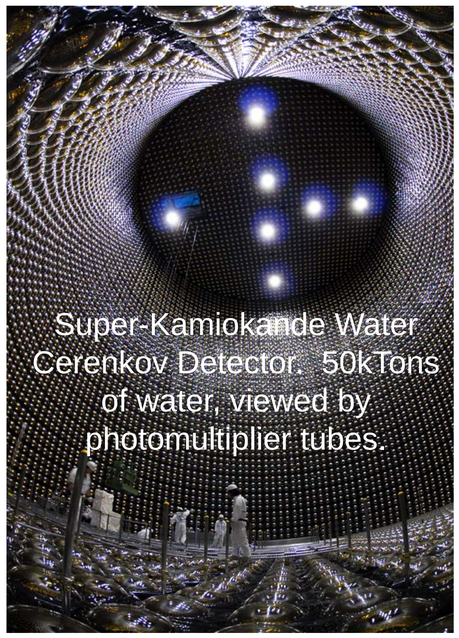
# MINERvA: Bringing Neutrinos into Sharp Focus

## MINERvA: Goals And Methods

Neutrino oscillations offer a chance to find a ***new source of matter-antimatter asymmetry***.

The Universe is matter-antimatter asymmetric. What caused this? Inquiring minds want to know.

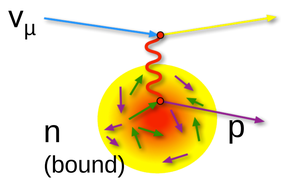



Water Cerenkov detectors can only see high velocity particles that exceed the speed of light in water. They miss a lot!

Neutrinos rarely interact, so neutrino oscillation experiments use massive nuclear targets with limited detection abilities. But these same detectors must be able to ***identify neutrino flavor*** and ***measure neutrino energy***.

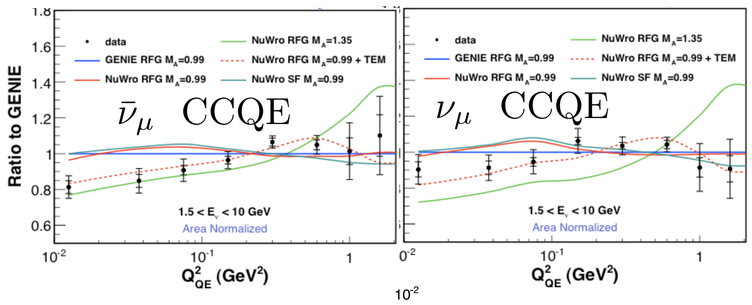
## Quasi-Elastic Scattering

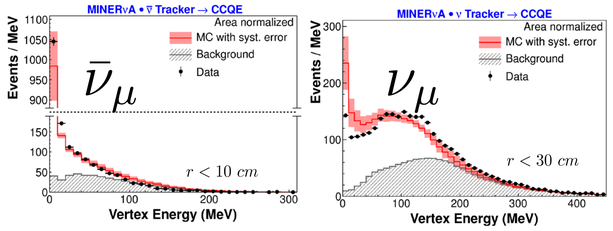
Phys Rev. Lett. 111, 002051 and 002052 (2013)




What is effect of nucleus?

Compare shape of $d\sigma/dQ^2$ to models



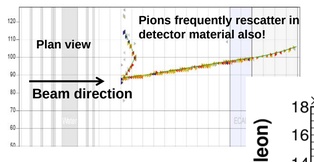

Look for energy near vertex consistent with extra nucleons *Data would prefer if 25±9% of events ejected initial state np pairs (final state nn or pp)*

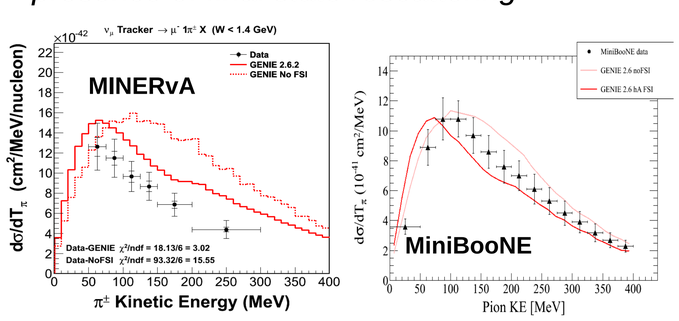
Rate vs $Q^2$ and vertex energy hint at initial state correlated nucleons

## Pion Production

**Do we correctly model nuclear rescattering, "final state interactions"?**

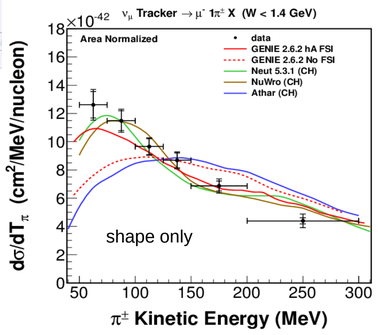
*Our data on pion momenta only agrees in the presence of final state rescattering*



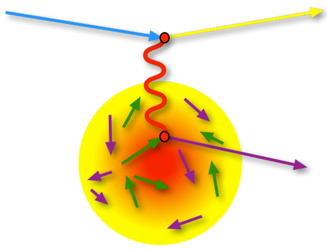







MiniBooNE's measurement sees more events, higher momenta and suggests less rescattering.

## Neutrinos Striking Nuclei



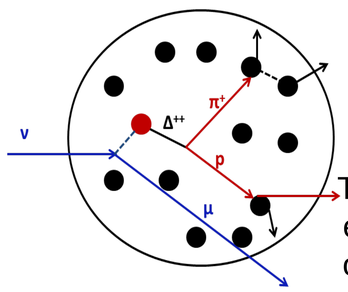
The nucleus is more than a collection of protons and neutrons.

At the transition between elastic and inelastic scattering, the nucleus behaves like a group of coupled springs.

Models are usually effective theories, rather than complete calculations. Data is needed to check and guide models.

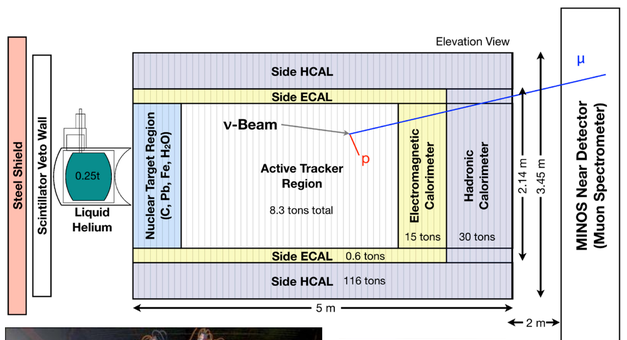
Consider pion "resonant" production, $\nu_\mu p \to \mu^- \Delta^{++}$, $\Delta^{++} \to p\pi^+$. "Recipe" model:

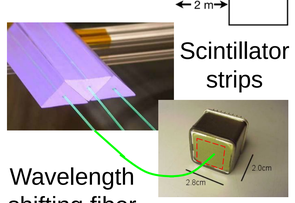
1. $\nu_\mu p \to \mu^- \Delta^{++}$, on the bound proton
2. $\Delta^{++}$ and its decay products travel in nucleus




This neglects known effects (correlations of nucleons). ***Need data to know if it is good enough.***

## MINERvA's Detector

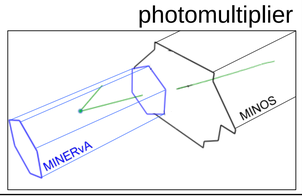





Scintillator strips

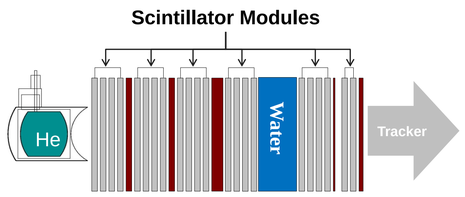
Wavelength shifting fiber

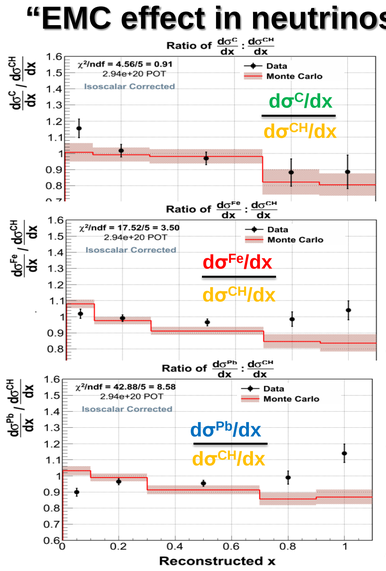
64 channel multi-anode photomultiplier

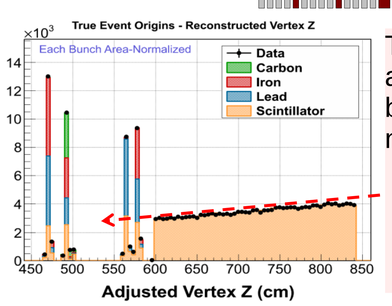



## Reaction Rate Ratios on Nuclei

**How are inclusive charged current reactions modified by nucleus?**
**"EMC effect in neutrinos"**



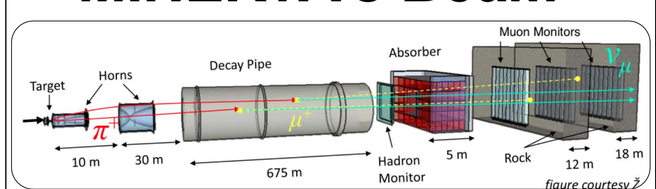

Targets are passive and there is background from nearby scintillator.

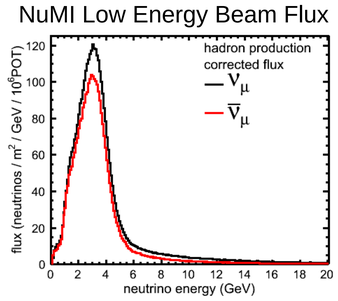
*Use events in the tracker modules to predict the plastic background*

We observe two primary effects not predicted in models used in oscillation experiments:

1. *At low x, "shadowing" is large and increases with heavier nuclei*
   (Large shadowing at our low $Q^2$? Axial current?)
2. *At high x, see higher rate for heavy nuclei*
   (Inadequate modeling of initial state momenta? Pauli blocking poorly modeled?)

## MINERvA's Beam




MINERvA uses the NuMI beam at Fermilab.
Today's results from low energy beam; currently running in higher rate, higher energy beam (NOvA project).

NuMI Low Energy Beam Flux