Single Top Production at CMS

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1 Introduction

Single top production via electroweak interaction in hadron-hadron collisions was observed for the first time at the Tevatron collider [1]. The process is an excellent benchmark to study the physics of the top quark on the Standard Model (SM), and is also sensitive to the existence of new physics beyond the SM. For instance, single-top cross section provides direct information on the CKM matrix element V_{tb}, and at the same time is sensitive to the existence of new heavy resonances, flavour changing currents or anomalous couplings, not present in the SM. The dominant mechanism for single-top production is the t-channel, with a predicted cross-section of $62.3^{+2.3}_{-2.4}$ pb in the 5-flavour scheme at the next-to-leading order [2], for a top mass of $m_t = 172.5$ GeV/c^2, for pp collisions at 7 TeV. Other production mechanisms are the associated W (pp$\rightarrow$ tW) and s-channels, with much lower cross-sections.

This contribution reports on the first measurement of the t-channel single top cross section at the LHC. The measurement uses 36 pb^{-1} of data taken with the CMS detector [3] during 2010, in pp collisions at 7 TeV.

Two analyses are presented: one of them, referred to in this proceedings as the two-dimensional (2D) angular analysis, relies on the very characteristic angular properties of the t-channel single-top production, differentiated from other background processes. This feature arises from the V-A structure of the electroweak interaction that leads to almost 100% polarized single-tops. Another measurement uses a Boosted Decision Tree (BDT) multivariate analysis to estimate the compatibility of each event with the expected SM signal. In this case, the signal to background separation relies on a prior knowledge of the kinematics and properties of the expected final state.

In both analyses, only leptonic final states were considered, where the top decays always as t$\rightarrow$Wb and the W decays further into a neutrino + a muon or an electron. Single top in tW and s-channels are treated as background.

The BTD analysis uses the maximum information available from each event, maximizing the measurement sensitivity. On the other hand, 2D analysis exploits a very particular property of the signal, being more robust against imperfections on data to Monte Carlo (MC) agreement, a key issue on the former. The final result is presented as a combined measurement.

2 Event Selection and background estimation

The data sample used in this analysis was collected using a trigger based on the presence of at least one lepton (electron or muon) of high transverse momentum p_T. Offline, events were required to pass the following selection criteria: 1) at least one primary vertex reconstructed from at least 4 tracks; 2) exactly one isolated lepton, with $p_T > 20$ GeV/c if the lepton is a muon or $p_T > 30$ GeV/c if an electron; 3) exactly two jets with $p_T > 30$ GeV/c and pseudorapidity $|\eta| <5$; 4) one of the two jets is tagged as a b-jet, being the tagger based on requirements on the impact parameter significance of the third track of the vertex, ordered on significance (Track Counting High Purity tagger [4]); 5) W transverse mass $M_T > 40$ GeV for muonic ($M_T > 50$ GeV for electronic) decays.

Further requirements are applied to comply with the objectives of each analysis: in the 2D analysis only, events are vetoed in case the second final-state jet is also b-tagged; the requirement $\Delta\phi(j_1, j_2) < 3.0$ is applied only on the BDT analysis to improve data/MC agreement.

Background events passing the final event selection may come from the following processes: $t\bar{t}$, single top on s- and tW-channels, di-bosons, inclusive bosons, also with associated jets, and multi-jets QCD. The QCD normalization is extracted from template fits to the M_T data distribution: the shape of the signal (single top) M_T distribution is taken from a single top t-channel MadGraph [5] simulated sample; the multi-jets background is modelled with a data sample where the selection criteria is similar to that described above, except that the leptons are required to be anti-isolated, that is, that they fail isolation criteria. The background normalization is determined by adjusting the relative contribution of the two templates to the data, being the data selected as in the main analysis. M_T requirement 5) is not applied to the templates nor to the fitted data. In the 2D analysis, the normalization of the W+light jets constribution is also estimated using template fits to data control regions. Contributions from di-bosons and γ+jets were simulated using PYTHIA 6 [6] and from all the other processes were estimated using MadGraph simulations.

3 Cross-section measurements

Since the top lifetime is shorter than the hadronization scale, its polarization – almost 100% left-handed polarization with respect to the spin axis – is accessible via its decay products, which are produced according to $\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta^*_{lj}} = \frac{1}{2}(1 + A\cos\theta^*_{lj})$, where θ^*_{lj} is the angle between the direction of the outgoing lepton and the spin axis, and A is the coefficient of spin asymmetry, equal to +1 for charged leptons. The $\cos\theta^*_{lj}$ distributions for electrons (muons) are shown in Fig. 1, upper left (right) plots. The accompanying recoil jet, from the fragmentation of a light quark, also has a particular angular distribution, and can discriminate the signal from background. The pseudorapidity of the light jet, η_{lj} is shown in Fig.1, bottom plots.

The cross-section on the 2D angular analysis is measured by performing a simultaneous unbinned likelihood fit to the $\cos\theta^*_{lj}$, η_{lj} data distributions. Templates on the two variables were built, using the single top simulated sample and the relative contributions from each background process (estimated as in the previous section) to determine the signal background shapes of the distributions. Then the overall normalization of the templates was allowed to float, yielding the measured cross sections displayed in Table 1.

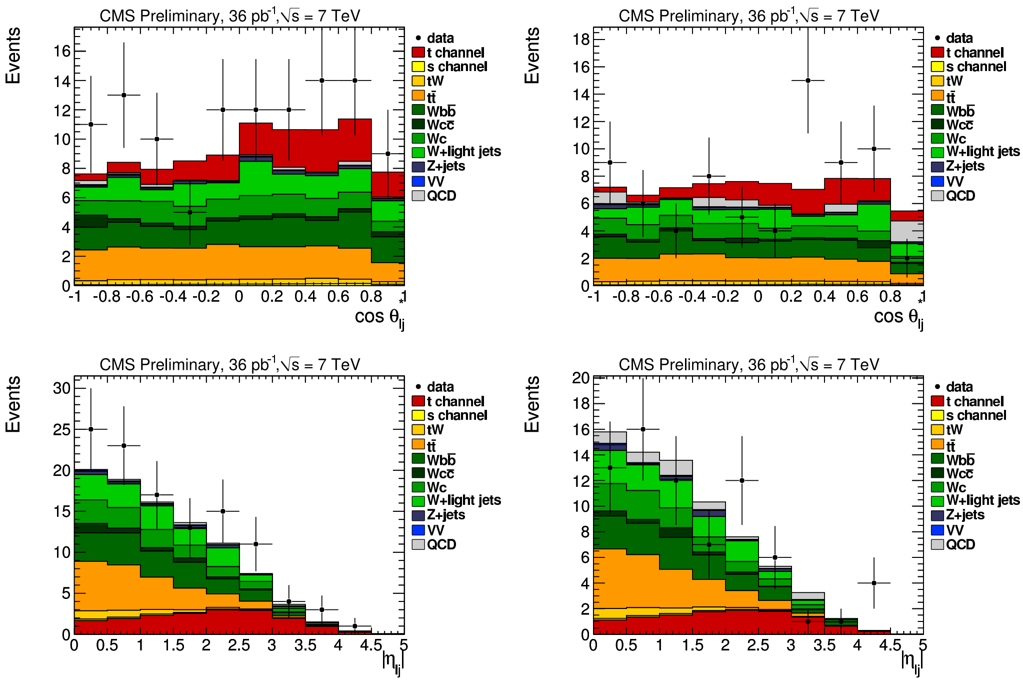

Figure 1: Variables used on the 2D analysis: $\cos\theta^*_{lj}$ (up) and η_{lj} (down) for muon (left) and electron (right) decay channel.

In the BDT analysis, 37 variables characterizing the event final state, among which are the two variables used in the 2D analysis, were used to extract the cross-section. The variables were chosen for their power to discriminate signal from background, covering the following aspects of the process: kinematics and properties of the leptons and the jets and correlations between these objects; properties of their combinations, the W-boson, the top quark, and the sum of the hadronic four-momenta;

angular distributions between final state particules and finally, event related observables sphericity and the total and transverse energies contained in the parton collision process. Events are classified as signal or background using a boosted decision trees technique. A machine learning technique combines all the 37 variables into one final classifier, the *bdt*, taking into acount their correlations as expected for simulated events. The cross section is then extracted from a binned likelihood fit to *bdt* with a Bayesian approach. In the fit, systematic uncertaities and background normalizations estimated with MC are treated as nuisance parameters. Distributions of the *bdt* are shown in Fig. 2 for muons and electrons, and cross-section results are presented in Table 1.

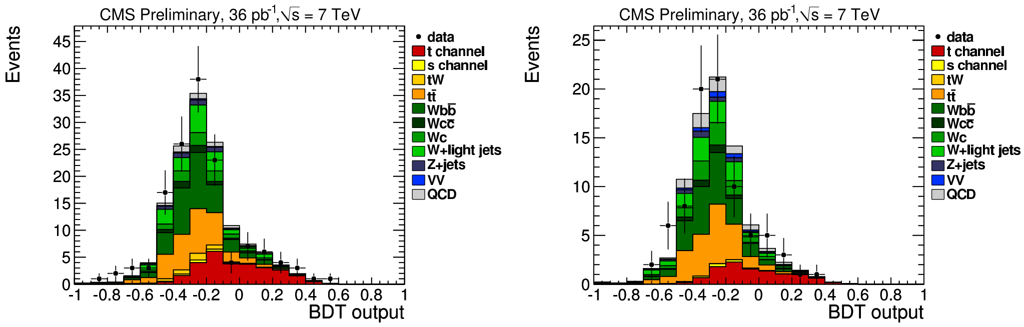

Figure 2: Boosted decision tree output (*bdt*) in the muon (left) and electron (right) channel. Predicted backgrounds are scaled to the medians of their posteriors

The measurements are mainly affected by systematic uncertainties changing both the rate and the shape of the distributions used for signal extraction. They are: the uncertainties on the Q^2 scale and amount of initial/final state radiation of the most important background samples, jet energy scale, and missing transverse energy determination, and the uncertainty on the b-tagging efficiency. The latter is the largest source of uncertainty, affecting the measured cross-section on about 20% (15%) on the 2D (BDT) analysis. Other sources affecting only the rate of the distributions, such as the normalization of each background sample and the signal model, were also considered. Finally, uncertanties on the lepton efficiencies and normalization of bosons+jets were considered on the BDT analysis, and those from W+light jets determination on the 2D analysis.

The cross sections measured with the two methods, individually on the muon and electron channels and both channels combined, are summarized on Table 1. Statistical, systematic and luminosity uncertainties are displayed separately.

Analysis	muon channel	electron channel	combined
2D	$104.1{\pm}42.3^{+24.8}_{-28.0} \pm 4.2$	$154.2 \pm 56^{+40.6}_{-46.6} \pm 6.2$	$124.2 \pm 33.8^{+30.0}_{-33.9} \pm 5.0$
BDT	$90.4{\pm}35.1^{+16.5}_{-19.7} \pm 3.6$	$59.2 \pm 35.1^{+13.1}_{-13.7} \pm 2.4$	$78.7 \pm 25.4^{+13.2}_{-14.6} \pm 3.1$

Table 1: Single top t-channel cross sections measured with 2D and BDT analyses: σ±(stat.)±(syst.)±lumi, all values in pb.

4 Results and conclusions

The t-channel cross-section for single-top production was measured for the first time at the LHC, using 36 pb^{-1} of pp collisions data collected with the CMS detector.

The precision of 36% on the cross-section was achieved using the combination of two analysis techniques, either exploiting the angular distribution of the final state objects (2D), or using a sophisticated multivariate (BDT) analyses. The measurements were combined using the BLUE method, considering their correlations: 60% correlation on the statistical uncertainties, 50% on the QCD normalization uncertainty and 100% on the other systematic uncertainties common to both analysis. We measure a t-channel cross-section of

$$83.6{\pm}29.8(\text{stat.+syst}){\pm}3.3(\text{lumi})\ \text{pb}.$$

Assuming that $|V_{td}| << |V_{tb}|$ and $|V_{ts}| << |V_{tb}|$, we use the NLO prediction $\sigma^{th} = 62.3^{+2.3}_{-2.4}$ pb [2] to obtain

$$|V_{tb}| = \sqrt{\frac{\sigma^{exp}}{\sigma^{th}}} = 1.16 \pm 0.22(exp) \pm 0.02(th).$$

All measurements are consisted with the SM expectations.

References

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