Non-Oscillation Physics with the NuMI Beam

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The MINOS Collaboration Meeting
at Caltech
January 3-6, 2002

Workshop on Low-Energy Neutrino Nucleus Interactions: Overview

More detailed discussions with emphasis on implications for the MINOS Monte Carlo (NEUGEN) and subsequent analysis will take place at the April MINOS collaboration meeting.

Roy Holt (Nuclear Physics Perspective), Jorge G. Morfín

General Outline

- 60 Participants from Japan, States and Europe.
- Presentations:
  - **31 plenary talks**,
  - 8 talks describing Monte Carlo generators,
  - 7 theory benchmark calculations,
  - 6 topics for panel discussions.
- Transparencies from 35 of the above already available on the web. **http://neutrino.kek.jp/~nuint01/program.html**
- Contributions to Proceedings due by end of February, to be published, perhaps, by the Fall.

Topics Discussed

- Theory: Dynamics and kinematics of νN (within a nucleus) interactions:
  - Cross sections of exclusive states, (Rein-Sehgal augmented with calculations from Manny Paschos)
  - Bridging the gap from resonance to DIS, (Duality results from Jlab)
  - Global Boson-nucleus effects, (Shadowing, anti-shadowing, .S. Kumano and T. Thomas)
  - Pauli suppression,
  - Extended Fermi Gas model,
  - Nuclear correlations,
  - Hadron Formation Length and Nuclear transparency,
  - Final State Interactions.

Topics Discussed

- Experiment: What can we learn from eN (within a nucleus) interactions: (final state interactions the same)
  - Jlab results with duality and e-Nucleus experiments,
  - HERMES results with e-Nucleus.

- Experiment: What can we learn from νN (within a nucleus) interactions:
  - SKAT
  - NOMAD (Veltri - events with multiple backward-going protons)
  - K2K (Walters - necessity of nuclear effects in quasi-elastic analysis)

Topics Discussed

- Monte Carlo Generators:
  - SUPER-K/K2K NUANCE
  - SUPER-K/K2K NEUT
  - CHORUS
  - NOMAD
  - ICARUS
  - MINOS NEUGEN
  - MINIBOONE

Dave Casper is organizing an Inter-Monte-Carlo working group to, eventually, produce a "universal" Monte Carlo employing the best of the existing MCs plus new input from nuclear physics theorists presented at this meeting. They'll present their conclusions at NuInt02.

Topics Discussed

- **Future Facilities**:
  - CERN; mini ν factory
  - FNAL; mini ν factory
  - JHF
  - Jlab, 12 GeV upgrade

- **Future Experiments:**
  - K2K; new near detector
  - Mini-ICARUS
  - Second NuMI Near Experiment

General Consensus: We need experimental input from ν–nuclei experiments to completely understand these nuclear effects.

Proposal for a Study of ν-**Nuclei** Scattering in the NuMI Beam

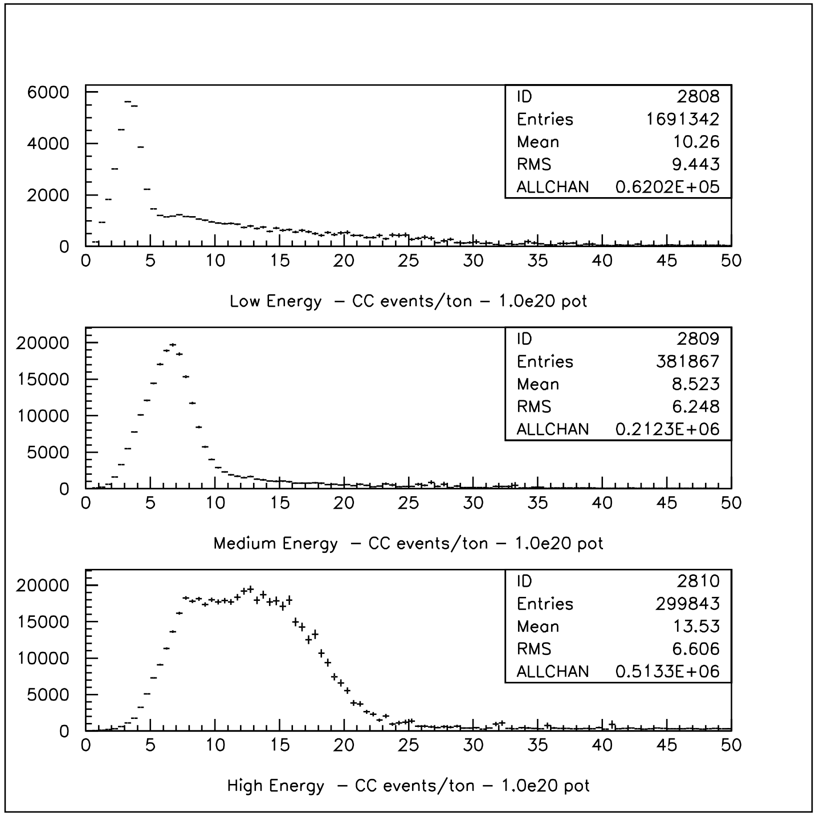
Roy Holt - ANL and Jorge G. Morfín - Fermilab

Study of ν-**Nuclei** Scattering in the NuMI Beam

- Collaboration of **nuclear** and **particle physics** communities led by Roy Holt (Argonne) and J.G.M (Fermilab).
- Nuclear community already shows considerable interest:
  - **Argonne National Lab, Colorado, Illinois, Indiana, Los Alamos National Lab, Rutgers**
- Goal is to sign up many MINOS collaborators and add more NP.
- Submit Proposal to the Fermilab PAC in 2002.
- Start running parasitically with MINOS in 2005 time scale.
  - Neutrinos only, emphasis on low energy running
- Run as prime users perhaps starting in 200?.
  - Higher Energy running with ν and $\bar{\nu}$.

Neutrino Event Energy Distributions and Statistics

- le-configuration: **Events-** $E_{peak} = 3.0$ GeV, $<E_\nu> = 10.2$ GeV, rate = 62 K events/ton - 10^{20} pot.
- me-configuration: **Events-** $E_{peak} = 7.0$ GeV, $<E_\nu> = 8.5$ GeV, rate = 215 K events/ton - 10^{20} pot.
- he-configuration: **Events-** $E_{peak} = 12.0$ GeV, $<E_\nu> = 13.5$ GeV, rate = 515 K events/ton - 10^{20} pot.
- Reasonably expect (3-3.5) x 10^{20} pot per year of NuMI running --> multiply above rates by a factor ≥ 3.



With E-907 at Fermilab to measure particle spectra from the NuMI target, expect to know neutrino flux to ± <u>5%.</u>

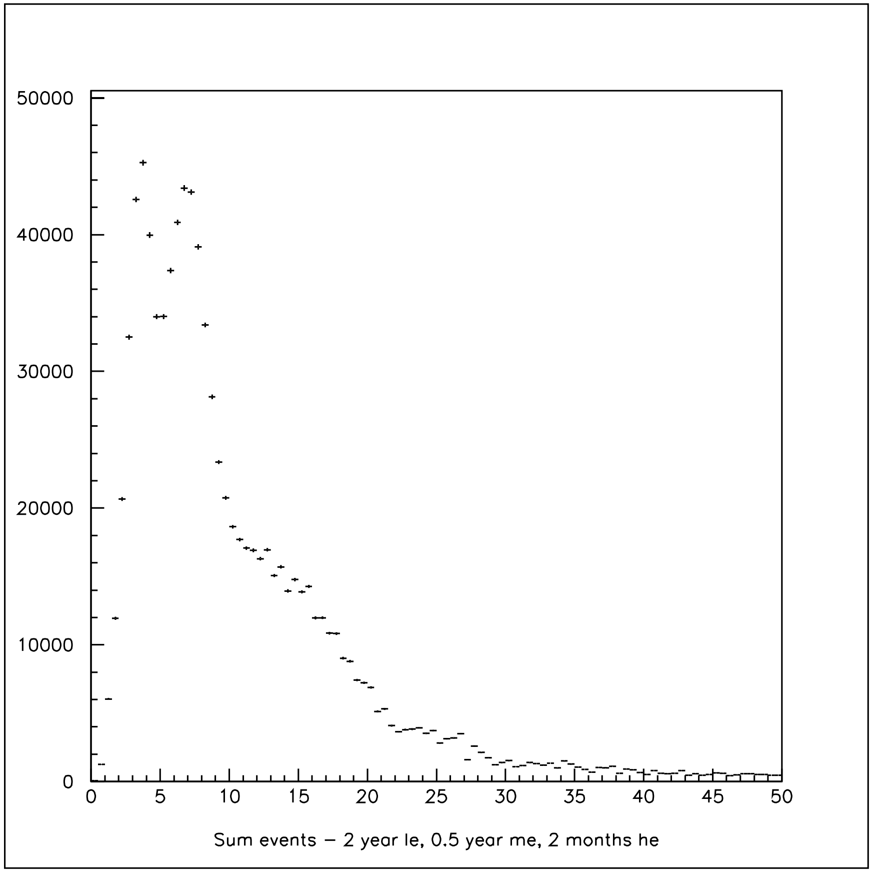
Parasitic Running with MINOS

- Two phases:
  - **Run parasitic to MINOS experiment using MINOS designated beam**.
  - Have control of energy and flavor of neutrino beam.

- **Physics Goals: Parasitic Running**
  - High statistics study of Quasi-elastic channel to extract Δs.
  - Measure ν-nucleus nuclear effects (CH, C, Fe and W targets).
  - Measure $d\sigma^{\nu}/dxdQ^2$ off a variety of nuclei.
    - » Anti-shadowing with neutrinos?
    - » A-dependence of neutrino EMC-effect?
  - (Study of ν-resonance production off various nuclei.)

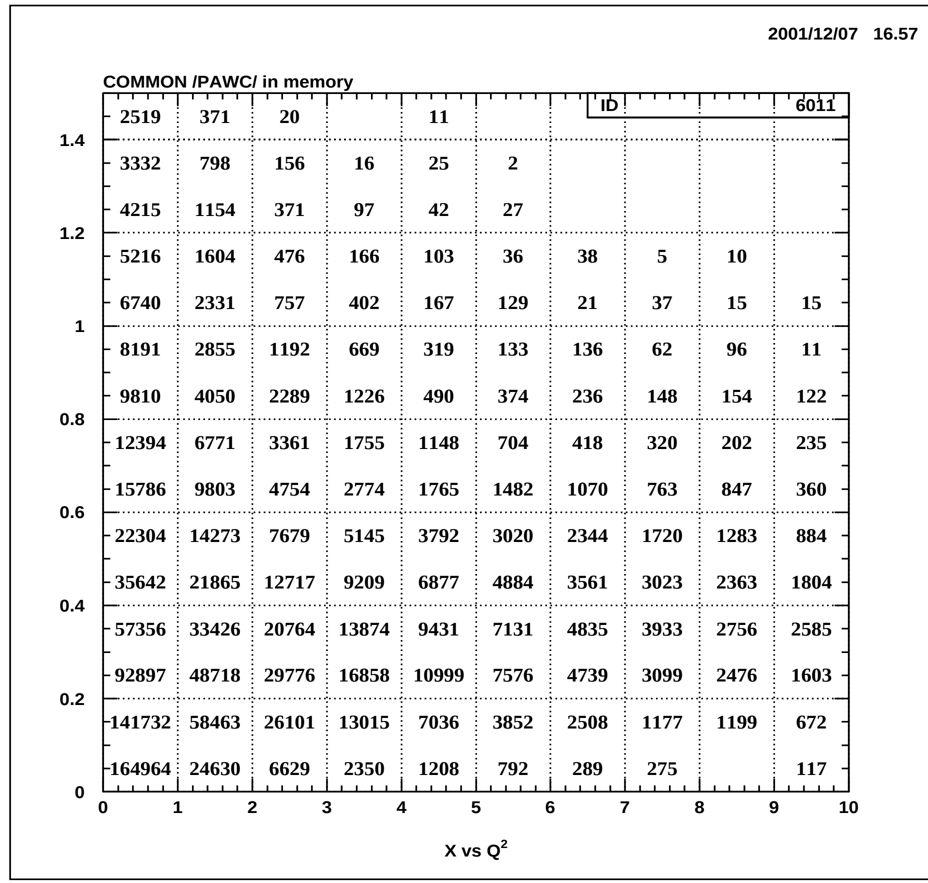
Parasitic Running: Event Energy Distribution

- MINOS oscillation experiment uses mainly le beam with shorter me and he runs for control and minimization of systematics.
- An example of a running cycle would be:
  - 12 months le beam
  - 3 months me beam
  - 1 month he beam
- Assuming 2 such cycles (3 year run) with $3x10^{20}$ protons/year: **950 K events/ton**. $<E_\nu> = 10.5$ GeV (with semi-me/he beams this becomes 800 K events/ton)



Parasitic Running: Event Kinematic Distributions

- Total of **0.95 M events/ton**.
- **DIS** (W > 2 GeV, $Q^2 > 1.0$ GeV^2) : **0.40 M events / ton**.
- **Quasi elastic**: **0.15 M events / ton.**
- **Resonance + "Transition"** : **0.40 M events / ton**
- Recalculating for semi-me/he beams.



David Potterveld - ANL

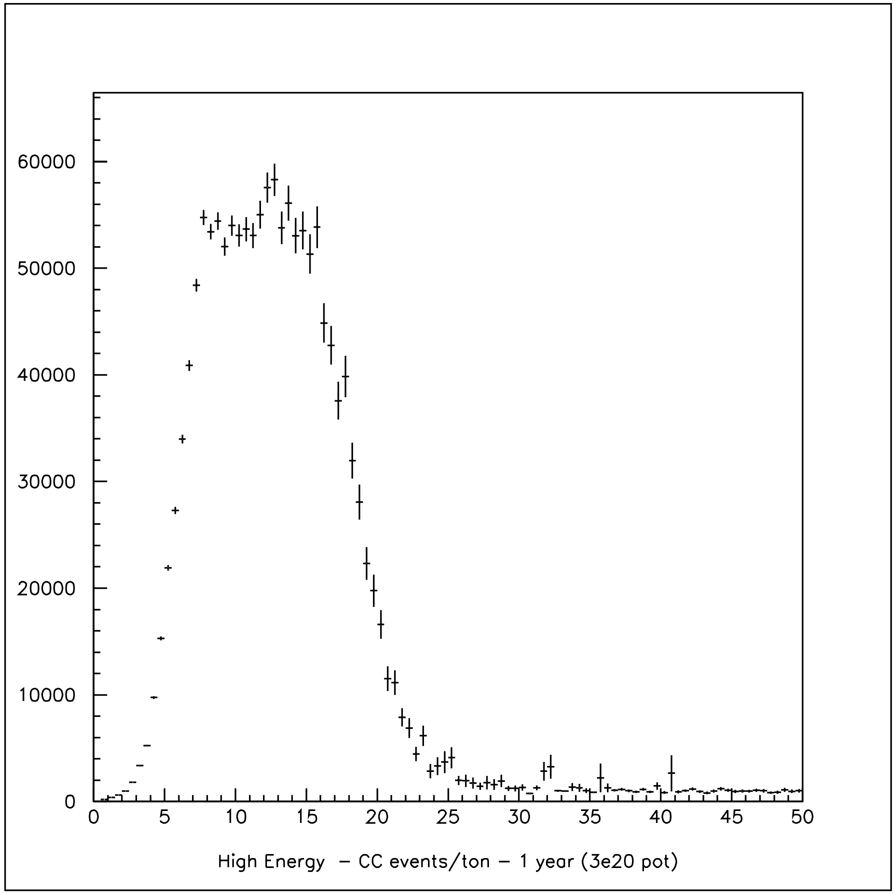
Prime User of the NuMI Beam

- Two phases:
  - Run parasitic to MINOS experiment using MINOS designated beam.
  - **Have control of energy and flavor of neutrino beam.**

- Physics Goals: Prime User
  - Continue measurement of $\nu/\bar{\nu}$ -nucleus nuclear effects.
  - Measure $d\sigma^{\nu}/dxdQ^2$ and $d\sigma^{\bar{\nu}}/dxdQ^2$ off of CH, C, Fe and W targets:
    - » **Shadowing, anti-shadowing and EMC-effect with neutrinos and anti-neutrinos**
    - » **Measure nuclear effects on NC/CC ratio in ν and $\bar{\nu}$ to check NuTeV 3σ effect!!**
  - Extract F_2 (x,Q^2) and xF_3 (x,Q^2) off of these nuclei:
    - » **Measure nuclear effects off valence and sea quarks independently**
  - With sufficient statistics and control of systematics extract all 6 structure functions.

Prime User: Event Energy Distribution

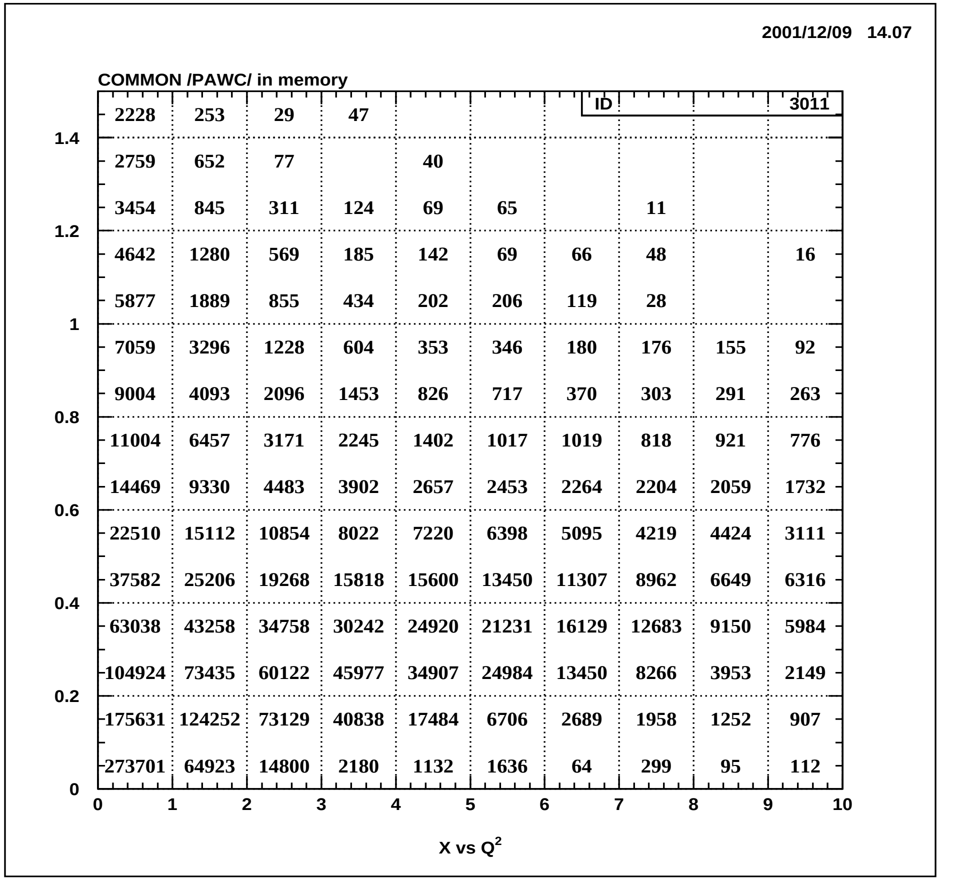
- Run he beam configuration only!
- For example, 1 year neutrino plus 2 years anti-neutrino would yield:
  - 1.6 M ν - events/ton
  - 0.7 M ν = events/ton
- The energy distribution of neutrino events is at right. $<E_{\nu}> = 13.5$ GeV



Prime User: Event Kinematic Distributions

- Distribution for 1 year ν running.

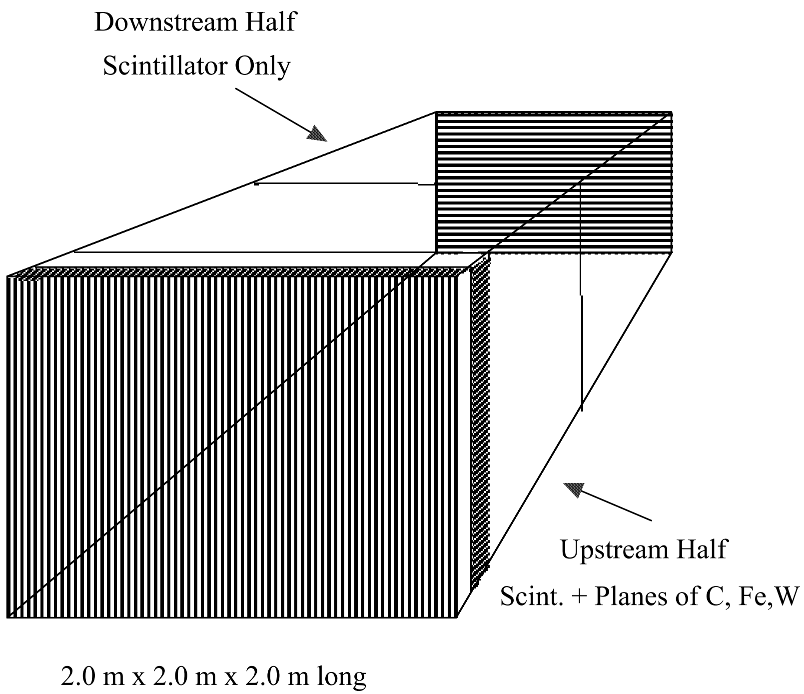
- Using the same definition:
  DIS (W > 2 GeV, Q^2 > 1.0 GeV^2):
  0.9 M ν and .35 M $\bar{\nu}$ events / ton.
- In the shadowing region (x < 0.1):
  0.35 M events/ton



David Potterveld - ANL

Detector: Conceptual Design

- 2m x 2 cm x 2cm scintillator (CH) strips with fiber readout.
- Fiducial volume: r = .8m L = 1.5:
  3 tons of scintillator
- Downstream half: pure scintillator
- Upstream half: scintillator plus ≈1 cm thick planes of C, Fe and W.
  - 8 planes C = 0.37 ton (+Scintillator)
  - 3 planes Fe = 0.47 ton (+MINOS)
  - 2 planes W = 0.77 ton
- Readout: combination of VLPC and MINOS multi-anode PMT system.
- Use MINOS near detector as muon identifier / spectrometer.



Detector: Event Rates

Event rates (3 x 10^{20} protons per year)

	Parasitic Running (3 years)	**Prime User** (1 year, ν)
CH	2.85 M	4.80 M
C	0.35 M	0.59 M
Fe	0.45 M	0.76 M
W	0.73 M	1.23 M

Multiply Parasitic values by
0.85 for semi-me/he running

Physics Goals: Δs -- Roy Holt, ANL

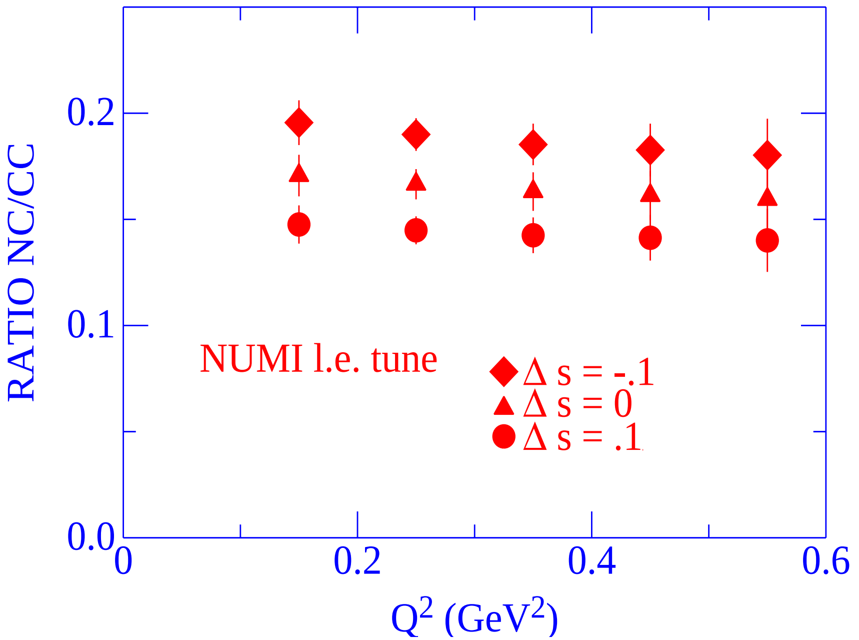
- **Strange Spin of the Proton.**

- Status $\Delta s = -0.12 \pm 0.03$, BUT:
  - Large x --> 0 extrapolation
  - Assume SU(3) symmetry
  - Factorization in semi-inclusive DIS

- Neutrino NC Scattering yields Δs directly.

- Measure:

  $\nu_\mu p \dashrightarrow \nu_\mu p \,/\, \nu_\mu n \dashrightarrow \mu^- p$



Physics Goals: Nuclear Effects 1

- Compare characteristics of ν_μN events where N is CH, C, Fe and W.
- Look at multiplicities, the ratio of charged to neutral energy, neutrino energy distribution, muon 3-vector, hadron shower 3-vector.
- Perhaps compare quasi-elastic production off of N.

Physics Goals: Nuclear Effects 2

- S.A.Kulagin has calculated shadowing for F_2 and xF_3 in ν-A interactions based on a non-perturbative parton model.

- At 5 GeV^2, ratio of shadowing $xF_3 : F_2 \approx 0.5$ at $x = .02$ to ≈ 2 at $x = .0001$.

- Most recently calculated shadowing in VMD region (lower Q^2 : dominant for $x < .01$) and finds significantly stronger shadowing.

Physics Goals: Nuclear Effects

- Following figures are for 2 years ν and 4 years $\bar{\nu}$ events.
- Taking ratios allows for cancellation of beam systematic effects.
- Assume relative target systematics same as Tevatron Muon Experiment – order (1-2)%.

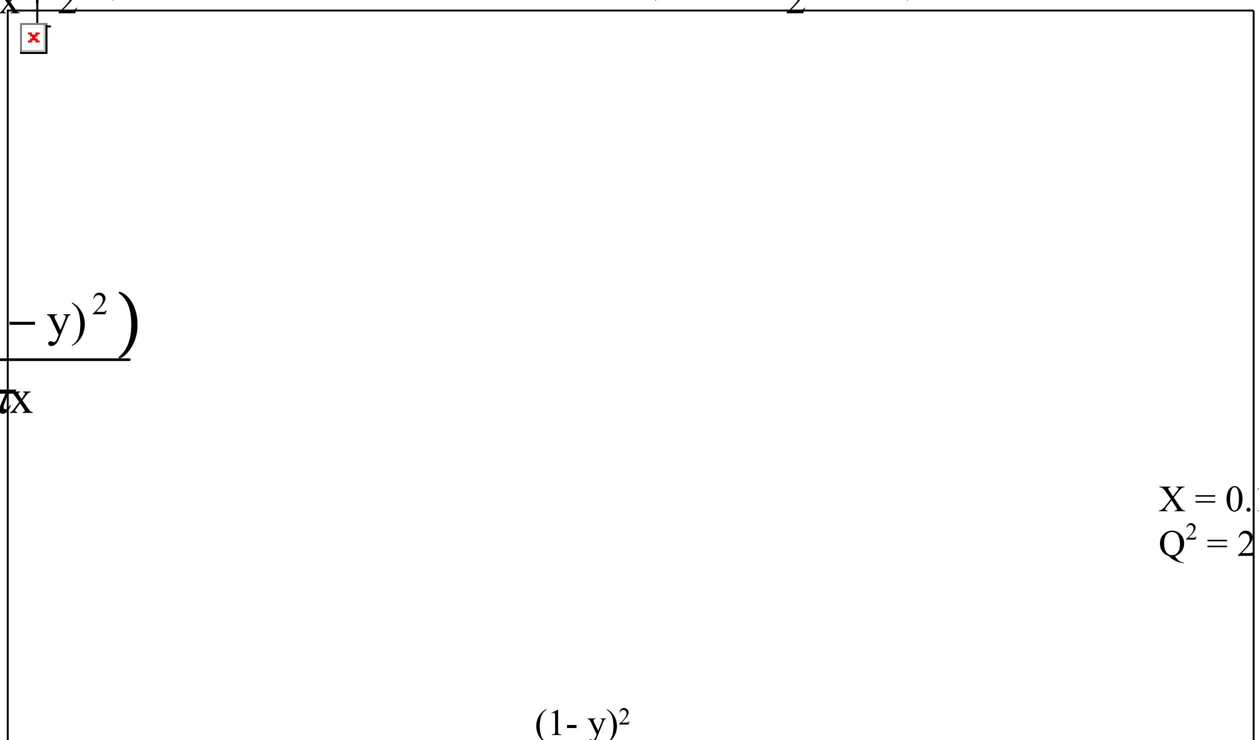
Physics Goals: Six Structure Functions

$$\frac{d\sigma^{\nu A}}{dxdQ^2} = \frac{G_F^2}{2\pi x}\left[\frac{1}{2}\left(F_2^{\nu A}(x,Q^2) + xF_3^{\nu A}(x,Q^2)\right) + \frac{(1-y)^2}{2}\left(F_2^{\nu A}(x,Q^2) - xF_3^{\nu A}(x,Q^2)\right)\right]$$

$$\frac{d\sigma^{\bar{\nu} A}}{dxdQ^2} = \frac{G_F^2}{2\pi x}\left[\frac{1}{2}\left(F_2^{\bar{\nu} A}(x,Q^2) - xF_3^{\bar{\nu} A}(x,Q^2)\right) + \frac{(1-y)^2}{2}\left(F_2^{\bar{\nu} A}(x,Q^2) + xF_3^{\bar{\nu} A}(x,Q^2)\right)\right]$$

$+ y^2 F_L$

$$\frac{\sigma\left(x, Q^2, (1-y)^2\right)}{G^2/2\pi x}$$



What Can We Learn With All Six Structure Functions?

Leading order expressions:

$$F_2^{\bar{\nu}N}(x,Q^2) = x\left[u + \bar{u} + d + \bar{d} + 2\bar{s} + 2c\right]$$

$$F_2^{\nu N}(x,Q^2) = x\left[u + \bar{u} + d + \bar{d} + 2s + 2\bar{c}\right]$$

$$xF_3^{\bar{\nu}N}(x,Q^2) = x\left[u + d - \bar{u} - \bar{d} - 2\bar{s} + 2c\right]$$

$$xF_3^{\nu N}(x,Q^2) = x\left[u + d - \bar{u} - \bar{d} + 2s - 2\bar{c}\right]$$

- Does s = s and c = c over all x? $F_2^{\nu} - F_2^{\bar{\nu}} = 2\left[(s - \bar{s}) + (\bar{c} - c)\right]$
- If so.....

$$F_2^{\nu} - xF_3^{\nu} = 2\left(\bar{u} + \bar{d} + 2\bar{c}\right) = 2U + 4\bar{c}$$

$$F_2^{\bar{\nu}} - xF_3^{\bar{\nu}} = 2\left(\bar{u} + \bar{d} + 2\bar{s}\right) = 2U + 4\bar{s}$$

$$xF_3^{\nu} - xF_3^{\bar{\nu}} = 2\left[(s + \bar{s}) - (\bar{c} + c)\right] = 4\bar{s} - 4\bar{c}$$

Summary

- Forming Collaboration of Nuclear and Experimental Particle physicists for a Second NuMI Experiment.

MANY THESIS TOPICS !!

- Study Δs, nuclear effects in $\nu_\mu N$ events(N is CH, C, Fe and W).
- Study nuclear effects in NC/CC to check $\sin^2(\theta_W)$ measurement.
- Study nuclear effects of valance and sea quarks independently.
- Extract high precision structure functions,isolate individual pdfs.
- Submit proposal 2002, run parasitic with MINOS starting $\approx$ 2005, prime users in 2008 timeframe.
- We will distribute written summary of physics goals, detector requirements and expected statistics,

We Invite YOU to join us!