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Search for long-lived massive particles in events with displaced vertices and missing transverse momentum in $\sqrt{s} = 13$ TeV pp collisions with the ATLAS detector

PoS(EPS-HEP2017)713

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A search for long-lived particles at the electroweak scale, which are predicted by a number of theories beyond the Standard Model, such as long-lived gluino in Split Supersymmetry, is presented. The search uses 32.7 fb^{-1} of 13 TeV pp collision data collected by the ATLAS detector at the LHC, and explores a multi-track vertex displaced from the collision point of proton-proton beams. The observed yield is consistent with the expectation from the background only hypothesis, resulting in 95% confidence-level exclusion of the long-lived gluino with masses up to 2.4 TeV at around $\tau = 0.17$ ns.

The European Physical Society Conference on High Energy Physics
5-12 July, 2017
Venice

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Many theories beyond the Standard Model predict that various long-lived particles with masses at the electroweak scale can be produced at the Large Hadron Collider [1]. In this article, the gluino ($\tilde{g}$), the supersymmetric (SUSY) partner of the gluon, giving rise to a displaced vertex (DV) from a primary vertex (PV) is considered as a benchmark. Figure 1 shows the decay of the gluino to the lightest SUSY particle ($\tilde{\chi}_1^0$) and two quarks (q). In the context of Split SUSY, SUSY partners of quarks ($\tilde{q}$) are supposed to have several orders of magnitude heavier mass than the gluino mass, which makes the gluino long-lived [2]. After the discovery of the Higgs boson and the non-discovery of the SUSY particles, the Split SUSY has become more appealing.

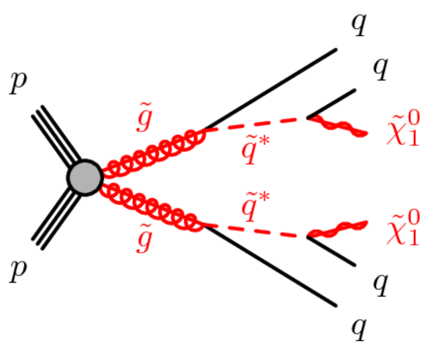

Figure 1: Feynman diagram of the production and decay of the gluino, which is long-lived in Split SUSY due to the heavy intermediate squarks.

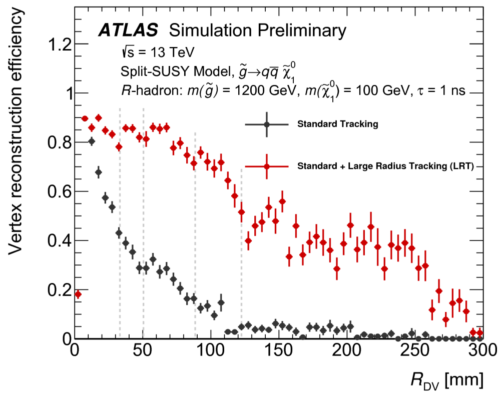

Figure 2: The vertex reconstruction efficiency as a function of its displacement from the PV in the transverse plane [8].

In the search for the long-lived gluino, 32.7 fb^{-1} of 13 TeV pp collision data collected by the ATLAS detector [3] in 2016 is used. A E_T^{miss} trigger is employed. The analysis strategy is based on the method used in Ref. [5] [1], which exploits the performance of the ATLAS detector to reconstruct decay products, such as dozens of hadrons from the long-lived gluino. The number of decay products depends on $\Delta M = m_{\tilde{g}} - m_{\tilde{\chi}_1^0}$. For this purpose, a special reconstruction for tracks with large transverse and longitudinal impact parameters (d_0 and z_0) has been developed [7], using only hits that are not associated with already reconstructed tracks with the standard tracking algorithm. Requirements on the impact parameters are relaxed, allowing tracks to have $|d_0| < 300$ mm and $|z_0| < 1500$ mm; the standard tracking algorithm requires $|d_0| < 10$ mm and $|z_0| < 250$ mm.

In the DV reconstruction, a selection for displaced tracks of $|d_0| > 2$ mm is applied in order to reject tracks from the PVs. In addition, a DV is required to be separated by 4 mm in the transverse plane from all reconstructed PVs. Figure 2 shows the vertex reconstruction efficiency. In the analysis, the signal region is defined to only contain a DV composed of at least 5 tracks with an invariant mass of more than 10 GeV.

To suppress the background arising from hadronic interactions with the ATLAS detector,

[1] A considerable improvement in this search from Ref. [5] is a significant gain of sensitivity in low ΔM region, which was pointed out in Ref. [4]. This will be described in a forthcoming publication in details [6].

material-dominated regions identified by studying reconstructed DVs in $\sqrt{s} = 13$ TeV minimum bias data are removed from the search. After the rejection, the dominant source of background is low-mass DVs, such as vertices generated from the decays of K_S^0 and Λ^0, crossed by unrelated tracks. The subdominant background is that two independent low-mass DVs are closely generated by chance and reconstructed as a merged DV with a larger invariant mass. These backgrounds are evaluated with a data-driven method that uses actual tracks associated with a reconstructed DV. Consequently, the number of background vertices in the signal region is estimated as 0.02 ± 0.02 events. Analysis details are described in Ref. [8].

Figure 3 shows the number of observed events after all the selections; the number of observed events in the signal region is zero. Therefore, exclusion limits with 95% confidence level are placed. Figure 4 shows lower limit of the gluino mass as a function of its lifetime, assuming $m_{\tilde{\chi}_1^0} = 100$ GeV. Long-lived gluinos with a mass larger than 2000 GeV are already excluded for wide range of lifetime. The best exclusion limit is obtained with $m_{\tilde{g}} = 2.4$ TeV and $\tau = 0.17$ ns.

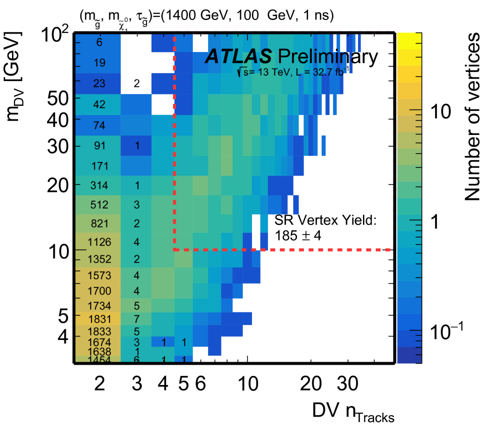

Figure 3: The number of events after all the selections. Numbers correspond to the observations in data, while the color contour shows an example distribution of the gluino signal [8].

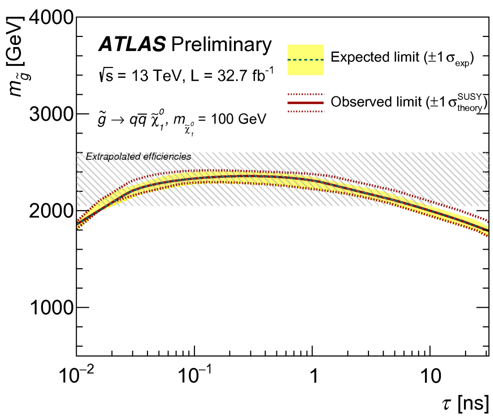

Figure 4: Exclusion limits with 95% confidence level on $m_{\tilde{g}}$ as a function of τ for $m_{\tilde{\chi}_1^0} = 100$ GeV [8].

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