A SEARCH FOR W_R AND HEAVY NEUTRINOS IN THE DILEPTONS+JETS FINAL STATE WITH THE ATLAS DETECTOR

Reza Yoosoofmiya^a, on behalf of the ATLAS Collaboration
Department of Physics and Astronomy, University of Pittsburgh,
Pittsburgh PA 15260, USA

Abstract. This report describes a search for heavy Majorana neutrinos and W_R gauge bosons predicted by the Left-Right Symmetric Model and Effective Lagrangian Operators, in dilepton+dijet final state. The results were obtained from data collected in $\sqrt{s} = 7$ TeV proton-proton collisions with the ATLAS detector at the Large Hadron Collider (LHC) at CERN. Events observed in data corresponding to 34 pb^{-1} of integrated pp luminosity are consistent with the expectations for the Standard Model backgrounds. The exclusion limits are placed on masses of W_R and heavy neutrinos.

1 Introduction

The discovery of neutrino oscillations has firmly established that at least some of the known neutrinos have non-zero masses. One of the possible explanations for the small masses of the known neutrinos is the see-saw mechanism, *i.e.*, $m_\nu \approx m_D^2/M_N$, where, for each generation, m_ν is the mass of a known neutrino, m_D is the Dirac mass term for charged fermions of the same generation, and M_N is the mass of the new heavy neutrino.

If known neutrinos acquire masses via the see-saw mechanism, this implies neutrinos are Majorana particles, which makes lepton number violation possible, allowing for final states with same-sign lepton pairs. The search [1] for heavy Majorana neutrinos presented in this report is performed in the context of Left-Right Symmetric Model (LRSM) and the Effective Lagrangian Operators framework.

LRSM extends gauge group of the SM and introduces new force particles (W_R and Z') possibly manifesting themselves directly at LHC energies [3, 4]. In this model, the heavy neutrinos N are produced in the decays of a W_R via $q\bar{q} \rightarrow W_R \rightarrow lN$, with N decaying subsequently to $N \rightarrow lW_R^* \rightarrow ljj$. The final state is two high transverse momentum (p_T) leptons (electron or muon) and two high- p_T jets. The N and W_R invariant masses can be fully reconstructed from the decay products. Similarly to SM neutrinos, heavy Majorana neutrinos can mix if their masses are different. Both scenarios of no-mixing and maximal mixing between two generations of lepton flavour (e or μ) are investigated.

The second approach explores possible sources of new physics with heavy Majorana neutrinos using a Lagrangian of effective operators [5]. As the theory is built on effective operators, it allows probing any new physics that could explain the possible existence of heavy Majorana neutrinos. The considered

^ae-mail: reza@cern.ch

production process is $q\bar{q} \rightarrow Nl^\pm$, where N decays promptly via a three-body process as $N \rightarrow l^\pm jj$.

2 ATLAS Detector and Event Selection

The ATLAS detector [6] is a multipurpose particle physics apparatus with a forward-backward symmetric cylindrical geometry and a nearly 4π coverage in solid angle^b. The inner tracking detector (ID) provides high precision measurements for trajectories of charged particles, while a high-granularity liquid-argon (LAr) sampling electromagnetic calorimeter measures energies deposited by electromagnetically interacting particles. An iron scintillator tile calorimeter provides hadronic energy measurements in the central rapidity region; in the forward rapidity regions electromagnetic and hadronic measurements are provided by LAr calorimeters. The muon spectrometer (MS) surrounds the calorimeters, and measure the trajectories of muons.

Criteria for electron and muon identification closely follow those described in [7]. Accepted electrons are required to have $p_T > 20 \text{ GeV}$ and reconstructed in $|\eta| < 2.47$. Electrons whose tracks match muon candidates' ID tracks are rejected. Muons are required to have $p_T > 20 \text{ GeV}$ and $|\eta| < 2.4$. Additional selection criteria are applied to suppress muons from cosmics and hadronization. Jets are reconstructed using the anti- k_t jet clustering algorithm [8] with a radius parameter $R = 0.4$. Only jets with $p_T > 20 \text{ GeV}$ and $|\eta| < 2.8$ are considered. Jets closest to electron candidates (within a distance $\Delta R < 0.5$) are discarded. Details of the object selection can be found elsewhere [1].

Events are required to have at least one reconstructed primary vertex with five or more tracks consistent with this vertex. At least one of the lepton candidates must trigger the event at the last stage of the single-lepton trigger decision. Additionally, to suppress Drell-Yan and heavy flavor backgrounds, while keeping sufficient statistics needed to validate the relevant SM background estimates, the dilepton invariant mass, m_{ll} , is required to be greater than 110 GeV . The signal region is then subdivided into same-sign (SS) and opposite-sign (OS) dilepton events. The invariant mass m_{lljj} (which represents the final state for W_R candidates' decays) is required to be greater than 400 GeV . To further reduce the larger SM background contribution in the OS dilepton channels, the scalar sum of the transverse energies of the leptons and two highest p_T jets, denoted by S_T , is required to be greater than 400 GeV .

^bATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the center of the detector and the z -axis coinciding with the axis of the beam pipe. The x -axis points from the IP to the center of the LHC ring, and the y axis points upward. Cylindrical coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the beam pipe. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln \tan(\theta/2)$.

Figure 1: Combined exclusion limit for all channels (ee , $\mu\mu$ and $e\mu$) [2] for the mass of Heavy Majorana Neutrino for four-fermion operator V , assuming $\Lambda = 1$ TeV, $\alpha = 1$

3 Experimental Results

The numbers of events observed in data and expected according to the SM backgrounds in signal region in the SS and OS final states after preselection and final selection are shown in Table 1. A good agreement is observed between the numbers of data events and the predicted backgrounds. Figures 1 and 2 show limits obtained in the context of Effective Lagrangian Operators and LRSM, respectively.

Table 1: A summary of the expected and observed numbers of events for the SS and OS dilepton channels [1]. The top of the table gives the numbers of events obtained for events with two leptons, at least one jet and $m_{ll} > 110$ GeV. The bottom part of the table shows the numbers of events satisfying also requirements $M_{lljj} > 400$ GeV and, for the OS channel, $S_T > 400$ GeV. For each entry the statistical uncertainty is followed by the systematic uncertainty (the integrated luminosity uncertainty is not included). The uncertainty due to the integrated luminosity is 3.4% for all backgrounds except for the fake (i.e. heavy flavor) lepton background, which is measured from data.

Physics Processes	SS	OS
Preselection		
Diboson	$0.18 \pm 0.01 \pm 0.01$	$4.0 \pm 0.1 \pm 0.4$
$t\bar{t}$ + single top	$0.39 \pm 0.01 \pm 0.06$	$56.3 \pm 0.6 \pm 8.0$
$Z \rightarrow ll$	$0.81 \pm 0.06 \pm 0.15$	$106.6 \pm 3.2 \pm 14.0$
Fake lepton(s)	$5.81 \pm 1.27 \pm 2.06$	$6.9 \pm 2.3 \pm 2.7$
Expected background	$7.2 \pm 1.3 \pm 2.1$	$173.8 \pm 3.9 \pm 16.7$
Observed in data	5	177
Final selection		
Expected background	$1.9 \pm 0.4 \pm 0.5$	$13.3 \pm 1.2 \pm 2.1$
Observed in data	2	10

Figure 2: Observed and expected 95% CL lower limits [1] on masses for the heavy Majorana neutrino and W_R for the combined SS+OS channels obtained from the cross-section times branching ratio predictions. The no-mixing and maximal mixing scenarios are shown on the left and on the right, respectively. The exclusion region is inside solid-hatched boundary. The contours show the observed upper limit on $\sigma \times BR$ [pb] as the function of masses of heavy Majorana neutrino and W_R , where σ is the production cross-section for the W_R , and BR is the branching ratio to $ee, \mu\mu$ in the no-mixing scenario and $ee, \mu\mu, e\mu$ in the maximal mixing scenario.

4 Conclusion

Events observed in (34 pb^{-1}) of pp data are consistent with the expectations for the SM backgrounds. New limits are placed on W_R mass in the context of Left Right Symmetric Model. In the context of effective Lagrangian framework, for V operator (assuming $\alpha = 1$, $\Lambda = 1 \text{ TeV}$), heavy neutrinos of masses up to 460 GeV are excluded at 95% CL.

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