Available on CMS information server

CMS CR -2013/025

The Compact Muon Solenoid Experiment

Conference Report

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

25 January 2013 (v3, 28 January 2013)

Measurement of the top-quark mass with all-jets final states in pp collisions at 7 TeV

Eike Schlieckau for the CMS Collaboration

Abstract

A measurement is presented of the top-quark mass in the all-jets channel using a sample of ttbar candidate events requiring at least six jets in the final state. The data have been collected by CMS in pp collisions at 7 TeV and correspond to an integrated luminosity of 3.54/fb. In this channel, a very tight event selection is needed to reduce the huge amount of multi-jet events. In addition, the signal fraction and mass resolution is improved by the use of a kinematic fit. An ideogram method is used to measure the top-quark mass with the background estimated from data through an event mixing technique. The top-quark mass is measured to be $m_t = 173.5 \pm 0.7(stat.) \pm 1.3(syst.)$ GeV.

Presented at *TOP2012 5th International Workshop on Top Quark Physics*

Measurement of the top-quark mass with all-jets final states in pp collisions at 7 TeV

Eike Schlieckau for the CMS Collaboration

Phd Student, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

E-mail: `eike.schlieckau@desy.de`

Abstract. A measurement is presented of the top-quark mass in the all-jets channel using a sample of $\mathrm{t\bar{t}}$ candidate events requiring at least six jets in the final state. The data have been collected by CMS in pp collisions at 7 TeV and correspond to an integrated luminosity of 3.54 fb^{-1}. In this channel, a very tight event selection is needed to reduce the huge amount of multi-jet events. In addition, the signal fraction and mass resolution is improved by the use of a kinematic fit. An ideogram method is used to measure the top-quark mass with the background estimated from data through an event mixing technique. The top-quark mass is measured to be $m_\mathrm{t} = 173.5 \pm 0.7$ (stat.) $\pm$ 1.3 (syst.) GeV.

1. Introduction

A first top-quark mass (m_t) measurement in all-jets final states is presented with the CMS detector [1]. This final state yields the largest signal, however, it is dominated by multijet background. The detailed descriptions of this analysis can be found in Ref. [2].

The event selection is very similar to the one from the CMS $\mathrm{t\bar{t}}$ cross section measurement in the same final state [3]. The analysis employs a kinematic fit of the $\mathrm{t\bar{t}}$ final state and likelihood functions for each event ("ideograms") that depend on m_t and jet energy scale (JES).

2. Data Samples and Event Selection

The analysis uses two multijet triggers which collected 3.54 fb^{-1} of the 2011 data sample. The method has been developed and evaluated with simulated events, while the background from multijet events is estimated from data employing an event mixing method.

Jets are clustered with the anti-k_t algorithm ($R = 0.5$) [4, 5] from particles reconstructed by a particle flow algorithm [6]. Events are selected with at least four (five, six) central jets with a transverse momentum of $p_\mathrm{T} > 60$ $(50, 40)$ GeV. Additional central jets are considered with $p_\mathrm{T} > 30$ GeV. At least two jets originating from bottom quarks are required, being tagged with an algorithm that combines reconstructed secondary vertices and track-based lifetime information.

For the final selection, a kinematic least-squares fit [7] is applied, exploiting the characteristic topology: two W bosons reconstructed from untagged jets with an invariant mass of 80.4 GeV [8] and two top quarks of equal mass reconstructed from the W bosons and b-tagged jets.

The fit procedure is repeated for every experimentally distinguishable jet permutation using all jets that pass the selection criteria, to find the correct jet combination. Per event, the permutation with the smallest χ^2 is chosen and accepted with a goodness-of-fit probability $P_\mathrm{gof} = P\left(\chi^2, n = 3\right) > 0.09$.

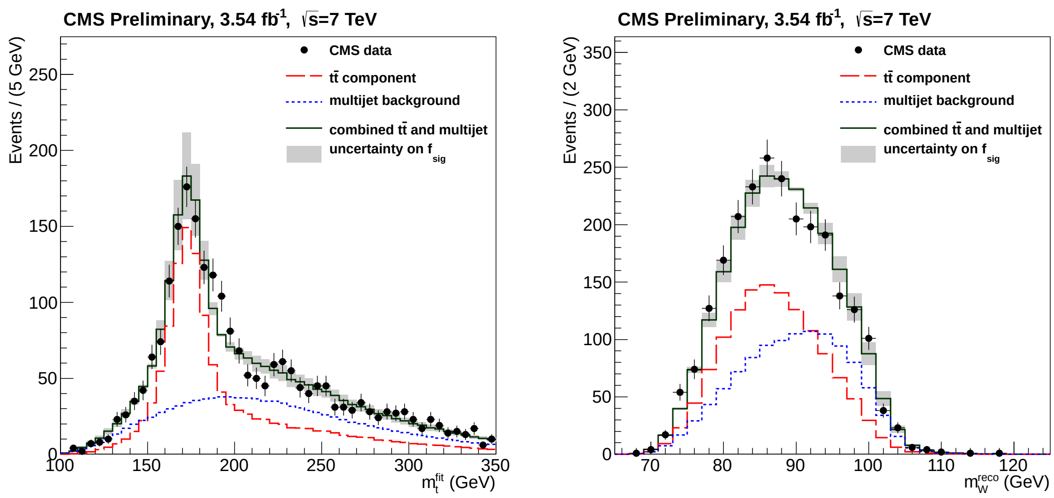

Figure 1. Reconstructed top-quark mass from the kinematic fit (left) and average reconstructed W-boson mass before being constrained by the kinematic fit (right). The simulated $\mathrm{t\bar{t}}$ signal ($m_{\mathrm{t,gen}}$ = 172.5 GeV) and background from event mixing are normalized to data with an uncertainty band from the signal fraction f_{sig}.

To further reduce the multijet background from bb production, an additional criterion on the distance of the two bottom quark candidates, $\Delta R_{\mathrm{b\bar{b}}} = \sqrt{\Delta\phi^2_{\mathrm{b\bar{b}}} + \Delta\eta^2_{\mathrm{b\bar{b}}}} > 1.5$, is imposed.

The $\mathrm{t\bar{t}}$ events are classified into three categories based on the jet-parton associations in simulation: correct permutations ($f_{cp} = 27.9\%$), wrong permutations ($f_{wp} = 22.6\%$) where at least one jet is not associated to the correct parton, and unmatched permutations ($f_{un} = 49.4\%$), with at least one quark from the $\mathrm{t\bar{t}}$ decay not matched unambiguously to a jet.

3. Background Modeling

The multijet background is estimated by an event mixing technique. All events after the b-tagging selection are taken as input, mixing the jets between the different events such that in every newly generated event all jets are originating from different events, keeping at least two b-tagged jets in the new event.

The simulated $\mathrm{t\bar{t}}$ sample and modeled background are normalized to data with an expected signal fraction (f_{sig}) from simulation, which depends on the cross section [9, 10, 11] and the selection efficiency for $\mathrm{t\bar{t}}$ events.

4. Ideogram Method

A likelihood function is constructed that allows the simultaneous determination of JES and m_{t}. Based on this likelihood function, two different estimates of m_{t} are performed: with a fixed JES ("1-D analysis") or simultaneously with the JES ("2-D analysis").

The observable used for measuring m_{t} is the top-quark mass from the kinematic fit ($m_{\mathrm{t}}^{\mathrm{fit}}$). The average reconstructed W-boson mass before they are constrained by the kinematic fit ($m_{\mathrm{W}}^{\mathrm{reco}}$) is taken as an estimator for measuring a global JES. Figure 1 compares data, expectation from simulation, and modeled background for $m_{\mathrm{t}}^{\mathrm{fit}}$ and $m_{\mathrm{W}}^{\mathrm{reco}}$.

A likelihood ($\mathcal{L}$) to estimate m_{t} and JES given the observed data sample can be defined as:

$$\mathcal{L}\left(m_{\mathrm{t}}, \mathrm{JES}|\mathrm{sample}\right) \propto \mathcal{L}\left(\mathrm{sample}|m_{\mathrm{t}}, \mathrm{JES}\right) = \prod_{\mathrm{events}} P\left(m_{\mathrm{t}}^{\mathrm{fit}}, m_{\mathrm{W}}^{\mathrm{reco}}|m_{\mathrm{t}}, \mathrm{JES}\right)^{P_{\mathrm{gof}}}.$$

There is no correlation between $m_{\mathrm{t}}^{\mathrm{fit}}$ and $m_{\mathrm{W}}^{\mathrm{reco}}$, hence, the probability $P\left(m_{\mathrm{t},i}^{\mathrm{fit}}, m_{\mathrm{W}}^{\mathrm{reco}}|m_{\mathrm{t}}, \mathrm{JES}\right)$ factorizes into

$$\begin{aligned} P\Big(m_{\mathrm{t}}^{\mathrm{fit}}, m_{\mathrm{W}}^{\mathrm{reco}}|m_{\mathrm{t}}, \mathrm{JES}\Big) &= f_{\mathrm{sig}} \cdot \sum_j f_j P_j\Big(m_{\mathrm{t}}^{\mathrm{fit}}|m_{\mathrm{t}}, \mathrm{JES}\Big) \cdot P_j\Big(m_{\mathrm{W}}^{\mathrm{reco}}|m_{\mathrm{t}}, \mathrm{JES}\Big) \\ &\quad + (1 - f_{\mathrm{sig}}) \cdot P_{\mathrm{bkg}}\Big(m_{\mathrm{t}}^{\mathrm{fit}}\Big) \cdot P_{\mathrm{bkg}}\Big(m_{\mathrm{W}}^{\mathrm{reco}}\Big), \end{aligned}$$

where f_j and P_j with $j \in \{cp, wp, un\}$ are the relative fraction and the probability density functions for signal of the three different permutation cases, which are determined from simulated $\mathrm{t\bar{t}}$ events with different generated top-quark masses ($m_{\mathrm{t,gen}}$) and different JES. The $m_{\mathrm{t}}^{\mathrm{fit}}$ distributions are fitted with a Breit-Wigner function convoluted with Gaussian resolution for the *cp* case and with the sum of a Landau function and a Gaussian function with common means for the *wp* and *un* cases for different $m_{\mathrm{t,gen}}$ and JES. The $m_{\mathrm{W}}^{\mathrm{reco}}$ distributions are fitted with asymmetric Gaussian functions. The parameters of all fitted signal functions are parametrized linearly in terms of $m_{\mathrm{t,gen}}$, JES, and the product of the two. As the background is modeled from data, its probability density distributions do not depend on m_{t} nor JES.

In the 1-D analysis, m_{t} is estimated from $-2\ln\{\mathcal{L}(m_{\mathrm{t}}, \mathrm{JES} = 1|\mathrm{sample})\}$. In the 2-D analysis, the most likely m_{t} and JES are obtained by minimizing $-2\ln\{\mathcal{L}(m_{\mathrm{t}}, \mathrm{JES}|\mathrm{sample})\}$.

For each combination of m_{t} and JES 10 000 pseudo-experiments are conducted using simulated $\mathrm{t\bar{t}}$ events and modeled background events from event mixing to calibrate the measurement and its statistical uncertainty.

5. Systematic Uncertainties

An overview of the different sources of systematic uncertainties is shown in Table 1.

As expected, the main systematic uncertainty in the 1-D measurement stems from the uncertainty in JES and the 2-D measurement reduces this uncertainty to a small p_{T}- and η-dependent JES uncertainty. However, the 2-D approach leads to increased uncertainties for color reconnection effects, underlying event, and the modeling of the non-$\mathrm{t\bar{t}}$ background.

Overall, the 1-D measurement offers a better precision because of the strong impact of the underlying event on the top-quark mass measurement in the 2-D approach.

Table 1. Overview of systematic uncertainties. The total is defined by adding in quadrature the contributions from all sources.

	1-D analysis	2-D analysis	
	$\delta_{m_{\mathrm{t}}}$ (GeV)	$\delta_{m_{\mathrm{t}}}$ (GeV)	δ_{JES}
Fit calibration	0.13	0.14	0.001
Jet energy scale	0.97	0.10	0.002
b-JES	0.49	0.52	0.001
Jet energy resolution	0.15	0.13	0.003
b tagging	0.06	0.10	0.001
Trigger	0.24	0.26	0.006
Pileup	0.06	0.10	0.001
Parton distribution functions	0.06	0.10	0.001
Q^2 scale	0.22	0.34	0.005
ME-PS matching threshold	0.24	0.34	0.003
Underlying event	0.32	0.88	0.007
Color reconnection effects	0.15	0.58	0.006
Non-$\mathrm{t\bar{t}}$ background	0.20	0.62	0.008
Total	1.25	1.46	0.015

6. Results

Out of 3.54 fb^{-1} of 2011 data, 2418 events are selected and with a fixed JES=1 result in:

$$m_{\mathrm{t}} = 173.49 \pm 0.69\ (\mathrm{stat.}) \pm 1.25\ (\mathrm{syst.})\ \mathrm{GeV}$$

The overall uncertainty of the presented 1-D analysis is 1.43 GeV.

A simultaneous fit of m_{t} and JES to the same data yields:

$$\begin{aligned} m_{\mathrm{t}} &= 174.28 \pm 1.00\ (\mathrm{stat.{+}JES}) \pm 1.46\ (\mathrm{syst.})\ \mathrm{GeV} \\ \mathrm{JES} &= 0.991 \pm 0.008\ (\mathrm{stat.}) \pm 0.015\ (\mathrm{syst.}) \end{aligned}$$

The measured JES confirms the JES in data measured in events with Z bosons and photons [12]. The overall uncertainty in the top-quark mass of the presented 2-D analysis is 1.77 GeV.

The measured top-quark masses in both analyses are in agreement, with the 1-D analysis yielding a higher precision than the 2-D analysis.

7. Summary

A measurement of the top-quark mass is presented using events with all-jets final states, collected by CMS in pp collisions at $\sqrt{s} = 7$ TeV in 2011. A constrained fit reconstructs the complete kinematics of each event. For each selected event a likelihood is calculated as a function of assumed top-quark mass. Using a data sample with an integrated luminosity of 3.54 fb^{-1}, 2418 candidate events are observed and the mass of the top-quark is measured to be $m_{\mathrm{t}} = 173.5 \pm 0.7\ (\mathrm{stat.}) \pm 1.3\ (\mathrm{syst.})$ GeV. To date, this measurement constitutes the most precise determination of the top-quark mass in all-jets final states.

References

[1] Chatrchyan S *et al.* (CMS Collaboration) 2008 *JINST* **3** S08004
[2] CMS Collaboration 2012 *CMS Physics Analysis Summary* **CMS-PAS-TOP-11-017**
[3] CMS Collaboration 2011 *CMS Physics Analysis Summary* **CMS-PAS-TOP-11-007**
[4] Cacciari M and Salam G P 2006 *Phys. Lett. B* **641** 57
[5] Cacciari M, Salam G P and Soyez G 2008 *JHEP* **04** 063
[6] CMS Collaboration 2010 *CMS Physics Analysis Summary* **CMS-PAS-PFT-10-002**
[7] D'Hondt J *et al.* 2006 Fitting of event topologies with external kinematic constraints in CMS Tech. Rep. CMS-NOTE-2006-023 CERN Geneva
[8] Beringer J *et al.* (Particle Data Group) 2012 *Phys. Rev. D* **86** 010001
[9] Kidonakis N 2010 *Phys. Rev. D* **82** 114030
[10] Aliev M, Lacker H, Langenfeld U, Moch S, Uwer P *et al.* 2011 *CPC* **182** 1034–1046
[11] Ahrens V *et al.* 2010 *JHEP* **09** 097
[12] Chatrchyan S *et al.* (CMS Collaboration) 2011 *JINST* **6** P11002