Electroweak-inos constraints in the pMSSM with SModelS

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On behalf of SModelS collaboration

Overview

- Previous ATLAS work on pMSSM
- Doing this task with SModelS public software
- Going further with analysis combination in SModelS

BSM search at colliders and SUSY: pMSSM .

- The standard Model is very successfull but: Neutrino masses, Dark Matter, Hierarchy problem ...
- New physics involved ?
- at LHC, many searches were performed looking for BSM in specific final states and interpreted as Simplified ModelS (SMS).

BSM search at colliders and SUSY: pMSSM .

- Experimentally motivated reduction of the R-parity conserved MSSM free parameters.
  - No new CP-violation.
  - sfermion masses and trilinear coupling matrices are diagonal.
  - First and second generation considered degenerate and trilinear couplings are only considered for the third generation.

  $\rightarrow$ We go down to 19 free parameters

- Electroweak-ino sector: Bino, Wino, Higgsinos mixed together.
  The neutral mass eigenstates are called neutralinos ($\tilde{\chi}_1^0$,$\tilde{\chi}_2^0$,$\tilde{\chi}_3^0$,$\tilde{\chi}_4^0$) ordered by mass and the charged ones charginos ($\tilde{\chi}_1^\pm$,$\tilde{\chi}_2^\pm$).

- Rich phenomenology of SUSY: many different final states can be investigated to constrain the pMSSM.

ATLAS pMSSM study. arXiv:2402.01392

ATLAS recent work: Run 2 searches for electroweak production of supersymmetric particles interpreted within the pMSSM. 8 Run 2 searches considered (all 140 fb^{-1} and 13 TeV) as well as Higgs constraints. scan the pMSSM parameter space.

Parameter	Min	Max	Note
$M_{\tilde{L}_1}$ $(=M_{\tilde{L}_2})$	10 TeV	10 TeV	Left-handed slepton (first two gens.) mass
$M_{\tilde{e}_1}$ $(=M_{\tilde{e}_2})$	10 TeV	10 TeV	Right-handed slepton (first two gens.) mass
$M_{\tilde{L}_3}$	10 TeV	10 TeV	Left-handed stau doublet mass
$M_{\tilde{e}_3}$	10 TeV	10 TeV	Right-handed stau mass
$M_{\tilde{Q}_1}$ $(=M_{\tilde{Q}_2})$	10 TeV	10 TeV	Left-handed squark (first two gens.) mass
$M_{\tilde{u}_1}$ $(=M_{\tilde{u}_2})$	10 TeV	10 TeV	Right-handed up-type squark (first two gens.) mass
$M_{\tilde{d}_1}$ $(=M_{\tilde{d}_2})$	10 TeV	10 TeV	Right-handed down-type squark (first two gens.) mass
$M_{\tilde{Q}_3}$	2 TeV	5 TeV	Left-handed squark (third gen.) mass
$M_{\tilde{u}_3}$	2 TeV	5 TeV	Right-handed top squark mass
$M_{\tilde{d}_3}$	2 TeV	5 TeV	Right-handed bottom squark mass
M_1	−2 TeV	2 TeV	Bino mass parameter
M_2	−2 TeV	2 TeV	Wino mass parameter
μ	−2 TeV	2 TeV	Bilinear Higgs boson mass parameter
M_3	1 TeV	5 TeV	Gluino mass parameter
A_t	−8 TeV	8 TeV	Trilinear top coupling
A_b	−2 TeV	2 TeV	Trilinear bottom coupling
A_τ	−2 TeV	2 TeV	Trilinear τ-lepton coupling
M_A	0 TeV	5 TeV	Pseudoscalar Higgs boson mass
$\tan\beta$	1	60	Ratio of the Higgs vacuum expectation values

ATLAS pMSSM study. arXiv:2402.01392

Summary of the analyses considered in ATLAS study and similar results implemented in SModelS.

Type	Analysis	In SModelS
0 leptons	SUSY-2018-41	YES
1 lepton + 2 b-jets	SUSY-2019-08	YES
2 leptons + 0 jets	SUSY-2018-32	YES
2 leptons + Jets	SUSY-2018-05	YES
3 leptons on shell 3 leptons off shell	SUSY-2019-09	YES
4 leptons	SUSY-2018-02	SUSY-2017-03
Compressed	SUSY-2018-16	YES
Disappearring Track	SUSY-2018-19	SUSY-2016-06
h $\rightarrow$ invisible constraint	HIGG-2021-05	NO
CP odd Higgs Boson constraint	HIGG-2018-57	NO

SModelS: goals and useful features for this work

SModelS: public tool for reinterpreting simplified model results from the LHC. makes use of CMS and ATLAS results.

- Fast (no MC)
- well suited for parameter scans
- Not as precise as recasting.

Input: mass spectrum, branching ratios, production cross-sections.

Results given as an r-value: r=$\frac{\sigma^{\text{BSM}}}{\sigma_{95}}$ Experimental results in SModelS:

- Upper Limits (UL): function of the simplified model parameters which gives an upper limit on the signal cross section. $\sigma_{\text{BSM}}=\sigma \prod \text{BR}$

- Efficiency Maps (EM): enable likelihood computation, and thus statistical tests, signal regions combination as well as analysis combination. $\sigma_{\text{BSM}}=\sigma \times \varepsilon \times \mathcal{A} \prod \text{BR}$

Our setup

We reuse the EWkino scan provided by ATLAS (12 280 points).

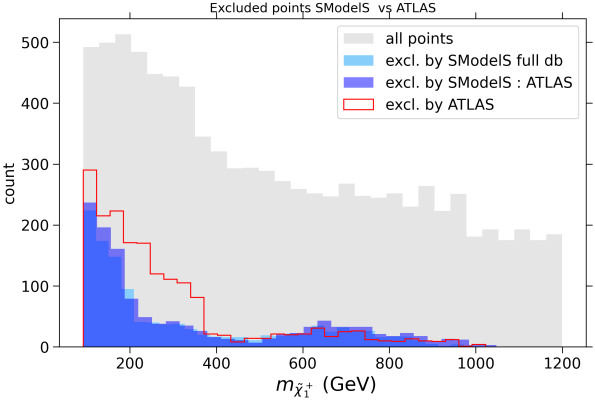
Filters: Points filtered out by ATLAS (no sensitivity) .
points excluded by h→inv and/or m_A constraint (no such constraint in SModelS database)

Additionally, we filter some non physical spectra: $m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0}$ does not meet the lower bound computed at two loop in the literature.
$\sim$ 9000 points left

NLO production cross sections for EWKino computed at 8 TeV and 13 TeV using Resummino v3.1.2 (*J. Fiaschi, B. Fuks, M. Klasen, A. Neuwirth, arXiv:2304.11915*)
Run SModelS v3.0 (*Altakach et al. arXiv:2409.12942*)

Single analysis results

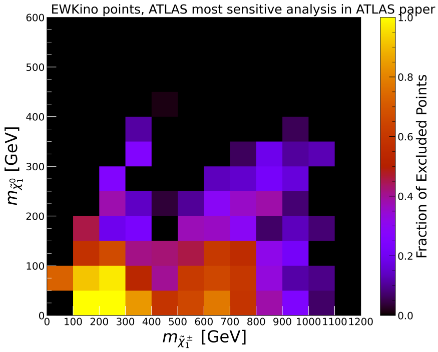
- Good agreement between SModelS and ATLAS
- Good agreement between ATLAS and CMS
- 200 - 400 GeV: disappearing track search (only 36 fb^{-1} results available in SModelS)
- Some additional but non-dominant analysis in the SModelS results



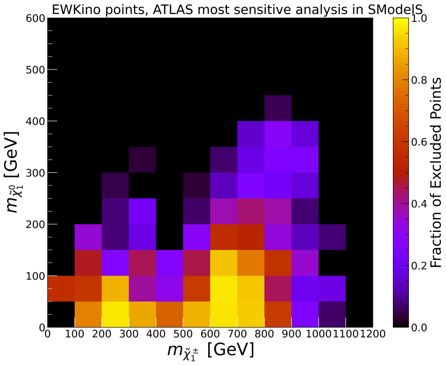
Comparison to ATLAS results

Hadronic search (ATLAS-SUSY-2018-41) in SModelS excludes 166 points that were not excluded in ATLAS pMSSM study.

ATLAS



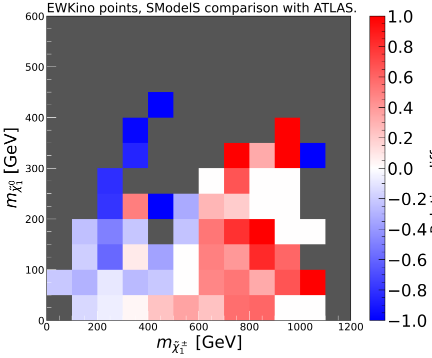
SMODELS

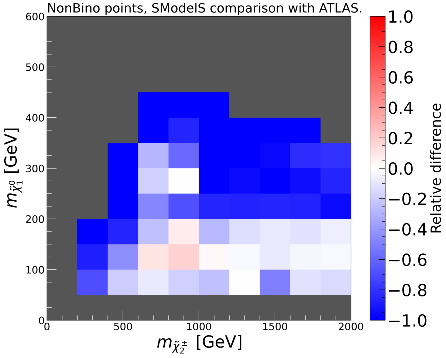


Plots of $\frac{\text{excluded points}}{\text{all points}}$ (*curtesy Théo Reymermier , IP2I*)

SModelS and ATLAS results agree especially in low mass region.

- Blue bins
  - disappearing track search (ATLAS-SUSY-2018-19 vs ATLAS-SUSY-2016-06)
  - di-leptons + jets (ATLAS-SUSY-2018-05) for which SModelS cannot take some decay channels into account.
- Red bins
  - overestimation of expected and observed exclusion of a MET + hadronically decaying bosons analysis in SModelS (ATLAS-SUSY-2018-41).

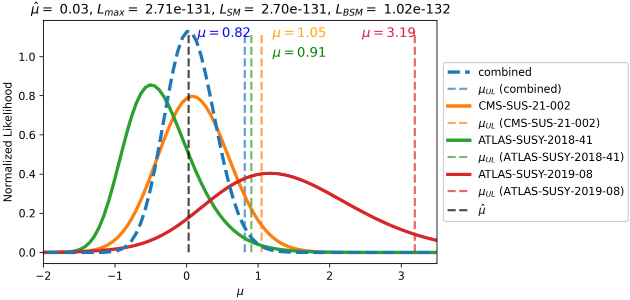




Plots of $\frac{\text{SModelS exc. - ATLAS exc.}}{\text{ATLAS exc.}}$ (*curtesy Théo Reymermier , IP2I*)

Going further: Analysis combination.

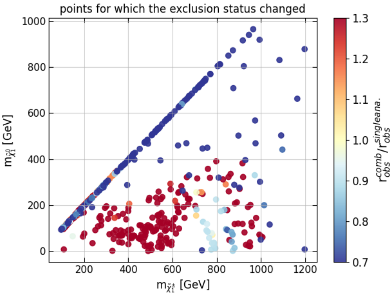
How far we can go in constraining those points robustly ?
→ We can combine independent analyses in SModelS to reduce statistical fluctuations and increase the confidence we have in the result. (*Altakach et al. arXiv:2306.17676 , arXiv:2312.16635*)
Combining up to 33 analyses (21 from ATLAS, 12 froms CMS).

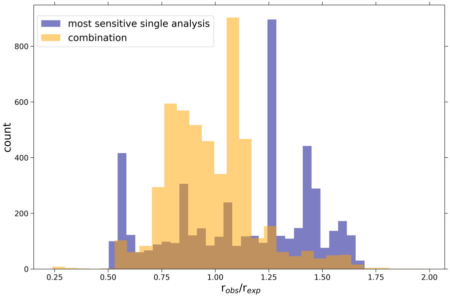


SModelS database contains results sensitive to the gluino masses generated in the scan. We add $\tilde{g}\tilde{g}$ production at NNLL as well as gluino-EWKino production cross sections at NLO and then run combination.

Combination results

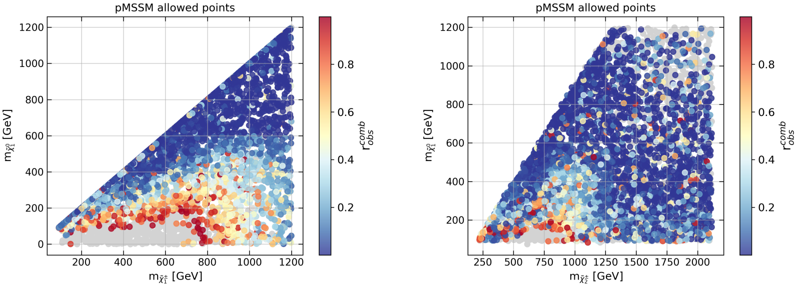
Analysis combination reduces statistical fluctuations
Newly excluded points:329
Newly non-excluded points:207
Before combination, proportion of excess ($r_{obs}/r_{exp}<1$): 34% of points
after combination, proportion of excess ($r_{obs}/r_{exp}<1$): 55% of points





Combination results

Allowed pMSSM parameter space from this scan.
Disappearing track result from ATLAS pMSSM study of the points is considered.
Red-orange points not excluded but in range to be more thoroughly tested in the future (Run 3).



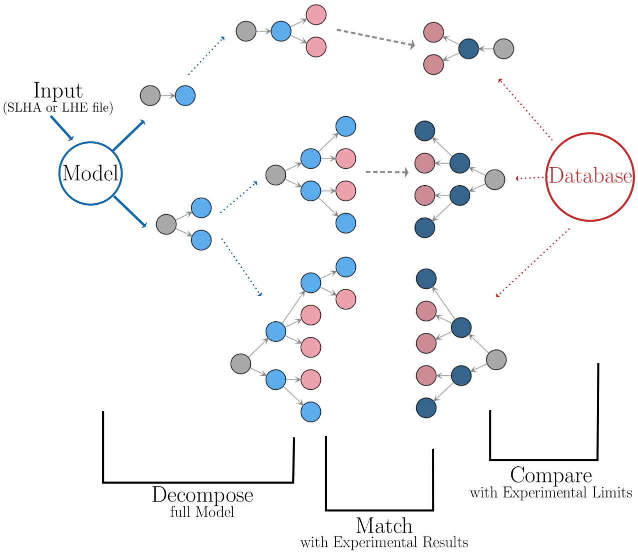
Taken from *L.C., S. Kraml, F. Mahmoudi arXiv:2505.11251*

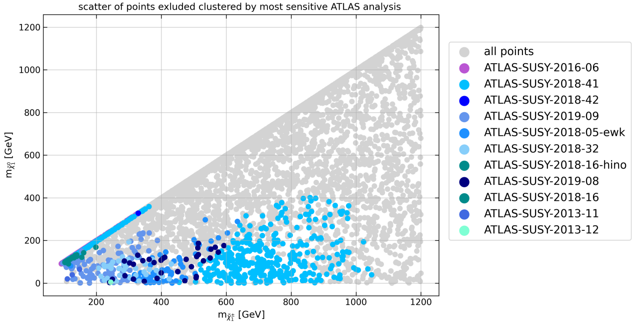
Summary

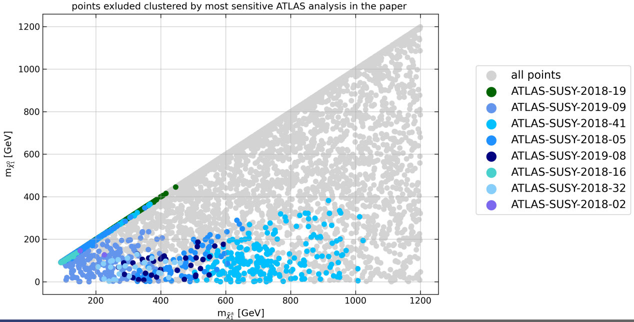
- For SUSY models, there is a need to go beyond the simplified model interpretation to assess the limits in more complex scenarios.
- SModelS is a well suited software do do such tasks: good agreement which increases as new analysis are implemented in the database.
- Analysis combination uses more data, thus allows to compensate for statistical fluctuation and boost sensitivity, giving more robusts results. (500 points changed exclusion status over the 1800 excluded points after combination)
- Light SUSY still alive !

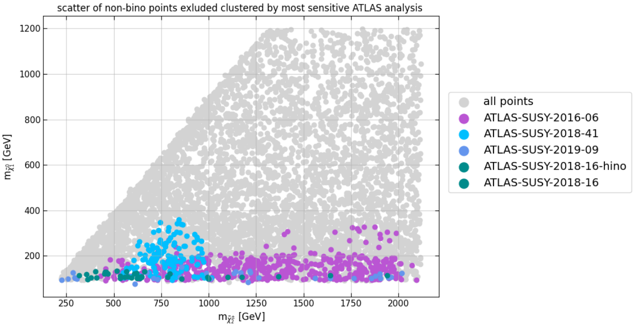
Thanks !

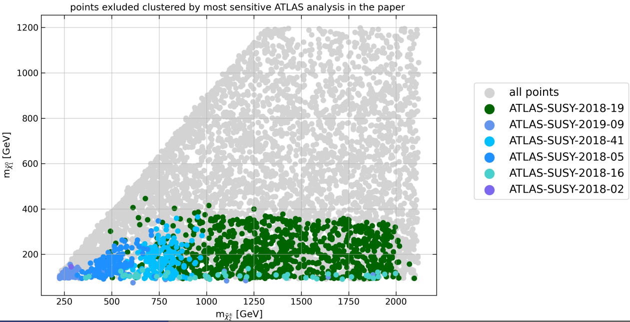
SModelS Working principle




scatter of points exluded clustered by most sensitive ATLAS analysis
$m_{\tilde{\chi}_1^0}$ [GeV]
$m_{\tilde{\chi}_1^\pm}$ [GeV]
0
200
400
600
800
1000
1200
all points
ATLAS-SUSY-2016-06
ATLAS-SUSY-2018-41
ATLAS-SUSY-2018-42
ATLAS-SUSY-2019-09
ATLAS-SUSY-2018-05-ewk
ATLAS-SUSY-2018-32
ATLAS-SUSY-2018-16-hino
ATLAS-SUSY-2019-08
ATLAS-SUSY-2018-16
ATLAS-SUSY-2013-11
ATLAS-SUSY-2013-12


points exluded clustered by most sensitive ATLAS analysis in the paper
$m_{\tilde{\chi}_1^0}$ [GeV]
$m_{\tilde{\chi}_1^\pm}$ [GeV]
0
200
400
600
800
1000
1200
all points
ATLAS-SUSY-2018-19
ATLAS-SUSY-2019-09
ATLAS-SUSY-2018-41
ATLAS-SUSY-2018-05
ATLAS-SUSY-2019-08
ATLAS-SUSY-2018-16
ATLAS-SUSY-2018-32
ATLAS-SUSY-2018-02


scatter of non-bino points exluded clustered by most sensitive ATLAS analysis
$m_{\tilde{\chi}_1^0}$ [GeV]
$m_{\tilde{\chi}_2^\pm}$ [GeV]
1200
1000
800
600
400
200
250
500
750
1000
1250
1500
1750
2000
all points
ATLAS-SUSY-2016-06
ATLAS-SUSY-2018-41
ATLAS-SUSY-2019-09
ATLAS-SUSY-2018-16-hino
ATLAS-SUSY-2018-16


points exluded clustered by most sensitive ATLAS analysis in the paper
$m_{\tilde{\chi}_1^0}$ [GeV]
$m_{\tilde{\chi}_2^\pm}$ [GeV]
1200
1000
800
600
400
200
250
500
750
1000
1250
1500
1750
2000
all points
ATLAS-SUSY-2018-19
ATLAS-SUSY-2019-09
ATLAS-SUSY-2018-41
ATLAS-SUSY-2018-05
ATLAS-SUSY-2018-16
ATLAS-SUSY-2018-02

Change in the exclusion status