Search for R -Parity Violating Supersymmetry and Long Lived Particles with the ATLAS Detector

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Abstract. We present the results of two recent searches for physics beyond the Standard Model in pp -collision data with a center-of-mass energy of 7 TeV collected by the ATLAS detector at the Large Hadron Collider. The first analysis searches for heavy particles which decay a significant distance from their production point into a final state containing a high-momentum muon, and is based on a 33 pb^{-1} data sample. The second is a search for a heavy neutral particle decaying into an $e^\pm \mu^\mp$ final state and is based on 0.87 fb^{-1} of data. Both searches are motivated by models of R -parity violating supersymmetry, although alternative new physics interpretations are also considered in both cases.

Keywords: R -parity, Supersymmetry, Long-lived, Lepton Flavor, ATLAS, LHC

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MOTIVATION

Supersymmetry (SUSY) is an attractive theoretical model for physics beyond the Standard Model (SM). Searches for SUSY are an important part of the physics program at the Large Hadron Collider, and results from the ATLAS and CMS Collaborations have recently been presented [1]. R -parity is a quantum number defined as $(-1)^{3(B-L)+2s}$ in terms of the baryon number, lepton number, and spin quantum numbers B , L , and s , respectively. While R -parity is frequently taken to be a conserved quantity in SUSY, renormalizable R -parity violating couplings are generally allowed [2] and such models may lead to distinctive experimental signatures.

The production mechanisms for RPV SUSY are very similar to R -parity conserving models, with strong production of colored squarks and gluinos dominating the cross sections at the LHC. Unlike R -parity conserving models, however, the lightest supersymmetric particle (LSP) produced at the end of the decay chains is unstable and decays into SM particles via one or more R -parity violating couplings. These couplings mediate processes which violate lepton number, lepton flavor, or baryon number conservation. There are strong constraints from low-energy measurements, including proton decay and cosmology, that these some of the coupling constants (or products of coupling constants) are small. Such small coupling constants may imply small a decay width, and therefore a long lifetime, for the LSP.²

We present the results of two recent searches for R -parity violating SUSY, the first searching for a long-lived particle signature and the second for lepton-flavor violation.

SEARCH FOR EVENTS WITH DISPLACED VERTICES

One generic feature of RPV SUSY models for specific ranges of coupling constants is the prediction of massive long-lived particles [2]. We present here the results of a search for a new heavy particle decaying into several charged particles in events containing a high-momentum muon, at a distance of order millimeters to centimeters from the pp interaction point. Such a signature might arise from a neutralino LSP decaying as $\tilde{\chi}^0 \rightarrow \mu \tilde{\mu} \rightarrow \mu q_i q_j$ via an intermediate virtual $\tilde{\mu}$ and the RPV coupling λ'_{2ij} [3].

Events are triggered by the presence of a high-momentum muon. We identify the primary vertex (PV) in the event by requiring at least five well-reconstructed tracks; for events with multiple PV candidates, we select the one with the highest scalar sum of the momenta of associated tracks. We then select tracks which have a large impact parameter

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² The long-lived particle search presented here is sensitive to lifetimes $c\tau \sim 1\text{--}100 \text{ mm}$, but the LSP lifetime may be much shorter or much longer.

FIGURE 1. Results of the search for displaced vertices. The left figure shows the observed distribution of vertex mass versus number of tracks. No events are observed in the signal region. The right figure shows the derived 95% C.L. upper limits on the production cross section times branching fraction as a function of the neutralino lifetime, for several different squark and neutralino mass hypotheses. For a 150 GeV squark, the expected cross section times branching fraction would be 95 pb.

relative to the PV and, from this set of tracks, use an iterative procedure to construct secondary vertex candidates. We require the selected tracks to have a good fit ($\chi^2/\text{degrees of freedom} < 5$) to the vertex. We require that the vertex be located within the central fiducial volume of the pixel detector, to ensure the most precise measurement of the secondary vertex location, and that the vertex be displaced at least 4 mm from the PV. The typical spatial resolution on the vertex position ranges from tens to hundreds of microns, depending on the decay position.

Dominant backgrounds to this search arise from combinatorial vertices and from material interactions. In order to suppress these backgrounds, we require that the number of tracks associated to the secondary vertex be at least four, and that the invariant mass of all associated tracks be greater than 10 GeV. We further veto vertices which are reconstructed in regions of high material density, using a material map derived from minimum-bias events.

Simulated event samples are used to estimate the expected backgrounds, with the efficiencies for events to pass the muon and trigger requirements evaluated independently of the secondary vertex selection. Based on simulation studies, we set a conservative limit on the expected background, $N_{BG} < 0.03$ events in our 33 pb^{-1} sample. The combinatorial vertex background is independently estimated in a sample of non-diffractive events in data and found to agree with the simulation, and the efficiency of the vertex mass cut is independently validated in a jet-triggered event sample. The dominant systematic uncertainties are due to the track-reconstruction and muon identification efficiencies as functions of the track impact parameter relative to the PV. These are studied in control samples with displaced tracks, including cosmic-ray muons and pions from K_S^0 decay, and the simulation is found to describe the data within 3–8%.

Figure 1 shows the results of this search. The left figure shows the distribution of vertex mass versus number of tracks observed in data. No events are observed in the signal region. Based on this observation, we set upper limits on the production cross section times the branching fraction for various SUSY models. For a 150 GeV squark, this limit is below the expected 95 pb cross section for most of the sensitive range of $c\tau$. We also set a model-independent limit on the cross section times branching fraction times acceptance of 0.09 pb at 95% C.L.

SEARCH FOR A RESONANCE DECAYING TO $e^\pm \mu^\mp$

R -parity violating SUSY includes couplings which violate lepton flavor conservation. We present the results of a search for a new heavy neutral particle decaying to an $e^\pm \mu^\mp$ pair [4]. In RPV SUSY, this may arise via the sneutrino decay $\tilde{\nu}_\tau \rightarrow e^- \mu^+$ with the $\tilde{\nu}_\tau$ produced via the RPV coupling λ'_{311} and decaying via λ_{312} [2]. The search is sensitive to other new physics processes as well, including new gauge bosons Z' with lepton-flavor-violating couplings [5].

Events are triggered by the presence of a high momentum electron or muon. An opposite charge $e\mu$ pair is

FIGURE 2. Results of the search for an $e^\pm\mu^\mp$ resonance. The left figure shows the $e^\pm\mu^\mp$ invariant mass spectrum observed in data and the expected backgrounds. Simulated signals are also shown for a 650 GeV $\tilde{\nu}_\tau$ (dotted line) and a 700 GeV Z' (dashed line). No evidence for a resonant structure is seen. The figure on the right shows the observed 95% C.L. upper limits on the $\tilde{\nu}_\tau$ cross section times branching ratio as a function of the $\tilde{\nu}_\tau$ mass, which varies from 130 to 11 fb between $\tilde{\nu}_\tau$ masses of 100 and 1000 GeV. The dashed line shows the limit from the previous ATLAS search. Theoretical predictions are shown for two RPV models, $\lambda'_{311} = 0.1$, $\lambda'_{312} = 0.05$ and $\lambda'_{311} = 0.01$, $\lambda'_{312} = 0.01$.

reconstructed with both leptons well isolated from hadronic activity in the event. This search is an update of a previous ATLAS search [6] with a data sample 25 times larger, tighter lepton momentum and isolation requirements, and a more robust data-driven background estimation technique.

Two types of background processes are considered. Events with two real prompt leptons, including $t\bar{t}$, $Z \rightarrow \tau\tau$, and WW , are estimated using simulated event samples. Instrumental backgrounds, including fake leptons and secondary leptons from b - and c -hadron decays, are estimated in data using a matrix technique based on looser lepton identification criteria. We extrapolate backgrounds into the signal region by measuring signal and background efficiencies in dedicated control regions in data: $Z \rightarrow e^\pm e^\mp / \mu^\pm \mu^\mp$ for electron and muon efficiencies, and QCD dijet events for jet fake rates. After background estimation, good agreement is seen between data and simulation in a number of important kinematic variables, giving confidence that a potential high-mass resonance would also be well described.

Figure 2 shows the results of the $e^\pm\mu^\mp$ resonance search. The left figure shows the $e^\pm\mu^\mp$ invariant mass spectrum observed in data and the expected backgrounds. No evidence for a resonant structure is seen. The figure on the right shows the observed 95% C.L. upper limits on the $\tilde{\nu}_\tau$ cross section times branching ratio as a function of the $\tilde{\nu}_\tau$ mass. These limits improve upon the previous ATLAS result by about one order of magnitude. We also set limits on Z' production; at 700 GeV (2 TeV) Z' mass, the cross section times branching ratio is less than 10.6 (10.0) fb.

SUMMARY AND OUTLOOK

We have presented the results of two recent searches for R -parity violating supersymmetry with the ATLAS detector, one for new heavy particles produced in association with a muon and decaying with a long lifetime, and the other a search for a new heavy resonance decaying to $e^\pm\mu^\mp$. No excesses beyond the Standard Model backgrounds have been seen yet, but there is an active ongoing search program at the LHC and we continue to push the limits to constrain the allowable SUSY parameter space.

REFERENCES

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