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PREDICTIONS OF "SPIN" DYNAMICS MECHANISM FOR HADRON INTERACTIONS AT SUPERHIGH ENERGIES

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Some important results obtained at the CERN collider $S\bar{p}pS$ and future development of accelerator techniques (FNAL and UNK colliders) attract our attention to the elastic hadron scattering at small angles. 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 which connect different reaction channels introduced in paper by N.N.Bogolubov on the disperion theory /1/ and rigorous constraints and asymptotic conditions for physical observables proved by A.A.Logunov /2,3/. The results of $S\bar{p}pS$ collider show a still continuing growth of the total cross section as $\sim \ln^2 s$, the diffraction peak shrinkage and a slow growth of $\sigma_{el} / \sigma_{tot}$ and $\rho = Re\,T(s,0) / Im\,T(s,0)$.

A particular interest is caused by a rapid growth of the differential cross section at $|t| \sim 1\ GeV^2$ and energies $\sqrt{s} \geqslant 100\,GeV$. As a result, the diffraction structure has changed to a "shoulder".

The very important problem is the role of spin effects in high and superhigh energy hadron scattering. In most of early models the spin effects were supposed to be unimportant at these energies. However, in some models /4/ the spin-flip amplitudes which don't
crease with growing energy were predicted. For example, in the
del /5/ the absence of the second diffraction minimum was explai-
d by the spin-flip contributions.

In paper /6/ the dynamical model for particle interaction which
s into account the hadron structure at large distances was deve-
d. In this model a small spin-flip amplitude appeared which does
ecrease with increasing energy. This amplitude is determined by
uasipotential $\beta(s,\tau)$. Summation of large-distance
ts performed in this case on the basis of the Logunov-Tavkhelidze
potential approach shows that in the eikonal phase of the spin-
flip amplitude a term growing as $\sqrt{s}\cdot\beta^2(s,\tau)$. (The ano-
s term in what follows). It was shown /8/ that this effect may
e the dynamics of strong interaction at superhigh energies.
odel describes different properties of meson-nucleon and nucleon-
eon scattering in the diffraction region, including spin effects.
pp -differential cross-section picture at ISR energies was
itatively explained on the basis of this model. The prediction
$\bar{p}p$ - scattering is in accordance with experiment.

In this paper the role of "spin" mechanism in hadron scattering at superhigh energies is investigated on the basis of the dynamical model. It is shown that in the energy region $\sqrt{s} \geqslant 1\,TeV$ this mechanism is the principal one. The differential cross section at momentum transfer $0 \leqslant |t| \leqslant 3\ GeV^2$ for proton-proton and proton-antiproton scattering is investigated up to the energies $\sqrt{s} = 40\,TeV$. The model predictions about the change of scattering process properties at superhigh energies are confirmed by the $S\bar{p}pS$ experiments at $\sqrt{s}$ =540, 630 and 960 GeV and can be checked at future accelerators (UNK, $S\bar{p}pS$, collider FNAL) we compare our predictions with the results too.

In /9/ on the basis of sum rules it was shown that the main contribution to hadron interaction at large distances comes from the triangle diagrams with 2π-meson exchange in the t-channal. As a result, the hadron amplitude can be represent as a sum of central and peripheral parts of interaction:

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

In /10/ we calculate the matrix element of the peripheral part of the nucleon-nucleon scattering amplitude at high energies and small momentum transfers. The quasipotentials in τ-space are determined by the Fourier transformation.

The solution of the quasipotential equation with obtained quasipotentials leads to the following representation for the nucleon-nucleon scattering amplitudes.

$$T(k,p) = \overset{+}{\chi}(k)\otimes\overset{+}{\chi}(-k)\cdot\Big\{T_{\substack{++\\++}}(k,p) + i\sigma_y^{(1)}T_{\substack{+-\\++}}(k,p) + i\sigma_y^{(2)}T_{\substack{++\\+-}}(k,p)\Big\}\cdot\chi(p)\otimes\chi(-p),$$

where

$$T_{\substack{++\\++}}(k,p) = \frac{i}{2\pi^2}\int \rho\, d\rho\, J_0(\rho\Delta)\left[1 - e^{\tilde{\chi}(s,\rho)}\right],$$

$$T_{\substack{+-\\++}}(k,p) = T_{\substack{++\\+-}}(k,p) = -\frac{1}{2\pi^2}\int \rho\, d\rho\, J_1(\rho\Delta)\chi_1(s,\rho)e^{\tilde{\chi}(s,\rho)} \qquad (2)$$

$$\tilde{\chi}(s,\rho) = -\frac{2}{i}\int_{-\infty}^{\infty}\left\{d_c(s,z) + d_p(s,z) - \frac{\sqrt{s}}{2}\cdot\left[\beta_p^2(\rho,z) + \frac{1}{16}\alpha_p^2(\rho,z)\right]\right\}dz$$

$$= \chi_c(s,\rho) + \tilde{\chi}_p(s,\rho); \qquad \tilde{\chi}_p = \chi_p^0 + \chi_{spin}\frac{\sqrt{s}}{2} \qquad (3)$$

Here $\chi_c(s,\rho)$ is the central part of the eikonal phase determined phenomenologically, $\tilde{\chi}_p(s,\rho)$ is the peripheral part of the eikonal phase which includes the growing as $\sqrt{s}$ terms calculated in the model.

Representation (2) is in form equivalent to the standard eikonal representation. The difference is the term $\chi_{spin}(s,\rho)\frac{\sqrt{s}}{2}$ in (3) growing as $\sqrt{s}$ and proportional to small anomalous terms of the quasipotential squared. These terms are of a spin nature because the quasipotentials $\beta_p(\rho,z)$ and $\alpha_p(\rho,z)$ determine the spin-flip and double-spin flip amplitude, respectively.

We want to note that the eikonal phases with the quasipotential squared were obtained in /11/. In the case of slow energy dependence of spin effects on these eikonal phases the growing as $\sqrt{s}$ terms appear too.

The anomalous terms of the eikonal phase are unimportant at low energies. At superhigh energies they lead to a rapid total-cross-section growth and some other effects which we discuss below.

With growing energy the terms with double spin-flip of one particle in $\tilde{\chi}(s,\rho)$ become dominating and the helicity amplitudes are determined by the quasipotential $\beta(\rho,z)$ contribution. The model permits us to calculate the quasipotentials $d_p(s,z)$; $\beta_p(s,z)$; $\alpha_p(s,z)$. (In what follow we shall omit the $\alpha_p^2(s,z)$ contribution because $\beta_p^2(s,z) \gg 1/16\,\alpha_p^2(s,z)$). So, we know the magnitude of $\tilde{\chi}_p(s,\rho)$ and $\chi_1(s,\rho)$ in formula (2) and therefore we can predict the spin effects and the behaviour observables at superhigh energies having determined the parameters of the central part of eikonal phase.

The magnitude of the $d_c(s,z)$ contribution was found from the proton-proton and proton-antiproton differential cross section at 9.7 GeV $\leq \sqrt{s} \leq$ 546 GeV and 0.05 GeV^2 $\leq |t| \leq$ 4.2 GeV^2.

The model predictions for polarization effects in proton-proton scattering are in accordance with experiment. So, we may conclude that the calculation of $\beta(s,z)$ quasipotential in the model is correct. This quasipotential determines the "spin" contribution to the spin-non-flip eikonal phase $\tilde{\chi}_p$. It can essentially change the cross-section behaviour at superhigh energies.

Let us consider the "spin" mechanism dynamics predictions at energies $\sqrt{s} >$ 100 GeV. The quasipotential $\beta(s,z)$ leads to the following exponential asymptotic behaviour of the eikonal phase at large impact parameters /8/:

$$\chi_{spin} \simeq \chi_{spin}(0)\cdot\exp(-2M_a\cdot\rho). \qquad (4)$$

In this case for the total cross section we obtain:

$$\sigma_{tot} \underset{s\to\infty}{\sim} \frac{\pi}{M_a^2}\cdot\ln^2\left(\frac{\sqrt{s}}{2}\cdot\chi_{spin}(0)\right). \qquad (5)$$

Thus, at superhigh energies the model leads to a rapid total cross section growth which does not contradict the Froissart bound and has a spin character . The results for the total cross section up to $\sqrt{s}$ =150 TeV are shown in fig.1.

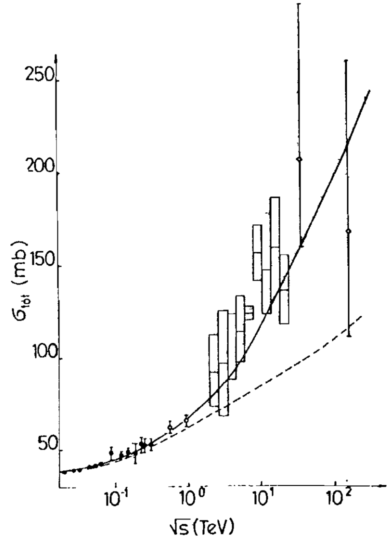

Fig.1.

The total pp-scross-sections are calculated in the model ———— with and - - - - - - - without account of the "spin" mechanism.

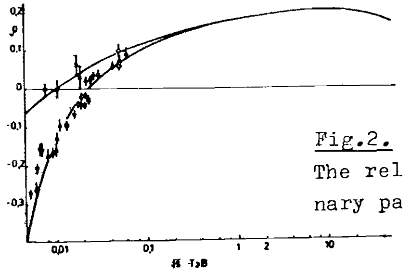

Fig.2.

The relation of the real to imaginary part of the scattering amplitude.

The main contribution to the total cross section growth at energies $\sqrt{s} \leq$ 100 GeV comes from the standard mechanism related with the effective-radius growth with energy. At higher energies the "spin" mechanism becomes essential and its contribution to σ_{tot} at $\sqrt{s}$ = 540 Gev is approximately equal to 6 mb. . The ratio

$$\rho = \mathrm{Re}\,T(s,0)/\mathrm{Jm}\,T(s,0)$$

for proton-proton and proton-antiproton scattering is consistent with experiment at energies $\sqrt{s} \geqslant 7$ GeV (fig.2). The anomalous terms do not change its energy behaviour.

The model results for the diffraction peak slope and total cross sections are as follows

Diffraction peak slope (GeV^2) ($\sqrt{s}$=540 GeV)	$\|t\|$	0. GeV^2	0.1 GeV^2	0.3 GeV^2
	th	16.0	15.2	13.6
	exp	-	15.3 ± 0.2	13.4 ± 0.3
Total cross section (σ_{tot}) mb	$\sqrt{s}$	540 GeV	630 GeV	960 GeV
	Th	60.4	61.2	66.6
	exp	61.1 ± 1.8	-	66.6 ± 3

Here the experimental data are shown for comparison. We want to note the nonstandard behaviour of the diffraction peak slope with changing s and t-variables (fig.3).

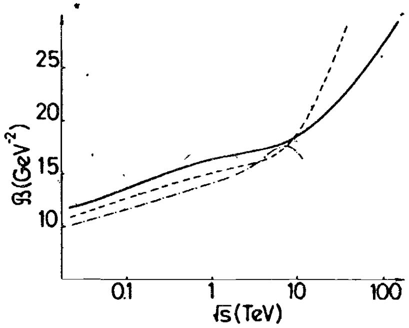

Fig.3.

The dependence of the slope of the diffraction peak $B(s,t)$ on s

——————— at /t/= 0.05 GeV^2

– – – – – – at /t/= 0.15 GeV^2

—·—·—·— at /t/= 0.3 GeV^2

The B grows with energy as $\ln s$ at $\sqrt{s} \leqslant 100$ GeV and at t approximately equal to zero. At higher energies $B(0)$ grows with energy as $\ln^2(s)$. The diffraction peak slope has a complicated behaviour at $\sqrt{s} > 1$ TeV in a different momentum transfer region. For example B grows with energy as $\ln^2 s$ at /t/=0.1 GeV^2 however, at t=0.2 ± 0.5 GeV^2 $B(s)$ decreases. This effect is due to the contribution to the scattering amplitude at small /t/ from the anomalous "spin" term in the eikonal phase of a peripheral character.

The anomalous term starts to work at lower energies in the diffraction minimum region. Really, the rapid change of the differential cross section near the diffraction minimum is observed at energies $\sqrt{s} \gtrsim 100$ GeV as a consequence of the growth of the eikonal phase with energy. The differential cross-section at 1 $GeV^2 \leqslant |t| \leqslant 1.8\ GeV^2$ and $\sqrt{s}$ =540 GeV increases by an order of magnitude. As a result, the model prodicts that the diffraction structure almost disappears at CERN $\bar{p}p$ collider energies /8,12/ and a "shoulder" appears in the differential cross sections (fig.4). The results of the UA-4 experiment (CERN $\bar{p}p$ collider) are shown in the figure too. They are

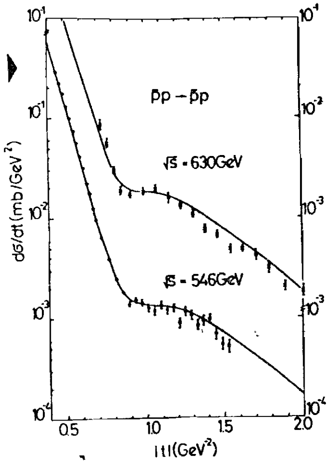

Fig.4.

The differential cross-sections of $\bar{p}p$- scattering at $\sqrt{s}$ = = 546 GeV and 630 GeV.

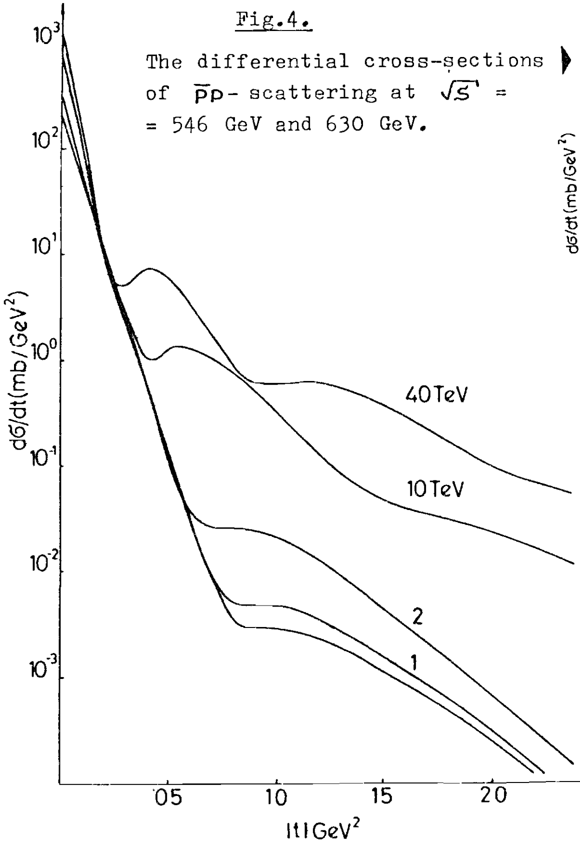

Fig.5.

The role of "spin" mechanism in differential cross-sections at super high energies from 0.8 TeV up to 40 TeV.

in full agreement with our predictions. Predictions of the dynamical model without "spin" mechanism /15/, the standard factorized eikonal model /16/ and some other model /17/ are in disagreement with experiment at $|t| \sim 1.0 \div 1.2\ GeV^2$ by one or two orders of magnitude.

The "spin" mechanism effects can be observed in fig.5.

The questions are the following : How uniquely is the "spin"-mechanism influence determined and in what case can the existence of this mechanism be considered to be proved in hadron interactions. To answer these questions, we compare our predictions with other efficient models predictions.

Now there are obtained theoretical values for $\bar{p}p$ - differential cross sections at $\sqrt{s}$ =540 GeV in some models as a result of different modifications.

In model /18/ a qualitative description is obtained of experiment with a weakly marked diffraction minimum and maximum. The model is based on the assumption that in a small-angle region there are two different mechanisms: the first is the diffraction and the second is the "hard" mechanism connected with the two-quark exchange in the ω -meson form. The main prediction of this model is that at higher energies up to $\sqrt{s}$ =40 TeV the differential cross sections change slowly and the diffraction minimum slowly disappears.

The Regge-eikonal model with a large three-gluon contribution in the diffraction-minimum region is proposed in /19/. The model leads to the diffraction minimum in pp -scattering at superhigh energies and its absence in $\bar{p}p$ at energies higher than 50 GeV. This is a consequence of the negative signature of the three-gluon exchange amplitude. As a result, this amplitude is compensated by the real part of the pomeron exchange in pp -scattering and is added to it in the $\bar{p}p$ scattering case.

The results which rather well describe the experimental data at $\sqrt{s} \doteq 540$ GeV were obtained in /20/. The model reproduces the pp -polarization behaviour at sufficiently low energies and predicts large polarization effects at superhigh energies. Note that like in all modifications of the Chow-Yang model, it predicts the appearance of a strongly marked diffraction structure at superhigh energies. Thus, it is clear that most distinctive predictions of different models belong to the range of /t/ ~1 GeV (see for example the table). It is just in this range that the measurement of the differential cross sections at future accelerators will give a final conclusion about the validity or other representations about the strong interaction dynamics at superhigh energies. Note that the continuous suffrecently fast growth of the cross section in this range, predicted in our model and caused by the spin mechanism is at present confirmed by experiment at $\sqrt{s}$ =630 GeV. It can be seen from the Table that the differences in the model predictions also are for the relation of the real to imaginary part of the scattering amplitude and for the relation of the elastic to total cross sections. Note that in our model the value ρ reaches its maximum in the range $\sqrt{s} \sim 10\ TeV$, where it is sufferently different from the prediction of the model /20/.

Table

The comparison of the predictions at superhigh energies for $pp(\bar{p}p)$--scattering. I - our predictions, II - work /12/.

$\sqrt{s}$, TeV		.540	1	2	10.	20.	40.
σ_{tot}, mb	I	60.4.	67.2	78.	118	140	167
	II	62.	67.9	76.1	98.4	109.4	121.2
σ_{el}, mb	I	12.4	15.3	19.0	39.7	51.32	63.8
	II	—	14.9	17.9	26.8	31.4	36.4
$\frac{\sigma_{el}}{\sigma_{tot}}$	I	0.2	0.22	0.24	0.34	0.37	0.38
	II	0.21	0.22	0.235	0.27	0.287	0.3
ρ	I	0.14	0.16	0.19	0.198	0.196	0.17
	II	0.13	0.128	0.128	0.122	0.118	0.114
$\frac{d\sigma}{dt}\cdot 10^3, \frac{mb}{GeV^2}$	I	1.35	4.7	21.3	330.	390.	600.
$\lvert t\rvert = 1\ GeV^2$	II	1.92	3.47	11.2	38.6	49.9	53.7
$B(t,s)$, GeV^{-2}	I	15.5	16.1	16.6	18.7	21.1	24.6
$0 < \lvert t\rvert \leq 0.15\ GeV^2$	II	15.6	—	—	18.6	19.6	20.7

Thus, on the basis of a unified eikonal representation a consistent account of the spin structure of interacting particles leads to a new "spin" mechanism in the strong interaction dynamics which is leading in the range of small-angle scattering at superhigh energies. On the basis of this mechanism in the framework of the model, which takes into account the hadron structure, a self-consistent picture of hadron scattering at high and superhigh energies is obtained. We can clearly conclude that the obtained at CERN experimental data at $\sqrt{s}$ = 546 GeV and 630 GeV are the first confirmation of this new "spin" mechanism. Such a picture of the strong interaction at super high energies leads to new effects which can be verified at future accelerators.

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Голоскоков С.В., Кулешов С.П., Селюгин О.В. E2-86-497
Предсказания механизма "спиновой" динамики
для взаимодействия адронов сверхвысоких энергий

Показано, что последовательный учет спиновой структуры взаимодействующих адронов, на основе единого эйконального представления, приводит к возможности возникновения нового механизма "спиновой" динамики взаимодействия, который при сверхвысоких энергиях в области малых углов рассеяния становится определяющим. Проявления этого механизма в рассеянии при сверхвысоких энергиях рассмотрены в рамках модели, учитывающей внутреннюю структуру нуклона. Предсказан ряд ярко выраженных эффектов для физических величин, которые могут быть проверены на ускорителях следующего поколения /УНК, $S\bar{p}pS$, FNAL/.

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Goloskokov S.V., Kuleshov S.P., Seljugin O.V. E2-86-497
Predictions of "Spin" Dynamics Mechanism
for Hadron Interactions at Superhigh Energies

It is shown that on the basis of unified eikonal representation a consistent account of the spin structure of interacting particles leads to a new "spin" mechanism in the strong interaction dynamics which governs small-angle scattering at superhigh energies. On the basis of the model which takes into account the hadron structure at large distances the manifestation of this mechanism is investigated at superhigh energies. Some clear effects for observable values are predicted to be verified at future accelerators (UNK, $S\bar{p}pS$, FNAL).

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

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