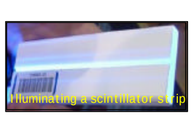
Test beam results from the MINOS Calibration Detector

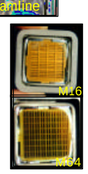
David A. Petyt

The MINOS Calibration Detector

The MINOS Calibration Detector (CalDet) is a smaller version of the MINOS Near and Far detectors:

- 1m×1m×3.7m
- 1" steel plates
- 1cm×4.1cm×1m solid scintillator strips with embedded wavelength-shifting (WLS) fiber
- Two-sided readout:
  - One end: 6m **clear** fiber
  - Other end: 4m green WLS fiber
- Successive planes rotated by 90º to provide x,z and y,z views
- Readout electronics corresponding to near and far detectors:
  - Near: fast QIE electronics with Hamamatsu M64 multi-anode phototube
  - Far: Viking electronics with M16 phototube





Purpose of the Calibration Detector

- To provide the absolute energy calibration for the MINOS detectors (requirements: 5% absolute, 2% relative near to far)
- To compare the response of the Near and Far Detector readout (PMTs and electronics)
- To understand event topologies:
  - For pattern recognition in Near and Far Detectors
  - For tuning Monte Carlo
- To test calibration procedures
  - Full calibration chain requires ~1 month of running to carry out at Far Detector (~500 cosmic rays m/strip/month)
  - <1 hour at CalDet

Calibration Strategy

Step 1: ADC®Photoelectrons

- Light injection system measures/monitors PMT gains and linearity of readout system/electronics

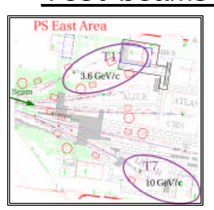
Step 2: PE®MIP units

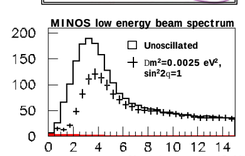
- CR muons provide strip-to-strip calibration
- Apply attenuation and path length corrections to establish MIP scale

Step 3: MIP units®GeV

- Use CalDet results (measured response of particles of known energy) to provide conversion between MIP units and GeV

Test beams at the CERN PS





CalDet exposed to beams in the T7 and T11 areas at the CERN PS

- T11 – low energy running – 400 MeV – 3.6 GeV
- T7 – high energy running – 0.8 GeV – 10 GeV
- Beam composition – p,p,e,m
- Positives and negatives
- 10-100K events of each particle type recorded at 0.2 GeV intervals between 0.2-3.6 GeV and 1.0 GeV intervals between 4.0 and 10.0 GeV.

MINOS low energy beam peaks at 3 GeV

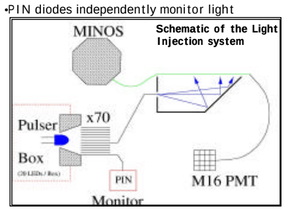
- Oscillation 'dip' occurs between 1-3 GeV assuming Super-K Δm^2 range. Important to study pi/mu separation at these low energies.
- Response of higher energy particles also of interest – e/pi separation critical for ν_e appearance search

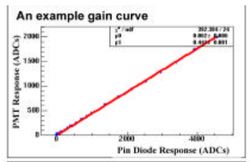
History of CalDet beam exposures

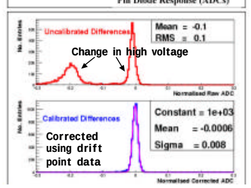
- 2001-02:
  - Far detector runs in T11 and T7
- Sept-Oct 2002:
  - Mixed near/far electronics run (7 planes of near electronics) in T11
  - Far-only runs in T7 and T11
- Sept-Oct 2003 (planned)
  - Mixed near/far electronics (60 planes of near electronics) in T7
  - Near-only runs in T7. One sided readout with mirrorred connectors on far side – to match near detector configuration

The Light Injection calibration system

- Bright blue LEDs illuminate WLS fiber
- Light follows same optical path as scintillator signals
- Two modes of operation:
  - Drift point: pulse at single light level.
    - provides short-term gain drift corrections
  - Gain curve: pulse at a range of light levels.
    - Calibrates linearity of PMTs and readout electronics (should be at 1% level up to 300 p.e.)
- PIN diodes independently monitor light







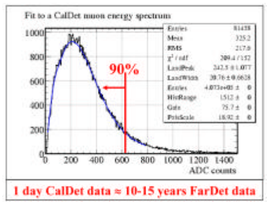
Using the LI system to correct gain drifts

Cosmic ray calibration

Cosmic ray muons at CalDet provide strip-to-strip calibration. Accounts for variations in:

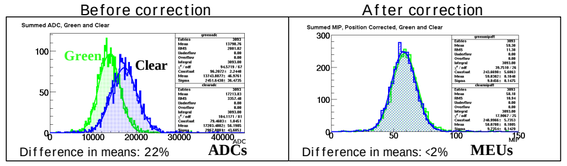
- scintillator light output
- fibre/connector transmission efficiency
- PMT/electronics gain

Calibration constants found by taking truncated mean/fitting ADC spectra. Produces ADC®MIP conversion factors.



1 day CalDet data ≈ 10-15 years FarDet data

Before correction / After correction



Particle ID at CalDet

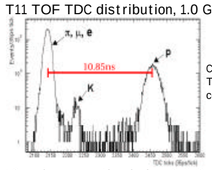
Threshold Cerenkov and Time of flight counters in T7 and T11 provide particle ID at Caldet:

- TOF: p/π separation
- CER: electron ID

Event ID:

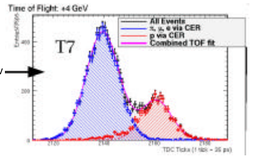
- Electrons: CER signal (T11), signal in both CER (T7)
- Protons: no CER signal (T11/T7)
- Pions: no CER signal (T11), signal in downstream CER (T7, above 3 GeV)

T11 TOF TDC distribution, 1.0 GeV



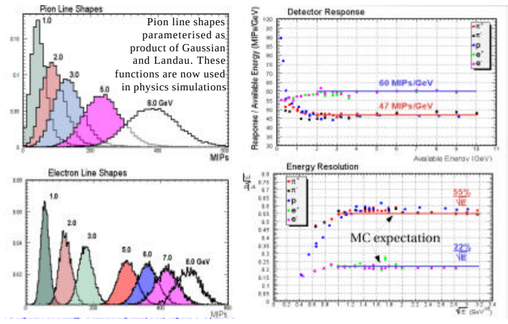
>3σ π/p separation below 3.6 GeV

Check of TOF/Cerenkov consistency



Good agreement between TOF/CER signals

Hadron and Electron response functions



Calibration of near and far electronics

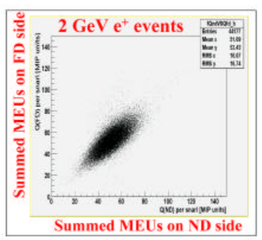
Mixed near/far electronics run in T11, Sept 2002:

•7 planes on one side of detector instrumented with near detector readout (QIE electronics, M64 PMTs)

•60 planes of far readout on opposite side of detector

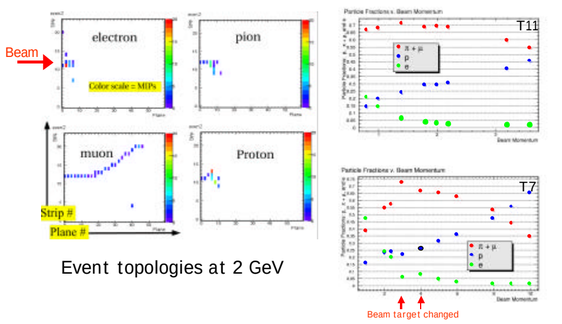
•Configuration used to check for systematic differences in response

•Preliminary results show agreement in near/far energy calibration to ~5%



Comparison of near/far response (calibrated units). Clean e⁺ sample selected by topological cuts

Event topologies and particle fractions



Event topologies at 2 GeV

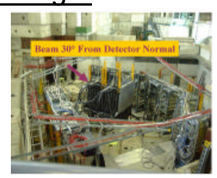
Particle types determined by TOF/Cerenkov

CalDet at an angle

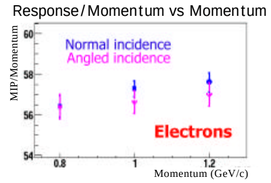
Special runs taken in T11 with CalDet rotated 30º to beam axis

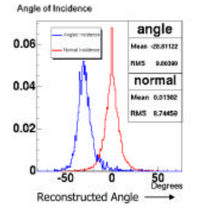
- check response and resolution functions
- Check of shower reconstruction algorithms

Resolution and response unaffected by detector rotation



Response/Momentum vs Momentum



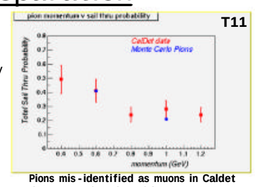


Pion/Muon separation

Single (non-showering) pions constitute a significant background to the ν_μ CC signal in MINOS at low energies (see plots below)

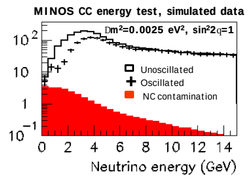
CalDet data used to estimate the probability that a pion will be mis-identified as a muon

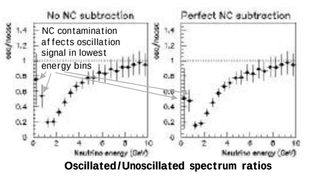
- Used topological cuts and PID system to isolate a sample of muon-like events in T11
- Simulation of T11 beamline elements used to predict muon contribution. Subtract this to yield a sample of mis-identified pions
- Good agreement between data and Geant Monte Carlo mis-identification probabilities



Pions mis-identified as muons in Caldet data, as a function of beam momentum

MINOS CC energy test, simulated data





Oscillated/Unoscillated spectrum ratios