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HEAVY QUARK PRODUCTION AT THE TEVATRON AS A TEST OF UNINTEGRATED GLUON DISTRIBUTIONS

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In the framework of the k_T-factorization approach, we consider the production of b quark pairs in $p\bar{p}$ collisions at the Fermilab Tevatron. We study the dependence of the differential cross sections and b–$\bar{b}$ azimuthal correlations on the choice of unintegrated gluon densities. For many of the tried densities, our theoretical results are found to be in good agreement with all available D∅ and CDF data.

1 Introduction

Heavy flavour production processes are rightfully regarded as essential tests of Quantum Chromodynamics. In the traditional factorization scheme, the available data [1], [2] can be described on the basis of perturbative LO+NLO calculations [3]. The previously observed factor of 2 discrepancy has been successfully eliminated after a careful reconsideration of the b quark fragmentation function [4].

A different strategy is represented by the k_T-factorization approach [5]-[8] (see also recent reviews [9] and references therein). In this approach, one focuses on the resummation of "small x" logarithms (i.e., the terms $[\ln(\mu^2/\Lambda^2)\,\alpha_s]^n$, $[\ln(\mu^2/\Lambda^2)\ln(1/x)\,\alpha_s]^n$, and $[\ln(1/x)\,\alpha_s]^n$) to all orders in n and takes into account the effects of finite transverse momenta of partons. The resummation [10] results in the "unintegrated" parton distributions which generalize the QCD factorization beyond the collinear approximation. The latter approach is taken as the basis for the present analysis.

2 Theoretical framework

For an introduction to the k_T-factorization approach, we find pedagogical reasons to start from the analogy between Quantum Chromodynamics and Quantum Electrodynamics. In QED, one knows the Weizsäcker-Williams approximation $F_\gamma(x) = \alpha/(2\pi x)\ [1+(1-x)^2]\ \ln(s/(4m_e^2))$, which is essentially the collinear parton model approximation giving the probability to find a photon (parton) carrying the longitudinal momentum fraction x with respect to the parent particle. The emitted photon is considered on mass shell, and its transverse momentum is neglected. On the other hand, there exists a more accurate Equivalent Photon Approximation $F_\gamma(x, Q^2) = \alpha/(2\pi x)\cdot 1/Q^2\cdot[1+(1-x)^2]$ showing an explicit dependence on the photon virtuality, and there is a kinematic relation between the photon virtuality Q^2 and its transverse momentum k_T: $Q^2 \simeq k_T^2/(1-x)$. In QCD, this idea manifests in the form of noncollinear, or unintegrated, parton distributions $\mathcal{F}(x, k_T^2, \mu^2)$.

Further on, it can be easily shown that the off-shell gluon spin density matrix is similar to that of the off-shell photon. The latter is given by the full lepton tensor $\overline{\epsilon^\mu \epsilon^{*\nu}} \sim L^{\mu\nu} = 8\, p^\mu p^\nu - 4(pk)\, g^{\mu\nu}$, where p is the momentum of the beam particle, and k the momentum of the photon. Neglecting the second term in the right hand side in the small x limit, $p \gg k$, one arrives at the spin structure $\overline{\epsilon^\mu \epsilon^{*\nu}} \sim p^\mu p^\nu$. It can be rewritten in the form [5]-[8] $\overline{\epsilon^\mu \epsilon^{*\nu}} = k_T^\mu k_T^\nu / |k_T|^2$, where we have represented the 4-momentum k as $k = xp + k_T$ and applied a gauge shift $\epsilon^\mu \to \epsilon^\mu - k^\mu/x$. This formula converges to the usual $\sum \epsilon^\mu \epsilon^{*\nu} = -g^{\mu\nu}$ when $k_T \to 0$.

In the numerical analysis, we have tried four different sets of k_T-dependent gluon densities. In the approach of Ref. [11] based on leading-order perturbative solution of the BFKL equation, the unintegrated gluon density $\mathcal{F}_g(x, k_T^2, \mu^2)$ is calculated as a convolution of ordinary (collinear) gluon density $G(x, \mu^2)$ [12] with universal weight factors. Another set [13] is obtained from a unified BFKL and DGLAP description of F_2 data and includes the so called consistency constraint [14]. The consistency constraint introduces a large correction to the LO BFKL equation; about 70% of the full NLO corrections to the BFKL exponent λ are effectively included in this constraint, as is argued in [15]. The third approach originally proposed in [5] recalls the kinematic relation between the virtuality Q^2 and the transverse momentum of a parton. In this approach, the unintegrated gluon density is derived from the ordinary density $G(x, Q^2)$ by differentiating it with respect to Q^2 and setting $Q^2 = k_T^2$. The fourth set taken from Ref. [16] represents a convenient parametrization of the "gluon saturation".

The computational technique is explained in our previous publications [17], [18] in every detail and needs not to be reproduced here again. Note that, in contrast with the collinear factorization approach, our calculations include the leading order off-shell matrix elements only.

3 Numerical results

In the present study, we concentrate on the role of the unintegrated gluon distributions. In calculations we set the renormalization and factorization scales equal to the initial gluon virtualities, $\mu_R = \mu_F = k_{T1,2}^2$, as in [6], and used the quark mass value $m_b = 4.75$ GeV. With the above set of parameters, we reproduce the data on the b quark, B-meson and decay muon transverse momentum distributions in the central and forward regions, as well as the muon rapidity distributions, and even the correlated distributions when some additional cuts have been applied to the accompanying (anti)quark or muon. The theoretical predictions show, however, only a little sensitivity to the choice of the unintegrated gluon densities. All these results have been presented in our previous work [19].

The data on the $b\bar{b}$ azimuthal correlations (measured as the decay muon azimuthal correlations, $d\sigma/d\Delta\Phi_{\mu\mu}$) are much more informative. Fig. 1 displays our predictions together with the experimental data collected by D$\emptyset$. One can clearly see the difference between the different gluon parametrizations.

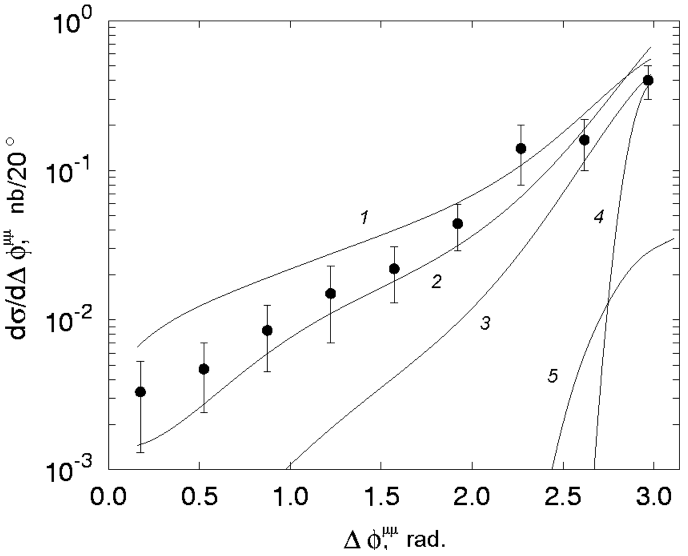

Figure 1. Azimutal muon-muon correlations at the Tevatron conditions. The curves *1 – 4* correspond to the k_T-factorization results with JB [11], KMS [13], DGRV [5], and GBW [16] unintegrated gluon distributions, respectively. Curve *5* shows the collinear approximation result with LO matrix elements and GRV [12] gluon densities. Experimental data are from DØ [2].

At the same time, this figure demonstrates an important theoretical difference between the collinear and k_T-factorization approaches. In the collinear approximation, the b quarks can only be produced back-to-back, leading to $\Delta\Phi_{\mu\mu} \approx \pi$, unless the NLO contributions are included. In the k-factorization, the NLO effects arise due to the gluon evolution, and so, the azimuthal correlation data are well reproduced with LO matrix elements.

4 Conclusions

We have considered the production of $b\bar{b}$ pairs and beauty mesons at the Tevatron conditions and found that the k_T-factorization approach with LO gluon-gluon fusion matrix elements successfully describes all the available data. Among the different kinematic distributions, the $b\bar{b}$ azimuthal correlations appear to be very sensitive to the choice of unintegrated gluon densities, thus serving as a high quality probe for the latter. The data give preference to KMS parametrization [13], although the agreement with JB set [11] is also not bad. We also found that GBW parametrization [16] is inconsistent with the data (because of the absense of realistic k_T evolution in this function) and, therefore, is ruled out.

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