Electroweakinos at the LHC: Testing the Higgsino-Singlino Sector of the NMSSM

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Aim, given the absence of significant BSM excesses at the LHC:

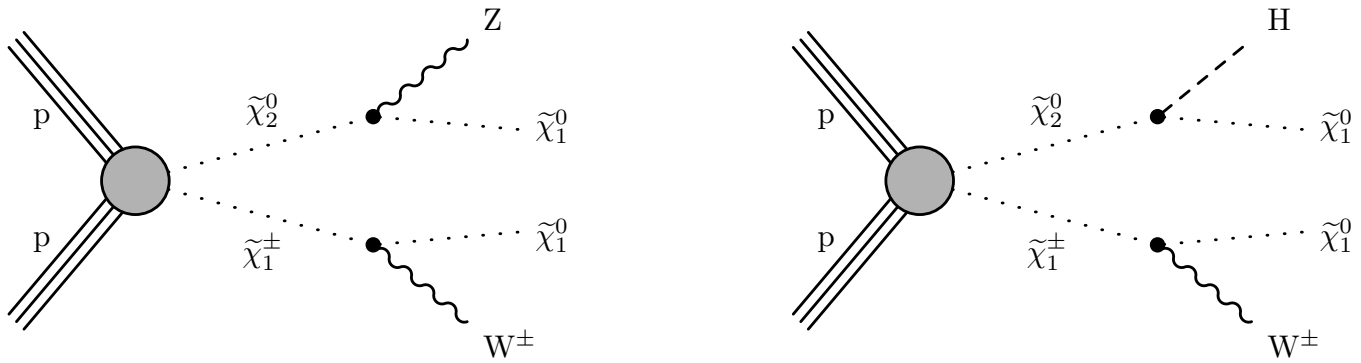
- Derive strict limits (as general as possible) on sparticle masses, here: NMSSM
- Byproduct: Pin down dark spots in present searches

Bottom up strategy:
Start with electroweakinos, the "lower ends" of realistic decay cascades
Subsequently allowed electroweakino masses and couplings can be used to constrain realistic decay cascades of squarks, stops, gluinos, ...

Assume, as promised by Supersymmetry:
A dark matter relic density in the WMAP/Planck window,
consistent with constraints from direct DM detection

In the NMSSM, a light singlino-like LSP $\tilde{\chi}_1^0$ with some higgsino component allows for a dark matter relic density in the WMAP/Planck window consistent with constraints from direct detection experiments, notably from PandaX-II on spin dependent dark matter – neutron scattering

Constrained by searches at the LHC for electroweak production of charginos and neutralinos?

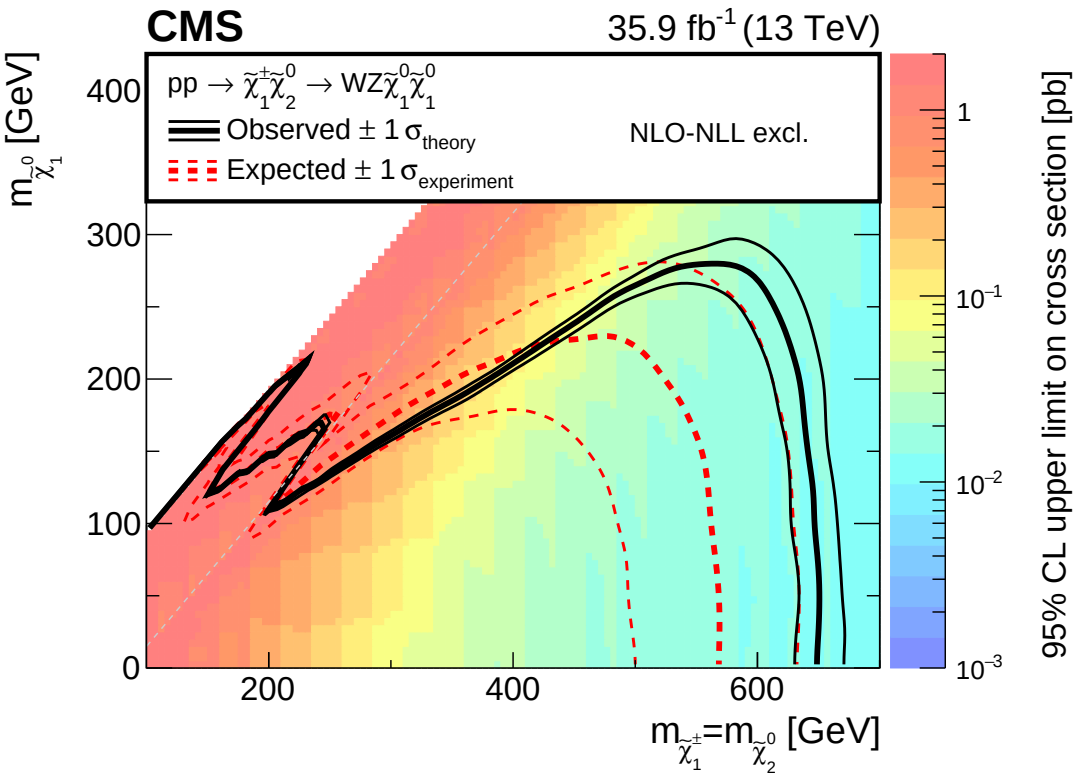


Note: In the NMSSM, "H" includes H_{SM} and mostly singlet-like H_1/A_1; due to a sum rule H_1 is automatically light if a pseudoscalar A_1 with $M_{A_1} \approx 2M_{singlino}$ reduces the singlino relic density to the WMAP/Planck value via annihilation with A_1 in the s-channel

AND: $\tilde{\chi}_1^\pm$, $\tilde{\chi}_2^0$ (and $\tilde{\chi}_3^0$) are higgsinos, not winos!

— Light higgsinos are natural ($\leftrightarrow$ μ parameter not far above M_Z)
— Heavier winos are motivated by a GUT relation $M_2 \approx M_3/3$ among the wino mass parameter M_2 and the gluino mass M_3, and lower bounds on $M_3 \gtrsim 2$ TeV

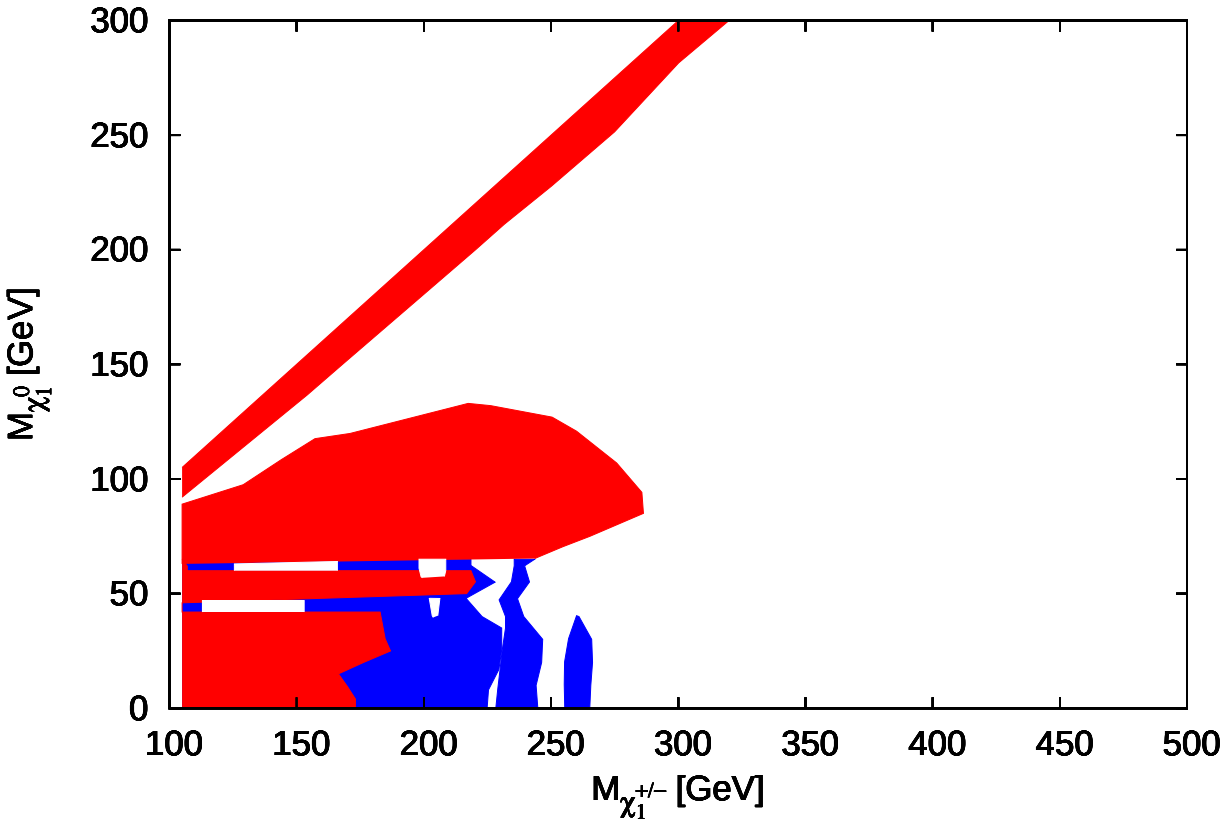
$\longrightarrow$ Higgsinos have smaller cross sections, leading to weaker bounds on cross sections $\times$ branching fractions than from wino production e.g. from CMS-SUS-17-004 (1801.03957) in the plane $M_{\tilde{\chi}_1^\pm} - M_{\tilde{\chi}_1^0}$:



After a scan over viable NMSSM parameters requiring good dark matter, we recast these limits using the resulting higgsino/singlino masses and couplings

First: Simplifying (technical) assumption: Heavy sleptons (staus)

$\longrightarrow$ Strictly excluded regions in the plane $M_{\tilde{\chi}_1^\pm} - M_{\tilde{\chi}_1^0}$:



Red: Excluded by constraints on the relic density/from direct detection

Blue: Excluded mostly by searches for charginos and neutralinos iff the bino mass satisfies $M_1 > 300$ GeV as motivated by the GUT relation $M_1 \approx M_3/6$

Reasons for the alleviated constraints from searches for $\tilde{\chi}_1^{\pm} \to \tilde{\chi}_1^0 + W$, $\tilde{\chi}_{(2,3)}^0 \to Z + \tilde{\chi}_1^0$:

— Smaller production cross sections (although there are two nearly degenerate higgsinos)

— Decays $\tilde{\chi}_{(2,3)}^0 \to H_{SM} + \tilde{\chi}_1^0$, on which limits are much weaker, have branching fractions of $\sim 30 - 50\%$ (averaging over both higgsinos)

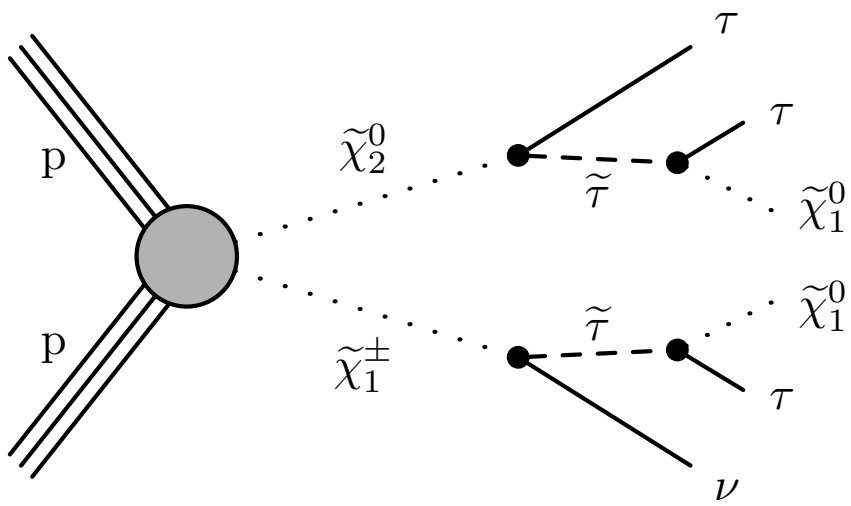
— If decays $\tilde{\chi}_{(2,3)}^0 \to Z + \tilde{\chi}_1^0$ are kinematically forbidden for Z on-shell, decays $\tilde{\chi}_{(2,3)}^0 \to H_1/A_1 + \tilde{\chi}_1^0$ can be dominant where H_1/A_1 are NMSSM specific light scalars/pseudo scalars; difficult to detect!
(Taking constraints on H_1/A_1 from searches at LEP/LHC and $H_{SM} \to H_1 + H_1$ into account)

Still, searches for $\tilde{\chi}_1^{\pm} \to \tilde{\chi}_1^0 + W$, $\tilde{\chi}_{(2,3)}^0 \to Z + \tilde{\chi}_1^0$ do constrain light higgsinos/singlinos except . . .

Relaxing the "simplifying (technical)" assumption (1):

Allowing for light staus:

$\longrightarrow$ Higgsinos $\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_{2,3}^0$ prefer to decay into staus instead of the LSP $\tilde{\chi}_1^0$:



Constraints from corresponding searches by CMS in CMS-PAS-SUS-17-002, but weak for light $\tilde{\tau}$

$\longrightarrow$ No NMSSM-points get excluded by searches for charginos and neutralinos if staus are lighter than higgsinos (of mass $\sim \mu$)

Relaxing assumption (2):

Allowing for a bino lighter than higgsinos, the neutralinos are:
$\tilde{\chi}_1^0$: Singlino as before
$\tilde{\chi}_2^0$: Bino
$\tilde{\chi}_{(3,4)}^0$: Higgsinos
$\tilde{\chi}_5^0$: wino, assumed heavy

$\longrightarrow$ In the presence of a light singlet-like scalar H_1 (or A_1) with

$$M_{H_1} < M_{higgsino} - M_{bino}$$

the higgsinos can decay via the cascade

$$\tilde{\chi}_{(3,4)}^0 \to H_1 + \tilde{\chi}_2^0 \to H_1 + H_1 + \tilde{\chi}_1^0$$

and decays $\tilde{\chi}_1^\pm \to \tilde{\chi}_2^0 + W^{(*)}$ become possible

$\longrightarrow$ Constraints from existing searches for charginos and neutralinos can be circumvented

Conclusions:

— For strict constraints it seems reasonable to start with the electroweakino sector, to use subsequently for realistic decay cascades

— In the NMSSM, where a singlino-like LSP can satisfy the constraints on dark matter, it is appropriate to impose these constraints;
these exclude already a sizeable region in the plane $M_{\tilde{\chi}_1^\pm} - M_{\tilde{\chi}_1^0}$

— If heavy staus and bino are assumed, additional regions in this plane are definitively excluded by recent searches for neutralinos/charginos

— Dark spot 1: light staus!
(Not excluded by searches for stau pair production at the LHC)

— Dark spot 2: light bino, leading to higgsino decay cascades via light H_1/A_1
$\longrightarrow$ To include in electroweakino searches? (Difficult, of course)

— BMpoints and planes will be proposed in a forthcoming paper