Neutrino Scattering Physics at Superbeams and Neutrino Factories

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5th International Workshop on Neutrino Factories & Superbeams
Columbia University, New York, June 5-11, 2003

- Introduction
- High-energy spin physics
- Nuclear structure functions
- Low/medium-energy scattering (long baseline)

June 5, 2003

Related talks in WG2

Refs. **C. Albright et al.**, hep-ex/0008064,
M. L. Mangano et al., hep-ph/0105155,
Y. Kuno et al., NuFact-J studies, version 1.0.

Monday, June 9

Strangeness

- **W. Albrecio** Neutrino-nucleon scattering and strange form factors
- **R. Tayloe** Measuring the Strange Spin of the Nucleon with Neutrinos
- **Y. Miyachi** Neutrino Scattering on the Nucleon and Parton Distribution Functions

Deep Inelastic Scattering

- **U. Yang** Unified approach for modelling neutrino and electron scattering cross section from very high Q^2 to Q^2=0
- **F. Sergiampietri** Near liquid argon detector for near future
- **B. Bernstein** NuTeV Structure Functions: Preliminary Results and Future Work

$\sin^2\theta_W$: Recent Results and Future Measurements

- **I. Younus** First Results from SLAC E-158; Measuring Parity Violation in Moller Scattering
- **P. Reimer** DIS-Parity: Measuring $\sin^2\theta_W$ with Parity Violating Deep Inelastic Scattering
- **J. Yu** Precision Measurement of $\sin^2\theta_W$ at a Neutrino Factory

Tuesday, June 10

Neutrino Cross-Sections (with WG1)

- **G. Zeller** How well do we understand neutrino cross-sections?
- **C. Walter** Low energy neutrino-nucleus cross-sections
- **K. McFarland** Cross-section measurements at MINerVA/FINeSE/JHF

Why nucleonic & nuclear structure at ν factory?

(1) Basic interest to understand hadron structure, determination of fundamental constants

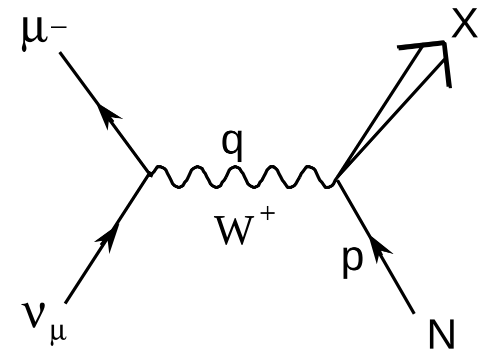
- perturbative & non-perturbative QCD
- fundamental constants: α_s , $\sin^2\theta_W$

(2) Practical purpose: to describe hadron cross sections precisely. For hadron reactions with Q^2>1 GeV^2, accurate PDFs (parton distribution functions) are needed.

For example,

- heavy-ion reactions: quark-gluon plasma signature
- exotic events at large Q^2:
  physics of “beyond current framework”
- neutrino oscillation: nuclear effects in ν + ^{16}O

Neutrino deep inelastic scattering (CC)



$$d\sigma = \frac{1}{4k\cdot p}\,\frac{1}{2}\sum_{spins}\sum_{X}(2\pi)^4\,\delta^4(k+p-k'-p_X)\,|M|^2\,\frac{d^3k'}{(2\pi)^3\,2E'}$$

$$M = \frac{1}{1+Q^2/M_W^2}\,\frac{G_F}{\sqrt{2}}\,\bar{u}(k',\lambda')\,\gamma^\mu\,(1-\gamma_5)\,u(k,\lambda)\,<X|J_\mu^{CC}|p,\lambda_p>$$

$$\frac{d\sigma}{dE'd\Omega} = \frac{G_F^2}{(1+Q^2/M_W^2)^2}\,\frac{k'}{32\pi^2 E}\,L^{\mu\nu}\,W_{\mu\nu}$$

$$L^{\mu\nu} = 8\left[\,k^\mu k'^{\nu} + k^\nu k'^{\mu} - g^{\mu\nu}k\cdot k' + \underline{i\varepsilon^{\mu\nu\rho\sigma}k_\rho k'_\sigma}\,\right]$$

where $\varepsilon_{0123}=+1$

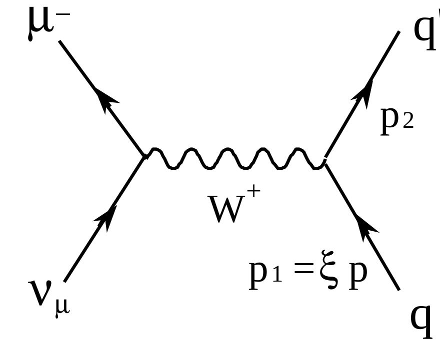
$$W_{\mu\nu} = -W_1\left(g_{\mu\nu} - \frac{q_\mu q_\nu}{q^2}\right) + W_2\,\frac{1}{M^2}\left(p_\mu - \frac{p\cdot q}{q^2}q_\mu\right)\left(p_\nu - \frac{p\cdot q}{q^2}q_\nu\right) \boxed{+\,\frac{i}{2M^2}\,W_3\,\varepsilon_{\mu\nu\rho\sigma}\,p^\rho q^\sigma}$$

$$MW_1 = F_1\,,\quad \nu W_2 = F_2\,,\quad \nu W_3 = F_3\,,\quad x = \frac{Q^2}{2p\cdot q}\,,\quad y = \frac{p\cdot q}{p\cdot k}$$

$$\frac{d\sigma^{CC}_{\nu,\bar{\nu}}}{dx\,dy} = \frac{G_F^2\,(s-M^2)}{2\pi(1+Q^2/M_W^2)^2}\left[xy^2F_1^{CC} + \left(1-y-\frac{Mxy}{2E}\right)F_2^{CC}\,\underline{\pm\,xy\left(1-\frac{y}{2}\right)F_3^{CC}}\,\right]$$

Neutrino-quark scattering (CC)

$$\int d\xi\, q(\xi)\, d\sigma_{\nu_\mu+q}$$



$$J_\mu^{CC} = \bar{u}(p_2,\lambda_2)\,\gamma_\mu\,(1-\gamma_5)\,[\,d(p_1,\lambda_1)\cos\theta_c + s(p_1,\lambda_1)\sin\theta_c\,]$$
$$+\,\bar{c}(p_2,\lambda_2)\,\gamma_\mu\,(1-\gamma_5)\,[\,s(p_1,\lambda_1)\cos\theta_c - d(p_1,\lambda_1)\sin\theta_c\,]$$

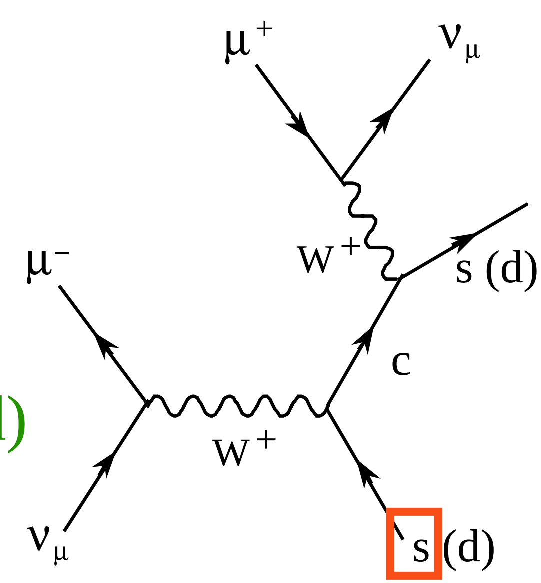
$$F_1^{\nu p(CC)} = F_2^{\nu p(CC)}/2x$$
$$F_2^{\nu p(CC)} = 2x[d(x)+s(x)+\bar{u}(x)+\bar{c}(x)]\,, \qquad F_2^{\nu n(CC)} = 2x[u(x)+s(x)+\bar{d}(x)+\bar{c}(x)]$$
$$xF_3^{\nu p(CC)} = 2x[d(x)+s(x)-\bar{u}(x)-\bar{c}(x)]\,, \qquad xF_3^{\nu n(CC)} = 2x[u(x)+s(x)-\bar{d}(x)-\bar{c}(x)]$$

$$\rightarrow \quad \frac{1}{2}[F_3^{\nu p} + F_3^{\bar{\nu} p}]_{CC} = \underline{u_v + d_v} + s - \bar{s} + c - \bar{c}$$

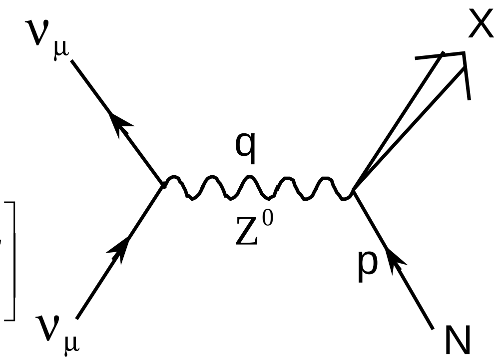
valence-quark distributions

$$\frac{1}{4}[F_3^{\nu(p+n)} - F_3^{\bar{\nu}(p+n)}]_{CC} = s + \bar{s} - (c + \bar{c})$$

also $\nu\, p \rightarrow \mu^-\mu^+ X$ for finding $2\,\bar{s}\,/\,(\bar{u}+\bar{d})$



Neutrino deep inelastic scattering (NC)



$$\frac{d\sigma^{NC}}{dx\,dy}=\frac{\rho^2 G_F^2\,(s-M^2)}{2\pi(1+Q^2/M_Z^2)^2}\left[x\,y^2F_1^{NC}+\left(1-y-\frac{M\,x\,y}{2\,E}\right)F_2^{NC}+x\,y\left(1-\frac{y}{2}\right)F_3^{NC}\right]$$

Neutrino-quark scattering (NC)

$$J_\mu^{NC}=\sum_q \overline{q}(p_2,\lambda_2)\,\gamma_\mu\,[\,g_L^q\,(1-\gamma_5)+g_R^q\,(1+\gamma_5)\,]\,q(p_1,\lambda_1)$$

$$g_L^{u,c}\equiv u_L=+\frac{1}{2}-\frac{2}{3}\sin^2\theta_W\;,\quad g_R^{u,c}\equiv u_R=-\frac{2}{3}\sin^2\theta_W$$

$$g_L^{d,s}\equiv d_L=-\frac{1}{2}+\frac{1}{3}\sin^2\theta_W\;,\quad g_R^{d,s}\equiv d_R=+\frac{1}{3}\sin^2\theta_W$$

$$F_1^{\nu p(NC)}=F_2^{\nu p(NC)}/2x$$

$$F_2^{\nu p(NC)}=2x\,[\,(u_L^2+u_R^2)\{u^+(x)+c^+(x)\}+(d_L^2+d_R^2)\{d^+(x)+s^+(x)\}\,]$$

$$xF_3^{\nu p(NC)}=2x\,[\,(u_L^2-u_R^2)\{u^-(x)+c^-(x)\}+(d_L^2-d_R^2)\{d^-(x)+s^-(x)\}\,]$$

$$q^\pm(x)=q(x)\pm\overline{q}(x)$$

Sum rules in νN reactions

Adler $$S_A = \int_0^1 \frac{dx}{x}\left[F_2^{\bar{\nu}p}(x,Q^2) - F_2^{\nu p}(x,Q^2)\right] = 2$$

"unpolarized" Bjorken $$S_{Bj} = \int_0^1 dx\left[F_1^{\nu n}(x,Q^2) - F_1^{\nu p}(x,Q^2)\right]$$

$$= 1 - \frac{2}{3}\frac{\alpha_s(Q^2)}{\pi} + \cdots + O\left(\frac{1}{Q^2}\right)$$

Gross-Llewellyn Smith

$$S_{GRS} = \frac{1}{2}\int_0^1 dx\left[F_3^{\bar{\nu}p}(x,Q^2) + F_3^{\nu p}(x,Q^2)\right] = 3\left[1 - \frac{\alpha_s(Q^2)}{\pi} + \cdots\right] + O\left(\frac{1}{Q^2}\right)$$

→ determination of α_s **→ higher-twist effects**

WG3 talks at NuFact02 (Weiss, Kataev, Bodek, Cvetic)

http://www.hep.ph.ic.ac.uk/NuFact02/Scientific-programme/files/wg3.html
or hep-ph/0211052

Recent unpolarized distributions

see **http://durpdg.dur.ac.uk/hepdata/pdf.html**

CTEQ6, JHEP 0207 (2002) 012; **GRV98**, Eur. Phys. J. C5 (1998) 461;

MRST02, hep-ph/0211080

suppose $E_\nu = 50$ GeV

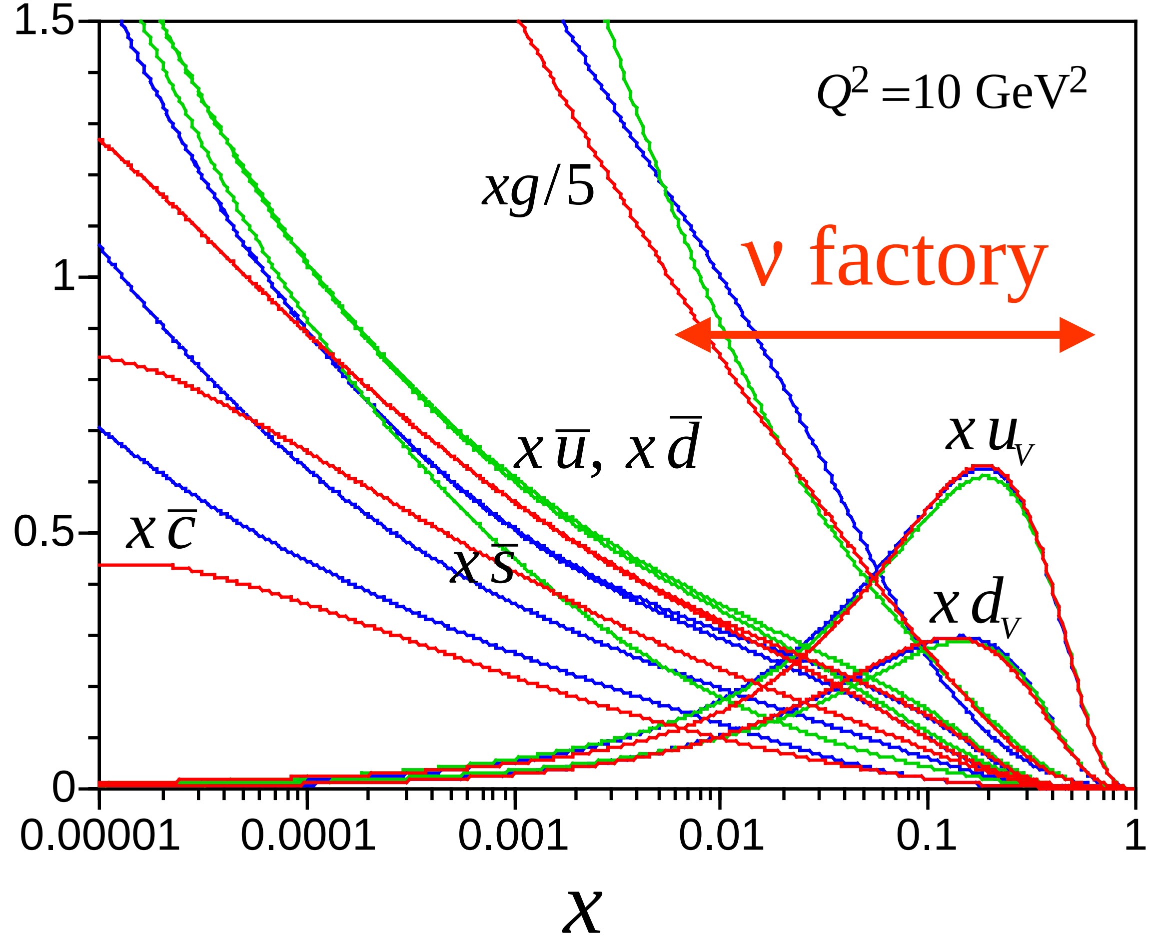
$$x = \frac{Q^2}{2\,M\,q_0}$$

$$x_{min} = \frac{\min(Q^2)}{2\,M\,\max(q_0)} = \frac{1}{2\cdot 1\cdot 50}$$

$= 0.01$

where $\min(Q^2) \sim 1\ \mathrm{GeV}^2$

$\max(q_0) = E_\nu$



High-energy spin physics

in ν scattering

Polarized PDF analysis
of e/μ scattering data

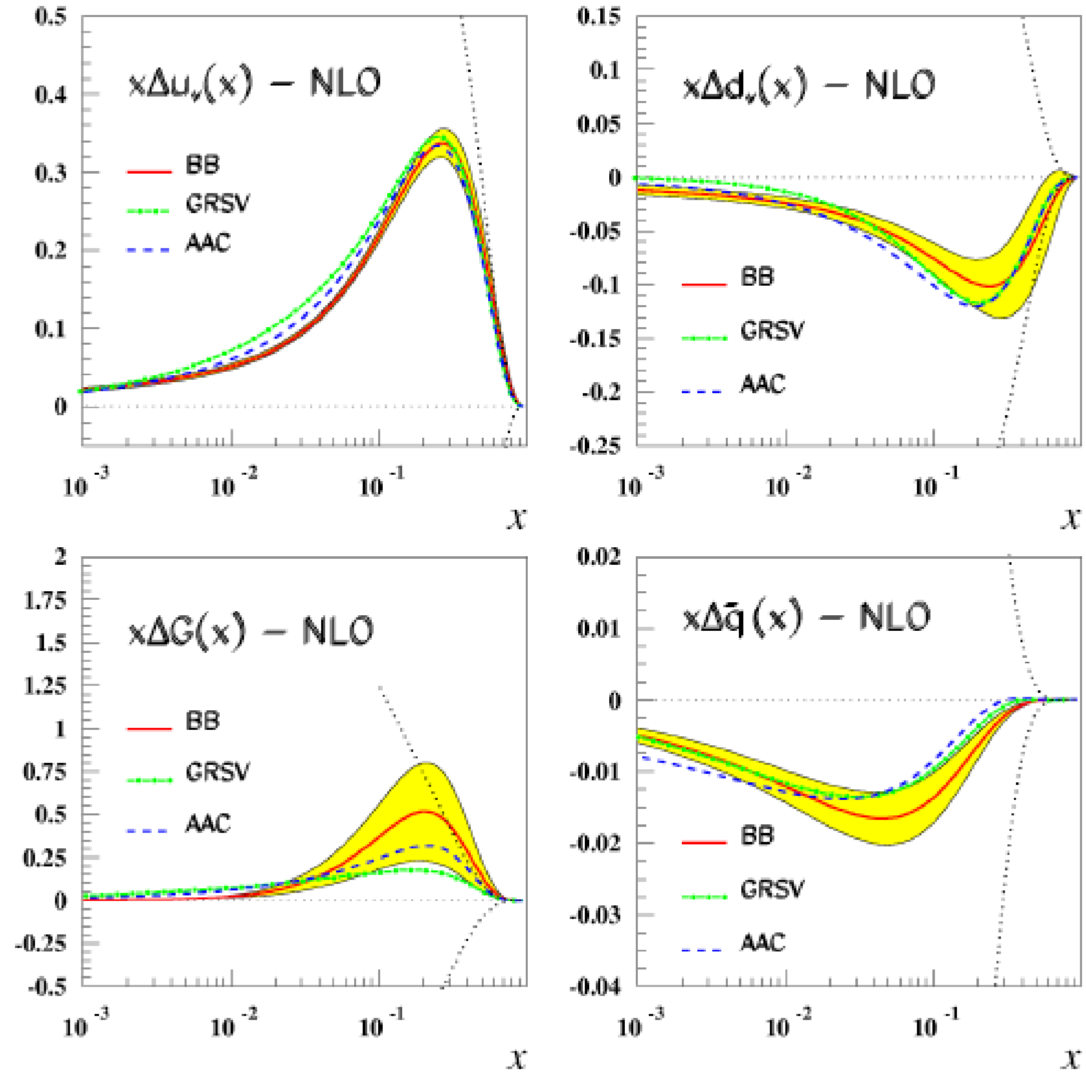
J. Blümlein & H. Böttcher
Nucl. Phys. B636 (2002) 225.

$$A_1 = \frac{\sigma^T_{1/2} - \sigma^T_{3/2}}{\sigma^T_{1/2} + \sigma^T_{3/2}} \cong g_1 \frac{2x(1+R)}{F_2}$$

$$\text{where } \mathrm{R} = \frac{F_L}{2xF_1} \cong \frac{F_2 - 2xF_1}{2xF_1}$$

$$g_1^{LO} = \frac{1}{2} \sum_i e_i^2 \, (\Delta q_i + \Delta \bar{q}_i)$$

$$\Delta q \equiv q^{\uparrow} - q^{\downarrow}$$



Polarized neutrino-proton scattering (CC)

$$W_{\mu\nu} = \left(-g_{\mu\nu} + \frac{q_\mu q_\nu}{q^2}\right) F_1 + \frac{\hat{p}_\mu \hat{p}_\nu}{p\cdot q} F_2 - i\,\varepsilon_{\mu\nu\lambda\sigma} \frac{q^\lambda p^\sigma}{2p\cdot q} F_3$$

where $\hat{p}_\mu = p_\mu - \frac{p\cdot q}{q^2} q_\mu$

$$+ i\,\varepsilon_{\mu\nu\lambda\sigma} \frac{q^\lambda s^\sigma}{p\cdot q} g_1 + i\,\varepsilon_{\mu\nu\lambda\sigma} \frac{q^\lambda (p\cdot q\, s^\sigma - s\cdot q\, p^\sigma)}{(p\cdot q)^2} g_2$$

$$\boxed{+ \left[\frac{\hat{p}_\mu \hat{s}_\nu + \hat{s}_\mu \hat{p}_\nu}{2p\cdot q} - \frac{s\cdot q\, \hat{p}_\mu \hat{p}_\nu}{(p\cdot q)^2}\right] g_3 + \frac{s\cdot q\, \hat{p}_\mu \hat{p}_\nu}{(p\cdot q)^2} g_4 + \left(-g_{\mu\nu} + \frac{q_\mu q_\nu}{q^2}\right) \frac{s\cdot q}{p\cdot q} g_5}$$

new structure functions g_3, g_4, g_5

be careful about "various" definitions of g_3, g_4, g_5 !

$$\frac{d(\sigma^{CC}_{\lambda_p=-1} - \sigma^{CC}_{\lambda_p=+1})}{dx\,dy} = \frac{G_F^2 Q^2}{\pi(1+Q^2/M_W^2)^2 xy} \Big\{ \boxed{\left[-\lambda_\ell y(2-y) x g_1^{CC} - (1-y) g_4^{CC} - y^2 x g_5^{CC}\right]}$$

$$\boxed{\begin{aligned} &+ 2xy\frac{M^2}{Q^2}\Big[\lambda_\ell x^2 y^2 g_1^{CC} + \lambda_\ell 2x^2 y\, g_2^{CC} + \left(1 - y - x^2 y^2 \frac{M^2}{Q^2}\right) x\, g_3^{CC} \\ &- x\left(1 - \frac{3}{2}y - x^2 y^2 \frac{M^2}{Q^2}\right) g_4^{CC} - x^2 y^2 g_5^{CC}\Big]\Big\} \end{aligned}}$$

0 at $Q^2 >> M^2$

g_1, g_4, g_5 in parton model (CC)

$$\Delta q \equiv q^{\uparrow} - q^{\downarrow}$$

$$g_4 = 2x g_5$$

$$g_1^{\nu p} = +\Delta d + \Delta s + \Delta \bar{u} + \Delta \bar{c} \ , \quad g_1^{\bar{\nu} p} = +\Delta u + \Delta c + \Delta \bar{d} + \Delta \bar{s}$$

$$g_5^{\nu p} = -\Delta d - \Delta s + \Delta \bar{u} + \Delta \bar{c} \ , \quad g_5^{\bar{\nu} p} = -\Delta u - \Delta c + \Delta \bar{d} + \Delta \bar{s}$$

$$\Downarrow$$

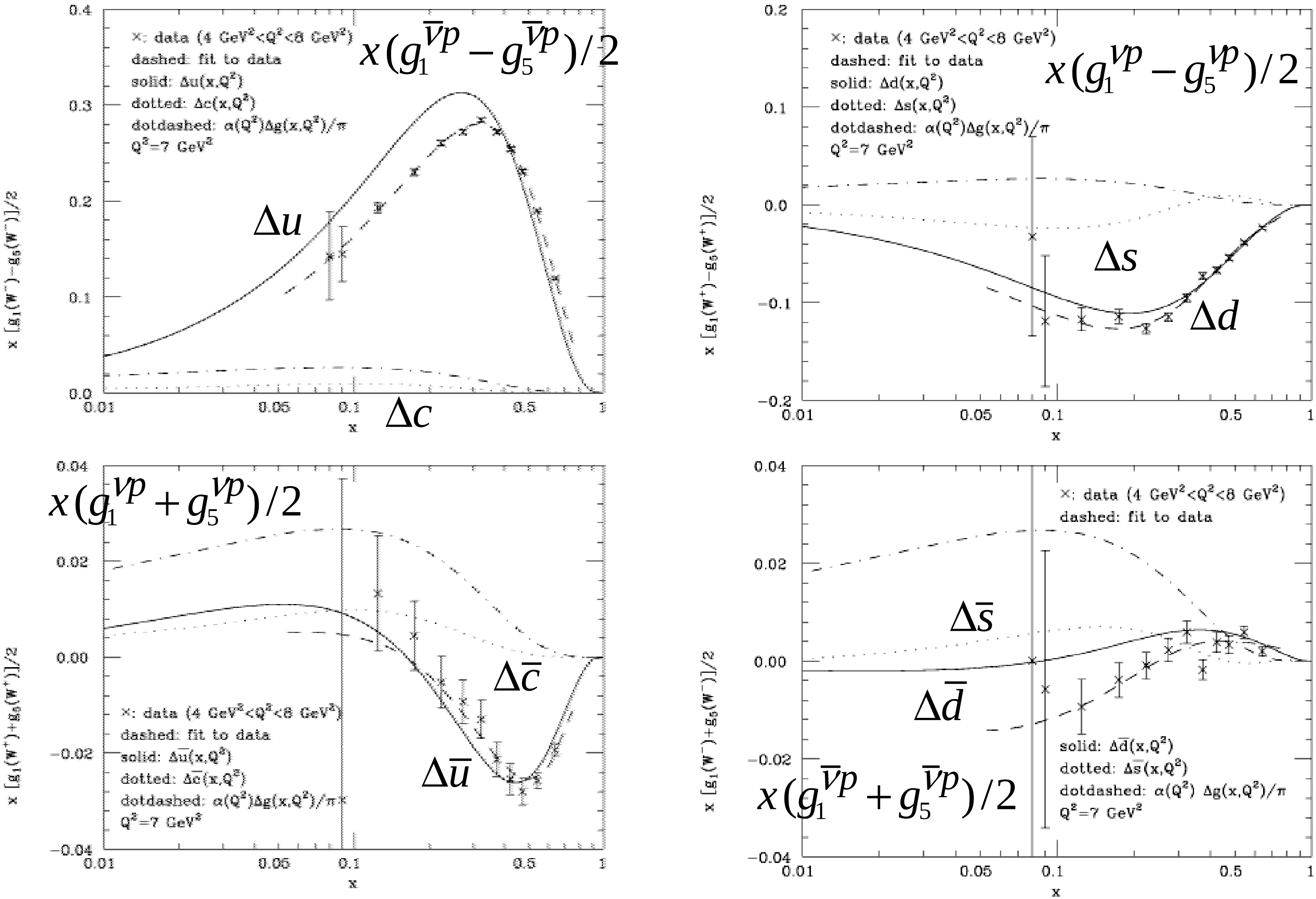
$$g_5^{\nu p} + g_5^{\bar{\nu} p} = -\underline{(\Delta u_v + \Delta d_v)} - (\Delta s - \Delta \bar{s}) - (\Delta c - \Delta \bar{c})$$

determination of valence polarization

$$g_5^{\nu (p+n)/2} - g_5^{\bar{\nu} (p+n)/2} = -\underline{(\Delta s + \Delta \bar{s}) + (\Delta c + \Delta \bar{c})}$$

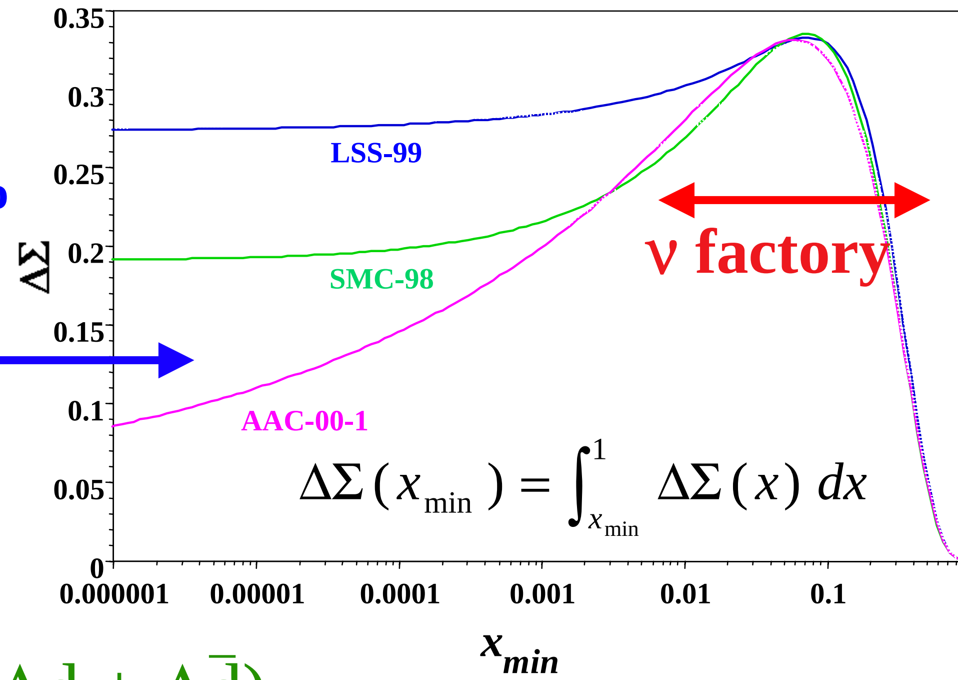
Possibilities at ν factory

S. Forte, M. L. Mangano, G. Ridolfi
Nucl. Phys. B602 (2001) 585.



Quark spin content

e/μ scattering → ΔΣ = 0 ~30%
It is not uniquely determined.



ν scattering

$$g_1^{\nu p} + g_1^{\bar{\nu} p} = (\Delta u + \Delta\bar{u}) + (\Delta d + \Delta\bar{d}) + (\Delta s + \Delta\bar{s}) + (\Delta c + \Delta\bar{c})$$

Δs: talks by Albrecio, Tayloe, Miyachi

in LO $\int dx\, (g_1^{\nu p} + g_1^{\bar{\nu} p}) = \Delta\Sigma$

independent determination of quark spin content ΔΣ !

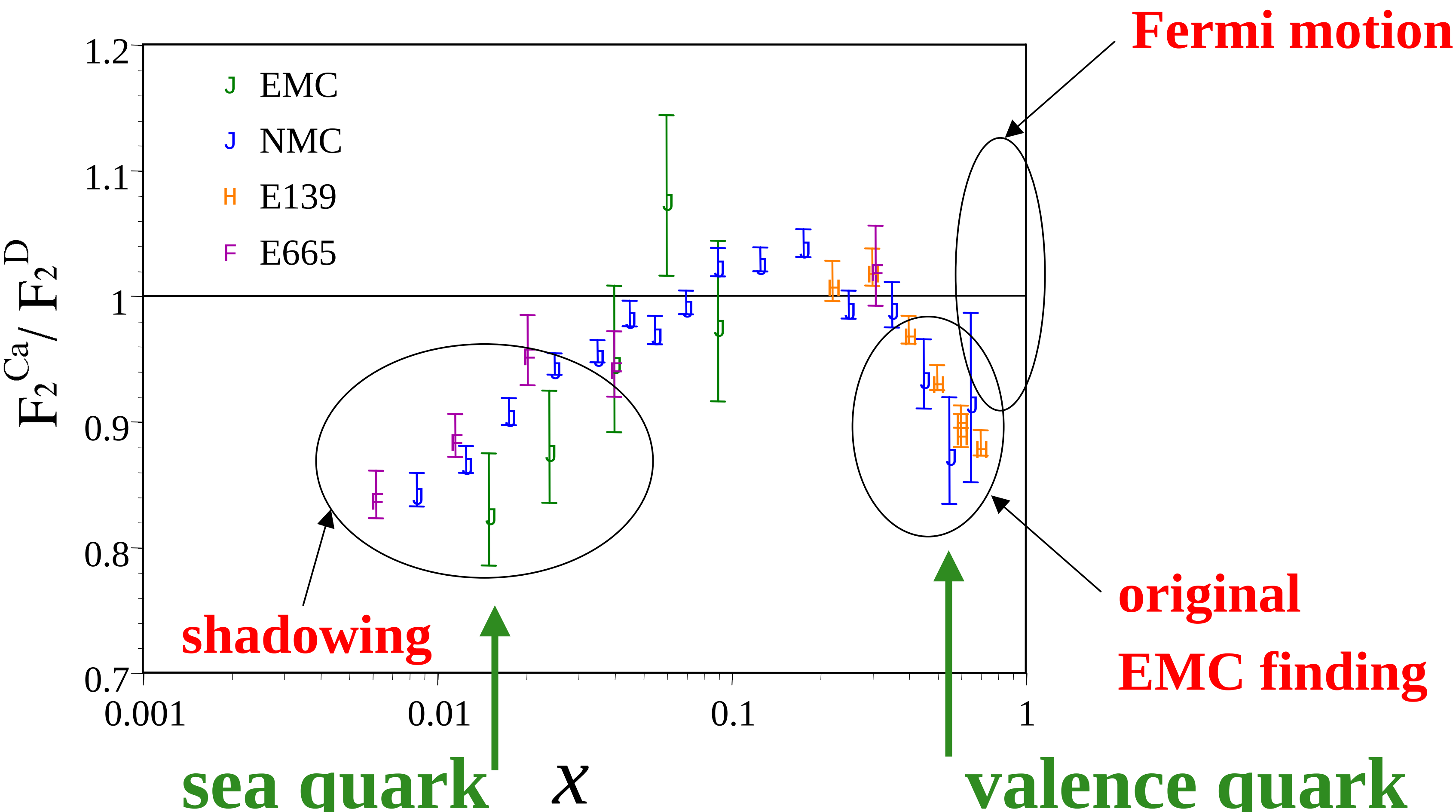
Nuclear structure functions

in ν scattering

Nuclear modification

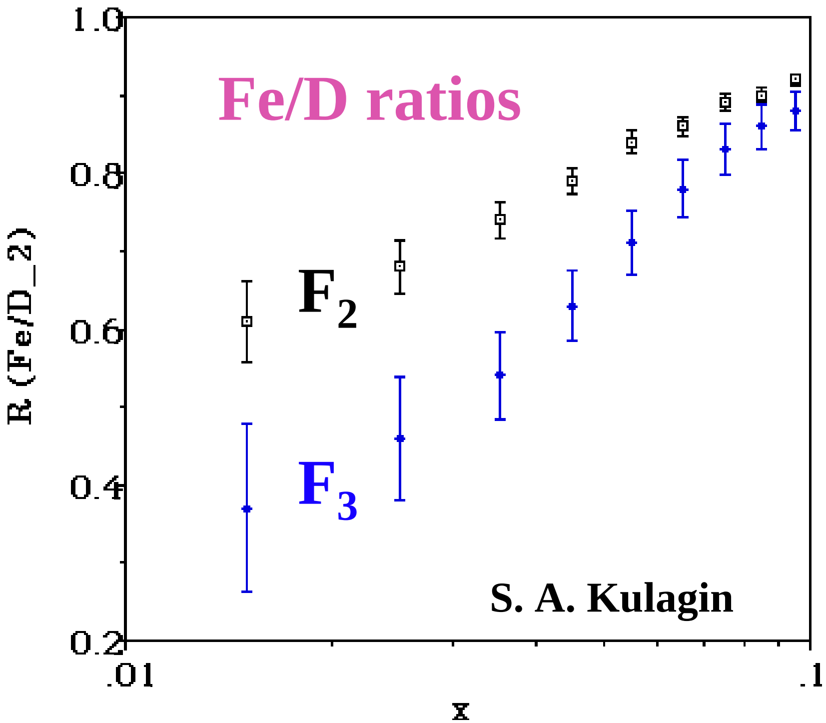
$$F_2^A = \sum_i e_i^2\, x \left[q_i(x) + \bar{q}_i(x)\right]_A$$

Nuclear modification of F_2^A / F_2^D is well known in electron/muon scattering.



NuMI

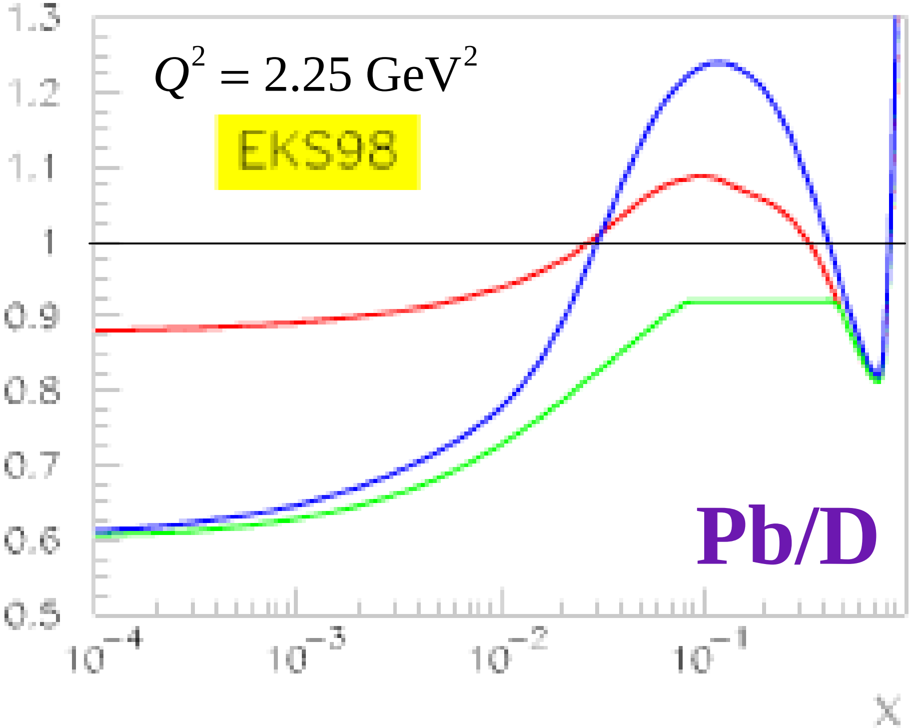
$$\frac{1}{2}[F_3^{\nu N}+F_3^{\bar{\nu}N}]_{CC}\cong u_{\rm v}+d_{\rm v}$$

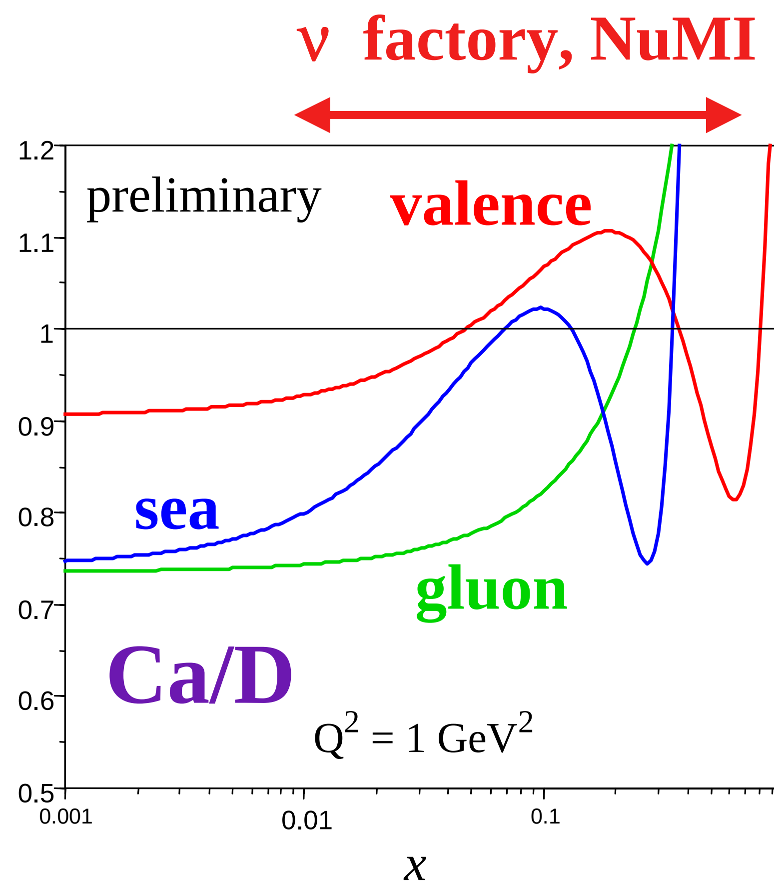


- **test of shadowing models**
  F_3 (valence) shadowing
  vs. F_2 (sea) shadowing
- **accurate determination of nuclear PDFs**

J. G. Morfin at NuFact02/NuInt02

Nuclear PDFs





Eskola, Kolhinen, Ruuskanen, Salgado
Nucl. Phys. B535 (1998) 351;
Eur. Phys. J. C9 (1999) 61.

Hirai, SK, Miyama
PRD, 64 (2001) 034003;
research in progress.

“HERMES effect” (nuclear effect on R=L/T)

HERMES, Ackerstaff el al., PL B 475 (2000) 386;

Erratum, hep-ex/0210067; hep-ex/0210068.

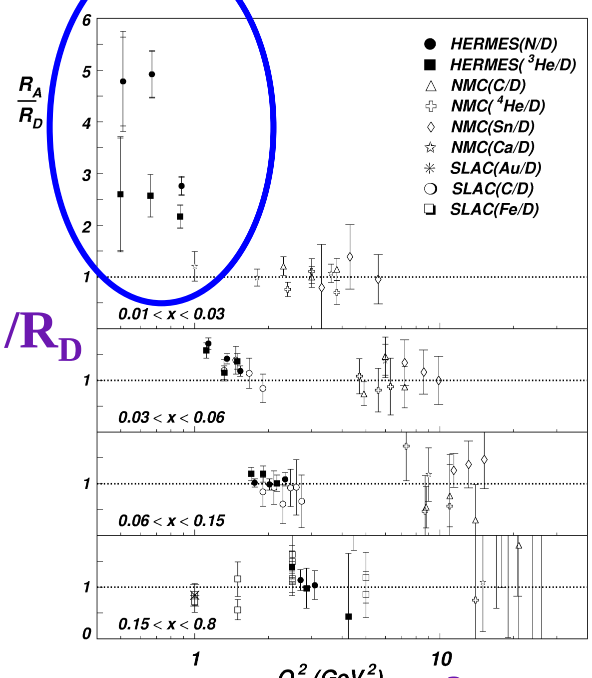
Miller, Brodsky, Karliner, PL B 481, 245 (2000).

Longitudinal and transverse components

$$W_\lambda = \varepsilon_\lambda^{\mu\,*}\,\varepsilon_\lambda^{\nu}\,W_{\mu,\nu}$$

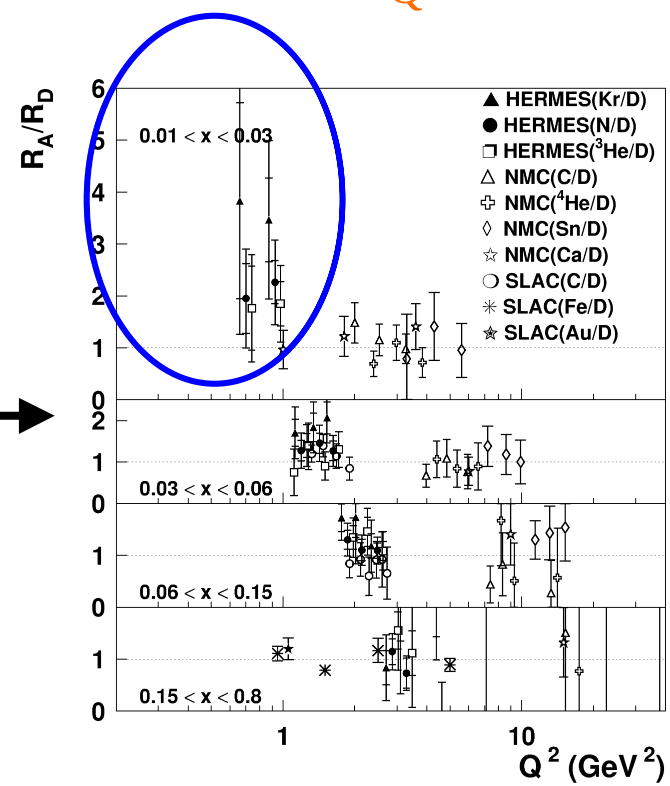
$$W_T = \frac{1}{2}\left(W_{\lambda=+1} + W_{\lambda=-1}\right) = W_1 \qquad W_L = W_{\lambda=0} = \left(1 + \frac{\nu^2}{Q^2}\right) W_2 - W_1$$

R_A/R_D

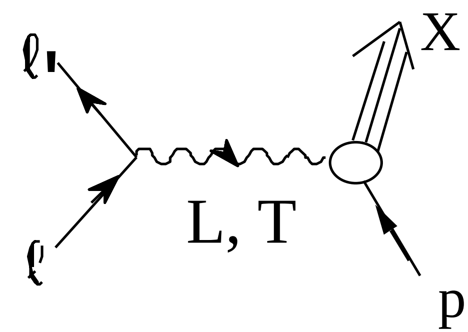


Q^2 (GeV^2)

(2000)



(2002)-preprint



Nuclear effects on R=L/T by CCFR/NuTeV

Yang et al., PRL 87 (2001) 251802.

● CCFR ☐ HERMES
● SLAC

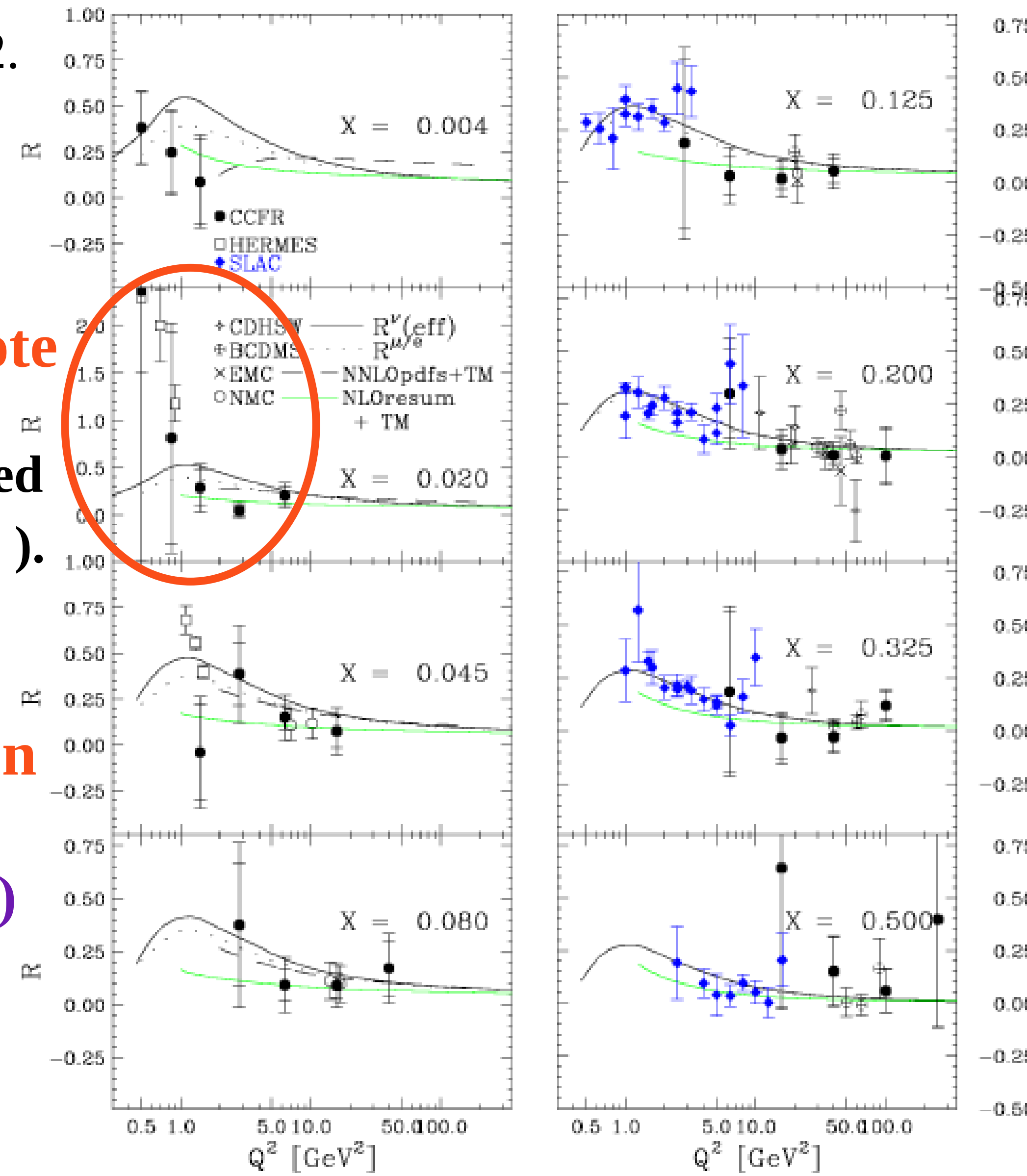
No significant deviation is measured from the nucleon case ( ).

↓

No large nuclear modification of R is observed in ν+Fe!

(note: CCF/NuTeV target is Fe)

note



Nuclear effects on R=L/T at medium & large x

M. Ericson and SK, Phys. Rev. C67 (2003) 022201

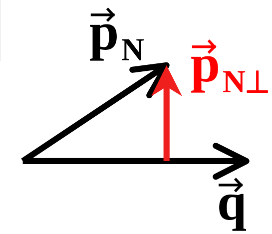
$S(p_N)$ = spectral function

Calculating $W^A_{1,2} = \hat{P}^{\mu\nu}_{1,2}\, W^A_{\mu\nu} = \hat{P}^{\mu\nu}_{1,2} \int d^4p_N\, S(p_N)\, W^N_{\mu\nu}$,

$$\tilde{p}_\mu = p_\mu - \frac{p\cdot q}{q^2}\, q_\mu$$

$$2\, x_A\, F_1^A = \int d^4p_N\, S(p_N)\, z\, \frac{M_N}{\sqrt{p_N^2}} \left[\left(1 + \frac{\vec{p}_{N\perp}^{\,2}}{2\,\tilde{p}_N^{2}}\right) 2\, x_N\, F_1^N(x_N, Q^2) + \frac{\vec{p}_{N\perp}^{\,2}}{2\,\tilde{p}_N^{2}}\, F_L^N(x_N, Q^2) \right]$$

$$F_L^A = \int d^4p_N\, S(p_N)\, z\, \frac{M_N}{\sqrt{p_N^2}} \left[\left(1 + \frac{\vec{p}_{N\perp}^{\,2}}{\tilde{p}_N^{2}}\right) F_L^N(x_N, Q^2) + \frac{\vec{p}_{N\perp}^{\,2}}{\tilde{p}_N^{2}}\, 2\, x_N\, F_1^N(x_N, Q^2) \right]$$



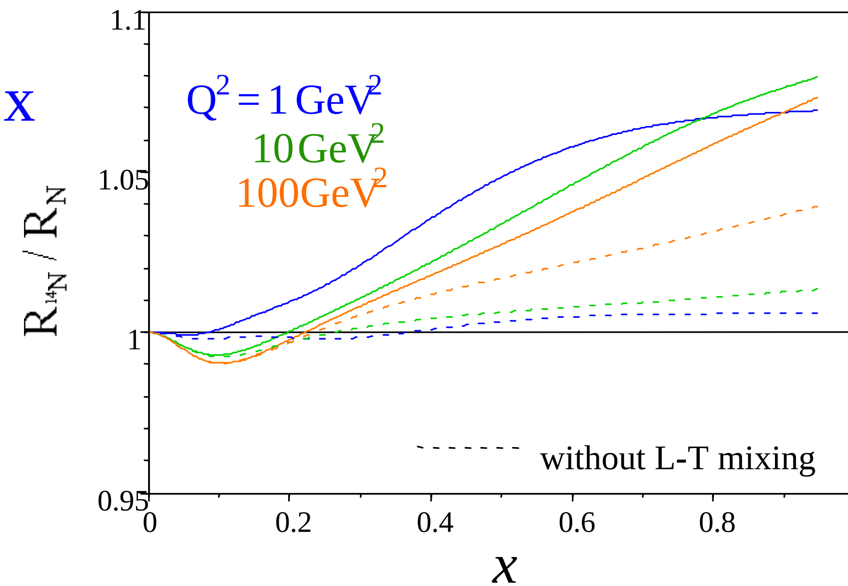
Modification of R does exist at large x

(1) transverse nucleon motion

→ T-L admixture (F_1^N & F_L^N)

(2) binding and Fermi-motion effects

in the spectral function



Transverse-longitudinal admixture $\dfrac{\vec{p}_{N\perp}^{\,2}}{\tilde{p}_N^{2}} \approx \dfrac{4\, x_N^2\, \vec{p}_{N\perp}^{\,2}}{Q^2}$

NuTeV $\sin^2\theta_W$ anomaly NuTeV, PRL 88 (2002) 091802

talks on $\sin^2\theta_W$ by Younus, Reimer, Yu

Others: $\sin^2\theta_W = 1 - m_W^2/m_Z^2 = 0.2227 \pm 0.0004$

NuTeV: $\sin^2\theta_W = 0.2277 \pm 0.0013$ (stat) ± 0.0009 (syst)

Studies on nuclear effects in iron

McFarland et. al., NP B112 (2002) 226.
nuclear modification of structure functions, deviation from isoscalar nucleus

Miller & Thomas, hep-ex/0204007: shadowing effects (VMD)

Zeller et. al., hep-ex/0207052: VMD issues: Paschos-Wolfenstein, NC/CC ratio

Kovalenko, Schmidt, Yang, PL B546 (2002) 68: modifications of nuclear PDFs

SK, PRD 66 (2002) 111301: difference between nuclear modifications of u_v and d_v

Kulagin, PRD 67 (2003) 091301: neutron excess correction

$\sin^2\theta_W$ anomaly from a nuclear physicist's point of view

Paschos-Wolfenstein relation

$$R^- = \frac{\sigma_{NC}^{\nu N} - \sigma_{NC}^{\bar{\nu} N}}{\sigma_{CC}^{\nu N} - \sigma_{CC}^{\bar{\nu} N}} = \frac{1}{2} - \sin^2\theta_W$$

N = isoscalar nucleon

NuTeV target: ^{56}Fe (Z = 26, N = 30), not isoscalar nucleus

$\longrightarrow$ nuclear effects should be carefully taken into account

$$R_A^- = \frac{\sigma_{NC}^{\nu A} - \sigma_{NC}^{\bar{\nu} A}}{\sigma_{CC}^{\nu A} - \sigma_{CC}^{\bar{\nu} A}} = \frac{\{1-(1-y)^2\}\,[\,(u_L^2 - u_R^2)\{u_v^A(x) + c_v^A(x)\} + (d_L^2 - d_R^2)\{d_v^A(x) + s_v^A(x)\}]}{d_v^A(x) + s_v^A(x) - (1-y)^2\{u_v^A(x) + c_v^A(x)\}}$$

Neutron excess and a related function: $\hat{\varepsilon}_n = \dfrac{N-Z}{A}$, $\varepsilon_n(x) = \hat{\varepsilon}_n \dfrac{u_V(x) - d_V(x)}{u_V(x) + d_V(x)}$

Nuclear effects are in the weight functions: w_{u_v} and w_{d_v}

$$u_v^A(x) = w_{u_v}(x)\,\frac{Z\,u_v(x) + N\,d_v(x)}{A}, \quad d_v^A(x) = w_{d_v}(x)\,\frac{Z\,d_v(x) + N\,u_v(x)}{A}$$

Difference between nuclear modifications of u_V and d_V: $\varepsilon_v(x) = \dfrac{w_{d_V}(x) - w_{u_V}(x)}{w_{d_V}(x) + w_{u_V}(x)}$

$$R_A^- = \frac{(\frac{1}{2} - \sin^2\theta_W)\{1 + \varepsilon_v(x)\,\varepsilon_n(x)\} + \frac{1}{3}\sin^2\theta_W\{\varepsilon_v(x) + \varepsilon_n(x)\} + (\frac{1}{2} - \frac{2}{3}\sin^2\theta_W)\,\varepsilon_s(x) + (\frac{1}{2} - \frac{4}{3}\sin^2\theta_W)\,\varepsilon_c(x)}{1 + \varepsilon_v(x)\,\varepsilon_n(x) + \frac{1 + (1-y)^2}{1-(1-y)^2}\{\varepsilon_v(x) + \varepsilon_n(x)\} + \frac{2\{\varepsilon_s(x) - (1-y)^2\,\varepsilon_c(x)\}}{1-(1-y)^2}}$$

Expand in ε_v, ε_n, ε_s, ε_c << 1

small effect which increases the deviation

Zeller et al., PRD 65 (2002) 111103

$$R_A^- = \frac{1}{2} - \sin^2\theta_W + O(\varepsilon_v) + O(\varepsilon_n) + O(\varepsilon_s) + O(\varepsilon_c)$$

taken into account in the NuTeV analysis

SK (2002): **rather small**

but not so obvious

Kulagin (2003): **deviation becomes small**

$\sin^2\theta_W = 0.2277 \to 0.2251$

(other data: 0.2227)

(This may need confirmation by including NuTeV kinematical effects.)

Low/medium-energy ν scattering

(Current long baseline neutrino reactions)

Nuclear effects are becoming important!

The details are found in

(1) NuInt01, http://neutrino.kek.jp/nuint01/

(2) NuInt02, http://nuint.ps.uci.edu/

Attempt to describe DIS & resonance region

Empirical formula

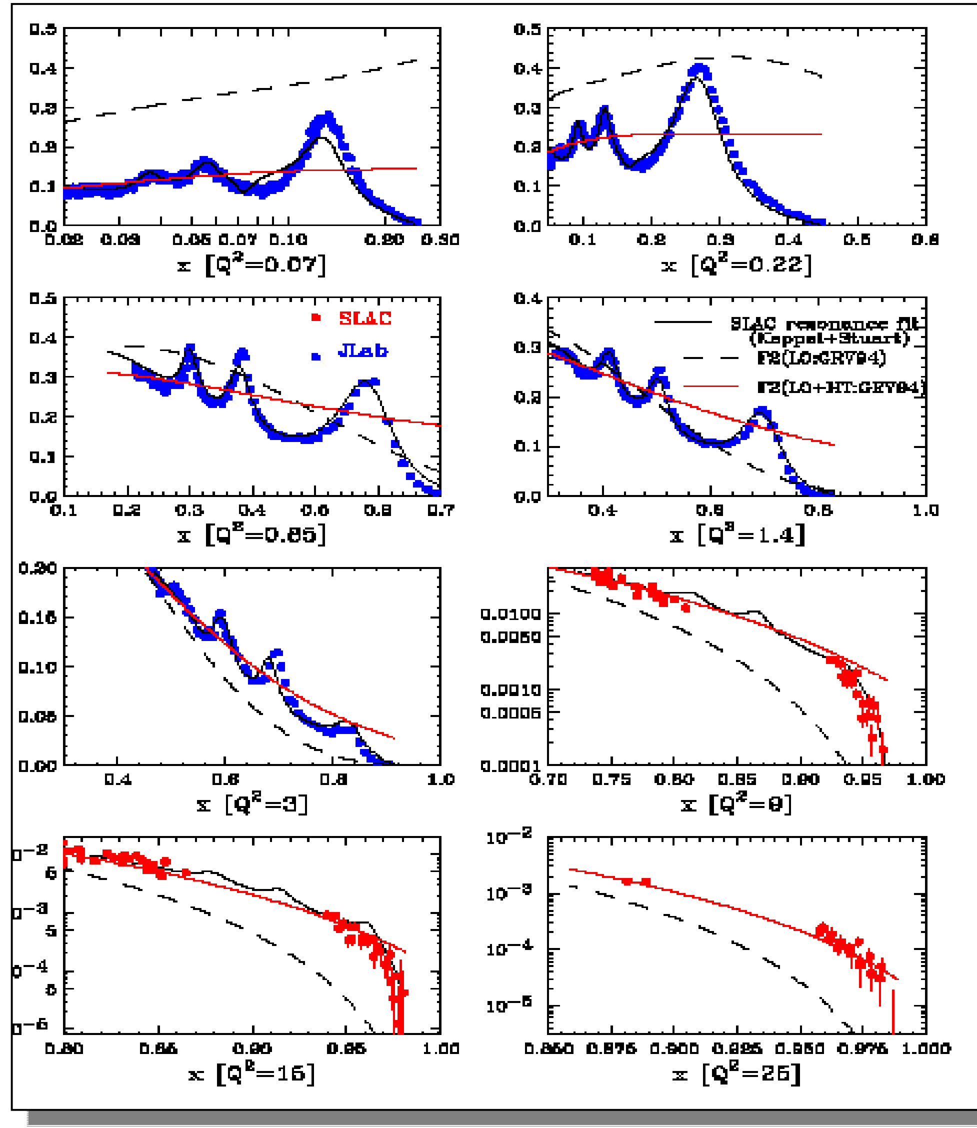
$$F_2(x) = \frac{Q^2}{Q^2 + 0.188} F_2(x_w)$$

where $x_w = x \dfrac{Q^2 + 0.624}{Q^2 + 1.735x}$

GRV94

Bodek-Yang

NP B 112 (2002) 70



Neutrino-Nucleus Interactions in the Few-GeV Region

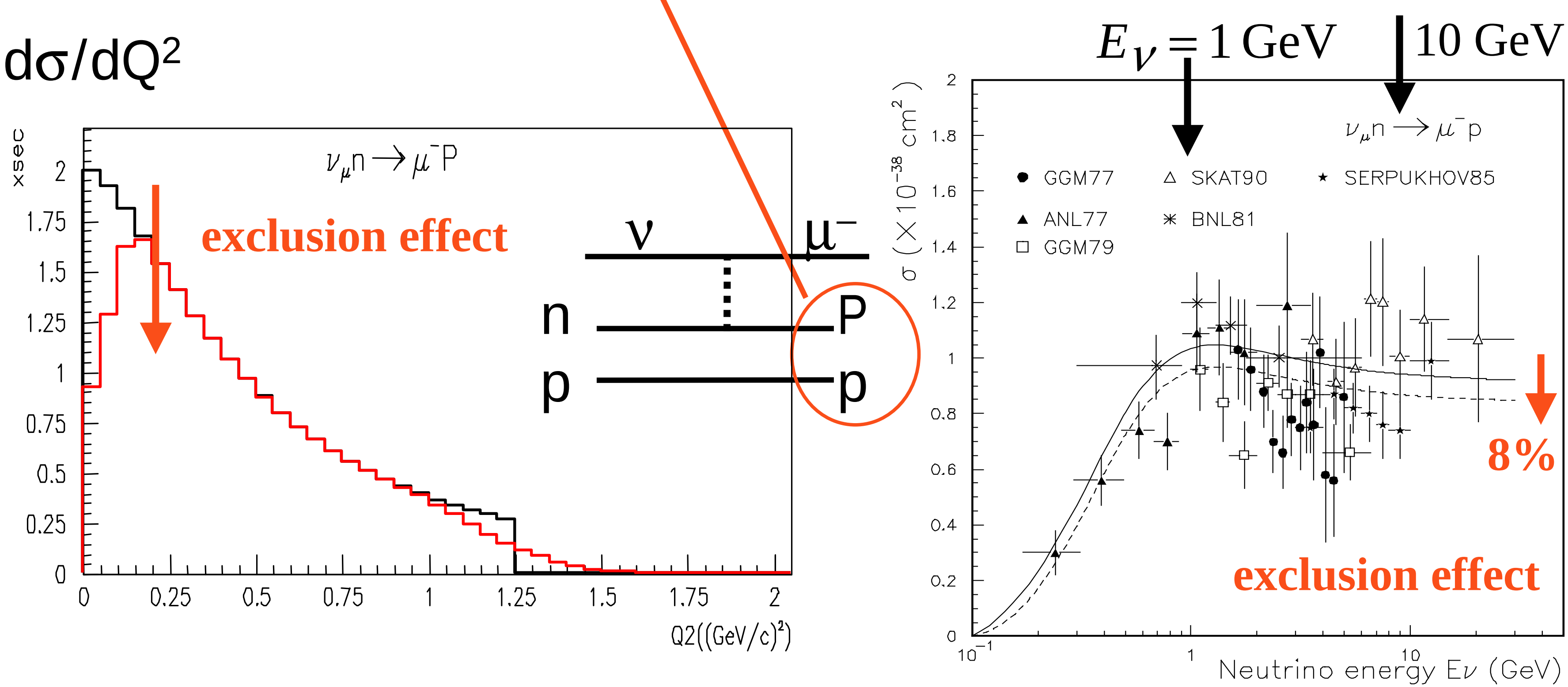
M. Sakuda at NuInt02

talks by Zeller, Walter, McFarland

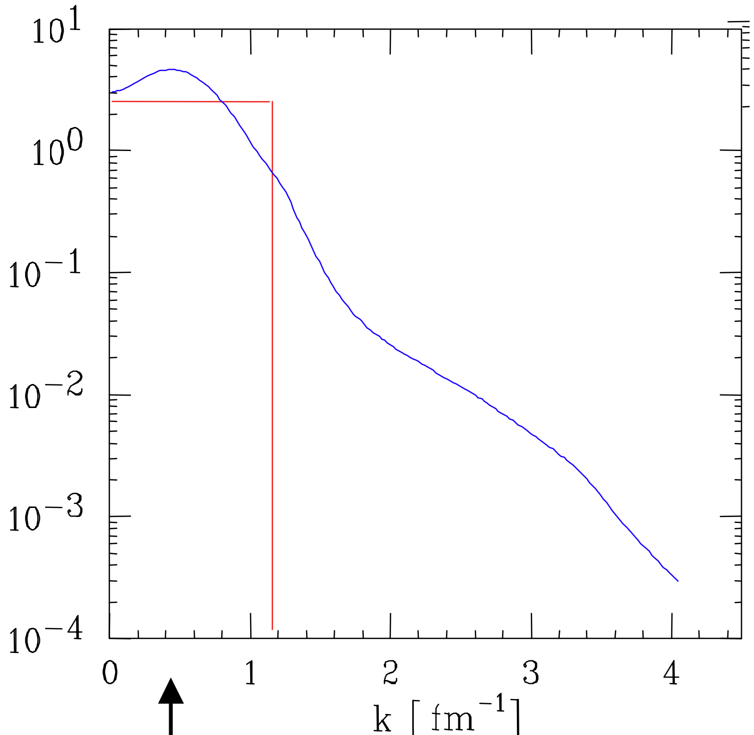
ν-nucleus cross sections are not well known at E_ν=0.5-20 GeV. (20% accuracy)
For accurate oscillation measurements, a few % accuracy is needed.

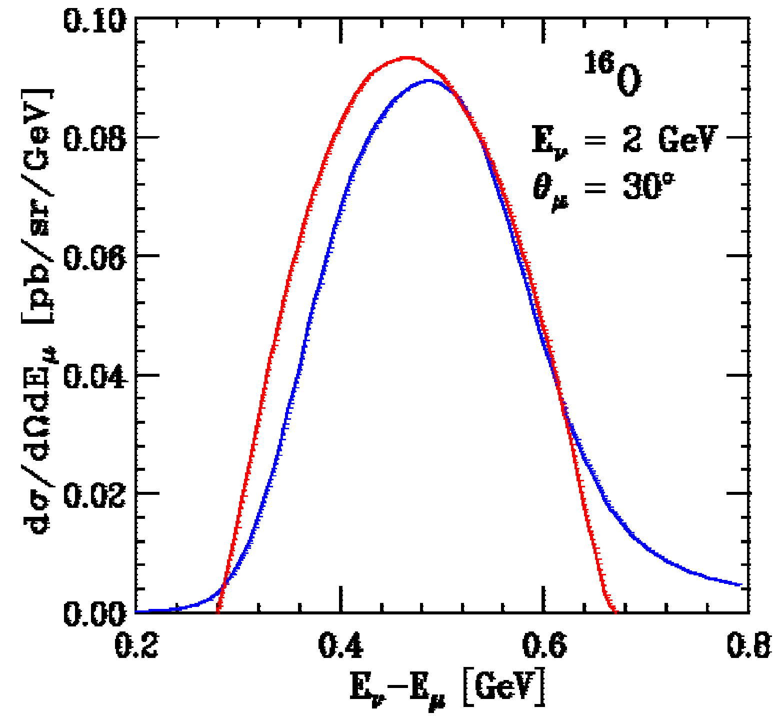
→ **Nuclear corrections in ^{16}O are important!**

Binding, Fermi motion, Pauli exclusion, NN correlation, PDF modification, …



Example of nuclear effects: NN correlation





Fermi gas

With NN correlation

Benhar, Gallagher, Nakamura
at NuInt02

Spectral function

= nucleon momentum distribution in a nucleus

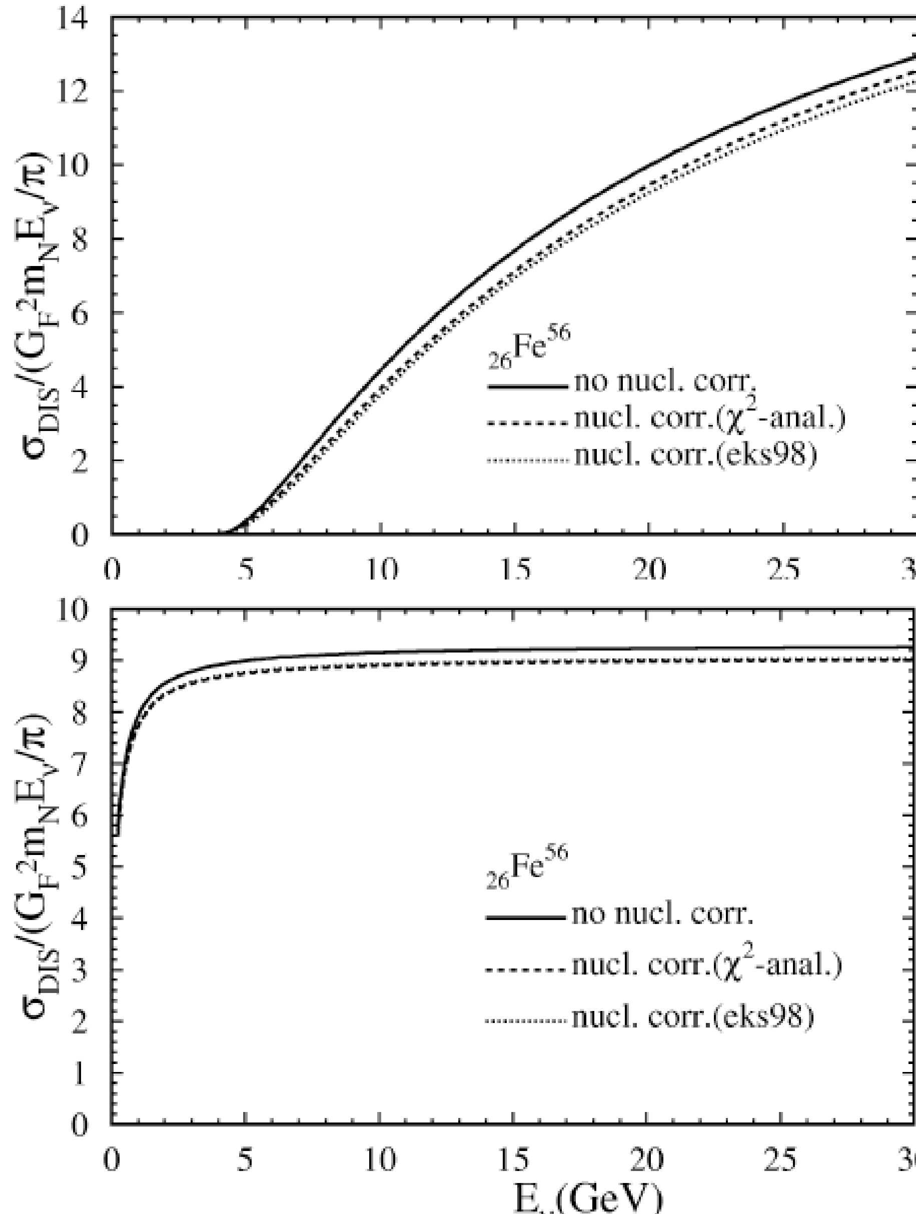
Another example: nuclear PDF corrections

Ref. Paschos & Yu,
PRD 65 (2002) 033002.

Nuclear PDF effects on
$(\nu+Fe)_{CC}$, $(\nu+Fe)_{NC}$

——— **no nuclear correction**

- - - - - - **with nuclear PDF**
········ **corrections**



Summary on ν scattering physics

- pQCD, non-pQCD (PDFs), sum rules
- fundamental constants: α_s , $\sin^2\theta_W$
- nuclear structure functions
- quark spin content $\Delta\Sigma$, new spin structure functions
- low energy: nuclear effects, form factors, resonances

These studies have influence on

- QCD (hadron models)
- heavy-ion physics
- finding new physics beyond
  the current theoretical framework
- neutrino properties (long baseline physics)