On the Coverage of the pMSSM with Simplified Models

(preliminary results)

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(Re)interpretation Workshop
CERN - June 2016

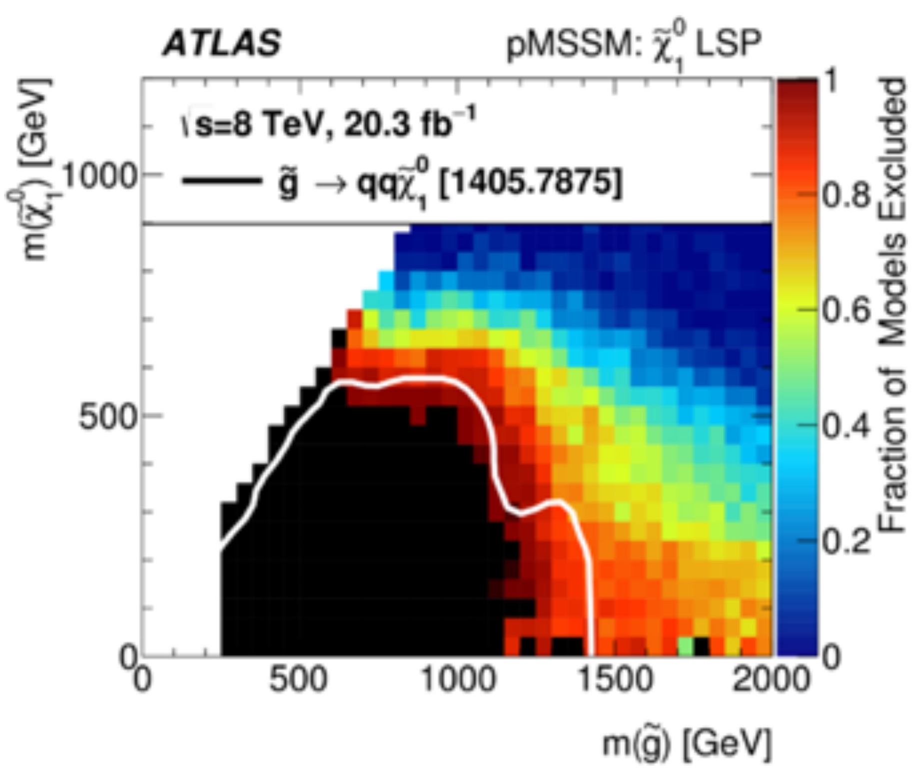
LPSC Grenoble   LAPTh   Enigmass

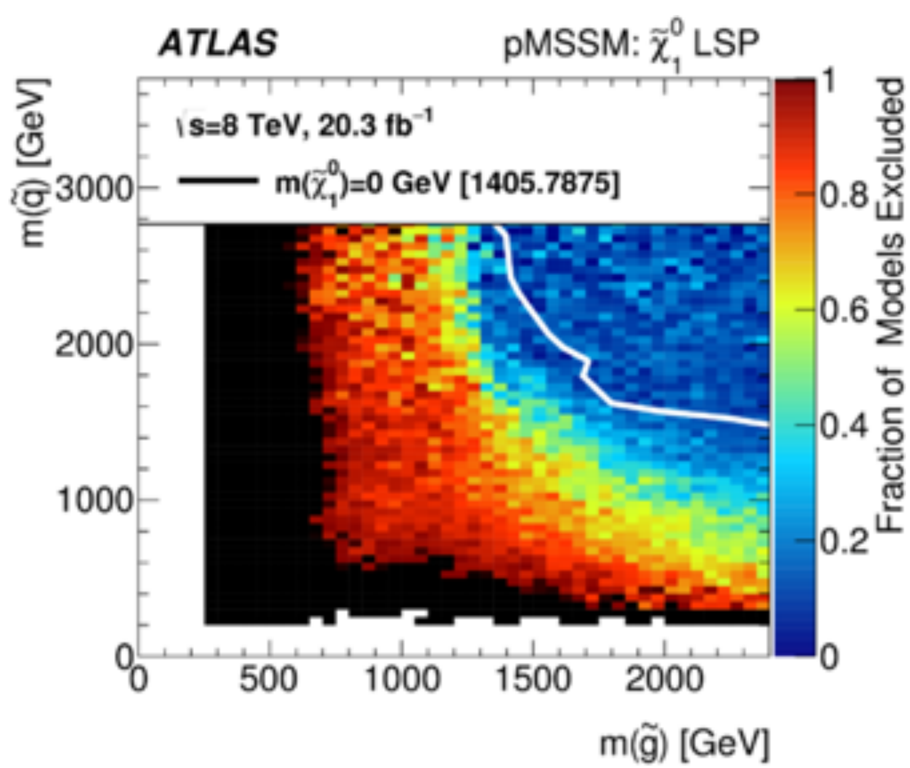
ATLAS pMSSM Scan

- Random scan in 19 free parameters, in reach of LHC8
- Sampling such that after selection similar number of points with Bino-, Wino- and Higgsino-like LSP remain
- SLHA files + exclusion information available on HepData !

LSP type	Definition	Sampled	Simulated Number	Simulated Fraction	Weight
'Bino-like'	$N_{11}^2 > \max(N_{12}^2, N_{13}^2 + N_{14}^2)$	480×10^6	103,410	35%	1/24
'Wino-like'	$N_{12}^2 > \max(N_{11}^2, N_{13}^2 + N_{14}^2)$	20×10^6	80,233	26%	1
'Higgsino-like'	$(N_{13}^2 + N_{14}^2) > \max(N_{11}^2, N_{12}^2)$		126,684	39%	1
Total		500×10^6	310,327		

arXiv:0812.0980
arXiv:1206.4321
arXiv:1211.1981
arXiv:1407.4130
arXiv:1508.06608





- Light gluino robustly constrained
- Well described by SMS exclusion, but constraints weakened in case of alternative decay chains and because of non-degenerate squarks

Result Summary

Multijet + MET

Monojet
(mostly overlapping with Multijet exclusion)

Stop searches
(less important, stop mostly heavy following Higgs constraints)

Disappearing tracks
(important for Wino-like LSP!)

Analysis	All LSPs	Bino-like	Wino-like	Higgsino-like	
0-lepton + 2–6 jets + E_T^{miss}	32.1%	35.8%	29.7%	33.5%	✔
0-lepton + 7–10 jets + E_T^{miss}	7.8%	5.5%	7.6%	8.0%	✔
0/1-lepton + 3b-jets + E_T^{miss}	8.8%	5.4%	7.1%	10.1%	✔
1-lepton + jets + E_T^{miss}	8.0%	5.4%	7.5%	8.4%	✔
Monojet	9.9%	16.7%	9.1%	10.1%	✗
SS/3-leptons + jets + E_T^{miss}	2.4%	1.6%	2.4%	2.5%	✔
$\tau(\tau/\ell)$ + jets + E_T^{miss}	3.0%	1.3%	2.9%	3.1%	✔
0-lepton stop	9.4%	7.8%	8.2%	10.2%	✔
1-lepton stop	6.2%	2.9%	5.4%	6.8%	✔
2b-jets + E_T^{miss}	3.1%	3.3%	2.3%	3.6%	✔
2-leptons stop	0.8%	1.1%	0.8%	0.7%	✔
Monojet stop	3.5%	11.3%	2.8%	3.6%	✔
Stop with Z boson	0.4%	1.0%	0.4%	0.5%	✔
tb+E_T^{miss}, stop	4.2%	1.9%	3.1%	5.0%	✔
ℓh, electroweak	0	0	0	0	✔
2-leptons, electroweak	1.3%	2.2%	0.7%	1.6%	✔
2-τ, electroweak	0.2%	0.3%	0.2%	0.2%	✔
3-leptons, electroweak	0.8%	3.8%	1.1%	0.6%	✔
4-leptons	0.5%	1.1%	0.6%	0.5%	✔
Disappearing Track	11.4%	0.4%	29.9%	0.1%	✗
Long-lived particle	0.1%	0.1%	0.0%	0.1%	✗
$H/A \to \tau^+\tau^-$	1.8%	2.2%	0.9%	2.4%	✗
Total	40.9%	40.2%	45.4%	38.1%	

41% of the points excluded by ATLAS → How well can they be covered using Simplified Models?

Results from SModelS

- Run SModelS on points excluded by ATLAS
- Database includes results from 20 ATLAS and 17 CMS searches at 8 TeV + efficiency maps generated by Fastlim
- Discard points with non-prompt decays

→ do not consider Wino-like LSP scenarios here

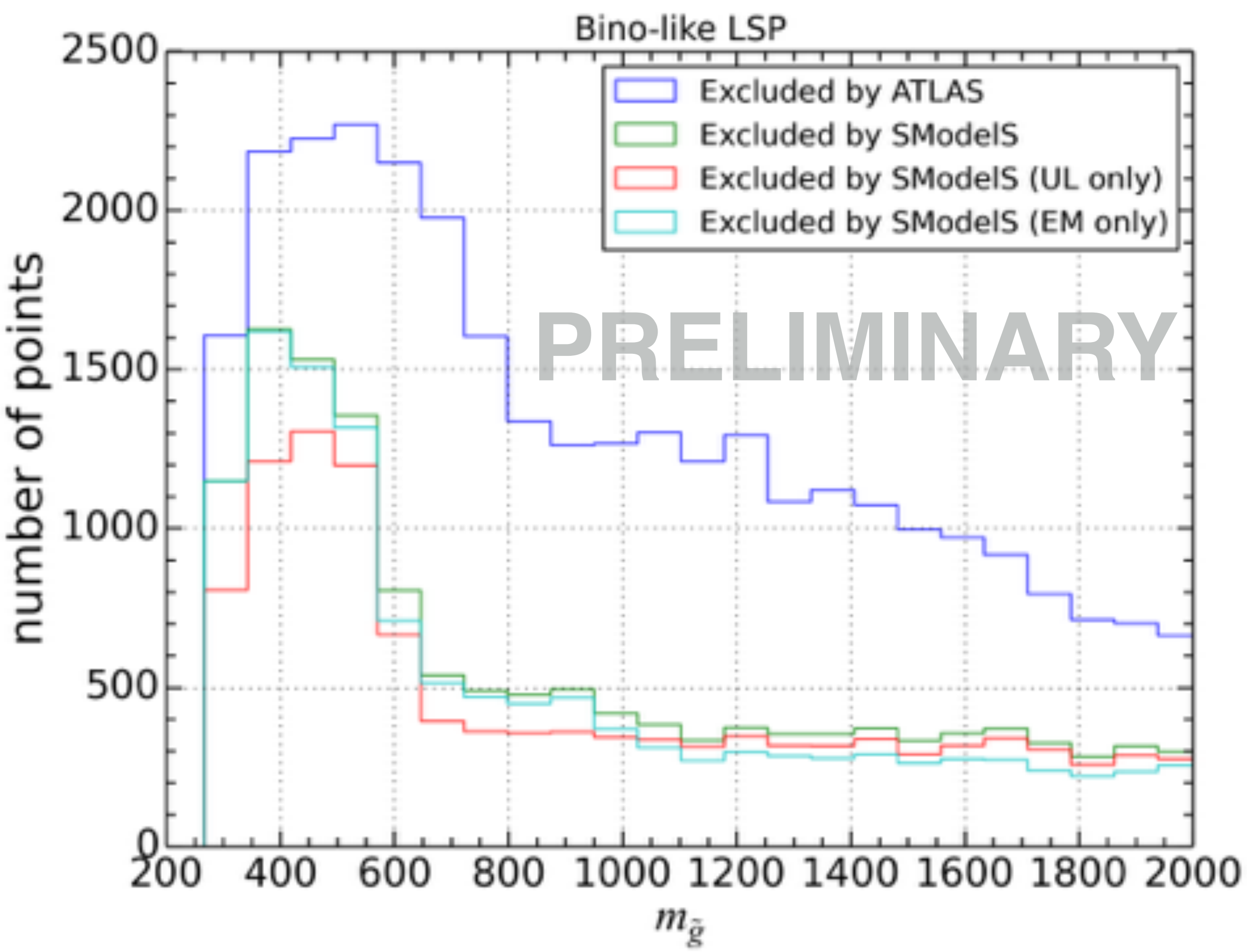
Results:

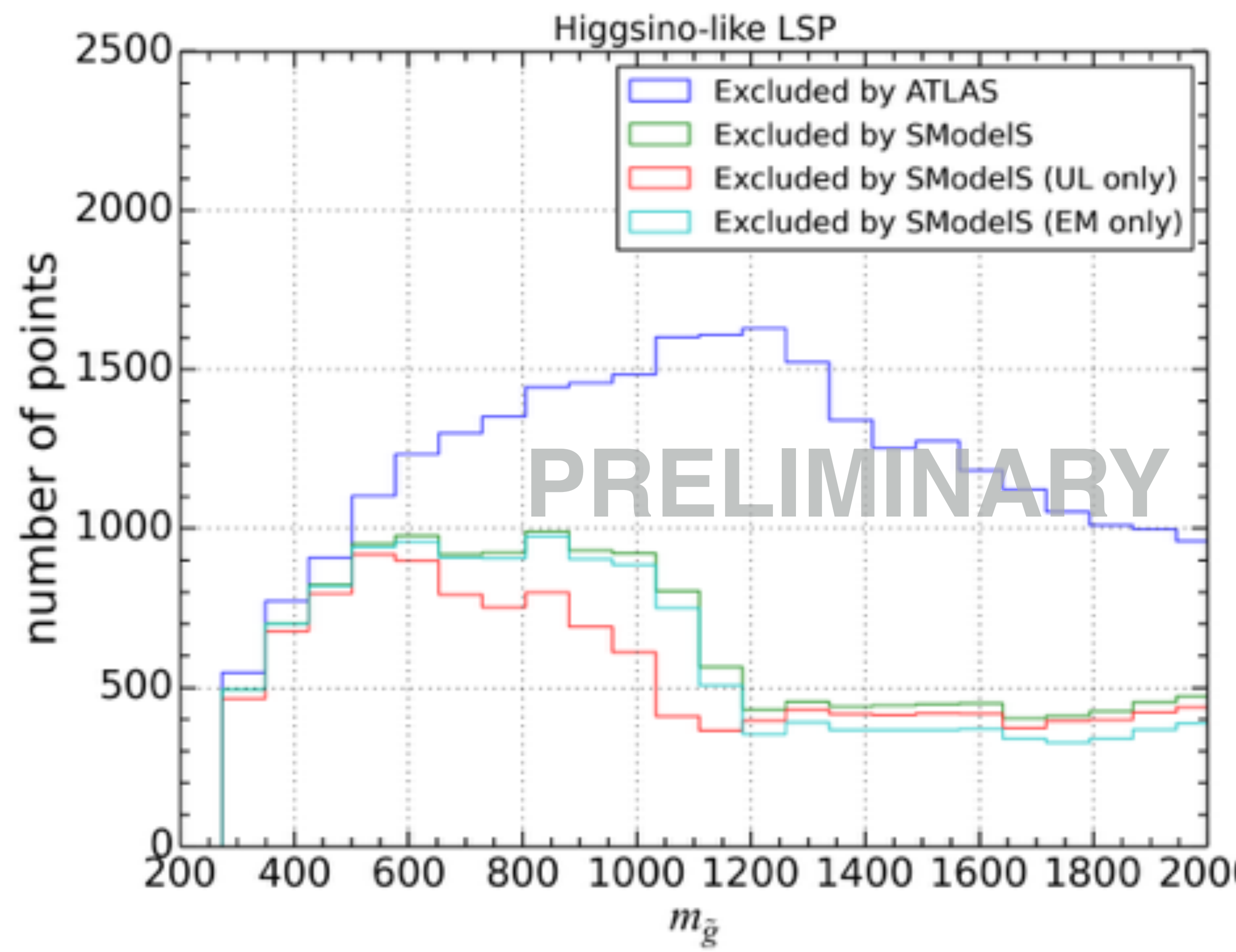
	Bino LSP	**Higgsino LSP**
# points excluded by ATLAS	42039	48703
# points excluded by SModelS	18461	25260
coverage in SModelS	44%	52%

PRELIMINARY

SModelS:
arXiv:1312.4175
arXiv:1412.1745
&
talk by Andre Lessa on Wed.
&
smodels.hephy.at

Coverage as Function of Gluino Mass





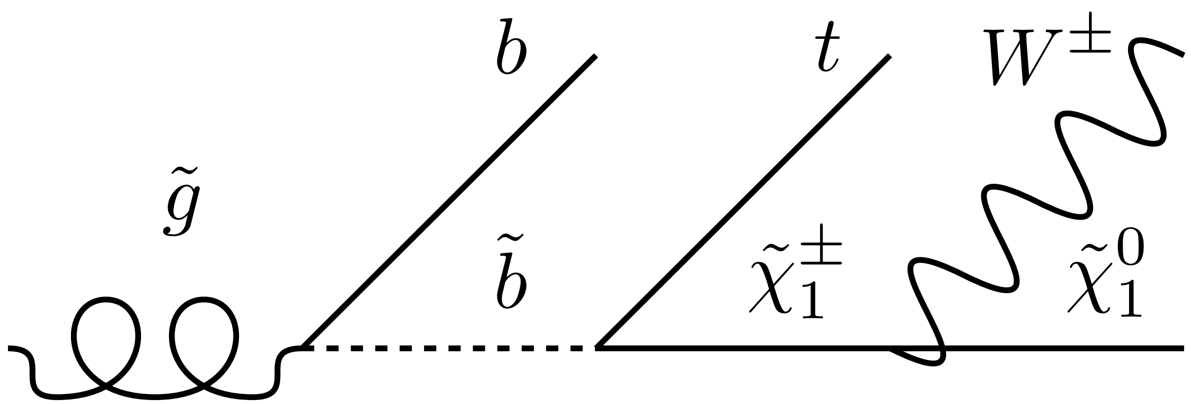
Excluded by ATLAS

Excluded by SModelS

Coverage for points with gluino mass below 1 TeV

- 50 % for Bino-like LSP
- 75 % for Higgsino-like LSP

Light Gluinos escaping SMS constraints

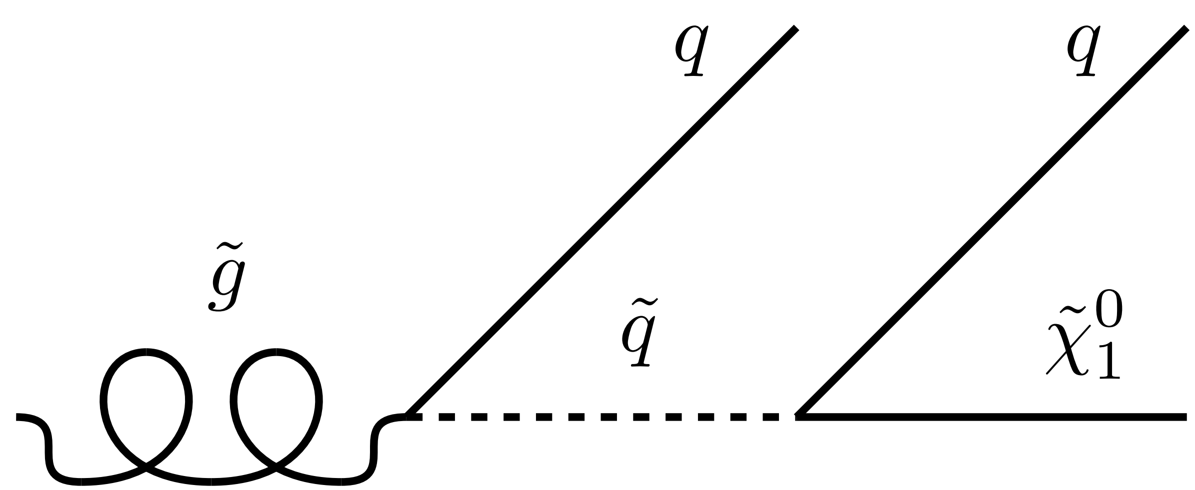


long cascade decays

- at least 4 mass parameters
- asymmetric branches likely

one step decays via squarks

- both gluino pair production and gluino squark have large cross section
- both not constrained by generic SMS

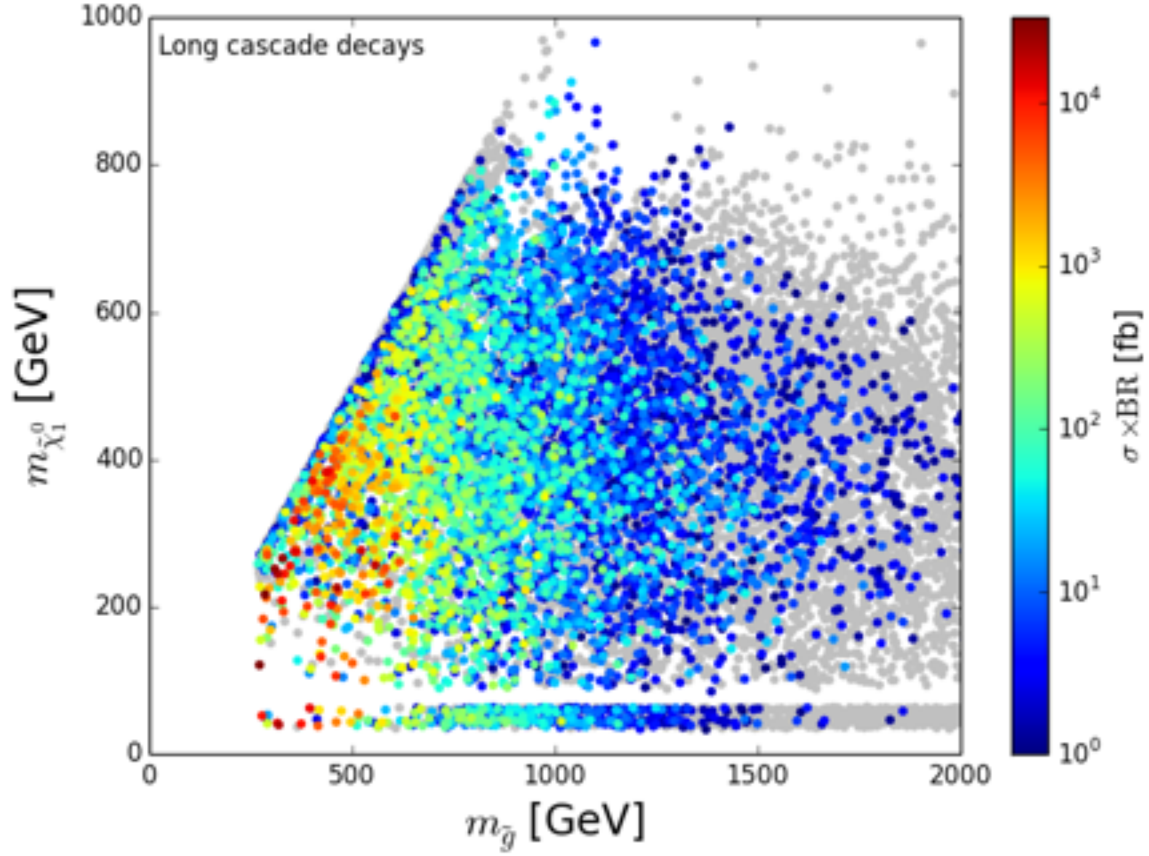


+ decays to heavy neutralinos or chargino

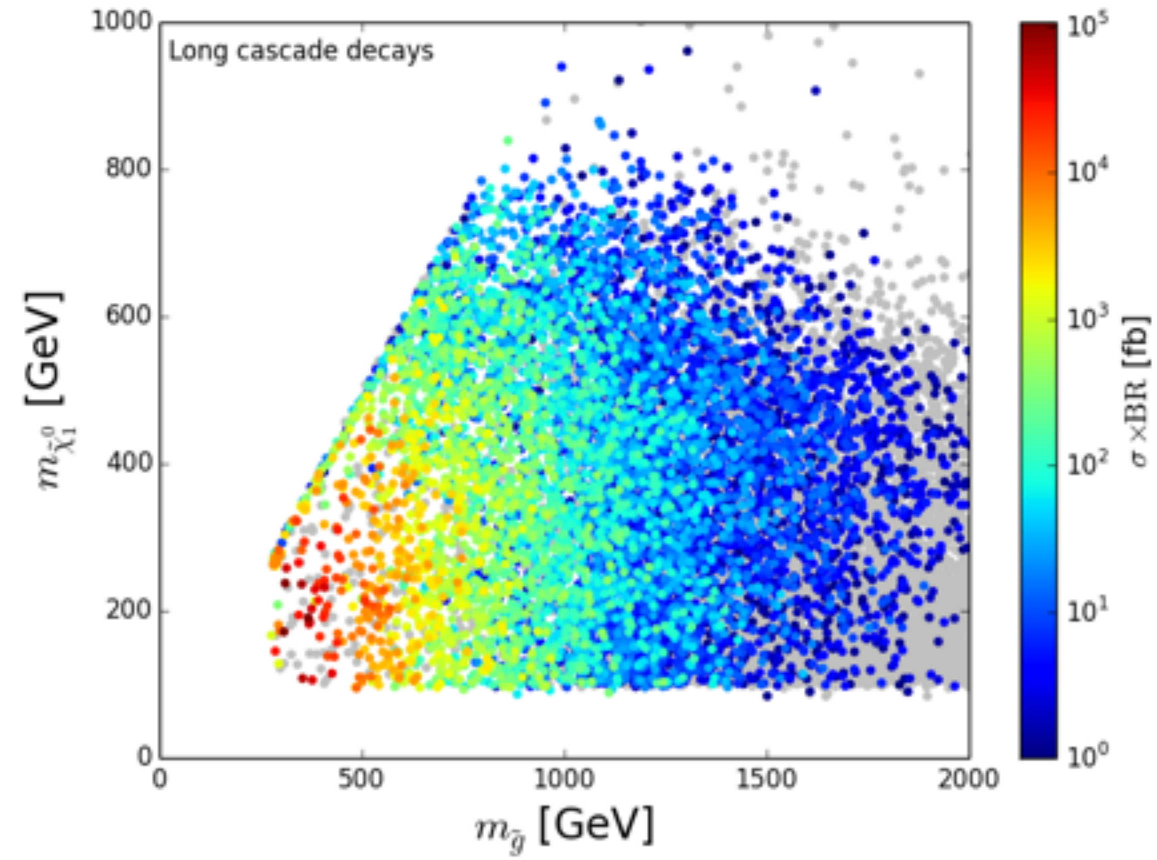
Gluino decays into long cascades

$\sigma \times BR$ from gluino production followed by long cascade decay (more than one intermediate particle), for all points allowed by SModelS

Bino LSP



Higgsino LSP



- Simplified Model approach not efficient (need to cover at least 4 dimensional parameter space, as well as asymmetric branches)
- Existing SMS results presented in one mass plane only

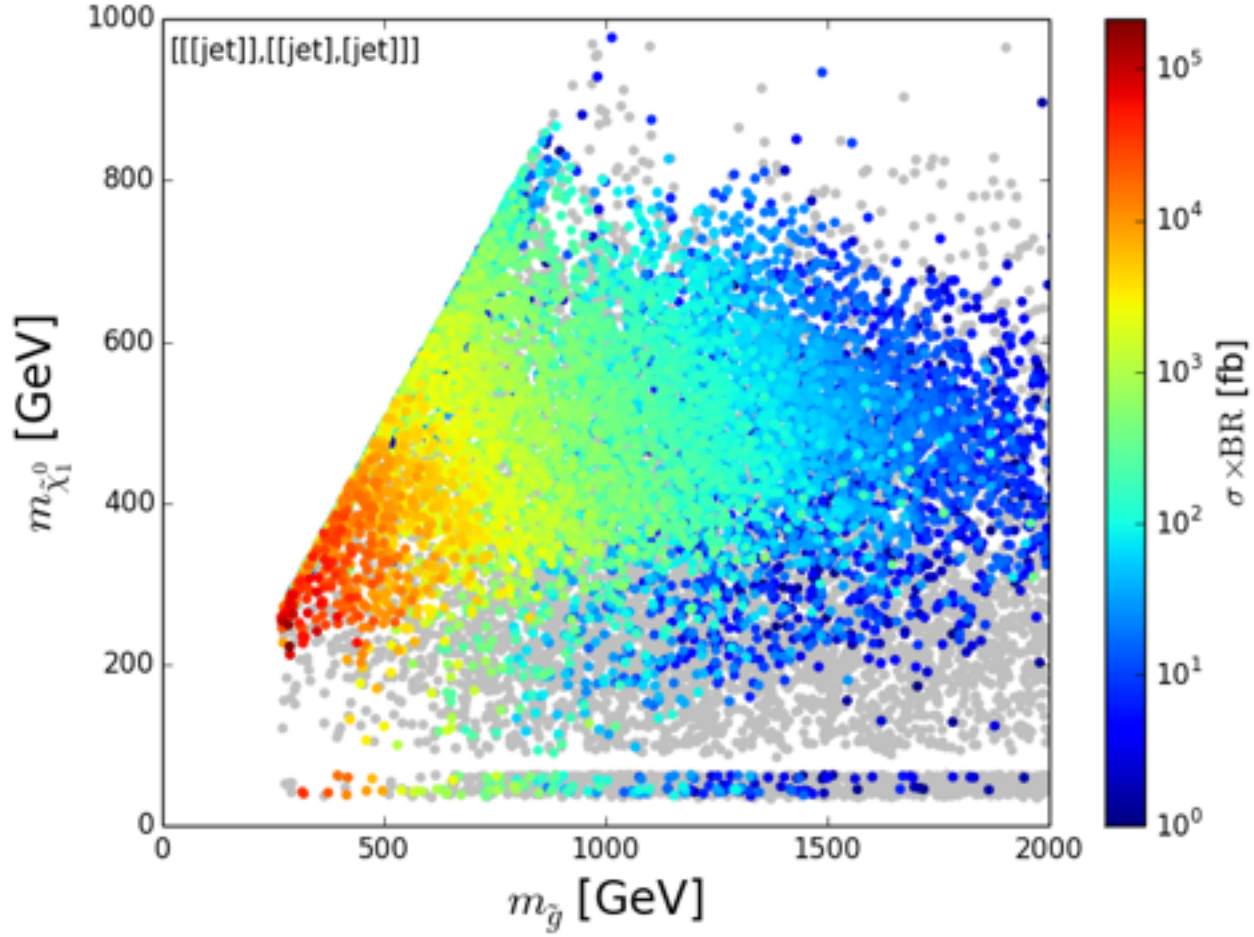
→ best constrained using event simulation

Gluino one step decays via squarks

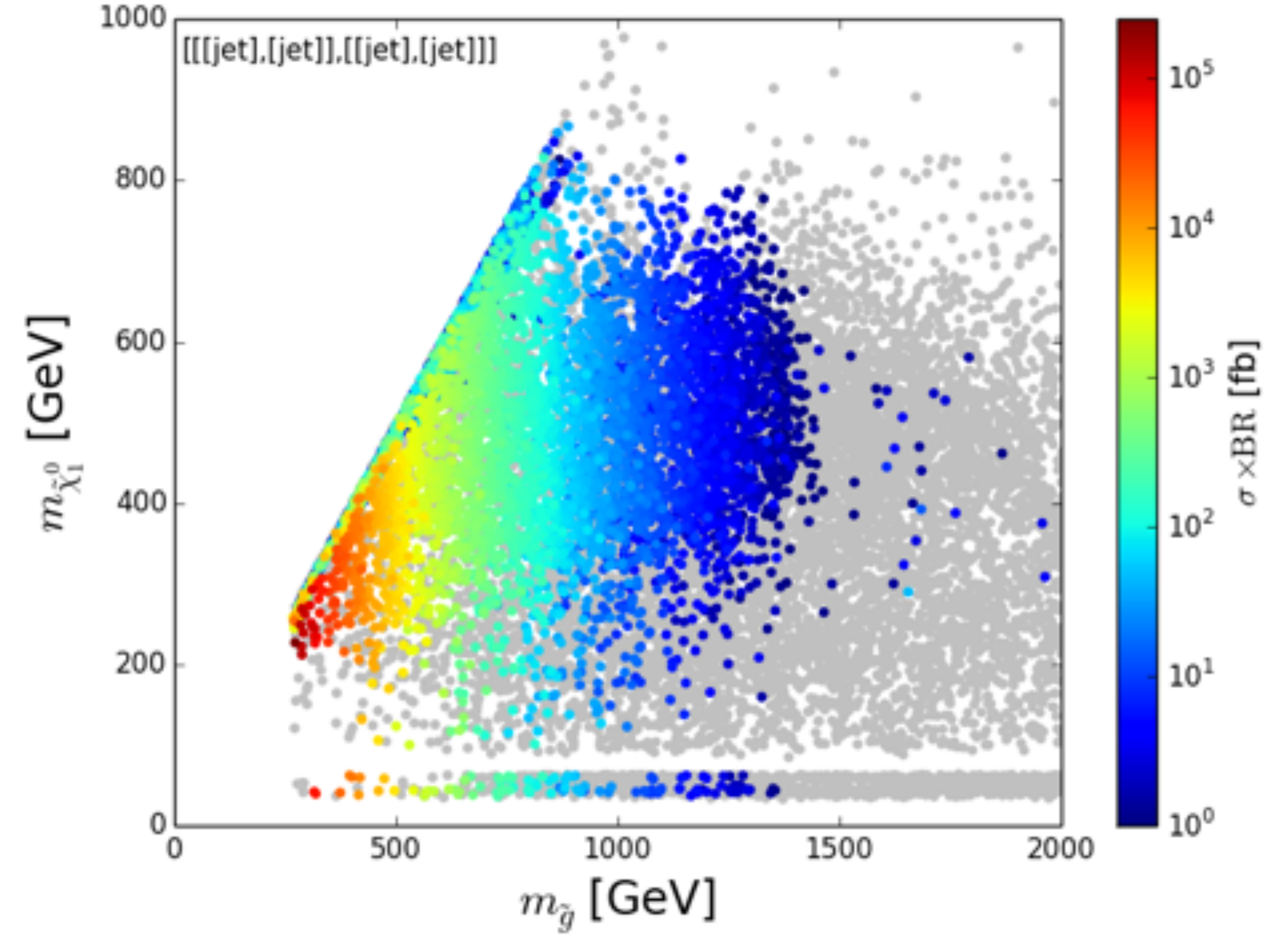
- Constraints on light squarks considerably weakened if there are not 8 mass degenerate states
- Currently no generic SMS results for gluino decays via on-shell squarks available
- Points with light gluinos & squarks can escape all SMS constraints

$\sigma \times BR$ for allowed points with Bino-like LSP, as function of gluino and LSP mass

Gluino-Squark production



Gluino-pair production

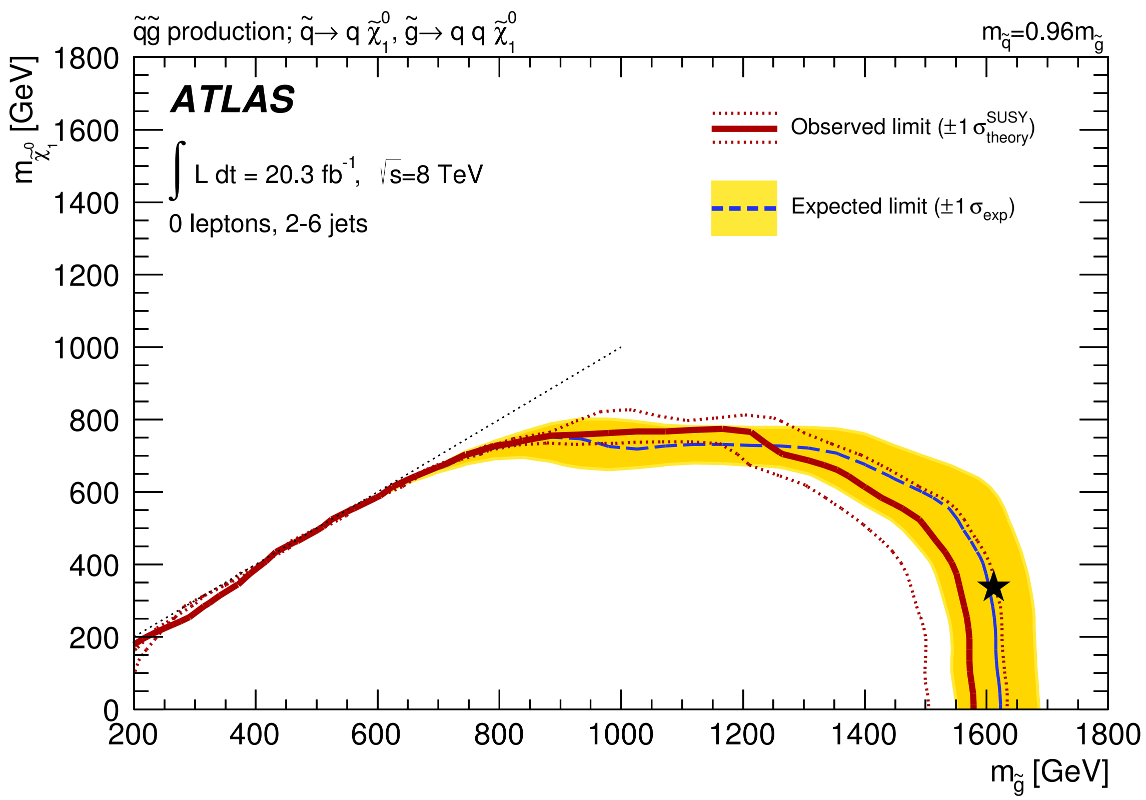


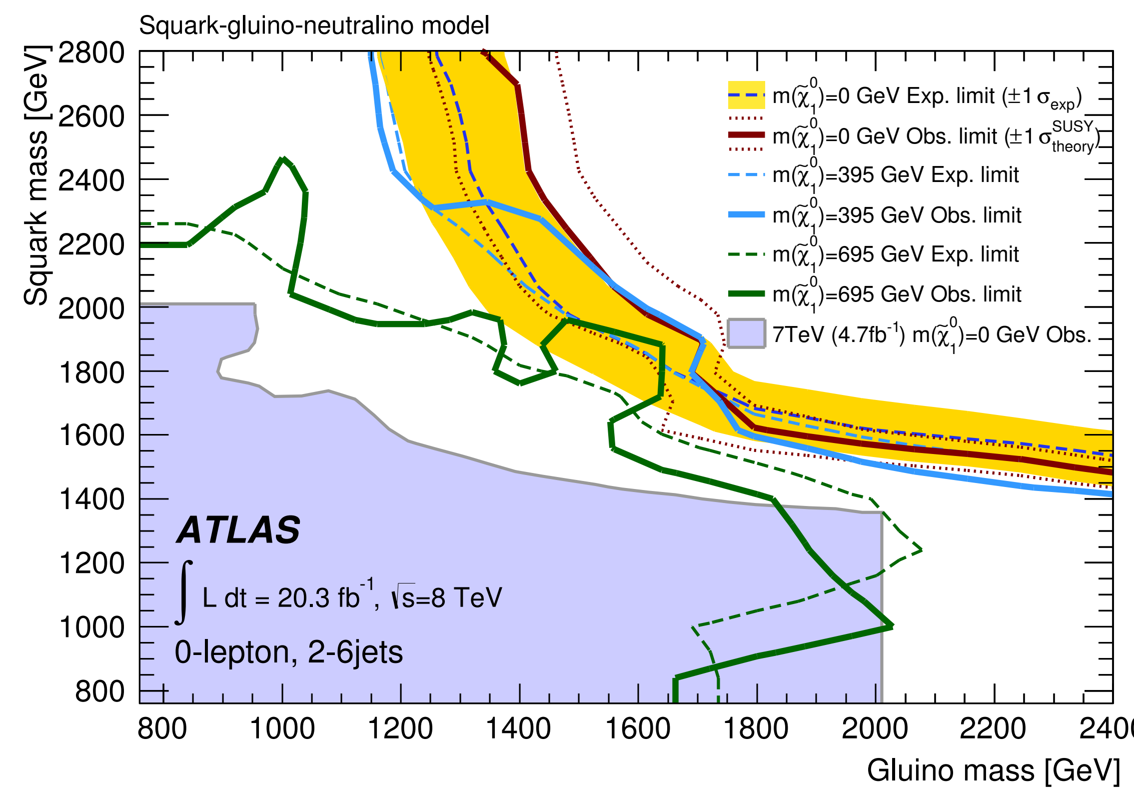
Gluino-Squark Simplified Model in ATLAS

Only valid for 8 degenerate squarks !

Only valid if $m_{\tilde{q}} = 0.96 m_{\tilde{g}}$

Covers 3 values of LSP mass





(from ATLAS-SUSY-2014-06)

- Use efficiency maps to combine various production channels for arbitrary number of light squarks
- Generate efficiency maps with 3 free parameters: gluino mass, squark mass, LSP mass

Conclusions

- Within SModelS SMS results can exclude about 45-50% of pMSSM parameter points excluded by ATLAS
- Light gluinos are robustly constrained by ATLAS
- They can escape SMS exclusion if
  - decays via long cascades are dominant (SMS approach no longer effective as number of free parameters grows)
  - decays via (combinations of) charginos and heavy neutralinos are dominant
  - gluino decay into non-degenerate light squarks possible
- Constraints can be improved using efficiency maps, taking into account as many (short) decays as possible ("home-grown" efficiency maps by SModelS foreseen)
- Parameter points where long cascade decays are dominant are best constrained using event simulation

BACKUP

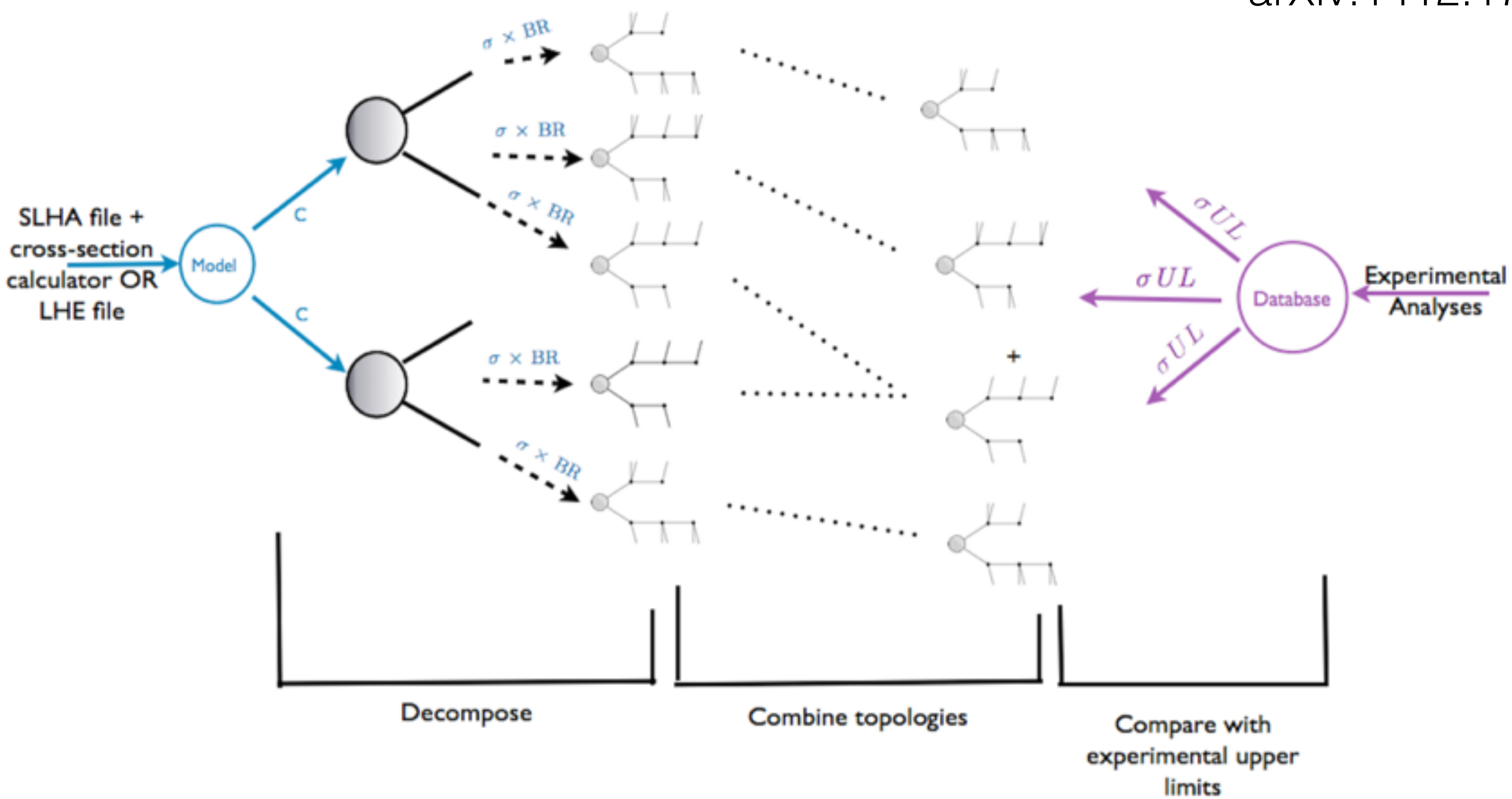
ATLAS pMSSM Scan - Details

Parameter	Min value	Max value	Note
$m_{\tilde{L}_1} (= m_{\tilde{L}_2})$	90 GeV	4 TeV	Left-handed slepton (first two gens.) mass
$m_{\tilde{e}_1} (= m_{\tilde{e}_2})$	90 GeV	4 TeV	Right-handed slepton (first two gens.) mass
$m_{\tilde{L}_3}$	90 GeV	4 TeV	Left-handed stau doublet mass
$m_{\tilde{e}_3}$	90 GeV	4 TeV	Right-handed stau mass
$m_{\tilde{Q}_1} (= m_{\tilde{Q}_2})$	200 GeV	4 TeV	Left-handed squark (first two gens.) mass
$m_{\tilde{u}_1} (= m_{\tilde{u}_2})$	200 GeV	4 TeV	Right-handed up-type squark (first two gens.) mass
$m_{\tilde{d}_1} (= m_{\tilde{d}_2})$	200 GeV	4 TeV	Right-handed down-type squark (first two gens.) mass
$m_{\tilde{Q}_3}$	100 GeV	4 TeV	Left-handed squark (third gen.) mass
$m_{\tilde{u}_3}$	100 GeV	4 TeV	Right-handed top squark mass
$m_{\tilde{d}_3}$	100 GeV	4 TeV	Right-handed bottom squark mass
$\|M_1\|$	0 GeV	4 TeV	Bino mass parameter
$\|M_2\|$	70 GeV	4 TeV	Wino mass parameter
$\|\mu\|$	80 GeV	4 TeV	Bilinear Higgs mass parameter
M_3	200 GeV	4 TeV	Gluino mass parameter
$\|A_t\|$	0 GeV	8 TeV	Trilinear top coupling
$\|A_b\|$	0 GeV	4 TeV	Trilinear bottom coupling
$\|A_\tau\|$	0 GeV	4 TeV	Trilinear τ lepton coupling
M_A	100 GeV	4 TeV	Pseudoscalar Higgs boson mass
$\tan\beta$	1	60	Ratio of the Higgs vacuum expectation values

Parameter	Minimum value	Maximum value
$\Delta\rho$	-0.0005	0.0017
$\Delta(g-2)_\mu$	-17.7×10^{-10}	43.8×10^{-10}
$\mathrm{BR}(b \to s\gamma)$	2.69×10^{-4}	3.87×10^{-4}
$\mathrm{BR}(B_s \to \mu^+\mu^-)$	1.6×10^{-9}	4.2×10^{-9}
$\mathrm{BR}(B^+ \to \tau^+\nu_\tau)$	66×10^{-6}	161×10^{-6}
$\Omega_{\tilde{\chi}_1^0} h^2$	—	0.1208
$\Gamma_{\mathrm{invisible(SUSY)}}(Z)$	—	2 MeV
Masses of charged sparticles	100 GeV	—
$m(\tilde{\chi}_1^\pm)$	103 GeV	—
$m(\tilde{u}_{1,2}, \tilde{d}_{1,2}, \tilde{c}_{1,2}, \tilde{s}_{1,2})$	200 GeV	—
$m(h)$	124 GeV	128 GeV

SModelS

arXiv:1312.4175
arXiv:1412.1745



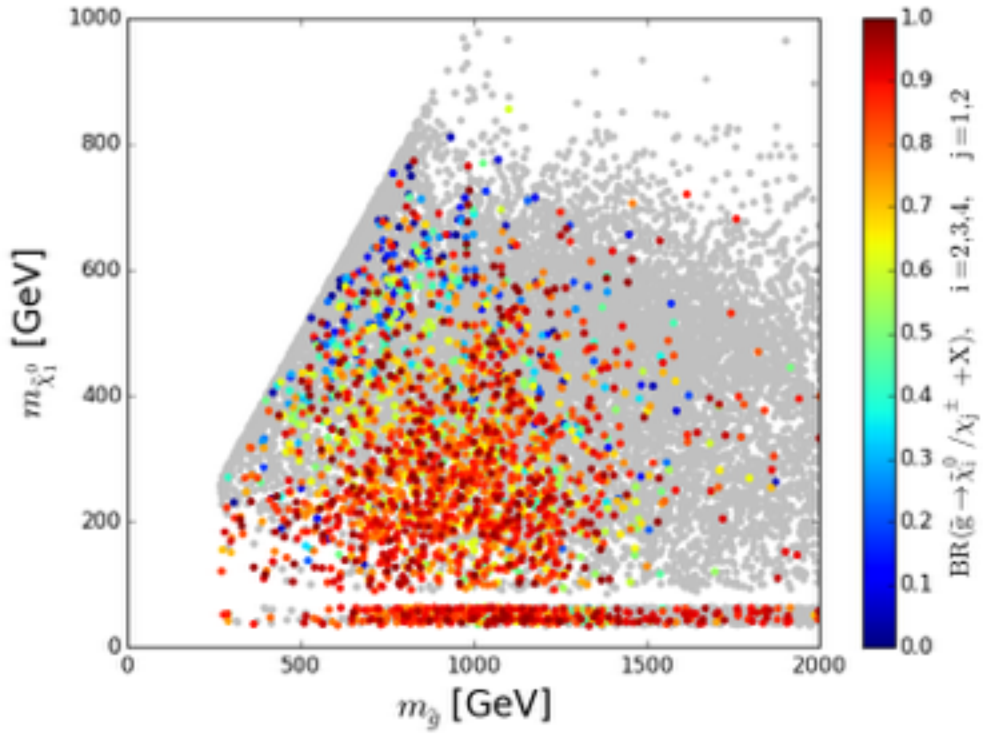
see talk by A. Lessa on
Wednesday

smodels.hephy.at

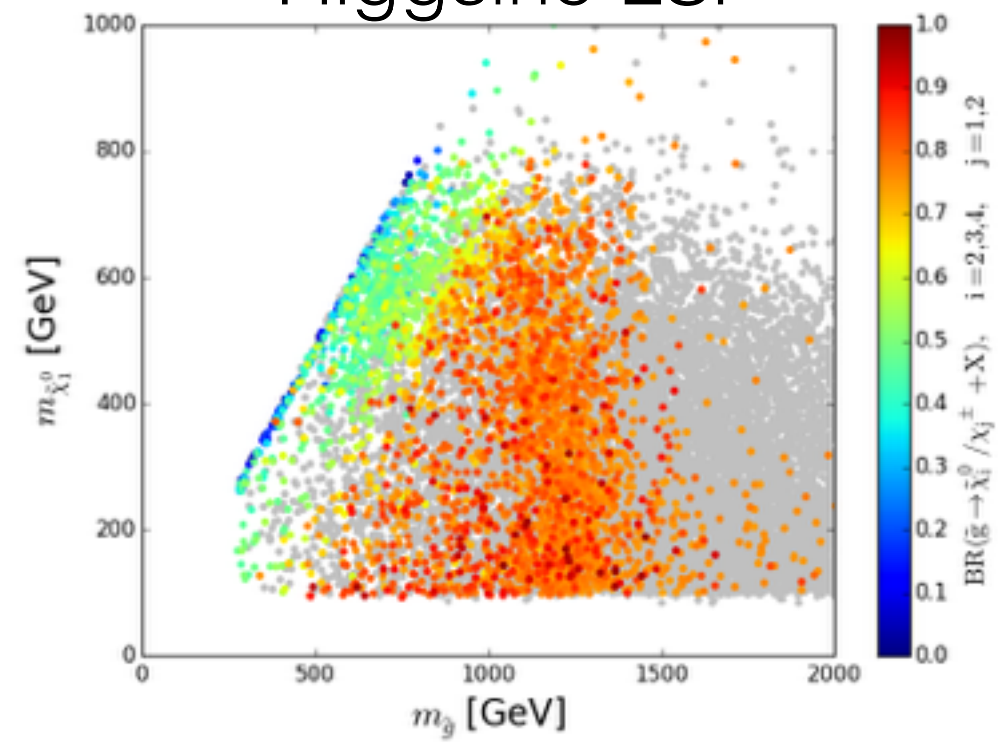
Gluino decays into chargino / heavy neutralino

Sum of branching ratios of gluino decays into chargino and heavy neutralino, for all points allowed by SModelS

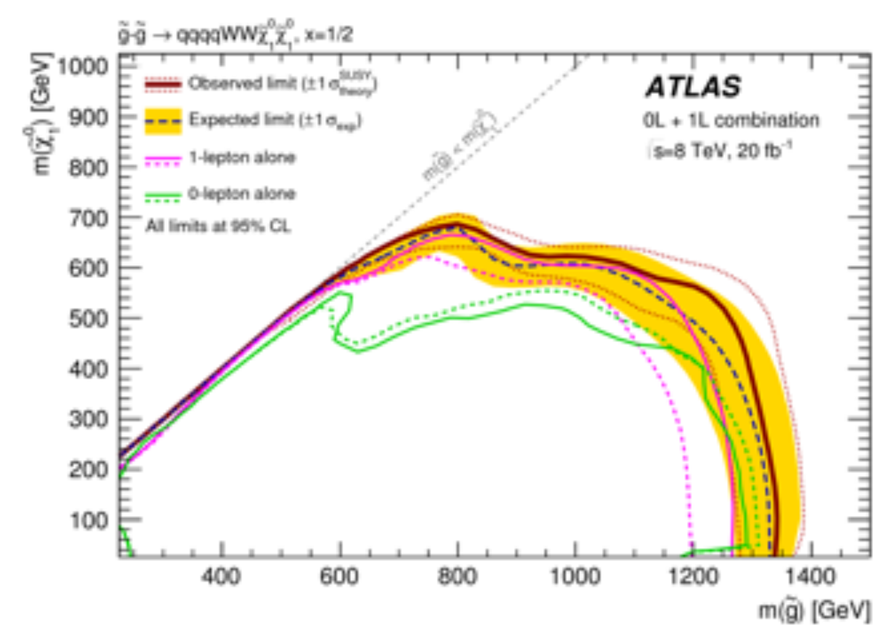
Bino LSP



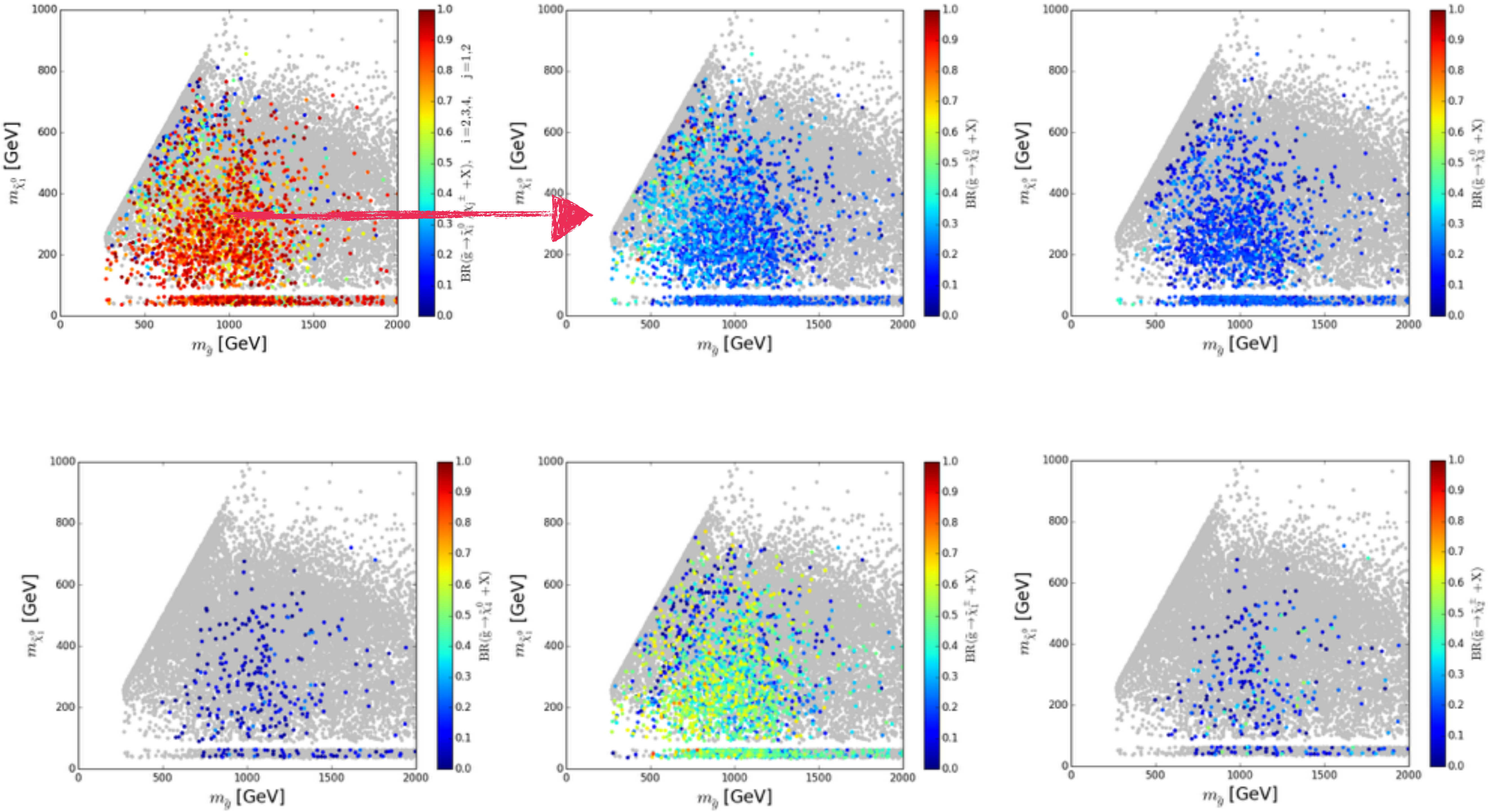
Higgsino LSP



- often more than one channel important
- decay via chargino considered by ATLAS & CMS but typically interpretation in one (or two) mass planes only
- e.g. in ATLAS-SUSY-2014-06



Classification of BRs for Bino LSP

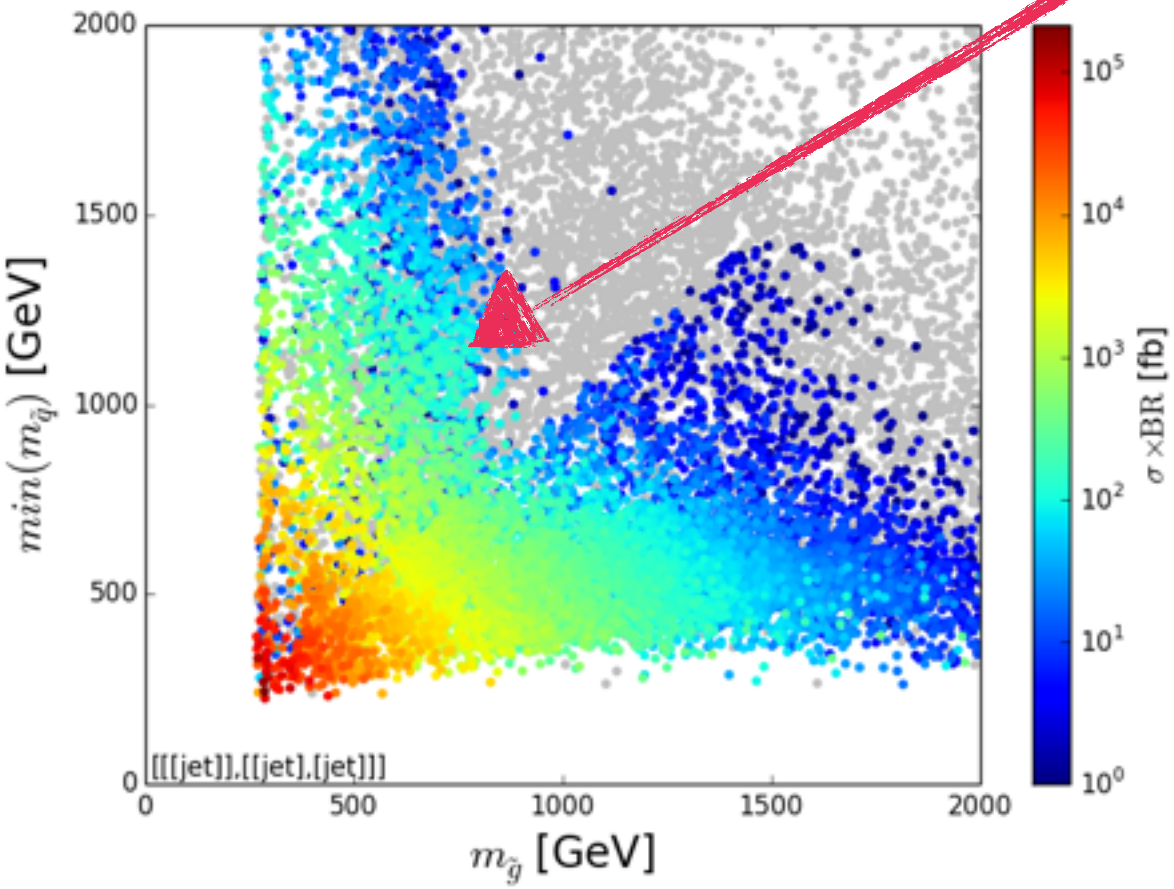


Gluino one step decays via squarks

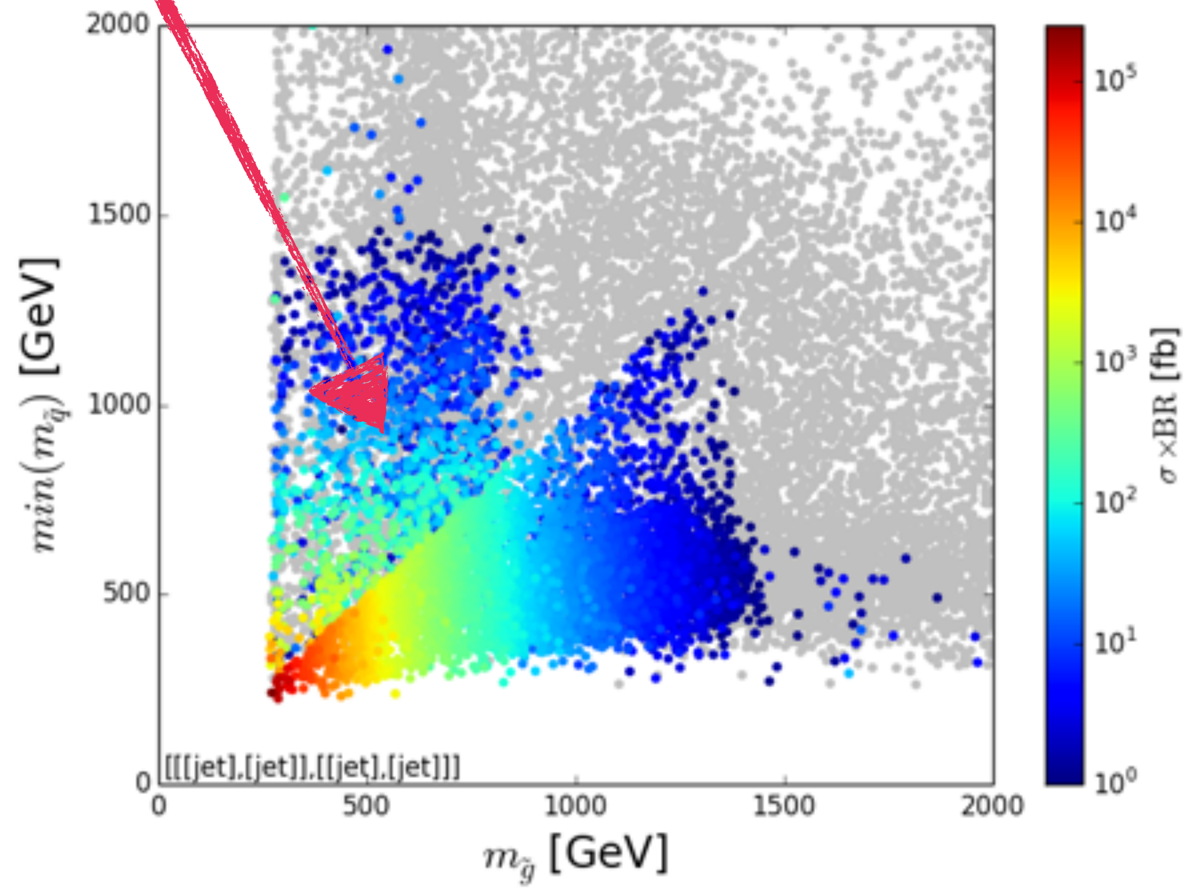
$\sigma \times BR$ for allowed points with Bino-like LSP, as function of gluino and squark mass

radiative gluino decay
to gluon + LSP

Gluino-Squark production



Gluino-pair production



Example points

489804839.slha

```
BLOCK MASS  # Mass Spectrum
# PDG code           mass         particle
   1000001     7.37182646E+02    # ~d_L
   2000001     1.17572389E+03    # ~d_R
   1000002     7.33259013E+02    # ~u_L
   2000002     5.02158051E+02    # ~u_R
   1000003     7.37182646E+02    # ~s_L
   2000003     1.17572389E+03    # ~s_R
   1000004     7.33259013E+02    # ~c_L
   2000004     5.02158051E+02    # ~c_R
   1000005     3.86685459E+03    # ~b_1
   2000005     4.00843110E+03    # ~b_2
   1000006     2.74516322E+03    # ~t_1
   2000006     3.93556802E+03    # ~t_2
   1000021     6.51578232E+02    # ~g
   1000022     4.87251524E+02    # ~chi_10
   1000023     8.85267547E+02    # ~chi_20
   1000025    -3.97532163E+03    # ~chi_30
   1000035     3.97575507E+03    # ~chi_40
   1000024     8.85433637E+02    # ~chi_1+
   1000037     3.97611803E+03    # ~chi_2+

#         PDG            Width
DECAY   1000021     5.10223642E+00   # gluino decays
#          BR         NDA      ID1       ID2
     2.50004966E-01    2     2000002        -2   # BR(~g -> ~u_R  ub)
     2.50004966E-01    2    -2000002         2   # BR(~g -> ~u_R* u )
     2.49995034E-01    2     2000004        -4   # BR(~g -> ~c_R  cb)
     2.49995034E-01    2    -2000004         4   # BR(~g -> ~c_R* c )
#         PDG            Width
DECAY   2000002     4.42213104E-03   # sup_R decays
#          BR         NDA      ID1       ID2
     1.00000000E+00    2     1000022         2   # BR(~u_R -> ~chi_10 u)
#         PDG            Width
DECAY   2000004     4.03417627E-03   # scharm_R decays
#          BR         NDA      ID1       ID2
     1.00000000E+00    2     1000022         4   # BR(~c_R -> ~chi_10 c)

Missing topologies with the highest cross-sections (up to 10):
Sqrts (TeV)   Weight (fb)        Element description
  8.0  1.554E+03    #                 [[[jet]],[[jet],[jet]]]
  8.0  7.577E+02    #        [[[jet],[jet]],[[jet],[jet],[jet]]]
  8.0  5.975E+02    #              [[[jet],[jet]],[[jet],[jet]]]
```

148832733.slha

```
#         PDG            Width
DECAY   1000021     2.03434400E-06   # gluino decays
#          BR         NDA      ID1       ID2
     5.49161306E-01    2     1000022        21   # BR(~g -> ~chi_10 g)
#          BR         NDA      ID1       ID2       ID3
     9.37815416E-02    3     1000022         1        -1   # BR(~g -> ~chi_10 d  db)
     1.31630911E-01    3     1000022         2        -2   # BR(~g -> ~chi_10 u  ub)
     9.37815416E-02    3     1000022         3        -3   # BR(~g -> ~chi_10 s  sb)
     1.31630911E-01    3     1000022         4        -4   # BR(~g -> ~chi_10 c  cb)
     1.37878757E-05    3     1000022         5        -5   # BR(~g -> ~chi_10 b  bb)
#         PDG            Width
DECAY   1000002     5.59851584E-02   # sup_L decays
#          BR         NDA      ID1       ID2
     7.32421070E-02    2     1000022         2   # BR(~u_L -> ~chi_10 u)
     9.26757893E-01    2     1000021         2   # BR(~u_L -> ~g       u)
#         PDG            Width
DECAY   1000001     1.16431353E-01   # sdown_L decays
#          BR         NDA      ID1       ID2
     3.97733028E-02    2     1000022         1   # BR(~d_L -> ~chi_10 d)
     9.60226697E-01    2     1000021         1   # BR(~d_L -> ~g       d)

BLOCK MASS  # Mass Spectrum
# PDG code           mass         particle
   1000001     5.74278124E+02    # ~d_L
   2000001     1.15472173E+03    # ~d_R
   1000002     5.69688344E+02    # ~u_L
   2000002     2.07502014E+03    # ~u_R
   1000003     5.74278124E+02    # ~s_L
   2000003     1.15472173E+03    # ~s_R
   1000004     5.69688344E+02    # ~c_L
   2000004     2.07502014E+03    # ~c_R
   1000005     2.13003692E+03    # ~b_1
   2000005     3.15138039E+03    # ~b_2
   1000006     2.10998772E+03    # ~t_1
   2000006     3.08212821E+03    # ~t_2
   1000021     5.60120001E+02    # ~g
   1000022    -5.02691367E+02    # ~chi_10
   1000023    -1.83633555E+03    # ~chi_20
   1000025     1.83774188E+03    # ~chi_30
   1000035    -3.62537467E+03    # ~chi_40
   1000024     1.83583321E+03    # ~chi_1+
   1000037     3.62554027E+03    # ~chi_2+

Missing topologies with the highest cross-sections (up to 10):
Sqrts (TeV)   Weight (fb)        Element description
  8.0  9.664E+02    #                 [[[jet]],[[jet],[jet]]]
  8.0  7.927E+02    #             [[[jet]],[[jet],[jet,jet]]]
  8.0  7.466E+02    #             [[[jet],[jet]],[[jet,jet]]]
  8.0  6.129E+02    #         [[[jet],[jet,jet]],[[jet,jet]]]
  8.0  3.885E+02    #        [[[jet],[jet]],[[jet],[jet,jet]]]
  8.0  2.369E+02    #             [[[jet],[jet]],[[jet],[jet]]]
```