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Anomalous tqV couplings and FCNC top quark production[1]

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Abstract

We discuss FCNC top quark production via anomalous tqV couplings at the Tevatron and HERA colliders. We calculate higher-order soft-gluon corrections to such processes and demonstrate the stabilization of the cross section when these corrections are included.

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1 Introduction

Flavor-changing neutral-current (FCNC) processes involving the top quark appear in several models of physics beyond the Standard Model. The effective Lagrangian involving anomalous tqV couplings can be written as $\Delta\mathcal{L}^{eff} = \frac{1}{\Lambda}\,\kappa_{tqV}\,e\,\bar{t}\,\sigma_{\mu\nu}\,q\,F_V^{\mu\nu} + h.c.$ where κ_{tqV} is the anomalous coupling, with q denoting an up or charm quark and V a photon or Z-boson with field tensor $F_V^{\mu\nu}$; $\sigma_{\mu\nu} = (i/2)(\gamma_\mu\gamma_\nu - \gamma_\nu\gamma_\mu)$ with γ^μ the Dirac matrices; and Λ is an effective scale which we set equal to the top quark mass, m.

The present TeV energy scale colliders – Tevatron and HERA– can probe FCNC interactions in the top-quark sector and set limits on $\kappa_{tq\gamma}$ and κ_{tqZ}. However, there are large uncertainties in the lowest-order results from variation of the factorization/renormalization scales, μ. Therefore the stabilization of the cross section for these FCNC processes is timely and important. We have calculated next-to-leading order (NLO) and next-to-next-to-leading order (NNLO) soft-gluon corrections for the following processes: $gu \to tZ$, $gu \to t\gamma$, and $uu \to tt$ at the Tevatron [1]; and $eu \to et$ at HERA [1, 2]. As a result, we show that inclusion of QCD corrections significantly stabilizes the cross sections.

2 FCNC top quark cross sections

We define $s_4 = s + t + u - \sum m^2$, with s, t, u standard kinematical invariants, and where the sum is over the masses squared of the particles in the scattering. At threshold $s_4 \to 0$. The soft-gluon corrections [3, 4] are of the form $[(\ln^l(s_4/m^2))/s_4]_+$, where $l \leq 2n-1$ for the order α_s^n corrections. These corrections are expected to dominate the cross section in the near-threshold region, which is relevant for the processes studied here. The leading logarithms (LL) are those with $l = 2n-1$ while the next-to-leading logarithms (NLL) are those with $l = 2n-2$. Here we calculate NLO and NNLO corrections in α_s at NLL accuracy, i.e. keeping LL and NLL at each order in α_s. We denote them as NLO-NLL and NNLO-NLL, respectively, and calculate them using the master formulas in Ref. [5].

Figure 1: Tree-level diagrams for $gu \to tZ$.

First we study the process $gu \to tZ$ in $p\bar{p}$ collisions at the Tevatron. In Fig. 1 we show the lowest-order Feynman diagrams.

In Fig. 2 we show plots versus top quark mass of the Born, NLO-NLL, and NNLO-NLL cross sections and of various K-factors, which are defined as ratios of cross sections at different orders. Note that K-factors are independent of the notation/specification for the anomalous couplings. We have set the scale μ equal to the top quark mass and set $\kappa_{tuZ} = 0.1$.

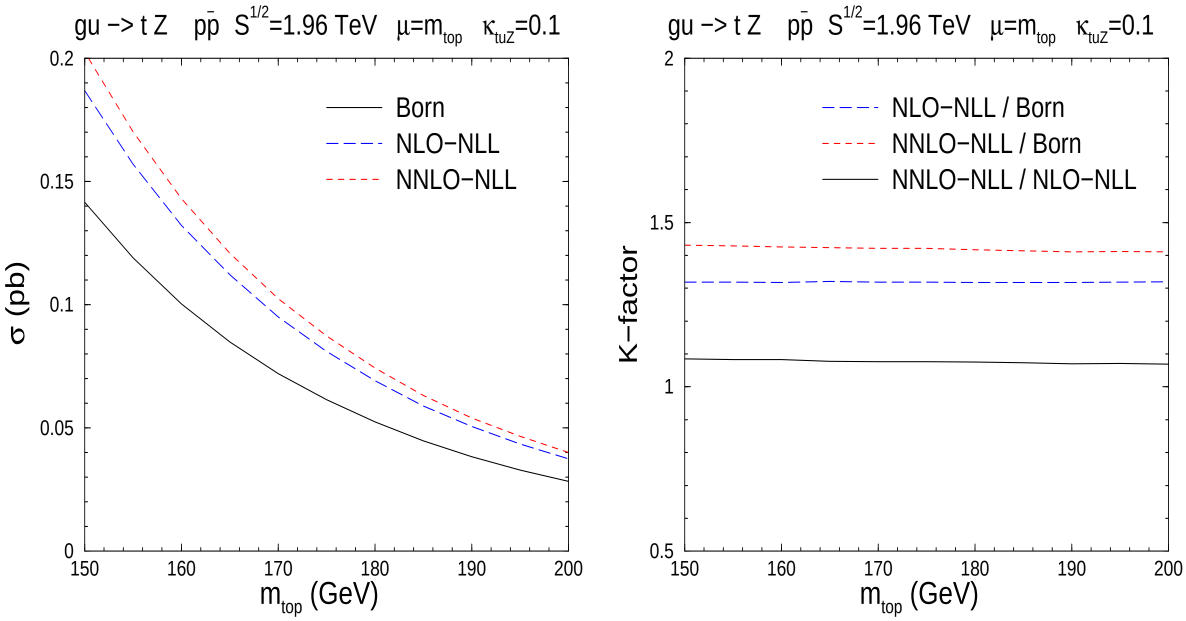

Figure 2: Cross sections (left) and K-factors (right) for $gu \to tZ$ at the Tevatron.

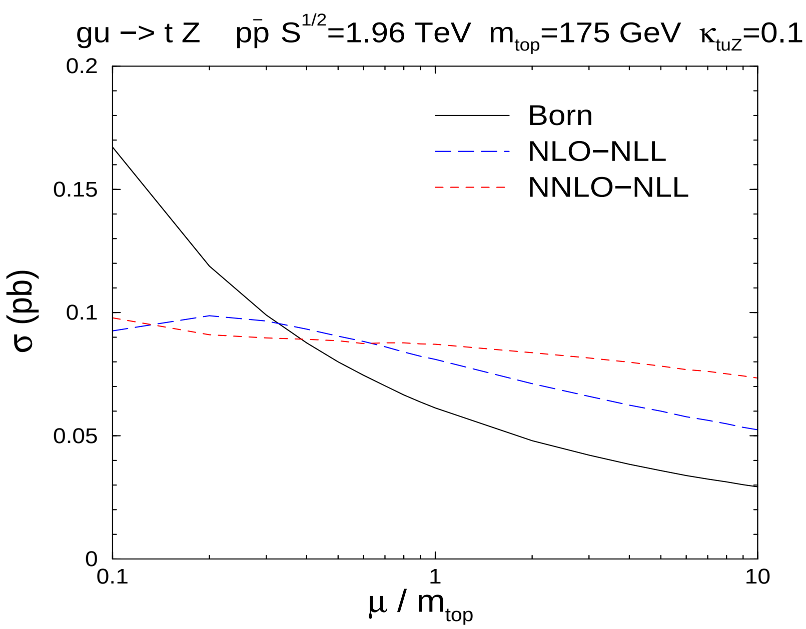

Figure 3: The scale dependence of the $gu \to tZ$ cross section at the Tevatron.

In Fig. 3 we plot the scale dependence of the cross section for a top mass $m = 175$ GeV. It's clear that the dependence of the cross section on scale is significantly decreased when we add the NLO-NLL and NNLO-NLL corrections. For $\mu = m = 175$ GeV, $\kappa_{tuZ} = 0.1$ and $\sqrt{S} = 1.96$ TeV we find $\sigma^{gu\to tZ}_{NNLO-NLL} = 87^{+2}_{-3}$ fb where the uncertainty comes from scale variation between $m/2$ and $2m$. We note that the cross section for the process

$gc \to tZ$, involving the charm quark, is negligible by comparison. We also note that the cross section for anti-top production, $g\bar{u} \to \bar{t}Z$, is the same as for top production.

The results for $gu \to t\gamma$ are qualitatively the same – we find again stabilization of the cross section versus scale variation, as well as a similar cross section level ($\sigma^{gu\to t\gamma}_{NNLO-NLL} = 95^{+17}_{-11}$ fb for $\mu = m = 175$ GeV and $\kappa_{tu\gamma} = 0.1$). In the case of the process $uu \to tt$ the cross section is also stabilized; however, this process is qualitatively different: it has a significantly lower cross section ($\sigma^{uu\to tt}_{NNLO-NLL} = 1.74^{+0.00}_{-0.02}$ fb for $\mu = m = 175$ GeV and $\kappa_{tuZ} = \kappa_{tu\gamma} = 0.1$) but a much cleaner signature [1].

Figure 4: Tree-level diagrams for $eu \to et$.

Next we study the process $eu \to et$ in ep collisions at HERA [6, 7, 8]. In Fig. 4 we show the lowest-order Feynman diagrams. In Fig. 5 we show plots of the Born, NLO-NLL,

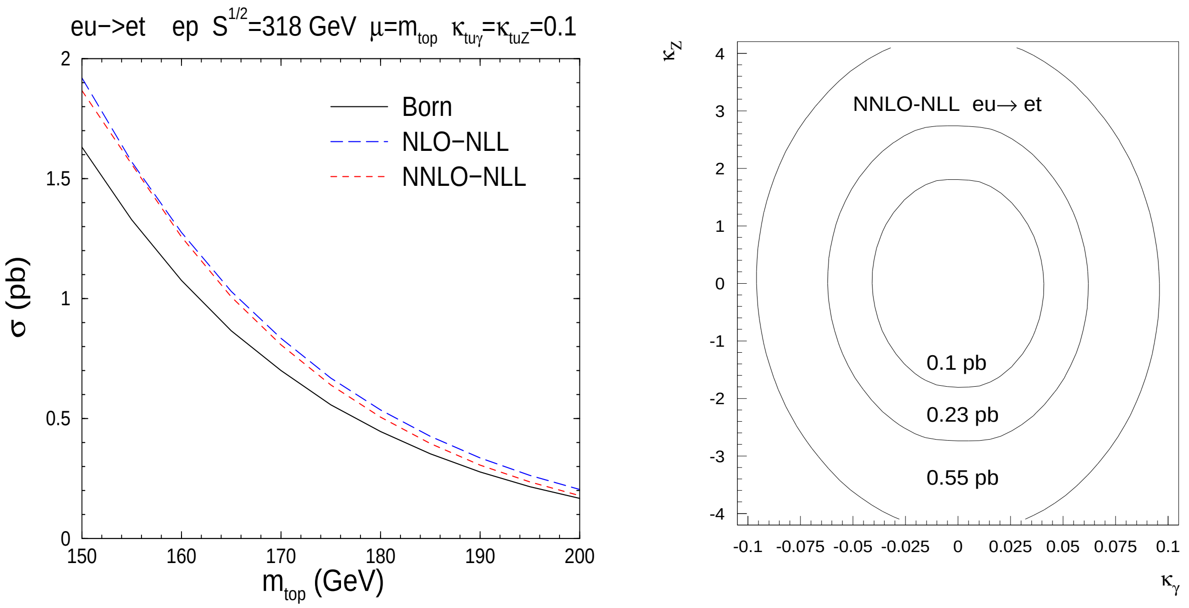

Figure 5: Cross sections (left) and HERA reach (right) for the process $eu \to et$.

and NNLO-NLL cross sections versus top mass, and of contour levels in the $\kappa_{tu\gamma}, \kappa_{tuZ}$ plane. We have set $\mu = m$. It is evident that HERA is much more sensitive to the $\kappa_{tu\gamma}$ coupling than to κ_{tuZ}. The NNLO-NLL cross section at HERA for $\mu = m = 175$ GeV, $\kappa_{tu\gamma} = \kappa_{tuZ} = 0.1$ and $\sqrt{S} = 318$ GeV is $\sigma^{eu\to et}_{NNLO-NLL} = 0.64^{+0.05}_{-0.04}$ pb, where again the uncertainty comes from scale variation between $m/2$ and $2m$. We note that almost all of the cross section comes from the κ_{γ} coupling. We also note that contributions from charm are negligible. In the case of $e\bar{t}$ production, involving the anti-top, the cross section is quite small $\sigma_{NNLO-NLL}^{e\bar{u}\to e\bar{t}} = 0.0079$ pb, and thus assymetrical to et production.

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