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

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A search for single top-quark production via flavour changing neutral current processes from gluon plus up- or charm–quark initial states 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. Introduction

The top quark is the most massive elementary particle known with a mass close to the electroweak symmetry breaking scale. At the LHC, top quarks are primarily produced in pairs via the strong interaction. In addition to the predominant pair-production process, top quarks are also produced singly via the weak interaction. Transitions between top quarks and other quark flavours mediated by neutral gauge bosons, so-called flavour-changing neutral currents (FCNC), are forbidden at tree level and suppressed at higher orders. However, several extensions to the SM exist that significantly enhance the production rate of FCNC processes [1]. For the $t \to qg$ mode, the best sensitivity can be achieved by searching for anomalous single top-quark production ($qg \to t$) where a u- or c-quark and a gluon g, originating from the colliding protons, interact to produce a single top quark. Anomalous FCNC couplings can be described in a model-independent manner using an effective operator formalism, which assumes the SM to be the low-energy limit of a more general theory that is valid at very high energies. The effects of this theory below a lower energy scale, Λ, are perceived through a set of effective operators of dimension higher than four. The corresponding strong FCNC Lagrangian usually is written as:

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

with the real and positive parameters κ_{gqt} $(q = u, c)$ that relate the strength of the new couplings to the strong coupling strength, g_{s}, and where t denotes the top-quark field. The parameters f_q and h_q are real, vector and axial chiral parameters, respectively, which satisfy the relation $|f_q|^2 + |h_q|^2 = 1$. In the allowed region of parameter space for κ_{qgt}/Λ, the FCNC production cross-section for single top quarks is of the order of picobarns, while the branching fraction for FCNC decays is very small, i.e. below 1 %. Top quarks are therefore reconstructed in the SM decay mode $t \to Wb$. The W boson can decay into a quark–antiquark pair ($W \to q_1\bar{q}_2$) or a charged lepton–neutrino pair ($W \to \ell\nu$); only the latter is considered here.

2. Selection and signal and background discrimination

This analysis is performed using $\sqrt{s} = 8$ TeV proton–proton (pp) collision data recorded by the ATLAS experiment [2]. Stringent detector and data quality requirements are applied, resulting in a data sample with a total integrated luminosity of 20.3 fb^{-1}. The search targets the signature from the $qg \to t \to W(\to \ell\nu)b$ process. Events are characterised by an isolated high-energy charged lepton (electron or muon), missing transverse momentum from the neutrino and exactly one jet produced by the hadronisation of the b-quark. Several SM processes have the same final-state topology and are considered as background. The main backgrounds are W/Z+jets production (especially in association with heavy quarks), SM top-quark production, diboson production, and multi-jet production. More details are given in Ref. [3]. A neural-network (NN) classifier that combines a three-layer feed-forward neural network with a preprocessing of the input variables is used to discrimination between signal and background events. Table 1 shows a summary of the 10 most important variables used. The modeling of the input variables in the control and signal region as well as the modeling of the resulting neural-network output distributions in the control

Variable	Definition
$m_{\mathrm{T}}(\mathrm{top})$	Transverse mass of the reconstructed top quark
p_{T}^{ℓ}	Transverse momentum of the charged lepton
$\Delta R(\mathrm{top},\ell)$	Distance in the η–ϕ plane between the rec. top quark and the charged lepton
$p_{\mathrm{T}}^{b\text{-jet}}$	Transverse momentum of the b-jet
$\Delta\phi(\mathrm{top},b\text{-jet})$	Difference in azimuth between the reconstructed top quark and the b-jet
$\cos\theta(\ell,b\text{-jet})$	Opening angle of the three-vectors between the charged lepton and the b-jet
q^{ℓ}	Charge of the lepton
$m_{\mathrm{T}}(W)$	W-boson transverse mass
η^{ℓ}	Pseudorapidity of the charged lepton
$\Delta\phi(\mathrm{top},W)$	Difference in azimuth between the reconstructed top quark and the W boson

Table 1: Variables used in the training of the neural network ordered by their descending importance.Taken from Ref. [3].

region is checked and an overall good agreement within systematic uncertainties between data and the prediction is found.

Systematic uncertainties are assigned to account for detector calibration and resolution uncertainties, as well as the uncertainties on theoretical predictions. These can affect the normalisation of the individual backgrounds and the signal acceptance (acceptance uncertainties) as well as the shape of the neural-network output distribution (shape uncertainties). The total uncertainty is dominated by the jet energy resolution uncertainty, the modelling of $E_{\mathrm{T}}^{\mathrm{miss}}$ and the uncertainty on the normalisation and the modelling of the multi-jet background.

3. Statistical analysis and result

In order to estimate the signal content of the selected sample, a binned maximum-likelihood fit to the complete neural-network output distributions in the signal region is performed. Since no significant rate of FCNC single top-quark production is observed, an upper limit is set using hypothesis tests. The CL$_s$ method is used to derive confidence levels (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, while the expected upper limit is $2.9^{+1.9}_{-1.2}$ pb. To visualise the observed upper limit in the neural-network output distribution, the FCNC signal process scaled to 3.4 pb stacked on top of all background processes is shown in Fig.1. Using the NLO predictions for the FCNC single top-quark production cross-section [4, 5] and assuming $\mathscr{B}(t \to Wb) = 1$, the upper limit on the cross-section can be interpreted as a limit on the coupling constants divided by the scale of new physics: $\kappa_{ugt}/\Lambda < 5.8 \times 10^{-3}\,\mathrm{TeV}^{-1}$ assuming $\kappa_{cgt}/\Lambda = 0$, and $\kappa_{cgt}/\Lambda < 13 \times 10^{-3}\,\mathrm{TeV}^{-1}$ assuming $\kappa_{ugt}/\Lambda = 0$. Distributions of the upper limits on the coupling constants for combinations of cgt and ugt channels are shown in Fig.2. Limits on the coupling constants can also be interpreted as limits on the branching fractions using $\mathscr{B}(t \to qg) = \mathscr{C}\,(\kappa_{qgt}/\Lambda)^2$, where $\mathscr{C}$ is calculated at NLO [6]. Upper 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 $\mathscr{B}(t \to ug) = 0$, are derived and presented in Fig.2.

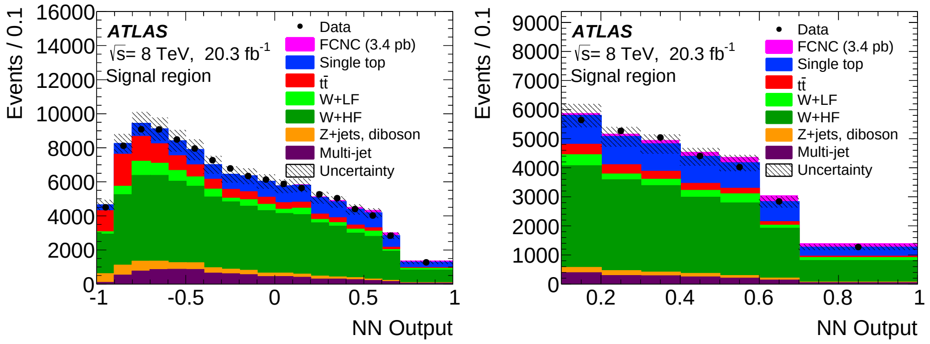

Figure 1: Neural-network output distribution in the signal region and in the signal region with neural network output above 0.1. In both figures, taken from Ref. [3], the signal contribution scaled to the observed limit is shown. The hatched band indicates the total posterior uncertainty.

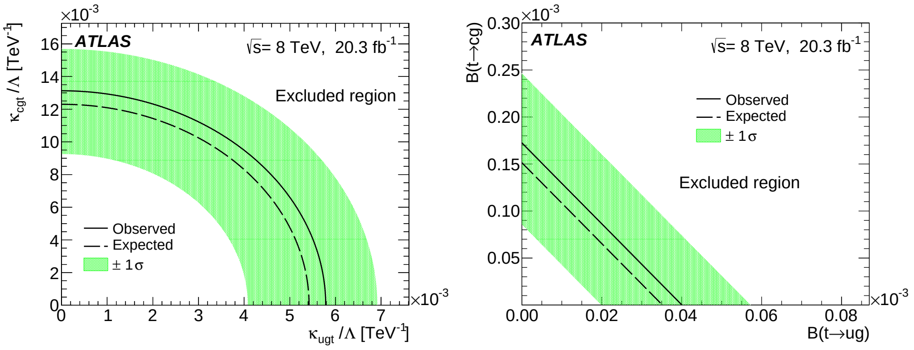

Figure 2: Upper limit on the coupling constants κ_{ugt} and κ_{cgt} (left) and on the branching fractions $\mathscr{B}(t \to ug)$ and $\mathscr{B}(t \to cg)$ (right). The shaded band shows the one standard deviation variation of the expected limit. Taken from Ref. [3].

References

[1] F. Larios, R. Martinez, and M. Perez, *New physics effects in the flavor-changing neutral couplings of the top quark*, *Int. J. Mod. Phys. A* **21** (2006) 3473–3494, [`hep-ph/0605003`].

[2] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, *JINST* **3** (2008) S08003.

[3] ATLAS Collaboration, *Search for single top-quark production via flavour-changing neutral currents at 8 TeV with the ATLAS detector*, `arXiv:1509.00294`. submitted to EPJC.

[4] J. Gao, C. S. Li, L. L. Yang, and H. Zhang, *Search for anomalous top quark production at the early LHC*, *Phys. Rev. Lett.* **107** (2011) 092002, [`arXiv:1104.4945`].

[5] J. J. Liu, C. S. Li, L. L. Yang, and L. G. Jin, *Next-to-leading order QCD corrections to the direct top quark production via model-independent FCNC couplings at hadron colliders*, *Phys. Rev. D* **72** (2005) 074018, [`hep-ph/0508016`].

[6] J. J. Zhang, C. S. Li, J. Gao, H. Zhang, Z. Li, et al., *Next-to-leading order QCD corrections to the top quark decay via model-independent FCNC couplings*, *Phys. Rev. Lett.* **102** (2009) 072001, [`arXiv:0810.3889`].