Electromagnetic Structure Functions and Neutrino Nucleon Scattering

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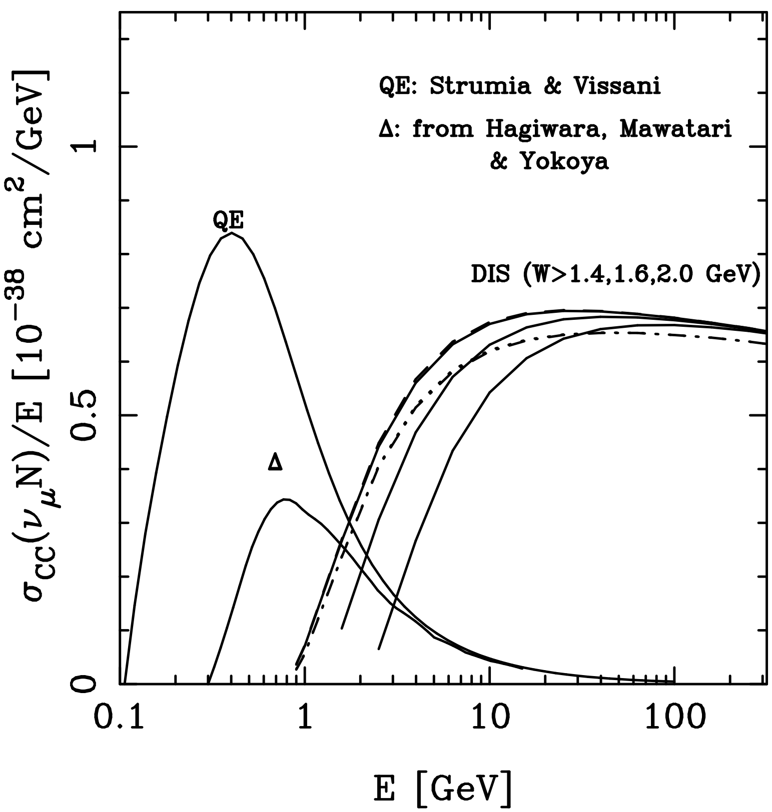
Introduction

- It has been know for a long time that in the few GeV energy region, the quasi-elastic, few pion and inclusive contributions to the cross section are nearly equal. Lipari, Lusignoli and Sartogo, 1995



- All components important to understand neutrino oscillation experiments, the balance of which depends on e.g., the minimum invariant mass of the final hadronic state, $W^2_{\rm min}$. Recent work by Kuzmin, Lyubushkin, Naumov, hep-ph/0511308 attempts to find the $W_{\rm min}$ so that the components best represent current neutrino measurements.

- The inelastic component is not currently well calculated in this energy regime because of the necessity of low-Q^2 structure functions.

- This talk is about extrapolations to low-Q^2 of structure functions for $W^2 > W^2_{\rm min}$ in the inelastic component of $\sigma(\nu N)$.

- I'll assume local quark-hadron duality – here meaning that the structure function are averages over the remaining resonances.

- Target mass corrections: work with Stefan Kretzer, Phys. Rev. D66,D69.

Plan

- Brief review neutrino scattering in NLO QCD with target mass corrections (TMC) and the importance of the low-Q^2 contribution to the cross section.

- Comparison of NLO+TMC with a parameterization of F_2^{ep}. (NLO+TMC overestimates F_2 at low Q^2.)

- The Capella, Kaidalov, Merino and Thanh Van (CKMT) parameterization of F_2^{ep} and the already well studied Bodek-Yang-Park parameterization PRL 82 (1999), hep-ex/0308007, Nucl. Phys. Proc. Suppl. 139 (2005). See also Kulagin and Petti, Nucl. Phys. A 765 (2006).

- The translation to νN scattering.

Mass Corrections

Differential cross section (charged current) M=nucleon mass:

$$\begin{aligned}\frac{d\sigma}{dx\,dy} &= \frac{G_F^2 ME}{\pi(1+Q^2/M_W^2)^2}\Bigg[xy^2F_1^{TMC}(x,Q^2,M^2)\\ &+ \left(1-y-\frac{Mxy}{2E}\right)F_2^{TMC}(x,Q^2,M^2)\\ &+ \left(xy-\frac{xy^2}{2}\right)F_3^{TMC}(x,Q^2,M^2)\Bigg]\end{aligned}$$

TMC

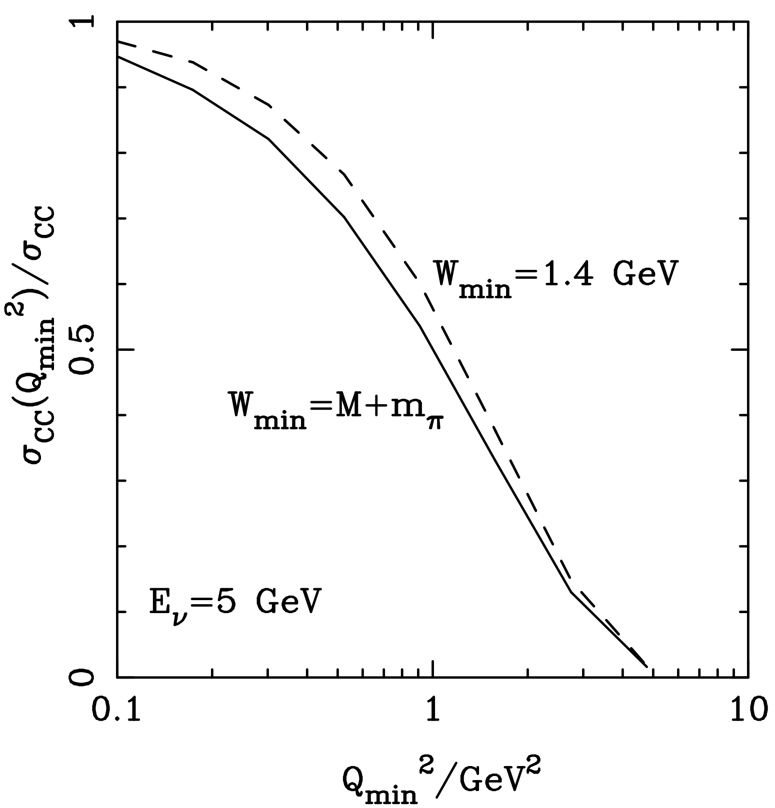
TMC corrections come from:

- $x \to \xi$ in PDFs with

$$\frac{1}{\xi} = \frac{1}{2x} + \sqrt{\frac{1}{4x^2} + \frac{M^2}{Q^2}} \iff \xi = \frac{2x}{1 + \sqrt{1 + \frac{4M^2x^2}{Q^2}}}$$

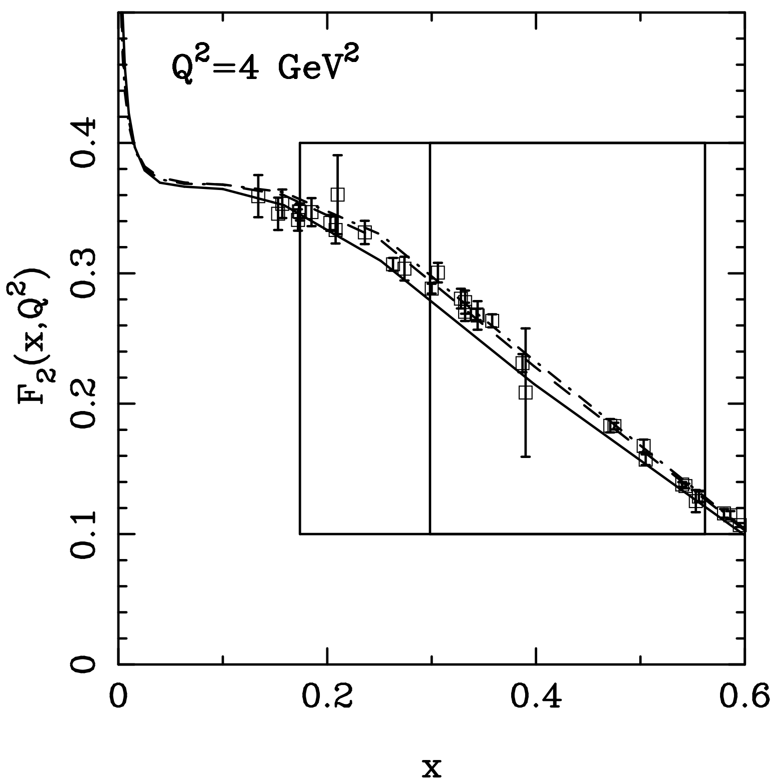
- A "mismatch" between quark momentum p and nucleon momentum P: proton momentum $P^2 = M^2$ and incident parton momentum $p^2 = 0$, then $p^+ = \xi P^+$, but $p^- \neq \xi P^-$.
- Including non-collinear partons in the nucleon, with $k_T < M$. R.K. Ellis et al.

DIS CC cross sections



- Neutrino-nucleon CC cross section for $Q^2 > Q^2_{\rm min}$ normalized to the νN cross section.
- Calculated using NLO+TMC.
- Half the cross section comes from $Q^2 < 1$ GeV^2.

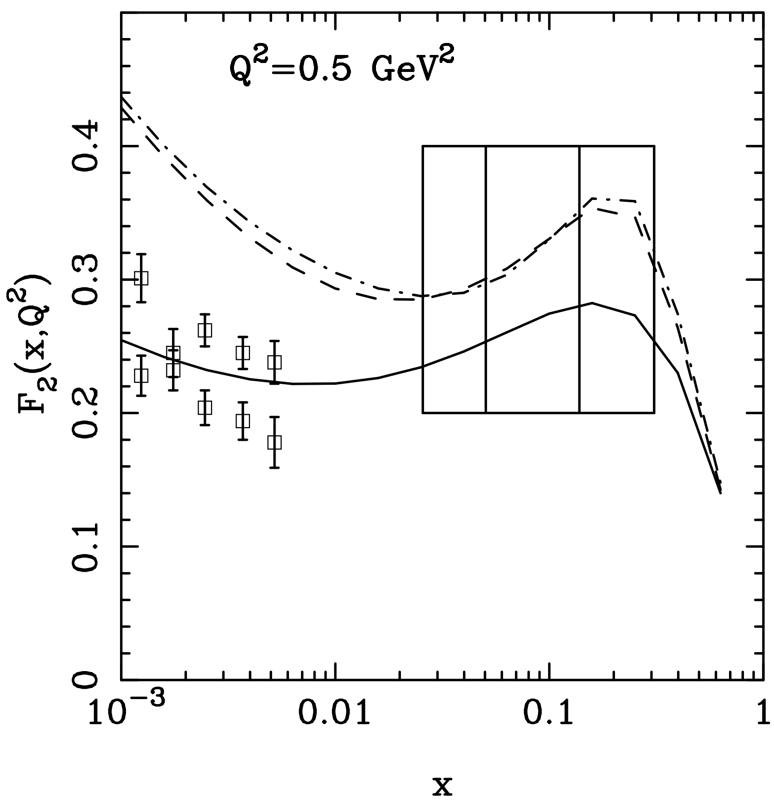
F_2^{ep}, $Q^2 = 4$ GeV^2



Use the Abramowicz, Levin, Levy and Maor (ALLM) parameterization (solid) of F_2 represent ep data. ALLM, Phys. Lett. 1991, AL hep-ph/9712415. This has 23 parameters.

Also shown, NLO+TMC and NNLO+TMC and SLAC data for $Q^2 = 3.7 - 4.3$ GeV^2. L. Whitlow et al., Phys. Lett. B (1990).

$F_2^{ep}, \ Q^2 = 0.5$ **GeV**^{2}



ALLM (solid), data from E665 M. Adams et al., Phys. Rev. D 54 (1996) with $Q^2 = 0.43, \ 0.59$ GeV^2 NLO+TMC, NNLO+TMC.

Capella, Kaidalov, Merino and Thanh Van

CKMT, Phys. Lett. B 337, 358 (1994), Moriond 1994, 7 parameters in

$$
\begin{aligned}
F_2(x,Q^2) &= F_2^{sea}(x,Q^2) + F_2^{val}(x,Q^2) \\
&= Ax^{-\Delta(Q^2)}(1-x)^{n(Q^2)+4}\left(\frac{Q^2}{Q^2+a}\right)^{1+\Delta(Q^2)} \\
&+ Bx^{1-\alpha_R}(1-x)^{n(Q^2)}\left(\frac{Q^2}{Q^2+b}\right)^{\alpha_R} \\
&\times \Big(1+f(1-x)\Big)
\end{aligned}
$$

CKMT Valence in ep scattering

CKMT fit $\alpha_R = 0.4250$ and $b = 0.6452$ GeV^2.

$$F_2^{val}(x, Q^2) = Bx^{1-\alpha_R}(1-x)^{n(Q^2)}\left(\frac{Q^2}{Q^2+b}\right)^{\alpha_R}\Big(1+f(1-x)\Big)$$

$B = B_u$ is calculated to be 1.2064, $f = B_d/B_u = 0.15$ is also calculated. They are calculated invoking valence counting rules at $Q^2 = 2$ GeV^2. Also fit is $c = 3.5489$ GeV^2 in

$$n(Q^2) = \frac{3}{2}\left(1 + \frac{Q^2}{Q^2+c}\right)$$

CKMT "Sea" in ep scattering

CKMT fit $A = 0.1502$ and $a = 0.2631$ GeV^2.

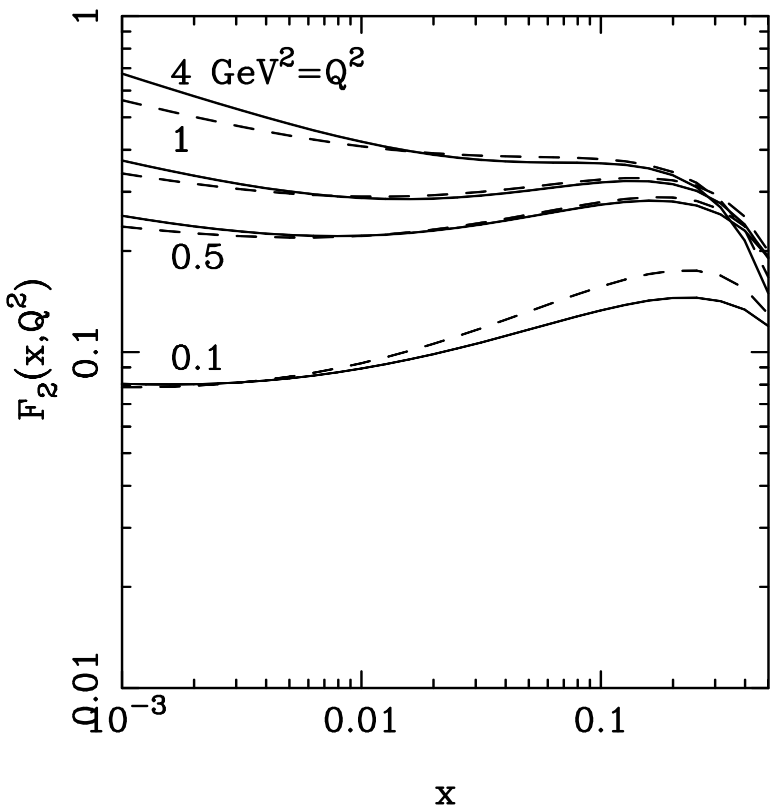
$$F_2^{sea}(x, Q^2) = A x^{-\Delta(Q^2)}(1-x)^{n(Q^2)+4}\left(\frac{Q^2}{Q^2+a}\right)^{1+\Delta(Q^2)}$$

Also fit is $\Delta_0 = 0.07684$ and $d = 1.1170$ GeV^2 in

$$\Delta(Q^2) = \Delta_0\left(1 + \frac{2Q^2}{Q^2+d}\right)$$

Δ_0 is similar to power law in generalized vector meson dominance at low Q^2, where it is pomeron dominated.

Comparison: ALLM and CKMT in ep scattering



ALLM (solid), and CKMT (dashed).

CKMT in νN scattering

See CKMT Moriond Proceedings.

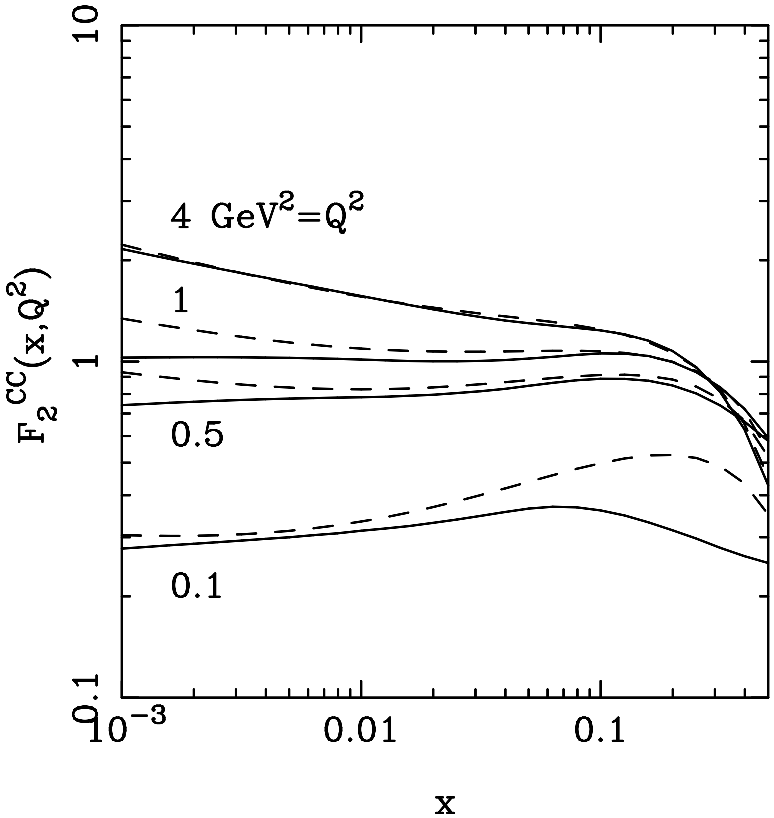
- F_2^{sea} changes only overall normalization: $A \to A_\nu = 0.60$, which I fixed at $Q^2 = 10$ GeV^2 to match reasonably well with the NLO+TMC evaluation.

- For the valence part, recalculate B and f at $Q^2 = 2$ GeV^2. I get

$$B_\nu = 2.695 \qquad f_\nu = 0.595$$

- For F_1, use a parameterization of R (Whitlow et al., Phys. Lett. 1990) to convert F_2. Modify F_2 form to fit F_3 (overall normalization, change A).

Comparison: BYP and CKMT in νN scattering

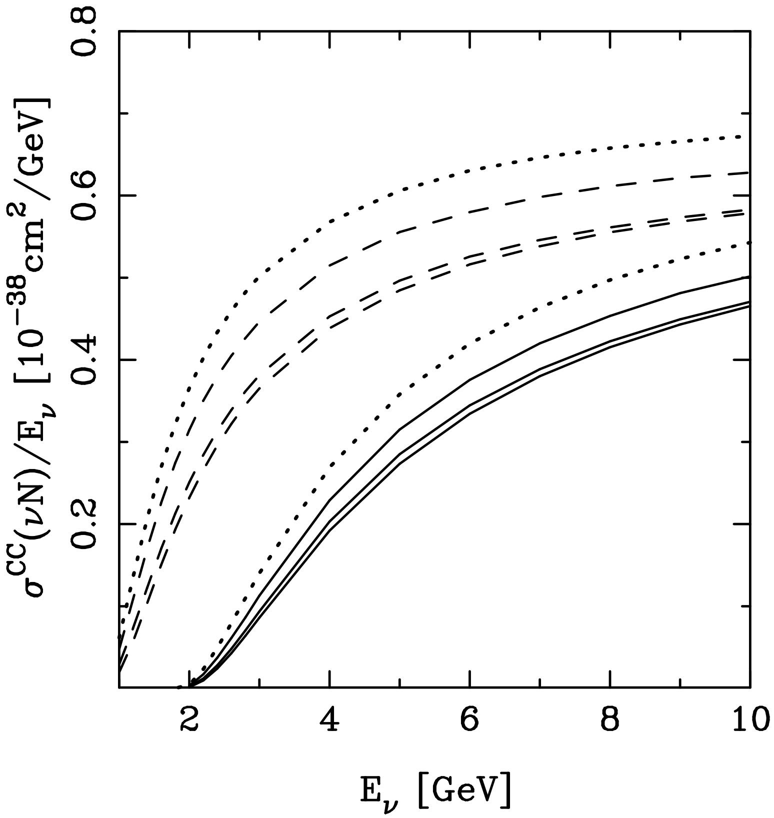


Bodek-Yang-Park (BYP) (solid) extraction of the flavor components of "effective PDFs", and CKMT (dashed).

Strategy for cross sections

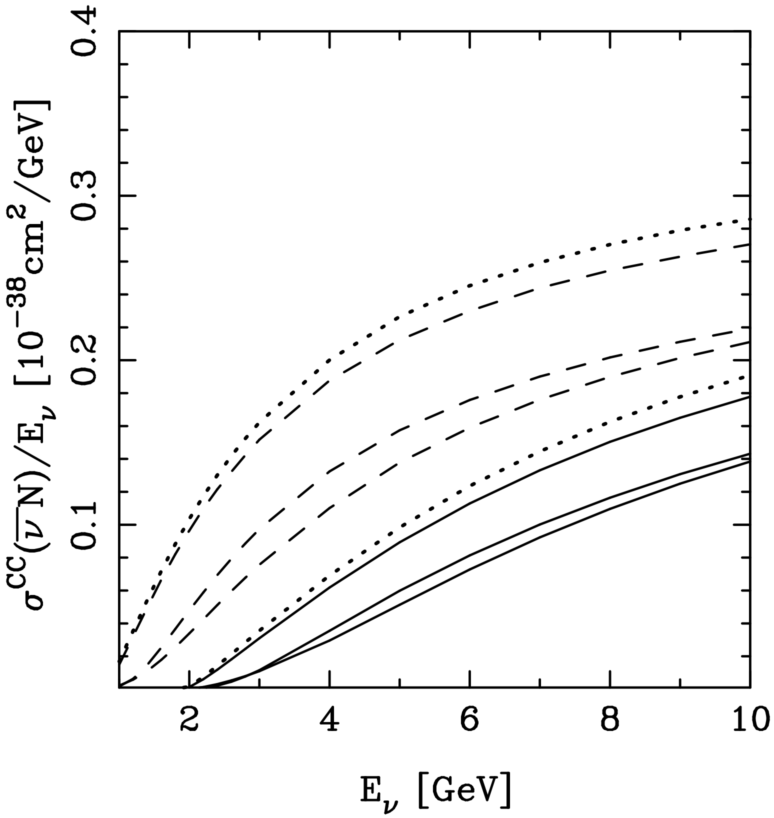
- Use NLO+TMC in for $Q^2 > Q_0^2$. Attach a parameterization for $Q^2 < Q_0^2$.
- Results shown for $Q_0^2 = 4$ GeV^2, not very sensitive to this specific choice.

νN CC cross section



- Solid lines, $W^2_{\rm min} = 4$ GeV^2, dashed lines for $W^2_{\rm min} = 2$ GeV^2.
- Upper solid and dashed are NLO+TMC, lower two are CKMT and BYP extrapolations below Q_0^2.
- Dotted lines show LO+TMC.

$\bar{\nu}N$ CC cross section



- Solid lines, $W^2_{\rm min} = 4$ GeV^2, dashed lines for $W^2_{\rm min} = 2$ GeV^2.
- Upper solid and dashed are NLO+TMC, lower two are CKMT and BYP extrapolations below Q_0^2.
- Dotted lines show LO+TMC.

Summary

- The CKMT and BYP extrapolations yield similar results on the cross sections. CKMT is slightly larger. Gives support to BYP results for $\sigma(\nu N)$.

- The neutrino cross section is reduced by 7-8% for $W^2_{\rm min} = 2$ GeV^2 at 10 GeV, 11-13% at 5 GeV, relative to the NLO+TMC result.

- Antineutrino scattering is impacted more, with changes of order 20% at 10 GeV. (Lower Q^2 emphasized because of $(1-y)^2$ factor with valence PDFs.)

- CKMT parameterization has a simple interpretation. One can rescale the standard sea and valence PDFs by the same Q^2 dependent factors in the CKMT parameterization and get essentially the same results.