Neutrino Interactions on Nucleons and Nuclei

NuInt02 Conference Summary

Sunday December 15, 2002 11:45-12:30

36 Talks --> 45 Min --> 1.5 Transparencies/Talk

(what to do?)

Arie Bodek, Univ. of Rochester

http://nuint.ps.uci.edu/

UC Irvine, California - Dec 12-15,2002

http://www.pas.rochester.edu/~bodek/SummaryIrvine.ppt

My Apologies to those talks that I have not covered.
Better to cover a few topics in more details.

Also, I have prepared most of this talk at the
Restaurant Conference Dinner…….So I had to make some choices

Advice to Future Speakers at this conference
And theorists who would like to help us in the future.
From an Advance Copy of the National Academy of Science Report
"Physics in the 21st century" (to appear 2003 on the WWW).

1. If your stuff is not on the WWW, it does not exist
(and is not in this talk)

2. If your model cannot be implemented in a Monte
Carlo… It does not exist..

3. Any model must be implemented to predict BOTH neutrino
and electron scattering cases. So that some parameters can be
tuned with precision electron scattering experiments

Since I have prepared most of this talk at the
Restaurant Conference Dinner - this talk is organized
(if you call this organized). As follows:

1. Slides I prepared during the **salad** (without the goat cheese)

2. Slides that I prepared during the **appetizer** (also without the cheese)

3. Slides that I prepared during the main course

4. Slides that were prepared with **dessert and coffee**

5. Slides that were not prepared yet, but will be prepared for The proceedings.

My apologies if some of the results are in the wrong section of This talk.

US National Academy of Science
National Research Council Report 2002

In the first decade of the 21st Century,

new discoveries are expected in the fast growing

"areas on the boundaries between

the established disciplines"

Examples that come to mind are:

Physics-Biology-Genetics-Medicine

Physics-Astronomy

Computer Science - Biology-Genetics

Computer Science and Physics

Etc.

Within the discipline of Physics, we can make new Discoveries by drawing the expertise of physicists Across the various disciplines of Nuclear Physics, Particle Physics, Astrophysics

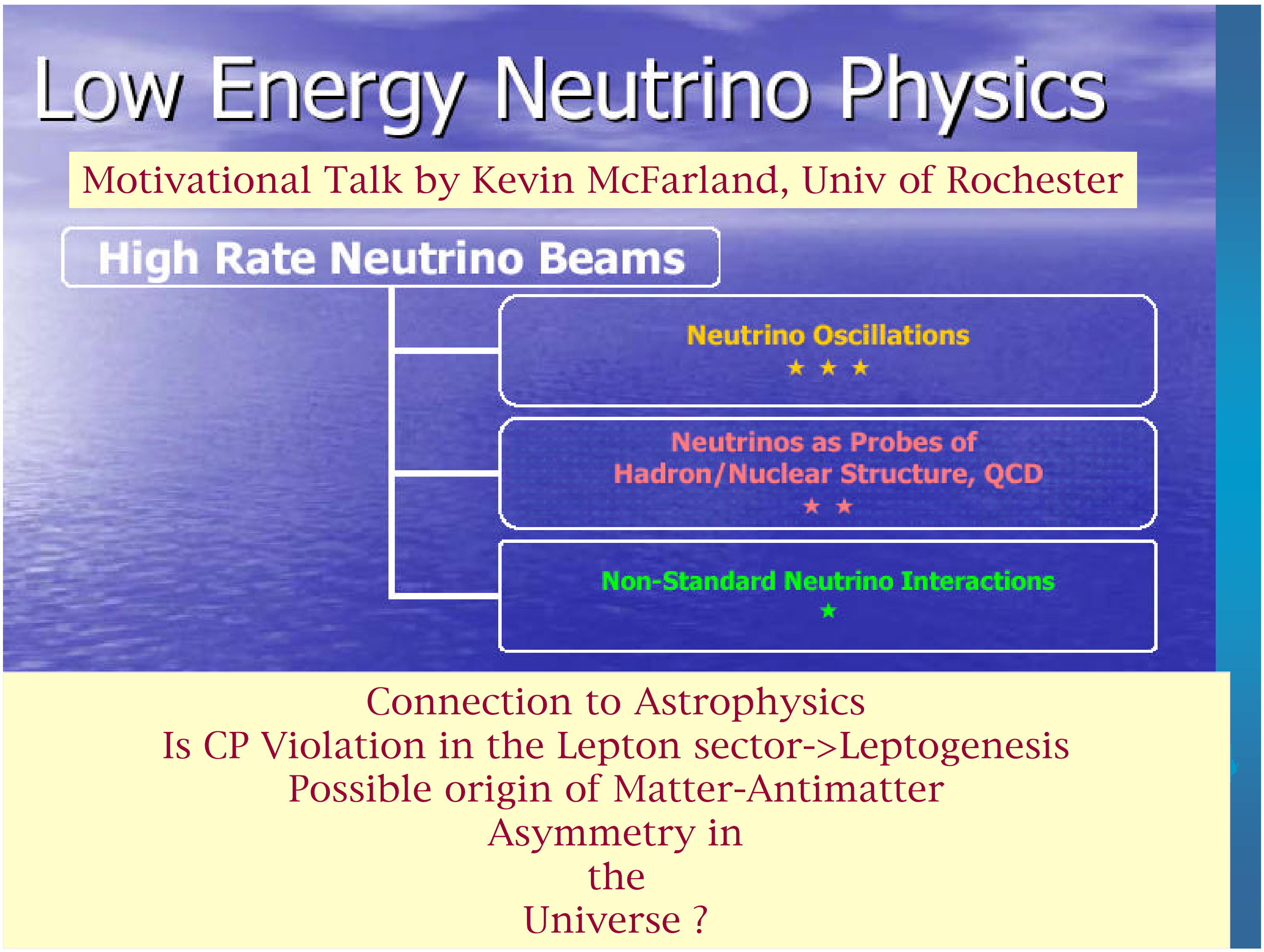
It is appropriate that in 2001 the first year Of the 21 century, NuInt01 was started as The first of series of conferences focusing on

A single overlying unifying goal

"Neutrino Oscillations

Which requires drawing on contributions from Nuclear, Particle, and Astrophysics and

Requires Understanding of non-perturbative QCD


Low Energy Neutrino Physics
Motivational Talk by Kevin McFarland, Univ of Rochester
High Rate Neutrino Beams
Neutrino Oscillations
★ ★ ★
Neutrinos as Probes of
Hadron/Nuclear Structure, QCD
★ ★
Non-Standard Neutrino Interactions
★
Connection to Astrophysics
Is CP Violation in the Lepton sector->Leptogenesis
Possible origin of Matter-Antimatter
Asymmetry in
the
Universe ?

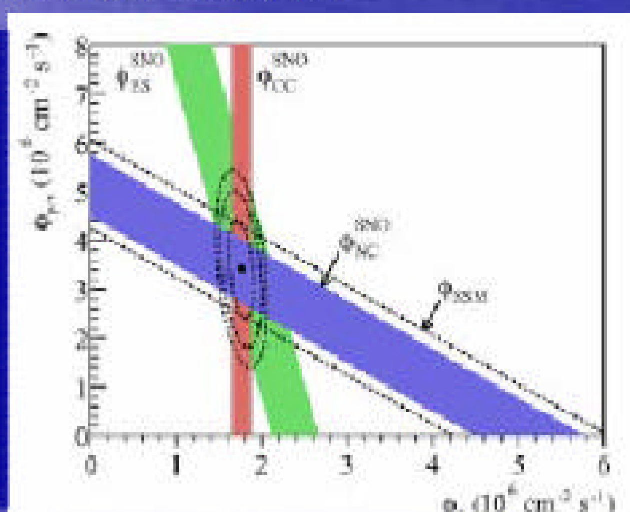
Solar Neutrino Oscillations

- Deficit of electron neutrinos from sun observed in many experiments
- SNO has recently shown these appear as other flavors

Fluxes

(10^6 cm^{-2} s^{-1})

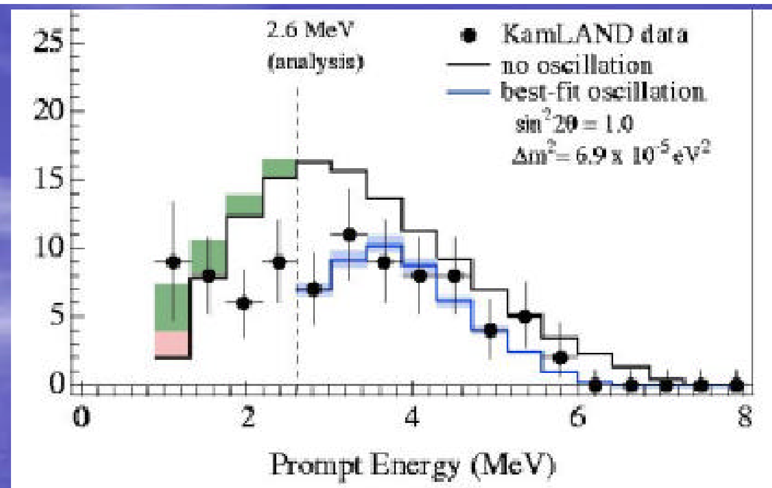
ν_e:	1.76(11)
$\nu_{\mu\tau}$:	3.41(66)
ν_{total}:	5.09(64)
ν_{SSM}:	5.05

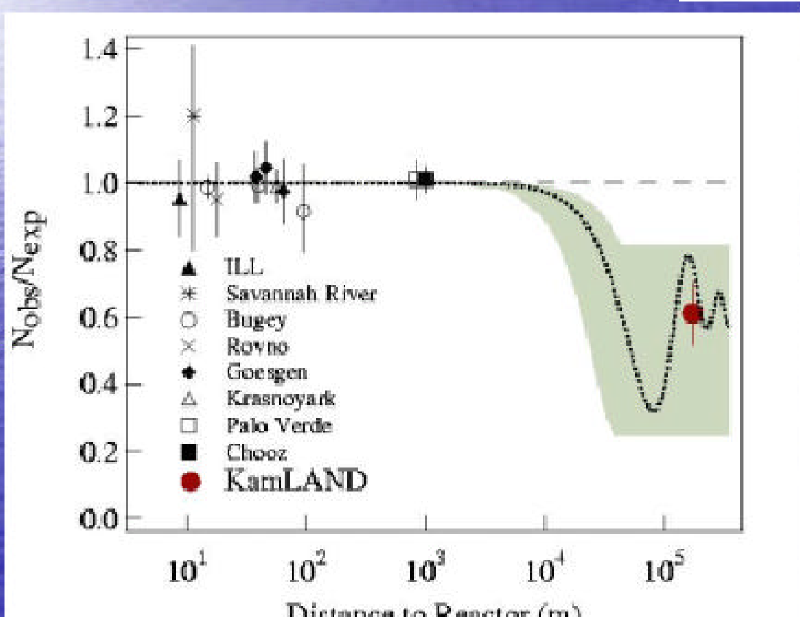


Note that both SNO and KAMLAND Use Theoretical Cross Sections 3% Precision (assumed) between 5 -175 MeV

KAMLAND

- $\overline{\nu}_e$ disappear!
- First observation with reactor source





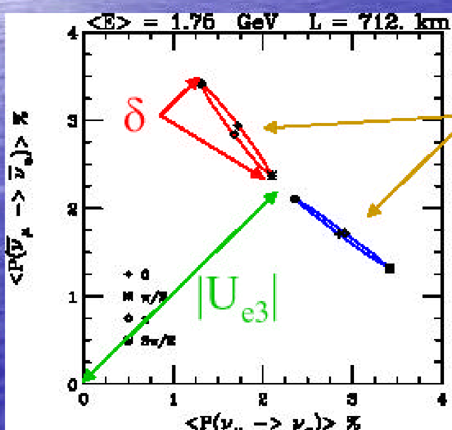
- Consistent with sola
neutrino MSW explanation
- Not (yet) enough precision to measur
δm^2

GOOD NEW FOR FUTURE CPV

Precision $P(\nu_\mu \rightarrow \nu_e)$ and $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$

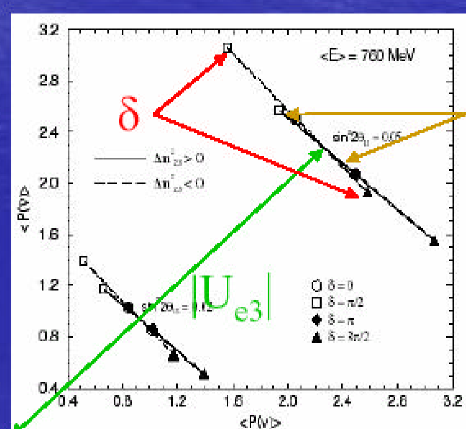
- Comparison of two *precise* measurements of $\nu_\mu \rightarrow \nu_e$ can untangle magnitude and phase of U_{e3} and mass hierarchy
  - ν and anti-ν measurements
  - or two ν measurements at different *E* or *L/E*
  - This is not easy
    - low statistics and incoherent systematic uncertainties

Requires good knowledge of cross sections



Sign of δm_{23}

(Minakata et al.)



Sign of δm_{23}

Good News: solar ΔM^2 LARGE - GOOD FOR CPV

BAD NEWS: WE NEED PRECISION NEUTRINO σ

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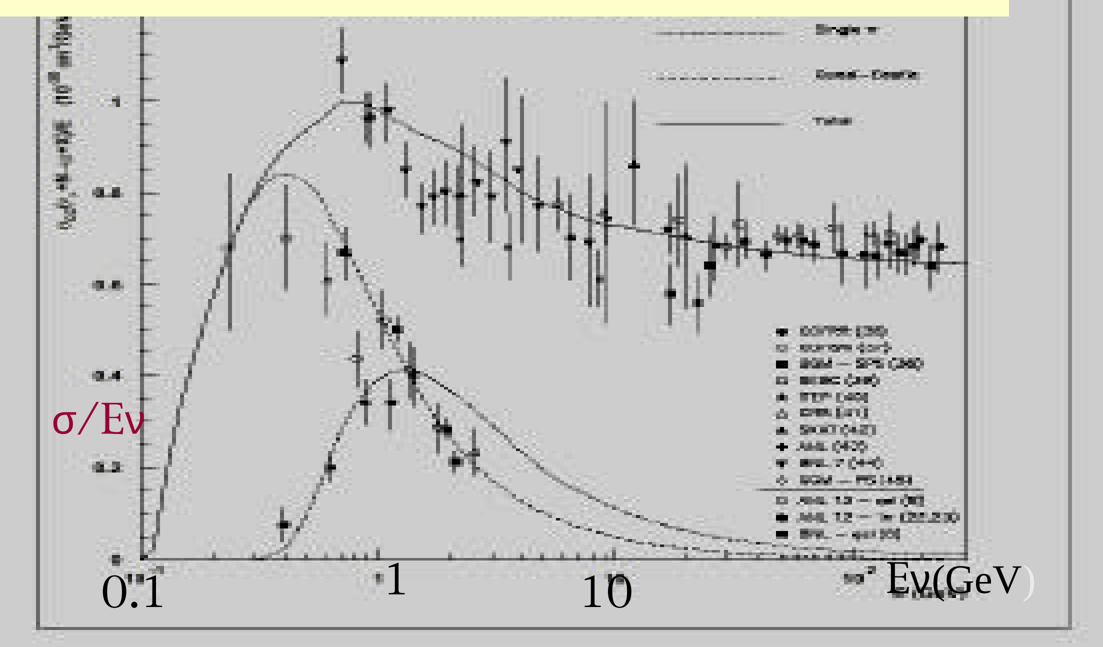
1 Pion production/ resonances

Quasielastic W=Mp

------total σ including DIS W>2GeV

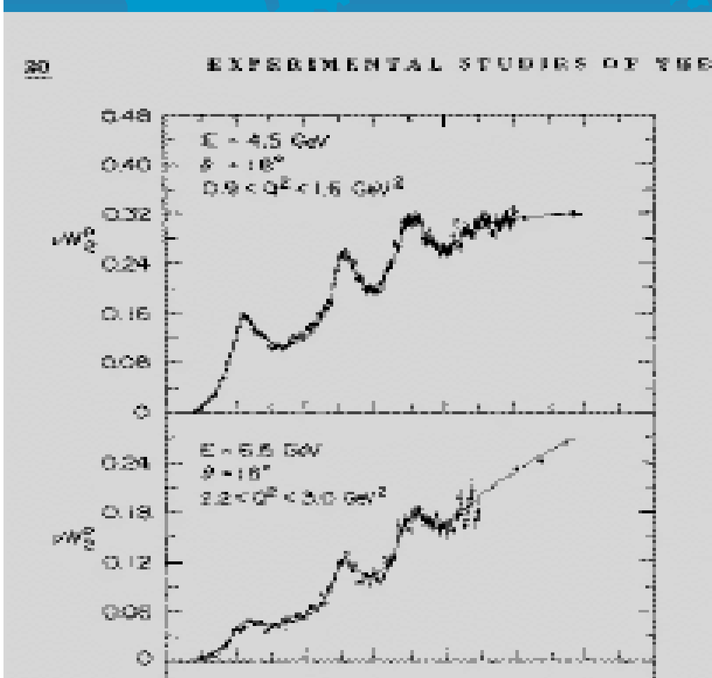


1. **Bubble Chamber language. - Exclusive final states**
2. **Resonance language. - Excitation Form Factors of Resonances and decays**
3. **Deep Inelastic Scattering -PDFs and fragmentation to excl. final states**

-Note: Form Factors can be converted to PDFs

MIT SLAC DATA 1972 e.g. E0 = 4.5 and 6.5 GeV

e-P scattering A. Bodek PhD thesis 1972

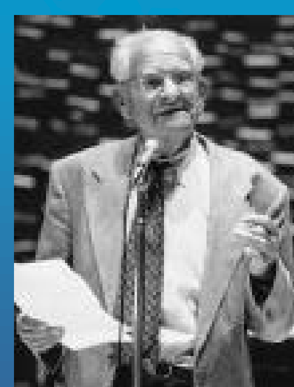


'The electron scattering data in the Resonance Region is the "Frank Hertz Experiment" of the Proton. The Deep Inelastic Region is the "Rutherford Experiment" of the proton' SAID

V. Weisskopf * (former faculty member at Rochester and at MIT when he showed these data at an MIT Colloquium in 1971 (* died April 2002 at age 93)

What do The Frank Hertz" and "Rutherford Experiment" of the proton' have in common?

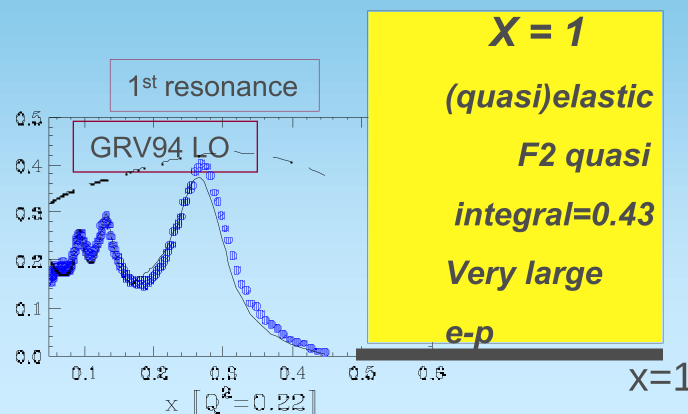
A: Quarks! And QCD



(e/ μ /ν)-N cross sections at low energy

Neutrino interactions --

- **Quasi-Elastic / Elastic (W=Mp)**
  $\nu_\mu + n$ --> $\mu^- + p$ (x =1, W=Mp)
  Described by form factors (but need to account for Fermi Motion/binding effects in nucleus) e.g. Bodek and Ritchie (Phys. Rev. D23, 1070 (1981)
- **Resonance (low Q^2, W< 2) ν_μ + p --> μ^- + p + nπ**
  Poorly measured , Adding DIS and resonances together without double counting is tricky. 1st resonance and others modeled by Rein and Seghal. Ann Phys 133, 79, (1981)
- **Deep Inelastic**
  $\nu_\mu + p$ --> $\mu^- + X$ (high Q^2, W> 2)
  well measured by high energy experiments and well described by quark-parton model (pQCD with NLO PDFs), but doesn't work well at low Q^2 region.



(e.g. SLAC data at Q^2=0.22)

- **Issues at few GeV :**
- **Resonance production and low Q^2 DIS contribution meet.**
- **The challenge is to describe ALL THREE processes at ALL neutrino (or electron) energies**
- **HOW CAN THIS BE DONE? - Subject of this TALK**

What do we want to know about low energy ν_μ reactions and why

- <u>Intellectual Reasons:</u>
- **Understand how QCD works in both neutrino and electron scattering at low energies - different spectator quark effects. (*There are fascinating issues here as we will show*)**
- **How is fragmentation into final state hadrons affected by nuclear effects in electron versus neutrino reactions.**
- **Of interest to : Nuclear Physics/Medium Energy, QCD/ Jlab communities**
- ***<u>IF YOU ARE INTERESTED in QCD</u>***

- **<u>Practical Reasons</u>:**
- **Determining the neutrino sector mass and mixing matrix precisely**
  - **requires knowledge of both Neutral Current (NC) and Charged Current(CC) differential Cross Sections and Final States**
  - **These are needed for the NUCLEAR TARGET from which the Neutrino Detector is constructed (e.g Water, Carbon, Iron)-of interest to**
- **Particle Physics/ HEP/ FNAL /KEK/ Neutrino communities**
- ***<u>IF YOU ARE INTERESTED IN NEUTRINO MASS and MIXING</u>*.**

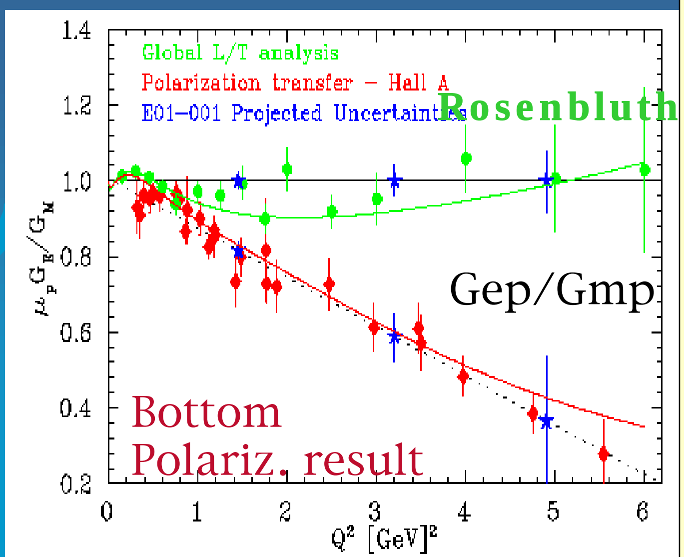
Astrophysics community interested in both

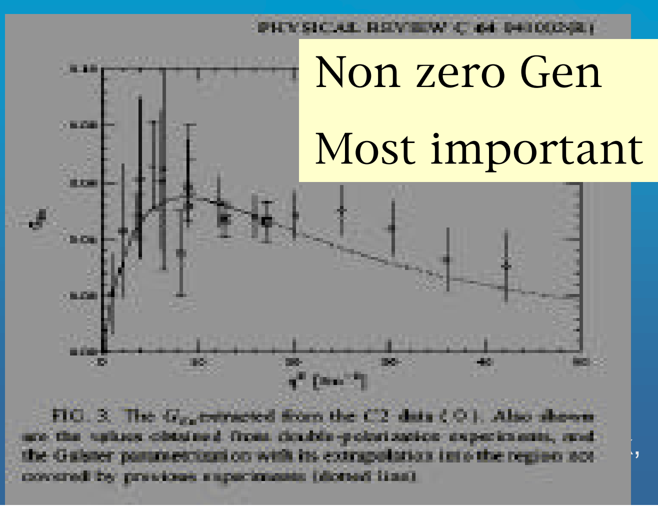
Focus on recent results from collaborative efforts between Jlab and Neutrino Community

Start with results from one collaboration between Jlab Medium Energy Physicists and High Energy Neutrino Physicists (As a result of NuInt01) ON NUCLEON ELASTIC FORM FACTORS

Howard Budd, Arie Bodek
University of Rochester
and
John Arrington - Argonne/Jlab

With the help of Will Brooks, Andrei Semenov And Cynthia Keppel (who got us together),





For $Q^2 < 1$ GeV^2 ONLY

New precision polarization Transfer measurements on Gep/Gmp agree with Standard Rosenbluth technique.

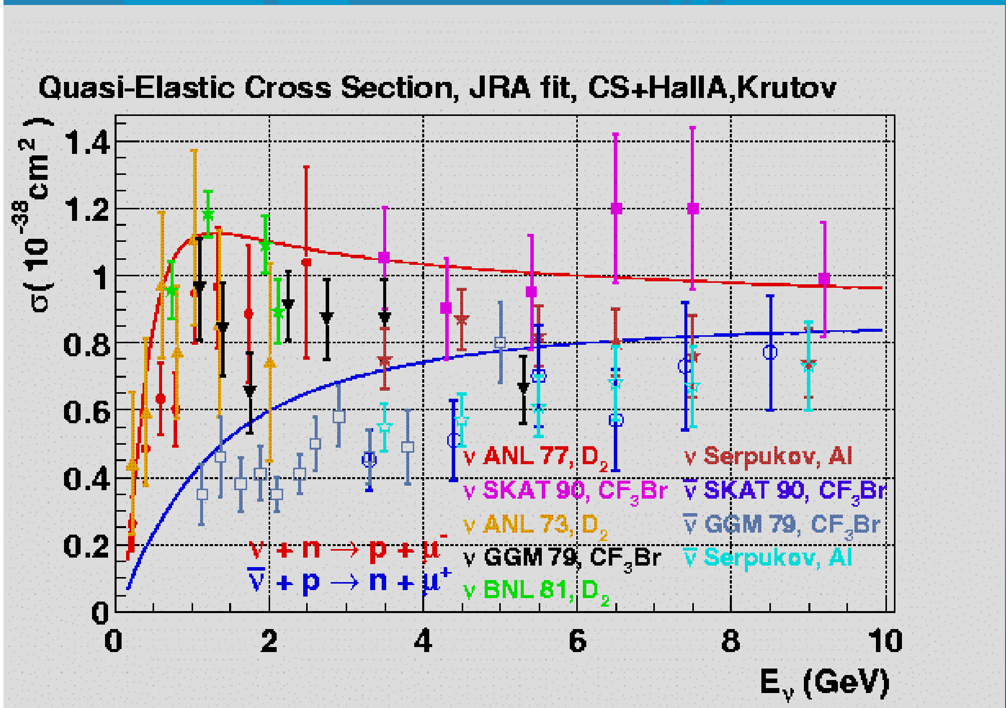
***HOWEVER: Above $Q^2 > 1$ GeV^2 There is disagreement*.**

Note, this high Q^2 region Is not relevant to neutrino Experiments. So use latest Gen, Gep, Gmn, Gmp form factors As new input Vector form Factors for quasi-elastic Neutrino scattering.

$\sigma_{\text{quasi-elastic neutrinos on Neutrons}}$ - Calculated

$\sigma_{\text{quasi-elastic Antineutrinos on}}$ Protons - Calculated

From H. Budd -U of Rochester (NuInt02) (with Bodek and Arrington) DATA - FLUX ERRORS ARE 10%

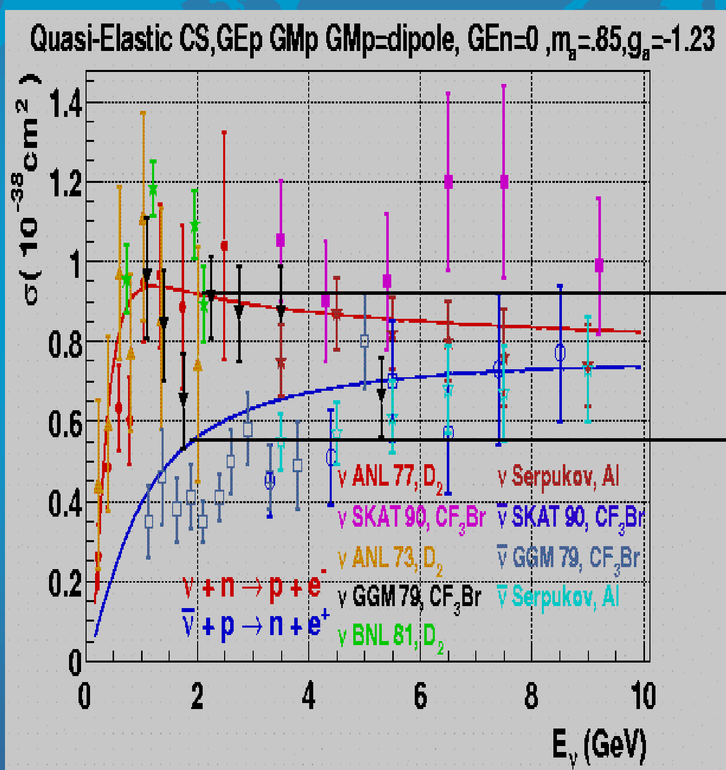


With the most Up to date Form Factors The agreement With data is ***not spectacular***

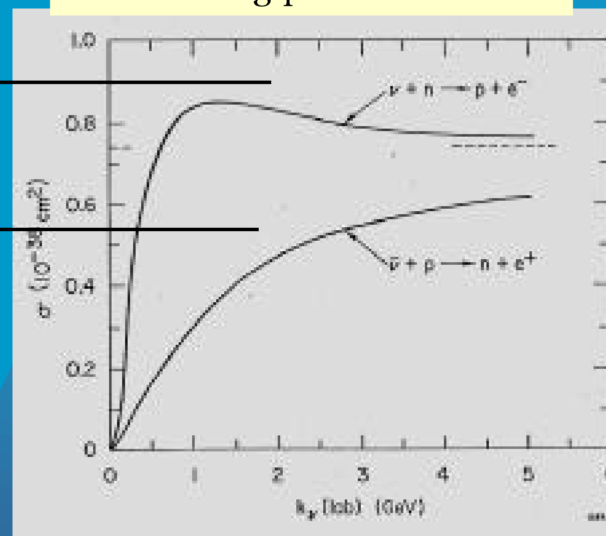
Antineutrino data mostly on nuclear targets

Compare to Original Llewellyn Smith Prediction (H. Budd)

Antineutrino data on nuclear targets



Old LS results with
Old ga=-1.23 and
Ma below. Plot in LS paper
Is 10% lower than the cross
Section we calculate with the
Same wrong parameters.



Neutrino Cross Sections

H. M. Gallagher and M. C. Goodman

NuMI-112
PDK-626
Nov. 10, 1995

They implemented The Llewellyn-Smith Formalism for NUMI

$$\frac{d\sigma}{d|q^2|}\begin{pmatrix}\nu n \to l^- p \\ \overline{\nu} p \to l^+ n\end{pmatrix} = \frac{M^2 G^2 cos^2\theta_c}{8\pi E_\nu^2}\left[A(q^2) \mp B(q^2)\frac{(s-u)}{M^2} + \frac{C(q^2)(s-u)^2}{M^4}\right]. \qquad (2)$$

In this expression, G is the Fermi coupling constant and θ_c is the Cabibbo mixing angle ($G = 1.16639 \times 10^{-5}\mathrm{GeV}^{-2}$). The functions A, B, and C are convenient combinations of the nucleon form factors.

Contraction of the hadronic and leptonic currents yields: Non zero

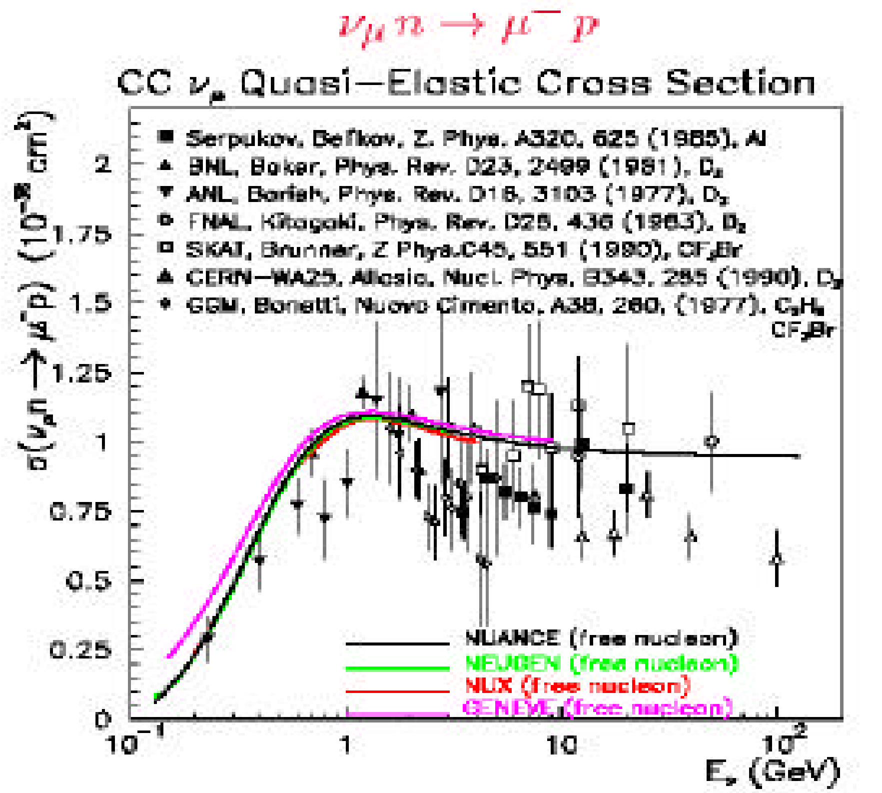
$$A = \frac{(m^2-q^2)}{4M^2}\left[\left(4-\frac{q^2}{M^2}\right)|F_A|^2 - \left(4+\frac{q^2}{M^2}\right)|F_V^1|^2 - \frac{q^2}{M^2}|\xi F_V^2|^2\left(1+\frac{q^2}{4M^2}\right) - \frac{4q^2 ReF_V^{1*}\xi F_V^2}{M^2} \right. \qquad (3)$$

$$\left. + \frac{q^2}{M^2}\left(4-\frac{q^2}{M^2}\right)|F_T|^2 - \frac{m^2}{M^2}\left(|F_V^1+\xi F_V^2|^2 + |F_A+2F_P|^2 + \left(\frac{q^2}{M^2}-4\right)\left(|F_S|^2 + |F_P|^2\right)\right)\right]$$

$$B = -\frac{q^2}{M^2}ReF_A^*(F_V^1+\xi F_V^2) - \frac{m^2}{M^2}Re\left[\left(F_V^1 + \frac{q^2}{4M^2}\xi F_V^2\right)^* F_S - \left(F_A + \frac{q^2 F_P}{2M^2}\right)^* F_T\right] \qquad (4)$$

$$C = \frac{1}{4}\left(|F_A|^2 + |F_V^1|^2 - \frac{q^2}{M^2}\left|\frac{\xi F_V^2}{2}\right|^2 - \frac{q^2}{M^2}|F_T|^2\right), \qquad (5)$$

where m is the final state lepton mass. Ignoring second-class currents (those which violate G-parity) allows us to set the scalar and tensor form factors to zero. According to the CVC



- Selecting a consistent set of parameters:
  - $\hookrightarrow$ $M_A = 1.032$ GeV
  - $\hookrightarrow$ $M_V = 0.84$ GeV
  - $\hookrightarrow$ $F_A(q^2) = \frac{F_A(0)}{(1-q^2/M_A^2)^2}$; $F_A(0) = -1.25$

Monte Carlo Session. **Sam Zeller@NuInt02 Talk compares Various Monte Carlos for Quasi Elastic scattering**

NOTE: Budd-Bodek-Arrington code **Gives same results With the same Input form factors**

Also Much Thanks to Zeller, Hawker, etc for All the Physics Archeology.

$$F_V^1(q^2) = \left(1 - \frac{q^2}{4M^2}\right)^{-1} \left[G_E^V(q^2) - \frac{q^2}{4M^2} G_M^V(q^2)\right] \quad (6)$$

$$\xi F_V^2(q^2) = \left(1 - \frac{q^2}{4M^2}\right)^{1} \left[G_M^V(q^2) - G_E^V(q^2)\right]. \quad (7)$$

The electromagnetic form factors are determined from electron scattering experiments:

UPDATE: Replace by

$G_E^V = G_E^P - G_E^N$

$$G_E^V(1^2) = \frac{1}{\left(1 - \frac{q^2}{M_V^2}\right)^2} \qquad G_M^V(q^2) = \frac{1 + \mu_p - \mu_n}{\left(1 - \frac{q^2}{M_V^2}\right)^2}.$$

UPATE: Replace by

$G_M^V = G_M^P - G_M^N$

The situation is slightly more complicated for the hadronic axial current. $F_A(q^2 = 0) = -1.261 \pm .004$ is known from neutron beta decay. The q^2 dependence has to be inferred or $M_A = 1.032 \pm .036$ GeV [7]. ector case we assume the same dipole form:

$$F_A(q^2) = \frac{-1.23}{\left(1 - \frac{q^2}{M_A^2}\right)^2}. \quad (9)$$

$Q^2 = -q^2$

g_A, M_A need to Be updated

$$F_P(q^2) = \frac{2M^2 F_A(q^2)}{M_\pi^2 - q^2}. \quad (10)$$

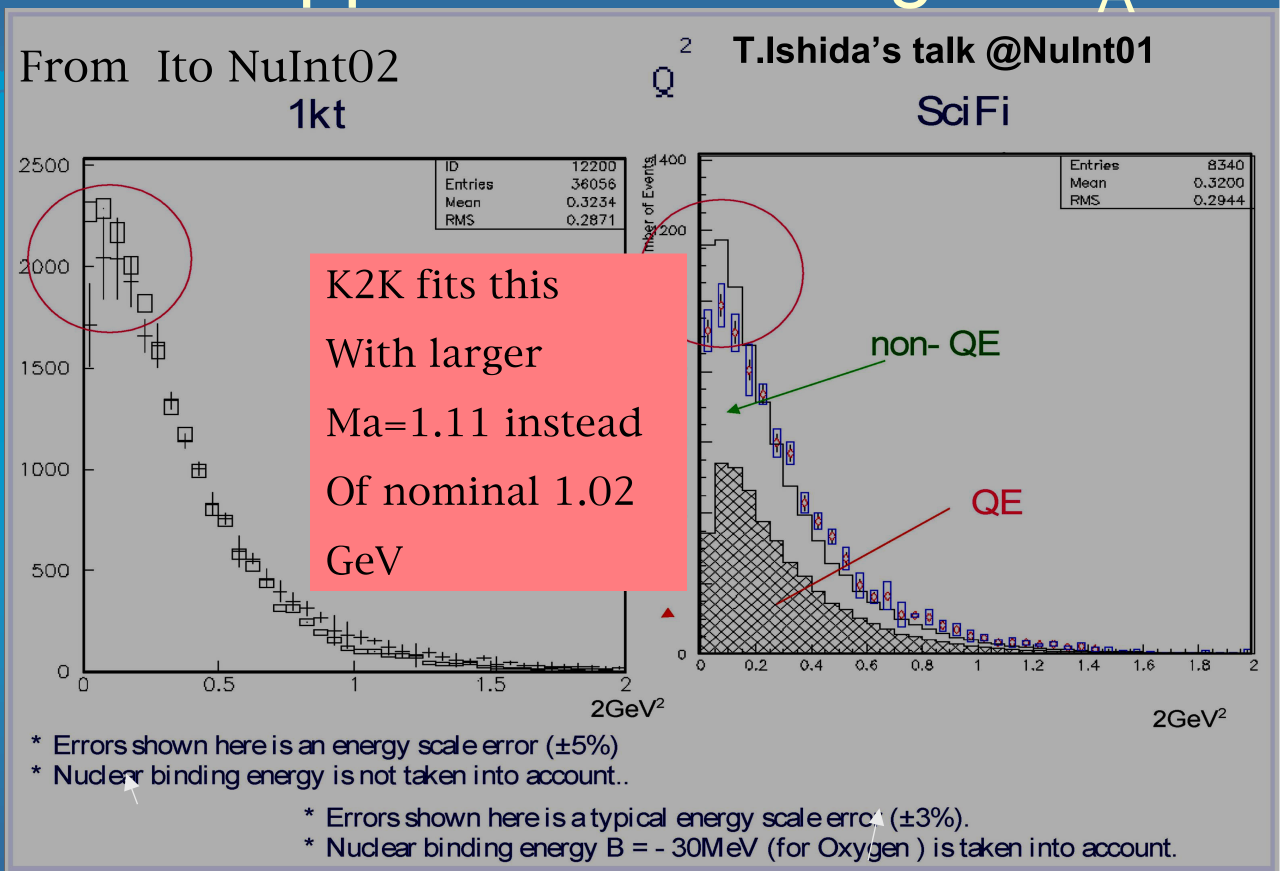
Fp important for Muon neutrinos only at Very Low Energy

The inclusion of F_P leads to an approximately 5% reduction in both the ν_τ and ν_τ quasi-elastic cross sections. The only remaining parameters needed to describe the quasi-elastic cross section are thus M_V and M_A. $M_V = .71$ GeV, as determined with high accuracy

From C.H. Llewellyn Smith (SLAC). SLAC-PUB-0958 Phys.Rept.3:261,1972

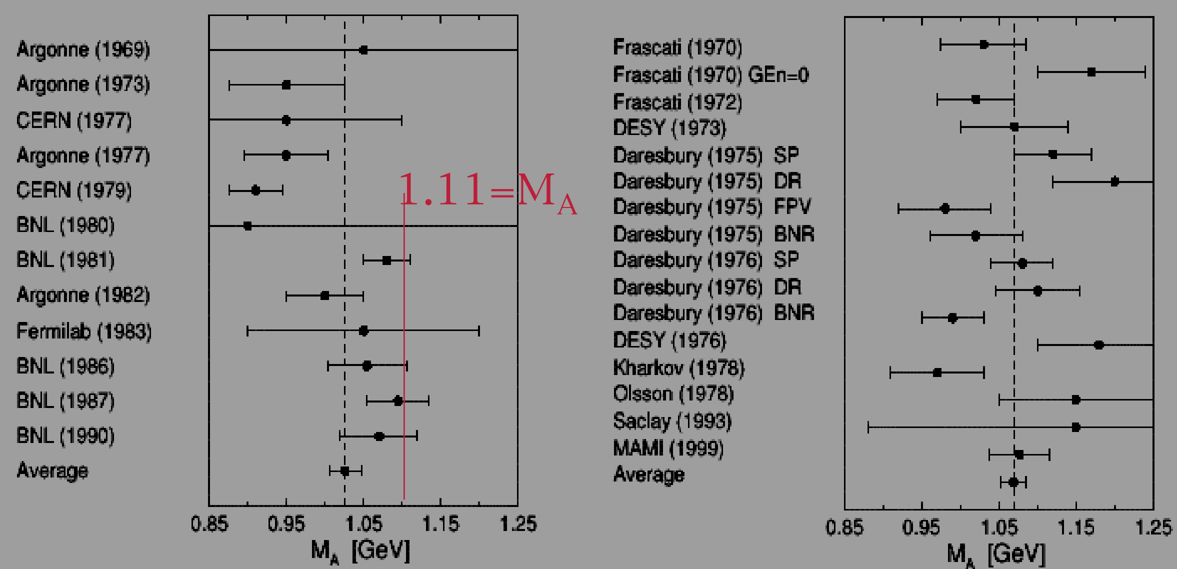
First result done at NuInt02 (yesterday)

Low-Q2 suppression or Larger M_A?



Axial structure of the nucleon Hep-ph/0107088 (2001)

Véronique Bernard†, Latifa Elouadrhiri‡, Ulf-G Meißner§



For updated M_A expt. need to be reanalyzed with new g_A, and G_E^N

Difference In Ma between Electroproduction And neutrino Is understood

Figure 1. Axial mass M_A extractions. Left panel: From (quasi)elastic neutrino and antineutrino scattering experiments. The weighted average is $M_A = (1.026 \pm 0.021)$ GeV. Right panel: From charged pion electroproduction experiments. The weighted average is $M_A = (1.069 \pm 0.016)$ GeV. Note that value for the MAMI experiment contains both the statistical and systematical uncertainty; for other values the systematical errors were not explicitly given. The labels SP, DR, FPV and BNR refer to different methods evaluating the corrections beyond the soft pion limit as explained in the text.

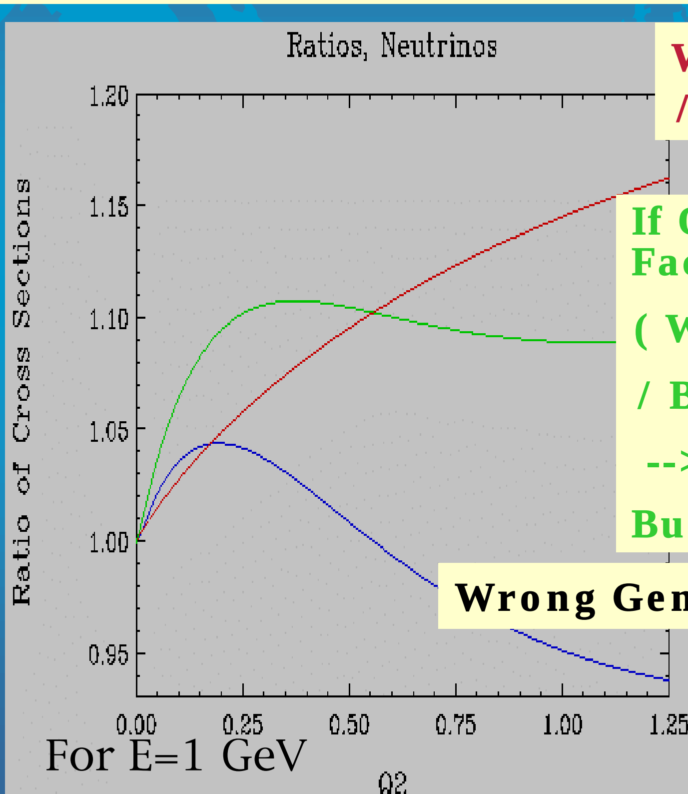
M_A from neutrino expt. No theory corrections needed

ANSWER - Neutrino Community Using Outdated Form Factors

blue = (D0DD ma=1.02)/JhaKJhaJ = **(Dipole, Gen=0, Ma=1.02)/ Best Model**

red = (D0DD ma=1.1)/(D0DD ma=1.02) = **(Ma =1.1) / (Ma =1.02)**

green = (D0DD ma=1.1)/JhaKJhaJ = **(Dipole, Gen=0, Ma=1.1)/ Best Model**



Wrong Ma=1.1 (used by K2K) / Ma=1.02 (Ratio)

If One Uses Both wrong Form Factors (used in K2K MC)

(Wrong Gen =0 +Wrong Ma=1.1)

/ Best Form Factors (Ratio)

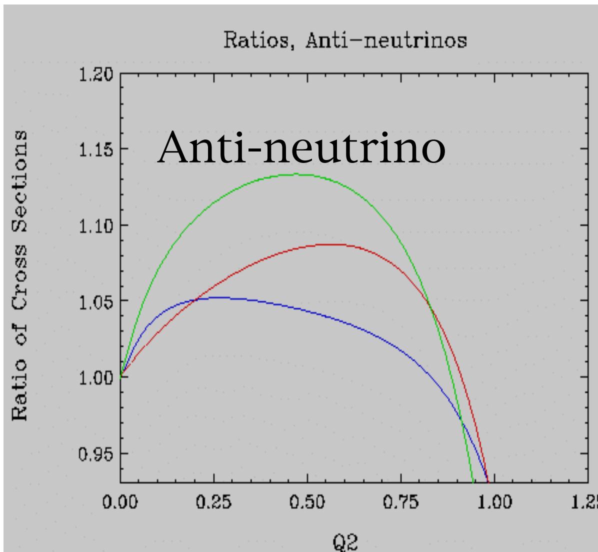
--> Get right shape

But wrong normalization of 10%

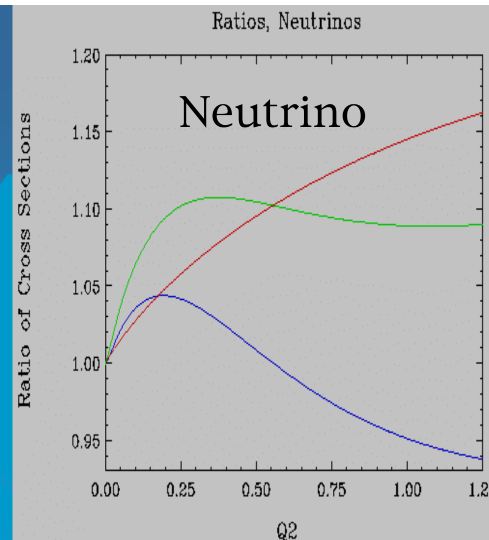
Wrong Gen /Best Form Factors (Ratio)

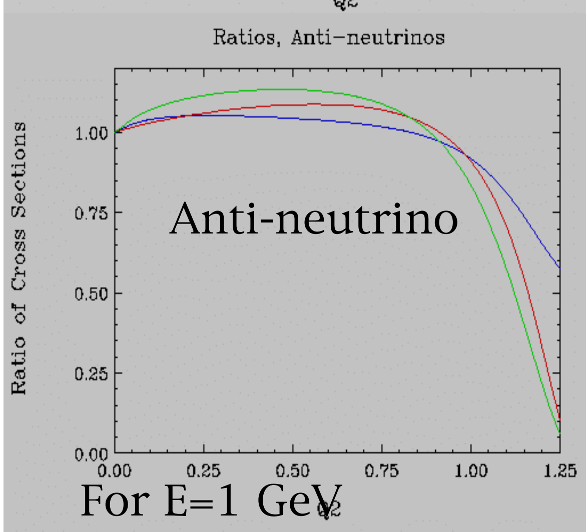
Talk by Budd at NuInt02

(work of Budd, Bodek Arrington)



What about in Anti-Neutrino running (e.g. MiniBoone) Is there greater sensitivity to Gen or Ma -<u>Greater sensitivity to Gen</u>





Red Ma=1.1 (used by K2K)

/ Ma=1.02 (Ratio)

Green: If One Uses Two wrong Form Factors (used in K2K MC)

(Wrong Gen =0 +Wrong Ma=1.1) / Best Form Factors (Ratio)

Blue:

Wrong Gen /Best Form Factors (Ratio)

What about Nuclear Effects? Get Lots of Information from Jlab Data (Talk by Rolf Ent). e. e. e. e.g Polarization Double Ratio

Using Polarization Transfer Experiments

--> Gep/Gmp for Protons Bound in He4 (Hard copy transp)

Divided by Gep/Gmp Free (or PWIA = plane wave

Impulse approximation) for Q2 between 0.4 to 1.0

= 0.9 +- 0.03 (JLAB E93-049, and Phys.Lett. B500,47(2001)

Expect 0.92 from Thomas RDWIA (QMC - Quark Meson Clouds) Relativistic Distorted Wave Impulse Approximation, and 0.96 from Udias RDWIA model.

So Gep may have binding effects of order -10%. Or Gmp may have binding effect of +10%. Effect on neutrino cross sections will be estimated By Budd, Bodek and Arrington)- could not be done in time for this summary.

Need to understand if this is real. (PLEASE REPEAT THIS AT Q2 CLOSE TO ZERO WHERE NO EFFECT IS EXPECTED in Gep -- Charge conservation)

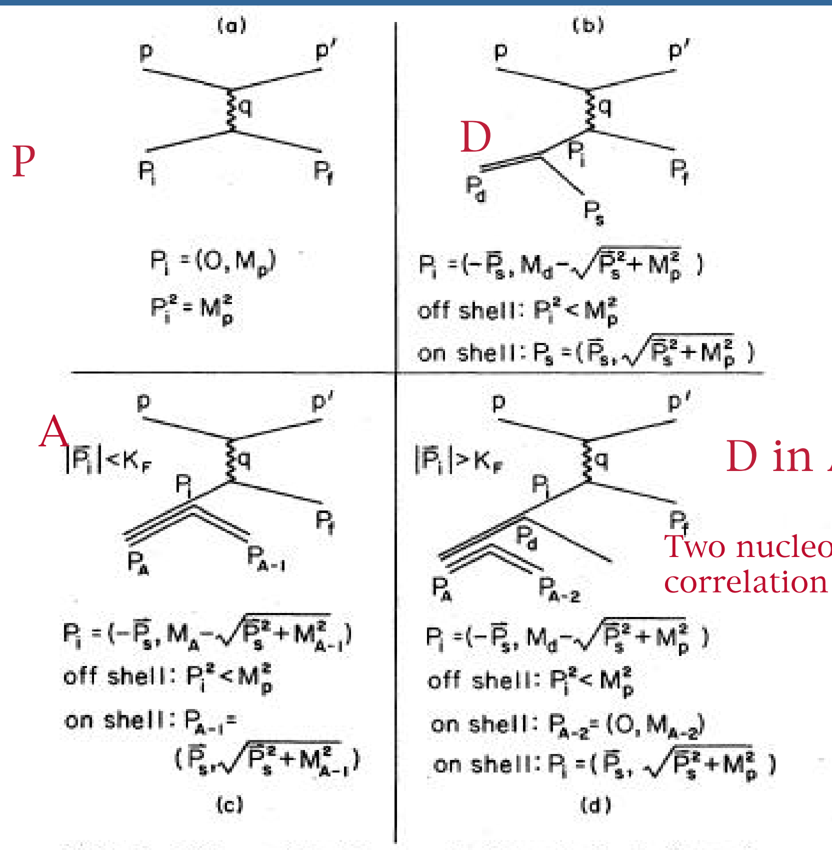


FIG. 1. Kinematics for on-shell and off-shell scat-

Off-shell kinematics, on shell

Dynamics. Q2, W final state

Bodek/Ritchie (1981)

Brief Review of (PWIA)

Plane Wave Impulse

Approximation.

Spectator System=

Excited **A-1 Nucleons**

Is ON SHELL

Interacting Nucleon is

OFF SHELL **and virtual**

Boson brings it on to

The mass Shell.

Structure Functions for

Bound Nucleon Must

Be functions of Q2, W,

And off-shell corrections

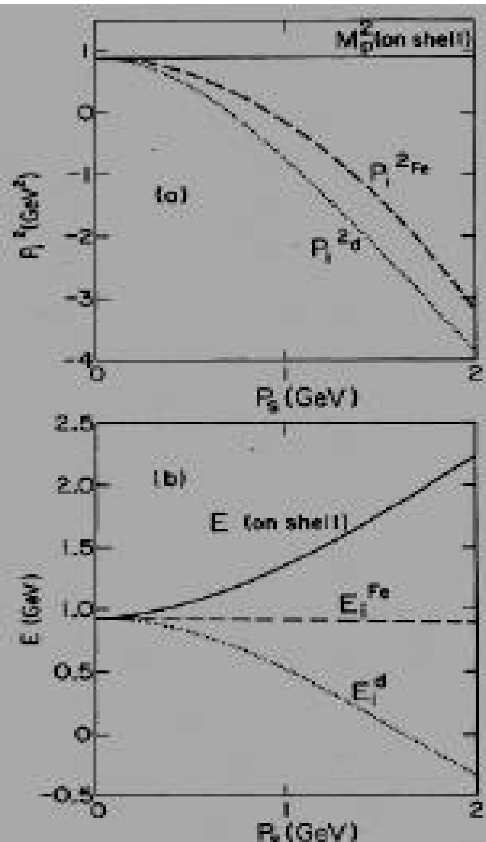


FIG. 2. A comparison of on-shell and off-shell kinematics. (a) The invariant mass squared. (b) The laboratory energy. Shown are the case of a heavy steel nucleus as a spectator (Fe) and a single nucleon as a spectator.

High momentumComponents aew from Two -Nucleon Correlations Or Quasi-deuterons.

$$\vec{P} = \vec{P}_i = -\vec{P}_s \quad \text{and} \quad E_i = M_d - (P_s^2 + M_p^2)^{1/2} . \quad (3)$$

After the scattering the invariant mass of the final state (neglecting the free spectator) is

$$P_f^2 = W'^2 = (P_i + q)^2 = P_i^2 + 2P_i \cdot q - Q^2 ,$$
$$W'^2 = (E_i^2 - \vec{P}_s^2) + 2E_i\nu - 2P_3|\vec{q}_3| - Q^2 , \quad (4)$$

$$\vec{P} = \vec{P}_i = -\vec{P}_s, \quad E_i = M_A - (\vec{P}_s^2 + M_{A-1}^2)^{1/2} ,$$

and (5)

$$W'^2 = (E_i^2 - \vec{P}_s^2) + 2E_i\nu - 2P_3|\vec{q}| - Q^2 .$$

Spectral Function **P** = Probability to have Mometum p and Recoil Excitation ε of Spectator A-1 nucleon system.The Fermi Motion model is just one Approximation P(p, ε)

Note, spectral functions have now Been measured all the way up to Gold

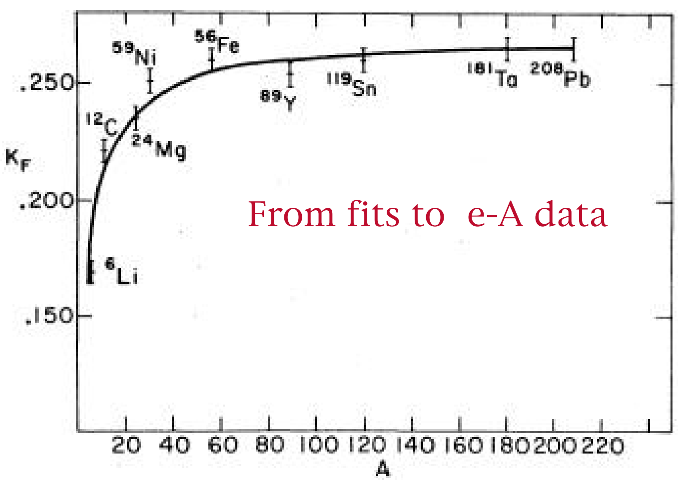


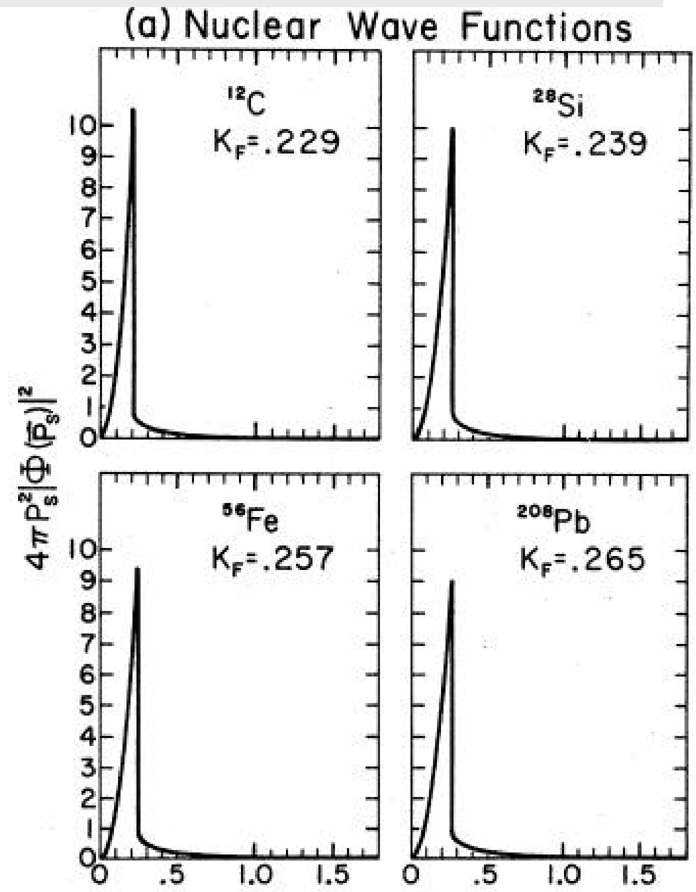
FIG. 3. The Fermi momenta K_F for various nuclei of atomic weight A from Moniz *et al*. (Ref. 6).

$$\int_0^{4\ \mathrm{GeV}/c} |\phi(\vec{P})|^2 4\pi P^2 dp = 1.0 .$$

$$|\phi(\vec{P})|^2 \ \frac{1}{C}\left[1 - 6\left(\frac{K_F a}{\pi}\right)^2\right] \quad \text{for } 0 < |\vec{P}| < K_F ,$$

$$= \frac{1}{C}\left[2R\left(\frac{K_F a}{\pi}\right)^2 \left(\frac{K_F}{P}\right)^4\right] \quad \text{for } K_F < |\vec{P}| < 4\ \mathrm{GeV}/c ,$$

$$0 \quad \text{for } |\vec{P}| > 4\ \mathrm{GeV}/c ,$$



High P tail From nuclear matter calculation

$$W^A_{\mu\nu} = Z \int |\phi(\vec{P})|^2 d^3\vec{P}\,[W^p_{\mu\nu}(p_i, q)]$$

$$+ \text{similar terms for the neutrons}. \qquad (12)$$

Equating individual tensor components, we obtain equations for W_1 and W_2 which are identical to those derived for the deuteron in Ref. 1 except that nuclear-momentum distributions are used for $|\phi(\vec{P})|^2$. In addition, the identification of the off-shell kinematics is as described in the previous section,

$$W_1^A = Z \int |\phi(\vec{P})|^2 d^3\vec{P}\left(W_1^p + \frac{W_2^p}{2M_p^2}(\vec{P}^2 - P_3{}^2)\right)$$

$$+ \text{similar terms for the neutrons}, \qquad (13)$$

$$W_2^A = Z \int |\phi(\vec{P})|^2 d^3\vec{P}\left[\left(1 - \frac{P_3 Q^2}{M_p \nu' q_3}\right)\left(\frac{\nu'}{\nu}\right)^2 + \frac{P^2 - P_3{}^2}{2M_p{}^2}\left(\frac{Q^2}{q_3{}^2}\right)\right] W_2{}^p \qquad (14)$$

$$+ \text{similar terms for the neutrons}.$$

Calculate

W1A

W2A

For a

Nucleus

EM Current

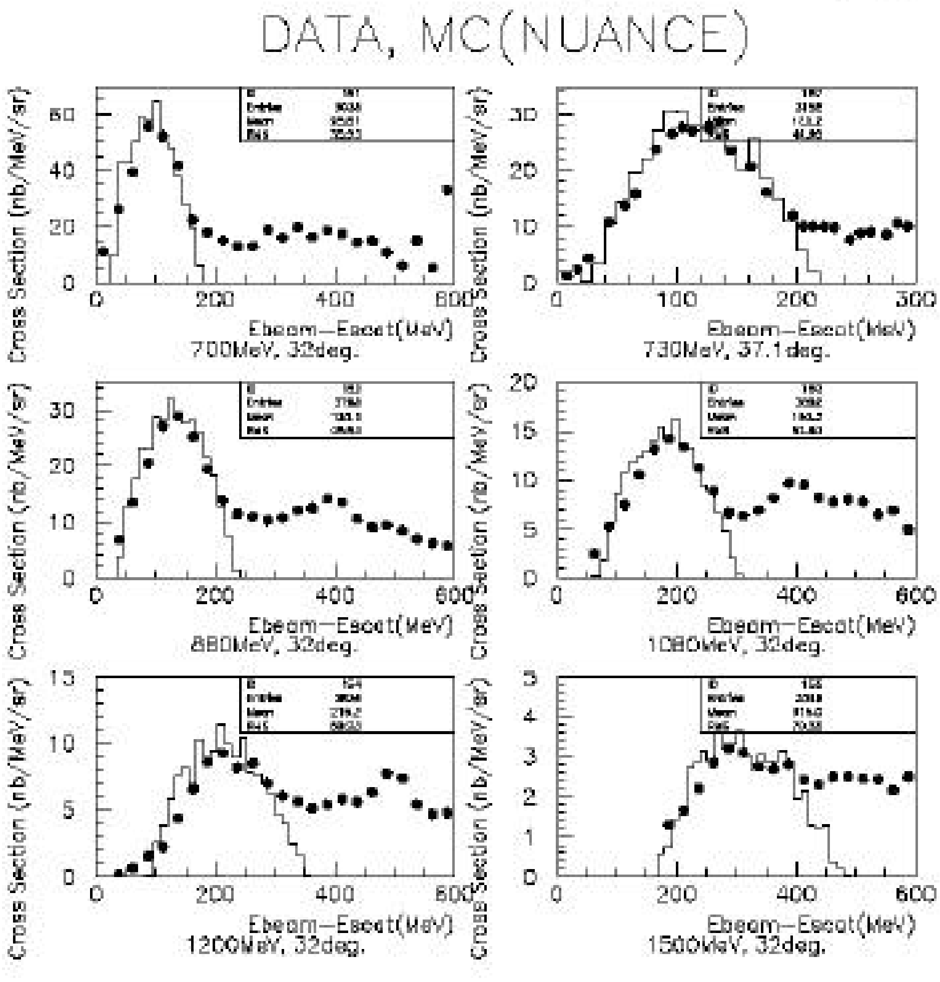
We DO NOT

SMEAR CROSS SECTIONS

ONLY MATRIX

ELEMENTS

Electron Scattering on Oxygen



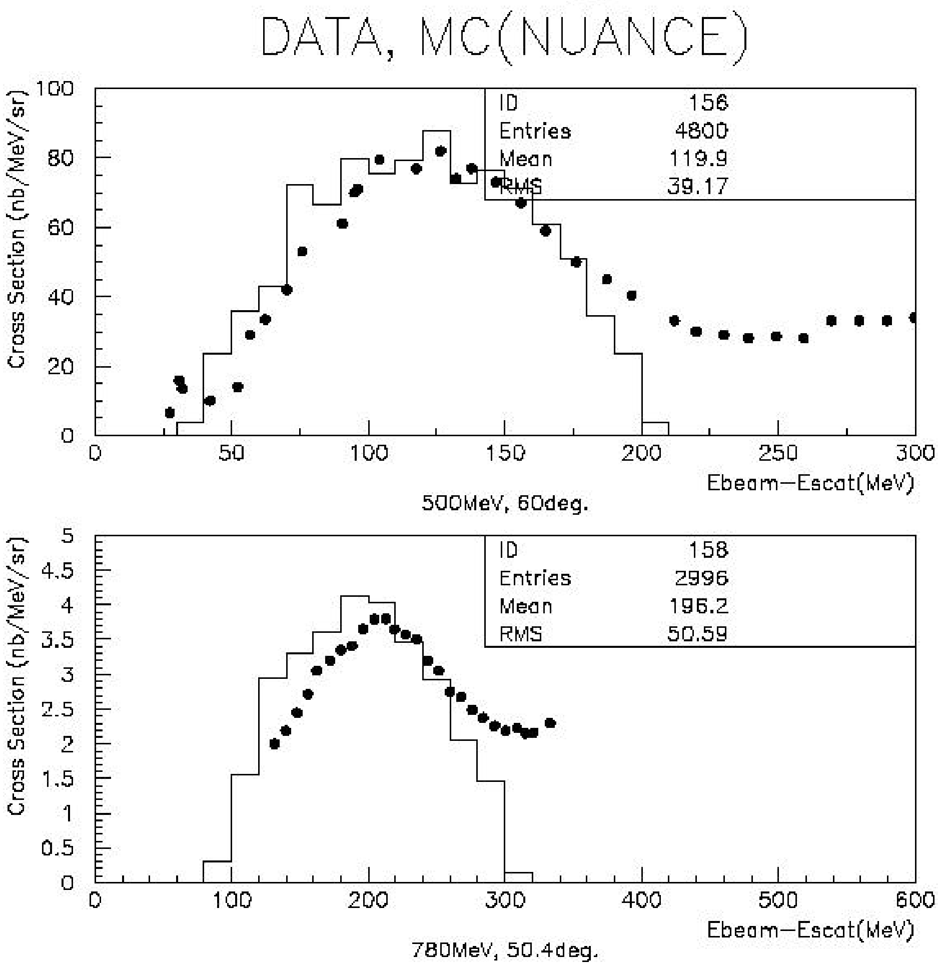
Neutrino Fermi Motion

NUANCE K2K MC with Recoil binding Energy of 25 GeV, No high Moment. Component.

Compare to Electron Data - can tune the model if needed. Need to Add inelastic and Rad corr.

Another case of JLAb - Neutrino community collaboration

Electron Scattering on Carbon



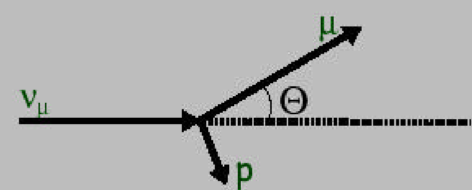
At present this is rather crude: Take Neutrino MC, select To electron Neutrinos.

Fix incident Energy and Scattering Angle for a Jlab electron Scattering Data set.

Need to add DIS and change couplings for better test

Energy resolution effects

- Actual equation for E_ν should also include Binding Energy.
- 20 MeV uncertainty at 700 MeV gives ~3% error
- We can use e-scattering to tune to ~5 MeV. (see S. Wood talk)



$$E_\nu = \frac{(m_N + B)E_\mu - (2 m_N B + B^2 + m_\mu^2)/2}{m_N + B - E_\mu + p_\mu \cos(\Theta_\mu)}$$

m_N = Neutron mass

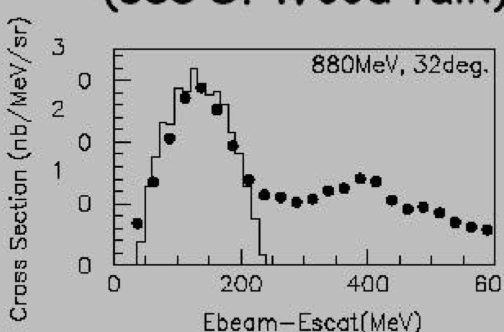
B = Binding energy = −30 MeV

E_μ = Muon energy

m_μ = Muon mass

p_μ = Muon momentum

Θ_μ = Muon angle wrt beam



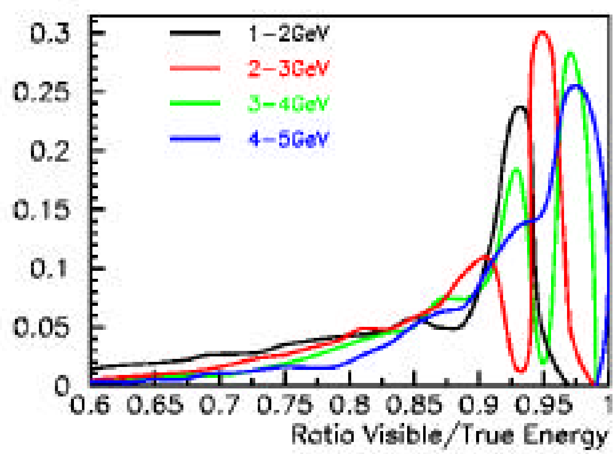
In Water Cerenkov counter

Only detect muons From C. Walter-Boston U Talk at NuInt02

Visible Energy in a Calorimeter is NOT equal to the True Neutrino Energy

- Kinetic Energy $\neq$ Total Energy
- Nuclear Effects cause some π to be reabsorbed
- Detector Resolution (not considered here)

Neugen Predicts:



As Energy gets higher, function gets narrower

Talk by

Debbie Harris-FNAL

Collaboration with Jlab Physicists provides the
Simplest way to test nuclear effects for neutrino experiments.

1. Any model is approximate and has some variable Parameters.

2. Models should Be set up to describe BOTH electron scattering and neutrino Scattering.

3. Tune Parameters on electron scattering data (high Precision), then compare to lower-precision neutrino Data. Not all parameters can be determined in e-N expt.

INFORM JLAB PEOPLE WHAT YOU WANT MEASURED

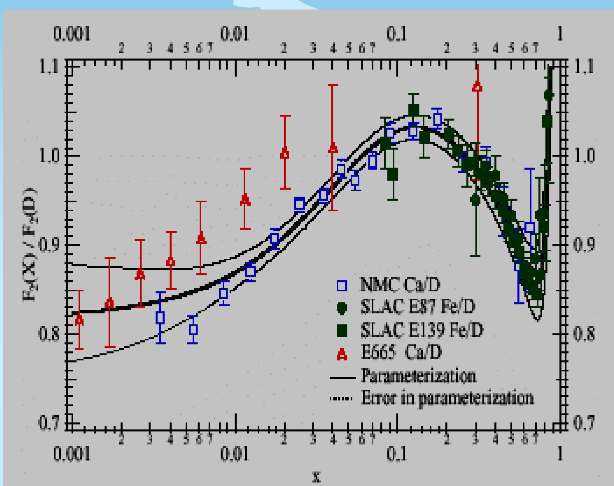
ESPECIALLY AT LOW Q2, which is not currently emphasized

Additional Lessons from Jlab data

1. Beyond the Fermi-Gas Models now give good description Of the binding energies in nuclei. Good wave functions for A<10 exist now, and O16 is OK since it is a closed shell. Other A<15 in a few years. (see hard copy R. Ent talk)

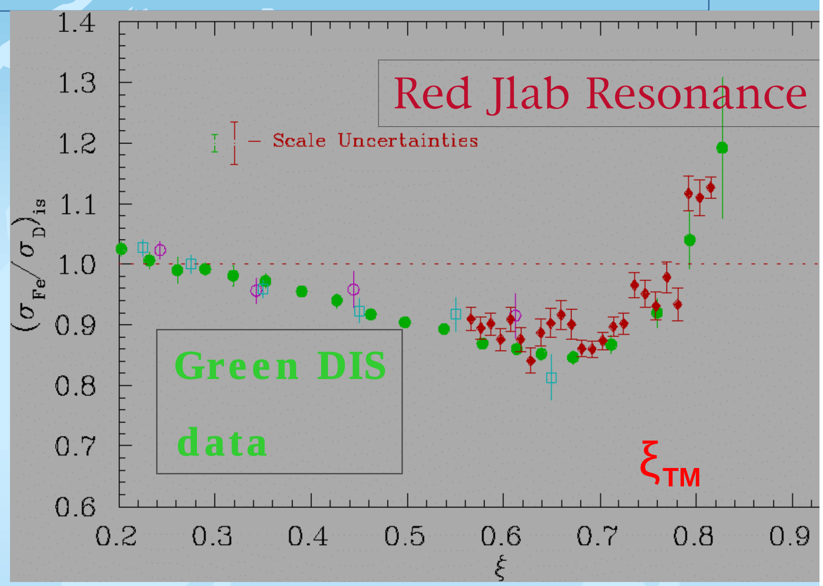
2. Hadron propagation through nuclear matter. Good news Is that for the Q2 range of interest, There is NO Color Transparency. I.e. low energy hadrons propagate through Nuclear matter with typical hadronic cross sections. Glauber Calculations, coupled with Beyond the Fermi Gas models Give a good descriptions of the data. (but need to include Pauli Blocking). R. Ent, D. Duttam W. Brooks S. Wood talks.

Correct for Nuclear Effects measured in e/μ expt. In DIS and resonance region Fe/D data



DIS Region

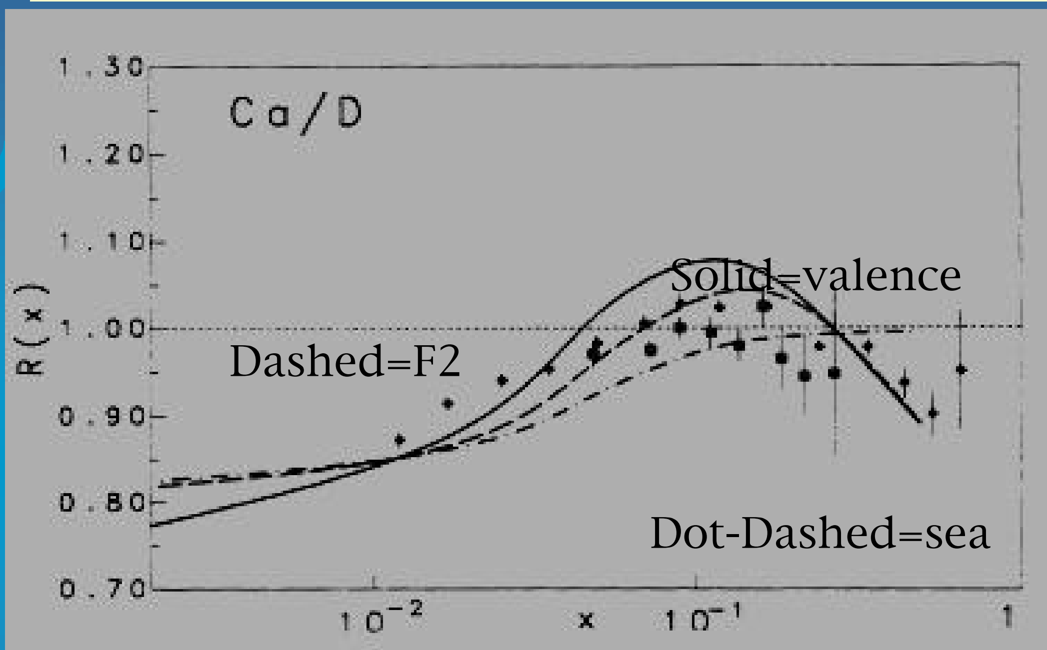
Figure 5. The ratio of F_2 data for heavy nuclear targets and deuterium as measured in charged lepton scattering experiments(SLAC,NMC, E665). The band show the uncertainty of the parametrized curve from the statistical and systematic errors in the experimental data [16].



Comparison of Fe/D F2 data
In resonance region (JLAB)
Versus DIS SLAC/NMC data
In ξ_{TM} (C. Keppel 2002).

MUST USE ξ_{TM}

M. Strikman NuIn02 Talk, ALSO PRL 65, 1725, (1990)



Shadowing/and anti-shadowing effects are different for Valence and Sea quarks At High Q2. Shadowing will be larger at low Q2 and small x for both F3 And F2.

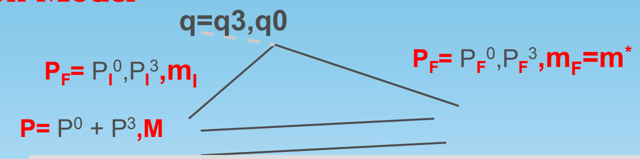
Future fits by Kumano for nuclear effects in the DIS region should be done in ξ_{TM} so that they can be used in resonance region

Initial quark mass m_I and final mass ,m_F=m * bound in a proton of mass M -- Summary: INCLUDE quark initial Pt) Get ξ scaling (not $x=Q^2/2M\nu$)

for a general parton Model

ξ Is the correct variable which is Invariant in any frame : q3 and P in opposite directions.

ξ



$$PI, P0 \qquad q3, q0$$

$$\xi = \frac{P_I^0 + P_I^3}{P_P^0 + P_P^3} \qquad \text{quark} \rightarrow \quad \leftarrow \text{photon}$$

$$(q + P_I)^2 = P_F^2 \quad \rightarrow q^2 + 2P_I \, q + P_I^2 = m_F^2$$

Please derive this on the plane

$$\xi_W = \frac{Q^2 + m_F^2 + A}{\{M\nu[1 + \sqrt{(1 + Q^2/\nu^2)}] + B\}} \qquad for \; m_I^2, Pt = 0$$

Special cases:

(1) Bjorken x, $x_{BJ}=Q^2/2M\nu$, ξ, -> x
For $m_F^2 = m_I^2 = 0$ and High ν^2,

(2) Numerator m_F^2: Slow Rescaling ξ as in charm production

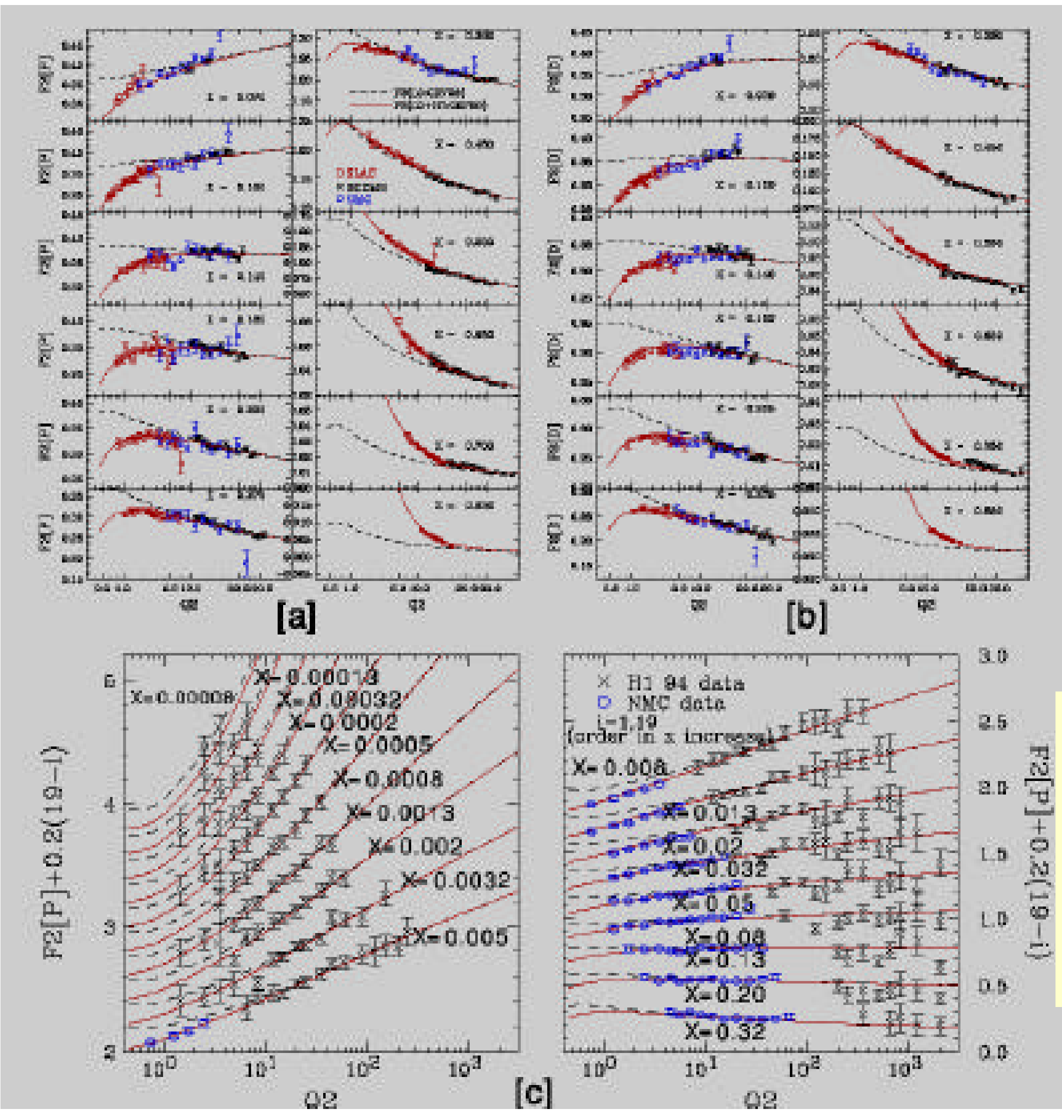
(3) Denominator: Target mass term
ξ =Nachtman Variable
ξ =Light Cone Variable
ξ =Georgi Politzer Target Mass var. (all the same ξ)

Most General Case: (Derivation in Appendix)

ξ'_w= [Q'^2 +B] / [$M\nu$ $(1+(1+Q^2/\nu^2))^{1/2}$ +A] (with A=0, B=0)<<<<<<<<

where $2Q'^2 = [Q^2 + m_F^2 - m_I^2] + \{ (Q^2 + m_F^2 - m_I^2)^2 + 4Q^2 (m_I^2 + P^2t) \}^{1/2}$

Bodek-Yang: Add B and A to account for effects of additional Δ m^2 from NLO and NNLO (up to infinite order) QCD effects. For case ξ_w with **P^2t** =0 see R. Barbieri et al Phys. Lett. 64B, 1717 (1976) and Nucl. Phys. B117, 50 (1976)



Bodek/Yang Modified GRV98 PDFs To DIS Data Fit to electron And muon Scattering DIS data.

Predict reson. Photo and Neutrino data

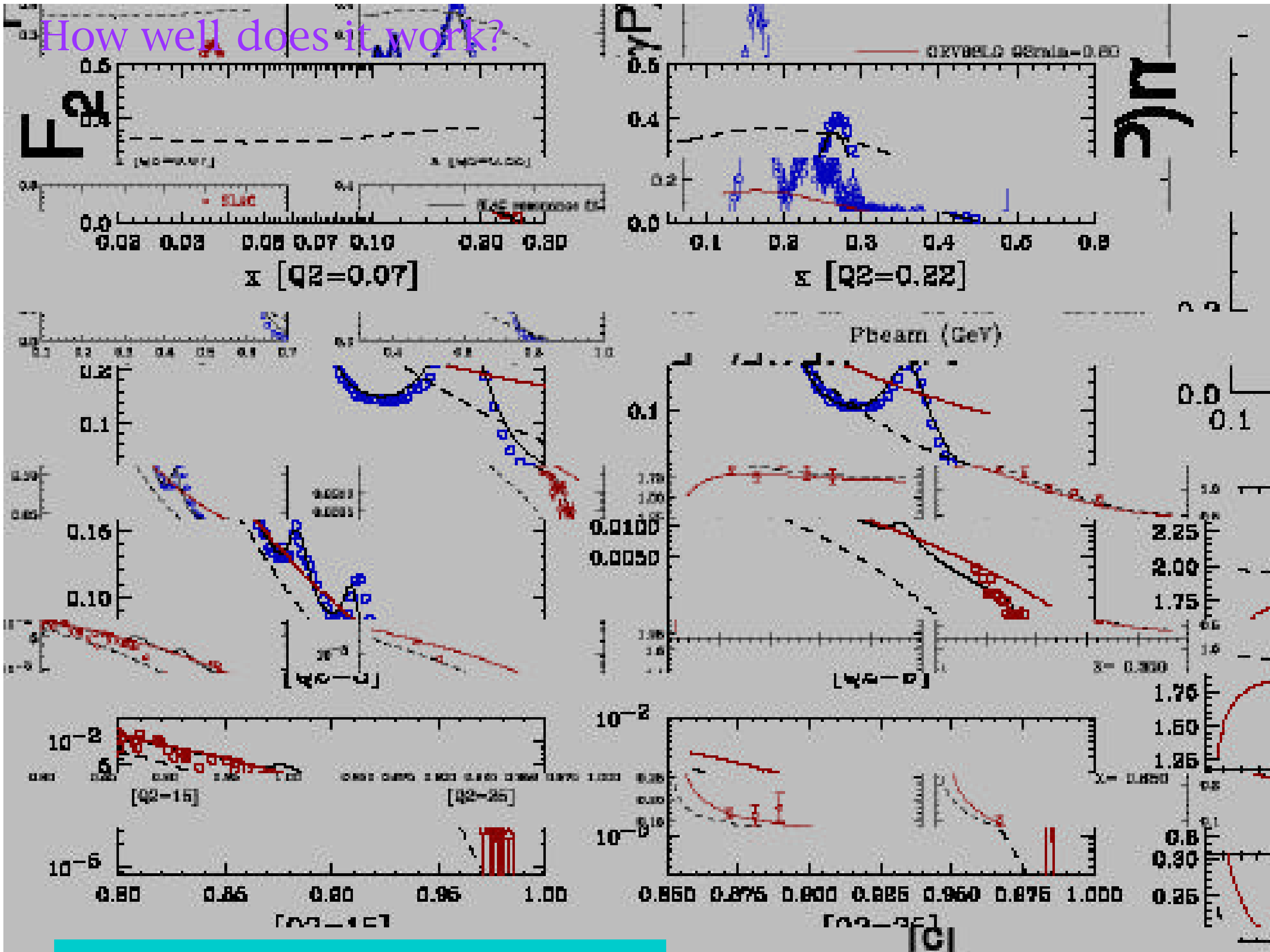
χ^2 = 1268 / 1200 DOF

Dashed=GRV98LO QCD
$F_2 = F_{2QCD}(x,Q^2)$

Solid=modified GRV98LO QCD

$F_2 = K(Q^2) * F_{2QCD}(\xi_w, Q^2)$

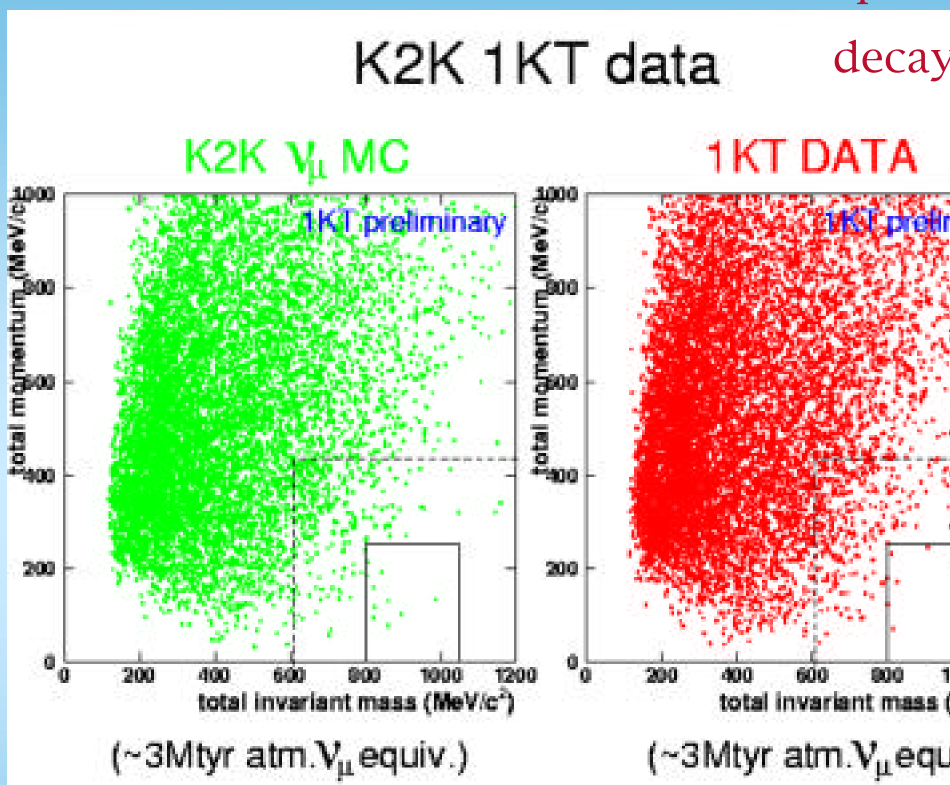
How well does it work?



Predict Resonance, Neutrino

And photoproduction data

Spinoffs e.g proton decay



It is crucial to verify the validity of neutrino MC used to estimate proton decay backgrounds by actual data. "For example, the backgrounds for p->epi0 search @ SK is checked by the K2K 1kt water Cerenkov data." From Mine's Talk NuInt02

NUMI Near Detectors at FNAL - First High Intensity Beams

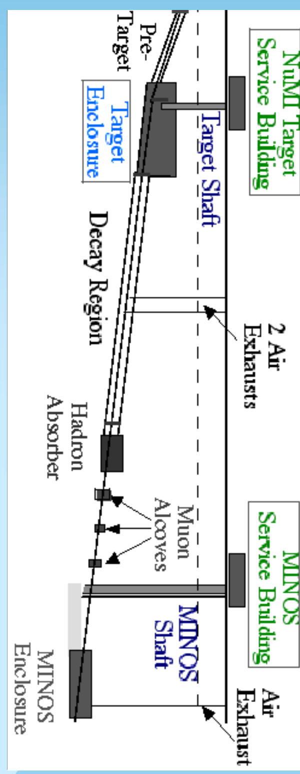
http://www.pas.rochester.edu/~ksmcf/eoi.pdf

1. EOI to FNAL program Committee - Off axis Near Detector.See Talk by: Steve Manly- Univ. of Rochester

2. See Talk by Jorge-Morfin - On Axis Near Detector

In principle off-axis near detector in the tunnel can be moved to on-axis location .

3. Also, On-Axis MinBoone EOI.



<--Down

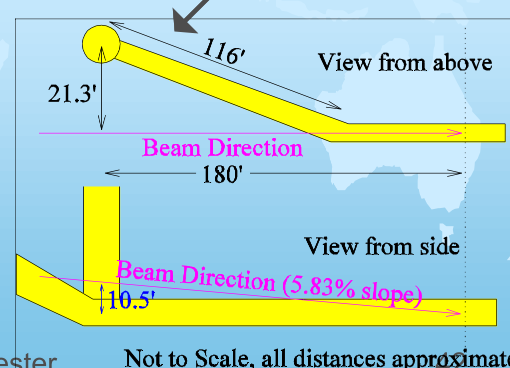
- **Narrow band beam, similar to far detector**
  - **Can study cross-sections (NBB)**
  - **Near/far for ν_μ -> ν_μ;**
  - **backgrounds for ν_μ ->ν_e**

Not everything

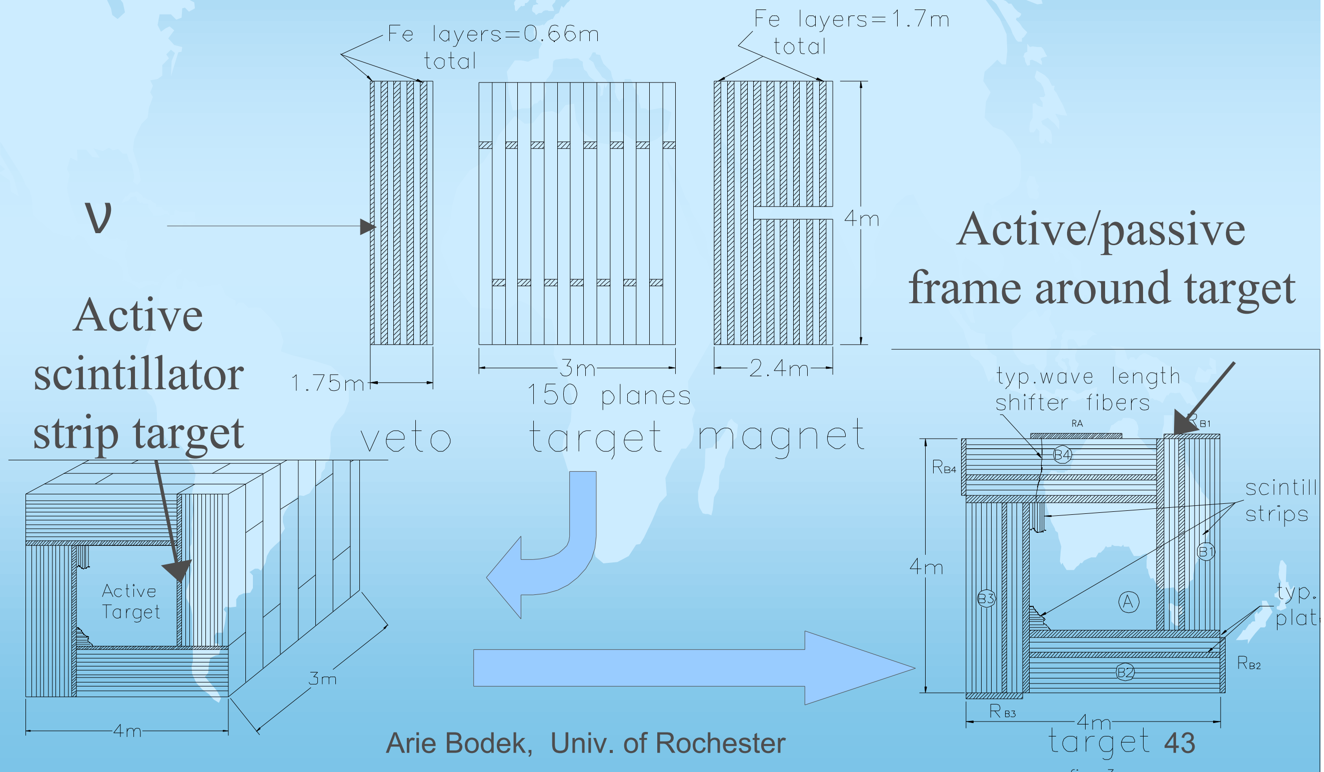
Can be done

At Jlab.

Locate off of access drift



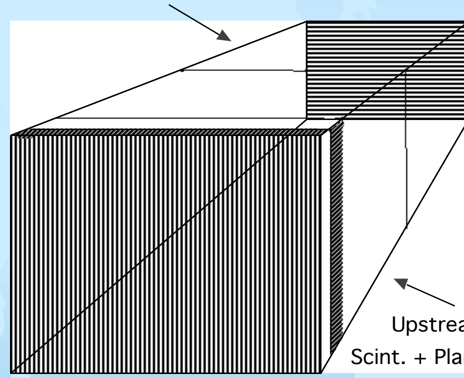
Fully-Active Off-Axis Near Detector (Conceptual)
Rochester - NUMI EOI
http://www.pas.rochester.edu/~ksmcf/eoi.pdf
(Kevin McFarland - Spokesperson)



ON AXIS DETECTOR (Morfin-FNAL)

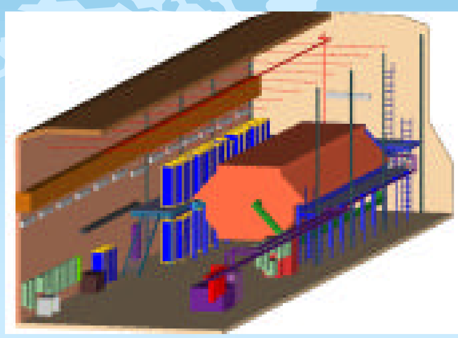
A Phased (Installation) High resolution ν Detector:
Basic Conceptual Design

- **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.**
- **Use MINOS near detector as forward μ identifier / spectrometer.**
- **Considering the use of side μ-ID detectors for low-energy μ identification.**

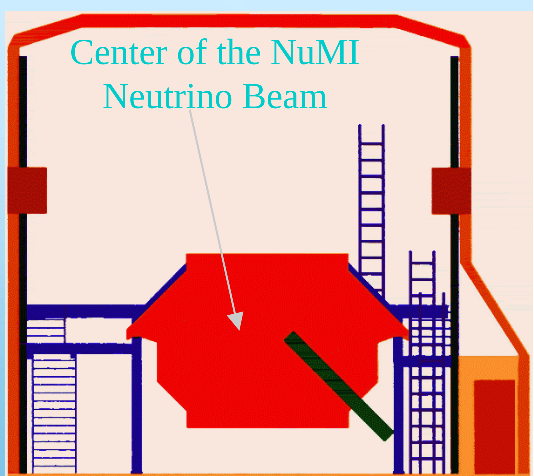
MINOS Near Detector in the NuMI Near Hall

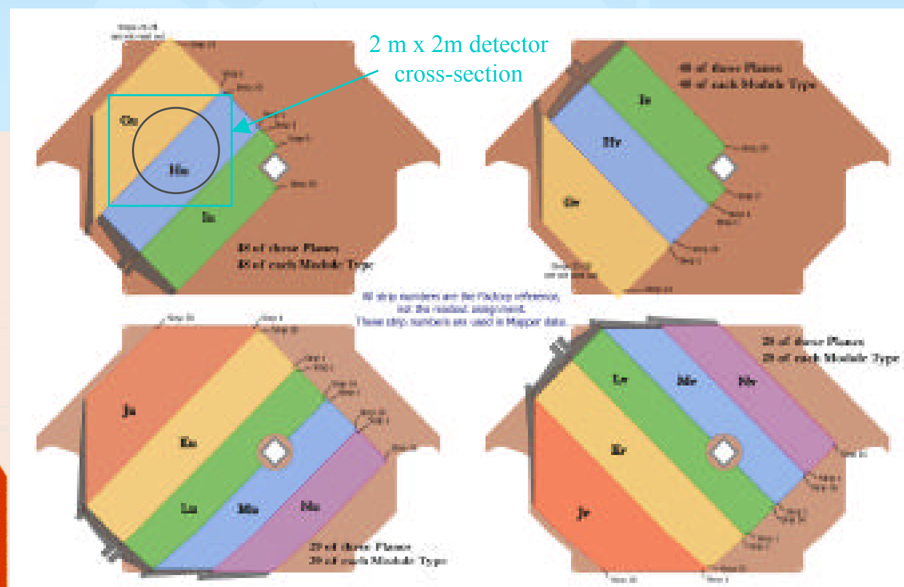


≈ 100 m underground

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

25 m clear upstream of MINOS detector





FNAL Program Committee report not yet released. Informal feedback is that since all three EOI's have very similar detectors (scintillator strips) and the cost is mostly in optical readout and electronics, a common R+D effort for All three groups may make sense. Further possibilities for collaboration Between US and Japan communities

I want to Conclude by a round applause for the Conference Organizers.

See you next year at NuInt03 --- Probably In Italy.