The Compact Muon Solenoid Experiment

Conference Report

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27 November 2012 (v5, 18 December 2012)

Top antitop quarks production in tau lepton + b-jets final states

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Presented at TAU2012: *The 12th International Workshop on Tau Lepton Physics*

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Results obtained by the ATLAS and CMS experiments, using data collected in 2011, on the $t\bar{t}$ production cross section in channels containing a tau lepton in the final state, are presented. The cross sections in the lepton-plus-tau and in the hadronic tau-plus-jets final states have been measured by both collaborations. The technique for the tau lepton reconstruction as well as for the b-jet identification, used by ATLAS and CMS, are described. The trigger and the offline strategies for these measurements are detailed. The results obtained by ATLAS and CMS are compatible with each other and in agreement with the Standard Model (SM) expectation. No hints of new physics are observed.

Keywords: Top quark, cross section measurement, tau lepton, b-tagging, Standard Model.

1. Introduction

The large sample of top antitop events at the LHC allows to study the experimentally challenging decay channels containing a tau lepton in the final state. These are important to test the SM and the lepton universality, but they represents also an important window for physics beyond the SM. If the charged higgs boson, $H^\pm$, exists with a mass lower than the top mass, the BR of the $t\bar{t}$ production to $\tau+b+\nu_\tau$ final state could be enhanced. In the following of this article the most recent results obtained using 2011 data, by the ATLAS [1] and CMS [2] collaborations, about the $t\bar{t}$ production cross section in channels containing tau lepton in the final states, are presented. A summary of the b-tagging algorithms used by the two collaborations, as well as of the tau lepton reconstruction, are presented.

2. B-tagging algorithms

Two classes of b-tagging algorithm exist in CMS. The first one is based on the reconstruction of the secondary vertex (the point where the b hadron decays), the second one is connected with the measure of the impact parameter significance ($IP/\sigma(IP)$) of the tracks (fig.1).

Figure 1: Sketch of the impact parameter (IP). The sign is positive (negative) when the angle between the impact parameter direction and the jet axis is smaller (larger) than 90° . The primary vertex (PV) is shown in green while the secondary vertex, the point where the b hadron decays, is shown in red.

For the top physics mainly two algorithms, which belong to the second class, are used. The first one, called Track Counting, identifies a jet as b-jet if at least N track of the jets have an $IP/\sigma(IP)$ higher than a given threshold. The second one, called Jet Probability,

is an extension of the Track Counting algorithm. More in details, starting from the negative side of the IP/ σ (IP) distribution it assigns to each track in the jets a probability to come from the PV. Then by combining all tracks in the jets it assigns to the jet a probability to come from the PV. Finally a discriminator variable is built as function of the probability of the jets. A description of the performance of the different b-tagging algorithms used in CMS can be found in [3].

Three algorithms have been used to tag the b-jets in the ATLAS collaboration. The first one is the JetFitter which exploits the topology of b and c hadron decays inside the jet in order to compute an approximated flight path for the b-hadron. The discrimination between b-jets and other jets is based on a likelihood using masses, momenta, flight-length significances, and track multiplicities of the reconstructed vertices. The second one, labeled IP3D, uses transverse and longitudinal impact parameter significances of each track within the jet to determine a likelihood that the jet originates from a b-quark. The latest one, called SV1, uses the properties on the reconstructed secondary vertex to split the b-jets from the light jets. Finally, the results from the JetFitter and the IP3D b-taggers are combined using a neural network to determine a single discriminant variable, called CombNN.

3. Tau lepton reconstruction

The tau lepton decays hadronically with a π^0 in the final state in most of the cases (fig.2).

Decay mode	Resonance	Branching ratio
$\tau^- \rightarrow h^- \nu_\tau$		11.6%
$\tau^- \rightarrow h^- \pi^0 \nu_\tau$	$\rho(770 \text{ MeV})$	26.0%
$\tau^- \rightarrow h^- \pi^0 \pi^0 \nu_\tau$	$a_1(1230 \text{ MeV})$	10.8%
$\tau^- \rightarrow h^- h^+ h^- \nu_\tau$	$a_1(1230 \text{ MeV})$	9.8%
$\tau^- \rightarrow h^- h^+ h^- \pi^0 \nu_\tau$		4.8%
Other hadronic decay mode		1.7%
Total hadronic decay mode		64.8%

Figure 2: Summary of the hadronic tau decay modes.

In CMS the Hadron plus Strip (HPS) algorithm [4] is used in order to reconstruct all intermediate mesons (ρ , a_1). The HPS algorithm starts from the particle flow (PF) particles [5]. These are clustered in jets with an anti-kt algorithm with $\Delta R \leq 0.5$.

Then, for each jet a charged hadron is combined with the nearby charged hadrons or photons to identify the decay mode. Hence, the π^0 are formed starting from PF-photons or PF-electrons found inside strips ($\Delta\phi$ angle)

Figure 3: Sketch of the strips algorithm.

which account for photon conversions (fig.3). Finally the isolation is computed in a cone $\Delta R < 0.5$ around the reconstructed decay mode axis. For the isolation computation the constituents corresponding to the tau candidate are subtracted.

At ATLAS the reconstruction of the tau lepton proceeds as following [6]: first each jet is considered as a τ candidate (jets are reconstructed with calorimeter information using an antikt algorithm). Then the energy clusters in the calorimeter associated with the τ candidate are used to calculate kinematic quantities (such as E_T) and the associated tracks are found. Hence, identification variables are calculated from the tracking and calorimeter information. Finally the identification variables are combined into a BDT discriminant which is used to separate jets and electrons misidentified as τ leptons from true taus. The BDTs are trained separately on 1prong and 3prong candidates.

4. Top anti top production cross section in semileptonic tau final states

At CMS the top quark pair production cross section in dilepton events with one electron or muon, and one hadronically decaying τ lepton from the decay $t\bar{t} \rightarrow (l\nu_l)(\tau_h \nu_\tau)bb$, ($l = e, \mu$) is measured in a data sample corresponding to an integrated luminosity of 2.0 fb^{-1} for the electron channel and 2.2 fb^{-1} for the muon channel [7].

The trigger strategy was different for the muon and the electron channels. For the muon channel, at least one muon with $p_T > 17$ (24) GeV¹ is required at online level. For the electron channel a selection based on the request of an electron with $p_T > 17$ (27) GeV, at least 2 jets

¹The p_T threshold has been increased according to the luminosity in order to keep under control the rate.

with $p_T > 30, 25$ GeV respectively, and the presence of $H_T^{miss} > 15(20)$ GeV is applied at trigger level.

The offline selection requires: one isolated muon or electron with $p_T > 30, 35$ GeV, one hadronic tau with $p_T > 20$ GeV and with opposite charge with respect to the selected lepton, at least 2 jets with $p_T > 35, 30$ GeV respectively and one of them has to be b-tagged. A strong cut on $E_T^{miss} > 40$ GeV is also applied.

Finally the signal is extracted from a fit of the top mass distribution. A data driven estimation of τ fake background is employed. This background is mainly due to W +jets events and $t\bar{t} \rightarrow \text{lepton} + \text{jets}$ event. The probability that a jet is misidentified as tau is determined as function of p_T, η, ϕ of the jet, assigned to each jet in the event and then combined. The reconstructed top quark mass for the muon and electron channels is shown in fig.4.

Figure 4: Reconstructed top quark mass m_{top} distribution for the τ dilepton candidate events after the full event selection, in the $e\tau_h$ (left) and $\mu\tau_h$ (right) final states. Distributions obtained from data (points) are compared with simulation. The hatched area shows the total systematic uncertainty.

The final result combined for the two channels is: $\sigma_{t\bar{t}} = 143 \pm 14(\text{stat.}) \pm 22(\text{syst.}) \pm 3(\text{lumi.})$ pb. The main systematic uncertainties are due to the jet energy scale (4%), b-tagging (5.5%), the background estimation (13%), and the τ lepton identification (7%).

The ATLAS collaboration used a single lepton trigger with thresholds of 18 GeV on the p_T of the muons and of 20(22) GeV for the p_T of the electrons [8]. At offline level the selection is the same one chosen by CMS, with exception of the application of a cut on $E_T^{miss} > 30$ GeV instead of the cut on $E_T^{miss} > 40$ GeV. To extract the signal a boosted decision tree (BDT) is built to discriminate true tau leptons from light jets. The selected lepton+tau sample is divided into events with no b-tagged jet (b-tag=0) and with at least one b-tagged jet (b-tag>=1). Then each subsample is divided in opposite sign events (OS) and same sign charge events (SS). The SS events are subtracted to remove b and gluon jet originated tau candidate. The resulting distribution is called

OS-SS. Finally the signal is extracted from background by fitting the OS-SS BDT distribution for the b-tag>=1 sample. The background template is derived from the b-tag=0 sample for the light jets background. For other small contribution the templates are taken from simulation. The final result is: $\sigma_{t\bar{t}} = 186 \pm 13(\text{stat}) \pm 20(\text{syst}) \pm 7(\text{lumi})$ pb, where the main systematic uncertainty come from b-tag (8%) and the simulation of the initial and final state radiation (4%). In fig.5 the final fit of the OS-SS BDT distribution is presented.

Figure 5: BDT (OS-SS) distributions of $1 + \tau$ (e and μ combined) events in the b-tag=0 data sample (black points). The expected contributions from τ and e are shown as a solid red line. The derived background templates are shown as dashed histogram with shaded/blue statistical uncertainty bands. The shapes of these background templates are used for the fits to the ≥ 1 b-tag distributions after applying MC corrections. The BDT is trained separately for 1-prong and 3-prong tau. The results for the 1-prong component is shown.

5. Top anti top production cross section in hadronic tau + jets final state

At CMS the top anti-top production cross section in hadronic tau + jets final state has been measured using 3.9 fb^{-1} of 2011 collision data at 7 TeV [9]. A dedicated trigger strategy, based on a multijet selection including the tau identification, has been employed to collect the data. The offline selection requires the presence of three particle flow jets with $p_T > 45$ GeV and a fourth jet with $p_T > 20$ GeV, one hadronic tau with $p_T > 45$ GeV, at least one b-tagged jets and $E_T^{miss} > 20$ GeV. After this selection a multivariate analysis has been performed in order to improve the signal/background ratio. Finally a fit to the neural network output distribution has been applied to extract the signal from background (fig.6). The template for the main multijet background

has been modeled on data by vetoing the b-tagged jet. The templates for the other background components, like Z+jets, W+jets, $t\bar{t}$ events, have been taken from simulation.

Figure 6: Distribution of the neural network output variable after a fit of the signal and multijet processes to the data.

The obtained result is: $\sigma_{t\bar{t}} = 156 \pm 12$ (stat.) ± 33 (syst.) ± 3 (lumi.) pb. The main sources of systematic uncertainties are due to the jet energy correction (11%), the jet energy resolution (2%), the tau energy correction (7%), the tau identification (9%), the b-tagging/b-mistagging efficiencies (3/5%) and the pileup description (2%).

At ATLAS to collect data for this measurement, a multijet trigger including 2 b-tagged jets has been used [10]. The offline selection requests at least 5 jets with $p_T > 20$ GeV at least two of them have to be b-tagged, 1 hadronic tau has to be selected among the jets and a cut on $E_T^{miss}/\sigma(E_T^{miss}) = E_T^{miss}/(0.5 * (\sqrt{E_T^{miss}})) > 8$ is applied. Finally, the signal has been extracted from background by fitting the distribution of the number of tracks associated to the tau candidate. It is a good variable to discriminate tau jets from light jets, since the number of tracks associated to the tau jets is usually 1 or 3 due to the particular hadronic decay mode of the tau lepton. While the signal template has been taken from the simulation, the main multijet background has been modeled on data. The result of the fit is shown in fig.7.

The measured cross section is: $\sigma_{t\bar{t}} = 200 \pm 19$ (stat.) ± 43 (syst.) pb. The main contributions to the systematic uncertainty are: b-tagging (10%) and simulation of the initial and final state radiation (5%).

Figure 7: The n_{track} distribution for τ_{had} candidates after all selection cuts. The black circles correspond to data, while the solid histogram is the result of the fit. The red, blue and magenta dashed curves show the fitted contributions from τ_{had} & electron “signal”, and the $multijets$ and $combinatorics$ backgrounds, respectively.

6. Conclusion

The $t\bar{t}$ production cross section results measured in final states containing a tau lepton, have been presented. The cross section measurements have been performed using data collected in 2011 by the ATLAS and the CMS collaborations. Powerful reconstruction techniques have been used in order to reconstruct the tau lepton as well as to identify the jets coming from the b quark hadronization. The final results, obtained by the two collaborations, are compatible with each other as well as with the SM expectation.

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