Double differential charged current $\bar{\nu}_\mu$ DIS cross section analysis at MINERvA

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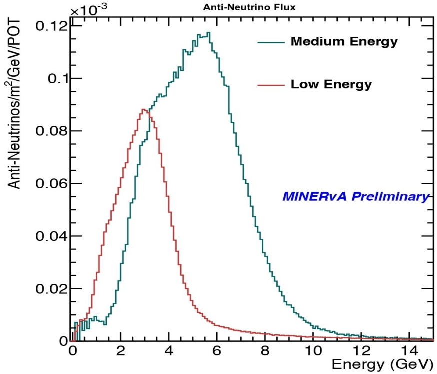
Introduction

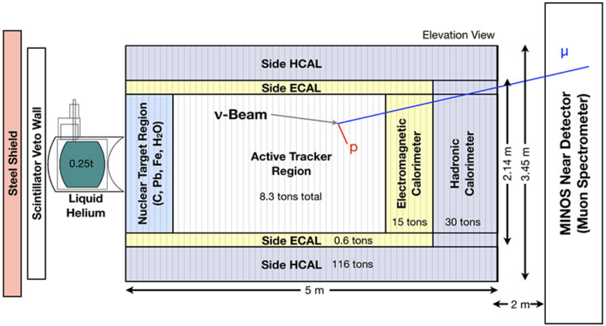
The knowledge of (anti)neutrino interactions with nucleons and nuclei is important in order to understand the hadronic interaction in the weak sector and to reduce the systematic uncertainty in the neutrino oscillation parameters.

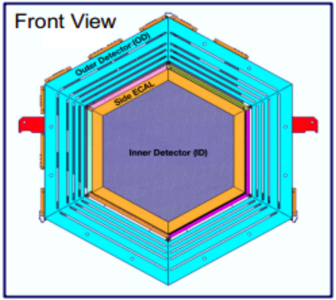
- Minerva is a (anti)neutrino-nucleus scattering experiment in the NuMI beamline.
- It has used $\nu_\mu(\bar{\nu}_\mu)$ beams in the low energy (3 GeV) and medium energy (6 GeV) with several targets like helium, carbon, water, Fe and Pb.
- The aim of experiment is to measure the scattering cross section and obtain the ratio for $\frac{\sigma_i}{\sigma_{CH}}$ and $\frac{d\sigma_i}{d\sigma_{CH}}$; (i= Fe, Pb, C, CH).



MINERνA experimental setup

Solid-scintillator tracking calorimeter





MINOS works as muon spectrometer

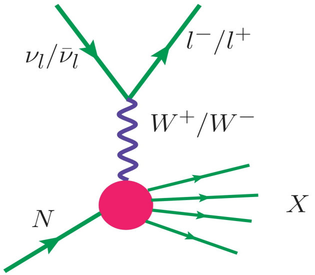
Analysis goal

The goal of this analysis is to extract the double differential antineutrino Deep Inelastic Scattering (DIS) cross section versus variables x (Bjorken variable) and Q^2 (four momentum transfer squared) in nuclear targets regions (C, Fe, Pb) as well as in the tracker region. We will also extract the cross section ratios of passive nuclear targets to the scintillator (CH).

$$\frac{d^2\sigma}{dxdQ^2} = \frac{\sum_{ij} U_{ij\alpha\beta}(N_{data,ij} - N_{ij}^{bkgd})}{A_{\alpha\beta}(\Phi T)(\Delta x \Delta Q^2)}$$

- $U_{ij\alpha\beta}$ Unfolding
- $A_{\alpha\beta}$ Efficiency correction
- $\Delta x \Delta Q^2$ Bin width normalization

Deep inelastic scattering process



$Q^2 \geq 1GeV^2$ & $W \geq 2GeV$

General expression for DIS process

$$\nu_l/\bar{\nu}_l(k) + N(p) \rightarrow l^-/l^+(k') + X(p')$$

Kinematics

Four Momentum transfer square $Q^2 = -q^2 = -(k-k')^2$; $Q^2 = 4E_l E_{l'}$

Energy transfer $\nu = E_l - E_{l'}$

Bjorken variable $x = -\frac{q^2}{2pq} = \frac{Q^2}{2M\nu}$ and Inelasticity $y = \frac{E_{had}}{E_\nu}$

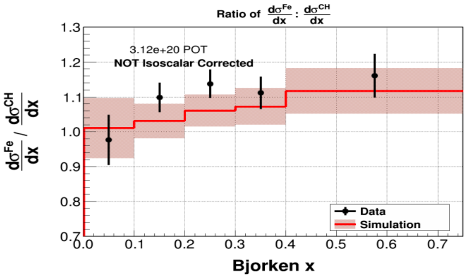
Invariant mass square $W^2 = (p+q)^2 = M^2 + q^2 + 2M\nu$

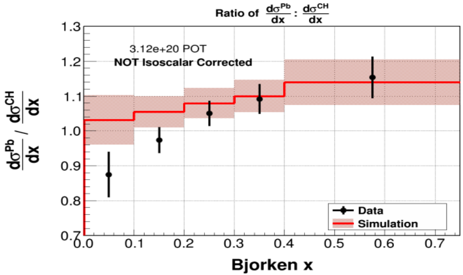
Double Differential cross section

$$\frac{d^2\sigma^{\nu(\bar{\nu})}}{dxdy} = \frac{G_F^2 M E_\nu}{\pi}\left(1+\frac{Q^2}{m_W^2}\right)^{-2}\Bigg(\left[y^2x + \frac{m_l^2 y}{2E_\nu M}\right]F_{1N}(x,Q^2) + \left[\left(1-\frac{m_l^2}{4E_\nu^2}\right) - \left(1+\frac{Mx}{2E_\nu}\right)y\right]F_{2N}(x,Q^2)$$
$$\pm \left[xy\left(1-\frac{y}{2}\right) - \frac{m_l^2 y}{4E_\nu M}\right]F_{3N}(x,Q^2)\Bigg)$$

DIS analyses at MINERvA

- DIS analysis in neutrino mode for low energy ($< E_{\nu_\mu} >$ $3GeV$) region is already published. PRD 93 (2016) 7, 071101
- One dimensional DIS analyses for both neutrino and antineutrino modes in medium energy ($< E_{\nu_\mu} >$ $6GeV$) region are almost done.
- Two dimensional DIS analyses for both neutrino and antineutrino modes in medium energy ($< E_{\nu_\mu} >$ $6GeV$) region are ongoing.





Analysis Details: Signal and Background estimation

Signal

All CC antineutrino DIS events that are in given material with E_μ 2-50GeV and $\theta_\mu < 17^0$

Two main backgrounds: Wrong material(Plastic background) and non-DIS (Physics background)
Other backgrounds: Neutral current and Wrong signed (ν contamination in $\bar{\nu}$), etc.

Non-DIS Backgrounds

Non-DIS events which entered in DIS sample due to imperfect reconstruction of the W and Q^2

Wrong Material Backgrounds

Scintillator events which got reconstructed in targets region

To extract the constraint background, we study the sideband regions just outside of the signal region and fit the Data MC ratio in each sideband region to extract the scaling factors

Non DIS backgrounds (Physics backgrounds)

- Events that passes Q^2 and W cuts in the reconstruction process due to because of imperfect detector resolution

- Non-DIS backgrounds are divided into two sideband regions

DIS signal

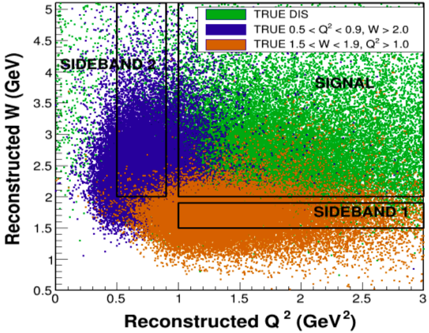
$Q^2 \geq 1 GeV^2$ & $W \geq 2 GeV$

Continuum or Low Q^2

$0.3 GeV^2 \leq Q^2 < 0.9 GeV^2$ & $W \geq 2 GeV$

Transition or Low W

$Q^2 \geq 1 GeV^2$ &$1.5 GeV \leq W < 1.9 GeV$

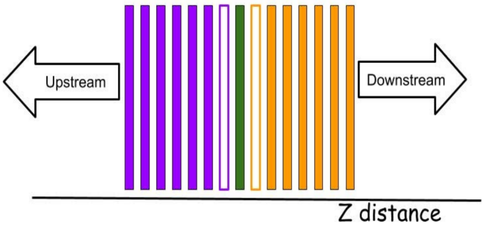


- Separate scale factors are extracted for both the sideband regions

Wrong Material Backgrounds (Plastic backgrounds)

- **Events that are coming from the neighboring scintillator planes but got reconstructed in the passive target**
- **These are also divided into two sideband regions, upstream and downstream sideband regions**

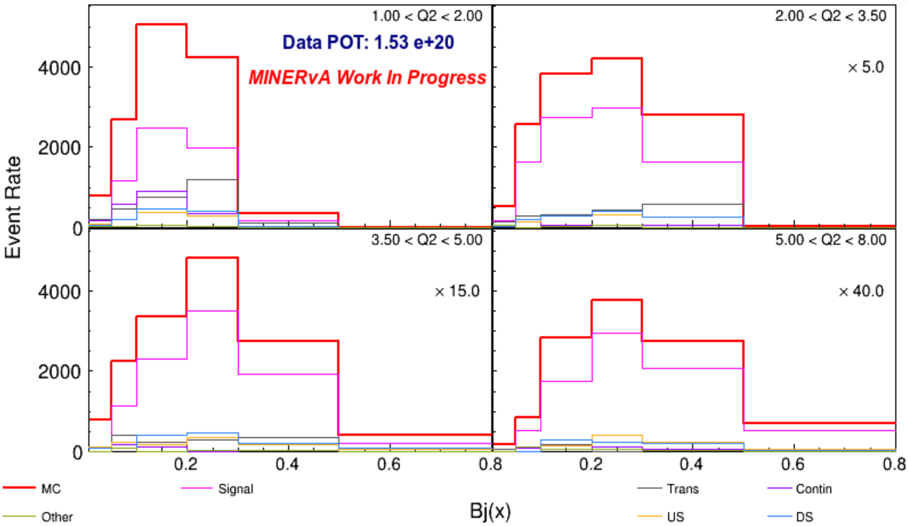
Upstream SB region: Interactions that took place upstream of the nuclear target region
Downstream SB region: Interactions that took place downstream of the nuclear target region



Event distribution $Bj(x)$ in bins of Q^2 with Bkg

Iron of all targets

- Using machine learning vertex reconstruction process
- $\frac{1}{8}$times statistics of total available
- Signal: $\sim$ 53%
- Total background:$\sim$ 47%

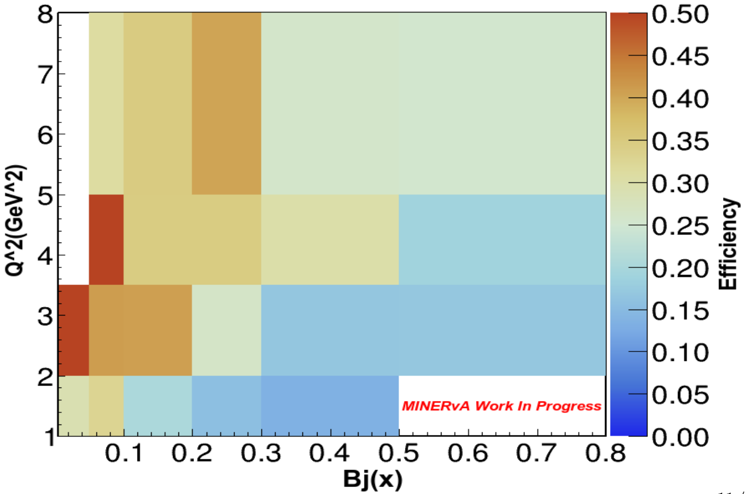


Efficiency $Bj(x)$ in bins of Q^2

Iron of all targets

Efficiency= $\frac{\text{Reconstructed sample (True and Reco Cuts)}}{\text{True sample (True cuts only)}}$

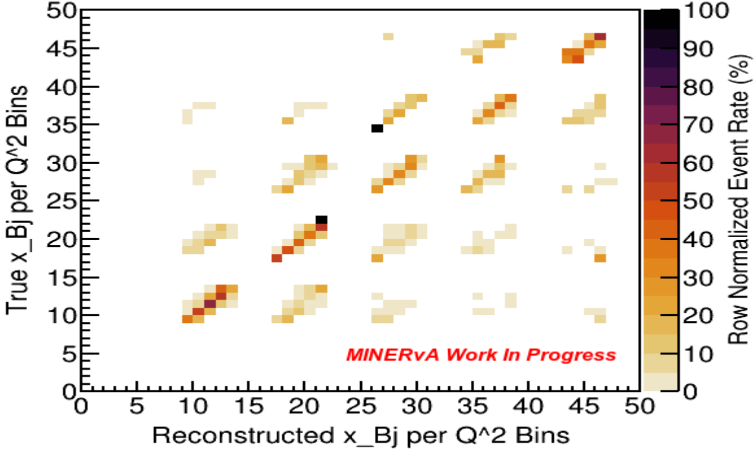
- Efficiency is the ratio of the reconstructed events which pass both True as well as Reco cuts to Truth events
- Due to the limited statistics,the efficiency plots are with combined targets



Migration (x & Q^2)

Iron of all targets

Migration matrix U_{ij} maps a reconstructed variable from the j bin to true variable in the i bin



- The migration matrix tells us how good our reconstruction process is.
- Events on the diagonal are the ones which were reconstructed in the correct bin.
- Each bigger box is a Q^2 bin while the smaller boxes in the big one are the x bins.

Conclusion

- The analysis is in progress and we are finalizing the production of data and simulation samples.
- This analysis will help us to understand the nuclear medium effects in the DIS region.
- Analysis will be useful in reducing the systematics in determination of neutrino oscillation parameters.
- Analysis will also help to understand the hadronic structure of nucleons.


Thank You