Regge Description of Spin-Spin Asymmetry in Photon Diffractive Dissociation

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Abstract: We explore the possibility to extract $\Delta G(x)$ from a comparison of experimental data on the longitudinal spin-spin asymmetry A_{LL} in γp diffractive deep inelastic scattering with calculations performed in perturbative QCD (pQCD). The data could be obtained at the HERA collider in scattering of polarized leptons off polarized protons. We have found a kinematic region where contributions to A_{LL} from soft processes are suppressed to guarantee an applicability of pQCD, hence the pQCD prediction can be reliably compared with data in this kinematical region.

1 Introduction

The gluon distributions extracted from inclusive data on deep inelastic scattering (DIS) of leptons on nucleons have large uncertainties. Recently it has been argued that the diffractive hadron production is more sensitive to the gluon distributions than inclusive DIS. The cross section for diffractive $\gamma^* p$ scattering of the unpolarized particles is proportional to the square of $G(x)$ meanwhile $\Delta G(x)$ can be obtained from data on diffractive scattering of the circularly polarized heavy photon off the longitudinally polarized proton. These predictions have been made within the framework of perturbative QCD (pQCD) when typical transverse momenta of produced diffractive hadrons and their total mass are large enough for pQCD to be applicable. In real experiments transverse momenta are $\lesssim 1$ GeV/c hence soft process contributions can be appreciable. In the present paper we look for a kinematic region where contributions to A_{LL} from reggeon exchanges (soft processes) are suppressed. In this region the pQCD predictions can be reliably compared with experimental data which can be obtained in the future at the collider HERA in DIS of polarized leptons off longitudinally polarized nucleons.

2 Model

The physical picture of the photon diffractive dissociation is as follows. The virtual photon dissociates into a quark-antiquark pair ($q\bar{q}$) which gives a final diffractive hadronic state after rescattering on the incident nucleon. When transverse distances ρ between q and $\bar{q}$ are small (transverse momenta of a quark k_T are large) the cross section of $q\bar{q}$ pair scattering off the nucleon is described by the gluon ladder graphs which correspond to hard pomeron exchange.

The polarization phenomena can presumably be well described in the leading logarithm approximation of pQCD too. We suppose that soft processes contribute to A_{LL} if $\rho \sim 1$ fm. We describe scattering of the $q\bar{q}$ pair with such ρ in the framework of Regge phenomenology. Quark-reggeon (qR) vertices have been extracted from nucleon-reggeon (NR) vertices making use of the quark wave function of the nucleon in the naive nonrelativistic quark model (see details in [1]). Parameters of the nucleon-reggeon vertices for natural parity reggeons $\mathbb{P}$(pomeron), $\rho(770)$, $f(1270)$, $A_2(1320)$, $\omega(782)$ have been taken from [2] and [3]. For unnatural parity reggeons π and $A_1(1260)$ we have used parameters taken from [3], [4]. This paper is the short version of the work [1] where more details and references can be found.

The transverse distance ρ is $\sim 1/\mu$ where $\mu^2 = Q^2\alpha(1-\alpha) + m_q^2$ and $q^2 = -Q^2 < 0$ denotes the photon virtuality, m_q is the quark mass. The light cone variable α denotes the heavy photon momentum fraction carried by the quark (the photon momentum fraction carried by the antiquark is equal to $1-\alpha$). We conclude that $\rho \sim 1$ fm for large Q^2 if α (or $1-\alpha$) is so small that $Q^2\alpha(1-\alpha) \lesssim m_q^2$ since $m_q \sim 1$ fm^{-1} for light quarks. The Mandelstam variables for quark-nucleon and antiquark-nucleon scattering are given by the approximate formulæ

$$S_{qN} \approx \alpha S_{\gamma N} \ , \quad S_{\bar{q}N} \approx (1-\alpha) S_{\gamma N} \tag{1}$$

where $S_{\gamma N}$ denotes the square of the center-of-mass energy for the γN collision.

The nucleon-reggeon vertex V and the quark-reggeon vertex v for the natural parity reggeons in the helicity representation look like

$$V = IV_s(\Delta_T^2) + i\sigma_y^N \frac{\Delta_T}{M} V_y(\Delta_T^2) \ , \quad v = Iv_s + i\sigma_y^q \frac{\Delta_T}{M} v_y \ , \tag{2}$$

where M is the nucleon mass and I denotes the unit matrix. The Pauli matrices σ_y^N and σ_y^q act on the helicity variables of the nucleon and quark, respectively. The dependence of the functions V_s and V_y on the transverse momentum transfer $\vec{\Delta}_T$ ($\Delta_T = |\vec{\Delta}_T|$) is related with a finite space range of the nucleon. For the pointlike quarks, v_s and v_y are constants. The y-axis is orthogonal to the qN scattering plane, x and z axes are parallel to $\vec{\Delta}_T$ and the photon three momentum, respectively. One has for the πN, πq NA_1, and qA_1 vertices [3], [4]

$$V_\pi = \frac{\Delta_T}{M} \sigma_x^N V_x(\Delta_T^2) \ , \quad v_\pi = \frac{\Delta_T}{M} \sigma_x^q v_x \ , \quad V_{A_1} = V_z(\Delta_T^2)\sigma_z^N \ , \quad v_{A_1} = v_z \sigma_z^q \ . \tag{3}$$

Formulæ (2), (3) follow from the parity, G-parity conservation and the time reverse invariance of the strong interaction [4], [5]. We restrict our consideration in the present paper with one, two and three reggeon exchange amplitudes only.

3 Numerical results and discussion

It is well known that pomeron exchanges dominate at a very high collision energy . It is also true for contributions to A_{LL} at $S_{\gamma N} \to \infty$ but it is not the case for the energies accessible at HERA. Indeed, A_{LL} is non-zero if the correlation $\sigma_z^N \sigma_z^q$ (or $\sigma_z^N \sigma_z^{\bar{q}}$) in qN (or $\bar{q}N$) scattering exists. From here on, we shall assume that some statement is valid both for quarks and antiquarks saying that it is true for quarks. We see from (2) that the $\sigma_z^N \sigma_z^q$ term is absent in one pomeron exchange since the qN amplitude has the spin-dependent terms σ_y^q, σ_y^N, $\sigma_y^N \sigma_y^q$ only. The two pomeron emission vertex is to be symmetric under permutation of their momenta since the pomerons obey the Bose statistics. As a result, the $\sigma_x^N\sigma_x^q$ term vanishes in the amplitude of two pomeron exchange. The term $\sigma_x^N\sigma_x^q$ appears for the first time in the three pomeron exchange amplitude. Its product by the term $\sigma_y^N\sigma_y^q$ provides the $\sigma_z^N\sigma_z^q$ correlation in the cross section and hence A_{LL} becomes non-zero. But the spin-dependent parts of the $N\mathbb{P}$ and $q\mathbb{P}$ vertices in (2) are much smaller than the spin-independent terms (see [1], [2]). Besides, the $\sigma_x^N\sigma_x^q$ term in the three pomeron exchange amplitude contains a small numerical factor [1]. As a result, the pure pomeron contribution to A_{LL} is less than 10^{-6} at $\Delta_T \leq 1.5$ GeV/c (see Fig. 1a). The vertex of emission of two different reggeons $R_1,\ R_2$ is not symmetric under permutation of their momenta and the amplitude of exchange with $R_1,\ R_2$ has the $\sigma_x^N\sigma_x^q$ term. This fact explains why the contributions of $f,\ \rho,\ \omega,\ A_2$ to A_{LL} are so important. Besides the spin-dependent parts of the $f,\ \rho,\ \omega,\ A_2$ vertices are greater than the spin-independent parts therefore exchanges with these reggeons have some advantage compared with pure pomeron exchanges.

The ratio of the amplitude of exchanges with some reggeon R and $n-1$ pomerons to the amplitude of n pomeron exchanges is proportional to the factor f_q ($f_{\bar{q}}$) for qN ($\bar{q}N$) scattering

$$f_q = (\alpha S_{\gamma N}/S_0)^{\alpha_R(0)-\alpha_P(0)}\ ,\quad f_{\bar{q}} = [(1-\alpha)S_{\gamma N}/S_0]^{\alpha_R(0)-\alpha_P(0)} \qquad (4)$$

in accordance with (1) (with the usual choice $S_0 \sim 1$ GeV^2). Since a difference of intercepts $\alpha_R(0) - \alpha_P(0) \approx -0.5$ for $R = f,\ \omega,\ \rho,\ A_2$ the factor $(S_{\gamma N}/S_0)^{\alpha_R(0)-\alpha_P(0)}$ in (4) coincides practically with ϵ where $\epsilon = \sqrt{S_0/S_{\gamma N}}$ and for π and A_1 this factor is $\leq \epsilon^2$ since $\alpha_R(0) < 0$. For the collider HERA $S_{\gamma N} \sim 10^3 - 10^5$ GeV^2 hence $\epsilon \lesssim 3\cdot 10^{-2}$. We decompose amplitudes, cross sections and A_{LL} into power series with respect to ϵ. The dominant contribution to the cross section (the denominator in the formula for A_{LL}) comes from $\alpha \sim 1$ hence pomeron exchanges ($\sim \epsilon^0$) dominate. We can see from Figs. 1a, 1b, 1c that the contribution to $A_{LL} \sim \epsilon$ is much greater than the pure pomeron one and the contribution $\sim \epsilon^2$ is greater than the first order contribution ($\sim \epsilon^1$) though $\epsilon \ll 1$. To explain this numerical result let us remember formula $M_X^2 = \frac{m_q^2+k_T^2}{\alpha(1-\alpha)}$ showing that $\alpha(1-\alpha)$ can be very small for large diffractive hadronic masses M_x and low k_T. If we apply the experimental cuts $k_T \geq k_{min}$ and $M_X \leq M_{max}$, then the dominant contribution to the numerator in the formula for A_{LL} comes from α close to α_{min} or α_{max} where

$$\alpha_{min} = 1 - \alpha_{max} \approx \frac{m_q^2 + k_{min}^2}{M_{max}^2}\ . \qquad (5)$$

For $M_{max} \sim 10$ GeV/c^2, $k_{min}^2 \sim m_q^2c^2 \sim 0.1$ (GeV/c)^2 we have $\alpha_{min} = 1-\alpha_{max} \sim 10^{-3}$. We see from (4) that f_q depends on the ratio of the two small parameters (ϵ^2, α_{min}) and $\epsilon^2/\alpha_{min} \sim 1$ at $S_{\gamma p} \sim 10^3$ GeV^2. This explains the "unnatural" hierarchy of contributions to A_{LL} at $S_{\gamma p} < 10^5$ shown in Fig. 1. The contributions of $\pi-$ and A_1-reggeons can be numerically of the same order as the $f,\ \omega,\ \rho,\ A_2$ contributions when $\epsilon^2/\alpha_{min} \sim 1$. The relative contribution of A_1 to A_{LL} is less than 10% in spite of the fact that the A_1-reggeon exchange amplitude contains the term $\sigma_z^N\sigma_z^q$. The $\pi-$reggeon contribution is important at $S_{\gamma p} < 10^5$ GeV^2 and even dominates for some kinematics since the pion-nucleon and pion-quark coupling constants are large.

Numerical calculations [1] has shown that A_{LL} is practically independent of Q^2 at $4 \leq Q^2 \leq 100$ (GeV/c)^2 and increases with Δ_T (see also Fig. 1). The asymmetry A_{LL} decreases with an increase of α_{min}, $1-\alpha_{max}$ and $S_{\gamma p}$ since the energy of qN and $\bar{q}N$ scattering increases which suppresses the relative contributions of secondary reggeons. The calculations done in [1] show that $A_{LL} \leq 10^{-4}$ at $S_{\gamma p} \geq 10^3$ GeV^2, $\Delta_T \leq 1$ GeV/c, $M_X \leq 10$ GeV/c^2, and

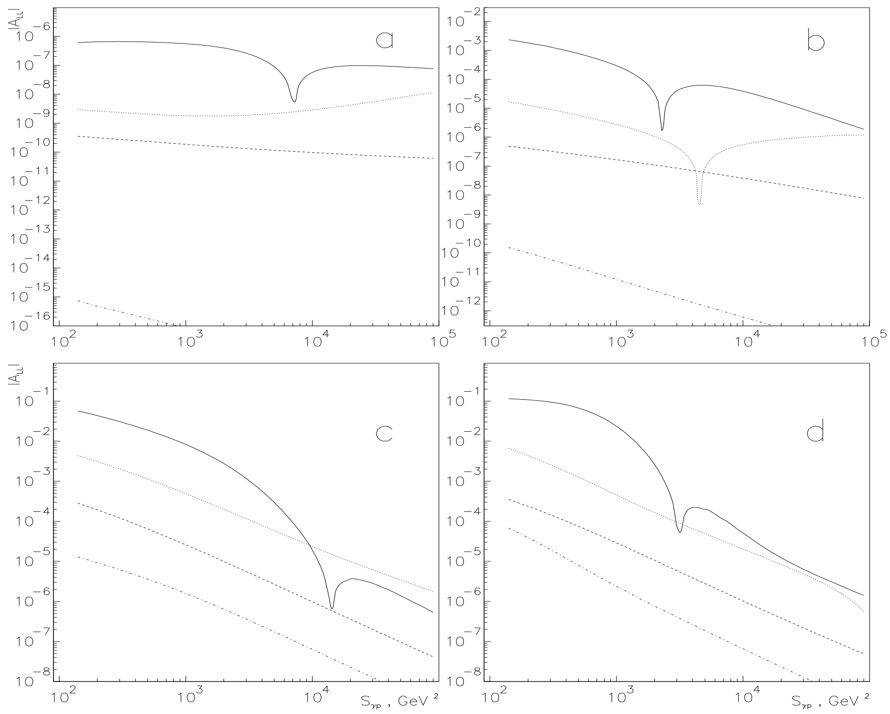

Figure 1: *Dependence of asymmetry A_{LL} on Δ_T and $S_{\gamma p}$. Figs. 1a and 1b show pure pomeron contribution and interference of contributions of f, ω, ρ, A_2 and $I\!P$ $(\sim \epsilon^1)$, respectively. Figs. 1c and 1d show contributions $\sim \epsilon^2$ and "total asymmetry" (no decomposition into power series in ϵ). Dash-dotted, dashed, dotted and solid curves are computed for* $\Delta_T = 0,\ 0.5,\ 1.0,\ 1.5$ *GeV/c, respectively. For all curves* $M_X = 10$ *GeV/c*^{2}, $Q^2 =$ *10 (GeV/c)*^{2}, $k_{min} = 0.2$ *GeV/c.*

$\alpha_{min} = 1 - \alpha_{max} > 0.03$. The last cut means that $k^2_{min}/M^2_{max} \geq 0.03$ according to (5). The contributions of both $I\!P$, f, ρ, ω, A_2 and π, A_1 reggeons have been taken into account. The value 10^{-4} is smaller than the lowest limit for A_{LL} which can be measured by modern experimental technique. Hence for the kinematical region under consideration the contribution of the soft processes to A_{LL} is negligible and the pQCD prediction can be reliably compared with the data. The experiment could be performed in the future at the HERA collider in scattering of longitudinally polarized leptons off the longitudinally polarized nucleons.

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