CALCULATION POLARIZATION EFFECTS IN THE PROTON - PROTON SCATTERING IN FRAME PERTURBATIVE QCD

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Regarding the fact that protons are formed by quarks, using Feynman gauge in perturbative quantum chromodynamics (PQCD) we calculated the differential cross-sections and the spin asymmetry of the hadron of the elastic proton-proton scattering.

1. As it is well known that the hadron physics can be explained by the quantum choromodynamics and this theoretical suggestion is supported by experiments carried out up to the present day. Obviously, to prove experimentally the validity of QCD proposals, the processes of the elastic and inelastic proton-proton scattering have a great importance.

In the high energy pp- interaction there is a scattering from the color charge between the incident proton quark and the target proton quark. In this situation, it is the inside area of the nucleon where the color charge is effective, and here the strong interaction constant is small, i.e. $\alpha_s(Q^2) < 0,14$. Therefore, since in this area perturbation is applicable to the calculations, we can use perturbative quantum chromodynamics (PQCD).

In QCD the Lagrangian of the strong interaction can be written as [1]:

$$L_{QCD} = \overline{q}\,(i\partial - m)\,q - g_s(\overline{q}\gamma_\mu T^a q)\,B_a^\mu - \frac{1}{4}G_{\mu\nu}^a G_a^{\mu\nu} \qquad (1)$$

where

$$G_{\mu\nu}^a = \frac{\partial B_\mu^a}{\partial x_\nu} - \frac{\partial B_\nu^a}{\partial x_\mu} + g_s f_{abc} B_\mu^b B_\nu^c .$$

Here $T^a = \dfrac{\lambda^a}{2}$ is the generator of the color group $SU_c(3)$, q is the wave function of the quark field, B_μ^a is the gluon field, f^{abc} - is the antisymmetric structure constant, and g_s - is the strong interaction constant.

Polarization effects are challenging especially from PQCD point of view, because in leading order massless QCD conserves helicity, whereas substantial helicity non-conserving effects have been observed experimentally [2-4].

The recent EMC measurement [5] of $g_1(x,Q^2)$ which is the structure function of spin dependence has renewed the interest in measurements of $g_1(X,Q^2)$ this X and Q^2. Several experiments have been proposed to check EMC results an to make additional measurements which should clarify the situation of spin dependence $g_1(x,Q^2)$ in the elastic pp-scattering [6-8]. Furthermore, some of the polarization effects which have been measured to be non-zero arise only when there are non-vanishing relative phases between various helicity amplitudes. It is commonly thought that in leading order perturbation all phases vanish, leading to the widespread but erroneous claim that the observed polarization effects are incompatible with PQCD predictions. This would be true if there were no integrations over quark functions [11].

It has been shown previously that in the inelastic proton-proton scattering whereas in the transverse polarization spin effects vanish with increasing energy but in the longitudinal polarization spin effects continue even at very high energies [9].

For this reason, in the present study we have calculated the asymmetry due to the polarization for the elastic pp-scatterings at high energies taking into account quark spin in PQCD.

2. Using Feynman gauge and considering all lowest order Feynman diagrams in QCD we get the following expression for the square of matrix element of the quark - quark scattering after summing over the spin and color;

$$|M|^2 = -\{ (P_1P_2) (P_3P_4) (S_2S_4) - (P_1P_2) (P_3S_4) (P_4S_2) -$$

$$- (P_1P_3) (P_2P_4) (S_2S_4) + (P_1P_3) (P_2S_4) (P_4S_2) + (P_1P_4) (P_2P_3) (S_2S_4) -$$

$$- (P_1P_4) (P_2P_3) - (P_1P_4) (P_2S_4) (P_3S_2) + (P_1S_2) (P_2P_4) (P_3S_4) -$$

$$- (P_1S_2) (P_2S_4) (P_3P_4) (P_1S_4) (P_2P_3) (P_4S_2) + (P_1S_4) (P_2P_4) (P_3S_2) \}/$$

$$/ (P_1P_3)^2 - [(P_1P_2) (P_3P_4) (S_2S_3) - (P_1P_2) (P_3P_4) - (P_1P_2) (P_3S_2) (P_4S_3) +$$

$$+ (P_1P_3) (P_2P_4) (S_2S_3) - (P_1P_3) (P_2P_4) - (P_1P_3) (P_2S_3) (P_4S_2) -$$

$$- (P_1P_4) (P_2P_3) (S_2S_3) + (P_1P_4) (P_2S_3) (P_3S_2) + (P_1S_2) (P_2P_4) (P_3S_4) -$$

$$- (P_1S_2) (P_2S_3) (P_3P_4) + (P_1S_3) (P_2P_3) (P_4S_2) - (P_1S_3) (P_2P_4) (P_3S_2)] /$$

$$/ (P_1P_4)^2 + [(P_1P_2) (P_3P_4) (S_2S_3) + (P_1P_2) (P_3P_4) (S_2S_4) +$$

$$+ (P_1P_2) (P_3P_4) (S_3S_4) - 2 (P_1P_2) (P_3P_4) - (P_1P_2) (P_3S_2) (P_4S_3) -$$

$$- (P_1P_2) (P_3S_4) (P_4S_2) - (P_1P_2) (P_3S_4) (P_4S_3) + (P_1P_3) (P_2P_4) (S_2S_3) -$$

$$- (P_1P_3) (P_2P_4) (S_2S_4) - (P_1P_3) (P_2P_4) (S_3S_4) - (P_1P_3) (P_2S_3) (P_4S_2) +$$

$$+ (P_1P_3) (P_2S_4) (P_4S_2) + (P_1P_3) (P_2S_4) (P_4S_3) - (P_1P_4) (P_2P_3) (S_2S_3) +$$

$$+ (P_1P_4) (P_2P_3) (S_2S_4) - (P_1P_4) (P_2P_3) (S_3S_4) + (P_1P_4) (P_2S_3) (P_3S_2) +$$

$$+ (P_1P_4) (P_2S_3) (P_3S_4) - (P_1P_4) (P_2S_4) (P_3S_2) + (P_1S_2) (P_2P_3) (P_4S_3) +$$

$$+ (P_1S_2) (P_2P_4) (P_3S_4) - (P_1S_2) (P_2S_3) (P_3P_4) - (P_1S_2) (P_2S_4) (P_3P_4) +$$

$$+ (P_1S_3) (P_2P_3) (P_4S_2) - (P_1S_3) (P_2P_4) (P_3S_2) + (P_1S_3) (P_2P_4) (P_3S_4) -$$

$$- (P_1S_3) (P_2S_4) (P_3P_4) - (P_1S_4) (P_2P_3) (P_4S_2) + (P_1S_4) (P_2P_3) (P_4S_3) +$$

$$+ (P_1S_4) (P_2P_4) (P_3S_2) - (P_1S_4) (P_2S_3) (P_3P_4)] / (P_1P_3) (P_1P_4) \qquad (2)$$

Here, quark masses are neglected and one of the incident particles has been taken unpolarized. Then we find the differential cross-section in the center of mass system as

$$\frac{d\sigma}{d\Omega} = \frac{9g_s^4}{8192 \cdot \Pi^2 E^2} \cdot K |M|^2 \qquad (3)$$

where (K is the constant resulting from quark - antiquark, gluon loops)

$$K = \left[1 + \left(\frac{13}{6} - \frac{\xi}{2} \right) \left(\eta - \ln \frac{-q^2}{\mu^2} - 1 \right) n - \frac{2}{3} \left(\eta - \ln \frac{-q^2}{\mu^2} + \frac{5}{3} - \ln 2 \right) n_f + \right.$$

$$+\frac{175}{36}n+\frac{\xi^2}{4}n\Bigg]^{7} \tag{4}$$

with

$$q^2=(p_1-p_3)^2,\ n_r=3,\ n=3,\ \mu^2=0,1;\ \xi=0,1;\ \eta=\ln\frac{M^2}{\mu^2}$$

Taking into account contributions of only the fourth component (helicity) of the spin, and overgoing from quarks to real particles (protons) the differential cross-section of the process ($p_{quark}\to p_{proton}$) becomes

$$\frac{d\sigma}{d\Omega}=\frac{9a_s^2}{512}K\Bigg\{\frac{2+2x^2+x^4+2x^2\cos\theta+x^4\cos^2\theta+(\cos\theta-x^2)\xi_2\xi_4}{(1-x^2\cos\theta)^2}+$$

$$+\frac{2+2x^2+x^4-2x^2\cos\theta+x^4\cos^2\theta-(\cos\theta+x^2)x^2\xi_2\xi_3}{(1+x^2\cos\theta)^2}+$$

$$+\frac{-2-6x^4+2x^4\xi_2\xi_4+(x^2-1-2x^2\cos^2\theta)\xi_3\xi_4}{(x^4\cos^2\theta-1)}\Bigg\} \tag{5}$$

Here $a_s=\frac{g_s^2}{4\Pi}$, x- is the amount of momentum shared be each proton quark, θ and is the scattering angle. The helicities of protons are indicated by ξ_2 before, and by ξ_3 and ξ_4 after the scattering. In the case of $\xi_3=\xi_4$, the differential cross section has the following form;

$$\frac{d\sigma}{d\Omega}=\frac{9a_s^2}{512}K\Bigg\{\frac{2\,(3+4x^2+2x^4+6x^4\cos^2\theta+x^8\cos^4\theta)}{(1-2x^4\cos^2\theta+x^8\cos^4\theta)}+$$

$$+\frac{1-5x^2+6x^2\cos^2\theta-x^4\cos^2\theta+x^6\cos^2\theta-2x^6\cos^4\theta}{1-2x^4\cos^2\theta+x^8\cos^4\theta}\xi_2\xi_4\Bigg\} \tag{6}$$

In order to analyse the expression (6), the differential cross section is plotted as a function of x and $\cos\theta$ in figures 1 and 2, respectively. As seen from the Fig.1, for a definite value of $\cos\theta$ the differential cross section is increasing as x increases. The rate of increase is greater for larger values of $\cos\theta$, and if quarks have a large portion of the proton
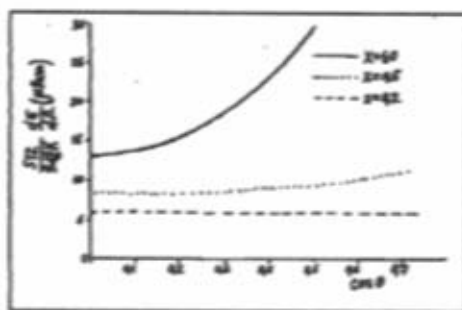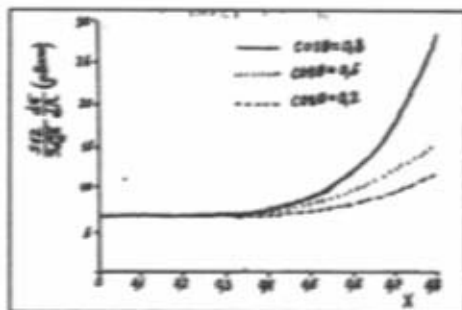
Fig.1. The differential cross section
as function of x for $pp \to pp$

Fig.2. The differential cross section
as function of $\cos\theta$ for $pp \to pp$.

momentum it becomes much more greater than the values for small $\cos\theta$. In other words, compared with small values of $\cos\theta$ the increase is more pronounced for large $\cos\theta$. The Fig.2 shows that although variation of the di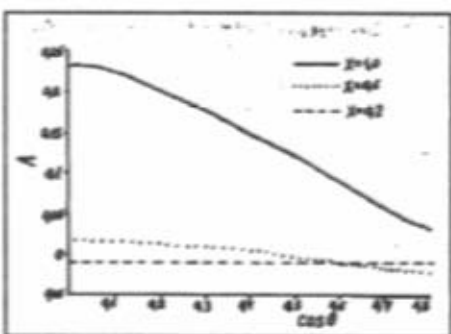fferential cross section with $\cos\theta$ is very small for certain small values of x it increases distinctly for $x = 1$.

Fig.3. The spin asymmetry as
function $\cos\theta$ for $pp \to pp$.

Using the expression (6), the parallel and antiparallel polarization asymmetries of hadron may be defined as

$$A = \frac{\frac{d\sigma}{d\Omega}(\uparrow\uparrow) - \frac{d\sigma}{d\Omega}(\uparrow\downarrow)}{\frac{d\sigma}{d\Omega}(\uparrow\uparrow) + \frac{d\sigma}{d\Omega}(\uparrow\downarrow)} \qquad (7)$$

For the spin asymmetry we have the following expression

$$A(x,\theta) = \frac{(1 - 5x^2 + 6x^2\cos^2\theta - x^4\cos^2\theta + x^6\cos^2\theta - 2x^6\cos^4\theta)x^2}{2(3 + 4x^2 + 2x^4 + 6x^4\cos^2\theta + x^8\cos^4\theta)} \qquad (8)$$

In Fig.3, the variation of $A(x,\theta)$ with $\cos\theta$ is given for certain values. This variation is very small for $0,2 < x < 0,5$, but for $x = 1$, $A(x,\theta)$ decreases from 0,25 to 0,05 as $\cos\theta$ increases.

3. Due to perturbative QCD effects in the elastic pp-scattering, the gluon interaction is more effective and the differential cross section of the elastic scattering becomes maximum if the quark has a large portion of the proton momentum. If quark have a very small portion of the proton momentum, the angle dependence of the spin asymmetry is weak. When $x = 1$ we think that for small values of QCD spin effects originate from gluon exchanges of the pp-interaction. For small values of x the dependence on $\cos\theta$ is very weak. At large scattering angles, the quark

taking a large portion of the momentum, QCD spin asymmetry have a maximum value of about 25%.

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PERTURBATİV KVANT XROMODİNAMİKASINDA PROTON-PROTON SƏPİLMƏSİ ÜÇÜN POLYARİZASİYA EFFEKTLƏRİNİN NƏZƏRƏ ALINMASI

İşdə perturbativ kvant xromodinamikasında Feynman kalibrovkasından istifadə edərək protonun - protondan elastiki səpilməsi prosesinin diferensial effektiv kəsiyi və adronun spin asimmetriyası hesablanmışdır.

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УЧЕТ ПОЛЯРИЗАЦИОННЫХ ЭФФЕКТОВ В ПРОТОН - ПРОТОННОМ РАССЕЯНИИ В РАМКАХ ПЕРТУРБАТИВНОЙ КХД

В настоящей работе в рамках пертурбативной квантовой хромодинамики с использованием калибровки Фейнмана вычислены дифференциальное эффективное сечение и спиновая асимметрия адрона при упругом протон-протонном рассеянии.