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# CMS Physics Analysis Summary

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2018/09/19

Measurement of the  $t\bar{t}$  production cross section, the top quark mass, and the strong coupling constant using events in the dilepton final state in pp collisions at  $\sqrt{s} = 13$  TeV

The CMS Collaboration

## Abstract

A measurement of the top quark-antiquark ( $t\bar{t}$ ) pair production cross section in proton-proton collisions at a centre-of-mass energy of 13 TeV is presented. The data correspond to an integrated luminosity of  $35.9 \text{ fb}^{-1}$ , recorded by the CMS experiment at the CERN LHC in 2016. Events containing two charged leptons are selected and the cross section is measured from a likelihood fit. For a fixed top quark mass parameter in the simulation of 172.5 GeV the fit yields a measured cross section  $\sigma_{t\bar{t}} = 803 \pm 2 \text{ (stat)} \pm 25 \text{ (syst)} \pm 20 \text{ (lum)} \text{ pb}$ , in agreement with the expectation from the standard model calculation at next-to-next-to-leading order (NNLO). A simultaneous fit of the cross section and the top quark mass parameter in the simulation is performed. The resulting cross section is used, together with the NNLO theory prediction, to determine the top quark mass and to extract a value of the strong coupling constant.

Table 5: Values of  $\alpha_S(m_Z)$  with their uncertainties obtained using different PDF sets. The pole mass scheme is used for the top quark mass treatment in the theory prediction.

PDF set (NNLO)	$\alpha_S(m_Z)^{\min}$
ABMP16	$0.1164 \pm 0.0021$ (fit + PDF) $^{+0.0024}_{-0.0014}$ (scale)
NNPDF3.1	$0.1184 \pm 0.0027$ (fit + PDF) $^{+0.0037}_{-0.0021}$ (scale)
CT14	$0.1186 \pm 0.0028$ (fit + PDF) $^{+0.0034}_{-0.0019}$ (scale)
MMHT14	$0.1205 \pm 0.0029$ (fit + PDF) $^{+0.0037}_{-0.0021}$ (scale)

calculation by the H1 experiment and challenges its precision.

The same procedure is used to extract the top quark mass, either in the  $\overline{\text{MS}}$  or in the pole mass scheme, by fixing the strong coupling constant to the nominal value at which the used PDF is evaluated. The fit is performed by varying the top quark mass in a 5 GeV range around the central values of each PDF. The uncertainties related to the variation of  $\alpha_S(m_Z)$  in the PDF are estimated by repeating the fit using the PDF eigenvectors evaluated at  $\alpha_S(m_Z)$  varied by its uncertainty, as provided by NNPDF3.1nnlo, MMHT2014nnlo, and CT14nnlo. In the case of ABMP16nnlo, the value of  $\alpha_S(m_Z)$  is a free parameter of the PDF fit and its uncertainty is implicitly included in the ABMP16nnlo PDF uncertainty eigenvectors. The resulting  $m_t(m_t)$  and  $m_t^{\text{pole}}$  values are summarized in Tables 6 and 7, respectively, where the fit uncertainty corresponds to the accuracy of the  $\sigma_{t\bar{t}}$  measurement. The results obtained with different PDF sets are in agreement, although the ABMP16nnlo PDF set yields systematically lower values. This difference is expected and has its origin in a larger value of  $\alpha_S(m_Z)$  of 0.118 assumed in the NNPDF3.1, MMHT2014, and CT14 PDFs.

Table 6: Extraction of  $m_t(m_t)$  at NNLO from  $\sigma_{t\bar{t}}$  using different PDF sets.

PDF set (NNLO)	$m_t(m_t)$ [ GeV ]
ABMP16	$161.6 \pm 1.6$ (fit + PDF + $\alpha_S$ ) $^{+0.1}_{-1.0}$ (scale)
NNPDF3.1	$164.5 \pm 1.5$ (fit + PDF + $\alpha_S$ ) $^{+0.1}_{-1.0}$ (scale)
CT14	$165.0 \pm 1.7$ (fit + PDF) $\pm 0.6$ ( $\alpha_S$ ) $^{+0.1}_{-1.0}$ (scale)
MMHT14	$164.9 \pm 1.7$ (fit + PDF) $\pm 0.5$ ( $\alpha_S$ ) $^{+0.1}_{-1.1}$ (scale)

Table 7: Extraction of  $m_t^{\text{pole}}$  at NNLO from  $\sigma_{t\bar{t}}$  using different PDF sets.

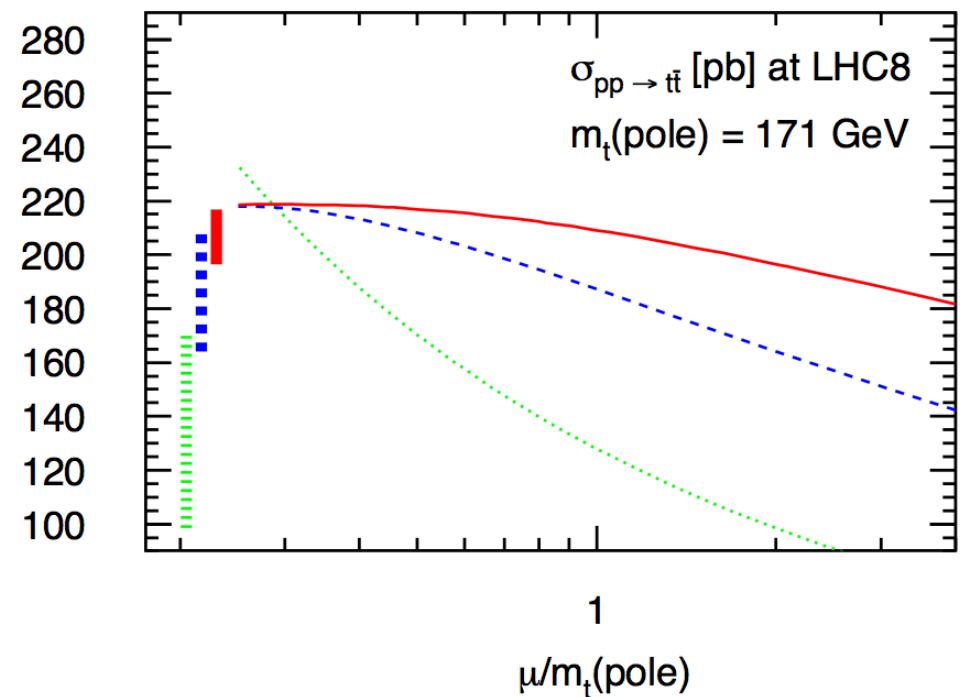
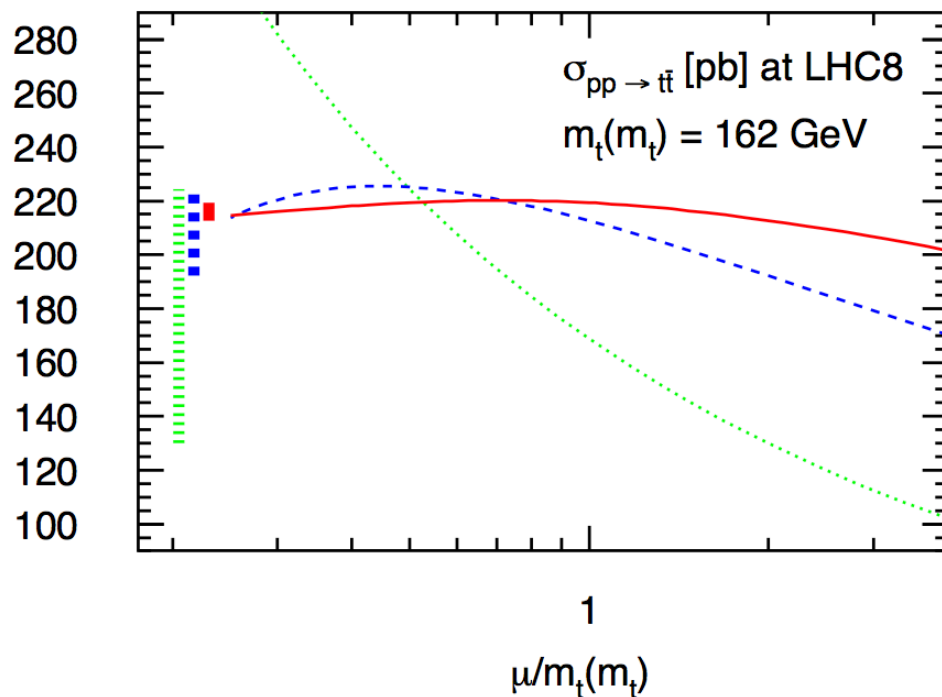
PDF set (NNLO)	$m_t^{\text{pole}}$ [ GeV ]
ABMP16	$169.1 \pm 1.8$ (fit + PDF + $\alpha_S$ ) $^{+1.3}_{-1.9}$ (scale)
NNPDF3.1	$172.4 \pm 1.6$ (fit + PDF + $\alpha_S$ ) $^{+1.3}_{-2.0}$ (scale)
CT14	$172.9 \pm 1.8$ (fit + PDF) $\pm 0.7$ ( $\alpha_S$ ) $^{+1.4}_{-2.0}$ (scale)
MMHT14	$172.8 \pm 1.7$ (fit + PDF) $\pm 0.6$ ( $\alpha_S$ ) $^{+1.3}_{-2.0}$ (scale)

Similar to the case of  $\alpha_S(m_Z)$  extraction, the scale variation uncertainties in the top quark mass values obtained in the  $\overline{\text{MS}}$  scheme are smaller than those determined in the pole mass scheme. This observation reflects a better convergence of the perturbative series while using the  $\overline{\text{MS}}$  renormalization scheme in the calculation of  $\sigma_{t\bar{t}}$ . The values of  $m_t$  are in agreement with those originally used in the evaluation of each PDF set. The results for  $m_t(m_t)$  and  $m_t^{\text{pole}}$  are shown in Fig. 12 for the four different PDF sets.

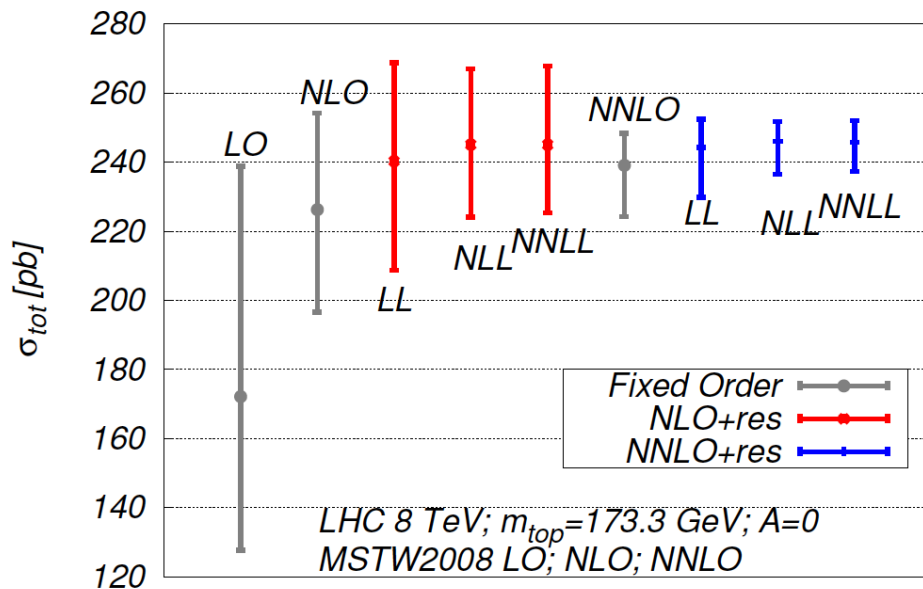
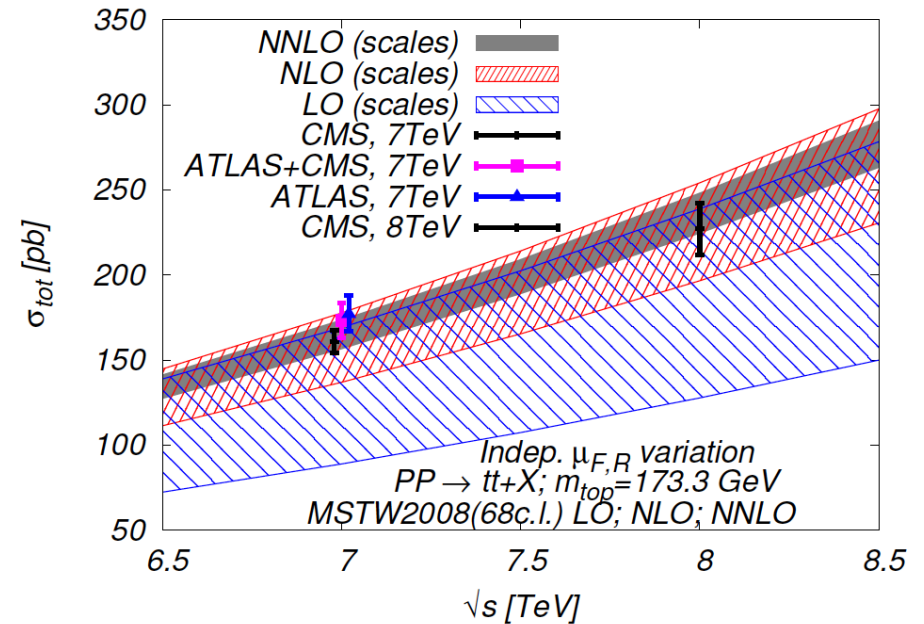
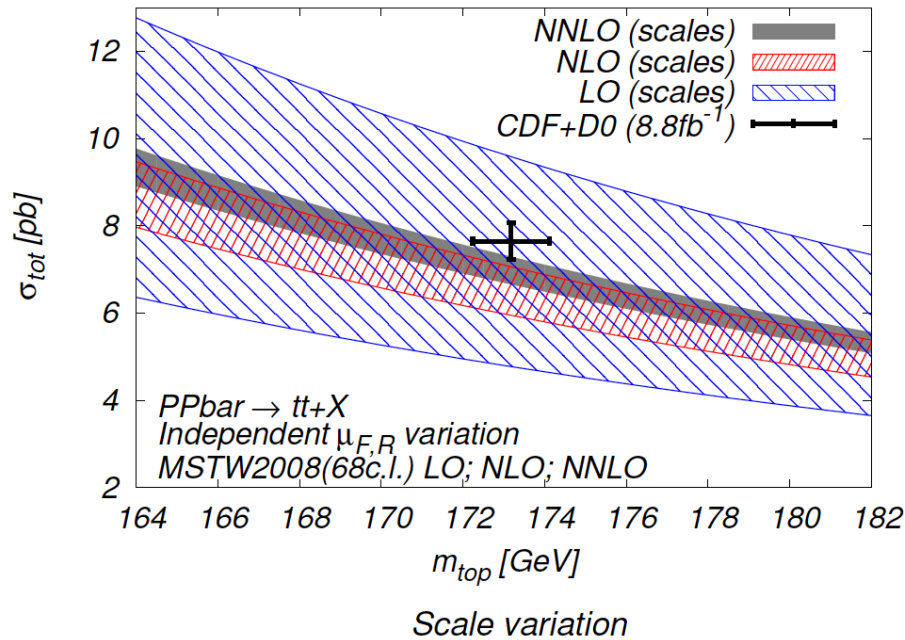
The dependence of the obtained  $\alpha_S(m_Z)$  using different PDFs on the assumption on the top quark mass  $m_t(m_t)$  is investigated by performing the  $\chi^2(\alpha_S)$  scan for ten values of  $m_t(m_t)$ , varying from 160.5 GeV to 165.0 GeV. A linear dependence is observed, which is somewhat flatter for ABM16nnlo than for the other PDFs, as shown in Fig. 13.

# Perturbation Theory Convergence

- It has been argued that it is better to use the  $\overline{\text{MS}}$  mass to improve convergence
- Is there a better scale in the on-shell scheme?
- Relevant for differential Monte Carlo description



# Perturbation Theory Convergence



## Concurrent uncertainties:

Scales	$\sim 3\%$
pdf (at 68%cl)	$\sim 2\text{-}3\%$
$\alpha_s$ (parametric)	$\sim 1.5\%$
$m_{\text{top}}$ (parametric)	$\sim 3\%$

Soft gluon resummation makes a difference:  $5\% \rightarrow 3\%$

# Searching for the right scale

- Monte Carlo simulations use dynamical scales since they are fully differential
- Several possible choices based on

$$H_T = \sqrt{m_t^2 + p_{Tt}^2} + \sqrt{m_t^2 + p_{T\bar{t}}^2} \quad H'_T = H_T + \sum_i p_{Tj_i} \quad E_T = \sqrt{\sqrt{m_t^2 + p_{Tt}^2} \sqrt{m_t^2 + p_{T\bar{t}}^2}}$$

