

Measurement of Deep Inelastic Scattering Cross Section in MINOS

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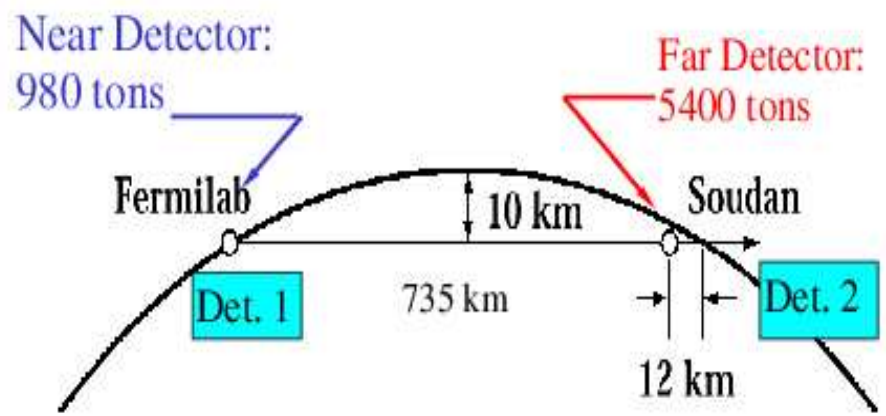
for the MINOS Collaboration

April APS 2006

Outline

- The MINOS Experiment.
- Overview of the Physics.
- Motivation.
- Procedure.
- Conclusion.

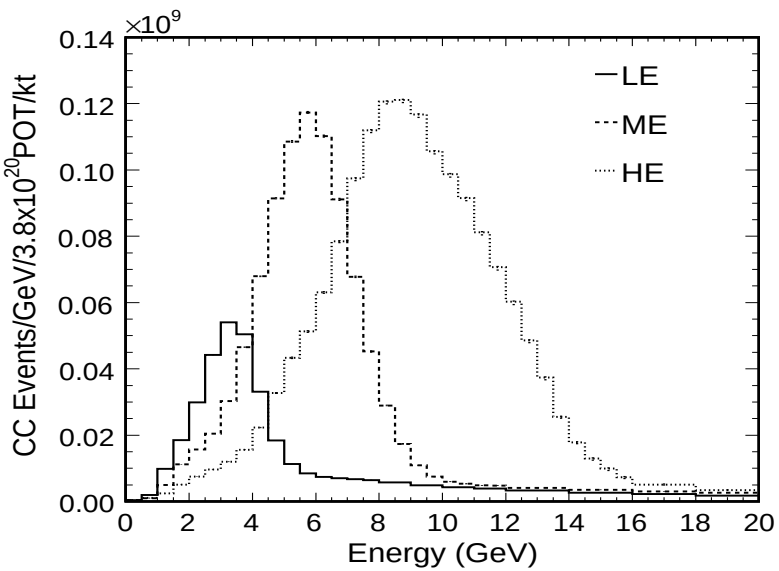
The MINOS Experiment



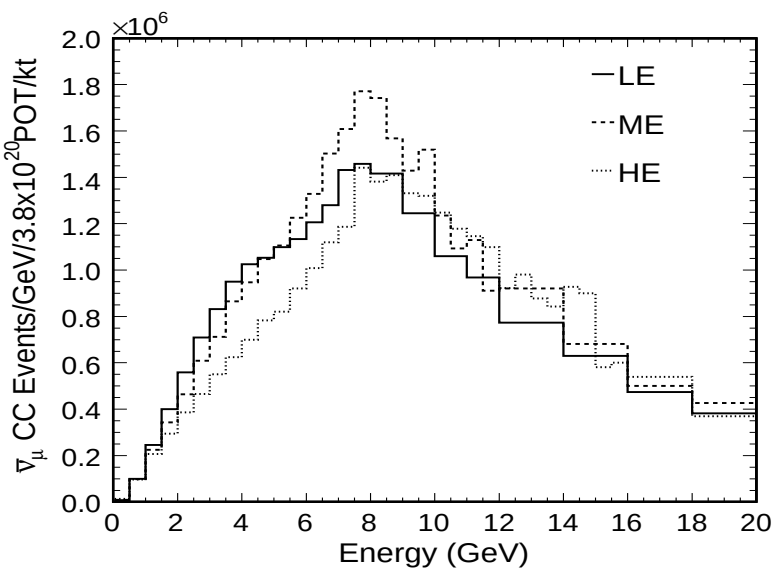
- Long (735 km) baseline.
- The Near Detector at Fermilab, Far Detector at Soudan, MN.
  - The ν energy spectrum at the near and far detector are compared to investigate oscillations.
- MINOS Collaboration: 175 Physicists, 32 Institutions

The NUMI Beam

NEUTRINO(ν_μ)



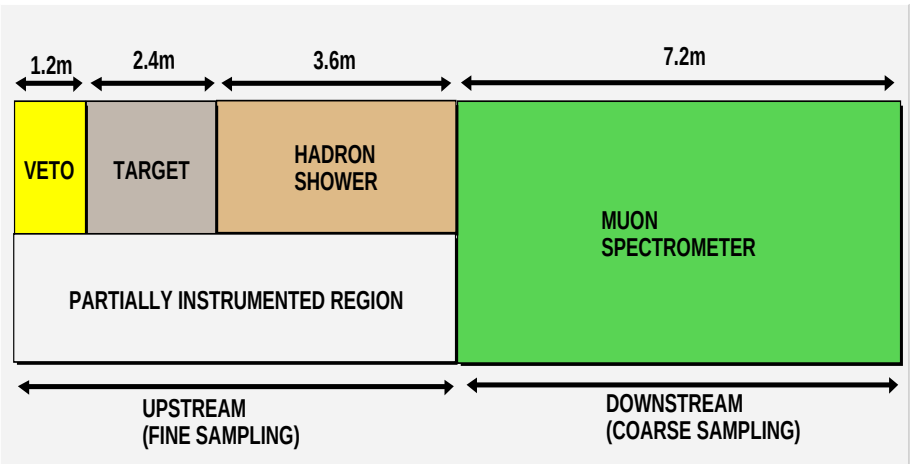
ANTI-NEUTRINO($\bar{\nu}_\mu$)

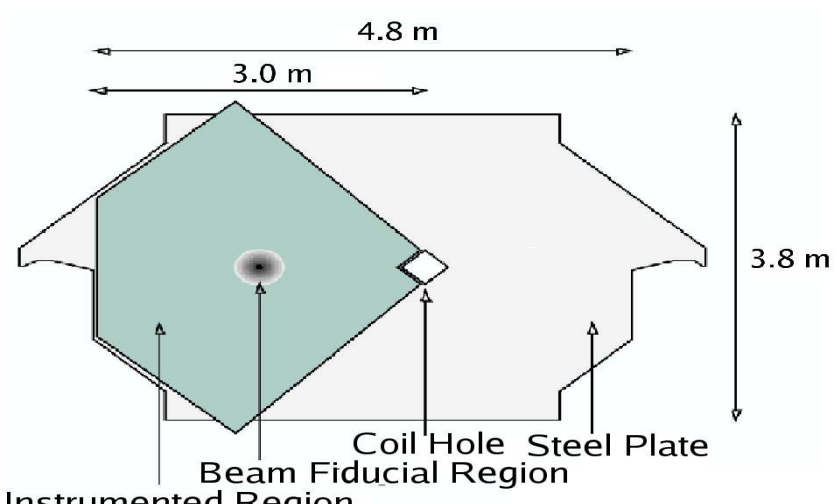


- Currently running in the LE configuration.
- Beam Composition :
  - 98.5% ν_μ + $\bar{\nu}_\mu$ (6.5% $\bar{\nu}_\mu$)
  - $\bar{\nu}_\mu$ peaks at a higher energy compared to the ν_μ beam(LE,ME).
  - 1.5% ν_e + $\bar{\nu}_e$

The MINOS Near Detector

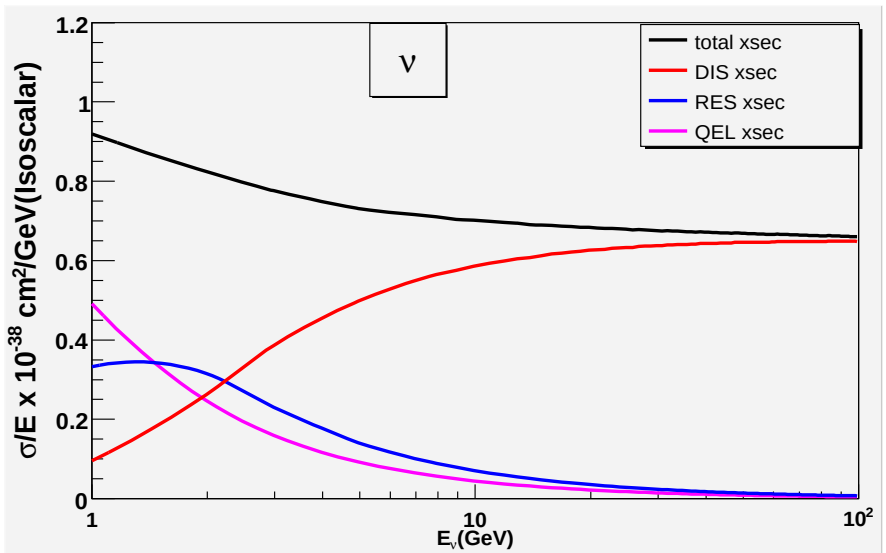
- The DIS cross-section will be measured on the data from the near detector.
- 980 tons, 3.8 m$\times$4.8 m Octogonal.
- 153 active-planes.
  - Sampling every plane in calorimeter region.
  - Sampling every 5th plane in spectrometer region.
- Magnetic field $B = 1.2\ T$

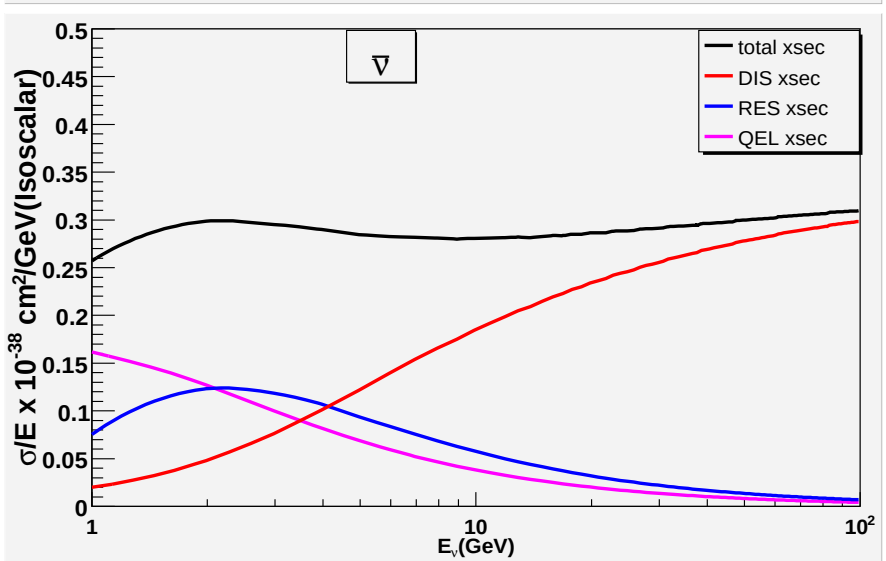




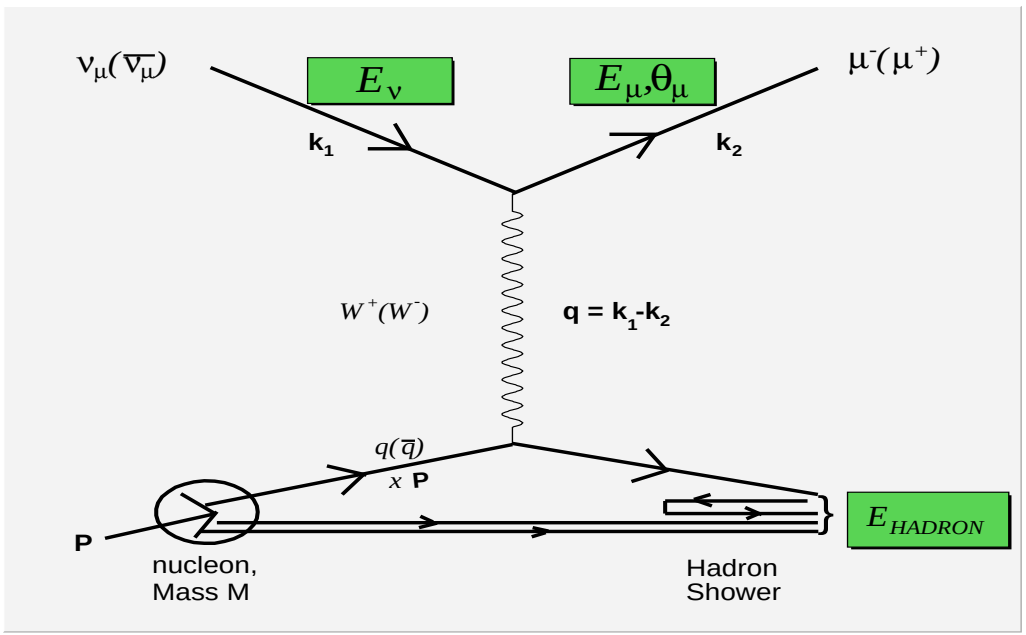
Neutrino Nucleon Scattering

- Total νN scattering cross section: $\sigma_{QE} + \sigma_{RES} + \sigma_{DIS}$
- For Quasi Elastic
  $\nu(\overline{\nu})n(p) \rightarrow \mu^{-}(\mu^{+})p(n)$
  ν scatters off an entire nucleon.
- For Resonance $\nu N \rightarrow \nu N^{*}$
  the excited nucleon decays into low multiplicity final states.
  $\nu_{\mu}p(n) \rightarrow \mu^{-}\pi^{+}p(n)$
  $\nu_{\mu}n \rightarrow \mu^{-}\pi^{0}p$
- For Deep Inelastic Scattering
  $\nu(\overline{\nu})N \rightarrow \mu^{-}(\mu^{+})X$
  the neutrino scatters off the constituents of the nucleon.





Physics Background

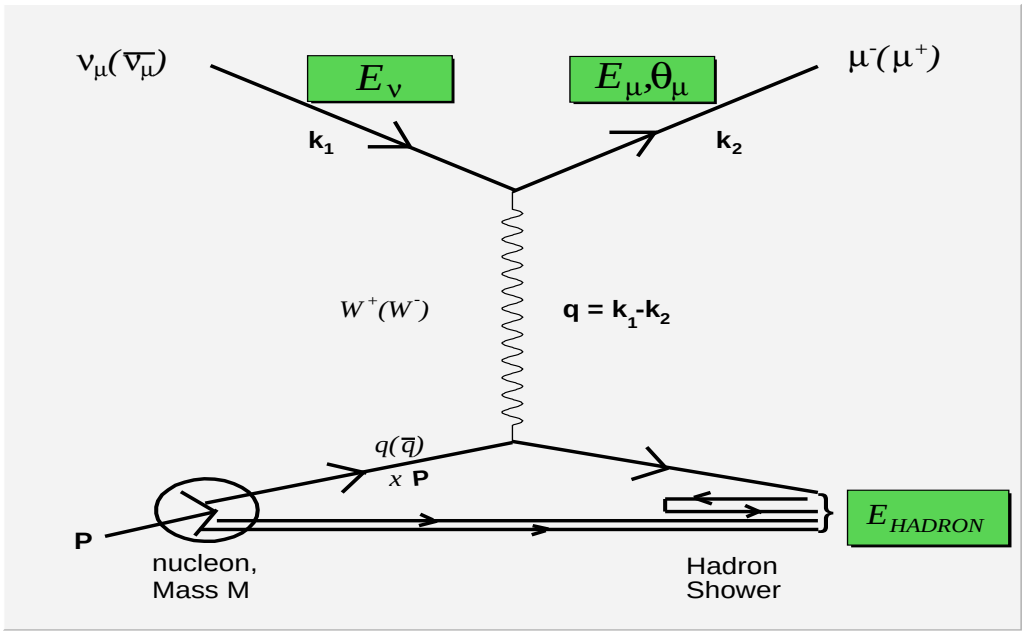


Charge Current ν-Nucleon scattering

Measured quantities:

E_μ, θ_μ and E_{HAD}

Physics Background



Charge Current ν-Nucleon scattering

Measured quantities:

E_μ, θ_μ and E_{HAD}

Invariant quantities in the interaction

$\nu = \frac{p.q}{M}$ (energy transfer to the had. system)

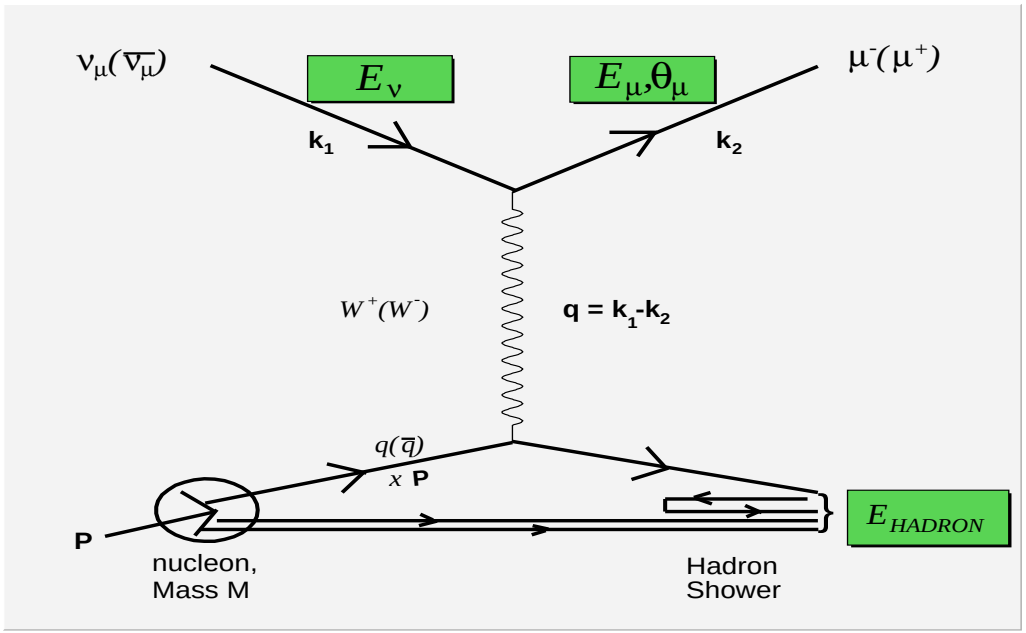
$y = \frac{p.q}{p.k_1}$ (Inelasticity)

$Q^2 = -q^2$ (negative squared 4-momentum)

$x = \frac{Q^2}{2p.q}$ (Bjorken Scaling variable)

$W^2 = (p+q)^2$ (sq. inv. mass of hadrons)

Physics Background



Charge Current ν-Nucleon scattering

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In the Lab frame

$\nu = E_{HAD}$

$y = \frac{E_{HAD}}{E_\nu}$

$Q^2 = 2E_\nu E_\mu(1 - cos\theta_\mu)$

$x = \frac{2E_\nu E_\mu(1-cos\theta_\mu)}{2ME_{HAD}}$

$W^2 = M^2 + 2ME_{HAD} - Q^2$

The Differential Cross Section

$$\frac{d^2\sigma^{\nu(\bar{\nu})}}{dxdy} = \frac{G_F^2 M E_\nu}{\pi(1+Q^2/M_W^2)^2}[(1-y-\frac{Mxy}{2E_\nu})F_2^{\nu(\bar{\nu})}(x,Q^2) + \frac{y^2}{2}2xF_1^{\nu(\bar{\nu})}(x,Q^2) \pm y(1-\frac{y}{2})xF_3^{\nu(\bar{\nu})}(x,Q^2)]$$

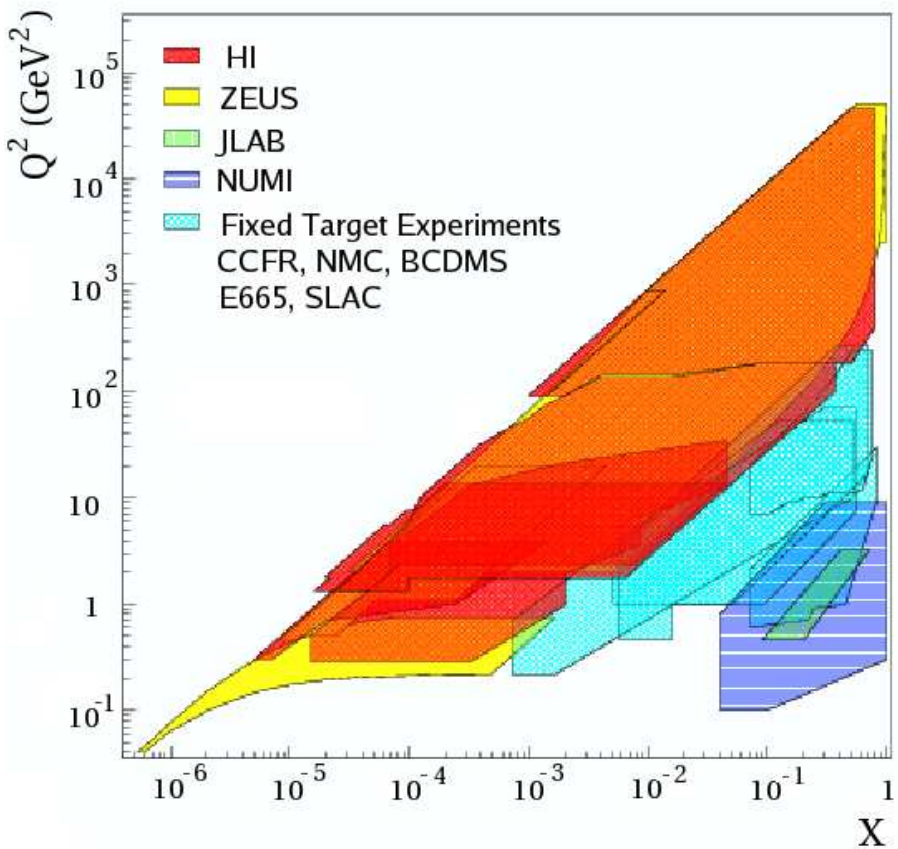
- where,
  - G_F is the Fermi constant,
  - M is the nucleon mass,
  - M_W is the W boson mass.
- The F_is contain information about the structure of the nucleon target.
- $F_2(x,Q^2)$ and $2xF_1(x,Q^2)$ are related by

$$\boxed{\frac{F_2(x,Q^2)}{2xF_1(x,Q^2)} = \frac{1+R(x,Q^2)}{1+(4M^2x^2/Q^2)}}$$

- xF_3 can only be measured from neutrino nucleon scattering.

Motivation

- The MINOS kinematic regime:
  High x, low Q^2
  - This kinematic regime has been explored for charged-lepton scattering.
  - New kinematic coverage for ν+N SF's.



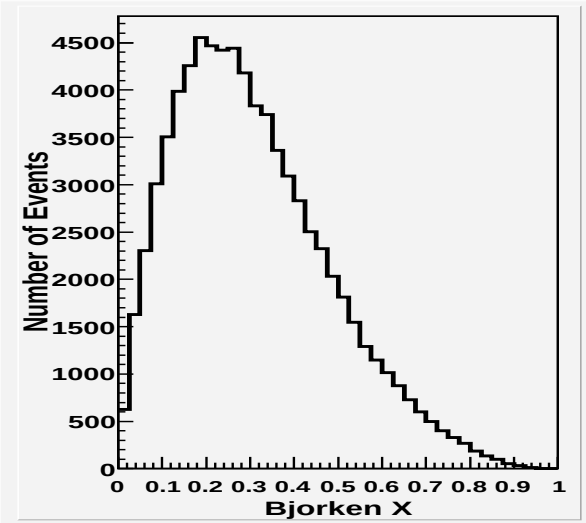
- To measure the oscillation parameters accurately we need to know the E_ν spectrum at the near detector.
  - To do this we need to know the Cross-section, Flux and the detector response.

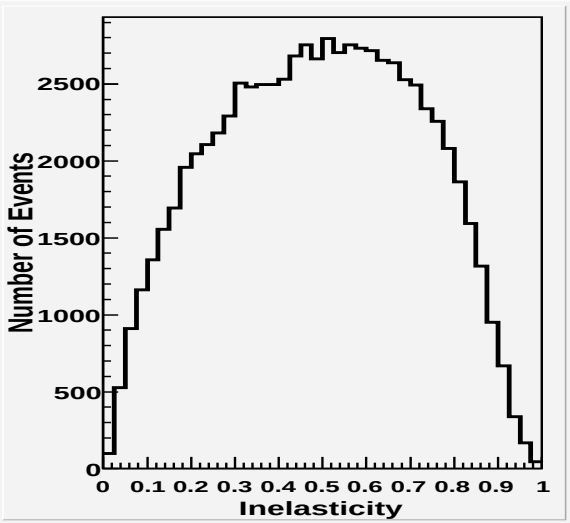
Charged Current DIS sample

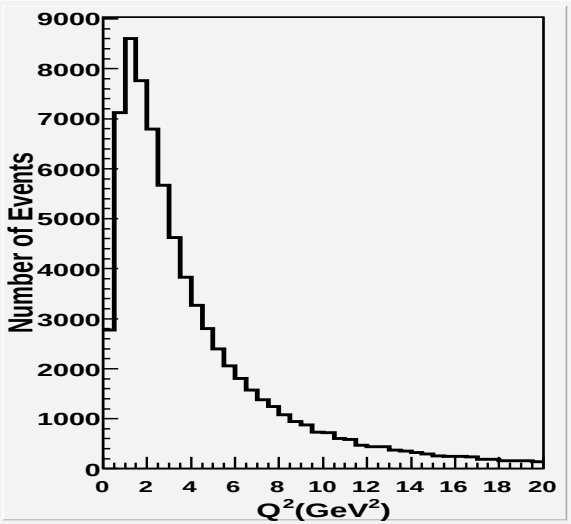
- DIS is the largest contribution to the MINOS event sample.
  DIS(58%),RES(26%),QE(16%)
- To Select DIS events : apply cuts on Neutrino Energy, Shower Energy and Q^2.
  - $E_\nu >$ 5 Gev, $E_{shw} >$1 Gev, $Q^2 > 1\ GeV^2$.
- The statistics for the CC DIS sample will be high
  (for a total of $7.4 * 10^{20}$ pots)
  - ν sample - $2.6 * 10^6$ (NUTEV/CCFR - $1.0 * 10^6$)
  - $\bar{\nu}$ sample - $0.3 * 10^6$ (NUTEV- $0.3 * 10^6$,CCFR - $0.8 * 10^6$)
  - The ν sample is 2.5 times that of NUTEV/CCFR sample.
  - The measurement will be systematics limited.

Kinematic Variables (DIS sample)

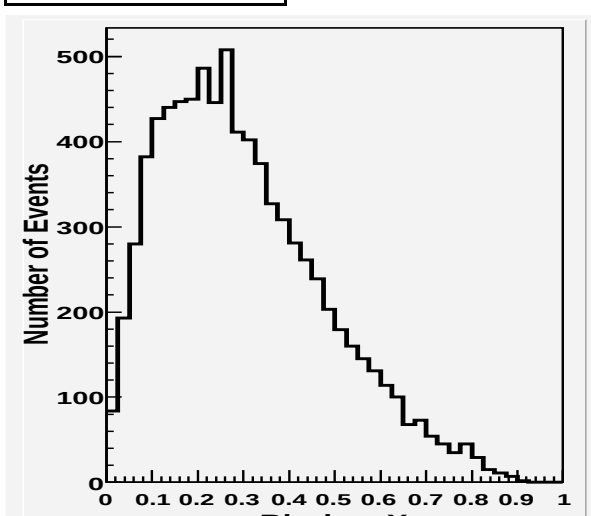
Neutrino (true variables from Monte Carlo)

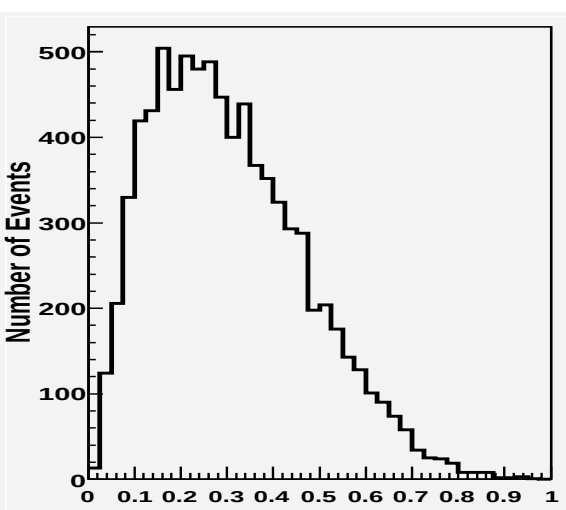


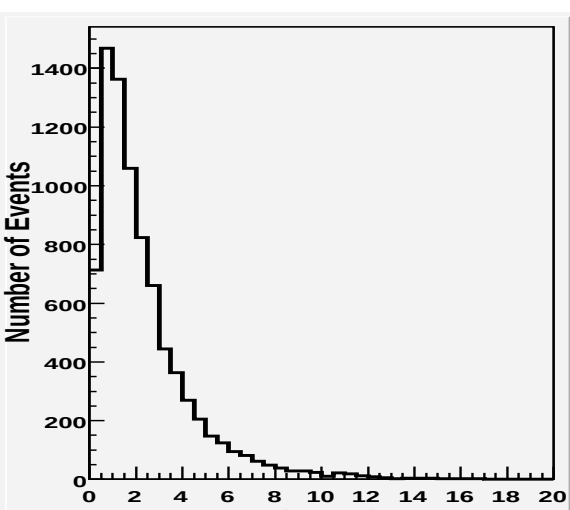




Antineutrino (true variables from Monte Carlo)

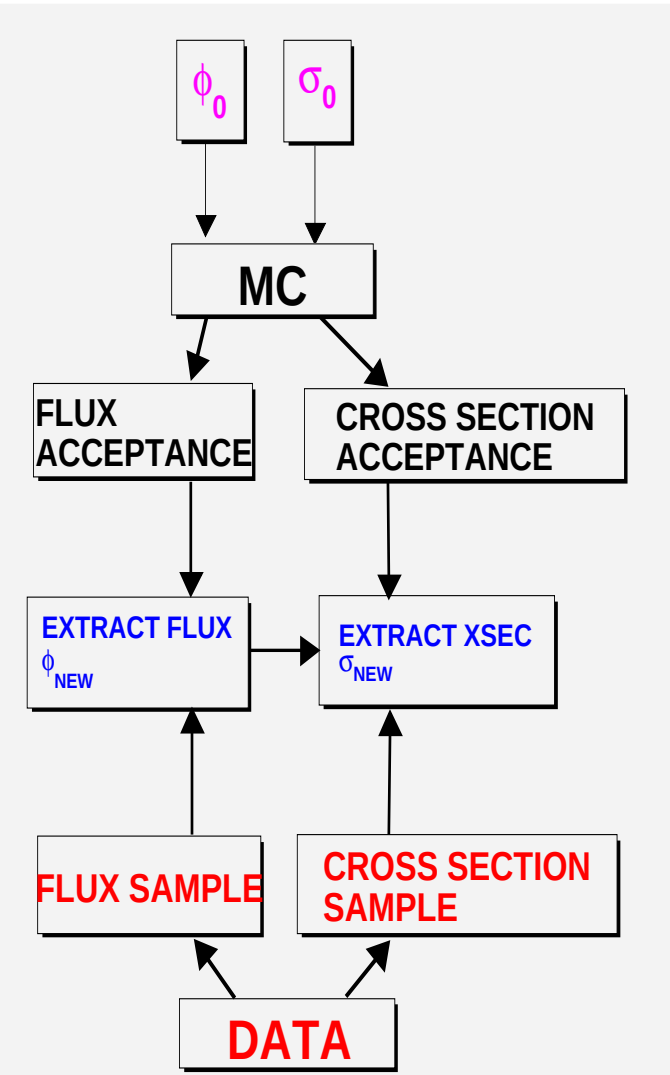






details

Procedure



Cross-section extraction

- Bin data in E,x and y bins.
- Apply acceptance correction
  $\frac{N_{genMC}(x_i,y_j,E_k)}{N_{recoMC}(x_i,y_j,E_k)}$
- $N_{\mathrm{CORR}}(x_i, y_j, E_k) =$
  $N_{\mathrm{RECO}}(x_i, y_j, E_k) * \frac{N_{\mathrm{genMC}}(x_i,y_j,E_k)}{N_{\mathrm{recoMC}}(x_i,y_j,E_k)}$
- Divide by the extracted flux
  $\frac{d^2\sigma}{dxdy} = \frac{N_{\mathrm{CORR}}(x_i,y_j,E_k)}{\Phi(E_k)}$
- The flux can be obtained by:
  - Using the QEL sample.
  - Using the low ν(shower energy) flux extraction method.
  - Using the beam Monte Carlo.

Structure Function Extraction

Extracting F_2

$$[\frac{d^2\sigma^\nu}{dxdy} + \frac{d^2\sigma^{\bar\nu}}{dxdy}]\frac{\pi}{G_F^2 ME} = 2\bar{F_2}\,(1 - y - \frac{Mxy}{2E} + \frac{y^2}{2}\frac{1+4M^2x^2/Q^2}{1+R}) + y(1-\frac{y}{2})\Delta xF_3$$

Extracting xF_3

$$[\frac{d^2\sigma^\nu}{dxdy} - \frac{d^2\sigma^{\bar\nu}}{dxdy}]\frac{\pi}{G_F^2 ME} = \Delta F_2(1\ - y - \frac{Mxy}{2E} + \frac{y^2}{2}\frac{1+4M^2x^2/Q^2}{1+R}) + 2y(1-\frac{y}{2})x\bar{F_3}$$

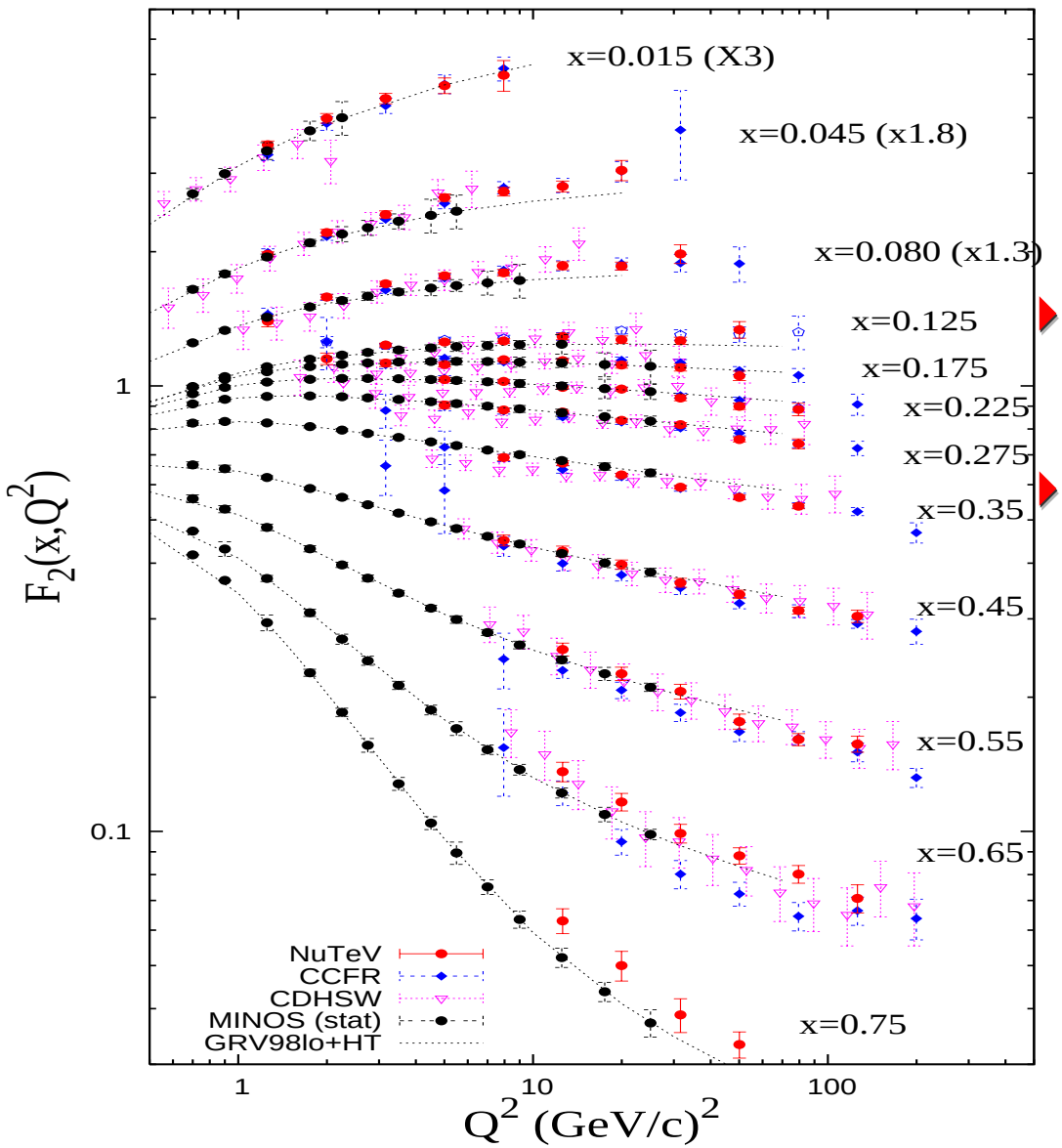
F_2 extraction

- $\bar{F_2} = (F_2^\nu + F_2^{\bar\nu})/2 \sim F_2^\nu$
- $\Delta xF_3 = xF_3^\nu - xF_3^{\bar\nu}$
- R and ΔxF_3 will be used from model.
- perform 1-parameter fit for F_2

xF_3 extraction

- $x\bar{F_3} = x(F_3^\nu + F_3^{\bar\nu})/2$
- $\Delta F_2 \sim 0$
- perform 1-parameter fit for xF_3

Structure Function



- Predicted minos F_2 with statistical errors only.
- The structure function measurement will be dominated by systematic error(from energy scale uncertainties)

Conclusion

- Minos will extract the differential cross section and structure functions at low Q^2 and low energy from neutrino iron scattering.
- The measurement will cover a new range of kinematics for neutrino iron scattering.
  - The results will overlap with charged lepton scattering results from SLAC and JLAB.
- This measurement will be useful in constraining the DIS neutrino cross sections at low energies.

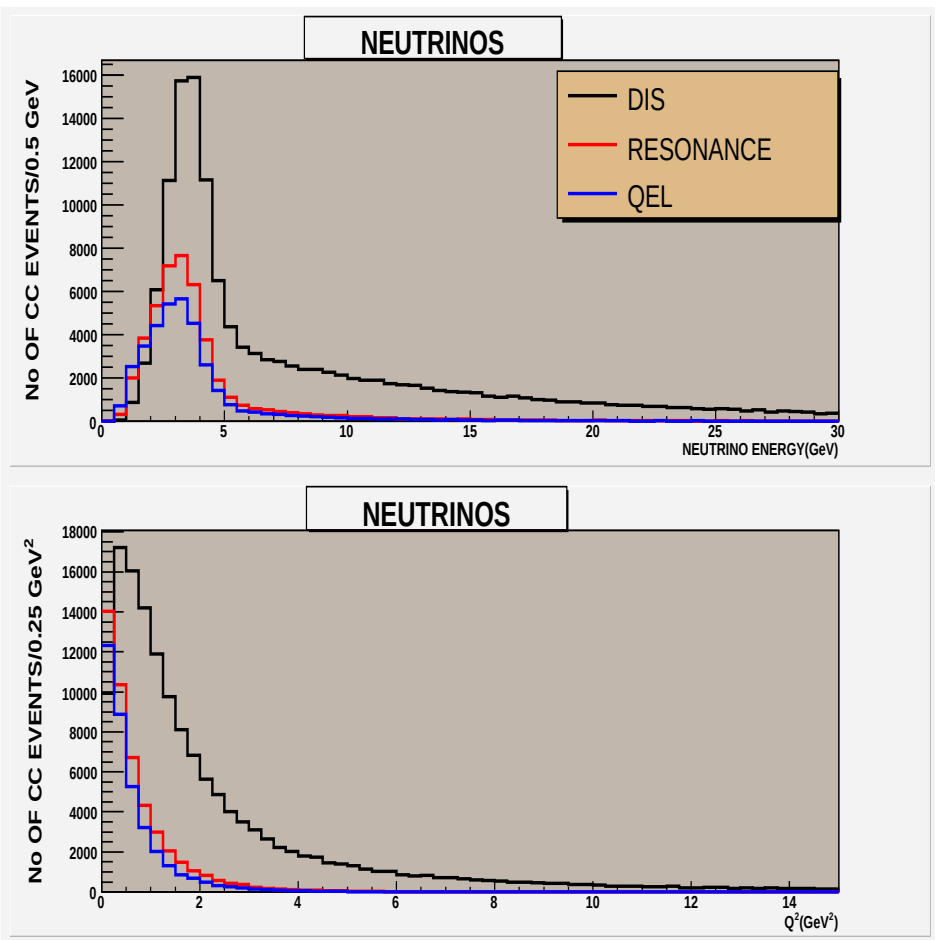


BACKUP

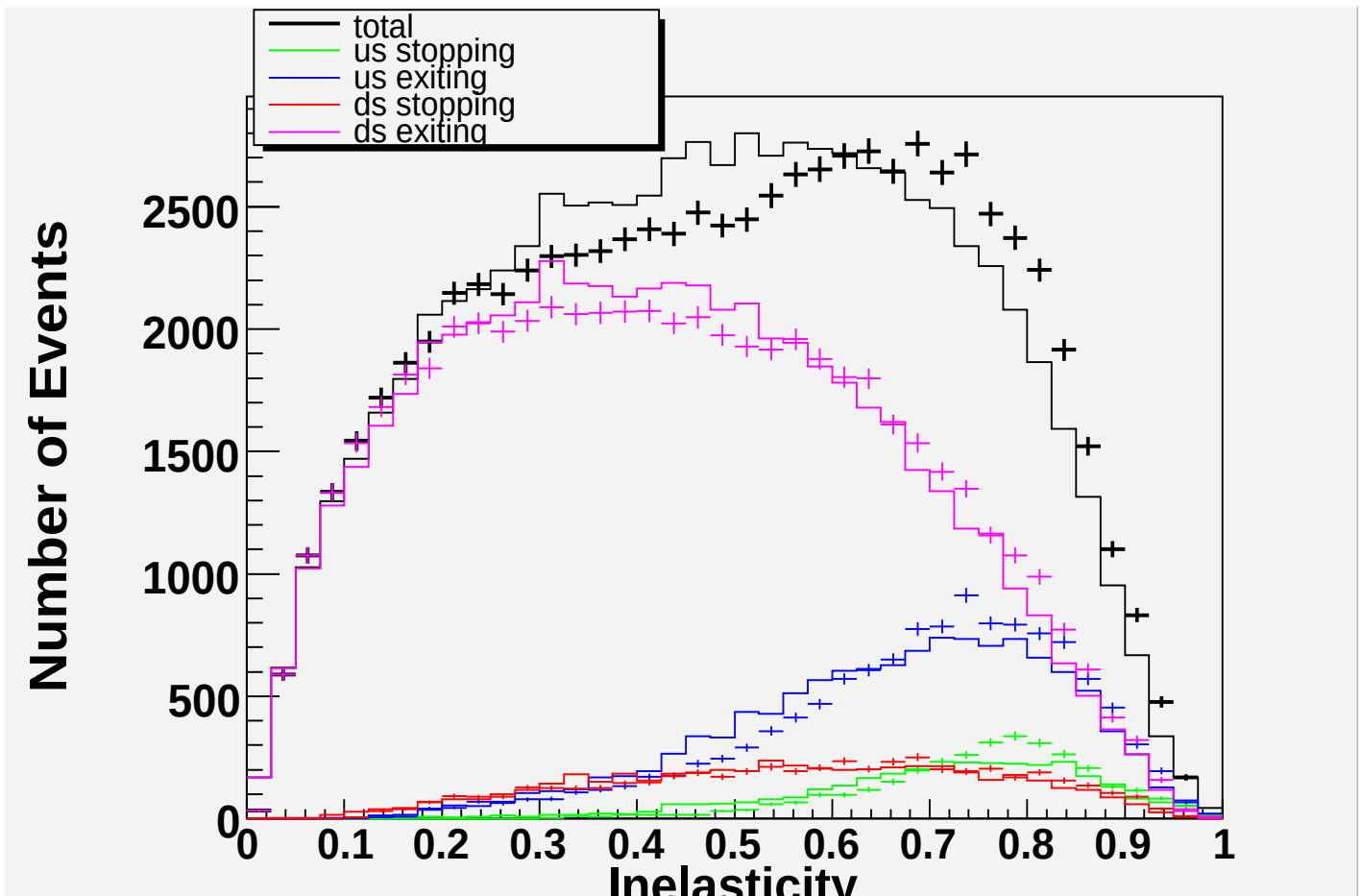


Selecting DIS events

- Events with atleast <u>one muon track</u>.
- PID > -0.1
  - Rejects NC background.
- Reconstructed $E_{shw} > 1$ GeV
  - To reject QEL.
- Reconstructed $E_{\nu} > 5$ GeV.
  - DIS events dominate.
  - Ratio of $\frac{\overline{\nu_\mu}}{\nu_\mu}$ is higher.
- A cut of $Q^2 > 1GeV^2$
  - To further reject QEL and RES events.

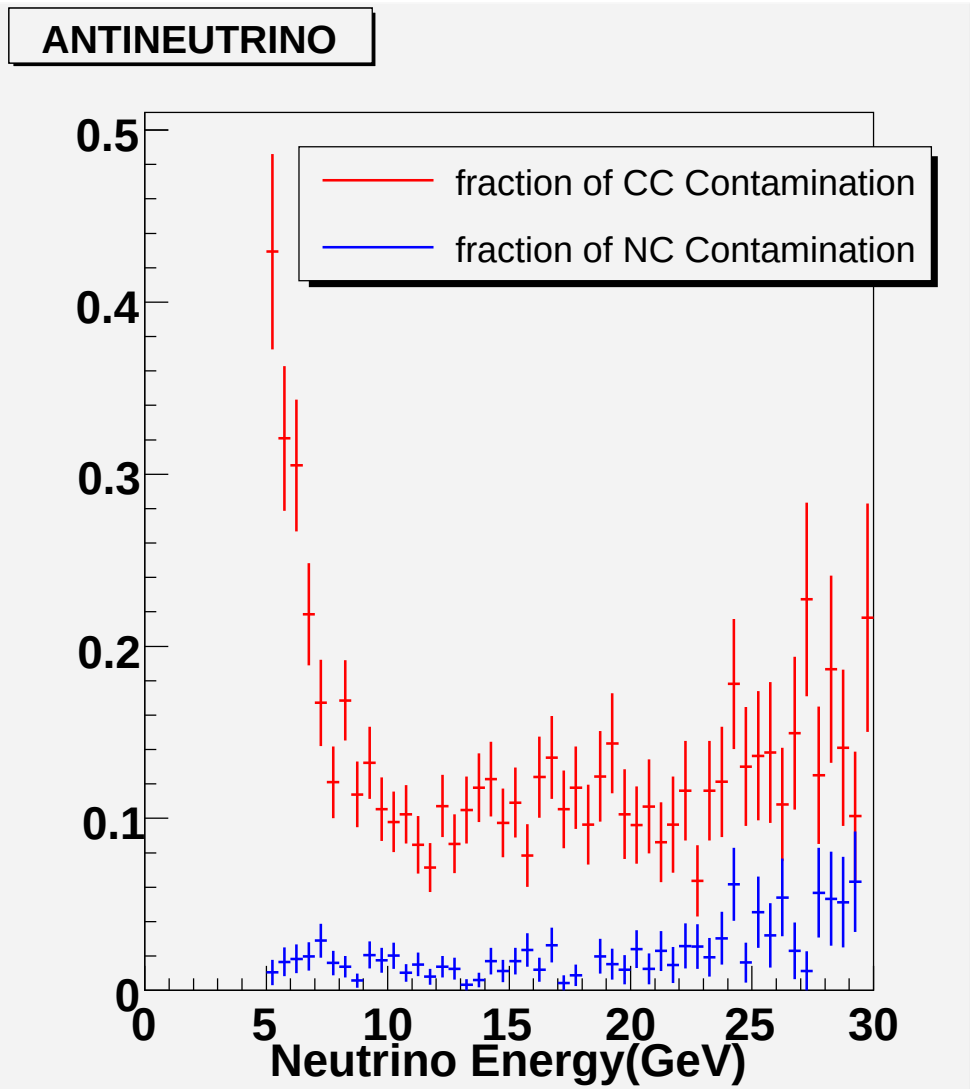


Inelasticity for neutrinos



back

contaminations in the $\bar{\nu}_\mu$ sample



- Neutral Current(NC) Contamination - Tracks in the shower being identified as μ^+s.
- Charged Current(CC) Contamination - Tracks from ν_μ CC being identified as μ^+s.
- Cuts applied on this plot:
  - Fiducial volume cuts.
  - DIS kinematic CUTS.

Low ν Relative Flux Extraction

- Start with the differential cross section equation , integrate over x for fixed ν

$$\frac{d\sigma}{d\nu} = A(1 + \frac{B}{A}\frac{\nu}{E} - \frac{C}{A}\frac{\nu^2}{2E^2})$$

$$A = \frac{G_F^2 M}{\pi}\int F_2(x)dx$$

$$B = -\frac{G_F^2 M}{\pi}\int (F_2(x) \mp xF_3(x))dx$$

$$C = B - \frac{G_F^2 M}{\pi}\int F_2(x)(\frac{1+2Mx/\nu}{1+R} - \frac{Mx}{\nu} - 1)dx$$

- To get the flux,integrate up to $\nu_o(\nu_0 = 1GeV)$

$$\Phi(\mathrm{E}) \propto \int_0^{\nu_0} \left(\frac{\frac{dN(\mathrm{E})}{d\nu}}{1 + \frac{B}{A}\frac{\nu}{E} - \frac{C}{A}\frac{\nu^2}{2E^2}} \right) d\nu$$

- At small ν/E

$$\frac{d\sigma^{\nu}}{d\nu} = \frac{d\sigma^{\overline{\nu}}}{d\nu} = A$$

relative flux is given by: $\Phi(E_\nu) \propto N(E_\nu)_{(\nu \to 0)}$

- Use the total cross-section to get the flux normalization.

Relative Flux Extraction(contd.)

- The first order corrections in ν/E depend on B/A

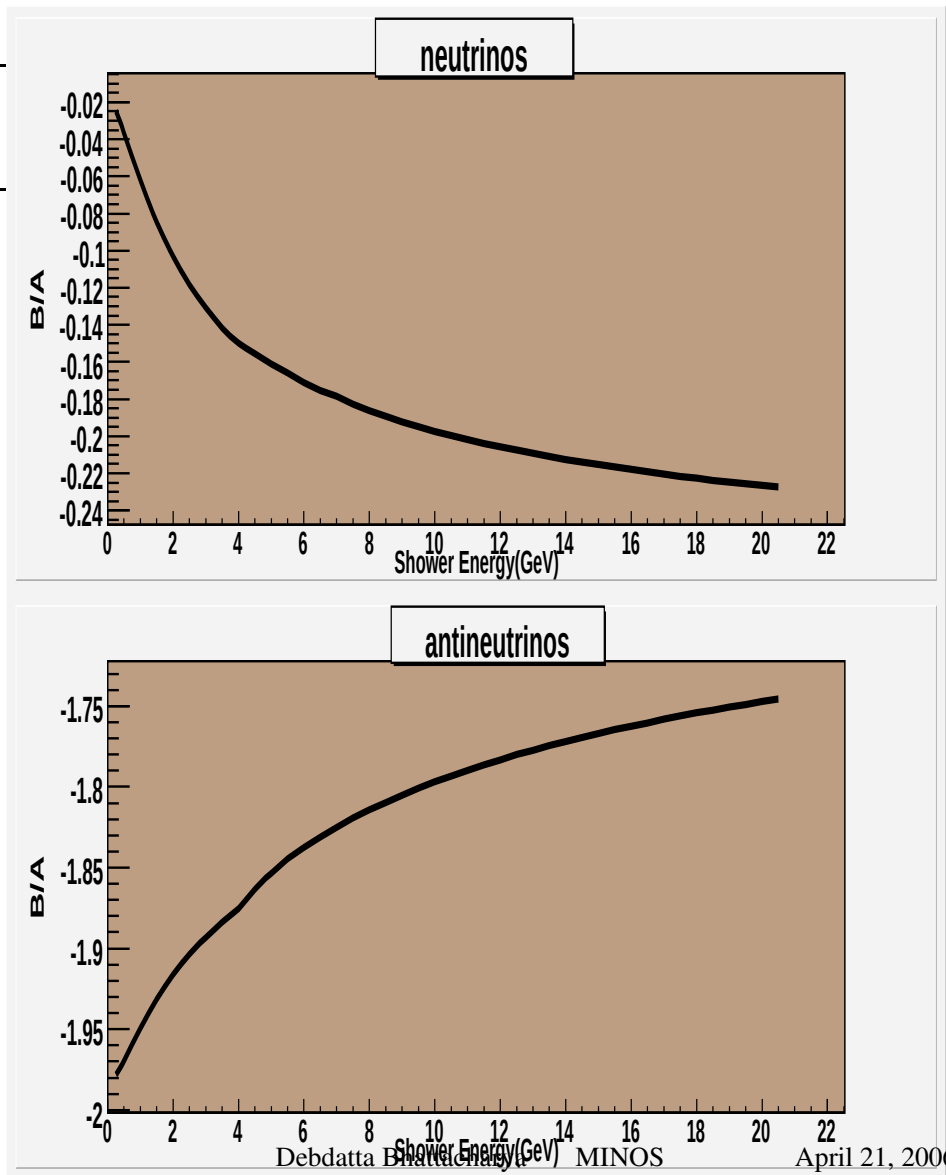
$$\left(\frac{B}{A}\right)^{\nu,\bar{\nu}} = -\frac{\int (F_2(x) \mp x F_3(x)) dx}{F_2(x) dx}$$

- We can get an estimate of B/A from the cross-section model. (theoretical uncert. at low ν).

- Maximum $(B/A)^{\nu}$ = -0.22 ,$(B/A)^{\overline{\nu}}$ = -2

E_ν (GeV)	effect of $\frac{B}{A}\frac{\nu}{E}$ corr (neutrinos)	effect of $\frac{B}{A}\frac{\nu}{E}$ corr (antineus)
5	2.2%	25%
10	1.1%	11%
20	0.55%	5%

- For neutrinos, correction small above 5 GeV.



Flux extraction with QEL

- To get the shape:A QEL enriched sample along with the knowledge of the cross-section shape will be used to extrapolate the flux(E_ν <10 GeV).
- To get the normalization:An inclusive CC sample along with the knowlegde of the total CC cross-section will used to get the normalization(10< E_ν <20 GeV).