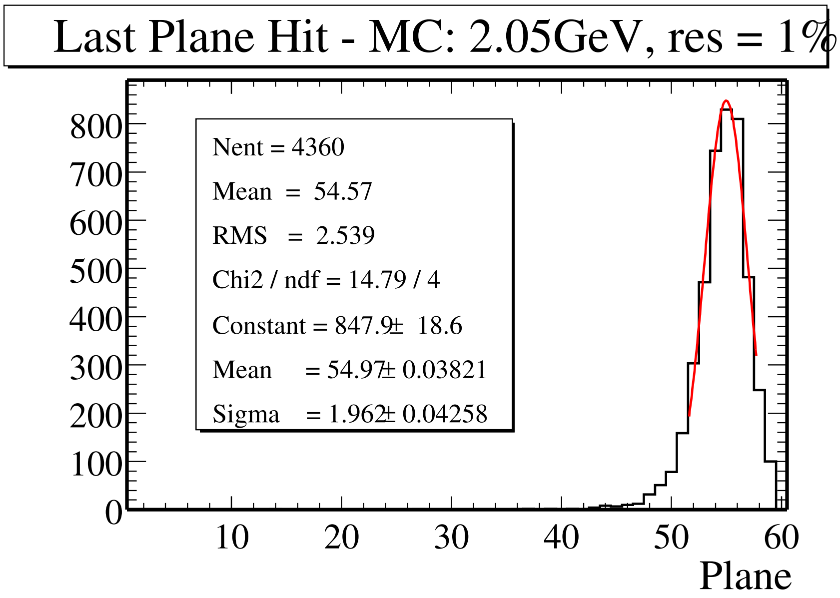
- LPH repeated with real data (as Page 9)

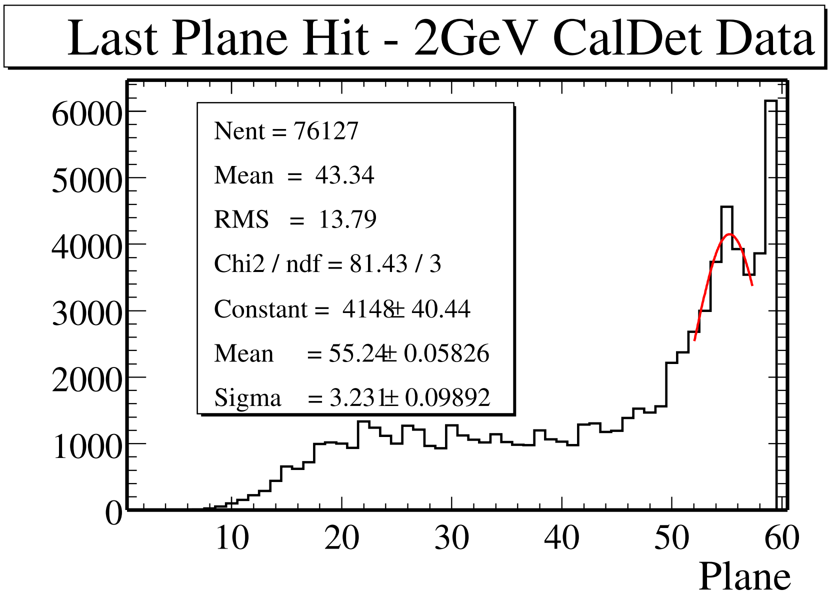


- Its set to 2 GeV but it looks like 2.05 GeV!
- The focussing magnets have deviated

MC to Data Comparison

- At 2.05 GeV, things still don't look right...

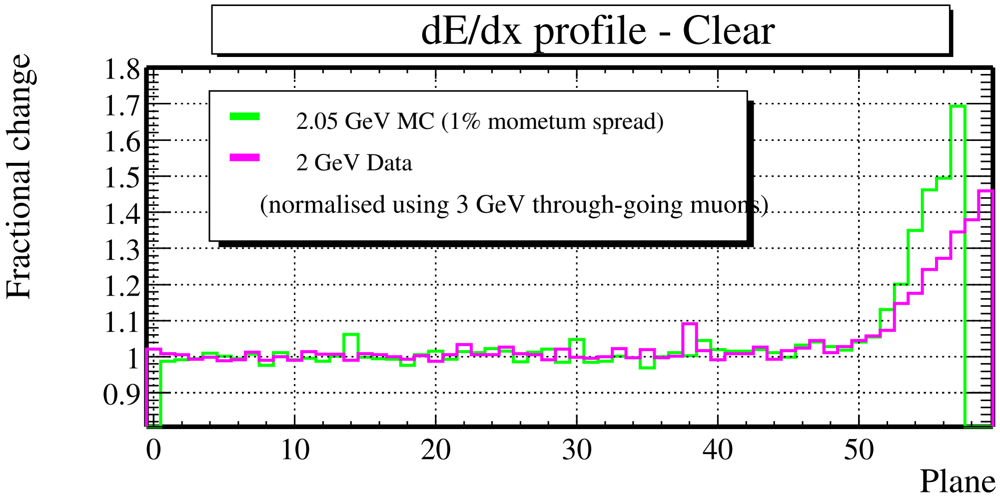


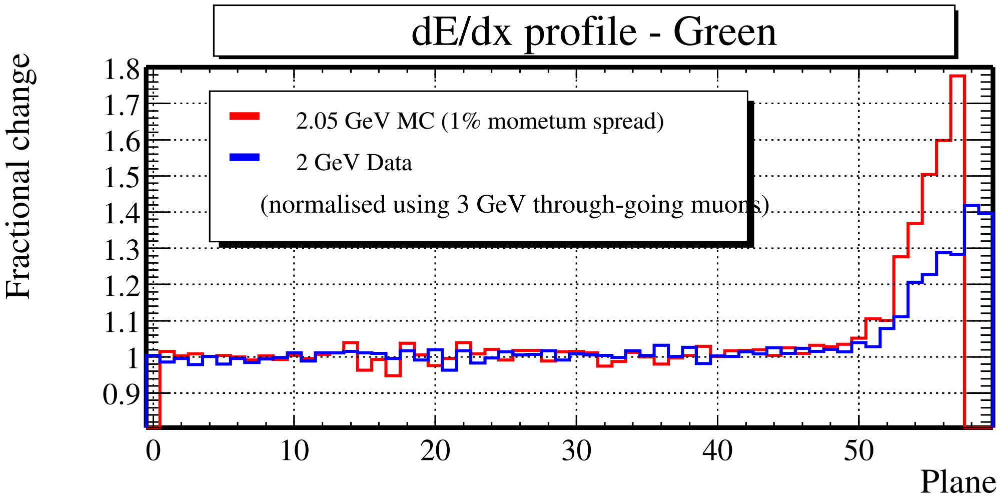


- There are lots of muons that pass all the way through in the data

MC to Data Comparison

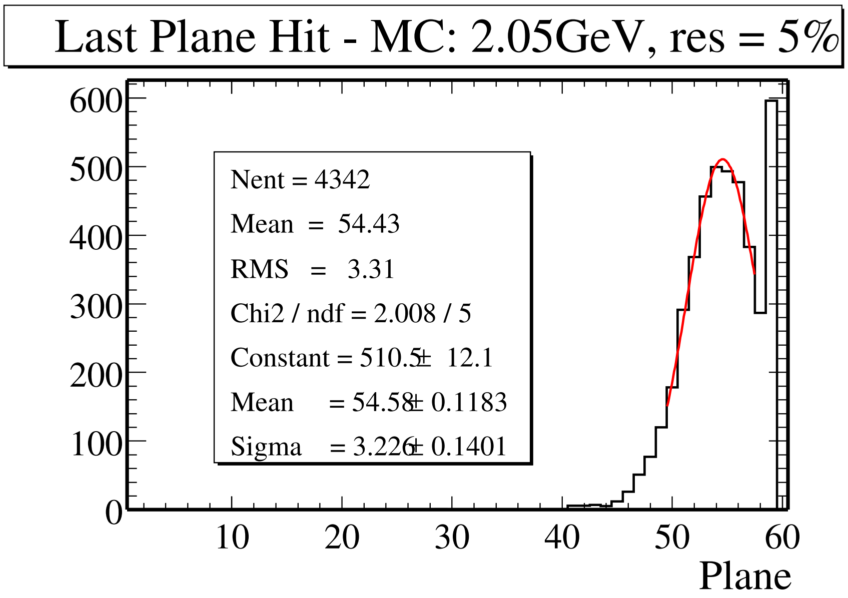
- de/dx still doesn't look right either



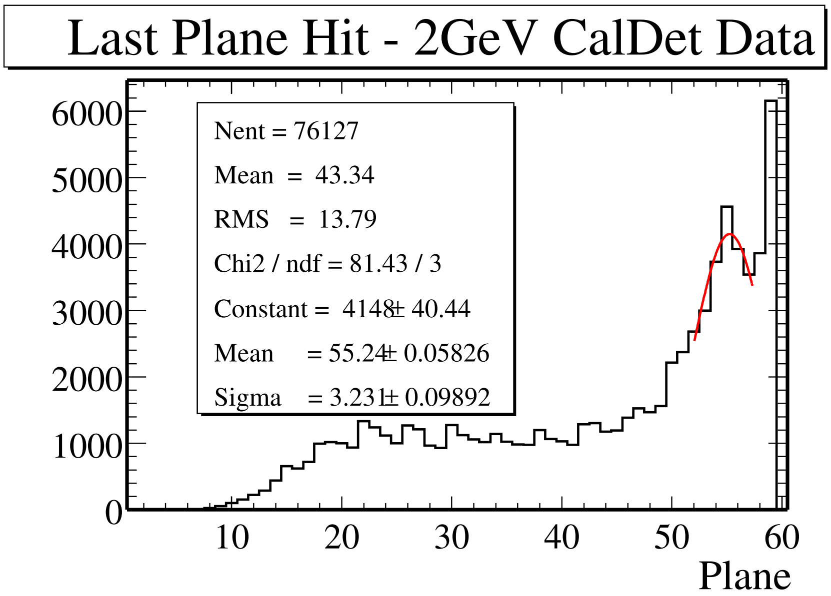


MC to Data Comparison

- However... adjusting particle momentum spread in the Monte Carlo...

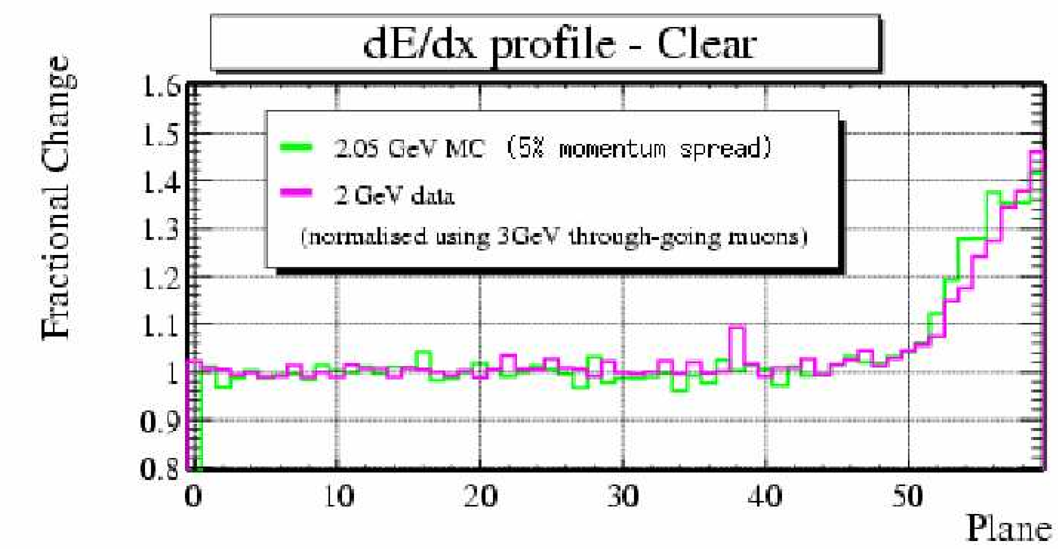


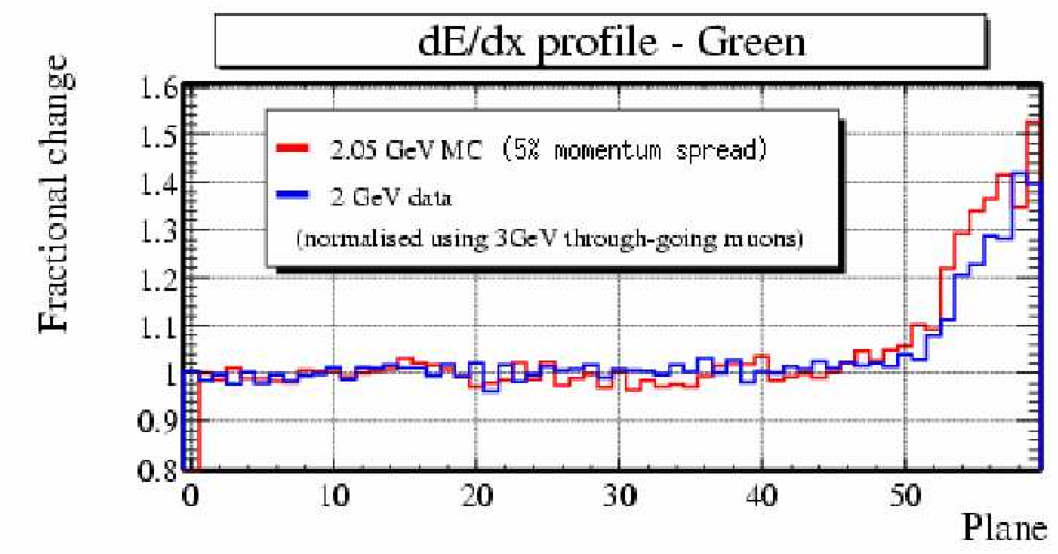
- and things looks much better



MC to Data Comparison

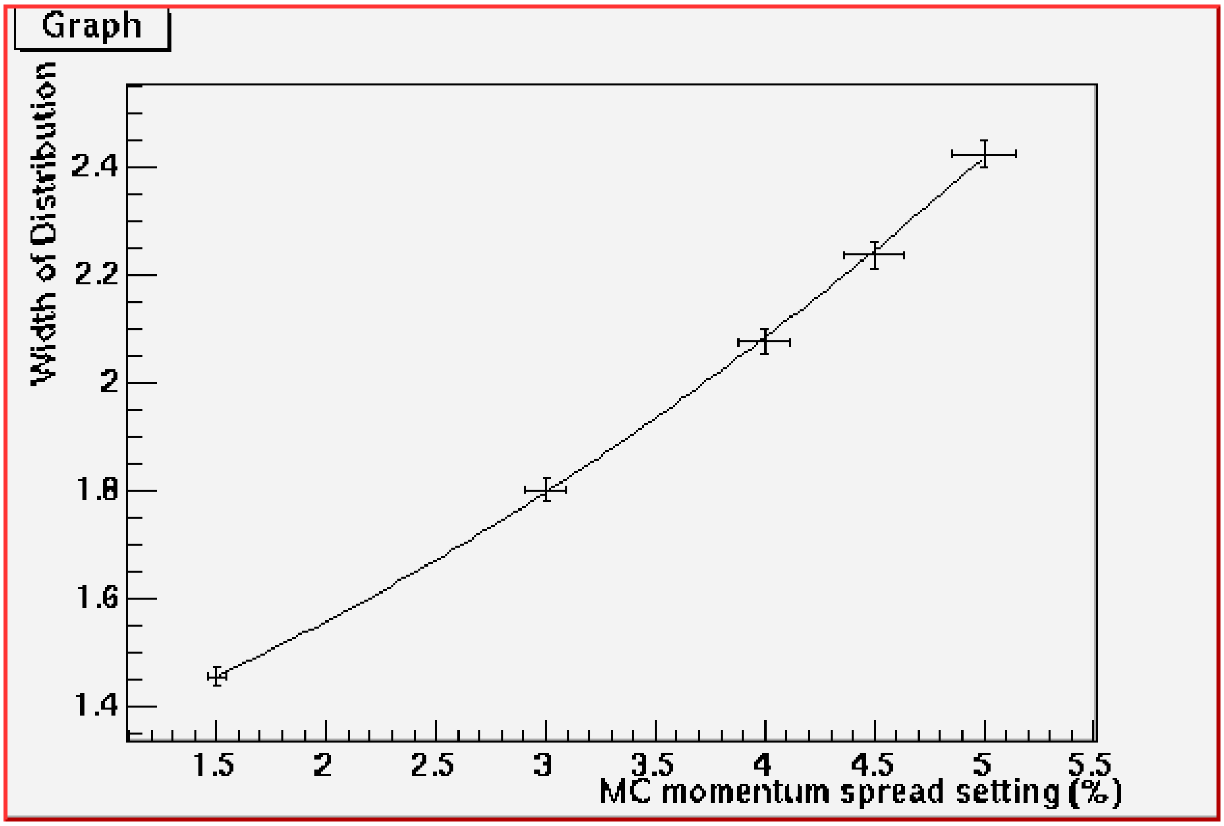
- And de/dx looks good





Results

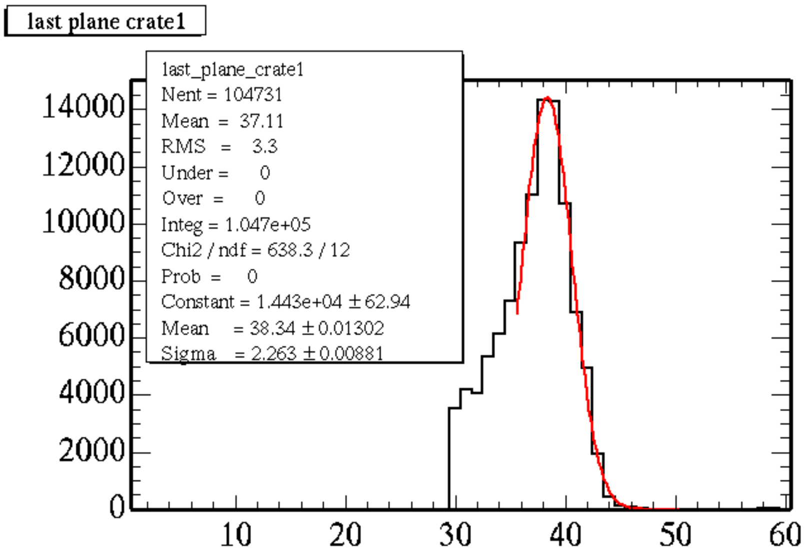
- So it seems the beam specifications don't match the beam
- Extract widths at differing momentum settings
- Plot and fit a line

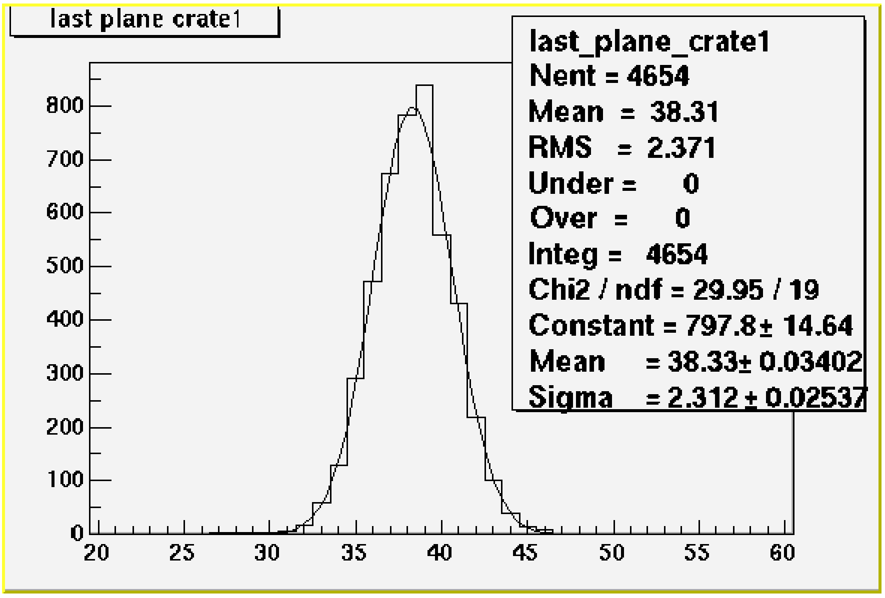


- Best Fit at 4.6%
- A similar procedure produces a best energy fit of 1.454GeV
- 3.86% above expected

Results

- But the final comparison is good





Conclusion and Further Analyses

- By tweaking the Monte Carlo a good comparison is made
- But the momentum spread is higher than expected
- And so is the energy

- Look at other energies
- Same energy, different beamline to check consistency and MC validity
- Compare to cosmic muon data
- MEU $\longrightarrow$ Visible Data