Neutrino Interaction Physics

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Imperial College London

- Neutrino nucleus interactions
- Atmospheric neutrino interactions
- MINERνA

Neutrino Nucleus Interactions

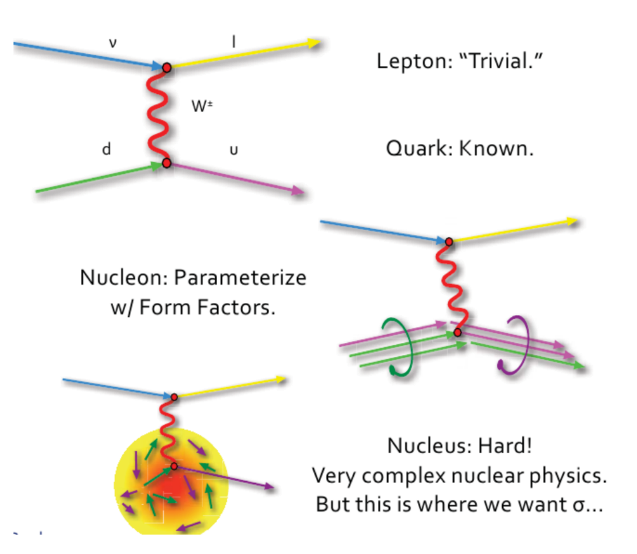
Introduction

We measure neutrino event rates with our detectors:

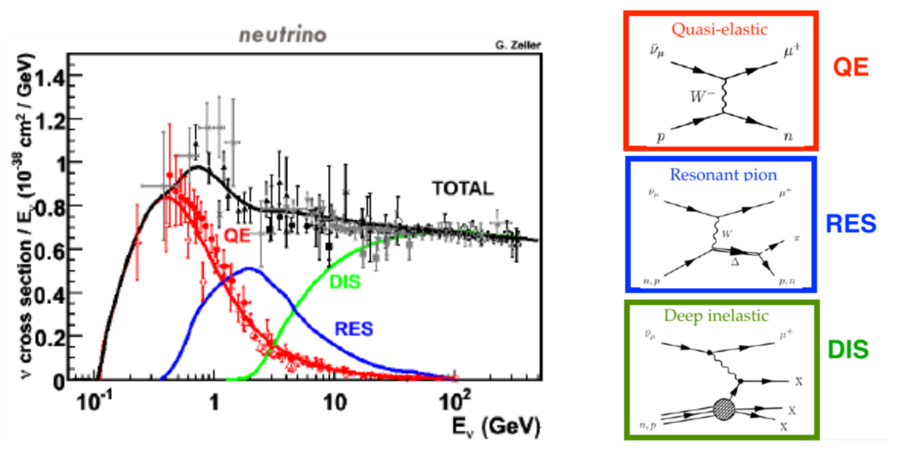
$$\text{Event rate} = \text{Flux} \times \text{Cross Section} \times \text{Detector Smearing}$$

This means we need to understand our detectors and neutrino nucleus interaction cross sections in order to extract the flux (including oscillation parameters)

The Problem



G. Purdue


neutrino
G. Zeller
ν cross section / E$_ν$ (10^{-38} cm^2 / GeV)
E$_ν$ (GeV)
TOTAL
QE
DIS
RES
Quasi-elastic
QE
Resonant pion
RES
Deep inelastic
DIS

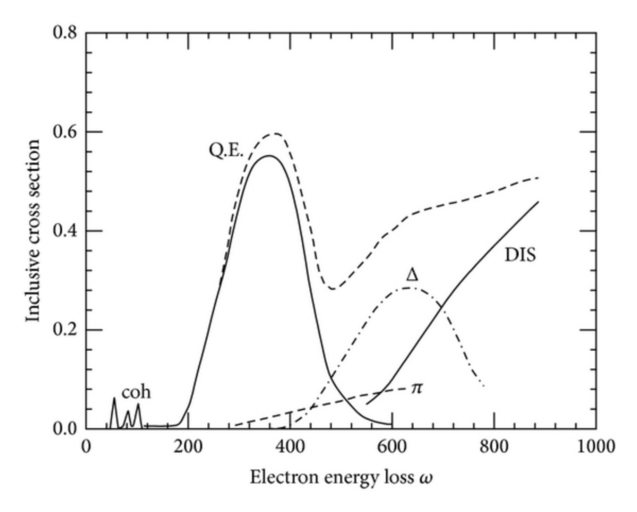
G. Zeller

- Different neutrino interaction modes dominate at different energies
- Below 1 GeV predominantly CCQE
- Above a GeV resonant pion production, higher resonances, DIS
- Above 10 GeV predominantly DIS

Electron Scattering

- You can also use electron/muon scattering to probe many effects
- No axial current but can measure energy transfer
- Same nuclear initial state and final state effects

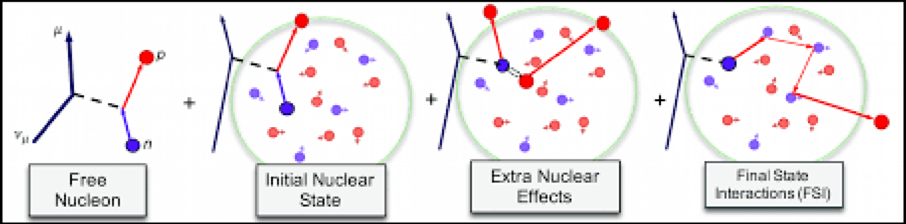
Sketch of Electron Scattering



Advances in High Energy Physics, 912702, 2013

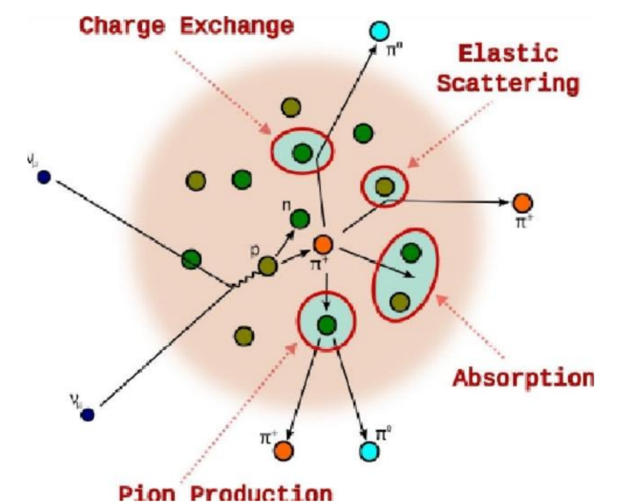
But wait, there's more

- Non-resonant pion production
- Multi-nucleon interactions
- Higher resonances
- Final state interactions
- Nuclear scaling
- …


Free
Nucleon
Initial Nuclear
State
Extra Nuclear
Effects
Final State
Interactions (FSI)
+
+
+

C. Wilkinson

Final State Interactions



T. Golan

Short Range Correlations between nucleons

Nucleons can occupy high momentum states in pairs (or triplets etc) inside nuclei, observed in electron scattering

- Nucleons preferentially form proton-neutron pairs where possible
- Larger nuclei (like argon) contain more neutrons than protons
- This means neutrons have a higher probability than protons be unpaired
- Possible implication for neutrino vs antineutrino interactions

Results from CLAS (Electron Scattering)

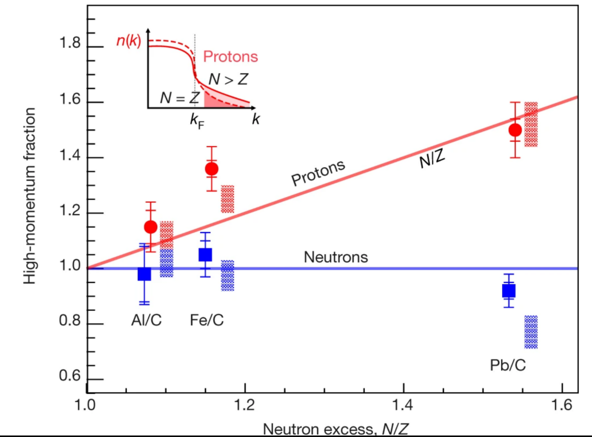


Image: Nature volume 566, pages 354–358 (2019)

More on nuclear scaling

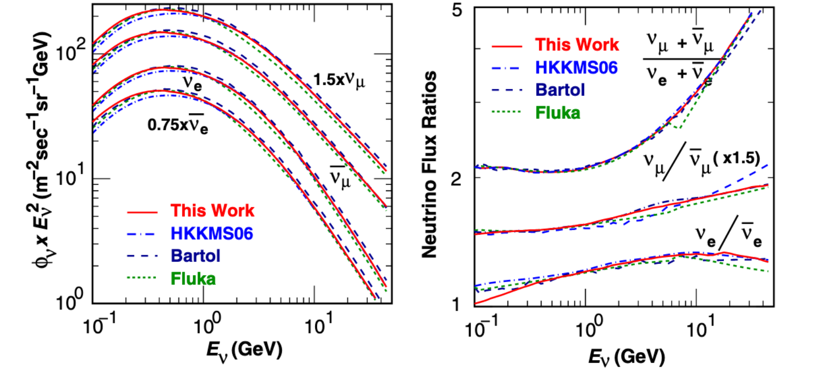
See Anežka Klustová's talk later!

15:30 - 16:30 Student quick fire talk session

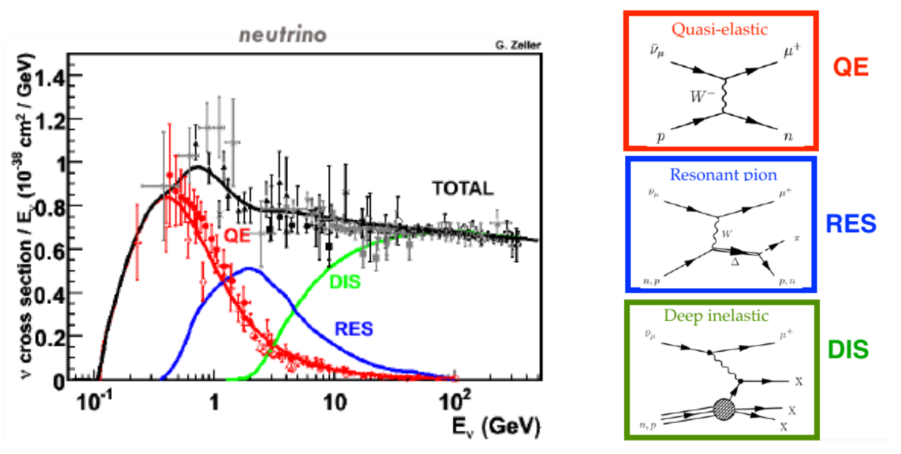
- 15:30-15:40 Atmospheric muon measurement in DMIce (Rogan Clark)
- 15:40-15:50 The MaCh3 Oscillation Analysis Fitter (Thomas Holvey)
- 15:50-16:00 Measurement of Nuclear Dependence in Inclusive Antineutrino Scattering with MINERvA (Anežka Klustová)
- 16:00-16:10 Extracting intranuclear dynamics of the argon nucleus with ProtoDUNE (Kang Yang)
- 16:10-16:20 Hyper-Kamiokande event reconstruction using machine learning technique (Joanna Gao)

Atmospheric Neutrino Interactions

Atmospheric Neutrino Flux



Phys. Rev. D 83, 123001 (2011)


neutrino
G. Zeller
ν cross section / E$_\nu$ (10^{-38} cm^2 / GeV)
E$_\nu$ (GeV)
TOTAL
QE
DIS
RES
Quasi-elastic
W^-
Resonant pion
Deep inelastic
QE
RES
DIS

G. Zeller

Mass Hierarchy

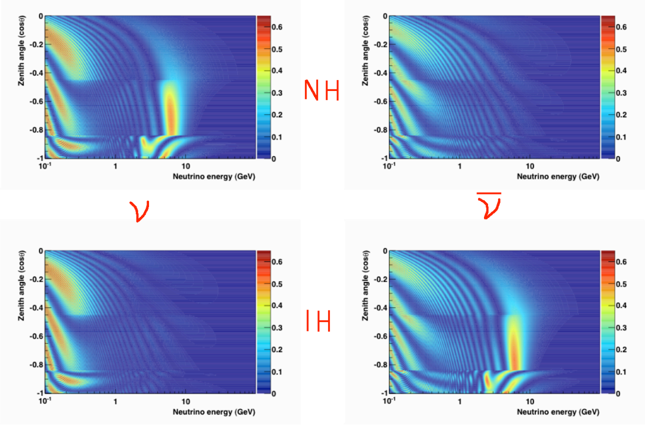


Figure 1. Neutrino oscillation probabilities from muon neutrino to electron neutrino (ν_μ to ν_e) as a function of cosine of zenith angle and neutrino energy. The cases of normal hierarchy are shown in the upper figures, and inverted hierarchy are lower. Left (right) are those of neutrino.

K. Okumura / Physics Procedia 61 (2015) 619 – 626

Mass Hierarchy

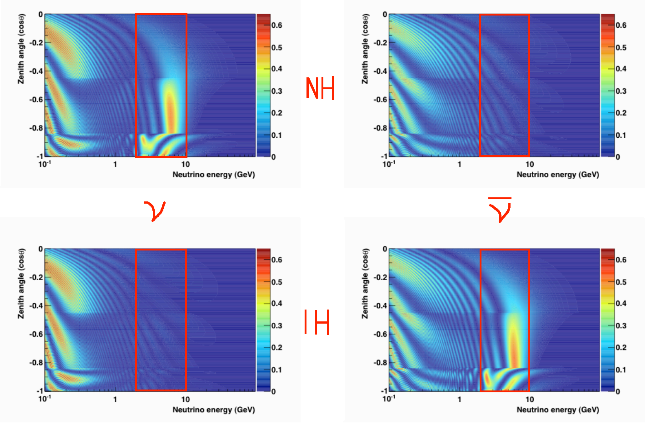
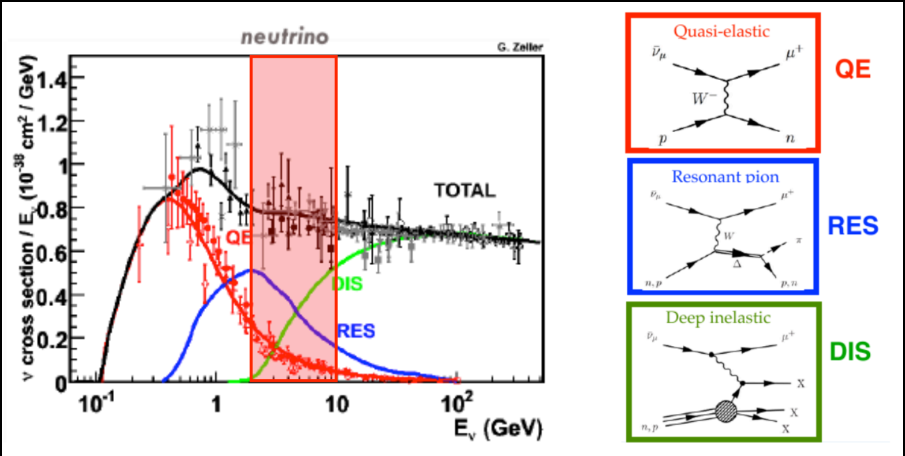


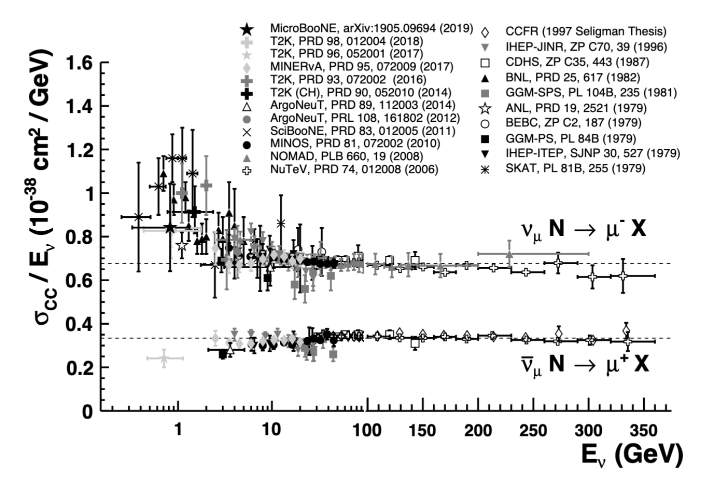
Figure 1. Neutrino oscillation probabilities from muon neutrino to electron neutrino (ν_μ to ν_e) as a function of cosine of zenith angle and neutrino energy. The cases of normal hierarchy are shown in the upper figures, and inverted hierarchy are lower. Left (right) are those of neutrino.

Mass Hierarchy

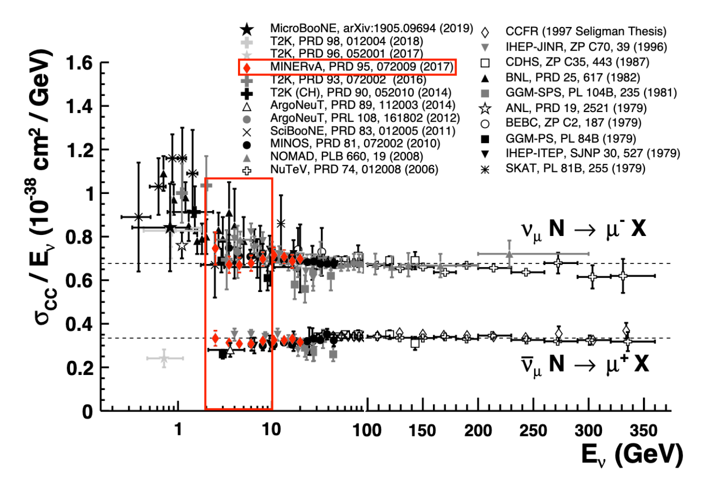
- Different matter resonance in 2-10 GeV region


neutrino
G. Zeller
ν cross section / E_ν (10^-38 cm^2 / GeV)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
10^-1
1
10
10^2
E_ν (GeV)
TOTAL
QE
DIS
RES
Quasi-elastic
W^-
p
n
QE
Resonant pion
Δ
π
RES
Deep inelastic
X
X
X
DIS

Experimental Landscape



PDG



In 2-10 GeV region, leading measurements from MINERνA

MINERνA

MINERνA

MINERνA (Main Injector Neutrino ExpeRiment to study ν-A interactions)

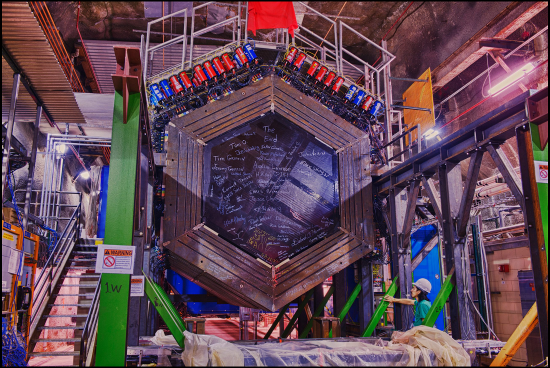
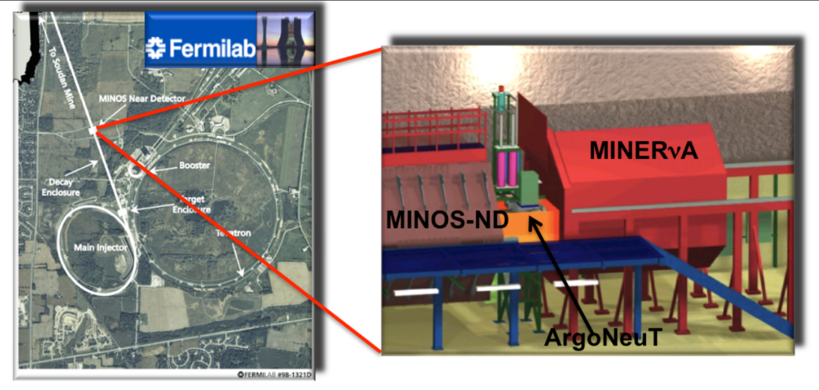


Image: Reidar Hahn

MINERνA



M. Antonello

MINERνA

Accelerator neutrino beam, similar to atmospheric neutrino production but controlled

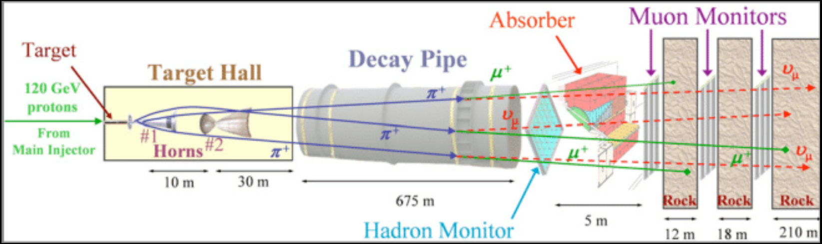
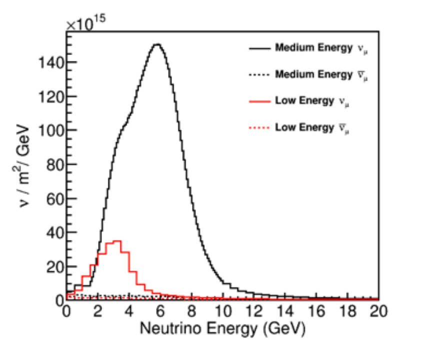


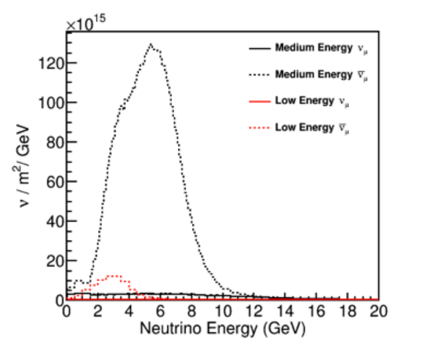
Image: Alex Sousa

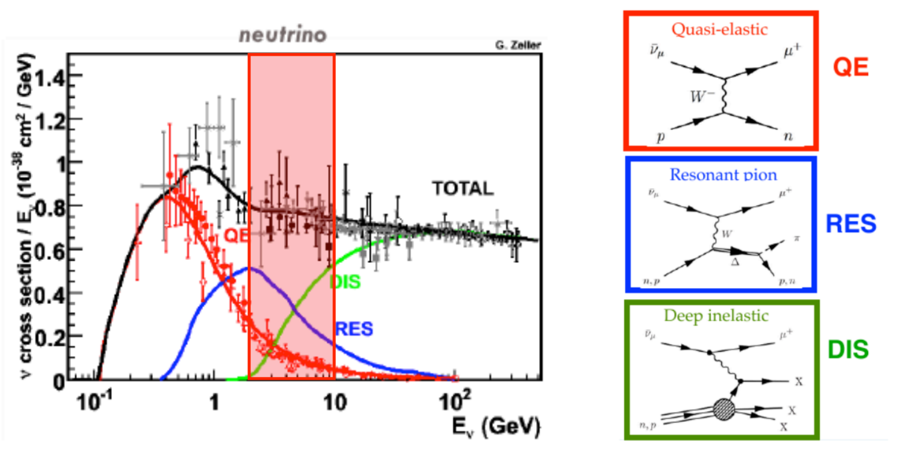
MINERνA

- Highly segmented plastic scintillator detector plus nuclear targets
- Recently completed data taking
- Wealth of published and yet to be published results
- In particular antineutrino data, 20x previously published interactions

MINERνA Flux

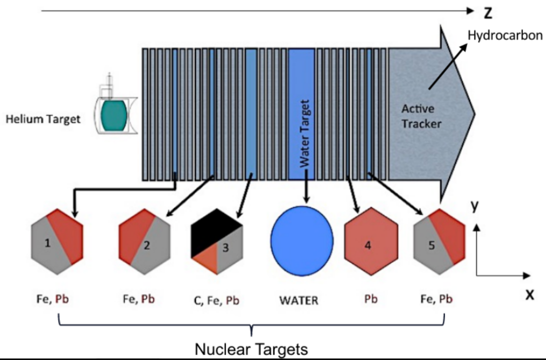






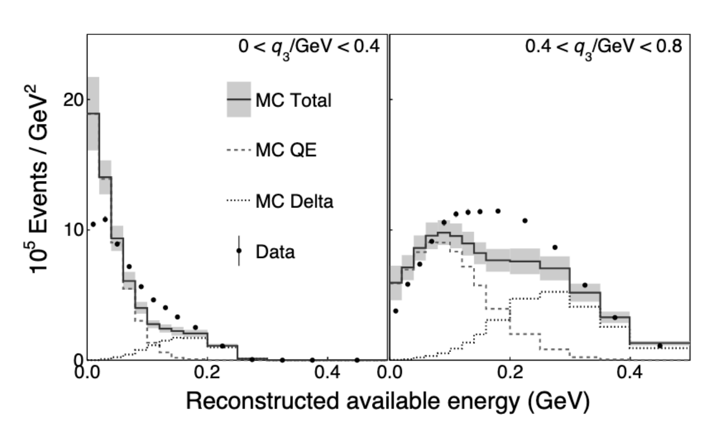
Exactly the energy range we were interested in!

MINERνA



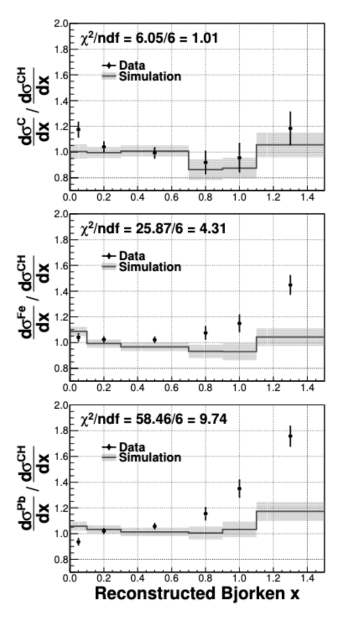
MINERνA has nuclear targets that are both lighter and heavier than argon and water, and high statistics neutrino and antineutrino data

MINERνA Low Three Momentum Transfer (Low Energy Beam)

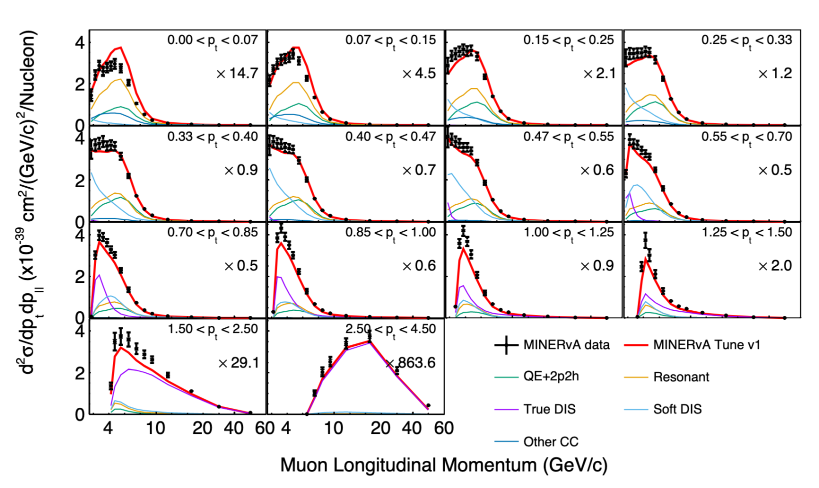


arχiv: 1511.05944

MINERνA Nuclear Scaling (LE) (arχiv: 1403.2103)



MINERνA Nuclear Scaling (Medium Energy Beam) (arχiv: 2106.16210)



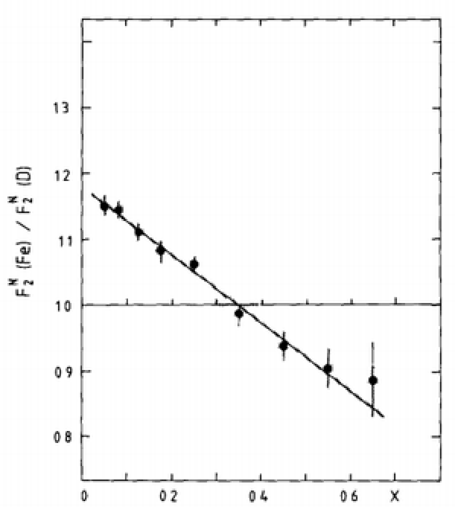
Summary

- There are many open questions in neutrino interaction physics
- Atmospheric neutrinos cover a broad energy range and are subject to many different nuclear effects
- MINERνA making important interaction measurements in the interesting region for mass hierarchy determination

Thank You

Back Up

The EMC Effect in Nuclear Scaling



Phys. Lett. B 123 275-278 (1983)