Expression of Interest submitted to FNAL PAC

To Perform a High-Statistics (On-Axis) Neutrino Scattering Experiment using a Fine-grained Detector in the NuMI Beam

40 Collaborators from

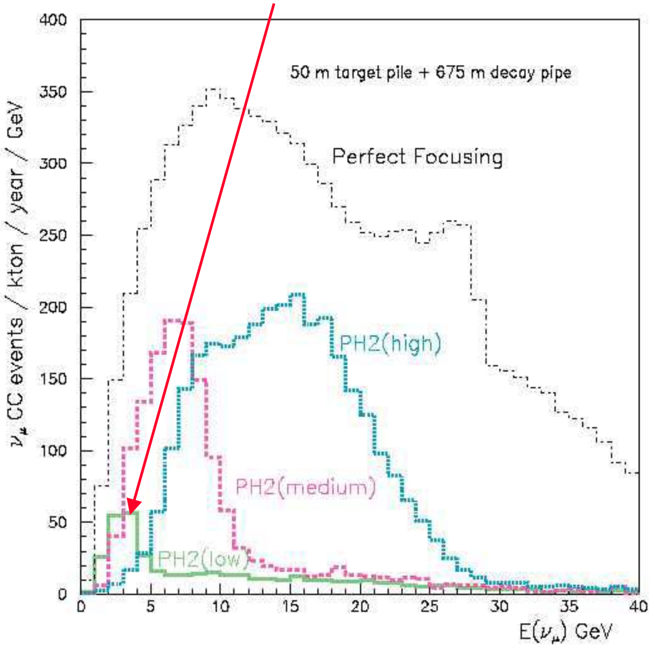
Argonne - Athens - California/Irvine - Colorado - Duke - Fermilab - Hampton - I I T - James Madison - Jefferson Lab - M I T - Minnesota - Pittsburgh - Rutgers - South Carolina - Tufts

16 Groups: Red = HEP, Blue = NP

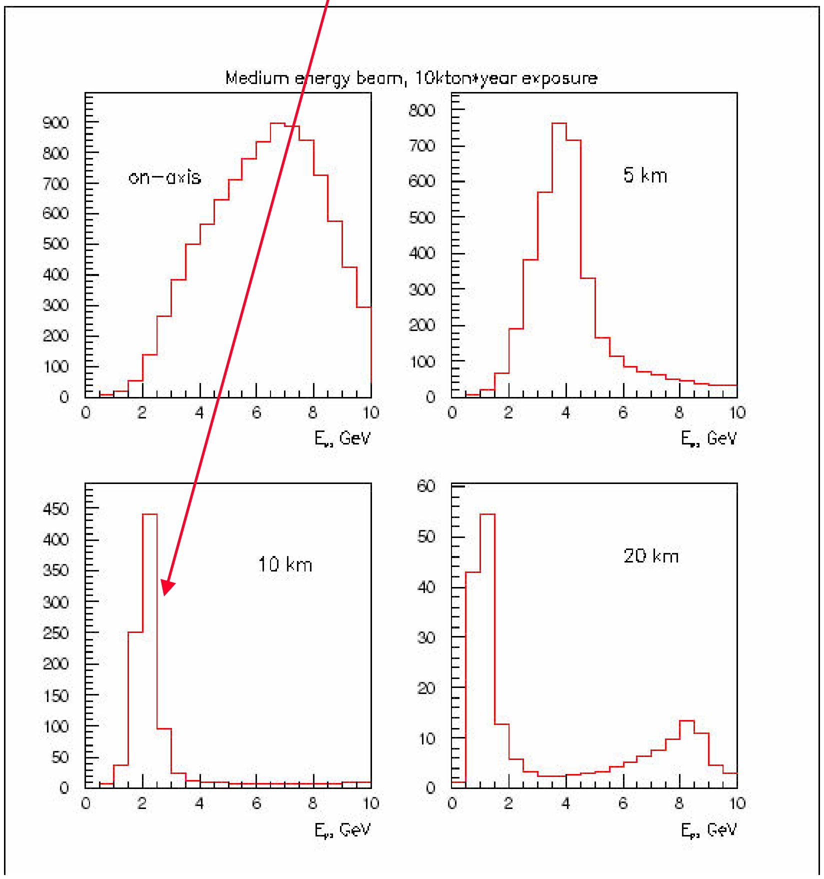
Jorge G. Morfín - Fermilab

Motivation: Current/Future ν Oscillation Experiments use a Few GeV ν on a C, O_2 or Fe Nucleus

MINOS: Low-Energy Beam

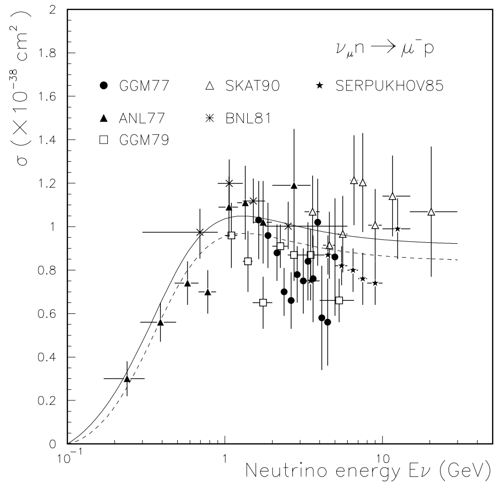


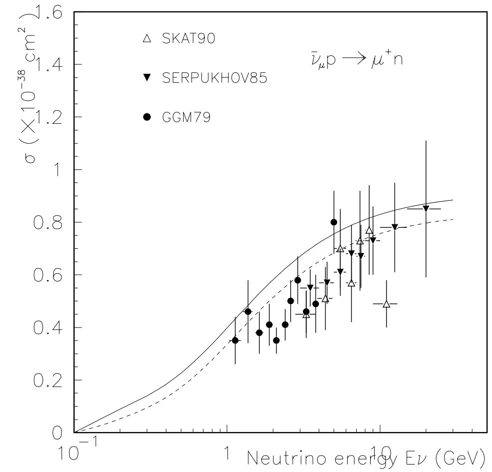
NuMI Off-axis Beam



We need to understand low energy ν-Nucleus interactions!

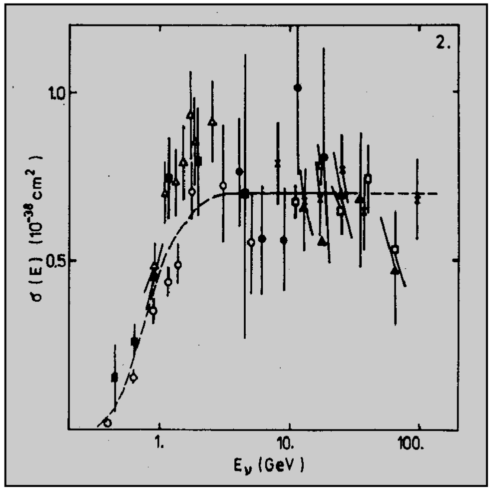
Motivation: Exclusive Cross-sections at Low Energies (elastic): Status - DISMAL

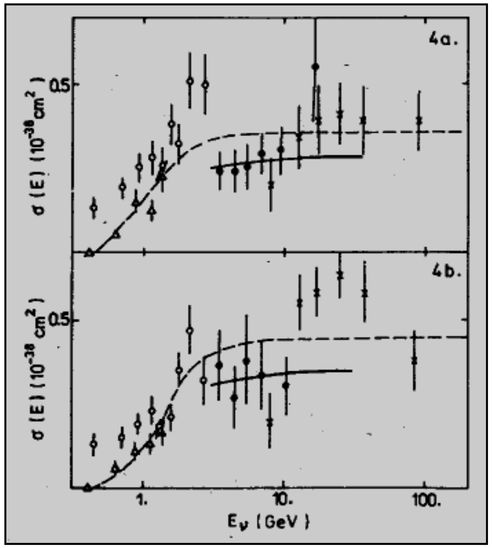




- World sample statistics is still fairly miserable!
- Cross-section important for understanding low-energy atmospheric neutrino oscillation results.
- Needed for all low energy neutrino monte carlos.
- Added Bonus: Garvey et al showed that $\nu+p \rightarrow \nu+p$ at $Q^2 = 0$ sensitive to contribution of the s-quark to the spin of the proton.

Motivation: Exclusive Cross-sections at Low Energies (1-Pion and Strange Particle): Status - DISMAL





CC

$\nu p \rightarrow \mu^- p \pi^+$

$\nu n \rightarrow \mu^- p \pi^0$

$\nu n \rightarrow \mu^- n \pi^+$

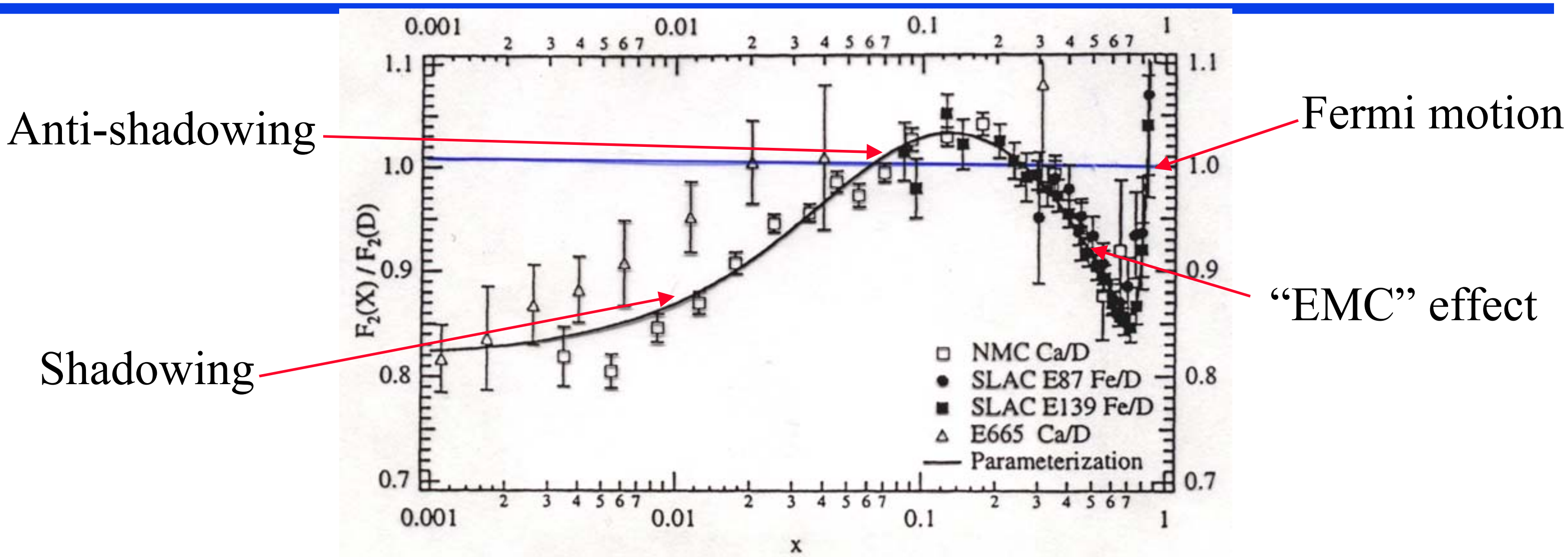
World's sample of NC 1-π

- ANL
  - $\nu\ p \rightarrow \nu\ n\ \pi^+$ (7 events)
  - $\nu\ n \rightarrow \nu\ n\ \pi^0$ (7 events)
- Gargamelle
  - $\nu\ p \rightarrow \nu\ p\ \pi^0$ (178 evts)
  - $\nu\ n \rightarrow \nu\ n\ \pi^0$ (139 evts)
- K2K
  - Starting a careful analysis of single π^0 production.

Strange Particle Production

- Gargamelle-PS - **15** Λ events.
- FNAL 15' ≈ 100 events
- ZGS - 7 events
- BNL - 8 events

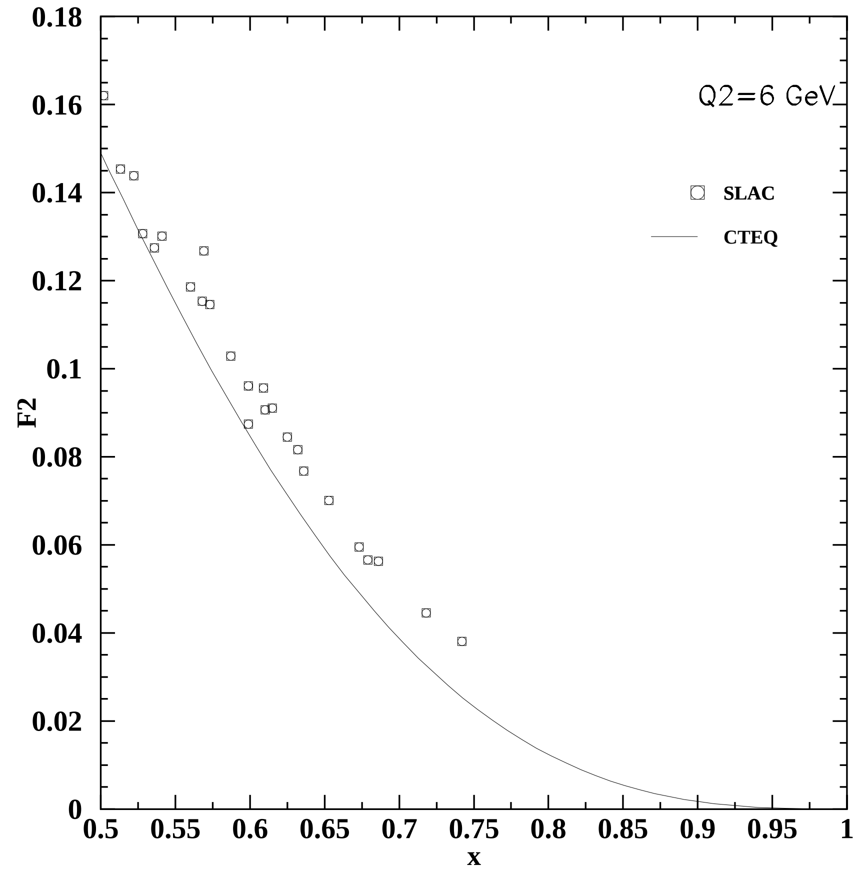
Motivation: Knowledge of Nuclear Effects with Neutrinos: essentially NON-EXISTENT



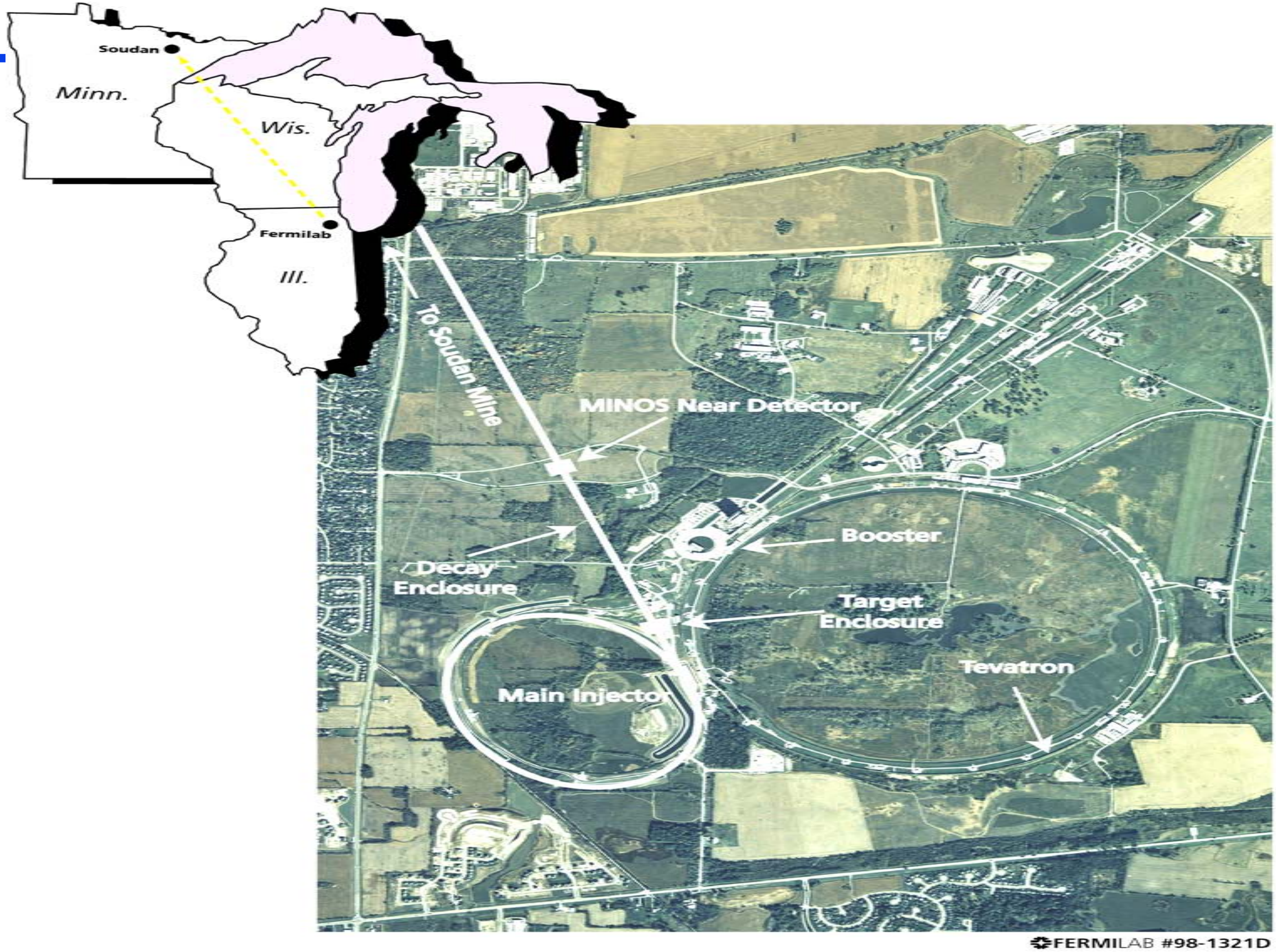
- F_2 / nucleon changes as a function of A. Measured (with high statistics) in μ-A **not in ν–A**
- **Good reason to consider nuclear effects DIFFERENT in ν -A**. Presence of axial-vector current. SPECULATION: Much stronger shadowing for ν -A but somewhat weaker "EMC" effect? different nuclear effects for valance and sea --> stronger shadowing for xF_3 compared to F_2? different nuclear effects for d and u quarks?
- **NUCLEAR EFFECTS EXPLAIN SOME/ALL OF THE NuTeV $SIN^2\Theta_W$ RESULT?**
- ***LET'S MEASURE NC/CC AND NUCLEAR EFFECTS WITH $\nu - A_1, A_2, A_3$...***

Motivation: Detailed comparison of ν-A with Jefferson Lab Results on e-A

- Particular interest in the high -x_{Bj} region where there seems to be a discrepancy between global fits and data.
- Study of structure functions off various nuclear targets, again at high-x_{Bj}, allows comparison with nuclear structure models where sensitivity is large.
- Close examination of the non-PQCD and pQCD transition region, in context of quark-hadron duality, with axial-vector probe.
- CTEQ working group in association with C. Keppel (Jlab) formed to investigate high -x_{Bj} region.



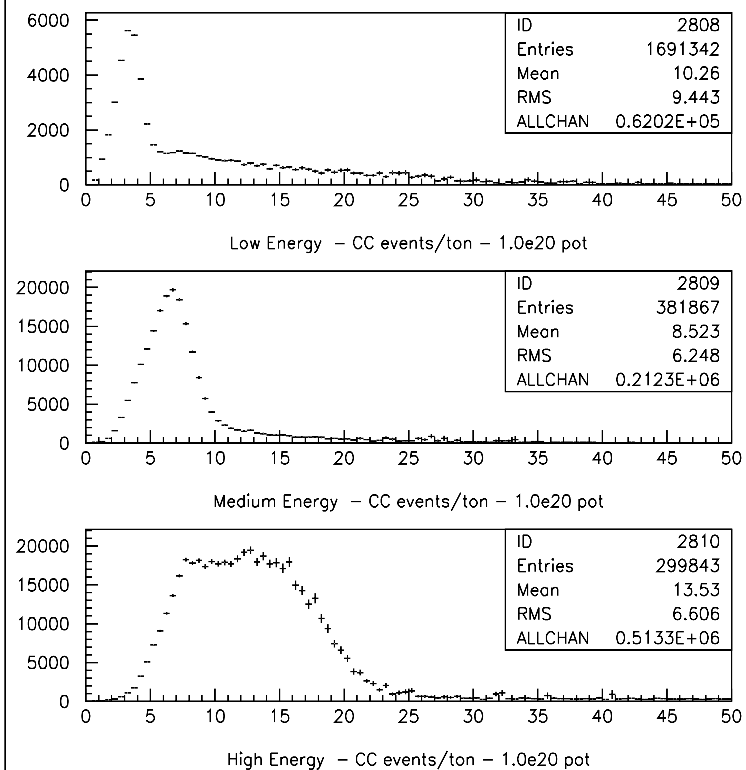
NuMI Beamline on the Fermilab Site



Neutrino Event Energy Distributions and Statistics in the NuMI Near Hall

- Reasonably expect 2.5 x 10^{20} pot per year of NuMI running.
- le-configuration: **Events-** (E_μ >0.35 GeV)
  E_{peak} = 3.0 GeV, $\langle E_\nu \rangle$ = 10.2 GeV,
  rate = 200 K events/ton - year.
- me-configuration: **Events-**
  E_{peak} = 7.0 GeV, $\langle E_\nu \rangle$ = 8.5 GeV,
  rate = 675 K events/ton - year
  s-me rate = 540 K events/ton - year.
- he-configuration: **Events-**
  E_{peak} = 12.0 GeV, $\langle E_\nu \rangle$ = 13.5 GeV,
  rate = 1575 K events/ton - year
  s-he rate = 1210 K events/ton - year.

NuMI Beam like a ZOOM LENS



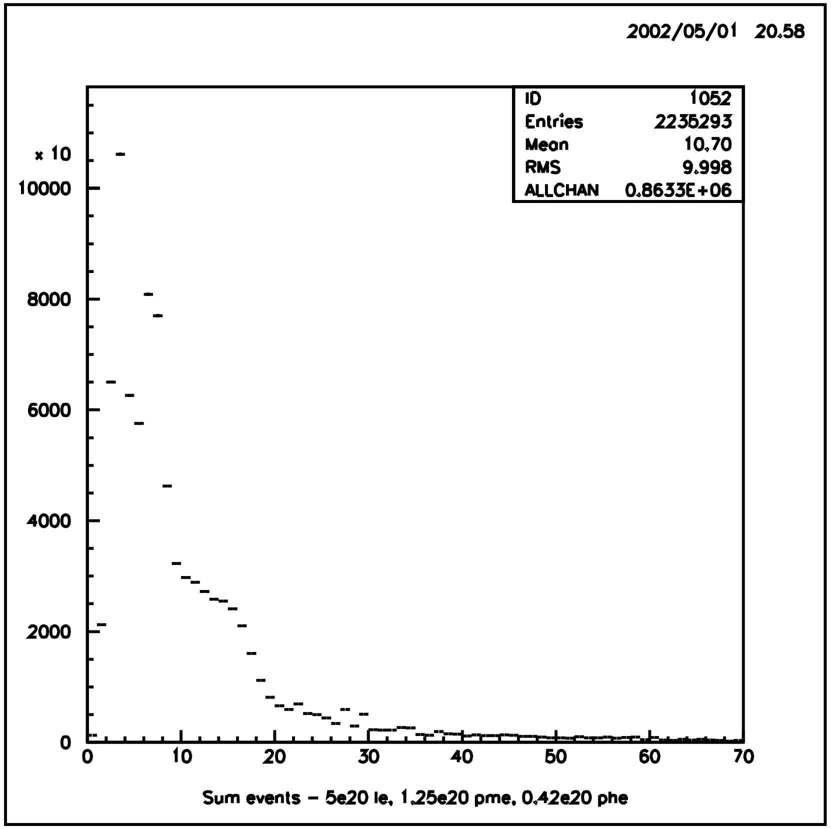
With E-907 at Fermilab to measure particle spectra from the NuMI target, expect to know neutrino flux to $\approx \pm 3\%$.

MINOS Parasitic Running: Statistics & Topologies

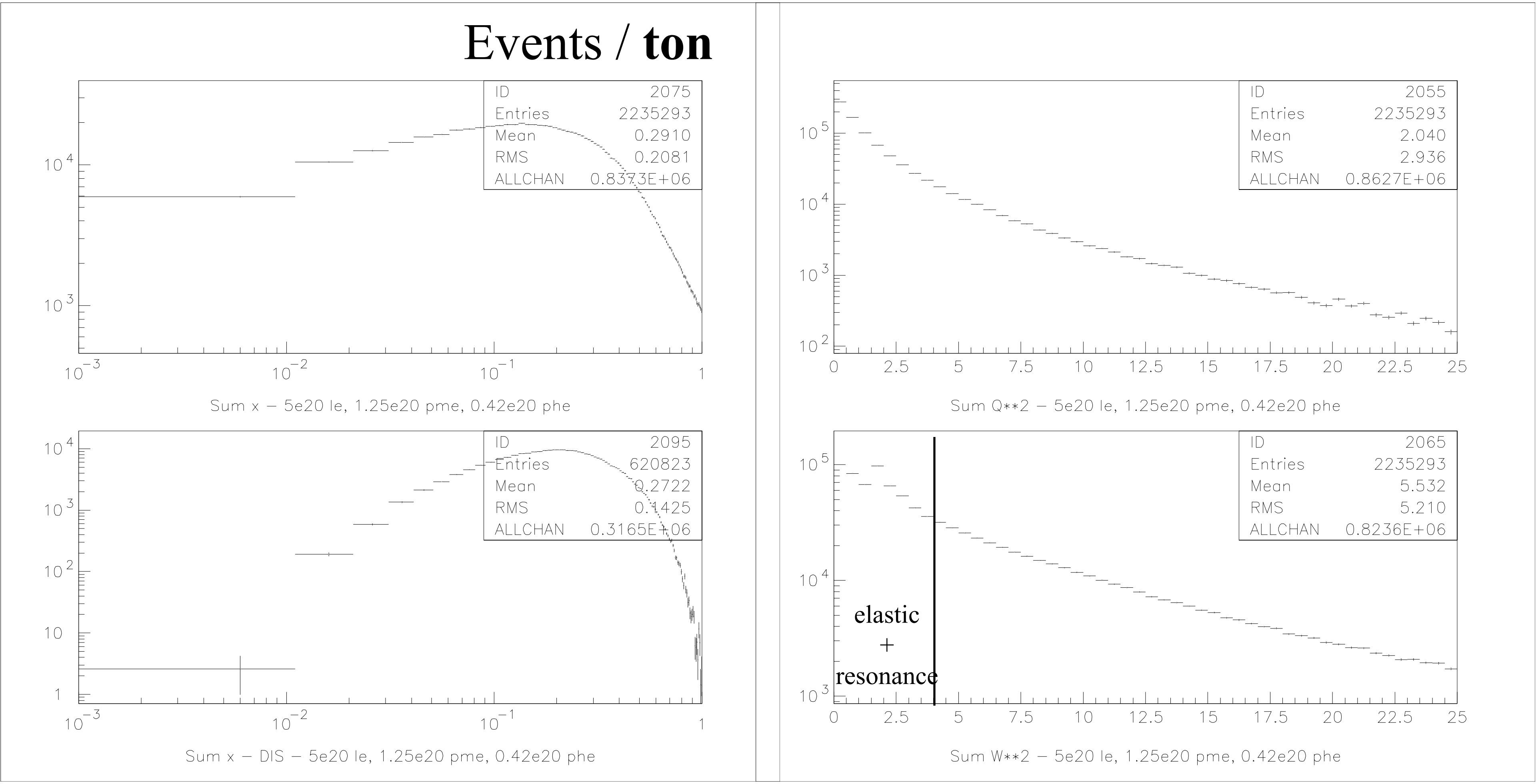
- MINOS oscillation experiment uses mainly le beam with shorter s-me and s-he runs for control and minimization of systematics.

- An example of a running cycle would be:
  - 12 months le beam
  - 3 months s-me beam
  - 1 month s-he beam

- Consider 2 such cycles (3 year run) with 2.5×10^{20} protons/year: **860 K events/ton**. $\langle E_\nu \rangle = 10.5$ GeV
  - **DIS** ($W > 2$ GeV, $Q^2 > 1.0$ GeV^2): **0.36 M events / ton**
  - **Quasi elastic**: **0.14 M events / ton.**
  - **Resonance + "Transition"**: **0.36 M events / ton**
    - » **1 π production: 0.15 M events / ton.**



MINOS Parasitic Running: x, Q^2 and W^2



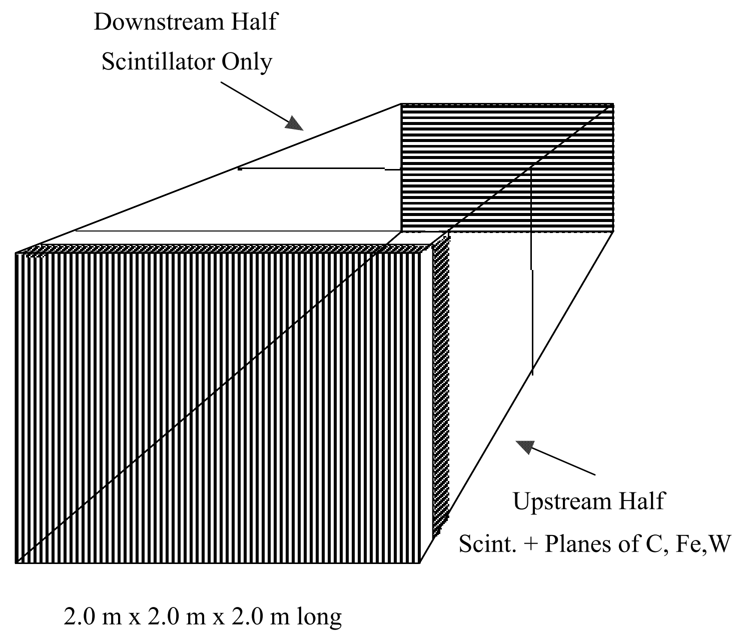
A Phased (Installation) High-resolution ν Detector: Basic Conceptual Design

- 2m x 2 cm x 2cm scintillator (CH) strips with fiber readout. (λ_{int} = 80 cm, X_0 = 44 cm)
- Fiducial volume: (r = .8m L = 1.5 m):   3.1 tons

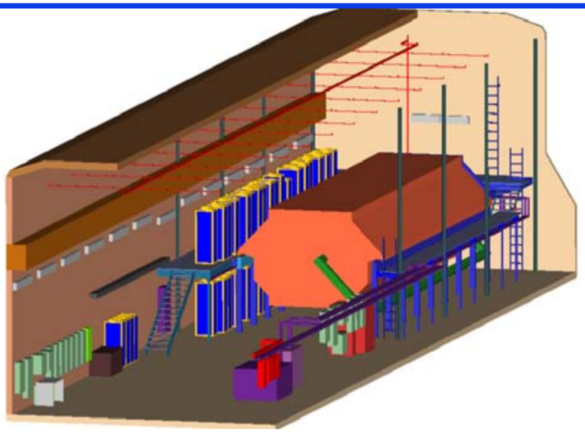
  R = 1.5 m - p: μ =.45 GeV, π = 51, K = .86, P = 1.2

  R = .75 m - p: μ =.29 GeV, π = 32, K = .62, P = .93

- Also 2 cm thick planes of C, Fe and Pb.
  - 11 planes C = 1.0 ton (+Scintillator)
  - 3 planes Fe = 1.0 ton (+MINOS)
  - 2 planes Pb = 1.0 ton
- Readout: Current concept is VLPC. (How about PMT or CCD + Image Intensifier?)
- Use MINOS near detector as forward μ identifier / spectrometer.
- Considering the use of side μ-ID detectors for low-energy μ identification.



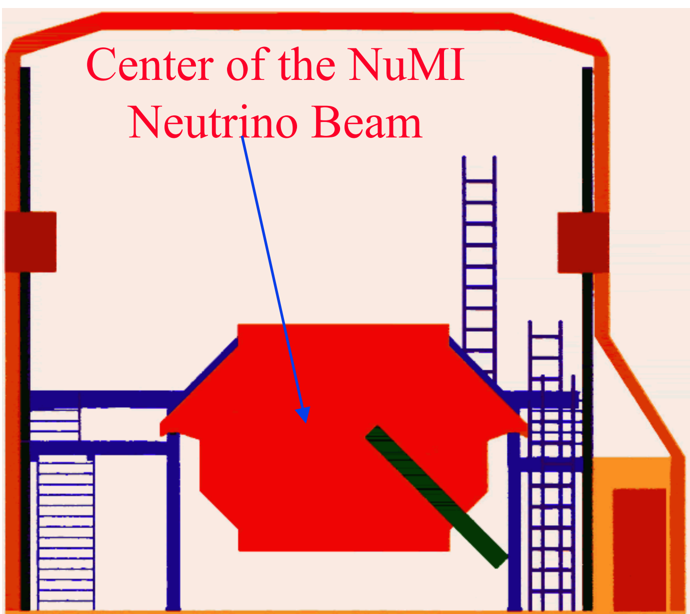
MINOS Near Detector in the NuMI Near Hall

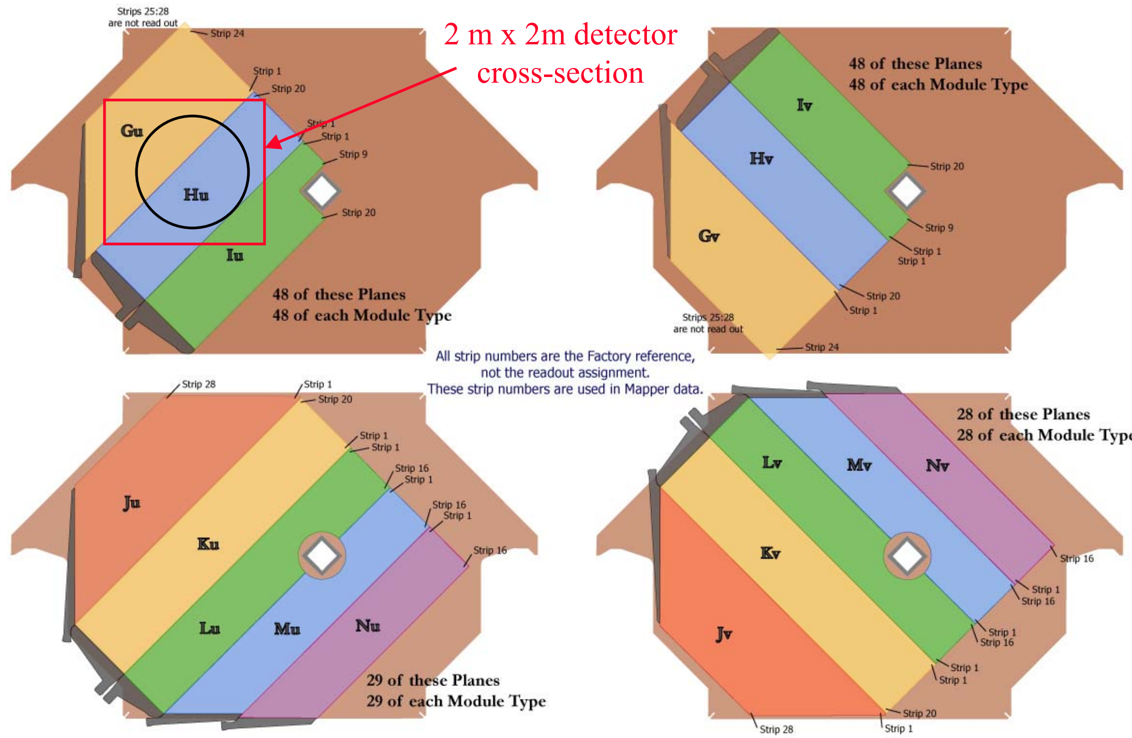


≈ 100 m underground

Length: 45m - Height: 9.6m - Width: 9.5m

25 m clear upstream of MINOS detector





Many Detector Questions Still Unanswered

(aside from fundamental question of readout/electronics choice)

We have a detector with sufficient granularity to resolve 1, 2, 3… particle final states. How do we determine the mass and momentum of these particles?

- **Do we need the side-muon detectors?** Without them, over 20% of MINOS parasitic events become CC/NC ambiguous, many of them at high-x.
- **How much can we do without a magnetic field?** - We can measure stopping proton energy by range. What about the $\pi^{\pm}/K^{\pm}/P$ ambiguity? Can we see the pion decay? How much does de/dx in the last few cms of track help resolve π /P ambiguity?. If we need a B-field would the first 20 planes of MINOS do?
- **Will a TOF system solve the particle ID problem?** - can we resolve the π^{+}/π^{-}- ambiguity via observation of the μ^{+}/e^{+} chain? Can we use the MINOS detector to resolve π^{+}/π^{-}- ambiguity? Can we measure the charge and momentum in MINOS? How well do we measure the 1 π^{0}- state?
- **How does the plastic perform as an hadronic calorimeter?** What is the error on the hadronic energy?

PRELIMINARY ORGANIZATIONAL MEETING OF GROUP TO ADDRESS DETECTOR ISSUES HELD HERE FRIDAY NIGHT

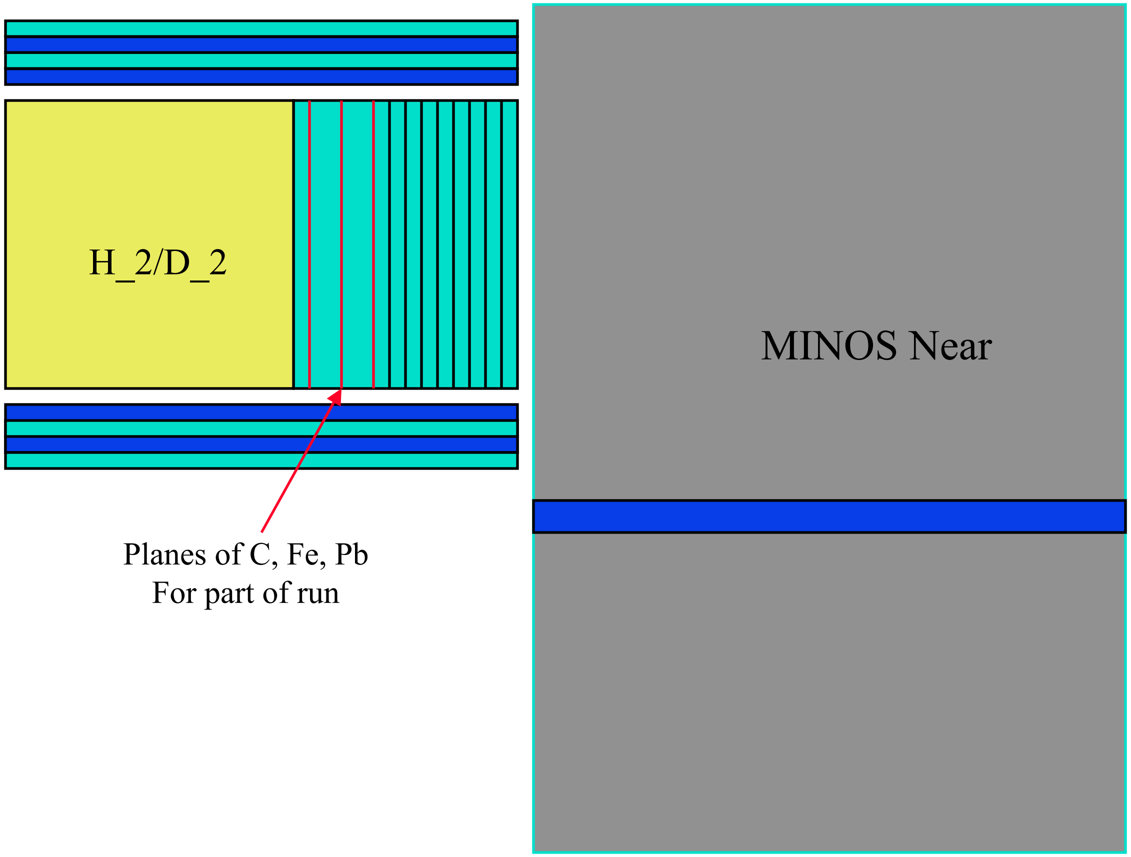
After initial (MINOS) run - add a Liquid H_2/D_2(/O/Ar) Target

Fid. vol:
r = 80 cm. l = 150 cm.

350 K CC evts in LH_2
800 K CC evts in LD_2
per year he-ν running.

Technically **easy/inexpensive** to build and operate.

Meeting **safety** specifications the **major** effort.



Detector: Event Rates; CC - $E_\mu > 0.35$ GeV

Event rates (2.5×10^{20} protons per year)

	MINOS Parasitic (3 years)	Off-axis Parasitic (1 year, me- ν)	**Prime User** (1 year, he-ν)	**Prime User** (2 year, he -$\bar{\nu}$)
CH	2.60 M	2.10 M	4.80 M	2.70 M
C	0.85 M	0.70 M	1.60 M	0.90 M
Fe	0.85 M	0.70 M	1.60 M	0.90 M
Pb	0.85 M	0.70 M	1.60 M	0.90 M
LH_2		0.15 M	0.35 M	0.20 M
LD_2		0.35 M	0.80 M	0.45 M

ν-Scattering Physics Topics with NuMI Beam Energies and Statistics

Measure during initial MINOS exposure

- **Quasi-elastic neutrino scattering and associated form-factors.**
- **Contribution of the strange quark to proton spin through ν elastic scattering.**
- **Resonance production region.**
- **Nuclear effects involving neutrinos, including NC/CC ratio.**

Need antineutrinos for (maximal) physics output

- $\sin^2\theta_W$ via the ratio of NC / CC (as well as dσ/dy from ν-e scattering) to check the recent surprising NuTeV result.
- Very high-x parton distribution functions where $F_2 \approx xF_3$.
- **Nuclear effects for valence and sea quarks**.
- **Parton distribution functions (pdf) via all 6 structure functions.**
- Leading exponential contributions of pQCD.
- Charm physics including the mass of the charm quark m_c (improved accuracy by an order of magnitude, V_{cd}, s(x) and, independently, s(x.).
- Strange particle production for V_{us}, flavor-changing neutral currents and measurements of hyperon polarization.

Physics Result: Exclusive States - Elastic -1π Cross-sections and Strange Particle Production

(Contribution of s-quark to Spin of the Proton)

- Measure absolute σ_{el} and $\sigma_{1\pi}$ to ± 3% (Beam) ± Expt. Systematic: **Minimal statistical errors: ≈ 400 K each .**
- Much cleaner measurement of Δs (no large x --> 0 extrapolation & assume SU(3) symmetry)
  - Significantly reduce systematic errors in Δs by measuring the ratio: Measure R = $\nu+p \rightarrow \nu+p$ / $\nu+n \rightarrow \mu+p$ to ± 0.03 yields Δs to ± 0.03 C. Horowitz and R. Tayloe - Indiana
- In the 2-year $\bar{\nu}$ run, this experiment would accumulate:

430 K Λ events in CH, 145 K Λ in C/Fe/Pb and 90 K Λ in D_2.

Could also search for or measure

$$\bar{\nu} + p \longrightarrow \mu^+ + \Sigma$$
$$\bar{\nu} + p \longrightarrow \mu^+ + K^- + p$$

$$\bar{\nu} + n \longrightarrow \mu^+ + \Sigma^-$$
$$\bar{\nu} + n \longrightarrow \mu^+ + K^- + \Lambda$$

$$\bar{\nu} + p \longrightarrow \bar{\nu} + \Sigma \qquad \text{SCNC}$$
$$\bar{\nu} + p \longrightarrow \bar{\nu} + K + \Sigma^+$$
$$\bar{\nu} + p \longrightarrow \bar{\nu} + K + p \qquad \text{SCNC}$$

$$\bar{\nu} + n \longrightarrow \bar{\nu} + \Lambda \qquad \text{SCNC}$$
$$\bar{\nu} + n \longrightarrow \bar{\nu} + \Sigma \qquad \text{SCNC}$$
$$\bar{\nu} + p \longrightarrow \bar{\nu} + K + \Sigma$$

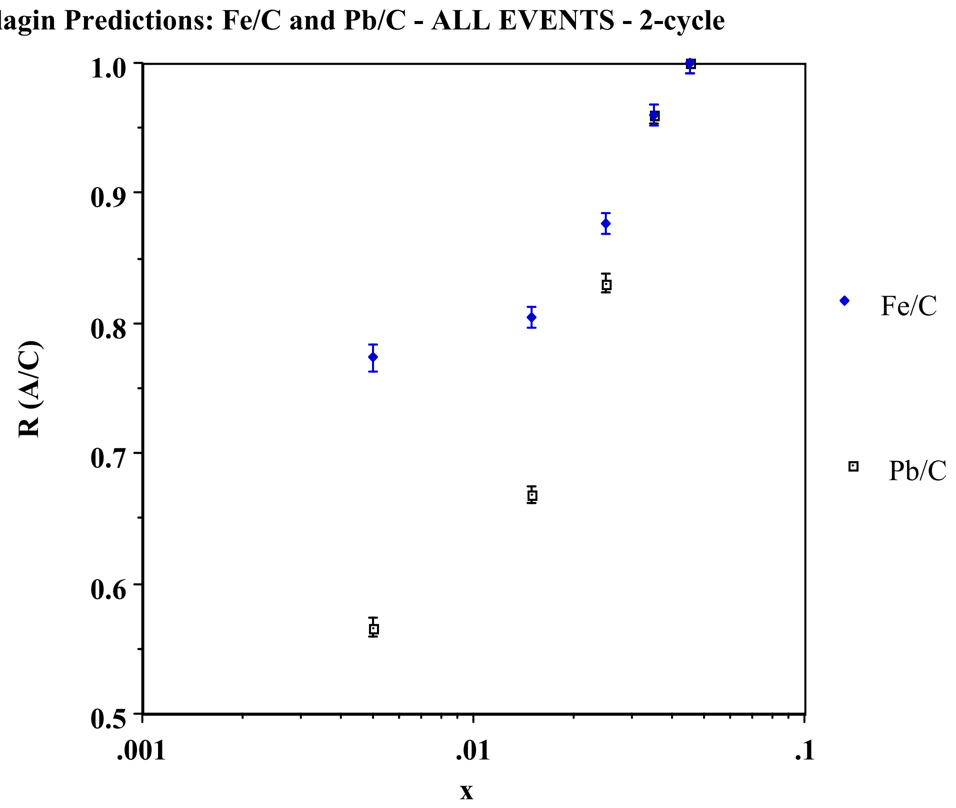
Physics Results: Nuclear Effects

(ν running only)

Ratio Fe/C: Statistical Errors From MINOS Parasitic Run

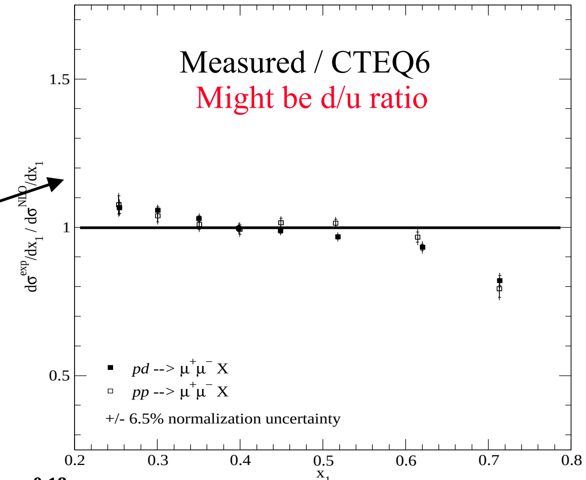
x_{Bj}	MINOS all	MINOS DIS
0.0 - .01	**1.8 %**	xxx
.01 - .02	**1.4**	**10 %**
.02 - .03	**1.3**	**6**
.03 - .04	**1.2**	**4**
.04 - .05	**1.1**	**3**
.05 - .06	1.1	**2.6**
.06 - .07	**1.0**	**2.3**

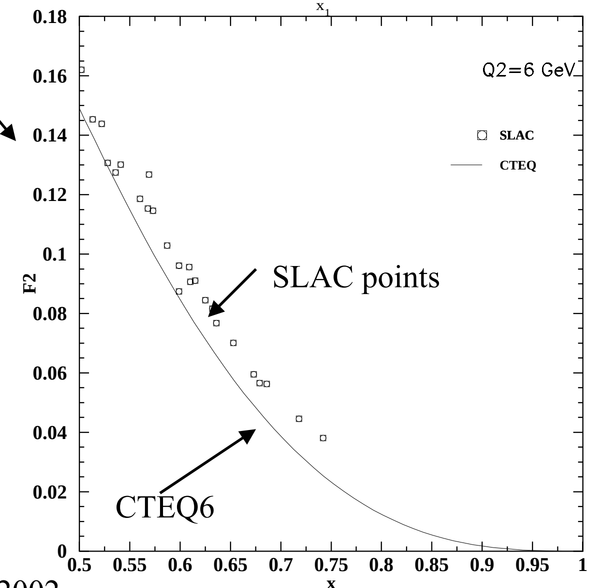
$Q^2 = 0.7\ GeV^2$



Physics Results: High-x_{Bj} Parton Distribution Functions

- The particular case of what is happening at high- x_{Bj} is currently a bit of controversial with indications that current global results not correct:
- Drell-Yan production results (E-866) may indicate that high-x_{Bj} (valence) quarks OVERESTIMATED.
- A Jlab analysis of Jlab and SLAC high x DIS indicate high-x_{Bj} quarks UNDERESTIMATED.





≈ Statistical Errors for 1 year of he-ν

x_{Bj}	CH	LH_2	LD_2
.6 - .65	**0.6%**	**2.2%**	**1.5%**
.65 - .7	**0.7**	**2.6**	**1.7**
.7 - .75	**1.0**	**3.7**	**2.5**
.75 - .8	**1.3**	**5**	**3**
.8 - .85	**2**	**7**	**5**
.85 - .9	**3**	**11**	**7**
.9 - 1.0	**4**	**14**	**10**

UNOFFICIAL Response of the Fermilab PAC to EOI

- Only unofficial summary is currently available! Official letter due in a week or two.
- We seem to be "encouraged" to continue developing the physics, detector and collaboration in order to submit a formal Proposal. How "encouraged" will have to wait for the official letter.
- An indication (quantitative) of how these results would aid neutrino oscillation experiments would be welcome.
- **A combined R&D program (multiple EOIs) for detector + readout technology is encouraged.**

Conclusions: NuMI ν Scattering Experiment

- NuMI Beam is **Intense and the ideal (perhaps only) place to do these measurements:**
  - yielding ≈ 860 K events/**ton** during MINOS approved run*
  - yielding ≈ 1.6 M events/**ton-year** in the he-mode and 0.7 M events/**ton-year** in the me-mode.
- NuMI Near Hall:
  - Plenty of space for new detector(s).
- NuMI Near Hall Physics:
  - cross section measurements: elastic, 1-π … total. Associated form-factor and Δs
  - nuclear effects of ν different than e/μ. Nuclear effects on valance- different than sea-quarks
  - NC / CC ($\sin^2\theta_W$)on various nuclear targets
  - PDFs, particularly high-x, both on nucleon and nuclear targets,
  - strange particle production
  - Study of the perturbative/non-perturbative transition (quark-hadron duality) with neutrinos.
- NuMI ν – Scattering Detector studies underway, phased installation:
  - "solid scintillator" + planes of various A: 3 - 4 ton fiducial volume
  - Plenty of Questions still to be answered
  - liquid H_2 / D_2 (/O/Ar): large target technically no challenge
- **Real and growing interest from both the NP and HEP communities.**
- **Apparently, an encouraging response from the Fermilab PAC to produce a formal Proposal! A joint (3 groups) effort to develop a detector being established.**