Search for long-lived massive particles with the ATLAS detector

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Abstract. Several supersymmetric and exotics theories extending the Standard Model predict massive long-lived particles. Such particles may be detected through abnormal specific energy loss, appearing or disappearing tracks, displaced vertices, long time-of-flight or late calorimetric energy deposits. Results are presented from searches for massive stable particles in proton-proton collisions at $\sqrt{s}$ = 7 TeV with the ATLAS detector.

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SEARCHES AT ATLAS

Long-lived massive particle searches at ATLAS [1] can be divided into three categories: *charged*, *neutral*, and *stopped* particle searches. A neutral particle does not leave a track; therefore searches for long-lived massive *neutral* particles typically focus on the identification of displaced vertices or trackless jets. Charged particles, on the other hand, leave tracks; searches for long-lived massive *charged* particles typically focus on the unique characteristics of tracks left by massive charged particles: massive particles are slow and thus highly ionizing; their decay can cause the track to kink or disappear. Finally, massive particles can be so slow as to stop in the detector; so-called *stopped* particle searches focus on their decay being highly delayed relative to the hard-scatter.

Examples of long-lived neutral particle searches include a search for decays of Hidden Valley particles [2], and a search for *R*-parity violating decays of SUSY particles [3]. Both searches rely on the identification of displaced vertices. Long-lived charged particle searches include searches for R-hadrons [4, 5], stable stau leptons [6], Highly Ionizing Particles (HIP) [7], and displaced decays in Anomaly Mediated SUSY Breaking (AMSB) models [8]. These searches involve tracks with anomalously high energy loss (dE/dx) in the pixel detector or in the Transition Radiation Tracker (TRT), low velocity determined from timing measurements or track fitting, or truncated tracks. Finally, a search has been performed for particles that stop in the ATLAS detector: the stopped R-hadron search [9] which identifies jets in empty or unpaired bunch crossings.

Here three of the above ATLAS analyses are briefly described and results presented.

Hidden Valley

A Hidden Valley [10] (HV) model was considered [2] in which a light Higgs boson decays to two hidden-sector valley-pions (π_v). Each π_v is a neutral pseudo-scalar with a displaced decay to heavy fermion pairs. Higgs masses of 120 and 140 GeV and π_v masses of 20 and 40 GeV were studied, with the π_v decaying predominantly to $b\bar{b}$.

This analysis considered decays specifically in the Muon Spectrometer (MS). The expected signal is a large number of tracks in the MS from the bottom quark decays, but isolated from jets and inner detector tracks. A signature-driven trigger, the Muon Cluster Trigger, was developed to trigger on events containing a cluster of track segments isolated from jets and inner detector tracks. For the offline analysis, a vertex-finding algorithm was developed to identify "MS vertices" from π_v decays in the MS.

Since two π_v are expected to be produced in each event, the possible identification of multiple MS vertices can be exploited to reduce backgrounds. The final event selection required the identification of two separated MS vertices, each isolated from jets and inner detector tracks. Zero events were found to pass the event selection in 1.94 fb^{-1} of 2011 data.

The number of expected background events was calculated using a data-driven technique. The probability P_{vertex} that a random event contains a vertex in the MS was calculated by measuring the fraction of events containing an MS vertex in a random sample of events provided by the Zero Bias stream. The probability P_{reco} to reconstruct a vertex in events that pass the Muon Cluster trigger was calculated by measuring the fraction of triggered events that contain an MS vertex. The number of background events with two MS vertices was then calculated to be P_{vertex} times the number of events with one MS vertex and one triggering Muon Cluster, plus P_{reco} times the number of events with one MS vertex and two separate triggering Muon Clusters. The final number of expected background events was found to be: 0.03±0.02.

Depending on the π_v lifetime and assuming BR($h \rightarrow \pi_v \pi_v$)=100%, between zero and 100 events are expected if the signal hypothesis were correct. As a result, π_v proper decay lengths between 0.45 m and 26.75 m were excluded at 95% CL, depending on the higgs, π_v mass point.

Anomaly Mediated SUSY Breaking

An anomaly-mediated supersymmetry-breaking [11] (AMSB) model was considered [8], in which the lightest chargino is predicted to be long-lived. A search was performed for disappearing tracks resulting from decaying charginos in the minimal AMSB framework with chargino masses of 90 GeV, 118 GeV, and 148 GeV.

This analysis considered decays specifically in the TRT. The candidate chargino track was identified as an isolated track with $p_T > 10$ GeV, with fewer than five hits in the outer module of the TRT (N_{TRT}^{outer}). Along with the decay of the chargino, the cascade decay of gluinos and squarks results in a final state with multiple jets and large missing transverse energy (E_T^{miss}). In addition to a candidate chargino track, the final event selection required three jets ($p_T > 130, 60, 60$ GeV), $E_T^{miss} > 130$ GeV, and zero electron or muon candidates with $p_T > 10$ GeV. 304 events were found to pass the event selection in 4.7 fb^{-1} of 2011 data.

Two main background sources that result in high-p_T disappearing tracks were identified: interacting hadron tracks, and badly reconstructed tracks. Interacting hadron tracks dominate the background, and result from charged hadrons in jets that interact inside the TRT. Badly reconstructed tracks result from low p_T particles that scatter in the inner detector material and are incorrectly reconstructed. The number of expected background events was calculated by constructing MC signal and background track p_T templates, and fitting them to the data. The p_T templates for the background were measured on data, by identifying two control regions, one for interacting hadron tracks with $N_{TRT}^{outer} > 10$, and another for mismeasured tracks with no pixel hits and $E_T^{miss} < 100$ GeV. The best fit to the data results in zero contribution from the signal template, and constraints on the AMSB chargino mass and lifetime are set: a chargino having a mass below 90 (118) GeV and 0.2 (1) < τ < 90 (2) ns is excluded at 95% CL.

R-Hadron

A model in which the Lightest Susy Particle is a stable gluino in the mass range 200–1000 GeV was considered [4]. In such a model, the gluino can hadronize with quarks and gluons to form a massive long-lived charged R-hadron [12]. Such an R-hadron travels slowly through the detector, and is thus highly ionizing. This fact was exploited to make a mass measurement using the track momentum and the dE/dx measured in the pixel detector.

The R-hadron deposits only a small amout of energy in the calorimeter and can produce missing transverse energy. The final event selection required $E_T^{miss} > 85$ GeV, and an isolated R-hadron candidate track with $p_T > 50$ GeV and an η-dependent dE/dx cut. 333 events were found to pass the event selection in 2.1 fb^{-1} of 2011 data.

The number of expected background events was estimated by normalizing the track mass distribution to data in a low-mass control region. The expected mass distribution for the background was built by sampling randomly p, η and dE/dx values from low dE/dx and low momentum control regions. The number of expected background events was 332, and the resulting limit on the gluino-based R-hadron mass was 810 GeV at 95% CL.

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