DIFFERENTIAL DISTRIBUTIONS FOR SINGLE TOP QUARK PRODUCTION AT THE LHEC

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INTRODUCTION

The Large Hadron Electron Collider (LHeC) is a proposed facility of using a newly built electron beam to collide with the intense hadron beams of the LHC. The LHeC will provide a cleaner environment for the study of single top quark production.The single top quark production have been used to measure the CKM matrix element Vtb and to extract the top-quark mass. Besides, various new physics have been searched for at the LHC with no discovery yet. For the LHeC, single top quark production via charged-current DIS is dominant in all the top quark production channels. We can utilize this unprecedented facility to measure the precise properties of the top quark and search for new physics. [1]

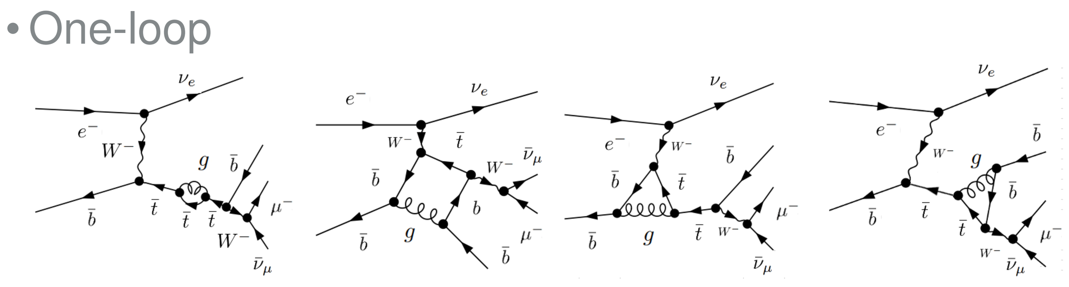
NLO CALCULATION

The generic processes under consideration:

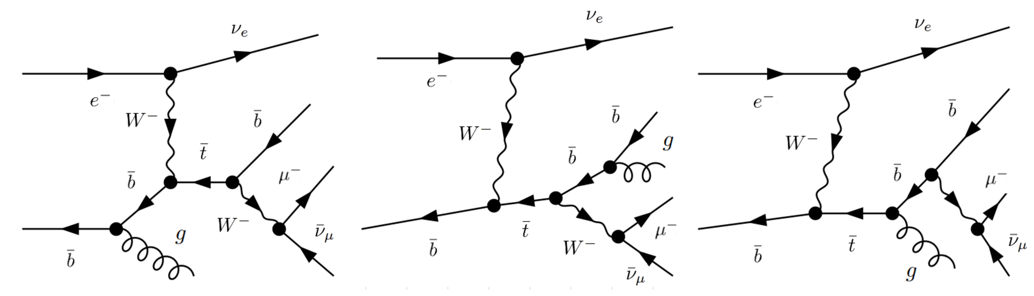
- $e^- \bar{b} \to \nu_e \bar{t} \to \nu_e \ell^- \bar{\nu}_\ell \bar{b}$
- $e^- b \to \nu_e \ell^- \bar{\nu}_\ell b$

Feynman diagrams:

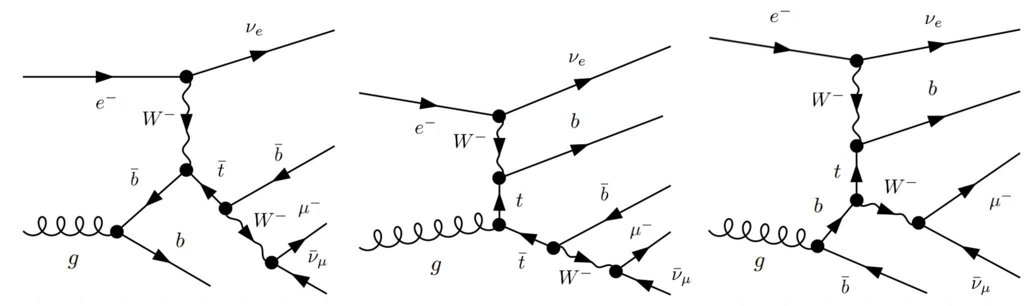
- One-loop



- $\bar{b}$ initial-state real emission



- g initial-state real emission



We adopt the dipole subtraction method to calculate the NLO cross section: [2]

$$\begin{aligned}&\sigma^{\mathrm{NLO}\{5\}}(p) + \sigma^{\mathrm{NLO}\{4\}}(p) + \int_0^1 dx \hat{\sigma}^{\mathrm{NLO}\{4\}}(x; xp) \\ &\equiv \int_5 \left[\left(\mathrm{d}\sigma^{\mathrm{R}}(p) \right)_{\epsilon=0} - \left(\sum_{\text{dipoles}} \mathrm{d}\sigma^{\mathrm{B}}(p) \otimes \mathrm{d}V_{\text{dipole}} \right)_{\epsilon=0} \right] \\ &+ \int_4 \left[\mathrm{d}\sigma^{\mathrm{V}}(p) + \mathrm{d}\sigma^{\mathrm{B}}(p) \otimes \boldsymbol{I} \right]_{\epsilon=0} \\ &+ \int_0^1 dx \int_4 \left[\mathrm{d}\sigma^{\mathrm{B}}(xp) \otimes (\boldsymbol{P}+\boldsymbol{K})(x) \right]_{\epsilon=0} \end{aligned} \tag{1}$$

NUMERICAL RESULT

We use $m_t = 172.5\,\mathrm{GeV}$ at the LHeC with an electron beam energy of 70 GeV and a proton beam energy of 7 TeV. The selection cuts are:

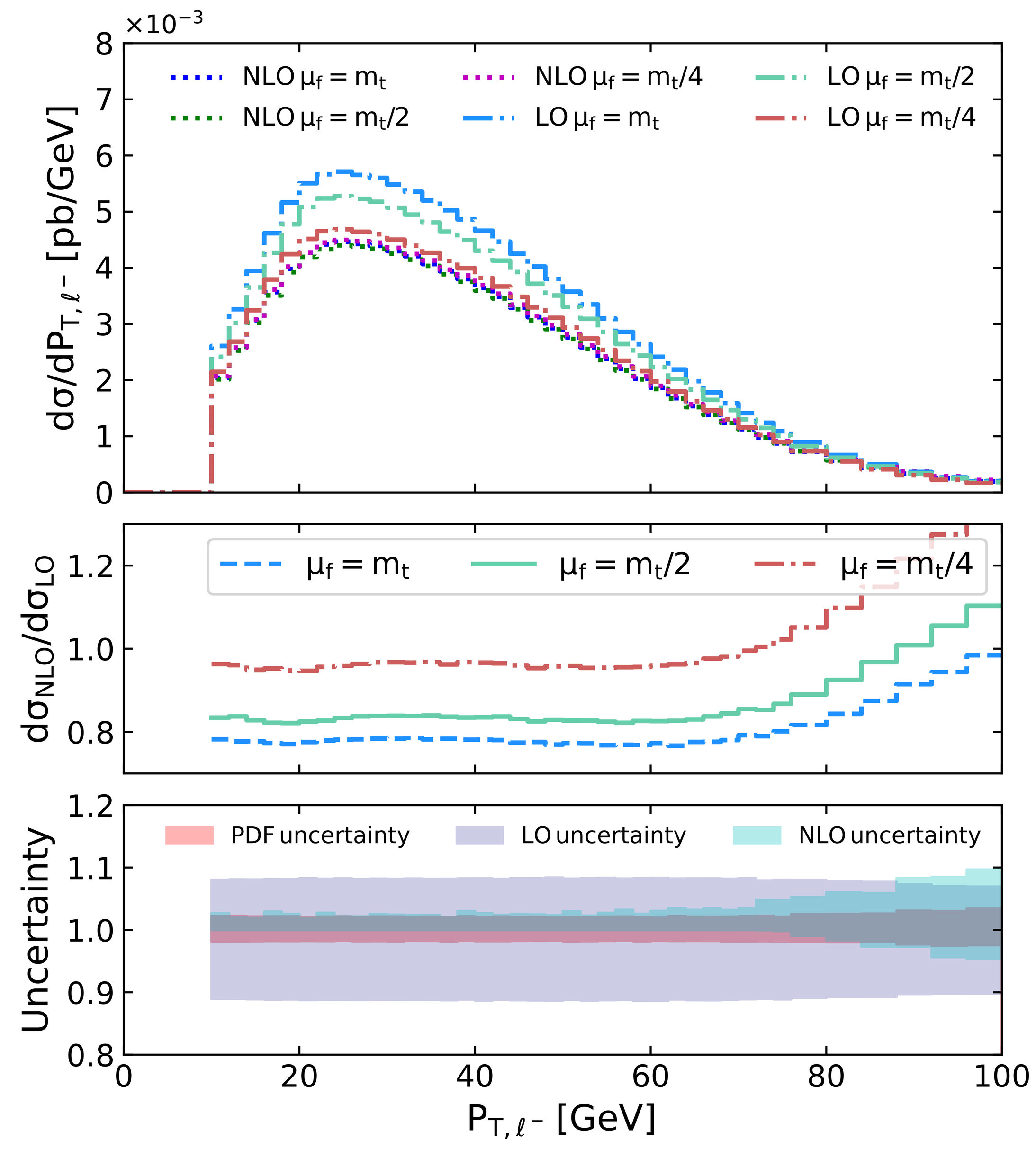
$$\begin{aligned}|\eta_{\ell^-}| < 5,\ p_{T,\ell^-} > 10\,\mathrm{GeV} \\ |\eta_j| < 5,\ \ p_{T,jet} > 30\,\mathrm{GeV}\end{aligned} \tag{2}$$

Fiducial cross sections with scale choice of $m_t/2$:

fiducial [pb]	LO	NLO
$\sigma[total]$	$0.242^{+8.1\%}_{-11\%}$	$0.205^{+0.76\%}_{+3.1\%}$
$\sigma[\bar{b}]$	0.242	0.207
$\sigma[b]$	5.01×10^{-4}	4.62×10^{-4}
$\sigma[g]$		-2.95×10^{-3}

DIFFERENTIAL DISTRIBUTION

Transverse momentum distributions of the charged lepton(ℓ^-) with fiducial cuts applied at LO and NLO with a nominal scale choice of $m_t/2$ and alternative scale choices of $m_t/4$ and m_t.



TOP QUARK MASS

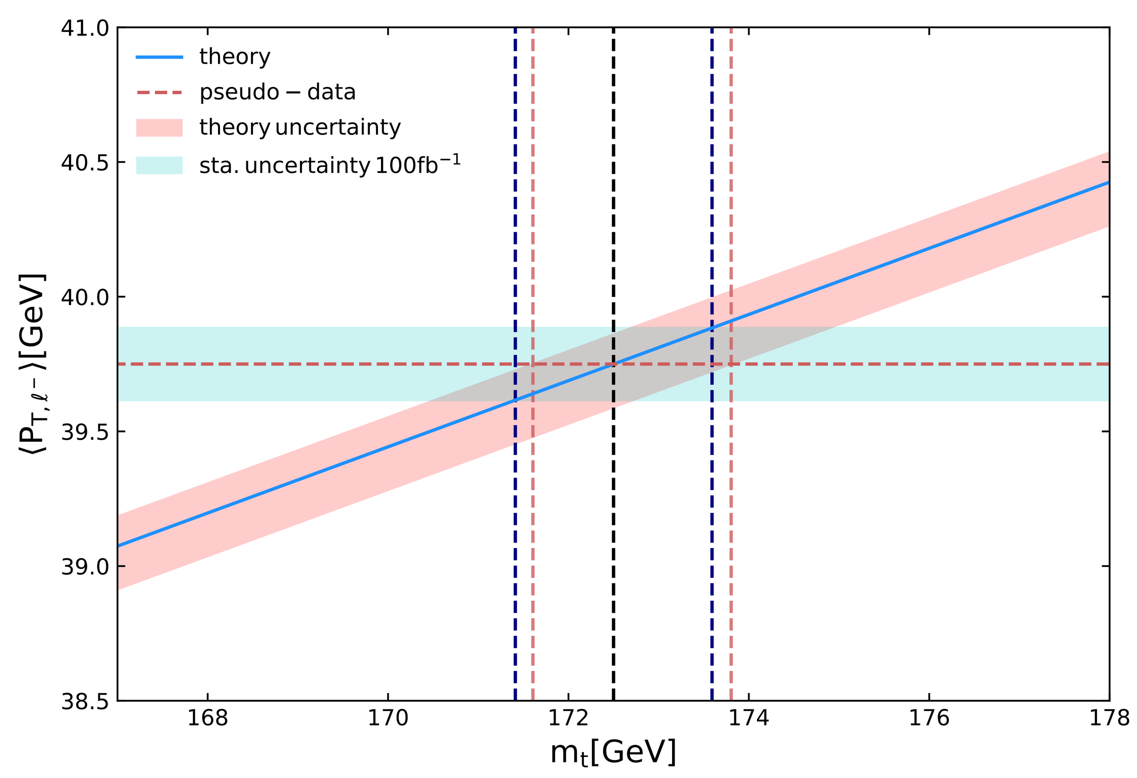
We use a linear model on dependence of the average P_{T,ℓ^-} on the top-quark mass

$$\langle p_{T,\ell^-} \rangle = p_{T,0} + \lambda \left[\frac{m_t}{\mathrm{GeV}} - 172.5 \right]. \tag{3}$$

This table shows various parametric uncertainties, expected statistical error and dependence on the top-quark mass, of the average P_{T,ℓ^-}.

$[GeV]$	$\delta\langle p_{T,\ell^-}\rangle$
$PDFs(68\%C.L.)$	$+0.0126 - 0.0081$
$\alpha_S(m_Z)(0.001)$	$+0.0034 - 0.0031$
$m_b(0.5GeV)$	± 0.0011
$Statistical\ error$	0.1341
$m_t(1.0GeV)$	0.1225

We present the projection of the top-quark mass measurement with a hypothetical value of 172.5 GeV. Vertical lines indicate various uncertainties of the extracted top-quark mass.



SIGNAL OF NEW PHYSICS

We can write the effective Wtb vertex including SM contributions and those from new physics as [3]

$$\begin{aligned}\mathcal{L}_{tbW} = &-\frac{g}{\sqrt{2}} \bar{b}(\gamma^\mu ((V_{tb} + \delta V_L) P_L + V_R P_R) \\ &- \frac{i\sigma^{\mu\nu} q_\nu}{m_W} (g_L P_L + g_R P_R)) t W_\mu^- + h.c.\end{aligned} \tag{4}$$

We consider the asymmetry of various observables including $\Delta\eta(b,\ell^-)$, $\Delta\varphi(b,\ell^-)$, $\Delta\varphi(b,\not{E}_T)$, $\Delta\varphi(\ell^-,\not{E}_T)$ and cos(b,ℓ^-):

$$A(X, X_0) = \frac{\sigma(X > X_0) - \sigma(X < X_0)}{\sigma(X > X_0) + \sigma(X < X_0)} \tag{5}$$

$Observable$	LO	NLO	$stats.error$
$\Delta\eta(b,\ell^-)$	-0.374^{-0}_{+0}	$-0.411^{+0.007}_{-0.008}$	0.006
$\Delta\varphi(b,\ell^-)$	$0.420^{+0.001}_{-0.002}$	$0.388^{+0.004}_{-0.002}$	0.006
$\Delta\varphi(b,\not{E}_T)$	0.805^{-0}_{+0}	$0.746^{+0.012}_{-0.013}$	0.005
$\Delta\varphi(\ell^-,\not{E}_T)$	0.346^{+0}_{-0}	$0.292^{-0.008}_{+0.010}$	0.007
$cos(b,\ell^-)$	$0.419^{-0.009}_{+0.011}$	$0.548^{-0.018}_{+0.018}$	0.006

We can set constraints on the new physics by comparing the SM predictions with the projected measurements. We show the projected bounds on the effective couplings g_R and δV_L at the 95% CL.

	NLO	$NLO + \Delta scale$
$g_R(\sigma_{tot})$	[-0.039,0.036]	[-0.057,0.050]
$g_R(\Delta\eta(b,\ell^-))$	[-0.060,0.051]	[-0.071,0.059]
$\delta V_L(\sigma_{tot})$	[-0.0073,0.0071]	[-0.010,0.010]

CONCLUSION

We present a detailed phenomenological study of the single top (anti-)quark production with leptonic decays at the LHeC at NLO in QCD. The calculations are based on the dipole subtraction method and the complex-mass scheme. The NLO corrections reduce the inclusive cross section by 8.5%. While in a typical fiducial region, the NLO corrections reduce the cross section by 14%. We also present predictions of various distributions. The NLO predictions exhibits strong stability under scale variations for both the total cross section and the distributions. The PDF uncertainty can be larger than the scale variations at the NLO depending on the kinematic region considered.

We find that the statistical error of the extracted top-quark mass amounts to 1.1 GeV. The theoretical uncertainty due to the scale variations at the NLO are +1.3 GeV and −0.9 GeV. Besides, we study the possible improvement on searches of new physics with the NLO predictions of the single top quark production. We obtain better constraints on Wtb effective couplings g_R and δV_L using the NLO predictions comparing with the LO predictions. We anticipate our best bounds on g_R and δV_L at the 95% CL being [-0.057, 0.050] and [-0.010, 0.010] respectively as derived using the NLO SM predictions with scale variations.

References

[1] Meisen Gao et al. "Differential distributions for single top quark production at the LHeC". In: *Phys. Rev. D* 104.5 (2021), p. 053005. DOI: 10.1103/PhysRevD.104.053005. arXiv: 2103.15846 [hep-ph].

[2] S. Catani et al. "A General algorithm for calculating jet cross-sections in NLO QCD". In: *Nucl. Phys. B* 485 (1997). [Erratum: Nucl.Phys.B 510, 503–504 (1998)], pp. 291–419. DOI: 10.1016/S0550-3213(96)00589-5. arXiv: hep-ph/9605323.

[3] I. A. Sarmiento-Alvarado et al. "Analysis of top-quark charged-current coupling at the LHeC". In: *J. Phys. G* 42.8 (2015), p. 085001. DOI: 10.1088/0954-3899/42/8/085001. arXiv: 1412.6679 [hep-ph].

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