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PROSPECTS FOR QUARK SEARCHES AND THEIR IMPACT ON HIGGS SEARCHES IN ATLAS

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Abstract. - The ATLAS experiment at the LHC will be searching for physics beyond the standard model. A large number of the new models predict heavy quarks. This letter reviews the ATLAS discovery prospects for such particles and also discusses their impact on Higgs searches.

Although the Standard Model (SM) explains all the, so far conducted, particle physics experiments, there remains some doubt about the SM being the ultimate theory of fundamental particles and their interactions. The supersymmetric SM (or one of its variations) is a promising candidate for a general theory valid at higher energies [1]. Examples of alternative models are Fourth SM Family [2], GUT inspired E6 [3, 4], Little Higgs [5], universal extra dimensions[6], compositeness [7] etc. The first three predict the existence of new heavy quarks in all scenarios whereas the remaining ones have the same prediction in some specific scenarios. Additionally there are recent hints from the Tevatron and from B-Factory experiments. Both the CDF 2σ fluctuation [8] and the Belle 5.5σ signal [9] can be explained by a new heavy quark. This letter will concentrate on the ATLAS discovery prospects for the first two models in the above list using their heavy fermion search channels and their implications for Higgs boson searches. At the LHC, the heavy quarks can be easily produced in pairs via QCD processes. The heavy quark invariant mass can be fully reconstructed since there isn't any missing ET signal. This is a distinguishing feature compared to SUSY processes. The fourth SM family (FF) is the simplest modification to the SM as we know it today as it only predicts four new fermions (u_4, d_4, e_4, ν_4) with masses of $O(100)$ GeV. The search strategy for these new quarks depends on the decay channels dictated by the 4×4 Cabibbo-Kobayashi-Maskawa matrix [10]. If the fourth family quarks prefer to mix with first and/or second family members, the experimental signature is given by $q_4 \to Wj$ where $q_4 = u_4, d_4$ and j is a light-quark jet. If the DMM approach [2] is assumed as the theoretical motivation, then the FF quarks are expected to be mass-wise quasi-degenerate in mass as $|m_{u_4} - m_{d_4}| < m_W/2$. This condition makes the signals from u_4 and d_4 indistinguishable at the LHC. In this case the signal cross section is doubled and FF quarks with a mass of 500 GeV can be discovered with 400 pb^{-1} integrated luminosity as seen from Fig. 1.

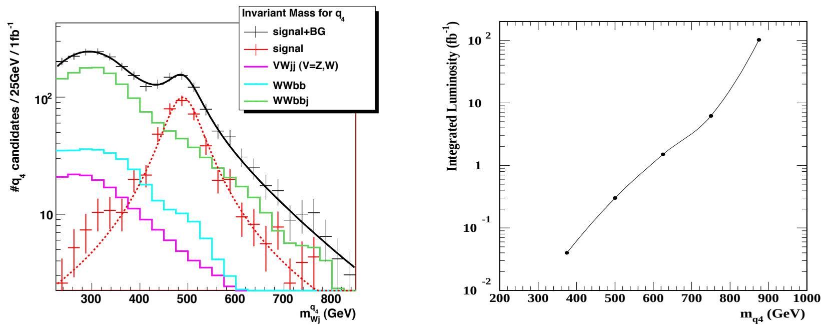

Figure 1: Left: Invariant mass distribution for the reconstructed q_4 candidates from signal and SM background events for a quark of mass 500 GeV. The colored solid lines show the backgrounds from various processes, the solid black curve represents the fit to the sum of the background and signal events whereas the dotted line is the signal component of the fit. Right: the integrated luminosity needed for a 5σ discovery of the signal, as a function of the new quark mass [10].

In GUTs, the SM gauge group $SU(3)_C \times SU(2)_L \times U(1)_Y$ is embedded into a larger symmetry group, which is recovered at a higher scale. The E6 group [3, 4] is among the most frequently studied. Its **27**-plets contain a $Q = -1/3$ singlet quark per fermion generation. Their main decay channels are both charged and neutral currents and Higgs interactions, with branching fractions of 50%, 25% and 25%, respectively. The lightest singlet quark, denoted as D, is assumed to couple preferentially to the first generation so that the relevant decays are $D \to W^- u$, $D \to Zd$, $D \to Hd$. The decay products of $D\bar{D}$ quark pairs would thus be two bosons and two jets. Fig. 2, left side shows the reconstructed invariant mass of a 600 GeV D quark in the $Z + jet$ and $W + jet$ channels where both bosons decay leptonically. Fig. 2, right side shows the effect of the combination of different channels: it is seen that a 500 GeV D quark can be observed with less than 1 fb^{-1} of integrated luminosity.

Additional heavy quarks influence Higgs production by enhancing the ggH vertex due to the fourth family quark contribution, The cross-section of the Higgs boson production via gluon fusion is $5 - 8$ times larger than with three SM families (see Fig. 3 left side). This will clearly improve the Higgs search in the "golden" mode (see Fig. 3 right side), and 3 fb^{-1} integrated luminosity will be sufficient to discover the Higgs boson with $M_H > 130$ GeV in this mode alone. Moreover, 100 pb^{-1} will be enough if 190 GeV $< M_H <$ 250 GeV.

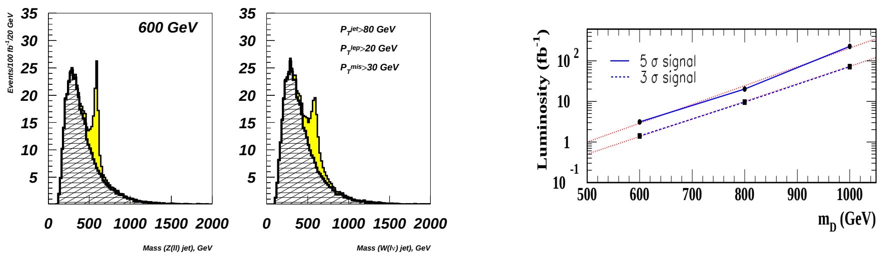

Figure 2: Left: reconstructed invariant mass of a 600 GeV D quark in the $Z+jet$ and $W+jet$ channels. Right: required luminosity for the 3σ observation limit (dashed line) and the 5σ discovery limit as a function of the D quark mass ATLAS [11, 12].

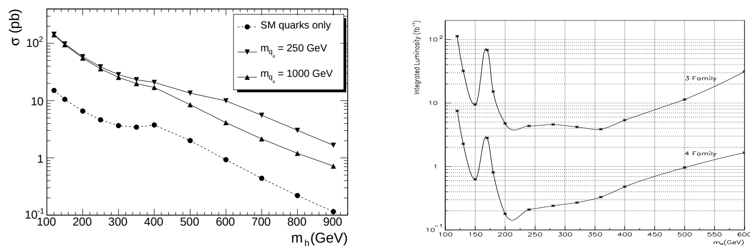

Figure 3: Left: Higgs boson production cross section as a function of the Higgs mass, for SM (circles), SM + fourth family for $m_{q_4} = 1000$ GeV (upwards triangles) and similarly for $m_{q_4} = 250$ GeV (downwards triangles) [13]. Right: LHC luminosity values corresponding to 5σ significance level of the "golden" mode signal for three and four SM families [14].

If the Higgs boson is lighter than the new quark D, the decay channel $D \to Hd$ is available. Figure 4 (left plot) shows the branching fractions for the case of a light Higgs boson (120 and 135 GeV) as a function of the D quark mass. Its pair production and subsequent decay involving H yields a substantial increase in the LHC discovery potential for a light Higgs boson. The presence of additional paired objects in the event makes possible the reconstruction of the H from its $b\bar{b}$ decay mode which is otherwise overwhelmed by the SM background. Figure 4 (middle plot) shows the result of such a reconstruction for a scenario with $m_H = 120$ GeV and $m_D = 500$ GeV using the $pp \to D\bar{D}X \to hjWj \to j_b j_b j \ell \nu j$ channel alone, where j_b is a b-tagged jet. The same search can be extended to other mass values to consider a double discovery of both the D quark and the Higgs boson. The required integrated luminosities for observation and discovery of both of them are presented in Fig. 4 (right plot). It should be noted that for a light Higgs with $M_H = 120$ GeV, if m_D is lighter than 500 GeV, this channel alone provides a signal significance which is equal to or better than all the channels combined for ATLAS.

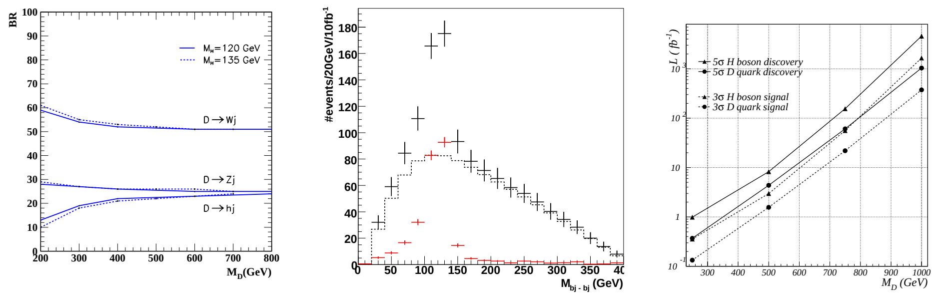

Figure 4: Left: D quark branching fractions in the presence of a light Higgs boson. Middle: reconstructed invariant masses of Higgs boson together with the SM background (dotted lines) for 30 fb^{-1} of integrated luminosity. Right: required luminosities for the observation or discovery of the D quark and H boson ($m_D = 500$ GeV and $m_H = 120$ GeV) [15].

In conclusion, ATLAS will be searching for heavy quarks predicted by various models. If such quarks exist, they will also enhance the Higgs boson production and detection prospects. If their masses are about 500 GeV or lower, the early LHC runs with about 1fb^{-1} integrated luminosity might yield simultaneous discovery of both heavy quarks and the Higgs boson.

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