PROCEEDINGS OF SCIENCE

First measurements of top quark mass and other properties with Run-2 data in CMS

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Measurements of top quark properties using data collected by the CMS experiment at 13 TeV are presented. The top quark mass is measured in the lepton+jets and all-jets channels. The results are consistent with the CMS measurements of Run-1. The top quark mass is also studied as a function of the event kinematical properties. For the first time at the LHC, the width of the top quark is directly probed during Run-2. The result constitutes the most precise direct bound of the top quark width performed to date.

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1. Introduction

The top quark, the heaviest known elementary particle, has an extremely short life time ($\approx 5\cdot10^{-25}$ s). This property inhibits the formation of top quark bound states and gives the unique possibility to study the top quark, in particular, its mass m_t, by reconstructing the top quark decay products. The top quark mass is a fundamental parameter in Quantum Chromodynamics (QCD) that is used in the theoretical predictions of particle production cross section. Measuring precisely m_t is necessary to explore the Higgs boson properties in terms of the standard model as well as to place constraints on new physics models. The most accurate value of the top quark mass was measured by the CMS Collaboration [1] using the Run-1 data and yields $m_t = 172.35 \pm 0.51$ GeV [2]. The latest combined result of m_t coming from the ATLAS experiment is $m_t = 172.69 \pm 0.48$ GeV [3]. The combined measurement by the Tevatron collaborations yields $m_t = 174.30 \pm 0.65$ GeV [4]. The theoretical interpretations of the measured top quark mass and its uncertainties are significantly improved and some studies are discussed in Refs. [5, 6].

Besides the mass of the top quark, the precise measurement of the top quark width, Γ_t, is also an important part of the LHC physics program. As the deviation of the measured width value from the standard model prediction would indicate a non-standard model decay channel of the corresponding particle. The top quark width is determined less accurately and the latest results coming from the CMS Collaboration is found to be $\Gamma_t = 1.36 \pm 0.02(\mathrm{stat})^{+0.14}_{-0.11}(\mathrm{syst})$ GeV [7].

In this work, the first measurements of m_t obtained from proton-proton (pp) collision data collected in 2016 at center-of-mass energies of 13 TeV [8, 9] are presented. These analyses are restricted to the following decay channels of the pair-produced top quarks ($t\bar{t}$): all-jets, $t\bar{t} \to WbWb \to (q\bar{q}b)(q\bar{q}b)$, and lepton+jets, $t\bar{t} \to WbWb \to (l\nu_l b)(q\bar{q}b)$. In case of the lepton+jets decay mode, a combined sample of events selected in the muon+jets and electron+jets final state are analyzed. A first measurement of the direct bound on the top quark decay width is performed using 12.9 fb^{-1} of pp collision data collected at a center-of-mass energy of 13 TeV [10] is also presented. The analysis exploits the dilepton, $t\bar{t} \to W^+bW^-b \to (l^+\nu_l b)(l^-\nu_l b)$, decay channel, where the charged lepton is either a muon or an electron.

2. Measurements of m_t at 13 TeV

Various methods to measure the top quark mass are known. The most precise m_t value was measured using the ideogram method [2]. The ideogram method constructs a two-dimensional event-by-event likelihood function with a jet energy scale factor (JSF) as a free parameter in addition to the top quark mass itself. The jet energy scale factor (JSF) is used on top of the standard CMS jet energy calibration and aims to reduce the corresponding uncertainty that is one of the leading systematic uncertainties in this analysis. Event-by-event likelihoods are constructed to reflect the ambiguity in the events arising from the different possible jet-parton assignments. Moreover, along with the implementation of the ideogram method a kinematic fit of the decay products to a $t\bar{t}$ hypothesis is applied. The kinematic fit helps to achieve a better resolution of the kinematic properties of the reconstructed objects, and increase the fraction of the proper parton-jet assignment ($t\bar{t}$ correct permutations). A goodness-of-fit probability of $P_{gof} > 0.1$ (0.2) in case of all-jets (lepton+jets) final state is required. The top quark mass and JSF are measured using distributions of m_t^{fit} obtained after applying the kinematic fit and the reconstructed W boson mass m_W^{reco}, before it is constrained by the kinematic fit. The fitted top quark mass m_t^{fit} distributions in all-jets and lepton+jets final states are shown in Fig. 1, where in case of the all-jets final state background is estimated directly from data.

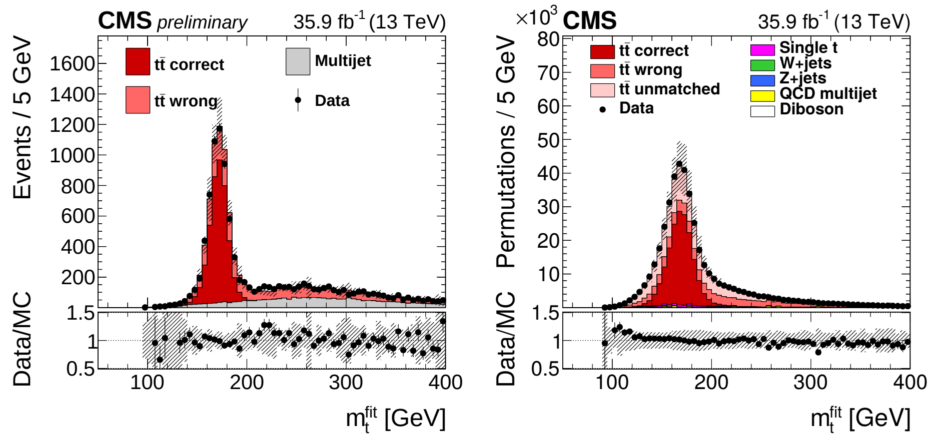

Figure 1: The fitted top quark masses m_t^{fit} after the goodness-of-fit selection. (left) The distribution of the best permutation in the all-jets channel [8] and (right) the distribution of all permutations weighted by P_{gof} for the lepton+jets channel [9]. The vertical bars show the statistical uncertainty and the hatched bands show the statistical and systematic uncertainties added in quadrature. The lower portion of each panel shown the ratio of the yields between the collision data and the simulation.

The final results obtained from the joint-likelihood fit using $t\bar{t}$ all-jets [8] candidate events yields: $m_t = 172.34 \pm 0.20(\text{stat+JSF}) \pm 0.76(\text{syst})$ GeV and JSF $= 0.997 \pm 0.002(\text{stat}) \pm 0.007(\text{syst})$. The corresponding fit to the selected lepton+jets [9][1] events yields: $m_t = 172.25 \pm 0.08(\text{stat+JSF})$ $\pm 0.62(\text{syst})$ GeV and JSF $= 0.996 \pm 0.001(\text{stat}) \pm 0.008(\text{syst})$. In both analyses, due to the higher $t\bar{t}$ cross section at 13 TeV and the larger integrated luminosity, the statistical uncertainty is reduced compared to the Run-1 [1] result. A more advanced treatment of the modeling uncertainties is performed, mainly by evaluating of a broader set of color-reconnection models that were not available in Run-1. This, in turn, causes larger systematic uncertainties with respect to the Run-1 result [2]. In addition, the corresponding new color-reconnection models are considered in differential measurements of m_t as a function of the kinematic properties of the $t\bar{t}$ system that are sensitive to the color-reconnection effect. Within statistical precision of the results from data, no significant deviation in the value of the measured m_t is observed.

3. Measurements of Γ_t at 13 TeV

A direct measurement of the top quark width is performed using distributions of the invariant mass of the lepton-b-tagged jet systems reconstructed in different event categories. These observables are used by a hypothesis test to compare simulated expectations for different top quark width (Γ_t) scenarios, where for each hypothesis, a likelihood fit is performed. By building likelihood ratios between the alternative and standard model hypotheses, a test statistic is obtained that is used for the hypothesis separation via the CL_S [10] criterion. The evolution of the CL_S as a function of Γ_t is shown in Fig. 2. The observed bounds at the 95% of confidence level corresponds to $0.6 \leqslant \Gamma_t \leqslant 2.5$ GeV [10] .

[1]Updated results are available in Ref. [11]

4. Conclusions

The mass of the top quark is measured using full 2016 data at 13 TeV in the all-jets [8] and the lepton+jets [9] final states. The results are consistent with the Run-1 measurements. A more advanced treatment of the modelling uncertainties is used compared to the Run-1. The first direct measurement at the LHC of the top quark width is performed using 12.9 fb^{-1} of data at 13 TeV [10]. This is found to be the most precise direct bound of Γ_t performed to date.

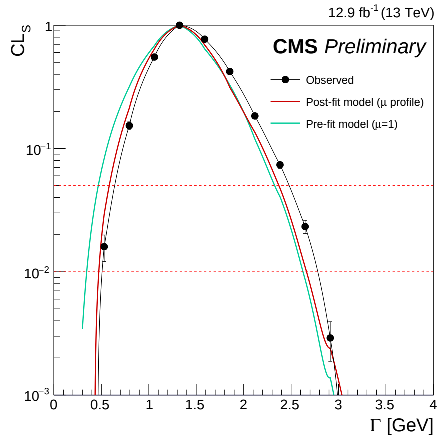

Figure 2: Evolution of the CL_S as a function of the top quark width [10]. The derived limits at the 95% (99%) confidence level are represented as the intersection of the fits to the line at CL_S 0.05 (0.01).

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