Measurement of Neutrino Induced Resonance Production

Xinchun Tian

Department of Physics and Astronomy

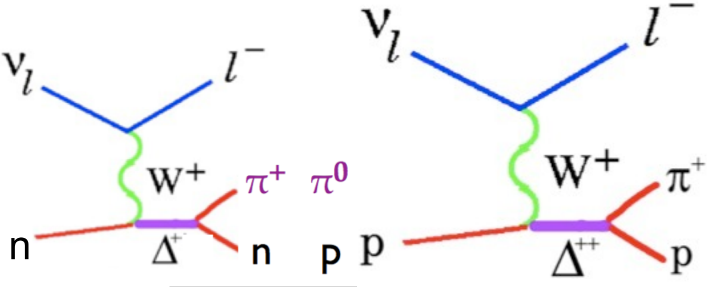
UNIVERSITY OF SOUTH CAROLINA

DIS 2015 @ Dallas, TX, 4/27-5/1, 2015

Outline

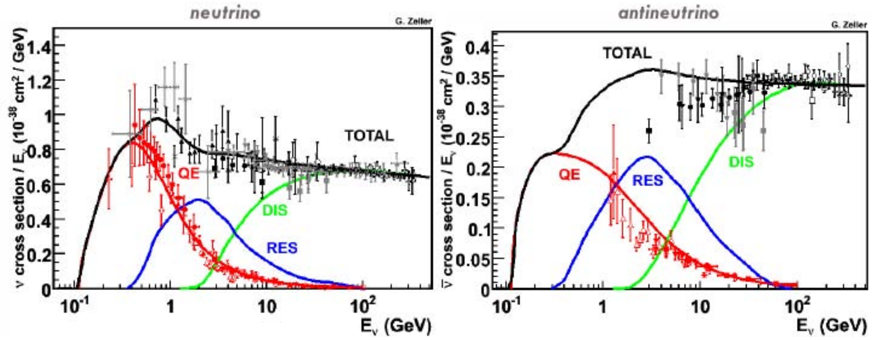
Introduction

Single Pion Production



- A neutrino inelastically scatters off target nucleon, with a short-lived resonant state of the excited target nucleon created (N^*, Δ) which decay into a nucleon and a single pion
  - $\nu_\mu + p \to \mu^- + \Delta^{++} \to \mu^- + p + \pi^+$
  - $\nu_\mu + n \to \mu^- + \Delta^+ \to \mu^- + n + \pi^+$
  - $\nu_\mu + n \to \mu^- + \Delta^+ \to \mu^- + p + \pi^0$

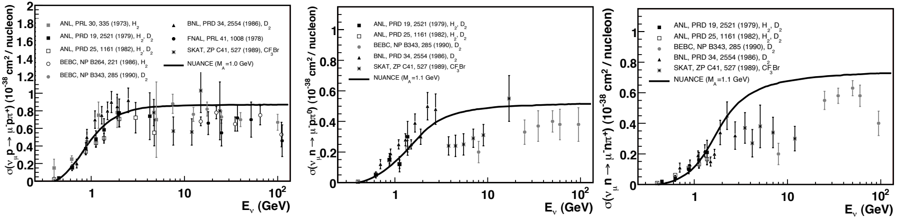
Why Single Pion Production



- The most important channel for the next generation long-baseline neutrino experiments in few-GeV energy region, e.g. DUNE

Why Single Pion Production

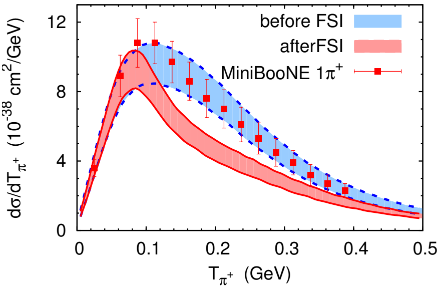
Rev. Mod. Phys. 84, 1307-1341 (2012)



- The resonance production is the least measured
- Many of the measurements on light targets (H_2 & D_2)
- Heavy targets suffer from nuclear effects

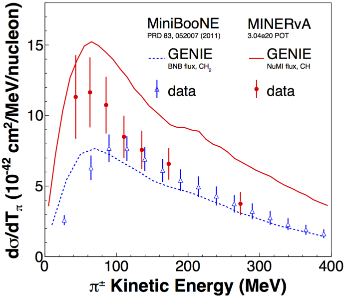
Why Single Pion Production - Puzzles

O. Lalakulich and U. Mosel



- Better agreement between MiniBooNE and GiBUU w/o FSI

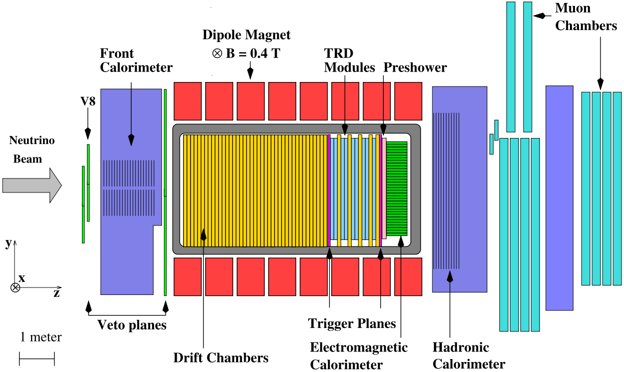
MINERνA, arXiv:hep-ex/1406.6415



- According to GENIE, MINERνA cross section should be $\sim \times 2$ that large as MiniBooNE, but is not
- According to GENIE both distributions have peak at $\sim$ 60 MeV, which is the case for MINERνA, but not for MiniBooNE

The NOMAD Detector

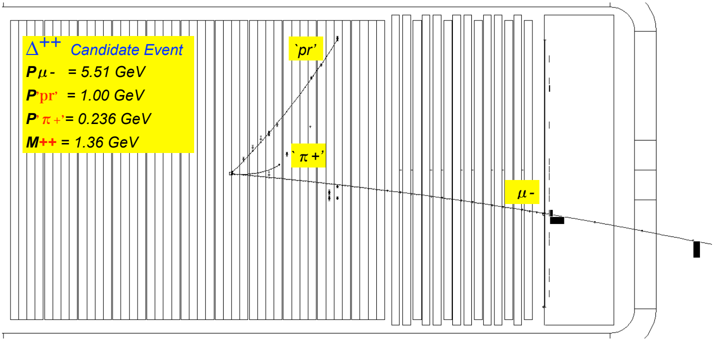
Average neutrino energy is $\sim$ 25 GeV



sub-detectors		performance
Drift Chambers (2.7 tons) $\rho = 0.1$ g/cm^3	Target & tracking	$\delta r < 200\ \mu$m $\delta p \sim 3.5\%$@$p < 10$ GeV/c
Transition Radiation Detector (TRD)	$e^{\pm}$ identification	90% $e^{\pm}$ eff. with π rejection @10^3
Muon Chambers	Muon identification	$\epsilon \sim 97\%$@$p_\mu > 5$ GeV/c
Electromagnetic Calorimeter (ECL)	Lead glass	$\frac{\sigma(E)}{E} = (1.04 \pm 0.01)\% + \frac{3.22 \pm 0.07}{\%} E(\mathrm{GeV})$
Hadronic Calorimeter (HCAL)	neutron and K_L^0 veto	

Resonance Topologies in NOMAD Detector

Good resolution to measure the Δ^{++} product

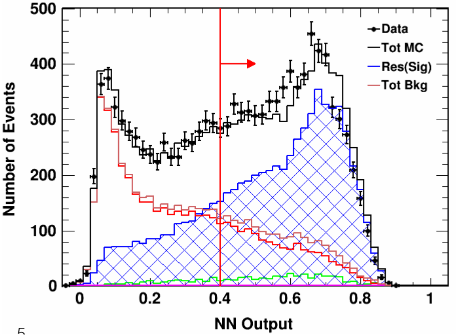


- Two topologies considered
  - 3-Track: $\nu_\mu + p \to \mu^- + \Delta^{++} \to \mu^- + p + \pi^+$
  - 2-Track: $\nu_\mu + n \to \mu^- + \Delta^+ \to \mu^- + n + \pi^+$
    $\nu_\mu + n \to \mu^- + \Delta^+ \to \mu^- + p + \pi^0$
  - Dominate background: CC-DIS

3-Track Analysis

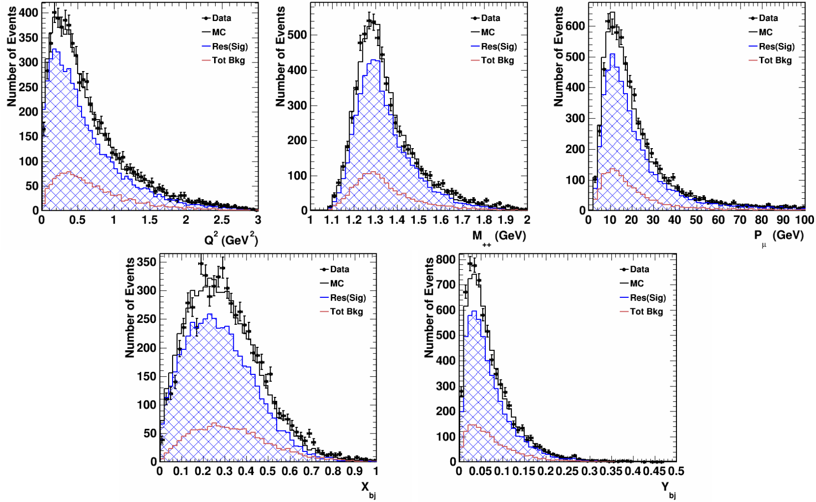
3-Track Analysis

- Selec μ^- and (+,+) topology
- Soft kinematic cuts to reduce DIS background
- Multivariate analysis



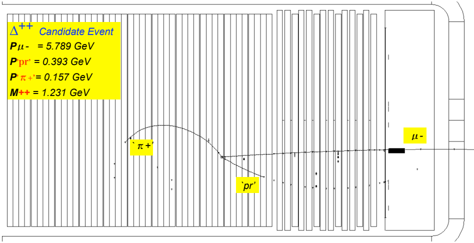
GENIE Prediction Agrees Quite Well With Data

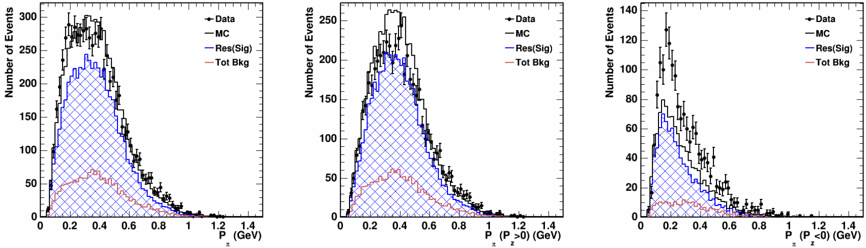
Agreement between Data and MC (GENIE), overall, is satisfactory. But disagreement seen in specfic kinematic region.



Backward-going Pions

- The pion momentum is most sensitive to nuclear effects
- Although overall MC agree with data, backward-going pions are not well described by GENIE ($\sim$ 34% π backward going)
- Could provide a handle to constrain nuclear effects





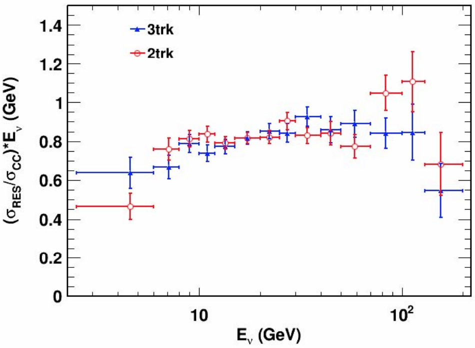
2-Track Analysis

2-Track Analysis

- μ^- and positive track
- Less well constrained than 3-Track $\Rightarrow$ larger background, larger systematic errors
- Rate $(R_{2-\mathrm{Track}}/R_{\mathrm{CC}})$ and cross section agree between the two topologies

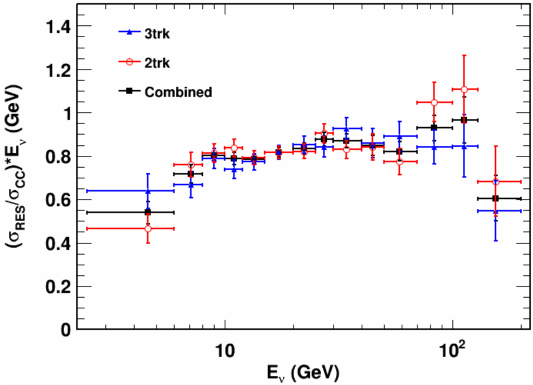
Combined Analysis

3-Track + 2-Track Combined Analysis



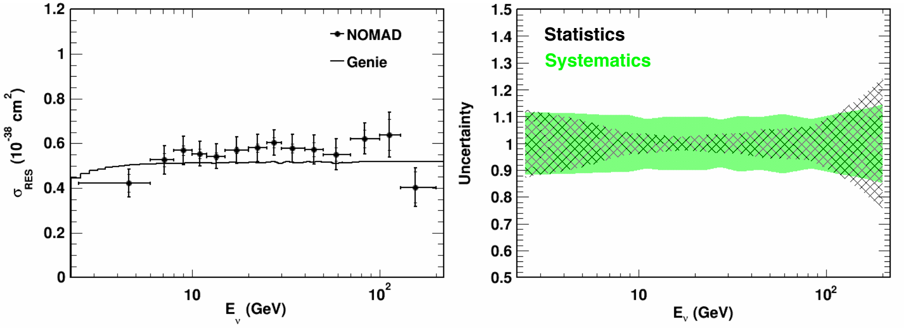
- Result shown as ratio of fully-corrected resonance events to inclusive charged current events
- 2-track result is consistent with 3-track analysis
- Combine 3-track result with 2-track result to reduce statistic uncertainty. Also the combined analysis is less sensitive to some systematics

3-Track + 2-Track Combined Analysis



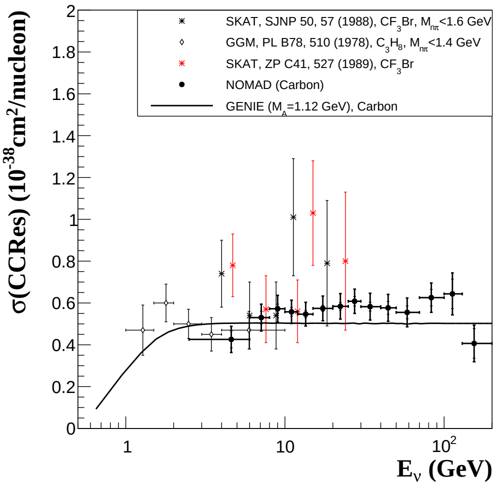
- Result shown as ratio of fully-corrected resonance events to inclusive charged current events
- 2-track result is consistent with 3-track analysis
- Combine 3-track result with 2-track result to reduce statistic uncertainty. Also the combined analysis is less sensitive to some systematics

Cross-Section and Systematics



- Cross-section measurement agrees with GENIE prediction ($M_A = 1.12$ GeV, $M_V = 0.84$ GeV)
- Systematic uncertainties $\pm 5.3\%$
  - MC modeling (M_A, M_V, MFP) – $\pm 3.2\%$
  - Event selections (pre-selection cuts, NN) – $\pm 1.2\%$
  - Flux – $\pm$ 2.5% overall (4.1% in lowest two bins)

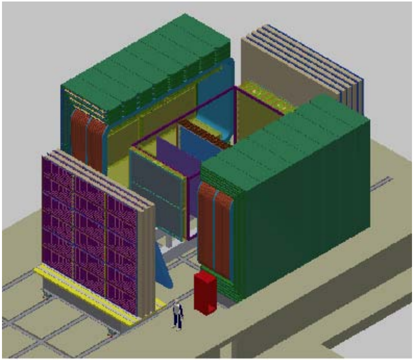
Resonance Cross-Section



Sensitivity Study of Resonance Production in a Fine Grain Straw Tube Tracker (STT) - the proposed DUNE Near Detector

- The DUNE ND will have a much a higher resolution and statistics ($\times 50$) than NOMAD, but lower energy ($\sim 1/4$)

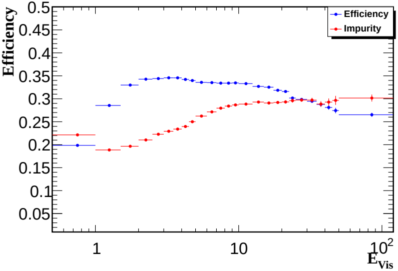
The proposed High Resolution DUNE/LBNF Near Detector

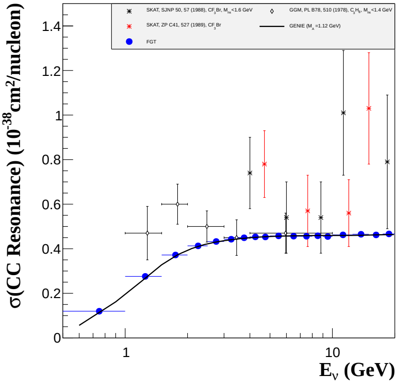


Performance Metric	FGT
Straw Tube Detector Volume	3.5m x 3.5m x 6.4m
Straw Tube Detector Mass	8 tonnes
Vertex Resolution	0.1 mm
Angular Resolution	2 mrad
E_e Resolution	5%
E_μ Resolution	5%
$\nu_\mu/\bar{\nu}_\mu$ ID	Yes
$\nu_e/\bar{\nu}_e$ ID	Yes
NCπ^0/CCe Rejection	0.1%
NCγ/CCe Rejection	0.2%
CCμ/CCe Rejection	0.01%

- Built on the NOMAD experience
- Determination of the beam flux at the Near Site and the measurement of ν_e-appearance backgrounds (Primary purpose)
- Precision Standard Model neutrino physics measurements, such as precise measurement of neutrino-nucleus cross sections, the weak mixing angle

Resonance Production at DUNE ND





- Preliminary study shows, for 3-track Resonance, the average signal efficiency is 33% with 23% background
- The projected precision has statistical error only, systematical uncertainties under investigation

Summary

- We have conducted a measurement of resonance interaction using NOMAD data.
- Kinematics like Q2, invariant mass, hadron momentums are consistent with GENIE prediction.
- Backward-going pions are poorly predicted by GENIE.
- The most precise measurement of resonance interaction in 2.5 GeV 200 GeV.
- An important benchmark to validate the proposed DUNE/ELBNF Fine-Grained Tracker near detector, which has a similar design as NOMAD.