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Exclusive and Semiinclusive Central Diffraction

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Abstract

Exclusive double diffractive events (EDDE) and their semiinclusive counterparts (SI DDE) are considered in the framework of the Regge-eikonal approach and perturbative calculations for ”hard” subprocesses. Total and differential cross-sections for processes $p+p \to p+M+p$ and $p+p \to p+XMY+p$ are calculated, where X and Y are ”soft” radiation products inside the central region. Some applications of these processes to the future investigations at LHC are proposed.

1 Itroduction

With the first LHC run coming closer the hopes for confirmation of various theory predictions get heated. The huge amount of works is related to the search of fundamental particles of the Standardt Model or its extensions (Higgs boson, Superpartners, gravitons and so on) and to the investigations of so called ”hard” QCD processes, which correspond to very short space-time scales. ”Soft” diffractive proceses take in this raw its own, distinctive place.

LHC collaborations aimed at working in low and high p_T regimes related to typical undulatory (diffractive) and corpuscular (point-like) behaviours of the corresponding cross-sections may offer a very exciting possibility to observe an interplay of both regimes [1]. In theory the ”hard part” can be (hopefully) treated with perturbative methods whilst the ”soft” one is definitely nonperturbative.

Below we give several examples of such an interplay: exclusive particle production by diffractively scattered protons, i.e. the processes $p + p \to p + M + p$, where $+$ means also a rapidity gap and M represents a particle or a system of particles consisting of or strongly coupled to the two-gluon state [2]. Also in this paper we extend exclusive processes to the case $p + p \to p + X\ \ M\ \ Y + p$, when we have additional ”soft” radiation X and Y inside the central rapidity region.

These processes are related to the dominant amplitude of exclusive and semiinclusive two-gluon production. Driving mechanism of the diffractive processes is the Pomeron. Data on the total cross-sections demands unambiguosly for the Pomeron with larger-than-one intercept, thereof the need to take into account the ”soft” rescattering (i.e. ”unitarisation”).

EDDE gives us unique experimental possibilities for particle searches and investigations of diffraction itself. This is due to several advantages of the process: a) clear signature of the process; b) possibility to use ”missing mass method” that improve the mass resolution; c) background is strongly suppressed; d) spin-parity analysis of the central system can be done; e) interesting measurements concerning the interplay between ”soft” and ”hard” scales are possible [3]. All these properties can be realized in common CMS/TOTEM detector measurements at LHC [4].

SI DDE is important as a source of main backgrounds for the exclusive processes.

2 Exclusive double diffraction

The exclusive double diffractive process is related to the dominant amplitude of the exclusive two-gluon production. Driving mechanism of this processes is the Pomeron.

To calculate an amplitude of the EDDE, we use an approach which was considered in detail in Ref. [2]. In the framework of this approach, the amplitude can be sketched as shown in Fig. 1. After the tensor contraction of the amplitudes $T_{1,2}$ with the gluon-gluon fusion vertex, the full “bare” amplitude T_M depicted in Fig. 1 looks like

$$T_M = \frac{2}{\pi}\, c_{gp}^2\, e^{b(t_1+t_2)} \left(-\frac{s}{M^2}\right)^{\alpha_P(0)} F_{gg\to M}\, I_s\ . \tag{1}$$

Here

$$b = \alpha'_P(0) \ln\left(\frac{\sqrt{s}}{M}\right) + b_0\ , \tag{2}$$

$$b_0 = \frac{1}{4}\,(\frac{r_{pp}^2}{2} + r_{gp}^2)\ , \tag{3}$$

with the parameters of the “hard” Pomeron trajectory, that appears to be the most relevant in our case, presented in Table 1. The last factor in the RHS of (1) is

$$I_s = \int\limits_0^{\mu^2} \frac{dl^2}{l^4}\, F_s(l^2,\mu^2) \left(\frac{l^2}{s_0 + l^2/2}\right)^{2\alpha_P(0)}\ , \tag{4}$$

where $l^2 = -q^2 \simeq \mathbf{q}^2$, $\mu = M/2$, and s_0 is a scale parameter of the model which is also used in the global fitting of the data on pp ($p\bar{p}$) scattering for on-shell amplitudes [1]. The fit gives $s_0 \simeq 1$ GeV^2. If we take into account the emission of virtual ”soft” gluons, while prohibiting the real ones, that could fill rapidity gaps, it results in a

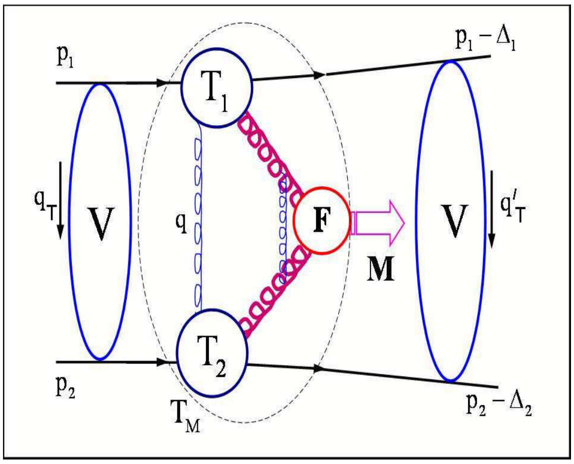

Figure 1: Model for EDDE

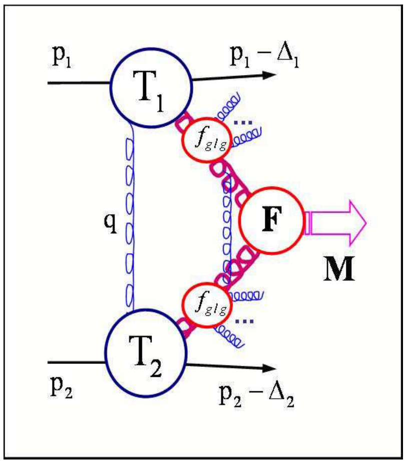

Figure 2: Amplitude T_M for SI DDE.

Sudakov-like suppression [5]:

$$F_s(l^2,\mu^2) = \exp\left[-\int\limits_{l^2}^{\mu^2}\frac{dp_T^2}{p_T^2}\,\frac{\alpha_s(p_T{}^2)}{2\pi}\int\limits_{\Delta}^{1-\Delta} zP_{gg}(z)dz + \int\limits_0^1\sum_q P_{qg}(z)dz\right], \tag{5}$$

$$P_{gg}(z) = 6\frac{(1-z(1-z))^2}{z(1-z)}, \tag{6}$$

$$\Delta = \frac{p_T}{p_T+\mu}. \tag{7}$$

The off-shell gluon-proton amplitudes $T_{1,2}$ are obtained in the extended unitary approach [6]. The "hard" part of the EDDE amplitude, $F_{gg\to M}$, is the usual gluon-gluon fusion amplitude calculated perturbatively in the SM or in its extensions.

Table 1: Phenomenological parameters of the "hard" Pomeron trajectory obtained from the fitting of the HERA and Tevatron data (see [2], [7]), and data on pp ($p\bar{p}$) scattering [1].The value of the c_{gp} is corrected in accordance with the latest data from CDF [8], which is depicted in the Fig. 3 with the range of possible curves. The best fit corresponds to the value $c_{gp}=2.85$.

$\alpha_P(0)$	$\alpha'_P(0)$, GeV^{-2}	r^2_{pp}, GeV^{-2}	r^2_{gp}, GeV^{-2}	c_{gp}
1.203	0.094	2.477	2.54	2.7→3.8

The data on total cross-sections demand unambiguously the Pomeron with larger-than-one intercept, thereof the need in unitarization. The amplitude with unitary corrections, T_M^{unit}, are depicted in Fig. 1. It is given by the following analytical expressions:

$$T_M^{unitar}(p_1,p_2,\Delta_1,\Delta_2) = \frac{1}{16\,ss'}\int\frac{d^2\mathbf{q}_T}{(2\pi)^2}\,\frac{d^2\mathbf{q}'_T}{(2\pi)^2}\,V(s,\mathbf{q}_T) \times T_M(p_1-q_T,p_2+q_T,\Delta_{1T},\Delta_{2T})\,V(s',\mathbf{q}'_T), \tag{8}$$

$$V(s,\mathbf{q}_T) = 4s\,(2\pi)^2\,\delta^2(\mathbf{q}_T)+4s\int d^2\mathbf{b}\,e^{i\mathbf{q}_T\mathbf{b}}\left[e^{i\delta_{pp\to pp}}-1\right], \tag{9}$$

where $\Delta_{1T}=\Delta_1-q_T-q'_T$, $\Delta_{2T}=\Delta_2+q_T+q'_T$, and the eikonal function $\delta_{pp\to pp}$ can be found in Ref. [1]. Left and right parts of the diagram in Fig. 1b denoted by V represent "soft" re-scattering effects in initial and final states, i.e. multi-Pomeron exchanges. As was shown in [9], these "outer" unitary corrections strongly reduce the value of the corresponding cross-section and change an azimuthal angle dependence.

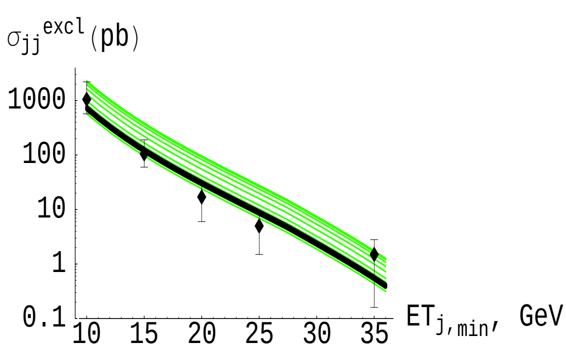

Figure 3: The latest data from CDF and predictions for EDDE.

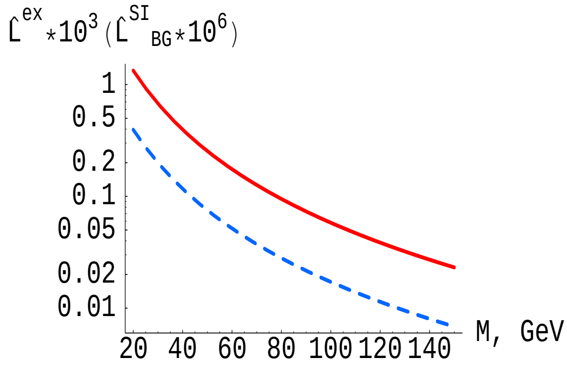

Figure 4: $g^{IP}g^{IP}$ luminocities for EDDE (solid curve) and SI DDE (dashed curve) for the ”soft” radiation with $k_T < 7$ GeV and $x_{g,hard} > 0.8$.

In the equation (1) we present only the Born terms from amplitudes $T_{1,2}$. It is sufficient for $|t_{1,2}| < 1$ GeV due to fast decrease of the differential cross-section in $t_{1,2}$, and the contribution of these corrections to the total cross-section are less than several percents. But when we consider the diffractive pattern in the region of $1 < |t_{1,2}| < 5$ GeV, we have to take into account rescattering corrections inside the amplitudes $T_{1,2}$. In this case I_s in the equation (1) changes to the following expression:

$$I_s^{corr} = \int\limits_0^{\mu^2} \frac{dl^2}{l^4} F_s(l^2) \left(\frac{l^2}{s_0 + l^2/2}\right)^{\alpha_P(t_1)+\alpha_P(t_2)} (1 + h(v, t_1))(1 + h(v, t_2)) \;, \tag{10}$$

$$h(v,t) = \sum_{n=2}^{\infty} \frac{(-1)^{n-1}}{n! \cdot n} \left(\frac{c_{gp}}{8\pi\, b_1(v)} \exp\left[-\frac{i\pi(\alpha_P(0)-1)}{2}\right] v^{\alpha_P(0)-1} \right)^{n-1} \exp\left[\frac{b_1(n-1)}{n}|t|\right] \;, \tag{11}$$

$$v = \frac{\sqrt{s}}{M} \frac{l^2}{s_0 + l^2/2} \;, \tag{12}$$

and b to

$$b_1 = \alpha'_P(0) \ln v + b_0 \;. \tag{13}$$

To calcuate differential and total cross-sections for exclusive processes we can use the formula

$$\frac{d\sigma^{EDDE}}{dM^2\, dy\, d\Phi_{gg\to M}}|_{y=0} = \hat{L}^{EDDE} \frac{d\hat{\sigma}^{J_z=0}}{d\Phi_{gg\to M}} \;, \tag{14}$$

$$\hat{L}^{EDDE} = \frac{c_{gp}^4}{2^5\pi^6} \left(\frac{s}{M^2}\right)^{2(\alpha_P(0)-1)} \frac{1}{4b^2} I_s S^2 \;, \tag{15}$$

$$S^2 = \frac{\int d^2\vec{\Delta}_1 d^2\vec{\Delta}_2 |T_M|^2}{\int d^2\vec{\Delta}_1 d^2\vec{\Delta}_2 |T_M^{unitar}|^2} \;, \tag{16}$$

where $d\hat{\sigma}^{J_z=0}/d\Phi_{gg\to M}$ is the ”hard” exclusive singlet gluon-gluon fusion cross-section and S^2 is the so called ”soft” survival probability. In this work the quantity $\hat{L}$ is called $g^{IP}g^{IP}$ luminocity.

3 Soft corrections to the exclusive process

We can extend our approach to the case of additional ”soft” radiation in the central rapidity region. This process is depicted in Fig. 2. First of all we have to calculate unintegrated gluon distribution inside a gluon. For this task we use the method similar to the one presented in [10] (convenient for Monte-Carlo simulation) or [11]. For simplicity we solve the modified evolution equation in pure gluodynamics

$$\frac{d\left[f_{g/g}(x,p_T^2)F_s(p_T^2,\mu^2)\right]}{d\ln\left(\frac{p_T^2}{\Lambda_{QCD}^2}\right)} = \frac{\alpha_s(p_T)}{2\pi}\int\limits_x^{1-\Delta} dz\; P_{gg}(z)f_{g/g}(\frac{x}{z},p_T^2)F_s(p_T^2,\mu^2) \tag{17}$$

with the condition $f_{g/g}(x,q_0^2)=\delta(1-x)$, $q_0=0.3$ GeV and obtain the unintegrated distribution [11]:

$$\hat{f}(x,p_T^2,\mu^2) = F_s(p_T^2,\mu^2)\frac{\alpha_s(p_T)}{2\pi}\int\limits_x^{1-\Delta} dz\; P_{gg}(z)f_{g/g}(\frac{x}{z},p_T^2) \tag{18}$$

After the loop integration and sum of all the contributions of "soft" gluonic radiation we get the integrated luminocity $\hat{L}^{SI}$, which is similar to the exclusive one with some replacements:

$$\hat{L}^{SI} = \frac{c_{gp}^4}{2^5\pi^6}\left(\frac{s}{M^2}\right)^{2(\alpha_P(0)-1)}\frac{1}{4b^2}I_s^{SI}S^2\;, \tag{19}$$

$$I_s^{SI} = \int\limits_0^{\mu^2}\frac{dl^2}{l^4}F_s^{SI}(l^2,\mu^2)\left(\frac{l^2}{s_0+l^2/2}\right)^{2\alpha_P(0)}\;, \tag{20}$$

$$F_s^{SI} = \left[\int\limits^{k_{T,max}^2}\frac{dk_t^2}{k_t^2}\int dx\; x^{2(\alpha_P(0)-1)}\hat{f}(x,k_t^2,\mu^2)\right]^2\;. \tag{21}$$

And the differential cross-sections can be expressed in terms of $\hat{L}^{SI}$:

$$\frac{d\sigma^{SI}}{dM^2\;dy\;d\Phi_{gg\to M}}|_{y=0} = \hat{L}^{SI}\frac{d\hat{\sigma}}{d\Phi_{gg\to M}}\;. \tag{22}$$

Here $d\hat{\sigma}/d\Phi_{gg\to M}$ is the inclusive singlet "hard" gluon-gluon fusion cross-section.

Exclusive and semi-inclusive luminocities are presented in the Fig. 4. Here we consider the radiation with the transverse momenta less than 7 GeV, and the ratio $M_{jj}/M_{jj+soft}>0.8$.

Now we can estimate the backgrounds for exclusive Higgs production. Rates for these processes at the integrated luminocity 100 fb^{-1} are summarized in the table 2 (parameter $c_{gp}=3.8$, i.e. we use more optimistic values). From this table we can obtain signal to background ratio ~ 1. More exact estimations will be made in the nearest future after Monte-carlo simulations.

Table 2: Rates for the exclusive Higgs production and different backgrounds at the integrated luminocity 100 fb^{-1} and $\Delta M_{missing}=4$ GeV. The probability to misidentify gluon jets with b-jets is taken to be 1%.

process	N events
$\sigma^{EDDE}\left(H\to bb\right)$	27
$\sigma^{SI}\left(H\to b\bar{b}\right)$	2
$\sigma^{EDDE}\left(b\bar{b}\right)$	12
$\sigma^{EDDE}\left(b\bar{b}g\right)$	1
$\sigma^{EDDE}\left(gg\right)\cdot 10^{-4}$	14
$\sigma^{EDDE}\left(ggg\right)\cdot 10^{-4}$	2

Aknowledgements

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