An Update on the MINOS Experiment

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Neutrino Oscillations

- Natural to expect neutrinos to have mass
- Likely that mass and flavour eigenstates are different
- Can expect CKM-like matrix for leptons

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

(Assuming 3 generations)

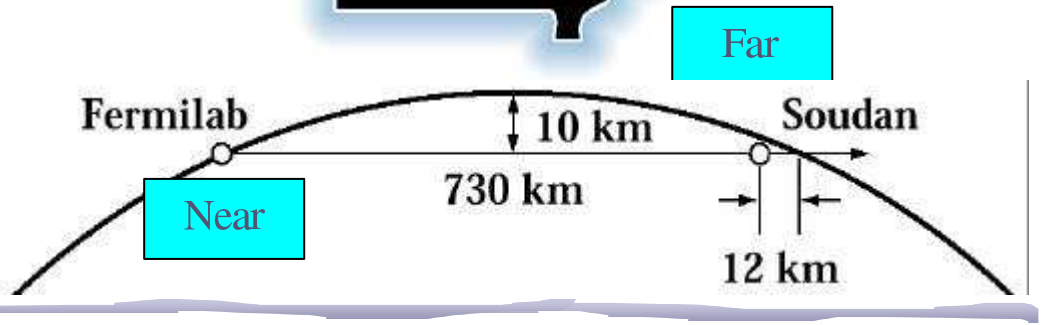
- Considering only 2 generation mixing:

$$\begin{pmatrix} \nu_e \\ \nu_\mu \end{pmatrix} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_e \end{pmatrix} \qquad P(\nu_\mu \rightarrow \nu_e) = \sin^2 2\theta \sin^2(1.27\,\Delta m^2 L/E)$$

- Δm^2, $\mathrm{Sin}^2 2\theta$ are oscillation parameters
- L and E are experimental parameters

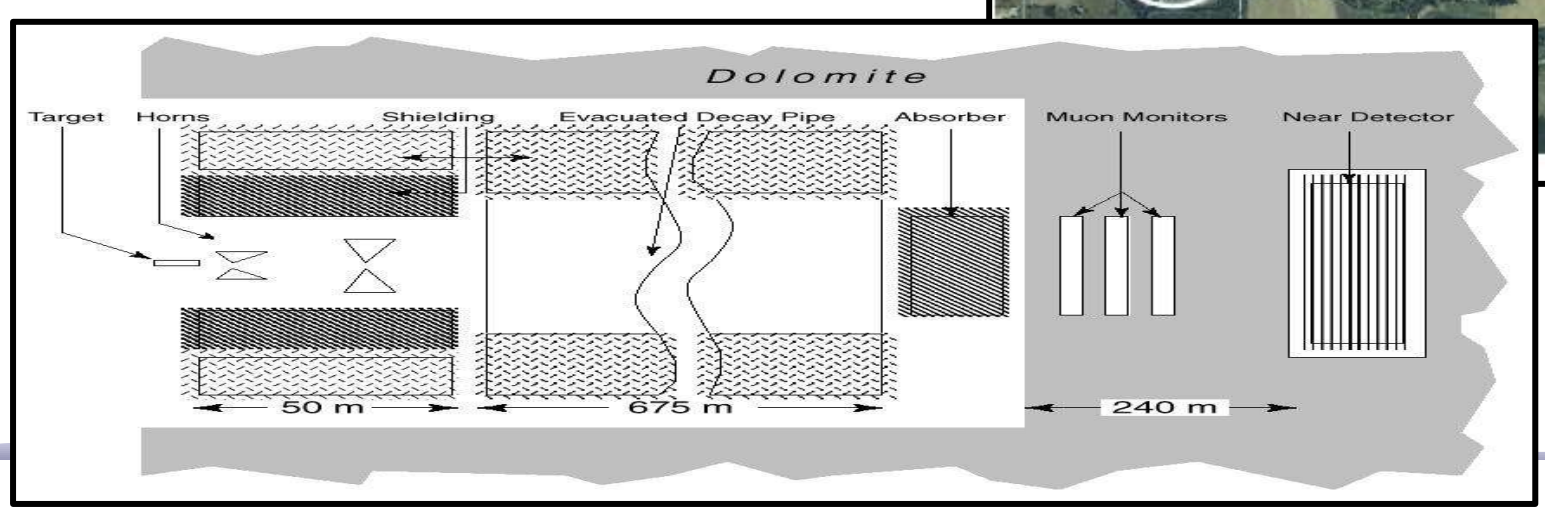
MINOS Experiment

- 2 detector, long baseline experiment
- Four crucial components:
  - ➢ NuMI beam (Neutrinos at the Main Injector)
  - ➢ Near Detector – on site at Fermilab
  - ➢ Far Detector – 730km away in Soudan mine, Minnesota
  - ➢ Calibration Detector – In a series of test-beams at CERN



The NUMI Beam

- 120 GeV Protons fired at carbon target
- Resulting pions focussed by two magnetic horns
- Decays to μ,ν occur in long evacuated pipe
- Absorber & rock remove hadrons and muons
- Neutrinos intercept Near Detector ~1km downstream

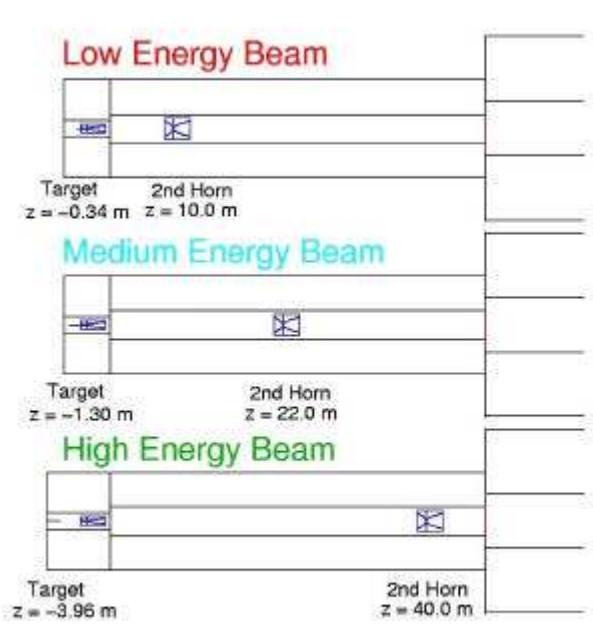


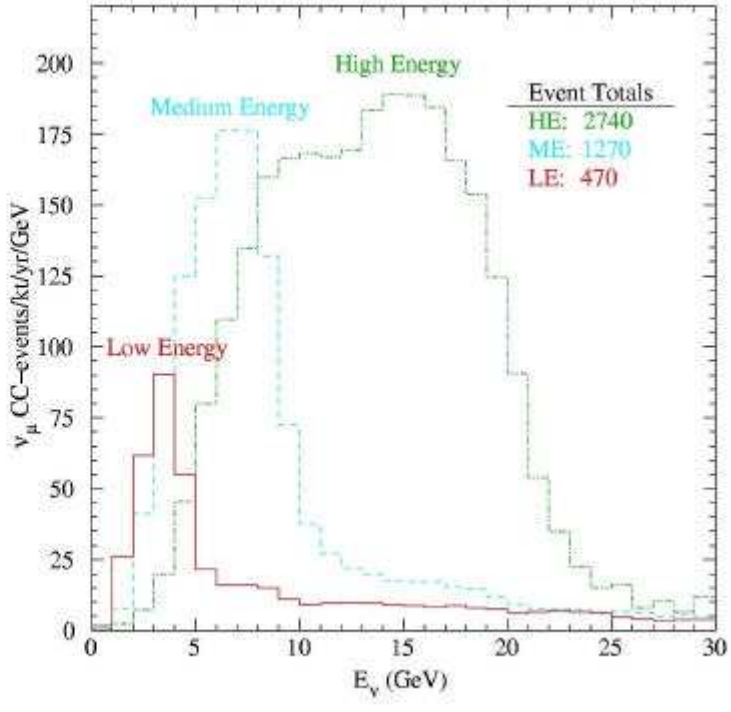
NuMI Beam

- Moveable target & horns

- High, Medium and Low Energy beams possible

- MINOS will initially run with low energy beam



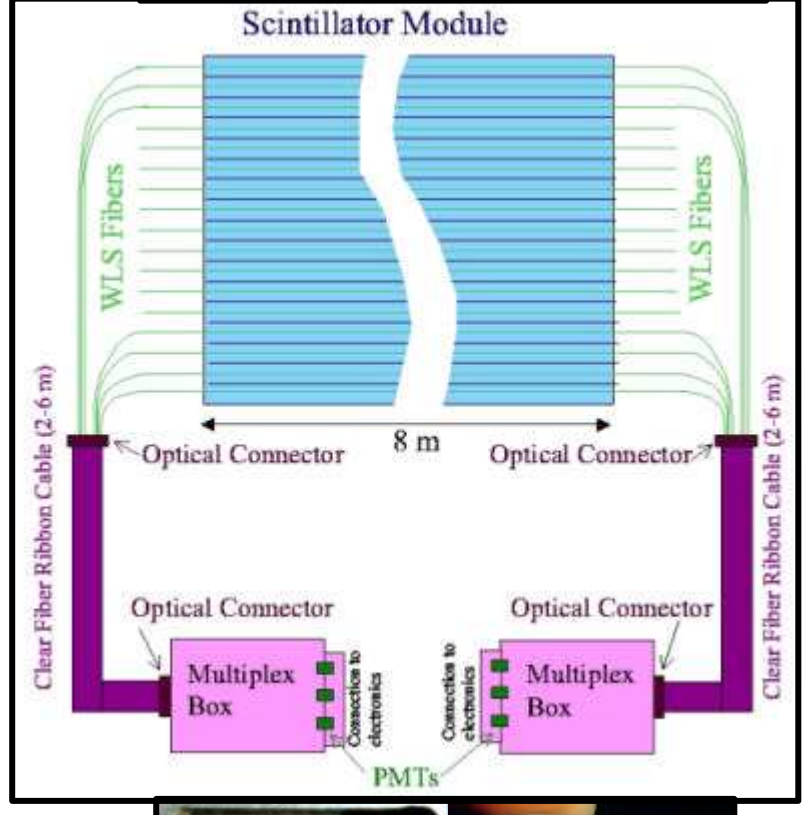


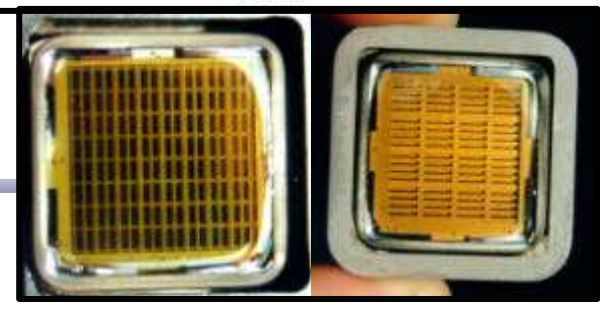
- CC Event rate in Far Detector:

  ➢ expect ~2500 events per year

The MINOS Detectors

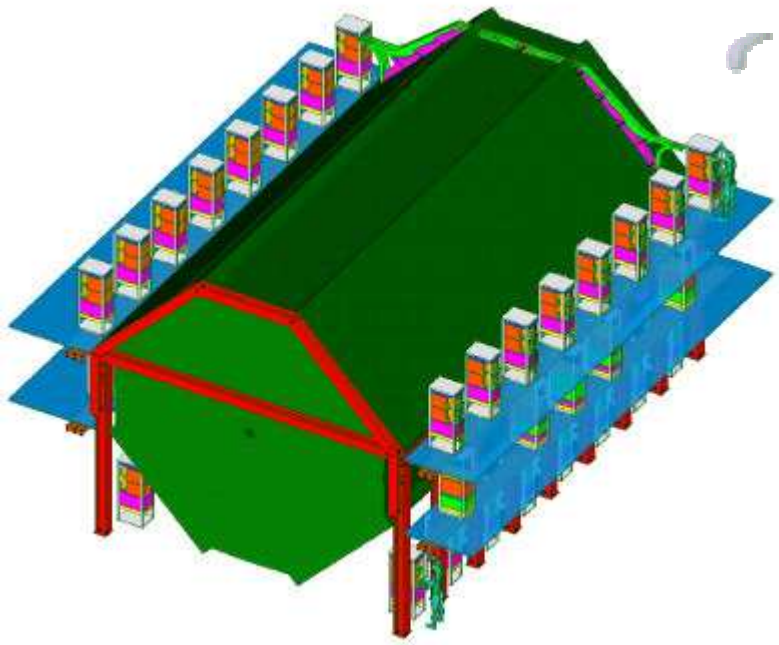
- Iron/Scintillator tracking calorimeter
  - Fe/Air/Scint: 2.54/2.5/1cm
- Scintillator planes divided in strips
  - 4.1cm wide, up to 8m long (FD)
- Readout via Wavelength Shifting Fibre
  - 1.4mm diameter
- Signals detected by Multi-Anode PMT
  - Hammamatsu M16, M64





Detectors designed to be as similar as possible

The Far Detector



- Largest of the MINOS Detectors, 5.4kT
- 486 octagonal planes, 8m diameter
- 1.3T toroidal magnetic field

- Double ended readout
- Sample and hold electronics
- Now being installed

➢ ~20% complete!

FD Installation

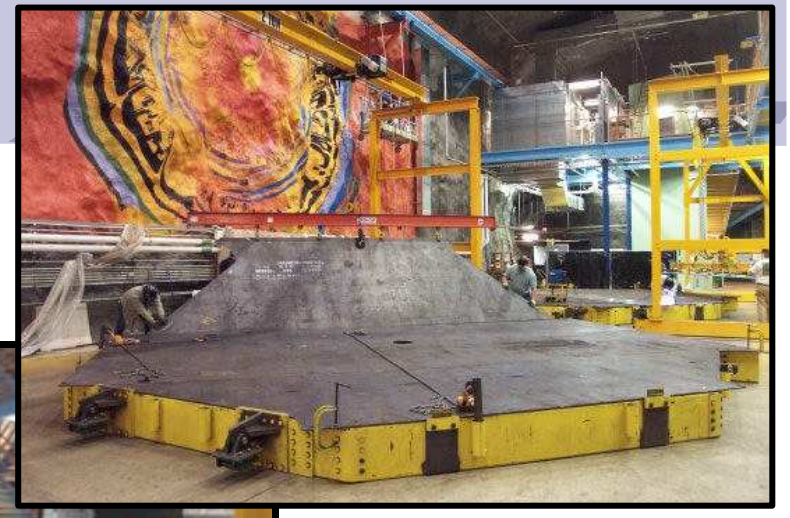
How to build a MINOS plane:

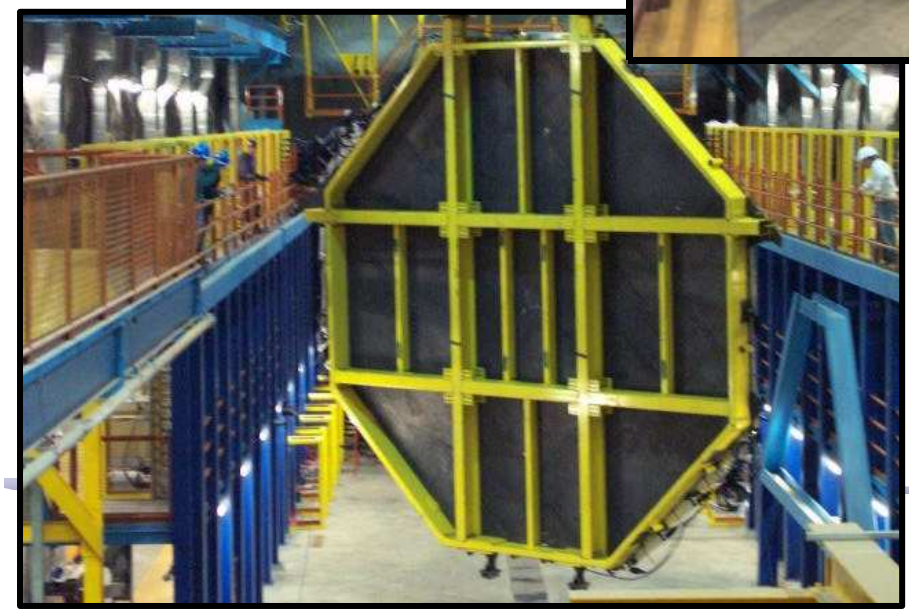
- Shaft down to MINOS cavern only 2x2m – 8m octagonal planes!

- Steel and Scintillator planes manufactured as long segments
- Planes assembled underground

FD Installation

- Steel sheets laid and welded on strongback
- Scintillator modules secured to steel planes
- Optical fibres attached

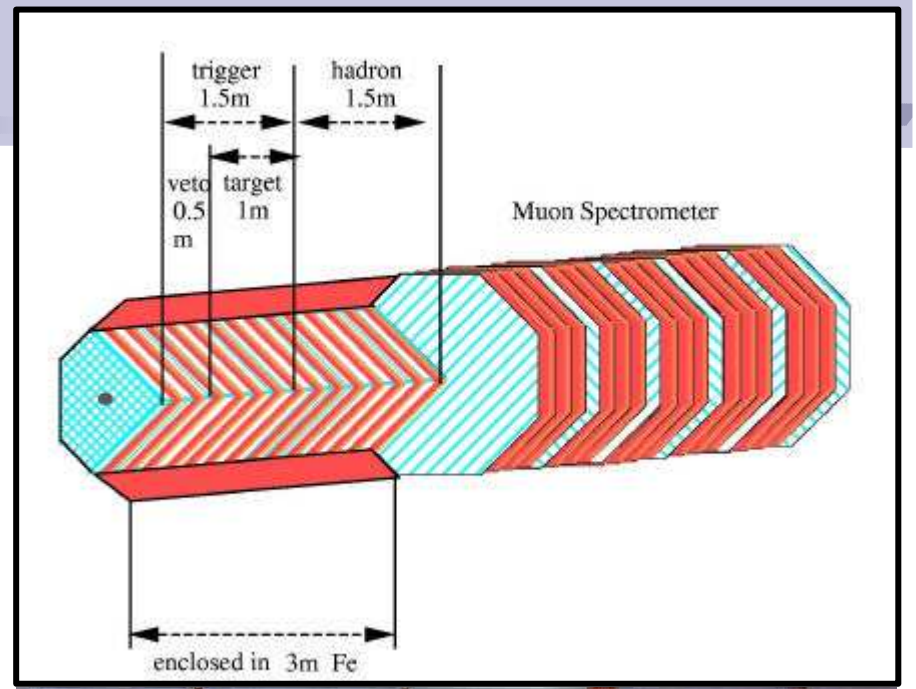




- Current Status:
  - 1/3 completed! 161 Planes installed (as of 22/3/02)
  - Currently taking data

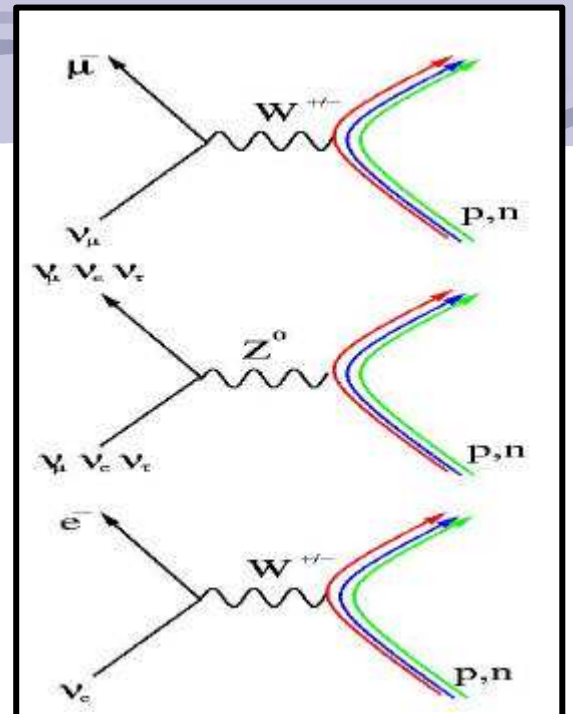
The Near Detector

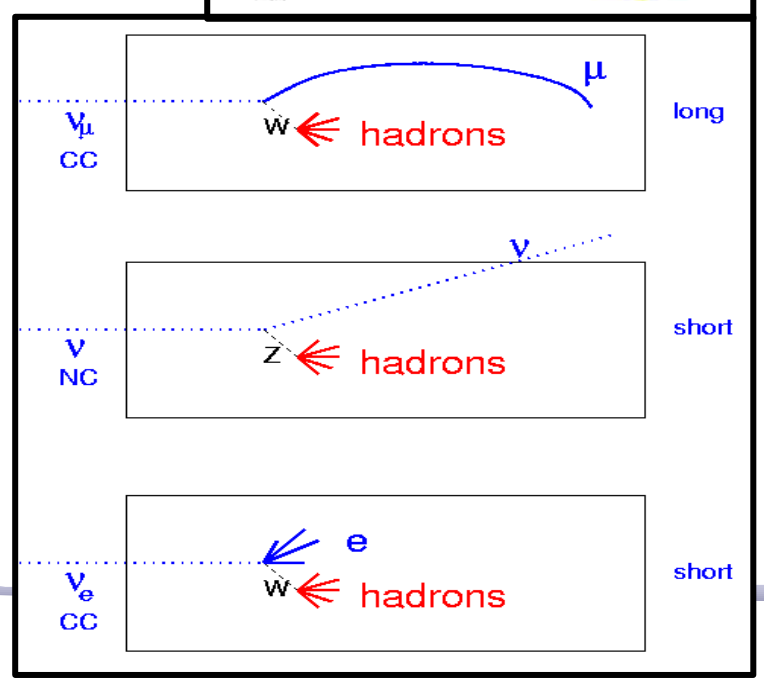
- 16.6m long, 980 tons
- 282 “squashed octagon” planes
- Forward Section (trigger/calorimeter): 120 planes
  - ➢ 4/5 only partially instrumented
  - ➢ 1/5 planes: full area coverage
- Spectrometer Section: 162 planes
  - ➢ 3/4 not instrumented
  - ➢ 1/4 planes: full area coverage
- Single ended readout with reflector



Physics Goals of MINOS

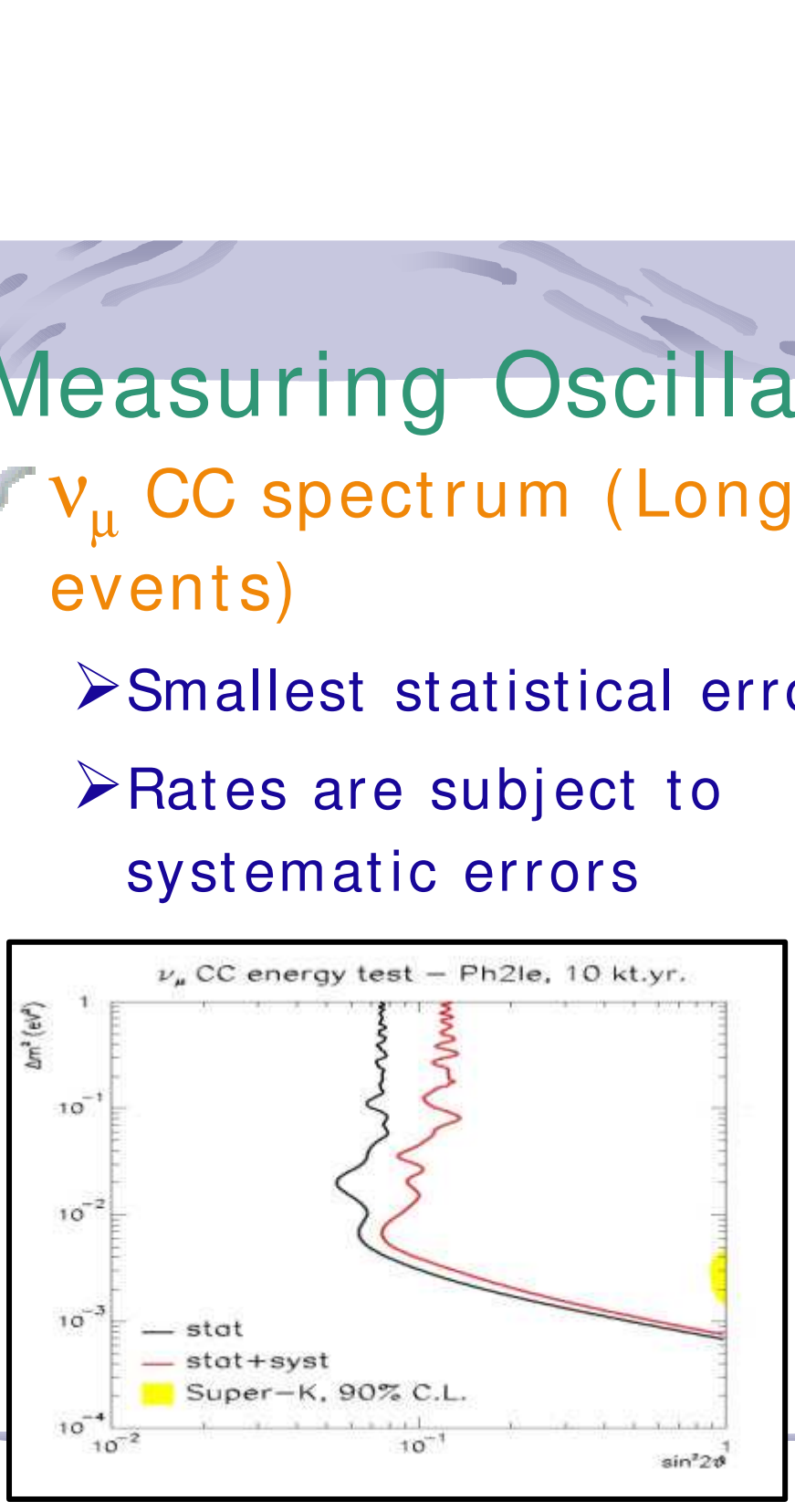
- To first order, 2 types of events:
  - "Long" events – mainly CC ν_μ
  - "Short" events – CC ν_e,ν_τ+ all NC
- Long events distinguishable by muon track
  - Some background from CC ν_τ
- Short events are showering events:
  - Some distinction between electromagnetic and hadronic showering possible

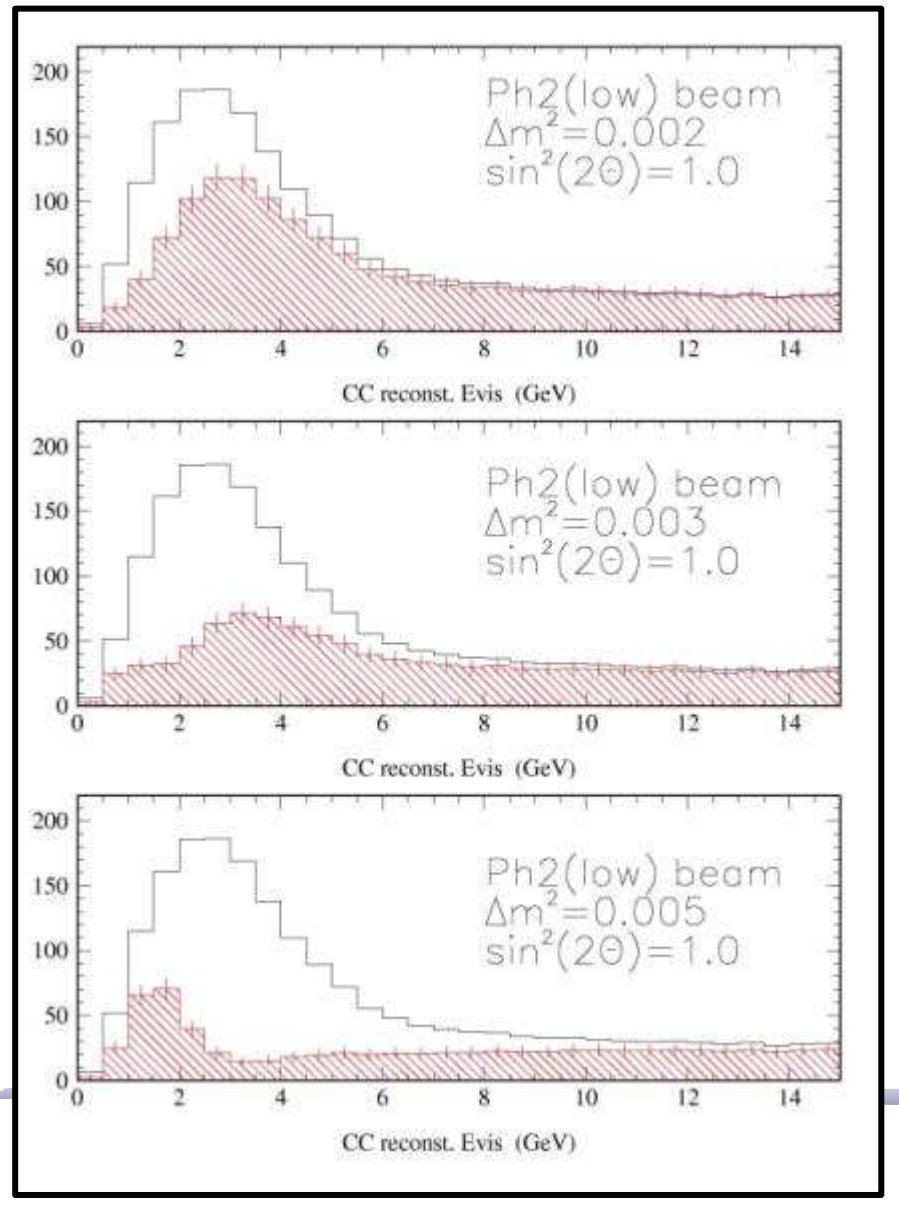




Measuring Oscillation Parameters

- ν_μ CC spectrum (Long events)
  - Smallest statistical error
  - Rates are subject to systematic errors

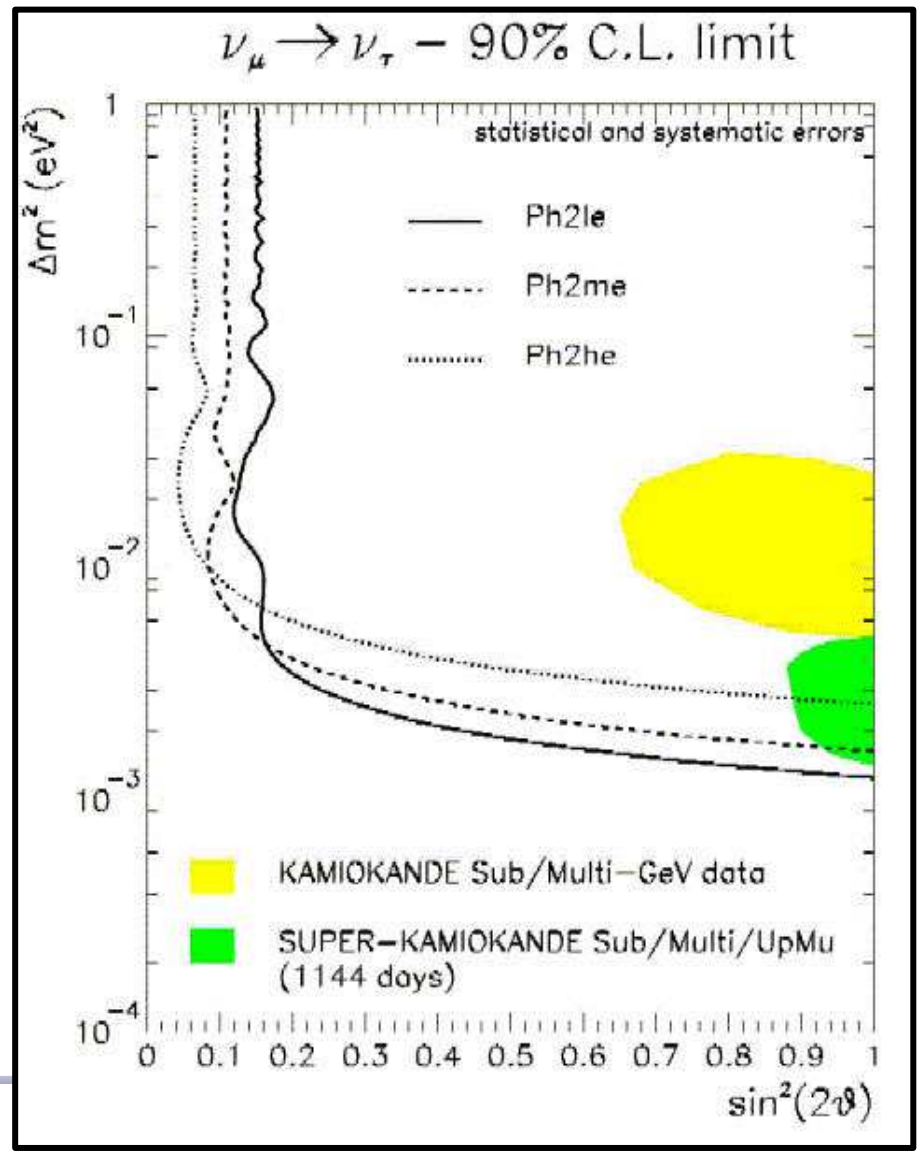




Measuring Oscillation Parameters

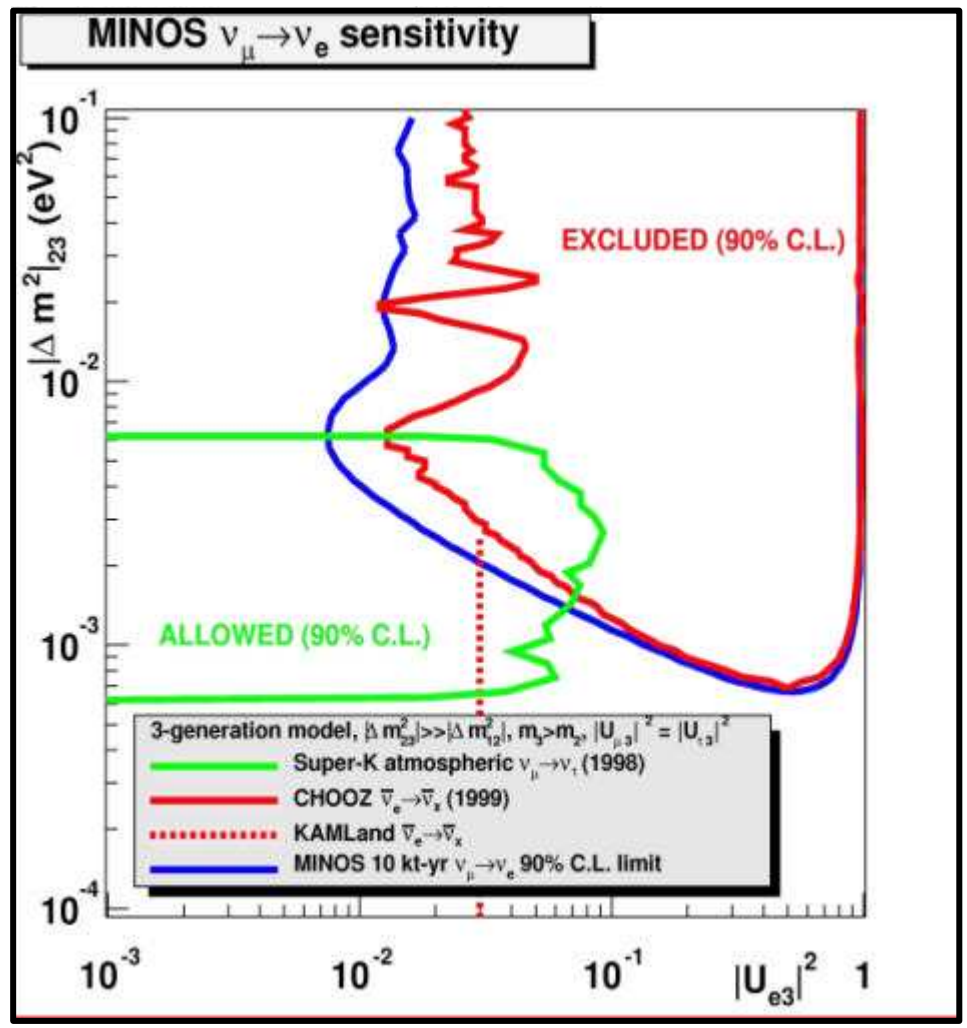
- $(NC/CC)_{Near}/(NC/CC)_{Far}$ ratio

  (Short/Long events)
  - Limited by low NC statistics
  - Independent of near/far normalisation to first order
    - NC/CC slowly rises with energy => calibration important!



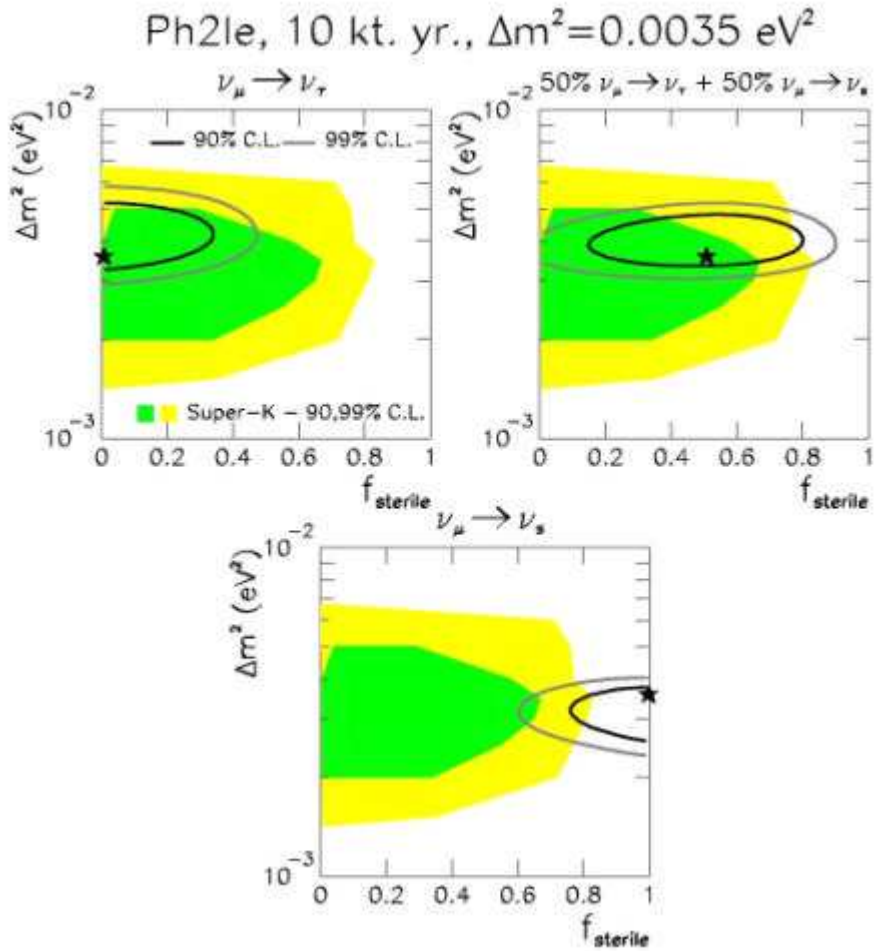
Measuring Oscillation Parameters

- ν_e CC appearance
  - ➢ Can distinguish electromagnetic from hadronic showers
    - Can measure ν_μ->ν_e oscillation parameters
    - Or confirm CHOOZ and Super-K measurements + improve limits



Measuring Oscillation Parameters

- Consistency between measurements essential for signal confirmation
- Also provides limits on other oscillation modes:
  - NC-like spectrum + ν_μ disappearance sets limits on $\nu_{sterile}$



Calibration of MINOS

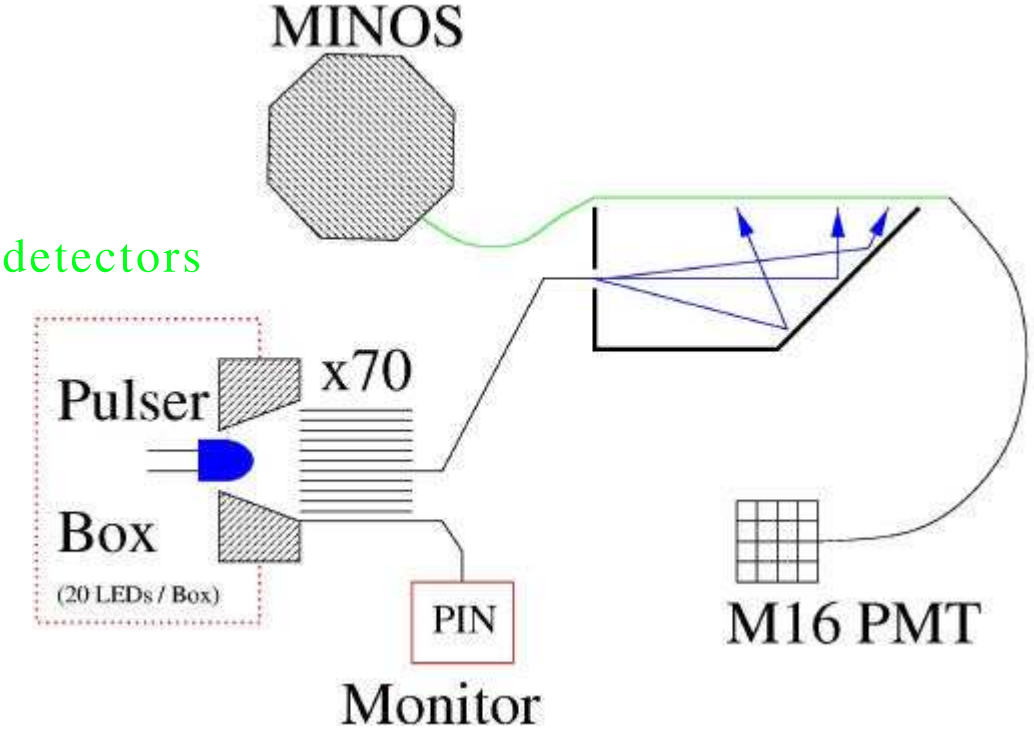
- Need energy response calibration to 2% Near-Far and 5% absolute
- Calibration achieved as follows:

➢Cosmic ray muons

- strip to strip normalisation
- energy scale calibration across detectors

➢ Light Injection system

- PMT/electronics nonlinearity
- PMT gain drifts

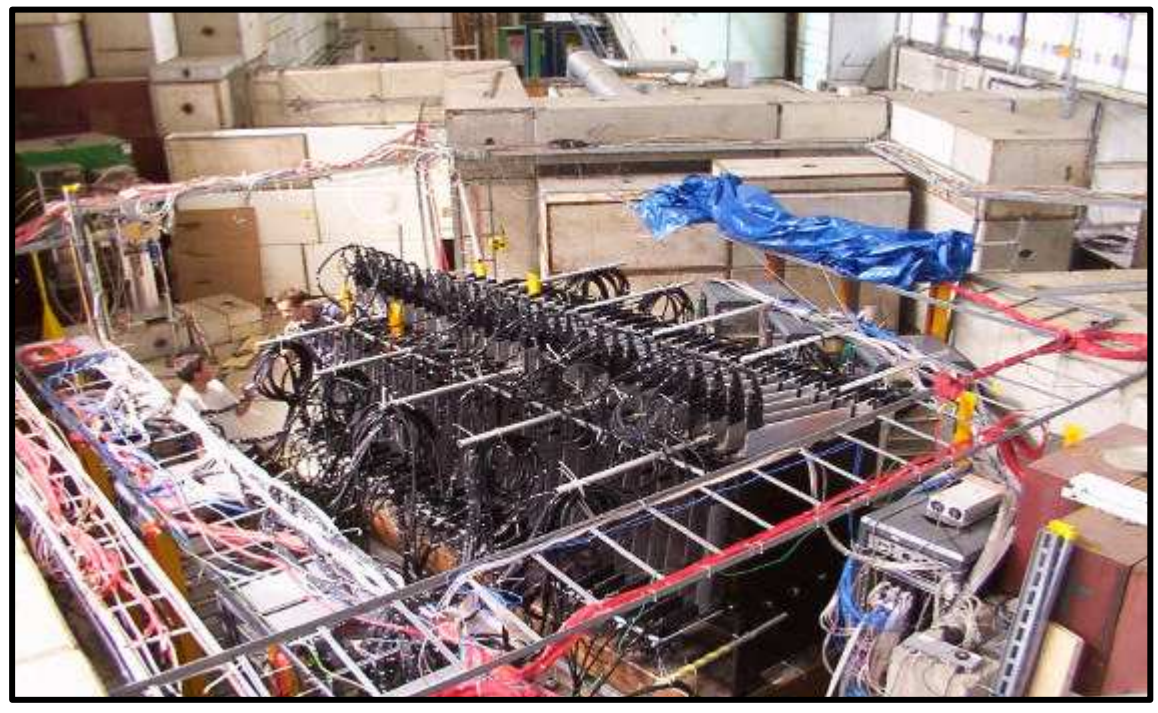


➢Calibration Detector

- to characterise muon, electron and hadron responses
- relate Muon Energy Unit to GeV for MINOS detectors

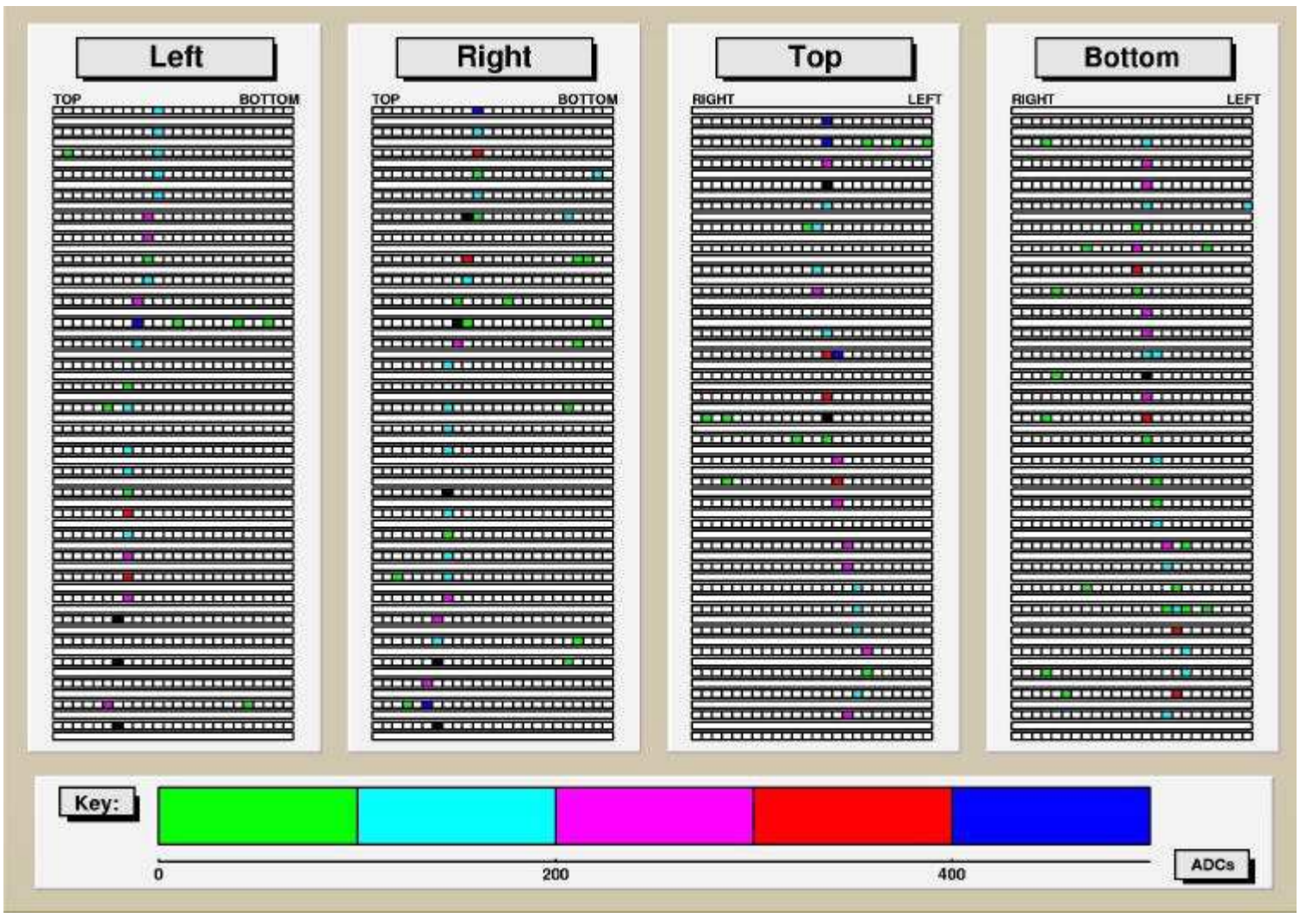
The Calibration Detector

- 1x1m cut-out section of the larger MINOS detectors
- 60 planes; only 1 ton
- 2 sided readout:
  - one side clear fibre
  - one side green fibre



- Built at CERN last summer
- Exposed to T11 test-beam for 2 months summer '01
- Lots of data analysis

A CalDet Beam Event



Schedule

- NuMI:
  - Expected to be commissioned 2004-2005
- Far Detector
  - 1/3 completed
  - Expect to complete first Supermodule by Summer ‘02
  - 10kt-years by 2005
- Near Detector
  - Assembly and installation to begin Oct ’03
  - Expected to take 8-9 months
- Calibration Detector
  - CERN test-beams Summer ‘02 and ‘03

Summary

- Much evidence for neutrino oscillations over past few years
  - Super K, SNO...
- MINOS in a good position to study oscillation signals and make measurements and improve limits
  - High statistics, good control of systematics
- Good progress being made in all areas
  - Over 1/3 of FD installation complete
  - First data from Soudan and CERN
- Exciting results to come!