NNLO fits of top-quark mass using total, single-differential and double-differential $t\bar{t} + X$ cross-section data

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We describe the fits of the top-quark mass value at NNLO using as input the double-differential distributions in rapidity and invariant mass of $t\bar{t}$ pairs obtained by the ATLAS and CMS collaborations from unfolding of their experimental data to the parton level, compared to NNLO theory predictions. We consider different state-of-the-art PDF sets, finding results of the fits compatible among each other within uncertainties. On the other hand, we observe some tension among the fits to different datasets.

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The top-quark mass is a parameter of the Standard Model. Knowing its precise value is relevant for considerations on the stability of our Universe and for the understanding of the Electroweak Symmetry Breaking mechanism. This value has been measured with both direct and indirect techniques (for a review see, e.g., Ref. [1]). It is possible to extract it in a well-defined mass renormalization scheme, by comparing data on $t\bar{t} + X$ hadroproduction cross sections to theoretical predictions. Our NNLO extraction of the on-shell mass m_t^{pole} uses as ingredients single- and double-differential cross-section measurements by the ATLAS and CMS collaborations, as well as NNLO theoretical predictions computed with an in-house optimized version of the `MATRIX` [2, 3] code, specifically tailored for this process, interfaced to `PineAPPL` [4] to facilitate fitting operations. We consider as input various state-of-the-art (PDFs+$\alpha_s(M_Z)$) sets. More detail is provided in Ref. [5] and references therein. We perform a χ^2 analysis, including in the covariance matrix experimental statistical uncertainties, experimental systematic correlated and uncorrelated uncertainties, theoretical uncertainties related to the specific methodology used for computing the cross sections, as well as PDF uncertainties. To reduce the effects of the lack of information on correlations of systematic uncertainties of different analyses providing data at the differential level, we use datasets of normalized differential cross sections. Scale uncertainties are evaluated separately, building a separate χ^2 for each of the renormalization and factorization scale combinations (μ_r, μ_f), considering seven-point variation around a central scale $H_T/4$, and accounting for the spread in the fitted m_t^{pole} values. The χ^2's close to their minima show a parabolic shape for all considered (PDFs+$\alpha_s(M_Z)$) sets and scale combinations. We assume that the top-quark mass value is the minimum of each parabola fitting the χ^2 as a function of m_t^{pole} in the three points m_t^{pole} = 170, 172.5, 175 GeV. The χ^2's for the various sets are shown in Fig. 1, left, together with the best-fit m_t^{pole} values. The minima for different sets turn out to be similar. We interpret this as an indication of the robustness of our analysis. In the case of ABMP16 [6], the χ^2's for different (μ_r, μ_f) combinations are shown in Fig. 1, right. The uncertainty value Δm_t^{pole} = 0.3 GeV, quoted in the inset of the latter plot, takes into account all uncertainties included in the covariance matrix. Our main results using different differential datasets in Run 1 and 2, as well as differential and total cross-section datasets from both runs simultaneously, are summarized in the three panels of Fig. 2, respectively. This shows that Run 2 differential datasets have larger constraining power than Run 1 ones, and the most stringent constraints are played by the dataset of the CMS semileptonic analysis at $\sqrt{S}$ = 13 TeV [7], based on the full Run 2 integrated luminosity. Datasets for $t\bar{t}$ pairs decaying semileptonically point in general towards m_t^{pole} values slightly larger than the dileptonic datasets, but still compatible within 2σ's. This tension decreases when performing simultaneous fits of PDFs and top-quark mass values considering their correlations (see e.g. our recent work Ref. [8]). On the other hand, the total inclusive cross-section data play a much less relevant role in the fit. The m_t^{pole} values extracted for all (PDFs+$\alpha_s(M_Z)$) sets turn out to be compatible among each other and also with the PDG 2024 m_t^{pole} value [9]. Our best fit values, including the uncertainties, are also reported for each set for our most global fit in the inset in the right panel of Fig. 2. For the time being, in the case of our most global analysis, data uncertainties amount to $\sim 0.2 - 0.3$ GeV, PDF uncertainties to $\sim 0.1 - 0.2$ GeV, and NNLO scale uncertainties have size similar to the PDF ones. In the near future, data uncertainty reduction will push for theoretical computations beyond NNLO. On the one hand, NNLL corrections due to soft-gluon emissions close to threshold can be incorporated in our analysis. On the other hand, approximate N^{3}LO predictions have been obtained for total cross sections and selected

differential distributions considering soft-gluon resummation close to threshold [10], but further work is needed to generalize to other distributions, like e.g. those double-differential in $M(t\bar{t})$ and $y(t\bar{t})$ considered in this work, providing sensitivity to the top-quark mass.
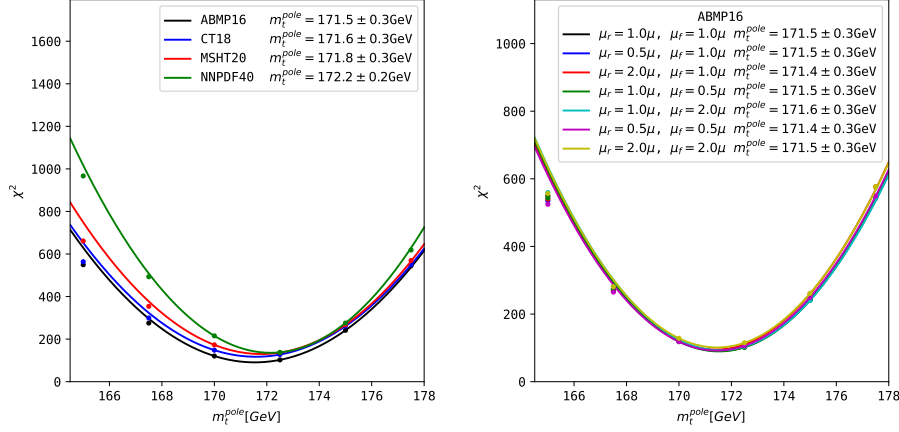

Figure 1: χ^2 for different m_t^{pole} values, as well as the best-fit parabolic interpolation to the χ^2 values for m_t^{pole} = 170, 172.5, 175 GeV, for different (PDFs+$\alpha_s(M_Z)$) sets (left panel). χ^2 for different (μ_r, μ_f) combinations in the case of the ABMP16 set (right panel).
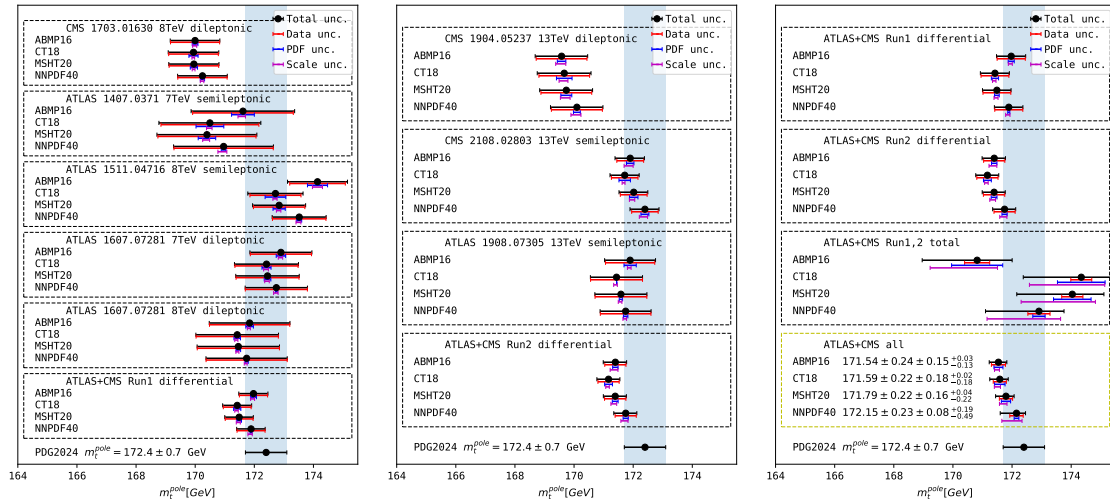

Figure 2: m_t^{pole} values extracted using datasets on normalized (multi-)differential cross sections obtained at the LHC in Run I (left panel) and Run 2 (central panel), as well as datasets from a global analysis of Run 1 + Run 2 differential and total inclusive cross sections (right panel), compared to the PDG 2024 m_t^{pole} value. Our best-fit m_t^{pole} values are reported together with uncertainties for each considered PDF + $\alpha_s(M_Z)$ set.

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