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# BEAUTY AND CHARM PRODUCTION IN FIXED TARGET EXPERIMENTS

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We present calculations of NNLO threshold corrections for beauty and charm production in $\pi^- p$ and $pp$ interactions at fixed-target experiments.

## 1 Introduction

Recent calculations for heavy quark hadroproduction have included next-to-next-to-leading-order (NNLO) soft-gluon corrections [1] to the double differential cross section from threshold resummation techniques [2]. These corrections are important for near-threshold beauty and charm production at fixed-target experiments, including HERA-B and some of the current and future heavy ion experiments.

Soft-gluon corrections dominate the cross section near threshold. They take the form of logarithms, $[\ln^l(x_{\rm th})/x_{\rm th}]_+$, with $l \le 2n-1$ for the order $\alpha_s^n$ corrections, where $x_{\rm th}$ is a kinematical variable that measures distance from threshold. In NNLO calculations ($n=2$) we denote leading logarithms (LL) with $l=3$, next-to-leading logarithms (NLL) with $l=2$, and next-to-next-to-leading logarithms (NNLL) with $l=1$. The latest calculation used the methods of Ref. [3] to include next-to-next-to-next-to-leading logarithms (NNNLL, $l=0$) at NNLO [4,5]. These NNNLL terms minimize the kinematics and scale dependence of the cross section.

Our calculation is done in single-particle-inclusive (1PI) kinematics since, in this kinematics, the NLO threshold approximation to the full NLO result is very good, as shown in Ref. [5]. In 1PI kinematics, we define $s=(p_a+p_b)^2$, $t_1=(p_b-p_1)^2-m^2$, $u_1=(p_a-p_1)^2-m^2$ and $s_4=s+t_1+u_1$ for the process $i(p_a)+j(p_b)\longrightarrow Q(p_1)+X[\overline{Q}](p_2)$ with $ij=q\bar{q}$ or $gg$. At threshold $s_4\to 0$ and the soft corrections take the form $[(\ln^l(s_4/m^2))/s_4]_+$.

## 2 Beauty production

There is not much data on beauty hadroproduction at fixed-target energies. The $\pi^- p$ data [6,7,8,9,10] are shown on the left-hand side of Fig. 1 along with our calculations with several choices of bottom quark mass and scale. We use the GRV98 HO proton parton densities [11] with the GRS pion densities [12]. For our central value of the bottom quark mass, $m = 4.75$ GeV, we present the exact NLO cross section (solid curve), the 1PI NNLO-NNLL cross section (dot-dashed) and the 1PI NNLO-NNNLL+$\zeta$ cross section (dashed). Here NNLO-NNLL indicates that we include the NNLL terms at NNLO, while, for NNLO-NNNLL+$\zeta$, we include the NNNLL terms and some virtual $\zeta$ terms [5]. We also show the 1PI NNLO-NNNLL+$\zeta$ cross sections for $m = 4.5$ GeV (dotted) and 5 GeV (dot-dot-dot-dashed). On the right-hand side of Fig. 1 we present the $K$ factors for $m = 4.75$ GeV. We show $\sigma_{\rm NLO}/\sigma_{\rm LO}$ (solid), $\sigma_{\rm NNLO-NNLL}/\sigma_{\rm NLO}$ (dashed), and $\sigma_{\rm NNLO-NNNLL+\zeta}/\sigma_{\rm NLO}$ (dot-dashed).

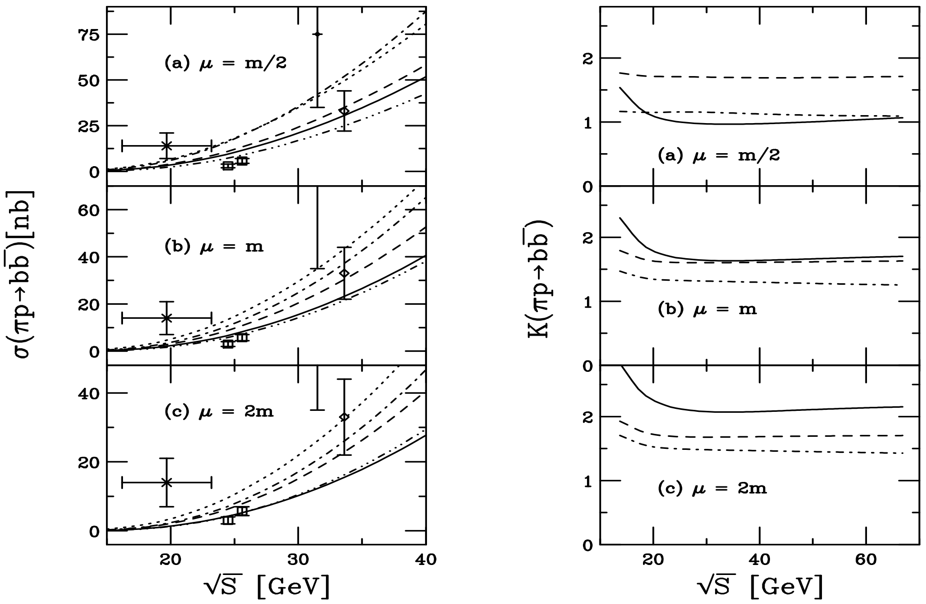


Figure 1. Beauty production cross sections and $K$ factors in $\pi^- p$ interactions.

We now turn to beauty production in $pp$ interactions. The data points from three experiments [13,14,15] are compared to our calculations with the MRST2002 NNLO parton densities [16] on the left-hand side of Fig. 2.

On the right-hand side of Fig. 2, we plot the scale ($\mu$) dependence of the cross section at HERA-B for $0.3 < \mu/m < 10$ with $\sqrt{S} = 41.6$ GeV and $m = 4.75$ GeV. We show results for the Born, NLO, and NNLO-NNNLL+$\zeta$ cross sections. The scale dependence decreases with increasing order of the cross section. The plateau at $\mu/m \approx 0.4$ is broader for the NNLO-NNNLL+$\zeta$ cross section and the overall scale dependence is reduced relative to the exact NLO cross section.

The NNLO-NNNLL+$\zeta$ $b\bar{b}$ cross section at $\sqrt{S} = 41.6$ GeV and $\mu = m = 4.75$ GeV with the MRST2002 NNLO parton densities is $\sigma^{\rm MRST2002NNLO}_{\rm NNLO-NNNLL+\zeta} = 28 \pm 9^{+15}_{-10}$ nb. The GRV98 densities give $\sigma^{\rm GRV98}_{\rm NNLO-NNNLL+\zeta} = 25^{+7+13}_{-8-9}$ nb. The first

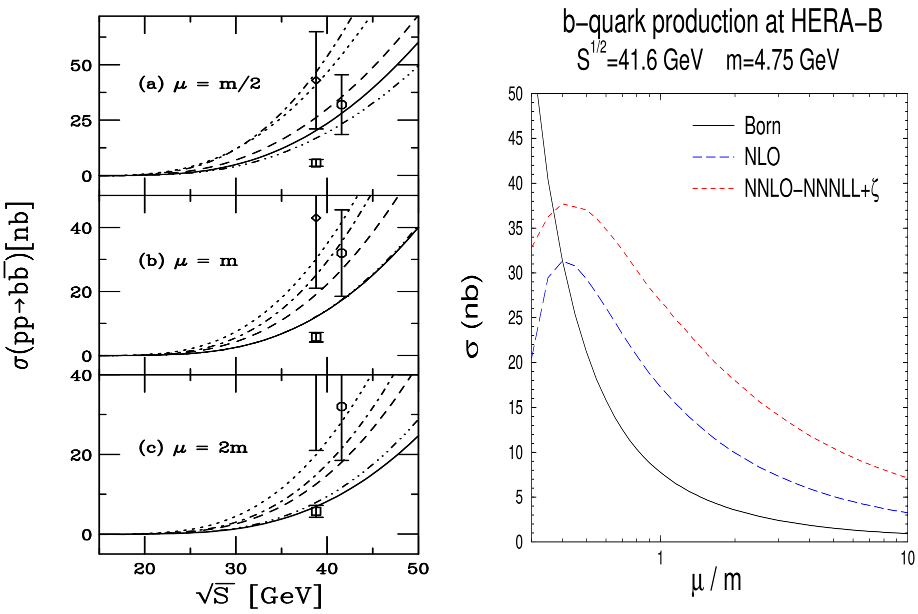


Figure 2. Beauty production in (left) $pp$ interactions and (right) at HERA-B.

uncertainty is due to the scale variation, $m/2 \leq \mu \leq 2m$, while the second is due to mass variation, 4.5 GeV $\leq m \leq$ 5 GeV.

Finally, we note that we find a reduction of the scale dependence for the NNLO-NNNLL+$\zeta$ $b\bar{b}$ cross section over all energies for both $\pi^- p$ and $pp$ interactions [5].

## 3 Charm production

We now turn to charm quark production. There is much more data on charm than bottom production.

In Fig. 3 we compare the $\pi^- p$ data from Refs. [17,18,19,20,21] with the exact NLO (solid), 1PI NNLO-NNLL (dashed) and 1PI NNLO-NNNLL+$\zeta$ (dot-dashed) cross sections, calculated with the GRV98 HO proton parton densities and the GRS pion parton densities. The mass of the charm quark is 1.2 GeV in (a) and (b), 1.5 GeV in (c) and (d), and 1.8 GeV in (e) and (f). On the left-hand side $\mu = m$ while, on the right, $\mu = 2m$.

Finally, we consider $pp \to c\bar{c}$ interactions. In Fig. 4, we compare the data from Refs. [17,18,22] with exact NLO, 1PI NNLO-NNLL and 1PI NNLO-NNNLL+$\zeta$ cross sections calculated with the MRST2002 NNLO proton parton densities.

We note that the $K$ factors are larger for charm than for beauty production and that the reduction of the scale dependence is not as large [5].

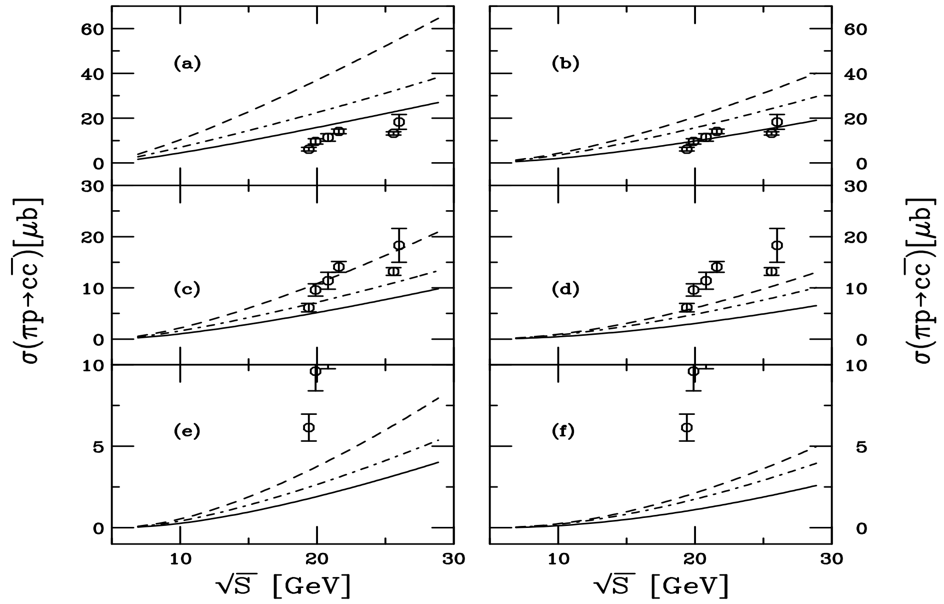


Figure 3. Charm quark production in $\pi^- p$ interactions.

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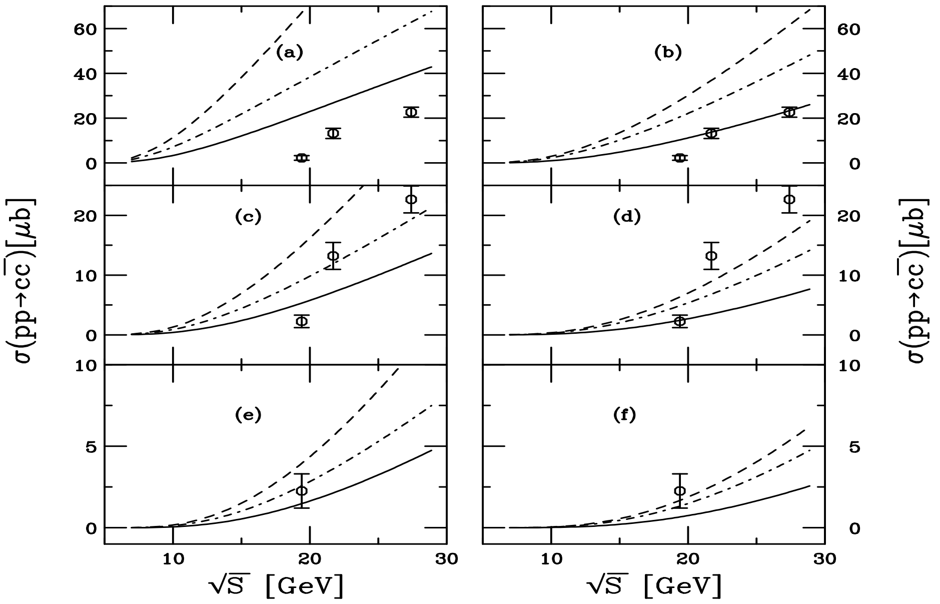


Figure 4. Charm quark production in $pp$ interactions.

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