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NEW ROLE OF SPIN IN HIGH ENERGY HADRON SCATTERING

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At present the role of spin effects in high energy hadron scattering is not yet clear [1]. Within most of approaches the spin of particles is unimportant in a high energy region.

Some models include spin-flip amplitudes, contributions of which to the differential cross section slowly change with energy. Here it is shown that a consistent consideration of the spin of the particles leads to the new "spin" dynamics of hadron interaction.

We shall consider these question on the basis of the dynamical model for nucleon-nucleon scattering with taking into account the spin of particles [2].

The model assumes a central part of a nucleon to exist, where valence quarks are concentrated, surrounded by a meson cloud. The contribution from scattering of the central part of one hadron on the meson cloud of the other can be written as follows:

$$T_p(s,t) = \frac{g^2}{i(2\pi)^4} \int d^4q M_{\pi p}(s',t)\phi[(k-q)^2, q^2]\phi[(p-q)^2, q^2] \times$$
$$\times \frac{\gamma_5(\hat{q}+m)\gamma_5}{(q^2-m^2+i\epsilon)[(k-q)^2-\mu^2+i\epsilon][(p-q)^2-\mu^2+i\epsilon]}; \quad (1)$$
$$s' = (k+k'-q)^2 .$$

Here m and μ are nucleon and meson masses, respectively. The distribution of matter inside the nucleon is taken into account by the vertex function ϕ in (1). $M_{\pi p}$ is the meson-nucleon scattering amplitude.

The proton-proton scattering amplitude (1) calculated in the model has the form:

$$T_p(s,t) = \frac{\sqrt{s}}{2}\alpha_p(s,t) + a_p(s,t) + (\frac{\sqrt{s}}{2}\beta_p(s,t) + b_p(s,t)) \times$$
$$\times [\hat{n}(-\vec{\ell}) \otimes \hat{I} + \hat{I} \otimes \hat{n}(\vec{\ell})] + d_p(s,t) \cdot \hat{n}(-\vec{\ell}) \otimes \hat{n}(\vec{\ell}) , \quad (2)$$

$$\hat{n}(\ell) = \gamma_0 - \vec{\gamma}\vec{\ell}/|\vec{\ell}| ; \quad \vec{\ell} = (\vec{p}+\vec{k})/2 ,$$

where a, a', β, b, d logarithmically depend on the energy. Let us assume the amplitude (2) to be a Born term of the scattering amplitude. In this approximation the leading terms of the helicity amplitudes look as follows:

$$T_{++,++}(s,t) \simeq d_p(s,t); \quad T_{++,+-}(s,t) \simeq \sqrt{|t|}\,\beta_p(s,t). \tag{3}$$

The double spin-flip amplitude is suppressed as a power. So, in the model the ratio

$$\left.\frac{|T_{++,+-}(s,t)|}{|T_{++,++}(s,t)|}\right|_{t - \text{fixed}} \sim f(\ln s)$$

is a logarithmic function of the energy.

It may be shown that the term connected with the double scattering on the potential $\beta(s,r)$ determines the superhigh energy behaviour of the spin-non-flip amplitude in the second Born approximation:

$$T^{2B}_{++,++} \simeq \sqrt{s}\,\beta^2. \tag{4}$$

It is a term with the double change of the spin of one particle. We can sum up the terms of this type by using the quasipotential dynamical equation [3]. As a result, we obtain a modification of the eikonal formular for helicity amplitudes at small angles [2,4]

$$\begin{aligned} T_{++,++}(s,t) &= i\int_0^\infty \rho\, d\rho\, J_0(\rho\Delta)[1 - e^{\tilde{\chi}_0(\rho,s)}];\\ T_{++,+-}(s,t) &= -\int_0^\infty \rho\, d\rho\, J_1(\rho\Delta)\chi_1(\rho,s)e^{\tilde{\chi}_0(\rho,s)};\\ \tilde{\chi}_0(\rho,s) &= -\frac{2}{i}\{\int_{-\infty}^{\infty}[d_c(s,r)+d_p(s,r)]dz - \frac{\sqrt{s}}{2}\int_{-\infty}^{\infty}\beta^2(s,r)dz\} =\\ &= \chi_0 + \frac{\sqrt{s}}{2}\chi_{spin}; \quad \chi_1(\rho,s) = \frac{1}{2i}\int_{-\infty}^{\infty}dz\,\frac{d\beta(s,r)}{d\rho}. \end{aligned} \tag{5}$$

Upon being summed up, the terms (4) contribute to the eikonal phase $\tilde{\chi}_0(\rho,s)$ that determines the non-spin-flip amplitude. The model estimations [2] show that the contribution of this spin term to the phase χ_0 is unimportant at energies $\sqrt{s} \le 100$ GeV. Therefore, we can use the amplitude (5) obtained in the model for pp scattering without the spin contribution

in $\tilde{\chi}_0$ in this energy range. The parametrization of scattering of the central hadron parts, which contributes to $\tilde{\chi}_0(\rho,s)$, was the following:

$$\chi_c(\rho,s) = \frac{2}{i}\int_{-\infty}^{\infty} d_c(r,s)\,dz = he^{-\mu(s)\sqrt{b^2(s)+\rho^2}}.$$

The form of the $1/\sqrt{s}$ contribution to the eikonal phase was similar to $\chi_0(\rho,s)$ in accordance with the geometrical scaling. In the model we have found a quantitative description of the pp differential cross section at $19.4\ \text{GeV} \le \sqrt{s} \le 62$ GeV and $0 \le |t| \le 14\ \text{GeV}^2$ [5]. The obtained $s \to u$ crossing predictions for the $p\bar{p}$ scattering [6] at $\sqrt{s} = 9.78$ GeV are plotted in fig.1 together with the data. The calculation in the model of the spin-flip amplitude (5) determined by the β-potential permits up to make a prediction for the polarization. The obtained polarization is in agreement with the data at $100\ \text{GeV} \le p_L \le 300$ GeV (fig.2). At higher energies the model predicts a rapid change of the polarization at $|t| \sim 1.4\ \text{GeV}^2$ (fig.2). This phenomenon is connected with the zero of $\text{Re}\,T_{++,++}(t_{min})$ at $\sqrt{s} \sim 28$ GeV. Experiments are needed to check up this prediction.

We may thus conclude that the model results for the β-potential are correct. This potential defines the spin contribution to the eikonal phase $\tilde{\chi}_0$ (5) at superhigh energies. We must take into account this contribution at CERN $p\bar{p}$ collider energies.

The model predictions with and without the spin contribution to $\tilde{\chi}_0$ are shown in fig.3. When the spin part contributes to $\tilde{\chi}_0$ the differential cross-sections near $|t| \sim 1.2$ GeV increase by an order of magnitude as compared to the case without this contribution. As a result, the diffraction structure almost disappears at CERN $p\bar{p}$ collider energies and a "shoulder" appears in the differential cross section. The results of the model [7] are shown in fig.3. The model predictions are different near $|t| \sim 1.0 \div 2.0$ GeV. The experimental investigations are needed to determine the character of scattering processes at superhigh energies.

The spin contribution to $\tilde{\chi}_0$ leads to the new spin mechanism of the total-cross-section growth [4]. At superhigh energies

$$\sigma_{tot} \sim \frac{1}{\mu_\pi^2}\ln^2\sqrt{\frac{s}{s_0}}, \qquad s_0 \sim 10^5\ \text{GeV}^2$$

and the Froissart bound is saturated. In the model the contribution of the new mechanism to σ_{tot} at $\sqrt{s} = 540$ GeV is equal to 5-6 mb and $\sigma^{pp}_{tot}(540) \simeq 57$ mb.

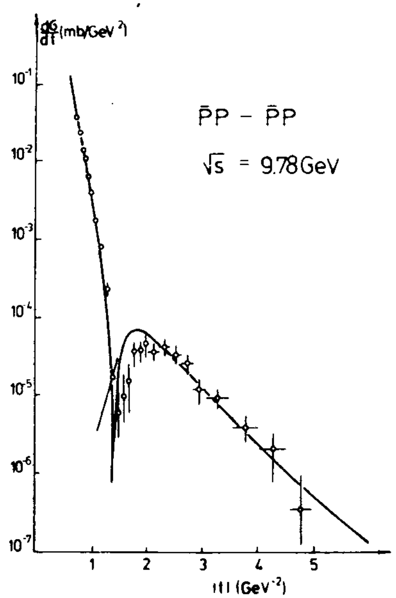
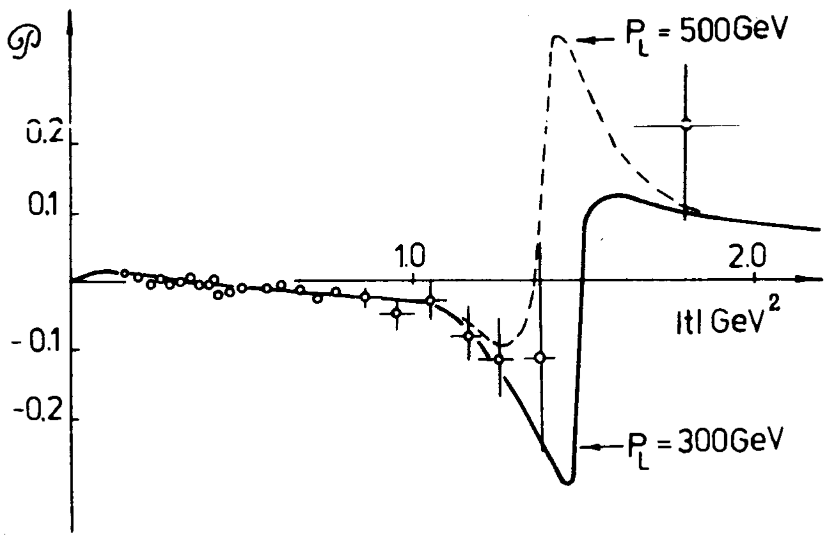


Fig.1. Proton-antiproton elastic scattering at $\sqrt{s} = 9.78$ GeV. ——— Our $s \to u$ crossing predictions from the analysis of proton-proton data.

Fig.2. The predicted rapid change of polarization at the diffraction minimum.



The model predictions for the diffraction peak slope at different $|t|$ are as follows

$\mathcal{B}(0) = 15.8\ \mathrm{GeV}^{-2}$; $\mathcal{B}(0,1) = 14.4\ \mathrm{GeV}^{-2}$; $\mathcal{B}(0,2) = 13.7\ \mathrm{GeV}^{-2}$.

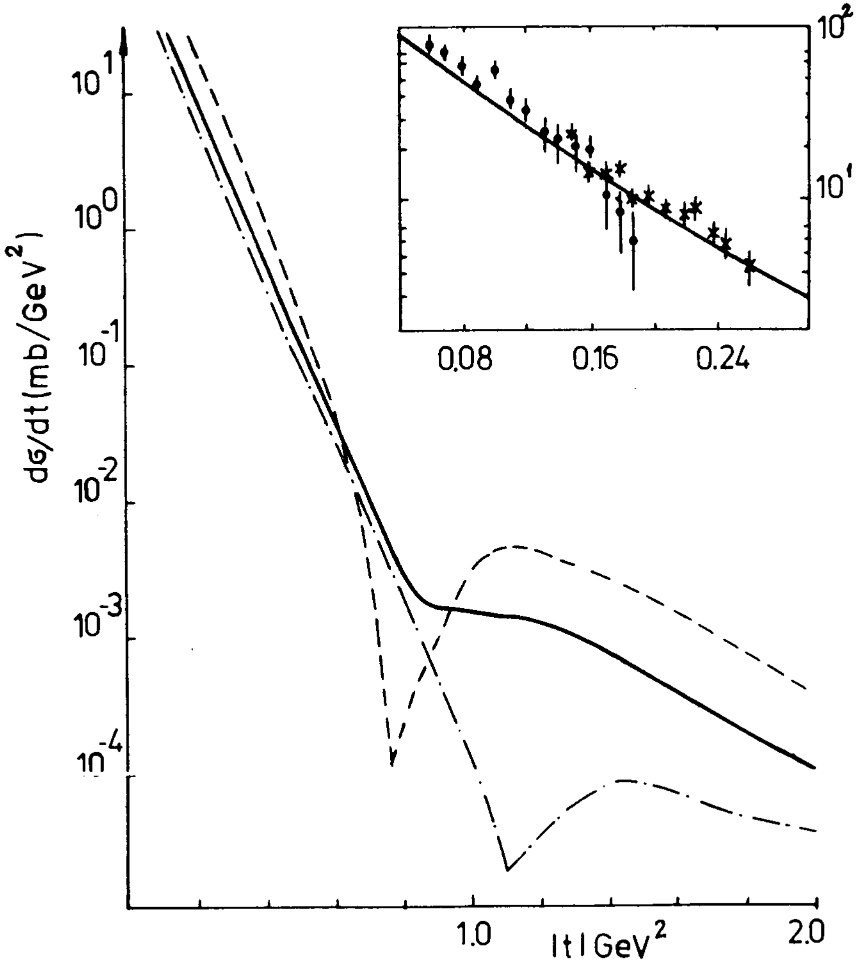


Fig.3. Predictions of different model for elastic $p\bar{p}$ scattering at $\sqrt{s} = 540$ GeV. ——— Our model with the spin contribution; — · — the same without $\sqrt{s}/2 \cdot \gamma_{spin}$ (geometrical scaling) ------ the Chou-Yang model /7/ (factorized eikonal).

These results are in agreement with CERN UA-1 and UA-4-collaboration experiments (see fig.3).

So, it is shown that the spin of particles can lead to the new dynamics of hadron interactions at superhigh energies. In this case both the spin-flip and spin-non-flip amplitudes are completely determined by the contribution of the β potential (5), and we have found the new possibility, the "spin" dynamics of hadron interactions, at asymptotically high energies. First signs of these effects can be observed at CERN $p\bar{p}$ collider energies, and detailed experimental investigations are necessary.

Note that in our model the potential β is determined by the meson-cloud contribution. As a result, the potential has a peripheral character. Its interaction radius approximately equals 2 fm.

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Голоскоков С.В., Селюгин О.В. E2-83-448

Новая роль спина в высокоэнергетическом рассеянии адронов

Рассмотрена возможность существования новой "спиновой" динамики упругого рассеяния адронов при сверхвысоких энергиях. Обсуждены ее следствия при энергиях коллайдера ЦЕРН'а.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

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Goloskokov S.V., Seljugin O.V. E2-83-448

New Role of Spin in High Energy Hadron Scattering

The possibility of a new "spin" dynamics of elastic hadron interaction at superhigh energies is considered. Its consequences at CERN $p\bar{p}$ collider energies are discussed.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

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