LHC constraints on electroweakino dark matter revisited

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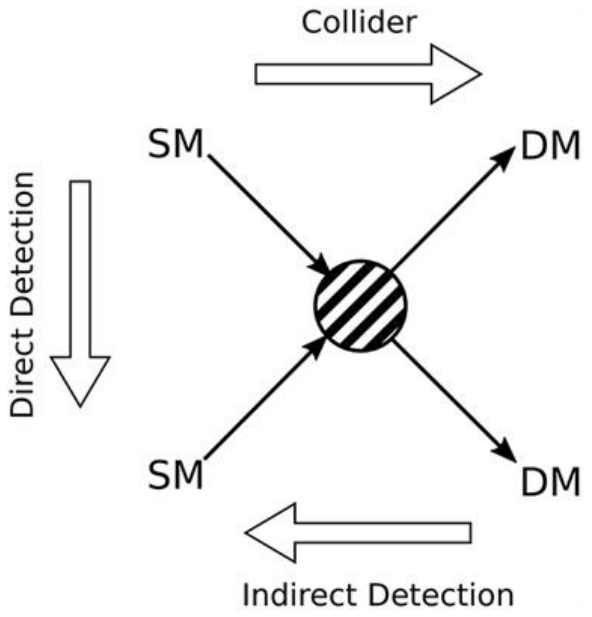
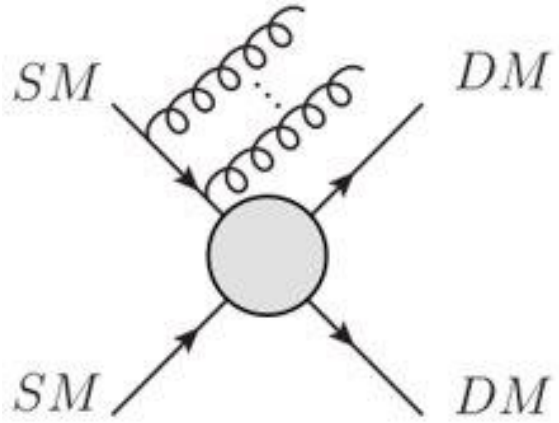
Supersymmetric DM

- DM existence strongly suggested by cosmological data.
- Weakly interacting massive particle fits well the picture.
- No direct detection and/or collider signal thus far.
- Supersymmetric partners of gauge and Higgs bosons are strong candidates but remain elusive.





Hadron colliders may produce DM particles in pairs, associated with a few high pT jets originating from initial state QCD radiation

SUSY scenarios to re-visit:

Light higgsinos/gauginos and rest of the spectrum decoupled. ➔ Jets+MET signal originated from Initial State Radiation.

Quick summary of chargino-neutralino sector:

$$\mathcal{L}_{\tilde{\chi}} = \overline{\tilde{\chi}_i^-}(\not{p}\delta_{ij} - P_L(U^* X V^\dagger)_{ij} - P_R(V X^\dagger U^T)_{ij})\tilde{\chi}_j^- + \frac{1}{2}\overline{\tilde{\chi}_i^0}(\not{p}\delta_{ij} - P_L(N^* Y N^\dagger)_{ij} - P_R(N Y^\dagger N^T)_{ij})\tilde{\chi}_j^0$$

$$X = \begin{pmatrix} M_2 & \sqrt{2} M_W \sin\beta \\ \sqrt{2} M_W \cos\beta & \mu \end{pmatrix}$$

diagonalised via $\mathbf{M}_{\tilde{\chi}^+} = U^* X V^\dagger$

$$Y = \begin{pmatrix} M_1 & 0 & -M_Z c_\beta s_W & M_Z s_\beta s_W \\ 0 & M_2 & M_Z c_\beta c_W & -M_Z s_\beta c_W \\ -M_Z c_\beta s_W & M_Z c_\beta c_W & 0 & -\mu \\ M_Z s_\beta s_W & -M_Z s_\beta c_W & -\mu & 0 \end{pmatrix}$$

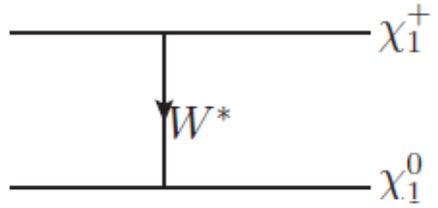
diagonalised via $\mathbf{M}_{\tilde{\chi}^0} = N^* Y N^\dagger$

Small mixing expected if there is a hierarchy between M_1, M_2 and μ and/or particles much heavier than the EW scale.

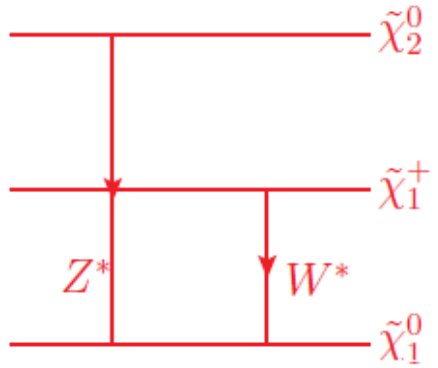
We concentrate in three cases:

bino-wino: almost mass degenerate winos and bino LSP

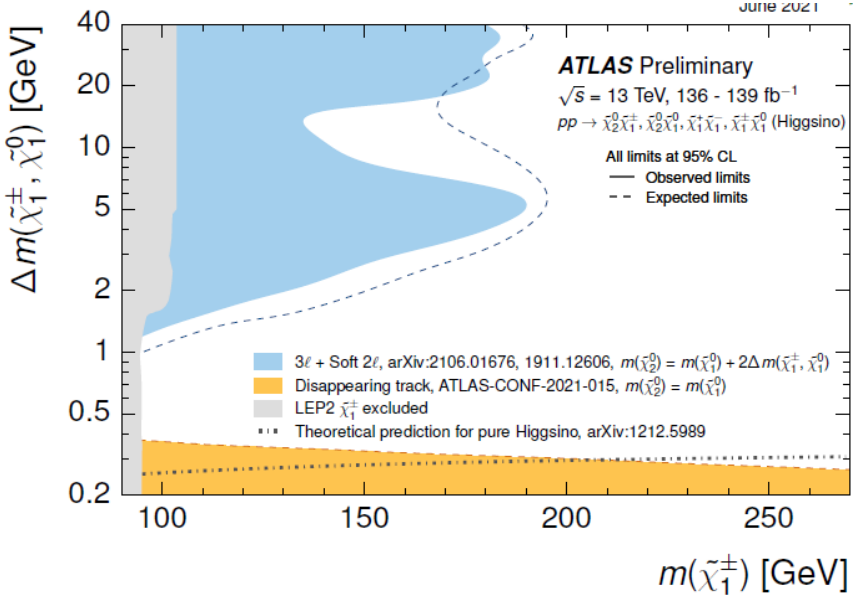
wino LSP: $M_2 \ll M_1, \mu$, two quasi-degenerate states: χ_1^0, $\chi_1^\pm$

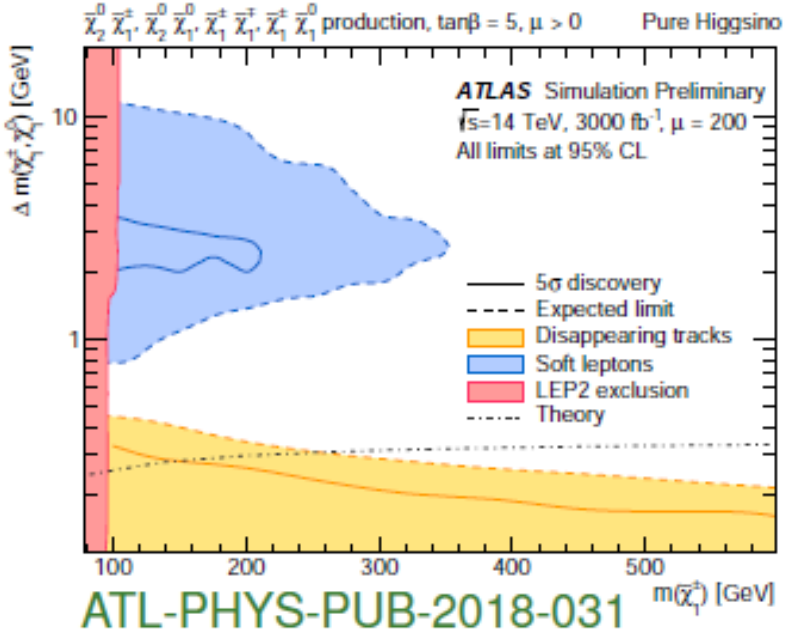


higgsino LSP, $\mu \ll M_1, M_2$, three quasi-degenerate states: $\tilde{\chi}_1^0$, $\tilde{\chi}_1^\pm$, $\tilde{\chi}_2^0$



At the LHC this scenarios has been constrained focusing on:





- Disappearing tracks: for sufficiently small mass gap, heavier states are long-lived.
- Soft leptons: For a mass difference $\gtrsim$1 GeV look for soft decay products.
- Long-standing limit at $\sim$ 100 GeV from LEP

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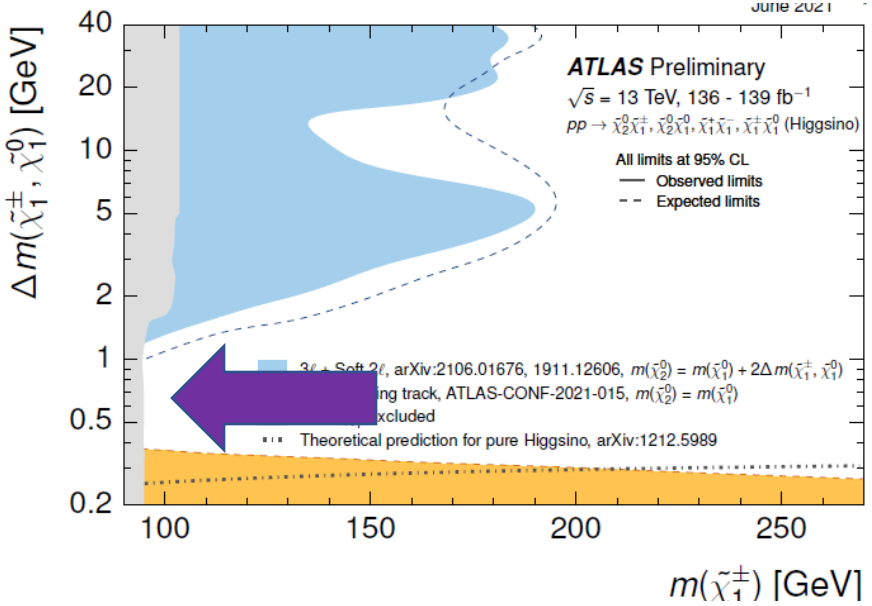

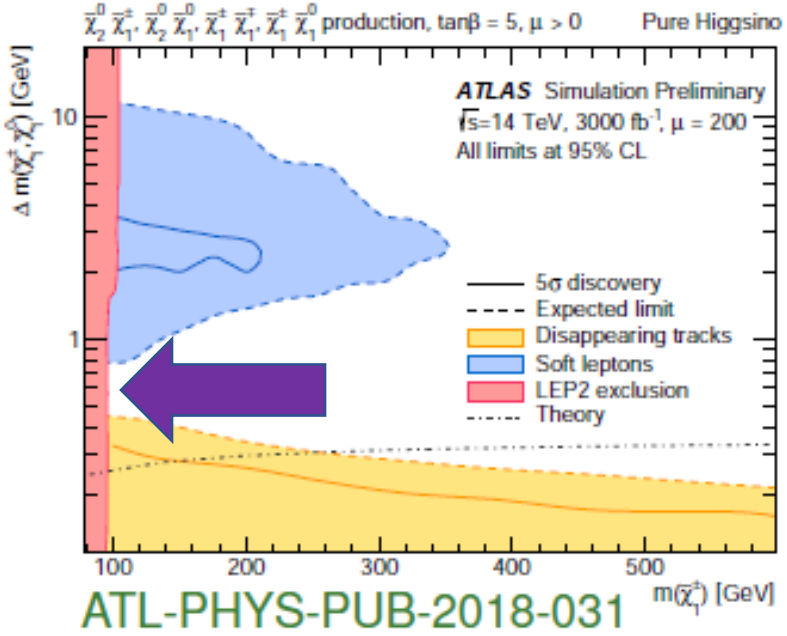

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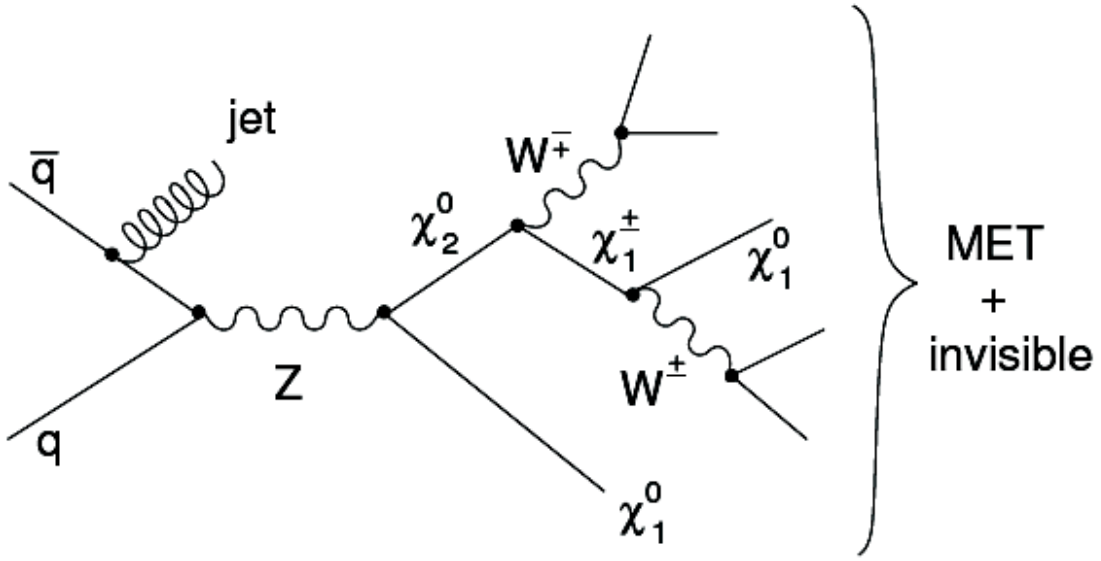
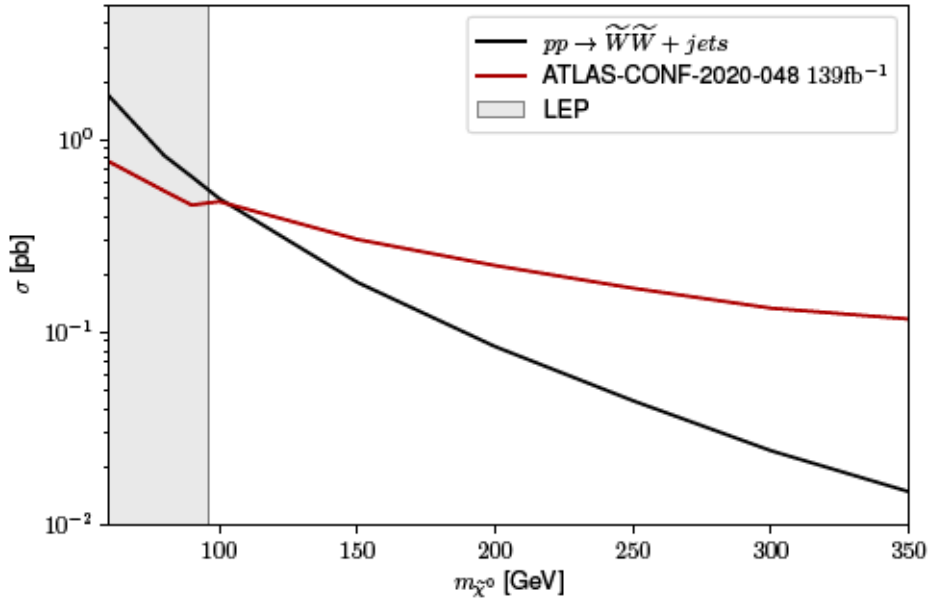
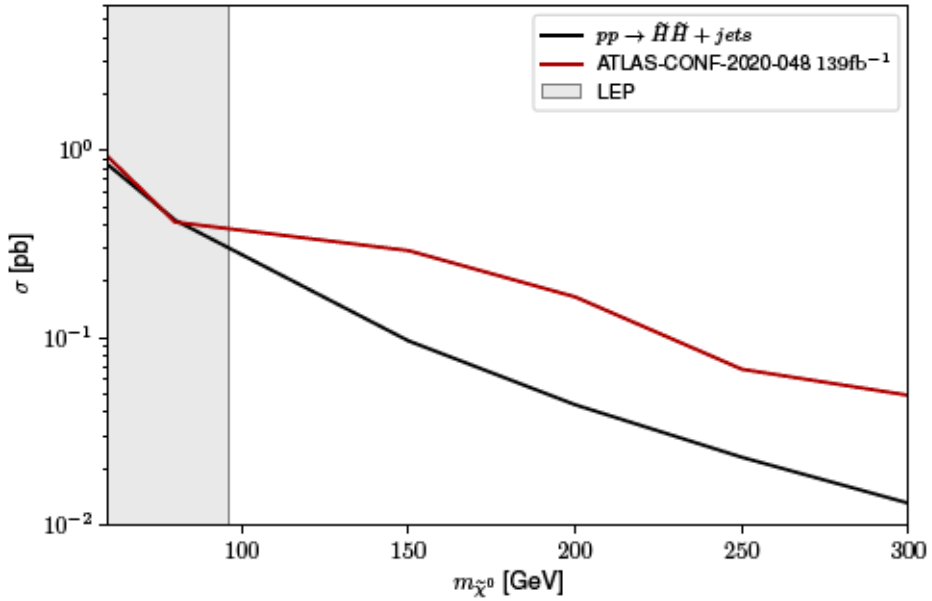
GAP between the two LHC searches. Use Mono/few-jets searches on this region.

- Monojet (and -photon) signal at ATLAS and CMS
- Requires $p^j_{leading} > 150$ GeV, $E_T^{miss} > 200$ GeV
- Note: "mono"≡ "up to 4"
- Decay products soft and scaping detection



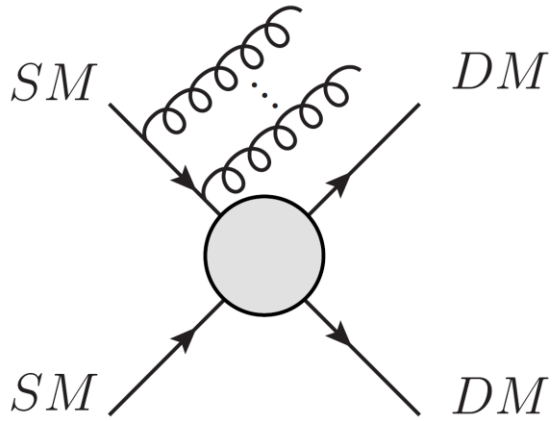




Monojet searches from ATLAS and CMS are not sensitive (yet) to *electroweakino* DM.

More than one jet emitted is possible, thus *more-than-one-jet* searches may be used also.

- We recast with CheckMATE a general search for squarks and gluinos, arXiv:2010.14293, in total 70 signal regions.
- Basic (preselection) signal requirements:
  - no electrons or muons.
  - 2–6 jets
  - large missing energy > 300 GeV
  - hard leading jet p_T > 200 GeV
  - large effective mass > 800 GeV



- Some overlap of the final states with “mono”-jet.
- We focus on bins with the largest sensitivity (originally intended for squark pair production):

2–3 jets, $p_{\mathrm{T}}^{\mathrm{jet1}}, p_{\mathrm{T}}^{\mathrm{jet2}} > 250$ GeV
effective mass > 1600 GeV
$E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}} > 16\sqrt{\mathrm{GeV}}$

- Multi-bin fit using pyhef.

CHECKMATE

Analysis based on a multi-bin fit with a simplified background model

We build the simplified likelihood following the prescription in ATL-PHYS-PUB-2021-038:

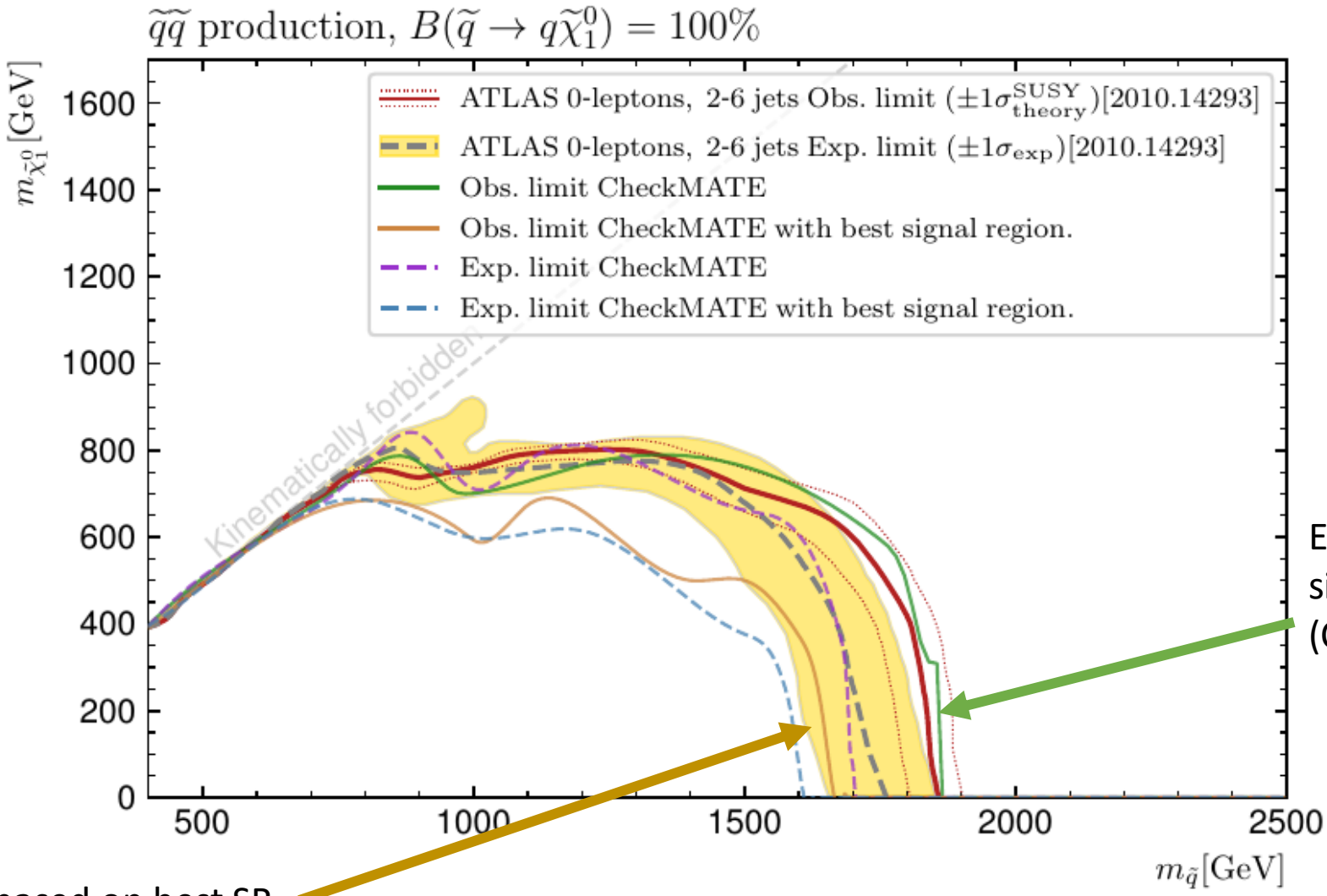
- *"In the simplified likelihood introduced herein, the background model is approximated with a single background sample, representing the total SM background rate in the different analysis channels. "*
- *"The pre-fit sample rate of the total background sample is set to the total post-fit background rate obtained in the background-only fit in the full likelihood"*
- *"…the complete set of nuisance parameters in the original full likelihood is reduced to a single constrained parameter… . It is constrained by a Gaussian G(α = 0 | α. σ = 1) and is correlated over all bins in each channel"*

$$L(n_{obs}|\mu,\theta) = \prod_{i=0}^{n_{bins}} \frac{(\mu s_i + b_i + \theta_b)^{n_{obs_i}} e^{-(\mu s + b_i + \theta_b)}}{n_{obs_i}} e^{-\frac{(\theta_b)^2}{2\sigma^2}}$$

Profile likelihood ratio test to find the 95% upper limit on signal strenght (μ) using the CLs method.

We obtain comparable results for selected points using the full statistical model published by ATLAS in .json format

Validation of the ATLAS results



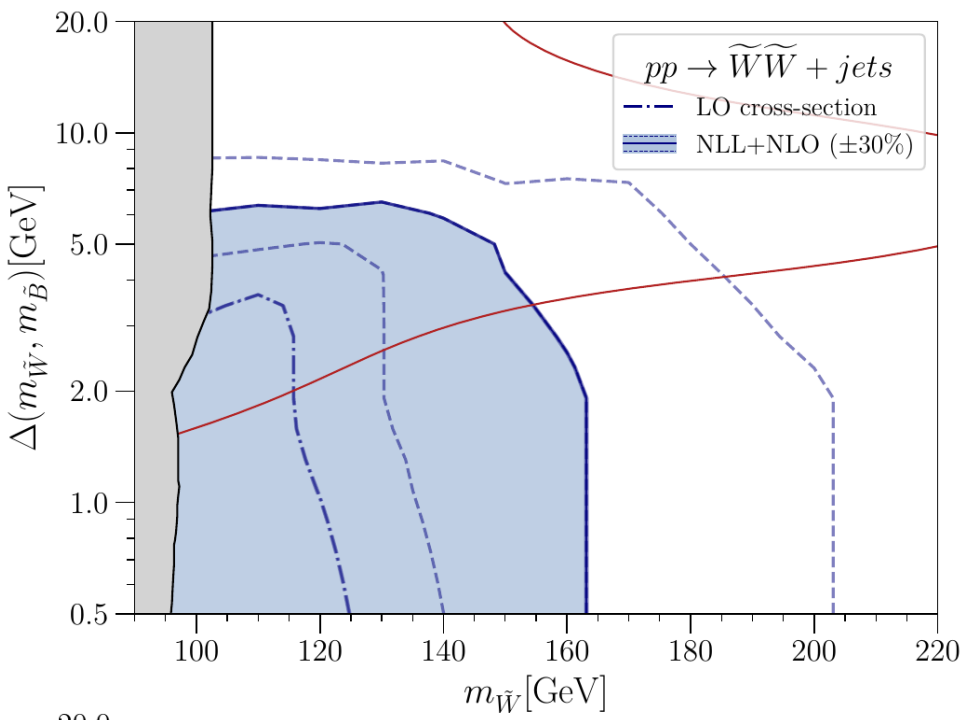
Exclusion based on simplified Likelihood (CheckMATE)

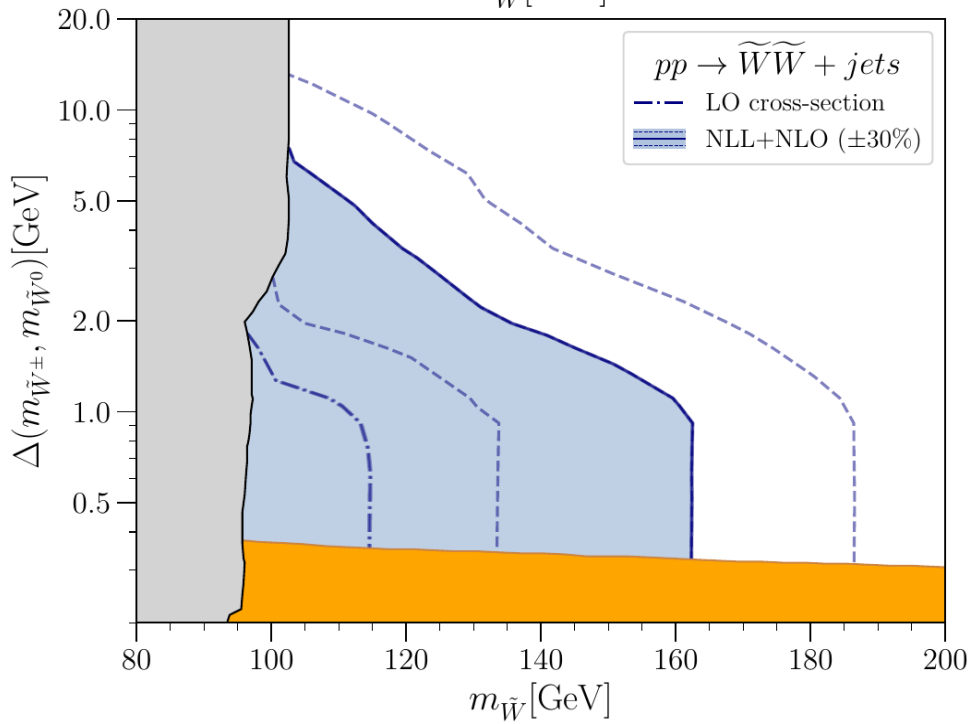
Exclusion based on best SR (CheckMATE)

Limits over Wino

- bino-wino model
- $\widetilde{W}^{\pm} \to \widetilde{B}^0 W^*, \widetilde{W}^0 \to \widetilde{B}^0 Z^*$
- comparison with ATLAS exclusion (red line)

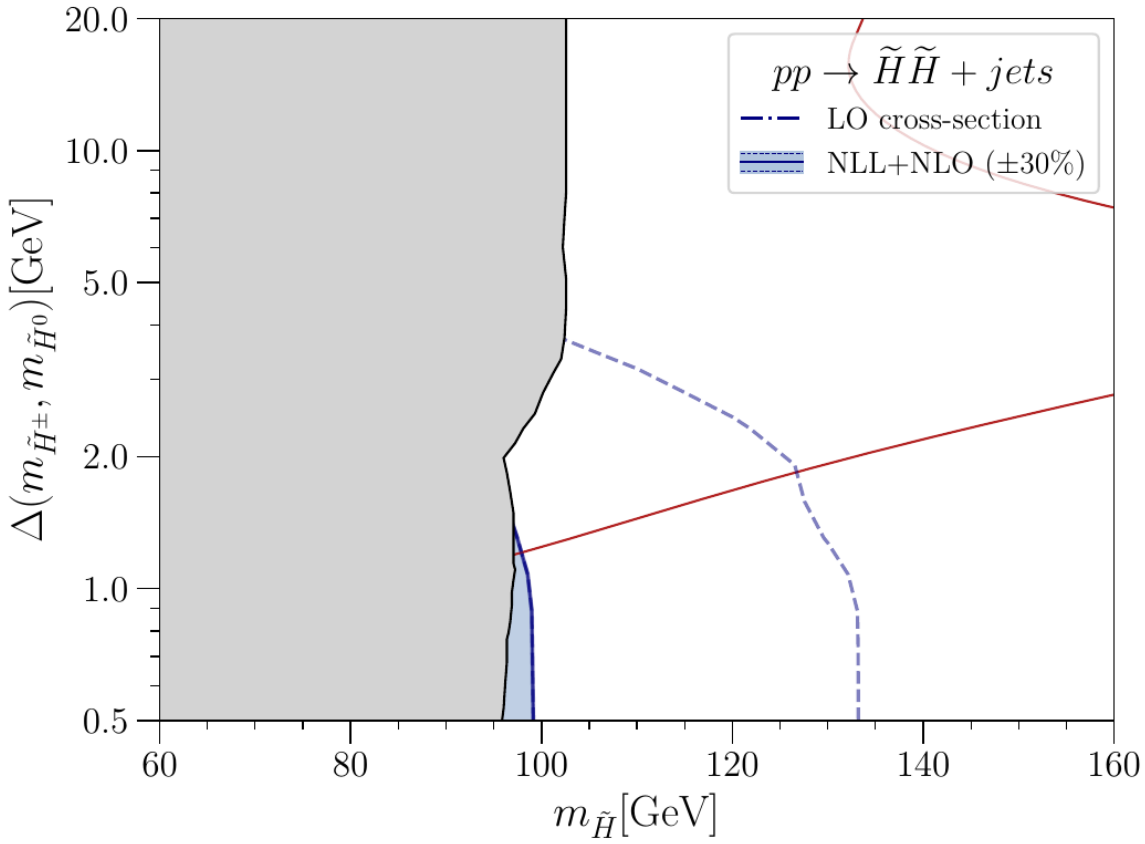
- wino model
- $\widetilde{W}^{\pm} \to \widetilde{W}^0 W^*$
- the new exclusion on top of LEP and long-lived charged wino limits





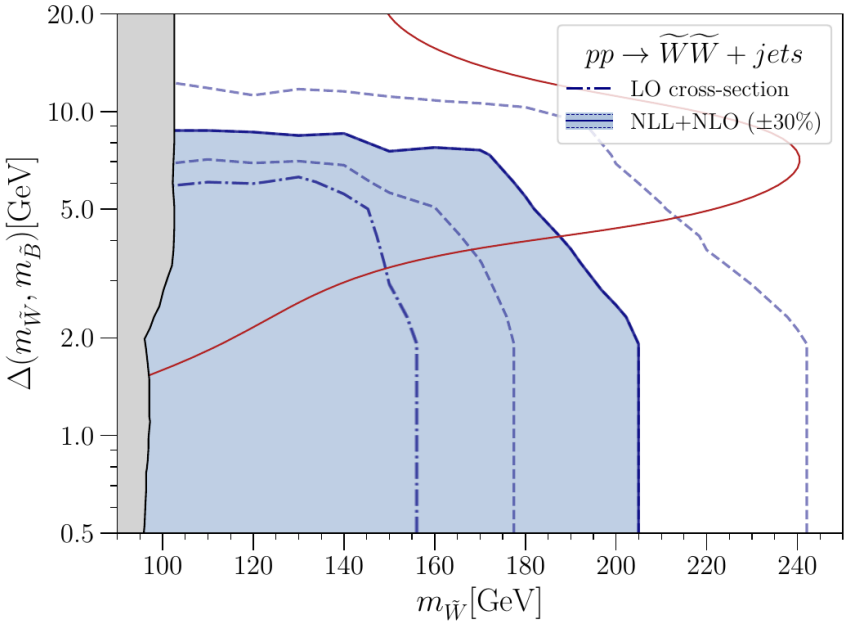
Limits over Higgsino

- higgsino model
- $pp \to \widetilde{H}^{\pm}\widetilde{H}^{0}_{1,2}, \widetilde{H}^{+}\widetilde{H}^{-}, \widetilde{H}^{0}_{1}\widetilde{H}^{0}_{2}$
- $\widetilde{H}^{\pm} \to \widetilde{H}^{0}_{1}W^{*}, \widetilde{H}^{0}_{2} \to \widetilde{H}^{0}_{1}Z^{*}$

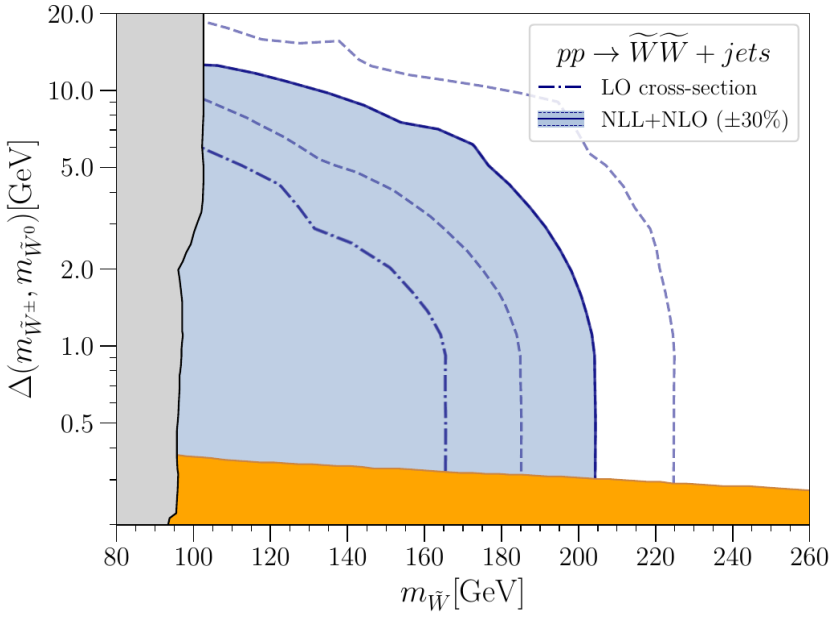


Prospects for Run 3

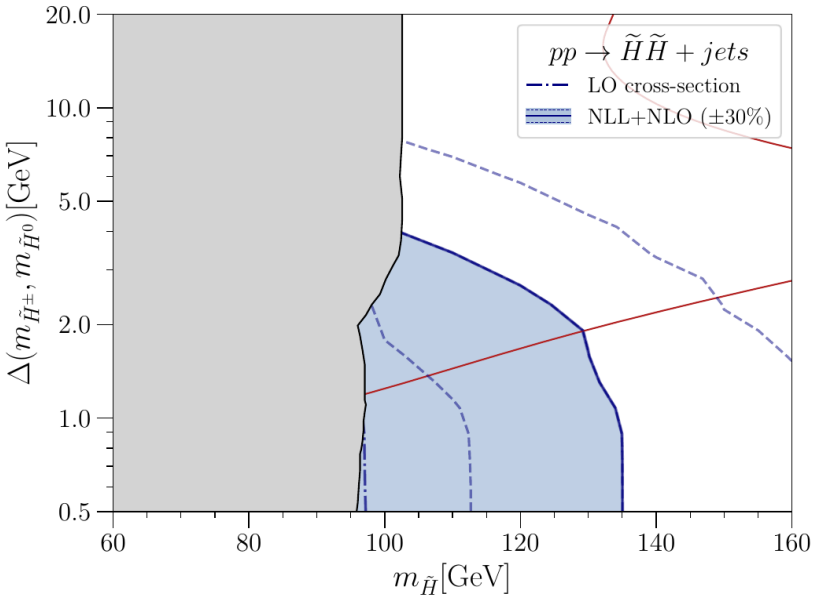
Wino-bino model



Wino model



Higgsino



Summary

- Initial state radiation can give a handle on challenging bits of LSP parameter space.
- Squark search outperforms dedicated monojet analysis for electroweakinos.
- New constraints closing the gap in (model independent) wino exclusion.
- Higgsinos more difficult but with some promise.
- HL prospects to be seen.
- Important information for future colliders.

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Understanding the Early Universe: interplay of theory and collider experiments

Joint research project between the University of Warsaw & University of Bergen

Additional material