Hard diffraction and proton spin problem

N.I. Kochelev

Institut für Theoretische Physik, Freie Universität Berlin,
Berlin, Germany

Abstract

It is shown, that the hard component of quarks distribution functions induced by
instantons gives the essential contribution to hard diffractive processes. We predict
large polarization effects in these processes.

Submitted to: Physics Letters B

1On leave of absence from Joint Institute for Nuclear Research,
Laboratory of High Energy, Head Post Office P.O.Box 79, SU-101000 Moscow, Russia
E-mail: kochelev@dec1.physik.fu-berlin.de
In the conventional approach the diffraction is connected with pomeron exchange Fig.1. In the framework of the perturbative QCD the "hard" pomeron appears as result of the sum of a gluon ladder and it has the very high intercept \( \alpha_{\text{hard}}(0) \approx 1.5 \). This value is contradicted by the experimental data on total, elastic and diffractive hadron-hadron cross-sections which support the conception of the "soft" pomeron \( \alpha_{\text{soft}}(0) \approx 1.08 \). On the other hand, this small intercept is contradicted by the new data on deep-inelastic structure functions \( \text{[3], [4]} \). For the explanation of the anomalous growth of these structure functions at low \( x \) the hard pomeron is more suitable \( \text{[3]} \). However, both of these kinds of pomeron can not explain the date from NMC \( \text{[6]} \) and EMC \( \text{[7]} \), where the large flavour and spin asymmetries of the sea quarks distribution functions have been observed.

In paper \( \text{[8]} \) the new mechanism for anomalous behavior of the structure functions has been proposed. It is related to the growth of the quark-quark cross-section induced by nonperturbative fluctuation of gluon fields-instantons \( \text{[1]} \).

In this paper it was shown that the mixture in the nucleon wave function of valence and sea quark components with high transfer momentum \( (k_{\perp} \approx 1 \text{GeV}) \) is induced by instantons \( \text{[10]} \), determines the growth of the structure function \( F_2^N(x) \) at \( 0.0001 < x < 0.1 \). At the same time the strong dependence of this interaction \( \text{[11]} \)

\[
\frac{sd_2^2 \sigma_{\text{diff}}^{\text{inst}}}{\pi d t d M_x^2} = \frac{9 \beta^4 (F_1(t))^2}{4 \pi^2} \left( \frac{s}{M_x^2}\right)^{2a_p(t)-1} (1 - \frac{M_x^2}{s}) F_2^{\text{inst}}(x),
\]

where \( \beta^2 = 3.43 \text{GeV}^2 \) is the parameter which is determined from the fit of elastic cross-sections, \( F_1(t) \) is the Dirac formfactor of the proton, \( x = Q^2/(M_x^2 + Q^2) \), \( Q^2 = -t \) and

\[
F_2^{\text{inst}}(x) = x(u_v^I(x) + d_v^I(x) + 2\bar{u}^I(x) + 2\bar{d}^I(x) + 2s^I(x)).
\]

In \( \text{[3]} \) \( q^I(x) \) is the instanton induced part of valence and sea quarks distribution functions.

In \( \text{[8]} \) from the consideration of the diagram Fig.2a the following form for instanton induced valence and sea chirality and flavour distribution functions were obtained:

\[
2\bar{u}_L^I(x) = \frac{2 N_f d_v(x) x^{a_v}}{3 \alpha_I} f_u(x), \quad 2\bar{u}_T^I(x) = \frac{1}{3} N_f d_v(x) x^{a_v} f_u(x),
\]

\[\text{For simplicity, we present here only the instanton-induced lagrangian for case } N_f = 2.\]

The case of \( N_f = 3 \) was considered in ref. \( \text{[12]} \).
by the Carlitz-Kaur model \[17\] and therefore it is taken in the form using quark-counting rules:

\[
2d^I_+(x) = \frac{1}{6} N_I u_v(x)x^{\alpha_v} f_u(x), \quad 2d^I_-(x) = \frac{5}{6} N_I u_v(x)x^{\alpha_v} f_u(x),
\]

\[
2s^I_+(x) = 2(\bar{u}^I_+(x) + \bar{d}^I_+(x)), \quad 2s^I_-(x) = 2(\bar{u}^I_-(x) + \bar{d}^I_-(x)),
\]

\[
u^I_{v+}(x) = \frac{5}{6} N_I u_v(x)x^{\alpha_v} f_u(x), \quad \nu^I_{v-}(x) = \frac{1}{6} N_I u_v(x)x^{\alpha_v} f_u(x),
\]

\[
d^I_{v+}(x) = \frac{2}{3} N_I d_v(x)x^{\alpha_v} f_u(x), \quad d^I_{v-}(x) = \frac{1}{3} N_I d_v(x)x^{\alpha_v} f_u(x), \tag{4}
\]

where \(N_I\) is a constant, \(u_v(x)\), \(d_v(x)\) are the valence distribution functions:

\[
u_v(x) = N_u x^{-\alpha_v}(1 - x)^{bu}, \quad d_v(x) = N_d x^{-\alpha_v}(1 - x)^{bd}, \tag{5}
\]

and

\[
f_u(x) = \begin{cases} 1, & \text{if } x > x_0; \\ \exp(-(x_0/x - 1)), & x \leq x_0. \end{cases} \tag{6}
\]

The quark sea induced by the perturbative gluons does not differ in chirality or flavor, and therefore it is taken in the form using quark-counting rules:

\[
\bar{u}(x)^p_{+,-} = \bar{d}(x)^p_{+,-} = 2\bar{s}(x)^p_{+,-} = N_s(1 - x)^{5/x^\alpha_{soft}(0)}. \tag{7}
\]

Chirality distribution functions for valence quarks have been chosen in the form given by the Carlitz-Kaur model \[17\]

\[
\Delta u_v(x) = (u_v(x) - 2d_v(x)/3)\cos\Theta_D(x) \quad \Delta d_v(x) = -(d_v(x)\cos\Theta_D(x)/3, \tag{8}
\]

where \(\cos\Theta_D(x)\) takes into account the depolarization of the valence quarks in the low \(x\)-region. The factor \(\cos\Theta_D(x)\) can be interpreted as the contribution of confinement forces to the valence quark chirality violation. It has the following form

\[
\cos\Theta_D(x) = (1 + H_1(1 - x)^2/x^\alpha_v)^{-1}. \tag{9}
\]

From \(4\)-\(9\) one can obtain the unpolarized \(\bar{q}(x) = \bar{q}_+(x) + \bar{q}_-(x)\) and the polarized \(\Delta \bar{q}(x) = \bar{q}_+(x) - \bar{q}_-(x)\) distribution functions. The values of the parameters obtained by fitting of unpolarized and polarized structure functions at \(Q^2 = 5 GeV^2\) are:

\[
\begin{align*}
bu &= 2.79; \quad bd = 3.46; \quad \alpha_v = 0.37; \quad N_s = 0.095; \\
N_I &= 0.0046; \quad H_1 = 0.14; \quad x_0 = 0.0005; \quad \alpha_I = 1.36.
\end{align*}
\]

The region \(-t = Q^2 \geq 1 GeV^2\) is related to the hard diffraction region \[15\] and therefore the equation \(2\) determines the contribution of instantons to the hard diffractive cross-section. The hard diffractive cross-section coming from the perturbative part of the proton wave function is given by the same formula \(2\) simply exchanging

2
$F_{2}^{\text{inst}}(x) \rightarrow F_{2}^{\text{pert}}(x)$, where $F_{2}^{\text{pert}}(x)$ is the singlet structure function without instanton contribution. Thus the fraction of events induced by instantons in hard diffractive processes is:

$$\frac{d\sigma_{\text{diff}}^{\text{inst}}(x)}{d\sigma_{\text{diff}}^{\text{tot}}(x)} = \frac{F_{2}^{\text{inst}}(x)}{F_{2}^{\text{pert}}(x) + F_{2}^{\text{inst}}(x)} \quad (10)$$

In Fig. 3 the result of the calculation of the instanton contribution is shown. From this picture we conclude, that the large fraction ($\approx 30\%$) of hard diffractive processes is induced by instanton interaction.

The sea quarks distribution, induced by instantons, has the valence like hard form at large $x$ \(\mathbb{I}\). To our point of view, this hard component has been already observed in the UA8 experiment \[18\]. In this experiment about 30\% of the observed hard diffraction events can be explained only by the hypothesis of the existence of the very hard sea component inside the proton.

It should be mentioned also that the H1 and ZEUS Collaborations have also observed the unusual events with the large rapidity gaps \[4\]. In the framework of the perturbative QCD these diffractive events are high twist in the deep-inelastic scattering \[19\]. Therefore they should have a very small cross-section. This prediction is in contradiction to experiment \[4\], where $5 \div 10\%$ events have a large rapidity gap. In the framework of the nonperturbative QCD, the instanton induced interaction gives the contribution to the DIS diffraction and to the hadron-hadron diffraction in the same order (see Fig. 2). It is connected with the structure of the lagrangian \(\mathbb{I}\), which includes the colourless exchanging part. This part can give the contribution to the DIS diffraction. The simple estimation of the matrix elements from the lagrangian \(\mathbb{I}\) shows that about 50\% from all events, induced by instantons, are without colour exchange between quarks. In the kinematical interval of the H1 and ZEUS Collaborations the instanton induced contribution to the $F_{2}^{\text{ep}}(x)$ structure function is $5 \div 30\%$ Fig. 4. Therefore, their contribution to the DIS diffraction is approximately $5 \div 15\%$ from all events with $10^{-1} < x < 10^{-4}$. This value is in agreement with the preliminary results from the H1 and ZEUS Collaborations \[4\].

It was pointed out above that interaction \(\mathbb{I}\) has a specific dependence from the chirality of the quarks. So, in the instanton field the chirality of the quarks is changed by the value $\Delta Q = -2N_{f}$. The changing of the quarks chirality leads to an appearance of the quarks orbital momentum. The direction of this orbital momentum is strong correlated with the direction of the spin of the proton \[11\]. Thus the problem of how the transfer of the total angular momentum to the orbital momentum of the quarks has to be described, is solved and then the proton spin problem has been decided.

The existence of the orbital motion of quarks leads to an appearance of one-spin asymmetries in hadron-hadron interactions \[20\], \[21\]. In the framework of these models the values of these asymmetries are determined by the value of the reduction of the quark spin contribution to the proton spin.

Instantons give the essential contribution to the reduction of the quarks spin contribution to the proton spin \[8\] and to hard diffractive processes. And therefore in these processes large polarized effects should be observed.
For example, we can estimate one-spin asymmetry in diffractive pp-collision by using the following formula:

\[ A(x) \approx \frac{\Delta \tilde{F}_2(x)}{\tilde{F}_2(x)}, \]  

where

\[ \Delta \tilde{F}_2(x) = x(\Delta u(x) + \Delta d(x) + \Delta s(x)) \]

and \( \Delta q(x) \) is the chirality carried by the proton quarks.

The result of the calculation of the one-spin asymmetry in hard diffraction pp-processes is shown in Fig.5. At large \( x \) the value of the one-spin asymmetry is determined by the chirality carried by the valence quarks and at low \( x \) region it is dependent from the chirality of the sea quarks. The value of the asymmetry at low \( x \) is determined by the contribution of the instantons and its large value comes from the large polarization of sea quarks in this region.

It should be stressed that the isosinglet combination \( (12) \) is the fraction of the proton spin carried by the quarks. Therefore the polarized hard diffractive processes allow to measure this value.

It is also very important that in these processes we can measure the chirality distributions of quarks at very low values for \( x \). For example, in the experiment UA8 \([18]\) the values of \( M_x^2 \) and \( t \) were changing in limits: \( M_x^2 = (2 \div 4)10^4 GeV^2; -t = (0.9 \div 2.3) GeV^2 \). This corresponds to the value \( x = 10^{-4} \). At present time such a small value of \( x \) is not accessible in DIS with polarized lepton beams. Therefore the measurement of one- and two-spin asymmetries in polarized hard diffraction at RHIC Spin Collaboration \([22]\) and at HERA \([23]\) can gives the unique possibility to find the decision of the proton spin problem.

The author is sincerely thankful to A.E.Dorokhov for useful discussions, Prof.Meng Ta-chung for warm hospitality at the Free University of Berlin and the DFG (Project: ME 470/7-1) for financial support.

References

[1] L.N.Lipatov Sov. Phys. JETP 63 (1986) 904;  
E.A.Kuraev, L.N.Lipatov, V.S.Fadin Sov. Phys. JETP 45 (1977) 199

[2] A.Donnachie, P.V.Landshoff Nucl. Phys B231 (1984) 189

[3] NMC Phys. Lett. B295 (1992) 159

[4] H1 Collaboration, Report on PANIC’93 Conference, Preprint DESY 93-113;  
ZEUS Collaboration. Report on PANIC’93 Conference.

[5] A.D.Martin, W.J.Stirling, R.G.Roberts Phys. Lett. B306 (1993) 145.
[6] NMC, P.Amaudruz et al. *Phys. Rev. Lett.* **66** (1991) 2712; Preprint CERN-PPE/93-1993.

[7] EMC, J.Ashman et al. *Nucl. Phys.* **B328** (1990) 1.

[8] N.I.Kochelev Preprint FUB-HEP/93-13 [hep-ph/9307246], submitted to *Phys. Lett.*

[9] A.Ringwald *Nucl. Phys.* **B330** (1990) 1;
O.Espinosa *Nucl. Phys.* **B343** (1990) 310;
I.I.Balitsky, M.G.Ryskin *Phys. Lett.* **B296** (1992) 185.

[10] A.E.Dorokhov, N.I.Kochelev *Phys. Lett.* **B259** (1991) 335;
*Phys. Lett.* **B304** (1993) 167; *Int. J. of Mod. Phys.* **A8** (1993) 603.

[11] 't Hooft *Phys. Rev.* **D14** (1976) 3432.

[12] M.A.Shifman, A.I.Vainstein, V.I.Zakharov *Nucl. Phys.* **B163** (1980) 46.

[13] K.Gottfried *Phys. Rev. Lett.* **18** (1967) 1154

[14] J.Ellis, R.L.Jaffe, *Phys. Rev.* **D9** (1974) 1444.

[15] H.Fritzsch, K.H.Streng *Phys. Lett.* **B164** (1985) 391;
G.Ingelman, P.E.Schlein *Phys. Lett.B152* 256;
E.L.Berger, J.C.Collins, D.E.Soper, G.Sterman *Nucl. Phys.* **B286** (1987) 704;
A.Donnachie, P.V.Landshoff *Nucl. Phys.* **B303** (1988) 634;
L.Frankfurt, M.Strikman *Phys. Rev. Lett.* **63** (1989) 1914;
J.C.Collins, L.Frankfurt, M.Strikman *Phys. Lett.* **B307** (1993) 161.

[16] A.Donnachie, P.V.Landshoff *Nucl. Phys.* **B244** (1984) 322

[17] R.D.Carlitz, J.Kaur *Phys. Rev. Lett.* **38** (1977) 673.

[18] UA8 Collaboration *Phys. Lett.* **B297** (1992) 417.

[19] A.Donnachie, P.V.Landshoff *Phys. Lett.* **B285** (1992) 172;
Hung Jung Lu, Joseph Milana *Phys. Lett.* **B313** (1993) 234;
see also the last reference in [15].

[20] N.I.Kochelev, M.V.Tokarev *Phys. Lett.* **309** (1993) 416.

[21] C.Boros, Liang Zuo-Tang, Meng Ta-chung *Phys. Rev. Lett.* **70** (1993) 1751.

[22] RHIC Spin Collaboration,G Bunce et al. *Part. World* **3** (1992) 1.
[23] HERMES Collaboration, report on PANIC’93 Conference; 
Wolf-Dieter Nowak, Single spin asymmetries in proton-proton scattering 
at HERA energies, preprint DESY 93.
Figure Captions:

**Fig.1**: Hard diffractive process.

**Fig.2**: The contribution to the a) DIS structure functions and b) diffraction due to instantons. The circle is an instanton.

**Fig.3**: The dependence of the fraction of the hard diffraction processes induced by instantons from the variable \( x = -t/M^2_x \).

**Fig.4**: The dependence of the instantons induced contribution to the DIS structure function \( F_2^{ep}(x) \) from the Bjorken variable \( x \).

**Fig.5**: The dependence of the one-spin asymmetry in the hard diffractive processes from variable \( x = -t/M^2_x \). Dashed line is the result of the calculation without instanton contribution.
This figure "fig1-1.png" is available in "png" format from:

http://arxiv.org/ps/hep-ph/9312310v1
This figure "fig2-1.png" is available in "png" format from:

http://arxiv.org/ps/hep-ph/9312310v1
This figure "fig1-2.png" is available in "png" format from:

http://arxiv.org/ps/hep-ph/9312310v1
This figure "fig2-2.png" is available in "png" format from:

http://arxiv.org/ps/hep-ph/9312310v1
This figure "fig1-3.png" is available in "png" format from:

http://arxiv.org/ps/hep-ph/9312310v1