Single spin asymmetries and vector meson production in DIS

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Abstract

We discuss possible measurements and origins of single spin asymmetries in DIS and of some unusual spin properties of vector mesons produced in ℓN, γN and $\gamma\gamma$ interactions. Such effects have already been observed in other processes.

Single spin asymmetries in DIS

Single spin asymmetries in large p_T inclusive hadronic reactions are forbidden in leading-twist perturbative QCD, reflecting the fact that single spin asymmetries are zero at the partonic level and that collinear parton configurations inside hadrons do not allow single spin dependences. However, experiments tell us in several cases, [1, 2] that single spin asymmetries are large and indeed non negligible.

The usual arguments to explain this apparent disagreement between pQCD and experiment invoke the moderate p_T values of the data – a few GeV, not quite yet in the true perturbative regime – and the importance of higher-twist effects. Several phenomenological models have recently attempted to explain the large single spin asymmetries observed in $p^\uparrow p \to \pi X$ as twist-3 effects which might be due to intrinsic partonic $\boldsymbol{k}_\perp$ in the fragmentation [3] and/or distribution functions [4]-[6].

A measurement of such single spin asymmetries also in Deep Inelastic Scattering (DIS) would add valuable information; a detailed analysis of single spin asymmetries in the inclusive, $\ell N^\uparrow \to \ell + jets$ and $\ell N^\uparrow \to hX$, reactions looking at possible origins and devising strategies to isolate and discriminate among them can be found in Ref. [7].

We recall here only the main ideas and refer to Ref. [7] for details and a full explanation of notations and the formalism.

a) $\ell N^\uparrow \to \ell + 2\, jets$

This case is the usual DIS on a nucleon N with spin S and one avoids any fragmentation effect by looking at the fully inclusive cross-section for the process $\ell N^\uparrow \to \ell + 2\, jets$, the 2 jets being the target and current ones. Within the QCD factorization theorem one has

$$\frac{d^2\sigma^{\ell+N,S\to\ell+X}}{dx\,dQ^2} = \sum_q \int d^2\boldsymbol{k}_\perp\, \tilde{f}^{N,S}_{q/N}(x,\boldsymbol{k}_\perp)\, \frac{d\hat\sigma^{q,P_q}}{d\hat t}(x,\boldsymbol{k}_\perp)\,. \tag{1}$$

In this case the elementary interaction is a pure QED, helicity conserving one, $\ell q \to \ell q$, and $d\hat\sigma^{q,P_q}/d\hat t$ cannot depend on the quark polarization. Some spin dependence might only remain in the distribution function $\tilde{f}^{N,S}_{q/N}$, due to intrinsic $\boldsymbol{k}_\perp$ effects [4]-[6], but is expected to be strongly suppressed by (necessary) initial state interactions. A dependence on the transverse nucleon spin of Eq. (1) is in principle possible, but would be very surprising and intriguing [10].

b) $\ell N^\uparrow \to h + X\ (2\, jets,\ \boldsymbol{k}_\perp \neq 0)$

One looks for a hadron h, with transverse momentum $\boldsymbol{k}_\perp$, inside the quark current jet; the final lepton may or may not be observed. The elementary subprocess is $\ell q \to \ell q$ and one has [8, 9]

$$\begin{aligned} &\frac{E_h\, d^5\sigma^{\ell+N^\uparrow\to h+X}}{d^3\boldsymbol{p}_h d^2\boldsymbol{k}_\perp} - \frac{E_h\, d^5\sigma^{\ell+N^\downarrow\to h+X}}{d^3\boldsymbol{p}_h d^2\boldsymbol{k}_\perp} \\ = &\sum_q \int \frac{dx}{\pi z}\, \Delta_{{}_T} q(x)\, \Delta_{{}_N}\hat\sigma^q(x,\boldsymbol{k}_\perp)\, \left[\tilde{D}^h_{q^\uparrow}(z,\boldsymbol{k}_\perp) - \tilde{D}^h_{q^\uparrow}(z,-\boldsymbol{k}_\perp)\right] \end{aligned} \tag{2}$$

where $\Delta_{{}_T} q$ (or h_1) is the polarized number density for transversely spinning quarks q and $\Delta_{{}_N}\hat\sigma^q$ is the elementary cross-section double spin asymmetry

$$\Delta_{{}_N}\hat\sigma^q = \frac{d\hat\sigma^{\ell q^\uparrow\to\ell q^\uparrow}}{d\hat t} - \frac{d\hat\sigma^{\ell q^\uparrow\to\ell q^\downarrow}}{d\hat t}\,. \tag{3}$$

In Eq. (2) we have neglected the $\boldsymbol{k}_\perp$ effect in the distribution function, which can be done once the asymmetry discussed in *a)* turns out to be negligible. We are then testing directly the mechanism suggested in Ref. [3] and a non zero value of the l.h.s. of Eq. (2) would be a decisive test in its favour and would allow an estimate of the new function $[\tilde{D}^h_{q^\uparrow}(z, \boldsymbol{k}_\perp) - \tilde{D}^h_{q^\uparrow}(z, -\boldsymbol{k}_\perp)]$. Notice that even upon integration over $d^2\boldsymbol{k}_\perp$ the spin asymmetry of Eq. (2) might survive, at higher twist order $k_\perp/p_T$, due to some $\boldsymbol{k}_\perp$ dependence in $\Delta_N \hat{\sigma}^q$.

Several other cases are considered in Ref. [7].

$\rho_{1,-1}(V)$ in $\ell N \to V + X$, $\gamma N \to V + X$ and $\gamma\gamma \to V + X$

In Ref. [11] it was suggested how the coherent fragmentation of $q\bar{q}$ pairs created in $e^+e^- \to q\bar{q} \to V + X$ processes might lead to non zero values of the off-diagonal element $\rho_{1,-1}$ of the helicity density matrix of the vector mesons V; in Ref. [12] actual predictions were given for several spin 1 particles produced at LEP energies in two jet events, provided they carry a large fraction x_E of the parent quark energy and have a small intrinsic $\boldsymbol{k}_\perp$, *i.e.* they are collinear with the parent jet.

The values of $\rho_{1,-1}(V)$ are related to the values of the off-diagonal helicity density matrix element $\rho_{+-;-+}(q\bar{q})$ of the $q\bar{q}$ pair, generated in the $e^-e^+ \to q\bar{q}$ process [12]:

$$\rho_{1,-1}(V) \simeq [1 - \rho_{0,0}(V)]\, \rho_{+-;-+}(q\bar{q}) \tag{4}$$

where the value of the diagonal element $\rho_{0,0}(V)$ can be taken from data. The values of $\rho_{+-;-+}(q\bar{q})$ depend on the elementary short distance dynamics and can be computed in the Standard Model. Thus, a measurement of $\rho_{1,-1}(V)$, is a further test of the constituent dynamics, more significant than the usual measurement of cross-sections in that it depends on the product of different elementary amplitudes, rather than on squared moduli:

$$\rho_{+-;-+}(q\bar{q}) = \frac{1}{4N_{q\bar{q}}} \sum_{\lambda_-,\lambda_+} M_{+-;\lambda_-\lambda_+}\, M^*_{-+;\lambda_-\lambda_+}\,, \tag{5}$$

where the M's are the helicity amplitudes for the $e^-e^+ \to q\bar{q}$ process and $N_{q\bar{q}}$ is the normalization factor. With unpolarized e^+ and e^-, at LEP energy, $\sqrt{s} = M_Z$, one has [12]

$$\rho_{+-;-+}(q\bar{q}) \simeq \rho^Z_{+-;-+}(q\bar{q}) \simeq \frac{1}{2}\, \frac{(g_V^2 - g_A^2)_q}{(g_V^2 + g_A^2)_q}\, \frac{\sin^2\theta}{1 + \cos^2\theta}\,\cdot \tag{6}$$

Eq. (4) is in good agreement with OPAL Collaboration data on ϕ, D^* and K^*, including the θ dependence induced by Eq. (6) [13, 14]; however, no sizeable value of $\rho_{1,-1}(V)$ for $V = \rho, \phi$ and K^* was observed by DELPHI Collaboration [15]. Further tests are then necessary.

We consider here other interactions – of interest for the Jefferson Lab program – in which the value of $\rho_{1,-1}(V)$ could be measured, namely $\gamma N \to VX$, $\ell N \to \ell VX$ and possibly $\gamma\gamma \to VX$, with $V = \phi, D^*$ or B^*. The choice of a heavy vector meson implies the dominance in each of these cases of particular elementary hard contributions, $\gamma g \to q\bar{q}$, $\gamma^* g \to q\bar{q}$ and $\gamma\gamma \to q\bar{q}$, with $q = s, c$ or b.

The hadronization process – the fragmentation of a $q\bar{q}$ pair – is then similar to the one occurring in e^+e^- annihilations; however, the value of $\rho_{1,-1}(V)$ in these cases should be different from that observed in $e^-e^+ \to VX$ at LEP, due to a different underlying elementary dynamics, *i.e.* a different value of $\rho_{+-;-+}(q\bar{q})$. A measurement of $\rho_{1,-1}(V)$ in agreement with our predictions in these other processes would be an unambiguous test of both the quark hadronization mechanism and the real nature of the constituent interactions.

Details of the calculation can be found in Ref. [16]; we find again Eq. (4) with, neglecting quark masses and for real photons:

$$\rho_{+-;-+}(q\bar{q}) = \rho^{\gamma,g}_{+-;-+}(q\bar{q};\theta^*) = \frac{1}{2}\,\frac{\sin^2\theta^*}{1+\cos^2\theta^*}\,. \tag{7}$$

This value of $\rho^{\gamma,g}_{+-;-+}(q\bar{q})$ is the same for all the possible elementary processes initiated by a real photon or a real gluon, *i.e.* also for resolved photon contributions; θ^* is the production angle of q and V in the partonic *c.m.* frame.

The situation is different and potentially very interesting in case of DIS, because the value of $\rho^{\gamma^* g\to q\bar{q}}_{+-;-+}$ strongly depends on the DIS variables [16]

$$\rho^{\gamma^* g\to q\bar{q}}_{+-;-+}(q\bar{q};y,z,\theta^*) = \frac{\sin^2\theta^*}{2(1+\cos^2\theta^*)}\,\frac{1-A(y,z)}{1+A(y,z)\sin^2\theta^*/(1+\cos^2\theta^*)} \tag{8}$$

where

$$A(y,z) = \frac{8z(1-z)(1-y)}{[(1-z)^2+z^2]\,[1+(1-y)^2]}\,. \tag{9}$$

Insertion of Eqs. (8) and (9) into Eq. (4) gives our prediction for $\rho_{1,-1}(V)$ in DIS, and its dependence on the variables $y = Q^2/(sx)$, $z = x/x_g$, the production angle θ^* of V in the $\gamma^* g$ *c.m.* frame and the measured value of $\rho_{0,0}(V)$.

The two issues considered here are only two examples of interesting spin physics possible at Jefferson Lab; many other spin observables and spin effects should be measurable and should allow to collect precious information on subtle and little known properties both of quark distributions and fragmentation.

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