Possible evidence for color transparency from dijet production with large rapidity gaps in γp scattering at HERA and how to test it in $\gamma p, \gamma A$ scattering

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Abstract: We argue that the probability of gap survival in dijet production in γp scattering as measured by ZEUS may be due to the color transparency phenomenon and suggest ways to test this hypothesis in the future γp and γA processes.

The interaction of spatially small systems with a hadron has been the subject of discussions for a long time now (for the long and somewhat contradictory history of the theoretical and experimental investigations of this phenomenon see ref [1]). One expects that small color singlets interact weakly if energies are not extremely high - color transparency (CT). The current HERA data are in the kinematic region where the coherent length $l_c = 1/2m_N x$ significantly exceeds the nucleon radius. In this kinematic range color coherent effects should reveal themselves most clearly. Here we explain a practical idea how to search for CT in high p_t dijet production at HERA both in γp and γA collisions.

1 Gap survival for γp case

In order to study soft interactions which accompany a hard scattering, Bjorken [3] suggested to investigate the ratio of the cross sections of the high p_t dijet production with a large rapidity gap (LRG) to that of dijets without a rapidity gap:

$$f_{ac} = \frac{\sigma(a + c \to (jet(p_t) + X) + LRG + (jet(-p_t) + Y))}{\sigma(a + c \to jet(p_t) + jet(-p_t) + Z)} = \kappa P_{LRG} \qquad (1)$$

Here c can be a proton or a nuclear target. To account for the difference between scales of hard and soft processes quantify the role of soft physics Bjorken evaluated f_{ac} as the product of 2 factors:

$$f_{ac} \equiv \kappa P_{RGS}. \qquad (2)$$

Factor κ is the probability of producing a rapidity gap in hard subprocess, while P_{RGS} characterizes probability of gap survival due to soft interactions of constituents which do not participate in the hard collision.

Natural mechanism for the colorless hard collision is the exchange by 2 gluons. At first sight this contribution should be 0. Really it follows from the QCD factorization theorem that the exchange by an extra gluon between the partons involved in a hard collision is canceled out for the total cross section of dijet production. However for diffractive processes the presence of the LRG trigger in the final state destroys the cancelation between different terms, leading to the factorization theorem breaking[7]. In perturbative QCD κ, can be estimated as the ratio of cross sections of hard collisions of partons due to a double gluon color singlet exchange to that due to a single gluon exchange [3, 4, 5], give $\kappa \sim 0.15$ cf.discussion in [6] which depends rather weakly on p_t of the jets. Account for the leading $\alpha_s \ln x$ corrections may lead to a certain increase of κ with the length of rapidity gap. κ is different for the hard collisions of partons belonging to the different representations of $SU(3)_{color}$. This leads to a certain dependence of κ on the kinematics and to a weak dependence on a projectile.

Within the framework of conventional soft dynamics P_{RGS} should be approximately independent of the projectile. This is because of the different geometry of collisions characteristic for soft and for hard collisions. Hard collisions are concentrated at small impact parameters which are characterized by the average slope of the diffractive cross section: $a + b \rightarrow X_1 + X_2$, where X_1, X_2 are diffractive states. On the contrary, soft interactions are predominantly peripheral, at impact parameters increasing with energy. This has been established experimentally via the observation of the diffractive cone shrinkage with increase of the energy. Thus a reasonable approximation is that P_{RGS} is determined by collisions at zero impact parameters. Within the eikonal approximation used by Bjorken [3] the eikonal phase at zero impact parameters is a function of the dimensionless ratio $\sigma_{tot}(ac)/B_{ac}$, where B_{ac} is the slope of the differential cross section for the soft ac scattering. We observe that this ratio is practically the same for proton and photon projectiles. Here for a photon projectile we use as a guide the vector dominance model where $B_{\gamma c} \approx B_{\pi c}$ and $\sigma_{inel} \approx \sigma_{\pi c}$. Hence in the eikonal approximation:

$$P_{RGS}(p\bar{p}) = P_{RGS}(\gamma p). \tag{3}$$

This projectile independence is because a collision at central impact parameters is almost black.

A second possible source of filling the gap between the jets can be radiation from the two gluon exchange. This radiation should be a small effect since both gluons are located at the same parameter. In this case radiation of gluons with transverse momenta $\ll p_t$ is cancelled out because such a gluon can not resolve colorless exchange, cf.[8]. Radiation of hard gluon is suppressed by the smallness of the coupling constant. Besides, this radiation is projectile independent since it is determined by the properties of the 2 gluon exchange.

Very recently photoproduction events which have two or more jets have been observed in the $W_{\gamma p}$ range $135 < W_{\gamma p} < 280 GeV$ with the ZEUS detector at HERA [2]. A class of the events is observed with little hadronic activity between the jets. The value of $f_{\gamma p} = 0.07 \pm 0.03$ is reported based on the last bin: $\Delta\eta \geq 3$. This value is rather close to the estimates in perturbative QCD [3, 4, 5] neglecting absorptive effects due to interactions of spectator partons in colliding particles, i.e.assuming $P_{RGS} \sim 1$. It is significantly larger that the values reported by D0 [9] and CDF [10] at $\sqrt{s}$=1.8 TeV: $f_{p\bar{p}} = 0.0107 \pm 0.0010(stat.)^{+0.0025}_{-0.0013}(sys.)$ [9], and 0.0086 ± 0.0012 [10]. The difference in the gap survival probability is another manifestation of the lack of factorization in the hard processes when extra constraints are imposed on the event selection, see review in [11].

We thus conclude that the probability of gap survival seems to be an effective probe of soft interactions which accompany hard interactions. Specifics of the photon projectile is that its wave function contains a significant $q\bar{q}$ component with large transverse momenta where color is screened. For such configurations, CT would lead to significant enhancement of P_{RGS}. In the ZEUS experiment the requirement of observing two high p_t jets in the acceptance of the detector have led to an effective selection of jets carrying a fraction of more than 0.7 of the photon momentum. This component of the wave function is dominated by the small size $q\bar{q}$

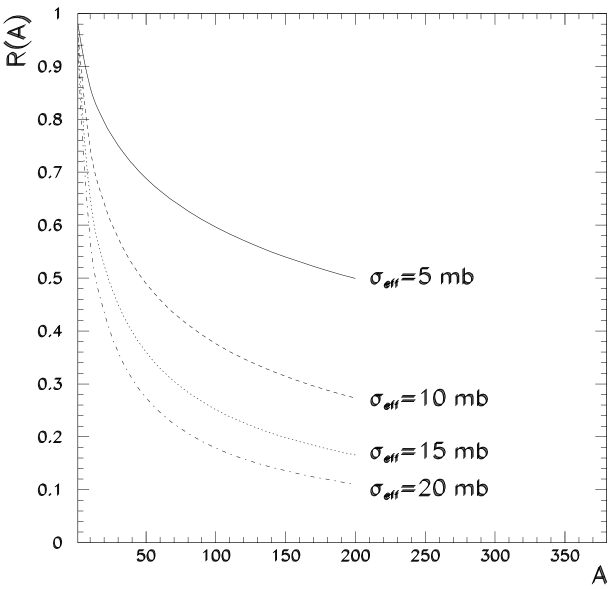

Figure 1: A dependence of the rapidity gap survival probability on σ_{eff}.

component of the photon wave function since the soft component is suppressed at least by a factor $1-z$. Hence the larger value of $f_{\gamma p}$ observed in this experiments as compared to f_{pp} maybe a manifestation of CT. In other words, kinematics of of the ZEUS experiment may **effectively suppress the soft component in the parton wave function of photon**. One of the ways to check this interpretation is to investigate the dependence of P_{RGS} as a function of the fraction of the photon momentum carried by the jet. The prediction is a significant depletion of $f_{\gamma p}$ when this fraction decreases to values below 0.5. One should also try to introduce a cut for the jet fraction larger that 0.7, but to avoid kinematics when the jet from accompanying quark would fill the gap. This may increase the color transparency effect.

2 A-dependence of gap survival

Another way to check the color transparency interpretation of the ZEUS data would be to study the A-dependence of P_{RGS}. One can address here in **a quantitative way** the key question of *how large is the effective cross section for the interaction of the photon in the configuration which leads to the production of events with rapidity gaps between jets?* Is it close to the average value of σ_{eff} ~20 mb or maybe much smaller, as the CT interpretation of the ZEUS data suggests.

Let us define

$$R(A) = \frac{f_{\gamma A}(\Delta\eta)}{f_{\gamma p}(\Delta\eta)}, \tag{4}$$

for $\Delta\eta \geq 3$ where $f_p(\Delta\eta)$ flattens out. It is easy to calculate the A-dependence of $R(A)$ using the eikonal approximation [12]:

$$R(A) = \int d^2B\tilde{T}(B)\exp(-\sigma_{eff}\tilde{T}(B)). \tag{5}$$

Here $\tilde{T}(B)$ is the standard nuclear thickness function: $\tilde{T}(B) = \int_{-\infty}^{\infty} dz\rho_A(\sqrt{B^2+z^2})$, where the nuclear density $\rho_A(r)$ is normalized according to $\int \rho_A(r)d^3r = 1$. σ_{eff} is the cross section of inelastic soft interaction of the hadronic component of the photon wave function, excluding diffractive cross section. The results of the calculation of $R(A)$ are presented in Fig.1 as a function A for several values of σ_{eff}. One can see that measurements with nuclear targets could provide a quantitative measurement of σ_{eff} and hence shed a new light on the dynamics of strongly interacting color singlet object responsible for the jet events with rapidity gaps. If one would observe $\sigma_{eff} \leq 10mb$ this would provide a clear evidence for CT in the production of dijets with LRG. It seems that the optimal range of the targets is $A \leq 40$ since for larger A, $R(A)$ depends rather weakly on A.

3 Acknowledgments

We would like to thank A.Levy for useful comments. This work was supported in part by U.S.Department of Energy and by BSF.

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