Why is the odderon contribution invisible in the high-energy total cross sections?

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An explanation is offered as to why the odderon contribution to the high-energy total cross sections is nearly invisible while the status of the odderon and pomeron in pQCD is almost identical.

The odderon is the C-odd partner of the pomeron. It was introduced, in addition to the pomeron, as a phenomenological object which can induce a difference between the high energy pp and $p\bar{p}$ cross sections and also a noticeable real part of the forward $p\bar{p}$ amplitude.[1] The modern high energy $p\bar{p}$ data show no contribution of the odderon to the total cross section; it is $\leqslant 1/40$ as compared with the pomeron cross section.[2]

1. Let us begin with the discussion of the *semihard region*, in which pQCD is valid:

$$s \gg |t| \gg \mu^2 \quad (\mu \approx 0.3 \text{ GeV is the QCD scale}). \tag{1}$$

The status of the pomeron and the odderon in pQCD is nearly identical.

The pomeron corresponds to a sum of diagrams with a C-even colorless exchange in the t channel; the simplest of these diagrams has two gluons in the t channel (see Ref. 3 and other papers). This pQCD (BFKL) pomeron is related (via unitarity) to the inelastic processes in which the transverse momenta of the gluons are not too small $p_\perp$ (1). These gluons can be associated with mini jets (see, e.g., Ref. 4).

The odderon corresponds to a sum of diagrams with a C-odd colorless exchange in the t channel; the simplest of these diagrams has three gluons in the t channel.

It is expected that both of these amplitudes—pomeron and the odderon—have a similar energy dependence in some respect (see Ref. 5).

At $\sqrt{s} \approx 1$ TeV, the $p\bar{p}$ total cross section is approximately twice as large compared with $\sqrt{s} \approx 12$ GeV. The raised part of the total cross section is usually associated with the pQCD pomeron. The manifestation of the pQCD odderon here would seem to be natural. However, the observed high-energy total cross sections are described with the pomeron only; the odderon contribution is invisible in modern experiments.

Two facts are essential for the explanation of this phenomenon:

1) In the approach which we are discussing the raised part of the cross section can be obtained by a factorization relation, i.e., by convolution of the elementary parton cross section with the parton densities in the protons (the structure functions). Since gluon density is the largest one at small x, its contribution to the high-energy cross sections is dominant. Next, the pomeron is coupled with quarks and gluons. In contrast, the odderon is coupled with quarks only, its coupling with gluons (the gg-odderon) is forbidden due to C

parity conservation. Indeed, the odderon is C-odd colorless object and gluons have the definite C parity (negative). Therefore, the above vertex breaks the C parity conservation.$^{1),2)}$

2) In addition, at the two-gluon colorless exchange the ratio of the cross sections for scattering on a quark and a gluon is small (see, e.g., Ref. 6):

$$\sigma_q/\sigma_g = 16/81 \approx 1/5. \qquad (2)$$

These facts lead to a strong suppression of the odderon contribution in the raised part of the total cross section.

2. Our experience in high-energy phenomena shows that the last statement can be extended to the total cross section. To do this, one can use, for example, an approach similar to that developed in Refs. 7 and 8 for a description of the diffractive processes at $|t| \lesssim 1$ GeV^2. There the pomeron and the odderon are described as two-gluon and three-gluon exchanges in the t channel with Reggeized nonperturbative gluons.

The problem being discussed here was investigated in Ref. 8. It was found that the C-odd (odderon) quark–quark amplitude is suppressed in comparison with the C-even (pomeron) amplitude by a factor $f_q \approx 1/4$. This suppression, however, is insufficient to explain the data. (In a similar approximation of pQCD the quantity $f_q \sim \alpha_s^2 < 1/4$.)

In Refs. 7 and 8 the quark content of hadrons only was taken into account. In my opinion, it should add the gluon component of the hadron, which is not small.$^{3)}$

The ratio of the odderon and pomeron contributions in such model is much smaller than $f_q \sigma_{q/g}$ [cf. (2)].

It is necessary to take into account the ratio $v_{q/qg}$ of the total quark flux in a proton to that of the quark+gluon for processes with $p_\perp > p_{\perp\,0}$ (for definiteness, we use $p_{\perp\,0} = 1.5$ GeV). For a rough estimate we can write these fluxes as integrals of the corresponding structure functions over x at $x > 4p_{\perp\,0}^2/s$. Using the structure functions from Ref. 9, we find that the above ratio varies from 0.25 at $\sqrt{s} = 15$ GeV to 0.07 at $\sqrt{s} = 1000$ GeV.

The product of these factors shows roughly the relative contribution of the odderon in the high-energy pp scattering: (Moreover, perhaps the odderon contribution decreases as compared with the pomeron contribution, while the energy increases).

$$v_{q/qg} \sigma_{q/g} f_q \sim 0.0012 - 0.004.$$

This estimate is consistent with the phenomenological estimate given above.^{2}

3. Therefore, the comparative investigation of the pomeron and the odderon seems to be an important problem both in the semihard region (1) and in the soft region. It is useful to separate their contributions in the different reactions such as the quasidiffractive (small-angle) photoproduction of neural mesons at HERA:$^{10-12}$

$$\gamma p \to V + X; \quad V = \rho^0, \omega, \varphi, \ldots \Psi, \quad \Upsilon, \ldots, \gamma \text{ (pomeron)}, \qquad (4)$$

$$\gamma p \to P + X; \quad \gamma p \to T + X; \quad P = \pi^0, \eta, \eta', \ldots; \quad T = a_2, f, f', \ldots \text{ (odderon)}. \qquad (5)$$

These mesons V, P, T and other hadrons should be separated in rapidity (rapidity gap). The variation of this rapidity gap corresponds to the variation of the value of x.

At a moderately small value of x, the odderon does not interact with the gluon system; at a smaller x (when shadowing in the pomeron contribution becomes essential) the interaction of the odderon with the gluon system (e.g., with two gluons simultaneously) is switched on. These processes have been observed at HERA at $p_\perp \sim 3$–8 GeV (Ref. 12). A detailed investigation of shadowing seems to be a realistic task at HERA.

A comparative investigation of these processes at $p_\perp \lesssim 1$ GeV should give us information about the role of the gluon component of a proton in models like those of Refs. 7 and 8. (Certainly, at small values of the rapidity gap the ω exchange contribution should be taken into account.)

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1) The odderon is often represented as a three-gluon system. There are two colorless three-gluon systems: the C-odd (like odderon) $d^{abc}g^a g^b g^c$ and the C even $f^{abc}gag^b g^c$. The pair of gluons is coupled with the C-even three-gluon system only (which can enter into the pomeron).

2) As the energy increases, the effects of shadowing in the gluon subsystem become important at small x. It corresponds to noticeable probabilities for the collision of two gluons from one proton simultaneously. This collision can produce an odderon + gluon $(g+g \to O+g)$. In this region the interaction of the odderon with the gluon system is switched on, but it is weaker than the interaction of a pomeron with the gluon system.

3) It is thus necessary to change some parameters in the expressions used to preserve the main results related to the pomeron.

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