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LHC differential top-quark pair production cross sections in the ABMP16 PDF fit

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We investigate the impact of recent LHC measurements of differential top-quark pair production cross sections on the proton parton distribution functions (PDFs) using the ABMP16 methodology. The theoretical predictions are computed at NNLO QCD using the state-of-the-art MATRIX framework. The top-quark mass and strong coupling constant are free parameters of the fit, and we pay particular attention to the values of these parameters and their correlation as obtained from variants of the fit using different input datasets. We discuss the compatibility of different datasets and the compatibility of the fitted PDFs with those extracted from other datasets in the global ABMP16 fit, as well as with other modern global PDF sets.

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In our work [1], we provide the first simultaneous fit of the parton distribution functions (PDFs), $\overline{\mathrm{MS}}$ top-quark mass, $m_t(m_t)$, and strong coupling constant, $\alpha_s(M_Z)$, at next-to-next-to-leading order (NNLO) in the $\overline{\mathrm{MS}}$ scheme using double-differential data on top-quark pair production, following the next-to-leading (NLO) fits already published by the CMS experimental collaboration in Ref. [2] and by us in our previous work [3] and the approximate NNLO fit by Ref. [4]. As a basis we rely on the ABMP16 fit methodology, extensively described in Ref. [5]. For the double-differential $t\bar{t} + X$ distributions we used a customized version of `MATRIX` [6] interfaced to `PineAPPL` [7], as described in detail in our previous work [8].

The new PDF fit is named ABMPtt. It includes updated results for the absolute total cross sections for $t\bar{t} + X$ hadroproduction at the Tevatron and the LHC [9–18]. Furthermore, the fit includes data on single-top hadroproduction in the s- and t-channel from the Tevatron [19] and in the t-channel from the LHC [20–22]. Finally, the fit includes the available datasets of normalized cross sections double-differential in $M(t\bar{t})$ and $y(t\bar{t})$ at $\sqrt{S} = 13$ TeV [2, 14, 23, 24]. The methodology to perform this fit is the same as in Ref. [5], using the Hessian approach to compute eigenvectors and uncertainties. A tolerance criterion $\Delta\chi^2 = 1$ is applied to the χ^2, defined as in the previous ABMP16 paper. Further details can be found in Ref. [5].

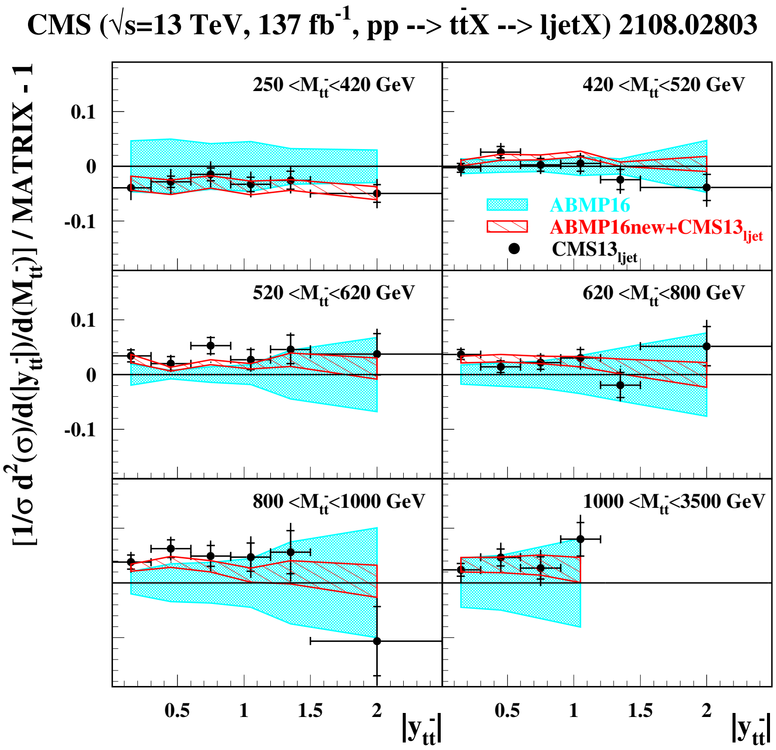

Figure 1: Pulls of CMS semileptonic data from the analysis of Ref. [14] with respect to predictions using as input ABMP16 PDFs (light-blue solid band) and the fit including besides all ABMP16 datasets the specific double-differential cross-section dataset indicated (red dashed band).

As an example, the pulls of the double-differential cross-section data collected in the $t\bar{t}+X$ CMS semileptonic are shown in Fig. 1, with respect to theory predictions using as input the original ABMP16 PDF fit, and an ABMPtt fit variant obtained after including only the specific dataset. The uncertainty band on the pulls computed with the new fit turns out to be smaller than the ABMP16 one by about a factor of two.

Experiment	Dataset	$\sqrt{s}$ (TeV)	NDP	χ^2		
				I	II	III
ATLAS	ATLAS13$_{ljet}$	13	19	34.0 (42.8)	28.2	–
	ATLAS13$_{had}$	13	10	11.9 (11.7)	11.6	–
CMS	CMS13$_{ll}$	13	15	20.7 (15.9)	–	19.6
	CMS13$_{ljet}$	13	34	44.3 (52.0)	–	42.4

Table 1: The values of χ^2 obtained for various $t\bar{t}+X$ datasets included in different variants of the present analysis (column I: variant including both ATLAS and CMS double-differential cross-section datasets; column II: variant including only ATLAS ones; column III: variant including only CMS ones). The figures in parenthesis give the values of χ^2 obtained for the corresponding dataset using as input the central ABMP16 PDFs without re-fit.

We consider different fit variants, as detailed in Table 1. In particular, in the analyses where the two ATLAS datasets are included (column II) or the two CMS datasets are included (column III), the χ^2 values slightly worsen with respect to the cases of including only a single dataset at a time (not explicitly shown here). Nevertheless, we always observe reasonable values of χ^2, as compared to the number of data points (NDP).

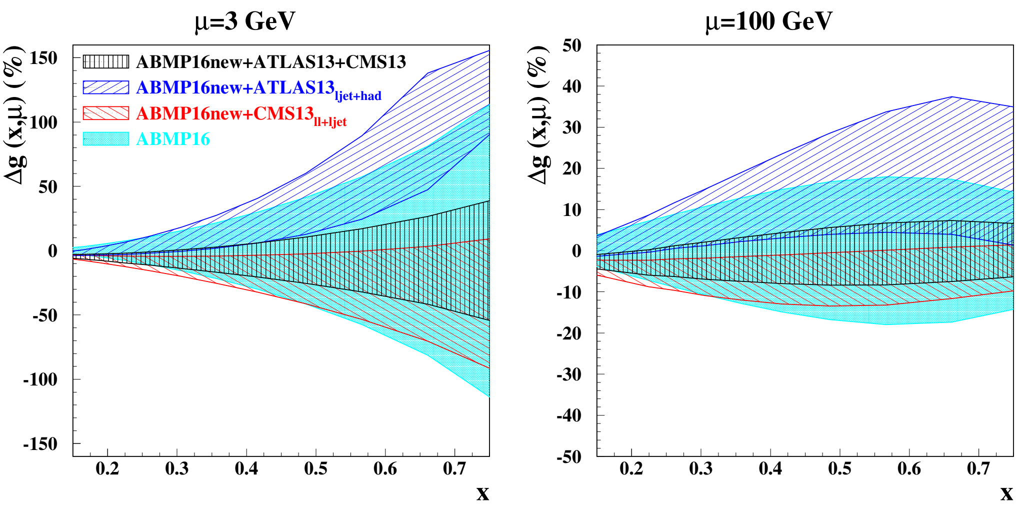

Figure 2: Percentage difference of the gluon distribution as a function of x for the variants of the ABMPtt fit of Table 1, including ATLAS $t\bar{t}+X$ double-differential cross-section datasets (right-tilted hatched area), CMS ones (left-tilted hatched areas), or both (vertical hatched area) and the ABMP16 case used as reference (light-blue solid area). The left panel refers to factorization scale $\mu = 3$ GeV, whereas the right panel refers to $\mu = 100$ GeV.

In Fig. 2 we plot the percentage differences between the gluon distributions extracted from the variants analyzed in Table 1 and the ABMP16 one as a function of x at the starting scale $\mu = 3$ GeV and evolved to $\mu = 100$ GeV. The gluon distributions in the ABMPtt fit variants are compatible with the ABMP16 one, and present uncertainties decreased by a factor ~ 2 with respect to ABMP16 in the large x region, $x \gtrsim 0.1$. The simultaneous determination of the PDFs, $m_t(m_t)$ and $\alpha_s(M_Z)$ in the ABMPtt global fit leads to the value of $\alpha_s(M_Z)$ in the $n_f = 5$ flavor scheme at NNLO

$$\alpha_s^{(n_f=5)}(M_Z) \quad = \quad 0.1150 \pm 0.0009\,, \tag{1}$$

which is very similar, both in terms of central value, and in terms of uncertainty, to the ABMP16 one 0.1147 ± 0.0008. For the top-quark mass in the $\overline{\mathrm{MS}}$ scheme we obtain at NNLO the best-fit value

$$m_t(m_t) \quad = \quad 160.6 \pm 0.6 \ \text{GeV}\,, \tag{2}$$

which is also well compatible with the ABMP16 one 160.9 ± 1.1 GeV, and with uncertainties reduced by a factor of approximately two. As an illustration of the correlation between the

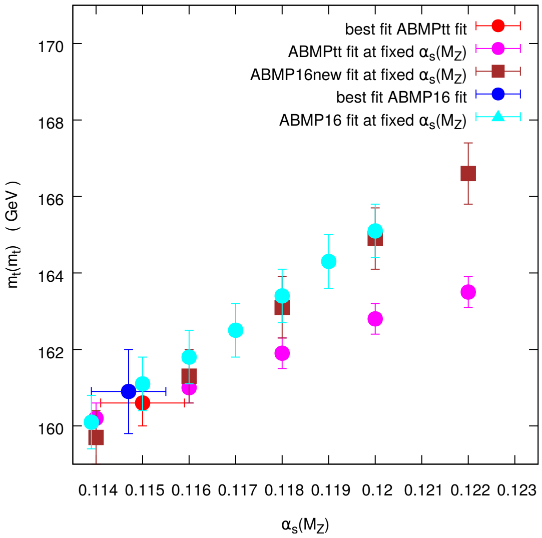

Figure 3: Values of $m_t(m_t)$ (extracted together with the PDFs) at fixed $\alpha_s(M_Z)$, for the ABMP16 and the ABMPtt fits. The best fit values of $m_t(m_t)$ and $\alpha_s(M_Z)$ are also shown in both cases for the most general analyses, where also $\alpha_s(M_Z)$ is allowed to vary simultaneously with the PDFs and $m_t(m_t)$.

$m_t(m_t)$ and $\alpha_s(M_Z)$ values, in Fig. 3 one can see an approximately linear increase of $m_t(m_t)$ with $\alpha_s(M_Z)$, with a correlation coefficient decreased with respect to the ABMP16 fit. Altogether, our findings confirm that the double-differential distributions considered in this analysis, differential in $M(t\bar{t})$ and in $y(t\bar{t})$, are not particularly sensitive to $\alpha_s(M_Z)$.

In summary, we have shown that the use of state-of-the-art data on absolute total inclusive and normalized cross sections double differential in $M(t\bar{t})$ and $y(t\bar{t})$ in a simultaneous NNLO fit of PDFs, $\alpha_s(M_Z)$ and $m_t(m_t)$ following the ABMP methodology, leads to a reduction of the uncertainties by a factor ∼ 2 on both the gluon PDF and the $m_t(m_t)$ value, with respect to the previous ABMP16 fit. The value of $\alpha_s(M_Z)$ remains essentially unchanged, but its correlation with the top-quark mass is decreased.

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