On the Coverage of the pMSSM with Simplified Models

(preliminary results)

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EPS-HEP

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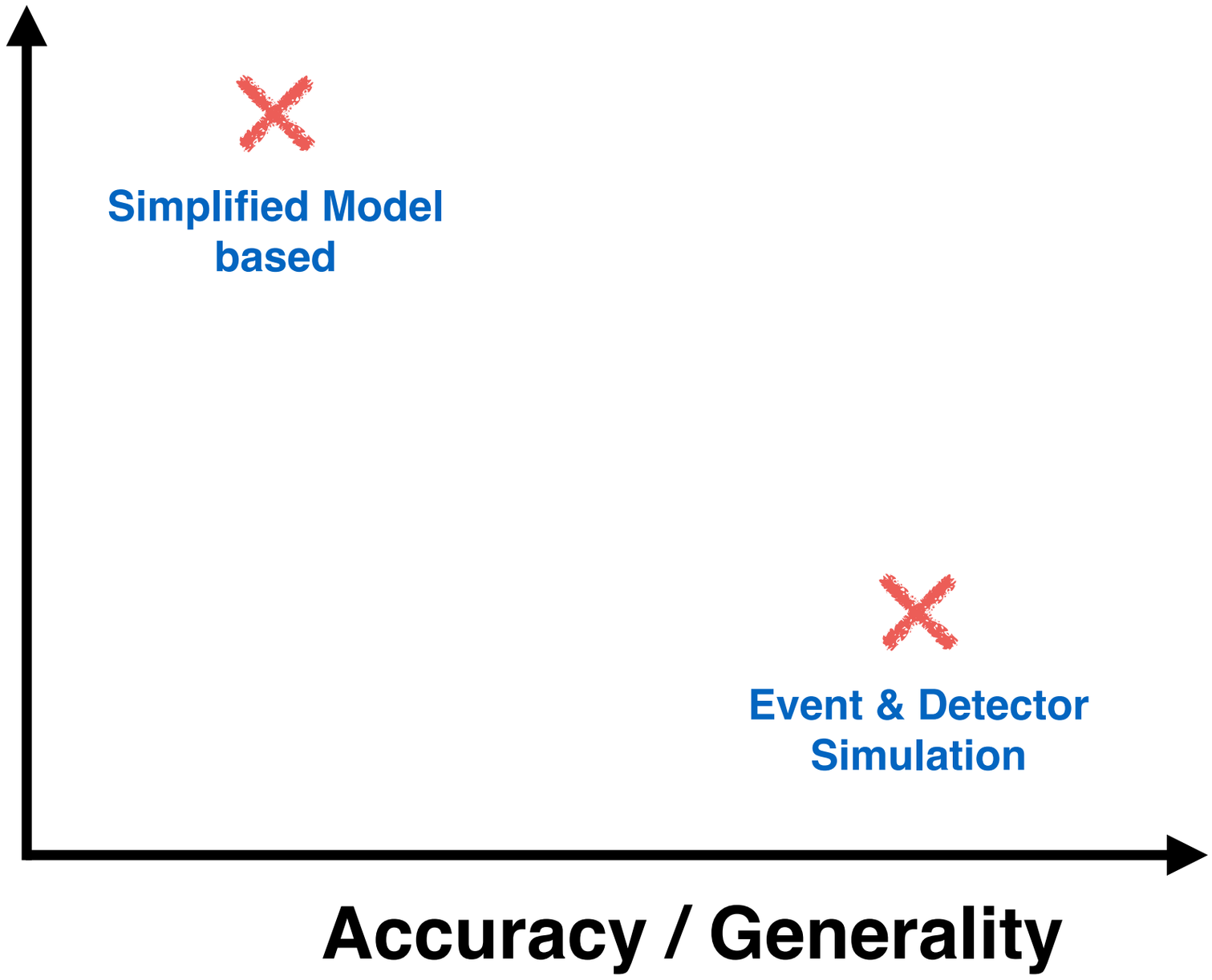
Reinterpretation of Search Results



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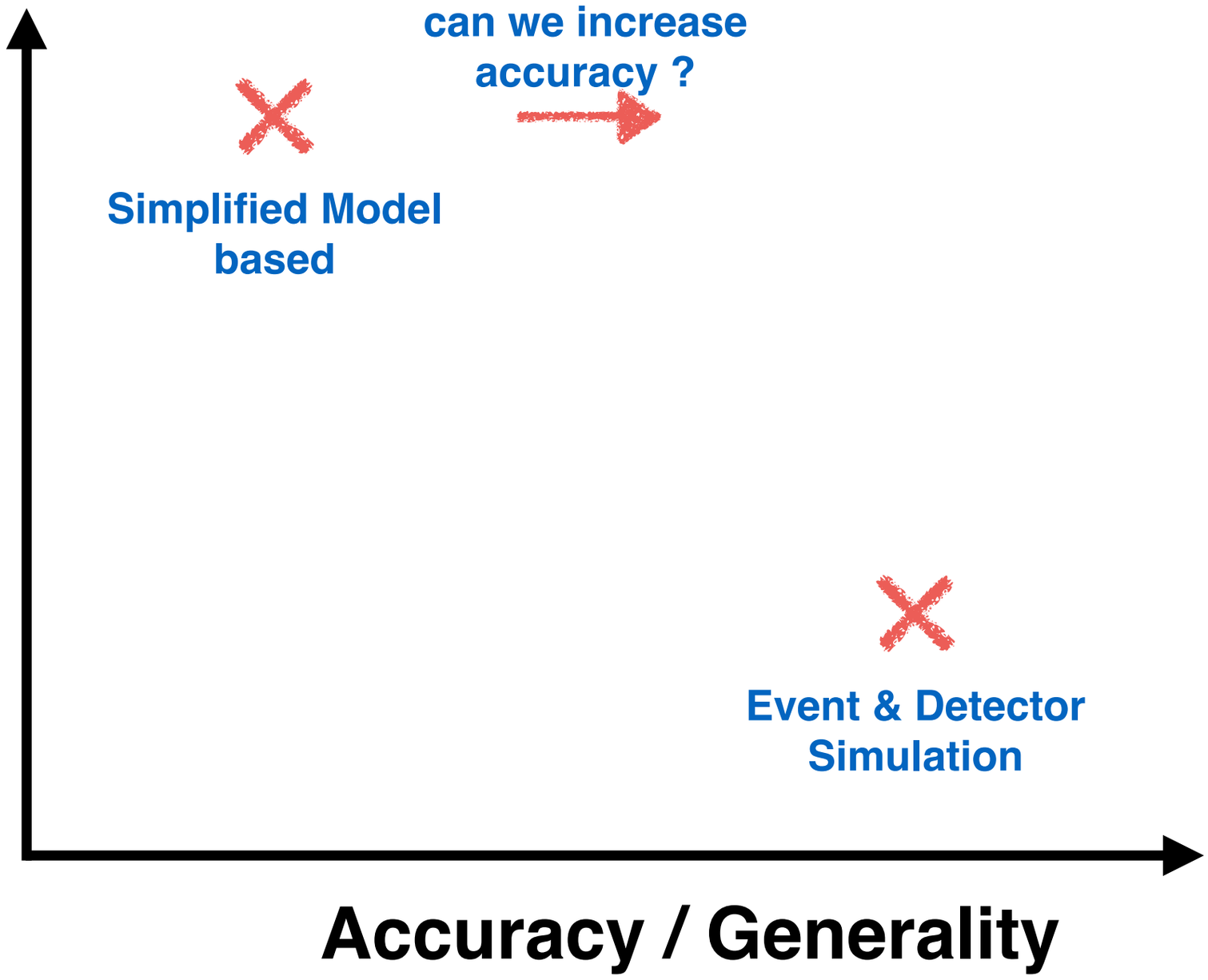

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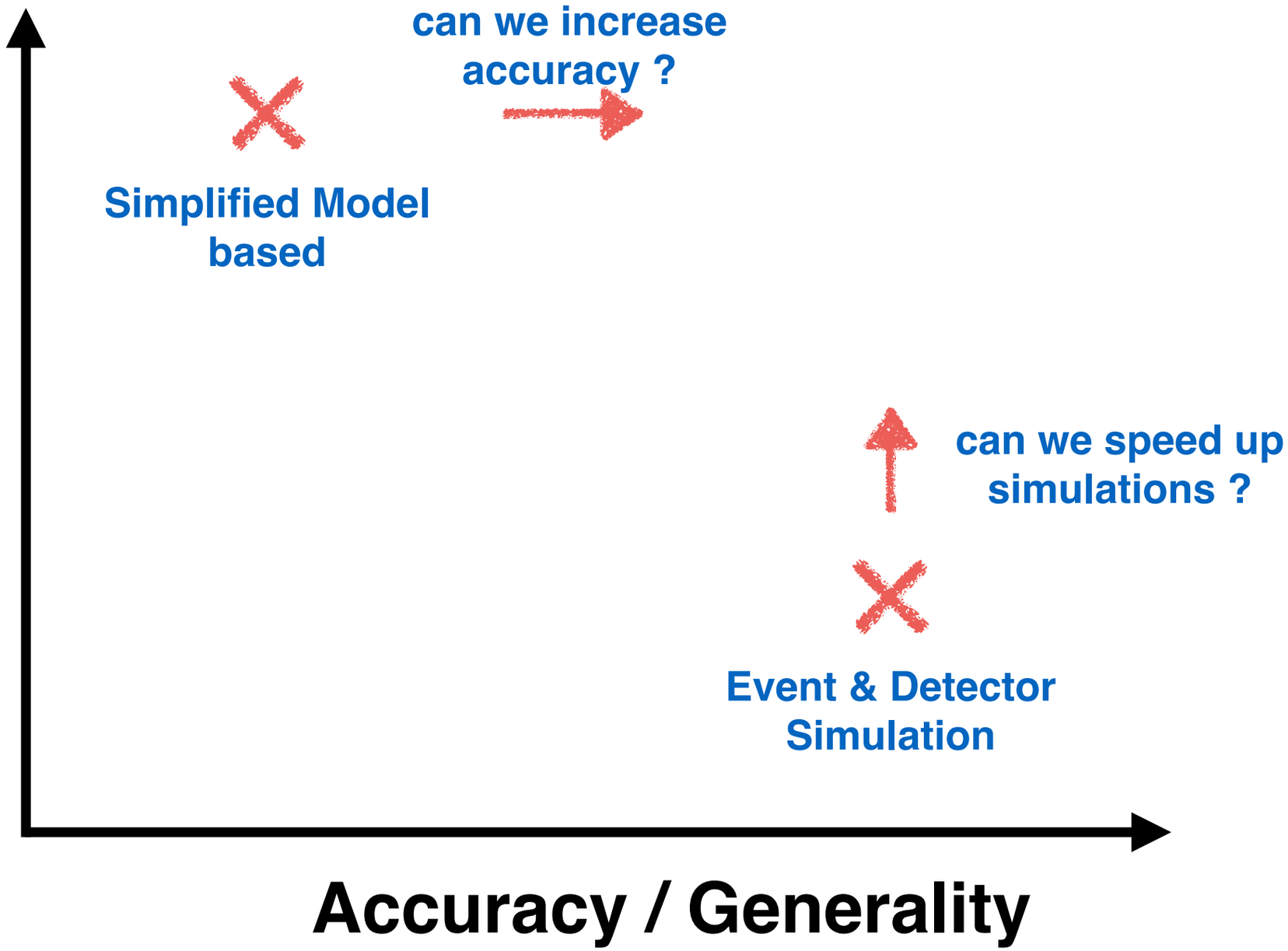

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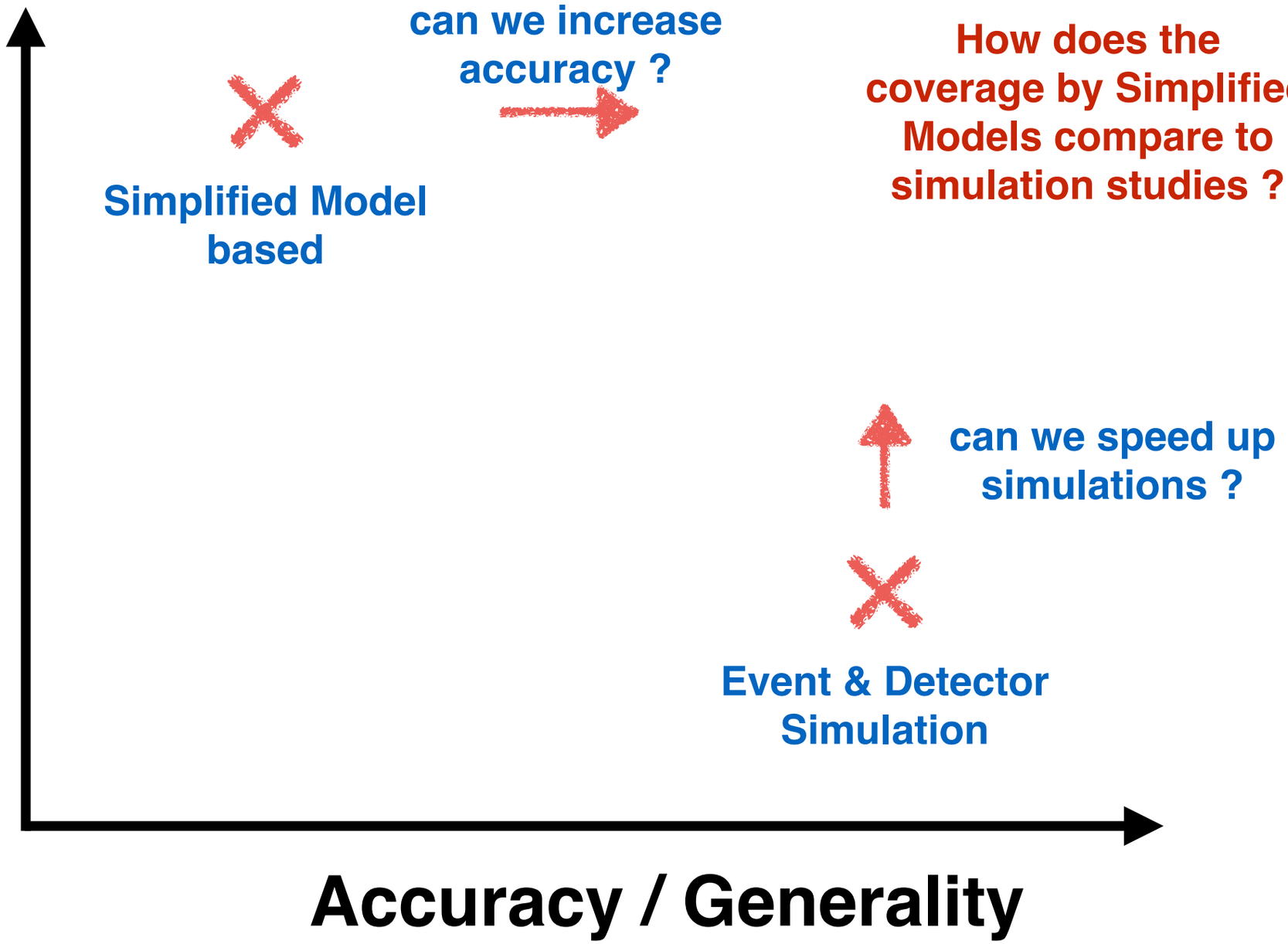


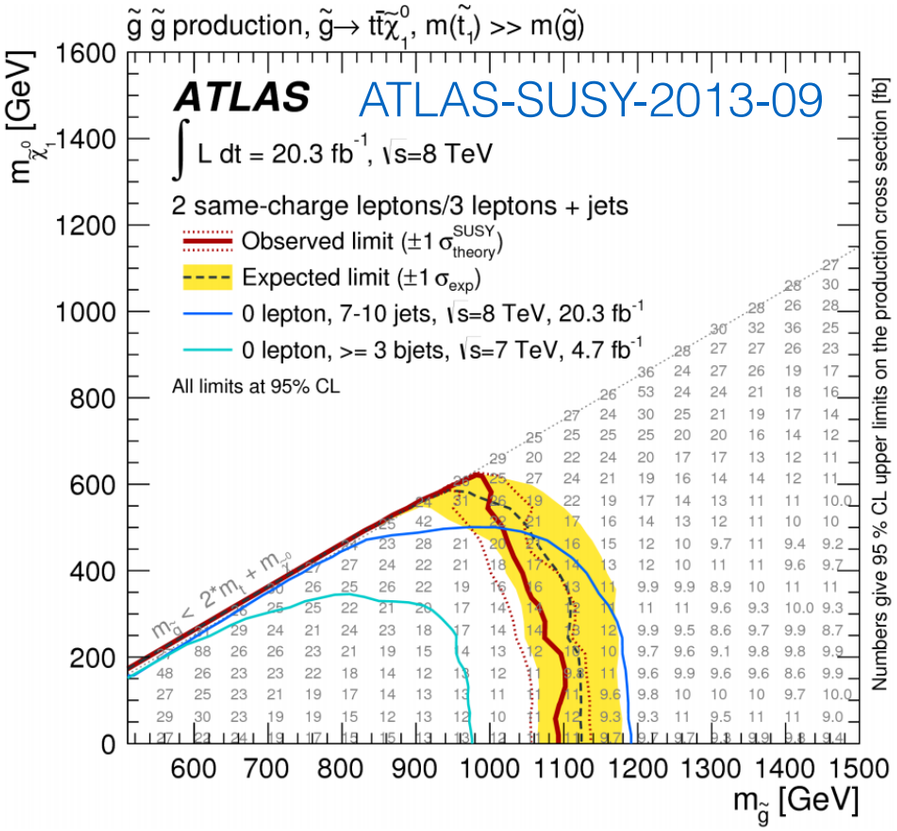
Reinterpretation of Search Results with Simplified Models

arXiv:1312.4175
arXiv:1412.1745
arXiv:1701.06586

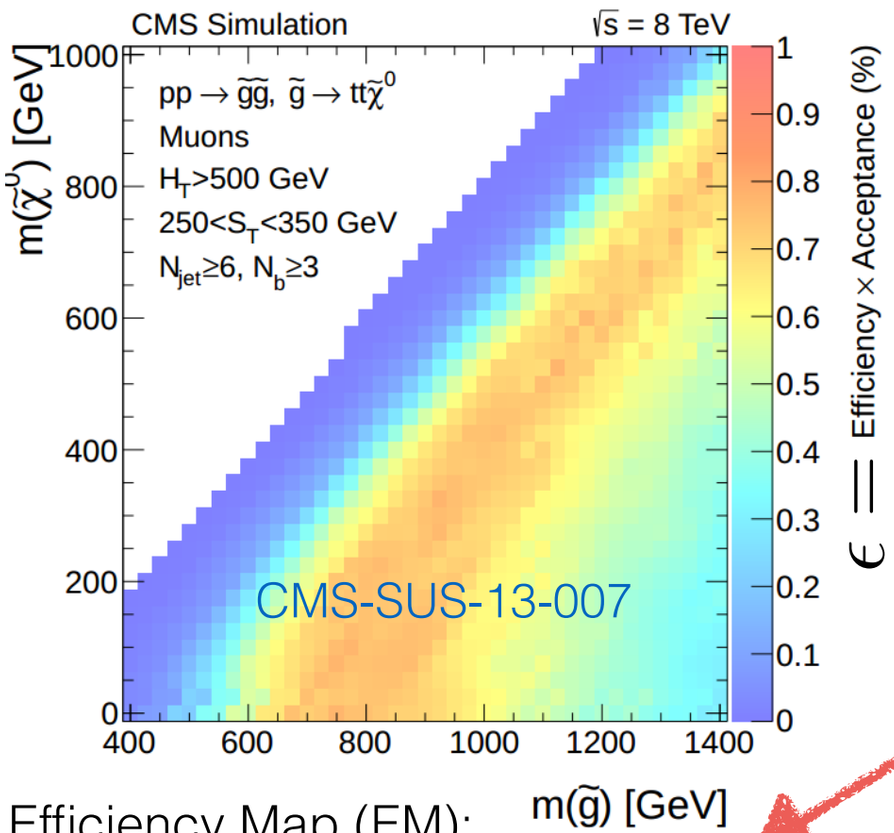
SModelS

smodels.hephy.at

- Efficiencies / upper limits are known for given set of Simplified Models (SMS)
- "Decompose" full model into Simplified Model topologies
- Compare to upper limit on Simplified Model production cross section or visible cross section in one signal region



Upper Limit (UL) Map:
directly constrains $\sigma \times \mathcal{B}$



EM results: can combine signal contributions from different Simplified Model topologies!

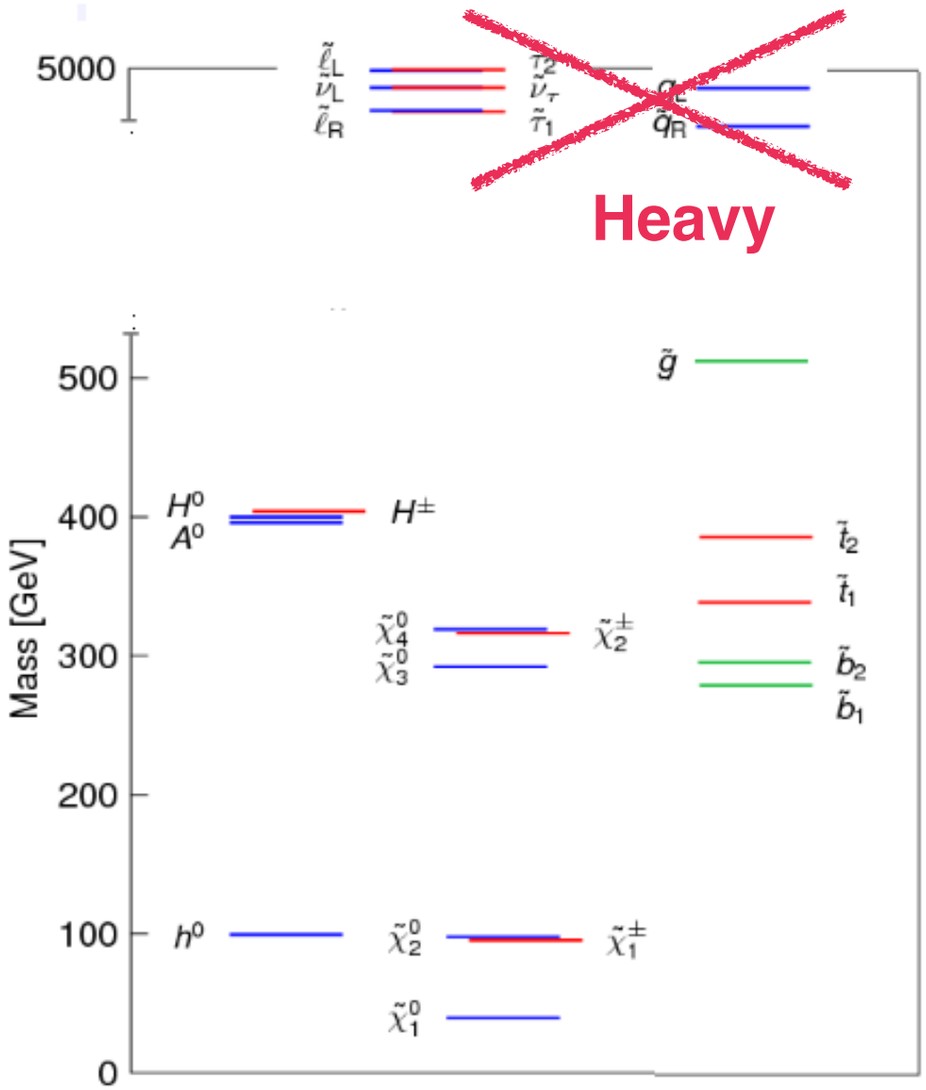
Efficiency Map (EM):
provides ϵ to calculate total visible cross section

$$\sum \sigma \times \mathcal{B} \times \epsilon$$

(sum over different topologies)

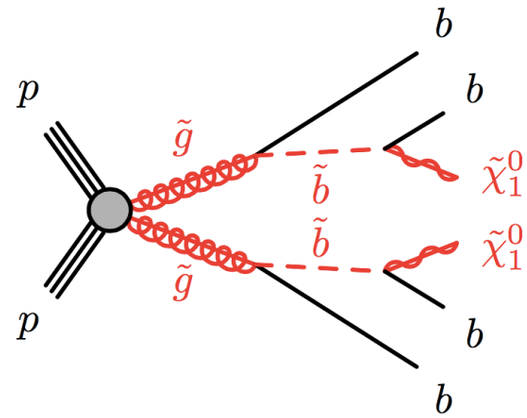
Decomposition into Simplified Models

BSM model (input)

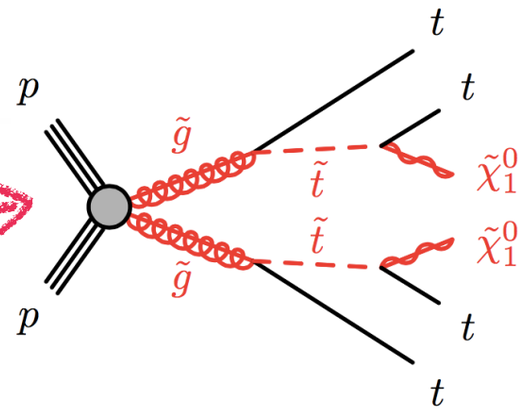


SMS Decomposition

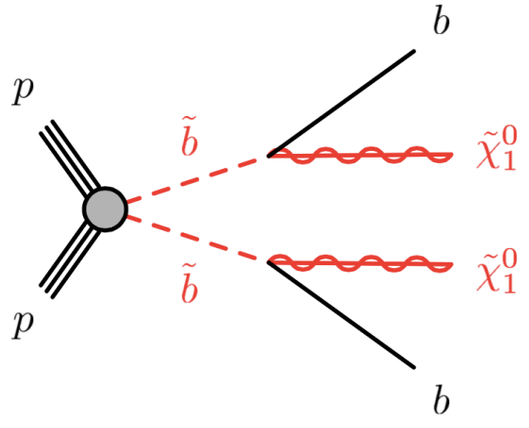
$(\sigma \times BR)_1$



$(\sigma \times BR)_2$



$(\sigma \times BR)_3$



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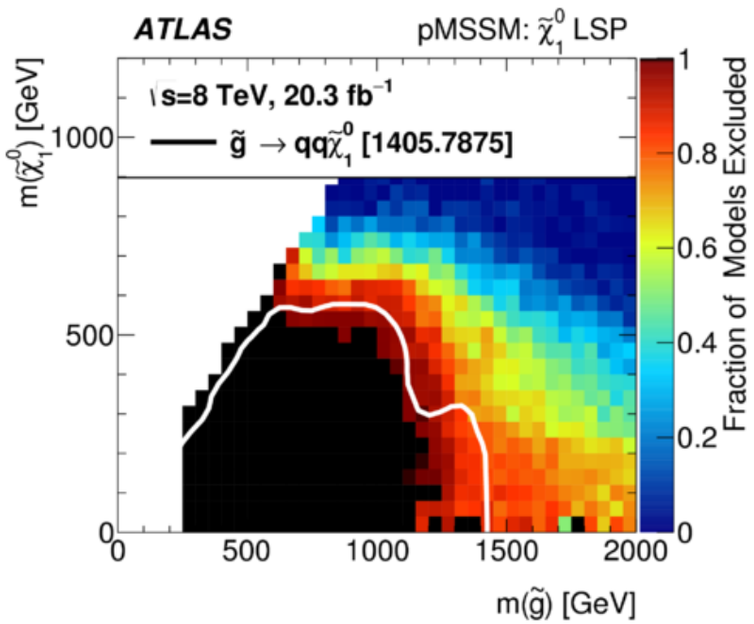
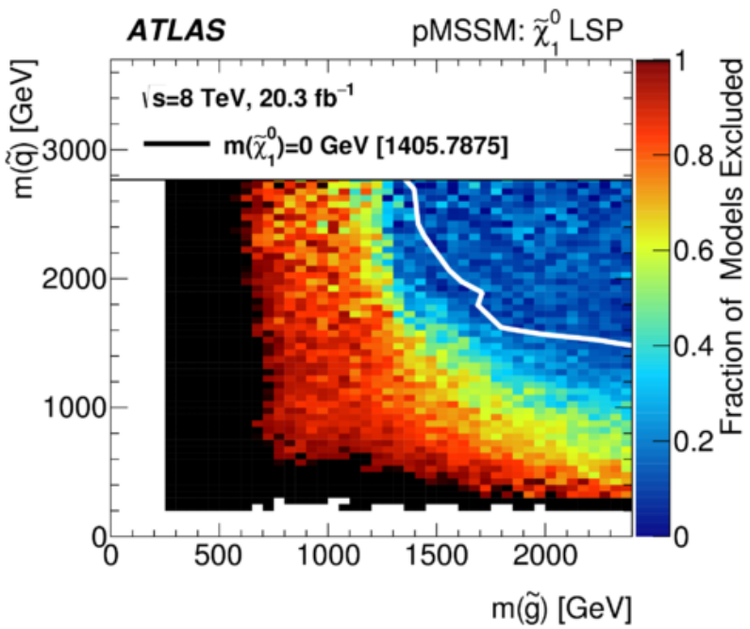
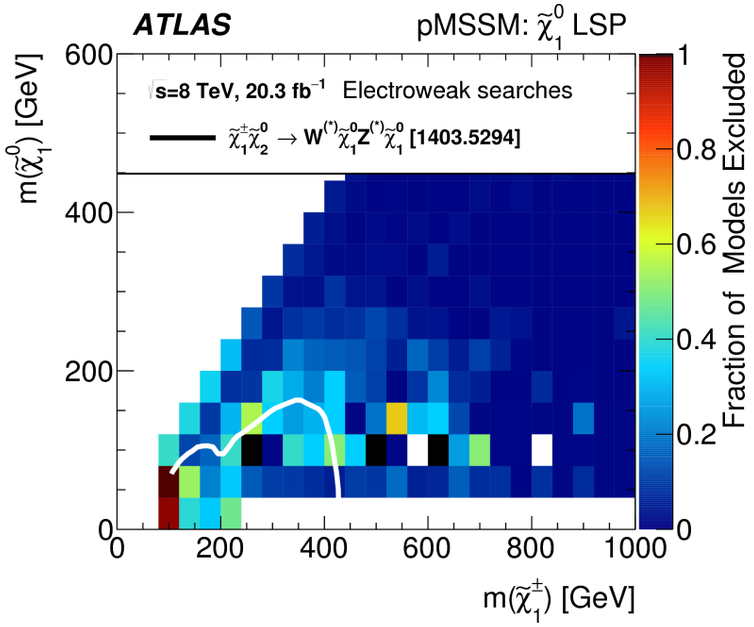
ATLAS pMSSM Scan

arXiv:1508.06608

- ATLAS interpreted 22 SUSY analyses in the phenomenological MSSM (pMSSM)
- 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 !







How many of the excluded points can also be excluded using only reinterpretation of Simplified Model results ?

Results used by ATLAS

Simplified Models results available in SModelS

	Analysis	ID	SModelS database
Inclusive	0-lepton + 2–6 jets + $E_T^{\rm miss}$	SUSY-2013-02*	6 UL, 2 EM
	0-lepton + 7–10 jets + $E_T^{\rm miss}$	SUSY-2013-04*	1 UL, 10 EM†
	1-lepton + jets + $E_T^{\rm miss}$	SUSY-2013-20*	1 UL from CONF-2013-089
	$\tau(\tau/\ell)$ + jets + $E_T^{\rm miss}$	SUSY-2013-10	—
	SS/3-leptons + jets + $E_T^{\rm miss}$	SUSY-2013-09	1 UL (+5 UL, CONF-2013-007)
	0/1-lepton + 3b-jets + $E_T^{\rm miss}$	SUSY-2013-18*	2 UL, 2 EM
	Monojet	—	— (but monojet stop, see below)
Third generation	0-lepton stop	SUSY-2013-16*	1 UL, 1 EM
	1-lepton stop	SUSY-2013-15*	1 UL, 1 EM
	2-leptons stop	SUSY-2013-19*	2 UL
	Monojet stop	SUSY-2013-21	4 EM
	Stop with Z boson	SUSY-2013-08	1 UL
	2b-jets + $E_T^{\rm miss}$	SUSY-2013-05*	3 UL, 1 EM†
	tb+$E_T^{\rm miss}$, stop	SUSY-2014-07	—
Electroweak	ℓh	SUSY-2013-23*	1 UL
	2-leptons	SUSY-2013-11	4 UL, 4 EM†
	2-τ	SUSY-2013-14	—
	3-leptons	SUSY-2013-12	5 UL
	4-leptons	SUSY-2013-13	—
	Disappearing Track	SUSY-2013-01	*n.a. in current framework*
Other	Long-lived particle	—	*n.a. in current framework*
	$H/A \to \tau^+\tau^-$	—	*n.a. in current framework*

large number of "homegrown" efficiency maps for hadronic search

produced using MadAnalysis5 and CheckMATE

standard monojet search not applicable in current framework

no Simplified Model results for reinterpretation available

non-MET searches not included in SModelS at the moment

* **+ Fastlim EMs covering natural SUSY scenarios for preliminary versions (conf notes) of ATLAS analyses** Papucci et al. arXiv:1402.0492

Additional Results used in SModelS

In addition to the ATLAS search results we also use the following CMS results

	Analysis	ID	SModelS database
Gluino, Squark	jets + E_T^{miss}, α_T	SUS-12-028	4 UL
	3(1b-)jets + E_T^{miss}	SUS-12-024	2 UL, 3 EM
	jet multiplicity + H_T^{miss}	SUS-13-012	4 UL, 20 EM †
	$\geq$ 2 jets + E_T^{miss}, M_{T2}	SUS-13-019	8 UL
	$\geq 1b$ + E_T^{miss}, Razor	SUS-13-004	5 UL
	1 lepton + $\geq 2b$-jets + E_T^{miss}	SUS-13-007	3 UL, 2 EM
	2 OS lept. + $\geq$4(2b-)jets + E_T^{miss}	PAS-SUS-13-016	2 UL
	2 SS leptons + b-jets + E_T^{miss}	SUS-13-013	4 UL, 2 EM
	b-jets + 4 Ws + E_T^{miss}	SUS-14-010	2 UL
Third gen.	0 lepton + $\geq$ 5(1b-)jets + E_T^{miss}	PAS-SUS-13-015	2 EM
	0 lepton + $\geq$ 6(1b-)jets + E_T^{miss}	PAS-SUS-13-023	4 UL
	1 lepton + $\geq$ 4(1b-)jets + E_T^{miss}	SUS-13-011	4 UL, 2 EM
	b-jets + E_T^{miss}	PAS-SUS-13-018	1 UL
	soft leptons, few jets + E_T^{miss}	SUS-14-021	2 UL
EW	multi-leptons + E_T^{miss}	SUS-13-006	6 UL

† incl. 'home-grown' EMs produced with MadAnalysis5 or CheckMATE recasting.

large number of "homegrown" efficiency maps for hadronic search

similar analyses, but additional SMS topologies

Analysis in SModelS

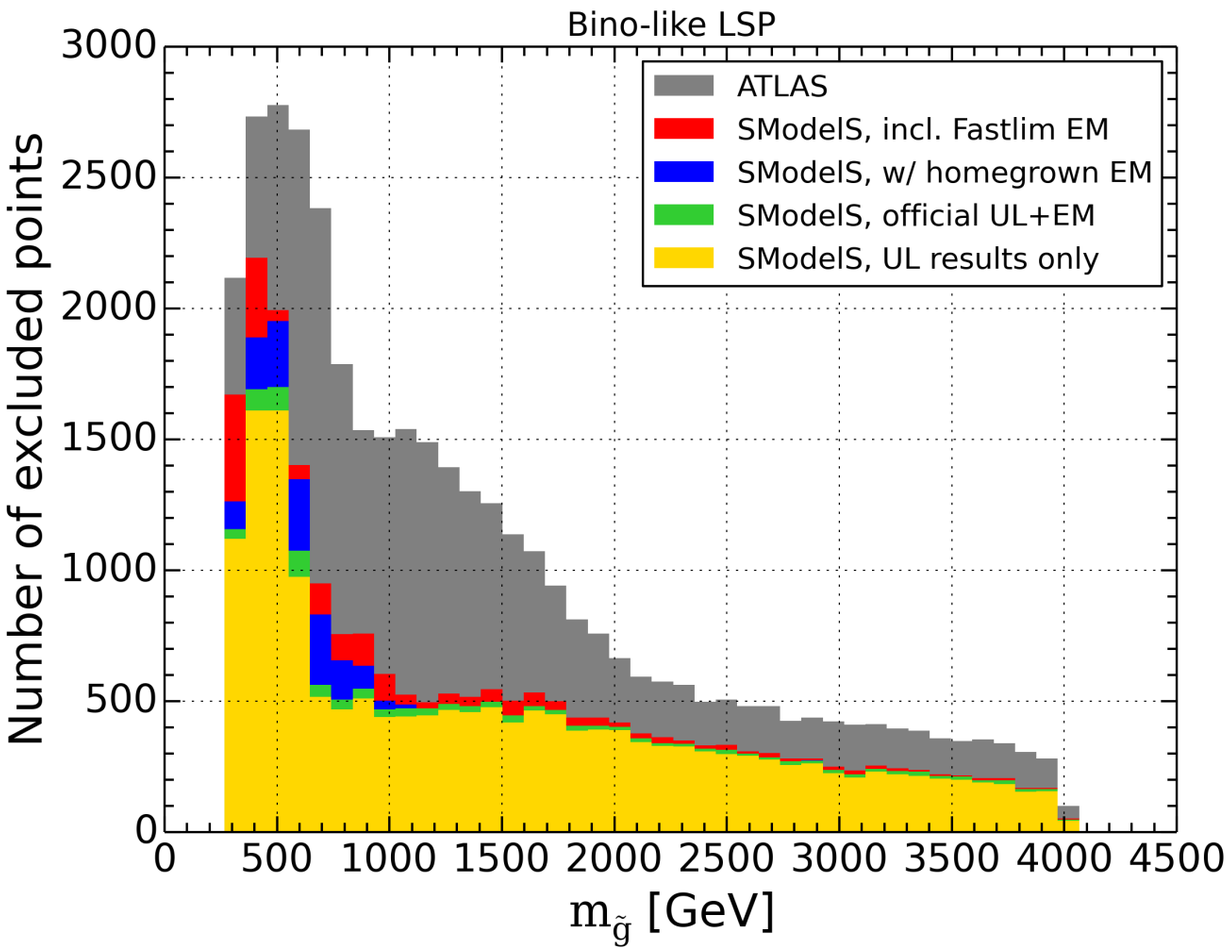
- Run SModelS on points excluded by ATLAS SUSY searches
- Points not tested in SModelS:
  - Non-prompt decays (in particular we do not consider Wino-like LSP scenarios here)
  - Resonant production (do not consider points excluded only by heavy Higgs searches)

Results Overview

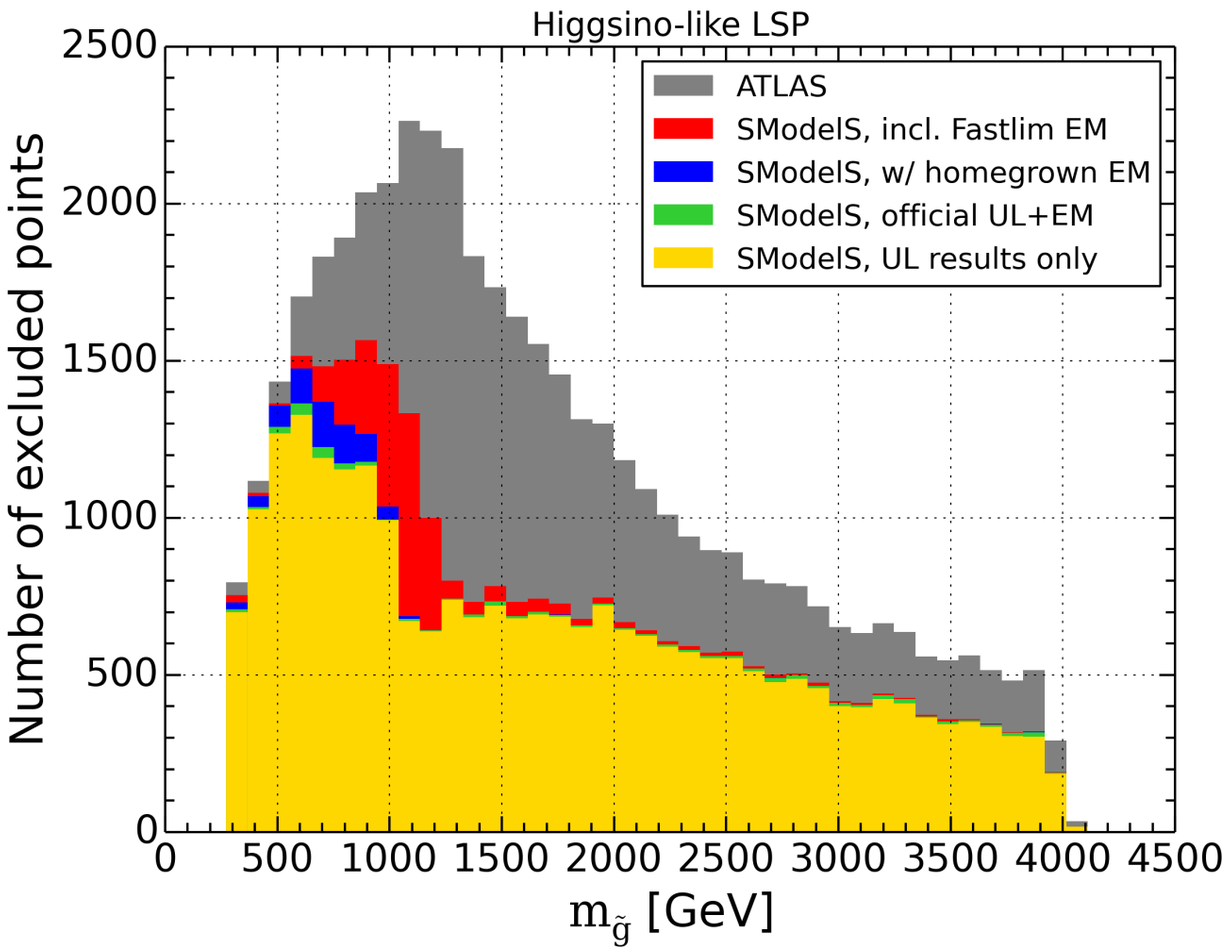
	Bino LSP	**Higgsino LSP**
# points tested	38,575	45,594
# points excluded by SModelS (UL)	16,957 (44%)	25,024 (55%)
# points excluded by SModelS (UL+EM)	21,151 (55%)	28,669 (63%)

Coverage as Function of Gluino Mass

Bino-like LSP



Higgsino-like LSP



Fraction of excluded points for scenarios with light gluinos:

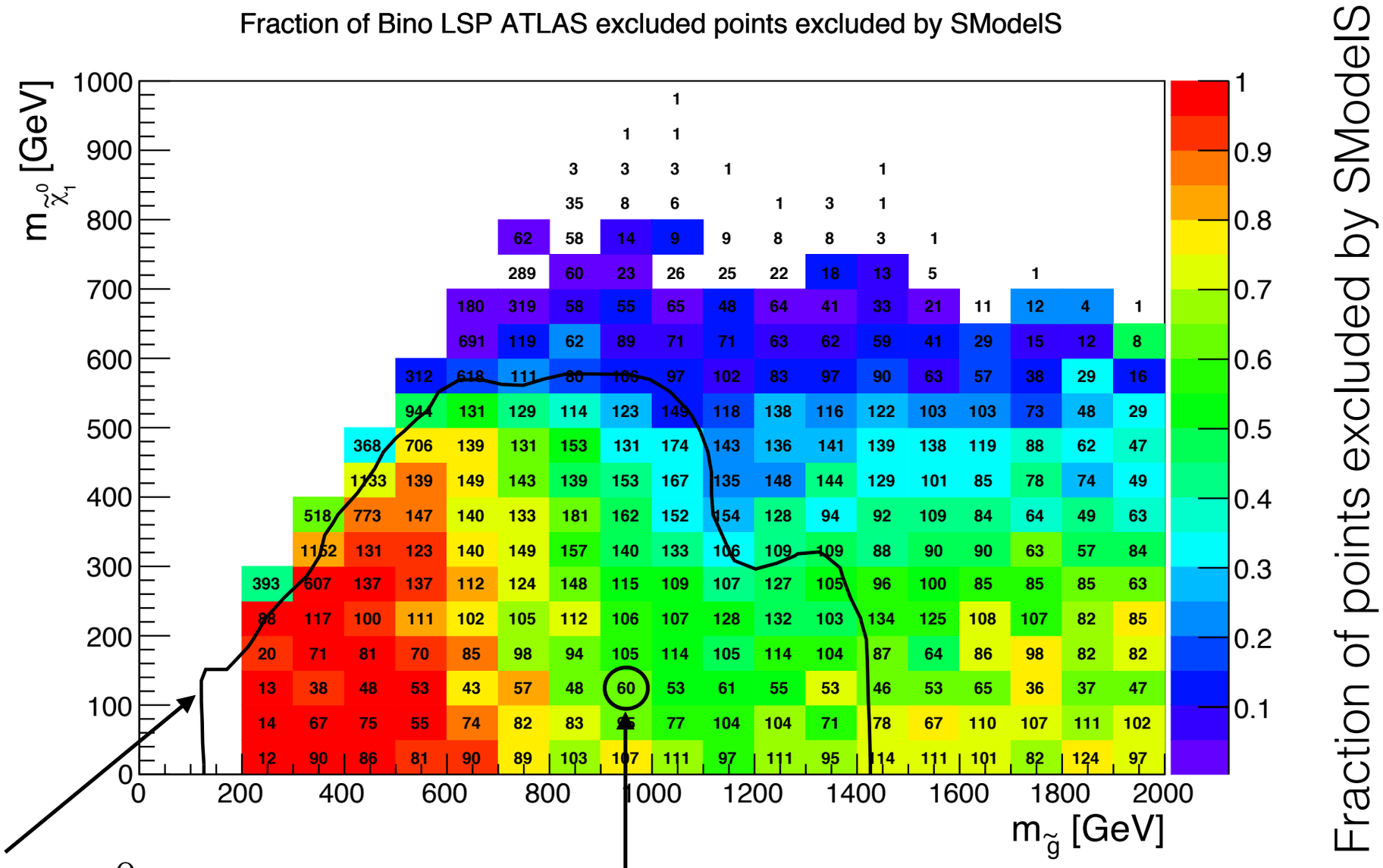
$m_{\tilde{g}} < 600$ GeV	80%
$m_{\tilde{g}} < 1400$ GeV	60%

$m_{\tilde{g}} < 600$ GeV	97%
$m_{\tilde{g}} < 1400$ GeV	74%

Coverage as Function of Gluino and Neutralino Mass

(Bino-like LSP scenarios)

- Light gluino well covered except for compressed region
- Coverage drops for intermediate gluino masses
- Main reasons: cascade decays preferred, many topologies not covered by existing Simplified Model interpretations



$\tilde{g} \rightarrow qq\tilde{\chi}_1^0$

exclusion from ATLAS

arXiv:1405.7875

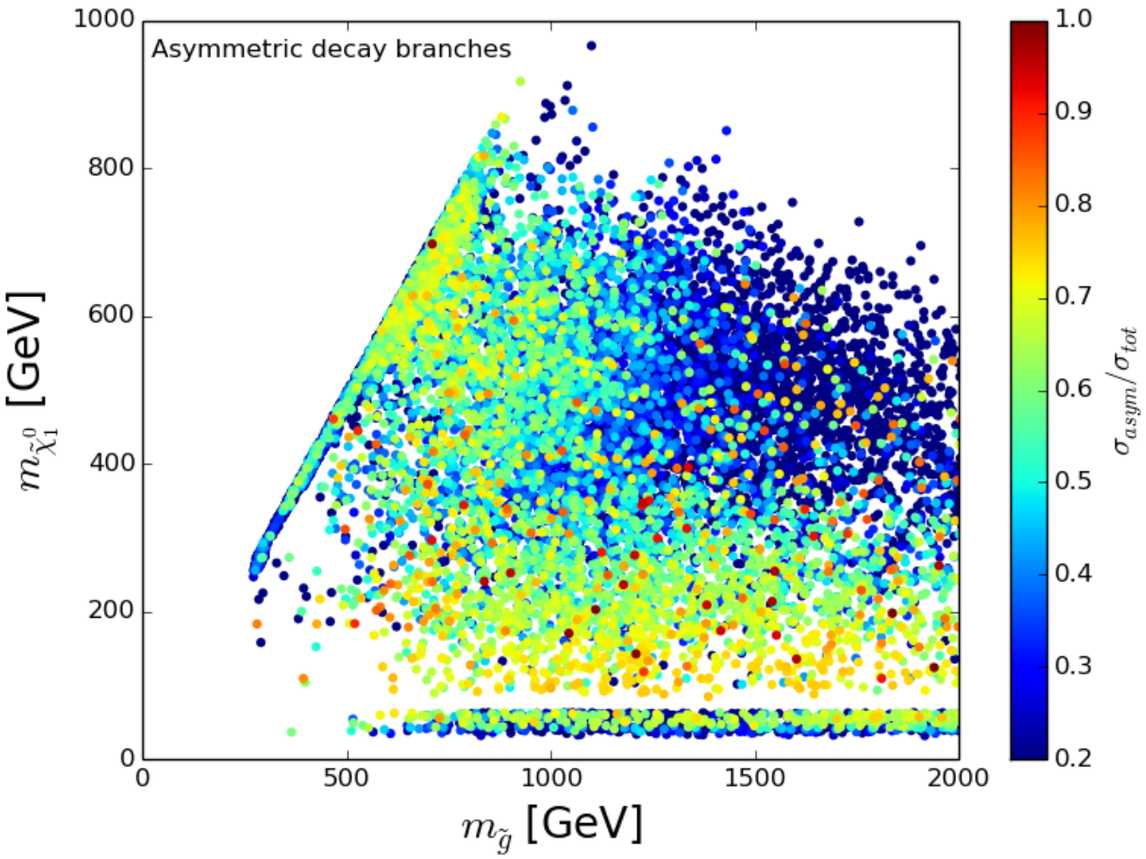
Number of points tested (i.e. points excluded by ATLAS)

Asymmetric Branches vs Long Cascade Decays

(Bino-like LSP scenarios)

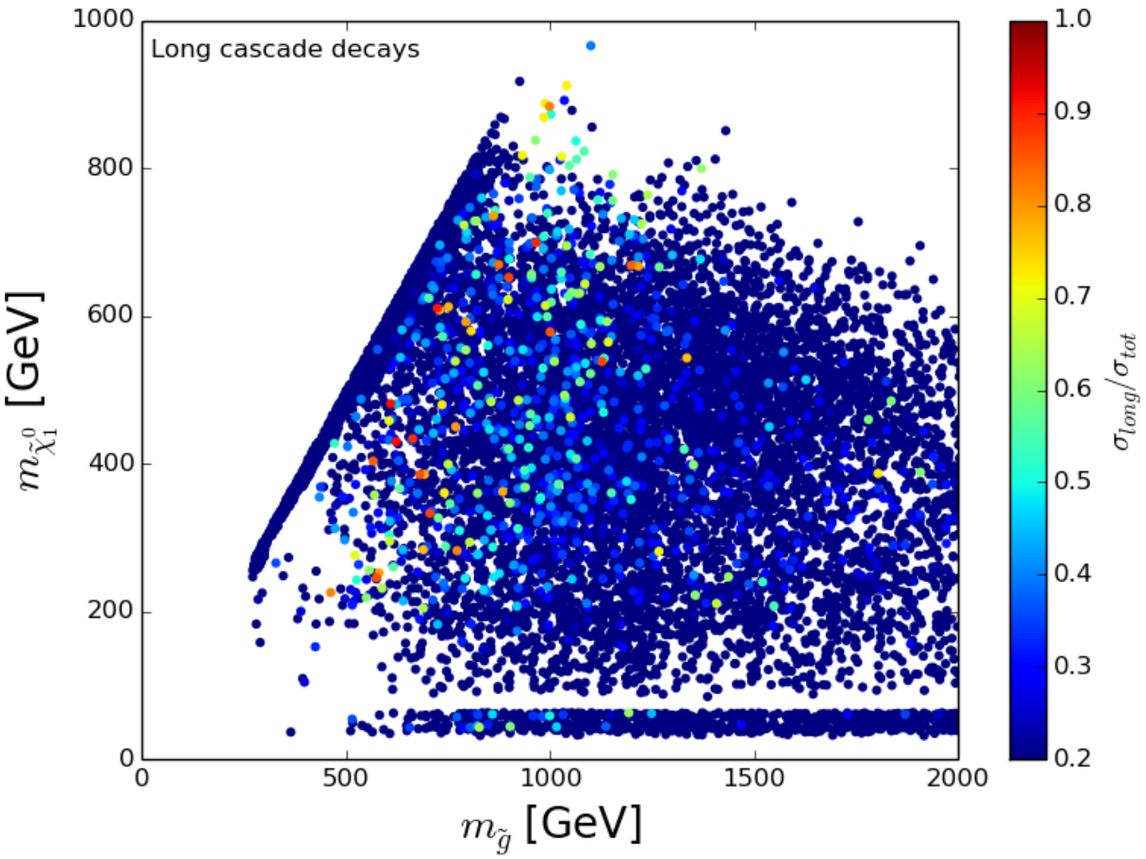
For points allowed by SModelS but excluded by ATLAS, what is the relative cross section in (not covered) asymmetric branches or long cascade decays?

Asymmetric Branches



Asymmetric branches: short decay (at most one intermediate particle in each branch) where the two branches are not equal

Long Cascade Decays

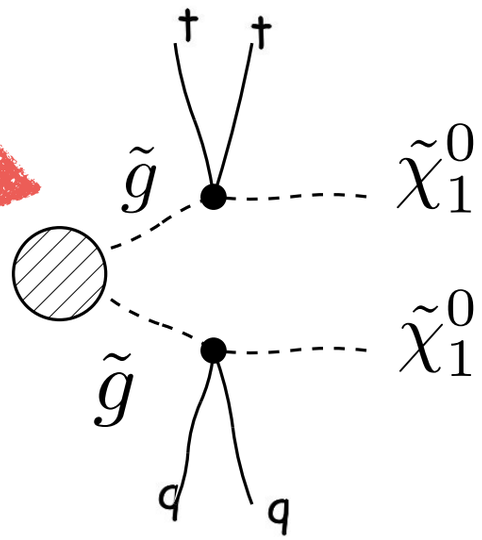


Long cascade decays: more than one intermediate odd particle in the cascade decay

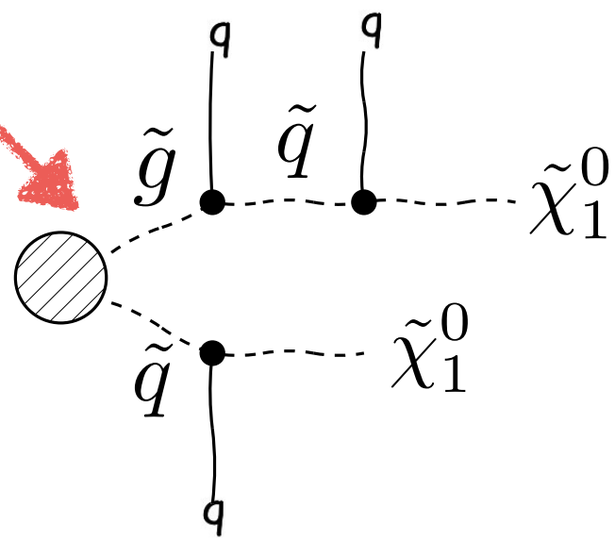
Asymmetric Branches vs Long Cascade Decays

Asymmetric branches examples

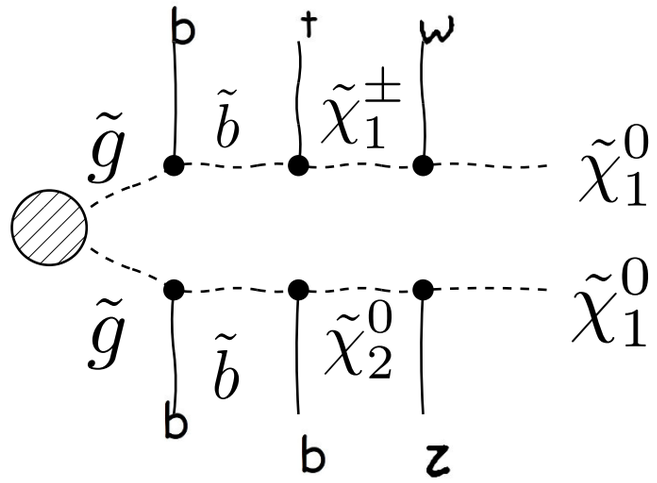
covered by Fastlim EMs (incl. in SModelS)



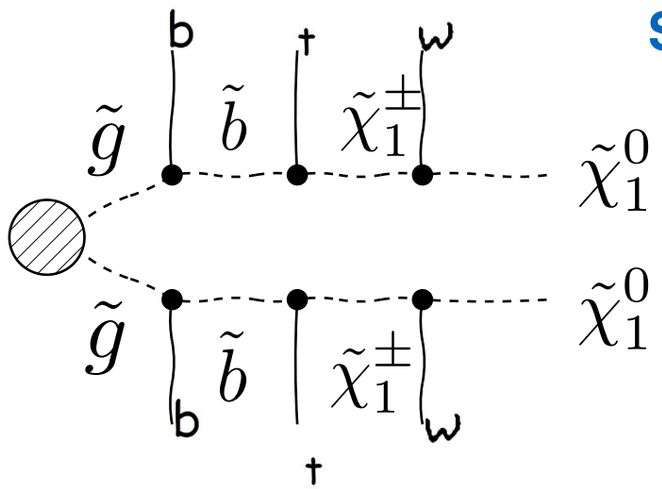
important topology but no SMS results available!



Long cascade decay examples



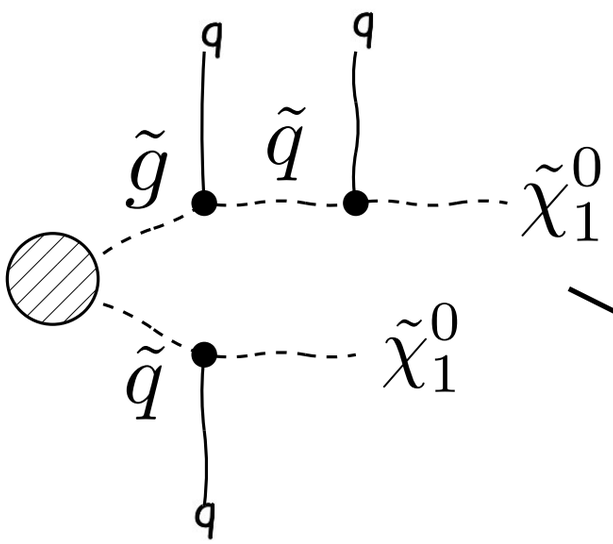
at least 4 free mass parameters, not viable Simplified Model



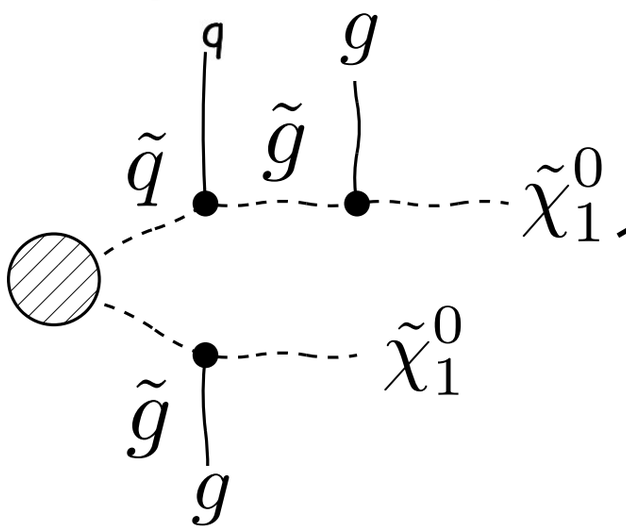
Gluino-Squark Production

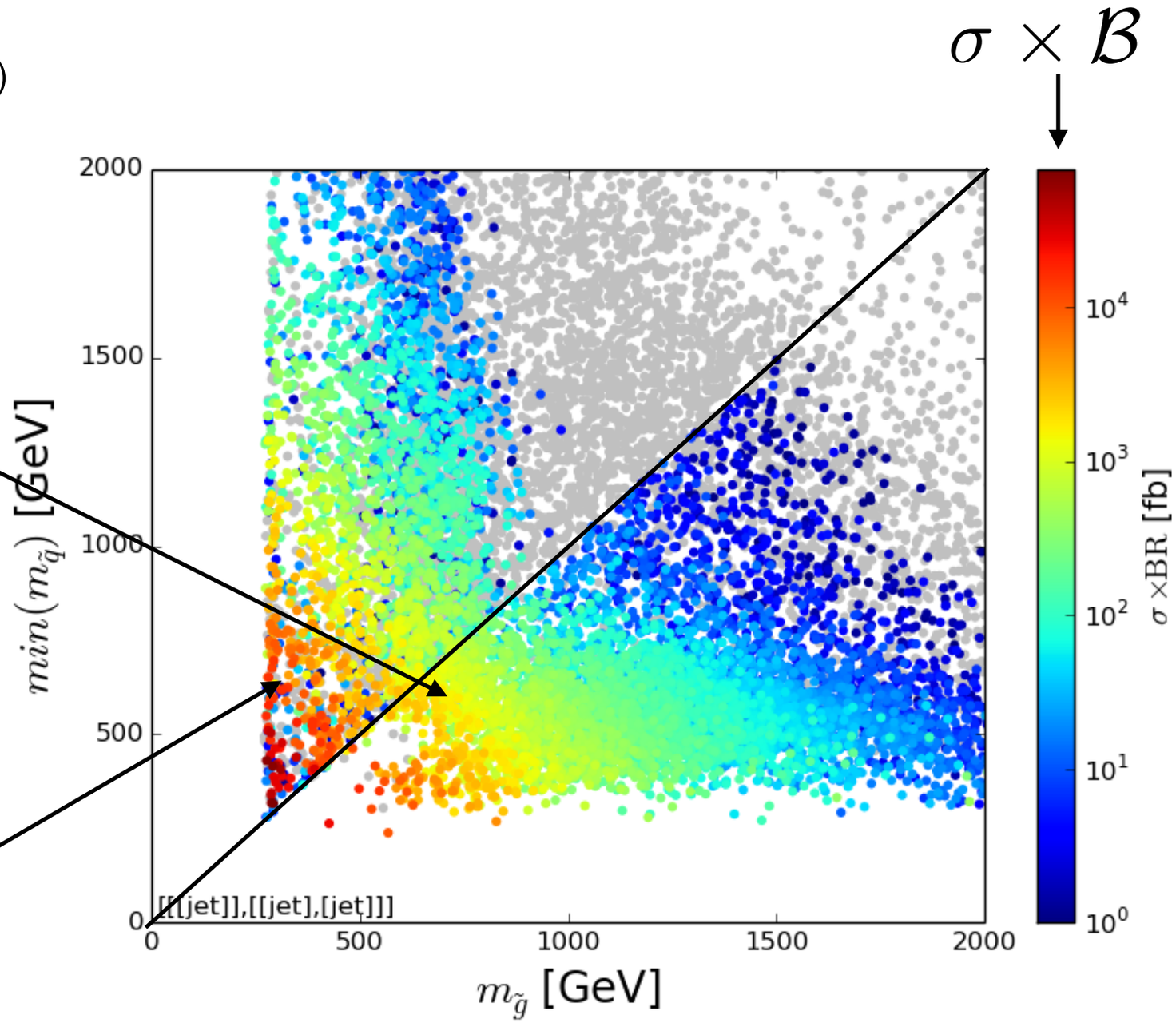
(Bino-like LSP scenarios)

Gluino-Squark production where (one of) the squarks are lighter than the gluino



Gluino-Squark production where the gluino is lighter than all squarks





Should be included in SModelS to improve coverage

Conclusions

- Available Simplified Model results can exclude about 55-63% of pMSSM parameter points excluded by ATLAS
- Light gluinos are robustly constrained by ATLAS, but often evade Simplified Model limits
- The most important class of “missing topologies” features short but asymmetric branches
- Particularly interesting: topologies featuring gluino-squark production
- We can improve the coverage by adding efficiency maps for such missing topologies to the database
- Discussion of top and bottom squark and ew production channels will be included in upcoming publication

BACKUP

ATLAS pMSSM Scan - Details

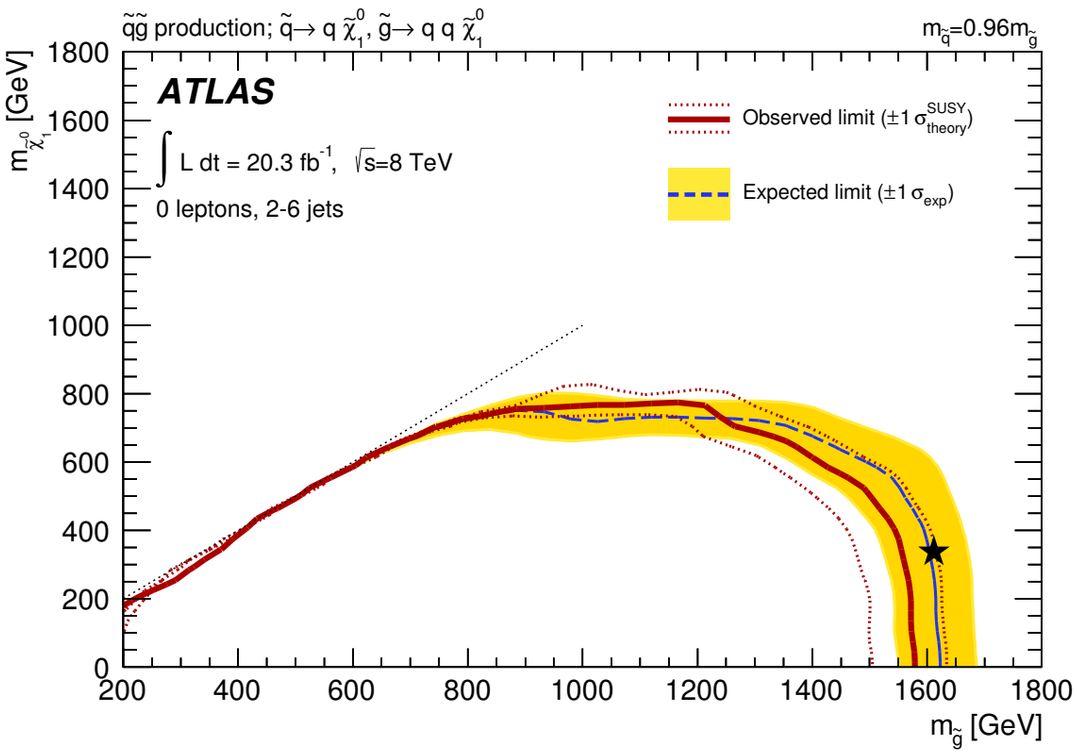
Parameter	Min value	Max value	Note
$m_{\tilde{L}_1}(= m_{\tilde{L}_2})$	90 GeV	4 TeV	Left-handed slepton (first two gens.) mass
$m_{\tilde{e}_1}(= m_{\tilde{e}_2})$	90 GeV	4 TeV	Right-handed slepton (first two gens.) mass
$m_{\tilde{L}_3}$	90 GeV	4 TeV	Left-handed stau doublet mass
$m_{\tilde{e}_3}$	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
$\lvert M_1\rvert$	0 GeV	4 TeV	Bino mass parameter
$\lvert M_2\rvert$	70 GeV	4 TeV	Wino mass parameter
$\lvert\mu\rvert$	80 GeV	4 TeV	Bilinear Higgs mass parameter
M_3	200 GeV	4 TeV	Gluino mass parameter
$\lvert A_t\rvert$	0 GeV	8 TeV	Trilinear top coupling
$\lvert A_b\rvert$	0 GeV	4 TeV	Trilinear bottom coupling
$\lvert A_\tau\rvert$	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}
BR($b\to s\gamma$)	2.69×10^{-4}	3.87×10^{-4}
BR($B_s\to\mu^+\mu^-$)	1.6×10^{-9}	4.2×10^{-9}
BR($B^+\to\tau^+\nu_\tau$)	66×10^{-6}	161×10^{-6}
$\Omega_{\tilde{\chi}_1^0}h^2$	—	0.1208
$\Gamma_{\text{invisible(SUSY)}}(Z)$	—	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

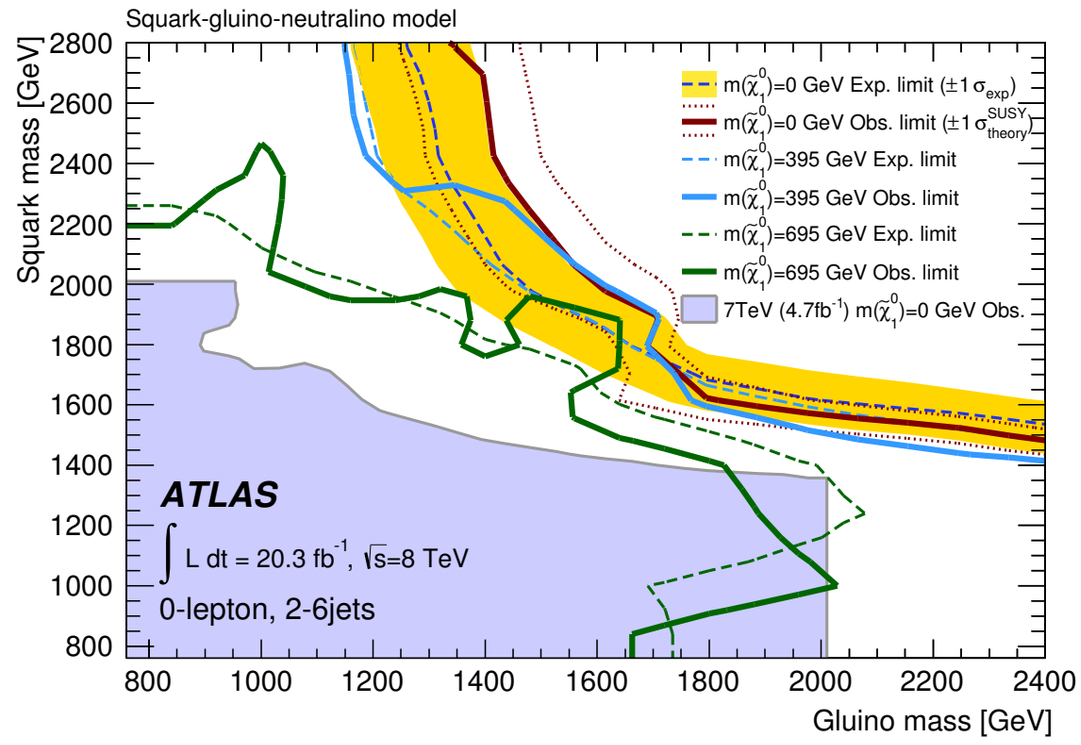
Gluino-Squark Simplified Model in ATLAS

Only valid for 8 degenerate squarks !

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



Covers 3 values of LSP mass



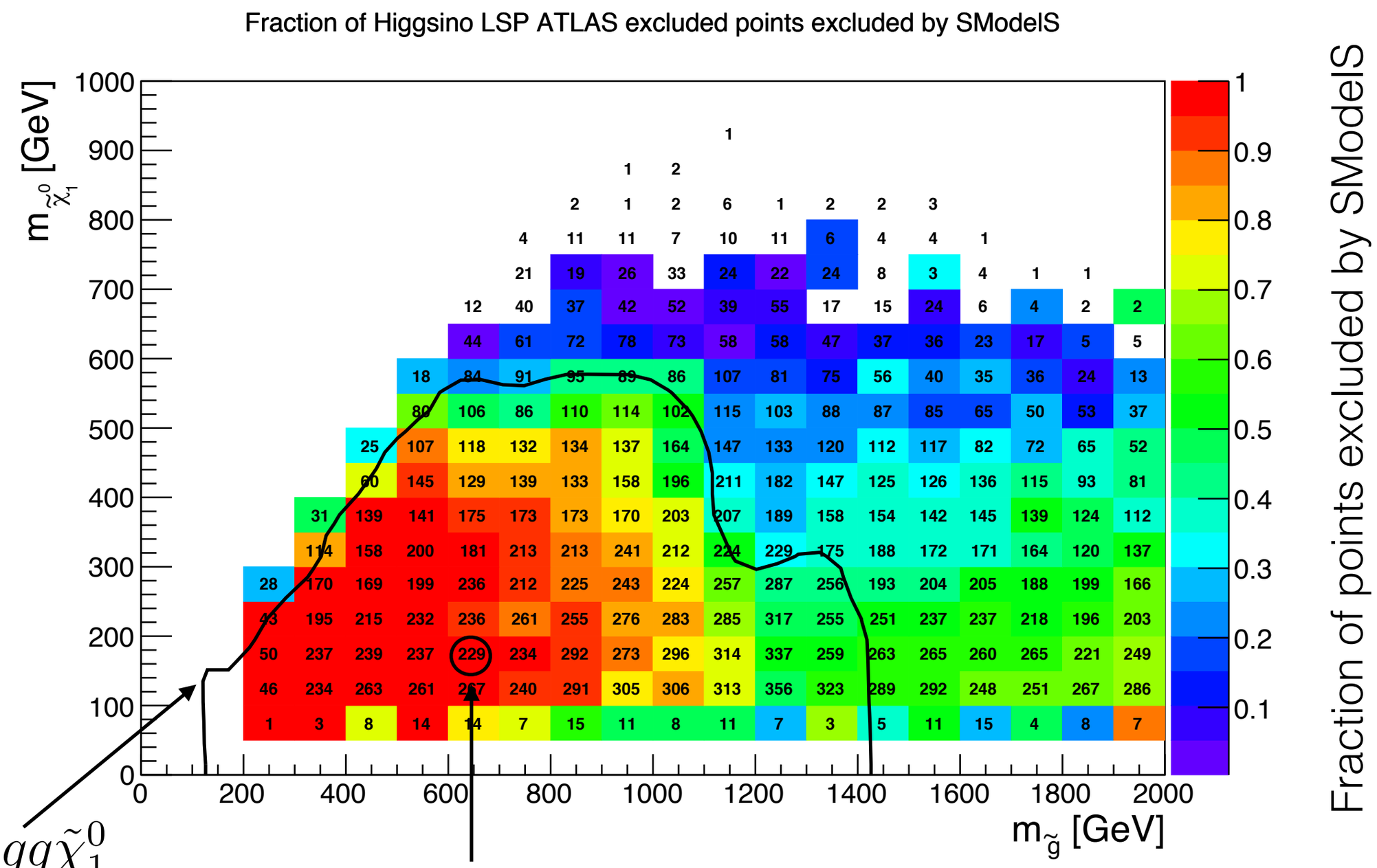
(from ATLAS-SUSY-2014-06)

What we would like to have for reinterpretation:

- Need efficiency maps separately for the various production channels to evaluate signal prediction for arbitrary number of light squarks
- Efficiency maps should have 3 free parameters: gluino mass, squark mass, LSP mass (e.g. 3 mass planes for interpolation)

Coverage as Function of Gluino and Neutralino Mass

(Higgsino-like LSP scenarios)



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Number of points tested (i.e. points excluded by ATLAS)

Asymmetric Branches vs Long Cascade Decays

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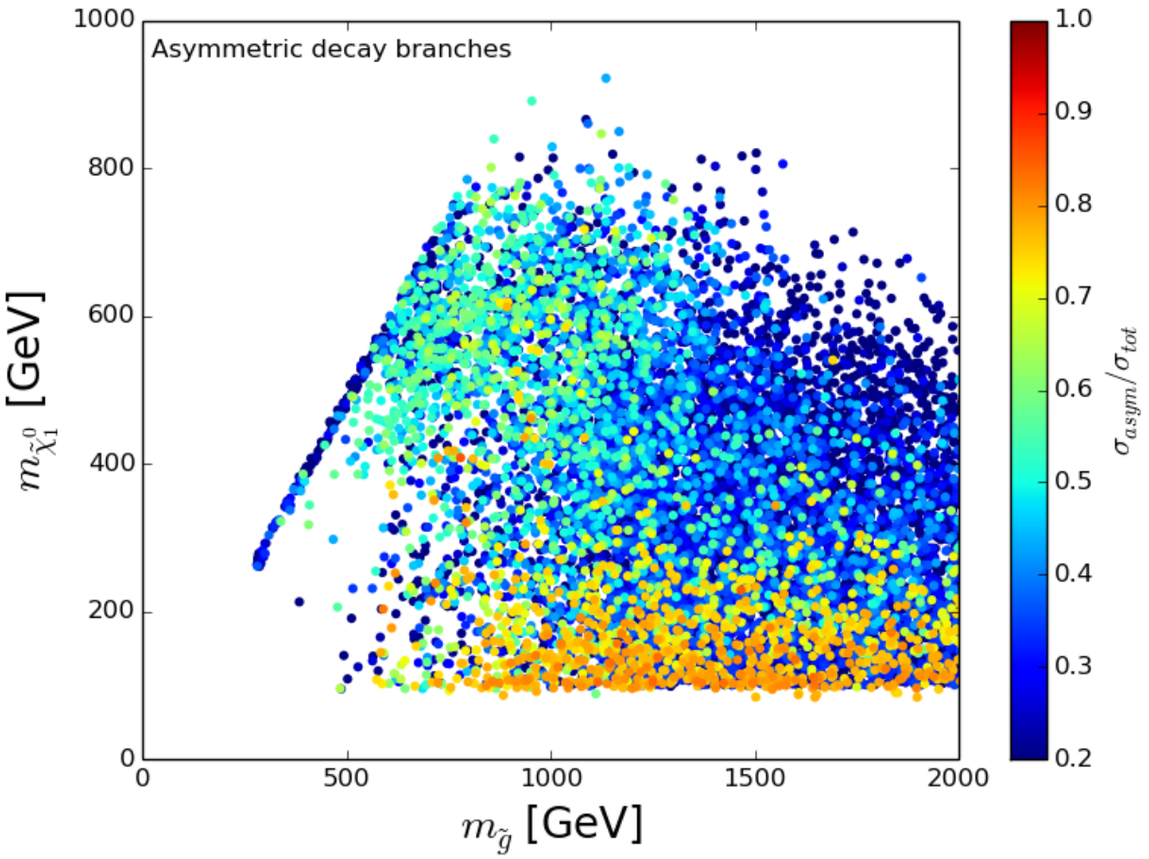
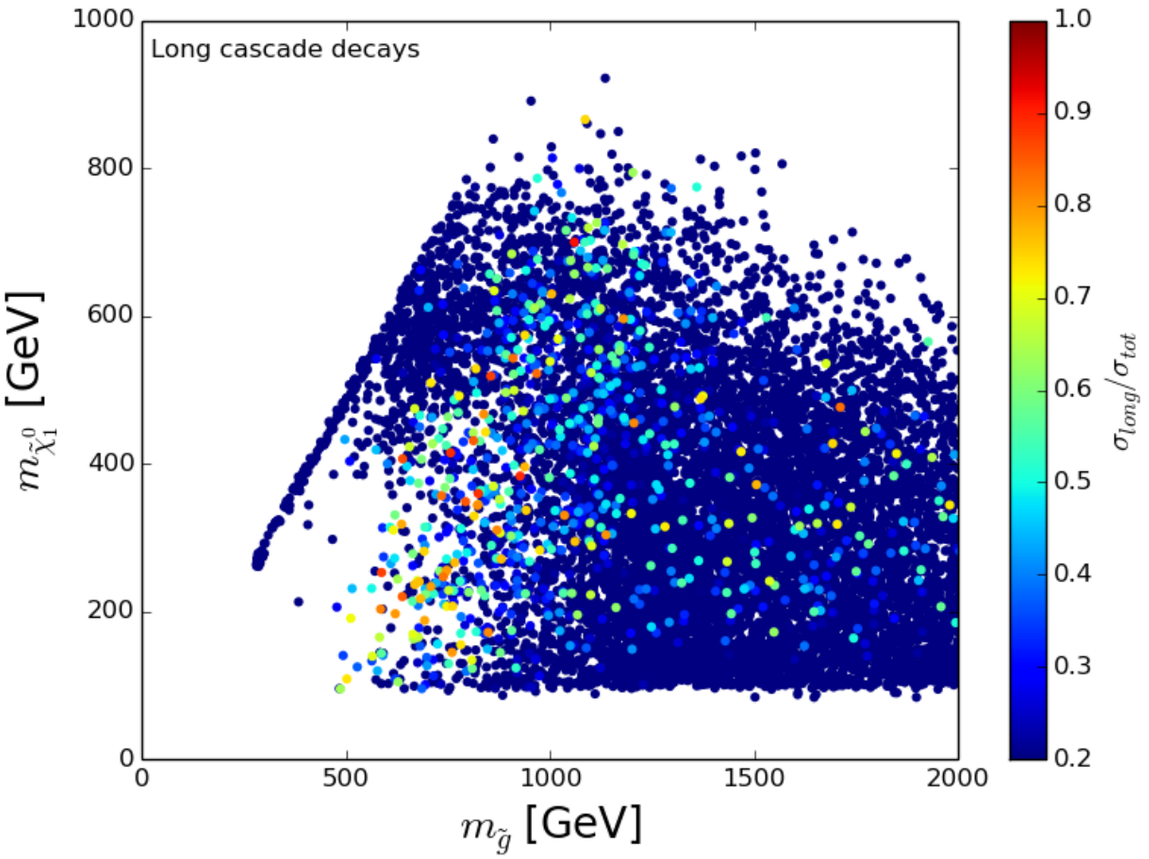
Asymmetric Branches



Asymmetric branches: short decay (at most one intermediate particle in each branch) where the two branches are not equal

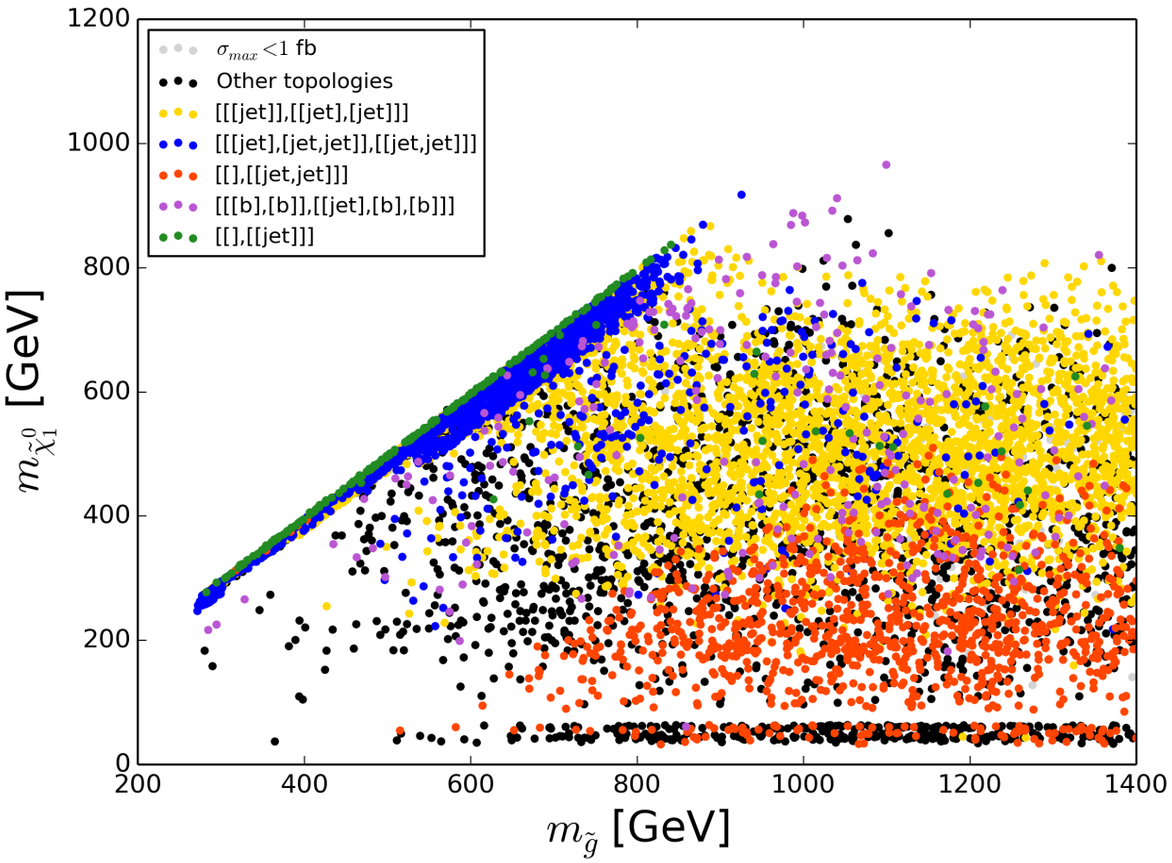
Long Cascade Decays



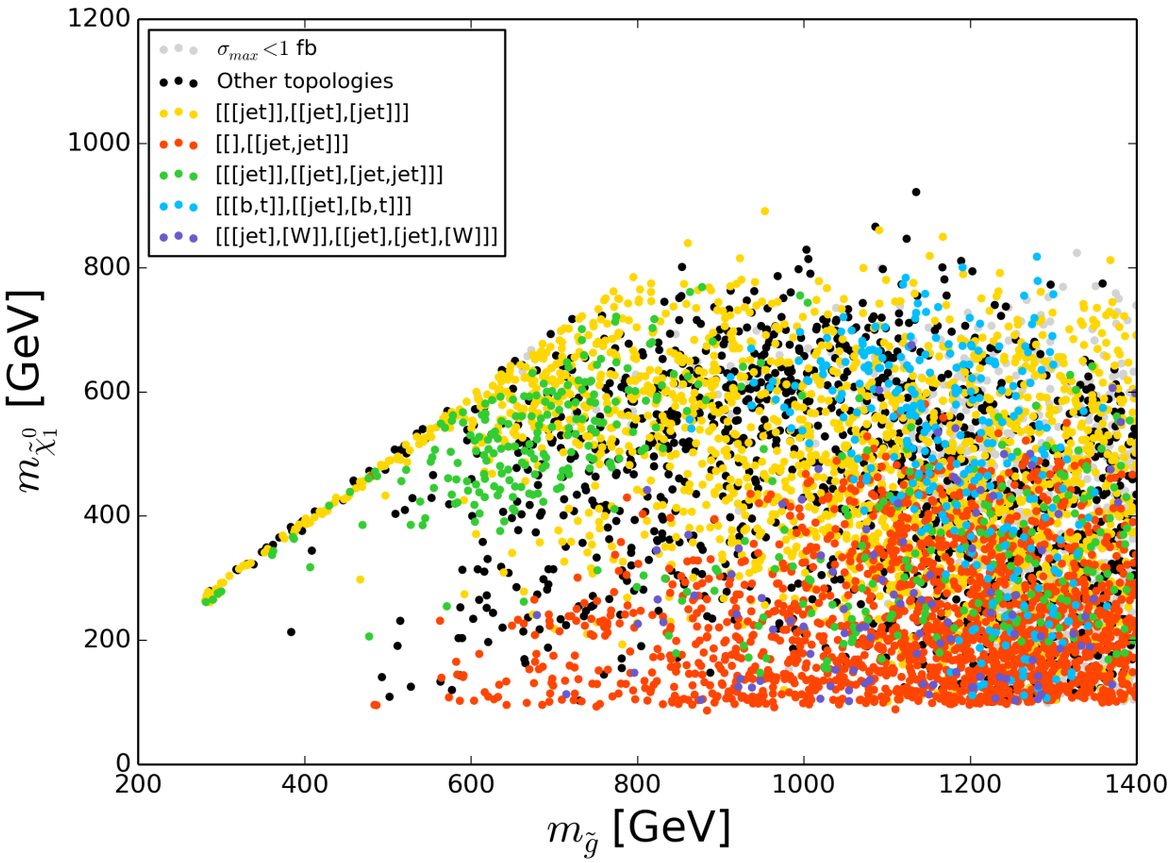
Long cascade decays: more than one intermediate odd particle in the cascade decay

Missing Topologies

Bino-like LSP

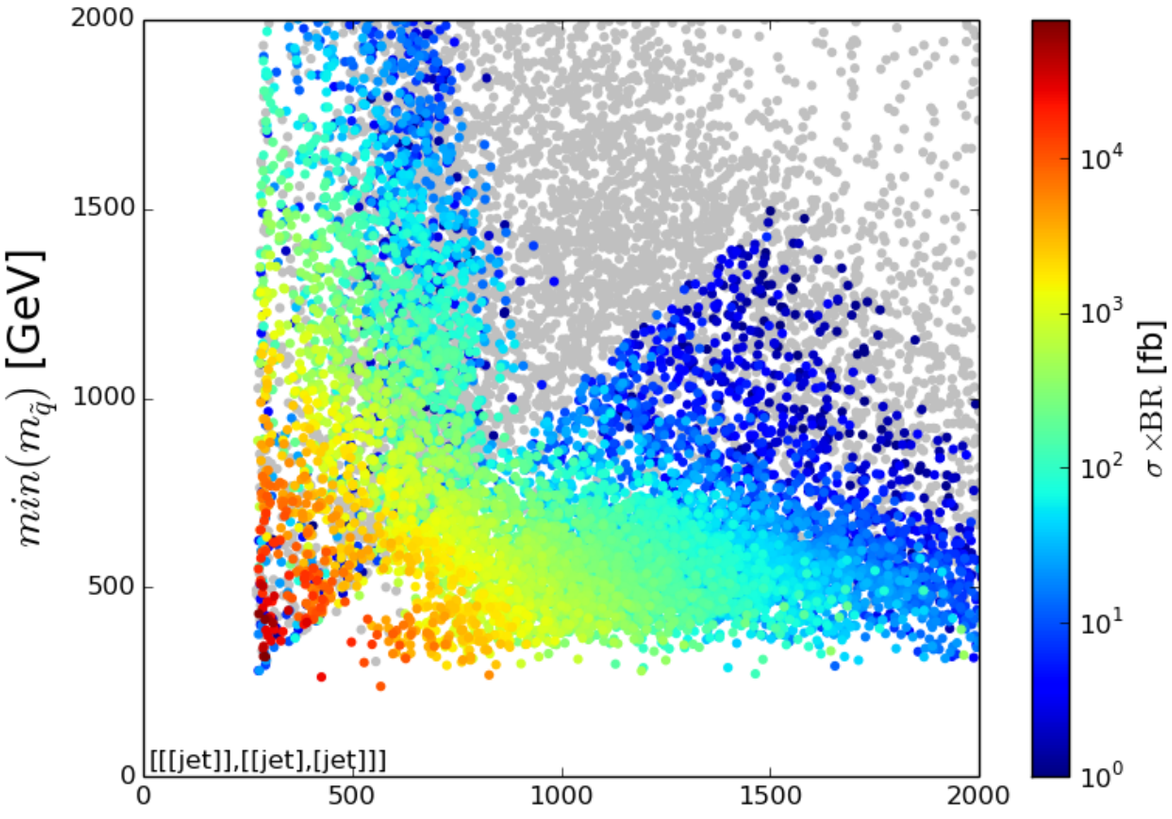


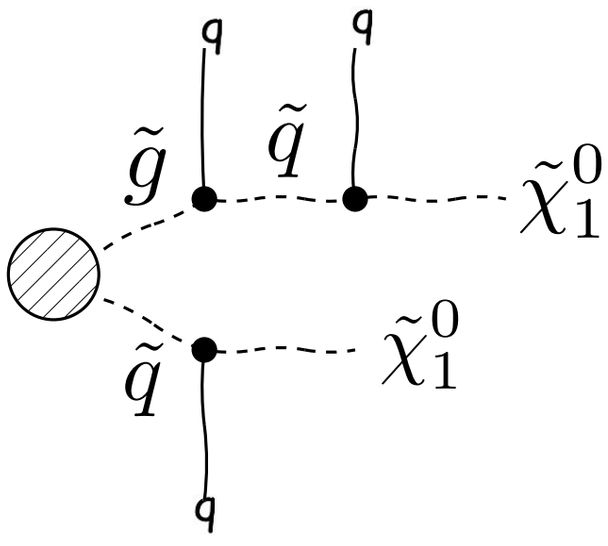
Higgsino-like LSP



Missing Topologies

Bino-like LSP





and

Higgsino-like LSP