Transverse spin effects in proton-proton scattering and $Q\bar{Q}$ production

S.V. Goloskokov

Bogoliubov Laboratory of Theoretical Physics, Joint Institute for Nuclear Research, Dubna 141980, Moscow region, Russia

Abstract. We discuss transverse spin effects caused by the spin-flip part of the Pomeron coupling with the proton. The predicted spin asymmetries in proton-proton scattering and QQ production in proton-proton and lepton-proton reactions are not small and can be studied in future polarized experiments.

In this report, we discuss what future facilities can be used to ascertain the existence of the spin spin-flip part of the Pomeron coupling. The spin structure of the Pomeron was analysed by different authors (see [1, 2] and reference therein). Its manifestation can be investigated in the elastic pp scattering at low t [3]. We shall analyze here the single spin asymmetries in the elastic pp scattering near the diffraction minimum and of the $Q\bar{Q}$ production in the pp reaction. The double spin asymmetries of $Q\bar{Q}$ production in lepton-proton reactions for a longitudinally polarized lepton and a transversely polarized proton will be studied too. It will be shown that these asymmetries are sensitive to the spin-flip part of the Pomeron coupling and predicted asymmetries are not small, about 10%. They can be used to obtain information about the spin structure of the Pomeron coupling. To study spin effects in diffractive reactions, we use the two- gluon exchange model , which is directly connected with the Pomeron. On the other hand, diffractive processes can be expressed in terms of the generalized or skewed parton distribution (GPD) in the nucleon $F_\zeta(x)$, $K_\zeta(x)$ [4]. The connection of the two-gluon model with GPD will be shown.

The two-gluon coupling with the proton can be parametrized in the form [5]

$$\begin{aligned} V_{pgg}^{\alpha\beta}(p,t,x_P,l_\perp) &= B(t,x_P,l_\perp)(\gamma^\alpha p^\beta + \gamma^\beta p^\alpha) \\ &+ \frac{iK(t,x_P,l_\perp)}{2m}(p^\alpha \sigma^{\beta\gamma} r_\gamma + p^\beta \sigma^{\alpha\gamma} r_\gamma) + \ldots . \end{aligned} \quad (1)$$

Here m is the proton mass. In the matrix structure (1) we wrote only the terms with the maximal powers of a large proton momentum p which are symmetric in the gluon indices α, β. The structure proportional to $B(t,\ldots)$ determines the spin-non-flip contribution. The term $\propto K(t,\ldots)$ leads to the transverse spin-flip at the vertex.

The spin-dependent cross section of diffractive processes are expressed in terms of the soft gluon coupling (1), which in the case of hadron production is convoluted with the hard hadron production amplitude. The spin asymmetries are expressed in terms of the functions $B(t,\ldots)$ and $K(t,\ldots)$ integrated over the gluon transverse momentum $l_\perp$.

The helicity-non-flip and helicity-flip amplitudes of the polarized proton off the spinless particle (a meson or unpolarized proton) can be written in terms of the invariant functions $\tilde{B}$ and $\tilde{K}$

$$F_{++}(s,t) = is[\tilde{B}(t)]\,f(t);\;\; F_{+-}(s,t) = is\frac{\sqrt{|t|}}{m}\tilde{K}(t)\,f(t), \tag{2}$$

where f(t) is determined by the Pomeron coupling with the other hadron. The functions $\tilde{B}$ and $\tilde{K}$ are defined by the integrated over $l_\perp$ structures from (1).

There are some models that provide spin-flip effects which do not vanish at high energies. In the model [1], the amplitudes K and B have a phase shift caused by the soft Pomeron rescattering effect. The vector diquarks in the diquark model [2] generate the K amplitude which is out of phase with the Pomeron contribution to the amplitude B. The value $|\tilde{K}|/|\tilde{B}| \sim 0.1$ found in [1, 2] will be used in our estimations of the asymmetry in diffractive hadron production.

The single spin asymmetry is determined by

$$A_N \sim 2\frac{\sqrt{|t|}}{m}\frac{\mathrm{Im}(BK^*)}{|B|^2}. \tag{3}$$

The models [1, 2] describe the experimental data on single spin transverse asymmetry A_N [6] quite well. Thus, the weak energy dependence of spin asymmetries in exclusive reactions is now not in contradiction with the experiment [1, 7].

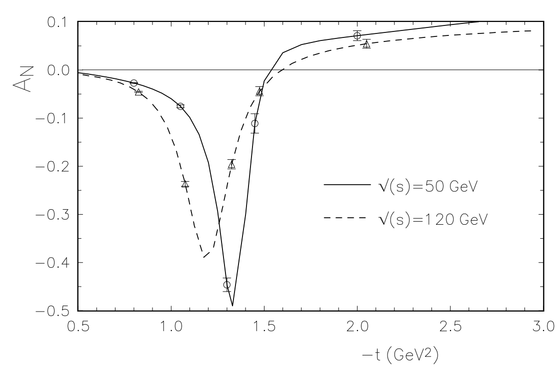

FIGURE 1. Predictions of the model [1] for single-spin transverse asymmetry of the *pp* scattering at RHIC energies [7]. Error bar indicates expected statistical errors for the PP2PP experiment at RHIC.

In the diffraction minimum the imaginary part of the amplitude B is equal to zero and the asymmetry is determined by the product $(\mathrm{Re}B\,\mathrm{Im}K)$. Thus, the asymmetry near the diffraction minimum is sensitive to the imaginary part of the spin–flip K, amplitude and study of the A_N asymmetry in the PP2PP experiment at RHIC can give a direct information about the energy dependence of the amplitude K. There are model predictions for A_N in this region. The model [1] predicts a large negative value of A_N asymmetry near the diffraction minimum which weakly depends on s at the RHIC energy range [7] and A_N is of about 10% for $|t| \sim 3\mathrm{GeV}^2$ (Fig.1). Other model predictions for single-spin asymmetry at small momentum transfer was discussed in [8].

The single spin asymmetry of diffractive $Q\bar{Q}$ production in polarized pp reaction was estimated in [9]. It was found that A_N is determined by Eq. (3) which is modified by the amplitude of hard $Q\bar{Q}$ production. The expected value of the single spin asymmetry in this case is about 5% in the RHIC energy range.

Let us study now diffractive double spin asymmetries of $Q\bar{Q}$ production in lepton-proton reactions for a longitudinally polarized lepton and a transversely polarized proton within the two-gluon model. This model should describe the cross sections of hard and light quark production at small $x < 0.1$ as well. The spin-dependent cross section can be written in the form

$$\frac{d^5\sigma(\pm)}{dQ^2 dy dx_p dt dk_\perp^2} = \binom{(2-2y+y^2)}{(2-y)} \frac{C(x_P, Q^2)\, N(\pm)}{\sqrt{1-4(k_\perp^2+m_q^2)/M_X^2}}. \tag{4}$$

Here $C(x_P, Q^2)$ is a normalization function which is common for the spin average and spin dependent cross section; $N(\pm)$ is determined by a sum of graphs integrated over the gluon momenta l and l'. The function $N(+)$ determines the spin-average cross section. It has the form

$$N(+) = \left(|\tilde{B}|^2 + |t|/m^2 |\tilde{K}|^2\right) \Pi^{(+)}(t, k_\perp^2, Q^2), \tag{5}$$

with

$$\begin{aligned}
\tilde{B} &\sim \int_0^{l_\perp^2 < k_0^2} \frac{d^2 l_\perp (l_\perp^2 + \vec{l}_\perp \vec{r}_\perp)}{(l_\perp^2+\lambda^2)((\vec{l}_\perp+\vec{r}_\perp)^2+\lambda^2)} B(t, l_\perp^2, x_P, \ldots) = F^g_{x_P}(x_P, t, k_0^2) \\
\tilde{K} &\sim \int_0^{l_\perp^2 < k_0^2} \frac{d^2 l_\perp (l_\perp^2 + \vec{l}_\perp \vec{r}_\perp)}{(l_\perp^2+\lambda^2)((\vec{l}_\perp+\vec{r}_\perp)^2+\lambda^2)} K(t, l_\perp^2, x_P, \ldots) = K^g_{x_P}(x_P, t, k_0^2),
\end{aligned} \tag{6}$$

where $k_0^2 \sim (k_\perp^2 + m_q^2)/(1-\beta)$. The connection of the two-gluon structure functions from (1) with GPD $F^g_{x_P}(x_P, t, k_0^2)$ and $K^g_{x_P}(x_P, t, k_0^2)$ is written. This connection is general and is shown for a vector meson and $Q\bar{Q}$ production in [5].

The function $N(-)$ which determines the spin-dependent cross sections looks like

$$\begin{aligned}
N(-) = \sqrt{\frac{|t|}{m^2}} \left(\tilde{B}\tilde{K}^* + \tilde{B}^*\tilde{K}\right) [&\frac{(\vec{Q}\vec{S}_\perp)}{m} \Pi_Q^{(-)}(t, k_\perp^2, Q^2) \\
&+ \frac{(\vec{k}_\perp \vec{S}_\perp)}{m} \Pi_k^{(-)}(t, k_\perp^2, Q^2)].
\end{aligned} \tag{7}$$

The other form of interference between B and K with respect to (3) appears in (7) because we consider here the double spin effects. The large value of asymmetry will appear for a small phase shift between the amplitudes.

The asymmetry is approximately proportional to the ratio of polarized and spin–average gluon distribution functions

$$A_{LT}^{Q\bar{Q}} \sim C^{Q\bar{Q}} \frac{K^g_\zeta(\zeta)}{F^g_\zeta(\zeta)} \quad \text{with } \zeta = x_P \text{ and } |\tilde{K}|/|\tilde{B}| \sim 0.1 \tag{8}$$

The spin-dependent contribution to the asymmetry which is proportional to $\vec{k}_\perp \vec{S}_\perp$ in (7) will be analyzed for the case when the transverse jet momentum $\vec{k}_\perp$ is parallel to the target polarization $\vec{S}_\perp$. The asymmetry is maximal in this case. To observe this contribution to asymmetry, it is necessary to distinguish experimentally the quark and antiquark jets. If we do not separate events with $\vec{k}_\perp$ for the quark jet, e.g., the resulting asymmetry will be equal to zero because the transverse momentum of the quark and antiquark are equal and opposite in sign.

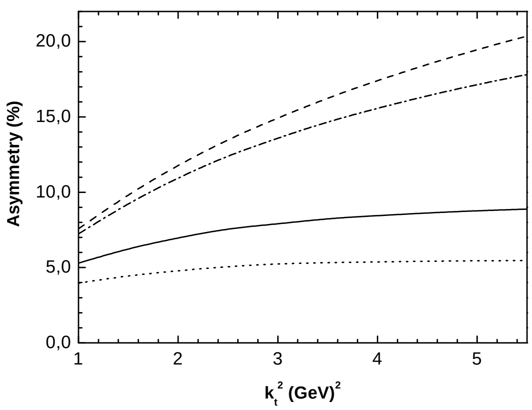

FIGURE 2. The A_{lT}^k asymmetry in diffractive heavy $Q\bar{Q}$ production at $\sqrt{s} = 20$GeV for $x_P = 0.1$, $y = 0.5$, $|t| = 0.3$GeV^2: dotted line-for $Q^2 = 0.5$GeV^2; solid line-for $Q^2 = 1$GeV^2; dot-dashed line-for $Q^2 = 5$GeV^2; dashed line-for $Q^2 = 10$GeV^2.

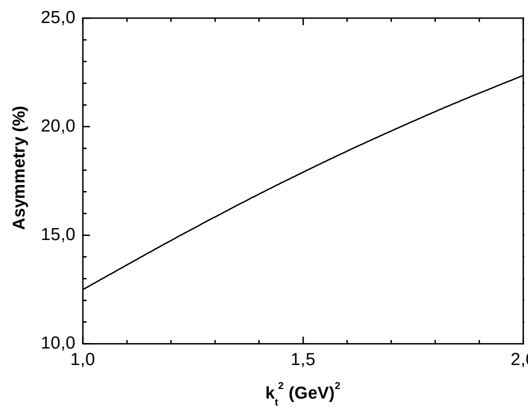

FIGURE 3. The A_{lT}^k asymmetry in diffractive light $Q\bar{Q}$ production for $Q^2 = 5$GeV^2, $x_P = 0.1$, $y = 0.5$, $|t| = 0.3(GeV)^2$ at $\sqrt{s} = 7$GeV.

The predicted asymmetry for heavy $c\bar{c}$ production at the COMPASS energies is shown in Fig.2. The asymmetry for light quark production is approximately of the same order of magnitude. The expected A_{lT} asymmetry for light quark production at HERMES is shown in Fig.3. The function $C_k^{Q\bar{Q}}$ in (8) is quite large, about 1.5 at the HERMES energy for $k_\perp^2 = 1.3$GeV^2, $Q^2 = 5$GeV^2, $x_P = 0.1$, $y = 0.5$, and $|t| = 0.3$GeV^2. The spin–dependent cross section vanishes for $Q^2 \to 0$, while the spin–average cross section is constant in this limit. As a result, the asymmetry can be estimated as $A_{lT} \propto Q^2/(Q^2+Q_0^2)$ with $Q_0^2 \sim 1$GeV^2. This shows a possibility of studying the polarized gluon distribution $K_\zeta^g(x)$ in the COMPASS and HERMES experiment at $Q^2 \geq 0.5$GeV^2.

The contribution to asymmetry $\propto \vec{Q}\vec{S}_\perp$ in (7) is simpler to study experimentally. The expected asymmetry in this case is not small too, about 5% or a little bit smaller. The predicted $C_Q^{Q\bar{Q}}$ in (8) in this case is about 0.3. In contrast to the A_{lT}^k term, the A_{lT}^Q asymmetry has a strong mass dependence [5].

Similar analyses have been carried out for diffractive J/Ψ production which is described by the same two-gluon exchange. Unfortunately, the double spin A_{lT} asymmetry in this case is proportional to x_P which is fixed here by $x_P \sim (m_V^2 + Q^2 + |t|)/(sy)$. As a result the expected asymmetry is small and $C_g(J/\Psi) \sim 0.007$ for vector meson production in the HERMES energy range. It is difficult to expect experimental study of such small asymmetry.

I this report we have studied the transverse asymmetries caused by the spin structure of the Pomeron coupling with the proton. Similar to the low energy experiments [6] we predict the large negative asymmetry in the vicinity of the diffractive minimum in elastic pp scattering at the RHIC energies. If the weak energy dependence of the asymmetry in this region is found in the PP2PP experiment at the RHIC, it will give a definite indication of the spin-dependent Pomeron coupling. Another possibility is to study the single-spin asymmetry of diffractive $Q\bar{Q}$ production at RHIC which is predicted to be about 5%.

The diffractive hadron leptoproduction for a longitudinally polarized lepton and a transversely polarized proton at high energies has been studied. The A_{lT} asymmetry is found to be proportional to the ratio of structure functions $A_{lT} = CK^g/F^g$. If the Pomeron has a spin structure, the ratio K^g/F^g should have a weak x dependence at low $x < 0.1$. The A_{lT} asymmetry can be used to get information on the transverse distribution $K^g_{x_P}(x_P, t)$ from experiment if the function C in (8) is not small. We predict that $C_k^{Q\bar{Q}} \sim 1$ for the term $\propto \vec{k}_\perp \vec{S}_\perp$ and $C_Q^{Q\bar{Q}} \sim 0.3$ for the contribution $\propto \vec{Q}\vec{S}_\perp$ in the asymmetry (7). We can see that the expected values of C are quite large and such asymmetries might be excellent objects to study transverse spin effects in the proton– gluon coupling.

The results presented here should be applicable to the reactions with heavy quarks. For processes with light quarks, our predictions can be used in the small x region ($x \leq 0.1$ e.g.) where the contribution of quark GPD is expected to be small. In the case of light quark production the polarized u and d quark GPD might be studied together with the gluon distribution in the region of not small $x \geq 0.1$. Such experiments can be conducted at the HERMES and COMPASS spectrometers for a transversely polarized target and future eRHIC. We conclude that important information on the spin–dependent GPD $K_\zeta(x)$ at small x can be obtained from the asymmetries in diffractive pp and lp reactions for longitudinally polarized lepton and transversely polarized hadron targets.

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REFERENCES

1. Goloskokov S.V., Kuleshov S.P., Selyugin O.V., Z. Phys. **C50** 455-464 (1991).
2. Goloskokov S.V., Kroll P., Phys. Rev. **D60** 014019 1-8 (1999).
3. Buttimore N.H. et al., Phys.Rev. **D59** 114010 1-18 (1999); Kopeliovich B.Z., "PP elastic scattering at low t". This Proceedings.
4. Radyushkin A.V., Phys. Rev, **D56** 5524-5557 (1997). Ji X., Phys.Rev. **D55** 7114-7125 (1997).
5. Goloskokov S.V., Euro. Phys. J. **C24** 413-424 (2002).
6. Fidecaro G. et al., Phys. Lett. **B76** 369-373 (1978), **B105** 309-314 (1981).
7. Akchurin N., Goloskokov S.V., Selyugin O.V., Int.J.Mod.Phys. **A14**, 253-269 (1999).
8. Martini A.F., Predazzi E., Diffractive effects in spin-flip pp amplitudes and predictions for relativistic energies. E-print: hep-ph/0209027.
9. Goloskokov S.V., Phys.Rev. **D53** 5995-5999 (1996).