Note on recasting the 13 TeV ATLAS multi-track Displaced Vertex + MET search

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This notes describes the procedure for recasting the 13 TeV ATLAS multi-track DV+MET search in Ref. [1]. ATLAS has recently publish this paper superseding ATLAS-CONF-2017-026, with a prescription using parametrized efficiencies (as a function of vertex radial distance, number of tracks and mass) that can be applied to vertices and events passing certain particle level acceptance requirements using the truth MC event record. These recasting at the truth level is done in Section I. We produce upper limits on the gluino cross-section. Our recasting of the exclusion plots have small discrepancies, finding the parametrized efficiency tables ideal for recasting.

Before this latest analysis, we did a recast using only the information in the internal note ATLAS-CONF-2017-026, and found it insufficient for proper recasting. Particularly, the vertex reconstruction efficiency presented for the simplified gluino model is not enough for extracting a parametrization of the efficiency at the track level. We find that having an explicit functional form for track efficiency is necessary for example to not overestimate the number of tracks coming from the displaced vertex. Also if we have this, one can then perform (and properly validate) a vertex-level efficiency. We try three different parametrization for track efficiency based on relevant displaced variables. We produce upper limits on the gluino cross-section. Our recasting of the exclusion plots have large discrepancies for some of the track parameterizations used.

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I. RECASTING USING TRUTH DISPLACED VERTICES AND NEW PARAMETRIZED EFFICIENCIES PROVIDED BY ATLAS

A. Introduction

The ATLAS DV+MET search in [1] looks for high mass, high track multiplicity displaced vertices in association with large missing transverse momenta at $\sqrt{s} = 13$ TeV and 32.7fb^{-1}. The results of the search are interpreted in a split SUSY simplified model with a long-lived gluino that hadronizes forming an R-hadron before decaying, $\tilde{g} \to q\bar{q}\tilde{\chi}_1^0$, with lifetimes between 10^{-2} ns to 100 ns, so the decays are reconstructed inside the inner tracker of the ATLAS detector.

B. Event simulation and selection

We generate event samples with Pythia 8.2 [2]. The ATLAS gluino simplified model we wish to validate was provided by Andre. The spectrum and decay information is communicated via SUSY Les Houches Accord (SLHA) files [3, 4]. We use truth level missing transverse momenta and identify displaced vertices at the truth level (by identifying the truth R-hadron decay position and decay products), as the collaboratin provides selction efficiencies that can be directly applied to this truth level quantities. These efficiencies can be found in [5], and are given at the event-level as a function of the truth missing transverse momenta and displaced vertex radial distance, and at the vertex level parametrized as function of vertex invariant mass and number of tracks, and are given for different regions in the detector encapsulating also the effect of the material veto cut.

The selection of events used for the signal region requires [5]:

- truth level missing transverse momenta > 200 GeV.
- one trackless jet with $p_T > 70$ GeV, or two trackless jets with $p_T > 25$ GeV. A trackless jet is defined as a jet with $\sum_{tracks} p_T < 5$ GeV.

In addition, events must have at least one displaced vertex with [5]:

- transverse distance between the IP and the decay position > 4 mm.

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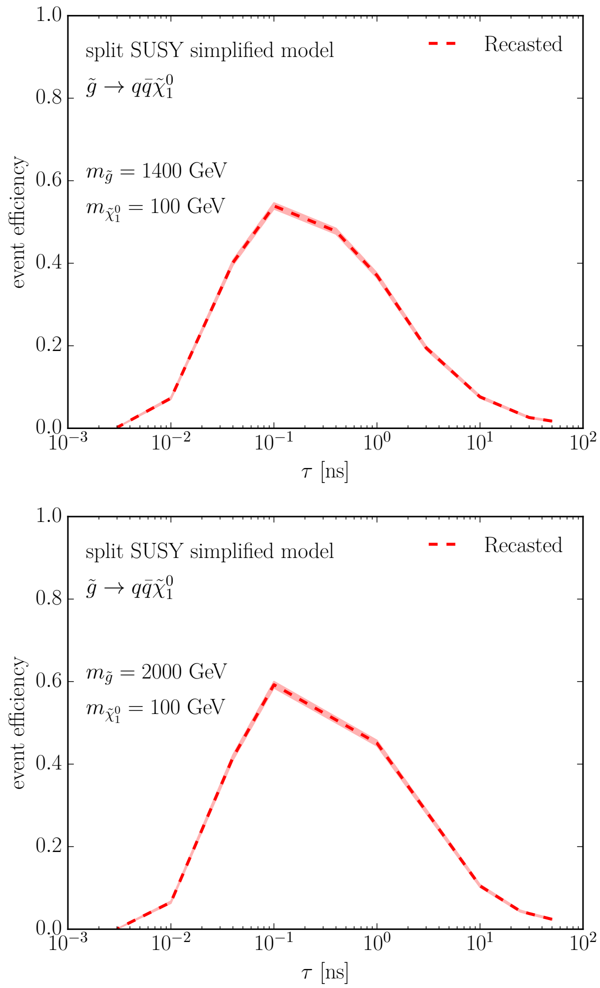

FIG. 1. Recasted event level efficiency against gluino proper decay lifetime τ.

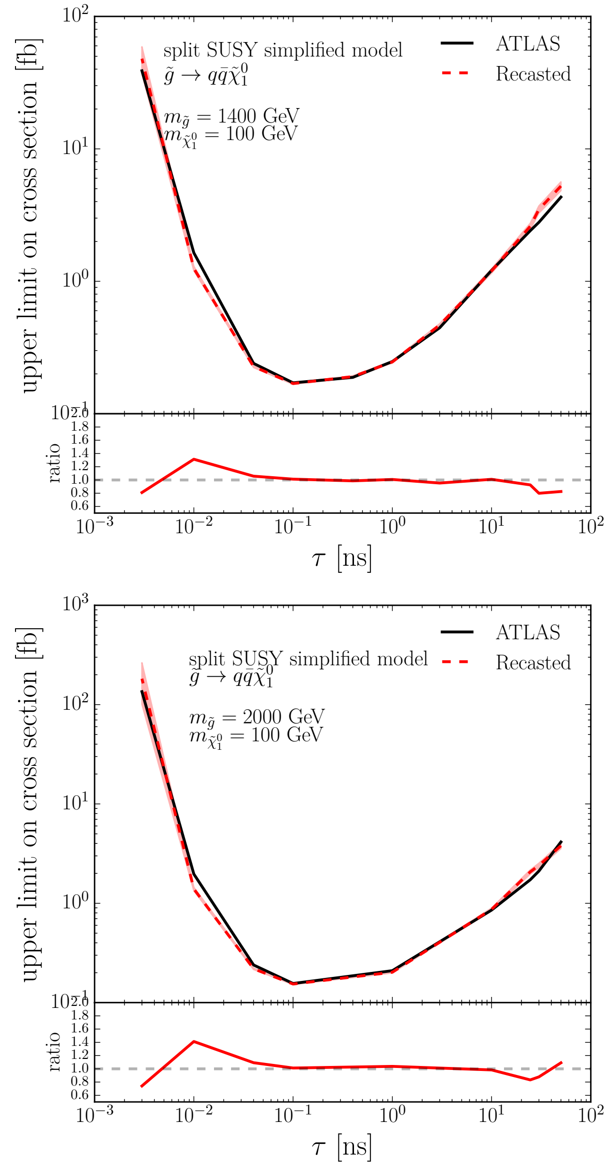

FIG. 2. Comparison of upper limit in the production cross section.

- the decay position must lie in the fiducial region $r_{DV} < 300$ mm and $|z_{DV}| < 300$ mm.
- the number of selected decay products must be at least 5, where selected decay products are charged and stable, with $p_T > 1$ GeV and $|d_0| > 2$ mm.
- the invariant mass of the truth vertex must be larger than 10 GeV, and is constructed assuming all decay products have the mass of the pion.

C. Recasting results

Applying the cuts and efficiencies, we get the following event-level efficiencies for the two benchmarks in Figure 1.

Based on the efficiency curves we can extract 95% CL upper limits on the total visible cross section for the two gluino masses. We know that

$$N_{\text{signal}} = \sigma \times \varepsilon \times \mathcal{L}, \tag{1}$$

Inserting in Equation 2 $N = N_{\text{upper}} = 3$ (which is a 95% interval of the observation of zero events) the luminosity $\mathcal{L} = 32.7$ fb^{-1} and since the estimated number of background vertices is 0.02 (see Ref. [6]), we get the results in Figure 5. For reference, assuming 100% efficiency we get an upper limit of 0.09113 fb with this approximation.

D. Comments on this recasting procedure

- The parametrized efficiencies are extremely useful for recasting.

II. RECASTING USING DISPLACED VERTEX RECONSTRUCTION AND PROPOSING A FUNCTIONAL FORM FOR TRACK EFFICIENCY

A. Introduction

The ATLAS DV+MET search in [6] looks for high mass, high track multiplicity displaced vertices in association with large missing transverse momenta at $\sqrt{s} = 13$ TeV and 32.7fb^{-1}. The results of the search are interpreted in a split SUSY simplified model with a long-lived gluino that hadronizes before decaying, $\tilde{g} \to q\bar{q}\tilde{\chi}_1^0$, with lifetimes between 10^{-2} ns to 50 ns, so the decays are reconstructed inside the inner tracker of the ATLAS detector.

B. Event simulation and selection

This displaced vertex analysis performs an actual reconstruction of a secondary vertex using track information. Events are selected with a MET trigger.

We generate event samples with Pythia 8.2 [2], using FastJet 3.1.3 [7] for jet reconstruction. The ATLAS gluino simplified model we wish to validate was provided by Andre. The spectrum and decay information is communicated via SUSY Les Houches Accord (SLHA) files [3, 4]. We use the same detector simulation implemented in Pythia 8 and we reconstruct displaced vertices in the same way as described in Ref. [8].

The selection of events used for the signal region (and our approximations to real detector simulation) are described in Table I.

The ATLAS analysis re-runs the experiment's standard tracking algorithms on events passing the trigger in order to determine the efficiency for the displaced tracks. Given the fact that we do not have access to such algorithms, we assign each track a reconstruction probability (defined in [8]). We know that the efficiency for reconstructing a multi-track DV is highly dependent on track reconstruction and track selection, as detailed in Ref. [9]. This means that the vertex reconstruction efficiency will be a non-trivial combination of different aspects of the track reconstruction efficiency. For instance the vertex reconstruction efficiency is worst at large radii, which is due to tracking efficiency decreasing. This is one of the reasons is important to have an efficiency defined at the track level.

For making the displaced vertices we used the same procedure as in Reference [8]: *Undiscarded displaced tracks are input into our vertex reconstruction algorithm, which compares and clusters the tracks' origins [10]. If the origins of two displaced tracks are less than 1 mm apart, then they are clustered together into one DV. Picking the first track, we compute the d value (i.e. the physical distance in the laboratory frame $\sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2}$) to each of the other tracks, clustering tracks that have a small enough d value to the first track. Then we repeat for the next unclustered track and so on, until each track is assigned to a single vertex. The ATLAS analysis (and ours) combines vertices into a DV if they are less than $d = 1$ mm apart. The DV position is defined as the average position of all the track origins in the cluster.*

To ensure consistency of the vertex position and the direction of the tracks, we require at least two tracks in the vertex to have $\vec{d} \cdot \vec{p} > -20$ mm, where we define $\vec{d}$ to be the vector from the interaction point to the DV and $\vec{p}$ to be the momentum of the displaced track. In the ATLAS analysis, DVs are vetoed if they are reconstructed in high density material regions, since this is the main source of background vertices. We simulate this by requiring 4 mm $< r <$ 300 mm and $|z| <$ 300 mm. We also require decay positions of the DVs to not be inside any of the three ATLAS pixel layers (our approximation to this DV material cut is shown in Table I) [11]. As the table shows, events are further selected if they have at least one reconstructed DV with 5 tracks or more and a DV invariant mass (computed assuming all tracks have the pion mass) of at least 10 GeV.

p_T^{miss}	>250 GeV
DV reconstruction*	DV made from tracks with $p_T > 1$ GeV, $|\eta| < 2.5$ and $|d_0| > 2$ mm. Vertices within 1 mm are merged. Note: a tracking efficiency needed here; we try three different functional forms described in the validation procedure
DV fiducial	DV within 4 mm $< r_{\rm DV} <$ 300 mm (i.e separated by 4 mm from the primary vertex) and $|z_{\rm DV}| <$ 300 mm
DV material*	No DV in regions near beampipe or within pixel layers: Discard tracks with $r/\text{mm} \in \{[25, 38], [45, 60], [85, 95], [120, 130]\}$.
$N_{\rm trk}$	DV track multiplicity ≥ 5
$m_{\rm DV}$	DV mass $>$ 10 GeV (made from tracks using pion mass hypothesis)

TABLE I. Implementation of cuts applied in the ATLAS multi-track DV + jets search. * These are approximations to the experimental analysis in the absence of the full detector simulation.

Now we can produce efficiency curves at the event level for the two different gluino masses and proper decay lifetimes presented in the ATLAS CONF-NOTE (which are

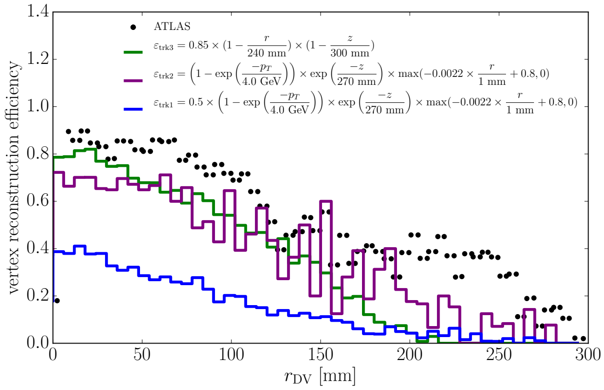

FIG. 3. Vertex level efficiency against radial position of the displaced vertex $r_{\rm DV}$. We show the ATLAS data [a] from Figure 2 of Reference [6]. We also show the vertex level efficiency for three different parameterizations of the track efficiency. The vertex level efficiency is defined as the probability for a true gluino decay to be matched [b] with a reconstructed vertex fulfilling all cuts in Table I, with the exception of the material veto. Basically is the number of (truth matched) reconstructed DVs divided by all truth DVs found in the MC). This is done for a sample with $m_{\tilde{\chi}_1^0} = 100$ GeV, $m_{\tilde{g}} = 1200$ GeV and $\tau = 1$ ns.

[a] This data was digitalized "by hand" by Andre Lessa.
[b] The match is defined such that two daughter tracks coming from the displaced vertex share the same event Monte Carlo index consistent with a displaced gluino truth mother index.

varied by hand in the SLHA file). The event level efficiencies can be seen in Figure 4. We particularly notice that the track efficiency parametrization that gives a better fit is not the one that reproduces best the vertex level efficiency in Figure 3, highlighting the need for an appropriate functional form.

C. Recasting results

Based on the efficiency curves we can extract 95% CL upper limits on the total visible cross section for the two gluino masses. We know that

$$N_{\rm signal} = \sigma \times \varepsilon \times \mathcal{L}, \tag{2}$$

Inserting in Equation 2 $N = N_{\rm upper} = 3$ (which is a 95% interval of the observation of zero events) the luminosity $\mathcal{L} = 32.7$ fb^{-1} and since the estimated number of background vertices is 0.02 (see Ref. [6]), we get the results in Figure 5. For reference, assuming 100% efficiency we get an upper limit of 0.09113 fb with this approximation.

D. Comments on this recasting procedure

- It would be useful if the experiment provides the same benchmark for the vertex level efficiency (which has $m_{\tilde{g}} = 1200$ GeV) than for the final exclusion limits, presented for ($m_{\tilde{g}} = 1400, 2000$ GeV).

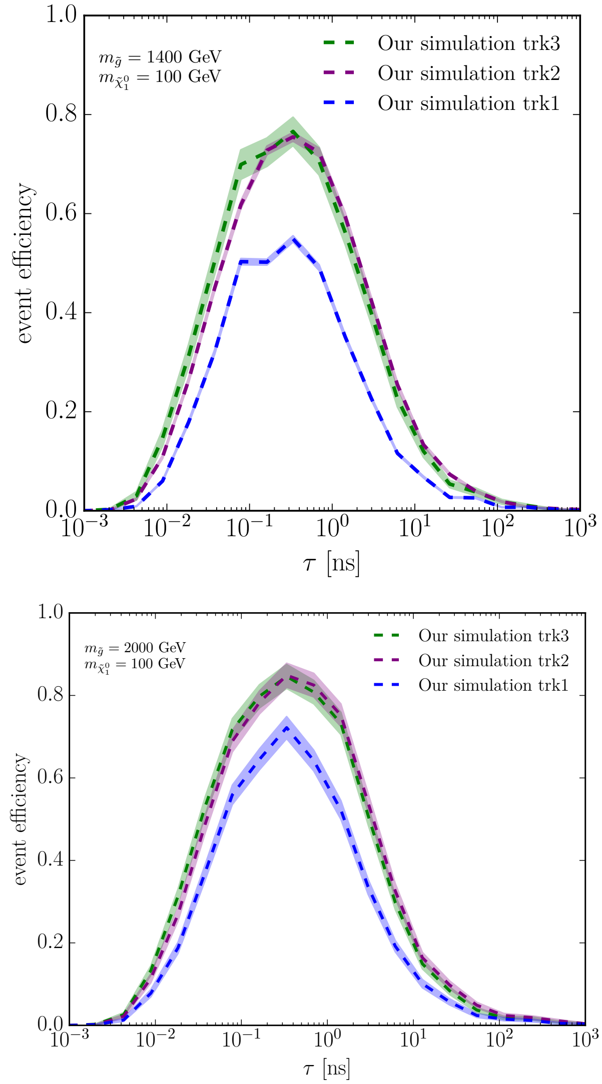

FIG. 4. Event level efficiency against gluino proper decay lifetime τ for three different track efficiencies.

- It would be useful if the experiment provides efficiency curves at the event level as well as vertex level, as these are the ones that actually are used in the limit setting procedure.

- Not enough public information in the CONF-NOTE is available for a proper and trustworthy recast. A parametrization of the track efficiency is highly desirable. Even though one could have used the vertex level efficiency provided by ATLAS directly on "truth-level" vertices, a track efficiency is needed to not overestimate the number of tracks

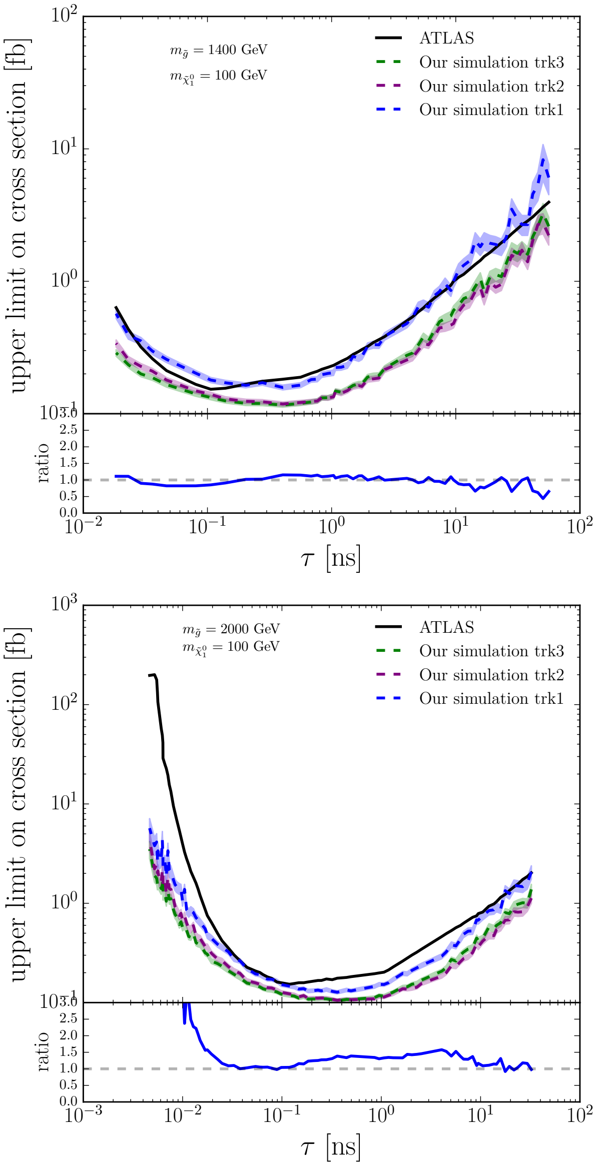

FIG. 5. Comparison of upper limit in the production cross section for three different track efficiencies.

when reconstructing the displaced vertices from the tracks directly, as done in this analysis.

- The track efficiency parametrization that gives a better fit for $r_{\rm DV} < 150$ (trk3) at the vertex level is not the one that reproduces better the event level exclusion plots. Also at the vertex level, trk1 does not fit well across all $r_{\rm DV}$ values but is the one that seems to work better at the event level. A clear form for track efficiency is necessary to understand this issues.

ACKNOWLEDGMENTS

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[10] ATLAS performs a complicated vertex χ^2 fit in order to reconstruct DVs. Here, we simply use the truth information to define the track's origin to be the point at which

the gluino decays, and start comparing the distance between tracks' origins to cluster them into vertices.

[11] Note that the material veto performed in the ATLAS analysis is far more complex than this, since ATLAS makes use of a 3D material map of the detector that is difficult to implement.