The Startup of MINOS

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LES RECONTRES DE PHYSIQUE DE LA VALEE D'AOSTE
1 March 2005
La Thuile

Outline

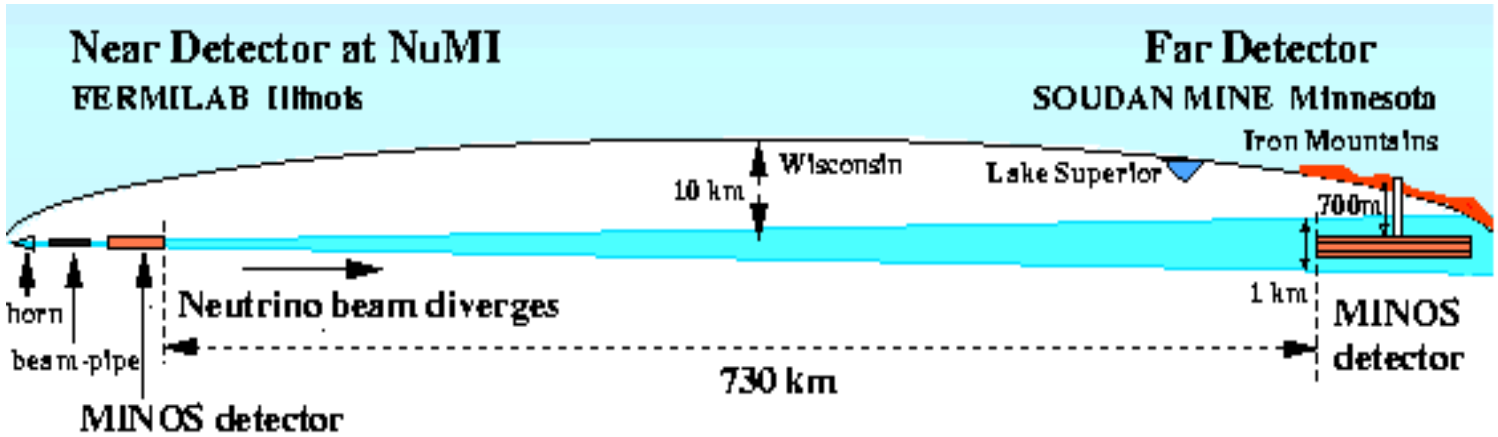
Introduction to the MINOS experiment

The NuMI Beamline

The MINOS Detectors

First neutrino beam events

Main Injector Neutrino Oscillation Search Long-Baseline Experiment

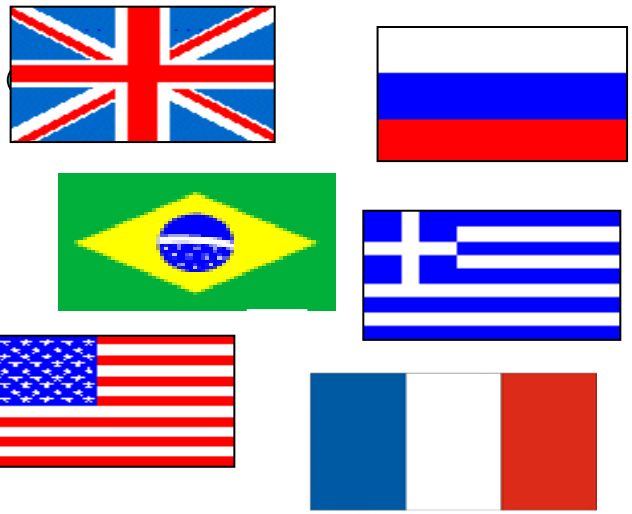


Muon Neutrino beam provided by 120GeV protons from Fermilab Main Injector

- **Near Detector at Fermilab, 1kt, to measure beam composition and neutrino energy spectrum**
- **Far Detector in the Soudan Mine, 5kt, to search for evidence of neutrino oscillations**

The MINOS Collaboration

175 physicists from 32 institutes in 6 countries

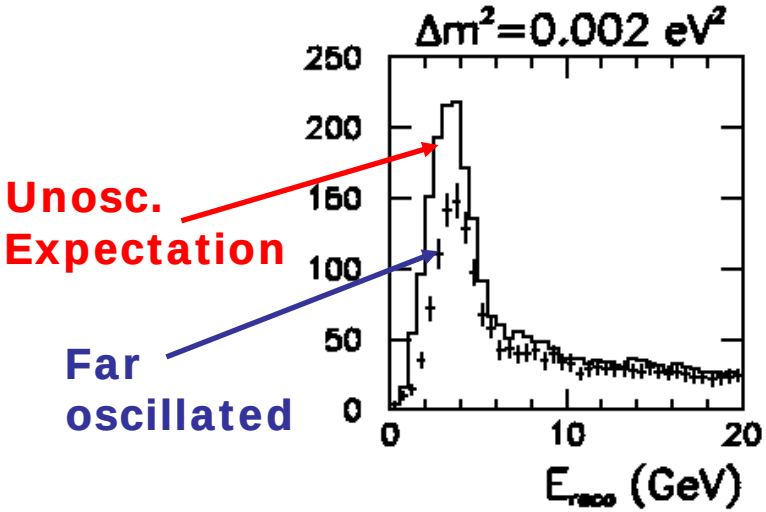


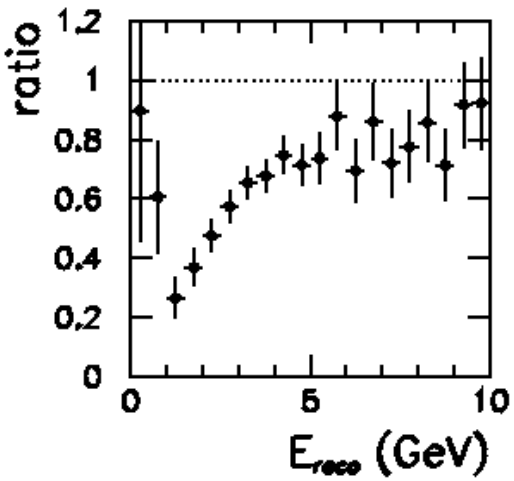
Argonne – Athens – Benedictine – Brookhaven – Caltech – Cambridge – Campinas – Fermilab – College de France – Harvard – IIT – Indiana – ITEP Moscow – Lebedev – Livermore – Minnesota, Twin Cities – Minnesota, Duluth – Oxford – Pittsburgh – Protvino – Rutherford Appleton – Sao Paulo – South Carolina – Stanford – Sussex – Texas A&M – Texas-Austin – Tufts – UCL – Western Washington – William & Mary - Wisconsin

MINOS Collaboration members at Fermilab with the Near Detector surface bldg in the background (right)

Physics Goals

- **Demonstrate oscillation behaviour**
  - Confirm flavour oscillations
  - Provide high statistics for discrimination against alternatives





Depth of minimum ➡ $\sin^2 2\theta$

Position of minimum ➡ Δm^2

- **Precise measurement of Δm^2_{23} ~10%**
- **Search for sub-dominant $\nu\mu \longrightarrow \nu e$ oscillations**
- **MINOS is the first large deep underground detector with a B-field**
  - First direct measurements of ν vs $\bar{\nu}$ oscillations from atmospheric neutrino events

MINOS Physics Reach

D. Petyt

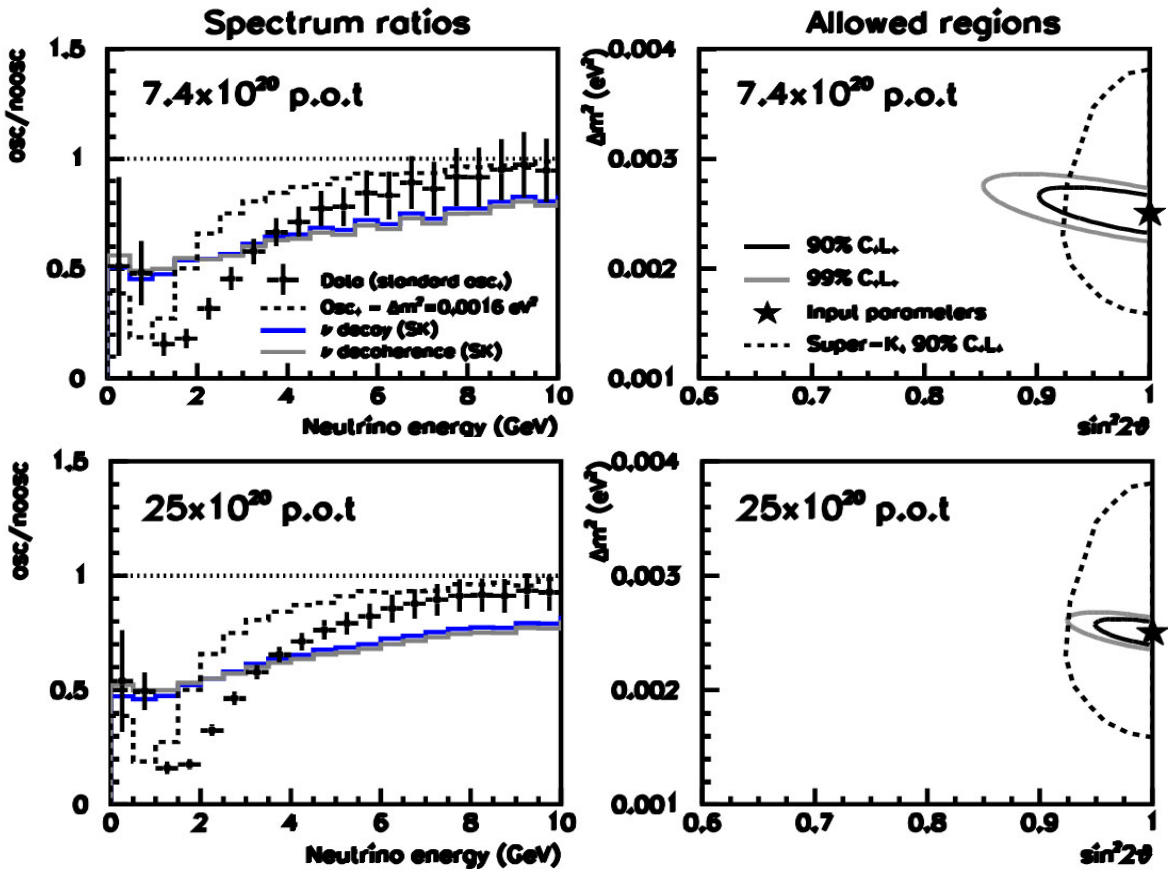
- MINOS Sensitivity to ν_μ disappearance
  (plotting ratio of yield at FarDet to expectation based on NearDet)

Assuming:

$\delta m^2 = 0.0025 eV^2$,

$\sin^2 2\theta = 1.0$

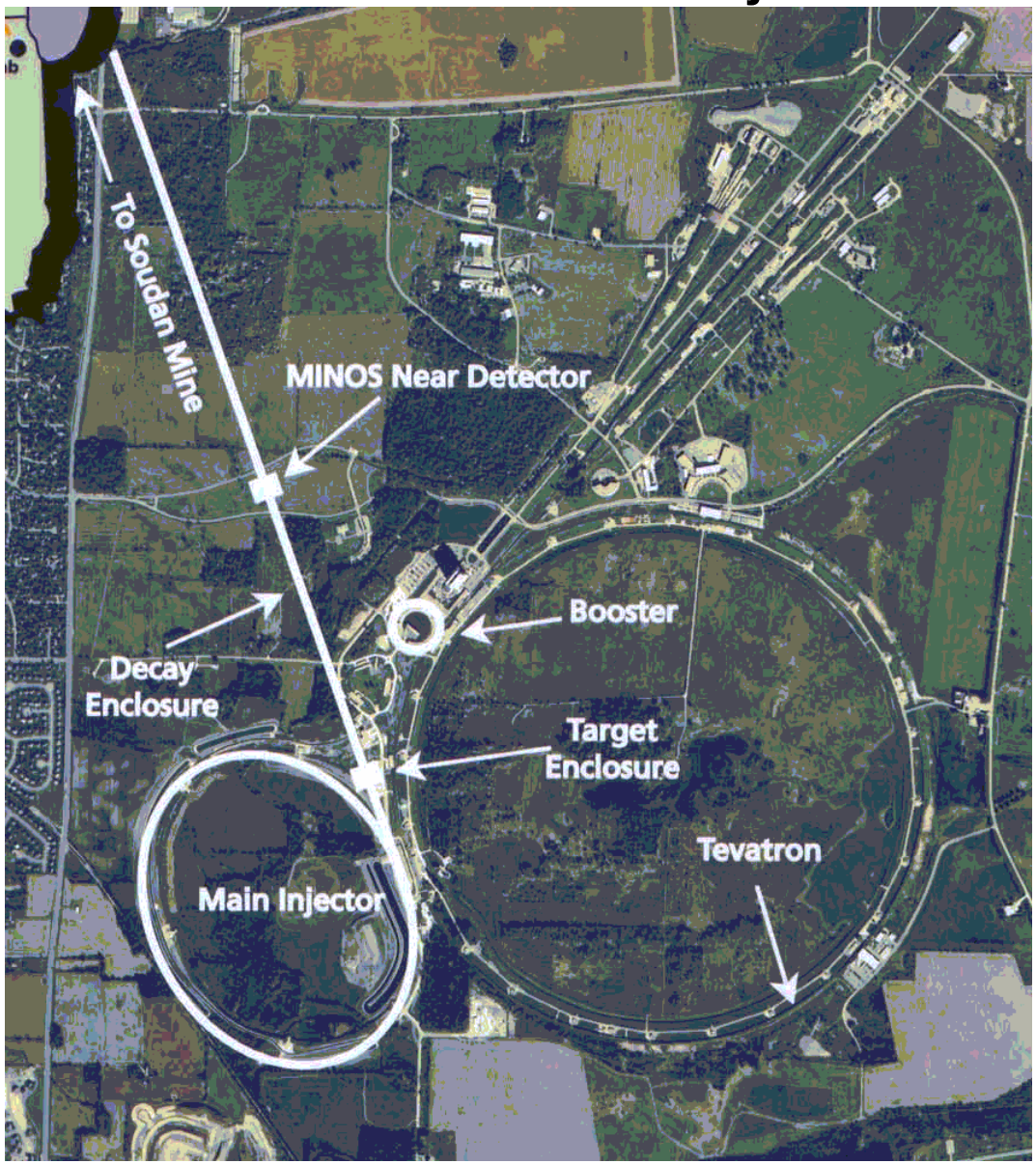
After: 3yrs at nom. intensity (top) & w/ possible intensity upgrages (bottom)



Characteristic 'dip': location & depth yield δm^2 & $\sin^2 2\theta$.

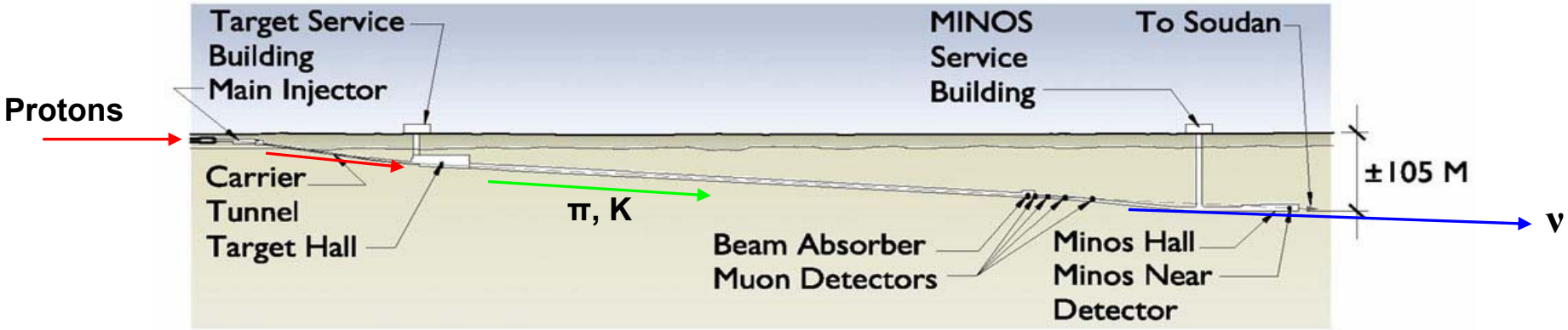
→ Will determine δm^2 to precision of < 10%,
can also rule out exotic models of oscillations.

Main Injector Beam



- 120 GeV protons extracted from Main Injector in a single turn (8.7μs)
- 1.9s repetition rate
- $2.5X10^{13}$ protons / pulse
- 0.3 MW primary proton beam
- Initial intensity ~ $2.5X10^{20}$ protons / year
- Neutrino energy tuneable !

Neutrino Beamline (NuMI)

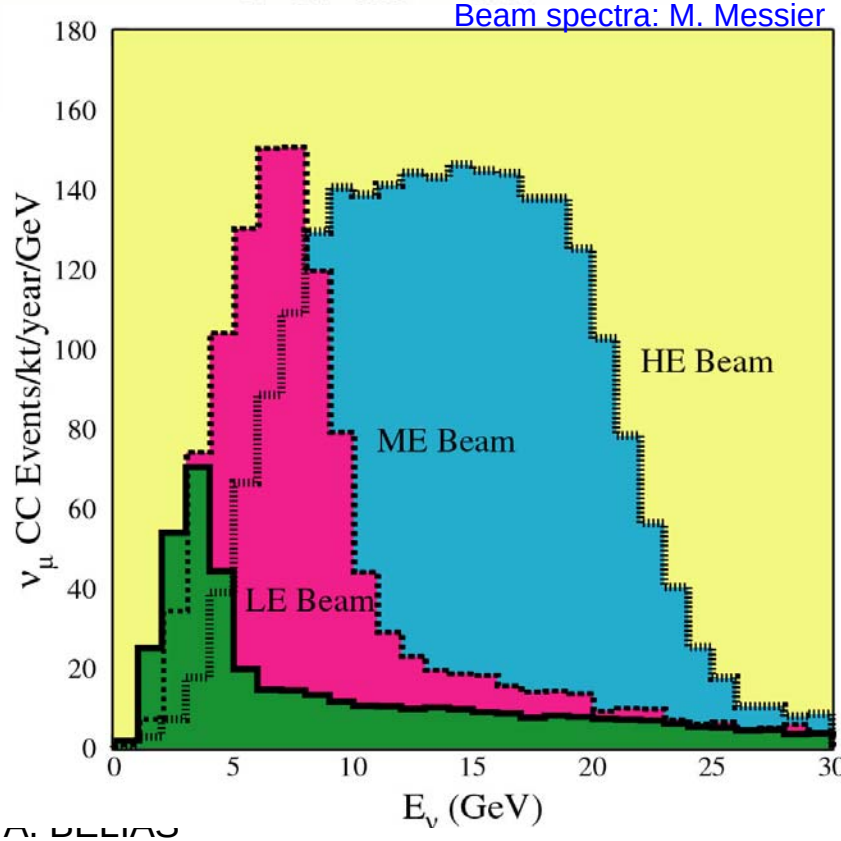


- Beam inclined 3.3° to point at Soudan
- Protons strike graphite target
- Margnetic horns focus charged hadrons
- Target position relative to horns tunes E_ν
- Decay pipe followed by hadron absorber
- Near Detector ~ 1km downstream target

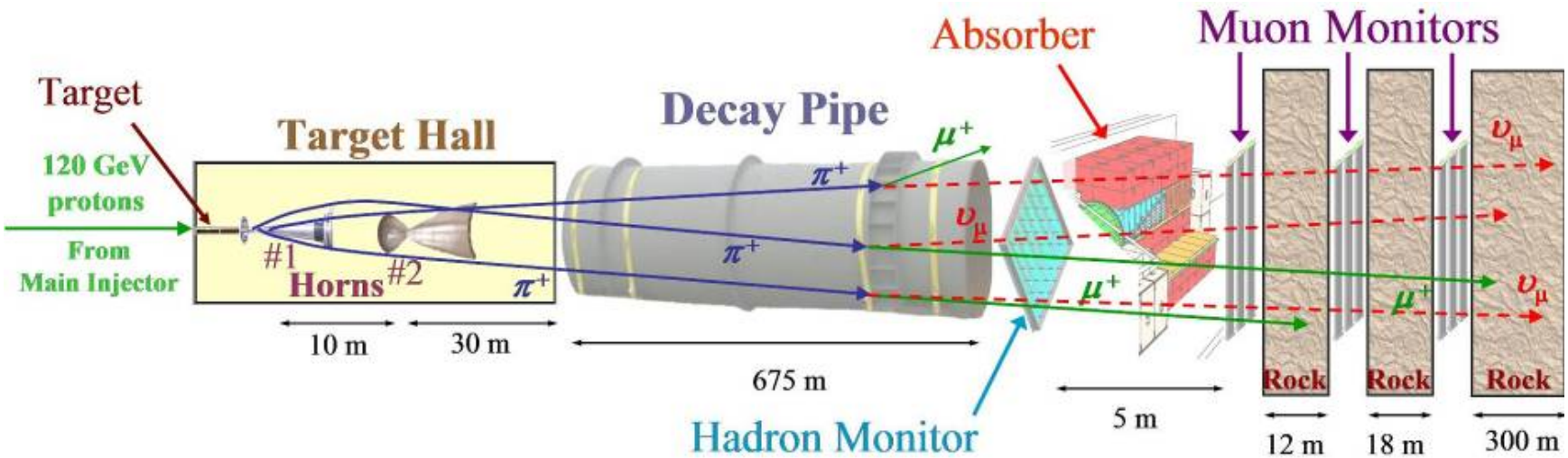
Start with LE beam to accommodate
$\Delta m^2 \sim 0.002\ eV^2$

ν_μ CC Events/year (no oscillations)		
Low	**Medium**	**High**
1,600	**4300**	**9250**

Beam spectra: M. Messier



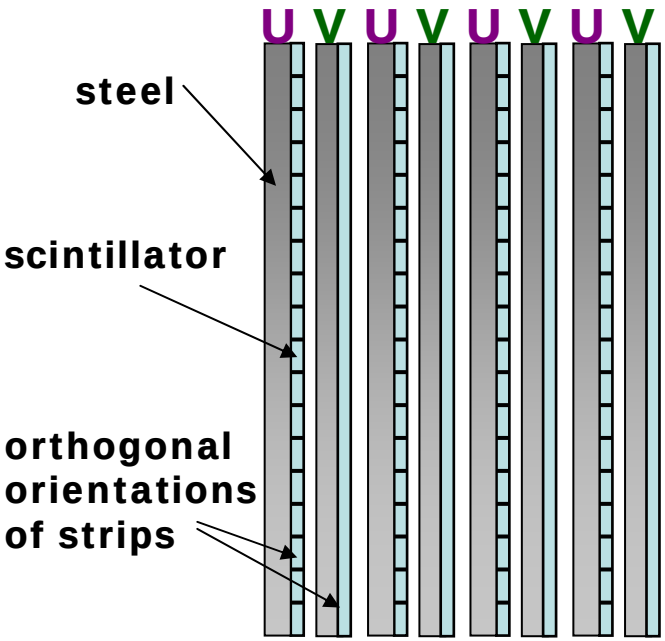
Neutrino Beam Devices

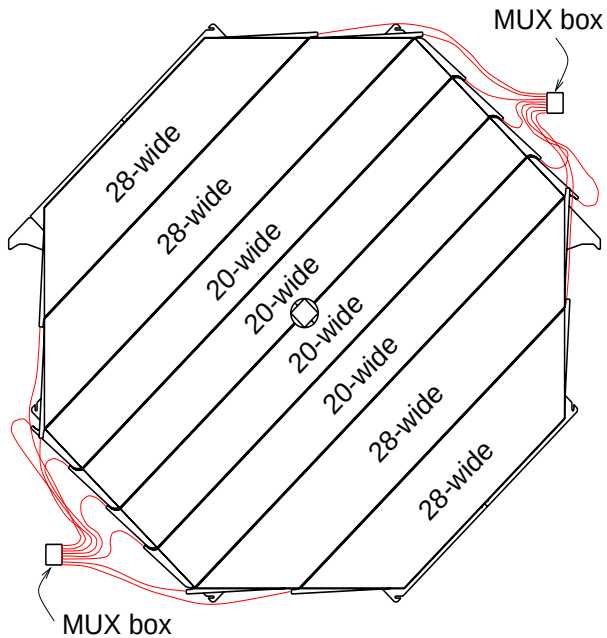


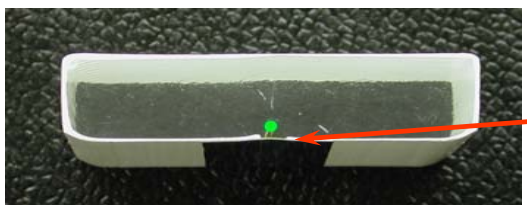
- Graphite Target: 6.4mm wide, 28mm tall, 95cm long
- Graphite baffle to protect Horns: 150cm long, 11mm ID
- Horns, pulsed at 200kA, (focus π^+, deflect π^-)
- Moving Target upstream of horns means higher energy π's focused
- 675m long steel decay pipe (1.5 Torr, encased in 2-3m concrete)
- Hadron absorber downstream of decay pipe
- Hadron and Muon Monitor, ceramic plate ionisation chambers

MINOS 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 4.2cm wide strips**
- Alternate planes have **orthogonal strip orientations (U and V)**



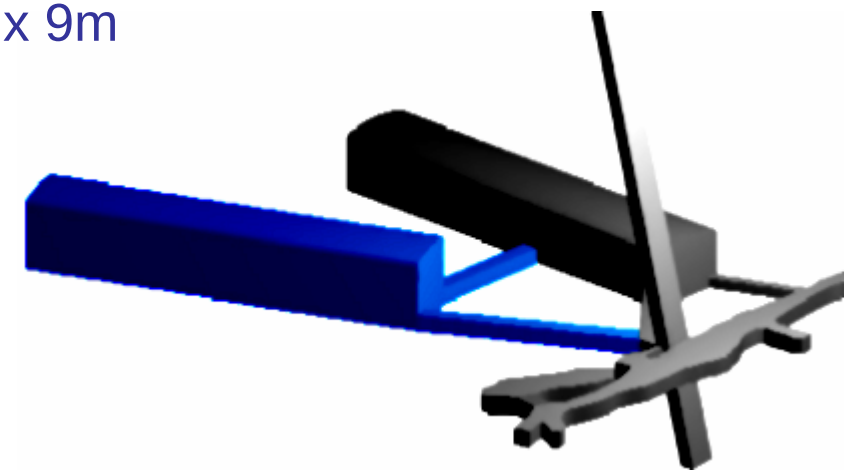




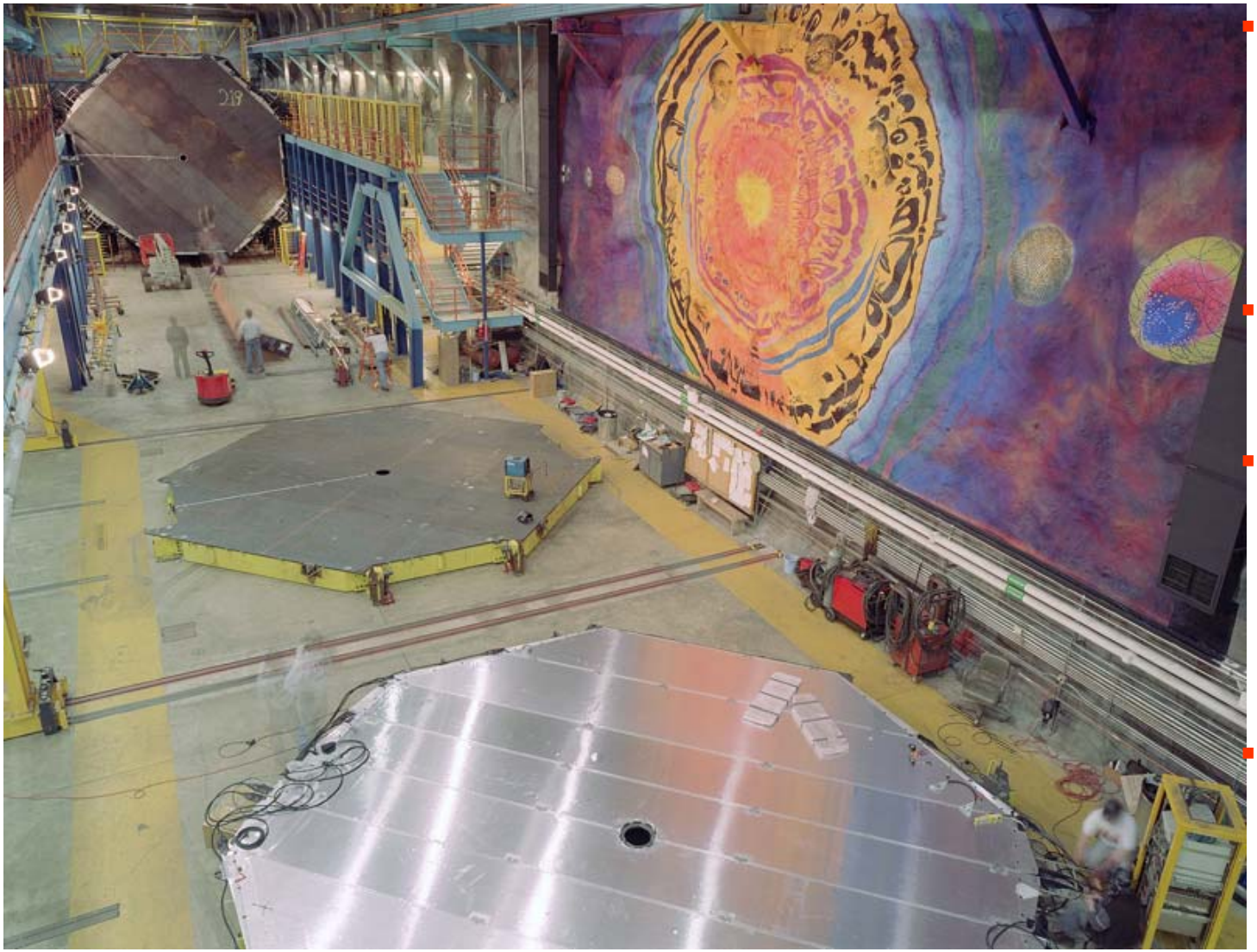
Scintillation light collected by WLS fibre glued into groove
Readout by multi-pixel PMTs

Soudan Underground Laboratory

- Operated by U. of Minn. and Minnesota Dept. of Natural Resources
- Soudan Mine – hosts Far Detector, 735km baseline
- 1 elevator shaft limits loads to 1m x 2m x 9m

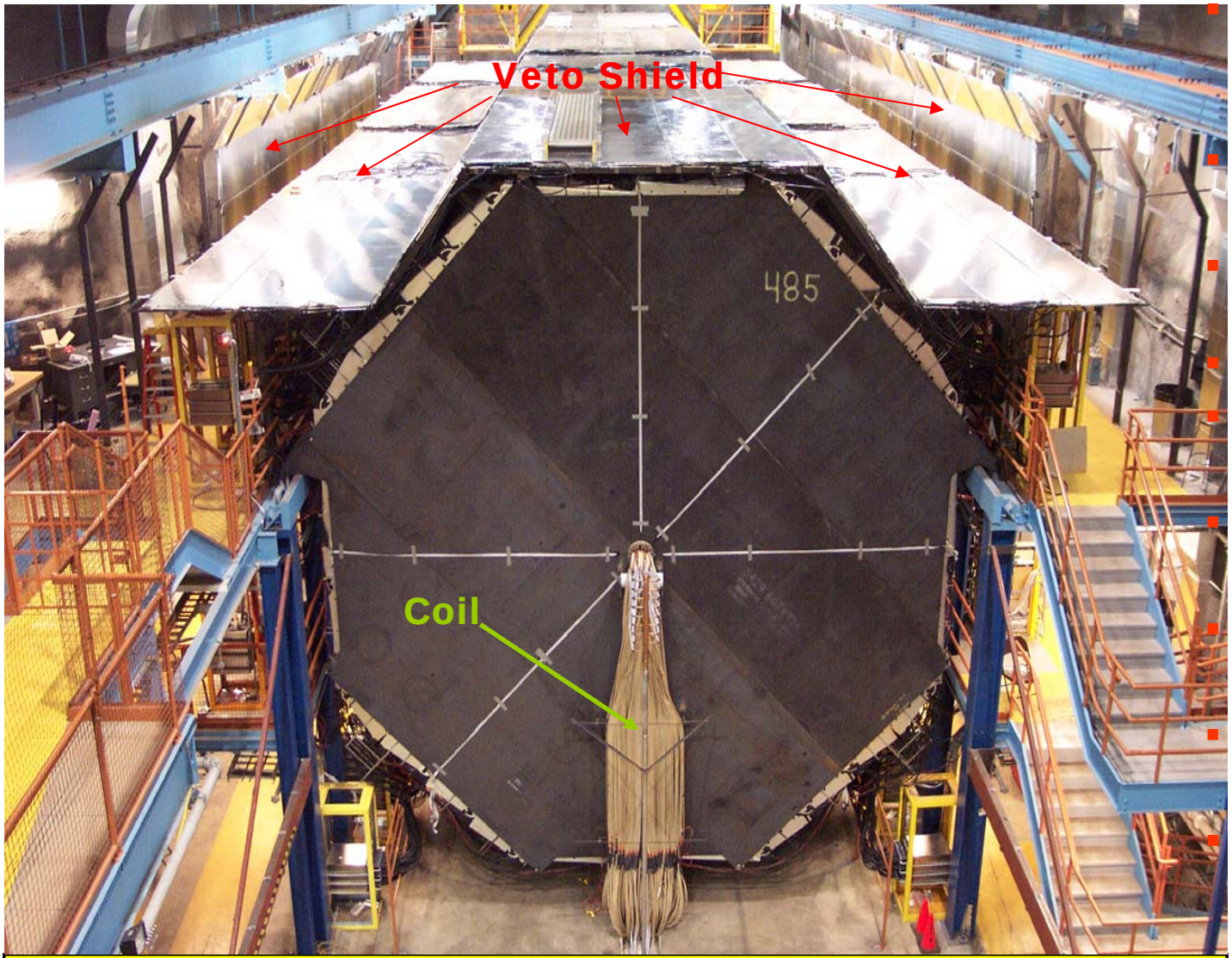


Far Detector installation



- Assembly of all steel planes took place underground in the Detector Cavern
- Steel planes welded together from plates
- Scintillator modules attached and tested before mounting a plane
- Worlds deepest Mural

Far Detector completed

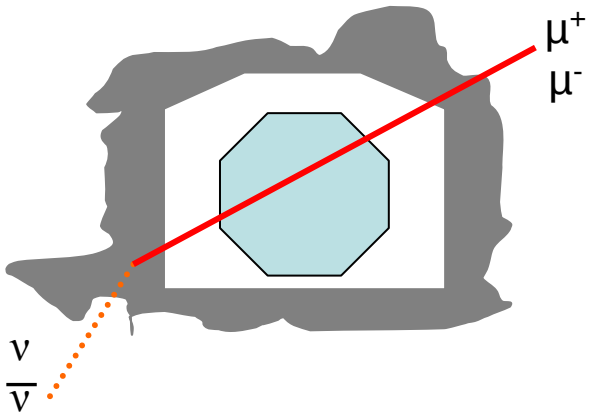


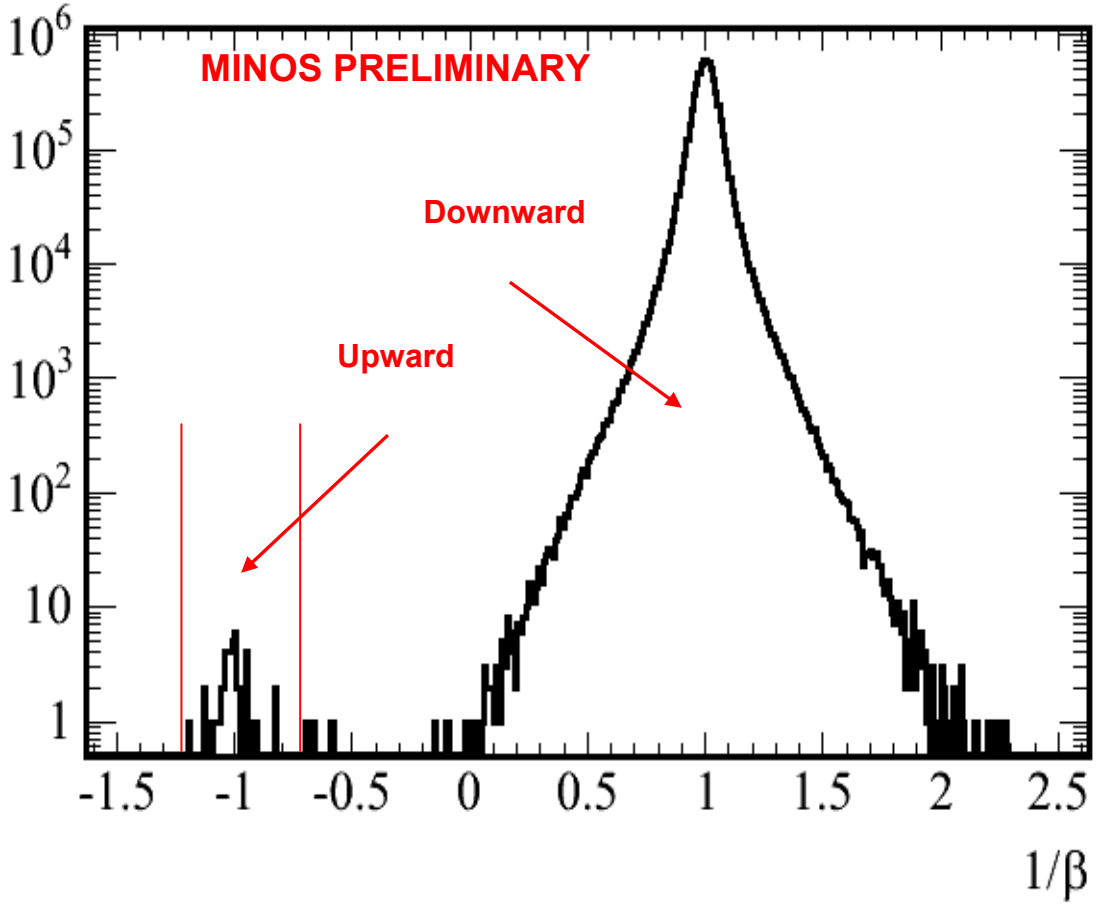
- 8m steel & scintillator tracking calorimeter
- 5.4 kton, 710m depth
- 484 steel/ scintillator planes
- 2 modules, 15m each
- Veto shield, scintillator
- Magnetised, B ~1.5 T
- Time resolution ~ 2 ns
- GPS time-stamping
- Spill info from Near Detector available for DAQ

Data taking since September 2001 **Installation fully completed July 2003.**

Upward going muons

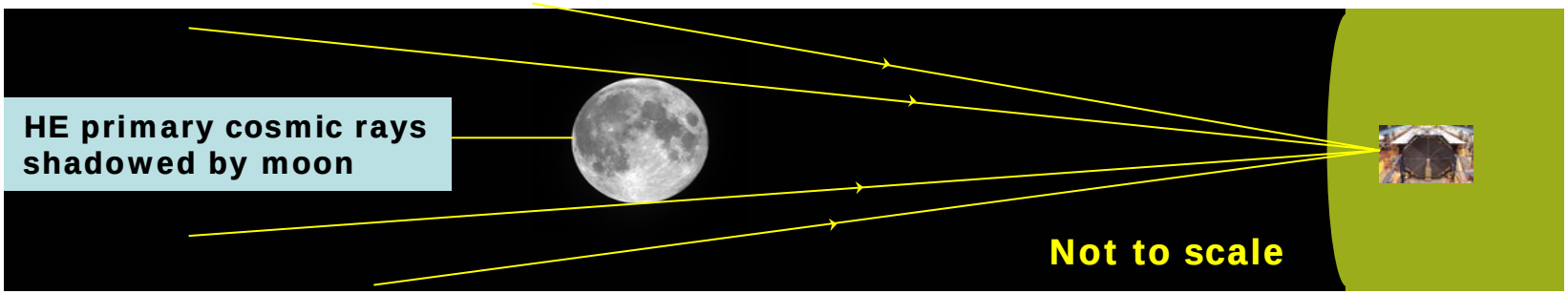
Collecting samples of contained vertex atmospheric neutrinos and neutrino induced upward muons.
Muon direction determined by timing, res. ~2 ns





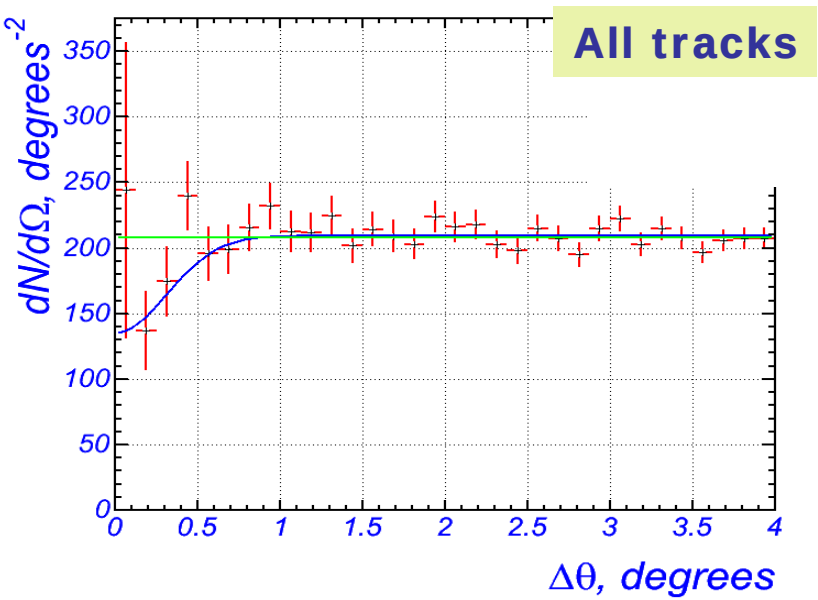
Expect : 1 event / 6 days

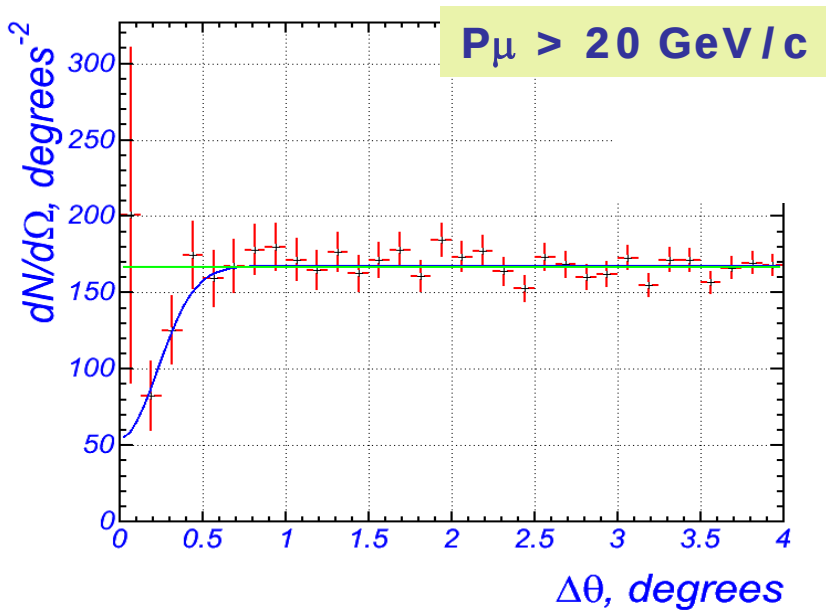
Seeing the moon underground



- Have recorded 10 M cosmic muons and observed shadow of moon
- Angular res. improved by selecting high momenta muons

MINOS Preliminary



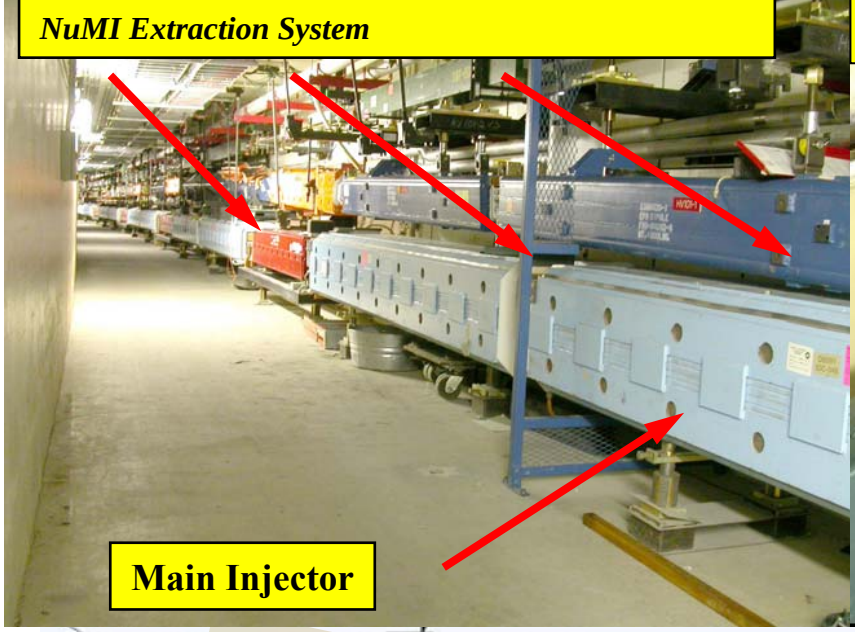


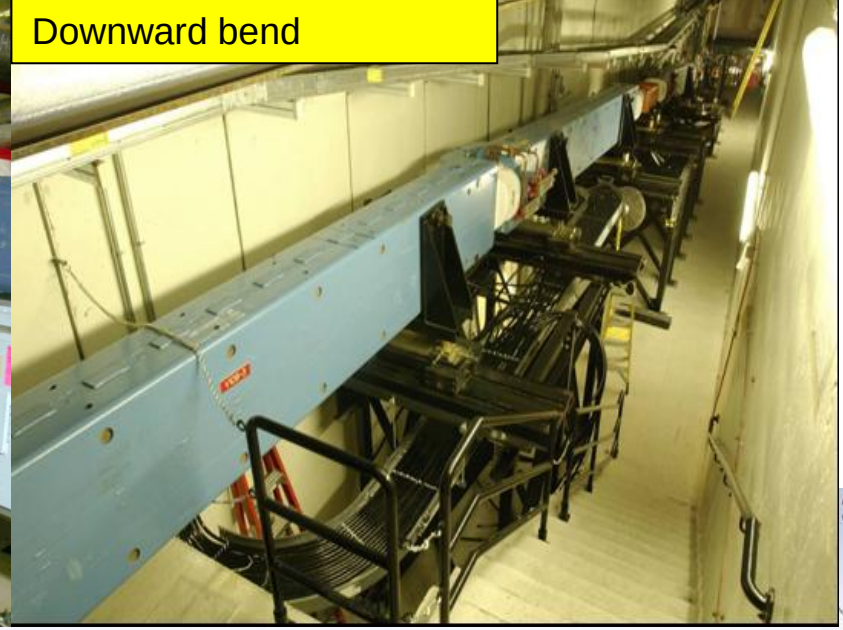
Near Detector at Fermilab

Near Detector – Ready for Beam

- 3.8 x 4.8m steel & scintillator tracking calorimeter
- 1 kton, 90m depth
- 282 steel planes, 153 scintillator planes
- Calorimeter partial instrumented except 1/5 full coverege
- Spectrometer 1/5 instrumented
- Magnetised, B ~1.3 T
- GPS time-stamping
- FEE gated with MI to trigger readout in spill

Data taking since April 2004 **Installation fully completed Aug 2004**

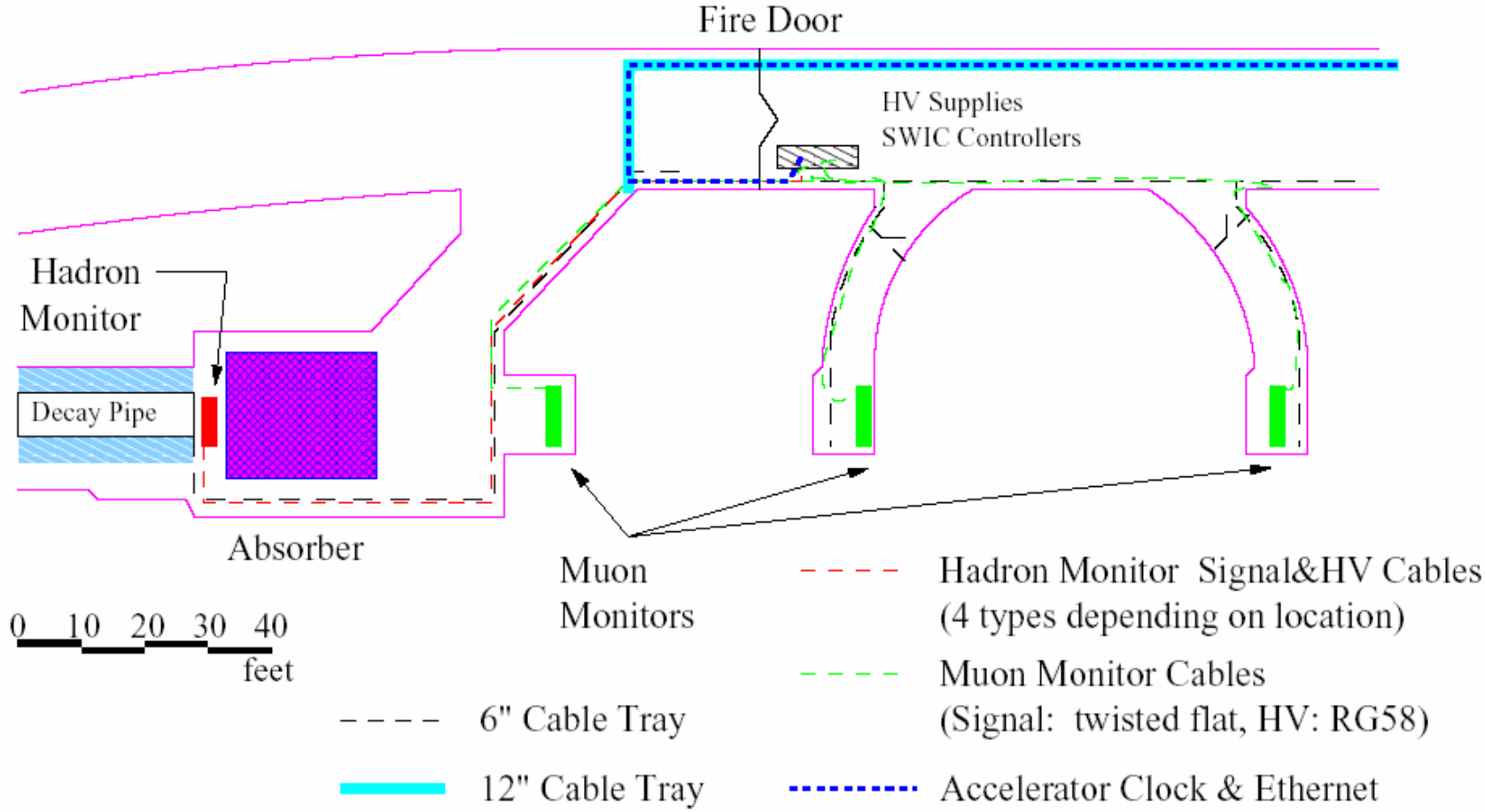

NuMI Extraction System
Main Injector


Downward bend

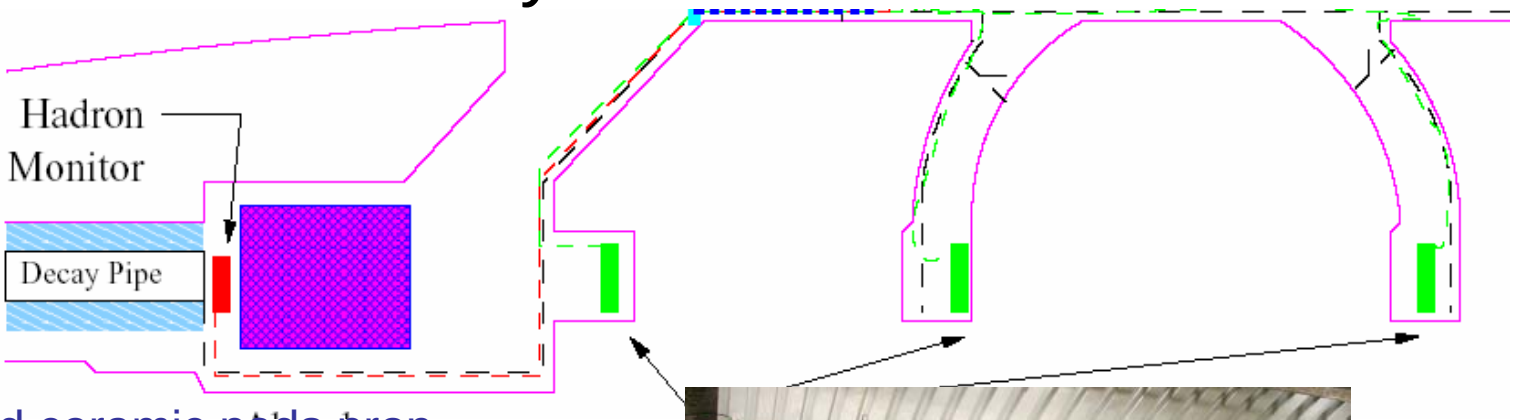

Soudan
p beam
Carrier
Tunnel
Target Hall
Pion beam
Decay Pipe
Beam Absorber
Muon Detectors
Minos Hall
Minos Near


Decay Pipe,
downstream end

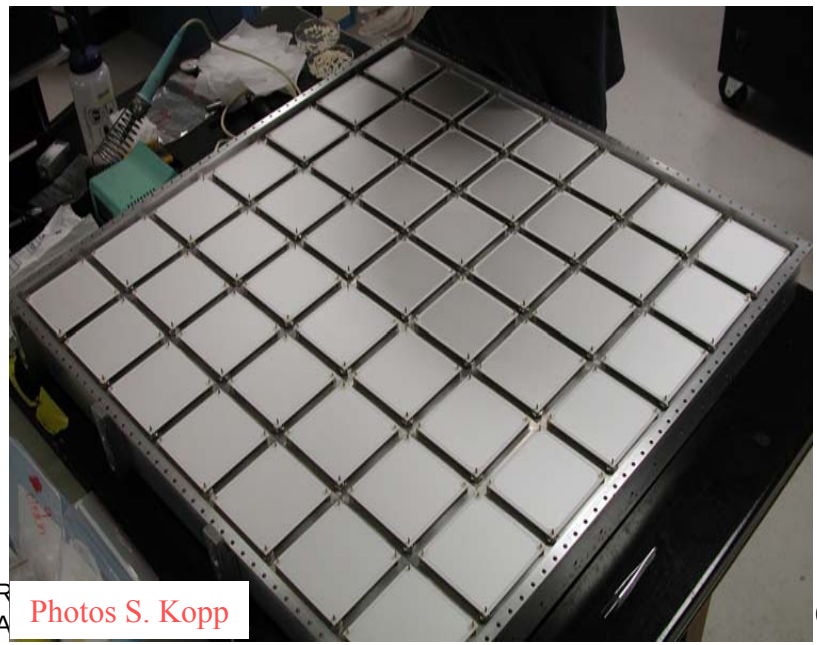
Secondary Beam Monitors



Secondary Beam Monitors



Plated ceramic pads prop. chambers (He).
Hadron monitor 1mm,
Muon monitor 3mm gap.



Photos S. Kopp

Beam Commissioning

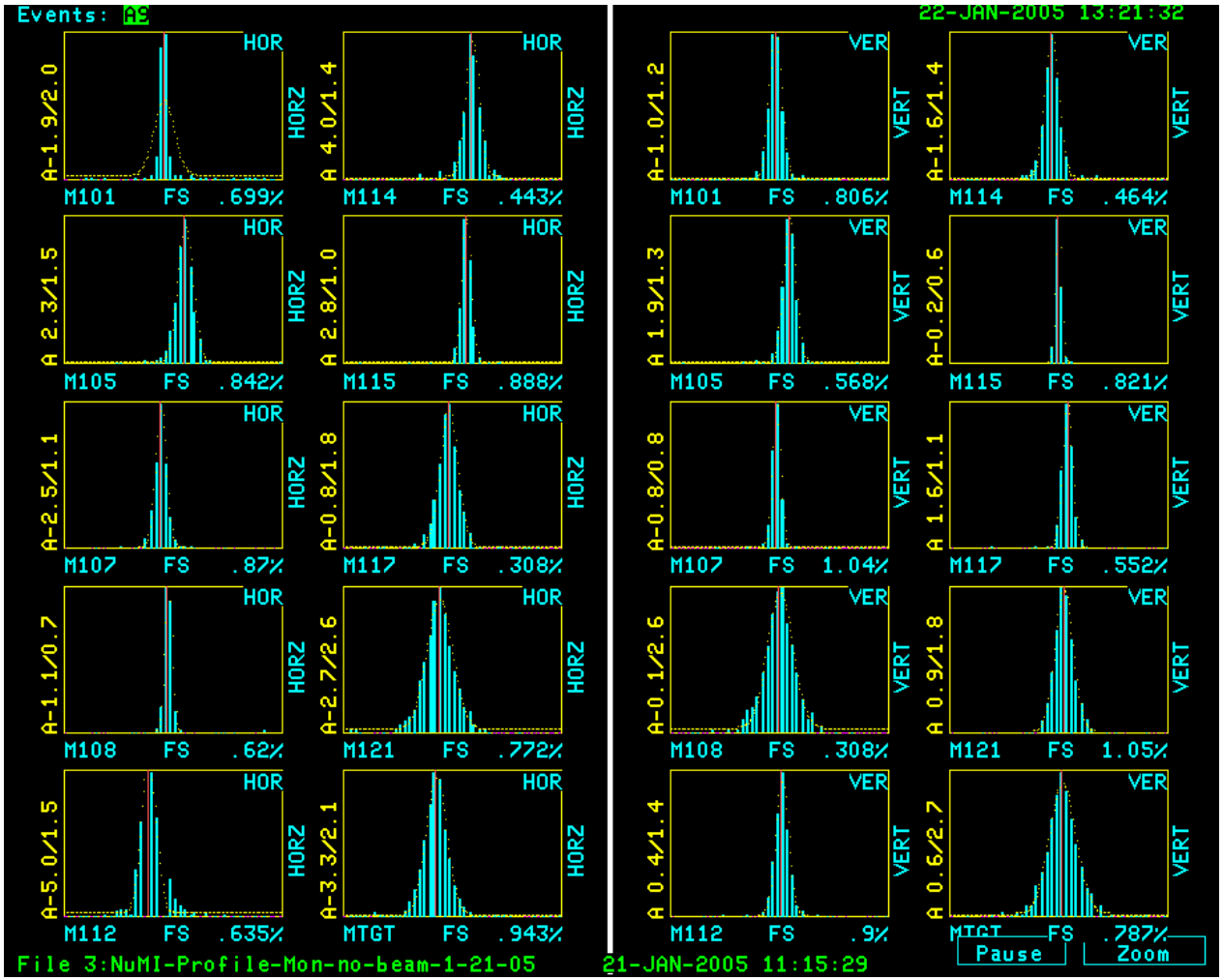
- December 3 - 4, 2004
  - beam transported to target hall & onto hadron absorber
    - target out -- so no neutrinos; goal is beam line commissioning
    - small number of carefully planned pulses (to limit radiation)

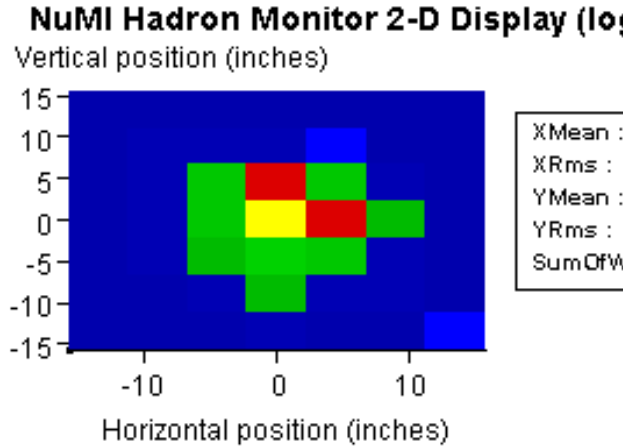
- January 21 - 22, 2005
  - first beam on target !!
    - horns powered
    - target at z= -1 m from nominal → "pseudo-medium energy beam"
    - MI operating w/ single Booster batch *(nominally 5 or 6)*
    - 864 spills at 60-180 second intervals *(nominally 2 seconds)*
    - typical (max) intensity: 2.6e12 (4.1e12) protons per spill

- February 18 - 22, 2005
  - Nominal intensity running w/ 5 Booster batches, ~2e13 protons per spill

First beam in beamline

December 3-4, 2004





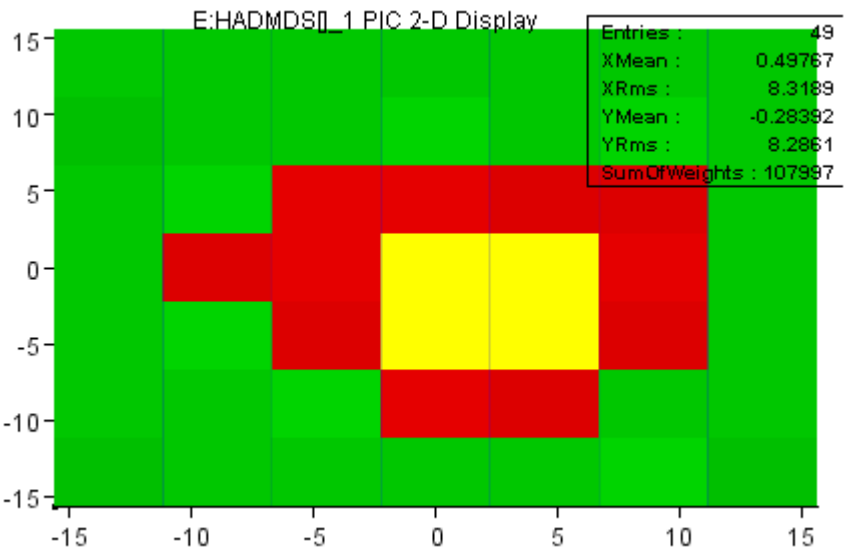
- 10 pulses to get proton beam to hadron monitor
- Extraction works
- Beam Instrumentation
- Magnet correct polarity
- Hadron, muon monitors
- Beam direction correct to <.01 mr

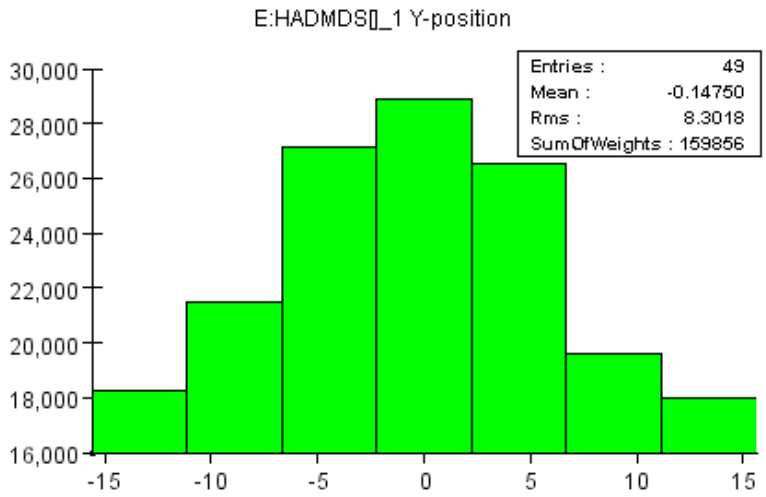
Profile monitor output along the beamline from thin-foil SEM's

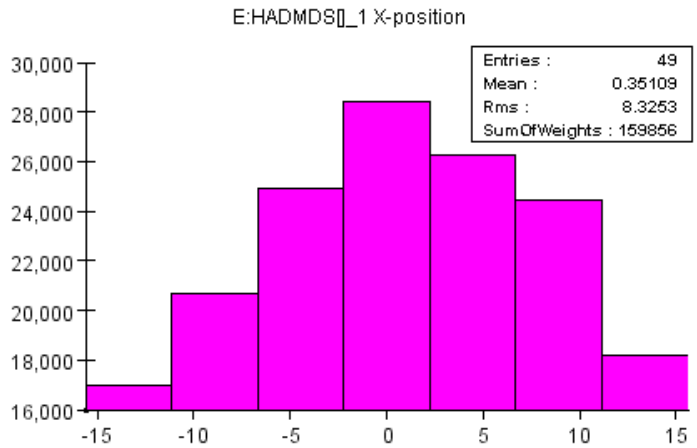
First Beam Neutrinos in Beamline

January 21-23, 2005

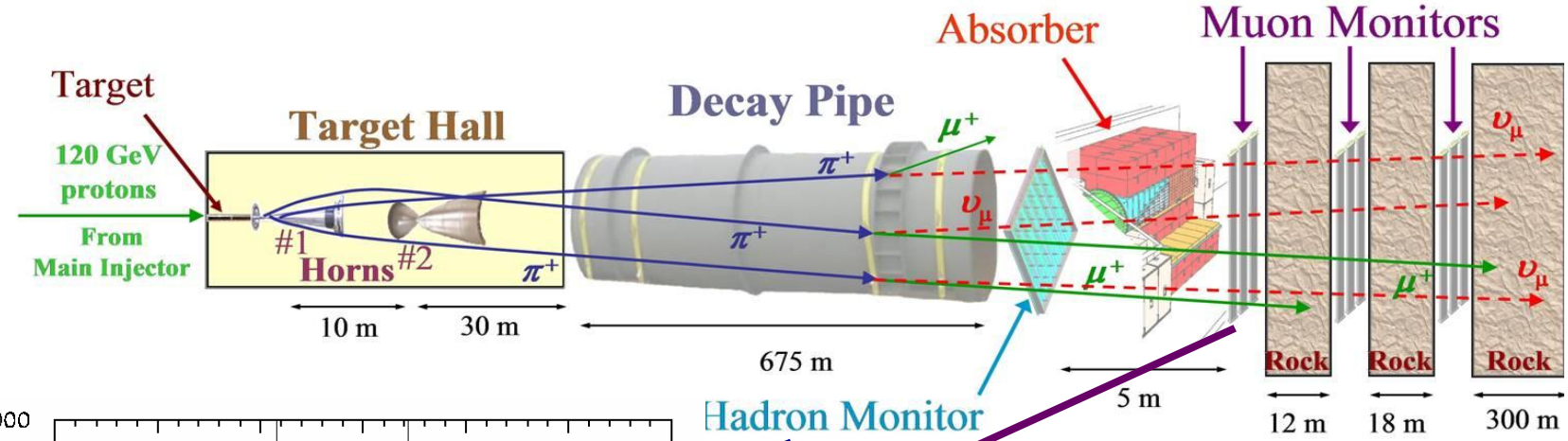
- Start up in same settings as in December
- Hit target on first pulse
- Start pulsing horns shortly thereafter

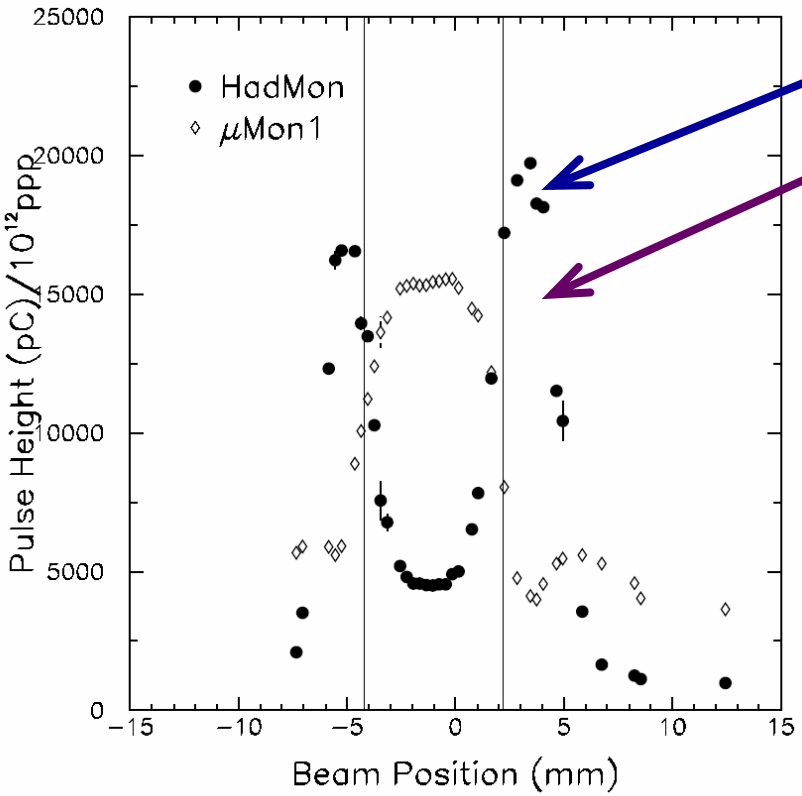


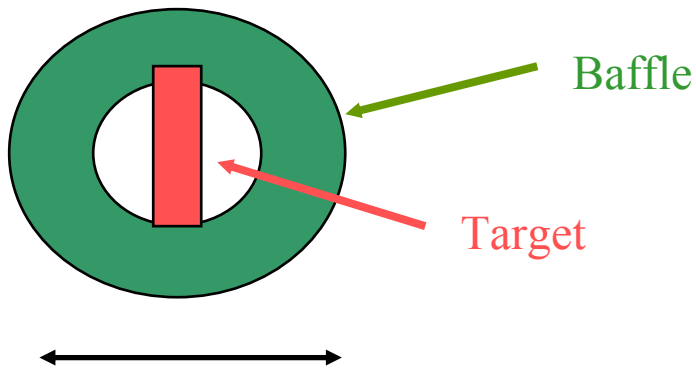




Beam commissioning - Target horizontal scan





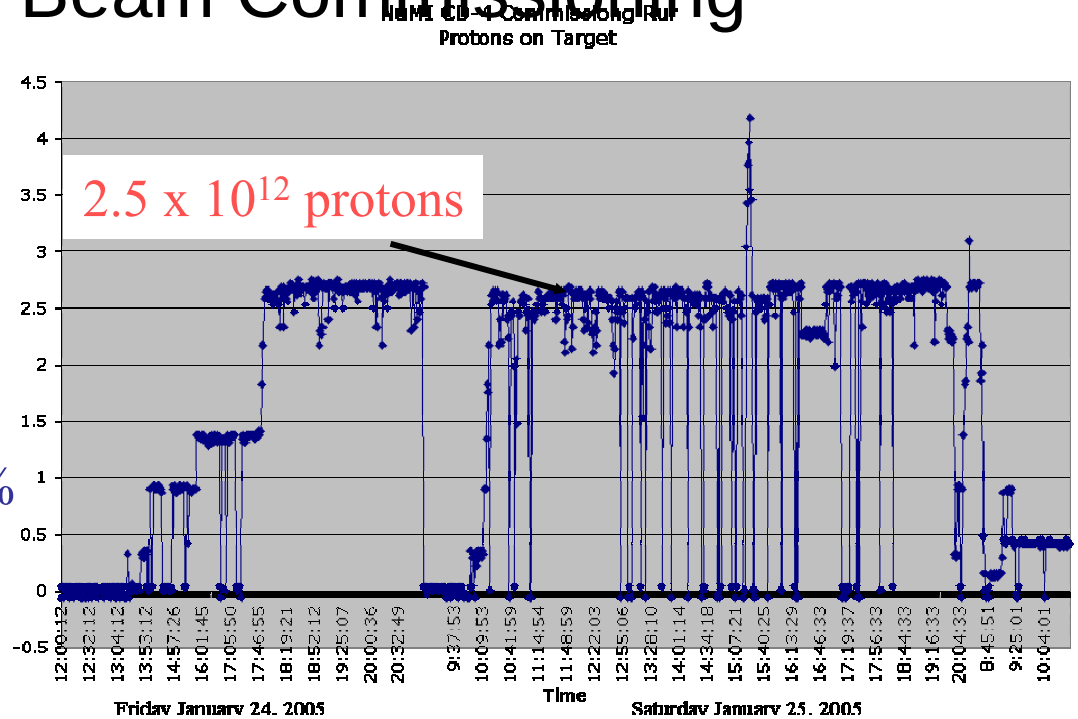


NuMI/MINOS Beam Commissioning

Pulses once per minute

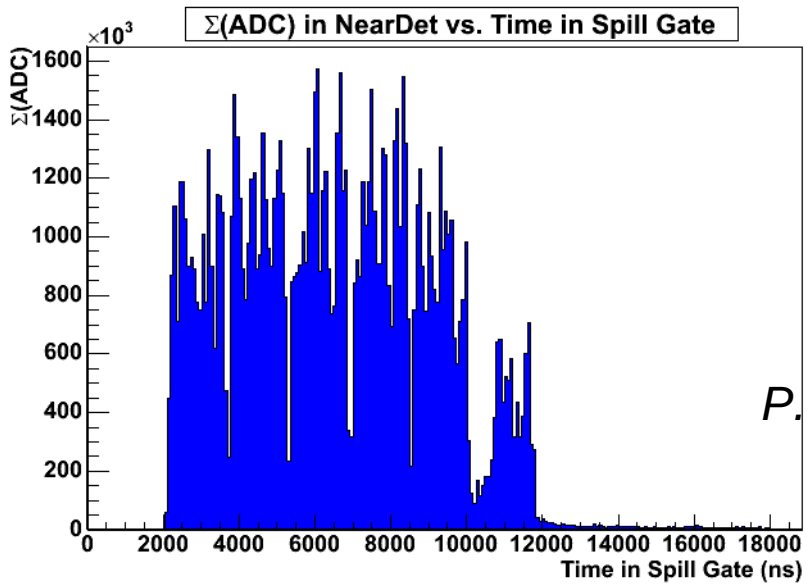
Instantaneous rate comparable to initial operating conditions

Approx. 2 x 10^{15} POT, of which 50% usable for detector commissioning



Time distribution of energy deposited in the Near Detector with 6 Booster Batches:

Beam gate open 2 μs before start of beam spill; open for 18 μs.



P. Shanahan

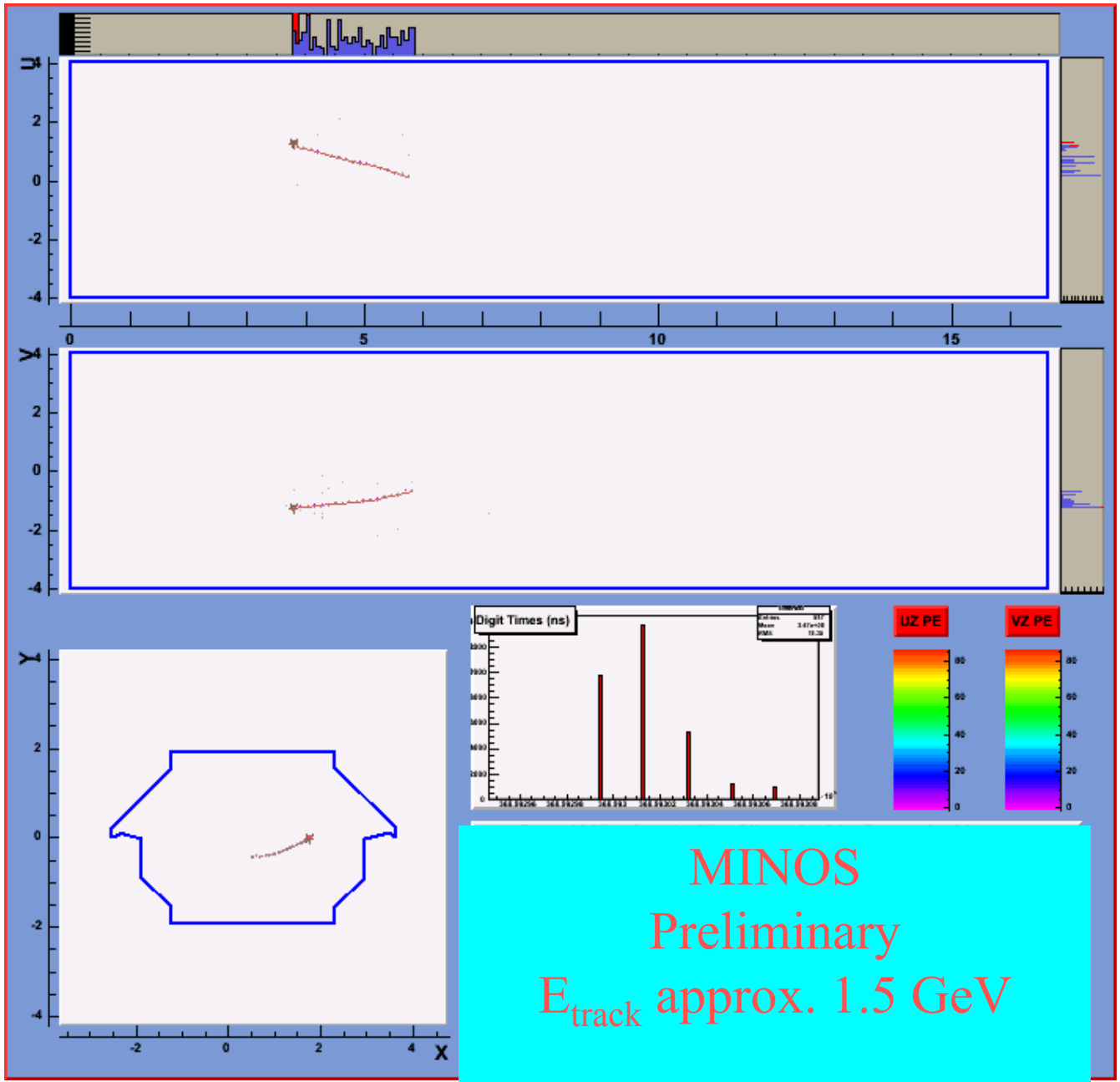
Near Detector Event

Top panel shows UZ view

Middle is VZ view

Bottom left is XY

Histogram shows times recorded for each hit



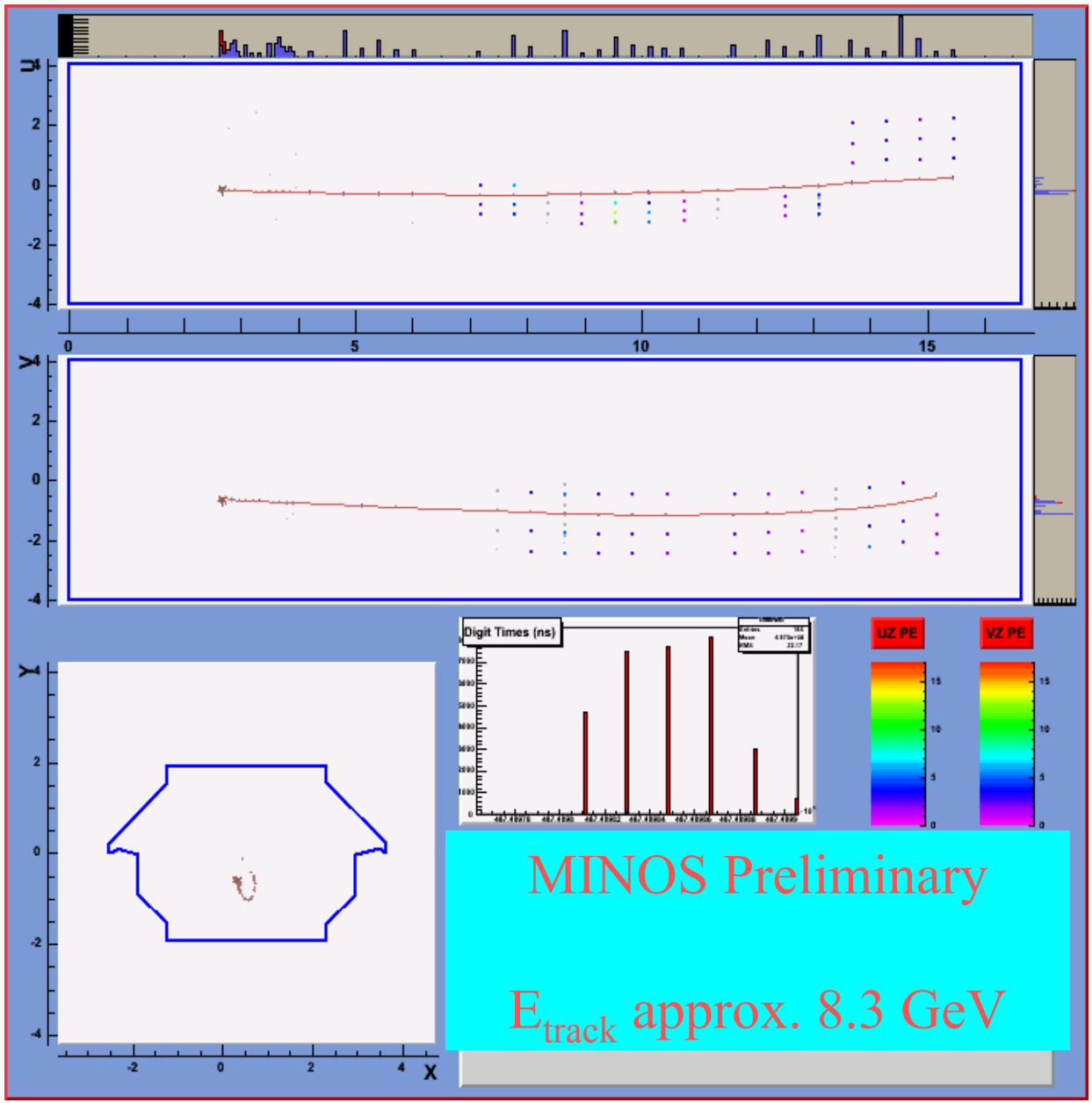
Low-energy track from fiducial region

MINOS
Preliminary
E_{track} approx. 1.5 GeV

Another Near Detector Event

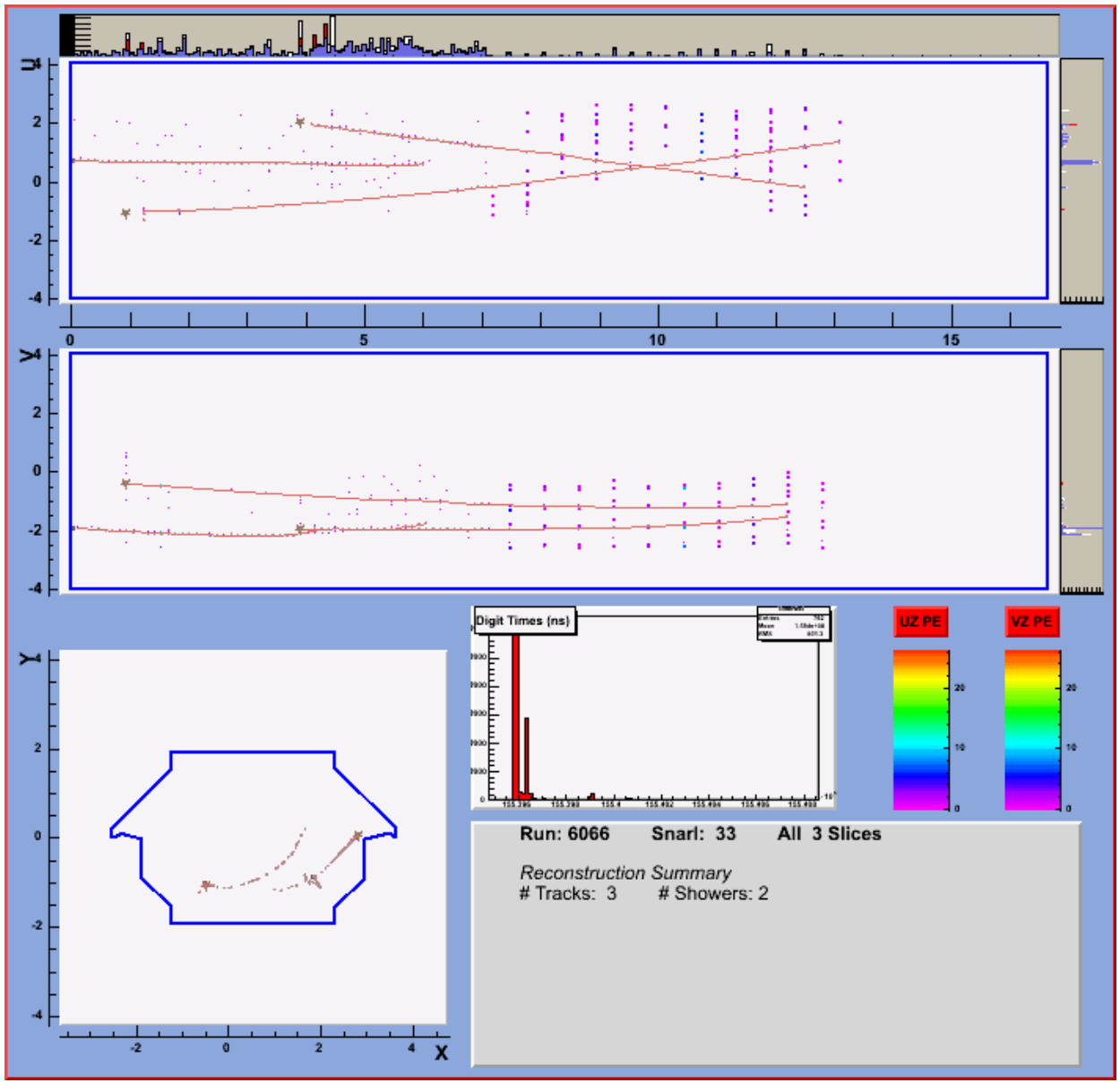
High-energy track

Tracking in residual steel magnetic field, although current not on.



Rock Muons and Neutrinos

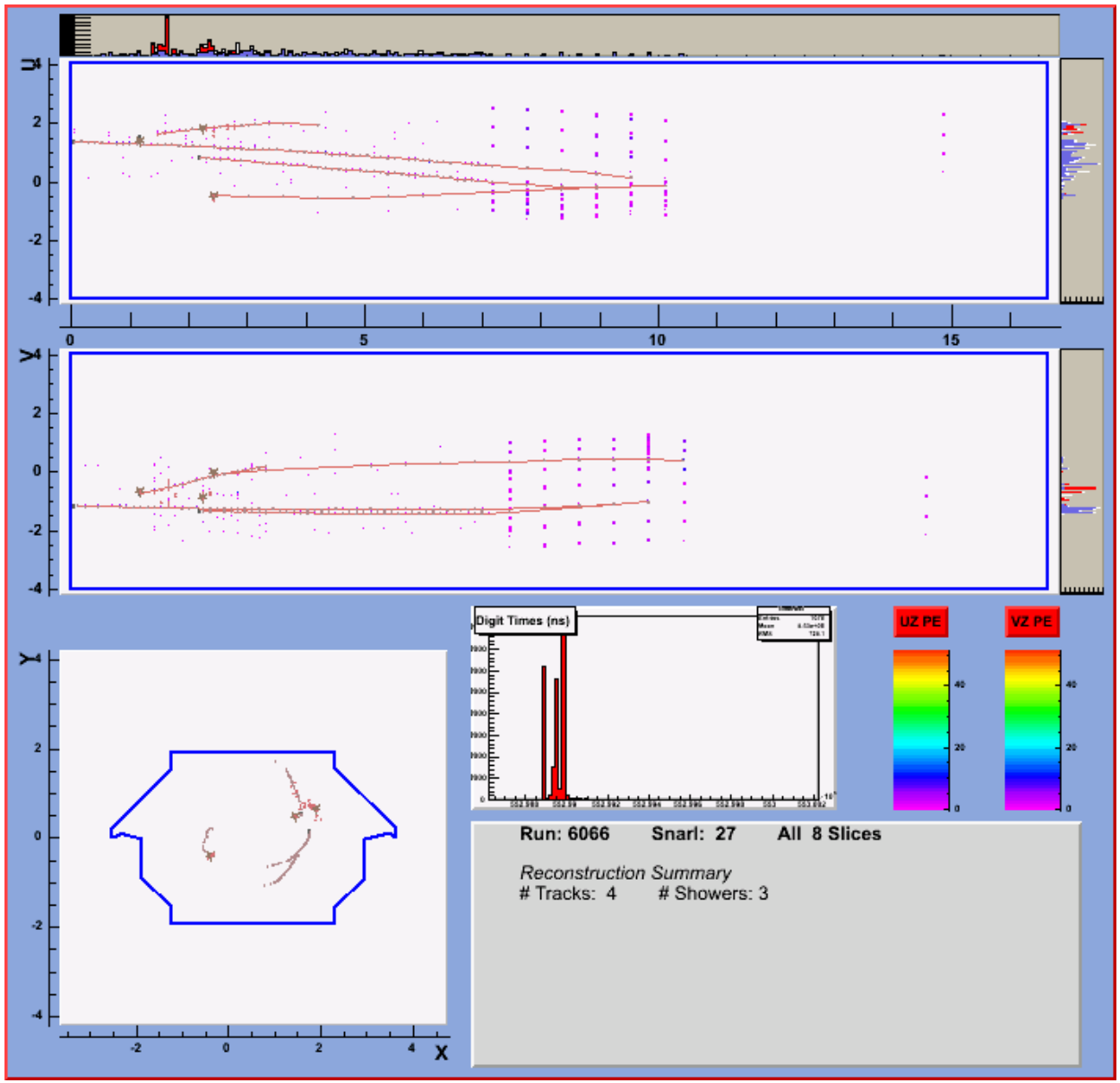
3 tracks and 2 showers found in this spill



Multiple Interactions from Single Spill

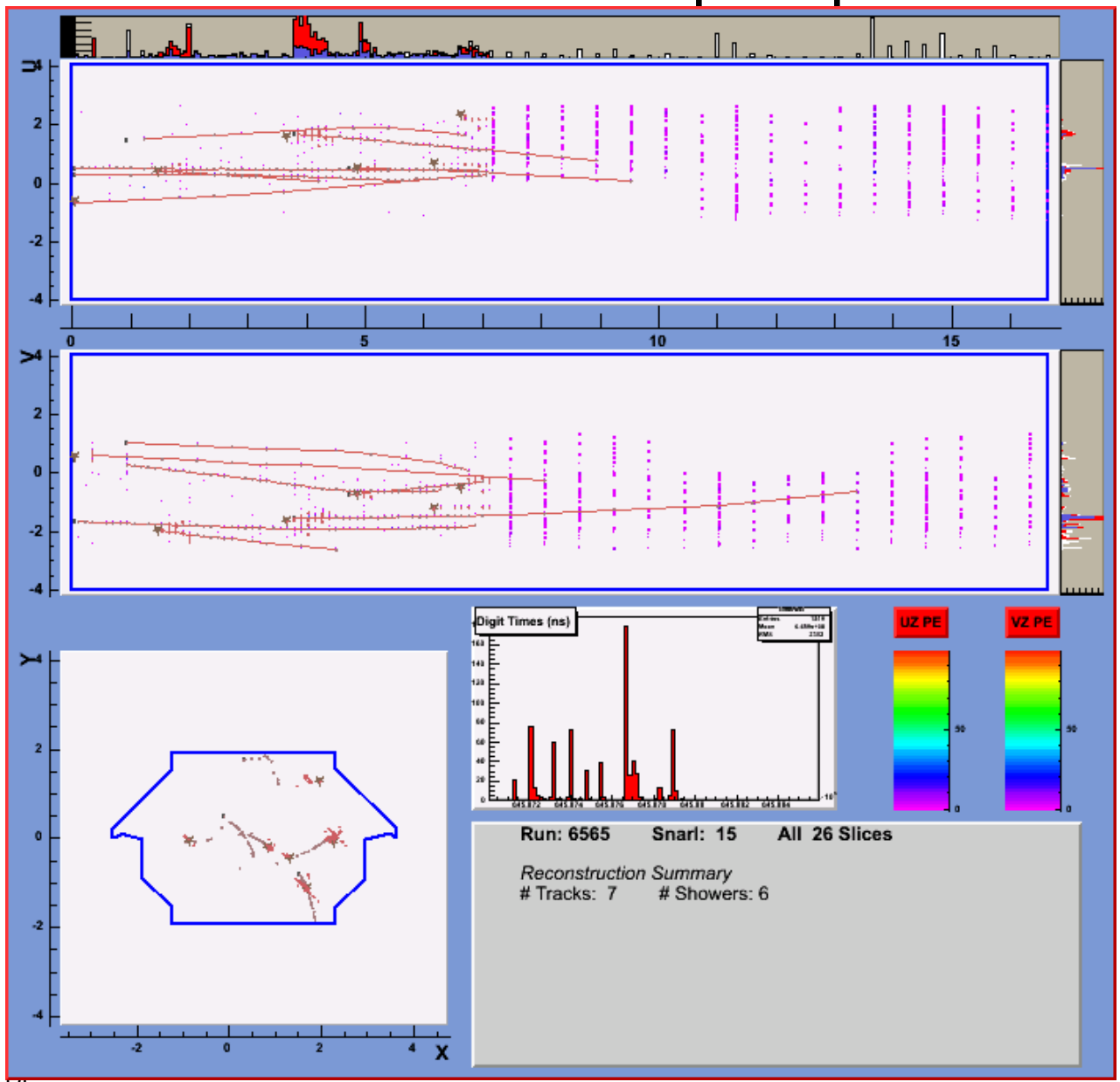
4 tracks and 3 showers found in this spill

Detector read out in 19 ns buckets, allows event separation.

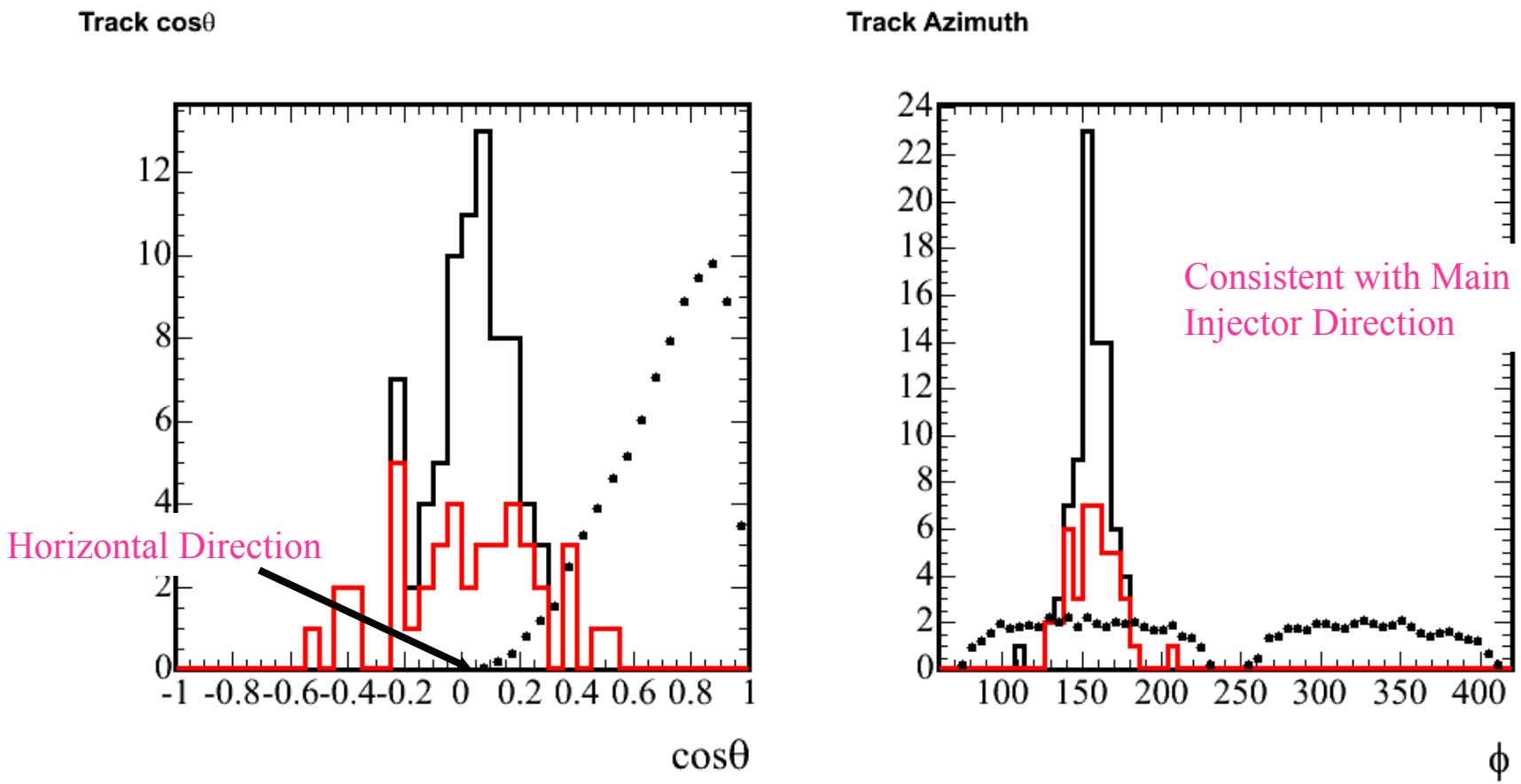


Multiple interactions from multiple spills

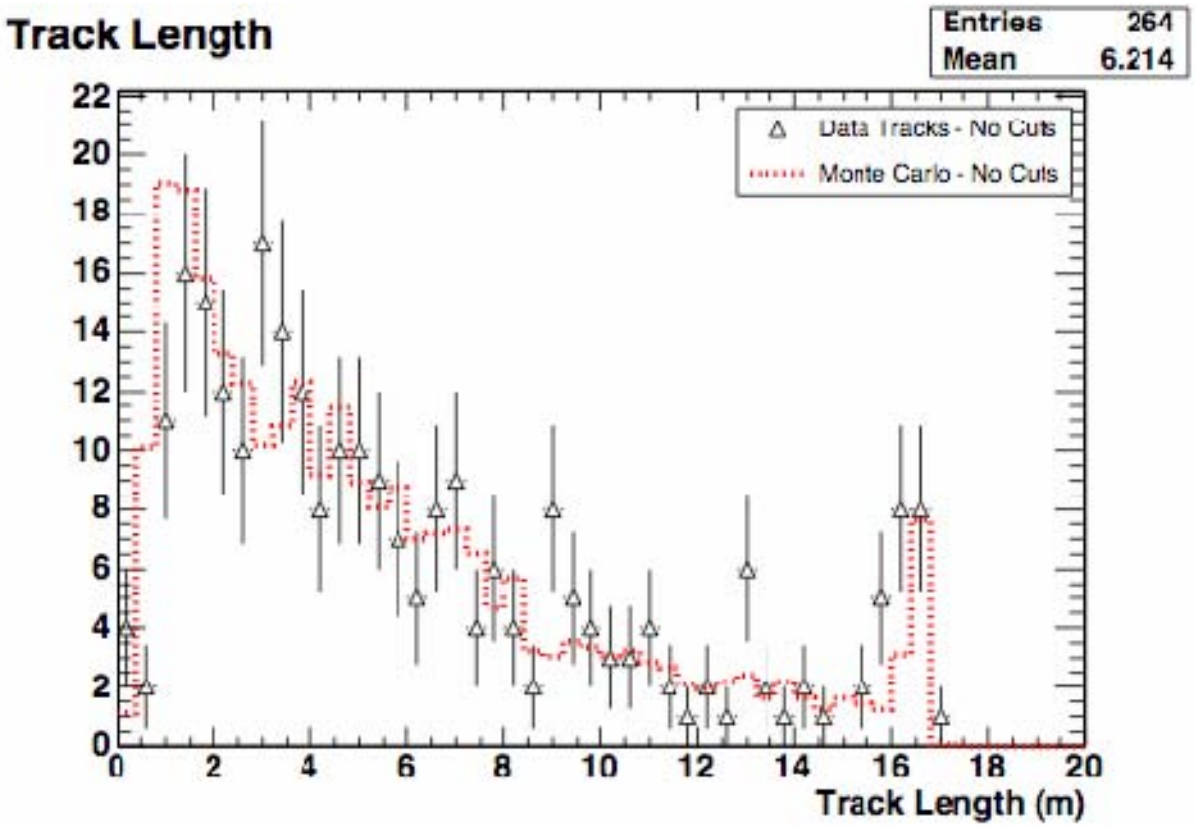
7 tracks and 6 showers found from 5 spills



Neutrino Event Angular Distributions



Track Length Distribution



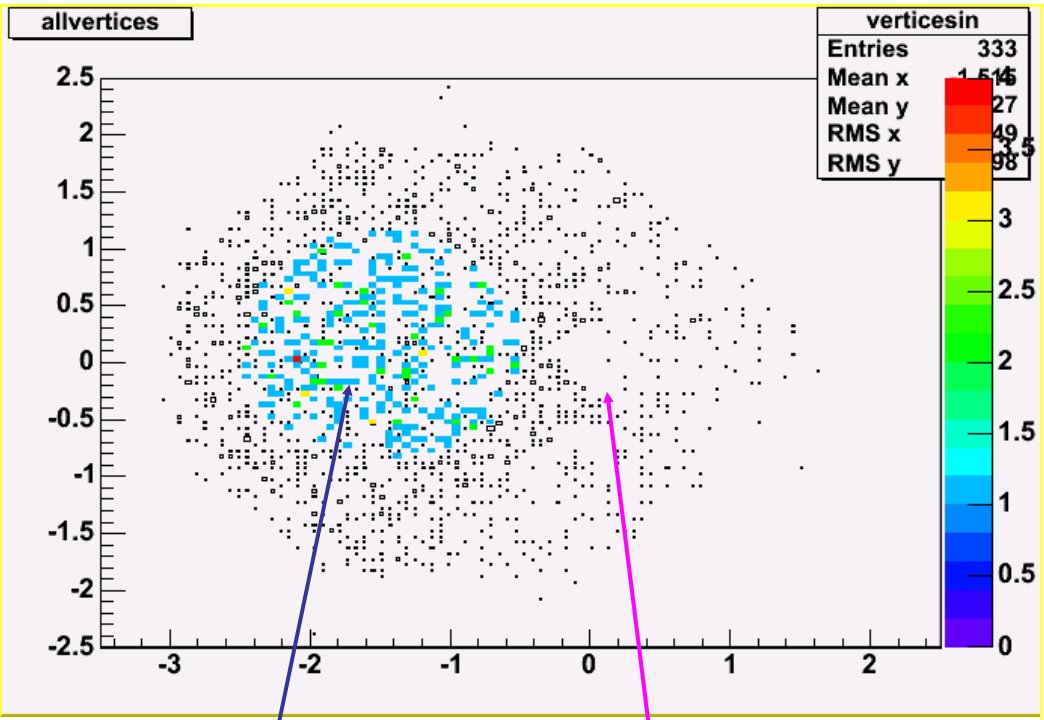
A. Marino

Includes entering rock muons and non-fiducial neutrinos

More neutrino distributions

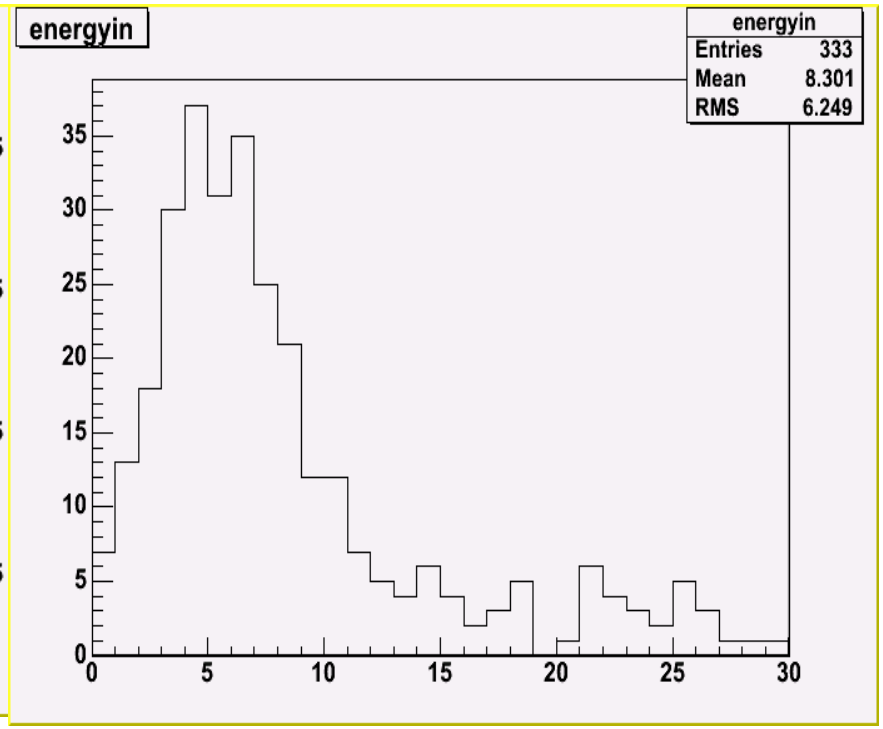
Roughly 1 day's data at 1 pulse/minute (rather than every 2 sec) at ~1.3 x 10^{12} ppp

x-y distribution of vertices



Fiducial region

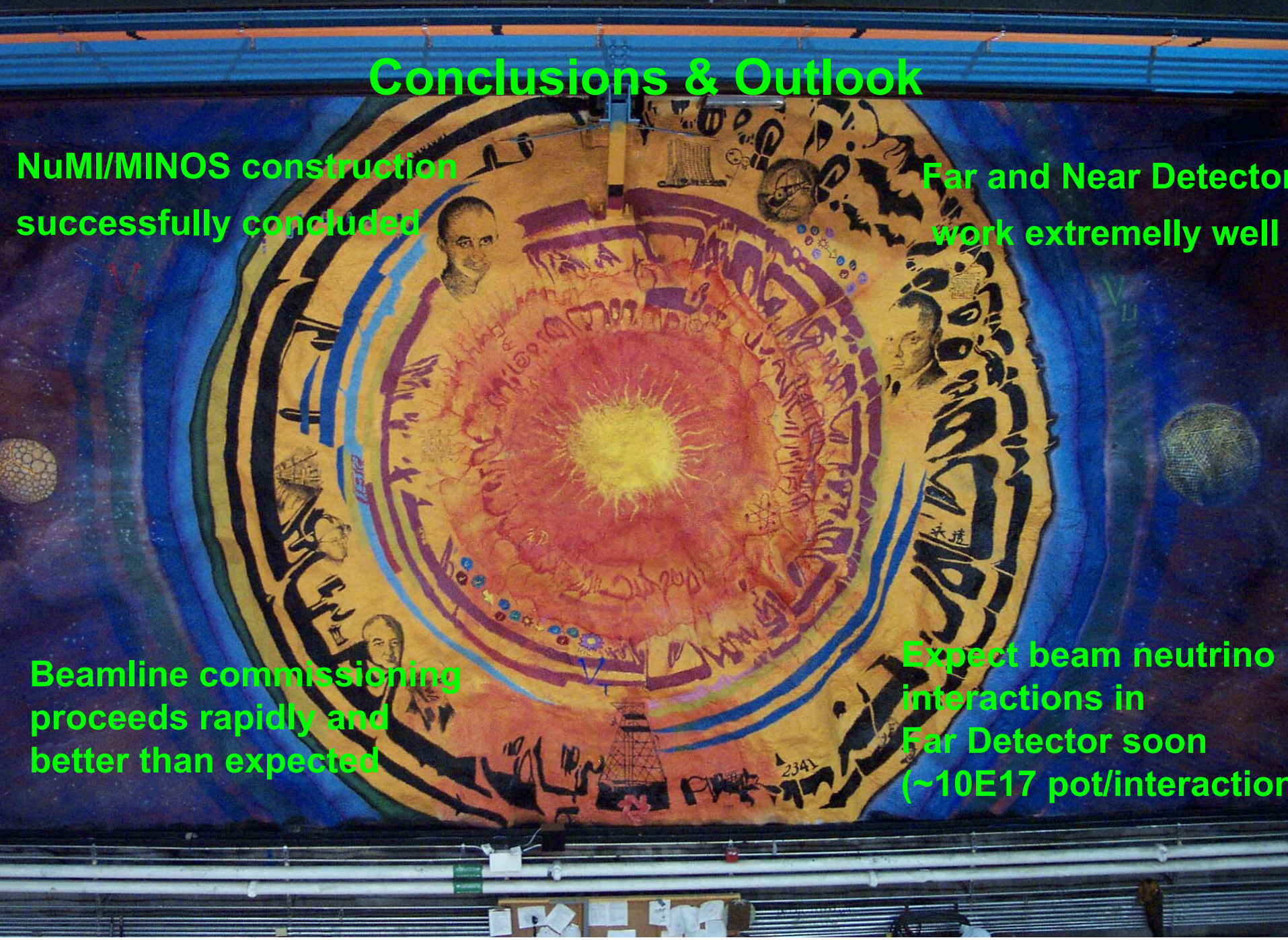
Coil hole



neutrino "energy" distribution (for contained events only)

Caveat: No B field, residual field only

Conclusions & Outlook



NuMI/MINOS construction successfully concluded

Far and Near Detector work extremelly well

Beamline commissioning proceeds rapidly and better than expected

Expect beam neutrino interactions in Far Detector soon (~10E17 pot/interaction