N^{3}LO approximate results for top-quark differential cross sections and forward-backward asymmetry

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- **Higher-order corrections**
- **Total $t\bar{t}$ cross sections**
- **Top p_T distributions**
- **Top rapidity distributions**
- **Top forward-backward asymmetry**

Higher-order corrections

QCD corrections significant for top-antitop pair production

Soft-gluon corrections are important

Soft terms: $\left[\frac{\ln^k(s_4/m_t^2)}{s_4}\right]_+$ **with** $k \leq 2n-1$, s_4 **distance from threshold**

Resum these soft corrections - factorization and RGE

NNLL accuracy–two-loop soft anomalous dimensions

Approximate N^{3}LO (aN^{3}LO)differential cross sections from expansion of resummed expressions

Calculation is for partonic threshold for the double-differential cross section using the standard moment-space resummation in perturbative QCD

Latest results:
total cross section: **Phys. Rev. D 90, 014006 (2014) [arXiv:1405.7046 [hep-ph]]**
p_T and y distributions: **Phys. Rev. D 91, 031501 (2015) [arXiv:1411.2633 [hep-ph]]**
$A_{\rm FB}$: **Phys. Rev. D 91, 071502 (2015) [arXiv:1501.01581 [hep-ph]]**

Partonic threshold approximation

Approximation works very well for LHC and Tevatron energies

less than 1% difference between approximate and exact cross sections at both NLO and NNLO

also true for p_T and rapidity distributions and $A_{\rm FB}$

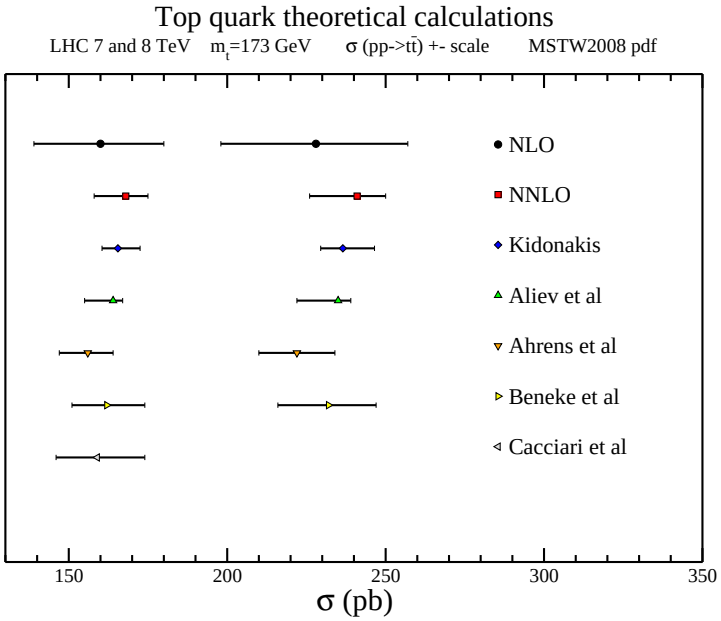
fixed-order expansion - no prescription is used

stability of the theoretical NNLO approximate result in this double-differential pQCD resummation approach over the past decade

the reliability of the NNLO approximate result and near-identical value to exact NNLO is very important for several reasons

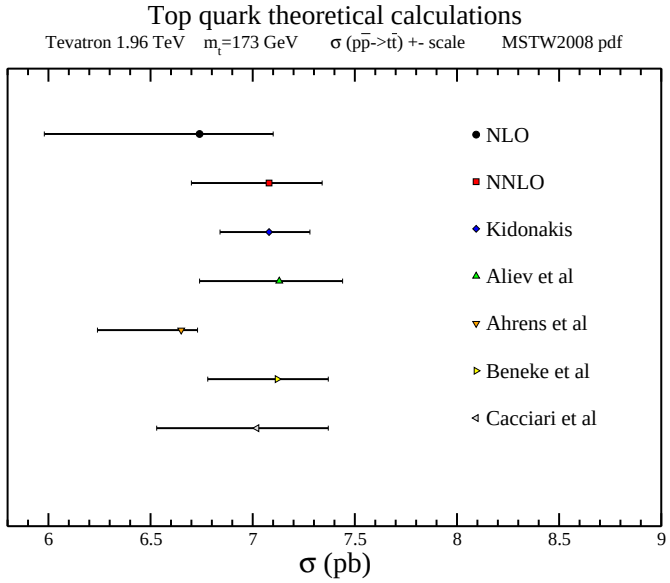
- **provides confidence of application to other processes (single-top, W, etc)**
- **used as background for many analyses (Higgs, etc)**

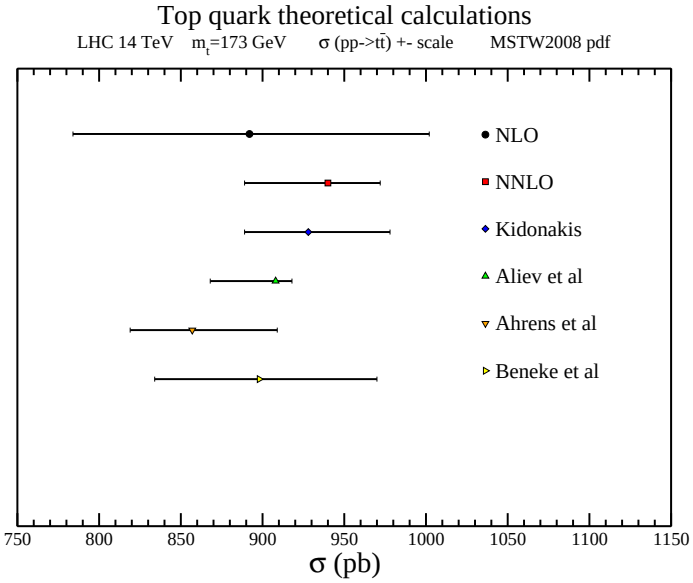
add aN^{3}LO corrections for best result



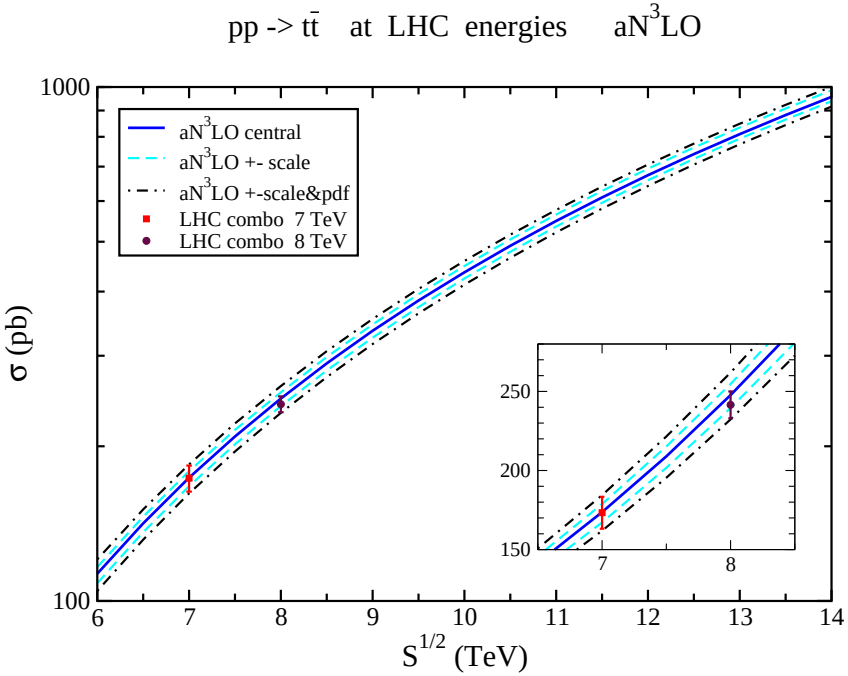
Comparison of various NNLO approx approaches
all with the same choice of parameters

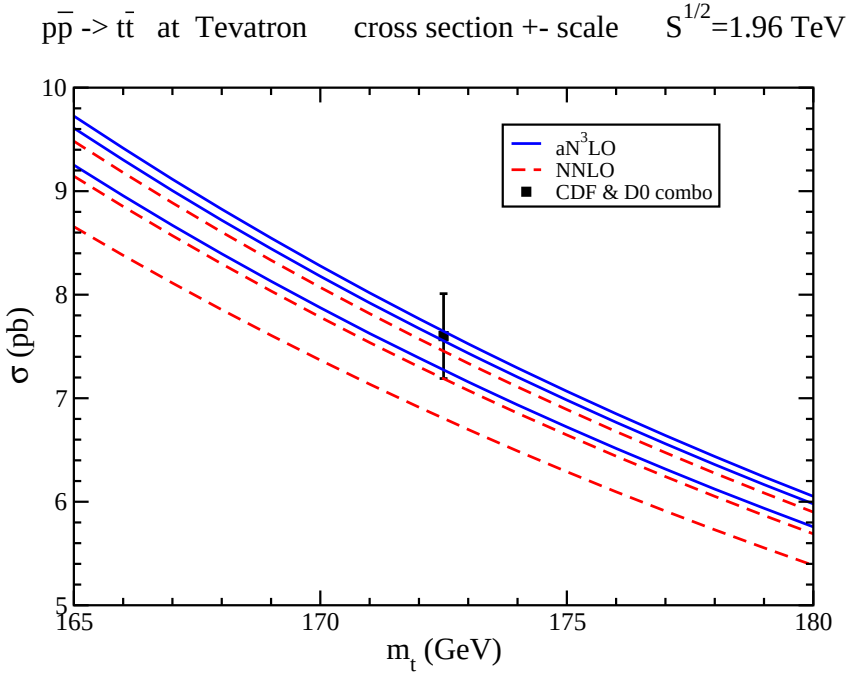
Kidonakis, PRD 82, 114030 (2010) differential-pQCD
Aliev *et al*, CPC 182, 1034 (2011) total-pQCD
Ahrens *et al*, PLB 703, 135 (2011) differential -SCET
Beneke *et al*, NPB 855, 695 (2012) total-SCET
Cacciari *et al*, PLB 710, 612 (2012) total-pQCD





Top-pair cross sections at the LHC and the Tevatron





aN^{3}LO total $t\bar{t}$ cross sections with $m_t = 173.3$ GeV

Tevatron 1.96 TeV: $7.37^{+0.09+0.38}_{-0.27-0.28}$ **pb**

LHC 7 TeV: 174^{+5+9}_{-7-10} **pb**

LHC 8 TeV: 248^{+7+12}_{-8-13} **pb**

LHC 13 TeV: 810^{+24+30}_{-16-32} **pb**

LHC 14 TeV: 957^{+28+34}_{-19-36} **pb**

Relative size of perturbative corrections

$$\sigma^{\rm aN^3LO} = \sigma^{(0)} \left[1 + \frac{\sigma^{(1)}}{\sigma^{(0)}} + \frac{\sigma^{(2)}}{\sigma^{(0)}} + \frac{\sigma^{(3)}}{\sigma^{(0)}} \right]$$

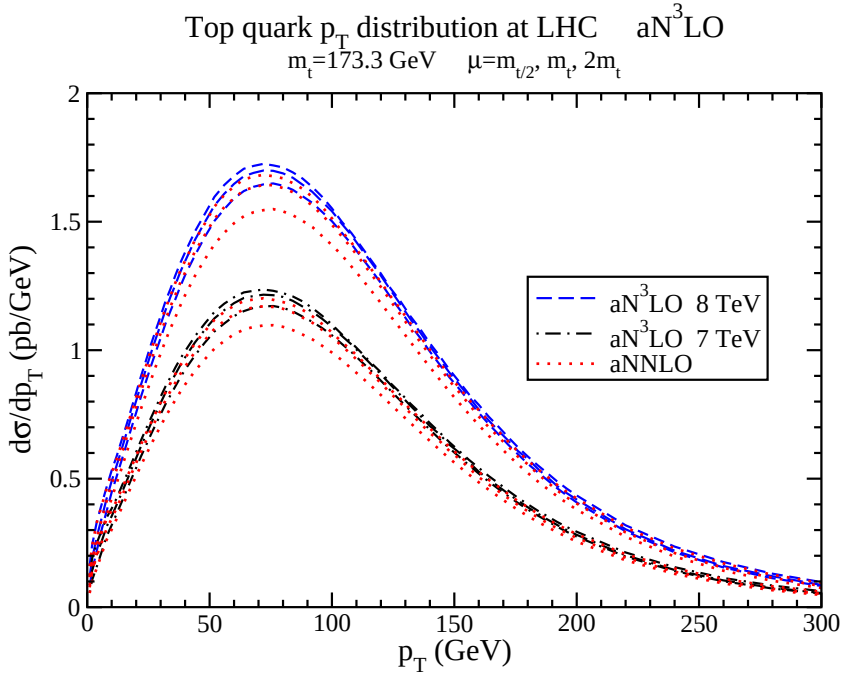
Fractional contributions to the perturbative series for the $t\bar{t}$ cross section					
corrections	Tevatron	LHC 7 TeV	LHC 8 TeV	LHC 13 TeV	LHC 14 TeV
$\sigma^{(1)}/\sigma^{(0)}$	0.236	0.470	0.476	0.493	0.496
$\sigma^{(2)}/\sigma^{(0)}$	0.106	0.178	0.177	0.172	0.170
$\sigma^{(3)}/\sigma^{(0)}$	0.068	0.066	0.059	0.045	0.043

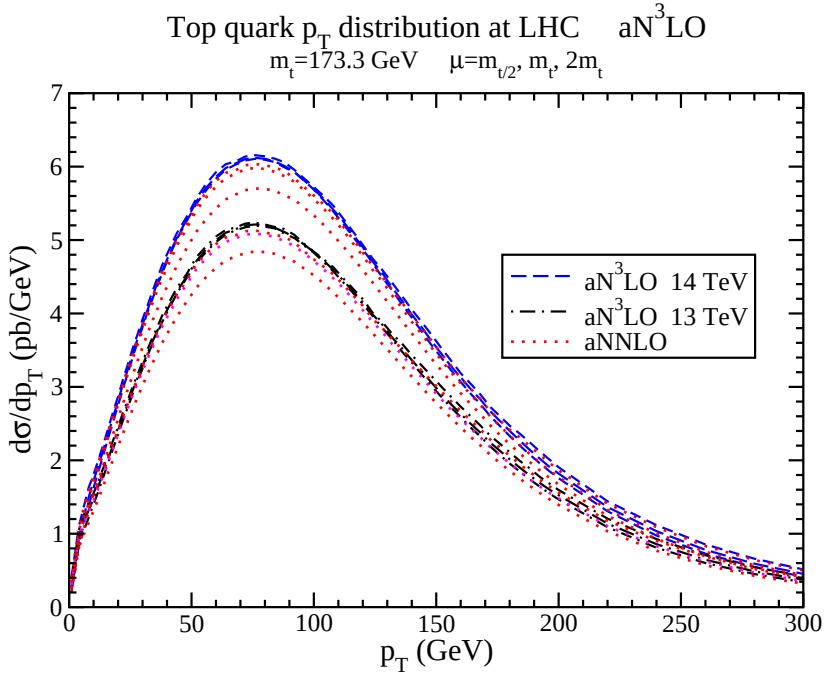
At 14 TeV $\sigma^{\rm aN^3LO} = 1.709\,\sigma^{(0)}$

Series approximated well by $\sum_{n=1}^{4} 1/n! = 1.708\cdots$

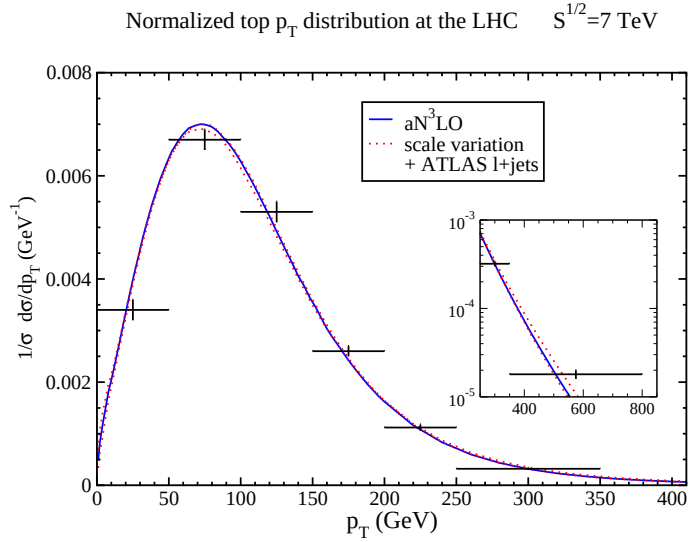
It is amusing to note that $\sum_{n=1}^{\infty} 1/n! = e - 1 = 1.718\cdots$

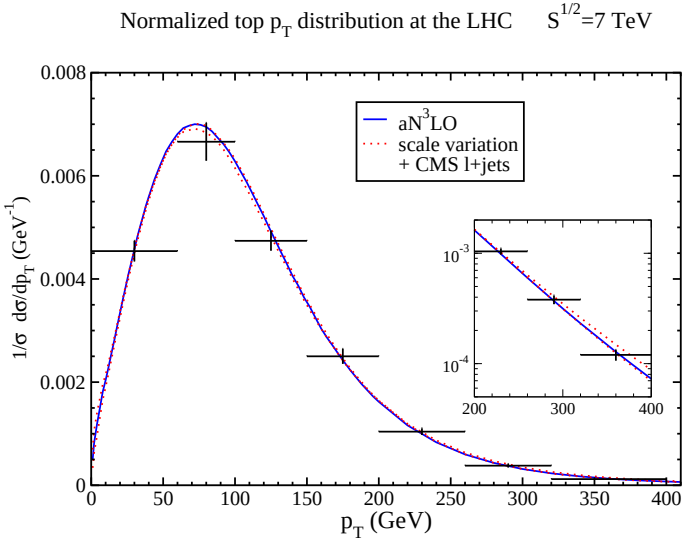
Top quark p_T distribution at the LHC

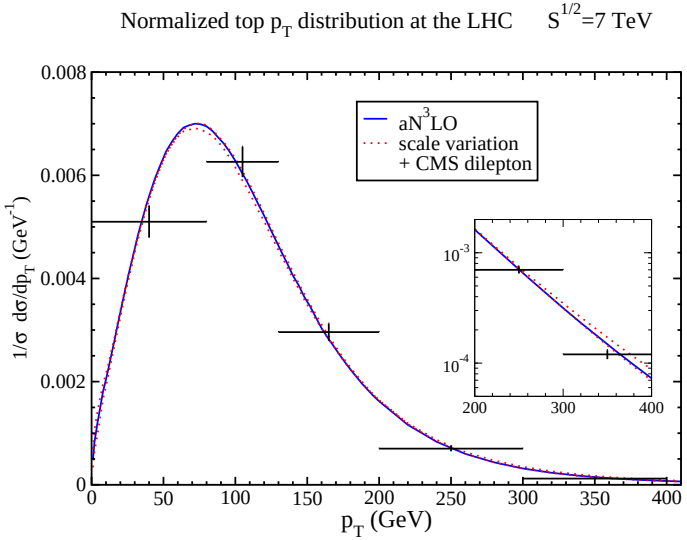


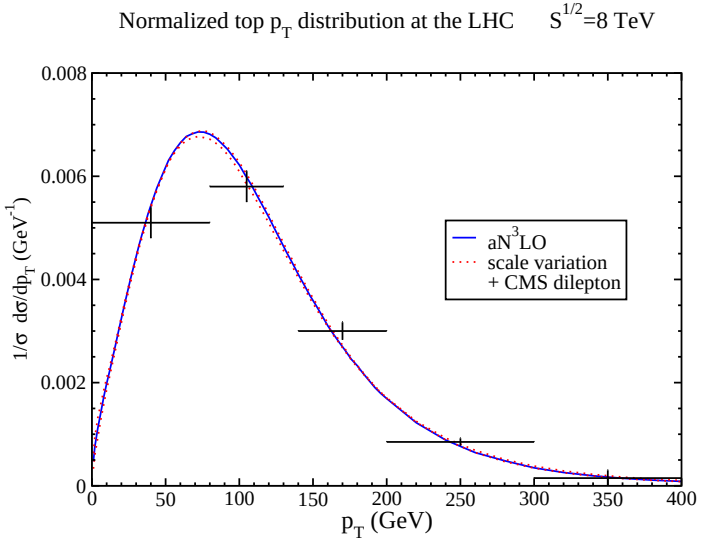


Normalized top quark p_T distribution at the LHC

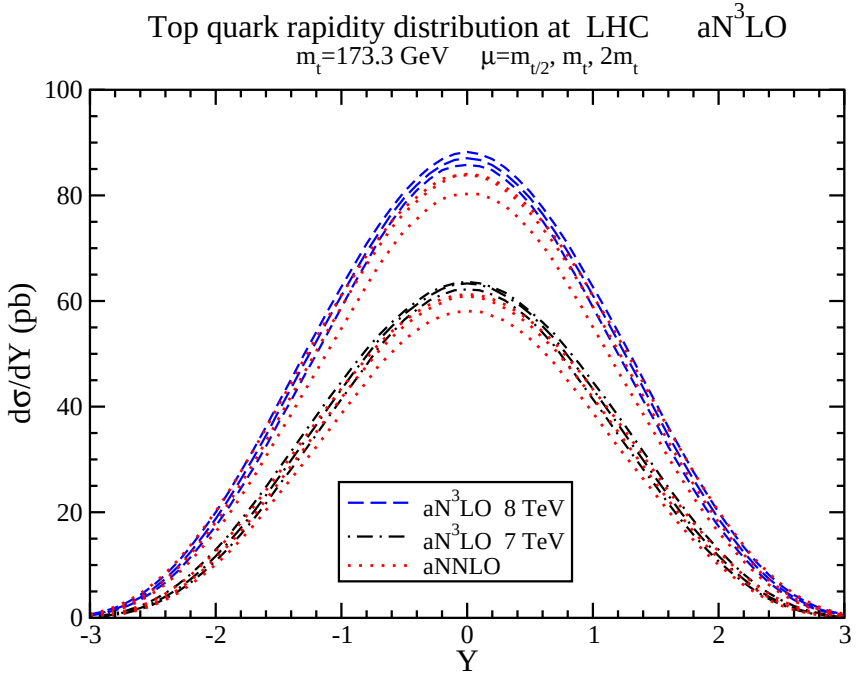


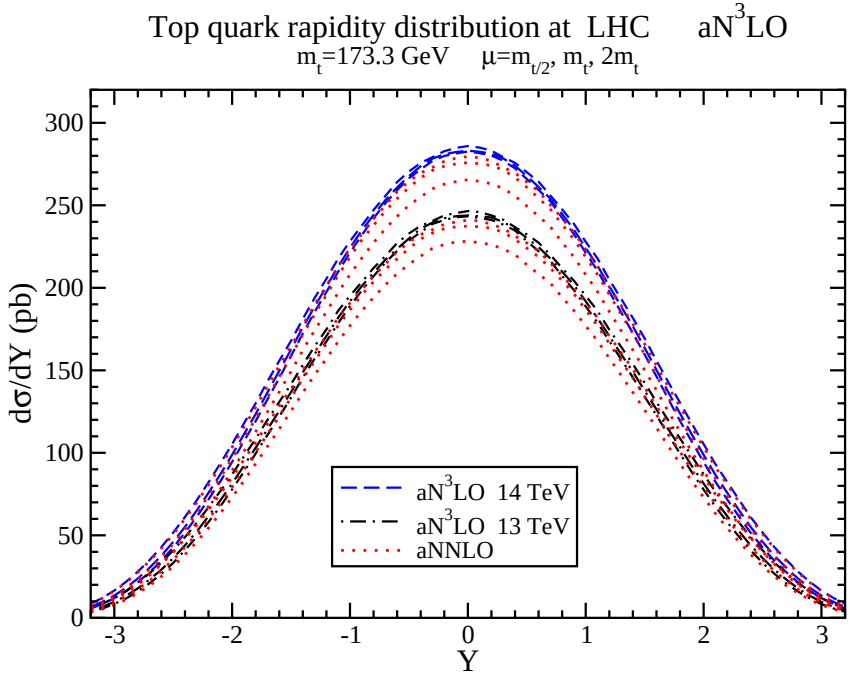




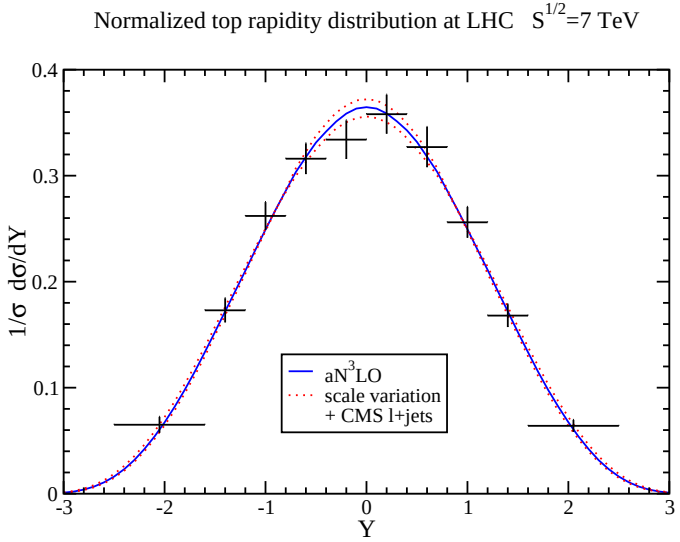


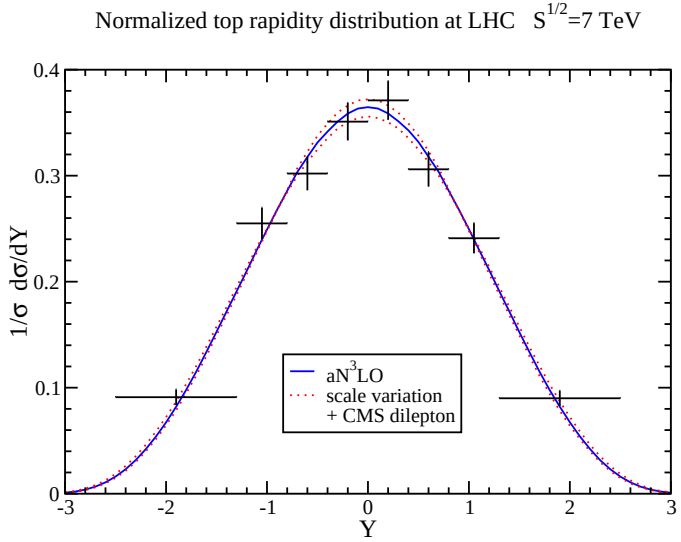
Top quark rapidity distribution at the LHC

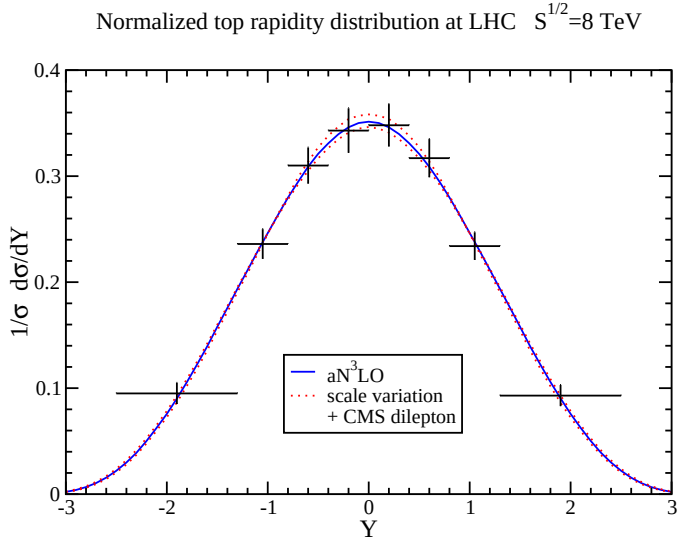




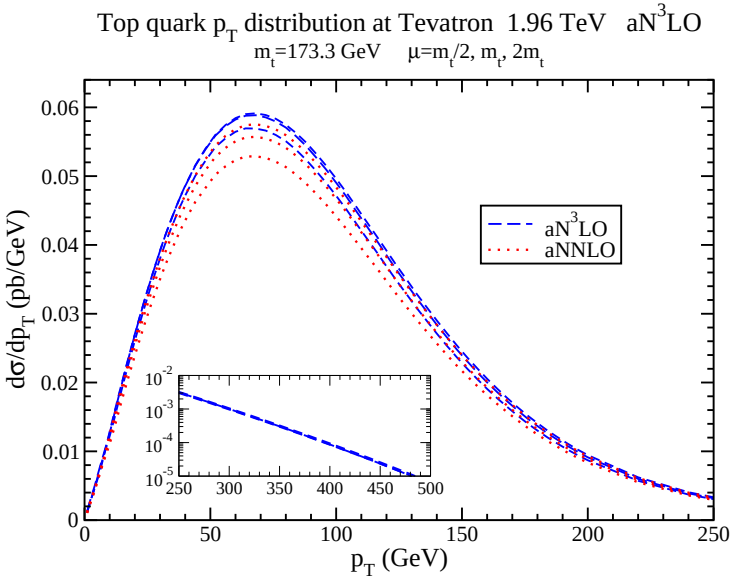
Normalized top quark rapidity distribution at the LHC

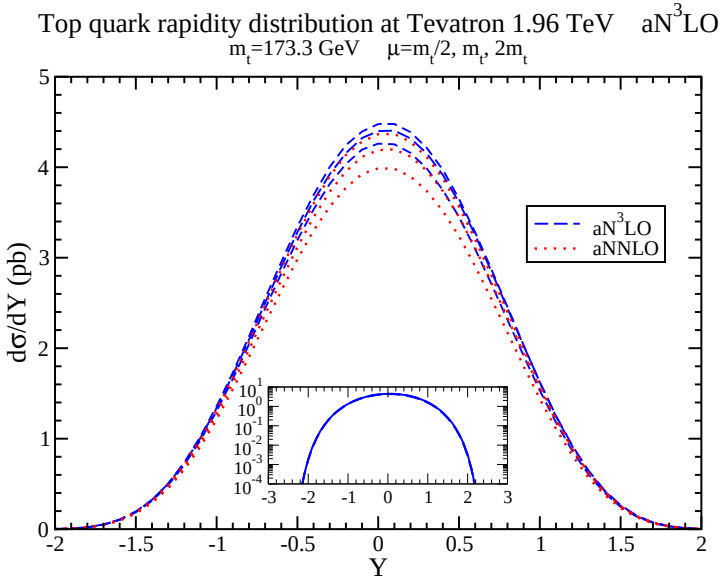


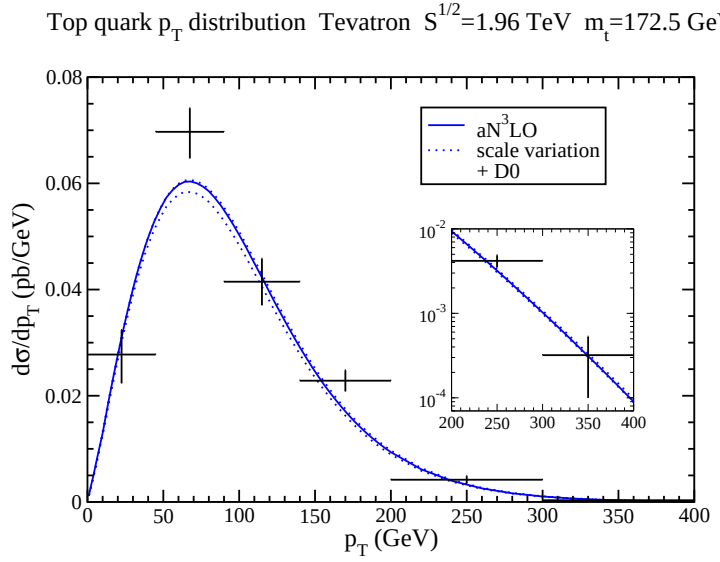


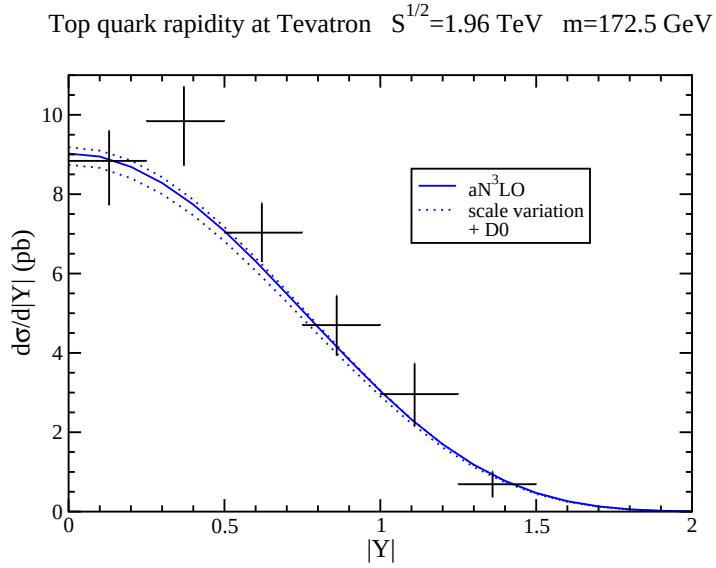


Top quark p_T and rapidity distributions at the Tevatron









Top forward-backward asymmetry at the Tevatron

$$A_{\rm FB} = \frac{\sigma(y_t > 0) - \sigma(y_t < 0)}{\sigma(y_t > 0) + \sigma(y_t < 0)} \equiv \frac{\Delta\sigma}{\sigma} \tag{1}$$

$$A_{\rm FB} = \frac{\Delta\sigma^{\rm EW} + \alpha_s^3\,\Delta\sigma^{(1)} + \alpha_s^4\,\Delta\sigma^{(2)} + \alpha_s^5\,\Delta\sigma^{(3)} + \cdots}{\alpha_s^2\,\sigma^{(0)} + \alpha_s^3\,\sigma^{(1)} + \alpha_s^4\,\sigma^{(2)} + \alpha_s^5\,\sigma^{(3)} + \cdots} \tag{2}$$

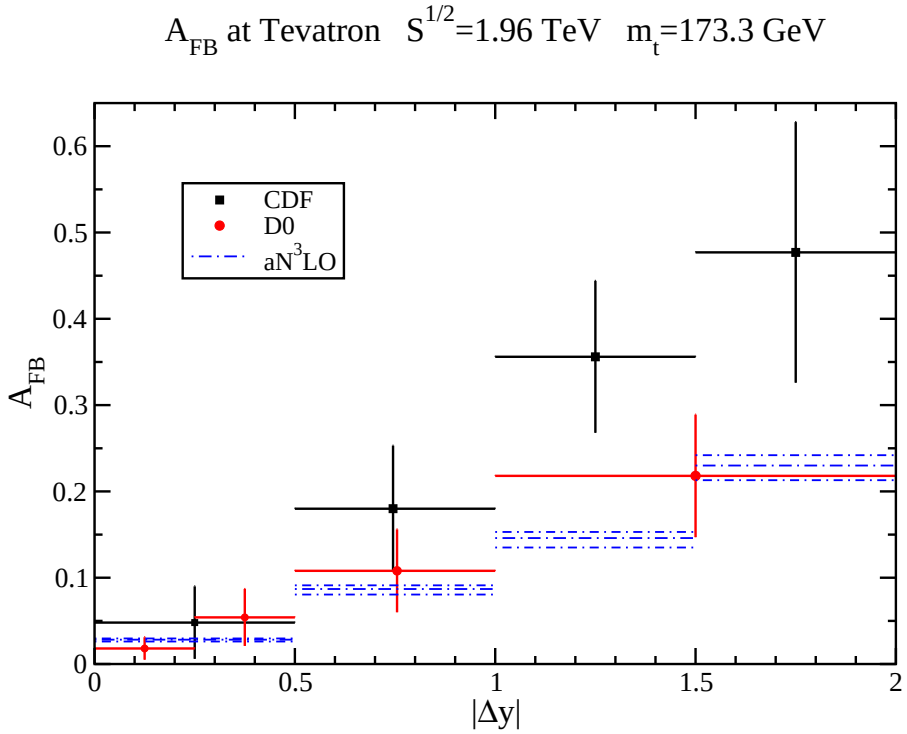
$$A_{\rm FB} = \frac{\Delta\sigma^{\rm EW}}{\alpha_s^2\,\sigma^{(0)}} + \alpha_s\frac{\Delta\sigma^{(1)}}{\sigma^{(0)}} - \frac{\Delta\sigma^{\rm EW}\,\sigma^{(1)}}{\alpha_s\,(\sigma^{(0)})^2} + \alpha_s^2\left[\frac{\Delta\sigma^{(2)}}{\sigma^{(0)}} - \frac{\Delta\sigma^{(1)}\,\sigma^{(1)}}{(\sigma^{(0)})^2}\right]$$
$$+ \frac{\Delta\sigma^{\rm EW}}{(\sigma^{(0)})^3}\left[(\sigma^{(1)})^2 - \sigma^{(0)}\,\sigma^{(2)}\right] + \alpha_s^3\left[\frac{\Delta\sigma^{(3)}}{\sigma^{(0)}} - \frac{\Delta\sigma^{(2)}\,\sigma^{(1)}}{(\sigma^{(0)})^2} + \frac{\Delta\sigma^{(1)}(\sigma^{(1)})^2}{(\sigma^{(0)})^3} - \frac{\Delta\sigma^{(1)}\,\sigma^{(2)}}{(\sigma^{(0)})^2}\right] + \cdots \tag{3}$$

Top-quark asymmetry at the Tevatron		
aN^{3}LO A_{FB} %	$p\bar{p}$ frame	$t\bar{t}$ frame
QCD only Eq. (2)	$5.6^{+0.3}_{-0.4}$	$8.1^{+0.4}_{-0.6}$
QCD only Eq. (3)	6.0 ± 0.1	8.7 ± 0.2
QCD+EW Eq. (2)	$6.4^{+0.5}_{-0.6}$	$9.4^{+0.7}_{-0.9}$
QCD+EW Eq. (3)	6.8 ± 0.3	10.0 ± 0.6

large corrections: aN^{3}LO/NNLO ratio is 1.08 [Eq. (2)] or 1.05 [Eq. (3)]

Top differential $A_{\rm FB}$ at the Tevatron

$$A_{\rm FB}^{\rm bin} = \frac{\sigma_{\rm bin}^{+}(\Delta y) - \sigma_{\rm bin}^{-}(\Delta y)}{\sigma_{\rm bin}^{+}(\Delta y) + \sigma_{\rm bin}^{-}(\Delta y)} \quad \text{with} \quad \Delta y = y_t - y_{\bar{t}}$$



Summary

- **N^{3}LO soft-gluon corrections for top-pair production**
- **total cross sections**
- **top quark p_T and rapidity distributions**
- **top quark forward-backward asymmetry**
- **corrections are significant at the LHC and Tevatron**
- **excellent agreement with LHC and Tevatron data**