Measurement of the Inclusive and Fiducial Cross-Section of Single Top-Quark $t$-Channel Events in $pp$ Collisions at $\sqrt{s} = 8$ TeV.

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Abstract. This article presents the measurement of a $t$-channel single top-quark production fiducial cross-section in the lepton+jets channel with 20.3 fb$^{-1}$ of 8 TeV data using a neural-network discriminant.

A fiducial cross-section quoted within the detector acceptance of $\sigma_{\text{fid}} = 3.37 \pm 0.05$ (stat.) $\pm 0.47$ (syst.) $\pm 0.09$ (lumi.) pb is obtained. The total inclusive $t$-channel cross-section is calculated using the acceptance predicted by various Monte Carlo generators. If the acceptance from the aMC@NLO + HERWIG event generator is used, a value of $\sigma_t = 82.6 \pm 1.2$ (stat.) $\pm 11.4$ (syst.) $\pm 3.1$ (PDF) $\pm 2.3$ (lumi.) pb is obtained, consistent with a theory calculation. Using the ratio of the measured inclusive cross-section to the predicted cross-section and assuming that the top-quark-related CKM matrix elements obey the relation $|V_{tb}| \gg |V_{ts}|, |V_{td}|$, the coupling strength at the $W$-$t$-$b$ vertex is determined to be $|V_{tb}| = 0.97^{+0.10}_{-0.09}$. Assuming that $|V_{tb}| \leq 1$ a lower limit of $|V_{tb}| > 0.78$ is obtained at the 95% confidence level.

1. Introduction

At the LHC the most dominant production of top quarks is given by the strong interaction. Beside the strongly produced $t\bar{t}$ pairs, singly produced top quarks emerge via the weak interaction. Three production channels, of singly produced top quarks, are distinguished by the virtuality of the exchanged $W$ boson. The $t$-channel exchange of a virtual $W$ boson provides the leading contribution to the production rate at the LHC.

This article presents the first measurement of the production cross-section in the fiducial volume in single top-quark topologies. The measurement of the fiducial cross-section has advantages over a fully inclusive measurement. The fiducial cross-section has reduced model dependence, enabling direct comparisons between predictions, at the present and in the future. The reduced model dependence is also reflected in a lower total systematic uncertainty, compared to a fully inclusive cross-section. Events are characterized by one isolated high-$p_T$ charged lepton, exactly two jets one of which is required to be $b$-tagged and missing transverse momentum. The main background processes are top quark associated diagrams, $t\bar{t}$ pair production as well as other single top-quark production channels. Processes with $W/Z+\text{jets}$, especially produced with heavy quark jets, diboson production and multijet production complete the background contributions.
2. Event Selection
Based on the expected signature of the single top-quark signal events, events are selected with exactly two jets, out of which one is identified as a $b$-quark jet, one isolated electron or muon and missing transverse momentum.

Offline electron and muon candidates are required to be isolated and satisfy $p_T > 25$ GeV and $|\eta| < 2.5$.

Jets are clustered using the anti-$k_t$ algorithm with a cone parameter of 0.4. Jets must fulfill $p_T > 30$ GeV and $|\eta| < 4.5$ requirements. In the endcap-forward calorimeter region, $2.75 < |\eta| < 3.5$, jets are required to have $p_T > 35$ GeV. One of the selected jets is required to be identified as a $b$-quark jet by the MV1c $b$-tagging algorithm.

A set of cuts is placed to reduce the multijet background contribution. The transverse $W$-boson mass ($m_T(W)$) must be higher than 50 GeV as well as $E_T^{\text{miss}} > 30$ GeV. A second set of cuts is imposed in the plane spanned by the $p_T$ of the lepton and the $\Delta \phi(j_1, \ell)$, see Equation 1.

$$p_T > 40 \text{GeV} \cdot \left(1 - \frac{\pi - |\Delta \phi(j_1, \ell)|}{\pi - 1}\right),$$

where $\ell$ denotes the selected lepton and $j_1$ is the leading jet in $p_T$.

3. Background Estimation
The normalisation of the background processes is obtained from two different sources. For all processes, except the multijet contribution, the number of selected events is predicted using theory calculation. The normalisation of the multijet process is not predicted, and has to be obtained using a binned maximum likelihood fit to collision data. The model used for the multijet process is different for the electron and muon channel. In the electron channel, the jet-lepton method selects events containing a jet, which is likely to be misidentified as a lepton in the detector, from dijet monte carlo events. In the muon channel, the anti-muon method uses inverted identification criteria, to select fake lepton events from collision data. Both methods are explained in detail in [4]. The templates are used in the respective channels in a fit to the $E_T^{\text{miss}}$ distribution. For the fit, the requirement $E_T^{\text{miss}} > 30$ GeV is omitted.

4. Signal Discrimination
To obtain a high separation between signal and background events, a neural network is employed. The neural network is trained with 14 observables which facilitate the most discrimination power between signal and background events. All 14 input variables have been tested for good agreement between data and simulation. Figure 1 depicts the Neural Network output distribution, signal and backgrounds are normalised to the fit result of the Neural Network discriminant distribution.
5. Systematic uncertainties
Systematic uncertainties on the normalisation of the individual backgrounds and on the signal acceptance as well as uncertainties on the shape of the individual predictions affect the measured t-channel cross-section. Both rate and shape uncertainties are taken into account by generating correlated pseudo-experiments. The impact of the systematic uncertainties on the t-channel cross-section measurement is estimated from these pseudo-experiments. The classes of the considered uncertainties include objects modelling, monte carlo generator, PDF, background normalisation and Luminosity uncertainties.

6. Cross-section Measurement
The extraction of the t-channel single top-quark cross-section in this analysis is done in a fiducial volume within the detector acceptance. The fiducial cross-section $\sigma_{\text{fid}}$ is defined as:

$$\sigma_{\text{fid}} = \frac{\epsilon_{\text{corr, sel}}}{\epsilon_{\text{corr, fid}}} \cdot \frac{\hat{\nu}}{\mathcal{L}} = R_f \cdot \frac{\hat{\nu}}{\mathcal{L}},$$  \hspace{1cm} (2)

where $\epsilon_{\text{corr, sel}}$ is the fraction of events which are selected by the offline selection to be within the fiducial volume and $\epsilon_{\text{corr, fid}}$ is the fraction of events within the fiducial volume to be selected by the offline selection. The ratio of these two quantities is defined as $R_f$ and is of the order of 3.5. The estimated number of expected t-channel single top-quark events is named $\hat{\nu}$ and obtained by the binned maximum-likelihood fit. The fiducial cross-section can then be extrapolated to the total inclusive cross-section $\sigma$ with:

$$\sigma = \frac{1}{\epsilon_{\text{fid}}} \cdot \sigma_{\text{fid}},$$  \hspace{1cm} (3)

where $\epsilon_{\text{fid}}$ is the selection efficiency of the particle-level selection. The particle-level selection is imposed on objects defined on stable particles. The definition of the fiducial phase space is close to the phase space of the reconstructed and selected data set.

7. Results
The estimated number of t-channel single top-quark events $\hat{\nu}$ obtained from the binned maximum-likelihood fit of the network output distribution is used to calculate the fiducial cross-section.

$$\sigma_{\text{fid}} = 3.37 \pm 0.05 \text{ (stat.)} \pm 0.47 \text{ (syst.)} \pm 0.09 \text{ (lumi.) pb.}$$

The uncertainty on $\hat{\nu}$ is obtained from pseudo experiments and propagated to the measured cross-section. The total relative uncertainty on the measurement of the fiducial cross-section is $\pm 14\%$, the dominant contributions being the uncertainty on the JES $\eta$-intercalibration and the t-channel generator modelling.

A comparison of predictions for the fiducial cross-section for different NLO MC event generators and the matched LO generator ACERMC together with the measured value is shown in Figure (2). The fiducial cross-section is calculated using the inclusive cross section for each generator and the corresponding selection efficiency of the particle-level selection.
Using various MC generator models, the fiducial cross-section can be extrapolated to the full phase space and can be compared to the NLO+NNLL calculation. There is an additional uncertainty on the extrapolation due to the uncertainty on the PDF with a size of 3.8%. A summary of these inclusive cross-sections is presented in Figure (3). The values deduced with the acceptances obtained with the NLO generators POWHEG and aMC@NLO are in excellent agreement with the NLO+NNLL prediction and have only a difference of 1.7% to each other.

Single top-quark production in the $t$-channel proceeds via a $W$-$t$-$b$ vertex and the measured cross-section is proportional to $|V_{tb}|^2$, where $V_{tb}$ is the relevant CKM matrix element. The value of $|V_{tb}|$ is extracted by dividing the extrapolated single top-quark $t$-channel cross-section using the acceptance of the aMC@NLO + HERWIG generators, by the SM expectation.[5]

The corresponding coupling at the $W$-$t$-$b$ vertex is determined to be $|V_{tb}| = 0.97^{+0.09}_{-0.10}$ and the 95% C.L. lower limit on the CKM matrix element $|V_{tb}|$ is 0.78.

References
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