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Top quark mass and properties measurements with CMS

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Abstract

We present measurements of the top quark mass and other properties, obtained from CMS data collected in 2010-2011 at a centre-of-mass energy of 7 TeV. The mass of the top quark is measured using several methods. We use the lepton+jets, as well as the dilepton and the fully hadronic decay channels. The results are combined. Top pair production cross section measurements are used to place an indirect constraint on the top quark mass through the predicted dependence of the cross section on the mass. Further results include measurements of top quark charge, the W helicity in top decays and search for anomalous couplings.

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Measurement of the Top Quark mass and other properties with CMS

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1 Introduction

The top quark, discovered in 1995 at the Tevatron Collider, plays a crucial role in the Standard Model (SM) since it is the heaviest known fundamental particle. As the top quark is expected to couple strongly to particles predicted in Beyond the Standard Model theories, the study of its properties is a key ingredient in the search for new phenomena. In 2011, the Large Hadron Collider delivered a dataset of $5fb^{-1}$ at a center-of-mass energy of 7TeV to the CMS experiment resulting in a very large sample of top quark pairs. This has allowed CMS to perform precise measurements of the properties of the top quark.

2 The top quark mass

2.1 Top mass measurement in the l+jets channel

In the μ+jets decay channel, the Ideogram method [1] is applied to measure m_{t} and the Jet Energy Scale (JES) using $4.7fb^{-1}$ of data. Using the four leading jets in the event, there are 12 unique jet-quark assignments possible. By imposing a b-tagging criterion the number of possible combinations can be reduced. To make the final jet-quark assignment, a kinematic fit of the entire event is used for each possible jet combination where an equal-mass constraint is applied on the two top quarks and two m_W constraints. The kinematic fit returns the fitted top-quark mass $m_{\mathrm{t},i}^{\mathrm{fit}}$ and the fit probability P_{fit}^{i}. An event-by-event likelihood function, shown in eq. (1), is constructed and a global likelihood fit to all selected yields a top mass of $172.6 \pm 0.6(\mathrm{stat}) \pm 1.2(\mathrm{syst})$ GeV is obtained.

$$\mathcal{L}(\mathrm{event} \mid m_{\mathrm{t}}, \mathrm{JES}) = \left(\sum_{i=1}^{n} P_{\mathrm{fit}}^{i} \cdot P\left(m_{\mathrm{t},i}^{\mathrm{fit}}, m_{\mathrm{W},i}^{\mathrm{reco}} \mid m_{\mathrm{t}}, \mathrm{JES}\right)\right)^{\sum_{i=1}^{n} P_{\mathrm{fit}}^{i}} \quad (1)$$

This is the most precise LHC result where the systematic uncertainty is dominated by the JES of b-jets and the factorization scale uncertainty. The effects of color reconnection and underlying event are still under study.

2.2 Top mass measurement in the di-lepton channel

The top quark mass is measured in the di-lepton channel with the KINb method [2] using $2.3 fb^{-1}$ of data. This method consists of solving the kinematic equations multiple times for each jet-quark assignment, each time varying the event kinematics within the experimental resolutions. The top quark mass for each event, m_{KINb}, is then defined as the mean of the gaussian fit to the distribution of the reconstructed top quark mass for all the different solutions of the kinematic equations for the chosen jet-quark assignment. Finally a top mass of $m_{\mathrm{t}} = 173.3 \pm 1.2(\mathrm{stat})^{+2.5}_{-2.6}(\mathrm{syst})$ GeV is extracted from a likelihood fit to the m_{KINb} distribution being the most precise top quark mass measurement to date in the di-lepton channel with similar precision to the D0 measurement [3].

2.3 Top mass determination from the top quark pair cross section

The top quark mass can also be derived from the measured top quark pair cross section because the event selection used in the cross section analysis introduces a dependence on the top quark mass [4]. This derivation is performed using the di-lepton cross section result for $1.14 fb^{-1}$. The dependence of the cross section on the top mass is parametrized by third order polynomials in each di-lepton channel. The cross section can be either related to $m_{\mathrm{t}}^{\mathrm{pole}}$, which is essentially the quantity measured by the direct reconstruction method, or to $m_{\mathrm{t}}^{\overline{\mathrm{MS}}}$. The method yields $m_{\mathrm{t}}^{\mathrm{pole}} = 170.3^{+7.3}_{-6.7}$ GeV and $m_{\mathrm{t}}^{\overline{\mathrm{MS}}} = 163.1^{+6.8}_{-6.1}$ GeV for the pole mass and the $\overline{\mathrm{MS}}$ mass, respectively.

3 Measurement of the difference in top quark and anti-top quark mass

In the SM, one of the fundamental symmetries is CPT invariance which states that a particle and its anti-particle have equal mass. The analysis is performed using lepton+jets events selected from a data sample corresponding to an integrated luminosity of $4.96 fb^{-1}$. The mass difference between the top quark and its anti quark is measured [5]. The charge of the selected lepton in the event is used to distinguish between hadronically decaying top and anti-top quarks. The mass of the hadronically decaying top and anti-top quark is measured using the well established Ideogram method on the two distinct samples. Then the mass difference is calculated by subtracting the masses obtained in each measurement. The subtraction results in significant reduction of systematic errors. The mass difference is measured to be $\Delta m_{\mathrm{t}} = -0.44 \pm 0.46(\mathrm{stat}) \pm 0.27(\mathrm{syst})$ GeV and is the most precise measurement to date.

4 Other top quark properties

4.1 Measurement of the W boson polarization

In the t→Wb decay, the W boson may have a longitudinal, left-handed or right-handed polarization. Measuring the respective helicity fractions (F_0, F_L and F_R) with great precision will enhance the search for anomalous couplings. The helicity fractions have been measured in the muon+jets channel on a dataset corresponding to an integrated luminosity of $2.2 fb^{-1}$ [6]. The helicity fractions are extracted from a likelihood fit to the $\cos(\theta^*)$ distribution while a kinematic fit on the entire event is used to improve the Missing Transverse Energy (MET) resolution. The measured fractions $F_0 = 0.567 \pm 0.074$ (stat) $\pm$ 0.047 (syst), $F_L = 0.393 \pm 0.045$ (stat) $\pm$ 0.029 (syst) and $F_R = 0.040 \pm 0.035$ (stat) $\pm$ 0.044 (syst) are in good agreement with SM predictions $F_0 = 0.7$ and $F_L = 0.3$.

4.2 Probing the heavy flavor content in top decays

In the SM with three generations of quarks, the $|V_{tb}|$ CKM-matrix element is expected to be close to unity as a consequence of the unitarity of the CKM matrix and of the measurements of the other elements.This means that the top quark will decay almost exclusively into a W-boson and a b-quark. To test the validity of this theory, the branching fraction of the t→Wb decay is measured relative to the one of t →Wq decay. Using a di-lepton $t\bar{t}$ sample, corresponding to an integrated luminosity of $2.2 fb^{-1}$, the R=B(t → Wb)/B(t → Wq) variable is measured [7]. A likelihood fit on the b-tag multiplicity distribution, including gaussian smearing terms for experimental effects, yields R=0.98±0.04 consistent with the SM. The dominant systematics in this measurement are the b-tagging uncertainty and the uncertainty on the factorization scale.

4.3 Search for Flavor Changing Neutral Currents (FCNC)

As opposed to the SM prediction that B(t → Wb) ∼ 1, the top quark could decay into a Z-boson and a light quark through a Flavor Changing Neutral Current (FCNC) interaction. In a top quark pair decay, one possible signature is the three-lepton final state from $t\bar{t} \to Zq + Wb \to \ell^+\ell^- j + \ell^\pm \nu b$. This particular topology has been searched for using a cut-based analysis technique[8]. Events with three leptons $p_T > 20$ GeV are selected requiring $60 < m_{\ell^+\ell^-} < 120 GeV$ for same flavor lepton pairs. To enhance the signal yield over background, an extra criterion on HTs $= \sum p_{T\ell} + \sum E_{Tj} + \not{E}_T > 250$ GeV and $10 < m_{Wb}, m_{Zq} < 250$ GeV is applied. All backgrounds are estimated from simulation except for the $t\bar{t}$ and Drell-Yan backgrounds which have been estimated from data. For a dataset corresponding to an integrated luminosity of $4.6 fb^{-1}$, 16.2 ± 3.9(stat.) $\pm$ 2.6 (syst.) events are expected in the background hypothesis only. In total 11 events where observed resulting in $Br(t \to Zq) < 0.34\%$ at 95% C.L.

4.4 Constraining the top quark charge

In the SM, the top quark has an electric charge of +2/3e. However, more exotic charge hypotheses exist. The top quark charge is reconstructed by exploiting the charge correlation between the high p_T muon from the W-boson decay and the soft muons from B-hadron decay inside the b-jet. To discriminate between the expected charge of +2/3e and a more exotic scenario of -4/3e, a normalized test statistic (A) is constructed such that A=-1 corresponds to the -4/3e scenario. The measured value of $A_{meas} = 0.97 \pm 0.12(stat) \pm 0.31(syst)$ is in good agreement with the SM A=1 expectation ruling out the exotic scenario at 99.9% C.L.

5 Summary

With the excellent performance of the Large Hadron Collider and the high data-taking efficiency of the CMS experiment, the exploration of the top quark sector is advancing well. The CMS experiment has measured the top quark mass using a wide range of techniques in different channels resulting in a combined value of $m_t = 172.6 \pm 0.4(stat) \pm 1.2(syst)$ GeV and is continuing to increase precision. To further test the SM, the CMS experiment has performed many measurements. The difference in the top and anti-top quark mass was measured as well as deviations in the heavy flavor content. Searches were conducted for the existence of FCNC, anomalous couplings, and the existence of top quarks with a non-SM charge. So far no deviations from the SM have been observed.

References

[1] CMS Collaboration, "Measurement of the top quark mass in the muon+jets channel", *CMS Physics Analysis Summary* **CMS-PAS-TOP-11-015** (2012).

[2] CMS Collaboration, "Measurement of the $t\bar{t}$ production and the top-quark mass in the di-lepton channel in pp collisions at $\sqrt{s} = 7$ TeV", *JHEP* **07** (2011) 049. arXiv:1105.5661.

[3] D0 Collaboration, "Measurement of the top quark mass in $p\bar{p}$ collisions using events with two leptons", submitted to *Phys. Rev. Lett.* arXiv:1201.5172.

[4] CMS Collaboration, "Determination of the Top Quark Mass from the $t\bar{t}$ Cross Section at $\sqrt{s} = 7$ TeV", *CMS Physics Analysis Summary* **CMS-PAS-TOP-11-008** (2011).

[5] CMS Collaboration, "Measurement of the mass difference between top and antitop quarks", *JHEP* **06** (2012) 109. arXiv:1204.2807.

[6] CMS Collaboration, "Measurement of the W boson polarization in semileptonic top pair decays with the CMS detector at the LHC", *CMS Physics Analysis Summary* **CMS-PAS-TOP-11-020** (2012).

[7] CMS Collaboration, "First measurement of $B(t \to Wb)/B(t \to Wq)$ in the dilepton channel in pp collisions at $\sqrt{s} = 7$ TeV", *CMS Physics Analysis Summary* **CMS-PAS-TOP-11-029** (2012).

[8] CMS Collaboration, "Search for Flavor Changing Neutral Currents in Top Quark Decays in pp Collisions at $\sqrt{s} = 7$ TeV", *CMS Physics Analysis Summary* **CMS-PAS-TOP-11-028** (2012).

[9] CMS Collaboration, "Constraints on the Top-Quark Charge from Top-Pair Events", *CMS Physics Analysis Summary* **CMS-PAS-TOP-11-031** (2012).