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Search for supersymmetric higgsinos in compressed mass scenarios using soft displaced tracks with the ATLAS Detector(*)

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Summary. — Progress of a novel search for the direct electroweak production of supersymmetric higgsinos with very compressed mass spectra in final states with large missing transverse energy and soft displaced tracks is reported. Exploiting such a topology aims to bridge the existing sensitivity gap where the mass splitting is too large to produce a disappearing track signature and too small for efficient lepton reconstruction. The search uses *pp* collision data recorded by the ATLAS Detector during the Run-2 of the LHC (2015–2018), corresponding to a total integrated luminosity of 140 fb^{-1} at a center-of-mass energy of $\sqrt{s} = 13$ TeV.

1. – Supersymmetry in compressed mass scenarios

In 2012, the ATLAS [1] and CMS [2] experiments discovered a particle consistent with the Standard Model (SM) [3,4] Higgs boson [5], culminating half a century of high-energy physics discoveries strongly supporting its validity. Still, the SM is known to be an incomplete theory due to a lack of clear explanations to many issues, like the nature of the dark-matter or the Higgs hierarchy problem.

Extensions of the SM that include new states with nearly degenerate masses can help to solve the aforementioned issues while evading high-energy collider constraints. Supersymmetry (SUSY) [6] represents one of the most compelling of such extensions. It predicts a range of new particles differing from their SM partners by half a unit of spin, *i.e.*, for each SM fermion (boson) SUSY predicts the existence of a superpartner of bosonic (fermionic) nature. Similarly to what happens within the SM, SUSY gauginos (gauge bosons superpartners) and higgsinos (Higgs boson superpartners) can mix

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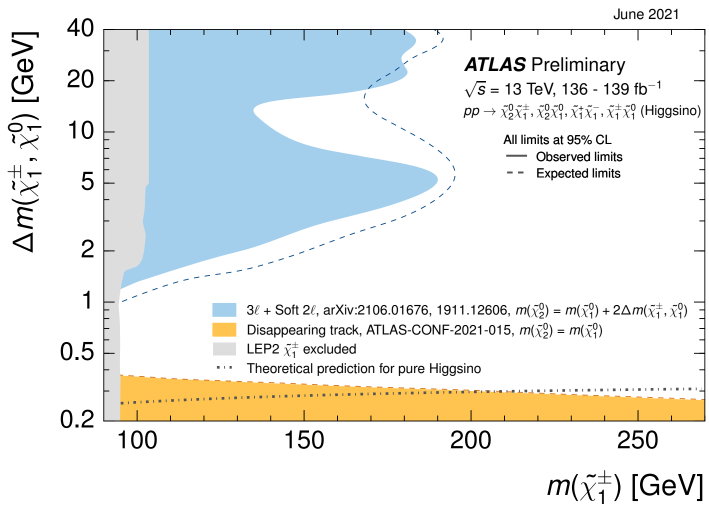

Fig. 1. – Exclusion limits at 95% CL for higgsino pair production $\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^\pm\tilde{\chi}_1^0$, $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$, $\tilde{\chi}_1^0\tilde{\chi}_2^0$ with off-shell SM mediated decays to the lightest neutralino $\tilde{\chi}_1^0$. Taken from ref. [9].

together to create mass eigenstates called charginos, $\tilde{\chi}_{1,2}^\pm$, and neutralinos, $\tilde{\chi}_{1,2,3,4}^0$, collectively referred to as electroweakinos. Here, the subscripts indicate increasing mass. Assuming an R-parity conserving model, the lightest neutralino $\tilde{\chi}_1^0$ is stable, thus it is also a viable dark-matter candidate.

If the wino and bino mass parameters are relatively large compared to the higgsino mass term μ, the two lightest neutralinos and the lightest chargino will be mainly made of higgsinos and will form a quasi-degenerate triplet of states, with masses close to μ and to the electroweak energy scale. The mass splitting between the three states can vary from few hundreds of MeV to few tens of GeV, leading to different scenarios. If the mass splitting is $\mathcal{O}$(GeV) or larger, the soft leptons produced by the decay of the second lightest neutralino ($\tilde{\chi}_2^0$) can be used to place limits on the corresponding mass scenario, as done in ref. [7]. This is not viable for smaller mass differences since the leptons are too soft to be properly identified and reconstructed. However, for mass splittings up to about 300 MeV, the lifetime of the chargino is long enough to let it travel through the entire ATLAS Pixel Detector before decaying, thus resulting in a "disappearing track" signature which can be usefully exploited to set experimental constraints on the electroweakino production [8]. For mass splittings larger than 300 MeV but still less than few GeVs, the lifetime of the electroweakinos becomes short enough that their decay takes place in the space between the beam pipe and the innermost pixel layer. In such a case, charged pions as decay products can be reconstructed as tracks showing a finite displacement from the collision point as a result of the finite electroweakinos' lifetime.

A summary of the existing experimental constraints set by searches conducted at LEP and at the LHC by the ATLAS Collaboration is visible in fig. 1. It is worth noticing that, as mentioned before, neither via soft leptons nor via a disappearing track signature it is possible to probe the 0.3 GeV $\lesssim \Delta m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0) \lesssim$ 1.5 GeV area, dubbed as "higgsino gap", which is precisely the target of the present analysis exploiting mildly-displaced pion tracks.

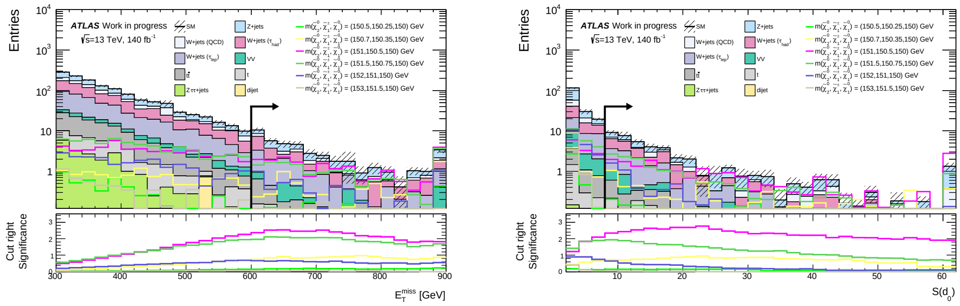

Fig. 2. – SM background distributions superimposed to SUSY signals assuming different mass and mass splitting hypotheses in the $E_{\mathrm{T}}^{\mathrm{miss}}$ (left) and $S(d_0)$ variables (right) used to optimize the definition of the SRs. Backgrounds and signals are both taken from MC simulations.

2. – Displaced Track Analysis Strategy

The analysis relies on the full Run-2 dataset collected at the LHC at a center-of-mass energy of $\sqrt{s} = 13$ TeV by the ATLAS Detector, between 2015 and 2018, corresponding to a total integrated luminosity of 140 fb^{-1}.

Its general strategy is based on ref. [10], *i.e.*, using an isolated and displaced soft track jointly with the request of large missing transverse energy, $E_{\mathrm{T}}^{\mathrm{miss}}$, arising from $\tilde{\chi}_1^0$ pairs, in order to suppress SM backgrounds. Indeed, several SM processes can emulate the SUSY final state topology of interest so that the presence of a new signals is expected to correspond to an excess of data over SM background predictions. In this analysis, background contributions come primarily from $Z/W +$ jets events, where decays of massive bosons to final states containing neutrinos and pile-up tracks([1]) can mimic the displaced track signature.

The analysis is performed selecting kinematic regions optimized to have a good signal-to-background ratio (Signal Regions, SRs). The $E_{\mathrm{T}}^{\mathrm{miss}}$ and the significance of the track's impact parameter $S(d_0)$ are the key discriminating variables used in such optimization procedure. Here, $S(d_0)$ is defined as the ratio between the measured impact parameter of a selected track in the transverse plane (*i.e.*, the plane orthogonal to the direction of flight of the proton beams) and its uncertainty. An example of their distributions is visible in fig. 2. $E_{\mathrm{T}}^{\mathrm{miss}} > 600$ GeV is chosen as minimum cut due to the quick fall of SM contributions over almost constant SUSY signals; instead, $S(d_0) > 8$ is chosen to efficiently suppress pileup tracks, which appear to increase their contribution to the SRs the lower the $S(d_0)$ is. As visible in the bottom panels of the same plots, this set of cuts leads to significances as high as 3σ depending on the exact mass splitting assumption, that is the displaced track search is expected to reach a good sensitivity to SUSY signals in the higgsino gap.

Since SUSY signals are expected to have small cross sections, a precise background estimation is required. Additional kinematic regions, named Control Regions (CRs), are defined for such purpose by simply inverting one or more selections used to design the SRs. CRs are then used to estimate the background contributions in the SRs by either

([1]) Tracks originating from secondary *pp* collisions in the same bunch crossing of the primary hard-scattering collision.

employing dedicated data-driven techniques or constraining the Monte Carlo simulation backgrounds across all kinematic regions in a simultaneous fit to the data.

3. – Conclusions

A new search in progress targeting the electroweak production of supersymmetric higgsinos in very compressed mass scenarios with soft displaced tracks has been presented. At the time of writing, the search is well established and expected to largely improve the existing experimental constraints in the higgsino gap, a phase space region never explored since LEP's activity.

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