SModelS

A tool for interpreting simplified model results from the LHC

http://smodels.hephy.at

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MC4BSM
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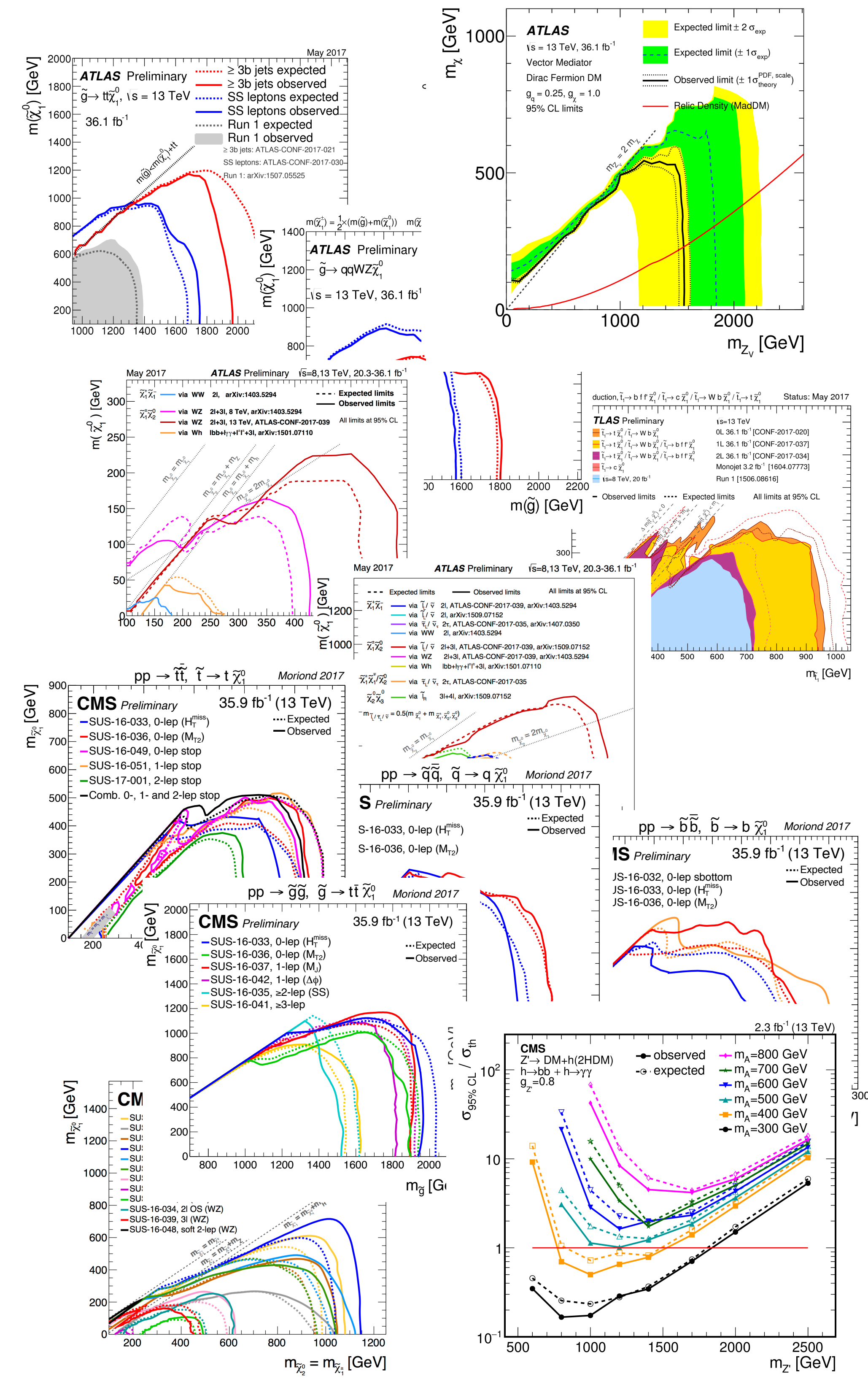
MC4BSM

Introduction

- It has become standard that ATLAS and CMS present the results of their BSM searches in terms of “**simplified model**” constraints.
- Simplified models (SMS) reduce full models with a plethora of particles and parameters to subsets with just 2-3 new states and a simple decay pattern.
- Concept used by SUSY, Exotics, DM searches
- Very convenient for optimising analyses that look for a particular final state, as well as for comparing the reach of different strategies.
- **Understanding how SMS results constrain a realistic model** with a multitude of parameters, relevant production channels and decay modes is, however, a **non-trivial task**.



Introduction

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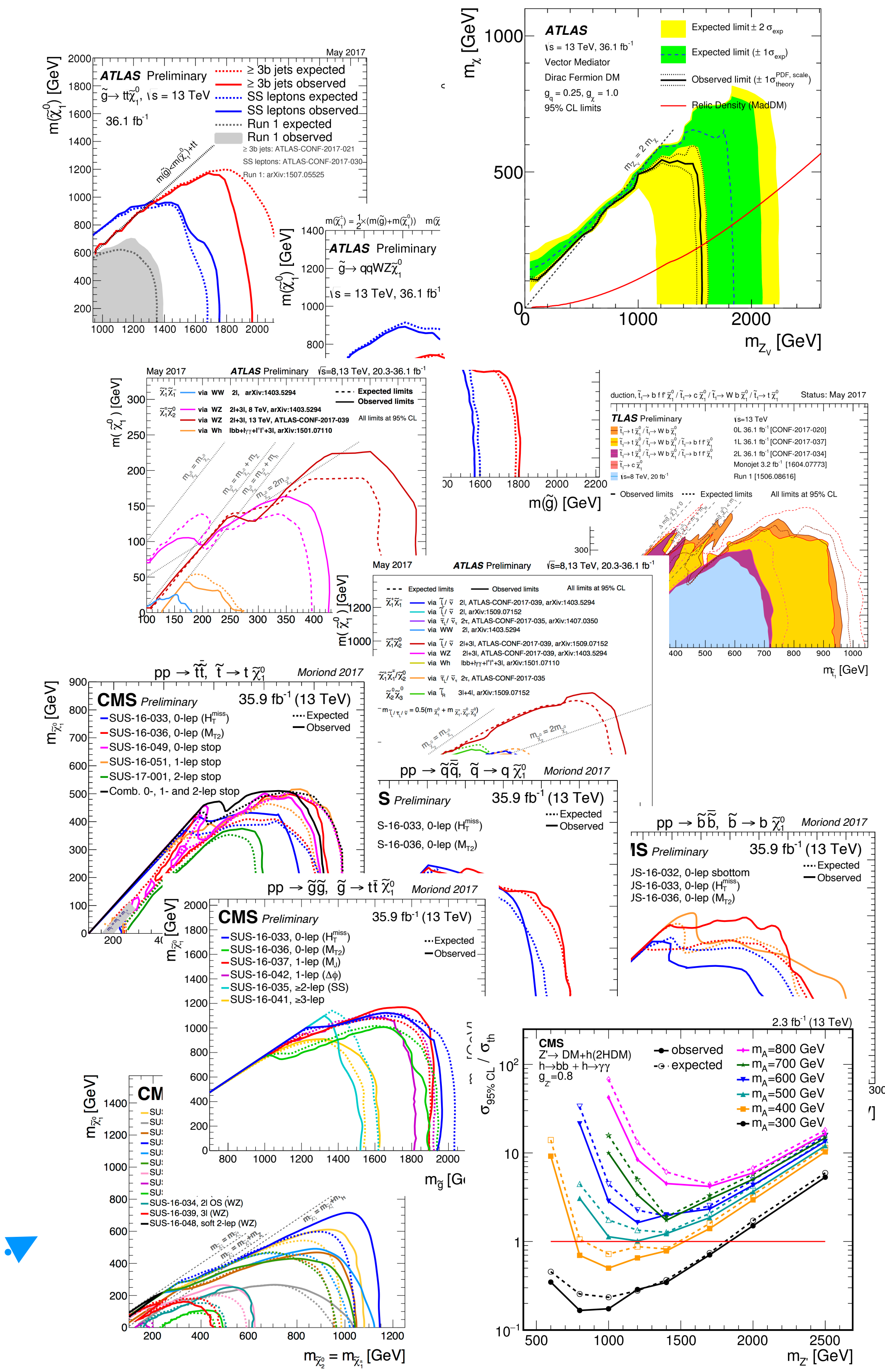
what do these mean for my model?

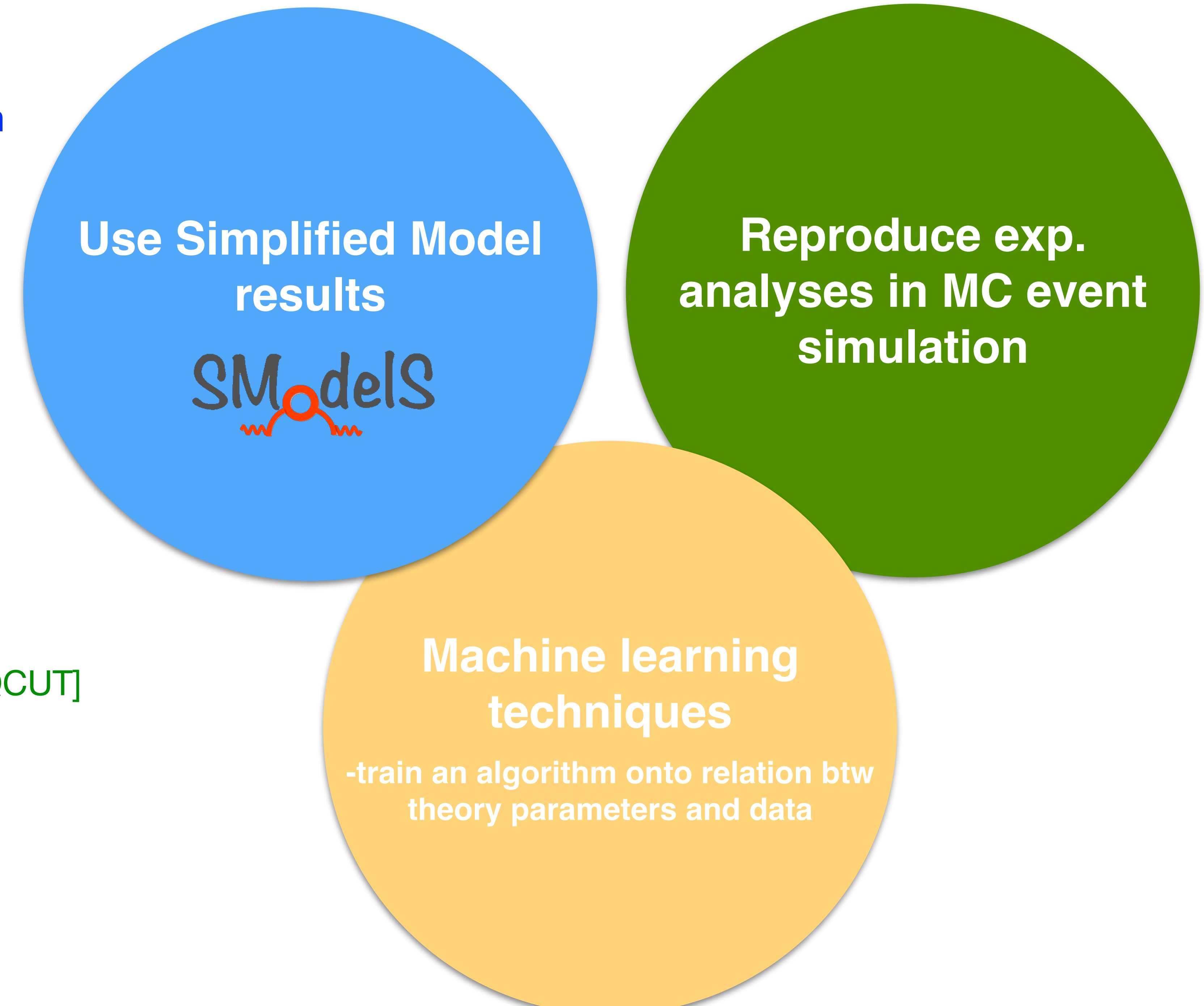


(Re)interpretation methods

Plus
- Fast, suitable for scans and model surveys
- Easy classification of uncovered signatures

Minus
- Only simple topologies
- Availability of re-usable results (useful format)
- Validity of SMS assumptions

[SModelS, Fastlim, XQCUT]



Plus
- More general, more precise
- Can test prospects of improving an analysis

Minus
- Need detailed information from experiment about each analysis
- Need emulation of detector effects
- Very CPU time consuming
- So far only cut&count analyses

[CheckMATE, MadAnalysis5, Rivet, Gambit]

Fast and precise, but so far model-specific

[SUSY-AI, SCINet]

Simplified model idea : origins

- *“MARMOSET: The Path from LHC Data to the New Standard Model via On-Shell Effective Theories”* Arkani-Hamed et al., hep-ph/0703088

- *“Simplified Models for a First Characterization of New Physics at the LHC”* Alval, Toro, Schuster, 0810.3921

> We propose a specific approach to characterizing the first robust evidence for new physics seen at the LHC. We present four “simplified models”, each with a small set of unambiguous parameters, based on the phenomenology typical of SUSY but stripped of much of the complexity possible in the full parameter space of supersymmetry [….] use these models as a basis for comparison of data with theoretical models such as the MSSM.
>
> The simplified models are expected to reproduce kinematics and multiplicities of observed particles remarkably well in a wide variety of SUSY-like new physics models — even when the spectrum of unstable particles in the full model is far more complex than the simplified model permits. The simplified model fits can then be used as a representation of the data, and can be compared to any full model by simulating both in a simple detector simulator. This last process of comparison can be done by phenomenologists outside the LHC collaborations.

- *“Simplified Models for LHC New Physics Searches”* Alves et al., 1105.2838

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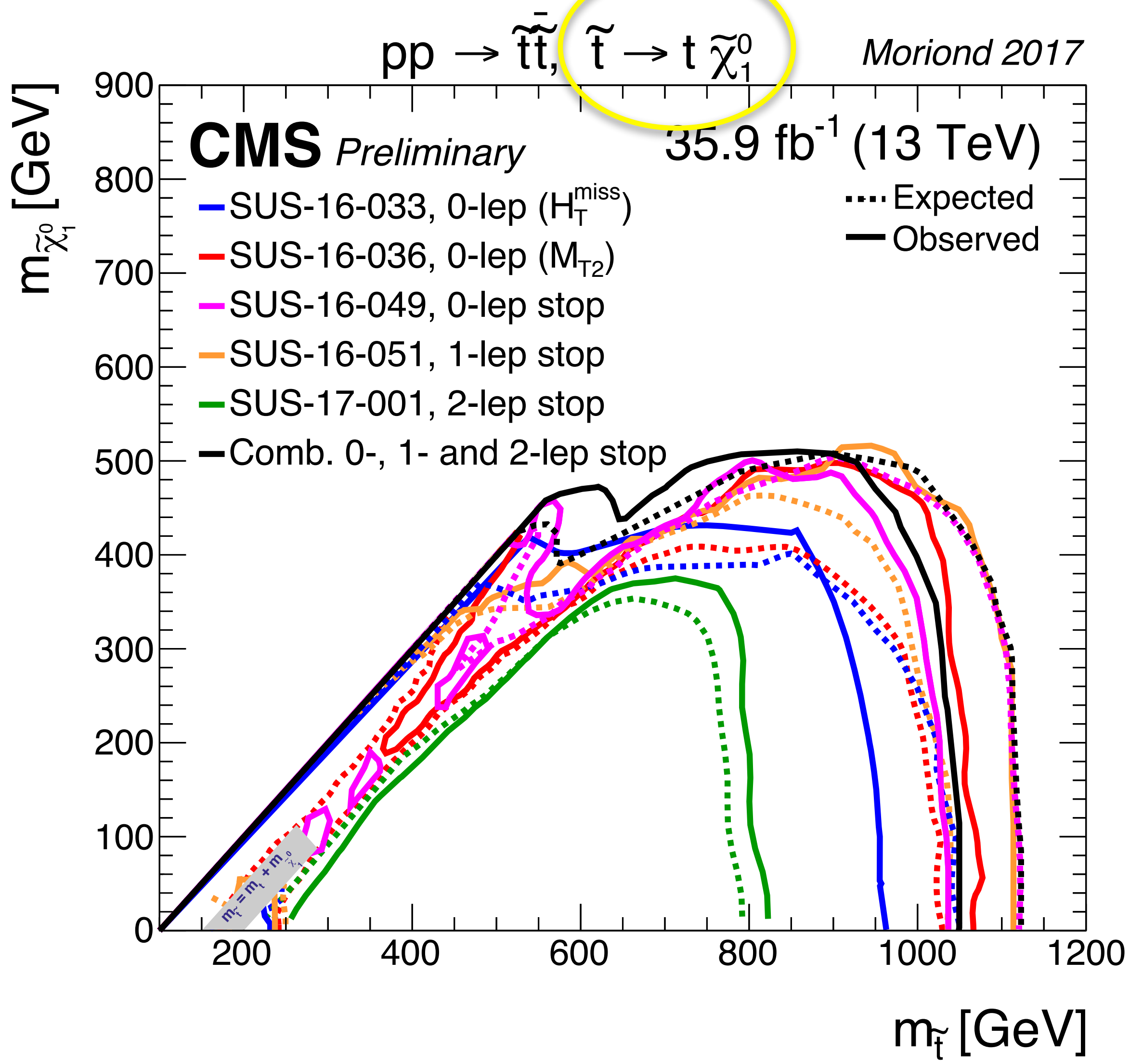
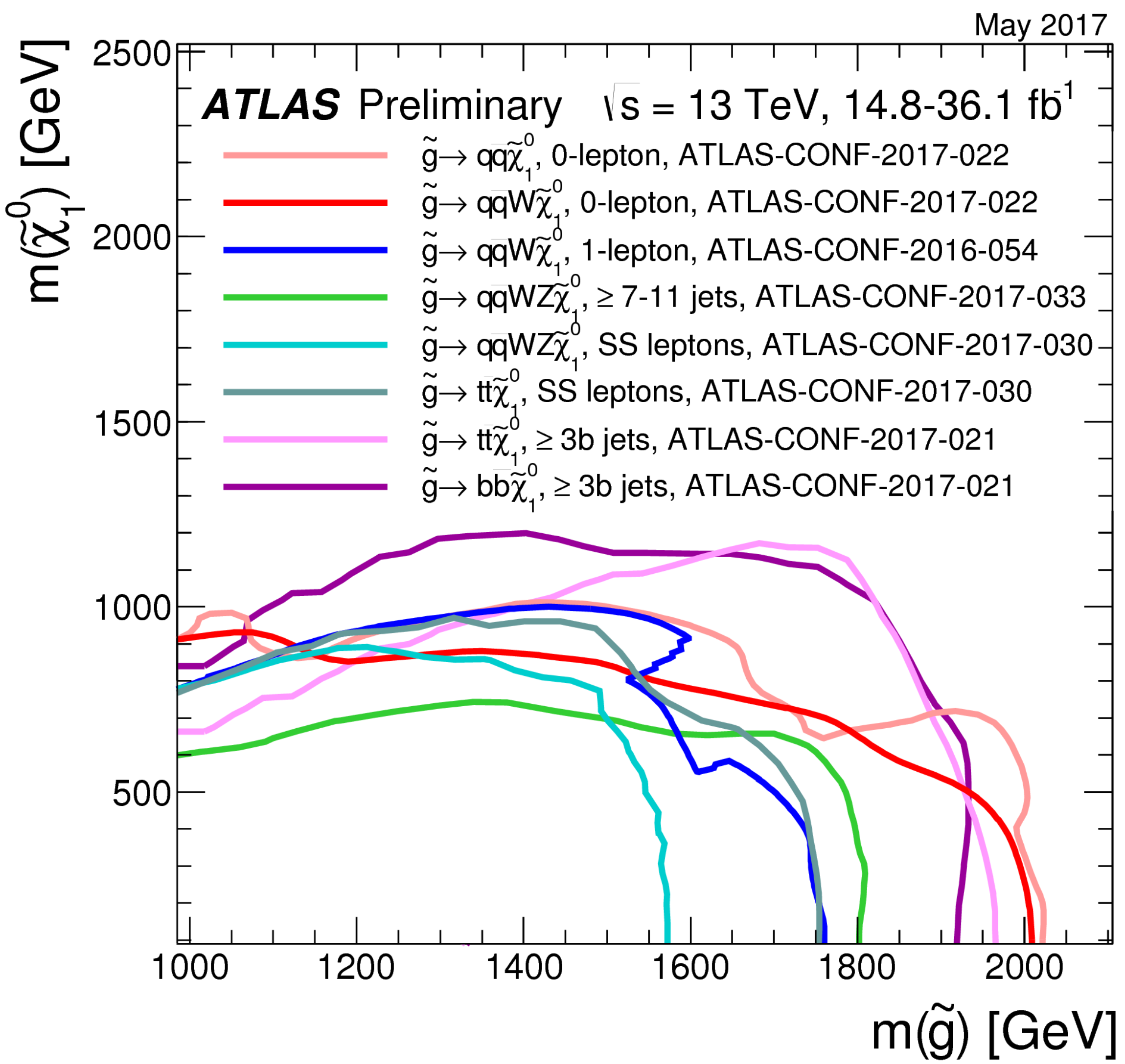
- *"Simplified Models for LHC New Physics Searches"* Alves et al., 1105.2838

> A model of new physics is defined by a TeV-scale effective Lagrangian describing its particle content and interactions. A simplified model is specifically designed to involve only a few new particles and interactions. Many simplified models are limits of more general new-physics scenarios, where all but a few particles are integrated out. Simplified models can equally well be described by a small number of parameters directly related to collider physics observables: particle masses (and their decay widths, which can sometimes be neglected), production cross-sections, and branching fractions.
>
> Simplified models are clearly not model-independent, but they do avoid some pitfalls of model-dependence. The sensitivity of any new-physics search to a few-parameter simplified model can be studied and presented as a function of these parameters and in particular over the full range of new particle masses. Though defined within a simplified model, these topology-based limits also apply to more general models giving rise to the same topologies.

fixed stop decay mode, BR=100%

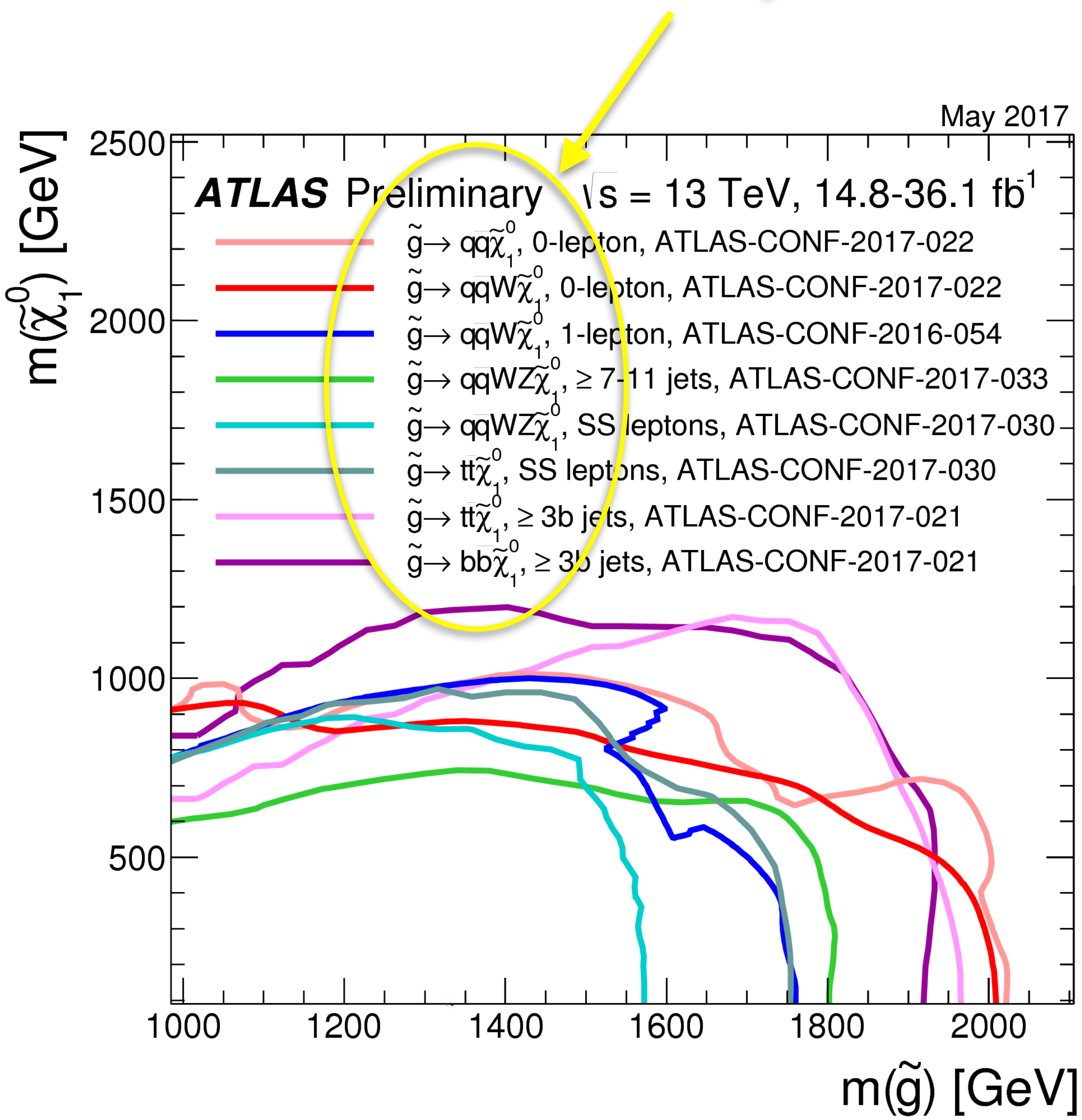


Interesting to compare reach of different analyses,
but what if the stop has (a mix of) different decay modes?

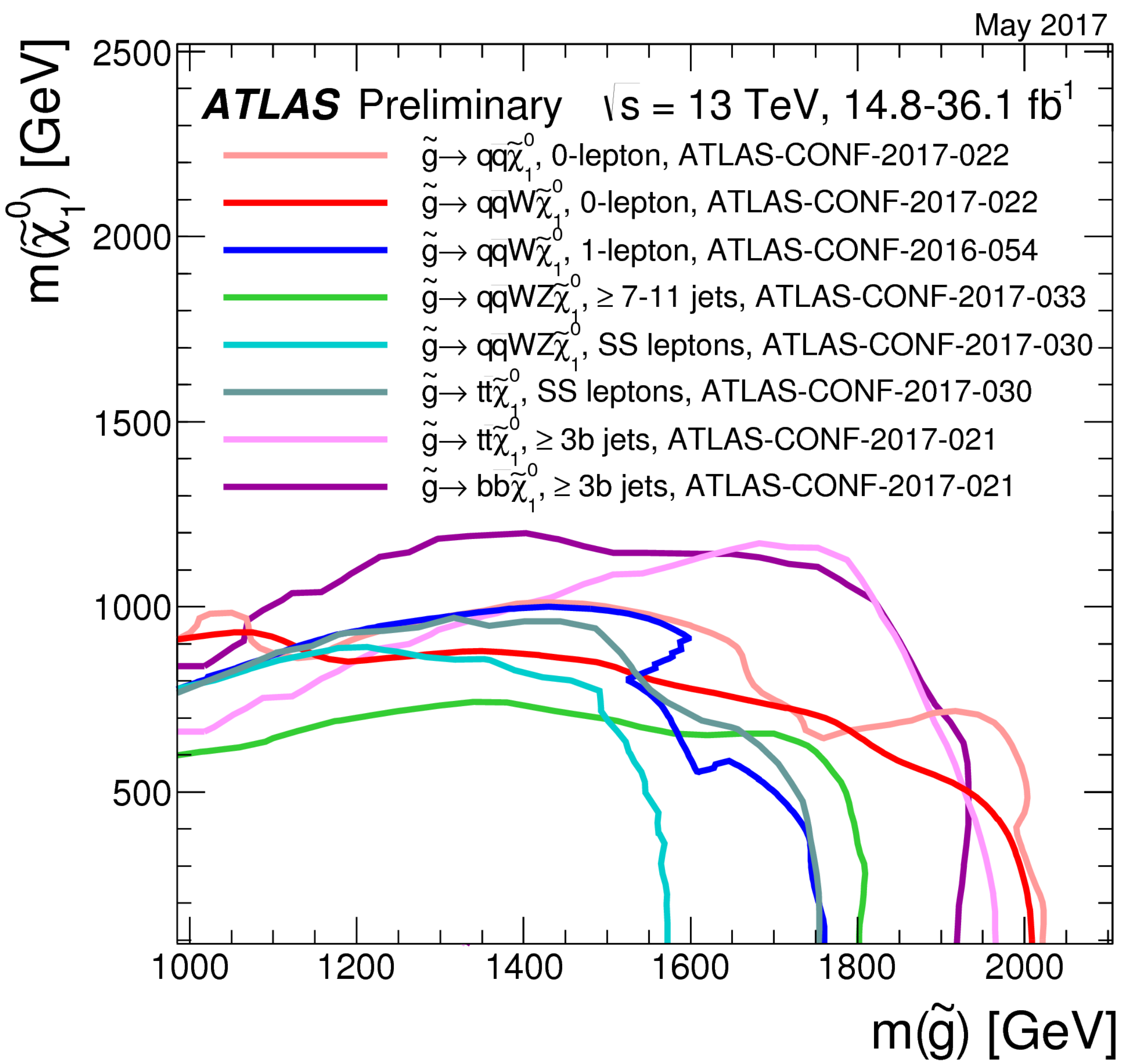


Limits vary depending on decay mode (assumed to be 100%).

gluino-pair production, both gluinos assumed to decay the same way, BR=100%



Limits vary depending on decay mode (assumed to be 100%).



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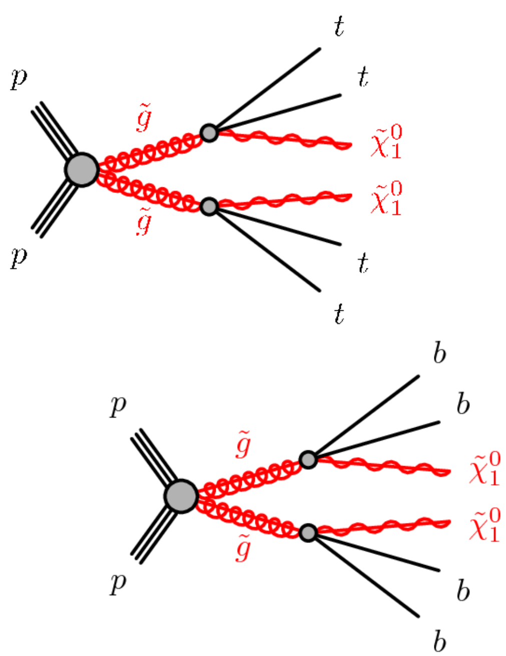

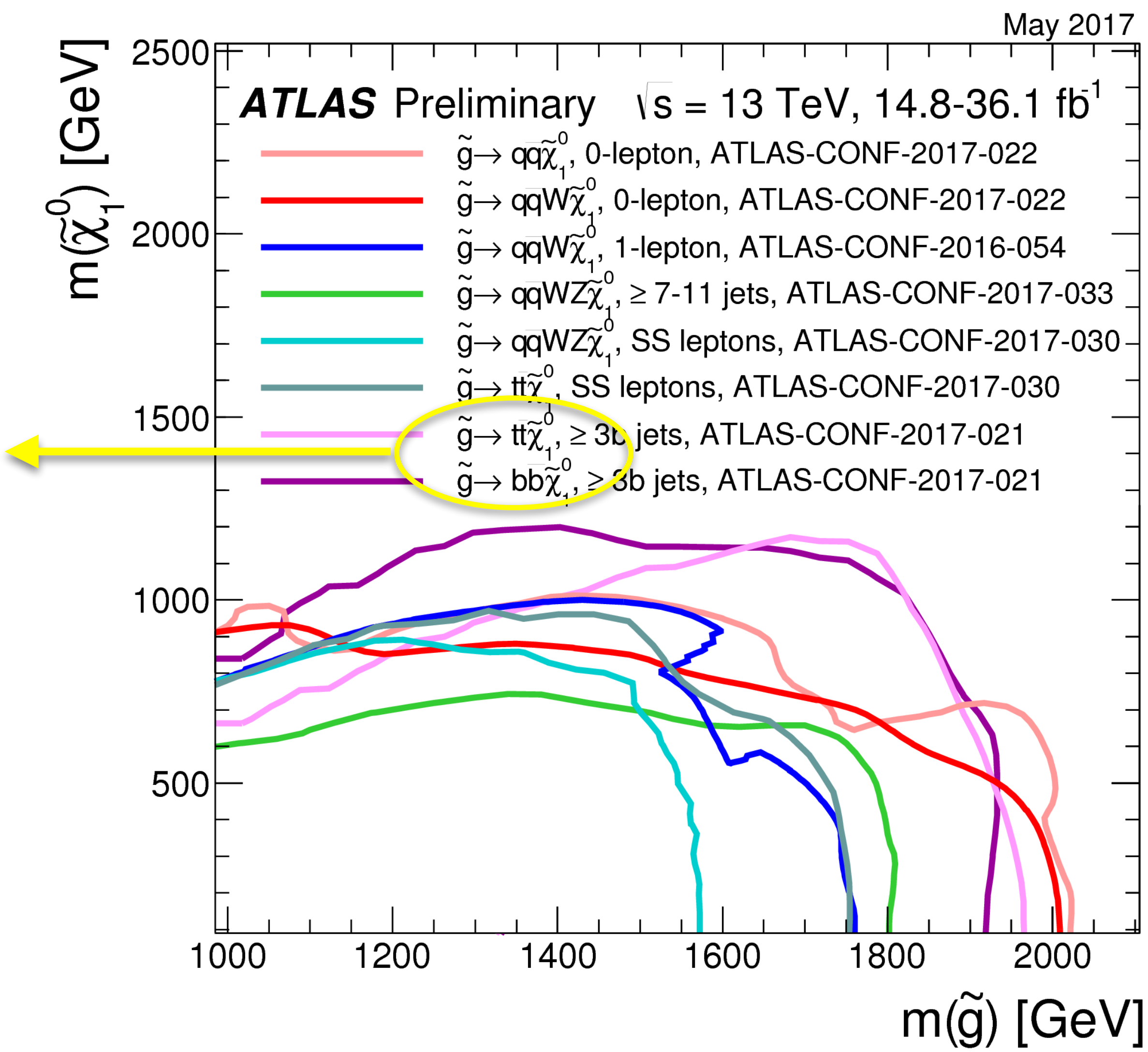

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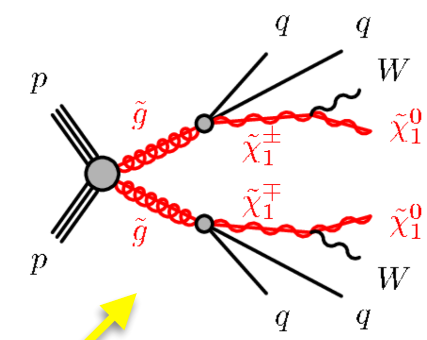
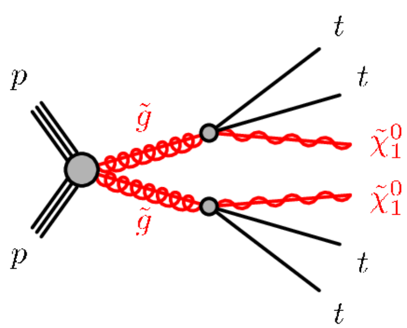
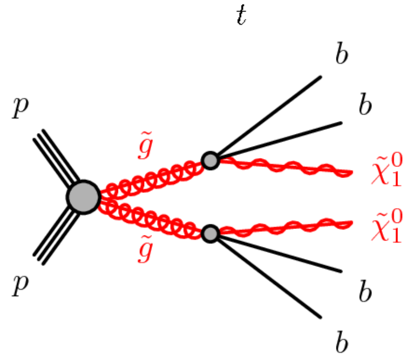
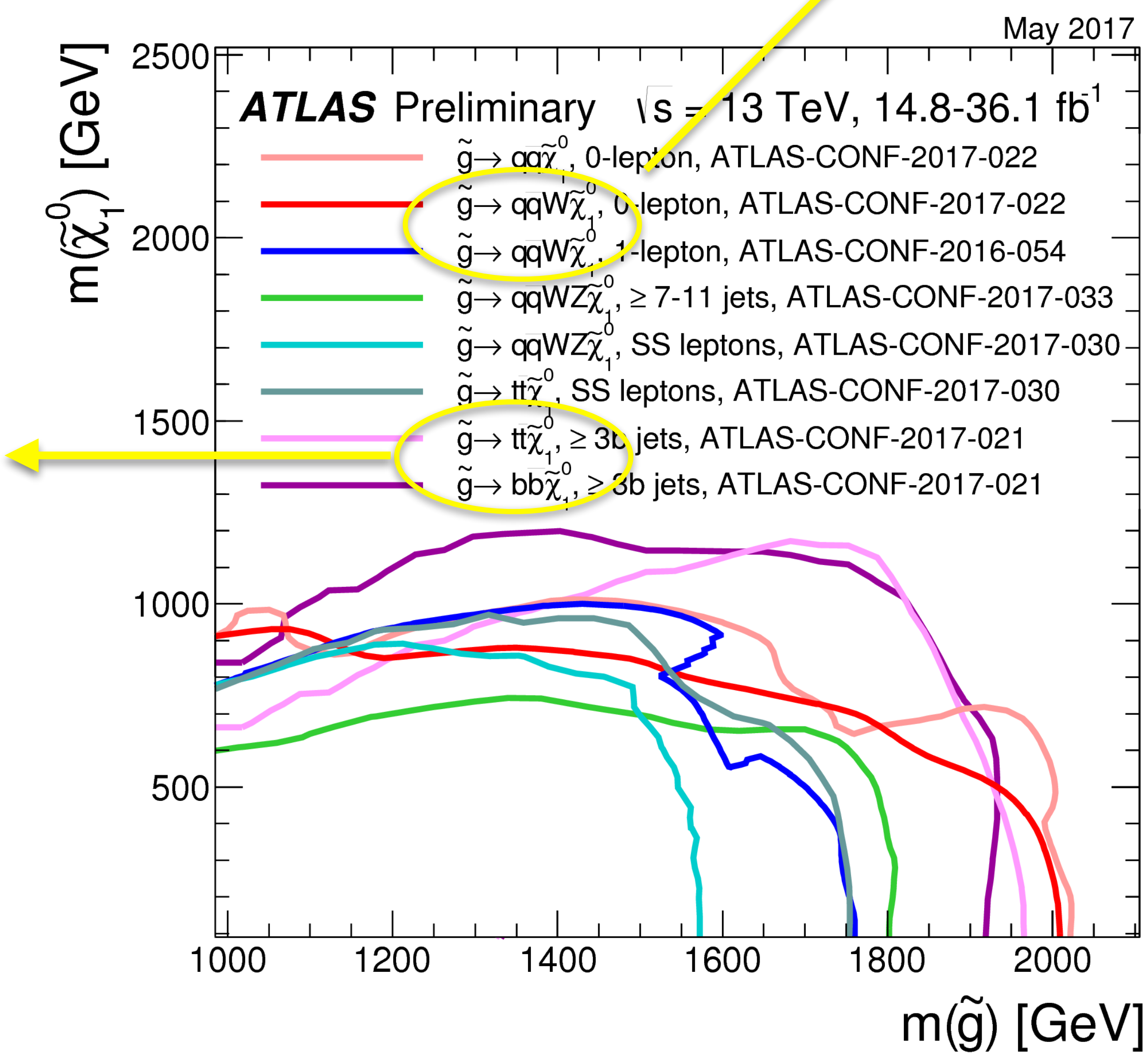


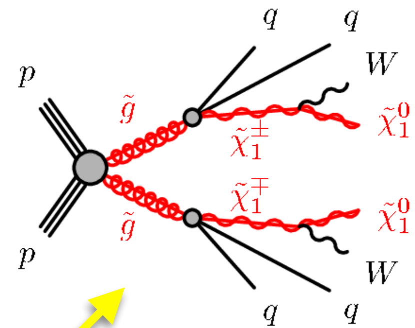
chargino1 mass fixed as
m_ch1 = 0.5(m_gl + m_nt1)



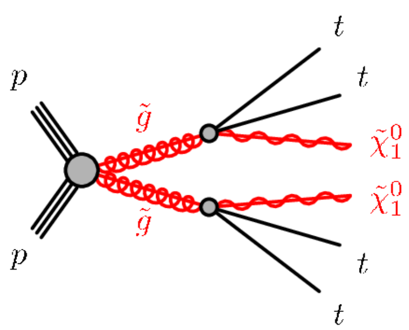


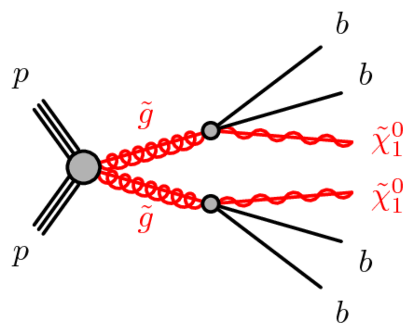


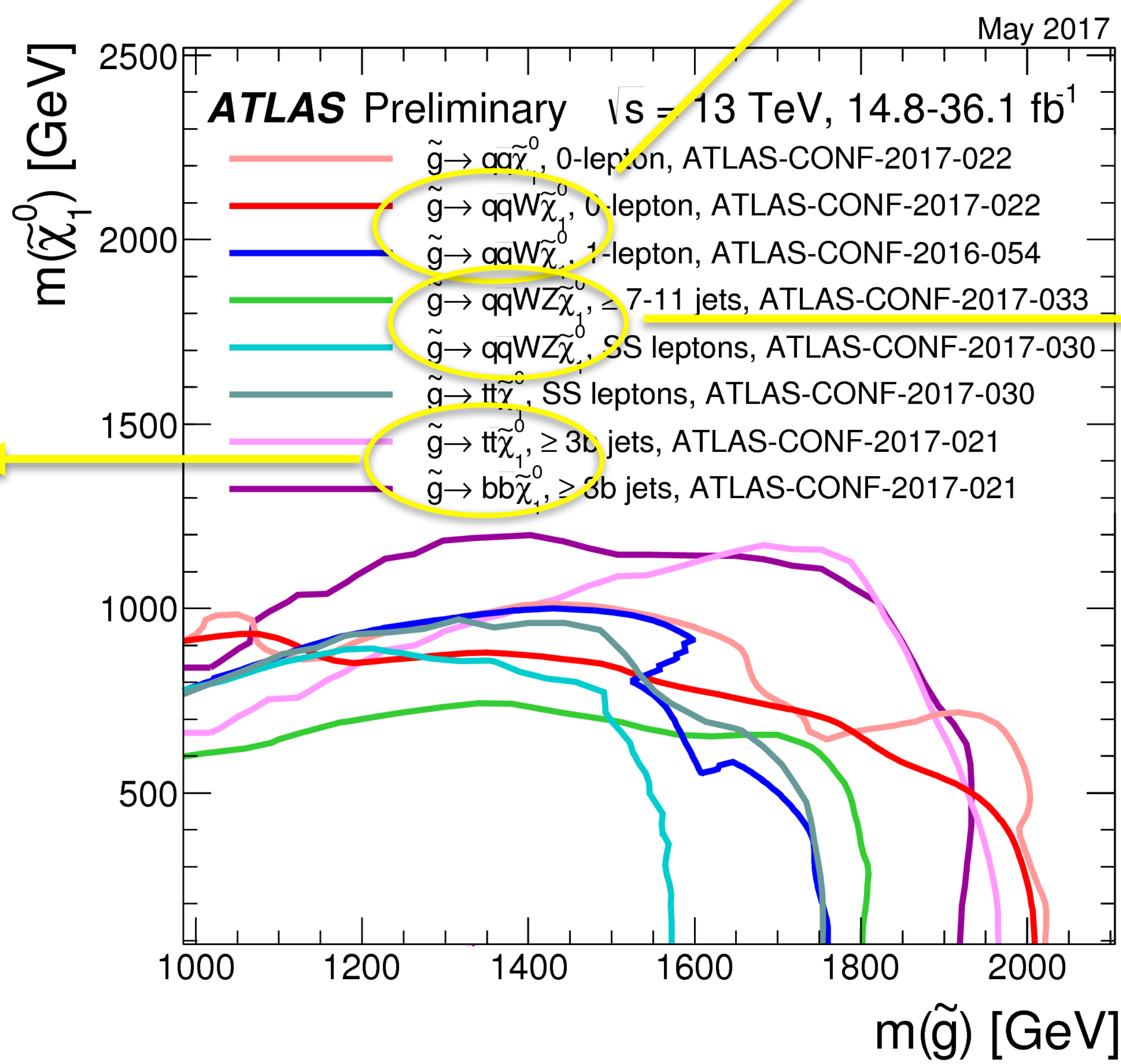
Limits vary depending on decay mode (assumed to be 100%).

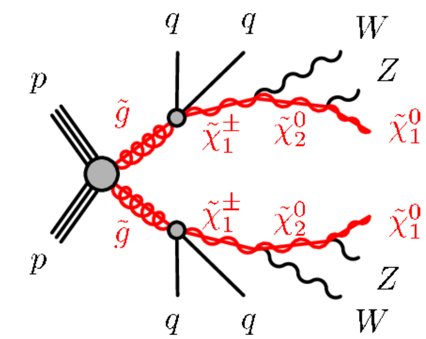


chargino1 mass fixed as
m_ch1 = 0.5(m_gl + m_nt1)





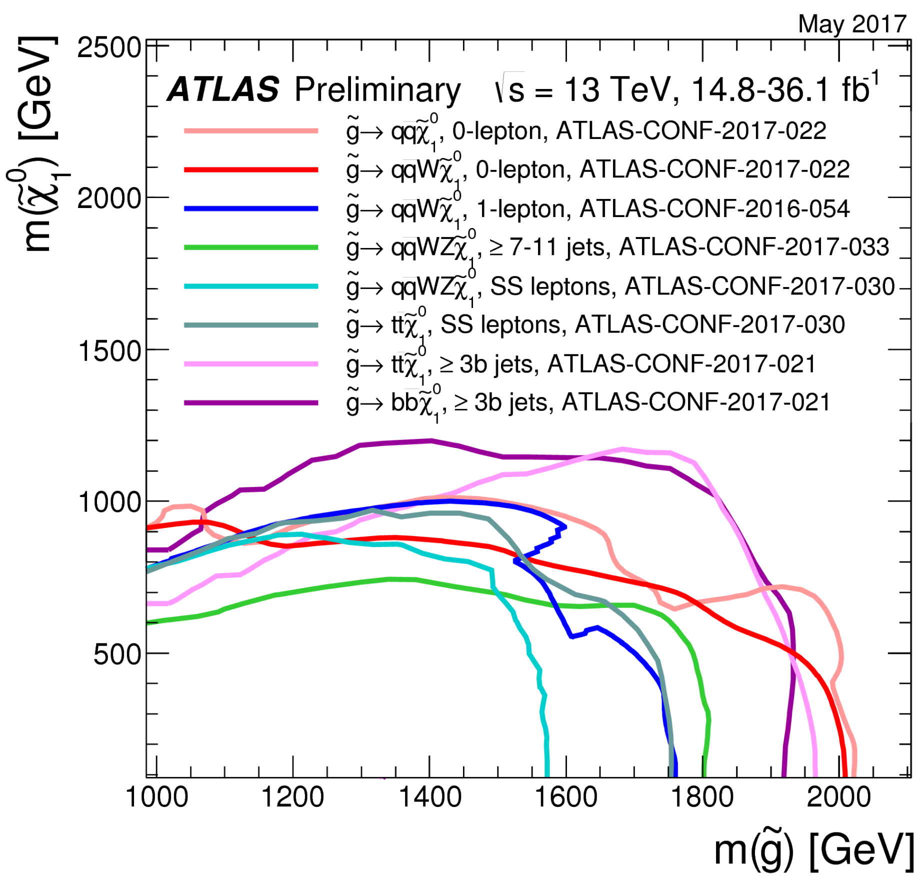




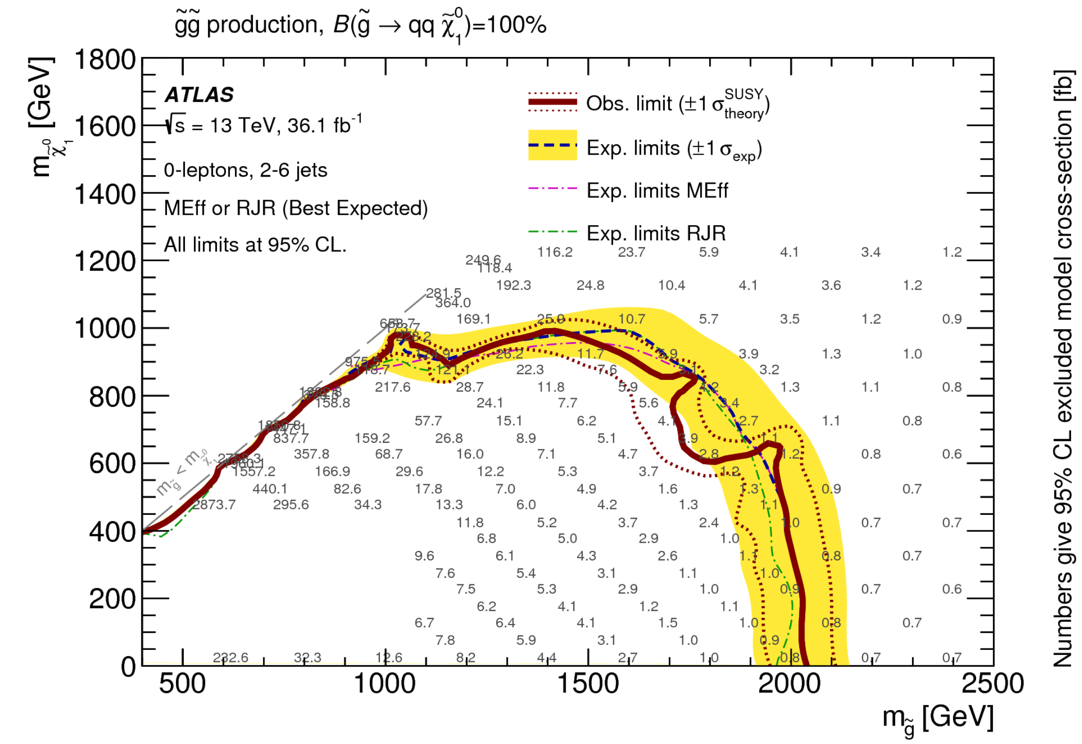
ch1 **and** nt2 masses fixed:
m_ch1 = 0.5(m_gl + m_nt1),
m_n2 = 0.5(m_ch1 + m_nt1)

Limits vary depending on decay mode (assumed to be 100%).

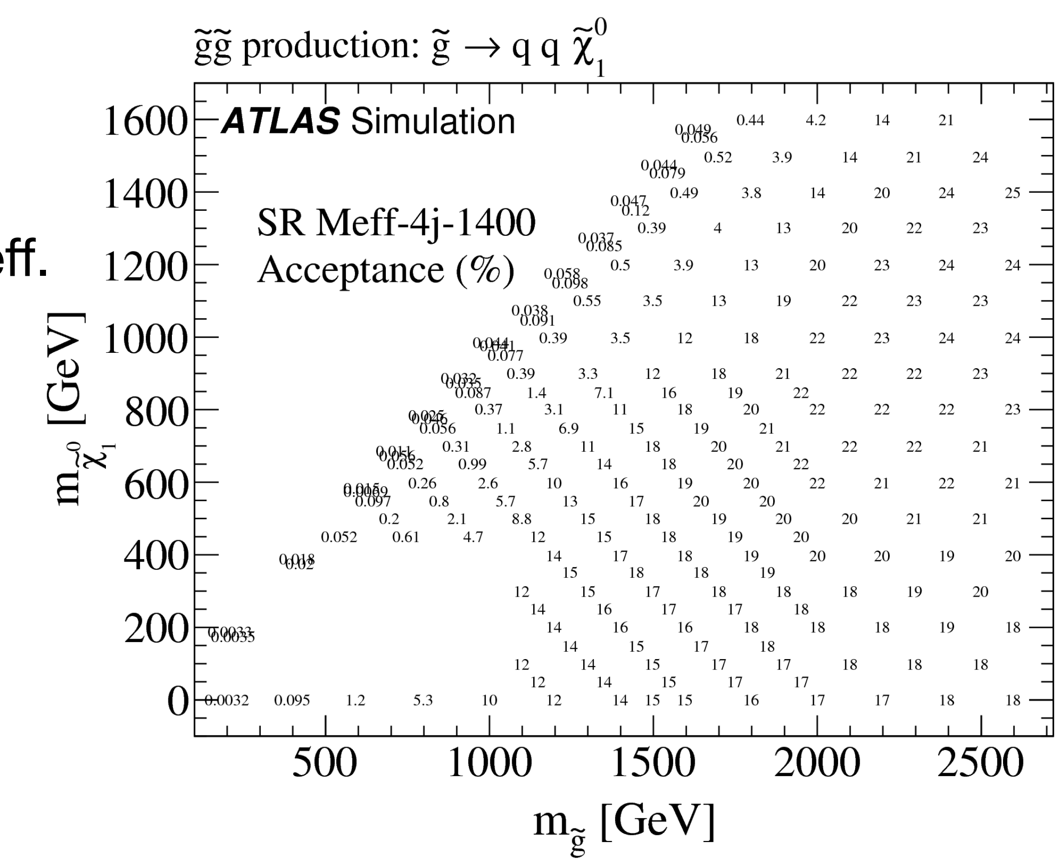
Necessary information



cross section limits



acceptance x eff. values



SModelS

SModelS

arXiv:1312.4175 (v1.0)
arXiv:1701.06586 (v1.1)

Federico Ambrogi, SK, Suchita Kulkarni, Ursula Laa, Andre Lessa, Veronika Magerl, Jory Sonneveld, Michael Traub, **Wolfgang Waltenberger**

http://smodels.hephy.at

in a nutshell:

SModelS employs a general procedure to decompose the collider signatures of BSM models presenting a Z_2 symmetry into SMS topologies, which are then confronted with the relevant experimental constraints.

Also identifies the most important 'missing topologies' for which no experimental result is available.

Large database of experimental results: cross section upper limit maps and efficiency maps.

Any BSM model with a Z2 symmetry
17 ATLAS and 16 CMS SUSY analyses from Run 1 *)
20 CMS SUSY analyses for 36/fb from Run 2 **)

***) plus Fastlim-1.0 efficiency maps**
****) also 4 ATLAS analyses for 3.2/fb**

SModelS

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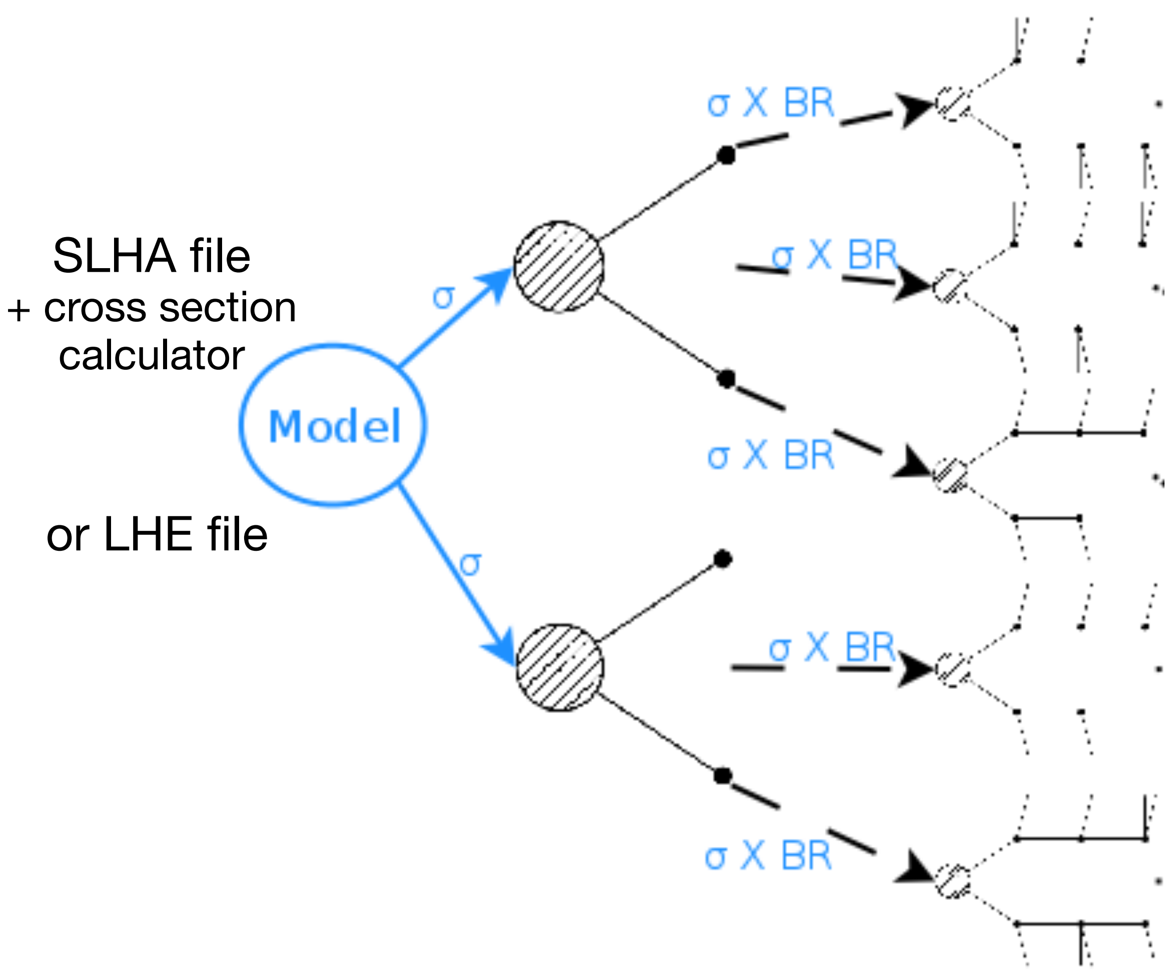
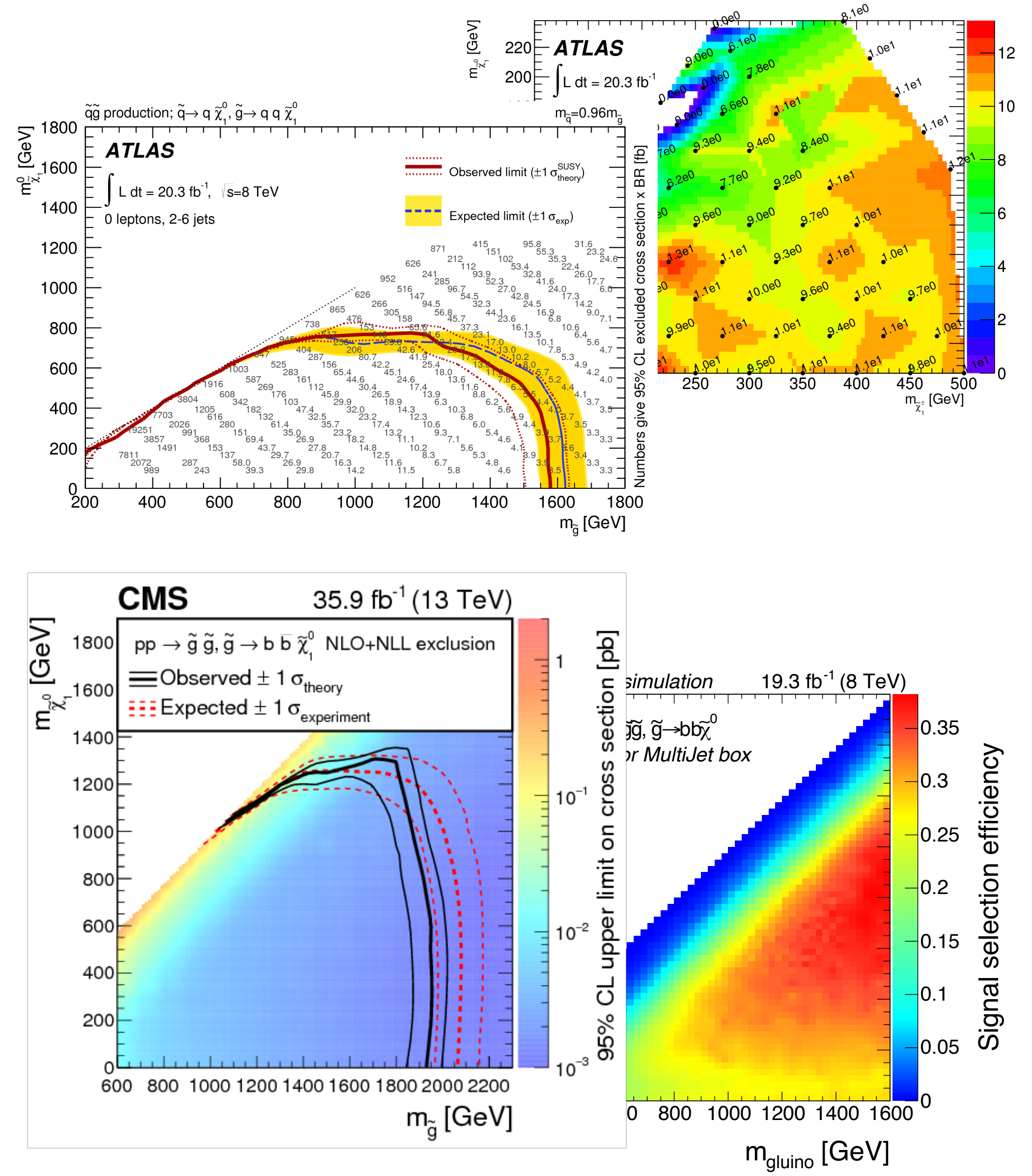




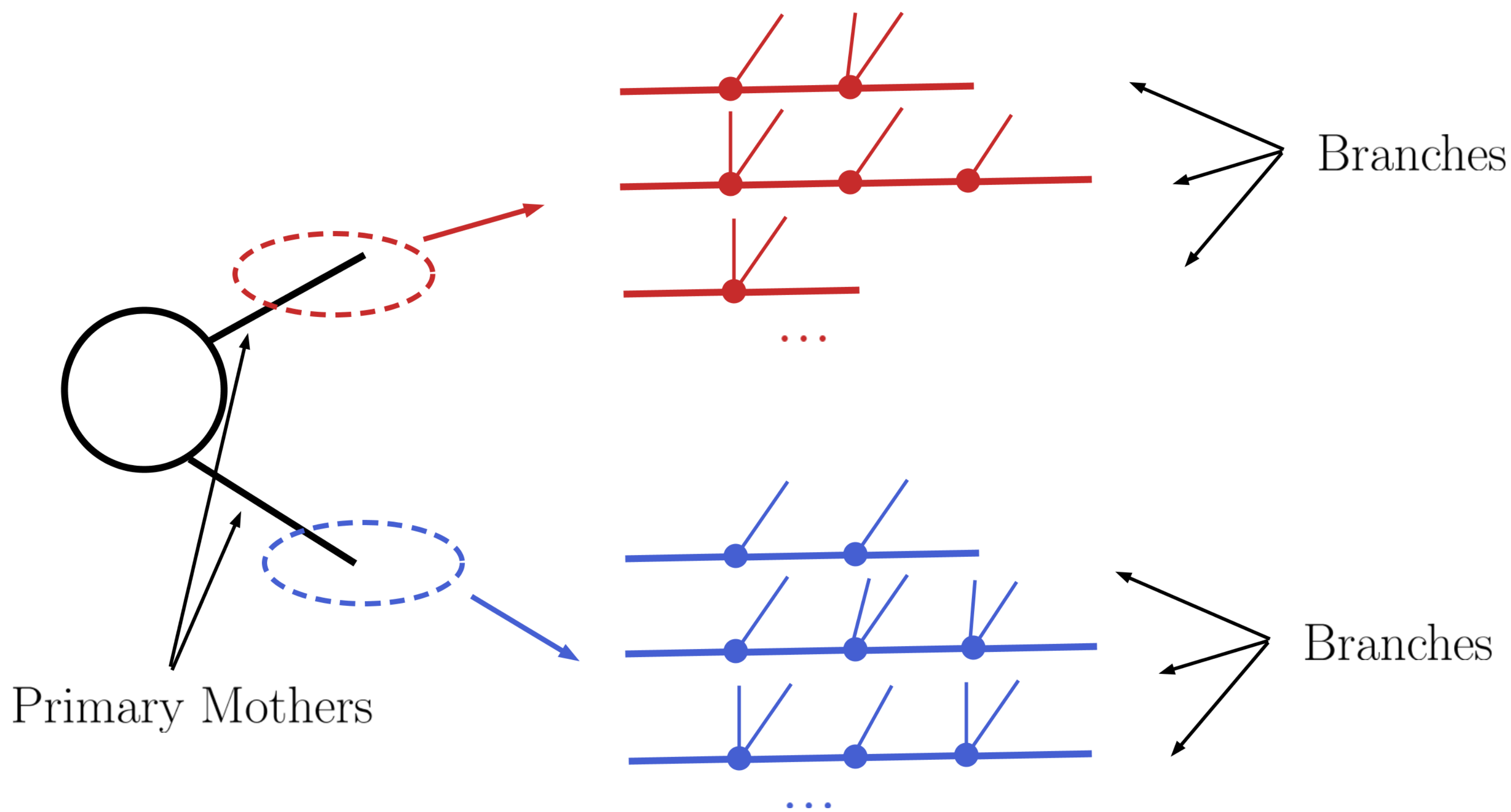
Decompose signatures of full model into SMS elements

Compare with experimental constraints in SModelS database

http://smodels.hephy.at

Decomposition procedure

SModelS takes an SLHA spectrum (with decay table and cross section information) or particle level MC events as input and determines from this all relevant **SMS topologies** ("elements") and their weights (**σ×BR**).



Working assumption: **Z_2 symmetry**; i.e. new particles are produced in pairs (2-branch structure) and cascade-decay promptly to the lightest one, which is stable and leads to missing energy.

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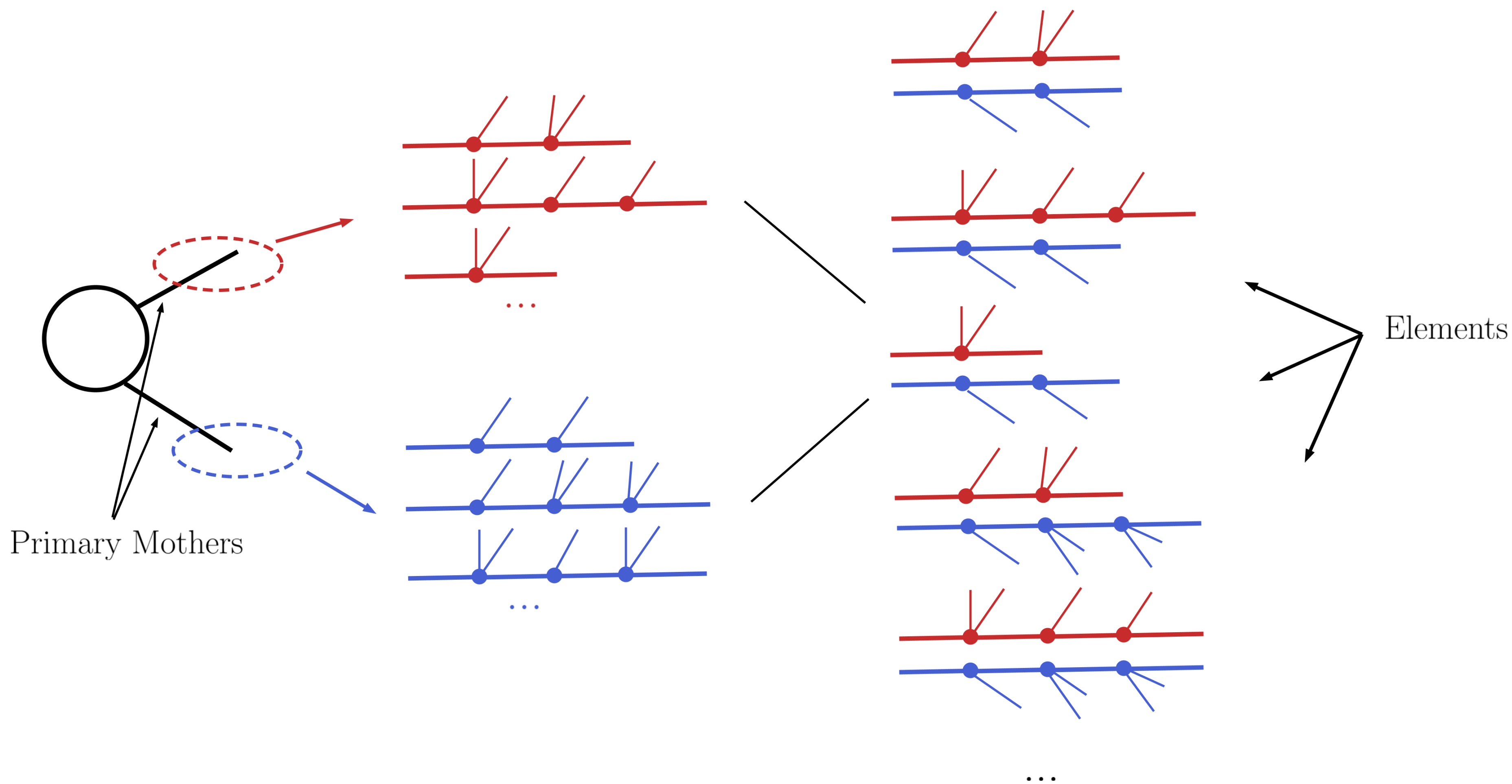

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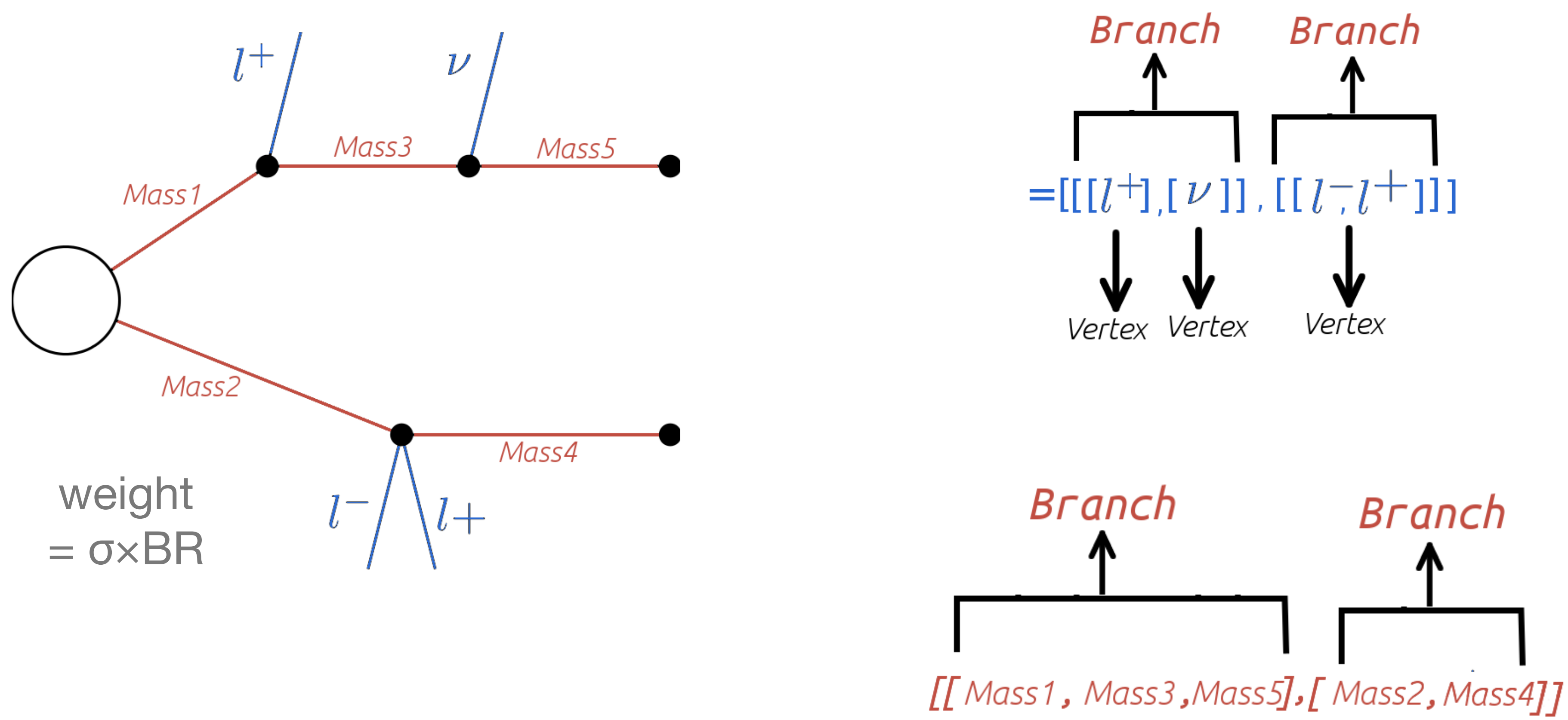
Topology description

An SMS topology is then entirely defined by the **number of vertices in each branch** together with **SM particles originating from each vertex** (final states) and a **mass array** containing the ordered Z_2-odd masses



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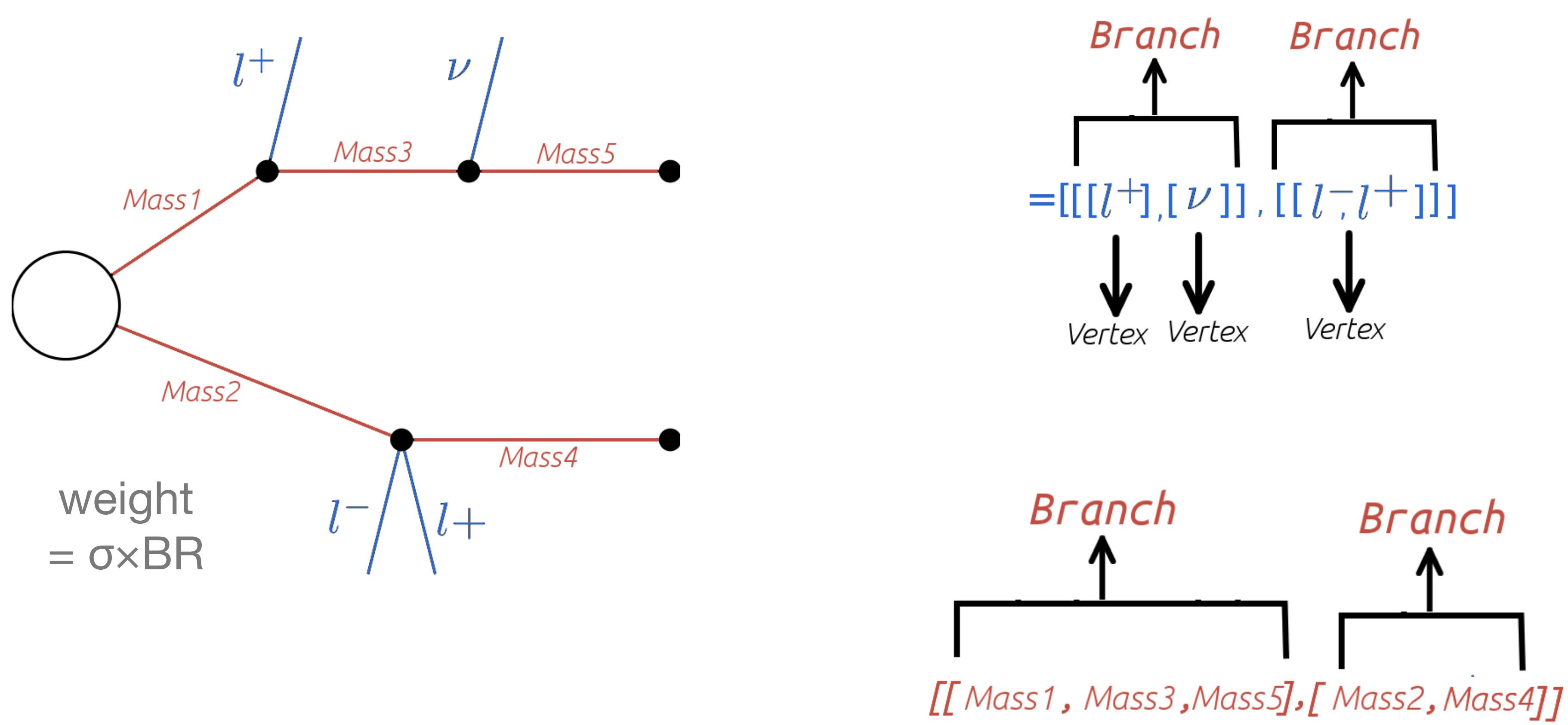


Mass compression: decays of almost degenerate BSM particles into each other are treated as invisible.
Invisible compression: several inv. final-state particles at the end of the decay chain are combined into one.

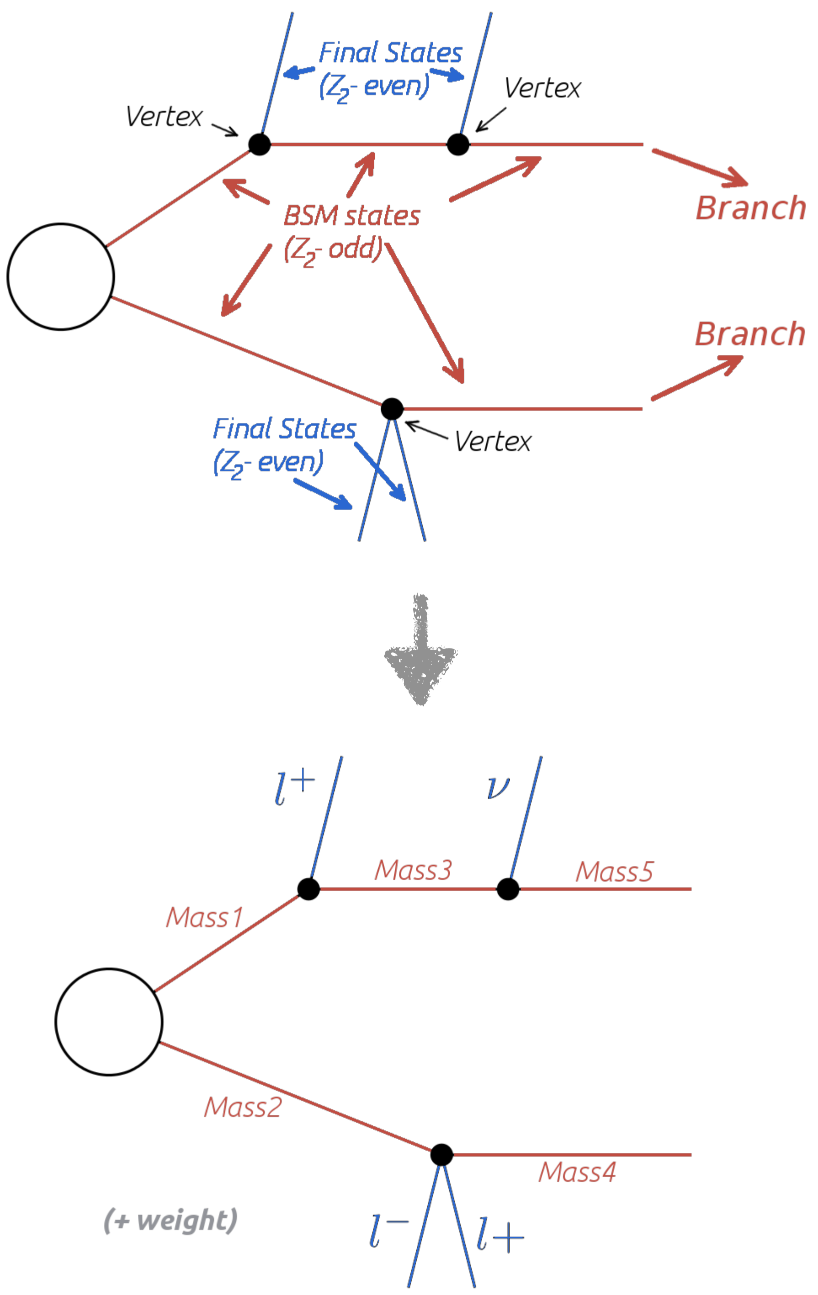
Assumptions

- BSM particles are described only by their masses, production cross sections and branching ratios.
- Underlying assumption is that differences in the event kinematics from, e.g., different production mechanisms or the spins of the BSM particles, do not significantly affect the signal selection efficiencies.

Arkani-Hamed et al., hep-ph/0703088
Alves et al., arXiv:1105.2838

- Procedure applicable to any model with a Z_2 symmetry
- Tested for and successfully applied to minimal and non-minimal SUSY (NMSSM, UMSSM, sneutrino LSP), as well as extra quark, UED models …

SK et al, 1312.4175; Belanger et al, 1308.3735;
Barducci et al., 1510.00246; Arina et al., 1503.02960;
Edelhauser et al., 1501.03942; Belanger et al, 1506.00665;
SK et al,1607.02050 and 1707.09036.

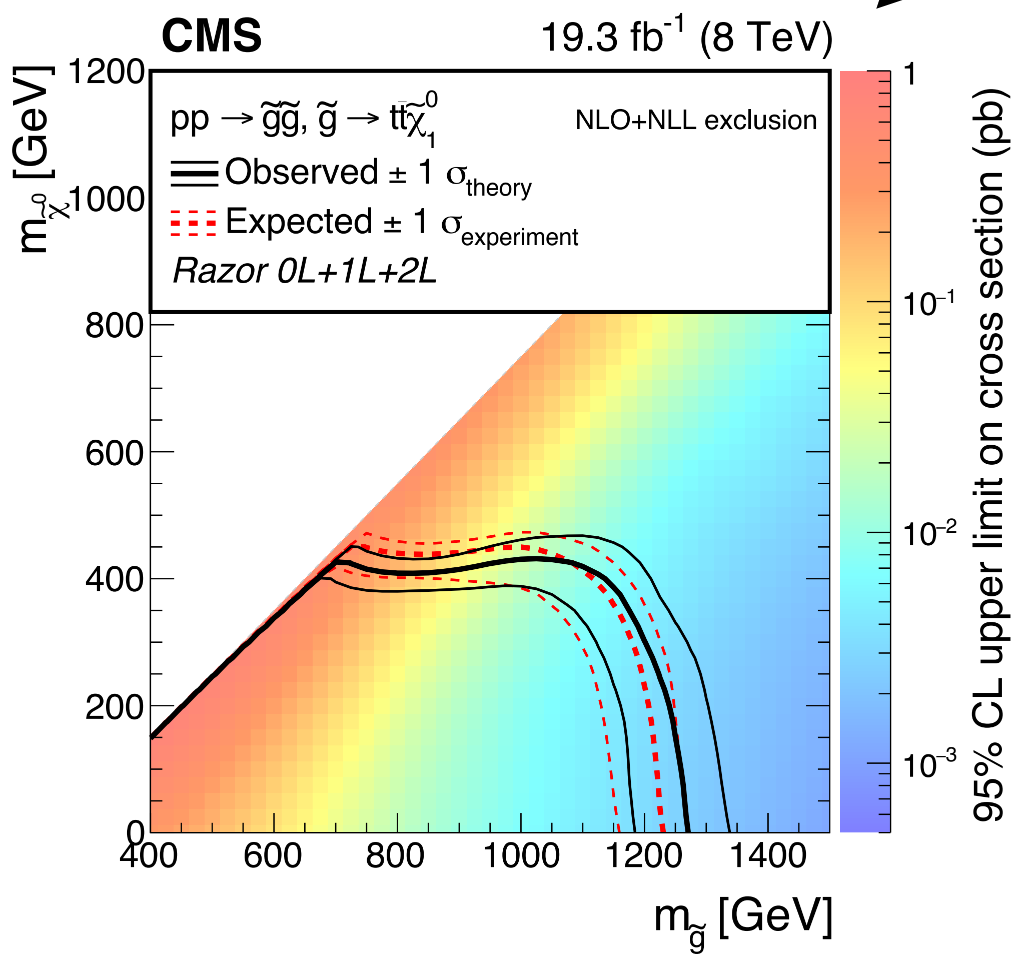


Information used to classify topologies

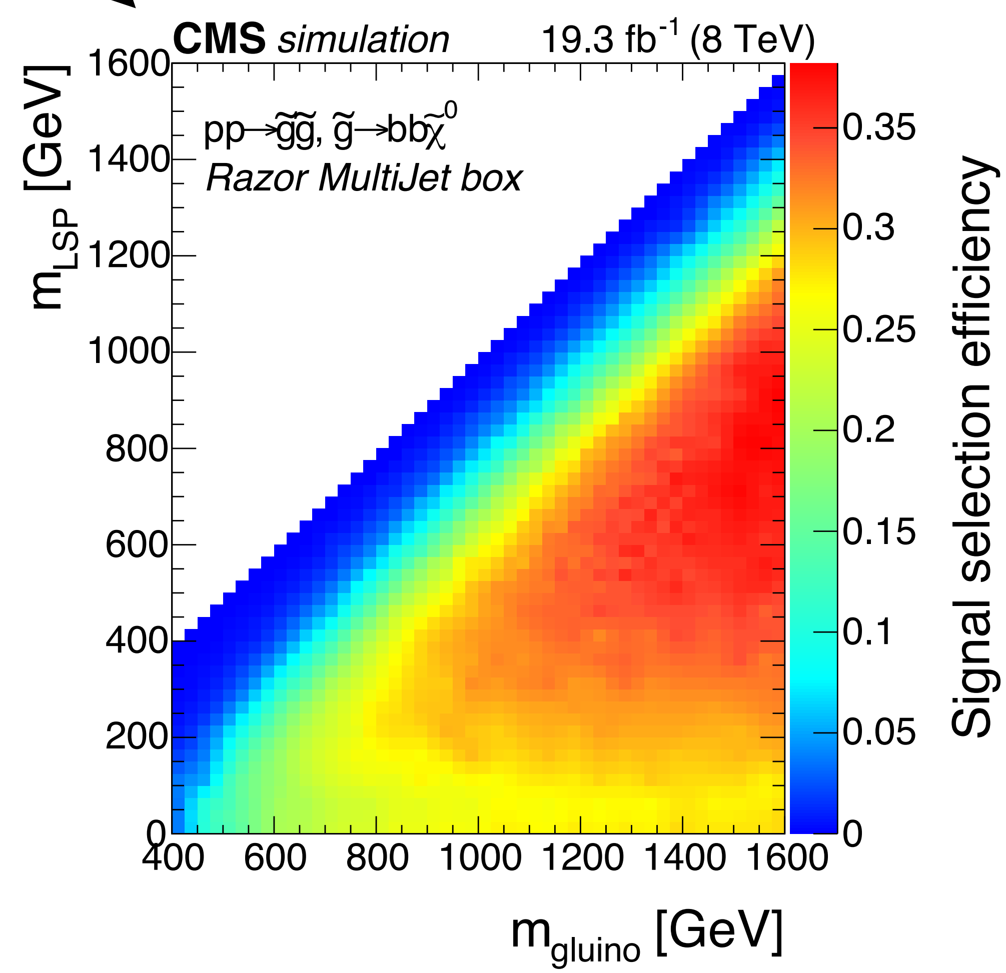
Experimental constraints

Great if these are available in numerical form!

Upper Limit (UL) maps



Efficiency maps (EM)



Upper Limit maps give the 95% CL upper limit on cross section x branching ratio for a specific SMS.

The UL values can be based on the best SR (for each point in parameter space), a combination of SRs or more involved limits from other methods.

Efficiency maps correspond to a grid of simulated acceptance x efficiency values for a specific signal region for a specific simplified model.

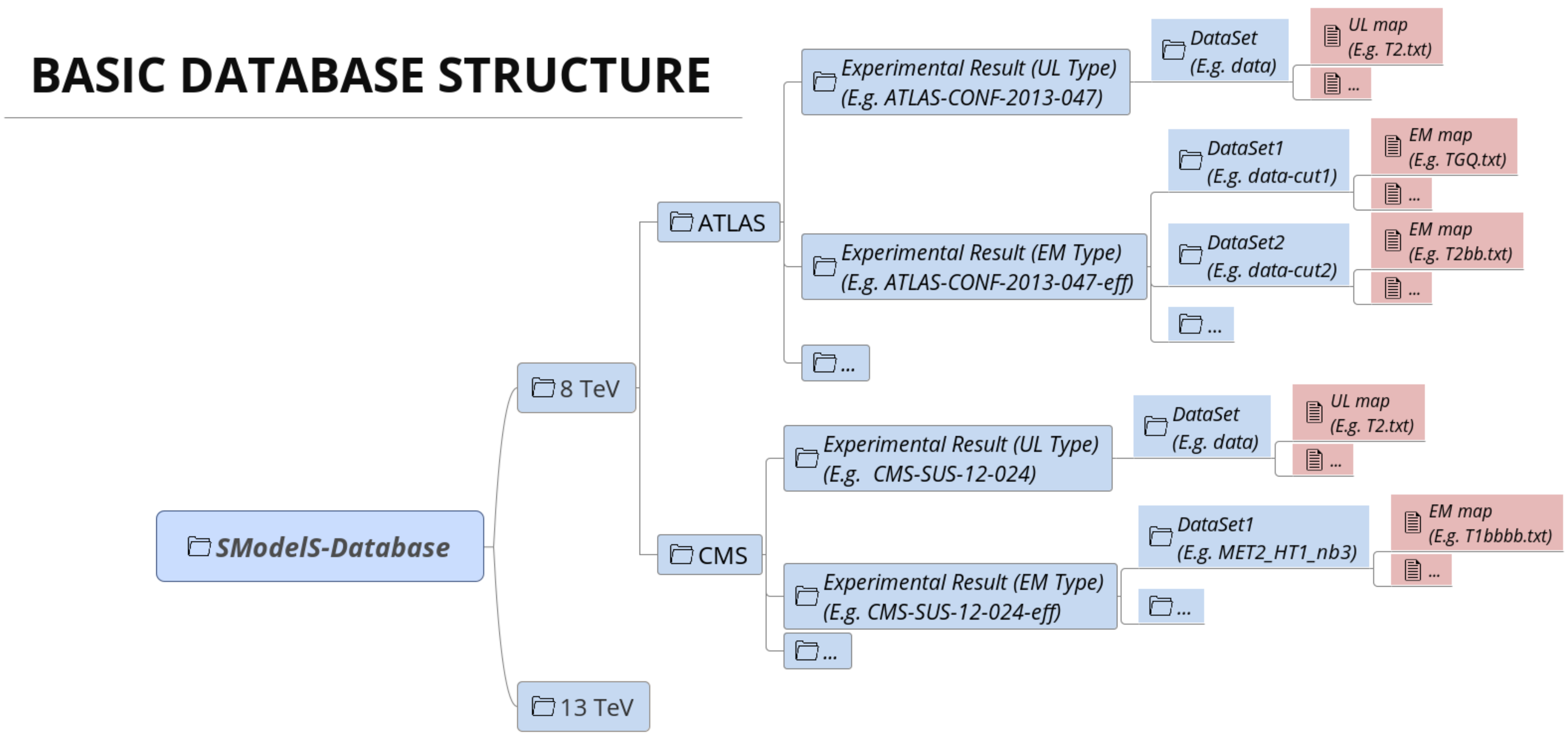
Together with the observed and expected #events in each SR, this allows to compute a likelihood.

Limit on σ×BR

Limit on Σε×σ×BR

NB: the 95%CL exclusion curve is not used, cannot be re-interpreted

Database of experimental results



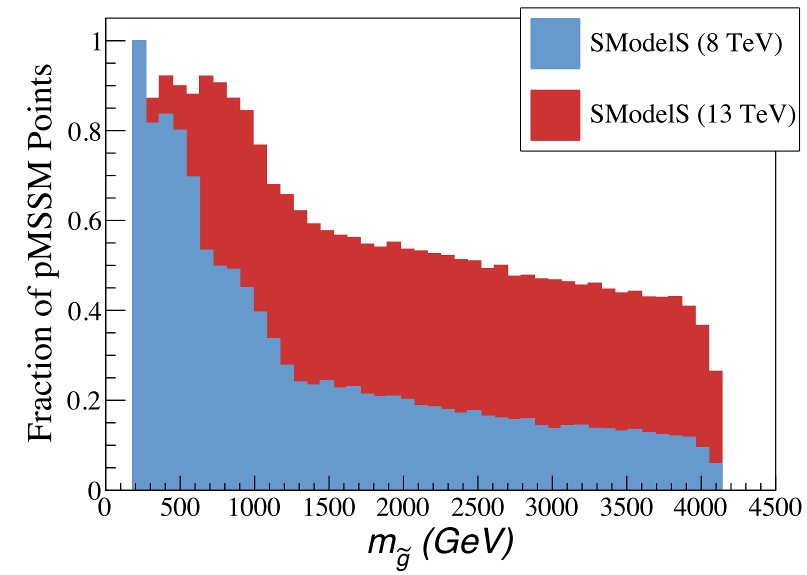
http://smodels.hephy.at/wiki/ListOfAnalysesv112

CMS 36/fb results from Run 2 in SModelS

J. Dutta, SK, A. Lessa, W. Waltenberger
arXiv:1803.02204

Summer Conferences 2017 (36 fb^{-1})

channel	PAS/arXiv	webpage	conference	
0L + top tag	SUS-16-050	link	LHCP	✓
1L compressed stop	SUS-16-052	link	EPS	✓
Hadronic staus	SUS-17-003	link	EPS	✓
Ewkino combination	SUS-17-004	link	EPS	✓
1L RPV	SUS-16-040	link	LP	✗



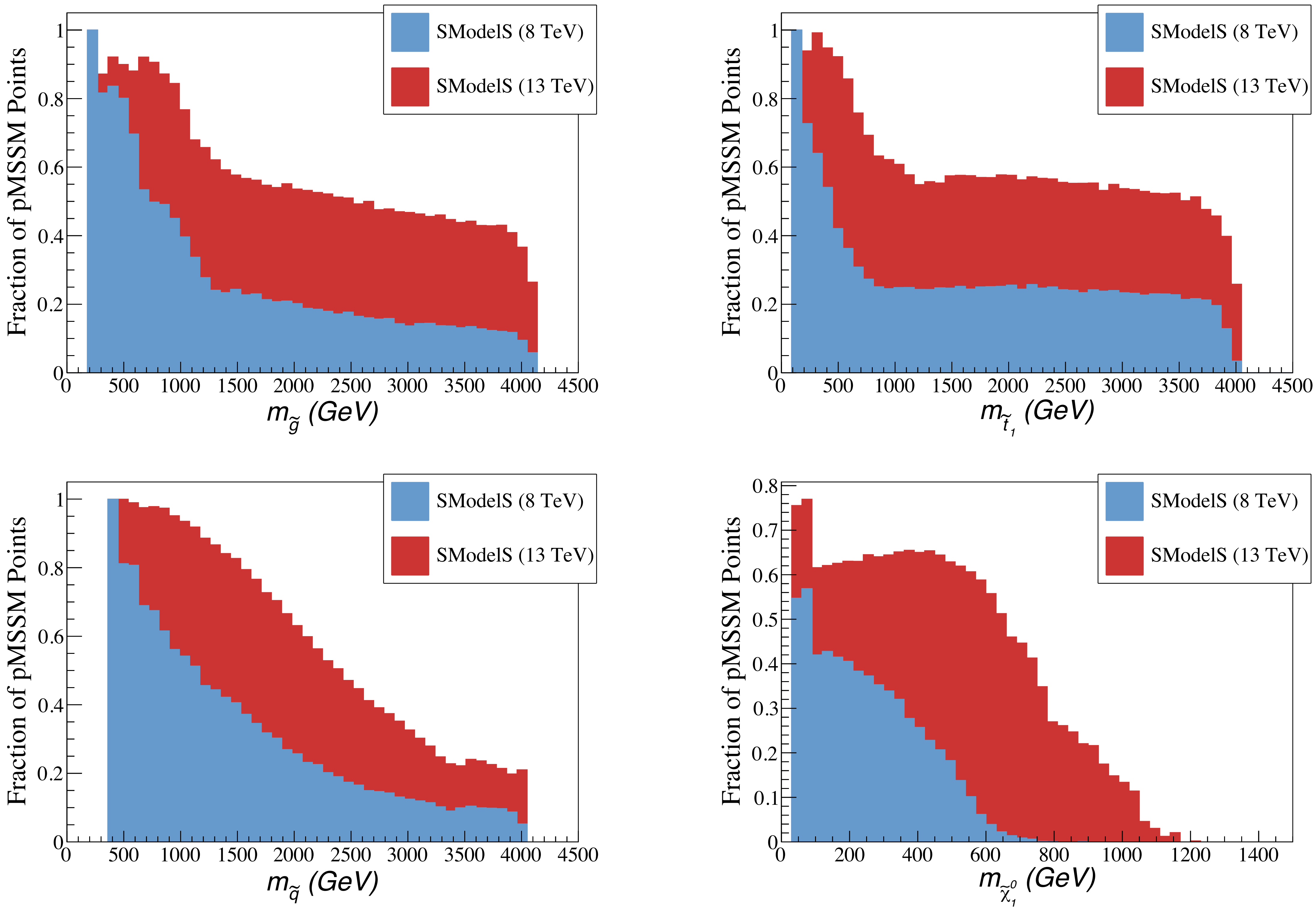
Moriond 2017 (36 fb^{-1})

channel	PAS/arXiv	webpage		channel	PAS/arXiv	webpage	
0L + jets with MHT	SUS-16-033	link	✓	Photon + MET	SUS-16-046	link	✓
0L + jets with MT2	SUS-16-036	link	✓	Photon + HT	SUS-16-047	link	✓
1L + jets + MET with MJ	SUS-16-037	link	✓	Stop 0L	SUS-16-049	link	✓
1L + jets + MET with ΔΦ	SUS-16-042	link	✓	Stop 1L	SUS-16-051	link	✓
2SS Leptons	SUS-16-035	link	✓	Stop 2L	SUS-17-001	link	✓
multilepton EWK	SUS-16-039	link	✓	Sbottom and compressed stop	SUS-16-032	link	✓
multileptons + jets	SUS-16-041	link	✓	GMSB Higgsinos in 4b	SUS-16-044	link	✗
2L soft	SUS-16-048	link	✗	2OS leptons	SUS-16-034	link	✓
Razor + Higgs->gg	SUS-16-045	link	✓	EWK WH(bb)	SUS-16-043	link	✓

Implementation of ATLAS Run 2 results ongoing

J. Dutta, SK, A. Lessa, W. Waltenberger
arXiv:1803.02204

Impact on pMSSM



19 free parameters; using ATLAS pMSSM scan from arXiv:1508.06608

Installing SModelS

Requirements, dependencies

SModelS is a Python library that requires Python version 2.6 or later (including version 3) with the following external Python libraries:

- unum >= 4.0.0
- numpy >= 1.13.0
- argparse
- requests >= 2.0.0
- docutils >= 0.3
- scipy >= 1.0.0
- pyslha >= 3.1.0

In addition, the MSSM cross section computer provided by smodelsTools.py requires:

- Pythia 8.2 (requires a C++ compiler) or Pythia 6.4.27 (requires gfortran)
- NLL-fast 1.2 (7 TeV), 2.1 (8 TeV), and 3.1 (13 TeV) (requires a fortran compiler)

These tools need not be installed separately, as the SModelS build system takes care of that. The current default is that both Pythia6 and Pythia8 are installed together with NLLfast. However, the user can easily adapt the Makefile in the lib/ directory to fit his or her needs. Finally, the database browser provided by smodelsTools.py requires IPython.

http://smodels.readthedocs.io/en/latest/Installation.html

Download and installation

Download:

from SModelS homepage: http://smodels.hephy.at/wiki/SModelS
or clone from GitHub https://github.com/SModelS/smodels

Installation using Python setup tools :

If Python's setuptools is installed in your machine, SModelS and its dependencies can be installed with:

```
python setup.py install
```

If the python libraries are installed in a system folder (as is the default behavior), it will be necessary to run the install command with superuser privilege. Alternatively, one can run setup.py with the "–user" flag:

```
python setup.py install --user
```

If setuptools is not installed, you can try to install the external libraries manually and then rerun setup.py.

Detailed instructions on http://smodels.readthedocs.io/en/latest/Installation.html

Installation via pip

https://pypi.org/project/smodels/1.1.1.post2

If pip is installed in your machine, you can do:

```
pip install smodels
```

In this case, gfortran and g++ need to be installed separately, if one wishes to compute cross sections with pythia6 and pythia8, respectively. Also, it might be necessary to perform:

```
sudo smodelsTools.py fixpermissions
```

in case of system-wide installs. User-specific installations on the other hand:

```
pip install --user smodels
```

will install SModelS into the user's ~/.local directory.

Depending on your platform, the environment variables $PATH, $PYTHONPATH, $LD_LIBRARY_PATH (or $DYLD_LIBRARY_PATH) might have to be set appropriately.

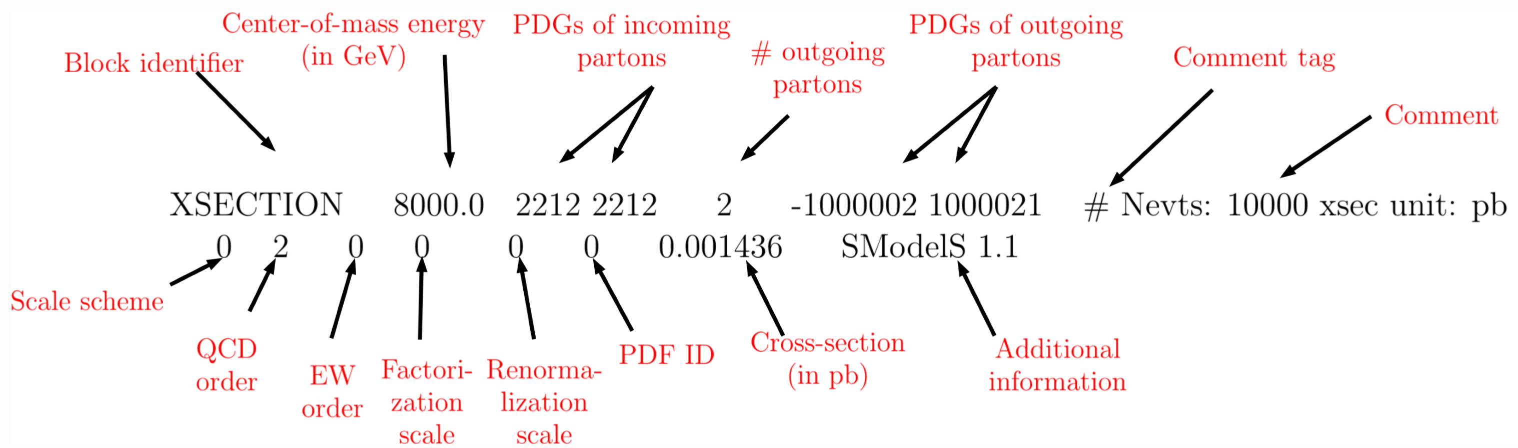
http://smodels.readthedocs.io/en/latest/Installation.html

Using SModelS

Basic input

The main input for SModelS consists of masses, cross sections and branching ratios for the BSM states, which can be given in the two following forms:

- **SLHA (SUSY Les Houches Accord)** input: needs BLOCK MASS, decay tables and cross sections in SLHA format



  For MSSM particles, cross sections can be appended to an existing SLHA file with `smodelsTools.py xseccomputer` (-h for usage help)

- **LHE (Les Houches Event)** file containing parton level events; these can be generated for any BSM model through the use of your favorite MC generator. Note that in this case the precision of the results is limited to the MC statistics used to generate the file.

http://smodels.readthedocs.io/en/latest/BasicInput.html

runSmodels.py

runSModelS.py covers several different applications of the SModelS functionality, with the option of turning various features on or off, as well as setting the basic parameters

To show all arguments:

```
./runSModelS.py -h
```

Usage example:

```
./runSModelS.py -f inputFiles/slha/simplyGluino.slha
```

Default: screen output and summary in results/simplyGluino.slha.smodels

http://smodels.readthedocs.io/en/latest/RunningSModelS.html

```
# Input File: inputFiles/slha/simplyGluino.slha
# maxcond = 0.2
# minmassgap = 5
# ncpus = 1
# sigmacut = 0.03
# Database version: 1.1.2
================================================================================
#Analysis  Sqrts  Cond_Violation  Theory_Value(fb)  Exp_limit(fb)  r  r_expected

    CMS-SUS-16-033  1.30E+01    0.0  4.309E+03  1.990E+01  2.165E+02  N/A
 Signal Region:  (UL)
 Txnames:  T1
--------------------------------------------------------------------------------
    CMS-SUS-16-036  1.30E+01    0.0  4.309E+03  2.786E+01  1.547E+02  N/A
 Signal Region:  (UL)
 Txnames:  T1
--------------------------------------------------------------------------------
 ATLAS-SUSY-2015-06  1.30E+01    0.0  3.545E+01  1.790E+00  1.981E+01  1.162E+01
 Signal Region:  SR5j
 Txnames:  T1
 Chi2, Likelihood =  3.025E+01  2.885E-08
--------------------------------------------------------------------------------
[.....]

================================================================================
The highest r value is = 216.503897171
```

SModelS reports it's results in the form of "r-values"

r = (theory prediction) / (95%CL upper limit)

The parameters file

The basic options and parameters used by runSModelS.py are defined in the parameters file. An example, including all available parameters together with a short description, is provided in the `parameters.ini` file.

If no parameter file is specified, the default parameters stored in `smodels/etc/parameters_default.ini` are used.

—> show `parameters.ini` file

Adding cross sections

For MSSM particles, cross sections can be appended to an existing SLHA file with `smodelsTools.py xseccomputer` (-h for usage help)

Example: download slha files from Indico page and put them in the `inputFiles/slha` directory

then type:

```
./smodelsTools.py xseccomputer -f inputFiles/slha/3989872XS.slha -s 13 -e 25000 -p -8 -N
```

This will generate 25K events with Pythia 8 for the tree-level cross sections and add K-factors for colored particles from NLLfast.

http://smodels.readthedocs.io/en/latest/Tools.html

Check the SLHA file before/after, then run

```
./runSModelS.py -f inputFiles/slha/3989872XS.slha -p parameters.ini
```

Beyond the MSSM

SModelS can be used for any BSM model presenting a Z_2 symmetry. All you need to do *(besides providing the model input, see “basic input”, p. 26)* is to specify the particle content in the `particles.py` file in the `smodels` directory.

```
rOdd = {1000021 : "gluino",
        1000022 : "N1",
        1000023 : "N2",
        1000025 : "N3",
        1000035 : "N4",
        1000024 : "C1",
        1000037 : "C2",
        1000039 : "gravitino",
        1000001 : "squark",
        1000002 : "squark",
        1000003 : "squark",
        1000004 : "squark",
        2000001 : "squark",
        2000002 : "squark",
        2000003 : "squark",
        2000004 : "squark",
        1000005 : "sbottom",
        2000005 : "sbottom",
        1000006 : "stop",
        2000006 : "stop",
```

```
rEven = {25 : "higgs",
        -25 : "higgs",
         35 : "H0",
        -35 : "H0",
         36 : "A0",
        -36 : "A0",
         37 : "H+",
        -37 : "H-",
         23 : "Z",
        -23 : "Z",
         22 : "photon",
        -22 : "photon",
         24 : "W+",
        -24 : "W-",
         16 : "nu",
        -16 : "nu",
         15 : "ta-",
        -15 : "ta+",
         14 : “nu",
        -14 : "nu",
```

This works the same way for SUSY and non-SUSY models

Running SModelS in micrOMEGAs

micrOMEGAs 4.3 onwards has an interface to SModelS which provides a convenient way to generate SModelS input for any model. By calling the function

```
smodels(Pcm, nf, csMinFb, fileName, wrt)
```

micrOMEGAs generates

- an SLHA-type input file, containing the mass spectrum, decay tables and production cross sections for the parameter point under investigation;
- particles.py defining the particle content of the model.

`Pcm` is the proton beam energy in GeV

nf is the number of parton flavors used to compute the production cross sections

csMinFb defines the minimum production cross section in pb for Z_2-odd particles

`fileName` is the name of the SLHA file for the parameter point under investigation

`wrt` is a steering flag for the screen output; if wrt.neq.0 the computed cross sections will be also written on the screen.

```
BLOCK SModelS_Exclusion
 0 0 1     #output status (-1 not tested, 0 not excluded, 1 excluded)
 1 0 T2                #txname
 1 1 6.161E+00         #r value
 1 2 N/A               #expected r value
 1 3 0.00              #condition violation
 1 4 CMS-SUS-13-019    #analysis
 1 5 (UL)              #signal region
 1 6 N/A               #Chi2
 1 7 N/A               #Likelihood
```

NB currently only SModelSv1.0;
update to SModelSv1.1.1 in preparation

Outlook to v1.1.2

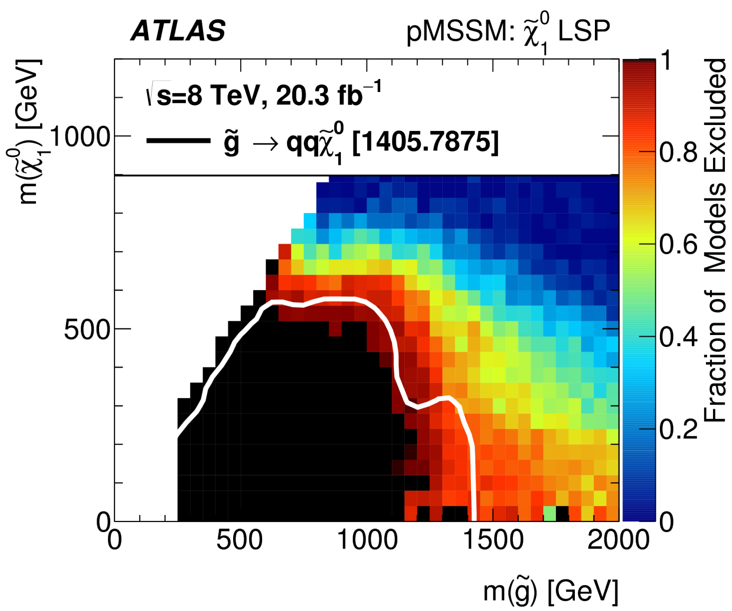
- Database path allows URLs —> automatic update
- More convenient selection of analyses via wildcards, e.g. ATLAS*
- Path to particles.py as an (optional) input
- Use of **covariances** for combination of signal regions
- Better installation support, updated documentation, etc.

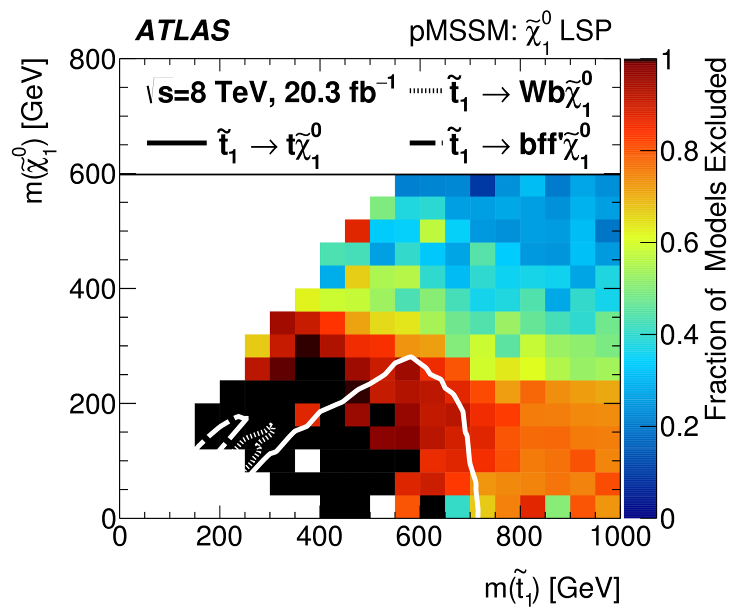
Full models can easily be decomposed into simplified model components.

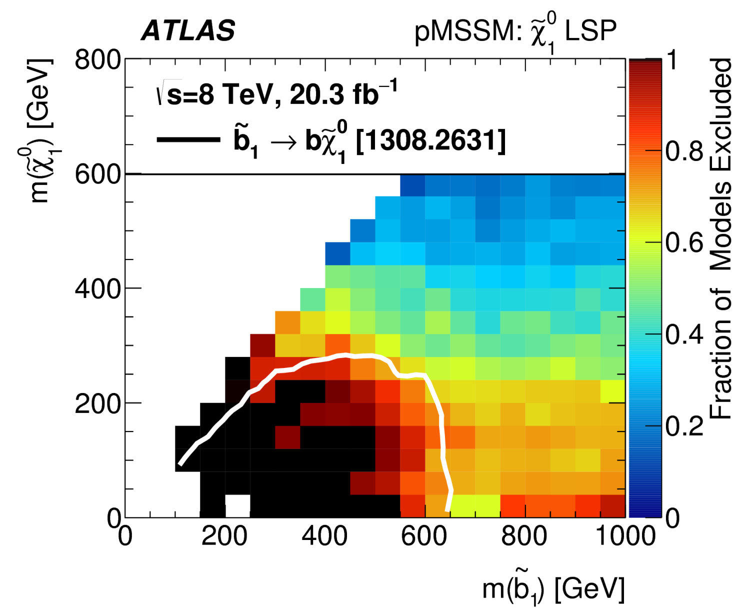
But: to what extent do the available SMS results actually map a full model?

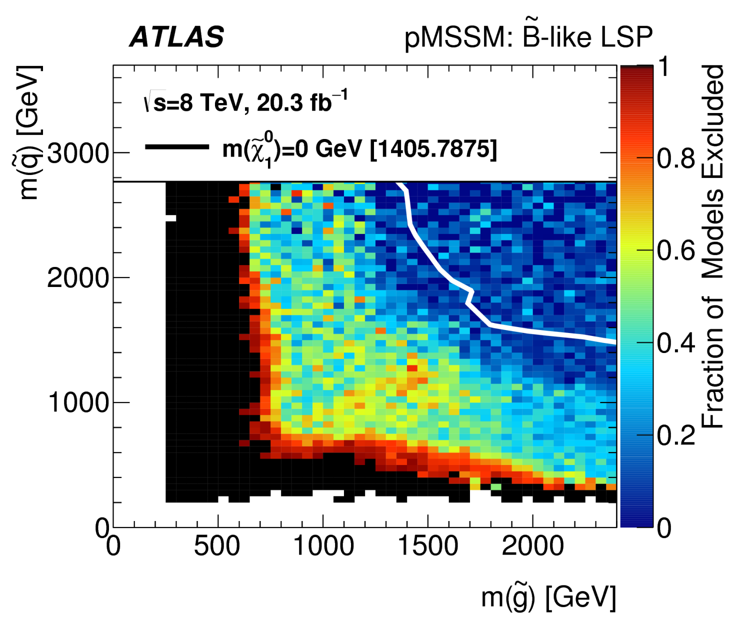
ATLAS pMSSM study

In 1508.06608, ATLAS interpreted the results from 22 separate ATLAS searches in the context of the 19-parameter phenomenological MSSM (pMSSM)   [vast scan]









How well can we reproduce the ATLAS exclusion by using simplified model results?

SHLA files from the scan are public on HepData together with the information whether or not they are excluded, and by which search. So let's run them through SModelS …

8 TeV results in SModelS v1.1.1 database

ATLAS

	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*

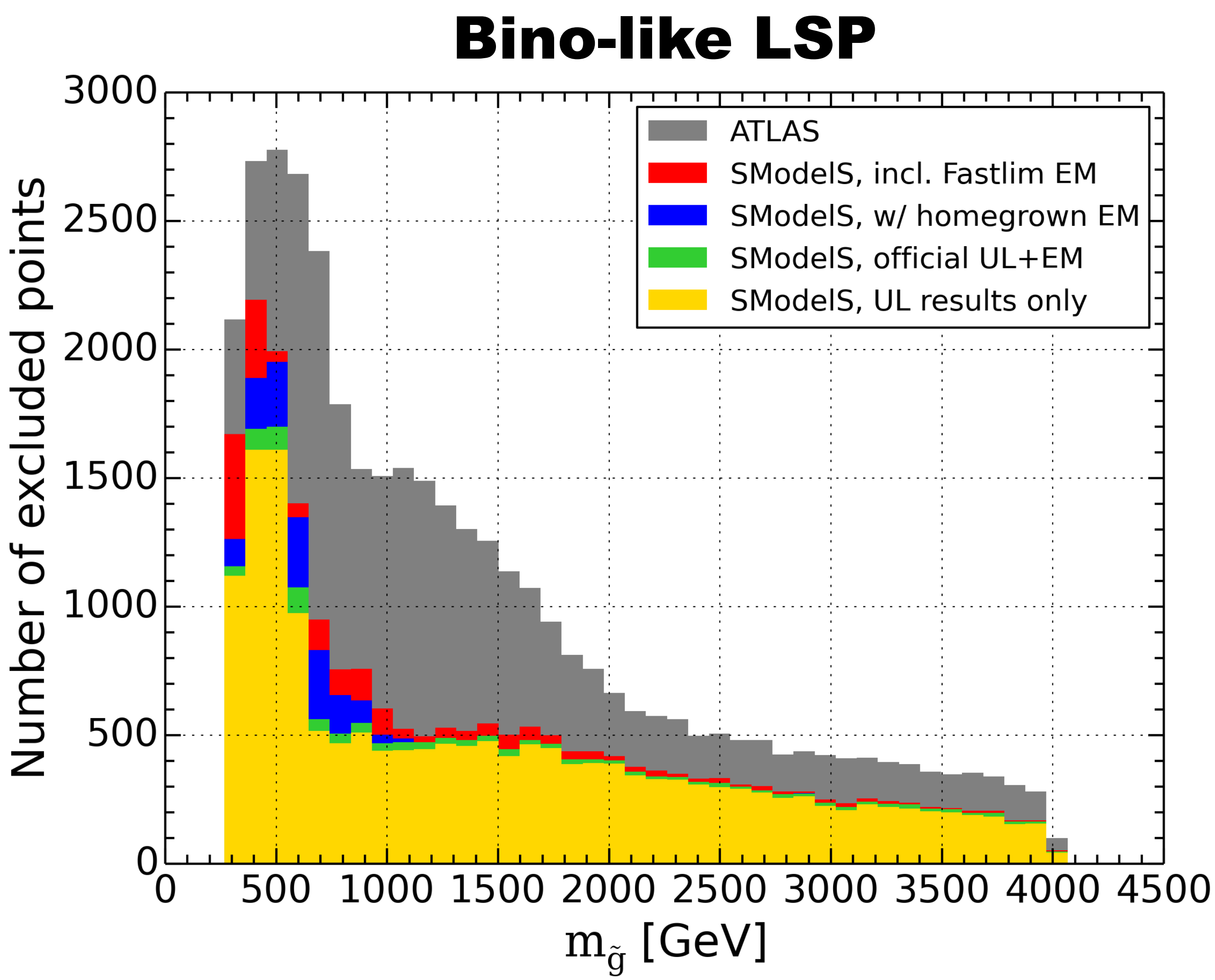
* plus Fastlim EMs for preliminary version (conf note) of the analysis.
‡ incl. 'home-grown' EMs produced with MadAnalysis5 or CheckMATE recasting.

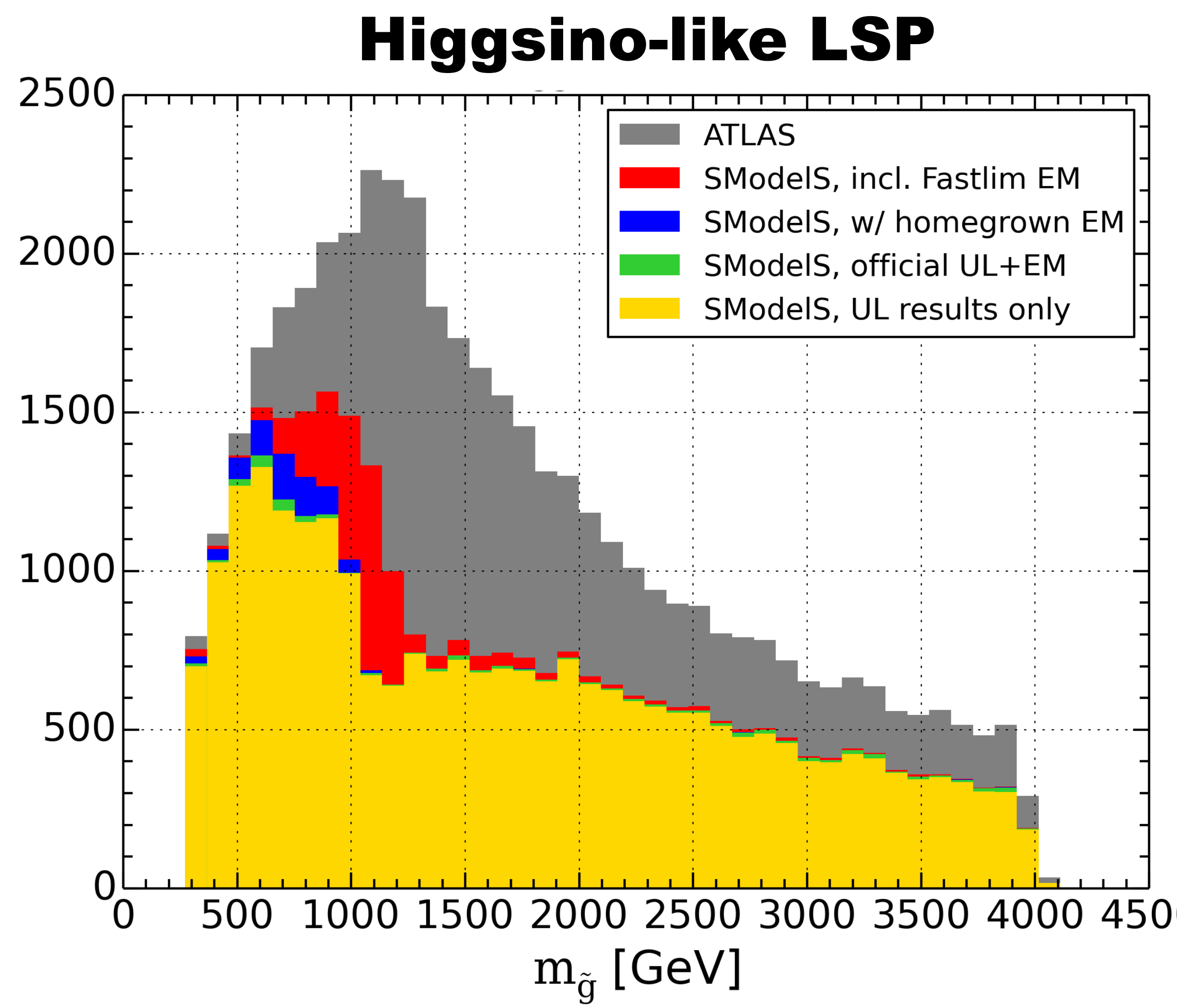
CMS

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

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

Coverage in terms of gluino mass



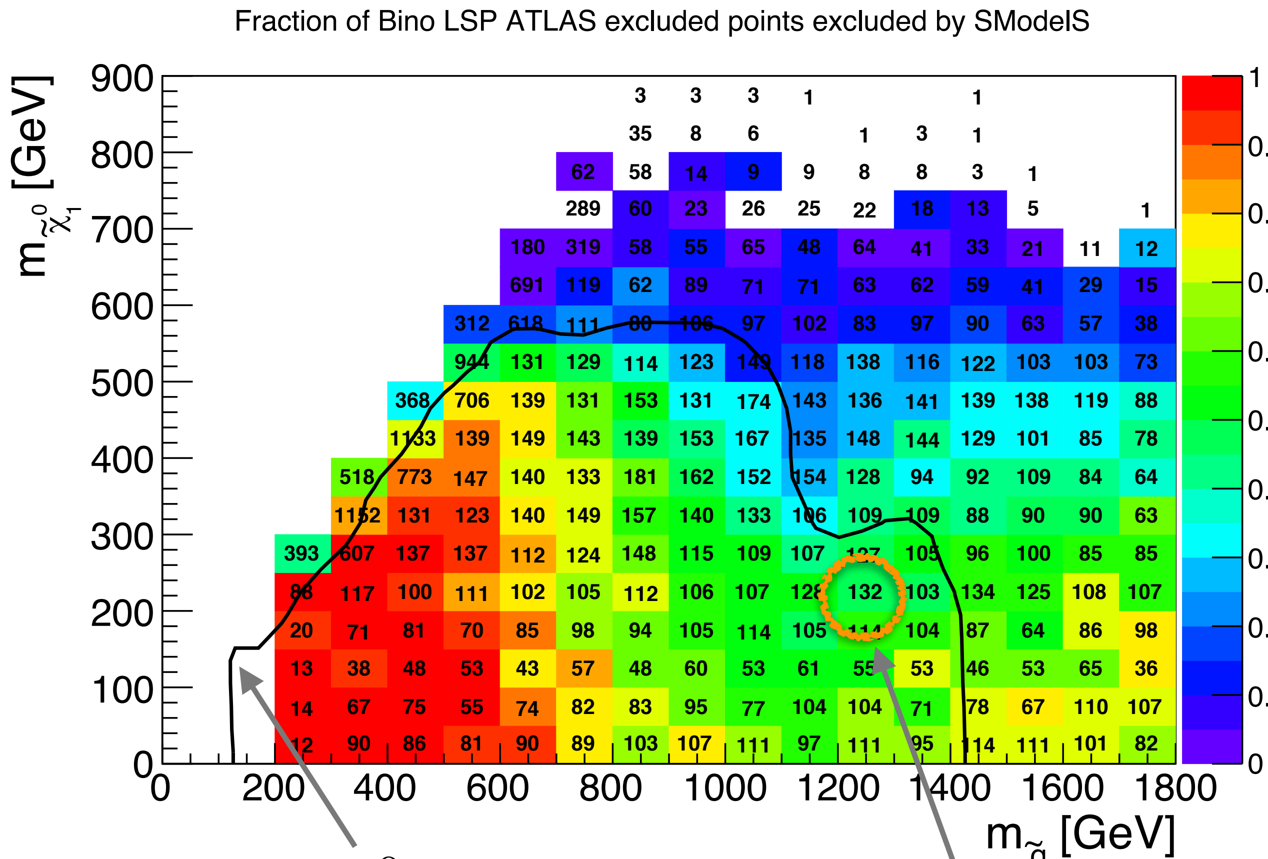


Fraction of excluded points w.r.t. ATLAS (after filtering)

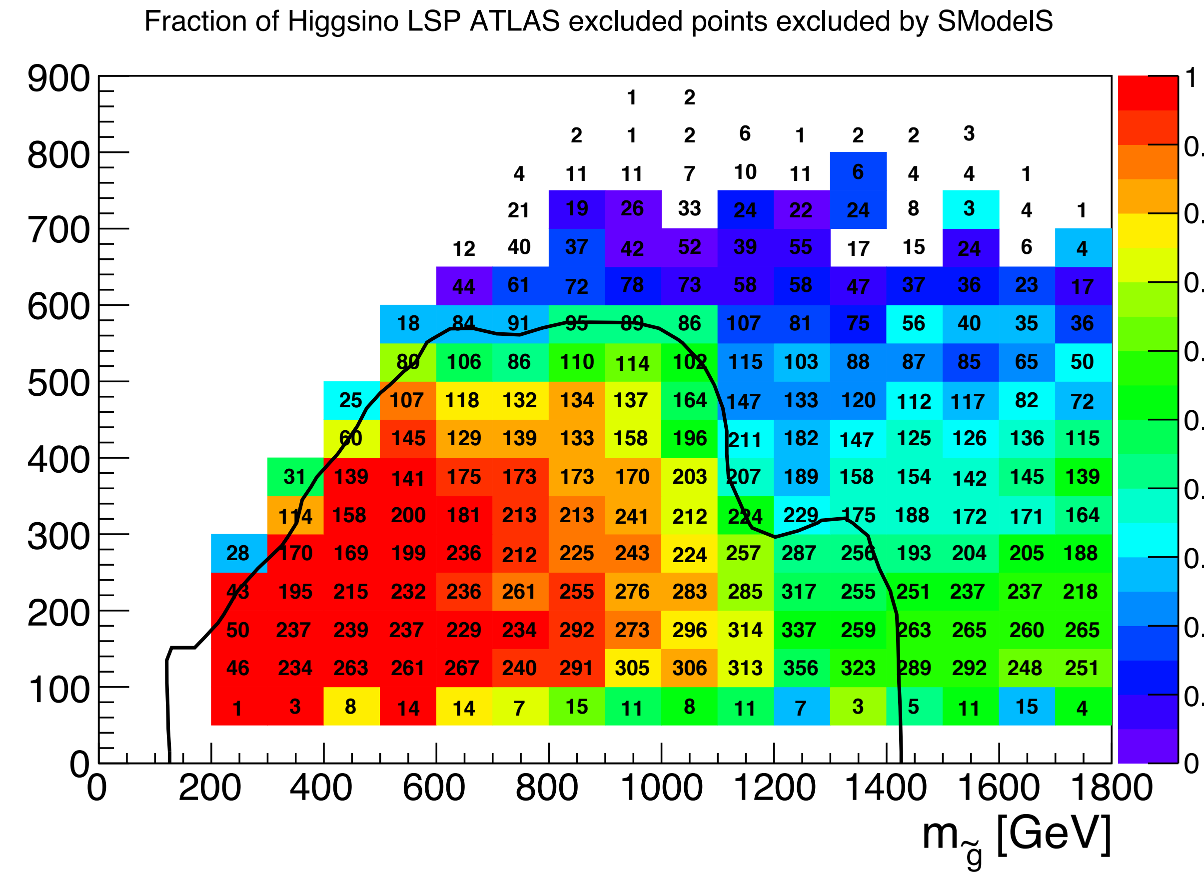
	bino LSP	higgsino LSP
m(gluino) < 600 GeV	80%	97%
m(gluino) < 1400 GeV	60%	74%

Gluino vs. neutralino mass plane

Bino-like LSP



Higgsino-like LSP



$\tilde{g} \to q\bar{q}\tilde{\chi}_1^0$ exclusion line from ATLAS 1405:7875

number of points in each bin (excluded by ATLAS)

- Coverage drops for intermediate gluino masses, where a larger variety of decay channels becomes available; more pronounced for bino than for higgsino LSP.
- Coverage also drops in compressed region and for heavy LSP.
- Need results for asymmetric topologies to improve coverage

What about DM (mono-X) simplified model results?

Dark matter simplified model results

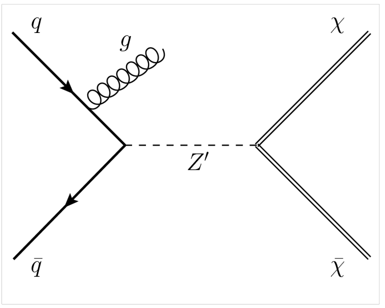
- At the LHC, DM production is searched for in mono-X signatures, e.g. mono-jet, or in association with heavy flavour quarks.

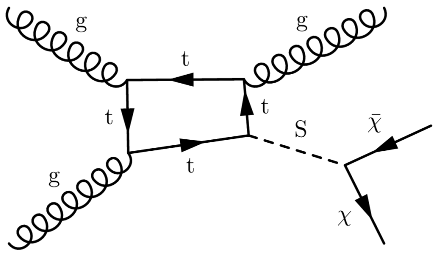
- Interpreted in terms of EFT or simplified model with a **DM particle plus a mediator**.

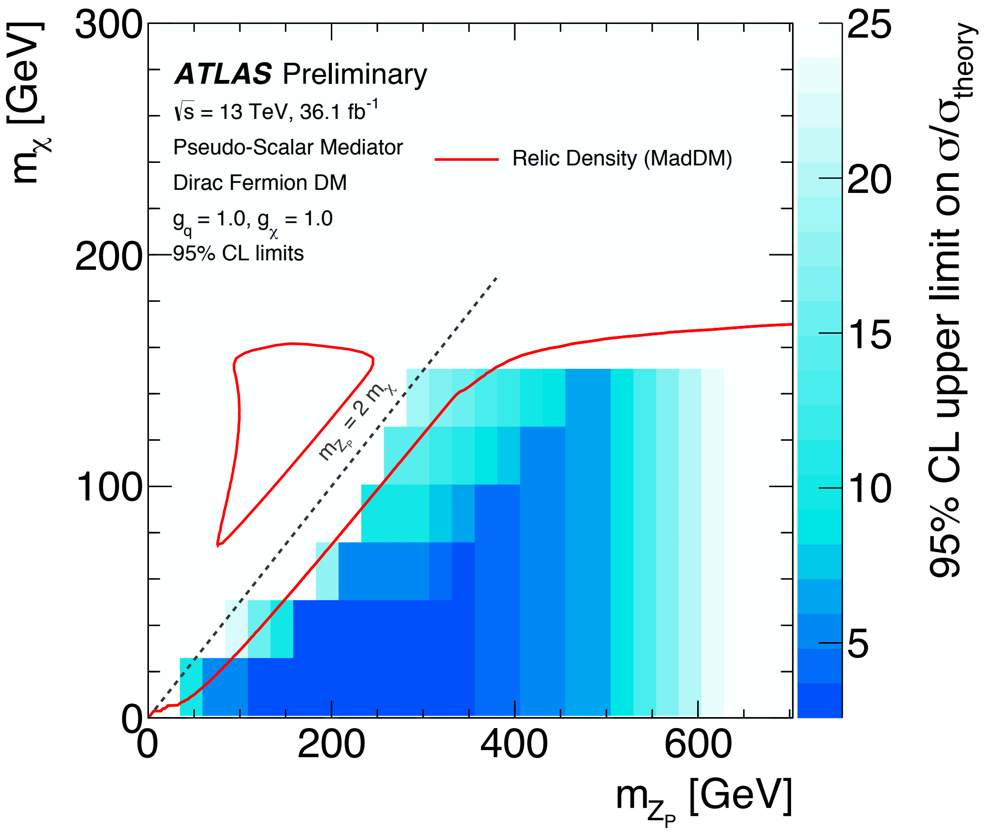
- *Primary presentation recommended [...] are plots of the experimental confidence level (CL) limits on the signal cross sections as a function of the two mass parameters m_{DM} and M_{med} .*

LHC DM WG,1603.04156

- In practice, constraints are presented by ATLAS and CMS as **95%CL limits on σ/σ_{theory}**, which is **highly model dependent.**







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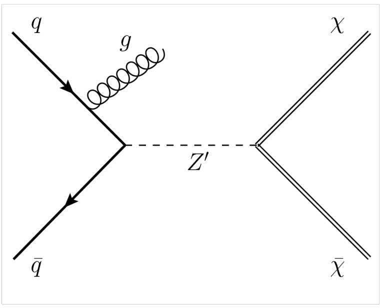
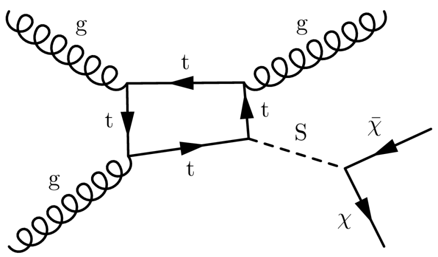
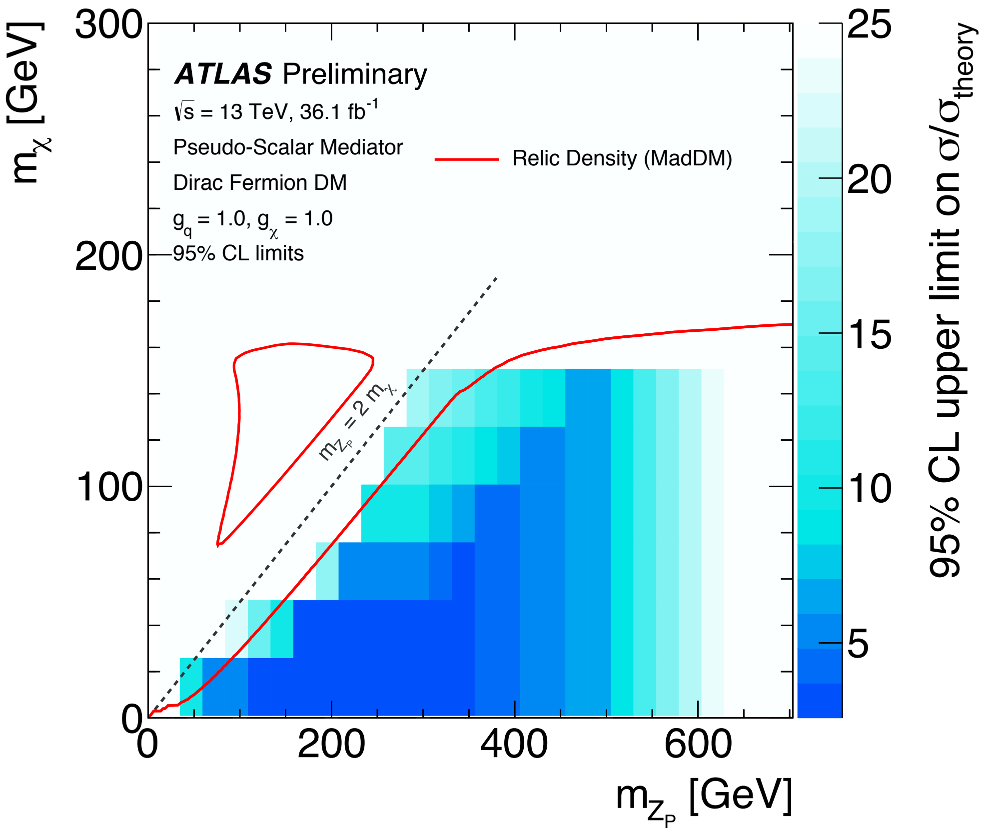
  - Would need to unfold σ_{theory} to use these results, but reference cross section not provided. Source of systematic uncertainty.







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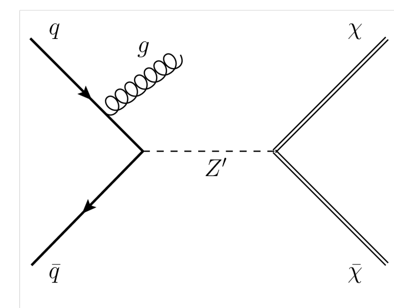

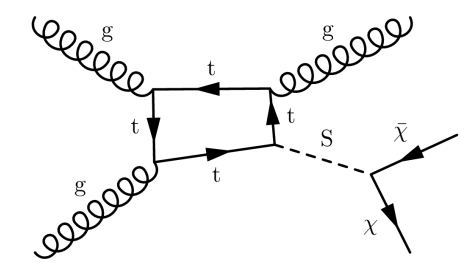

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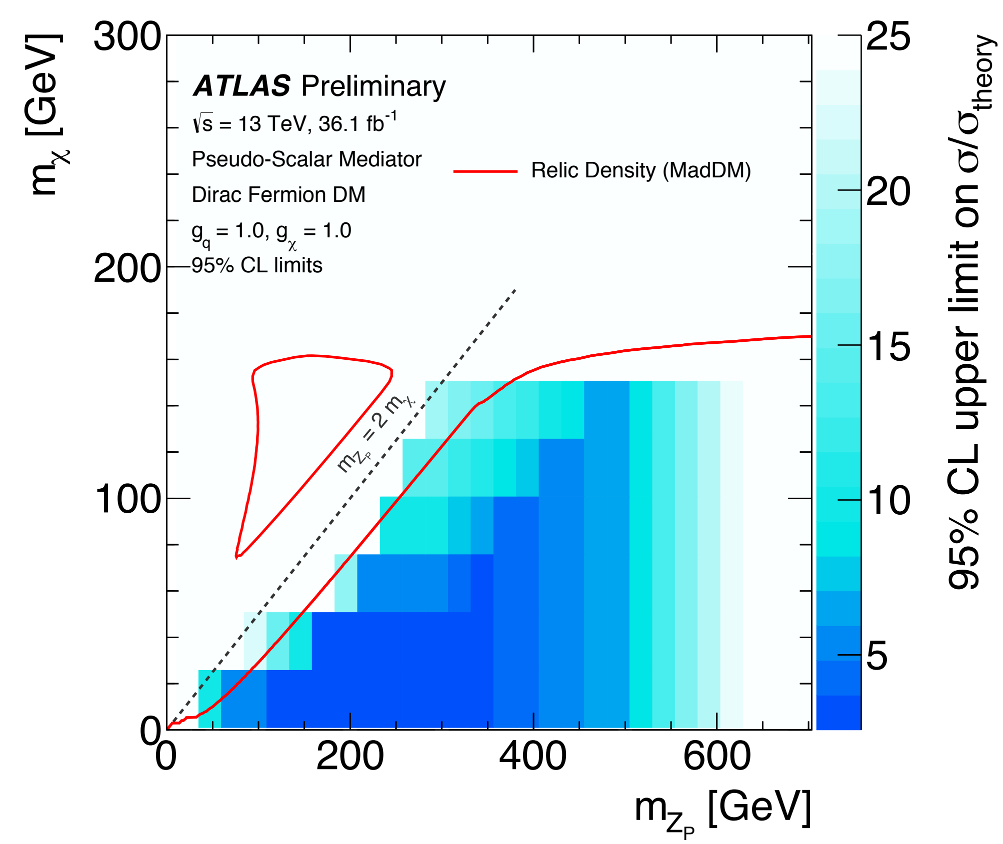
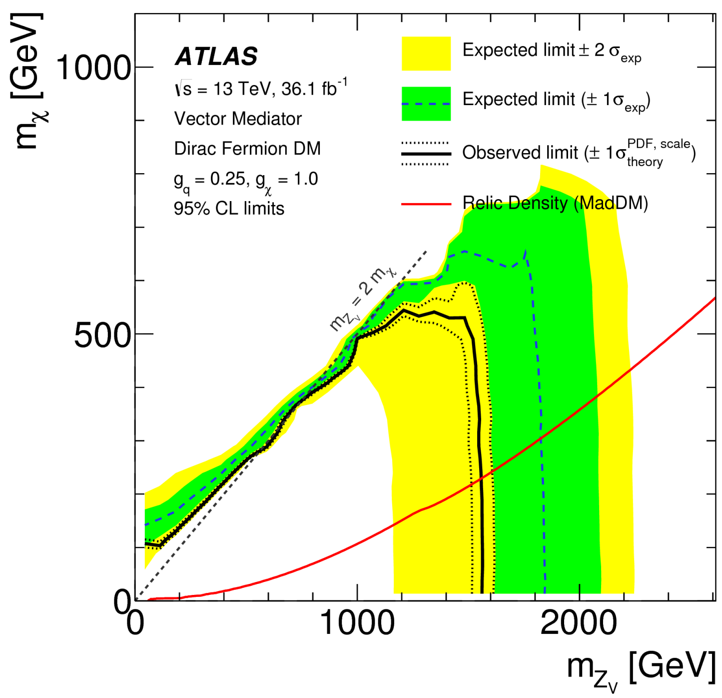


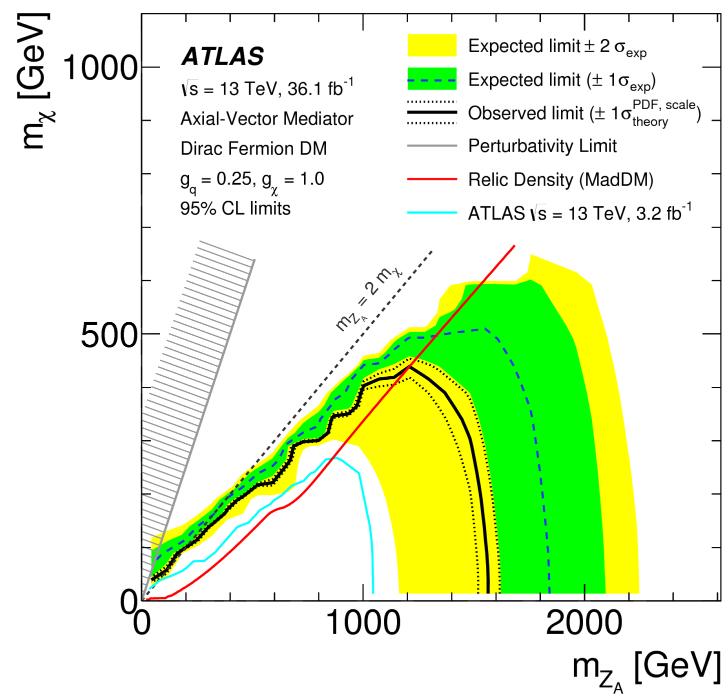
- Would need to unfold σ_{theory} to use these results, but reference cross section not provided. Source of systematic uncertainty.

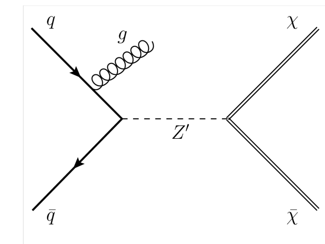
- When variety of signal topologies exists, efficiency maps would b useful.

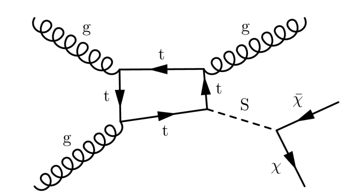
Dark matter simplified model results

ATLAS-EXOT-2016-27

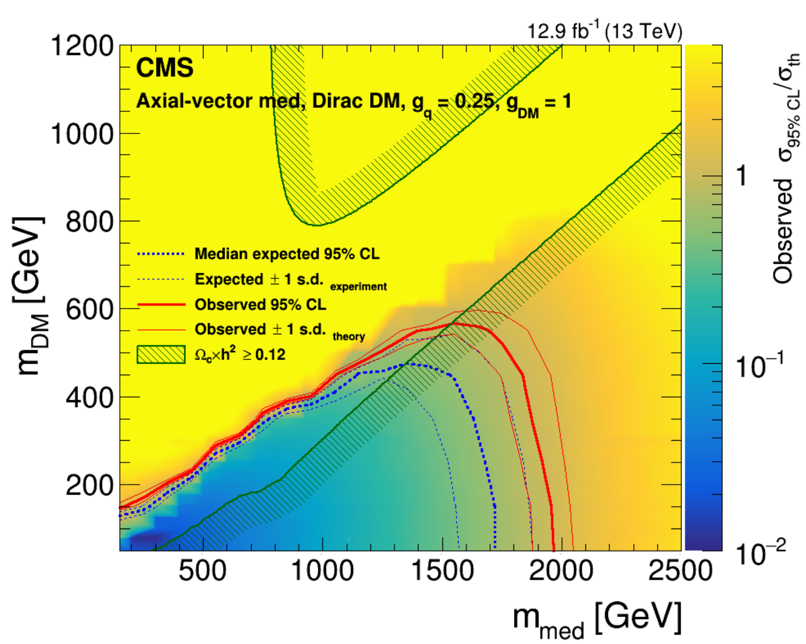


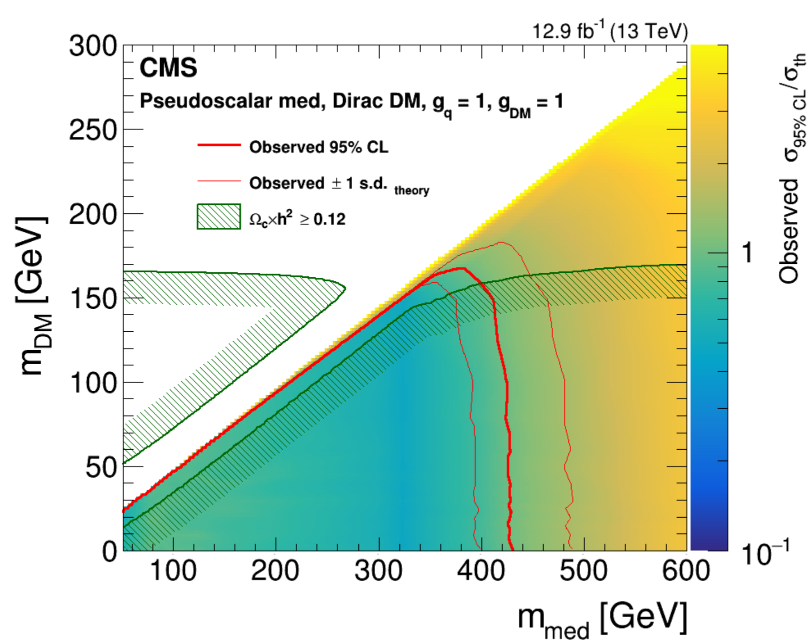






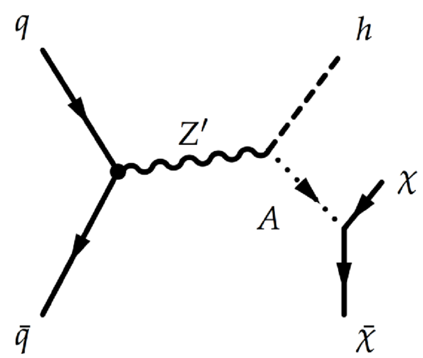
CMS-EXO-16-037



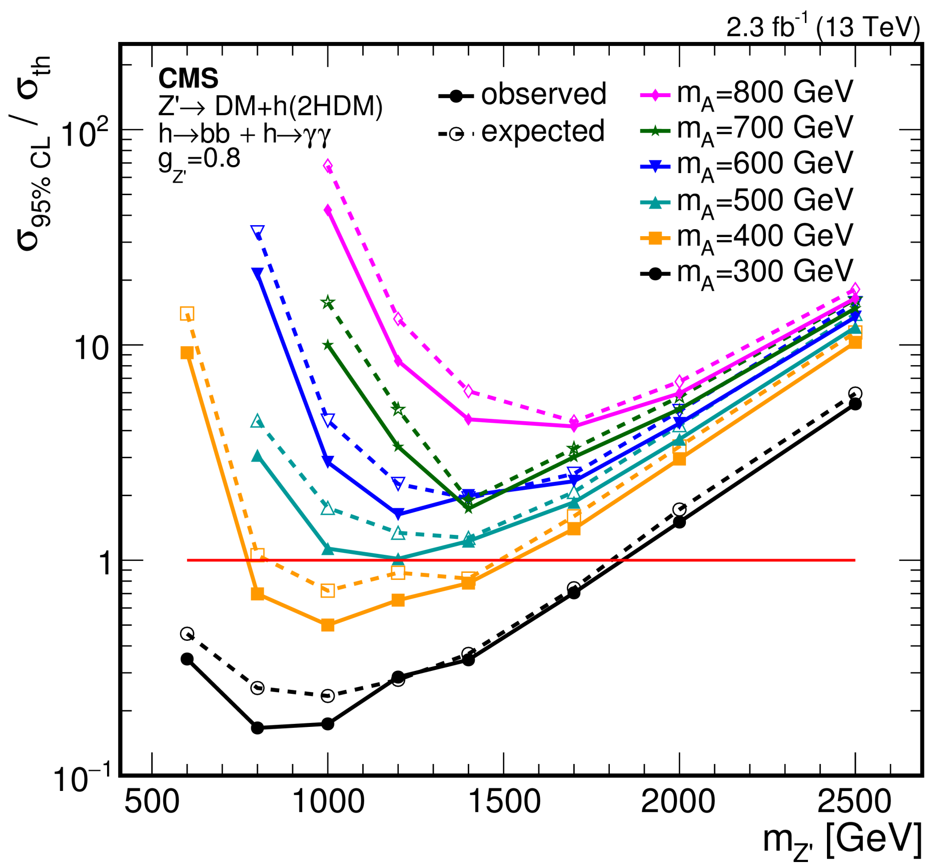


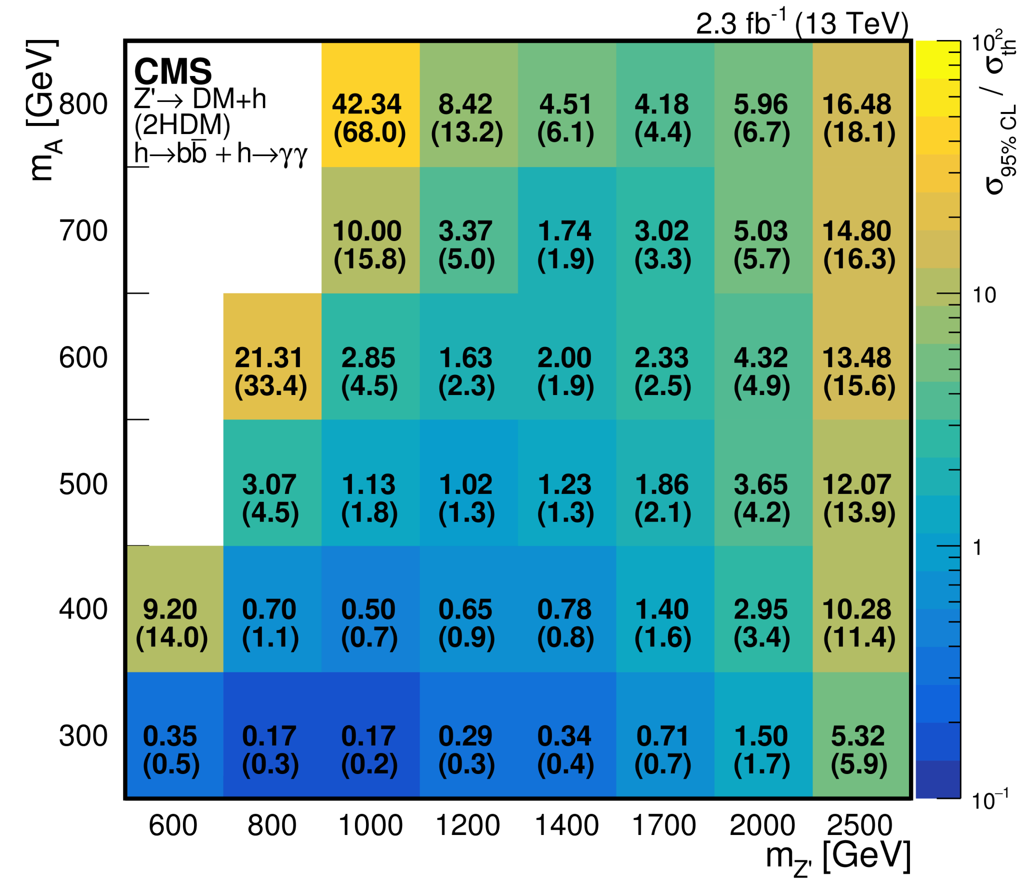
- Big differences in the mass limits come to large extent from big differences in model cross sections
- How different are the acceptances?
- Would want limits on absolute cross section, or efficiency maps to re-use these results
- Plots should be available in numerical form (SUSY groups do ….)

Dark matter simplified model results



CMS-EXO-16-012





"The theoretical cross section is calculated using $g_{Z'}$ = 0.8"

Good to have a numerical map in mass-mass plane.

If the limits were given without normalisation, they could be re-used w/o introducing additional uncertainties (provided NWA holds)

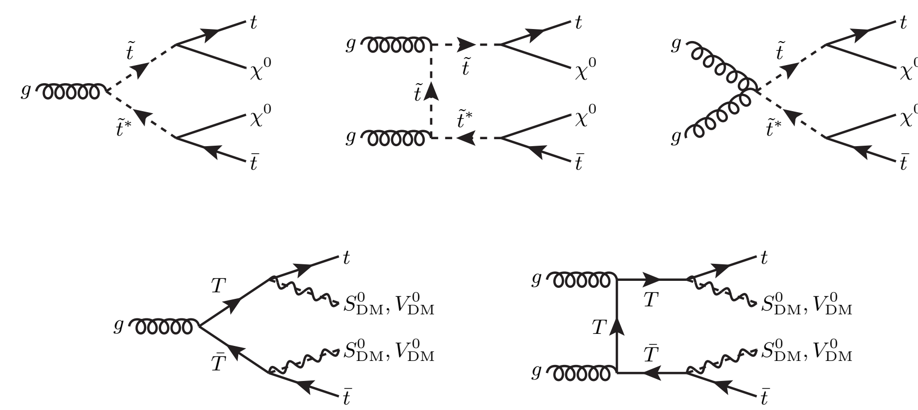
BACKUP

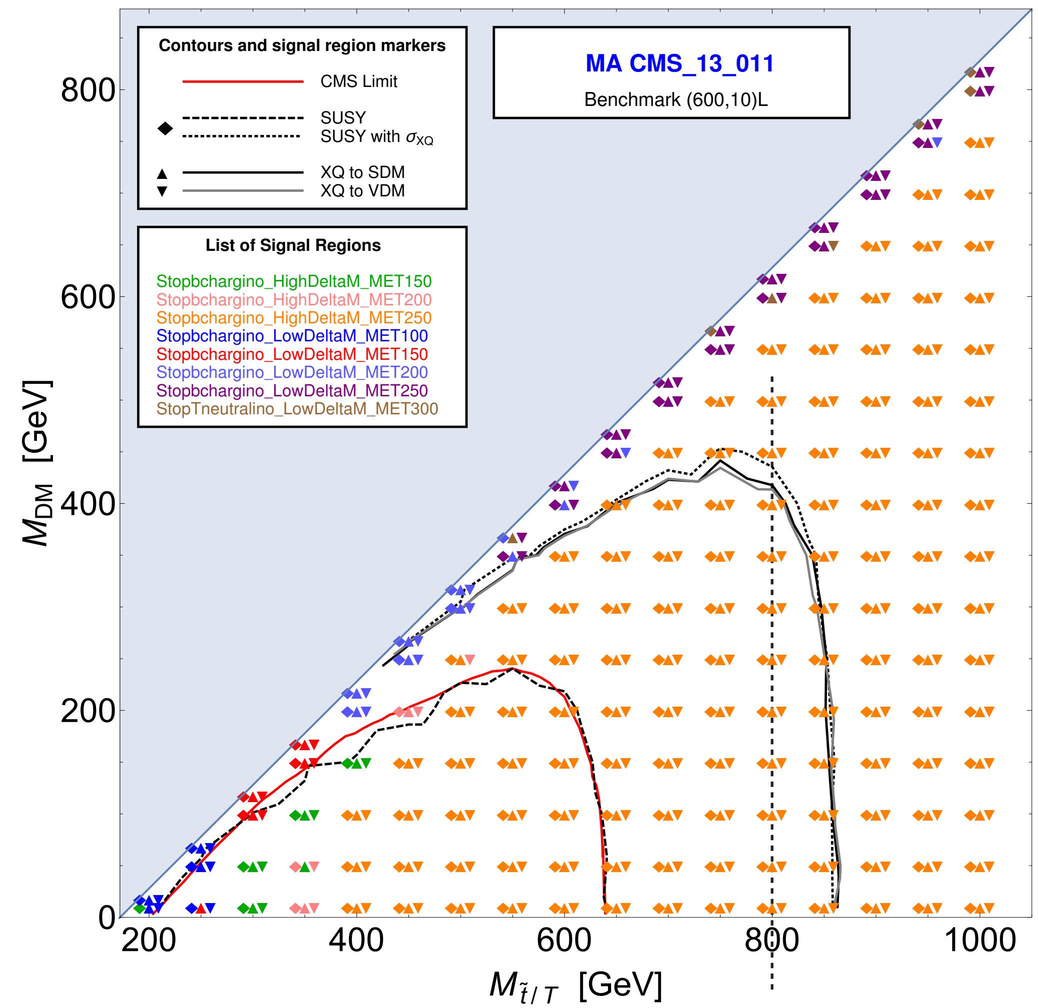
Scalar versus fermionic top-partner interpretation of ttbar + MET searches

SK, Laa, Panizzi, Prager, 1607.02050

- Used ATLAS and CMS SUSY searches in ttbar+MET final state at Run 1 to constrain scenarios with a fermionic top partner and a dark matter candidate.
- Recasting with CheckMATE and MadAnalysis5
- Efficiencies in all-hadronic, 1-lepton and 2-lepton channels are very similar for scalar and fermionic top partners.
- SMS results for stop–neutralino simplified models can also be applied to fermionic top-partner models, provided the narrow width approximation holds in the latter.
- Official eff. maps don't extend to high enough masses, so we provide our own:

http://lpsc.in2p3.fr/projects-th/recasting/susy-vs-vlq/ttbarMET/





official ATLAS/CMS plots stop here

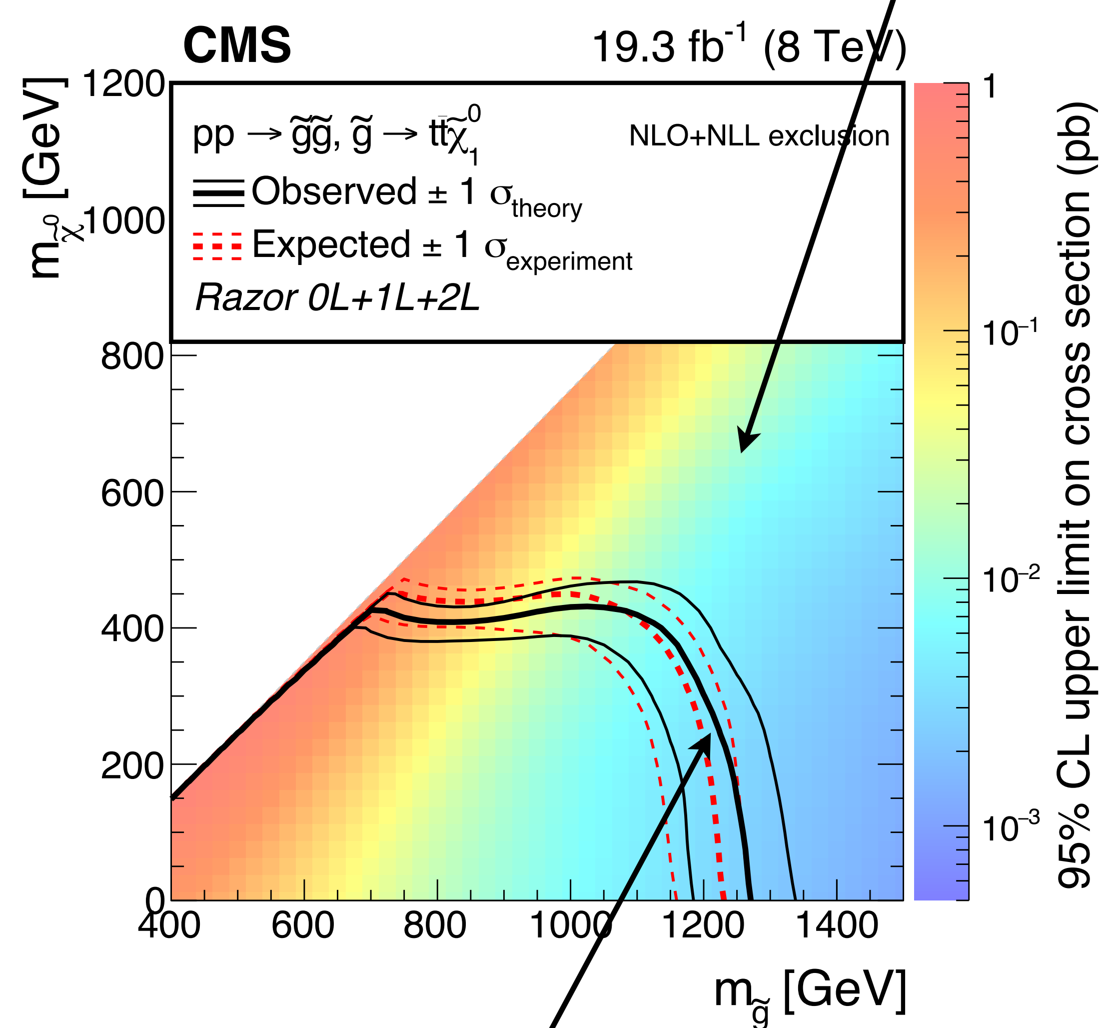
SMS results in the database

— Cross section upper limit (UL) maps —

- Upper Limit maps give the 95% CL upper limit on σ×BR(×BR…) for a specific SMS.
- The UL values can be based on the best SR (for each point in parameter space), a combination of SRs or more involved limits from other methods.
- Comparison of predicted σ×BR to the UL tells whether a point is excluded or not.

binned σ×BR upper limits

[[[t,t]], [[t,t]]]



NB the exclusion curve is never used by SModelS.

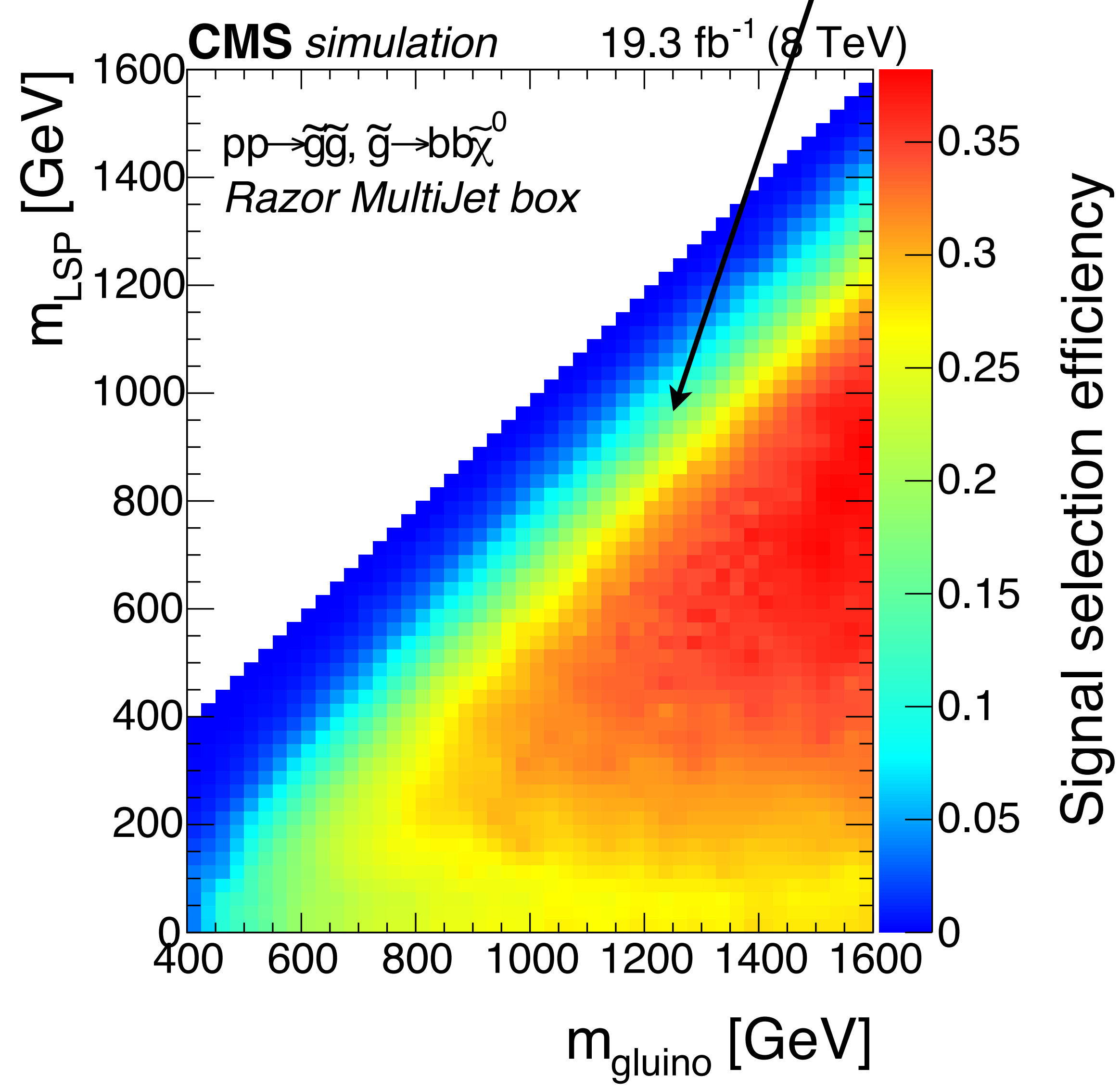
SMS results in the database

— Efficiency maps (EM) —

v1.1 onwards:

- Efficiency maps correspond to a grid of simulated acceptance x efficiency values for a specific signal region (SR) for a given simplified model.
- Together with the observed and expected numbers of events in each SR, this allows to compute a likelihood.
- Advantage: allows to add up contributions from different topologies to the same SR
- Disadvantage: no combination of SRs (yet)

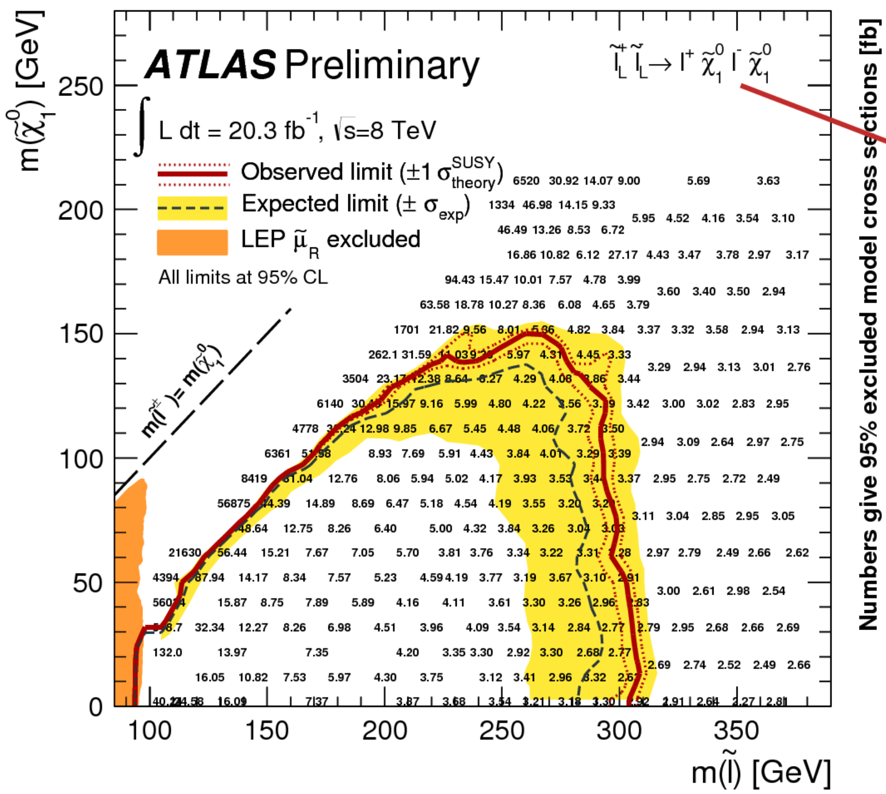
$A\times\varepsilon$ in SR

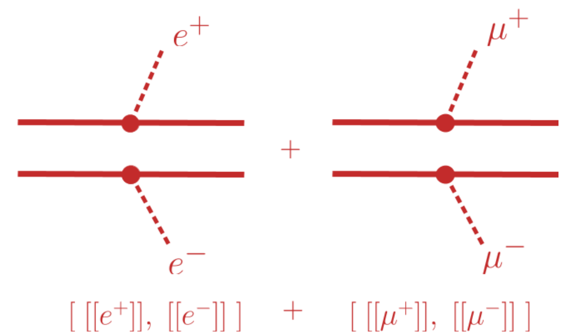


Limit on $\Sigma(A\times\varepsilon)\times\sigma\times\text{BR}$

SMS results in the database

— constraints and conditions —

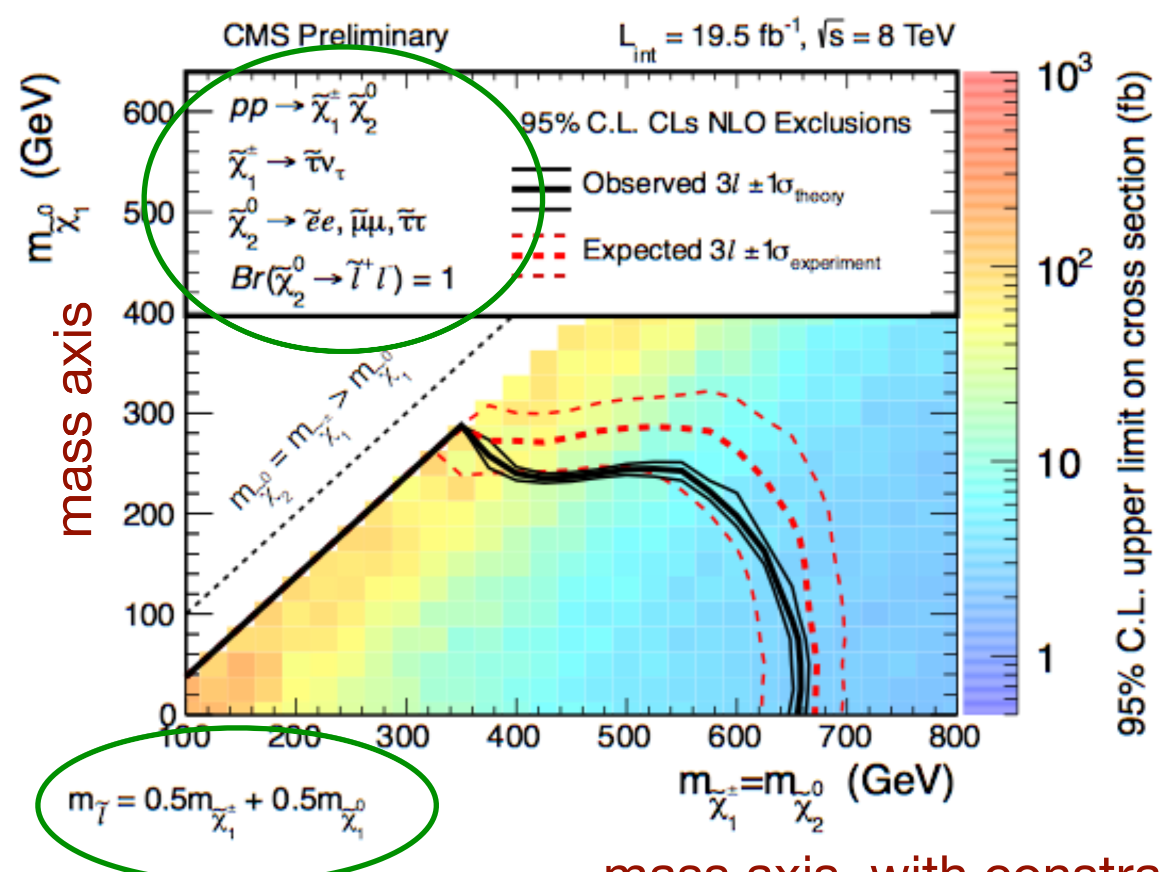




requires equal number of electrons and muons

[[[nu],[tau]], [[l],[l]]]

mass axis



conditions

mass axis, with constraint

Analyses considered (ATLAS)

Used by ATLAS **available in SModelS v1.1.1**

	Analysis	ID	SModelS database
Inclusive	0-lepton + 2–6 jets + E_T^{miss}	SUSY-2013-02*	6 UL, 2 EM
	0-lepton + 7–10 jets + E_T^{miss}	SUSY-2013-04*	1 UL, 10 EM‡
	1-lepton + jets + E_T^{miss}	SUSY-2013-20*	1 UL from CONF-2013-089
	$\tau(\tau/\ell)$ + jets + E_T^{miss}	SUSY-2013-10	—
	SS/3-leptons + jets + E_T^{miss}	SUSY-2013-09	1 UL (+5 UL, CONF-2013-007)
	0/1-lepton + 3b-jets + E_T^{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^{miss}	SUSY-2013-05*	3 UL, 1 EM‡
	tb+E_T^{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*

* plus Fastlim EMs for preliminary version (conf note) of the analysis.
‡ incl. 'home-grown' EMs produced with MadAnalysis5 or CheckMATE recasting.

Analyses considered (ATLAS)

Used by ATLAS **available in SModelS v1.1.1**

	Analysis	ID	SModelS database
Inclusive	0-lepton + 2–6 jets + E_T^{miss}	SUSY-2013-02*	6 UL, 2 EM
	0-lepton + 7–10 jets + E_T^{miss}	SUSY-2013-04*	1 UL, 10 EM‡
	1-lepton + jets + E_T^{miss}	SUSY-2013-20*	1 UL from CONF-2013-089
	$\tau(\tau/\ell)$ + jets + E_T^{miss}	SUSY-2013-10	—
	SS/3-leptons + jets + E_T^{miss}	SUSY-2013-09	1 UL (+5 UL, CONF-2013-007)
	0/1-lepton + 3b-jets + E_T^{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^{miss}	SUSY-2013-05*	3 UL, 1 EM‡
	tb+E_T^{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*

* plus Fastlim EMs for preliminary version (conf note) of the analysis.

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several EM produced by us with MadAnalysis5/CheckMATE

Dark matter simplified model results are very model dependent
(note also mono-jet analysis is largely overlapping with multi-jet one)

no SMS interpretation available in exp. publication

Current SModelS framework requires MET signature

Analyses considered (ATLAS)

Used by ATLAS — **available in SModelS v1.1.1**

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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
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	2b-jets + $E_T^{\rm miss}$	SUSY-2013-05*	3 UL, 1 EM‡
	tb+$E_T^{\rm miss}$, stop	SUSY-2014-07	—
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	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*

* plus Fastlim EMs for preliminary version (conf note) of the analysis.
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Current SModelS framework requires MET signature

Fastlim-1.0 [arXiv:1402.0492] efficiency maps converted to SModelS format; target "natural SUSY" scenarios

Analyses considered (CMS)

CMS 8 TeV **available in SModelS v1.1.1**

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

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

large number of `home-grown' EM; cover additional topologies

Very similar to ATLAS analyses, comparable reach,
but (in part) complementary SMS topologies in SModelS database

Number of points

	bino-like LSP	higgsino-like LSP
tested by ATLAS	103.410	126.684
excluded by ATLAS	41.570	48.266
of these, tested in SModelS*	38.575	45.594
excluded by SModelS	21,151 (55%)	28,669 (63%)

* discarded points which cannot be tested in SModelS: points with long-lived particles and points which are excluded only by searches for heavy Higgses

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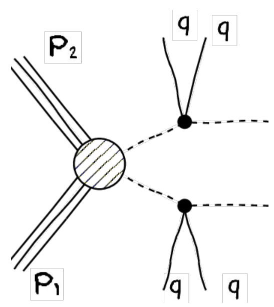
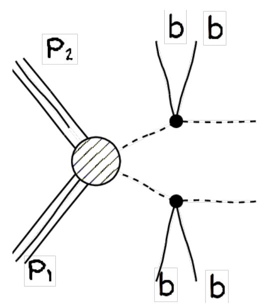
Why are SMS results missing light gluinos?

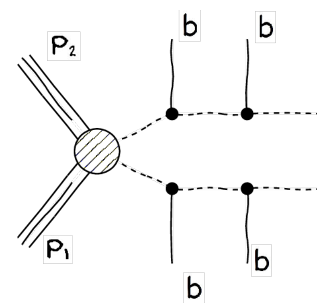
- Most SMS results assume pair production followed by the same simple cascade decay on either branch.



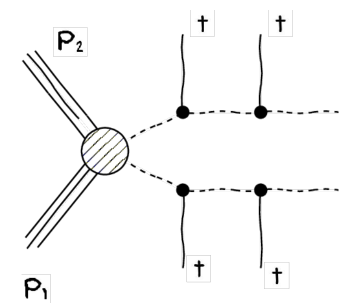
$\tilde{g} \to q\bar{q}\tilde{\chi}_1^0$



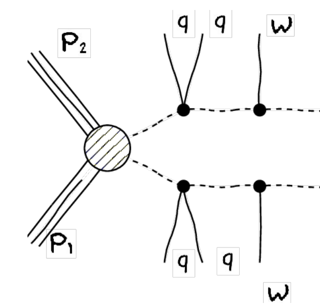
$\tilde{g} \to b\bar{b}\tilde{\chi}_1^0$



$\tilde{g} \to b\tilde{b},\, \tilde{b} \to b\tilde{\chi}_1^0$

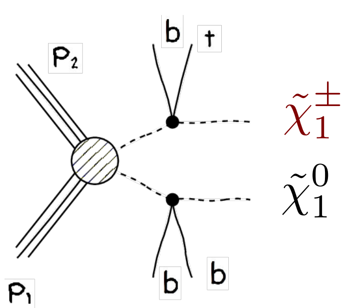


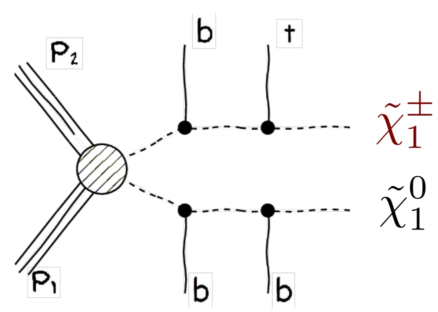
$\tilde{g} \to t\tilde{t},\, \tilde{t} \to t\tilde{\chi}_1^0$



$\tilde{g} \to q\bar{q}'\tilde{\chi}_1^\pm,\, \tilde{\chi}_1^\pm \to W\tilde{\chi}_1^0$

- Fastlim efficiency maps contain also some asymmetric topologies, e.g.





assumes decay products of chargino decay are too soft too be visible (very small mass difference of chargino-neutralino; typical higgsino-LSP case)

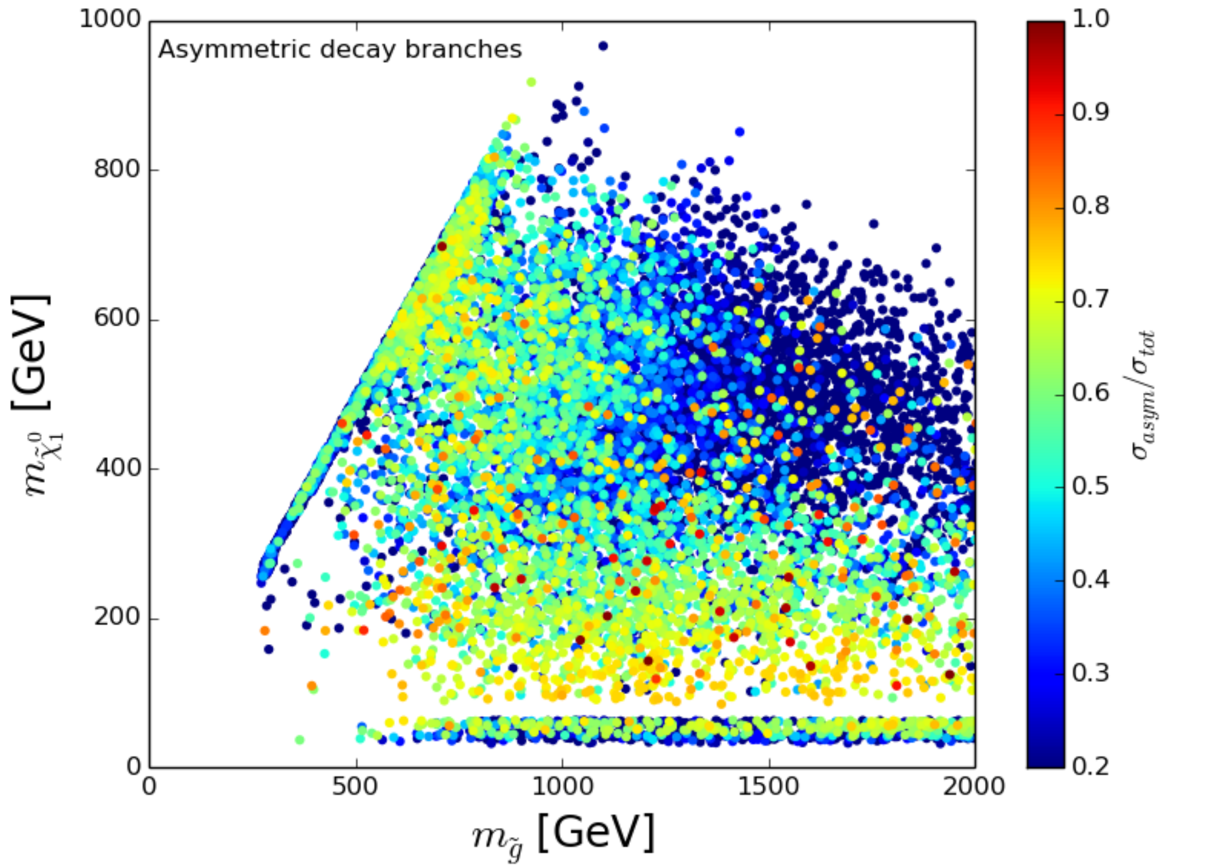
- In general much more variety possible, including mixed decays via heavy neutralinos, longer cascades, asymmetric branches from associated production, etc.

NB some ATLAS/CMS results available for long cascades, but not applicable in general because only one mass plane with fixed intermediate masses.

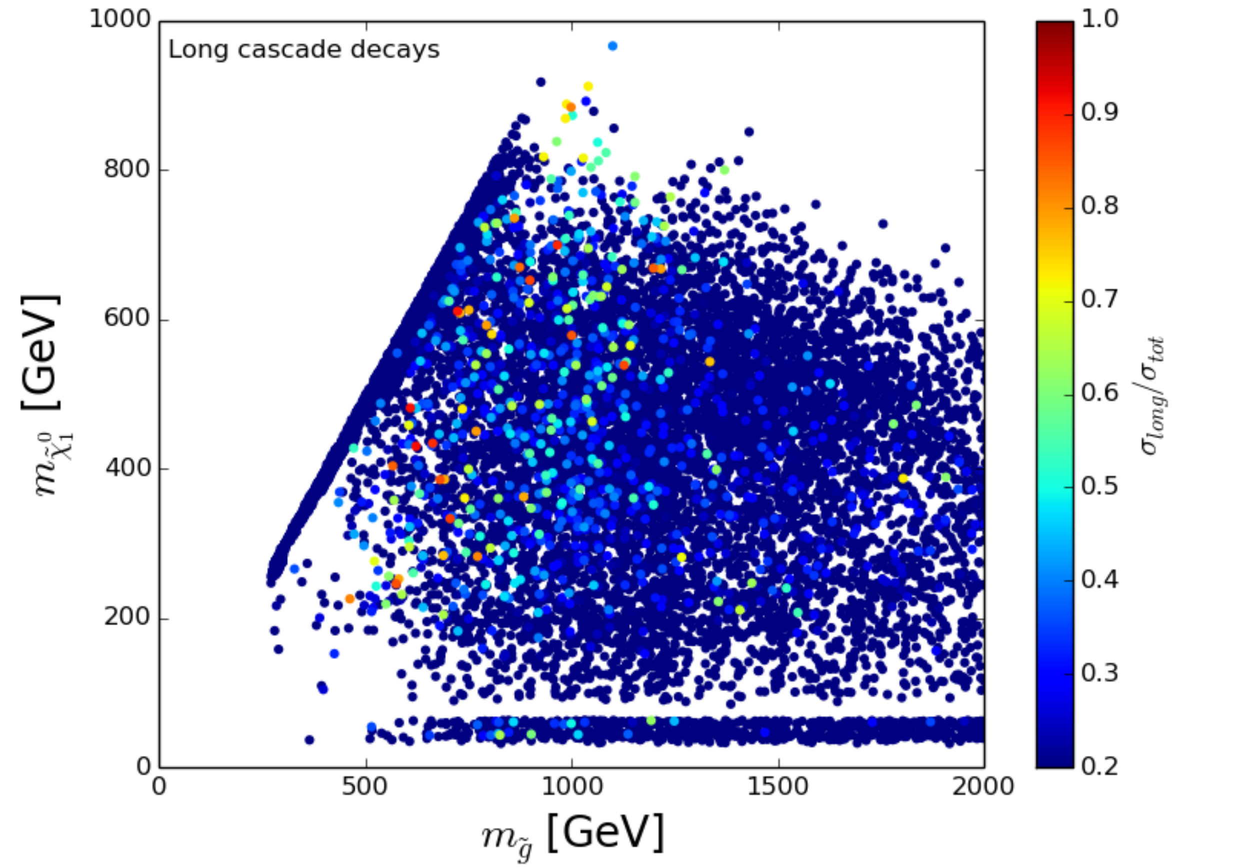
Asymmetric or long cascade decays?

Points excluded by ATLAS but not by SModelS: how much of the cross section goes into asymmetric branches or long cascade decays for which we have no SMS results?

Asymmetric topologies



Long cascade decays



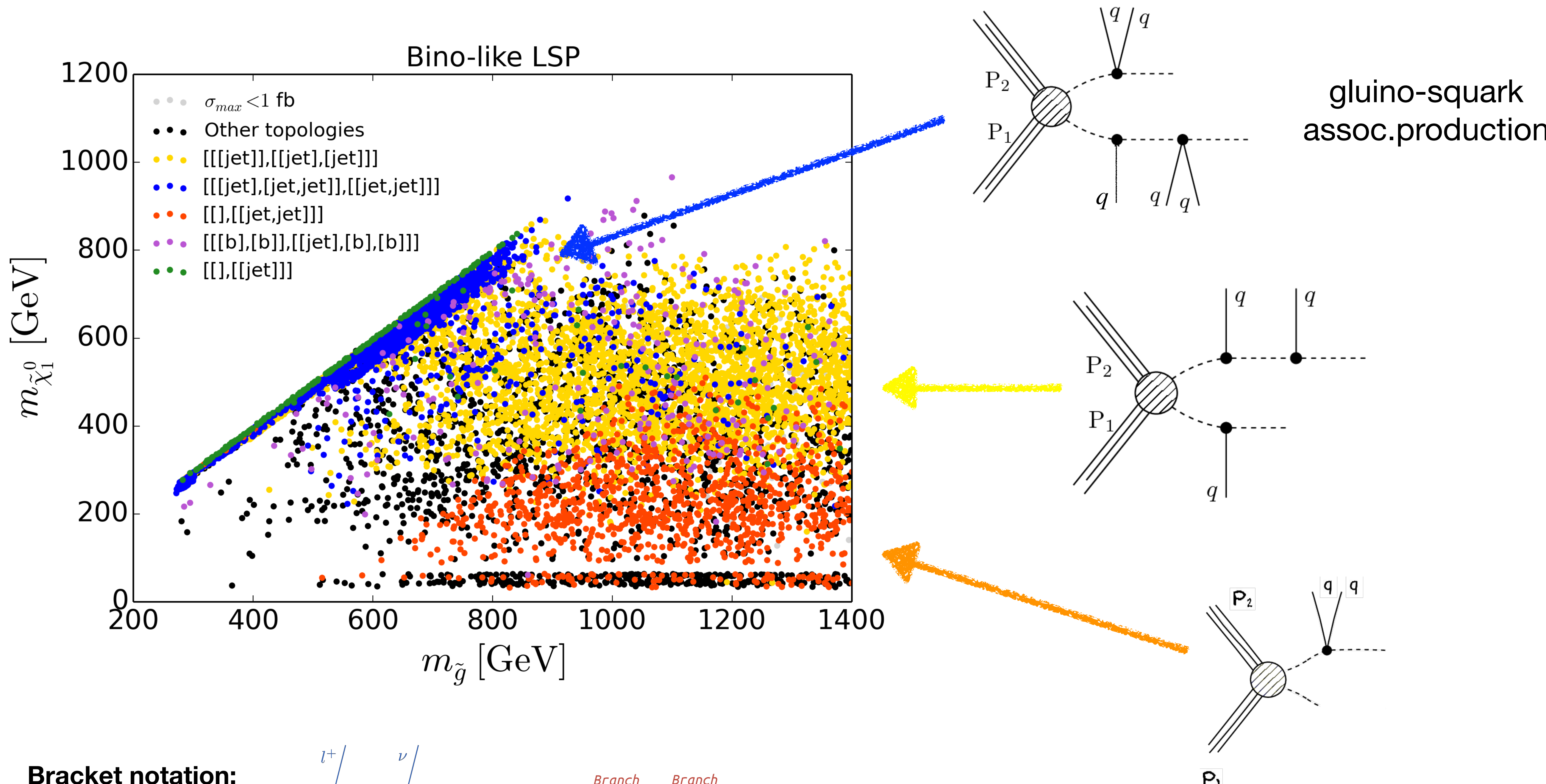
Asymmetric topologies: short decays (max. one intermediate particle) but different final states from the two branches

Long cascade decays: more than one intermediate SUSY particle in the decay chain (4 or more mass parameters).

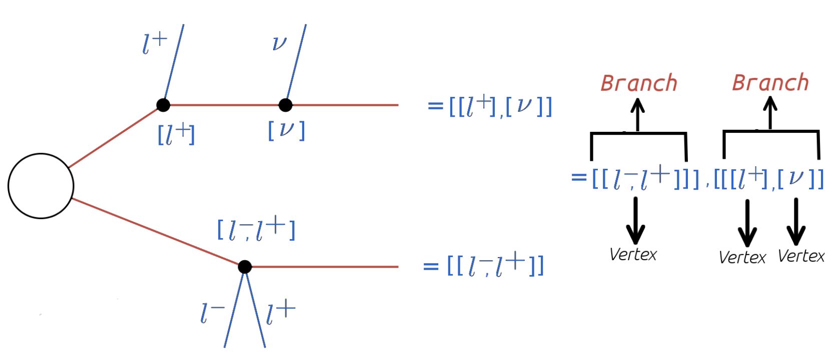
Plots are for bino-like LSP case, but look similar for higgsino-like LSP.

Most important missing topologies

i.e. topologies for which no SMS results are available



Bracket notation:



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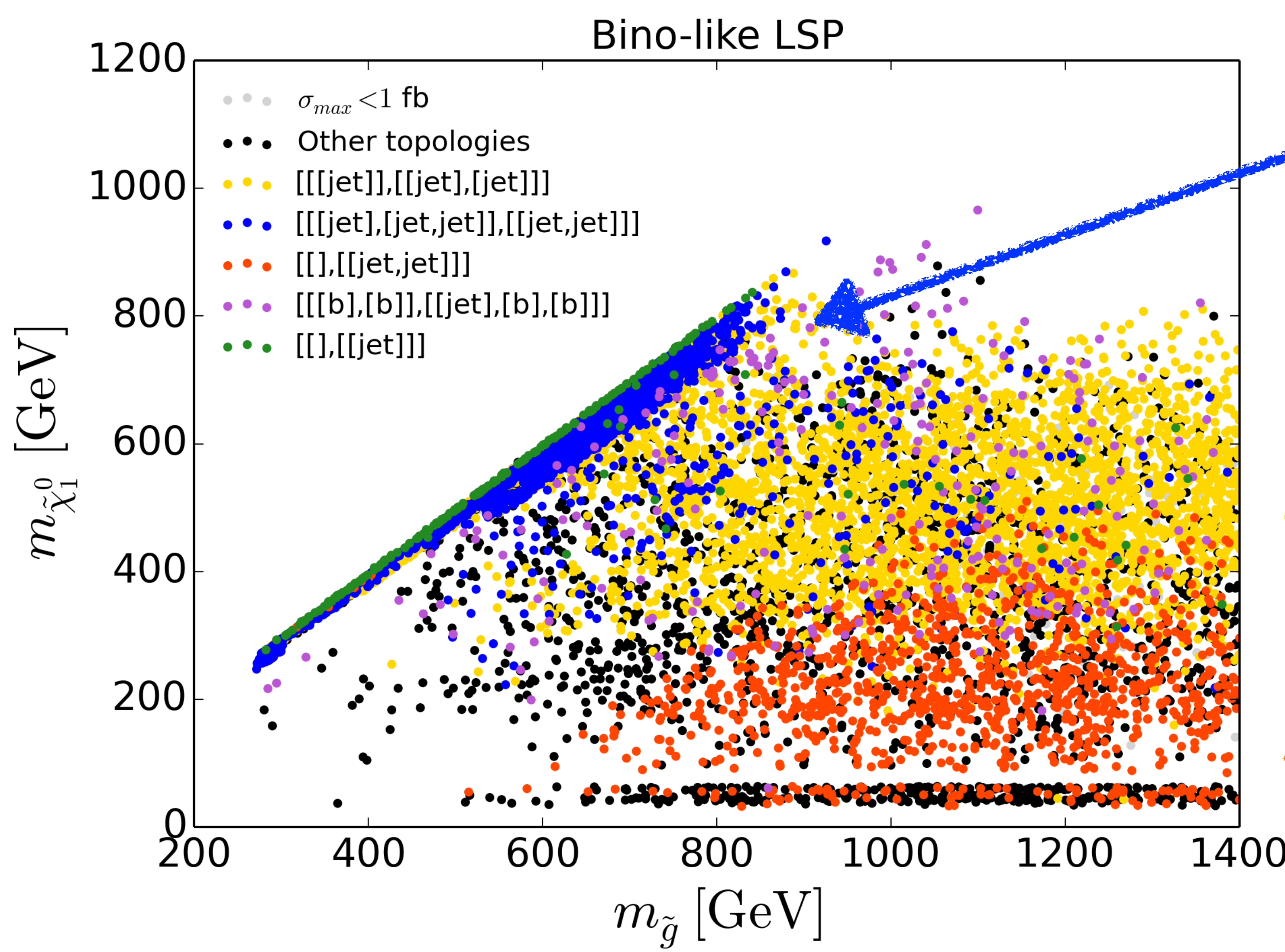
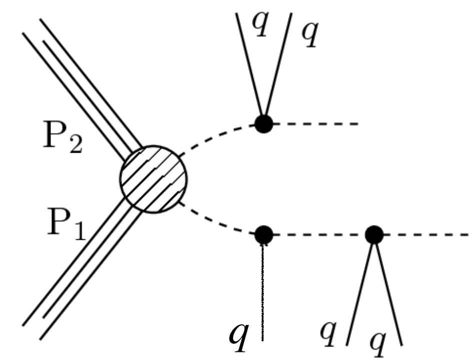
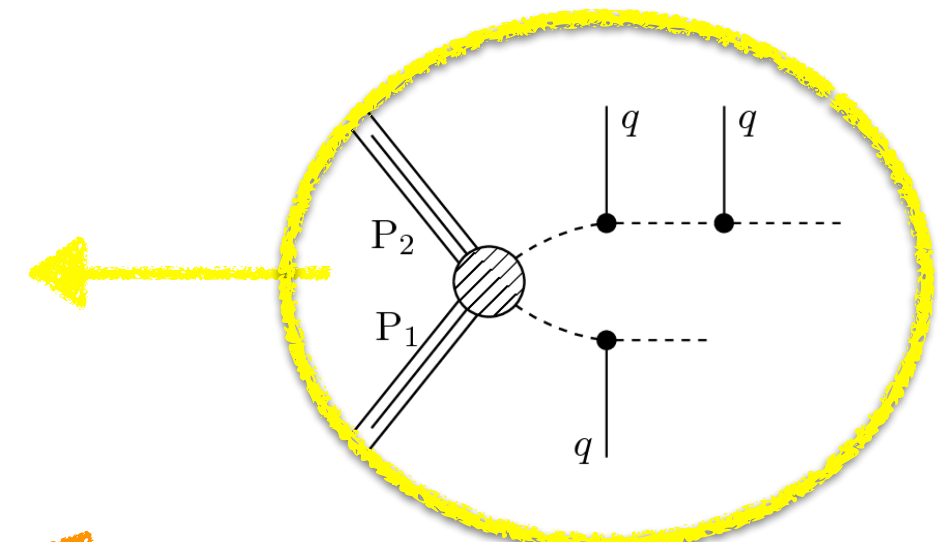
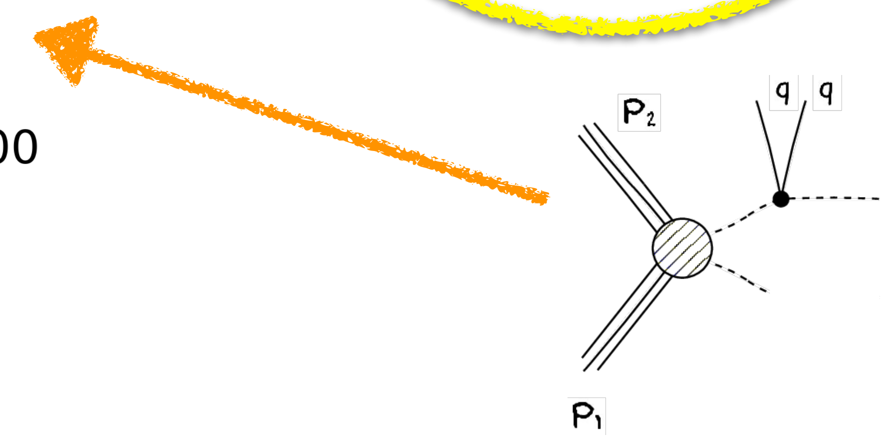




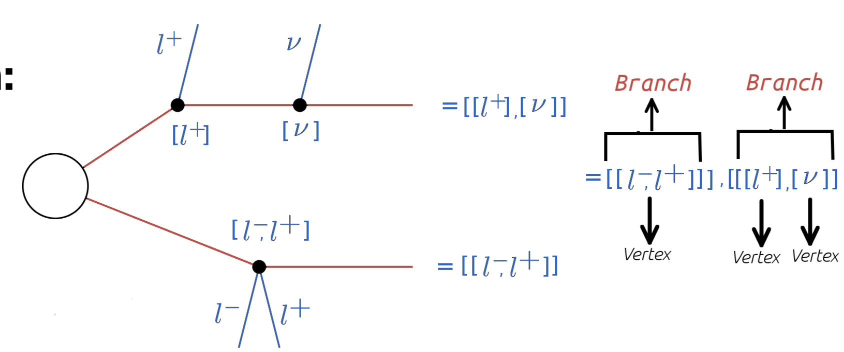
gluino-squark assoc.production





assoc. production with LSP

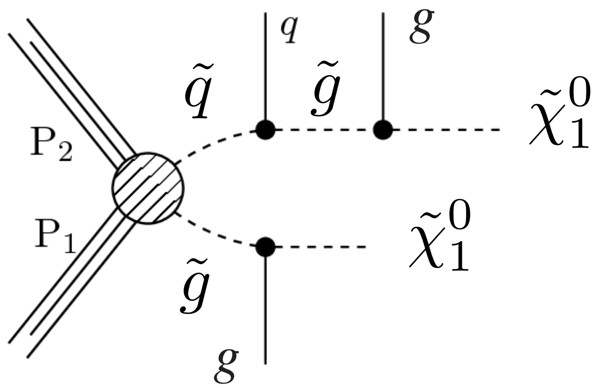
Bracket notation:



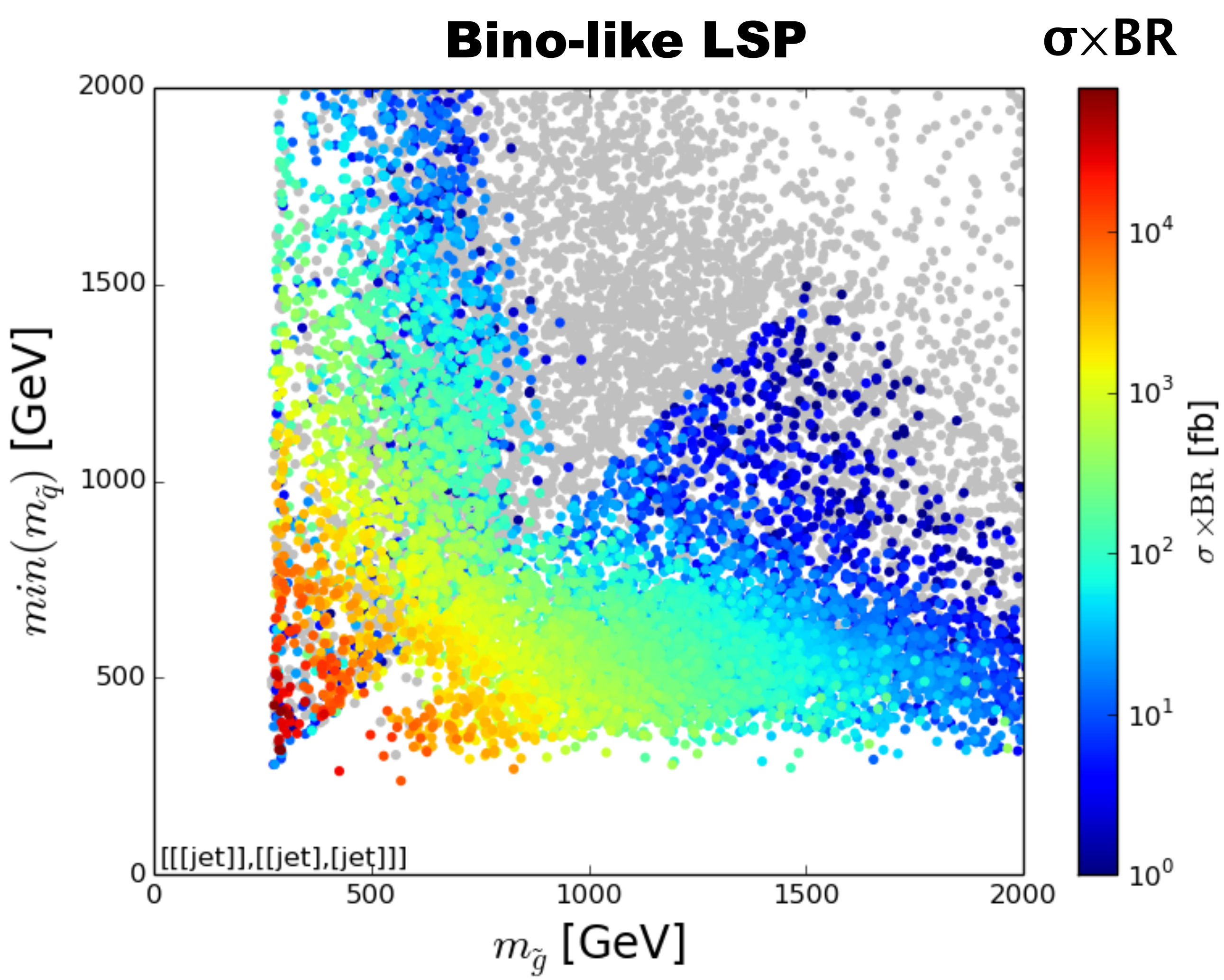
Gluino-squark associated production

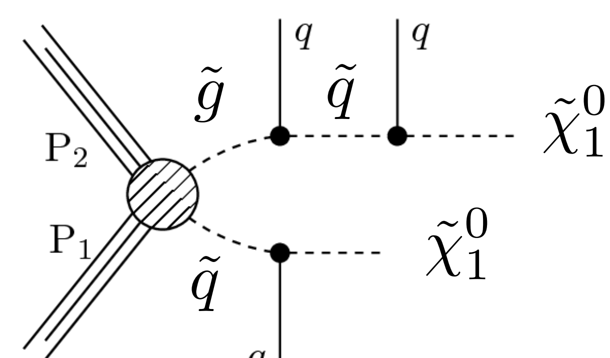
particularly important missing topology when one squark is lighter than the others

can have very large cross section



NB: gluino loop decay more important than 3-body decay via highly split squarks.





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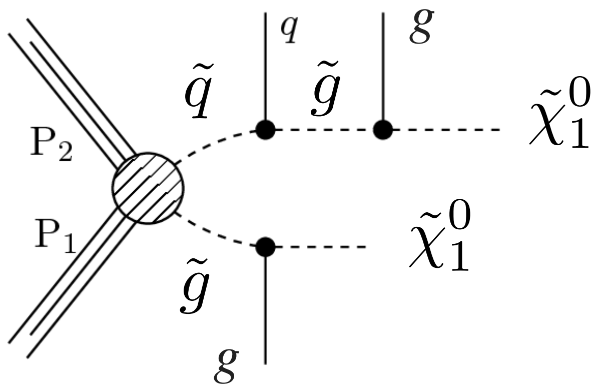

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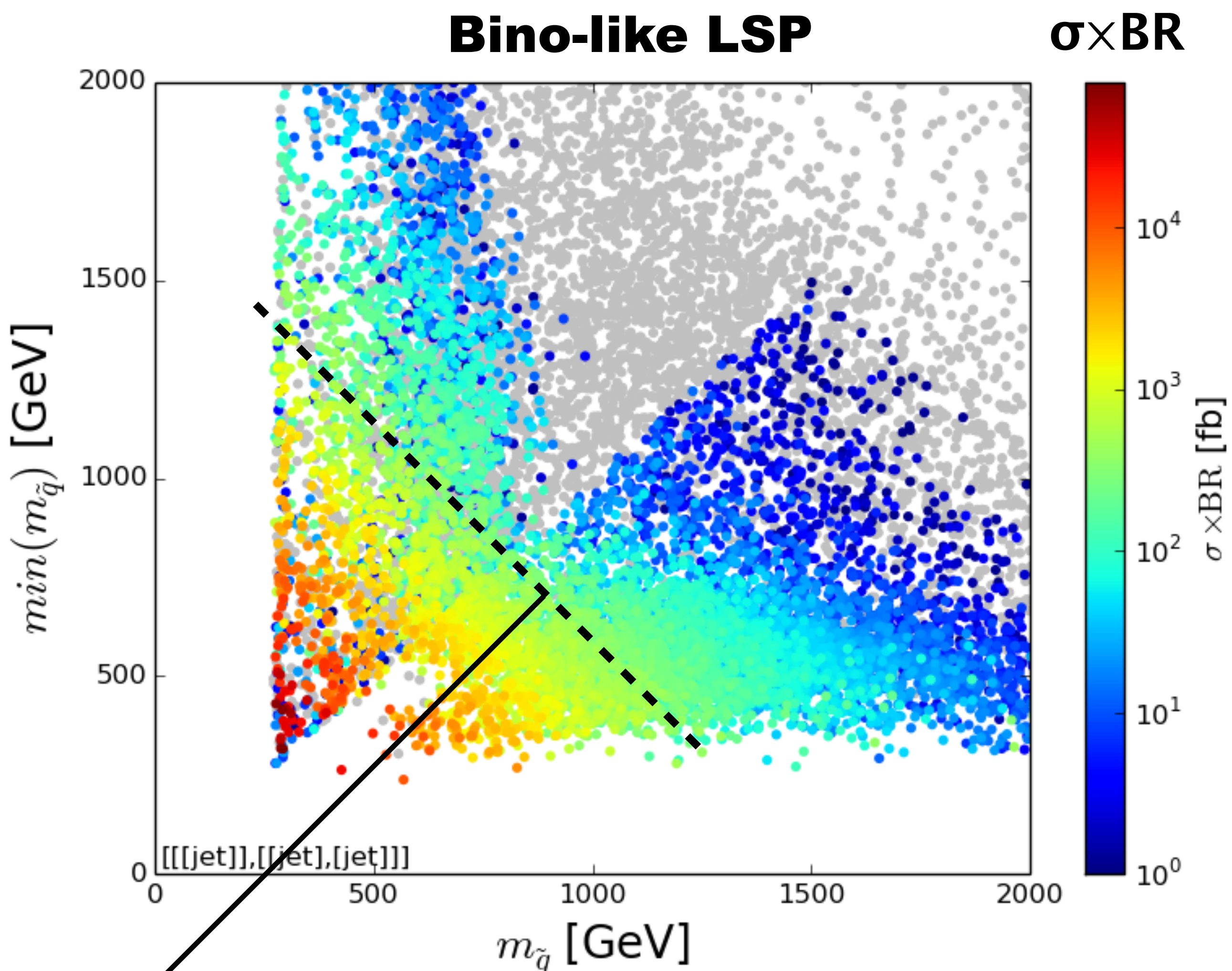
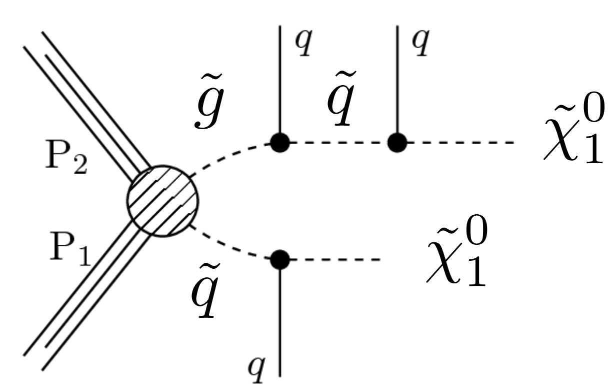


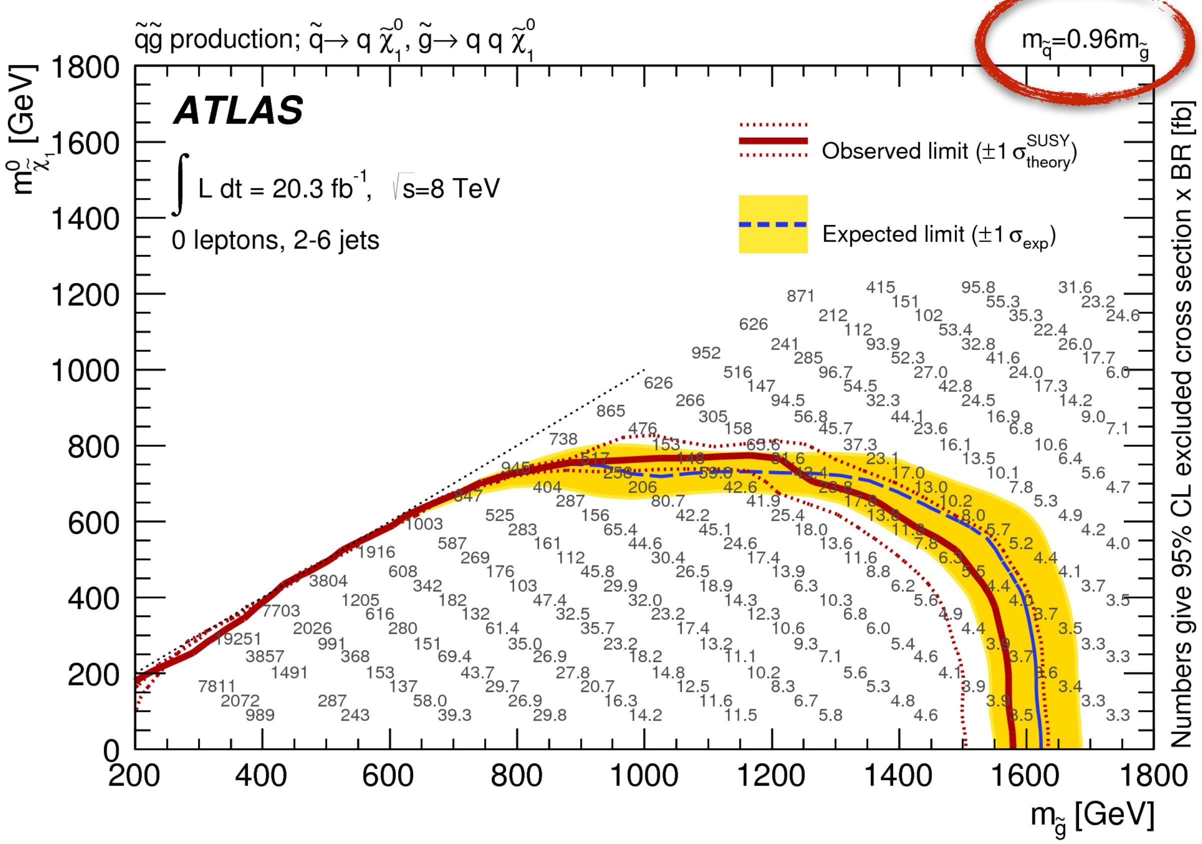
could likely cover this region if the relevant SMS results existed

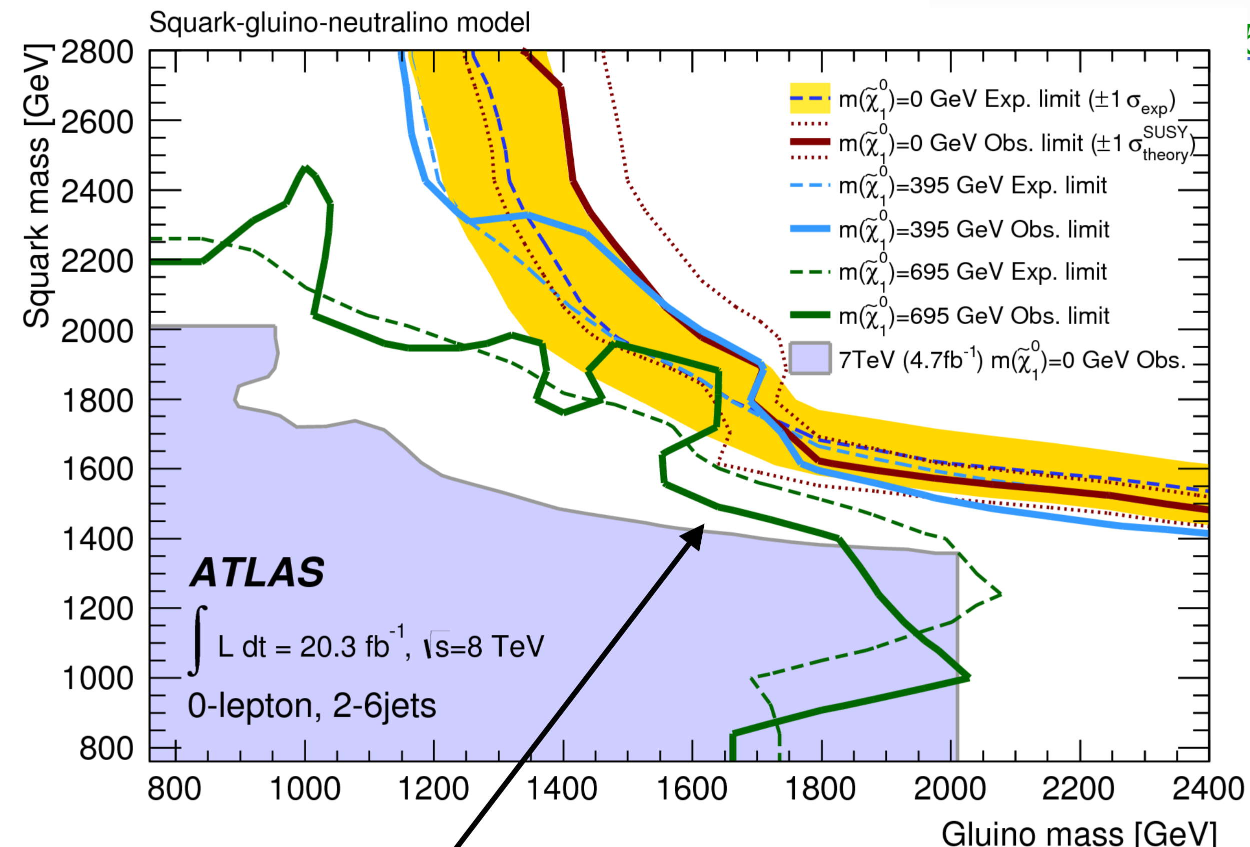


Gluino-squark simplified model in AT

assumes 8 degenerate squarks

fixed mass relation





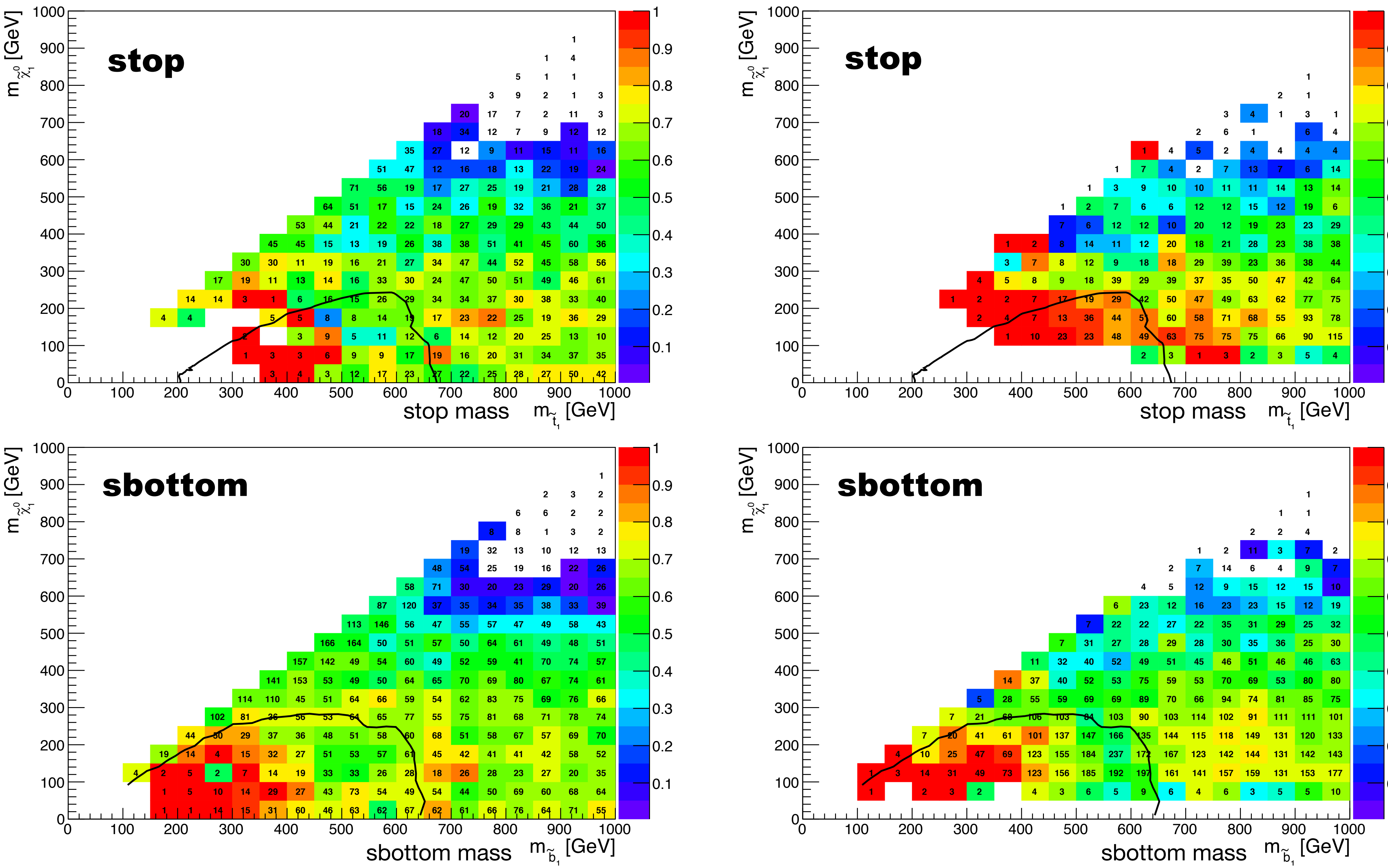
gluino-squark mass limits for 3 different LSP masses

But no cross section upper limits or efficiency maps available for these :-(

Coverage of 3rd generation

note small number
of points in each bin

Bino-like LSP | **Higgsino-like LSP**



missing: SMS for decays via heavier EW-inos with visible decays to LSP

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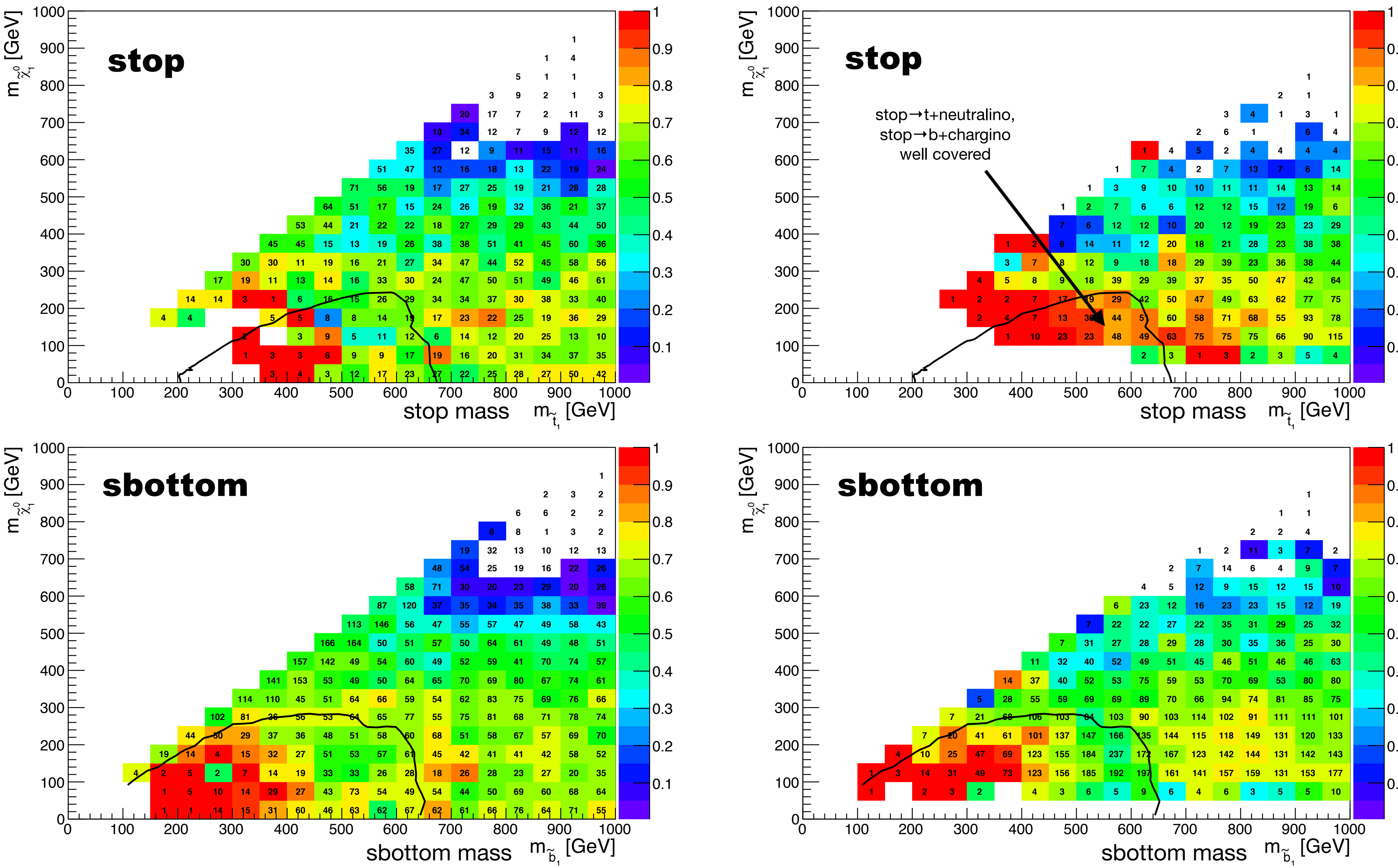

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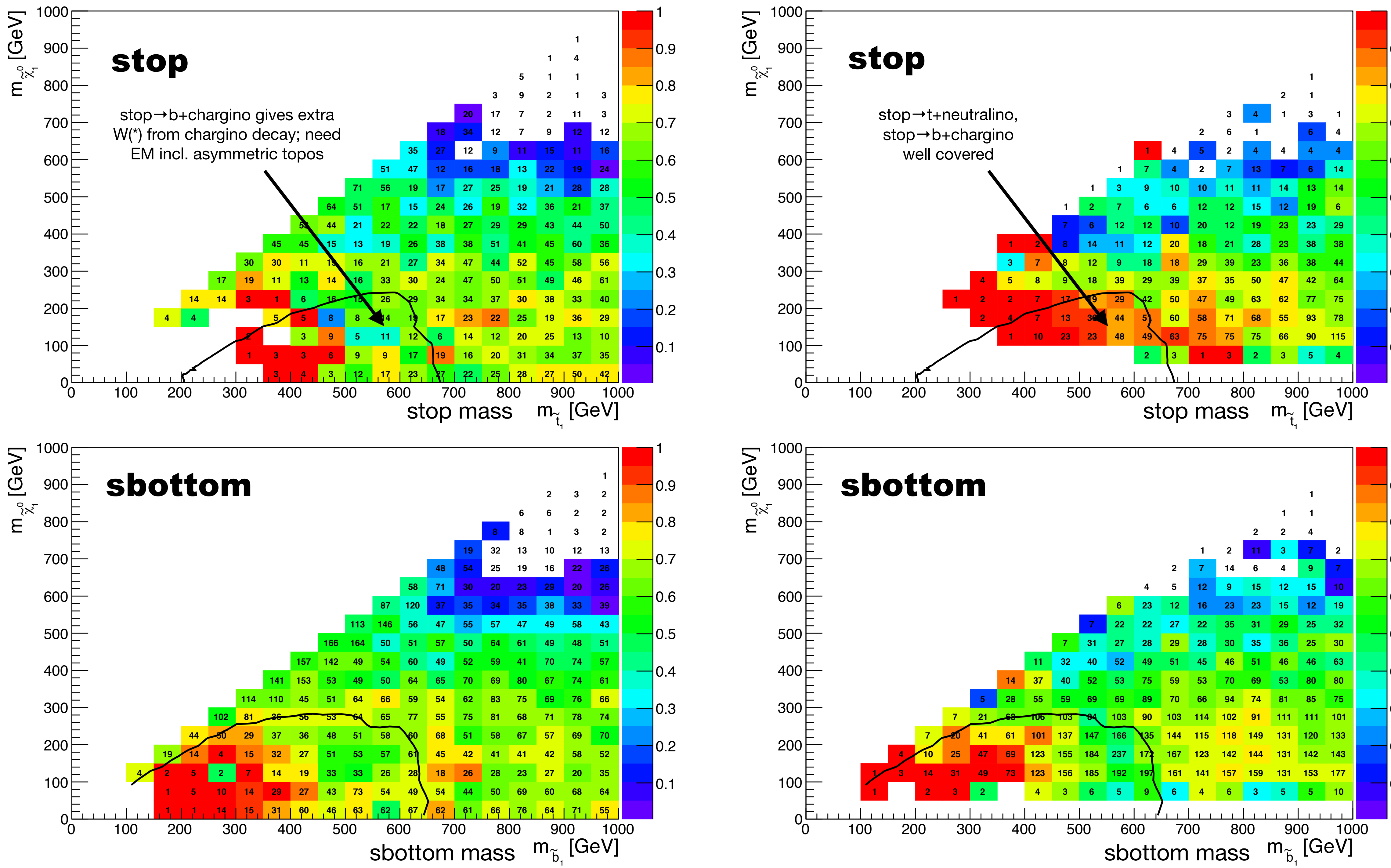
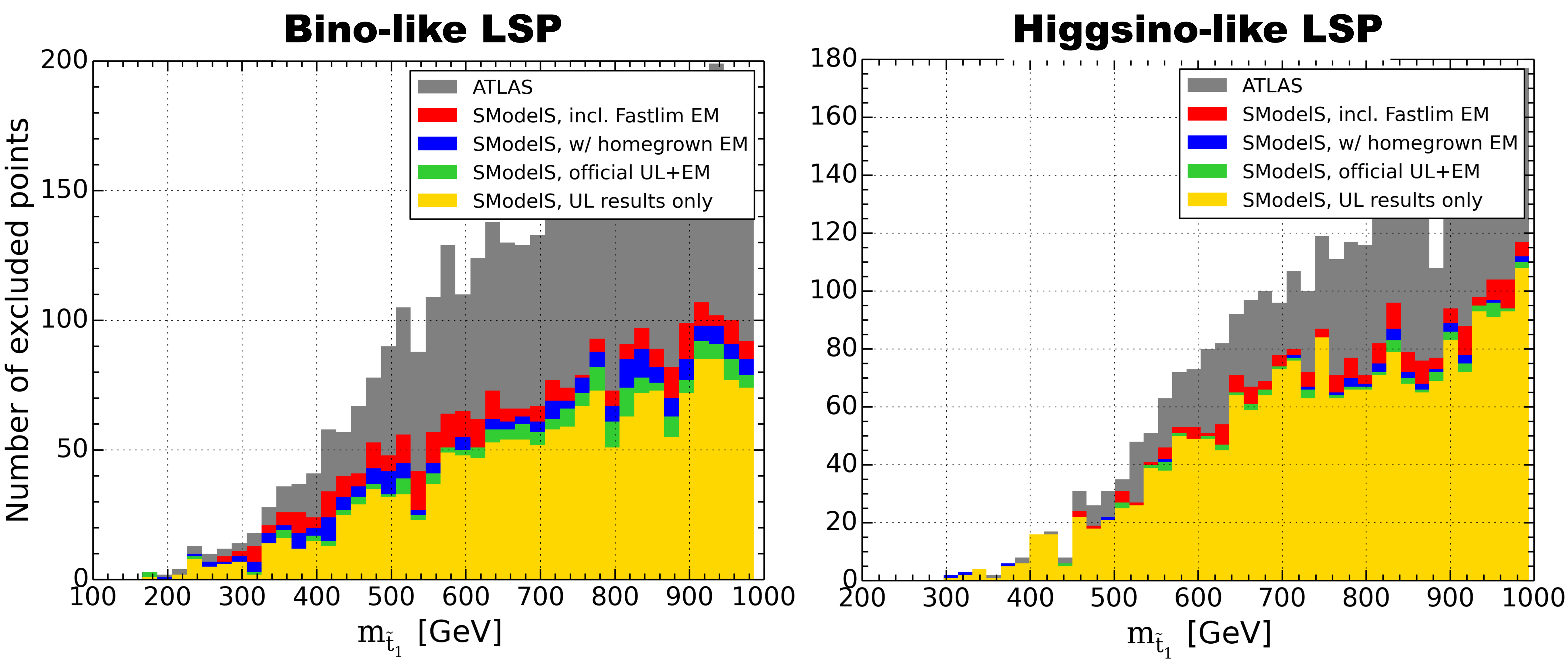


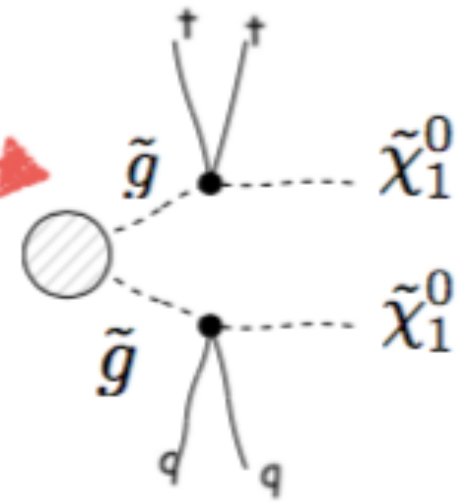
missing: SMS for decays via heavier EW-inos with visible decays to LSP

Coverage of light stops (1D)

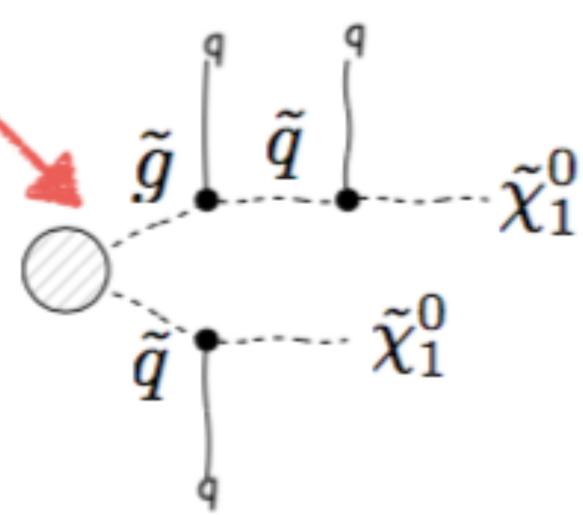


Asymmetric decay branch examples

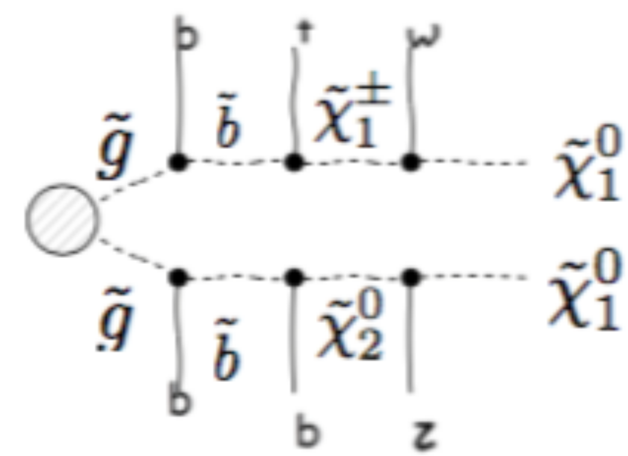
covered by Fastlim EMs (incl. in SModelS)

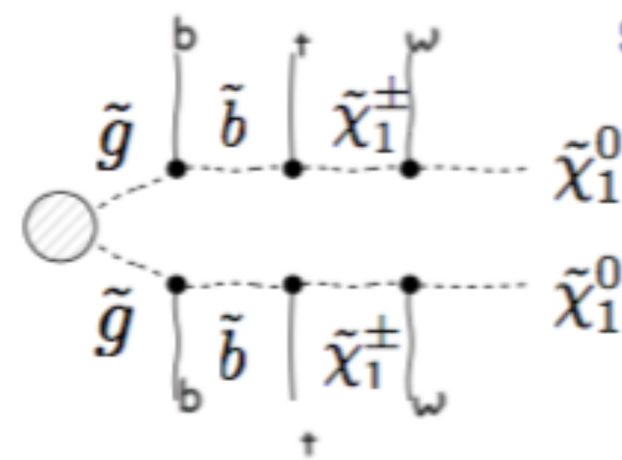


important topology but no SMS results available!



Long cascade decay examples



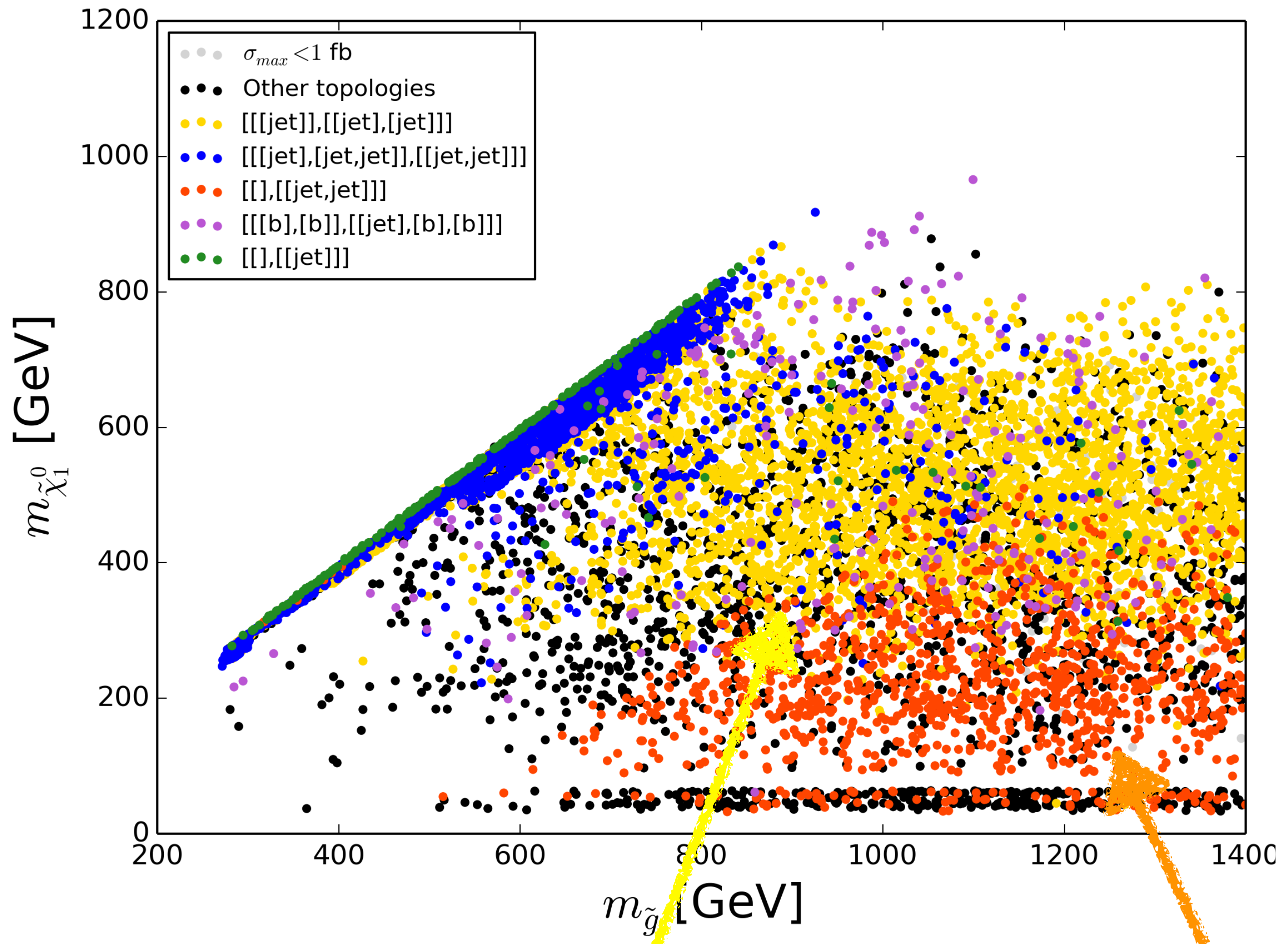


at least 4 free mass parameters, not viable Simplified Model

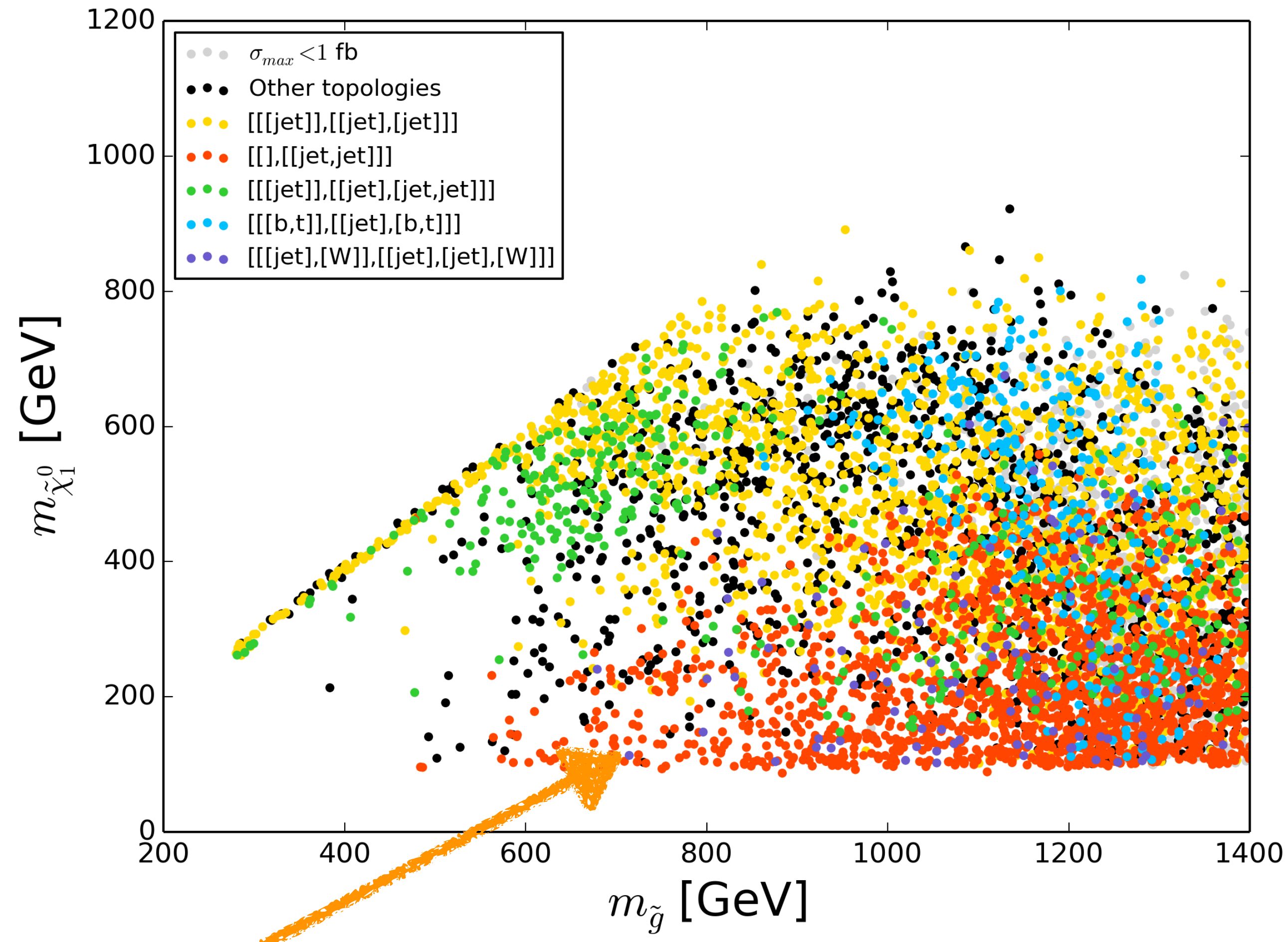
curtesy Ursula Laa

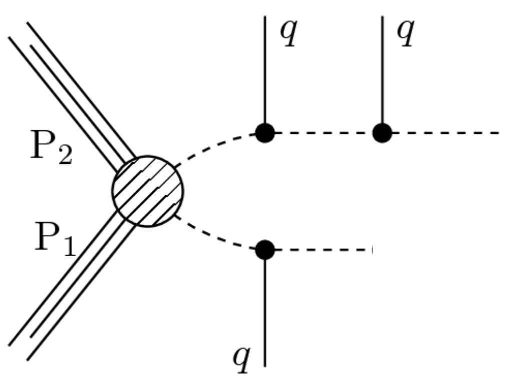
Most important missing topologies

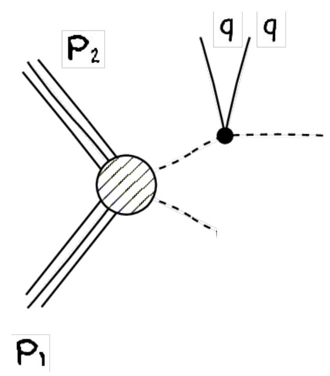
Bino-like LSP

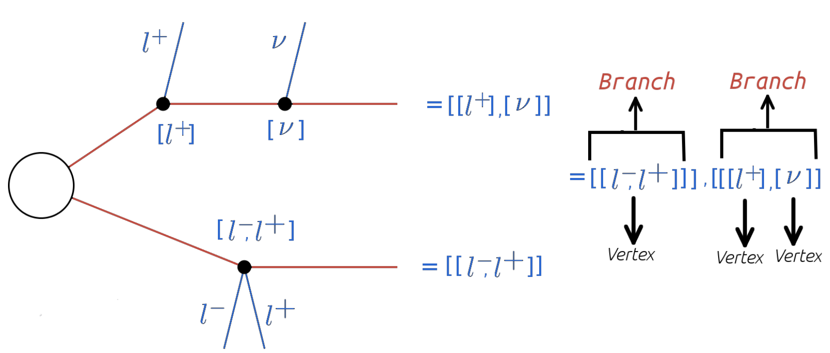


Higgsino-like LSP

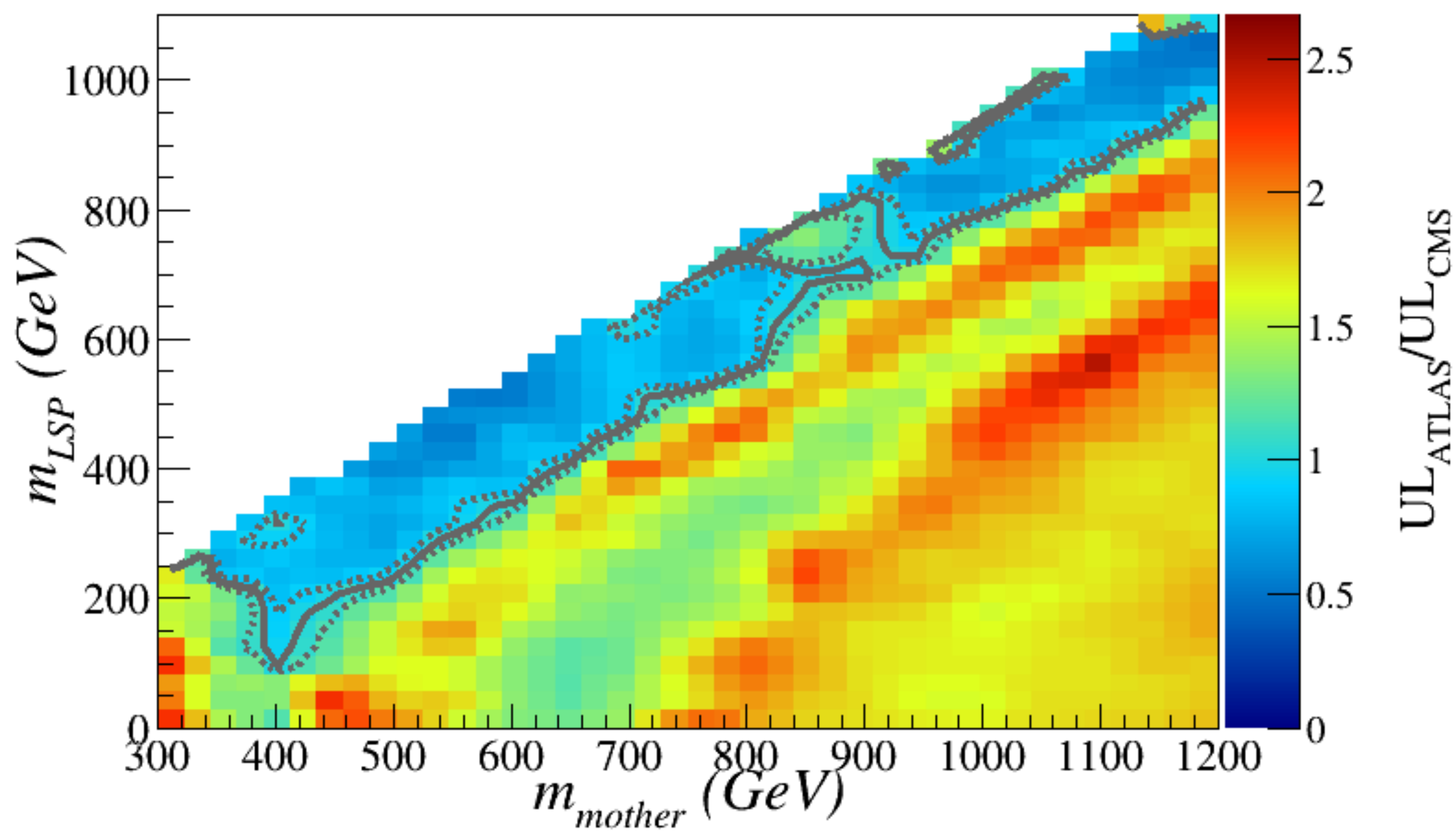








T2 upper limit ratio



> 2 jets + MET @ 8 TeV : for small mass differences, CMS excludes a bit more than ATLAS