Constituent Particle Scattering in the Regge Region

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Scattering cross sections of hadronic constituents have been inferred from high energy reactions and it has been shown that the QCD calculation for the quark-gluon system realizes experiments reasonably well. For the processes that have been analyzed so far, fairly large angle scattering of the constituent particles mainly contributes and consequently the perturbation calculation for the quark and gluon system is valid with the effective coupling constant. For small angle scattering of the constituent particles, which may have large effects on the Regge region of the deep inelastic structure functions, we have no reliable method of calculation because higher order terms should be taken into account. We assume here the Regge behavior for high energy peripheral scattering of the constituent particles and evaluate the Regge poles from the electroproduction structure functions.

We have analyzed experimental data for $e-p$, $e-d$, $\mu-p$ processes via the operator product expansion (OPE). Applying the Ninomiya and Watanabe theory on properties of the reduced matrix elements of the local operators appearing in OPE, we have investigated the Regge poles for the quark-quark and gluon-gluon scattering amplitudes and have shown that the same Regge poles can be taken for the constituent particles as in the hadronic scattering processes. The Regge poles were, however, not accurately determined due to the experimental inaccuracy in the small $x$ region.

Recently very accurate data of proton structure functions have been given in the very small $x$ region, $x \sim 0.003$. We analyze the new data in this short note to determine the Regge poles for high energy quark-quark and gluon-gluon scattering. The structure functions are parametrized as in Refs. 9) and 11) and the parameters are determined from the electron and muon production data. We illustrate in Fig. 1 the numerical results for the structure function $\nu W_2$ and in Fig. 2 $R=\sigma_L/\sigma_T$. The quark is assumed to be the four color triplet as in Refs. 8) and 9) and the quark-gluon interaction is mediated by the non-Abelian gauge gluon with the AFGT parameters $A=0.3 \text{GeV}$ and $Q_0^2=1 \text{GeV}^2$.

Now Regge poles for constituent particle scattering are determined as follows: For gluon-gluon scattering and quark-quark scattering with the singlet state in the $q\bar{q}$ channel, $\alpha_{gl}(0) \sim 0.9$ and $\alpha_{qq}(0) \sim 0.75$ re-
Letters to the Editor

1425

Fig. 1. The theoretical fit of $\nu W^2$. The solid curves are calculated for $Q^2=1.5, 3.0, 6.0, 12.0, 22.5,$ and $40.0\text{GeV}^2$. The black circles denote the $\mu-p$ data and the open circles the $e-p$ data. The error bars in the $\mu-p$ data are taken to be the maximum value given in Ref. 9. The dashed curves stand for the incorporation of Abelian vector field.

Fig. 2. The theoretical fit of $R=\sigma_L/\sigma_T$. The experimental data are taken from Ref. 3.

spectively and for quark-quark scattering with the non-singlet state in the $q\bar{q}$ channel $\alpha_{NS}(0) \sim 0.3$. In Fig. 1 we enter the results obtained by the incorporation of Abelian vector fields as an illustration of the asymptotically not free field with the coupling constant $g^2/4\pi = 0.02$. In this case the Regge poles are determined as follows: $\alpha_{gl}(0) = \alpha_{V}(0) = 0.9$, the Regge poles for the gluon-gluon and the Abelian vector-vector respectively, where the same values for $\alpha_{NS}(0)$ and $\alpha_{Nq}(0)$ are taken.

The Regge poles for constituent particle scattering thus determined coincide with that of hadronic processes. It may support the quark model interpretation of the Regge behavior for hadron-hadron scattering: The Regge poles may be explained as the multiperipheral exchange of the quark and anti-quark pair, and the Pomeron the exchange of non-Abelian gauge gluons. The same mechanism works for high energy constituent particle scattering and consequently we may expect the same Regge
Letters to the Editor

poles and Pomerons for the quark and gluon system.

Let us now discuss the effect of Abelian fields on the deep inelastic structure functions. As is shown in Fig. 1, by the addition of Abelian vector field a small rise is observed in the structure functions for a large \( Q^2 \) region with small \( x \). According to the recent experiment via \( \mu \)-Fe reaction\(^\text{16}\) a rise is observed in the proton structure function \( \nu W_2 \) for large \( Q^2 \) with small \( x \), and there are systematic deviations from the parton model calculation with QCD.\(^\text{17} \) It must be noticed that the \( \mu \)-Fe data agree with the \( \mu \)-p data\(^\text{18} \) for \( Q^2 \lesssim 50 \text{ GeV}^2 \) and our field theoretical calculation with QCD reproduces the \( \mu \)-Fe data quite well without using further assumptions such as color excitation.\(^\text{19} \) By the addition of Abelian vector field the theoretical fit becomes a little better. We now remark on the \( R \)-value. The theoretical value for \( R \) is smaller than the experiment and no improvement is obtained by the addition of the Abelian fields so long as the Callan-Gross relation is assumed for the quark and gluon structure functions\(^\text{20} \) because the Abelian field-quark coupling constants should be kept small.

To conclude this paper we discuss the possible non-Regge behavior of the deep inelastic structure functions that arises from the essential singularity of the anomalous dimensions in the lowest order approximation.\(^\text{19} \) The experimental data nearly shows the Regge behavior for small \( x \), \( x \sim 0.003 \), and we are able to fit the data with the lowest order approximation for the anomalous dimensions. For the deep inelastic structure functions extremely small \( x \) region is required to observe the non-Regge behavior or the higher order effects of the anomalous dimensions that were noticed by Ninomiya.\(^\text{20} \)

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