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Odderon-Pomeron Interference*

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Abstract

We show that the asymmetry in the fractional energy of charm versus anticharm jets produced in high energy diffractive photoproduction is sensitive to the interference of the Odderon ($C = -$) and Pomeron ($C = +$) exchange amplitudes in QCD. We predict the dynamical shape of the asymmetry in a simple model and estimate its magnitude to be of the order 15% using constraints from proton-proton vs. proton-antiproton elastic scattering. Measurements of this asymmetry at HERA could provide the first evidence for the presence of Odderon exchange in the high energy limit of strong interactions.

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The existence of odd charge-conjugation, zero flavor-number exchange contributions to high energy hadron scattering amplitudes is a basic prediction of quantum chromodynamics, following simply from the existence of the color-singlet exchange of three reggeized gluons in the $t-$channel [1]. In Regge theory, the "Odderon" contribution is dual to a sum over $C = P = -1$ gluonium states in the t-channel [2]. In the case of reactions which involve high momentum transfer, the deviation of the Regge intercept of the Odderon trajectory from $\alpha_{\mathcal{O}}(t = 0) = 1$ can in principle be computed [3–6] from perturbative QCD in analogy to the methods used to compute the properties of the hard BFKL pomeron [7]. (For a more complete history of the Odderon we refer the reader to [8] and [9] and references therein.)

In the case of low momentum transfer reactions, the Odderon exchange amplitude should yield a roughly energy-independent contribution to the difference of proton-proton vs. proton-antiproton cross sections. It should also be seen in high energy diffractive pseoduscalar meson photoproduction, such as $\gamma p \to \pi^0 p$ [10–12] and $\gamma\gamma \to \pi^0\pi^0$ [13], since these amplitudes demands odd C exchange. Despite these theoretical expectations, there is as yet no firm experimental evidence for any Odderon contribution in the high-energy limit $s \gg |t|$. A realisation of the Odderon in perturbation theory is represented by the Landshoff contribution to large angle pp scattering [14].

Recent results from the electron-proton collider experiments at HERA [15]—the rapidly-rising behavior of proton structure functions at small x, the rapidly-rising diffractive vector meson electroproduction rates, and the steep rise of the J/ψ photoproduction cross section have brought renewed interest in the nature and behavior of the pomeron in QCD (see for example [16,17]). In this letter we propose an experimental test well suited to HERA kinematics which should be able to disentangle the contributions of both the Pomeron and the Odderon to diffractive production of charmed jets. By forming a charge asymmetry in the energy of the charmed jets, we can determine the relative importance of the Pomeron ($C = +$) and the Odderon ($C = -$) contributions, and their interference, thus providing a new experimental test of the separate existence of these two objects. Since the asymmetry measures the Odderon amplitude linearly, even a relatively weakly-coupled amplitude should be visible.

Consider the diagrams in Fig. 1 describing the amplitude for diffractive photoproduction of a charm quark anti-quark pair. The leading diagram is given by single Pomeron exchange (two reggeized gluons), and the next term in the Born expansion is given by the exchange of one Odderon (three reggeized gluons). In the following we will focus on the situation when the diffractively scattered proton p' stays intact; however, the formulae will be equally valid when the diffractively scattered proton is excited to a low mass system Y. We only require the invariant mass of the system M_Y^2 to be small compared to the invariant mass of the $c\bar{c}$ pair M_X^2. In fact, as pointed out by Rueter *et al.* [11], the cross-section for the diffractively excited protons can be significantly larger than the elastic cross-section. The virtuality of the incoming photon Q^2 can be zero or small since the invariant mass of the $c\bar{c}$ pair M_X^2 is large. Thus we are considering both diffractive photoproduction and leptoproduction, although in the following we will specialize to the case of photoproduction for which the rate observed at HERA is much larger. Our results can easily be generalized to non-zero Q^2.

The total center of mass energy of the γp system will be denoted $s_{\gamma p}$ which should be distinguished from the total ep cms energy. Denoting the photon momentum by q, the

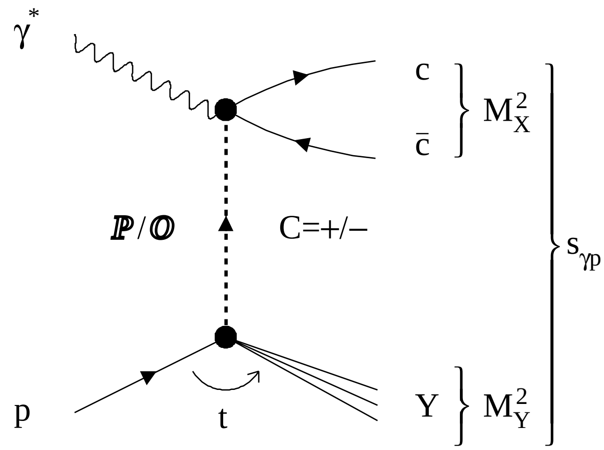

FIG. 1. The amplitude for the diffractive process $\gamma p \to c\bar{c}Y$ with Pomeron ($\mathcal{P}$) or Odderon ($\mathcal{O}$) exchange.

proton momentum by p, and the momenta of the charm quark (antiquark) by p_c ($p_{\bar{c}}$), the energy sharing of the $c\bar{c}$ pair is given by the variable

$$z_{c(\bar{c})} = \frac{p_{c(\bar{c})}p}{qp} = \frac{E_{c(\bar{c})}}{E_{\gamma^*}} \tag{1}$$

where the latter equality is true in the proton rest frame. It follows that $z_c + z_{\bar{c}} = 1$ in Born approximation at the parton level. The finite charm quark mass restricts the range of z to

$$\frac{1}{2} - \sqrt{\frac{1}{4} - \frac{m_c^2}{M_X^2}} \leq z \leq \frac{1}{2} + \sqrt{\frac{1}{4} - \frac{m_c^2}{M_X^2}} \tag{2}$$

where M_X^2 is the invariant mass of the $c\bar{c}$ pair which is related to the total γp cms energy $s_{\gamma p}$ by

$$M_X^2 = (\xi p + q)^2 \simeq 2\xi pq \simeq \xi s_{\gamma p} \tag{3}$$

where ξ is effectively the longitudinal momentum fraction of the proton carried by the Pomeron/Odderon and the proton mass is neglected.

Regge theory, which is applicable in the kinematic region $s_{\gamma p} \gg M_X^2 \gg M_Y^2$, together with crossing symmetry, predicts the phases and analytic form of high energy amplitudes (see, for example, Refs. [18] and [19]). The amplitude for the diffractive process $\gamma p \to c\bar{c}p'$ with Pomeron ($\mathcal{P}$) or Odderon ($\mathcal{O}$) exchange can be written as

$$\mathcal{M}^{\mathcal{P}/\mathcal{O}}(t, s_{\gamma p}, M_X^2, z_c) \propto g_{pp'}^{\mathcal{P}/\mathcal{O}}(t) \left(\frac{s_{\gamma p}}{M_X^2}\right)^{\alpha_{\mathcal{P}/\mathcal{O}}(t)} \times \frac{\left(1 + S_{\mathcal{P}/\mathcal{O}} e^{-i\pi\alpha_{\mathcal{P}/\mathcal{O}}(t)}\right)}{\sin \pi\alpha_{\mathcal{P}/\mathcal{O}}(t)} g_{\mathcal{P}/\mathcal{O}}^{\gamma c\bar{c}}(t, M_X^2, z_c) \tag{4}$$

where $S_{\mathcal{P}/\mathcal{O}}$ is the signature[†] which is $+(-)1$ for the Pomeron (Odderon). In the Regge approach the upper vertex $g^{\gamma c\bar{c}}_{\mathcal{P}/\mathcal{O}}(t, M_X^2, z_c)$ can be treated as a local real coupling such that the phase is contained in the signature factor. In the same way the factor $g^{\mathcal{P}/\mathcal{O}}_{pp'}(t)$ represents the lower vertex. For our purposes it will be convenient to rewrite the signature factor in the following way,

$$\frac{\left(1 + S_{\mathcal{P}/\mathcal{O}} e^{-i\pi\alpha_{\mathcal{P}/\mathcal{O}}(t)}\right)}{\sin \pi\alpha_{\mathcal{P}/\mathcal{O}}(t)} = \begin{cases} \dfrac{\cos \frac{\pi\alpha_{\mathcal{P}}(t)}{2} - i \sin \frac{\pi\alpha_{\mathcal{P}}(t)}{2}}{\sin \frac{\pi\alpha_{\mathcal{P}}(t)}{2}} & \text{for } S_{\mathcal{P}} = 1 \\[2ex] \dfrac{\sin \frac{\pi\alpha_{\mathcal{O}}(t)}{2} + i \cos \frac{\pi\alpha_{\mathcal{O}}(t)}{2}}{\cos \frac{\pi\alpha_{\mathcal{O}}(t)}{2}} & \text{for } S_{\mathcal{O}} = -1 \end{cases} . \tag{5}$$

In the literature it has become customary to absorb the pole factors $1/\sin\frac{\pi\alpha_{\mathcal{P}}(t)}{2}$ and $1/\cos\frac{\pi\alpha_{\mathcal{O}}(t)}{2}$ into the couplings $\left(g^{\mathcal{P}/\mathcal{O}}_{pp'}(t)\right)^2$, but we will keep them explicit since we want to treat the upper and lower vertex separately.

In general the Pomeron and Odderon exchange amplitudes will interfere, as illustrated in Fig. 2. The contribution of the interference term to the total cross-section is zero, but it does contribute to charge-asymmetric rates. Thus we propose to study photoproduction of c-$\bar{c}$ pairs and measure the asymmetry in the energy fractions z_c and $z_{\bar{c}}$. More generally, one can use other charge-asymmetric kinematic configurations, as well as bottom or strange quarks.

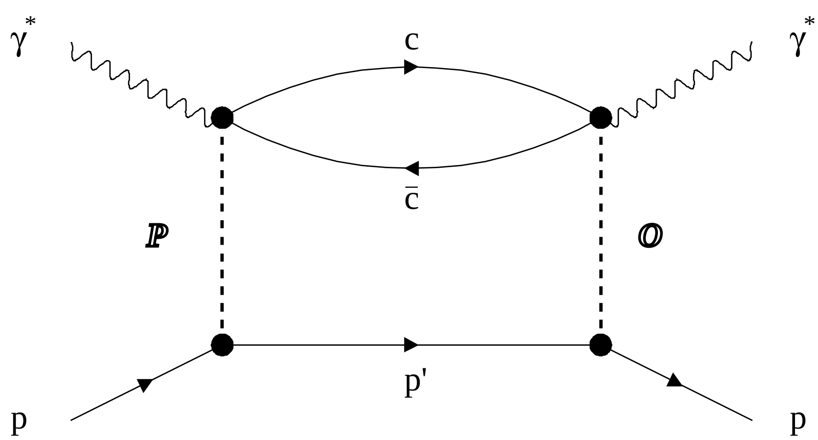

FIG. 2. The interference between Pomeron ($\mathcal{P}$) or Odderon ($\mathcal{O}$) exchange in the diffractive process $\gamma p \to c\bar{c}p'$.

Given the amplitude (4), the contribution to the cross-section from the interference term depicted in Fig. 2 is proportional to

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[†]Even (odd) signature corresponds to an exchange which is (anti)symmetric under the interchange $s \leftrightarrow u$.

$$
\begin{aligned}
\frac{d\sigma^{int}}{dtdM_X^2dz_c} &\propto \mathcal{M}^{\mathcal{P}}(t,s_{\gamma p},M_X^2,z_c)\left\{\mathcal{M}^{\mathcal{O}}(t,s_{\gamma p},M_X^2,z_c)\right\}^{\dagger}+h.c. \\
&= g_{pp'}^{\mathcal{P}}(t)g_{pp'}^{\mathcal{O}}(t)\left(\frac{s_{\gamma p}}{M_X^2}\right)^{\alpha_{\mathcal{P}}(t)+\alpha_{\mathcal{O}}(t)}\frac{2\sin\left[\frac{\pi}{2}\left(\alpha_{\mathcal{O}}(t)-\alpha_{\mathcal{P}}(t)\right)\right]}{\sin\frac{\pi\alpha_{\mathcal{P}}(t)}{2}\cos\frac{\pi\alpha_{\mathcal{O}}(t)}{2}} \\
&\quad\times g_{\mathcal{P}}^{\gamma c\bar{c}}(t,M_X^2,z_c)g_{\mathcal{O}}^{\gamma c\bar{c}}(t,M_X^2,z_c)\ . \qquad (6)
\end{aligned}
$$

In the same way we obtain the contributions to the cross-section from the non-interfering terms for Pomeron and Odderon exchange,

$$
\frac{d\sigma^{\mathcal{P}/\mathcal{O}}}{dtdM_X^2dz_c}\propto=\begin{cases}\left[g_{pp'}^{\mathcal{P}}(t)\left(\frac{s_{\gamma p}}{M_X^2}\right)^{\alpha_{\mathcal{P}}(t)}g_{\mathcal{P}}^{\gamma c\bar{c}}(t,M_X^2,z_c)/\sin\frac{\pi\alpha_{\mathcal{P}}(t)}{2}\right]^2 & \text{for } S_{\mathcal{P}}=1 \\ \left[g_{pp'}^{\mathcal{O}}(t)\left(\frac{s_{\gamma p}}{M_X^2}\right)^{\alpha_{\mathcal{O}}(t)}g_{\mathcal{O}}^{\gamma c\bar{c}}(t,M_X^2,z_c)/\cos\frac{\pi\alpha_{\mathcal{O}}(t)}{2}\right]^2 & \text{for } S_{\mathcal{O}}=-1\end{cases}\ . \qquad (7)
$$

We note the different charge conjugation properties of the upper vertices:

$$
\begin{aligned}
g_{\mathcal{P}}^{\gamma c\bar{c}}(t,M_X^2,z_c) &= -g_{\mathcal{P}}^{\gamma c\bar{c}}(t,M_X^2,z_{\bar{c}}) \\
g_{\mathcal{O}}^{\gamma c\bar{c}}(t,M_X^2,z_c) &= g_{\mathcal{O}}^{\gamma c\bar{c}}(t,M_X^2,z_{\bar{c}})\ . \qquad (8)
\end{aligned}
$$

The interference term can then be isolated by forming the charge asymmetry,

$$
\mathcal{A}(t,M_X^2,z_c)=\frac{\dfrac{d\sigma}{dtdM_X^2dz_c}-\dfrac{d\sigma}{dtdM_X^2dz_{\bar{c}}}}{\dfrac{d\sigma}{dtdM_X^2dz_c}+\dfrac{d\sigma}{dtdM_X^2dz_{\bar{c}}}}\ , \qquad (9)
$$

Inserting Eqs. (6), (7) and (8) into Eq. (9) then gives the predicted asymmetry,

$$
\mathcal{A}(t,M_X^2,z_c)=\frac{g_{pp'}^{\mathcal{P}}g_{pp'}^{\mathcal{O}}\left(\frac{s_{\gamma p}}{M_X^2}\right)^{\alpha_{\mathcal{P}}+\alpha_{\mathcal{O}}}\frac{2\sin\left[\frac{\pi}{2}\left(\alpha_{\mathcal{O}}-\alpha_{\mathcal{P}}\right)\right]}{\sin\frac{\pi\alpha_{\mathcal{P}}}{2}\cos\frac{\pi\alpha_{\mathcal{O}}}{2}}g_{\mathcal{P}}^{\gamma c\bar{c}}g_{\mathcal{O}}^{\gamma c\bar{c}}}{\left[g_{pp'}^{\mathcal{P}}\left(\frac{s_{\gamma p}}{M_X^2}\right)^{\alpha_{\mathcal{P}}}g_{\mathcal{P}}^{\gamma c\bar{c}}/\sin\frac{\pi\alpha_{\mathcal{P}}}{2}\right]^2+\left[g_{pp'}^{\mathcal{O}}\left(\frac{s_{\gamma p}}{M_X^2}\right)^{\alpha_{\mathcal{O}}}g_{\mathcal{O}}^{\gamma c\bar{c}}/\cos\frac{\pi\alpha_{\mathcal{O}}}{2}\right]^2} \qquad (10)
$$

where the arguments have been dropped for clarity. This is the general form of the Pomeron-Odderon interference contribution in Regge theory. In the following we will give numerical estimates for the different components and also calculate the asymmetry using the Donnachie-Landshoff model for the Pomeron [20].

The functional dependence of the asymmetry on the kinematical variables can be obtained by varying the kinematic variables one at a time. In this way it will be possible to obtain new information about Odderon exchange in relation to pomeron exchange. Furthermore, we expect the main dependence in the different kinematic variables to come from different factors in the asymmetry. For instance, the invariant mass M_X dependence is mainly given by the power behavior, $(s_{\gamma p}/M_X^2)^{\alpha_{\mathcal{O}}(t)-\alpha_{\mathcal{P}}(t)}$, and will thus provide direct information about the difference between $\alpha_{\mathcal{O}}$ and $\alpha_{\mathcal{P}}$. Another interesting question which can be addressed from observations of the asymmetry is the difference in the t-dependence of $g^{\mathcal{O}}_{pp'}$ and $g^{\mathcal{P}}_{pp'}$.

We also make the following general observations about the predicted asymmetry:

- As a consequence of the differing signatures for the Pomeron and Odderon, there is no interference between the two exchanges if they have the same effective power $\alpha(t)$ since then $\sin\left[\frac{\pi(\alpha_{\mathcal{O}}-\alpha_{\mathcal{P}})}{2}\right]=0$. In fact, in a perturbative calculation at tree-level the interference would be zero in the high-energy limit $s \gg |t|$ since the two- and three-gluon exchanges are purely imaginary and real respectively. This should be compared with the analogous QED process, $\gamma Z \to \ell^+\ell^- Z$, where the interference of the one- and two-photon exchange amplitudes can explain [21] the observed lepton asymmetries, energy dependence, and nuclear target dependence of the experimental data [22] for large angles. The asymmetry is in the QED case proportional to the opening angle such that it vanishes in the limit $s \gg |t|$.

- The overall sign of the asymmetry is not predicted by Regge theory. (The couplings g can be both positive and negative.) However, the pole at $\alpha_{\mathcal{O}}=1$ leads to the asymmetry having different sign for $\alpha_{\mathcal{O}}(t)<1$ and $\alpha_{\mathcal{O}}(t)>1$ respectively. Thus, provided that the Odderon intercept is smaller than 1, as the more recent theoretical developments show [4–6], then the asymmetry will change sign for some larger t where $\alpha_{\mathcal{O}}(t)$ goes through 1.

The ratio of the Odderon and Pomeron couplings to the proton, $g^{\mathcal{O}}_{pp'}/g^{\mathcal{P}}_{pp'}$, is limited by data on the difference of the elastic proton-proton and proton-antiproton cross-sections at large energy s. Following [12] we use the estimated limit on the difference between the ratios of the real and imaginary part of the proton-proton and proton-antiproton forward amplitudes,

$$|\Delta\rho(s)| = \left|\frac{\Re\{\mathcal{M}^{pp}(s,t=0)\}}{\Im\{\mathcal{M}^{pp}(s,t=0)\}} - \frac{\Re\{\mathcal{M}^{p\bar{p}}(s,t=0)\}}{\Im\{\mathcal{M}^{p\bar{p}}(s,t=0)\}}\right| \leq 0.05 \tag{11}$$

for $s \sim 10^4$ GeV^2 to get a limit on the ratio of the Odderon and Pomeron couplings to the proton. Using the amplitude corresponding to Eq. (4) for proton-proton and proton-antiproton scattering we get for $t=0$,

$$\Delta\rho(s) = 2\frac{\Re\{\mathcal{M}^{\mathcal{O}}(s)\}}{\Im\{\mathcal{M}^{\mathcal{P}}(s)\}+\Im\{\mathcal{M}^{\mathcal{O}}(s)\}} \simeq -2\left(\frac{g^{\mathcal{O}}_{pp'}}{g^{\mathcal{P}}_{pp'}}\right)^2 \left(\frac{s}{s_0}\right)^{\alpha_{\mathcal{O}}-\alpha_{\mathcal{P}}} \tan\frac{\pi\alpha_{\mathcal{O}}}{2}, \tag{12}$$

where s_0 is a typical hadronic scale ~ 1 GeV^2 which replaces M_X^2 in Eq. (4). In the last step we also make the simplifying assumption that the contribution to the denominator from the Odderon is numerically much smaller than from the Pomeron and therefore can be neglected. The maximally allowed Odderon coupling at t=0 is then given by,

$$\left|g^{\mathcal{O}}_{pp'}\right|_{\max} = \left|g^{\mathcal{P}}_{pp'}\right| \sqrt{\frac{\Delta\rho_{\max}(s)}{2}\cot\frac{\pi\alpha_{\mathcal{O}}}{2}\left(\frac{s}{s_0}\right)^{\alpha_{\mathcal{P}}-\alpha_{\mathcal{O}}}}. \tag{13}$$

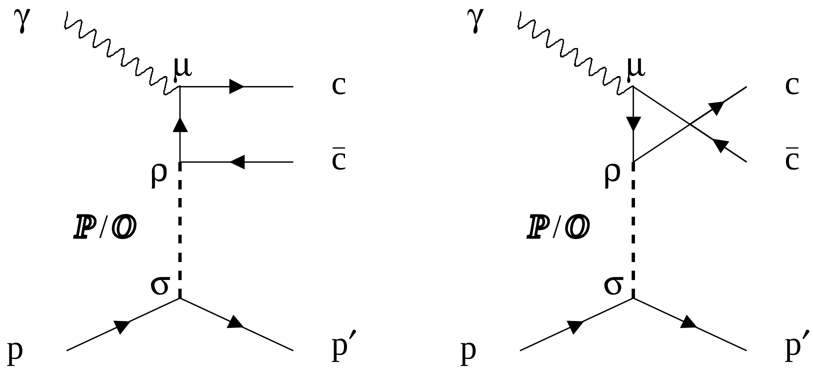

FIG. 3. The amplitudes for the asymmetry using the Donnachie-Landshoff [20] model for the Pomeron/Odderon coupling to the quark and the proton.

The amplitudes can be calculated using the Donnachie-Landshoff [20] model for the Pomeron and a similar ansatz for the Odderon [12]. The coupling of the Pomeron/Odderon to a quark is then given by $\kappa_{\mathcal{P}/\mathcal{O}}(t)\gamma^\rho$, *i.e.* assuming a helicity preserving local interaction. In the same way the Pomeron/Odderon couples to the proton with $F_{\mathcal{P}/\mathcal{O}}(t)\gamma^\sigma$ if we only include the Dirac form-factor. The amplitudes shown in Fig. 3 can then be obtained by replacing $g_{pp'}^{\mathcal{P}/\mathcal{O}}(t)g_{\mathcal{P}/\mathcal{O}}^{\gamma c\bar{c}}(t, M_X^2, z_c)$ in Eq. (4) by,

$$
\begin{aligned}
g_{pp'}^{\mathcal{P}/\mathcal{O}}(t)g_{\mathcal{P}/\mathcal{O}}^{\gamma c\bar{c}}(t, M_X^2, z_c) &= F_{\mathcal{P}/\mathcal{O}}(t)\bar{u}(p-\ell)\gamma^\sigma u(p)\left(g^{\rho\sigma} - \frac{\ell^\rho q^\sigma + \ell^\sigma q^\rho}{\ell q}\right)\kappa_{\mathcal{P}/\mathcal{O}}(t)\epsilon^\mu(q) \\
&\times \bar{u}(p_c)\left\{\gamma^\mu \frac{\not{\ell} - \not{p}_{\bar{c}} + m_c}{(1-z)M_X^2}\gamma^\rho - S_{\mathcal{P}/\mathcal{O}}\gamma^\rho \frac{\not{p}_c - \not{\ell} + m_c}{zM_X^2}\gamma^\mu\right\}v(p_{\bar{c}})
\end{aligned}
$$

where $\ell = \xi p$ is the Pomeron/Odderon momentum and $g^{\rho\sigma} - \frac{\ell^\rho q^\sigma + \ell^\sigma q^\rho}{\ell q}$ stems from the Pomeron/Odderon "propagator". Note the signature which we have inserted for the crossed diagram to model the charge conjugation property of the Pomeron. The Pomeron amplitude written this way is not gauge invariant and therefore we use radiation gauge also for the photon, *i.e.* the polarization sum is obtained using $g^{\mu\nu} - \frac{q^\mu p^\nu + q^\nu p^\mu}{pq}$. The leading terms in a t/M_X^2 expansion of the squared amplitudes for the Pomeron and Odderon exchange as well as the interference are then given by,

$$
\begin{aligned}
\left(\frac{g_{pp'}^{\mathcal{P}} g_{\mathcal{P}}^{\gamma c\bar{c}}}{F_{\mathcal{P}}\kappa_{\mathcal{P}}}\right)^2 &\propto \frac{z_c^2 + z_{\bar{c}}^2}{z_c z_{\bar{c}}}\frac{t(1-\xi)}{\xi^2} \\
\left(\frac{g_{pp'}^{\mathcal{O}} g_{\mathcal{O}}^{\gamma c\bar{c}}}{F_{\mathcal{O}}\kappa_{\mathcal{O}}}\right)^2 &\propto \frac{z_c^2 + z_{\bar{c}}^2}{z_c z_{\bar{c}}}\frac{t(1-\xi)}{\xi^2} \\
\frac{g_{pp'}^{\mathcal{P}} g_{pp'}^{\mathcal{O}} g_{\mathcal{P}}^{\gamma c\bar{c}} g_{\mathcal{O}}^{\gamma c\bar{c}}}{F_{\mathcal{P}} F_{\mathcal{O}}\kappa_{\mathcal{P}}\kappa_{\mathcal{O}}} &\propto \frac{z_c - z_{\bar{c}}}{z_c z_{\bar{c}}}\frac{t(1-\xi)}{\xi^2},
\end{aligned}
\tag{14}
$$

with corrections that are of order t^2/M_X^2 and therefore can be safely neglected. The ratio between the interference term and the Pomeron exchange is thus given by,

$$\frac{g_{pp'}^{\mathcal{O}} g_{\mathcal{O}}^{\gamma c\bar{c}}}{g_{pp'}^{\mathcal{P}} g_{\mathcal{P}}^{\gamma c\bar{c}}} = \frac{F_{\mathcal{O}}\kappa_{\mathcal{O}}}{F_{\mathcal{P}}\kappa_{\mathcal{P}}} \frac{z_c - z_{\bar{c}}}{z_c^2 + z_{\bar{c}}^2} = \frac{F_{\mathcal{O}}\kappa_{\mathcal{O}}}{F_{\mathcal{P}}\kappa_{\mathcal{P}}} \frac{2z_c - 1}{z_c^2 + (1-z_c)^2} \tag{15}$$

To obtain a numerical estimate of the asymmetry, we shall assume that $t \simeq 0$ and use $\alpha_{\mathcal{P}} = 1.13$ [23] and $\alpha_{\mathcal{O}} = 0.95$ [5] for the Pomeron and Odderon intercepts respectively. In addition we will also assume $\kappa_{\mathcal{O}}/\kappa_{\mathcal{P}} \sim C_F \alpha_s(m_c^2) \simeq 0.4$ and use the maximal Odderon-proton coupling, $F_{\mathcal{O}}/F_{\mathcal{P}} = g_{pp'}^{\mathcal{O}}/g_{pp'}^{\mathcal{P}} = 0.1$, which follows from Eq. (13) for $s = 10^4$ GeV^2, $s_0 = 1$ GeV^2 and $\Delta\rho_{\max}(s) = 0.05$. We again make the simplifying assumption that the Odderon contribution can be dropped in the denominator in Eq. (10) giving,

$$\mathcal{A}(t, M_X^2, z_c) \simeq 2\sin\left[\frac{\pi\left(\alpha_{\mathcal{O}} - \alpha_{\mathcal{P}}\right)}{2}\right] \left(\frac{s_{\gamma p}}{M_X^2}\right)^{\alpha_{\mathcal{O}}-\alpha_{\mathcal{P}}} \frac{g_{pp'}^{\mathcal{O}}}{g_{pp'}^{\mathcal{P}}} \frac{g_{\mathcal{O}}^{\gamma c\bar{c}}}{g_{\mathcal{P}}^{\gamma c\bar{c}}} \frac{\sin\frac{\pi\alpha_{\mathcal{P}}}{2}}{\cos\frac{\pi\alpha_{\mathcal{O}}}{2}}. \tag{16}$$

Inserting the numerical values discussed above together with the ratio of the vertices given by Eq. (15) then gives

$$\mathcal{A}(t \simeq 0, M_X^2, z_c) \simeq 0.3 \left(\frac{s_{\gamma p}}{M_X^2}\right)^{-0.18} \frac{2z_c - 1}{z_c^2 + (1-z_c)^2}\ , \tag{17}$$

which for a typical value of $\frac{s_{\gamma p}}{M_X^2} = 100$ becomes a ~ 15 % asymmetry for large z_c as illustrated in Fig. 4. In the case of diffractive dissociation we can expect an even larger asymmetry. Using $g_{pY}^{\mathcal{O}}/g_{pY}^{\mathcal{P}} = \kappa_{\mathcal{O}}/\kappa_{\mathcal{P}} = 0.4$ gives an asymmetry which is four times large, *i.e.* of the order ~ 50 % for large z_c. Finally we also note that the asymmetry can be integrated over z_c giving

$$\mathcal{A}(t \simeq 0, M_X^2) = \int_{0.5}^{1} \mathcal{A}(t \simeq 0, M_X^2, z_c) - \int_{0}^{0.5} \mathcal{A}(t \simeq 0, M_X^2, z_c) \simeq 0.2 \left(\frac{s_{\gamma p}}{M_X^2}\right)^{-0.18} . \tag{18}$$

In summary we have presented a sensitive test for detecting the separate existence of the Pomeron and the Odderon exchange contributions in the high-energy limit $s \gg |t|$ as predicted by QCD. By observing the charge asymmetry of the quark/antiquark energy fraction (z_c) in diffractive $c\bar{c}$ pair photoproduction the interference between the Pomeron and the Odderon exchanges can be isolated and the ratio to the sum of the Pomeron and the Odderon exchanges measured. In a simple model for the Pomeron/Odderon coupling to the photon the asymmetry is predicted to be proportional to $(2z_c - 1)/(z_c^2 + (1-z_c)^2)$ and the magnitude is of order 15% (and possibly significantly larger for diffractive proton dissociation). Such a test could be performed by current experiments at HERA measuring the diffractive production of open charm in photoproduction or electroproduction. Such measurements could provide the first experimental evidence for the existence of the Odderon, as well as the relative strength of the Odderon and Pomeron couplings. Most important, the energy dependence of the asymmetry can be used to determine whether the Odderon intercept is in fact greater or less than that of the Pomeron.

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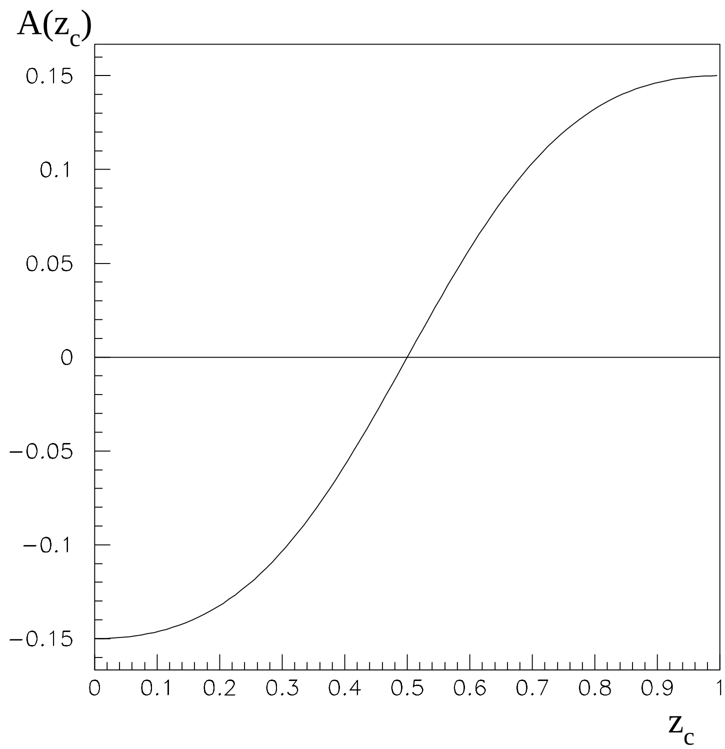

FIG. 4. The asymmetry in fractional energy z_c of charm versus anticharm jets predicted by our model using the Donnachie-Landshoff Pomeron for $\alpha_{\mathcal{P}} = 1.13$, $\alpha_{\mathcal{O}} = 0.95$ and $s_{\gamma p}/M_X^2 = 100$.

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