Inclusive and associated b-quark production in the Regge limit of QCD

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The study of b-jet production at high-energy colliders is of great interest for the test of perturbative quantum chromodynamics (QCD). The presence of a heavy b quark, with mass $m_b \gg \Lambda_{\rm QCD}$, where $\Lambda_{\rm QCD}$ is the asymptotic scale parameter of QCD, in such processes guarantees a large momentum transfer that keeps the strong-coupling constant small $\alpha_s(m_b) \lesssim 0.1$.

The total center-of-mass energy at the Tevatron, $\sqrt{S} = 1.96$ TeV in Run II, sufficiently exceeds the scale μ of the relevant hard processes, so that $\sqrt{S} \gg \mu \gg \Lambda_{\rm QCD}$. In this regime, the contributions to the production cross section from subprocesses involving t-channel exchanges of partons (gluons and quarks) may become dominant. Then, the off-shell properties of the incoming partons can no longer be neglected, and t-channel partons become Reggeized. In this so-called quasi-multi-Regge kinematics (QMRK), the particles (multi-Regge) or groups of particles (quasi-multi-Regge) produced in the collision are strongly separated in rapidity. For the inclusive b-jet production, this implies that a single b quark is produced in the central region of rapidity, while other particles, including a $\bar{b}$ quark, are produced at large rapidities. In the case of $b\bar{b}$ pair and $b\gamma$ associated production in the central rapidity region, we also assume that there are no other particles in this region, so that these particles are considered as quasi-multi-Regge pairs. The QMRK approach [1] is particularly appropriate for this kind of high-energy phenomenology. It is based on an effective quantum field theory implemented with the non-Abelian gauge-invariant action including fields of Reggeized gluons [2] and quarks [3].

First, we investigate inclusive single b-jet production in $p\bar{p}$ collisions. To leading order (LO) in the QMRK approach, there is only one partonic subprocess, $Q_b + R \to b(k)$ [4], where R and Q_b are the Reggeized gluon and b quark (with four-momentum k), respectively. At next-to-leading order (NLO), the main contribution arises from the partonic subprocess $R + R \to b + \bar{b}$, where the b and $\bar{b}$ quarks are produced close in rapidity, and its squared amplitude was obtained in Ref. [5]. In Fig. 1(a), the preliminary data presented by the CDF Collaboration [6] are compared with our predictions. Throughout all our analysis, the renormalization and factorization scales are chosen to be $\mu = \xi k_T$, where $1/2 \leq \xi \leq 2$, and the resulting theoretical uncertainties are indicated as shaded bands. In Fig. 1(a), we observe that the contribution due to LO subprocess greatly exceeds the one due to NLO subprocess and practically exhausts the full result. It nicely agrees with the CDF data throughout the entire k_T range.

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In our analysis, we adopt the Kimber-Martin-Ryskin prescription [7] for unintegrated parton distribution functions (PDFs), using as input the Martin-Roberts-Stirling-Thorne collinear PDFs of the proton [8].

$b\bar{b}$-dijet production receives contributions from both subprocess $R + R \to b + \bar{b}$ and the annihilation of a Reggeized quark-antiquark pair, $Q_q + \bar{Q}_q \to b + \bar{b}$, where $q = u, d, s, c, b$. The induced vertex of the latter was obtained in Ref. [3] and the squared amplitudes in Ref. [9]. The CDF data [10] as distributions in the leading-jet (jet with the maximal transverse energy) transverse energy E_{1T}, the dijet invariant mass $M_{b\bar{b}}$, and the azimuthal separation angle $\Delta\phi$ are compared with our QMRK predictions in Figs. 1(b)–(d), where the two LO contributions are shown separately along with their superpositions. We observe that the total QMRK predictions nicely describe all the three measured cross section distributions. The contributions due to Reggeized gluon fusion dominate for $E_{1T} \lesssim 200$ GeV and $M_{b\bar{b}} \lesssim 300$ GeV and over the whole $\Delta\phi$ range considered. The peak near $\Delta\phi = 0.4$ in Fig. 1(d) arises from the isolation cone condition $R_{\rm cone} = \sqrt{\Delta y^2 + \Delta\phi^2} > 0.4$.

At last, there are two mechanisms of photon-associated b-quark production: direct photon production via the LO partonic subprocess in the QMRK $Q_b + R \to b + \gamma$ [11], and the fragmentation of final-state partons into photons. In Figs. 1(e)–(f), we observe that the contribution due to direct photon production greatly exceeds the one due to photon production by fragmentation, by about of one order of magnitude at $k_{T\gamma} > 40$ GeV and by about a factor 5 at $k_{T\gamma} \approx 30$ GeV. The direct photon contribution practically exhausts the full result. It nicely agrees with the D0 data [12] throughout the entire $k_{T\gamma}$ range considered.

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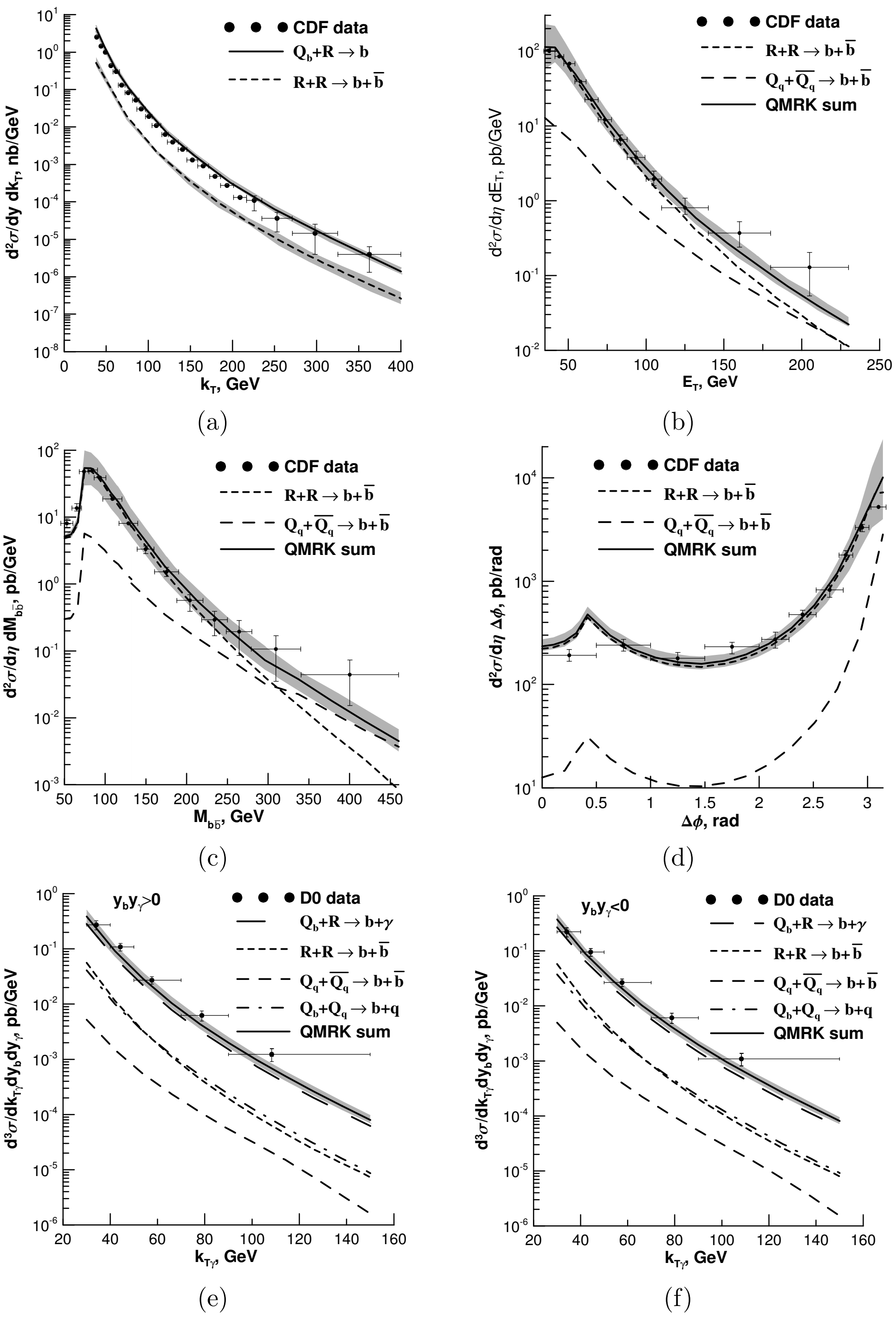

Figure 1: The distribution in (a) transverse momentum of inclusive single b-jet hadroproduction [6], the ones in (b) leading-jet transverse energy, (c) dijet invariant mass, and (d) azimuthal separation angle of inclusive $b\bar{b}$-dijet hadroproduction [10], and the ones in transverse momentum of $b\gamma$ hadroproduction [12] for (e) $y_b y_\gamma > 0$ and (f) $y_b y_\gamma < 0$ are compared with the QMRK predictions.