Soft gluons in top processes at high energies

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- **Higher-order soft-gluon corrections**
- **Top-pair and tW production**

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Soft-gluon corrections

partonic processes (in general $2 \to n$)

$$f_1(p_1) + f_2(p_2) \to t(p_t) + X$$

define $s = (p_1 + p_2)^2$, $t = (p_1 - p_t)^2$, $u = (p_2 - p_t)^2$ and $s_4 = s + t + u - p_t^2 - p_X^2$

At partonic threshold $s_4 \to 0$

Soft corrections $\left[\frac{\ln^k(s_4/m_t^2)}{s_4}\right]_+$ with $k \leq 2n-1$ for the order α_s^n corrections

Resum these soft corrections for the double-differential cross section

Finite-order expansions-no prescription needed

Approximate NNLO (aNNLO) and N^{3}LO (aN^{3}LO) predictions

for cross sections and differential distributions (single and double)

Soft-gluon Resummation

factorized expression for the cross section in moment space

$$d\sigma^{f_1 f_2 \to tX}(N,\epsilon) = H_{IL}^{f_1 f_2 \to tX}\left(\alpha_s(\mu_R)\right) S_{LI}^{f_1 f_2 \to tX}\left(\frac{m_t}{N\mu_F}, \alpha_s(\mu_R)\right)$$
$$\times \psi_1\left(N_1, \mu_F, \epsilon\right) \psi_2\left(N_2, \mu_F, \epsilon\right) \prod J\left(N, \mu_F, \epsilon\right)$$

$H_{IL}^{f_1 f_2 \to tX}$ **is hard function and** $S_{LI}^{f_1 f_2 \to tX}$ **is soft function**

$S_{LI}^{f_1 f_2 \to tX}$ **satisfies the renormalization group equation**

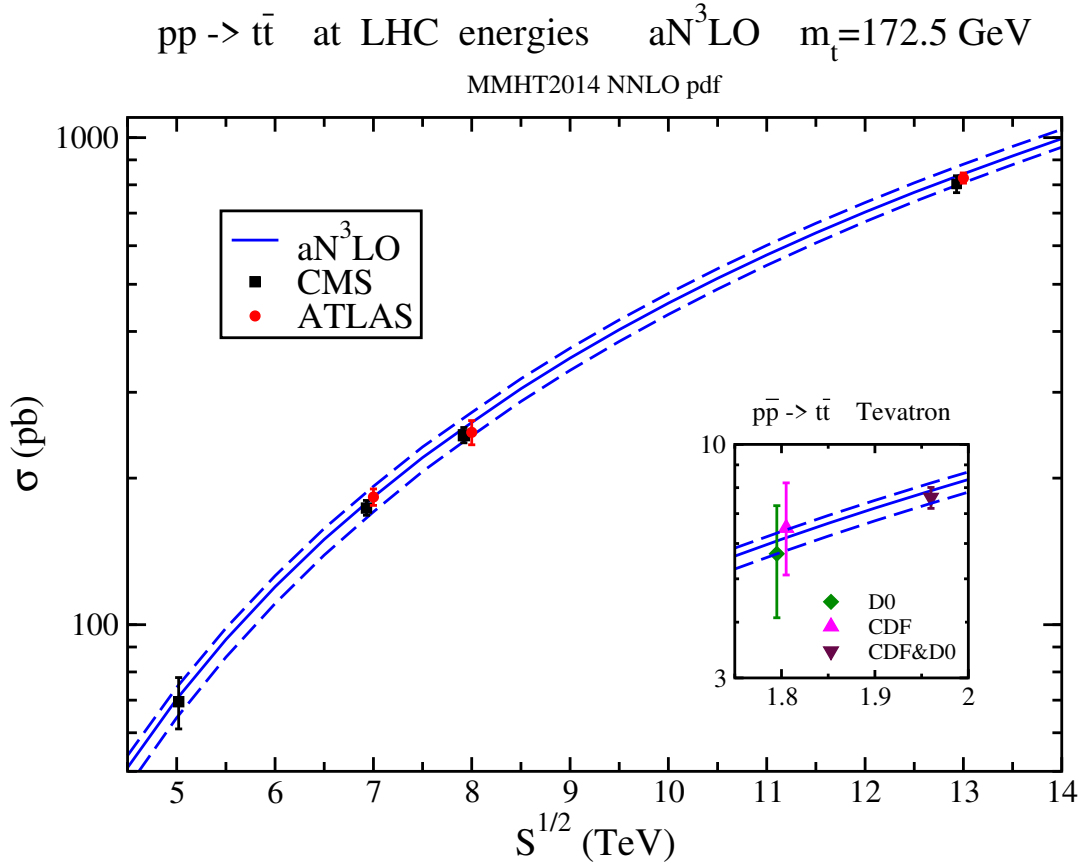
$$\left(\mu_R \frac{\partial}{\partial \mu_R} + \beta(g_s)\frac{\partial}{\partial g_s}\right) S_{LI}^{f_1 f_2 \to tX} = -(\Gamma_S^\dagger)_{LK}^{f_1 f_2 \to tX} S_{KI}^{f_1 f_2 \to tX} - S_{LK}^{f_1 f_2 \to tX} (\Gamma_S)_{KI}^{f_1 f_2 \to tX}$$

Soft anomalous dimension $\Gamma_S^{f_1 f_2 \to tX}$ **controls the evolution of the soft function which gives the exponentiation of logarithms of** N

At NLL accuracy we need one-loop soft anomalous dimensions

At NNLL need two-loop and at N^{3}LL three-loop soft anomalous dimensions

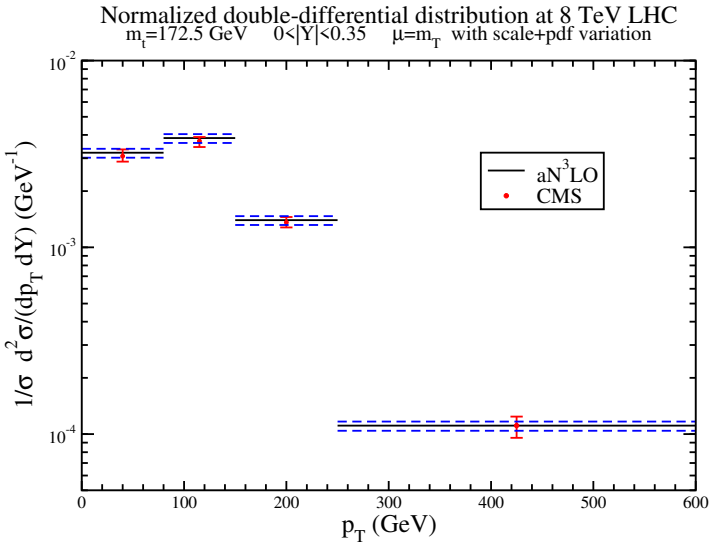
Top-antitop pair production

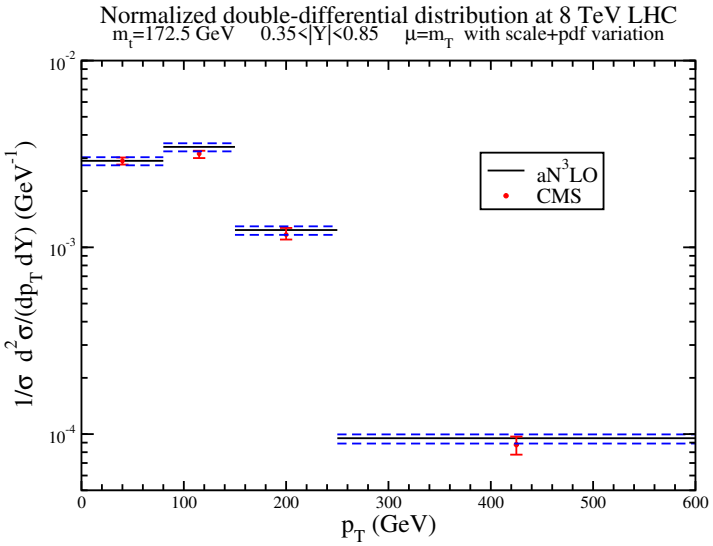


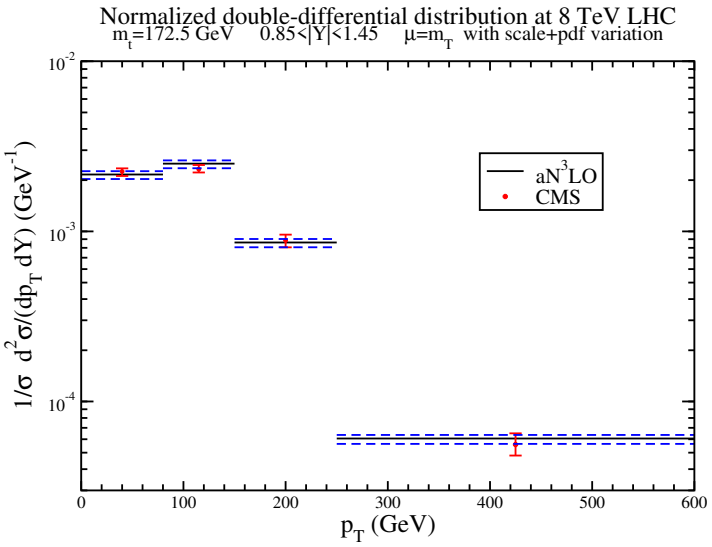
soft-gluon corrections dominant at LHC for total & differential cross sections

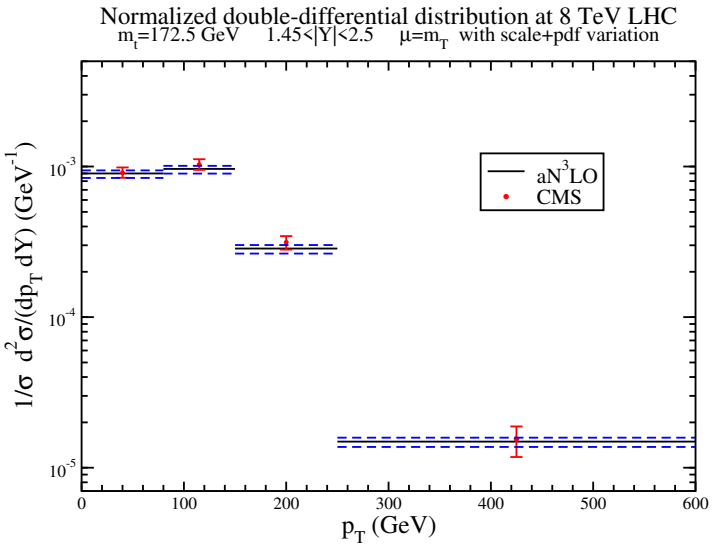
also dominant at higher energies at future colliders → more studies

Top double-differential distributions in $t\bar{t}$ production

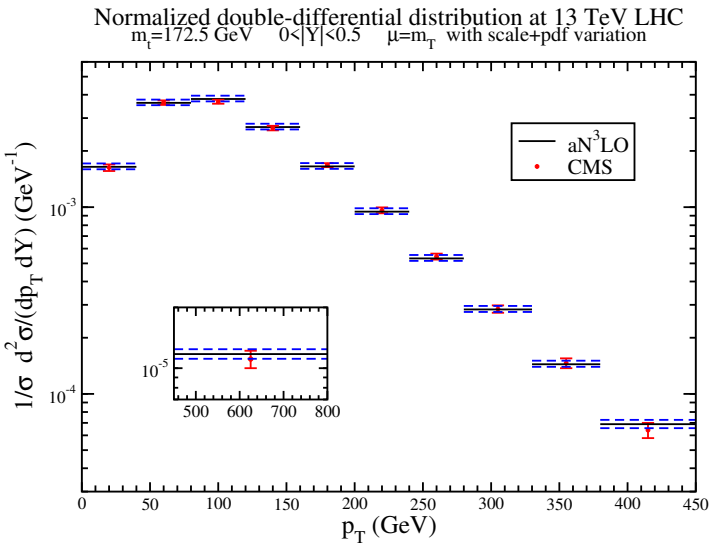


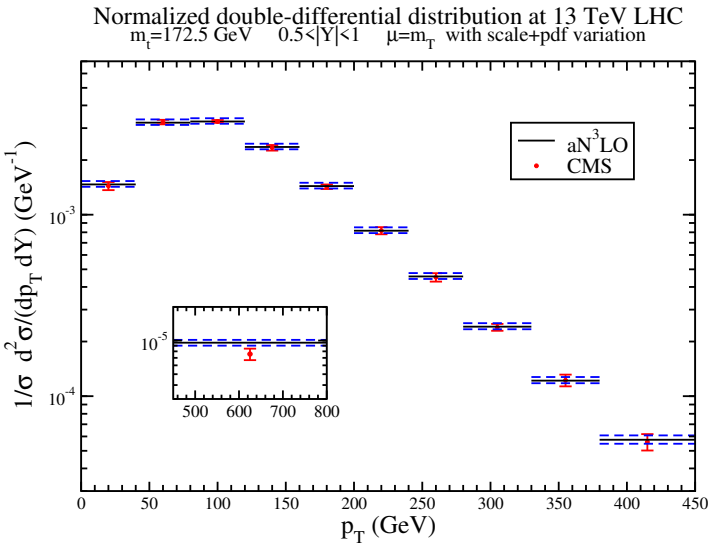


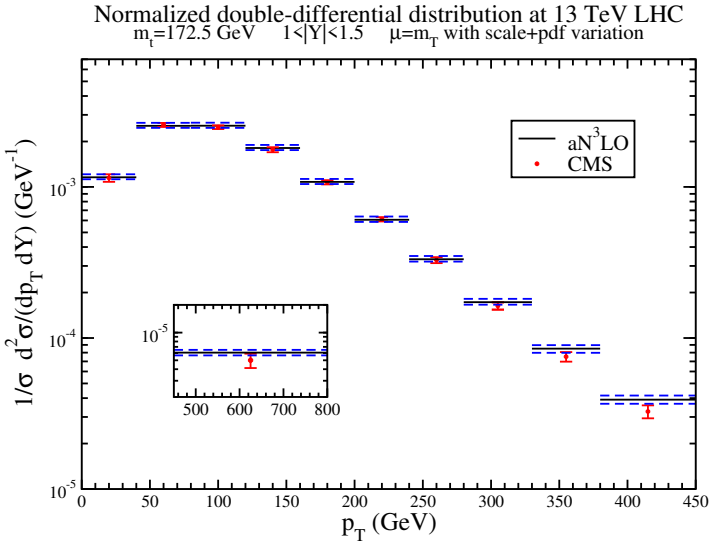


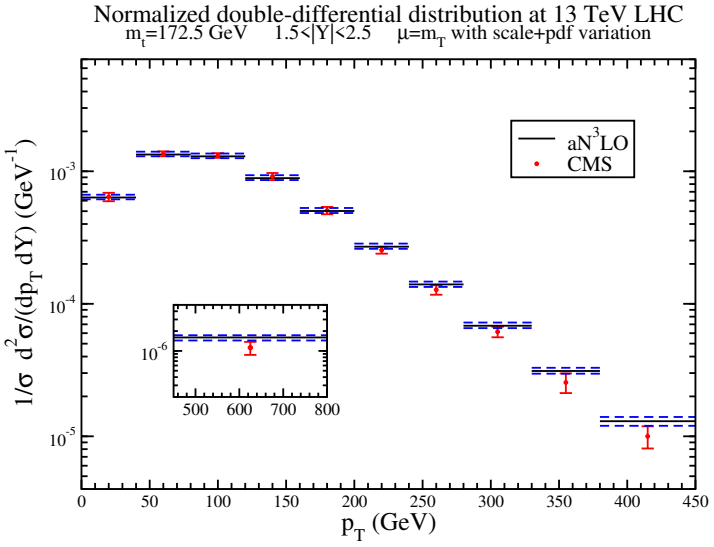


Top double-differential distributions in $t\bar{t}$ production









tW production

At one loop

$$\Gamma_S^{(1)bg\to tW} = C_F\left[\ln\left(\frac{m_t^2-t}{m_t\sqrt{s}}\right)-\frac{1}{2}\right]+\frac{C_A}{2}\ln\left(\frac{u-m_t^2}{t-m_t^2}\right)$$

At two loops

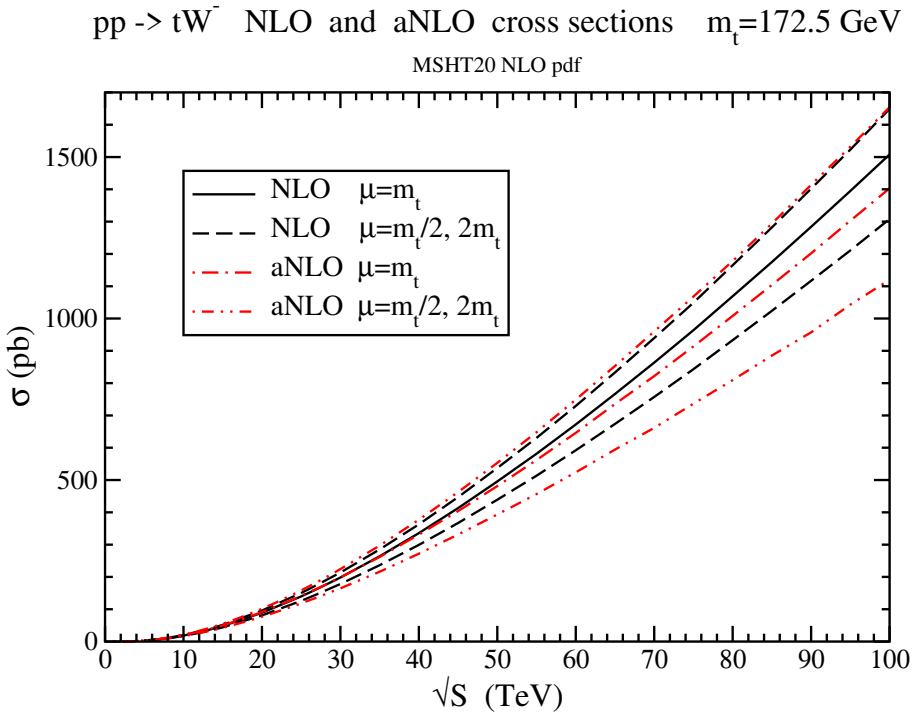
$$\Gamma_S^{(2)bg\to tW} = K_2\,\Gamma_S^{(1)bg\to tW}+\frac{1}{4}C_FC_A(1-\zeta_3)$$

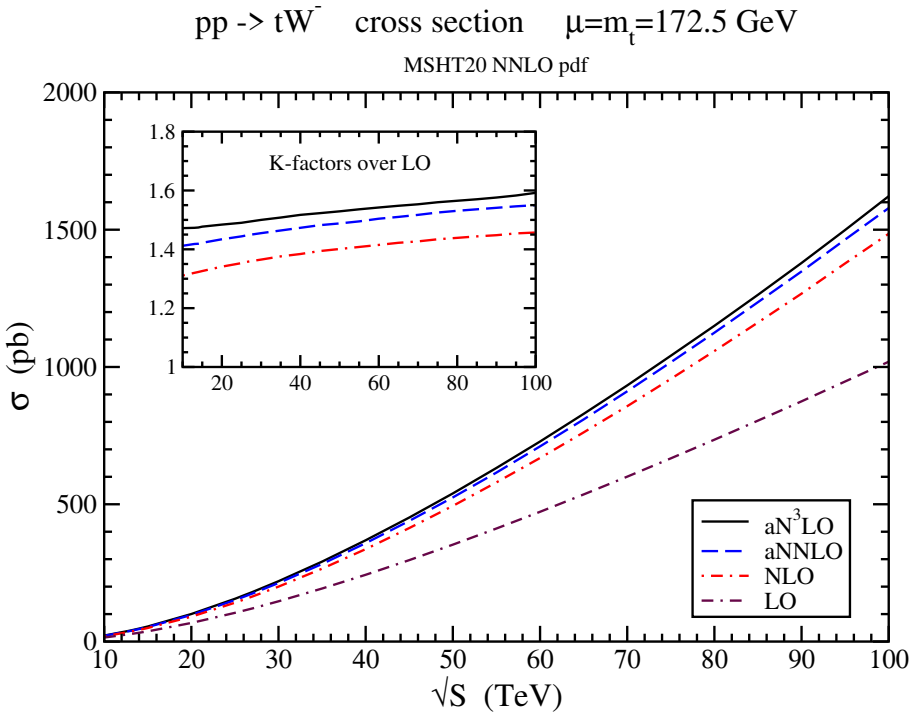
At three loops

$$\Gamma_S^{(3)bg\to tW} = K_3\,\Gamma_S^{(1)bg\to tW}+\frac{1}{2}K_2C_FC_A(1-\zeta_3)+C_FC_A^2\left(-\frac{1}{4}+\frac{3}{8}\zeta_2-\frac{\zeta_3}{8}-\frac{3}{8}\zeta_2\zeta_3+\frac{9}{16}\zeta_5\right)$$

tW production at high-energy colliders

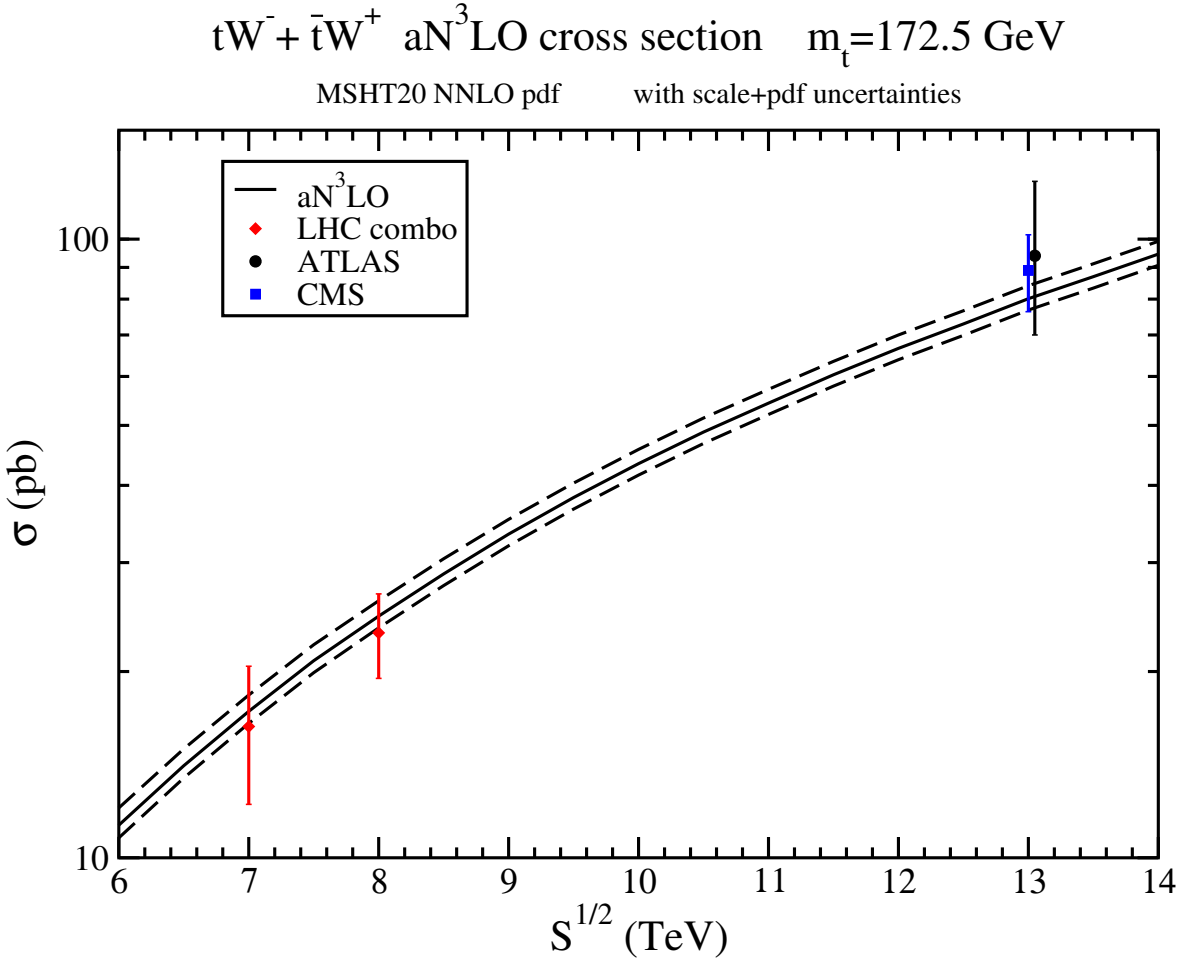
(with Nodoka Yamanaka, arXiv:2102.11300)





The aNLO cross section is a very good approximation to the complete NLO result for all forseeable collider energies
$\rightarrow$ the soft-gluon corrections are dominant

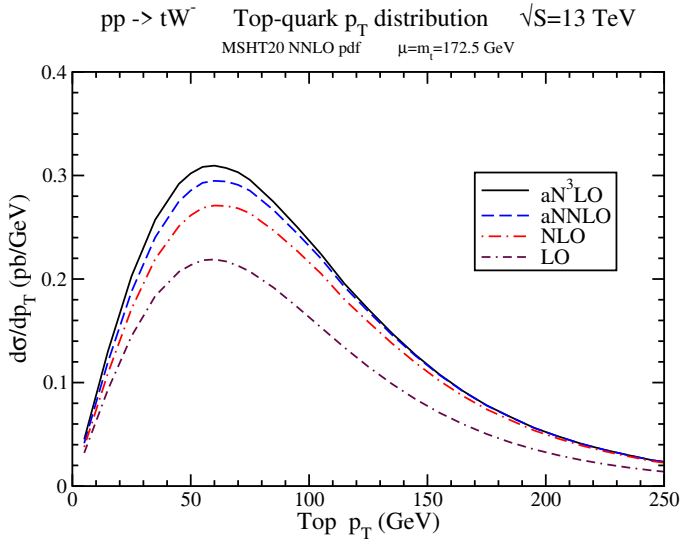
The aNNLO and aN^{3}LO corrections (at NNLL) are also significant

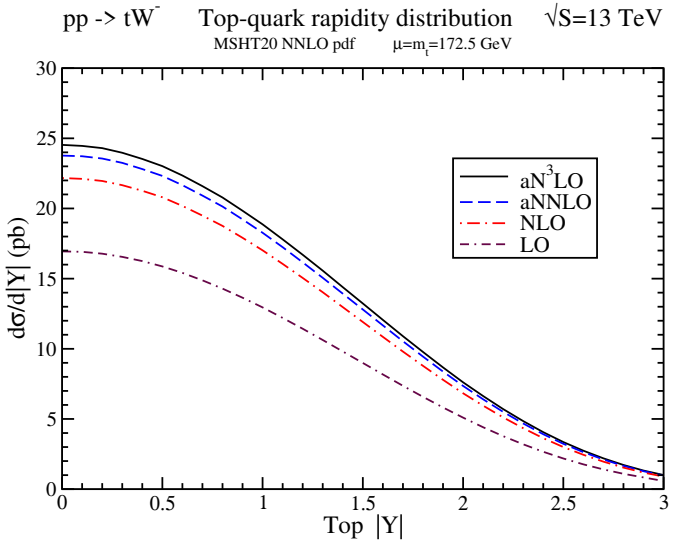


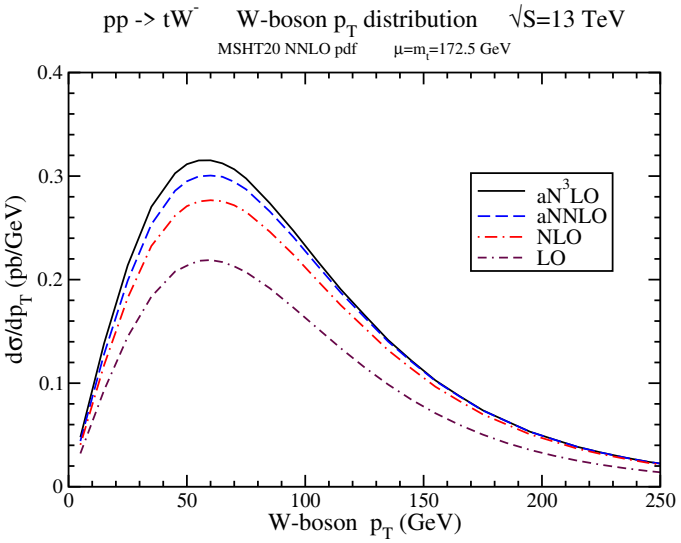
The aN^{3}LO cross section with scale and pdf (MSHT20) uncertainty is

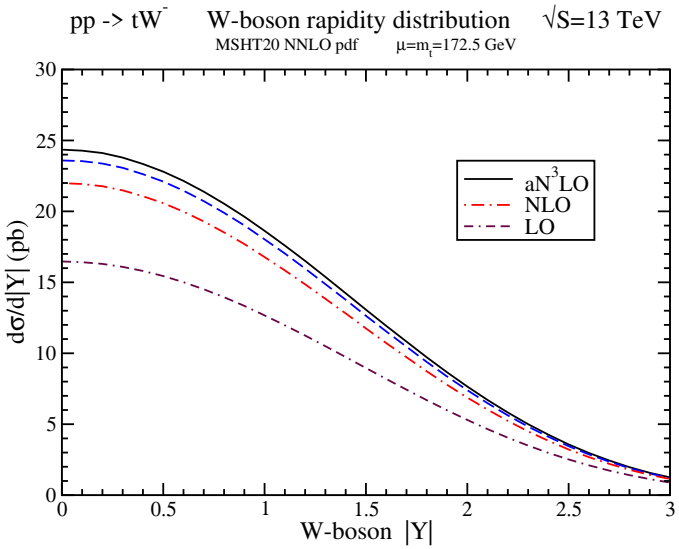
at 13 TeV: $79.5^{+1.9+2.0}_{-1.8-1.4}$ **pb** **at 14 TeV** $94.0^{+2.2+2.2}_{-2.1-1.6}$ **pb**

Top-quark and W-boson distributions in tW production









Summary

- **soft anomalous dimensions at three loops**
- **top-antitop pair production**
- **top-quark double-differential distributions in $t\bar{t}$ production**
- **tW cross sections and top-quark, W-boson distributions**
- **soft-gluon corrections are dominant and they are significant through aN^{3}LO**