

Prospects for Discovery of Leptoquarks, Right-Handed W Bosons, and Heavy Neutrinos in Final States with Two Leptons and Jets

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Many Beyond the Standard Model scenarios predict final states with two leptons and jets, which provide a robust signature for early discovery with the LHC. To examine event topologies in such final states, two prominent models for leptoquarks and Left-Right Symmetry are discussed. Studies are based on the fully simulated response of the ATLAS detector to physics beyond the Standard Model at 14 TeV center-of-mass energy. The discovery potential for 100pb^{-1} of integrated luminosity is reported.

2008 Physics at LHC

Split, Croatia

September 29 – 4 October 2008

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1. Introduction

Exotic processes could provide the first discoveries in early ATLAS data. Models for physics Beyond the Standard Model (BSM) introduce many new, usually very massive, particles. Previous searches have placed limits on the masses and couplings of such particles, but the LHC will probe new regions of parameter space. Models for leptoquarks and Left-Right Symmetry are used to estimate discovery potential in final states with at least two charged leptons and two jets.

1.1 Leptoquarks

The experimentally observed symmetry between leptons and quarks has motivated the search for leptoquarks (LQ), hypothetical bosons with fractional charge carrying both baryon and lepton quantum numbers. Leptoquarks can be either vector or scalar, but only scalars, which are expected to be lighter than vectors, are considered here¹⁻². Limits on lepton number violation, flavor-changing neutral currents, and proton decay favor three generations of leptoquarks, where each LQ couples to a lepton and quark from the same SM generation³. Tevatron experiments CDF⁴ and DØ⁵ placed lower limits on 1st gen. leptoquarks at $m_{LQ} > 236$ GeV and $m_{LQ} > 292$ GeV, respectively. Their limits on 2nd gen. leptoquarks are $m_{LQ} > 226$ GeV and $m_{LQ} > 316$ GeV for CDF⁶ and DØ⁷, respectively. At the LHC, leptoquarks can be produced in pairs by strong interactions or in association with a lepton via the leptoquark-quark-lepton coupling, as shown in the Feynman diagrams in Figure 1. Only pair production processes where LQ decays to an electron and a quark or a muon and a quark will be discussed here.

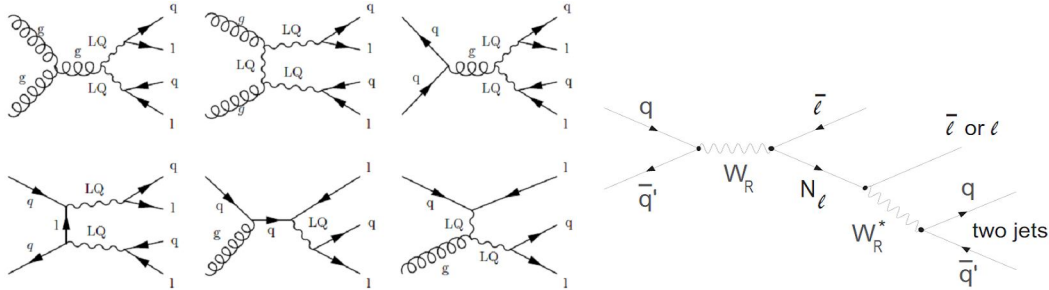


Figure 1: Feynman diagrams for leptoquark production (left) and W_R production and decay to heavy Majorana Neutrino (right).

1.2 Left-Right Symmetry

Left-Right Symmetric Models (LRSMs) conserve parity at high energies, introducing three new heavy right-handed Majorana neutrinos, new intermediate vector bosons W_R and Z' , Higgs bosons, and the left-right mixing parameter. At low energies, the Left-Right (LR) symmetry is broken, and parity is violated. Heavy right-handed neutrinos can explain the non-zero masses of light neutrinos via the seesaw mechanism⁸ and can allow for baryogenesis via leptogenesis. Constraints from the observed $K_L - K_S$ mass difference place a lower limit on $m_{WR} > 1.6$ TeV, although this is subject to possibly large corrections from higher-order QCD effects. Supernova data are consistent with right-handed neutrinos with masses of a few

hundred GeV⁹. At the LHC, new intermediate vector bosons would be produced via the Drell-Yan process, and their decay would produce the new heavy neutrinos as seen in the Feynman diagram in Figure 1.

2.Reconstruction, Signal Selection, and Background Suppression

Events included in these analyses must contain at least two good quality isolated electrons or muons and two jets, all with $p_T > 20$ GeV¹⁰. Background suppression variables include dilepton mass and the scalar sum of final state particles' p_T (S_T), which are shown in Figure 2 for the LRSM analysis in the electron channel. The signals must satisfy high p_T inclusive single lepton triggers. Trigger efficiencies in the dielectron (dimuon) channel are 97% (96.5%) and 96.4% (94.5%) for LQ ($m_{LQ} = 400$ GeV) and LRSM ($m_{WR} = 1.5$ TeV and $m_N = 500$ GeV) analyses, respectively.

The dominant backgrounds to LQ and LRSM signals are DY processes, top pair production, and diboson interactions. In addition, dijet events represent a potentially dangerous source of background for dielectron analyses and are discussed in more detail in Ref. 10.

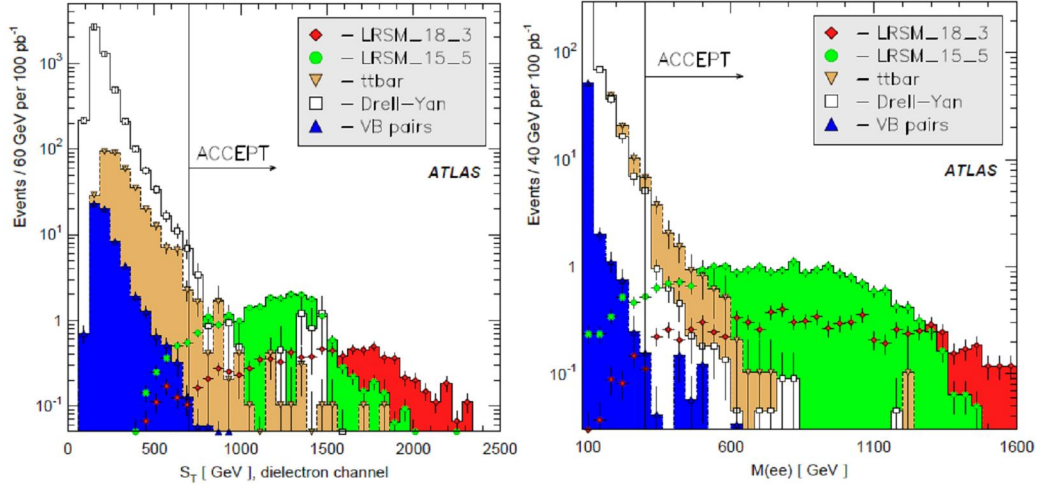


Figure 2: S_T (left) and m_{ee} (right) in LRSM dielectron channel.

There are two possible combinations when reconstructing LQ pairs from two leptons and two jets; the one yielding the smallest mass difference between the two lepton-jet masses is chosen. To suppress background in the 1st gen. leptoquark analysis, the following m_{ee} and S_T selection criteria were applied: $m_{ee} > 120$ GeV, $S_T > 490$ GeV. In addition, for the purpose of sensitivity and discovery potential estimates, only events where both LQ candidates have masses near the test mass are included. These mass windows are 320 GeV $< m_{ej} < 480$ GeV for $m_{LQ} = 400$ and 700 GeV $< m_{ej} < 900$ GeV for $m_{LQ} = 800$ GeV. In the 2nd gen. leptoquark analysis, the selection criteria $m_{\mu\mu} > 110$ GeV, $S_T > 600$ GeV, $p_{T\mu} > 60$ GeV, and $p_{Tjet} > 25$ GeV are applied. In addition, the average of the two LQ masses is required to be $300 < m_{ij} < 500$ for $m_{LQ} = 400$ GeV and $600 < m_{ij} < 1000$ GeV for $m_{LQ} = 800$ GeV. The distributions of reconstructed masses of LQ candidates before and after background suppression are shown in Figure 3 for 1st and 2nd gen. leptoquarks where $m_{LQ} = 400$ GeV.

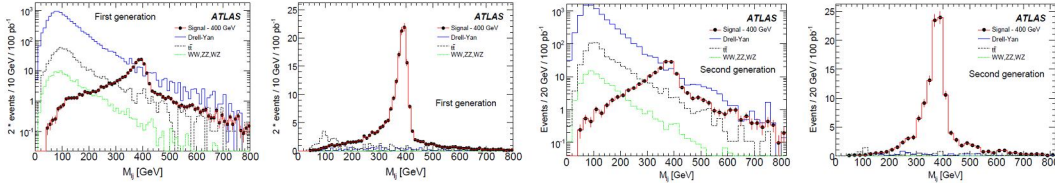


Figure 3: 1st (left) and 2nd (right) gen. reconstructed LQ mass before and after background suppression.

In the LRSM analyses, the two highest p_T leptons and two highest p_T jets are assumed to be the products of W_R boson decay. Due to the Majorana nature of the heavy neutrino, these analyses don't require the leptons to be oppositely charged, but it should be noted that same-sign dileptons is an important signal signature, since it is distinct to Majorana neutrinos and has negligible background. Both jets are added to each lepton, and the combination yielding the smaller invariant mass is taken to be the heavy neutrino (see Figure 1). When the ratio m_{W_R}/m_N becomes larger than 2, the lepton from heavy neutrino decay often begins to merge with one of the jets. The rate of merging of the Majorana decay products increases with the ratio m_{W_R}/m_N , and its effects on signal reconstruction are discussed in more detail in Ref. 10. In order to suppress background, the selection criteria $S_T > 700$ GeV and $m_{ll} > 300$ GeV are applied, and reconstructed neutrino masses before and after background suppression are shown in Figure 4.

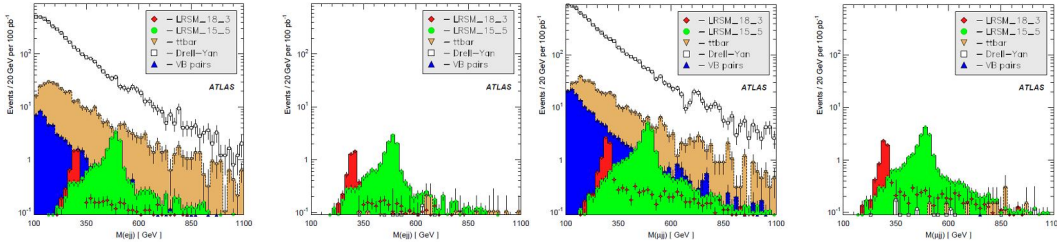


Figure 4: Reconstructed Majorana neutrino mass in dielectron (left) and dimuon (right) channels before and after background suppression.

3. Systematic Uncertainties and Results

For purposes of discovery potential estimates, significances are defined in units of gaussian standard deviations corresponding to the one-sided probability of observing a certain number of events exceeding expected background, $CL_b(N)$, where $N = N_s + N_b$ is the number of observed events, and N_s and N_b are estimated central values for the signal and background.

Uncertainties affect both signal and background efficiencies. However significances are affected mainly by backgrounds, where for the first 100 pb^{-1} , the systematic uncertainties are expected to be dominated by uncertainties in luminosity (20%), jet energy scale (16-35%), jet energy resolution (6-28%), and limited MC statistics (15-30%). A detailed discussion of systematics can be found in Ref. 10. These conservative estimates of uncertainties do not correspond to optimal detector performance and are estimated for the first 100 pb^{-1} .

Figure 5 shows the discovery potential for 1st and 2nd gen. leptoquarks in terms of the squared branching fraction β (for LQ decaying to a charged lepton and quark) vs. integrated luminosity and LQ mass. Our studies predict that ATLAS will be sensitive to LQ masses of 565 GeV and 575 GeV for 1st and 2nd gen. LQ, respectively, for $\beta=1$ with 100 pb^{-1} of data.

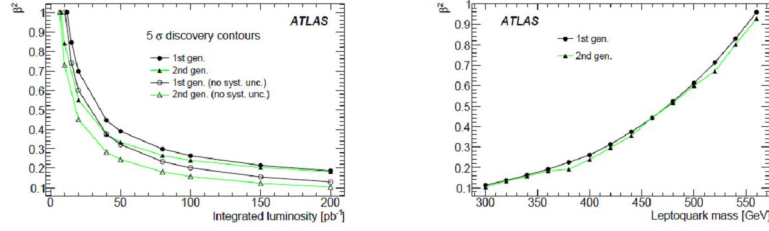


Figure 5: β^2 (where β is branching fraction $LQ \rightarrow l^+q$) vs. integrated luminosity needed for 5σ discovery for $m_{LQ}=400\text{GeV}$ (left) and β^2 needed for 5σ discovery vs. LQ mass with 100pb^{-1} of integrated luminosity (right).

Figure 6 (left) shows the significance of the LRSM signals vs. integrated luminosity. The two plots on the right in Figure 6 show the product of signal cross-section and dilepton branching fractions vs. integrated luminosity required for 5σ discovery. The discovery of the W_R boson and heavy neutrino considered here ($m_{WR} = 1.8\text{ TeV}$, $m_N = 300\text{ GeV}$ and $m_{WR} = 1.5\text{ TeV}$, $m_N = 500\text{ GeV}$) in the dielectron or dimuon channels would require 150pb^{-1} and 40pb^{-1} of integrated luminosity, respectively.

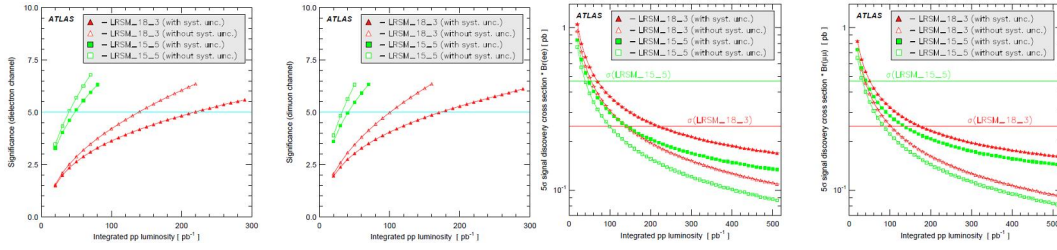


Figure 6: Significance (left) and partial cross-section (right) needed for 5σ discovery vs. integrated luminosity for dielectron and dimuon channels, respectively.

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