New Physics in the Higgs era

BSM conveners:
Gustaaf Brooijmans
Andreas Weiler

Les Houches 2013

Captain Obvious*

* Contrary to popular belief, Captain Obvious is capable of flying but is afraid to, so he drives around the country in an RV, constantly on the lookout for blatantly obvious things to explain to the general public.

From the wiki:

wikilink

New Physics

BSM physics in the context of a ~125 GeV Higgs boson

Higgs bosons

- Additional Higgses
- Composite Higgs
- Higgs in NP decay chains

The third generation

- New physics producing tops: classify according to the number of final state top quarks?
- Stop and sbottom searches

Vector-like fermions

Soft BSM at LHC

- Compressed spectra

"Effective New Physics" and a 125 GeV Higgs

- Effective lagrangian (also see session 1?), but how to treat resonances?
- Simplified model approach beyond SUSY

A 125 GeV Higgs and Dark Matter

- Higgs decays into light neutralinos

Simplified model for a heavy spin-1 resonance with EW quantum numbers (rho)

- MC implementation
- derive current exclusion limits

Simplified models in the SUSY context

- SModleS development
- Improving SMS interpretations
- Wishlist for the presentation of SMS results
- see dedicated SMS page

Reinterpreting New Physics Searches / Presentation of Results

2011 Les Houches recommendations for the presentation of LHC search results

Another (lazy) phenomenologist's wishlist

Reinterpreting SUSY searches with non-minimal flavor violation

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Stops and Sbottoms

Interested people: Dipan, Genevieve, Rohini, Sabine, Suchita, Benjamin, Sophio Pataraia…

Stops from gluino production: 4 top final state

Exploiting top polarization

Boosted tops at LHC13

- Stop and sbottom searches

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Simplified models in the SUSY context

Interested people: Suchita, Wolfgang, Sabine ….

Contact person: Suchita

Improving SMS interpretations of SUSY searches

Wishlist for the presentation of SMS results

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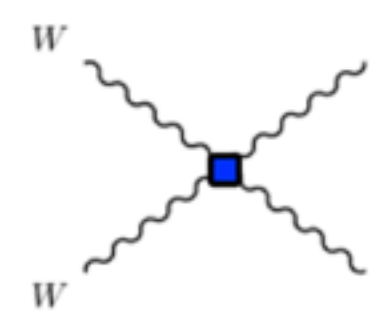
Another (lazy) phenomenologist's wishlist → exp score card

Reinterpreting SUSY searches with non-minimal flavor violation

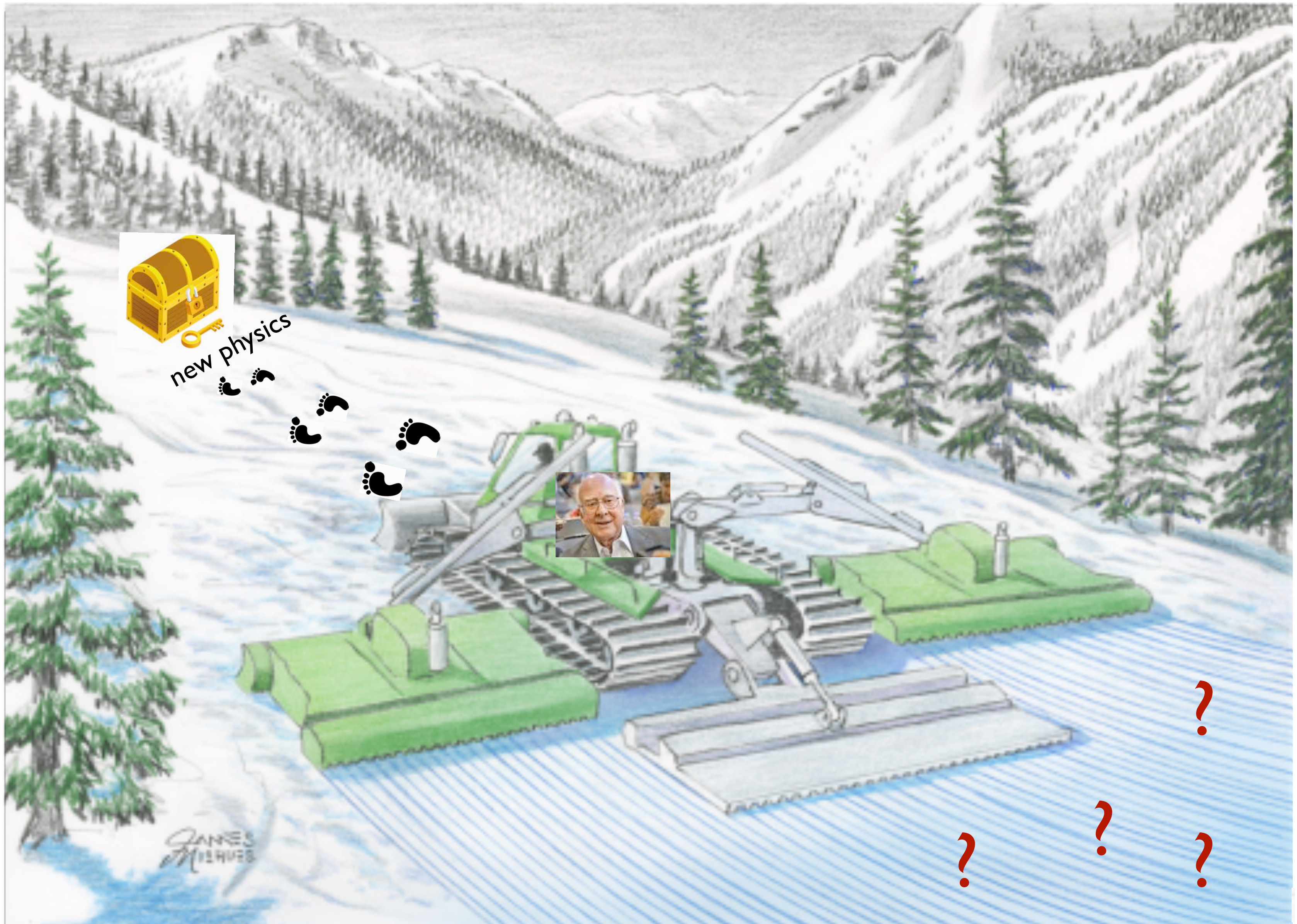
We used to have a NP scale: $\sim 4\sqrt{\pi}v \approx 1.7\,\mathrm{TeV}$

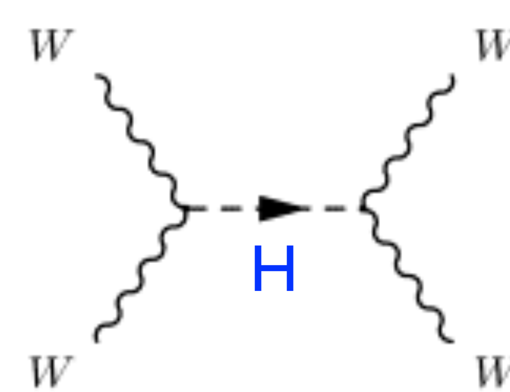
$$W_L W_L \to W_L W_L$$

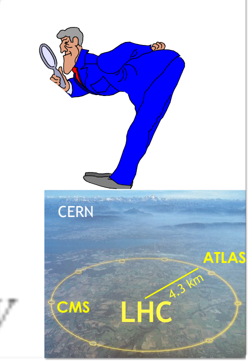


picture: G. Perez

A (tuned) SM Higgs works $\Lambda \gg 100000 \ldots 0\,\text{TeV}$







picture: G. Perez

A light Higgs is unnatural

$$V(h) = \epsilon\Lambda^2 h^2 + \lambda h^4$$

For $\epsilon = \pm\,\mathcal{O}(1)$

$$\langle h \rangle = 0$$

$$\langle h \rangle = \Lambda$$

Need: $\sqrt{\epsilon} \sim m_{\text{Higgs}}/\Lambda$

A light Higgs is unnatural

$$V(h) = \epsilon\Lambda^2 h^2 + \lambda h^4$$

For $\epsilon = \pm\,\mathcal{O}(1)$ $\quad \langle h \rangle = 0$, $\quad \langle h \rangle = \Lambda$

Need: $\sqrt{\epsilon} \sim m_{\mathrm{Higgs}}/\Lambda$

For Λ = M_{Planck}, M_{GUT}, *10 TeV* : $\epsilon \sim 10^{-32}, 10^{-28}, 10^{-4}$

Electro-weak symmetry breaking in times of austerity

light Higgs

light stops$_{1,2}$, sbottom$_L$, higgsinos, gluinos, …

light top partners (Q=5/3,2/3,1/3), anything else ?

SUSY

Fine-tuning of (Higgs mass)^2

$$\frac{m^2_{Higgs}}{2} = -|\mu|^2 + \ldots + \delta m^2_H$$

SUSY

Fine-tuning of (Higgs mass)^2

$$\frac{m_{Higgs}^2}{2} = -|\mu|^2 + \ldots + \delta m_H^2$$

Higgsinos

SUSY

Fine-tuning of (Higgs mass)^2

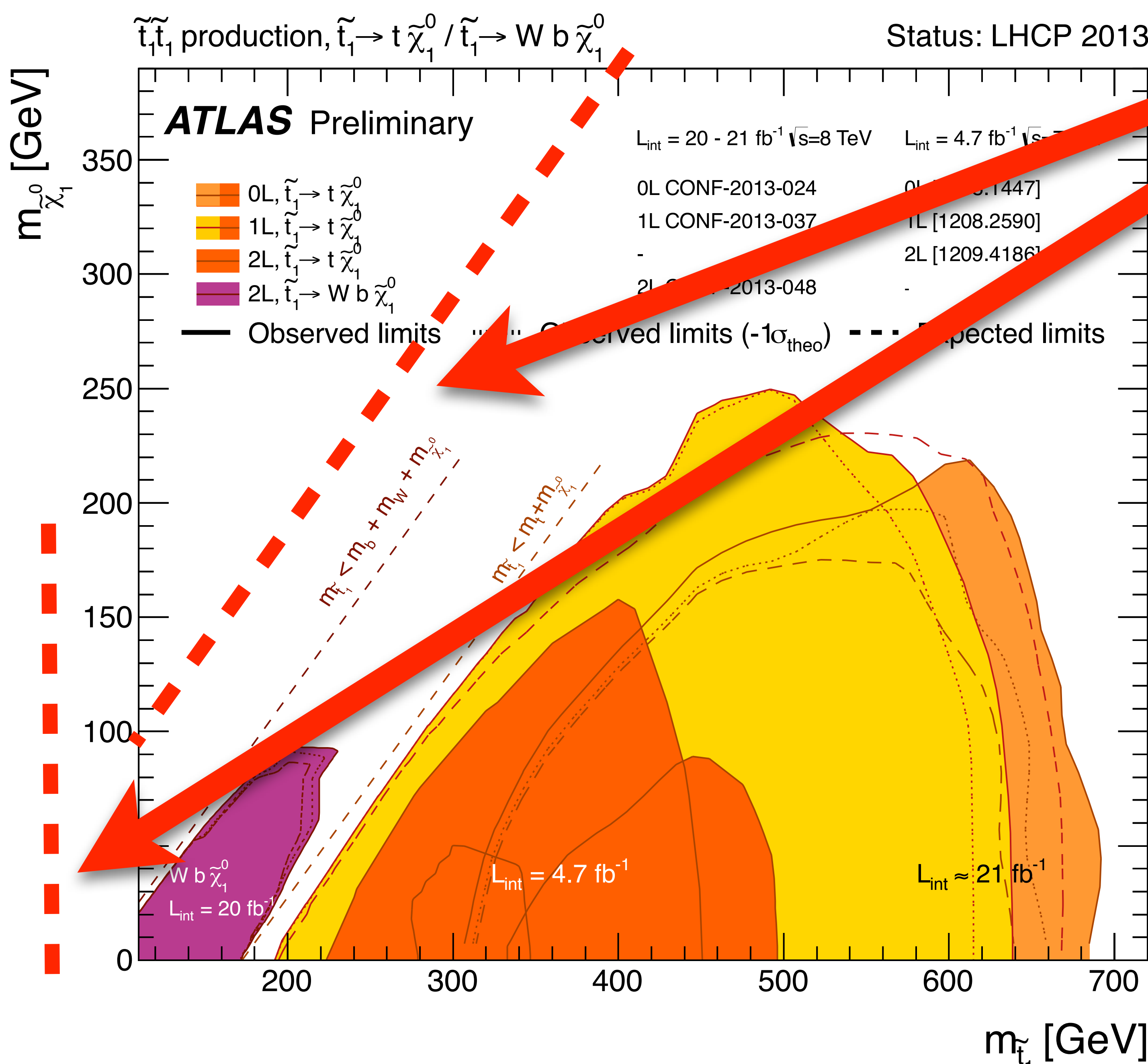
$$\frac{m^2_{Higgs}}{2} = -|\mu|^2 + \ldots + \delta m^2_H$$

Higgsinos

$$\delta m^2_H|_{stop} = -\frac{3}{8\pi^2} y_t^2 \left(m^2_{U_3} + m^2_{Q_3} + |A_t|^2 \right) \log \left(\frac{\Lambda}{\mathrm{TeV}} \right)$$

stops, sbottom$_L$

Impressive limits, but significant parameter space remains

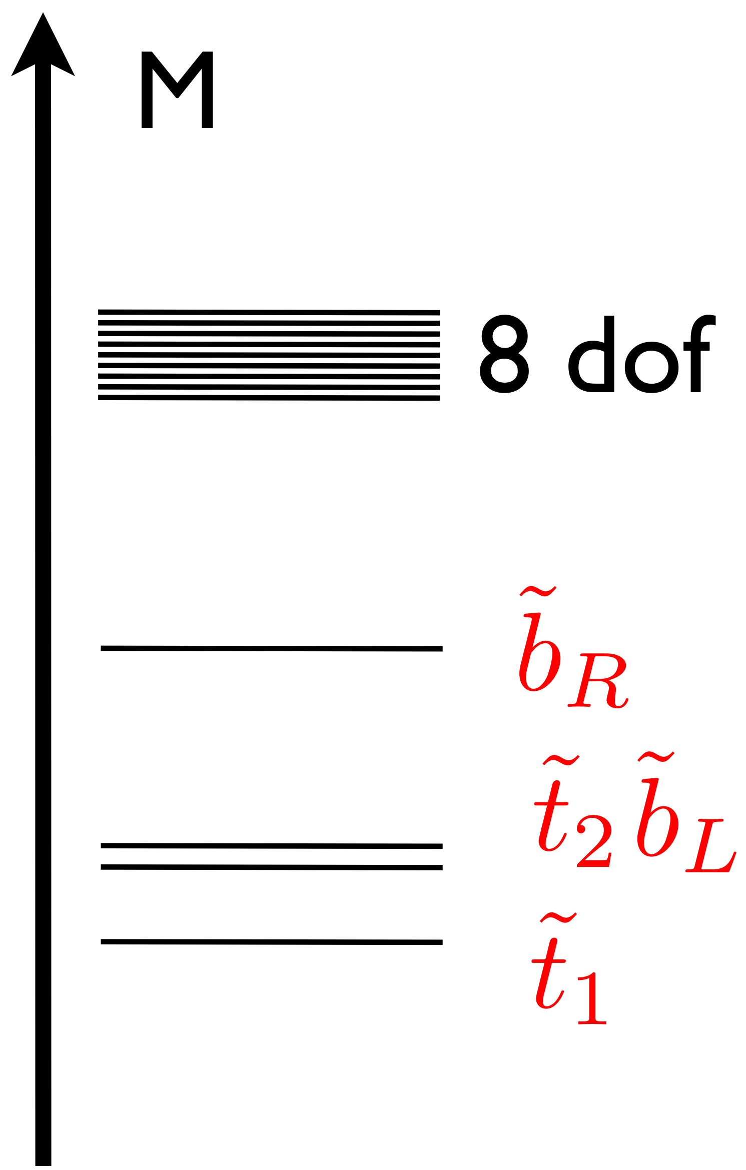


Ideas?

(see e.g. arXiv:1212.6847)

ALEPH limit ~ 80 GeV

Naturalness requires split squarks



$(\tilde{u}, \tilde{d})_L,\ \tilde{u}_R,\ \tilde{d}_R,$

$(\tilde{c}, \tilde{s})_L,\ \tilde{c}_R,\ \tilde{s}_R$

Splitting via RGE?

Papucci, Ruderman, AW '11

Splitting via renormalization group does not help

$$\delta m_H^2 \simeq 3\left(m_{Q_3}^2 - m_{Q_{1,2}}^2\right) \simeq \frac{3}{2}\left(m_{U_3}^2 - m_{U_{1,2}}^2\right)$$

1-loop, LLog,
tanß moderate

Higgs fine-tuning = RGE mass splitting

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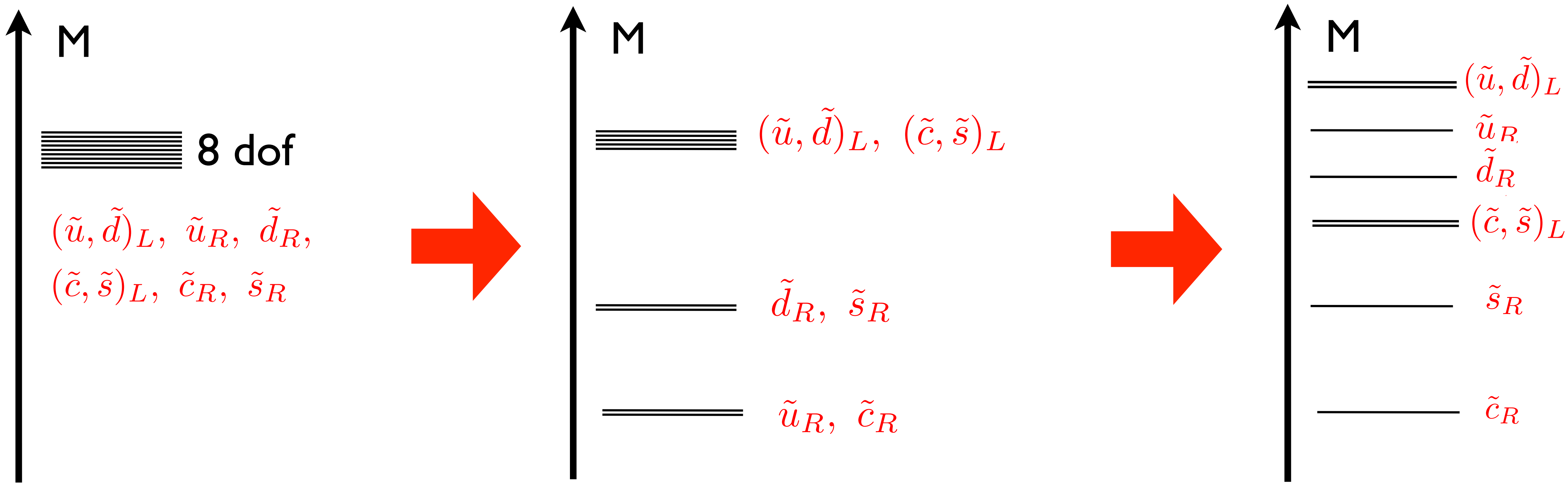
→ Flavor non-trivial susy breaking!

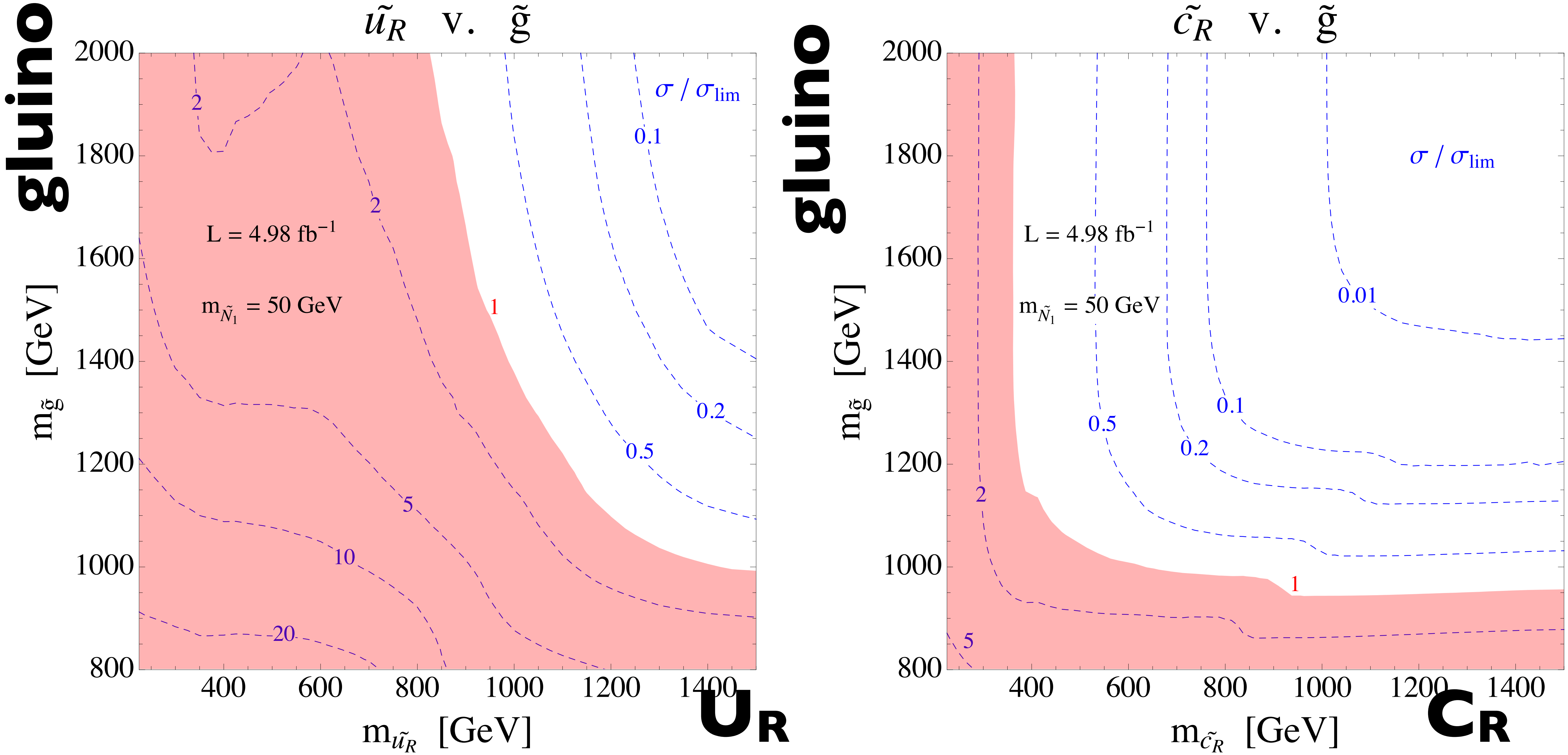


Degenerate | Minimal Flavor | Anarchy!

mSugra, CMSSM,
pMSSM, . . .

Think about beyond MFV susy searches.
Sensitivities change dramatically...
Are the MC tools ready (NLO prod'?)?

M. Papucci, J. Ruderman
G. Perez, R. Mahbubani, AW



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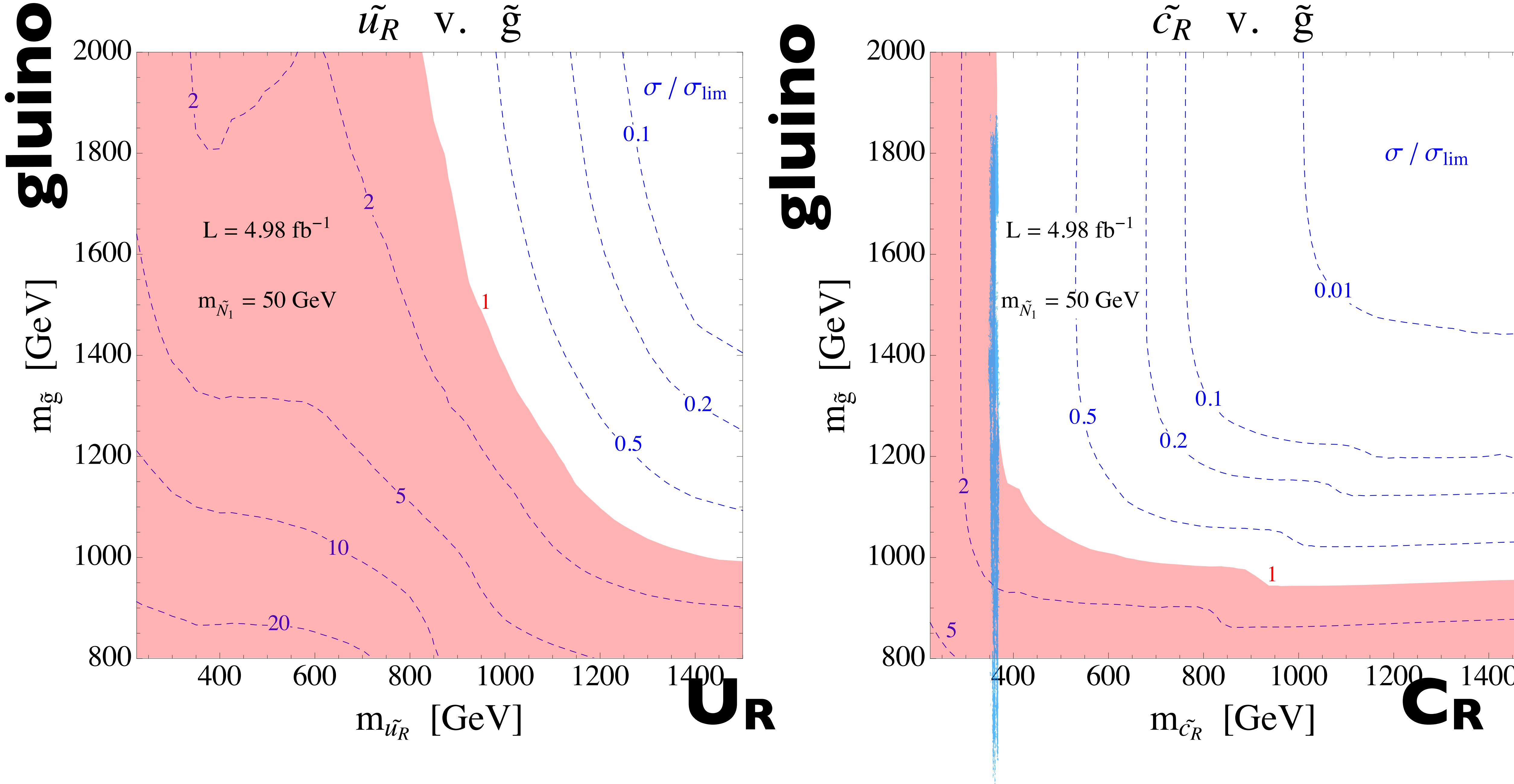

Sea squarks can still be < 350 GeV

Composite Higgs

Composite Higgs

Light Higgs implies light fermionic top partners

$$m_h^2 \simeq \frac{N_c}{\pi^2}\left[\frac{m_t^2}{f^2}\frac{m_{Q_4}^2 m_{Q_1}^2}{m_{Q_1}^2 - m_{Q_4}^2}\log\left(\frac{m_{Q_1}^2}{m_{Q_4}^2}\right)\right]$$

Contino et. al,
Pomarol, Riva 12

Matsedonskyi,Panico,Wulzer; Redi,Tesi 12;
Marzocca,Serone,Shu;

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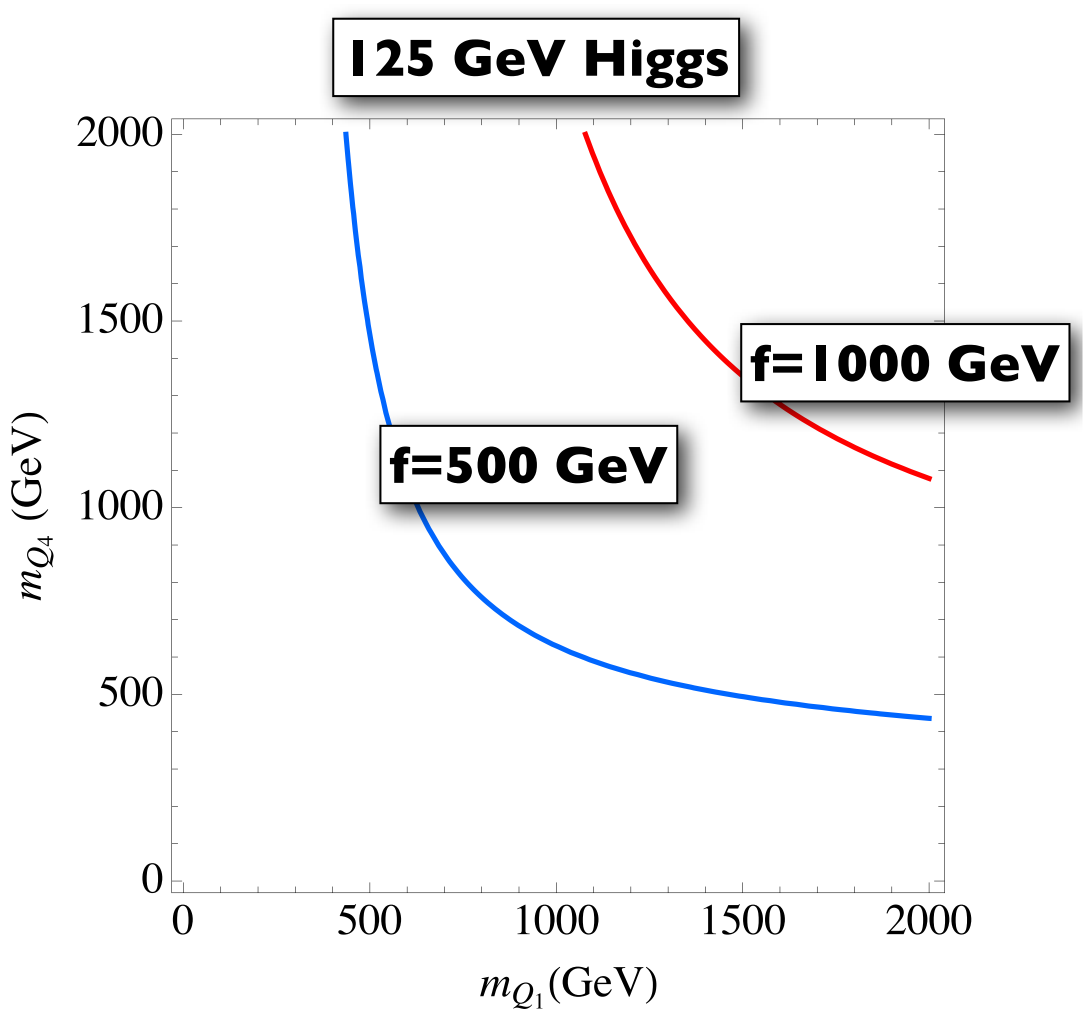

Matsedonskyi,Panico,Wulzer; Redi,Tesi 12; Marzocca,Serone,Shu;

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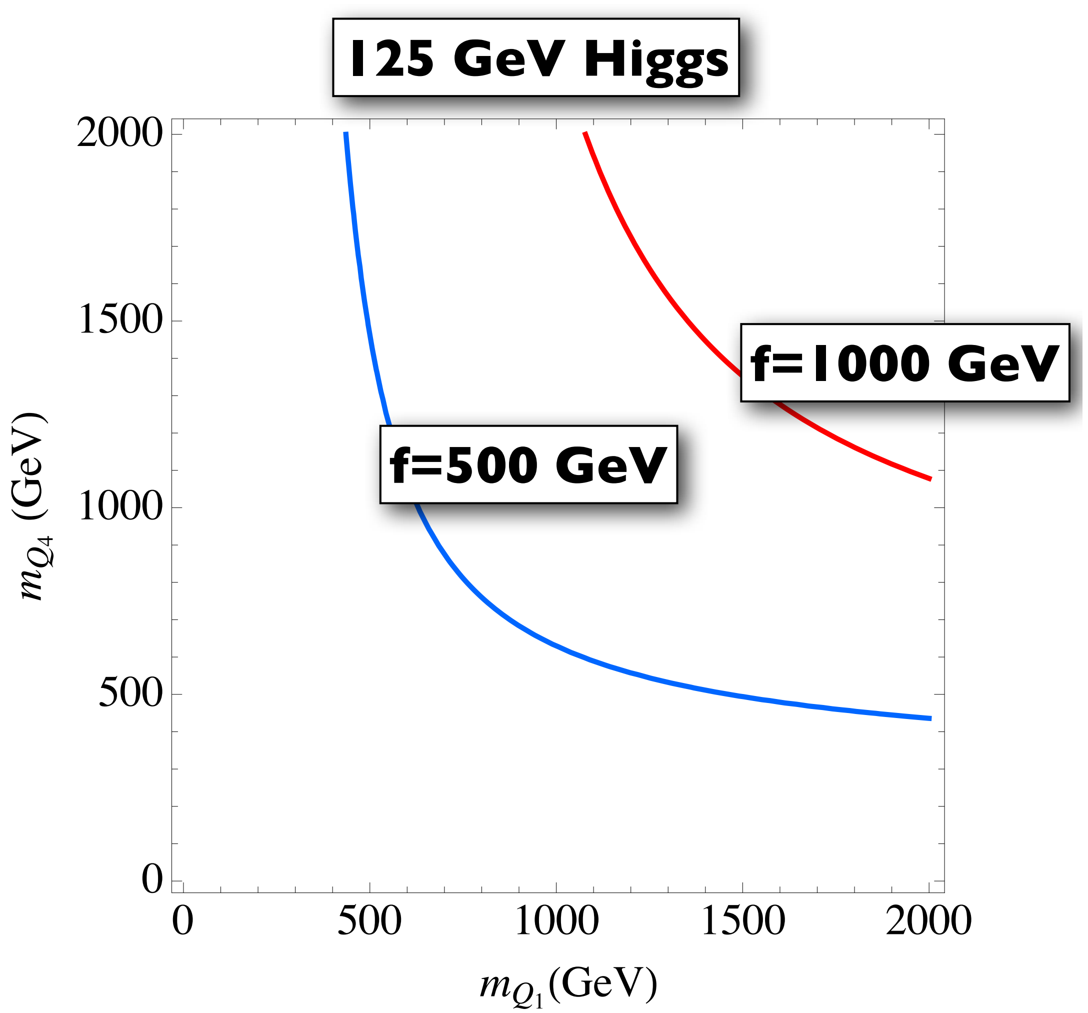
Pomarol, Riva 12



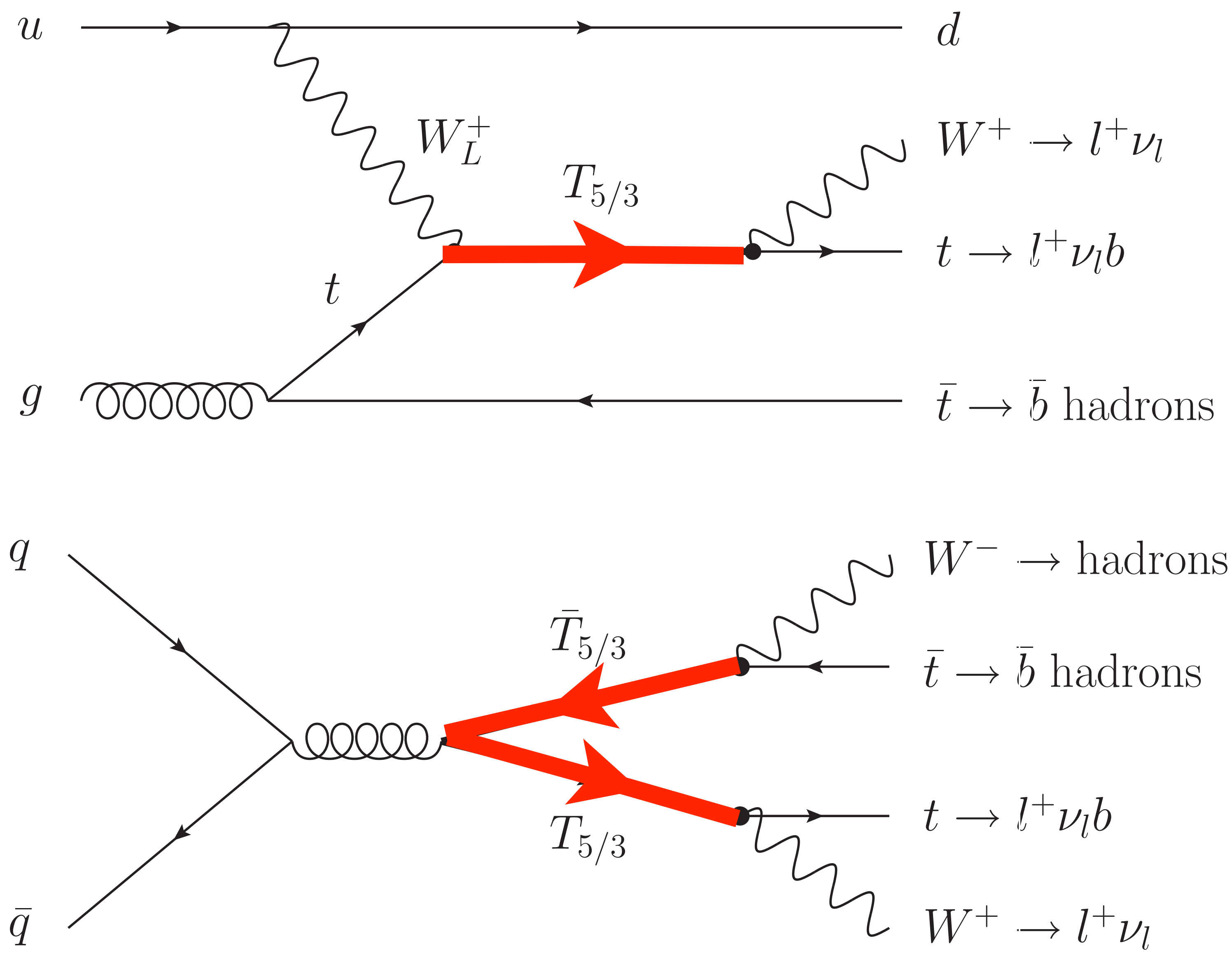
5 = 4 + 1
Q_4 Q_1

with EM charges 5/3, 2/3,-1/3

Matsedonskyi,Panico,Wulzer; Redi,Tesi 12;
Marzocca,Serone,Shu;

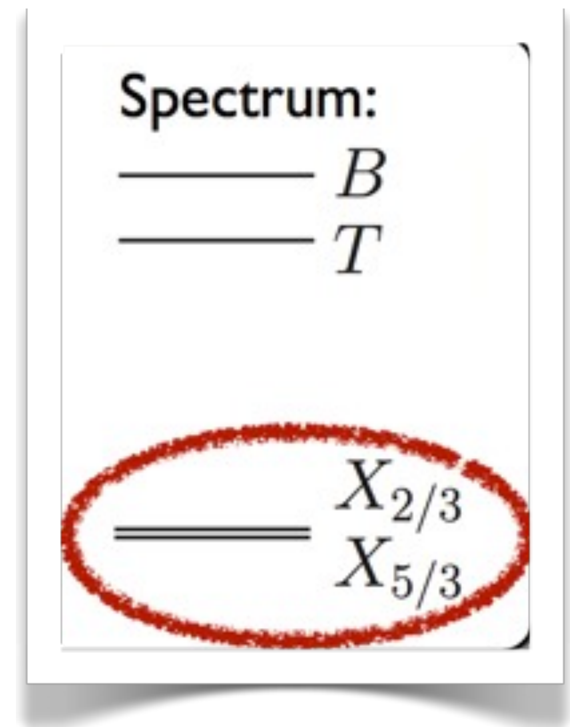
$T_{5/3}$

e.g. Perelstein, Pierce, Peskin
Contino, Servant; Mrazek, Wulzer;
De Simone, Matsedonkyi, Rattazzi, Wulzer



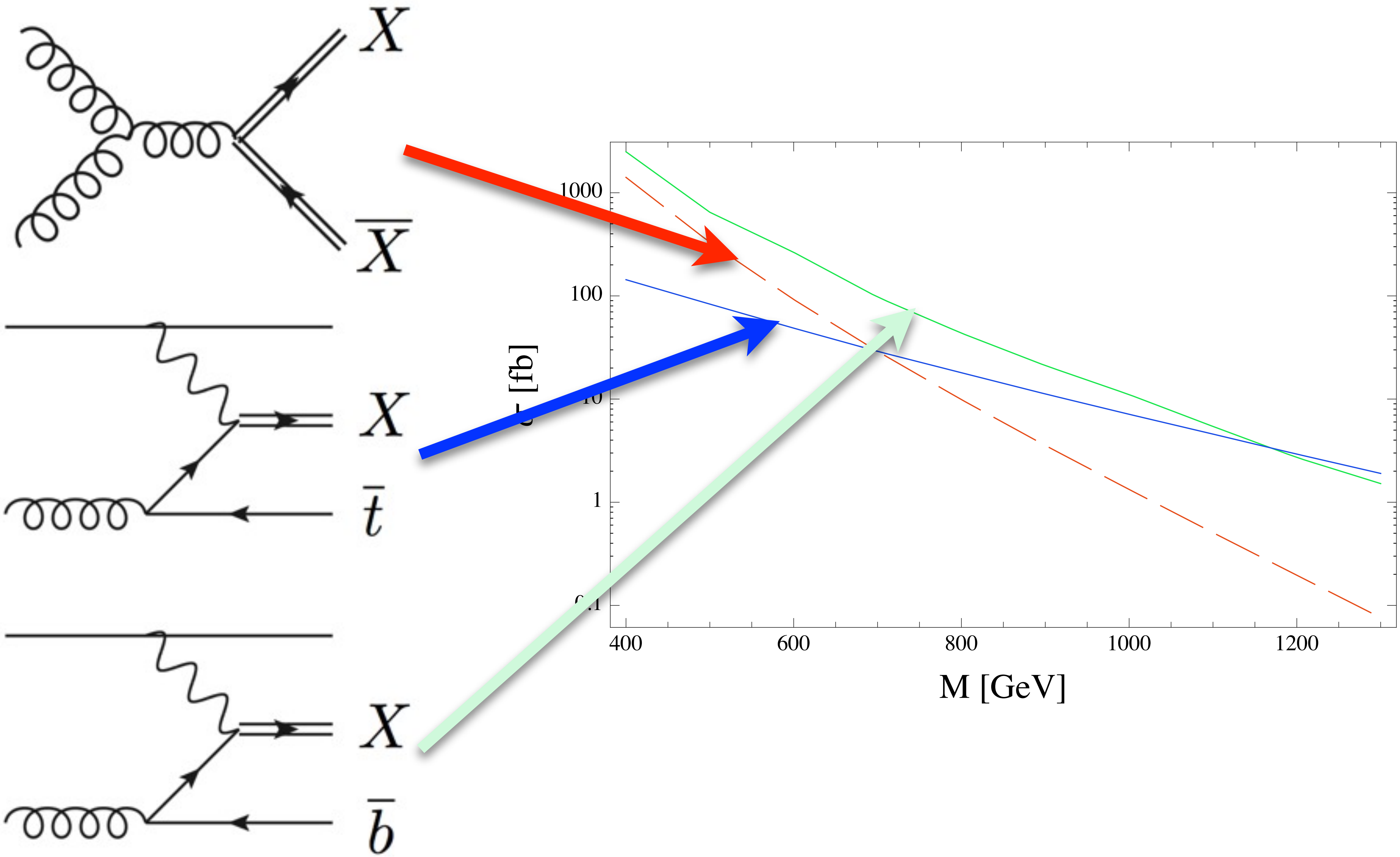
Single

Double



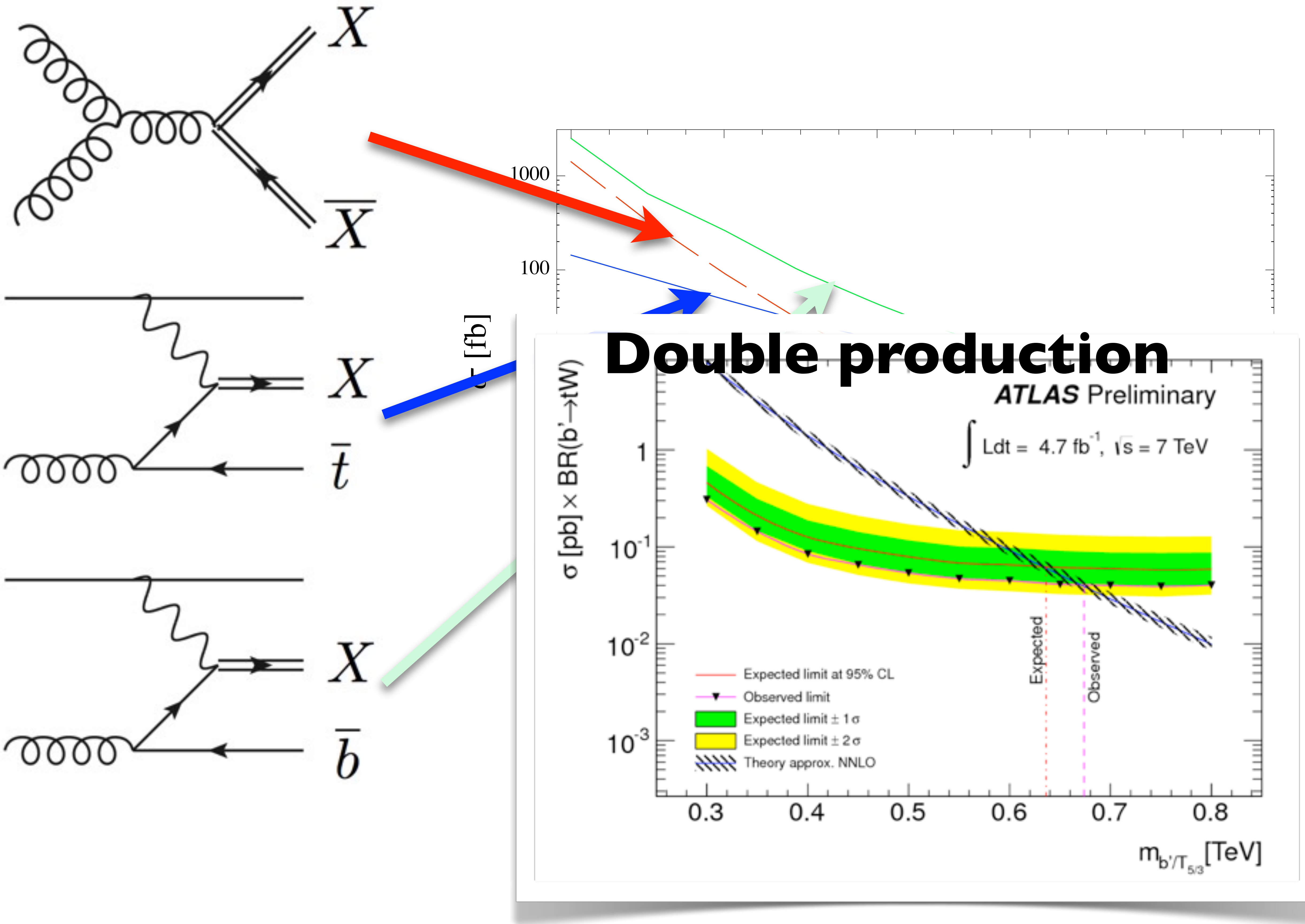
Same sign dileptons (trileptons) + b + 3 (2) jets

Production mechanism



see e.g. arXiv:1211.5663

Production mechanism



Simplified models

SUSY simplified models

Model name	Production mode	Decay	Visibility
T1	$\tilde{g}\tilde{g}$	$\tilde{g} \to q\bar{q}\tilde{\chi}^0_1$	All-Hadronic
T2	$\tilde{q}\,\tilde{q}^*$	$\tilde{q} \to q\tilde{\chi}^0_1$	All-Hadronic
T5zz	$\tilde{g}\tilde{g}$	$\tilde{g} \to q\bar{q}\tilde{\chi}^0_2, \tilde{\chi}^0_2 \to Z\tilde{\chi}^0_1$	All-Hadronic
			Opposite-Sign Dileptons
			Multileptons
T3w	$\tilde{g}\tilde{g}$	$\tilde{g} \to q\bar{q}\tilde{\chi}^0_1$	Single Lepton + Jets
		$\tilde{g} \to q\bar{q}\tilde{\chi}^\pm, \tilde{\chi}^\pm \to W^\pm\tilde{\chi}^0_1$	
T5lnu	$\tilde{g}\tilde{g}$	$\tilde{g} \to q\bar{q}\tilde{\chi}^\pm, \tilde{\chi}^\pm \to \ell\nu\tilde{\chi}^0_1$	Same-Sign Dileptons
T3lh	$\tilde{g}\tilde{g}$	$\tilde{g} \to q\bar{q}\tilde{\chi}^0_1$	Opposite-Sign Dileptons
		$\tilde{g} \to q\bar{q}\tilde{\chi}^0_2, \tilde{\chi}^0_2 \to \ell^+\ell^-\tilde{\chi}^0_1$	
T1bbbb	$\tilde{g}\tilde{g}$	$\tilde{g} \to b\bar{b}\tilde{\chi}^0_1$	All-Hadronic (b)
T1tttt	$\tilde{g}\tilde{g}$	$\tilde{g} \to t\bar{t}\tilde{\chi}^0_1$	All-Hadronic (b)
			Single Lepton + Jets (b)
			Same-Sign Dileptons (b)
			Inclusive (b)
T2bb	$\tilde{b}\,\tilde{b}^*$	$\tilde{b} \to b\tilde{\chi}^0_1$	All-Hadronic (b)
T6ttww	$\tilde{b}\,\tilde{b}^*$	$\tilde{b} \to t\tilde{\chi}^-, \tilde{\chi}^- \to W^-\tilde{\chi}^0_1$	Same-Sign Dileptons (b)
T2tt	$\tilde{t}\,\tilde{t}^*$	$\tilde{t} \to t\tilde{\chi}^0_1$	All-Hadronic (b)
TChiSlepSlep	$\tilde{\chi}^\pm\tilde{\chi}^0_2$	$\tilde{\chi}^0_2 \to \ell^\pm\tilde{\ell}^\mp, \tilde{\ell} \to \ell\tilde{\chi}^0_1$	Multileptons
		$\tilde{\chi}^\pm \to \nu\tilde{\ell}^\pm, \tilde{\ell}^\pm \to \ell^\pm\tilde{\chi}^0_1$	
TChiwz	$\tilde{\chi}^\pm\tilde{\chi}^0_2$	$\tilde{\chi}^\pm \to W^\pm\tilde{\chi}^0_1, \tilde{\chi}^0_2 \to Z\tilde{\chi}^0_1$	Multileptons
TChizz	$\tilde{\chi}^0_2\tilde{\chi}^0_3$	$\tilde{\chi}^0_2, \tilde{\chi}^0_3 \to Z\tilde{\chi}^0_1$	Multileptons
T5gg	$\tilde{g}\,\tilde{g}$	$\tilde{g} \to q\bar{q}\tilde{\chi}^0_2, \tilde{\chi}^0_2 \to \gamma\tilde{\chi}^0_1$	Photons
T5wg	$\tilde{g}\,\tilde{g}$	$\tilde{g} \to q\bar{q}\tilde{\chi}^0_2, \tilde{\chi}^0_2 \to \gamma\tilde{\chi}^0_1$	Photons
		$\tilde{g} \to q\bar{q}\tilde{\chi}^\pm, \tilde{\chi}^\pm \to W^\pm\tilde{\chi}^0_1$	

CMS-SUS-11-016

Simplified Models

→ more in Benjamin's & Sezen's presentation

Established tool, very useful in communicating results (caveats!)

Used extensively in Susy searches, how about non-susy BSM?

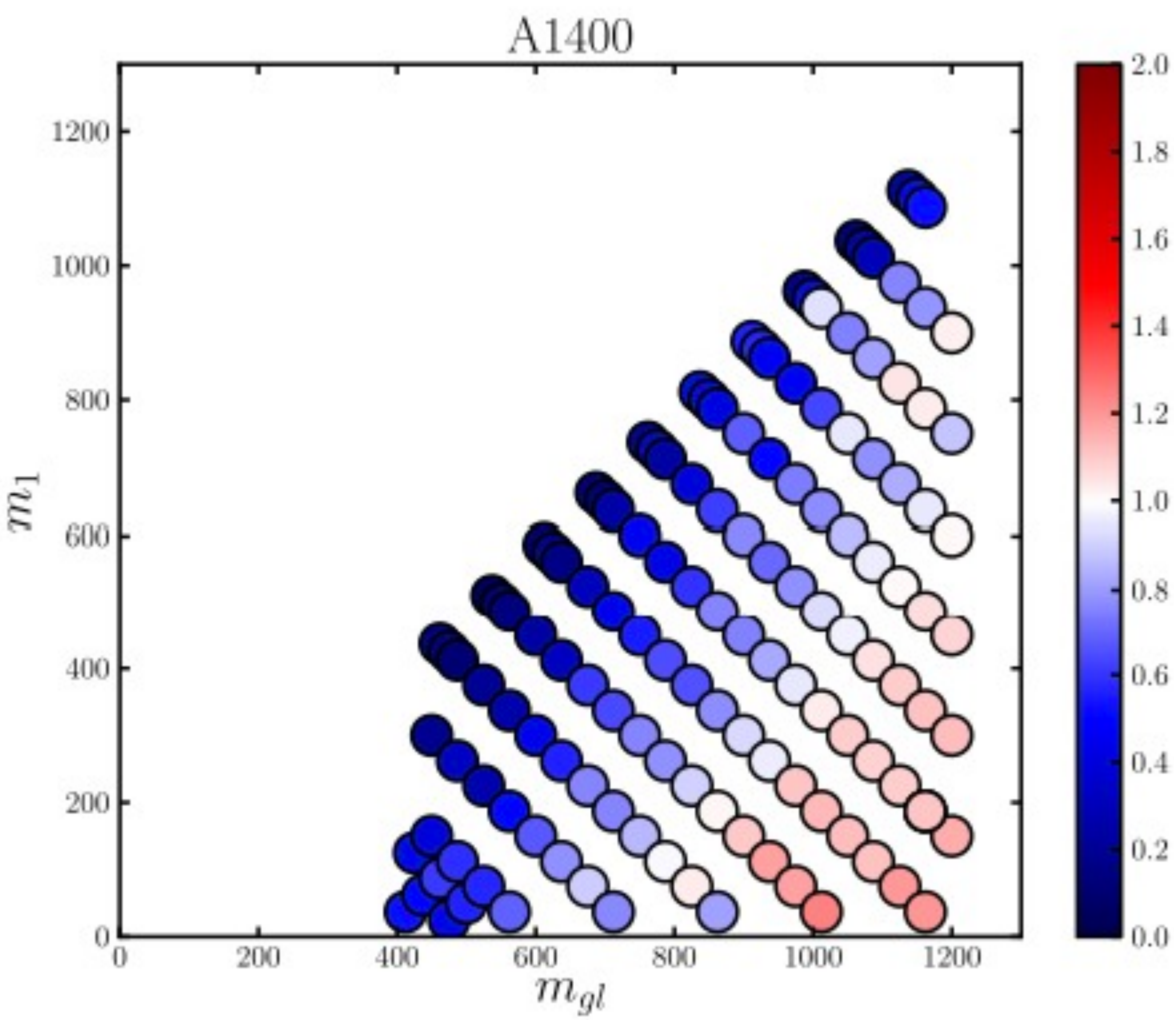
Definition of the models should be as precise as possible, including MC parameters, slha files, etc.

Importance of the MC

with K. Sakurai, M. Papucci, L. Zeune

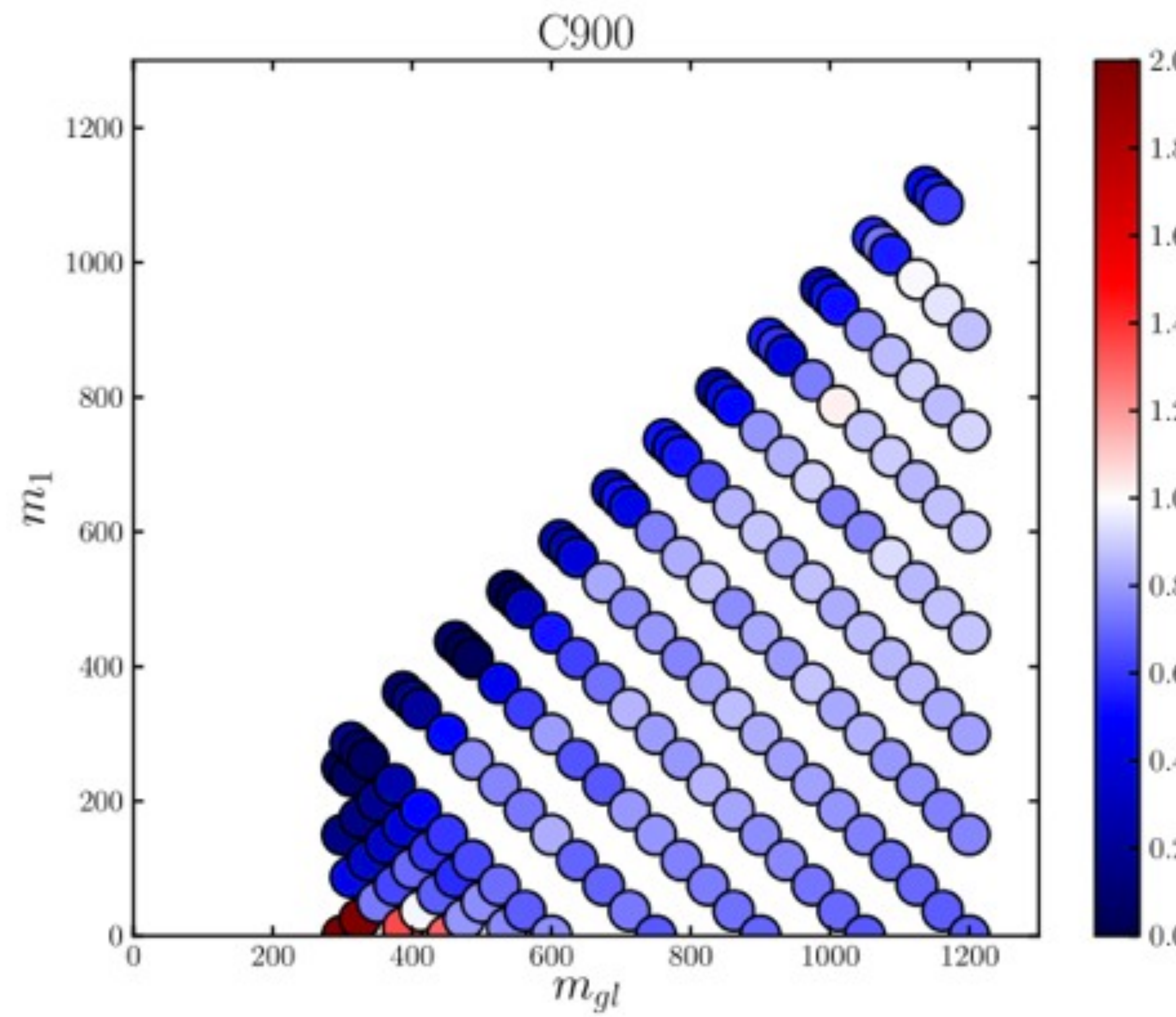
Recast of efficiencies in gluino SiMo

unmatched



very bad close to deg. region

with ME/PS matching



~ 20% agreement

Simplified Models

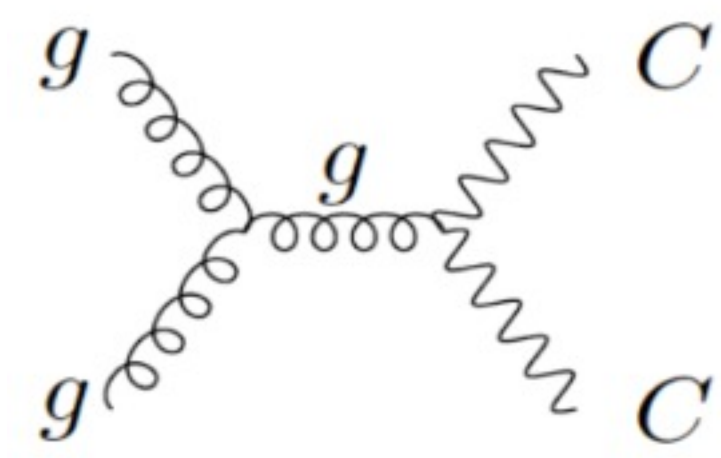
→ more in Benjamin's & Sezen's presentation

Is the coverage sufficient? Missing SMS's ?

Can we close the loop (take SMS limits and apply to full models)? Get information on missing models, low sensitivity spectra?

Simplified models in non-susy searches

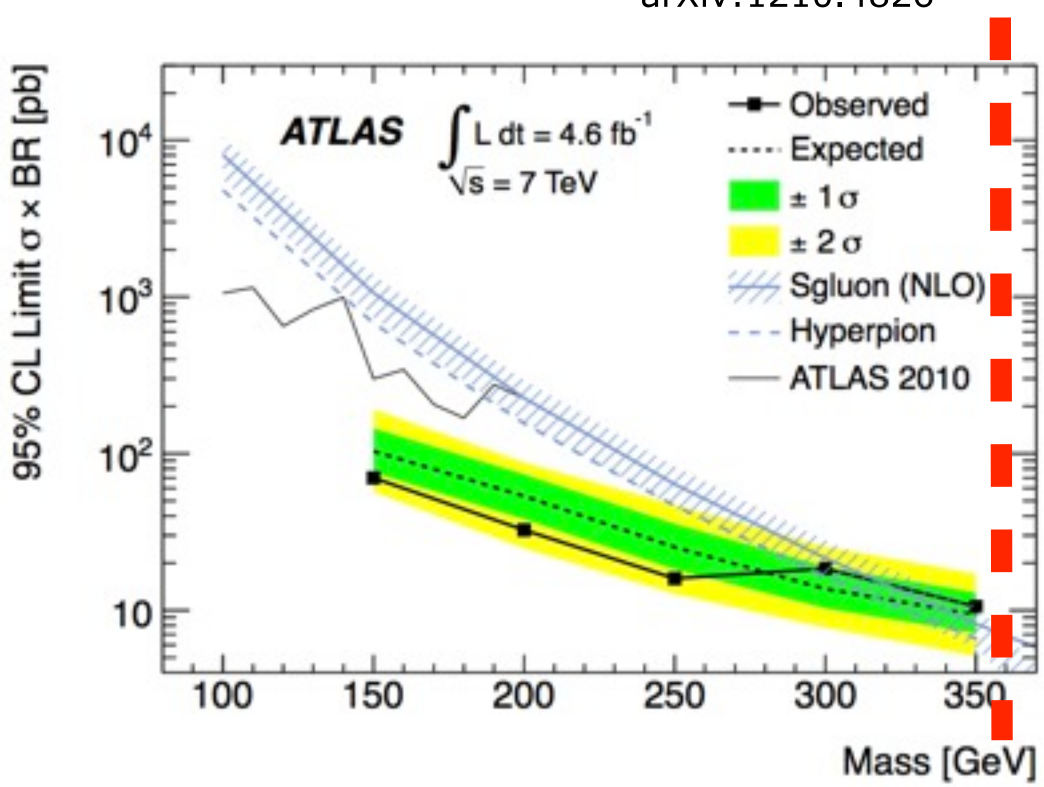
Example: double dijet resonance search



with **C → jj**

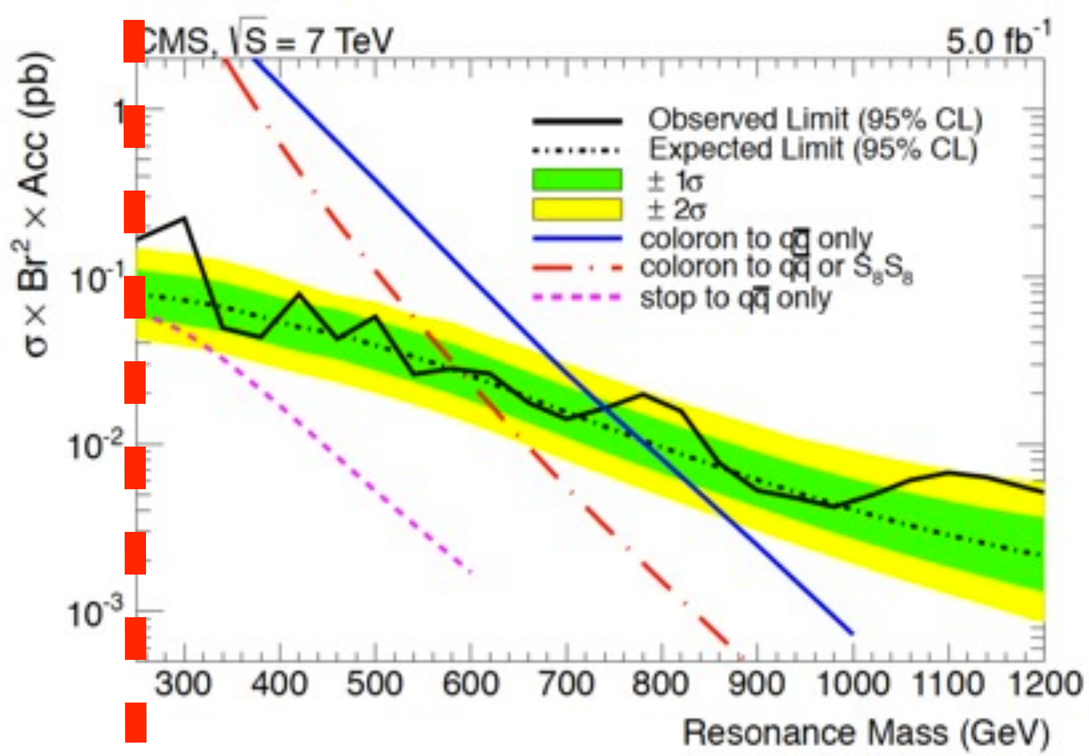
Model assumptions drive the studied region …

arXiv:1210.4826



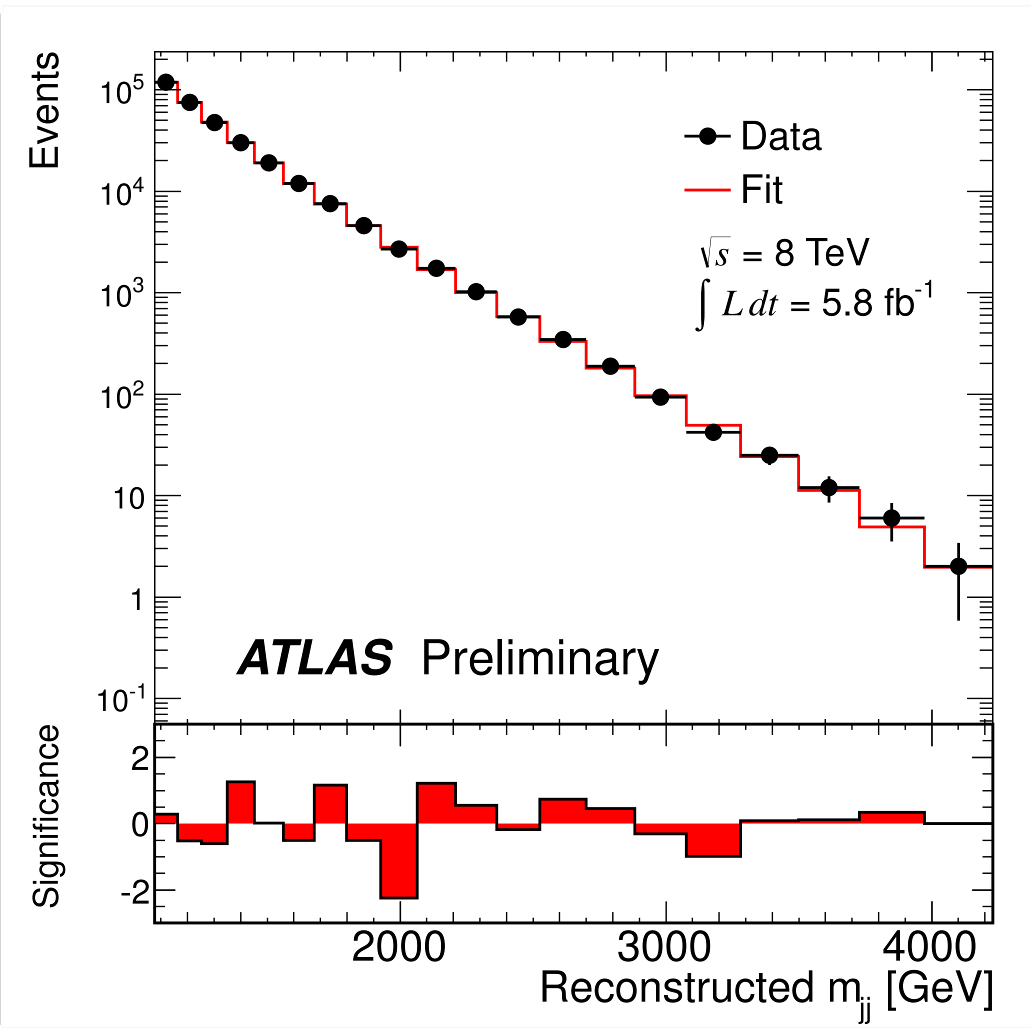
stops at 350 GeV!

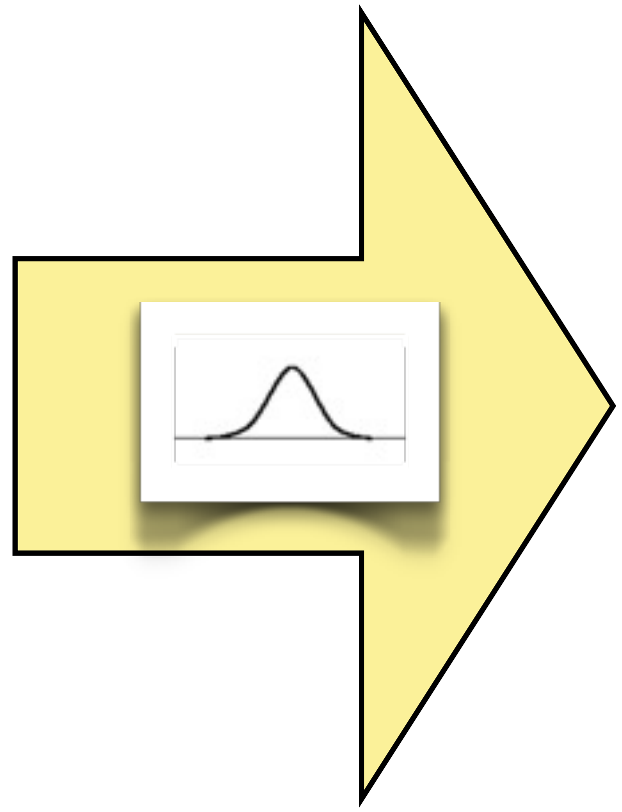
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO11016



starts at ~300 GeV

Dijet resonance search





m_G (GeV)	σ_G/m_G 7%	10%	15%
1500	0.12	0.16	0.16
1550	0.10	0.12	0.13
1600	0.088	0.10	0.11
1650	0.079	0.096	0.094
1700	0.074	0.083	0.089
1750	0.064	0.067	0.069
1800	0.057	0.057	0.066
1850	0.047	0.047	0.059
1900	0.037	0.042	0.055
1950	0.031	0.038	0.053
2000	0.029	0.036	0.048
2100	0.030	0.037	0.046
2200	0.030	0.033	0.039
2300	0.028	0.032	0.033
2400	0.024	0.027	0.029
2500	0.020	0.024	0.023
2600	0.018	0.020	0.019
2700	0.015	0.016	0.015
2800	0.013	0.013	0.012
2900	0.010	0.010	0.010
3000	0.007	0.008	0.009
3200	0.004	0.005	0.006
3400	0.004	0.004	0.004
3600	0.003	0.003	0.003
3800	0.002	0.002	0.002
4000	0.002	0.002	0.002

95% CL upper limit on $\sigma \times \mathcal{A}$ [pb] for the Gaussian model

http://cds.cern.ch/record/1460400/files/ATLAS-CONF-2012-088.pdf

Simple to recast…

1. Run MC of your model, get geometric acceptance
2. Cut around resonance: $0.8\,m < m_{jj} < 1.2\,m$
3. Extract acceptance, look up $\sigma_{95} = \sigma_{95}(m, \Gamma)$

m_G (GeV)	σ_G/m_G 7%	10%	15%
1500	0.12	0.16	0.16
1550	0.10	0.12	0.13
1600	0.088	0.10	0.11

…

[1305.3818](1305.3818)

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1. Run MC of your model, get geometric acceptance
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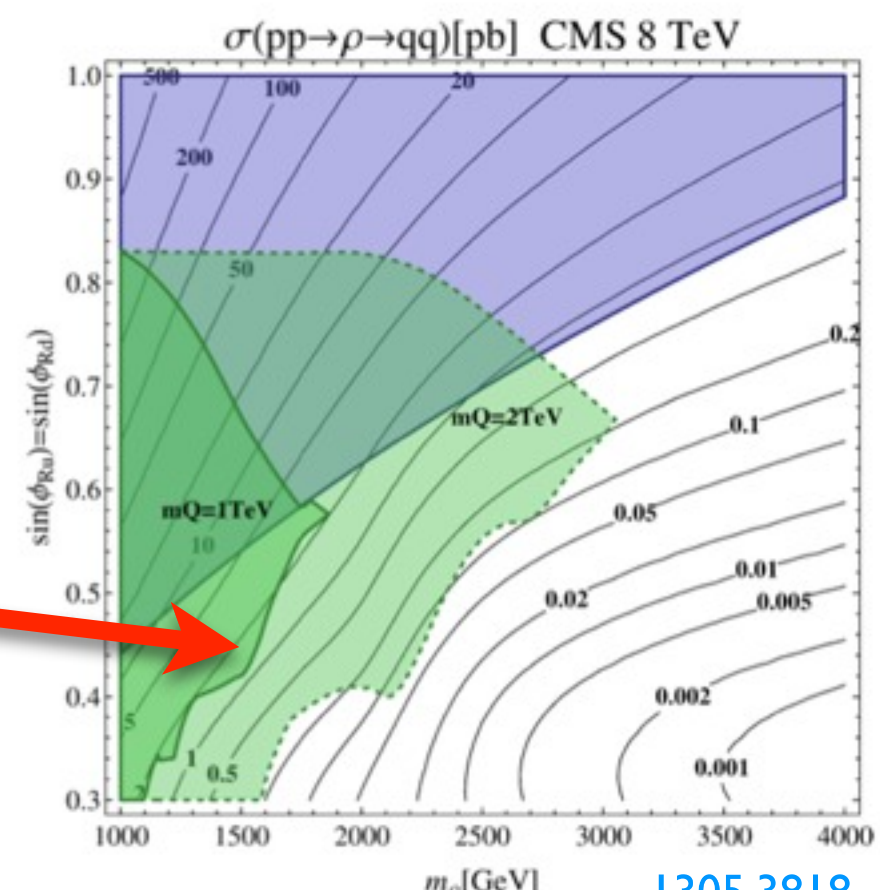
m_G (GeV)	σ_G/m_G 7%	10%	15%
1500	0.12	0.16	0.1[illegible]
1550	0.10	0.12	0.13
1600	0.088	0.10	0.11

…

write a paper!



1305.3818

60% of the time, it works every time.

General Framework for Resonance Searches?

Provide a simplified model ... use spin1 toy ?

Describes resonances in

$$l^+l^-, \, (W^+W^-, \, ZZ, ZW^+), \, t\bar{t}, jj, jjj, \ldots$$

and present results as limit (or excess) x-sec:

$$\sigma_{95} = \sigma_{95}(m, \Gamma)$$

Model-independent, easy to recast, very general!

Possible discussions here:

Experimental issues? Can the dijet approach straightforwardly extended?

Theoretical issues? Does it map onto the most interesting models? Can the specific resonance model be important?

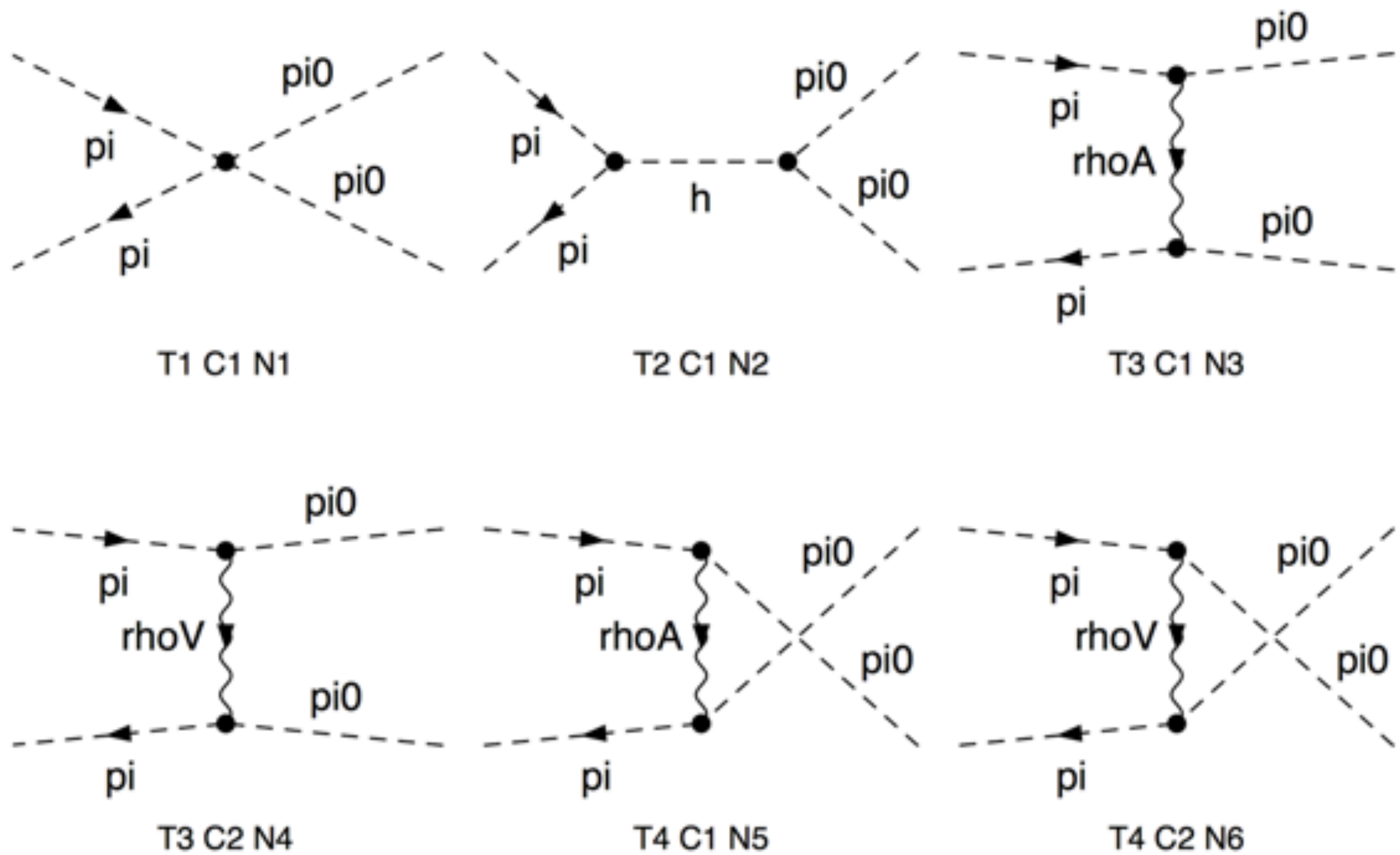
Provide a MC implementation?

Top partner simplified models

- Stop simplified models (beyond $\tilde{t}_1 \to t\tilde{\chi}_0$, polariz’)
- Fermionic top partner simplified models? Status of the searches? Single prod’? Boosted search at LHC14?

Spin 1 resonances

Strong EWSB and spin 1



$$W_L W_L \to W_L W_L$$

DY prod' of SO(5)/SO(4) spin 1 resonances

DY a bit more model-dependent

Attempt a classification, cast in simplified model

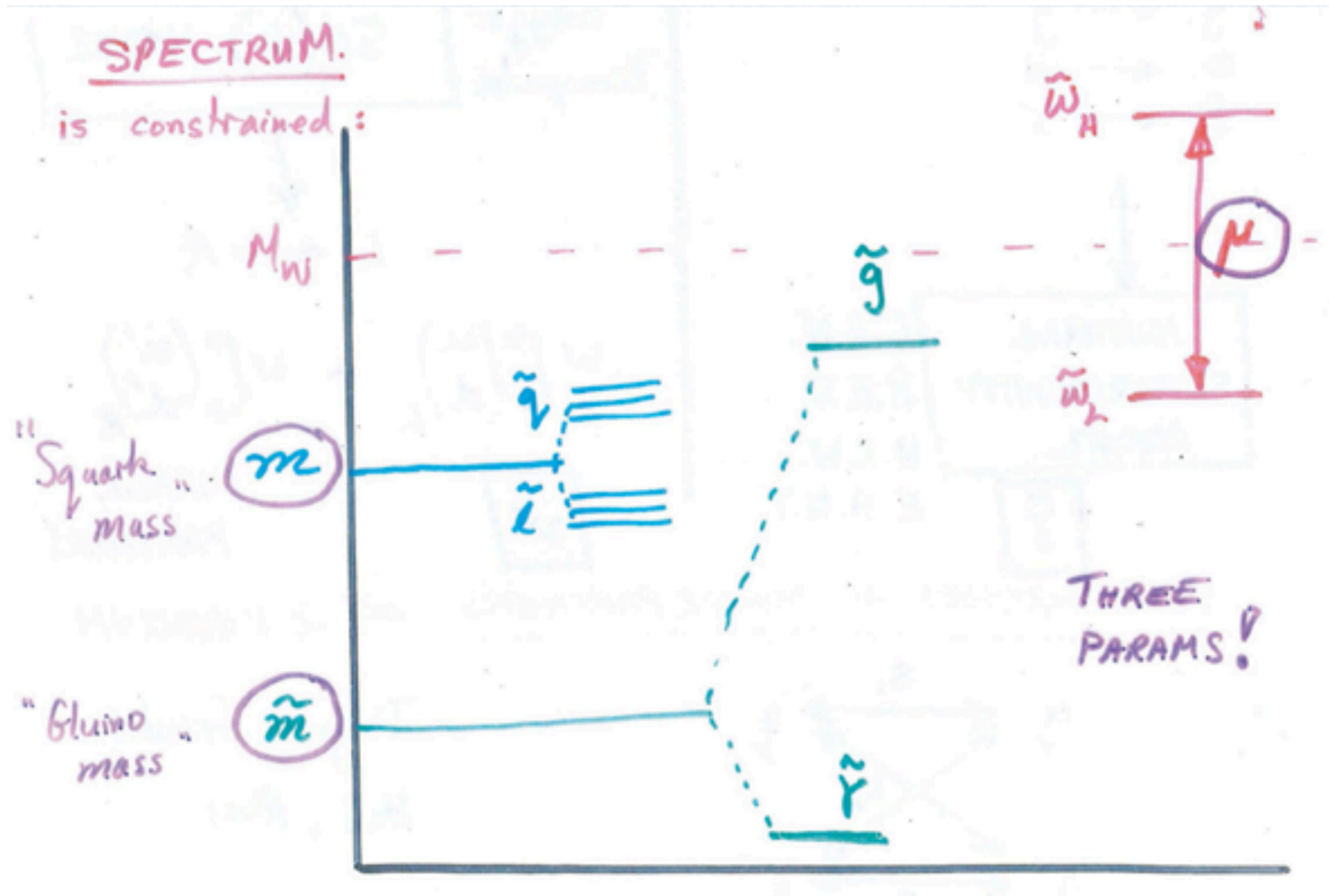
Minimal coupling to 1st/2nd gen' fermions $\sim g/g_\rho$
3rd generation coupling might be different

Decay to Vh, VV, tt, tb

Generic searches?

All of our ideas might be wrong…

Exhibit 1:
Susy expectation
ca. 1984



M_W

L.Hall GGI '12

All of our ideas might be wrong…

Exhibit 2:
Imagine a world in which your favorite model hasn't been thought of yet (susy?)…

$\exists$ Useful way to do a model-independent search?

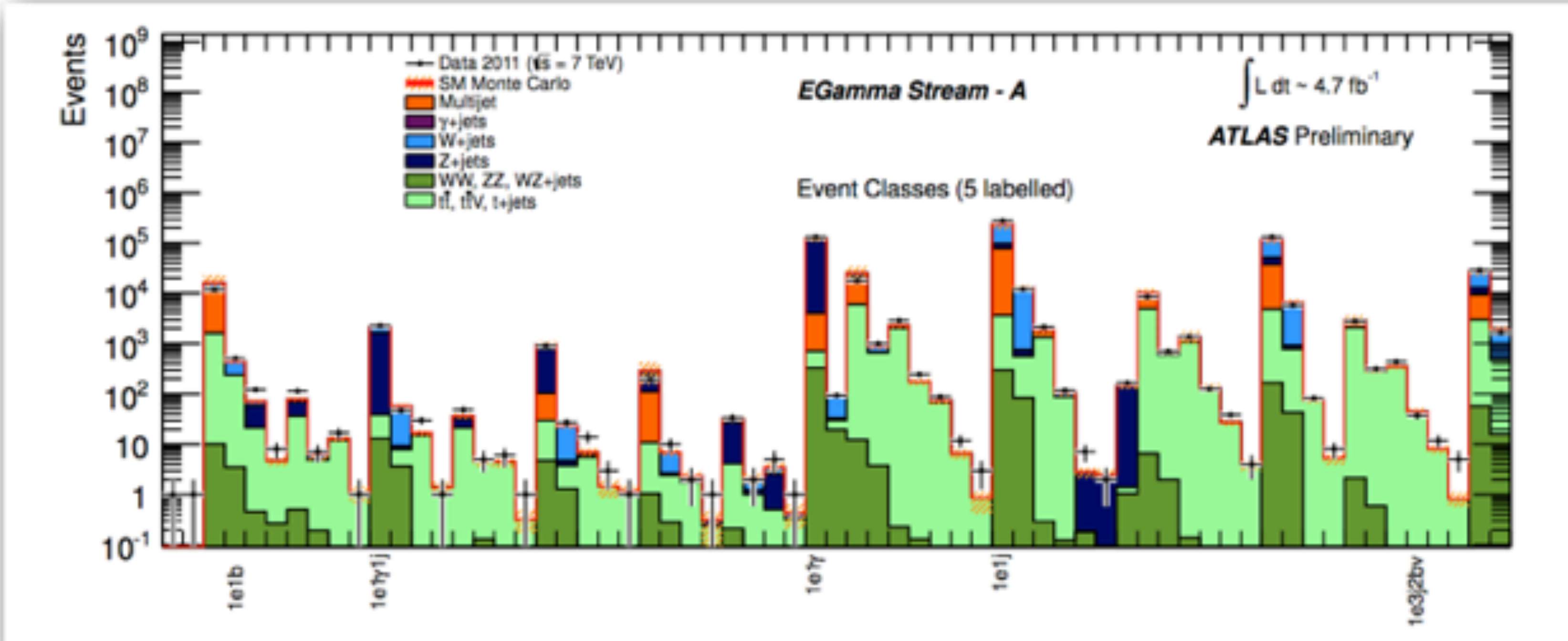
Model-independent generic search

- Look for an excess in the entire dataset !
  - Not optimized for a specific signal, no complicated reconstruction
  - Background estimates not as accurate
  - Large trial factor, the larger the number of SR the likely it is to have statistical fluctuation (decrease sensitivity.
- Doesn't replace dedicated search, can trigger them
- 655 exclusive channels, as a function of number of jets, b-jets, electrons, muons, photons, MET

object	jet	b-jet	electron	muon	photon	E_T^{miss}
label	j	b	e	μ	γ	ν
lower p_T cut	50 GeV	50 GeV	25 GeV	20 GeV	40 GeV	130 GeV

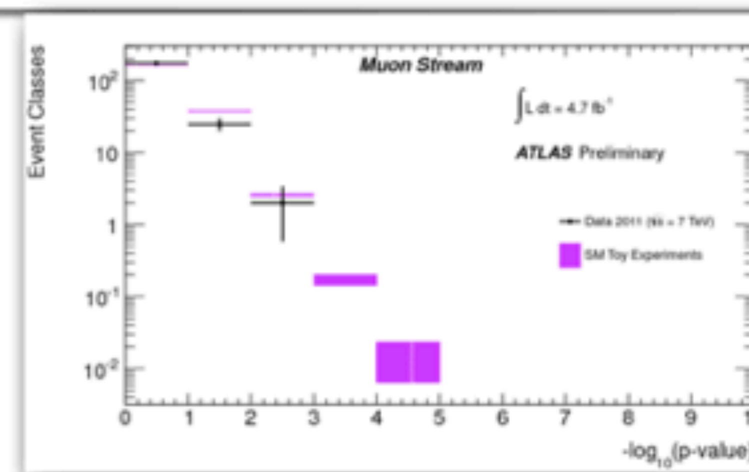
- BG - MC estimated, conservative Xsect uncertainty

Model-independent generic search



- **Using lowest unprescaled trigger in the e/gamma, muon and jet/MET/tau streams**
- **Quantify an excess: compute SR p-value= prob that BG fluctuates > observed # of events. Toy MC estimate LEE**

No excess in the three search regions
A clear demonstration of our MC precision



LHC14 preparations
boosted objects?
other issues?

WE NEED YOU!

From the wiki:

New Physics

BSM physics in the context of a ~125 GeV Higgs boson

Higgs bosons

- Additional Higgses
- Composite Higgs
- Higgs in NP decay chains

The third generation

- New physics producing tops: classify according to the number of final state top quarks?
- Stop and sbottom searches

Vector-like fermions

Soft BSM at LHC

- Compressed spectra

"Effective New Physics" and a 125 GeV Higgs

- Effective lagrangian (also see session 1?), but how to treat resonances?
- Simplified model approach beyond SUSY

A 125 GeV Higgs and Dark Matter

- Higgs decays into light neutralinos

Simplified model for a heavy spin-1 resonance with EW quantum numbers (rho)

- MC implementation
- derive current exclusion limits

Simplified models in the SUSY context

- SModleS development
- Improving SMS interpretations
- Wishlist for the presentation of SMS results
- see dedicated SMS page

Reinterpreting New Physics Searches / Presentation of Results

2011 Les Houches recommendations for the presentation of LHC search results

Another (lazy) phenomenologist's wishlist

Reinterpreting SUSY searches with non-minimal flavor violation

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Stops and Sbottoms

Interested people: Dipan, Genevieve, Rohini, Sabine, Suchita, Benjamin, Sophio Pataraia…

Stops from gluino production: 4 top final state

Exploiting top polarization

Boosted tops at LHC13

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Simplified models in the SUSY context

Interested people: Suchita, Wolfgang, Sabine ....

Contact person: Suchita

Improving SMS interpretations of SUSY searches

Wishlist for the presentation of SMS results

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