Formation of Color-Singlet Gluon-Clusters and Inelastic Diffractive Scattering

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The observation [1] of large rapidity gap (LRG) events in the small-x_B region of DIS shows that inelastic diffractive scattering can take place not only in hadron-hadron collisions [2] but also in small-x_B DIS where interacting soft gluons play the dominating role [3]. Hence, this observation gives rise to a number of questions: Are the mechanisms which lead to diffractive scattering processes in different reactions related to one another? In particular, if it is indeed "the exchange of colorless objects" which is responsible for diffractive scattering in hadron-hadron collisions, is it *the same kind of "colorless objects"* which are also responsible for diffractive scattering in deep-inelastic lepton-hadron scattering processes? What *are* such "colorless objects"? Can they be understood in terms of QCD — the only candidate for hadronic interactions? What is the relationship between such "colorless objects" and the interacting soft gluons which play the dominating role in this kinematical region?

In order to answer these questions, it has been proposed in a recent letter [4] that the "colorless" objects which manifest themselves in large rapidity gap events are color-singlet gluon-clusters due self-organized criticality (SOC), and that optical-geometrical concepts and methods are useful in examining the space-time properties of such objects. The main result of Ref. [4] has been presented at DIS98 in Brussels [5].

Further results and detailed discussions of this approach to inelastic diffractive scattering are given in the papers written by C. Boros, T. Meng, R. Rittel, Y. Zhang, and myself [6]; and in this talk, I shall try to summarize those results which are not covered in Refs. [4] and [5].

Before presenting the new results, I think it is useful to recall why SOC is expected to play a significant role in diffractive scattering processes: First, we note that the fundamental properties of gluons, in particular the *local gluon-gluon coupling* prescribed by the QCD-Lagrangian, the *non-conservation of gluon numbers*, and *the confinement* show that a system of interacting soft gluons should be considered as an *open, dynamical, complex system* with *many degrees of freedom* which is in general *far from equilibrium.* Next we recall that there exist many open dynamical complex systems in Nature, and it has been observed by Bak, Tang, and Wiesenfeld (BTW) [7] more then ten years ago that such kind of systems can evolve into self-organized critical states, which are barely stable. Local perturbations can propagate like avalanches (we call them BTW-avalanches) over all length scales. The distribution of the size (S) and the distribution of the lifetime (T) of such avalanches obey power laws:

$$D_S(S) \propto S^{-\mu} \text{ and } D_T(T) \propto T^{-\nu} \qquad (1)$$

These characteristic features are known as the fingerprints of SOC.

Having seen these facts it is quite natural to ask: Can SOC and BTW-avalanches also exist in the microscopic world, at the level of gluons and quarks? Is it possible, that the colorless objects observed in inelastic diffractive scattering processes are gluon-clusters in form of BTW-avalanches? How can this be probed experimentally?

We carried out a systematic data-analysis in Ref. [6] to answer these questions. In order to test the size distribution of the colorless objects, we note the following: The interaction between the colorless objects are (similar to nuclear forces) of Van der Waals type, such that these objects can be easily knocked out. Furthermore, x_P is the energy fraction carried by the colorless object, and thus it is the size of the struck colorless BTW-avalanche. Last but not least, we can use concepts and methods of the parton model to examine the data for diffractive DIS, and make use of the following analogy: while for normal events F_2/x_B gives the quark distribution, $F_2^{D(3)}/x_P$ can be interpreted as the size distribution of the colorless objects. Note that, since x_P and $F_2^{D(3)}$ are measureable quantities, *no* further theoretical input is needed to extract the momentum distribution of such colorless BTW-avalanches. Furthermore, to compare the result for diffractive DIS with other inelastic diffractive processes we can also plot the differential cross section $\frac{1}{x_P}\frac{d^2\sigma}{dx_P dQ^2}$ instead of the structure function. The result is shown in figure 1. This im-

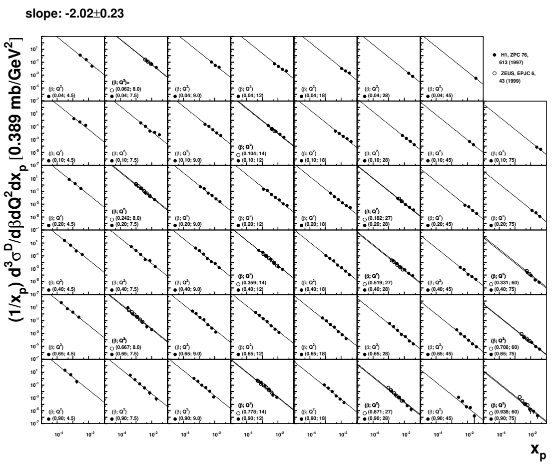

Figure 1. The differential cross section $\frac{1}{x_P}\frac{d^2\sigma}{dx_P dQ^2}$ is plotted against x_P for diffractive DIS. This gives directly the size distribution of the gluon-clusters. The data are taken from [8].

plies that the size distribution of the gluon clusters obeys a power law with an exponent approximately -2. The corresponding plot for diffractive photo-production also shows a power law behavior with the same exponent -2 (see figure 2). Finally (see Ref. [6]), inelastic diffractive

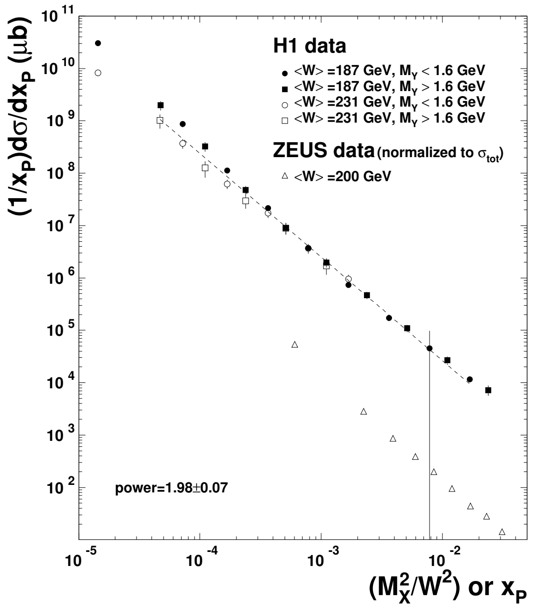

Figure 2. The corresponding plot for diffractive photo-production. The data are taken from [9]

(anti)proton-proton scattering gives the same result.

Hence, for all the different considered inelastic diffractive processes the size distribution of the colorless objects turns out to be a power law with exponent -2. Furthermore (see Ref. [6]), the lifetime distribution shows the same behavior. Hence, we indeed see the characteristic fingerprints of SOC.

The following picture emerges: The beam particle (this can be $\gamma^\star$, γ, p, or $\bar{p}$) sees a cloud of colorless gluon-clusters which are due to self-organized criticality in the system of interacting soft gluons in the proton. There is no typical size, and no typical lifetime for the gluon clusters. As BTW-avalanches they have no static structure and cannot be considered as hadrons.

In order to test this picture, we recall, that diffraction can be and has been used as an instrument to determine the geometrical structure of the scatterer. So we ask: "Are the considered inelastic diffractive processes comparable with diffraction in Optics?" The answer is "Yes".

In particular, the well-known formula, which relates the scattering amplitude f in $\vec{q}$-space to the amplitude α in impact parameter $\vec{b}$-space as Fourier-transforms, is valid for real photon-, virtual photon-, as well as hadron-beams, and for elastic scattering on a static screen, as well as for inelastic scattering off a dynamical complex system [4–6]. The amplitude α_{inel} can be calculated using the space-time properties of the scattering screen: taking into account (a) SOC in the system of interacting soft gluons, (b) the confinement, and (c) causality, we arrive at the expression [6]

$$\alpha_{inel}(b|x_P) \propto x_P^{-1/3}(a^2+b^2)^{-3/2}, \tag{2}$$

where $a^2 = 3/5 r_P^2$ is directly related to the proton radius. Performing the Fourier-transform of this and squaring it, we get the result for the double differential cross section

$$\frac{d^2\sigma}{dx_P dt} = N x_P^{-2/3} \exp(-2a\sqrt{|t|}). \tag{3}$$

In connection with this simple analytical formula we note the following: The t-dependence turns out to be an exponential in $\sqrt{|t|}$. The slope parameter a can be calculated from the proton radius. The comparison with the data is shown in figure 3. Note that Eqs.(2) and (3) also lead to the analytical formula for $d\sigma/dt$ shown in Refs. [4] and [5].

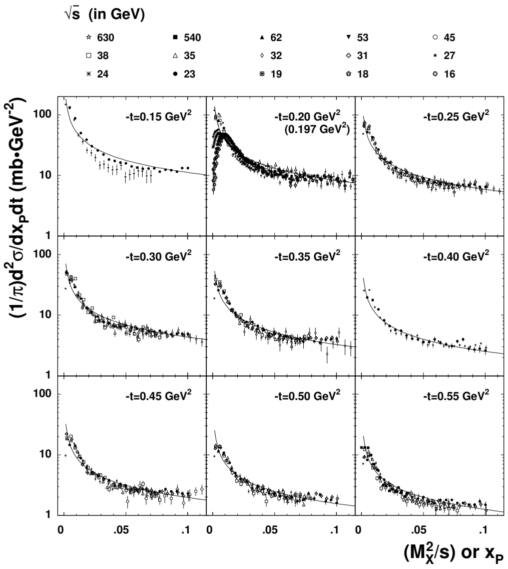

Figure 3. Part of the calculated result for $d^2\sigma/dx_P dt$ for diffractive (anti)proton-proton scattering. The data are taken from [2]. The results for 0.60 GeV$^2 \leq |t| \leq$ 4.15 GeV^2, which are not shown here, are given in [6].

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