Inclusive cross section for pion production in proton - proton collisions are calculated based on unintegrated parton distribution functions (uPDFs). In addition to purely gluonic terms the present approach includes also quark degrees of freedom. Phenomenological fragmentation functions from the literature are used. The new mechanisms are responsible for $\pi^+ - \pi^-$ asymmetry. In contrast to standard collinear approach, application of $2 \rightarrow 1 k_T$ factorization approach can be extended towards much lower transverse momenta, both at mid and forward rapidity region. The results of the calculation are compared with SPS and RHIC data.

Keywords: unintegrated parton distributions; fragmentation functions; inclusive cross section.

PACS numbers: 11.25.Hf, 123.1K

1. Introduction

The distributions of mesons at large transverse momenta in $pp$ or $p\bar{p}$ collisions are usually calculated in the framework of perturbative QCD using collinear factorization (see e.g. [123]). While the shape at transverse momenta larger than 2-4 GeV can be relatively well explained, there are discrepancies at lower transverse momenta. In this analysis, the calculations are performed using a new approach, based on the unintegrated parton distributions. In recent years only gluon degrees of freedom are taken explicitly in this context [12]. In the present analysis, in addition to the $gg \rightarrow g$ mechanism, We include also $qf \rightarrow qf$ and $gqf \rightarrow qf$ mechanisms and similar ones for antiquarks, in order to obtain a fully consistent description.
The new contributions $q_f g \rightarrow q_f$ and $g q_f \rightarrow q_f$ are comparable to the contribution of the $g g \rightarrow g$ diagram at midrapidities and are dominant in the fragmentation region. The new mechanisms are responsible for $\pi^+ - \pi^-$ asymmetry. A purely gluonic mechanism would lead to identical production of positively and negatively charged hadrons. The recent results of the BRAHMS experiment [11] show that the $\pi^-/\pi^+$ and $K^-/K^+$ ratios differ from unity. This put into question the successful description of Ref. [9]. In the light of this experiment, it becomes obvious that the large rapidity regions have more complicated flavour structure. At lower energies these ratios are known to differ from unity drastically [20]. 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 [13, 14, 15] have shown how to solve the so-called CCFM equations by introducing unintegrated parton distributions in the space conjugated to the transverse momenta [13]. We present results for pion and kaon production based on the unintegrated parton (gluon, quark, antiquark) distributions.

2. Inclusive cross section for partons

The formulae for inclusive quark/antiquark distributions are similar to the formula for $g g \rightarrow g$ [12]

$$\frac{d\sigma^A}{dy d^2 p_t} = \frac{16 N_c}{N_c^2 - 1} \frac{1}{p_t^2} \int \alpha_s(\Omega^2) f_{g/1}(x_1, \kappa_1^2, \mu^2) f_{g/2}(x_2, \kappa_2^2, \mu^2)$$

$$\delta^2(\vec{\kappa}_1 + \vec{\kappa}_2 - \vec{p}_t) d^2\kappa_1 d^2\kappa_2,$$

(1)

These seemingly 4-dimensional integrals can be written as 2-dimensional integrals after a suitable change of variables [10]. The formulae can be written in the equivalent way in terms of the parton distributions in the space conjugated to the transverse momentum [21].

3. Inclusive cross section for hadrons

There are a few sets of fragmentation functions available in the literature, details were described e.g. in [16, 17, 22]. The inclusive distributions of hadrons (pions, kaons, etc.) can be obtained through a convolution of inclusive distributions of partons and flavour-dependent fragmentation functions. One dimensional distributions of hadrons can be obtained through the integration over the other variable (see [21]).

4. Results

In Fig. [11] we compare the model invariant cross sections for $pp \rightarrow \pi^+$ (left panel) and $pp \rightarrow \pi^-$ (middle panel) as a function of pion transverse momentum at $W =$
27.4 GeV for different values of the parameter $b_0$ of our Gaussian nonperturbative form factor (for explanation see [21]) with the experimental data from Ref. 19, 20. In principle, the result should not exceed experimental data especially in the perturbative regime of $p_t > 2$ GeV where the perturbative $2 \rightarrow 2$ parton subprocesses are crucial. This limits the value of the nonperturbative form factor to $b_0 > 0.5$ GeV$^{-1}$. 

Inclusion of diagrams $B_1 (q_f g \rightarrow q_f)$ and $B_2 (g q_f \rightarrow q_f)$ (see 21) in conjunction with the flavour dependent fragmentation functions leads to the $\pi^+ - \pi^-$ asymmetry. In the right panel of Fig. 1 we show the asymmetry as the function of pion transverse momentum. The asymmetry is well described by this model, in contrast to individual distributions. This seems to suggest the right relative contributions of diagram $A (gg \rightarrow g), B_1$ and $B_2$. The asymmetry depends only weakly on the value of the parameter $b_0$ of the Gaussian nonperturbative form factor.

The PHENIX collaboration has measured invariant cross section as a function of the $\pi^0$ transverse momentum at $W = 200$ GeV in a very narrow interval of pseudorapidity $\eta = 0.0 \pm 0.15$. In Fig. 2 we show full result (diagrams $A$, $B_1$ and $B_2$ [21,22]) for different fragmentation functions [16,17,22].

In Fig. 3 we present dependence of the invariant cross section for kaon production, calculated for $W = 27.4$ GeV, on the value of the parameter $b_0$ of the Gaussian nonperturbative form factor. The data for $p_t > 0.5$ GeV are well described by the $k_t$-factorisation approach with the Kwieciński UPDFs for the parameter $b_0 = 0.5$ GeV$^{-1}$. This is the same value of the parameter as that obtained for pions in the same energy range (see Fig. 1). More examples can be found in 24 and 25.

5. Conclusions

The formalism based on uPDFs, which fulfill so-called Kwieciński evolution equations, provides a reasonable description of the experimental data, including SPS as...
Fig. 2. Invariant cross section for $\pi^0$ production as a function of pion transverse momentum at $W = 200$ GeV and $\eta = 0.0$. The $k_t$-factorization results are shown for different sets of fragmentation functions. The experimental data of the PHENIX collaboration are from \[23\].

well as recent data of the PHENIX, BRAHMS and STAR collaborations. A good agreement with experimental data is obtained, especially at relatively small transverse momenta and large values of pseudorapidity. The mechanisms, which involve quark/antiquark degrees of freedom are significant and lead to an asymmetry in the production of $\pi^+$ and $\pi^-$ mesons.

**Acknowledgments**

This work was supported by the Polish State Committee for Scientific Research under grant no. 1 P03B 097 29.
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