PROCEEDINGS OF SCIENCE

Search for long-lived particles in events with a displaced vertex using the ATLAS detector with the full Run 2 dataset

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A large number of physics models beyond the Standard Model predict the existence of new, massive, long-lived particles. Searches for these particles rely on the detection of the decay products at a significant distance from the collision point. This signature provides interesting technical challenges due to their special reconstruction requirements as well as their unusual backgrounds. Recent results are presented on the search for long-lived SUSY particles using a displaced vertex in association with jets with the ATLAS full Run 2 data.

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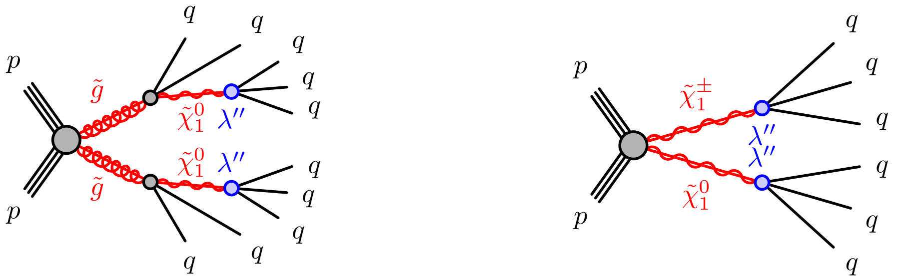
1. Analysis target

A large number of physics models beyond the Standard Model predict the existence of new, massive, long-lived particles (LLPs). We search for LLPs decaying inside the inner detector creating displaced vertices (DVs) in the multi-jets final state with the ATLAS full Run-2 dataset [1]. Figure 1 shows the diagrams of our target benchmark model, the R-parity violating (RPV) SUSY model [3]. In this model, small RPV coupling between neutralinos and Standard Model (SM) particles makes the neutralino long-lived and its decay vertex displaced from the interaction point. Quarks are detected as jets, and the final state includes multiple jets.



(a) **(b)**

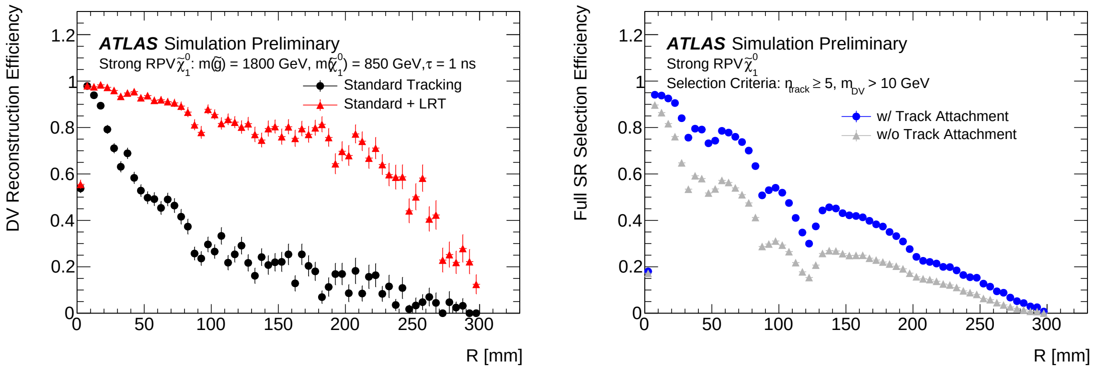
Figure 1: Diagrams of target benchmark models: (a) the gluino pair ($\tilde{g}\tilde{g}$) production model, in which each gluino decays into a pair of quarks and a long-lived neutralino ($\tilde{\chi}_1^0$), and (b) the chargino-neutralino pair ($\tilde{\chi}_1^\pm \tilde{\chi}_1^0$) production model. The $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_1^0$ decay to three quarks via the RPV coupling λ''.

2. Special reconstruction

The signal processes targeted in this search include massive particles with mean proper lifetimes τ up to $O(10)$ ns. Several charged particles originate from locations far from the primary pp interaction point and require dedicated techniques for efficient reconstruction.

First, Large Radius Tracking (LRT) [4] is introduced to reconstruct tracks derived from DVs. The standard track reconstruction algorithm in the ATLAS experiment assumes only tracks derived from decay points near the interaction point. Thus a large inefficiency for the signals is observed. The LRT method reconstructs tracks from decay points about 300 mm away from the interaction point by using only the detector hit points not used in the standard tracking. Then, DVs are reconstructed using the standard tracks and the tracks reconstructed by LRT with the following order: 1. Form two-track seed vertices with high-quality tracks, 2. Merge the seed vertices to form N-trk vertices, 3. Attach lower-quality tracks to the vertices [5].

Figure 2(a) shows the vertex reconstruction efficiency with only standard tracking and with standard tracking and LRT. The vertex reconstruction efficiency is recovered largely in the region with a large radial distance from the beam axis (R) by using the LRT. Figure 2(b) shows the vertex selection efficiency which satisfies the signal region (SR) requirements defined in Section 3 with and without attached lower-quality tracks. The selection efficiency is recovered by up to 20% by attaching the lower-quality tracks.



(a) **(b)**

Figure 2: Combined vertex and track reconstruction efficiency as a function of radial position R. The efficiency is defined as the probability for a true neutralino decay to be matched with a reconstructed DV. In (a), the efficiencies with and without the special LRT processing are shown for one benchmark signal. In (b), the impact of attached tracks on the total SR selection efficiency is shown.

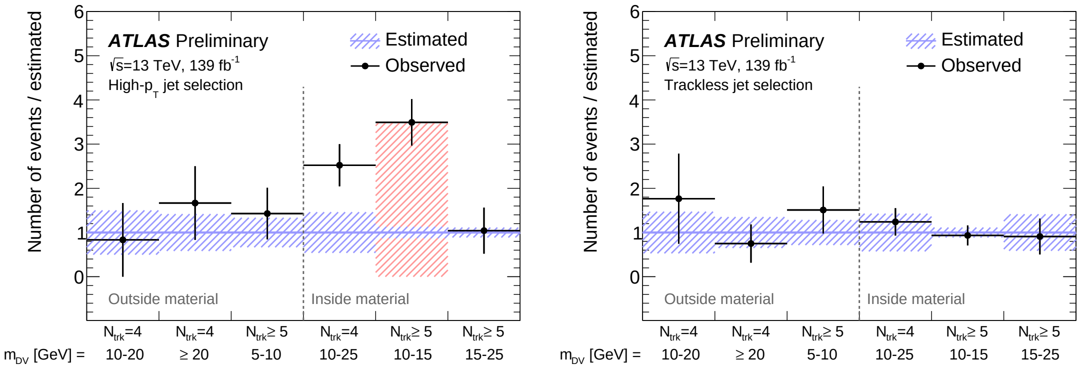
3. Event selection and background estimation

Two SRs are defined, which are called the High-p_T SR and the Trackless SR focused on the models of Figure 1(a) and Figure 1(b), respectively. These SRs require several jets and at least one DV passing the DV selections. The thresholds of the jets depend on the jet multiplicity and range from 90 to 250 GeV for the High-p_T SR and from 55 to 137 GeV for the Trackless SR. For the Trackless SR, at least one jet not associated with tracks is required additionally. The DV selections require good quality for the DV reconstruction ($\chi^2/N_{\mathrm{dof}} < 5$), the DV to be before silicon strip detector, the DV to be displaced more than 4 mm from primary vertex, the DV to be outside the material (i.e. detectors and support structures) region, and finally, the DV to have at least 5 tracks and the invariant mass reconstructed from these tracks greater than 10 GeV.

No high-mass SM particles give rise to displaced decays, and the background originates only from three instrumental sources: the interactions with material, the random track crossing, and incorrectly merged DVs. In the previous analysis, these backgrounds were estimated independently, but the increased statistics in data required the consideration of the correlations between the background sources. We established a new method to estimate all backgrounds inclusively including the correlations between backgrounds, track density, and the number of track jets. Figure 3 shows the validation results of this method, and the estimation agree with data within error.

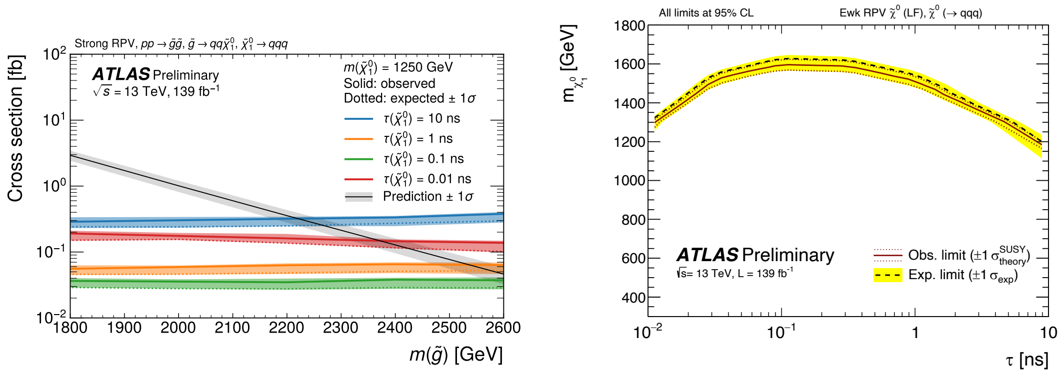
4. Results

Expected background yields in the High-p_T SR and Trackless SR are $0.46^{+0.27}_{-0.30}$ and $0.83^{+0.51}_{-0.53}$, and observed yields are one and zero, respectively. There is no significant excess, and the exclusion limits at 95% CL are set. Figure 4 shows the exclusion limits on the production cross section of gluino pairs and the exclusion limits on the lifetime and mass of the $\tilde{\chi}_1^0$ in electroweakino pair production models. At 95% CL, $m(\tilde{\chi}_1^0)$ values up to 1.58 TeV for $\tau = 0.1$ ns are excluded, and the limit surpasses 1.5 TeV for all lifetimes in the range from 0.03 ns to 1 ns.



(a) **(b)**

Figure 3: Validation of background estimate in the sideband validation regions. The uncertainty based on observed non-closure inside the material region is separately shown in red. This non-closure is considered to be additional uncertainty in the SR.



(a) **(b)**

Figure 4: Exclusion limits at 95% CL on (a) the production cross section of gluino pairs as a function of $m(\tilde{g})$ and (b) the lifetime and mass of the $\tilde{\chi}_1^0$ in electroweakino pair production models. The limits in (a) are shown for several values of $\tau(\tilde{\chi}_1^0)$ along with the nominal signal production cross section and its theoretical uncertainty. In (b), the dashed line and the shaded band are the expected limit and its $\pm 1\sigma$ uncertainty, respectively. The thick solid line is the observed limit for the central value of the signal cross-section. The expected and observed limits do not include the effect of theoretical uncertainties in the signal cross-section. The dotted lines show the effect on the observed limit of varying the signal cross-section by $\pm 1\sigma$ of the theoretical uncertainty. The area below the solid line is the excluded parameter space.

References

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