Unitarity corrections in the p_T distribution for the Drell-Yan process

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Abstract

In this contribution we investigate the Drell-Yan transverse momentum distribution considering the color dipole approach, taking into account unitarity aspects in the dipole cross section. The process is analyzed in the current energies on pp collisions ($\sqrt{s} = 62$ GeV) and at LHC energies ($\sqrt{s} = 8.8$ TeV). The unitarity corrections are implemented through the multiple scattering Glauber-Mueller approach.

1 Introduction

The high energies available in the hadronic reactions at RHIC (BNL Relativistic Heavy Ion Collider) and to be reached at LHC (CERN Large Ion Collider) will provide a better knowledge concerning the parton saturation and nuclear effect phenomena. In such a kinematical region the massive lepton pairs production in hadronic collisions (Drell-Yan process [1]) can be used to investigate the high parton density limit, since it is a clean reaction probing the quark distributions.

In the target rest frame, the Drell-Yan (DY) process looks like a bremsstrahlung of a virtual photon decaying into a lepton pair [2], rather than a parton annihilation as represented in the infinite momentum frame [1]. The bremsstrahlung of the virtual photon can occur after or before the interaction with the gluonic field of the target. The advantage of this formalism is that the corresponding cross section can be considered in terms of the same dipole cross section extracted from small-x Deep Inelastic Scattering (DIS) in the color dipole picture [3] although, diagrammatically no dipole is present. In this frame, the DY reaction gives a finite differential cross section for the lepton pair p_T distribution at small p_T, even in the leading order calculation, in contrast with the infinite momentum frame, where the perturbative calculations give a divergent behavior in the small p_T kinematical region.

The goal of this work is to investigate the DY dilepton transverse momentum distribution considering unitarity aspects into the dipole cross section, described by the multiple scattering Glauber-Mueller approach [4].

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2 Drell-Yan cross section in the color dipole approach

In the following we present the main formula concerning the DY dilepton production in the target rest frame and write them in terms of the color dipole degrees of freedom. The differential cross section in p_T for radiation of a virtual photon from a quark scattering on a proton, using the explicit expressions for the wave functions in the color dipole picture reads as [5],

$$\frac{d\sigma(qp\to q\gamma^* p)}{d\ln\alpha\, d^2p_T} = \frac{\alpha_{\rm em}}{\pi^2}\left\{[m_q^2\alpha^4+2M^2(1-\alpha)^2]\left[\frac{1}{p_T^2+\eta^2}R_1-\frac{1}{4\eta}R_2\right]\right. \\ \left. +\,[1+(1-\alpha)^2]\left[\frac{\eta p_T}{p_T^2+\eta^2}R_3-\frac{R_1}{2}+\frac{\eta}{4}R_2\right]\right\}, \quad (1)$$

where the functions R_i are taken from appendix A in the Ref. [5]. In these functions there is a dependence on the cross section for a color dipole-nucleon scattering, in which the unitarity effects are present. The hadronic differential cross section for the Drell-Yan process is expressed in a factorized form, embedding the partonic cross section, Eq. (1), into the hadronic environment, in the following way [2],

$$\frac{d\,\sigma^{DY}}{dM^2\,dx_F\,d^2p_T}=\frac{\alpha_{\rm em}}{6\,\pi M^2}\,\frac{1}{(x_1+x_2)}\int_{x_1}^{1}\frac{d\alpha}{\alpha}\,F_2\left(\frac{x_1}{\alpha},\,M^2\right)\frac{d\sigma(qp\to q\gamma^* p)}{d\ln\alpha\,d^2p_T}. \quad (2)$$

The factor $\alpha_{\rm em}/(6\,\pi M^2)$ is due to the photon decay into the lepton pair. The differential cross section $d\sigma/d\ln\alpha\, d^2p_T$ is defined in Eq. (1), where we have a dependence on the dipole cross section σ_{dip} in the functions R_i. In Eq. (2), the quark structure of the projectile is described by the $F_2(x,Q^2)$ structure function.

In the target rest frame the projectile quark carries momentum fraction $x = x_1/\alpha$ (which is larger than x_1), of the parent hadron, and correspondingly, x_1 is the momentum fraction of the proton carried by the photon. The variable x_2 is the momentum fraction of the proton carried by the gluon exchange in the t-channel. The dipole color picture is valid for small x_2 and it takes into account only the gluonic (sea quarks) sector from the target, disregarding its valence content. However, both valence and sea quarks in the projectile are parametrized in the proton structure function in Eq. (2). As x_2 increases, non-gluonic (valence) contributions to the process are not negligible and it should be included in the parameterization for the target interaction. In a Regge language, this contribution corresponds to a reggeon instead of a Pomeron exchange in the t-channel [6]. The $r_\perp$ dependence of the DY cross section is essential to characterize the perturbative and non-perturbative contributions to the process. It should be stressed that large dipole sizes correspond to the non-perturbative sector of the reactions, whereas small size configurations give the perturbative piece.

The cross section for a color dipole-nucleon scattering can be obtained considering the perturbative dynamics at high energy. However, there is a large uncertainty coming from non-perturbative aspects (infrared region) of the scattering and higher orders associated with a perturbative expansion (higher twists). A close connection with the DGLAP parton densities can be obtained in the double logarithmic approximation, which is the common limit to the referred perturbative evolutions. In that limit, the dipole cross section reads as,

$$\sigma_{dip}(x, r_\perp) = \frac{\pi^2\,\alpha_s}{3}\; r_\perp^2\, x\, G^{\rm DGLAP}(x, \tilde{Q}^2)\,, \tag{3}$$

where $xG^{\rm DGLAP}(x, \tilde{Q}^2)$ is the usual DGLAP gluon distribution at momentum fraction x and virtuality scale $\tilde{Q}^2 = r_0^2/r_\perp^2$. The scale r_0^2 appearing in the virtuality scale $\tilde{Q}^2 = r_0^2/r_\perp^2$, has been taken as $r_0^2 = 4$ from Ref. [6]. Concerning the non-perturbative contribution, our procedure is to freeze the dipole cross section in a suitable scale larger than $r_{\rm cut}^2$, which corresponds to the initial scale on the gluon density perturbative evolution $Q_0^2 = 4/r_{\rm cut}^2$.

At high energies, an additional requirement should be obeyed. The partons density (mostly gluons) growth has to be tamed, since an uncontrolled increasing would violate the Froissart-Martin bound. Then, the black disc limit of the target has to be reached at quite small Bjorken x. We implement this feature by using the multiple scattering Glauber-Mueller approach, which reduces the gluon distribution growth in an eikonal way in the impact parameter space [4]. Therefore, one substitutes $xG^{\rm DGLAP}$ in Eq. (3) by the corrected distribution taking unitarity effects. A more extensive derivation of the GM dipole cross section and the expression of $x\,G^{GM}$ can be seen in the Sec. III of the Ref. [6].

Our main goal here is to investigate the GM dipole cross section in the p_T distribution to the DY process. The dipole cross section Eq. (3) represents the asymptotic gluonic (Pomeron) contribution to the process and at large x (low energy) a non-asymptotic quark-like content should be included (regeeon), then, we have added to the dipole cross section, Eq. (3), a reggeon contribution which is parametrized in a simple way, $\sigma_{dip}^{I\!R} = \sigma_0\, r_\perp^2\, x\, q_{\rm val}\,(x, \tilde{Q}^2)\,,$ where we have obtained $\sigma_0 = 7$ in order to describe reasonably the E772 data on mass distribution and obtaining similar results to Ref. [6]. The quantity $q_{\rm val}$ is the valence quark distribution from the target.

3 Results and Conclusions

We calculate the p_T distribution to the DY process at LHC energies in *pp* collisions ($\sqrt{s} =$ 8.8 TeV). One evaluates the x_F-integrated dilepton transverse momentum distribution and compares the result with the available data on *pp* reactions at $\sqrt{s} = 62$ GeV and mass interval $5 \leq M \leq 8$ GeV [7]. The results are presented in Fig. 1. In the Fig. 1(a) the solid line is the GM distribution with unitarity effects, the dashed line is the result using GRV94 in the gluon distribution and the dot-dashed line represents the result using GRV98; the aim of this comparison is to verify in what extent an updated parameterization can absorb unitarity effects in the fitting procedure. It is verified that in the LHC energies, the unitarity effects

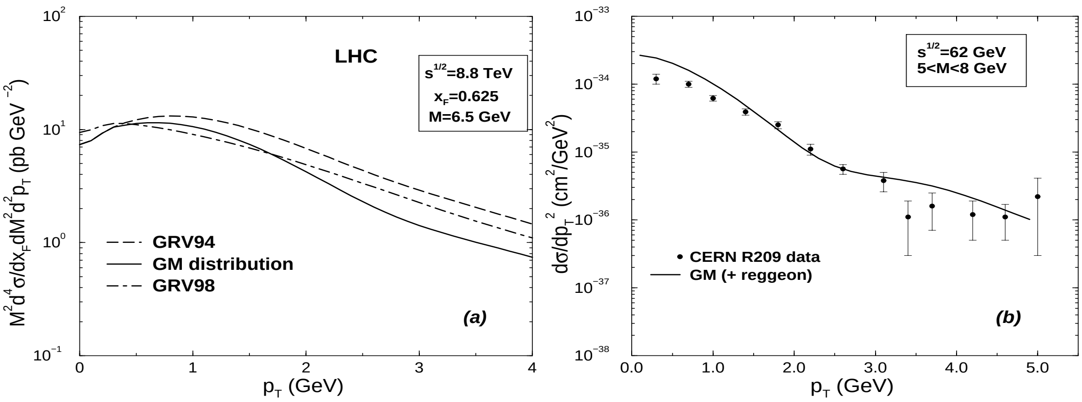

Figure 1: The Drell-Yan p_T distribution at LHC energies (a) and CERNR209 energies $\sqrt{s} = 62$ GeV (b).

could not be absorbed in the parameterization. In the Fig. 1(b) the solid curve denoting the Glauber-Mueller calculation, including the non-asymptotic valence content (GM + reggeon); The GM result is in good agreement with the overall normalization and behavior presented by data. A complete version of this work is in preparation in Ref. [8]

Acknowledgements

M.A.B and M.V.T.M. thank the organization of the event for the support.

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