Full of charm neutrino DIS

small-x and non-conservation of weak currents

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weak currents are not conserved.

In what way they are not conserved?
Gell-Mann,Levy and Nambu - PCAC:

$$\partial_\mu A_\mu = m_\pi^2 f_\pi \varphi$$

$$A_\mu = \bar{u}\gamma_\mu\gamma_5 d$$

Adler converted PCAC into observables

$$F_L^{ud}(x, Q^2 \to 0) = \frac{f_\pi^2}{\pi}\sigma_\pi(\nu)$$

$$x = \frac{Q^2 + M^2}{2m_N\nu}$$

to test PCAC

measure

$$F_2(x,Q^2) = F_L(x,Q^2) + F_T(x,Q^2)$$

extrapolate $F_2(x,Q^2)$ down to $Q^2 = 0$ and make use of

$$F_T(x,Q^2 \to 0) \to 0$$

then compare $F_L(x,Q^2 = 0)$ with $f_\pi^2 \sigma_\pi / \pi$

Assumption: the excitation of charm is irrelevant

our findings

abundant production of charm and strangeness by longitudinally polarized EW bosons already at $x < 0.01$ and for $Q^2 \lesssim m_c^2$.

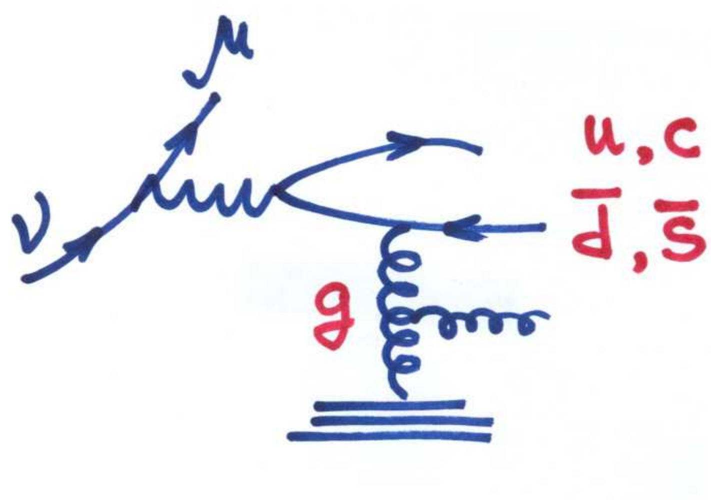
The longitudinal structure function

$$F_L = F_L^{ud} + F_L^{cs}$$

is dominated by its charmed-strange component, F_L^{cs}.

At $Q^2 = 0$ (Adler's kinematics) F_L^{cs} rises with $1/x$ much faster than F_L^{ud}

'small-x' means



- predominance of the t-channel gluon exchange
- weakening of the mass threshold effect

$$x = \frac{Q^2 + M^2}{2m_N\nu} \ll 1$$

$$M^2 \sim (m_c + m_s)^2$$

two fundamental reasons

for the $c\bar{s}$ excitation to prevail over $u\bar{d}$

1. non-conservation of the axial current

$$\partial_\mu A_\mu \propto m_c + m_s$$

2. non-conservation of the flavor changing vector current

$$\partial_\mu V_\mu \propto m_c - m_s$$

$$m_c \gg m_s$$

Very Important Paper: V. Barone, M. Genovese, N. Nikolaev, E. Predazzi and B. Zakharov, hep-ph/9403236, *Phys.Lett.* **B328** (1994) 143

one more reason

(much less fundamental) is pQCD
DGLAP ordering of $c\bar{s}$ dipole sizes

$$m_c^{-2} < r^2 < m_s^{-2}$$

and the multiplication of $\log$'s like

$$\alpha_S \log\left(\frac{m_c^2}{m_s^2}\right) \log\left(\frac{1}{x}\right)$$

to higher orders of perturbative QCD

color dipole factorization. BFKL

F_L through the absorption cross section $\sigma_L(x, Q^2)$:

$$F_L(x, Q^2) = \frac{Q^2}{4\pi^2 \alpha_W} \sigma_L(x, Q^2)$$

factorization:

$$\sigma_L(x, Q^2) = \int dz d^2\mathbf{r} |\Psi_L(z, \mathbf{r})|^2 \sigma(x, r)$$

$|\Psi_L(z, \mathbf{r})|^2$ - light-cone density of $c\bar{s}$ states
$\sigma(x, r)$ - color dipole cross section
$\mathbf{r}$ - $c\bar{s}$-dipole size
z - Sudakov's variable of c-quark

light-cone density of $c\bar{s}$ states

$$|\Psi_L(z,\mathbf{r})|^2 = |V_L(z,\mathbf{r})|^2 + |A_L(z,\mathbf{r})|^2$$

At $Q^2 \gg m_c^2$ the S-wave $c\bar{s}$ state dominates

$$|A_L(z,\mathbf{r})|^2 \propto Q^2 z^2 (1-z)^2 K_0^2(\varepsilon r)$$

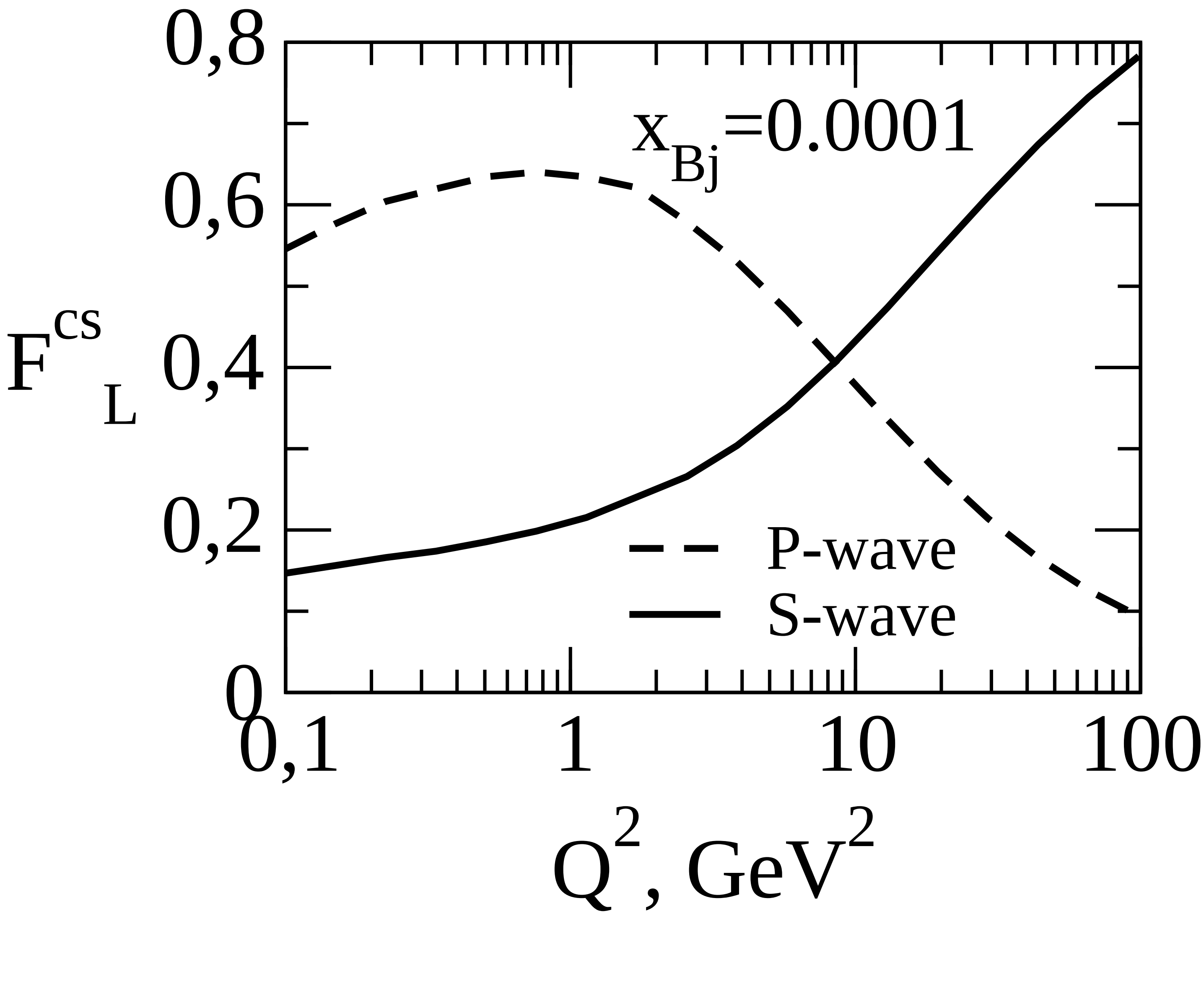
$\varepsilon^2 = z(1-z)Q^2 + (1-z)m_c^2 + zm_s^2$ - the attenuation parameter

At $Q^2 \lesssim m_c^2$ the P-wave component takes over

$$|A_L(z,\mathbf{r})|^2 \propto \frac{(m_c+m_s)^2}{Q^2}\varepsilon^2 K_1^2(\varepsilon r)$$

The P-wave $c\bar{s}$-state arises only due to the weak current non-conservation

P-wave, S-wave



qualitative estimates: high Q^2

color dipole factorization again:

$$F_L(x, Q^2) = \frac{Q^2}{4\pi^2 \alpha_W} \int dz d^2\mathbf{r} |\Psi_L(z, \mathbf{r})|^2 \sigma(x, r)$$

for small dipoles (Nikolaev & Zakharov):

$$\sigma(x, r) \approx \frac{\pi^2 r^2}{N_c} \alpha_S(r^2) G(x, A/r^2)$$

for large dipoles:

$$|\Psi_L(z, \mathbf{r})|^2 \propto Q^2 z^2 (1-z)^2 \exp[-2\varepsilon r]$$

integrating over $\mathbf{r}$ yields a broad symmetric z-distribution

$$F_L^{cs} \sim Q^4 \int_0^1 dz \frac{z^2(1-z)^2}{\varepsilon^4} \alpha_S(\varepsilon^2) G(x, A\varepsilon^2)$$

dominated by the “non-partonic” $z \sim 1/2$. That leads to

$$F_L^{cs} \sim \alpha_S(Q^2) G(x, Q^2)$$

μDIS - Dokshitzer
νDIS - Barone, Genovese, Nikolaev, Predazzi and Zakharov

At high Q^2 the S-wave component of $|\Psi_L|^2$ dominates F_L

z-distribution at $Q^2 \lesssim m_c^2$

becomes highly asymmetric, with the “parton model peak” at $z \to 1$ (the P-wave dominance),

$$\frac{dF_L^{cs}}{dz} \sim \frac{1}{1+\delta-z},$$

where

$$\delta = \frac{m_s^2}{m_c^2+Q^2}.$$

survives the limit $Q^2 \to 0$.

relevant dipole sizes

integrate first over z

$$F_L^{cs} \sim m_c^2 \int_0^1 dz \int_0^{1/\varepsilon^2} \frac{dr^2}{r^2} \sigma(r)$$

$$\sim \frac{m_c^2}{m_c^2 + Q^2} \int_{1/(m_c^2+Q^2)}^{1/m_s^2} \frac{dr^2}{r^4} \sigma(r)$$

$$\sim \frac{m_c^2}{m_c^2 + Q^2} \int_{1/(m_c^2+Q^2)}^{1/m_s^2} \frac{dr^2}{r^2} \alpha_S(r^2) G(x, A/r^2)$$

the DLLA ordering of sizes:

$$m_s^{-2} < r^2 < (m_c^2 + Q^2)^{-1}$$

Born approximation

The $c\bar{s}$ Fock state of the light-cone W-boson interacts with the target via the two-gluon exchange (not unreasonable phenomenologically at moderate Q^2 and $x \sim 0.01$)

$$F_L^{cs} \sim \frac{N_c C_F}{8} \frac{m_c^2}{m_c^2 + Q^2} \frac{1}{2!} L^2$$

where

$$L = \frac{\alpha_S}{\pi} \log \left(\frac{m_c^2 + Q^2}{m_s^2} \right)$$

the DLLA ordering of sizes:

$$m_s^{-2} < r^2 < (m_c^2 + Q^2)^{-1}$$

the rise of F_L^{cs} to smaller x

is generated by interactions of the higher Fock states $c\bar{s} + gluons$. Leading term $c\bar{s} + one\ gluon$:

$$\Delta F_L^{cs} \sim \frac{N_c C_F C_A}{8} \frac{m_c^2}{m_c^2 + Q^2} \log\left(\frac{x_0}{x}\right) \frac{1}{3!} L^3$$

with $C_A \log(x_0/x) L$ as the DLLA expansion parameter. The slope parameter

$$\Delta = \frac{1}{3} C_A L$$

is rather large. Even at $Q^2 = 0$ and for moderate x, $\Delta \simeq 0.4$. $F_L^{cs}(x, Q^2)$ rises rapidly towards still smaller x.

one can think of the DGLAP growth of the gluon density

$$G \propto \exp(2\sqrt{\xi})$$

with

$$\xi = \frac{4C_A}{\beta_0} \log\left(\frac{\alpha_S(m_s^2)}{\alpha_S(m_c^2 + Q^2)}\right) \log\left(\frac{1}{x}\right)$$

which is tamed, however, by the P-wave factor

$$\frac{m_c^2}{m_c^2 + Q^2}$$

in F_L^{cs}

Adler's theorem

allows only a slow rise of

$$F_L^{ud}(x,0) = \frac{f_\pi^2}{\pi}\sigma_\pi(\nu)$$

with $\nu \propto x^{-1}$,

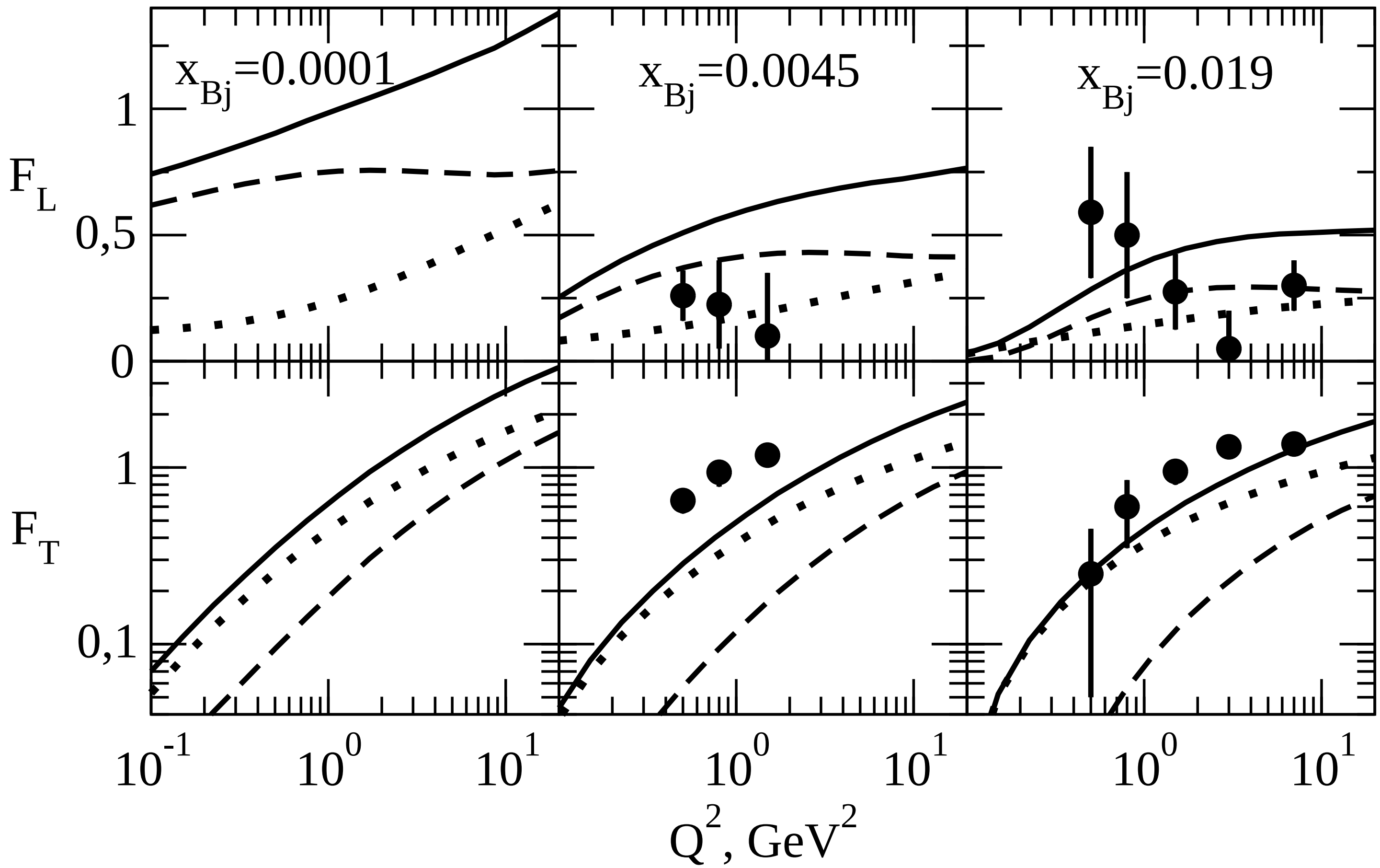
$$F_L^{ud}(x,0) \propto (1/x)^{\Delta_{soft}}$$

where

$$\Delta_{soft} \simeq 0.08$$

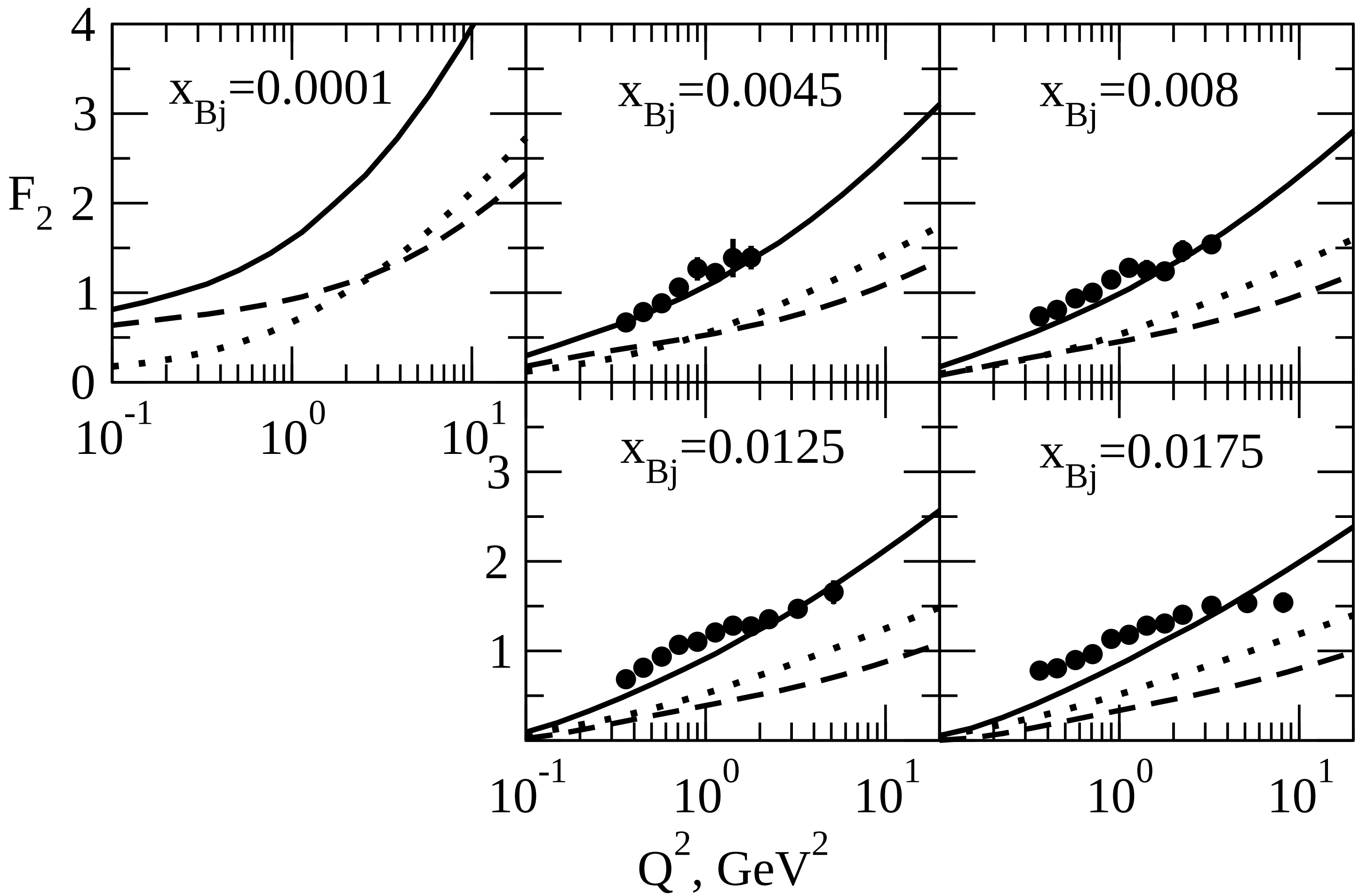
is typical of the πN total cross section.
For ν well above the charm-strangeness mass threshold ($x \lesssim 0.01$) the diffractive excitation of charm dominates the longitudinal structure function F_L.

$F_L(x, Q^2), F_T(x, Q^2)$



Data: U.K. Yang et al. *Phys. Rev. Lett.* **87** (2001) 251802

$F_2(x, Q^2)$



Data: B.T. Fleming et al. *Phys. Rev. Lett.* **86** (2001) 5430

Conclusions

- We developed the color dipole BFKL description of the CCNC phenomenon in the neutrino DIS at small Bjorken x,
- quantified the effect in terms of the tree level light-cone wave functions,
- found that the charmed-strange component of the longitudinal structure function prevails over its light quark component already at $x \sim 0.01$,
- found that the excitation of charm and strangeness dominates the structure function $F_2(x, Q^2)$ at $Q^2 \lesssim m_c^2$ and small enough x.
- the neutrino beam energy required is not too high, $E_\nu \gtrsim 100$ GeV, one can try to observe the phenomenon.