Is there a hadron spin-flip contribution
to the Coulomb-hadron interference at small transfer momenta
and high energies

O.V. Selyugin
BLTPh, JINR, Dubna, Russia

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Abstract. The analysing power \( A_N \) is examined in the range of the Coulomb-hadron interference on the basis of the experimental data from \( p_L = 6 \, \text{GeV/c} \) up to \( 200 \, \text{GeV/c} \) taking account of a phenomenological analysis at \( p_L = 6 \, \text{GeV/c} \) and a dynamic high-energy spin model. The results are compared with the new RHIC data at \( p_L = 100 \, \text{GeV/c} \). The new experimental data obtained at RHIC indicate small contributions of the hadron spin-flip amplitude.

PACS. 11.80.Cr Analysing power, Coulomb-hadron interference, - 13.85.Dz Elastic scattering

1 Introduction

Most of the recent experiments require the knowledge of the polarization of beams with high accuracy. This especially relates to the large spin programs at RHIC. 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 \cite{1} to measure very exactly and fast the beam polarization \cite{2}. This effect appears from the interference of the imaginary part of the hadron non-spin-flip amplitude and the real part of the electromagnetic spin-flip amplitude determined by the charge-magnetic moment interaction. Now the new very precise experimental data are obtained at RHIC \cite{8,13}.

Determination of the structure of the hadron scattering amplitude is an important task for both the theory and experiment. Perturbative Quantum Chromodynamics cannot be used in calculation of the real and imaginary parts of the scattering amplitude in the diffraction range. A worse situation is for the spin-flip parts of the scattering amplitude in the domain of small transfer momenta. On the one hand, the usual representation says that the spin-flip amplitude dies at superhigh energies, and, on the other hand, we have different non-perturbative models which lead to a non-dying spin-flip amplitude at superhigh energies \cite{1,3,6,7}.

Note that the interference of the hadronic and electromagnetic amplitudes may give an important contribution not only at very small transfer momenta but also in the range of the diffraction minimum \cite{8}. However, for that one should know the phase of the interference of the Coulombic and hadronic amplitude at sufficiently large transfer momenta too.

Before the RHIC experiments experimental data on the measurement of the spin correlation parameters at very small transfer momenta were very poor except the unique experiment \cite{4} though with large errors. After the first paper \cite{10} a number of papers appeared which considered these questions and tried to estimate a possible contribution of the hadron-spin-flip amplitude to the CNI effect \cite{11,12,13}.

Our difficulty is mostly defined by the lack of experimental data at high energies and small transfer momenta. We should examine the available experimental data at different energies and in different domains of transfer momenta. In most analyses the experimental data at \( p_L = 45.5 \, \text{GeV/c} \) and with \( 0.06 < |t| < 0.5 \, \text{GeV}^2 \) and the data at \( p_L = 200 \, \text{GeV/c} \) with \( 0.003 < |t| < 0.05 \) are used. These experimental data overlap on the axis of transfer momenta but are measured at different energies. In most analyses the energy difference of all parameters determining the scattering amplitude is not considered. Of course, we have plenty of experimental data in the domain of small transfer momenta at low energies \( 3 < p_L < 12 \) (GeV/c).

At these energies we have many contributions to the hadron-spin-flip amplitudes coming from different regions of exchange. In \cite{13} note that at not-high energies the Reggions \( \rho \) and \( A_2 \) give a dominant contributions in the hadron spin-flip amplitude. However, Regge-pole-exchange contributions occur in exchange-degenerate pairs, their imaginary parts cancelling. Now we cannot exactly calculate all contributions and find their energy dependence. However, a great amount of the experimental material allows us to make full phenomenological analyses, and obtain the size and form of the different parts of the hadron scattering amplitude. The difficulty is that we do not know the energy dependence of these amplitudes and individual
contributions of the asymptotic non-dying spin-flip amplitudes. As was noted in [15], the spin-dependent part of the interaction in pp scattering is stronger than was expected and a good fit to the data in the Regge model requires an enormous number of poles.

Usually, one takes the assumptions that the imaginary and real parts of the spin-non-flip amplitude have the exponential behavior with the same slope and the imaginary and real parts of the spin-flip amplitudes, without the kinematic factor \( \sqrt{t} \). For example, in [15], the spin-flip amplitude was chosen in the form

\[
F^f_t = \sqrt{-t/(2m_p)}(R_5 + iR_3)ImF^m_h. \tag{1}
\]

That is not so simple as regards the \( t \) dependence shown in Ref. [12], where \( F^f_t \) multiply the exponential form by the special function dependent on \( t \). Moreover, one mostly takes the energy independence of the ratio of the spin-flip parts to the spin-non-flip parts of the scattering amplitude. All this is our theoretical uncertainty [17].

2 Model approximation

In [18], the phenomenological analysis of the experimental data was carried out to estimate the size of the hadron spin-flip amplitude from the experimental data on differential cross sections, the influence of the hadron-spin flip amplitude on the CNI effect and a possibility of estimating this contribution from the experimental data on measurement of the analyzing power in the nucleon-nucleon elastic scattering. Now we can compare those results with the new experimental data obtained at RHIC.

The differential cross sections measured in an experiment are described by the square of the scattering amplitude which is used to fit experimental data determining the electromagnetic and hadron amplitudes and the Coulomb-hadron phase.

For the electromagnetic helicity amplitudes, one takes the usual one-photon approximations (see [19,20])

\[
\begin{align*}
F^m_{1,3}(t) &= \frac{\alpha}{t} f_1(t)^2; \\
F^m_2(t) &= -F^m_4(t) = \alpha f_2(t); \\
F^m_5(t) &= -\frac{\alpha}{\sqrt{|t|}} f_1(t) f_2(t). \tag{2}
\end{align*}
\]

with

\[
\begin{align*}
f_1(t) &= \frac{4}{m_p^2 - (\mu_p - 1) t} G_D; \\
f_2(t) &= \frac{2}{m_p^2 - t} G_D; \\
G_D(t) &= \frac{1}{1 - t/0.71^2}; \\
\mu_p &= 2.793; \quad m_p = 0.93827 \text{ GeV.} \tag{3}
\end{align*}
\]

As a result, the total helicity amplitudes can be written as

\[
F_i(s, t) = F^H_i(s, t) + F^m_i(t)e^{-i\varphi(s, t)}, \tag{4}
\]

with the Coulomb-hadron phase \( \varphi \) calculated for the whole diffraction range with taking into account the hadron form-factors. The differential cross sections and spin correlation parameters are

\[
\begin{align*}
\frac{d\sigma}{dt} &= 2\pi(|F_1|^2 + |F_2|^2 + |F_3|^2 + |F_4|^2 + 4|F_5|^2). \tag{5}
\end{align*}
\]

\[
A_N \frac{d\sigma}{dt} = -4\pi Im[(F_1 + F_2 + F_3 - F_4) \ast F_5^*]. \tag{6}
\]

We shall restrict our discussion to the analysis of \( A_N \). In the standard pictures the spin-flip and double spin-flip amplitudes correspond to the spin-orbit (LS) and spin-spin (SS) coupling terms. The contribution to \( A_N \) from the hadron double spin-flip amplitudes already at \( p_L = 6 \text{ GeV}/c \) is of the second order compared to the contribution from spin-flip amplitude. So, with the usual high energy approximation for the helicity amplitudes at small transfer momenta we suppose that \( F_1 = F_3 \) and we can neglect the contributions of the hadron parts of \( F_2 - F_4 \). Note that if \( F_1, F_3, F_5 \) have the same phases, their interference contribution to \( A_N \) will be zero, though the size of the hadron spin-flip amplitude can be large. Hence, if this phases has a different \( s \) and \( t \) dependence, the contribution from the hadron spin-flip amplitude in \( A_N \) can be zero at \( s_i, t_i \) and non-zero at other \( s_j, t_j \). It means that the comparison of the size \( A_N(s) \) at one \( t_i \), as made for example in [21], at different \( s \) has the strong assumption about energy independence many different parameters determining the size of \( A_N(s, t) \).

The analysing power corresponding to the pure electromagnetic-hadron interference (with \( F^H_3 = 0 \)) will be denoted by \( A_N^{CH} \). Its size is proportional, in major part, to the interference of the imaginary part of the hadron spin-non-flip amplitude with the real part of the electromagnetic spin-flip amplitude. Note that there is also a small contribution from the interference of the real and imaginary part of the above mentioned amplitudes.

The existing experimental data at sufficiently high energy shows the significant size of \( A_N \) in the \( t \)-region of the dip of the differential cross sections. At the present moment, we have, as has been noted above, that in some models the hadron asymptotical spin-flip amplitude is not dying at super-high energy. However, most part of the experimental data of the analyzing power lies at low energies. Hence, we should take the low energy amplitudes and build a continuous transition to the asymptotic amplitudes.

As asymptotic amplitudes let us take those calculated in the dynamical model (DM) [17]. In [22] on the basis of sum rules it has been shown that the main contribution to a hadron interaction at large distances comes from the triangle diagram with the \( 2\pi \) -meson exchange in the \( t \)-channel. As a result, the hadron amplitude can be represented as a sum of central and peripheral parts of the interaction

\[
F(s, t) \propto F_c(s, t) + F_p(s, t), \tag{7}
\]

where \( F_c(s, t) \) describes the interaction between the central parts of hadrons; and \( F_p(s, t) \) is the sum of contributions of diagrams corresponding to the interactions of
the central part of one hadron on the meson cloud of the other. The contribution of these diagrams to the scattering amplitude with an \( N(\Delta\text{-isobar}) \) in the intermediate state looks like \[ F_{N(\Delta)}(s,t) = \left( \frac{g_{\pi NN(\Delta)}}{i(2\pi)^4} \right) \int d^4q F_{\pi N}(s',t) \]

\[ \times \left[ \left( k-q \right)^2 \varphi_{N(\Delta)}(q',p',k) \right] \]

\[ \left[ q^2 - M_{N(\Delta)}^2 + i\epsilon \right] \]

\[ \left[ (k-q)^2 - \mu^2 + i\epsilon \right] \left[ (p-q)^2 - \mu^2 + i\epsilon \right]. \] (8)

Here \( \lambda_1 \) and \( \lambda_2 \) are the helicities of nucleons; \( F_{\pi N} \) is the \( \pi N \)-scattering amplitude; \( \Gamma \) is a matrix element of the numerator of the diagram representation; \( \varphi \) are vertex functions chosen in the dipole form with the parameters \( \beta_{N(\Delta)} \):

\[ \varphi_{N(\Delta)}(l^2, q^2 \propto M_{N(\Delta)}^2) = \frac{\beta_{N(\Delta)}^4}{\beta_{N(\Delta)}^2 - l^2}. \] (9)

The model with the \( N \) and \( \Delta \) contribution provides a self-consistent picture of the differential cross sections and spin phenomena of different hadron processes at high energies. Really, parameters in the amplitude determined from, for example, elastic \( pp \)-scattering, allow one to obtain a wide range of results for elastic meson-nucleon scattering and charge-exchange reaction \( \pi^- p \rightarrow n^0 h \) at high energies.

It is essential that the model predicts large polarization effects for all considered reactions at high and superhigh energies \[11\]. The predictions are in good agreement with the experimental data in the energy region available for experiment. Also note that just the effect of large distances determines a large value of the spin-flip amplitude of the charge-exchange reaction \[23\].

The results weakly depend on the model for the spin-non-flip amplitude. Different models must give the same differential cross sections in a wide range of transfer momenta and energies. Moreover, they must describe the energy dependence of \( \rho(s) = Re F(s,0)/Im F(s,0) \). Basically, only the behavior of the real part of the spin-non-flip amplitudes in the range of the diffraction minimum may depend on the model and leads to different predictions. In this paper, we consider a usual picture of the proton-proton and proton-antiproton cross sections with the crossing symmetry fulfilled.

As a low energy amplitude let us take the one obtained in \[15\] where the full analysis of experimental data was carried out and the full set of the helicity spin amplitudes and their eikonal the proton-proton scattering at \( p_L = 6 \text{ GeV/c} \) was extracted. Let us take the eikonal of the spin-non-flip amplitudes in the form similar to the form and size obtained in \[13\] at \( p_L = 6 \text{ GeV/c} \):

\[ 1 - e^{X(s)} = h_1 e^{-c_1 b^2} - h_2 e^{-c_2 b^2} + h_3 e^{-c_3 b^2} + i (h_4 e^{-c_4 b^2} - h_5 e^{-c_5 b^2} + h_6 e^{-c_6 b^2}) \] (10)

and for the hadron spin-flip amplitude

\[ \chi_{ls}(b) = h_{ls} [1 + b e^{\mu(s)(\delta - b_0)}]^{-1} \] (11)

where \( h_i, c_i, h_{ls} \) and \( b_0 \) are the parameters obtained in Ref. \[13\]. As we know, these amplitudes reproduce the analyzing power at \( p_L = 6 \text{ GeV/c} \). In fact, these amplitudes are a sum of terms falling, constant and growing with energy. However, this form has no energy dependence of the parameters which change the form of these amplitudes with increasing energy in both the spin-non-flip and spin-flip parts. To obtain the energy dependence of some part of the amplitude \[10 \ 11\], let us multiply \[11\] by the falling term \( s_1/s \) and take into account the change of the form of \[11\] with energy; let us introduce the energy dependence into the parameter \( \mu \rightarrow \mu_s \)

\[ \mu(s) = \mu_0 (\log s_0/\log s), \]

where \( s_0 = 13.152 \text{ GeV} \) corresponds to \( p_L = 6 \text{ GeV/c} \) and \( \mu_0 \) corresponds to the values of Ref. \[15\].

The DM amplitude also includes the falling, constant, and increasing terms, but it is not suitable for describing low-energy data. So this is not a simple task to sew these two amplitudes, low energy phenomenological and high energy model amplitudes. To obtain a smooth transform to the DM representation, let us multiply these amplitudes by the factor-functions \( f_{th}^{\text{ff}}(s) \) quickly decreasing with energy, and multiply the DM amplitudes by the factor-functions \( f_{th}^{\text{ff}}(s) \) with energy; let us introduce the energy dependence into the parameter \( \mu \rightarrow \mu_s \)

\[ f_{s_{th}}^{\text{ff}}(s) = \exp[-(s/s_0)^{\alpha} + (s_0/s_0)^{\alpha}]; \]

\[ f_{s_{th}}^{\text{ff}}(s) = 1 - \exp[-(s/s_0)^{\alpha} + (s_0/s_0)^{\alpha}]; \]

\[ f_{s_{th}}^{\text{ff}}(s) = \exp[-(s/s_0)^{\alpha} + (s_0/s_0)^{\alpha}]; \]

\[ f_{s_{th}}^{\text{ff}}(s) = 1 - \exp[-(s/s_0)^{\alpha} + (s_0/s_0)^{\alpha}]; \]

where \( s_0 = 13.152 \text{ GeV} \) is correspond to \( p_L = 6 \text{ GeV/c} \). In this case, we obtain that the analyzing power at \( p_L = 6 \text{ GeV/c} \) is described only by the amplitudes obtained in Ref. \[15\] and at superhigh energies only by the DM amplitude. In the domain of approximately \( 6 \leq p_L \leq 200(\text{GeV/c}) \) the analyzing power has both the contributions. The parameters \( s_0^{\text{ff}} \) and \( s_0^{\text{ff}} \) were chosen to obtain the description of experimental data available in this energy range: \( s_0^{\text{ff}} = 40 \text{ GeV}^2; \  s_0^{\text{ff}} = 64 \text{ GeV}^2 \). We do not carry out the fitting procedure. The values of these parameters were chosen to obtain a qualitative description of the polarization data at \( p_L = 11.75 \text{ GeV/c} \).

We do not take into account the data of the differential cross sections. However, to check up our procedure we calculate the differential cross sections at \( p_L = 50 \text{ GeV/c} \) and at \( p_L = 100 \text{ GeV/c} \) and compare them with the existing experimental data.

The calculated analyzing power at \( p_L = 6 \text{ GeV/c} \) is shown in Fig.1a Of course, in the original phenomenological analysis made in \[15\] all helicity amplitudes were used, but it can be seen that a good description, practically the same as in \[15\], of experimental data on the analyzing power can be reached only with one hadron-spin flip amplitude.

The experimental data at \( p_L = 11.75 \text{ GeV/c} \) seriously differ from those at \( p_L = 6 \text{ GeV/c} \) but our calculations reproduce them sufficiently well (Fig.1b ). It is shown that
Fig. 1. The analyzing power $A_N$ of $pp$-scattering calculated: a) at $p_L = 6$ GeV/c (the experimental data [24,25]), and b) at $p_L = 11.75$ GeV/c (the experimental data [26,28]).

Fig. 2. The analyzing power $A_N$ of $pp$-scattering calculated: a) at $p_L = 45.5$ GeV/c (the experimental data [27]), and b) at $p_L = 200$ GeV/c (the experimental data [28,29]).

our energy dependence was chosen correctly and we may hope that further we will obtain correct values of the analyzing power.

Really, our calculations at $p_L = 45.5$ GeV/c show a satisfactory description of the experimental data (see Fig.2a). At this energy both of our parts of the amplitude give important contributions. The contributions to the analyzing power of the amplitudes (10, 11) are approximately twice as large as the contributions of the model amplitudes. From Fig.2a we can see that in the region $|t| \approx 0.2$ GeV$^2$ the contributions from the hadron spin-flip amplitudes are most important.

At last, Fig.2b shows our calculations at $p_L = 200$ GeV/c. At this energy, the contributions of the phenomenological amplitudes are already very small and can be compared with the contributions of the model amplitudes only at $|t| = 0.5$ GeV$^2$ where both the contributions are very small.

Let us check up how our amplitudes describe the differential cross sections, especially for intermediate region where both the solutions give one-order contributions. The calculations for $p_L = 50$ GeV/c and $p_L = 100$ GeV/c are presented on Fig. 3. The non-normalized experimental data [11,13] were normalized to the experimental data [30] at $p_L = 50$ GeV/c and [32] at $p_L = 100$ GeV/c. It is clear that the coincidence of the theoretical curves and experimental data was obtained sufficiently good for both the energies and the whole examined region of the momentum transfer. We should like to emphasize that we do not make a fit of the differential cross sections. We only sew the low and high energy solutions [15] and [7]. The parameters of the factor-functions were chosen to obtain a qualitative description of the form of $A_N$ at $p_L = 11.5$ GeV/c and then they were fixed.

Note that we obtain a different energy dependence of the additional contributions $\Delta A_N$ to the pure $A_{CH}^N$ effect at different points of transfer momenta. The contribution at $|t| = 0.1$ GeV$^2$ has a clear downfall with growing $\sqrt{s}$, but in the range of maximum of $A_{CH}^N$ we have nearly constant contributions which are independent of energy. So we cannot make the conclusion about energy dependence of $\Delta A_N$ at maximum of $A_{CH}^N$ measuring the energy dependence of the analyzing power at other points of the transfer momentum. However, it is one of the central points of many other analyses of the electromagnetic-hadron interference effect.

The comparison of our calculations with the recent final experimental data obtained at RHIC [33] (see fig.4) at $p_L = 100$ GeV/c shows suitable agreement. The preliminary experimental data were slightly above than the final ones and showed, on our opinion, the existence of the hadron spin-flip contributions. The final data, say ac-
amplitude (without the kinematic factor amplitude to the imaginary part of hadron spin-non-flip. The value of ergies. The corresponding predictions were made in [34].

Especially note that it is very important to continue electromagnetic-hadron interference reaches at maximum the size 4.37%. On the contrary, in the talks and publications, the preliminary new experimental data are compared with the curve of $A_N^{CH}$ which reaches at its maximum approximately 4.67%. From the comparison of the curve with the new experimental data the authors made a conclusion that the contribution from the hadron-spin flip amplitude disappears.

We study this problem to understand the contradic-

There is one important note. On Fig. 4 our curve for pure

where $a_h$ is a spin-non-flip amplitude. In the case of a small real part of $a_h$ this form leads to the size of $A_N^{CH}$ independent of the size of $\sigma_{tot}$. However, this formula gives a small dependence of the size of $A_N^{CH}$ on the $\rho(s,t)$ - the ratio of the real to imaginary part of the hadron spin-non-flip amplitude. Over a period of time this short version of $A_N^{CH}$ was rewritten in the different forms which led to the different energy dependence. Our opinion is that when we calculate such a small correlations effect we have to take the complete form of $A_N^{CH}$, formula (14). All the approxi-

There is an important energy dependence which is connected with the energy dependence of the Coulomb-hadron interference term in the differential cross sections. This term is in most part proportional to the size of $\rho(s,t)$. The position of the maximum of the contribution of this term to the differential cross section at $t$ coincides approximately with the position of the maximum $A_N^{CH}$.

Hence, the energy dependence of $\rho(s,t)$ strongly impacts that of the maximum of $A_N^{CH}$.

In our semi-phenomenological descriptions we obtained the following values at $p_L = 100$ GeV:

$$\sigma_{tot} = 38.3 \text{ mb}; B(-t = 0.003 \text{ GeV}^2) = 11.6 \text{ GeV}^{-2};$$
The available experimental data (see [38]) are:

\[
B(-t = 0.03) = 11.3 \text{ GeV}^{-2}; \rho(-t = 0.003 \text{ GeV}^2) = -10.15.
\]

The phenomenological \( A_N^{SH} \) of pp scattering calculated at \( p_L = 100 \text{ GeV/c} \) (the full and dashed lines are the calculations with \( \rho = -0.1 \) and with \( \rho = 0 \)); the experimental data [3]

\[
B(-t = 0.03) = 11.3 \text{ GeV}^{-2}; B(-t = 0.003 \text{ GeV}^2) = 38.46 \pm 0.04 \text{ mb}; \rho(-t = 0.03) = 11.3 \text{ GeV}^{-2}; \rho = -0.1.
\]

So our values practically coincide with the existing experimental data.

Of course, there also exists an energy dependence of the Coulomb-hadron phase which impacts the size of the differential cross sections. In our original calculation we used this phase, which was obtained in [8] with taking into account all correction factors. To check up the results, we used the Coulomb-hadron phase which impacts the size of the experimental data.

Of course, there also exists an energy dependence of the hadron spin-flip amplitude for the cases of the exponential form (17) is shown in the first row. If we take \( \rho \) as a free parameter, \( \chi^2 \) essentially decreases but the size of \( \rho \) arrives at the value which strongly differs from the experimental data. The same situation is obtained if \( \sigma_{\text{tot}} \) is taken as a free parameter. The last row (5a) of the upper part of Table presents the calculation of \( \chi^2 \) on the base of the model calculations but without the hadron spin-flip contribution. Note that we did not make the variation of the parameters of our model calculations for that case. The \( \chi^2 \) was calculated by comparing the model calculations with the values of the experimental points.

In the low part of Table (1b-6b) the different fits with the existence of the hadron spin-flip amplitude are presented. Again the \( \chi^2 \) on the base of the model calculations with the hadron spin-flip contribution was calculated without the variations of the parameters. In this case, \( \chi^2 \) decreased on the 4 points. A more remarkable decrease in \( \chi^2 \) was obtained in the variations of the parameters of the hadron spin-flip amplitude for the cases of the exponential form of the helicity amplitudes. Of course, when both the parameters \( k_r \) and \( k_i \) are varied, the errors are large (see lines 2b in Table 1). If \( k_r \) is fixed by some value or zero, the errors in the determination of the imaginary part of the hadron spin-flip amplitude are 30%. It is to be note that the coefficient \( k_r \) is multiplied by \( \rho \) in the definition of the real part of the hadron spin-flip amplitude. Hence, the ratability between the imaginary and real parts \( F_h^{sf} \) and \( F_h^{nf} \) is practically the same but the signs are different, thus leading to the difference between the corresponding phases. As the fitting procedure shows, the small real part of \( F_h^{sf} \) can be take with \( k_r = 0 \). In this case, the \( k_i \) grows (line 4b in Table 1). It is interesting that if we make the fit of \( \rho \) and \( k_i \) simultaneously, the size of \( \rho \) practically

![Image](image_url)

**Fig. 5.** The phenomenological \( A_N^{SH} \) of pp - scattering calculated at \( p_L = 100 \text{ GeV/c} \) (the full and dashed lines are the calculations with \( \rho = -0.1 \) and with \( \rho = 0 \)); the experimental data [3].

| n  | Form of \( F_i(s,t) \) | \( \sigma_{\text{tot}}(\text{mb}) \) | \( \rho \)   | \( k_i \) | \( k_r \) | \( \sum_{i=1}^{14} \chi^2 \) |
|----|------------------------|----------------|-----------|-------|-------|----------------|
| 1a | exponential            | 38.46         | -0.105    | 0     | 0     | 30.62         |
| 2a | exponential            | 38.46         | -0.047 ± 0.02 | 0     | 0     | 23.22         |
| 3a | exponential            | 36.5 ± 0.81   | -0.1       | 0     | 0     | 24            |
| 4a | model                  | 38.3          | -0.105    | 0     | 0     | 29.38         |
| 1b | model                  | 38.3          | -0.105    | -0.065| -0.15  | 26.11         |
| 2b | exponential            | 38.46         | -0.1       | 0.023 ± 0.06 | -0.022 ± 0.02 | 20.64         |
| 3b | exponential            | 38.46         | -0.1       | 0.02   | 0.023 ± 0.01 | 20.65         |
| 4b | exponential            | 38.46         | -0.1       | 0.028 ± 0.01 | 0.021 ± 0.014 | 20.58         |
| 5b | exponential            | 38.46         | -0.091 ± 0.032 | 0.02  | 0.021 ± 0.014 | 20.58         |
| 6b | exponential            | 38.46         | -0.1 ± 0.03 | 0.028 ± 0.015 | 0.021 ± 0.014 | 20.58         |

Table 1. Table

And with the Coulomb-hadron phase of (16). We take the hadron-spin flip amplitude in the form

\[
F_h^{sf}(s,t) = \frac{\sigma_{\text{tot}}(s)}{4\pi} (k_r \rho + ik_i) \exp(B(s)/t/2). \tag{18}
\]

First, let us make the fit of the experimental data without the hadron-spin-flip amplitude. This case is presented in the upper part of Table (1a-4a). The fit with parameters obtained in the model calculations but with the form of the amplitudes in the simple exponential form (17) is shown in the first row. If we take \( \rho \) as a free parameter, \( \chi^2 \) essentially decreases but the size of \( \rho \) arrives at the value which strongly differs from the experimental data. The same situation is obtained if \( \sigma_{\text{tot}} \) is taken as a free parameter. The last row (5a) of the upper part of Table presents the calculation of \( \chi^2 \) on the base of the model calculations but without the hadron spin-flip contribution. Note that we did not make the variation of the parameters of our model calculations for that case. The \( \chi^2 \) was calculated by comparing the model calculations with the values of the experimental points.

In the low part of Table (1b-6b) the different fits with the existence of the hadron spin-flip amplitude are presented. Again the \( \chi^2 \) on the base of the model calculations with the hadron spin-flip contribution was calculated without the variations of the parameters. In this case, \( \chi^2 \) decreased on the 4 points. A more remarkable decrease in \( \chi^2 \) was obtained in the variations of the parameters of the hadron spin-flip amplitude for the cases of the exponential form of the helicity amplitudes. Of course, when both the parameters \( k_r \) and \( k_i \) are varied, the errors are large (see lines 2b in Table 1). If \( k_r \) is fixed by some value or zero, the errors in the determination of the imaginary part of the hadron spin-flip amplitude are 30%. It is to be note that the coefficient \( k_r \) is multiplied by \( \rho \) in the definition of the real part of the hadron spin-flip amplitude. Hence, the ratability between the imaginary and real parts \( F_h^{sf} \) and \( F_h^{nf} \) is practically the same but the signs are different, thus leading to the difference between the corresponding phases. As the fitting procedure shows, the small real part of \( F_h^{sf} \) can be take with \( k_r = 0 \). In this case, the \( k_i \) grows (line 4b in Table 1). It is interesting that if we make the fit of \( \rho \) and \( k_i \) simultaneously, the size of \( \rho \) practically
does not change (see line 6b and compare with line 2a in Table).

4 Conclusion

The size of the parameters of the hadron spin-flip amplitude which can be obtained from the new experimental data at \( p_L = 100 \text{ GeV/c} \) are determined with large errors. However, \( \chi^2 \) decreases essentially. It is shown at least that the imaginary part of the hadron spin-flip amplitude differs from zero in this transfer momentum region and \( p_L = 100 \text{ GeV/c} \). Note that the imaginary part of the spin-flip amplitude gives the contribution not only to the interference with the hadron spin-non-flip amplitude but also to the interference with the Coulombic part. Hence, any case, we cannot make a conclusion about the absence of a contribution of the hadron spin flip amplitude at least on the base of these new experimental data.

It is obvious from our analysis that examining the contributions of the hadron spin-flip amplitudes in the CNI effect using the experimental data in a wide energy region, one should take into account the energy dependence of all parts of the hadron scattering amplitude and its dependence on transfer momenta. Our descriptions of all available experimental data give about 3.5% of the predictions for RHIC energies for the contributions of the hadron spin-flip amplitude to the maximum of the CNI effect. Of course, this estimation is very rough, but the comparison of the calculated \( A_N \) and \( A_{NS}^{CH} \) with the new experimental data obtained at RHIC shows that at this energy the contribution of the hadron spin-flip amplitude is presented. More accurate estimations can be carried out only after a new experiment in this domain of transfer momenta at higher energies and wider transfer momenta, especially in the dip region.

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