Differential cross sections for top-quark and W-boson production

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- **Higher-order two-loop corrections**
- **NNLL resummation and NNLO expansions**
- **Top p_T and rapidity distributions in pair production**
- **Top p_T in single-top production**
- **W production at large p_T**

Higher-order corrections

QCD corrections significant for single top, top pair, and W production

Soft-gluon corrections from emission of soft (low-energy) gluons

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

Soft-gluon corrections are dominant near threshold

Resum these soft corrections - factorization and RGE

Complete results at NNLL–two-loop soft anomalous dimension

Approximate NNLO cross section from expansion of resummed cross section

Calculation is for partonic threshold at the double differential cross section level using the standard moment-space resummation in pQCD

Factorization and Resummation

Resummation follows from factorization properties of the cross section - performed in moment space

$\sigma = (\prod \psi)\, H_{IL}\, S_{LI}\, (\prod J)$ H: **hard function** S: **soft-gluon function**

Use RGE to evolve soft-gluon function

$$\left(\mu \frac{\partial}{\partial \mu} + \beta(g_s) \frac{\partial}{\partial g_s}\right) S_{LI} = -(\Gamma^\dagger_S)_{LB} S_{BI} - S_{LA} (\Gamma_S)_{AI}$$

Γ_S **is the soft anomalous dimension - a matrix in color space and a function of kinematical invariants** s, t, u

Resummed cross section

$$\hat{\sigma}^{res}(N) = \exp\left[\sum_i E_i(N_i)\right] \exp\left[\sum_j E'_j(N')\right] \exp\left[\sum_{i=1,2} 2 \int_{\mu_F}^{\sqrt{s}} \frac{d\mu}{\mu}\, \gamma_{i/i}\left(\tilde{N}_i, \alpha_s(\mu)\right)\right]$$

$$\times \operatorname{tr}\left\{H\left(\alpha_s\right) \exp\left[\int_{\sqrt{s}}^{\sqrt{s}/\tilde{N}'} \frac{d\mu}{\mu}\, \Gamma_S^\dagger\left(\alpha_s(\mu)\right)\right] S\left(\alpha_s\left(\frac{\sqrt{s}}{\tilde{N}'}\right)\right) \exp\left[\int_{\sqrt{s}}^{\sqrt{s}/\tilde{N}'} \frac{d\mu}{\mu}\, \Gamma_S\left(\alpha_s(\mu)\right)\right]\right\}$$

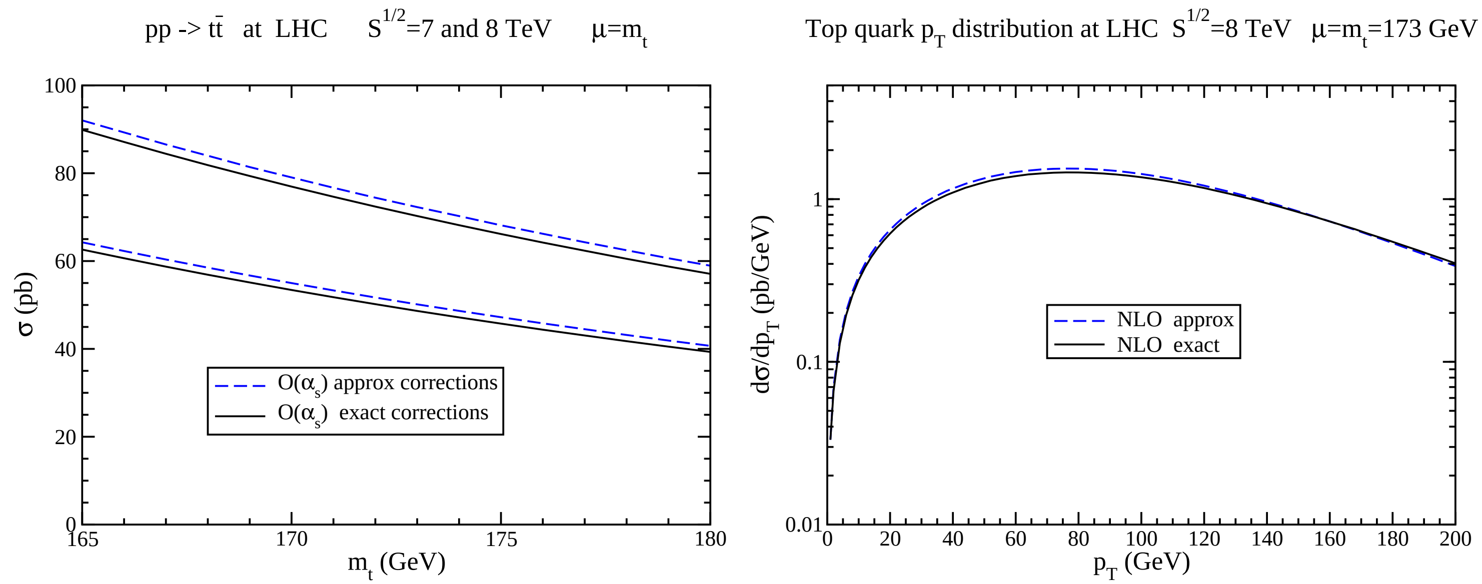
determine Γ_S **from ultraviolet poles in dimensionally regularized eikonal diagrams**

Γ_S **is process-dependent; calculated at two loops**

We are resumming $\ln^k N$ **- we can expand to fixed order and invert to get** $\ln^k(s_4/m_t^2)/s_4$

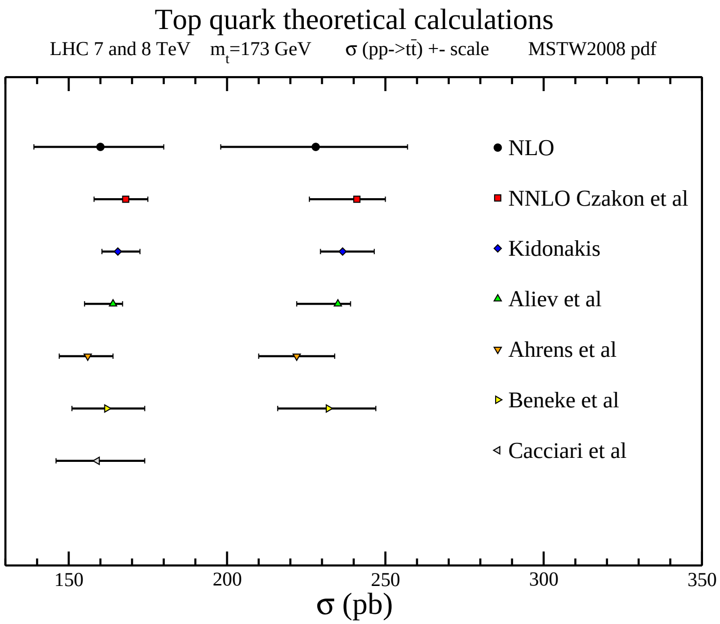
Threshold approximation

Approximation works very well not only for Tevatron but also for LHC energies because partonic threshold is still important



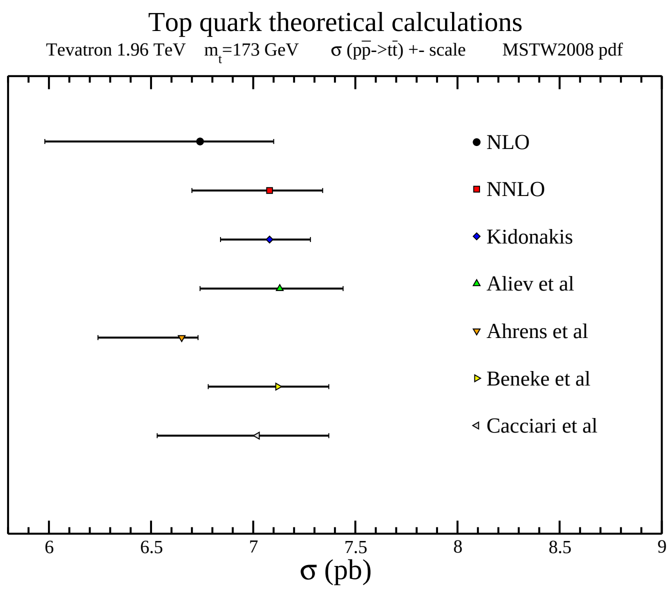
excellent approximation:
less than 1% difference between NLO approximate and exact cross sections
Also excellent for differential distributions

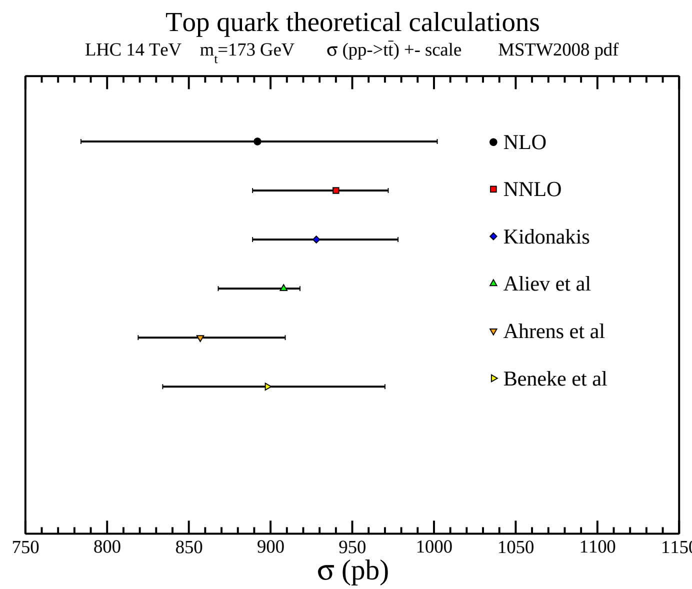
For best prediction add NNLO approx corrections to exact NLO result



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





The result from my formalism is very close to the exact NNLO:
both the central values and the scale uncertainty are nearly the same
true for all collider energies and top quark masses

This was expected from comparison to NLO, and analytical/numerical study of NNLO corrections in different kinematics

(PRD 68, N. Kidonakis & R. Vogt; see also discussion in PRD78 and PRD82)

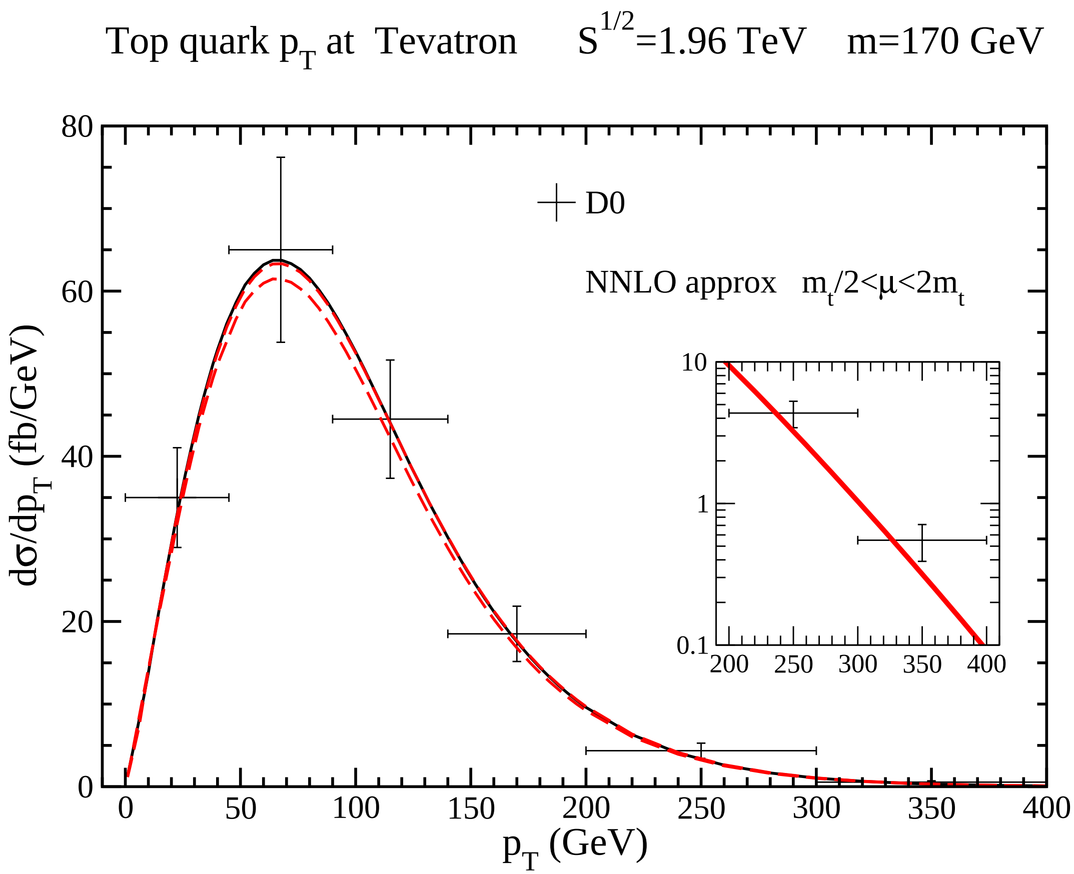
$\sim$1% difference between approximate and exact cross sections at both NLO and NNLO

stability of the theoretical NNLO approx result over the past decade

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

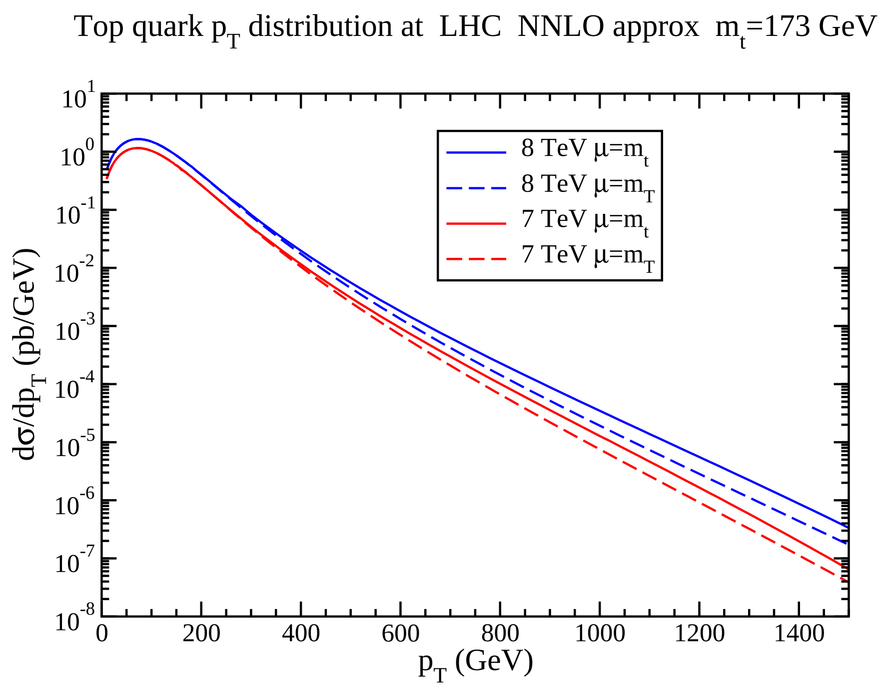
- **provides confidence of application to other processes (single-top, W, etc)**
- **results used as background for many analyses (Higgs, etc)**
- **means that we have near-exact NNLO p_T and rapidity distributions**

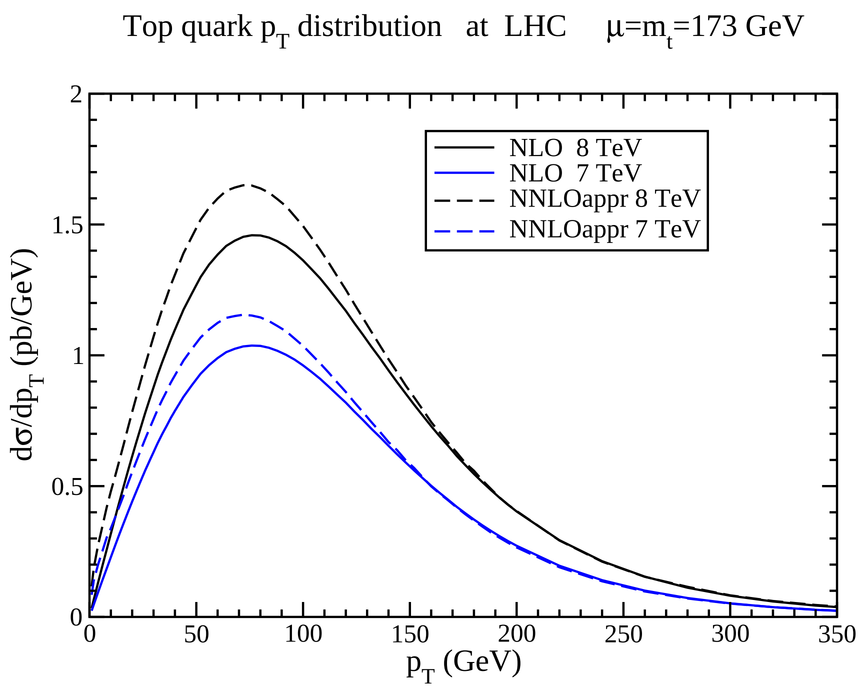
Top quark p_T distribution at Tevatron



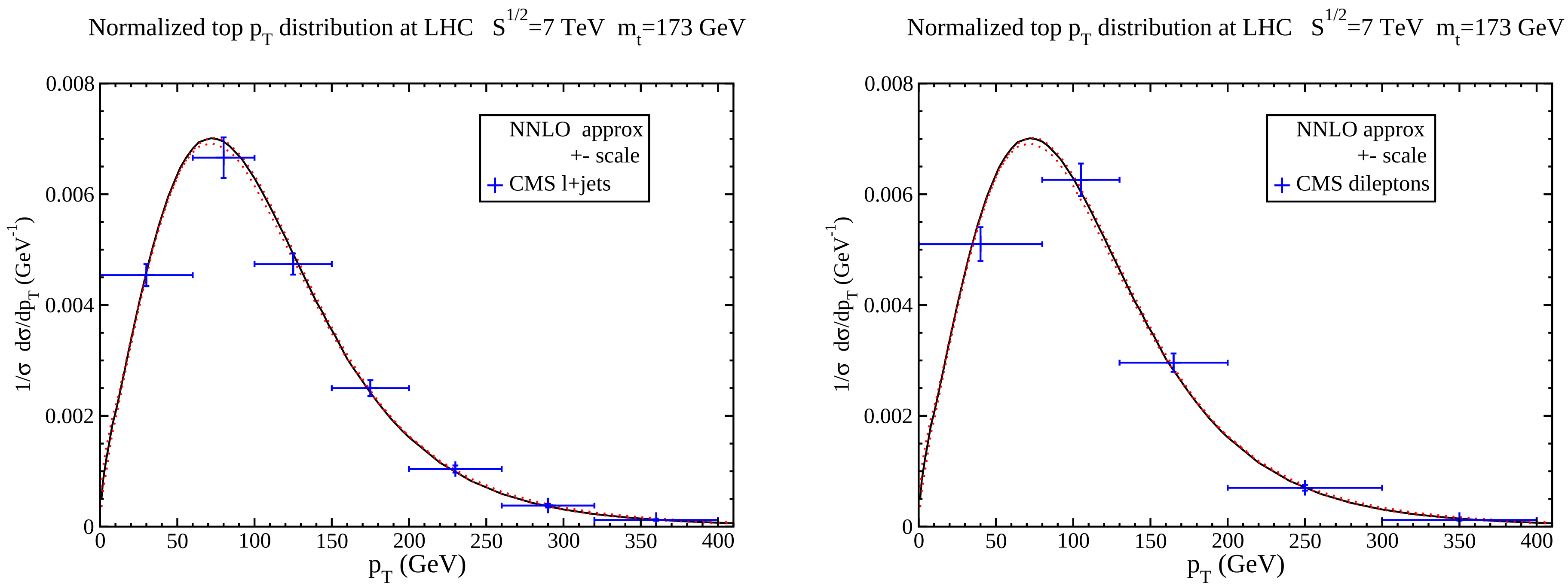
Excellent agreement of NNLO approx results with D0 data

Top quark p_T distribution at the LHC



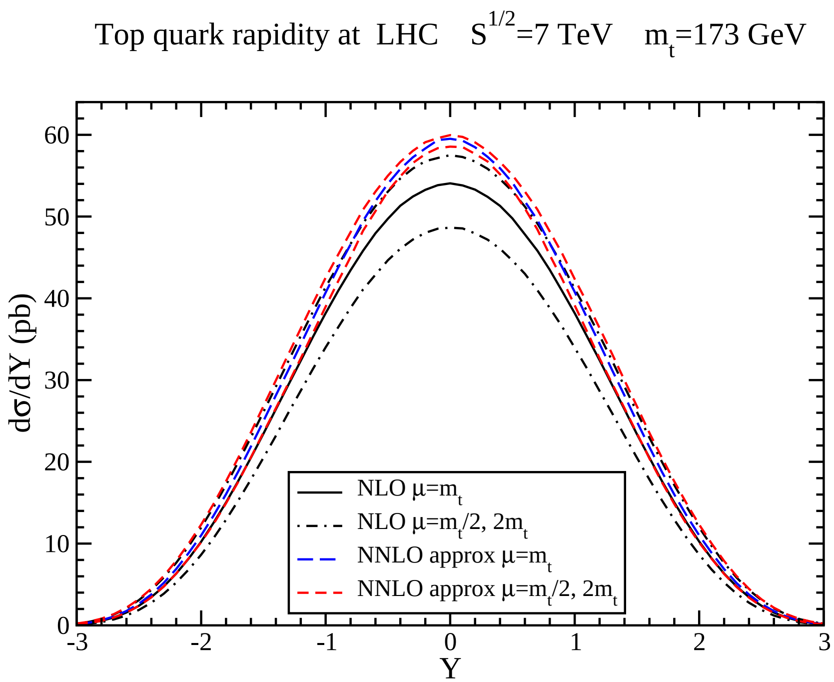


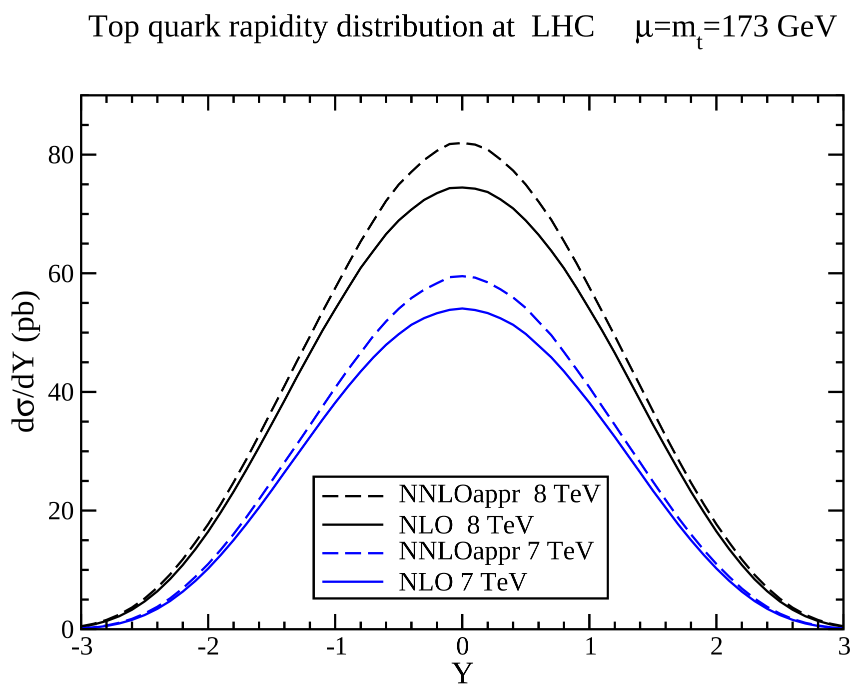
Normalized top quark p_T distribution at the LHC



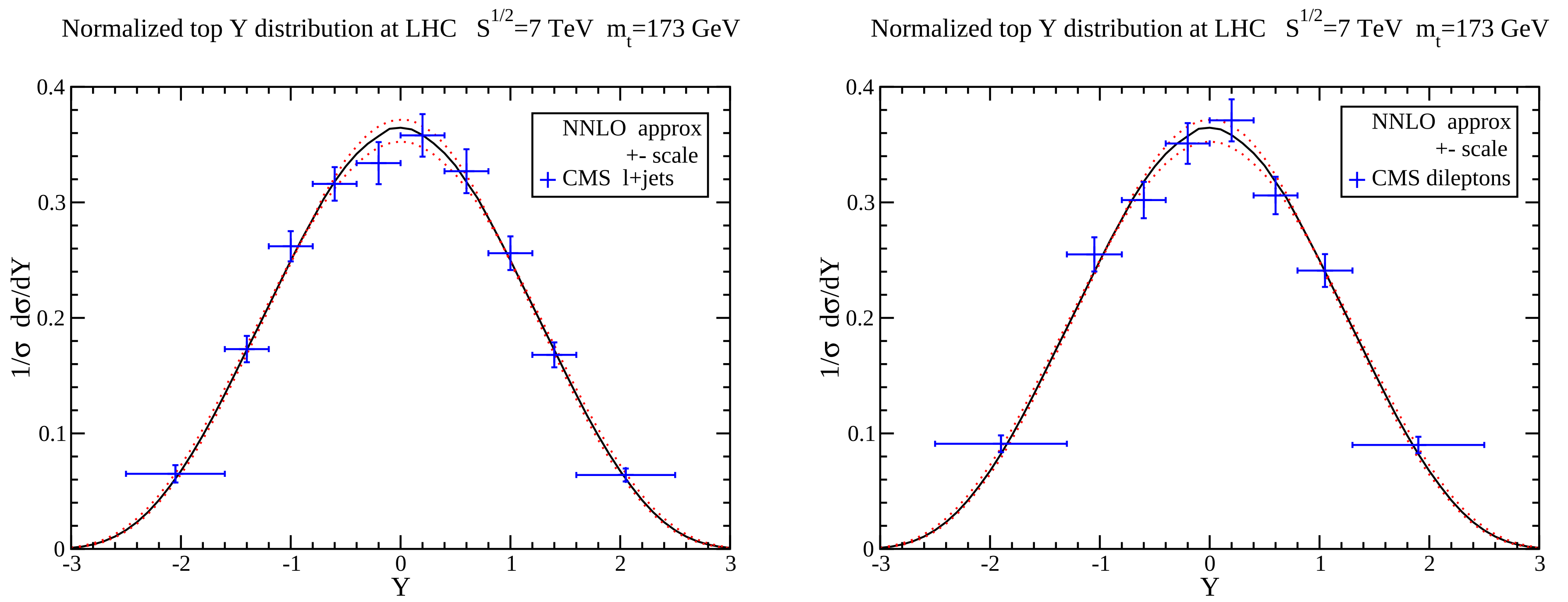
Excellent agreement with CMS data at 7 TeV; also at 8 TeV

Top quark rapidity distribution at LHC



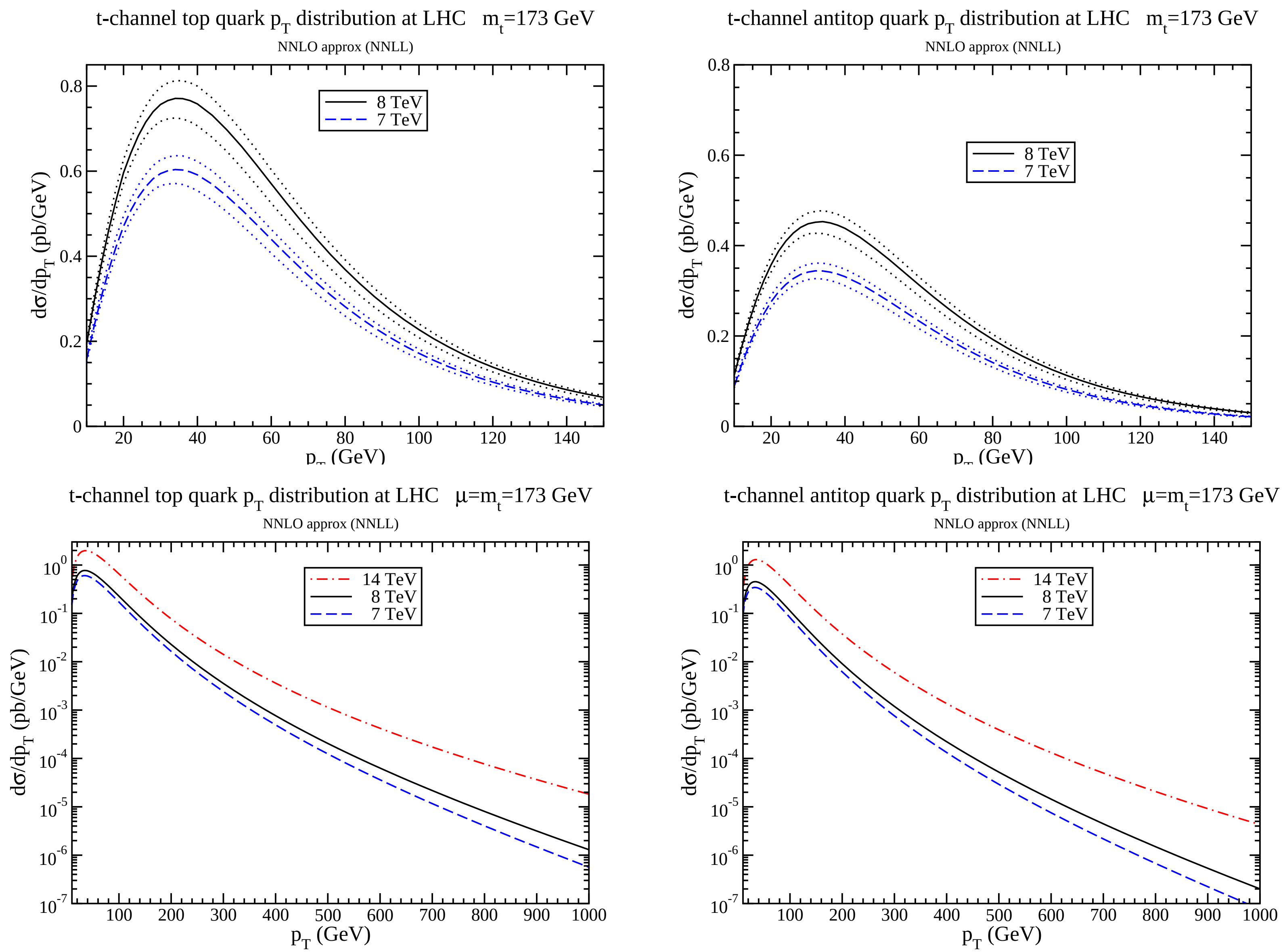


Normalized top quark rapidity distribution at LHC

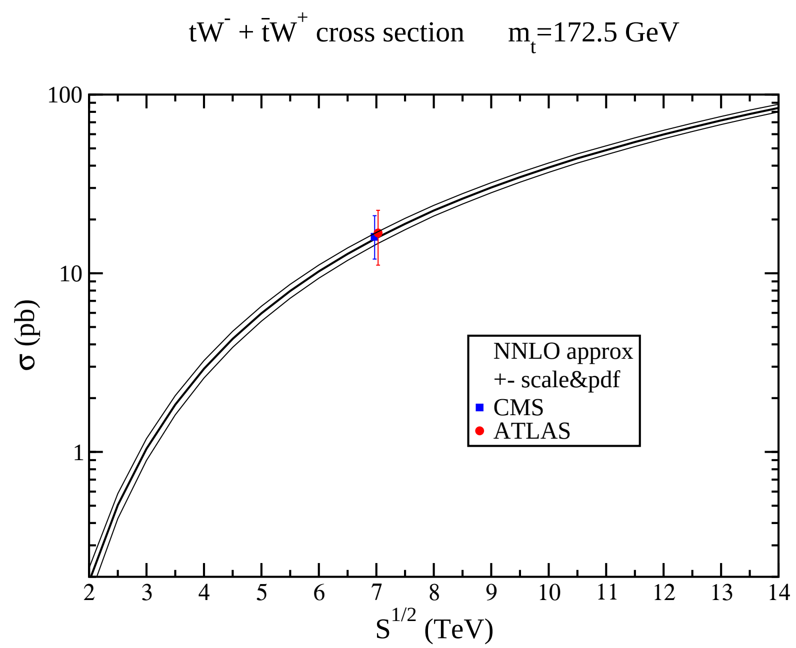


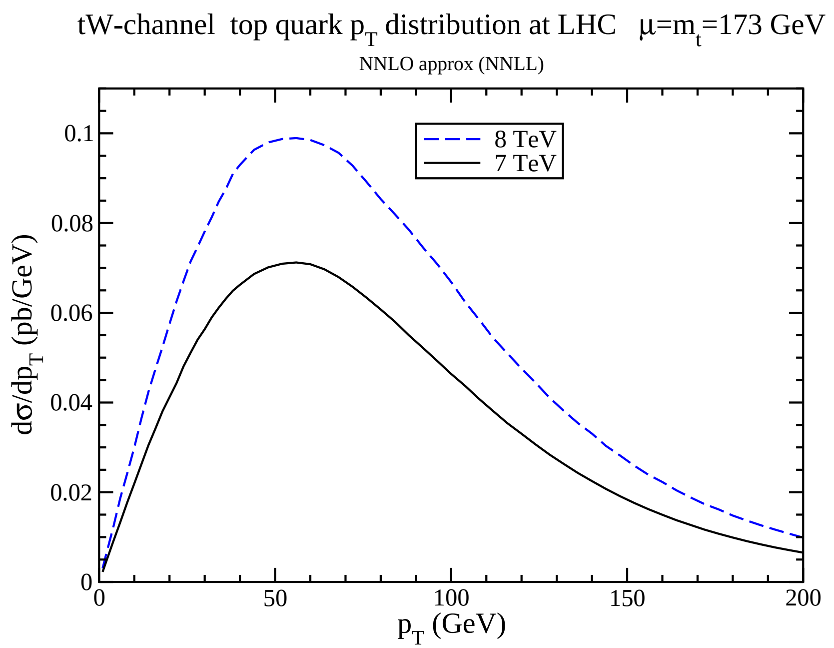
Excellent agreement with CMS data at 7 TeV; also at 8 TeV

t-channel top and antitop p_T distributions at LHC



Associated tW^- production at the LHC





Cross section for $\bar{t}W^+$ production is identical to tW^-

W production at large p_T

W hadroproduction useful in testing the SM and in estimates of backgrounds to Higgs production and new physics (new gauge bosons)

p_T distribution falls rapidly as p_T increases

Partonic channels at LO

$q(p_a) + g(p_b) \longrightarrow W(Q) + q(p_c)$

$q(p_a) + \bar{q}(p_b) \longrightarrow W(Q) + g(p_c)$

with $s = (p_a + p_b)^2$, $t = (p_a - Q)^2$, $u = (p_b - Q)^2$ **and** $s_4 = s + t + u - Q^2$

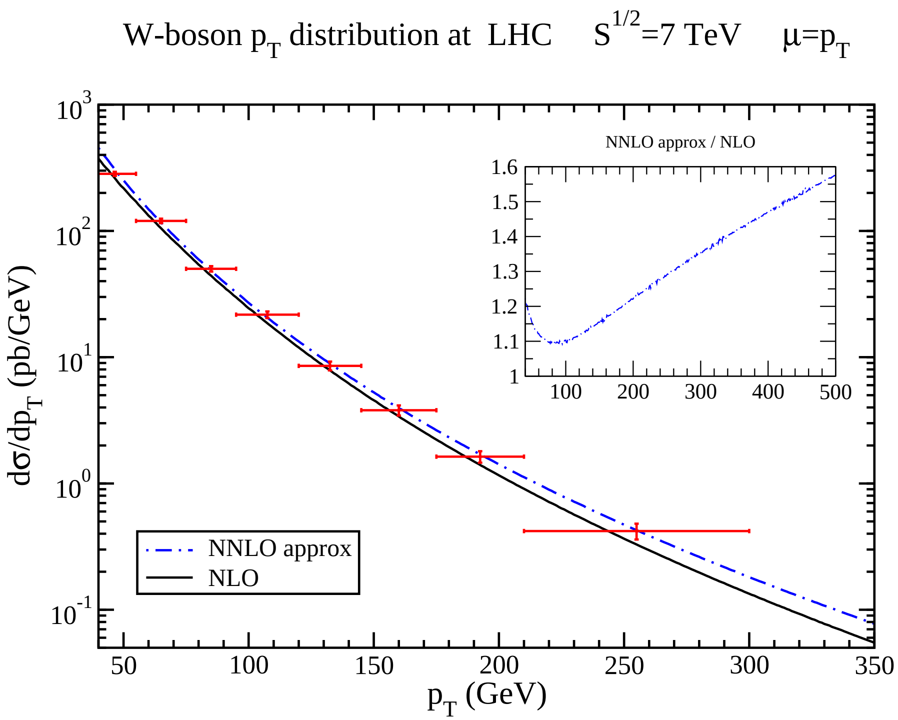
At threshold $s_4 \to 0$

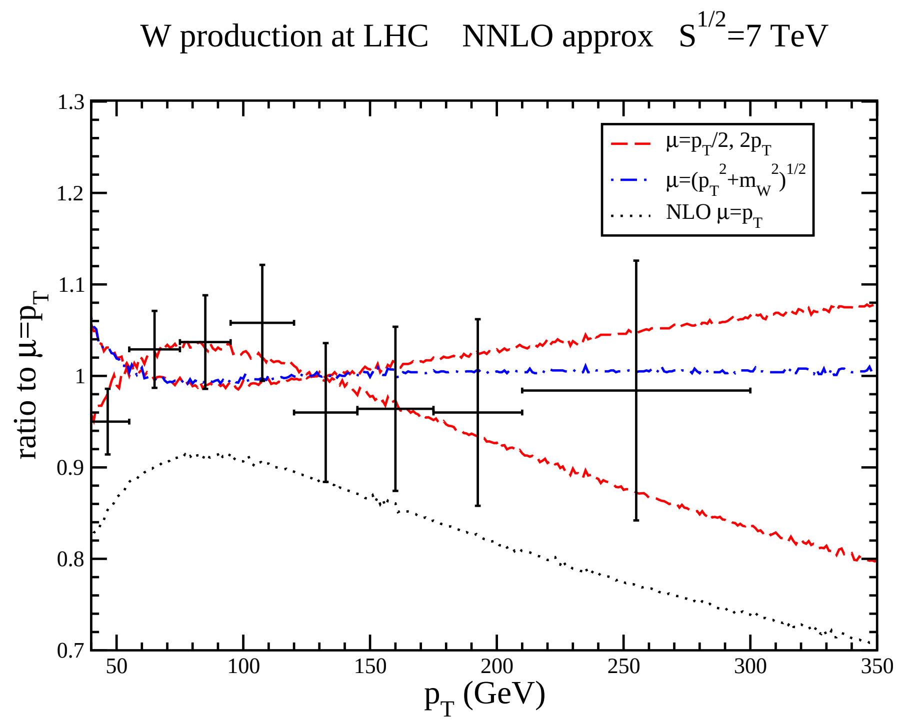
Soft corrections $\left[\frac{\ln^l(s_4/p_T^2)}{s_4}\right]_+$

approximate NNLO from NNLL resummation:

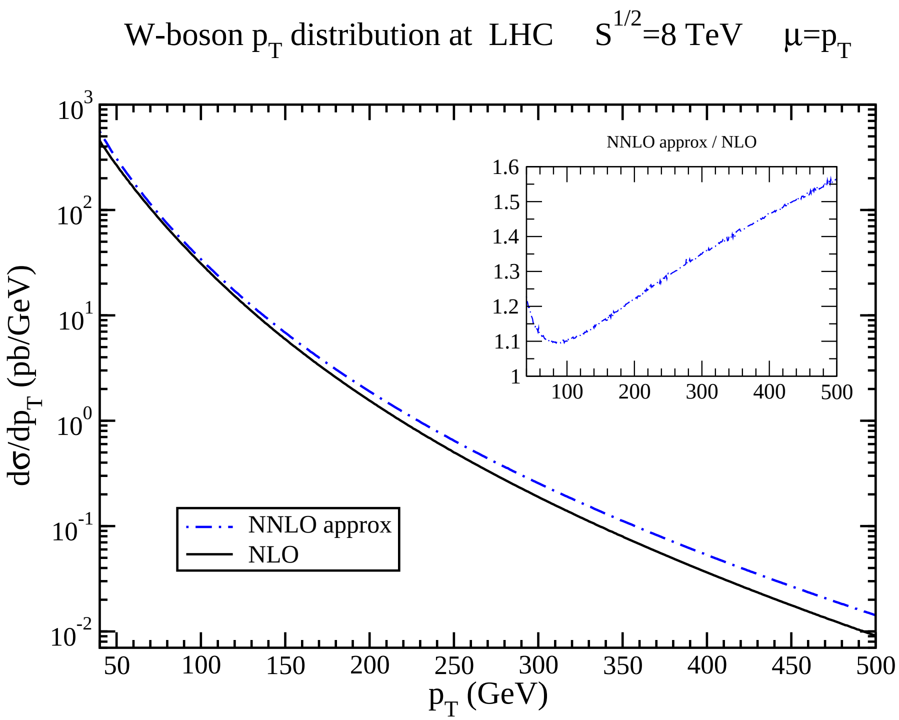
N. Kidonakis and R.J. Gonsalves, Phys. Rev. D 87, 014001 (2013)

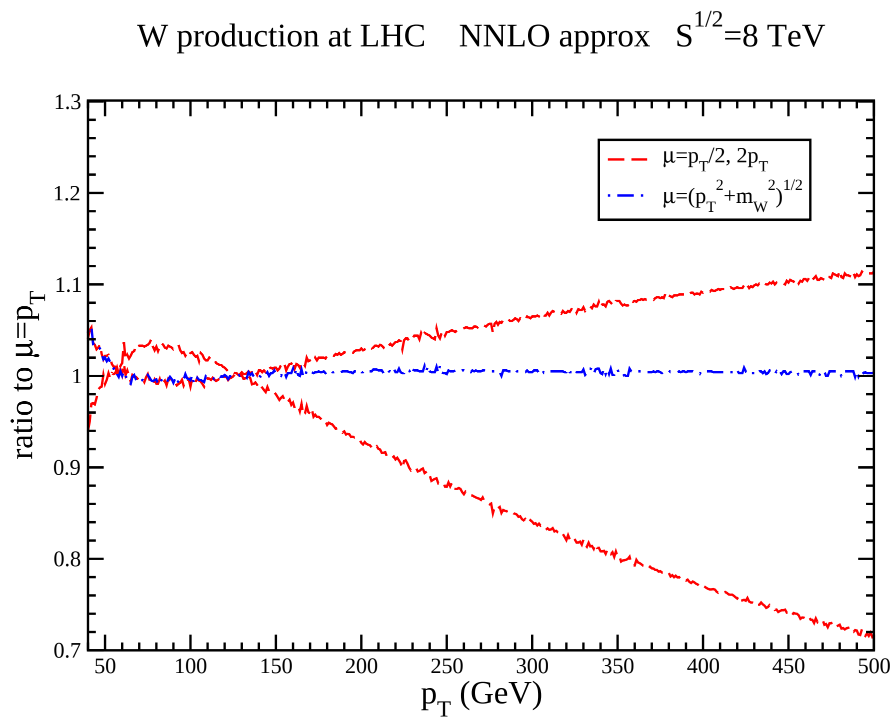
W production at large p_T at the LHC - 7 TeV





W production at large p_T at the LHC - 8 TeV





Summary

- **NNLL resummation for top-pair and single-top production**
- **top quark p_T and rapidity distributions**
- **W production at large p_T**
- **NNLO approx corrections are significant at the LHC and the Tevatron**
- **excellent agreement with LHC and Tevatron data**
- **future work on more differential distributions**