HEAVY QUARK PRODUCTION AND NON-LINEAR GLUON EVOLUTION AT THE LHC *

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We investigate the importance of unitarity corrections to parton evolution in heavy flavor production at the LHC. The gluon distribution is determined with a fit to HERA data applying a unified BFKL-DGLAP approach, in which the non-linear evolution is described by the Balitsky-Kovchegov equation. First we estimate $b\bar{b}$ production at CDF and D0. Then, cross sections for heavy quark production at various LHC experiments are estimated, tracing the impact of the unitarity corrections.

1. Non-linear gluon evolution

HERA measurements found a steep power-like growth of the gluon density with decreasing x which would lead to a violation of unitarity at very small x values. Recently, a successful description of unitarity corrections to DIS was derived within the color dipole formulation of QCD. This is the Balitsky-Kovchegov (BK) equation [1,2] which describes the BFKL evolution of the gluon in a large target, including a non-linear term corresponding to gluon recombination at high density.

In our analysis, we determine the unintegrated gluon distribution from the BK equation unified with the DGLAP equation following KMS (Kwieciński, Martin and Staśto) [3,4,5,6]. We use the abbreviation KKMS (Kutak, Kwieciński, Martin and Staśto) [5,6] for the unified non-linear equation. The linear part of this equation is given by the BFKL kernel with subleading $\ln(1/x)$ corrections, supplemented by the non-singular parts of the DGLAP splitting functions. Thus resummation of both the leading $\ln Q^2$ and $\ln(1/x)$ terms are achieved. The subleading terms in $\ln(1/x)$ are

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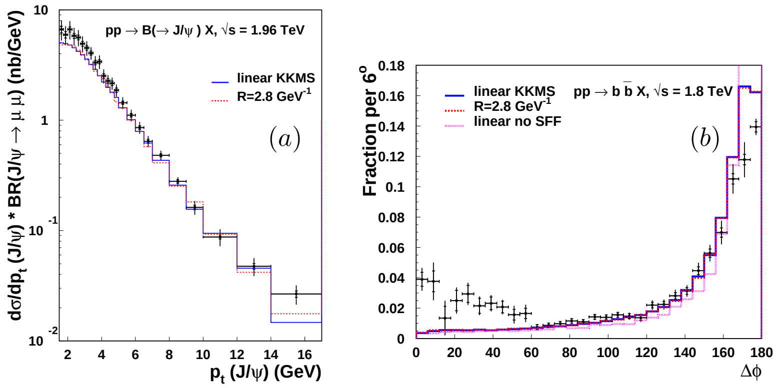

Figure 1. Bottom production, measured by CDF, is compared to predictions using CASCADE with linear and non-linear KKMS evolution. (a) The p_T distribution of B meson decays to J/ψ. (b) The azimuthal angle, $\Delta\phi$, distribution of $b\bar{b}$ pair production smeared by the experimental resolution.

approximated by the so-called consistency constraint and the running coupling constant. The non-linear part is taken directly from the BK equation, ensuring that the unitarity constraints are preserved. One expects that this framework provides a more reliable description of the gluon evolution at extremely small x, where $\ln(1/x) \gg 1$ and the unitarity corrections are important, than does DGLAP.

The size of the dense gluon system inside the proton is assumed to be $R = 2.8$ GeV^{-1}, in accord with the diffractive slope, $B_d \simeq 4$ GeV^{-2}, of the elastic J/ψ photoproduction cross section at HERA. In this process, the impact parameter profile of the proton defines the t dependence of the elastic cross section, $B_d \simeq R^2/2$, by Fourier transform.

2. Constraints from HERA and cross checks at the Tevatron

The initial distribution was obtained by fitting the HERA F_2 measurements [7,8] using the Monte Carlo CASCADE [9] for evolution and convolution with the off-shell matrix elements. The fits were repeated both with the standard KMS evolution without the non-linear contribution and with extended KMS evolution including the non-linear part. The predicted F_2 is equivalent for both linear and non-linear evolution.

Next, this constrained gluon density was used to calculate the charm structure function F_2^c at HERA and $gg \to b\bar{b}$ production at the Tevatron as a cross-check of the fit and the evolution formalism. We use $m_c = 1.4$ GeV, $m_b = 4.75$ GeV and a renormalization scale in α_s of $Q^2 = 4m_q^2 + p_T^2$. Sudakov Form Factor is included in the calculation. The predicted cross section was then compared to both H1 [10], Zeus [11] and CDF [12], D0 [13] measurements respectively. The predictions agree reasonably well with the data.

As an example of these cross-checks, in Fig. 1(a) the cross section for B decays to J/ψ is shown as a function the J/ψ p_T [12]. The KKMS gluon density fits the data both in the linear and non-linear scenarios with a comparable accuracy to the NLO collinear approach [14].

In Fig. 1(b), the azimuthal angle distribution between the b and $\bar{b}$ quarks, $\Delta\phi$, is given. The $\Delta\phi$ and $b\bar{b}$ p_T distributions are correlated since $\Delta\phi < 180°$ corresponds to higher pair p_T. Since the k_T-factorization formula allows the incoming gluons to have sizable transverse momenta, the calculated $\Delta\phi$ distribution agrees very well with the data for $\Delta\phi > 60°$ with only smearing due to the experimental resolution. It is interesting to note that the inclusion of the Sudakov From Factor improves the description significantly. For a comparison, we also plotted the result as obtained without the Sudakov Form Factor (dotted line). The enhancement of the data relative to the calculations at low $\Delta\phi$ requires further study.

3. Heavy quark production at the LHC

We computed heavy quark cross sections for various kinematical regions of the LHC. In Fig. 2(a), the $b\bar{b}$ production cross section is computed within the ATLAS and CMS acceptance ($p_T > 10$ GeV and $|\eta| < 2.5$ for both the b and $\bar{b}$ quarks). In Fig. 2(b), the same cross section is computed within the LHCb acceptance where the b quark p_T can be measured to 2 GeV for $1.9 < \eta < 4.9$. Similarly, we investigated $c\bar{c}$ production at ALICE, Fig. 2(c). In ALICE, it will be possible to measure the D^0 down to $p_T \sim 0.5$ GeV in $|\eta| < 0.9$. In the computations the same quark masses and scale was used as described in the previous section.

In all three cases the results of the linear evolution (solid line) and the results of the non-linear evolution (dashed line) are very similar. There is no significant effect observable for non-linear evolution due to gluon saturation. For $c\bar{c}$ production at ALICE saturation effects have been predicted [16] within the GLR approach [15] in the collinear limit (even with a larger saturation radius). This result [16] could not be confirmed with our calculations.

The presented results, Fig. 2, suggest that linear gluon evolution and

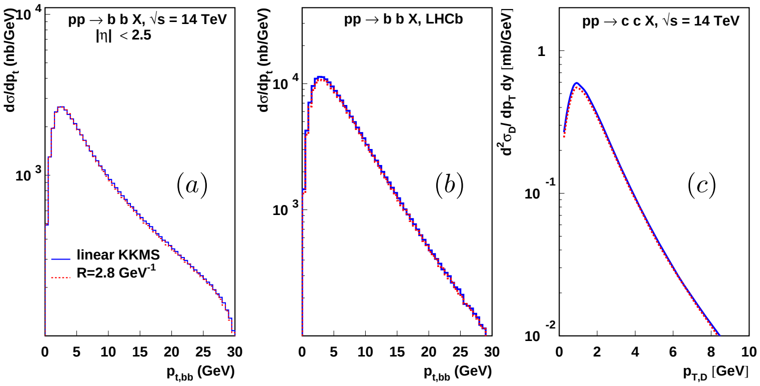

Figure 2. (a) and (b) show $b\bar{b}$ production as a function of pair p_T in the ATLAS/CMS (a) and the LHCb acceptance (b). The D^0 meson p_T distribution in the ALICE acceptance is shown in (c).

k_T-factorization can safely be applied in the discussed kinematical regions of the LHC.

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