Top quark production at the LHC: differential cross section and phenomenological perspectives.

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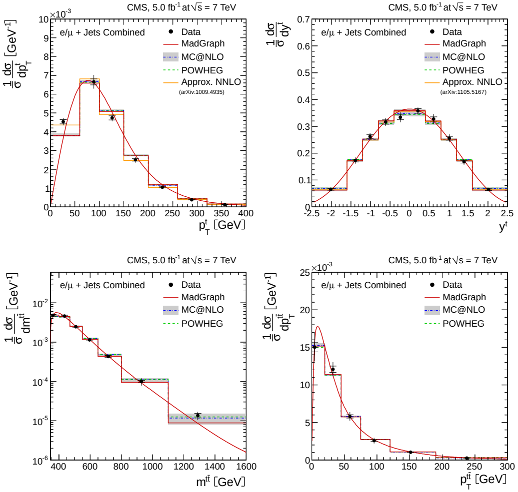
Motivations

- Top quark production at the LHC: crucial in the near future phenomenology!
- $t\bar{t}$ pairs are copiously produced in PP reactions at the LHC, $\Longrightarrow$ inflow of precise measurements of top-quark production cross section with unprecedented accuracy
- Precise measurements of differential cross section as a function of different observables: already available!

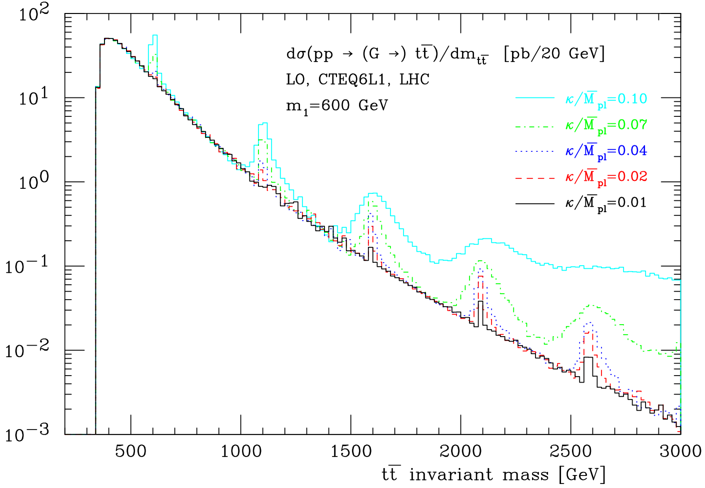


The CMS Collaboration arXiv:1211.2220 [hep-ex], $\int Ldt = 5.0[\text{fb}]^{-1}$, $\sqrt{S} = 7$ TeV, MORE DATA ON TAPE! $\int Ldt \approx 20[\text{fb}]^{-1}$, $\sqrt{S} = 8$ TeV

A lot work to do on the phenomenological side

- crucial to test Standard Model (SM) properties: $m_t \approx m_H \rightarrow$ glimpse of the Higgs sector!
- ongoing efforts in precise determination of m_t
- investigation of the correlation $\alpha_s(M_Z)$, m_t, and *PDFs*
- QCD factorization
- A new realm of precision calculations

Physics Beyond the SM: is there any?



from F. Maltoni and R. Frederix, JHEP 0901 (2009) 047

We need precise theoretical predictions beyond NLO QCD!

..Reduction of theoretical systematic uncertainties associated to variation of scales in the calculation (although this is not the end of the story...)

Lots of work has been done in the past years on soft-gluon resummation

Remarkable progress recently on fixed order NNLO calculations

Recent progress

The NNLO exact calculation for the $t\bar{t}$ total cross section is now complete up to $O(\alpha_s^4)$

- Czakon, Fiedler, Mitov (2013); Czakon, Mitov (2012), (2013); Baernreuther, Czakon, Mitov (2012)

Exact NLO tools available

- MCFM Campbell, Ellis, Williams; MadGraph5 Alwall, Maltoni, et al.; MC@NLO Frixione, Stoeckli, Torrielli, Webber, White; POWHEG Alioli, Hamilton, Nason, Oleari, Re.

Approx. NNLO including threshold resummation

- Czakon, Mitov, Sterman, (2009); Kidonakis (2010); Moch, Uwer, Vogt (2012); Cacciari, Czakon, Mangano, Mitov, Nason (2012)

Progress in Soft Collinear Effective Theory (SCET)

- Ahrens, Ferroglia, Neubert, Pecjak, Yang, (2011) Development of tools for phenomenology:

We report on the progress on DESY & University of Hamburg side

Approx. NNLO calculation including NNLL threshold resummation
(A Mellin-space resummation computer code, Sven Moch and M.G.)

Some known facts about resummation and kinematics...

Remnants of long-distance dynamics in a hard scattering function can be large in regions of phase space near partonic threshold and dominate higher order corrections: $\rightarrow$ logarithmic corrections

Threshold resummation organizes double-logarithmic corrections to all orders, thereby extending the predictive power of QCD to these phase space regions. G. Sterman (1987); S. Catani and L. Trentadue (1989); H. Contopanagos, E. Laenen, and G. Sterman (1997)

The kinematics of inclusive heavy quark hadroproduction depend on which final state momenta are reconstructed.
In threshold resummation, a kinematic choice manifests itself at next-to-leading-logarithmic level.

Resummation in single-particle inclusive (1PI) and pair-invariant mass kinematics (PIM)

Near threshold heavy quark hadroproduction in 1PI kinematics is defined by reaction is dominated by the partonic subprocesses

$$i(k_1) + j(k_2) \to Q(p_1) + X[\bar{Q}](p_2') \qquad p_2' = \bar{p}_2 + k \tag{1}$$

where is k any additional radiation, and $s_4 = p_2' - m^2 \to 0$ momentum at the threshold.

In the pair-inclusive kinematics (PIM)

$$i(k_1) + j(k_2) \to Q\bar{Q}(p') + X'(k) \tag{2}$$

$X'(k) = 0$ the reaction is at the threshold $p'^2 = M^2$.

Approx. NNLO+NNLL differential cross section at parton level in 1PI, here $s_4 = \hat{s} + \hat{t}_1 + \hat{u}_1$

$$s^2 \frac{\hat{\sigma}_{ij}}{du_1 dt_1}|_{1PI} = F_{ij}^{Born} \frac{\alpha_s^2(\mu_R^2)}{\pi^2} \left\{ D_{ij}^{(3)} \left[\frac{ln^3(s_4/m_t^2)}{s_4} \right]_+ \right.$$
$$\left. + D_{ij}^{(2)} \left[\frac{ln^2(s_4/m_t^2)}{s_4} \right]_+ + D_{ij}^{(1)} \left[\frac{ln(s_4/m_t^2)}{s_4} \right]_+ + D_{ij}^{(0)} \left[\frac{1}{s_4} \right]_+ + R_{ij} \delta(s_4) \right\} .$$

$$\alpha_s^n \left[\frac{\ln^m(s_4/m_t^2)}{s_4} \right]_+ \qquad m = 0, \cdots, 2n-1, \tag{3}$$

Recent progress in Soft Collinear Effective Theory, where one apdopts a different approach to compute the soft function and resums slightly different logs

$$\alpha_s^n \left[\ln^m \left(\frac{s_4}{\sqrt{s_4 + m_t^2}} \right) \right]_+ . \tag{4}$$

These kind of corrections can be numerically important. Detailed analysis by Ahrens, Ferroglia, Neubert, Pecjak, Yang, (2011), (2012).

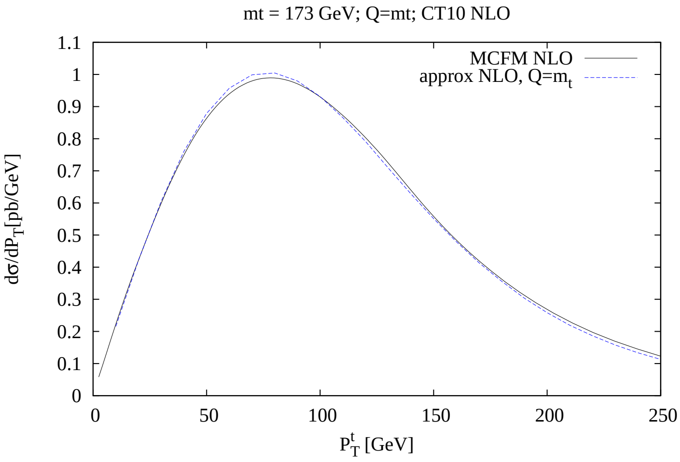
What is it good for?

- precise forthcomig data
- theory @ NLO and approx NNLO sizeable K-factors (perturbative level)
- non-perturbative parameter $\alpha_s(M_Z)$, m_t, gluon(x) $\Rightarrow$ simultaneous determination $\Rightarrow$ global fit predictions!
  attempt in this direction with state-of-the-art $\sigma_{t\bar{t}}^{NNLO}$ by Czakon, Mangano, Mitov, Rojo (2013), although we can discuss about statistical significance.
- Tools development:
  - flexible OPEN SOURCE code for experimentalists
  - possibility of manipulating inputs: $(PP, P\bar{P})$, m_t, mu_F, mu_R, α_s evol., lhapdf interface, perturbative order, logarithmic approximation etc..

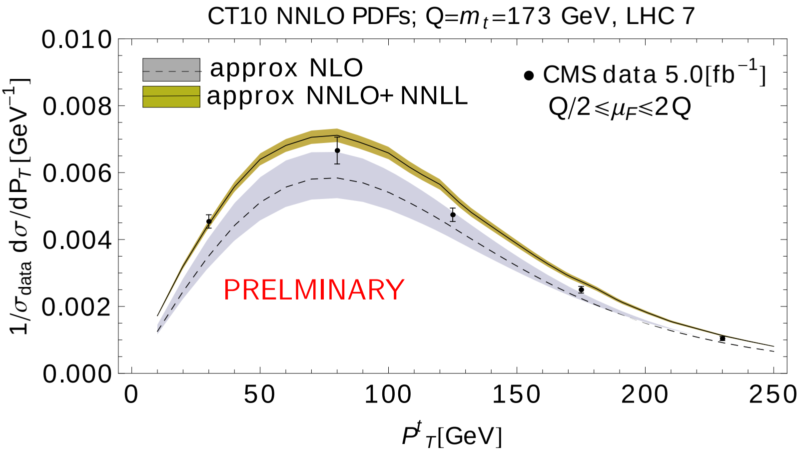
Results

Quality check:

NLO Exact Calculation vs approx NLO

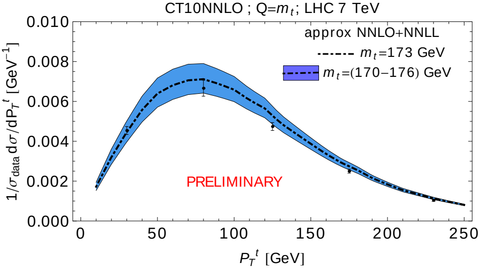


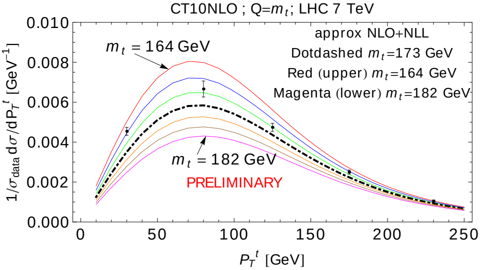
K-factors are large! CMS-TOP-11-013



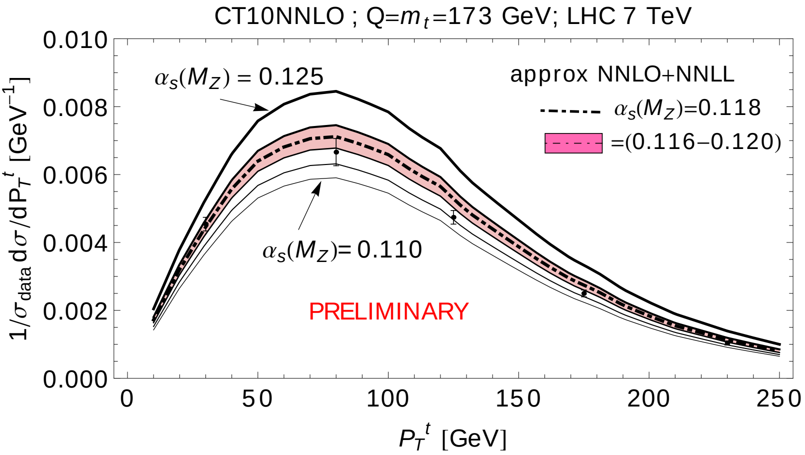
Error band at NNLO Kidonakis PRD82 (2010) 114030 ≈ 2-3%

Dependence on m_t

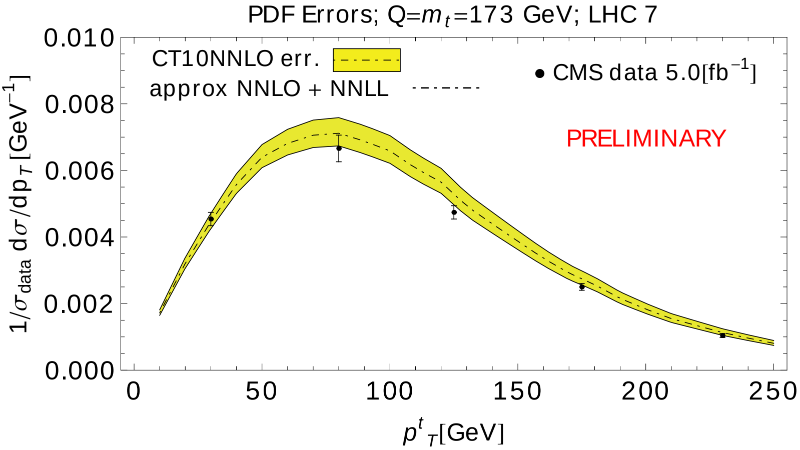




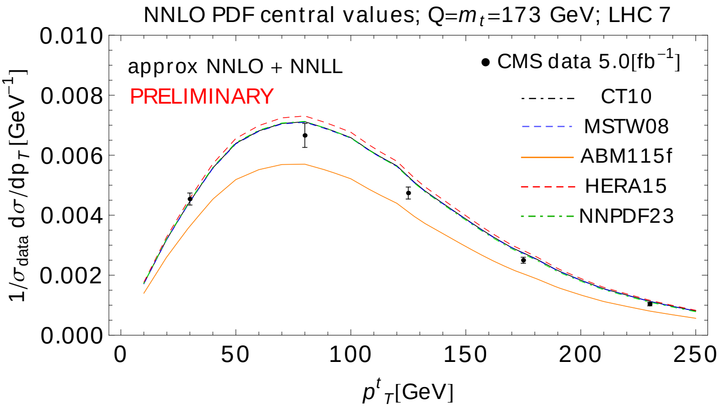
$\alpha_s(M_Z)$ dependence within CT10NNLO PDFs



Estimate of the PDF uncertainty at 90% C.L.

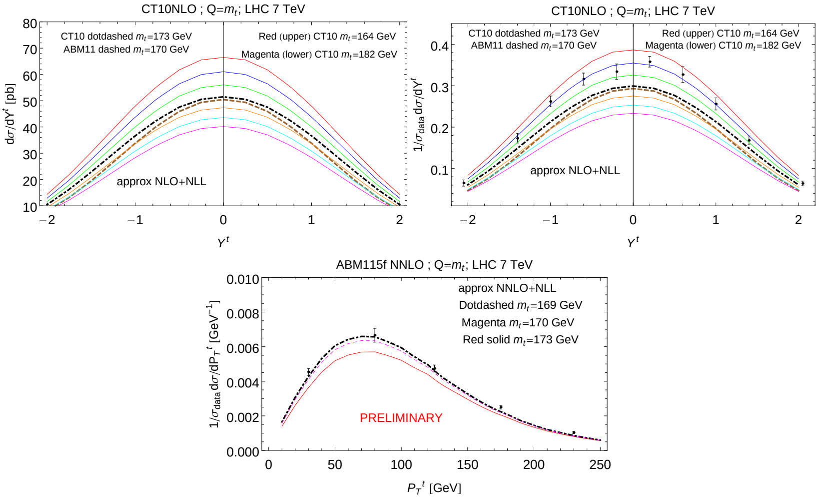


P_T^t-differential distribution



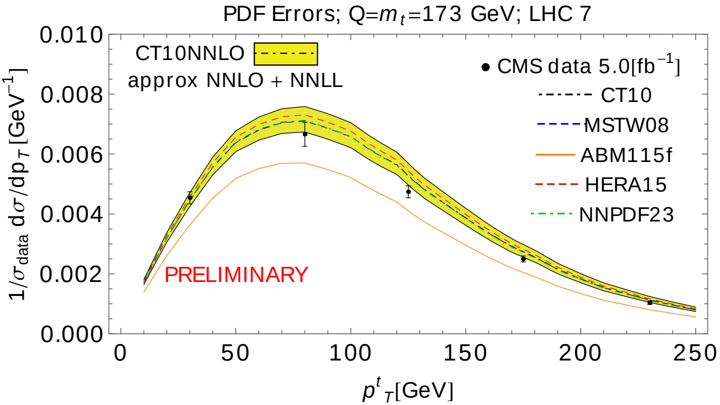
NNLO PDFs preferred m_t value: CT10, MSTW08, NNPDF2.3, $m_t \approx 173 - 175$ GeV; ABM115F $m_t \approx 170$ GeV, HERA15NNLO $m_t \approx 176$ GeV. Similar plot for the rapidity distrib. in the Backup.

Y^t differential cross section dependence on m_t



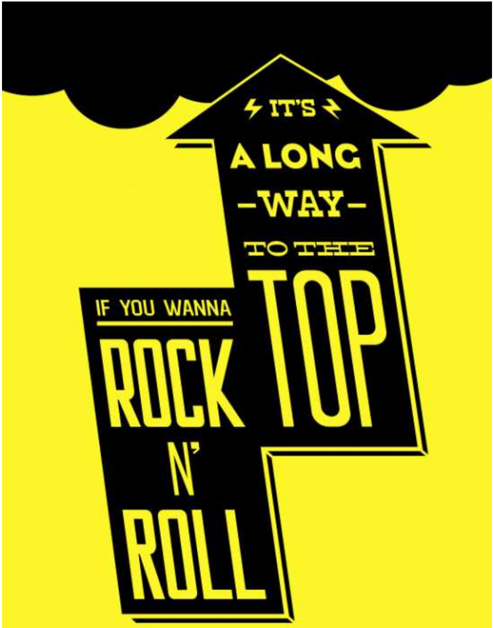
The AMB115F set prefers a smaller value of $m_t \approx 170$ GeV to get closer to the other PDFs.

Estimate of the PDF uncertainty



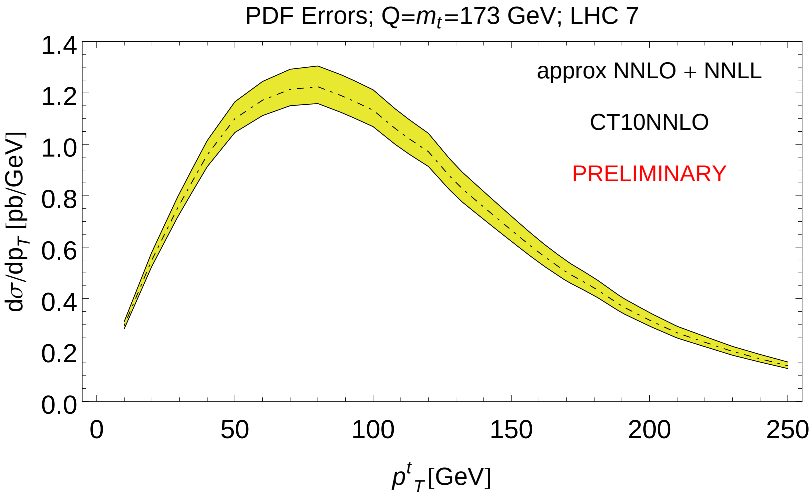
Conclusions

- work in progress on developments of tools for phenomenological analyses
- More data needed: new data are on the way !
- More comparisons data-theory for differential observables are in progress.
- Work in progress on the improvements on theoretical side
- It will be very interesting to plug in all of this into PDF fits!


IT'S
A LONG
WAY
TO THE
TOP
IF YOU WANNA
ROCK
N'
ROLL

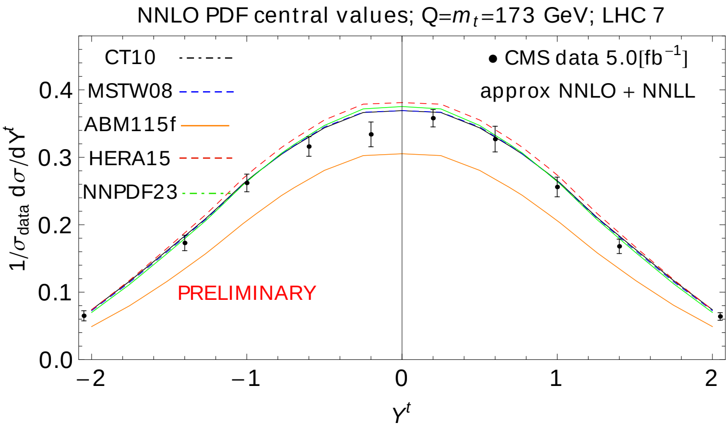
BACKUP

Estimate of the PDF uncertainty



Not normalized

Y^t-differential distribution



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