Role of Gluons in Soft pp Collisions at LHC

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1 Introduction

As is well known, hard processes involving incoming protons, such as deep-inelastic lepton-proton scattering (DIS), are described using the scale-dependent parton distribution functions (PDFs). A distribution like this is usually calculated as a function of the Bjorken variable x and the square of the four-momentum transfer $q^2 = -Q^2$, integrated over the parton transverse momentum k_t. However, for semi-inclusive processes, such as inclusive jet production in DIS, electroweak boson production, etc., the parton distributions unintegrated over the transverse momentum k_t are more appropriate. The theoretical review on the unintegrated quark and gluon PDFs can be found, for example, in [1]. The gluon distribution function $g(k_t)$ at fixed Q^2 has the very interesting behaviour at small $x \leq 0.01$, it increases very fast starting from almost zero values of k_t and decreases when k_t grows. In contrast, the quark distribution $q(k_t)$ is almost constant in the whole region of k_t. In this paper we analyze the inclusive spectra of the hadrons produced in pp collisions at LHC energies in the mid-rapidity region including the possible creation of soft gluons in the proton. We estimate the unintegrated gluon distribution function (UGDF) at low intrinsic transverse momenta $k_t \leq 1.5 - 1.6$ GeV/c and extract its parameters from the best description of the LHC data at low transverse momenta p_t of the produced hadrons. We also show that our UGDF is similar to the UGDF obtained in [2, 3] at large values of k_t.

2 Inclusive spectra of hadrons in pp collisions

Let us analyze the hadron production in pp collisions within the QGSM [4] including the transverse motion of quarks and diquarks in colliding protons, see, for example, [5]. The general form for the invariant inclusive hadron spectrum within the QGSM is the following [4]:

$$\rho(x, p_t) \equiv E\frac{d\sigma}{d^3\mathbf{p}} = \sum_{n=1}^{\infty} \sigma_n(s)\phi_n(x, p_t) \ , \tag{1}$$

where $E, \mathbf{p}$ are the energy and three-momentum of the produced hadron h in the l.s. of colliding protons respectively; x, p_t are the Feynman variable and the transverse momentum of h; σ_n is the cross section for production of the n-pomeron chain (or $2n$ quark-antiquark strings) decaying into hadrons, calculated within the "eikonal approximation" [6], $\phi_n(x, p_t)$ is the parton interaction function that is the convolution integral of the PDF and the fragmentation function, see the details, for example, in [5]

According to the Abramovskiy-Gribov-Kancheli cutting rules (AGK) [7], at mid-rapidity only Mueller-Kancheli type diagrams contribute to the inclusive spectrum of hadrons. The sea quarks contribute to the inclusive spectrum at $n \geq 2$ [4, 5]. Assuming possible creation of soft gluons in the proton, which are split into $q\bar{q}$ pairs and should vanish at the zero intrinsic transverse momentum ($k_t \sim 0$), one can describe the inclusive spectrum at $x \simeq 0$ and low transverse momenta of produced hadrons rather satisfactorily [8].

3 Gluon distribution function within GBW model

The conventional QGSM does not include the distribution of gluons in the proton. However, as is well known, at large transverse momenta p_t of hadrons the gluons in the proton play very important role in description of the experimental data. Therefore, one can assume that the contribution of the gluon distribution in the proton to the inclusive spectrum of the produced hadrons slowly appears when p_t increases and it will be sizable at high values of p_t. This assumption is also confirmed by the increase of the UGDF in the proton at $x \sim 0$ as a function of the internal transverse momentum k_t when k_t grows [2, 3].

According to Refs.[2, 3], the UGDF, as a function of k_t at some value of Q_0 and low x is presented in the following form:

$$xg(x, k_t, Q_0) = C_0 R_0^2(x) k_t^2 \exp\left(-R_0^2(x) k_t^2\right) , \tag{2}$$

where $C_0 = 3\sigma_0/\left(4\pi^2\alpha_s(Q_0)\right)$, $R_0(x) = \mathrm{GeV}^{-1}(x/x_0)^{\lambda/2}$, x_0, λ and σ_0 are defined in [2, 3]; $\alpha_s(Q_0)$ is the QCD coupling constant. To get the UGDF at low k_t we assume the possible creation of the soft gluons in the proton which appears at nonzero k_t. We calculated the gluon contribution as the cut graph of the one-pomeron exchange in the gluon-gluon interaction (Fig.1, right) using the splitting of the gluons into the $q\bar{q}$ pair. Then the calculation was made in a way similar to the calculation of the sea quark contribution to the inclusive spectrum within the QGSM at $n = 2$. Calculating the diagram of Fig.1 (right) we assumed the following form for the $xg(x, k_t, Q_0)$:

$$xg(x, k_t, Q_0) = C_0 C_3 (1-x)^{b_g} \times \\ \left(R_0^2(x) k_t^2 + C_2 (R_0(x) k_t)^a\right) \exp\left(-R_0(x) k_t - d(R_0(x) k_t)^3\right) , \tag{3}$$

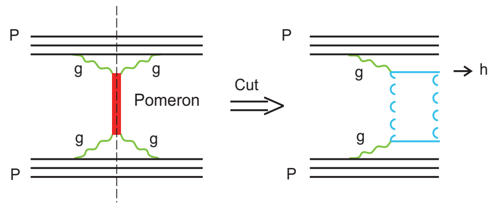

Figure 1: The one-pomeron exchange graph between two gluons in the elastic pp scattering (left) and the corresponding cut graph (right).

$C_3 = 0.3295$; $a = 0.7$; $C_2 = 2.3$; $\lambda = 0.22$; $b_g = 1$; $d = 0.2$; $R_0 = (x/x_0)^{\lambda/2}$; $x_0 = 4{\cdot}10^{-4}$

where C_2, a, b_g and λ are the parameters which we found from the best description of data. The coefficient C_1 is found from the normalization to $xg(x)$ after integrating $xg(x, k_t, Q_0)$ over d^2k_t [8].

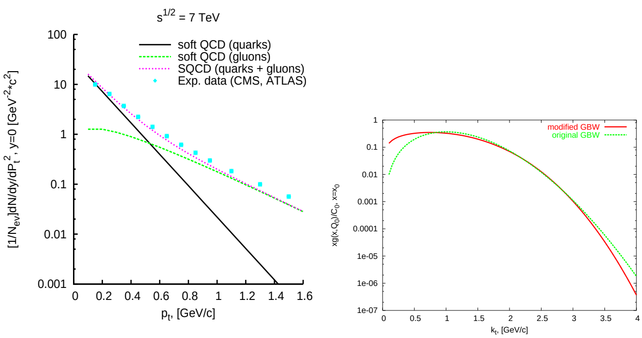

Figure 2: The inclusive spectrum of charged hadrons as a function of p_t (GeV/c) in the central rapidity region ($y = 0$) at $\sqrt{s}$ =7 TeV and $p_t \leq 1.6$ GeV/c compared with the CMS (ATLAS) data (left), the solid line is the quark contribution, the dashed line is the contribution of the soft gluons, the dotted line is the sum of these contributions. The unintegrated gluon distribution $xg(x, k_t, Q_0)/C_0$ as a function of k_t at $x = x_0$ (right).

4 Conclusion

We assume that the contribution of the gluon distribution in the proton to the inclusive spectrum of the produced hadrons slowly appears when p_t increases and it will be sizable at high values of p_t. This assumption is also confirmed by the increase of the unintegrated gluon distribution in the proton at $x \sim 0$ as a function of the internal transverse momentum k_t when k_t grows [1]

Therefore, to illustrate this hypothesis we fit the experimental data on the inclusive spectra of charged particles produced in the central pp collisions at energies larger than the ISR starting by the sum of the quark contribution and the gluon contribution [8]. The parameters of this fit do not depend on the initial energy in that energy interval. From the best fit of the LHC data on the inclusive spectra of the charged hadrons produced in the mid-rapidity pp collisions at low p_t we found a new parametrization of the unintegrated gluon distribution in the proton at small values of the intrinsic momentum k_t. This is similar to the UGDF obtained in [2, 3] at large k_t using the saturation effect for the gluon density. Therefore, our satisfactory description of the LHC data on the inclusive spectra in pp collisions at the mid-rapidity and low p_t confirms the saturation effect in QCD.

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