Neutrino structure functions predictions for high energy and high precision neutrino experiments

Mairon Melo Machado *

Instituto Federal Farroupilha, Campus São Borja
São Borja, Rio Grande do Sul, Brazil
mairon.machado@iffarroupilha.edu.br

*** In collaboration with M. V. T. Machado**

Motivations

- Interaction of high energy neutrinos on hadron targets are an important probe to test QCD and to understand the parton properties of hadron structure

- Combinations of neutrino and anti-neutrino scattering data used to determine the structure functions

- The structure function F_2 is the singlet distribution

$$F_2^{\nu N} \propto x q^S = x \sum (q + \bar{q})$$

- Phenomenology using saturation models within the Color Dipole Approach successfully describes current small-x data [1]

[1]GAY DUCATI, M. B., MACHADO, M. M., MACHADO, M. V. T. – PLB 644 (2007) 340;

Motivations (MINERvA)[2]

- Fermi National Accelerator Laboratory
- First neutrino experiment in the world to use a high-intensity beam to study neutrino reactions with five different nuclei
- First self-contained comparison of interactions in different elements.
- High precision measurements of neutrino interactions
- Information about proton‘s structure
- Water, helium, carbon, iron, lead, and plastic.

[2]http://minerva.fnal.gov/

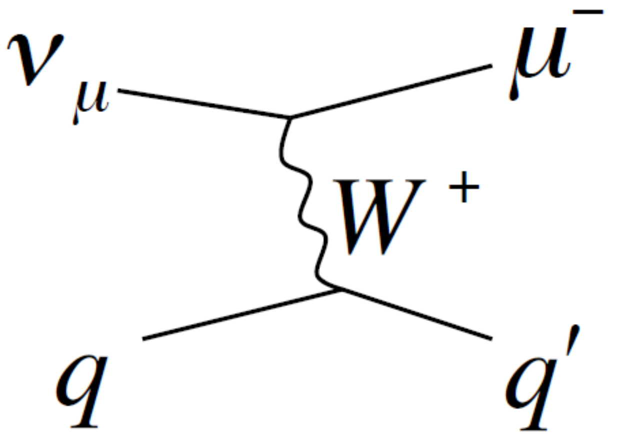
Motivations (NuSOnG)

- Purpose of a new high-energy, ultra-high statistics neutrino scattering experiment
- Neutrino Scattering On Glass (NuSOnG)[3]
- Variety of issues including precision QCD measurements, extraction of structure functions, and the derived Parton Distribution Functions (PDFs)
- Tevatron-based neutrino beam to obtain DIS events
- Discerning tests of fundamental Standard Model parameters

[3] T. ADAMS et al, Int.J.Mod.Phys.A25:909-949,2010

Neutrino-nucleon collision

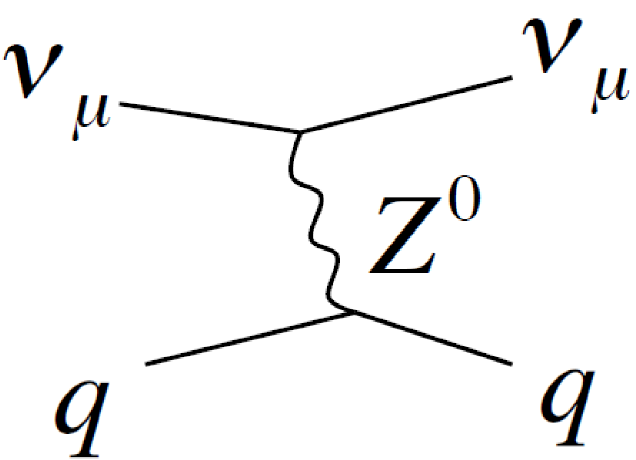
CC



$$s = 2ME \qquad y = \frac{pq}{ME}$$

$$x = \frac{Q^2}{2pq} \qquad Q^2 = -q^2$$

NC



- M is the nucleon mass
- E is the neutrino energy
- p and q are the nucleon and boson four-momenta
- Charged-current interactions and neutral current interactions

Neutrino-nucleon cross section [4]

$$\frac{\partial^2 \sigma^{\mathrm{NC}}_{(\nu,\bar{\nu})}}{\partial x\, \partial y} = \frac{G_F^2\, m_N\, E_\nu}{\pi} \left(\frac{m_Z^2}{Q^2 + m_Z^2} \right)^2 \left[\frac{1 + (1-y)^2}{2} F_2^{\mathrm{NC}}(x, Q^2) - \frac{y^2}{2} F_L^{\mathrm{NC}}(x, Q^2) \right]$$

- G_F is the Fermi constant

  $1.166.10^{-5}$ GeV^{-2}

- M_i is the boson mass

- F_2, F_L and F_3 are the structure functions

$$Q^2_{min} = 1 GeV^2 \qquad y = Q^2/(xs)$$

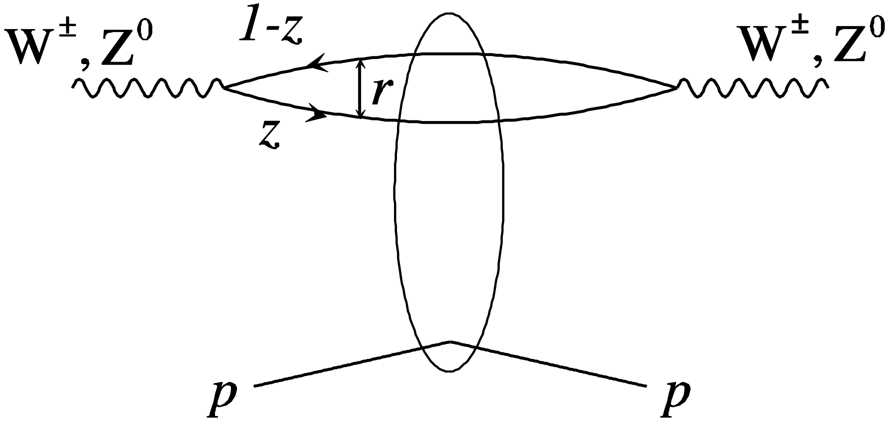
$$\frac{d\sigma^{\nu(N)}}{dxdy} = \frac{G_F^2 m_N E_\nu}{\pi} \left[xq(x) + x\bar{q}(x)(1-y)^2 \right]$$

$$\frac{d\sigma^{\bar{\nu}(N)}}{dxdy} = \frac{G_F^2 m_N E_\nu}{\pi} \left[xq(x)(1-y)^2 + x\bar{q}(x) \right]$$

$$\sigma^{\mathrm{NC}}_{(\nu,\bar{\nu})}(E_\nu;\, A) = \int_{Q^2_{\mathrm{min}}}^{s} dQ^2 \int_{Q^2/s}^{1} dx\, \frac{1}{xs} \frac{\partial^2 \sigma^{\mathrm{NC}}_{(\nu,\bar{\nu})}}{\partial x\, \partial y}$$

[4] ROBERTS, R. G., "*The structure of the proton*", Cambridge University Press (1993);

Color dipole phenomenology



- Ψ's are the wave functions for electroweak bosons
- z is the momentum fraction of quark and (1-z) is the momentum fraction of the antiquark
- λ_1 and λ_2 are the helicities of the quarks (1/2 or -1/2)
- r is the transversal size of the dipole
- σ_{dip} is parametrized and fitted to the experiment .

$$\sigma_{L,R}(x,Q^2) = \int d^2\mathbf{r} \int_0^1 dz \sum_{\lambda_1,\lambda_2} |\Psi_{L,R}^{\lambda_1,\lambda_2}(z,\mathbf{r},Q^2)|^2 \sigma_{dip}(x,\mathbf{r})$$

Neutrino Structure functions

$$F_{T,L}^{CC,NC}(x,Q^2) = \frac{Q^2}{4\,\pi^2}\int d^2r \int_0^1 dz\,|\psi_{T,L}^{W^\pm,Z^0}|^2\,\sigma_{dip}$$

$$|\psi_T^{W^\pm}| = \frac{4N_c}{(2\pi)^2}\left\{[(1-z)^2 m_q + z^2 m_{\bar{q}}^2]K_0^2(\epsilon r) + [z^2 + (1-z)^2]\epsilon^2 K_1^2(\epsilon r)\right\}$$

$$|\psi_L^{W^\pm}| = \frac{4N_c}{(2\pi)^2 Q^2}\left\{[(z(1-z)Q^2 + \epsilon^2)^2 + m_q^2 m_{\bar{q}}^2]K_0^2(\epsilon r) + [\frac{a_-^2 + a_+^2}{2}]\epsilon^2 K_1^2(\epsilon r)\right\}$$

$$|\bar{\psi}_T^Z(r,z,Q^2)|^2 = \frac{3}{2\pi^2}(L_u^2 + L_d^2 + R_u^2 + R_d^2)[z^2 + (1-z)^2]\bar{Q}^2 K_1^2(\bar{Q}r)$$

$$|\bar{\psi}_L^Z(r,z,Q^2)|^2 = \frac{6}{\pi^2}(L_u^2 + L_d^2 + R_u^2 + R_d^2)z^2(1-z)^2 Q^2 K_0^2(\bar{Q}r)$$

Chiral coupling

$$L_u = 1 - \frac{4}{3}sin^2\theta_W \qquad L_d = -1 + \frac{2}{3}sin^2\theta_W$$

$$R_u = -\frac{4}{3}sin^2\theta_W \qquad R_d = \frac{2}{3}sin^2\theta_W$$

$\sin^2\theta_W = 0.23120$

$$a_+ = (m_q + m_q),\ a_- = (m_q - m_q)$$

$$\bar{Q}^2 = z(1-z)Q^2$$

$$\epsilon^2 = z(1-z)Q^2 + (1-z)m_q^2 + zm_{\bar{q}}^2$$

$K_{0,1}$ are the McDonald functions

Quark distribution

- Gluon emits a quark-antiquark pair changing the quark distribution in the nucleon

- These quarks are called *sea quarks*

- Quark content is given by the sum of valence quarks and sea quarks

$$
\begin{aligned}
u(x) &= u_v(x) + u_s(x), \\
d(x) &= d_v(x) + d_s(x) \\
u_s(x) = \bar{u}_s(x) = d_s(x) &= \bar{d}_s(x) = s_s(x) = \bar{s}_s(x)
\end{aligned}
$$

$$2xF_1 = F_2 = 2x\sum_i (q_i + \bar{q}_i)$$

$$xF_3 = 2x\sum_i (q_i - \bar{q}_i)$$

Dipole cross section

- Golec-Biernat-Wusthoff (GBW) [5]

$$\sigma_{dip}(x, r^2) = \sigma_0 \left[1 - \exp\left(-\frac{r^2 Q_{sat}^2}{4} \right) \right]$$

$$\bar{x} = x[1 + (4m_f^2/Q^2)]$$

$$Q_{sat}^2(x) = \left(\frac{x_0}{\bar{x}} \right)^{\lambda} GeV^2$$

- σ_0 = 23 mb,
- $\lambda \sim 0.288$,
- $x_0 \sim 3.10^{-4}$ m,
- m_f = 0.14 GeV

[5] GOLEC-BIERNAT, K; WUSTHOFF, M. PRD 60, 1140231 (1998);

Neutrino-nuclei interaction [6]

- Dipole cross section for bosons transversally or longitudinally polarized are extended for nuclei using Glauber-Gribov formalism

$$\sigma_{L,R}(x,Q^2) = <\Psi_\lambda|\sigma^A(x,r)|\Psi_\lambda> = \int d^2r \int_0^1 dz \sum_{\lambda_1,\lambda_2} \left|\Psi_{L,R}^{\lambda_1,\lambda_2}(z,r,Q^2)\right|^2 \sigma_{dip.}^A(x,r)$$

$$\sigma_{dip}^{\text{nucleus}}(x,\,r;\,A) = 2\int d^2b\,\left\{1-\exp\left[-\frac{1}{2}T_A(b)\,\sigma_{dip}^{\text{nucleon}}(x,\,r)\right]\right\}$$

- Nuclear profile function $T_A(b)$

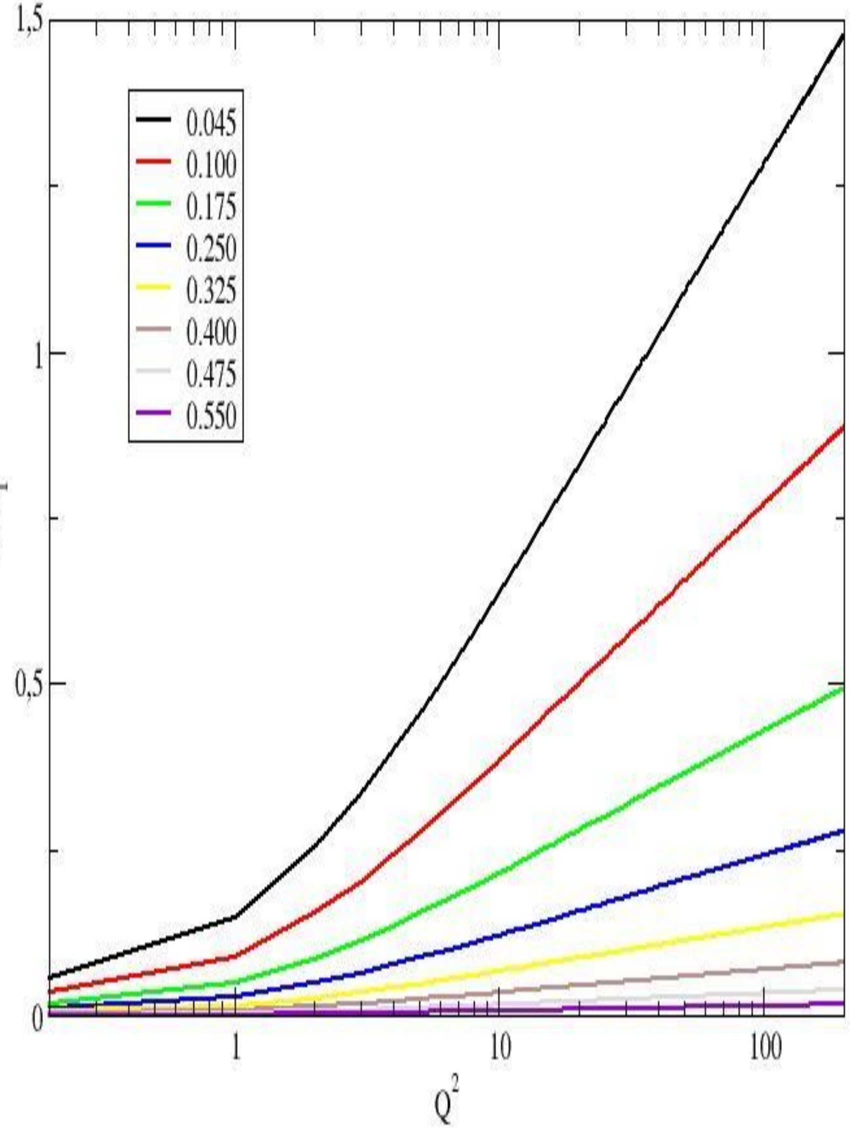
$$T_A(b) = \int_{-\infty}^{+\infty} dz\, n(\sqrt{z^2+b^2})$$

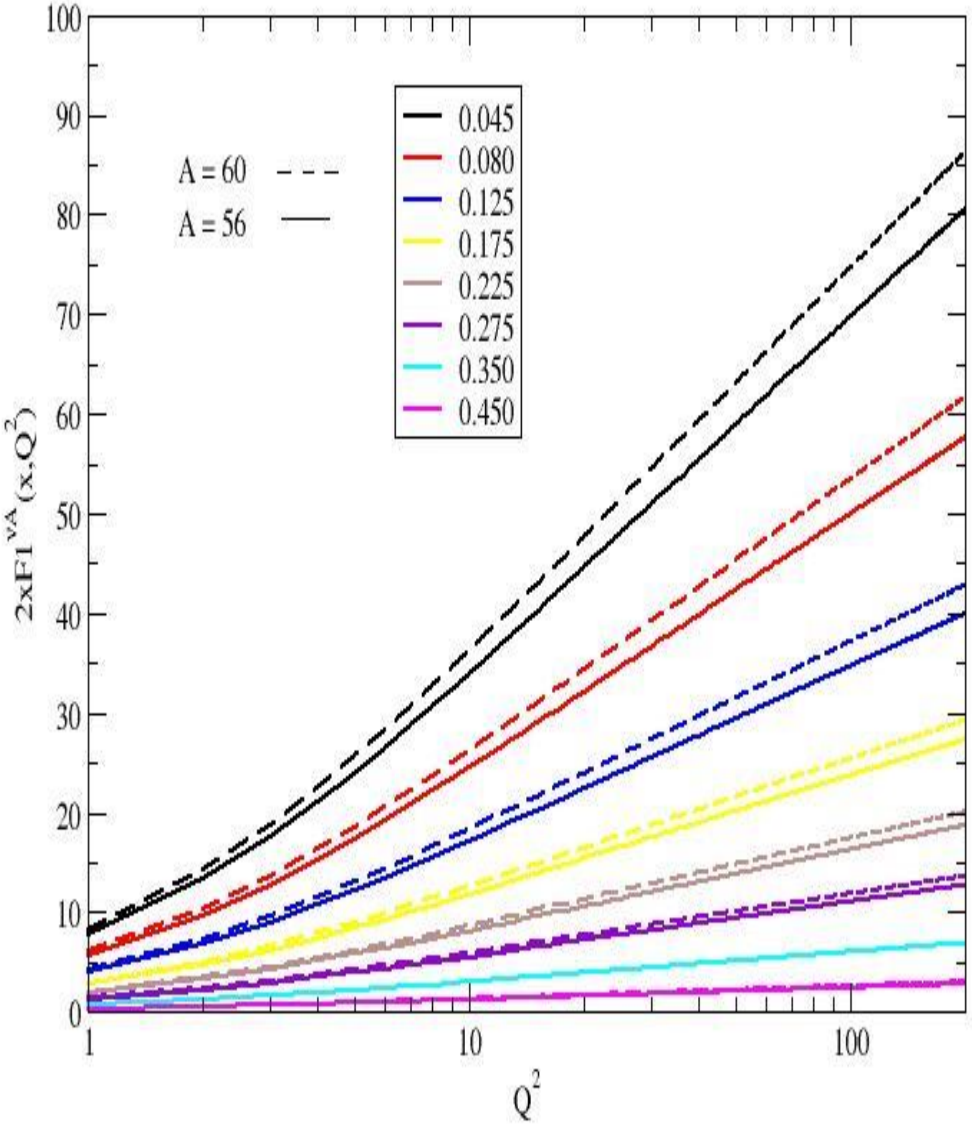
- b is the impact parameter and n(r) is the nuclear matter density normalized as

$$\int d^3r\, n(r) = A$$

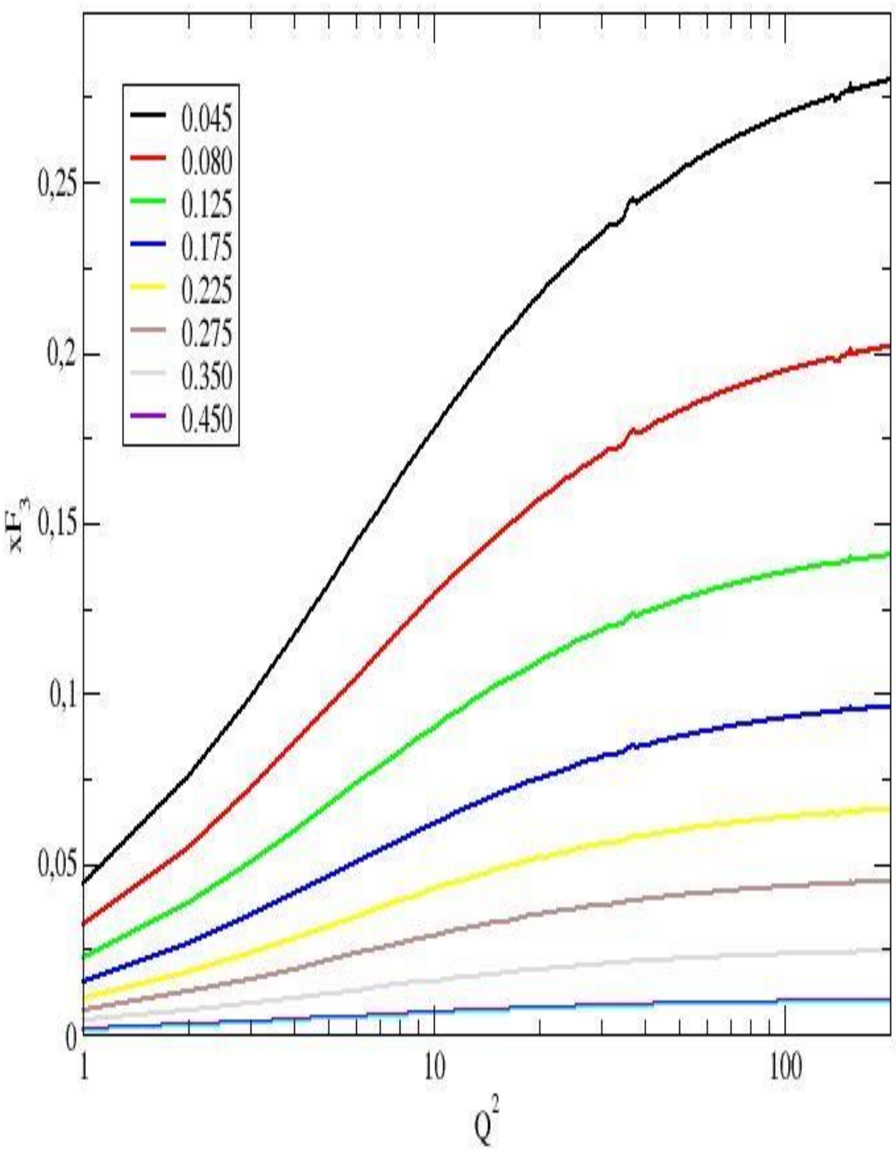
[6] WATT, G. KOWALSKI, H. PRD 78 (2008) 014016

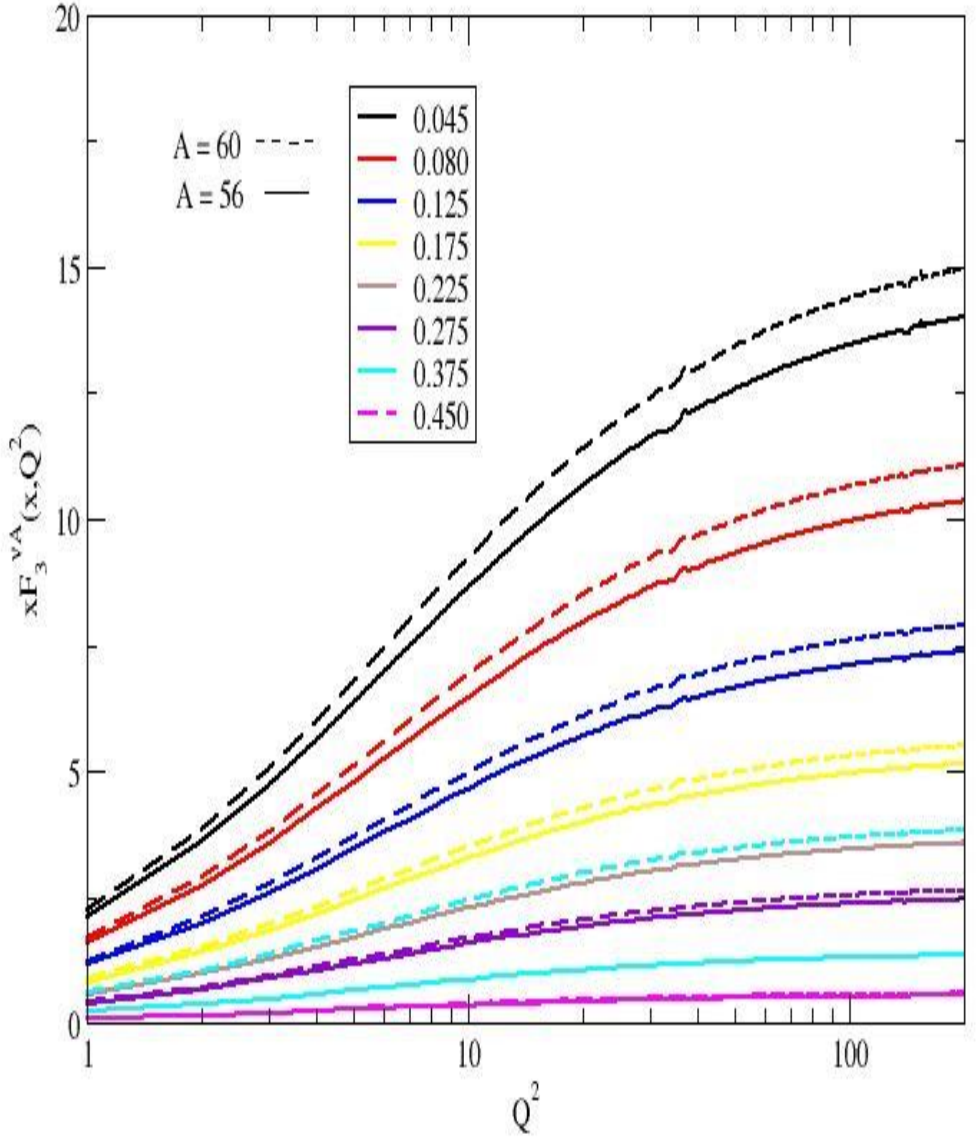
xF_1 Structure functions (x fixed GBW model)



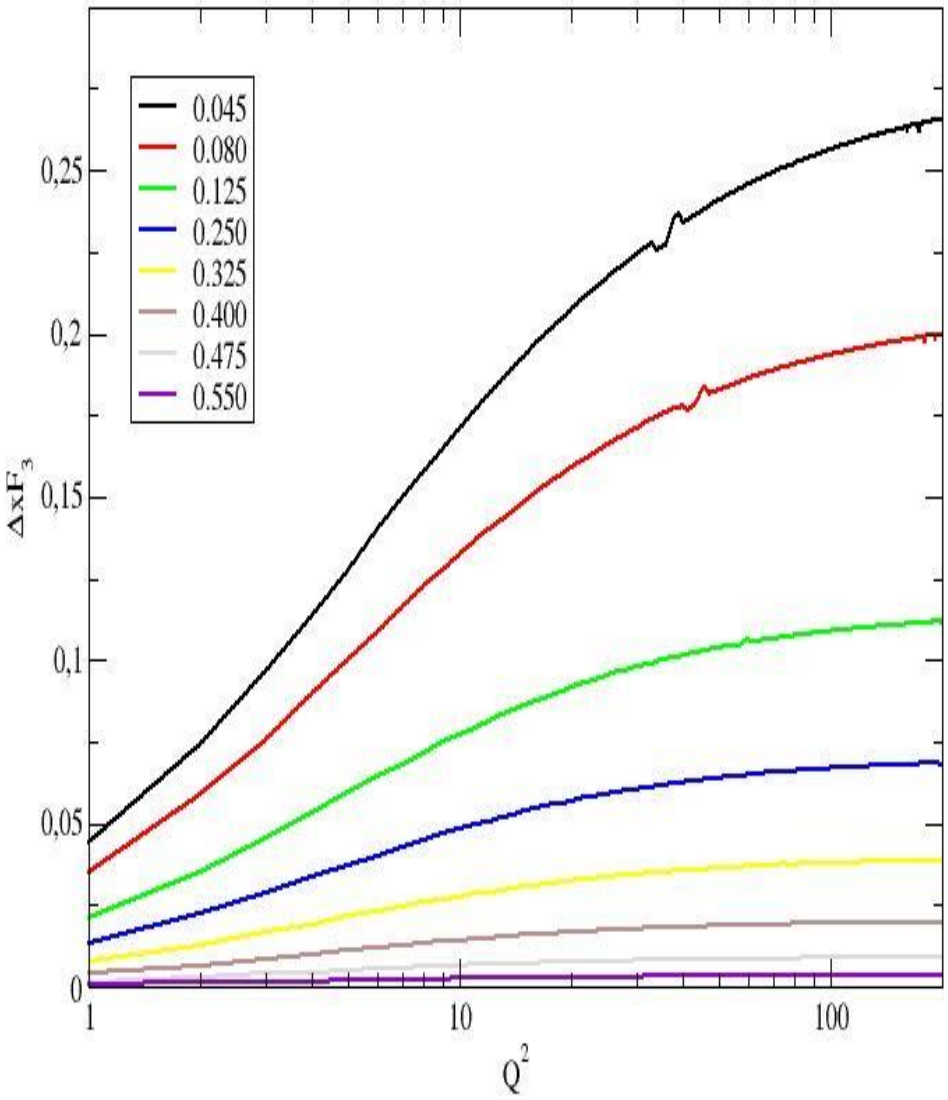


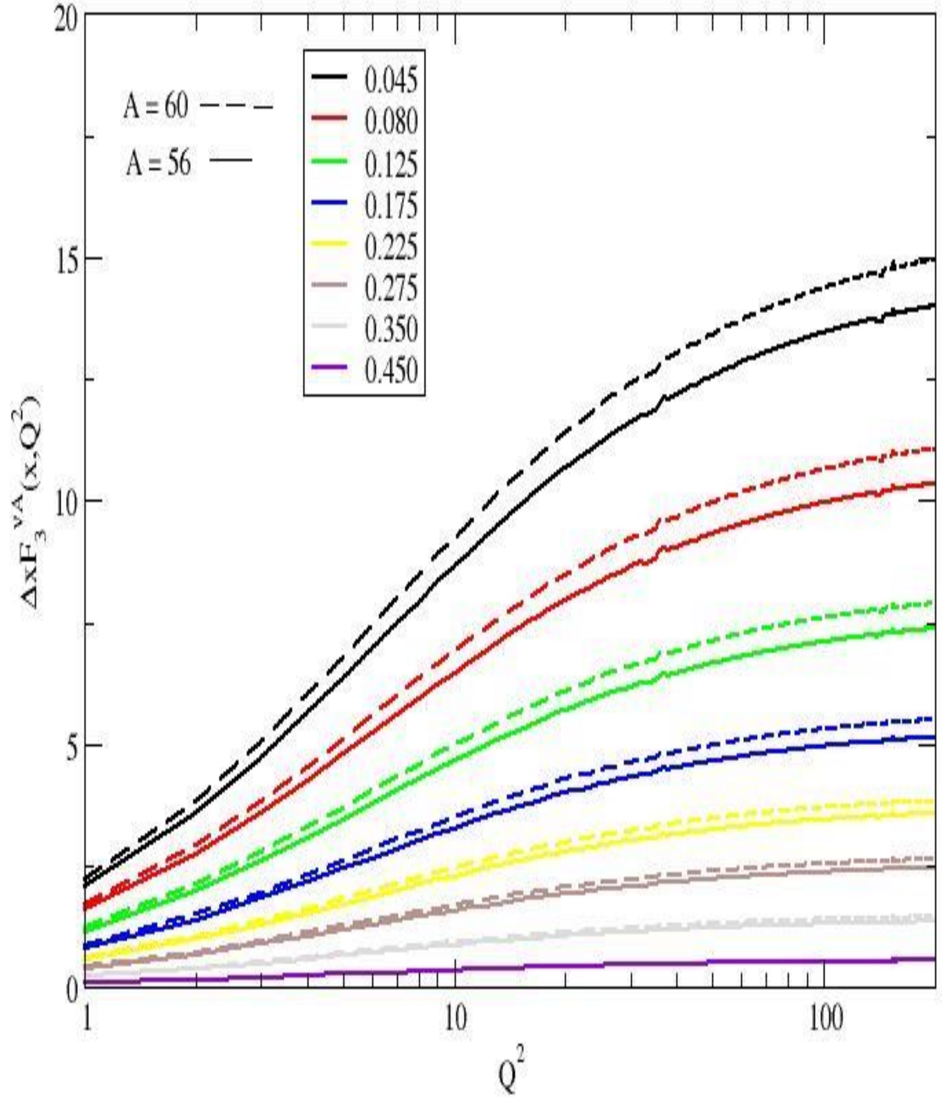
xF_3 Structure functions (x fixed)





ΔxF₃ Structure functions (x fixed)





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Conclusions

- Analysis of small-x neutral current neutrino-nucleus is performed within the color dipole formalism

- Two new experimental with nuclei collisions (MINERvA and NuSOnG)

- Structure functions xF_1, ΔxF_3 and xF_3 are investigated

- Predictions for Iron and Glass nuclei collisions

- Further investigations are requested