Beyond simplified models;

ATLAS supersymmetry searches re-interpreted in the pMSSM framework

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October 22nd 2024

Partikeldagarna 2024

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ATLAS EXPERIMENT

Where is supersymmetry…?

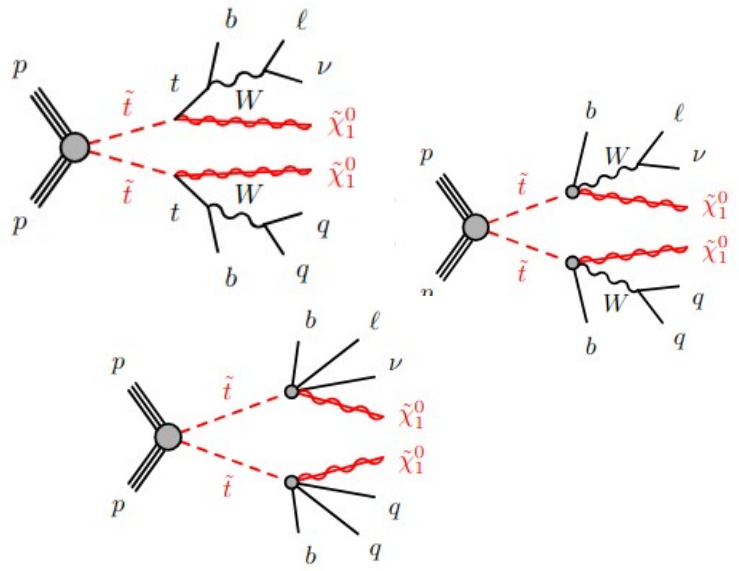
Source

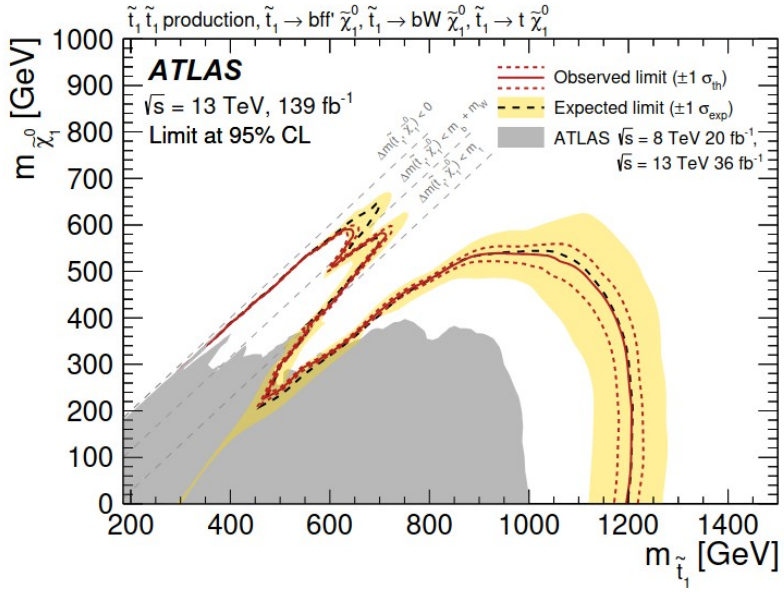
Where have we searched for SUSY?

And where else could it be?

Many searches are done in ATLAS

Interpretations of search results assume **simplified models**





ArXiv:2012.03799v2

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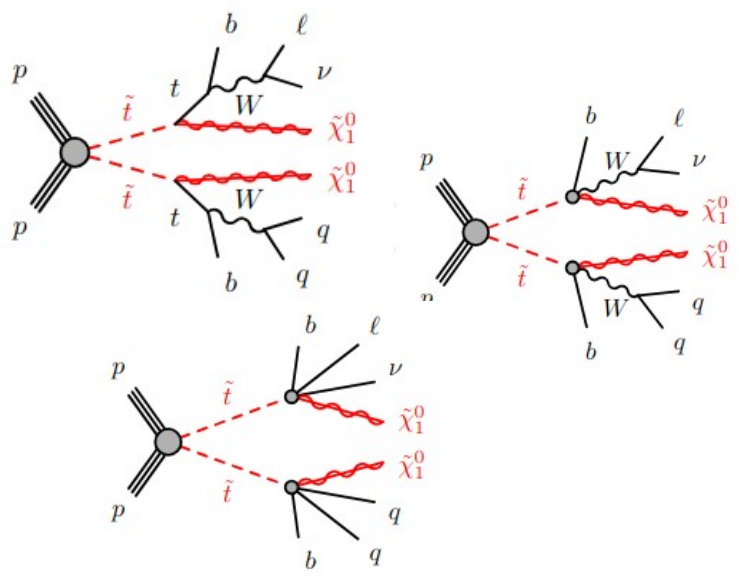
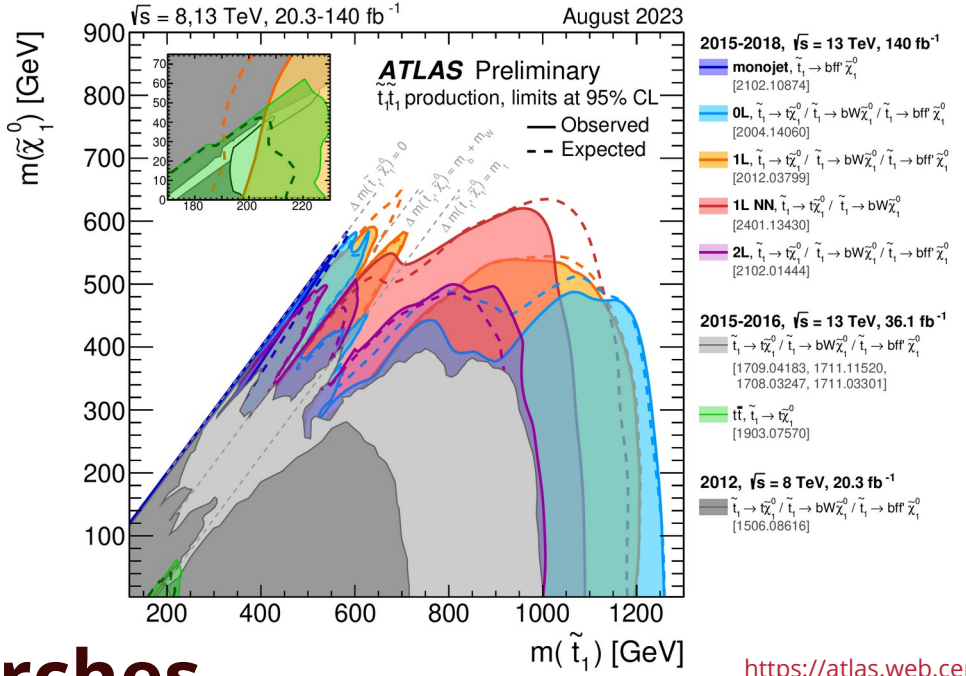




And many more searches…

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2024-014

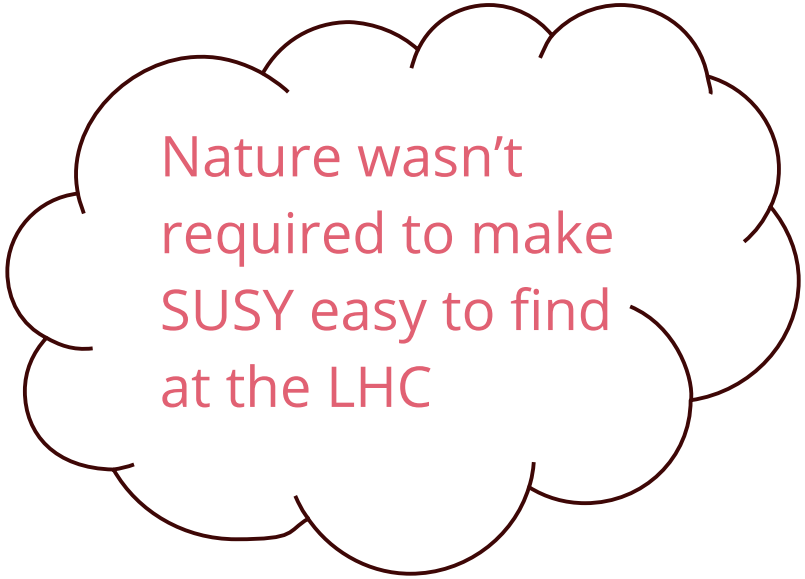
Let’s complicate life…

- Neutralinos and charginos not pure bino/wino/higgsino states

  → More complicated decays, no 100% branching ratios, cascade decays, …

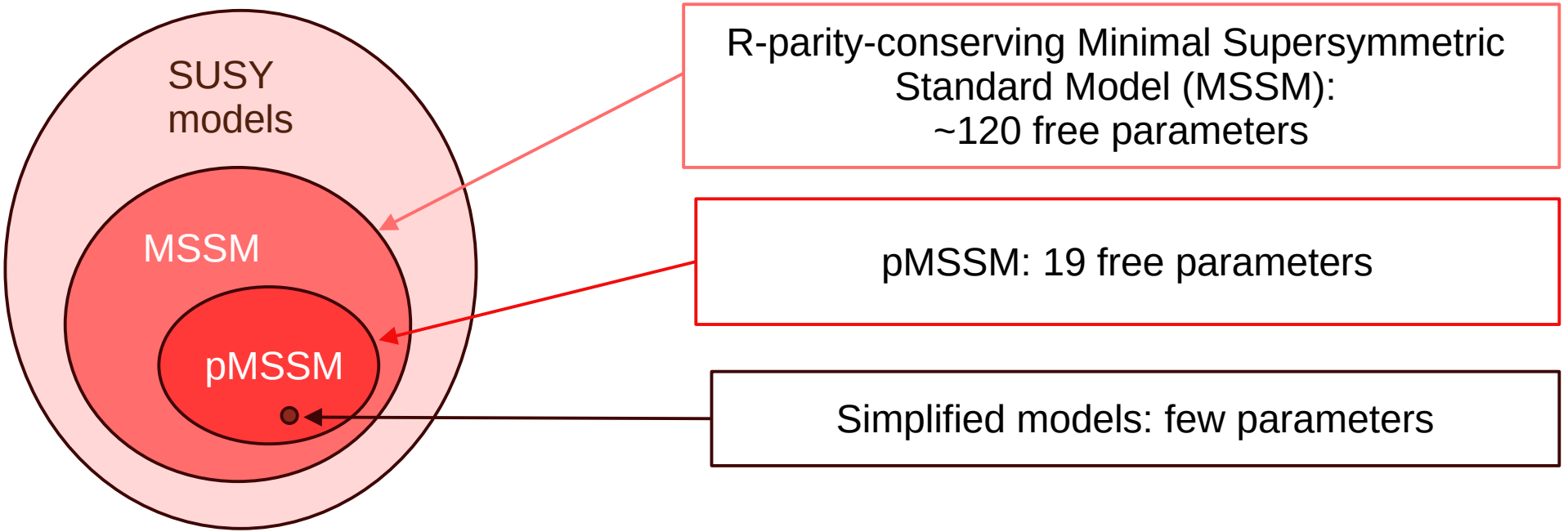
- Some external measurements can indirectly constrain SUSY models, but multiple sparticles and couplings could contribute to a single measurement

  → Take this better into account with more complex models



Phenomenological MSSM (pMSSM)

pMSSM provides a framework to explore more complex SUSY models



The plan

1) Scan pMSSM parameters to obtain possible models
2) Run models through pMSSMFactory to test if they are excluded by current set of ATLAS SUSY analyses
3) Apply constraints from external measurements on models

Goal: Test the pMSSM parameter space with existing ATLAS searches and external measurements and find gaps in our sensitivity

Constraints from external measurements

Constraint	Lower bound	Upper bound	Notes
Preselection			
m(h)	120 GeV	130 GeV	Conservative approach based on a 125 GeV Higgs
m($\tilde{\chi}_1^{\pm}$)	90 GeV	– –	Combined LEP chargino constraint (`https://lepsusy.web.cern.ch`)
Flavour			
BR($b \to s\gamma$)	2.87×10^{-4}	4.11×10^{-4}	2022 PDG average [44]
BR($B_s \to \mu\mu$)	2.19×10^{-9}	3.83×10^{-9}	Most recent LHCb result [45]
BR($B^+ \to \tau\nu$)	5.80×10^{-5}	1.60×10^{-4}	2022 PDG average [44]
EW precision			
$\delta\rho$	−0.00047	0.00172	Updated global electroweak fit by `GFitter` group [46] (not including CDF W-mass measurement [47])
$\Gamma_{\text{inv}}(Z)$	– –	2 MeV	Precision electroweak measurements on the Z-resonance from experiments at the SLC and LEP colliders [48].
m(W)	80.353 GeV	80.401 GeV	2022 PDG result (excluding CDF W-mass measurement [47]) [44]
m(W)(extended)	80.346 GeV	80.408 GeV	2022 PDG result (excluding CDF W-mass measurement [47]) [44] but with the 2σ window expanded by 6 MeV to allow for uncertainty due to the top-quark mass in the MSSM Higgs calculation [49]
m(W) (inc. CDF)	80.4147 GeV	80.4523 GeV	2022 PDG result (including CDF W-mass measurement [47]) [44]
Dark matter			
DM relic density	– –	0.12	Latest bound from Planck [50]
DD $\sigma_{\text{Spin-independent}}$			Exclusion contour from the LZ collaboration [51]
DD $\sigma_{\text{Spin-dependent}}$			Exclusion contour from PICO-60 [52]

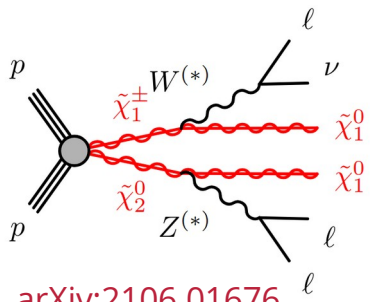
arXiv:2402.01392v2

Four complimentary scans

[1] arXiv:2402.01392v2

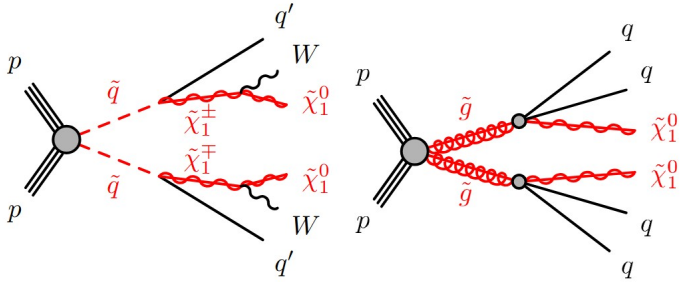
- Four different scans
  - Electroweak scan: focus on electroweak production [1]
  - General scan: all production channels (strong & electroweak)
  - 3rd generation scan: production of stop/sbottom pair production
  - Gauge-mediated SUSY breaking: electroweak production with extra massless gravitino from gauge-mediated SUSY breaking as lightest supersymmetric particle

Electroweak production



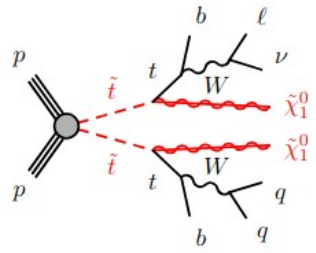
arXiv:2106.01676

Strong production



arXiv:2010.14293

3G (strong) production



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- Four different scans
  - Electroweak scan: focus on electroweak production
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  - Gauge-mediated SUSY breaking: electroweak production with extra massless gravitino from gauge-mediated SUSY breaking as lightest supersymmetric particle
- Third generation squarks interesting because light stop and sbottom usually required to have a somewhat natural small Higgs mass that agrees with observation

3G scan parameters

- Get pMSSM models by randomly sampling over ranges (with flat prior)
- Parameter ranges based on:
  - Kinematically accessible at LHC
  - Fixed light squarks at 5 TeV (no stop to squark decay)
  - Reduced max. value of stop mass
  - Fixed gluino mass at 3 TeV so does not take part in production and decay

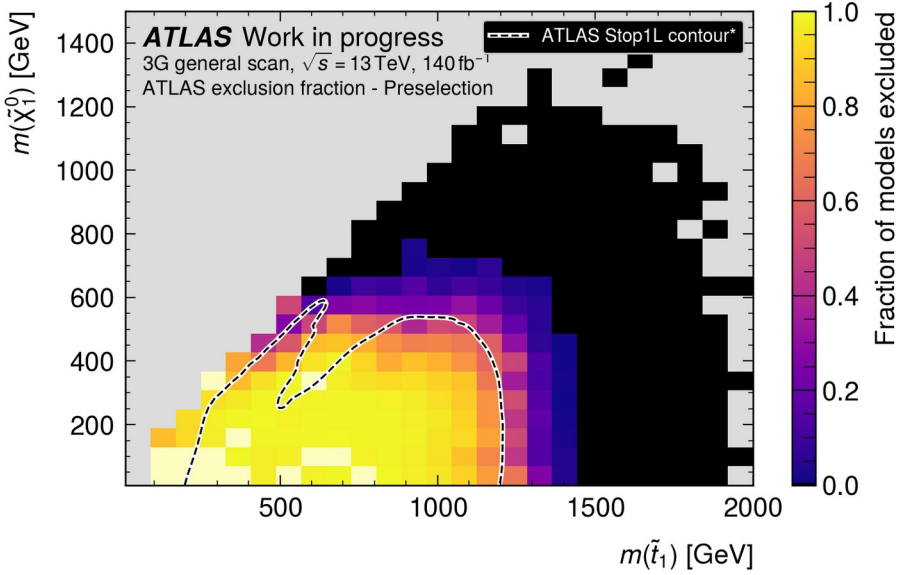
Table 1: 3G general scan ranges

Parameter	Min value	Max value	Note
$m_{\tilde{L}_1}(=m_{\tilde{L}_2})$	0 TeV	2 TeV	Left-handed slepton (first two gens.) mass
$m_{\tilde{e}_1}(=m_{\tilde{e}_2})$	0 TeV	2 TeV	Right-handed slepton (first two gens.) mass
$m_{\tilde{L}_3}$	0 TeV	2 TeV	Left-handed stau doubles mass
$m_{\tilde{e}_3}$	0 TeV	2 TeV	Right-handed stau mass
$m_{\tilde{Q}_1}(=m_{\tilde{Q}_2})$	5 TeV	5 TeV	Left-handed squark (first two gens.) mass
$m_{\tilde{u}_1}(=m_{\tilde{u}_2})$	5 TeV	5 TeV	Right-handed up-type squark (first two gens.) mass
$m_{\tilde{d}_1}(=m_{\tilde{d}_2})$	5 TeV	5 TeV	Right-handed down-type squark (first two gens.) mass
$m_{\tilde{Q}_3}$	0 TeV	2 TeV	Left-handed squark (third gen.) mass
$m_{\tilde{u}_3}$	0 TeV	2 TeV	Right-handed top squark mass
$m_{\tilde{d}_3}$	0 TeV	2 TeV	Right-handed bottom squark mass
$\lvert M_1\rvert$	0 TeV	2 TeV	Bino mass parameter
$\lvert M_2\rvert$	0 TeV	2 TeV	Wino mass parameter
$\lvert\mu\rvert$	0 TeV	2 TeV	Bilinear Higgs mass parameter
M_3	3 TeV	3 TeV	Gluino mass parameter
$\lvert A_t\rvert$	0 TeV	8 TeV	Trilinear top coupling
$\lvert A_b\rvert$	0 TeV	2 TeV	Trilinear bottom coupling
$\lvert A_\tau\rvert$	0 TeV	2 TeV	Trilinear τ lepton coupling
M_A	0 TeV	5 TeV	Pseudoscalar Higgs boson mass
$\tan\beta$	1	60	Ratio of Higgs vacuum expectation values

* exclusion contour from
ArXiv:2012.03799v2

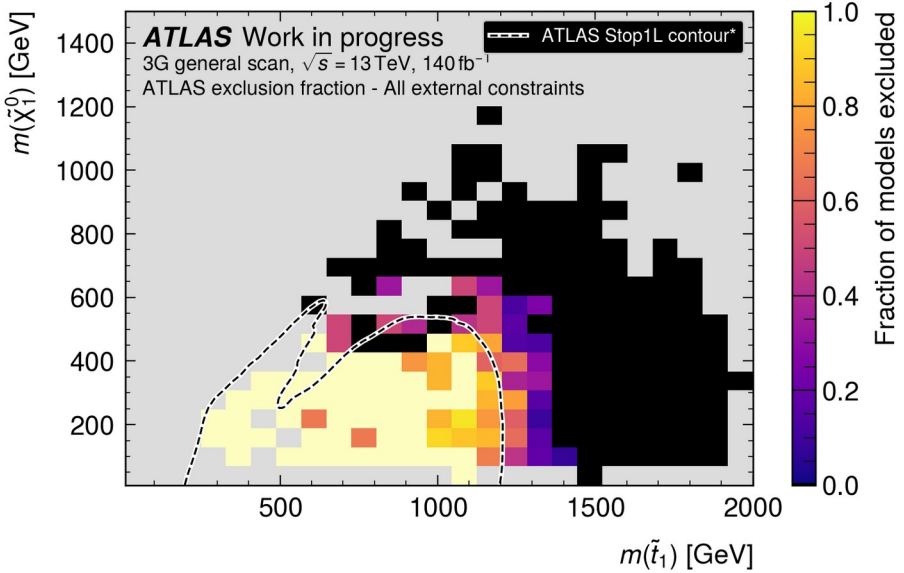
Results

Models after basic selection



Fraction of excluded pMSSM models agrees well with ATLAS exclusion contour

Models after external constraints



Removed models mainly due to flavour constraints (BR(b→sγ))

Summary

- The pMSSM parameter space is scanned for viable models
- The models are tested for exclusion by ATLAS searches and by other measurements
- The exclusion of pMSSM models generally agrees well with exclusion from ATLAS searches based on simplified models
- Low mass stops and sbottoms are mostly excluded, but there are exceptions

Outlook

- What kind of pMSSM models are not excluded?
- Improving the model sampling → ML-guided techniques
- More pMSSM scans (long lived particles, r-parity violating models, ...)?

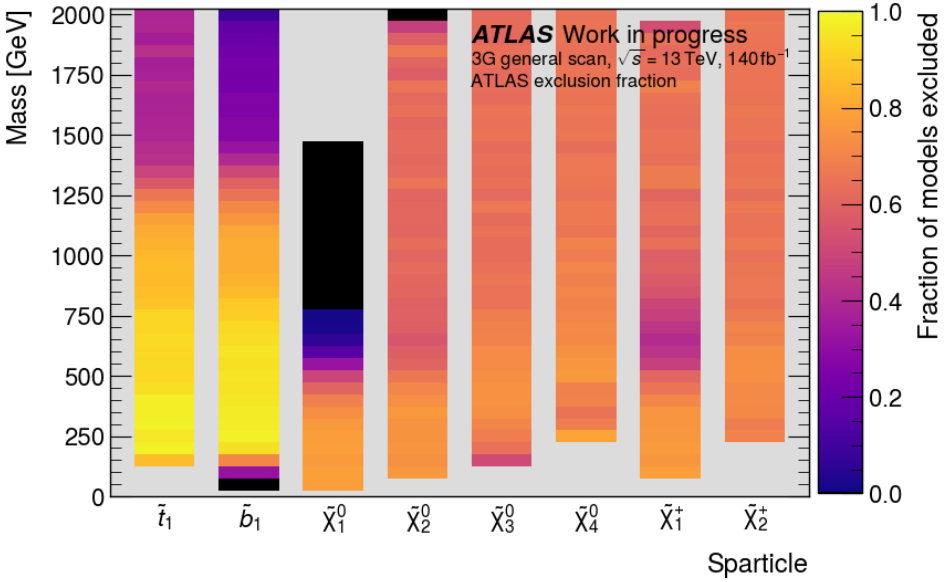
Backup

Stockholm University

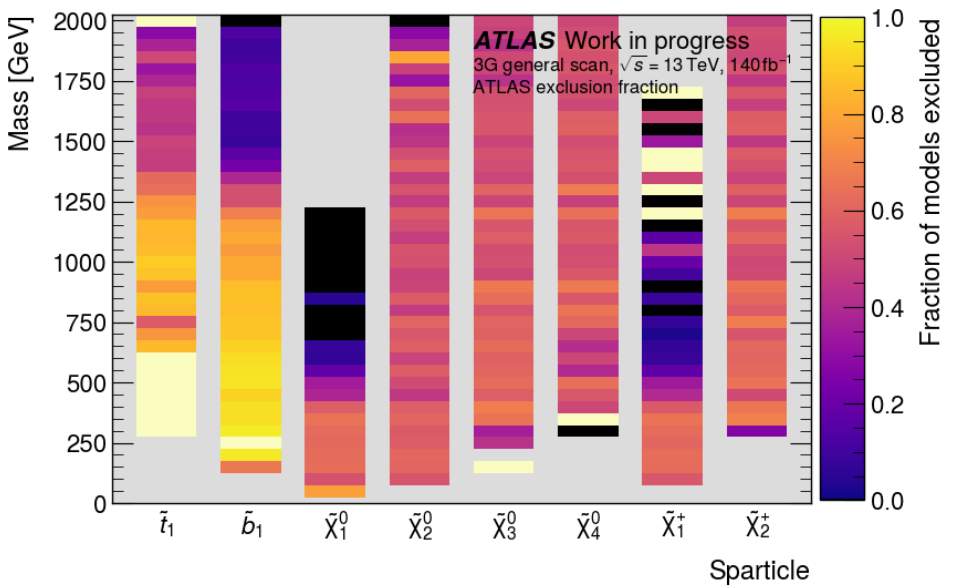
* exclusion contour from ArXiv:2012.03799v2

Results

Models after basic selection



Models after external constraints

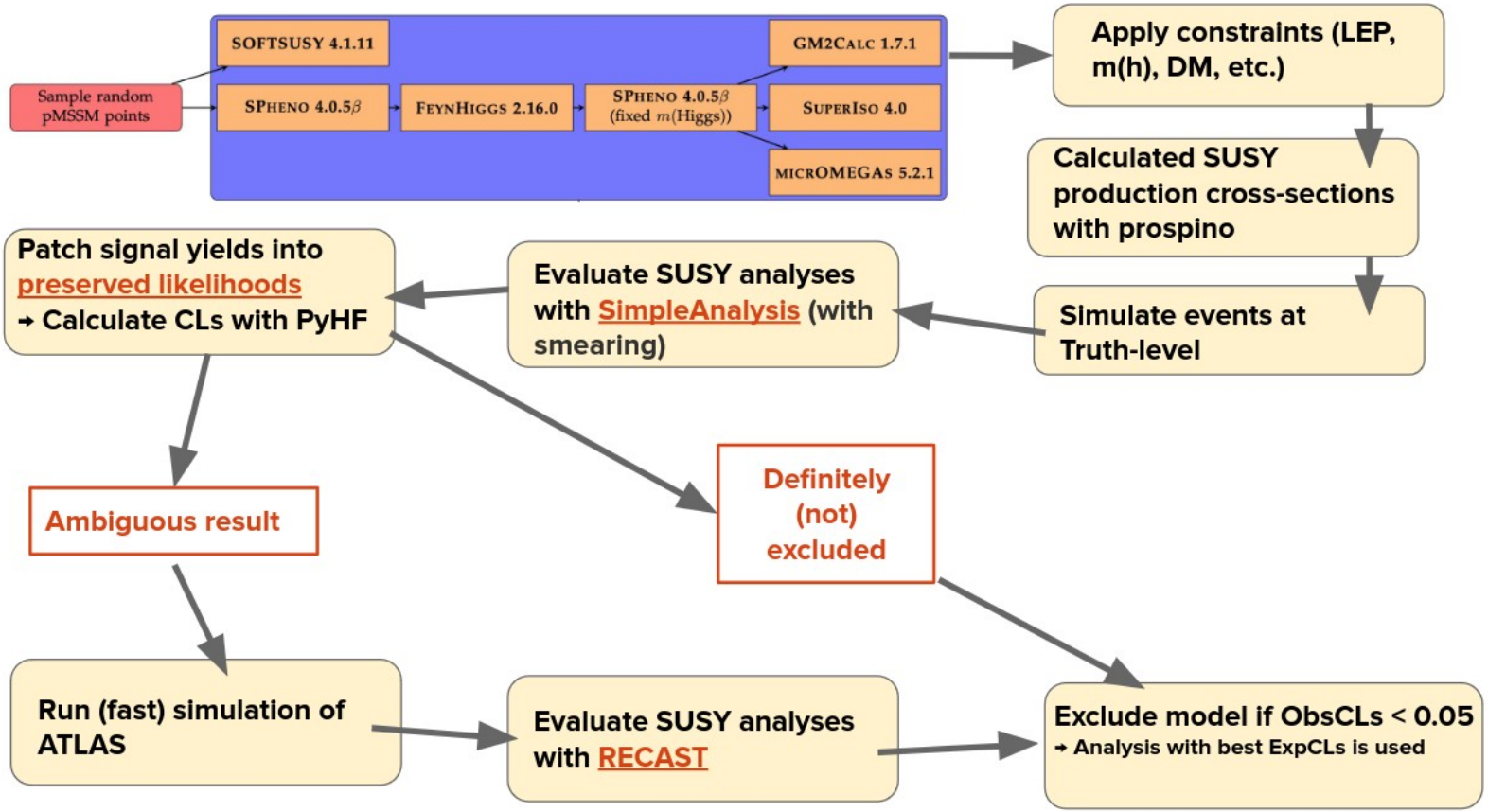


Low mass stops and sbottoms mostly excluded, but there are some exceptions where models with rather light stops and sbottoms survive all constraints

pMSSM

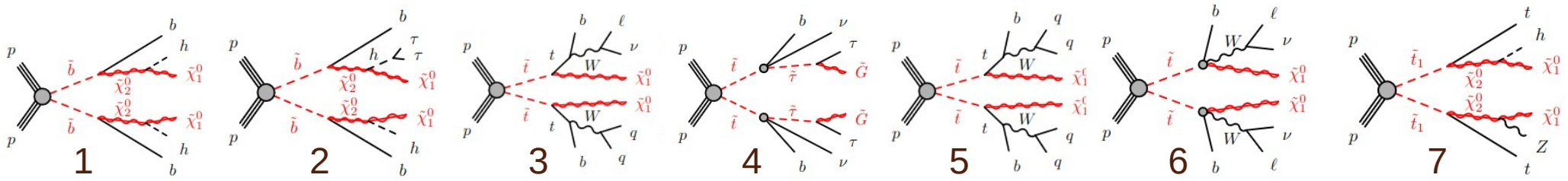
- R-parity conserving MSSM has ~120 free parameters
- pMSSM assumptions to go to 19 free parameters
  - R-parity is exactly conserved
  - No sources of CP violation exist beyond the ones in the CKM matrix
  - Minimal flavour violation is imposed at EW scale
  - The first two generations of squarks and sleptons with the same quantum numbers are degenerate, and their Yukawa couplings are too small to affect sparticle production or precision observables
  - The LSP is the lightest neutralino
- 19 parameters:
  - Bino, wino and gluino masses $M_{1,2,3}$
  - Higgsino mass parameter μ
  - Ratio of Higgs vevs for the two doublets $\tan\beta$
  - Pseudoscalar Higgs mass m_A
  - 10 sfermion masses
  - 3rd generation trilinear couplings of $b/t/\tau$

pMSSM Factory

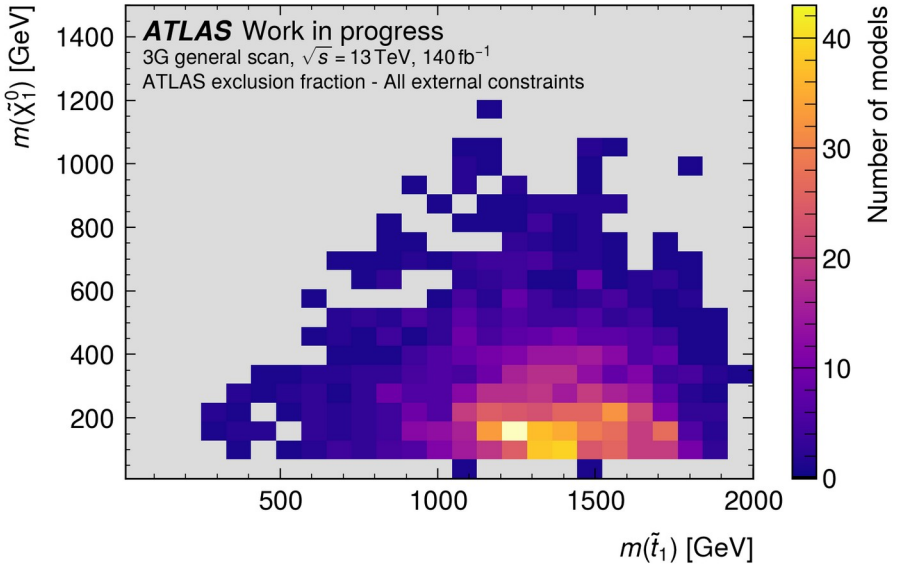


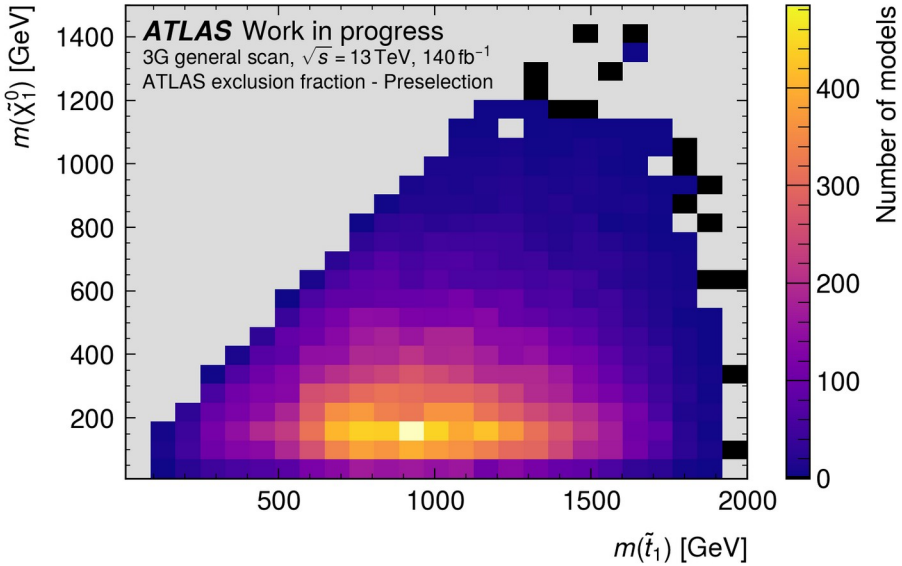
Model exclusion

- After models are generated, run through pMSSMFactory and see how many models would be excluded by analyses
- 3G analyses considered:
  1) SUSY-2018-31 SbottomMultiB2018
  2) SUSY-2018-40 SbottomTau2018
  3) SUSY-2018-07 StopOneLepton2018
  4) SUSY-2019-18 StopStau2018
  5) SUSY-2018-12 StopZeroLepton2018
  6) SUSY-2018-08 StopTwoLepton 2018
  7) SUSY-2018-21 StopZ2018 & Stoph2018



Model distribution





Model generation

Requirement	# of model points (eff)	
All	**2,970,000**	
Programs ran	**321,767**	
Neutrino LSP	**169,416**	Bino-like: 32.6% Wino-like: 29.6% Higgsino-like: 37.8%
120 < Higgs mass < 130 GeV	*86,240*	Bino-like: 32.5% Wino-like: 29.5% Higgsino-like: 37.9%
Chargino mass > 90 GeV	*138,536*	
All above	**69,706**	Bino-like: 38.2% Wino-like: 27.3% Higgsino-like: 34.5%

Efficiency = 2.3%

Number of models surviving:

- Preselection: Higgs mass, neutralino LSP & LEP constraint → 60,639
- Preselection and external constraints without flavour → 13,797
- Preselection and all external constraints → 4,260
- Preselection and all external constraints without b→sy → 10,716
- Preselection, flavour and EW precision → 10,487