We study Pomeron-Odderon interference effects giving rise to charge and single-spin asymmetries in diffractive electroproduction of a $\pi^+ \pi^-$ pair. We calculate these asymmetries in the Born approximation of QCD in a kinematical domain accessible to HERA experiments.
1 Introduction

Hadronic reactions at low momentum transfer and high energies (for charge-even exchange) are described in QCD in terms of QCD-Pomeron described by the BFKL equation [1]. The charge-odd exchange is less well understood although the corresponding BKP equations [2] have attracted much attention recently [3, 4, 5, 6], thus reviving the relevance of phenomenological studies of the Odderon exchange pointed out years ago in Ref. [7]. Unfortunately, the recent studies of specific channels where the QCD Odderon contribution is expected to be singled out have turned out to be very disappointing. In particular, recent experimental studies at HERA of exclusive $\pi^0$ photoproduction [8] indicate a very small cross section for this process which stays in contradiction with theoretical predictions based on the stochastic vacuum model [9].

The general feature of all meson production processes is that scattering amplitude describing Odderon exchange enters quadratically in the cross section. This observation lead to the suggestion in Ref. [10], that the study of observables where Odderon effects are present at the amplitude level - and not at the squared amplitude level - is mandatory to get a convenient sensitivity to a rather small normalization of this contribution. This may be achieved by means of charge asymmetries, as for instance in open charm production [10]. Since the final state quark-antiquark pair has no definite charge parity both Pomeron and Odderon exchanges contribute to this process. Another example [11] is the charge asymmetry in soft photoproduction of two pions. Bearing in mind perturbative QCD (pQCD) description, we calculated the ”hard” analogs of these asymmetries [12], and supplemented them by the single spin asymmetries, which may be studied at HERA with polarized lepton beam [13].

2 Method and Results

We consider the process $e^-(p_e)N(p_N) \rightarrow e^-(p'_e)\pi^+(p_+)\pi^-(p_-)N'(p'_N)$. The application of pQCD for the calculation of a part of this process is justified by the presence of a hard scale: the squared mass $-Q^2 = -(p_e - p'_e)^2$ of the virtual photon, $Q^2$ being of the order of a few GeV$^2$. The amplitude of this process (Fig.1) includes the convolution of a perturbatively calculable hard subprocess with two non-perturbative inputs, the 2-pion generalized distri-
distribution amplitude (GDA) and the Pomeron-Odderon (P/O) proton impact factors. Since the $\pi^+\pi^-$ system is not a charge parity eigenstate, the GDA includes two charge parity components and allows for a study of the corresponding interference term. The relevant GDA is just given by the light cone wave function of the two pion system \[14\].

2.1 Charge asymmetry

We define the forward-backward or charge asymmetry $A(Q^2, t, m_{2\pi}^2, y, \alpha)$ by

$$\frac{\sum_{\lambda=+,-} \int \cos \theta \, d\sigma(s, Q^2, t, m_{2\pi}^2, y, \alpha, \theta, \lambda)}{\sum_{\lambda=+,-} \int d\sigma(s, Q^2, t, m_{2\pi}^2, y, \alpha, \theta, \lambda)}$$  \hspace{1cm} (1)$$

as a weighted integral over polar angle $\theta$ of the relative momentum of two pions. Although this asymmetry depends on the full set of the kinematical variables, different dependencies, due to factorization, come from different sources. The most clean one are the dependencies on $Q^2$, coming from the hard subprocess, and on dipion mass $m_{2\pi} = \sqrt{(p_+ + p_-)^2}$, coming from GDA. The specific form of $m_{2\pi}$ dependence is explained by the fact, that the phase of GDA\[14\] should add to the phase shift between Pomeron and Odderon. The $Q^2$ dependence, which is a subject to corrections from BFKL, BKP and ERBL evolution, is due to the different $Q^2$ dependence of Pomeron and Odderon coefficient functions (perturbative impactfactors), the latter having the extra propagators, leading to the decrease of asymmetry with $Q^2$. The typical scale of $\alpha_s$ is determined by the gluons transverse momenta $k_i$ (see Fig.1) and we checked that the result is not changed substantially if "hard" $\alpha_S(Q^2)$ is used for coefficient function and "soft" $\alpha_S \sim 0.5$ is used for non-perturbative proton impactfactors. The latter objects, together with the coefficient functions, define the dependence of asymmetry on $t = (p_N - p'_N)^2$. As to the dependence on the standard leptonic variables $y$ (the lepton energy
fraction carried by the virtual photon) and $\alpha$ (the angle between lepton and photon scattering planes), it is determined by the relative size of the virtual photon helicity amplitudes and allows to estimate the promising kinematical region $^{[13]}$.

### 2.2 Spin Asymmetry

The single spin asymmetry $A_S(Q^2, t, m_{2\pi}^2, y, \alpha)$ is defined by

$$A_S = \frac{\sum_{\lambda=+,-} \lambda \int \cos \theta d\sigma(s, Q^2, t, m_{2\pi}^2, y, \alpha, \theta, \lambda)}{\sum_{\lambda=+,-} \int d\sigma(s, Q^2, t, m_{2\pi}^2, y, \alpha, \theta, \lambda)}$$

and requires to fix the lepton beam polarization $\lambda$. Contrary to charge asymmetry, this effect is proportional to the imaginary, rather than to real part of the interference term. As the Pomeron amplitude is imaginary and the Odderon one is real the relative phase between them is the maximal one for the emergence of single spin asymmetries $^{[13]}$. The effect should be therefore maximal for zero relative phase between isoscalar and isovector GDA’s, providing a complementary probe. This complementarity can be seen from the dependence of spin asymmetry on $m_{2\pi}$ and $Q^2$ (Fig.2) The smaller numerical value of spin asymmetry is to a large extent due to the kinematical factor $\sqrt{t}$. This asymmetry may be therefore important in the region of large $t$, which would become a relevant QCD scale and allow to have smaller $Q^2$. 

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Figure 2: Dependence of charge asymmetry on $m_{2\pi}$ and $Q^2$
3 Conclusions

We found that a sizable charge asymmetry may be a useful tool to look for QCD Odderon contribution at HERA. The spin asymmetry is smaller, but it can be important at larger $t$ and smaller $Q^2$. Note finally, that the numerical value of our predictions depend on the adopted model for proton impact factors, so the observation of the predicted effects with the different magnitude and/or $t$–dependence might be considered as an indirect experimental determination of these important non-perturbative objects.

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