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SLOPE OF DIFFERENTIAL CROSS SECTIONS AND SIZE OF HADRON SPIN-FLIP AMPLITUDE

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The determination of the structure of the hadron scattering amplitude is an important task both for theory and experiment. The Perturbative Quantum Chromodynamics is unable to calculate the real and imaginary parts of the scattering amplitude in the diffraction range. On the one hand, the usual Regge representation says that the spin-flip amplitude dies out at superhigh energies, and on the other hand there are different nonperturbative models which lead to nondying spin-flip amplitude at superhigh energies [1]. Moreover, some models show the possibility that the ratio of the spin-flip to non-flip amplitude (not including the kinematical factor) can reach ± 1 [2].

There are now large spin programs at RHIC, LHC. These programs include measurements of the spin correlation parameters in the diffraction range of elastic proton-proton scattering. There is a proposal to use the Coulomb-nucleon interference (CNI) effects [3] to measure the beam polarization very accurately and in on-line regime [4, 5, 6]. This effect appears from the interference of the imaginary part of the hadron non-spin-flip amplitude Φ_1^h and the real part of the electromagnetic spin-flip amplitude Φ_5^e determined by the magnetic moment of the nucleon. The objections against this project say that the possible unknown hadron spin-flip amplitude can give a noticeable contribution to the CNI effect.

Unfortunately, we practically have no experimental data on the measurement of the spin correlation parameters at very small transfer momenta except the experiment [7] but with large statistical errors. After work [8], a number of papers, which consider these questions and try to estimate a possible contribution of the hadron-spin-flip amplitude to the CNI effect [9, 10, 11], appeared. But the question remains unclear as we have very different conclusions.

In this paper, we examine a possible way to learn something about the hadron spin-flip amplitude Φ_5^h at very small transfer momenta independently of the knowledge of the beam polarization. For that, we will concentrate ourselves mainly on the form of the differential cross sections at small transfer momenta.

With the usual high energy approximation for the spiral amplitudes at very small transfer momenta we suppose that $\Phi_1 = \Phi_3$ and Φ_2 , Φ_4. negligible at high energy and small t. This is true for the electromagnetic amplitudes and only an assumption for the hadron amplitudes

There are many different systems of the representations of the hadron spin-flip amplitude and the analyzing power. In this work, as we discuss the slope of the differential cross sections, we follow the paper [11]. Hence, for the hadron spin flip amplitude we have

$$\Phi_5^h = \tau \sqrt{|t|/m^2}\Phi_1^h, \tag{1}$$

where τ is an unknown complex function of s, but we assume that it is independent of t in the domain of small transfer momenta. It was shown [12] that such an assumption is fulfilled for the spin-flip amplitude at $p_L = 6\ GeV/c$ and in [13] it has been shown that it is correct at higher energies and $|t| \leq 0.1\ GeV^2$.

Numerous discussions of the value of the ratio of the real-to-imaginary part of the forward spin-non-flip amplitude $\rho = ReF^{nf}/ImF^{nf}$ measured by UA4/2 [14] Collaborations at $\sqrt{s} = 546\ GeV$ have revealed the ambiguity in the definition of this parameter [15], and as a result, it has been shown that we have some trouble in the definition of the total cross sections and the value of the real part of the scattering amplitude. Of course, we should develop new experimental and theoretical methods to obtain the exact values of the hadron differential cross sections and the structure of the hadron spin-non-flip amplitude [16]. In this paper, we suppose that we know the differential cross- sections of the elastic nucleon scattering sufficiently well.

For the differential cross sections we have

$$\frac{d\sigma}{dt} = \frac{1}{16\pi}(1+\rho^2)\sigma_{tot}^2(1-2|\tau|^2\frac{t}{m^2})e^{b_0 t}. \quad (2)$$

where $b_0/2$ is the slope of the imaginary part of the hadron spin-non-flip amplitude supposed constant at very small transfer momenta.

Can we determine the size of the hadron spin-flip amplitude from the exactly measured differential cross sections? In paper [11] we have got a negative answer. But the formula from that paper

$$b' = b - 2\frac{|\tau|^2}{m^2} + 2\frac{|\tau|^4 t}{m^4} + O(t^2). \quad (3)$$

was derived in some approximation and in (3) some information was lost . It is clear from the form of the hadron spin-flip amplitude that at very small transfer momenta this amplitude grows very fast and the slope of differential cross section should somewhat decrease when $t \to 0$. At some point of t this amplitude reaches its maximum and the slope of differential cross sections will be very close to the slope of the spin-non flip amplitude.

If we calculate the slope without approximation, we can obtain an exact form of the slope of the differential cross section in the presence of the hadron spin-flip amplitude

$$b(t) = b_0 - 2\frac{\tau^2}{2\tau^2|t|+m^2} \quad (4)$$

It can be seen from (4) that we have the dependence of the slope on transfer momenta. For example, let us examine the situations at $\sqrt{s} = 500\ GeV$. If we have the large spin-flip amplitude, i.e. with $\tau^2 = 1$, we have for $b_0 = 17.5 GeV^{-2}$

$$b_t(|t| = 0.001) = 15.23\ GeV^{-2}; \quad b_t(|t| = 0.12) = 15.71\ GeV^{-2}. \quad (5)$$

These calculations are shown in Fig.1 by the full line (the numerical calculations are direct from (2)) and by the circles (the calculations in (4)). In this case, we can find the deviation of the slope of the differential cross sections at the different ranges of t.

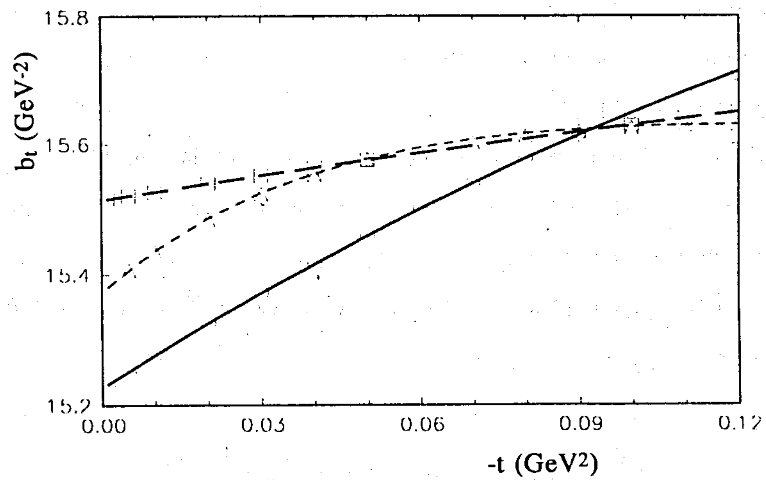

Fig. 1: Slope of the differential cross sections calculated by numerically directly from differential cross sections (2),(7)/lines/ and by formula (4) /circle and square/ and by formula (8) /triangle/. [$\sqrt{s} = 500\ GeV$]

If $\tau^2 = 0.5$, the slope of the differential cross sections for $b_0 = 16.65\ GeV^{-2}$ will be

$$b_t(|t| = 0.001) = 15.51\ GeV^{-2}; \quad b_t(|t| = 0.12) = 15.65\ GeV^{-2}. \quad (6)$$

These calculations are shown in Fig.1 by the dashed line (the numerical calculations are from (2)) and by square (the calculations in (4)).

This deviation of the slope is already very small and we can find it only in a very precise experiment. This size of τ is in fact the bound on which we can find the size of the spin-flip amplitude in differential cross sections with our supposition about the size and form of the hadron spin-flip amplitude.

However, such suppositions can lead to a large contribution of the spin-flip amplitude to the differential cross sections when the kinematical factor $\sqrt{|t|}$ grows to unity. The behavior of differential cross sections of the nucleon-nucleon scattering in the region of $\sqrt{s} \simeq 30\ GeV$ says about another situation. From fig.1 we can see that the slope grows rather fast in the case of a large spin-flip amplitude. If we want to explain the experimental data without special additional suppositions about the spin-non-flip amplitude, we come to the conclusion that the spin-flip amplitude is either very small or has the slope larger than that of the spin-non-flip amplitude.

Let us suppose that the slope of the spin flip amplitude is larger on $\Delta B/2$ than the slope of the spin-non-flip amplitude. In this case, we have for the differential cross sections:

$$\frac{d\sigma}{dt} = \frac{1}{16\pi}(1+\rho^2)\sigma_{tot}^2(1-2|\tau|^2\frac{t}{m^2}e^{\Delta bt})e^{b_0 t}. \tag{7}$$

And for the total slope b_t we obtain

$$b_t(t) = b_0 - \frac{2\tau^2(1+t\Delta b)}{m^2+2\tau^2|t|exp(\Delta bt)}e^{\Delta bt}. \tag{8}$$

If we take, for example, the slope of the hadron spin-flip amplitude without the kinematical factor in twice larger than the slope of the hadron spin-non-flip amplitude ($\Delta b = b_0$), we can find the influence of the spin flip amplitude on the

behavior of the slope at very small transfer momenta with more precise values. The minimum of the size, on which we can establish the existence of the spin flip amplitude in a very precise experiment, sufficiently decreases and reaches $\tau^2 \simeq 0.1$. For that case we obtain with $b_0 = 15.6\ GeV^{-2}$

$$b_t(|t|=0.001) = 15.38\ GeV^{-2}; \quad b_t(|t|=0.12) = 15.63\ GeV^{-2}. \tag{9}$$

This case is shown in Fig.1 by the dotted line (the numerical calculations from the differential cross sections) and the triangles (the calculations by formula (8)). From these calculations we can see that this case does not contradict the existing experimental data. This situation probably exists in the very precise experiment of the UA4/2 Collaboration [14] and has been analyzed in paper [15].

In Fig.2, it is shown that if one reduces the interval of transfer momenta from $|t| = 120.\cdot 10^{-3}GeV^2$ to $|t| = 18\cdot 10^{-3}GeV^2$, one will obtain a new value ρ_i and the slope of the imaginary part of spin-non flip amplitude $b_i/2$. We show that ρ_i grows and b_i decreases in magnitude. But if we take into account the spin-flip amplitude with the slope $b_{sf}/2 = 2(b_{nf}/2)$, we restore the usual exponential form of the spin-non-flip amplitude (see fig.2).

Of course, this method gives only the absolute value of the coefficient of the spin-flip amplitude. Separately, sizes of the imaginary and real parts of the spin-flip amplitude can be found only from the measurements of the spin correlation coefficient. But, in any case, the upper bound of the size of the hadron spin-flip amplitude gives the valuable information for obtaining the structure of the hadron spin-flip amplitude by using the form of analyzing power independently of the knowledge of the beam polarization.

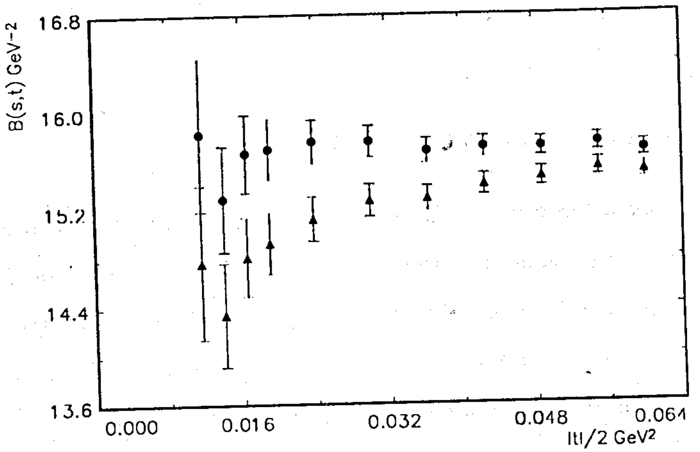

Fig. 2: The dependence of the slope - b_0 on the experimental interval of t is obtained from UA4/2 data ; (triangles are without the spin-flip part and circles are with the spin-flip part of the scattering amplitude)

So, in this paper we show that a very precise experiment measuring the spin-average cross sections carried out at superhigh energies can give valuable information from which we can obtain the size of the hadron-spin flip amplitude but only after a rather careful and complicated analysis. After that, one can use the CNI effect for the precise measurement of the beam polarization. Further theoretical researches are required to find the structure of the hadron spin-flip amplitude and the relative size of its real and imaginary parts at superhigh energies. It will help to in developing an experimental procedure to extract this information from experimental data.

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