PROCEEDINGS OF SCIENCE

Searches for electroweak SUSY production with the full CMS Run II sample

Denis Rathjens[a,1,*]

[a] *Mitchell Institute for Fundamental Physics and Astronomy, Texas A&M University (TAMU), College Station, TX USA*

E-mail: Denis.Rathjens@cern.ch

We present the results from searches for SUSY signatures produced via the electroweak interaction. All searches use proton-proton collision data at a centre-of-mass energy of 13 TeV, recorded with the CMS detector during Run II of the LHC operations. The analyzed data correspond to an integrated luminosity of 137/fb. The results are interpreted within simplified models of electroweakino or slepton pair production and they are consistent with expectations from the Standard Model. We also present a combination of these results, which provides a more comprehensive coverage of the model parameter space than the individual searches and adds sensitivity in the compressed mass parameter regions.

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[1] on behalf of the CMS collaboration
[*] Speaker

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1. Introduction

The standard model of particle physics (SM) has been extremely successful, yet it leaves a few questions unanswered. Supersymmetry (SUSY) has been an attractive extension of the SM that, if realized in nature, could provide loop corrections fixing the hierarchy problem, unify gauge couplings close to the Planck scale, and, if R-parity is conserved, provide a potential dark matter candidate with the lightest stable particle (LSP).

In the context of these proceedings, it is specifically electroweak (EW) variants of supersymmetry that are discussed, as the limits on coloured sparticles are stringent already and coannihilation scenarios of EW gauginos or sleptons have the added benefit of both providing good solutions for cold dark matter cosmological scenarios as well as being elusive to find, possibly hiding in compressed spectra.

2. Electroweak Run 2 combination

The CMS Run2 electroweak combination [1] combines six reference publications [2–7], each of which is relevant to EW SUSY parameter space. In this combination, overlaps between signal regions have been properly accounted for and on top of that, improvements to the parametric signal extraction have been made. An overview of the involved analyses is provided in Table 1.

	gaugino		GMSB			higgsino-bino			sleptons
Search	WZ	WH	ZZ	HZ	HH	WW	HH	WH	$\ell^+\ell^-$
$2/3\ell$ soft [2]	all								2ℓ soft
2ℓ on-Z [3]	EW		EW	EW					
2ℓ non-res. [3]									Slepton
$\geq 3\ell$ [4]	SS, A(NN)	SS, A-F	all	all	all			SS, A-F	
1ℓ2b [5]		all						all	
4b [6]					all		3-b, 4-b, 2-bb		
Hadr. WX [7]	all	b-tag				b-veto		b-tag	

Table 1: Overview from the combination paper [1] regarding its constituent analysis channels and their impact on different EW SUSY interpretations. GMSB means Gauge-mediated Supersymmetry Breaking. SS denotes same-sign categories. For specific channel nomenclature, please consult the specific source analysis.

As an improvement with respect to the original publication, the 2 or 3 ℓ (soft) analysis [2] also reoptimized its binning for each compressed scenario, specifically. All following interpretations shown are for R-parity-conserving models.

2.1 Gaugino WH

To commence with wino-bino models, the combination probes WH final states where $\tilde{\chi}_1^{\pm} \rightarrow W^{\pm}$ and $\tilde{\chi}_2^0 \rightarrow H$ occur. The general process diagram, the exclusion of the individual channels and their combination, as well as which channels have the highest impact in which part of parameter space are shown for this case (see Figure 1) and all following cases.

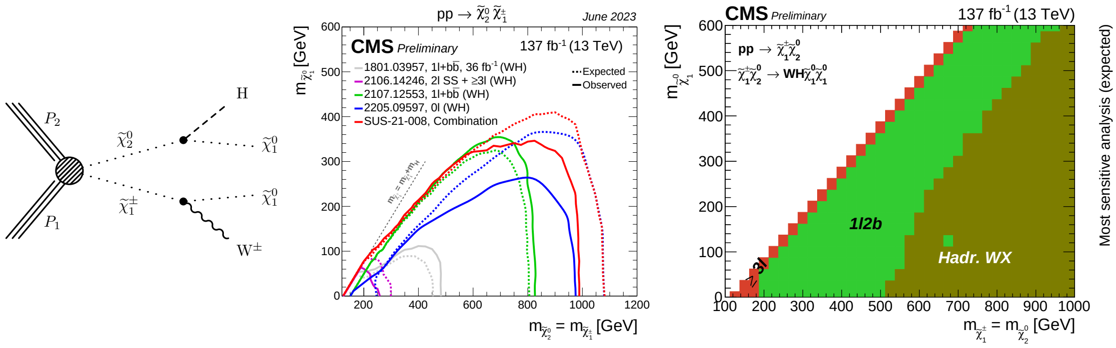

Figure 1: The diagram of chargino and neutralino to WH decays in this Wino-Bino model interpretation is shown (left). The constituent analyses individual reaches in the case of equal $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^\pm$ masses (middle) are put into the context of their combination (red) and the most contributing channel to the combination (right) in the same parameter space.

Some improvements have been made by the combination for the case where the chargino to LSP decays are degenerate with the SM Higgs peak. Small improvement on driving the $\tilde{\chi}_2^0$ equaling $\tilde{\chi}_1^\pm$ mass edge around almost a TeV are complemented by larger improvements in excluding more parameter space towards the high mass edge with large LSP masses of up to 340 GeV.

2.2 Gaugino WZ

In the same kind of Wino-Bino model, but in a WZ final state, where $\tilde{\chi}_1^\pm \to W^\pm$ and $\tilde{\chi}_2^0 \to Z$ happen, the same three considerations are shown as in WH case in Figure 2.

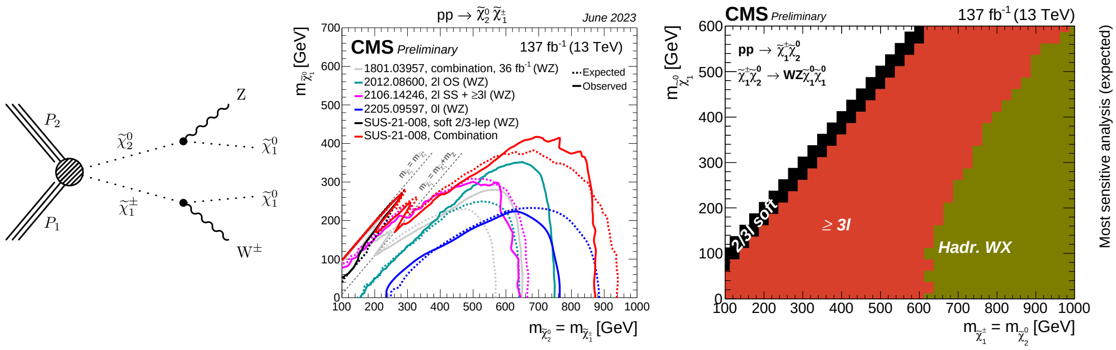

Figure 2: The diagram of chargino and neutralino to WZ decays in this wino-bino model interpretation is shown (left). The constituent analyses individual reaches in the case of equal $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^\pm$ masses (middle) are put into the context of their combination (red) and the most contributing channel to the combination (right) in the same parameter space.

The combination has improved limits close to the region where chargino to LSP decays are degenerate with the SM Z peak up to 240 GeV LSP mass. Further, the combination limits have improved to around 870 GeV $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^\pm \to W^\pm$ mass and limits are also set for LSP masses up to around 420 GeV.

2.3 Direct slepton pair production

For direct slepton pair production, two different cases become important: On the one hand, driving the mass edge towards the highest possible slepton mass exclusions is important, which is done by the 2ℓ non-res. channel. On the other hand, compressed spectra are another frontier that also deserves to be probed, in this case by the 2ℓ soft channel. The diagram is identical, yet the backgrounds and challenges of each of these cases are unique. The exclusions for them are shown in Figure 3.

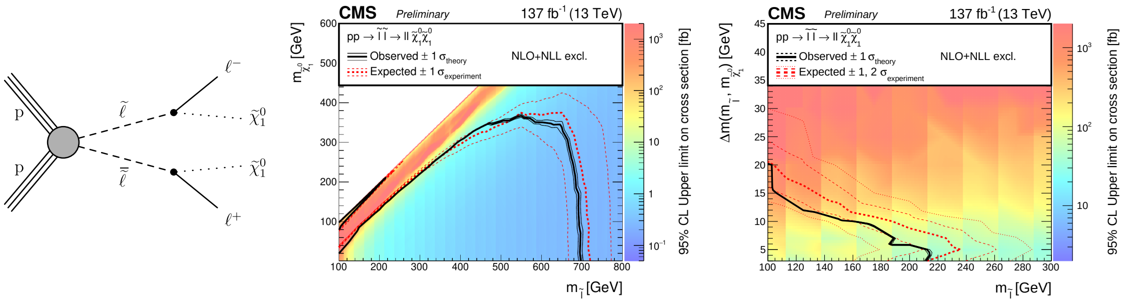

Figure 3: For direct slepton production (left), exclusions for the high mass interpretation (middle) and the compressed spectrum limits (right) are shown.

Compressed slepton masses down to 3 GeV slepton-LSP mass gap can be excluded up to 210 GeV slepton mass while mass gaps up to 20 GeV for a 100 GeV slepton mass are also excluded. On the high end, slepton masses up to 700 GeV and sleptons decaying to LSPs of up to 360 GeV have been limited.

2.4 GMSB neutralino pair production

In the case of GMSB models, the LSP is not the lightest neutralino, but the gravitino. Consequently, the $\tilde{\chi}_1^0$ can decay to the $\tilde{G}$ via a H or a Z, depending on the mixing. Dedicated analyses for the pure cases of either of these have been performed and therefore their combination is able to push the limits most in the equal mixing case, as shown in Figurre 4.

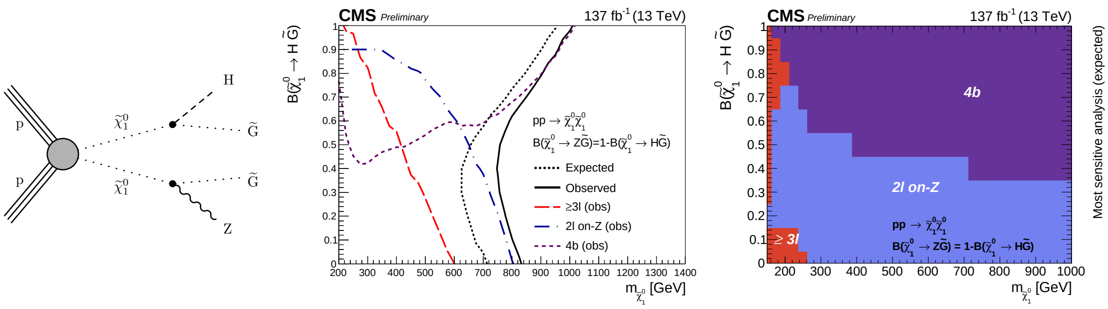

Figure 4: Neutralino pair production decaying to gravitinos (left) is shown. Limits are set as a function of lightest Neutralino mass and branching ratio fraction to Higgs as opposed to Z bosons (middle). The highest sensitivity channel in this parameter space is illustrated (right).

LSP masses up to 1 TeV can be excluded for a 100% branching ratio (BR) to H bosons while up to 840 GeV exclusions for a 100% BR to Z bosons are also possible. Mixed cases can be weakened to limits down to 740 GeV, which in combination is still a marked improvement over the individual analyses.

2.5 Higgsino-bino interpretation

Finally, in this higgsino-bino interpretation, the lightest neutralino remains the LSP, but is set into the context of a mass-degenerate higgsino triplet. WW, HH, and WH final states are considered. Various channels from the $\geq 3\ell$, $1\ell 2$b, 4b, and Hadr. WX analyses contribute to excluding the diagrams shown in Figure 5 and the subsequent limits assuming that all charginos decay to W and all neutralinos to Higgs bosons.

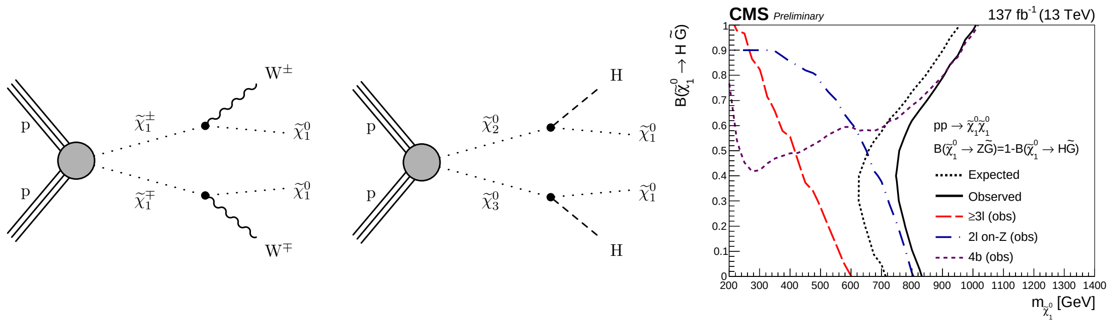

Figure 5: The different decay channels considered (left, middle) with equal and full branching ratios and leaving out the mixed WH final state result in the limits (right) set in equal chargino and neutralino mass vs LSP mass space.

Chargino and neutralino 2 and 3 masses can be excluded up to around 800 GeV while exclusions can be set for LSP masses up to 200 GeV.

3. Disappearing track search - electroweak results

So far, the high mass and the lightly compressed mass spaces have been handled by the electroweak combination. As well, extremely compressed scenarios are possible in SUSY parameter space and other experimental methods have to be utilized to access those. The disappearing track search [8] uses the disappearing tracks of long-lived charginos with mass differences $O(100\,\text{MeV})$. In such cases, pions or off-shell Z bosons ensue in decays within the tracker. The signature is therefore one ($\geq$ two) disappearing track(s) and at least one jet. The latter is necessary for triggering.

This type of search is improved by a new machine-learning-based classifier for genuine disappearing tracks and conducted in hadronic and leptonic search categories. Limits are set on a pure higgsino dark matter model with the diagrams and exclusions shown in Figure 6.

Chargino and LSP masses can be excluded up to 200 GeV.

4. Summary

Electroweak SUSY is being hunted in every corner CMS can access. A combination of electroweak analyses and their combined results for winos, binos, higgsinos, and sleptons is presented. The complimentarity between search channels and their parameter spaces drives improvements in

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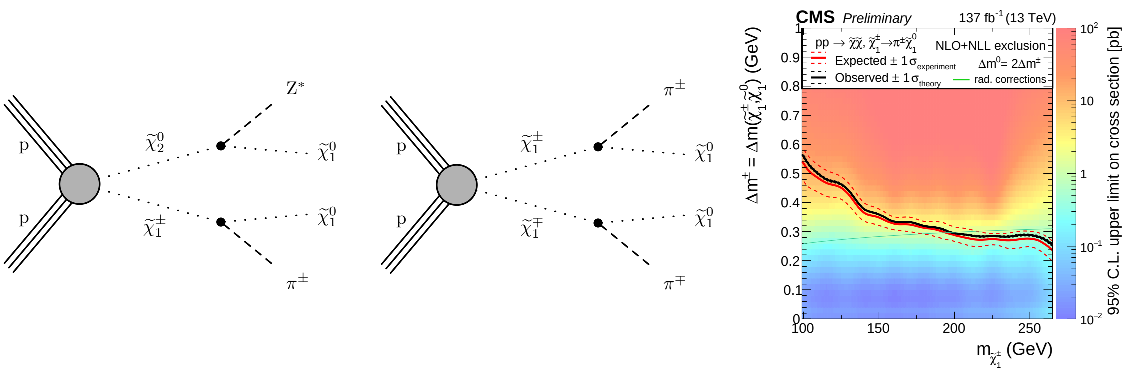

Figure 6: Production diagrams for disappearing tracks in a pure higgsino dark matter model (left, middle) leaving out direct $\tilde{\chi}_1^\pm\tilde{\chi}_1^0$ case are shown and limits are set as a function of chargino mass and the mass gap between chargino and LSP.

limit setting, even without new data. Results on higgsino dark matter in disappearing tracks was also presented, allowing limits to be set in extremely compressed scenarios of the sub-GeV scale.

References

[1] CMS collaboration, *Combined search for electroweak production of winos, binos, higgsinos, and sleptons in proton-proton collisions at $\sqrt{s} = 13$ TeV*, https://cds.cern.ch/record/2853345 .

[2] CMS collaboration, *Search for supersymmetry in final states with two or three soft leptons and missing transverse momentum in proton-proton collisions at $\sqrt{s} = 13$ TeV*, *JHEP* **04** (2022) 091 [2111.06296].

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[8] CMS collaboration, *Search for supersymmetry in final states with disappearing tracks in proton-proton collisions at $\sqrt{s} = 13$ TeV*, 2309.16823.