Odderon and Photon Exchange in Pseudoscalar Meson Production

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We consider exclusive π^0 production in ep-scattering. At high energies odderon and photon exchange contribute. The photon exchange contribution is evaluated exactly using data for the total virtual photon-proton absorption cross section. The odderon exchange contribution is calculated in nonperturbative QCD, using functional integral techniques and the model of the stochastic vacuum. For the proton we assume a quark-diquark structure as suggested by the small odderon amplitude in pp and $p\bar{p}$ forward scattering. We show that odderon exchange leads to a much larger inelastic than elastic π^0 production cross section. Observing our process at HERA would establish the soft odderon.

1. INTRODUCTION

The soft (nonperturbative) odderon $\mathcal{O}$ is introduced in elastic hadron-hadron scattering as the $C = P = -1$ partner of the pomeron $\mathcal{P}$ [1]. In perturbation theory the existence of $C = P = -1$ contributions is clear (3-gluon exchange). It is even believed [2], that 3-gluon exchange dominates the pp-scattering amplitude T_{pp} for momentum transfers $|t| \gtrsim 4$ GeV^2. On the other hand, for $|t| \to 0$ it seems that odderon contributions play no role asymptotically or even are absent. An example is the measurement of $\rho_{p\bar{p}} = Re(T_{p\bar{p}})/Im(T_{p\bar{p}})$ at $\sqrt{s} = 546$ GeV [3]. Together with pp scattering data at smaller energies one deduces $|\rho_{pp} - \rho_{p\bar{p}}| \leq 0.05$. In other words the soft odderon couples very weakly to the nucleon.

Since soft elastic high energy scattering is totally dominated by the pomeron, it is useful to look at a reaction where pomeron exchange does not contribute. In the following we discuss some results of [4] considering exclusive π^0 production in high energy ep-scattering. The π^0 is produced (see Fig. 1) by $\gamma\mathcal{O}$-fusion and by $\gamma\gamma$-fusion, but can not be produced by $\gamma\mathcal{P}$-fusion since the π^0 has positive C-parity. In Fig. 1 X stands for a proton or resonances or a sum over resonances. Here we treat the very small $Q^2 := -q_1^2$ range. In the H1 experiment at HERA the kinematical cuts for this so called photoproduction region are

$$y_{\min} = 0.3 \leq y \leq 0.7 = y_{\max},$$
$$0 < Q^2 < 0.01\,\mathrm{GeV}^2, \tag{1}$$

where, in the proton rest frame $y = (pq_1)/(pp_1)$ is the fractional energy loss of the incoming lepton. This allows us to use the equivalent photon approximation

$$\sigma_{ep} = \int_{y_{min}}^{y_{max}} \frac{dy}{y}\, n(y)\, \sigma_{\gamma p}(s_2),$$
$$s_2 = ys + (1-y)m_p^2. \tag{2}$$

where m_p is the nucleon mass, $\sigma_{\gamma p}$ is the total

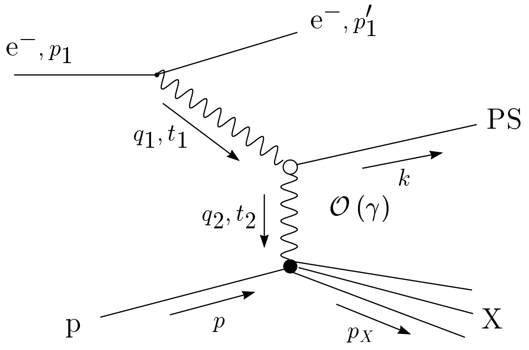

Figure 1. Feynmann diagrams for pseudoscalar meson production in ep scattering at high energies with odderon (photon) exchange.

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photoproduction cross section for the reaction, and $n(y)$ is the equivalent photon number.

2. ODDERON EXCHANGE

We look at γp-scattering in the c.m. system and choose $\vec{q}_1$ as 3-direction. Then the photon and the proton have very large momenta in ± 3-direction. In the following we discuss the cases, (i) that the proton, which is assumed to be a quark-diquark system with a scalar diquark stays intact or (ii) gets diffractively exited into the resonances $N(1520)$ with $J^P = \frac{3}{2}^-$ and $N(1535)$ with $J^P = \frac{1}{2}^-$, described as exited quark-diquark systems.

When considering unpolarized cross sections, summed over both resonances in case (ii), the quark spin degree of freedom becomes irrelevant and the calculation reduces to one where a spinless state stays intact or is exited to a 2P resonance. For (ii) the helicity amplitudes are [4]

$$\begin{aligned} T(s_2,t_2)_{\lambda,\lambda_\gamma} &= -2is_2 \int d^2b\, e^{i\vec{q}_{2T}\vec{b}}\, \hat{J}_{\lambda,\lambda_\gamma}(\vec{b}), \\ \hat{J}(\vec{b})_{\lambda,\lambda_\gamma} &= \int \frac{d^2r_1}{4\pi} dz \int \frac{d^2r_2}{4\pi} \\ &\times \sum_{f,h_1,h_2} \Psi^{*\pi^0}_{fh_1h_2}(\vec{r}_1,z)\Psi^{\gamma}_{\lambda_\gamma,\,fh_1h_2}(\vec{r}_1,z) \\ &\times \Psi^{*\,2\mathrm{P}}_{\lambda}(\vec{r}_2)\Psi^{p}(\vec{r}_2)\ \tilde{J}(\vec{b},\vec{r}_1,z,\vec{r}_2). \end{aligned} \quad (3)$$

Here $\lambda_\gamma(\lambda)$ is the helicity of the photon (2P state) and z is the momentum fraction of the photon, carried by the quark. The physical picture arising from (3) is the following (Fig. 2). The photon fluctuates into a $q\bar{q}$ pair, described by Ψ^γ. By soft color interaction (odderon exchange), calculated from the functional integral of two lightlike Wegner-Wilson loops ($\tilde{J}$) the $q\bar{q}$ pair turns into a π^0 and the proton either stays intact or gets exited (described by $\Psi^{2\mathrm{P}}$).

Now, when the proton stays intact there occurs in (3) the quark-diquark density ($\Psi^{2\mathrm{P}}_\lambda \to \Psi^p$). But, since this density is symmetric under a parity transformation whereas the odderon coupling changes sign, there is a cancelation when we integrate over all angles. On the other hand when the proton gets exited to a negative parity state like the resonances $N(1520)$ and $N(1535)$ there is no cancelation (the overlap is odd under parity) and the odderon couples to the nucleon without any restriction [4,5]. Thus in our model the odderon couples only if breakup of the proton occurs.

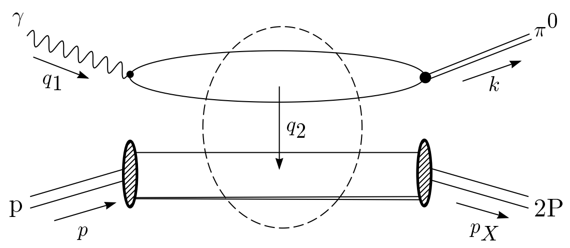

Figure 2. π^0 production in γp-scattering. The dashed circle indicates the nonperturbative interaction (odderon exchange) of the colour dipoles.

2.1. Results

In Fig. 3 we show our result for the differential cross section in γp-scattering, $d\sigma_{\gamma p}/dt$. The slope of $d\sigma^{\mathcal{O}}_{\gamma p}/dt$ at $t=0$ is around $5/\mathrm{GeV}^2$. The integrated cross section is [4]:

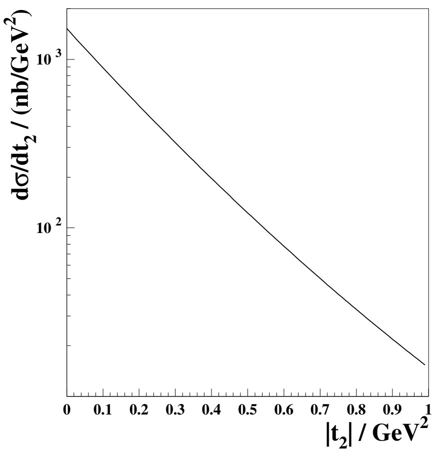

Figure 3. The differential cross section $d\sigma^{\mathcal{O}}_{\gamma p}/dt_2$ of the process $\gamma p \to \pi^0\{2\mathrm{P}\}$ as a function of t_2.

$$\sigma^{\mathcal{O}}_{\gamma\,\mathrm{p}}(\gamma\mathrm{p} \to \pi^0\{2\mathrm{P}\}) = 294\ \mathrm{nb}. \quad (4)$$

As this photoproduction cross section is constant, i.e. independent of s_2, the EPA conversion to electroproduction can be achieved by simply multiplying it with a constant $c_{\text{EPA}} = 0.0136$ corresponding to the y integration in (2). This gives

$$\sigma^{\mathcal{O}}(ep \to e\pi^0\{2\text{P}\}) = 4010 \text{ pb}. \qquad (5)$$

In the following we consider only ep-scattering. An experimentally prefered observable is the k_T spectrum, the transverse momentum distribution of the π^0 with respect to the beam direction. At HERA k_T distributions can be measured for values of k_T greater than $O(0.1 \text{ GeV})$. The photoproduction cuts of (1) restrict the transverse momentum of the incident photon to be smaller than $O(0.1 \text{ GeV})$, so in our case there is practically no distinction between the beam axis and the photon axis. The k_T spectrum is displayed in Fig. 4

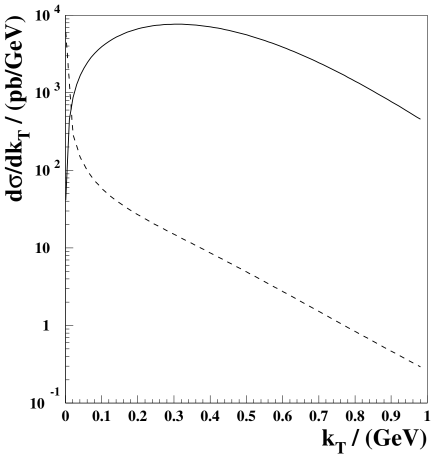

Figure 4. The k_T distribution in pion production from the 2P resonance channels for odderon exchange (solid line) compared to the complete electromagnetic result (dashed line). Interference contributions are not taken into account.

3. PHOTON EXCHANGE

In this section we consider PS production mediated by photon rather than odderon exchange (Fig. 1). Again the proton, now hit by the photon, is allowed to go into some hadron final state X. The process has been calculated in [6] for X being a proton. In [4] we have calculated the cross section, when X is a hadron final state in the invariant mass (M_X) range $1.11 \leq M_X \leq 1.99$ GeV. In Fig. 4 we show the distribution of the pion's k_T summed over the elastic and all inelastic channels for the electromagnetic exchange. As we can see there the photon exchange is larger than the odderon exchange only for very small k_T. For $k_T \gtrsim 0.1$ GeV the Odderon exchange dominates by orders of magnitude. The integrated cross section is [4]:

$$\sigma^{\gamma}(ep \to e\pi^0\{\text{p} + \text{X}\}) = 80.1 \text{ pb} \qquad (6)$$

which has to be compared with the odderon cross section (5).

In addition we have estimated in [4] contributions from reggeon (ω) exchange and from a possible background process, namely an additional final state photon emitted from the π^0 vertex (Fig. 1), where we have used realistic cuts. Both contributions are of the same order of magnitude as the photon exchange contribution.

The conclusion is: With the large odderon cross section as given in our model the process should be observable at HERA. This would establish the soft odderon as an exchange-object in high energy scattering on an equal footing with the soft pomeron.

REFERENCES

1. L. Lukaszuk and B. Nicolescu: Nuov. Cim. Lett. **8** (1973) 405;
   D. Joynson, E. Leader, C. Lopez, and B. Nicolescu: Nuov. Cim. A **30** (1975) 345.
2. A. Donnachie, P. V. Landshoff, Z. Phys. C**2** (1979) 55.
3. C. Augier, Phys. Lett. B**315** (1993) 503.
4. E. R. Berger, A. Donnachie, H. G. Dosch, W. Kilian, O. Nachtmann, M. Rüter, report hep-ph/9901376, to be published in Eur. Phys. J. **C**.
5. M. Rueter , H.G. Dosch , O. Nachtmann, report hep-ph/9806342,
   Phys. Rev. **D59** (1999) 014018.
6. W. Kilian, O. Nachtmann, Eur. Phys. J. **C5** (1998) 317.