

# Top-pair and $tW$ production at approximate $N^3LO$

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- Higher-order corrections
- Top-antitop pair production
- $tW$  production



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## Higher-order corrections

QCD corrections are very significant for  $t\bar{t}$  and  $tW$  production

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

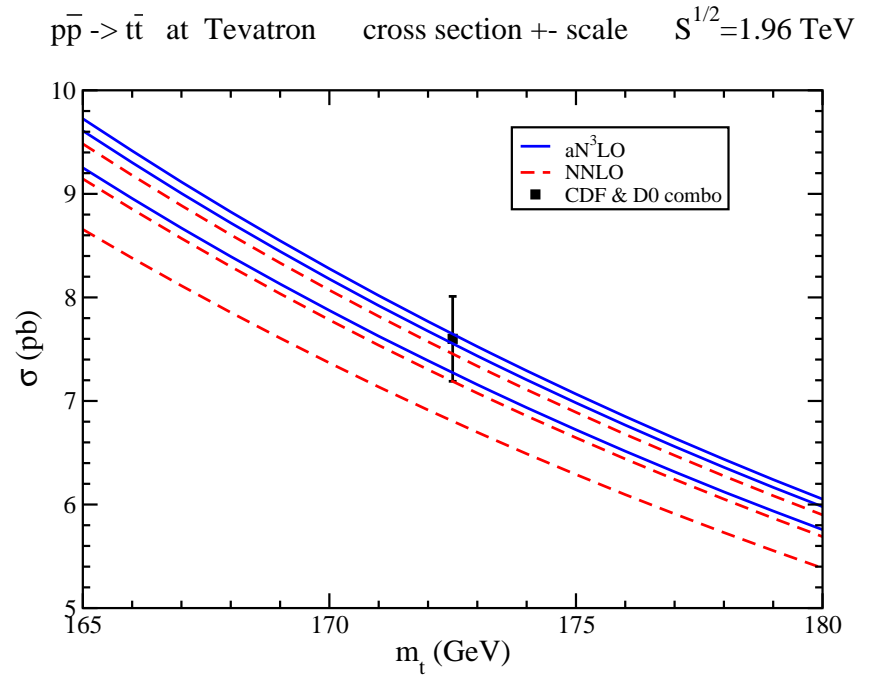
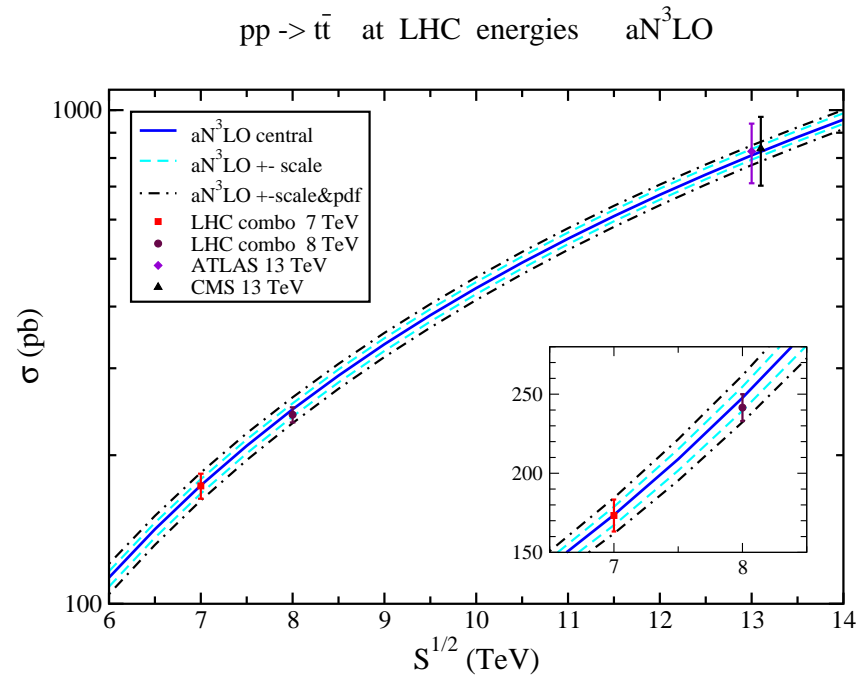
Calculate/resum these soft corrections at NNLL accuracy  
for the double-differential cross section

Approximate  $N^3LO$  ( $aN^3LO$ ) predictions for cross sections are derived  
by adding third-order soft corrections to fixed-order results

**NNLO is not enough**

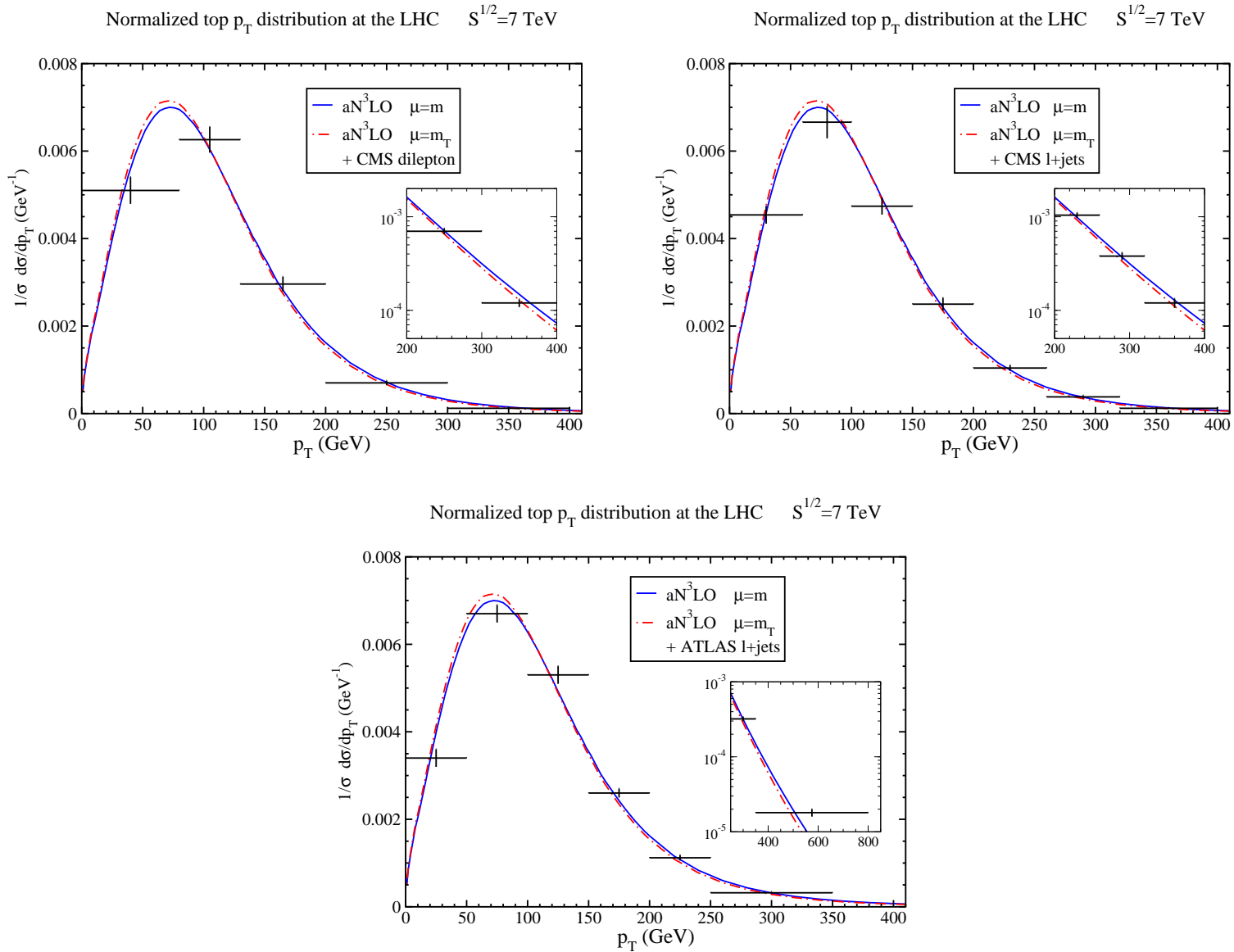
$aN^3LO$  needed for precision physics

# Top-pair cross sections at the LHC and the Tevatron

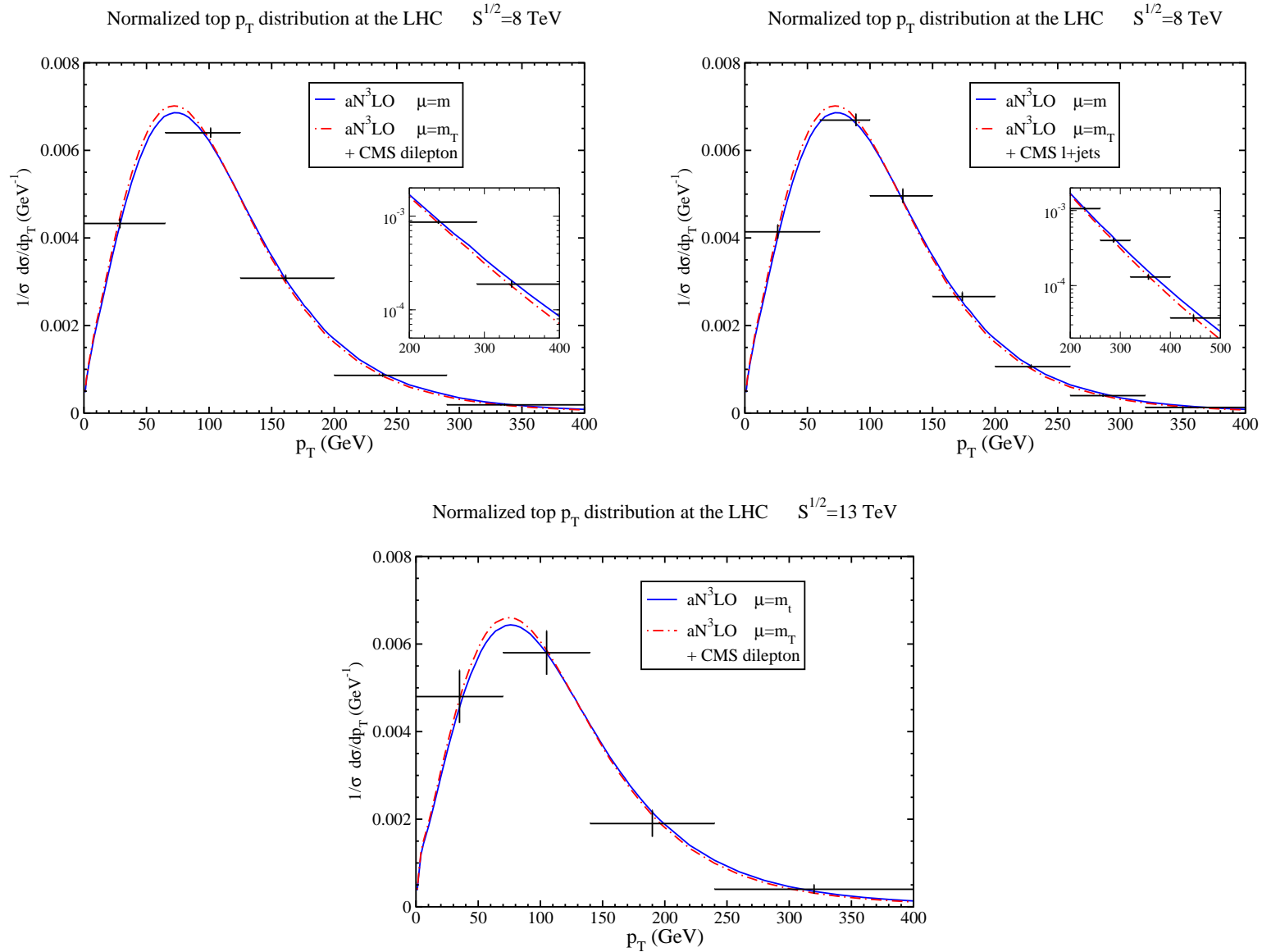


aN<sup>3</sup>LO total  $t\bar{t}$  cross sections  $\pm$  scale  $\pm$  pdf MMHT2014 uncertainties

# Normalized top quark $p_T$ distributions at 7 TeV LHC

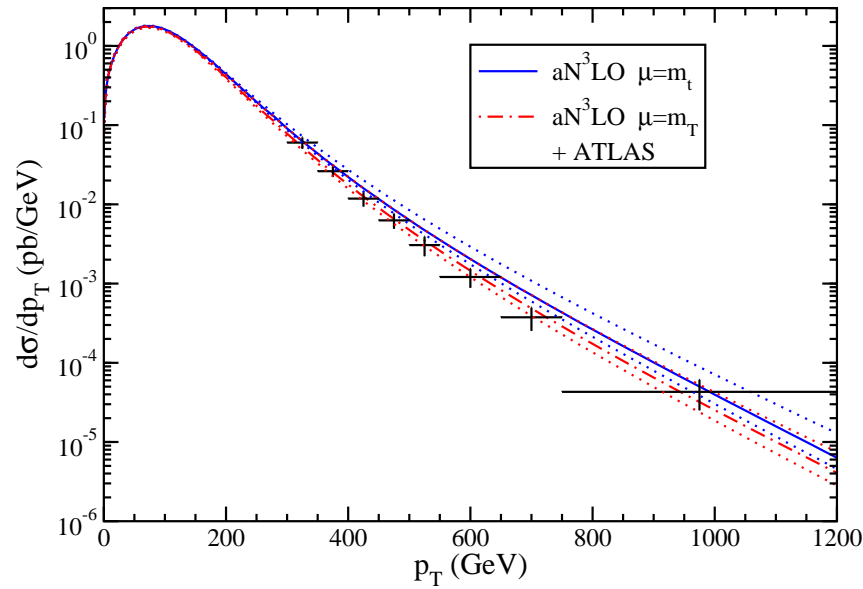


# Normalized top quark $p_T$ distributions at 8 and 13 TeV LHC

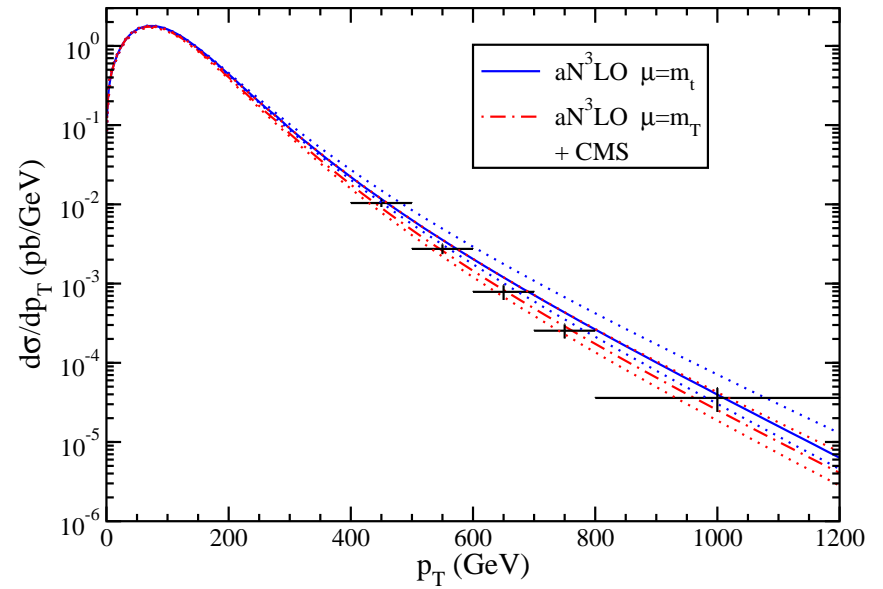


# Boosted top quark $p_T$ distributions at 8 TeV LHC

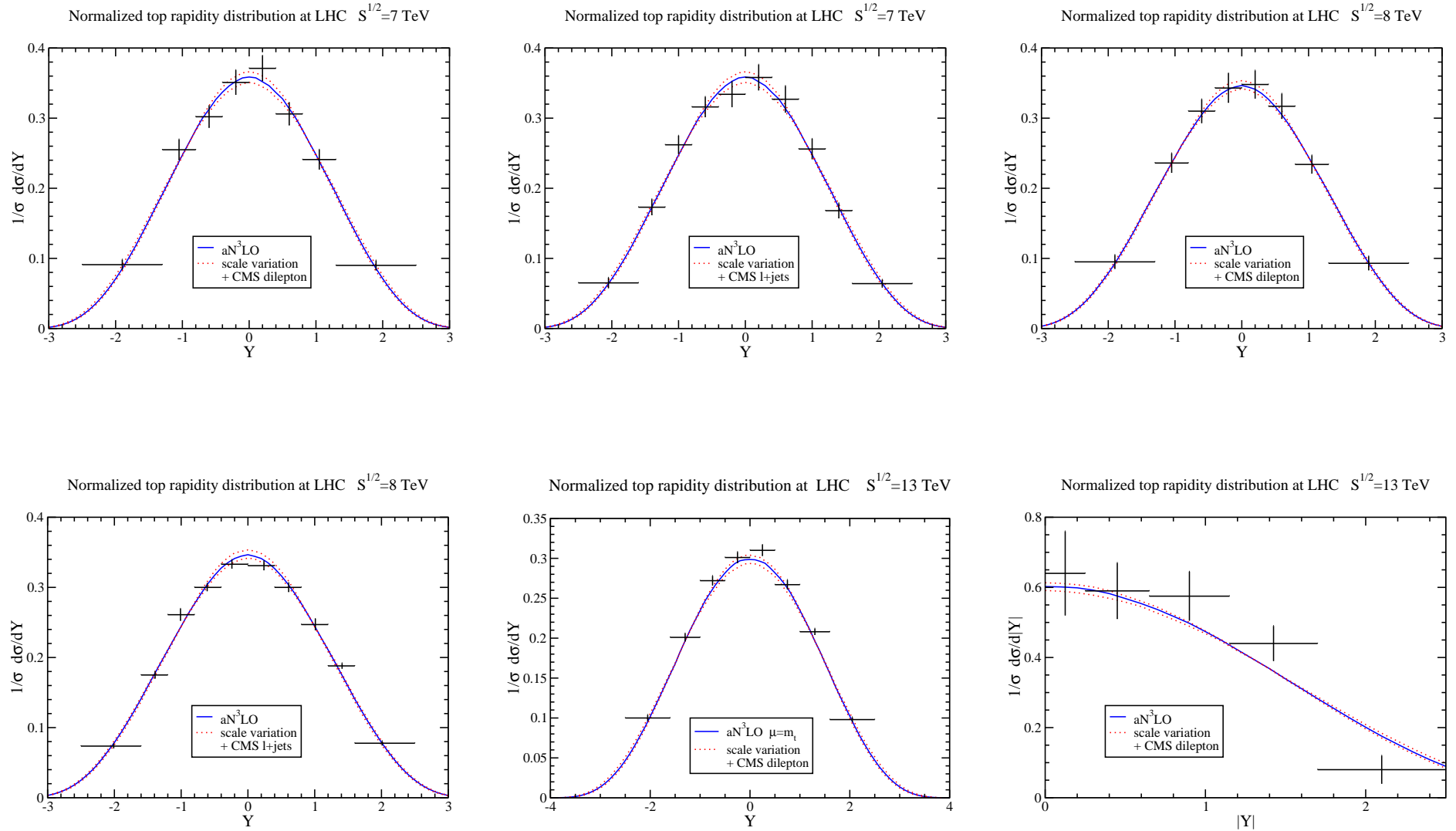
Top quark  $p_T$  distribution at LHC  $S^{1/2}=8$  TeV  $m_t=172.5$  GeV



Top quark  $p_T$  distribution at LHC  $S^{1/2}=8$  TeV  $m_t=172.5$  GeV

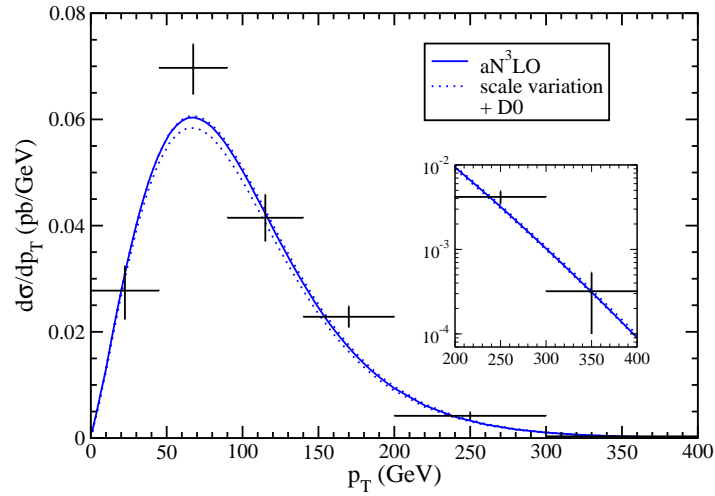


# Normalized top quark rapidity distributions at the LHC

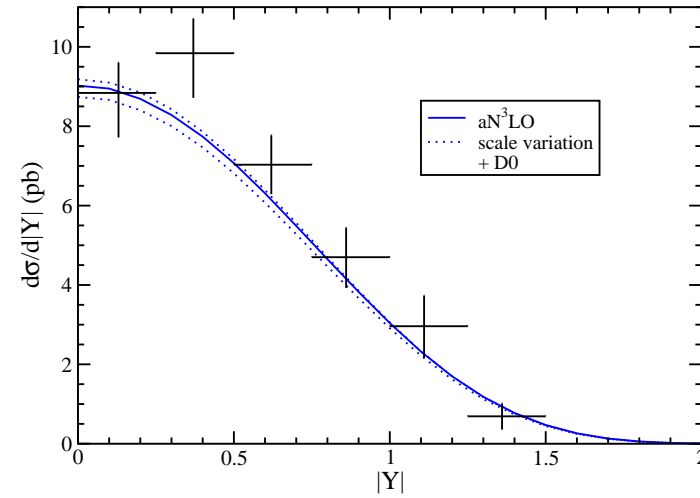


# Top quark $p_T$ and rapidity distributions and $A_{FB}$ at the Tevatron

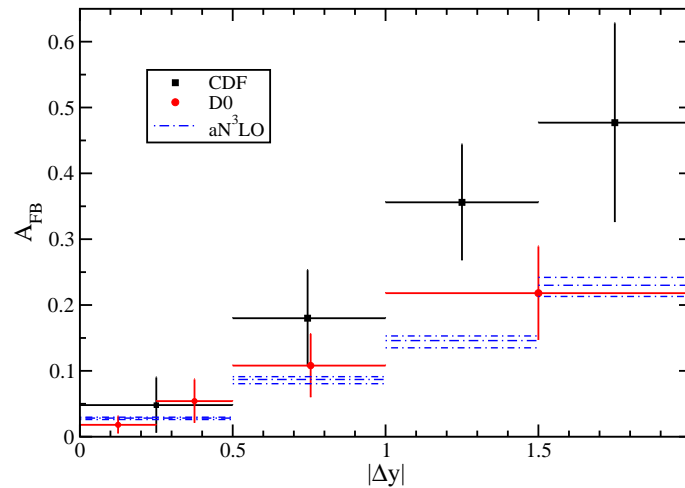
Top quark  $p_T$  distribution Tevatron  $S^{1/2}=1.96$  TeV  $m_t=172.5$  GeV



Top quark rapidity at Tevatron  $S^{1/2}=1.96$  TeV  $m_t=172.5$  GeV



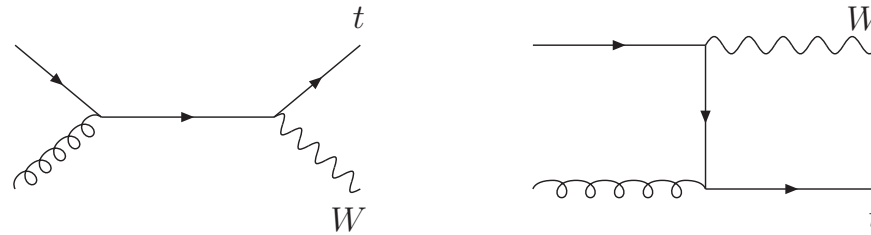
$A_{FB}$  at Tevatron  $S^{1/2}=1.96$  TeV  $m_t=173.3$  GeV





## $tW$ production

associated  $tW$  production:  $bg \rightarrow tW^-$



very small cross section at Tevatron  
but significant at LHC

# Associated $tW^-$ production at aN<sup>3</sup>LO at the LHC

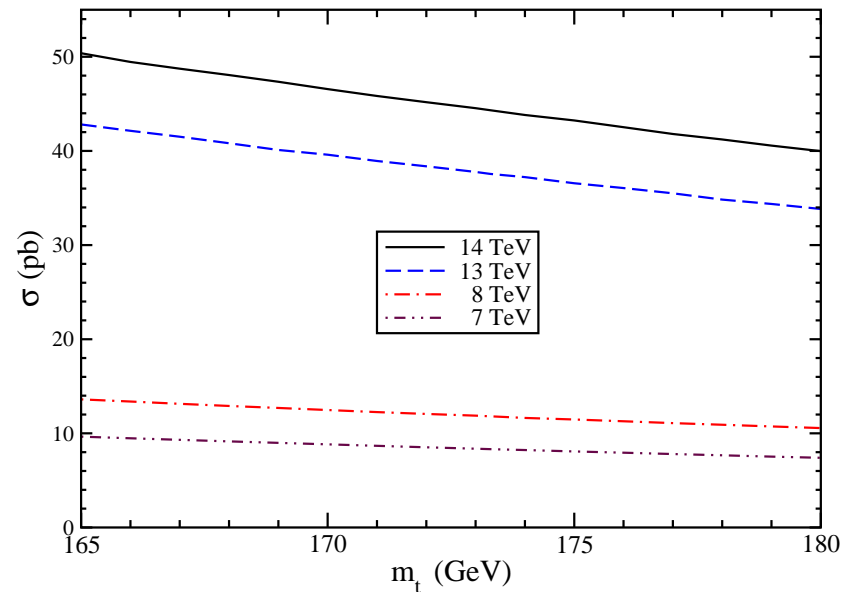
MMHT2014 NNLO pdf

$m_t = 173.3$  GeV

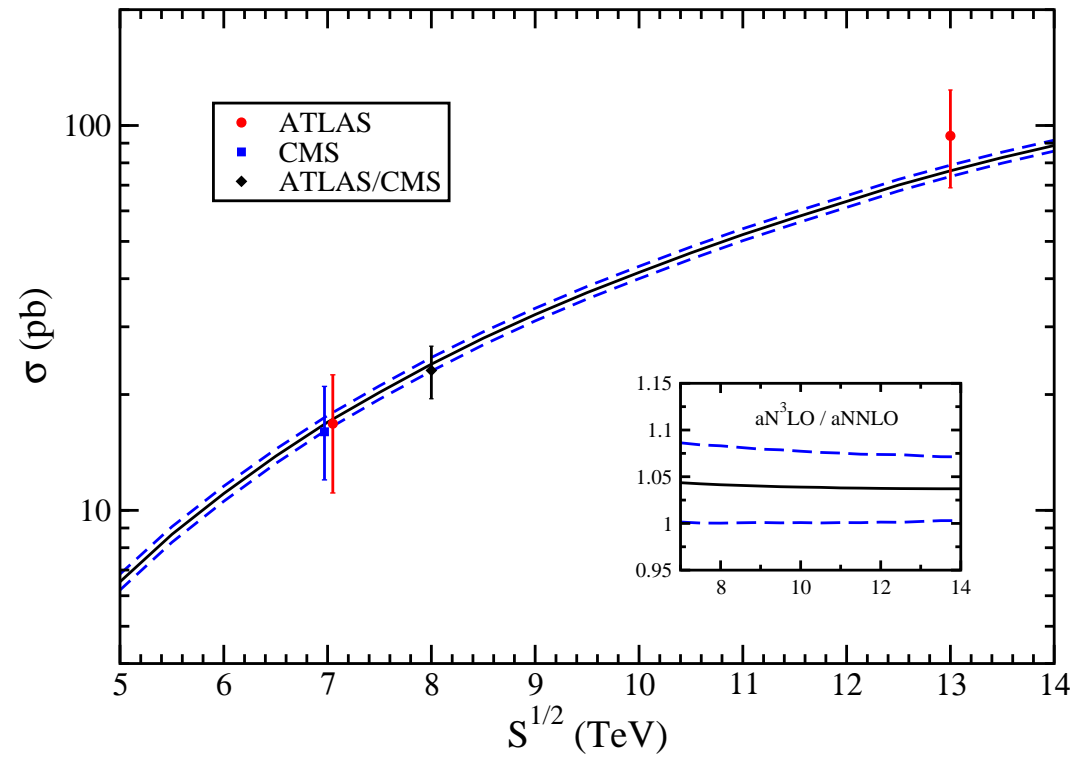
$\pm$  scale  $\pm$  pdf errors

LHC	$tW^-$
13 TeV	$37.6 \pm 0.9 \pm 0.9$
14 TeV	$44.3 \pm 1.0 \pm 1.1$

bg  $\rightarrow$   $tW^-$  at LHC aN<sup>3</sup>LO  $\mu=m_t$



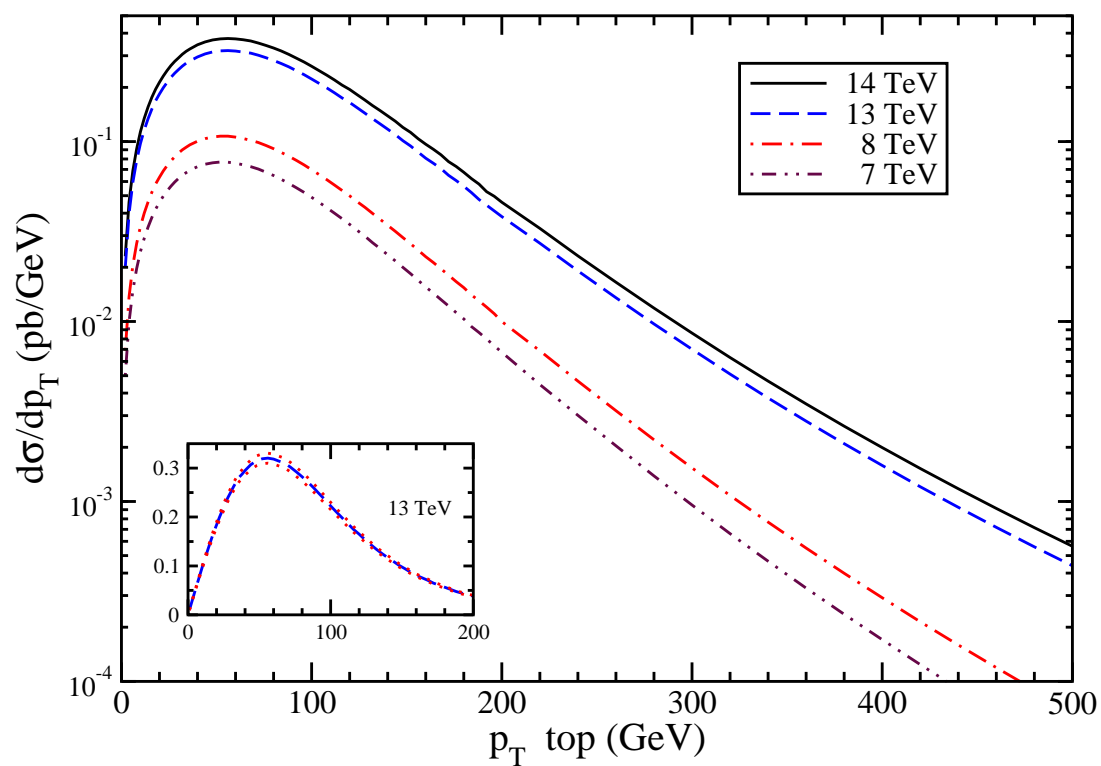
$tW^- + \bar{t}W^+$  aN<sup>3</sup>LO +-uncertainty  $m_t=172.5$  GeV



Excellent agreement of theory with data

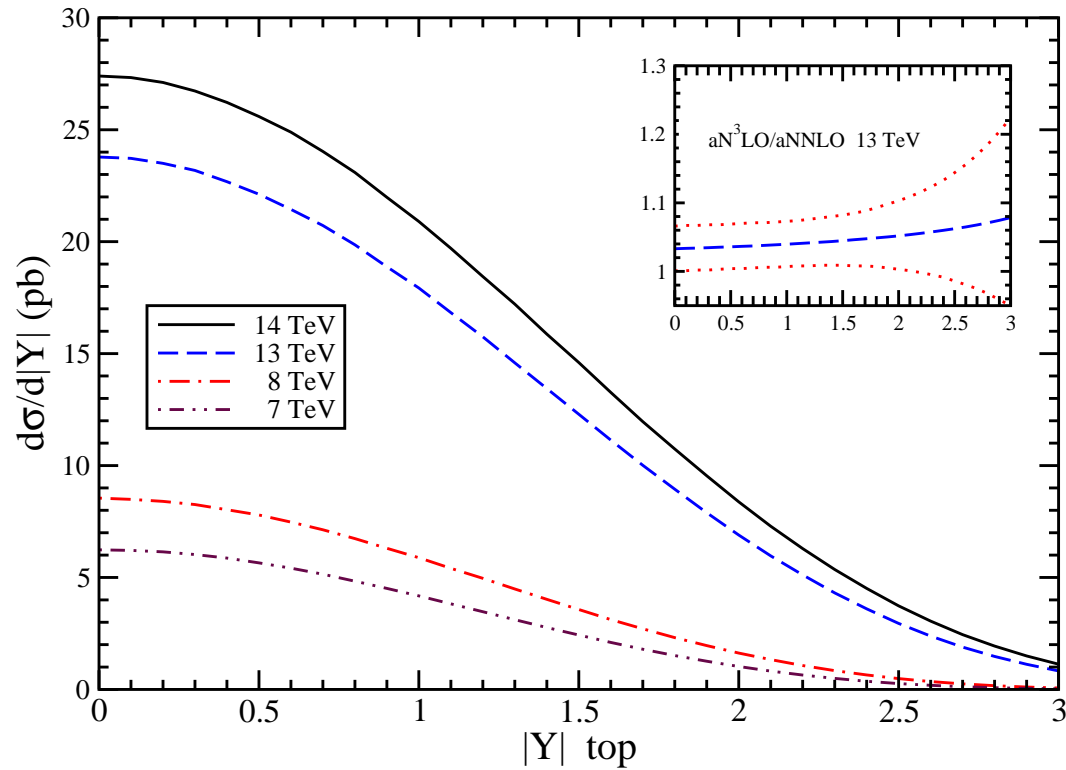
## Top quark $p_T$ distributions in $tW$ production

Top  $p_T$  distribution in  $tW^-$  production at LHC  $aN^3LO$   $m_t=173.3$  GeV



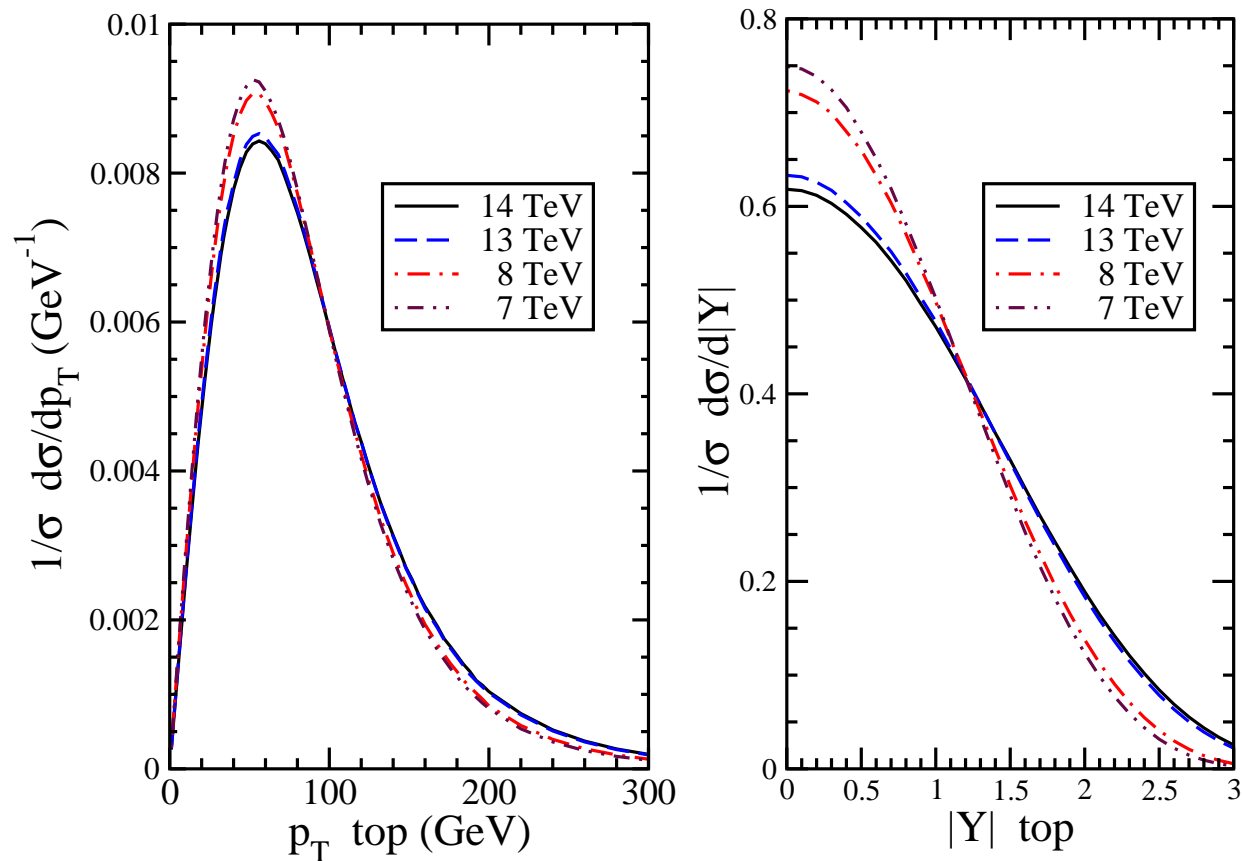
# Top quark rapidity distributions in $tW$ production

Top rapidity distribution in  $tW$  production at LHC  $aN^3LO$   $m_t=173.3$  GeV



# Normalized top quark distributions in $tW$ production

Normalized top  $p_T$  distribution  $tW^-$  aN<sup>3</sup>LO Normalized rapidity distribution



## Summary

- cross sections and distributions for  $t\bar{t}$  through aN<sup>3</sup>LO
  - top quark  $p_T$  and rapidity distributions
  - top quark forward-backward asymmetry
- cross sections and distributions for  $tW$  production through aN<sup>3</sup>LO
- high-order corrections are very significant
- excellent agreement with LHC and Tevatron data