Top results from CMS

Alicia Calderon
Instituto de Fisica de Cantabria (CSIC - University of Cantabria)
Avda. Los Castros, s.n. Santander, SPAIN
On behalf of the CMS collaboration.

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 [1] 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 W b pair. At the LHC [2], the top quark is predominantly produced in pairs, via the strong interaction, with a total cross-section of 158^{+23}_{-24} [3] 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 the single-top production, via the electro-weak interaction. The theory of electroweak interactions predicts three different production mechanisms for single top quarks in hadron-hadron collisions: t channel, s channel, and tW (or W-associated). In 7 TeV proton-proton collisions the t-channel is by far the most abundant of the three mechanisms with a NLO cross section of $59.1^{+3.0}_{-4.0}pb$ in the 4-flavour scheme and $62.3^{+2.3}_{-2.4}pb$ in the 5-flavour [4], for a top mass of 172.5 GeV/c^2.

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 2 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 [5].

3 Measurements of the top quark pair production cross section

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 [6], 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 [7], 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 ± 14(stat) ± 36 (syst) ± 7(lumi)) and (150 ± 9(stat) ± 17(syst) ± 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 ± 18(stat) ± 14(syst) ± 7(lumi)) pb [8].

The final top quark cross section provided by the CMS collaboration is obtained by combining the result from the semi-leptonic analysis and the result from the dileptonic analysis. This combination, using the Best Linear Unbiased Estimate (BLUE) technique [9], divides the uncertainties between the uncorrelated and the correlated ones. The final cross section from CMS is 158 ± 19 pb [10], consistent with the SM expectation, as seen in Figure 1.

4 Measurement of the single top t-channel cross section

The first measurement of the t-channel single top production cross section in pp collisions at 7 TeV has been performed by CMS using two analysis methods [12]. The first method makes use of a template fit to two angular variables sensitive to the t-channel

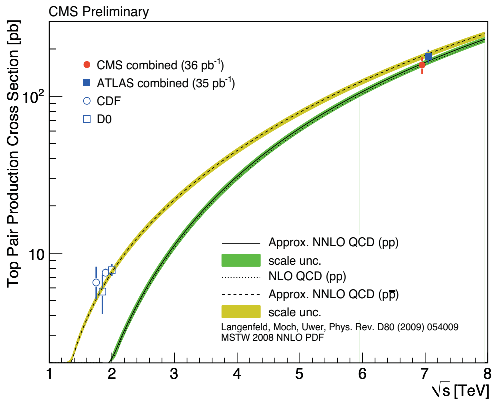

Figure 1: Top pair production cross section as a function of $\sqrt{s}$, for both pp and $p\bar{p}$ collisions. Data points are slightly displaced horizontally for better visibility. Theory predictions at approximate NNLO are obtained using HATHOR [11]. The error band of the prediction corresponds to the scale uncertainty.

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 t-channel cross section is measured to be $(83.6 \pm 29.8(\text{stat} + \text{syst}) \pm 3.3(\text{lumi}))$ pb which is consistent with the standard model prediction.

5 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 [13] and the fully kinematic method [14] to measure the top quark mass in the dileptonic channel. Combining the results yielded by the two methods, the mass was measured to be $(175.5 \pm 4.6(\text{stat}) \pm 4.6(\text{syst}))$ GeV$/c^2$ [8].

In the semi-leptonic channel a simplified version of the Ideogram technique, used by D0 for the top quark mass measurement in the same channel [15], has been used. It uses a constrained fit to reconstruct the full kinematics of each event, and calculates an event-by-event likelihood taking into account all possible jet-parton assignments and the possibility that the event is $t\bar{t}$ signal or background.The main difference with the D0 implementation is that no in-situ fit of the jet energy scale (JES) is performed. B-tagging information is not used for the selection of events, but it is used in the event likelihood calculation to improve the extraction of top mass information from the events. Both the muon+jets and electron+jets channels are included. The top quark mass is measured to be (173.1 ± 2.1(stat) $^{+2.8}_{-2.5}$ (syst)) GeV/c^2 [16].

A combination with the CMS results obtained in the dilepton channel on the same data sample, was performed using the BLUE method [9]. Since the event samples used in dilepton and lepton+jets measurements are constructed to be non-overlapping, the statistical uncertainty in each measurement is uncorrelated. The systematic uncertainties that are common to both measurements are considered to be fully correlated, with the exception of the jet energy scale (JES). The combination yields a top quark mass of (173.4 ± 1.9(stat) $\pm$ 2.7(syst)) GeV/c^2.

6 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 [17], 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 [18]. 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 Figure 2.

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 standard model, 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 [19, 20]. 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, $|\eta_t| - |\eta_{\bar{t}}|$. CMS measures an asymmetry of (0.060 ± 0.134(stat) $\pm$ 0.026(syst)), consistent with the SM expectations [14].

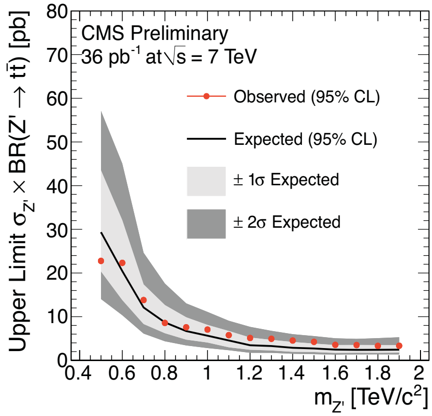

Figure 2: Expected and observed 95 % C.L. upper limits for $\sigma(pp \to Z') \times BR(Z' \to t\bar{t})$ for 36 pb^{-1} of data as a function of the Z' mass.

7 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] CDF and D0 Collaborations, arXiv:1007.3178 [hep-ex] (2010).

[2] L. Evans and P. Bryant (editors), JINST 3, S08001 (2008).

[3] http://mcfm.fnal.gov/

[4] J. M. Campbell, R. Frederix, F. Maltoni et al., JHEP 10, 042 (2009).

[5] CMS Collaboration, JINST 0803 (2008) S08004.

[6] CMS Collaboration, arXiv:1106.0902 [hep-ex] (2011).

[7] CMS Collaboration, arXiv:1108.3773 [hep-ex] (2011).

[8] CMS Collaboration, arXiv:1105.5661 [hep-ex] (2011).

[9] L. Lyons, D. Gibaut, and P. Clifford, Nucl. Instrum. Meth. A270, 110 (1988).

[10] CMS Collaboration, CMS TOP-11-001 (2011).
(http://cdsweb.cern.ch/record/1336491?ln=en)

[11] M. Aliev, H. Lacker, U. Langenfeld et al., Comput.Phys.Commun. 182, 1034-1046 (2011).

[12] CMS Collaboration, arXiv:1106.3052 [hep-ex] (2011).

[13] D0 Collaboration, Phys. Rev. Lett. 80, 2063 (1998).

[14] CDF Collaboration, Phys. Rev. D73, 112006 (2006).

[15] D0 Collaboration, Phys. Rev. D75, 092001 (2007).

[16] CMS Collaboration, CMS-PAS-TOP-11-009 (2011).
(http://cdsweb.cern.ch/record/1356578?ln=en)

[17] 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.

[18] CMS Collaboration, CMS-PAS-TOP-10-007 (2011).
(http://cdsweb.cern.ch/record/1335720?ln=en

[19] CDF Collaboration, Phys. Rev. Lett. 101, 202001 (2008).

[20] D0 Collaboration, D0 note 6062-CONF (2010).

[21] CMS Collaboration, CMS-PAS-TOP-10-010 (2011).
(http://cdsweb.cern.ch/record/1335714?ln=en)