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JOINT RESUMMATION FOR HEAVY QUARK PRODUCTION

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We present the joint threshold and recoil resummed transverse momentum distributions for heavy quark hadroproduction, at next-to-leading logarithmic accuracy. We exhibit their dependence on the production channel and the color configurations, and compare these distributions to eachother and to NLO.

Keywords: Resummation; heavy quark production.

1. Joint threshold and recoil resummation

The formalism [1,2,3] of hadronic cross sections for the joint resummation of distributions singular at partonic threshold and at zero recoil has so far been applied to Z/W production [4], Higgs production [5], and prompt photon hadroproduction [6]. For the latter $2 \to 2$ process, the formalism implements the notion that, in the presence of QCD radiation, the actual transverse momentum produced by the hard collision is not $\vec{p}_T$ but rather $\vec{p}_T - \vec{Q}_T/2$, with $\vec{Q}_T$ the total transverse momentum of unobserved soft recoiling partons. The joint-resummed partonic p_T spectrum has the form of a hard scattering cross section as a function of $p'_T \equiv |\vec{p}_T - \vec{Q}_T/2|$, convoluted with a *perturbative*, albeit resummed $\vec{Q}_T$ distribution. We have extended [7] the joint resummation formalism to the p_T distribution of heavy quarks produced in hadronic collisions. Key differences with the prompt-photon case are, first, the presence of the heavy quark mass m, preventing a singularity in the hard scattering function when $Q_T = 2p_T$ and, second, the possibility of multiple colored states for the produced heavy quark pair.

2. Resummed heavy quark transverse momentum spectra

We consider the inclusive p_T distribution of a heavy quark produced via the strong interaction in a hadron-hadron collision at center of mass (cm) energy $\sqrt{S}$. Exact

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higher order corrections to the differential cross sections for these partonic processes have been computed to NLO [8,9,10,11]. Up to corrections $\mathcal{O}(1/p_T^2)$, the observable may at any order [12] be written in the following factorized form

$$\frac{d\sigma_{AB\to Q+X}}{dp_T} = \sum_{a,b}\int_0^1 d\xi_a d\xi_b\, \phi_{a/A}(\xi_a,\mu)\phi_{b/B}(\xi_b,\mu)\frac{d\hat{\sigma}_{ab\to Q+X}}{dp_T}(\xi_a,\xi_b,\alpha_s(\mu),p_T)\,, \tag{1}$$

with $d\hat{\sigma}_{ab\to Q+X}/dp_T$ the partonic differential cross-section, $\phi_{a/A}$ and $\phi_{b/B}$ parton densities, and μ the factorization/renormalization scale.

Threshold enhancements essentially involve the energy of soft gluons. In the context of the factorization (1) we define hadronic and partonic threshold by the conditions $S = 4m_T^2$ and $\hat{s} = 4m_T^2$, respectively, with m_T the transverse mass $\sqrt{m^2+p_T^2}$. It is convenient to define the scaling variables

$$x_T^2 = \frac{4m_T^2}{S}\,, \qquad \hat{x}_T^2 = \frac{4m_T^2}{\xi_a\xi_b S}\,, \tag{2}$$

so that hadronic (partonic) threshold is at $x_T^2 = 1$ ($\hat{x}_T^2 = 1$). The higher order corrections to the partonic cross section $d\hat{\sigma}_{ab}/dp_T$ contain distributions that are singular at partonic threshold. Threshold resummation organizes such distributions to all orders.

There are also recoil effects, resulting from radiation of soft gluons from initial-state partons. We wish to treat these effects in the context of joint threshold and recoil resummation. We identify a hard scattering with reduced cm energy squared Q^2 and at transverse momentum $\vec{Q}_T$ with respect to the hadronic cm system. This hard scattering produces a heavy quark with transverse momentum

$$\vec{p}\,'_T \equiv \vec{p}_T - \frac{\vec{Q}_T}{2}\,. \tag{3}$$

The kinematically allowed range for the invariant mass Q of the heavy quark pair in this hard scattering is limited from below by $2m'_T = 2\sqrt{m^2+p'^2_T}$ so that threshold in the context of joint resummation is defined by

$$\tilde{x}_T^2 \equiv \frac{4m'^2_T}{Q^2} = 1\,. \tag{4}$$

A refactorization analysis [2] leads to the following expression for the observable in Eq. (1)

$$\frac{d\sigma_{AB\to Q+X}}{dp_T} = \int d^2Q_T\,\theta(\bar{\mu}-|\vec{Q}_T|)\frac{d\sigma_{AB\to Q+X}}{dp_T d^2\vec{Q}_T}\,, \tag{5}$$

where $\bar{\mu}$ is a cut-off and

$$\frac{d\sigma_{AB\to Q+X}}{dp_T d^2\vec{Q}_T} = \sum_{ab=q\bar{q},gg} p_T \int \frac{d^2b}{(2\pi)^2} e^{i\vec{b}\cdot\vec{Q}_T} \int \frac{dN}{2\pi i} \phi_{a/A}(N,\mu)\, \phi_{b/B}(N,\mu)\, e^{E_{ab}(N,b)}$$
$$\frac{e^{-2\,C_F\,t(N)\,(\mathrm{Re}L_\beta+1)}}{4\pi S^2} \left(\tilde{M}^2_{\mathbf{1}}(N) + \tilde{M}^2_{\mathbf{8}}(N) e^{C_A\,t(N)\left(\ln\frac{m_T^2}{m^2}+L_\beta\right)} \right)$$
$$\times \left(\frac{S}{4(m^2+|\vec{p}_T-\vec{Q}_T/2|^2)} \right)^{N+1}. \tag{6}$$

Notice in particular the last factor, which provides a kinematic link between recoil and threshold effects. The exponential functions E_{ab} [2,6] are to next-to-leading logarithmic (NLL) accuracy

$$E_{ab}(N,b) = \int_{\chi(N,b)}^{Q} \frac{d\mu'}{\mu'} [A_a(\alpha_s(\mu')) + A_b(\alpha_s(\mu'))] 2\ln\frac{\bar{N}\mu'}{Q} - gb^2\,, \qquad \bar{N} = Ne^{\gamma_E}\,, \tag{7}$$

where the coefficients A_a and A_b can be found elsewhere [2], and the function $\chi(N,b)$ is chosen to reproduce either NLL resummed recoil or threshold distributions in the appropiate limits [4]. We also added to the perturbative exponent the non-perturbative (NP) Gaussian smearing term $-gb^2$, in terms of the impact parameter b. We have introduced the variables

$$t(N) = \int_Q^{Q/N} \frac{d\mu'}{\mu'} \frac{\alpha_s(\mu')}{\pi}\,, \quad \mathrm{Re}L_\beta = \frac{1+\beta^2}{2\beta}\left(\ln\frac{1-\beta}{1+\beta}\right)\,, \quad \beta = \sqrt{1-m^2/m_T^2}. \tag{8}$$

The functions $\tilde{M}^2_{\mathbf{1}}(N), \tilde{M}^2_{\mathbf{8}}(N)$ are the Mellin moments of the lowest order heavy quark production matrix elements for either the $q\bar{q}$ or gg channel, as appropiate, the index labeling the color-state of the heavy quark pair. Their explicit expressions can be found elsewhere[7]. The threshold-resummed result can now easily be derived, by substituting Eq. (6) into (5) and neglecting $\vec{Q}_T$ in the last factor in Eq. (6). Then the $\vec{Q}_T$ integral sets $\vec{b}$ to zero everywhere, yielding the threshold-resummed result.

To illustrate these analytic results, we show for the case of top quark production at the Tevatron the p_T distribution for the dominant $q\bar{q}$ channel in Fig. 1. We observe that, while the resummed and NLO curves are close for small and moderate p_T (the inset provides a somewhat better view of the low p_T region), for large p_T values the resummed curves depart significantly from the NLO curve. Of course, cross sections for top quark production at such large p_T at the Tevatron are far too small to be measured, so that our plots at large p_T have only theoretical interest. For such large p_T values, the hadronic threshold, defined in Eq. (2), approaches the partonic one, where larger N values dominate, a prerequisite for seeing significant effects for both resummations. The enhancements relative to the Born cross section are shown in the form of a K-factor. Threshold resummation produces an overall enhancement of the cross section that increases with increasing p_T, yielding e.g. an enhancement

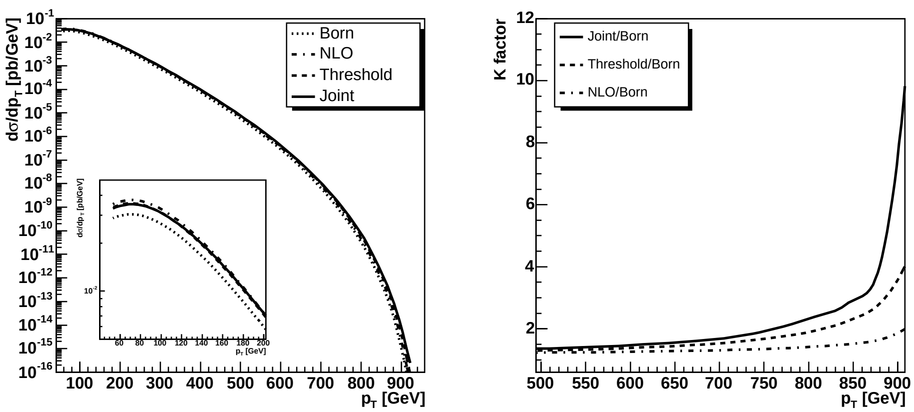

Fig. 1. Top quark p_T spectra and K-factors for the $q\bar{q}$ channel.

over NLO at $p_T = 800\,\mathrm{GeV}$. Joint resummation almost doubles that effect: the joint-resummed enhancement at large p_T effectively constitutes a smearing of the threshold-resummed p_T spectrum by a resummed recoil function.

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