объединенный
институт
ядерных
исследований
дубна

E2-80-608

S.V.Goloskokov, S.P.Kuleshov, O.V.Seljugin

HIGH ENERGY PROTON-PROTON SCATTERING IN A WIDE MOMENTUM TRANSFER REGION AND ENERGY DEPENDENCE OF EIKONAL PHASE

Submitted to ЯФ

1980

In 1973-78 a series of new experiments on elastic scattering provided rich experimental information, that raises a number of new questions: absence of the second diffraction minimum at $|t| \sim 3\text{-}15\ \mathrm{GeV}^2$, the energy dependence of the slope of differential cross sections at small $|t|$, etc.

At present there exists a wide spectrum of models proposed for description of elastic hadron scattering. Many of them can reproduce main features of hadron-hadron scattering [3-6]. Among the latter, we should like to point out the models based on the hypothesis of composite structure of interacting hadrons and on the Glauber representation for scattering amplitude [4-6].

Most of eikonal models can be divided into two classes. The first class uses the hypothesis of geometrical scaling [7] which states that the whole energy dependence of proton-proton scattering amplitude may be included in the effective proton radius growing with energy. Then the eikonal phase can be represented in the form:

$$\chi(b,s) = \chi(b/R(s)). \tag{1}$$

On the other hand, the hypothesis of factorized eikonal [8] is often considered according to which the energy dependence of the eikonal phase is factorized into a factor $f(s)$ and in this case the eikonal phase is rewritten as

$$\chi(s,b) = f(s)\cdot\chi_0(b), \tag{2}$$

$\chi_0(b)$ being related to the hadronic matter distribution of the incident particles.

Since at present these hypotheses are not yet proved theoretically, attempts have been made to find the form of the eikonal phase experimentally and to establish its energy dependence [9-11].

However, because of uncertainty in the experimental information one can arrive both at the dependence (2) specific to the hypothesis of factorized eikonal [9] and at (1) confirming the hypothesis of geometrical scaling [8]. Apparently, one should admit work [10] to be more correct which uses a larger numerical material and takes into account the real part of scattering amplitude. Besides, results of the last article are confirmed to some extent in ref. [11].

As is shown, the scattering amplitude should satisfy general principles of quantum field theory like analyticity, unitarity, etc. Based on the analytical properties for scattering amplitude a model of the eikonal type was constructed[13]. This model leads to the only diffraction minimum and with the minimum number of free parameters (3 parameters) reproduces quantitatively all properties of the proton-proton scattering in the energy range $\sqrt{s} \geq 23.5$ GeV and $0 \leq |t| \leq 15\ \mathrm{GeV}^2$. In the framework of this model a modified expression of the geometrical scaling was constructed at large momentum transfers[14] that is consistent with recent experimental data.

Since the model[13] does allow a quantitative description for the behaviour of differential cross sections of proton-proton scattering, it can serve as a tool for the investigation of the form of the energy dependence of eikonal phase.

In this work, on the basis of model[13] a comparative analysis is made for two hypotheses: geometrical scaling and factorized eikonal. It is shown that the hypothesis of geometrical scaling, with $\sigma_{tot} \sim \ln s$ is in better agreement with the modern experimental situation.

Let us consider the high energy scattering of two spinless particles with equal mass at small angles in the framework of the Logunov-Tavkhelidze quasipotential approach[15]. Using the smoothness hypothesis for the local quasipotential[16], one can obtain the scattering amplitude as a power series in $\sqrt{s}$ [17] and its leading term has the eikonal form

$$T_0(s,t) = is \int_0^\infty \rho\, d\rho\, J_0(\rho,\Delta)(1-e^{i\chi(\rho,s)}), \qquad (3)$$

where the eikonal phase $\chi(\rho,s)$ is connected with the quasipotential

$$\chi(\rho,s) = \frac{1}{s} \int_{-\infty}^{\infty} V(\sqrt{\rho^2 + z^2}, s)\, dz. \qquad (4)$$

It can be shown[18], that if the scattering amplitude satisfies dispersion relations, the quasipotential can be represented as a superposition of Yukawa potentials

$$V(r,s) = \int_{\mu_0}^{\infty} d\mu \frac{e^{-\mu r}}{r} \rho(\mu,s). \qquad (5)$$

One possible kind of these quasipotentials was suggested in ref.[19].

With these requirements, we may take the main term of the eikonal phase in the form:

$$\chi_0(\rho,s) = i\delta_0(\rho,s) = i h e^{-\mu\sqrt{b^2+\rho^2}}, \tag{6}$$

where the parameters h,μ,b that corresponds to the effective constant, effective mass, and effective radius can change slowly with energy. Taking into account, besides elastic rescattering, also some possible inelastic effects with the particle beams in intermediate states, one comes to the eikonal phase in the form:

$$\delta(\rho,s) = \delta_0(\rho,s) - \gamma\delta_0^2(\rho,s), \tag{7}$$

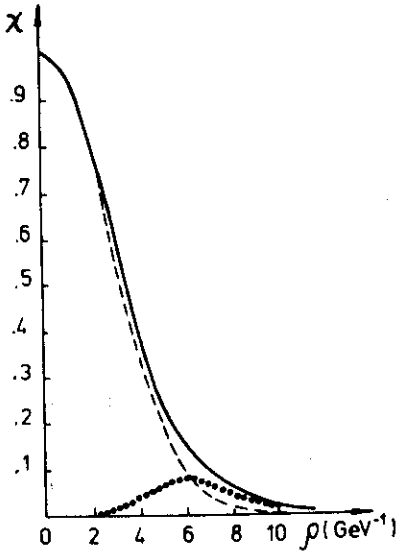

Fig.1. The form of eikonal phase in the representation of impact parameter.
——— the eikonal phase
– – – the central part of eikonal phase
...... peripheral part of the eikonal phase

which can reproduce quantitatively all properties of the proton-proton scattering in the high energy range and wide momentum transfer range[13,14].

For deeper understanding of the mechanism of interaction of hadrons it is useful to consider the form of eikonal phase (7) in the impact-parameter representation in more detail. Analysis of its form permits the conclusion that it can be decomposed into some central part, possibly, corresponding to the hadron core, and a rather smaller in magnitude peripheral part of interaction. Then, the central part of phase may be represented in a Gaussian form with radius $R\sim 3.3$ GeV^{-1} and the peripheral part has a maximum at $\rho\sim 6.3$ GeV^{-1} and falls exponentially at large impact parameters (Fig.1).

Now let us consider the energy dependence of the eikonal phase. For the case of geometrical scaling this dependence is as follows: h = const, $\mu=\mu_0/\kappa$, $b=b_0\cdot\kappa$,

$$\kappa=(1+\alpha\,(\ln s-i\frac{\pi}{2}))^{1/2},$$

and in the range of asymptotic high energy $\sigma_{tot}\sim\ln s$.

The eikonal phase obtained allows a quantitative description for the modern experimental data on elastic proton-proton scattering (Fig.2) $\chi^2/\overline{\chi^2}$ being equal to 1.21 (for $\chi^2=541$, $\overline{\chi^2}=449$, the number of free parameters equals 3).

For further consideration it is to be noted that in ref.[13] a satisfactory description was obtained without norm coefficients, which take into account the systematic errors at different experiments ($\chi^2/\overline{\chi^2}=1.45$).

Thus, the above considered model reproduces quantitatively experimental data under the assumption of geometrical scaling for the scattering amplitude. Using another energy dependence of free parameters with the same experimental data, the hypothesis of factorized eikonal can be examined. In this case the eikonal phase should be of the following form:

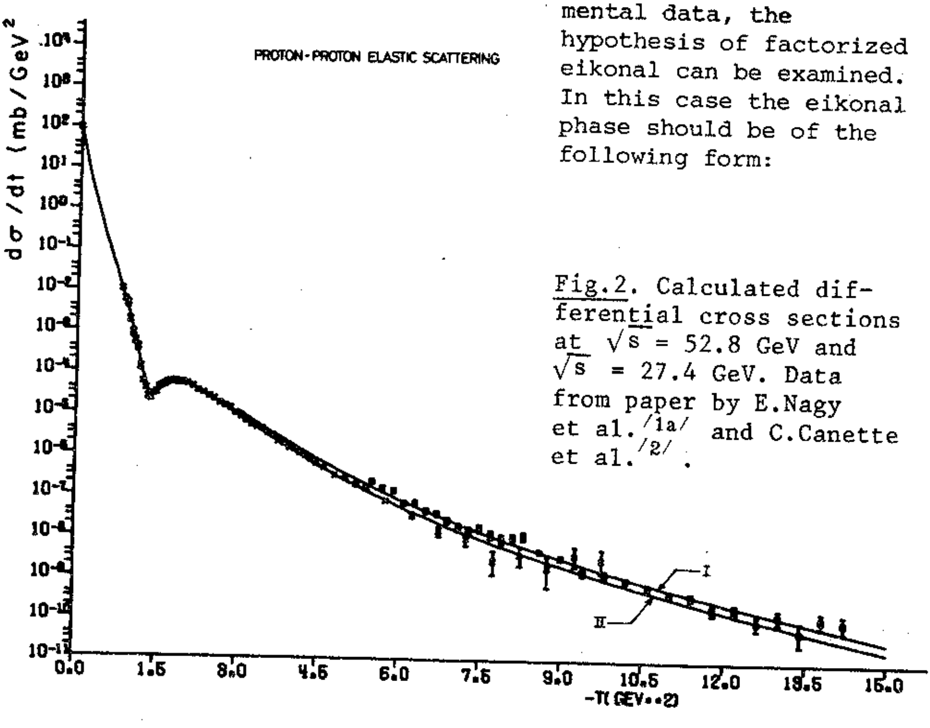

Fig.2. Calculated differential cross sections at $\sqrt{s}$ = 52.8 GeV and $\sqrt{s}$ = 27.4 GeV. Data from paper by E.Nagy et al.[1a] and C.Canette et al.[2].

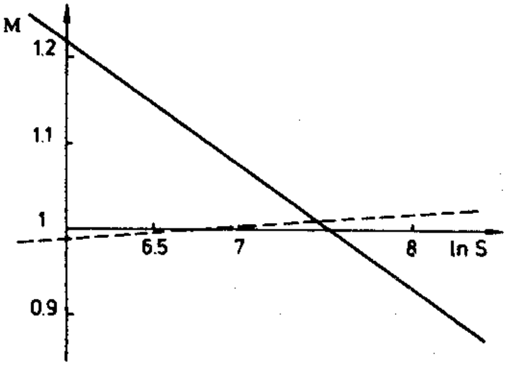

Fig.3. Energy dependence of norm coefficients approximated by ten independent experiments
——— for factorized eikonal
– – – for geometrical scaling

$$\chi(s,b) = h(s)\cdot e^{-\mu\sqrt{b^2+\rho^2}} \times$$
$$\times (1-e^{-\mu\sqrt{b^2+\rho^2}}), \qquad (8)$$

where μ and b are no longer dependent on s and $h(s)$ is chosen in the form

$$h(s) = h_1 \cdot s^{\alpha_1} \cdot e^{-i\frac{\pi}{2}\alpha_1}.$$

Both the phases coincide in magnitude for a certain energy, that is, at this energy the description of experimental data in both cases is the same. Consequently, the whole difference in the description of the complete set of experimental data comes from the phase energy-dependence.

Besides the above considered case of geometrical scaling with $\alpha = 0.075$ the experimental data were analysed for three cases of the factorized eikonal:

a) - with the fixed $\alpha_1 = 0.06$, close to the choice of $\alpha = 0.075$ in our previous case;

b) - with α_1 free, that is with four free parameters;

c) - also with four free parameters and, in addition, with bounds of norm coefficients for every individual experiment up to 20%.

The results are shown in the Table

Form of s dependence		$\chi^2/\overline{\chi^2}$	n -free parameters	M_0	β_N	limit N_i
Geometrical scaling		1.2	3	0.97	0.014	< 8%
Factorized eikonal	a	3.0	3	1.2	-0.057	< 8%
	b	2.15	4	1.76	-0.059	< 8%
	c	1.4	4	2.1	-0.069	< 20%

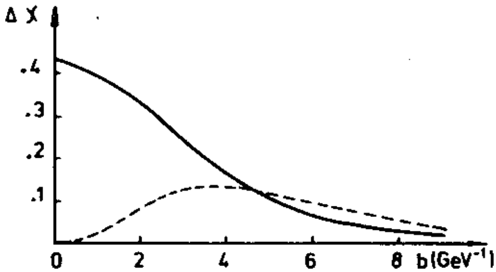

Fig.4. Energy dependence of the eikonal phase $\Delta\chi = \Delta\chi(s_1,b) - \Delta\chi(s_2,b)$ $\sqrt{s_2} = 40$ GeV, $\sqrt{s_1} = 62$ GeV
——— for factorized eikonal
– – – for geometrical scaling.

It is seen from the Table that in case a) $\overline{\chi}^2/\chi^2 = 3$, that is much worse as compared to the geometrical scaling case. Sufficiently good quantitative description is attained only in case c). However, in this case, the norm coefficients are strongly dependent on energy. This dependence can be approximated as:

$$M_i = M_0(1+\beta_N \ln s_i).$$

Parameters obtained by analysing ten individual experiments, and M_0, β_N are shown in the Table for all above considered cases. The corresponding curves are compared in Fig.3. One can see from Fig.3 and the Table that the norm coefficients give no energy dependence while using the hypothesis of geometrical scaling whereas for the factorized eikonal the norm coefficients change essentially the energy dependence of differential cross section. As a result, it is clear that satisfactory quantitative description for this latter case was achieved only at the expense of the energy dependence in the norm coefficients. Figure 4 shows the difference of phases $\Delta\chi = \chi(s_1,b) - \chi(s_2,b)$ for the hypotheses of factorized eikonal and of geometrical scaling. $\sqrt{s_2}$ was chosen to be equal to 40 GeV, at this energy the phases coincide practically in magnitude, $\sqrt{s_1}$ equal to 62.1 GeV is the maximal energy reached at ISR in CERN. From Fig.4 one can see that the maximum of $\Delta\chi$ is at about 0.8 fm for the case of geometrical scaling. The form of $\Delta\chi$ thus obtained is close to that found in ref. /11/.

Thus, analysis presented permits, by an example of one model, the conclusion that the hypothesis of geometrical scaling, with the supposition $\sigma_{tot} \sim \ln s$ is in better agreement with the ultrahigh energy experimental data presently available.

Note here, that the form of the slope of differential proton-proton cross sections, predicted by the model, in the range of small angles

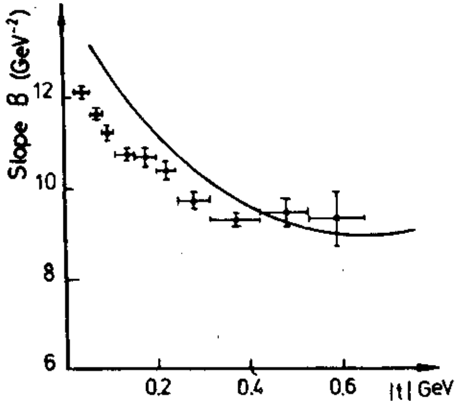

Fig.5. The slope $B(t)=\frac{d}{dt}(\ln(\frac{d\sigma}{dt}))$
——— prediction by model [13] for $\sqrt{s}$ = 23.4 GeV
— — experimental data from ref. [20] for $\sqrt{s}$ = 19.4 GeV.

$$B(t)=\frac{d}{dt}(\ln(\frac{d\sigma}{dt}))$$

is in qualitative agreement with the recent experimental results of FNAL [20] at E_L = 200 GeV (Fig.5). Some difference of the obtained slope from experimental data is due to the approximations: the spin effects and terms $1/\sqrt{s}$ in the scattering amplitude were not calculated. These terms seem to be important at energies $\sqrt{s} \leq 20$ GeV. Nevertheless, the form of the slope justifies the model at small momentum transfers.

The authors express their deep gratifude to V.A.Matveev, A.N.Tavkhelidze for interest in the work and useful remarks. We thank also A.V.Koudinov, M.A.Smondyrev for fruitful discussions.

REFERENCES

1. a) Bohm A. et al. Aachen-CERN-Geneve-Harvard-Torino-Collaboration. Phys.Lett., 1974, 49B, p.491.
   b) Nagy E. et al. CERN-Geneve-Switzerland-Hamburg-Heidelberg-Annecy-Wien. Nucl.Phys., 1979, B150, p.221.
2. Canetti S. et al. Cornell-Mc-Gill-Moscow-Collaboration. Phys.Rev.Lett., 1978, 41, p.924.
3. Tsarev V.A. Rapporteur's Talk at the XIX Int.Conf. on High Energy Phys., Tokyo, 1978.
4. Wakaizumi S., Tanimoto M. Phys.Lett., 1977, 70B, p.55; Progress of Theor.Phys., 1978, 60, No 4, p.1040.
5. Bialas A. et al. Acta Phys.Pol., 1977, B8, p.855.

6. Goloskokov S.V. et al. JINR, E2-12565, Dubna, 1979.
7. Dias de Deus J. Nucl.Phys., 1973, B59, p.231.
Buras A.I., Dias de Deus I. Nucl.Phys., 1974, B71, p.481.
8. Hayot F., Sukhatme V.P. Phys.Rev., 1974, D10, p.2183.
9. Chou T.T. Nucl.Phys., 1978, B139, p.260.
10. Amaldi U., Schubert H.R. CERN-EP/79-155.
11. Franca H.M., Hama Y. Phys.Rev., 1979, D19, p.3261.
12. Brouzan J.B., Kane G.G., Sukhatme U.P. Phys.Lett., 1974, 49B, p.272.
Gerdt V.P., Inozemtsev V.I., Meshcheryakov V.A. Yad.Fiz., 1976, 24, v.1, p.176.
13. Goloskokov S.V., Kuleshov S.P., Seljugin O.V. Yad.Fiz., 1980, 31, p.741.
14. Goloskokov S.V., Kuleshov S.P., Seljugin O.V. JINR, E2-12923, Dubna, 1979.
15. Logunov A.A., Tavkhelidze A.N. Nuovo Cimento., 1963, 29, p.380.
16. Alliluyev S.P., Gershtein S.S., Logunov A.A. Phys.Lett., 1965, 18, p.195.
17. Garsevanishvili V.R. et al. TMF, 1971, 6, p.36.
18. Filippov A.T. In: Winter School on Theoretical Physics, in JINR, Dubna, 1964, v.2, p.80.
19. Mestvirishvili M.A., Rcheulishvili G.L. TMF, 1971, 8, p.206.
20. Schiz et al. Fermilab-Pub.79/81-EXP.

Received by Publishing Department
on September 12 1980.