Description of elastic vectormeson production and $F_2$ by two pomeron$^*$

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Using the Model of the Stochastic Vacuum many diffractive processes have been calculated by investigating the dipole-dipole scattering at a cm-energy of 20 GeV. In this work we extend the calculation to larger energies and small dipoles. We assume that there are two pomeron, the hard- and the soft-pomeron, which cause the different energy dependence for processes dominated by small or large dipoles. The physical processes are obtained by smearing the dipole-dipole amplitude with wavefunctions. For small dipoles the leading perturbative contribution is taken into account. By that way we can describe in addition to the already calculated low energy results (20 GeV) also the HERA data for the considered processes in nearly the whole energy and $Q^2$ range.

1. Method

In this very short note we can only present some results for the $Q^2$ and energy dependence of elastic vectormeson production and the proton structure function $F_2$ and have to refer for technical steps, discussions and comparison with related works to our original publication [1]. The building block of our calculation is the dipole-dipole scattering amplitude. It is calculated in the framework of the Model of the Stochastic Vacuum (MSV) [2, 3]. Within this framework elastic hadron-hadron scattering [4, 5, 6], hadron-dipole scattering [7], photo- and electroproduction of vectormesons [8, 9] and $\pi^0$ [10] and the proton structure function $F_2$ [11] were calculated but the cm-energy was always fixed at 20 GeV. We now extend this approach to higher energies by coupling a soft-pomeron, which trajectory is given by the Donnachie-Landshoff parameterization [12], to large dipoles (both dipoles larger than a new introduced cut $c$) and a hard-pomeron with an intercept of 1.28 and a vanishing slope to small dipoles (at least one dipole smaller than $c$). Because the MSV can not be used for very small dipoles we cut these contributions if one of the dipoles is smaller than a second new cut $r_{cut}$. By that way we can already describe the data for not to large $Q^2 \leq 35$ GeV$^2$. In this regime one observes the transition from the soft to the hard behavior and it is the regime of our main interest. If we want to extend our approach to even harder processes we include for very small dipoles (smaller than $r_{cut}$) the leading perturbative contribution with a running coupling which is frozen in the infra-red to be $\alpha_s(\infty) = 0.75$. By smearing this dipole-dipole scattering with process dependent wavefunctions, which we take from the cited references, we obtain different effective energy dependencies due to the different dipole sizes mainly involved. The two cuts $c$ and $r_{cut}$ are the important new parameters. We did not perform a fit to the data but started with physical values and adjusted a little bit with the result: $c = 0.35$ fm, $r_{cut} = 0.16$ fm.

2. Results

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2.1. Vectormeson production

All our old results, where only large dipoles contributed, are unchanged at 20 GeV and we obtain an energy dependence through the soft-pomeron in agreement with experiment. An example is elastic hadron-hadron scattering or photoproduction of $\rho, \omega$ and $\phi$. For the $J/\Psi$ already small dipoles contribute and the energy dependence is much stronger (see Fig. 3). For electroproduction the effective pomeron slope increases with $Q^2$ as can be seen from Fig. 2 for the $\rho$. The simple exponential fit $\sigma_{\text{tot}}^\rho = a(W/20 \text{ GeV})^b$ describes our result very good for large $W > 80$ GeV and we obtain

| $Q^2(\text{GeV}^2)$ | 0.5 | 2  | 7 | 10 | 12 | 20 |
|--------------------|-----|----|---|----|----|----|
| $a$ (mb)           | 206.6 | 291 | 17.5 | 7.25 | 4.43 | 1.08 |
| $b$                | 0.34 | 0.44 | 0.71 | 0.77 | 0.82 | 0.92 |

The rising of $b$ with $Q^2$ shows that by increasing the virtuality one probes smaller and smaller dipoles which are coupled to the hard-pomeron. This rise of the effective pomeron power with $Q^2$ is in agreement with the experiment. For the $J/\Psi$ this effect is smaller since already for photoproduction the dipoles are quite small.

2.2. $F_2(x,Q^2)$ and the total cross section of $\gamma p$ scattering

Using the different photon wavefunctions depending on the polarization we obtain the total cross sections $\sigma_L$, $\sigma_T$ and the proton structure function $F_2$ and $F_L$ can be calculated

$$F_2 = \frac{1}{4\pi^2\alpha_{\text{em}}} \frac{Q^4(1-x)}{Q^2 + 4m_p^2x^2} (\sigma_L + \sigma_T)$$

$$F_L = \frac{1}{4\pi^2\alpha_{\text{em}}} \frac{Q^4(1-x)}{Q^2 + 4m_p^2x^2} \sigma_L.$$  

The energy $W$ can be expressed by $W^2 = Q^2/x - Q^2 + m_p^2$. In our approach we are limited to large energies, $W > 20$ GeV, and small $x \leq 0.05$ because we only take the pomeron and not the Regge contributions into account. In Fig. 3 we compare our result for $F_2$ with the experimental data for few values of $0.11 \text{ GeV}^2 \leq Q^2 \leq 5000 \text{ GeV}^2$. The figures show that our model describes all the data in the limited $W$ and $x$ range very well. To obtain the effective energy dependence of the structure function for different scales we calculate the effective pomeron power $\lambda_{\text{eff}}$ by fitting our results for $10^{-4} \leq x \leq 10^{-2}$ with

$$F_2(x,Q^2) = a \frac{Q^4(1-x)}{Q^2 + 4m_p^2x^2} \left( \frac{Q^2}{x} - Q^2 + m_p^2 \right)^{\lambda_{\text{eff}}}.$$
The proton structure function for fixed low-energy data are \[ [33, 34, 35] \], \[26, 27] \], the ZEUS data \[1-5\] are \[ [28, 29, 30, 31, 32] \] and the low-energy data are \[ [24, 25, 38] \].

Figure 3. The proton structure function \( F_2(x,Q^2) \) for fixed values of \( Q^2 \) as a function of \( x \). The H1 data \([24, 25]\) and the ZEUS data \([28, 29, 30, 32]\) and the low-energy data are \([26, 27]\). We also calculate the so called Q-slope:

\[
\frac{\partial F_2(x,Q^2)}{\partial \ln Q^2}
\]

for fixed \( Q^2 \). We also investigate different contributions to \( F_2 \) like the charm contribution \([1]\) or the longitudinal and transversal part by calculating the ratio of them as shown in Fig.4.

Figure 4. In the top the effective pomeron power \( \lambda_{\text{eff}} \) as a function of \( Q^2 \). The error bars are due to the numerical error of our results for \( F_2 \). In the bottom the Q-slope as a function of \( x \). The result is shown together with the result for \( \lambda_{\text{eff}} \) in Fig.4. Our results are in very good agreement with the experimental data \([26, 27, 38]\) and show the transition of the effective behavior going from large to small dipoles. Especially the Q-slope decreases for small \( x \) as measured by the experiment. We also calculated the total \( \gamma p \) cross section where we can include the photoproduction.
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