FastLim: a fast LHC limit calculator

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In collaboration with:

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LHC Physics discussion 8/7/2013 @ DESY

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- Introduction
- A fast LHC limit calculation and FastLim
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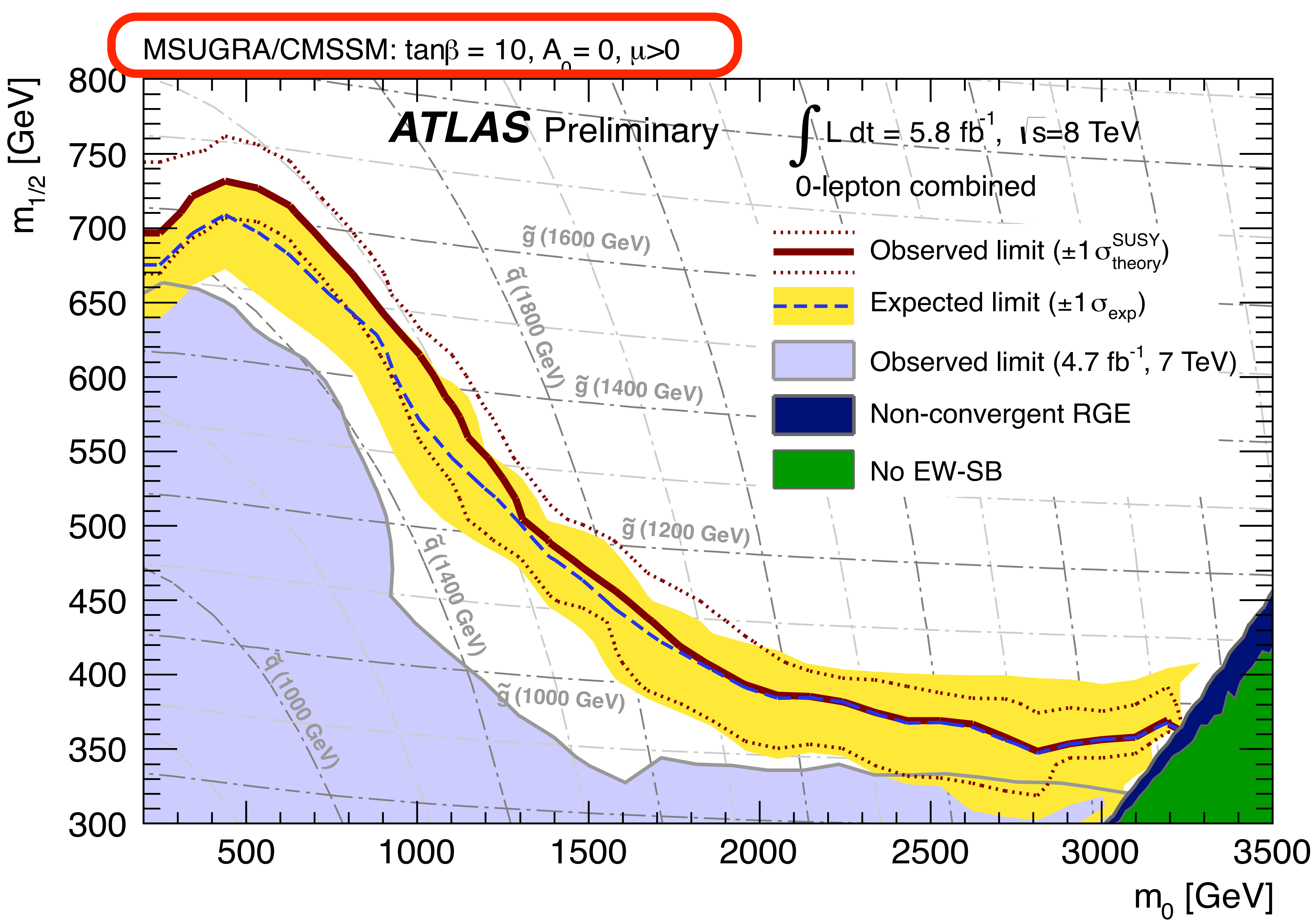
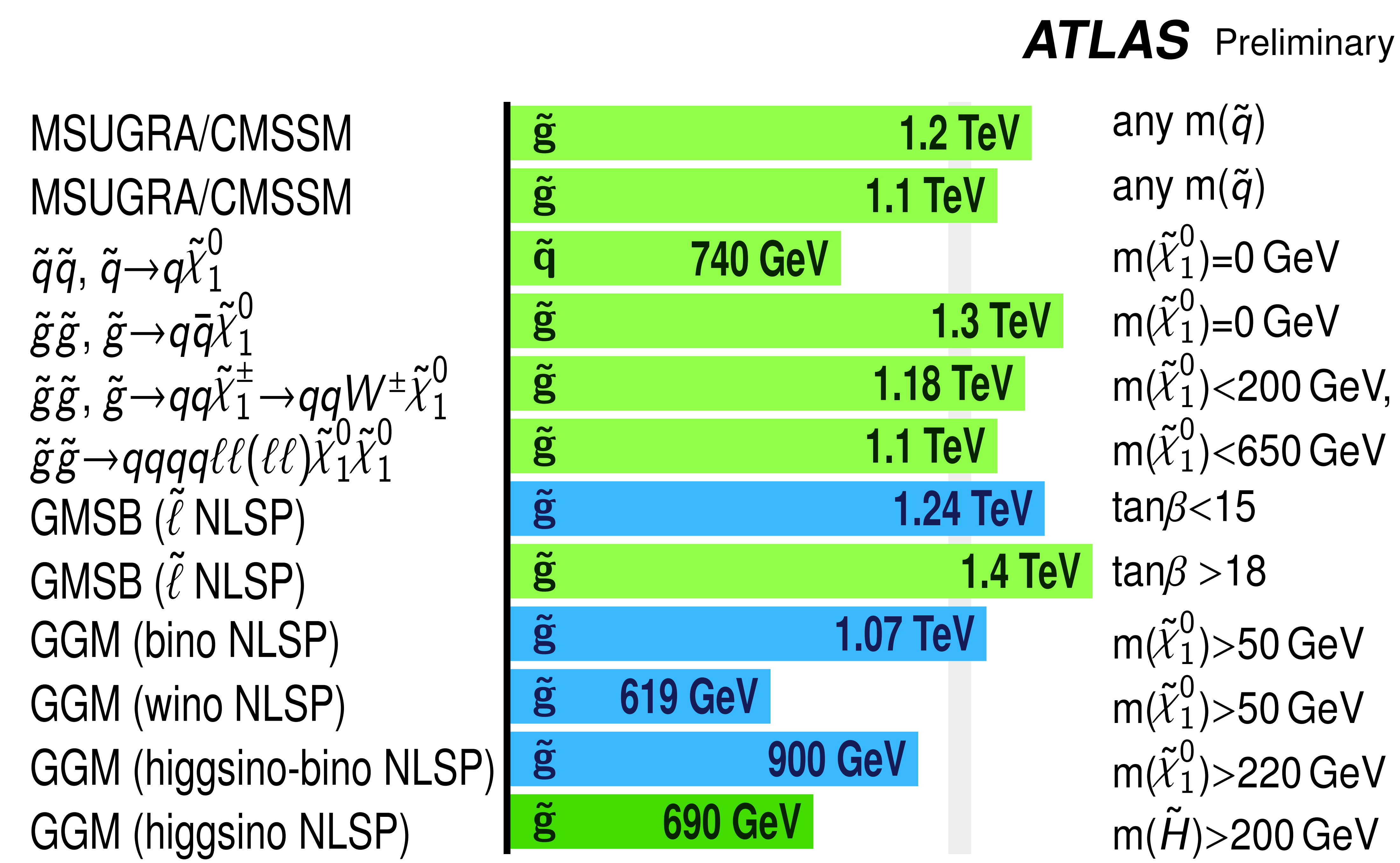
- Summary

Introduction

- LHC worked well and produced a lot of SUSY limits
- The limits are not generic and employ assumptions → cannot be applied to your model
- MSSM has more than 100 parameters → no way to calculate/visualise the generic limit





How to find the limit on your model?

ATLAS-CONF-2011-086

Signal Region	≥ 2 jets	≥ 3 jets	≥ 4 jets
E_T^{miss} [GeV]	> 130	> 130	> 130
Leading jet p_T [GeV]	> 130	> 130	> 130
Second jet p_T [GeV]	> 40	> 40	> 40
Third jet p_T [GeV]	–	> 40	> 40
Fourth jet p_T [GeV]	–	–	> 40
$\Delta\phi(\text{jet}_i, E_T^{miss})_{min}$ $(i = 1, 2, 3)$	> 0.4	> 0.4	> 0.4
E_T^{miss}/m_{eff}	> 0.3	> 0.25	> 0.25
m_{eff} [GeV]	> 1000	> 1000	> 1000

Process	Signal Region		
	≥ 2 jets	≥ 3 jets	≥ 4 jets
Prediction	12.1 ± 2.8	10.1 ± 2.3	7.3 ± 1.7
Observed	10	8	7

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additional contribution from SUSY events

N_{SUSY} = ..., 2, ..., 10, ... ?

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statistically consistent

How to find the limit on your model?

$$\frac{N^{(i)}_{\rm SUSY}}{N^{(i)}_{\rm UL}} \equiv R^{(i)} \begin{cases} > 1 & \text{: excluded} \\ \leq 1 & \text{: allowed} \end{cases}$$

95% CL upper limit

$N_{\rm UL}$

allowed ← → excluded

additional contribution from SUSY events

$N_{\rm SUSY}$ = ..., 2, ..., 10, ... ?

Process	Signal Region		
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statistically consistent

How to evaluate N_{SUSY} ?

by Feynman diagram calc. (Prospino, NLLfast, ...)

$$N^{(i)}_{\rm SUSY} = \epsilon^{(i)}_{\rm SUSY} \cdot \sigma_{\rm SUSY} \cdot \mathcal{L}_{\rm int}$$

fixed

How to evaluate $N_{\rm SUSY}$?

by Feynman diagram calc. (Prospino, NLLfast, ...)

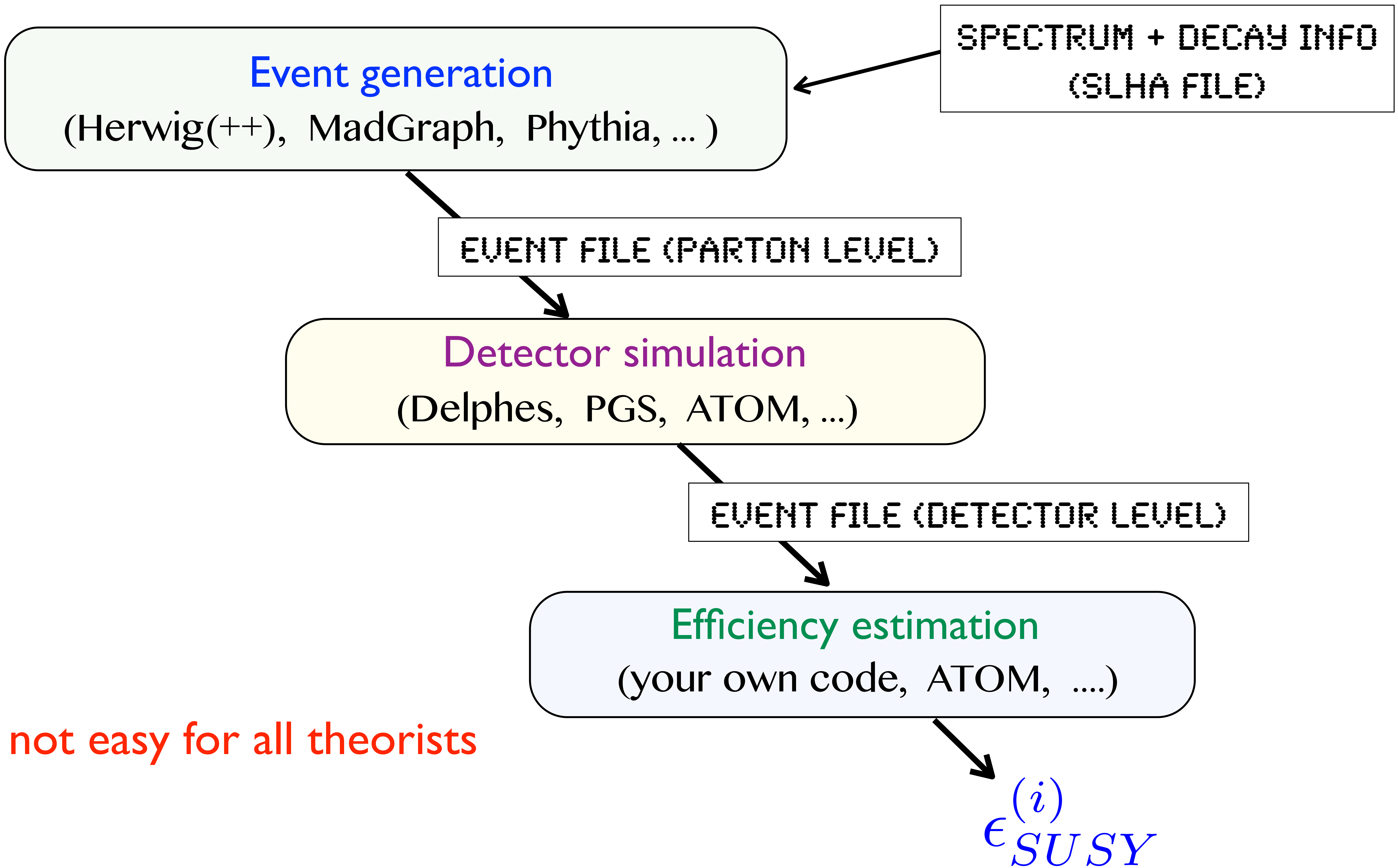
$$N_{\rm SUSY}^{(i)} = \boxed{\epsilon_{\rm SUSY}^{(i)}} \cdot \sigma_{\rm SUSY} \cdot \mathcal{L}_{\rm int}$$

fixed

requires a chain of MC simulations

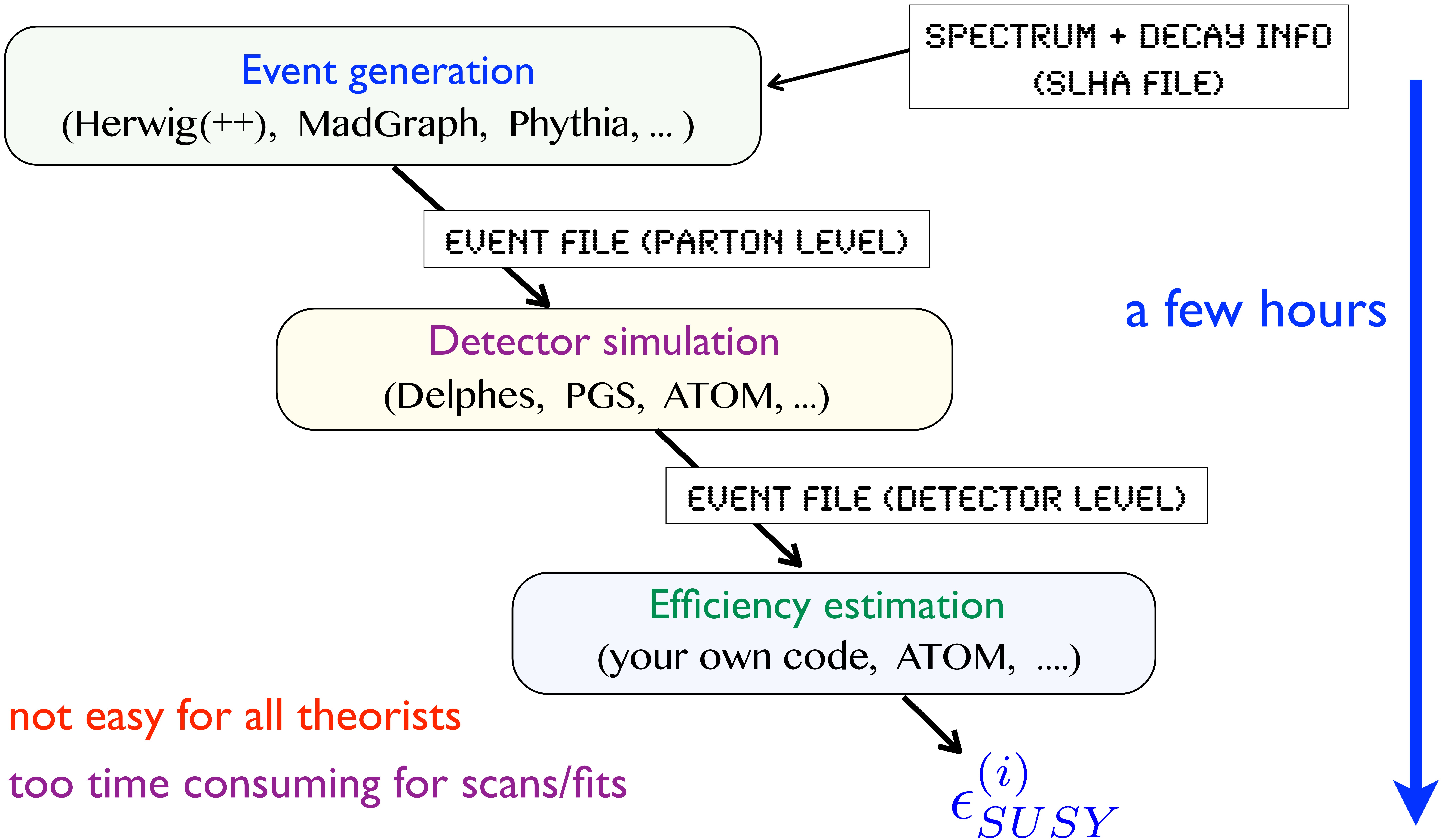
$$\epsilon_{\rm SUSY}^{(i)} = \lim_{N_{\rm MC}^{\rm gen.} \to \infty} \frac{N_{SR}^{(i)}\left(\begin{array}{c}\text{Events fall into} \\ \text{Signal Region } (i)\end{array}\right)}{N_{MC}^{\rm gen.}}$$

Chain of simulations



- not easy for all theorists

Chain of simulations



- not easy for all theorists
- too time consuming for scans/fits

A fast evaluation of N_{SUSY}

$\mathrm{Q} = \tilde{q}$

$\mathrm{G} = \tilde{g}$

$\mathrm{N1} = \tilde{\chi}_1^0$

- We propose a new approach to estimate N_{SUSY}

Key Idea: to reconstruct N_{SUSY} using simplified model processes

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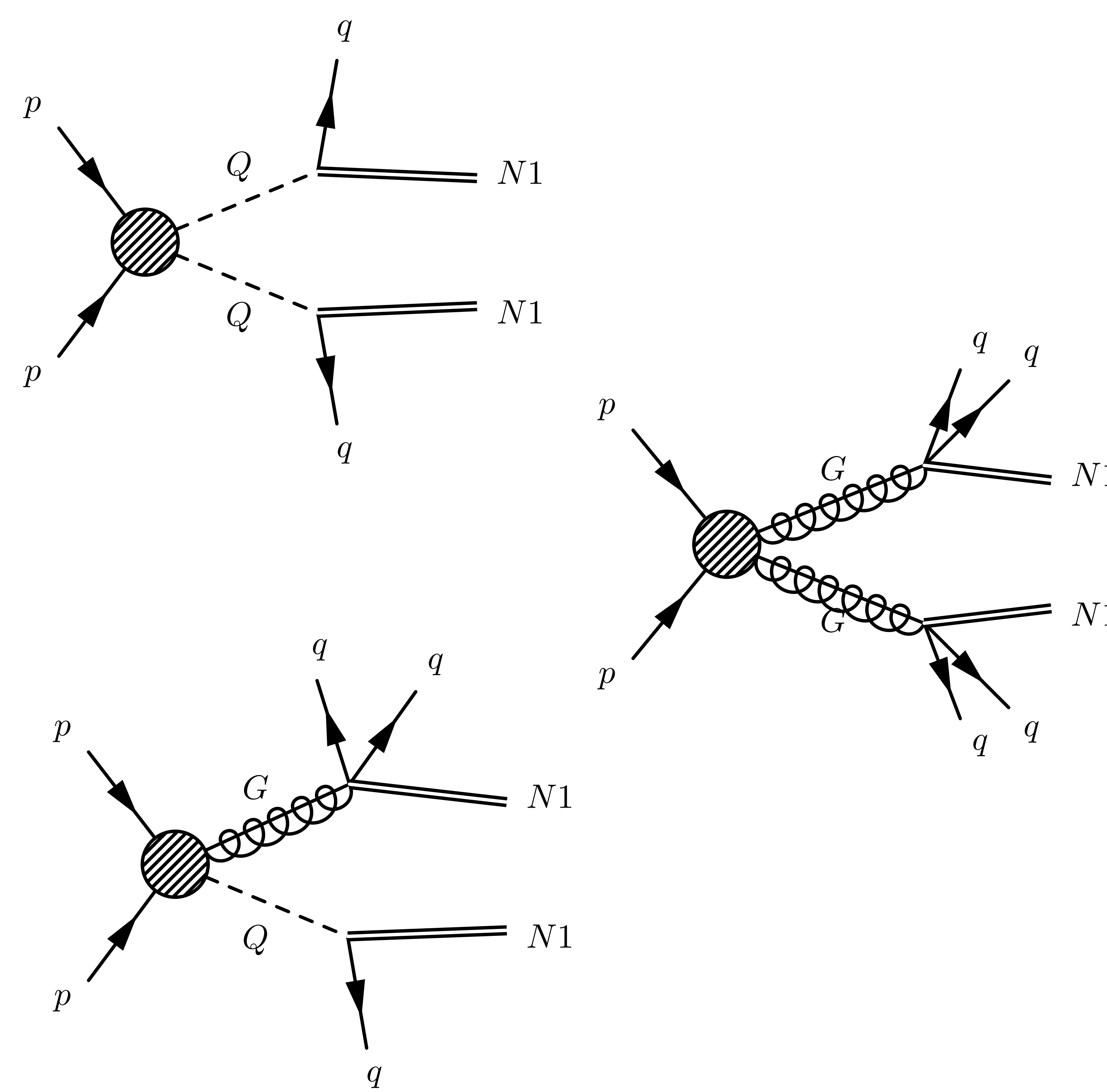
Key Idea: to reconstruct N_{SUSY} using simplified model processes

$$\mathrm{N}_{SUSY}^{(i)} = \left\{ \begin{array}{c} \mathrm{N}_{\mathrm{QqN1:QqN1}} \\ + \\ \mathrm{N}_{\mathrm{GqqN1:GqqN1}} \\ + \\ \mathrm{N}_{\mathrm{GqqN1:QqN1}} \\ + \\ \vdots \end{array} \right.$$



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- We propose a new approach to estimate N_{SUSY}

Key Idea: to reconstruct N_{SUSY} using simplified model processes

$$N^{(i)}_{SUSY} = \begin{cases} N_{QqN1:QqN1} = \varepsilon_{QqN1:QqN1}(mQ, mN1) \cdot \sigma_{QQ} \cdot BR_{QqN1:QqN1} \cdot L_{int} \\ + \\ N_{GqqN1:GqqN1} = \varepsilon_{GqqN1:GqqN1}(mG, mN1) \cdot \sigma_{GG} \cdot BR_{GqqN1:GqqN1} \cdot L_{int} \\ + \\ N_{GqqN1:QqN1} = \varepsilon_{GqqN1:QqN1}(mQ, mG, mN1) \cdot \sigma_{GQ} \cdot BR_{GqqN1:QqN1} \cdot L_{int} \\ + \\ \vdots \end{cases}$$

A fast evaluation of N_{SUSY}

$Q = \tilde{q}$

$G = \tilde{g}$

$N1 = \tilde{\chi}_1^0$

Efficiencies for simplified processes depend only on a few mass parameters

$$N_{SUSY}^{(i)} = \begin{cases} N_{QqN1:QqN1} = \varepsilon_{QqN1:QqN1}(mQ, mN1) \cdot \sigma_{QQ} \cdot BR_{QqN1:QqN1} \cdot L_{int} \\ + \\ N_{GqqN1:GqqN1} = \varepsilon_{GqqN1:GqqN1}(mG, mN1) \cdot \sigma_{GG} \cdot BR_{GqqN1:GqqN1} \cdot L_{int} \\ + \\ N_{GqqN1:QqN1} = \varepsilon_{GqqN1:QqN1}(mQ, mG, mN1) \cdot \sigma_{GQ} \cdot BR_{GqqN1:QqN1} \cdot L_{int} \\ + \\ \vdots \end{cases}$$

A fast evaluation of N_{SUSY}

$Q = \tilde{q}$

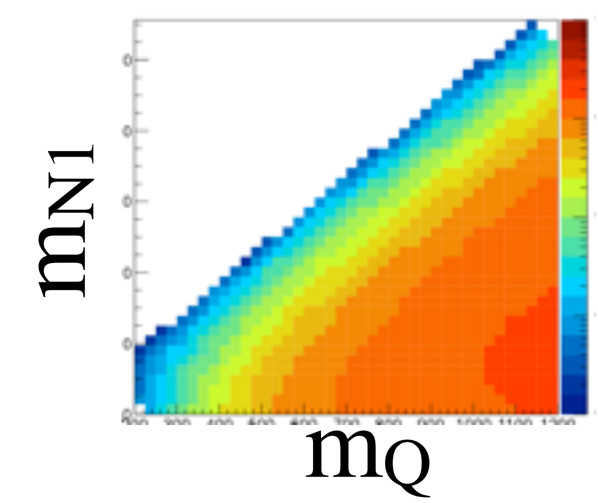
$G = \tilde{g}$

$N1 = \tilde{\chi}_1^0$

- Once one has the efficiency tables for the simplified model processes, one can read off the efficiencies and re-assemble N_{SUSY} of your model.

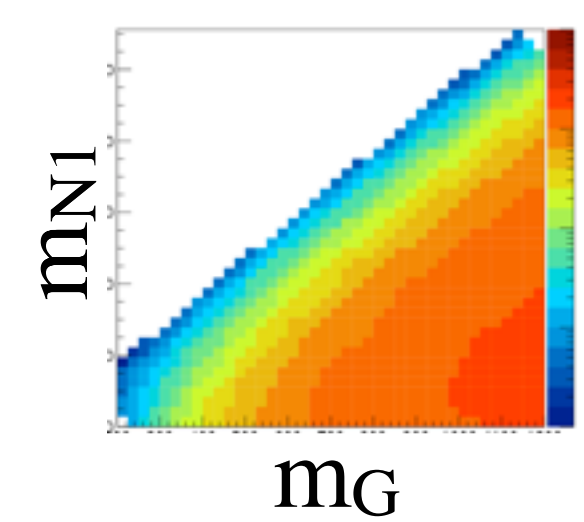
no MC simulation is required !

$N_{SUSY}^{(i)} =$

$N_{QqN1:QqN1} =$ 

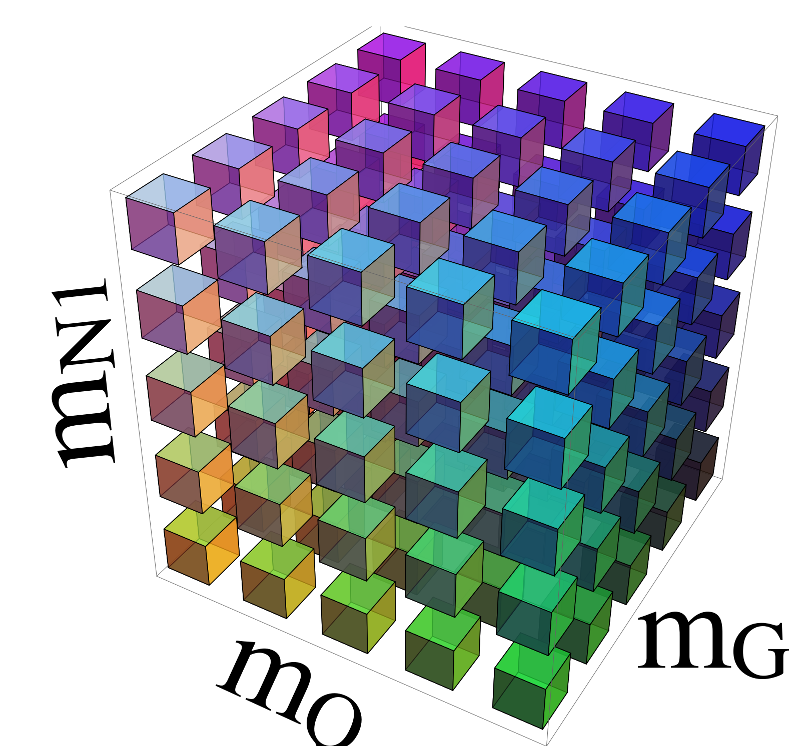
$\cdot\ \sigma_{QQ} \cdot BR_{QqN1:QqN1} \cdot L_{int}$

$+$

$N_{GqqN1:GqqN1} =$ 

$\cdot\ \sigma_{GG} \cdot BR_{GqqN1:GqqN1} \cdot L_{int}$

$+$

$N_{GqqN1:QqN1} =$ 

$\cdot\ \sigma_{GQ} \cdot BR_{GqqN1:QqN1} \cdot L_{int}$

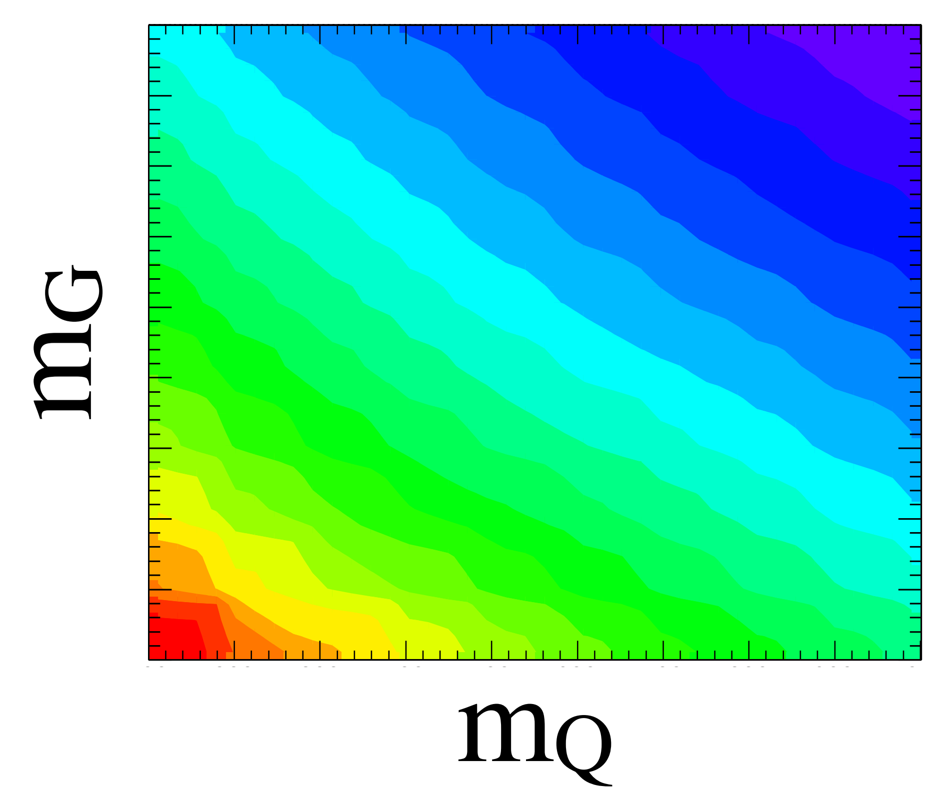
$+$

$\vdots$

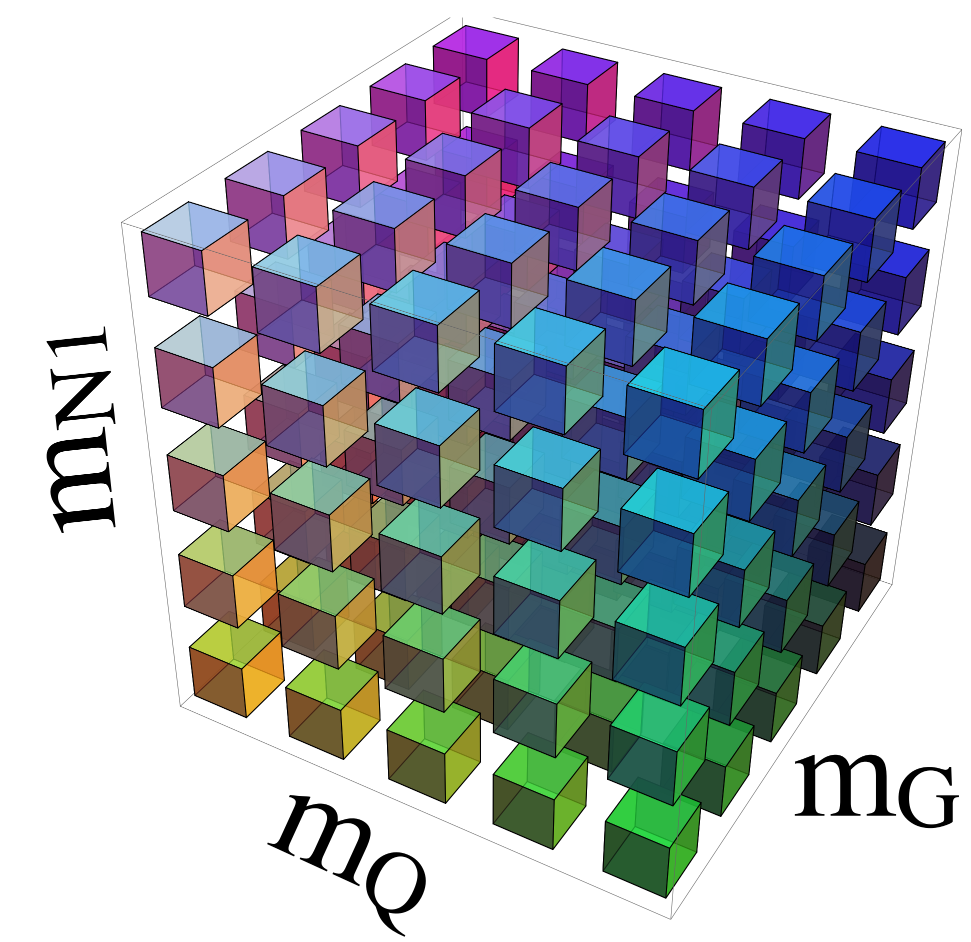
FastLim

Xsec

$\sigma_{QQ}, \sigma_{GG}, \sigma_{QG}$



$\epsilon^{(i)}_{\mathrm{proc}(a)}$



pre-calculated cross section tables calculated by NLLfast

Prospino2.1 is interfaced for the EWkino cross section

efficiency tables for the simplified processes

taken from ATLAS/CMS if available

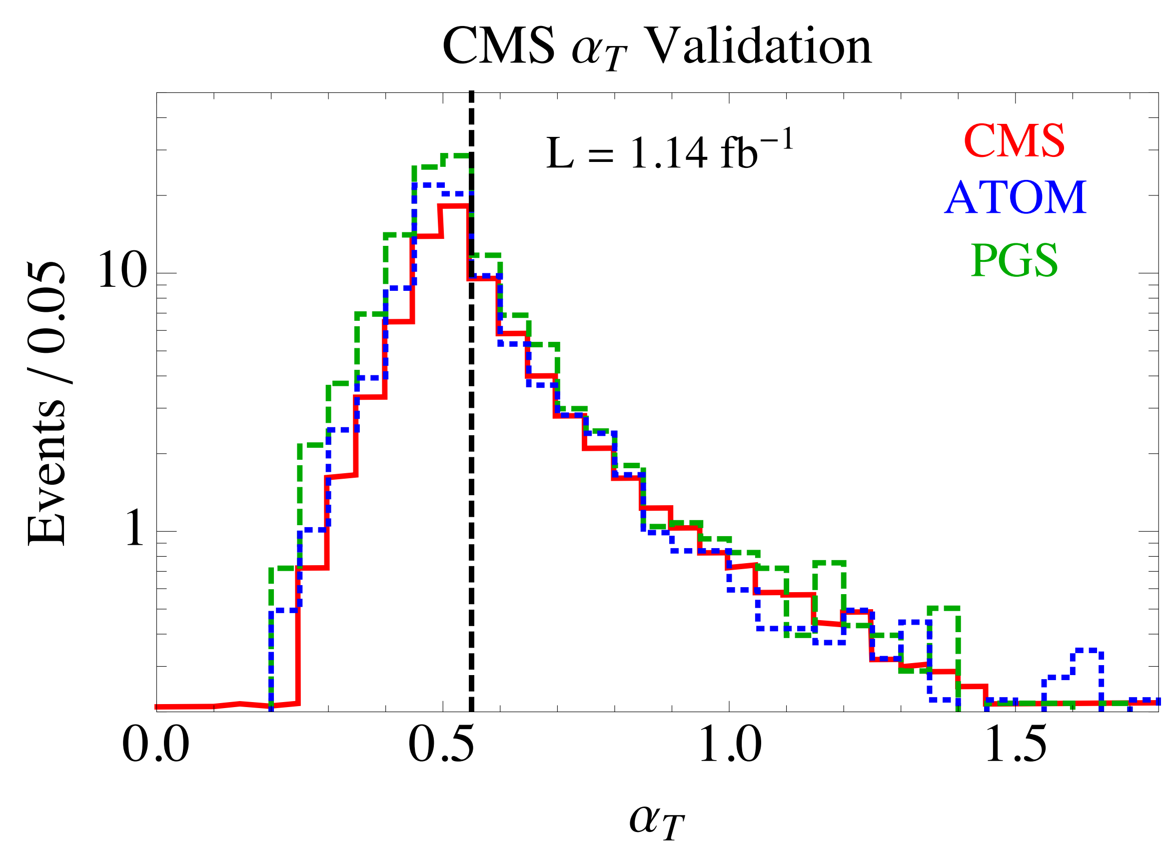
otherwise calculated by MadGraph + ATOM

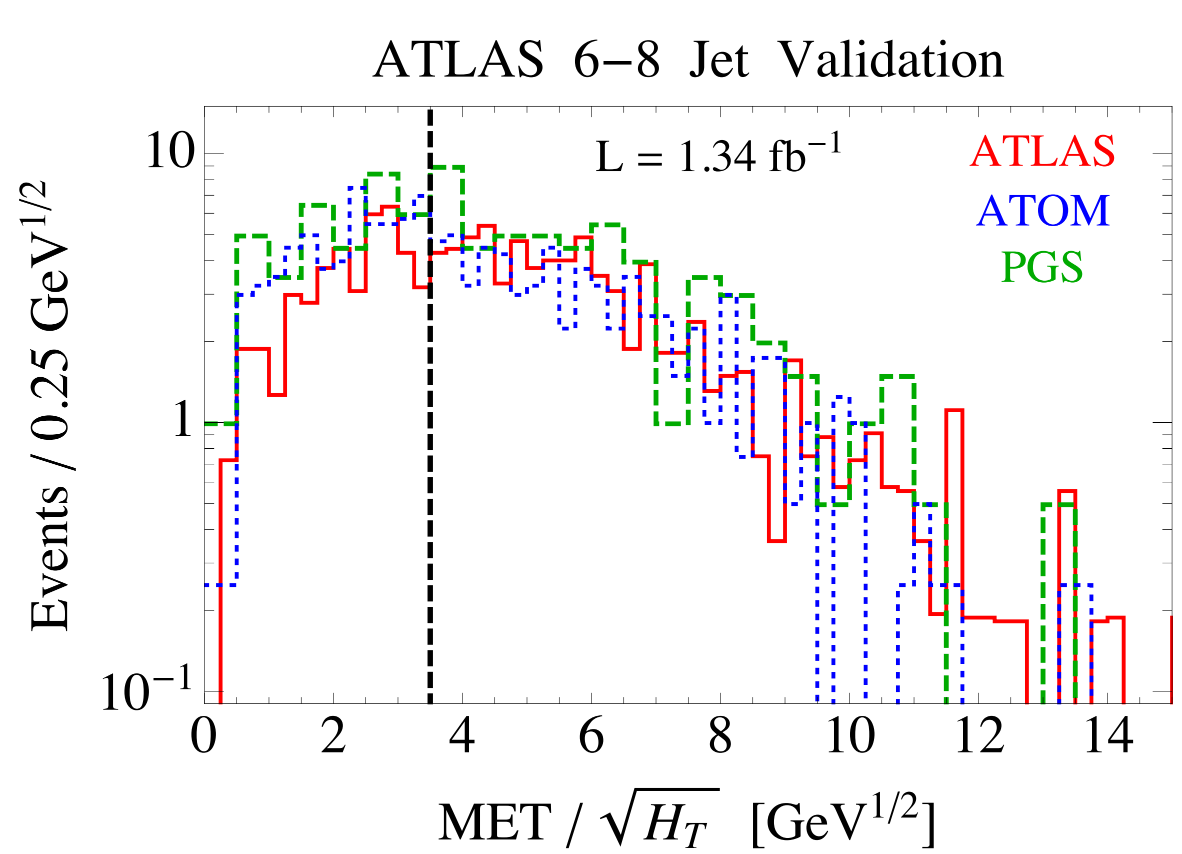
ATOM

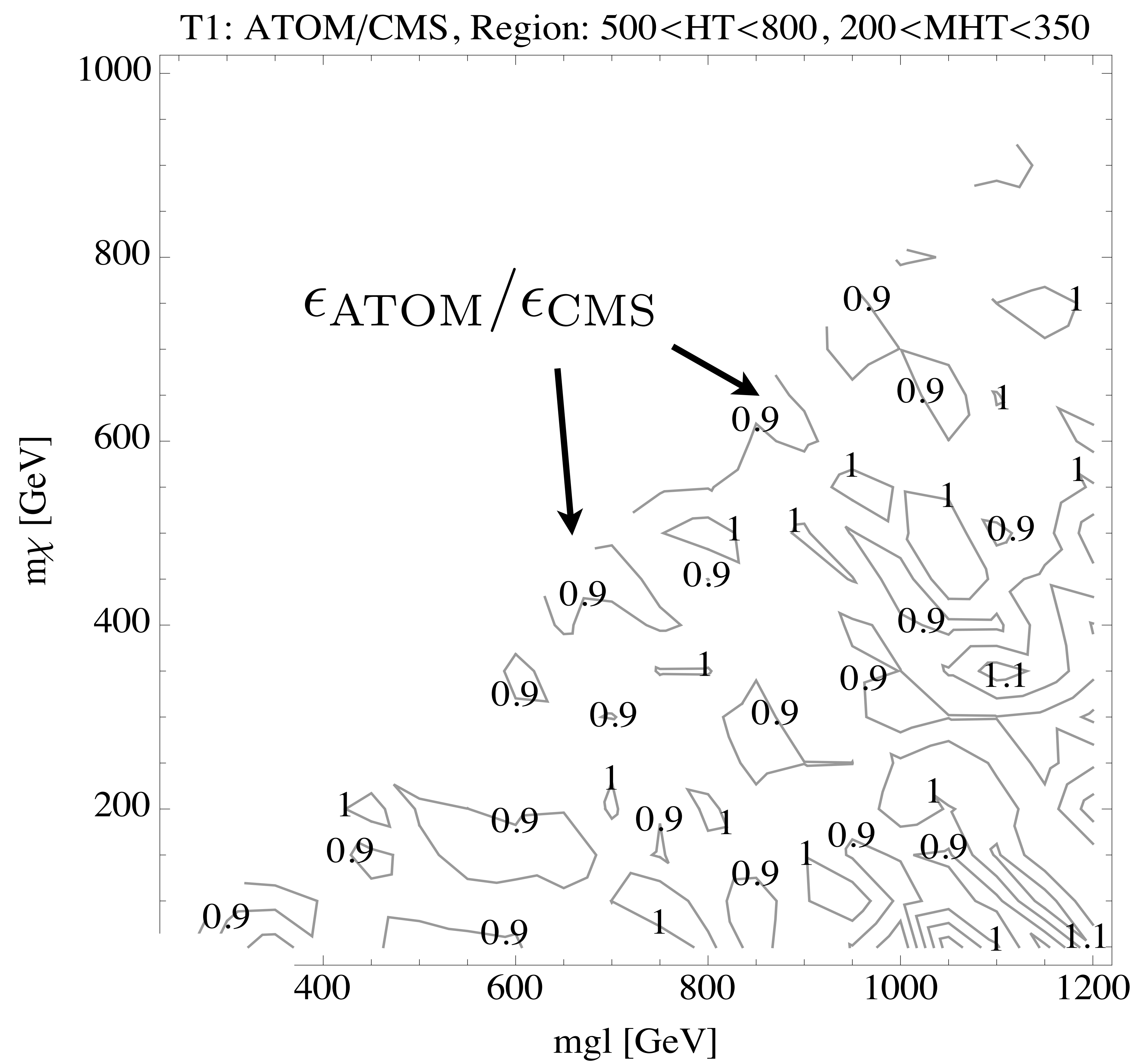
D. Neuenfeld, M. Papucci, A. Weiler

(Automated Testing Of Models)

- ATOM: a program to calculate the efficiencies including detector effects
- well validated and reliable



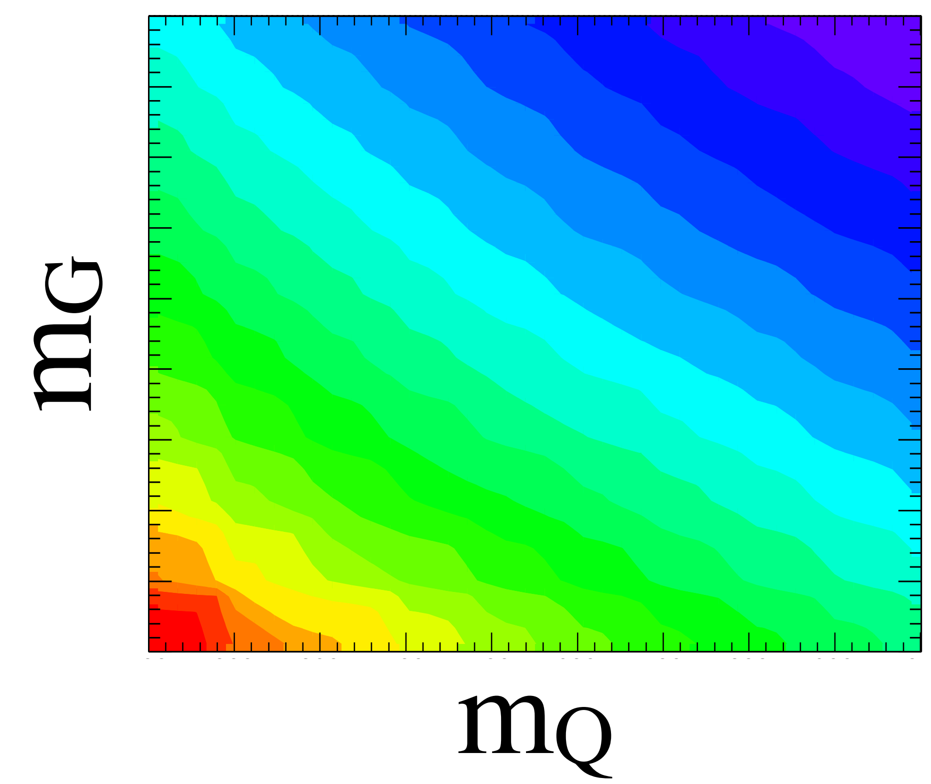




FastLim

Xsec

$\sigma_{QQ}, \sigma_{GG}, \sigma_{QG}$



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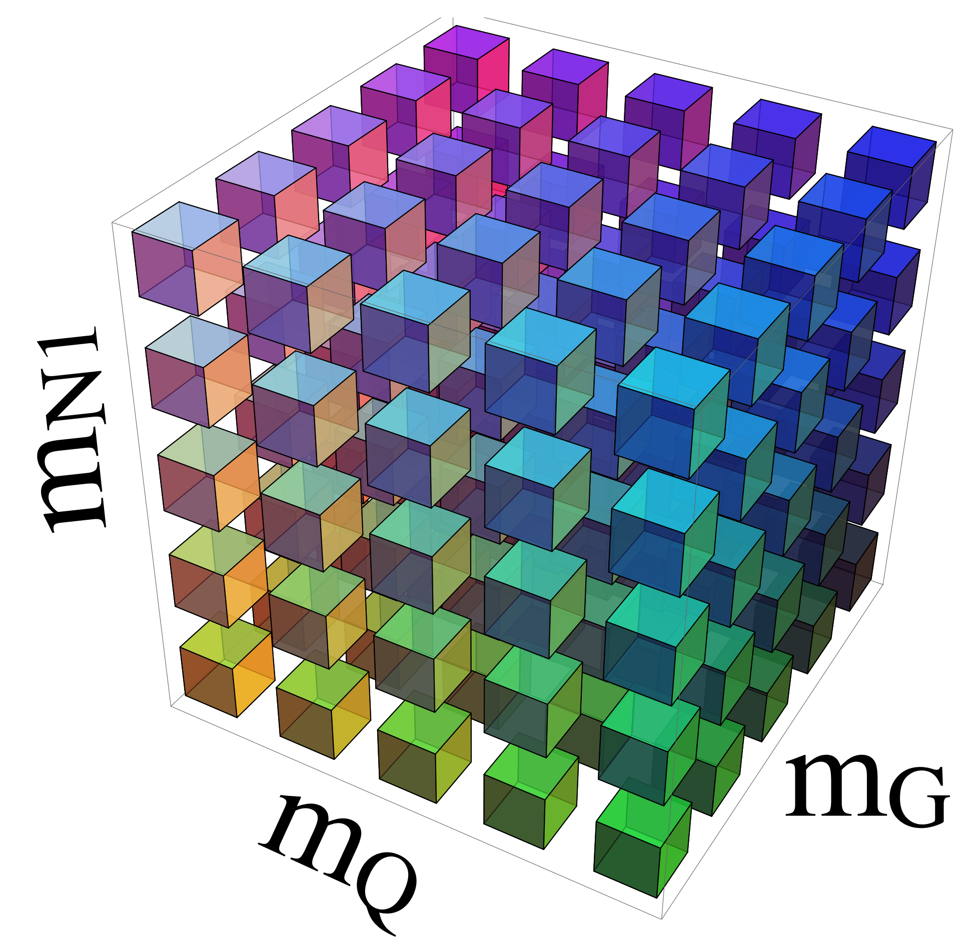
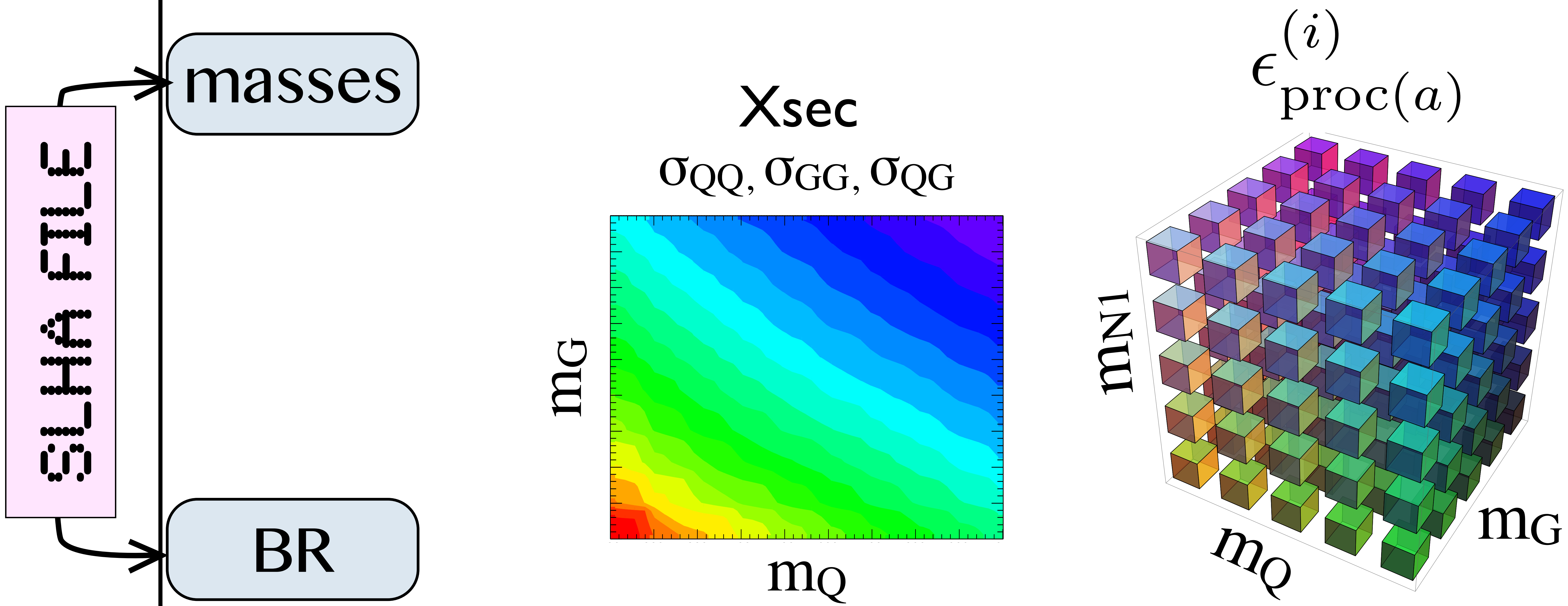
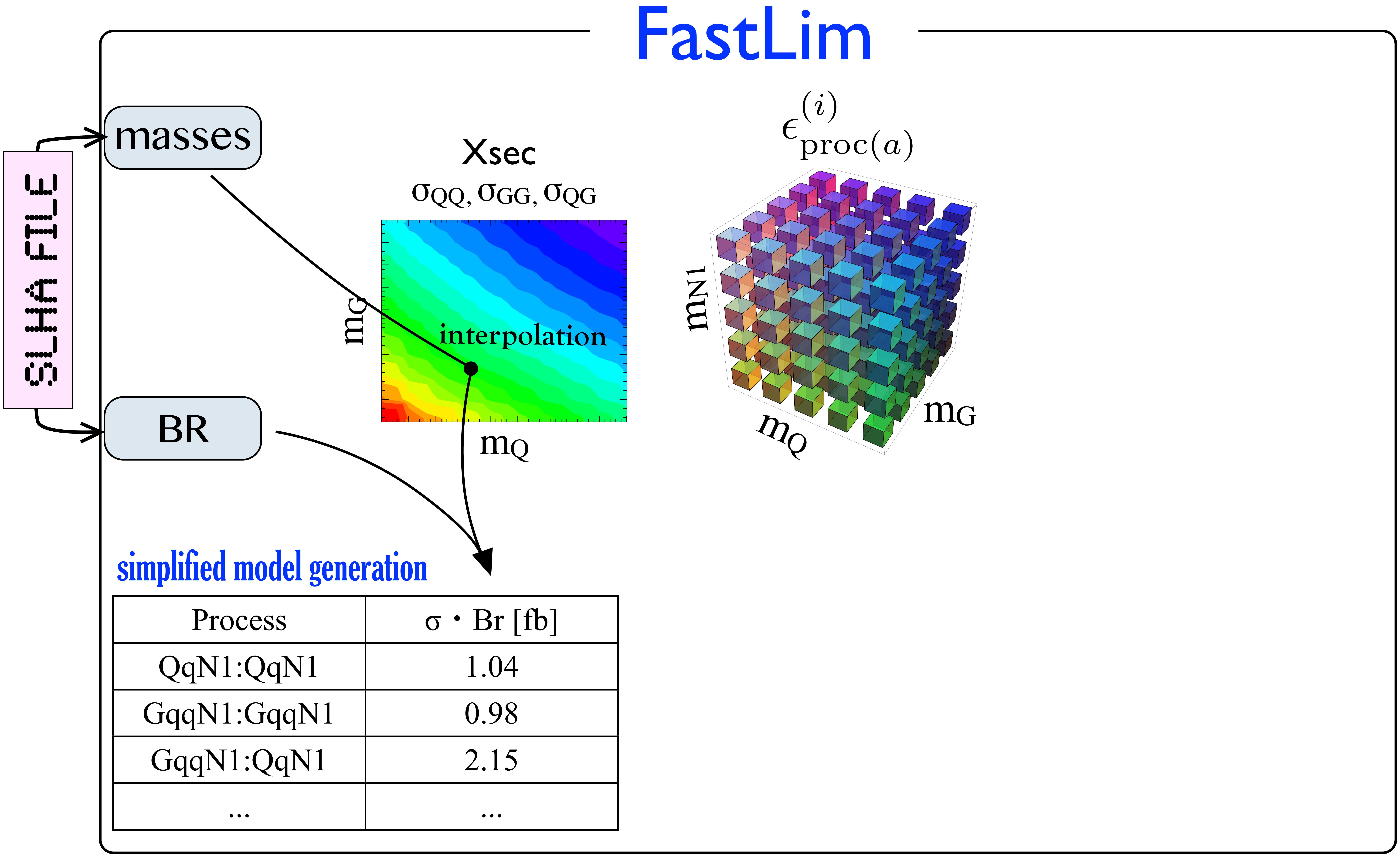


FastLim


SLHA FILE
masses
BR
Xsec
$\sigma_{QQ}, \sigma_{GG}, \sigma_{QG}$
m_G
m_Q
$\epsilon^{(i)}_{\mathrm{proc}(a)}$
m_{N1}
m_Q
m_G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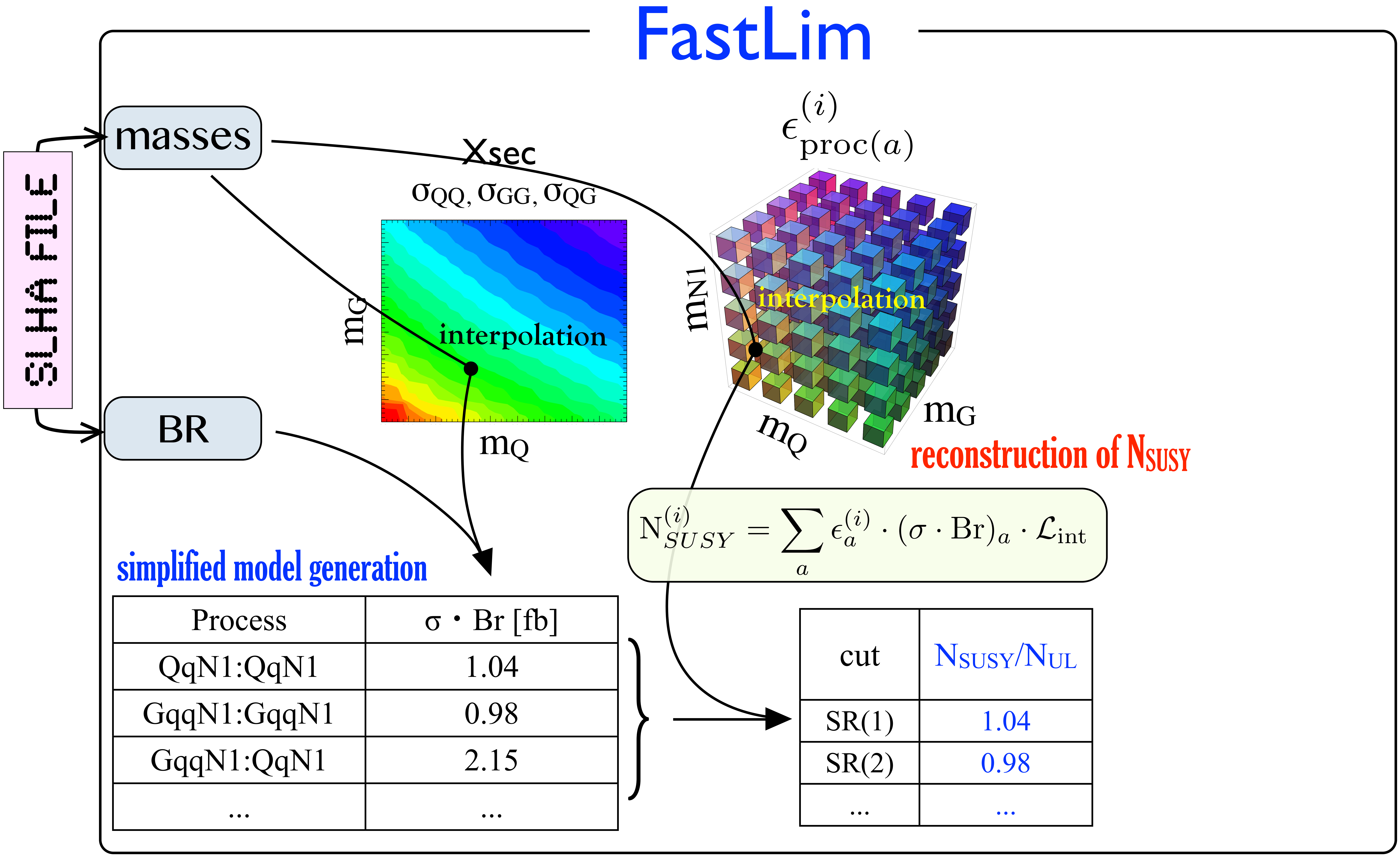
$\sigma_{QQ}, \sigma_{GG}, \sigma_{QG}$
m_G
m_Q
interpolation
$\epsilon^{(i)}_{\mathrm{proc}(a)}$
m_{N1}
m_Q
m_G
simplified model generation
Process | σ・Br [fb]
QqN1:QqN1 | 1.04
GqqN1:GqqN1 | 0.98
GqqN1:QqN1 | 2.15
... | ...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m_Q
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reconstruction of N_{SUSY}
$N^{(i)}_{SUSY} = \sum_a \epsilon^{(i)}_a \cdot (\sigma \cdot \mathrm{Br})_a \cdot \mathcal{L}_{\mathrm{int}}$
simplified model generation
Process
σ • Br [fb]
QqN1:QqN1
1.04
GqqN1:GqqN1
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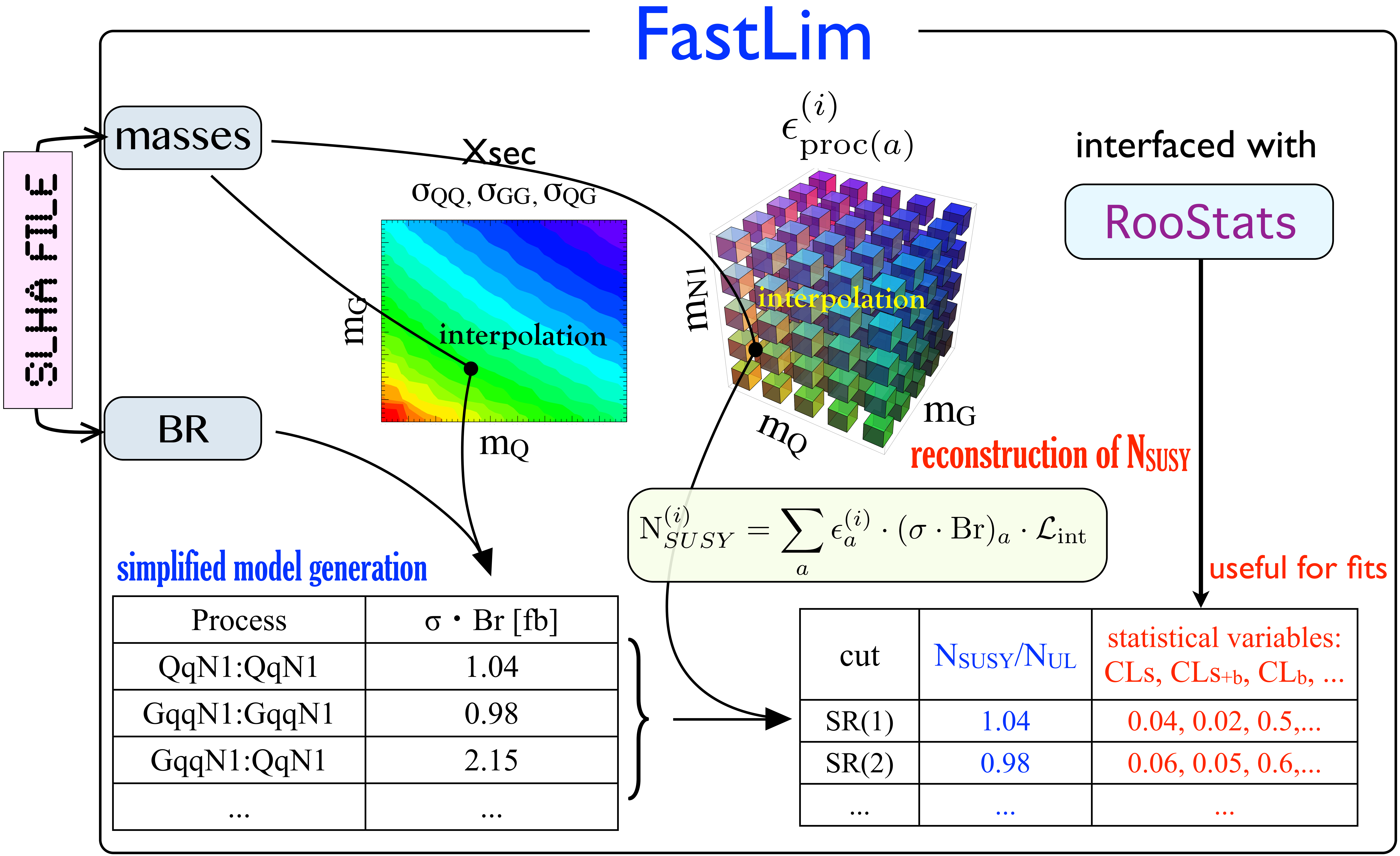
GqqN1:QqN1
2.15
...
...
cut
N_{SUSY}/N_{UL}
SR(1)
1.04
SR(2)
0.98
...
...


FastLim
SLHA FILE
masses
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$\sigma_{QQ}, \sigma_{GG}, \sigma_{QG}$
m_G
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interpolation
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m_{N1}
interpolation
m_Q
m_G
reconstruction of N_{SUSY}
interfaced with
RooStats
$N^{(i)}_{SUSY} = \sum_a \epsilon^{(i)}_a \cdot (\sigma \cdot \mathrm{Br})_a \cdot \mathcal{L}_{\mathrm{int}}$
useful for fits
simplified model generation
Process | σ • Br [fb]
QqN1:QqN1 | 1.04
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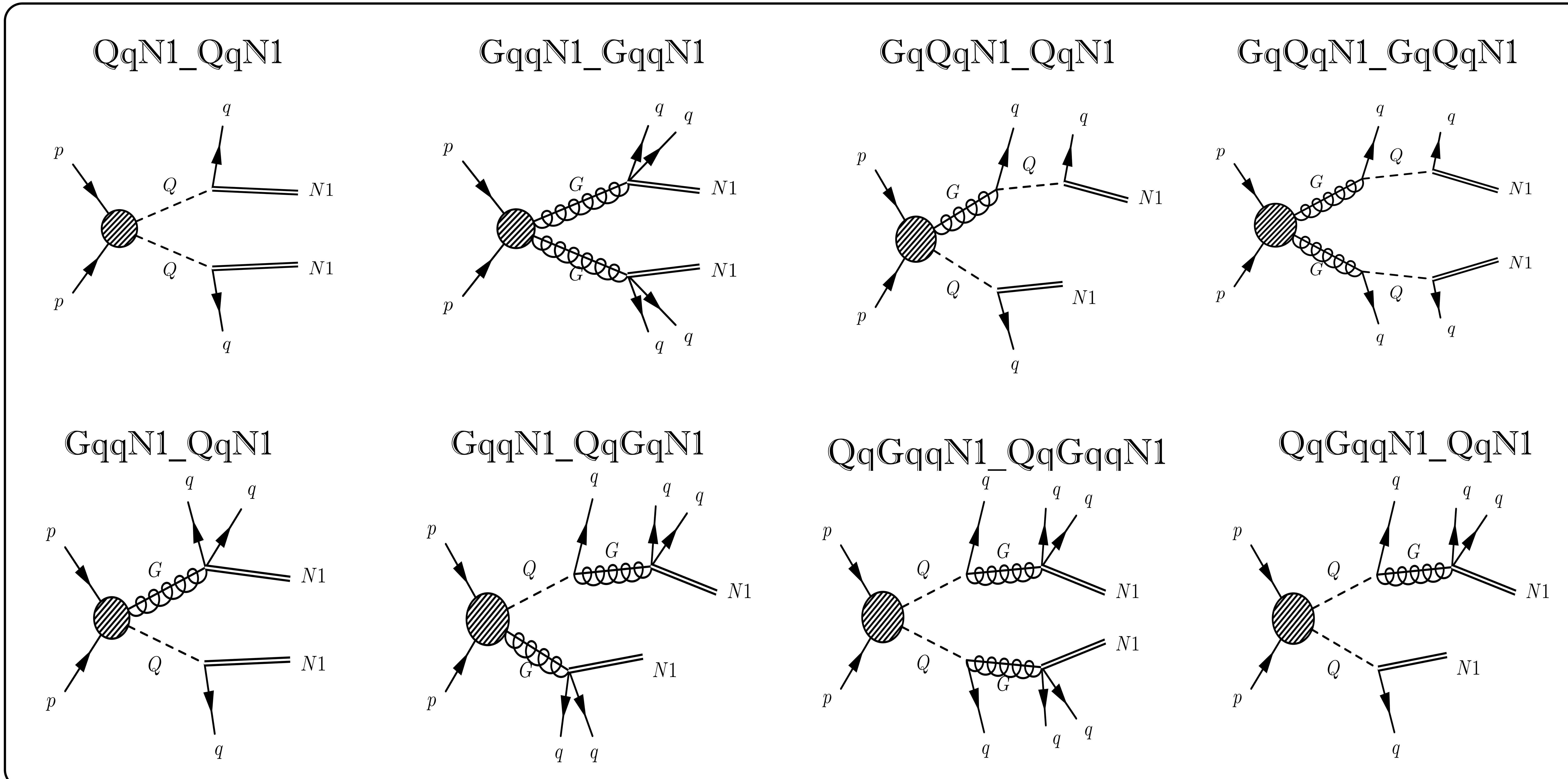
... | ...
cut | N_{SUSY}/N_{UL} | statistical variables: CL_s, CL_{s+b}, CL_b, ...
SR(1) | 1.04 | 0.04, 0.02, 0.5,...
SR(2) | 0.98 | 0.06, 0.05, 0.6,...
... | ... | ...

- A complete set of Q-G-N1 model (w/o top) has been implemented



The other processes are missing ➡ Reconstructed N_{SUSY} is conservative

- Many analyses have been implemented (thanks to ATOM)

Name	E_{cm}	Short description
ATLAS_2011_CONF_2011_086	7	Jets+MET at 7 TeV with 165pb^{-1}.
ATLAS_2011_CONF_2011_090	7	1lepton+jets+MET at 7 TeV with 165pb^{-1}.
ATLAS_2011_CONF_2011_098	7	bjets+MET+0L at 7 TeV with 830pb^{-1}.
ATLAS_2011_CONF_2011_126	7	Search for Anomalous Production of Prompt Like-sign Muon Pairs with 1.6 fb^{-1}.
ATLAS_2011_CONF_2011_130	7	bjets+1lept+jets+MET SUSY search at 7TeV with 1fb^{-1}
ATLAS_2011_S8970084	7	1lepton+jets+MET at 7 TeV with 35pb^{-1}.
ATLAS_2011_S8983313	7	Jets+MET at 7 TeV with 35pb^{-1}.
ATLAS_2011_S9011218	7	bjets+MET at 7 TeV with 35pb^{-1}.
ATLAS_2011_S9019553	7	SF lepton pairs SUSY search at 7 TeV with 35pb^{-1}.
ATLAS_2011_S9019561	7	2leptons+MET at 7TeV with 35pb^{-1}.
ATLAS_2011_S9225137	7	multijet SUSY search at 7TeV
ATLAS_2012_CONF_2012_033	7	2-6 jets + MET SUSY search at 7TeV
CMS_2011_S8932190	7	Jets+MET with alpha_T variable with 35pb^{-1}
CMS_2011_S8991847	7	OS dileptons at 7TeV with 35pb^{-1}
CMS_2011_S9036504	7	Same Sign dileptons at 7TeV in 35pb^{-1}
CMS_PAS_SUS_10_005	7	HT,MHT susy search in jets+MET at 7 TeV with 35pb^{-1}.
CMS_PAS_SUS_10_009	7	razor analysis on jets+MET and 1lepton+jets+MET at 7 TeV with 35pb^{-1}.
CMS_PAS_SUS_10_011	7	alpha_T analysis on b jets+MET at 7 TeV with 35pb^{-1}.
CMS_PAS_SUS_11_003	7	Jets+MET with alpha_T variable with 1.1 fb^{-1}
CMS_PAS_SUS_11_017	7	Search for New Physics in Events with a Z Boson and Missing Transverse Energy
ATLAS_2012_CONF_2012_109	8	2-6 jets + MET SUSY search at 8TeV
CMS_PAS_SUS_12_028	8	CMS 8 TeV analysis

FastLim
demonstration

Applications

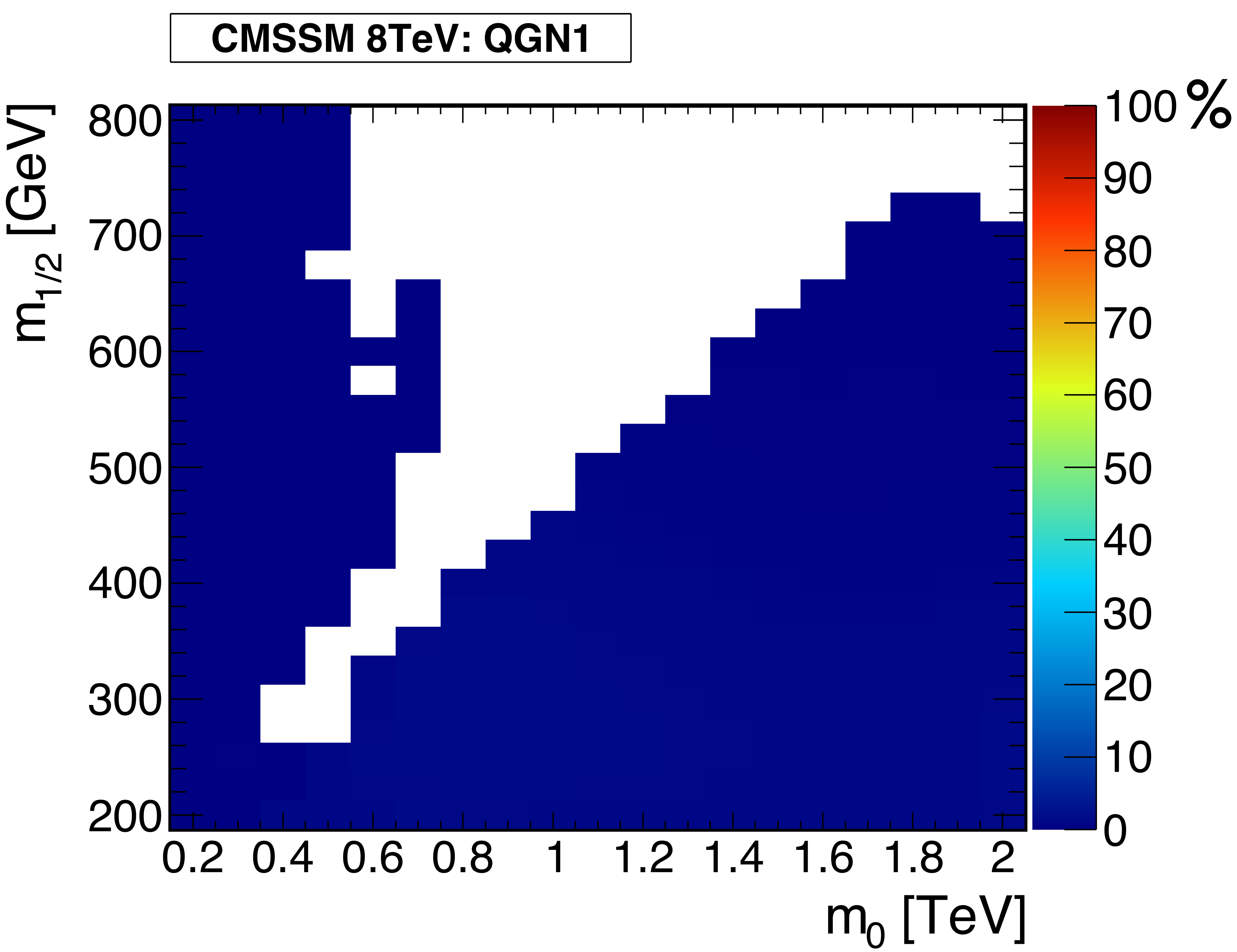
Because FastLim contains a finite set of simplified processes, we would like to check how well the code covers the interesting models:

- CMSSM
- NUHM
- natural SUSY
- spread SUSY

CMSSM coverage

$Q = \tilde{q}$
$G = \tilde{g}$
$C1 = \tilde{\chi}_1^{\pm}$
$N2 = \tilde{\chi}_2^0$
$N1 = \tilde{\chi}_1^0$

$$\text{Coverage} = \frac{\sum_i \sigma_i \left(\begin{array}{c}\text{implemented}\\ \text{processes}\end{array}\right)}{\sigma_{\text{tot}}}$$



(only Q, G and N1 can appear in the process)

Q-G-N1 model

GttN1_QqGttN1	GbbN1_QqGqqN1
GqqN1_QqGqqN1	QqGbbN1_QqGbbN1
GttN1_QqN1	QqGttN1_QqGttN1
GbbN1_GbbN1	GbbN1_QqN1
GbbN1_QqGttN1	GttN1_GttN1
QqGttN1_QqN1	QqGbbN1_QqGttN1
GbbN1_GttN1	QqGbbN1_QqGqqN1
QqGqqN1_QqGqqN1	GqQqN1_GqQqN1
GbbN1_GqqN1	GqqN1_QqGttN1
GttN1_QqGqqN1	GttN1_QqGbbN1
GqQqN1_QqN1	QqN1_QqN1
GqqN1_GttN1	QqGqqN1_QqN1
GqqN1_QqGbbN1	GbbN1_QqGbbN1
QqGbbN1_QqN1	QqGqqN1_QqGttN1
GqqN1_GqqN1	GqqN1_QqN1

CMSSM coverage

$$\mathrm{Q} = \tilde{q}$$
$$\mathrm{G} = \tilde{g}$$
$$\mathrm{C1} = \tilde{\chi}_1^{\pm}$$
$$\mathrm{N2} = \tilde{\chi}_2^0$$
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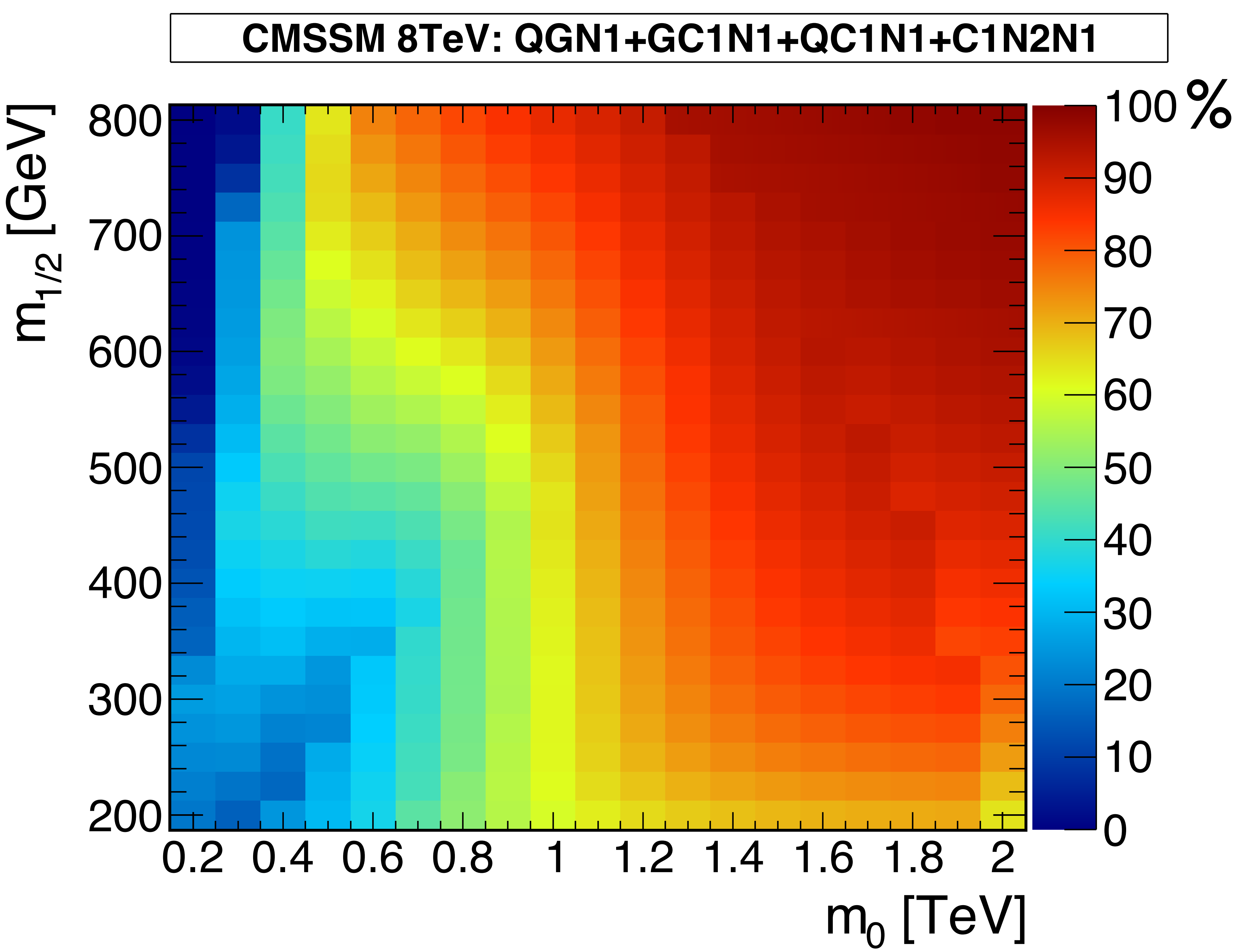


Q-G-N1 + G(Q)-C1-N1 + C1-N2-N1 model

GttN1_QqGttN1
GqqN1_QqGqqN1
GttN1_QqN1
GbbN1_GbbN1
GbbN1_QqGttN1
QqGttN1_QqN1
GbbN1_GttN1
QqGqqN1_QqGqqN1
GbbN1_GqqN1
GttN1_QqGqqN1
GqQqN1_QqN1
GqqN1_GttN1
GqqN1_QqGbbN1
QqGbbN1_QqN1
GqqN1_GqqN1

GbbN1_QqGqqN1
QqGbbN1_QqGbbN1
QqGttN1_QqGttN1
GbbN1_QqN1
GttN1_GttN1
QqGbbN1_QqGttN1
QqGbbN1_QqGqqN1
GqQqN1_GqQqN1
GqqN1_QqGttN1
GttN1_QqGbbN1
QqN1_QqN1
QqGqqN1_QqN1
GbbN1_QqGbbN1
QqGqqN1_QqGttN1
GqqN1_QqN1

GqqC1wN1_GttN1
GbtC1wN1_GqqC1wN1
GbbN1_GqqC1wN1
GqqC1wN1_GqqN1
GbtC1wN1_GttN1
GbbN1_GbtC1wN1
GqqC1wN1_GqqC1wN1
GbtC1wN1_GqqN1
GbtC1wN1_GbtC1wN1
QqC1wN1_QqN1
QqC1wN1_QqC1wN1
C1wN1_N2zN1
C1wN1_C1wN1
C1wN1_N2h0N1

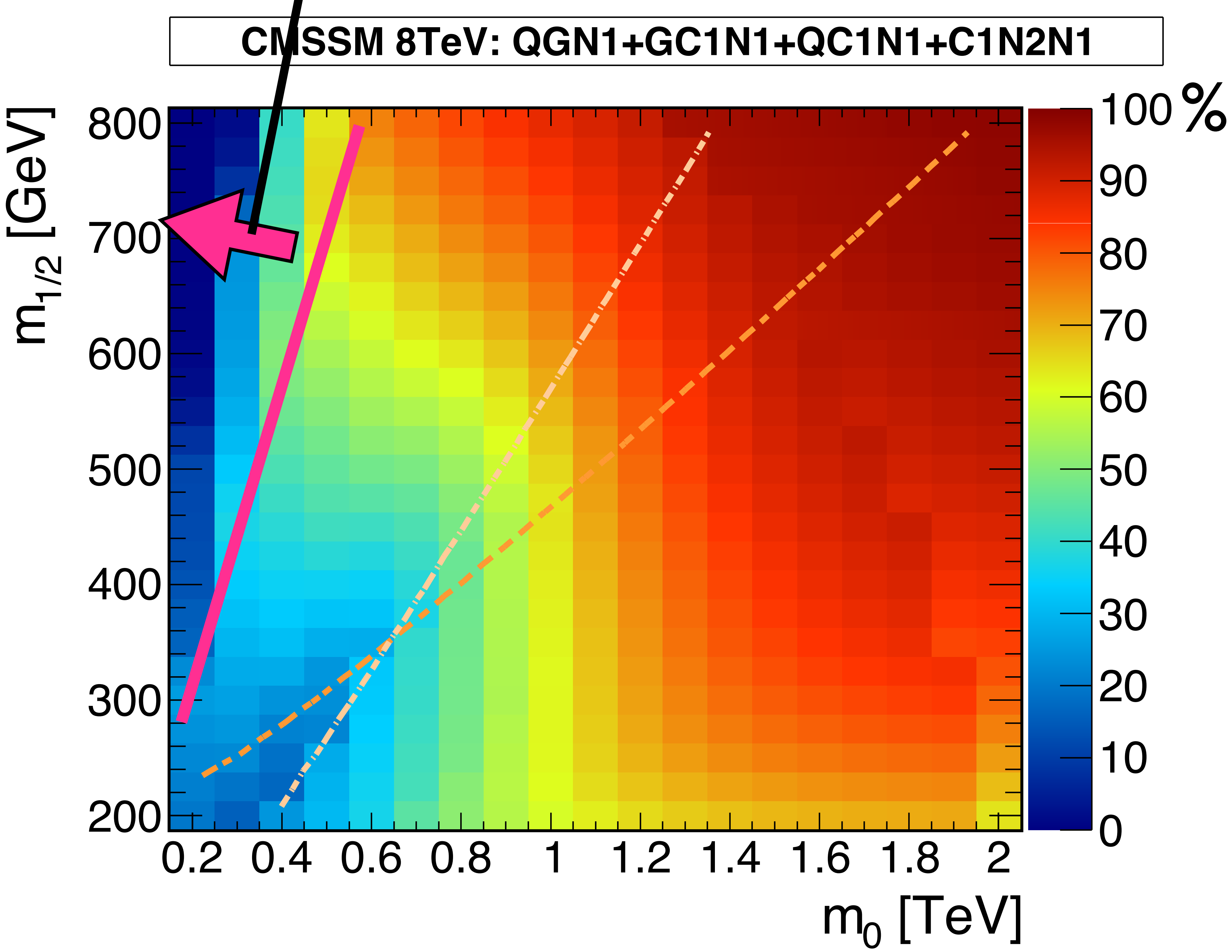
CMSSM coverage

$Q = \tilde{q}$
$G = \tilde{g}$
$C1 = \tilde{\chi}_1^{\pm}$
$N2 = \tilde{\chi}_2^0$
$N1 = \tilde{\chi}_1^0$

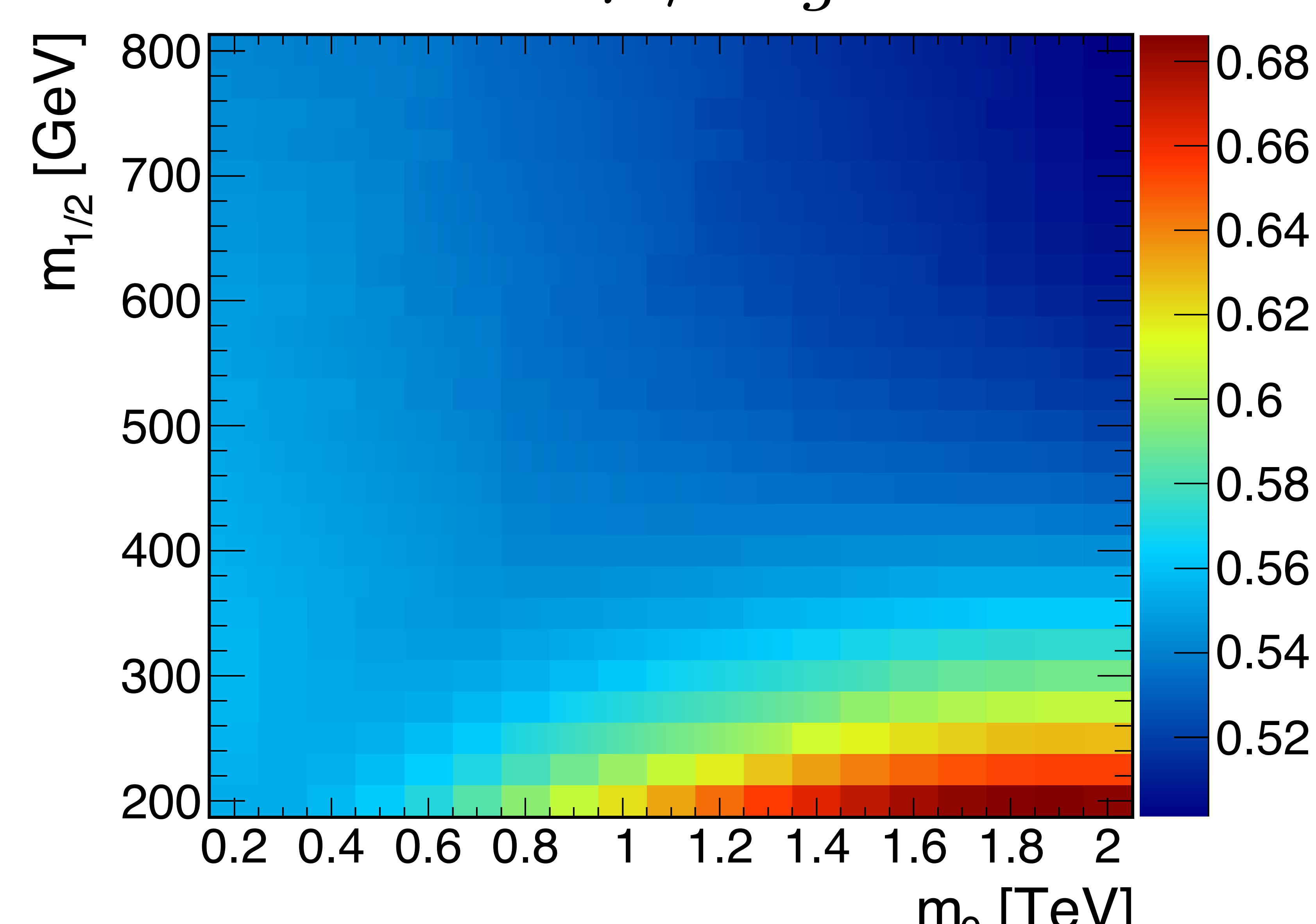
$\tilde{\chi}_1^+ \to \nu \tilde{\tau}^+$ open
$\tilde{\chi}_1^+ \to W^+ \tilde{\chi}_1^0$ suppressed

gluino decay modes to the higgsino states dominate due to the top Yukawa coupling and that makes decay chains longer

$\tilde{g} \to t\bar{t}\chi_3^0 \to \cdots$
$\tilde{g} \to b\bar{t}\chi_2^+ \to \cdots$



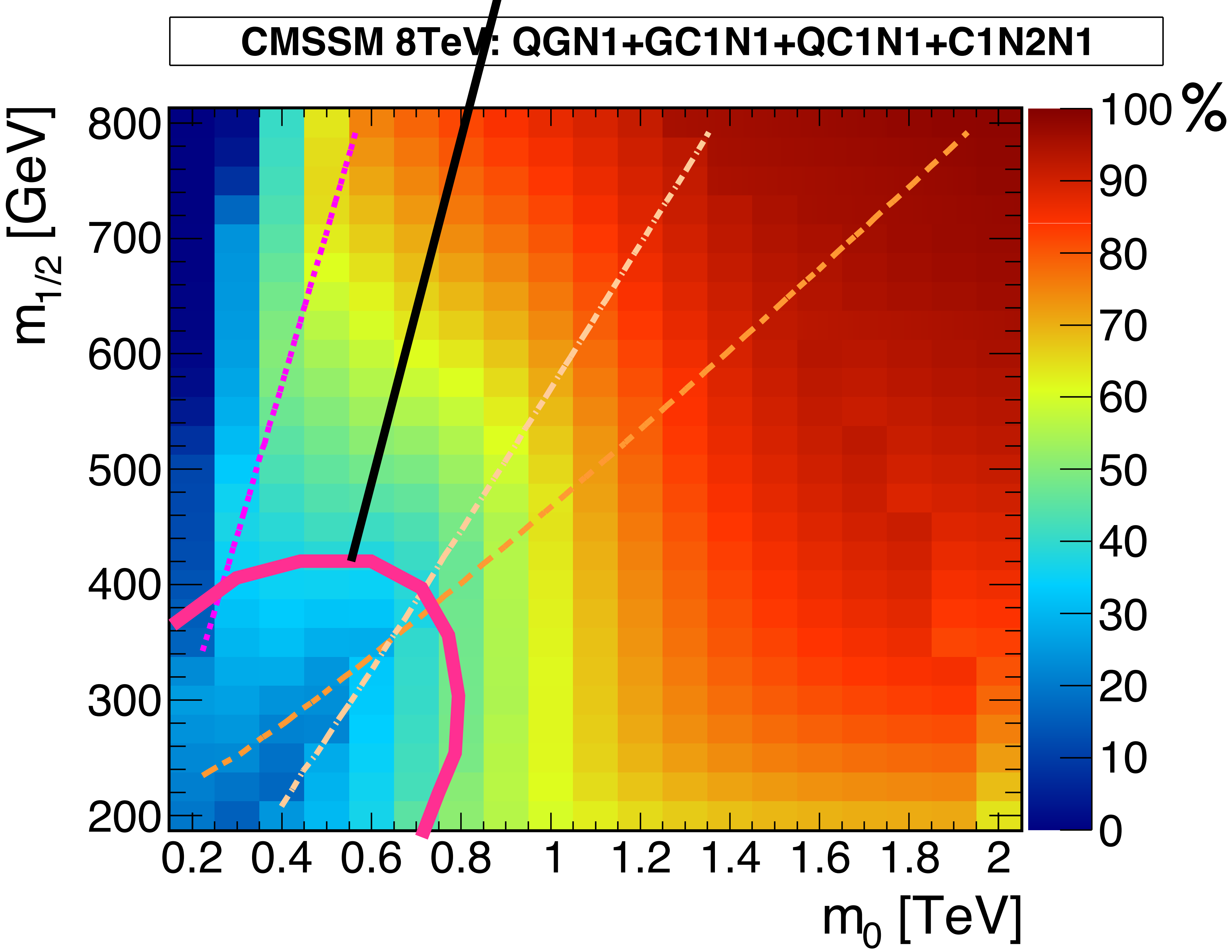
$\mu/m_{\tilde{g}}$

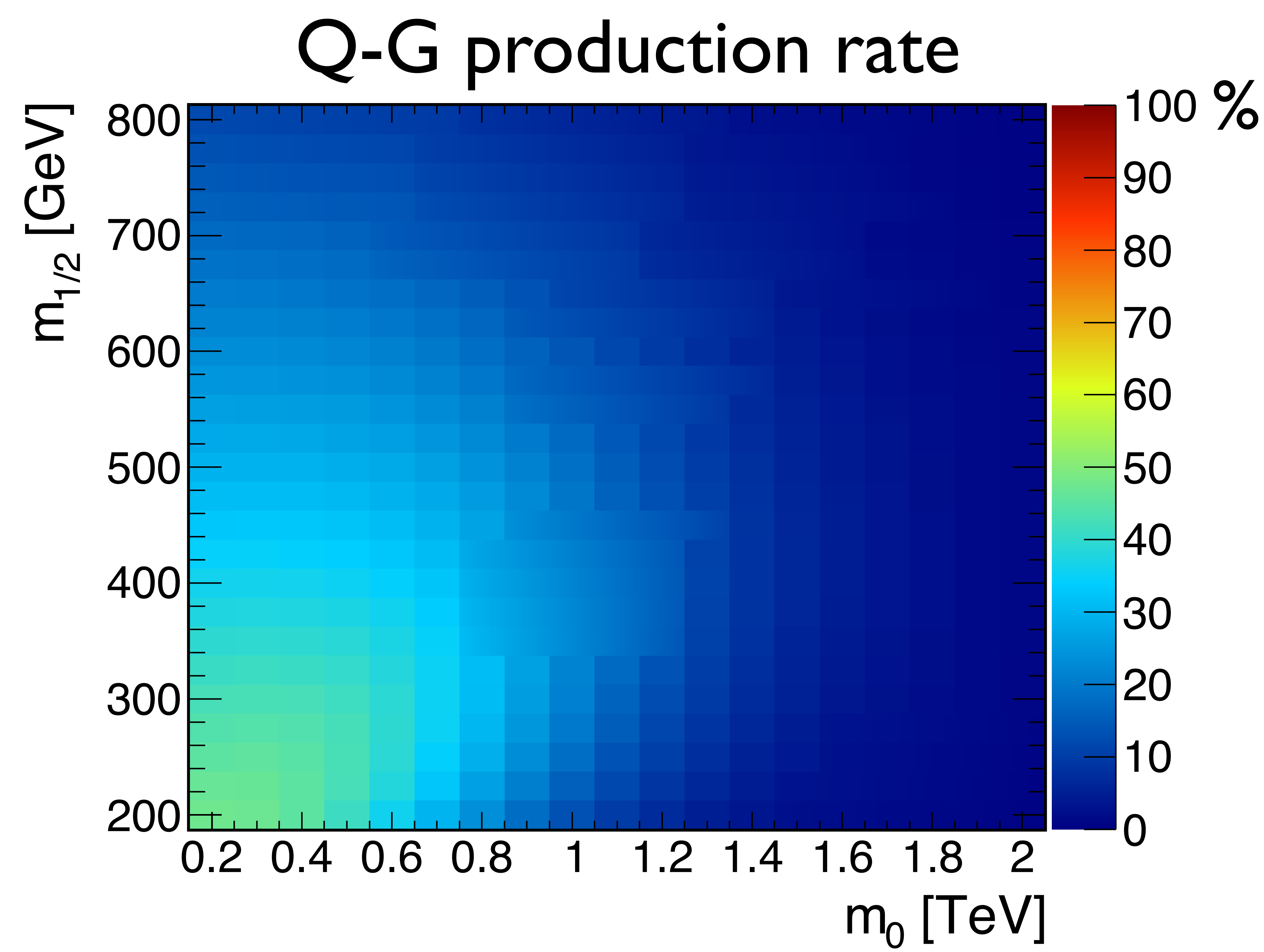


CMSSM coverage

$$Q = \tilde{q}$$
$$G = \tilde{g}$$
$$C1 = \tilde{\chi}_1^{\pm}$$
$$N2 = \tilde{\chi}_2^0$$
$$N1 = \tilde{\chi}_1^0$$

Q-G-C1-N1 model is necessary => 4 dimensional

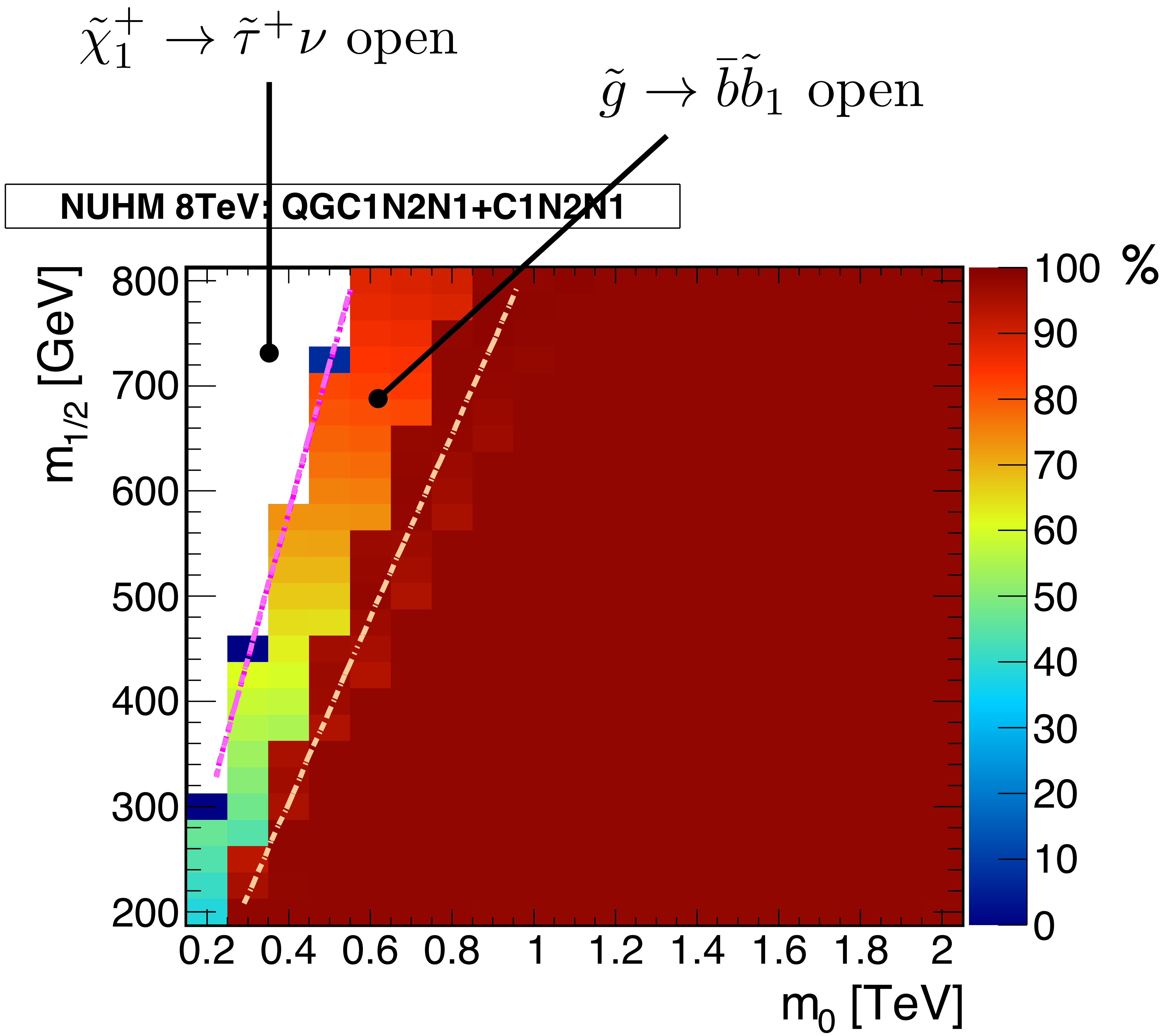




NUHM coverage

Non Universal Higgs Mass (NUHM) model

$\mu = m_A = 3\ m_{1/2}$



- $\tilde{g} \to t\bar{t}\tilde{\chi}_3^0,\ b\bar{t}\tilde{\chi}_2^+$ not open due to large μ
- 4D Q-G-C1(N2)-N1 model is assumed

- After the null SUSY search results and ~125GeV Higgs discovery at the LHC, **natural SUSY** and **spread SUSY** models become attractive

natural SUSY

- tension between fine tuning and null SUSY search results is optimised
- the Higgs sector should be extended to explain 125GeV Higgs mass, but such extension may not alter the LHC signatures

R.Kitano, Y.Nomura, 0602096

M.Papucci, J.T.Ruderman, A.Weiler, 1110.6926

...

spread SUSY

- EW naturalness is removed from the SUSY motivation
- no flavour/CP problem
- 125GeV Higgs mass is realised
- model building is simple

L.J.Hall, Y.Nomura, 1111.4519

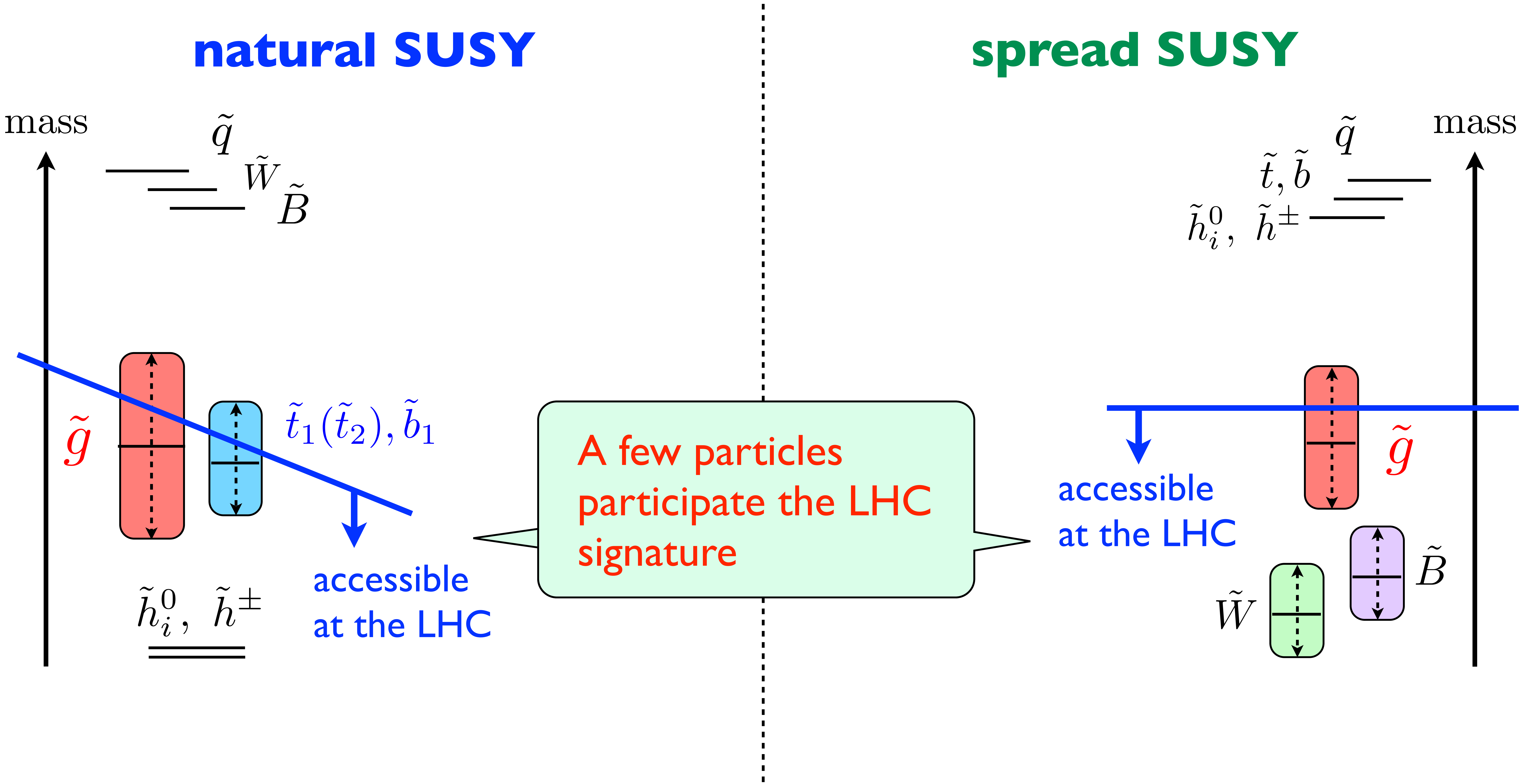
M.Ibe, S.Matsumoto, T.T.Yanagida, 1202.2253

A.Arvanitakia, N.Craigb, S.Dimopoulosa, G.Villadoroc, 1210.0555

N.Arkani-Hamed, A.Gupta, D.E.Kaplan, N.Weiner, T. Zorawski, 1212.6971

...

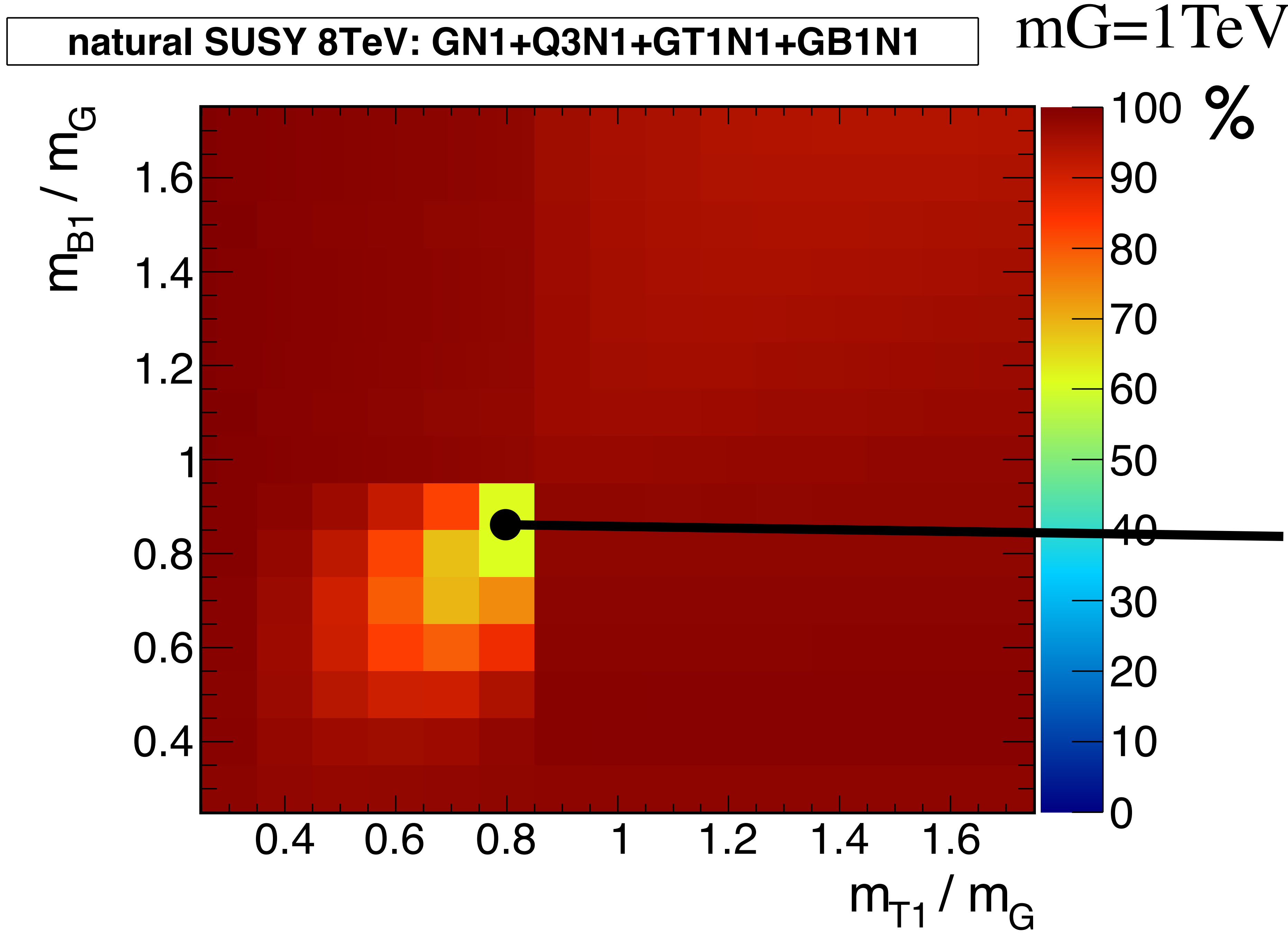
• After the null SUSY search results and ~125GeV Higgs discovery at the LHC, **natural SUSY** and **spread SUSY** models become attractive



- After the null SUSY search results and ~125GeV Higgs discovery at the LHC, **natural SUSY** and **spread SUSY** models become attractive

natural SUSY

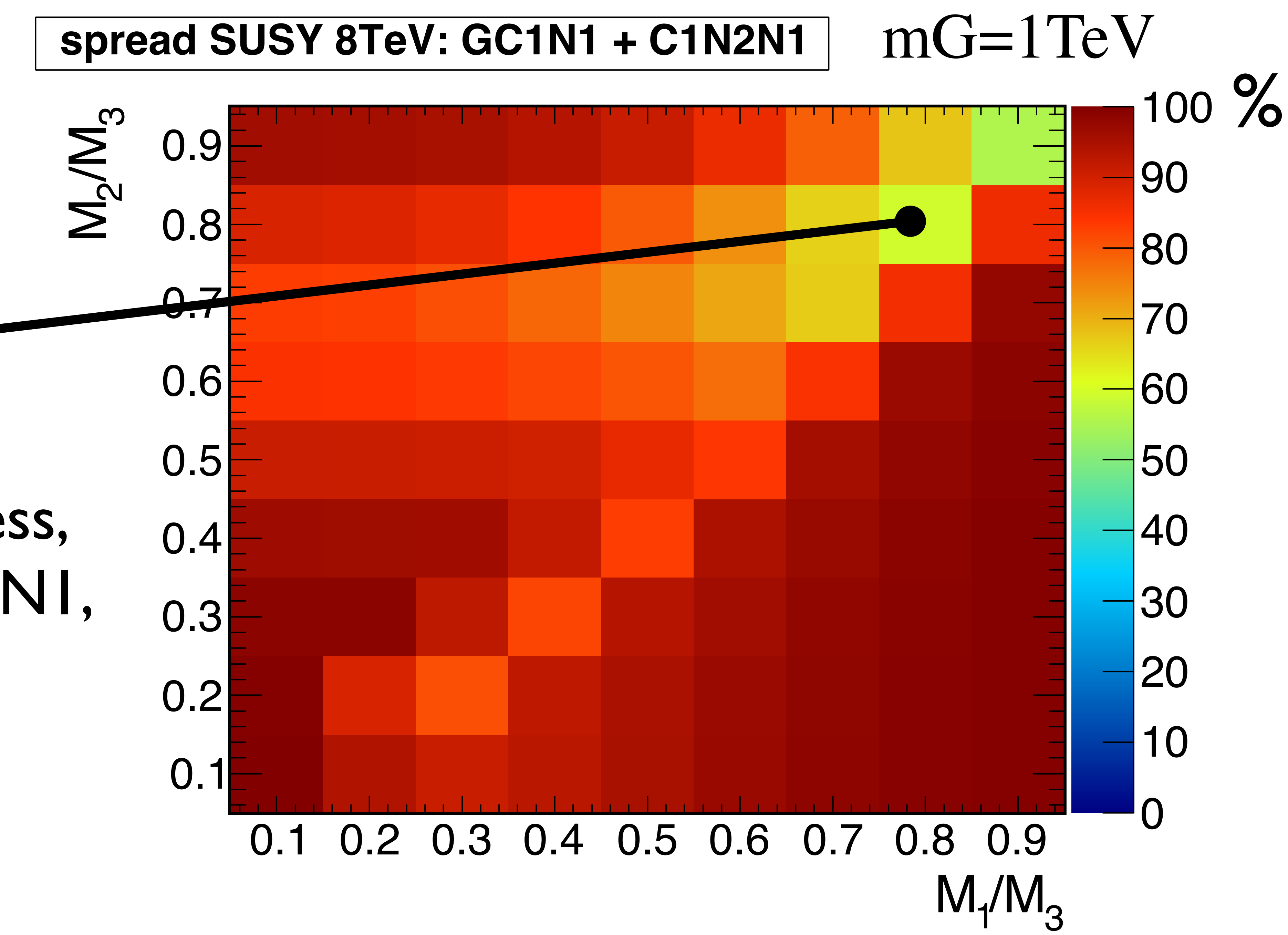
G-N1 + G-T1(B1)-N1 model



asymmetric process, GtT1tN1_GbB1bN1, required (4D)

spread SUSY

G-C1-N1 + C1-N2-N1 model



N2 is required

good coverage can be achieved by a few sets of simplified models

Summary

• FastLim reconstructs N_{SUSY} of a given model from the efficiency tables for the simplified processes and calculate the LHC constraints.

• A finite set of simplified processes are implemented in FastLim, but it can provide good coverage for interesting SUSY models: CMSSM, NUHM, natural SUSY, spread SUSY

simplified processes

your favourite models

Thank you for listening

G-N1 + G-T1(B1)-N1 model

GbbN1_GbtN1
GbtN1_GqqN1
GqqN1_GttN1
GttN1_GttN1
GbbN1_GbbN1
GbtN1_GbtN1
GbbN1_GttN1
GbtN1_GttN1
GbbN1_GqqN1
GqqN1_GqqN1
GtT1bN1_GtT1tN1
GtT1tN1_GtT1tN1
GtT1bN1_GtT1bN1
GbB1bN1_GbB1tN1
GbB1tN1_GbB1tN1
GbB1bN1_GbB1bN1
B1bN1_B1tN1
B1bN1_B1bN1
T1bN1_T1tN1
T1tN1_T1tN1
B1tN1_B1tN1
T1bN1_T1bN1

G-C1-N1 + C1-N2-N1 model

GbbN1_GbtN1
GqqN1_GttN1
GbbN1_GbbN1
GbbN1_GttN1
GqqN1_GqqN1
GbtN1_GqqN1
GbbN1_GqqN1
GbtN1_GbtN1
GbbN1_GbtC1wN1
GqqC1wN1_GqqN1
GbtN1_GqqC1wN1
GbtC1wN1_GqqN1
GbtC1wN1_GbtN1
GqqC1wN1_GqqC1wN1
GbtC1wN1_GbtC1wN1
GbtC1wN1_GqqC1wN1
GttN1_GttN1
GbtN1_GttN1
GbtC1wN1_GttN1
GbbN1_GqqC1wN1
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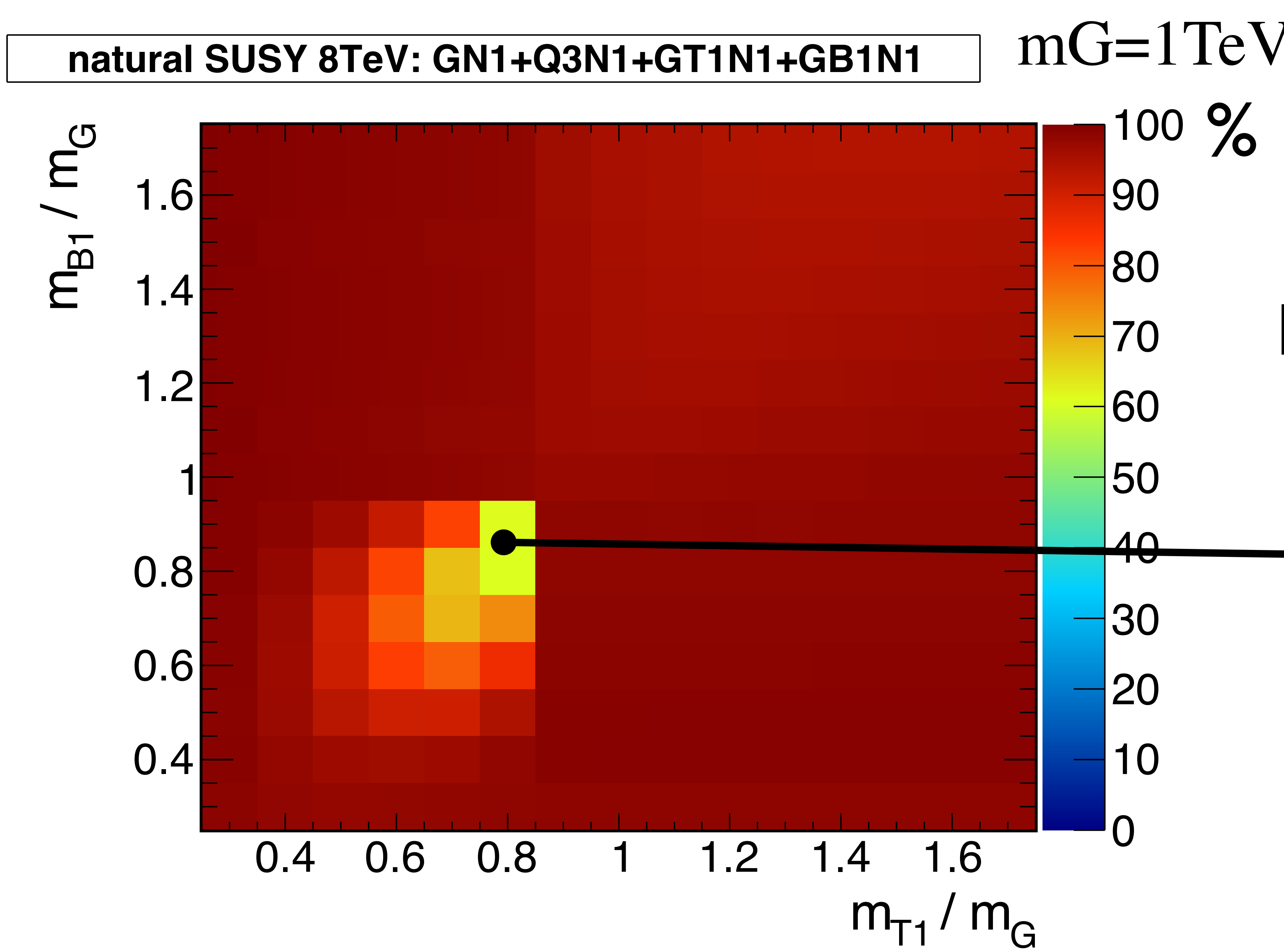
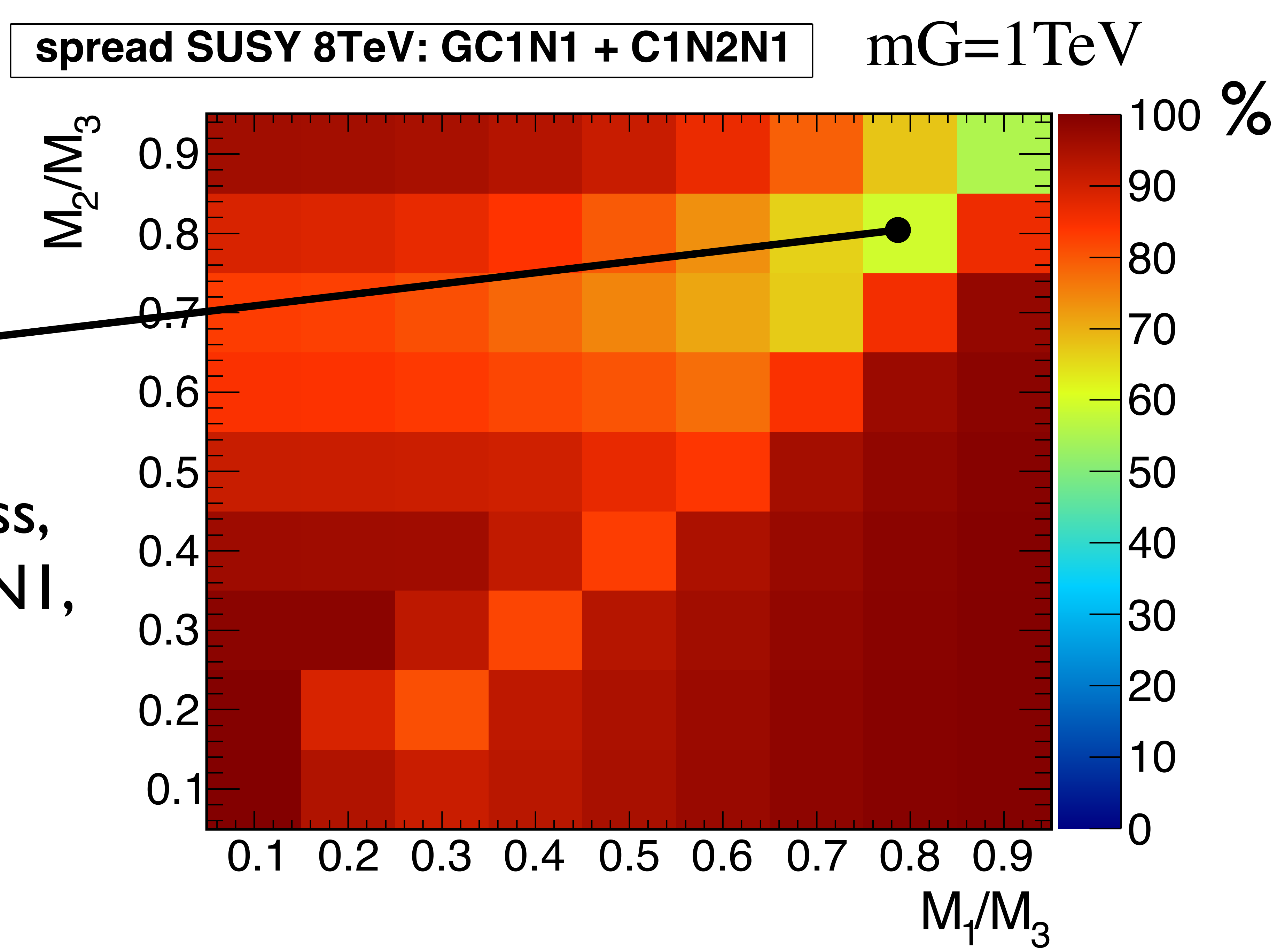
C1wN1_C1wN1
C1wN1_N2zN1
C1wN1_N2h0N1



asymmetric process, GtT1tN1_GbB1bN1, required (4D)

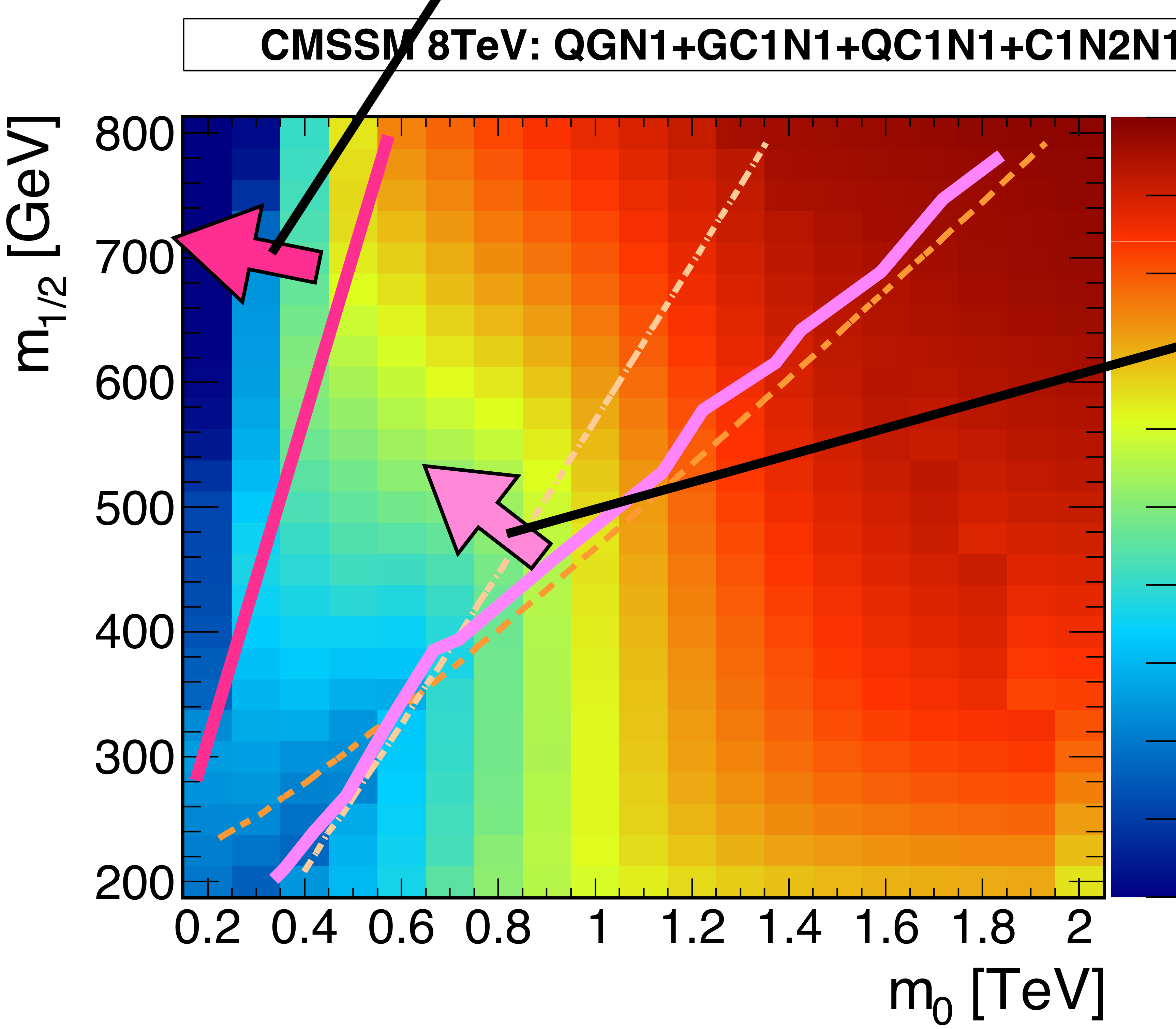
N2 is required



CMSSM coverage

$\mathrm{Q} = \tilde{q}$
$\mathrm{G} = \tilde{g}$
$\mathrm{C1} = \tilde{\chi}_1^{\pm}$
$\mathrm{N2} = \tilde{\chi}_2^0$
$\mathrm{N1} = \tilde{\chi}_1^0$

$\tilde{\chi}_1^+ \to \tilde{\tau}^+ \nu \to \tau^+ \nu \tilde{\chi}_1^0$ open
$\tilde{\chi}_1^+ \to W^+ \tilde{\chi}_1^0$ suppressed



$\tilde{g} \to \tilde{t}_1 t, \tilde{b}_1 b$ open

$\tilde{t}_1 \to b \tilde{\chi}_2^+ \to \cdots$
$\tilde{b}_1 \to b \tilde{\chi}_3^0 \to \cdots$

higgsinos make decay chains longer
BR is large due to the top Yukawa