PROCEEDINGS OF SCIENCE

Search for higgsinos in compressed mass spectra using a low-momentum displaced track with the ATLAS detector

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on behalf of the ATLAS Collaboration

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Supersymmetry (SUSY) models with nearly mass-degenerate higgsinos could solve the hierarchy problem as well as offer a suitable dark matter candidate consistent with the observed thermal-relic dark matter density. However, the detection of SUSY higgsinos at the Large Hadron Collider (LHC) remains challenging especially if their mass-splitting is $O(1\text{ GeV})$ or lower. A novel search using proton-proton (pp) collision data collected by the ATLAS detector at a center-of-mass energy $\sqrt{s}$ = 13 TeV and corresponding to 140 fb^{-1} of integrated luminosity is presented. This search targets final states with an energetic jet, missing transverse momentum and a low-momentum track with a large transverse impact parameter. Results are interpreted in terms of SUSY simplified models and mass-splittings between the lightest charged and neutral higgsinos from 0.3 GeV to 0.9 GeV are excluded up to 170 GeV of higgsino mass for the first time since the Large Electron Positron (LEP) collider era.

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1. Introduction

Higgsinos can be regarded as the fermionic supersymmetric partners of the Higgs bosons. The supersymmetric lightest neutral ($\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$) and the lightest charged ($\tilde{\chi}_1^{\pm}$) mass eigenstates form a nearly mass-degenerate triplet of Higgsino-like mass eigenstates if $|\mu| \ll |M_1|, |M_2|$, where μ, M_1 and M_2 are the higgsino, wino and bino masses, respectively. The natural solution of the hierarchy problem requires the higgsino mass to be around the electroweak scale while a small mass splitting, $\Delta m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0) \approx 250 - 400$ MeV, is induced by radiative corrections in the pure higgsino limit where the bino and the wino are decoupled in mass [1]. The target of this search [2] is represented by higgsinos with mass splittings $\Delta m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0) \approx 0.3 - 1$ GeV, where the current strongest constraints still come from the LEP experiments [3]. The search uses pp collisions collected by the ATLAS detector [4] at a center-of-mass energy $\sqrt{s} = 13$ TeV and corresponding to 140 fb^{-1} of integrated luminosity.

2. Experimental signature

The search for higgsinos with a displaced track signature was recently proposed by [5]. The experimental signature is a displaced track associated with a charged pion $\pi^{\pm}$ that arises from the $\tilde{\chi}_1^{\pm}$ decaying into a $\tilde{\chi}_1^0$, as shown in Figure 1. An initial state radiation jet is selected to boost the system forward and missing transverse energy, $E_{\mathrm{T}}^{\mathrm{miss}}$, is required to account for the boosted jet recoiling and the presence of invisible particles in the final state. The decay length for the higgsino is $c\tau \sim O(0.1 - 1)$ mm, well within the first ATLAS pixel layer but still measurable. The track displacement can be accounted for by the significance of the transverse impact parameter, $S(d_0) = |d_0|/\sigma_0$, where d_0 is the transverse impact parameter defined as the distance of closest approach of the charged particle trajectory in the transverse plane with respect to the primary interaction vertex and σ_0 its resolution. If multiple tracks pass the selection, the track with the highest $S(d_0)$ is selected as the signal candidate track.

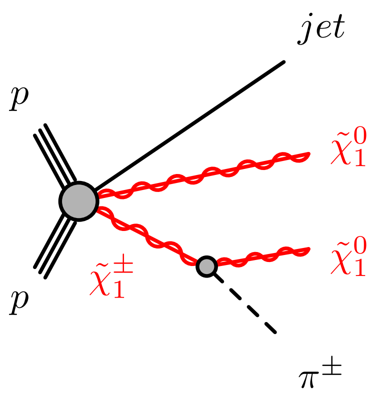

Figure 1: Feynman diagram for the $\tilde{\chi}_1^0\tilde{\chi}_1^{\pm}$ production process featuring a jet from initial state radiation. $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$, $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ and $\tilde{\chi}_2^0\tilde{\chi}_1^0$ production processes are considered in the search as well.

More precisely, all events are required to satisfy a mono-jet signature selection while all tracks must satisfy a soft displaced track selection. The events are selected requiring:

- Leading jet with $p_\mathrm{T} > 250$ GeV and $|\eta| < 2.5$;
- $\min[\Delta\phi(\text{any jet}, E_\mathrm{T}^\mathrm{miss})] > 0.4$;
- No leptons or photons;
- $n_\mathrm{jets} \leq 4$;
- $E_\mathrm{T}^\mathrm{miss} > 600$ GeV.

The tracks are selected by requiring to be:

- soft, $2 <$ track p_T [GeV] < 5, and with $|\eta| < 1.5$;
- associated with the hard-scatter vertex, $|d_0| < 10$ mm and $|z_0 \sin\theta| < 3$ mm;
- isolated by any other track with $p_\mathrm{T} > 1$ GeV within $\Delta R = 0.4$;
- displaced, $S(d_0) > 8$;
- aligned with the $E_\mathrm{T}^\mathrm{miss}$ direction, $\Delta\phi(\text{track}, E_\mathrm{T}^\mathrm{miss}) < 0.4$;
- matched to the *TightPrimary* working point with $n_\mathrm{hits}^\mathrm{IBL} > 0$;
- not matched to any secondary Λ^0, K_S^0 decay vertex.

3. Background estimation

There are two main backgrounds, referred to as τ track background and QCD track background. τ tracks are associated with pions or leptons from the decays of low-p_T τ leptons in W+jets events. QCD tracks come from the decays of heavy particles (Λ^0, K_S^0, etc.) in pileup or underlying events in W/Z+jets. Other minor background processes include diboson, $t\bar{t}$ and single top-quark production and are estimated using the Monte Carlo (MC) simulation.

A schematic illustration of the Control Regions (CRs) and the Validation Regions (VRs) for the τ track background is shown in Figure 2 (left), as a function of the track p_T and $p_\mathrm{T}^\mathrm{recoil}$, while a schematic illustration for the CRs and the VRs for the QCD track background is shown in Figure 2 (right), as a function of the selected object and $S(d_0)$.

$p_\mathrm{T}^\mathrm{recoil}$ is used as a proxy for the p_T of the $W/Z/\gamma$ boson, where the boson transverse momentum is estimated using the objects that recoil against its visible decay products. In the 0ℓ region, there are no visible decay products and $p_\mathrm{T}^\mathrm{recoil}$ coincides with $E_\mathrm{T}^\mathrm{miss}$ as it directly gives the total recoil. In the regions with leptons or photons, the transverse momenta of the reconstructed decay products are added vectorially to $E_\mathrm{T}^\mathrm{miss}$ to estimate the total recoil. Hence, $p_\mathrm{T}^\mathrm{recoil}$ corresponds to $|E_\mathrm{T}^\mathrm{miss} + p_\mathrm{T}(\ell)|$ in regions with 1ℓ where $\ell = e/\mu$, $p_\mathrm{T}^\mathrm{recoil}$ corresponds to $|E_\mathrm{T}^\mathrm{miss} + p_\mathrm{T}(\ell_1) + p_\mathrm{T}(\ell_2)|$ in 2ℓ regions and $p_\mathrm{T}^\mathrm{recoil}$ corresponds to $|E_\mathrm{T}^\mathrm{miss} + p_\mathrm{T}(\gamma)|$ in 1γ regions.

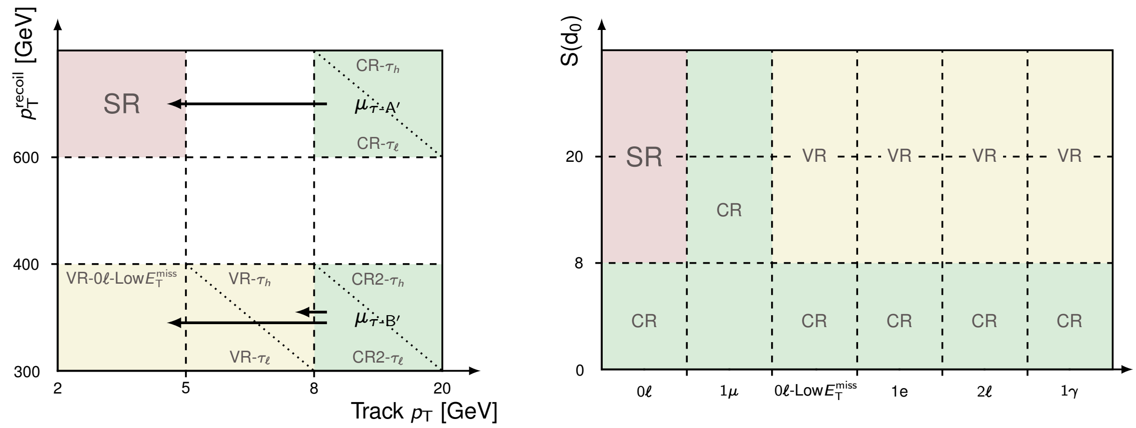

Figure 2: Schematic illustrations showing the selection of the CRs and VRs used to estimate the τ track background (left) and the QCD track background (right).

3.1 Estimation of the τ track background

The τ track background is estimated via normalisation of the MC simulation to data in dedicated CRs. CRs for the τ track background are defined by requiring $8 <$ track p_T [GeV] < 20 because τ tracks tend to have a harder p_T spectrum than signal tracks, as can be seen in Figure 3. Two CRs, CR-τ_h and CR-τ_ℓ, are defined for hadronic τ_h or leptonic τ_ℓ decays by requiring either 0 or 1 leptons, respectively. In these CRs, the τ track background dominates the background composition with $> 90\%$ purity.

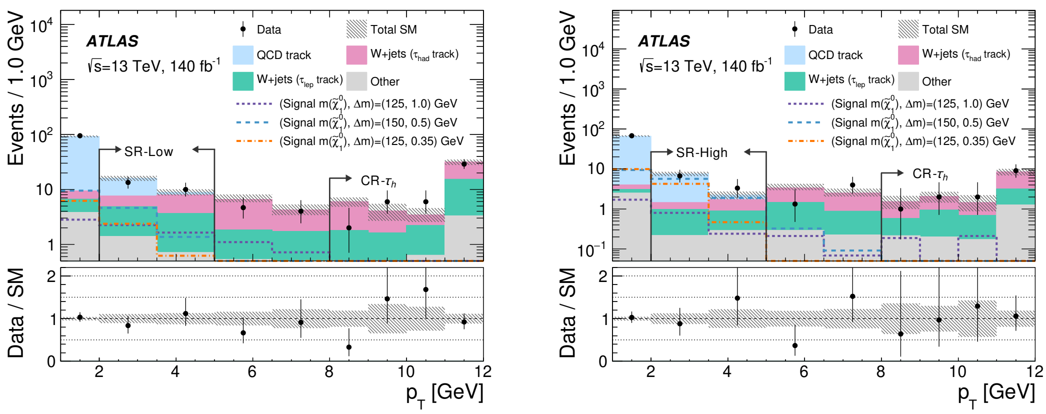

Figure 3: Distribution of the track p_T in the phase space regions requiring either $8 < S(d_0) < 20$ (left) or $S(d_0) > 20$ (right).

3.2 Estimation of the QCD track background

The QCD track background is estimated via a data-driven ABCD background. The shape of the $S(d_0)$ distribution is determined by the breakdown of the hadron components in the pileup jets or underlying events and it does not strongly depend on the details of a specific hard collision process.

Therefore, it is possible to use a phase space region with charged leptons to estimate the QCD track background in the Signal Region (SR), which is instead defined in the 0ℓ phase space region. The $S(d_0)$ distribution is extracted from data events in CR-1μ, mostly populated by $W(\rightarrow \mu\nu)$+jets. The QCD track background is then normalized in CR-0ℓ to obtain the estimate in the SR, where the main physics process is $Z(\rightarrow \nu\nu)$+jets.

3.3 Validation of the τ track and QCD track backgrounds

VRs for the τ track background are defined in a lower p_T^{recoil} phase space to reduce the signal contamination, namely 300 < p_T^{recoil} [GeV] < 400, and in the intermediate track p_T region between the SR and the CRs, namely 5 < track p_T [GeV] < 8, to increase the background purity. To validate the track p_T extrapolation in an isolated way, the estimates in the VRs are obtained by normalizing the MC in dedicated CRs with the same shifted p_T^{recoil} requirement, 300 < p_T^{recoil} [GeV] < 400. These CRs are denoted as CR2-τ_h and CR2-τ_ℓ in Figure 2 (left).

VRs for the QCD track background are defined requiring the presence of $1e$, 2ℓ or 1γ to validate the background estimation in phase spaces mostly populated by other processes, as shown in Figure 2 (right). These other processes have a similar matrix element to that of the $Z(\rightarrow \nu\nu)$+jets, the main physics process yielding the QCD track background in the SR, motivating the choice of these VRs for the validation of the QCD track background.

An additional VR, denoted as VR-0ℓ-LowE_T^{miss}, is defined by requiring 2 < track p_T [GeV] < 5 in the low E_T^{miss} phase space region (300 < p_T^{recoil} [GeV] < 400) to simultaneously validate the τ track and the QCD track backgrounds, where the τ track background is estimated by normalizing the MC in CR2-τ_h and CR2-τ_ℓ and the QCD track background is derived from the normalisation of the $S(d_0)$ shape in CR-0ℓ-LowE_T^{miss}.

Good agreement between the data and the Standard Model (SM) expected background predictions is found in the VRs after the profile likelihood fit in the CRs, as can be seen in Figure 4.

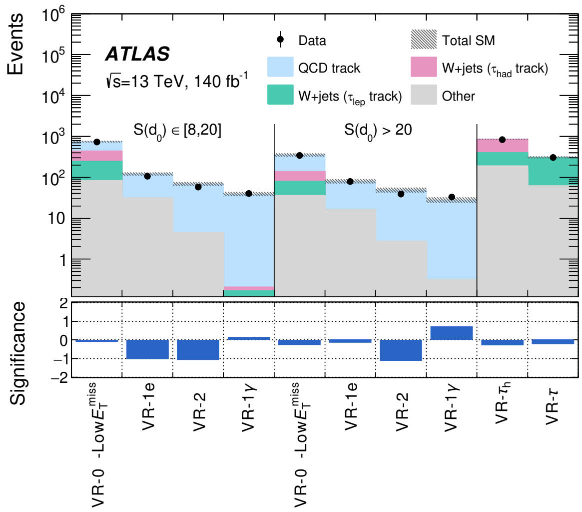

Figure 4: The observed number of data events and the expected SM background in the VRs after the profile likelihood fit in the CRs.

4. Results

Two SRs, SR-Low and SR-High, are defined by requiring $8 < S(d_0) < 20$ or $S(d_0) > 20$, respectively. The numbers of observed events and background predictions in the two SRs are reported in Table 1, while the post-fit $S(d_0)$ distribution in the SRs and in the adjacent CR-0ℓ is shown in Figure 5.

	SR-Low	SR-High
Observed data	35	15
SM prediction	37 ± 4	14.8 ± 2.0
QCD track	14.0 ± 1.7	10.0 ± 1.6
$W(\to \tau_\ell \nu)$ + jets	9.6 ± 1.6	2.0 ± 0.6
$W(\to \tau_h \nu)$ + jets	10.6 ± 2.0	1.9 ± 0.8
Others	3.2 ± 0.7	0.8 ± 0.4
$\langle\epsilon\sigma\rangle^{95}_{\text{obs}}$ [fb]	0.10	0.07
S^{95}_{obs}	13.5	9.9
S^{95}_{exp}	$15.1^{+6.3}_{-4.2}$	$9.6^{+4.4}_{-2.8}$

Table 1: Table with the numbers of observed data events and background predictions in the SRs. Upper limits on the visible cross section ($\langle\epsilon\sigma\rangle^{95}_{\text{obs}}$), on the number of generic observed (S^{95}_{obs}) and expected (S^{95}_{exp}) signal events are also reported.

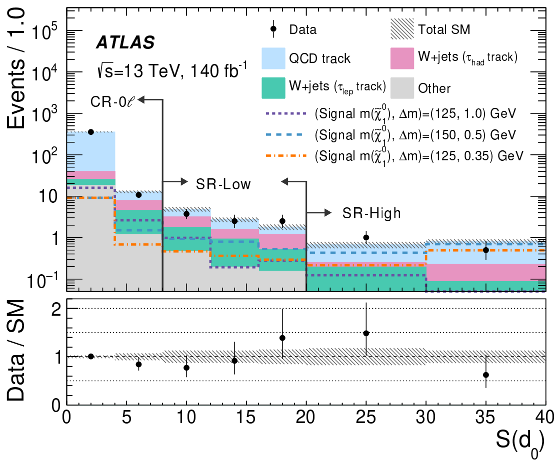

Figure 5: The post-fit $S(d_0)$ distribution in the SRs and in the adjacent control region CR-0ℓ.

No significant deviations of the observed data from the SM predictions for the background processes are found. Good agreement between data and the MC simulation of the background processes is translated into exclusion limits set at 95% confidence level (CL) for the simplified higgsino model, which are shown in Figure 6. Higgsinos are excluded in the range of mass

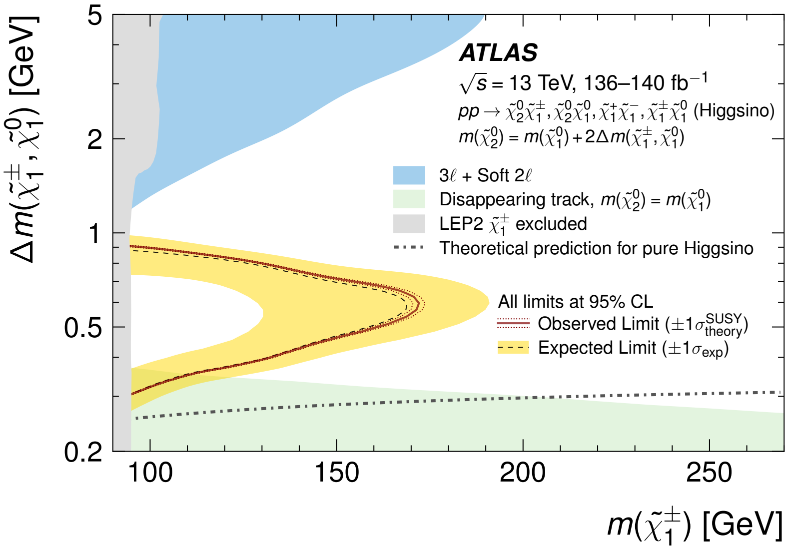

Figure 6: Exclusion limits set at 95% CL for the simplified higgsino model.

splittings $\Delta m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0)$ between 0.3 GeV and 0.9 GeV at 95% CL. For $\Delta m(\tilde{\chi}_1^{\pm}, \tilde{\chi}_1^0) = 0.6$ GeV, the $\tilde{\chi}_1^{\pm}$ is excluded with a mass up to 170 GeV at 95% CL. Model-independent upper limits are also derived and are reported in Table 1.

5. Conclusions

A new search for higgsinos in compressed mass spectra exploiting a displaced track signature has been presented [2]. The search used pp collisions collected by the ATLAS detector at a center-of-mass energy $\sqrt{s} = 13$ TeV and corresponding to 140 fb^{-1} of integrated luminosity. Higgsinos with mass splittings between 0.3 GeV and 0.9 GeV are excluded at 95% CL for the first time since LEP. Other compressed searches are being prepared and will also exploit the larger Run 3 dataset.

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