Using NuTeV Measurements to Extract $\nu/\bar{\nu}$-Fe Nuclear Effects and the MINERνA Experiment's Nuclear Effects Measurement Program

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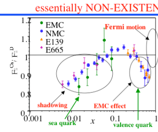
Experimental Studies of Nuclear Effects with Neutrinos: essentially NON-EXISTENT



- F_2 / nucleon changes as a function of A. Measured in μ/e - A. **not in ν – A**
- **Good reason to consider nuclear effects are DIFFERENT in ν - A.**
  - **Presence of axial-vector current.**
  - **Different nuclear effects for valance and sea --> different shadowing for xF_3 compared to F_2.**

Kulagin-Petti Model of Nuclear Effects

hep-ph/0412425

- Global Approach -aiming to obtain quantitative calculations covering the complete range of x and Q^2 available with thorough physics basis for fit to data.
- Different effects on structure functions (SF) are taken into account:

$$F_i^A = F_i^{p/A} + F_i^{n/A} + F_i^{\pi/A} + \delta F_i^{coh}$$

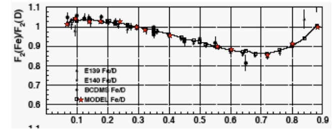
  - $F_i^{p(n)/A}$ bound proton(neutron) SF with Fermi Motion, Binding (FMB) and Off-Shell effect (OS)
  - $F_i^{\pi/A}$ nuclear Pion excess correction (PI)
  - δF_i^{coh} contribution from coherent nuclear interactions: Nuclear Shadowing (NS)

- **Fermi Motion** and **Binding** in nuclear structure functions is calculated from the convolution of nuclear spectral function and (bound) nucleon SFs:
- Since bound nucleons are off-mass shell there appears dependence on the nucleon virtuality $\kappa^2 = (M + \varepsilon)^2 - k^2$ where we have introduced an **off-shell structure function $\delta f_2(x)$**

$$F_2(x, Q^2, k^2) = F_2(x, Q^2)\left(1 + \delta f_2(x)(k^2 - M^2)/M^2\right)$$

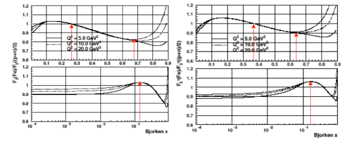
- Leptons can scatter off mesons which mediate interactions among bound nucleons yielding a **nuclear pion correction**

Kulagin-Petti compared to e/μ+Fe data F_2 (e/μ+Fe) / F_2 (e/μ+D)



Charged Lepton

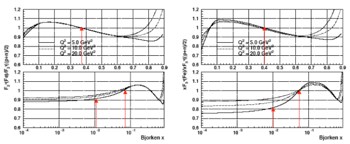
F_2 (μ+Fe) / F_2 (μ+N) compared to F_2 (ν+Fe) / F_2 (ν+N)



Charged Lepton

Neutrino

Kulagin-Petti: ν-Fe Nuclear Effects



F_2

xF_3

The Impact of new neutrino DIS and Drell-Yan data on large-x parton distributions

Joey Huston - MSU, Cynthia Keppel - Hampton, Steve Kuhlmann - ANL, JGM - Fermilab, Fred Olness - SMU, Jeff Owens - Florida State, Jon Pumplin and Dan Stump - MSU

Published in **Phys.Rev.D75:054030,2007**.
e-Print: **hep-ph/0702159**

In our study of high-x PDFs, we reached some interesting Conclusions regarding neutrino induced nuclear effects.

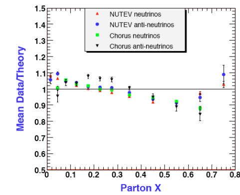
CTEQ High-x Study

reference fit

- Form reference fit mainly nucleon (as opposed to nuclear) scattering results:
  - BCDMS results for F_2^p and F_2^d
  - NMC results for F_2^p and F_2d/F_2^p
  - H1 and ZEUS results for F_2^p
  - CDF and DØ result for inclusive jet production
  - CDF results for the W lepton asymmetry
  - E-866 results for the ratio of lepton pair cross sections for pd and pp interactions
  - E-605 results for dimuon production in pN interactions.
- Correct for deuteron nuclear effects

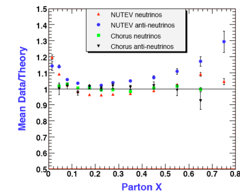
NuTeV(Fe) and CHORUS (Pb) ν scattering results compared to reference fit

no nuclear corrections



NuTeV σ(Fe) & CHORUS σ(Pb) ν scattering (shifted) results compared to reference fit

Kulagin-Petti nuclear corrections



Nuclear PDFs from neutrino deep inelastic scattering

I. Schienbein (SMU & LPSC-Grenoble, J-Y. Yu (SMU)
C. Keppel (Hampton & JeffersonLab) J.G.M. (Fermilab),
F. Olness (SMU), J.F. Olness (Florida State U)

e-Print: **arXiv:0710.4897** [hep-ph]

Formalism

- PDF Parameterized at Q_0 = 1.3 GeV as

$$xf_i(x,Q_0) = \begin{cases} A_0 x^{A_1}(1-x)^{A_2} e^{A_3 x}(1+e^{A_4}x)^{A_5} & : i = u_v, d_v, g, \bar{u}+\bar{d}, s, \bar{s}, \\ A_0 x^{A_1}(1-x)^{A_2} + (1+A_3 x)(1-x)^{A_4} & : i = \bar{d}/\bar{u}, \end{cases}$$

- PDFs for a nucleus are constructed as:

$$f_i^A(x,Q) = \frac{Z}{A} f_i^{p/A}(x,Q) + \frac{(A-Z)}{A} f_i^{n/A}(x,Q)$$

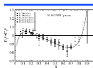
- Resulting in nuclear structure functions:

$$F_i^A(x,Q) = \frac{Z}{A} F_i^{p/A}(x,Q) + \frac{(A-Z)}{A} F_i^{n/A}(x,Q)$$

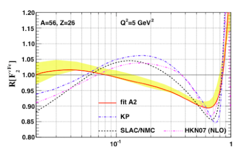
- The differential cross sections for CC scattering off a nucleus::

$$\frac{d^2\sigma}{dx\,dy}^{\overset{(-)}{\nu}A} = \frac{G^2 ME}{\pi}\left[(1-y-\frac{Mxy}{2E})F_2^{\overset{(-)}{\nu}A} + \frac{y^2}{2}2xF_1^{\overset{(-)}{\nu}A} \pm y(1-\frac{y}{2})xF_3^{\overset{(-)}{\nu}A}\right]$$

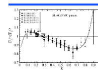
F_2 Structure Function Ratios: ν-Iron

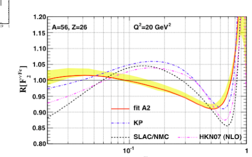


- Use ACOT - heavy quark mass Effects - in NLO QCD.
- Q > 2.0 GeV, W > 3.5 GeV
- Use same reference fit as in first publication

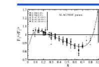


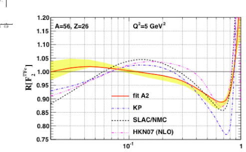
F_2 Structure Function Ratios: ν-Iron



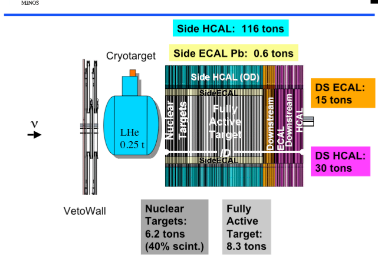


F_2 Structure Function Ratios: $\bar{\nu}$-Iron

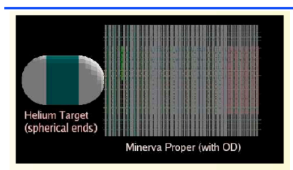


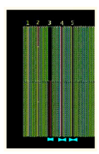


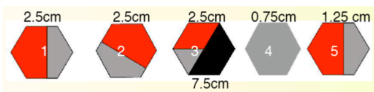
Complete MINERνA Experimental Set-up



MINERνA Nuclear Target Section







MINERνA Event Rates

14.5 Million total CC events in a 4 - year run

Assume **4.0x10^{20} in LE and** 12.0x10^{20} **ME NuMI beam configurations in 4 years**

Fiducial Volume = 3 tons CH, 0.2t He, 0.15t C, 0.7t Fe and 0.85t Pb
Expected CC event samples:
9.0 M ν events in 3 tons of CH
0.6 M ν events in He
0.4 M ν events in C
2.0 M ν events in Fe
2.5 M ν events in Pb

Main CC Physics Topics (Statistics in CH)

Quasi-elastic	0.8 M events
Resonance Production	1.7 M total
Transition: Resonance to DIS	2.1 M events
DIS, Structure Funcs. and high-x PDFs	4.3 M DIS events
Coherent Pion Production	89 K CC / 44 K NC
Strange and Charm Particle Production	> 240 K fully reconstructed events
Generalized Parton Distributions	order 10 K events
Nuclear Effects	He: 0.6 M, C: 0.4 M, Fe: 2.0 M and Pb: 2.5 M

Conclusions

- NuTeV ν-Fe scattering seems to see little or no evidence for shadowing
- Differences in nuclear effects between ν and $\bar{\nu}$, Fe and Pb are small in the region $0.1 < x < 0.6$
- The Kulagin-Petti corrections for Fe **considerably over-correct** (about a factor 0f 2) with respect to the reference fit when applied to the NuTeV Fe results.
- **Except at very high x, our correction factors differ in both shape and magnitude from charged lepton and K-P correction factors**
- The MINERνA Experiment will accumulate significant statistics off targets of helium, carbon, steel and lead.
- The MINERνA Experiment will measure the ratio of F_2 and xF_3 for various combinations of the four targets listed above for $Q^2 \leq 5$ GeV^2 and will cover the shadowing region down to $x \approx 0.01$ to check the hypothesis that the coherence length of A is different than V.