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Search for *s*-channel single top-quark production in pp collisions at 8 TeV with the CMS experiment at the LHC

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Abstract

A search for single top-quark production in the *s* channel in proton-proton collisions at a centre-of-mass energy of $\sqrt{s} = 8$ TeV by the CMS detector at the LHC is presented. Leptonic decay modes of the top quark with an electron or muon in the final state are considered. The signal is extracted by performing a maximum-likelihood fit to the distribution of a multivariate discriminant defined using Boosted Decision Trees to separate the expected signal contribution from the background processes. Data collected in 2012, corresponding to an integrated luminosity of 19.3/fb, lead to an upper limit on the cross section times branching ratio of 11.5 pb at 95% confidence level.

Keywords: single top, cross section, s channel, CMS, search

1. Introduction

The top quark, discovered at the Tevatron proton anti-proton collider in 1995 [1, 2], can be produced via strong interaction in association with the top anti-quark and via electroweak interaction as single top. Three are the different single top production modes, the *t* channel, the *s* channel and the tW production. The single top production in the *s* channel at the LHC is unfavoured with respect to the other two production modes, involving a quark and an anti-quark in the initial state (Figure 1). The SM prediction at NNLL (next-to-next-to-leading logarithmic) order for this process at the LHC and at 8 TeV is $\sigma^{\text{th}}_{s-\text{ch.}} = 5.55 \pm 0.08(\text{scale}) \pm 0.21(\text{PDF})$ pb [3]. Nonetheless the interest in this channel is focused on possible enhancement of its production due to new physics involving non-SM mediators, like W′ or charged Higgs boson [4].

The study presented here [5] analyses 19.3 fb^{-1} of data collected by the CMS detector [6] in 2012 at a centre-of-mass energy $\sqrt{s}$=8 TeV.
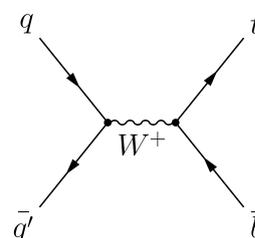

Figure 1: Leading order (LO) Feynman diagram for single top production in the *s* channel.

2. Event selection and multivariate analysis

The final state topology of the single top production in the *s* channel is characterised by the presence of one muon or electron and two b quarks, one coming from the top-quark decay and one recoiling against the top quark. The event selection considers exactly one isolated muon or one electron with $p_{\text{T}} > 26$ GeV/c, $|\eta| < 2.1$ and $p_{\text{T}} > 30$ GeV/c, $|\eta| < 2.5$, respectively. Exactly two jets, reconstructed by clustering particle flow candidates [7] using the anti-k_T algorithm [8], are required to have $p_{\text{T}} > 40$ GeV/c for $|\eta| < 4.5$ and events with

additional jets with $p_T > 30 \, \text{GeV}/c$ are rejected. The two selected jets are also required to be originated from b quarks, for which the track counting algorithm with high purity requirement [9] is adopted, restricting their acceptance to $|\eta| < 2.5$. These cuts allow a tight rejection of W+jets and multijet QCD backgrounds. Due to the ambiguity in the reconstruction of the top quark hypothesis from b jet, lepton and $\not{E}_T$, two top mass hypotheses are defined and the correct b jet-to-top assignment is taken based on the one which gives the closer invariant top mass to the reference value $172.5 \, \text{GeV}/c^2$.

The events passing the above selection define the signal region (henceforth 2j2t), while a control region, enriched in t$\bar{\text{t}}$ events, is defined selecting 3 jets with two of them passing b-tagging requirements (3j2t event category).

At the end the signal sample is still dominated by the backgrounds, mainly t$\bar{\text{t}}$, W+jets and t channel single top, and so a multivariate technique using Boosted Decision Trees (BDT) [10] is performed in order to take advantage of the different final state topology of the signal and the backgrounds. Two independent BDT trainings are set up in the 2j2t and 3j2t event categories, optimised for electron and muon decay channels. Among the kinematic and angular variables considered, the ones with the highest discriminating power are the vector sum of p_T of the two b-jets system and the W boson transverse mass (Figure 2). For the first variable the signal shows a lower p_T distribution with respect to t$\bar{\text{t}}$ since the two b jets carry a larger fraction of the original transverse momentum which peaks around zero. The W transverse mass, reconstructed from the lepton and the $\not{E}_T$, shows a clear jacobian peak for lepton-neutrino pairs coming from the same W-boson decay (signal), while presents a broader distribution for events where two W bosons, both decaying leptonically, are produced (t$\bar{\text{t}}$).

3. Signal extraction and results

The s-channel signal extraction consists in a binned maximum likelihood fit to the BDT distributions on data in the 2j2t and 3j2t categories simultaneously (Figure 3). The inclusion of the 3j2t category allows to constrain the t$\bar{\text{t}}$ and W+jets backgrounds while taking into account all possible correlations in the systematics uncertainties between the two regions. The signal and all the background models are taken from simulation except for the multijet QCD background, for which a dedicated treatment has been adopted. The QCD model is taken from a control region in data defined inverting the lepton isolation for muons and requiring that either the isolation cut or identification criteria fail for electrons.
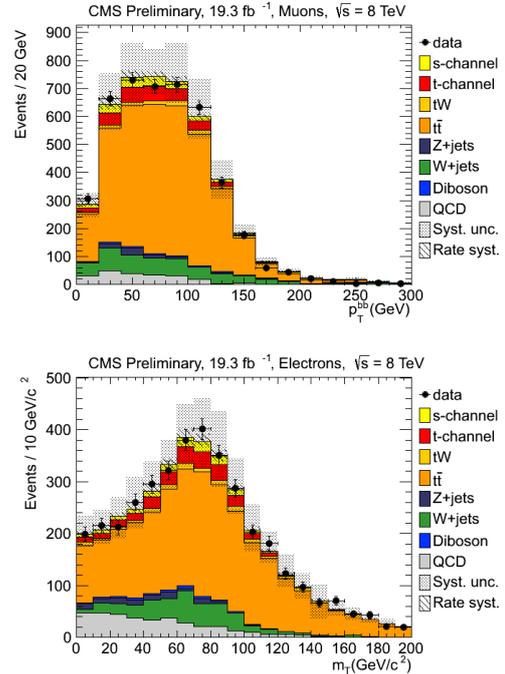

Figure 2: Two of the most discriminating variables used in the BDT to separate signal and backgrounds: vector sum of p_T of the two b-jets system (up) and the W boson transverse mass (bottom).

The QCD normalisation is estimated by a fit to the m_T (muons) or $\not{E}_T$ (electrons) and its uncertainty is conservatively assigned by repeating the fit in a QCD-enriched region and varying the non-QCD contributions by 20%.

The likelihood model includes the background rates as nuisance parameters with a coefficient for each background template with a log-normal prior. The prior uncertainties on the background normalisation have been taken from the recent measurements of the corresponding processes, i.e. 10% for t$\bar{\text{t}}$, 30% for W+jets, 10-30% for QCD (in the different event categories), 15% for single top in the t channel. The impact of the background rates uncertainties on the s-channel cross section measurement is evaluated removing one uncertainty at a time from the likelihood model and measuring the corresponding variation in the profile likelihood. The other instrumental (as jet energy scale and resolution, b-tagging efficiencies and pile-up) and theoretical (as renormalisation and factorisation scales, matrix element and parton showering matching thresholds, PDFs) uncertainties are evaluated performing two fits to the pseudodatasets generated with the up/down variations of the systematic source of interest (with other sources fixed to zero), and taking the difference in the fitted signal yield
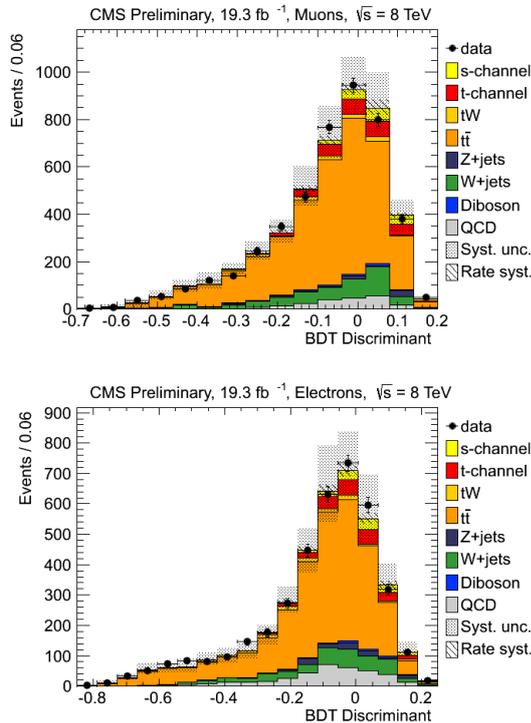
Figure 3: BDT discriminant for the muon (up) and electron (bottom) channels. The simulation is normalised to the fit results.

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between these fits and the nominal fit as the corresponding up/down uncertainties.

The systematic uncertainties with the highest impact on the measurement have been found to be the factorisation and renormalisation scales (∼80%), jet energy scales (∼50%), and matching thresholds (∼30%). The single top-quark *s*-channel inclusive production cross section has been measured to be $\sigma_{s-\mathrm{ch.}} = 6.2 \pm 5.4$ (exp.) ± 5.9 (th.) pb. Using the Feldman-Cousins unified approach [11] the 68% confidence level (CL) intervals which do not reach negative cross section values are reported as well: $\sigma_{s-\mathrm{ch.}} = 6.2^{+8.0}_{-5.1}$ pb. Finally, the measurement leads to an upper limit of 11.5 (17.0, 9.0) pb at 95% CL, evaluated using a Bayesian approach, where the numbers in parenthesis refer to the expected limits in presence of SM signal and in the background-only hypothesis.

Future extensions of this analysis will include the whole 7+8 TeV dataset to increase the sensitivity of the measurement and will exploit the reduced factorisation/renormalisation scale uncertainties from the next-to-leading order $t\bar{t}$ generators.