UNINTEGRATED PARTON DISTRIBUTIONS AND PARTICLE PRODUCTION IN HADRONIC COLLISIONS*

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The inclusive distributions of gluons and pions for high-energy NN collisions are calculated. The results for several unintegrated gluon distributions (UGDs) from the literature are compared. We find huge differences in both rapidity and p_t of gluons and πs in NN collisions for different models of UGDs. 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.

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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

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of this experiment, it becomes obvious that the large rapidity regions have more complicated flavour structure.

I discuss the relation between UGDs in hadrons and the inclusive momentum distribution of particles produced in hadronic collisions. The results obtained with different UGDs [3, 5, 7–9] 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 UGDs "in" both colliding hadrons [10]

$$\frac{d\sigma}{dy d^2 p_t} = \frac{16 N_c}{N_c^2 - 1} \frac{1}{p_t^2} \int \alpha_s(\Omega^2) \mathcal{F}_1(x_1, \kappa_1^2) \mathcal{F}_2(x_2, \kappa_2^2) \delta(\vec{\kappa}_1 + \vec{\kappa}_2 - \vec{p}_t) \, d^2\kappa_1 d^2\kappa_2 \, .$$
(1)

Above $\mathcal{F}_1$ and $\mathcal{F}_2$ are UGDs in hadron h_1 and h_2, respectively. The longitudinal momentum fractions are fixed by kinematics: $x_{1/2} = \frac{p_t}{\sqrt{s}} \exp(\pm y)$. 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 $\langle x_1 \rangle$ and $\langle x_2 \rangle$, shown in Fig. 1, only weakly depend on the model of UGD. For $y \sim 0$ at the RHIC energy $W = 200$ GeV one tests UGDs 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
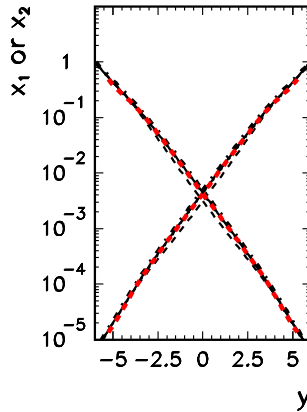

Fig. 1. $\langle x_1 \rangle$ and $\langle x_2 \rangle$ for $p_t > 0.5$ GeV and at $W = 200$ GeV.

x_2 is extremely small ($x_2 < 10^{-4}$). These are regions of gluon momentum fraction where the UGDs is rather poorly known. The approximation used in obtaining UGDs are valid certainly only for $x < 0.1$. In order to extrapolate the gluon distribution to $x_g \to 1$ 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 (FFs). 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 η_h and η_g are hadron and gluon pseudorapidity, respectively. Then

$$y_g = \operatorname{arsinh}\left(\frac{m_{t,h}}{p_{t,h}} \sinh y_h\right), \tag{2}$$

where the transverse mass $m_{t,h} = \sqrt{m_h^2 + p_{t,h}^2}$. In order to introduce phenomenological FFs one has to define a new kinematical variable. In accord with e^+e^- and ep collisions I define a quantity z by the equation $E_h = zE_g$. This leads to the relation

$$p_{t,g} = \frac{p_{t,h}}{z} J(m_{t,h}, y_h), \tag{3}$$

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

$$\begin{aligned}
\frac{d\sigma(\eta_h, p_{t,h})}{d\eta_h d^2 p_{t,h}} &= \int dy_g d^2 p_{t,g} \int dz D_{g \to h}(z, \mu_D^2) \\
&\times \delta(y_g - \eta_h)\delta^2\left(\vec{p}_{t,h} - \frac{z\vec{p}_{t,g}}{J}\right) \frac{d\sigma(y_g, p_{t,g})}{dy_g d^2 p_{t,g}}.
\end{aligned} \tag{4}$$

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

Let us analyse 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 UGDs. In this calculation FF from [12] has been used.

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
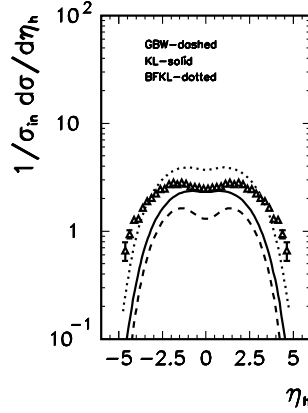
Fig. 2. Charged-pion pseudrapidity distribution at $W = 200$ GeV for different models of UGDs. In this calculation $p_{t,h} > 0.2$ GeV. The experimental data of the UA5 collaboration are taken from [14].

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 π^+/π^- 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.
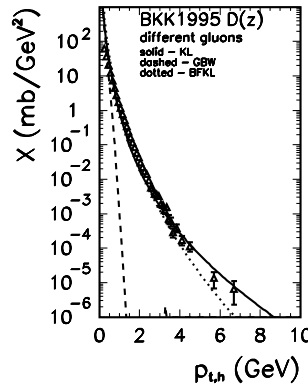

Fig. 3. Transverse momentum distributions of charged pions at $W = 200$ GeV for BKK1995 FF and different UGDs. The experimental data are taken from [15].

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].

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 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]

$$f_q(x, \kappa^2, \mu^2) = \frac{1}{2\pi} \int \exp\left(i\vec{\kappa}\vec{b}\right) \tilde{f}_q(x, b, \mu^2) d^2 b \,. \tag{5}$$

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

$$\tilde{f}_q(x, b, \mu^2) = \tilde{f}_q^{\mathrm{CCFM}}(x, b, \mu^2) F_q^{np}(b) \,. \tag{6}$$

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

$$F_q^{np}(b) = F^{np}(b) = \exp\left(\frac{b^2}{4b_0^2}\right) \tag{7}$$

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].
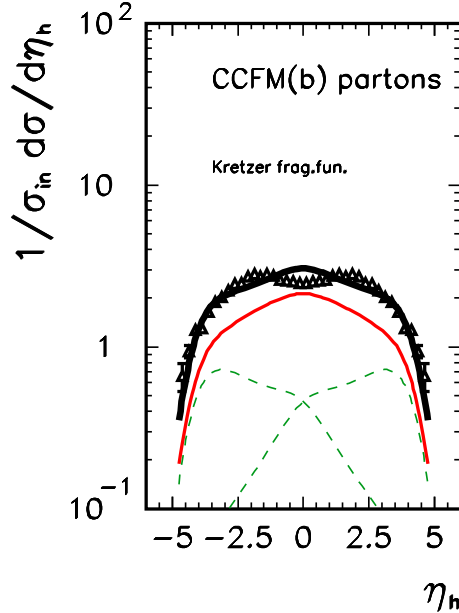
Fig. 4. Pseudorapidity distribution of charged pions at $W = 200$ GeV calculated with the CCFM parton distributions. The experimental data are taken from [15]. The thin solid line is the gluon–gluon contribution while the dashed lines represent the gluon–(anti)quark and (anti)quark–gluon contributions. In this calculation gluon, (anti)quark fragmentation functions from [13] have been used.

5. Conclusions

I have calculated the inclusive distributions of gluons and associated charged πs in the NN collisions through the $gg \to g$ mechanism in the k_t-factorisation approach. The results for several UGDs proposed recently have been compared. The results, especially $p_{t,h}$ distributions, obtained with different models of UGDs differ considerably.

Contrary to a recent claim in Ref. [3], I have found that the gluonic mechanism 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 UGDs 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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