Single-top and top-antitop cross sections

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- **Higher-order soft-gluon corrections**
- **t-channel and s-channel production**
- **tW, tH^-, anomalous tZ production**
- **$t\bar{t}$ production**

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QCD@Work 2018

Higher-order corrections

QCD corrections are very significant for single-top and top-pair production

Soft-gluon corrections are important and they approximate exact results very well

We calculate/resum these soft corrections at NNLL accuracy for the double-differential cross section

Finite-order expansions

Approximate NNLO (aNNLO) and N^3LO (aN^3LO) predictions for cross sections and differential distributions

Soft-gluon corrections

partonic processes

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

define

$s = (p_1 + p_2)^2$, $t = (p_1 - p_t)^2$, $u = (p_2 - p_t)^2$
and $s_4 = s + t + u - \sum m^2$

At partonic threshold $s_4 \to 0$

Soft corrections $\left[\frac{\ln^k(s_4/m_t^2)}{s_4}\right]_+$

For the order α_s^n **corrections** $k \leq 2n - 1$

Resum these soft corrections for the double-differential cross section

At NNLL accuracy we need two-loop soft anomalous dimensions

Soft-gluon Resummation

moments of the partonic cross section with moment variable N:
$\hat{\sigma}(N) = \int (ds_4/s)\; e^{-N s_4/s} \hat{\sigma}(s_4)$

factorized expression for the cross section in $4-\epsilon$ dimensions

$$\sigma^{f_1 f_2 \to tX}(N,\epsilon) = H_{IL}^{f_1 f_2 \to tX}\left(\alpha_s(\mu_R)\right)\, S_{LI}^{f_1 f_2 \to tX}\left(\frac{m_t}{N\mu_F}, \alpha_s(\mu_R)\right)$$
$$\times \prod J_{\rm in}\left(N,\mu_F,\epsilon\right) \prod J_{\rm out}\left(N,\mu_F,\epsilon\right)$$

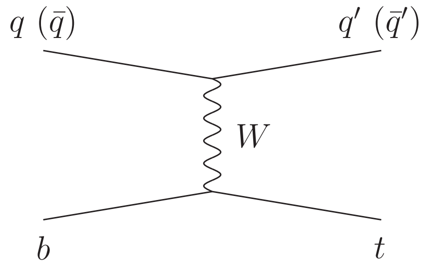
$H_{IL}^{f_1 f_2 \to tX}$ **is hard function and** $S_{LI}^{f_1 f_2 \to tX}$ **is soft function**

S_{LI} **satisfies the renormalization group equation**

$$\left(\mu \frac{\partial}{\partial \mu} + \beta(g_s)\frac{\partial}{\partial g_s}\right) S_{LI} = -(\Gamma_S^\dagger)_{LK} S_{KI} - S_{LK}(\Gamma_S)_{KI}$$

Soft anomalous dimension Γ_S controls the evolution of the soft function which gives the exponentiation of logarithms of N

t-channel production



At one loop

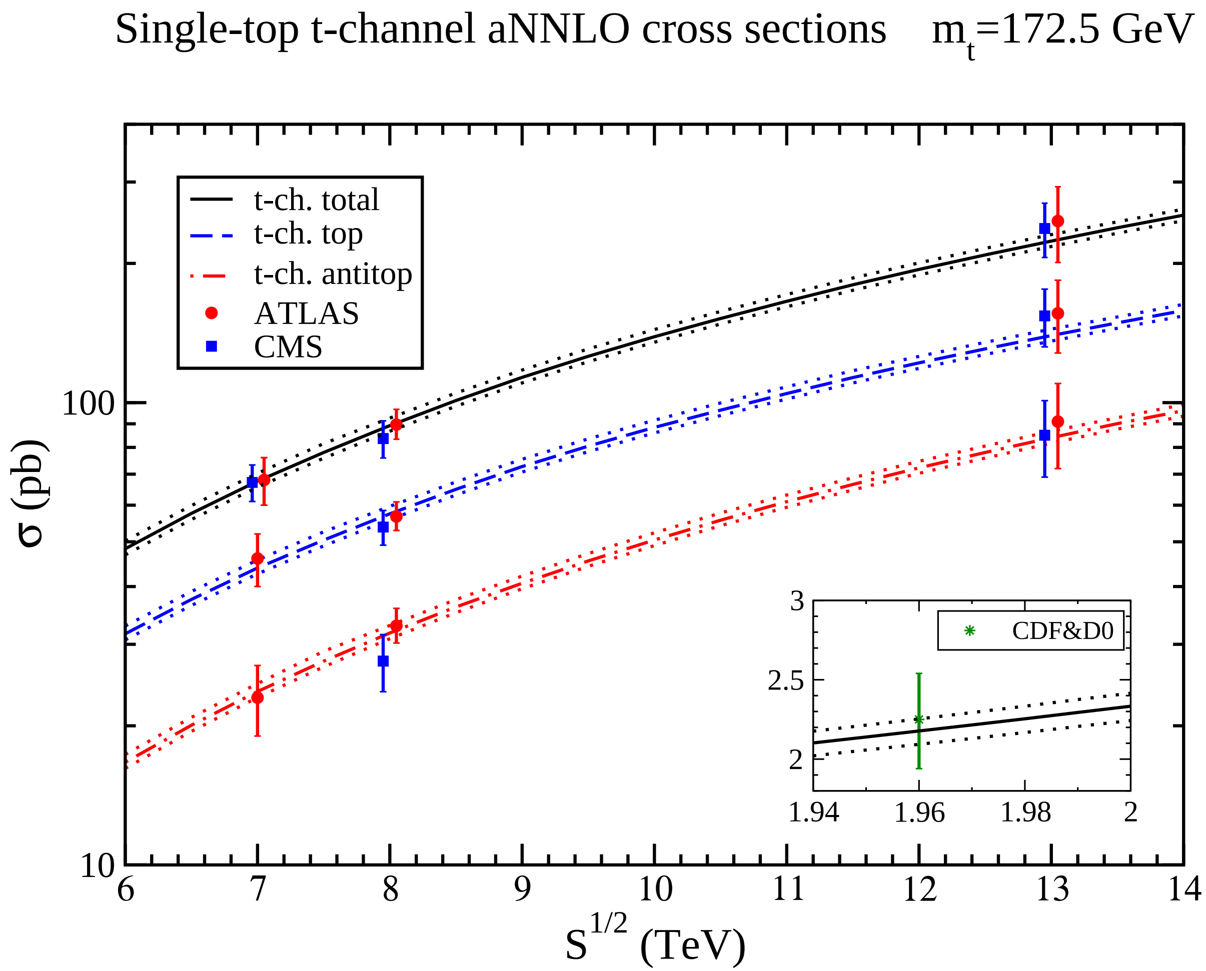
$$\Gamma_{S\,11}^{t\,(1)} = C_F \left[\ln\left(\frac{t(t-m_t^2)}{m_t s^{3/2}}\right) - \frac{1}{2}\right] \qquad \Gamma_{S\,12}^{t\,(1)} = \frac{C_F}{2N} \ln\left(\frac{u(u-m_t^2)}{s(s-m_t^2)}\right) \qquad \Gamma_{S\,21}^{t\,(1)} = \ln\left(\frac{u(u-m_t^2)}{s(s-m_t^2)}\right)$$

$$\Gamma_{S\,22}^{t\,(1)} = C_F \ln\left(\frac{s-m_t^2}{m_t\sqrt{s}}\right) - \frac{1}{2N}\ln\left(\frac{t(t-m_t^2)}{s(s-m_t^2)}\right) + \frac{(N^2-2)}{2N}\ln\left(\frac{u(u-m_t^2)}{s(s-m_t^2)}\right) - \frac{C_F}{2}$$

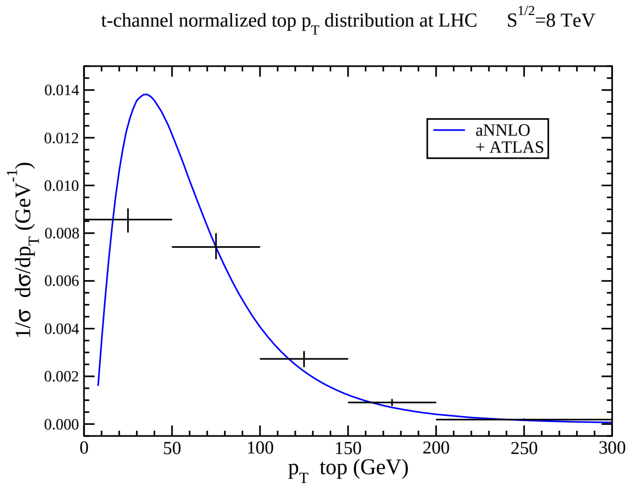
At two loops

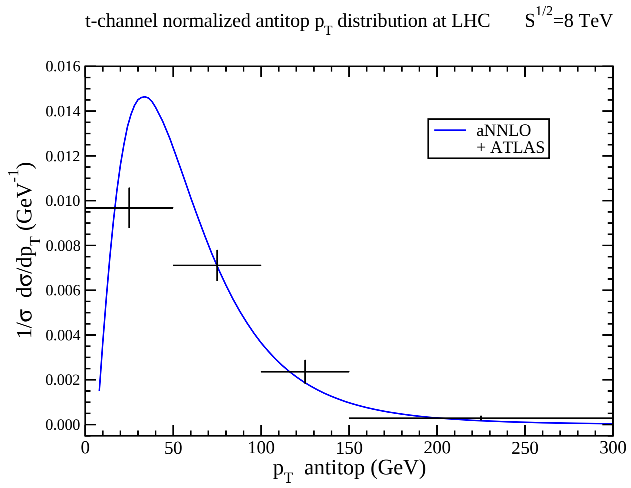
$$\Gamma_{S\,11}^{t\,(2)} = \left[C_A\left(\frac{67}{36} - \frac{\zeta_2}{2}\right) - \frac{5}{18}n_f\right]\Gamma_{S\,11}^{t\,(1)} + C_F C_A \frac{(1-\zeta_3)}{4}$$

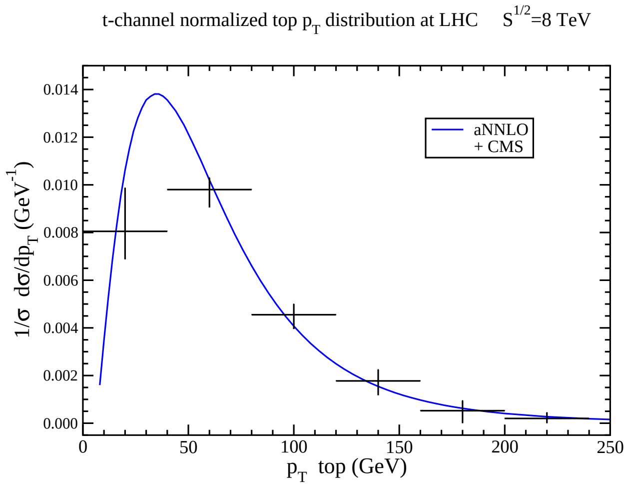
t-channel production at aNNLO

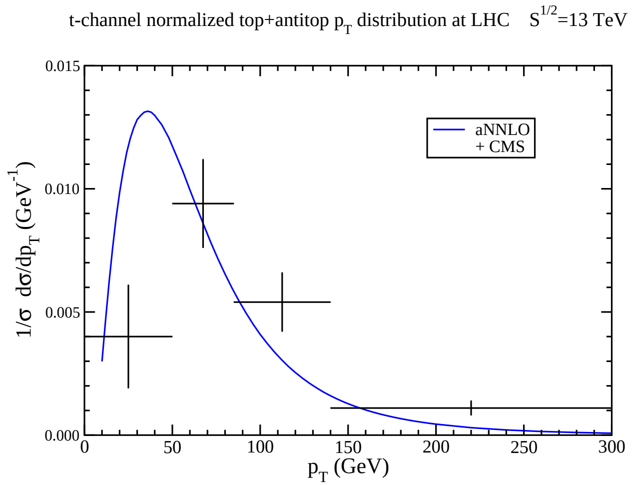


Top p_T distributions in t-channel production at the LHC

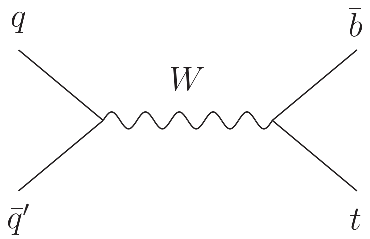








s-channel production



At one loop

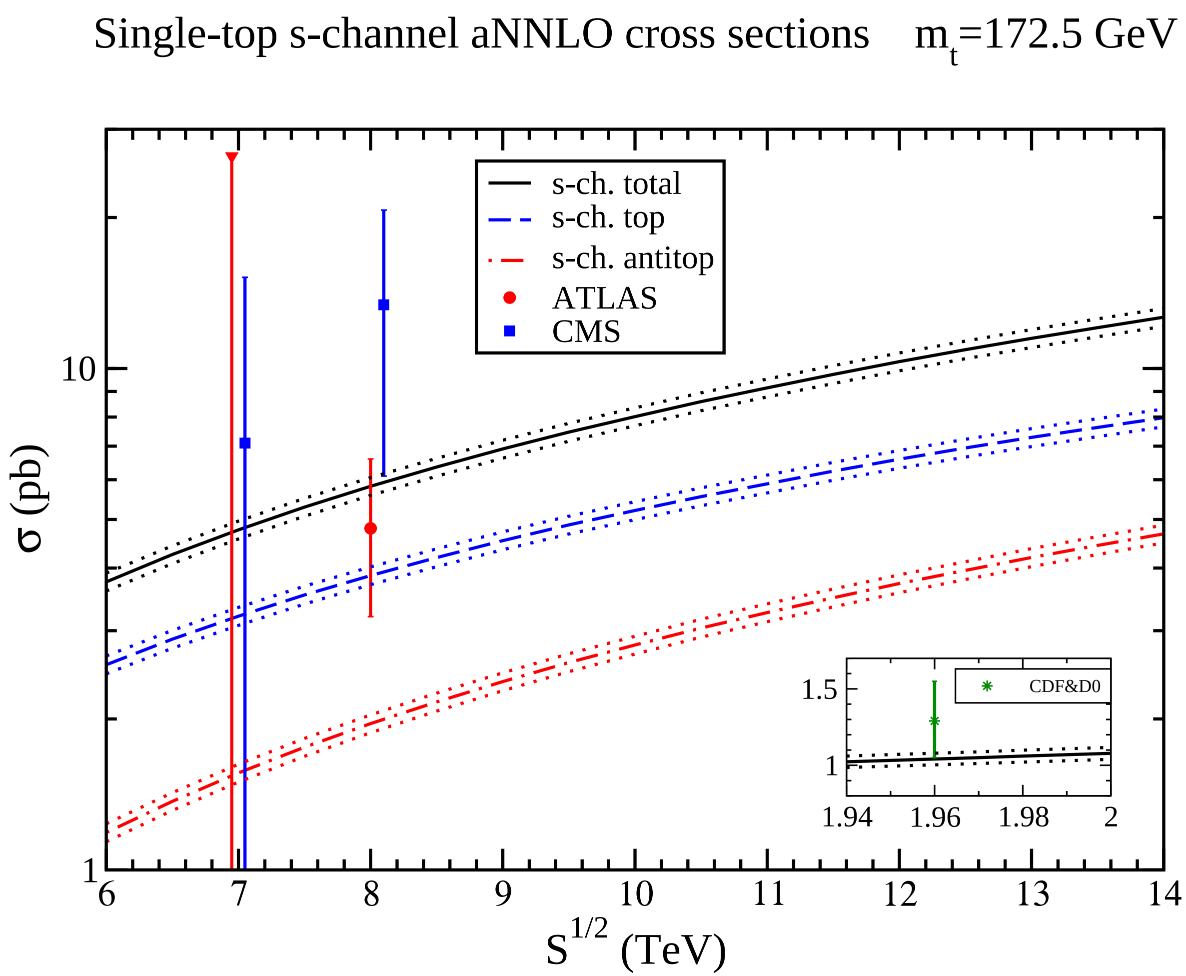
$$\Gamma_{S\,11}^{s\,(1)} = C_F \left[\ln\left(\frac{s-m_t^2}{m_t\sqrt{s}}\right) - \frac{1}{2}\right] \qquad \Gamma_{S\,12}^{s\,(1)} = \frac{C_F}{2N}\ln\left(\frac{u(u-m_t^2)}{t(t-m_t^2)}\right) \qquad \Gamma_{S\,21}^{s\,(1)} = \ln\left(\frac{u(u-m_t^2)}{t(t-m_t^2)}\right)$$

$$\Gamma_{S\,22}^{s\,(1)} = C_F \ln\left(\frac{s-m_t^2}{m_t\sqrt{s}}\right) - \frac{1}{N}\ln\left(\frac{u(u-m_t^2)}{t(t-m_t^2)}\right) + \frac{N}{2}\ln\left(\frac{u(u-m_t^2)}{s(s-m_t^2)}\right) - \frac{C_F}{2}$$

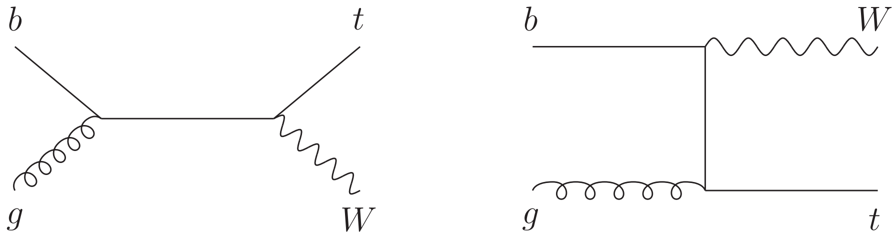
At two loops

$$\Gamma_{S\,11}^{s\,(2)} = \left[C_A\left(\frac{67}{36} - \frac{\zeta_2}{2}\right) - \frac{5}{18}n_f\right]\Gamma_{S\,11}^{s\,(1)} + C_F C_A \frac{(1-\zeta_3)}{4}$$

s-channel production at aNNLO



Associated tW production



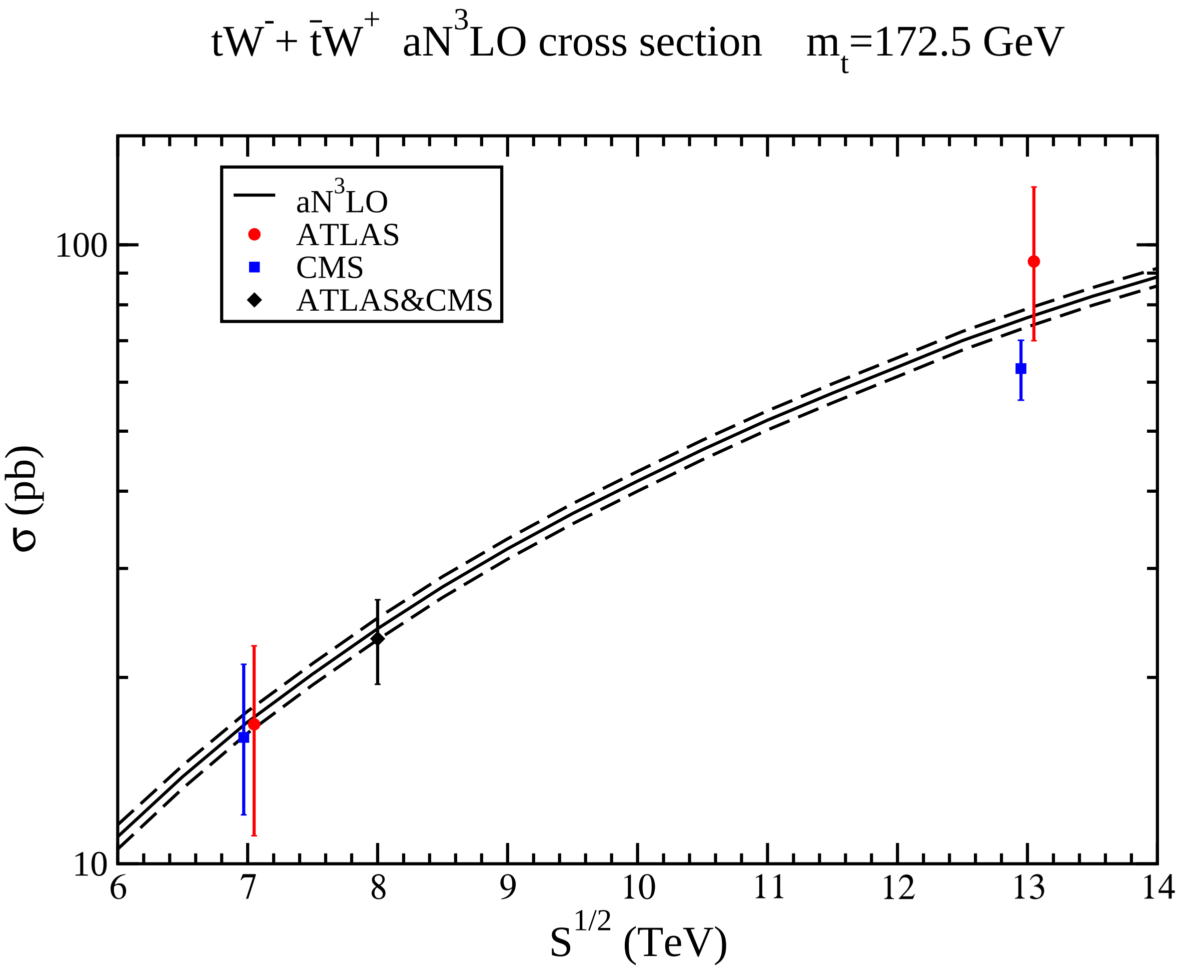
At one loop

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

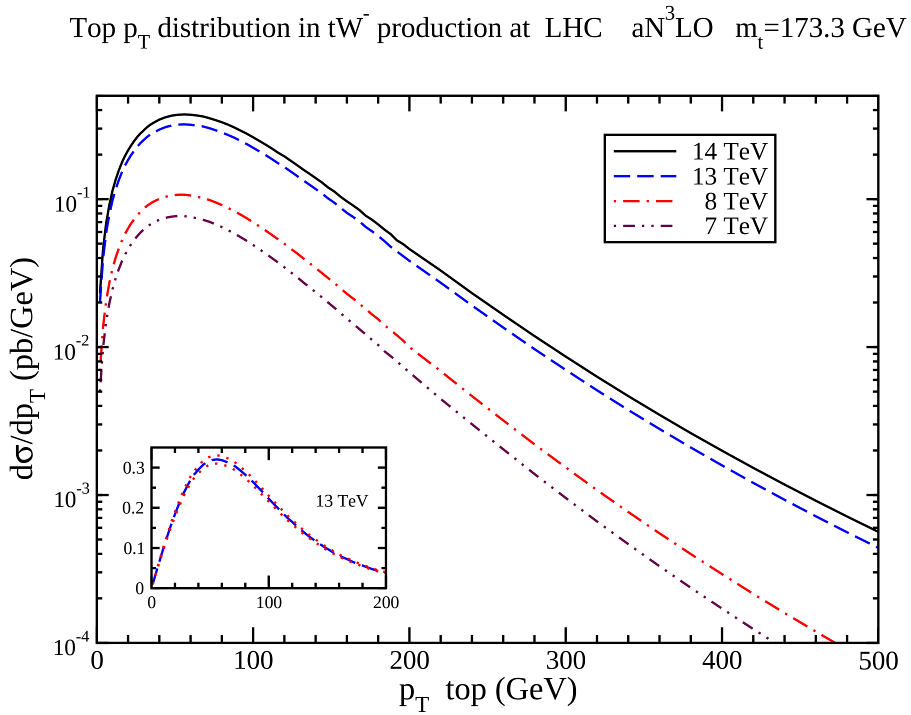
At two loops

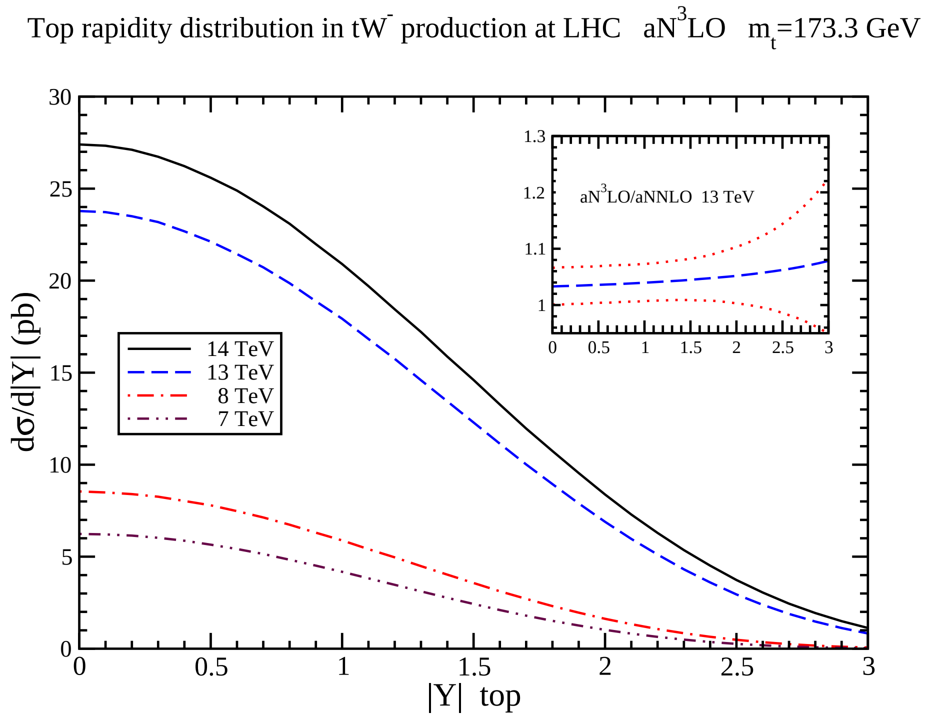
$$\Gamma_S^{tW^-\,(2)} = \left[C_A\left(\frac{67}{36} - \frac{\zeta_2}{2}\right) - \frac{5}{18}n_f\right]\Gamma_S^{tW^-\,(1)} + C_F C_A \frac{(1-\zeta_3)}{4}$$

tW production at aN^{3}LO

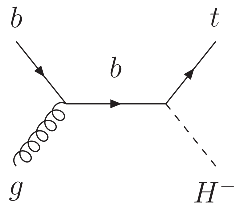


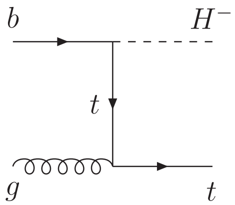
Top quark p_T and rapidity distributions in tW production

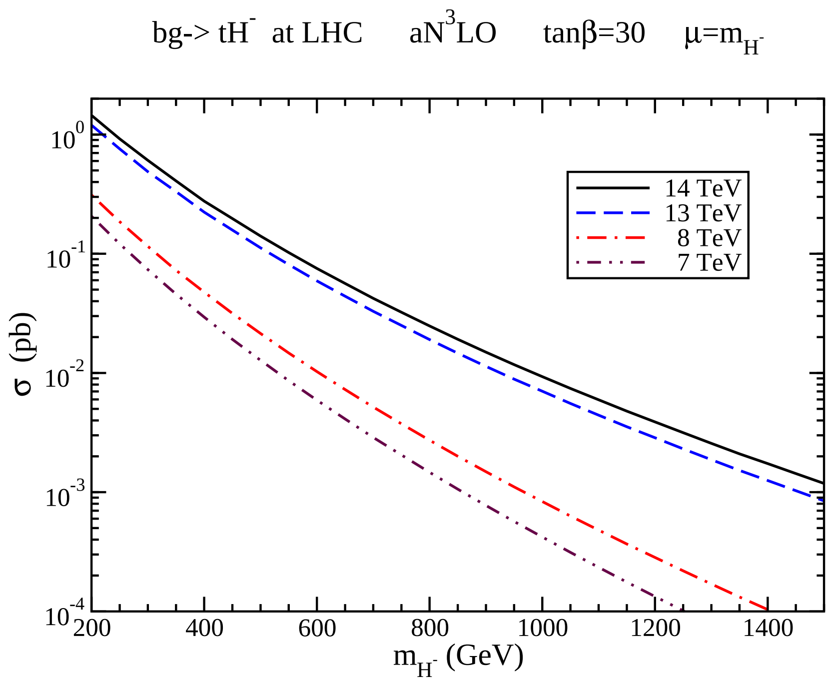


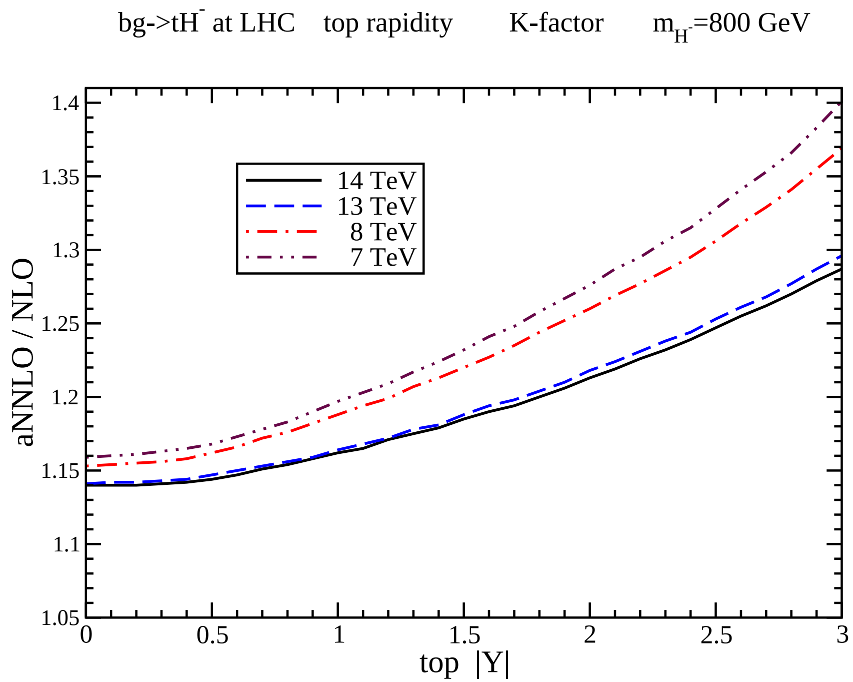


tH^- production

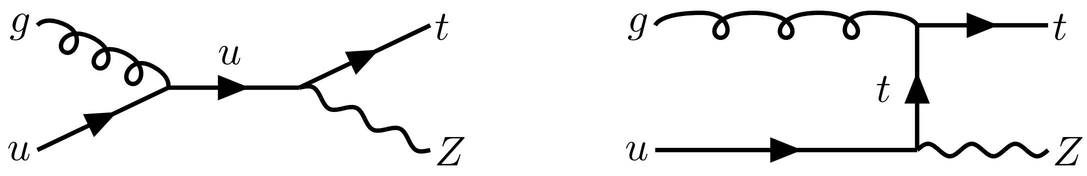




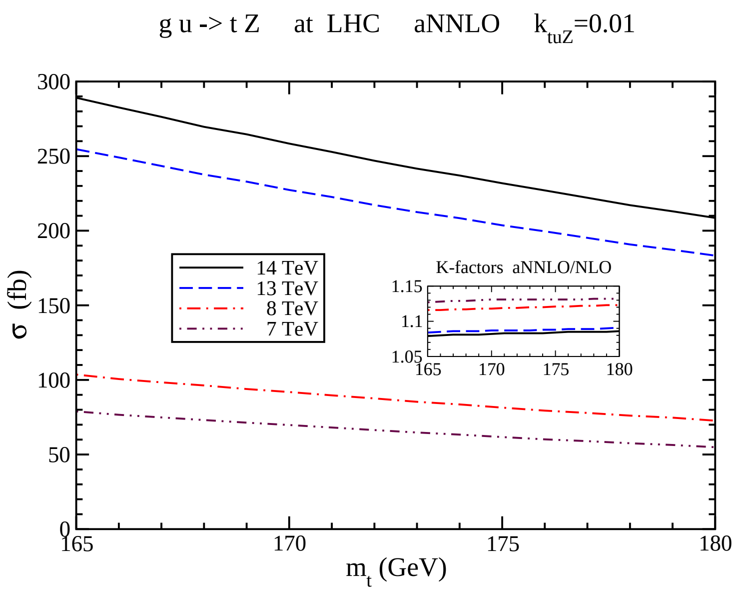


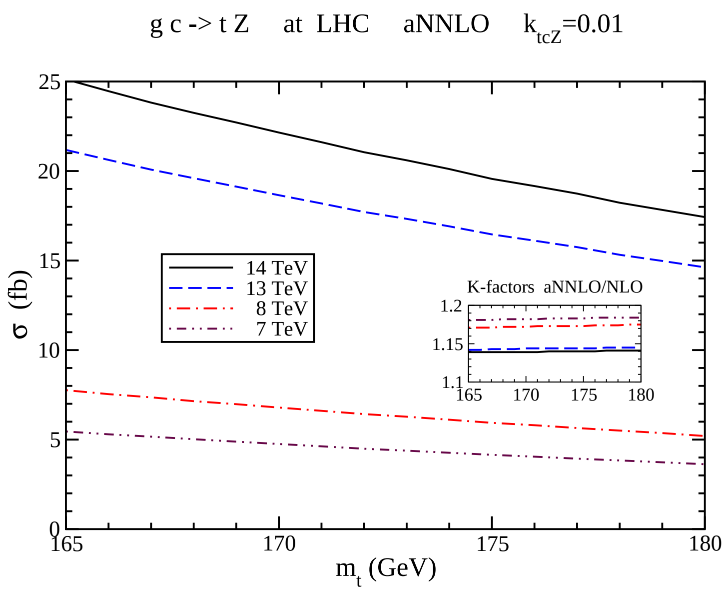


tZ production via anomalous couplings

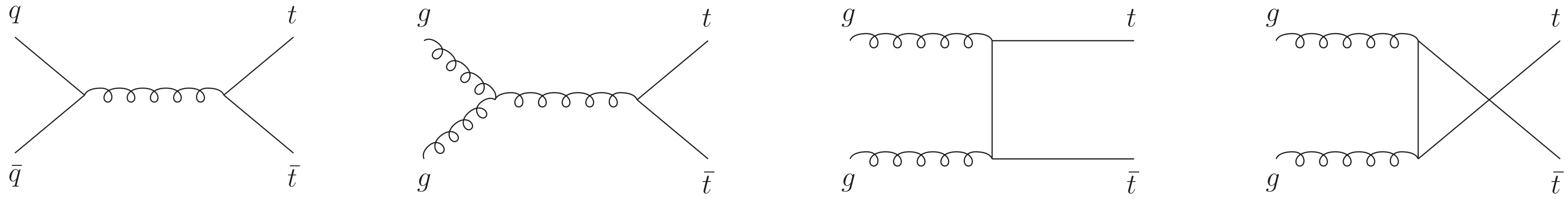


$$\Delta \mathcal{L}^{eff} = \frac{1}{\Lambda}\, \kappa_{tqZ}\, e\, \bar{t}\, (i/2)(\gamma_\mu \gamma_\nu - \gamma_\nu \gamma_\mu)\, q\, F_Z^{\mu\nu} + h.c.$$





Top-antitop pair production



At one loop for $q\bar{q} \to t\bar{t}$

$$\Gamma_{11}^{q\bar{q}\,(1)} = \Gamma_{\rm cusp}^{(1)}\,, \quad \Gamma_{12}^{q\bar{q}\,(1)} = \frac{C_F}{C_A} \ln\left(\frac{t_1}{u_1}\right)\,, \quad \Gamma_{21}^{q\bar{q}\,(1)} = 2\ln\left(\frac{t_1}{u_1}\right)$$

$$\Gamma_{22}^{q\bar{q}\,(1)} = \left(1-\frac{C_A}{2C_F}\right)\Gamma_{\rm cusp}^{(1)} + 4C_F \ln\left(\frac{t_1}{u_1}\right) - \frac{C_A}{2}\left[1+\ln\left(\frac{s m_t^2 t_1^2}{u_1^4}\right)\right]$$

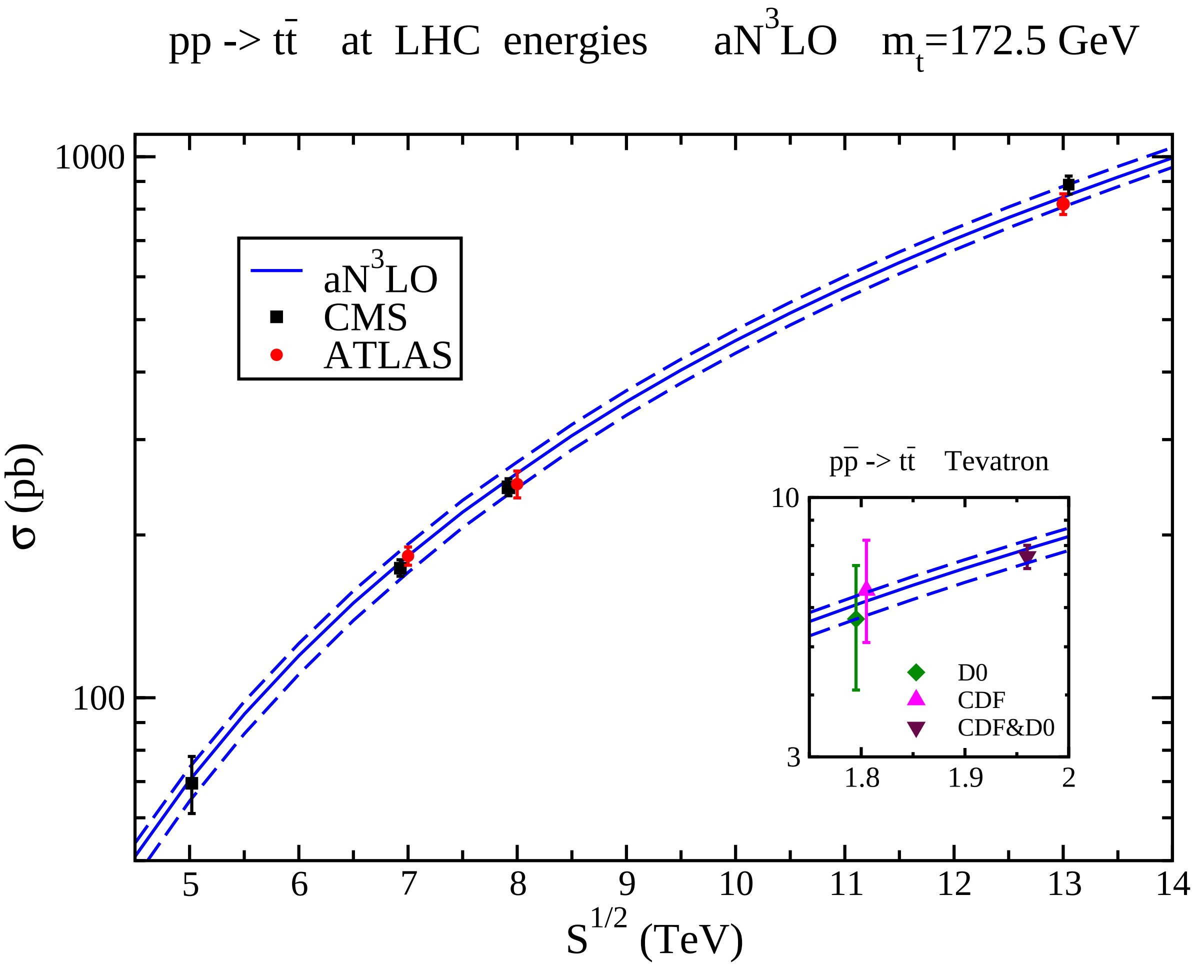
At two loops for $q\bar{q} \to t\bar{t}$

$$\Gamma_{11}^{q\bar{q}\,(2)} = \Gamma_{\rm cusp}^{(2)}\,, \quad \Gamma_{12}^{q\bar{q}\,(2)} = \left(\frac{K}{2}-\frac{C_A}{2}N_{2l}\right)\Gamma_{12}^{q\bar{q}\,(1)}\,, \quad \Gamma_{21}^{q\bar{q}\,(2)} = \left(\frac{K}{2}+\frac{C_A}{2}N_{2l}\right)\Gamma_{21}^{q\bar{q}\,(1)}$$

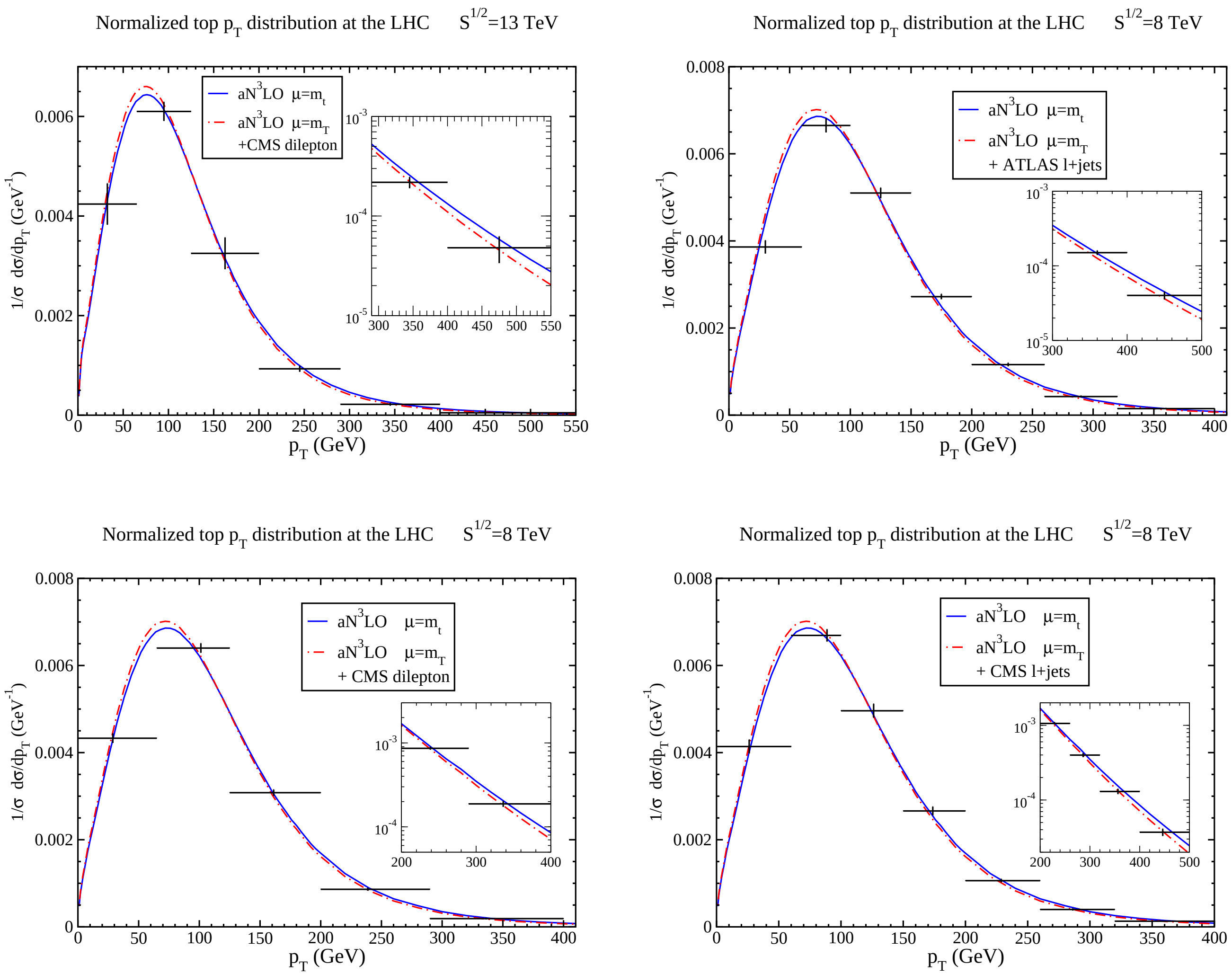
$$\Gamma_{22}^{q\bar{q}\,(2)} = \frac{K}{2}\Gamma_{22}^{q\bar{q}\,(1)} + \left(1-\frac{C_A}{2C_F}\right)\left(\Gamma_{\rm cusp}^{(2)} - \frac{K}{2}\Gamma_{\rm cusp}^{(1)}\right)$$

3×3 matrix for $gg \to t\bar{t}$

Top-antitop pair production

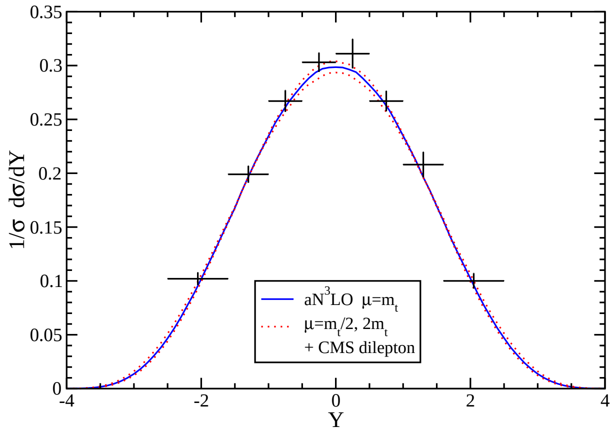


Top p_T distributions in $t\bar{t}$ production

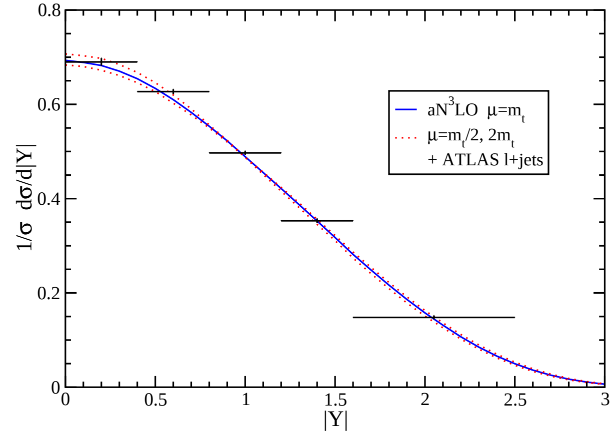


Top rapidity distributions in $t\bar{t}$ production

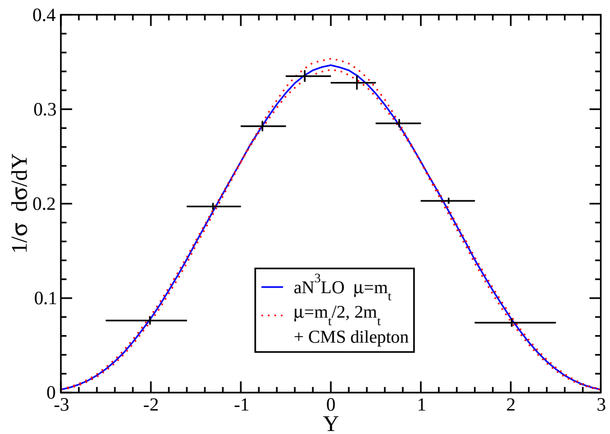
Normalized top rapidity distribution at LHC $S^{1/2}$=13 TeV



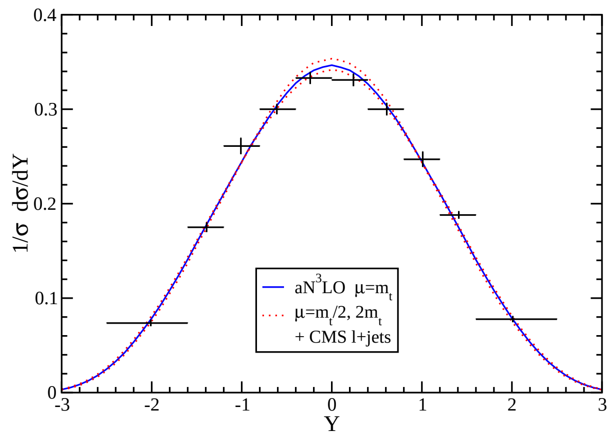
Normalized top rapidity distribution at LHC $S^{1/2}$=8 TeV



Normalized top rapidity distribution at LHC $S^{1/2}$=8 TeV



Normalized top rapidity distribution at LHC $S^{1/2}$=8 TeV



Summary

- **cross sections and distributions for top production**
- **soft-gluon corrections**
- t**-channel and** s**-channel single top at aNNLO**
- tW **production at aN^{3}LO**
- tH^- **and** tZ **production in new physics models**
- $t\bar{t}$ **production at aN^{3}LO**
- **excellent agreement with collider data**
- **high-order corrections are very significant**