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Determination of the top-quark pole mass and strong coupling constant from the $\mathrm{t\bar{t}}$ production cross section in pp collisions at $\sqrt{s} = 7\,\mathrm{TeV}$

The CMS Collaboration*

Abstract

The inclusive cross section for top-quark pair production measured by the CMS experiment in proton-proton collisions at a center-of-mass energy of 7 TeV is compared to the QCD prediction at next-to-next-to-leading order with various parton distribution functions to determine the top-quark pole mass, $m_{\mathrm{t}}^{\mathrm{pole}}$, or the strong coupling constant, α_S. With the parton distribution function set NNPDF2.3, a pole mass of $176.7^{+3.8}_{-3.4}$ GeV is obtained when constraining α_S at the scale of the Z boson mass, m_{Z}, to the current world average. Alternatively, by constraining $m_{\mathrm{t}}^{\mathrm{pole}}$ to the latest average from direct mass measurements, a value of $\alpha_S(m_{\mathrm{Z}}) = 0.1151^{+0.0033}_{-0.0032}$ is extracted. This is the first determination of α_S using events from top-quark production.

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*See Appendix A for the list of collaboration members

1 Introduction

The Large Hadron Collider (LHC) has provided a wealth of proton-proton collisions, which has enabled the Compact Muon Solenoid (CMS) experiment [1] to measure cross sections for the production of top-quark pairs ($\mathrm{t\bar{t}}$) with high precision employing a variety of approaches [2–10]. Comparing the presently available results, obtained at a center-of-mass energy, $\sqrt{s}$, of 7 TeV, to theoretical predictions allows for stringent tests of the underlying models and for constraints on fundamental parameters. Top-quark pair production can be described in the framework of quantum chromodynamics (QCD) and calculations for the inclusive $\mathrm{t\bar{t}}$ cross section, $\sigma_{\mathrm{t\bar{t}}}$, have recently become available to complete next-to-next-to-leading order (NNLO) in perturbation theory [11]. Crucial inputs to these calculations are: the top-quark mass, m_{t}; the strong coupling constant, α_S; and the gluon distribution in the proton, since $\mathrm{t\bar{t}}$ production at LHC energies is expected to occur predominantly via gluon-gluon fusion.

The top-quark mass is one of the fundamental parameters of the standard model (SM) of particle physics. Its value significantly affects predictions for many observables either directly or via radiative corrections. As a consequence, the measured m_{t} is one of the key inputs to electroweak precision fits, which enable comparisons between experimental results and predictions within and beyond the SM. Furthermore, together with the Higgs-boson mass and α_S, m_{t} has direct implications on the stability of the electroweak vacuum [12, 13]. The most precise result for m_{t}, obtained by combining direct measurements performed at the Tevatron, is 173.18 ± 0.94 GeV [14]. Similar measurements performed by the CMS Collaboration [2, 15–17] are in agreement with the Tevatron result and of comparable precision. However, except for a few cases [17], these direct measurements rely on the relation between m_{t} and the respective experimental observable, e.g., a reconstructed invariant mass, as expected from simulated events. In QCD beyond leading order, m_{t} depends on the renormalization scheme [18, 19]. The available Monte Carlo generators contain matrix elements at leading order or next-to-leading order (NLO), while higher orders are simulated by applying parton showering. Studies suggest that m_{t} as implemented in Monte Carlo generators corresponds approximately to the pole ("on-shell") mass, $m_{\mathrm{t}}^{\mathrm{pole}}$, but that the value of the true pole mass could be of the order of 1 GeV higher compared to m_{t} in the current event generators [20]. In addition to direct m_{t} measurements, the mass dependence of the QCD prediction for $\sigma_{\mathrm{t\bar{t}}}$ can be used to determine m_{t} by comparing the measured to the predicted cross section [13, 19, 21–24]. Although the sensitivity of $\sigma_{\mathrm{t\bar{t}}}$ to m_{t} might not be strong enough to make this approach competitive in precision, it yields results affected by different sources of systematic uncertainties compared to the direct m_{t} measurements and allows for extractions of m_{t} in theoretically well-defined mass schemes. It has been advocated to directly extract the $\overline{\mathrm{MS}}$ mass of the top quark using the $\sigma_{\mathrm{t\bar{t}}}$ prediction in that scheme [21]. The relation between pole and $\overline{\mathrm{MS}}$ mass is known to three-loop level in QCD but might receive large electroweak corrections [25]. In principle, the difference between the results obtained when extracting m_{t} in the pole and converting it to the $\overline{\mathrm{MS}}$ scheme or extracting the $\overline{\mathrm{MS}}$ mass directly should be small in view of the precision that the extraction of m_{t} from the inclusive $\sigma_{\mathrm{t\bar{t}}}$ at a hadron collider provides. Therefore, only the pole mass scheme is employed in this Letter.

With the exception of the quark masses, α_S is the only free parameter of the QCD Lagrangian. While the renormalization group equation predicts the energy dependence of the strong coupling, i.e., gives a functional form for $\alpha_S(Q)$, where Q is the energy scale of the process, actual values of α_S can only be obtained based on experimental data. By convention and to facilitate comparisons, α_S values measured at different energy scales are typically evolved to $Q = m_Z$, the mass of the Z boson. The current world average for $\alpha_S(m_Z)$ is 0.1184 ± 0.0007 [26]. In spite of this relatively precise result, the uncertainty on α_S still contributes significantly to many

QCD predictions, including expected cross sections for top-quark pairs or Higgs bosons. Furthermore, thus far very few measurements allow α_S to be tested at high Q and the precision on the average for $\alpha_S(m_Z)$ is driven by low-Q measurements. Energies up to 209 GeV were probed with hadronic final states in electron-positron collisions at LEP using NNLO predictions [27–30]. Jet measurements at the Tevatron and the LHC have recently extended the range up to 400 GeV [31], 600 GeV [32], and 1.4 TeV [33]. However, most predictions for jet production in hadron collisions are only available up to NLO QCD. Even when these predictions are available at approximate NNLO, as used in [34], they suffer from significant uncertainties related to the choice and variation of the renormalization and factorization scales, μ_R and μ_F, as well as from uncertainties related to non-perturbative corrections.

In cross section calculations, α_s appears not only in the expression for the parton-parton interaction but also in the QCD evolution of the parton distribution functions (PDFs). Varying the value of $\alpha_S(m_Z)$ in the $\sigma_{\mathrm{t\bar{t}}}$ calculation therefore requires a consistent modification of the PDFs. Moreover, a strong correlation between α_S and the gluon PDF at large partonic momentum fractions is expected to significantly enhance the sensitivity of $\sigma_{\mathrm{t\bar{t}}}$ to α_S [35].

In this Letter, the predicted $\sigma_{\mathrm{t\bar{t}}}$ is compared to the most precise single measurement to date [6], and values of $m_{\mathrm{t}}^{\mathrm{pole}}$ and $\alpha_S(m_Z)$ are determined. This extraction is performed under the assumption that the measured $\sigma_{\mathrm{t\bar{t}}}$ is not affected by non-SM physics. The interplay of the values of $m_{\mathrm{t}}^{\mathrm{pole}}$, α_s and the proton PDFs in the prediction of $\sigma_{\mathrm{t\bar{t}}}$ is studied. Five different PDF sets, available at NNLO, are employed and for each a series of different choices of $\alpha_S(m_Z)$ are considered. A simultaneous extraction of top-quark mass and strong coupling constant from the total $\mathrm{t\bar{t}}$ cross section alone is not possible since both parameters alter the predicted $\sigma_{\mathrm{t\bar{t}}}$ in such a way that any variation of one parameter can be compensated by a variation of the other. Values of $m_{\mathrm{t}}^{\mathrm{pole}}$ and $\alpha_S(m_Z)$ are therefore determined at fixed values of $\alpha_S(m_Z)$ and $m_{\mathrm{t}}^{\mathrm{pole}}$, respectively. For the $m_{\mathrm{t}}^{\mathrm{pole}}$ extraction, $\alpha_S(m_Z)$ is constrained to the latest world average value with its corresponding uncertainty (0.1184 ± 0.0007) [26]. Furthermore, it is assumed that the m_{t} parameter of the Monte Carlo generator that is employed in the $\sigma_{\mathrm{t\bar{t}}}$ measurement is equal to $m_{\mathrm{t}}^{\mathrm{pole}}$ within ±1.00 GeV [20]. For the α_S extraction, $m_{\mathrm{t}}^{\mathrm{pole}}$ is set to the Tevatron average of 173.18 ± 0.94 GeV [14]. To account for the possible difference between the pole mass and the Monte Carlo generator mass [20], an additional uncertainty, assumed to be 1.00 GeV, is added in quadrature to the experimental uncertainty, resulting in a total uncertainty on the top-quark mass constraint, $\delta m_{\mathrm{t}}^{\mathrm{pole}}$, of 1.4 GeV. Although the potential α_S dependence of the direct m_{t} measurements has not been explicitly evaluated, it is assumed to be covered by the quoted mass uncertainty.

2 Predicted Cross Section

The expected $\sigma_{\mathrm{t\bar{t}}}$ has been calculated to NNLO for all production channels, namely the all-fermionic scattering modes ($\mathrm{q\bar{q}}$, $\mathrm{qq'}$, $\mathrm{q\bar{q}'}$, $\mathrm{qq} \rightarrow \mathrm{t\bar{t}} + X$) [36, 37], the reaction $\mathrm{qg} \rightarrow \mathrm{t\bar{t}} + X$ [38], and the dominant process $\mathrm{gg} \rightarrow \mathrm{t\bar{t}} + X$ [11]. In the present analysis, these calculations are used as implemented in the program TOP++ 2.0 [39]. Soft-gluon resummation is performed at next-to-next-leading-log (NNLL) accuracy [40, 41]. The scales μ_R and μ_F are set to $m_{\mathrm{t}}^{\mathrm{pole}}$. In order to evaluate the theoretical uncertainty of the fixed-order calculation, the missing contributions from higher orders are estimated by varying μ_R and μ_F up and down by a factor of 2 independently, while using the restriction $0.5 \leq \mu_F/\mu_R \leq 2$. These choices for the central scale and the variation procedure were suggested by the authors of the NNLO calculations and used for earlier $\sigma_{\mathrm{t\bar{t}}}$ predictions as well [42].

Five different NNLO PDF sets are employed: ABM11 [43], CT10 [44], HERAPDF1.5 [45], MSTW-2008 [46, 47], and NNPDF2.3 [48]. The corresponding uncertainties are calculated at the 68%

confidence level for all PDF sets. This is done by recalculating the $\sigma_{t\bar{t}}$ at NNLO+NNLL for each of the provided eigenvectors or replicas of the respective PDF set and then performing error propagation according to the prescription of that PDF group. In the specific case of the CT10 PDF set, the uncertainties are provided for the 90% confidence level only. For this Letter, following the recommendation of the CTEQ group, these uncertainties are adjusted using the general relation between confidence intervals based on Gaussian distributions [26], i.e., scaled down by a factor of $\sqrt{2}\,\mathrm{erf}^{-1}(0.90) = 1.64$, where erf denotes the error function.

The dependence of the predicted $\sigma_{t\bar{t}}$ on the choice of m_t^{pole} is studied by varying m_t^{pole} in the range from 130 to 220 GeV in steps of 1 GeV and found to be well described by a third-order polynomial in m_t^{pole} divided by $(m_t^{\text{pole}})^4$. The α_S dependence of $\sigma_{t\bar{t}}$ is studied by varying the value of $\alpha_S(m_Z)$ over the entire valid range for a particular PDF set, as listed in Table 1. The relative change of $\sigma_{t\bar{t}}$ as a function of $\alpha_S(m_Z)$ can be parametrized using a second-order polynomial in $\alpha_S(m_Z)$, where the three coefficients of that polynomial depend linearly on m_t^{pole}.

Table 1: Default $\alpha_S(m_Z)$ values and $\alpha_S(m_Z)$ variation ranges of the NNLO PDF sets used in this analysis. Because the NNPDF2.3 PDF set does not have a default value of $\alpha_S(m_Z)$, preferring to provide the full uncertainties and systematic variations for various $\alpha_S(m_Z)$ points, the $\alpha_S(m_Z)$ value obtained by the NNPDF Collaboration with NNPDF2.1 [49] is used. The step size for the $\alpha_S(m_Z)$ scans is 0.0010 in all cases. The uncertainties on the default values are shown for illustration purposes only.

			Provided $\alpha_S(m_Z)$ scan	
	Default $\alpha_S(m_Z)$	Uncertainty	Range	# of points
ABM11	0.1134	± 0.0011	0.1040–0.1200	17
CT10	0.1180	± 0.0020	0.1100–0.1300	21
HERAPDF1.5	0.1176	± 0.0020	0.1140–0.1220	9
MSTW2008	0.1171	± 0.0014	0.1070–0.1270	21
NNPDF2.3	0.1174	± 0.0007	0.1140–0.1240	11

The resulting $\sigma_{t\bar{t}}$ predictions are compared in Fig. 1, both as a function of m_t^{pole} and of $\alpha_S(m_Z)$. For a given value of $\alpha_S(m_Z)$, the predictions based on NNPDF2.3 and CT10 are very similar. The cross sections obtained with MSTW2008 and HERAPDF1.5 are slightly higher while the predictions obtained with ABM11 are significantly lower due to a smaller gluon density in the relevant kinematic range [43]. In addition to the absolute normalization, differences in the slope of $\sigma_{t\bar{t}}$ as a function of $\alpha_S(m_Z)$ are observed between some of the PDF sets.

3 Measured Cross Section

In this Letter, the most precise single measurement for $\sigma_{t\bar{t}}$ [6] is used. It was derived at $\sqrt{s} =$ 7 TeV by the CMS Collaboration from data collected in 2011 in the dileptonic decay channel and corresponding to an integrated luminosity of 2.3 fb^{-1}. Assuming $m_t = 172.5$ GeV and $\alpha_S(m_Z) = 0.1180$, the observed cross section is 161.9 ± 6.7 pb. Systematic effects on this measurement from the choice and uncertainties of the PDFs were studied and found to be negligible.

The measured $\sigma_{t\bar{t}}$ shows a dependence on the value of m_t that is used in the Monte Carlo simulations since the change in the event kinematics affects the expected selection efficiency and thus the acceptance corrections that are employed to infer $\sigma_{t\bar{t}}$ from the observed event yield. A parametrization for this dependence, which is illustrated in Fig. 1, was already given in Section 8 of Ref. [6]. At $m_t = 173.2$ GeV, for example, the observed cross section is 161.0 pb. The

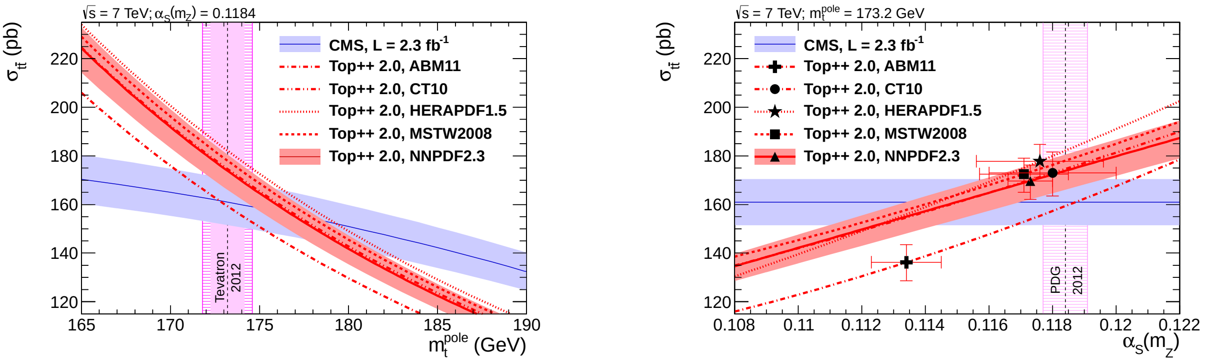

Figure 1: Predicted $\mathrm{t\bar{t}}$ cross section at NNLO+NNLL, as a function of the top-quark pole mass (left) and of the strong coupling constant (right), using five different NNLO PDF sets, compared to the cross section measured by CMS assuming $m_{\mathrm{t}} = m_{\mathrm{t}}^{\mathrm{pole}}$. The uncertainties on the measured $\sigma_{\mathrm{t\bar{t}}}$ as well as the renormalization and factorization scale and PDF uncertainties on the prediction with NNPDF2.3 are illustrated with filled bands. The uncertainties on the $\sigma_{\mathrm{t\bar{t}}}$ predictions using the other PDF sets are indicated only in the right panel at the corresponding default $\alpha_S(m_Z)$ values. The $m_{\mathrm{t}}^{\mathrm{pole}}$ and $\alpha_S(m_Z)$ regions favored by the direct measurements at the Tevatron and by the latest world average, respectively, are shown as hatched areas. In the left panel, the inner (solid) area of the vertical band corresponds to the original uncertainty of the direct m_{t} average, while the outer (hatched) area additionally accounts for the possible difference between this mass and $m_{\mathrm{t}}^{\mathrm{pole}}$.

relative uncertainty of 4.1% on the measured $\sigma_{\mathrm{t\bar{t}}}$ is independent of m_{t} to very good approximation.

Changes of the assumed value of $\alpha_S(m_Z)$ in the simulation used to derive the acceptance corrections can alter the measured $\sigma_{\mathrm{t\bar{t}}}$ as well, which is discussed in this Letter for the first time. QCD radiation effects increase at higher $\alpha_S(m_Z)$, both at the matrix-element level and at the hadronization level. The $\alpha_S(m_Z)$-dependence of the acceptance corrections is studied using the NLO CTEQ6AB PDF sets [50], and the POWHEG BOX 1.4 [51, 52] NLO generator for $\mathrm{t\bar{t}}$ production interfaced with PYTHIA 6.4.24 [53] for the parton showering. Additionally, the impact of $\alpha_S(m_Z)$ variations on the acceptance is studied with standalone PYTHIA as a plain leading-order generator with parton showering and cross-checked with MCFM 6.2 [54] as an NLO prediction without parton showering. In all cases, a relative change of the acceptance by less than 1% is observed when varying $\alpha_S(m_Z)$ by ±0.0100 with respect to the CTEQ reference value of 0.1180. This is accounted for by applying an $\alpha_S(m_Z)$-dependent uncertainty to the measured $\sigma_{\mathrm{t\bar{t}}}$. This additional uncertainty is also included in the uncertainty band shown in Fig. 1. Over the relevant $\alpha_S(m_Z)$ range, there is almost no increase in the total uncertainty of 4.1% on the measured $\sigma_{\mathrm{t\bar{t}}}$.

In the m_{t} and $\alpha_S(m_Z)$ regions favored by the direct measurements at the Tevatron and by the latest world average, respectively, the measured and the predicted cross section are compatible within their uncertainties for all considered PDF sets. When using ABM11 with its default $\alpha_S(m_Z)$, the discrepancy between measured and predicted cross section is larger than one standard deviation.

4 Probabilistic Approach

In the following, the theory prediction for $\sigma_{\mathrm{t\bar{t}}}$ is employed to construct a Bayesian prior to the cross section measurement, from which a joint posterior in $\sigma_{\mathrm{t\bar{t}}}$, $m_{\mathrm{t}}^{\mathrm{pole}}$ and $\alpha_S(m_Z)$ is derived.

Finally, this posterior is marginalized by integration over $\sigma_{\mathrm{t\bar{t}}}$ and a Bayesian confidence interval for $m_{\mathrm{t}}^{\mathrm{pole}}$ or $\alpha_S(m_Z)$ is computed based on the external constraint for $\alpha_S(m_Z)$ or $m_{\mathrm{t}}^{\mathrm{pole}}$, respectively.

The probability function for the predicted cross section, $f_{\mathrm{th}}(\sigma_{\mathrm{t\bar{t}}})$, is obtained through an analytic convolution of two probability distributions, one accounting for the PDF uncertainty and the other for scale uncertainties. A Gaussian distribution of width δ_{PDF} is used to describe the PDF uncertainty. Given that no particular probability distribution is known that should be adequate for the confidence interval obtained from the variation of μ_R and μ_F [42], the corresponding uncertainty on the $\sigma_{\mathrm{t\bar{t}}}$ prediction is approximated using a flat prior, i.e., a rectangular function that provides equal probability over the whole range covered by the scale variation and vanishes elsewhere. The resulting probability function is given by:

$$f_{\mathrm{th}}(\sigma_{\mathrm{t\bar{t}}}) = \frac{1}{2\left(\sigma_{\mathrm{t\bar{t}}}^{(h)} - \sigma_{\mathrm{t\bar{t}}}^{(l)}\right)} \left(\mathrm{erf}\left[\frac{\sigma_{\mathrm{t\bar{t}}}^{(h)} - \sigma_{\mathrm{t\bar{t}}}}{\sqrt{2}\,\delta_{\mathrm{PDF}}}\right] - \mathrm{erf}\left[\frac{\sigma_{\mathrm{t\bar{t}}}^{(l)} - \sigma_{\mathrm{t\bar{t}}}}{\sqrt{2}\,\delta_{\mathrm{PDF}}}\right] \right).$$

Here, $\sigma_{\mathrm{t\bar{t}}}^{(l)}$ and $\sigma_{\mathrm{t\bar{t}}}^{(h)}$ denote the lowest and the highest cross section values, respectively, that are obtained when varying μ_R and μ_F as described in Section 2. An example for the resulting probability distributions is shown in Fig. 2.

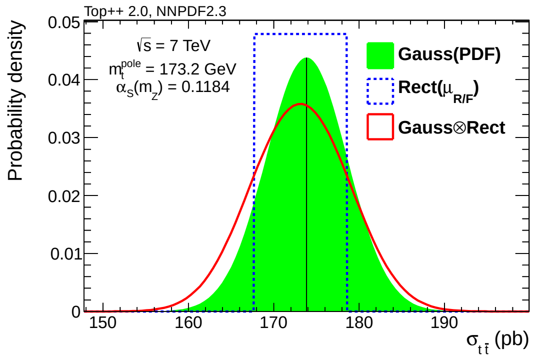

Figure 2: Probability distributions for the predicted $\mathrm{t\bar{t}}$ cross section at NNLO+NNLL with $m_{\mathrm{t}}^{\mathrm{pole}} = 173.2\,\mathrm{GeV}$, $\alpha_S(m_Z) = 0.1184$ and the NNLO parton distributions from NNPDF2.3. The resulting probability, $f_{\mathrm{th}}(\sigma_{\mathrm{t\bar{t}}})$, represented by a solid line, is obtained by convolving a Gaussian distribution (filled area) that accounts for the PDF uncertainty with a rectangular function (dashed line) that covers the scale variation uncertainty.

The probability distribution $f_{\mathrm{th}}(\sigma_{\mathrm{t\bar{t}}})$ is multiplied by another Gaussian probability, $f_{\mathrm{exp}}(\sigma_{\mathrm{t\bar{t}}})$, which represents the measured cross section and its uncertainty, to obtain the most probable $m_{\mathrm{t}}^{\mathrm{pole}}$ or $\alpha_S(m_Z)$ value for a given $\alpha_S(m_Z)$ or $m_{\mathrm{t}}^{\mathrm{pole}}$, respectively, from the maximum of the marginalized posterior:

$$P(x) = \int f_{\mathrm{exp}}(\sigma_{\mathrm{t\bar{t}}}|x)\, f_{\mathrm{th}}(\sigma_{\mathrm{t\bar{t}}}|x)\, \mathrm{d}\sigma_{\mathrm{t\bar{t}}}, \quad x = m_{\mathrm{t}}^{\mathrm{pole}},\ \alpha_S(m_Z).$$

Examples of $P(m_{\mathrm{t}}^{\mathrm{pole}})$ and $P(\alpha_S)$ are shown in Fig. 3. Confidence intervals are determined from the 68% area around the maximum of the posterior and requiring equal function values at the left and right edges.

The approximate contributions of the uncertainties on the measured and the predicted cross sections to the width of this Bayesian confidence interval can be estimated by repeatedly rescaling the size of the corresponding uncertainty component. The widths of the obtained confidence intervals are then used to extrapolate to the case in which a given component vanishes.

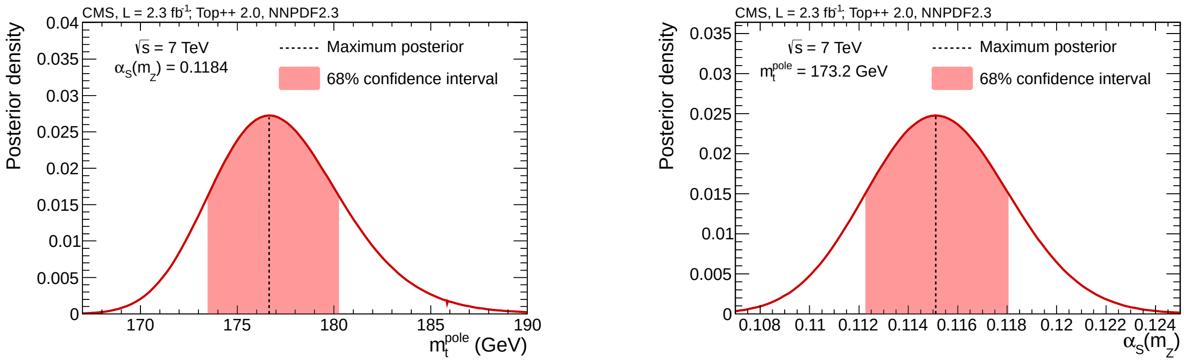

Figure 3: Marginal posteriors $P(m_{\mathrm{t}}^{\mathrm{pole}})$ (left) and $P(\alpha_S)$ (right) based on the cross section prediction at NNLO+NNLL with the NNLO parton distributions from NNPDF2.3. The posteriors are constructed as described in the text. Here, $P(m_{\mathrm{t}}^{\mathrm{pole}})$ is shown for $\alpha_S(m_Z) = 0.1184$ and $P(\alpha_S)$ for $m_{\mathrm{t}}^{\mathrm{pole}} = 173.2\,\mathrm{GeV}$.

To assess the impact of the uncertainties on the $\alpha_S(m_Z)$ and $m_{\mathrm{t}}^{\mathrm{pole}}$ values that are used as constraints in the present analysis, $P(m_{\mathrm{t}}^{\mathrm{pole}})$ is re-evaluated at $\alpha_S(m_Z) = 0.1177$ and 0.1191, reflecting the ± 0.0007 uncertainty on the $\alpha_S(m_Z)$ world average, and $P(\alpha_S)$ is re-evaluated at $m_{\mathrm{t}}^{\mathrm{pole}} = 171.8$ and 174.6 GeV, reflecting the $\delta m_{\mathrm{t}}^{\mathrm{pole}} = 1.4\,\mathrm{GeV}$ as explained in Section 1. The resulting shifts in the most likely values of $m_{\mathrm{t}}^{\mathrm{pole}}$ and $\alpha_S(m_Z)$ are added in quadrature to those obtained from the 68% areas of the posteriors calculated with the central values of the constraints.

5 Results and Conclusions

Values of the top-quark pole mass determined using the $\mathrm{t\bar{t}}$ cross section measured by CMS together with the cross section prediction from NNLO+NNLL QCD and five different NNLO PDF sets are listed in Table 2. These values are extracted under the assumption that the m_{t} parameter in the Monte Carlo generator that was employed to obtain the mass-dependent acceptance correction of the measured cross section, shown in Fig. 1, is equal to the pole mass. A difference of 1.0 GeV between the two mass definitions [20] would result in changes of 0.3–0.6 GeV in the extracted pole masses, which is included as a systematic uncertainty. As illustrated in Fig. 4, the results based on NNPDF2.3, CT10, MSTW2008, and HERAPDF1.5 are higher than the latest average of direct m_{t} measurements but generally compatible within the uncertainties. They are also consistent with the indirect determination of the top-quark pole mass obtained in the electroweak fits [55, 56] when employing the mass of the new boson discovered at the LHC [57, 58] under the assumption that this is the SM Higgs boson. The central $m_{\mathrm{t}}^{\mathrm{pole}}$ value obtained with the ABM11 PDF set, which has a significantly smaller gluon density than the other PDF sets, is also compatible with the average from direct m_{t} measurements. Note, however, that all these results in Table 2 are obtained employing the $\alpha_S(m_Z)$ world average of 0.1184 ± 0.0007, while ABM11 with its default $\alpha_S(m_Z)$ of 0.1134 ± 0.0011 would yield an $m_{\mathrm{t}}^{\mathrm{pole}}$ value of $166.3^{+3.3}_{-3.1}\,\mathrm{GeV}$.

The $\alpha_S(m_Z)$ values obtained when fixing the value of $m_{\mathrm{t}}^{\mathrm{pole}}$ to $173.2 \pm 1.4\,\mathrm{GeV}$, i.e., inverting the logic of the extraction, are listed in Table 3. As illustrated in Fig. 5, the results obtained using NNPDF2.3, CT10, MSTW2008, and HERAPDF1.5 are lower than the $\alpha_S(m_Z)$ world average but in most cases still compatible with it within the uncertainties. While the $\alpha_S(m_Z)$ value obtained with ABM11 is compatible with the world average, it is significantly different from the default $\alpha_S(m_Z)$ of this PDF set.

Modeling the uncertainty related to the choice and variation of the renormalization and factor-

Table 2: Results obtained for $m_{\mathrm{t}}^{\mathrm{pole}}$ by comparing the measured $\mathrm{t\bar{t}}$ cross section to the NNLO+NNLL prediction with different NNLO PDF sets. The total uncertainties account for the full uncertainty on the measured cross section ($\sigma_{\mathrm{t\bar{t}}}^{\mathrm{meas}}$), the PDF and scale ($\mu_{R,F}$) uncertainties on the predicted cross section, the uncertainties of the $\alpha_S(m_Z)$ world average and of the LHC beam energy (E_{LHC}), and the ambiguity in translating the MC-generator based mass dependence ($m_{\mathrm{t}}^{\mathrm{MC}}$) of the measured cross section into the pole-mass scheme.

	$m_{\mathrm{t}}^{\mathrm{pole}}$ (GeV)	Uncertainty on $m_{\mathrm{t}}^{\mathrm{pole}}$ (GeV)						
		Total	$\sigma_{\mathrm{t\bar{t}}}^{\mathrm{meas}}$	PDF	$\mu_{R,F}$	α_S	E_{LHC}	$m_{\mathrm{t}}^{\mathrm{MC}}$
ABM11	172.7	$^{+3.9}_{-3.5}$	$^{+2.8}_{-2.5}$	$^{+2.2}_{-2.0}$	$^{+0.7}_{-0.7}$	$^{+1.0}_{-1.0}$	$^{+0.8}_{-0.8}$	$^{+0.4}_{-0.3}$
CT10	177.0	$^{+4.3}_{-3.8}$	$^{+3.2}_{-2.8}$	$^{+2.4}_{-2.0}$	$^{+0.9}_{-0.9}$	$^{+0.8}_{-0.8}$	$^{+0.9}_{-0.9}$	$^{+0.5}_{-0.4}$
HERAPDF1.5	179.5	$^{+4.3}_{-3.8}$	$^{+3.5}_{-3.0}$	$^{+1.7}_{-1.5}$	$^{+0.9}_{-0.8}$	$^{+1.2}_{-1.1}$	$^{+1.0}_{-1.0}$	$^{+0.6}_{-0.5}$
MSTW2008	177.9	$^{+4.1}_{-3.6}$	$^{+3.4}_{-2.9}$	$^{+1.6}_{-1.4}$	$^{+0.9}_{-0.9}$	$^{+0.9}_{-0.9}$	$^{+0.9}_{-0.9}$	$^{+0.5}_{-0.5}$
NNPDF2.3	176.7	$^{+3.8}_{-3.4}$	$^{+3.1}_{-2.8}$	$^{+1.5}_{-1.3}$	$^{+0.9}_{-0.9}$	$^{+0.7}_{-0.7}$	$^{+0.9}_{-0.9}$	$^{+0.5}_{-0.4}$

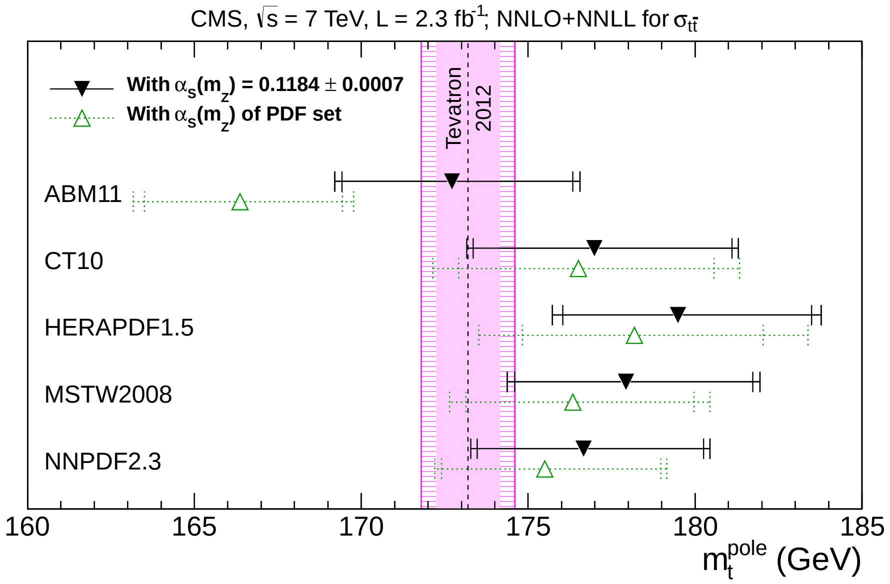

Figure 4: Results obtained for $m_{\mathrm{t}}^{\mathrm{pole}}$ from the measured $\mathrm{t\bar{t}}$ cross section together with the prediction at NNLO+NNLL using different NNLO PDF sets. The filled symbols represent the results obtained when using the $\alpha_S(m_Z)$ world average, while the open symbols indicate the results obtained with the default $\alpha_S(m_Z)$ value of the respective PDF set. The inner error bars include the uncertainties on the measured cross section and on the LHC beam energy as well as the PDF and scale uncertainties on the predicted cross section. The outer error bars additionally account for the uncertainty on the $\alpha_S(m_Z)$ value used for a specific prediction. For comparison, the latest average of direct m_{t} measurements is shown as vertical band, where the inner (solid) area corresponds to the original uncertainty of the direct m_{t} average, while the outer (hatched) area additionally accounts for the possible difference between this mass and $m_{\mathrm{t}}^{\mathrm{pole}}$.

Table 3: Results obtained for $\alpha_S(m_Z)$ by comparing the measured $\mathrm{t\bar{t}}$ cross section to the NNLO+NNLL prediction with different NNLO PDF sets. The total uncertainties account for the full uncertainty on the measured cross section ($\sigma_{\mathrm{t\bar{t}}}^{\mathrm{meas}}$), the PDF and scale ($\mu_{R,F}$) uncertainties on the predicted cross section, the uncertainty assigned to the knowledge of $m_{\mathrm{t}}^{\mathrm{pole}}$, and the uncertainty of the LHC beam energy (E_{LHC}).

	$\alpha_S(m_Z)$	Uncertainty on $\alpha_S(m_Z)$					
		Total	$\sigma_{\mathrm{t\bar{t}}}^{\mathrm{meas}}$	PDF	$\mu_{R,F}$	$m_{\mathrm{t}}^{\mathrm{pole}}$	E_{LHC}
ABM11	0.1187	$^{+0.0027}_{-0.0027}$	$^{+0.0018}_{-0.0019}$	$^{+0.0015}_{-0.0014}$	$^{+0.0006}_{-0.0005}$	$^{+0.0010}_{-0.0010}$	$^{+0.0006}_{-0.0006}$
CT10	0.1151	$^{+0.0034}_{-0.0034}$	$^{+0.0024}_{-0.0025}$	$^{+0.0018}_{-0.0016}$	$^{+0.0008}_{-0.0007}$	$^{+0.0012}_{-0.0013}$	$^{+0.0007}_{-0.0007}$
HERAPDF1.5	0.1143	$^{+0.0024}_{-0.0024}$	$^{+0.0018}_{-0.0019}$	$^{+0.0010}_{-0.0009}$	$^{+0.0005}_{-0.0004}$	$^{+0.0010}_{-0.0010}$	$^{+0.0006}_{-0.0006}$
MSTW2008	0.1144	$^{+0.0031}_{-0.0032}$	$^{+0.0024}_{-0.0025}$	$^{+0.0012}_{-0.0011}$	$^{+0.0008}_{-0.0007}$	$^{+0.0012}_{-0.0013}$	$^{+0.0007}_{-0.0008}$
NNPDF2.3	0.1151	$^{+0.0033}_{-0.0032}$	$^{+0.0025}_{-0.0025}$	$^{+0.0013}_{-0.0011}$	$^{+0.0009}_{-0.0008}$	$^{+0.0013}_{-0.0013}$	$^{+0.0008}_{-0.0008}$

ization scales with a Gaussian instead of the flat prior results in only minor changes of the $m_{\mathrm{t}}^{\mathrm{pole}}$ and $\alpha_S(m_Z)$ values and uncertainties. With the precise NNLO+NNLL calculation, these scale uncertainties are found to be of the size of 0.7–0.9 GeV on $m_{\mathrm{t}}^{\mathrm{pole}}$ and 0.0004–0.0009 on $\alpha_S(m_Z)$, i.e., of the order of 0.3–0.8%.

The energy of the LHC beams is known to an accuracy of 0.65% [59] and thus the center-of-mass energy of 7 TeV with an uncertainty of ±46 GeV. Based on the expected dependence of $\sigma_{\mathrm{t\bar{t}}}$ on $\sqrt{s}$, this can be translated into an additional uncertainty of ±1.8% on the comparison of the measured to the predicted $\mathrm{t\bar{t}}$ cross section, which yields an additional uncertainty of ±(0.5–0.7)% on the obtained $m_{\mathrm{t}}^{\mathrm{pole}}$ and $\alpha_S(m_Z)$ values.

For the main results of this Letter, the $m_{\mathrm{t}}^{\mathrm{pole}}$ and $\alpha_S(m_Z)$ values determined with the parton densities of NNPDF2.3 are used. The primary motivation is that parton distributions derived using the NNPDF methodology can be explicitly shown to be parametrization independent, in the sense that results are unchanged even when the number of input parameters is substantially increased [60].

In summary, a top-quark pole mass of $176.7^{+3.8}_{-3.4}$ GeV is obtained by comparing the measured cross section for inclusive $\mathrm{t\bar{t}}$ production in proton-proton collisions at $\sqrt{s} = 7$ TeV to QCD calculations at NNLO+NNLL. Due to the small uncertainty on the measured cross section and the state-of-the-art NNLO calculations, the precision of this result is higher compared to earlier determinations of $m_{\mathrm{t}}^{\mathrm{pole}}$ following the same approach. This extraction provides an important test of the mass scheme applied in Monte Carlo simulations and gives complementary information, with different sensitivity to theoretical and experimental uncertainties, than direct measurements of m_{t}. Alternatively, $\alpha_S(m_Z) = 0.1151^{+0.0033}_{-0.0032}$ is obtained from the $\mathrm{t\bar{t}}$ cross section when constraining $m_{\mathrm{t}}^{\mathrm{pole}}$ to 173.2 ±1.4 GeV. This is the first determination of the strong coupling constant from top-quark production and the first $\alpha_S(m_Z)$ result at full NNLO QCD obtained at a hadron collider.

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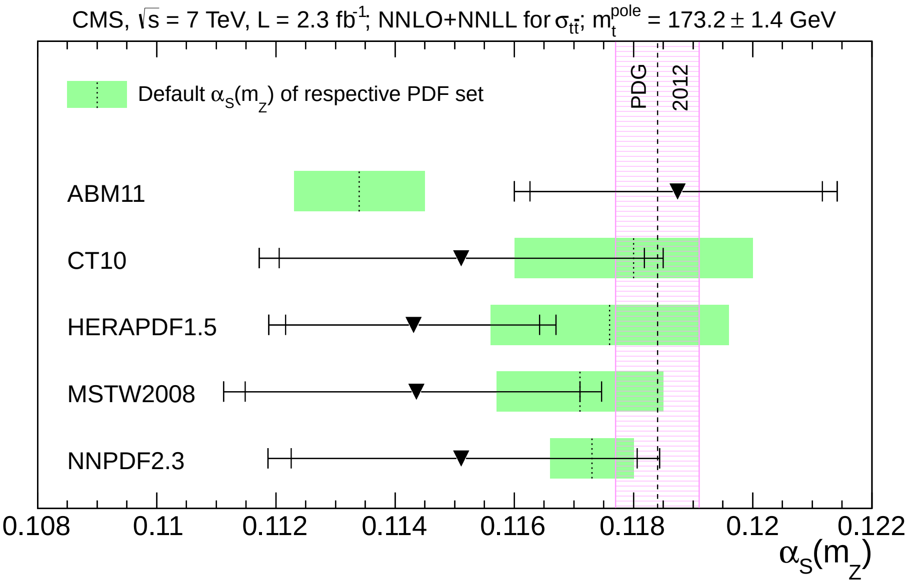

Figure 5: Results obtained for $\alpha_S(m_Z)$ from the measured $t\bar{t}$ cross section together with the prediction at NNLO+NNLL using different NNLO PDF sets. The inner error bars include the uncertainties on the measured cross section and on the LHC beam energy as well as the PDF and scale uncertainties on the predicted cross section. The outer error bars additionally account for the uncertainty on m_t^{pole}. For comparison, the latest $\alpha_S(m_Z)$ world average with its uncertainty is shown as a hatched band. For each PDF set, the default $\alpha_S(m_Z)$ value and its uncertainty are indicated using a dotted line and a shaded band.

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45: Also at Mersin University, Mersin, Turkey
46: Also at Izmir Institute of Technology, Izmir, Turkey
47: Also at Ozyegin University, Istanbul, Turkey
48: Also at Kafkas University, Kars, Turkey
49: Also at Suleyman Demirel University, Isparta, Turkey
50: Also at Ege University, Izmir, Turkey
51: Also at Mimar Sinan University, Istanbul, Istanbul, Turkey
52: Also at Kahramanmaras Sütcü Imam University, Kahramanmaras, Turkey
53: Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom
54: Also at INFN Sezione di Perugia; Università di Perugia, Perugia, Italy
55: Also at Utah Valley University, Orem, USA
56: Also at Institute for Nuclear Research, Moscow, Russia
57: Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
58: Also at Argonne National Laboratory, Argonne, USA
59: Also at Erzincan University, Erzincan, Turkey
60: Also at Yildiz Technical University, Istanbul, Turkey
61: Also at Texas A&M University at Qatar, Doha, Qatar
62: Also at Kyungpook National University, Daegu, Korea