PROCEEDINGS OF SCIENCE

Search for FCNC single top-quark production at 8 TeV with the ATLAS detector

Ozan Arslan[*†]
On behalf of the ATLAS Collaboration
University of Bonn
E-mail: arslan@physik.uni-bonn.de

A search for single top-quark production via flavour changing neutral current processes from initial states involving a gluon and up or charm quarks in proton–proton collisions at the LHC is presented. Data collected with the ATLAS detector in 2012 at a centre-of-mass energy of 8 TeV and corresponding to an integrated luminosity of 20.3 fb^{-1} are used. Candidate events for a top quark decaying into a lepton, a neutrino and a jet are selected and classified into signal- and background-like candidates using a neural network. No signal is observed and an upper limit on the production cross-section multiplied by the $t \to Wb$ branching fraction is set. The observed 95 % CL limit is $\sigma_{qg \to t} \times B(t \to Wb) < 3.4$ pb and the expected 95 % CL limit is $\sigma_{qg \to t} \times B(t \to Wb) < 2.9$ pb. The observed limit can be interpreted as upper limits on the coupling constants of the flavour changing neutral current interactions divided by the scale of new physics $\kappa_{ugt}/\Lambda < 5.8 \times 10^{-3}$ TeV^{-1} and $\kappa_{cgt}/\Lambda < 13 \times 10^{-3}$ TeV^{-1} and on the branching fractions $B(t \to ug) < 4 \times 10^{-5}$ and $B(t \to cg) < 17 \times 10^{-5}$.

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1. The top quark and the flavour changing neutral currents

The top quark is the heaviest elementary particle, with a mass $m_{\text{top}} = 173.3 \pm 0.8$ GeV [1] close to the electroweak symmetry breaking scale, making it a very good object to test the Standard Model (SM) and search for beyond SM phenomena.

At the Large Hadron Collider (LHC), the top quarks are predominantly produced in pairs via the strong interaction. In addition, they can be produced singly via the weak interaction though three different subprocesses; the t-channel process involving the exchange of a space-like W boson, the Wt production involving the production of a real W boson and the s-channel process involving the production of a time-like W boson. The predominant decay channel of the top quark is $t \to Wb$.

The flavour changing neutral currents (FCNC) are the neutral gauge bosons, which mediate the transition between the top quark and the other quarks. In the SM, the FCNC involving top quarks are forbidden at tree level and highly suppressed ($\mathscr{O}10^{-14}$) at higher orders [2]. However, several extensions to SM, such as two-Higgs-doublet models, the quark-singlet model, the minimal supersymmetric standard model and supersymmetry with R-parity violation, significantly enhance FCNC production rates with predicted branching fractions as large as 10^{-5} to 10^{-3} for a top quark decaying into a quark and a neutral boson [3] [4]. Therefore, evidence of a FCNC signal can directly indicate the existence of new physics.

The FCNC decay of a top quark with a gluon as the neutral current $t \to ug$, where u is a charm or an up quark and g is gluon, is very difficult to seperate from the multi-jet background through quantum chromodynamic (QCD) processes. However, in the production mode, $ug \to t$, it is possible to achieve much higher sensitivites by searching for anamolous single top-quark production. A leading order diagram for the production of a single top in $ug \to t$ mode together with the SM decay of of the top quark is shown in Fig. 1.

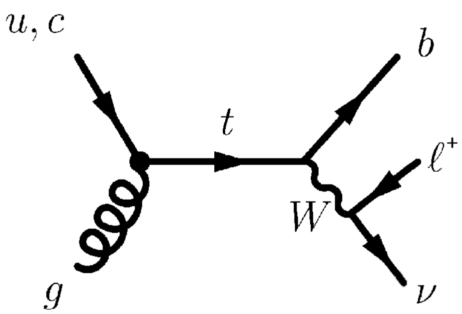

Figure 1: Leading-order Feynman diagram for FCNC top-quark production in the $ug \to t$ mode followed by the decay of the top quark into a b-quark and a W boson, where the W boson decays into a lepton and a neutrino. Taken from Ref. [7].

Anomalous FCNC couplings can be described in a model-independent manner using an effective operator formalism [5] which assumes the SM to be the low-energy limit of a more general theory. The corresponding strong FCNC Lagrangian $\mathscr{L}_{\text{S}}$ for this process can be written as [6]:

$$\mathscr{L}_{\text{S}} = -g_{\text{s}} \sum_{q=u,c} \frac{\kappa_{qgt}}{\Lambda} \bar{q} \lambda^a \sigma^{\mu\nu} (f_q + h_q \gamma_5) t G^a_{\mu\nu} + \text{h.c.}, \tag{1.1}$$

where Λ is the new physics scale, κ_{qgt} relate the strength of the new couplings to the strong coupling strength g_s, parameters f_q and h_q are the real vector and axial chiral parameters respectively, $G^a_{\mu\nu}$ is the gluon field strength tensor, λ^a are the Gell-Mann matrices and $\sigma^{\mu\nu}$ is the anti-symmetric tensor. The Lagrangian holds for both FCNC production and decay of top quarks.

2. Dataset and event selection

The analysis presented here [7] uses the data recoded by ATLAS detector [8] during 2012 with a centre-of-mass energy of 8 TeV and corresponding integrated luminosity of 20.3 fb^{-1}.

The event selection is performed considering the topology of the $ug \to t$ single top quark production process with the top quark decaying into a bottom quark and a W boson. The leptonic decay of the W boson, $W \to l\nu$ is assumed, where l is a lepton (muon or electron) and ν is a neutrino. Therefore, the objects that are required to be in the final state (signal region) are a lepton, missing transverse energy $E_{\mathrm{T}}^{\mathrm{miss}}$ due to the neutrino and a jet originating from a bottom quark (b-jet).

The electron candidates are required to have a transverse momentum $p_{\mathrm{T}} > 30$ GeV and $|\eta_{\mathrm{clus}}| < 2.47$ where $|\eta_{\mathrm{clus}}|$ denotes the pseudorapidity[1] of the deposited energy in the electromagnetic calorimeter. Electrons with high p_{T} associated with the W boson can be mimicked by jets reconstructed as electrons, photon conversions and electrons from decays of heavy quarks. In order to suppress these backgrounds, an isolation criteria in a cone around the electrons is required. The muon candidates are required to have a $p_{\mathrm{T}} > 25$ GeV and $|\eta| < 2.5$. In order to reduce the background events, where a high-p_{T} muon is produced in the decay of a heavy-flavour quark, isolation criteria are again applied. The jets are reconstructed using the anti-k_t algorithm with the distance parameter R set to 0.4. Exactly one jet with $p_{\mathrm{T}} > 25$ GeV and $|\eta| < 2.5$ is selected. The selected jet is required to originate from a bottom quark (b-tagged).

Furthermore, a cut on the $E_{\mathrm{T}}^{\mathrm{miss}}$ with $p_{\mathrm{T}} > 25$ GeV is applied. In order to suppress the multi-jet background, a cut on the transverse mass of the lepton and $E_{\mathrm{T}}^{\mathrm{miss}}$ system $m_{\mathrm{T}}(l, E_{\mathrm{T}}^{\mathrm{miss}}) > 50$ GeV and a triangular cut:

$$p_{\mathrm{T}}^{l} > 90\mathrm{GeV}\left(1 - \frac{\pi - |\Delta\phi(l,\mathrm{jet})|}{\pi - 2}\right). \tag{2.1}$$

is required. The dominant backgrounds are W boson production in association with jets (W + light flavour (LF) and W + heavy flavour (HF)) and the multi-jet background. The other backgrounds are Z boson production in association with jets (Z+jets), dibosons (WW, WZ and ZZ) and the single top quark production. In order to check the kinematic distributions of the variables reconstructed by the final state objects, a control region is defined by accepting the events with a jet which is not identified as a b-jet and rejecting the events with an identified b-jet. Figure 2 shows the kinematic distributions of the p_{T} of the lepton, η of the lepton, p_{T} of the jet, η of the jet, $E_{\mathrm{T}}^{\mathrm{miss}}$ and the transverse mass of the W boson $m_{\mathrm{T}}(W)$ in the control region.

[1] ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point in the centre of the detector and the z-axis is along the beam direction; the x-axis points towards the centre of the LHC ring and the y-axis points upwards. The pseudorapidity η is defined as $\eta = -\ln[\tan(\theta/2)]$, where the polar angle θ is measured with respect to the z-axis. The azimuthal angle, ϕ, is measured with respect to the x-axis.

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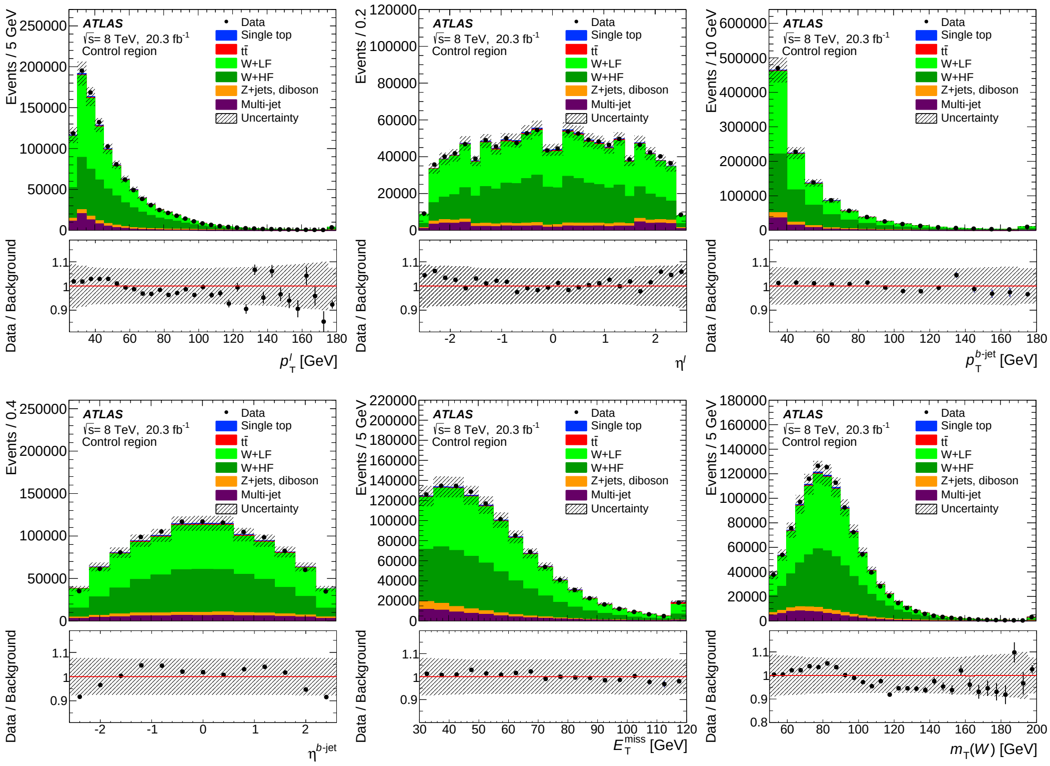

Figure 2: Kinematic distributions of (a) the transverse momentum and (b) pseudorapidity of the lepton, (c) the transverse momentum and (d) pseudorapidity of the jet, (e) the missing transverse momentum and (f) W-boson transverse mass in the control region. Taken from Ref. [7].

3. Signal separation and statistical analysis

No single variable has sufficient power to separate the signal from the background, therefore an application of the multivariate analysis techniques are necessary. A neural network (NN) classifier software provided by the NeuroBayes package [9] is used. Thirteen variables are selected as input for the NN training. Figure 3 shows the kinematic distributions of three most significant variables in terms of separation power in the signal region. The NN output distributions for the signal and control regions are shown in Fig. 4. A good agreement between the data and the background is observed in both the kinematic distributions of the selected variables by the NN training and the in NN output distribution. As no sign of a signal is observed, an upper limit on the FCNC single top-quark production cross-section is set using the frequentist methods based on pseudo-experiments, corresponding to an integrated luminosity of 20.3 fb^{-1}. Systematic uncertainties are included in the pseudo-experiments using variations of the signal acceptance. The three dominant uncertainties are the $E_{\mathrm{T}}^{\mathrm{miss}}$ modelling, jet energy resolution and the multi-jet background normalisation and modeling.

4. Results

The CL$_s$ method [10] is used to set expected and observed upper limits at 95% confidence

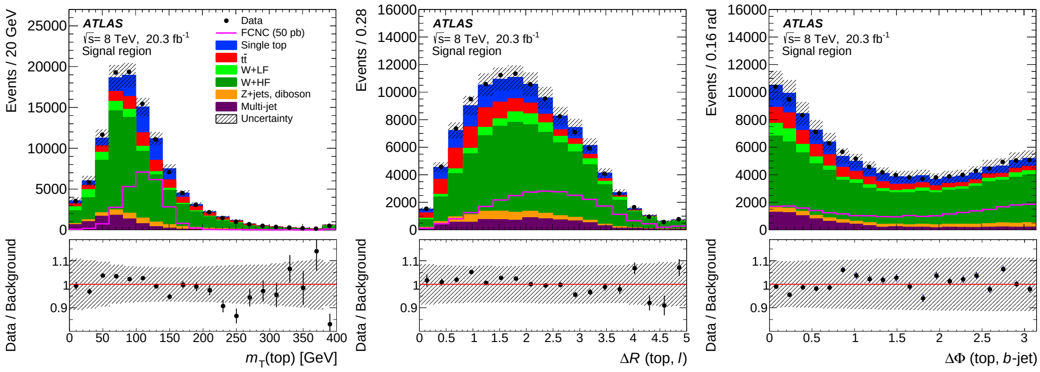

Figure 3: Distributions of three important discriminating variables (a) the top-quark transverse mass, (b) the ΔR between the lepton and the reconstructed top quark, (c) $\Delta\phi$ between the jet and the reconstructed top quark in the signal region. The FCNC signal cross-section is scaled to 50 pb and overlayed on the distributions. Taken from Ref. [7].

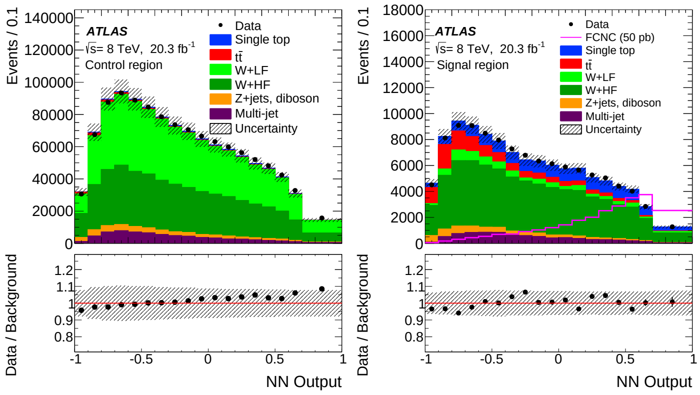

Figure 4: Neural-network output distribution (a) in the control region and (b) in the signal region. The shape of the signal scaled to 50 pb is shown in (b). Taken from Ref. [7].

level (CL). The observed 95% CL upper limit on the anomalous FCNC single top-quark production cross-section multiplied by the $t \to Wb$ branching fraction including all uncertainties is 3.4 pb and the expected upper limit is $2.9^{+1.9}_{-1.2}$ pb.

Assuming $\mathscr{B}(t \to Wb) = 1$, the observed upper limit on the cross-section can be interpreted as a limit on the coupling constants divided by the scale of new physics: $\kappa_{ugt}/\Lambda < 5.8 \times 10^{-3}\text{TeV}^{-1}$ assuming $\kappa_{cgt}/\Lambda = 0$, and $\kappa_{cgt}/\Lambda < 13 \times 10^{-3}\text{TeV}^{-1}$ assuming $\kappa_{ugt}/\Lambda = 0$. Limits on the coupling constants are also interpreted as limits on the branching fractions: $\mathscr{B}(t \to ug) < 4.0 \times 10^{-5}$, assuming $\mathscr{B}(t \to cg) = 0$ and $\mathscr{B}(t \to cg) < 17 \times 10^{-5}$, assuming $\mathscr{B}(t \to ug) = 0$. Figure 4 shows upper limits on coupling constants for combinations of cgt and ugt channels and and the limits on branching fractions.

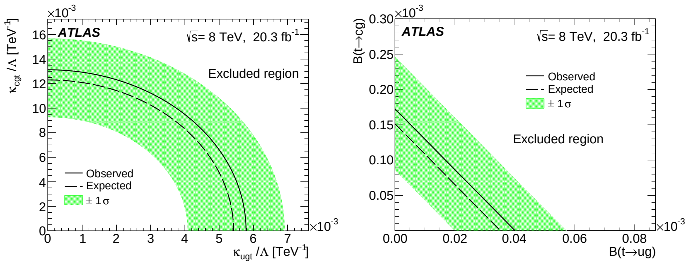

Figure 5: (a) Upper limit on the coupling constants κ_{ugt} and κ_{cgt} (b) on the branching fractions $\mathscr{B}(t \to ug)$ and $\mathscr{B}(t \to cg)$. The shaded band shows the one standard deviation variation of the expected limit. Taken from Ref. [7].

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