

Measurement of the top quark pole mass using $t\bar{t}$ +jet events in the dilepton final state at $\sqrt{s} = 13$ TeV with the CMS experiment

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In this contribution, a measurement of the top quark pole mass m_t^{pole} is presented. Events where a top quark-antiquark pair ($t\bar{t}$) is produced in association with at least one additional energetic jet ($t\bar{t}$ +jet) are analyzed. The data set recorded by the CMS experiment at a center-of-mass energy of 13 TeV, corresponding to a total integrated luminosity of 36.3 fb^{-1} , is used. Reconstructed events are required to contain two opposite-sign leptons in the final state. Machine learning methods are employed for the reconstruction of the main observable event classification. The normalized $t\bar{t}$ +jet production cross section as a function of the inverse of the invariant mass of the $t\bar{t}$ +jet system is measured at the parton level using a likelihood unfolding method. The value for m_t^{pole} is extracted by comparing the measurement to next-to-leading order theoretical predictions using two parton distribution functions (PDFs). For a reference set of the ABMP16NLO PDF, the resulting value is $m_t^{\text{pole}} = 172.94 \pm 1.37 \text{ GeV}$.

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1. Introduction

The top quark mass m_t is a free parameter of the standard model (SM) and its large mass value indicates that it plays a particular role in the SM. It is also of high relevance for global electroweak fits. Because m_t has to be determined experimentally, it motivates complementary methods for its measurement. Direct measurements of m_t , which rely on variables sensitive to the reconstructed energy of the top quark and are performed using template fits using multi-purpose Monte-Carlo (MC) simulation, reach a precision on the order of 0.5 GeV. The downside is the dependence on the modeling of non-perturbative effects by heuristic models tuned to experimental data. This leads to an interpretation problem when compared to well-defined masses, such as the top quark pole mass m_t^{pole} , and is commonly covered by an uncertainty on the order of 0.5–1 GeV.

In the presented measurement, the value of m_t^{pole} is extracted using the normalized differential cross section of top quark-antiquark pair ($t\bar{t}$) production in association with at least one additional jet ($t\bar{t}$ +jet) by the CMS Collaboration [1]. The cross section at parton level is measured as a function of the ρ observable, defined as $340 \text{ GeV}/m_{t\bar{t}+\text{jet}}$, where $m_{t\bar{t}+\text{jet}}$ is the invariant mass of the $t\bar{t}$ +jet system. The additional jet needs to have a transverse momentum of $p_T > 30 \text{ GeV}$ and an absolute pseudorapidity of $|\eta| < 2.4$. High mass sensitivity is expected for $\rho > 0.65$, close to the production threshold. The definition and analysis strategy follows the approach suggested in Refs. [2–4] and is the first time performed at a center-of-mass energy of 13 TeV. Similar measurements [5, 6] were performed previously by the ATLAS Collaboration, yielding a value of $m_t^{\text{pole}} = 171.1^{+1.2}_{-1.0} \text{ GeV}$.

2. Analysis setup and strategy

The data sample analyzed was recorded by the CMS experiment and corresponds to an integrated luminosity of 36.3 fb^{-1} . Events are selected based on a combination of single lepton and dilepton triggers, where events are retained in the offline selection if they contain at least one opposite-sign lepton pair ($ee, e\mu, \mu\mu$) with $p_T > 25$ (20) GeV for the leading (subleading) lepton. Jets are selected with $p_T > 30 \text{ GeV}$, and both leptons and jets are required to be reconstructed within $|\eta| < 2.4$. Jets originating from the hadronization of b quarks (b jets) are identified using a dedicated tagging algorithm. Additional selection requirements are imposed to suppress background contributions from Z+jets production. Finally, events are selected if they contain at least one reconstructed b jet.

Since a significant amount of missing transverse momentum arises for dileptonic $t\bar{t}$ events due to the escaping neutrinos, this leads to challenges in the kinematic reconstruction of the ρ variable. Thus, a dedicated neural network (NN) based regression method is developed to improve the efficiency and resolution with respect to classical analytical approaches. The resolution for the reconstructed value of ρ is shown in Fig. 1 left, where the NN regression is compared to two approaches used in previous CMS measurements. A significant improvement is visible, especially for large values of ρ .

The dominant background contribution arises from $t\bar{t}$ production without an additional jet ($t\bar{t}$ +0jet). The additional jet can originate from pileup effects or migrations due to the limited jet energy resolution. This leads to further challenges as the kinematic event properties of $t\bar{t}$ +0jet and $t\bar{t}$ +jet are similar, and the background is mainly dominant for large values of ρ . Hence, an

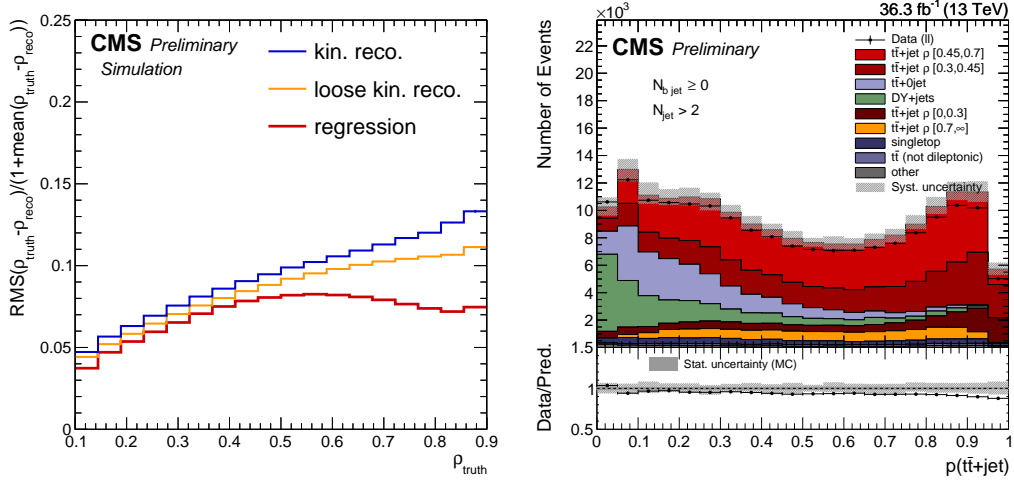


Figure 1: The ρ resolution as a function of the truth value for the NN regression and two analytical methods (left) [1]. The observed and MC predicted signal and background yields as a function of the signal output node of the classifier NN [1].

NN-based classifier is developed, and events are classified to originate from either $t\bar{t}+\text{jet}$, $t\bar{t}+0\text{jet}$, or $Z+\text{jets}$ production. The multiclass classification network is calibrated such that the performance is independent of the value of ρ . The response for the $t\bar{t}+\text{jet}$ output node of the NN is shown in Fig. 1 right, where the data is compared to the MC predictions.

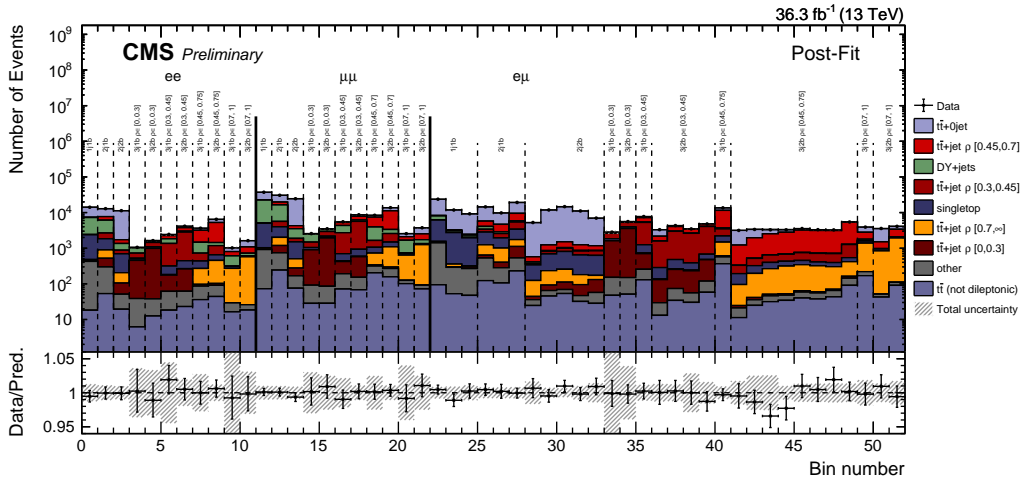


Figure 2: The measured data and MC predicted signal and background yields after the likelihood fit. The gray band indicates the total uncertainty after the fit to the data [1].

The parton level $t\bar{t}+\text{jet}$ cross section as a function of ρ is directly obtained from the result of a multidimensional likelihood fit to final-state observables. Events are separated based on the reconstructed value of ρ , the jet and b jet multiplicities, and the lepton channel. The binning of ρ at the detector and parton level follows studies on the diagonality of the response matrix and bin-to-bin migrations. It is determined to be: 0–0.3, 0.3–0.45, 0.45–0.7, and 0.7–1. The likelihood

function is constructed based on a Poisson description of the observed event yields, and systematic uncertainties are incorporated as nuisance parameters. Additionally, a free parameter is introduced for the top quark mass assumed in the MC simulation, m_t^{MC} , to reduce its dependence as it enters the modeling of the acceptance and the extrapolation to the full phase space. The observables used in the fit are the relative response of the NN classifier with respect to the $\bar{t}t+0\text{jet}$ background, the p_T of the lowest energetic jets, the invariant mass of the lepton and b jet pair, and the absolute event yield. This is to maximize the measurement precision while retaining sensitivity to dominant systematic uncertainties and m_t^{MC} . The distributions of the signal and background MC predictions after the fit to the data are shown in Fig. 2. A good agreement is observed for all categories and bins.

3. Results and top quark mass extraction

The measured normalized parton level $\bar{t}t+\text{jet}$ cross section is shown in Fig. 3 left, comparing it to next-to-leading-order (NLO) theoretical predictions [7]. Different values for m_t^{pole} are used for the NLO prediction to indicate the mass sensitivity. Here, the ABMP16NLO [8] parton distribution function (PDF) is considered. The value for m_t^{pole} is extracted from a χ^2 fit of the normalized differential cross section to the NLO predictions. In the covariance matrix used in the fit, all bin-to-bin correlations, as well as PDF uncertainties and uncertainties arising from the extrapolation to the full phase space are fully taken into account. The uncertainty due to the choice of the matrix-element scales is treated externally. A value for m_t^{pole} of 172.94 ± 1.27 (fit) $^{+0.51}_{-0.43}$ (scale) GeV is determined. When using the CT18NLO [9] PDF set, the value is 172.16 ± 1.35 (fit) $^{+0.50}_{-0.40}$ (scale) GeV. The measured cross section compared to the best-fit predictions is shown in Fig. 3 right.

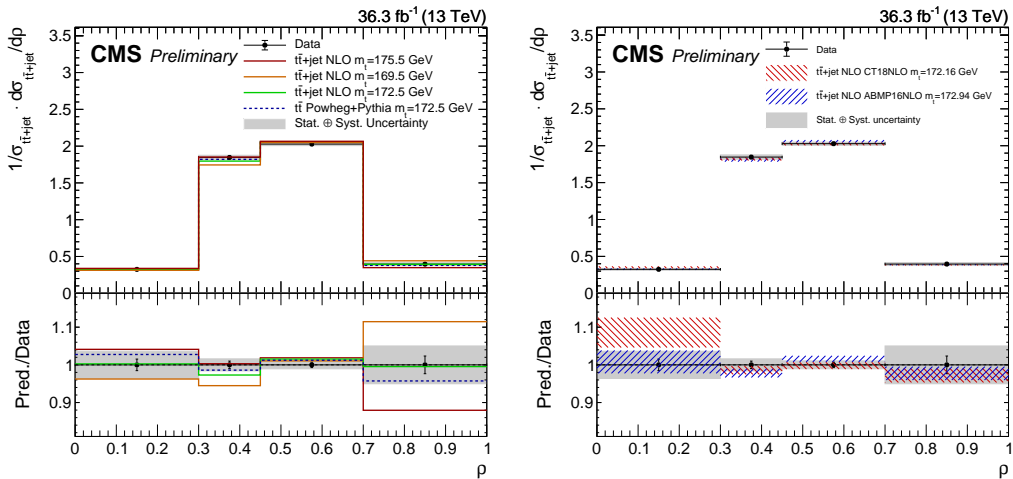


Figure 3: The normalized $\bar{t}t+\text{jet}$ differential cross section as a function of ρ , compared to NLO theoretical predictions assuming different top quark mass values (left) [1]. The same measured cross section is shown but now compared to the theoretical predictions using the best-fit values for m_t^{pole} (right) [1].

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