SPIN ASYMMETRIES IN PROTON-PROTON SCATTERING AT HIGH ENERGIES AND MODERATELY LARGE MOMENTUM TRANSFER

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We study pp scattering at high energies and moderately large momentum transfer using a QCD–based model in which the proton is viewed as being composed of a quark and a diquark. This model leads to spin asymmetries which are neither small nor vanish at high energies. The predicted ratio of helicity flip and non-flip amplitudes is about 0.2-0.3 and A_n asymmetry is about 20-30% for $|t| > 4\,\mathrm{GeV}^2$.

Theoretical investigation of spin effects in high-energy exclusive proces-ses at moderately large momentum transfer is one of the unsolved problems in QCD. In view of the polarization physics programs proposed for the future proton accelerators [1], this problem is very important. Massless QCD leads to hadronic helicity conservation and to zero single-spin asymmetries. Mass and higher order perturbative QCD corrections lead to non-vanishing single-spin transverse asymmetries but they are much smaller than the experimental results.

There are many experimental observations of large spin effects at high energies and moderately large momentum transfer [2]. The low-energy results for the A_n asymmetry at $p_B = 28$ GeV in the BNL [3] are of the same order of magnitide as the FNAL observations [4] at $p_B = 200$ GeV and similar values of t. In spite of large experimental errors, the conclusion might be done that spin effects in high-energy reactions exhibit a weak energy dependence.

In this report, we are interested in spin effects at high energies and moderately large momentum transfer ($3\ \mathrm{GeV}^2 < |t| << s$). Our approach is based on the diquark picture [5] where the proton is viewed as being composed of a quark and a diquark in the dominant valence Fock state instead of three quarks

$$|p,\lambda\rangle = f_S\,\varphi_S(x_1)\,B_S\,u(p,\lambda) + f_V\,\varphi_V(x_1)\,B_V(\gamma^\alpha + p^\alpha/m)\gamma_5\,u(p,\lambda)/\sqrt{3}\,. \quad (1)$$

The scalar(S) and vector(V) diquarks provide an effective description of non-perturbative effects. Their composite nature is taken into account by diquark form factors. The diquark picture of the proton simplifies our calculations drastically due to the reduced number of constituents. We use that model in combination with the two-gluon exchange picture as a representative of the Pomeron.

In the kinematic region of interest, the double helicity–flip amplitudes are believed to be much smaller than the helicity non–flip ones and the two non-flip amplitudes are equal in magnitude approximately. Therefore, we have to calculate or to model a non-flip and a flip amplitude only. We can, for convenience and without loss of generality, fix the helicities of two protons at $+1/2$. The structure of the amplitude then simplifies to

$$T_{\lambda_4+;\lambda_2+} = \bar{u}(p_4,\lambda_4)[sA(t,s) + \hat{p}_1 B(t,s)]u(p_2,\lambda_2) \tag{2}$$

The two-gluon graphs for the colour–singlet t-channel exchange have been considered for the invariant function A. The function A is calculated under the assumption that the t-channel gluons couple to one constituent, a quark or a diquark at the helicity non-flip vertex. Into the helicity flip vertex, we include the perturbative α_s correction. Hence, we consider minimally connected graphs which allow us to keep all constituents collinear. The used set of graphs leads to gauge-invariant scattering amplitudes. The invariant function B, dominating the helicity non-flip amplitudes, is parametrized by a standard phenomenological Pomeron. We use two different fits [6] which qualitatively describes the differential cross section of elastic pp scattering for $|t| \geq 3\,\mathrm{GeV}^2$.

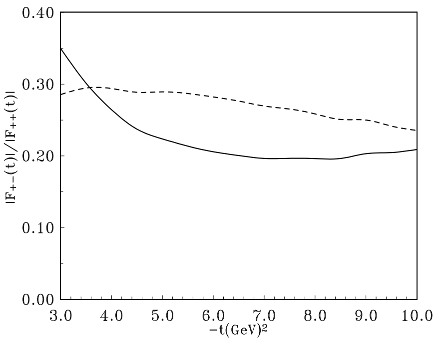

Fig.1

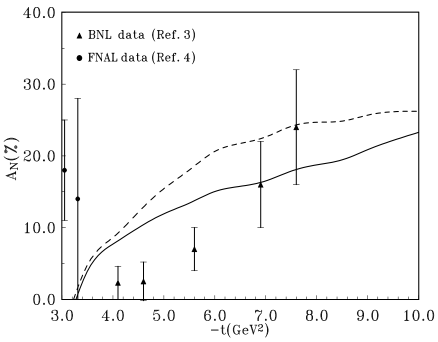

Fig.2

Figure 1: Absolute value of the ratio of helicity-flip to non-flip amplitudes.

Figure 2: Model predictions for single-spin asymmetry for two fits of the B amplitude [6].

The absolute value of the ratio of A to B is proportional to the ratio of helicity-flip and non-flip amplitudes (see Fig. 1). This ratio is fairly large $|A|/|B| \sim 0.1\,\mathrm{GeV}^{-1}$ at $|t| \geq 3\,\mathrm{GeV}^2$ thus indicating a substantial amount of helicity flips generated through the vector diquarks in the model.

In our model the helicity flips are generated by vector diquarks. It turns out that the invariant function A is of substantial magnitude and not in phase with the Pomeron contribution. Our model, therefore, provides a single-spin asymmetry A_N that is rather large for momenta transfer $|t| \geq 3\,\mathrm{GeV}^2$. Our prediction for A_N is shown in Fig. 2. The predicted asymmetry amounts to about 20–30% for $|t| > 6\,\mathrm{GeV}^2$; it is of the same order of magnitude as has been observed in the BNL experiment [3] and the FNAL experiment [4]. The decrease of the asymmetry at smaller momenta transfer is connected with the observed zero of $\mathrm{Re}A$. The double spin transverse asymmetry in this kinematic region is rather large in our model [6]. It turns out to be of an order of 10-15% for $|t| > 4\,\mathrm{GeV}^2$. Our results for spin asymmetries are rather close to those obtained in [7] although the latter are valid in the momentum transfer region $2\,\mathrm{GeV}^2 < |t| < 4\,\mathrm{GeV}^2$.

Thus, on the basis of the diquark model we have calculated spin effects in high-energy proton-proton scattering at moderately large momentum transfer. The spin-flip effects in the model are a consequence of the quark-diquark structure of the proton, which reflects the non-perturbative physics in the hadronic binding. Spin-1 diquarks which appear besides spin-0 diquarks as constituents of protons can change their helicity when interacting with gluons. Besides the quark-diquark structure, our model is based on the t-channel exchange of a colour-singlet two–gluon system and, in so far, bears resemblance to the Pomeron exchange. The important feature of the spin effects obtained in the diquark model is their approximate energy independence. On the other hand, they decrease with increasing momentum transfer. Our results are valid at large s and moderate momenta transfer, larger than few GeV^2. This kinematical region can be investigated, for instance, in the proposed HERA-$\vec{N}$ experiment [1].

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