Status of NuMI / MINOS

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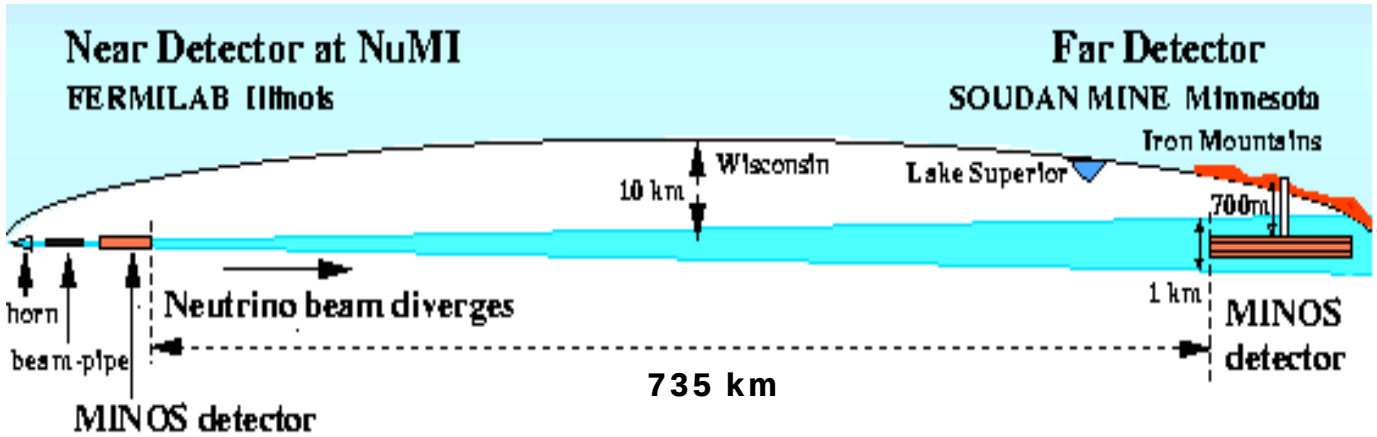
This talk:

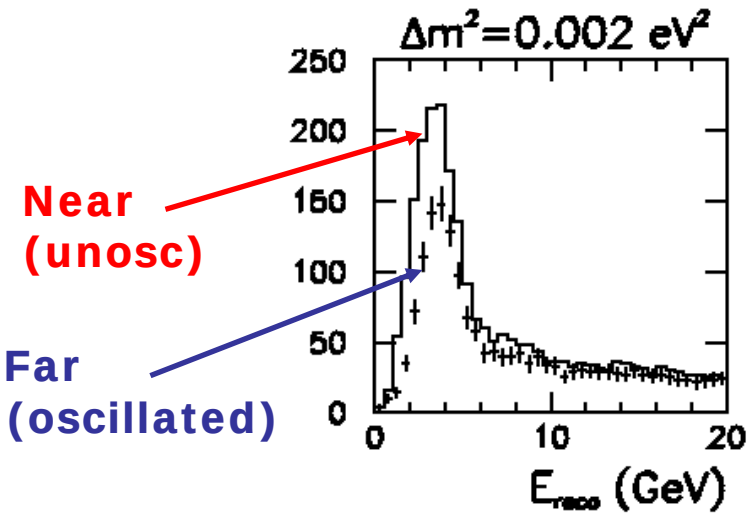
- **Overview**
- **NuMI Beam**
- **MINOS Far and Near Detectors**
- **Physics Capabilities**
- **First Data**
  - **cosmic muons**
  - **atmospheric νs**

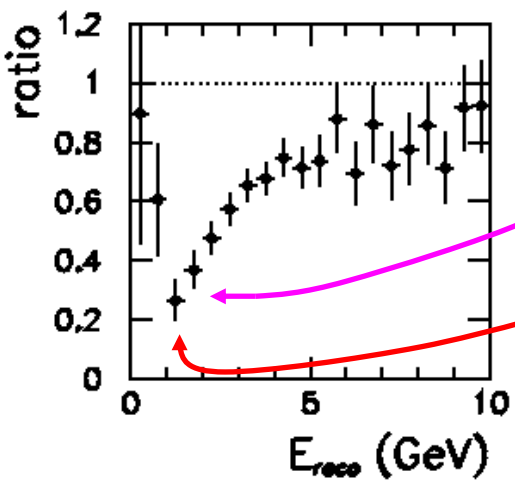
MINOS : Basic Idea



Measure ratio of neutrino energy spectrum in far detector (oscillated) to that in the near detector (unoscillated)

Partial cancellation of systematics





Depth of minimum ➡ $\sin^2 2\theta$

Position of minimum ➡ Δm^2

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 %

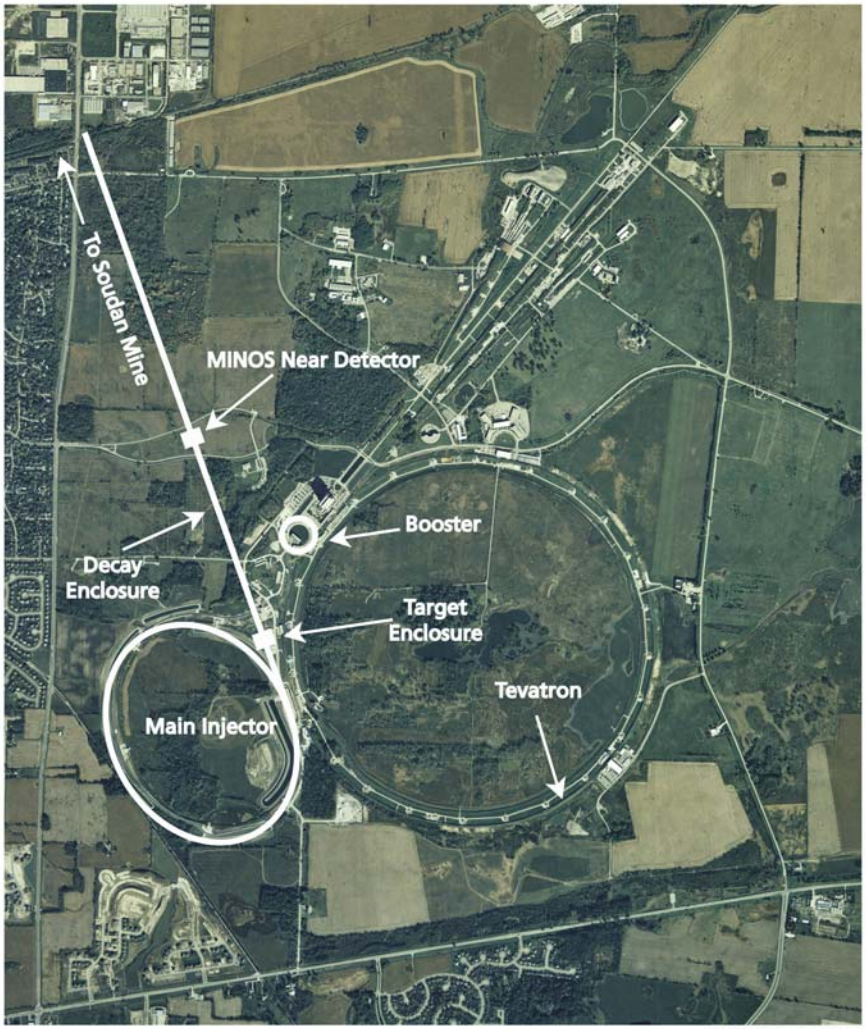
★ **Search for sub-dominant $\nu_\mu \rightarrow \nu_e$ oscillations**

- 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

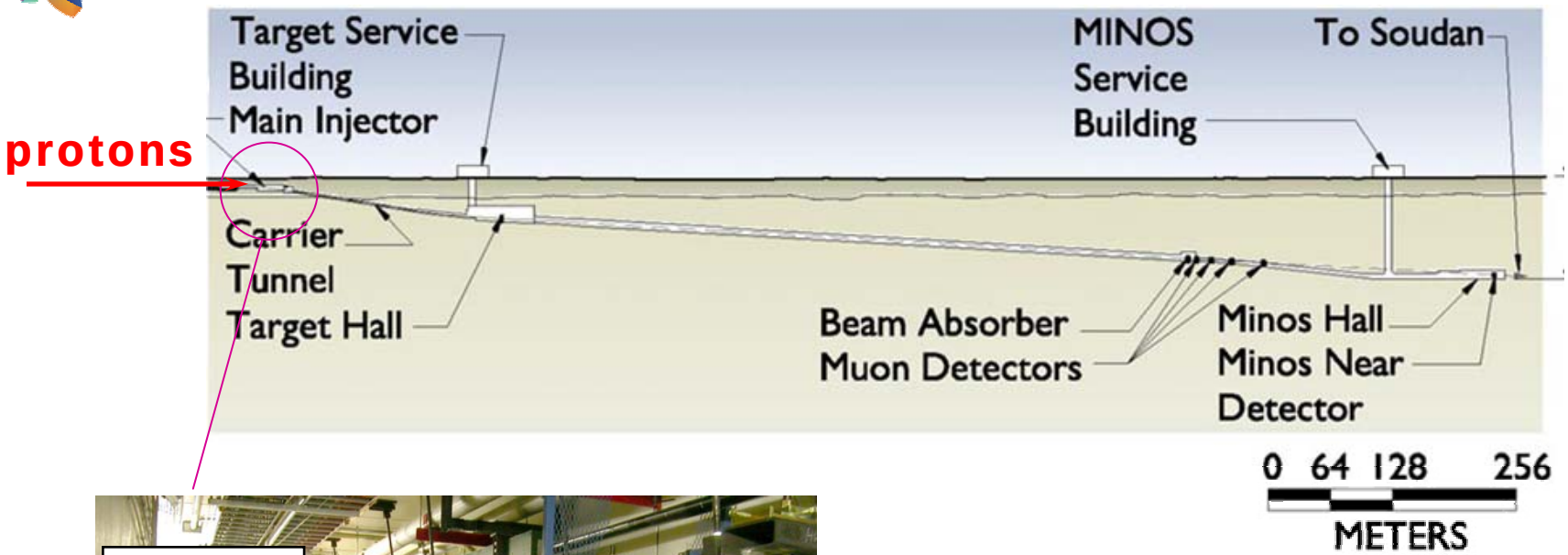
The NuMI beam

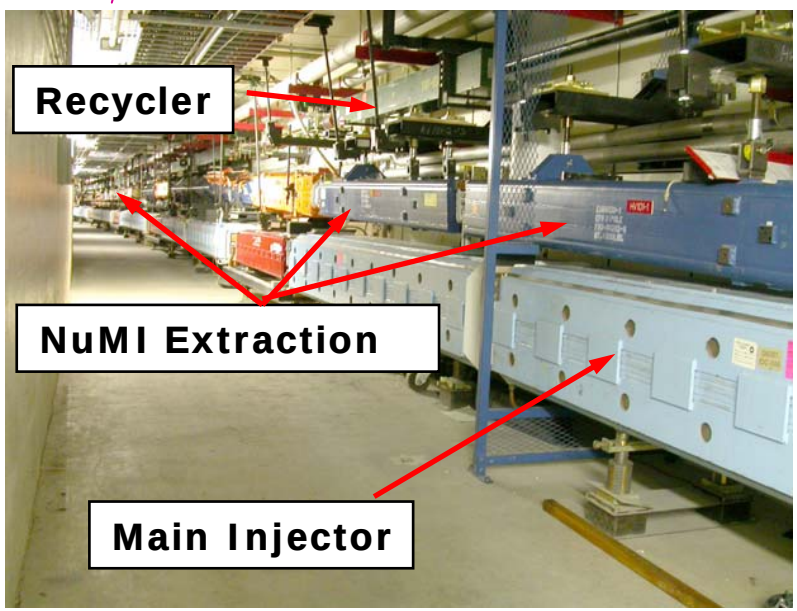


- ★ 120 GeV protons extracted from the MAIN INJECTOR in a single turn (8.7μs)
- ★ 1.9 s cycle time
- ★ *i.e.* ν beam `on' for 8.7μs every 1.9 s
- ★ 2.5×10^{13} protons/pulse
- ★ 0.3 MW on target !
- ★ Initial intensity

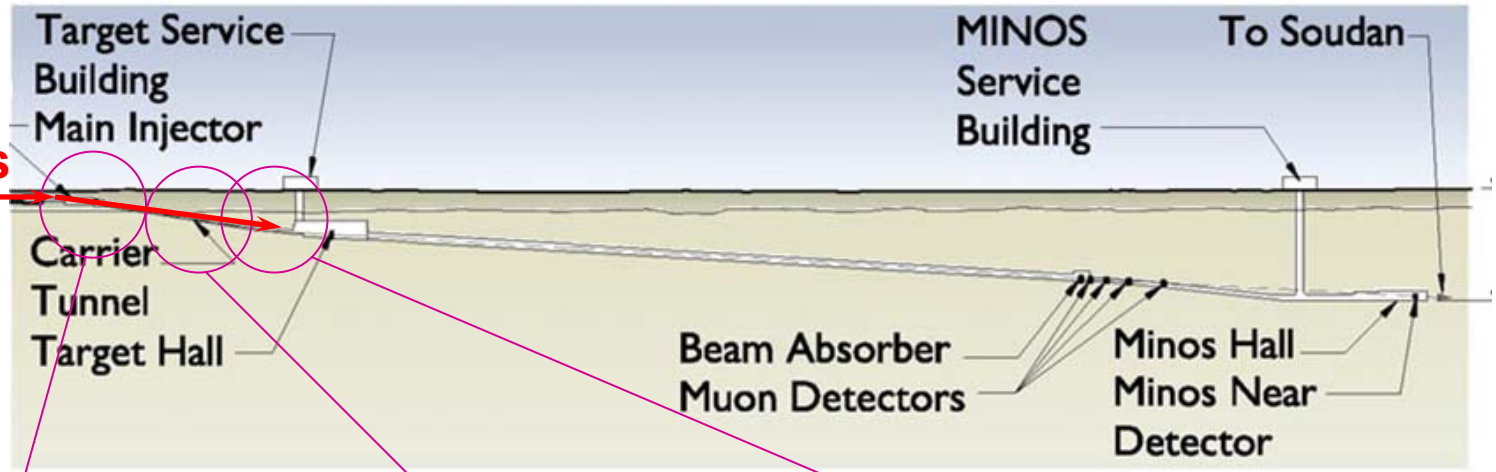
  2.5×10^{20} protons/year

The NuMI ν beam : I



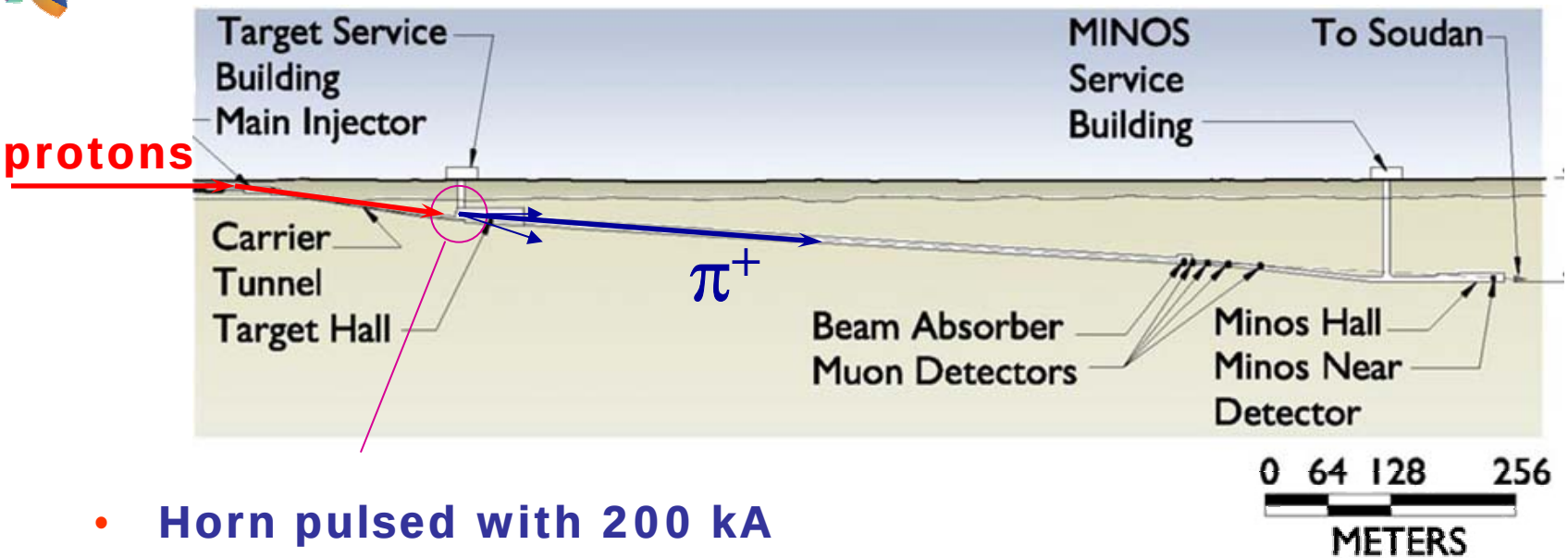


The NuMI ν beam : II

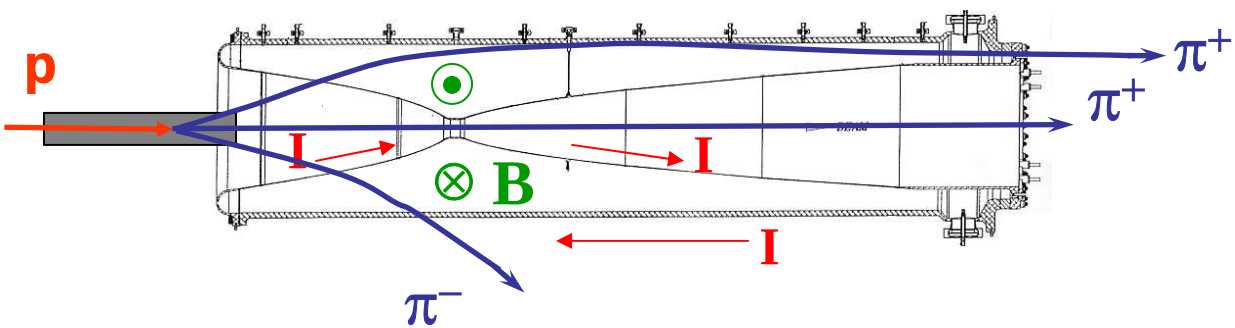


★Beam points 3.3° downwards

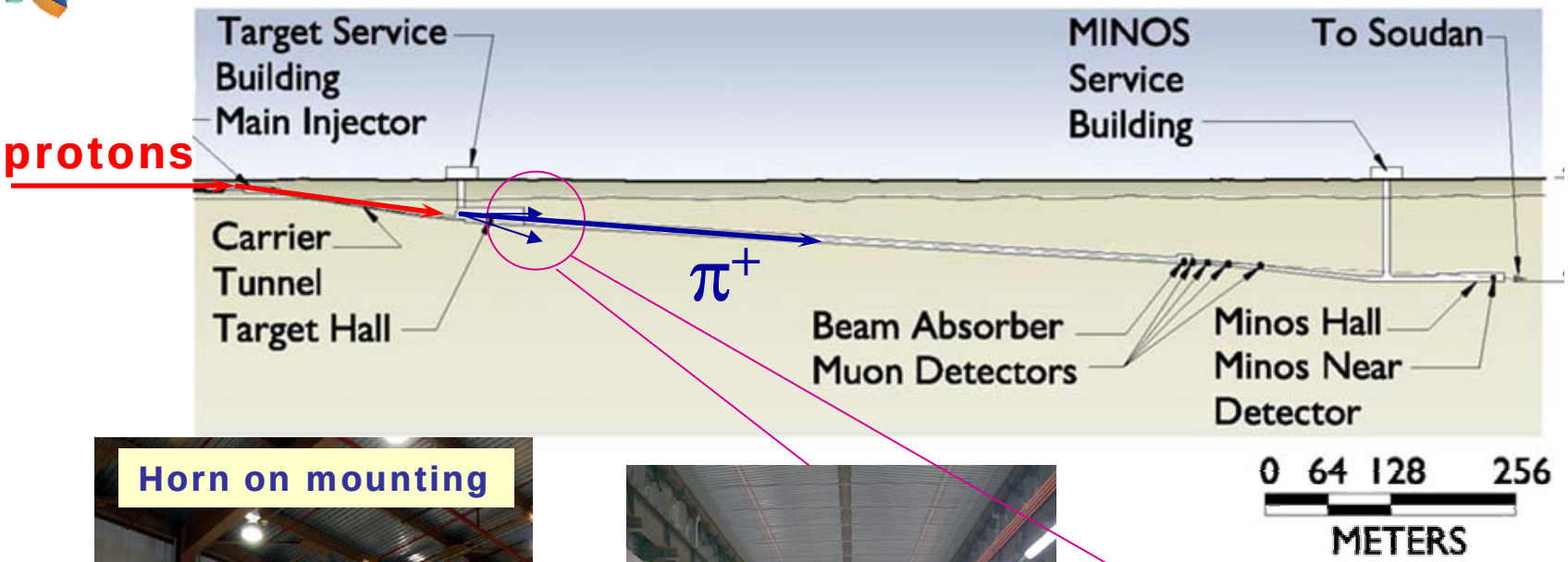
The NuMI ν beam : III



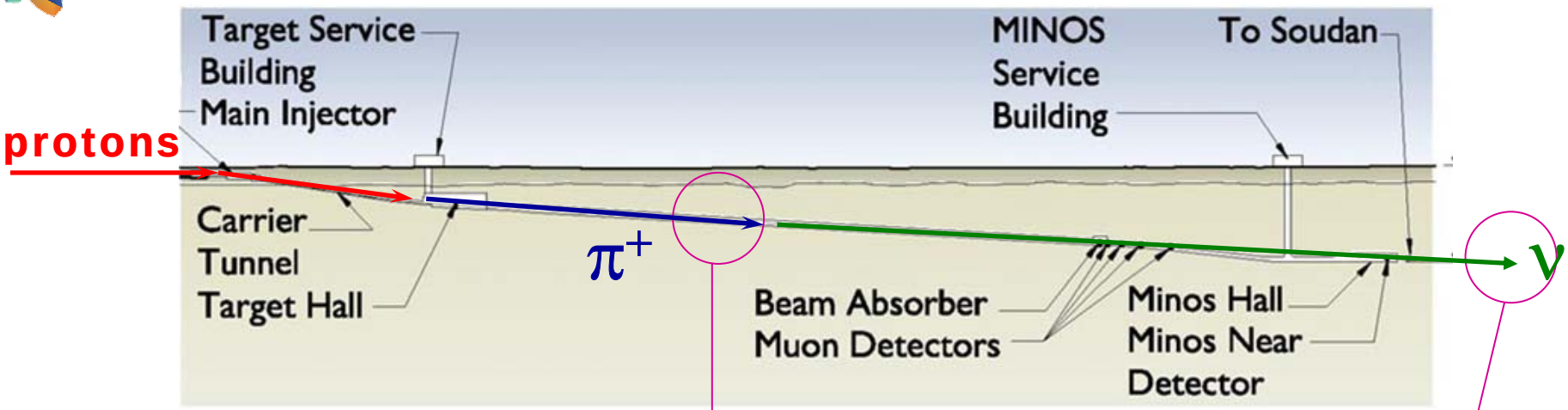
- Horn pulsed with 200 kA
- Toroidal Magnetic field $B \sim I/r$ between inner and outer conducters



The NuMI ν beam : IV

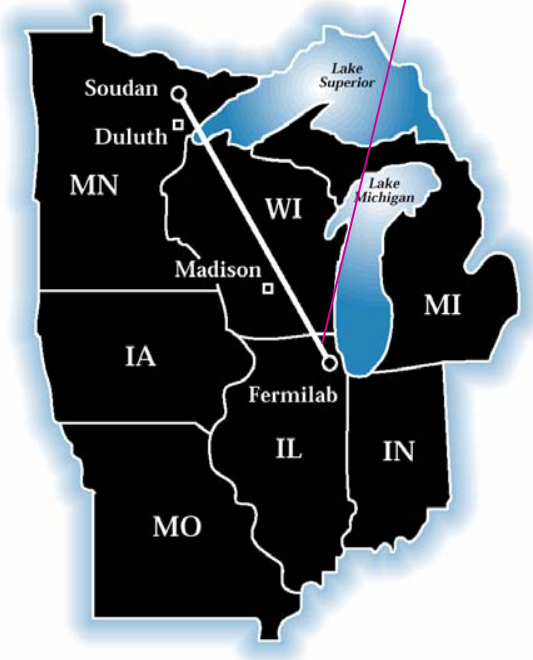


The NuMI ν beam : V



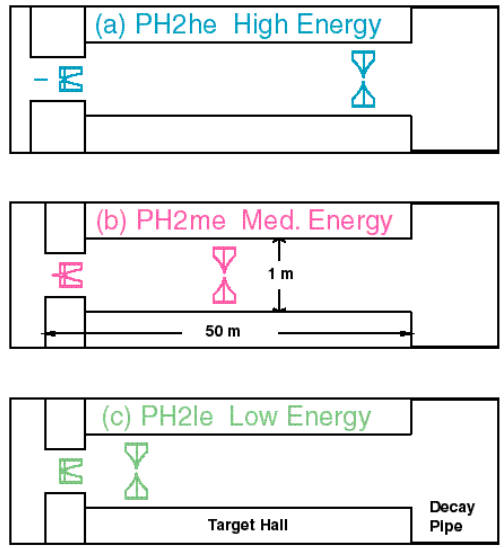
675 m long decay pipe

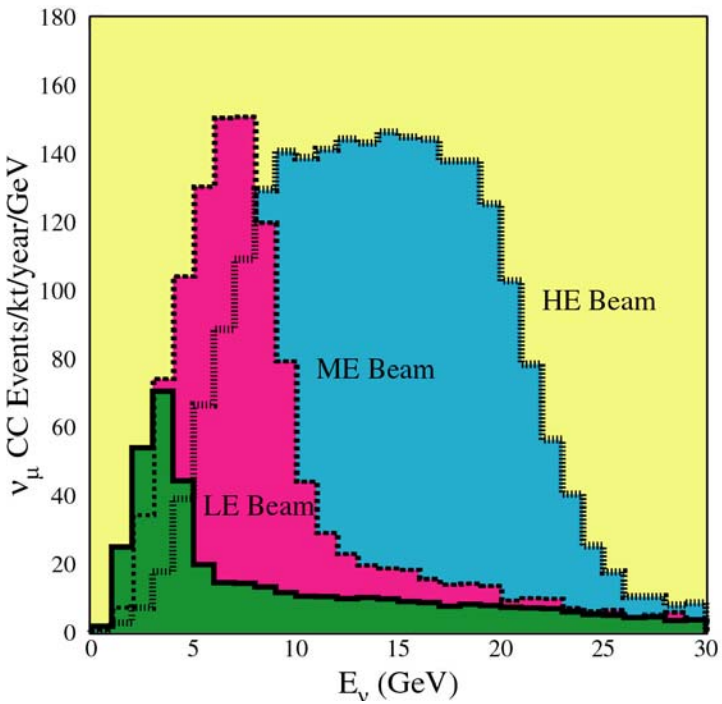
- ★ **Need long decay pipe:**
  for a 5 GeV π^+
  $\gamma c\tau \sim 200$ m
- ★ **Evacuated to 1.5 Torr**
- ★ **Steel decay pipe installed and encased in 2-3 m of concrete to protect ground water**



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:

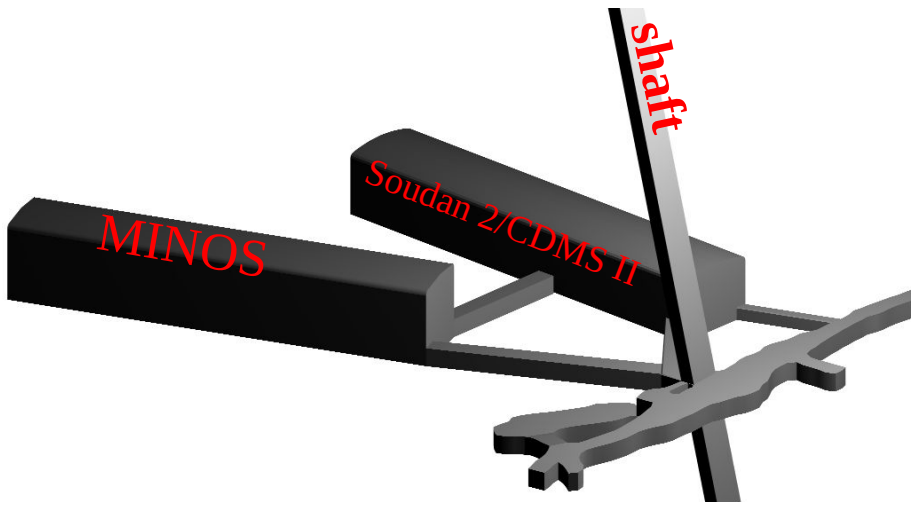
ν_μ **CC Events / year:**

Low	Medium	High
1600	4300	9250

(2.5×10^{20} protons on target / year)

Going underground

2070 mwe



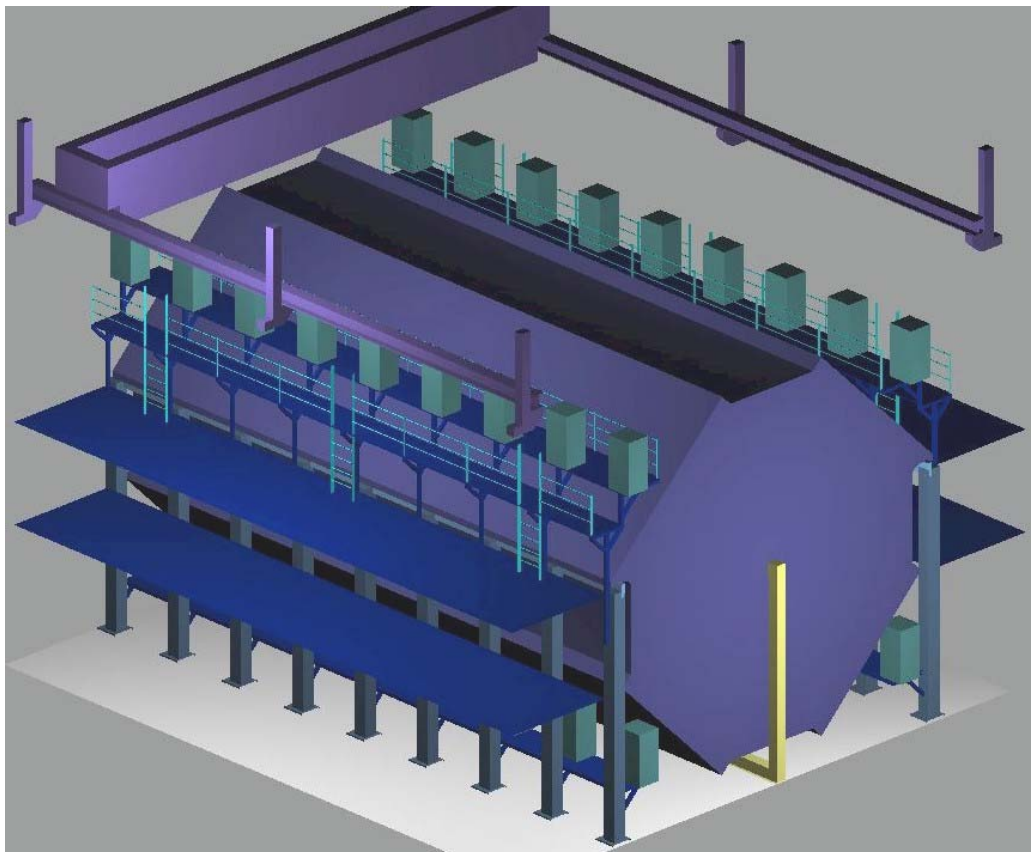
MINOS Far Detector

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)

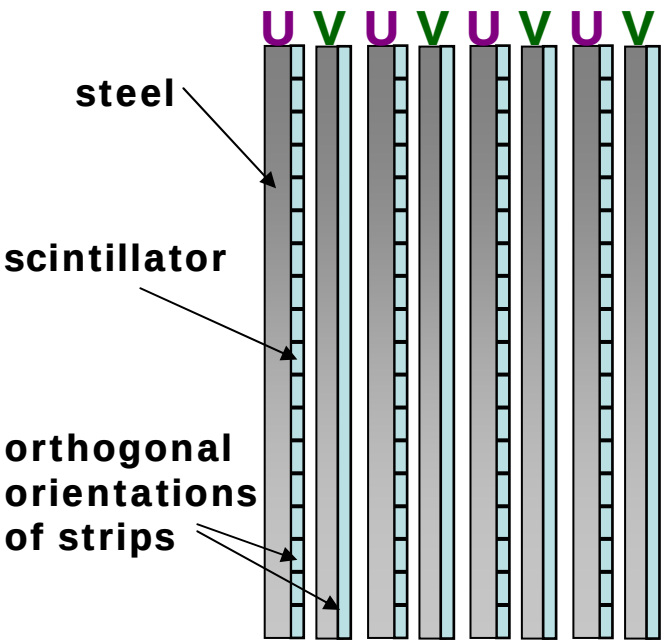
484 planes of scintillator

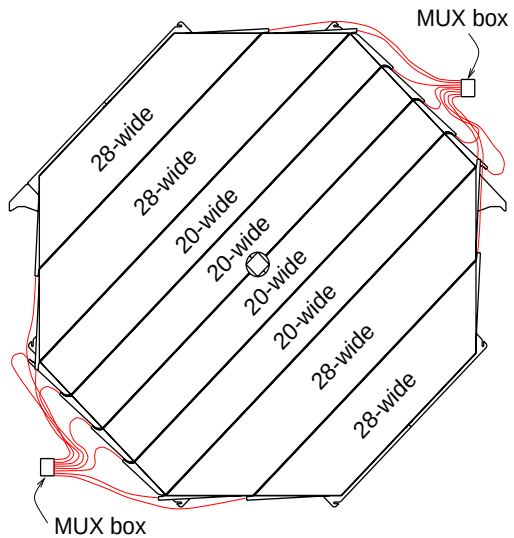


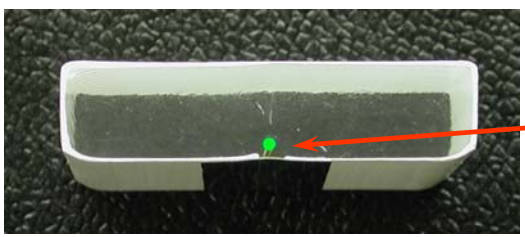
One Supermodule of the Far Detector…
Two Supermodules total.

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)

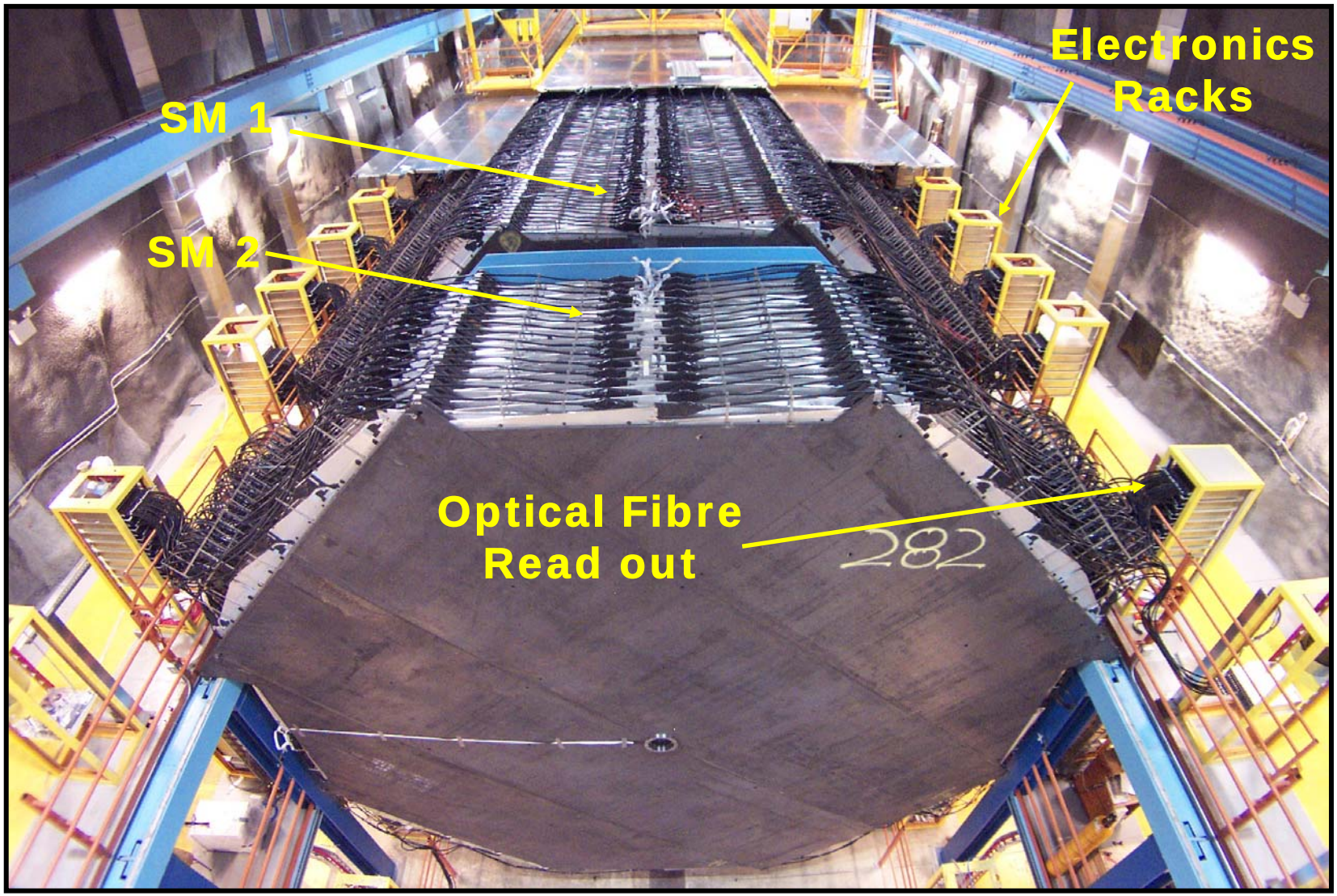




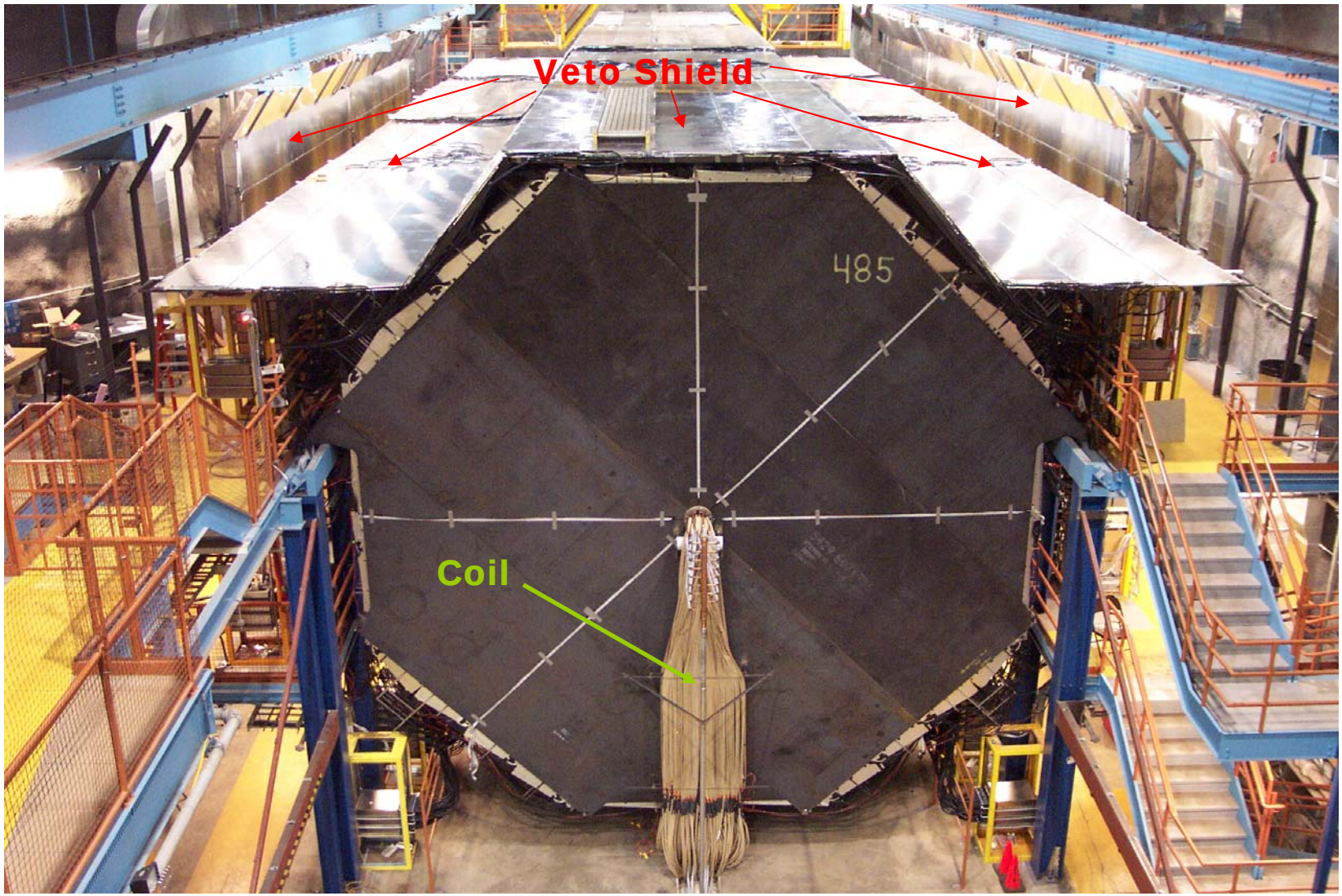


- ✦Scintillation light collected by WLS fibre glued into groove
- ✦Readout by multi-pixel PMTs

MINOS FarDet during installation

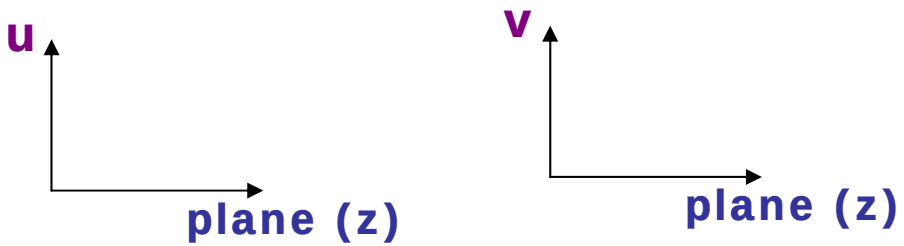


Far Detector fully operational since July 2003

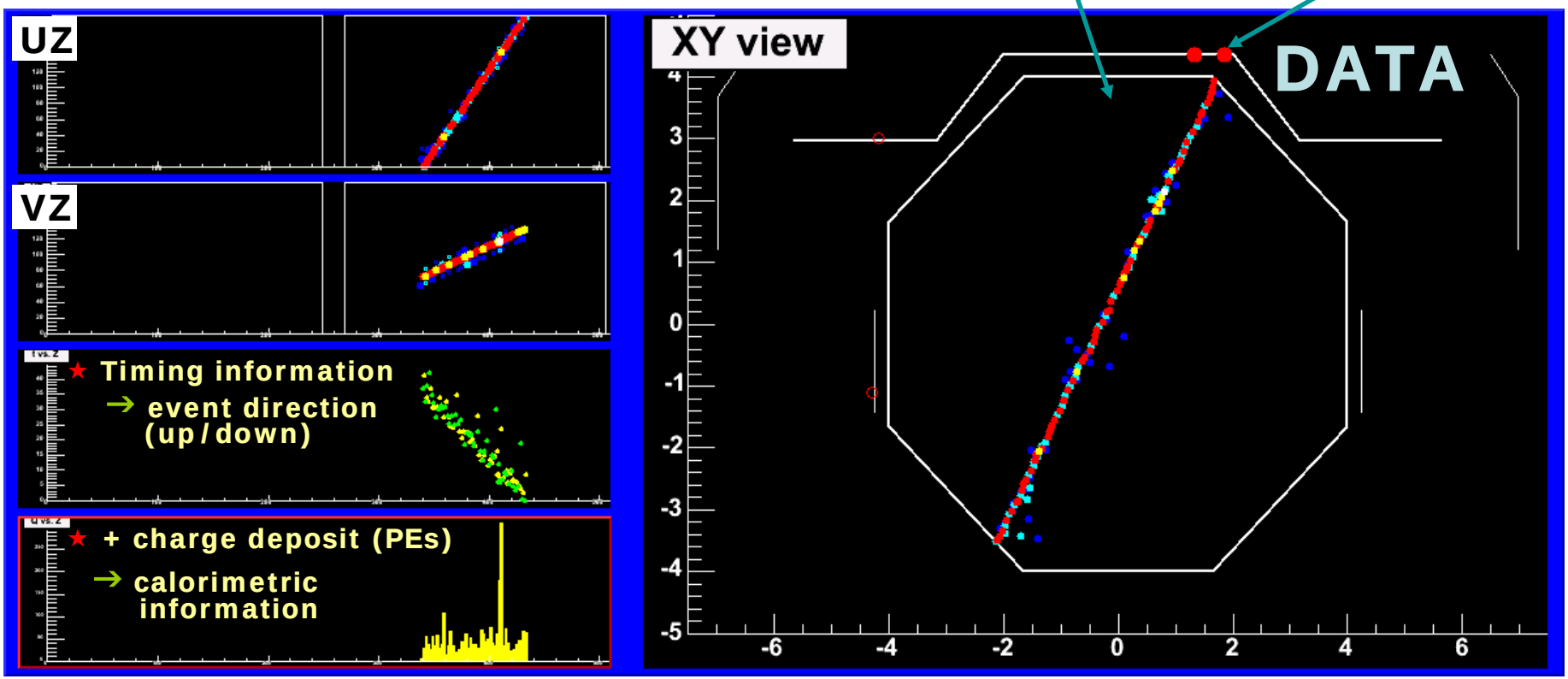


Event Information

- Two 2D views of event



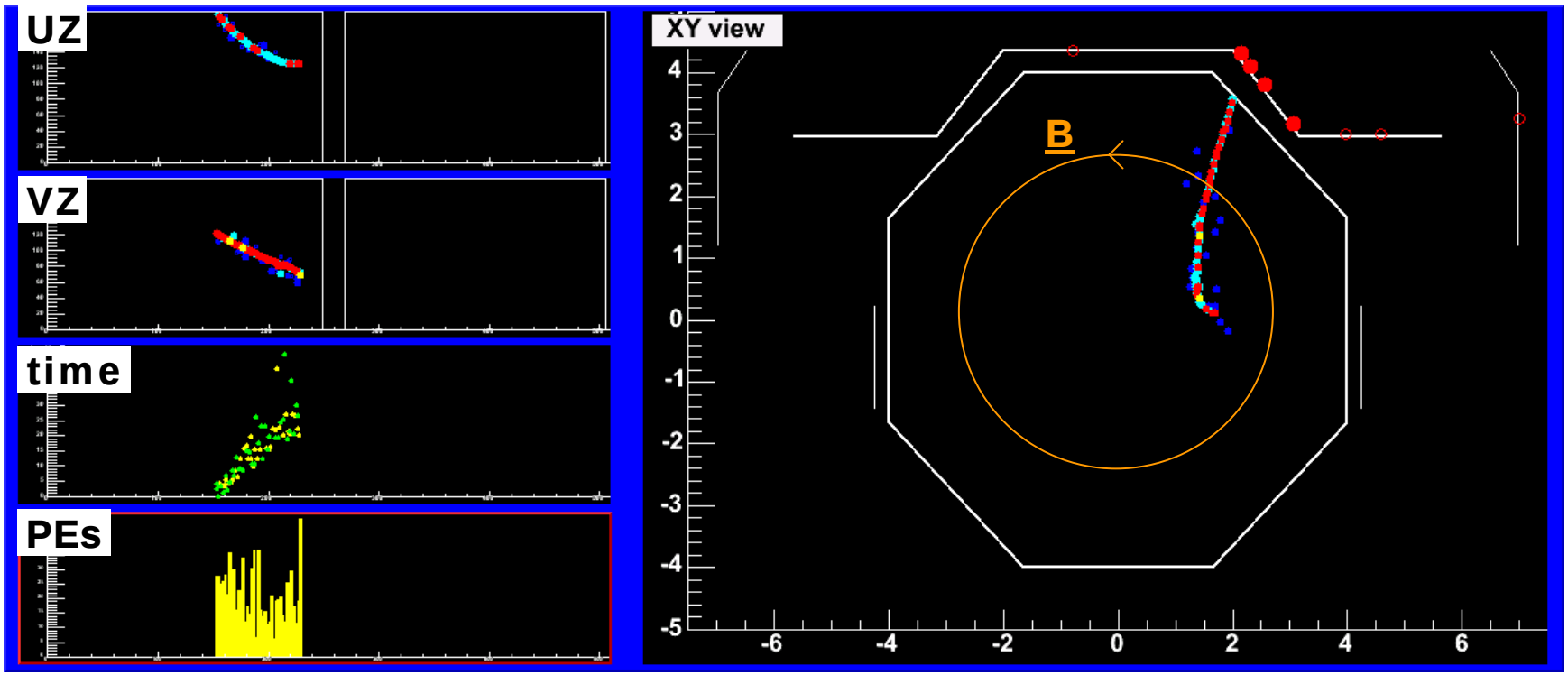
- Software combination to get `3D' event



B-Field

~ 1.5 T Magnetic Field

- ★ Charge separation
- ★ Momentum measurement



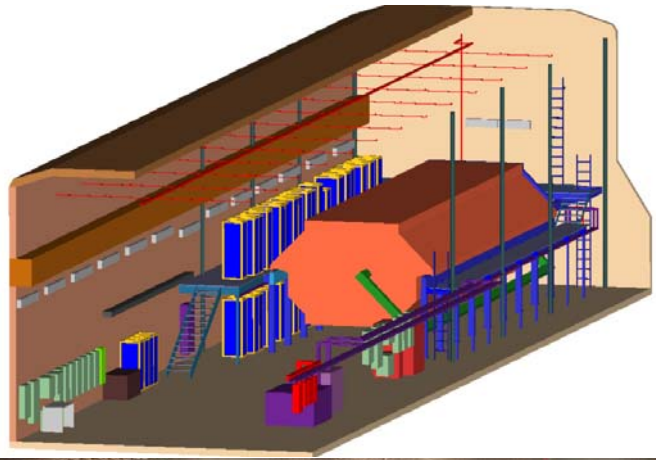
Single Hit Resolution : 2.5 ns

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
- ★ **Some differences, e.g:**

Faster electronics

Partially instrumented:

282 planes of steel

153 planes of scintillator

(Rear part of detector only used to track muons)

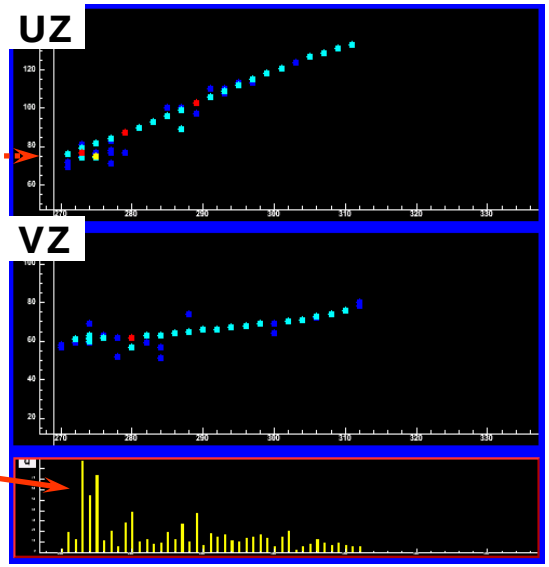
+.....

MINOS Beam Physics (MC)

ν_μ CC Event

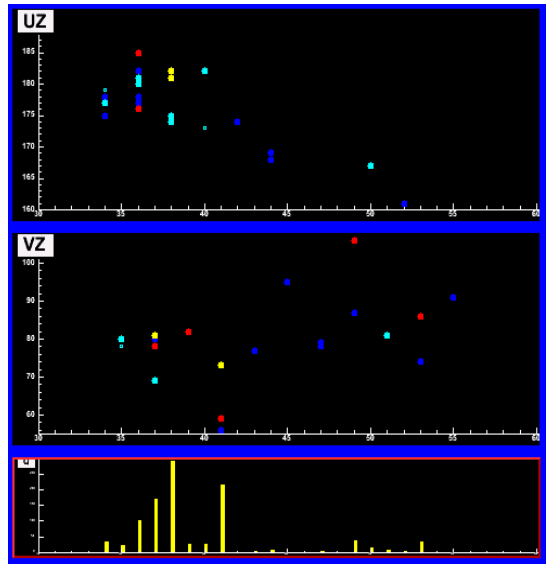
ν .....>

- μ track
- +hadronic activity



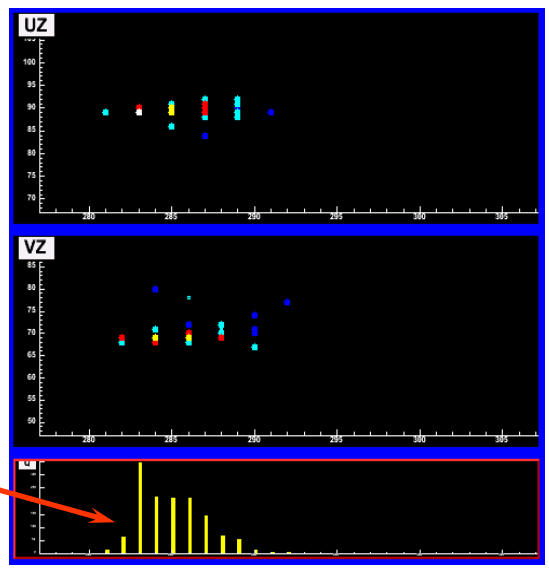
NC Event

- often diffuse



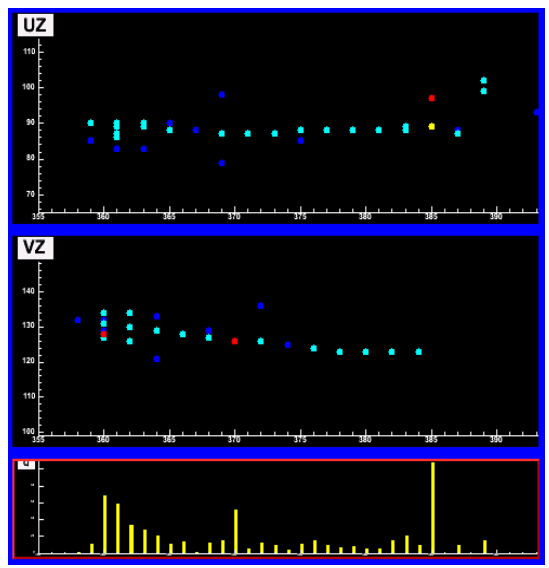
ν_e CC Event

- compact shower
- typical EM shower profile



NC Event

- can mimic ν_μ , ν_e

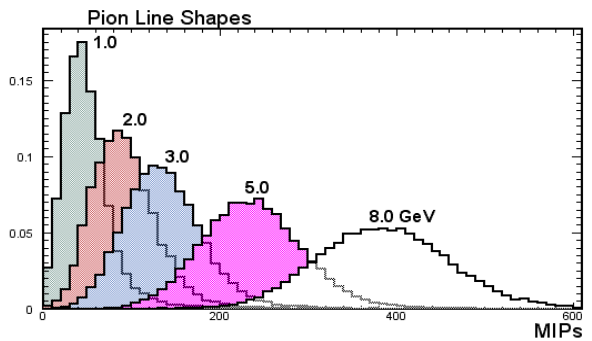


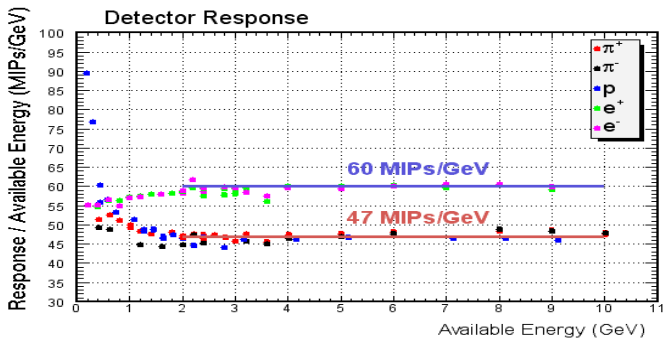
Test Beam

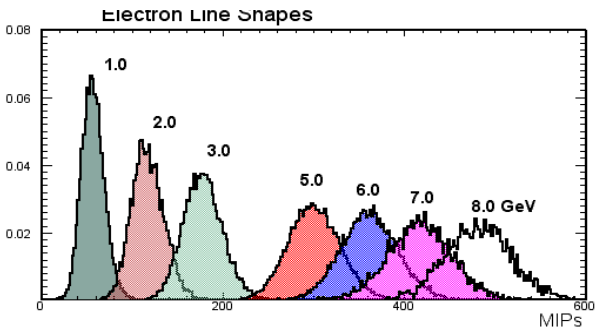
★ **Energy response is important – know L, need E_ν**

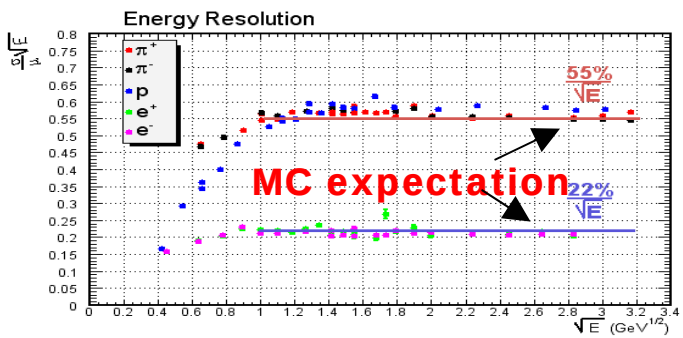
- ♦ **hadronic energy from pulse height ($\sigma_E/E \sim 55\%/E^{1/2}$)**
- ♦ **$E_\nu = p_\mu + E_{had}$**

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







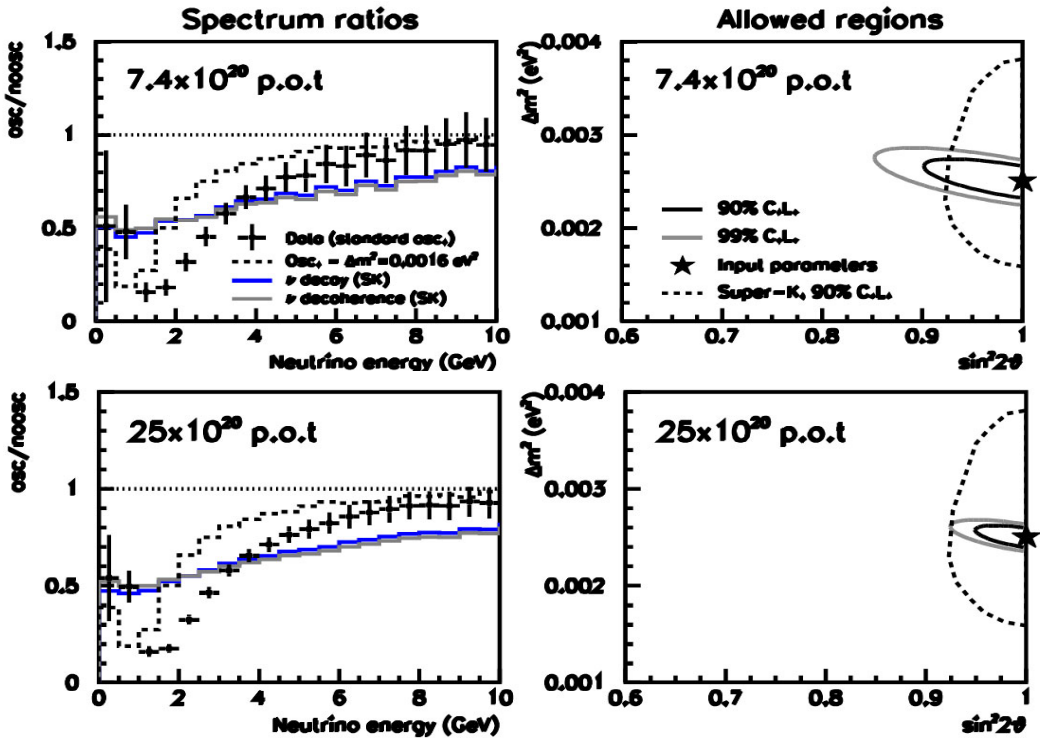


★ **Provides calibration information**

★ **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

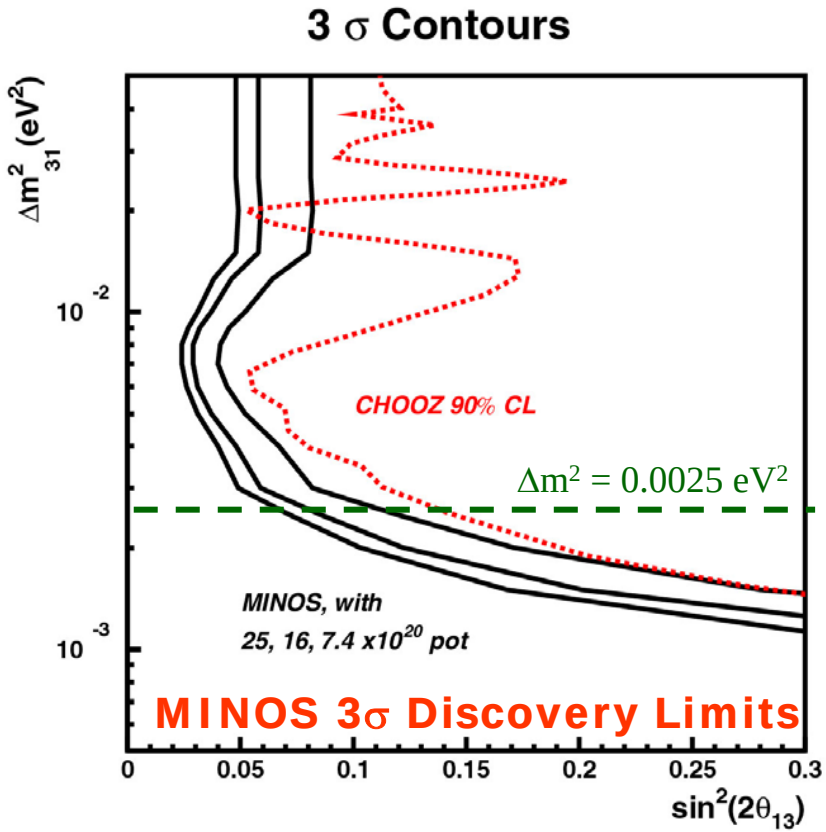
Large improvement in precision !

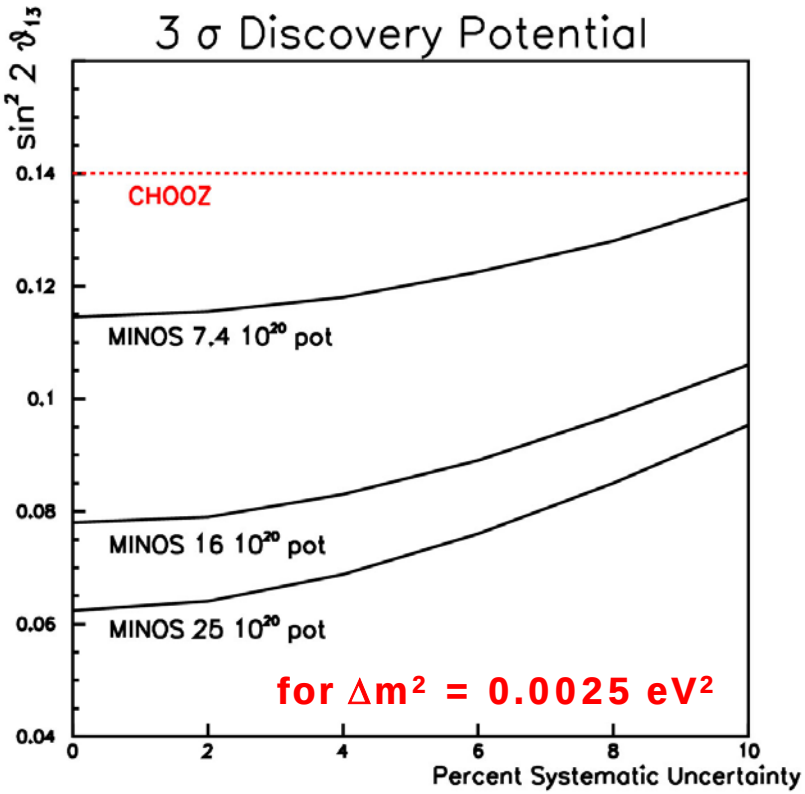
Final sensitivity depends on protons on target

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

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

ν_e Appearance



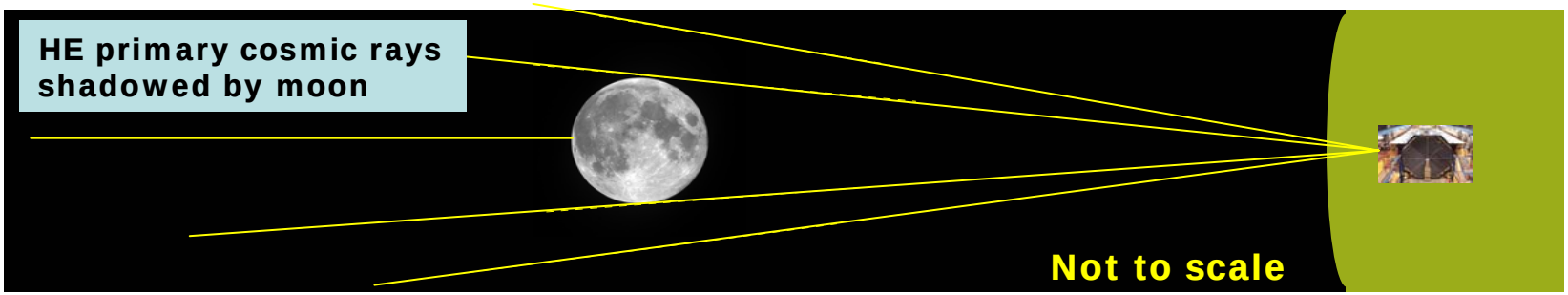


- **3 σ discovery potential may significantly eat into current allowed region – exact reach depends on protons on target**
- **reasonable chance of making the first measurement of θ_{13} !**

First beam in December 2004

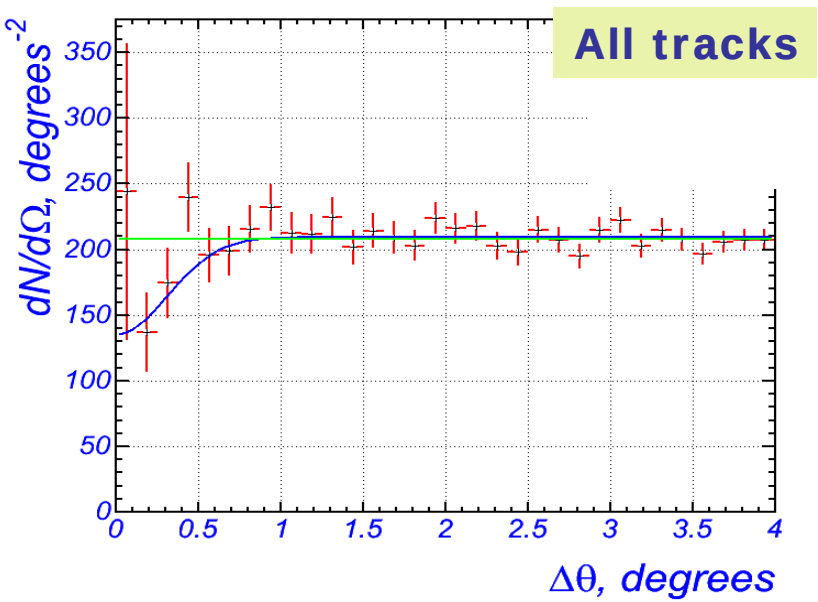
<u>BUT</u> Already Have Data....

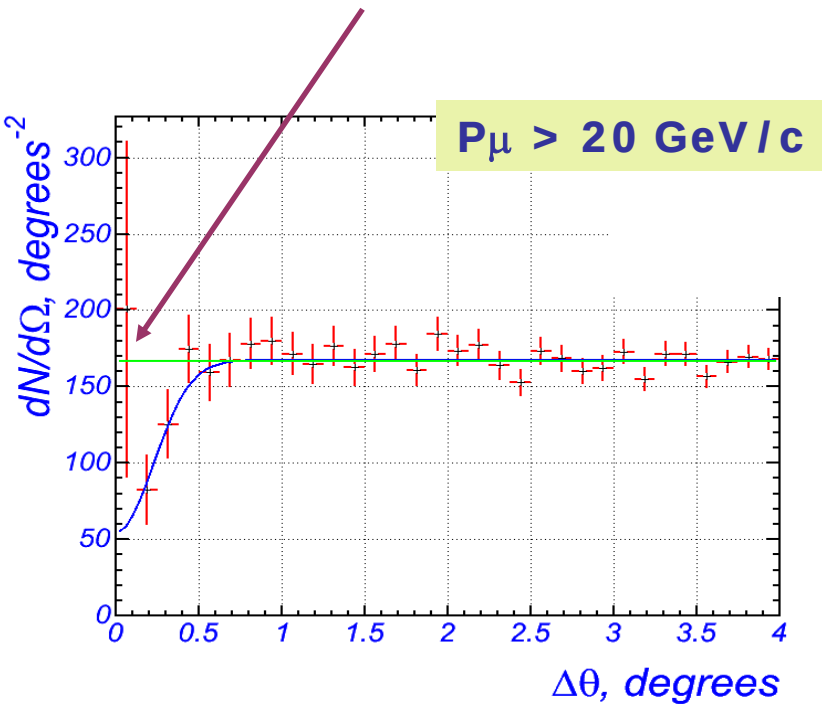
Moon Shadow



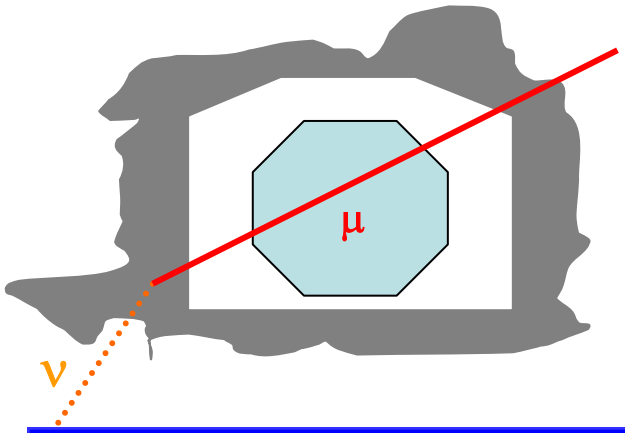
★ Have recorded 10 M cosmic muons
observed shadow of moon

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

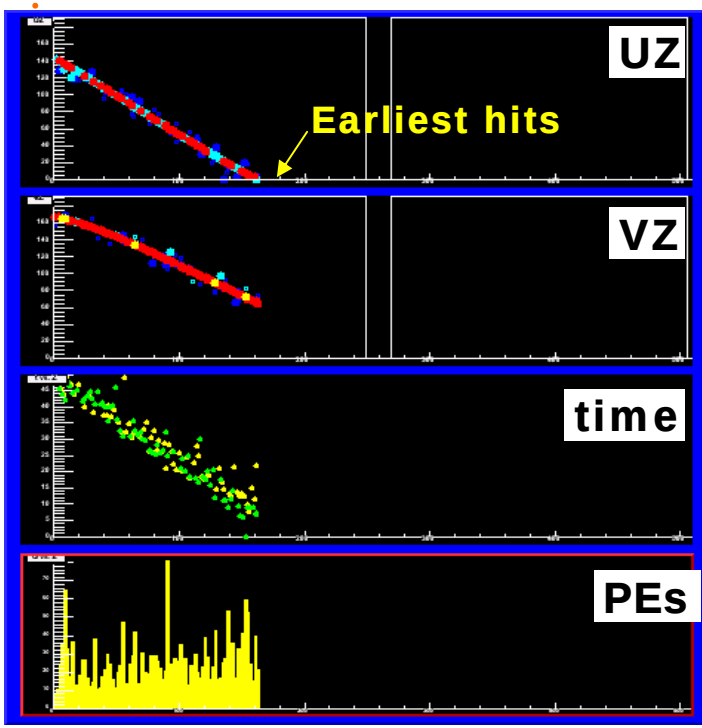


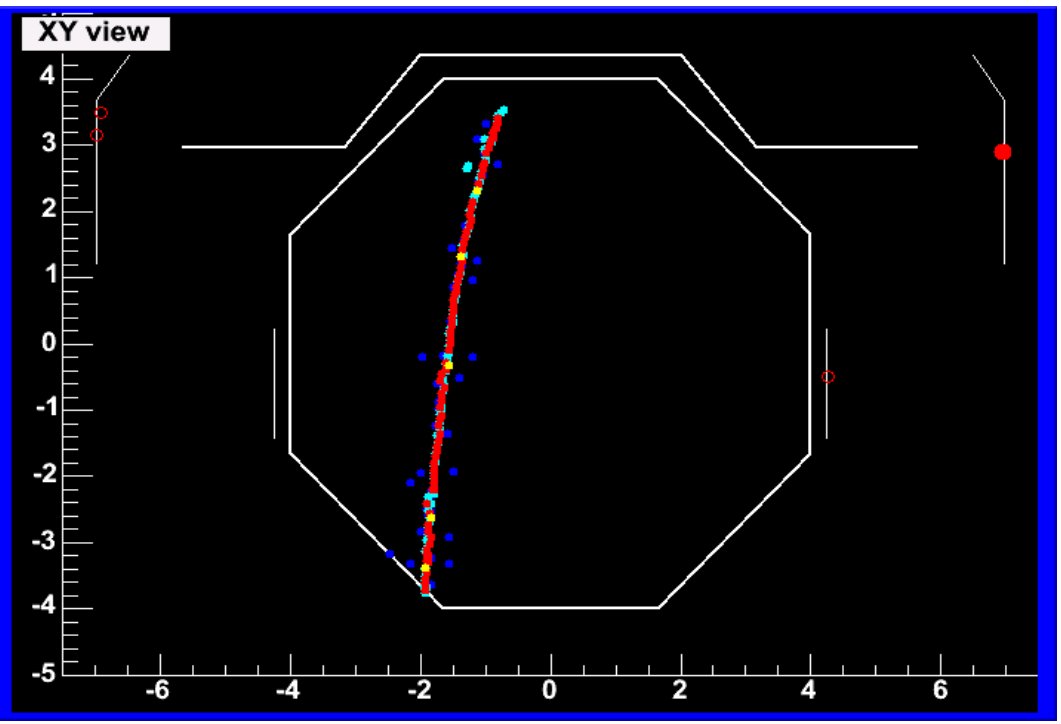


ν induced upward μ



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

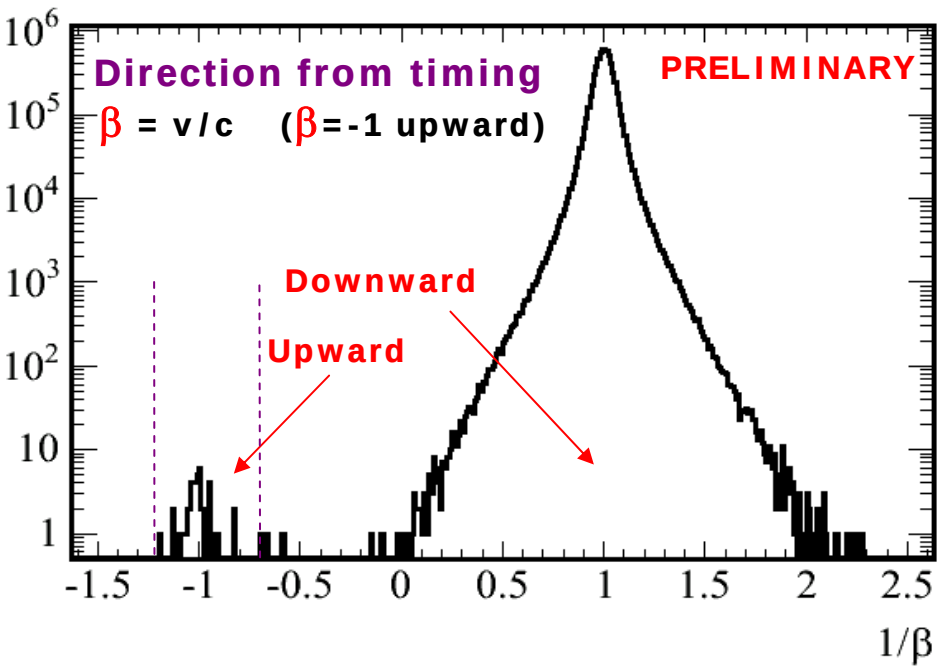




ν induced upward-going muons

- ★ 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

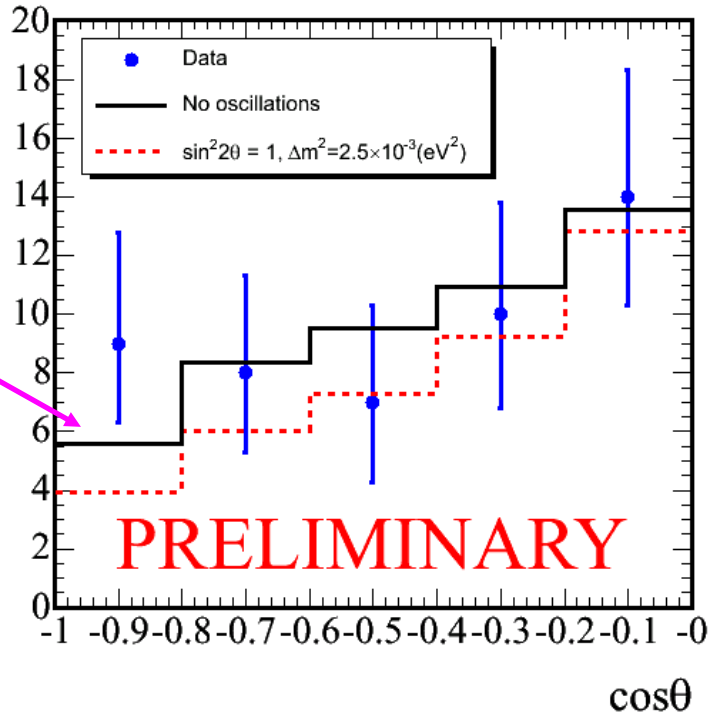
Upward μ Analysis: Data vs. MC

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

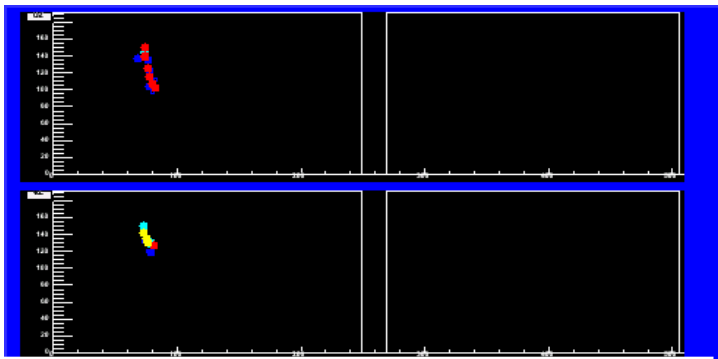


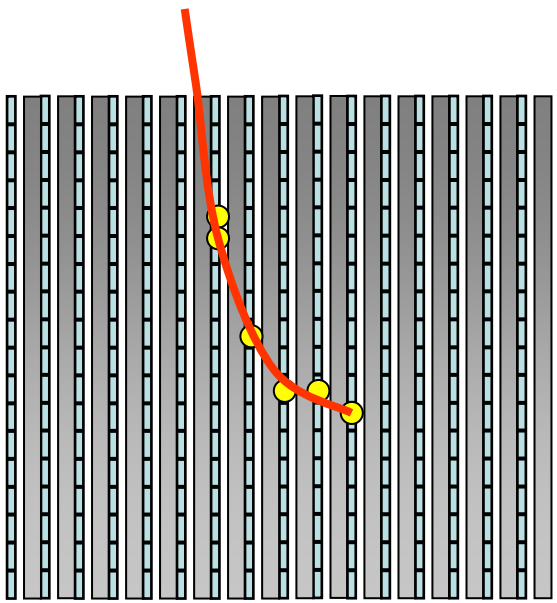
	ν	$\bar{\nu}$	$\nu/\bar{\nu}$?
Events	13	8	27

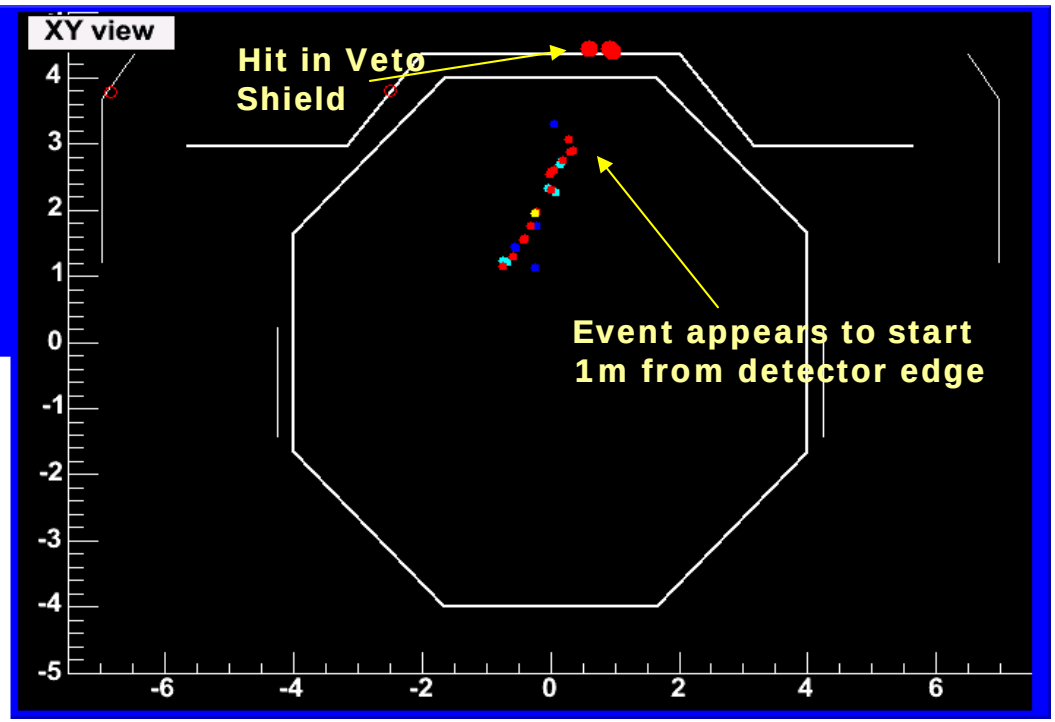
★Understanding systematics : Work in progress

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 !

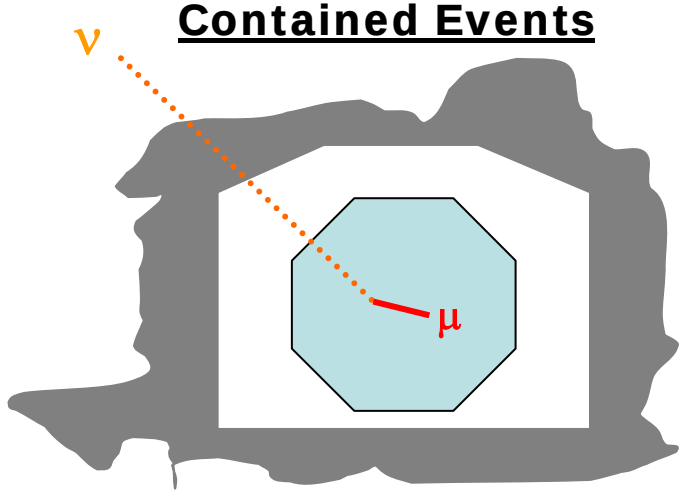
  Efficiency ~ 75 % with 98 % purity

Threshold E_ν > 0.5 GeV

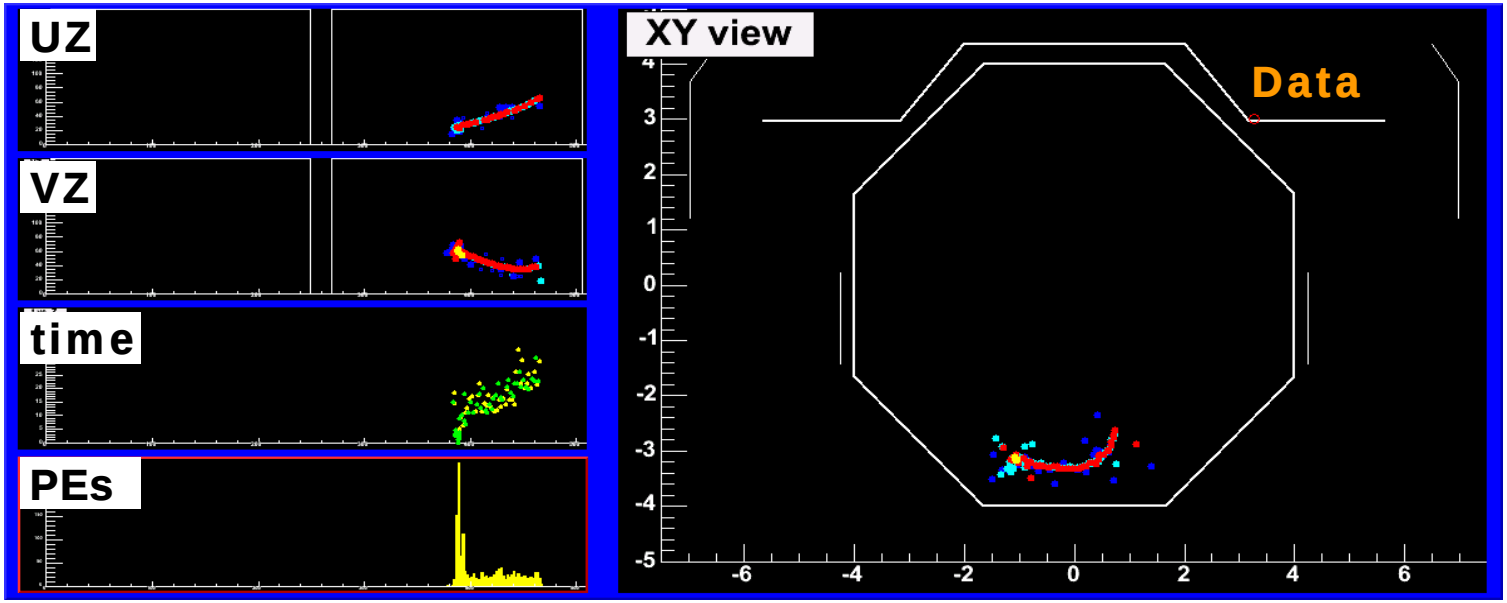
CC ν_μ EVENT SELECTION:

- 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 Events



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

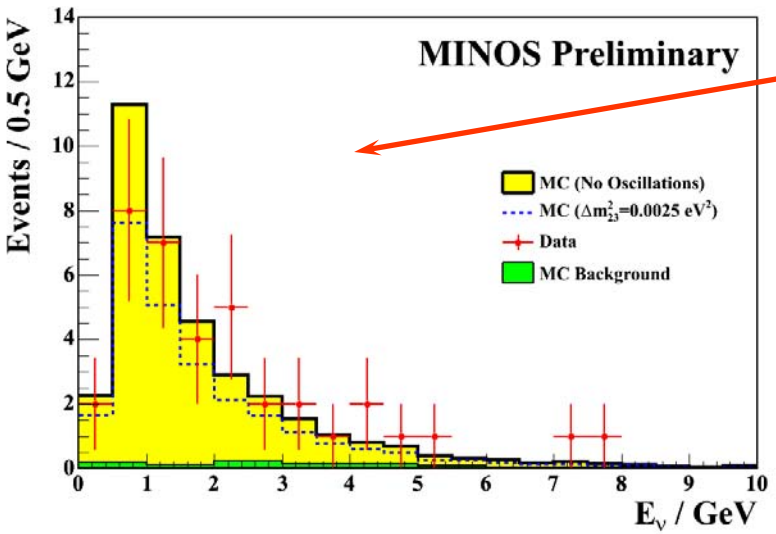
Measure cosmic μ bgd. from data using events solely rejected on basis of veto hit

Vetoed background agrees with MC expectation !

ν MC : Battistoni et al

* Does not include acceptance systematic uncertainties – work in progress

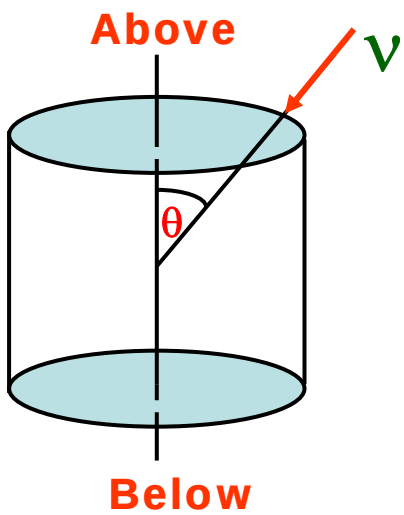
Event Distributions

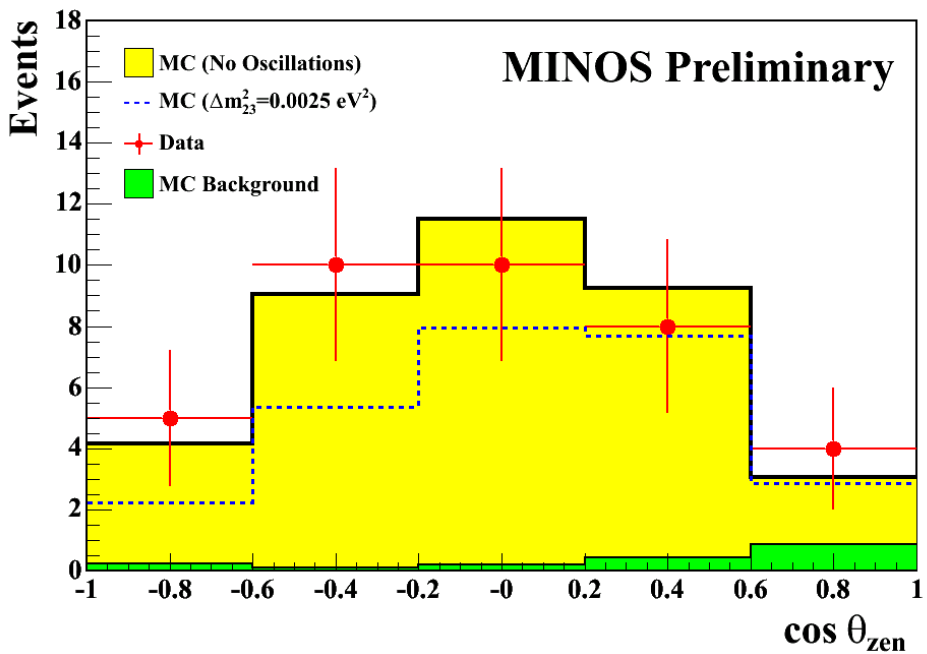


★$E_\nu = E_\mu + E_{had}$

★MC normalised to data (no oscillations)

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

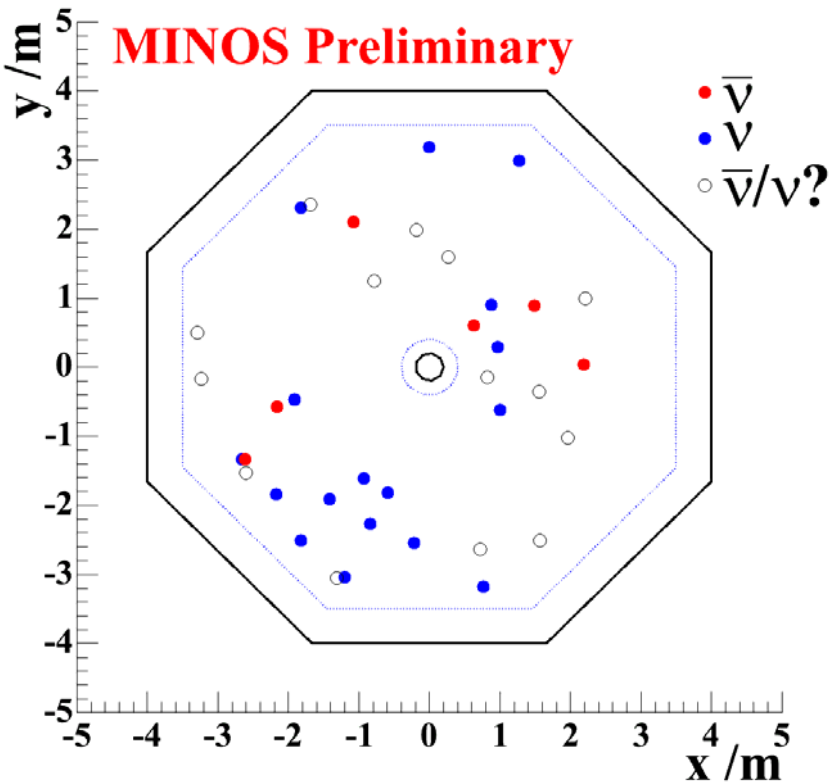


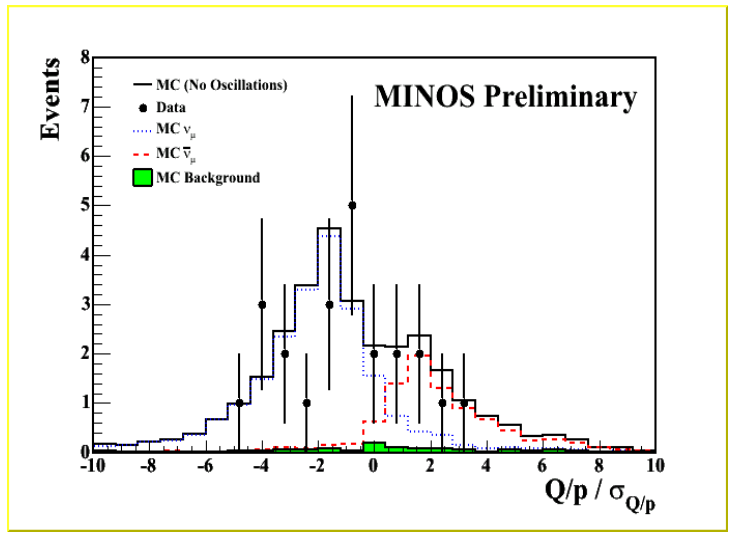


Charge Reconstruction

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 $\bar{\nu}/\nu$

⇨ $N\bar{\nu}/N\nu = 0.35 \pm 0.17$

(expect $0.51 \pm ?$ 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.**

For more details see poster session

MINOS en France