Vector meson production at HERA and at the LHC

László Jenkovszky[a]*, Diána Himics[b]†, and Henrietta Bán[c]‡

[a] *Bogolyubov Institute for Theoretical Physics, National Academy of Sciences of Ukraine, Kiev, 03680 Ukraine*

[b] *University of Pardubice, Czech Republic*

[c] *Uzhgorod National University, Ukraine*

Abstract

Exclusive diffractive vector meson production (VMP) in *ep* (HERA) and in ultra-peripheral *pp* collisions (LHC) is studied in a Regge pole model with a unique Pomeron comprising "soft" and "hard" dynamics.

1 Introduction

In this paper we study vector meson production (VMP) and deeply virtual Compton scattering (DVCS) in *ep* (HERA) as well as ultra-peripheral *pp* collisions (LHC) by means of a Regge pole model with a unique Pomeron combining "soft" and "hard" dynamics . The smooth transition from "soft" to "hard" dynamics is demonstrated. We assume that:

1. Regge factorization holds, *i.e.* the dependence on the virtuality of the external particle (photon) and the masses of the produced vector mesons enters only via the relevant vertex, not the propagator;

2. there is only one Pomeron in nature and it is the same in all reactions [1]. It may be complicated, e.g. containing many, at least two, components.

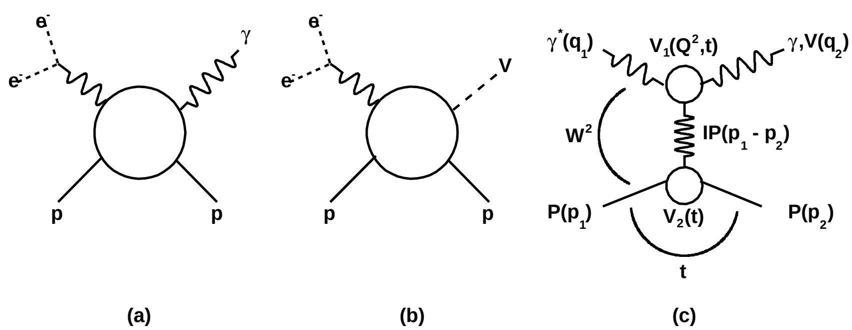

Figure 1: Diagrams of DVCS (a) and VMP (b); (c) DVCS (VMP) amplitude in a Regge-factorized form.

To reproduce the observed trend of hardening[1] as $\widetilde{Q^2}$ increas a two-term amplitude, characterized by a two-component - "soft" + "hard" - Pomeron, will be used. We stress that the Pomeron is unique, but we construct it as a sum of two terms. Then, the amplitude is defined as

$$A(\widetilde{Q^2}, s, t) = A_s(\widetilde{Q^2}, s, t) + A_h(\widetilde{Q^2}, s, t), \tag{1}$$

*e-mail: jenk@bitp.kiev.ua

†e-mail: himicsdia@hotmail.com

‡e-mail: banhenrietta@gmail.hu

[1] In what follows we use the variable $\widetilde{Q^2} = Q^2 + M_V^2$ as a measure of "hardness".

($s = W^2$ is the square of the c.m.s. energy), such that the relative weight of the two terms changes with $\widetilde{Q}^2$ in a right way, *i.e.* the ratio $r = A_h/A_s$ increases as the reaction becomes "harder" and v.v. It is interesting to note that this trend is not guaranteed "automatically": most of the related models show the opposite tendency, which may not be merely an accident and whose reason should be better understood. This "wrong" trend can and should be corrected, and in fact it was corrected [2] by means of additional $\widetilde{Q}^2$-dependent factors $H_i(\widetilde{Q}^2),\ i = s, h$ modifying the $\widetilde{Q}^2$ dependence of the amplitude in a such way as to provide increase of the weight of the hard component with increasing $\widetilde{Q}^2$. To avoid conflict with unitarity, the rise with $\widetilde{Q}^2$ of the hard component is finite (or moderate), and it terminates at some saturation scale, whose value is determined phenomenologically. In other words, the "hard" component, invisible at small $\widetilde{Q}^2$, gradually takes over as $\widetilde{Q}^2$ increases. An explicit example of these functions will be given below.

2 Single-component Reggeometric Pomeron

We start by reminding the properties and some representative results based on the single-term Reggeometric model [3].

The invariant scattering amplitude is defined as

$$A(Q^2, s, t) = \widetilde{H} e^{-\frac{i\pi\alpha(t)}{2}} \left(\frac{s}{s_0}\right)^{\alpha(t)} e^{2\left(\frac{a}{\widetilde{Q}^2}+\frac{b}{2m_N^2}\right)t}, \tag{2}$$

where

$$\alpha(t) = \alpha_0 + \alpha' t \tag{3}$$

is the linear Pomeron trajectory, s_0 is a scale for the square of the total energy s, a and b are two parameters to be determined with the fitting procedure and m_N is the nucleon mass. The coefficient $\widetilde{H}$ is a function providing the right behavior of elastic cross sections in $\widetilde{Q}^2$:

$$\widetilde{H} \equiv \widetilde{H}(\widetilde{Q}^2) = \frac{\widetilde{A_0}}{\left(1+\frac{\widetilde{Q}^2}{Q_0^2}\right)^{n_s}}, \tag{4}$$

where $\widetilde{A_0}$ is a normalization factor, Q_0^2 is the virtuality scale and n_s is a real positive number.

In this model we use an effective Pomeron, which can be "soft" or "hard", depending on the reaction and/or kinematical region defining its "hardness". In other words, the values of the parameters α_0 and α' must be fitted to each set of the data. Apart from α_0 and α', the model contains five more sets of free parameters, different in each reaction. The exponent in Eq. (2) reflects the geometrical nature of the model: $a/\widetilde{Q}^2$ and $b/2m_N^2$ correspond to the "sizes" of upper and lower vertices in Fig. 1c.

By using Eq. (4) with norm

$$\frac{d\sigma_{el}}{dt} = \frac{\pi}{s^2}|A(Q^2, s, t)|^2, \tag{5}$$

the differential and integrated elastic cross sections become

$$\frac{d\sigma_{el}}{dt} = \frac{A_0^2}{\left(1+\frac{\widetilde{Q}^2}{Q_0^2}\right)^{2n}} \left(\frac{s}{s_0}\right)^{2(\alpha(t)-1)} e^{4\left(\frac{a}{\widetilde{Q}^2}+\frac{b}{2m_N^2}\right)t} \tag{6}$$

and

$$\sigma_{el} = \frac{A_0^2}{\left(1+\frac{\widetilde{Q}^2}{Q_0^2}\right)^{2n}} \frac{\left(\frac{s}{s_0}\right)^{2(\alpha_0-1)}}{4\left(\frac{a}{\widetilde{Q}^2}+\frac{b}{2m_N^2}\right)+2\alpha' \ln\left(\frac{s}{s_0}\right)}, \tag{7}$$

where

$$A_0 = -\frac{\sqrt{\pi}}{s_0}\widetilde{A_0}.$$

The single-term model fails to fit both the high- and low-$|t|$ regions properly, especially when soft (photoproduction or low Q^2) and hard (electroproduction or high Q^2) regions are considered. One of the problems of the single-term Reggeometric Pomeron model, Eq. (2), is that the fitted parameters in this model acquire particular values for each reaction, which is one of the motivations for its extension to two terms (next Section).

The VMP results clearly show the hardening of Pomeron in the change of α_0 and α' when going from light to heavy vector mesons. In the ρ^0 case, a single exponent of the type Ae^{Bt} is not sufficient to reproduce the differential cross section above $|t| > 0.5$ in the electroproduction and especially in photoproduction. This is the reason why it is so difficult to describe ρ^0 production in the whole kinematic range within a single-term Pomeron model. These two phenomena ("hardening" of Pomeron trajectory and problems with ρ^0 production) motivate the introduction of a two-component Pomeron.

It is also interesting to note that the effective Pomeron trajectory for DVCS ($\alpha_0 = 1.23$, $\alpha' = 0.04$) is typically "hard", in contradiction with expectations that it should be "soft" at low-Q^2.

3 Two-component Reggeometric Pomeron

3.1 Amplitude with two, "soft" and "hard", components

Now we introduce the universal, "soft" and "hard", Pomeron model. Using the Reggeometric ansatz of Eq. (2), we write the amplitude as a sum of two parts, corresponding to the "soft" and "hard" components of a universal, unique Pomeron:

$$A(Q^2,s,t) = \widetilde{H_s}\, e^{-i\frac{\pi}{2}\alpha_s(t)}\left(\frac{s}{s_{0s}}\right)^{\alpha_s(t)} e^{2\left(\frac{a_s}{\widetilde{Q^2}}+\frac{b_s}{2m_N^2}\right)t} + \widetilde{H_h}\, e^{-i\frac{\pi}{2}\alpha_h(t)}\left(\frac{s}{s_{0h}}\right)^{\alpha_h(t)} e^{2\left(\frac{a_h}{\widetilde{Q^2}}+\frac{b_h}{2m_N^2}\right)t}. \quad (8)$$

Here s_{0s} and s_{0h} are squared energy scales, and a_i and b_i, with $i = s, h$, are parameters to be determined with the fitting procedure with

$$\widetilde{H_s} \equiv \widetilde{H_s}(\widetilde{Q^2}) = \frac{\widetilde{A_s}}{\left(1+\frac{\widetilde{Q^2}}{Q_s^2}\right)^{n_s}}, \qquad \widetilde{H_h} \equiv \widetilde{H_h}(\widetilde{Q^2}) = \frac{\widetilde{A_h}\left(\frac{\widetilde{Q^2}}{Q_h^2}\right)}{\left(1+\frac{\widetilde{Q^2}}{Q_h^2}\right)^{n_h+1}}, \quad (9)$$

where $\widetilde{A_s}$ and $\widetilde{A_h}$ are normalization factors, Q_s^2 and Q_h^2 are scales for the virtuality, n_s and n_h are real positive numbers. Each component of Eq. (8) has its own, "soft" or "hard", Regge (here Pomeron) trajectory:

$$\alpha_s(t) = \alpha_{0s} + \alpha'_s t, \qquad \alpha_h(t) = \alpha_{0h} + \alpha'_h t.$$

As input we use the parameters suggested by Donnachie and Landshoff [2],

$$\alpha_s(t) = 1.08 + 0.25t, \qquad \alpha_h(t) = 1.40 + 0.1t.$$

The "Pomeron" amplitude (8) is unique, valid for all diffractive reactions, its "softness" or "hardness" depending on the relative $\widetilde{Q^2}$-dependent weight of the two components, governed by the relevant factors $\widetilde{H_s}(\widetilde{Q^2})$ and $\widetilde{H_h}(\widetilde{Q^2})$.

In fitting Eq. (8) to the data, we have found that the parameters assume rather large errors and, in particular $a_{s,h}$ are close to 0. Thus, in order to reduce the number of free parameters, we simplified the model, by fixing $a_{s,h}=0$ and substituting the exponent $2\left(\frac{a_{s,h}}{\widetilde{Q^2}}+\frac{b_{s,h}}{2m_N^2}\right)$ with $b_{s,h}$ in Eq. (8). The proper variation with $\widetilde{Q^2}$ will be provided by the factors $\widetilde{H_s}(\widetilde{Q^2})$ and $\widetilde{H_h}(\widetilde{Q^2})$.

Consequently, the scattering amplitude assumes the form

$$A(s,t,Q^2,M_V^2)=\widetilde{H_s}\,e^{-i\frac{\pi}{2}\alpha_s(t)}\left(\frac{s}{s_{0s}}\right)^{\alpha_s(t)}e^{b_st}+\widetilde{H_h}\,e^{-i\frac{\pi}{2}\alpha_h(t)}\left(\frac{s}{s_{0h}}\right)^{\alpha_h(t)}e^{b_ht}. \tag{10}$$

The "Reggeometric" combination $2\left(\frac{a_{s,h}}{\widetilde{Q^2}}+\frac{b_{s,h}}{2m_N^2}\right)$ was important for the description of the slope $B(Q^2)$ within the single-term Pomeron model, but in the case of two terms the Q^2-dependence of B can be reproduced without this extra combination, since each term in the amplitude (10) has its own Q^2-dependent factor $\widetilde{H}_{s,h}(Q^2)$.

By using the amplitude (10) and Eq. (5), we calculate the differential and elastic cross sections by setting, for simplicity, $s_{0s}=s_{0h}=s_0$ to obtain

$$\frac{d\sigma_{el}}{dt}=H_s^2e^{2\{L(\alpha_s(t)-1)+b_st\}}+H_h^2e^{2\{L(\alpha_h(t)-1)+b_ht\}} \tag{11}$$

$$+2H_sH_he^{\{L(\alpha_s(t)-1)+L(\alpha_h(t)-1)+(b_s+b_h)t\}}\cos\left(\frac{\pi}{2}(\alpha_s(t)-\alpha_h(t))\right),$$

$$\sigma_{el}=\frac{H_s^2e^{2\{L(\alpha_{0s}-1)\}}}{2(\alpha_s'L+b_s)}+\frac{H_h^2e^{2\{L(\alpha_{0h}-1)\}}}{2(\alpha_h'L+b_h)}+2H_sH_he^{L(\alpha_{0s}-1)+L(\alpha_{0h}-1)}\frac{\mathfrak{B}\cos\phi_0+\mathfrak{L}\sin\phi_0}{\mathfrak{B}^2+\mathfrak{L}^2}. \tag{12}$$

In these two equations we use the notation

$$L=\ln(s/s_0)\,,\qquad \mathfrak{B}=L\alpha_s'+L\alpha_h'+(b_s+b_h),$$
$$\phi_0=\tfrac{\pi}{2}(\alpha_{0s}-\alpha_{0h}),\qquad \mathfrak{L}=\tfrac{\pi}{2}(\alpha_s'-\alpha_h'),$$

$$H_s(\widetilde{Q^2})=\frac{A_s}{\left(1+\frac{\widetilde{Q^2}}{Q_s^2}\right)^{n_s}},\qquad H_h(\widetilde{Q^2})=\frac{A_h\left(\frac{\widetilde{Q^2}}{Q_h^2}\right)}{\left(1+\frac{\widetilde{Q^2}}{Q_h^2}\right)^{n_h+1}},$$

with

$$A_{s,h}=-\frac{\sqrt{\pi}}{s_0}\widetilde{A}_{s,h}.$$

Finally, we notice that amplitude (10) can be rewritten in the form

$$A(s,t,Q^2,{M_v}^2)=\widetilde{A_s}e^{-i\frac{\pi}{2}\alpha_s(t)}\left(\frac{s}{s_0}\right)^{\alpha_s(t)}e^{b_st-n_s\ln\left(1+\frac{\widetilde{Q^2}}{Q_s^2}\right)}$$

$$+\widetilde{A_h}e^{-i\frac{\pi}{2}\alpha_h(t)}\left(\frac{s}{s_0}\right)^{\alpha_h(t)}e^{b_ht-(n_h+1)\ln\left(1+\frac{\widetilde{Q^2}}{Q_h^2}\right)+\ln\left(\frac{\widetilde{Q^2}}{Q_h^2}\right)}, \tag{13}$$

where the two exponential factors $e^{b_st-n_s\ln\left(1+\frac{\widetilde{Q^2}}{Q_s^2}\right)}$ and $e^{b_ht-(n_h+1)\ln\left(1+\frac{\widetilde{Q^2}}{Q_h^2}\right)+\ln\left(\frac{\widetilde{Q^2}}{Q_h^2}\right)}$ can be interpreted as the product of the form factors of upper and lower vertices.

Numerical fits to the data can be found in Refs. [3, 4].

4 Balancing between the "soft" and "hard" dynamics

Here we illustrate the important and delicate interplay between the "soft" and "hard" components of our unique Pomeron. Since the amplitude consists of two parts, according to the definition (1), it can be written as

$$A(Q^2,s,t) = A_s(Q^2,s,t) + A_h(Q^2,s,t). \tag{14}$$

Consequently, according to Eqs. (11) and (12), the differential and elastic cross sections contain also an interference term between "soft" and "hard" parts, so they read

$$\frac{d\sigma_{el}}{dt} = \frac{d\sigma_{s,el}}{dt} + \frac{d\sigma_{h,el}}{dt} + \frac{d\sigma_{interf,el}}{dt} \tag{15}$$

and

$$\sigma_{el} = \sigma_{s,el} + \sigma_{h,el} + \sigma_{interf,el}, \tag{16}$$

respectively.

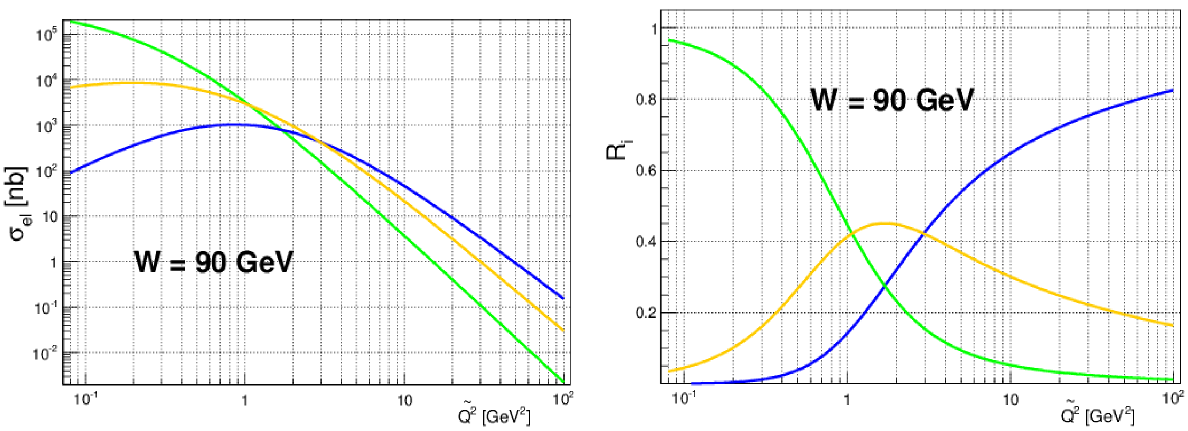

Figure 2: Interplay between soft (green line), hard (blue line) and interference (yellow line) components of the cross section $\sigma_{i,el}$ (left plot) and $R_i(\widetilde{Q^2},t)$ (right plot) as functions of $\widetilde{Q^2}$, for $W = 70$ GeV

By means of Eqs. (15) and (16) we can now define the following ratios:

$$R_i(\widetilde{Q^2},W,t) = \frac{\frac{d\sigma_{i,el}}{dt}}{\frac{d\sigma_{el}}{dt}} \tag{17}$$

and

$$R_i(\widetilde{Q^2},W) = \frac{\sigma_{i,el}}{\sigma_{el}}, \tag{18}$$

where i stands for $\{s, h, interf\}$.

Fig. 2 shows the interplay between the components for both $\sigma_{i,el}$ and $R_i(\widetilde{Q^2},t)$, as functions of $\widetilde{Q^2}$, for $W = 70$ GeV. Both plots show that not only $\widetilde{Q^2}$ is the parameter defining softness or hardness of the process, but such is also the combination of $\widetilde{Q^2}$ and t. On the whole, it can be seen from the plots that the soft component dominates in the region of low $\widetilde{Q^2}$ and t, while the hard compontent dominates in the region of high $\widetilde{Q^2}$ and t.

As expected, the "soft" term dominates at low values of $\tilde{Q}^2$", replaced by the soft one at high $\tilde{Q}^2$ (Fig 2, right panel). The contribution from the interference term is considerable, however it remains below the two (except for intermediate values of $\tilde{Q}^2$. The account for absorption corrections (shadowing, neglected in the present study) is expected to suppress the contribution from the interference term.

5 Hadron-induced reactions: high-energy pp scattering

Hadron-induced reactions differ from those induced by photons at least in two aspects. First, hadrons are on the mass shell and hence the relevant processes are typically "soft". Second, the mass of incoming hadrons is positive, while the virtual photon has negative squared "mass". Our attempt to include hadron-hadron scattering into the analysis with our model has the following motivations: a) by vector meson dominance (VMD) the photon behaves partly as a meson, therefore meson-baryon (and more generally, hadron-hadron) scattering has much in common with photon-induced reactions. Deviations from VMD may be accounted for by proper Q^2 dependence of the amplitude (as we do hope is in our case!); b) of interest is the connection between space- and time-like reactions; c) according to recent claims the highest-energy (LHC) proton-proton scattering data indicate the need for a "hard" component in the Pomeron (to anticipate, our fits do not support the need of any noticeable "hard" component in pp scattering).

Our aim here is not a high-quality fit to the pp data; that would be impossible without the inclusion of subleading contributions and/or the Odderon. Instead we normalized the parameters of our leading Pomeron term according to recent fits by Donnachie and Landshoff [2] including, apart from a soft term, also a hard one.

The pp scattering amplitude is written in the form similar to the amplitude (10) for VMP or DVCS, the only difference being that the normalization factor is constant since the pp scattering amplitude does not depend on Q^2:

$$A^{pp}(s,t) = A_s^{pp}\, e^{-i\frac{\pi}{2}\alpha_s(t)} \left(\frac{s}{s_0}\right)^{\alpha_s(t)} e^{b_s t} + A_h^{pp}\, e^{-i\frac{\pi}{2}\alpha_h(t)} \left(\frac{s}{s_0}\right)^{\alpha_h(t)} e^{b_h t}. \tag{19}$$

We fixed the parameters of Pomeron trajectories in accord with those of Refs. [2])

$$\alpha_s(t) = 1.084 + 0.35t, \qquad \alpha_h(t) = 1.30 + 0.10t.$$

With these trajectories the total cross section

$$\sigma_{tot} = \frac{4\pi}{s} Im\ A(s,t=0) \tag{20}$$

was found compatible with the LHC data. From the comparison of Eq. (20) to the LHC data we get

$$A_s^{pp} = -1.73\,\mathrm{mb}\cdot\mathrm{GeV}^2, \qquad A_h^{pp} = -0.0012\,\mathrm{mb}\cdot\mathrm{GeV}^2.$$

The parameter b_s was determined by fitting the differential and integrated elastic cross sections to the data.

Among the remaining open problems are:

- account for sub-leading Regge contributions, neglected in the present study. They must be included in any extension of the model to lower energies (below 30 GeV);
- the $\widetilde{Q^2}$ dependence of the scattering amplitude introduced in the present paper empirically has to be compared with the results of unitarization and/or QCD evolution;
- the "soft" component of the Pomeron dominates the region of small $|t|$ and small $\widetilde{Q^2}$. Hence, a parameter responsible for the "softness" and/or "hardness" of the processes should be a combination of t and Q^2.

6 VMP in pp at the LHC

The vector meson production (VMP) cross section can be written in a factorized form, see [5]. The distribution in rapidity Y of the production of a vector meson V in the reaction $h_1 + h_2 \to h_1 V h_2$, (where h may be a hadron, e.g. proton, or a nucleus, pPb, PbPb,...) is calculated according to a standard prescripion based on the factorization of the photon flux and photon-proton cross section (see below).

Generally speaking, the γp cross section depends on three variables: the total energy of the γp system, W, the squared momentum transfer at the proton vertex, t and virtuality $\tilde{Q}^2 = Q^2 + M_V^2$, where $Q^2 = -q^2$ is the photon virtuality. Since, by definition, in ultraperipheral, $b >> R_1 + R_2$ collisions, where b is the impact parameter, i.e. the closest distance between the centres of the colliding particles/nuclei and R is their radii, photons are nearly real, $Q^2 = 0$, and M_V^2 remains the only measure of "hardness" (NB: this might not be true for the peripheral $b \sim R_1 + R_2$ collisions and in Pomeron or Odderon exchange instead of the photon). Finally, the t-dependence (shape of the diffraction cone) is known to be exponential. It can be either integrated, or kept explicit. Extending this parametrization to include a $t-$dependent exponential is easy (see below). In any case, $\sigma_{\gamma p \to Vp}(\tilde{Q}^2, t, W)$, is well known from HERA.

We start with a simple parametrization of the $\sigma_{\gamma p \to Vp}(W)$ cross section, $\sigma_{\gamma p \to Vp}(W) = \int_{t_m}^{t_{thr}} \frac{d\sigma}{dt}$, suggested by Donnachie and Landshoff: $\sigma(W) \sim W^{\delta}$, $\delta \approx 0.8$.

The differential cross section as a function of rapidity reads:

$$\frac{d\sigma(h_1 + h_2 \to h_1 + V + h_2)}{dY} = \omega_+ \frac{dN_{\gamma/h_1}(\omega_+)}{d\omega} \sigma_{\gamma h_2 \to V h_2}(\omega_+) + \omega_- \frac{dN_{\gamma/h_2}(\omega_-)}{d\omega} \sigma_{\gamma h_1 \to V h_1}(\omega_-), \tag{21}$$

where $\frac{dN_{\gamma/h}(\omega)}{d\omega}$ is the "equivalent" photon flux [5] $\frac{dN_{\gamma/h}(\omega)}{d\omega} = \frac{\alpha_{em}}{2\pi\omega}[1 + (1 - \frac{2\omega}{\sqrt{s}})^2](\ln \Omega - \frac{11}{6} + \frac{3}{\Omega} - \frac{3}{2\Omega^2} + \frac{1}{3\Omega^3})$ and $\sigma_{\gamma p \to Vp}(\omega)$ is the total (integrated over t) cross section of the vector meson photoproduction subprocess (same as e.g. at HERA, see [3, 4]). Here ω is the photon energy, $\omega = W_{\gamma p}^2 / 2\sqrt{s}_{pp}$ with $\omega_{min} = M_V^2/(4\gamma_L m_p)$, where $\gamma_L = \sqrt{s}/(2m_p)$ is the Lorentz factor (Lorentz boost of a single beam), e.g., for pp at the LHC for $\sqrt{s} = 7$ TeV, $\gamma_L = 3731$. Furthermore, $\Omega = 1 + Q_0^2/Q_{min}^2$, $Q_{min}^2 = \omega/\gamma_L^2$, $Q_0^2 = 0.71 GeV^2$, $x = M_V e^{(-y)}/\sqrt{s}$, $Y \sim \ln(2\omega/m_V)$ is rapidity. The subscripts $\pm$ should be respected following Eq. (21). Furthermore we have: $\Omega = 1 + Q_0^2/Q_{min}^2$, where $Q_0^2 = 0.71$, $Q_{min}^2 = \omega/\gamma_L^2$, $\omega = m_V e^Y/2$, hence $\Omega_i = 1 + 0.71\gamma_L^2$, $\gamma_L^2 = 7/(2m_p) \approx 3.57$, $m_{V=J/\psi} = 3.1, \sqrt{s} = 7$, $\alpha_{em}/(2\pi) \approx 10^{-3}$, hence $Q_{min}^2 \approx 5.54e^Y$, $\Omega = 1 + 3.9e^{-Y}$. For definiteness we fix: a) the colliding particles are protons; b) the produced vector meson V is J/ψ, and c) the collision energy $\sqrt{s} = 7$ TeV. We comprise the constants in $A = \alpha_{em}/(2\pi)$, $c = Q_0^2\gamma_L^2$. (Notice that the shape of the distribution in Y is very sensitive to the value (and the sign) of the constant c!). The $i = \pm$ signs of ω correspond to the first or second term in Eq. (21), respectively, $\omega_\pm \sim e^{\pm Y}$.

7 Corrections for rapidity gap survival probabilities

The above results may be modified by initial and final state interactions, alternatively called rescattering corrections. The calculation of these corrections is by far not unambiguous, the result depending both on the input and on the unitarization procedure chosen. The better (more realistic) the input, the smaller the unitarity (rapidity gap survival probability) corrections. Since this is a complicated and controversial issue *per se* deserving special studies beyond the scope of the present paper, to be coherent with the "common trend", we use familiar results from the literature. The standard prescription is to multiply the scattering amplitude (cross section) by a factor (smaller than one), depending on energy and eventually other kinematic variables.

More details and fits to the data can be found in Ref. [5].

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