Spin dependence of diffractive DIS

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I review the recent progress in the theory of s-channel helicity nonconservation (SCHNC) effects in diffractive DIS including the unitarity driven demise of the Burkhardt-Cottingham(BC) sum rule and strong scaling departure from the Wandzura-Wilczek(WW) relation.

The motto of high energy QCD is the quark helicity conservation which is often believed to entail the s-channel helicity conservation (SCHC) at small x. Here I review the recent work ([1–5], which shows this belief is groundless and there is an extremely rich helicity-flip physics at small x.

The backbone of DIS is the Compton scattering (CS) $\gamma^*_\mu p \to \gamma^{*'}_\nu p'$, which at small-$x$ can be viewed as a (i) dissociation $\gamma^* \to q\bar{q}$ followed by (ii) elastic scattering $q\bar{q}p \to q\bar{q}p'$ with **exact** conservation of quark helicity and (iii) fusion $q\bar{q} \to \gamma^{*'}$. The CS amplitude $A_{\nu\mu}$ can be written as

$$A_{\nu\mu} = \Psi^*_{\nu,\lambda\bar{\lambda}} \otimes A_{q\bar{q}} \otimes \Psi_{\mu,\lambda\bar{\lambda}} \qquad (1)$$

where $\lambda, \bar{\lambda}$ stands for $q, \bar{q}$ helicities, $\Psi_{\mu,\lambda\bar{\lambda}}$ is the wave function of the $q\bar{q}$ Fock state of the photon. The $q\bar{q}$-proton scattering kernel $A_{q\bar{q}}$ does not depend on, and conserves, the $q, \bar{q}$ helicities and is calculable in terms of the gluon structure function of the target proton $G(x, \overline{Q}^2)$ taken at $\bar{x} = \frac{1}{2}(Q^2 + m_V^2)/(Q^2 + W^2)$ and a certain hard scale $\overline{Q}^2$(see below).

For nonrelativistic massive quarks, $m_f^2 \gg Q^2$, one only has transitions with $\lambda + \bar{\lambda} = \mu$. However, the relativistic P-waves give rise to transitions of transverse photons into the $q\bar{q}$ state with $\lambda + \bar{\lambda} = 0$ in which the helicity of the photon as transferred to the $q\bar{q}$ orbital angular momentum. This state $\lambda + \bar{\lambda} = 0$ is shared by the transverse (T) and longitudinal (L) photons which entails [1] the s-channel helicity nonconserving (SCHNC) single-helicity flip $T \to L$ which is $\propto \Delta$ and double-flip $\mu' = -\mu$ which is $\propto \Delta^2$ transitions in off-forward CS with $(\gamma^*, \gamma^{*'})$ momentum transfer $\vec{\Delta} \neq 0$. Similar SCHNC would persist also in diffractive vector meson production $\gamma^* p \to Vp'$ which is obtained from CS by continuation from spacelike γ^* to timelike V and swapping the Ψ^* for the photon for the vector meson lightcone wave function [2,3], for light vector mesons in the approximation of massless quarks see also [6]. The most exciting point about helicity flip in $\gamma^* p \to Vp'$ is that it uniquely probes spin-orbital angular momentum coupling and Fermi motion in vector mesons.

Experimentally the SCHNC LT-interference in diffractive DIS can be observed via azimuthal correlation between the (e, e') and (p, p') scattering planes. Our work on this asymmetry and its use for the determination of $R = \sigma_L/\sigma_T$ for diffractive DIS has been reported at DIS'97 & DIS'98 and published elsewhere [1]. Here I only recall that azimuthal asymmetry is the twist-3 effect,

$$A_{LT} \propto \frac{\Delta}{Q} g^D_{LT}(\bar{x}, \beta, Q^2)\,, \qquad (2)$$

where g^D_{LT} is the scaling structure function. Because of the excitation of $q\bar{q}$ state with $\lambda + \bar{\lambda} = 0$ is dual to production of longitudinal vector mesons, this result for diffractive DIS into continuum immediately entails that the dominant SCHNC effect in vector meson production will be the interference of production of longitudinal vector mesons by (SCHC) longitudinal and (SCHNC) transverse photons, i.e., the element r^5_{00} of the vector meson polarization density matrix.

The detailed discussion of the twist and sensitivity of SCHNC amplitudes to Fermi motion in

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vector mesons is found in [2,3], here I only show in fig. 1 a comparison between our theoretical estimates [4] of r^5_{00} for diffractive production of the ρ^0 treated as a pure S-wave $q\bar{q}$ state and the ZEUS [8] and H1 [7] experimental data. The agreement is very good, but much more theoretical work on sensitivity of spin-flip to short-distance properties of the vector meson wave function is called upon. Although one would wish to be in the pQCD domain, I emphasize that the existence of helicity flip does not require pQCD. In "normal" cases, i.e., helicity non-flip and single-helicity flip, the large virtuality of the photon and the form of the photon WF ensure the dominance by hard gluon exchange, but the double-flip amplitude remains dominated by soft gluon exchange, for more discussion see [2,3].

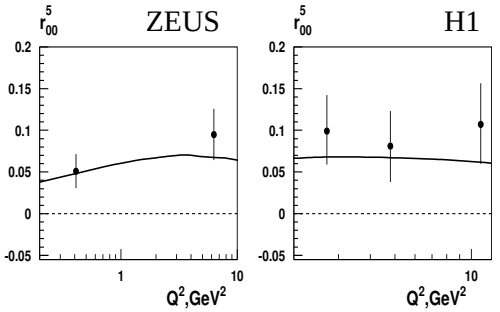

Figure 1. Our prediction [4] for SCHNC spin density matrix element r^5_{00} of diffractive ρ^0-meson vs. the data from ZEUS [8] and H1 [7].

In contrast to the S-wave state, in the D-wave case the total spin of $q\bar{q}$ pair is predominantly opposite to the spin of the D-wave vector meson. This results in a strikingly different structure of helicity-flip amplitudes for the D and S-wave states, which may facilitate the D-wave vs. $2S$-wave assignment of the $\rho'(1480)$ and $\rho'(1700)$ and of the $\omega'(1420)$ and $\omega'(1600)$, which remains one of hot issues in the spectroscopy of vector mesons.

Here I only cite the ratio ρ of helicity amplitudes for S- and D-wave states normalized to $V \to e^+e^-$ decay amplitudes [3]:

$$\begin{aligned}
\rho_{0L}(D/S) &= \frac{1}{5}\left(1-\frac{8m_V^2}{Q^2+m_V^2}\right), \\
\rho_{\pm\pm}(D/S) &= 3\left(1+\frac{4}{15}\frac{m_V^2}{Q^2+m_V^2}\right), \\
\rho_{0\pm}(D/S) &= -\frac{1}{5}(m_V a_S)^2\left(1+\frac{3m_V^2}{Q^2+m_V^2}\right), \\
\rho_{\pm L}(D/S) &= \frac{3}{40}(m_V a_S)^4 . \qquad (3)
\end{aligned}$$

Here a_S is the radius of the S-wave state and for the illustration purposes we used the harmonic oscillator wave functions. Notice that A^D_{0L} changes the sign at $Q^2 \sim 7m_V^2$ and the ratio $R^D = \sigma_L/\sigma_T$ has thus a non-monotonous Q^2 behavior and $R^D \ll R^S$. Second, because $m_V a_S \gg 1$, for D-wave states the SCHNC effects are much stronger and the leading SCHNC amplitude changes the sign from the S to D-wave sate. Third, notice the abnormally large higher twist corrections to the $0L$ and $0\pm$ helicity amplitudes for D-wave state.

The transverse spin asymmetry in polarized DIS is proportional to the amplitude of forward Compton scattering $\gamma^*_L p\uparrow \to \gamma^*_T p\downarrow$. This Compton amplitude and the transverse spin asymmetry are proportional to $g_{LT} = g_1 + g_2$. Because the photon helicity flip is compensated by the target proton helicity flip, the familiar forward zero of this helicity amplitude is lifted, but the price one pays for that is that in the standard $q\bar{q}$ and/or two-gluon t-channel tower approximation the pomeron exchange does not contribute to g_{LT} and the transverse asymmetry A_2 is believed to vanish at $x \to 0$. The vanishing A_2 follows also from the Wandzura-Wilczek relation between g_{LT} and g_1 [9].

The opening of diffractive DIS channels affects, via unitarity, the Compton scattering amplitudes. In [5] we have shown how diffractive LT interference in conjunction with spin-flip pomeron-nucleon coupling r_5 gives rise to a manifestly scaling unitarity correction to g_{LT} which rises steeply at small x,

$$g_{LT}(x,Q^2) \propto \frac{1}{x^2} r_5 \int_x^1 \frac{d\beta}{\beta} g^D_{LT}(x_{I\!P} = \frac{x}{\beta}, Q^2), \quad (4)$$

and gives rise to the transverse spin asymmetry $A_2 \propto x^2 g_{LT}$ which does not vanish at small x. Furthermore, at a moderately small x it even rises because $g_{LT}^D(x_{I\!P}, Q^2) \propto G^2(x_{I\!P}, \overline{Q}^2)$ where $\overline{Q}^2 \sim$ 0.5-1 GeV^2. In fig. 2 we show how the unitarity correction overtakes at small x the g_{LT} evaluated from the Wandzura-Wilczek relation starting with fits to the world data on g_1. As such the unitarity effect is a first nontrivial scaling departure from the WW relation

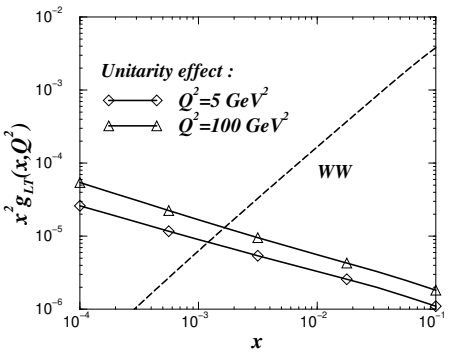

Figure 2. The unitarity correction to, and WW relation based evaluation of, g_{LT} [5].

Notice that neither pomeron nor multipomeron exchanges do contribute to g_1 and for small x where g_{LT} is dominated by the unitarity correction, $g_1 \ll g_{LT}$ and $g_2 \approx g_{LT}$. Consequently, g_2 rises at small x faster than $\propto \frac{1}{x^2}$, which invalidates superconvergence assumptions behind the derivation of the Burkhardt-Cottingham sum rule [10]. The BC integral simply diverges and the BC sum rule does not exist [5].

My final comment is on the longitudinal spin asymmetry A_L^V for vector meson production in polarized DIS on longitudinally polarized protons. The HERMES collaboration reported first evidence for this asymmetry in the ρ^0 production [11]. By the same token of analytic continuation from diagonal Compton scattering $\gamma^* p \to \gamma^* p'$ to $\gamma^* p \to V p'$, this spin asymmetry is a close counterpart of A_1 in inclusive polarized DIS. Furthermore, one can argue that for the starting approximation

$$A_L^V \approx 2 A_1^q(\bar{x}), \tag{5}$$

the trivial factor 2 being due to the fact that in vector meson production one measures the differential cross section, i.e., the amplitude squared, whereas in inclusive DIS one measures the total Compton cross section asymmetries which by the optical theorem are linear in the forward Compton scattering amplitude.

Recall that A_1 receives contributions from quarks and gluons. Recently it has been argued that contribution from polarized gluons to A_L^V is negligible [12]. Consequently, a difference $A_1 - \frac{1}{2} A_L^V$ is a direct measure of the still elusive gluon contribution to g_1 of the proton!

REFERENCES

1. N.N. Nikolaev, A.V. Pronyaev and B.G. Zakharov, *Phys. Rev.* **D59** (1999) 091501.
2. E.V. Kuraev, N.N. Nikolaev and B.G. Zakharov, *JETP Lett.* **68** (1998) 667.
3. I.P.Ivanov and N.N.Nikolaev, *JETP Letters* **69** (1999) 268.
4. I. Akushevich, I. Ivanov, N.N. Nikolaev and A. Pronyaev, paper in preparation.
5. I. Ivanov, N.N. Nikolaev, A. Pronyaev and W. Schaefer, hep-ph/9903228; *Phys. Lett.* **B**, in press.
6. D. Ivanov and R. Kirschner, *Phys. Rev.* **D58** (1998) 114026.
7. H1 Collab: B. Clerbaux, these proceedings.
8. ZEUS Collab: A. Savin, these proceedings.
9. S.Wandzura and F.Wilczek, *Phys. Lett.* **B72** (1977) 195.
10. H.Burkhardt and W.N.Cottingham, *Ann. of Phys. (USA)*, **56** (1970) 453.
11. HERMES Collab: F. Meissner, these proceedings.
12. M. Vanttinen and L. Mankiewicz, *Phys. Lett.* **B434** (1998) 141.