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SMALL X EFFECTS IN HEAVY QUARK PRODUCTION

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Effects coming from finite transverse momenta of the partons initiating a hard process are discussed. It is shown, that the most probable value of these transverse momenta is similar for HERA, the Tevatron and the LHC. The bottom production cross-section at the Tevatron is calculated with a CCFM uPDF obtained from HERA data. The scale uncertainties and the uncertainties coming from the b-mass are estimated within the k_t-factorization approach.

1 Introduction

The transverse momenta of the partons initiating a hard scattering process, like heavy quark production via $\gamma g \to Q\bar{Q}$ or $gg \to Q\bar{Q}$ in lepto- (hadro-) production, respectively, can be seen as being generated by two sources: the intrinsic (primordial) transverse momentum, which reflects the Fermi motion of the partons in the hadron, typically of the order of a GeV, and the transverse momentum generated by the QCD evolution (DGLAP or BFKL/CCFM/LDC), which can reach large values, in DGLAP up to the factorization scale.

Typically at small values of the momentum fraction x, the transverse momentum of the gluons can be of the same order as the longitudinal momentum, and therefore cannot be neglected. At HERA and Tevatron energies transverse momenta $k_t \sim E_g$ of the order of $1 - 2$ GeV are reached for values of $x \lesssim 0.02$. At LHC we obtain $k_t \sim 1$ GeV for $10^{-4} < x < 10^{-3}$.

Typical small x effects in the cross sections can therefore come from:

1. kinematic effects from non-vanishing transverse momenta
2. effects from the treatment of off-shell partons in the matrix elements
3. small x improved evolution equations, like BFKL/CCFM/LDC etc.

In standard (integrated) parton distributions the contribution of intrinsic and perturbative evolution cannot be easily separated. However using un-integrated parton distributions (uPDF) both contributions can be distinguished as shown in Fig. 1[1] In k_t-factorization the cross section for any process $ep \to eX$ can be written as:

$$\sigma = \int dx \int dk_t \mathcal{A}(x, k_t, q) \hat{\sigma}(x, k_t, q) \tag{1}$$

with $\mathcal{A}(x, k_t, q)$ being the uPDF, q defines the factorization scale and $\hat{\sigma}$ is the partonic cross section. It is understood, that for a hadron collider this formula has to be modified accordingly.

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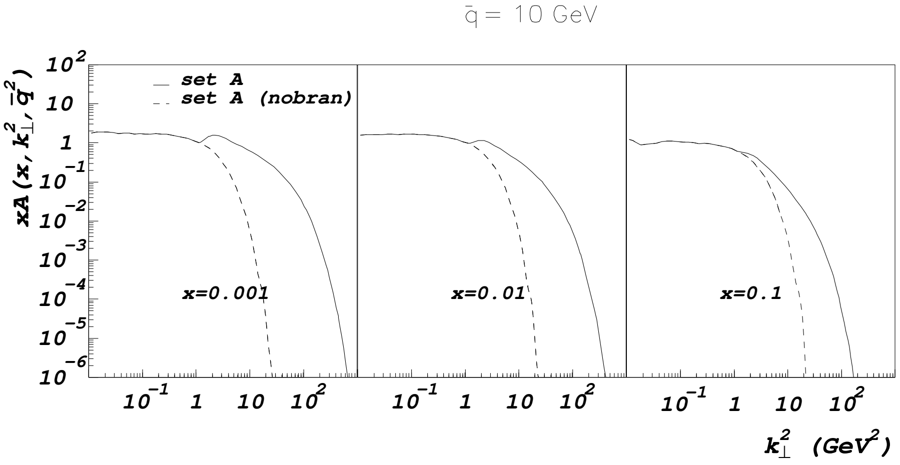

Figure 1. *The un-integrated gluon density obtained from the CCFM evolution [1]. Also shown is the contribution of the no-branching probability, reflecting the primordial transverse momentum distribution.*

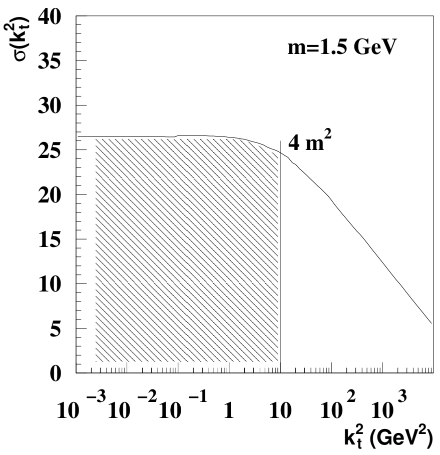

Figure 2. *The reduced cross section $\tilde{\sigma}(k_t)$ as a function of the transverse momentum k_t of the incoming gluon (from [2]).*

The off-shell matrix-elements $\hat{\sigma}$ are calculated in [3,4]. In Fig. 2 the partonic cross section is shown as a function of the transverse momentum of the incoming gluon (the final state is integrated over). It becomes obvious, that both the k_t dependence of the uPDF and of the matrix element will influence the cross section. The case of collinear factorization would correspond to approximating $\hat{\sigma}$ with a step function, which is constant for $k_t < q$ and vanishing for $k_t > q$ as indicated with the dashed box in Fig. 2. With such a simplified $\hat{\sigma}$ the k_t integration can performed and Eq.(1) will then reduce to:

$$\sigma = \int dx \hat{\sigma}(x, 0, q) \left(\int dk_t \mathcal{A}(x, k_t, q) \right) \hat{\sigma}(x, k_t, q) \tag{2}$$

with $\int dk_t \mathcal{A}(x, k_t, q) = g(x, q)$ being the standard gluon density.

The effects of finite transverse momenta are present independent of the evolution scheme: uPDFs can be defined also for the DGLAP evolution. Moreover the assumption of the collinear approach to neglect the transverse momenta k_t is not necessary for the proof of factorization [5]. However a region in phase space might exist, where k_t effects might be neglected: this is then the region of applicability of the collinear approach. Whether k_t effects are important or not, can only be decided after a careful investigation with a detailed Monte Carlo event generator, which simulates these effects.

2 Transverse Momentum effects at HERA, the Tevatron and the LHC

Heavy quark production is well suited to investigate effects coming from transverse momenta of the partons entering the heavy quark production process. In Fig. 3

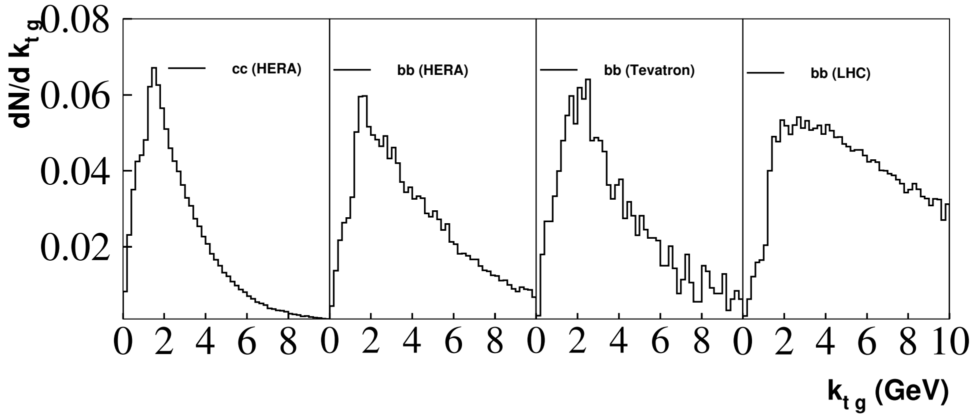

Figure 3. Transverse momenta of the gluons initiating heavy quark production at HERA, the Tevatron and the LHC

the tranverse momentum distribution of gluons entering the $\gamma g \to Q\bar{Q}$ (or $gg \to Q\bar{Q}$) process for charm and bottom production at HERA, the Tevatron and the LHC are shown. The visible phase space is defined according to [6,7] ([8]) for HERA (Tevatron), respectively. The LHC phase space was defined by requiring $p_t^b > 10$ GeV and $|\eta_b| < 2.5$. It is clearly seen, that the cross sections are largest for small k_t, with $k_t \sim 2 \cdots 4$ GeV, even for the LHC. The factorization scale in DGLAP indicates the maximum value, but as can be seen from Fig. 3 the most probable values are much smaller.

Two different regions of interest can be defined:

1. The large k_t region, which is governed by the perturbative evolution equations and fixed order parton level calculations. However, even in the large k_t region effects coming from the re-summation over all orders might be significant and can give results different from those obtained by a fixed order calculation.

2. The small k_t region, where typical small x effects can be expected. The gluon density will be large, and eventually recombination effects will occur. As the cross sections are dominated by the small k_t region, and not by its largest value, the investigation of the uPDF at these small k_t values is essential for any precise cross section estimate. For the dynamics of the QCD evolution, it is the virtuality, and therefore the transverse momentum k_t of the partons initiating the hard scattering which is the relevant quantity, and not to the tranverse momentum of the parton emerging from the hard scattering. Consequently, k_t is the relevant parameter setting the scale for saturation effects, and not the maximum allowed virtuality. Thus even at high p_t heavy quark (or jet) production, the gluon k_t can be in the region of the saturation scale, which is of the order of a few GeV.

3 Heavy Quark Production at HERA, the Tevatron and the LHC

In Ref. [1] the CCFM uPDF and its scale uncertainties were investigated. This uPDF are used to calculate the bottom production cross section at the Tevatron as measured by CDF [8] arc shown in Fig. 4.

The scale uncertainties, for the first time estimated in k_t-factorization approach, are also shown in Fig. 4. The renormalization scale was varied $0.5p_t < \mu_r < 2p_t$ and the factorization scale was chosen as $\mu_f = \sqrt{\hat{s} + Q_\perp^2}$ as discussed in [1]. The uncertainties coming from a variation of μ_f are small, which is understandable, as higher order corrections are included via the off-shell matrix elements and the all loop re-summed uPDFs in CCFM. The variations coming from the b-mass in the range 4.5 GeV $< m_b <$ 5 GeV are also estimated and shown. One should note that even without a full NLO calculation in k_t-factorization the method outlined in [1] can be used to estimate the scale uncertainties. This approach is only possible in k_t-factorization as different scale definitions enter already in the LO calculations. Within the scale and mass uncertainties the measurement of CDF is well described.

Acknowledgments

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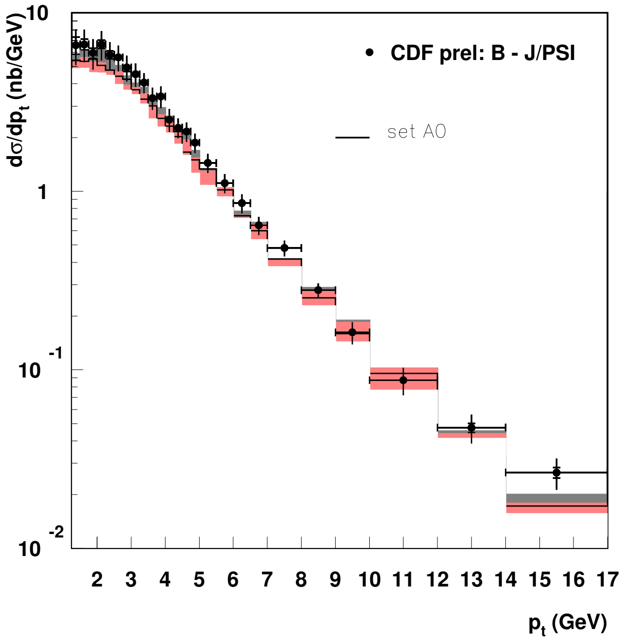

Figure 4. The cross section for $b \to J/\psi$ production as measured by CDF [8]. The prediction from CASCADE using the uPDF *set A0* [1] is shown. The uncertainty coming from a variation of the renormalization scale between 0.5 GeV$p_t < 2$ GeV is shown as the light band, the uncertainty coming from a variation of the b-mass within 4.5 GeV $< m_b <$ 5 GeV added quadratically to the renormalization uncertainty is shown with the dark band.

References

1. H. Jung, Un-integrated Parton Density Functions in CCFM, DIS 2004, Strbské Pleso, Slovakia.
2. S. P. Baranov et al., *Eur. Phys. J.* **C24** (2002) 425, DESY 02-017, hep-ph/0203025.
3. S. Catani, M. Ciafaloni, F. Hautmann, *Nucl. Phys.* **B 366** (1991) 135.
4. J. Collins, R. Ellis, *Nucl. Phys.* **B 360** (1991) 3.
5. J. C. Collins, X.-M. Zu, *JHEP* **06** (2002) 018.
6. ZEUS Collaboration; J. Breitweg et al., *Eur. Phys. J.* **C 6** (1999) 67.
7. Chekanov, S. et al (ZEUS Coll.), Beauty photoproduction measured using decays into muons in dijet events in *ep* collisions at $\sqrt{s} = 318$ GeV, 2003, hep-ex/0312057.
8. Bussey, Peter J. (CDF Coll.), Charm and beauty production at CDF, 2004, hep-ex/0408020.