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Precision measurements of the top quark mass and decay width using CMS experiment

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We report precise measurements of the mass and decay width of the top quark in the *t*-channel, which is the most dominant production process for single top quarks at the LHC. The final state comprises a top quark along with a light quark, resulting in at least two jets, one of which arises from the hadronization of a b-quark, an isolated high-momentum lepton (electron or muon), and a large missing transverse momentum due to an escaping neutrino from the W boson decay. The study uses proton-proton collision data recorded by the CMS experiment. We study dominant standard model backgrounds in complementary regions and deploy different techniques to separate the signal from these backgrounds. The measured top quark mass is $m_{\mathrm{t}} = 172.13\,^{+0.76}_{-0.77}$ GeV based on 39.5 fb^{-1} data collected by the CMS experiment during 2016. A simultaneous determination of the top quark mass and decay width using Monte-Carlo simulation predicts a combined statistical and profile uncertainty of 0.32 GeV for an expected decay width $\Gamma_{\mathrm{t}} = 1.54$ GeV.

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1. Introduction

A precise measurement of the top quark mass is profoundly important to check the stability of the electroweak vacuum because it is the largest contributor among all elementary particles in terms of radiative corrections to the mass of the Higgs boson. Similarly, a precise measurement of the top quark's decay width ensures the self-consistency of the standard model (SM). It opens the door for beyond the SM physics if the measured decay width deviates from the SM prediction. The top quark has a unique property of decaying preferentially to a b-quark and a W boson before it can hadronise. Therefore, its four-momentum (and hence mass) is reconstructed from its decay products, namely the charged lepton, the neutrino, and the b-tagged jet. This report summarizes the precision measurement of the top quark mass with Run-2 data collected during 2016 using singly reconstructed top quarks and key aspects that must be considered for an ongoing measurement of the top quark decay width.

2. Top quark mass measurement

In the reported measurement of the top quark mass [1], QCD templates are derived from sideband data for each event category separately. To reject the QCD contribution, the transverse mass of the lepton and neutrino system must be greater than 50 GeV. Several kinematic variables of the final-state particles are combined into a multivariate technique called boosted decision tree (BDT) to optimally separate single top quark events from backgrounds. A criterion on the BDT response has been applied, which results in 64% (58%) signal purity for the muon (electron) final state.

We consider the distributions of $\zeta = \ln(m_\mathrm{t}/1\ \mathrm{GeV})$ obtained from the muon and electron final states in a simultaneous maximum-likelihood fit. The distribution is described by a combination of parametric shapes, namely an asymmetric Gaussian core with a Landau tail, a Crystal Ball function, and a Novosibirsk function [2] to model the signal, top ($\mathrm{t\bar{t}}$+tw and s-channel) background, and electroweak background, respectively. The normalization for the signal, top and electroweak backgrounds are constrained using log-normal priors with 15%, 6% and 10% based on their respective cross-section results. The top quark mass is obtained from the postfit ζ distribution, as shown in Fig. 1, by taking the exponential of the postfit value of the parameter of interest ζ_0. The value is $m_\mathrm{t} = 172.13\,^{+0.76}_{-0.77}$ GeV [1], reaching a sub-GeV precision for the first time in such a phase space. The mass ratio $\frac{m_{\bar{\mathrm{t}}}}{m_\mathrm{t}}$ and difference $(m_\mathrm{t} - m_{\bar{\mathrm{t}}})$ are determined to be $0.9952\,^{+0.0079}_{-0.0104}$ and $0.83\,^{+1.79}_{-1.35}$ GeV. The sensitivity for this measurement is dominated by uncertainties due to the jet energy and parton shower scales.

3. Outlook of the decay width measurement

A key aspect of the decay width measurement is the top quark reconstruction. In contrast to the mass measurement described above, where an analytical fit is used, the decay width measurement must identify the mis-reconstructed top quark in both signal and background processes. Fig. 2 shows the unit-normalized m_t distribution in the signal and $\mathrm{t\bar{t}}$ background where it can be noticed that the reconstructed top mass peak will not drastically change when one adds the correctly reconstructed with the mis-reconstructed distribution.

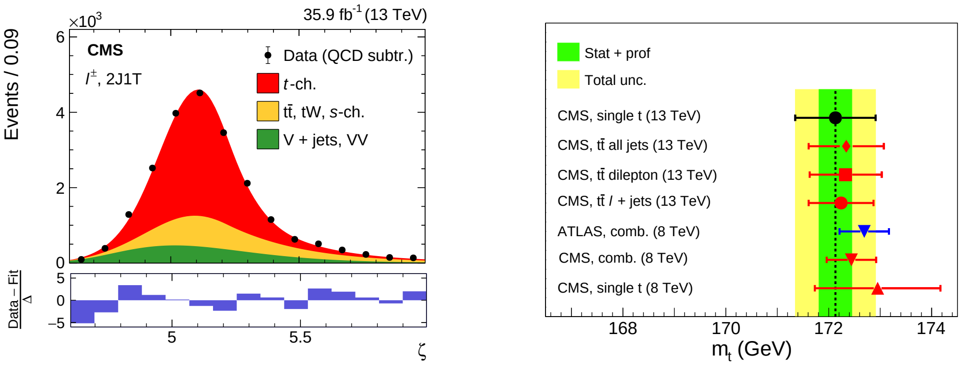

Figure 1: Projections of fit (left) result [1] onto the $\zeta = \ln(m_{\mathrm{t}}/1\ \mathrm{GeV})$ distributions for signal and background processes compared to data. A comparison of measured m_{t} values (right) from this analysis (black circle), with previous CMS [3–7] and ATLAS [8] results.

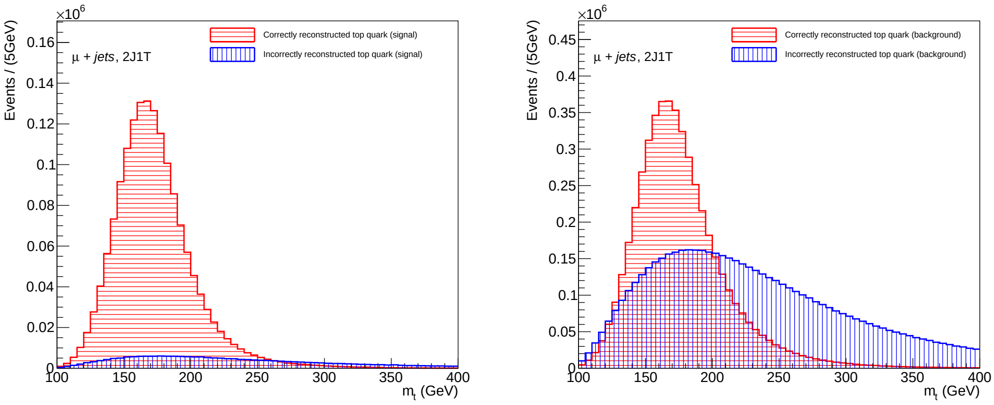

Figure 2: Unit normalized distributions of the correctly reconstructed and mis-reconstructed top quark events in signal (left) and $\mathrm{t\bar{t}}$ background (right).

The mis-reconstructed top quark contribution was not removed in the previous top quark mass measurement [1] since it did not impact much to the peak position of the mass distribution. On the other hand, removing the contamination introduced by the mis-reconstructed top quark events in signal and background is crucial for the top quark decay width measurement. For this purpose, we deploy advanced machine learning techniques like deep neural networks, which can identify mis-reconstructed top quarks from the signal and the background while optimally separating the signal from the background. After suppressing the mis-reconstructed top quarks contribution, we conduct a simultaneous measurement of the top quark mass and decay width (Γ_{t}) using Monte Carlo simulation in a signal enriched region to find [9]:

$$m_{\mathrm{t}} = 172.80 \pm 0.40\ (\mathrm{stat + prof}) \pm 0.11\ (\mathrm{calib\ only})\ \ \mathrm{GeV}, \tag{1}$$

$$\Gamma_{\mathrm{t}} = 1.54 \pm 0.30\ (\mathrm{stat + prof}) \pm 0.11\ (\mathrm{calib\ only})\ \ \mathrm{GeV} \tag{2}$$

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