2D Inclusive $\bar{\nu}_\mu$ CC Analysis in Medium Energy

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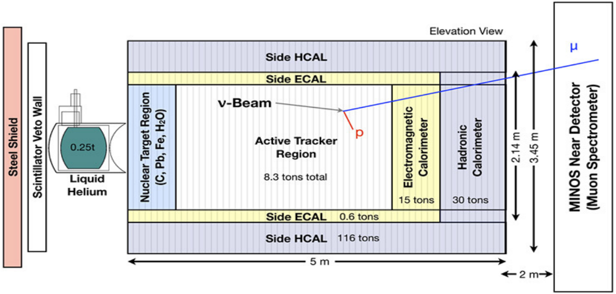
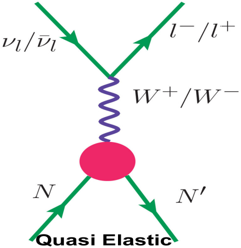
Working with MINERvA experiment

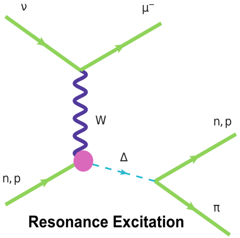


- MINERvA is a Neutrino-Scattering experiment in the NuMI (Neutrinos at the Main Injector) beamline in the average energy range of 3GeV and **6** GeV.
- It is 100m underground, sitting directly in front of MINOS detector. Source of the beam is Neutrinos at Main injector beamline NuMI which uses 120GeV proton beams from Fermilab main injector.

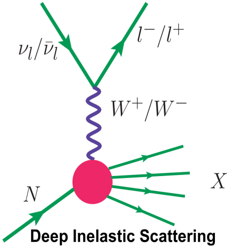
Inclusive Analysis



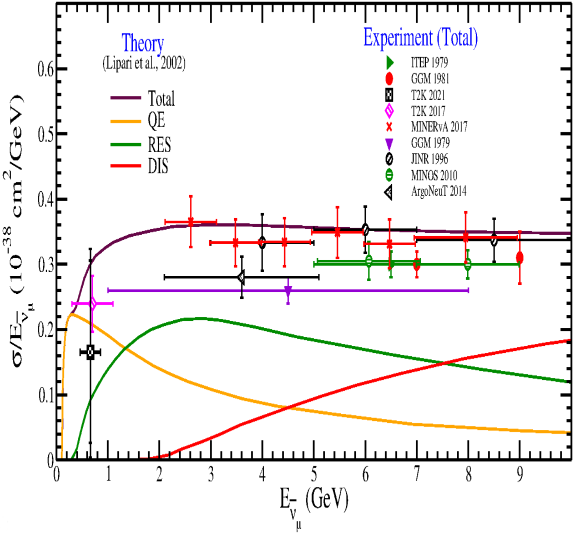
Quasi Elastic



Resonance Excitation



Deep Inelastic Scattering



Analysis Goal

- The goal of my analysis is to calculate **inclusive** double differential $\bar{\nu}_\mu$ CC cross section ratios in the nuclear target and the tracker region vs Bjorken x (or W) and Q^2, using medium energy (ME) beam at MINERvA.

$$Q^2 = -q^2 = 4E_\nu E_\mu sin^2\frac{\theta}{2} \quad \text{(Four momentum transfer squared)}$$

$$W = \sqrt{M^2 + 2p.q - Q^2} \quad \text{(Invariant Mass)}$$

$$x = \frac{Q^2}{2M(E_\nu - E_\mu)} \quad \text{(Bjorken variable x)}$$

for a scattering process like:

$$\nu_\mu(\bar{\nu}_\mu)(k) + N(p) \rightarrow \mu^-(\mu^+)(k') + N'(p')$$
$$\nu_\mu(\bar{\nu}_\mu)(k) + N(p) \rightarrow \mu^-(\mu^+)(k') + R(p')$$
$$\nu_\mu(\bar{\nu}_\mu)(k) + N(p) \rightarrow \mu^-(\mu^+)(k') + X$$

What do we do at MINERvA ?

- **Cross sections** for ν and $\overline{\nu}$ scattering off nucleons as a whole and also Deep inelastic scattering, where high energy neutrinos(antineutrinos) probe deep inside the nucleons and see individual quarks.

- **Medium effects** This is to study how Z and A or targets affect neutrino interactions. This is done by using various upstream targets like carbon, water, iron and lead.

- **Final state interactions** Products of a neutrino interaction and how they are affected by final-state interactions exiting the nucleus.

Cross Section Extraction

$$\left(\frac{d^2\sigma}{dxdQ^2}\right)_{\alpha\beta} = \frac{\Sigma_{ij} U_{ij\alpha\beta}(N_{\text{data},ij} - N_{ij}^{\text{Bkgd}})}{A_{\alpha\beta}(\Phi T)(\Delta x)_{\alpha}(\Delta Q^2)_{\beta}}$$

Cross Section Extraction

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where,

$N_{\textbf{data},ij}$ is the number of data events reconstructed in bin (i,j)

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$N_{\text{data},ij}$ is the number of data events reconstructed in bin (i,j)

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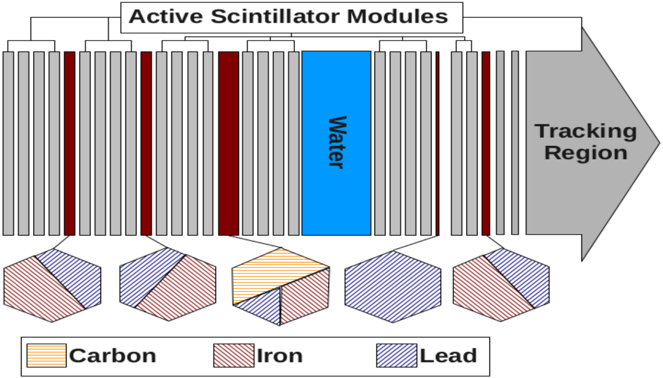
Target Region



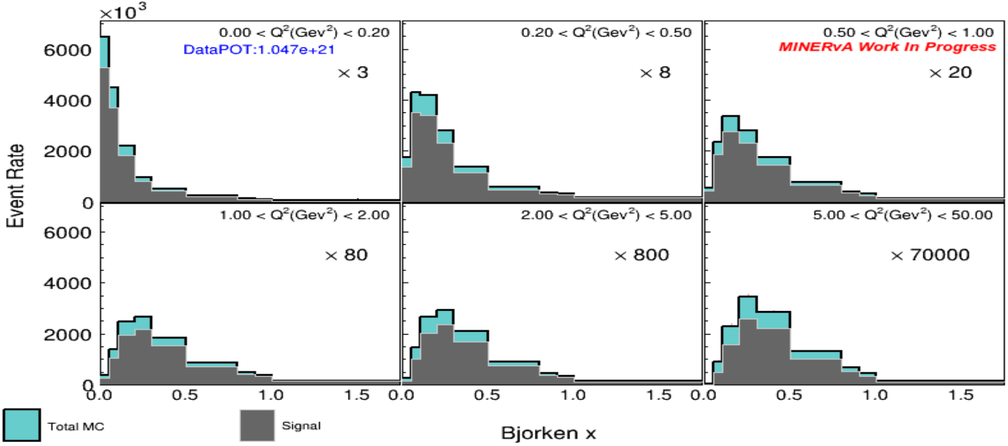
Event Distribution - Full Antineutrino sample - Combined IRON

Data POT : 1.05×10^{21}

Event Breakdown	Total events	Percentage events
Events passing through reconstruction cuts	199844	100%
Signal (CC $\bar{\nu}_\mu$)	165656	82.9%
Total Background	34188	17.1%
Wrong Material/Target	33467	97.9%
Plastic	31834	93.2%
Wrong material(Not Plastic)	1633	4.7%
Other(NC +WS)	721	2.1%
Wrong Signed	660	1.9%
Neutral Current	61	0.2%

Event Distribution → Reconstructed x - Q^2

Simlulation Statistics is ≈ 4 times data POT



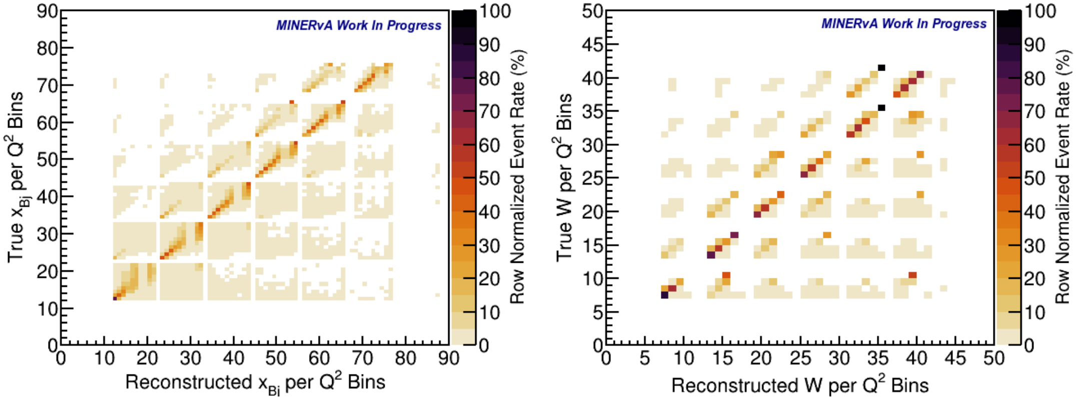
Binning for x = $\{0,0.05,0.1,0.2,0.3,0.5,0.8,0.9,1.0,1.75\}$

Cross Section Extraction

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

where,
$N_{\text{data},ij}$ is the number of data events reconstructed in bin (i,j)
N_{ij}^{Bkgd} is the estimated number of background events reconstructed in bin (i,j)
$U_{ij\alpha\beta}$ is the element of migration matrix connecting reconstructed bin (i,j) to true bin (α, β)

Migration Matrices (Combined Iron Target) full RHC sample



Binning for x = {0,0.05,0.1,0.2,0.3,0.5,0.8,0.9,1.0,1.75}
Binning for Q^2 = {0,0.2,0.5,1,2,5,50}
Binning for W = {0,2,5,8,10}

Cross Section Extraction

$$\left(\frac{d^2\sigma}{dxdQ^2}\right)_{\alpha\beta} = \frac{\Sigma_{ij} U_{ij\alpha\beta}(N_{\text{data},ij} - N_{ij}^{\text{Bkgd}})}{A_{\alpha\beta}(\Phi T)(\Delta x)_\alpha (\Delta Q^2)_\beta}$$

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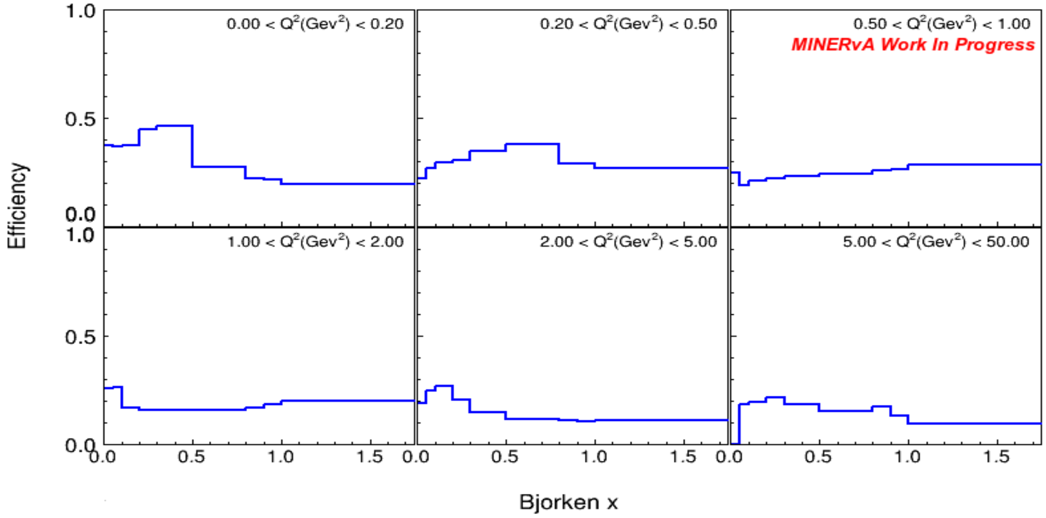
$A_{\alpha\beta}$ is the reconstruction efficiency for events in true bin (α, β)

Efficiency (Combined Iron Target) full RHC sample



Cross Section Extraction

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Φ is the flux of incoming (anti)neutrinos

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T is the number of scattering targets (number of protons)

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Δx_{α} is the width of bin α

Cross Section Extraction

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Φ is the flux of incoming (anti)neutrinos

T is the number of scattering targets (number of protons)

Δx_α is the width of bin α

ΔQ^2_β is the width of bin β

Conclusions

- Successfully performed background subtraction in both nuclear target and tracker region.
- Need to run the whole analysis with full systematic uncertainties.
- The measurement will help in benchmarking models to be used by future neutrino experiments.

- This is our chance to see how accurately oscillation experiments can predict antineutrino energy distributions given that so much energy goes into the neutrons that are invisible in most oscillation experiment detectors.


THANKS
FOR
BEING SO
SUPER!

Backup

(Tracker Region)

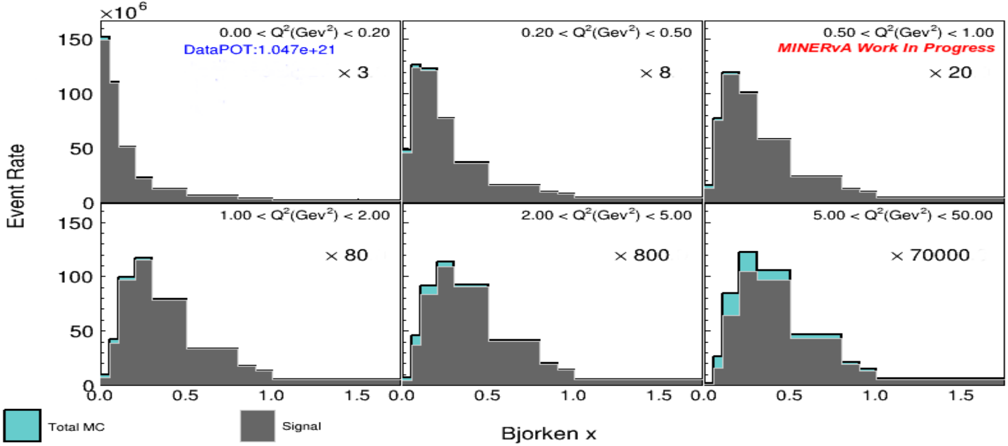
Inclusive Total Event Breakdown - Tracker

Data POT : 1.047×10^{21}

Event Breakdown	Total events	Percentage events
Events passing through reconstruction cuts	5.77×10^{6}	100%
Signal (CC $\bar{\nu}_\mu$)	5.66×10^{6}	98.5%
Total Background	82183	1.5%
Other(Vertex location outside fiducial)	62397	76%
Wrong Signed	17056	20.7%
Neutral Current	2730	3.3%

Event Distribution → x - Q^2

Simlulation Statistics is ≈ 4 times data POT



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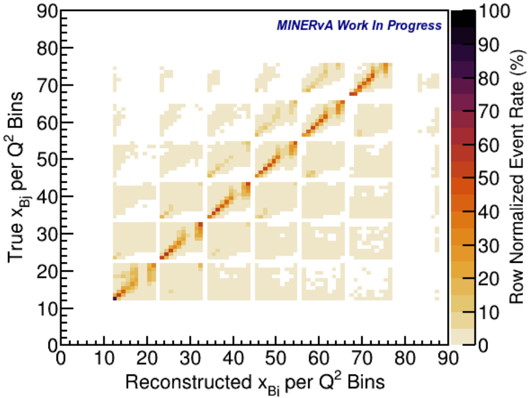
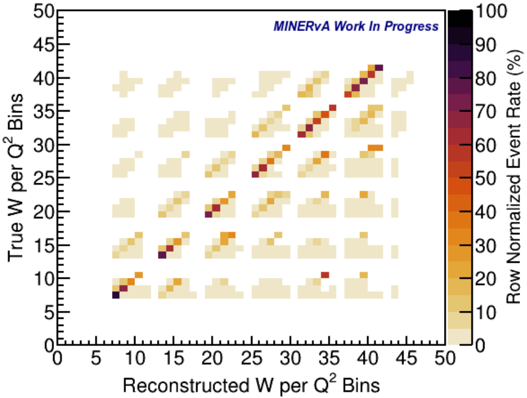
Migration Matrices (full tracker region) full RHC sample





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Efficiency (full tracker region) full RHC sample