IL NUOVO CIMENTO Vol. 35 C, N. 3 Maggio-Giugno 2011
DOI 10.1393/ncc/i2012-11232-7

Colloquia: TOP2011

Measurements of the top-quark-pair production cross section in the dilepton channel at LHC

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ricevuto l' 1 Marzo 2012

Summary. — Measurements of the total top-quark-pair production cross section at 7 TeV are presented, using data collected at the LHC by the ATLAS and CMS experiments in 2011. The total cross section is measured in the dilepton decay channels of the $t\bar{t}$ pair into two opposite-sign charged leptons and additional jets. The results are compared with the theory predictions.

PACS `14.65.Ha` – Top quark pair production.

1. – Introduction

The measurement of the $t\bar{t}$ cross section in pp collisions at the LHC is a useful and important measurement both as a test of Quantum Chromodynamics (QCD) and because of its sensitivity to physics beyond the Standard Model (BSM). The top quark is assumed to decay 100% of the time to a $W^{\pm}$ boson and a beauty/anti-beauty quark; the W can then decay either to a lepton and a neutrino or into two quarks, which then hadronise into jets. The ATLAS [1] and CMS [2] Collaborations have made a number of measurements of the $t\bar{t}$ cross section in which both W bosons decay leptonically. Both experiments have measured the cross section using events in which the leptons are electrons and/or muons [3, 4] and also using the $\mu\tau$ channel [5, 6]. In the former, ATLAS have measured the cross sections both with and without the use of algorithms to identify jets arising from b-hadrons (b-tagging), whilst CMS has measured them only with b-tagging.

The measurements presented here are the most recent made using the 2011 dataset, substantially larger than that collected during 2010. There has also been an increase in the level of pile-up in the data compared to 2010, such that there are, on average, 6 collisions per bunch crossing. The measurements themselves are now becoming limited by systematics.

2. – Event reconstruction

Events containing two leptonically decaying W bosons have a signature that consists of two isolated, high transverse momentum (p_T) leptons, two jets from the b-quarks and missing transverse energy from the neutrinos. The high p_T leptons can be used for trigger selection: ATLAS uses triggers based on the presence of at least one central electron or muon. CMS uses triggers based on the presence of two isolated, central leptons for the decay channels involving electrons or muons; for the $\mu\tau$ decay channel, the muon is used for triggering.

The event reconstruction and selection procedures for both experiments are described in detail elsewhere [3, 5, 7]. CMS uses the Particle Flow algorithm for the reconstruction of electrons and muons [8]. ATLAS uses deposits in the electromagnetic calorimeter matched to inner detector tracks for electrons and muon chamber tracks matched to inner detector tracks for muons. Both experiments reject events in which the invariant mass of the dilepton pair is consistent with the Z^0 mass, suppressing the background contribution from Z^0 plus jets events.

Both experiments use the anti-k_T algorithm for jet finding [9], requiring the presence of two or more centrally produced high-p_T jets. In the analyses presented here that use b-tagging, one or more of the jets must also satisfy b-tagging requirements. The two experiments use different b-tagging algorithms, but both have a b-tagging efficiency of about 80%. Both experiments also apply a missing transverse energy requirement in the e^+e^- and $\mu^+\mu^-$ channels. This selection requirement is needed to suppress background contamination from QCD multi-jet and Drell-Yan events. In addition, ATLAS imposes a requirement on the scalar sum of the transverse momenta of the leptons and jets, H_T in the $e\mu$ channel.

In the measurements from the $\mu\tau$ decay channel, the τ is identified through its hadronic decay. This means the production of either one or three charged mesons (mainly pions) accompanied by up to two π^0 mesons. CMS uses the so-called "Hadron plus strips" algorithm [10], which analyses jet constituents to identify the neutral mesons. These are then combined with the charged hadrons to reconstruct the τ.

In contrast, ATLAS uses a two-stage process to identify the hadronically decaying τ leptons [6]. The first step involves selecting jets that have either one, two or three tracks associated to them. A Boosted Decision Tree (BDT) is then used to enrich the jet sample in those that are formed by τ leptons and suppressing the contribution from electrons. This sample, although much improved in terms of purity, still remains dominated by background. In order to improve the purity, a second BDT is then used to select τ leptons that decay into either one or three charged mesons. The resulting BDT discriminant distributions are then fitted using templates to extract the signal.

3. – Background estimation

The principal sources of background come from the following sources: Z^0/γ^* plus jets, W plus jets, single top and di-boson events. They are described in detail elsewhere [3-6].

Although the background from Z^0/γ^* plus jets has already been strongly suppressed by the dilepton invariant mass cut (and by the H_T requirement in the $e\mu$ channel from ATLAS analysis), the contamination away from the Z^0 peak must be determined. It is estimated using the ratio of the number of events inside and outside the Z^0 peak region in data and Monte Carlo (MC). This is, of course, only a significant problem for the e^+e^- and $\mu^+\mu^-$ channels; the $e\mu$ channel can therefore be used to correct for other sources of background in the estimation process. The contribution from $Z^0/\gamma^* \to \tau^+\tau^-$ decays is not included in this estimation and is therefore determined from simulation.

The background from events containing either a misidentified or non-prompt lepton, which is dominated by W plus jets production, requires a more sophisticated data-driven matrix method for its estimation, which uses data samples enriched in either Z^0 plus jets or QCD multi-jets to determine lepton identification probabilities. The contamination from single top and di-boson events are estimated using MC samples: POWHEG [11] and PYTHIA [12] for CMS and MC@NLO [13] and ALPGEN [14] for ATLAS.

For the $\mu\tau$ decay channel, the background can be divided into two types: Genuine τ leptons or a source that can mimic the hadronic decay of τ leptons (fakes). The former come from Drell-Yan production, single top production, di-boson production and other $t\bar{t}$ decay channels and is estimated using simulation. The background from the latter is estimated using data-driven methods.

CMS estimates the probability for a jet to be mis-identified as a τ-jet using two data samples: A QCD multijet-enriched sample, which contains mainly gluon-initiated jets and a sample enriched in W plus jets events, which contains mainly quark-initiated jets. Quark jets have a higher probability of faking a τ-jet than gluon jets and, as the signal is a mixture of both, the efficiencies from the two samples are averaged to correct the data.

ATLAS exploits the fact that in the signal sample, the muon and the τ lepton will have opposite signs. The data sample in which they appear to have the same sign can then be used for background estimation. The contribution from QCD multijet events to the opposite-sign (OS) sample is approximately equal to that in the same-sign (SS) sample. Therefore, the latter can be used to subtract the contribution in the OS sample. The background arising from W plus jets events can also be estimated in this way. The remaining background is removed in the second stage of the BDT fitting process (see sect. **2**).

4. – Cross section measurements

The CMS cross section measurements have been measured using an integrated luminosity of $\mathcal{L} = 1.1\,\text{fb}^{-1}$. The cross section measurements by ATLAS for the decay channels involving electrons or muons are based on $\mathcal{L} = 0.7\,\text{fb}^{-1}$ of data, while the measurement using the $\mu\tau$ channel is based on an integrated luminosity of $\mathcal{L} = 1.1\,\text{fb}^{-1}$.

In order to extract the cross section measurements for each of the individual electron/muon channels, as well as the combined cross section value, ATLAS uses a likelihood fit based on the number of observed events in each channel, the integrated luminosity and the systematic uncertainties. A wide range of sources of systematic uncertainty have been considered, with the two most significant being the jet energy scale and the modeling of initial- and final-state radiation [4]. Overall, the systematic uncertainty is 7–20%, depending on which channel is being considered. The combined value for the analysis that includes b-tagging is $177 \pm 6(\text{stat.})^{+17}_{-14}(\text{syst.})^{+8}_{-7}(\text{lumi.})$ pb, whilst that from the analysis that does not include b-tagging is $171 \pm 6(\text{stat.})^{+16}_{-14}(\text{syst.}) \pm 8(\text{lumi.})$ pb.

In contrast, CMS uses a simple ratio of theory to data to extract the measured cross section for each of the individual electron/muon channels [3]. The combined cross section is then determined using the BLUE method [15]. Again, CMS have considered a wide range of sources of systematic uncertainty; in this case, the three most significant sources are: b-tagging, pile-up estimation in data and the lepton selection model. The overall systematic uncertainty is 9.5–11.3%. The measured cross section values for each channel can be found elsewhere [3]. The combined value is $169.9 \pm 3.9(\text{stat.}) \pm 16.3(\text{syst.}) \pm 7.6(\text{lumi.})$ pb. The results from the two experiments are consistent with each other and have been found to agree well with theory.

The measurements of the cross section using the $\mu\tau$ channel are: $\sigma_{t\bar{t}} = 148.7 \pm 23.6(\text{stat.}) \pm 26.0(\text{syst.}) \pm 8.9(\text{lumi.})$ pb from CMS and $\sigma_{t\bar{t}} = 142 \pm 21(\text{stat.})^{+20}_{-16}(\text{syst.}) \pm 5(\text{lumi.})$ pb from ATLAS. The systematic uncertainties are similar to those for the electron/muon channels, but with an additional uncertainty to cover the τ identification methods used (approximately 15% for CMS and 5.8–9.5% for ATLAS). Once again the measurements from the two experiments are consistent with each other and have been found to agree well with theory.

5. – Conclusions

The most recent measurements of the top pair production cross section using the dilepton decay channel from both ATLAS and CMS have been presented. Good agreement is observed between the two collaborations and with theory, indicating that the significantly higher pile-up present in 2011 data is under control, albeit at the expense of slightly increased systematic uncertainties. All the measurements presented here are limited by systematics and therefore the next challenge is to identify ways to reduce them.

REFERENCES

[1] ATLAS Collaboration, *JINST*, **3** (2008) S08003.

[2] CMS Collaboration, *JINST*, **3** (2008) S08004.

[3] CMS Collaboration, *Measurement of the $t\bar{t}$ production cross section in the dilepton channel in pp collisions at* $\sqrt{s} = 7\,\text{TeV}$ *with a luminosity of* $1.14\,\text{fb}^{-1}$, CMS PAS TOP-11-005.

[4] ATLAS Collaboration, *Measurement of the top-quark pair production cross-section in pp collisions at* $\sqrt{s} = 7\,\text{TeV}$ *in dilepton final states with ATLAS*, ATLAS-CONF-2011-100.

[5] CMS Collaboration, *First measurement of the $t\bar{t}$ production cross section in the dilepton channel with tau leptons in the final state in pp collisions at* $\sqrt{7}\,\text{TeV}$, CMS PAS TOP-11-006.

[6] ATLAS Collaboration, *Measurement of the top quark pair production cross section in pp collisions at* $\sqrt{s} = 7\,\text{TeV}$ *in $\mu + \tau$ final states with ATLAS*, ATLAS-CONF-2011-119.

[7] Garberson F., these proceedings.

[8] CMS Collaboration, *Commissioning of the Particle Flow Reconstruction in Minimum-Bias and Jet Events from pp Collisions at* 7 TeV, CMS PAS PFT-10-002; CMS Collaboration, *Commissioning of the Particle Flow Reconstruction with Leptons from J/ψ and $W^{\pm}$ decays at* 7 TeV, CMS PAS PFT-10-003.

[9] Cacciari M., Salam G. P. and Soyez G., *JHEP*, **04** (2008) 063.

[10] CMS Collaboration, *Performance of tau reconstruction algorithms in 2010 data collected with CMS*, CMS PAS TAU-11-001.

[11] Frixione S., Nason P. and Oleari C., *JHEP*, **11** (2007) 070.

[12] Sjöstrand T., Mrenna S. and Skands P., *JHEP*, **05** (2006) 026.

[13] Frixione S. and Webber B. R., *JHEP*, **06** (2002) 029; Frixione S., Nason P. and Webber B. R., *JHEP*, **08** (2003) 007; Frixione S., Laenen E., Motylinski P. and Webber B. R., *JHEP*, **03** (2006) 092.

[14] Mangano M. L., Moretti M., Piccinini F., Pittau R. and Polosa A. D., *JHEP*, **07** (2003) 001.

[15] Lyons L., Gibaut D. and Clifford P., *Nucl. Instrum. Methods A*, **270** (1988) 110.