Unintegrated parton distributions 
and particle production in hadronic collisions

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November 9, 2018

Abstract

The inclusive distributions of gluons and pions for high-energy NN collisions are calculated. The results for several unintegrated gluon distributions (UGD’s) from the literature are compared. We find huge differences in both rapidity and $p_t$ of gluons and $\pi$’s in NN collisions for different models of UGD’s. The Karzeev-Levin UGD gives good description of momentum distribution of charged hadrons at midrapidities. We find, however, that the gluonic mechanism discussed does not describe the inclusive spectra of charged particles in the fragmentation region. Some of the missing mechanisms are calculated with the help of unintegrated parton distributions from the solution of the CCFM equation.

PACS: 12.38.Bx, 13.85.Hd, 13.85.Ni

1 Introduction

The recent results from RHIC (see e.g. [1]) have attracted renewed interest in better understanding the dynamics of particle production, not only in nuclear collisions. Quite different approaches have been used to describe the particle spectra from the nuclear collisions [2]. The model in Ref.[3] with an educated guess for UGD describes surprisingly well the whole charged particle rapidity distribution by means of gluonic mechanisms only. Such a gluonic mechanism would lead to the identical production of positively and negatively charged hadrons. The recent results of the BRAHMS experiment [4] put into question the successful description of Ref.[3]. In the light of this
experiment, it becomes obvious that the large rapidity regions have more complicated flavour structure.

I discuss the relation between UGD’s in hadrons and the inclusive momentum distribution of particles produced in hadronic collisions. The results obtained with different UGD’s [3, 5, 7, 8, 9] are shown and compared. I present first results obtained with unintegrated parton distributions from the solution of the so-called CCFM equation.

2 Inclusive gluon production

At sufficiently high energy the cross section for inclusive gluon production in \( h_1 + h_2 \rightarrow g \) can be written in terms of the UGD’s “in” both colliding hadrons [10]

\[
\frac{d\sigma}{dyd^2p_t} = \frac{16N_c}{N_c^2 - 1} \int \alpha_s(\Omega^2) F_1(x_1, \kappa_1^2) F_2(x_2, \kappa_2^2) \delta(\vec{\kappa}_1 + \vec{\kappa}_2 - \vec{p}_t) d^2\kappa_1 d^2\kappa_2.
\]

(1)

Above \( F_1 \) and \( F_2 \) are UGD’s in hadron \( h_1 \) and \( h_2 \), respectively. The longitudinal momentum fractions are fixed by kinematics: \( x_1/2 = p_t/\sqrt{s} \cdot \exp(\pm y) \). The argument of the running coupling constant is taken as \( \Omega^2 = \max(\kappa_1^2, \kappa_2^2, p_t^2) \).

Here I shall not discuss the distributions of “produced” gluons, which can be found in [11]. Instead I shall discuss what are typical values of \( x_1 \) and \( x_2 \) in the jet (particle) production. Average value \( < x_1 > \) and \( < x_2 > \), shown in Fig 1, only weakly depend on the model of UGD. For \( y \sim 0 \) at the RHIC energy \( W = 200 \text{ GeV} \) one tests UGD’s at \( x_g = 10^{-3} - 10^{-2} \). When \( |y| \) grows one tests more and more asymmetric (in \( x_1 \) and \( x_2 \)) configurations. For large \( |y| \) either \( x_1 \) is extremely small (\( x_1 < 10^{-4} \)) and \( x_2 \rightarrow 1 \) or \( x_1 \rightarrow 1 \) and \( x_2 \) is extremely small (\( x_2 < 10^{-4} \)). These are regions of gluon momentum fraction where the UGD’s is rather poorly known. The approximation used in obtaining UGD’s are valid certainly only for \( x < 0.1 \).

In order to extrapolate the gluon distribution to \( x_g \rightarrow 1 \) I multiply the gluon distributions from the previous section by a factor \( (1 - x_g)^n \), where \( n = 5-7 \).

3 From gluon to particle distributions

In Ref. [3] it was assumed, based on the concept of local parton-hadron duality, that the rapidity distribution of particles is identical to the rapidity distribution of gluons. In the present approach I follow a different approach which makes use of phenomenological fragmentation functions (FF’s). For our present exploratory study it seems sufficient to assume \( \theta_h = \theta_g \). This is equivalent to \( \eta_h = \eta_g = y_g \), where \( \eta_h \) and \( \eta_g \) are hadron and gluon pseudo-
rapidity, respectively. Then
\[ y_g = \text{arsinh} \left( \frac{m_{t,h} \sinh y_h}{p_{t,h}} \right), \]
where the transverse mass \( m_{t,h} = \sqrt{m_h^2 + p_{t,h}^2} \). In order to introduce phenomenological FF’s one has to define a new kinematical variable. In accord with \( e^+e^- \) and \( ep \) collisions I define a quantity \( z \) by the equation \( E_h = z E_g \). This leads to the relation
\[ p_{t,g} = \frac{p_{t,h}}{z} J(m_{t,h}, y_h), \]
where \( J(m_{t,h}, y_h) \) is given in Ref. [11]. Now we can write the single particle distribution in terms of the gluon distribution as follows
\[ \frac{d\sigma(\eta_h, p_{t,h})}{d\eta_h d^2p_{t,h}} = \int dy_g d^2p_{t,g} \int dz \: D_{g \rightarrow h}(z, \mu_F^2) \delta(y_g - \eta_h) \delta^2 \left( \frac{p_{t,h}}{z} - \frac{z p_{t,g}}{J} \right) \frac{d\sigma(y_g, p_{t,g})}{dy_g d^2p_{t,g}}. \]

In the present calculation I shall use only LO FF’s from [12] or [13].

Let us analyze now how the results for pseudorapidity distributions depend on the choice of the UGD. In Fig. 2 I compare pseudorapidity distribution of charged pions for different models of UGD’s. In this calculation FF from [12] has been used.
Figure 2: Charged-pion pseudorapidity distribution at $W = 200$ GeV for different models of UGD’s. In this calculation $p_{t,h} > 0.2$ GeV. The experimental data of the UA5 collaboration are taken from [14].

In contrast to Ref. [3], where the whole pseudorapidity distribution, including fragmentation regions, has been well described in an approach similar to the one presented here, in the present approach pions produced from the fragmentation of gluons in the $gg \rightarrow g$ mechanism populate only midrapidity region, leaving room for other mechanisms in the fragmentation regions. These mechanisms involve quark/antiquark degrees of freedom or leading protons among others. This strongly suggests that the agreement of the result of the $gg \rightarrow g$ approach with the PHOBOS distributions [2] in Ref. [3] in the true fragmentation region is rather due to approximations made in [3] than due to correctness of the reaction mechanism. In principle, this can be verified experimentally at RHIC by measuring the $\pi^+/\pi^-$ ratio in proton-proton scattering as a function of (pseudo)rapidity in possibly broad range. The BRAHMS experiment can do it even with the existing apparatus.

In Fig. 3 I compare the theoretical transverse momentum distributions of charged pions obtained with different gluon distributions with the UA1 collaboration data [15]. The best agreement is obtained with the Karzeev-Levin gluon distribution. The distribution with the GBW model is much too steep in comparison to experimental data. This is probably due to neglecting QCD evolution in [7].

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4 Unintegrated parton distributions from the solution of the CCFM equation

Many unintegrated gluon distributions in the literature are ad hoc parametrizations of different sets of experimental data rather than derived from QCD. Recently Jan Kwieciński and collaborators [16, 17] have shown how to solve so-called CCFM equations by introducing unintegrated parton distributions in the space conjugated to the transverse momenta [16]

\[
\tilde{f}_q(x, \kappa^2, \mu^2) = \frac{1}{2\pi} \int \exp(i\vec{\kappa}\vec{b}) \tilde{f}_q(x, b, \mu^2) d^2b .
\] (5)

The approach proposed is very convenient to introduce the nonperturbative effects like internal (nonperturbative) transverse momentum distributions of partons in nucleons. It seems reasonable to include the nonperturbative effects in the factorizable way

\[
\tilde{f}_q(x, b, \mu^2) = \tilde{f}_q^{CCFM}(x, b, \mu^2) \cdot F_{q_{np}}(b) .
\] (6)

In the following, for simplicity, I shall use a flavour and \(x\)-independent form factor

\[
F_{q_{np}}(b) = F_{np}(b) = \exp\left(\frac{b^2}{4b_0}\right)
\] (7)
which describes the nonperturbative effects. In Fig.4 I show the distribution in pseudorapidity of charged pions calculated with the help of the CCFM parton distributions [17] and the Gaussian form factor (7) with $b_0 = 0.5$ GeV$^{-1}$, adjusted to roughly describe the UA5 collaboration data. Now both gluon-gluon and (anti)quark-gluon and gluon-(anti)quark fusion processes can be included in one consistent framework. As anticipated the missing up to now terms are more important in the fragmentation region, although its contribution in the central rapidity region is not negligible. More details concerning the calculation will be presented elsewhere [18].

5 Conclusions

I have calculated the inclusive distributions of gluons and associated charged $\pi$’s in the NN collisions through the $gg \rightarrow g$ mechanism in the $k_t$-factorization approach. The results for several UGD’s proposed recently have been compared. The results, especially $p_{t,h}$ distributions, obtained with different models of UGD’s differ considerably.

Contrary to a recent claim in Ref. [3], I have found that the gluonic mech-
anism discussed does not describe the inclusive spectra of charged particles in the fragmentation region, i.e. in the region of large (pseudo)rapidities for any UGD from the literature. I think that at presently available energies the gluonic mechanism is not the only one. Some of the missing mechanisms have been estimated in the approach based on parton distributions originating from the solution of the CCFM equation. It was found that the dominant missing mechanisms are (anti)quark-gluon and gluon-(anti)quark fusion processes.

The existing UGD’s lead to the contributions which almost exhaust the strength at midrapidities and leave room for other mechanisms in the fragmentation regions. It seems that a measurement at RHIC of $p_t$ distributions of particles for different rapidities should be helpful to test unintegrated parton distributions.

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