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10530

ЭКЗ. ЧИТ. ЗАЛА

E2 - 10530

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OF HADRON ELECTROMAGNETIC
FORM FACTORS IN THE DYNAMICAL MODEL
OF FACTORIZING QUARKS

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Submitted to "Письма в ЖЭТФ"

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E2 - 10530

Асимптотическое поведение электромагнитных формфакторов адронов в динамической модели факторизирующихся кварков

На основе динамической модели факторизирующихся кварков получены формулы, определяющие асимптотическое поведение электромагнитных формфакторов адронов и дейтона и содержащие зависимость от числа составляющих данный адрон кварков. Произведено сравнение предсказаний модели с экспериментальными данными по электромагнитным формфакторам π -мезона и протона.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1977

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E2 - 10530

Asymptotic Behaviour of Hadron Electromagnetic Form Factors in the Dynamical Model of Factorizing Quarks

Within the dynamical model of factorizing quarks we have derived formulae for the asymptotic behaviour of the hadron and deuteron electromagnetic form factors which depend upon the number of particle-constituent quarks. The model predictions well agree with the experimental data on the pion and proton electromagnetic elastic form factors.

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

Preprint of the Joint Institute for Nuclear Research. Dubna 1977

It is known that the small-angle hadron scattering is well described in the framework of the additive quark amplitude model ^{1/1}. The large-angle scattering seems to be controlled by another mechanism ^{1/2}. A hypothesis of factorizability of the quark scattering amplitudes ^{1/3} successfully describes the relations between cross sections of different large-angle scattering processes ^{1/4}. In this model the colliding quarks are thought of as to produce an effective force field V_{eff} and the scattering process is considered as the process of independent quark scattering on this field. For independent events the total probability is equal to the product of individual probabilities. Thus the scattering amplitude of the whole hadron at the angle θ is the product of the amplitudes of the quark scattering at θ on the effective potential.

In ^{1/5} the model of factorizing quarks (amplitudes) was enlarged by the dynamical assumption that the size of the interaction region, that determines the quark large-angle scattering in the kinematical region $-t, s \rightarrow \infty$ t/s fixed, is of an order of the quark Compton wave length $1/M_q$. To this picture there corresponds the following quark scattering amplitude ^{1/5}:

$$g_q(\theta) \sim \frac{y_q}{\text{sh } y_q} = \frac{2M_q^2 \text{Ch}\left(1 - \frac{t_q}{2M_q^2} + \frac{1}{2M_q^2} \sqrt{t_q(t_q - 4M_q^2)}\right)}{\sqrt{t_q(t_q - 4M_q^2)}}$$

where $y_q = \text{Arch}\left(1 - t_q/2M_q^2\right)$ is the rapidity,

corresponding to the transfer momentum per one quark

$iq \approx t/n^2 = [(P-K)/n]^2$ (n - it is the number of the valence quarks in a hadron and M_q is the effective quark mass, the parameter of our model). Really, the size of the interaction region for this amplitude is ^{16/}

$$\langle r_{int}^2 \rangle = 0 \quad \frac{\partial (y/s^h y)}{\partial t} \Big|_{t=0} = \frac{1}{M_q^2}$$

Thus, in the dynamical model of the factorizing quarks ^{15/} the cross section for the elastic fixed-angle scattering is defined by the formula

$$\frac{d\sigma}{dt}(ab \rightarrow ab) \sim \frac{1}{s^2} \left[\prod_{q_a}^n \frac{y_{q_a}}{s^h y_{q_a}} \prod_{q_b}^m \frac{y_{q_b}}{s^h y_{q_b}} \right]^2, \quad (1)$$

where n and m are the numbers of valence quarks in hadrons a and b resp.

Consider now the electron-hadron elastic scattering $eh \rightarrow eh$. Following the Wu-Yang idea on the analogy of the hadron electromagnetic structure to the distribution of the "strong-interacting" matter, we adopt that at large transfer momenta the photon-hadron block in a one-photon exchange diagram corresponds to the excitation of the same self-consistent field V_{eff} . Then the differential cross section is

$$\frac{d\sigma}{dt}(eh \rightarrow eh) \sim \frac{1}{t^2} \left[\prod_{q_h}^n \frac{y_{q_h}}{s^h y_{q_h}} \right]^2. \quad (2)$$

Comparing the latter with the Rosenbluth formula for the asymptotic cross section $\frac{d\sigma}{dt}(eh \rightarrow eh) \sim \frac{1}{t^2} G_h^2(t)$, we obtain the electromagnetic form factor $G_h(t)$ in the form

$$G_h(t) \sim \prod_{q_h} \frac{y_{q_h}}{s^h y_{q_h}} \quad (3)$$

At large transfer momenta $|t_q| \gg M_q^2$ $\frac{y_q}{s^h y_{q_h}} = \frac{e_n (|t_q|/M_q^2)}{|t_q|/M_q^2}$.
For the form factors of pion, proton and deuteron formula

(3) gives

$$G_\pi(t) \sim \left(\frac{y_{q_\pi}}{s^h y_{q_\pi}} \right)^2 = \left[\frac{e_n (|t|/4M_q^2)}{|t|/18M_q^2} \right]^2 \quad (4)$$

$$G_p(t) \sim \left(\frac{y_{q_p}}{s^h y_{q_p}} \right)^3 = \left[\frac{e_n (|t|/4M_q^2)}{|t|/18M_q^2} \right]^3 \quad (5)$$

$$G_d(t) \sim \left(\frac{y_{q_d}}{s^h y_{q_d}} \right)^6 = \left[\frac{e_n (|t|/36M_q^2)}{|t|/72M_q^2} \right]^6 \quad (6)$$

Formulae (4-6) can be rewritten in a form of the conventional power law $G_h(t) \sim (|t|/n^2 M_q^2)^{-N_{eff}}$, where n is the number of quarks in particle h and N_{eff} depends on the momentum transfer as follows

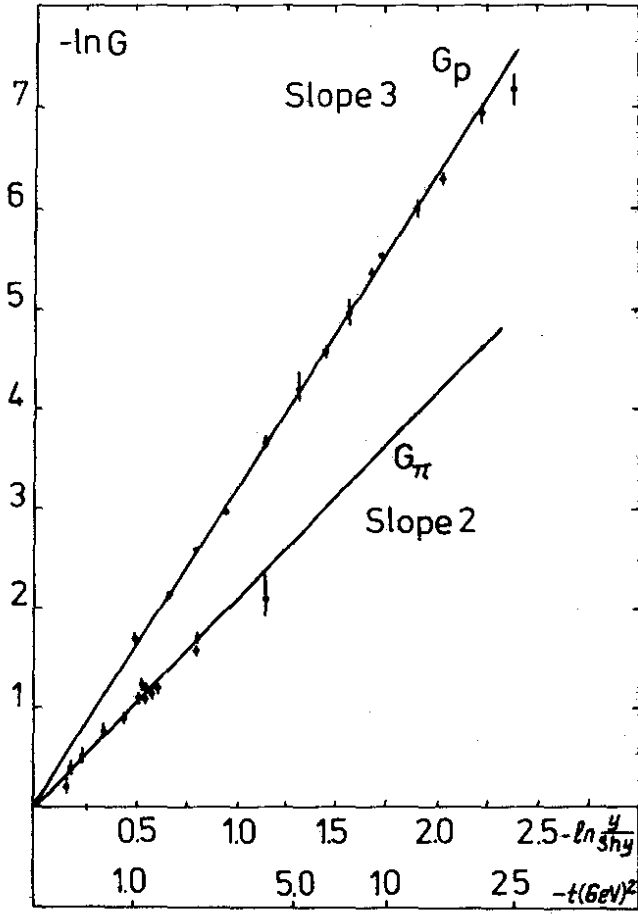
$$N_{eff} = n - n \frac{e_n e_n (|t|/n^2 M_q^2)}{e_n (|t|/n^2 M_q^2)} \quad (7)$$

With increasing $-t$, the effective power N_{eff} . (7) smoothly increases and reaches the asymptotic limit equal to the number of valence quarks in particle.

The Figure represents the results of comparison of predictions by formulae (4) and (5) with experimental data on the form factor of pion ⁸⁾ and proton ⁹⁾.

It is seen from the figure, that the experimental data are really grouping near the straight line with the integer values of the slope that is due to (2) equal to the number of the valence quarks. In fitting the data by formulae (4,5) we have obtained the following values of χ^2 per one degree of freedom: for proton $\chi^2_{d.f.} = 13.3/(14-2)$ for pion - $\chi^2_{d.f.} = 20.6/(16-2)$. It should be noted that the found effective quark mass $M_q = 0.16$ GeV, defining the pion form factor asymptotics coincides, within the experimental error, with the value of M_q found in fitting the data on the proton form factor and is consistent also with the value obtained in analysis of the pp -scattering ¹⁵⁾.

Formulae (4-6) contain manifestly the scale parameter the quark mass value M_q , thus the asymptotic behaviour of form factors depends on the ratio t_q/M_q^2 . Since the transfer momentum per one quark t_q is reciprocal to the squared number of valence quarks in particles, the asymptotic limit for the form factor of deuteron sets is later than for pion and proton.



Figure

The authors express their deep gratitude to D.I.Blokhintsev, V.G.Kadyshevsky, S.B.Gerasimov, A.F.Efremov, V.A.Meshcheryjakov, P.S.Isaev and A.F.Pashkov for useful discussions.

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Received by Publishing Department
on March 24, 1977