Dilepton p_T Distribution Through the Color Glass Condensate

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Abstract. We investigate the dilepton production in proton-nucleus collisions at the forward rapidity region using the Color Glass Condensate approach. We focus our attention on the dilepton transverse momentum distribution (p_T), more precisely in the low p_T region where the saturation effects are expected to be increasingly large.

At high energies, the linear evolution equations, based in the standard perturbative QCD, predict a high gluon density. At such kinematical regime, the growth of the parton density has to be controlled - otherwise violation of the Froissart-Martin bound would occur - and expected to saturate at a scale Q_s, forming a Color Glass Condensate (CGC)[1]. In this context, the search for signatures of a CGC description of the saturated regime is an outstanding aspect of investigation in the heavy ion colliders. The first results of RHIC, on charged hadron multiplicity in $Au-Au$ collisions, were treated considering that a natural qualitative explanation of the data can be given in the CGC approach [2]. However, there are several issues to be clarified, before we claim that the dynamics of the partonic system should be described by a CGC already at RHIC energies. Meanwhile, the experimental results for charged multiplicity distribution in pseudo-rapidity for deuteron-gold collision is compatible with the CGC description at the deuteron fragmentation region, being a probable signature of the saturated regime [3].

In order to investigate the high energy limit of the partonic interactions, the dilepton production was shown to be a sensitive probe of the shadowing and saturation dynamics considering proton-proton, proton-nucleus and nucleus-nucleus scattering [4, 5, 6, 7] in specific kinematical regions. In this work quantitative features of the dilepton production in the forward region of proton-nucleus collisions, treating the gluon distribution in the nucleus as a color glass condensate are investigated. In particular, the transverse momentum (p_T) distribution is studied and attention is focused to the small p_T region, where the saturation effects are expected to be more important.

At high energies the dilepton production in hadronic collisions looks like a bremsstrahlung of a virtual photon decaying into a lepton pair. Such production process can be summarized by the process $q(\mathbf{k})+A \to q(\mathbf{q})\gamma(\mathbf{p})X$. Considering the diagrams that contribute to such process, the cross section for the dilepton production

CP739, *IX Hadron Physics and VII Relativistic Aspects of Nuclear Physics: A Joint Meeting on QCD and QGP*
edited by M. E. Bracco, M. Chiapparini, E. Ferreira, and T. Kodama

in the CGC approach can be written in the form [6],

$$\frac{d\sigma^{pA\to ql^+l^-X}}{dp_T^2\, dM\, dx_F} = \frac{2\pi}{M}\pi R^2 \frac{2\alpha_{em}^2}{3\pi}\frac{1}{x_1+x_2}\int\frac{dl_T}{(2\pi)^3} l_T W(p_T,l_T,x_1)C(l_T,x_2), \tag{1}$$

where, p_T and M^2 are the transverse momentum and the squared invariant mass of the lepton pair, respectively. R^2 is the nuclear ratio, x_F is the longitudinal momentum fraction given by $x_F = x_1 - x_2$, and x_1 and x_2 are the momentum fraction carried by the quark from the proton and by the gluonic field from the nucleus, respectively. The variables x_1 and x_2 are defined in the usual form $x_{\binom{1}{2}} = \sqrt{\frac{M^2+p_T^2}{s}}\, e^{\pm y}$, where y is the rapidity and s is the squared centre of mass energy. Here, using the structure function $F_2(x,Q^2) = \sum_i e_{q_i}^2 x[q_i(x,Q^2)+\bar{q}_i(x,Q^2)]$, the weight function $W(p_T,l_T,x_1)$ can be written in the form,

$$\begin{aligned} W(p_T,l_T,x_1) &= \int_{x_1}^{1} dz z F_2(x_1/z,M^2)\left\{\frac{(1+(1-z)^2)z^2 l_T^2}{[p_T^2+M^2(1-z)][(p_T-zl_T)^2+M^2(1-z)]}\right. \\ &- \left. z(1-z)M^2\left[\frac{1}{[p_T^2+M^2(1-z)]}-\frac{1}{[(p_T-zl_T)^2+M^2(1-z)]}\right]^2\right\}, \end{aligned} \tag{2}$$

where $l_T = q_T + p_T$ is the total transverse momentum transfer between the nucleus and the quark. The function $C(l_T)$ is the field correlator function. All the information about the nature of the medium crossed by the quark is contained in the function $C(l_T)$, in particular the dependence on the saturation scale (and on the energy). In the McLerran-Venugopalan model [1], one introduces an energy dependence in the correlator field and obtains the form,

$$C(l_T,x,A)_{MV_{mod}} = \int d^2x_\perp e^{il_T\cdot x_\perp} e^{-\frac{Q_s^2(x,A)}{\pi}\int\frac{dp}{p^3}\left(1-J_0(px_\perp)\right)}. \tag{3}$$

$Q_s^2(x,A) = A^{1/3}(\frac{x_0}{x})^\lambda$ where the parameters (x_0, λ) are taken from the GBW fit [8] and from the CGCfit [9]. The nuclear saturation scale is parametrized of the form $Q_{s,A}^2 = A^{1/3}Q_s^2$.

In our computations the CTEQ6L parametrization [10] was used for the structure function and the lepton pair mass gives the scale for the projectile quark distribution. The function $W(p_T,l_T,x_1)$ plays the role of a weight function, selecting the regions of l_T larger than p_T [11].

Having addressed all the quantities that determine the dilepton cross section, now one evaluates the numerical results on the transverse momentum distribution of the dilepton production in the Color Glass Condensate. We consider pA collisions at RHIC ($\sqrt{s}$ = 350GeV) and LHC energies ($\sqrt{s}$ = 8.8 TeV) in the proton fragmentation region (positive rapidities or x_F). The calculations are performed fixing values of rapidities $y = 2.2$ and lepton pair mass $M = 3$ GeV. We use the function $C(l_T,x_2)$ based on the McLerran-Venugopalan model, however introducing an x dependence through the saturation scale.

In Fig. 1 the transverse momentum distribution for RHIC and LHC in *pA* collisions is presented. The solid line is the calculation with the McLerran-Venugopalan model, with the x dependence on the saturation scale, taking the parameters from CGCfit with quark mass $m_q = 10$ MeV. The dashed-line is the same calculation with the saturation scale taken from the GBW parametrization. The dot-dashed line is the calculation considering the asymptotic behavior of the MV correlator function. For the transverse momentum distribution at fixed mass and rapidities, the effects of quantum evolution is not too relevant in the range of transverse momentum investigated here, once the parametrization of the saturation scale assures that such a scale is almost fixed, changing only weakly with p_T.

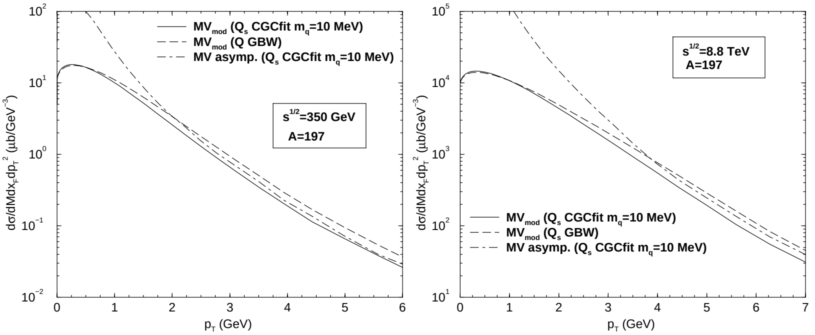

FIGURE 1. Dilepton production at RHIC and LHC energies in *pA* collisions, considering rapidity $y = 2.2$ and lepton pair mass $M = 3$ GeV.

In the Figure 1 the large saturation effects presented at $p_T < 2$ GeV and $p_T < 4$ GeV is verified if one compares the asymptotic behavior of the correlator function with the MV$_{mod}$ prediction at RHIC and LHC, respectively. The asymptotic behavior of the correlator function ($l_T >> Q_s$) depends on Q_s^2/l_T^4, allowing to verify that an increase of the saturation scale provides an increase in the differential cross section at large p_T. This is shown in the Fig. 1 where the GBW provides the largest saturation scale, while the CGCfit with $m_q = 10$ MeV a smallest one. The most interesting feature is that only at large p_T the effects of the choice of saturation scale affect the cross section.

This work was supported by CNPq, Brazil.

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