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Faculty of Physics

Neutrino production of hadrons at low energy and in the small Q^2 region
(neutrino/anti-neutrino -- CC/NC cross sections)

Paschos & Schalla | 28. November 2011

We compute the matrix elements as follows :

1) for Axial current from PCAC
2) for Vector current from analysis of electroproduction (LP—2005)
3) Interference term from form factors computed from the above

We appreciate informing us of more data to make comparisons :
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Formalism

PRD84(2011)013004
arXiv:1102.4466

PCAC relates Delta production to pion scattering:

$$\epsilon^{\mu}(\lambda=0)\,\langle\Delta^{++}\,|\,\mathcal{A}_{\mu}\,|\,p\rangle \approx -\frac{f_{\pi}\sqrt{2}}{\sqrt{Q^2}}A(\pi^{+}p\rightarrow\Delta^{++})$$

Differential cross section for axial contribution:

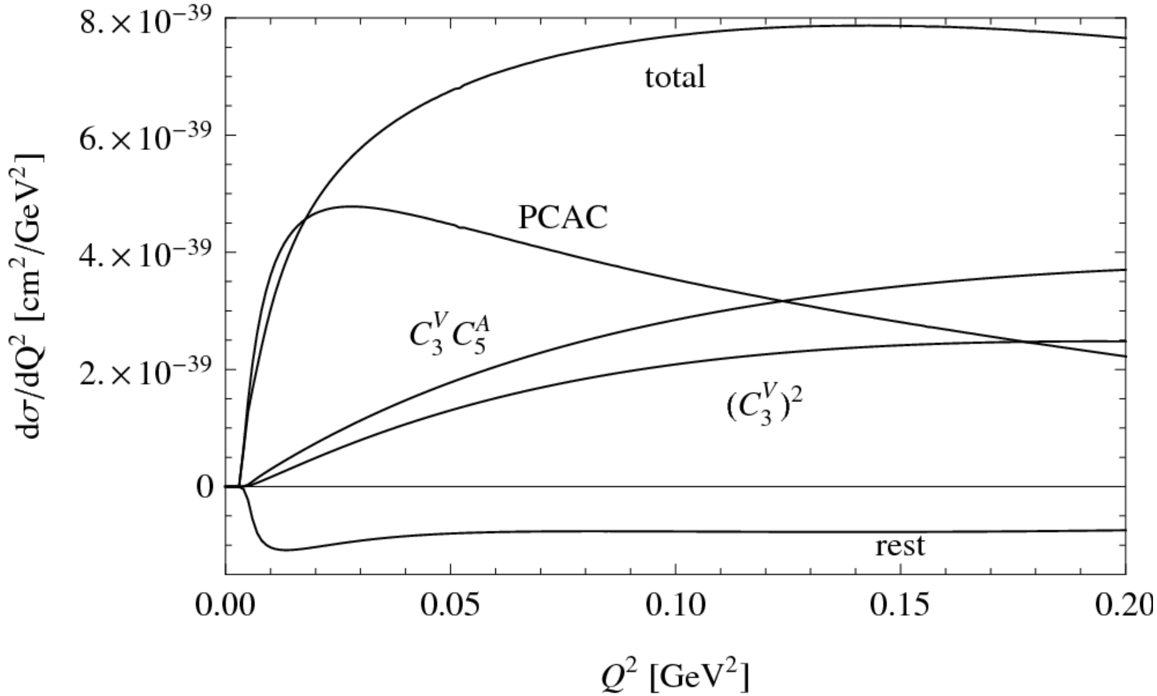
$$\frac{\mathrm{d}\sigma^{A}}{\mathrm{d}Q^{2}\mathrm{d}\nu}=\frac{G_F^2|V_{ud}|^2}{2\pi}\frac{1}{4\pi}\frac{\nu}{E_\nu^2}\frac{f_\pi^2}{Q^2}\tilde{L}_{00}\sigma(\pi^{+}p\rightarrow X^{++})$$

structure function:

$$W_2^A(Q^2,\nu)=\frac{2f_\pi^2}{\pi}\frac{\nu}{Q^2+\nu^2}\sigma(\pi^{+}p\rightarrow X^{++})$$

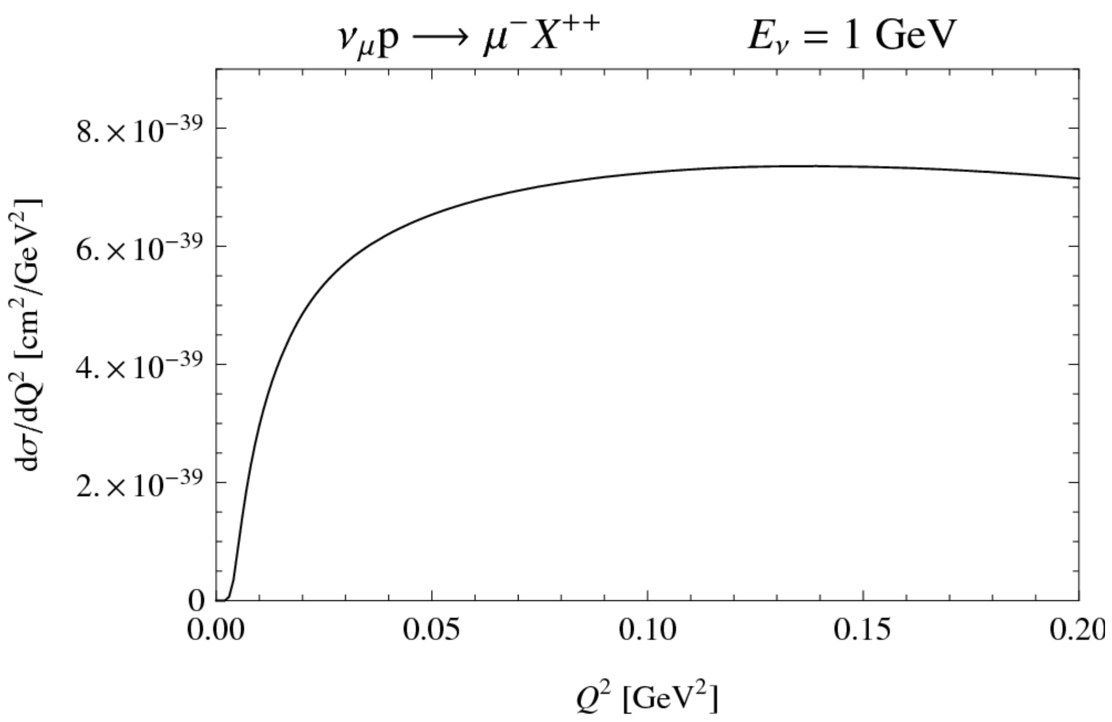
Contributions to the total cross section:

PCAC contribution corresponds to form factor C_5^A
of parametric description Lalakulich/Paschos PRD71(2005)074003 hep-ph/0501109
→ use PCAC for C_5^A and LP for all other contributions



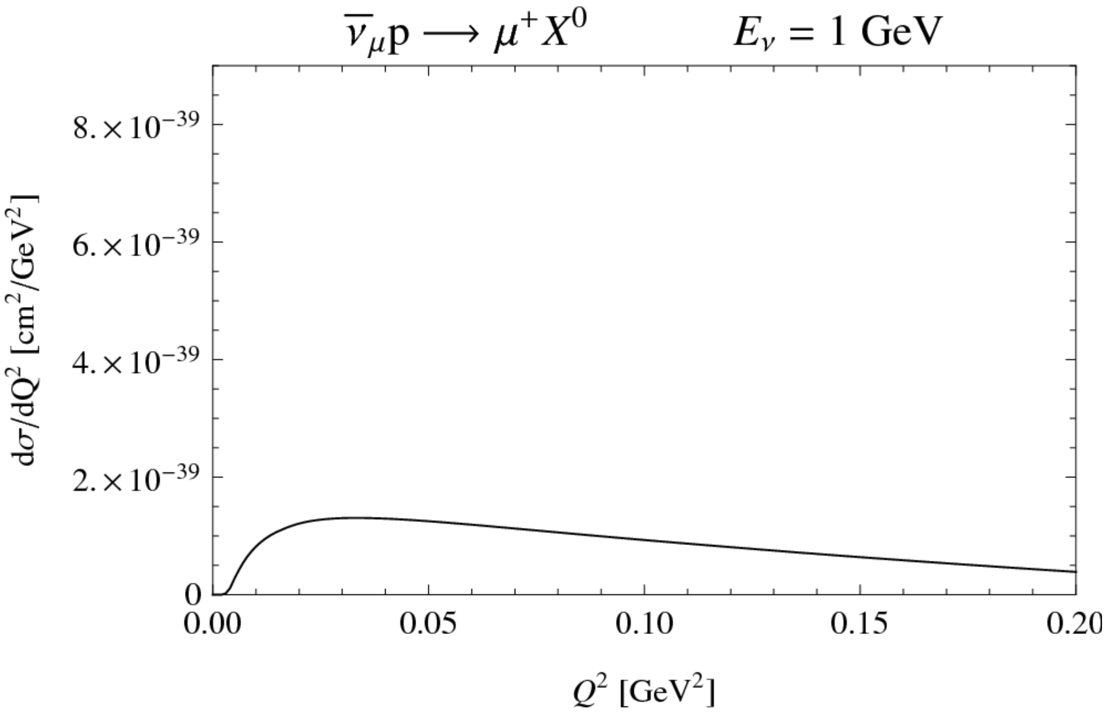
reference amplitude from $\nu p \to \mu^- X^{++}$

$$\langle X^{++} | J^+ | p \rangle = \sqrt{2} a^{3/2} \equiv \text{ref}$$



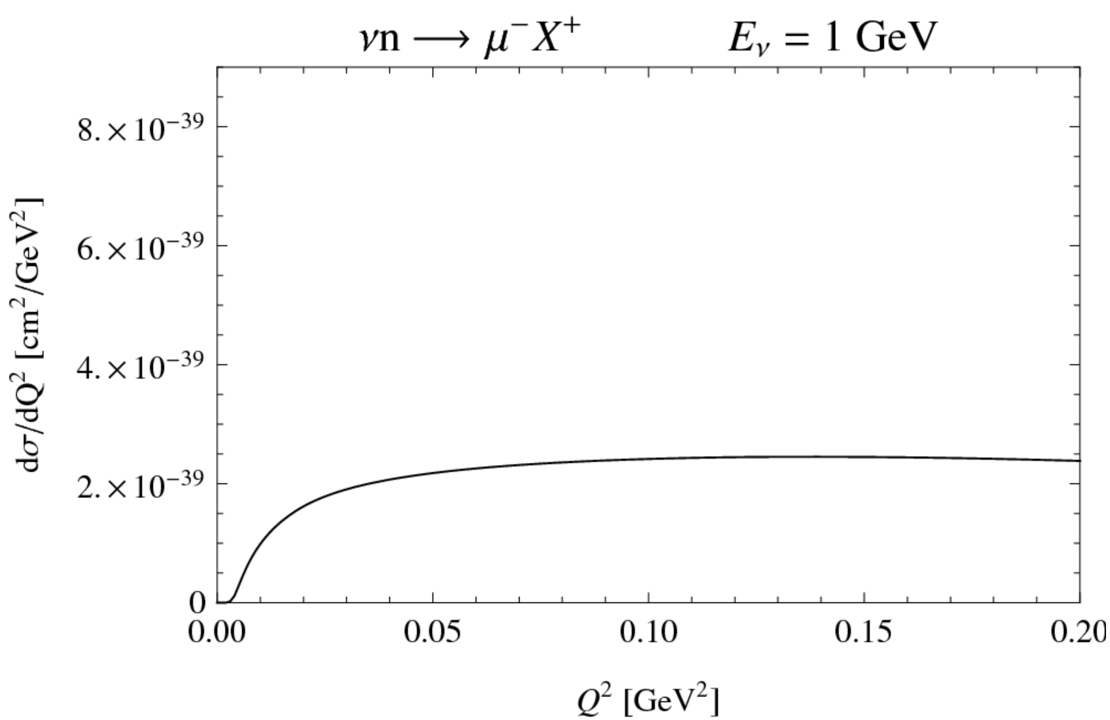
going to anti-neutrinos: $\overline{\nu} p \longrightarrow \mu^+ X^0$

$$\langle X^0 \,|\, J^- \,|\, p \rangle = \sqrt{\frac{2}{3}} a^{3/2} - \frac{2}{\sqrt{3}} a^{1/2} \approx \sqrt{\frac{1}{3}} \text{ref}$$ and $W_3 \longrightarrow -W_3$



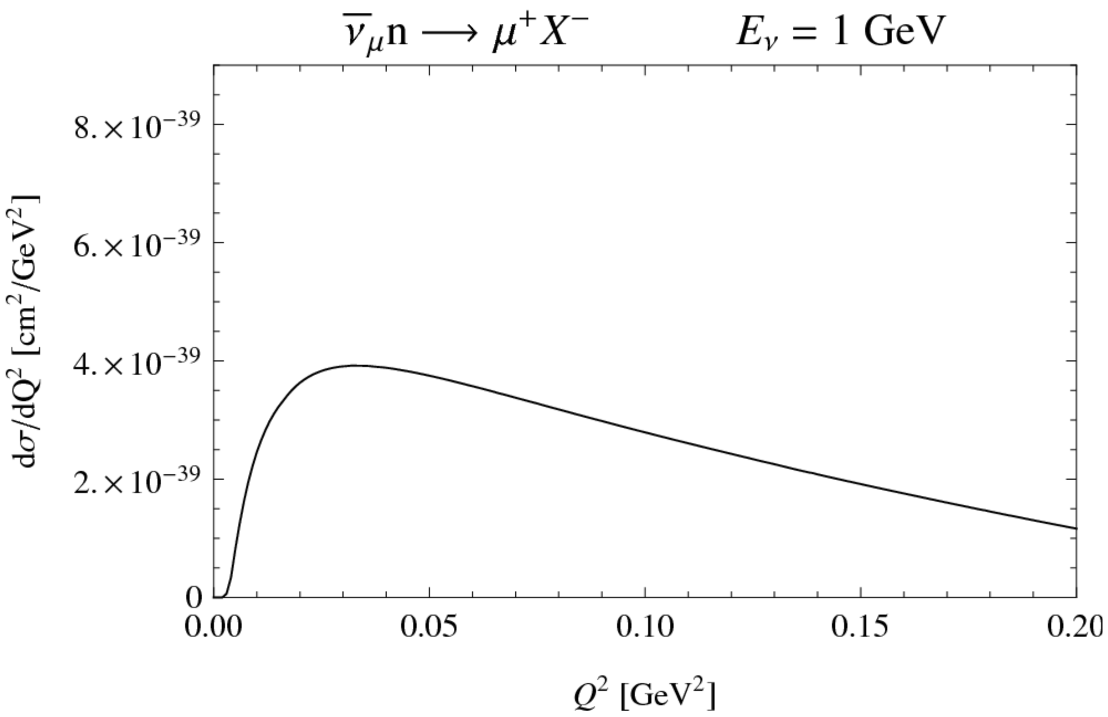
going to neutron targets: $\nu n \rightarrow \mu^- X^+$

$$\langle X^+ \,|\, J^+ \,|\, n \rangle = \sqrt{\frac{2}{3}} a^{3/2} + \frac{2}{\sqrt{3}} a^{1/2} \approx \frac{1}{\sqrt{3}} \text{ref}$$



going to neutron targets and anti-neutrinos: $\overline{\nu} n \rightarrow \mu^+ X^-$

$\langle X^- | J^- | n \rangle = \sqrt{2} a^{3/2} = \text{ref}$ and $W_3 \rightarrow -W_3$



Complex nuclei and nuclear corrections:

initial state pions:

$$\nu p \to \mu^- X^{++} \to \mu^- p \pi^+$$ CGC = 1

$$\nu n \to \mu^- X^{+} \to \mu^- p \pi^0$$ CGC = $\sqrt{2/3}$

$$\to \mu^- n \pi^+$$ CGC = $\sqrt{1/3}$

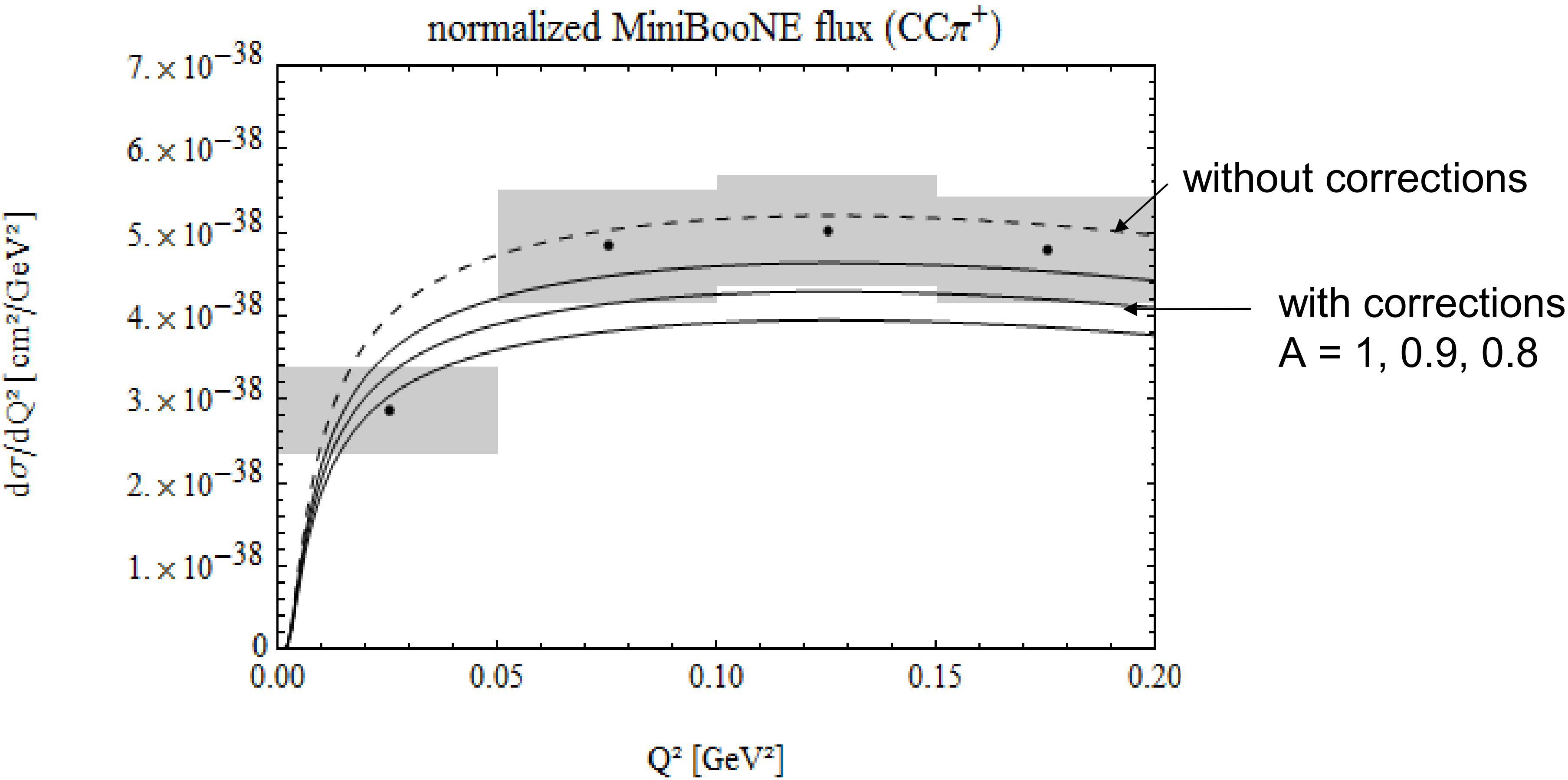
Nuclear corrections:

$$\begin{pmatrix} \pi_f^+ \\ \pi_f^0 \\ \pi_f^- \end{pmatrix} = \mathcal{M}({}^{12}_{6}C) \begin{pmatrix} \pi_i^+ \\ \pi_i^0 \\ \pi_i^- \end{pmatrix} = A \cdot \begin{pmatrix} 0.83 & 0.14 & 0.04 \\ 0.14 & 0.73 & 0.14 \\ 0.04 & 0.14 & 0.83 \end{pmatrix} \begin{pmatrix} \pi_i^+ \\ \pi_i^0 \\ \pi_i^- \end{pmatrix}$$

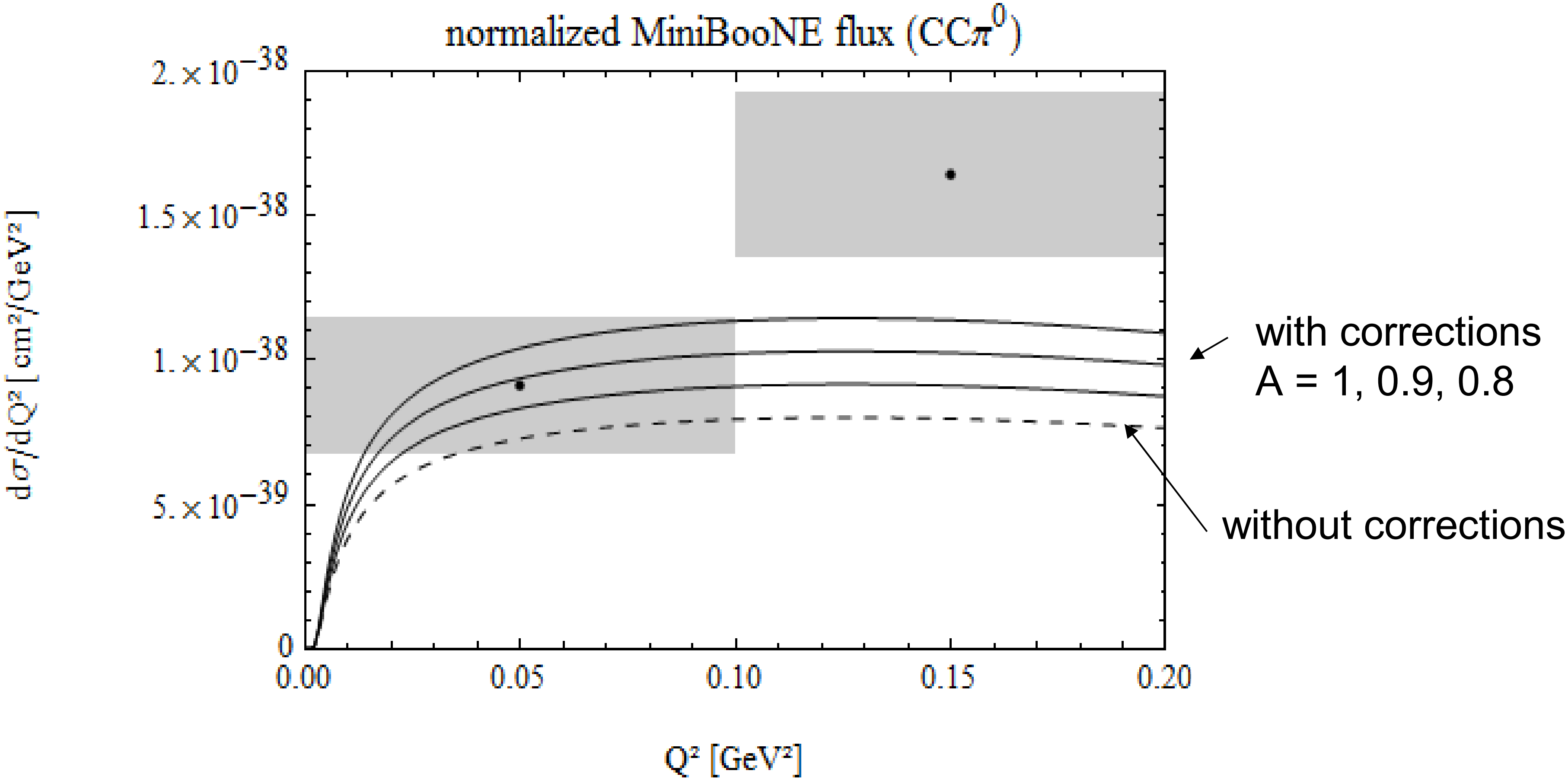
absorption (↑ A)

$$\pi_f^+(CH_2) = \pi_f^+(C_6^{12}) + 2 \cdot \pi_f^+(p)$$

MiniBooNE $CC\pi^+$ production:



MiniBooNE $CC\pi^0$ production:

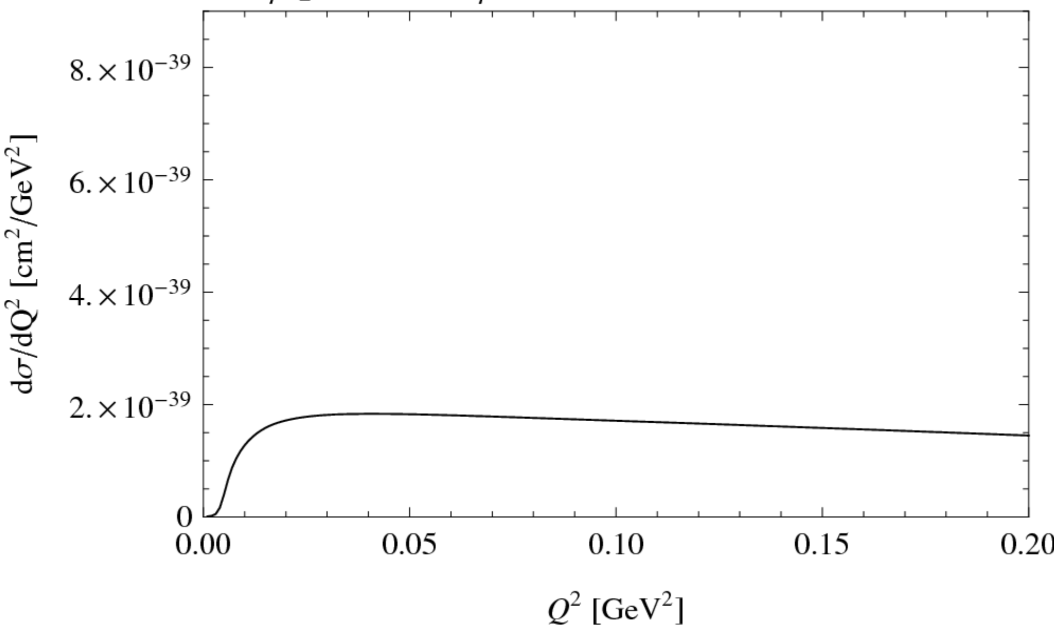


neutral current reaction: $\nu p(n) \rightarrow \nu X^+(X^0)$

$$\langle X^+ \,|\, J^{NC} \,|\, p\rangle = x\,\langle X^+ \,|\, V^3 \,|\, p\rangle + y\,\langle X^+ \,|\, A^3 \,|\, p\rangle + \gamma\,\langle X^+ \,|\, V^0 \,|\, p\rangle$$

e.g. $$\langle X^+ \,|\, V^3 \,|\, p\rangle = \sqrt{\frac{2}{3}}a^{3/2} - \sqrt{\frac{1}{3}}a^{1/2} \approx \frac{1}{\sqrt{3}}\text{ref}$$

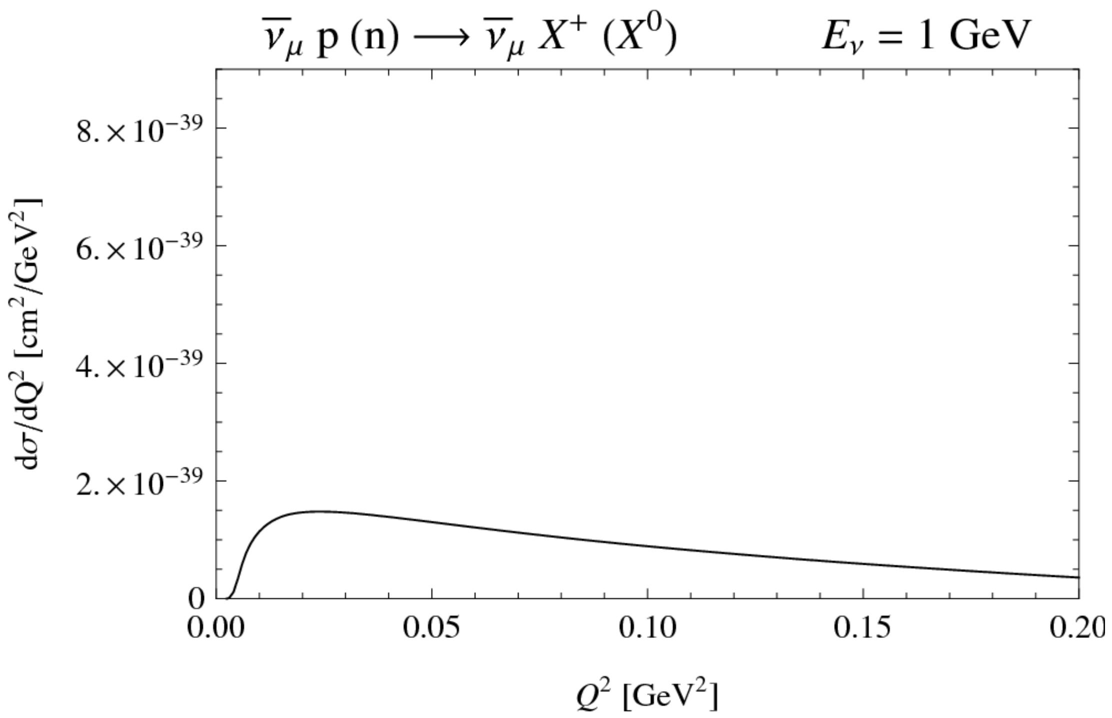
ν_μ p (n) $\longrightarrow \nu_\mu X^+ (X^0)$ $\quad E_\nu = 1$ GeV



$$x = 1 - 2\sin^2\theta_W$$
$$y = -1$$
$$\gamma = -2/3\sin^2\theta_W$$

neutral current reaction: $\overline{\nu}p(n) \to \overline{\nu}X^+(X^0)$

$\nu p(n) \to \nu X^+(X^0)$ with $W_3 \to -W_3$



Conclusions

For small Q^2 the cross sections for all the reactions are predicted.
Using inputs from the reaction

$$\nu_\mu + p \rightarrow \mu^- \Delta^{++}$$

We can predict the additional reactions by using

1) isospin relations
2) the relative magnitudes if axial, vector and interference terms
3) comparisons with MiniBooNE are good
4) I = ½ contributions seem to be small
5) Nuclear corrections a la ANP seem to work
6) we will try to exrend them to larger values of Q^2 using form factors.