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J. Fischer

P. Jakeš

and

M. Novák

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HIGH-ENERGY pp AND $\bar{p}p$ SCATTERING AND THE MODEL OF GEOMETRIC SCALING *

J. Fischer **
International Centre for Theoretical Physics, Trieste, Italy,
and
International School for Advanced Studies, Trieste, Italy,

P. Jakeš and M. Novák
Institute of Physics, Czechoslovak Academy of Sciences,
Prague, Czechoslovakia.

ABSTRACT

The model of geometric scaling is used to predict the evolution of the diffractive dip-peak structure of pp and $\bar{p}p$ differential cross-sections with increasing energy. Previous calculation for pp scattering made by Dias de Deus and Kroll is carried out with new data and their predictions confirmed. Recent data on $\bar{p}p$ scattering are used to make an analogous analysis for this process as well. It turns out that the $\bar{p}p$ differential cross-section behaves analogously, main difference being that, in the $\bar{p}p$ case, the dip-peak structure should not completely disappear with increasing energy.

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** Permanent address: Institute of Physics, Czechoslovak Academy of Sciences, Prague, Czechoslovakia.

I. INTRODUCTION

It is well known that, at sufficiently high energies, the differential cross-section of proton-proton elastic scattering exhibits a pronounced structure in the interval of the momentum transfer squared between the values $t = -1.3$ GeV^2 and -2.0 GeV^2 . Around $t = -1.4$ GeV^2, there is a well established dip which is followed by a secondary maximum. This structure gradually develops with increasing energy from a slight corrugation below ISR energies till its maximal appearance at a c.m. energy $\sqrt{s}$ of approximately 20-25 GeV.

Predictions [1] based on the model of geometric scaling [2] indicate that, with a further increase of energy, this dip should be gradually smoothed till it completely disappears at $\sqrt{s} \cong 300$ GeV, while it should later develop again at asymptotic energies.

The basic idea of the model of geometric scaling is that, at sufficiently high energies, the s- and t-dependences of a hadron-hadron scattering amplitude F(s,t) reduce to a dependence on one single kinematic variable, the scaling parameter τ ,

$$\tau = -\frac{t}{t_0} \ell n^2 \frac{s}{s_0} \quad . \tag{1.1}$$

If an amplitude asymptotically saturates the Froissart bound, i.e. if

$$F(s,0) \sim s\, \ell n^2 s \tag{1.2}$$

then, as was shown by Auberson, Kinoshita and Martin [3], it follows from the principles of local field theory that the function

$$\phi(\tau) = \lim_{s\to\infty} \frac{F\left(s, -t_0\tau\, \ell n^{-2} \frac{s}{s_0}\right)}{F(s,0)} \tag{1.3}$$

is analytic in τ and entire of the order $\frac{1}{2}$. In this case, the geometric scaling model appears as a consequence of first principles, provided that violently oscillating amplitudes are excluded. Let us remark in connection with the requirement (1.2) that the systematic analysis of the p-p scattering data made by Amaldi et al. [4] has led to the result that the total cross-section should behave like $\ell n^\alpha s$ with $\alpha = 2.1 \pm 0.1$.

Remarkable progress has been made recently in the experimental investigation of the proton-antiproton scattering as well. It has turned out that the differential cross-section exhibits a very similar dip-peak structure like in the case of pp scattering. The resemblance goes so far that the t-dependence of $\frac{d\sigma^{\bar{p}p}}{dt}$ at $\sqrt{s} = 9.8$ GeV [5] is experimentally indistinguishable from that of $\frac{d\sigma^{pp}}{dt}$ at $\sqrt{s} = 52.8$ GeV. It is therefore worth revising the geometric scaling model in relation to the existing pp and also $\bar{p}p$ high-energy data.

We repeated the calculation made by Dias de Deus and Kroll [1] using recent data on pp scattering, and obtained a confirmation of their prediction. The diffractive dip-peak structure of the differential cross-section should be gradually smoothed out and it should completely disappear at a c.m. energy $\sqrt{s}$ of approximately several hundreds of GeV. At still higher energies, the structure develops again to its full re-appearance at asymptotic energy. The process is controlled by the value of $\rho(s)$

$$\rho(s) = \frac{\mathrm{Re}\, F(s,0)}{\mathrm{Im}\, F(s,0)} \quad , \tag{1.4}$$

which rises from 0 to some positive value, and tends to zero again when $\sqrt{s}$ tends to infinity. Then, using the recent data on $\bar{p}p$ scattering, we made an analogous calculation for this reaction as well. It turns out that the diffractive structure should also be gradually smoothed out with increasing energy but, contrary to the pp case, not completely, again re-appearing with a further increase of $\sqrt{s}$.

II. THE METHOD

Following the standard derivation of geometric scaling model [2], we introduce the scaling function $\phi(\tau)$ such that

$$\mathrm{Im}\, F(s,\tau) = \mathrm{Im}\, F(s)\, \phi(\tau) \quad , \tag{2.1}$$

$$\mathrm{Re}\, F(s,\tau) = \mathrm{Re}\, F(s) \frac{d}{d\tau}(\tau\phi(\tau)) \quad , \tag{2.2}$$

where $\tau = -\sigma(s)\frac{t}{t_0}$ and $F(s) \equiv F(s,t=0)$, $\sigma(s)$ being the total cross-section. The set of quantities F, σ, ϕ and τ refers either to the pp or to the $\bar{p}p$ scattering.

Combining the relations (2.1) and (2.2) we obtain the following equation [1]:

$$\frac{d\sigma}{dt}(s,t) = \frac{d\sigma}{dt}(s,0)\left\{\phi^2(\tau) + \rho^2(s)\left(\frac{d}{d\tau}(\tau\phi(\tau))\right)^2\right\}\frac{1}{1+\rho^2(s)} \quad . \tag{2.3}$$

This is a differential equation for the scaling function $\phi(\tau)$, all other quantities being known from experiment. Once $\phi(\tau)$ has been determined at some energy value, then, assuming that the model is valid at all higher energies, one can preduct from (2.3) the behaviour of the differential cross-section with increasing energy.

In accordance with Ref.1, we assume that the dip in $\frac{d\sigma}{dt}$ is produced by a zero in $\phi(\tau)$,

$$\phi(\tau = \tau_D) = 0 \quad , \tag{2.4}$$

where τ_D is the position of the dip. Inserting this into Eq.(2.3) we obtain

$$\frac{d\sigma}{dt}(s,\tau_D) \Big/ \frac{d\sigma}{dt}(s,0) = K^2 \frac{\rho^2(s)}{1+\rho^2(s)} \quad , \tag{2.5}$$

where $K = \tau_D \left.\frac{d\phi}{d\tau}\right|_{\tau=\tau_D}$ is a constant. The left-hand side of (2.4) and $\rho(s)$ are determined by two independent measurements. We found this relation to be in a very good agreement with experimental data (see Sec.III for details).

Expanding $\phi(\tau)$ in powers of $\frac{\tau-\tau_D}{\tau_D}$ we have, because of (2.4),

$$\phi(\tau) = \sum_{n=1}^{\infty} \frac{\tau_D^n}{n!} \left.\frac{d^n\phi}{d\tau^n}\right|_{\tau=\tau_D} \left(\frac{\tau-\tau_D}{\tau_D}\right)^n \quad . \tag{2.6}$$

We approximate $\phi(\tau)$ by taking two, three or four terms of (2.6) and insert the approximant into Eq.(2.3). In doing so, we also take into account the fact that $\rho(s)$ does not exceed the value 0.14, and consider it to be of the same order of magnitude as $(\tau-\tau_D)/\tau_D$.

To determine the form of $\phi(\tau)$ in the given approximation, we used for pp scattering the data on $\frac{d\sigma}{dt}$ at $\sqrt{s} = 52.8$ GeV and $\sqrt{s} = 44.6$ GeV in the intervals

$$1.2\ \mathrm{GeV}^2 \leq -t \leq 1.7\ \mathrm{GeV}^2 \qquad (2.7)$$

and

$$1.2\ \mathrm{GeV}^2 \leq -t \leq 2.0\ \mathrm{GeV}^2 \ , \qquad (2.8)$$

respectively (see Ref.6, pages 283 and 280, respectively). In the case of $\bar{p}p$ scattering we used the data on $\frac{d\sigma}{dt}$ at $p = 50$ GeV/c ($\sqrt{s} = 9.8$ GeV) in the interval

$$1.2\ \mathrm{GeV}^2 \leq -t \leq 2.1\ \mathrm{GeV}^2 \qquad (2.9)$$

(see Ref.5).

III. DISCUSSION

It turned out that, in fitting the pp data in the interval (2.7), the third and fourth derivative of $\phi(\tau)$ at $\tau = \tau_D$ could be fixed at zero value, while in the interval (2.8) all the four derivatives were important. In the case of the $\bar{p}p$ data, the third and the fourth derivative of $\phi(\tau)$ could be put equal to zero in the whole interval (2.9), which might be connected with relatively larger errors of the input $\frac{d\sigma}{dt}$ data in this case.

As it was already mentioned, the values of $\rho(s)$ determined from the fits of $\frac{d\sigma}{dt}$ are in a very good agreement with those obtained by a direct measurement of $\rho(s)$, as can be seen from Table I

Table I

	$\sqrt{s}$ [GeV]	$-t$ [GeV^2]	$\rho(s)$ obtained from the fit	$\rho(s)$ measured [Ref]
pp	44.7	1.2 - 1.7	0.062 ± 0.005	0.062 ± 0.0.11 [7]
pp	44.7	1.2 - 2.0	0.063 ± 0.005	
pp	52.8	1.2 - 1.7	0.073 ± 0.007	0.078 ± 0.010 [7]
pp	52.8	1.2 - 2.0	0.072 ± 0.005	
$\bar{p}p$	9.8	1.2 - 2.1	0.025 ± 0.060	0.010 ± 0.018 [8] (at p = 70 GeV/c)

Results obtained for the pp differential cross-section are shown in Fig.1. The experimental points (corresponding to $\sqrt{s} = 52.8$ GeV) were used to determine $\phi(\tau)$, the full line representing the corresponding fit. The dashed curve plots the predicted behaviour of $\frac{d\sigma}{dt}$ at $\rho = 0.14$, which is the expected maximum value of $\rho(s)$, located at $\sqrt{s}$ equal to several hundreds of GeV. It is seen that the dip in $\frac{d\sigma}{dt}$ is completely smoothed out at this value of ρ.

In Fig.2, the experimental points of $\frac{d\sigma^{\bar{p}p}}{dt}$ at $\sqrt{s} = 9.8$ GeV and their fit (full line) are shown which were used to determine the scaling function $\phi(\tau)$ for $\bar{p}p$ scattering. The dashed curve represents the predicted behaviour of $\frac{d\sigma^{\bar{p}p}}{dt}$ at $\rho = 0.14$, which is again the expected maximum of $\rho(s)$. The dip is still clearly visible; its full vanishing would require a still higher value of ρ.

IV. CONCLUDING REMARKS

The existing data on pp and $\bar{p}p$ elastic scattering suggest that the model of geometric scaling, which has its rigorous basis at asymptotic energy, is applicable at presently accessible energies, even in the region of relatively large momentum transfers. It does not follow from the results obtained that the model is able to explain the diffractive dip-peak structure in the differential cross-section of pp or $\bar{p}p$ scattering. On the other hand, once such a structure is assumed at a certain energy, its evolution, vanishing and re-appearing is well described within the frame of the model. The model predicts a full and a partial vanishing of the diffractive dip in the differential cross-section of the pp and the $\bar{p}p$ scattering, respectively, in the energy range of several hundreds of GeV in the centre-of-mass frame. The existing data on pp scattering are in good agreement with its predictions.

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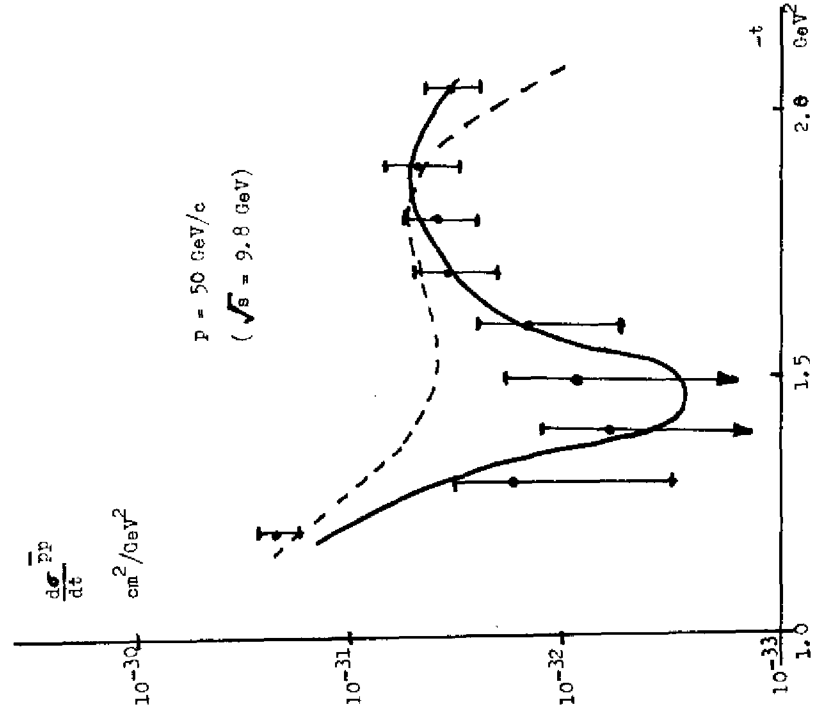

Fig. 2

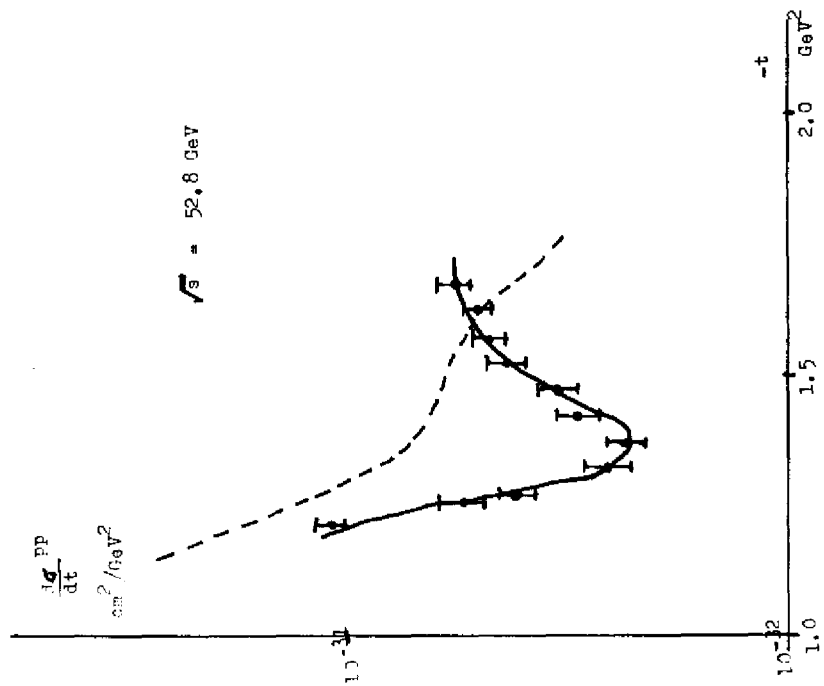

Fig. 1

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