Constraints on light SUSY-EW sector revisited

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arXiv:2208.04342, arXiv:2208.01651
in collaboration with
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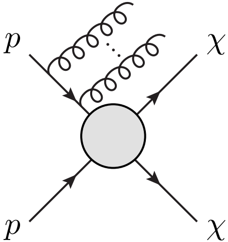
Outline

The case for dark matter

- dark matter existence strongly suggested by cosmological data
- weakly interacting massive particle fits well the picture
- no direct detection and collider signal thus far
- supersymmetric partners of gauge and Higgs bosons are strong candidates but remain elusive
- model-independent limits from LEP at around 100 GeV
- at the LHC the signal is challenging – the candidates escape detection
- in this talk: new limits based on existing ATLAS searches
- exploit initial state radiation, signal: jets+MET



Quick recap: chargino and neutralino sectors

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

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

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

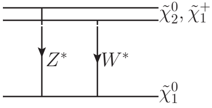
$$Y = \begin{pmatrix} M_1 & 0 & -M_Z c_\beta s_W & M_Z s_\beta s_W \\ 0 & M_2 & M_Z c_\beta c_W & -M_Z s_\beta c_W \\ -M_Z c_\beta s_W & M_Z c_\beta c_W & 0 & -\mu \\ M_Z s_\beta s_W & -M_Z s_\beta c_W & -\mu & 0 \end{pmatrix}$$

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

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

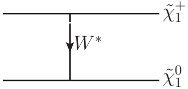
Models for this talk

- bino-wino: almost mass degenerate winos and bino LSP



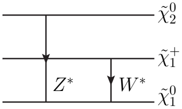
bino-wino

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



wino

- higgsino LSP, $\mu \ll M_1, M_2$, three quasi-degenerate states: $\tilde{\chi}_1^0$, $\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$
- mass splittings of order 100–1000 MeV



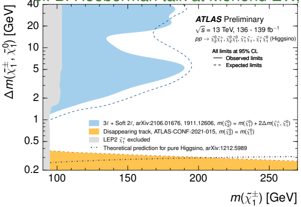
higgsino

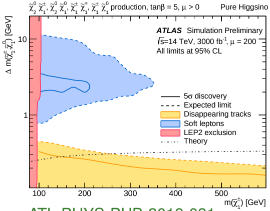
Search strategies

- for sufficiently small mass gap a long-lived massive particle travels macroscopic distance in the detector
- possible signatures: displaced vertex, heavy charged track, displaced jet etc.
- for a larger mass difference (> 1 GeV) look for soft decay products

- at HL the gap remains
- for winos no exclusion in soft ℓ search!

cf. B. Hooberman talk at Moriond EW, 14.03.22





ATL-PHYS-PUB-2018-031

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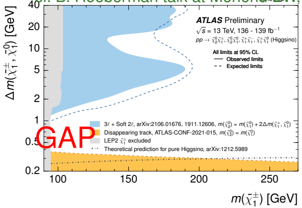

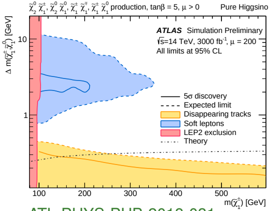

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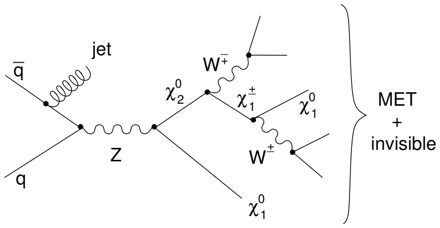
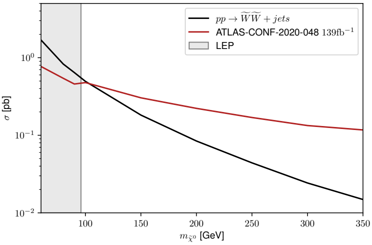
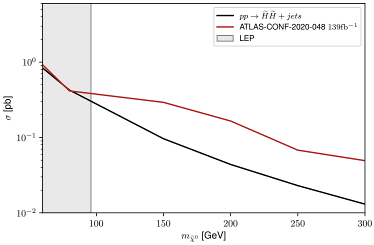
Search strategy: monojets

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





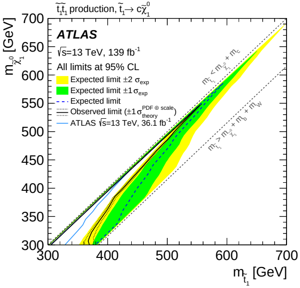


Outline

Principles of recasting

- experiments search for particular final states e.g. 1-4 jets and missing transverse energy
- certain additional requirements imposed on p_T, angular separation or flavour of the final state objects
- the number of observed events in a given category (signal region) is compared to the expected Standard Model background
- the result is interpreted in a specific model chosen by collaboration, often a simplified model with many more or less realistic assumptions

an energetic jet + $E_T^{\rm miss}$ (139 fb^{-1})
e, μ, τ, γ veto
$E_T^{\rm miss} > 200$
$p_T^{j_1} > 150$, $\lvert\eta^{j_1}\rvert < 2.4$
$N_j(p_T > 30, \lvert\eta\rvert < 2.8) \leq 4$
$\Delta\phi(\text{jet}, \mathbf{p}_T^{\rm miss}) > 0.4$ (0.6)
$E_T^{\rm miss}$binned



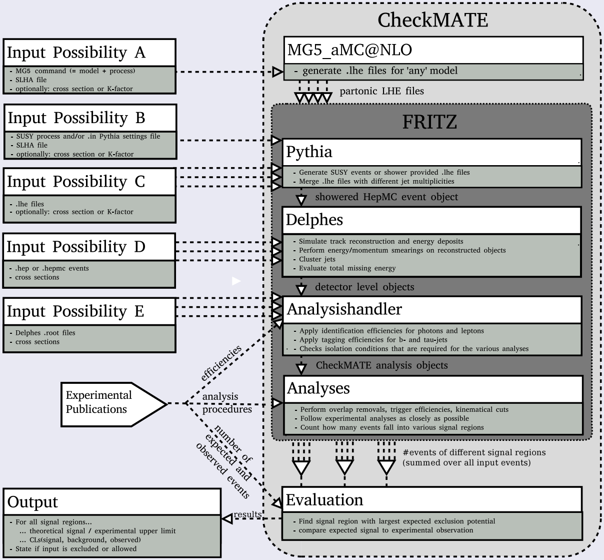
Principles of recasting/BSM reinterpretation

- what if theorist would like to know a constraint on a completely different model?
- the events for a new model needs to be generated and the same selection criteria applied, often for tens of signal regions
- MC events $\rightarrow$ detector simulation $\rightarrow$ selection criteria $\rightarrow$ statistical analysis/interpretation
- the procedure is tedious and complicated so there was a need to streamline the process
- in the ideal situation from UFO model to the result in one click
- several codes on the market:
  - SModelS
  - MadAnalysis
  - Gambit/ColliderBit
  - CheckMATE

Tools

- CheckMATE is a general tool for recasting arbitrary model
- based on Delphes for detector simulation
- using existing LHC searches calculates a limit
- one can easily constrain models that were not covered in the original ATLAS/CMS search
- currently more than 40 searches at 13 TeV coded, including 14 with full luminosity
- long-lived particles branch
- https://checkmate.hepforge.org/

Overview: Data Flow



Recasting a squark-gluino search

- 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
- note 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
  - $E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}} > 16\sqrt{\mathrm{GeV}}$
  - perform a multibin/shape fit using HistFitter

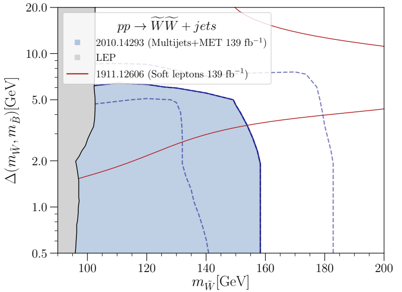
Outline

Event generation

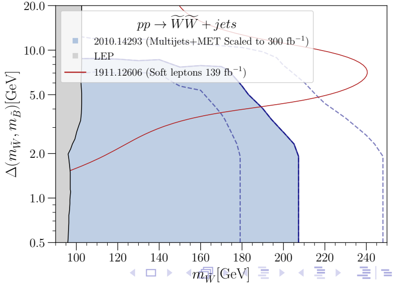
- events generated with MadGraph5_aMC@NLO
- up to 2 additional partons in the final state: $p\,p \to \tilde{\chi}\,\tilde{\chi}\,j\,j$
- Pythia MLM matching of different jet multiplicities
- for uncertainty estimation we vary renormalization and factorization scales and different PDF sets
- cross section normalized using Resummino at NLO-NLL

Results – bino-wino scenario: $pp \to \widetilde{W}^{\pm}\widetilde{W}^{0}, \widetilde{W}^{+}\widetilde{W}^{-}$

- $\widetilde{W}^{\pm} \to \widetilde{B}^{0}W^{*}, \widetilde{W}^{0} \to \widetilde{B}^{0}Z^{*}$
- decay products soft but become detectable with boost
- comparison with ATLAS soft leptons exclusion (red line)
- the exclusion up to 160 GeV with current data

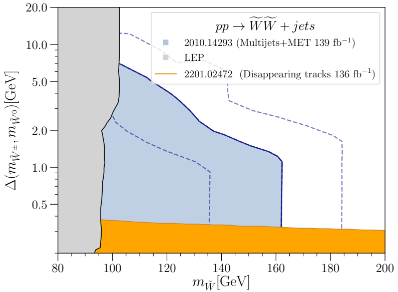


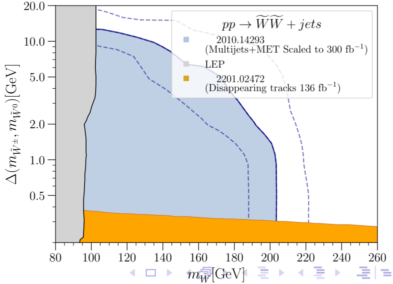
- after Run 3 the expected limit increases to 210 GeV



Results – wino scenario: $pp \to \widetilde{W}^{\pm}\widetilde{W}^{0}, \widetilde{W}^{+}\widetilde{W}^{-}$

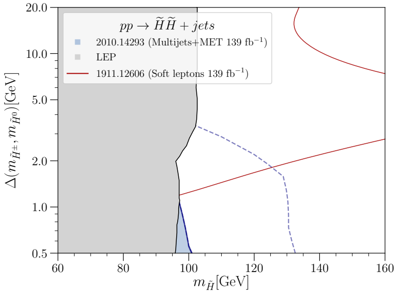
- $\widetilde{W}^{\pm} \to \widetilde{W}^{0} W^{*}$
- $\widetilde{W}^{0}$ stable (DM candidate)
- soft decay products but no same-flavour opposite-charge from Z^{*} and no limits
- the limits from LEP and the search for semi-stable chargino
- the new exclusion on top of LEP and long-lived charged wino limits
- after Run 3 the expected limit increases to 200 GeV

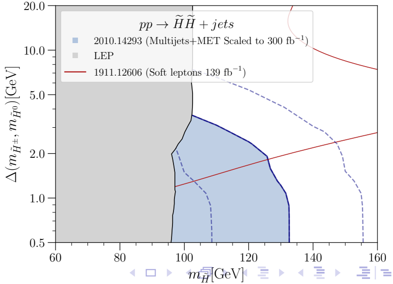




Results – higgsino scenario

- higgsino model
- $pp \to \widetilde{H}^{\pm}\widetilde{H}^{0}_{1,2}, \widetilde{H}^{+}\widetilde{H}^{-}, \widetilde{H}^{0}_{1}\widetilde{H}^{0}_{2}$
- $\widetilde{H}^{\pm} \to \widetilde{H}^{0}_{1}W^{*}, \widetilde{H}^{0}_{2} \to \widetilde{H}^{0}_{1}Z^{*}$
- currently the limit only slightly above LEP
- after Run 3 the expected limit increases to 130 GeV

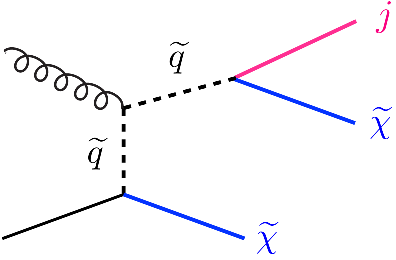




Outline

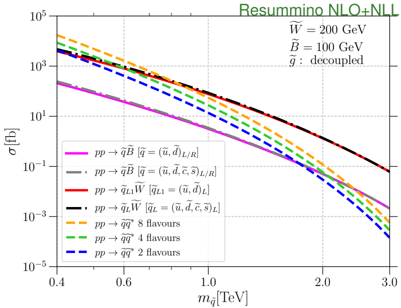
Gaugino-squark production

- light gauginos and squark, rest of the spectrum decoupled
- we consider associated squark-wino production
- $pp \to \widetilde{\chi}\tilde{q},\ \tilde{q} \to \widetilde{\chi}q$
- monojet-type signal
- specifically sensitive to 1st generation doublet
- order $\alpha\alpha_s$ compared to α_s^2 for squark pair production, so maybe can be neglected?



Gaugino-squark production

- three possibilities: $\widetilde{\chi} =$ wino, bino, higgsino
- $pp \to \widetilde{W}\tilde{q},\ \tilde{q} \to \widetilde{W}q$
- at squark mass ~ 1 TeV the cross section competitive with squark pair production ($m_{\widetilde{W}} = 200$ GeV)

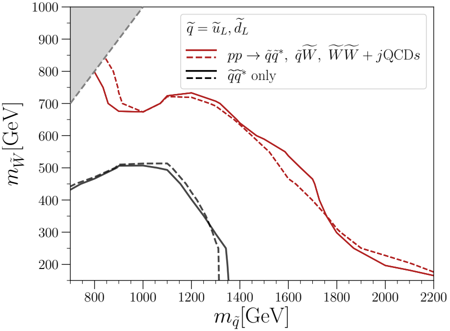


- $pp \to \widetilde{B}\tilde{q},\ \tilde{q} \to \widetilde{B}q$
- at squark mass ~ 2.2 TeV the cross section competitive with squark pair production ($m_{\widetilde{B}} = 100$ GeV)

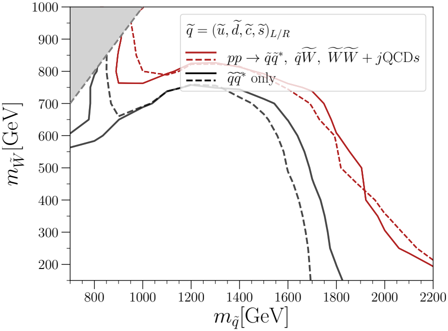
- higgsino production negligible - Yukawa suppressed

Results

first generation doublet only (2-fold degenerate)



2 generations, left and right (8-fold degenerate)



Outline

Summary

- initial state radiation can give a handle on challenging bits of LSP parameter space
- squark search outperforms dedicated monojet analysis
- new constraints closing the gap in (model independent) wino exclusion
- higgsinos more difficult but with some promise
- the idea to revisit LEP slepton limits
- HL prospects to be seen

Norway grants

NATIONAL SCIENCE CENTRE POLAND

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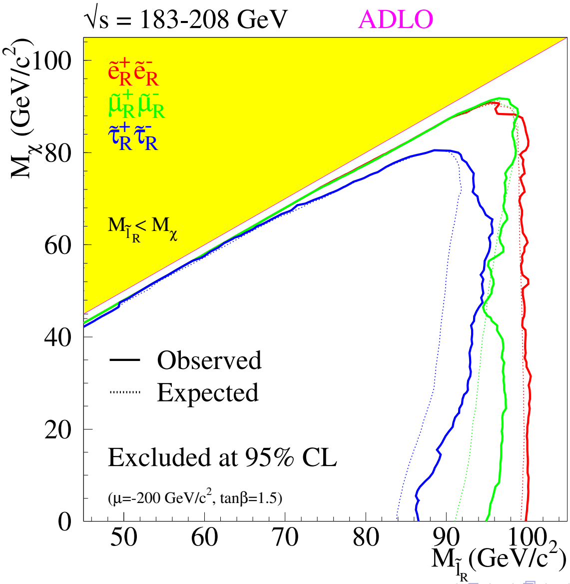
Understanding the Early Universe:
interplay of theory and collider experiments

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

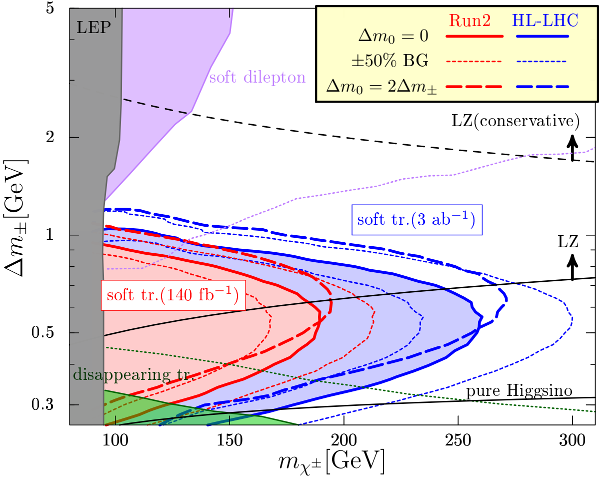
BACKUP

LEP slepton limits

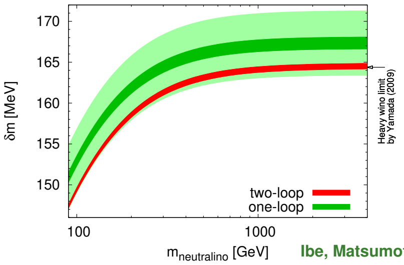


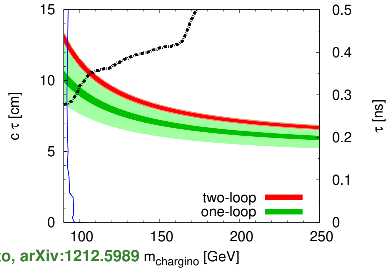
Search for soft tracks

Phys. Rev. Lett. 124, 101801

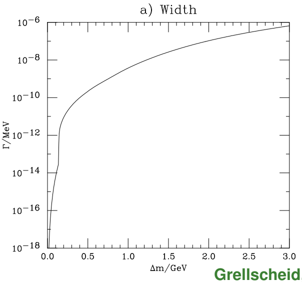


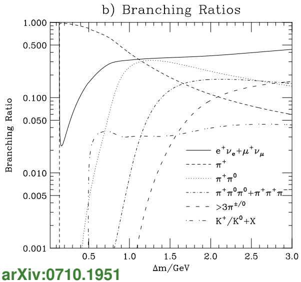
Width and decays





Ibe, Matsumoto, Sato, arXiv:1212.5989





Grellscheid, Richardson, arXiv:0710.1951