PROCEEDINGS OF SCIENCE

Rare processes with top quarks at CMS

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Recent measurements of rare processes involving top quark production at the CMS experiment are presented. We will describe a comprehensive set of measurements, from top/antitop quark pair accompanied with electroweak gauge bosons (W, Z or γ), to single top quark production in association with gauge bosons, and down to the production of four top quarks. The later process, to which the LHC experiments are starting to be sensitive, can be used to constrain the top quark Yukawa coupling.

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1. Rare processes with top quarks: an overview

Since the top quark discovery and detailed studies at the Tevatron, the increase of energy and luminosity at the LHC made possible to measure very rare processes involving the production of top quarks. These signatures constitute a wide range of tests for the standard model as they are sensitive to modified top quark - gauge boson coupling, Yukawa coupling, or flavour changing neutral currents. These proceedings will focus on the measurement of single top and $t\bar{t}$ with single gauge bosons, and the production of four top quarks at the CMS experiment [1]. A comparison of cross sections for these processes with other top quark processes is shown in Fig. 1.

2. Pair of top quarks with a vector boson

2.1. Pair of top quarks with a W or Z boson

The measurement of $t\bar{t}$ associated with a W or Z boson [3] constitutes a test for the top-boson coupling. Measuring it accurately is an important issue, as it is also the irreducible background in searches for $t\bar{t}H$ in the multilepton final state [4]. The $t\bar{t}W$ process is measured with two lepton same sign ($2\ell ss$) events. A boosted decision tree (BDT) is constructed, using kinematic observables as input, and binned in three categories. Additionnally, the events are split according to their charge, taking advantage of the larger $t\bar{t}W^+$ rate in p–p collisions. The background arising from charge mismeasurement of electrons is estimated from Drell-Yan events in data. The $t\bar{t}Z$ process is measured with 3 and 4 lepton events ($\geq 3\ell$). Events are classified according to their jets and b-tagged jets multiplicity. Despite lepton identification, both $2\ell ss$ and $\geq 3\ell$ categories have residual contamination from non-prompt leptons arising from jets, and must be measured. This is achieved by relaxing isolation in a QCD data sample and assigned a 30% systematic uncertainty. The $t\bar{t}W$ process is observed with 4.5σ (5.3σ expected) while $t\bar{t}Z$ process is observed with $\gg 5\sigma$. The main systematic uncertainty arises from lepton identification, trigger selections and non-prompt backgrounds. The measurement of $t\bar{t}W$ and $t\bar{t}Z$ cross sections is summarized in Fig. 1.

2.2. Pair of top quarks with a photon

The measurement of $t\bar{t}$ associated with a photon [5] is targetting semi-leptonic final states. The analysis measures the ratio of $t\bar{t}\gamma$ over $t\bar{t}$. After selection, a fit of the 3-jets mass is performed to the data, used to normalize the number of $t\bar{t}\gamma$ and $t\bar{t}$ in the simulation. Since the hadronic activity around photon candidates is higher for jets mimicking photons, the fraction of prompt photon is measured with a fit to the photon charged-hadron isolation. Template distributions are constructed from data, using cluster shape sidebands for the background, and random cone method (isolation from random regions of the detector having the same η as the photon candidate) for the signal. The prompt photon purity is higher than 50%. Eventually the relative fraction of $t\bar{t}\gamma$, $V\gamma$ and non-prompt photons is set by minimizing a χ^2. The main systematic uncertainties are arising from the statistical likelihood fit, the top quark mass, jet energy scale, and QCD fatorization and renormalization scales.

3. Single top quark with a vector boson

3.1. Single top quark with a Z boson

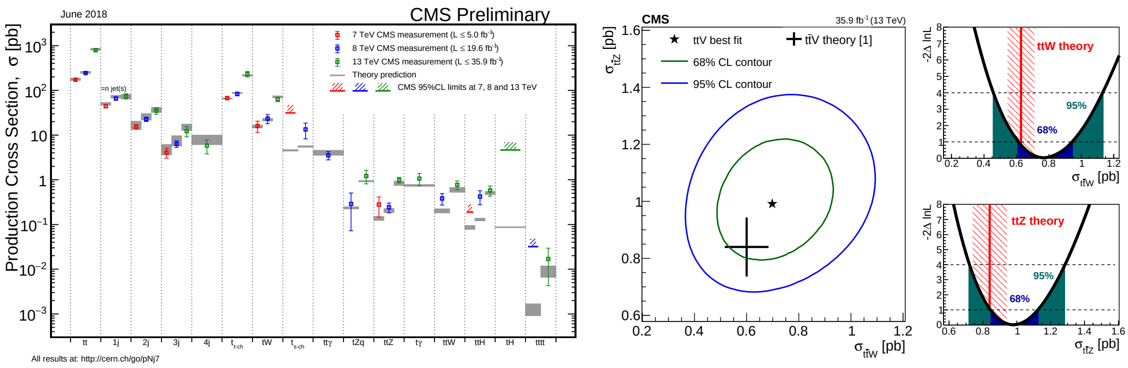

Figure 1: Left:Processes with top quarks at CMS. These proceedings will describe $tt\gamma$, tZq, ttZ, $t\gamma$ and $tttt$ [2]. Right: Results of the simultaneous fit for $t\bar{t}W$ and $t\bar{t}Z$ cross sections [3] (denoted as star), along with its 68 and 95% CL contours, and individual cross sections.

The single top + Z analysis [6] is performed in the 3ℓ final state, and makes use of the peculiar signature of the electroweak production of a single top: the presence of a forward jet in the events. The signal is extracted from a simultaneous likelihood fit in three categories: 1) a signal region (1 b-jet and 1 or 2 non-b-jets) constrains mainly the signal, helped with 2) a ttZ control region (2 b-jets $+\geq 0$ non-b-jets), while 3) a WZ region (0 b-jets $+\geq 1$ non-b-jets) measures the non-prompt lepton background and WZ background. BDTs are constructed using kinematic observables in regions 1) and 2). Variables built from a Matrix Element Method (MEM) are additionally used as input to the BDTs. Including the MEM improves the analysis significance by 20%. The discriminant variable used in the fit are shown in Fig. 2. Data shows evidence for tZq process at 3.7σ (3.2σ were expected).

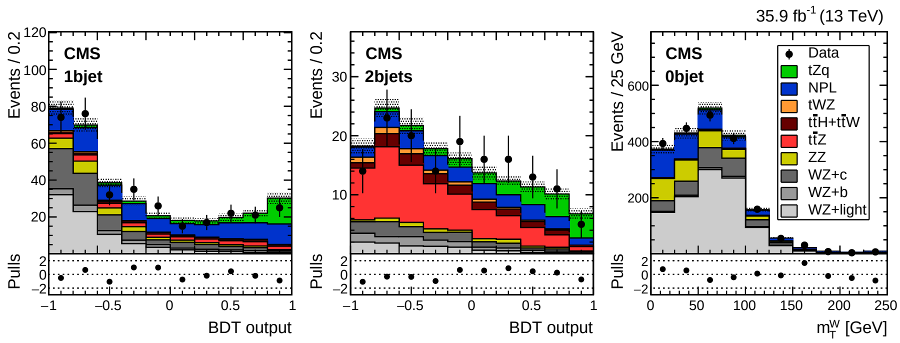

Figure 2: Template distributions used for signal extraction in tZq analysis [6]. Left: BDT discriminator in the 1bjet region; centre: BDT output in the 2bjets control region; right: m_{WT} in the 0bjet control region.

3.2. Single top quark with a photon

In the single top + photon analysis [7], the dominant background is $t\bar{t}+\gamma$. This background is measured using a template constructed from a control region with additional b-jet. However, jets faking photon background is also important and must be measured. A fake ratio method is used, consisting in relaxing photon identification requirements to measure the probability of mis-identifying a non-prompt photon as a prompt photon. Similarly to the tZq analysis, the single top + photon analysis makes use of the forward jet, whose pseudorapidity is included as an input variable to a BDT. The BDT output is shown in Fig. 3. A simultaneous fit of $t\gamma q$ and $t\bar{t}\gamma$ regions is performed, which led to the first evidence for $t\gamma q$ process with a significance of 4.4σ (3.0σ expected).

4. Four top quark production

The four top quark production process is predicted in the SM with the smallest cross section among the processes previously presented in these proceeding, 9.2 fb^{-1}. The data is analyzed in $2\ell ss$ and $\geq 3\ell$ final states [8], similarly to $t\bar{t}+W/Z$ analysis [3] or $t\bar{t}H$ [4], but taking advantage of the large multiplicity of jets in the event by requiring $HT > 300$ GeV (where HT is the scalar p_T sum of all objects in the event), and classifying events according to the number of jets and b-jets. In addition, $t\bar{t}W$ and $t\bar{t}Z$ control regions are used in the likelihood fit. Background measurement follow the same techniques as [3]. The main systematic uncertainty sources are the lepton identification, QCD scales and parton distribution functions, as well as initial/final state radiation modeling. The significance measured is 1.6σ (1.0σ expected). The $t\bar{t}t\bar{t}$ cross section is a tool to constrain the Yukawa coupling of the top quark. A value of $|y_t/y_t^{SM}| < 2.1$ at 95% C.L. is found (Fig. 3); it is complementary to, but not as precise as, measurements of κ_t in Higgs analyses.

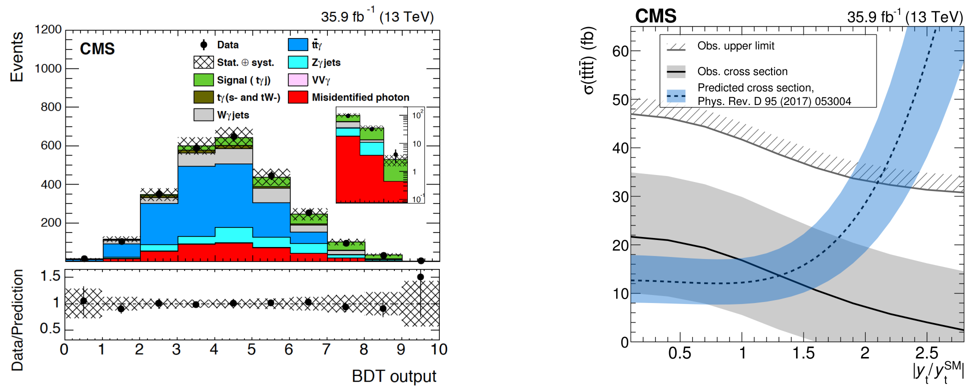

Figure 3: Left: The BDT output distribution for data and SM predictions in $t\gamma q$ measurement [7] after performing the fit. Right: Limits on four top cross section as a function of the Yukawa coupling [8].

References

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

[2] CMS Collaboration, https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsCombined

[3] CMS Collaboration, JHEP **1808** (2018) 011 [arXiv:1711.02547 [hep-ex]].

[4] CMS Collaboration, JHEP **1808** (2018) 066 [arXiv:1803.05485 [hep-ex]].

[5] CMS Collaboration, JHEP **1710** (2017) 006 [arXiv:1706.08128 [hep-ex]].

[6] CMS Collaboration, Phys. Lett. B **779** (2018) 358 [arXiv:1712.02825 [hep-ex]].

[7] CMS Collaboration, Accepted by Phys. Rev. Lett. [arXiv:1808.02913 [hep-ex]].

[8] CMS Collaboration, Eur. Phys. J. C **78** (2018) no.2, 140 [arXiv:1710.10614 [hep-ex]].