ATLAS New Heavy Quark Searches [1]

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1 Physics motivations

The number of fermion generations can be higher than three in the Standard Model. Since the discovery of neutrino oscillations, it is proven that neutrinos have mass. In the extra generations, very massive neutrinos with mass above the LEP limit $m_{\nu_4} > m_Z/2$ could exist. The Electro-Weak (EW) precision data also do not exclude extra generation of fermions, even though only one extra generation is allowed [2].

Fourth generation (4G) is the simplest extension of the Standard Model and it addresses currently some of the crucial open questions. In cosmology, only three generations do not provide enough CP violation to explain the Baryon Asymmetry of the Universe. 4G could provide an additional factor of order 10^{13} to 10^{15} to solve this problem. If heavy 4G quarks (t', b') have masses as high as $\sim$600 GeV, they would couple so strongly to the Goldstone bosons of EW symmetry breaking that the concept of an elementary scalar field is no longer appropriate. 4G fermion condensates could hence play the role of the Higgs via some strong interactions. Further information can be found in Ref. [3].

2 Experimental strategy

Detection of new heavy quarks will depend on their masses and on their mixing with the lighter generations. Assuming unitarity of a 4×4 CKM matrix, quark mixing of 4G to the other three generations is constrained to be small from fits to flavor-physics data. It has been recently pointed out [4] that if mixing angles are tiny $(\sim 10^{-13} < \theta_{bt'} <\sim 10^{-8})$ and $m_{t'} \sim m_{b'}$, heavy quarks could have a proper lifetime of $\sim 10^{-10}s < t_Q <\sim 1s$. Therefore, their decay length could range from a few millimeters, with potential displaced vertices close to the interaction point, to many meters (*stable* particles at the detector scale).

In the former case, experimental signatures are similar to top quark decays. ATLAS is looking for a Q_4 quark following the process $pp \to Q_4\overline{Q_4} \to W^+qW^-\overline{q}$. In the so-called 'di-lepton' analysis, both W's decay leptonically, and $q = u, d, c, s, b$, making no assumption on the mixing angles. Events with at least two jets, two leptons, and missing transverse energy from undetected neutrinos are hence selected. The analysis performs an approximate mass reconstruction by assuming that the boosted W's decay to a charged lepton and neutrino which are nearly collinear. It also uses the discrimating variable H_T (scalar sum p_T of everything in the event including missing energy) in order to discriminate the Q_4 signal from the different background processes. With 37 pb^{-1}, this analysis excluded at 95% of C.L. a Q_4 quark with mass below 270 GeV [5]. Another search is also looking at processes where only one W decays leptonically, while the other one decays into two quarks. This 'lepton+jets' analysis assumes $q = b$, and makes use of b-jet identification algorithms in order to suppress backgrounds.

In the later case, very massive long-lived particles could be 'slow-moving' in the detector ($\sim 0.3 < \beta < 1$) and deposit anomalous large ionization energy. This can be seen in ATLAS by looking at 'time-of-flight' from the tile calorimeter, and at charge deposits in the pixel and TRT detectors. These particles formed of heavy 4G quarks and light SM partons, could even alternate between charged and neutral states, and would appear as 'dashed-lines' in the detector. There is no dedicated ATLAS results for the time being but this study should be similar to the search for stops production conducted in [6], whose limits would need to be reinterpreted in the framework of 4G.

3 Discovery prospects

Given its production rate at the LHC, and the theoretical mass upper limits (coming mostly from tree level unitarity), it has been shown in the ATLAS TDR [7] that there is potential to discover or fully exclude 4G. Even at $\sqrt{s} = 7$ TeV, where the cross-section of $t'\overline{t'}$ production is ~1 pb for $m_{t'} \sim 400$ GeV, ATLAS is expected to be competitive with the Tevatron limits (excluding at 95% C.L. a $b'(t')$ quark with mass below 372(335) GeV) with the 2011 data.

References

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