Mono-Z/W Signal from Nearly Degenerate Higgsinos at the LHC*

Junichiro Kawamura[1,2]
[1] *Center for Theoretical Physics of the Universe, Institute for Basic Science (IBS), Daejeon 34051, Republic of Korea*
[2] *Department of Physics, Keio University, Yokohama 223-8522, Japan*

Abstract

In this paper, I point out that the hadronic mono-Z/W signal can give significant constraints on the higgsinos at the LHC. The higgsinos at $\mathcal{O}(100\,\text{GeV})$ are well motivated to explain the size of the electroweak (EW) scale in the minimal supersymmetric (SUSY) standard model. The higgsinos up to 110 (210) GeV can be excluded by the 139 (300) fb^{-1} data, and the 3000 fb^{-1} data will discover (exclude) the higgsinos up to 280 (520) GeV, assuming that the higgsino states are effectively invisible in the detector. This strategy could be applicable to other dark matter (DM) particles.

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1. INTRODUCTION

The higgsinos, SUSY partners of the Higgs bosons, are important to understand the size of the EW scale. In addition, the lightest higgsino is a good candidate for the DM [2].† Such light higgsinos are realized in certain SUSY-breaking scenarios [3, 4]. Despite these importances, the current limit of the higgsinos at the collider experiment is about 90 GeV obtained in the LEP experiment [5]. In this paper, I point out that the limit can be improved by using the mono-V ($V = Z, W$) boson signal at the Large Hadron Collider (LHC).

It is known that the monojet searches at the LHC can not constrain the higgsinos because of the large backgrounds. There are two strategies that can ameliorate this situation depending on the mass differences among the higgsino states, i.e., $\Delta m_{\tilde{\chi}_1^\pm} := m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0}$ and $\Delta m_{\tilde{\chi}_2^0} := m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$. Here, $\tilde{\chi}_1^0$ ($\tilde{\chi}_2^0$) is the (second) lightest neutral higgsino, and $\tilde{\chi}_1^\pm$ are the charged higgsinos. For $\Delta m_{\tilde{\chi}_2^0} \gtrsim 5\,\text{GeV}$, the soft leptons produced from $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \ell\ell$ ($\ell = e, \mu$) can be detected, and thus, the $1j + 2\ell + \not{E}_T$ searches give bounds on the higgsinos [6, 7]. However, for $\Delta m_{\tilde{\chi}_1^\pm} < 1\,\text{GeV}$, the heavier higgsinos are long-lived and may decay inside the detectors [8, 9, 10]. This feature allows us to probe higgsinos by exploiting disappearing tracks and/or displaced vertices. There remains, however, the gap around $\Delta m_{\tilde{\chi}_1^\pm} \sim 1\,\text{GeV}$ which can not be probed by either channel.

In this paper, we consider the hadronic mono-V signal instead of mono-jet, so that the gap is filled and the limit is improved up to about 500 GeV.

2. MONO-Z/W SEARCH

In this work, we consider the higgsino pair production in association with an electroweak (EW) gauge boson V, i.e., $pp \to \tilde{\chi}\tilde{\chi}V$ with $\tilde{\chi} = \tilde{\chi}_{1,2}^0, \tilde{\chi}_1^\pm$. We assume that the decays of the heavier states are effectively invisible, i.e., not counted as leptons or jets. The production cross section of the process is shown in the left panel of Figure 1. In this plot, the associated productions with a jet and an SM Higgs boson are also shown for comparison. Cross sections are calculated by using `MadGraph-5.2.8.2` [11], and $p_T > 150\,\text{GeV}$ is imposed for a parton in the jet-associated production. We see that the W boson-associated production is the dominant one.

We simulate events $pp \to \tilde{\chi}\tilde{\chi}V(\to q\bar{q})$, with q light-flavor quarks, using `MadGraph5`, and then the events are showered/hadronized by `Pythia8` [12]. The generated events are run through the fast detector simulator `Delphes3.4.2` [13]. We used the default ATLAS card for the detector simulation, but we added the large-R jet with $R = 1.0$ on top of the small-R jet with $R = 0.4$ using the anti-k_T jet clustering algorithm [14, 15]. The trimming algorithm [16] is applied, and subjets with radius parameter $R = 0.2$ whose transverse momentum (p_T) is below 5% of the original jet p_T are removed from the large-R jet in order to remove the energy deposits from the pile-up. The p_T thresholds to reconstruction efficiencies of electrons and muons are replaced to be 7 GeV following the experimental analysis. Further, the energy fractions of the higgsino-like chargino tracks to both ECAL and HCAL are set to zero, since the charginos decay before encountering the tracker.

We recast the ATLAS data [17] searching for the hadronic mono-V signal. Among the signal regions (SRs), the one with 0b-tagged jet and high purity (HP) is the most relevant for the higgsino signal. The SRs with b-tagged jets are not so efficient because the production is dominated by $W\tilde{\chi}\tilde{\chi}$ which does not include a bottom quark. We assume that the large-R jet is counted as HP with a 50% probability because the ATLAS analysis uses the Z/W tagger whose efficiency is constantly 50%.

The right panel of Figure 1 shows the $\not{E}_T$ distributions of the SM backgrounds and the higgsino signals. The red (blue) histogram is the signals with the μ parameter to be 200 (500) GeV. We see that the number of events decreases more slowly for heavier higgsinos.

3. RESULTS

The efficiencies in the $\not{E}_T$ bins of the production $pp \to \tilde{\chi}\tilde{\chi}V$ are shown in the left panel of Figure 2. The black line is the total number of events divided by 5. We see that the efficiencies increase as the higgsino mass increases, especially for those in the

*This paper represents a talk at the NuDM-202 conference based on [1].
†Precisely, the higgsinos are not mass eigenstates due to the mixing with the gauginos, and the mass eigenstates are the higgsino-like neutralinos/charginos. Nonetheless, we name the mass eigenstates as higgsinos for simplicity, assuming that the relevant states are mostly higgsino-like due to gauginos heavier than sub-TeV. See the original paper [1] for a more detailed discussion.

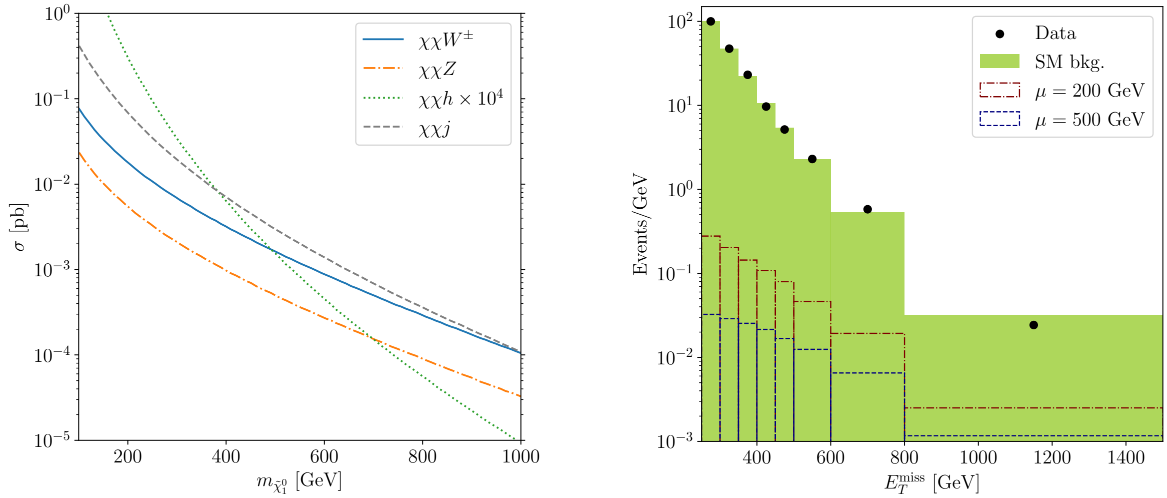

FIGURE 1: The production cross sections for higgsino pair production in association with an EW gauge boson or a jet at $\sqrt{s} = 13$ TeV (left). The $\not{E}_T$ distribution after the cut in the SR `0b-HP` when $\mu = 200$ and 500 GeV (right).

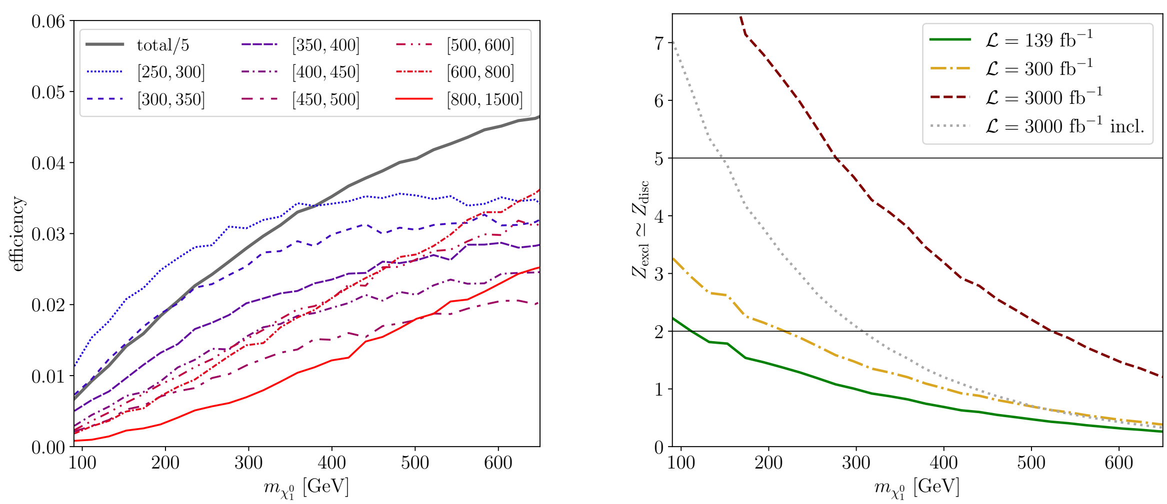

FIGURE 2: The efficiencies of $\tilde{\chi}\tilde{\chi}V$ production of each bin of $\not{E}_T$ in the SR `0b-HP` (left) and the future sensitivities at the LHC (right).

large $\not{E}_T$ bins. The right panel of Figure 2 shows the expected significance of the future LHC data. The green, yellow, and brown lines are the values with 139, 300, and 3000 fb^{-1} data, respectively. The 139 (300) fb^{-1} data will exclude the higgsino mass up to 110 (210) GeV. With the full 3000 fb^{-1} data, the higgsinos up to 280 (520) will be discovered (excluded). The black line is the value with the inclusive $\not{E}_T$ bins, and without using the $\not{E}_T$ bin data. The discovery (exclusion) potential is about 150 (300) GeV, so it is important to use the high $\not{E}_T$ bins to raise the sensitivity.

4. CONCLUSION

In this paper, we pointed out that the mono-Z/W signal at the LHC can give significant constraints on the higgsinos with $\Delta m_{\tilde{\chi}_1^{\pm}} \sim 1$ GeV. This mass parameter range has not been excluded by the LHC data. The obtained limits are stronger than those from the monojet-based searches. We emphasize that the signal is based on the invisibility of the higgsinos, and thus, the strategy could be applied to the other DM candidates.

CONFLICTS OF INTEREST

The author declares that there are no conflicts of interest regarding the publication of this paper.

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