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Searches for rare or BSM top quark decays at the LHC

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Summary. — Recent results for rare or beyond Standard Model processes involving top quark decays from ATLAS and CMS observed in collision data from the LHC running with $\sqrt{s} = 7\,\text{TeV}$ are described. ATLAS provides exclusion limits for light charged Higgs bosons decaying to a τ lepton and neutrino and to $c\bar{s}$. Exclusion limits for flavor-changing neutral current processes $t \to qZ$ and $gq \to t$ are also presented. From CMS, exclusion limits for a charged Higgs boson decaying to a τ lepton and for flavor-changing neutral currents in the process $T \to tZ$, where T is a vector-like quark of 2/3 charge, are presented. No evidence for processes beyond the Standard Model is observed.

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1. – Searches for Light Charged Higgs Bosons

Charged Higgs bosons are predicted by many non-minimal beyond Standard Model Higgs scenarios, such as Two-Higgs-Doublet-Models (2HDM) [1]. For charged Higgs boson masses, M_{H^+}, smaller than the top quark mass, m_t, the dominant production mode at the LHC for H^+ is the decay $t \to H^+ b$ of one of the top quarks in $t\bar{t}$ events. Therefore, the charged Higgs boson would be produced in the place of a W boson for a fraction of top quark decays in $t\bar{t}$ events. Previous to LHC results, an upper limit of $BR(t \to H^+ b) \simeq 0.2$ had been set by the D0 [2] and CDF [3] experiments at the Tevatron, for M_{H^+} between 80 and $155\,\text{GeV}/c^2$.

The Higgs sector of the Minimal Supersymmetric Standard Model (MSSM) is described by two parameters, taken to be M_{H^+} and $\tan\beta$. For $\tan\beta > 3$, the charged Higgs boson decays via $H^+ \to \tau\nu_\tau$ almost exclusively. However, for low values of $\tan\beta$, the process $H^+ \to c\bar{s}$ can become an important mode. For example, $BR(H^+ \to c\bar{s})$ is of the order of 40% for $M_{H^+} = 130\,\text{GeV}$ and $\tan\beta < 1$.

1˙1. *Charged Higgs boson searches in the ATLAS Collaboration.* – The ATLAS Collaboration has produced results for the modes $H^+ \to \tau\nu_\tau$ and $H^+ \to c\bar{s}$ [4,5]. The result for $H^+ \to c\bar{s}$ is found using $35\,\text{pb}^{-1}$ of integrated luminosity. In this case, the $t\bar{t}$ decay into a charged Higgs boson, a leptonically-decaying W boson, and two b quark jets. The final

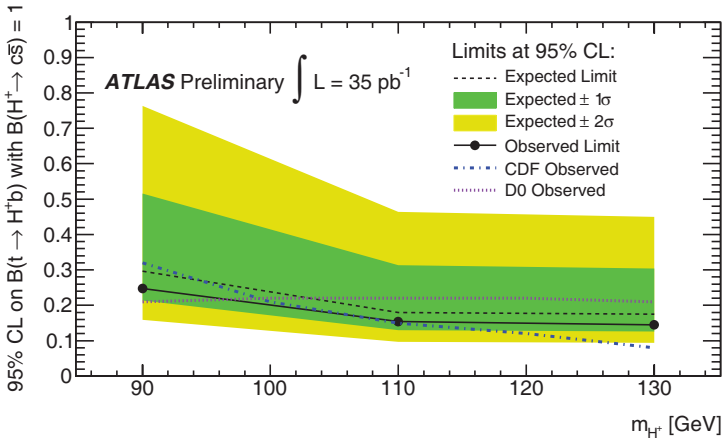

Fig. 1. – The extracted 95% CL upper limits on $BR(t \to H^+b)$ from the ATLAS data are compared with the expected results and results from the Tevatron. The results assume $BR(H^+ \to c\bar{s} = 100\%)$. The ATLAS limits shown are calculated using the CL_s limit setting procedure. Figure appears in [4].

discriminating variable used for limit setting is the di-jet mass, calculated from the two jets resulting from the hadronically decaying side of the $t\bar{t}$ event. This mass corresponds to the W boson mass within the Standard Model and the charged Higgs boson mass in physics beyond the Standard Model. The resulting upper limits for $BR(t \to H^+b)$ are shown in fig. 1.

The search for the charged Higgs boson in the mode $H^+ \to \tau\nu_\tau$ was performed using $1.0\,\text{fb}^{-1}$ integrated luminosity. This search involves a $t\bar{t}$ decay with a hadronically decaying W boson and a charged Higgs boson decaying into a τ lepton and neutrino. In this case, the final discriminating variable is the transverse mass $M_t(\tau, E_T^{Miss})$. In the case of the Standard Model background, this is related to the W boson mass, and in the case of the beyond Standard Model signal, it would be related to the charged Higgs boson mass. Upper limits on the branching ratio are shown in fig. 2.

1˙2. *Charged Higgs Boson searches in the CMS Collaboration.* – The CMS Collaboration searches for the charged Higgs boson in the mode $H^+ \to \tau\nu_\tau$, investigating three final states [6]. This search was performed using $1.1\,\text{fb}^{-1}$ integrated luminosity, and it is a counting experiment, with the limits based on the total number of events observed. The first channel consists of $t\bar{t}$ decaying into two b quark jets, a τ and neutrino, and a hadronically decaying W boson. The second channel is identical, except that it requires the W boson to decay leptonically, into $\mu\nu_\mu$. The third channel requires an electron, a muon, associated neutrinos, and $2b$ quark jets. The first two channels would see an excess of events in the case of the existence of a charged Higgs boson, and the third would see a lack of events. The combined upper limits on $BR(t \to H^+b)$ are shown in fig. 3.

2. – Searches for flavour changing neutral currents in top quark decays

Top quark flavour changing neutral currents (FCNC) are highly suppressed in the Standard Model, with branching fractions as low as $BR(t \to uZ) = 8 \times 10^{-17}$. However, several models of new physics predict higher branching ratios (up to $BR(t \to uZ) = 1.1 \times 10^{-4}$ for the quark-singlet model) for FCNC top quark decays [7]. FCNC may also

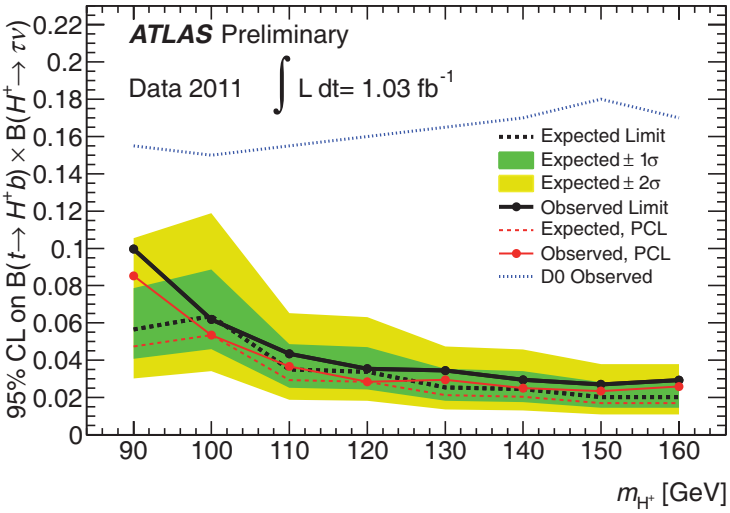

Fig. 2. – Expected and observed 95% CL exclusion limits for charged Higgs boson production from top quark decays as a function of m_{H^+} in terms of $BR(t \to H^+b) \times BR(H^+ \to \tau^+\nu_\tau)$ using the CL_s procedure. Power-Constrained limits (PCL) with a 50% power constraint are shown as well. Figure appears in [5].

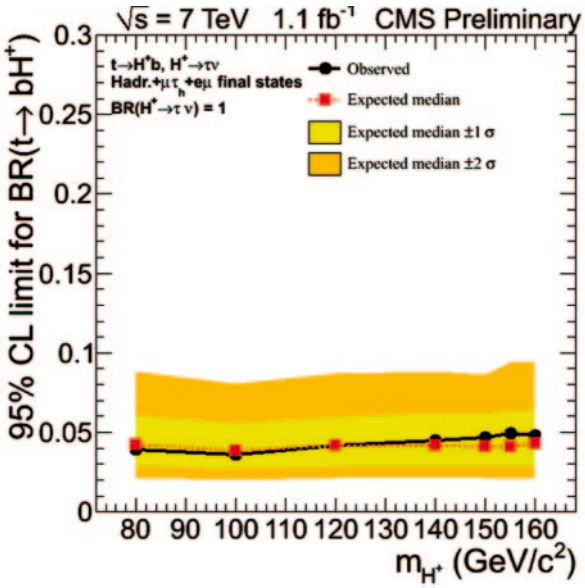

Fig. 3. – Upper limit on $BR(t \to H^+b)$ assuming $BR(H^+ \to \tau\nu_{tau}) = 1$ as a function of M_{H^+} for the combination of the three channels. Figure appears in [6].

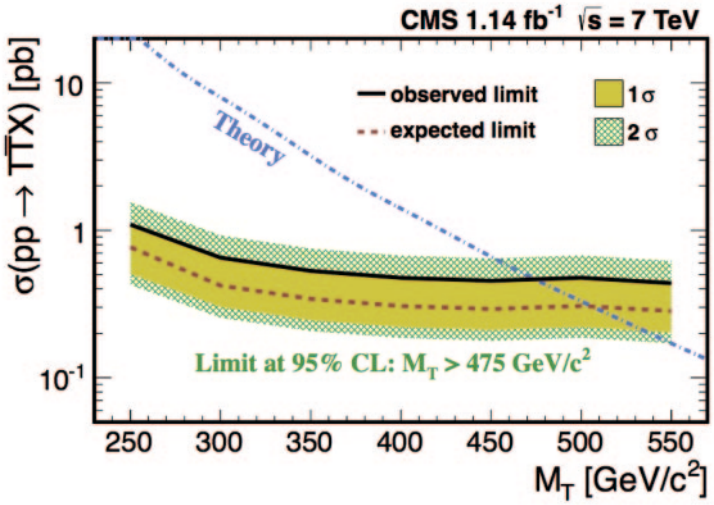

Fig. 4. – The 95% confidence level (CL) upper limit on the cross-section of the $pp \to TTX$ process, as a function of the T-quark mass. $BR(T \to tZ)$ is assumed to be 100%. The dot-dash line shows the value of the theoretical cross-section [12] for the TT process. Figure appears in [11].

be observed in processes that involve new particles, such as a vector-like quark (T) with charge 2/3, which is predicted by several models of new physics [8, 9]. If $T \to tH$ is kinematically forbidden, $BR(T \to tZ)$ could be nearly 100%.

2˙1. *Flavour changing neutral current searches in the ATLAS Collaboration.* – The ATLAS Collaboration has performed a search for the modes $t \to Zq$ and $gq \to t$, using $35\,\text{pb}^{-1}$ integrated luminosity [10]. The first search was performed using $t\bar{t}$ decaying into a leptonically decaying Z boson, a leptonically decaying W boson, and two b quark jets. An upper limit of 17% was set on the $BR(t \to Z)$. The search for $gq \to t$ was performed by searching for a single top quark, decaying into a leptonically decaying W boson and b quark jet. A neural network was used to separate the Standard Model background from the FCNC signal, and an upper limit of 17.3 pb was set on the production cross-section of $gq \to t$.

2˙2. *Flavour changing neutral current searches in the CMS Collaboration.* – The CMS Collaboration has performed a search for a new particle, a vector-like quark (T) of 2/3 charge, in the FCNC channel $T \to tZ$ [11]. This search was performed on $1.1\,\text{fb}^{-1}$ integrated luminosity. A final state is required with three leptons and two jets, and an upper limit on the sum of the transverse momentum of leptons and jets (excluding the leading two of each) further rejects the Standard Model background. A limit on the production cross-section with respect to the mass of the T quark is shown in fig. 4. By comparing the theoretical cross-section with the observed limit, a lower bound of $475\,\text{GeV}/c^2$ is found at the 95% confidence level, assuming $BR(T \to qZ) = 100\%$.

3. – Conclusions

The ATLAS and CMS Collaborations have set world-best limits on various rare and beyond Standard Model top quark decays. The ATLAS Collaboration has set limits

on several channels for top quark FCNC, and the CMS Collaboration has set limits on FCNC that could arise from a heavy top-like quark. Both collaborations have also set limits on the branching ratio $BR(t \to H^+b)$. While no evidence for processes beyond the Standard Model have yet been observed, the high performance of the LHC will allow stronger limits or discoveries in the coming years.

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These analyses have been performed by the ATLAS and CMS Collaborations, using collision data from the LHC.

REFERENCES

[1] Gunion J. F., Haber H. E., Kane G. and Dawson S., *The Higgs Hunter's Guide* (Addison-Wesley) 1990, p. 191.
[2] Abazov V. M. *et al.* (DO Collaboration), *Phys. Lett. B*, **682** (2009) 278.
[3] CDF Collaboration, *Phys. Rev. Lett.*, **103** (2009) 101803.
[4] ATLAS Collaboration, ATLAS-CONF-2011-094 (2011).
[5] ATLAS Collaboration, ATLAS-CONF-2011-138 (2011).
[6] CMS Collaboration, CMS-PAS-HIG-11-008 (2011).
[7] Aguilar Saavedra J. A., *Acta Phys. Polon. B*, **35** (2004) 2695.
[8] Lodone P., *JHEP*, **12** (2008) 029.
[9] Han T., *Phys. Rev. D*, **67** (2003) 095004.
[10] ATLAS Collaboration, ATLAS-CONF-2011-15 (2011).
[11] CMS Collaboration, arXiv:1109.4985v1 [hep-ex] (2011).
[12] Aliev M. *et al.*, *Comput. Phys. Commun.*, **182** (2011) 1034.