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E2 - 12923

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Submitted to ЯФ

E2 - 12923

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Геометрический скейлинг и энергетическая зависимость сечений pp-рассеяния при больших передачах импульса

В модели эйконального типа получено модифицированное выражение для геометрического скейлинга при больших передачах импульса. Показано, что геометрический скейлинг справедлив для амплитуды рассеяния в области передач $0 \leq |t| \leq 14$ ГэВ^2 при высоких энергиях.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1979

E2 - 12923

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Geometrical Scaling and Energy Dependence of Proton-Proton Scattering Cross Sections at Large Momentum Transfers

A modified expression of the geometrical scaling at large momentum transfers is constructed within the eikonal-type model. It is shown that the geometrical scaling is valid for the scattering amplitude at the momentum transfer range $0 \leq |t| \leq 14$ GeV^2.

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

Preprint of the Joint Institute for Nuclear Research. Dubna 1979

The present paper considers the predictions of the model earlier suggested by us for the description of the high-energy pp-scattering in a wide momentum transfer region[1] for the range after the second diffraction maximum.

The recent experimental data on the proton-proton scattering[2,3] have the following basic properties at large transfer momenta:

a) The absence of the diffraction dip at $|t| \sim 5-7$ GeV^2, which is predicted by many models[4,5].

b) The slope of the diffractional cross sections slowly changes from $B \sim 1.5-1.8$ GeV^2 to 0.7-0.4 GeV^2 with changing $|t|$ from 3 to 14 GeV^2. At the same time the experimental data fit well into the exponential fall-off in transverse momentum[6] in $p_\perp$.

Note, that the models proposed for the description of the pp-scattering at large momentum transfers[7] lead both to the exponential fall-off of the differential cross sections with increasing $|t|$ and to the behaviour of the Orier type[9]

$$\frac{d\sigma}{dt} \sim e^{-cp_\perp} \sim e^{-c'\sqrt{|t|}} \quad . \tag{1}$$

The model proposed in ref.[1] considers the eikonal representation for the scattering amplitude of two spinless hadrons

$$T(s, t) = i s \int \rho d\rho J_0 (\rho,\Delta)(1 - e^{-\delta(\rho, s)}), \tag{2}$$

where

$$\delta(\rho, s) = h(e^{-\mu(s)\sqrt{b^2(s)+\rho^2}} - e^{-2\mu(s)\sqrt{b^2(s)+\rho^2}}); \tag{3}$$

$$h = \text{const}; \quad \mu(s) = \mu_0/\kappa(s); \quad b(s) = b_0 \cdot \kappa(s);$$

$$\kappa(s) = \sqrt{1 + \alpha(\ln s - i\frac{\pi}{2})}.$$

The scattering amplitude (2) with the eikonal phase of type (3) reproduces quantitatively all the properties of the proton-proton differential cross section in the energy range $\sqrt{s} > 23$ GeV. This scattering amplitude is easily seen to satisfy the hypothesis of the geometrical scaling [10]

$$T(s,t) = i \cdot s \cdot b^2(s) \cdot f(\Delta, b(s)). \qquad (4)$$

Note, that representation (3) for the eikonal phase was chosen following from the analytical properties for the scattering amplitude, as the corresponding to (3) potential can be represented as a superposition of the Yukawa potentials [11]. The first term of the eikonal phase* determines the elastic rescatterings, the second term is related [1] to some possible inelastic effects with the particle beams in intermediate states.

It will be seen [1] that the elastic rescatterings give the dominating contribution to the range of small momentum transfers. The second term dominates at sufficiently large momentum transfers. Therefore, to study the range of large momentum transfers we may retain in (3) only the second term. Then, the scattering amplitude is:

$$T(s,t) = i s \sum_{n=1}^{\infty} \frac{(-h)^n}{(n-1)!} \frac{2\mu}{(4n^2\mu^2+\Delta^2)^{3/2}} (1 + b\sqrt{4n^2\mu^2+\Delta^2})\, e^{-b\sqrt{4n^2\mu^2+\Delta^2}}. \qquad (5)$$

At large momentum transfers $\Delta^2 >> 4\mu^2$ we may neglect the mass terms in (5) and derive the following approximate expression for the scattering amplitude

$$T(s, t) \sim \text{const} \cdot i s \frac{e^{-b\Delta}}{\Delta^2},$$

or for the differential cross sections

$$\frac{d\sigma}{dt} \sim \text{const} \cdot \frac{e^{-2\mathrm{Re}\, b\sqrt{|t|}}}{t^2}. \qquad (6)$$

Thus, this model leads to the behaviour of type (1) up to

*An analogous form of the eikonal phase in the Chou-Yong model was considered in ref. [12].

the factor $1/t^2$. As is seen from (4) the total cross sections are proportional to the real part of square of the radius

$$\sigma_{tot} \sim \gamma \mathrm{Re}\, b^2 .$$

Consequently, at high energies (6) can be rewritten in the form

$$t^2 \frac{d\sigma}{dt} \sim \mathrm{const} \cdot e^{-\beta \sqrt{\sigma_{tot} \, |t|}} . \tag{7}$$

Thus we have constructed modified version of the geometrical scaling at large momentum transfers, which differs profitably from the standard representation [10]

$$\frac{1}{\sigma_{tot}^2} \cdot \frac{d\sigma}{dt} = \phi(\sigma_{tot} \cdot |t|),$$

as (7) does not contain in the left-hand side the expression for the square of the total cross sections; this results in considerable errors due to a great uncertainty in σ_{tot} at high energies.

The experimental data, given in fig. 1, constructed in terms of the variables (7), show the validity of the geometrical scaling at large momentum transfers. Figure 2 shows the same data taking into account the normalization factors not exceeding 8%. The latter have been found in paper [1] when describing the whole set of the experimental data on the pp-scattering at $\sqrt{s} \geq 23.4$ GeV. For the experimental data $\sqrt{s} = 19.4$ GeV which have not been taken into account in ref. [1], the normalization factor is taken to be equal to 1.4.

At fixed momentum transfers the differential cross sections in this model have the following energy dependence:

$$\frac{d\sigma}{dt}\Big|_{t-\mathrm{const}} \sim e^{-c\sqrt{1+\alpha \ln s}} , \tag{8}$$

which is in good agreement with the experimental data (Fig. 3).

Note, that at small fixed scattering angles, one can easily calculate from (7) the effective degree of falling of the differential cross sections with increasing energy

$$\frac{d\sigma}{dt}\Big|_{\theta-\mathrm{const}} \sim \frac{A(\theta)}{s^{N_{eff}(s,\theta)}} ,$$

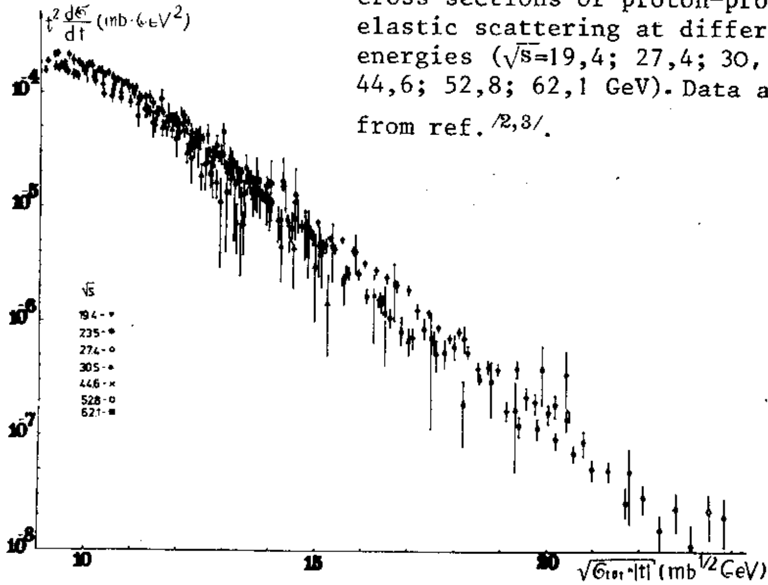

Fig. 1. Representation of the experimental data on differential cross sections of proton-proton elastic scattering at different energies ($\sqrt{s}$=19,4; 27,4; 30,5; 44,6; 52,8; 62,1 GeV). Data are from ref. /2,3/.

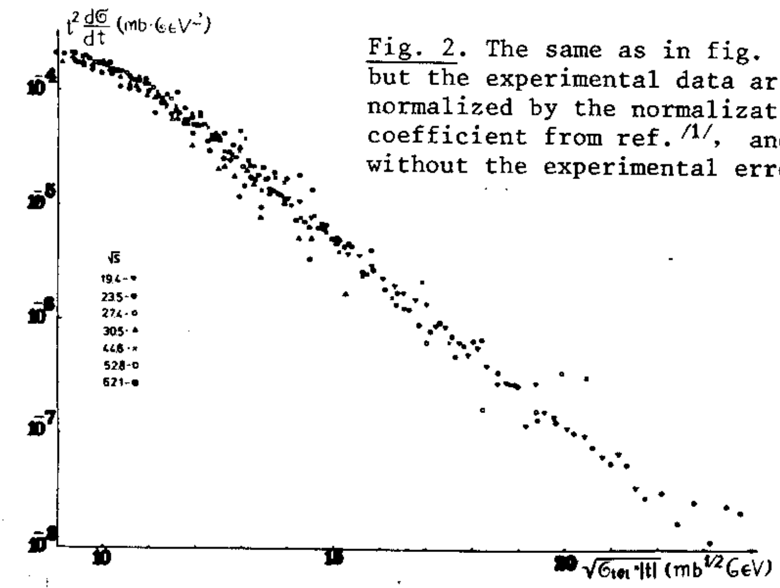

Fig. 2. The same as in fig. 1, but the experimental data are normalized by the normalization coefficient from ref. /1/, and without the experimental error.

the interaction of hadron constituents at small distances does not dominate here.

Thus the geometrical scaling for the scattering amplitude may be a good approximation in the whole momentum transfers range $0 \leq |t| \leq 14$ GeV, the relevant energy dependence of the differential cross sections corresponds fully to the available experimental data.

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

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Received by Publishing Department
on November 15 1979.

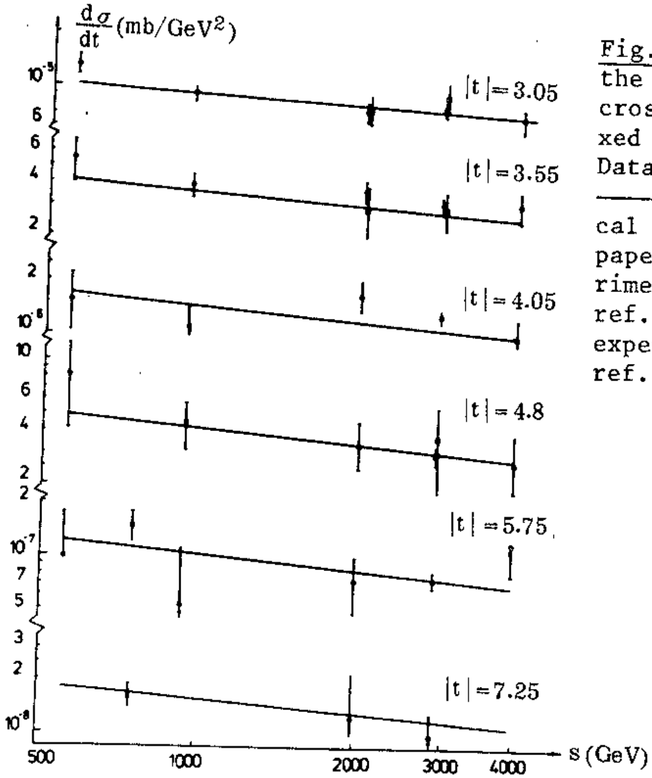

Fig. 3. Behaviour of the differential cross section of fixed momentum transfer. Data from papers [2,3] ——— - the theoretical curve is from paper [1], O - the experimental data from ref. [2], □,× - the experimental data from ref. [3].

where

$$N_{eff}\ (s,\theta) \simeq 1 + \frac{\beta}{2}\sqrt{s\cdot\sigma_{tot}\ (s)}\cdot\sqrt{\frac{1-\cos\theta}{2}}\ .$$

Hence, using the value $\beta = 077$,which corresponds to the average slope of the experimental data in fig. 1, we obtain the averaged values for the effective degree within the ISR energy region (1500 GeV $\leq s \leq$ 2000 GeV)

$$\bar{N}^{ISR}_{eff}\ (4.85^\circ) = (6.65 \pm 0.25)\ ,$$

and for the FNAL energy range (400 GeV $\leq S \leq$ 800 GeV)

$$\bar{N}^{FNAL}_{eff}\ (13^\circ) = (8.7 \pm 0.3)\ ;\ \bar{N}^{FNAL}_{eff}\ (15^\circ) = (9.7 \pm 0.3).$$

This is in good agreement with the results of refs. [2,6].

The observed deviations from the automodel behaviour $N = 10$ [13] in the given region of scattering angles are obviously due to that the scattering mechanism determined by