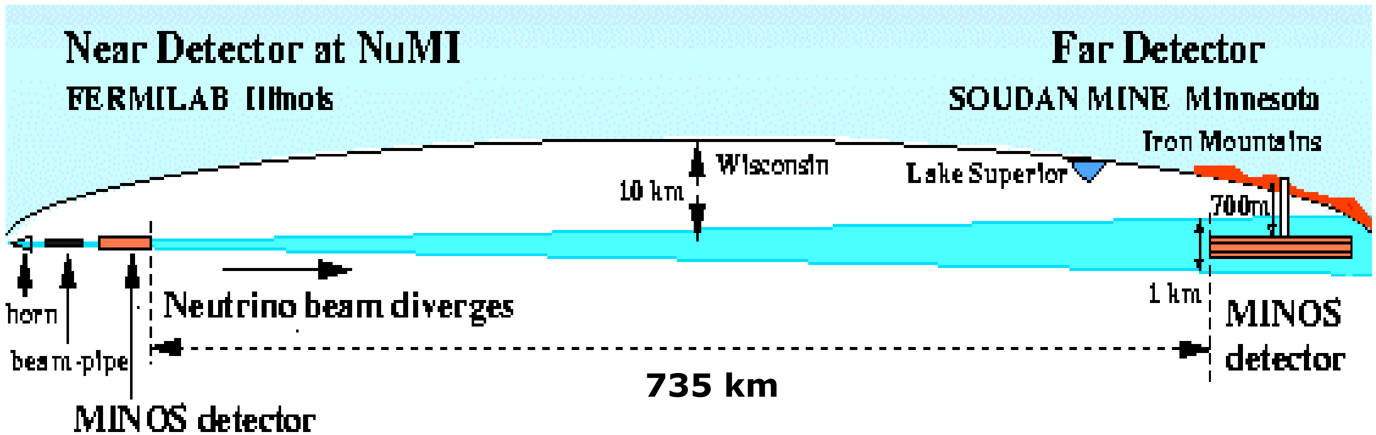
Status of NuMI/MINOS

Mark Thomson
University of Cambridge

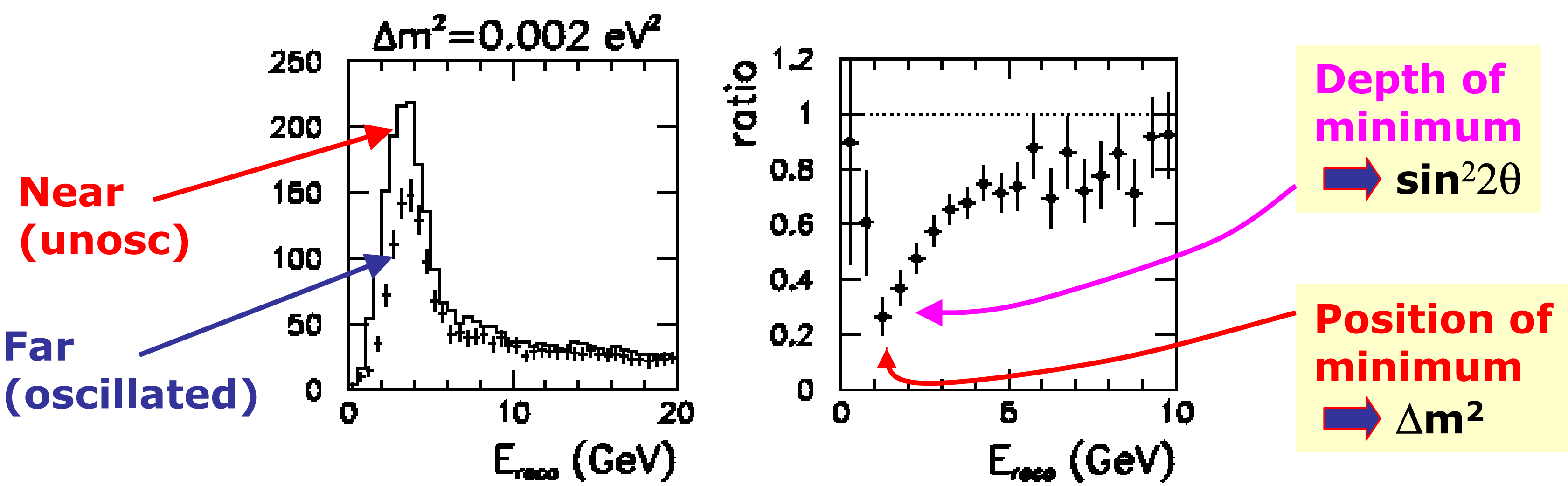
This talk:

- Overview
- NuMI Beam
- MINOS Far and Near Detectors
- Physics Capabilities
- First Data
  - cosmic muons
  - atmospheric νs

MINOS : Basic Idea



- **Measure ratio of neutrino energy spectrum in far detector (oscillated) to that in the near detector (unoscillated)**
- **Partial cancellation of systematics**



MINOS Physics Goals

★ **Demonstrate oscillation behaviour**

- confirm flavour oscillations describe data
- provide high statistics discrimination against alternative models:
  decoherence, ν decay, extra dimensions, etc.

★ **Precise Measurement of Δm^2_{23}**

- ~10 %

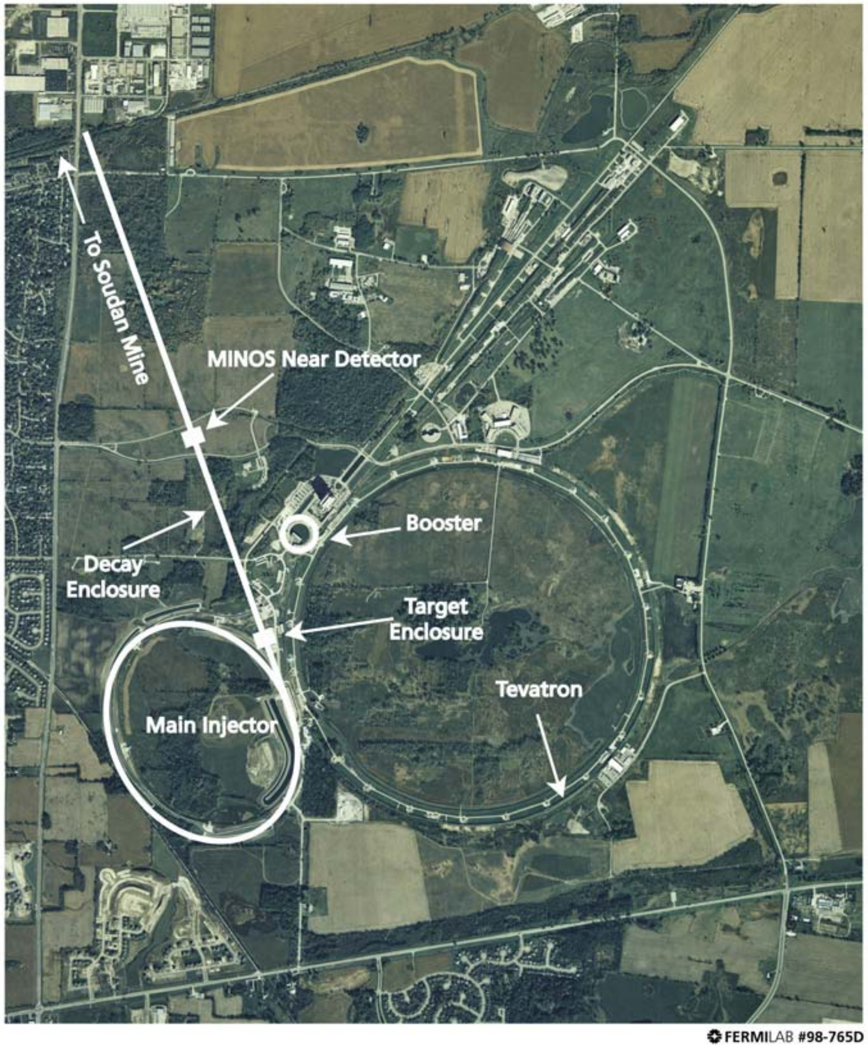
★ **Search for sub-dominant $\nu_\mu \rightarrow \nu_e$ oscillations**

- first measurements of θ_{13} ?

+ **MINOS is the 1st large deep underground detector with a B-field**

- first direct measurements of ν vs $\bar{\nu}$ oscillations from atmospheric neutrino events

The NuMI beam

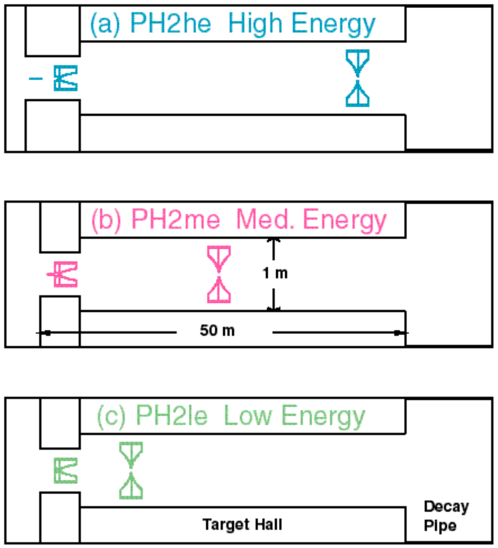


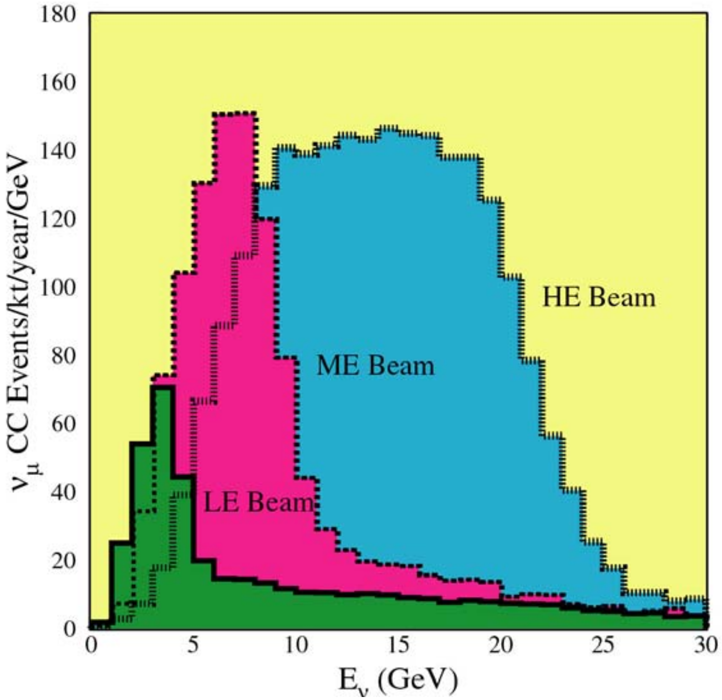
- ★ 120 GeV protons extracted from the MAIN INJECTOR in a single turn (8.7μs)
- ★ 1.9 s cycle time
- ★ *i.e.* ν beam \`on' for 8.7μs every 1.9 s
- ★ 2.5×10^{13} protons/pulse
- ★ 0.3 MW on target !
- ★ Initial intensity

  2.5×10^{20} protons/year

Tunable beam

- ★ Relative positions of the neutrino horns allow beam energy to be tuned. Act like a pair of (highly achromatic lenses)
- ★ Start with LE beam – best for $\Delta m^2 \sim 0.002\ eV^2$





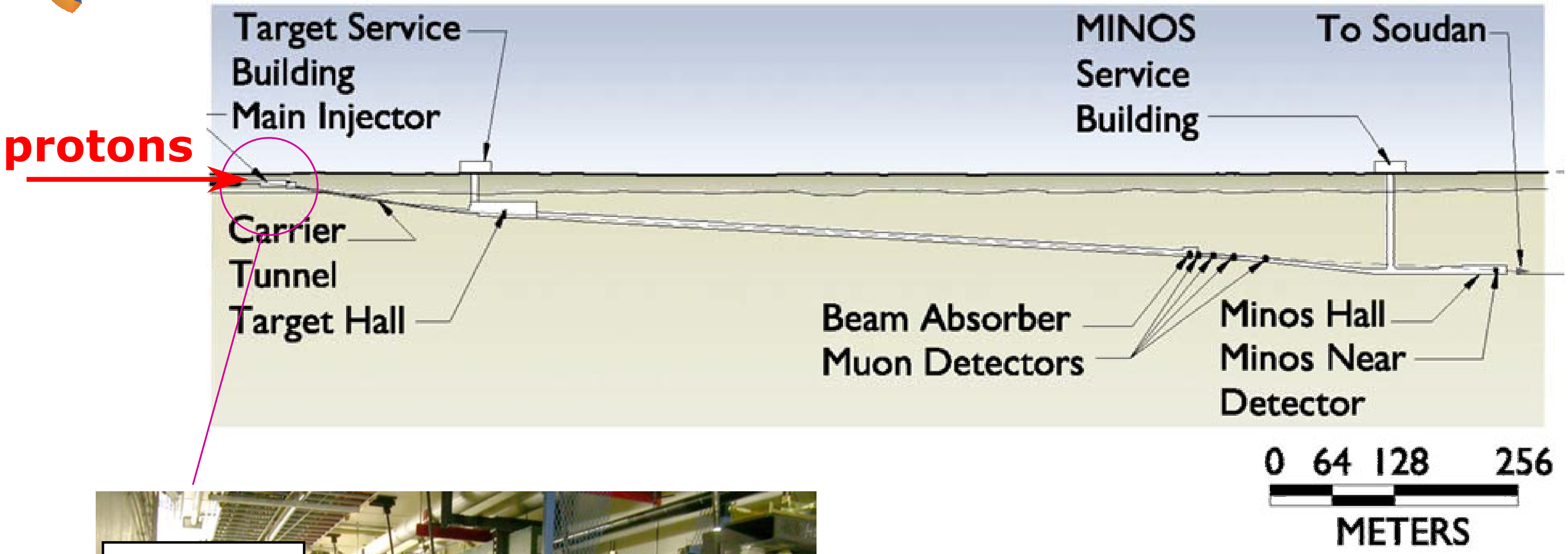
LE BEAM:

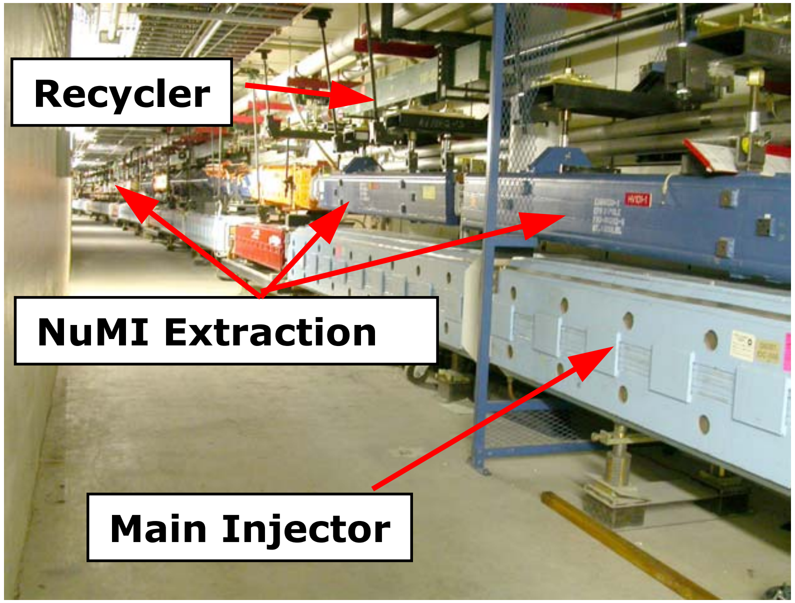
ν_μ CC Events/year:

Low	Medium	High
1600	4300	9250

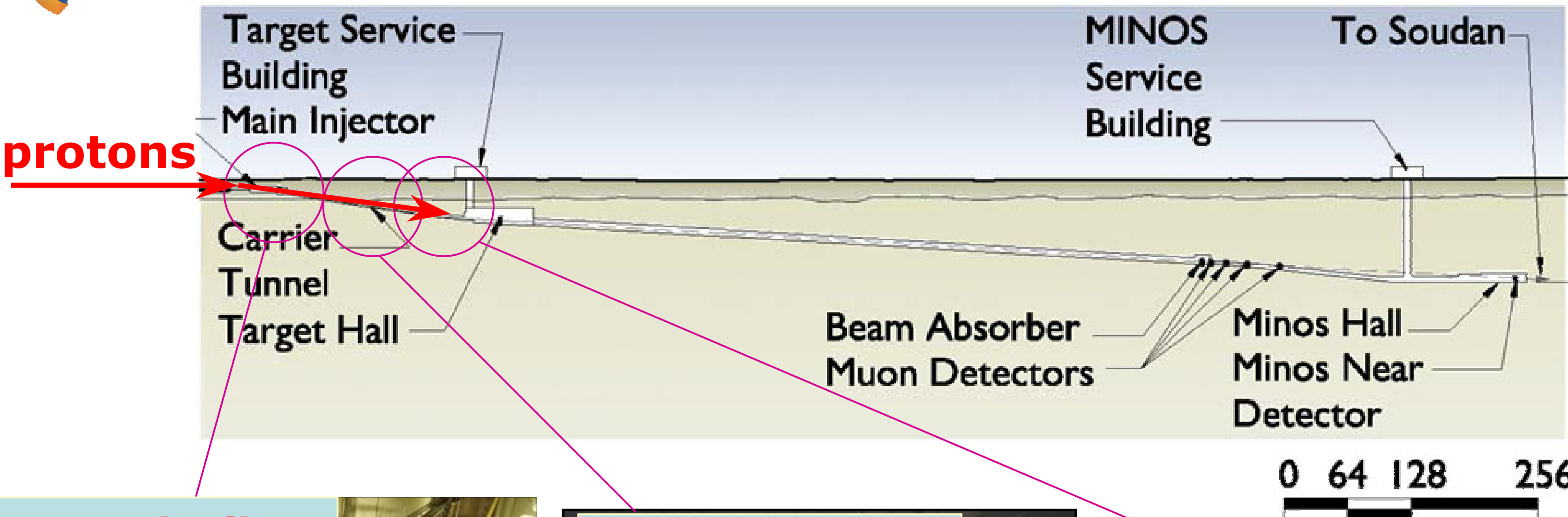
(2.5×10^{20} protons on target/year)

The NuMI ν beam : I



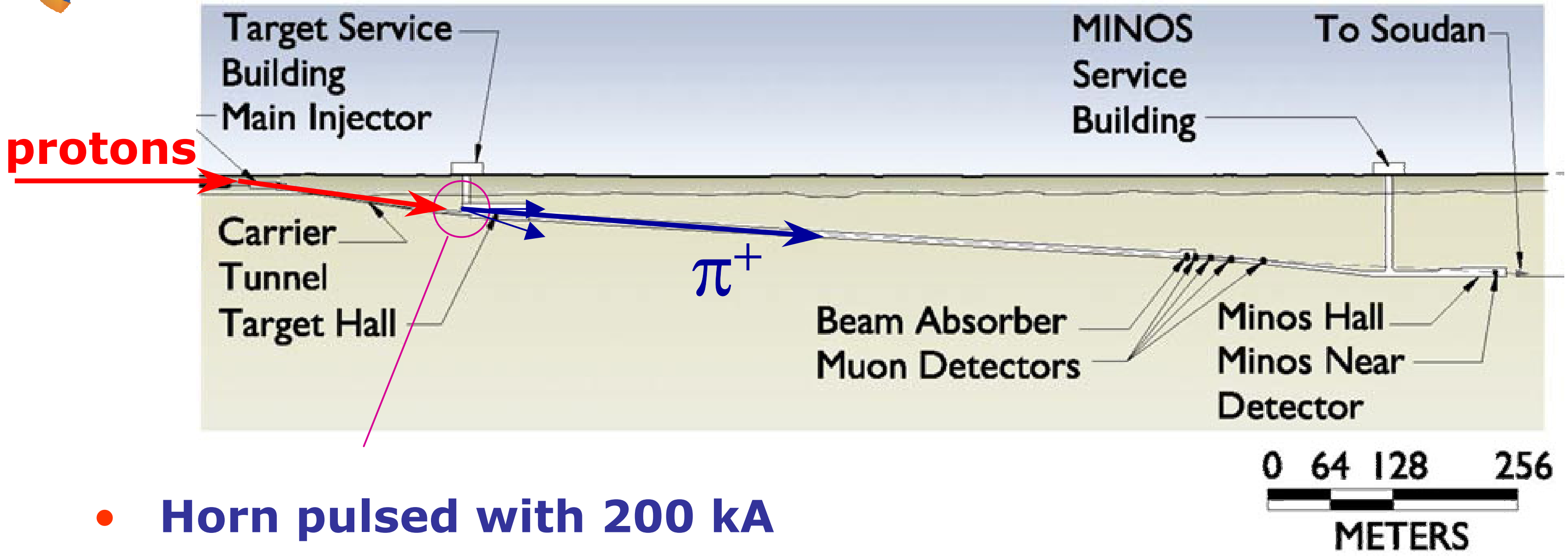


The NuMI ν beam : II

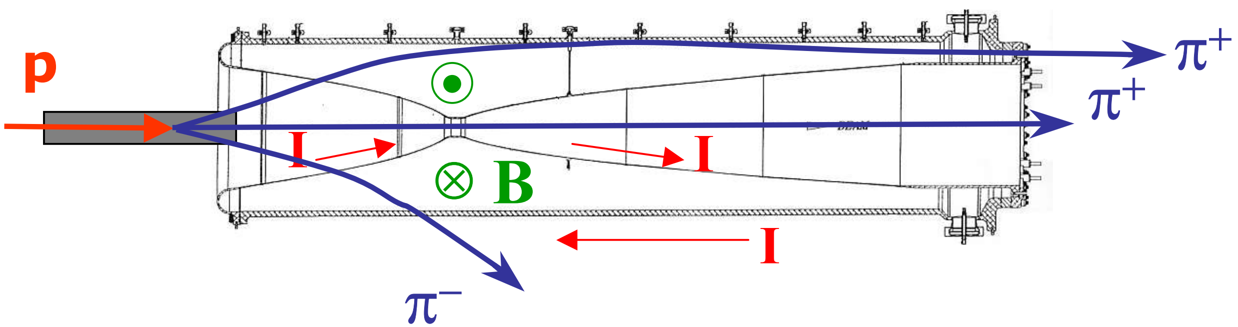


★ **Beam points 3.3° downwards**

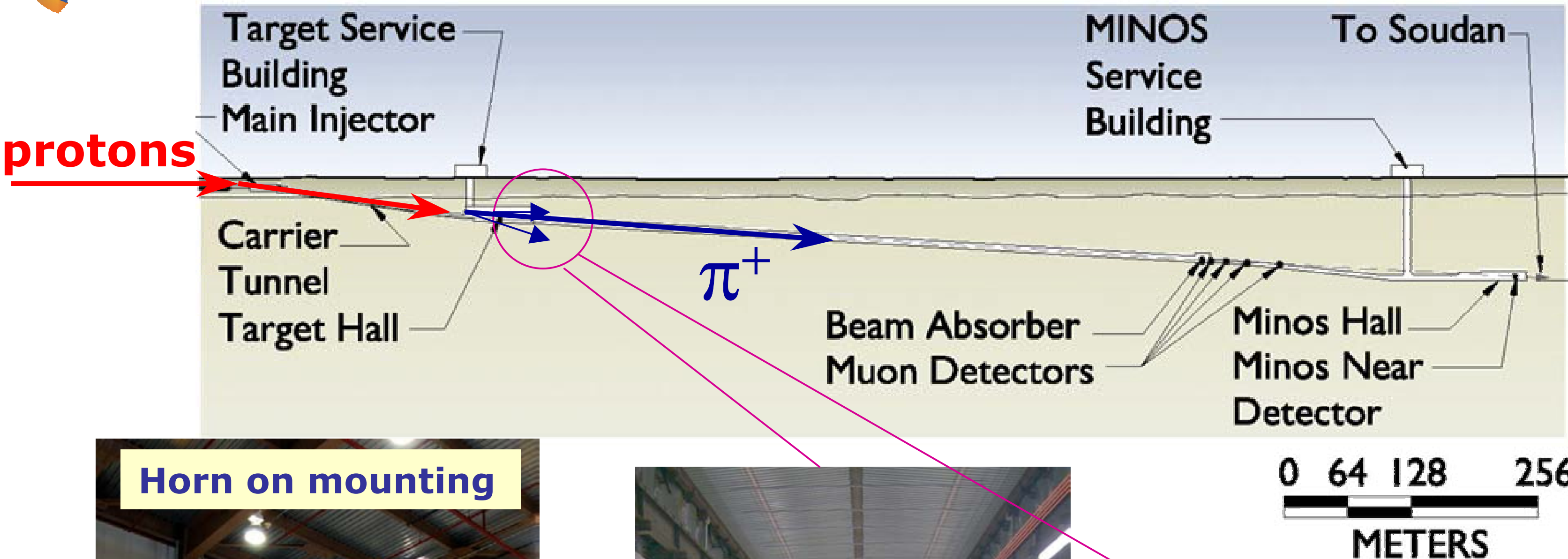
The NuMI ν beam : III



- Horn pulsed with 200 kA
- Toroidal Magnetic field $B \sim I/r$ between inner and outer conducters



The NuMI ν beam : IV

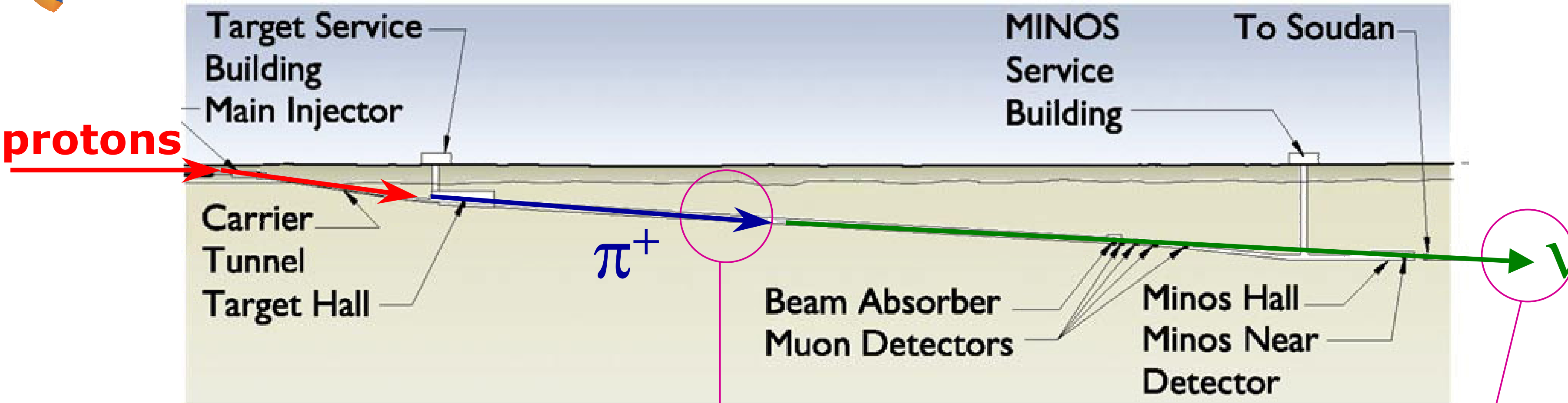



Horn on mounting


Before shielding


Shielding Installation

The NuMI ν beam : V

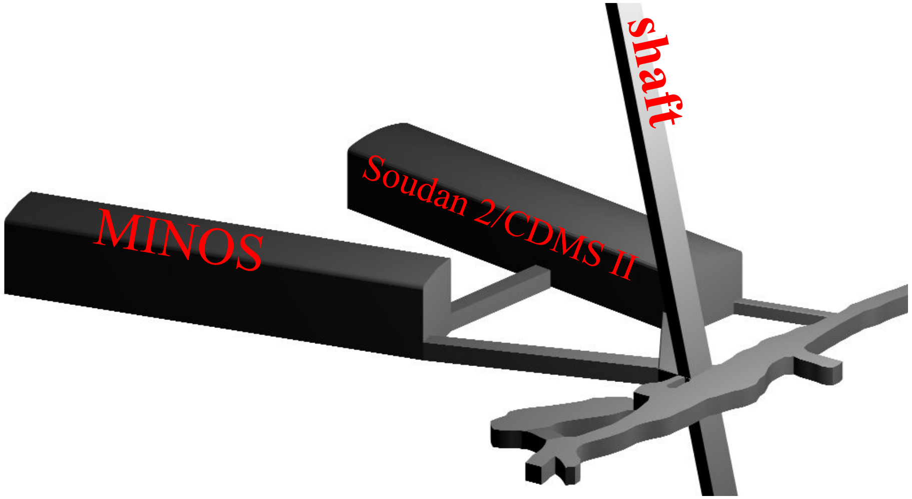


675 m long decay pipe

- ★ **Need long decay pipe:**
  for a 5 GeV π^+
  $\gamma c\tau$ ~ 200 m
- ★ **Evacuated to 1.5 Torr**
- ★ **Steel decay pipe installed and encased in 2-3 m of concrete to protect ground water**

Going underground

2070 mwe



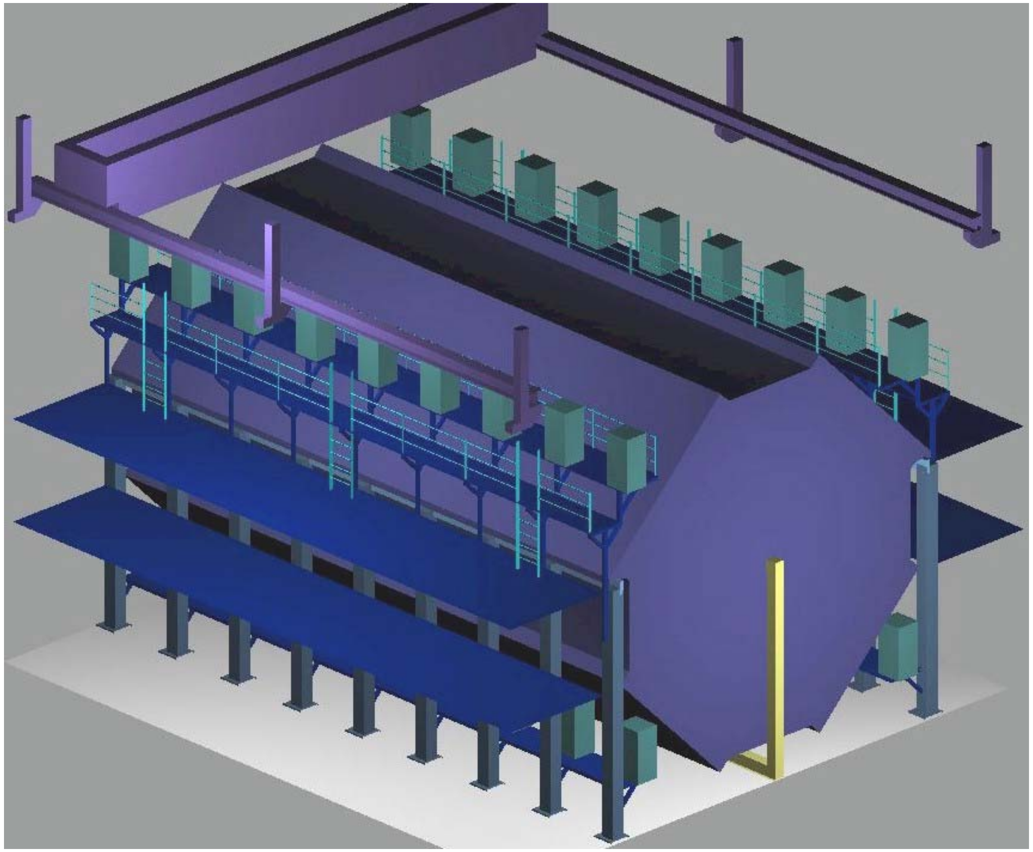
MINOS Far Detector

8m octagonal steel & scintillator tracking calorimeter

- **2 sections, 15m each**
- **5.4 kton total mass**
- **55%/√E for hadrons**
- **23%/√E for electrons**

Magnetized Iron (B~1.5T)

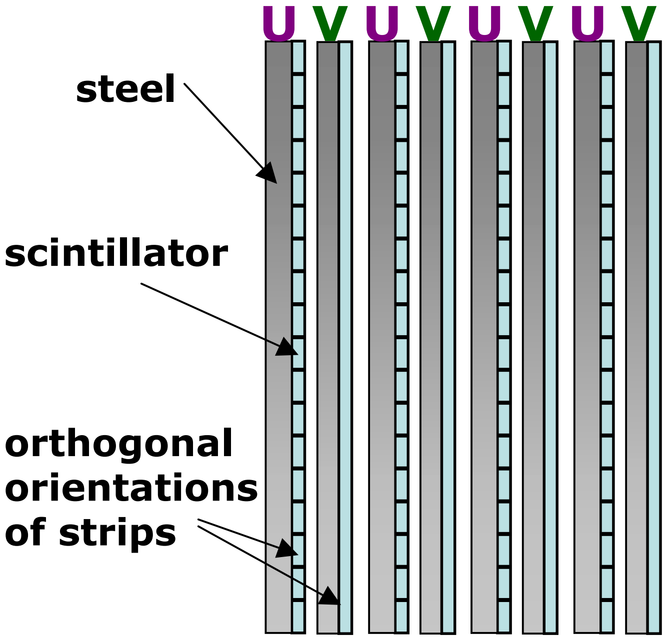
484 planes of scintillator

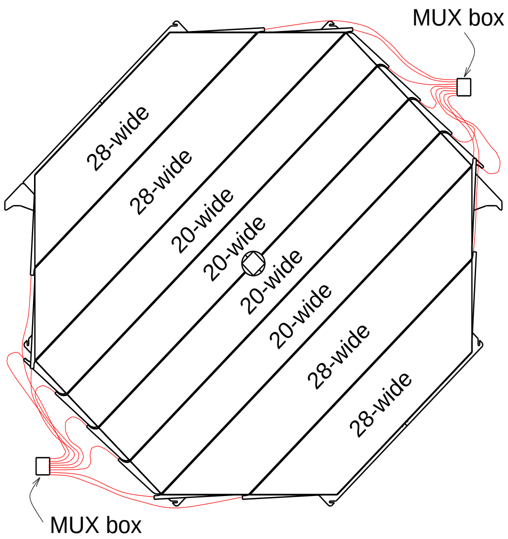


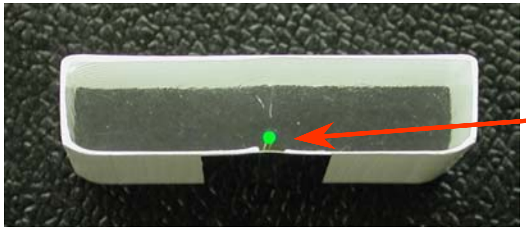
One Supermodule of the Far Detector… Two Supermodules total.

Detector Elements

- ★ Steel-Scintillator sandwich : **SAMPLING CALORIMETER**
- ★ Each plane consists of a **2.54 cm** steel +**1 cm** scintillator
- ★ Each scintillator plane divided into **192 x 4cm** wide strips
- ★ Alternate planes have **orthogonal** strip orientations (U and V)

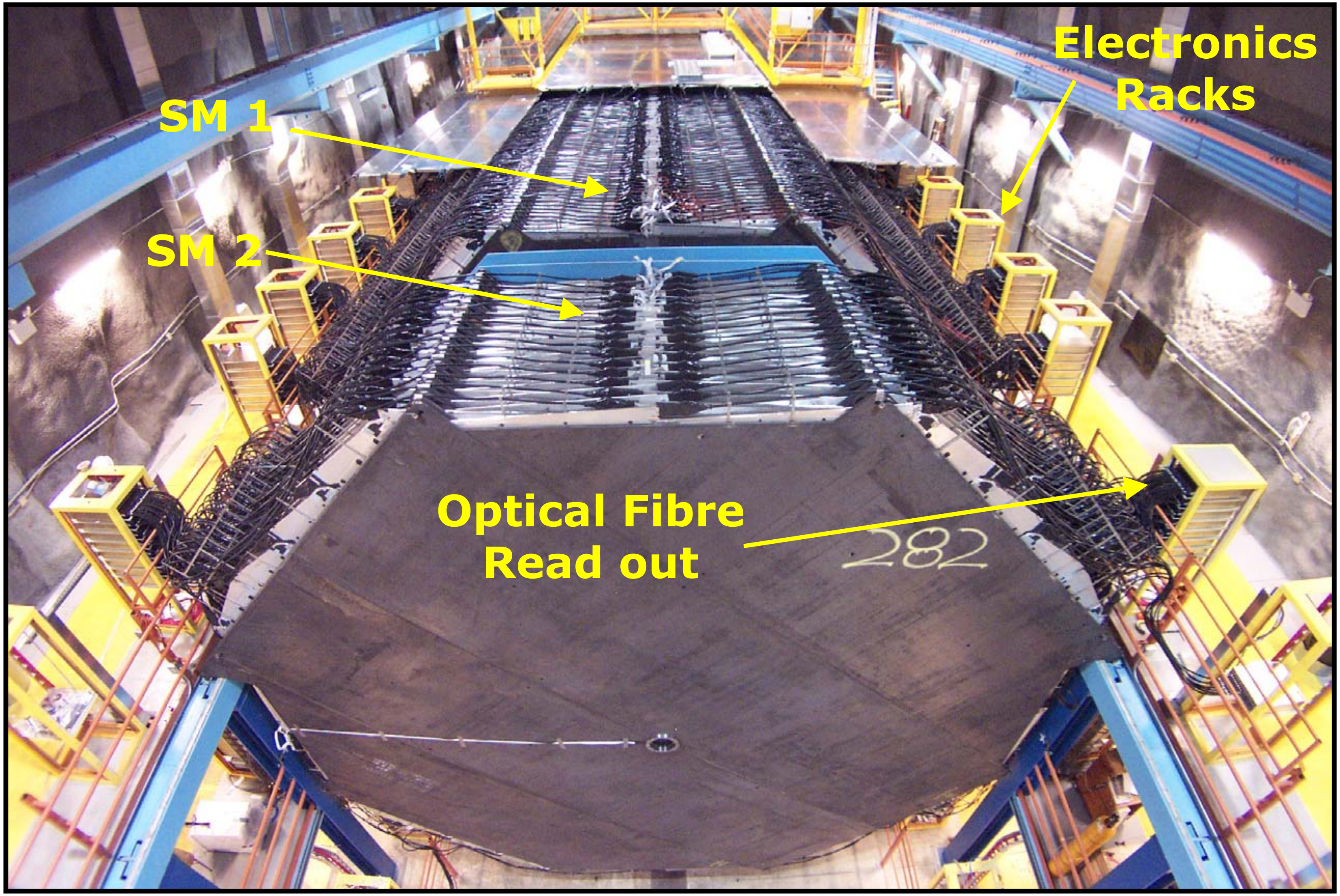




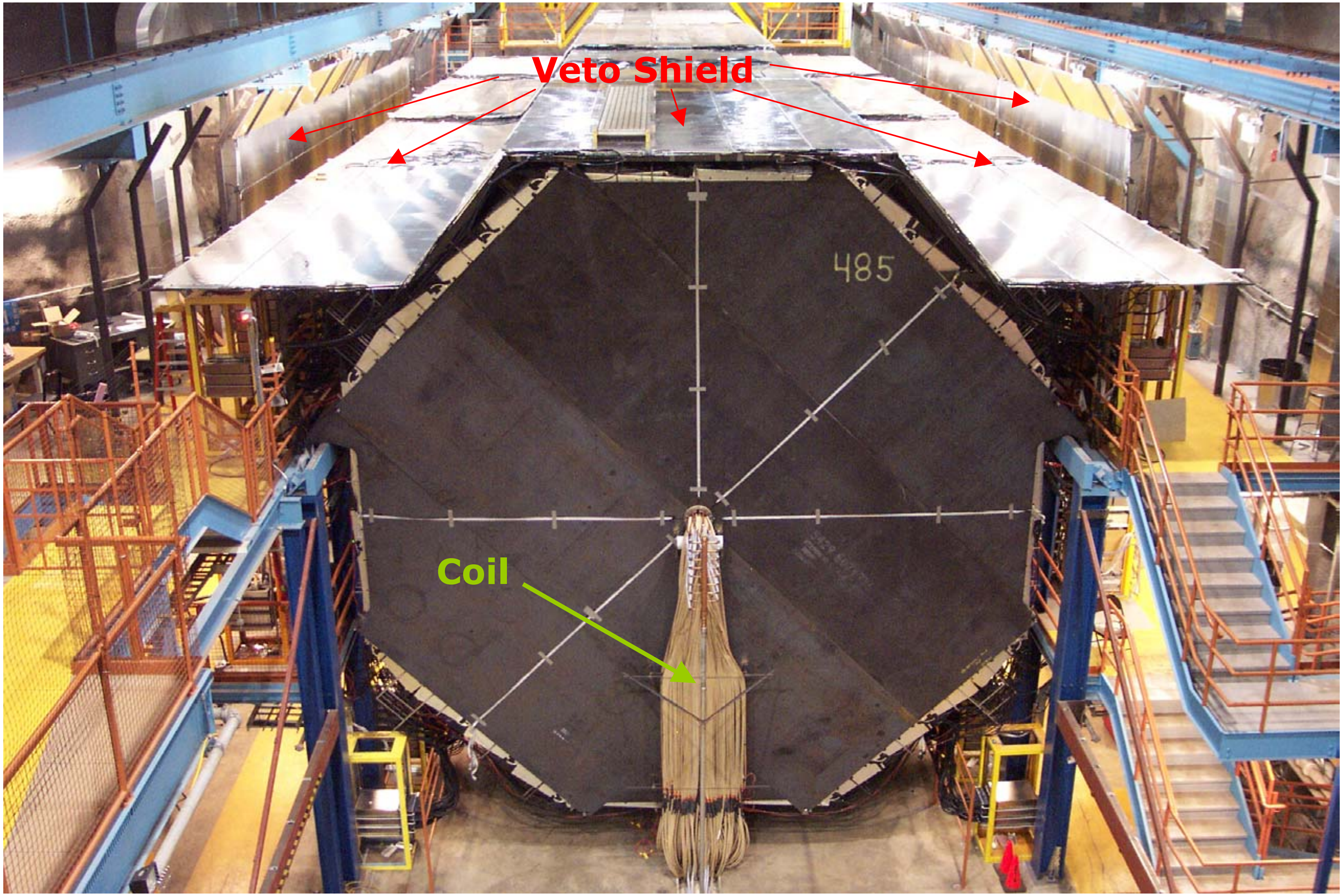


- ✦ Scintillation light collected by **WLS** fibre glued into groove
- ✦ Readout by multi-pixel PMTs

MINOS FarDet during installation

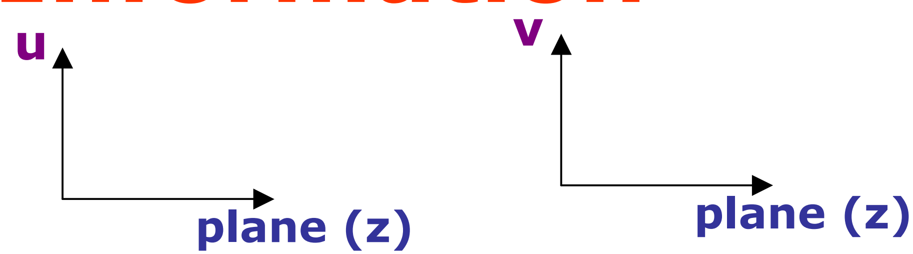


Far Detector fully operational since July 2003

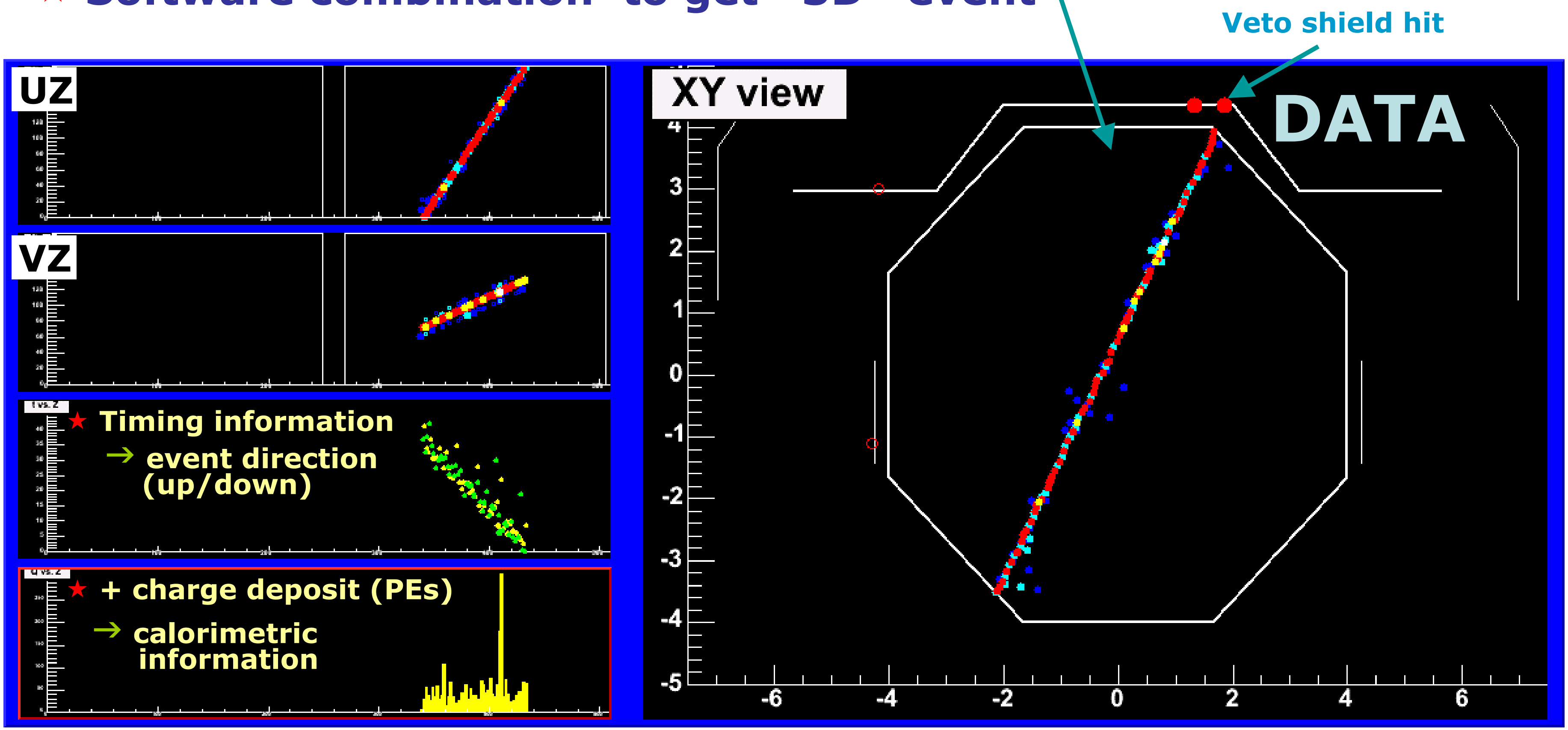


Event Information

- ★ **Two 2D views of event**



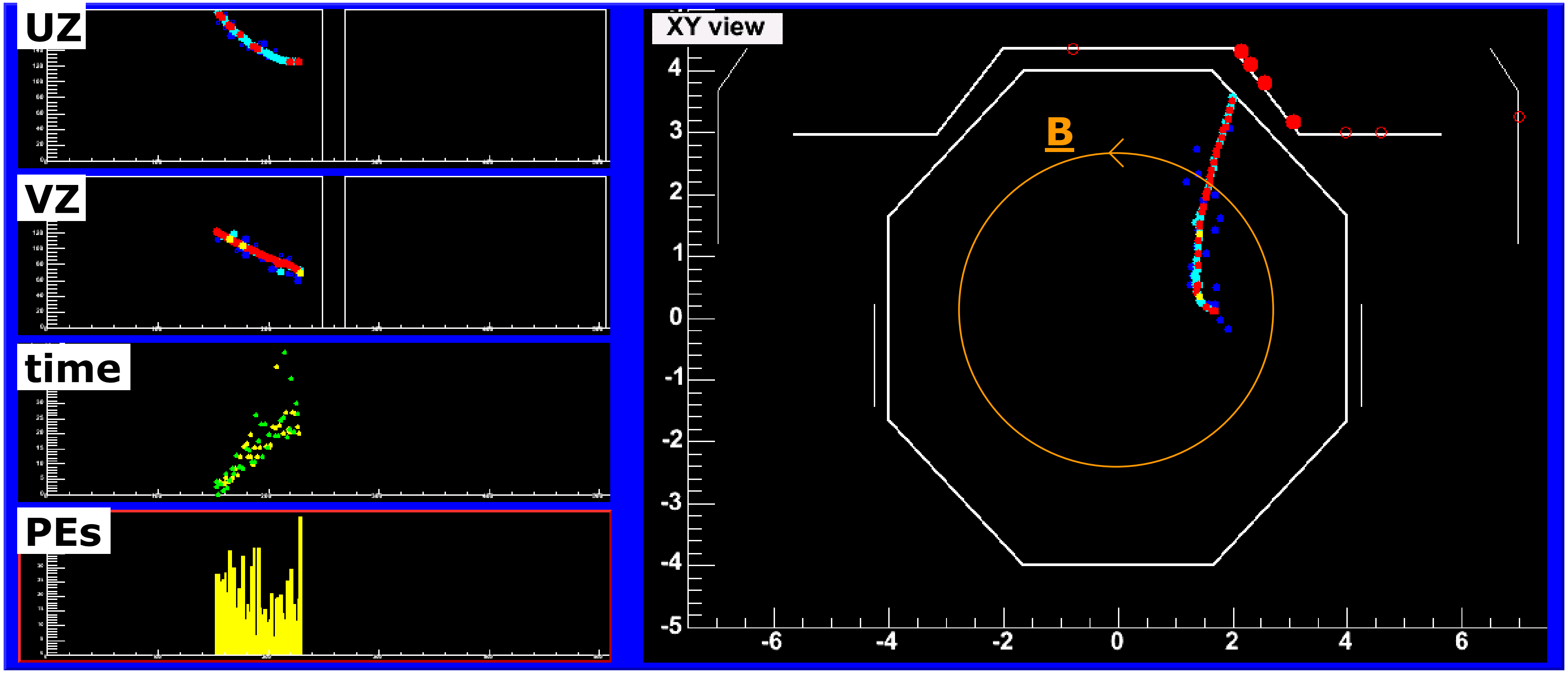
- ★ **Software combination to get `3D' event**



B-Field

~ 1.5 T Magnetic Field

- ★ Charge separation
- ★ Momentum measurement



Single Hit Resolution : 2.5 ns

Stopping muon

P_{range} = 3.86 GeV/c

$P_{curvature}$ = 4.03 GeV/c

MINOS Near Detector

- ★ **1 kton total mass**
- ★ **Same basic design**
  steel, scintillator, etc
- ★ **<u>Some differences, e.g:</u>**

Faster electronics

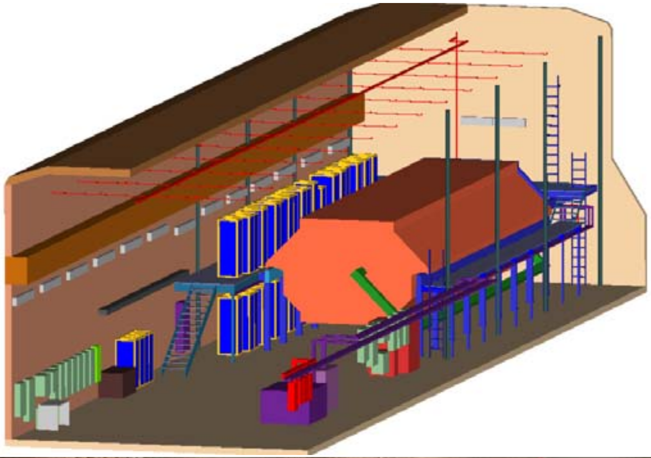
Partially instrumented:

282 planes of steel

153 planes of scintillator

(Rear part of detector only used to track muons)

+.....



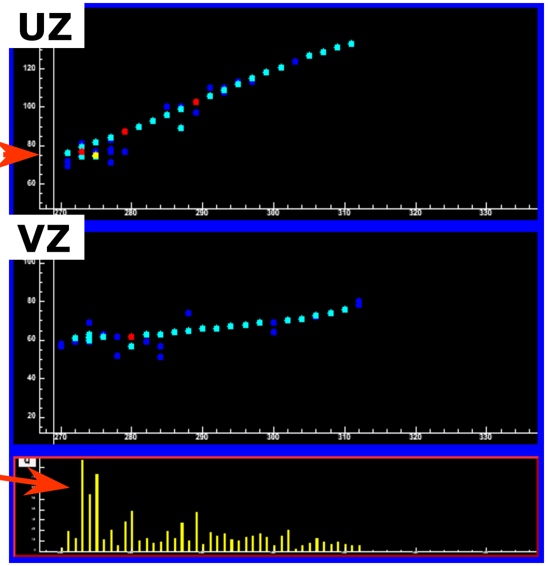
Currently being installed at Fermilab

MINOS Beam Physics (MC)

ν_μ CC Event

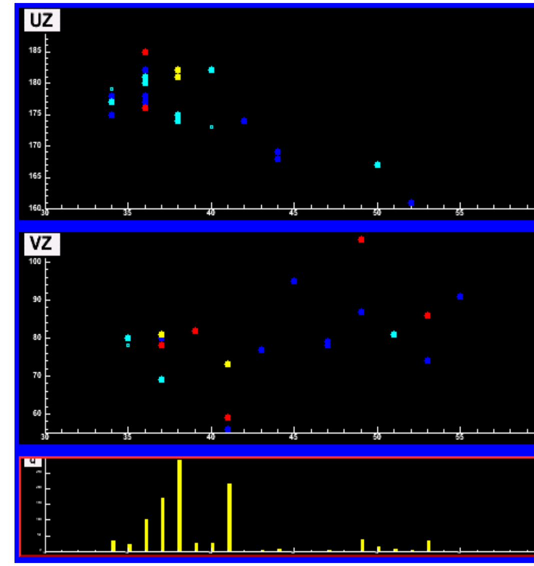
ν ·········

- μ track
- +hadronic activity



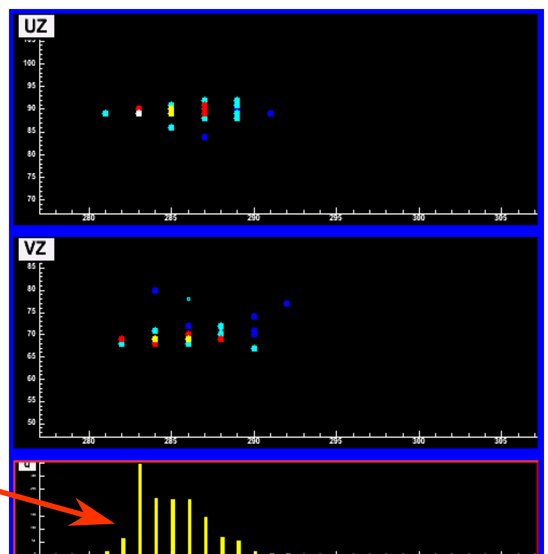
NC Event

- often diffuse



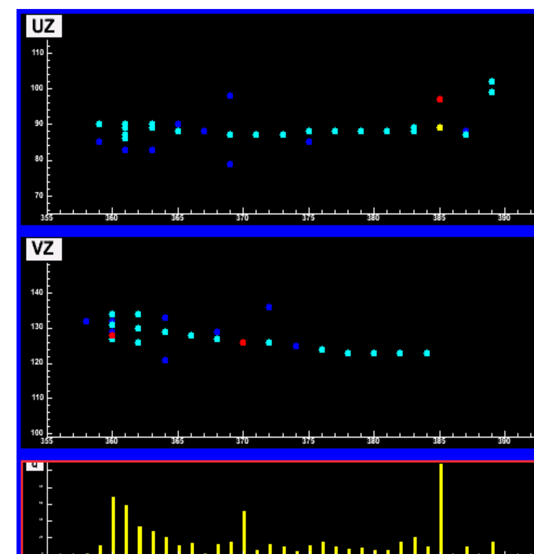
ν_e CC Event

- compact shower
- typical EM shower profile



NC Event

- can mimic ν_μ , ν_e

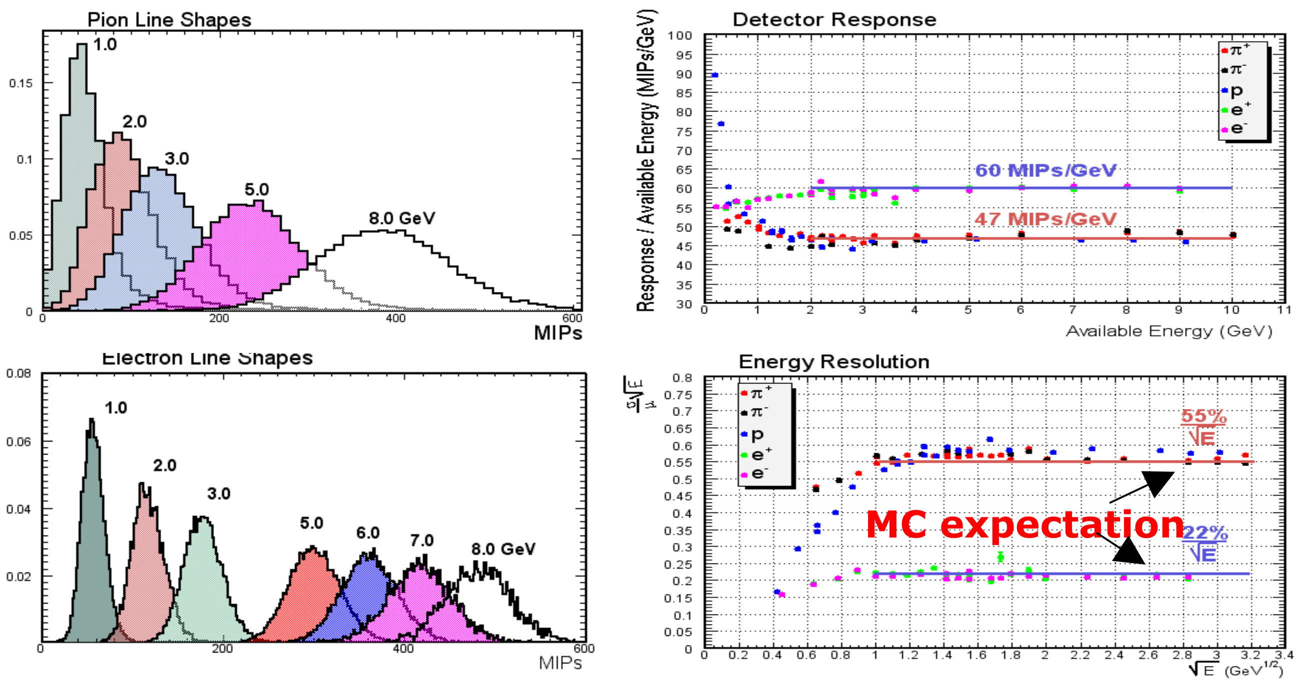


Test Beam

★ **Energy response is important – know L, need E$_\nu$**

- ♦ **hadronic energy from pulse height ($\sigma_E/E \sim 55\%/E^{1/2}$)**
- ♦ $E_\nu = p_\mu + E_{had}$

★ **Response measured in CERN test beam using a MINI-MINOS**

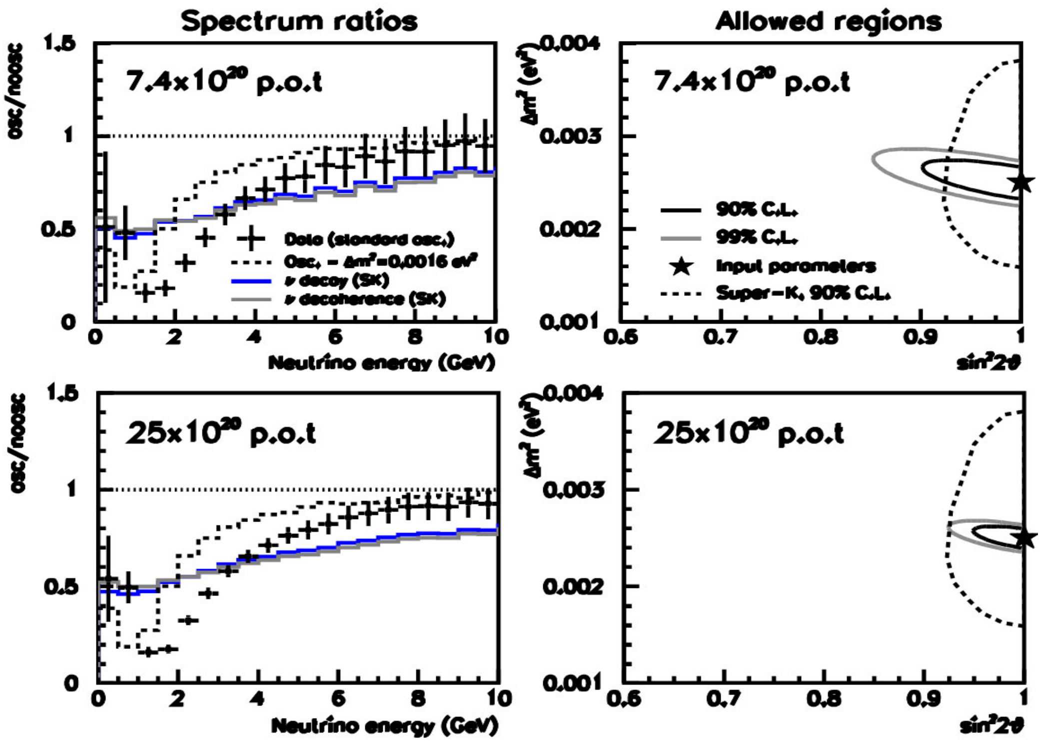


★ **Provides calibration information**

★ **Test of MC simulation of low energy hadronic interactions**

MINOS Physics Sensitivity

★ **Measurement of Δm^2 and $\sin^2 2\theta$**



For Δm^2 = 0.0025 eV², $\sin^2 2\theta$ = 1.0

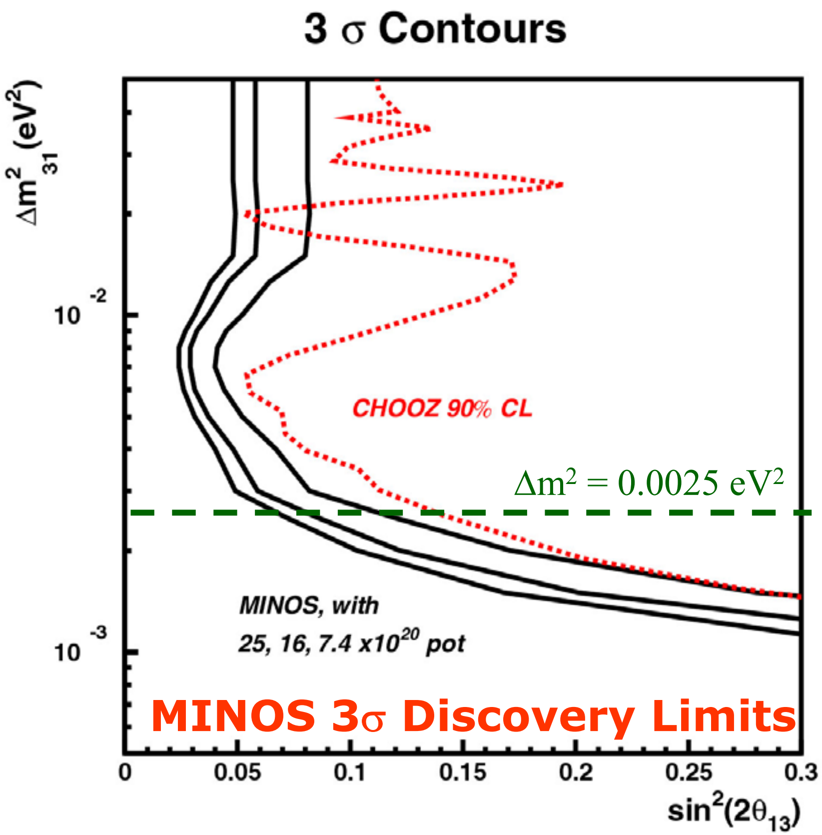
Large improvement in precision !

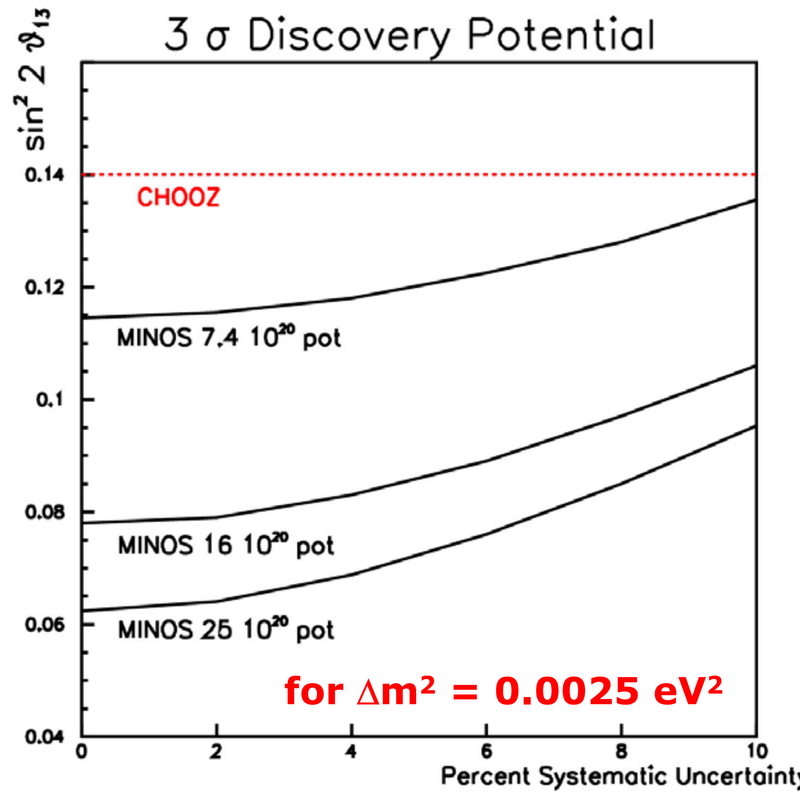
Final sensitivity depends on protons on target

★**Direct measurement of L/E dependence of ν_μ flux**

★**Powerful test of flavour oscillations vs. alternative models**

ν_e Appearance

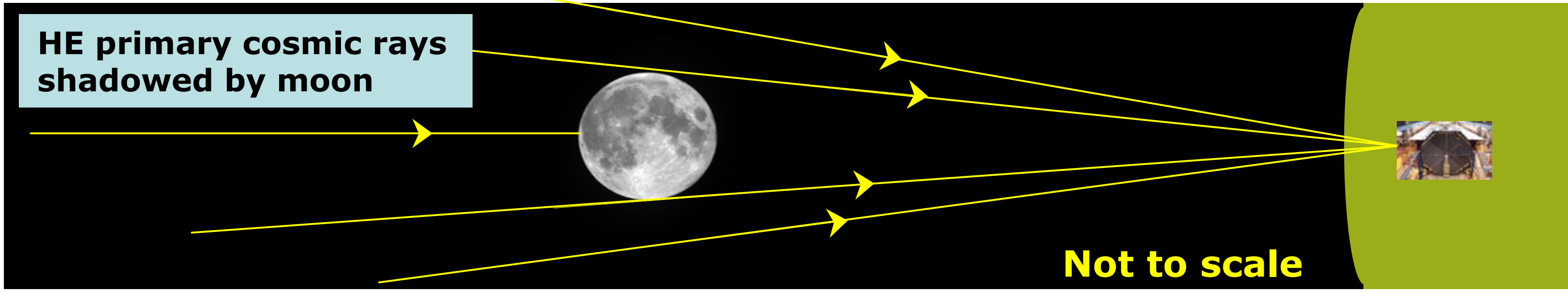




- **3 σ discovery potential** may significantly eat into current allowed region – exact reach depends on protons on target
- reasonable chance of making the first measurement of θ_{13} !

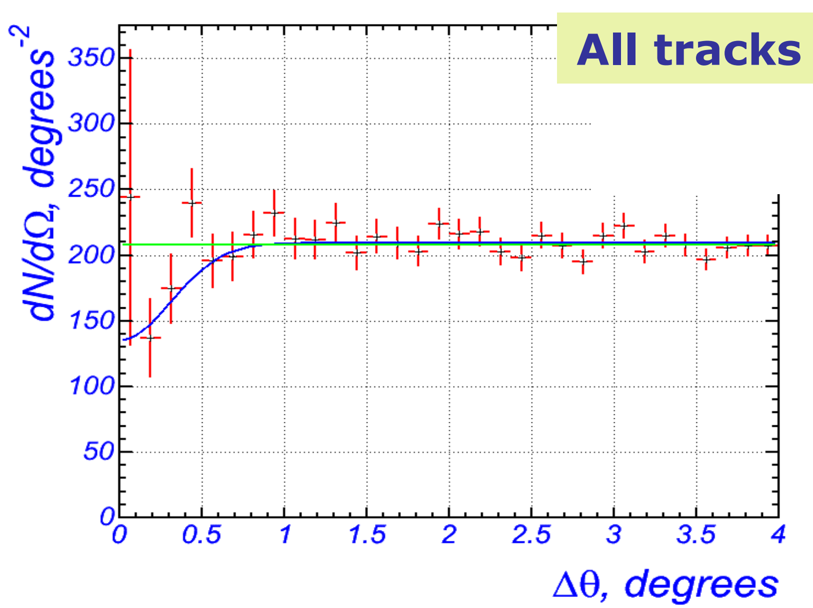
First beam in December 2004
BUT Already Have Data....

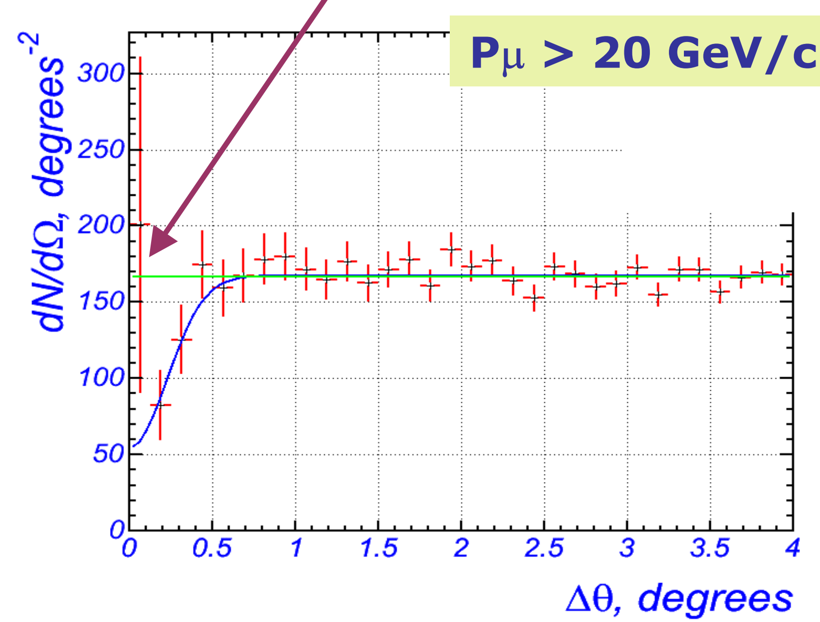
Moon Shadow



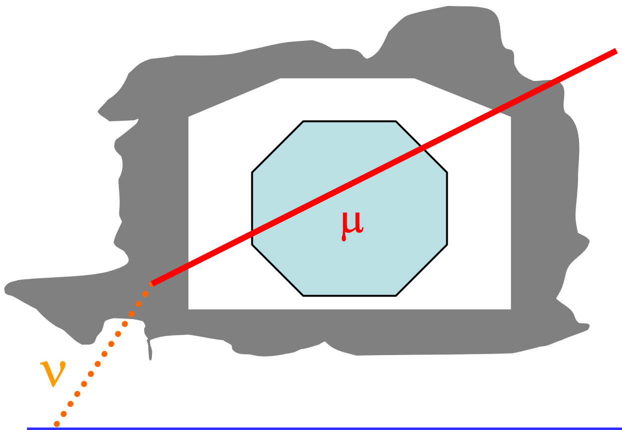
★ **Have recorded 10 M cosmic muons**
observed shadow of moon

★ **Angular res. improved by selecting high momenta muons**
(less multiple scattering)

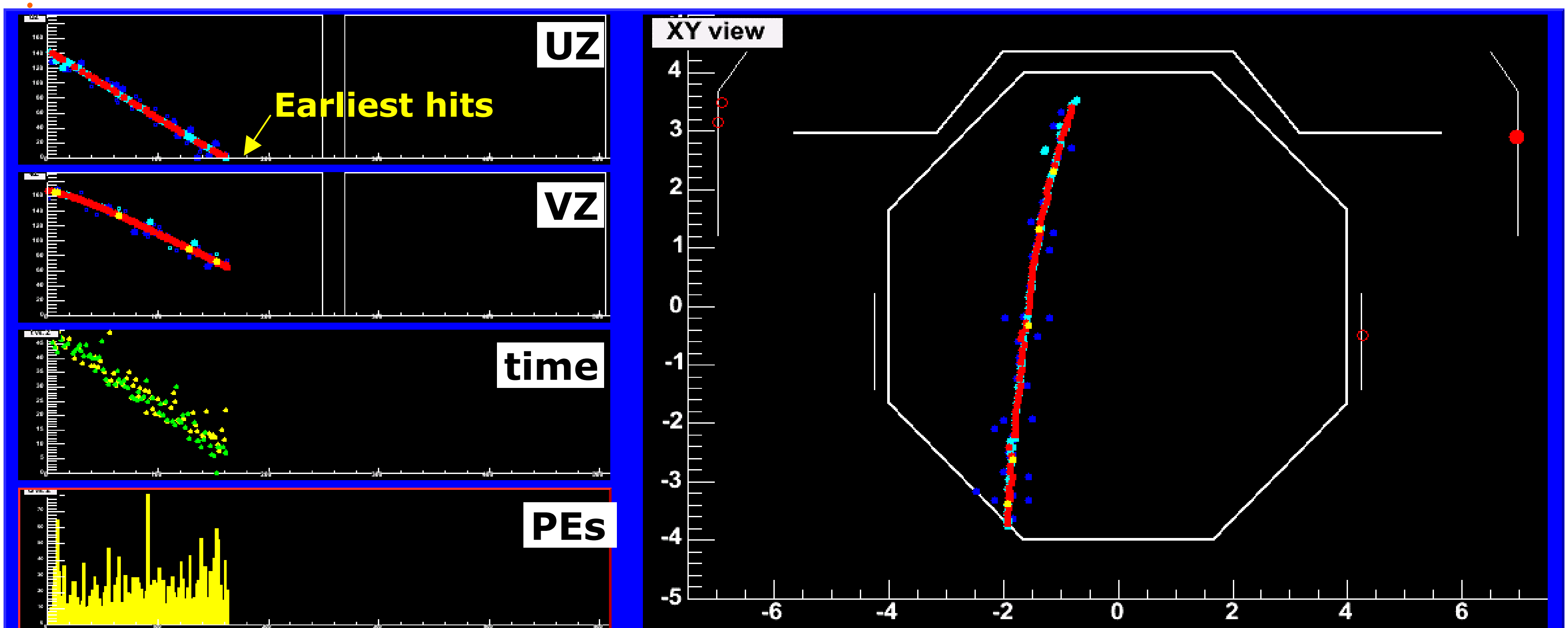




ν induced upward μ



- ★Expect : 1 Event/6 Days
- ★Identified on basis of timing

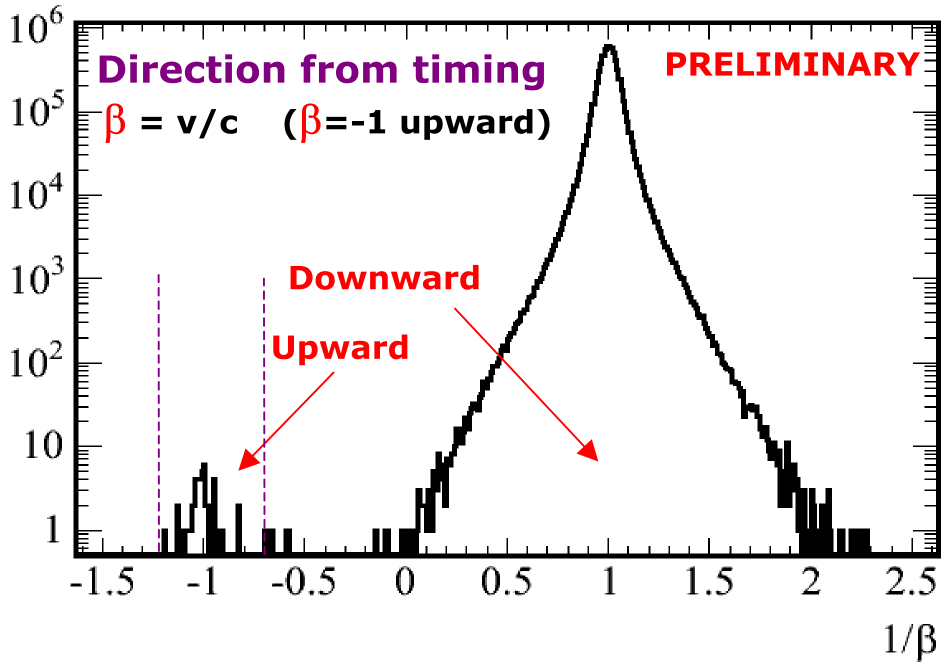


ν induced upward-going muons

★ Look for events coming from below horizon
★ Require clear **up/down** resolution from timing

- \`Good track' > 2.0 m
- >20 planes crossed

✸ Calculate muon velocity from hit times: $\beta = v/c$



★ Clear separation of up/down going μs !

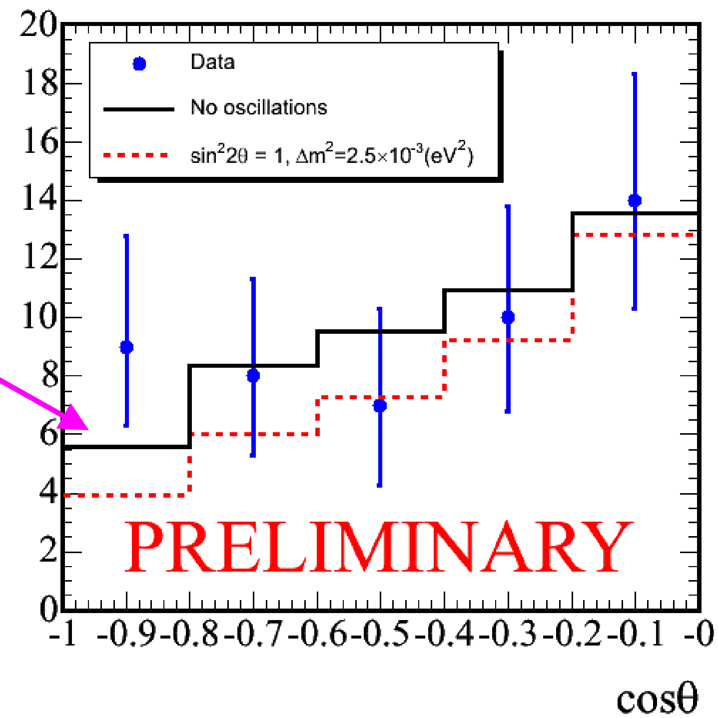
$\sigma_{1/\beta} \sim 0.05$

★ 48 Upward events

Upward μ Analysis: Data vs. MC

NUANCE generator:

- Bartol '96 flux
- MC normalised to data (assuming no oscillations)



Charge-tagging:

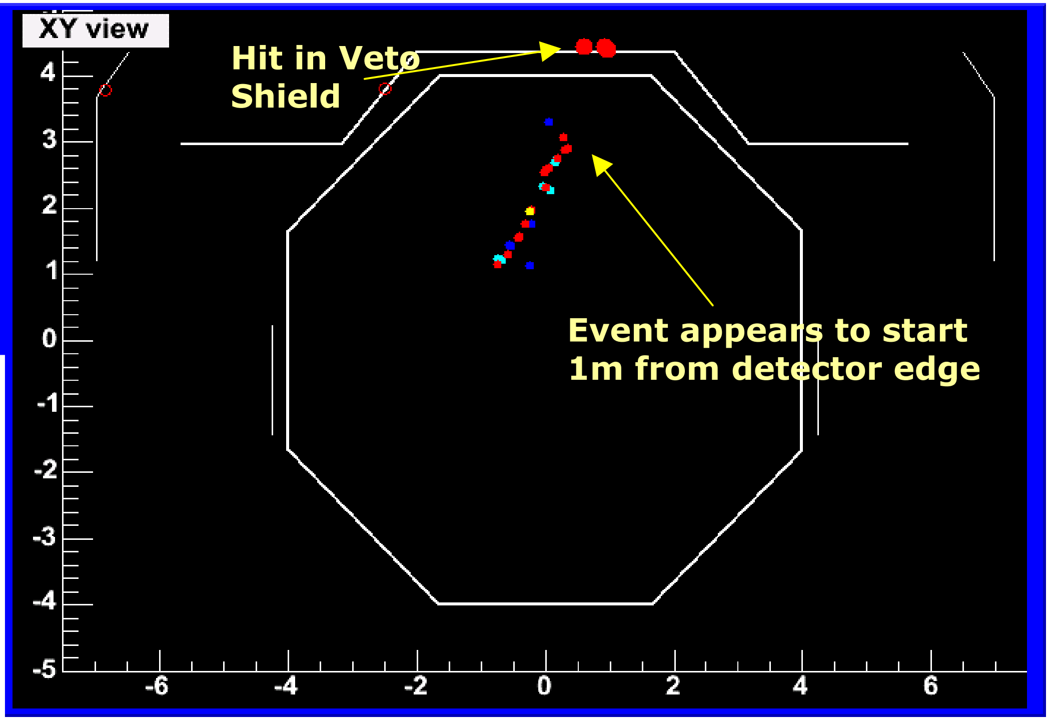
- Tag $\nu/\bar{\nu}$ using muon charge
- Efficiency depends on:
  - muon momentum
  - track length
  - orientation wrt B-field
- Clean charge ID for approx. **50 %** of events

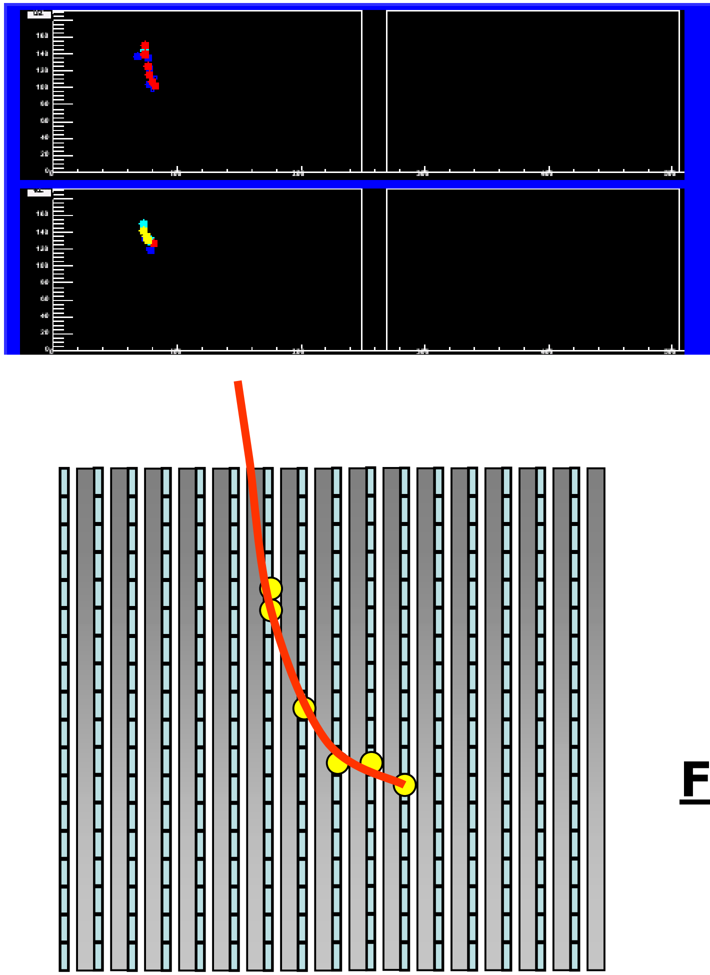
	ν	$\bar{\nu}$	$\nu/\bar{\nu}$?
Events	13	8	27

★ **Understanding systematics : Work in progress**

Contained Events

- ★ MINOS Designed for νs from FNAL – not atmospherics
- ★ Gaps between planes - potentially problematic





For Contained Atmospheric νs :

- ♦ use of **veto shield** significantly reduces background from cosmics sneaking in between plane gaps

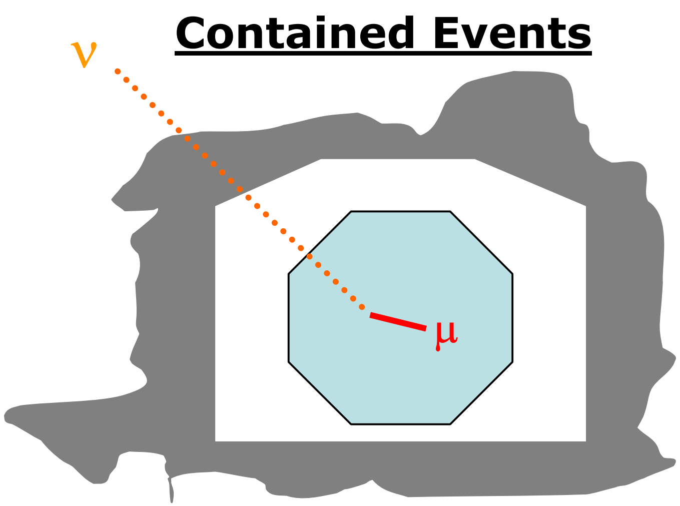
Contained Event Selection

- ★ Signal/Noise (cosmics) = 1/200,000
- ★ Veto Shield helps : efficiency ~ 97 %
- ★ Have achieved rejection factor of ~ 1:10,000,000 !

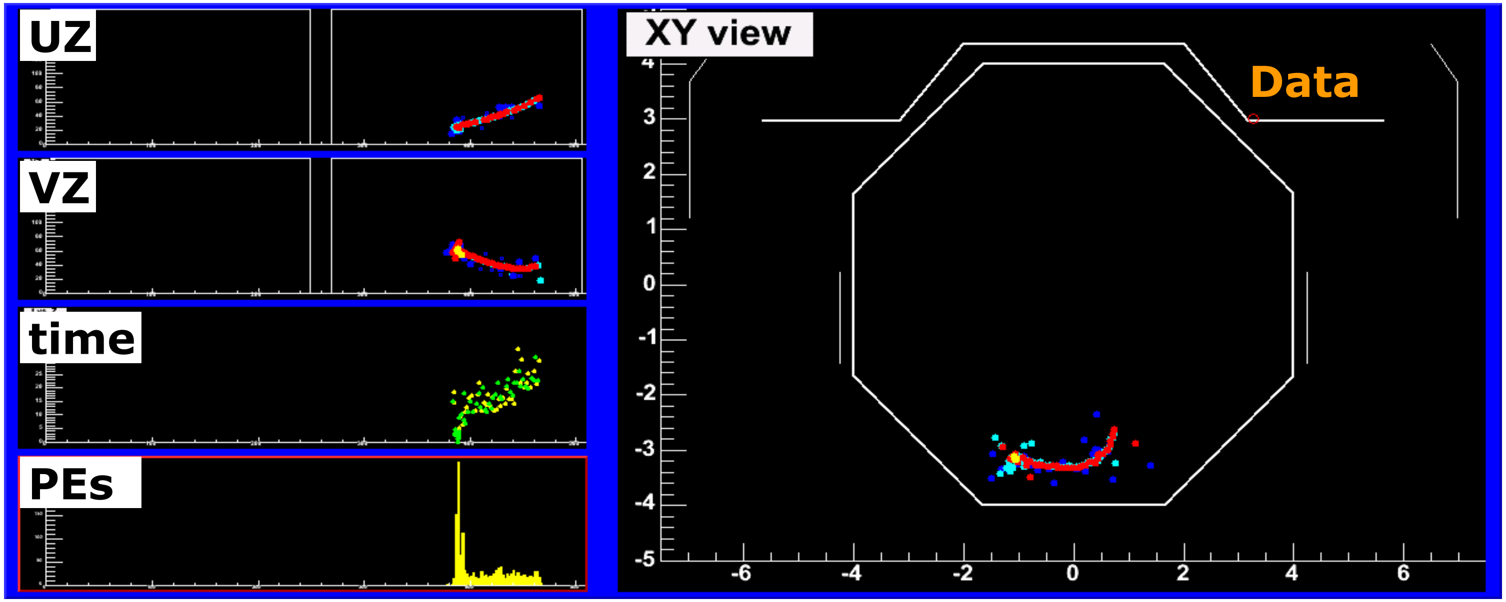
  Efficiency ~ 75 % with 98 % purity

CC ν_μ EVENT SELECTION:

- •Fiducial Volume:
  little activity within 50cm of detector edge
- •Reconstructed muon track
  track which crosses 8 planes
- •Cosmic muon rejection
  remove steep events
- • Veto Shield
  no `in-time' Veto shield hit



Contained Event Selection



MINOS Preliminary

	DATA	MC ν no osc.*	MC Cosmic backgnd.
Before VETO	88	39	63±6
VETOED	51	1	61±6
ν selection	37	38±8	2

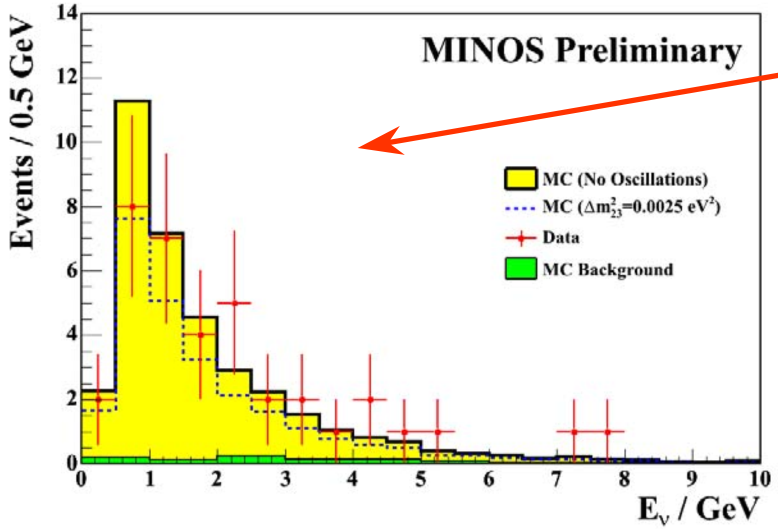
* Does not include acceptance systematic uncertainties – work in progress

Measure cosmic μ bgd. from data using events solely rejected on basis of veto hit

Vetoed background agrees with MC expectation !

ν MC : Battistoni et al

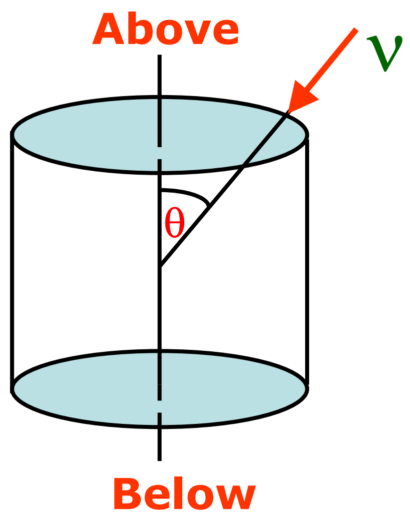
Event Distributions

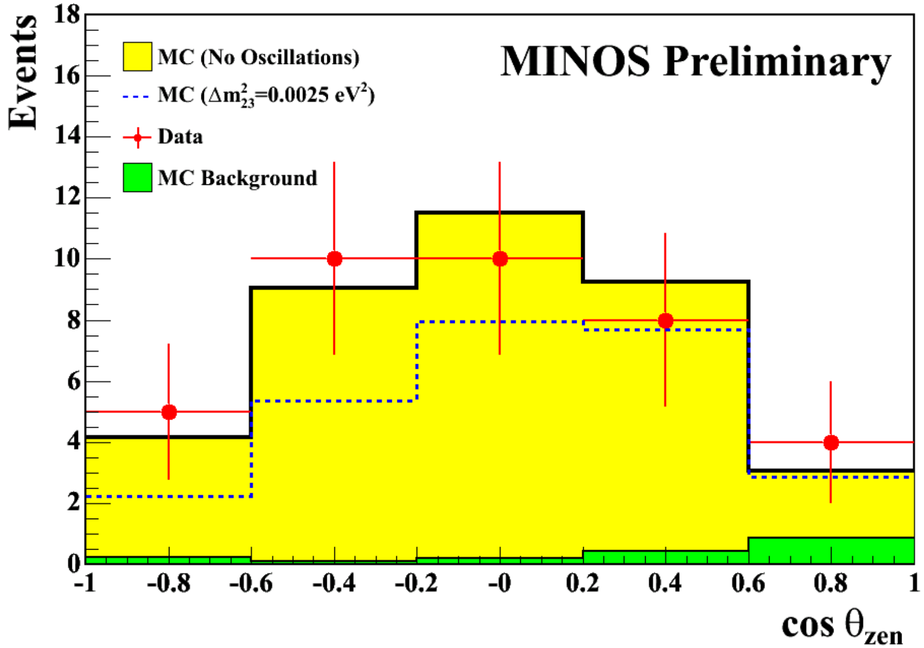


★ $E_\nu = E_\mu + E_{had}$

★ MC normalised to data (no oscillations)

★ Cosmic background from data
- from no. of vetoed events

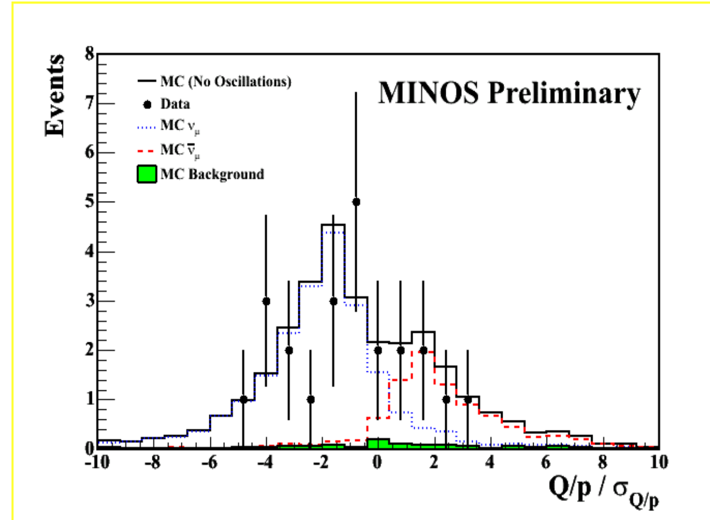


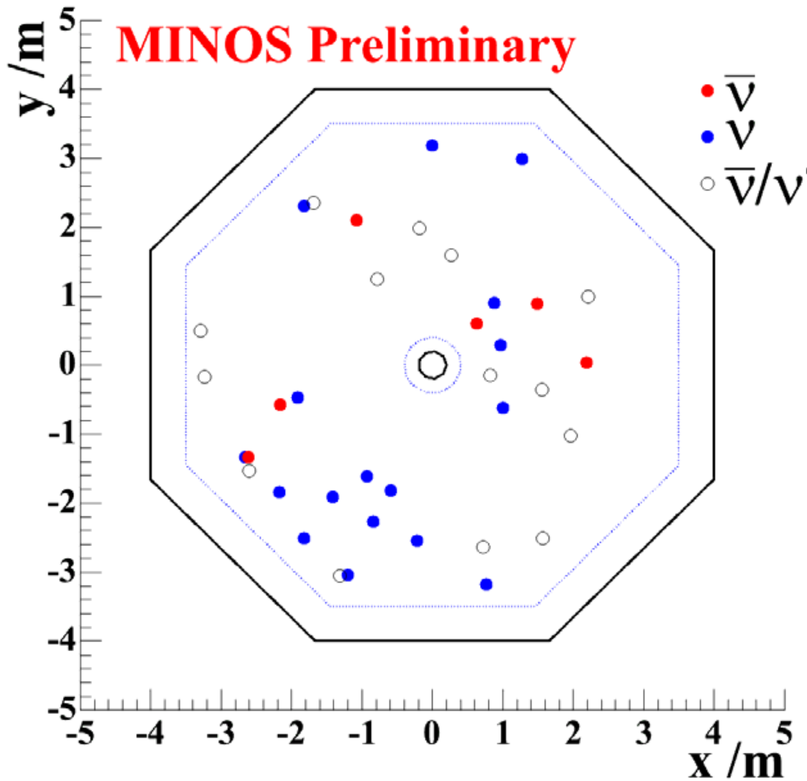


Charge Reconstruction

Tag $\nu/\bar{\nu}$ using muon curvature:

- ★ Curvature ⇨ **Q/p**
- ★ Select on basis of **$(Q/p)/\sigma_{Q/p}$**
- ★ Pure charge ID for **~70 %** of selected events





- ★ **6** $\bar{\nu}$ events
- ★ **17** ν events
- ★ **14** too short to ID $\bar{\nu}/\nu$

⇨ $N\bar{\nu}/N\nu$ = **0.35±0.17**

(expect 0.51±? if $\bar{\nu}/\nu$ oscillate with same parameters)

MINOS atmos ν analysis underway ! just need more data……

Conclusions

- NuMI beam installation progressing well !
  expect first protons on target December 2004 !
- MINOS Near Detector currently being installed/ commisioned at FermiLab
- MINOS Far Detector taking physics quality data since mid-2003
- Atmospheric νs already being seen in the MINOS Far Detector
- First direct observation of $\nu/\bar{\nu}$ separated atmospheric neutrinos
- Eagerly awaiting first beam physics data, expected early 2005 ! Exciting times for MINOS.

MINOS en France