



Universität Hamburg

DER FORSCHUNG | DER LEHRE | DER BILDUNG



Bundesministerium für Bildung und Forschung

SLHA or LHE input

Model

$\sigma \times BR$

$\sigma \times BR$

$\sigma \times BR$

Database

Experimental Analyses

$\sigma \times UL$

Interpreting LHC Results

Making sense of simplified model results with

SModels

Decompose

Combine Topologies

Compare with

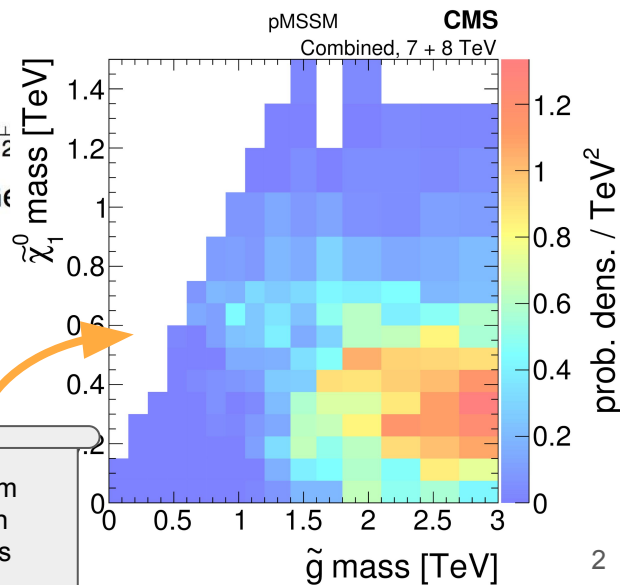
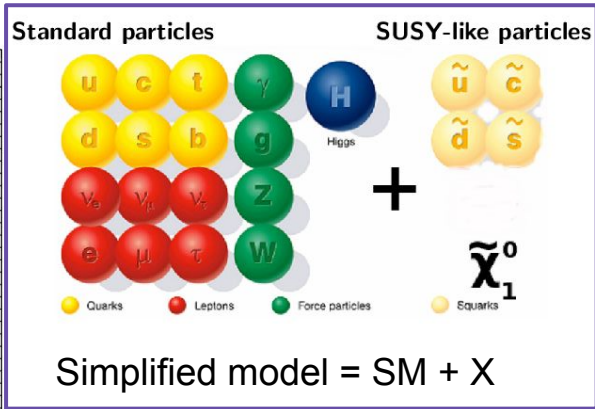
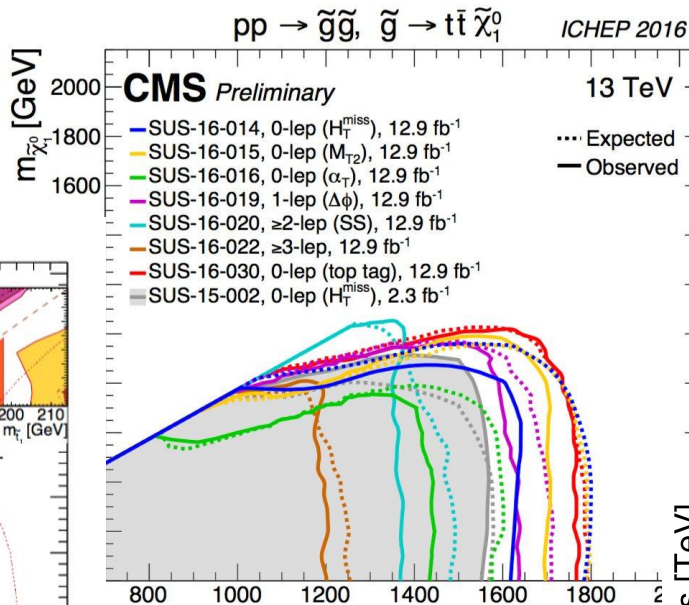
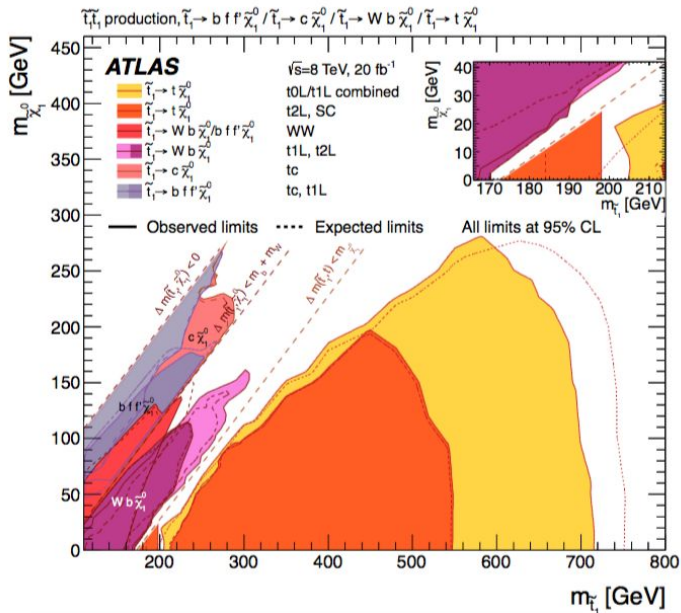
[arXiv:1412.1745](https://arxiv.org/abs/1412.1745)

[arXiv:1312.4175](https://arxiv.org/abs/1312.4175)

<http://smodels.hephy.at>

Jory Sonneveld in collaboration with/slides from:
Sabine Kraml, Suchita Kulkarni, Ursula Laa, Andre Lessa, Wolfgang Waltenberger

LHC Results



Theorist: what does this mean for my model?

Experimentalist: What do I search for next?

See talk by Sam Bein at 16:00 in SUSY searches

Interpreting LHC results

SUSY-AI
RIVET
XQCAT
RECAST...



MAD
Analysis 5

CHECKMATE

The logo for CHECKMATE, featuring the word 'CHECKMATE' in a bold, white, outlined font. To the right of the text is a black and white illustration of a chess king piece, with motion lines suggesting it is moving or falling.

SModelS

Fastlim

Either: recast your model

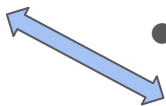
- Simulation: time-consuming
- Implementation of analysis

Or: apply existing simplified model results

- May not cover full model
- Valid under certain assumptions
- Can be used to show coverage of searches

Need analysis documentation

Need many simplified model results



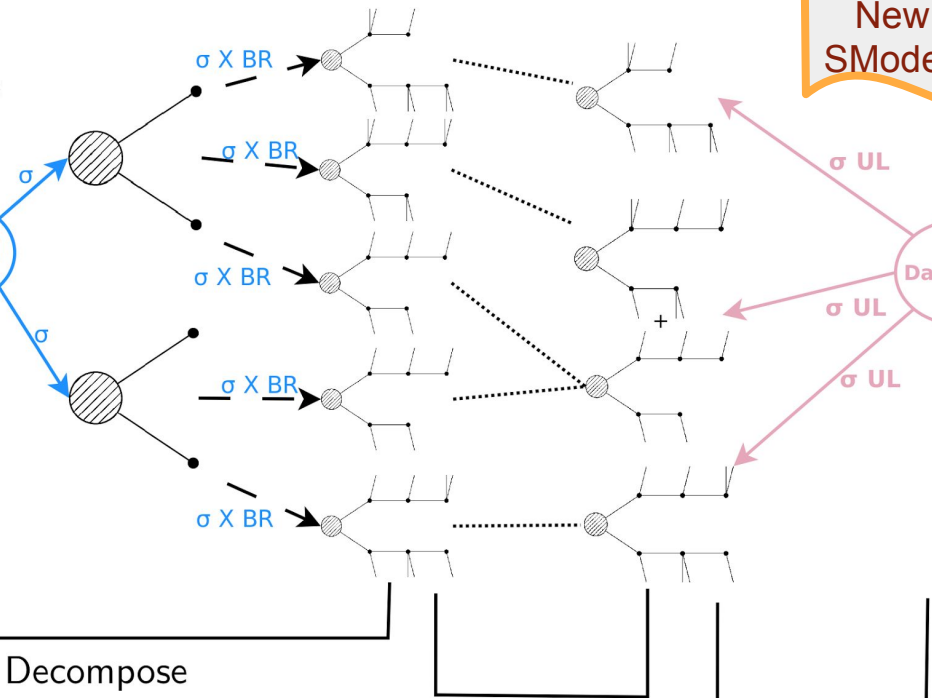
See talk by Marek Niedziela at 14:20 in SUSY searches

What does it mean for my model?

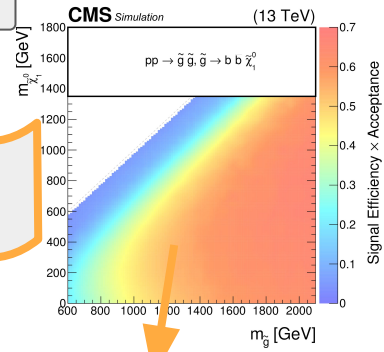


- (p)MSSM
- UED
- NMSSM
- HSCP
- U(1)MSSM ext
- ...

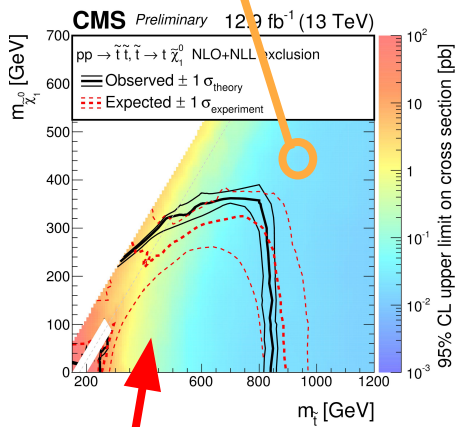
SLHA or LHE input



New in SModels



Experimental Analyses



The limits, NOT the lines!

SModelS database of experimental results

~ 14 publications + 16 CONF notes



~ 13 publications + 5 PAS

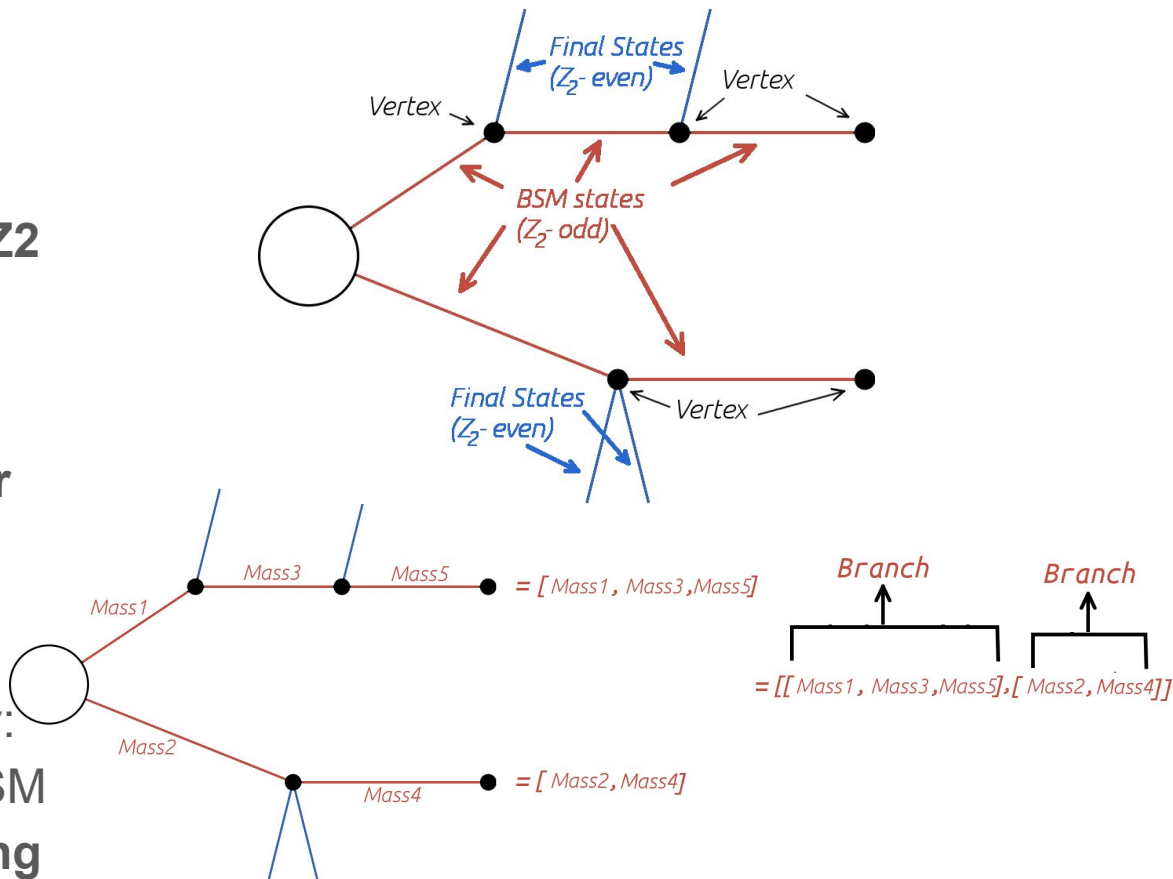


Experimental Result	\sqrt{s}	lumi	data type
ATLAS-CONF-2012-105	8	5.8	upperLimit
ATLAS-CONF-2012-166	8	13.0	upperLimit
ATLAS-CONF-2013-001	8	12.8	upperLimit
ATLAS-CONF-2013-007	8	20.7	upperLimit
...
ATLAS-SUSY-2013-14	8	20.3	upperLimit
ATLAS-SUSY-2013-15	8	20.3	efficiencyMap
ATLAS-SUSY-2013-15	8	20.3	upperLimit
ATLAS-SUSY-2013-16	8	20.1	efficiencyMap
ATLAS-SUSY-2013-16	8	20.1	upperLimit
ATLAS-SUSY-2013-18	8	20.1	efficiencyMap
ATLAS-SUSY-2013-18	8	20.1	upperLimit
ATLAS-SUSY-2013-19	8	20.3	upperLimit
ATLAS-SUSY-2013-23	8	20.3	upperLimit
ATLAS-SUSY-2014-03	8	20.3	efficiencyMap
ATLAS-SUSY-2015-09	13	3.2	upperLimit

Experimental Result	\sqrt{s}	lumi	data type
CMS-SUS-12-024	8	19.4	efficiencyMap
CMS-SUS-12-024	8	19.4	upperLimit
CMS-SUS-12-028	8	11.7	upperLimit
CMS-SUS-13-002	8	19.5	upperLimit
CMS-SUS-13-004	8	19.3	upperLimit
CMS-SUS-13-006	8	19.5	upperLimit
CMS-SUS-13-007	8	19.3	efficiencyMap
CMS-SUS-13-007	8	19.3	upperLimit
CMS-SUS-13-011	8	19.5	efficiencyMap
CMS-SUS-13-011	8	19.5	upperLimit
CMS-SUS-13-012	8	19.5	efficiencyMap
CMS-SUS-13-012	8	19.5	upperLimit
CMS-SUS-13-015	8	19.4	efficiencyMap
CMS-SUS-13-015	8	19.4	upperLimit
CMS-SUS-13-019	8	19.5	upperLimit
...
CMS-SUS-PAS-13-016	8	19.7	upperLimit
CMS-SUS-PAS-13-018	8	19.4	upperLimit
CMS-SUS-PAS-15-002	13	2.2	upperLimit

The decomposition

- The BSM model must have a **Z₂ symmetry** (DM inspired) like R-Parity, KK-parity, . . .
- For now we only consider **pair production** of Z₂-odd particles (no resonances, . . .)
- Each topology is described by: topology shape, final states, BSM masses, and xsec x BR **ignoring spin, color, etc.** of BSM states



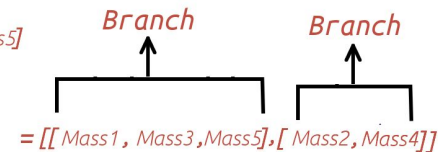
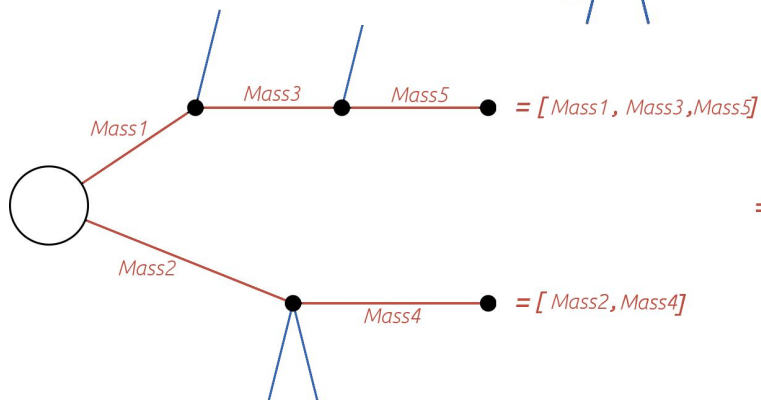
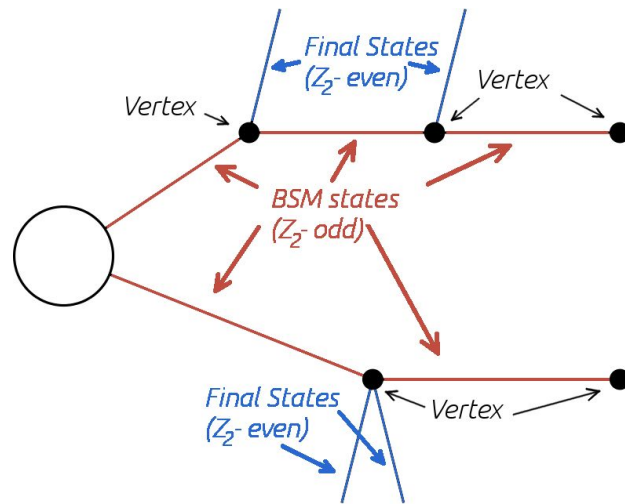
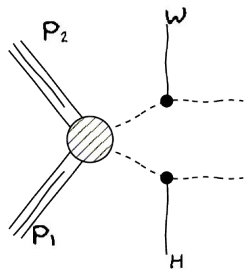
“Model independent”:
no reference to original model

The decomposition

Simplified model names:

<http://smodels.hephy.at/wiki/SmDictionary>

#22
TChiWH
vertices: (2)(2)
insertions: (1,0)(1,0)
[[[higgs]], [[w]]]



“Model independent”:
no reference to original model

What does it mean for my model?

```
./runSMModelS.py -f mymodel.slha
```

$$r_{\text{expected}} = \frac{\sigma_{\text{theo}}^{\text{pred}}}{\sigma_{\text{upper limit}}^{\text{expected}}}$$

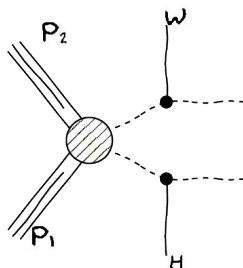
```
Total Number of Elements: 99
#Analysis Sqrts Cond. Violation Theory_Value(fb) Exp_limit(fb) r
-----
CMS-SUS-13-006 8.00E+00 0.0 2.107E-01 3.867E-01 5.450E-01
Signal Region: MET_100
Txnames: TChiWH
r_expected, chi2, likelihood = 5.427E-01 1.540E+00 5.554E-02
-----
CMS-SUS-13-019 8.00E+00 0.0 1.773E+00 3.762E+00 4.714E-01
Signal Region: (UL)
Txnames: T2 ?
-----
CMS-SUS-13-012 8.00E+00 0.0 1.255E-01 2.733E-01 4.593E-01
Signal Region: 6NJet8_1250HT1500_450MHTinf
Txnames: T1, T2, T5WW
r_expected, chi2, likelihood = 8.205E-01 1.791E-01 1.476E-01
-----
ATLAS-SUSY-2013-02 8.00E+00 0.0 6.617E+00 1.718E+01 3.851E-01
Signal Region: (UL)
Txnames: T6WW ? expected limits often not published
-----
ATLAS-SUSY-2013-02 8.00E+00 0.0 5.525E-01 1.818E+00 3.039E-01
Signal Region: SR2jt
Txnames: T1, T2
r_expected, chi2, likelihood = 3.653E-01 4.186E-02 2.542E-02
-----
ATLAS-SUSY-2013-02 8.00E+00 0.0 1.773E+00 6.097E+00 2.908E-01
Signal Region: (UL)
Txnames: T2 ?
-----
ATLAS-SUSY-2013-02 8.00E+00 0.0 9.069E+00 3.234E+01 2.805E-01
Signal Region: (UL)
Txnames: T5WW ?
```

$$r = \frac{\sigma_{\text{theo}}^{\text{pred}}}{\sigma_{\text{observed}}^{\text{upper limit}}}$$

Simplified model names:

<http://smodels.hephy.at/wiki/SmDictionary>

```
#22
TChiWH
vertices: (2)(2)
insertions: (1,0)(1,0)
[[[higgs]], [[W]]]
```



$$\chi^2 = -2 \log \frac{L(n_s)}{L_{\text{max}}(n_{\text{obs}} - n_b)}$$

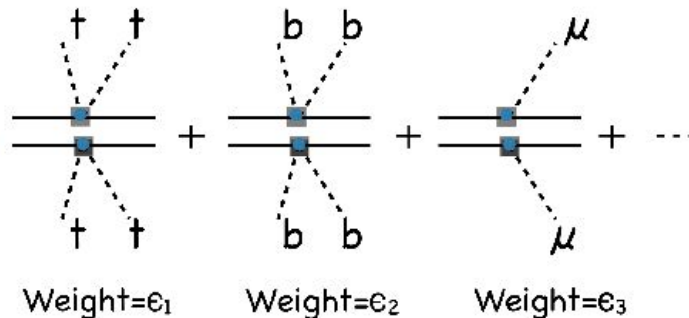
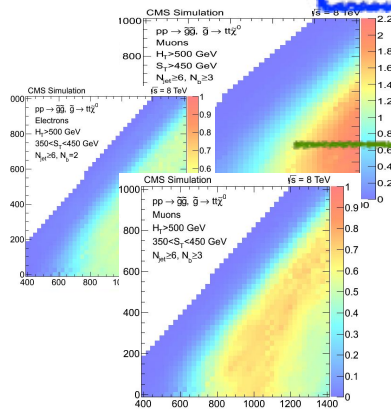
What it means for your model:
a likelihood (poiss*gauss)

New for EM results

$$L = \int_0^\infty dx \frac{(\lambda_s + \lambda_b)^{(n_{\text{obs}})} e^{-(\lambda_s + \lambda_b)}}{(n_{\text{obs}})!} \exp \left(\frac{(x - (n_s + n_b))^2}{2(\sigma_s^2 + \sigma_b^2)} \right)$$

New: efficiency map results

$$\text{Th. Prediction} = \sum_i \text{Weight}_i \times (\sigma \times \text{BR})_i$$

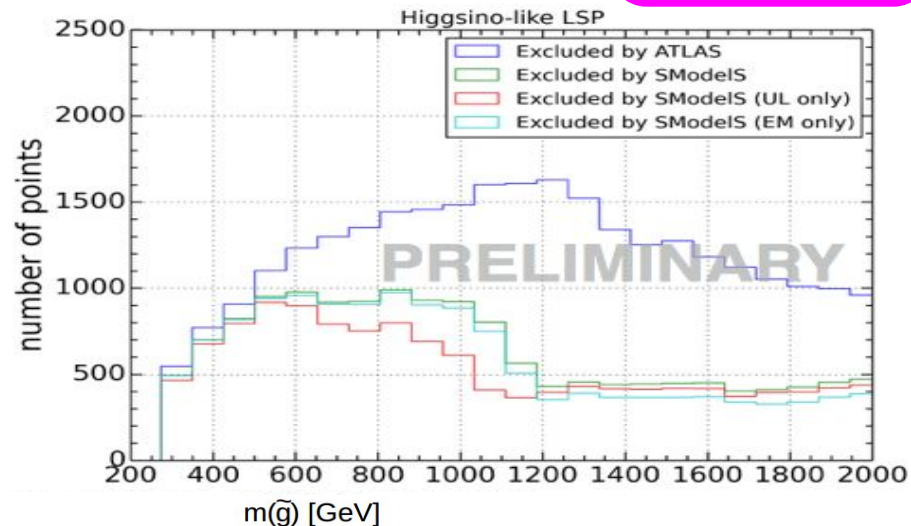
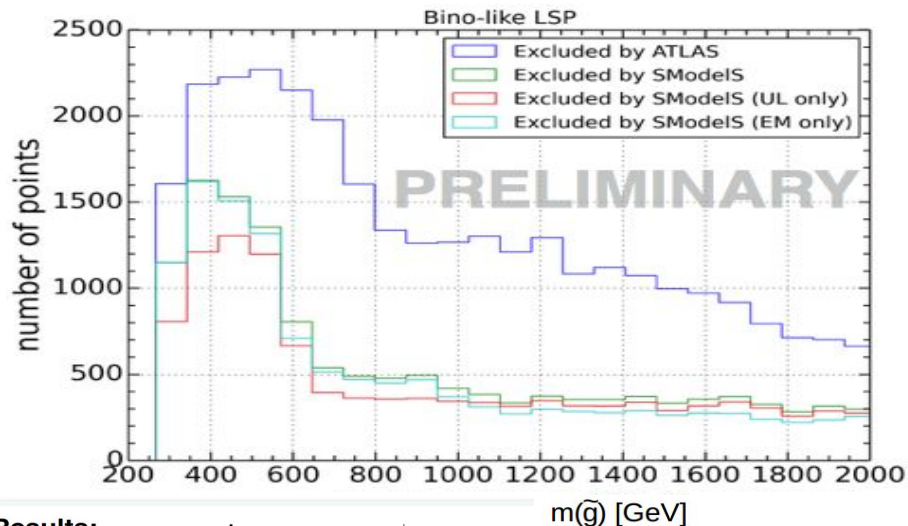


Each topology is weighted by the proper efficiency value

The best signal region, leading to the best expected limit, is used

CMS, where are your SLHA files?

Interpretation in pMSSM using ATLAS results



Results:

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

PRELIMINARY

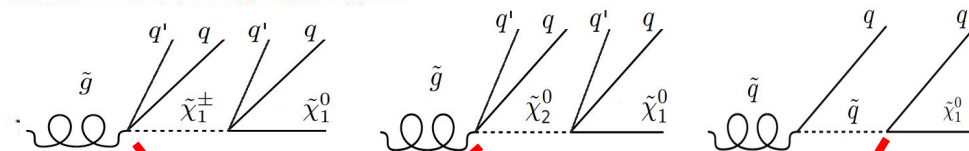
Note that not all simplified models are covered.
 Not all masses/mass parametrizations are covered.
 Not covered: analyses that do not have a simple SMS interpretation or a MET final state.

Missing topologies in the pMSSM

Light gluinos that escape SMS constraints:

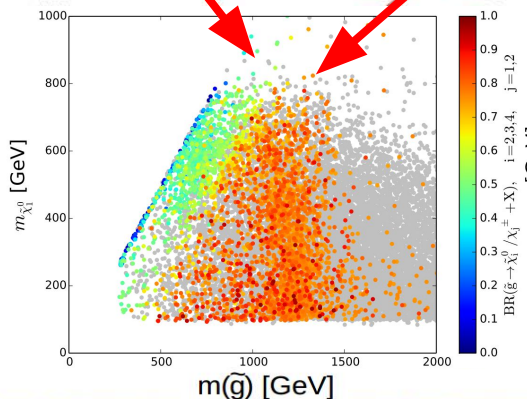
- Longer cascade decays
- Varying intermediate masses
- One-step decays via squarks
- Asymmetric branches
- Masses out of grid

Examples of Missing Topologies

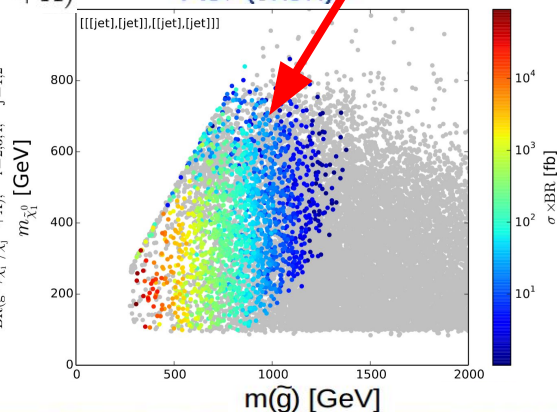


Non-degenerate right- and left-handed squarks

Branching Ratio Plot $BR(\tilde{g} \rightarrow \tilde{\chi}_i^0 / \chi_j^\pm + X)$



Plot ($\sigma \times BR$)



See also talk by U. Laa

https://indico.cern.ch/event/525142/contributions/2196600/attachments/1293495/1927612/interpretation_LAA.pdf

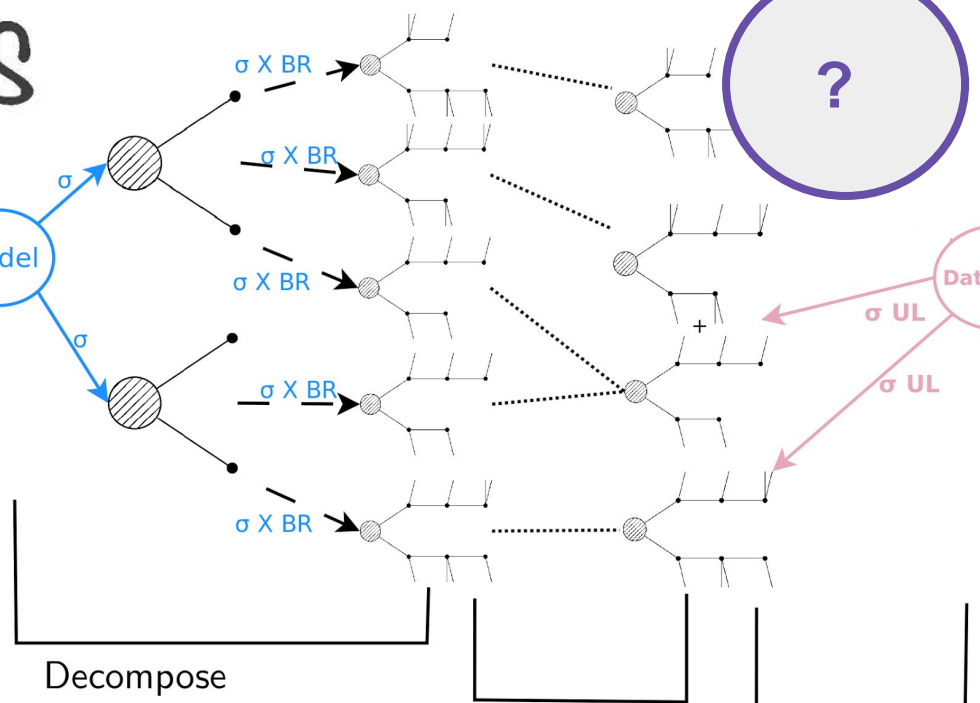
What to search for next?

SModels

- pMSSM
- UED
- NMSSM
- HSCP
- U(1)MSSM ext

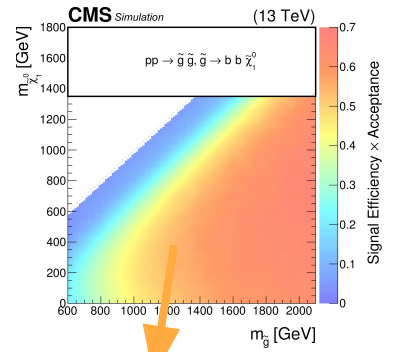
SLHA or LHE input

Model

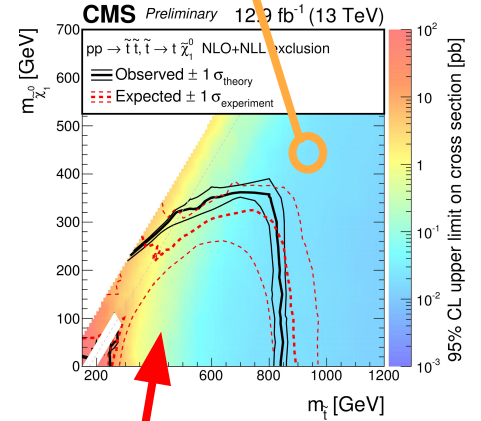


Missing SMS

Database



Experimental Analyses



The limits, NOT the lines!

UED arXiv:1501.03942, HSCP arXiv:1509.00473, U(1)MSSM ext. arXiv:1505.06243, NMSSM arXiv:1606.04416, sneutrino DM arXiv:1308.3735

What is missing?

=====
The highest r value is = 1.20463510281

Total missing topology cross section: 3.268E+03
Total cross section where we are outside the mass grid: 5.347E+02
Total cross section in long cascade decays: 7.177E+02
Total cross section in decays with asymmetric branches: 2.512E+03

Full information on unconstrained cross sections
=====

Missing topologies with the highest cross-sections (up to 10):

Sqrts (TeV)	Weight (fb)	Element description
8.0	6.440E+02 #	[[[jet, jet]], [[1, nu]]]
8.0	5.212E+02 #	[[[jet, jet]], [[nu, ta]]]
8.0	2.074E+02 #	[[[]], [[jet, jet]]]
8.0	8.475E+01 #	[[[b, b]], [[1, nu]]]
8.0	7.565E+01 #	[[[b, b], [jet, jet]], [[b, t], [jet, jet]]]
8.0	6.457E+01 #	[[[]], [[1, nu]]]
8.0	6.318E+01 #	[[[jet, jet]], [[1, 1]]]
8.0	6.027E+01 #	[[[b, t], [jet, jet]], [[jet], [W], [jet, jet]]]
8.0	5.177E+01 #	[[[1, nu]], [[1, nu]]]
8.0	5.164E+01 #	[[[1, nu]], [[nu, ta]]]

=====
Contributions outside the mass grid (up to 10):

Sqrts (TeV)	Weight (fb)	Element description
8.0	2.715E+02 #	[[[b, b]], [[jet, jet]]]
8.0	1.295E+02 #	[[[jet, jet]], [[nu, nu]]]
8.0	4.049E+01 #	[[[1, nu]], [[nu, nu]]]
8.0	2.019E+01 #	[[[nu, nu]], [[nu, ta]]]
8.0	9.789E+00 #	[[[b, b], [nu, nu]], [[b, t], [jet, jet]]]
8.0	8.035E+00 #	[[[b, b], [jet, jet]], [[b, b], [nu, nu]]]
8.0	6.402E+00 #	[[[b, b], [nu, nu]], [[jet], [W], [jet, jet]]]
8.0	3.845E+00 #	[[[b, b]], [[b, b]]]
8.0	3.845E+00 #	[[[b, b]], [[b, b], [nu, nu]]]
8.0	3.061E+00 #	[[[b, b], [nu, nu]], [[b, t], [1, nu]]]

=====
Long cascade decay by produced mothers (up to 10):

Mother1	Mother2	Weight (fb)
1000021	1000021	7.177E+02 # [1000021, 1000021]

=====
Asymmetric branch decay by produced mothers

Mother1	Mother2	Weight (fb)
1000023	1000024	9.171E+02 # [1000023, 1000024]
1000021	1000021	6.672E+02 # [1000021, 1000021]
1000024	1000024	6.126E+02 # [1000024, 1000024]
1000022	1000024	1.131E+02 # [1000022, 1000024]
1000035	1000037	4.413E+01 # [1000035, 1000037]
1000025	1000037	2.963E+01 # [1000025, 1000037]

Extra: how large is the signature of my theory?

SModelS also has a cross section calculator:

- For MSSM and SLHA input
- NNLO for strong cross-sections (NLLfast)
- LO for weak cross-sections (Pythia 6)
- writes the Les-Houches XSECTION block (pyslha-compatible):

<https://pypi.python.org/pypi/pyslha>

```
runTools.py xseccomputer -f <slhfile> -s <SQRTS>
```

```
XSECTION 8.00E+03 2212 2212 2 1000021 1000037 # Nevts: 10000  
xsec unit: pb  
0 0 0 0 0 4.00683855E-05 SModelS 0.99  
XSECTION 8.00E+03 2212 2212 2 1000001 1000003 # Nevts: 10000  
xsec unit: pb  
0 2 0 0 0 0 2.49305494E-04 SModelS 0.99  
XSECTION 8.00E+03 2212 2212 2 -1000002 2000002 # Nevts: 10000  
xsec unit: pb  
0 2 0 0 0 0 1.16052469E-03 SModelS 0.99
```


Where do these results come from?

Interpreting LHC Results: making data available

- Efficiencies and upper limits in SModelS database -- expanding (see right)
- FastLim
- Les Houches Analysis Description Accord
<https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHADApaser>
- CMS provides cutflows and efficiencies (generation info?)
- HEPdata:
<http://hepdata.cedar.ac.uk/>

"Homegrown" Maps

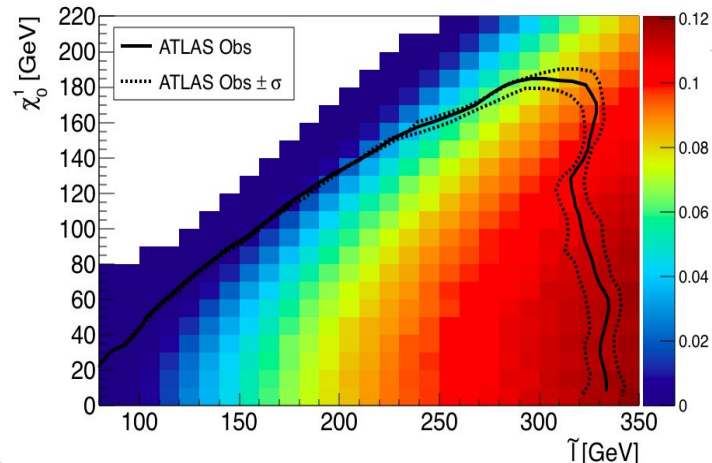
There are no available ATLAS/CMS EM for the production of sleptons

-> We used **MadAnalysis5** recasting of ATLAS-SUSY-2013-11 to produce "homegrown" efficiency maps

ATLAS-SUSY-2013-11

$$pp \rightarrow \tilde{l}\tilde{l}, \tilde{l} \rightarrow l\tilde{\chi}_1^0$$

Signal Region: mT2-90-SF



Federico Ambrogio (HEPHY, Vienna)

15

SUSY 2016 - Melbourne, 04 July

Workshop (Re)interpreting LHC results December 12-14 at CERN:

<https://indico.cern.ch/event/571190/timetable/>

<https://twiki.cern.ch/twiki/bin/view/LHCPhysics/InterpretingLHCResults>

Backup

Publications using SModels

- Collider and Dark Matter Searches in the **Inert Doublet Model** from Peccei-Quinn Symmetry by A. Alves et al, arXiv:1606.07086
- **Natural NMSSM** after LHC Run I and the Higgsino dominated dark matter scenario by Junjie Cao, Yangle He, Liangliang Shang, Wei Su and Yang Zhang, arXiv:1606.04416
- Collider limits on new physics within **micrOMEGAs** by D. Barducci et al, arXiv:1606.03834
- Simplified Models for **Exotic BSM Searches** by Jan Heisig, Andre Lessa, Loic Quertenmont, arXiv:1509.00473
- LHC constraints on **light neutralino dark matter** in the MSSM by Genevieve Belanger, Guillaume Drieu La Rochelle, Beranger Dumont, Rohini M. Godbole, Sabine Kraml, Suchita Kulkarni, arXiv:1308.3735

```
% time python2 runModelS.py -f inputFiles/slha/complicated.slha
INFO in databaseObj.loadBinaryFile() in 195: Loaded database from
/home/jory/hh/smodels-database/database.pcl in 22.3 secs.
python2 runModelS.py -f inputFiles/slha/complicated.slha 35.31s user
0.91s system 99% cpu 36.297 total
```

What does it mean for my model?

```
./runModelS.py -f mymodel.slha
```

```
Total Number of Elements: 99
#Analysis Sqrts Cond. Violation Theory_Value(fb) Exp_limit(fb) r
-----
CMS-SUS-13-006 8.00E+00 0.0 2.107E-01 3.867E-01 5.450E-01
Signal Region: MET_100
Txnames: TChiWH
r_expected, chi2, likelihood = 5.427E-01 1.540E+00 5.554E-02
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Signal Region: (UL)
Txnames: T2 ?
-----
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Signal Region: 6NJet8_1250HT1500_450MHTinf
Txnames: T1, T2, T5WW
r_expected, chi2, likelihood = 8.205E-01 1.791E-01 1.476E-01
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-----
ATLAS-SUSY-2013-02 8.00E+00 0.0 9.069E+00 3.234E+01 2.805E-01
Signal Region: (UL)
Txnames: T5WW ?
```

$$r = \frac{\sigma_{\text{theo}}^{\text{pred}}}{\sigma_{\text{observed}}^{\text{upper limit}}}$$

$$r_{\text{expected}} = \frac{\sigma_{\text{theo}}^{\text{pred}}}{\sigma_{\text{expected}}^{\text{upper limit}}}$$

$$\chi^2 = -2 \log \frac{L(n_s)}{L_{\text{max}}(n_{\text{obs}} - n_b)}$$

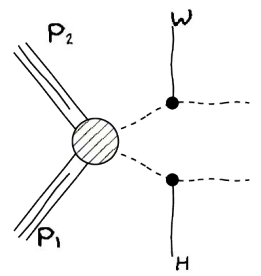
What it means for your model: a likelihood (poiss*gauss)

New for EM results

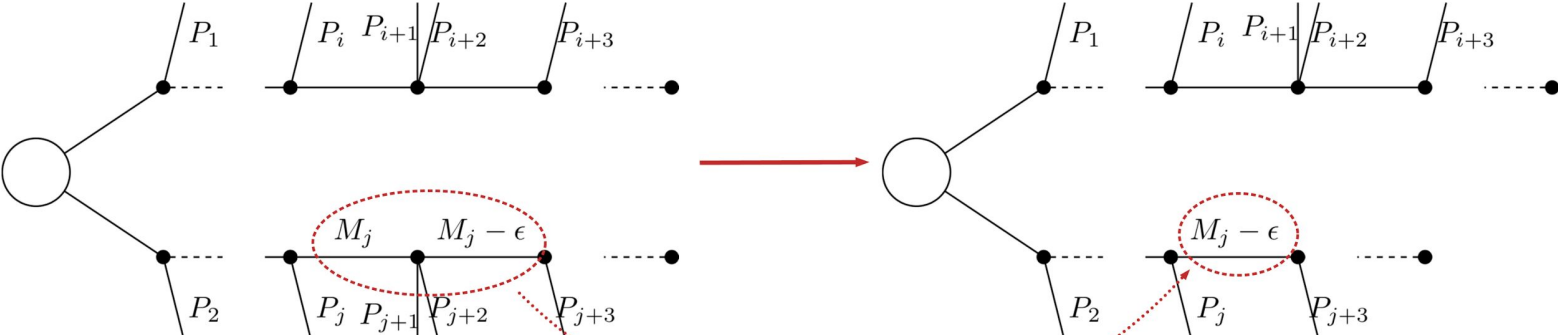
$$L = \int_0^\infty dx \frac{(\lambda_s + \lambda_b)^{(n_{\text{obs}})} e^{-(\lambda_s + \lambda_b)}}{(n_{\text{obs}})!} \exp \frac{(x - (n_s + n_b))^2}{2(\sigma_s^2 + \sigma_b^2)}$$

Simplified model names:
<http://smodels.hephy.at/wiki/SmDictionary>

```
#22
TChiWH
vertices: (2)(2)
insertions: (1,0)(1,0)
[[[higgs]], [[W]]]
```

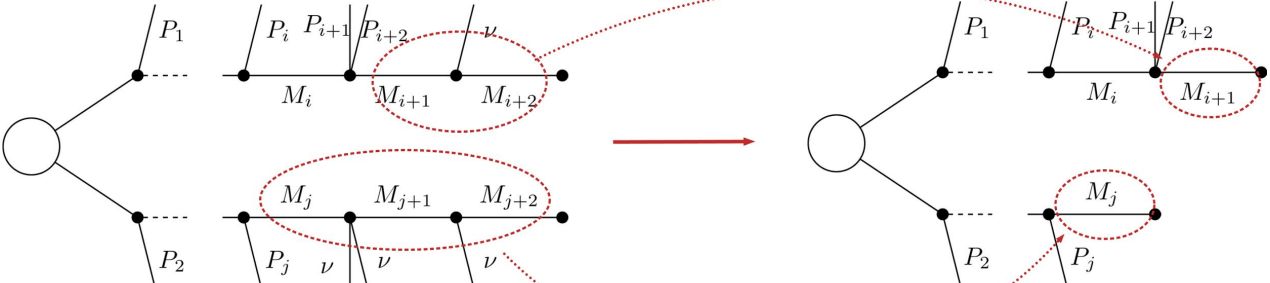


Compression



Soft Final State

Invisible Final State



Invisible Final States

Mass and invisible

What experimental results are already there?

SModelS has a database browser for general information and limits from analyses:

```
In [2]: import sys
        sys.path.append('/home/lessa/smodels')
        from smodels.tools import databaseBrowser
        from smodels.tools.physicsUnits import GeV
        browser = databaseBrowser.Browser('/home/lessa/smodels-database')

In [3]: print browser.getValuesFor(attribute='dataType')

['efficiencyMap', 'upperLimit']

In [7]: browser.selectExpResultsWith(txName = 'TSlepSlep')
        print len(browser), 'results constrain slepton pair production\n'
        for exp in browser:
            print exp.getValuesFor('id'), exp.getValuesFor('dataType')

5 results constrain slepton pair production

['ATLAS-CONF-2013-049'] ['upperLimit']
['ATLAS-SUSY-2013-11'] ['upperLimit']
['ATLAS-SUSY-2013-11'] ['efficiencyMap']
['CMS-SUS-13-006'] ['upperLimit']
['CMS-SUS-PAS-12-022'] ['upperLimit']

In [6]: mslep = 300.*GeV
        mlsp = 100.*GeV
        print 'UL=', browser.getULFor(expid='ATLAS-SUSY-2013-11', txname='TSlepSlep',
                                       massarray = [[mslep, mlsp], [mslep, mlsp]])

UL= 2.49E-03 [pb]
```