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Refined TMD gluon density in a proton from the HERA and LHC data

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It is well known that parton distribution functions in a proton (PDFs), $f_a(x,\mu^2)$ with $a = q$ or g, are an essential ingredient of any description of hard scattering at modern colliders energies. If only one scale is present in the process, $\mu \sim \sqrt{s} \gg \Lambda_{\rm QCD}$, then the PDFs can be described in Quantum Chromodynamics (QCD) via the Dokshitzer–Gribov–Lipatov–Altarelli–Parisi (DGLAP) equations [1–4]. However, in case of a two-scale process, $\sqrt{s} \gg \mu \gg \Lambda_{\rm QCD}$, the gluon dynamics can be described by the Balitsky–Fadin–Kuraev–Lipatov (BFKL) [5–7] or Catani–Ciafaloni–Fiorani–Marchesini (CCFM) [8–11] equations. It leads to Transverse Momentum Dependent (TMD, or unintegrated) gluon densities in a proton and k_T-factorization [12–15] approach. The TMD gluon densities can be calculated within some approaches, such as popular Kimber–Martin–Ryskin formalism [16–18], Parton Branching approach [19, 20] or obtained from the analytical or numerical solutions of BFKL-like QCD evolution equations. There are also investigations within the non-linear evolution in QCD. The CCFM equation, which resumes large logarithmic terms proportional to $\alpha_s^n \ln^n 1/x$ and $\alpha_s^n \ln^n 1/(1-x)$ and therefore valid at both low and large x, has been applied [21, 22]. In our previous study [22] a more physically motivated expression for the input distribution (LLM gluon) was chosen:

$$f_g(x,\mathbf{k}_T^2) = \qquad (1)$$
$$= c_g(1-x)^{b_g} \sum_{n=1}^{3} c_n \left[R_0(x)|\mathbf{k}_T|\right]^n \exp\left(-R_0(x)|\mathbf{k}_T|\right),$$

where $R_0^2(x) = (x/x_0)^\lambda/Q_0^2$, $b_g = b_g(0) + (4C_A/\beta_0)\ln\left[\alpha_s(Q_0^2)/\alpha_s(\mathbf{k}_T^2)\right]$, $C_A = N_C$, $\beta_0 = 11 - 2N_f/3$ and $Q_0 = 2.2\,\mathrm{GeV}$. Here b_g parameter is treated to be running at $\mathbf{k}_T^2 > Q_0^2$ only, whereas the fixed value $b_g = b_g(0)$ at $\mathbf{k}_T^2 \le Q_0^2$ is used. This expression is based on the description of the LHC data on soft hadron transverse momenta spectra in the framework of the modified soft quark gluon string model [23, 24] with taking into account gluon saturation effects important at small x and scales of about the order of saturation scale Q_s. Very recently it was shown [25] that some phenomenological parameters of the starting gluon density (1) need to be corrected in order to provide a good description of the low Q^2 data on proton structure function $F_2(x,Q^2)$ and reduced deep inelastic cross sections taken by H1 and ZEUS Collaborations. Simultaneous best fit to these HERA and LHC data on charged hadron production at small transverse momenta p_T in the mid-rapidity region leads to $c_1 = 5$, $c_2 = 3$, $c_3 = 2$, $x_0 = 1.3 \cdot 10^{-11}$ and $\lambda = 0.22$ [25]. Of course, other essential parameters, which cannot be determined from these data, have to be fitted from other measurements with taking into account the effects connected with the QCD evolution of gluon density. In the present Letter we continue the determination of phonemenological parameters (namely, $b_g(0)$ and c_g) with taking into account the effects of QCD evolution. Our procedure was based on a fit to a number of LHC and HERA data for processes sensitive to the gluon content of a proton at scale $\mu > Q_s$. The resulting fit quality ($\chi^2/d.o.f. = 1.773$) shows that the obtained gluon density does not contradict experimental data. We illustrate it additionally with latest HERA data on inclusive prompt photon photoproduction. Our results together with the ones [25] represent a self-consistent approach for the TMD gluon density in a proton valid in a wide kinematical region. The updated LLM gluon density supersedes previous version and can be used in different phenomenological applications for pp, $p\bar{p}$ and ep processes at modern and future colliders. It is available now in the TMDLIB library and Monte-Carlo event generator PEGASUS [26].

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