Searches for Fourth Generation Heavy Quarks with the ATLAS Detector

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The addition of one or more generations of heavy fermions is a natural extension to the Standard Model. Fourth generation heavy quarks can be produced at the LHC at rates that can be observed in the 2011 data samples, depending on the quark mass. The talk presents results from searches performed by the ATLAS collaboration for fourth generation quarks decaying via several potential decay channels.

Introduction

The addition of one or more generations of heavy fermions is a natural extension to the Standard Model (SM). New physics models with such heavy quarks can accommodate a heavier Higgs boson within the constraint of precision electroweak data, and extend the CKM matrix to provide new sources of CP violation [1, 2]. Here we presents several studies carried out with the ATLAS detector [3], using 7 TeV proton-proton collision data delivered by the LHC in 2011.

$t'\bar{t}'$ in the lepton+jets channel

This study searches for pair production of t', assuming it decays exclusively into Wb [4]. Signature expected here is an isolated lepton (e, μ), high missing transverse momentum ($E_{\mathrm{T}}^{\mathrm{miss}}$), and at least three energetic jets, one of which must be tagged as b-jet. The primary discriminant from SM top quark pair production is the t' mass (m_{recon}) reconstructed from the jets.

The m_{recon} distribution was analyzed by a binned log-likelihood ratio as test-statistic. With 1.04 fb^{-1} data, no excess was observed over the m_{recon} distribution. Using the CLs method [5, 6], upper limit on the $t'\bar{t}'$ cross-section is set as in figure 1. Comparing with theoretical prediction, t' with mass below 404 GeV is excluded at 95% confidence level.

$Q\bar{Q}$ in the opposite-sign di-lepton channel

This study searches for heavy quark (Q) pair production, under the assumption that Q decays to Wq $(q = u, d, c, s, b)$ [7]. This is applicable to both up-type and down-type fourth generation quarks and other exotic models. The expected final state contains two isolated leptons (e, μ) with opposite charges, and at least two energetic jets. In the $ee/\mu\mu$ channels, the Drell-Yan background is suppressed by imposing constraints on the di-lepton invariant mass and $E_{\mathrm{T}}^{\mathrm{miss}}$. In the $e\mu$ channel, a high value of H_T, defined as the scalar sum of E_T from all selected leptons and jets, is required.

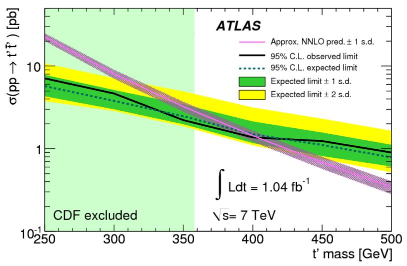


Figure 1: 95% C.L. upper limits on the $t'\bar{t}'$ cross-section as a function of the t' mass, in the lepton+jets channel.

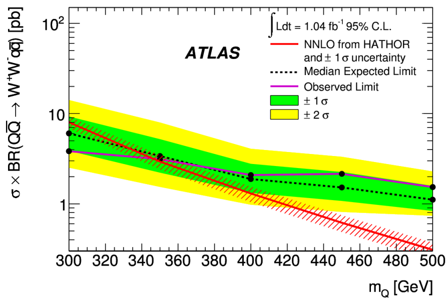


Figure 2: 95% C.L. upper limits on the $Q\bar{Q}$ cross-section as a function of the Q mass, in the di-lepton channel.

The observable in this analysis is again the reconstructed mass of Q. The $E_{\mathrm{T}}^{\mathrm{miss}}$ is solved into two neutrinos, by exploiting the small angular separation between the lepton and neutrino from the boosted W. The optimal directions of the neutrinos are solved by minimizing the mass difference between the two reconstructed heavy quarks. The final reconstructed mass ($m_{Collinear}$) of each event is the average of m_Q and $m_{\bar{Q}}$.

To enhance sensitivity, additional mass-dependent cuts are further applied on the several variables, including leading jet p_T, $E_{\mathrm{T}}^{\mathrm{miss}}$, and H_T+$E_{\mathrm{T}}^{\mathrm{miss}}$ v.s. $m_{Collinear}$ plane. The observed $m_{Collinear}$ distribution are in good agreement with the expected background, using 1.04 fb^{-1} data. Assuming 100% branching ratio of $Q \to Wq$, this analysis set a lower limit of m_Q at 350 GeV at 95% confidence level (figure 2).

$b'\bar{b}'$ in the same-sign di-lepton channel

This analysis is carried out in a model-independent approach, searching for new physics in the same-sign (SS) di-lepton (e, μ) final state [8]. A down-type heavy quark b' is assumed to decay exclusively to Wt. Thus, up to four W bosons are expected, giving a good chance of SS di-lepton final state. Besides two energetic leptons, at least two energetic jets and high $E_{\mathrm{T}}^{\mathrm{miss}}$ are required. Again, cuts on the di-lepton invariant mass and H_T are applied to suppress SM backgrounds. Most backgrounds in this analysis are derived by data-driven techniques.

In the end, observed numbers of events in 1.04 fb^{-1} data were compared to the background expectation, in six bins of different lepton flavors and charges. No excess was observed, and a lower bound of 450 GeV for the b' mass is derived at 95% confidence level (figure 3).

$b'\bar{b}'$ in the lepton+jets channel

This study searches for b' pair production in the single-lepton final state [9], again assuming 100% branching ratio for $b' \to Wt$. In addition to the lepton, the presence of at least six energetic jets and high $E_{\mathrm{T}}^{\mathrm{miss}}$ are required.

The hadronically-decayed W bosons are reconstructed from jet pairs with ΔR <1.0 and invariant mass within W mass window. Such selection has an efficiency as high as 80%, for energetic W bosons with p_T around 250 GeV.

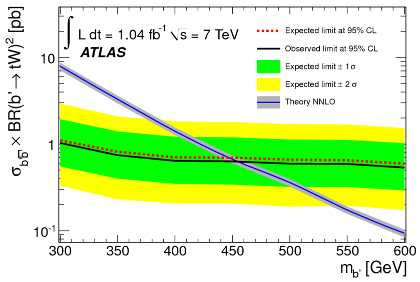


Figure 3: 95% C.L. upper limits on the $b'\bar{b}'$ cross-section as a function of the b' mass, in the same-sign di-lepton channel.

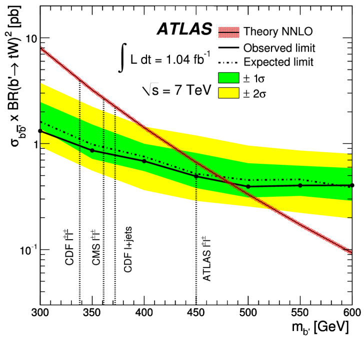


Figure 4: 95% C.L. upper limits on the $b'\bar{b}'$ cross-section as a function of the b' mass, in the lepton+jets channel.

Nine exclusive bins are examined, split by the multiplicity of hadronic W ($N_W = 0, 1, \geq 2$) and jet multiplicity ($N_{jet} = 6, 7, \geq 8$). A binned maximum likelihood fit is performed to derive the most likely cross-section of $b'\bar{b}'$. No evidence of b' production is observed with 1.04 fb^{-1} data. The b' masses below 480 GeV are excluded at 95% confidence level (figure 4).

$b'\bar{b}'$ in the $Z + b$ channel

This analysis looks for b' pair production with at least one b' decaying to a Z boson and a b quark [10]. It complements the above-mentioned searches in the $b' \to Wt$ decay mode, and is particularly relevant for the vector-like quarks in the high mass region.

The expected signature here is a Z boson and at least one b-tagged jet, with a high transverse momentum of the Z+b system. The Z boson is reconstructed from opposite charge electron pair, with invariant mass within Z mass window.

The observable here is the invariant mass of the Z+b system. The distribution of m_{Zb} from 2.0 fb^{-1} data is consistent with SM prediction, against all b' mass values considered. The cross-section limits can be seen in figure 5. This result can be interpreted as a b' mass limit of 400 GeV assuming 100% branching ratio of $b' \to Zb$. Alternatively, for a vector-like singlet b' mixing solely with the third SM generation, masses below 358 GeV are excluded from this search.

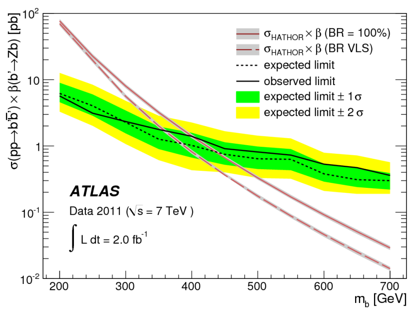


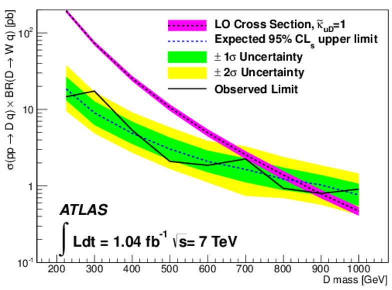
Figure 5: 95% C.L. upper limits on the $b'\bar{b}'$ cross-section as a function of the b' mass, in the $Z + b$ channel.

Vector-like quarks in the V+jets channel

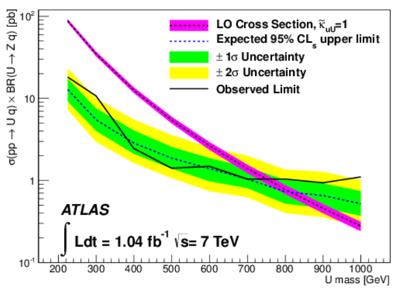
This analysis searches for single production of vector-like quarks (VLQ), assuming full coupling to a vector boson and light quarks [11]. Both the charged current (CC) channel and the neutral current (NC) channel are studied.

In the CC channel, the W boson is reconstructed from one isolated lepton (e, μ) and a high $E_{\mathrm{T}}^{\mathrm{miss}}$, with their transverse mass above certain threshold. As the W boson is highly boosted, angular separation between the lepton and the $E_{\mathrm{T}}^{\mathrm{miss}}$ should not be too large in the transverse plane. In addition, at least one jet in the event must be very energetic. In the NC channel, the Z boson is reconstructed from two same-flavor opposite-sign leptons. The invariant mass of the lepton pair must be within Z mass window, and the p_T of the di-lepton system should be large. In both channel, the presence of at least two jets are required. As a forward jet is expected, a minimum pseudo-rapidity separation is required between the leading-p_T jet and the second or third-leading jet.

The observable in this analysis is the mass of the VLQ, reconstructed from the vector boson and the leading jet. With 1.04 fb^{-1} data, no significant excess over background expectation is observed. This leads to 95% C.L. lower limit for the VLQ mass as 900 GeV in the CC channel and 760 GeV in the NC channel (figure 6).



(a)



(b)

Figure 6: 95% C.L. upper limits on the single VLQ production cross-section as a function of the VLQ mass, in the charged current channel (a) and the neutral current channel (b).

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