Neutrinos & the MINOS Experiment

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WF PW   2006

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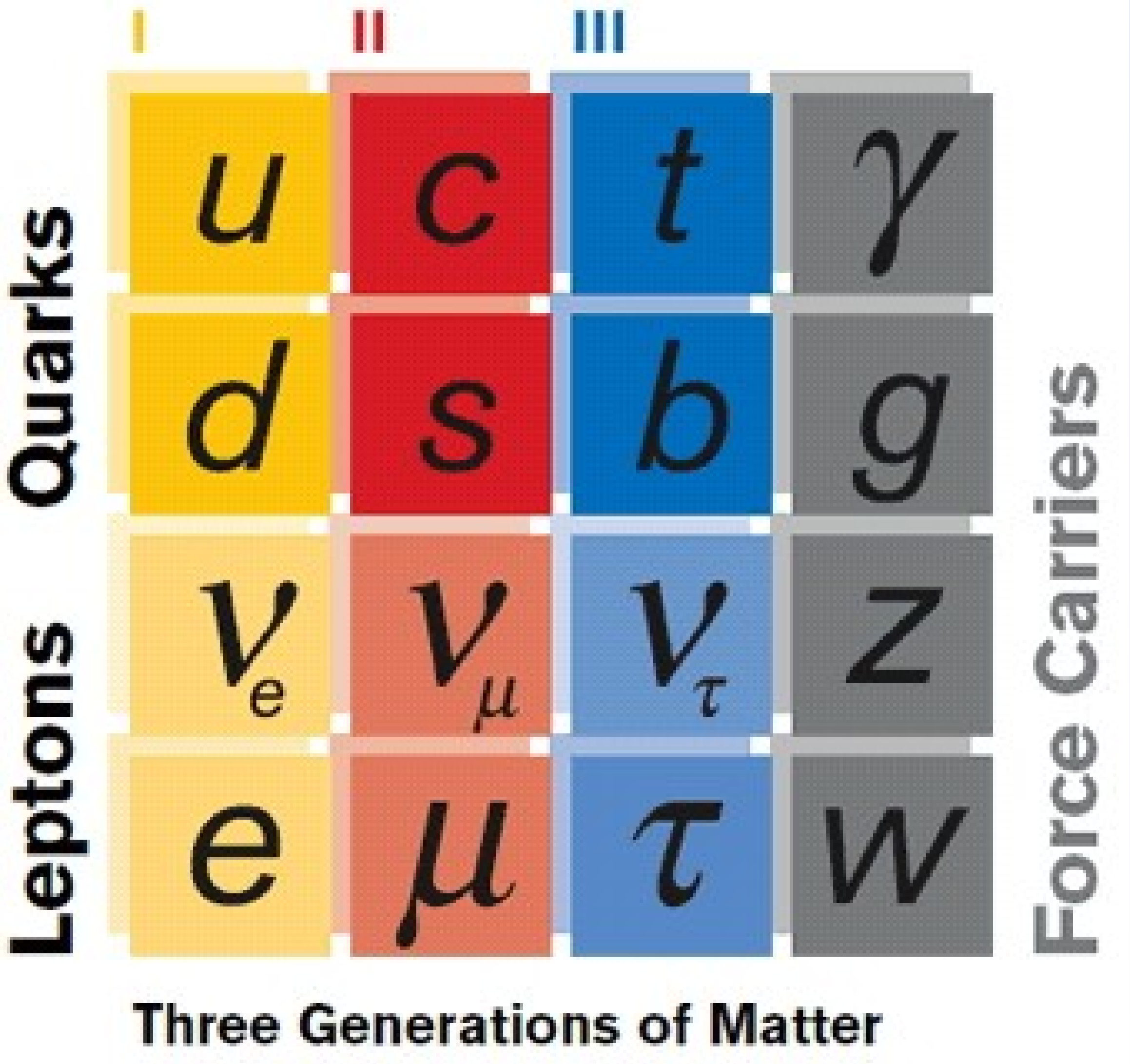
UW

Overview of the talk

- neutrinos' theory and physics goals
- introduction to the MINOS experiment
- neutrinos' beam & MINOS detectors
- detectors' construction
- components technology
- software analyze
- my postgraduate work & data
- summary

A little bit of theory

Standard model



- there are 3 generations of neutrinos
- neutrinos are non-charged leptons
- neutrinos have a very low mass
- neutrinos are not visible!
- we can detect them thanks to particle collisions

Theory

- in many neutrino experiment scientists proved, that neutrinos oscillated into each other
- the neutrino „flavour” is changing on the long way
- $\nu_\mu <\!\!-\!\!> \nu_\tau <\!\!-\!\!> \nu_e <\!\!-\!\!> \nu_\mu$ etc.

Theory

The approximate formula describing oscillations is:

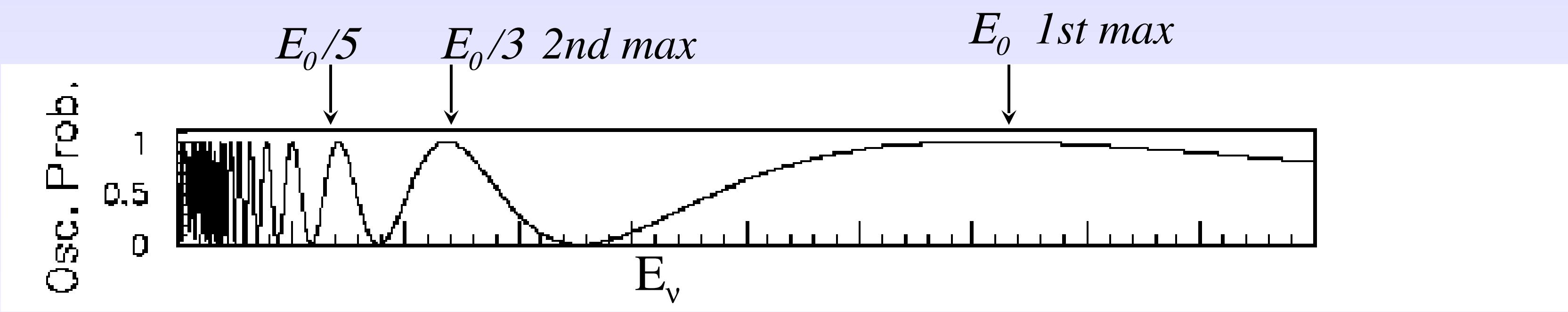
$$P(\nu_\alpha \rightarrow \nu_\beta) = \sin^2 2\theta \sin^2(1.27\, \Delta m^2\, L/E)$$

where L (source to detector distance) and E (neutrino energy) are experimental parameters

2θ (mixing angle) and Δm^2 (mass squared difference) are oscillation parameters

Experimental implications

- Accelerator experiments are done at fixed L (both locations fixed)
- If oscillations are present, we can see ν flux changes as a function of ν energy
- Ideally, one would want to observe at least 1 wavelength



- For fixed L and given Δm^2, there is an ideal E_ν because:
  - At high energy, the effect is small
  - At low energy, the effect is smeared out by resolution limitations
- Since Δm^2 is uncertain up to a factor of 10, we need to be able to adjust E_ν by up to a factor of 10

Physics goals

- Test the neutrinos oscillation hypothesis, especially ν_μ->ν_e and ν_μ->ν_τ
  - Measure precisely parameters of oscillation: $|\Delta m^2_{32}|$ and $\sin^2 2\theta_{23}$
- Digits 3 and 2 means number of quantum states of neutrinos
- Each flavour (e,μ,τ) is a result of 3 quantum states with **<u>different</u>** mass

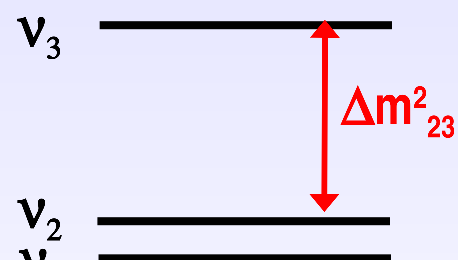
Physics goals

- In the MINOS experiment it is possible to measure the appearance probability:

ν_e appearance

$$\begin{pmatrix} e \\ \\ \\ \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{1} & U_{2} & U_{3} \\ U_{1} & U_{2} & U_{3} \end{pmatrix} \begin{pmatrix} 1 \\ 2 \\ 3 \end{pmatrix}$$

ν_μ disappearance

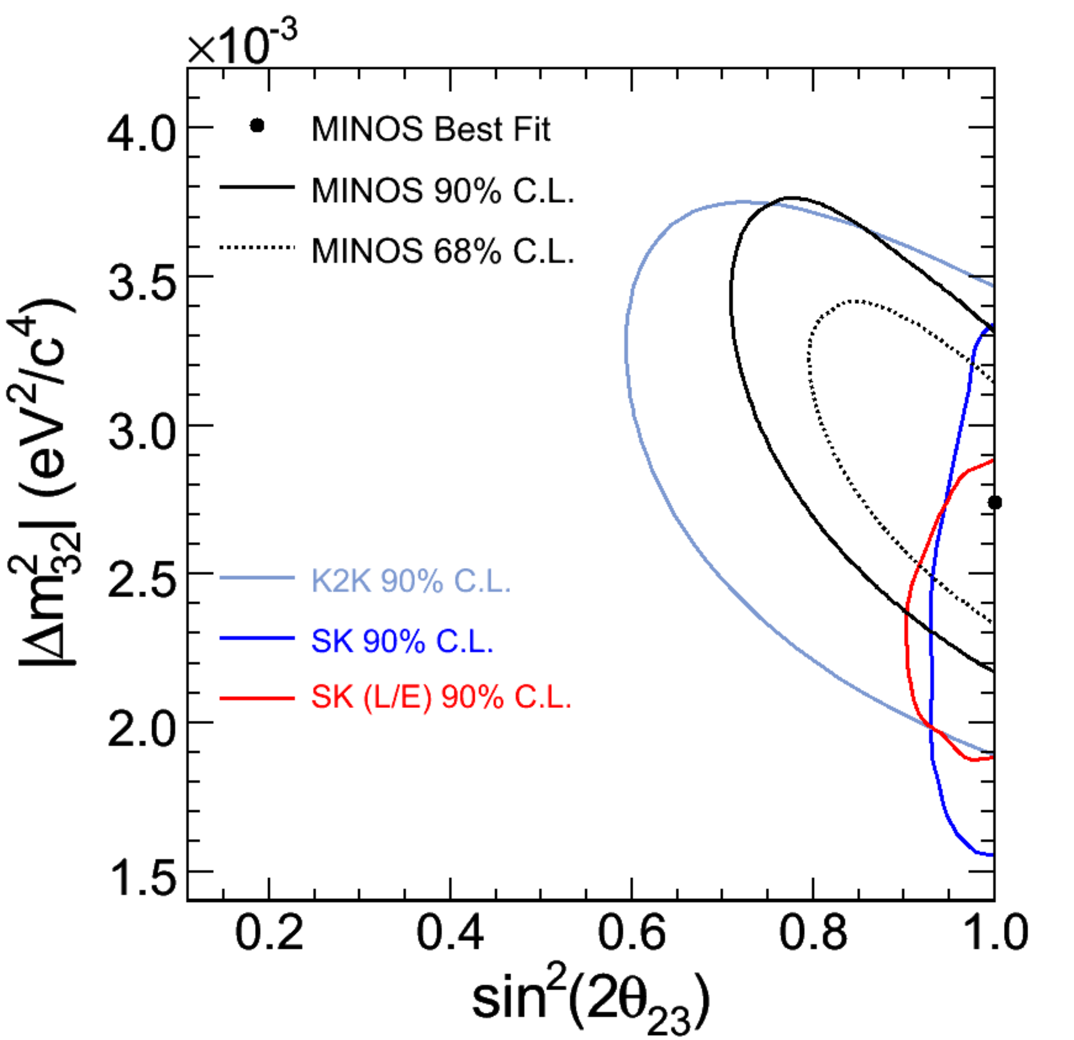


$$P(\ \rightarrow\ ) = 1 - \sin^2 2\ \sin^2(1.267$$

$$\sin^2 2\ = 4U^2_{3}(1 - U^2_{3})$$

$$\text{if}\, m^2_{23} >> m^2_{12}$$

Actual values of parameters



- Fit includes penalty terms for three main systematic uncertainties
- Fit is constrained to physical region: $\sin^2(2\theta_{23}) \leq 1$

$$| m^2_{32}| = 2.74^{+0.44}_{-0.26} \times 10^{-3}\,\mathrm{eV}^2$$

$$\sin^2 2\ _{23} = 1.00_{-0.13}$$

MINOS Experiment

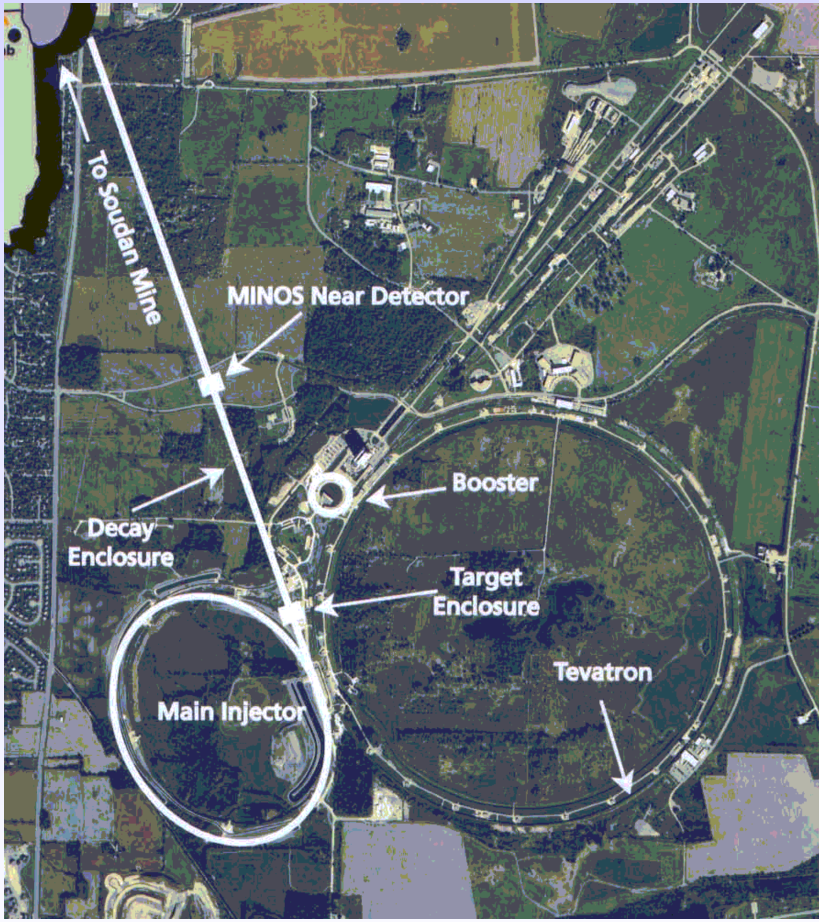
First informations

- Minos - mythical Greek king of Creta, son of Zeus and Europe
- Main Injector Neutrino Oscillation Search- a long-baseline neutrino oscillation experiment
  - Two detectors and the base in FermiLab
  - The MINOS experiment measures the neutrino oscillation between the detectors
- Experiment started in 2005
- First data at the beginning of 2006

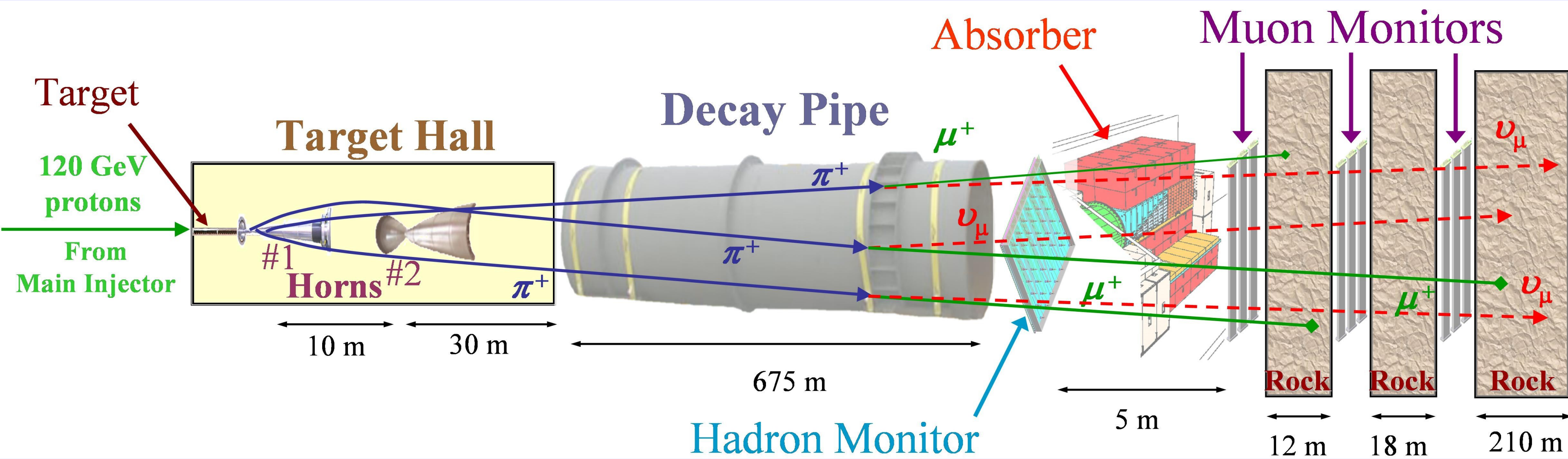
Beam production

Production of the beam

- FermiLab National Laboratory near Chicago
- 120 GeV protons from the Main Injector accelerator
- one pulse is 1.867 second long
- $4x10^{13}$ protons/pulse
- after that the protons beam is focuses on the target

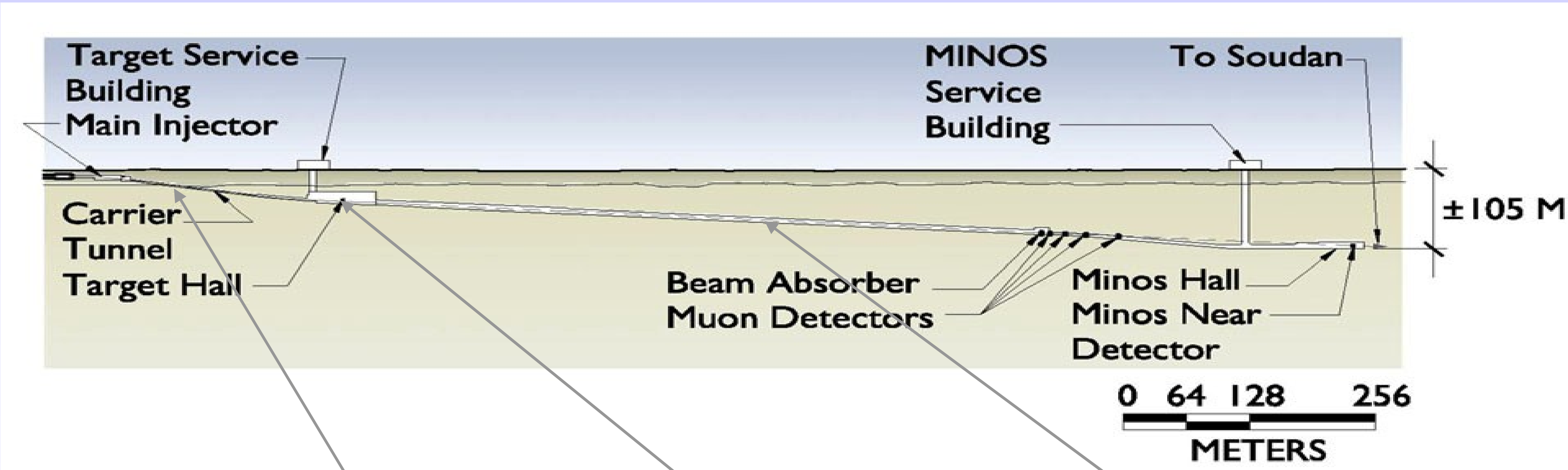


Producing the neutrino beam - the scheme



Proton beam collides with a graphite target. As a result there are many short-life particles (pions, kaons, etc.), which decay into muons. Muons decay into muon neutrinos. In such a way is the neutrino beam formed.

The NuMI beamline



Primary proton line

Target hall

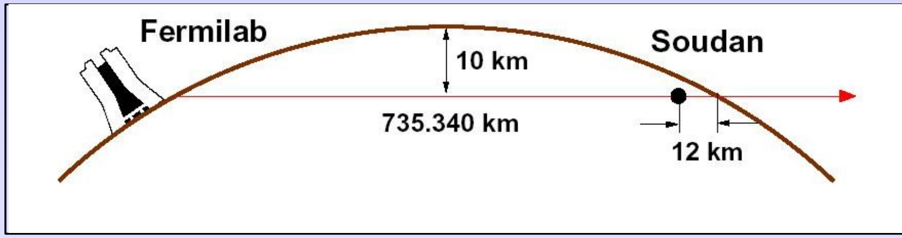
Decay pipe

MINOS long-baseline experiment detectors

MINOS Near Detector (ND)

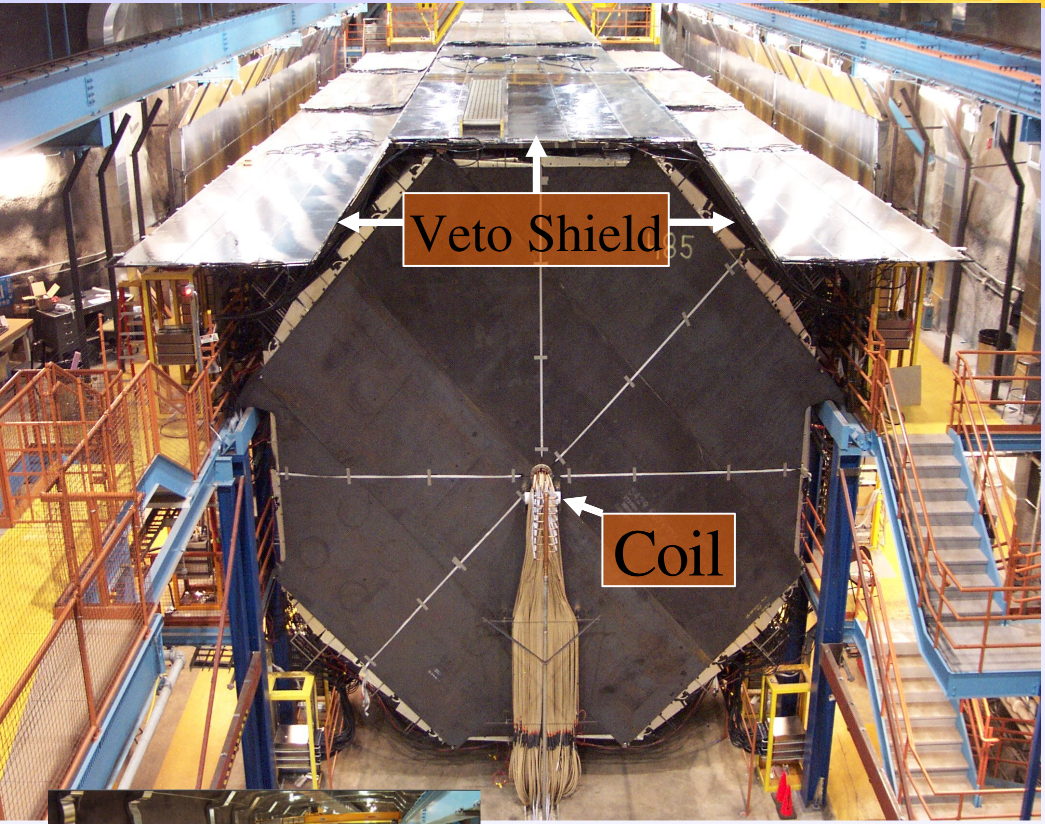
- Located at FNAL
- 1040m from target
- 103m underground
- 980 ton mass
- 3.8m x 4.8m x 16m
- 282 steel + 153 scintillator planes

Why „long-baseline” experiment?



- neutrino beam travels from the near detector to the far detector in Soudan Mine (Minnesota)

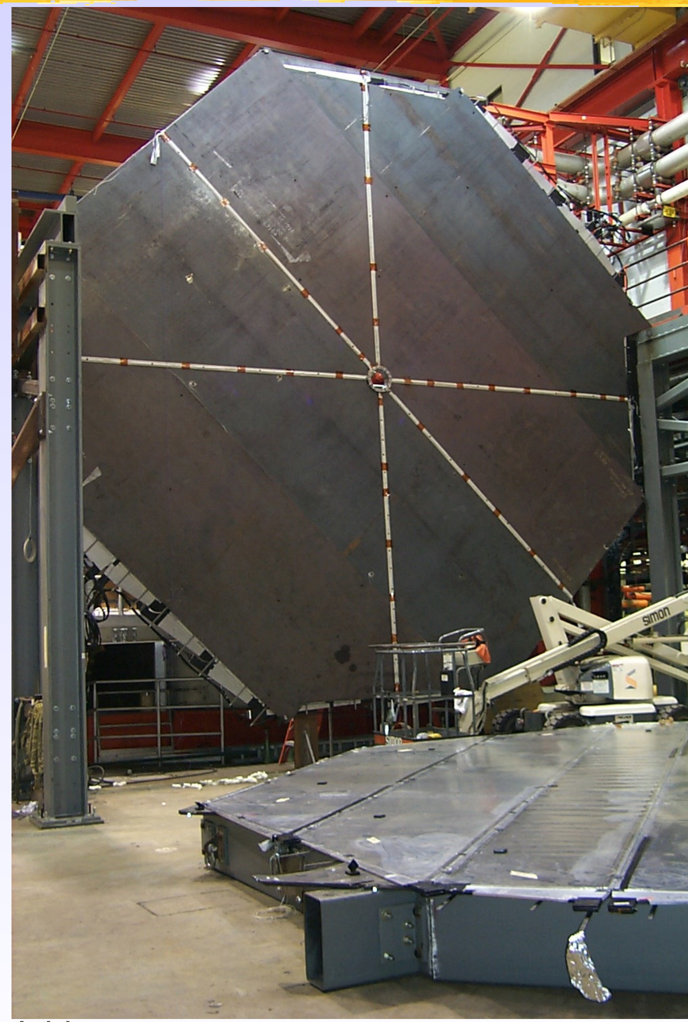
MINOS Far Detector (FD)



- 735 km from target
- 705m underground
- 5.4 kton mass
- 8m x 8m x 30m
- 484 scintillator planes
- Veto shield for cosmic ray rejection in atmospheric ν analysis
- GPS time stamping to synchronize FD to ND
- Main Injector spill times sent to FD for beam trigger

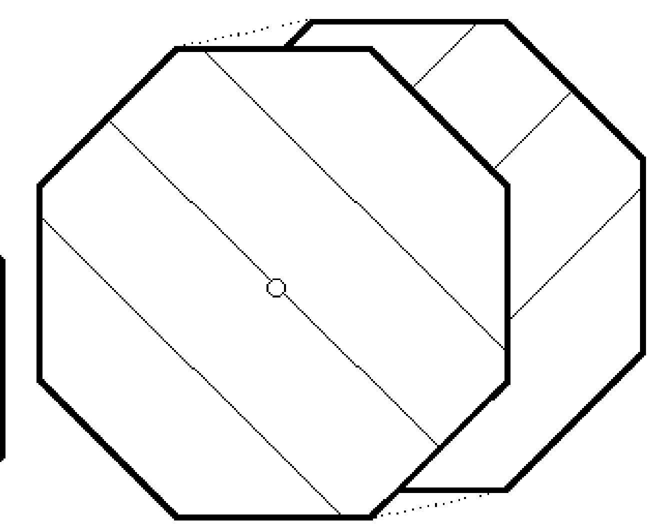
Building the FD

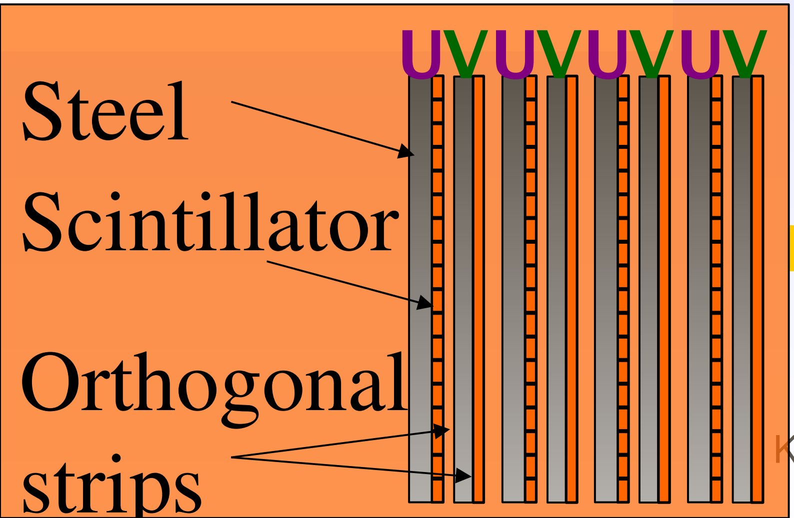
Built ‘99
Summer
at
Fermilab



Detectors' technology

Detectors construction

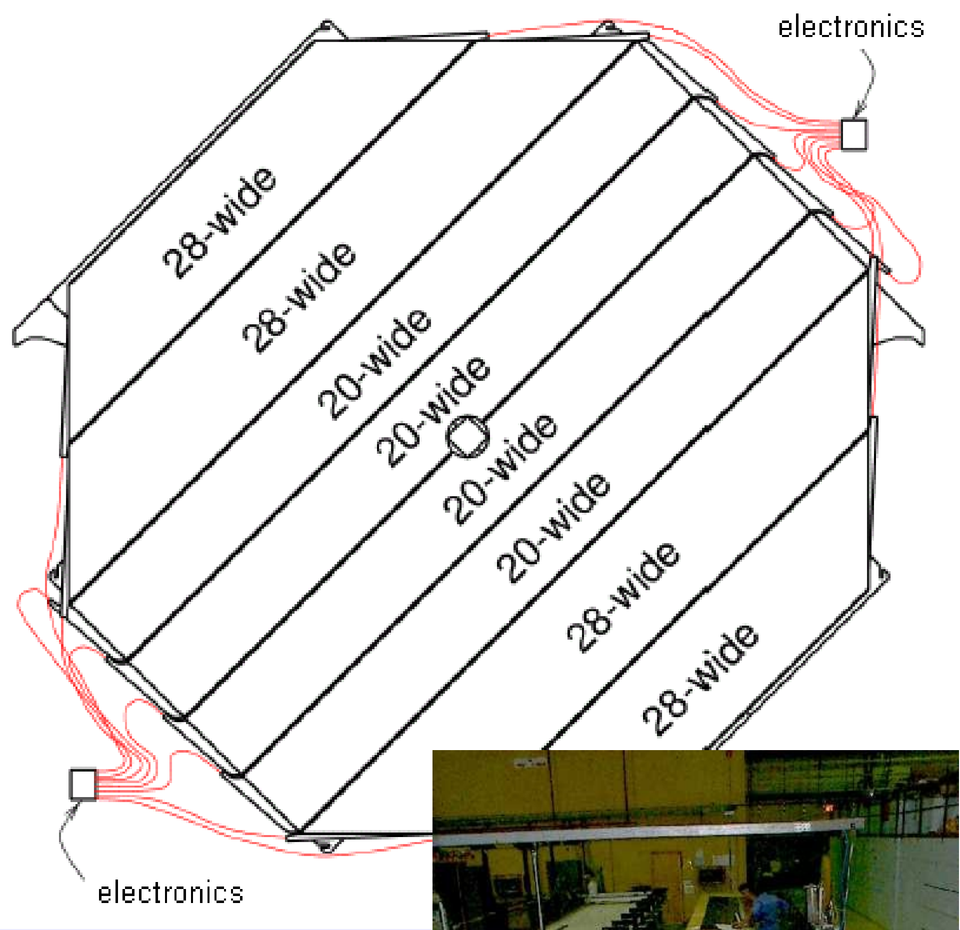


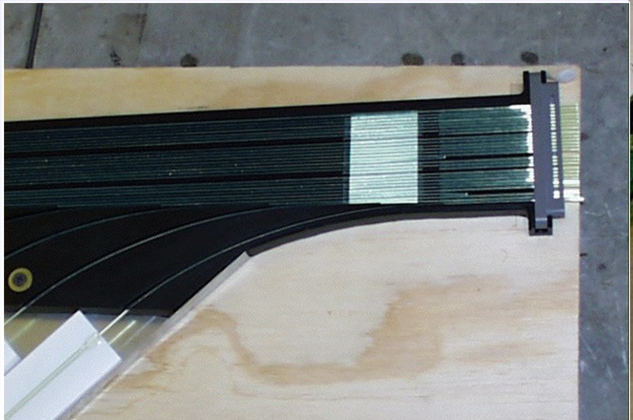


- Near & Far detectors are functionally identical
- They share the same basic detector technology and granularity:
  - Iron/Scintillator tracking calorimeters
  - 2.54cm thick magnetized steel planes <B> = 1.2T
  - 1cm thick scintillator planes
  - Alternate planes rotated by $\pm 90^{o}$ (U,V)
- thanks to this rotate we can find a track of the particle

FD's scintillator plane structure

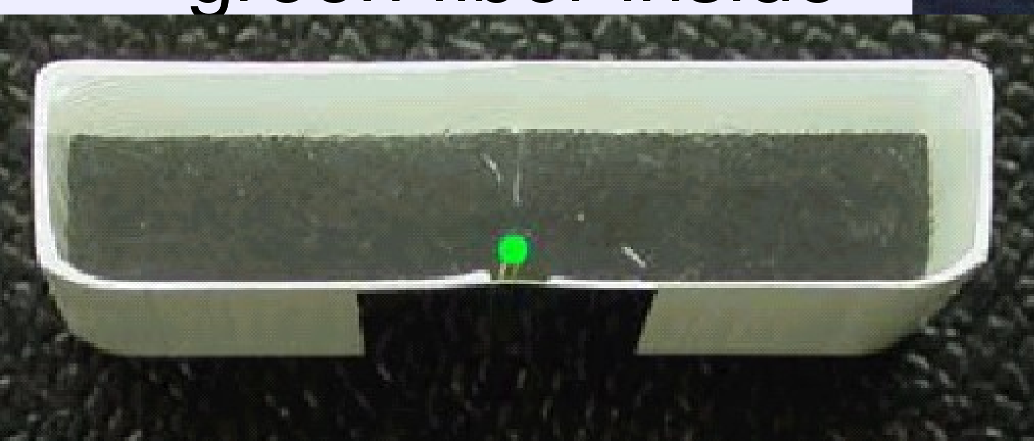
- 192 scintillator strips by plane
- scintillator strips are parallel to each other
- strips are connected to the electronics system by fibers



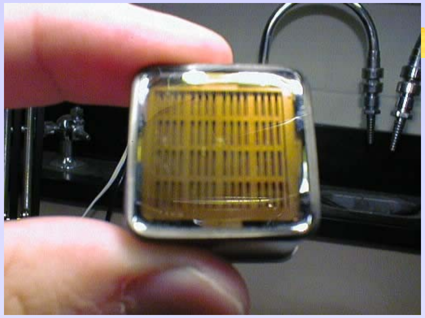


Scintillator strip

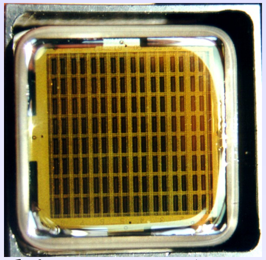
- polystyrene in TiO_2
- 1 cm thick
- 4,1 cm wide
- max. lenght: 8m
- green fiber inside



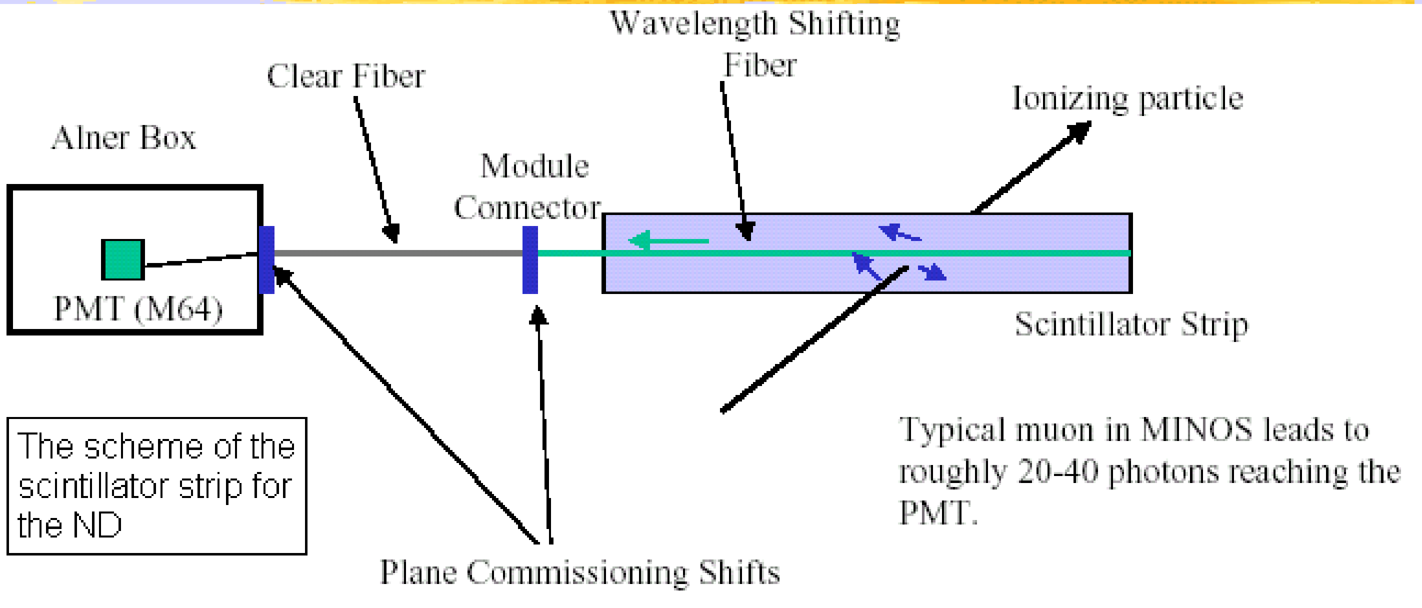
Signal from the scintillator



M16 PMT (FD)



M64 PMT (ND)

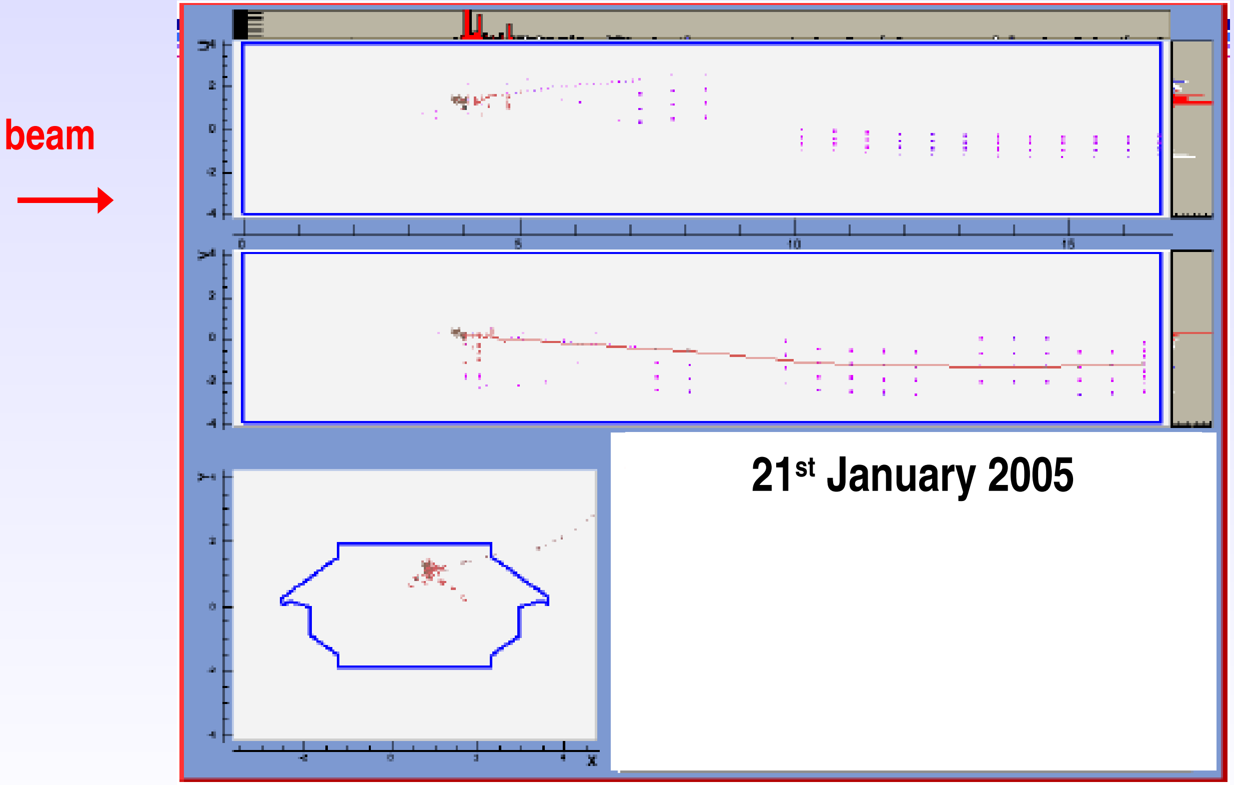


- ionizing particle (muon, electron, etc.) makes photons, which are transported by wavelenght shifting fiber.
- optical readout with multi-anode PMTs (photomultiplier)
- in the next step the signal is analized by computer

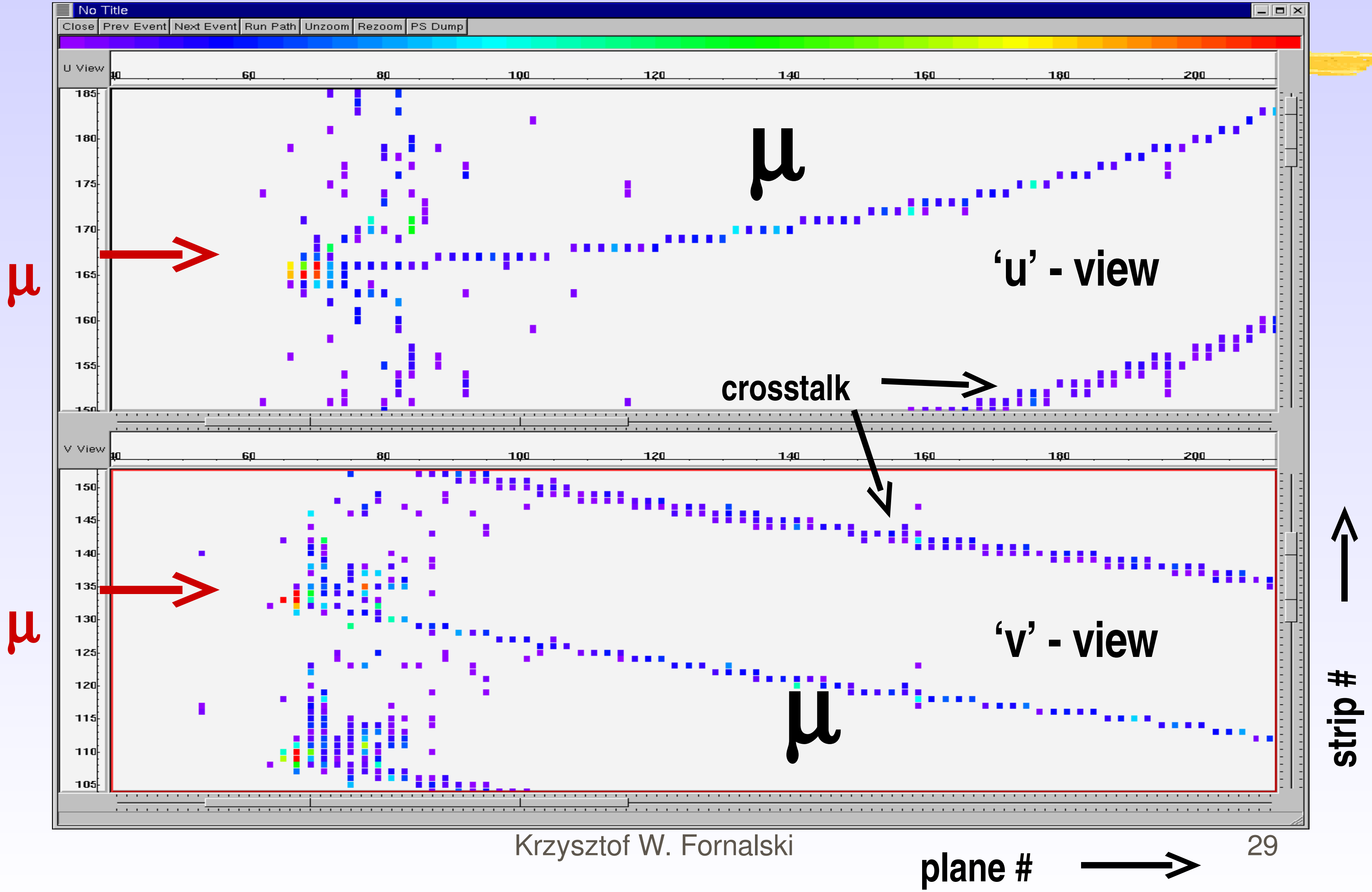
Computer's analyze

How you can see the signal

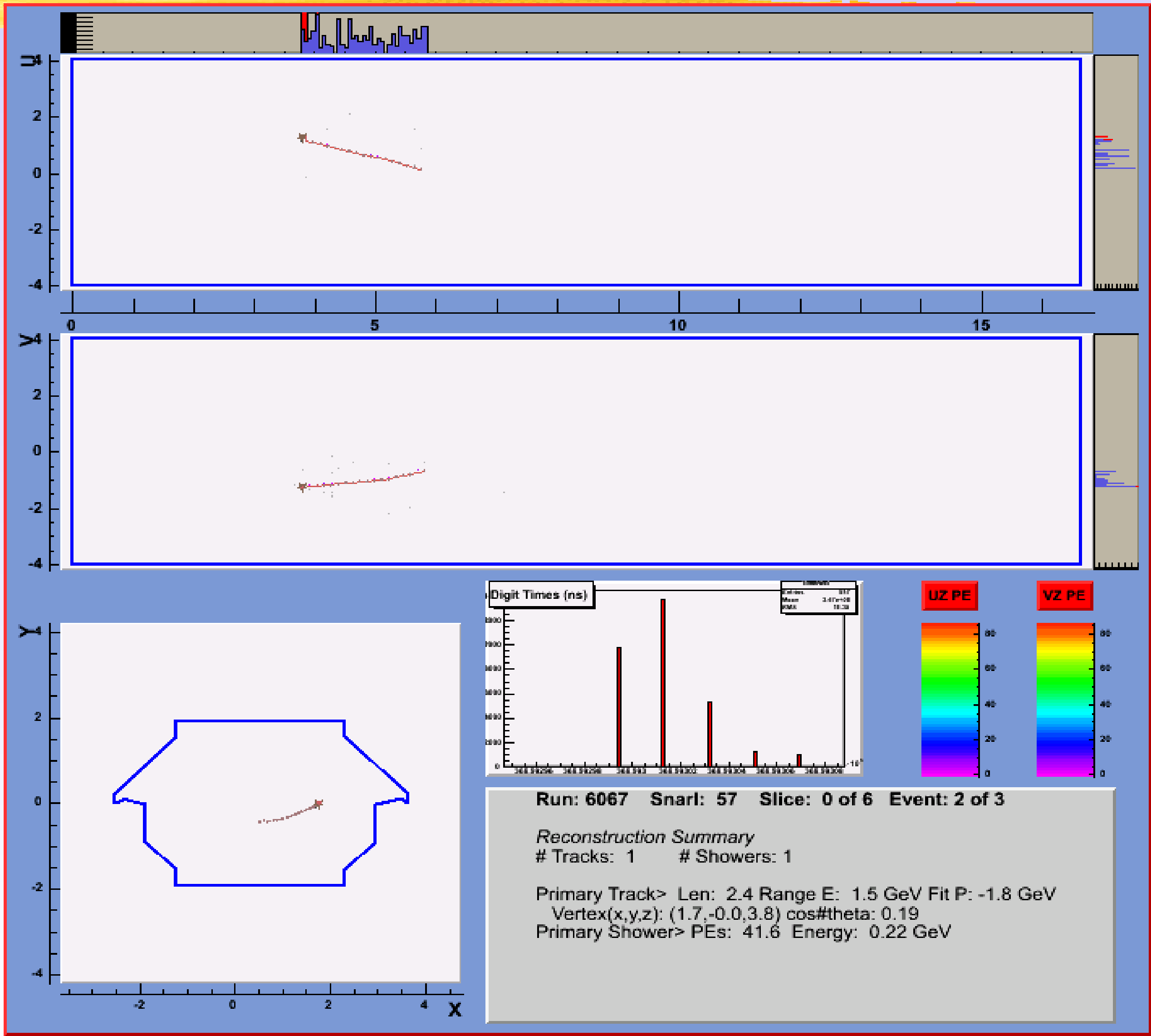
On the picture you can see track of the muon in ND as a result of neutrino interaction. Each point is a signal from one scintillator strip



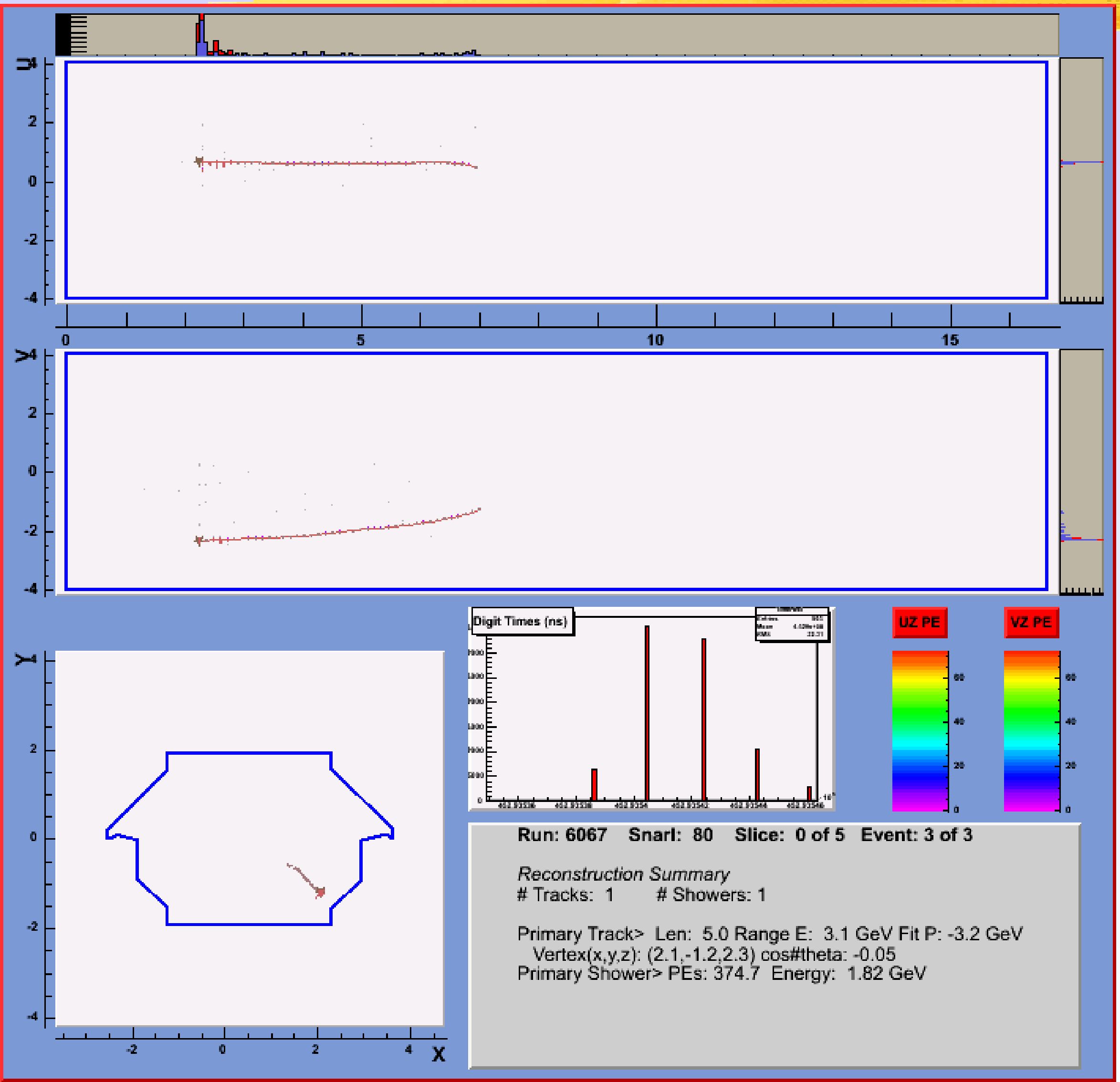
How you can see the signal



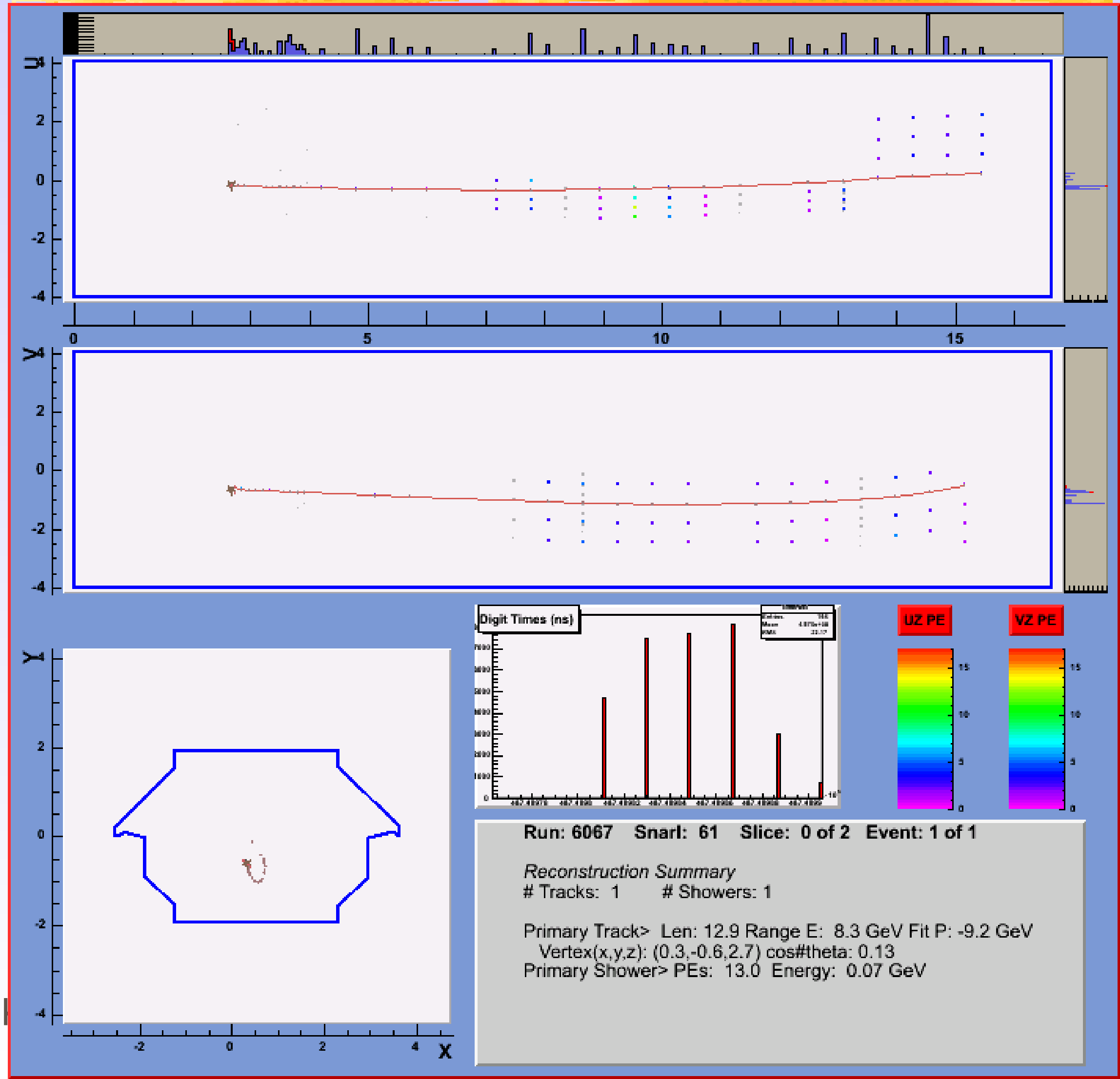
ND - low energy example



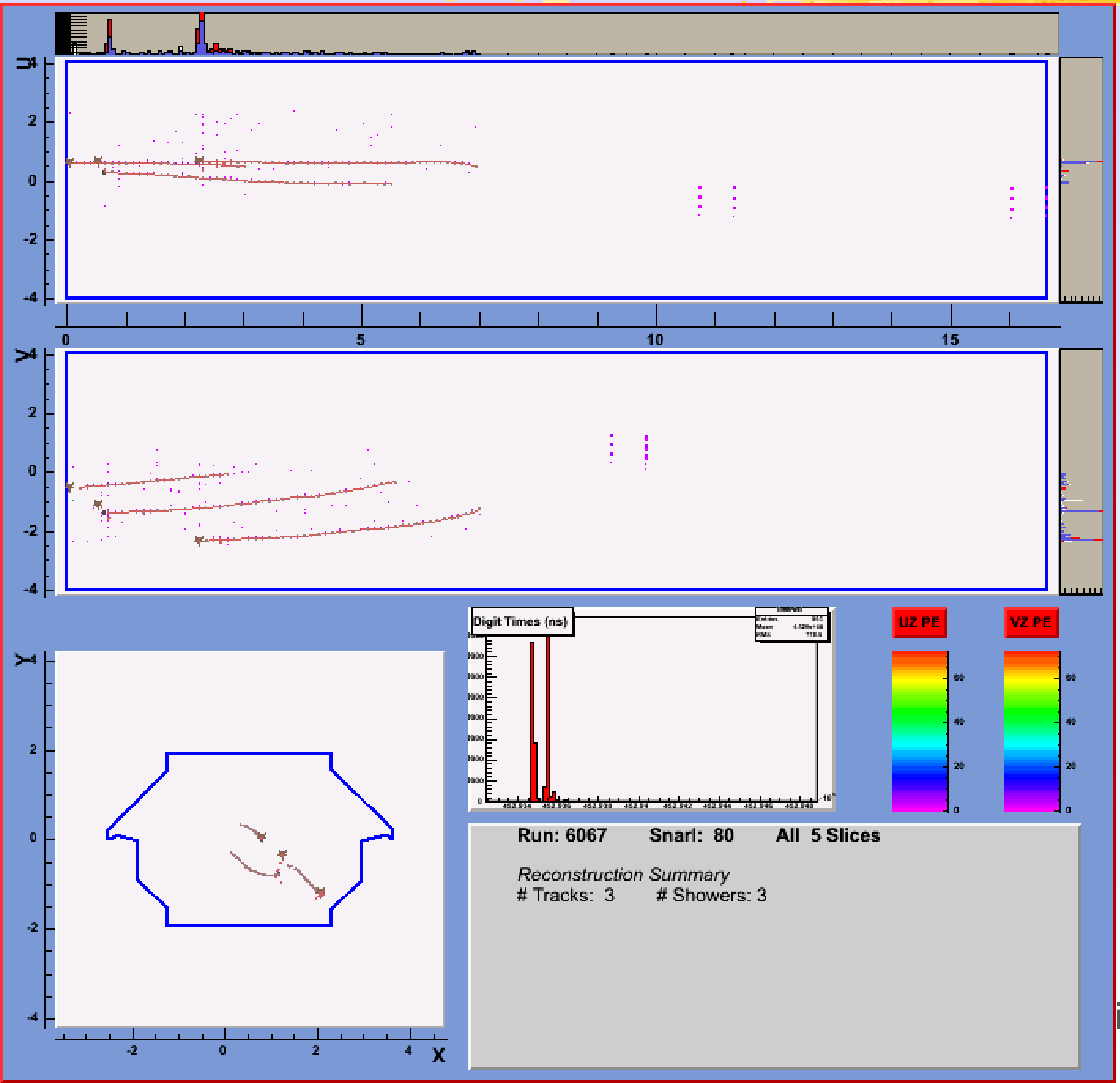
ND - medium energy example



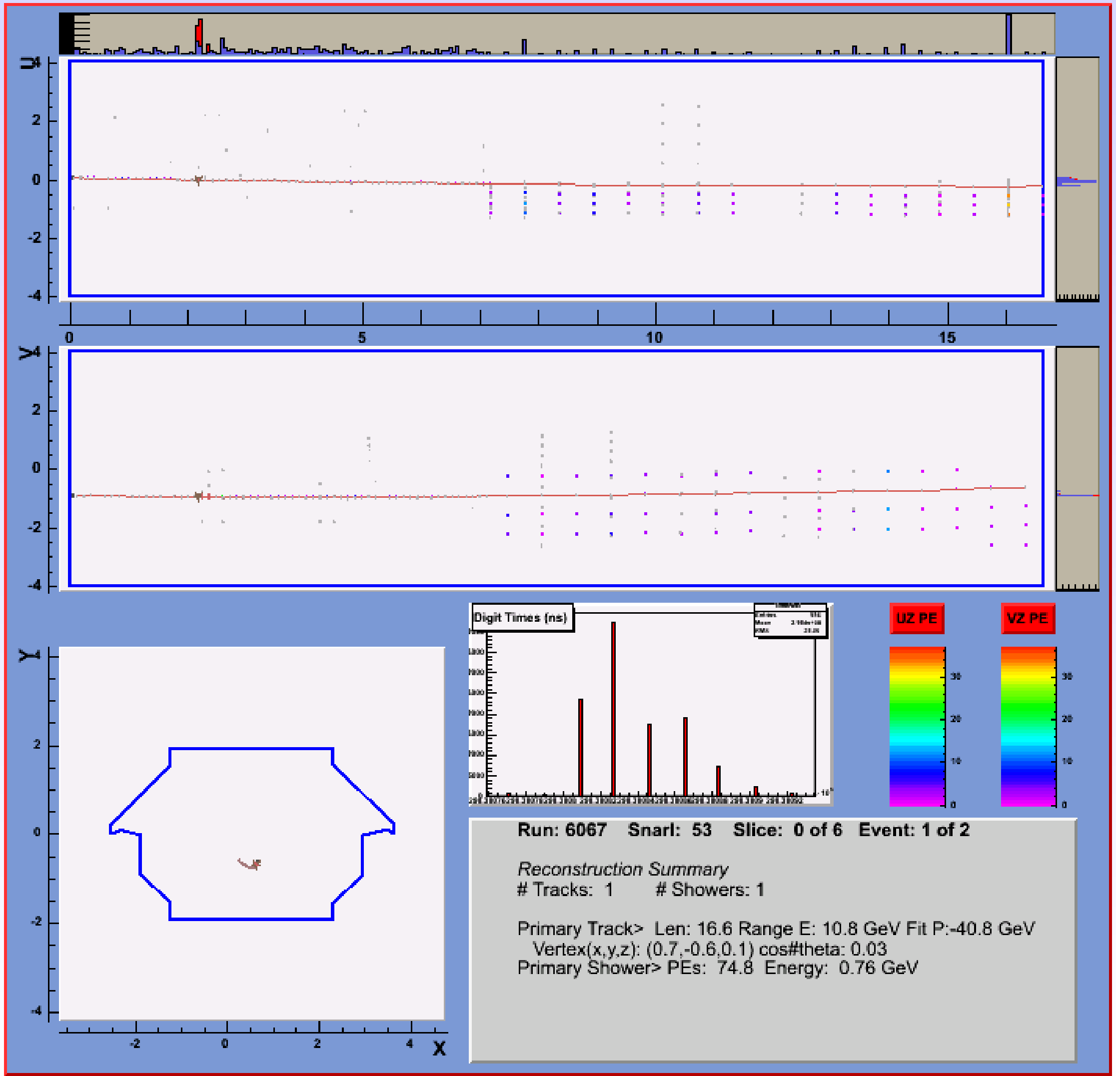
ND - high energy example



ND - multievent example

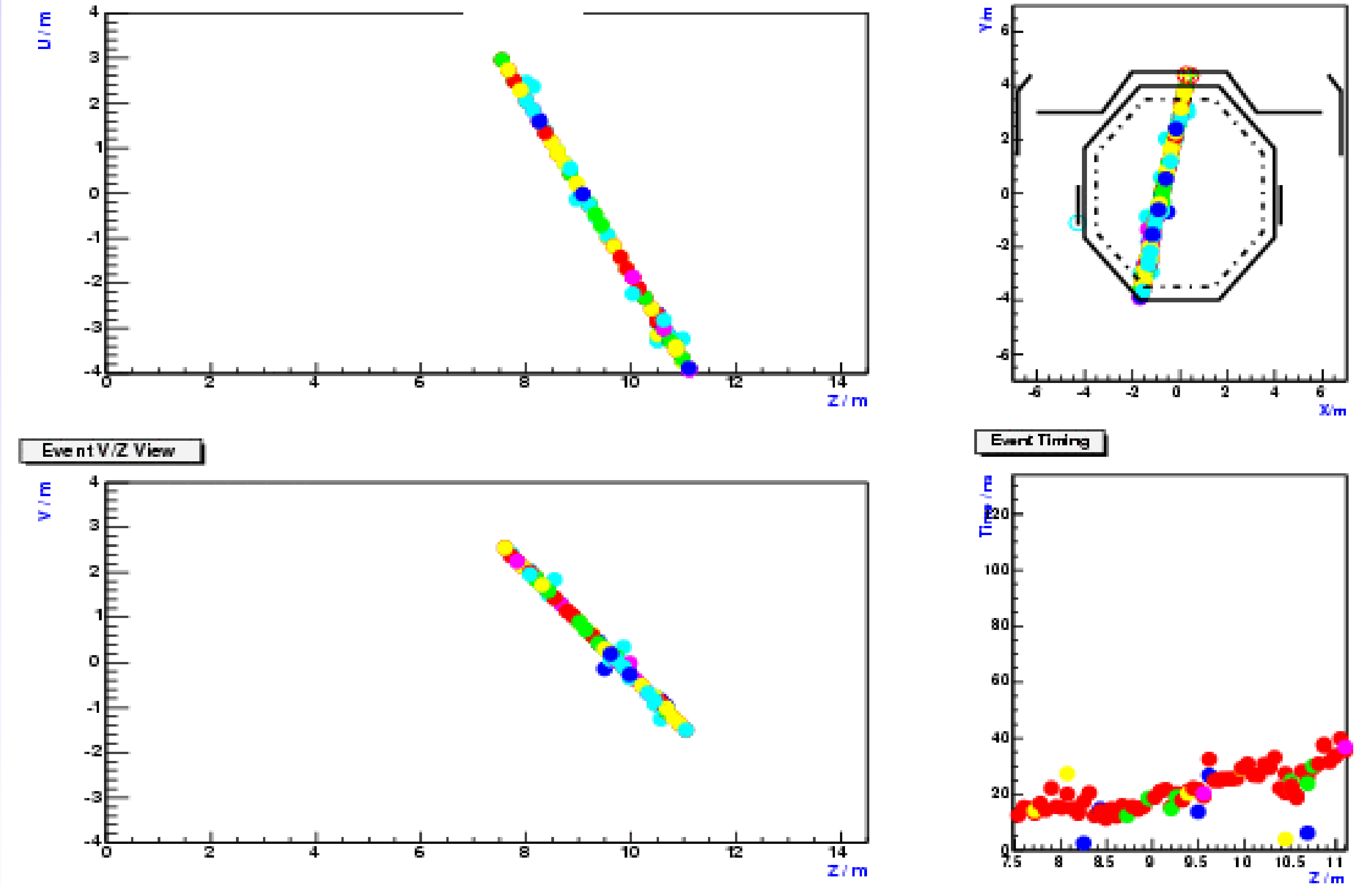


ND - muon from the rock



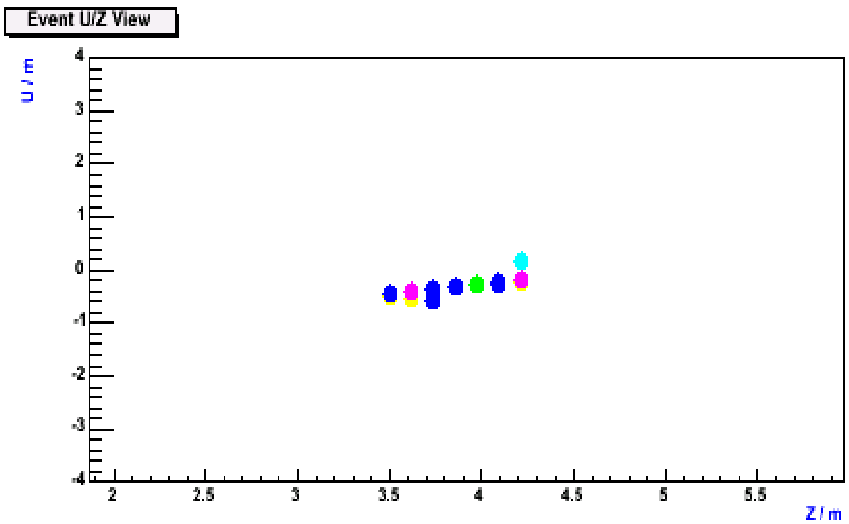
FD - cosmic muon (simulation MonteCarlo)

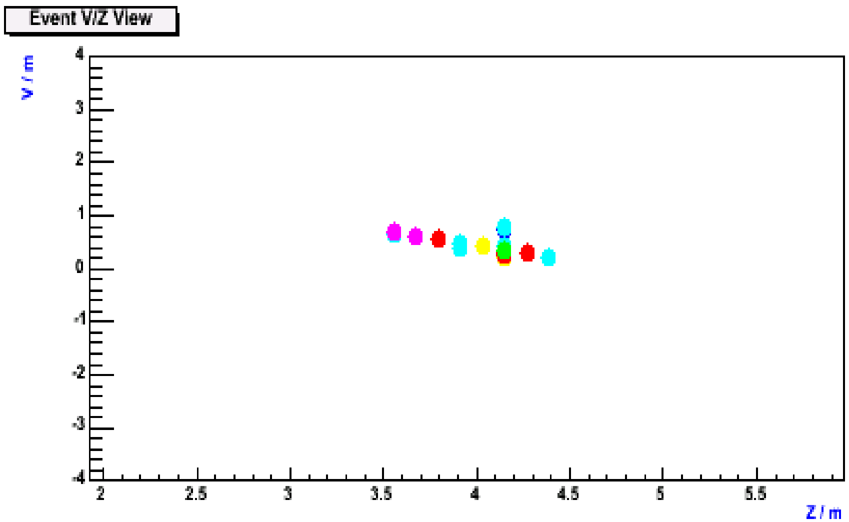
Reconstructed front view

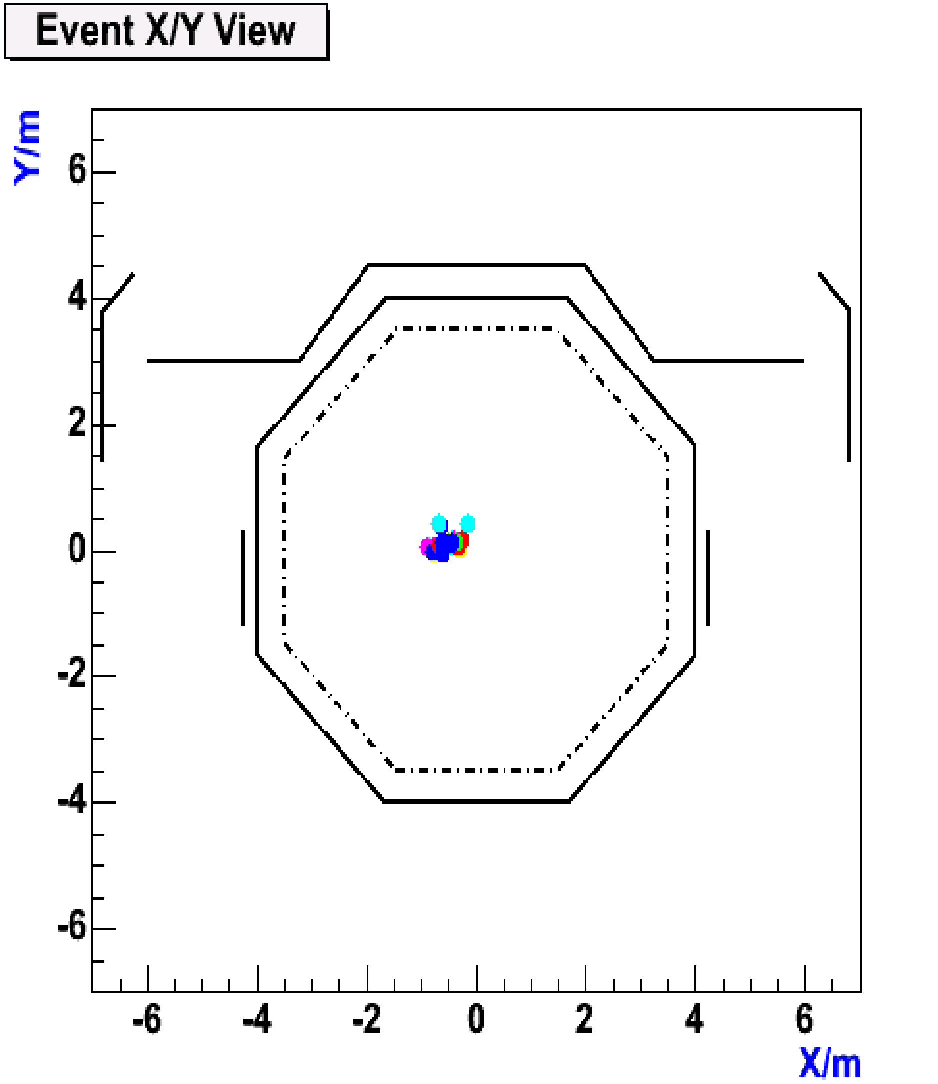


Timing

FD - low energy example

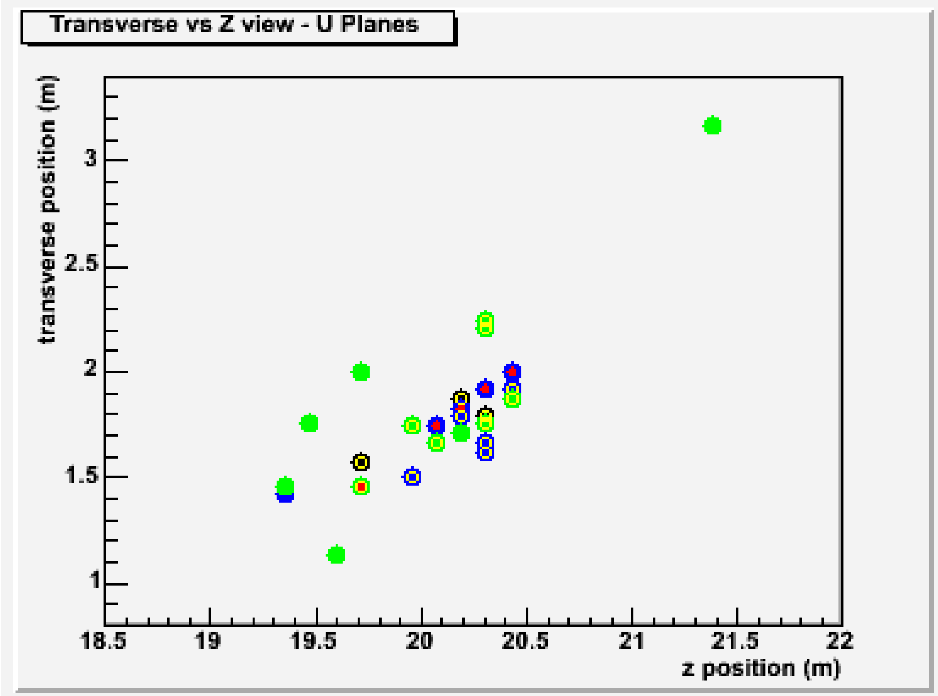


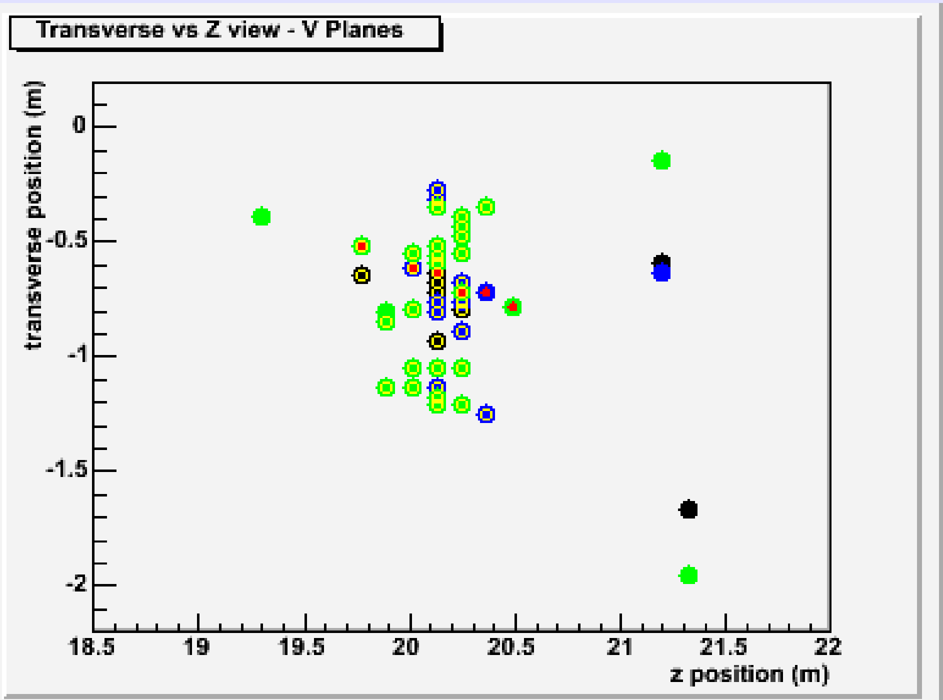




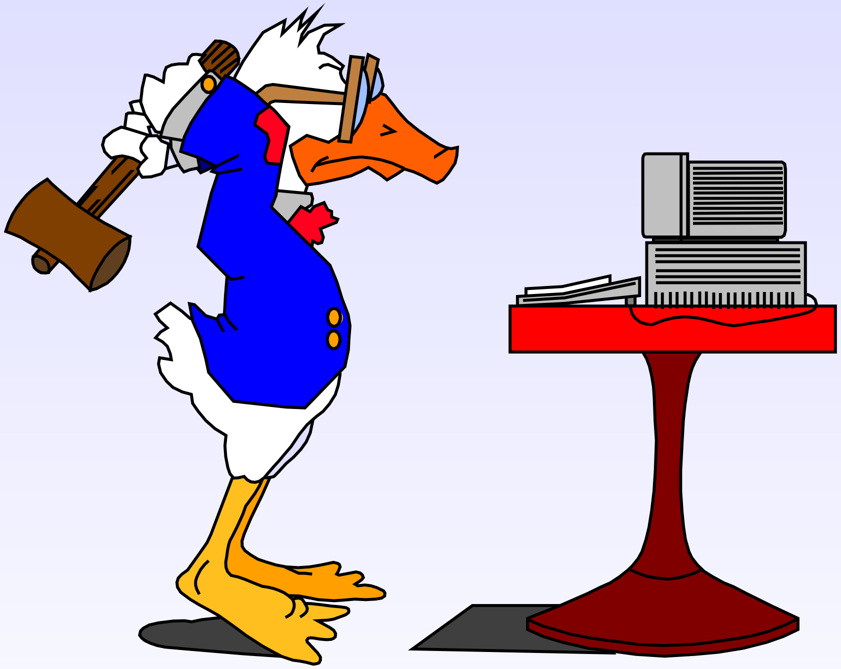
FD example

You can see electromagnetic shower- the result of ν_e interaction



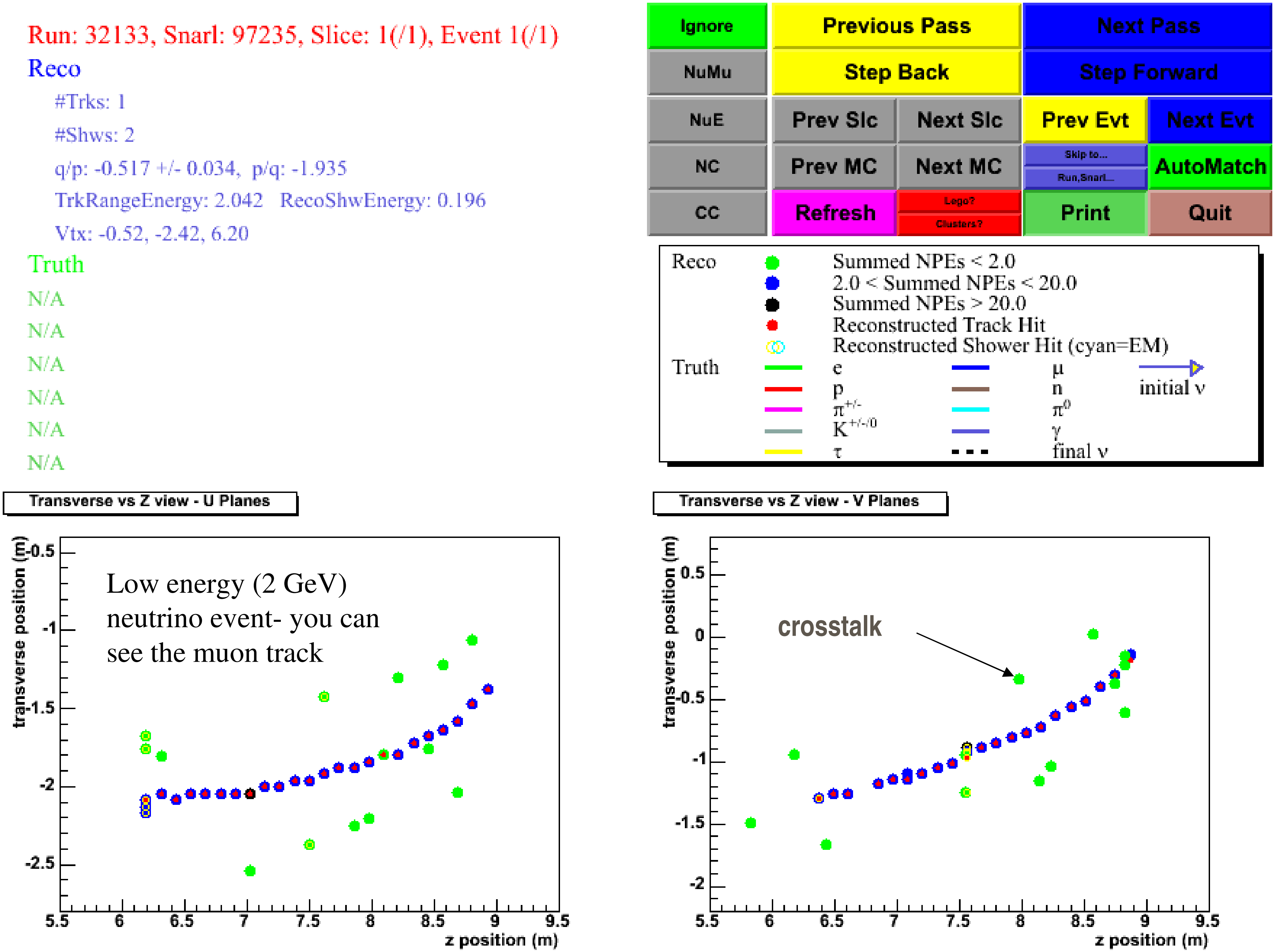


What can I do?



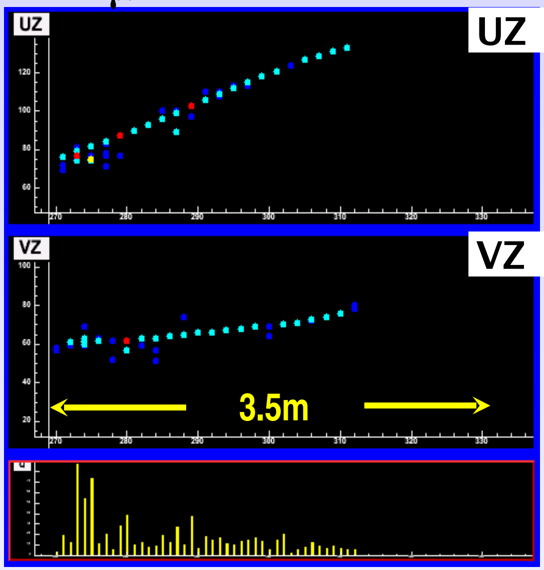
My postgraduate work

- study the theory
- learn the software in ROOT
- make some new software
- use the terabytes of data and MonteCarlo
- select the neutral current (NC) and charged current (CC) events
- estimate and compare the oscillation parameters

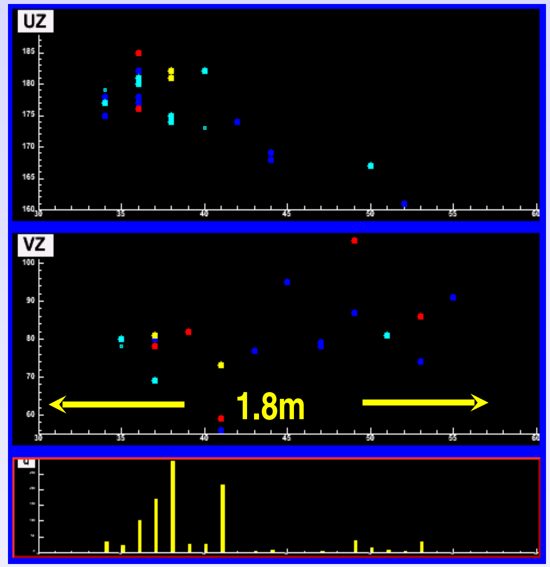

Run: 32133, Snarl: 97235, Slice: 1(/1), Event 1(/1)
Reco
#Trks: 1
#Shws: 2
q/p: -0.517 +/- 0.034, p/q: -1.935
TrkRangeEnergy: 2.042 RecoShwEnergy: 0.196
Vtx: -0.52, -2.42, 6.20
Truth
N/A
N/A
N/A
N/A
N/A
N/A
Ignore
Previous Pass
Next Pass
NuMu
Step Back
Step Forward
NuE
Prev Slc
Next Slc
Prev Evt
Next Evt
NC
Prev MC
Next MC
Skip to...
Run,Snarl...
AutoMatch
CC
Refresh
Lego?
Clusters?
Print
Quit
Reco
Summed NPEs < 2.0
2.0 < Summed NPEs < 20.0
Summed NPEs > 20.0
Reconstructed Track Hit
Reconstructed Shower Hit (cyan=EM)
Truth
e
μ
initial ν
p
n
π+/-
π0
K+/-/0
γ
τ
final ν
Transverse vs Z view - U Planes
Low energy (2 GeV) neutrino event- you can see the muon track
transverse position (m)
z position (m)
Transverse vs Z view - V Planes
crosstalk
transverse position (m)
z position (m)

Neutral Current or Charged Current?

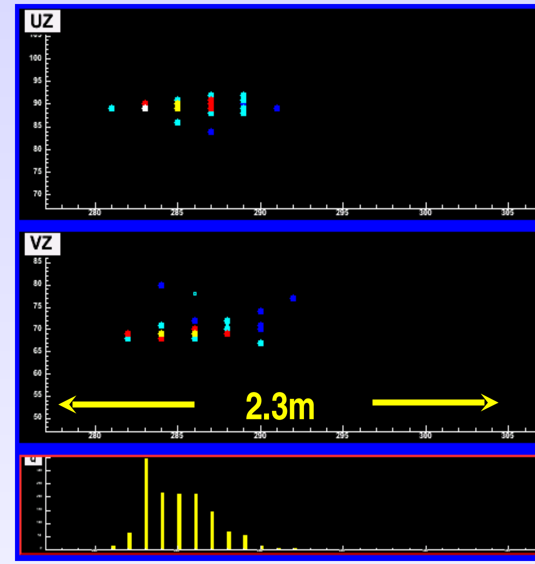
ν_μ CC Event



NC Event



ν_e CC Event



- We have μ with long μ track+ hadronic shower

- short event, often diffuse
- the neutrino is “deflected”!

- short, with typical EM shower profile
- no μ !

Overview of the Oscillation Measurement

- In order to perform the oscillation analysis, we need to predict the Far detector unoscillated true neutrino spectrum.
- The goal is to perform this procedure in such a way that we are as insensitive as possible to uncertainties related to beam modelling and cross-sections built-in to our nominal Monte Carlo.
- This is exactly the purpose of the Near detector, and therefore we directly use the Near detector data to perform the extrapolation, using our Monte Carlo to provide necessary corrections due to energy smearing and acceptance.

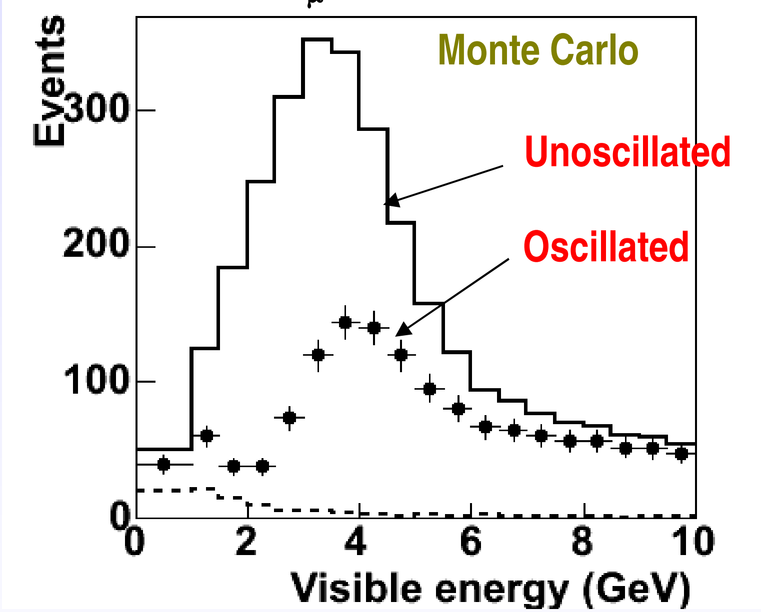
Example of a ν_μ disappearance measurement

- Look for a deficit of ν_μ events at FD

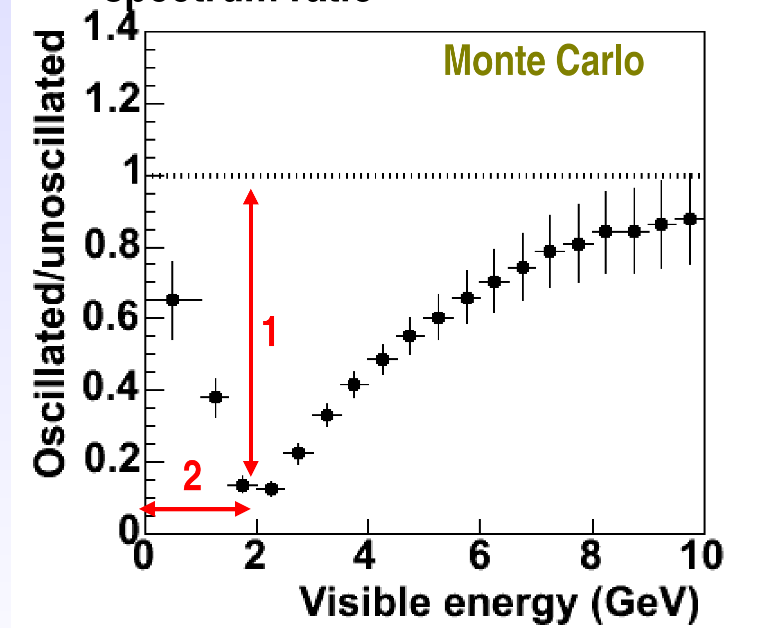
$$P(\quad \rightarrow \quad) = 1 - \sin^2 2 \quad \sin^2(1.267 \quad m^2 \, L/E)$$

1 2

ν_μ spectrum

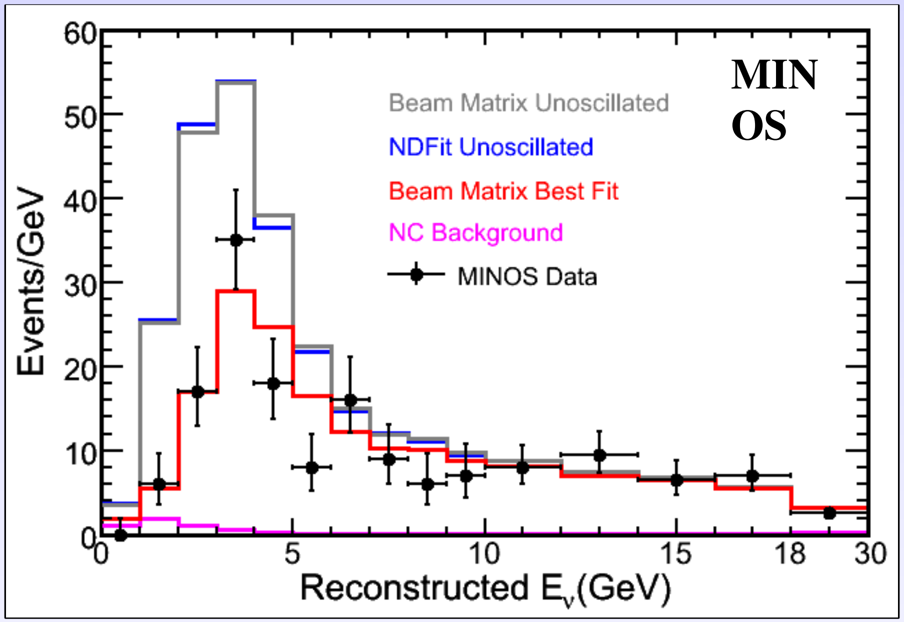


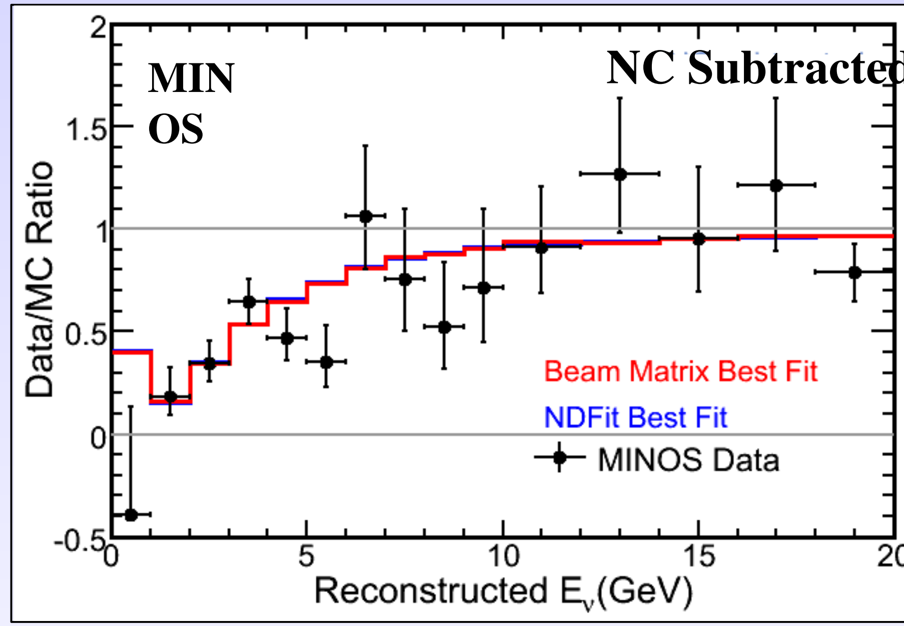
spectrum ratio



MINOS Best-Fit Spectrum

- Best-fit spectrum for 1.27×10^{20} POT





$$|\ m_{32}^2| = 2.74^{+0.44}_{-0.26} (\text{stat + syst}) \times 10^{-3}\ \text{eV}^2$$

$$\sin^2 2\ _{23} = 1.00_{-0.13} (\text{stat+ syst})$$

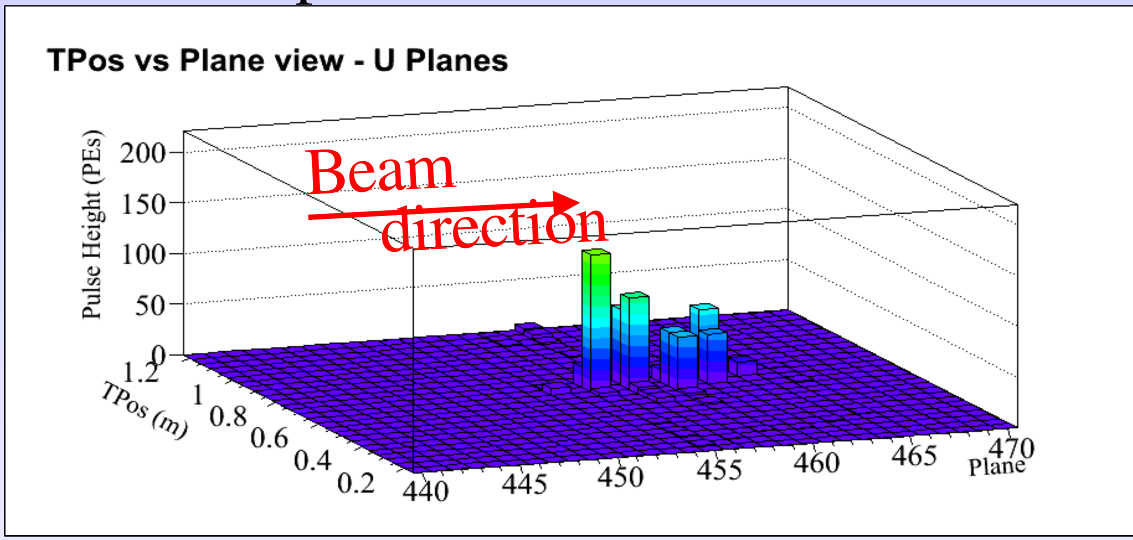
$$\text{Normalization} = 0.98$$

Measurement errors are 1

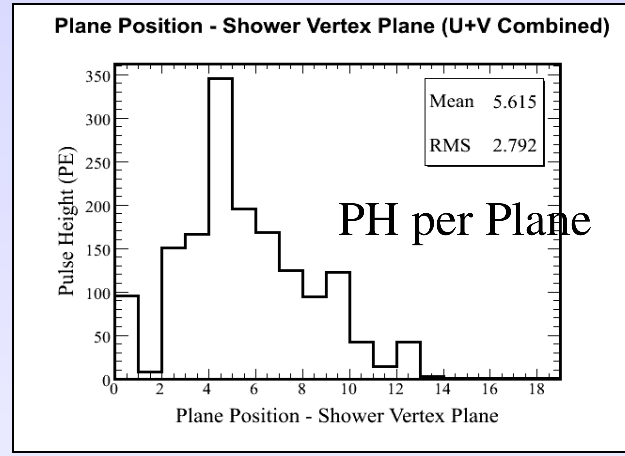
$$^2 = \sum_{i=1}^{\text{nbins}} \left[2 \left(e_i - o_i \right) + 2 o_i \ln \left(o_i / e_i \right) \right] + \sum_{j=1}^{\text{nsys}} s_j^2 / \ _{s_j}^2$$

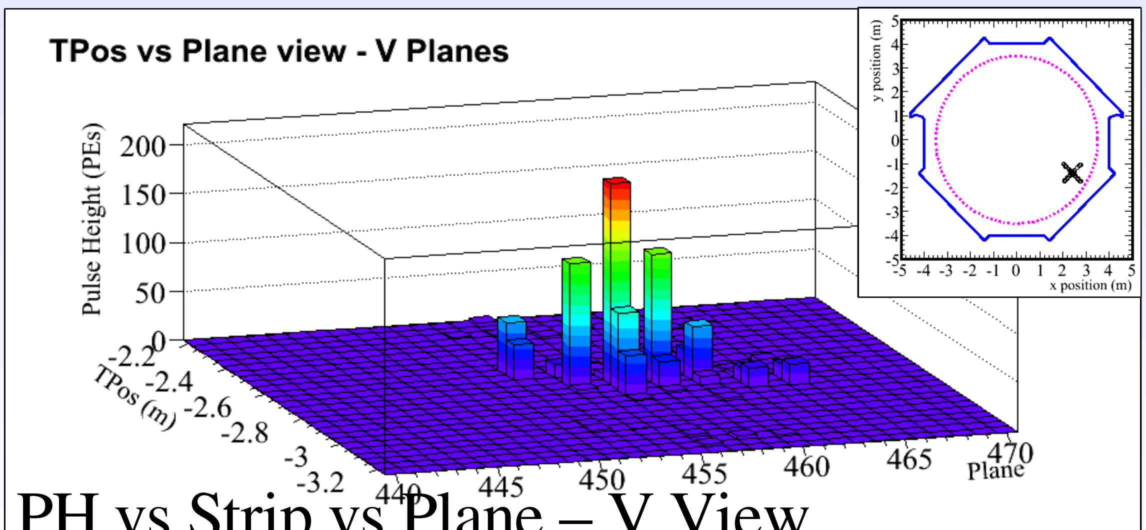
Candidate FD ν_e Event

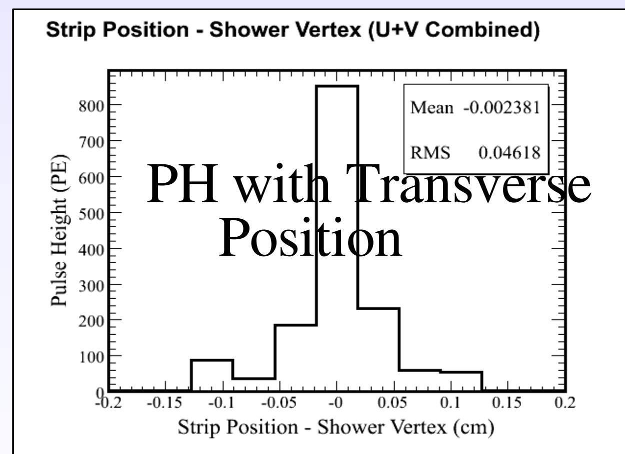
PH vs Strip vs Plane – U View



Run: 32617 Snarl: 105322
Reco Shower Energy: 8.7 GeV
ANN PID: 0.99







PH vs Strip vs Plane – V View

Summary

- MINOS is a new neutrino experiment in USA
- the main goal is to test oscillation hypothesis and measure the oscillation parameters
- it will give a new physics
- thanks to that I will get a new knowledge
- and the MSc...

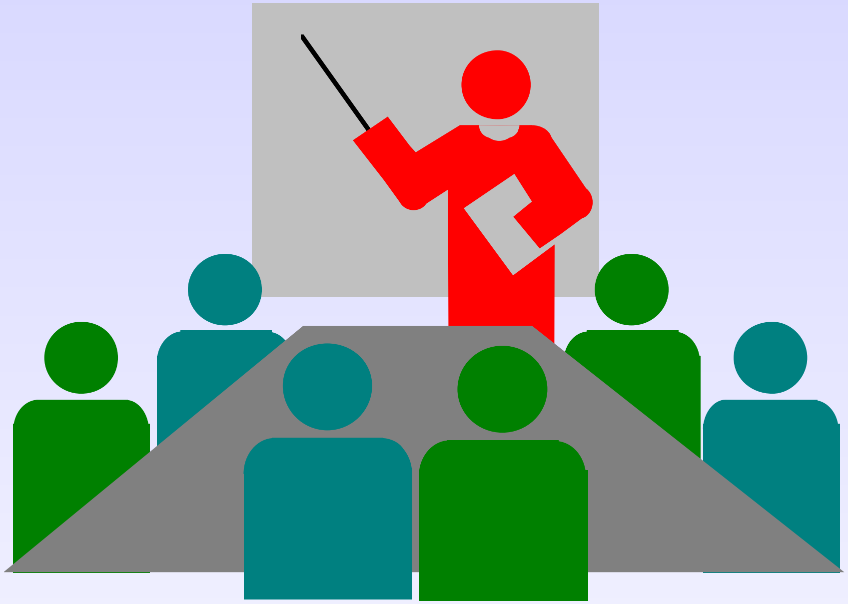
And after that...

References

- www-numi.fnal.gov

- **especially**:
- www-numi.fnal.gov/talks/results093e18.html
- www-numi.fnal.gov/talks/results127e18.html
- beaker.astro.indiana.edu/brebel/powerpoint/minos_overview.ppt

THANK YOU!



www.fuw.edu.pl/~minos

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