Prospect of Dimuon Analysis at the MINOS Near Detector

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Introduction

The production of oppositely charge charm induced dimuon in the neutrino-nucleon deep inelastic scattering provides important information about the structure of the nucleon, the dynamics of the heavy quark production and values of several fundamental parameters of the Standard Model.

In the Standard Model, opposite sign dimuon is produced in the neutrino-nucleon charged-current interaction by scattering off a down or strange quark to produce a charm quark. The charm quark subsequently fragments to a charm hadron which decays semi-muonically. Figure 1 shows the Feynman graph of dimuon production in the Standard Model.

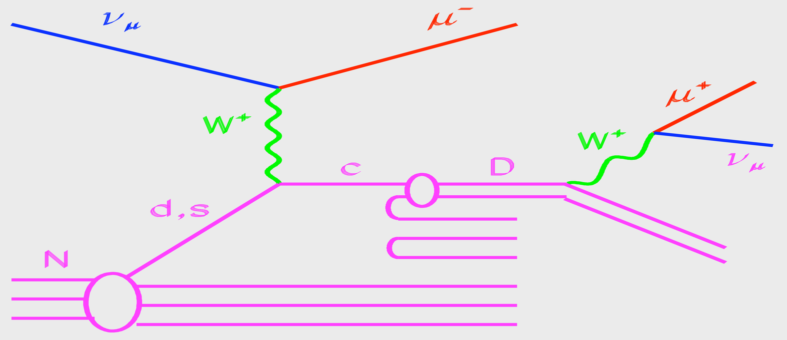


Figure 1: The Feynman graph for dimuon production in the Standard Model

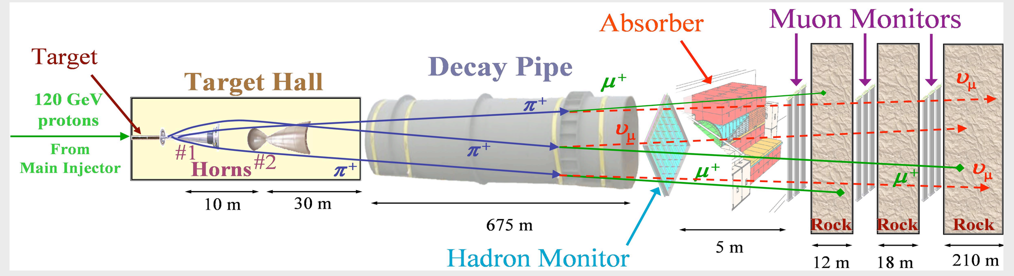
The dimuon production cross section is given by,

$$\frac{d^2\sigma_c^{LO}(\nu_\mu N \to \mu^- cX)}{d\xi\, dy} = \frac{2G_F^2 M E_\nu}{2\pi(1+Q^2/M_W^2)^2}\left(1-\frac{m_c^2}{2ME_\nu\xi}\right) \times \left[|V_{cs}|^2 s(\xi,Q^2) + |V_{cd}|^2\, d(\xi,Q^2)\right]\, D_z\, B_c$$

The goal of this analysis is to study the energy dependence of the cross section ratio of dimuon to single muon production and determine the charm mass.

The NuMI Facility

The NuMI receives 120 GeV protons from the Main Injector (MI) in a 10 micro-second spill and impinged upon the graphite target to produce mesons. Two toroidal magnets called "horn" sign-select and focus the mesons from the target. The mesons are directed into a 675 m long evacuated volume to allow them to decay to muons and neutrinos. The muons and remnant hadrons are absorbed in the absorbers. The NuMI facility is shown in the following diagram



The relative longitudinal positions of the two horns and the target optimizes the momentum focus for the pions and therefore the typical neutrino energy. The typical energy spectrum of neutrinos in the simulated events are shown for different target positions in figure 3.

The main features of NuMI

- 120 GeV protons from Main Injector (MI) impinge onto 50g graphite target
- 10μs spill with 2.4s cycle time
- 2.5 x 10^{13} protons per pulse
- beam power ~175 kW

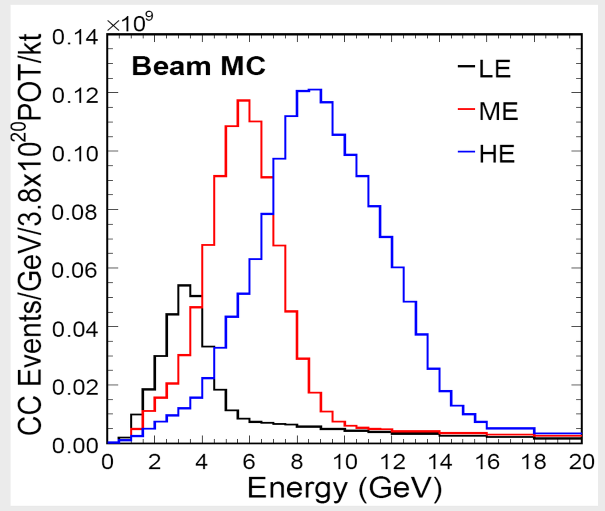


Figure 2: The neutrino energy distribution

MIONS Near Detector

The MINOS consists of two neutrino detectors separated by a long baseline. The MINOS Near Detector resides on the Fermilab site, 104 m underground and 1040 m downstream of the NuMI target. The MINOS Near Detector is a steel/scintillator tracking/sampling calorimeter designed to measure muon-neutrinos produced by NuMI beam. The active medium comprises of 4.1 cm wide, 1.0 cm thick plastic scintillator strips arranged side-by-side and encased within aluminum sheets to form light-tight modules of 20 or 28 strips. Modules are combined to form scintillator planes. The scintillator strips in successive planes are rotated 90 degree to measure the three dimensional event topology.

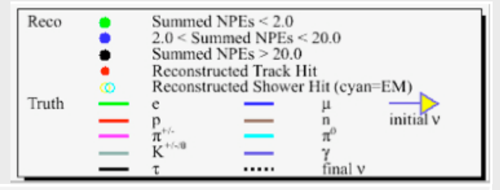
Figure 3 shows the MINOS Near Detector and main features are listed below

- 1.0 km away from target
- 100 m underground
- 1 kT mass
- 282 steel planes
- 153 scintillators planes
- Magnetized B = 1.2 T

Figure 3: MINOS Near Detector

Event Reconstruction

The reconstruction procedure uses the topology and timing of hits to identify neutrino interactions inside the detector. The high intensity NuMI beam produces multiple neutrino interactions inside the Near Detector in each beam spill. The first stage in reconstruction procedures divides the activity in the detector into one or more events, each of which contains hits that are localized in space and time. A track-finding algorithm is applied to each event to find track segments which are then chained together to form longer tracks. The track momentum is estimated from the range, if the track is contained within detector, or from the curvature for the tracks which exit the detector. The showers are reconstructed from clusters of strips that are localized in space and time after subtracting hits of any reconstructed tracks.



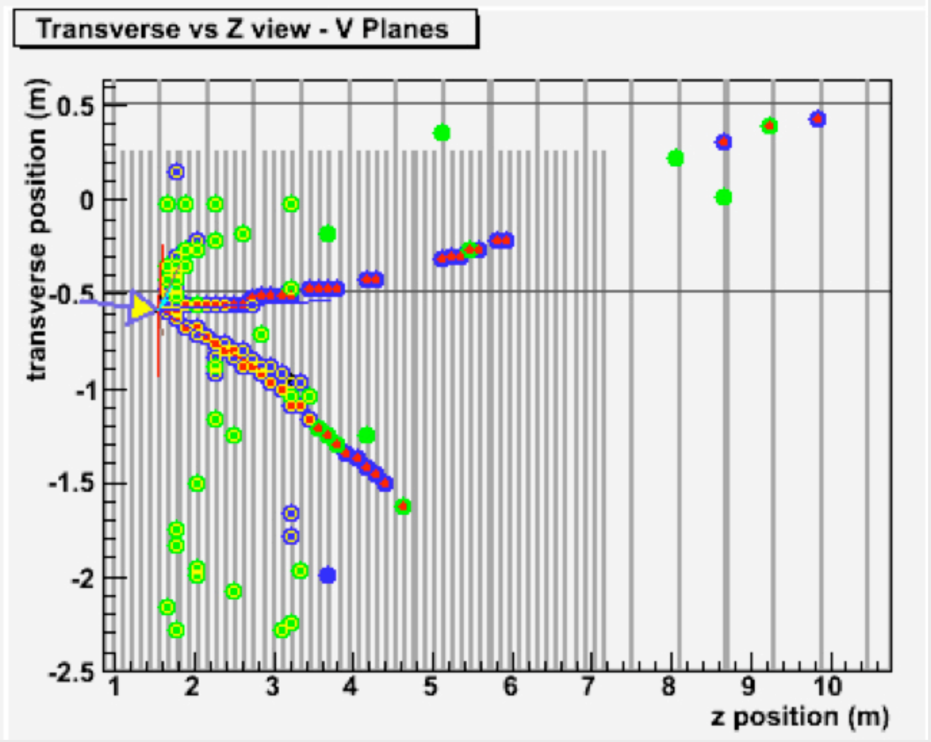


Figure 4: A simulated dimuon event in Near Detector

Event Selection

The dimuon events are selected using the distributions of topological and kinematic variables which provide the ability to accept signal but reject background. The events are selected only in a fiducial detector volume requiring that the z-position of event vertex must be located between 1 to 5m and within a radius of 1.2m from the beam center in x-y plane. Each event is required to have at least two reconstructed tracks. The two track reconstruction efficiency is 24.4 +/- 0.2% and shown in figure 4 as function of generated neutrino energy.

The figure shows the two track reconstruction efficiency as a function of generated neutrino energy obtained from high statistics charm enhance dimuon sample of 5.2 x 10^{21} POT.

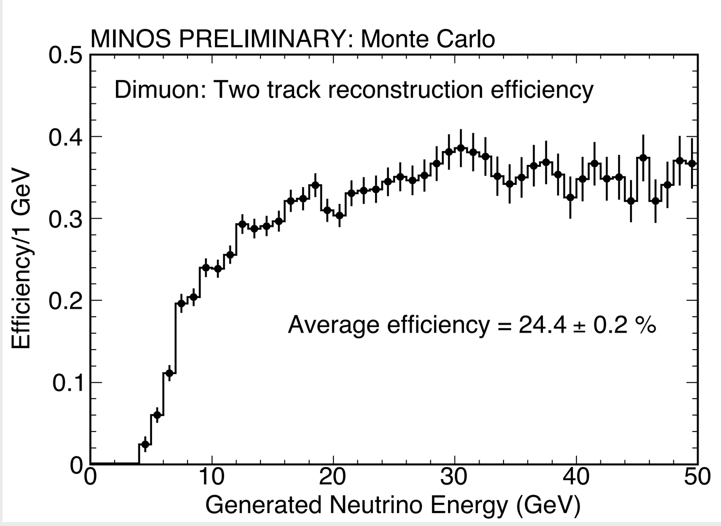


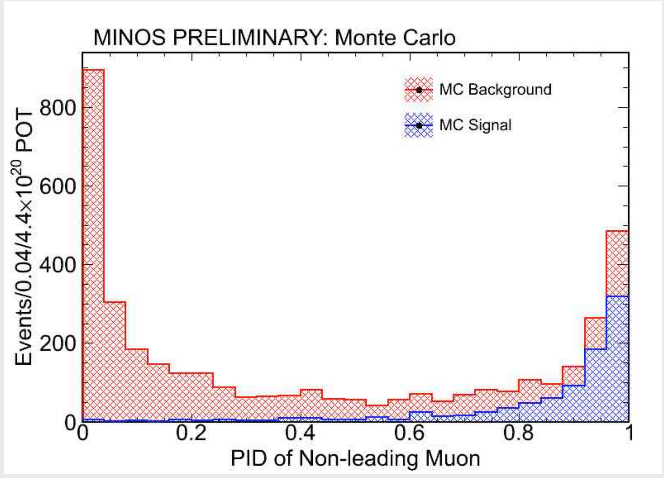
Figure 4: Two track reconstruction efficiency

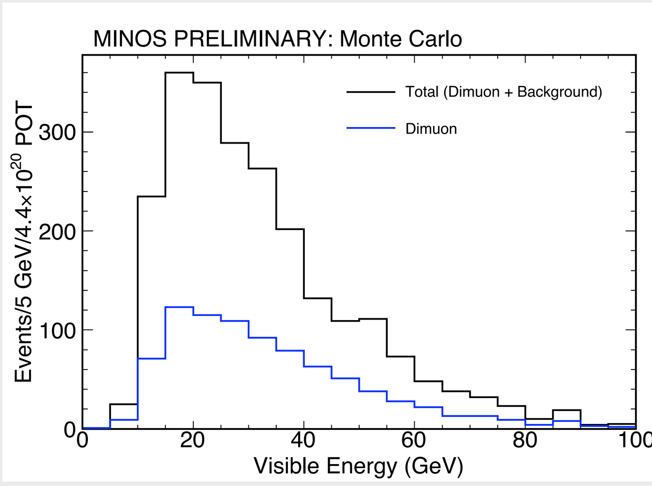
- Track reconstruction quality
  - Track fit is good
- Kinematic cuts
  - Muon and shower energies
- Muon PID cuts
  - Tracks are muon like
- Event reconstruction quality
  - Both tracks come from the same event vertex
- Two muons are opposite charge

Itemized are the topological and kinematic variables used for dimuon selection. The events in the fiducial volume with at least two reconstructed tracks are required to pass loose pre-selection cuts and then those events are passed to MINUIT to obtain the optimal cut positions by maximizing the efficiency times purity. The optimal selection gives:

- Efficiency 7.5 +/- 0.3%
- Purity 36.7 +/- 1.5%

The figure shows the distribution of muon identification variable obtained from track profile for the non-leading muon used in dimuon event selection.





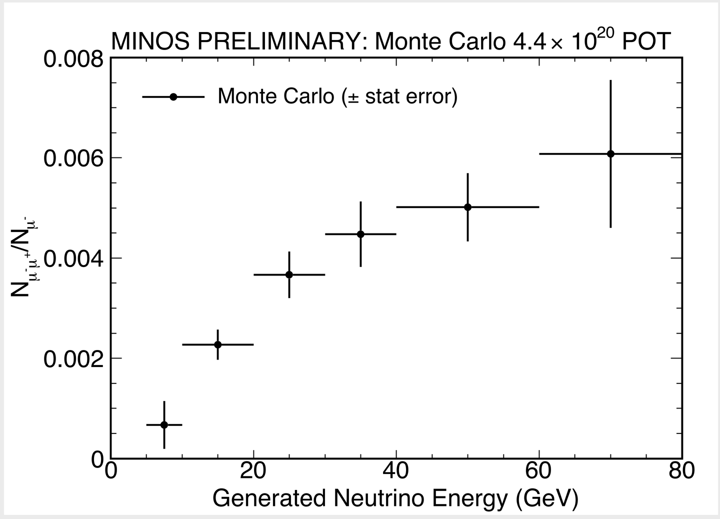
The figure shows the distribution of visible energy of all selected events. In a simulated sample of 4.4 x 10^{20} POT 933 signal and 1626 background events are selected.

In projected 7.0 x 10^{20} POT data about 1484 signal events are expected to be selected using this selection algorithm.

The Cross Section Ratio

The energy dependence of the ratio of charm enhanced dimuon to charge-current single muon production provides important information on charm mass and other CKM parameters. The ratio is insensitive to the description of beam profile.

The single muon charge-current events are selected by requiring that at least one reconstructed track identified as muon has negative charge. In a simulated events of 4.4 x 10^{20} POT about 9.1M single muon candidates are selected.

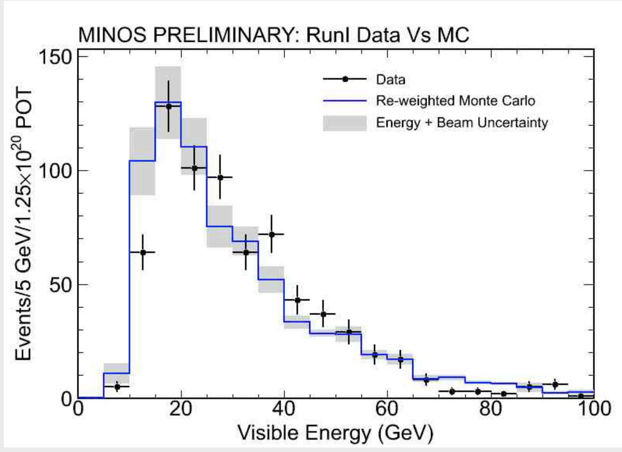


The figure shows the energy dependence of the ratio of dimuon to single muon production rate after acceptance corrections (efficiency and purity) as obtained from 4.4 x 10^{20} POT simulated events.

Like Sign Dimuon

The background to the opposite sign dimuon process arises from the muonic decays of hadrons produced in the hadronic decays or punch through hadrons. The amount of background can be estimated by studying the dimuon events in which both muons are same sign.

The figure shows the comparison between data and Monte Carlo of visible energy distribution of same sign dimuon events. The error band obtained from energy scale uncertainties of muons and shower plus flux uncertainty.



The table compares the predicted events obtained from simulation to the observed events in data.

	-,-	+,+	Total LSDM
Predicted events	615	103	718
Observed events	587	117	704

Conclusion

- We are studying charm enhanced opposite sign dimuon events at the MINOS Near Detector.
- Presently we select dimuon events using cut based selection algorithm. The selection algorithm gives 7.5% efficiency and 36.7% purity.
- We predict to observed about 1500 dimuon events in 7.0 x 10^{20} POT data.
- We measure the ratio of dimuon to single muon production cross sections obtained from simulated events and we are expected to measure the ratio in 7.0 x 10^{20} POT data to a statistical precision of about 10%.
- We have studied the like sign dimuon events and observed events in data agree well with the prediction estimated from simulated events.

Prepared for: NuInt 2009
Sitges, Barcelona, Spain