Snowmass2021 - Letter of Interest

Long-lived charginos in the MSSM and beyond

Thematic Areas:
■ (EF08) BSM: Model specific explorations
■ (EF10) BSM: Dark Matter at colliders
■ (TF07) Collider physics
■ (CompF2) Theoretical Calculations and Simulation

Contact Information:
Submitter Name/Institution: Suchita Kulkarni, University of Graz
Contact Email(s): amitadhikary@iisc.ac.in; biplob@iisc.ac.in; rohini@iisc.ac.in; sabine.kraml@lpsc.in2p3.fr; suchita.kulkarni@gmail.com; Rakhi.Mahbubani@cern.ch; rhitaja@iisc.ac.in

Authors:
Amit Adhikary - Indian Institute of Science, Bengaluru, India
Biplob Bhattacherjee - Indian Institute of Science, Bengaluru, India
Rohini Godbole - Indian Institute of Science, Bengaluru, India
Sabine Kraml - LPSC, Grenoble, France
Suchita Kulkarni - University of Graz, HEPHY, Austria
Rakhi Mahbubani - University of Hertfordshire, UK
Rhitaja Sengupta - Indian Institute of Science, Bengaluru, India

Abstract

We propose to investigate the precision with which mass differences and lifetimes are computed in scenarios with long-lived charginos, and how this may influence DM@collider studies, as well as benchmark studies of HSCP and disappearing track searches.

Motivation and scope

Long-lived charginos are often used as prototype benchmark scenarios in Heavy Stable Charged Particle (HSCP) and disappearing track (DT) searches. Such long-lived charginos can be realised in various ways in supersymmetric (SUSY) models. The most commonly studied scenario is the Minimal Supersymmetic Standard Model (MSSM) with a neutralino $\tilde{\chi}_1^0$ as the lightest SUSY particle (LSP) and dark matter (DM) candidate, and a chargino, $\tilde{\chi}_1^{\pm}$, which is nearly mass-degenerate with the $\tilde{\chi}_1^0$. The corners of parameter space where such near mass-degeneracy happens are the (almost) pure higgsino or wino-DM cases, but possibly also bino-wino or bino-higgsino DM scenarios. Analogous scenarios can be realised in simplified models of electroweak-ino multiplets. Relevant recent phenomenological studies are e.g. [1–3].

In any case, the chargino lifetime, $c\tau_0$, sensitively depends on the precise mass difference with the neutralino it decays into, $\Delta m = m_{\tilde{\chi}_1^{\pm}} - m_{\tilde{\chi}_1^0}$. This mass difference is subject to radiative corrections [4–6], which must be taken into account properly for precise predictions when computing masses and lifetimes from the model input parameters (e.g., gaugino and higgsino mass parameters in the MSSM). However, it has been pointed out previously[7], that these loop corrections are not fully implemented in all public spectrum generators.

The lifetime, $c\tau_0 \propto 1/\Gamma_{\rm tot}$, also sensitively depends on how the various partial decay widths are computed. Concretely, for small mass splittings, three-body decays via an off-shell W-boson, $\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0 + (W_\mu^\pm)^*$ dominate. In the window $m_\pi < \Delta m < 1.5$ GeV, however, it is not accurate to describe the W^* decays in terms of quarks. Instead we should treat the final states as one, two or three pions (with Kaon final states being Cabibbo-suppressed). While this is well known in principle, see e.g.[8,9], these decays into pions are also not fully implemented in the public tools, which compute SUSY particle decays.

Motivated by these observations, we propose to investigate the importance of radiative corrections and treatment of decays on chargino lifetime predictions within the MSSM, simplified electoweak-ino scenarios, and possibly also extended models beyond the MSSM. An important aspect shall be to compare the level of implementation in widely-used public tools, like `SuSpect2`[10], `SuSpect3`[11], `SoftSusy`[12,13], `SPheno`[14], and `SDECAY`[15]. Furthermore, we plan to reinterpret DT and HSCP analyses in order to see how their reaches relate to the masses and lifetimes that are attained in precision calculations.

To give some concrete examples: For the purely wino case, we plan to compare the lifetime of charginos as obtained when the analytic two-loop radiative corrections to the masses are used to those obtained from SUSY spectrum generators; for these lifetimes, one can then check the prospects of DT and HSCP analyses. Another idea is to study the validity of extending the pure electroweak-ino simplified model to larger mass splittings, particularly in the wino case where the splitting originates from a dimension-7 operator and one might expect the phenomenology to change significantly when there is large mixing.

Finally, we note that the precise mass splittings also strongly influence the DM relic density in such scenarios, and thus the interplay between collider and DM searches. This is another point, which we propose to study.

Relevance

We think this effort is relevant for the Snowmass initiative in several aspects:
1. to help determine which theoretical and tools developments will be needed in the future in order to match the experimental needs (for example for experimental analyses providing interpretations in concrete models)
2. to determine how benchmark scenarios used in prospective studies for future experiments—in particular regarding DT, HSCP, and DM@collider searches—relate to concrete model realisations (e.g., what ranges of mass vs. lifetime can indeed be realised in concrete models)
3. to help achieve a more precise comparison of DM limits from different frontiers, including future collider searches.

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