Threshold corrections in bottom and charm quark hadroproduction at next-to-next-to-leading order

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Calculations of heavy quark hadroproduction have included next-to-next-to-leading-order (NNLO) soft-gluon corrections [1–3] from threshold resummation techniques. These resummations are a consequence of QCD factorization which separates cross sections into universal nonperturbative parton densities and a perturbative partonic cross section. Near threshold, soft-gluon corrections, singular at partonic threshold, dominate the cross section. Threshold resummation techniques organize these singular distributions to all orders, extending the reach of QCD into this region.

The soft corrections take the form of logarithms, $[\ln^l(x_{\rm th})/x_{\rm th}]_+$, with $l \leq 2n-1$ for the order α_s^n corrections, where $x_{\rm th}$ is a kinematical variable that measures the distance from threshold and is zero at threshold. NNLO calculations ($n=2$) of the resummed cross section, expanded to finite order, for bottom and charm quark production have been done through next-to-next-to-leading-logarithmic (NNLL) accuracy, i.e. for the scale-independent terms, including leading logarithms (LL) with $l=3$, next-to-leading logarithms (NLL) with $l=2$, and NNLL with $l=1$ [1, 2]. In Refs. [1, 2], heavy quark production was studied in both single-particle-inclusive (1PI) and pair-invariant-mass (PIM) kinematics. Differences between the two kinematics choices were found, even near threshold. Thus subleading contributions beyond NNLL can be important and minimize the kinematics dependence of top quark production [3].

We showed in Ref. [3] that the subleading corrections bring the 1PI and PIM results into agreement near threshold for both the $q\overline{q} \to Q\overline{Q}$ and the $gg \to Q\overline{Q}$ channels while discrepancies away from threshold are also diminished, especially in the gg channel.

Here, we apply these new terms to bottom and charm quark production. Calculations of bottom and especially charm production are still not under solid theoretical control. HERA-B, at $\sqrt{S}=41.6$ GeV, is in the near threshold region for bottom production. The charm cross section is of particular interest for heavy ion physics. Some of the current and future experiments are in the near-threshold region. The NA60 experiment will take heavy ion data at $\sqrt{S}=17.3$ GeV and pA data at $\sqrt{S}=29.1$ GeV. A new facility at the GSI will measure charm at $\sqrt{S}=6.98$ GeV.

We studied the differences between the 1PI and PIM kinematics choices at NLO and found that 1PI kinematics gives a far better approximation to the exact NLO cross section. Thus our NNLO-NNNLL+ζ results are only given in 1PI kinematics.

Our main results [4] are presented in Table I.

$\sqrt{S}$ (GeV)	Order	MRST2002 NNLO	GRV98
bottom: σ (nb)			
41.6	NLO	$17\,^{+12}_{-7}\,^{+10}_{-6}$	$17\,^{+12}_{-7}\,^{+10}_{-6}$
41.6	NNLO	$28 \pm 9\,^{+15}_{-10}$	$25\,^{+7}_{-8}\,^{+13}_{-9}$
charm: σ (nb)			
6.98	NLO	$34\; -27\,^{+560}_{-32}$	$28\; -22\,^{+420}_{-26}$
6.98	NNLO	$90\; -70\,^{+1400}_{-85}$	$61\; -50\,^{+900}_{-57}$
charm: σ (μb)			
17.3	NLO	$3.8\; -2.1\,^{+13}_{-2.8}$	$2.8\; -1.4\,^{+8.3}_{-2}$
17.3	NNLO	$6.7\; -3.4\,^{+22.5}_{-4.9}$	$4.1\; -1.8\,^{+12.2}_{-3}$

TABLE I: The $b\overline{b}$ cross section at $\sqrt{S}=41.6$ GeV and the $c\overline{c}$ cross sections at $\sqrt{S}=6.98$ and 17.3 GeV, all in pp collisions. The exact NLO results and the approximate NNLO-NNNLL+ζ results, based on $m=\mu=4.75$ GeV (bottom) and 1.5 GeV (charm), are shown. The first uncertainty is due to the scale choice, the second, the quark mass.

We have found that these new subleading corrections reduce the size of the NNLO cross sections, and thus the K factors, as well as diminish the scale dependence of the cross section.

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