Constraints on sneutrino dark matter from LHC Run 1

arXiv:1503.02960

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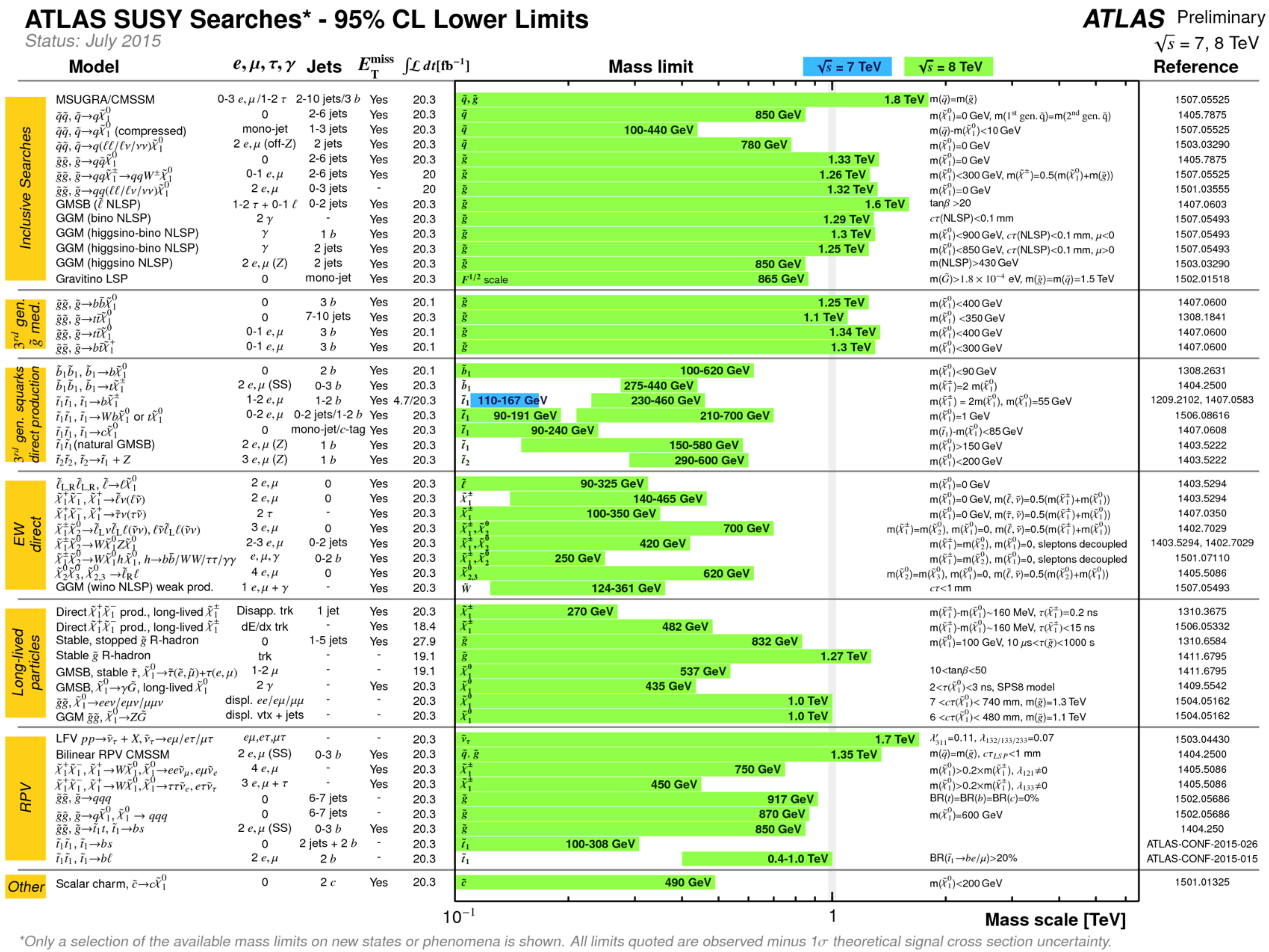
LPSC Grenoble & LAPTh Annecy

in collaboration with
Chiara Arina, Maria Eugenia Cabrerea Catalan,
Sabine Kraml and Suchita Kulkarni

SUSY, August 2015, Lake Tahoe

SUSY searches at the LHC



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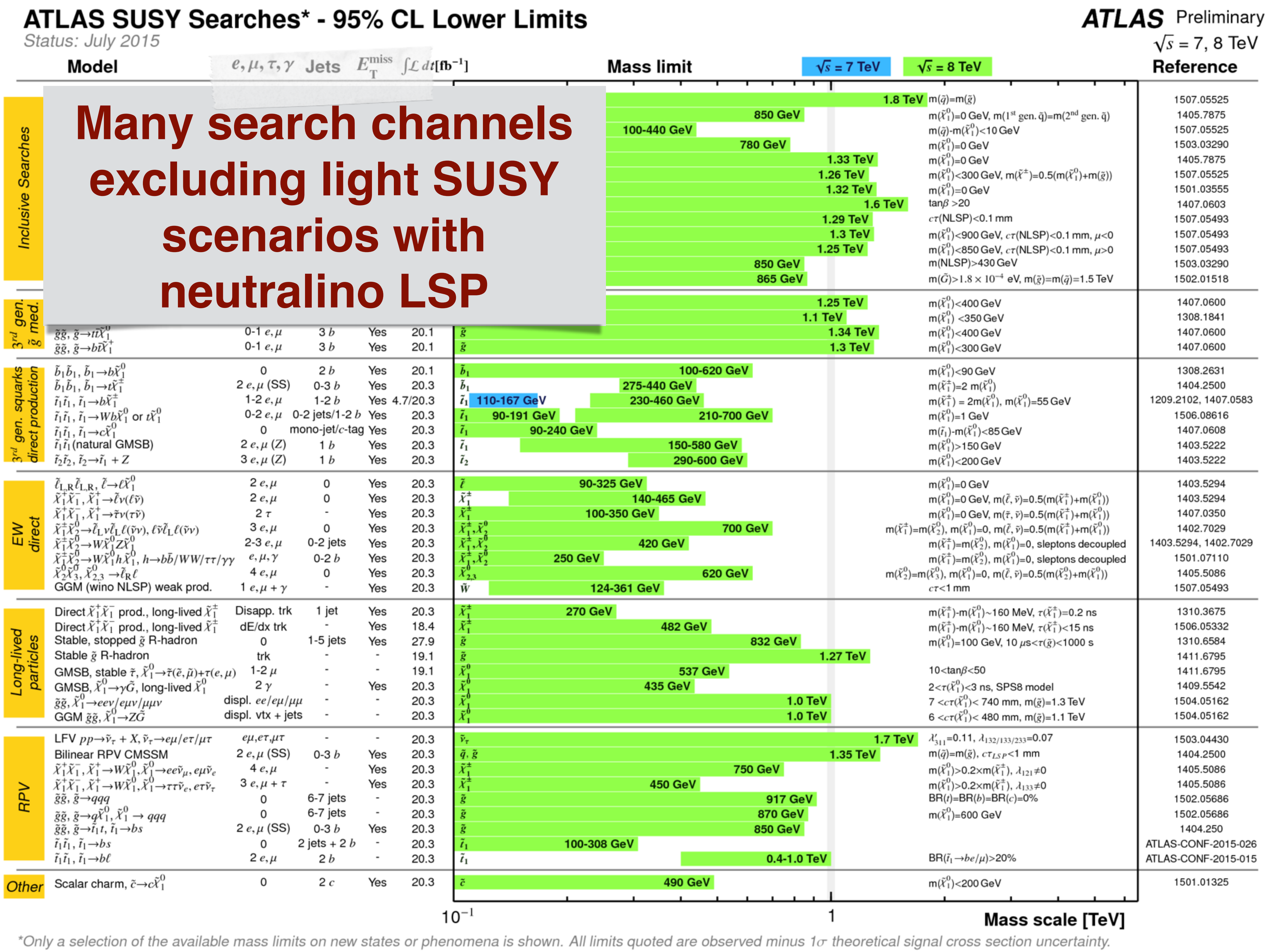
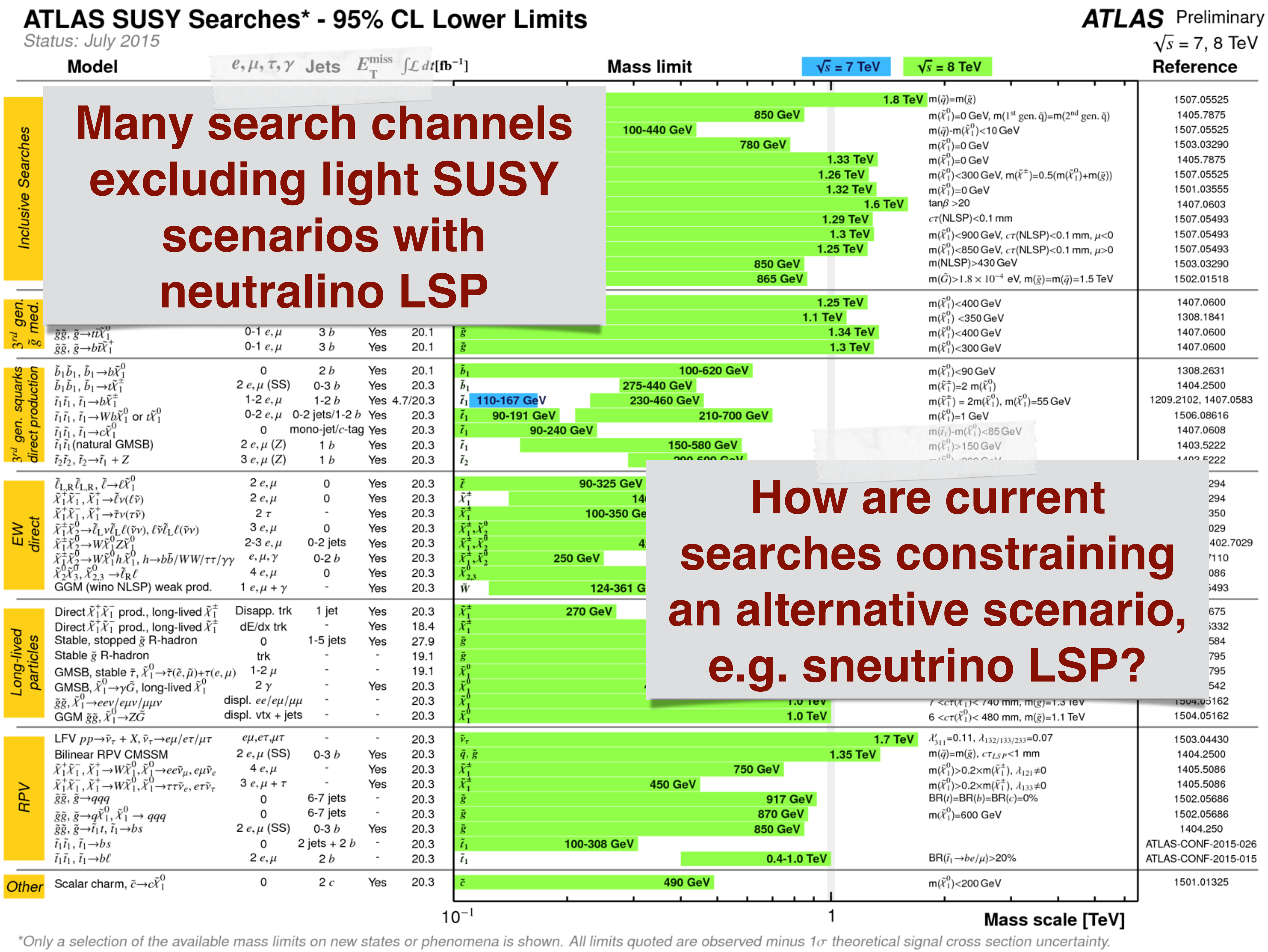


Many search channels excluding light SUSY scenarios with neutralino LSP

SUSY searches at the LHC



Many search channels excluding light SUSY scenarios with neutralino LSP

How are current searches constraining an alternative scenario, e.g. sneutrino LSP?

Why consider right-handed sneutrino DM?

- Left-handed sneutrino LSP cannot explain measured relic abundance and is excluded by direct detection experiments
- Mostly right-handed sneutrino is an interesting candidate, addressing both the origin of neutrino masses and the nature of dark matter
- Consider simple realisation: Dirac neutrinos, no lepton number violating terms

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→ we want to explore how LHC results constrain such a sneutrino LSP scenario

The MSSM+RN model

- superpotential for Dirac RH neutrino superfield

$$W = \epsilon_{ij}(\mu \hat{H}_i^u \hat{H}_j^d - Y_l^{IJ} \hat{H}_i^d \hat{L}_j^I \hat{R}^J + Y_\nu^{IJ} \hat{H}_i^u \hat{L}_j^I \hat{N}^J)$$

- additional terms in the soft-breaking potential

$$V_{\text{soft}} = (M_L^2)^{IJ}\, \tilde{L}_i^{I*} \tilde{L}_i^J + (M_N^2)^{IJ}\, \tilde{N}^{I*} \tilde{N}^J$$
$$-[\epsilon_{ij}(\Lambda_l^{IJ} H_i^d \tilde{L}_j^I \tilde{R}^J + \Lambda_\nu^{IJ} H_i^u \tilde{L}_j^I \tilde{N}^J) + \text{h.c.}]$$

- the sneutrino mass eigenstates are then given by

$$\begin{pmatrix} \tilde{\nu}_{k_1} \\ \tilde{\nu}_{k_2} \end{pmatrix} = \begin{pmatrix} -\sin\theta_{\tilde{\nu}}^k & \cos\theta_{\tilde{\nu}}^k \\ \cos\theta_{\tilde{\nu}}^k & \sin\theta_{\tilde{\nu}}^k \end{pmatrix} \begin{pmatrix} \tilde{\nu}_L^k \\ \tilde{N}^k \end{pmatrix}$$

with $\sin 2\theta_{\tilde{\nu}}^k = \sqrt{2}\dfrac{A_{\tilde{\nu}}^k\, v \sin\beta}{(m_{\tilde{\nu}_{k2}}^2 - m_{\tilde{\nu}_{k1}}^2)}$

Borzumati & Nomura, hep-ph/0007018
Arkani-Hamed et al., hep-ph/0006312

Parameters and constraints

Sample parameter space using MultiNest

- set of free parameters, allowing for non-universalities in gaugino and scalar sector:

$$M_1, M_2, M_3, m_L, m_R, m_N, m_Q, m_H, A_l, A_{\tilde{\nu}}, A_q, \tan\beta, \mathrm{sgn}\mu$$

- constraints implemented in the likelihood function:

$$m_h, \mathrm{BR}(B \to X_s\gamma), \mathrm{BR}(B_s \to \mu^+\mu^-), \Omega_{\mathrm{DM}}h^2,$$

$$\Delta\Gamma_Z^{\mathrm{invisible}}, \mathrm{BR}(h \to \mathrm{invisible}), m_{\tilde{\tau}_1^-}, m_{\tilde{\chi}_1^+}, m_{\tilde{e}}, m_{\tilde{\mu}}, m_{\tilde{g}}, \sigma_n^{\mathrm{SI}}$$

for discussion of resulting parameter space
see Arina & Cabrera, hep-ph/1311.6549

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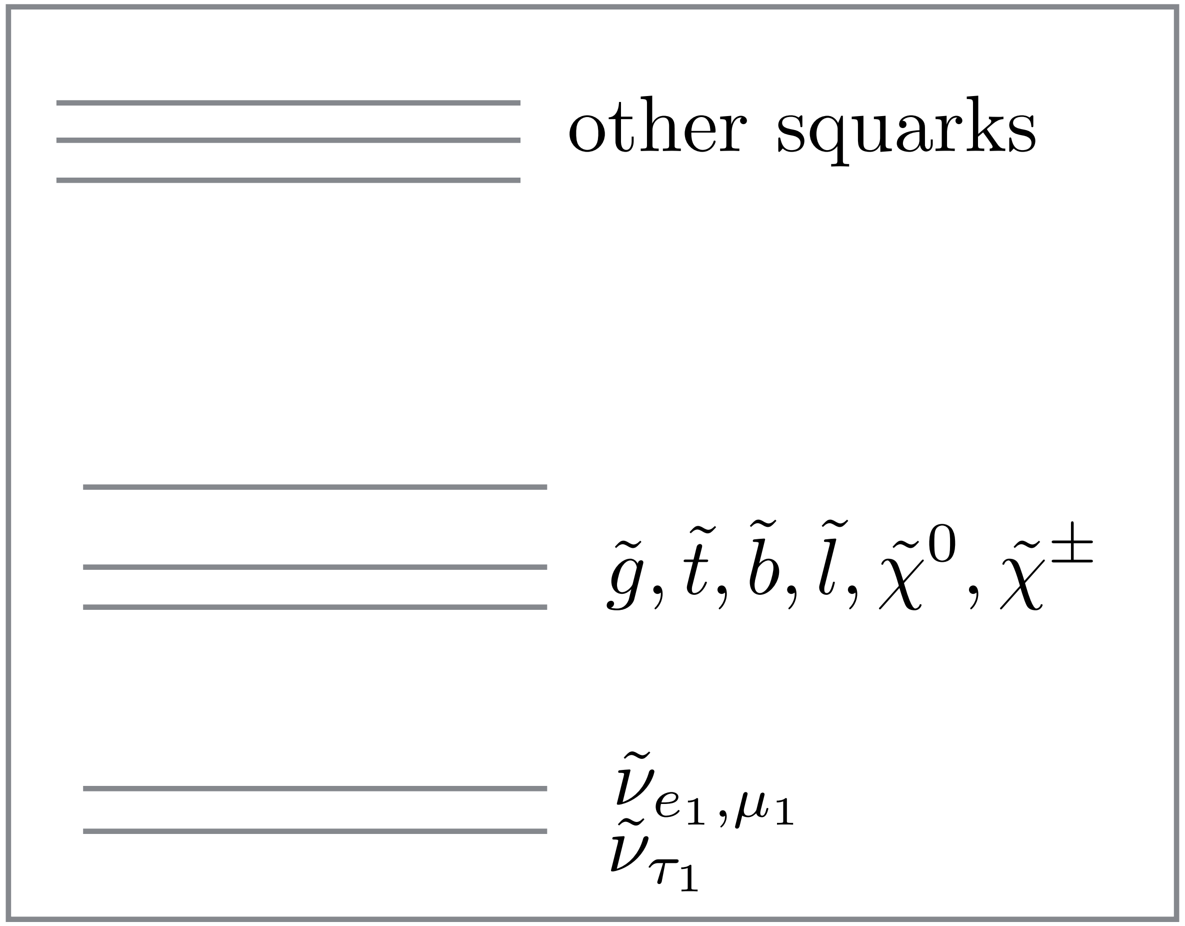
0.1186 ± 0.0031(exp) ± 20% (theo)

Typical spectrum



Sampling the parameter space such that we cover different scenarios, requiring either light gluinos or squarks, light gauginos or light sleptons

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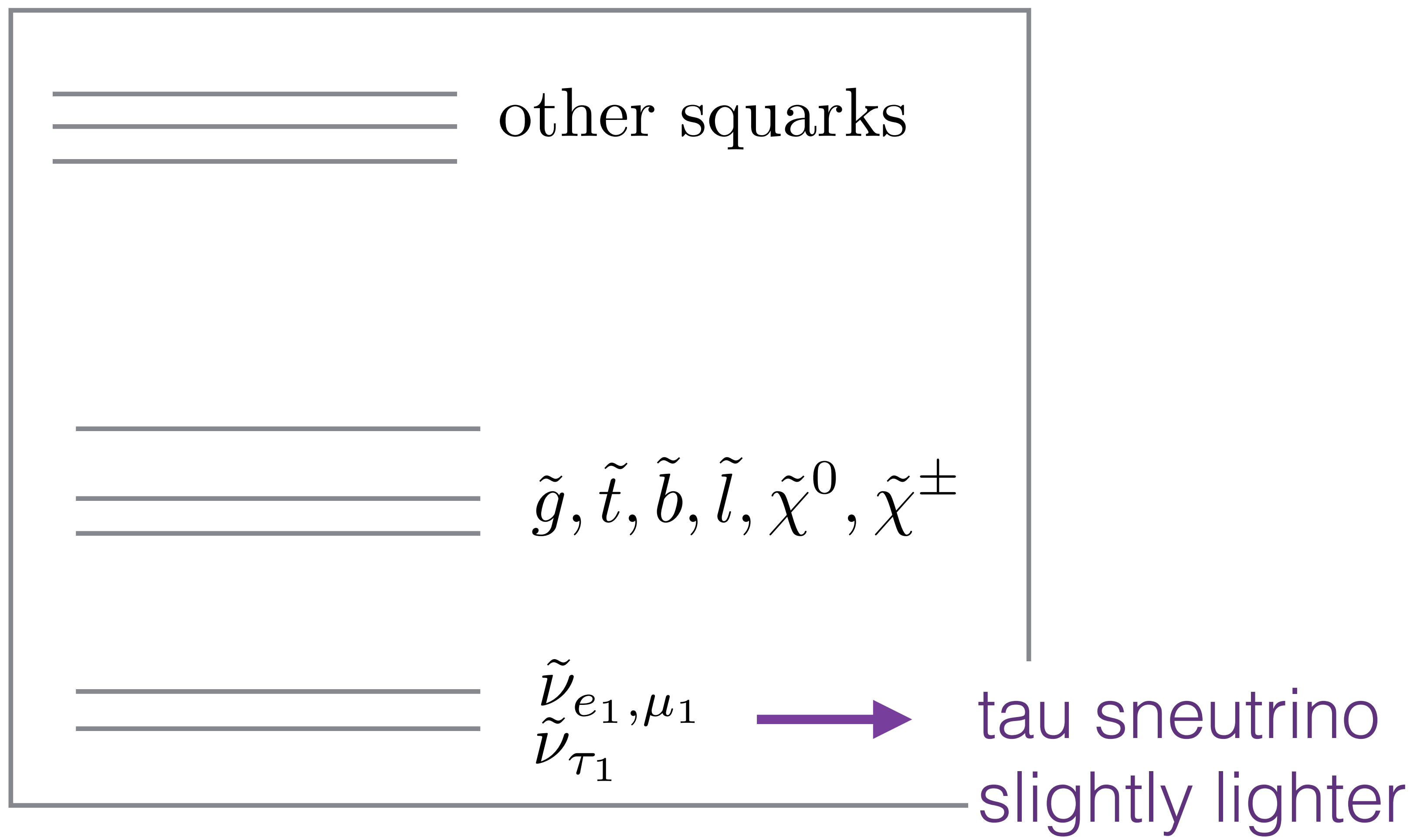

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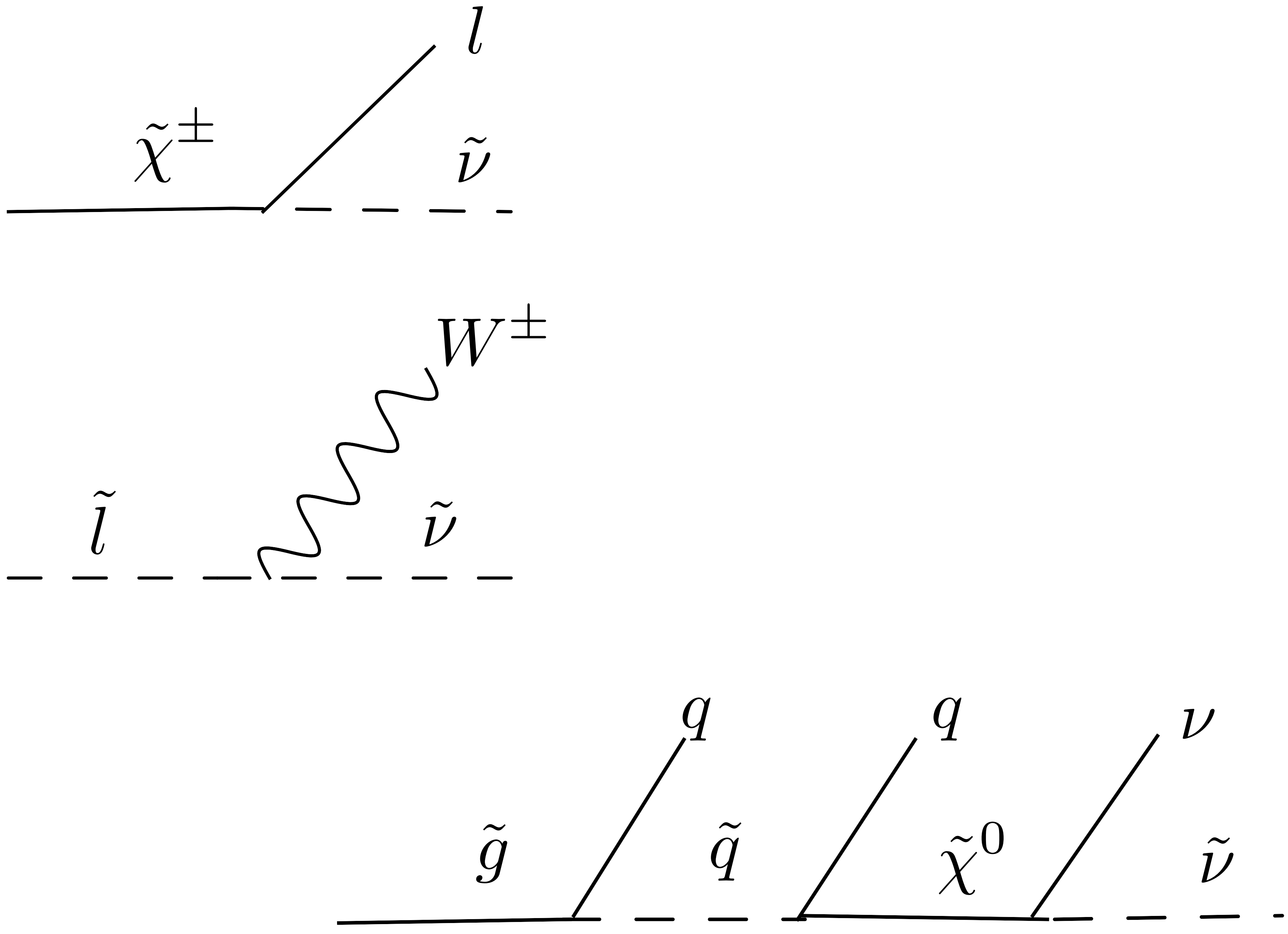

gluino decay indistinguishable from neutralino LSP scenario

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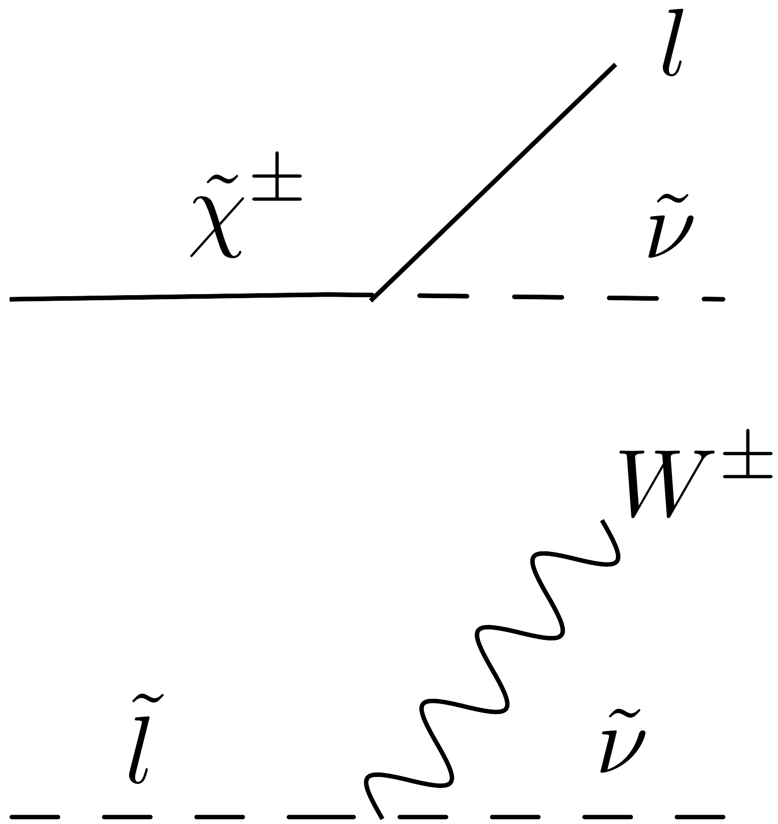
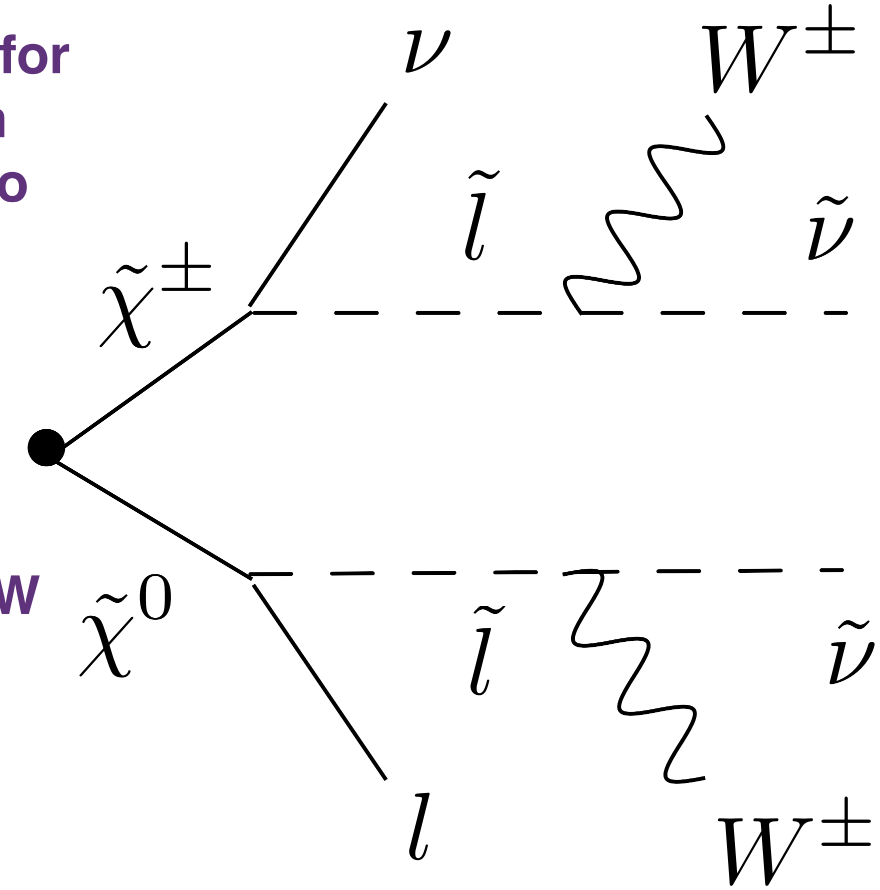
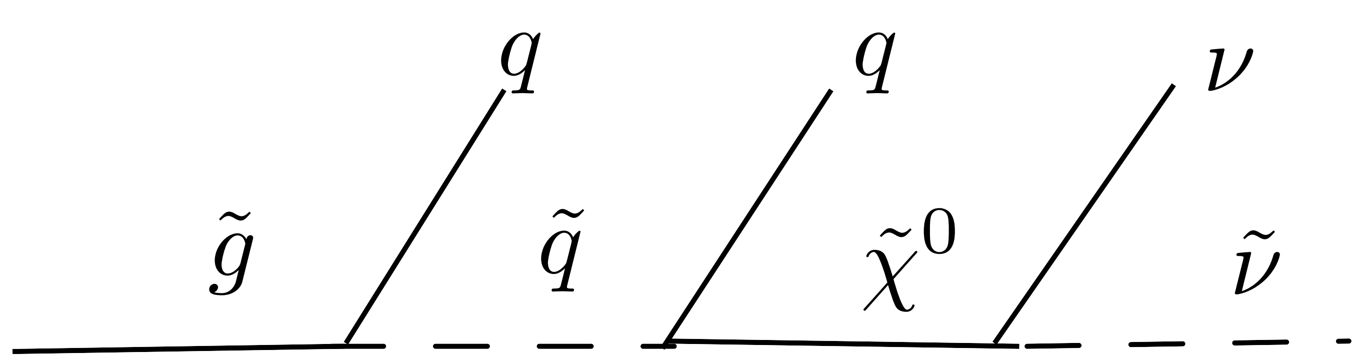


Opposite signatures for chargino and slepton decay as compared to neutralino LSP

can yield same-sign W signatures





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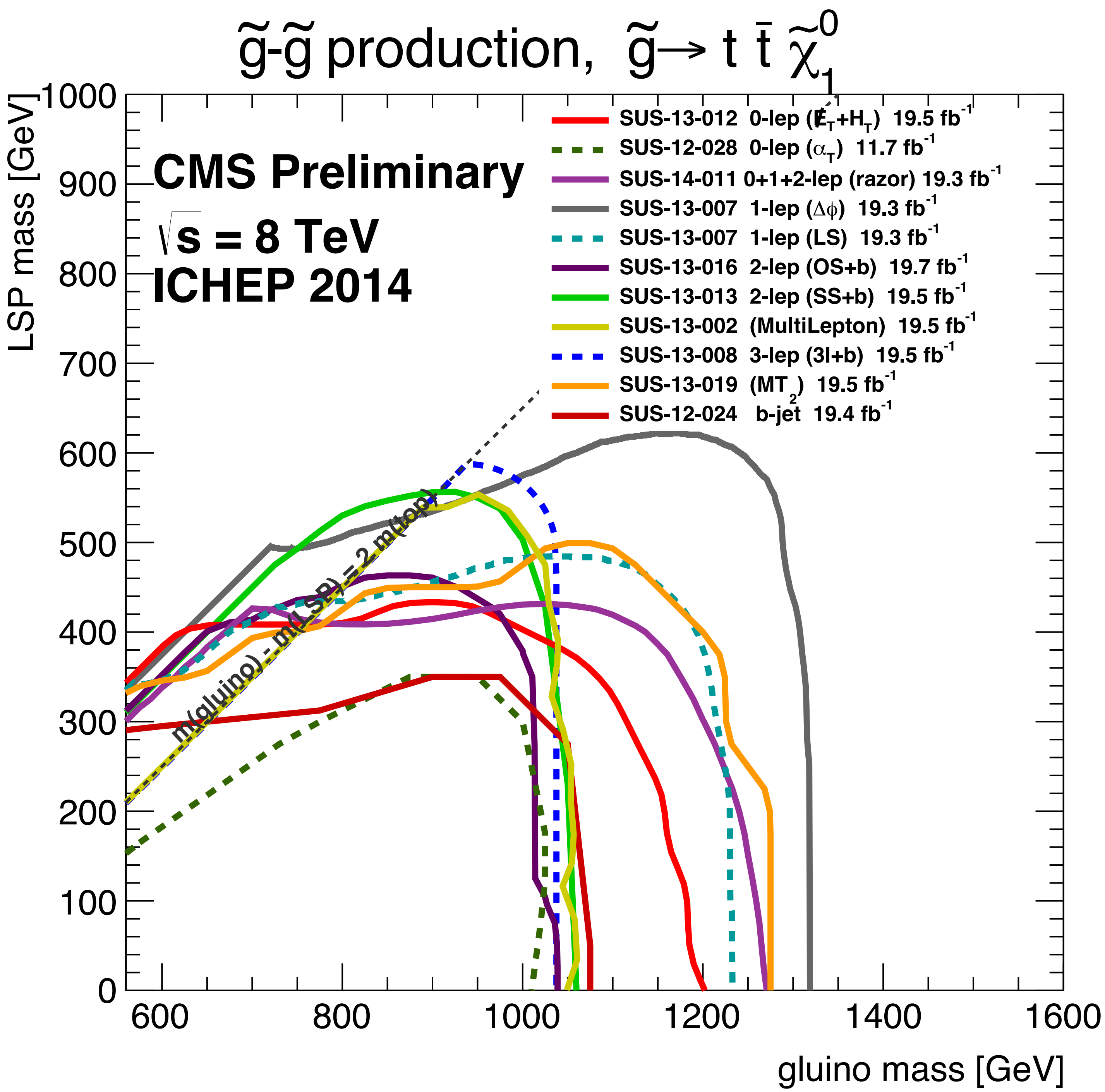
Testing the model against LHC constraints

- To test against large number of results we make use of Simplified Model Spectra (SMS) interpretation of LHC searches

Simplified Models



SMS are an effective Lagrangian description, containing only a few particles, 100% BR

The masses of the new particles are the free parameters of the Simplified Model

Testing the model against LHC constraints

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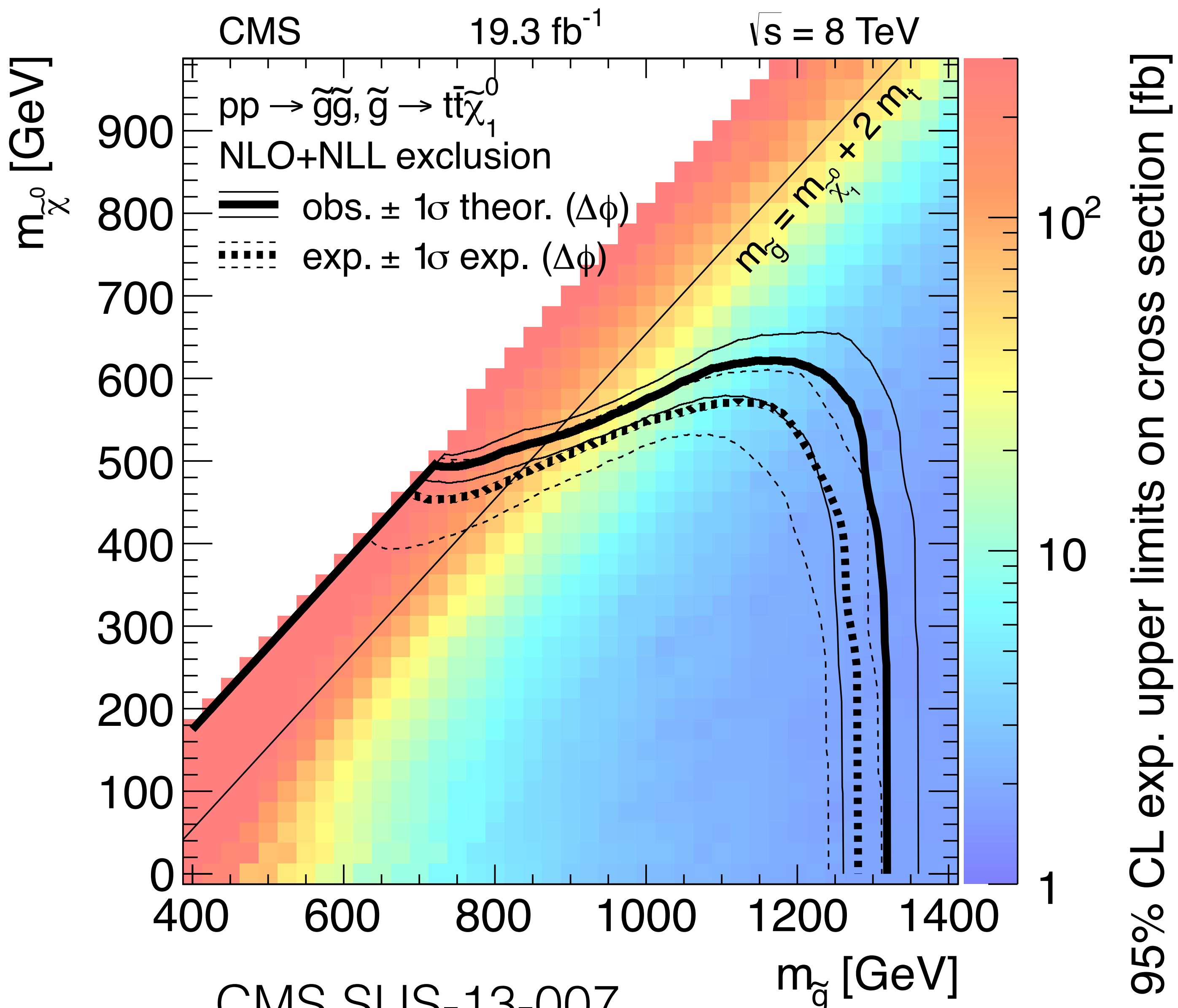
- Decompose realistic model into SMS components which can be tested against limits presented by ATLAS and CMS

Using SMS results



CMS SUS-13-007

To test realistic models, use upper limits on $\sigma \times \mathcal{BR}$ (exclusion line only valid in the simplified model)

Assumption:
upper limits on $\sigma \times \mathcal{BR}$ are mainly a function of the masses of the new particles

→ other quantum numbers may be neglected in first approximation

Testing the model against LHC constraints

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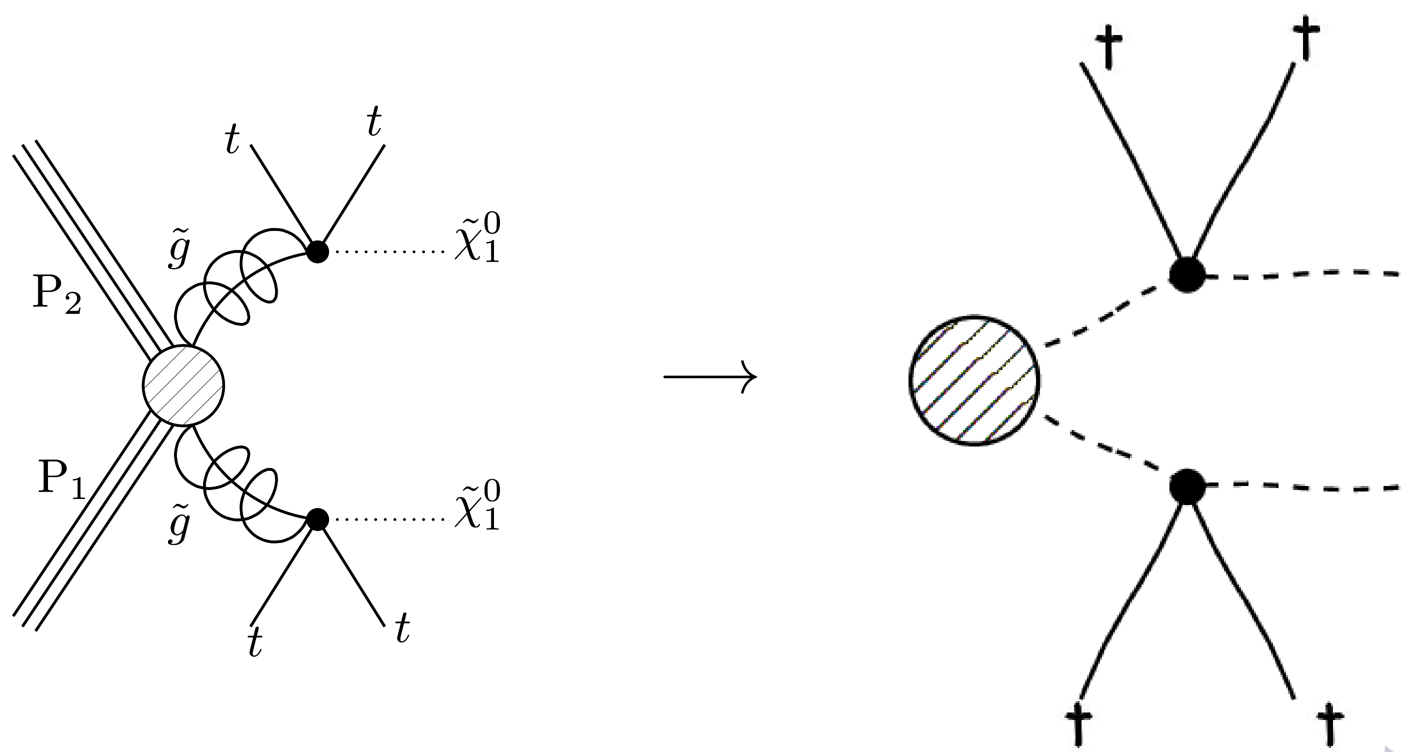
- Decompose realistic model into SMS components which can be tested against limits presented by ATLAS and CMS
- Additional assumption: these results depend mainly on the mass spectrum of the new particles, not on specifics of the model (spin structure, production process, …)

Description of SMS topologies

describe topology by vertex structure and outgoing SM particles in each vertex



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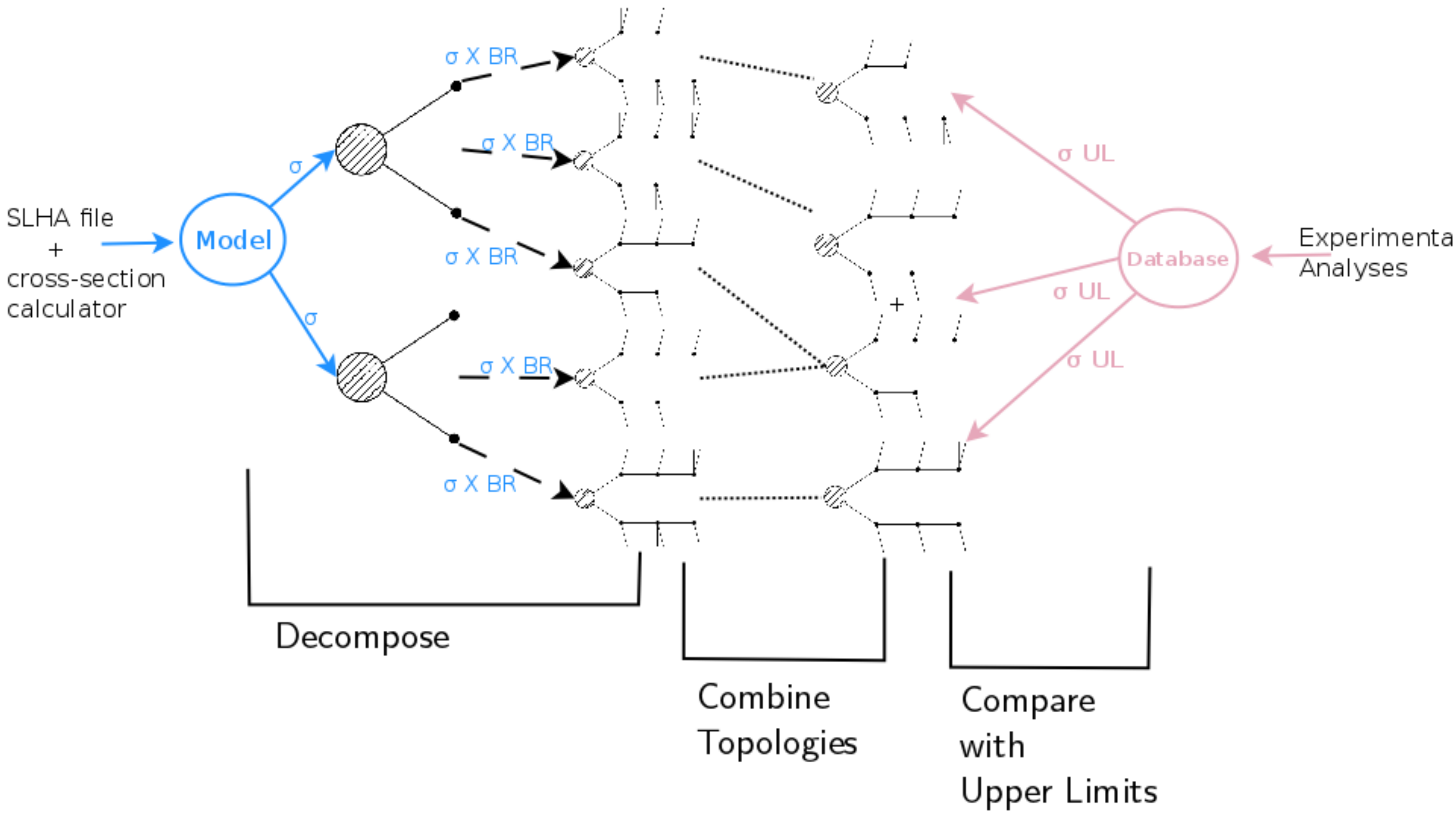
→ SModelS

Kraml, Kulkarni, UL, Lessa et al., hep-ph/1312.4175


SLHA file
+
cross-section
calculator
Model
σ
σ
σ X BR
σ X BR
σ X BR
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+
σ UL
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Database
Experimental
Analyses
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Combine
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Compare
with
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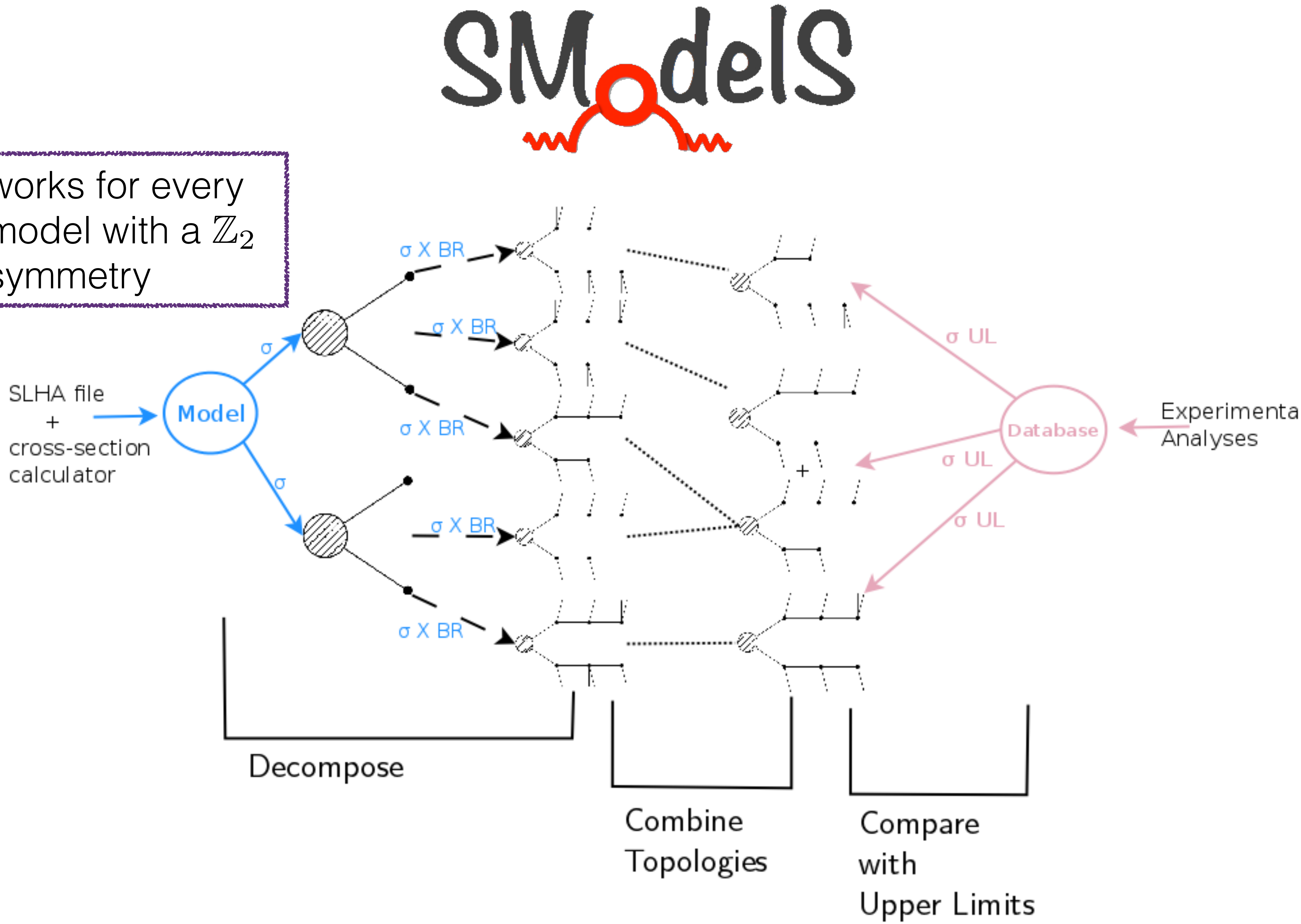
works for every model with a $\mathbb{Z}_2$ symmetry



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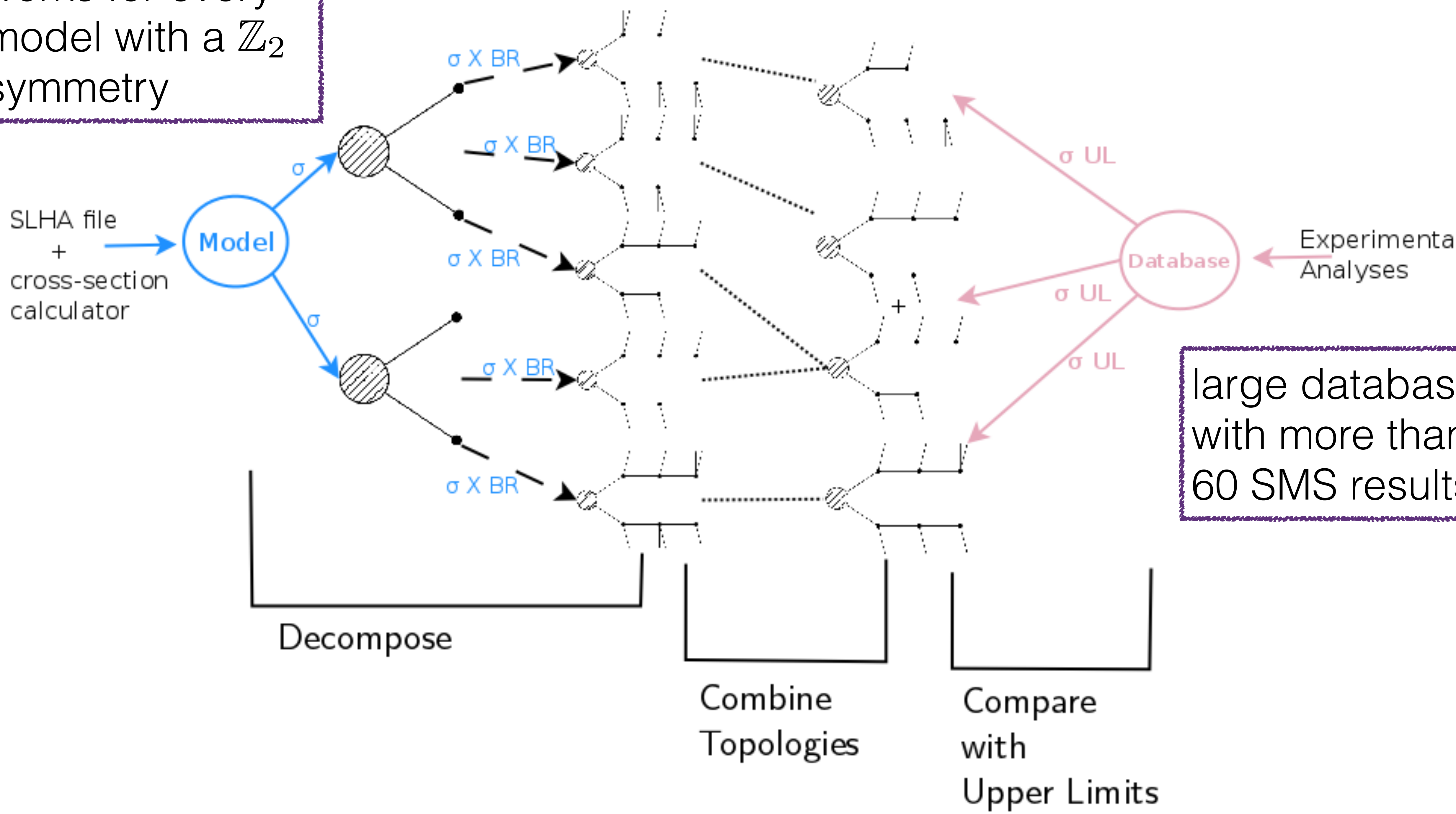

large database with more than 60 SMS results

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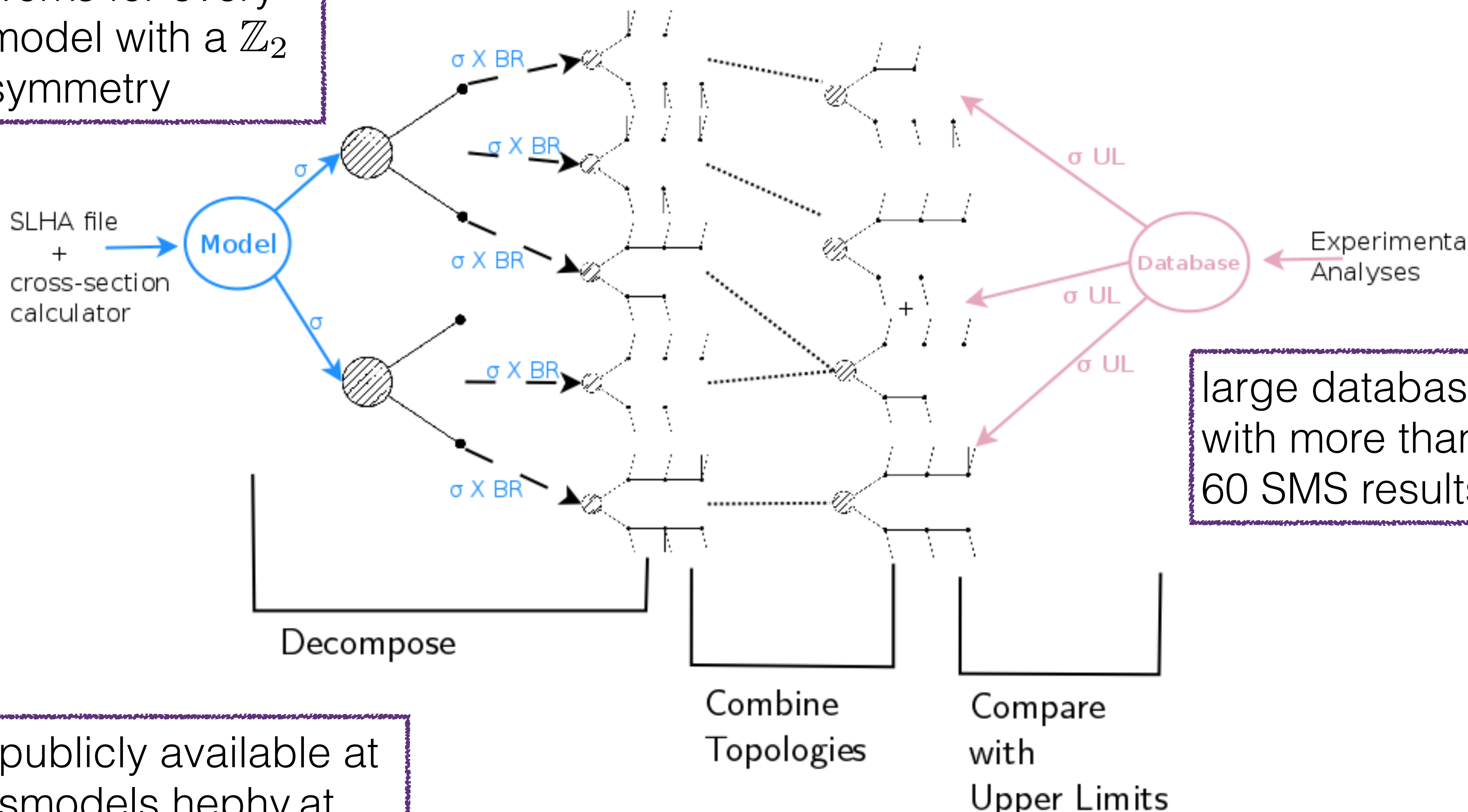

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publicly available at <u>smodels.hephy.at</u>

SModelS

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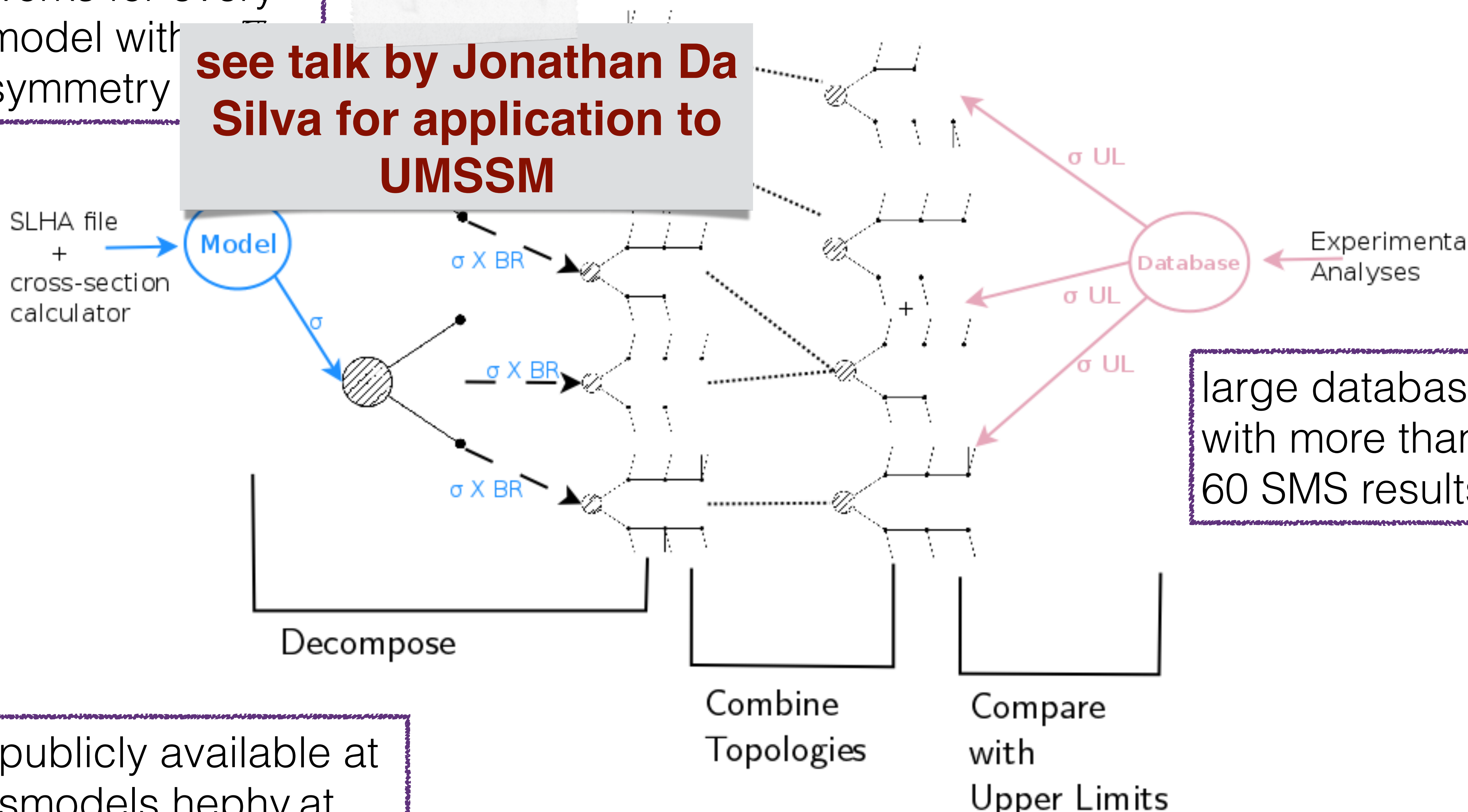
see talk by Jonathan Da Silva for application to UMSSM



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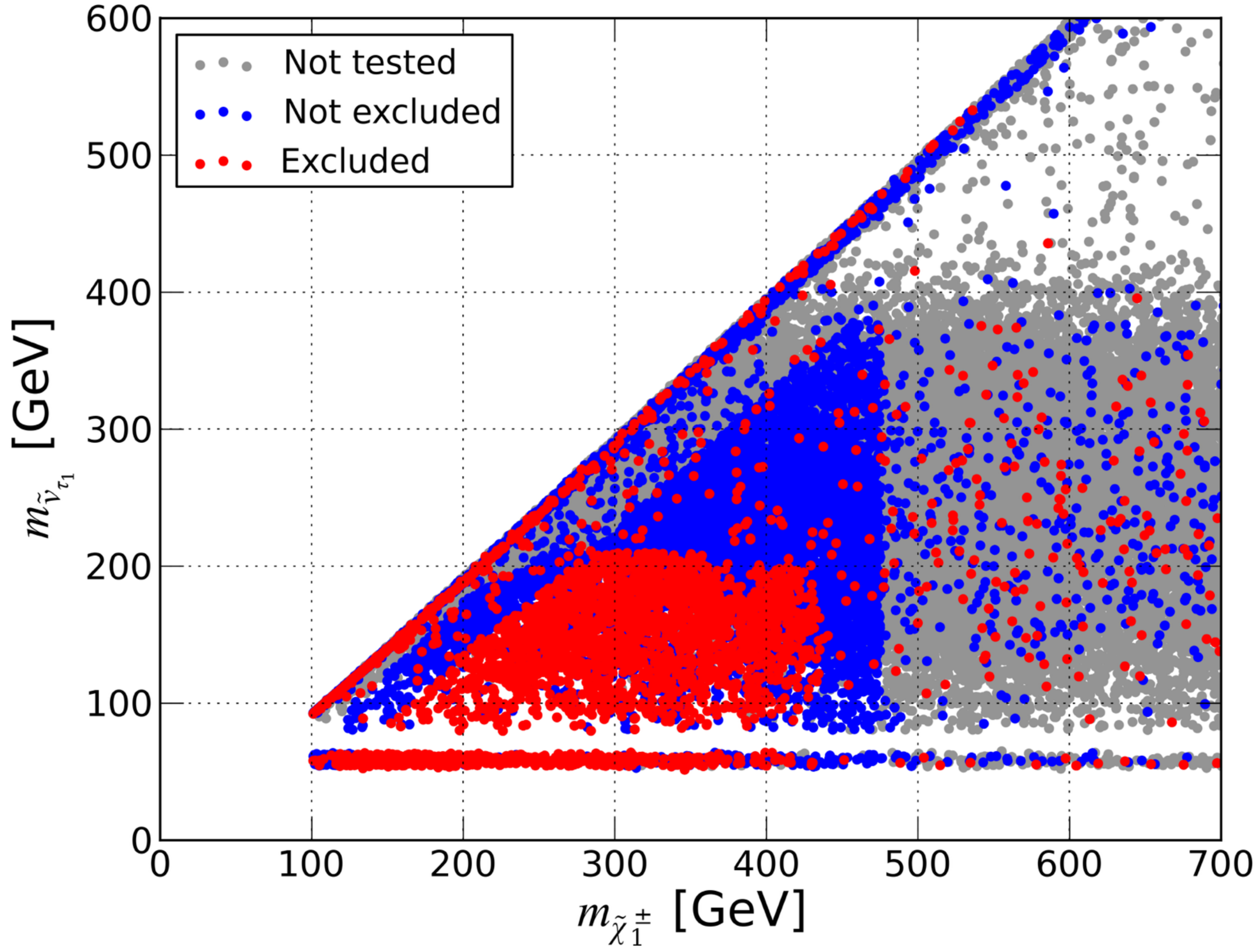
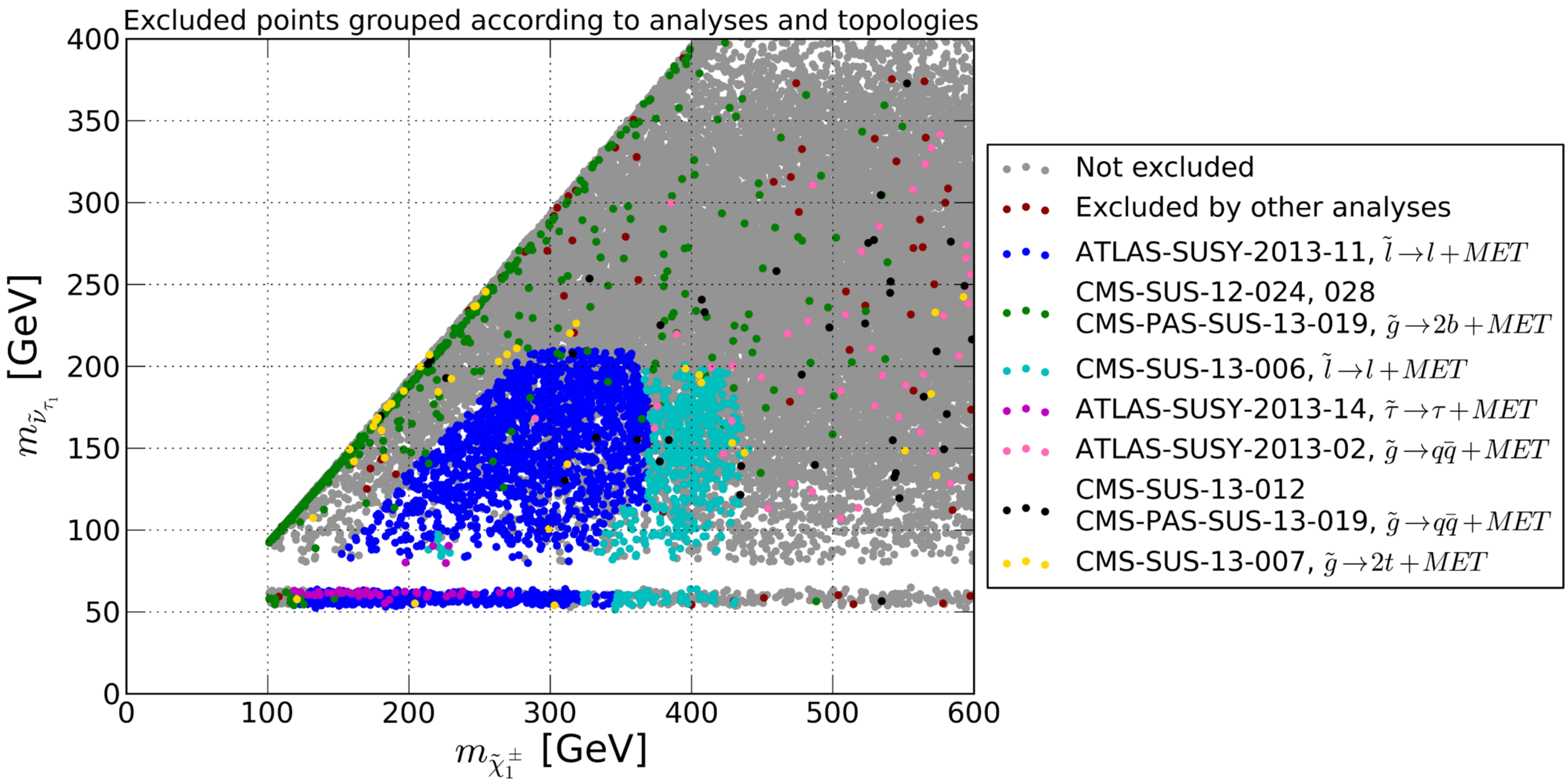
The results in the chargino - LSP mass plane



Which analyses give the most important constraints?



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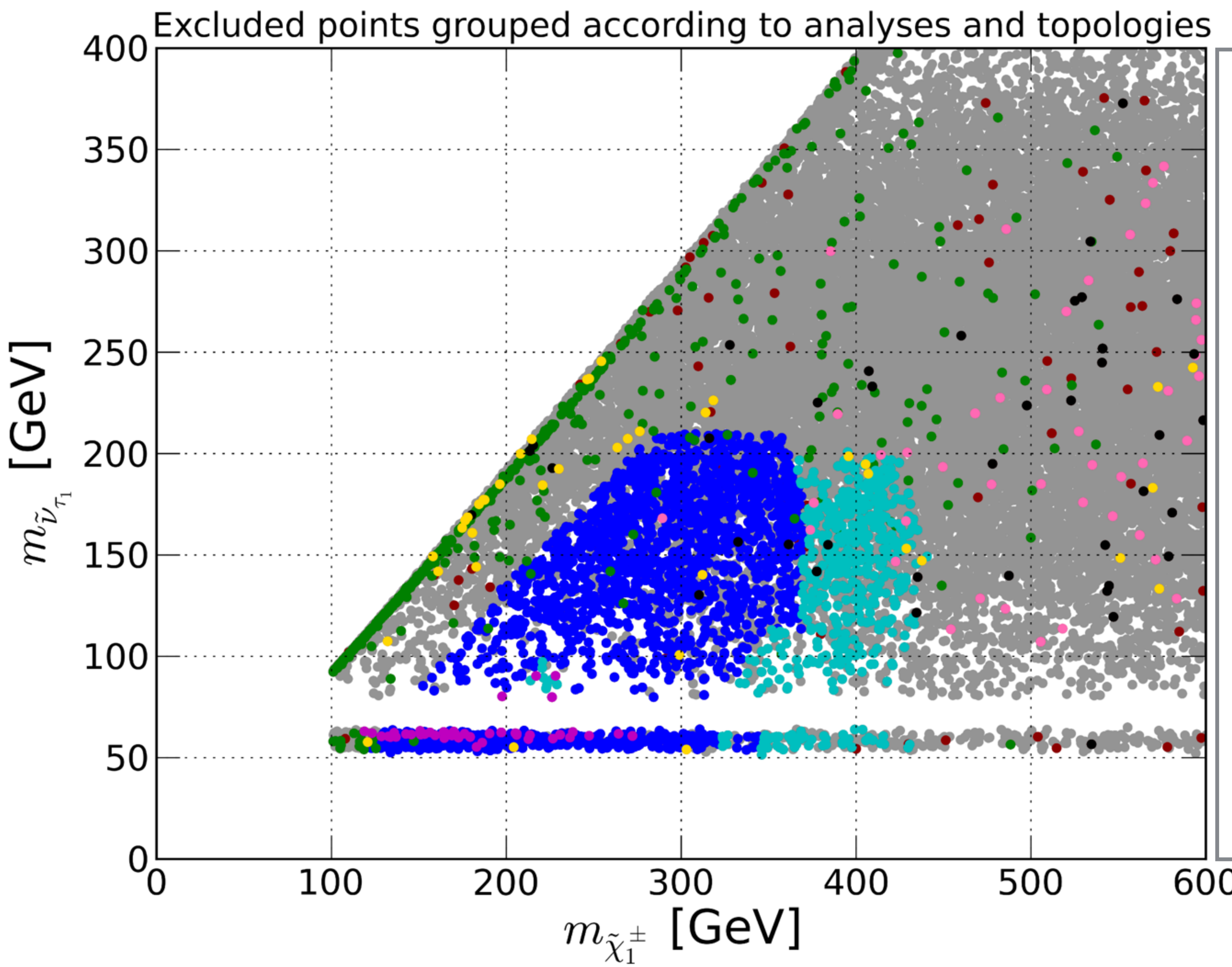

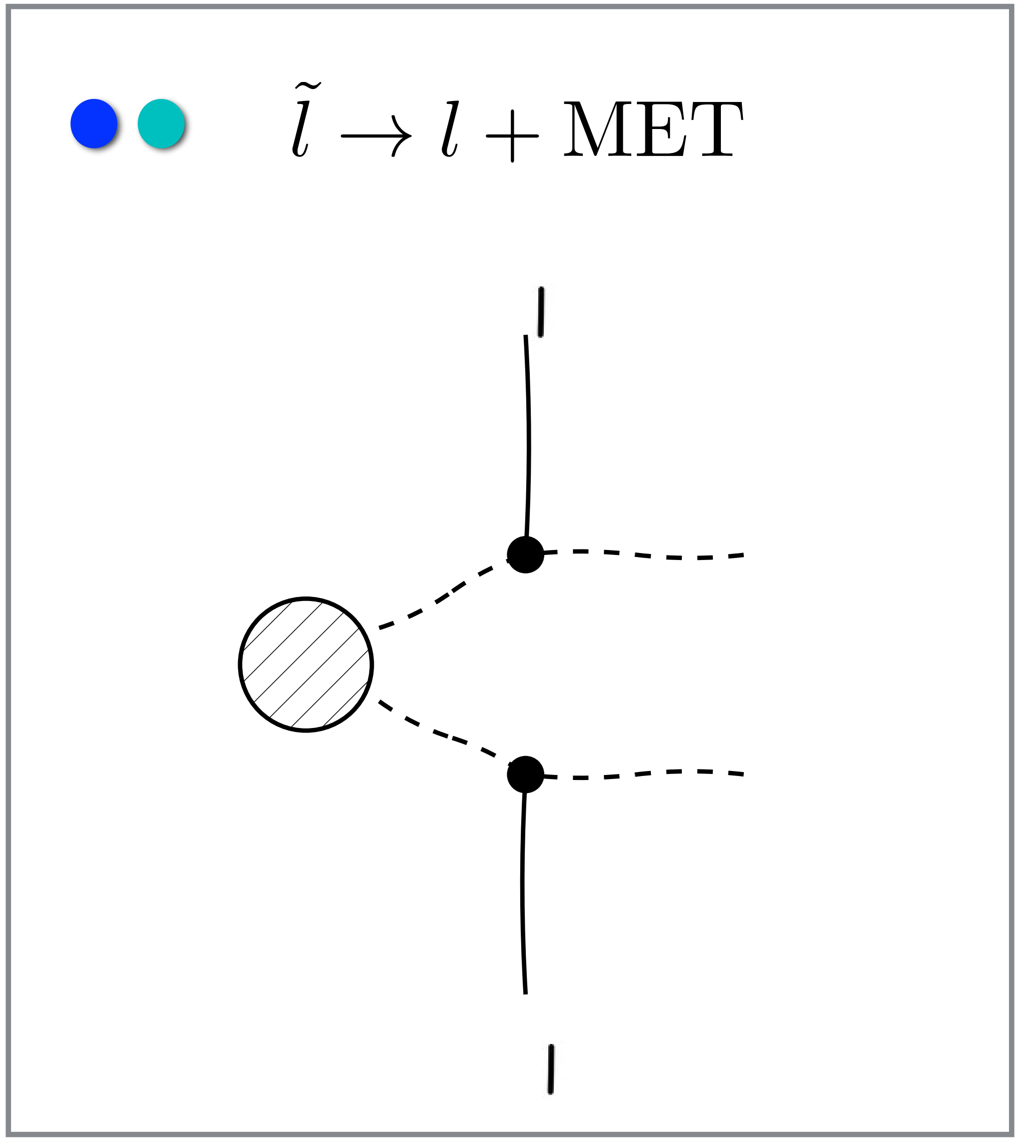

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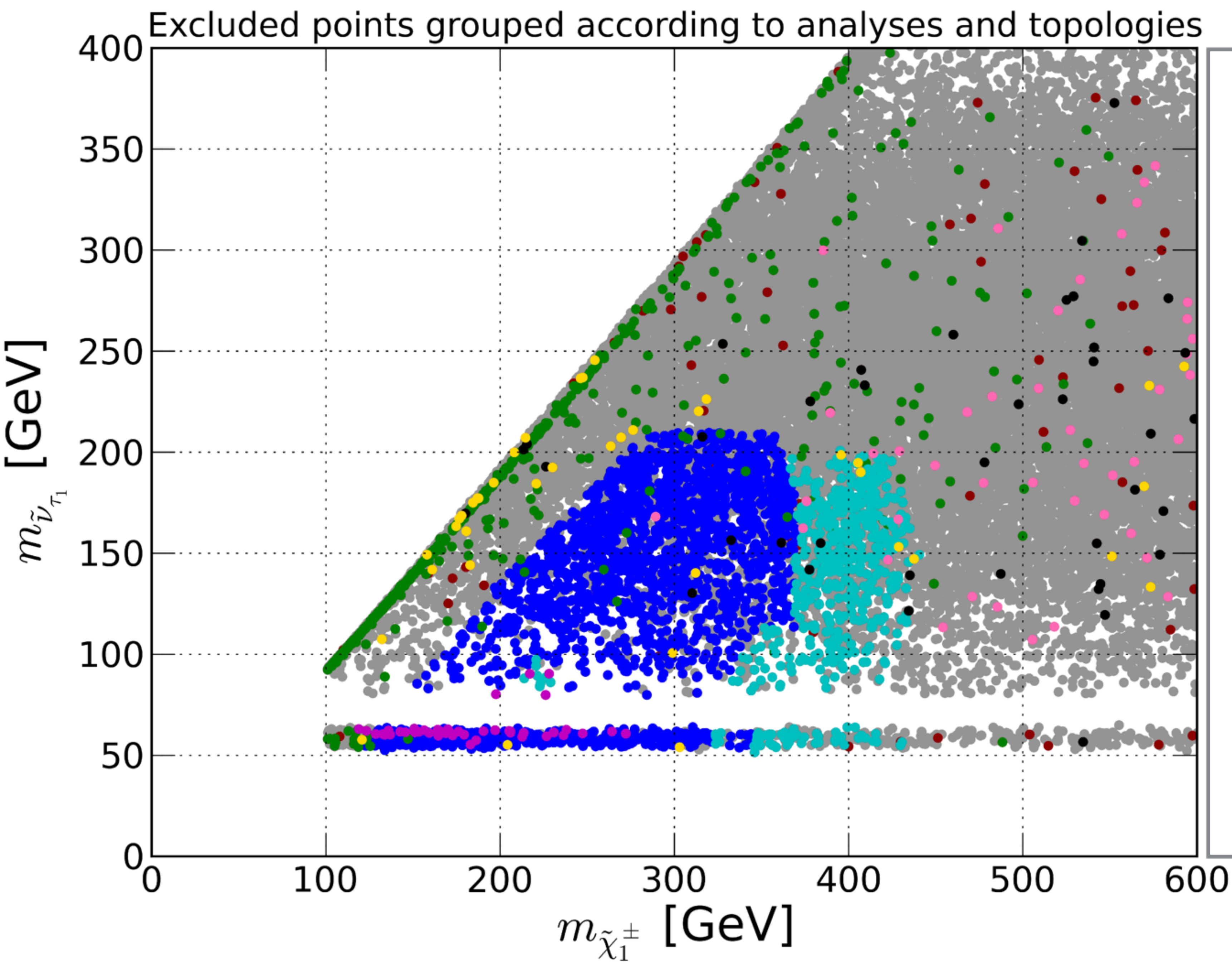

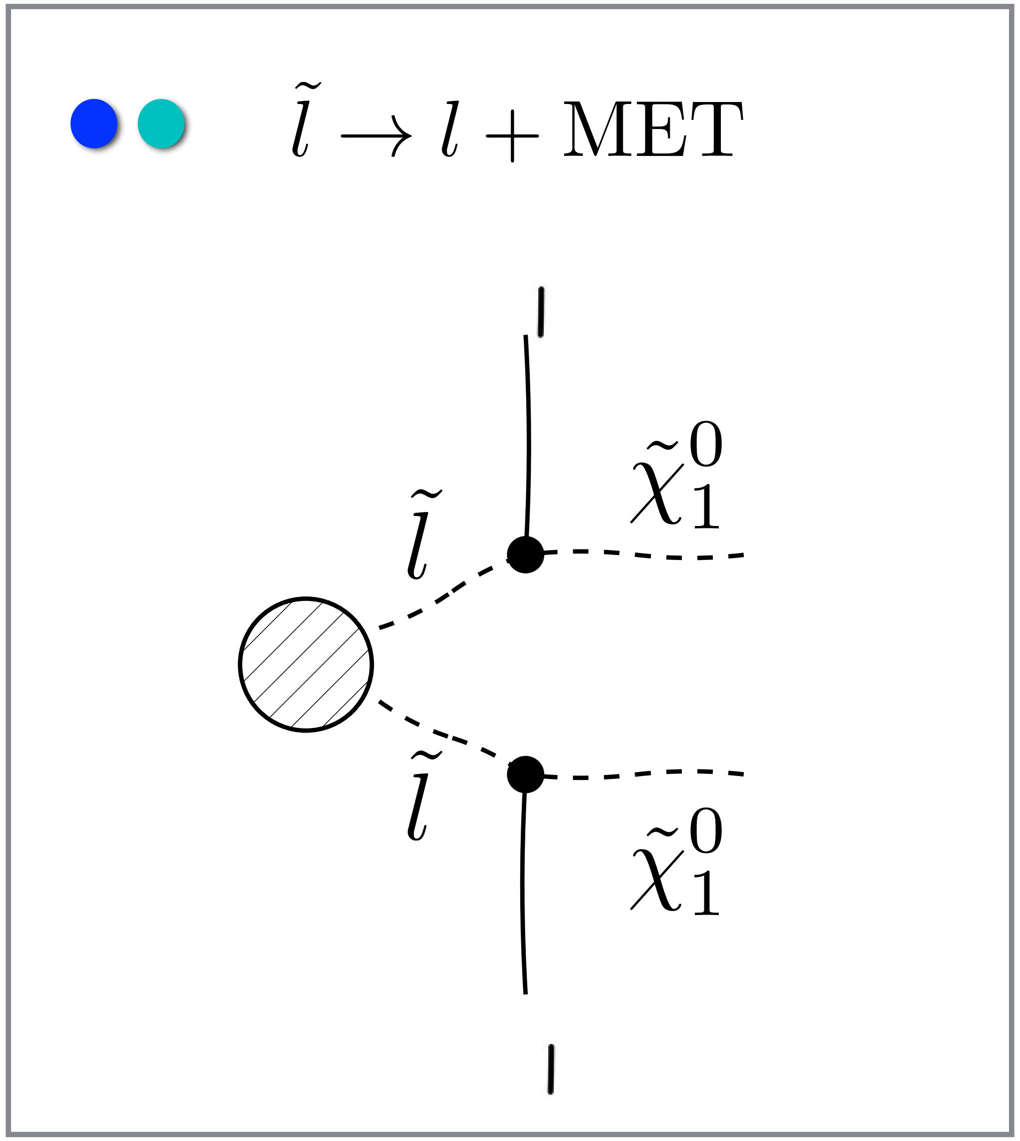

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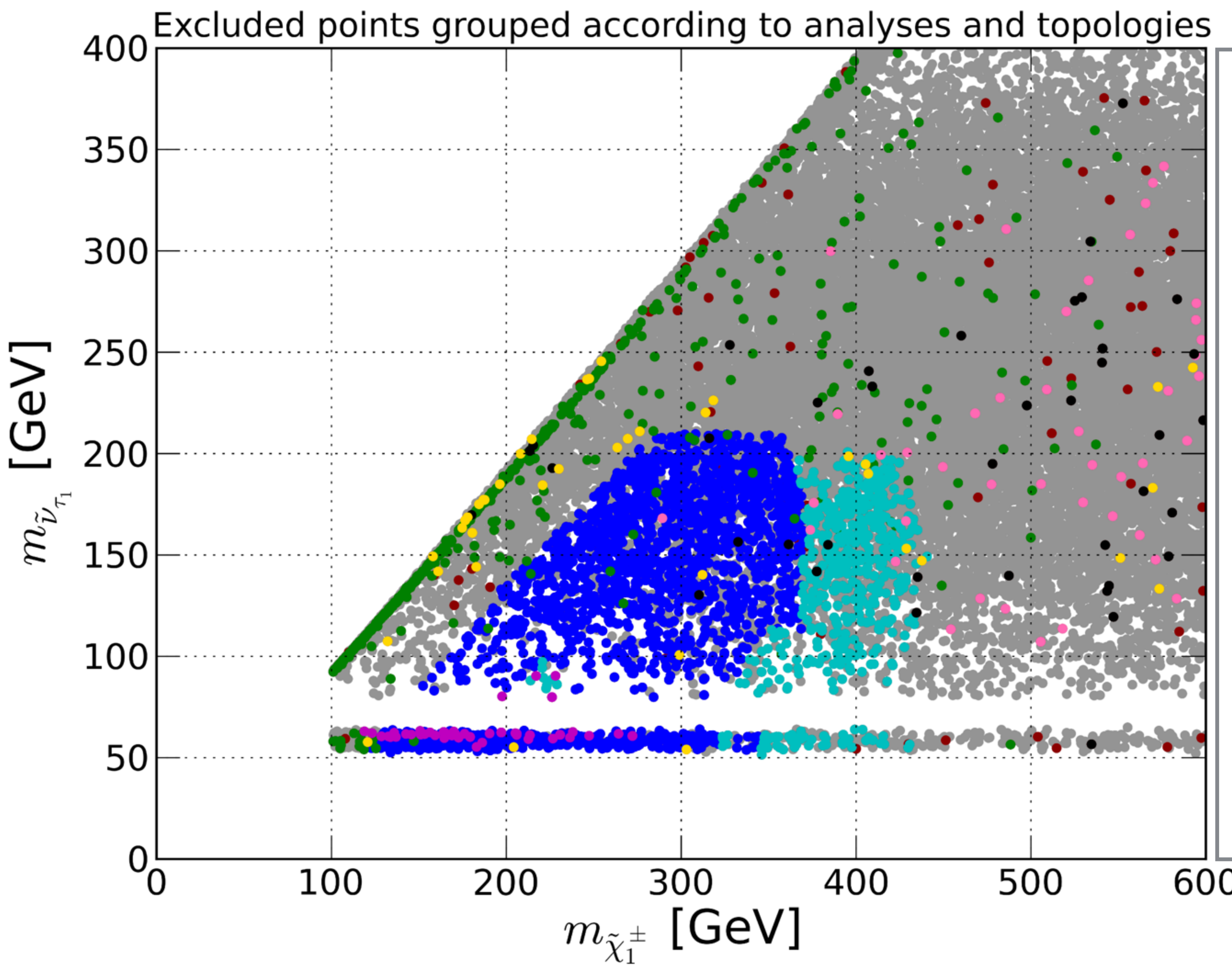

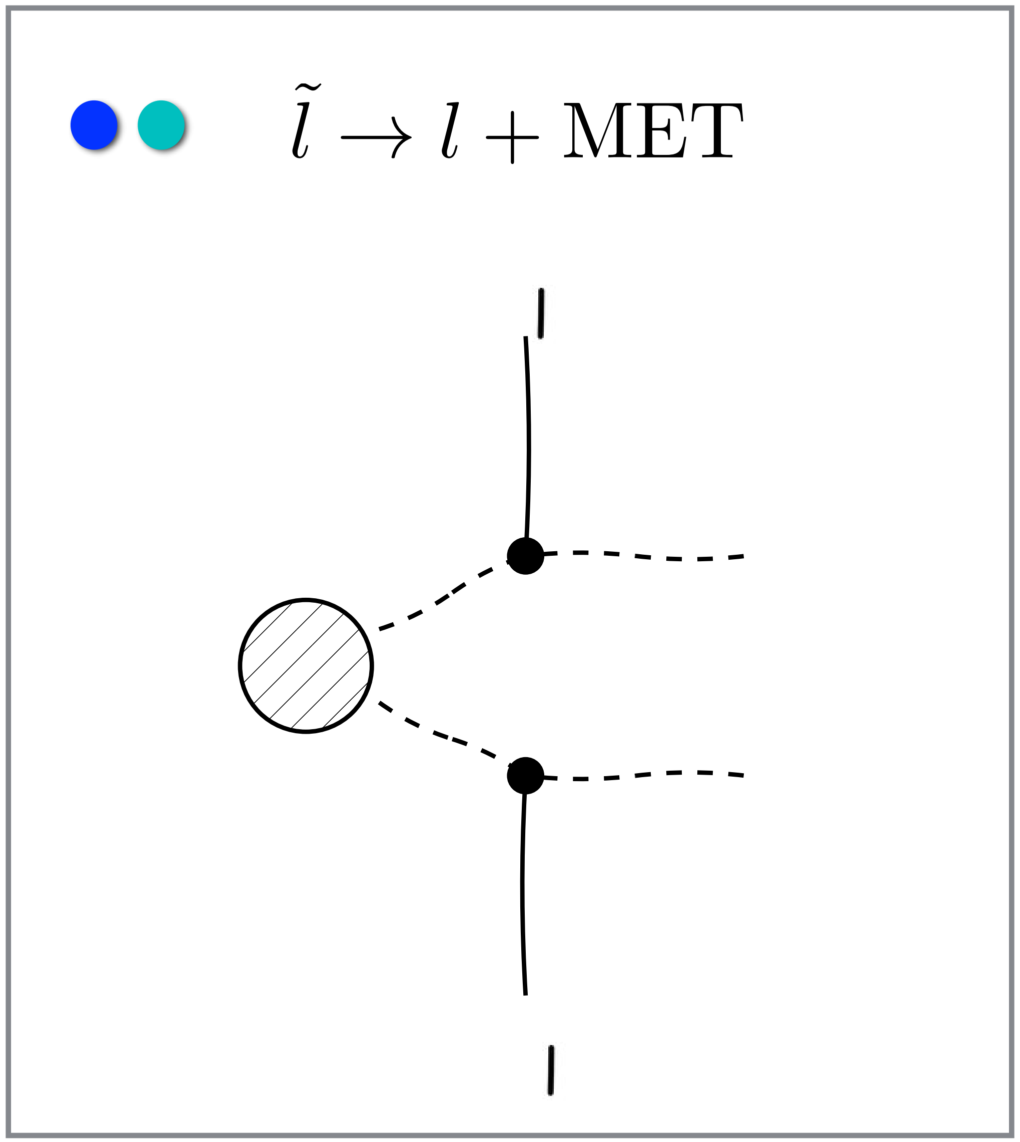

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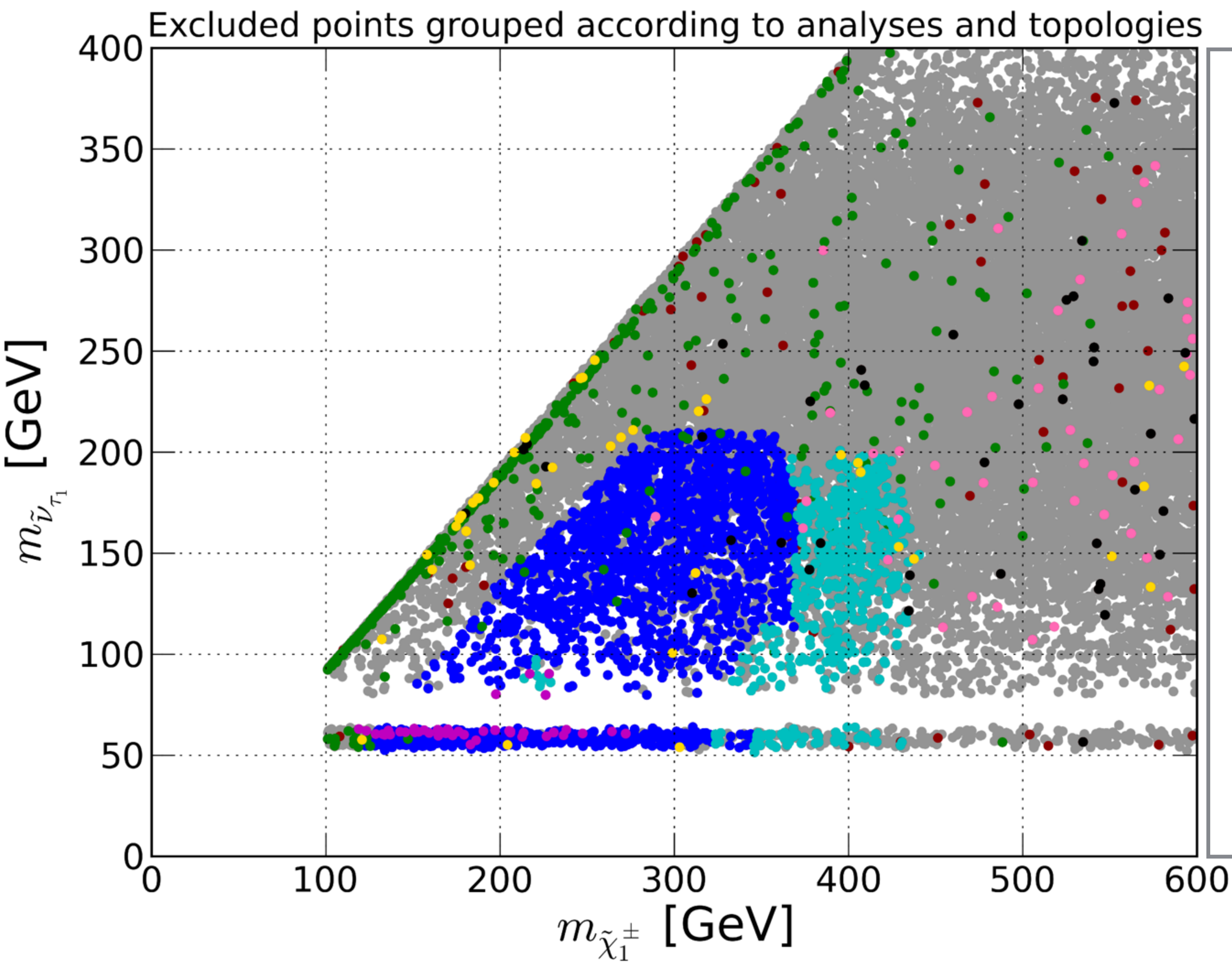

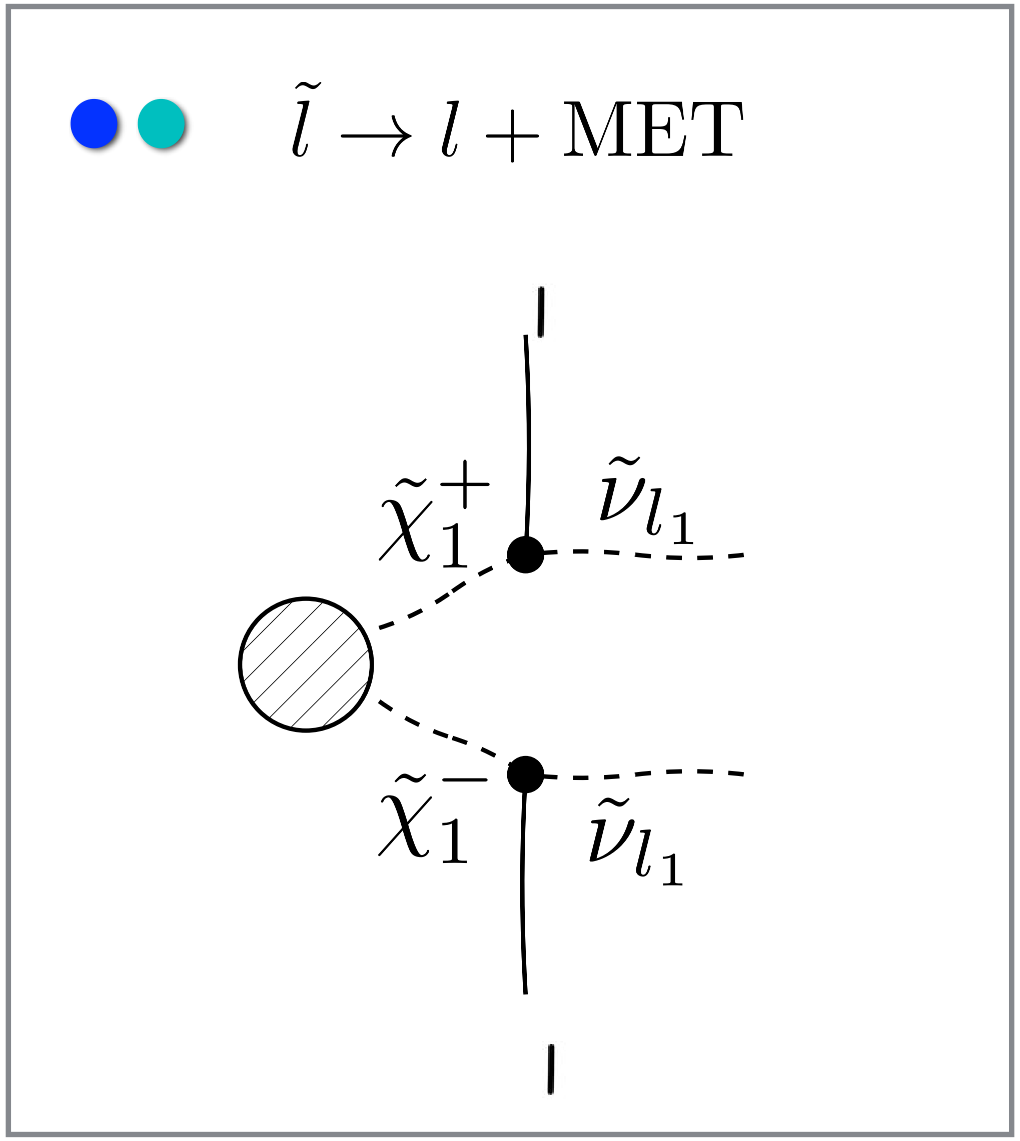

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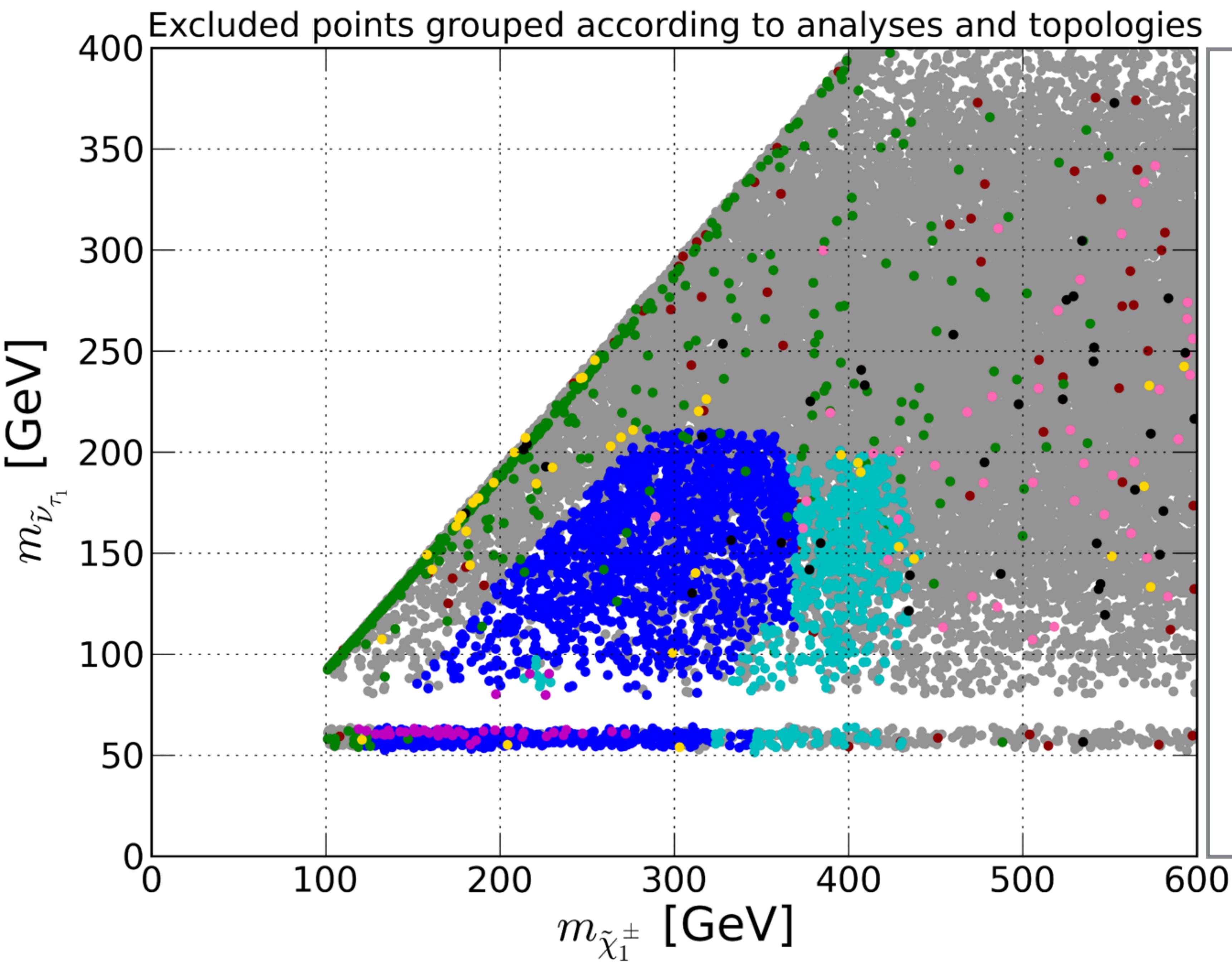

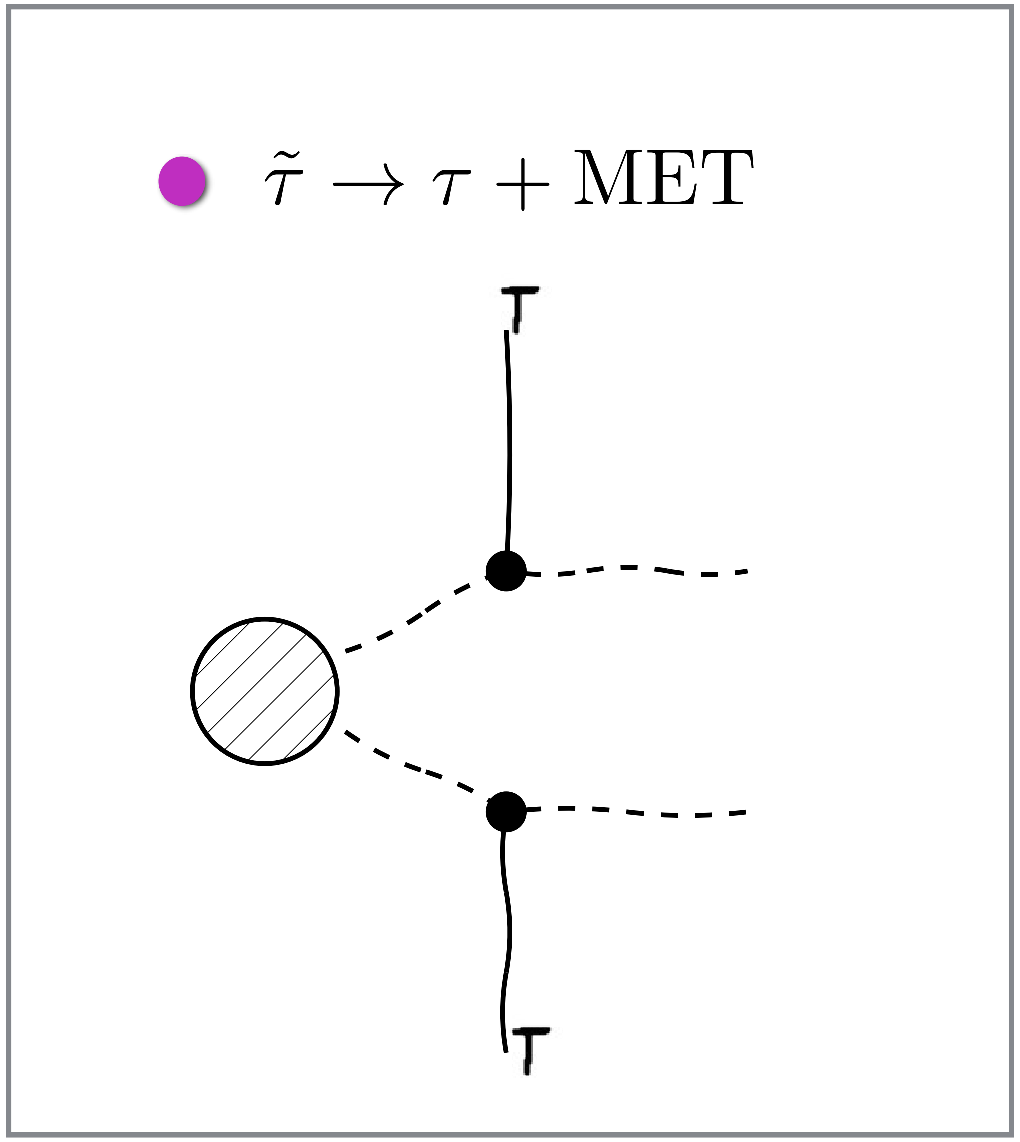

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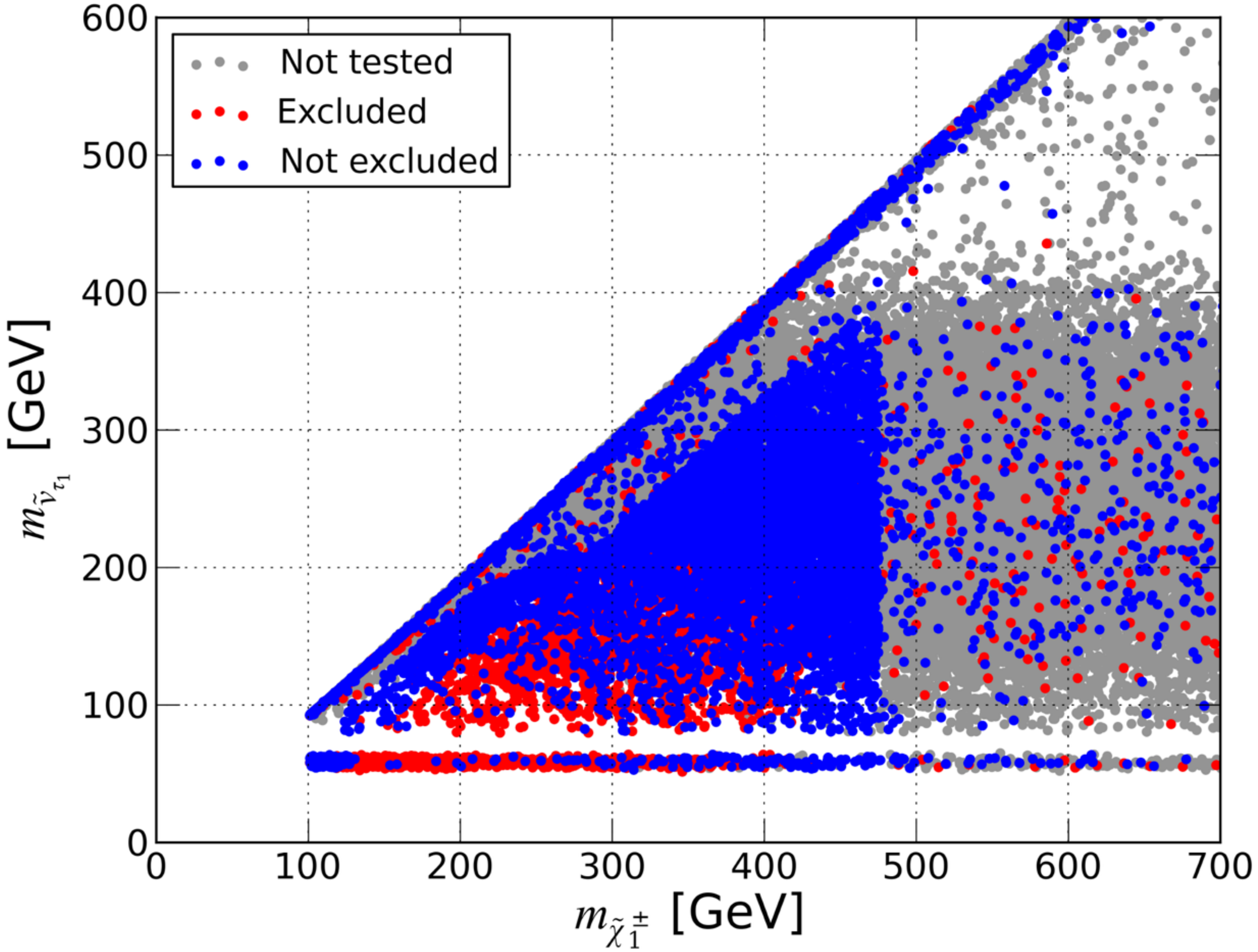

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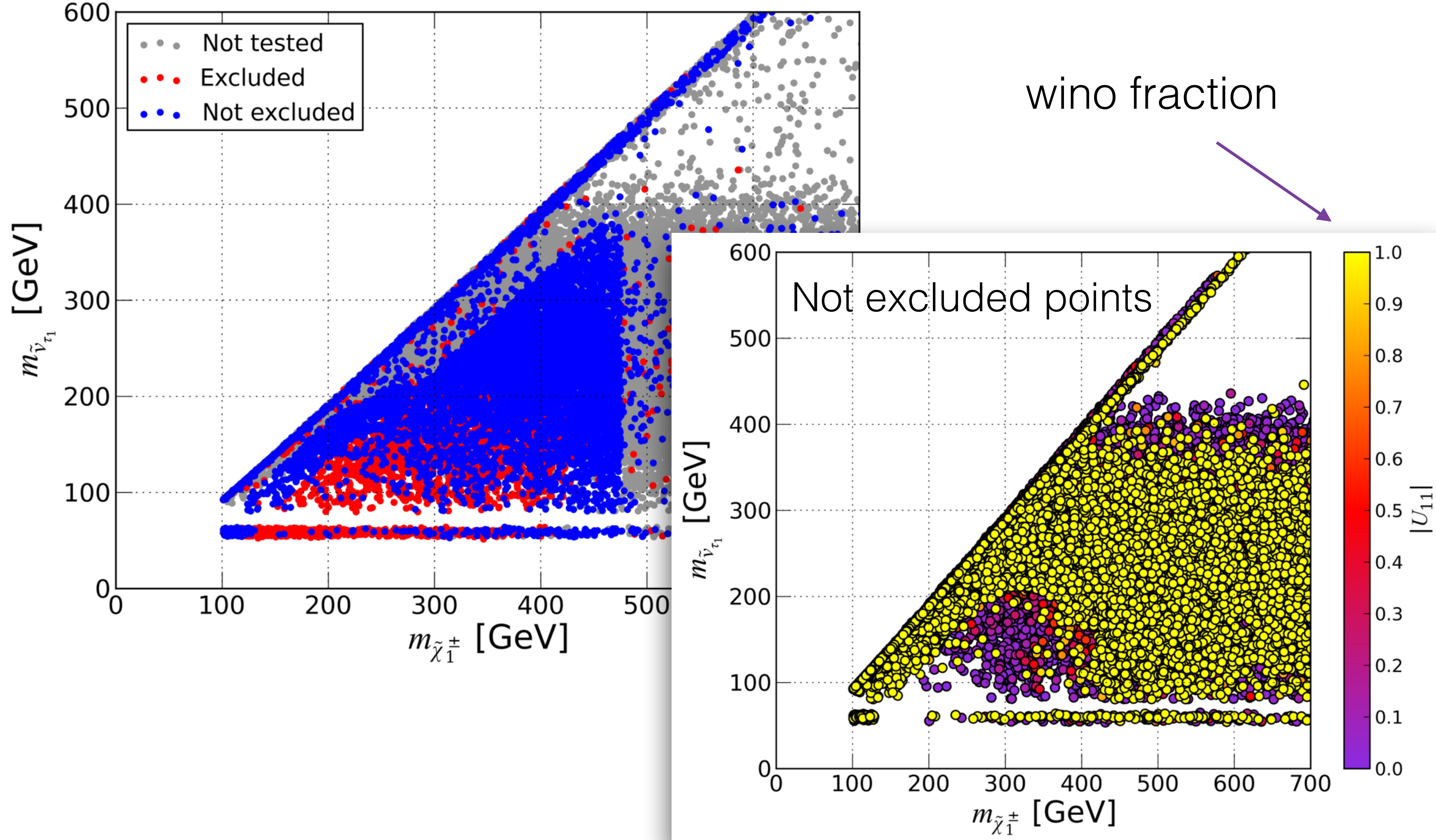

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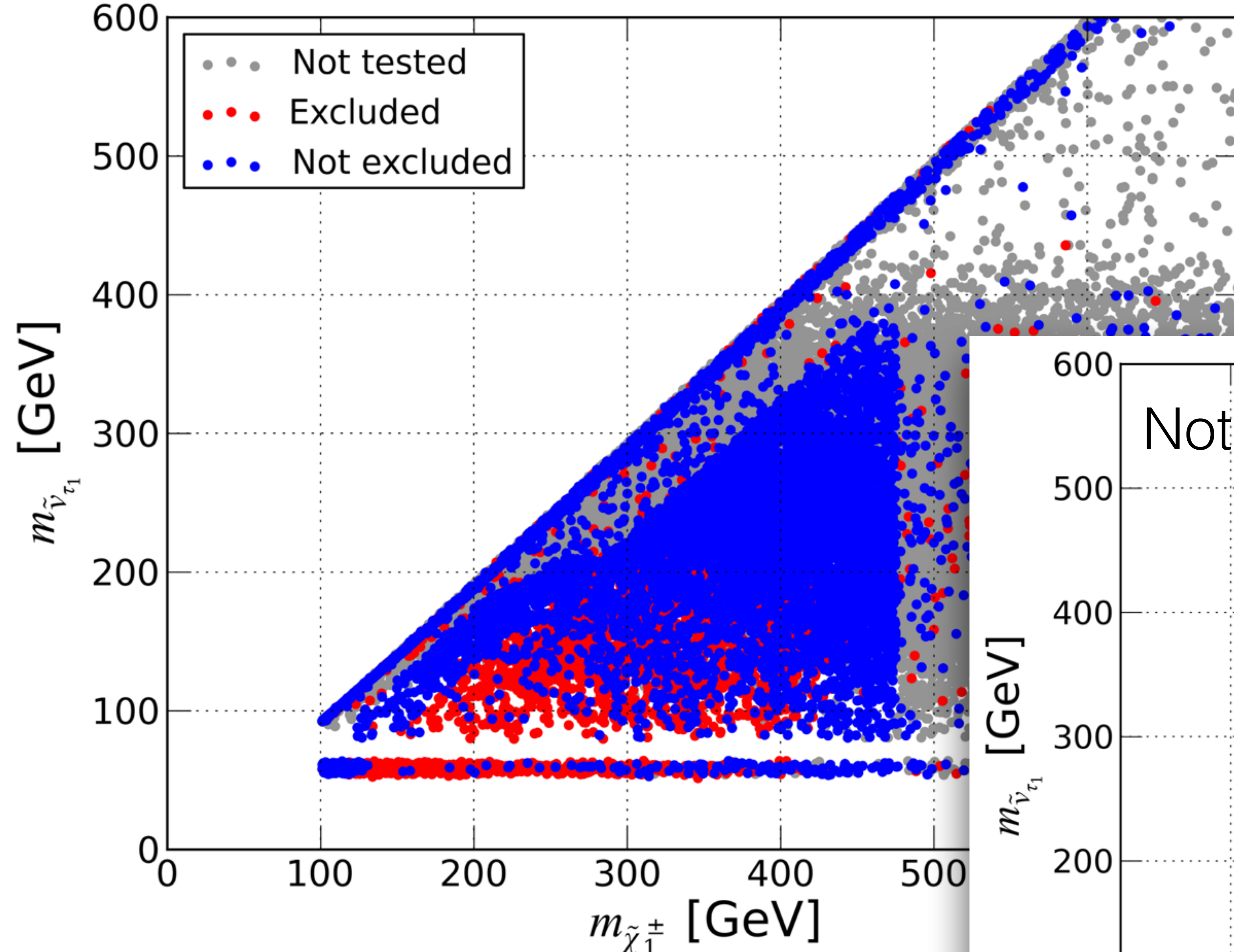
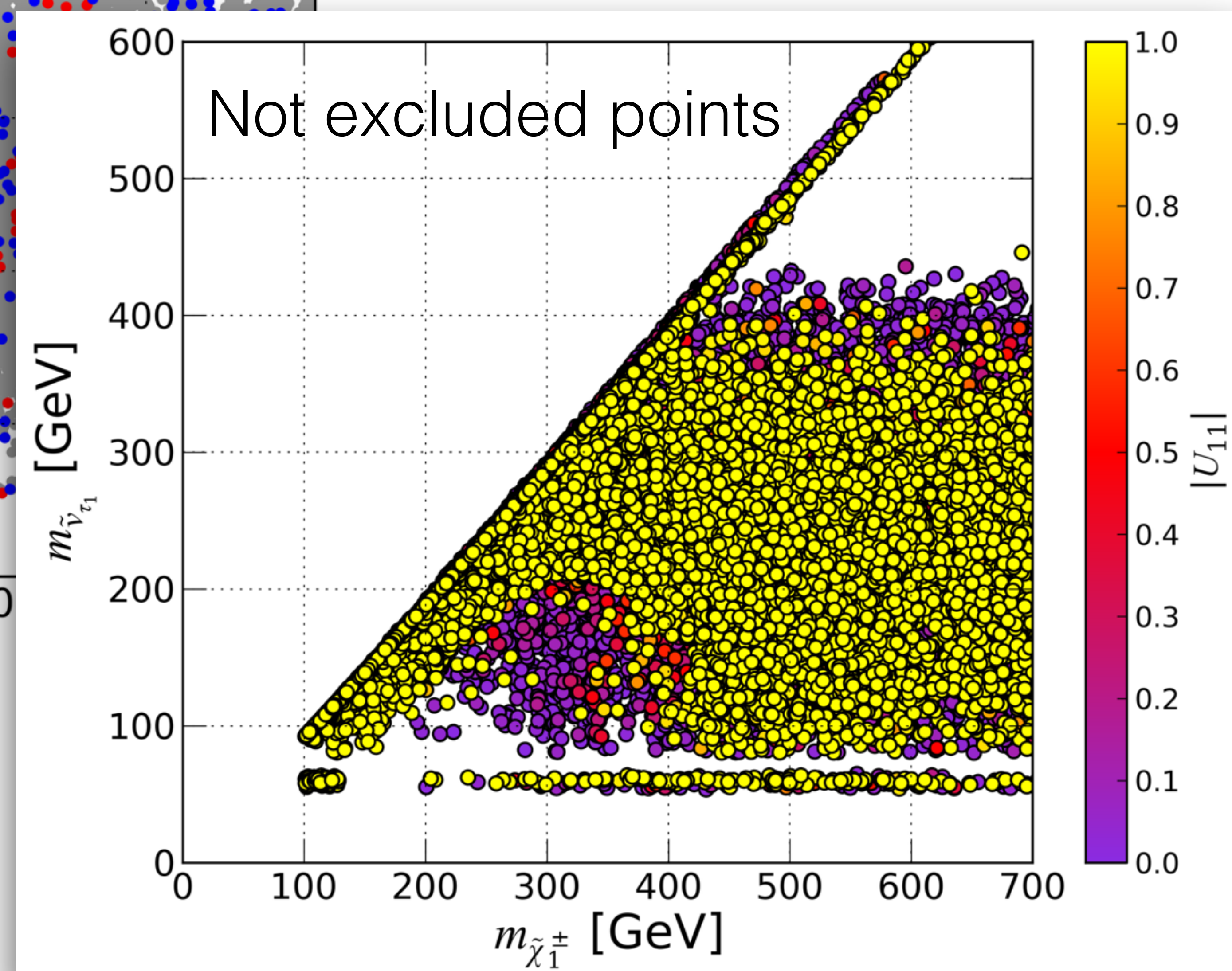


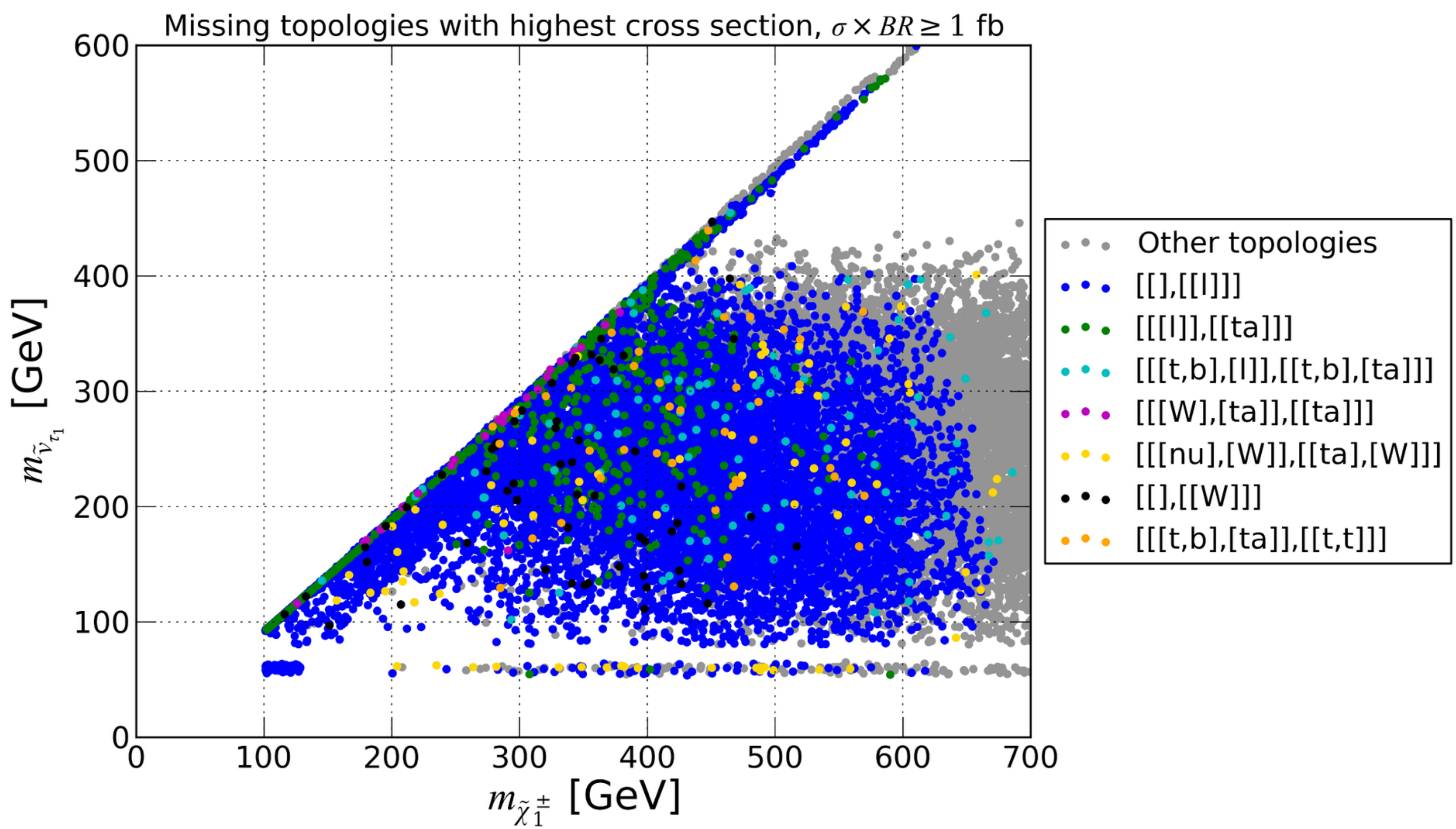
wino fraction



higgsino-like charginos

- smaller production cross section
- larger branching to tau final states

Those can be tested by topologies not yet considered by ATLAS and CMS



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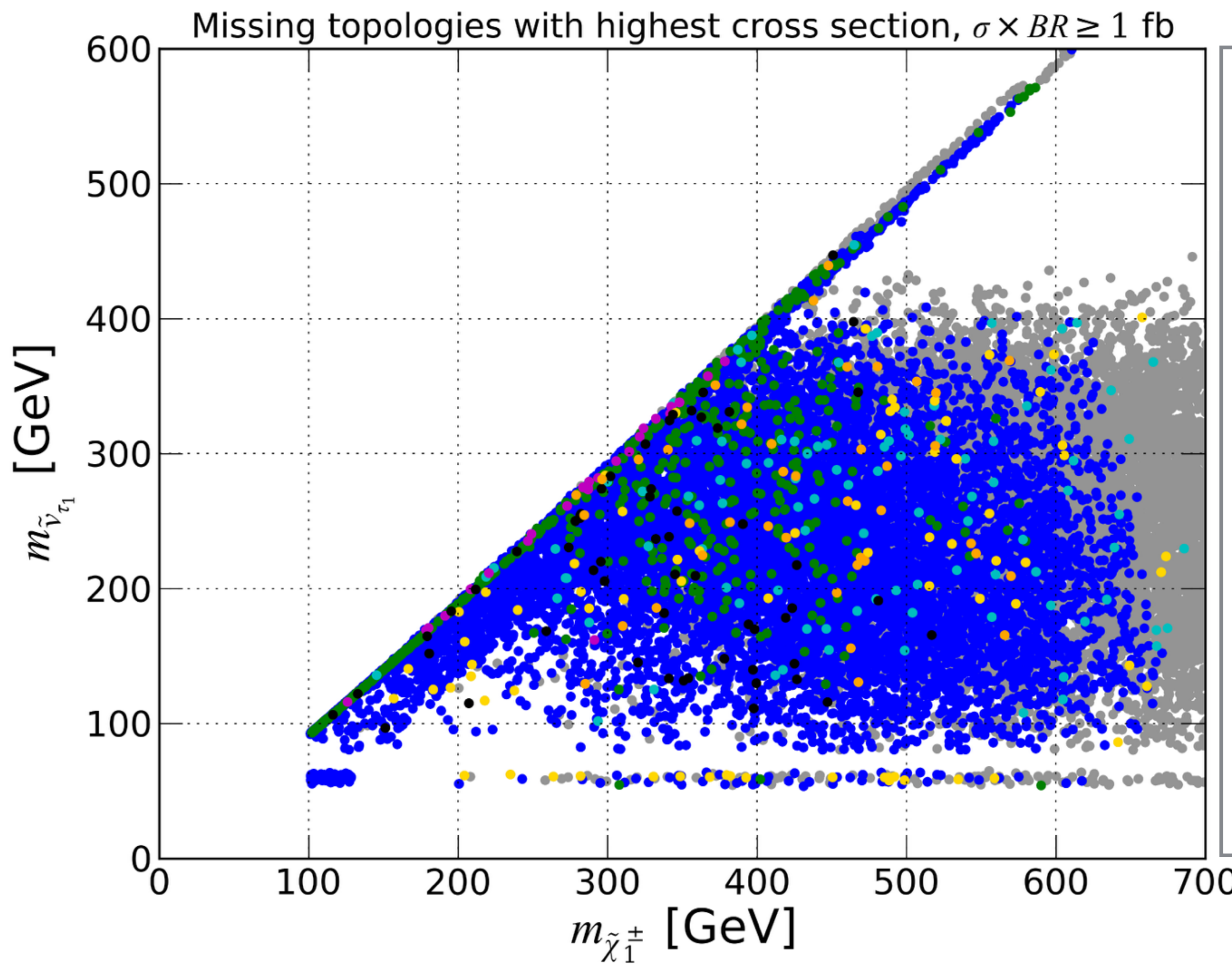

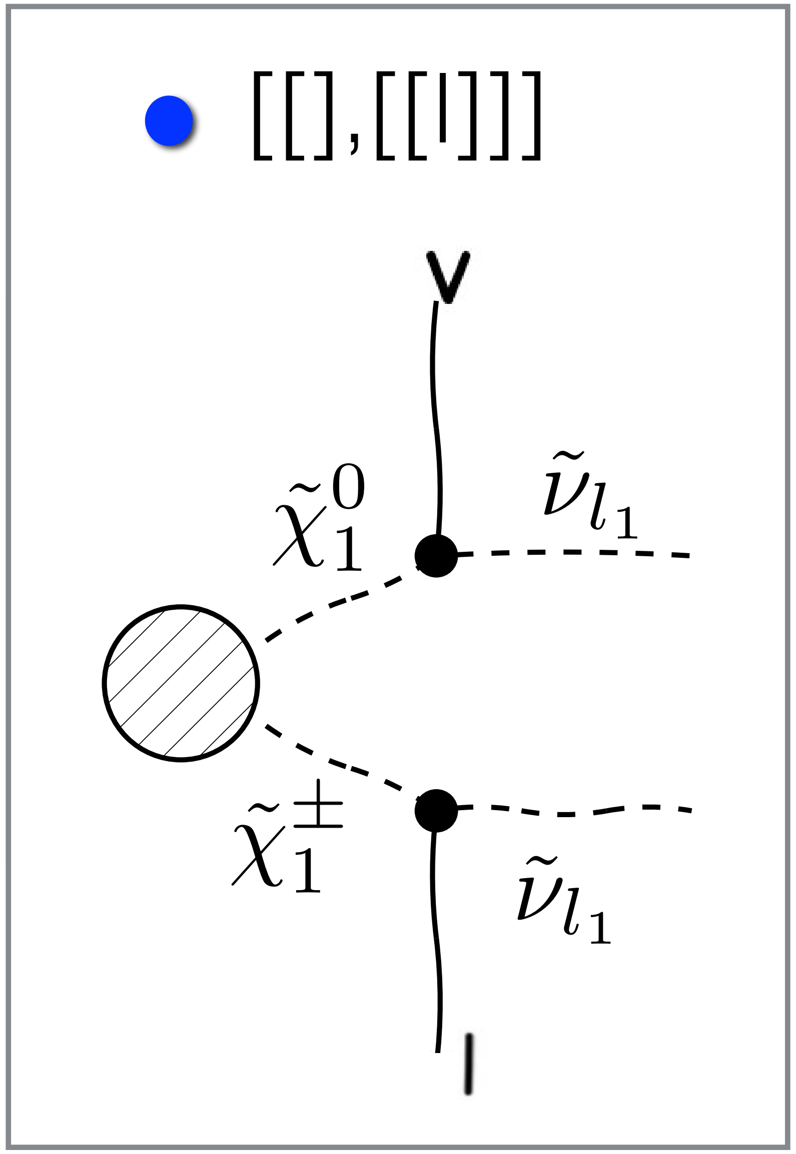

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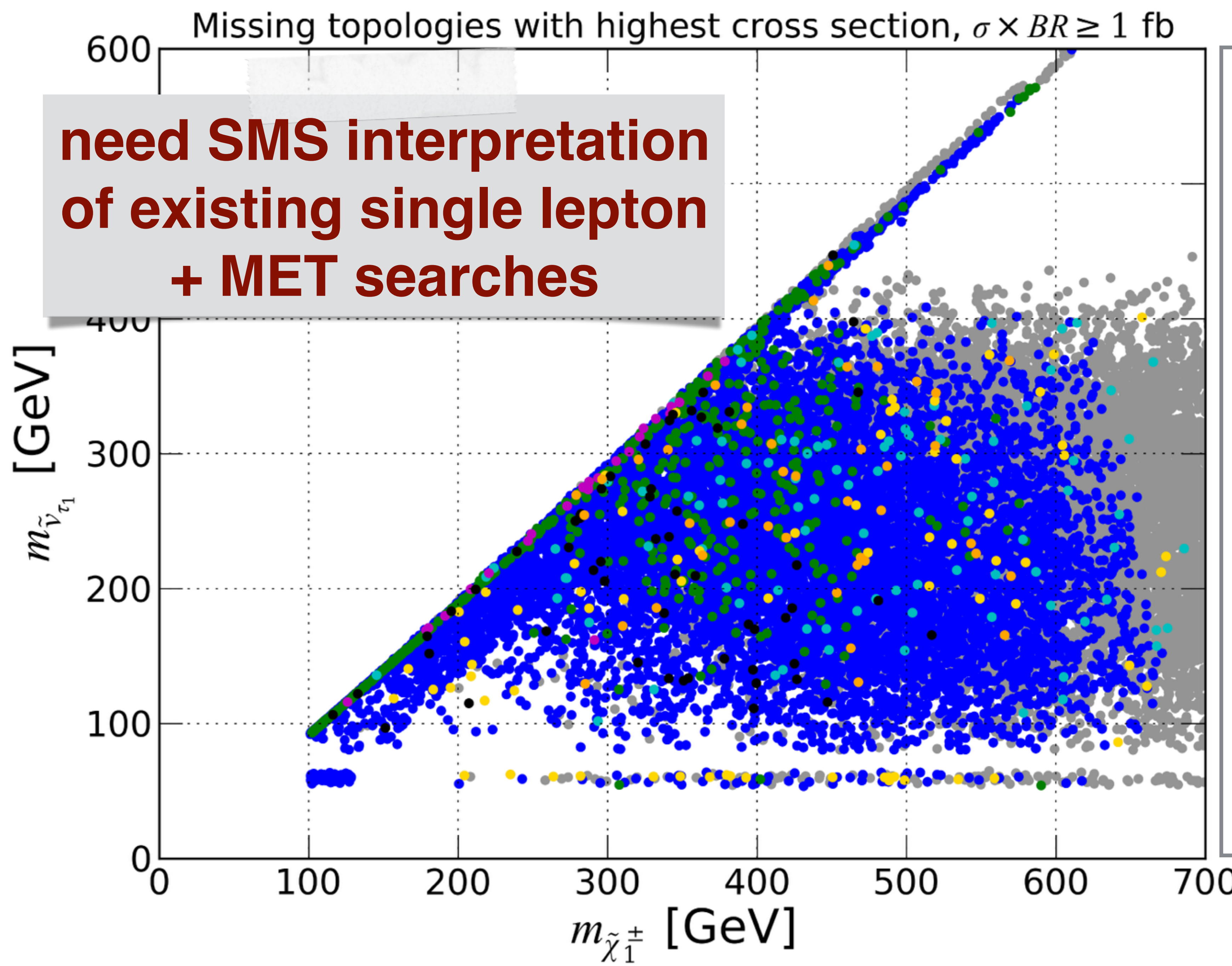
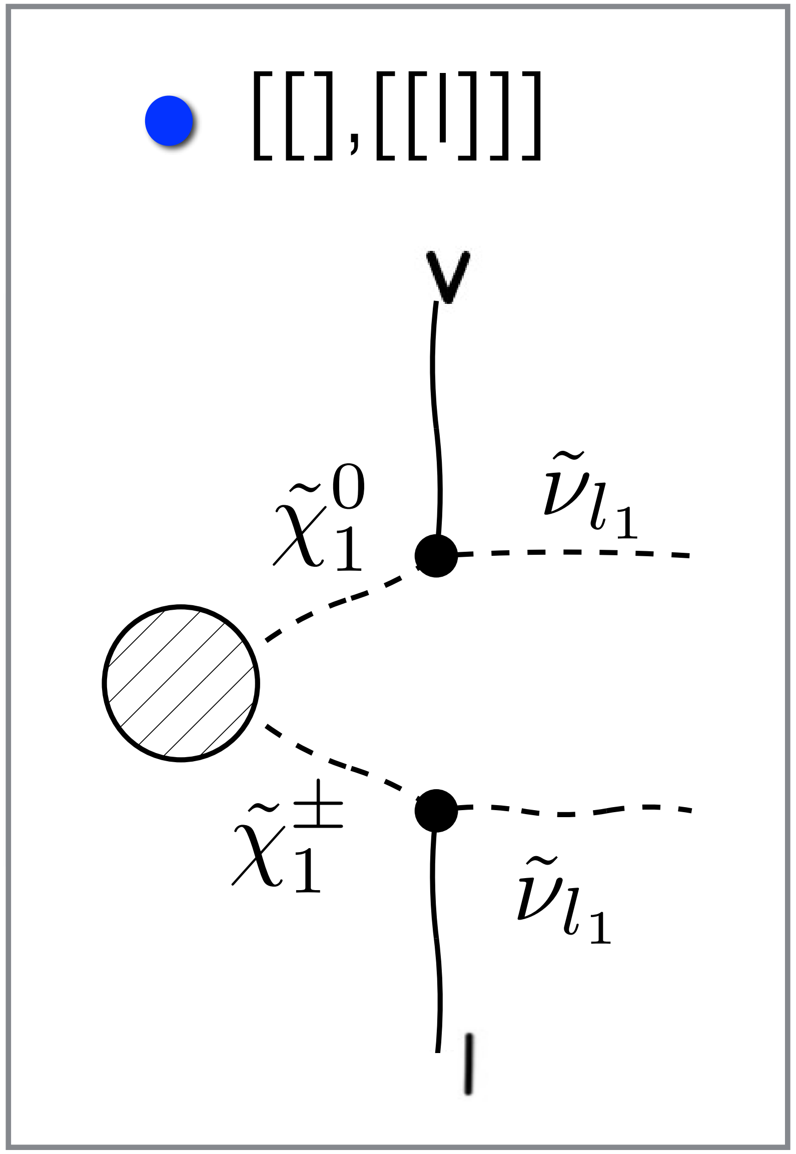
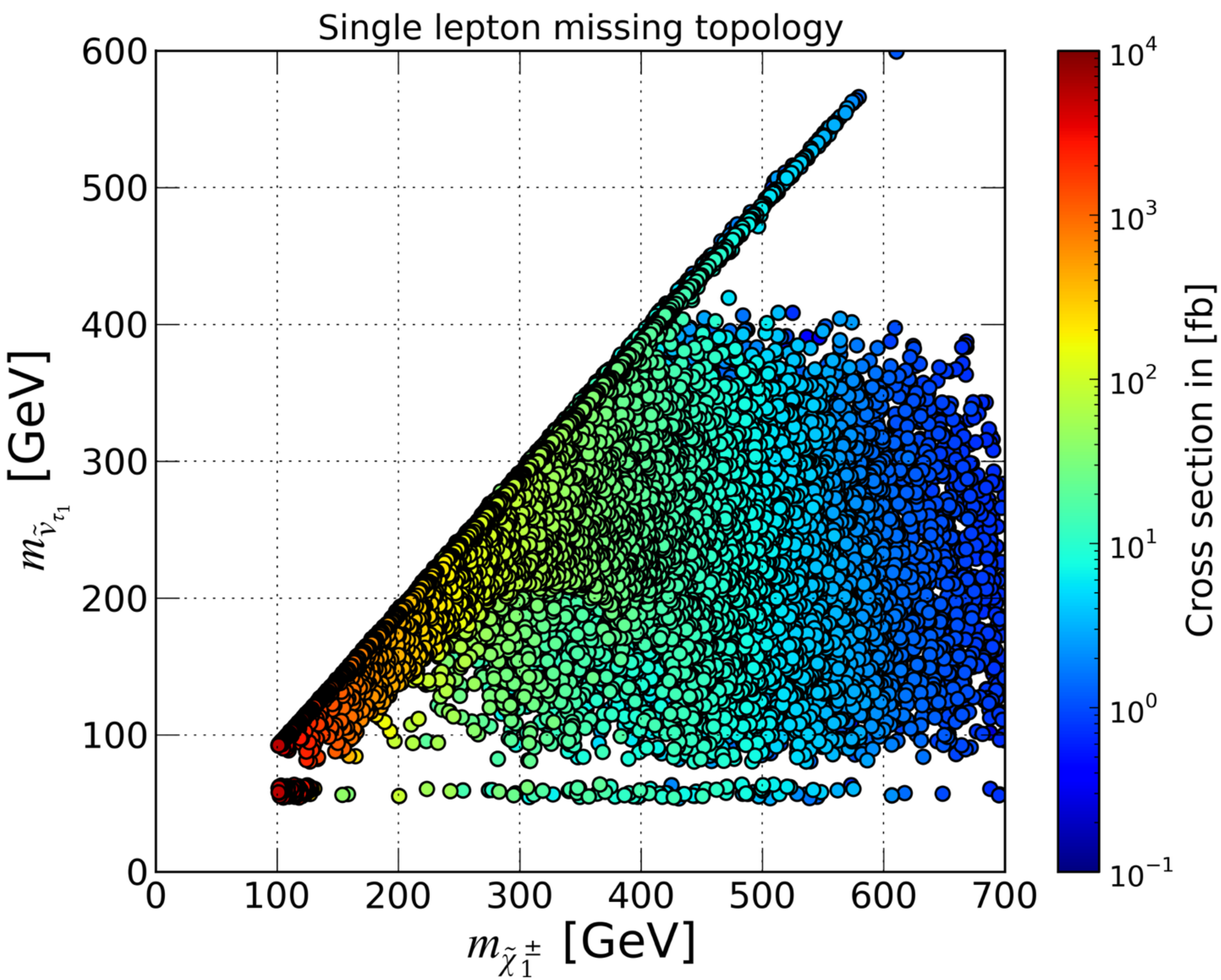


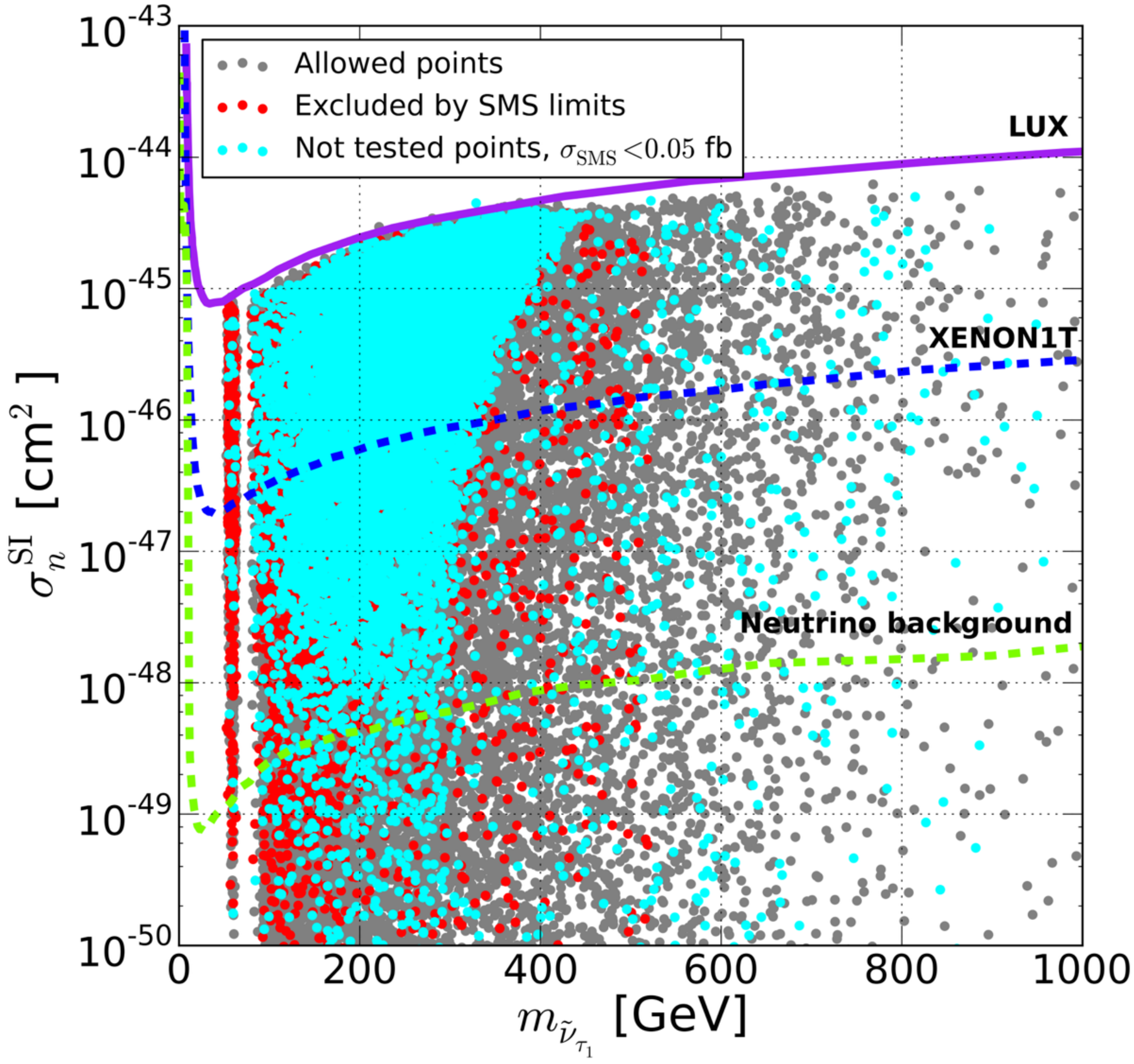
need SMS interpretation of existing single lepton + MET searches



The single lepton topology can have a large cross section



LHC searches and direct dark matter detection experiments are complementary



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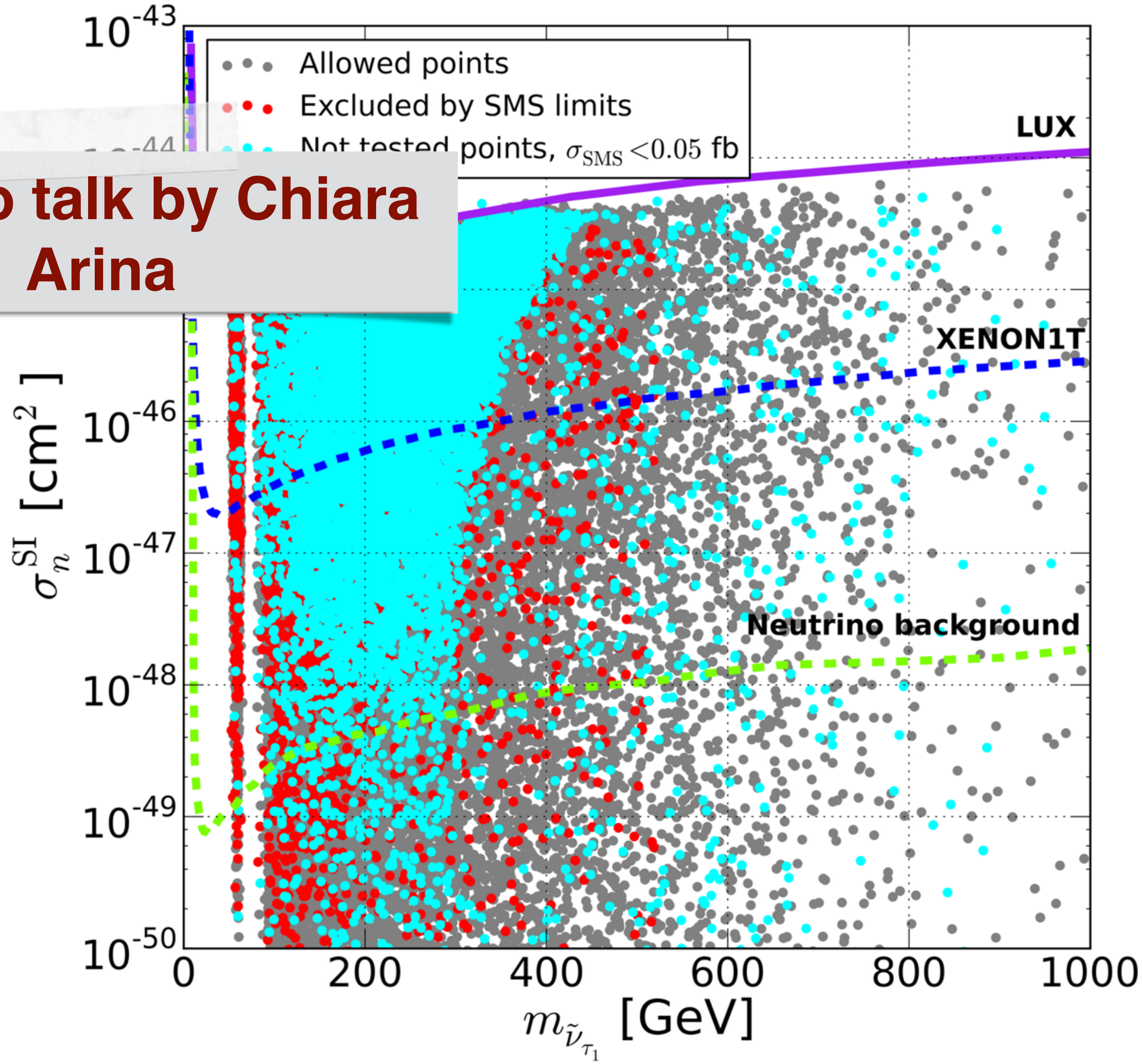

see also talk by Chiara Arina

Conclusion

- Existing LHC results can constrain the MSSM+RN
- In particular dilepton+MET searches constrain chargino pair production
- Constraints obtained for slepton production (followed by a decay to a neutralino) apply to pair produced charginos (decaying to a sneutrino)
- Single lepton searches considering chargino-neutralino production followed by a decay to sneutrino would test the model further
- LHC constraints are complementary to direct dark matter searches
- Many points feature long-lived gluinos (especially if it is the NLSP), those points were excluded from the study

Backup

We used MultiNest to sample the parameter space

GUT scale Parameters	Prior range
M_1, M_2	(-4000, 4000) GeV
$log_{10}(M_3/\mathrm{GeV})$	(-4, 4)
$log_{10}(m_Q/\mathrm{GeV})$	(2, 5)
m_L, m_R	(1, 2000) GeV
m_N	(1, 2000) GeV
$log_{10}(A_Q/\mathrm{GeV})$	(-5, 5)
A_L	(-4000, 4000) GeV
$A_{\tilde{\nu}}$	(-1000, 1000) GeV
$log_{10}(m_H/\mathrm{GeV})$	(1, 5)
$\tan\beta$	(3, 50)

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→ $A_{\tilde{\nu}}$	(-1000, 1000) GeV
$log_{10}(m_H/\text{GeV})$	(1, 5)
$\tan\beta$	(3, 50)

using the following observables and constraints

Observable	Value / constraint
m_h	125.85 ± 0.4 (exp) ± 4 (theo) GeV
$\mathrm{BR}(B \to X_s \gamma) \times 10^4$	3.55 ± 0.24 ± 0.09 (exp)
$\mathrm{BR}(B \to \mu^+ \mu^-) \times 10^9$	3.2 (+1.4 -1.2) (stat) (+0.5 -0.3) (sys)
$\Omega_{\mathrm{DM}} h^2$	0.1186 ± 0.0031 (exp) ± 20% (theo)
$\Delta\Gamma_Z^{\mathrm{invisible}}$	< 2 MeV (95% CL)
$\mathrm{BR}(h \to \mathrm{invisible})$	< 20% (95% CL)
$m_{\tilde{\tau}_1^-}$	> 85 GeV (95% CL)
$m_{\tilde{\chi}_1^+}, m_{\tilde{e},\tilde{\mu}}$	>101 GeV (95% CL)
$m_{\tilde{g}}$	> 308 GeV (95% CL)
σ_n^{SI}	$< \sigma_{\mathrm{LUX}}^{SI}$ (90% CL)

Measurements

Limits

To use SModelS with a non-MSSM scenario, just define all new particles as r-Even or r-Odd

You can then use SModelS to decompose a point in your BSM scenario, using as input

- an **LHE file** containing simulated events, or
- an **SLHA file** containing the full mass spectrum, decay tables and the SUSY production cross sections

To use SModelS with a non-MSSM scenario, just define all new particles as r-Even or r-Odd

You can then use SModelS to decompose a point in your BSM scenario, using as input

- an **LHE file** containing simulated events, or
- an **SLHA file** containing the full mass spectrum, decay tables and the SUSY production cross sections

↓

additional checks, in particular SModelS can flag points with long-lived particles, where current SMS limits do not apply

Using SModelS for non-MSSM scenarios

Simply declare all new particles as
R-even or R-odd in smodels/particles.py

Example

```
rOdd = {9000000 : "newROdd"
        1000021 : "gluino",
        1000022 : "N1",
        …

rEven = {8000000: "newREven"
         25 : “higgs",
         …
```

Additional feature for SLHA input files

SModelS can test the consistency of an SLHA input file

In particular

Current experimental constraints require final states containing missing transverse energy

→ results apply only for prompt decays

points with visible displaced vertices or heavy charged particle tracks cannot be tested against existing SMS results

→ we flag points with long-lived particles ($c\tau > 10$ mm)

Requires additional information on the quantum numbers of the new states

to decide if a displaced vertex is visible or not

this is also defined in smodels/particles.py

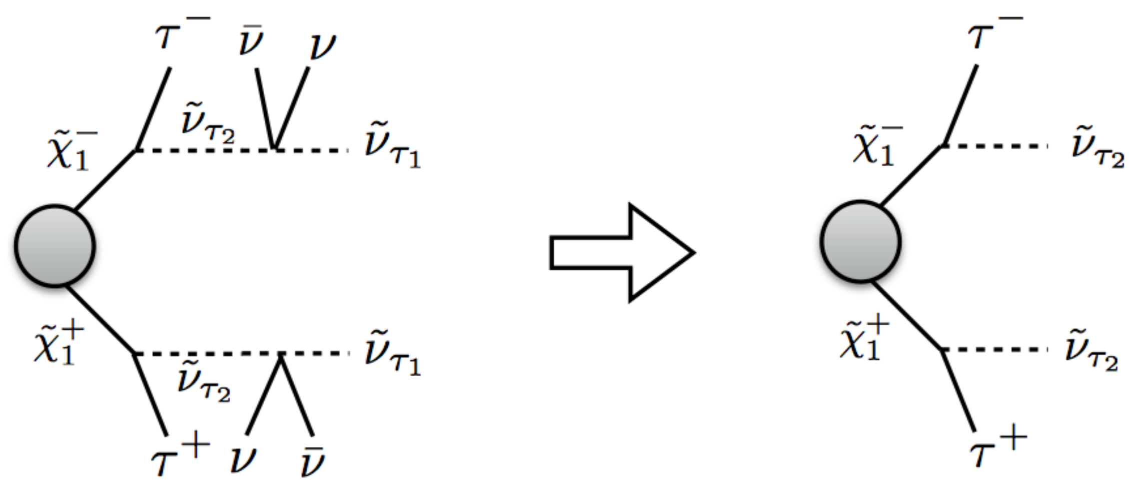
```
qNumbers={
 35:[0,0,1],
 36:[0,0,1],
 37:[0,3,1],
 1000024:[1,3,1],
 …
```

giving 2*spin, 3*electrical charge, colour dimension

Compression of final states

Invisible compression

compress fully invisible vertices at the end of a decay chain



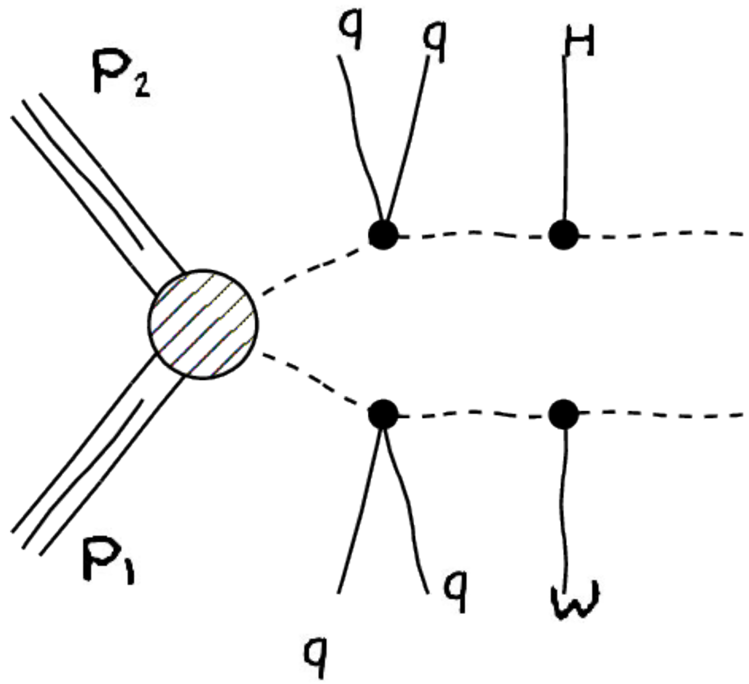
Mass compression

compress vertices where the mass splitting is small, decay products will be too soft to be detected

we used 5 GeV as the threshold value

How to read the element description

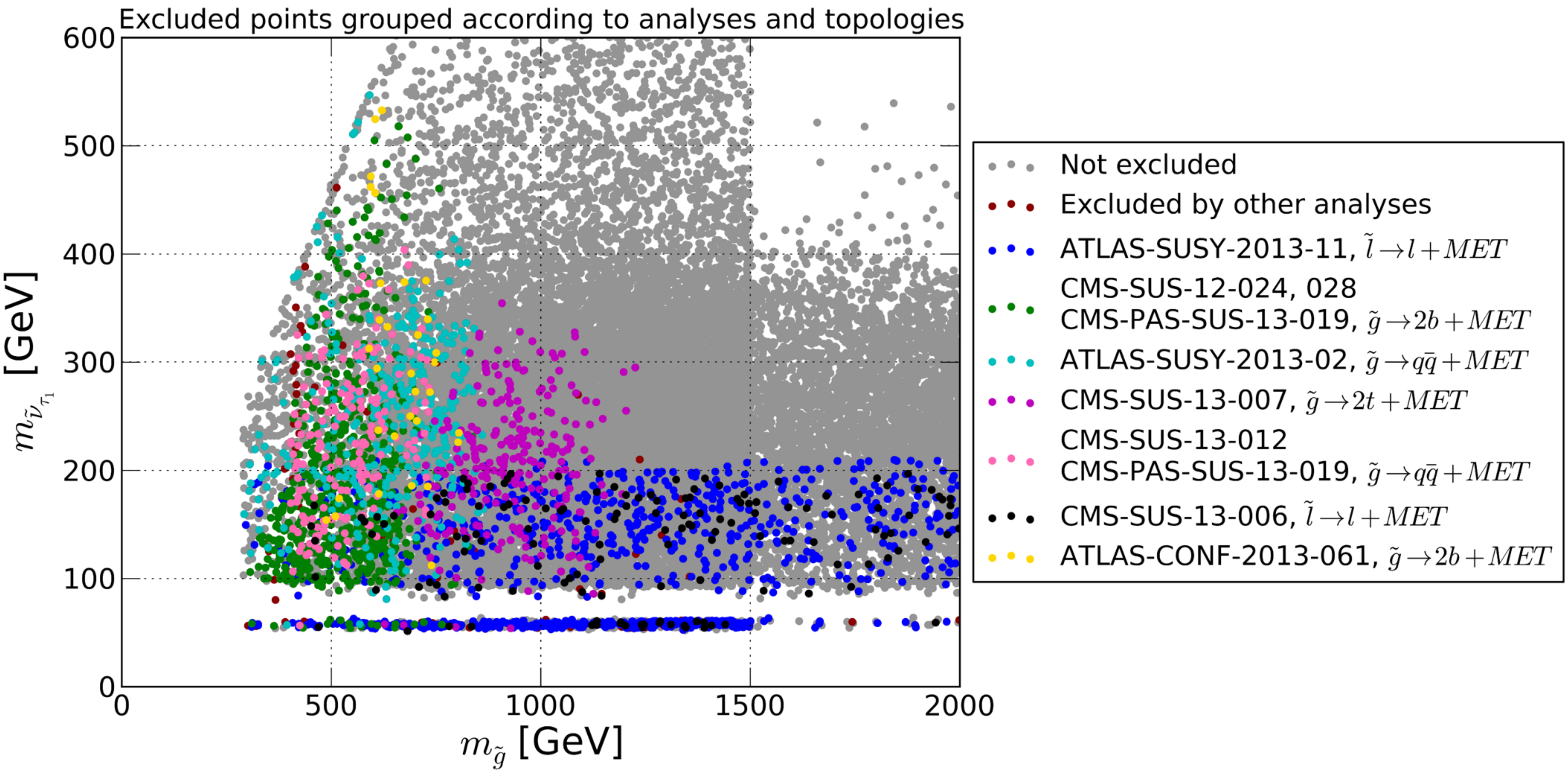
Example: gluino production, decay via chargino/neutralino



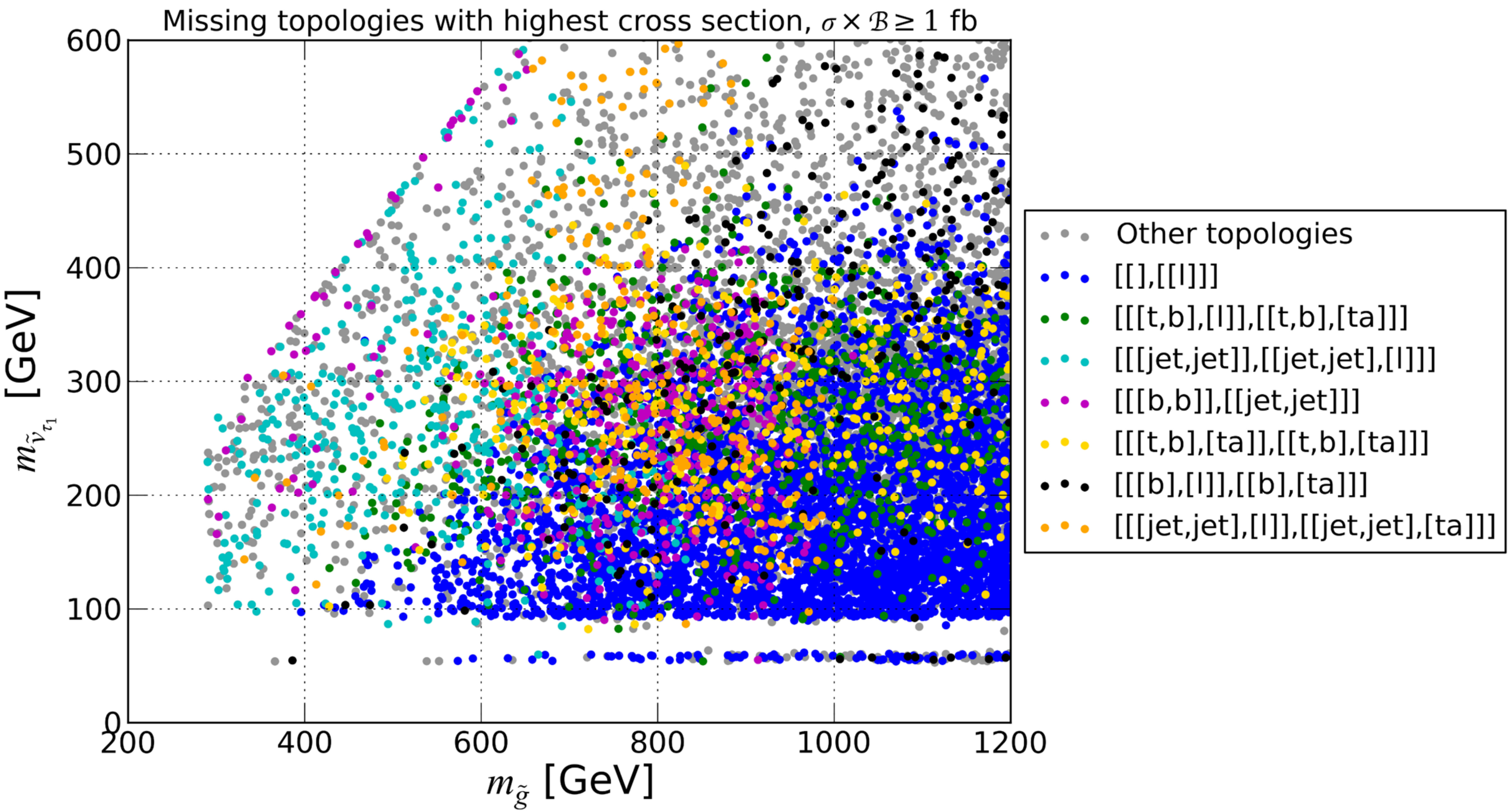
in SModelS language this is

[[[jet,jet],[H]],[[jet,jet],[W]]]

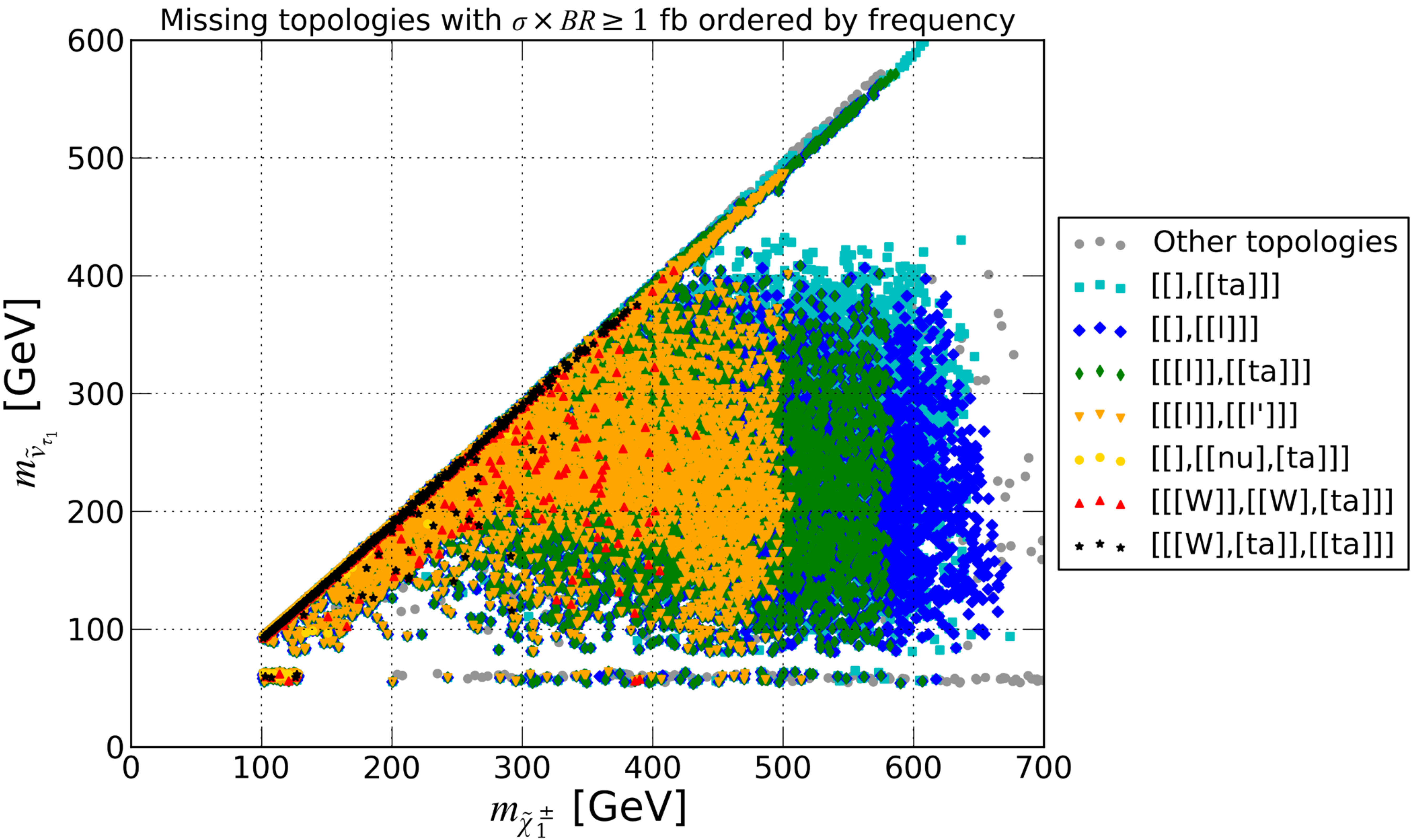
Constraints on the strong sector



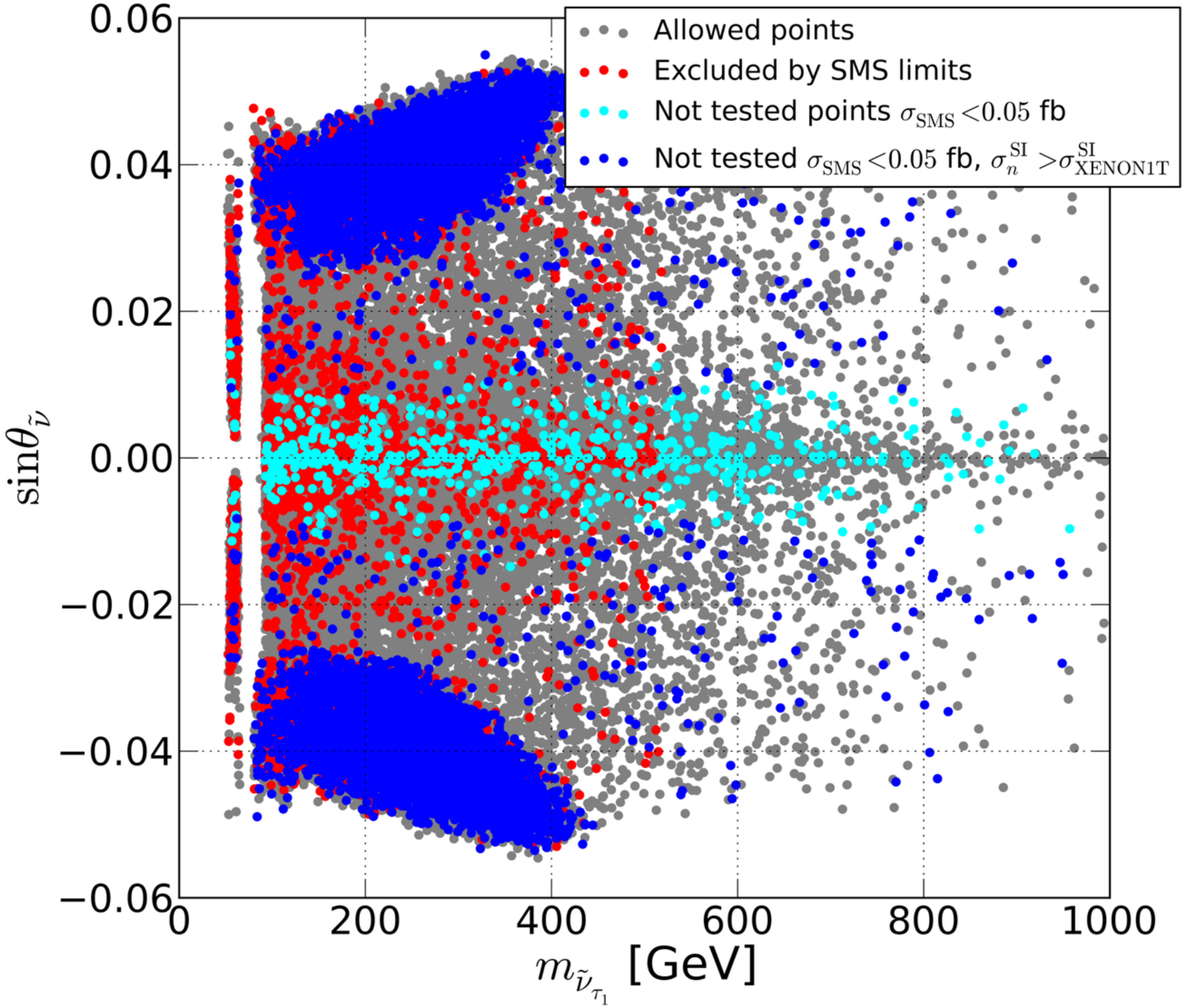
Missing topologies



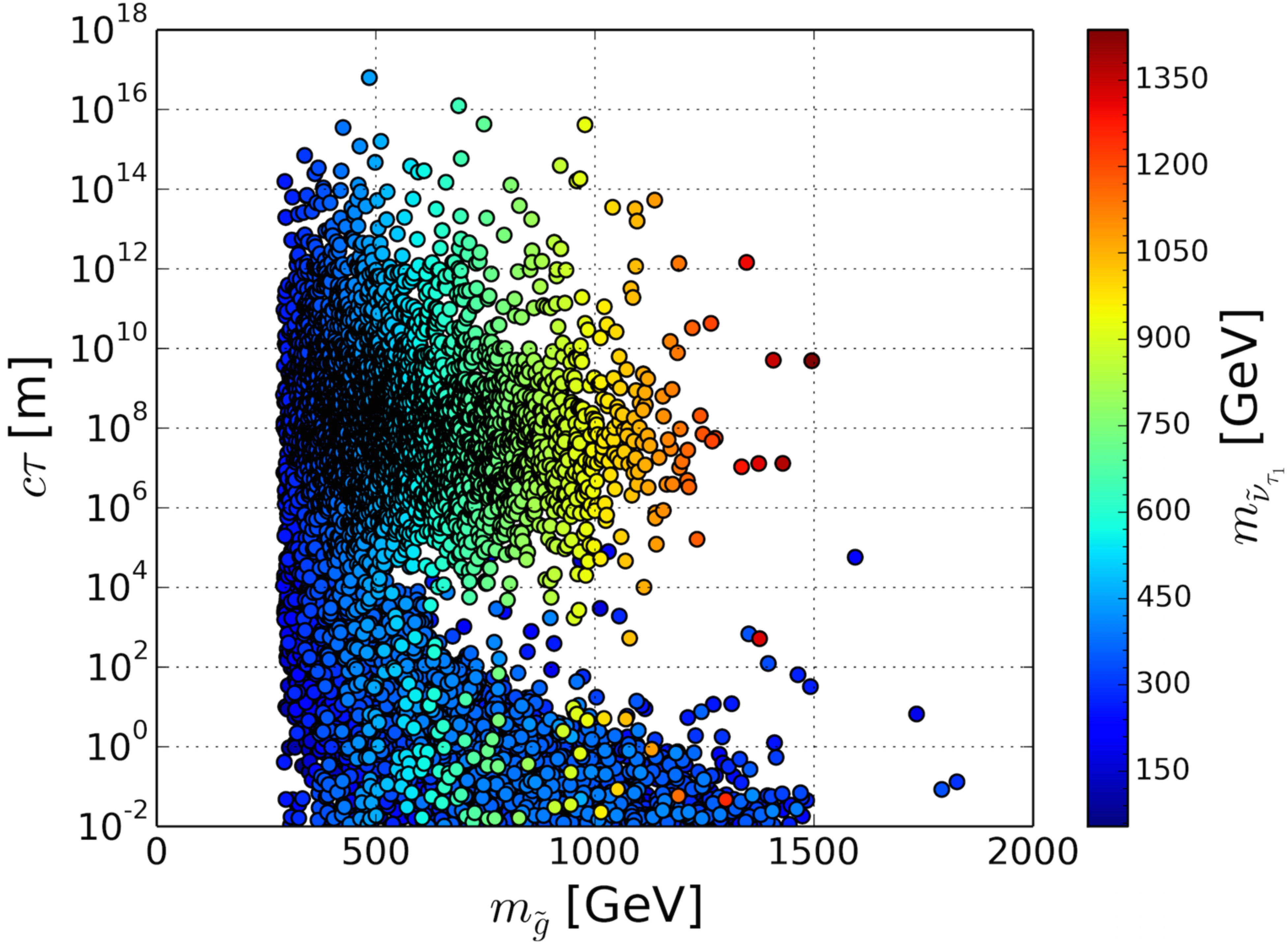
Most frequent missing topologies



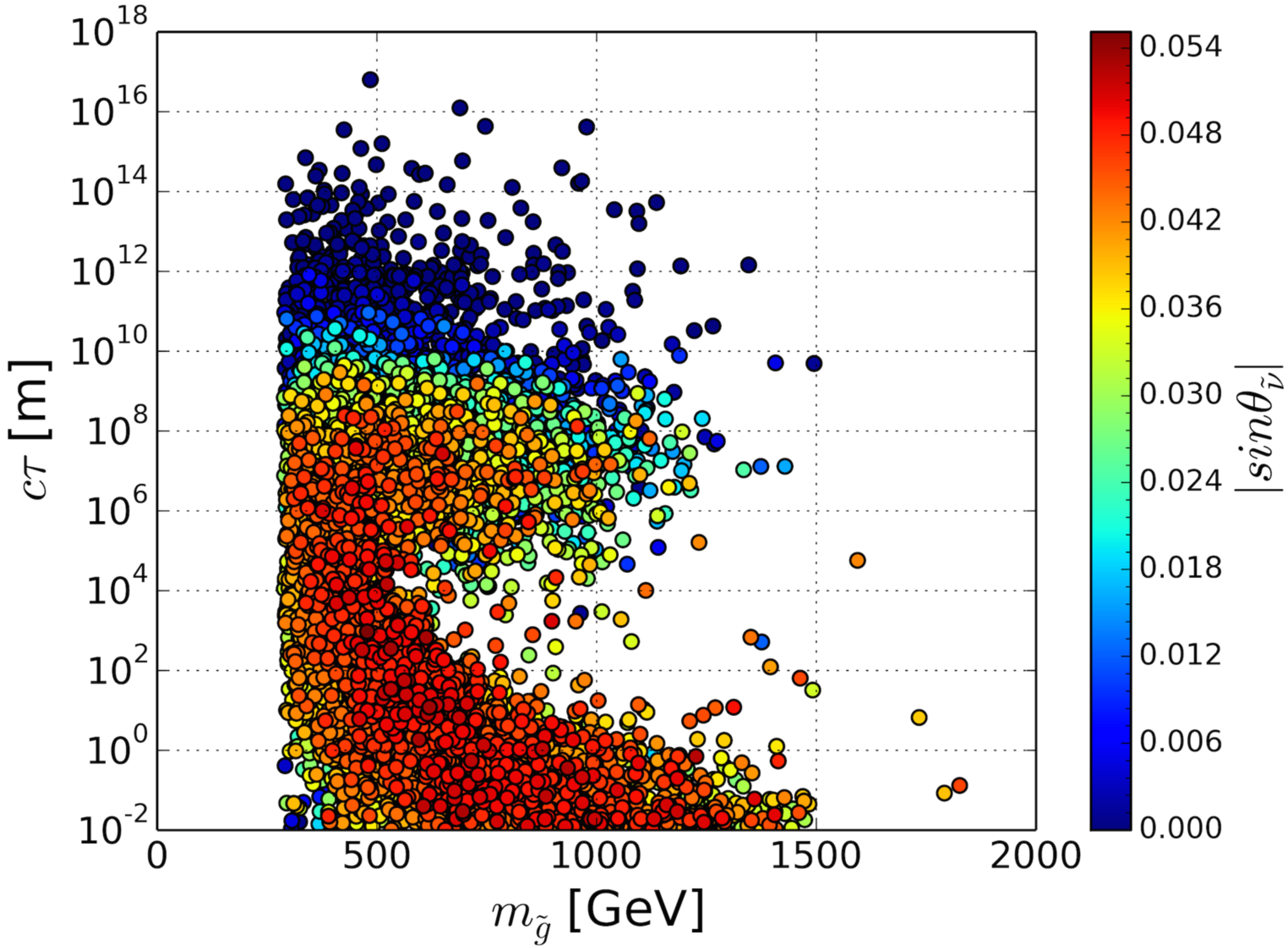
Dependence on the mixing angle



Many points feature long-lived gluinos



Many points feature long-lived gluinos

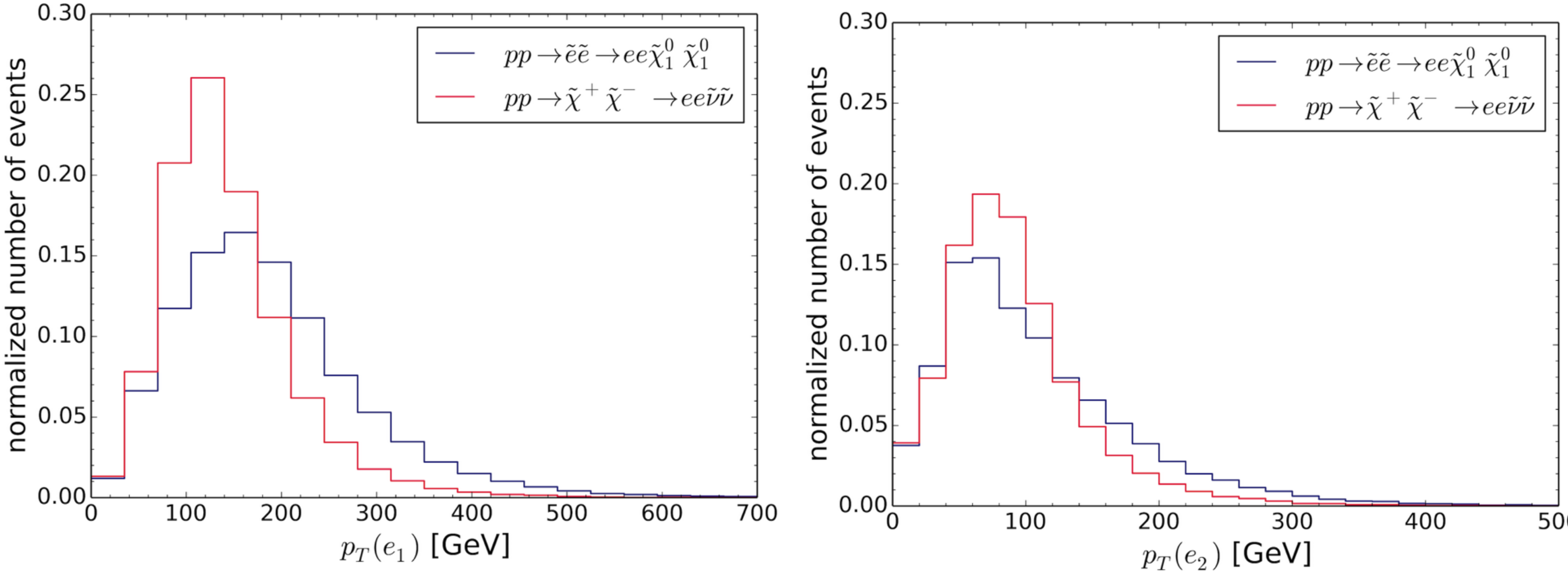


Do the slepton limits apply to chargino production?

test this for ATLAS-SUSY-2013-11, using the MadAnalysis 5 implementation (B. Dumont, INSPIRE-1326686)

Compare the corresponding efficiencies in a benchmark scenario with

$$m_{mother} = 270 \text{ GeV}, m_{LSP} = 100 \text{ GeV}$$



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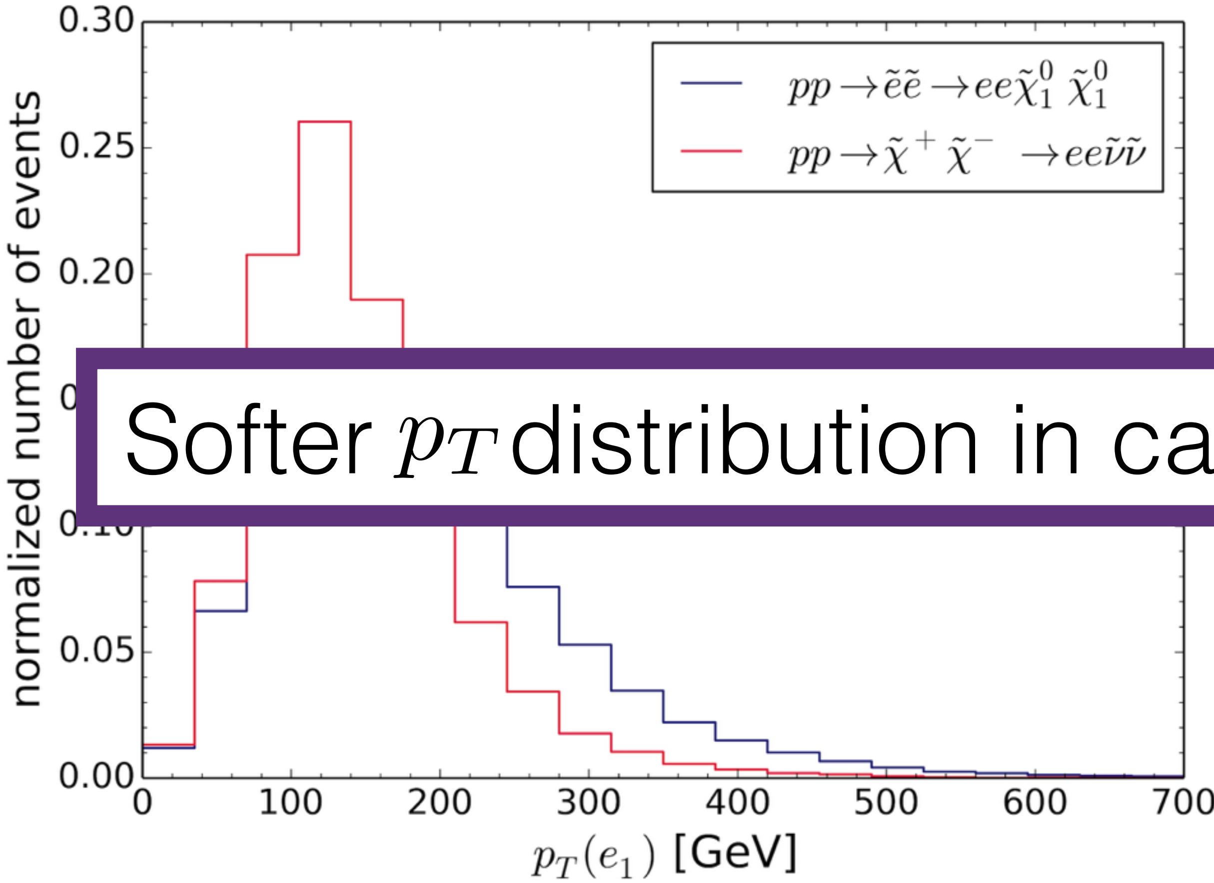

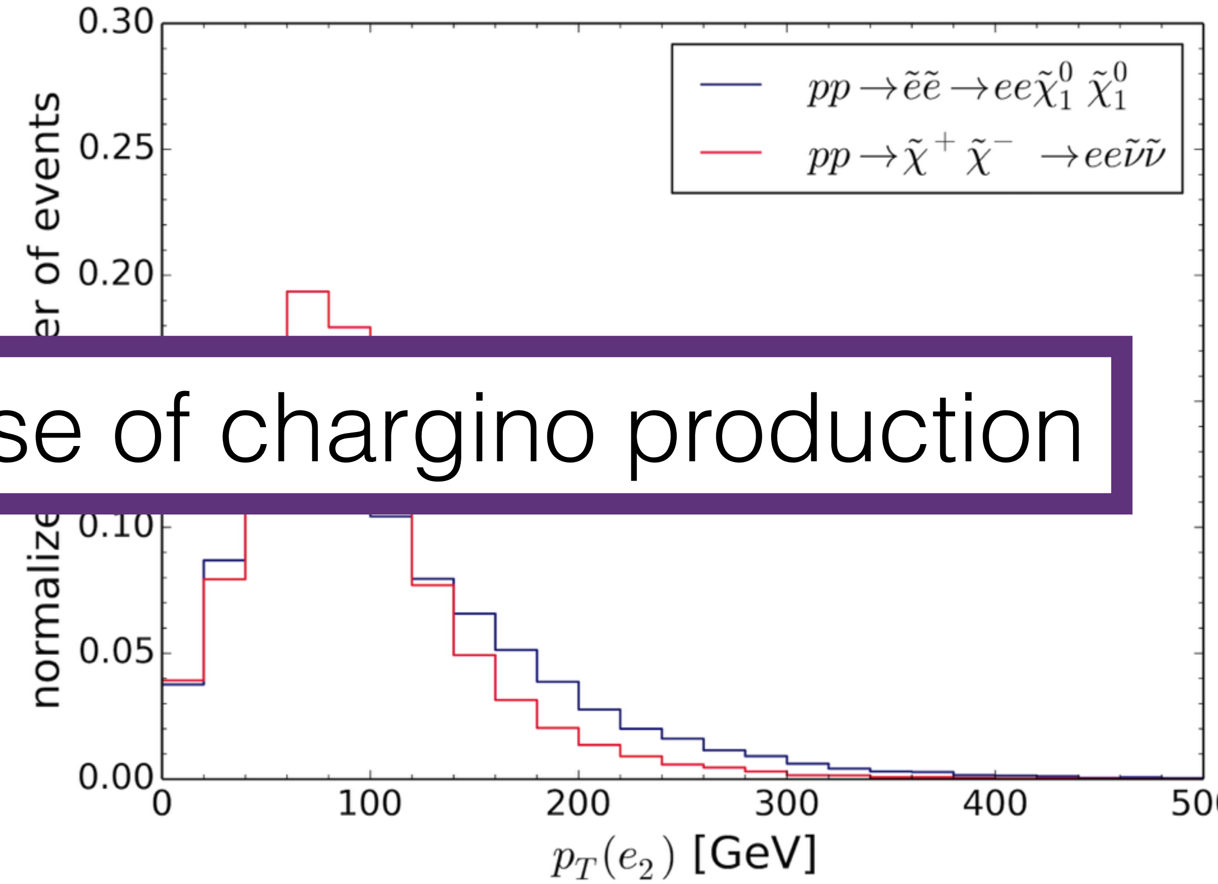

Softer p_T distribution in case of chargino production

Do the slepton limits apply to chargino production?

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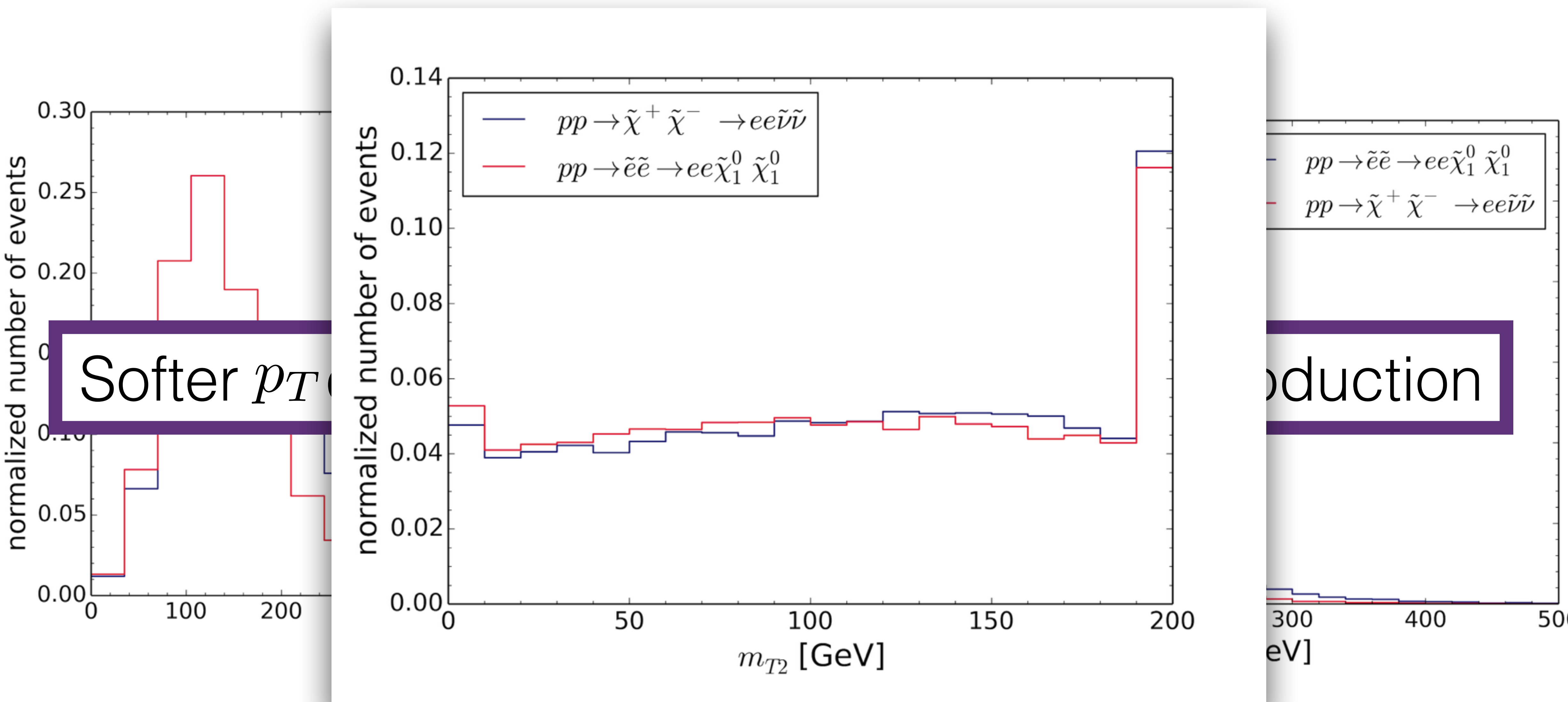

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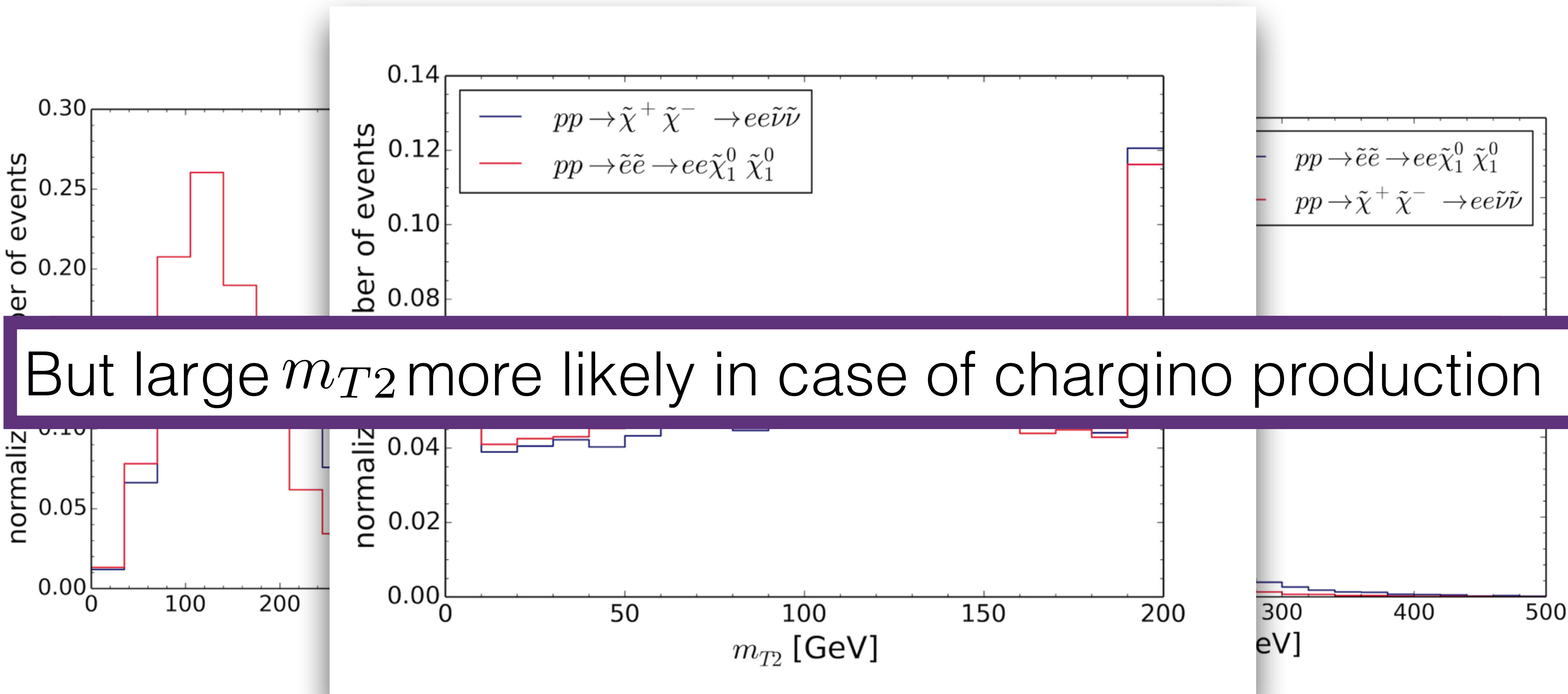

But large m_{T2} more likely in case of chargino production

Cutflow shows that final efficiencies are comparable

Cut	Slepton production	Chargino production
Common preselection		
Initial number of events	50000	50000
2 OS leptons	35133	33464
$m_{ll} > 20$ GeV	35038	33337
τ veto	35007	33318
ee leptons	35007	33318
jet veto	20176	19942
Z veto	19380	18984
Different m_{T2} regions		
$m_{T2} > 90$ GeV	11346	11594
$m_{T2} > 120$ GeV	8520	8828
$m_{T2} > 150$ GeV	5723	5926

→ We can safely use the results to constrain chargino production

Cutflow comparison for $m_{mother} = 270$ GeV, $m_{LSP} = 200$ GeV

Cut	Slepton production	Chargino production
Common preselection		
Initial number of events	50000	50000
2 OS leptons	29291	27244
$m_{ll} > 20$ GeV	29082	26964
τ veto	29050	26956
ee leptons	29050	26956
jet veto	16834	16114
Z veto	15281	14025
Different m_{T2} regions		
$m_{T2} > 90$ GeV	3028	3198
$m_{T2} > 120$ GeV	85	140
$m_{T2} > 150$ GeV	0	0