Spin asymmetries of the proton-proton elastic scattering at HERA-N

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Abstract

The spin correlation parameters, polarization - $A_N$ and double spin correlation parameters - $A_{NN}$, are calculated in the framework of dynamical model (GKS) of the hadron-hadron interection in the whole region of small angles and for energy HERA-N $\sqrt{s} = 40 GeV$. It is shown that the measurements of such spin effects at small transfer momenta, in the region of the dip structure and at $t = -4 GeV^2$ have to give significant values of such spin correlation parameters.
1 Introduction

The spin phenomena in diffraction processes can give us information about the structure of scattering amplitudes of hadron-hadron interaction in the nonperturbative region.

The measurement of polarization at very small transfer momenta up to \(-t = 10^{-4}\) GeV can give us the possibility to find out the structure of hadron spin dependent amplitudes. In this domain the analyzing power \(A_N\) is determined by the Coulomb-hadron interference effects. As we can calculate the Coulomb amplitude very precisely from the theory, we can obtain some information about the hadronic non-flip amplitude from this quantity. If we measure the double spin correlation parameters \(A_{NN}\) in that domain, we can find out the structure of the hadron double spin–flip amplitude \([5]\). Moreover the exact measurement of the point of maximum of the coulomb-hadron polarization at small transfer momenta gives us the information on how to use the new independent method of estimating the total cross section \([5]\).

The phenomena of interference of the hadronic and the coulombic amplitudes may give an important contribution not only at very small transfer momenta but also in the range of the diffraction minimum \([6]\). So one should know the phase of the interference of the coulombic and hadronic amplitude at sufficiently large transfer momenta too.

The majority of theoretical models describe the hadron scattering at small angles with the use of the eikonal approximation for the scattering amplitude

\[
F(s, t) = \frac{1}{2t} \int_0^{\infty} \rho d\rho J_0(\rho\Delta)(1 - e^{-2i\delta(\rho)});
\]

where the eikonal phase \(\delta(\rho)\) includes the Coulomb and hadron parts and depends on spin.

The interaction potential of charged hadrons is a sum of Coulomb and nuclear interactions

\[
F_{\text{Born}}(s, \Delta, \vec{s}) = F_{c, \text{Born}}(\Delta, \vec{s}) + F_{h, \text{Born}}(s, \Delta, \vec{s}).
\]

So, after the eikonal summation, terms with the Coulomb and nuclear interactions appear. The differential cross sections measured in experiment are described by the square of the scattering amplitude

\[
d\sigma/dt = \frac{\pi}{2} (F_C^2(t) + (1 + \rho^2(s, t)) Im F_N^2(s, t)) \\
\pm 2(\rho(s, t) + \alpha\varphi) F_C(t) Im F_N(s, t),
\]

where \(F_C = \pm 2\alpha G^2/|t|\) is the Coulomb amplitude; \(\alpha\) is the fine-structure constant and \(G^2(t)\) is the proton electromagnetic form factor squared; \(Re F_N(s, t)\) and \(Im F_N(s, t)\) are the real and imaginary parts of the nuclear amplitude; \(\rho(s, t) = Re F(s, t)/Im F(s, t)\).

In \([7]\) the phase of the Coulomb amplitude in the second Born approximation with the form factor was calculated in a wide region of transfer momenta. It was shown that the behaviors of \(\nu\) at non-small \(t\) are sharply different from the behaviors of \(\nu\) obtained in \([8]\).

In \([9]\) was shown how we can calculate the total Coulomb–hadron phase that can be used in the whole diffraction range of the elastic hadron scattering.

The obtained eikonal representation for the Coulomb-hadron phase is true in a wide region of transfer momenta. If we take the true hadron scattering eikonal which describes the experimental differential cross sections including the domain of the diffraction dip, we can calculate the Coulomb-hadron phase for that region of transfer momenta. This phase will have a real and a non-small imaginary part. This phase can be very important for the calculation of the spin correlation parameters owing to the coulomb-hadron interference effects in the domain of the
diffraction dip. Of course, the largest effects will be in the energy range where the diffraction minimum has a sharply defined form and hence the real part of the non-flip scattering amplitude will be less. So, it will be in the energy region when \(20 \leq \sqrt{s} \leq 60\text{(GeV)}\). It is clear that for the proton-proton scattering at HERA \(\sqrt{s} = 40\text{(GeV)}\) we can obtain significant spin correlation effects owing to the Coulomb-hadron interference.

2 The dynamical model of hadron-hadron interaction with spin

In papers [2], the dynamical model for a particle interaction which takes into account the hadron structure at large distances was developed. The model is based on the general quantum field theory principles (analyticity, unitarity, and so on) and takes into account basic information on the structure of a hadron as a compound system with the central part region where the valence quarks are concentrated and the long-distance region where the color-singlet quark-gluon field occurs. As a result, the hadron amplitude can be represented as a sum of the central and peripheral parts of the interaction:

\[
T(s, t) \propto T_c(s, t) + T_p(s, t). \tag{3}
\]

where \(T_c(s, t)\) describes the interaction between the central parts of hadrons. At high energies it is determined by the spinless pomeron exchange. The quantity \(T_p(s, t)\) is a sum of triangle diagrams corresponding to the interactions of the central part of one hadron with the meson cloud of the other. The meson - nucleon interaction leads to the spin flip effects at the pomeron-hadron vertex.

The contribution of these triangle diagrams to the scattering amplitude with \(N(\Delta\text{-isobar})\) in the intermediate state looks as follows [12]:

\[
T^{\lambda_1 \lambda_2}_N(s, t) = \frac{g_{\pi NN(\Delta)}}{i(2\pi)^4} \int d^4q T_{\pi N}(s', t) \varphi_{\pi N(\Delta)}((k - q), q^2) \varphi_N((p - q), q^2) \times \frac{\Gamma^{\lambda_1 \lambda_2}(q, p, k,)}{[q^2 - M^2_N(\Delta) + i\epsilon][(k - q)^2 - \mu^2 + i\epsilon][(p - q)^2 - \mu^2 + i\epsilon]} \tag{4}
\]

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

\[
\varphi_N(\Delta) \propto \frac{b^4_N(\Delta)}{(b^2_N(\Delta) - l^2)^2}. \tag{5}
\]

For a standard form of the pomeron contribution to the meson-nucleon scattering amplitude

\[
T_{\pi N}(s, t) = i\beta^\pi(t) \cdot \beta^N(t)s^\alpha(t)
\]

we can write the integral (4) in the form:

\[
T^{\lambda_1 \lambda_2}_N(s, t) = i\beta^{N(\lambda_1 \lambda_2)}(t) \cdot \beta^N(t)s^\alpha(t),
\]
where $\beta_{N(\lambda_1\lambda_2)}(t)$ is the $N$-nucleon or $\Delta_{33}$-isobar contribution to a spin-dependent nucleon-pomeron vertex function. The peripheral contribution calculated in the model leads to the spin effects in the Born term of the scattering amplitude which do not disappear with growing energy. Summation of rescatterings in s-channel has been performed with the help of the quasipotential equation. The total amplitude has an eikonal form. The explicit forms of helicity amplitudes and parameters obtained can be found in [12].

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, the parameters in the amplitude determined from one reaction, for example, elastic $pp$-scattering, allow one to obtain a wide range of results for elastic meson-nucleon scattering and charge-exchange reaction $\pi^- p \rightarrow \pi^0 n$ at high energies.

3 The model results at HERA-N energy

In Fig.1, shown are the model calculations for the analyzing power of the proton-proton scattering at $\sqrt{s} = 23.4$ GeV where we have the experimental data.

![Fig. 1: Polarization of the $pp$ - scattering calculated in the model GKS at $\sqrt{s} = 23.4$ GeV and the experimental points [13].](image)

It is clear that the model reproduces the experimental data well and we can think that the prediction of the model at HERA-N energy will be also sufficient good. This prediction for the analyzing power and the double spin correlation parameter $A_{NN}$ is shown in Figs. 2 and 3. The model predicts that at superhigh energies the polarization effects of particles and antiparticles are the same. After $\sqrt{s} = 50$ GeV, the analyzing power decreases very slowly and has a very determined form. It is small at small transfer momenta, before the diffraction peak, and has a narrow sufficiently large negative peak in the range of the diffraction minimum, see Fig. 2.
Behind the diffraction minimum $A_N$ changes its sign and has the bump up to $|t| = 6 GeV^2$. The position of maximum of this bump slowly changes towards larger $|t|$ and its magnitude somewhat changes around 10%; near $|t| = 3 GeV^2$ the magnitude is practically constant, $\simeq 8\%$. The behavior of the spin correlation parameter $A_{NN}$ is shown in fig.3. As is seen, the value of $A_{NN}$ becomes maximum in the range of the diffraction minimum, as in the case of the polarization. The magnitude of $A_{NN}$ becomes sufficiently large with the growth of $|t|$. The reason is that in this work we have used the strong form factors for the vertices $\pi NN$ and $\pi N\Delta$. The form of the spin-flip amplitude is determined in the model up to $|t|$ $\simeq 2 GeV^2$; hence, we can expect an adequate description of the experimental data up to $|t|$ $\simeq 3 \div 5.0 GeV^2$.

Note that the polarizations of $pp$- and $p\bar{p}$- scattering will coincide above the energies $\sqrt{s} > 30 GeV$.

Thus, the dynamical model considered, which takes into account the $N$ and $\Delta$ contribution, leads to a lot of predictions concerning the behavior of spin correlation parameters at high energies. In that model, the effects of large distances determined by the meson cloud of hadrons give a dominant contribution to the spin-flip amplitudes of different exclusive processes at high energies and fixed transfer momenta. Note that the results on the spin effects obtained here differ from the predictions of other models [14] at an energy above $\sqrt{s} \geq 30 GeV$. And the examination of these results gives new information about the hadron interaction at large distances.

**4 Conclusion**

In the HERA-N experimental energy region ($\sqrt{s} = 40 GeV$) we have proton-proton elastic scattering with a very deep first diffraction minimum. It is connected with the energy dependence of the real part of the spin non-flip amplitude. At this energy the real part is small and gives a small contribution at the point of the diffraction minimum. The relation of the real to imaginary parts of the spin-non flip amplitude $\rho$ equals 0.06 at small transfer momenta. In this case we can
obtain the spin effects larger in the diffraction dip domain than in other high energy experiments at $\sqrt{s} \geq 50$ GeV where $\rho \geq 0.095$. At the energy $\sqrt{s} = 40$ GeV we can more exactly explore the spin effect of the coulomb-hadron interference, as the uncertainty of the real part of the spin-non flip amplitude gives a small distortion and the contribution of the hadron spin–flip amplitude will be large and defined fluently. So, the measurement of spin effects in the elastic scattering at small angles at HERA-N is not the competition with other spin programs at RHIC and LHC but is the cooperation which gives the first and very important step in explore of the super-high energy spin physics.

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