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SPIN EFFECTS IN pp-SCATTERING AT DIFFRACTION RANGE AND RHIC ENERGIES

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Some important results are obtained at the CERN collider $S\bar{p}pS$ and FNAL in investigating elastic scattering. It is just this process that allows the verification of the results obtained from the main principles of quantum field theory: the concept of the scattering amplitude as a unified analytic function of its kinematic variables connecting different reaction channels was introduced in the dispersion theory by N.N. Bogolubov[1]. The results of $\bar{p}p$- collider show a still continuing growth of the total cross section, the diffraction peak shrinkage and a slow growth of the relation of $\sigma_{elastic}/\sigma_{tot}$. Especial question is about the behavior of $\rho = ReT(s,0)/ImT(s,0)$, which is tightly connected with the dispersion relation. The large magnitude of ρ measured by the UA4 Collaboration [2] is in contradiction with the first analysis of the UA4/2 Collaboration [3], but was confirmed by the next one [4]. In most of the early models, as in the ordinary picture of PQCD, the spin effects were suppressed at these energies. However, in some models [5], the spin-flip amplitudes which don't decrease with the growing energy, were predicted. For example, in the model [6] the absence of the second diffraction minimum was explained by the spin-flip contributions. In the framework of the QCD, spin effects weakly dependent on energy were shown to exist by analysing the spin structure of a quark-pomeron vertex [7]. Now, some different models examining the nonperturbative instanton contribution lead to sufficiently large spin effects at superhigh energies [8], [9]. Careful analyses of experimental data also show a possible manifestation of spin-flip amplitudes at high energies [4, 10]. The research of such spin effects will be a crucial stone for different models and will help us to understand the interaction and structure of particles, especially at large distances. All this raises the question about the measure of spin effects in the elastic hadron scattering at small angles at future accelerator (HERA, RHIC, LHC and UNK). Now, there are large programs of reserching spin effect at these accelerators. Especially, we should like to note the programs at RHIC [11], where the polarization of both the collider beams will be constructed. So, it is very important to obtain reliable predictions for the spin asymmetries at large energies. In this paper, we extend the model predictions for the spin asymmetries in the RHIC energy domain. The factorization of the scattering amplitude into the spin-dependent hadron-pomeron vertex function and high energy pomeron is shown in the model too.

In papers [12, 13], 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 [14]:

$$T(s,t) \propto T_c(s,t) + T_p(s,t), \qquad (1)$$

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 $T_p(s,t)$ is the sum of triangle diagrams corresponding to the interactions of the central part of one hadron on the meson cloud of the other. The meson-nucleon interaction leads to the spin flip effects in the pomeron-hadron vertex.

The contribution of these triangle diagrams to the scattering amplitude with $N(\Delta$-isobar) in the intermediate state looks like as follows [15]:

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

Here λ_1, λ_2 are helicities of nucleons; $T_{\pi N}$ is the πN-scattering amplitude; Γ is a matrix element of the numerator of the diagram ; φ are vertex functions chosen in the dipole

form with the parameters $\beta_{N(\Delta)}$:

$$\varphi_{N(\Delta)}(l^2, q^2 \propto M^2_{N(\Delta)}) = \frac{b^4_{N(\Delta)}}{(b^2_{N(\Delta)} - l^2)^2}. \qquad (3)$$

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 (2) in the form:

$$T^{\lambda_1\lambda_2}_{N(\Delta)}(s,t) = i\beta^{N(\lambda_1\lambda_2)}(t) \cdot \beta^N(t) s^{\alpha(t)},$$

where $\beta^{N(\lambda_1\lambda_2)}(t)$ is a N-nucleon or Δ_{33}-isobar contribution to a spin-dependent nucleon-pomeron vertex function. In the light-cone variables $q = (xp_+, q_-, q_\perp), q_\pm = q_0 \pm q_z$; it has the form:

$$\beta^{N(\lambda_1\lambda_2)} = \frac{\beta^{\pi}(t) g^2_{\pi NN(\Delta)} b^8_{N(\Delta)}}{2(2\pi)^3} \int_0^1 dx x^5 (1-x)^{\alpha(t)} \int \frac{d^2\vec{q}_\perp \Gamma^{\lambda_1\lambda_2}_{N(\Delta)}(\vec{q_\perp}, \vec{p}, \vec{k},)}{[q^2_\perp + d][q'^2_\perp + d][q^2_\perp + a]^2[q'^2_\perp + a]^2}. \qquad (4)$$

Here

$$\vec{q}' = \vec{q}_\perp + x(\vec{p} - \vec{k}); d = (M^2_{N(\Delta)} - xM^2_N)(1-x) + \mu^2 x;$$
$$a = (M^2_{N(\Delta)} - xM^2_N)(1-x) + b^2_{N(\Delta)} x.$$

As a consequence we obtain the factorization of the scattering amplitude into the spin-dependent hadron-pomeron vertex function and high energy pomeron, as it has been obtained early in the framework of QCD [7].

The matrix element of the nucleon-intermediate-state contribution has the form:

$$\Gamma^{++}_N = [M^2_N(1-x)^2/x + q^2_\perp/x - \vec{q}_\perp \vec{\Delta}_\perp]; \Gamma^{+-}_N = \Delta M_N(x-1); \qquad (5)$$

where Δ is the transfer momentum. From (5) it is seen that the spin-flip and spin-non-flip amplitudes have the same asymptotics in s.

The matrix element of the Δ_{33}-isobar contribution in the intermediate state has the form:

$$\Gamma^{\lambda_1\lambda_2}_{\Delta} = \bar{u}(p)^{\lambda_1}(\hat{q} + M_{\Delta})[(pk) - \frac{1}{3}\hat{p}\hat{k} - \frac{2(pq)(kq)}{3M^2_\Delta} + \frac{(pq)\hat{k} - (kq)\hat{p}}{3M_\Delta}]u(k)^{\lambda_2}. \qquad (6)$$

The spin-flip and no-flip matrix element can be found in [15].

The consideration of isotopic factors in integrals (2) leads to the following expressions for the amplitude of the NN interaction:

$$T^{+-} = 3T_N^{+-} + 2T_\Delta^{+-}. \qquad (7)$$

Different signs of the amplitudes (7) essentially compensate the contributions of N and Δ states with each other in elastic processes. The dipole parametrization for meson-baryon vertex functions is used with the following values of the parameters [16]:

$$b_N^2 = 3.4(GeV^2), b_\Delta^2 = 1.5(GeV^2)$$

and coupling constants [17]:

$$\frac{g_{\pi NN}^2}{4\pi} = 14.6; \frac{g_{\pi N\Delta}^2}{4\pi} = 21(GeV^2).$$

Note that in integrals (2) the $X \simeq 0.9$ range is essential, which makes it necessary a correct consideration of the contribution of a sufficiently-low-energy range $s' \simeq 0.1s$. For this, in calculating integrals (2) we use the spin-non-flip amplitude obtained in [18] with the $1/\sqrt{s}$ terms which describes the experimental data of meson-nucleon scattering in a wide energy range. 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 rescattering at s-channel has been performed with the help of the quasipotential equation. The total amplitude has an eikonal form. The explicit forms of the helicity amplitudes and the parameters obtained can be found in [15].

The model with the N and Δ 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 $\pi^- p \to \pi^0 n$ at high energies.

The model predicts that at superhigh energies the polarization effects of particles and antiparticles are the same. Though the polarization of the proton-antiproton scattering at $\sqrt{s} = 16.8GeV$ is larger than the proton-proton polarization , they become

practically equal at energy $\sqrt{s} \geq 30GeV$. After $\sqrt{s} = 50GeV$, the polarization decreases very slowly and has the very determining form. It is small at small transfer momenta, before the diffraction peak, and has the narrow, sufficiently large negative peak in the range of the diffraction minimum, see Fig.1.

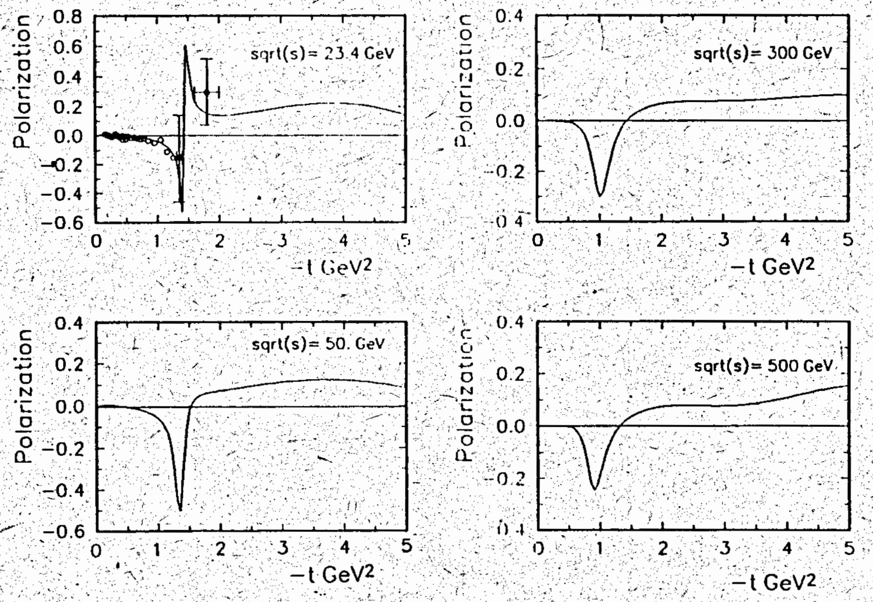

Fig.1.The predictions for the polarization at RHIC energies.

The magnitude of the negative peak slowly falls down from 0.52 at $\sqrt{s} = 50GeV$ up to 0.25 at $\sqrt{s} = 500GeV$. It has the width at half the height $\Delta(t) = 0.17GeV^2$ at $\sqrt{s} = 50GeV$ and nearly constant $\Delta(t) = 0.3GeV^2$ for $\sqrt{s} > 150GeV$. The position of the negative maximum slowly shifts to small transfer momenta, see Table 1. Behind the diffraction minimum the polarization changes its sign and has the bump up to $|t| = 6GeV^2$. The position of maximum of this bump slowly changes towards larger $|t|$ and its magnitude somewhat changes around 10%; near $|t| = 3GeV^2$ the magnitude is practically the constant = 8% (see Table 1).

$\sqrt{s}$ GeV	$\|t\|_{max}$ GeV^2	P_{1max} %	$\Delta(t)$ GeV^2	$P(\|t\| = 3GeV^2)$ %	P_{2max} %
50	1.337	-52	0.17	10.7	12.3
100	1.225	-41	0.26	8.5	9.2
150	1.15	-37	0.28	7.9	8.6
200	1.09	-34	0.29	7.8	8.6
250	1.05	-32	0.30	7.7	9.1
300	1.005	-30	0.30	7.7	10.1
350	0.98	-28	0.30	7.7	11.2
400	0.95	-27	0.30	7.7	12.8
450	0.925	-26	0.29	7.7	14.3
500	0.905	-24	0.29	7.7	16.0

Table 1: The theoretical predictions of the polarization at RHIC energies.

Our predictions coincide very closely with the results of the model [19] at sufficiently low energies ($\sqrt{s} \simeq 23.4 GeV$). But these models lead to very different predictions at superhigh (RHIC) energies. Especially, it concerns the range of the diffraction minimum. So, if our model leads to the negative polarization, the model [19] gives the positive polarization.

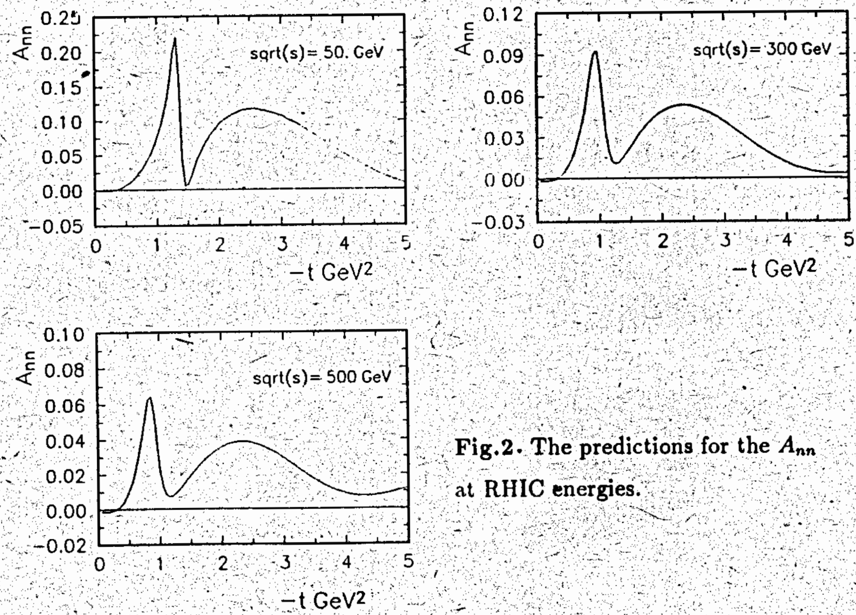

Fig.2. The predictions for the A_{nn} at RHIC energies.

The behavior of the spin correlation parameter A_{NN} is shown in fig.2. The magnitude of A_{nn}, its width at half the height - $\Delta(t)$, the magnitude A_{nn} at $|t| = 3GeV^2$ and in the second maximum are shown in Table 2. 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 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 πNN and $\pi N\Delta$. The form of the spin-flip amplitude is determined in the model up to $|t| \simeq 2$ GeV^2, hence,

$\sqrt{s}$ GeV	$\lvert t\rvert_{max}$ GeV^2	A_{nn}^{1max} %	$\Delta(t)$ GeV^2	$A_{nn}(\lvert t\rvert = 3GeV^2)$ %	A_{nn}^{2max} %
50	1.30	22	0.27	10.7	11.7
100	1.15	16.4	0.33	7.6	8.8
150	1.08	13.6	0.33	6.2	7.5
200	1.0	11.7	0.32	5.3	6.6
250	0.95	10.3	0.32	4.7	5.9
300	0.93	9.3	0.32	4.2	5.4
350	0.92	8.5	0.32	3.8	4.9
400	0.90	7.6	0.32	3.4	4.5
450	0.87	7.1	0.31	3.1	4.2
500	0.85	6.4	0.28	2.9	3.9

Table 2: The theoretical predictions of the A_{nn} at RHIC energies.

we can expect an adequate description of the experimental data up to $\mid t \mid \simeq 3 \div 5.0$ GeV^2.

It should be emphasized that the model gives the same energy dependence of the spin-flip and spin-non-flip amplitudes. Consequently, the obtained spin effects do not disappear in the asymptotic energy range. The model predicts large values of the polarization and spin correlation parameter A_{NN} which decrease slowly from 22% to 6.4% at the range of the diffraction minimum with increasing energy from $\sqrt{s} = 50GeV$ to $\sqrt{s} = 500GeV$. Note that the polarizations of pp- and $p\bar{p}$- scattering will coincide above the energies $\sqrt{s} > 30GeV$. Note that in our model the standard spiral amplitude ϕ_1 equals ϕ_3 and ϕ_2, ϕ_4 are an order as small as ϕ_1 and have kinematical factor $f(t)$. Hence $\Delta\sigma_L$ equals zero and $\Delta\sigma_T$ is practically invisible in the domain before diffraction minimum.

Thus, the dynamical model considered, which takes into account the N and Δ 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 [19] at an energy above $\sqrt{s} \geq 30GeV$. And the examination of these results gives new information about the hadron interaction at large distances.

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