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THEORETICAL STATUS OF THE TOP QUARK CROSS SECTION

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We discuss the most recent calculations of the top quark total cross section and transverse momentum distributions at the Tevatron and the LHC. These calculations include the soft-gluon corrections at next-to-next-to-leading order (NNLO). The soft NNLO corrections stabilize the scale dependence of the cross section.

Keywords: top quark; soft gluons; next-to-next-to-leading order

1. Introduction

Top quark pair production at the Tevatron and the LHC are processes that will establish fundamental properties of the top quark, including the mass and the cross section. The top quark is now actively studied in Run II at the Tevatron.[1] Top quark production at the Tevatron receives large corrections from soft gluons in the near threshold region.[2,3] The best estimates of the cross section include these corrections beyond next-to-leading order.

The calculation has been performed in both single-particle-inclusive (1PI) and pair-invariant-mass (PIM) kinematics.[4,5] In 1PI kinematics, $i(p_a)+j(p_b) \rightarrow t(p_1)+X[\bar{t}](p_2)$ with $ij = q\bar{q}$ or gg. 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 $s_4=s+t_1+u_1$. At threshold, $s_4 \rightarrow 0$ and the soft corrections take the form $[\ln^l(s_4/m^2)/s_4]_+$. In PIM kinematics, $i(p_a)+j(p_b) \rightarrow t\bar{t}(M)+X(k)$. At threshold, $z=M^2/s \rightarrow 1$ and the soft corrections are $[\ln^l(1-z)/(1-z)]_+$.

We denote the soft-gluon corrections by $\mathcal{D}_l(x_{\rm th}) \equiv [\ln^l(x_{\rm th})/x_{\rm th}]_+$ where $x_{\rm th}$ is defined as s_4 or $1-z$, depending on the kinematics. For the order α_s^n cor-

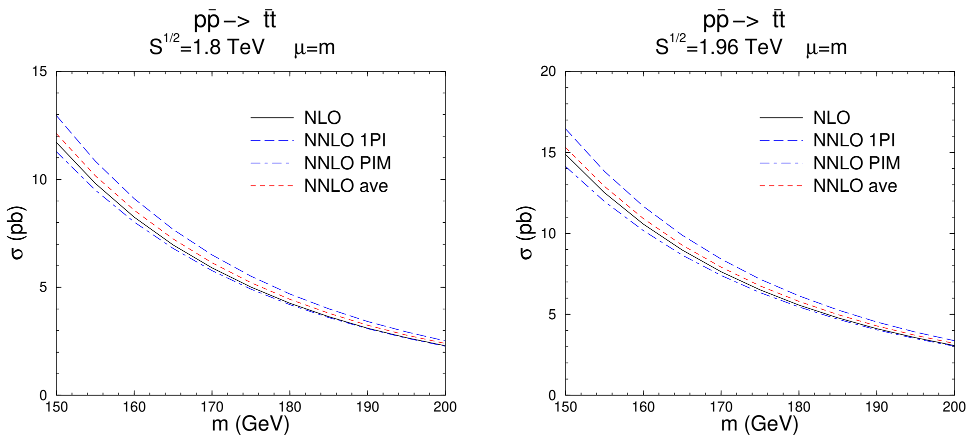

Fig. 1. Top quark pair production cross section at the Tevatron to NLO and NNLO. Here "NNLO ave" denotes the average of the 1PI and PIM results at NNLO. The left-hand side shows $\sqrt{S} = 1.8$ TeV while $\sqrt{S} = 1.96$ TeV is shown on the right-hand side. The results are shown for $\mu = m$.

rections, $l \leq 2n - 1$. At NLO, we have $\mathcal{D}_1(x_{\rm th})$ and $\mathcal{D}_0(x_{\rm th})$ terms. At NNLO, we have leading $\mathcal{D}_3(x_{\rm th})$, next-to-leading $\mathcal{D}_2(x_{\rm th})$, next-to-next-to-leading $\mathcal{D}_1(x_{\rm th})$, and next-to-next-to-next-to-leading logarithms (NNNLL) $\mathcal{D}_0(x_{\rm th})$. At present, all NNLO soft logarithms can be fully calculated except for some NNNLL two-loop[6] process-dependent terms which are expected to be numerically small.

We can formally resum the soft logarithms to all orders in α_s, but a resummed result is prescription dependent. If we expand to fixed order, however, we can derive prescription-independent results. A unified approach and a master formula for calculating these logarithms to NNLO in the fixed-order expansion for any process was presented in Ref. 7. It was applied to top pair production in Ref. 5 where logarithms through NNNLL at NNLO were calculated along with some virtual terms. We call this a NNLO-NNNLL+ζ calculation. Similar studies of related heavy quark and electroweak processes, including bottom and charm production,[8] FCNC top quark production,[9] charged Higgs production with a top quark,[10] and electroweak-boson production,[11] have also recently been completed.

2. Top quark pair production cross section

We now present our results for $p\bar{p} \to t\bar{t}$ production at the Tevatron. In Fig. 1 we plot the pair cross section as a function of top mass at 1.8 TeV (left) and 1.96 TeV (right). For $m = 175$ GeV, we find[5] $\sigma(\sqrt{S} = 1.8 \text{ TeV}) = 5.24 \pm 0.31$ pb and $\sigma(\sqrt{S} = 1.96 \text{ TeV}) = 6.77 \pm 0.42$ pb. The uncertainty is the kinematics ambiguity.

The scale dependence at the Tevatron Run II energy is shown on the left-hand side of Fig. 2. It is clear that the NNLO result is much more stable than the NLO. The top quark tranverse momentum, p_T, distribution at $\sqrt{S} = 1.96$ TeV, calculated in 1PI kinematics, is shown on the right-hand side of Fig. 2.

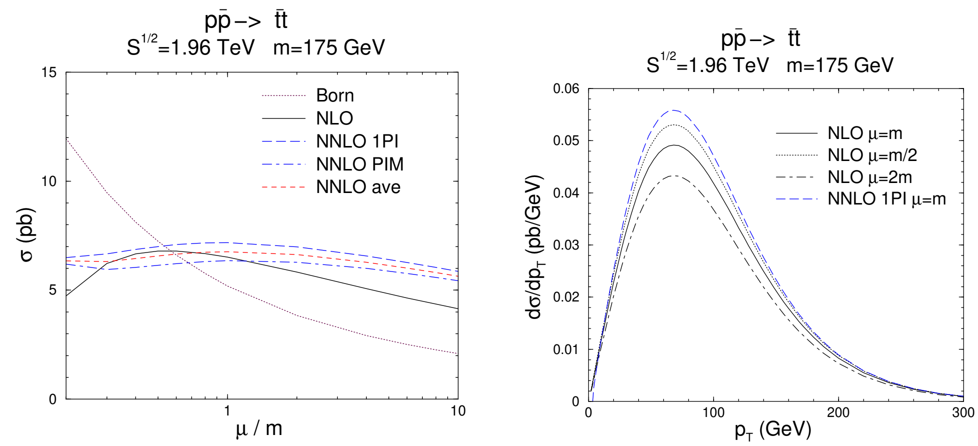

Fig. 2. The scale dependence of the $t\bar{t}$ cross section (left) and the top quark p_T distribution in 1PI kinematics (right) at $\sqrt{S} = 1.96$ TeV.

Finally, our best estimate for the $t\bar{t}$ total cross section at the LHC, $\sqrt{S} = 14$ TeV, is 873 pb for $m = 175$ GeV.[5]

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