Diffractive dissociation of hadrons into states with a large mass

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The mass dependence of the cross section for diffractive dissociation, which corresponds to a three-pomeron contribution, is determined by using the eigenstate method. The diffraction cross section is proportional to the derivative of the velocity of light of the active parton component of the constituent quark. The diffraction cross section is expected to decrease sharply at large energies, as compared with the prediction of Feynman scaling, consistent with the data obtained in cosmic-ray experiments.

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1. We shall examine the inclusive reaction $a+b\to X+b$ in the three-Reggeon region $M_X^2>>s_0$, $s/M_X^2>>1$. Here $s_0=1$ GeV^2, M_X^2 is the effective mass of the X state, and $\sqrt{s}$ is the total energy of a and b hadrons in the c.m.s. It is known (see, for example, Ref. 1) that the three-pomeron contribution

$$\left(s\,\frac{d^2\sigma}{dM_X^2\,dq^2}\right)_{PPP}=G_{PPP}(q_\perp^2)\left(\frac{s}{M_X^2}\right)^{2\alpha_P(q_\perp^2)-\alpha_P(0)}\left(\frac{s}{s_0}\right)^{\alpha_P(0)-1}\qquad(1)$$

is dominant in the cross section of this process as $x\to 1$ (where $x=1-M_X^2/s$).

If the pomeron intercept $\alpha_P(0)>1$, then the Feynman scaling is violated, since the cross section increases with the energy. We show below, however, that an increase of the cross section is followed by its rapid decrease with increasing energy.

2. The three-pomeron contribution to the cross section in the constituent-quark model corresponds to the process in which only one of the constituent quarks dissociates into a state with the mass M_X, while the remaining quarks of the hadron are spectators or produce a state with a small mass.[1]

We shall analyze the diffraction of a constituent quark by using the eigenstate method.[4-7] According to which the amplitude of the dissociation $\alpha\to\beta$ has the form $f_{\alpha\beta}=\Sigma_k c_k^\alpha c_k^{\beta *} f_k$, where f_k is the amplitude of elastic scattering in the state $|\alpha,k\rangle$ with a definite number $k=0,1,2,\ldots$ of slow partons. The coefficients $c_k^\alpha=<\alpha,k|\alpha>$. The two-component approximation can be used for the constituent quark,[4,5] when $f_k=f$ for $k\geqslant 1$ and $f_0=0$. In this case,[7] $f_{\alpha\beta}=f(\delta_{\alpha\beta}-c_0^\alpha c_0^\beta)$. The cross section for quark diffraction, which is summed over all the β states with the mass $M_\beta^2<M_X^2$, can be written as follows after subtracting the inelastic scattering cross section:

$$\frac{d\sigma_{diff}}{dq_\perp^2}=\frac{d\sigma_{el}}{dq_\perp^2}|c_0^q|^2\left(\sum_{M_\beta^2<M_X^2}|c_0^\beta|^2-|c_0^q|^2\right).\qquad(2)$$

Note that the sum $\Sigma_{M_\beta^2<M_X^2}|c_0^\beta|^2$ is equal to the contribution to the overall passive state $\langle q,0|q,0\rangle=1$ of those parton fluctuations in which all the partons have a larger velocity than $y=\ln(s/M^2)$. On the other hand, the sum of such states is equal to the relative probability of transition of the active state to the passive state as a result of systematic shifts of the reference frame of the velocity from $Y=\ln(s/s_0)$ to $y=\ln(s/M_X^2)$.[8] Therefore, $\Sigma_{M_\beta^2<M_X^2}|c_0^\beta|^2=|c_0^q(Y-y)|^2/|c_0^q(Y)|^2$. Substituting this expression in Eq. (2) and differentiating it with respect to M_X^2, we find that

$$s\frac{d^2\sigma}{dq_\perp^2\,dM_X^2}=-\frac{s}{M_X^2}\frac{d\sigma_{el}}{dq_\perp^2}\frac{1}{P_q^2(s)}\frac{dP_q(M_X^2)}{d\ln(M_X^2/s_0)}. \qquad (3)$$

Here $P_q=1-|c_0^q|^2$ is the weight of the active component of the quark.

3. Equation (3) makes it possible to determine very accurately the energy dependence of P_q from the data for diffractive dissociation. For example, for a quark energy of 100 GeV $P_q=0.57$ (Ref. 9), $\sigma_{qN}^{tot}=17$ mb, and $G_{PPP}^{qN}\approx G_{PPP}^{NN}\times\sigma_{tot}^{qN}/\sigma_{tot}^{NN}$, where $G_{PPP}^{NN}=3.2$ mb/GeV^2.[1] Substituting these values in Eqs. (3) and (1) for $t=0$, we obtain $d\ln P_q/d\ln(s/s_0)=-0.06$ for $s=200$ GeV^2. This value is in good agreement with the results of the analysis[10] of the data for regeneration of K° mesons by nuclei.

4. The expression $P(s)=P(\infty)/[1-[1-P(\infty)]\,s/s_0{}^{1-\alpha_P(0)\xi}$ was obtained in the parton-cascade model.[11] Substituting $\alpha_P(0)-1=0.07$ (Ref. 12) and $P_q(s=200\text{ GeV}^2)=0.57$ in this expression, we obtain $d\ln P_q(s)/d\ln(s/s_0)=-0.067$, in very good agreement with the value determined above.

The problem can be reversed: at $(\alpha_p(0)-1)\ln(s/s_0)\ll 1$ an approximate Feynman scaling can be obtained by substituting $P(s)$ from Ref. 11 on the right-hand side of the relation (3). The effective three-pomeron constant in this case can be calculated, in good agreement with the experiment.

5. The derivative $dP(s)/d\ln(s/s_0)$ tends to zero (Ref. 8) as (Ref. 11) $(s/s_0)^{1-\alpha_P}$ at high energies when $\ln(s/s_0)\gg(\alpha_P-1)^{-1}$. At the same time, $d\sigma^{el}/dt$ can increase only as the power of $\ln s$. Therefore, the Feynman scaling in (3) is strongly violated in the fragmentation region. Such effect, which was observed in cosmic-ray experiments (see, for example, Ref. 13), must occur at particle energies that will be reached in giant accelerators of the next generation.

6. A decrease of the quantity $P_q(s)$ with the energy and an increase of σ_{tot}^{qN} results in the fact that the total cross sections for interaction of hadrons with light nuclei increase and those for interaction with heavy nuclei decrease. At an energy of 100 GeV per quark the total cross sections decrease with the energy for nuclei with atomic number $A\gtrsim 30$. The cross section decreases very rapidly for Pb^{207} and U^{238} nuclei: $d(\ln\sigma_{tot}^{qA})/d(\ln s)\approx-0.03$, consistent with the experimental data.[14]

7. It follows from the ratio of the real part of the quark-nucleus elastic forward scattering amplitude to the imaginary part (the notations are the same as those in Ref. 15)

$$\frac{\mathrm{Re}\,F^{qA}}{\mathrm{Im}\,F^{qA}} = -\frac{4\pi}{\sigma^{qA}_{tot}} \int d^2b \int dM^2 \left.\frac{d^2\sigma^{qN}_{diff}}{dq_{\perp}^2 dM^2}\right|_{q_{\perp}=0} \left[1 - P_q + P_q\, e^{-\frac{\sigma^{qN}_{tot} T(b)}{2P_q}}\right]$$

$$\times \int_{-\infty}^{\infty} dl_1 \int_{-\infty}^{\infty} dl_2\, \rho(b, l_1)\, \rho(b, l_2)\, \sin(\Delta q_L \,|l_2 - l_1|) \qquad (4)$$

that this ratio does not depend on the energy if the Feynman scaling is present in the inclusive cross section. In fact, the quantity (4) must vary slightly in a broad energy range. At energies $\ln(s/s_0) \gg [\alpha_p(0) - 1]^{-1}$, however, $\mathrm{Re}F^{qA}$ vanishes.

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