Neutrinos from the NuMI beam line in the MiniBooNE detector

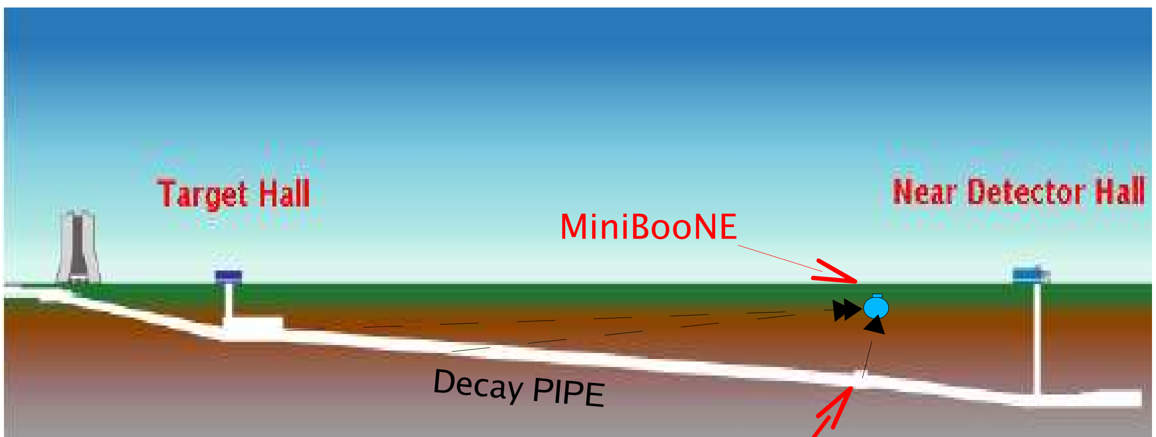
Alexis A. Aguilar-Arévalo
Columbia University
for the MiniBooNE/MINOS Collaborations

October 24, 2005
PANIC

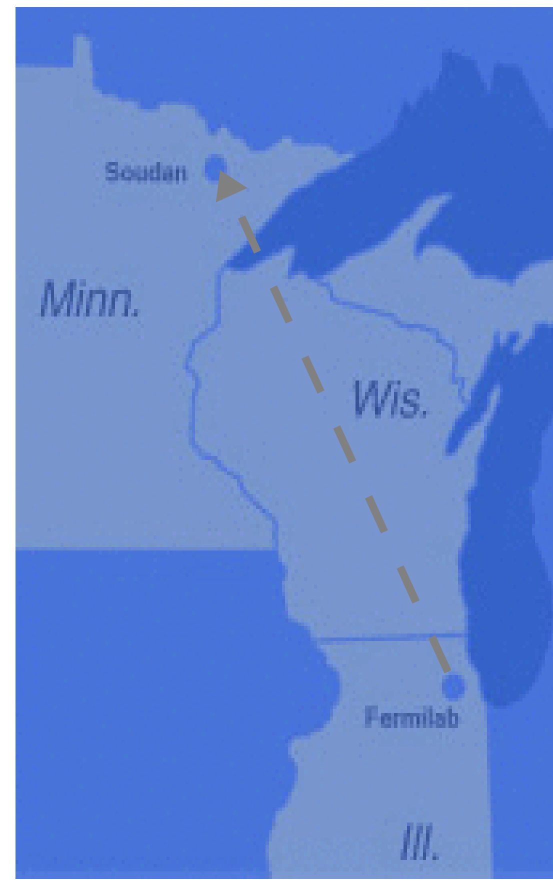
The NuMI beam line

- NuMI beam: provides neutrinos for the MINOS experiment studying neutrino oscillations in the atmospheric oscillations regime (Super-K).

- Other experiments will be users of this beam line (NOνA, MINERνA). MiniBooNE is “on the way” of NuMI neutrinos (slightly off axis) almost right above the NuMI beam absorber (DUMP), and has become the second user of this beam.



NuMI beam line



Neutrinos reach MiniBooNE from:

- Mesons decaying in flight along the NuMI DECAY PIPE.
- Mesons produced by protons hitting the BEAM DUMP, stopping and decaying isotropically.

Some characteristics of the NuMI beam of interest to us

- 120 GeV protons extracted from the Main Injector (kicker magnets)
  - 5-6 batches over a ~ 8-9 μs spill
  - Running with intensities up to 2 .7x 10^{13} protons /spill

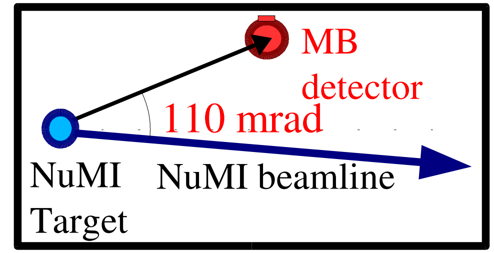
- Protons interact with 95 cm long graphite target
- Mesons produced focused by 2-horn system, decay along pipe
- Target position is varied to modify ν energy spectrum

- NuMI beamline tilted "downwards" at about 58 mrad (pointing to Soudan, MI)
- MiniBooNE at ~83 m perp. distance from NuMI beamline, Longitudinal distance along beamline ~745 m

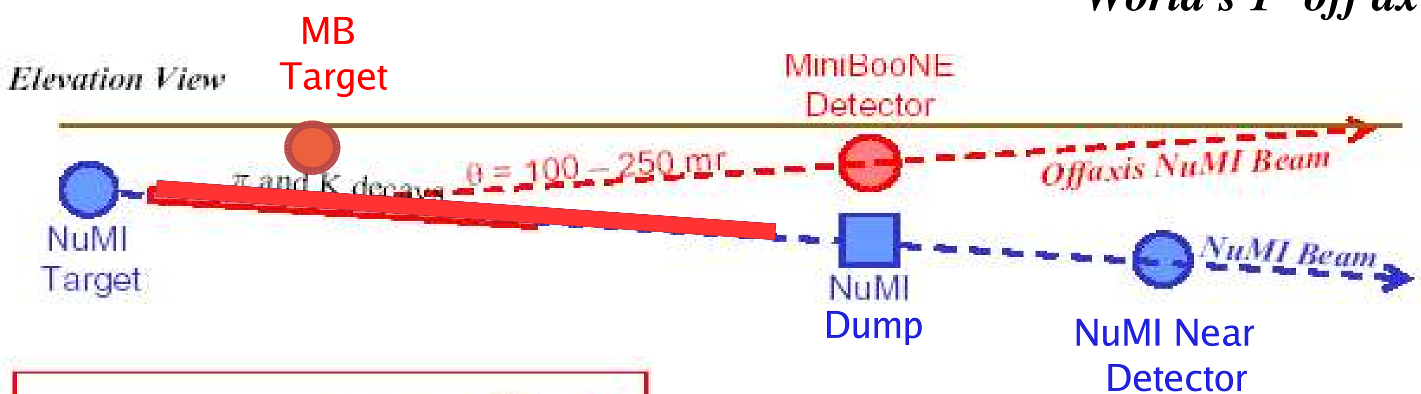
Using this information, Monte Carlo predicts a rate of ~ 1.75 x 10^{-15} ν/POT interacting in MiniBooNE. We must be able to see this!

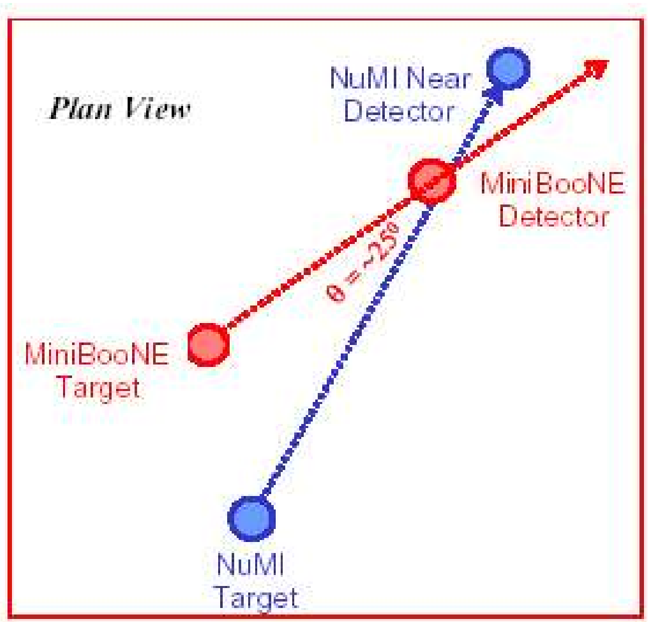
Schematic: NuMI and MiniBooNE

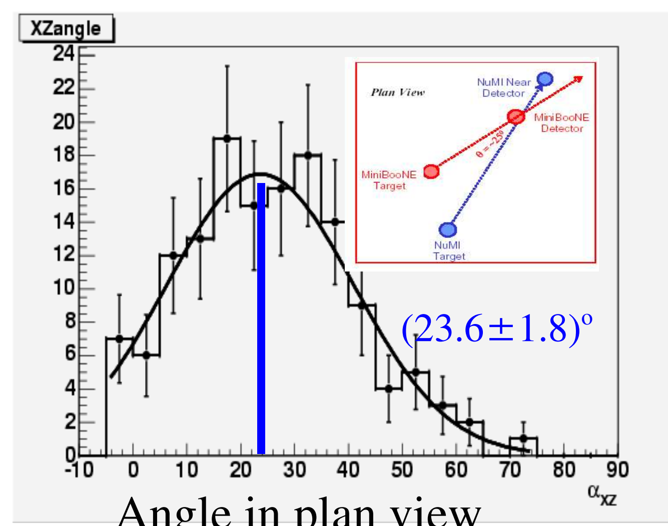
- MiniBooNE at an angle of 110 mrad (6.3°) relative to NuMI beam line (from face of 1st horn)



World's 1st off axis ν beam!

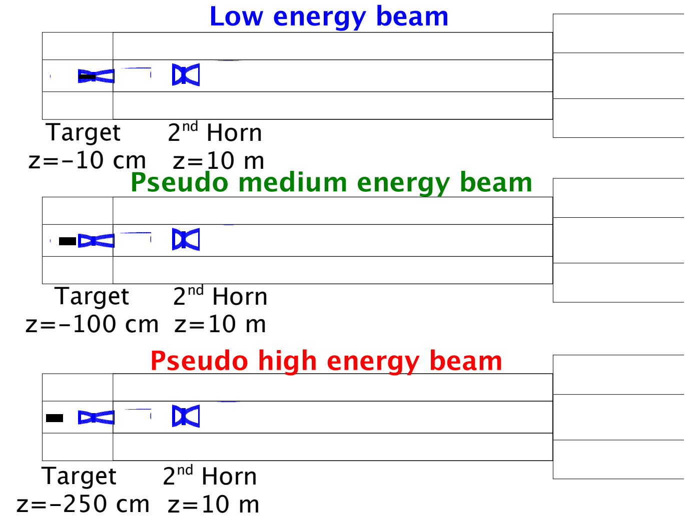


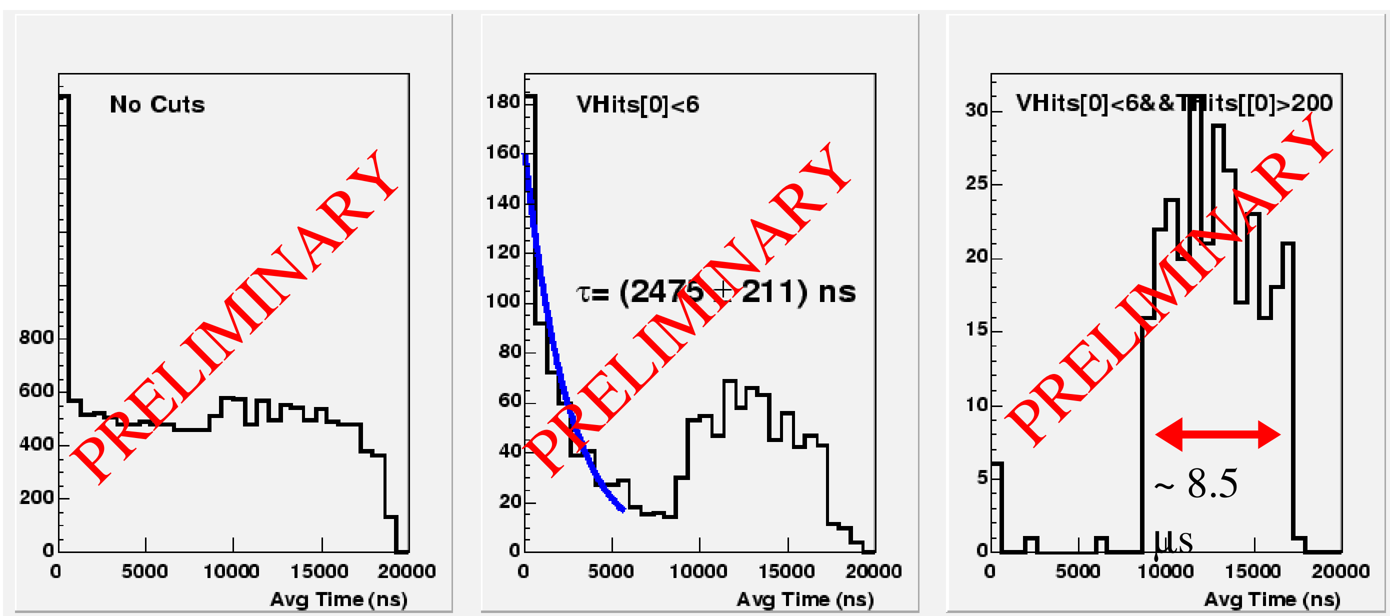




NuMI event trigger, Event Timing

- DAQ is triggered on firing of NuMI kicker magnets (Main Injector proton extraction).
- Simple cuts isolate neutrino candidate events
- Beam spill duration ~8-9 μs as expected
- Data taken in NuMI Low Energy (LE) [most data collected in this mode], Pseudo Medium Energy (PME), and Pseudo High Energy (PHE) beam configurations



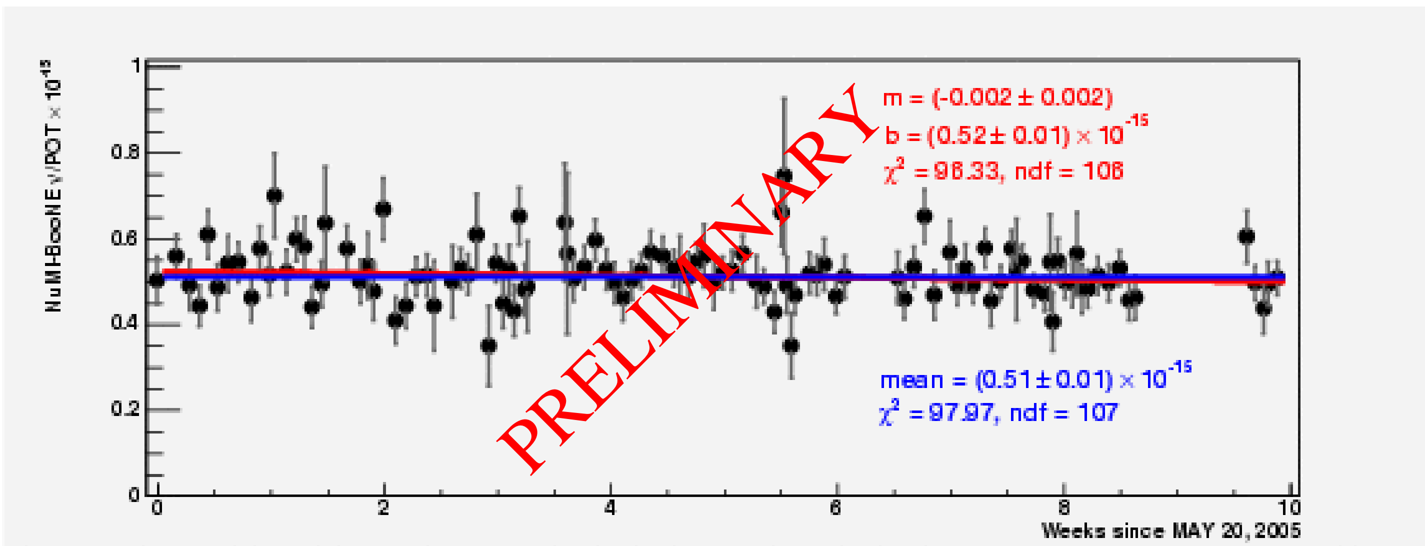


Excess isolated by ν candidate cuts: THits[0]>200 & Vhits[0]<6

These cuts also remove the decays-at-rest in the dump very effectively, keeping mostly decays-in-flight

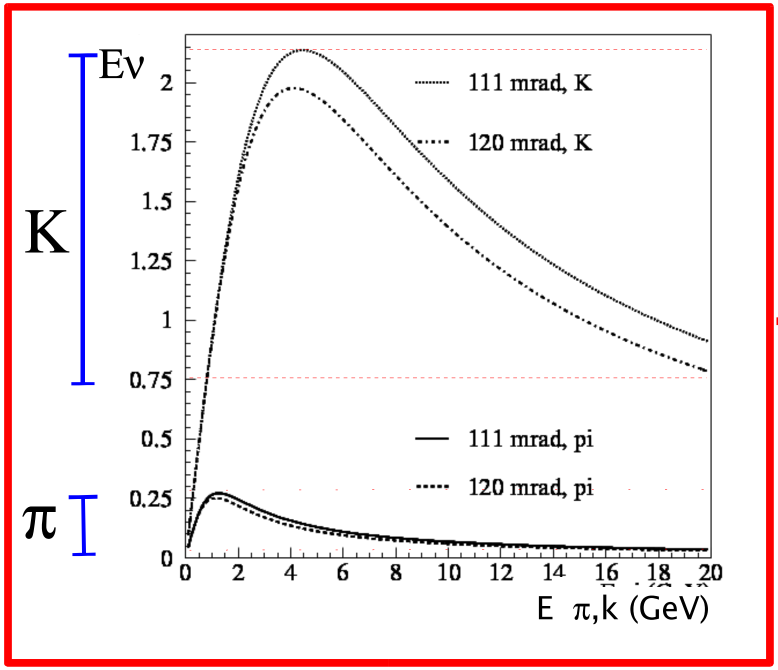
Candidates as a function of time:

- Applying beam quality cuts reduced the number of neutrino candidates by ~3%.
- For the ~10 weeks of processed data in the LE configuration, measured the **number of neutrino candidates per proton** delivered to the NuMI target:



- Each point contains ~100 evts. on average and corresponds to a 16-32 hrs period.
- Constant neutrino production over time.

MiniBooNE off axis beam

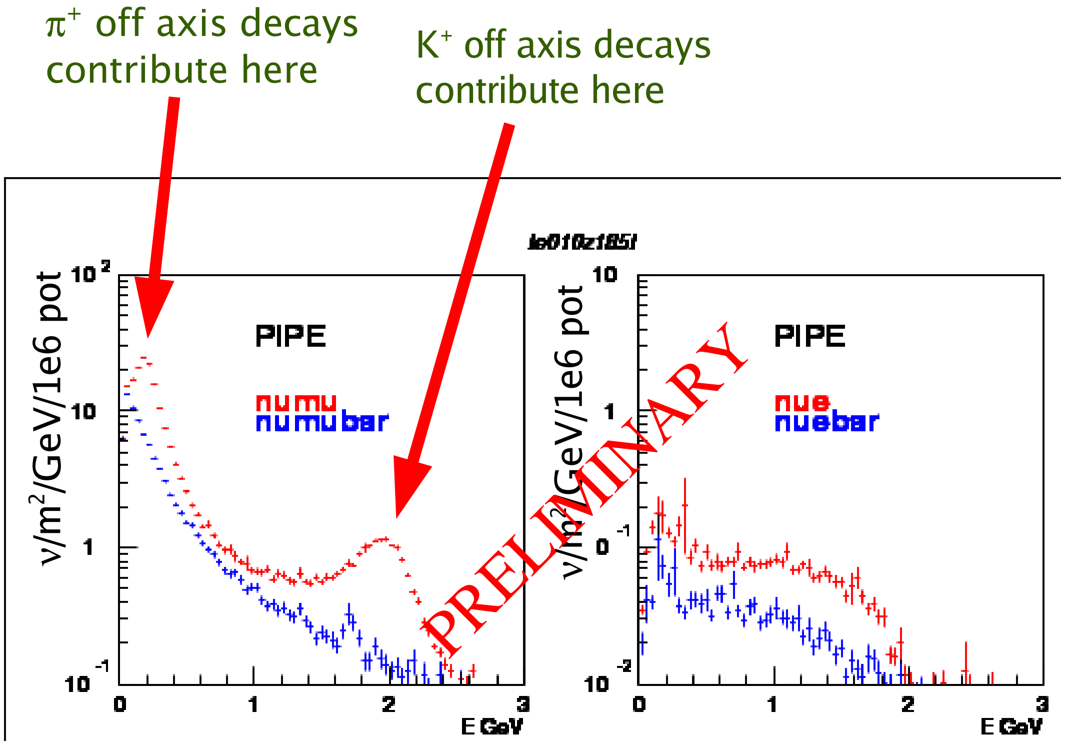


- Most of NuMI ν's in MiniBooNE come from mesons decaying at angles around 110 mrad.
- Electron ν component also important as calibration source for MiniBooNE (similar energy as signal events).

Neutrinos from each meson concentrate around a different energy.

ν flux: $$F = \left(\frac{2\gamma}{1+\gamma^2\theta^2}\right)^2 \frac{A}{4\pi z^2}$$

ν energy: $$E_\nu = \frac{0.43 E_\pi}{1+\gamma^2\theta^2},$$



Spectrum of ν's from decay-in-flight mesons, LE configuration.

Monte Carlo Simulation of NuMI events in MiniBooNE

- Fluxes are calculated with the **`gnumi`** Monte Carlo (provided by MINOS)

- Flux histograms for numu, numubar, nue, nuebar are input to our event generator (NUANCE) to produce neutrino interactions due to DUMP and PIPE neutrinos separately.

  - NUANCE uses a unidirectional neutrino beam, so we assume all neutrinos come from two point sources: the NuMI target and the Dump.

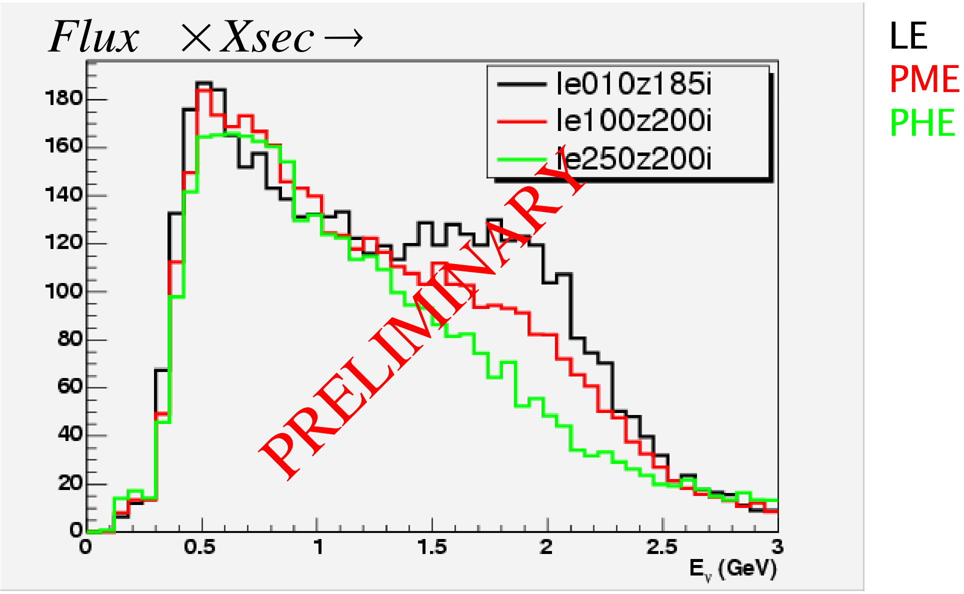
  - Neutrinos from the DECAY PIPE that are seen by MiniBooNE come mostly from the target vicinity, with an exponentially decaying component along the pipe

  - Neutrinos from the BEAM DUMP enter the detector with a defined direction and narrow spread. ν_μ 's from stopped kaons come at 236 MeV.

- Deposited energy can be compared in Data and Monte Carlo with small effects from the approximations.

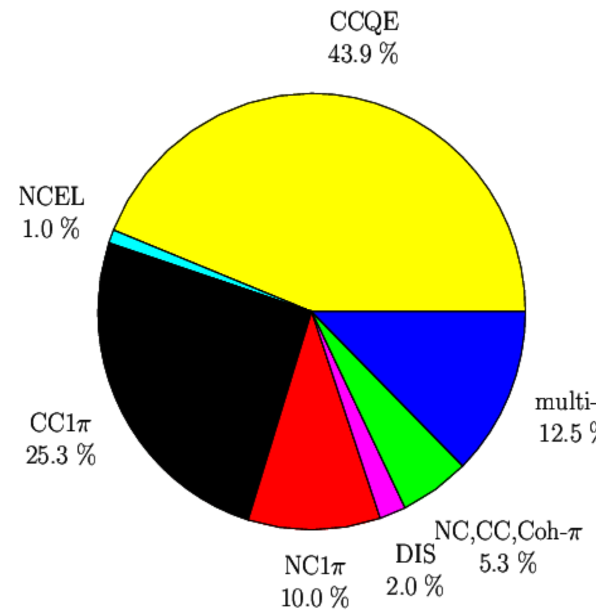
Comparing beam configurations: **LE, PME, PHE**

Number of events in MiniBooNE for 1×10^{19} p.o.t in each configuration as a function of the true neutrino energy has different shapes for the three configurations.



Energy spectrum of contained events (**Thits[0]>200 & VHits[0]<6**) in each configuration

Interactions in the LE configuration:

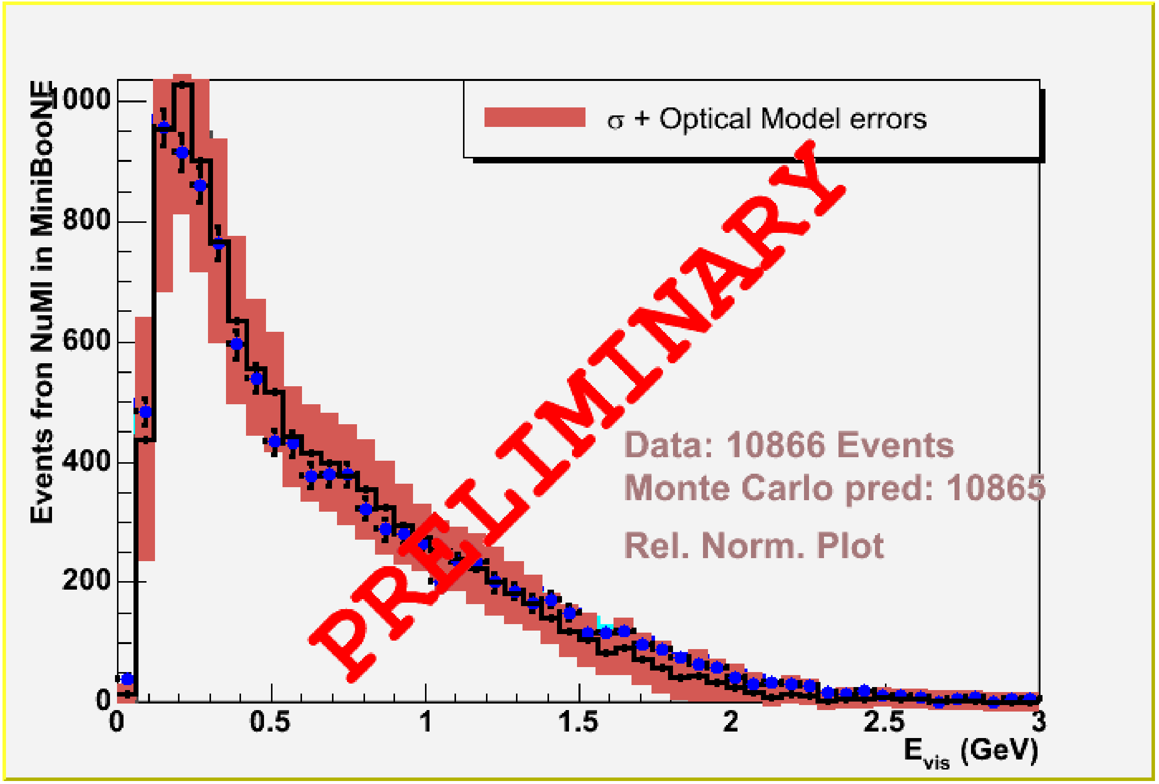


The THits[0]>200 cut designed to remove electrons from muon decays (***Michel*** e's)removes the decay-at-rest decays at the dump. The Vhits[0]<6 cut removes cosmic rays.

Visible Energy distribution LE beam:
(candidate events)

- 10866 LE ***candidate*** events matching a spill from the beam and satisfying beam quality cuts (10 weeks of LE running).

Equal area: Shape comparison only

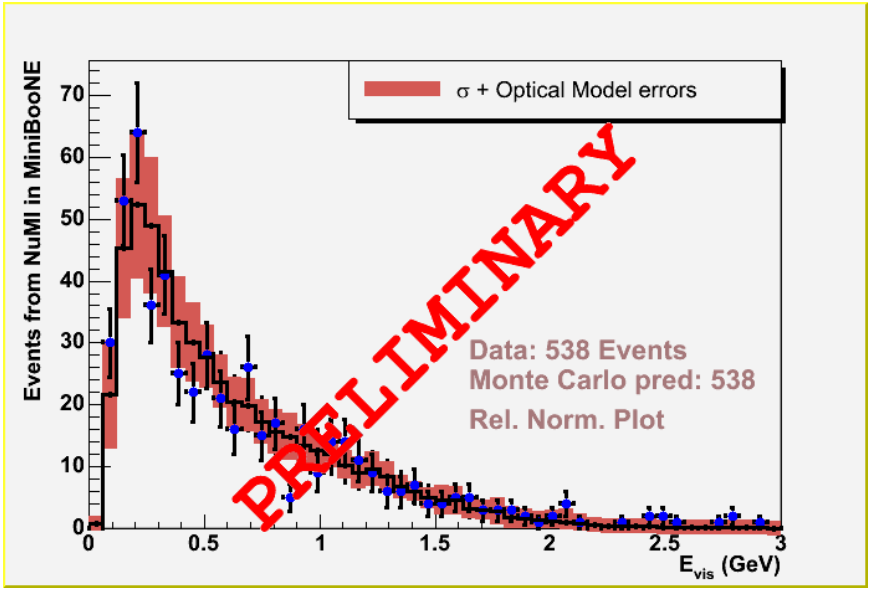


Data/MC discrepancies are covered by conservative optical model systematic variations (error bands have ~5% statistical fluctuations and were assumed uncorrelated)

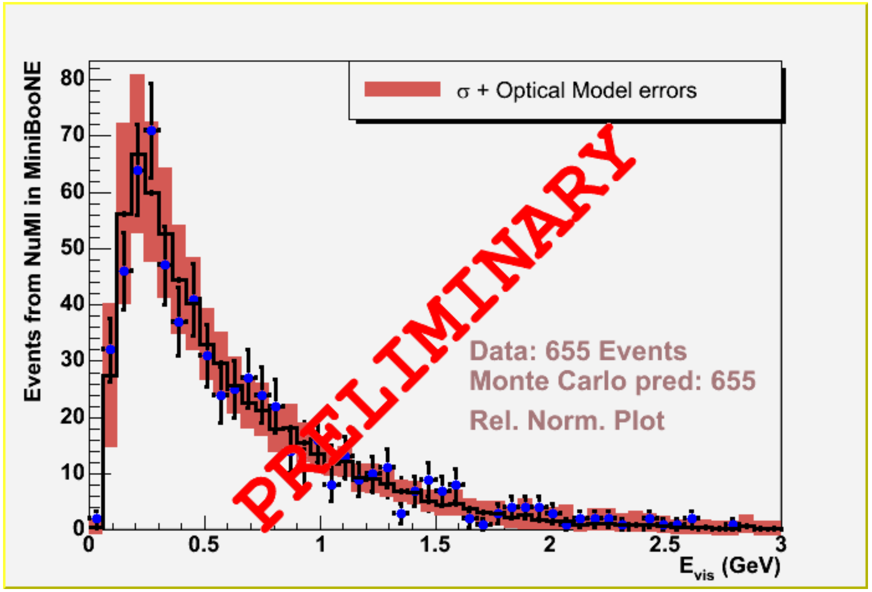
Visible Energy distribution PME and PHE beams: (contained events)

– Similar level of agreement in the other two configurations.

PME configuration



PHE configuration



Equal area: Shape comparison only

Data/MC discrepancies are covered by conservative optical model systematic variations (error bands have ~5% statistical fluctuations and were assumed uncorrelated)

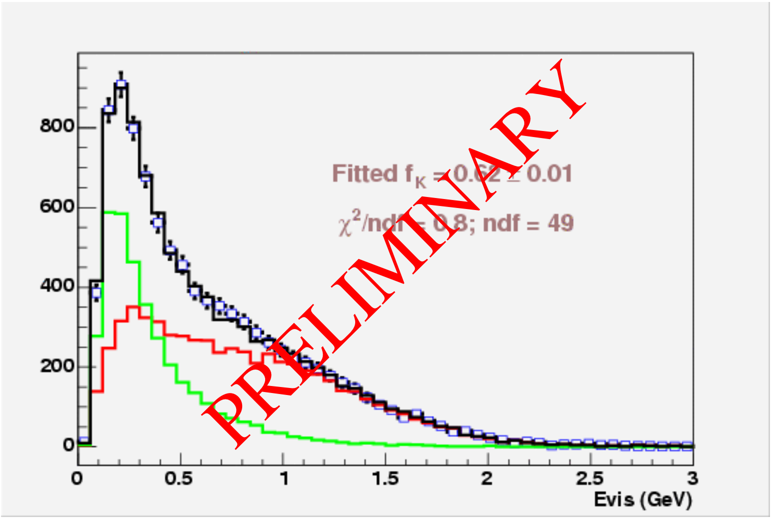
Kaon composition of the LE beam:

- Interesting for both MINOS and MiniBooNE is the study of the fraction of ν's coming from the decay of kaons produced at the NuMI target.

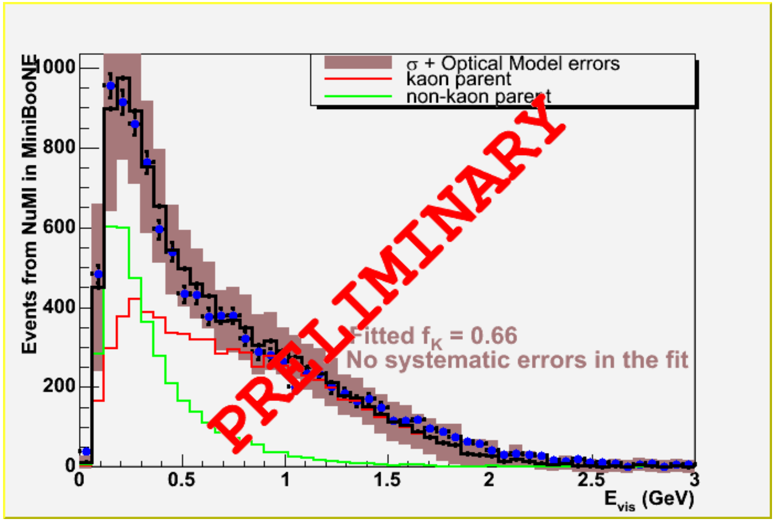
- Fit shape of the Evis distribution for kaon /non-kaon components:

$$\chi^2 = \Sigma_i \frac{(Data[i] - F[i](f_K))^2}{Data[i]} \quad , \quad F[i](f_K) = N_{Data}\left[f_K * Kaon[i] + (1 - f_K) * NonKaon[i] \right]$$

Fit to Monte Carlo distribution with Monte Carlo components shows that the fraction of n from Kaons in the MC is 62%.



Fit to Data distribution with Monte Carlo components is poor, but seems to prefer a higher fraction: 66%



Conclusions

– Neutrinos from NuMI beam line have been observed in the MiniBooNE detector (**first off-axis experiment**).

– First Data Monte Carlo comparisons made using the `gnumi` Monte Carlo look promising. MINOS collaboration is helping us to understand systematic errors in the flux prediction.

– NuMI event sample in MiniBooNE is potentially useful in providing cross checks for both experiments (e.g. constrain Kaon composition of the NuMI beam, systematic check for various MiniBooNE analyses).

– The work shown here represents an enormous collaborative effort between MiniBooNE and NuMI/MINOS collaborators.

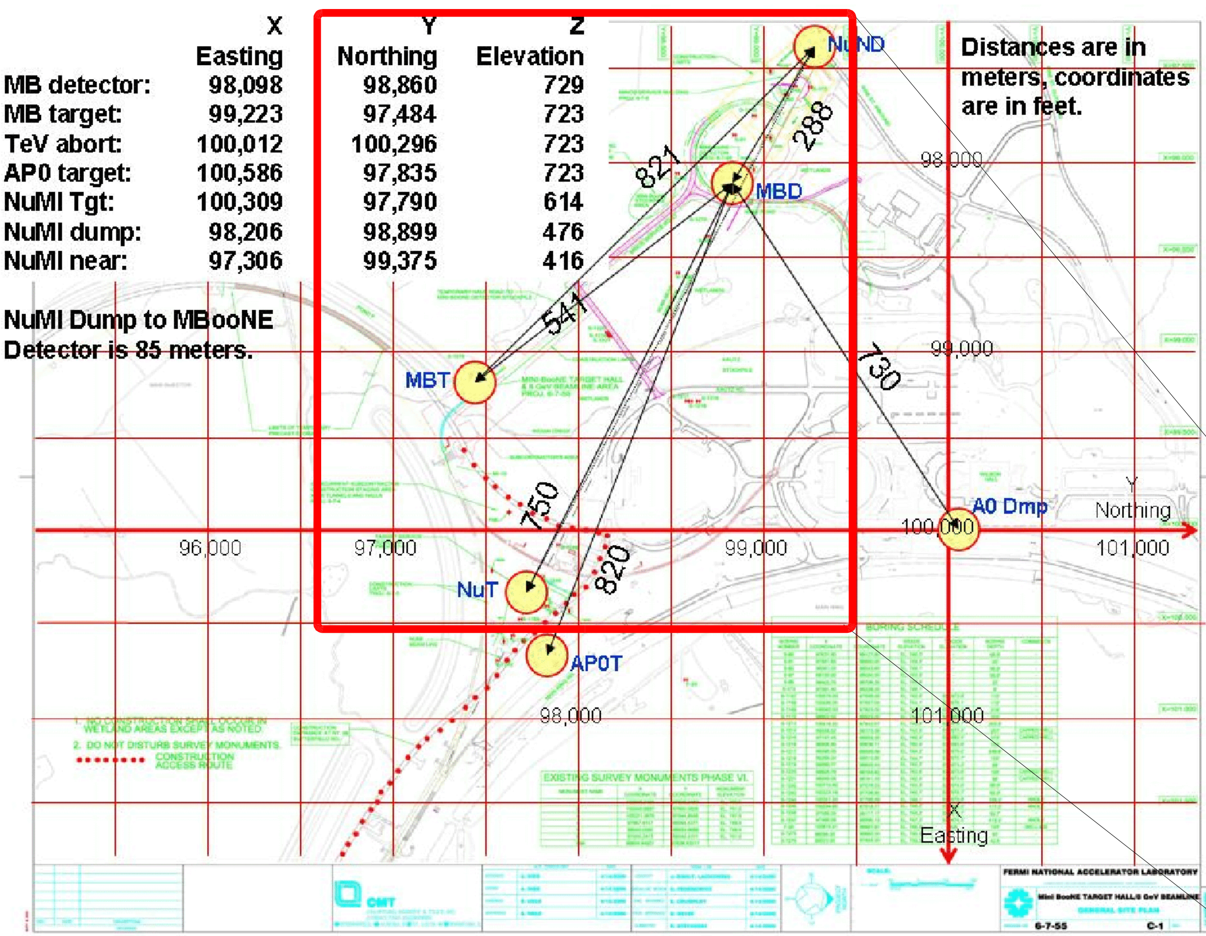
– Expect to collect ~40,000 candidates in the LE10 configuration by the next shutdown.

Backup Slides

Schematic: NuMI and MiniBooNE

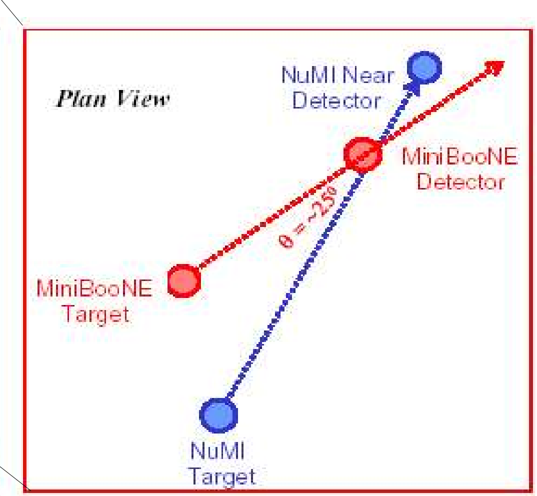
Neutrino sources and detectors in the Fermilab site
(Map by Ray Stefanski – FNAL)

	X Easting	Y Northing	Z Elevation
MB detector:	98,098	98,860	729
MB target:	99,223	97,484	723
TeV abort:	100,012	100,296	723
AP0 target:	100,586	97,835	723
NuMI Tgt:	100,309	97,790	614
NuMI dump:	98,206	98,899	476
NuMI near:	97,306	99,375	416



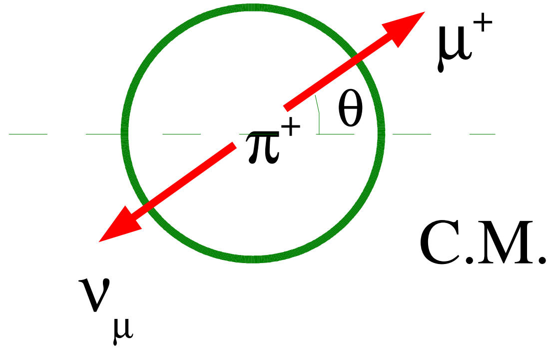
In NuMI beam coordinate frame:

$X_{MB} = 25.84$ m
$Y_{MB} = 78.42$ m
$Z_{MB} = 745.25$ m



Off axis beam

- π's and K's decay isotropically in their center of mass system



When boosted to the lab frame where the mesons are moving along the beamline:

A few examples:

(Flux of 1 decaying particle)

ν flux: $$F = \left(\frac{2\gamma}{1+\gamma^2\theta^2}\right)^2 \frac{A}{4\pi z^2}$$

ν energy: $$E_\nu = \frac{0.43 E_\pi}{1+\gamma^2\theta^2},$$