TRANSVERSE IMAGING OF THE PROTON IN EXCLUSIVE DIFFRACTIVE PP SCATTERING

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In a recent paper we describe a new approach to rapidity gap survival (RGS) in the production of high–mass systems (H = dijet, Higgs, *etc.*) in exclusive double–gap diffractive pp scattering, $pp \to p + H + p$. It is based on the idea that hard and soft interactions are approximately independent (QCD factorization), and allows us to calculate the RGS probability in a model–independent way in terms of the gluon generalized parton distributions (GPDs) in the colliding protons and the pp elastic scattering amplitude. Here we focus on the transverse momentum dependence of the cross section. By measuring the "diffraction pattern," one can perform detailed tests of the interplay of hard and soft interactions, and even extract information about the gluon GPD in the proton from the data.

Production of high–mass systems (H = dijet, diphotons, heavy quarkonium, Higgs boson, *etc.*) in exclusive double–gap diffractive pp scattering,

$$pp \;\; \to \;\; p + (\text{gap}) + H + (\text{gap}) + p, \tag{1}$$

is of importance both as a promising channel for the Higgs boson search at the LHC[1], and as a laboratory for studying strong interaction dynamics in high–energy collisions. Diffractive events arise as the result of a delicate interplay of hard and soft interactions. The high–mass system is produced in a hard scattering process, involving the exchange of two gluons between the protons; the requirement of the absence of QCD radiation ensures the localization of this process in space and time. In addition, one must require that the soft interactions between the spectator systems not lead to particle production. This results in a suppression of the cross section compared to the estimate based on the hard process alone, the so–called rapidity gap survival (RGS) probability[2].

In a recent paper[3] we describe a new approach to RGS in exclusive double–gap diffraction (1) based on the idea that hard and soft interactions proceed over very different time– and distance scales and are thus approximately independent (QCD factorization). We show that the amplitude can be calculated in a model–independent way in terms of the gluon generalized parton distributions (GPDs) in the colliding protons and the pp elastic scattering amplitude; excitation of inelastic intermediate states is suppressed. In these proceedings we focus on the transverse momentum dependence of the diffractive cross section.

Following Ref.[3], the amplitude for the hard scattering process in exclusive diffraction (see Fig. 1a) can be represented as

$$T_{\text{hard}}(\mathbf{p}'_{1\perp}, \mathbf{p}'_{2\perp}; \mathbf{p}_{1\perp}, \mathbf{p}_{2\perp}) \;=\; \kappa \, H_g(x_1, \xi_1, t_1) \; H_g(x_2, \xi_2, t_2), \tag{2}$$

where κ represents the overall normalization, H_g is the gluon GPD of the proton, $\xi_{1,2}$ the longitudinal momentum loss of the protons, $x_{1,2} \approx \xi_{1,2}$, and $t_1 \approx -(\mathbf{p}'_{1\perp} - \mathbf{p}_{1\perp})^2$ *etc.* the invariant momentum transfers to the protons. The gluon GPD refers to a scale, Q^2, of the order $\Lambda^2_{\text{QCD}} \ll Q^2 \ll M_H^2 \ll s$; by QCD evolution it can be related to the "diagonal" GPD at a lower scale. The amplitude for the diffractive process (1) (see Fig. 1b) is then given by (we suppress all arguments except the proton transverse momenta)

$$T_{\text{diff}}(\mathbf{p}'_{1\perp}, \mathbf{p}'_{2\perp}) = \int \frac{d^2\Delta_\perp}{(2\pi)^2} \, T_{\text{hard}}\,(\mathbf{p}'_{1\perp}, \mathbf{p}'_{2\perp}; \Delta_\perp, -\Delta_\perp) \;\, S_{\text{el}}(s, \Delta_\perp). \tag{3}$$

Here S_{el} is the S–matrix of pp elastic scattering, which can be expressed in terms of the elastic scattering amplitude, $T_{\text{el}}(s,t)$, *viz.* its profile function

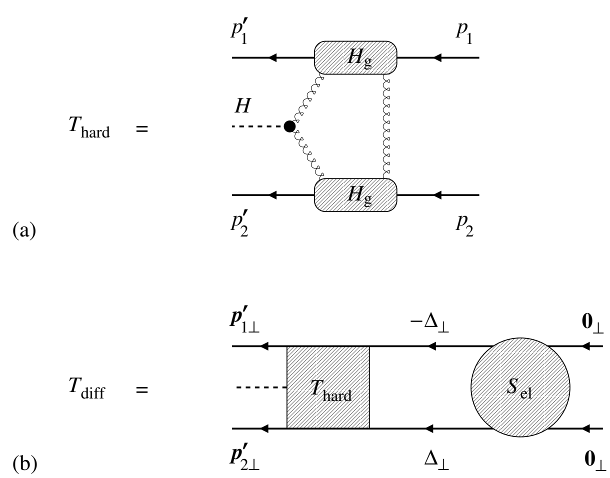

Figure 1.

in impact parameter representation, $\Gamma(s, \mathbf{b})$, as

$$S_{\rm el}(s, \Delta_\perp) = (2\pi)^2\, \delta^{(2)}(\Delta_\perp) \;+\; (4\pi i/s)\, T_{\rm el}(s, t = -\Delta_\perp^2) \tag{4}$$

$$= \int d^2 b\, e^{-i\Delta_\perp \cdot \mathbf{b}}\, [1 - \Gamma(s, \mathbf{b})] \,. \tag{5}$$

Equation (3) expresses the basic idea of RGS — the modification of the original hard scattering amplitude by soft elastic interactions. It actually describes an interference phenomenon: The diffractive amplitude is the sum of the original hard amplitude ["1" in Eq. (5)] and the amplitude modified by elastic scattering ["Γ" in Eq. (5)]. Eq. (3) reproduces the "geometric" expression for the RGS probability derived heuristically in Refs.[4,5]. It is based on the approximation of independence of hard and soft interactions. In Ref.[3] we show how correlations between hard and soft interactions (*e.g.* due to scattering from the proton's long–range pion field, or to parton clustering in "constituent quarks") can modify this simple result.

The profile function of the *pp* elastic amplitude has been determined from fits to the *pp* elastic and total cross section data. At TeV energies, it is expected that it approaches the black disk limit (BDL) at small impact parameters [4,5], $\Gamma(s, b) \rightarrow 1$ for $b < b_0(s)$. For illustrative purposes, we make a simple gaussian ansatz (although it satisfies the BDL only as $b \rightarrow 0$), $\Gamma(s, \mathbf{b}) = \exp\left\{-\mathbf{b}^2/\left[2B(s)\right]\right\}$, where $B = 21.8\,\mathrm{GeV}^{-2}$ at $\sqrt{s} = 14\,\mathrm{TeV}$ from extrapolation of fits to the present data. The t–dependence of the gluon GPD has been extracted from measurements of exclusive J/ψ photo/electroproduction[6]; see Ref.[5] for an overview. We parametrize it by a simple exponential, $H_g(x, \xi, t) \propto \exp(B_g t/2)$, with $B_g = 3.24\,\mathrm{GeV}^{-2}$ in the x– and Q^2 range relevant to production of a system with $M_H \approx 100\,\mathrm{GeV}$ at the LHC; see Ref.[3] for details. Notice that the average squared transverse radius of the distribution of hard gluons is much smaller than the squared radius of soft interactions: $2B_g \ll B$.

With the parametrizations for Γ and H_g we can explore the transverse momentum dependence of the diffractive amplitude (3). Figure 2 shows $|T_{\rm diff}|^2$ as a function of $\mathbf{p}'_{\perp 2}$, for fixed values of $\mathbf{p}'_{1\perp}$. The pattern can be understood as the wave generated by $T_{\rm hard}$ diffracting off the "hole" formed by the surface–dominated soft interaction profile, $1 - \Gamma(s, \mathbf{b})$. By measuring this dependence in dijet production one can perform detailed tests of the diffractive reaction mechanism, and even extract information about the gluon GPD in the proton. Such studies appear to be feasible with the proposed forward detectors at the LHC. In Higgs production, the diffraction pattern serves as an indicator of the quantum numbers of the produced system; in 0^+ production (shown here) the protons preferentially emerge at the same side of the beam, in 0^- production at a $90°$ angle.

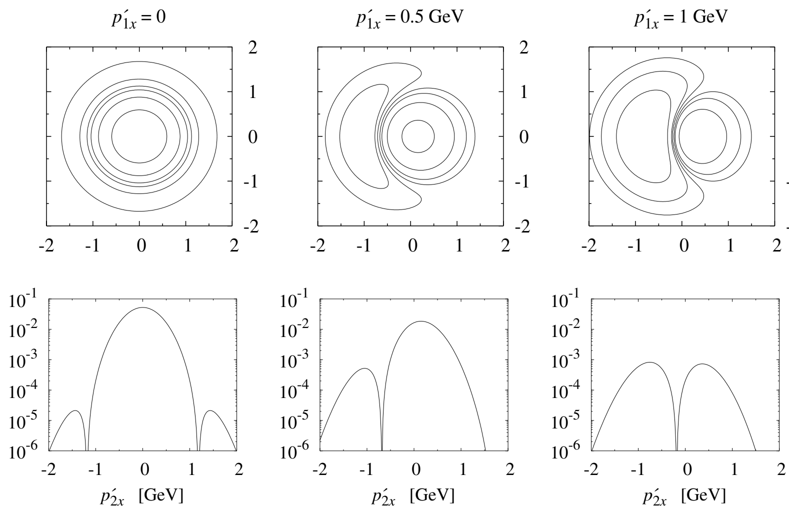

Figure 2. Transverse momentum dependence of the cross section for exclusive double–gap diffraction (1). The plots show $|T_{\rm diff}|^2$ (with $\kappa = 1$) as a function of $\mathbf{p}'_{2\perp}$, for three values of $\mathbf{p}'_{1\perp} = (p'_{1x}, 0)$. The top plots are 2–dimensional log–scale contour plots in $\mathbf{p}'_{2\perp}$; the bottom plots show the distributions for $\mathbf{p}'_{2\perp} = (p'_{2x}, 0)$.

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