Search for Leptoquarks of 1st Generation Using the ATLAS Detector

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Introduction

The Standard Model, although remarkably accurate at low energy, is at best an effective field theory at higher energy scales. A diverse spectrum of beyond the Standard Model physics has been proposed in an attempt to correctly describe nature at these higher energies. Similarities between generations of leptons and quarks suggest the possible existence of a symmetry relating the two particle classes beyond the Weak Scale. This symmetry would be mediated by a color-triplet gauge boson with fractional electric charge, a leptoquark (LQ). Scalar LQ pair-production cross sections, which depend only on the unknown LQ mass, have been calculated to next-to-leading order. Theories involving scalar LQ production have one additional free parameter, the branching fraction to charged leptons, β. Here we present a model independent search for pair-produced, 1st generation scalar leptoquarks, in pp collisions at $s^{1/2}$=7TeV.

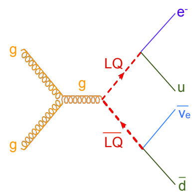

Figure 1: Feynman Diagram of LQ pair-production and decay in the single electron channel.

Background Modeling

A total of five control regions (CR) are defined with enhanced concentrations of the major backgrounds (V+Jets, ttbar), and negligible signal contamination. These CRs are used to check the background modeling, as well as to determine the major background normalizations. For each of the major backgrounds, an overall scale factor is determined by minimizing the χ^2 between the predicted and observed yields in each of the CRs. Correlations amongst the various CRs are taken into account, where necessary. CR background predictions and data yields are found to agree within systematic uncertainties.

The QCD contribution is estimated by fully data-driven methods. A shape template is derived from a QCD enhanced sample. Depending on the CR, either the MET or m_{ee} distribution is used to perform a log-likelihood fit. The relative fraction of QCD compared to all other backgrounds is allowed to float, while the sum is constrained to equal that of the data. The amount of QCD which minimizes the log-likelihood is taken as the QCD normalization. This is done separately in each channel, for the selected events and all CRs. Only the QCD normalization is affected by this procedure, not those of the other backgrounds.

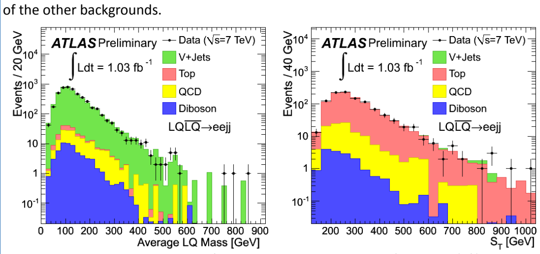

Figure 2: Control region plots for the eejj channel: Average LQ mass for Z+Jets CR (left), $S_T \equiv MET + \sum_i p_T(jet_i) + \sum_i p_T(e_i)$ for ttbar CR (right). The cumulative distributions show the various background contributions, and data are indicated by the full dots.

Event Selection

LQ pair-production can lead to an eejj or evjj final state (vvjj too, but this is not considered here). For both final states, event selection requirements are defined with high signal efficiency, yet dominated by SM backgrounds. The background scale factors described previously are applied to selected events. The data and background predictions agree within systematic uncertainties.

<table>
<tr><th>eejj channel:</th><th>evjj channel:</th></tr>
<tr><td colspan="2">All detector systems functioning</td></tr>
<tr><td colspan="2">Trigger</td></tr>
<tr><td colspan="2">Primary vertex with at least 3 tracks</td></tr>
<tr><td rowspan="4">Exactly 2 electrons</td><td>Exactly 1 electron</td></tr>
<tr><td>Muon veto</td></tr>
<tr><td>MET > 30 GeV</td></tr>
<tr><td>m_T(e,MET) = $\sqrt{2 \cdot p_T^e \cdot MET \cdot (1-\cos(\Delta\phi))}$ > 40 GeV</td></tr>
<tr><td colspan="2">At least 2 jets</td></tr>
<tr><td>m_{ee} > 40 GeV</td><td>Triangle cuts in ΔΦ(MET,jet$_{1,2}$), MET plane</td></tr>
</table>

Table 1: Event selection requirements for both single and di-electron channels.

Source \ Channel	eejj:	evjj:
Data	5615	76855
SM Background	5600 ± 50 (stat) ± 1000 (syst)	74000 ± 830 (stat) ± 11000 (syst)
LQ (m=600GeV)	7.5 ± 0.2 (stat) ± 0.5 (syst)	4.6 ± 0.1 (stat) ± 0.2 (syst)

Table 2: Observed and expected events for both single and di-electron channels.

Log-Likelihood Ratio

A log-likelihood method (LLR) is used to separate signal and background. Depending on the channel, 3 or 4 discriminating variables are chosen which differ considerably for signal and background.

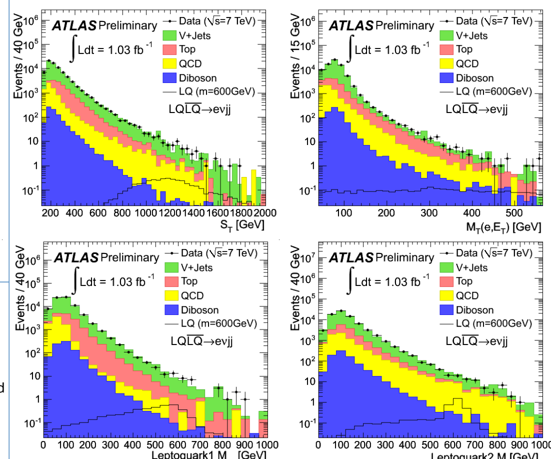

Figure 3: LLR input distributions for the evjj channel: S_T (upper left), m_T (upper right), LQ m_T (bottom left), and LQ mass (bottom right).

Probability distribution functions (PDF) are formed for each of these discriminating distributions, separately for signal and background. From these PDFs, joint likelihoods L_S and L_B are formed, as in equation 1, where P_s^i (P_b^i) is the probability of the i-th input distribution having a value of x_j in a signal (background) event. L_S distributions are formed for each LQ mass hypothesis tested, allowing a mass-dependent optimization. From these joint likelihoods, the log-likelihood ratio is formed, as in equation 2, and shown in Figure 4.

$$L_S \equiv \prod_i P_S^i(x_j) \qquad L_B \equiv \prod_i P_B^i(x_j) \qquad \text{Equation 1}$$

$$LLR = \log_{10}\left(\frac{L_S}{L_B}\right) \qquad \text{Equation 2}$$

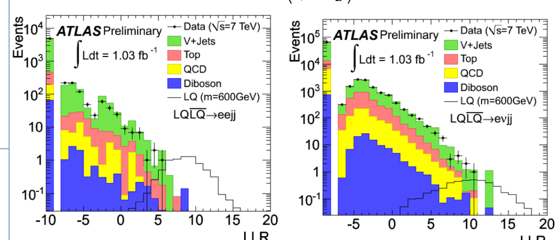

Figure 4: LLR distributions for the eejj channel (left) and evjj channel (right), assuming m_{LQ}=600GeV. Events in the first bin fall in a region of phase space with no signal prediction.

Results

No excess is observed at high LLR, in either channel. Thus, 95% CL upper limits on σ are set using a modified frequentist method, treating systematic uncertainties as nuisance parameters. These cross section upper bounds are reinterpreted in the β versus m_{LQ} plane, yielding the exclusion limits shown in figure 5, the most stringent to date.

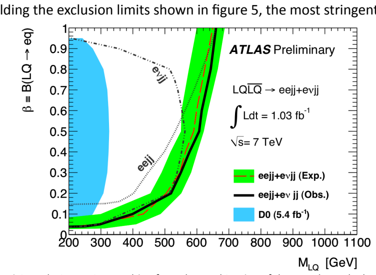

Figure 5: 95% CL exclusion region resulting from the combination of the two channels shown in the β versus LQ mass plane. The dotted and dotted-dashed lines indicate the individual limits for the eejj and the evjj, respectively. The combined expected limit is indicated by the dashed line, together with the systematics band resulting from the ±1σ variation. The combined observed limit is indicated by the solid black line.