Results on top-quark physics from the CMS experiment

S. Tosi
ON BEHALF OF THE CMS COLLABORATION

Institut de Physique Nucléaire de Lyon, Villeurbanne, 69100, France

Abstract

The most recent results on top-quark physics reported by the CMS experiment at the Large Hadron Collider (LHC) are presented in this talk. The results are based on a data sample of about 36 pb\(^{-1}\) of data collected during 2010 at a \(pp\) center-of-mass energy of 7 TeV.

PRESENTED AT

The Ninth International Conference on Flavor Physics and CP Violation
(FPCP 2011)
Maale Hachamisha, Israel, May 23–27, 2011
1 Introduction

The top quark has a special place in the Standard Model (SM). It is the heaviest elementary particle known to date, its mass being very close to the scale of electroweak symmetry breaking. As such it plays a special role in many models of new physics beyond the SM.

In the SM, the top quark decays almost exclusively to a $Wb$ pair. At the LHC \[1\], the top quark is predominantly produced in pairs, via the strong interaction, with a total cross-section of around 158 pb, at the NLO. From an experimental point of view, $t\bar{t}$ pairs can be classified in three channels according to the decay of the two $W$ bosons originated by the top and anti-top decays: dileptonic channel, when both $W$ decay leptonically; all-hadronic channel, when both $W$ decay to quarks; semi-leptonic channel, when one $W$ decays to leptons and the other to quarks. The three channels have a branching fraction of about 10, 48 and 42 %, respectively.

An additional production mechanism is single-top production, via the electro-weak interaction. Three possible channels exist with a total cross section of around 78 pb.

The top quark has a paramount importance at the LHC. Final states originated from top decays typically include jets, leptons and missing energy, hence typically involve almost all subdetectors and allow thorough tests of the performances of the detector. In addition, studies of top-quark production and properties represent an important tool to verify SM predictions and QCD calculations in the LHC environment.

Several extensions of the SM foresee a preferential coupling to the third generation and in particular to the top-quark sector. For example, new resonances may exist decaying to top-antitop pairs.

2 The LHC and CMS

The LHC started to deliver $pp$ collisions at the end of 2009. Following two periods of data taking at a $pp$ center-of-mass energy of 900 GeV and 2360 GeV, during year 2010 collisions at 7 TeV have been recorded. The total integrated luminosity in 2010, on which the results shown here are based, was about 36 pb$^{-1}$. During 2011 the LHC has already delivered more than 1 fb$^{-1}$ of data at a center-of-mass energy of 7 TeV.

The collisions produced by the LHC are recorded with high efficiency by the CMS detector, which is described in detail elsewhere \[2\].

3 Ingredients for top physics

The reconstruction of final states of top decays typically involves several basic objects at the same time: leptons, jets, missing energy.
At the trigger level, events containing top quarks are selected by requiring the presence of at least one electron or one muon. The minimum $E_T$ of the electrons was requested to exceed 10 GeV in the beginning of the data taking period, this threshold being raised with the increase of the event rate to 22 GeV. The efficiency of the electron trigger requirements is above 98%. Similarly, the minimum $p_T$ of muons was requested to exceed 9 GeV/c, the threshold being raised up to 15 GeV/c at higher event rates. The efficiency of the muon trigger requirements is above 92%.

Jets and missing energy are reconstructed using the “particle flow” algorithm, where the information from all sub-detectors is combined to determine the particle content of the events. This greatly improves on the performances of jet identification and resolution with respect to a reconstruction only based on energy deposits in the calorimeters. The energy scale uncertainty for jets typically varies between 3 to 5% depending on the $E_T$, and the uncertainty on the resolution is around 10%.

In events containing top pairs, two jets are originated from the hadronization of a $b$ quark. Several algorithms have been developed to identify the $b$-flavor of jets, which exploit various properties of $b$-hadrons, for instance the presence of a displaced secondary vertex or of secondary non-isolated leptons. These algorithms cover a broad range of signal efficiency and mis-identification rates and are chosen by each data analysis according to the specific needs.

### 4 Inclusive cross-section measurement

The inclusive cross section of $t\bar{t}$-pair production has been measured by CMS using both the semi-leptonic and the dileptonic channels. In both cases, electrons and muons have been considered. The cross section with the semileptonic channel has been measured both with and without the usage of $b$-tagging algorithms. In the latter case [3], the signal content is extracted by means of a binned likelihood fit to the missing energy and the invariant mass of the three jets yielding the highest summed $p_T$. In the former case [4], a binned likelihood fit to the invariant mass of all objects pertaining to the secondary vertex is performed, where systematic uncertainties are included as nuisance parameters in the fit. The cross section was measured to be $(173 \pm 14(stat) \pm^{36}_{29}(syst) \pm 7(lumi))$ and $(150 \pm 9(stat) \pm 17(syst) \pm 6(lumi))$ pb, respectively. In the dileptonic channel, the signal content is extracted by counting the events in jet multiplicity bins and the cross section is measured to be $(168 \pm 18(stat) \pm 14(syst) \pm 7(lumi))$ pb [10]. Combining the semi-leptonic and the dileptonic cross-section measurements, properly taking into account the correlations, CMS obtains $(158 \pm 19)$ pb [5], consistent with the SM expectation (Fig. [1]).
Figure 1: Top pair production cross section as a function of $\sqrt{s}$, for both $p\bar{p}$ and $pp$ collisions. Data points are slightly displaced horizontally for better visibility. Theory predictions at approximate NNLO are obtained using HATHOR [6]. The error band of the prediction corresponds to the scale uncertainty.

5 Single top

The first measurement of the $t$-channel single top production cross section in $pp$ collisions at $\sqrt{s} = 7$ TeV has been performed by CMS using two analysis methods [7]. The first method makes use of a template fit to two angular variables sensitive to the $t$-channel single top production, the pseudorapidity distribution of the light jet accompanying the top quark and the angle between this jet and the lepton issued in the top decay chain. The second method makes use of a multivariate boosted decision tree technique, combining 37 event-shape and kinematic variables. An evidence exceeding three standard deviations has been obtained with both methods, and the cross section is measured to be $(83.6 \pm 29.8(stat + syst) \pm 3.3(lumi))$ pb.

6 Measurement of the top-quark mass

The mass of the top quark is a fundamental parameter in the SM and it affects predictions of SM observables via radiative corrections. Several methods have been developed to measure the top-quark mass. CMS used improved versions of the matrix weighting technique [8] and the fully kinematic method [9]. Combining the results yielded by the two methods, the mass was measured to be $(175.5 \pm 4.6(stat) \pm 4.6(syst))$ GeV/c$^2$ [10].
7 Search for resonances decaying to $t\bar{t}$ and measurement of the charge asymmetry

New Physics can manifest itself in several ways in top-pair production \cite{11}, often with intermediate new resonances, generically referred to as $Z'$, that decay to $t\bar{t}$ pairs.

A direct search for narrow $Z'$ resonances decaying to $t\bar{t}$ pairs has been performed using the semi-leptonic channel \cite{12}. A template likelihood fit to the $t\bar{t}$ invariant mass has been used. No signal has been observed and upper limits on the $Z'$ production cross section have been derived as a function of the $Z'$ mass, as shown in Fig. 2.

Figure 2: Expected and observed 95 % C.L. upper limits for $\sigma(pp \to Z') \times BR(Z' \to t\bar{t})$ for $36 \text{ pb}^{-1}$ of data as a function of the $Z'$ mass.

Broad resonances can escape identification in a measurement of the invariant mass spectrum. However their presence can be inferred in other ways. One possibility is the measurement of the charge asymmetry. In the SM, top pairs are produced in a symmetric state, as far as the color charge is concerned, at the LO. At the NLO, a small asymmetry is present, which can be enhanced if the $t\bar{t}$ pair is originated by the decay of a heavy resonance. At the Tevatron experiments, where the initial state is $p\bar{p}$, a charge asymmetry yields a forward-backward asymmetry: the Tevatron experiments indeed reported a deviation of the forward-backward asymmetry from SM expectations by around 2 standard deviations \cite{13}. At the LHC, where the initial state is $pp$, a charge asymmetry can induce a difference of absolute pseudo rapidities
of top and anti-top quarks, $|\eta_t| - |\eta_{\bar{t}}|$ (Fig. 3). CMS measures an asymmetry of $(0.060 \pm 0.134(stat) \pm 0.026(syst))$, consistent with the SM expectations [14].

Figure 3: Distribution of the unfolded $|\eta_t| - |\eta_{\bar{t}}|$ spectrum. The shown theory curves are the prediction from the MADGRAPH generator and a NLO computation [15].

8 Conclusion

The CMS experiment has already reported several interesting results on top-quark physics. So far, all results are consistent with the SM predictions. A rich program of measurements of differential distributions and properties of the top quark is in place, including the usage of additional channels. A lot more data have already been recorded and exciting results are expected soon.

References

[1] L. Evans and P. Bryant (editors), “LHC Machine”, JINST 3 (2008) S08001.

[2] CMS Collaboration, “The CMS experiment at the CERN LHC”, JINST 0803 (2008) S08004.
[3] S. Chatrchyan et al. [CMS Collaboration], “Measurement of the Top-antitop Production Cross Section in pp Collisions at sqrt(s)=7 TeV using the Kinematic Properties of Events with Leptons and Jets,” arXiv:1106.0902 [hep-ex].

[4] CMS Collaboration, “Measurement of the t\bar{t} Pair Production Cross Section at $\sqrt{s} = 7$ TeV using b-quark Jet Identification Techniques in Lepton + Jet Events”, CMS TOP-11-001 (2011). https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP11001.

[5] CMS Collaboration, “Combination of top pair production cross sections in pp collisions at 7 TeV and comparisons with theory”, CMS TOP-11-001 (2011). http://cdsweb.cern.ch/record/1336491?ln=en

[6] M. Aliev, H. Lacker, U. Langenfeld et al., “HATHOR: HAdronic Top and Heavy quarks crOss section calculatoR”, Comput.Phys.Commun. 182 (2011) 1034-1046, arXiv:1007.1327.

[7] S. Chatrchyan et al. [CMS Collaboration], “Measurement of the t-channel single top quark production cross section in pp collisions at sqrt(s) = 7 TeV,” arXiv:1106.3052 [hep-ex].

[8] D0 Collaboration, “Measurement of the top quark mass using dilepton events”, Phys. Rev. Lett. 80 (1998) 2063, arXiv:hep-ex/9706014.

[9] CDF Collaboration, “Measurement of the top quark mass using template methods on dilepton events in proton antiproton collisions at $\sqrt{s} =1.96$ TeV”, Phys. Rev. D73 (2006) 112006, arXiv:hep-ex/0602008.

[10] S. Chatrchyan et al. [CMS Collaboration], “Measurement of the t t-bar production cross section and the top quark mass in the dilepton channel in pp collisions at sqrt(s) =7 TeV,” arXiv:1105.5661 [hep-ex].

[11] See for example: S. Dimopoulos and H. Georgi Nucl. Phys. B193 150; S. Weinberg Phys. Rev. D13 974; L. Susskind Phys. Rev. D20 2619; C. T. Hill and J. Parke Phys. Rev. D49 4454; R. S. Chivukula et al. Phys. Rev. D59 075003; N. Arkani-Hamed, A. G. Cohen, and H. Georgi Phys. Lett. B513 232; N. Arkani-Hamed, S. Dimopoulos, and G. R. Dvali Phys. Lett. B429 263; L. Randall and R. Sundrum Phys. Rev. Lett. 83 3370.

[12] CMS Collaboration, “Search for Resonances in Semi-leptonic Top-pair Decays Close to Production Threshold”, CMS-PAS-TOP-10-007. http://cdsweb.cern.ch/record/1335720?ln=en
[13] CDF Collaboration, “Evidence for a Mass Dependent Forward-Backward Asymmetry in Top Quark Pair Production”, arXiv:1101.0034; D0 Collaboration, “Measurement of the forward-backward production asymmetry of $t$ and $\bar{t}$ quarks in $pp \to t\bar{t}$ events”, DO note 6062-CONF (2010); CDF Collaboration, “Forward-Backward Asymmetry in Top Quark Production in $pp$ Collisions at $\sqrt{s} = 1.96$ TeV”, Phys. Rev. Lett. 101 (2008) 202001, arXiv:0806.2472.

[14] CMS Collaboration, “Measurement of the charge asymmetry in top quark pair production with the CMS experiment”, CMS-PAS-TOP-10-010. http://cdsweb.cern.ch/record/1335714?ln=en

[15] P. Ferrario and G. Rodrigo, “Massive color-octet bosons and the charge asymmetries of top quarks at hadron colliders”, Phys. Rev. D78 (2008) 094018, arXiv:0809.3354. P. Ferrario and G. Rodrigo, “Heavy colored resonances in top-antitop + jet at the LHC”, JHEP 02 (2010) 051, arXiv:0912.0687.