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"MESON CLOUD MODEL" OF HIGH ENERGY HADRON-HADRON SCATTERING

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An actual problem of the modern physics of elementary particles - the research of the strong interaction processes at high energies is considered in the framework of different approaches using various models of the structure of hadrons and the dynamics of its interactions.

The relativistic models of high energy scattering, based on the Logunov-Tavkhelidze quasipotential approach, take the important place among them. Here is essential the hypothesis about the existence of the local smooth quasipotential, giving an adequate description of the high energy scattering processes.

The smoothness of the quasipotential is related to the dynamics of two-particle interactions and means that at high energies the hadrons behave as loose extended objects with finite dimensions.

The dynamical equation for the scattering amplitude in the quasi-potential approach permits us to find its leading asymptotic term and also corrections to the leading term in different momentum transfer ranges /3/.

As a result, we have the decomposition of the scattering amplitude in a small parameter - the inverse power of the momentum in the c.m.s.

$$T(s,t) = T_0(s,t) + T_1(s,t) + \dots \qquad (1)$$

For the scattering of spinless particles the leading term satisfies the eikonal representation:

$$T_0(s,t) = \frac{is}{16\pi^3} \int d^2\rho \, e^{i\vec{\Delta}\vec{\rho}} \left(1 - e^{i\chi(\rho, s')}\right), \qquad (2)$$

where the eikonal phase χ is determined by the dynamics of strong interactions at large distances. It is connected with the quasipotential by the relation:

$$\chi = \frac{1}{s} \int dz \, V(s, \rho, z) . \qquad (3)$$

The smoothness of the quasipotential provides the smallness of corrections $\sim 1/p$ as compared to the leading term as $p \to \infty$.

The eikonal representation (2) with quasipotentials of the Gaussian type extensively used earlier to analyse the experimental data leads to the amplitude which is an entire function of the momentum transfer, what is not satisfactory in view of analytical properties [5].

It can be shown [6] that if the scattering amplitude satisfies dispersion relations, the quasipotential can be represented as a superposition of Yukawa potentials

$$V(s,r) = \int_{\mu_0}^{\infty} \frac{e^{-\mu r}}{r} \hat{\sigma}(\mu,s)\, d\mu, \qquad (4)$$

and it falls exponentially with $r \to \infty$.

In the present work we define the quasipotential in the framework of a scalar model, using the assumption of the existence of the central part of a hadron, where the valence quarks are concentrated, and taking into account effects of the mesonic "cloud" - "Mesonic cloud model".

The obtained form of the quasipotential permits us to quantitatively reproduce all basic properties of the hadron elastic scattering at superhigh energies in a wide momentum transfer region.

Let us represent the nucleon as a central part, where the valence quarks are concentrated [7,8] ("bare" nucleon), surrounded by the mesonic "cloud". As in work [9], we will regard the mesons of one type only.

The simplest diagrams of proton-proton scattering are shown in fig.1, where the contribution of the mesonic "cloud" is taken into account.

As a result, for the scattering amplitude we obtain:

$$T(s,t) = M_{pp}(s,t) + \phi_1(s,t) + \phi_2(s,t)\,. \qquad (5)$$

Here the first term corresponds to the diagram 1a, ϕ_1 is the sum of the diagrams b,c; and ϕ_2, the sum of the diagrams d,e.

For ϕ_1 we have the representation:

$$\phi_1(s,t) = \frac{g^2}{(2\pi)^4} \int \frac{d^4 M_{\pi p}(s',t)}{(q^2-M^2+i\epsilon)\,((k-q)^2-m^2+i\epsilon)\,((p-q)^2-m^2+i\epsilon)}, \qquad (6)$$

$$s' = (k+p-q)^2\,.$$

Using the light front variables $p_\perp$, p_z; $q_\perp$, q_-, q_+, $q_\pm = q_0 \pm q_z$, $q_\perp = xk^+$ and integrating over q_- we obtain

$$\phi_1(s,t) = \frac{ig^2}{(2\pi)^3} \int_0^1 dx \int \frac{d^2 q_\perp M_{\pi p}(s(1-x),t)}{[M^2(1-x)^2+q_\perp+xm^2][M^2(1-x)^2+q_\perp+xk^+\frac{\Delta^2}{2k}+2x\Delta q_\perp]},$$

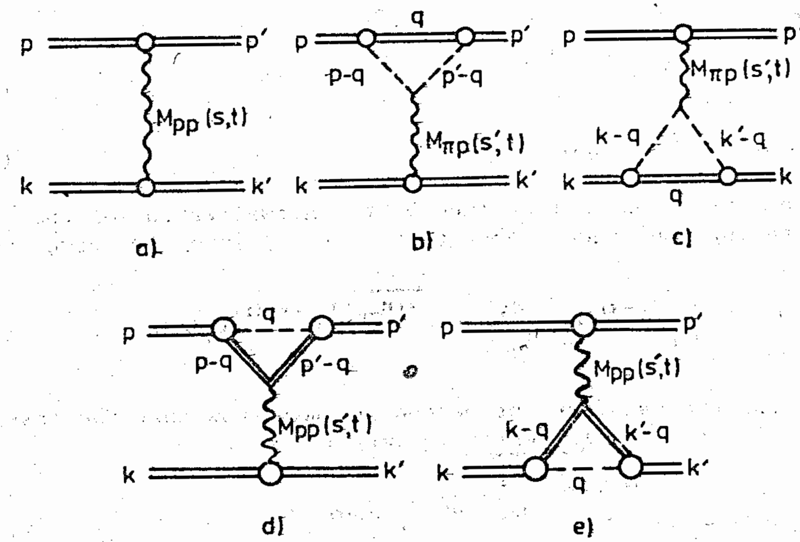

Fig.1. Simplest diagrams of nucleon-nucleon scattering, where the contribution of the mesonic "cloud" is taken into account.

The subsequent integration over $q_\perp$ leads to the representation

$$\phi_1(s,t) = \frac{ig^2}{8\pi^2} \int_0^1 \frac{dx}{x} M_{\pi p}(s(1-x),t) \int_0^1 \frac{d\alpha}{[\beta(x)+\alpha(1-x)\Delta^2]}, \qquad (7)$$

where

$$\beta(x) = \frac{1}{x^2}[M_p^2(1-x)^2 + m_\pi^2(x)].$$

Using the Gaussian form for the leading terms of nucleon-nucleon and meson-nucleon scattering amplitudes:

$$M_{pp}(s,t) = is A_{pp} e^{B_{pp}t},$$

$$M_{\pi p}(s,t) = is A_{\pi p} e^{B_{\pi p}t}$$

we can find the eikonal phase which is the two-dimensional Fourier transform of the amplitude (5). As a result, we have

$$\chi(\rho) = \chi_0(\rho) + \chi_1(\rho) + \chi_2(\rho)\,. \qquad (8)$$

where

$$\chi_0(\rho) = \chi(0)\; e^{-\rho^2/4B_{\pi p}} , \qquad (9)$$

$$\chi_{1,2}(\rho) = c\int \Delta d\Delta\; J_0(\rho\Delta)\;\phi_{1,2}(s,t) , \qquad (10)$$

where c is a constant defined by the normalization of the scattering amplitude. Substitution of (7) into (10) gives for

$$\chi_1(\rho) = -\frac{c}{2}\int_0^1 \frac{(1-x)}{x}\,dx \int_0^\infty \frac{dy}{(B_{\pi p}+y)}\; e^{-\frac{\rho^2}{4(B_{\pi p}+y)}}\; e^{-2y\beta(x)} K_0(2\beta(x)\,y) . \qquad (11)$$

By using the saddle-point method one may show that the integral (11) has the exponential asymptotic as $s\to\infty$:

$$\chi_1(\rho) \sim \frac{c}{\rho^3}\; e^{-2\rho\sqrt{m_\pi^2+\frac{M_p^2}{m_\pi^2}\frac{1}{\rho^2}}} \sim e^{-\mu_{eff}\rho} . \qquad (12)$$

The computer integration reveals that at distances of an order of the size of the hadron $\mu_{eff} \sim 0.6$ GeV and slowly falls with growing energy.

The investigation of the contribution of the diagrams d,e leads for ϕ_2 with the asymptotic form (12) where $m_\pi \to M_p$. It is clear that in this case $\mu'_{eff} \sim 2$ GeV $> \mu_{eff}$ and the contribution of ϕ_2 to the eikonal phase is small at large ρ. Thus, the terms χ_0 and χ_1 give the leading contribution to the eikonal phase (see fig.2).

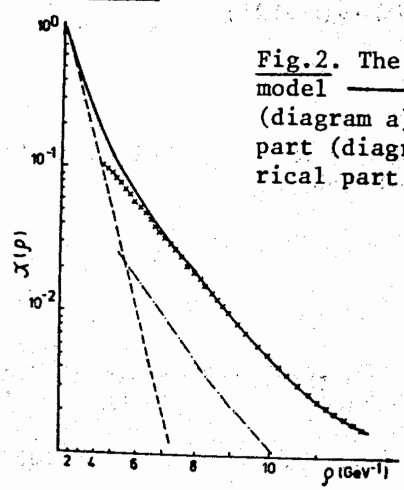

Fig.2. The form of eikonal phase obtained in model ———————, – – – – – – central part (diagram a)), ×××××××××××× – peripherical part (diagrams b), c)), —·—·—·— – peripherical part (diagrams d), e)).

Note that the form factor of the hadron should be taken into account in the diagrams fig.1 for a more accurate investigation of the contribution of the mesonic "cloud" of the hadron at small ρ. However, this should not change essentially the form of the eikonal phase.

The eikonal phase (8) obtained may be well approximated by the expression (see fig.2)

$$i\chi(\rho) = -h\,e^{-\mu(s)\sqrt{b^2+\rho^2}} \qquad (13)$$

where h, b, μ are, respectively, the effective interaction constant, the effective radius of the central part of the interaction, and the effective mass, and $\mu(s) \sim 0.6$ GeV.

The quasipotential, describing the interaction of two hadrons at the ultra high energies and corresponding to the eikonal phase (13), can easily be calculated by the relation

$$V(r) = \frac{2s}{\pi r}\,\frac{d}{dr}\int_z^\infty \frac{\eta\,\chi(\eta)\,d\eta}{\sqrt{\eta^2-r^2}} . \qquad (14)$$

As a result, we have

$$V(r) = \frac{2is\mu h}{\pi}\; K_0\left(\mu\sqrt{b^2+r^2}\right) . \qquad (15)$$

Note that the quasipotential (15) can be represented as a superposition of Yukawa potentials (4).

The scattering amplitude can be explicitly calculated:

$$\frac{1}{i}\,T(s,t) = -s\sum_{n=1}^{\infty}\frac{(-h)}{(n-1)!}\;\frac{\mu}{(n^2\mu^2+\Delta^2)^{3/2}}\;\left(1+b\sqrt{n^2\mu^2+\Delta^2}\right) e^{-b\sqrt{n^2\mu^2+\Delta^2}} . \qquad (16)$$

It is analytic function of t and has root branch-points at $t=\mu^2$, $(2\mu)^2$, $(3\mu)^2, \ldots$

At large momentum transfers all the terms of the sum (16) have the same behaviour what does not lead to the appearance of a large number of the diffraction minima.

Moreover, the asymptotics of the series (16) is positive as $\Delta\to\infty$, hence, the number of zeros should be even. It can be shown that the amplitude (16) at definite values of parameters has not zeros at all. So in this case the differential cross sections have not diffraction structure. This results cannot be obtained in the framework of standard eikonal models (see, e.g., review /10/).

We have used /13/ the eikonal phase (13), with taking into account some inelastic effects, for analysis of the experimental data /10,12/ on the elastic proton-proton scattering in ranges $\sqrt{s} \geq 2$ 3,4 GeV and $0 \leq |t| \leq 14.2$ GeV^2.

The energy dependences of the quasipotential parameters can be determined by using the hypothesis of geometrical scaling /14/, as a result the effective mass slowly decreases with growing energy, what is in accordance with our model.

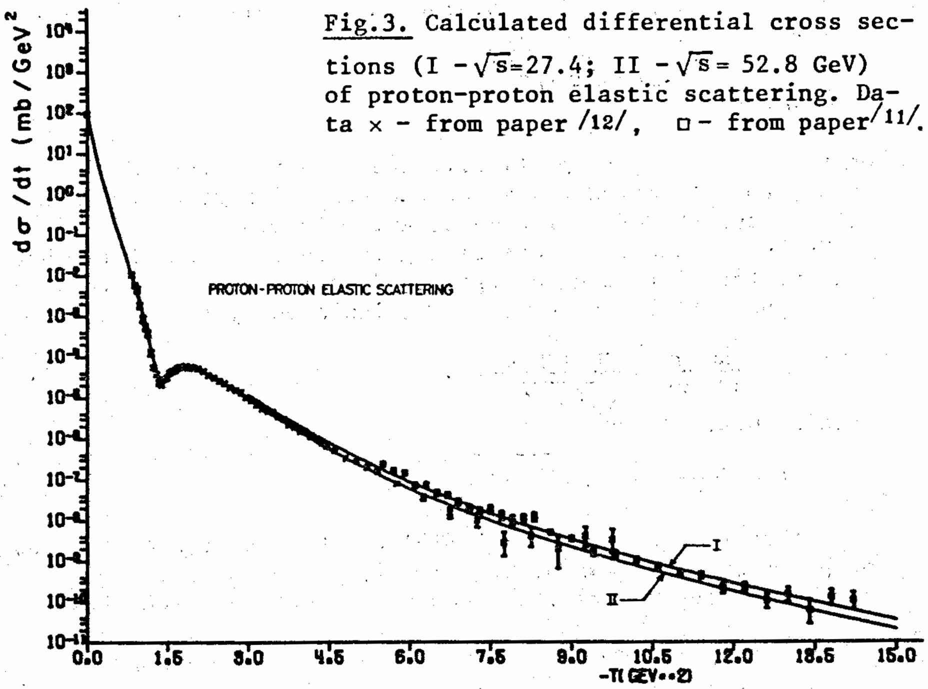

Fig.3. Calculated differential cross sections (I $-\sqrt{s}$=27.4; II $-\sqrt{s}$= 52.8 GeV) of proton-proton elastic scattering. Data × - from paper /12/, □ - from paper /11/.

It is clear from fig.3 that the quasipotential (15) allows one to quantitatively reproduce all properties of the differential cross sections in a wide momentum transfer region. Note, that for p_L= 400 GeV $\mu \approx$ 0.53 GeV that corresponds to the mass obtained within the model.

It is interesting to note that the "Mesonic cloud model" is valid for the case of meson-nucleon scattering. In this case minimal changes are required which do not influence essentially the shape of the eikonal phase that can be approximated, as in the nucleon-nucleon case, by the expression (13), and the effective mass being of the same order ~ 0.6 GeV.

The analysis of the available experimental data on $\pi^- p$ elastic scattering at p_L= 200 GeV /15,16/ gives a satisfactory fit of the data ($\chi^2/\bar{\chi}^2$=1.5 with μ_{eff} ~ 0.65 see Fig.4). It is clear from the figure, the model predicts the first diffraction minimum at |t| ~ 3 GeV

However, the absence of the experimental information in the high energy and transfer momentum range in the case of meson-proton scattering does not allow one to do the final conclusion about the position of the diffraction minimum. For that it

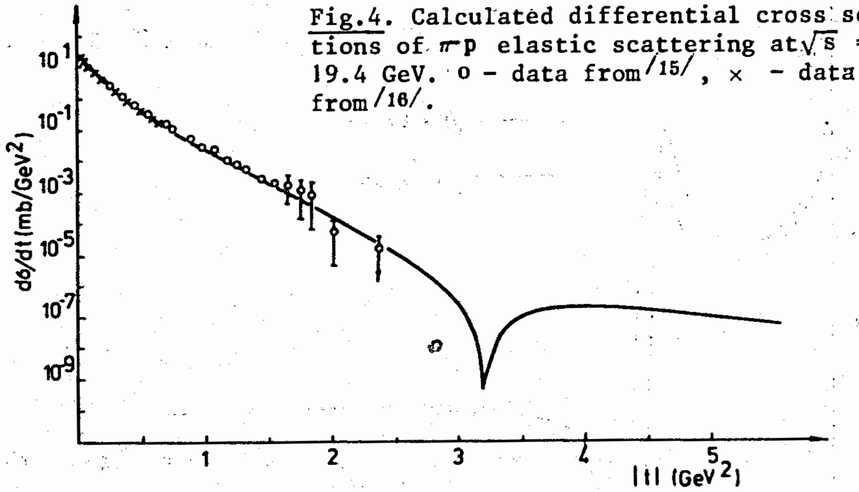

Fig.4. Calculated differential cross sections of $\pi^- p$ elastic scattering at $\sqrt{s}$ = 19.4 GeV. o - data from /15/, × - data from /16/.

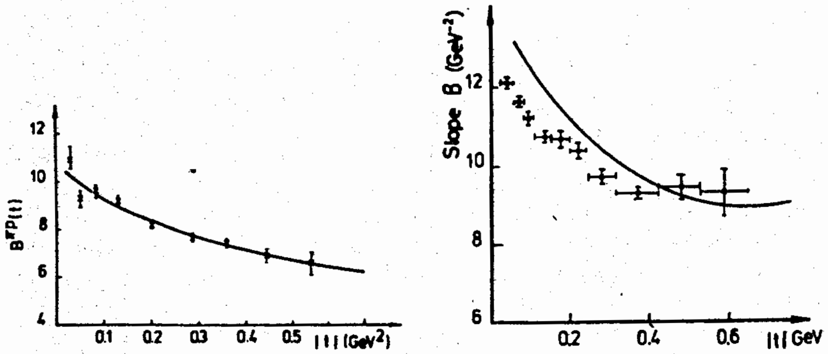

Fig.5. The slope $B = \frac{d}{dt}(\ln(d\sigma/dt))$ is calculated by the model: a) for πp elastic scattering at $\sqrt{s}$= 19.4 GeV, b) for pp elastic scattering at $\sqrt{s}$ = 23.4 GeV. Data from paper /16/ at $\sqrt{s}$ = 19.4 GeV.

is necessary to measure the cross sections of the meson-nucleon scattering at p_L= 400 GeV and |t|> 2 GeV.

It should be stressed that the "Mesonic cloud model" leads to the prediction about the smooth decrease of the slope of the diffraction peak with increasing momentum transfer which has been confirmed in recent experiments at p_L= 200 GeV /16/.

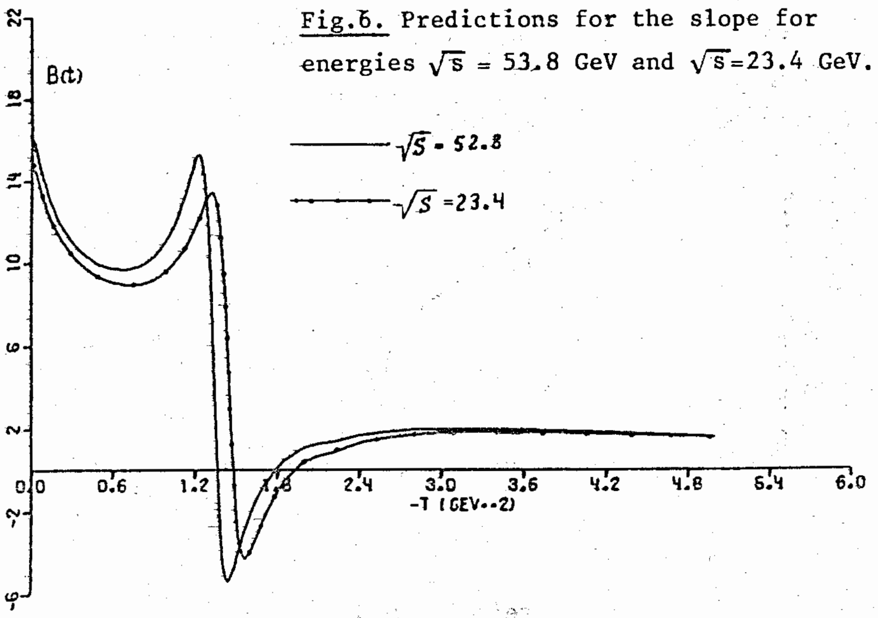

Fig.6. Predictions for the slope for energies $\sqrt{s}$ = 53.8 GeV and $\sqrt{s}$=23.4 GeV.

The form of the diffraction peak obtained in the model is consistent with these experimental data for πp and pp scattering (see Fig.5a,b).

The slope of differential cross sections in a wide momentum transfer region is shown in Fig.6. Note that the effective radius of the central part of the interaction region determining the behaviour of the scattering amplitude at large momentum transfers grows with energy as $\sqrt{\ln s}$. For the proton-proton scattering at energy $\sqrt{s}$=60 GeV b = 0'48 fm, that is approximately one half of the hadron radius. This result is close to the radius of "core" of the hadron found in /8/. Thus, the spinless model of the high energy particle scattering, which is based on the assumption of the existence of the central part of a hadron surrounded by the mesonic "cloud" and takes into account the analytical properties of the scattering amplitude, is proposed here.

The smooth quasipotential obtained permits us to reproduce quantitatively all known properties of high energy proton-proron scattering /13/. The model leads to the smooth change of the slope at small momentum transfers, and the strongly marked diffraction structure at $1.3 \leq |t| \leq 2$ GeV^2, and the small slope of the differential cross-sections behind the second diffraction maximum B_2 = 1.8 GeV at $|t| \sim 3$-5 GeV^2 and the absence of the subsequent diffraction minima up to the transfers $|t| \sim 15$ GeV^2.

In the case of the meson-nucleon scattering it allows one to do the following qualitative predictions: the slope of the diffraction peak decreases smoothly with increasing $|t|$, there are the diffraction minimum at $|t| \sim 3$ GeV^2 and the wide maximum near $|t| \sim 4$ GeV^2. The slope behind the second diffraction maximum at $|t| \sim 5$ GeV^2 is approximately 1.2 GeV^{-2}.

Thus, the "Mesonic cloud model" allows us to do a unique description, with the minimum number of free parameters, of the hadron-hadron scattering in a wide momentum transfer region. It is important to note that in the model the spin effects may be taken into account in a natural manner.

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