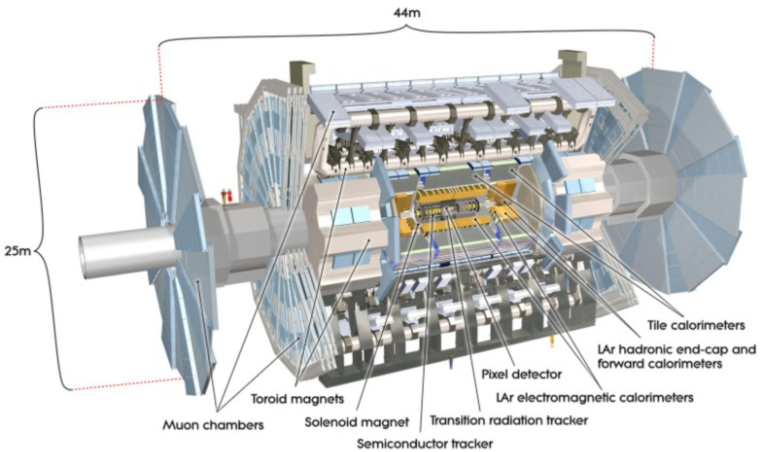
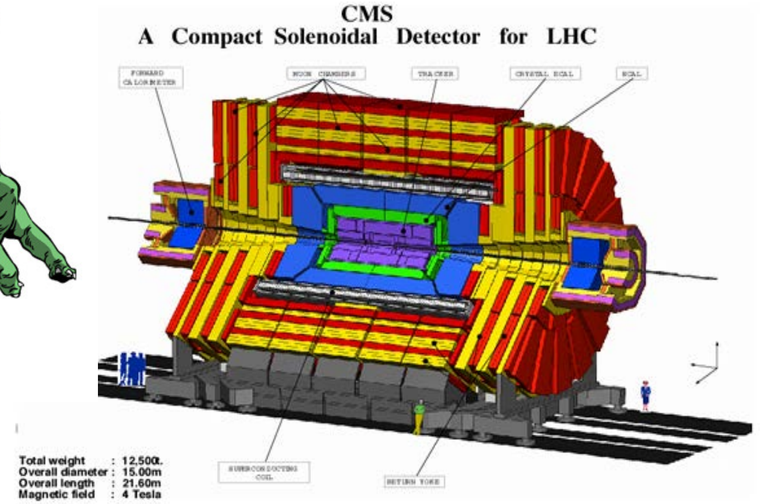
Higgs & SUSY Searches in the pMSSM @ the LHC





1206.4321, 1206.5800 & in preparation 9/13/12

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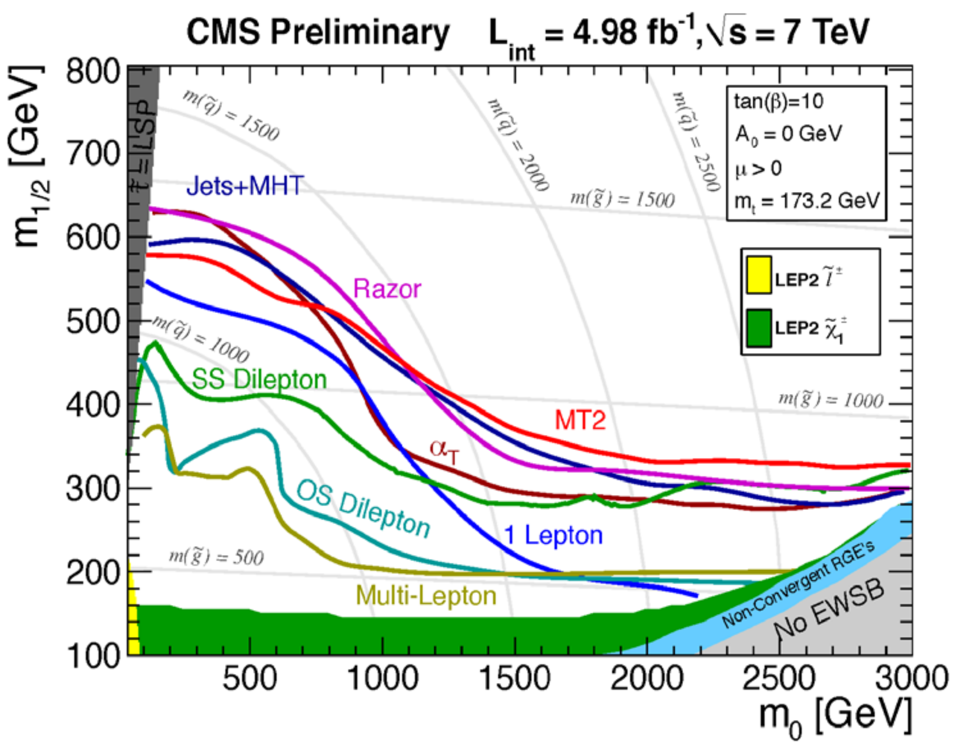
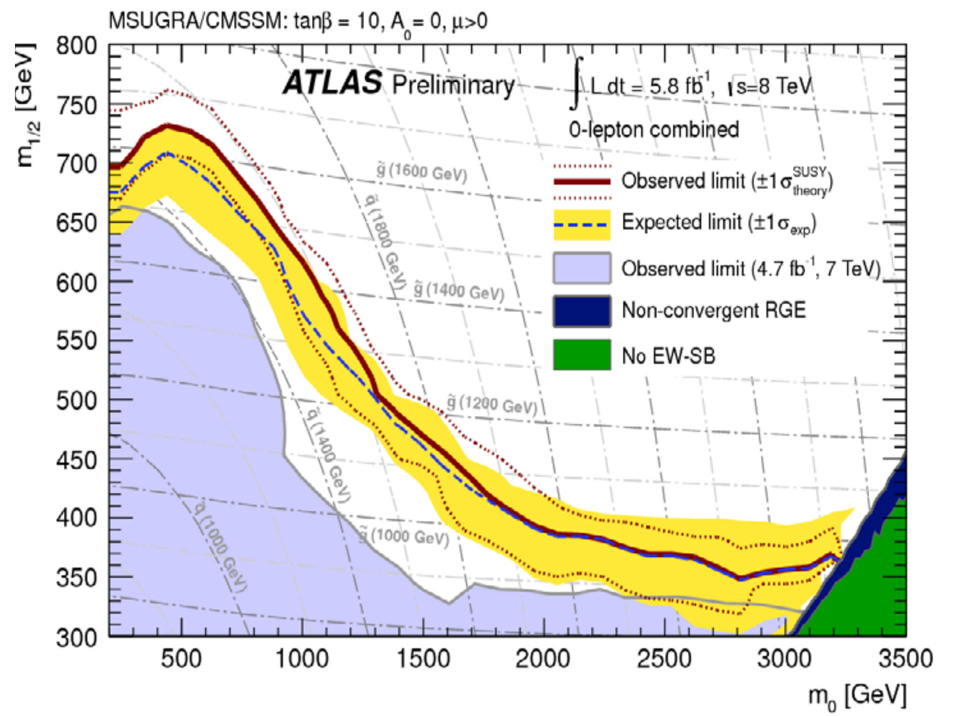
Searches for SUSY @ the LHC have not found any signals (yet)…

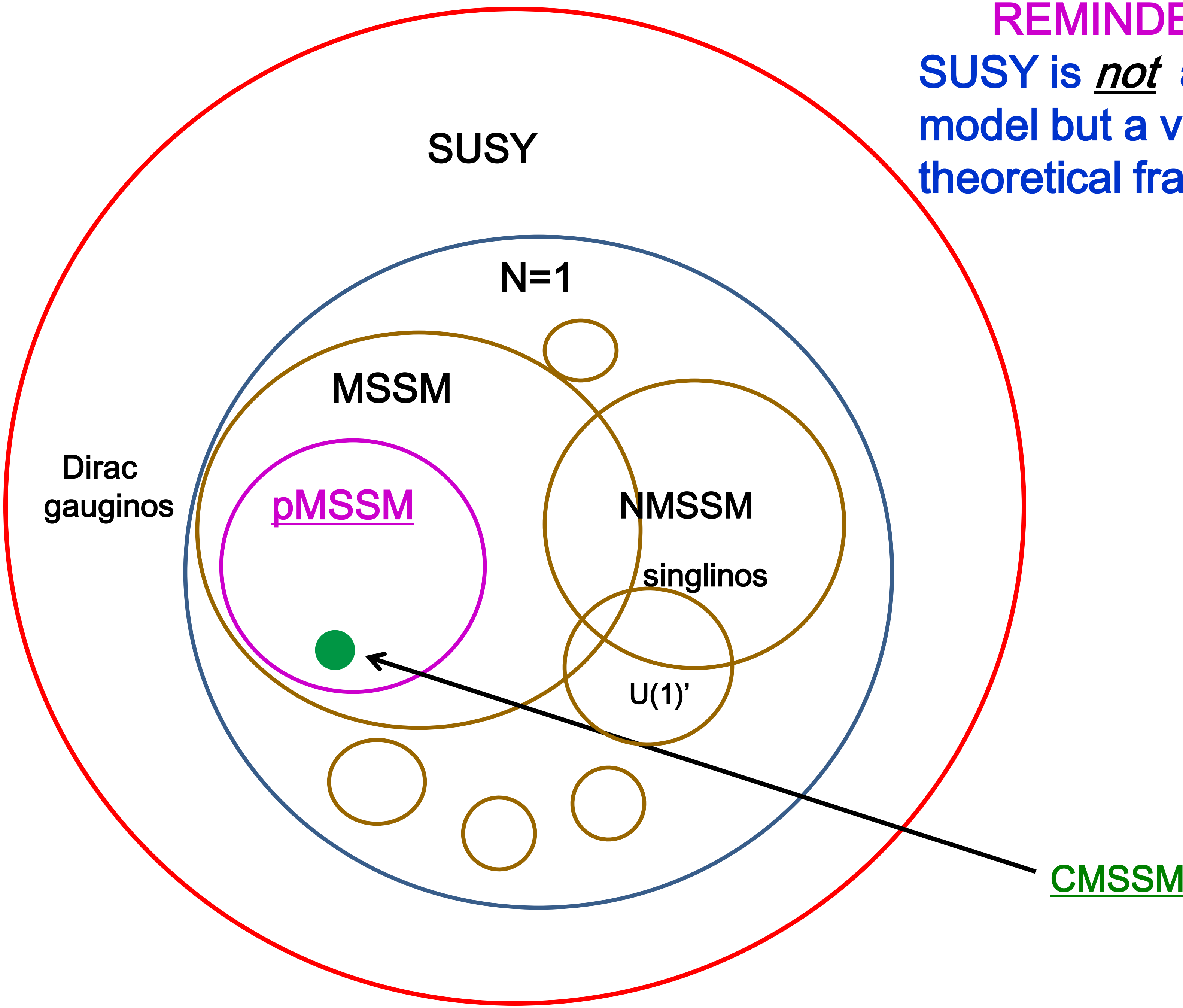
It would seem useful to go beyond the cMSSM or any particular SUSY breaking scheme to study the MSSM more generally but without giving up the correlations among experimental observables





REMINDER:

SUSY is *not* a single model but a very large theoretical framework



Our Approach: The p(henomenological)MSSM

The MSSM has too many parameters so we make assumptions to reduce these to a reasonable level

- The most general, CP-conserving MSSM with R-parity
- Minimal Flavor Violation at the TeV scale (the CKM controls flavor)
- The lightest neutralino or the gravitino is the LSP.
- The first two sfermion generations are degenerate
  (sfermion type by sfermion type).
- The first two generations have negligible Yukawa's.
- No assumptions about SUSY-breaking or GUT

→ the pMSSM with 19/20 real, TeV/weak-scale parameters…

Choose the ranges of these parameters & how they're selected

Scan: look for ~250k points in these spaces satisfying all existing data
& study their signatures @ the LHC & elsewhere.. NO FITS!

pMSSM Scans: Neutralino & Gravitino LSPs

(via SOFTSUSY +SuSpect + FeynHiggs)

$100\ \text{GeV} \leq m_{Le1,3} \leq 4\ \text{TeV}$

$400\ \text{GeV} \leq m_{Qud1} \leq 4\ \text{TeV}$ $200\ \text{GeV} \leq m_{Qud3} \leq 4\ \text{TeV}$

$50\ \text{GeV} \leq |M_1| \leq 4\ \text{TeV}$ $100\ \text{GeV} \leq |M_2, \mu| \leq 4\ \text{TeV}$

$400\ \text{GeV} \leq M_3 \leq 4\ \text{TeV}$ $|A_{t,b,\tau}| \leq 4\ \text{TeV}$

$100\ \text{GeV} \leq M_A \leq 4\ \text{TeV}$ (Flat scan)

$1 \leq \tan\beta \leq 60$

→→ For the gravitino LSP: $1\ \text{eV} \leq m_G \leq 1\ \text{TeV}$ (log scan)

- Generate points & then apply all the usual non-LHC + all LHC non-MET constraints (as of 12/1/2011) . Additional ones apply, eg, BBN , for the gravitino LSP case

Some Constraints

- $\Delta\rho$ / W-mass
- $b \to s\,\gamma$
- $\Delta(g-2)_\mu$
- $\Gamma(Z \to \text{invisible})$
- Meson-Antimeson Mixing
- $B \to \tau\nu$
- $B_s \to \mu\mu$

- Direct Detection of Dark Matter (SI & SD)
- WMAP Dark Matter density upper bound
- LEP and Tevatron Direct Higgs & SUSY searches
- LHC stable sparticle searches

- BBN energy deposition for gravitinos
- Relic ν's & diffuse photon bounds

- No tachyons or color/charge breaking minima
- Stable vacua only

Let's investigate the other side of life: gravitino LSPs

- pMSSM models w/ gravitino LSPs have never been studied
- NOT generalized GMSB.. NO assumptions except that the gravitino is the LSP. Anybody can be the NLSP.
- BBN… NLSPs in this scenario tend to be long lived & decays inject hadronic &/or EM energy, possibly disrupting BBN
- Lots of NEW code needed, e.g., generalize all NLSP/NNLSP decays to the case of arbitrary gravitino mass .. Existing codes inadequate !

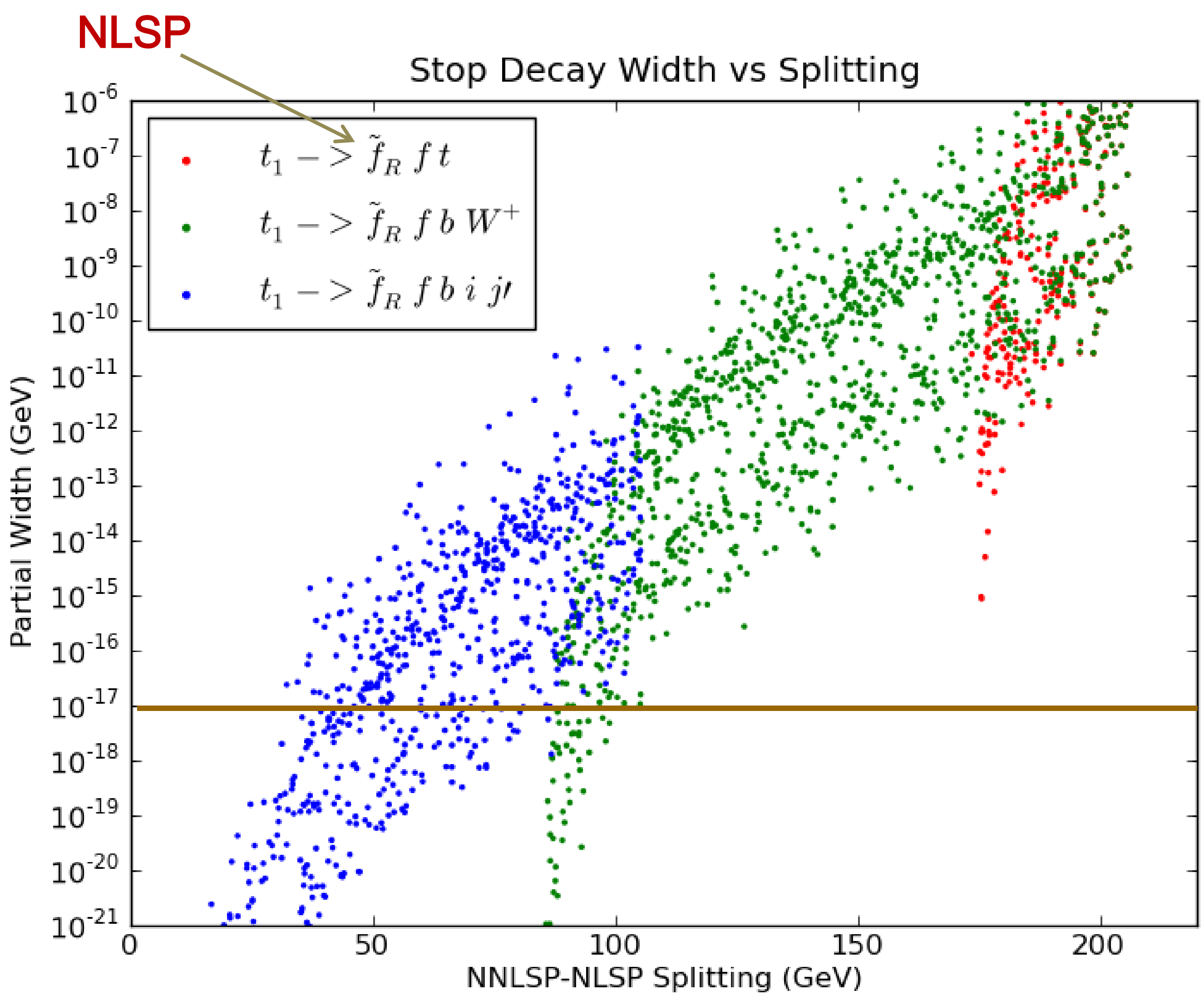
Some New Features

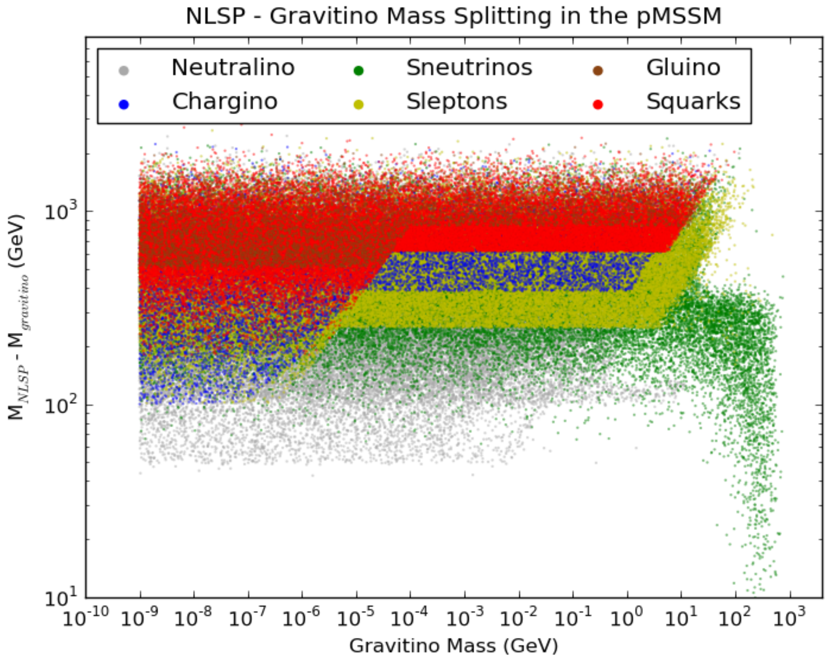
- For non-G decays (e.g., for the NNLSP → NLSP) add all 3-body sparticle decays not in SUSY-Hit via CalcHEP
- Add relevant 4 & 5-body decays for gluinos, t_1 & $\chi_1^{\pm}$

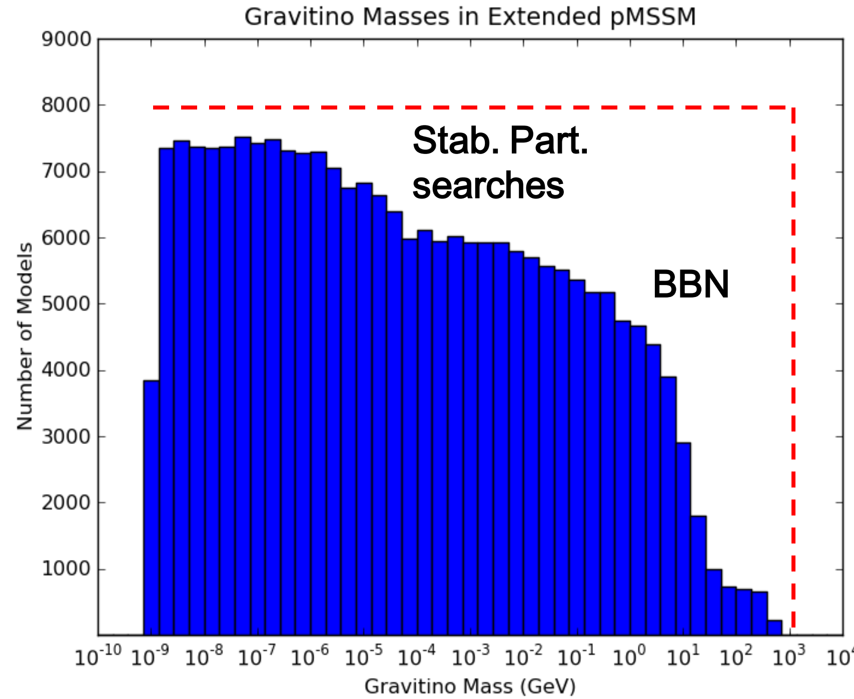
→ RESULT: NNLSPs can also be detector stable

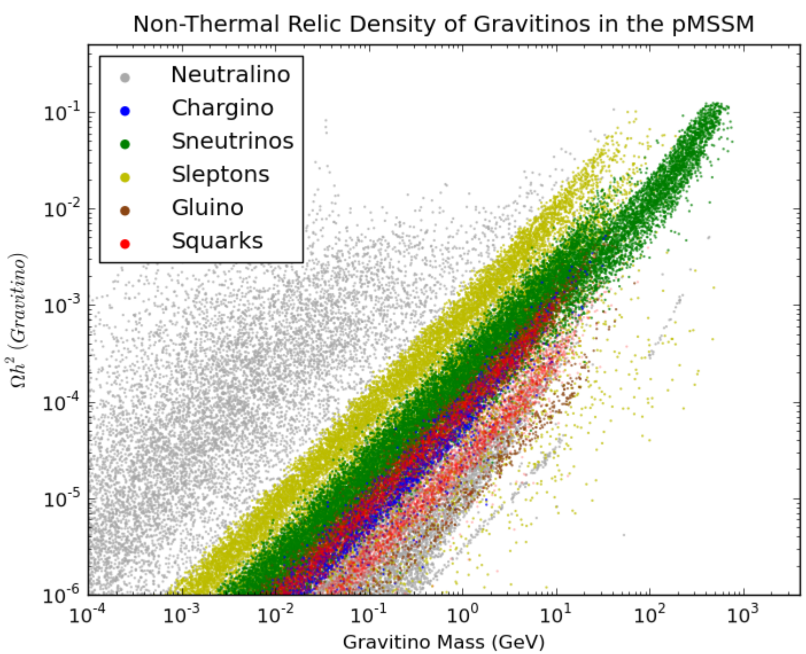
- For NLSP decays to G, add all 3- & 4-body modes w/ BBN relevant lifetimes (~10^{-4} to 10^{14} sec) via MadGraph
- Calculate NLSP density using Micromegas & rescale to the gravitino mass
- Use lifetime & BF info for NLSPs from modified SUSY-Hit & check the constraints on EM or hadronic energy deposition during BBN
- Apply constraints from the cosmo relic ν & diffuse photon fluxes

E.g., even if t_1 is the NNLSP it may STILL be detector stable



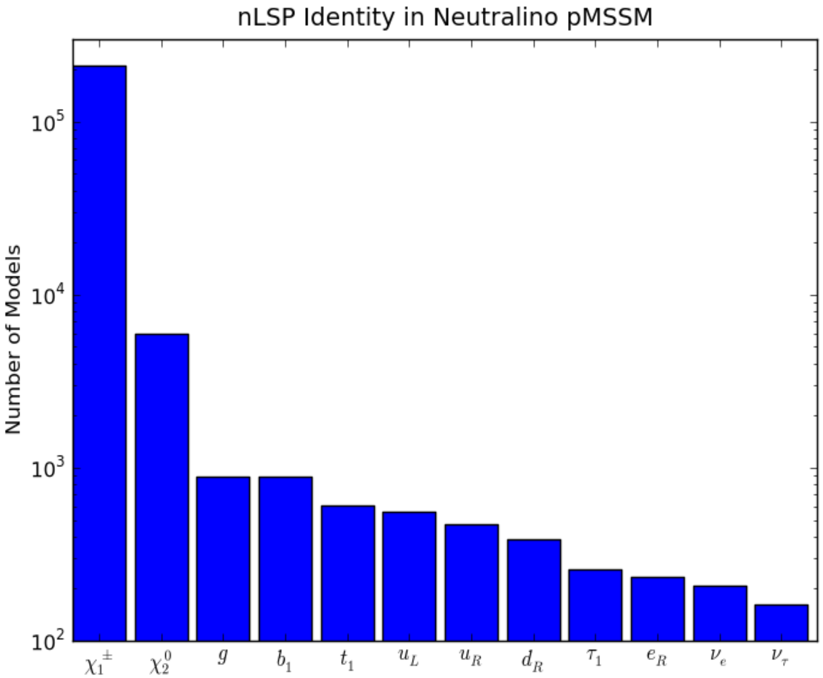


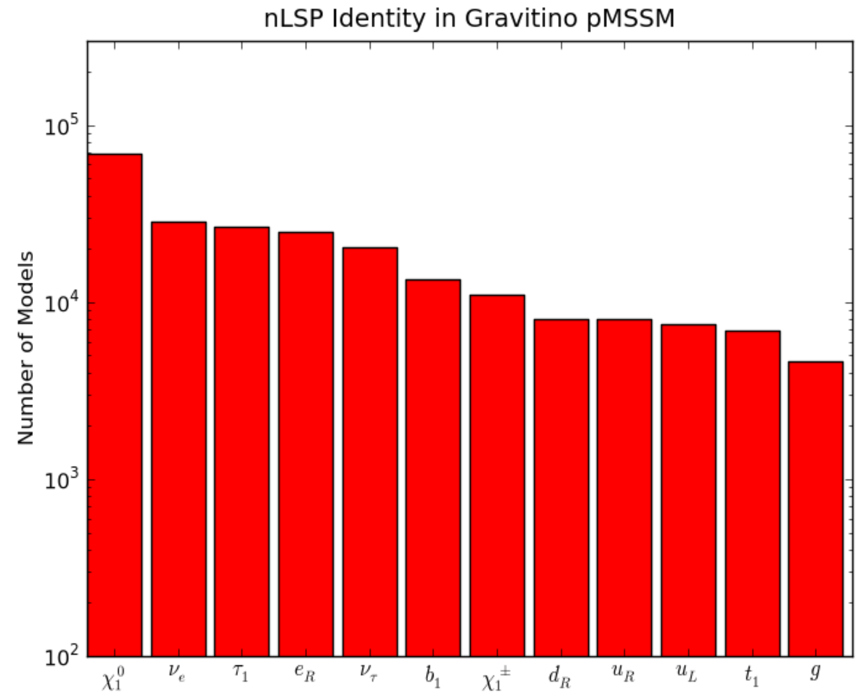




Some properties of the gravitino LSP models

At first glance gravitino LSP models appear to be a bit different that the neutralino LSP ones… A comparison is quite interesting.





- The frequency of various NLSP identities is very strongly dependent on the LSP choice
- This can have a potentially large influence on LHC SUSY searches (apart from, e.g., additional cascades)

Electroweak Content of χ_1^0

Lightest Neutralino	Definition	Neutralino LSP	Gravitino LSP
Bino	$\|N_{11}\|^2 > 0.95$	0.024	0.313
Mostly Bino	$0.80 < \|N_{11}\|^2 < 0.95$	0.002	0.012
Wino	$\|N_{12}\|^2 > 0.95$	0.546	0.296
Mostly Wino	$0.80 < \|N_{12}\|^2 < 0.95$	0.022	0.019
Higgsino	$\|N_{13}\|^2 + \|N_{14}\|^2 > 0.95$	0.340	0.296
Mostly Higgsino	$0.80 < \|N_{13}\|^2 + \|N_{14}\|^2 < 0.95$	0.029	0.029
All other models	$\|N_{11}\|^2, \|N_{12}\|^2, \|N_{13}\|^2 + \|N_{14}\|^2 < 0.80$	0.036	0.035

With most of the neutralino parameters ~ 1 TeV the mass & electroweak eigenstates are generally quite close !

ATLAS SUSY Analyses @ 7 & 8 TeV

- The first step is to apply the general SUSY MET searches to our χ set

- We (almost) exclusively follow the ATLAS analysis suite as closely as possible with fast MC (modified PGS/Pythia)

- 1 & 5 fb $^{-1}$ @7 TeV: this was 'straightforward' as numerous benchmark model results exist that we used to test/validate against.

- We combine the various analyses signal regions (as ATLAS does) into : nj0l, multi-j, nj1l, nj2l and we quote the coverage for each as well as the combined result.. This approach is CPU intensive

% models excluded

	7 TeV ~1 fb^{-1}	7 TeV ~5 fb^{-1}
nj0l [5/11]	6.68%	23.23%
multi-j [4/6]	0.36%	1.61%
nj1l [8/3]	0.81%	2.64%
nj2l [5]	0.16%	0.22%***
(sub)total	6.73%	23.28%

→ nj0l is by far dominant in these searches

*** At the time, we extrapolated to ~5 fb^{-1}. We assumed that the number of events observed equals the expected backgrounds & that the analysis cuts are exactly the same as at ~1 fb^{-1}

Now there is 8 TeV data since SUSY2012:

8 TeV 5.8 fb^{-1} **

	without m_h cut	with m_h cut
nj0l [12]	26.30%	23.41%
multi-j [6]	3.27%	2.76%
nj1l [1]	3.26%	2.94%
nj2l (SS) [1]	4.83%	4.32%
total	26.67%	23.73%

(125±2 GeV only)

..out of the subset of models passing the Higgs mass constraint

The Higgs mass cut doesn't change things too much but there is a minor degradation

** The corresponding analyses are

2012 Data (8 TeV)

Short Title of the CONF note	Date	√s (TeV)	L (fb^{-1})	Document	Plots
0 leptons + >=2-6 jets + Etmiss NEW	08/2012	8	5.8	ATLAS-CONF-2012-109	Link
0 leptons + >=6-9 jets + Etmiss NEW	08/2012	8	5.8	ATLAS-CONF-2012-103	Link
1 lepton + >=4 jets + Etmiss NEW	08/2012	8	5.8	ATLAS-CONF-2012-104	Link
2 same-sign leptons + >=4 jets + Etmiss NEW	08/2012	8	5.8	ATLAS-CONF-2012-105	Link

Comments

- Interestingly, 1.48% of the model set that SURVIVED the 8 TeV analysis were ALREADY KILLED by the 7 TeV one! Combining 7 & 8 TeV analyses kills 28.15% of all models

Here is a valuable lesson !

- It is likely that some reasonable fraction of SUSY points will get 'by-passed' as the LHC collision energy increases due to their inability to pass stiffer selection cuts

- It certainly helps to combine analyses performed at various energies but this is no guarantee of complete coverage

Extrapolating:

8 TeV & 25 fb^{-1}

	without m_h cut
nj0l [12]	25.22%
multi-j [6]	3.60%
nj1l [1]	3.78%
nj2l (SS) [1]	7.38%
total	25.93%

Assuming identical analyses

- Note that the most important nj0l analysis takes a hit when we compare w/ the lower lumi result !
- ATLAS saw fewer events than expected in nj0lw/ 5.8 fb^{-1}. BUT we have to conservatively assume that the number of events seen equals the background values when we extrapolate
- Thus: small changes in both S & B can make substantial changes in the extrapolated pMSSM coverage

Third Generation & Multi-lepton searches @ 7 TeV

- There are a huge number of searches (see next slide) & we have tried to simulate ALL of the ones that are relevant for our model sets
- We expect these searches to be complimentary to the more general MET searches
- To incorporate these searches required modifications to PGS to more precisely reflect the ATLAS b-tagging performance
- Unfortunately, PGS does not 'do well' for τ's (low efficiency & high mis-tag rates) so we had to omit these searches
- These & other results are PRELIMINARY !

2011 Data (7 TeV)

Short Title of the Paper	Date	√s (TeV)	L (fb^{-1})	Document	Plots+Aux. Material	Journal
1-2 leptons + >=2-4 jets + Etmiss NEW ✓	08/2012	7	4.7	1208.4688	Link	Submitted to PRD
2 leptons + >=1 jet + Etmiss [Very light stop] NEW ✓	08/2012	7	4.7	1208.4305	Link	Submitted to EPJC
3 leptons + Etmiss [Direct gauginos] NEW ✓	08/2012	7	4.7	1208.3144	Link	Submitted to PLB
2 leptons + Etmiss [Direct gauginos/sleptons] NEW ✓	08/2012	7	4.7	1208.2884	Link	Submitted to PLB
1 lepton + >=4 jets (>=1 b-jet) + Etmiss [Heavy stop] NEW ✓	08/2012	7	4.7	1208.2590	Link	Submitted to PRL
0 lepton + 1-2 b-jet + 5-4 jets + Etmiss [Heavy stop] NEW ✓	08/2012	7	4.7	1208.1447	Link	Submitted to PRL
~~0 lepton + >=2-6 jets + Etmiss NEW~~	08/2012	7	4.7	1208.0949	Link	Submitted to PRD
0 lepton + >=3 b-jets + >=(1-3) jets + Etmiss [Gluino med. stop/sb.] ✓	07/2012	7	4.7	1207.4686	Link	Submitted to EPJC
~~0 lepton + >=(6-9) jets + Etmiss~~	06/2012	7	4.7	1206.1760	Link	JHEP 1207 (2012) 167
Electron-muon continuum [RPV] X	05/2012	7	2.05	1205.0725	Link (inc. HEPData)	EPJC 72 (2012) 2040
Z->ll + b-jet + jets + Etmiss [Direct stop in natural GMSB] ✓	04/2012	7	2.05	1204.6736	Link (inc. HEPData)	PLB 715 (2012) 44

Short Title of the Conf. note	Date	√s (TeV)	L (fb^{-1})	Document	Plots
1-2 taus + 0-1 leptons + jets + Etmiss NEW X	08/2012	7	4.7	ATLAS-CONF-2012-112	Link
3 leptons + jets + Etmiss NEW ✓	08/2012	7	4.7	ATLAS-CONF-2012-108	Link
2 b-jets + Etmiss [Direct sbottom] NEW ✓	08/2012	7	4.7	ATLAS-CONF-2012-106	Link
muon + displaced vertex [RPV] NEW ✓	08/2012	7	4.7	ATLAS-CONF-2012-113	Link
Disappearing track + jets + Etmiss [Direct long-lived charginos - AMSB] NEW ✓ ✓	08/2012	7	4.7	ATLAS-CONF-2012-111	Link
~~*2-jet pair resonances [N=1/2 scalar gluons]* NEW~~	08/2012	7	4.7	ATLAS-CONF-2012-110	Link
~~*General new phenomena search* NEW~~	08/2012	7	4.7	ATLAS-CONF-2012-107	Link
Monophoton [ADD, WIMP]	07/2012	7	4.7	ATLAS-CONF-2012-085	Link
Monojet [ADD, WIMP]	07/2012	7	4.7	ATLAS-CONF-2012-084	Link
Long-Lived Particles [R-hadron, slepton] ✓	07/2012	7	4.7	ATLAS-CONF-2012-075	Link
2 photons + Etmiss [GGM] ✓	07/2012	7	4.8	ATLAS-CONF-2012-072	Link
2 leptons + jets + Etmiss [Medium stop] ✓	07/2012	7	4.7	ATLAS-CONF-2012-071	Link
1-2 b-jets + 1-2 leptons + jets + Etmiss [Light Stop] X	07/2012	7	4.7	ATLAS-CONF-2012-070	Link

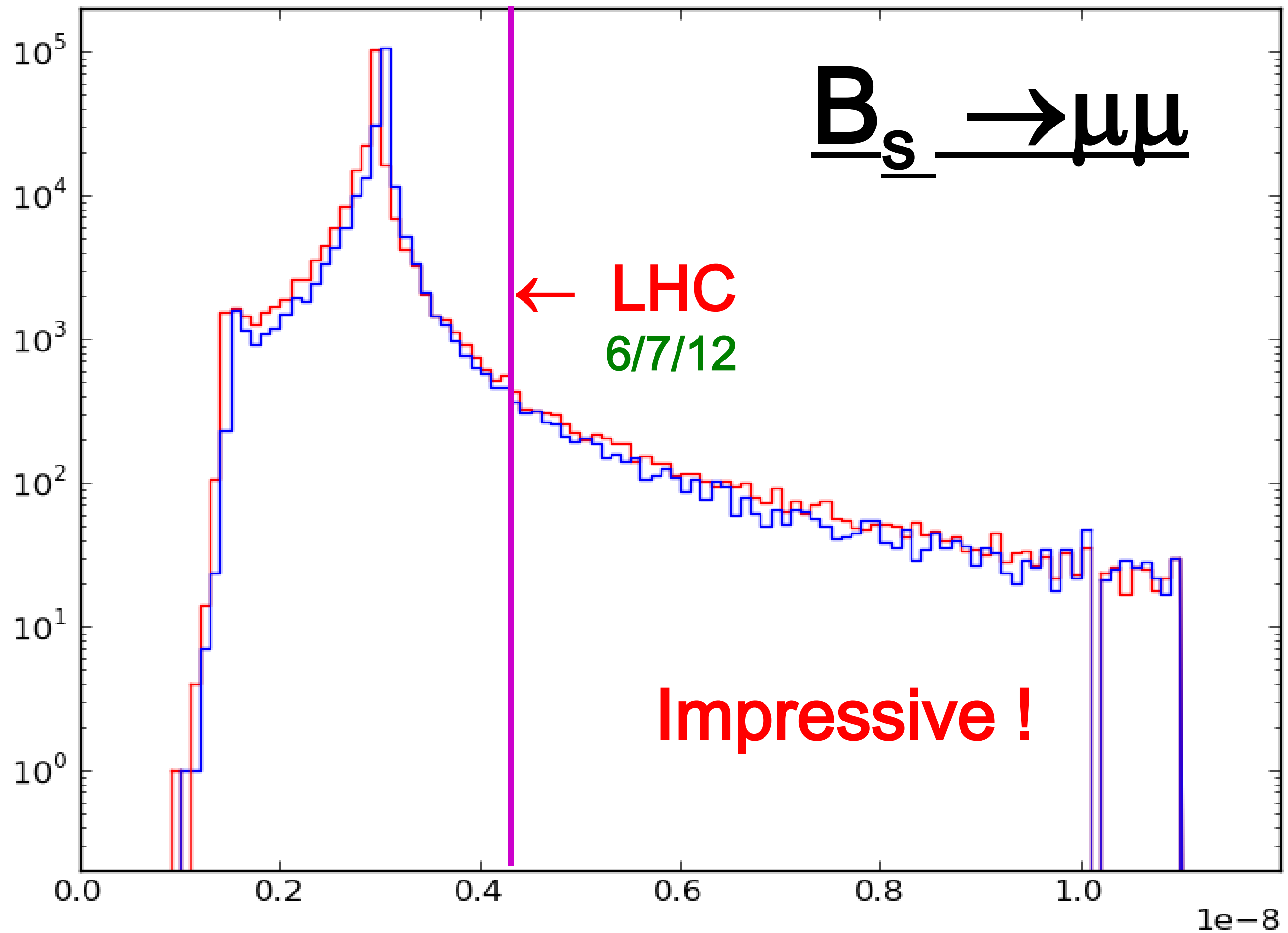
Third Generation & Multi-lepton searches @ 7 TeV

	w/o Higgs cut	w/ Higgs cut
1207.4686	4.89%	4.43%
1208.4305	<0.01%	0
-071	0.32%	0.22%
1208.1447	3.62%	3.02%
1208.2590	1.92%	1.62%
1204.6736	<0.01%	0
-106	2.43%	2.12%
-108	1.04%	0.90%
1208.4688	4.07%	3.48%
1208.2884	0.11%	0.11%
1208.3144	3.32%	2.62%
sub-total	7.93%	6.99%
All Searches	31.87%	31.05%

There are a lot of searches that provide very different coverage of the pMSSM model space

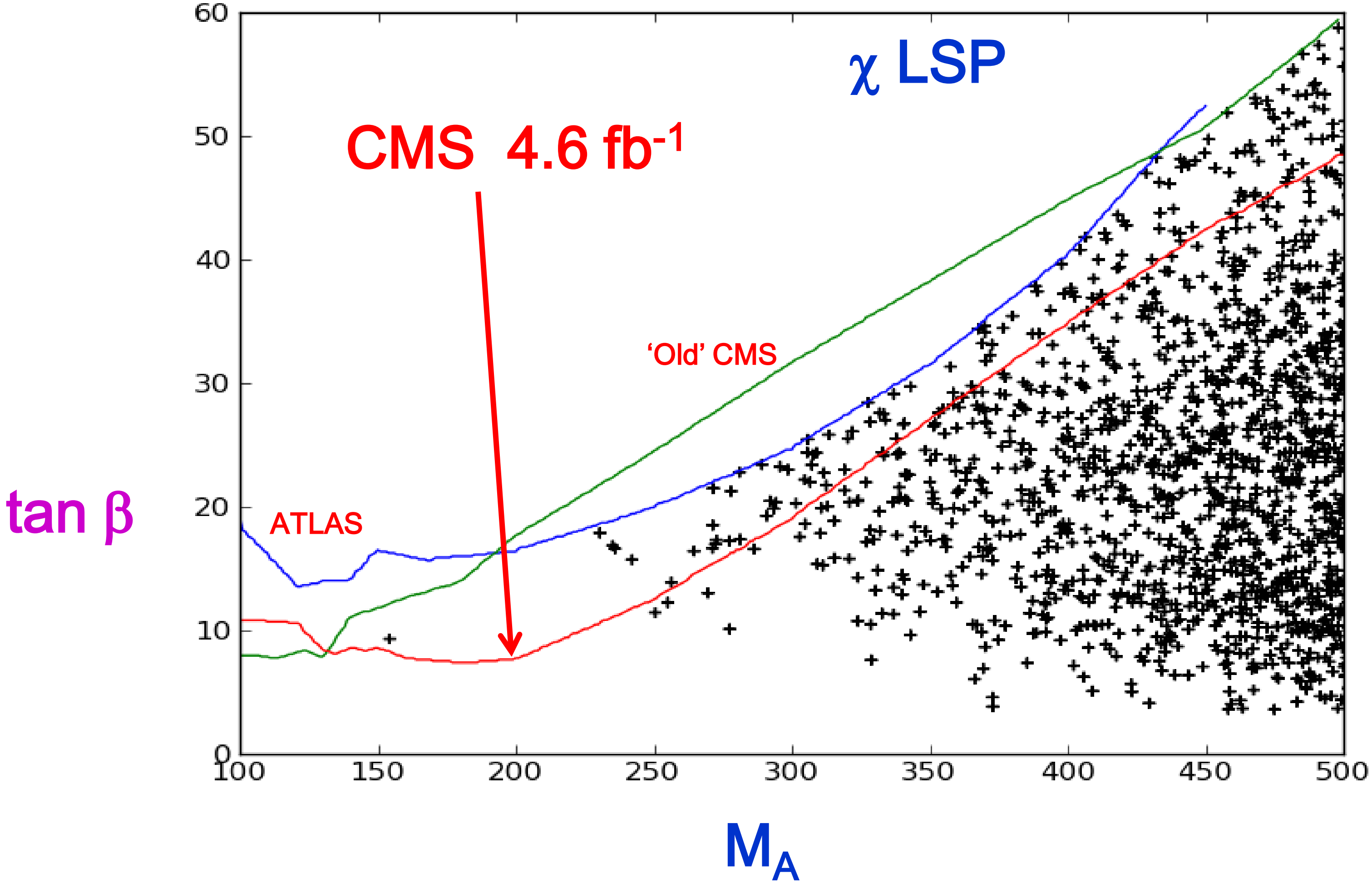
These add substantially to the TOTAL coverage as they are mostly orthogonal to the jet+MET generic searches

Again Higgs mass cuts are not very influential in changing total coverage

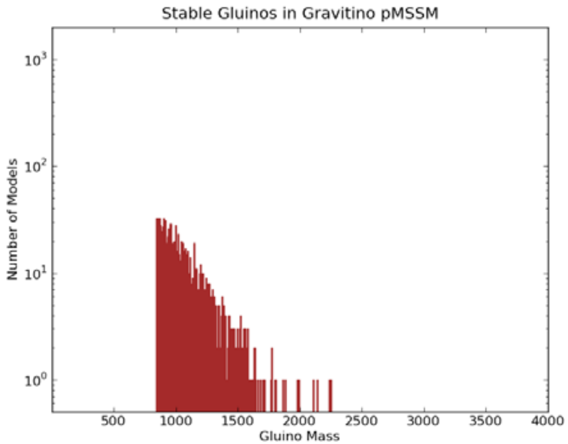


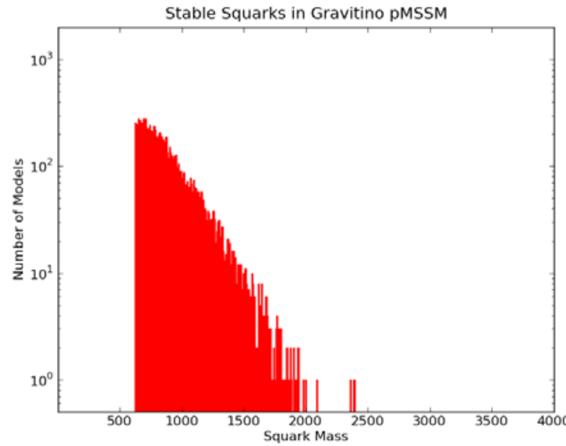
- The LHC result removes a total of 6035 (7147) models in the neutralino (G) LSP model set … The soon to be expected observation of this mode will have a very substantial impact
- non-MET searches REALLY ARE important !

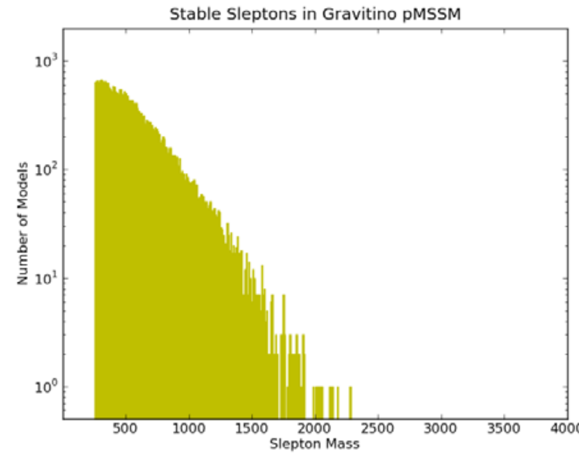
Impact of A,H $\rightarrow\tau\tau$ Searches

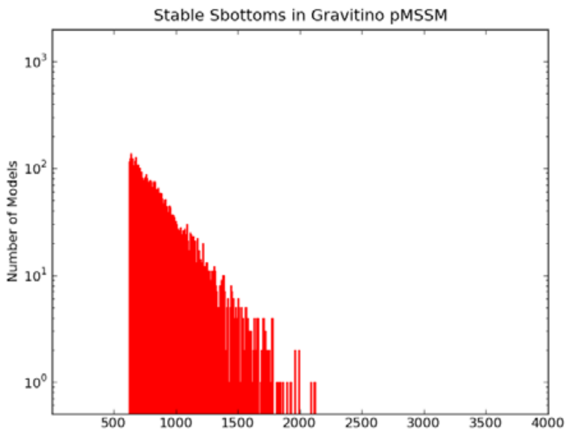


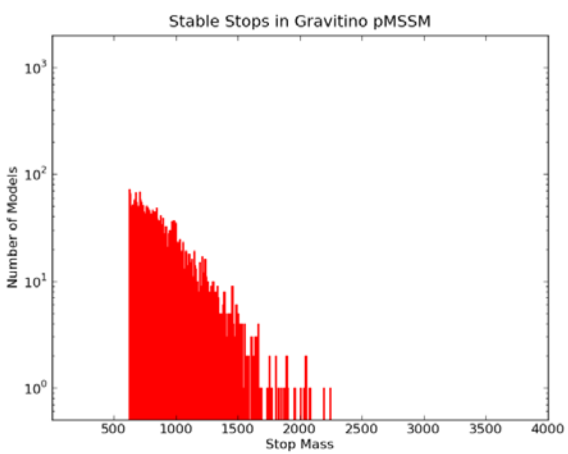
As in the case of $B_s \rightarrow\mu\mu$, improvement in non-MET searches impact the pMSSM analyses… 160(164) models removed from the χ (G) LSP set…

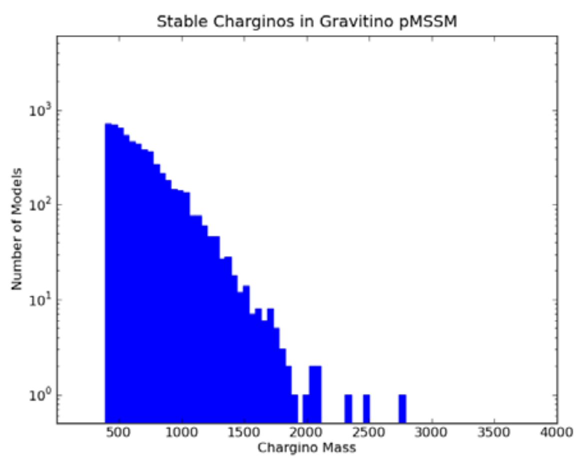












Gravitino LSP scenarios produce many models with detector-stable charged/colored sparticles over a very wide range of masses & species. Stable sparticle searches will then be a powerful means of probing these models. This additional handle will be critical as there will be reduced production of MET in decay chains that can end in HSCP.

Here we employ the CMS HSCP analysis

Gravitino Model Searches @ 7 TeV

	7 TeV ~5 fb^{-1}	with Higgs mass cut	
nj0l [11]	14.46%	13.09%	
multi-j [6]	3.32%	3.07%	
nj1l [3]	5.35%	4.65%	
(sub)total	16.44%	14.73%	Less MET !!!
HSCP	14.34%	12.81%	Clearly Important!!
(sub) total	30.75%	27.32%	

The subset w/ the Higgs mass cut has slightly degraded coverage

The 8 TeV 'jet + MET' search results are not yet available…jobs running now!

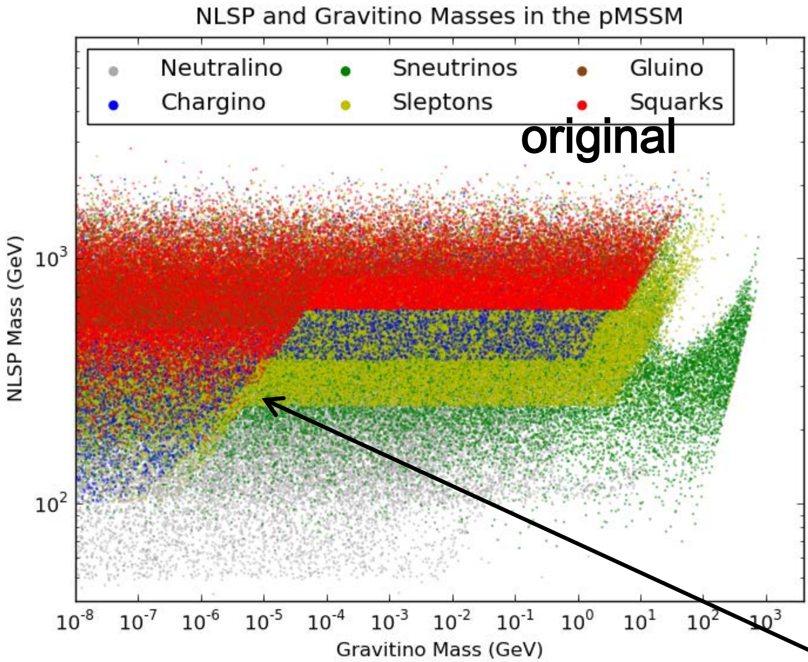
Third Generation & Multi-lepton searches @ 7 TeV

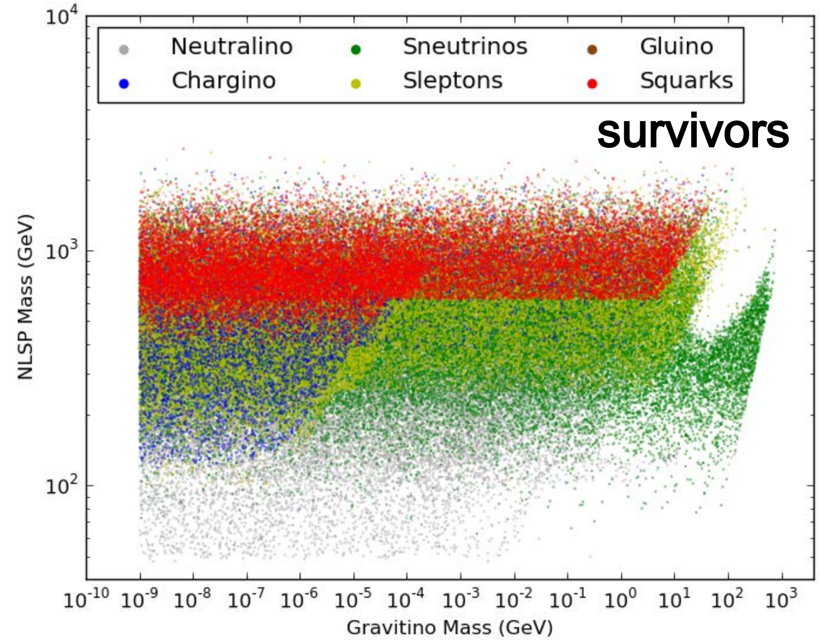
	w/o Higgs cut	w/ Higgs cut
1207.4686	4.57%	4.81%
1208.4305	0.02%	<0.01%
-071	5.29%	4.65%
1208.1447	3.78%	4.32%
1208.2590	2.69%	3.02%
1204.6736	0.12%	0.13%
-106	2.97%	2.98%
-108	7.17%	6.32%
1208.4688	9.93%	8.59%
1208.2884	1.44%	1.24%
1208.3144	6.71%	5.84%
sub-total	18.13%	17.46%
All Searches	38.23%	38.29%

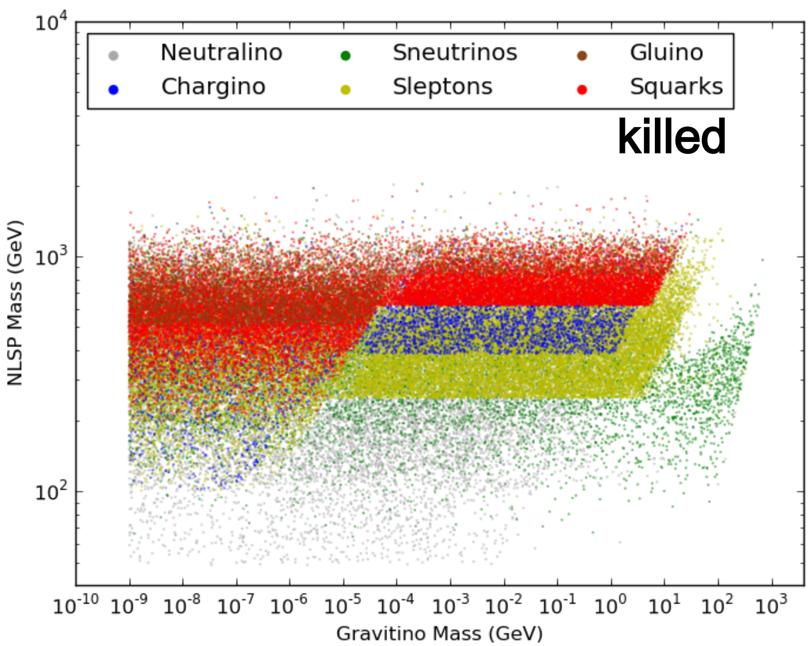
Third generation searches are significantly more effective for the gravitino set.

This is due to several factors including lighter stops and sbottoms & the relatively high frequency of slepton NLSPs producing leptons & MET

Again, OVERALL, there is little difference imposing the Higgs mass cut, but more so in individual searches



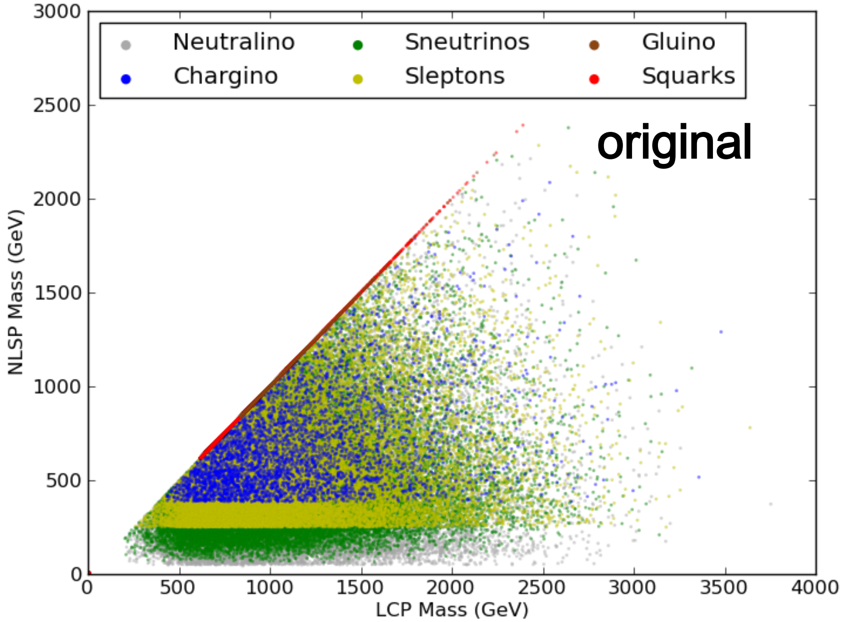


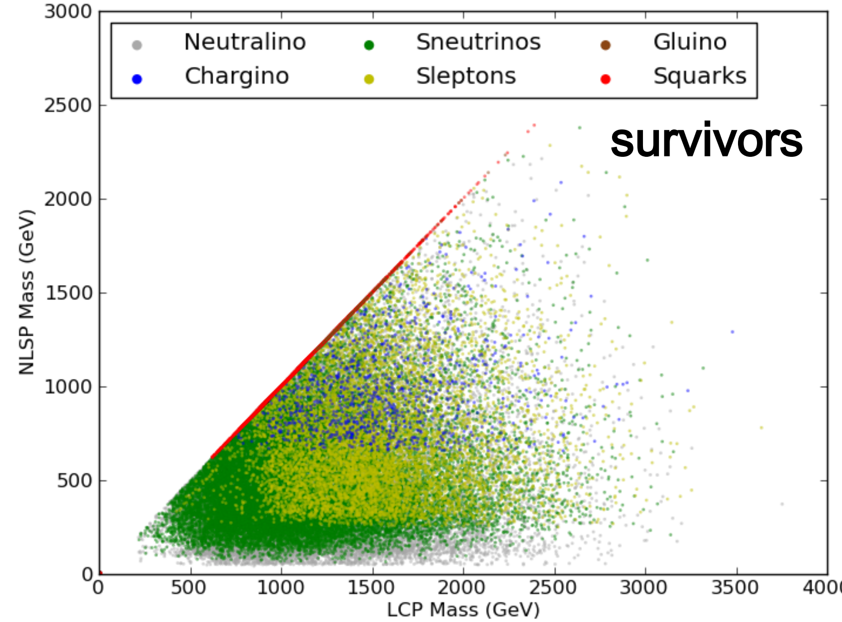


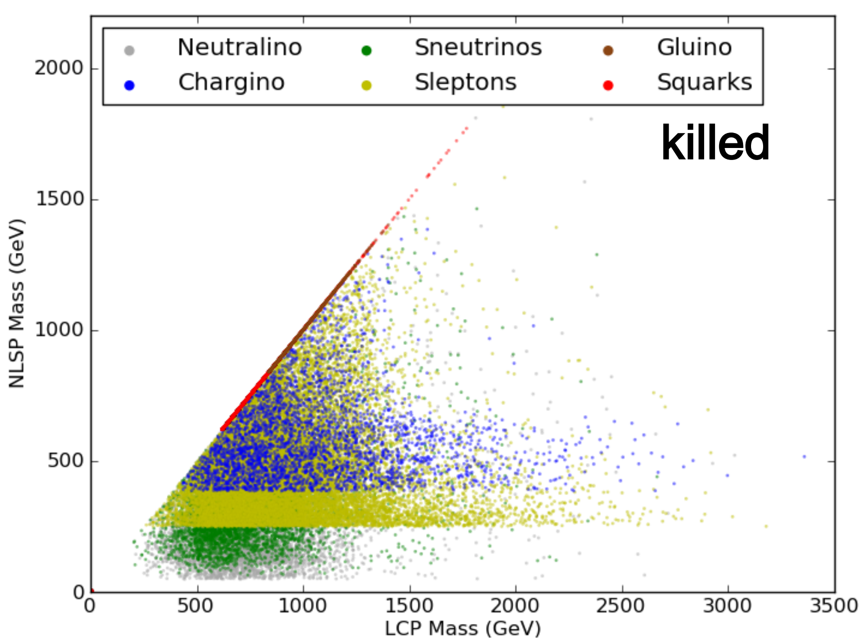
'Detector stable' line $\Gamma \sim m^5 / M_G^2$

Many models w/ chargino & slepton NLSPs are killed by these searches as are many w/ squark NLSPs

Some models w/ heavy NLSP masses are killed by $B_s \rightarrow \mu\mu$ constraints !



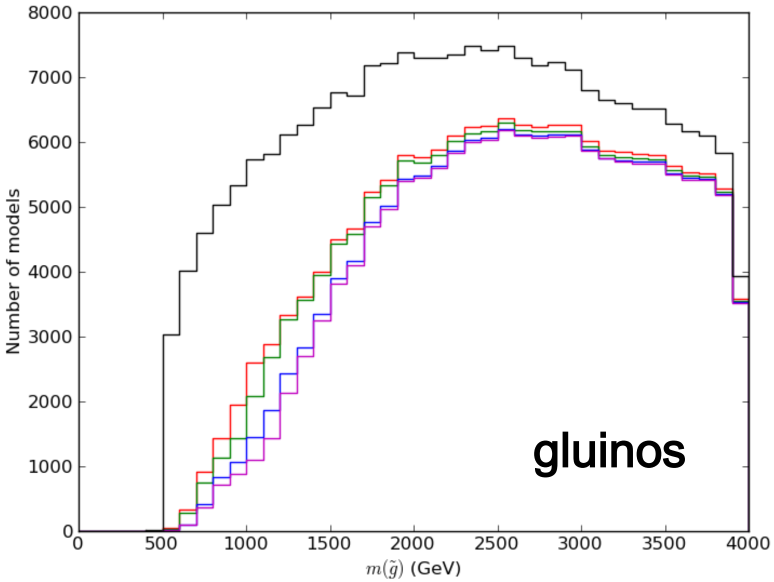


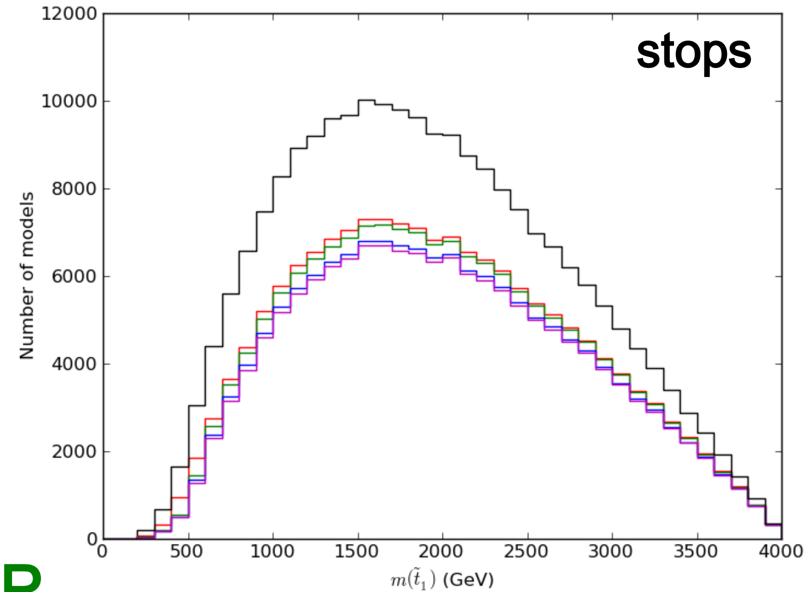


NLSP vs lightest colored sparticle mass & their dependencies on the NLSP identity

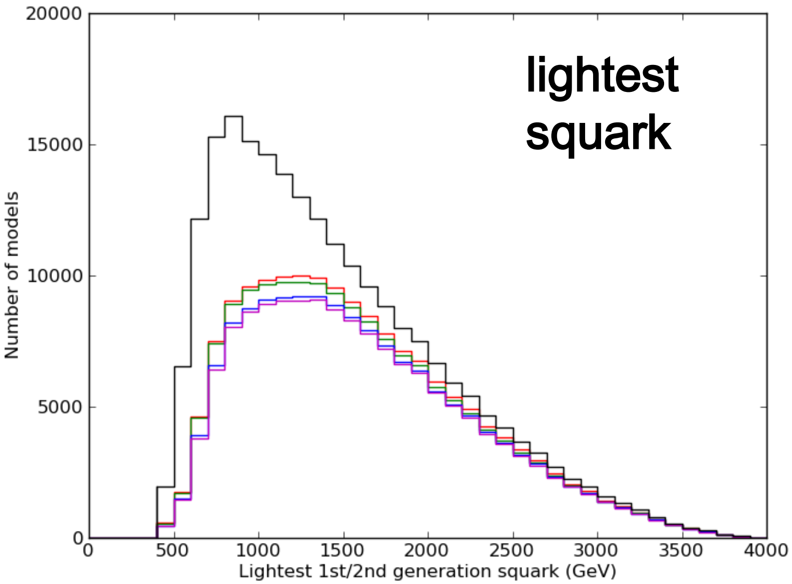
Many models with chargino & slepton NLSPs are killed by searches

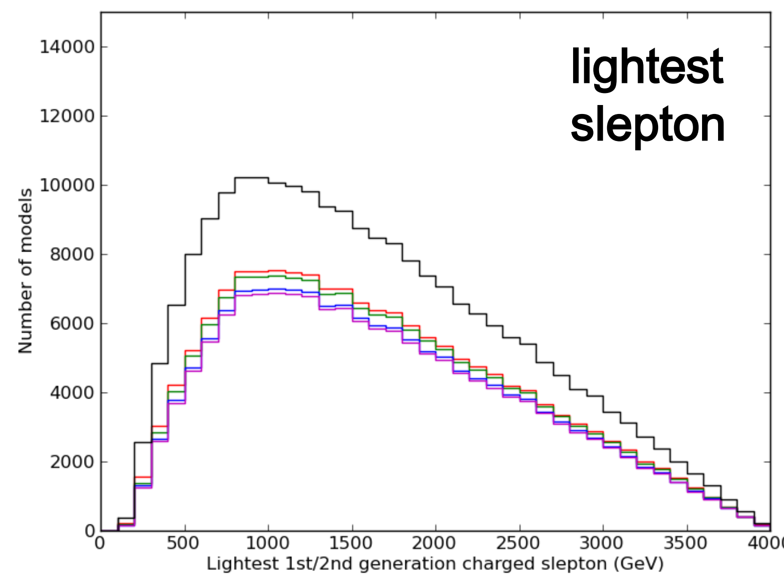
How does the pMSSM respond to negative searches ?





χ_1^0 LSP





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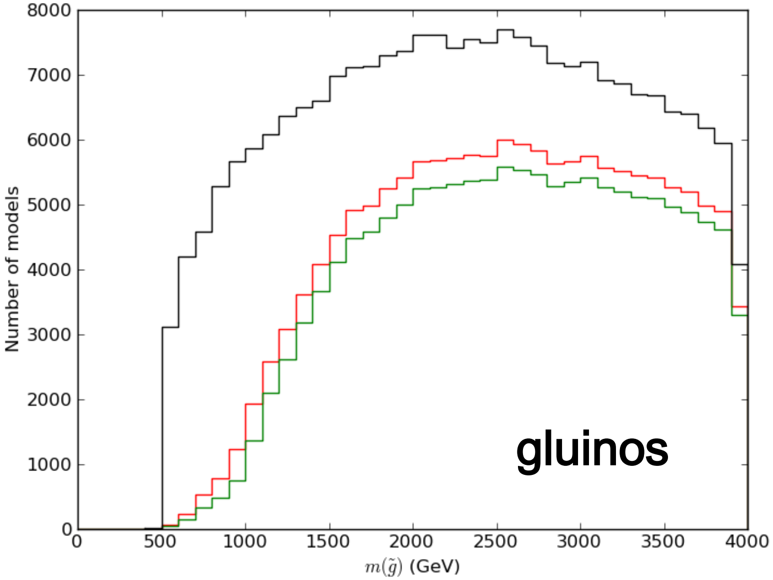
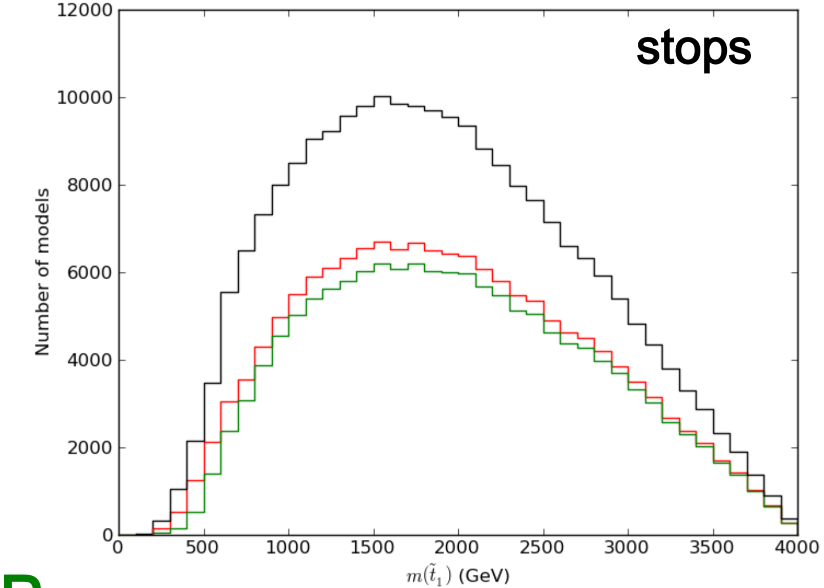
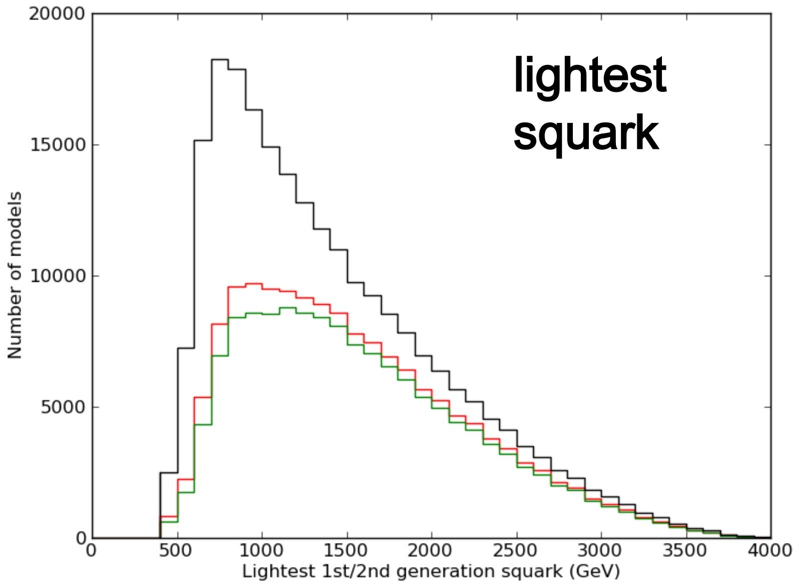
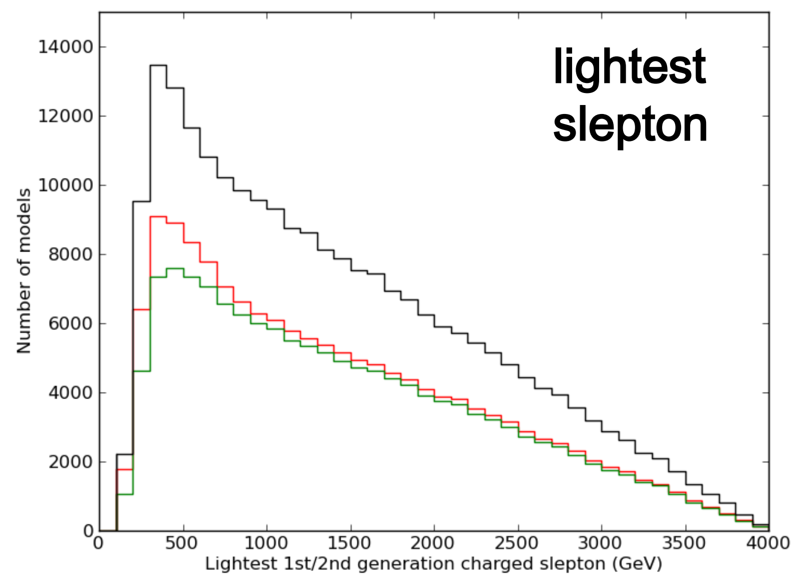


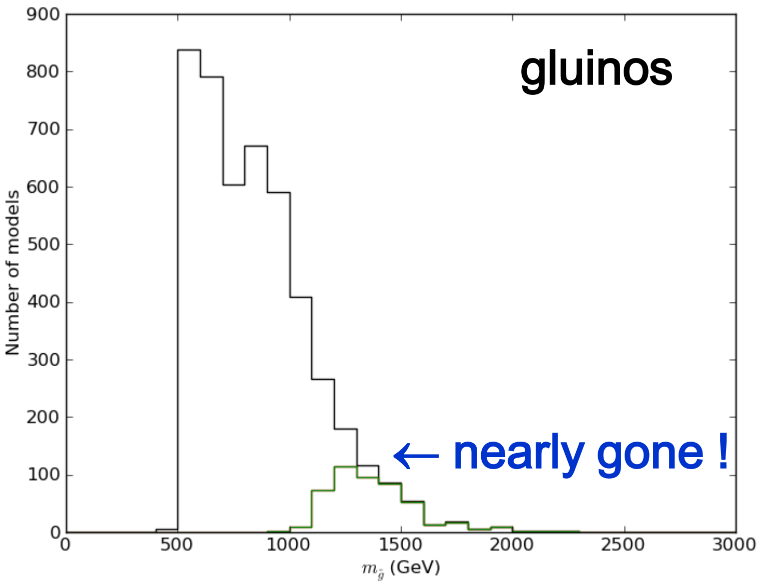


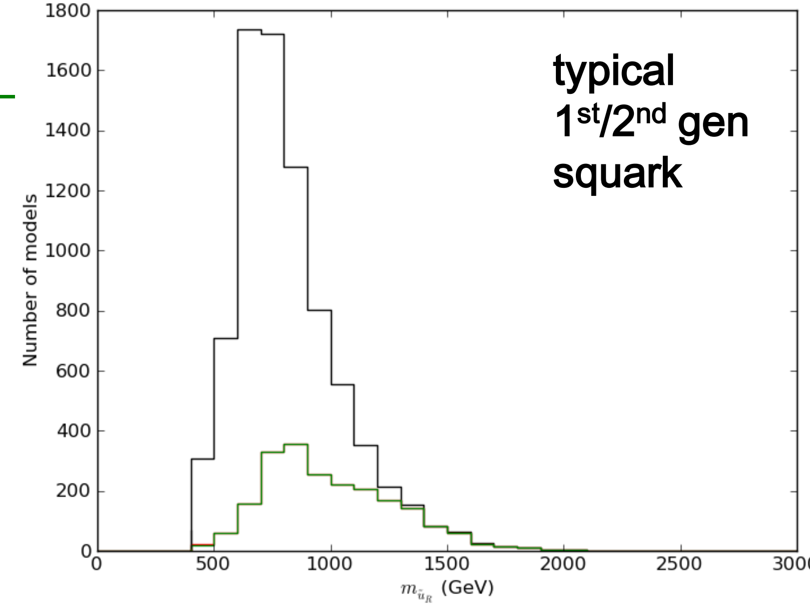
G LSP



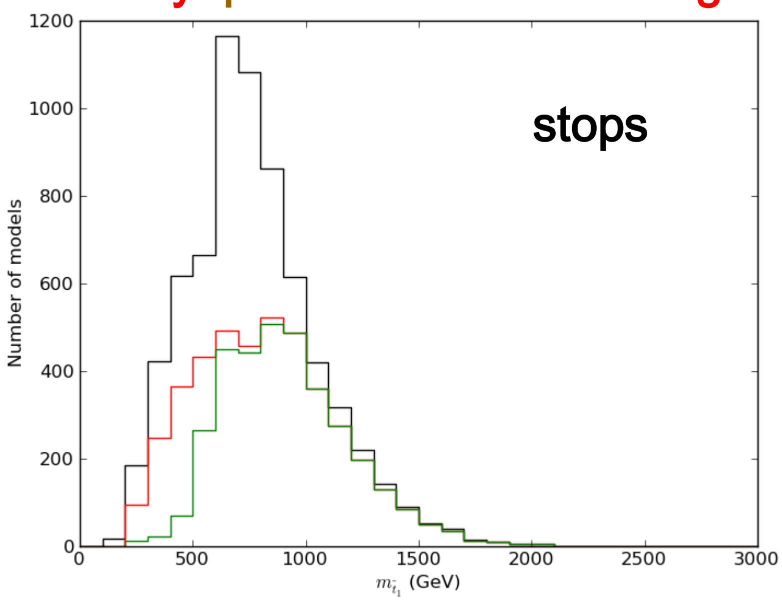


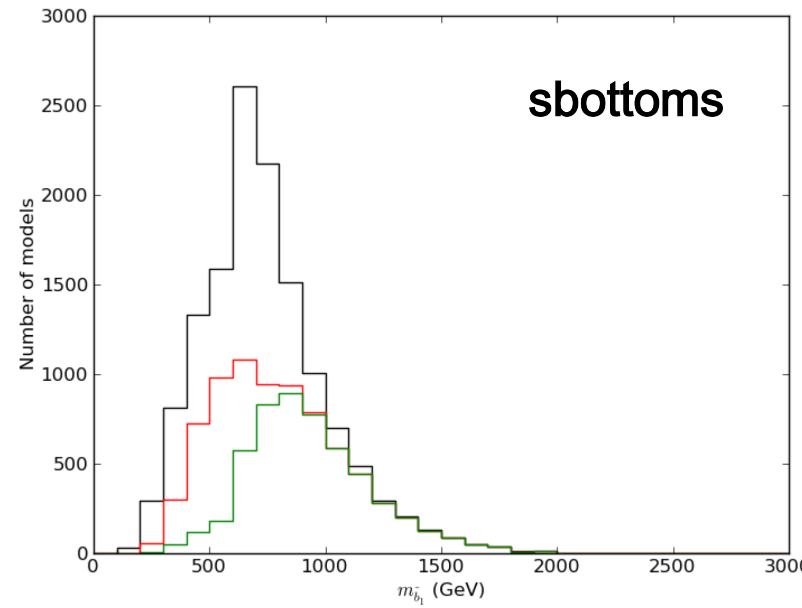
G LSP



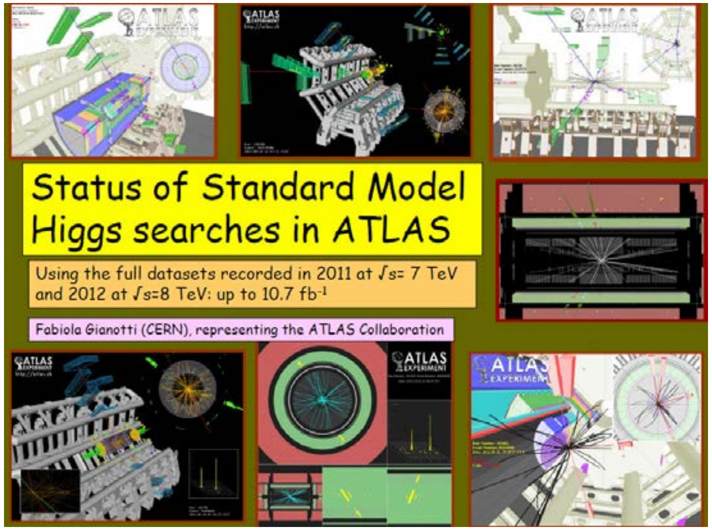


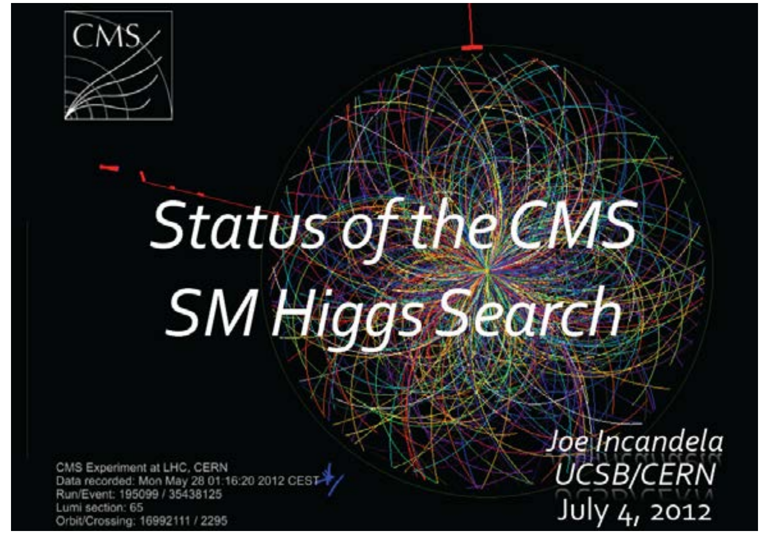
3rd gen. squark (and slepton) NLSPs at low masses are decimated by HF + Multi-l searches but gluinos and 1st /2nd squarks & gluinos are untouched although they are already quite uncommon among the survivors





Impact of LHC SM Higgs Searches



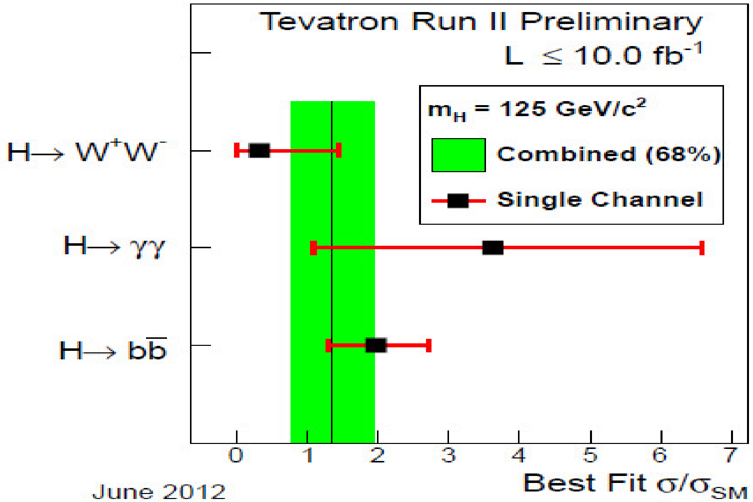


The BEHGHK Boson: "When the legend becomes fact, print the legend. "

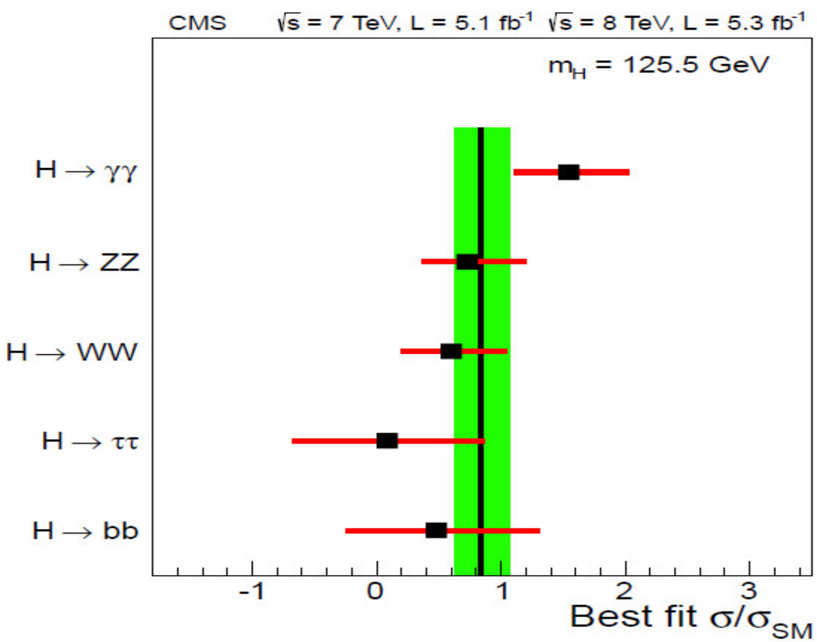
..or what does a Higgs at ~125-6 GeV tell us ?

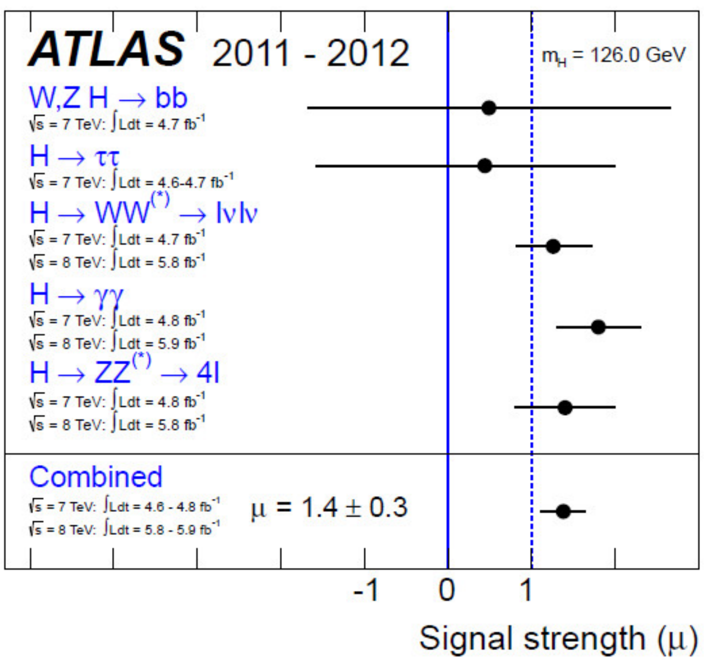
It is not higgs.
http://arXiv:physics/030201
(a meson, probably).
Hence, concepts and assertions of the electroweak theory and the quark-gluon theory are deduced from properties of probabilities of dot events without any ontological hypotheses.

Well…"generally" the Higgs is living up to the ~SM expectations.. so far..



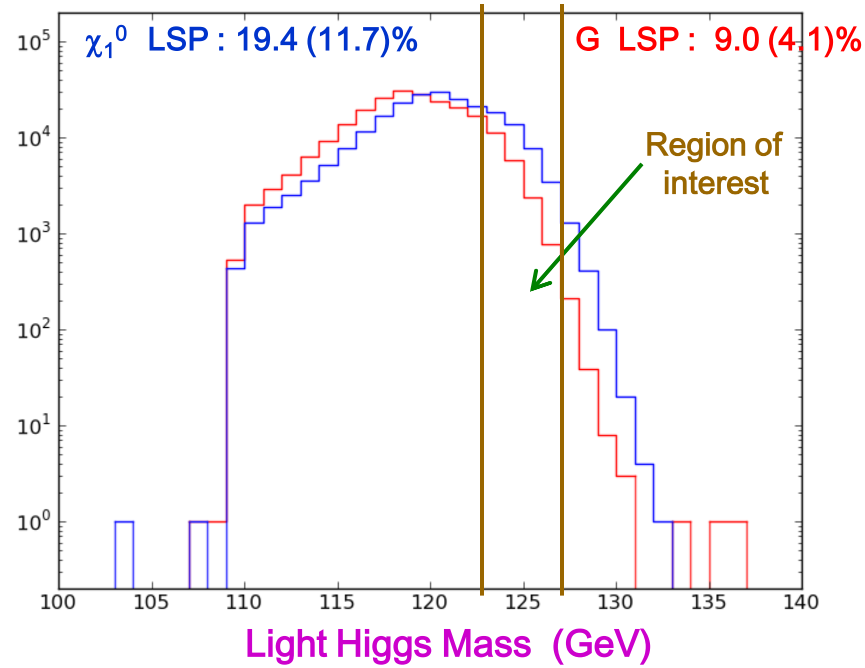
Maybe the γγ(bb) mode is a bit high(low) but, overall, things do look roughly right …in a few months we'll know better.



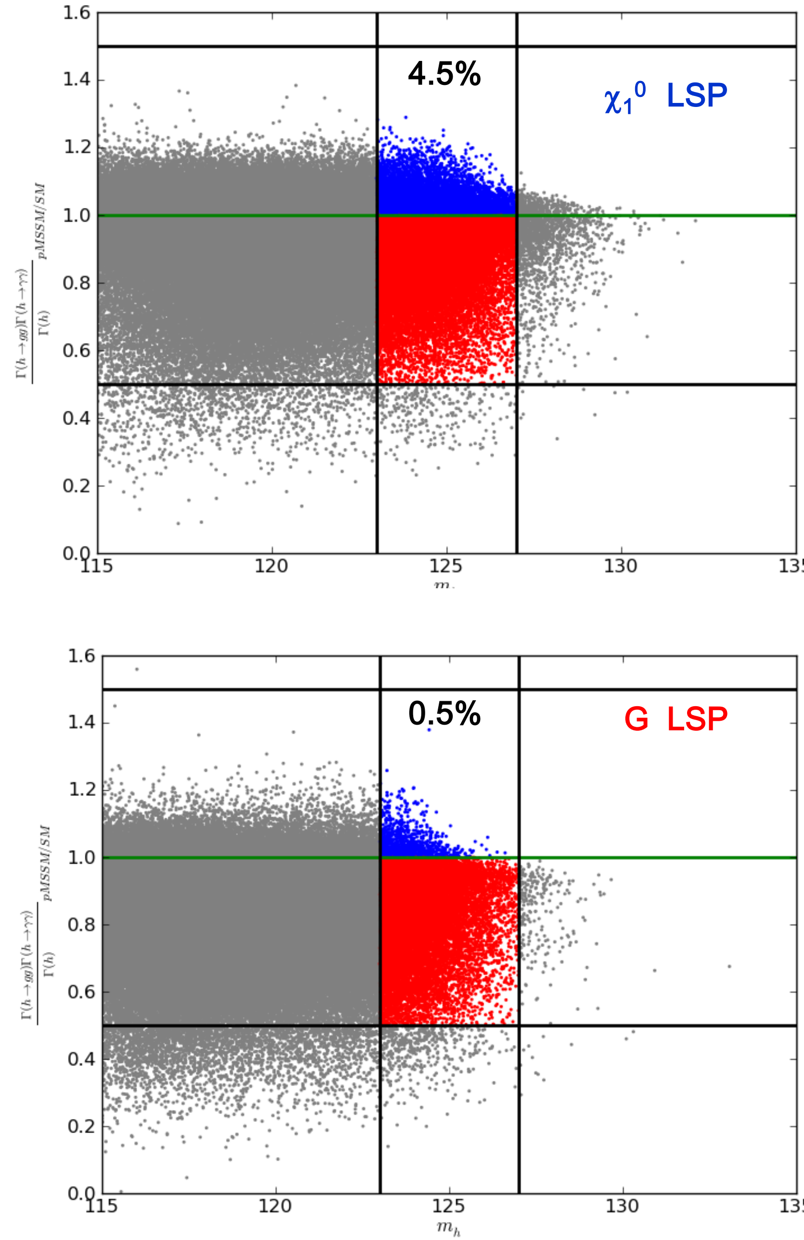


Distribution of Predicted Higgs Masses

(For m_h =125(126)±2 GeV)



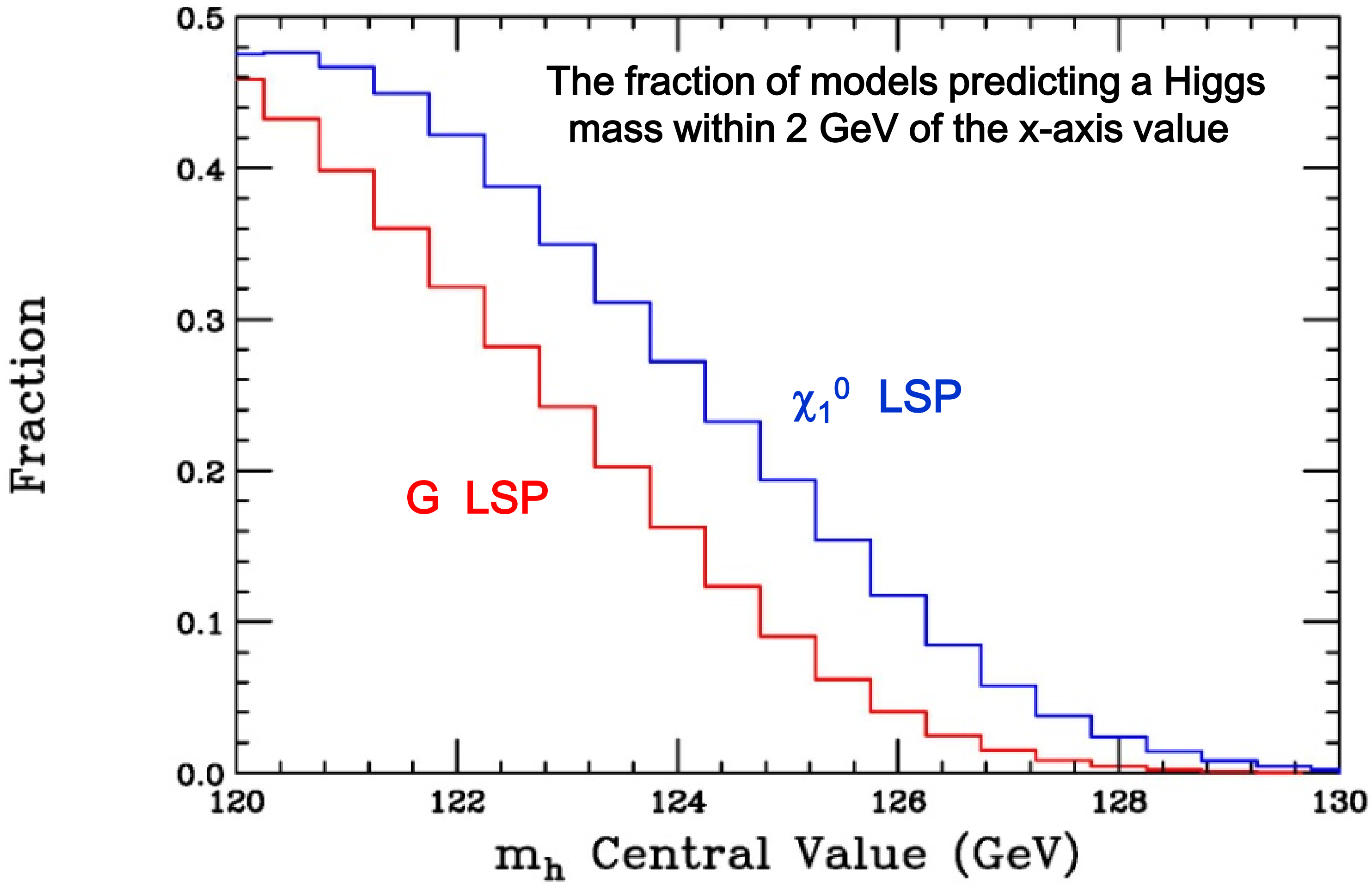
$R_{\gamma\gamma}$



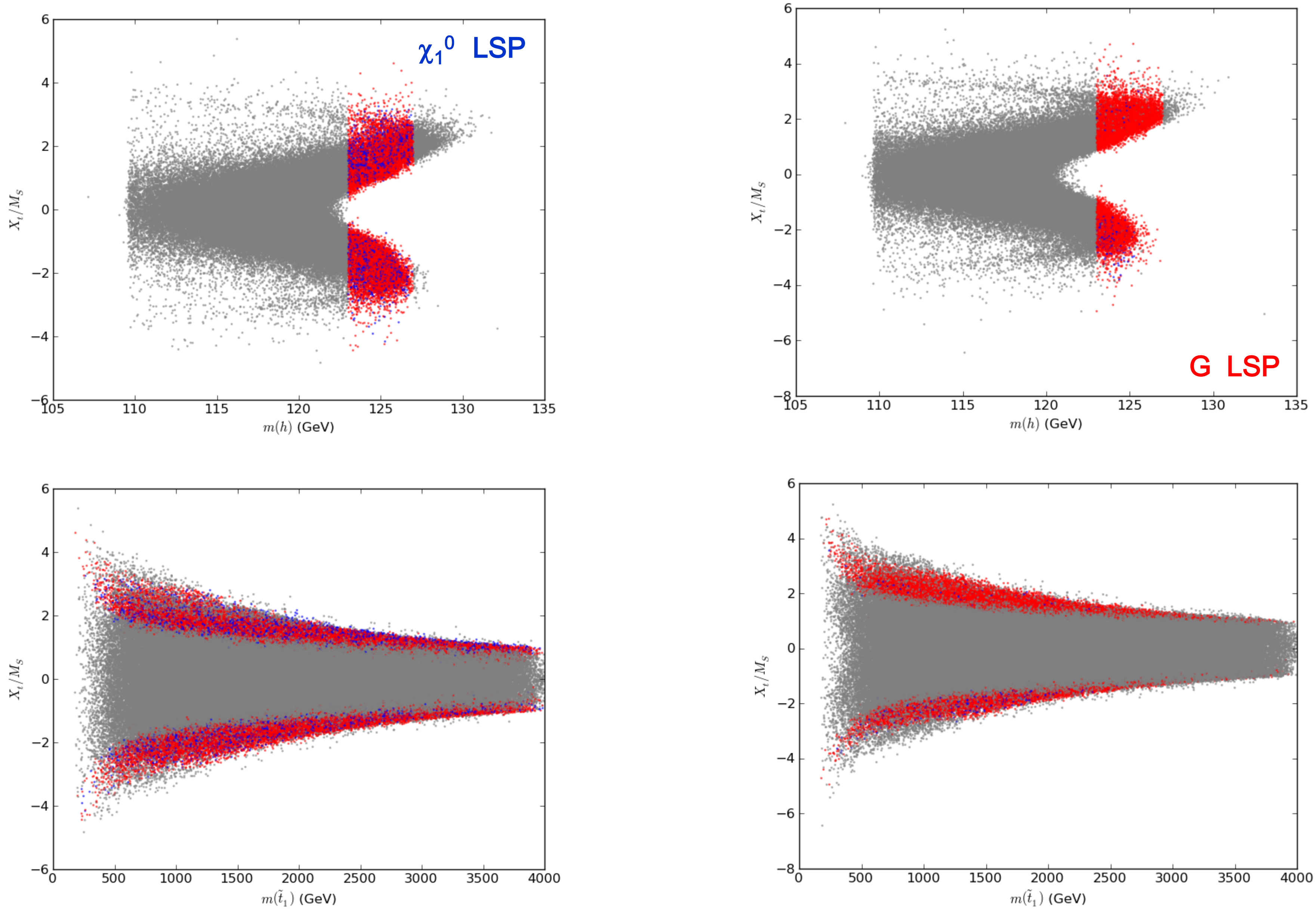
$R_{XX} = \sigma(gg \rightarrow h)\, B(h \rightarrow XX)|_{pMSSM/SM}$

The two different model sets lead to qualitatively similar yet quantitatively very different predictions…

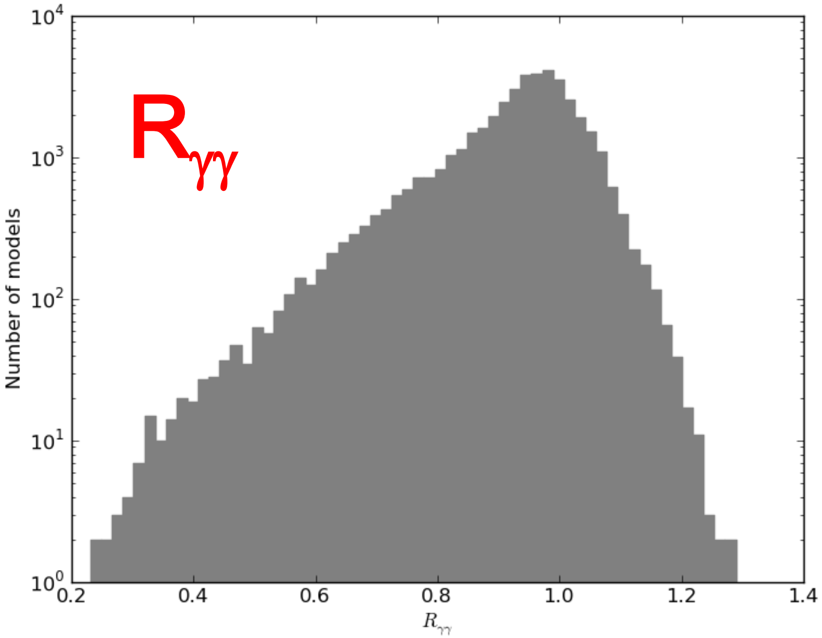
The ~125-6 GeV mass region is 'somewhat difficult' for MSSM SUSY



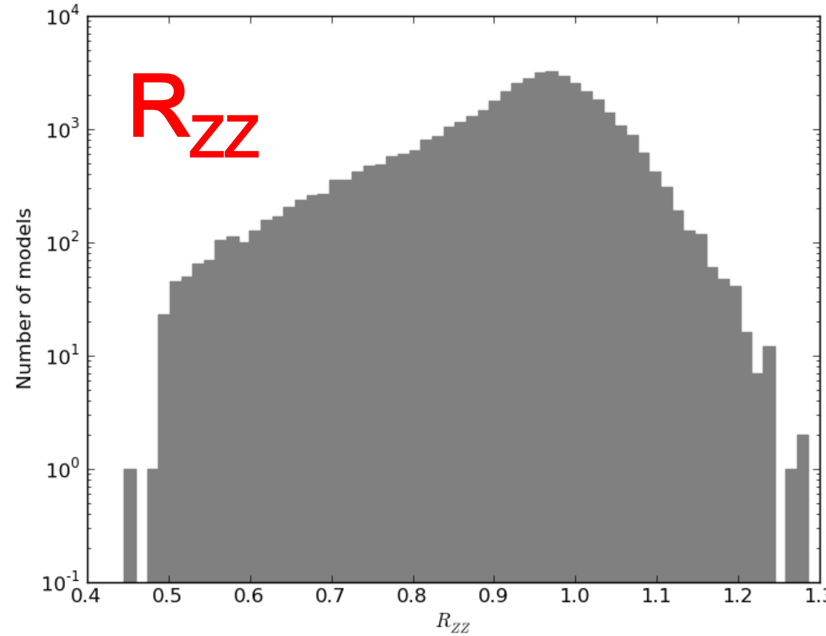
Special parameter regions needed for the125 GeV Higgs



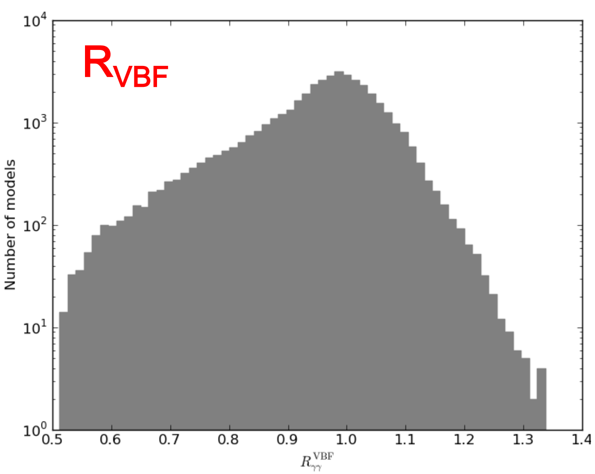
χ_1^0 LSP



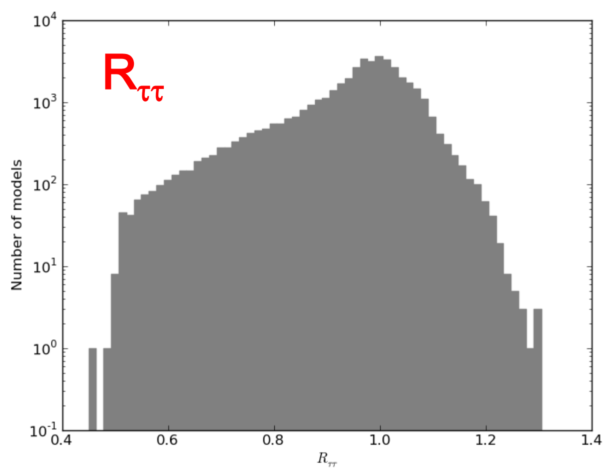
$R_{\gamma\gamma}$
Number of models
$R_{\gamma\gamma}$



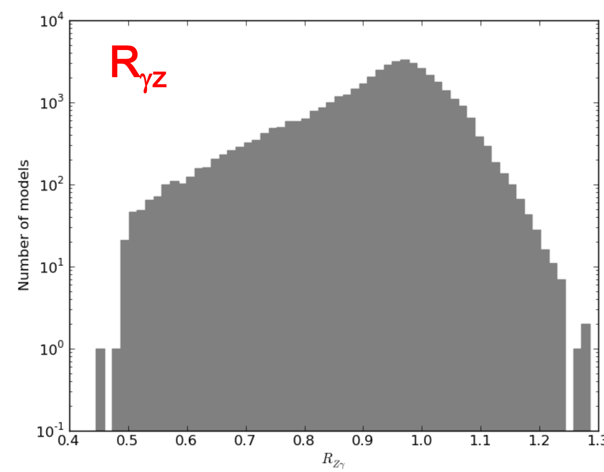
R_{ZZ}
Number of models
R_{ZZ}



R_{VBF}
Number of models
$R_{\gamma\gamma}^{VBF}$



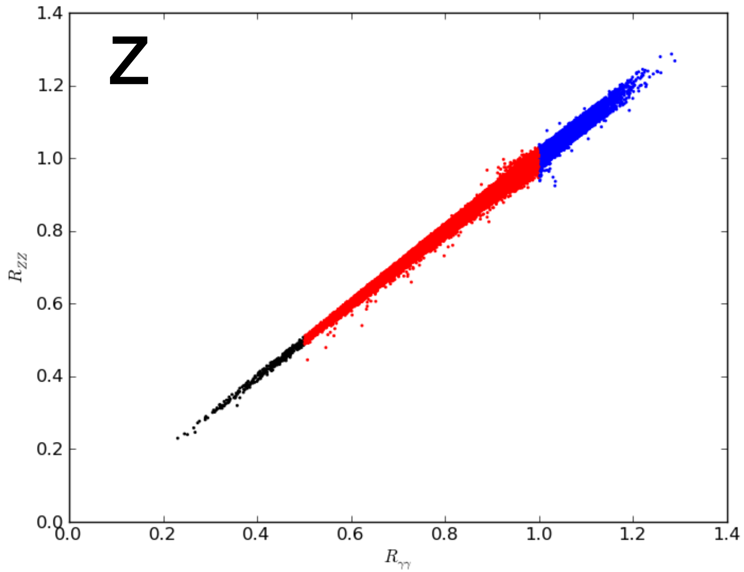
$R_{\tau\tau}$
Number of models
$R_{\tau\tau}$

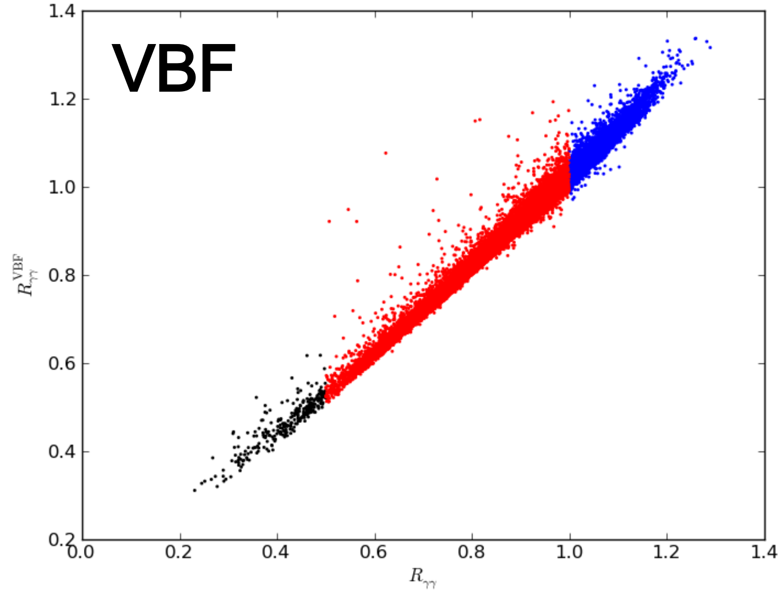


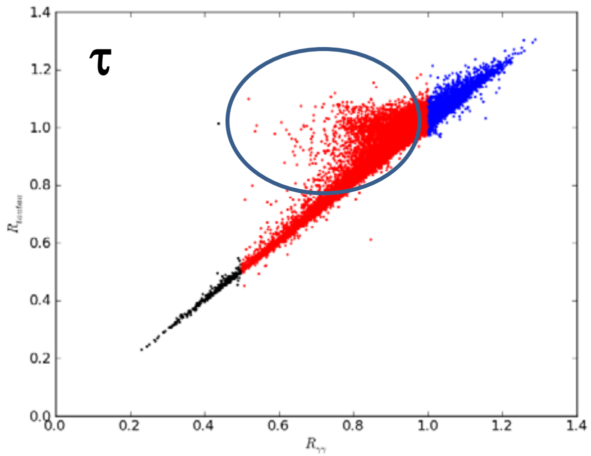
$R_{\gamma Z}$
Number of models
$R_{Z\gamma}$

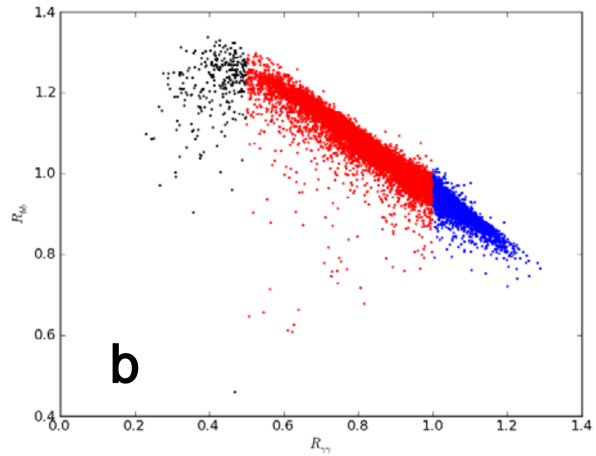
χ_1^0 LSP

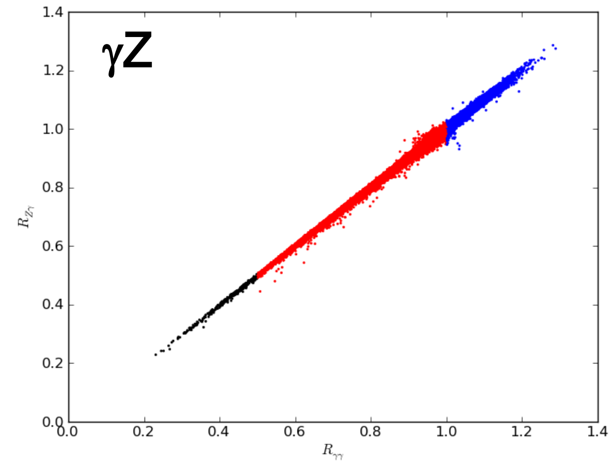
Very Highly Correlated !





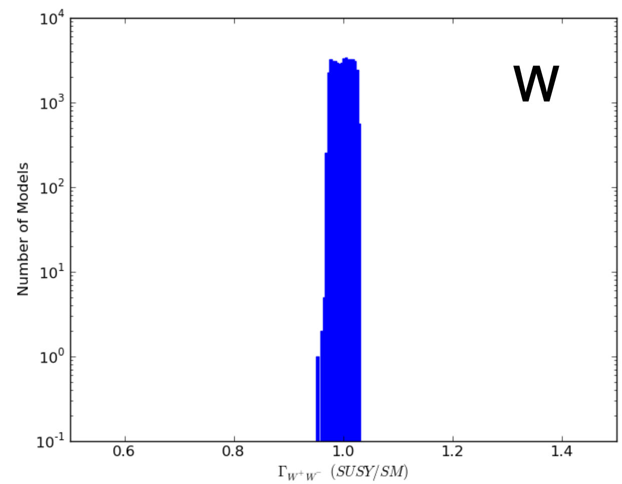


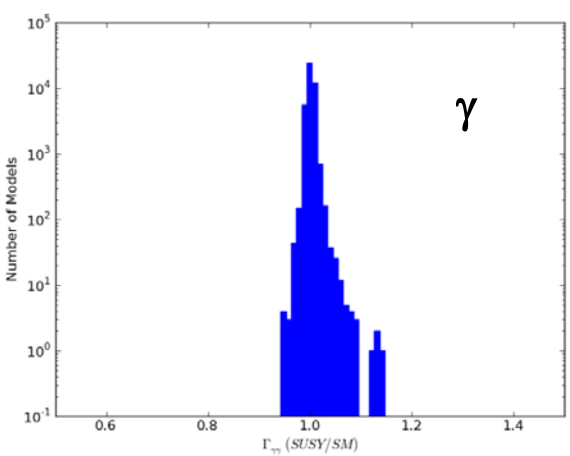


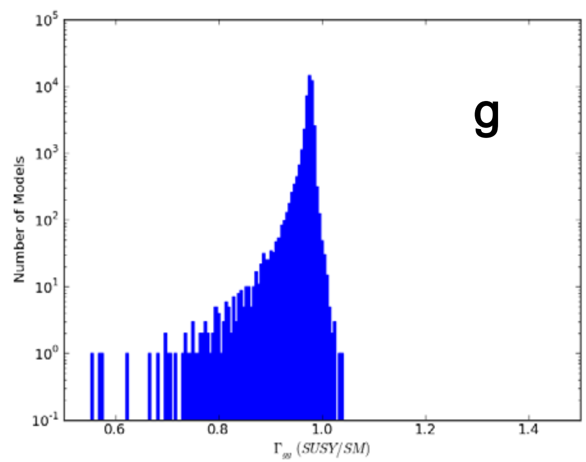


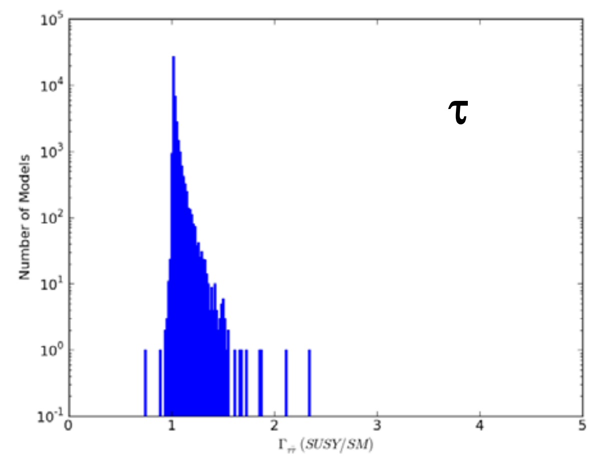
Why the correlations & why is ‘b’ different ?

- Actually (almost) all of the partial Γ’s are rather close to their SM values due to decoupling, i.e., for both LSP model sets we get highly peaked $r=\Gamma\,/\,\Gamma_{SM}$ distributions (here for the neutralino model set)

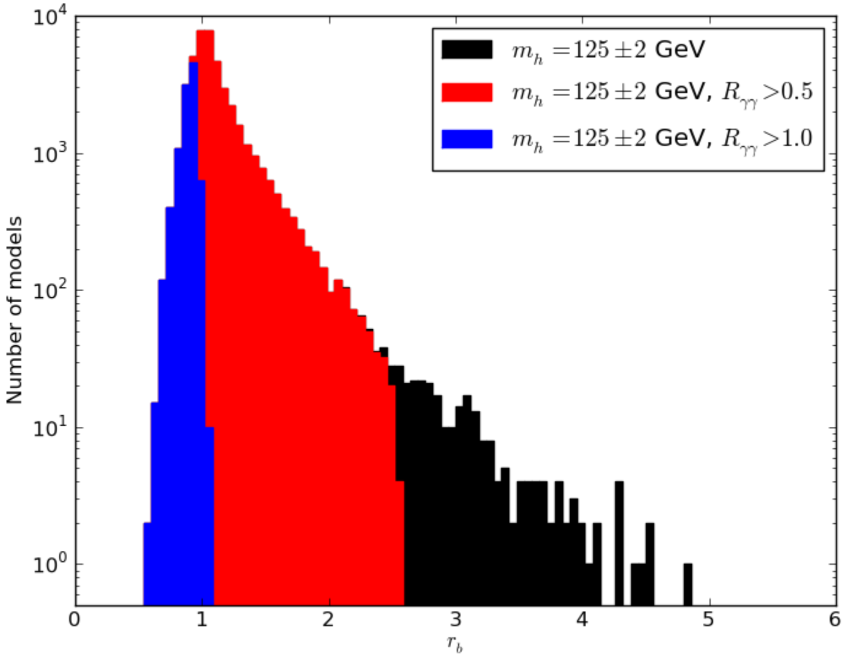


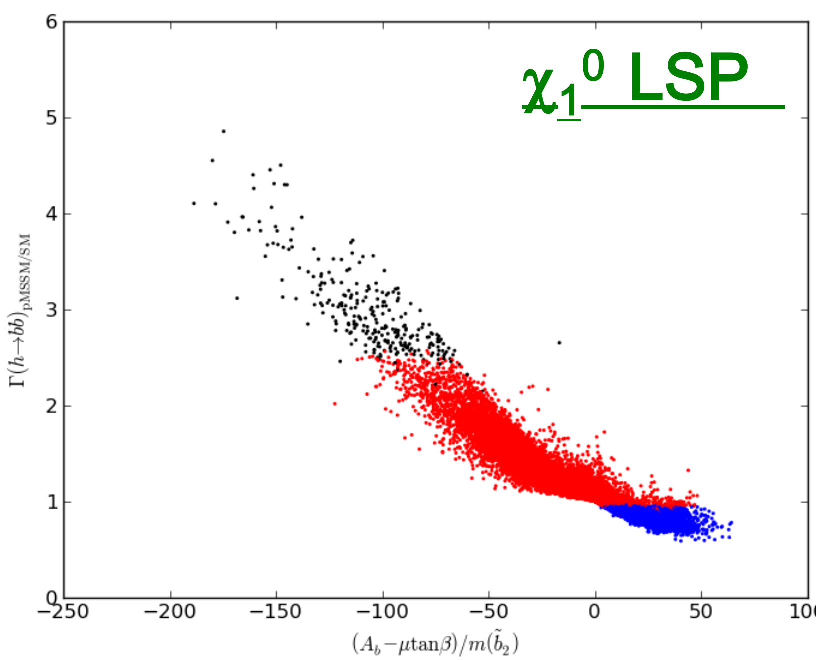


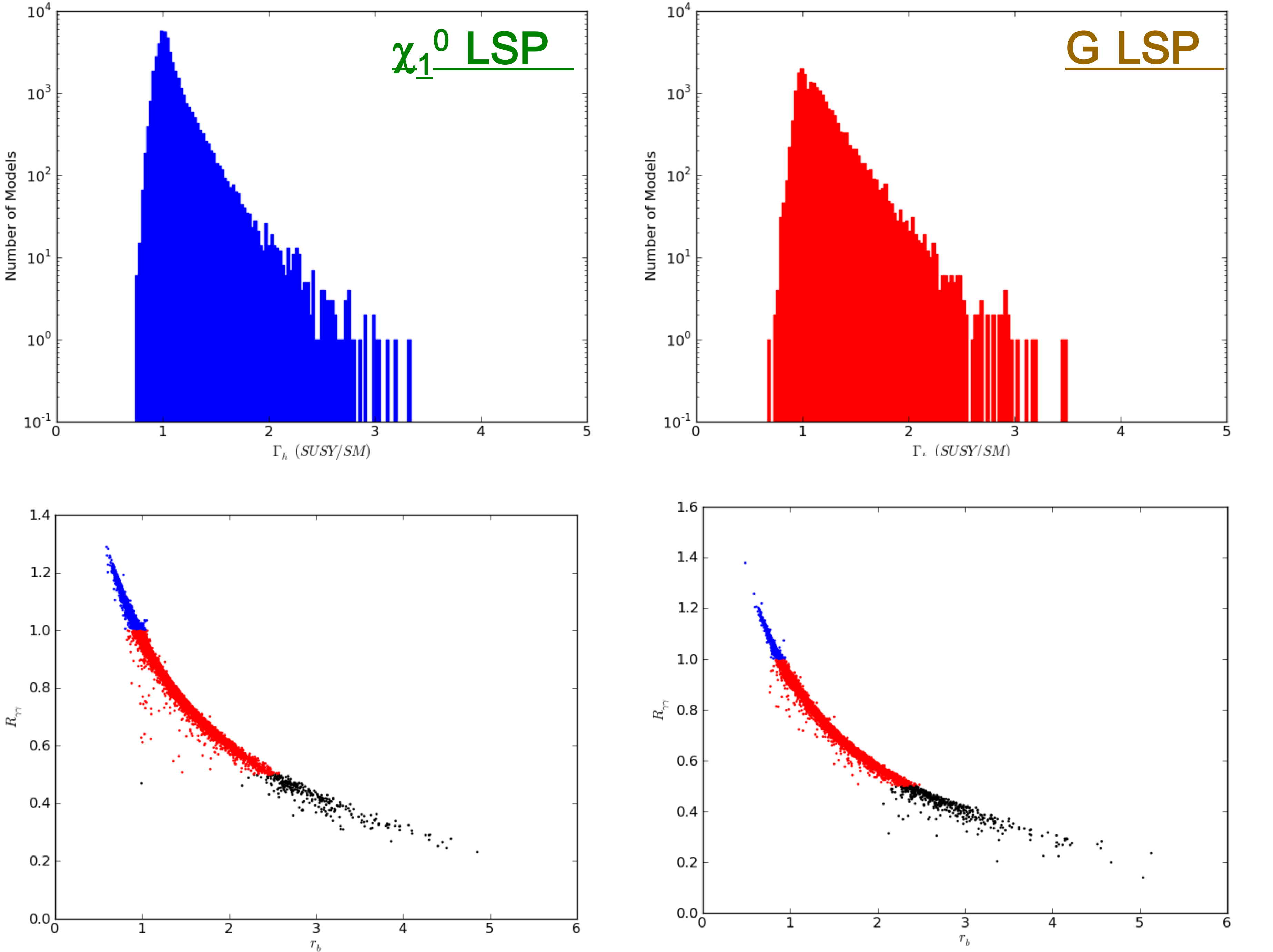




- However, for h→bb things are quite different…
- Large hbb coupling loop corrections decouple very slowly especially if there is large sbottom mixing (Haber etal.)
- These lead to a significant Higgs width increase/decrease since it is the dominant decay mode





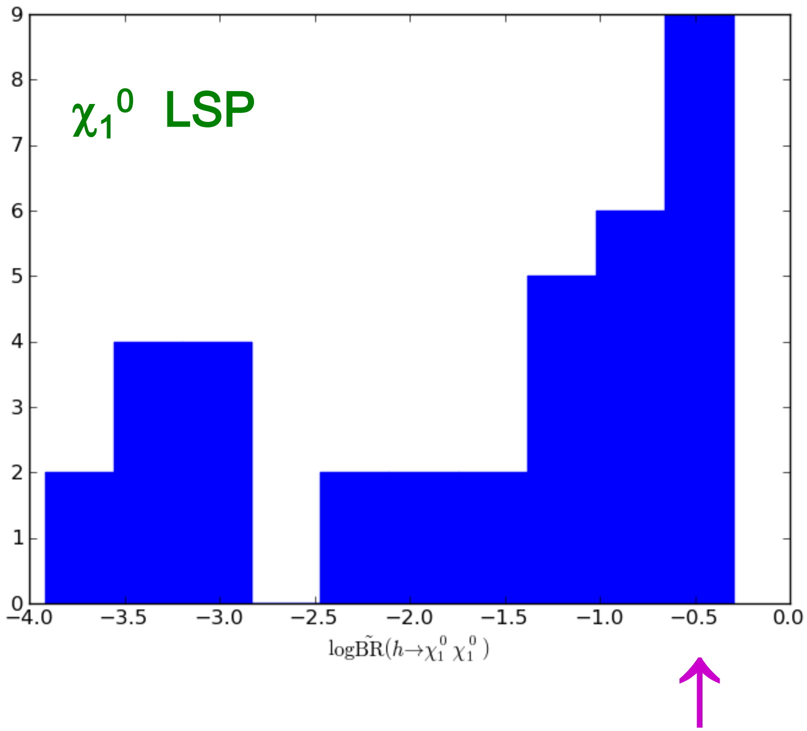

χ1 0 LSP
G LSP
Number of Models
Γh (SUSY/SM)
Rγγ
rb

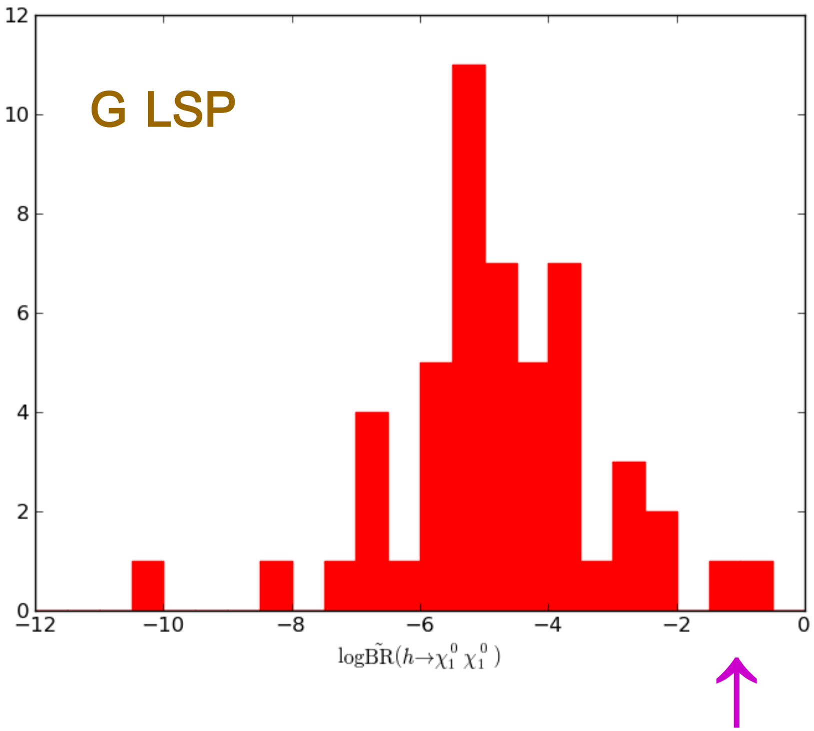
Rare Non-SM Higgs decays

- In the neutralino (gravitino) model set 36 (51) models have kinematically accessible h (=125 ±2 GeV) decays to pairs of neutralinos which are mostly bino w/ a small Higgsino admixture. (There are a higher fraction of bino χ_1^0 s in the gravitino set but there are fewer Higgs in this mass range.) The rate scales ~ as the product of the bino & Higgsino fractions.

- In the neutralino set this is the usual 'invisible Higgs decay'. 15/36 have an h → invisible BF > 10% & in one case it's ≈ 50%, above the present 'theorist limit' of ≈ 40% (see, e.g., 1207.1717)

- In the gravitino set, the NLSP neutralino will decay to γ +gravitino producing a $\gamma\gamma$ + (small ?) MET signature. The neutralinos in this set have high bino purity & thus we expect a lowering of the Higgs BF in this mode. Only 1/51 model leads to a BF > 1% (19% actually).





As expected the BF for this mode is higher in the neutralino set due to the high bino purity of the neutralino NLSP in the gravitino set

It will be important to continue to search for unusual Higgs decay modes as further tests of new physics beyond just measuring couplings to the SM fields.

Fine-tuning in the pMSSM

- m_h ~ 125-6 GeV in the MSSM requires large stop masses and/or mixings which then $\rightarrow$ significant FT expected

$$\frac{m_Z^2}{2} = \frac{(m_{H_d}^2 + \Sigma_d^d) - (m_{H_u}^2 + \Sigma_u^u)\tan^2\beta}{(\tan^2\beta - 1)} + \mu^2$$

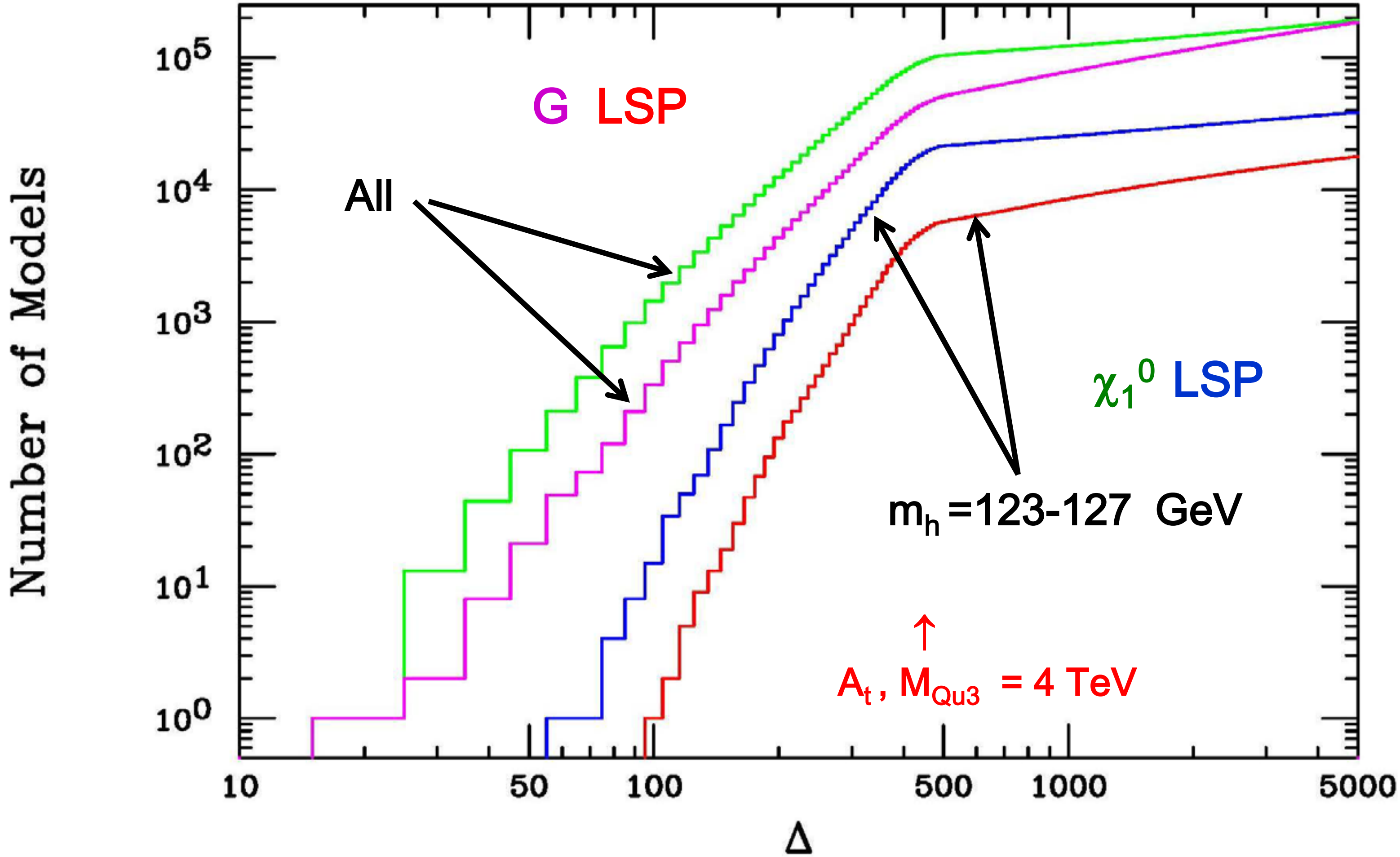
- To quantify FT we ask how the value of M_Z depends upon any of the 19 parameters , $\{ p_i \}$, up to (in some cases) the 2-loop, NLL level (c/o Martin & Vaughn). We follow the traditional FT approach of Ellis et.al. + Barbieri & Giudice :

$$A_i = |\partial \ln M_Z^2 / \partial \ln p_i| , \qquad \Delta = \max \{A_i\}$$

- This measure is sensitive to large logs occurring when treating the MSSM as an effective theory up to some larger mass scale

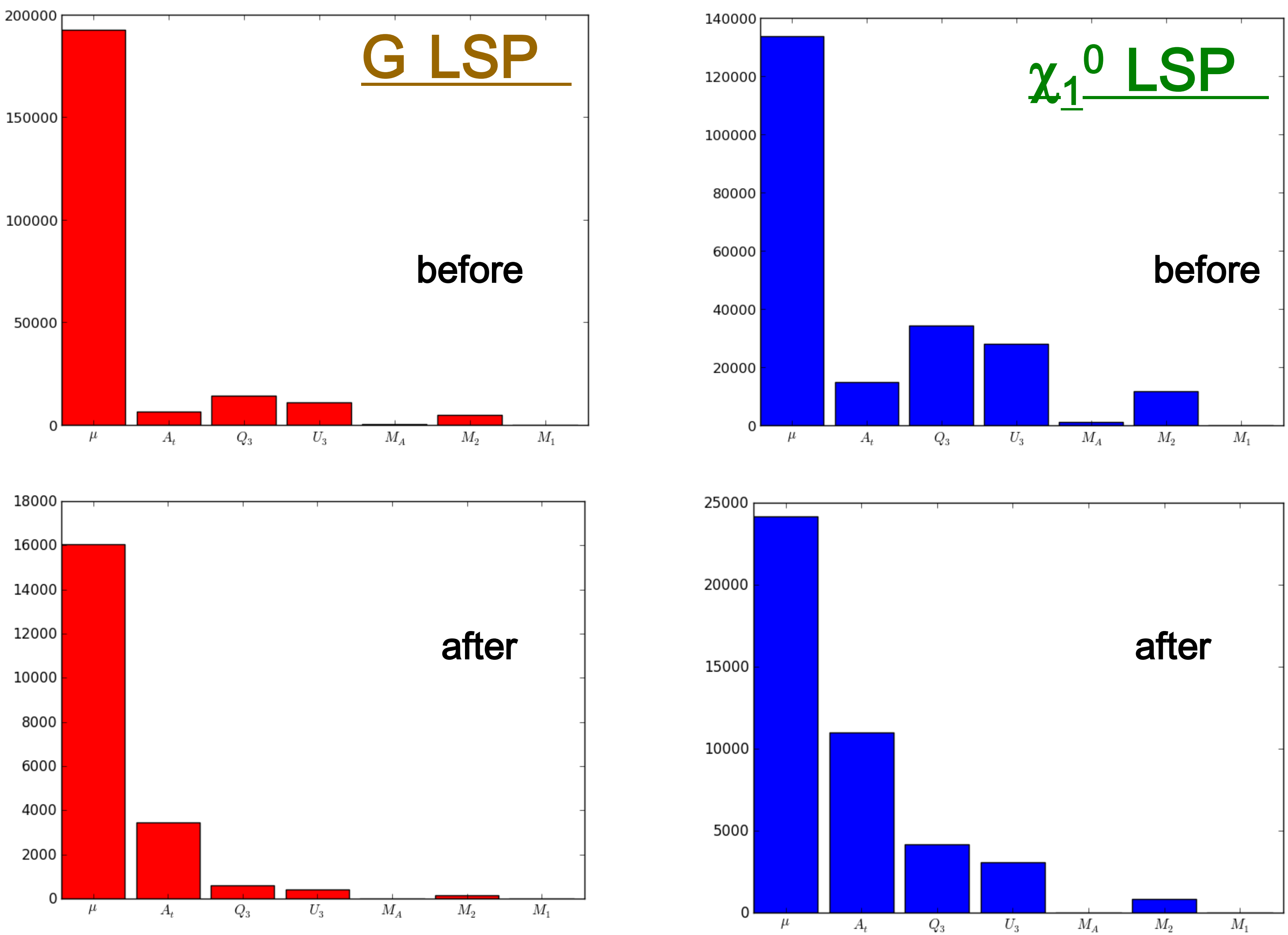
- How many models have Δ less than a specific value ?

Fine-tuning in the pMSSM



- Hence, as expected, the large Higgs mass ‘cut’ removes many of the models with the lowest FT values

Dominant FT Contributors



- NB: Requiring Higgs masses of 125±2 GeV , FT < 100(120) & also passing the 7 TeV MET (stable sparticle) LHC searches only 13(33) of the χ LSP models or 1(5) of the gravitino LSP models survive out of the original ~230k !

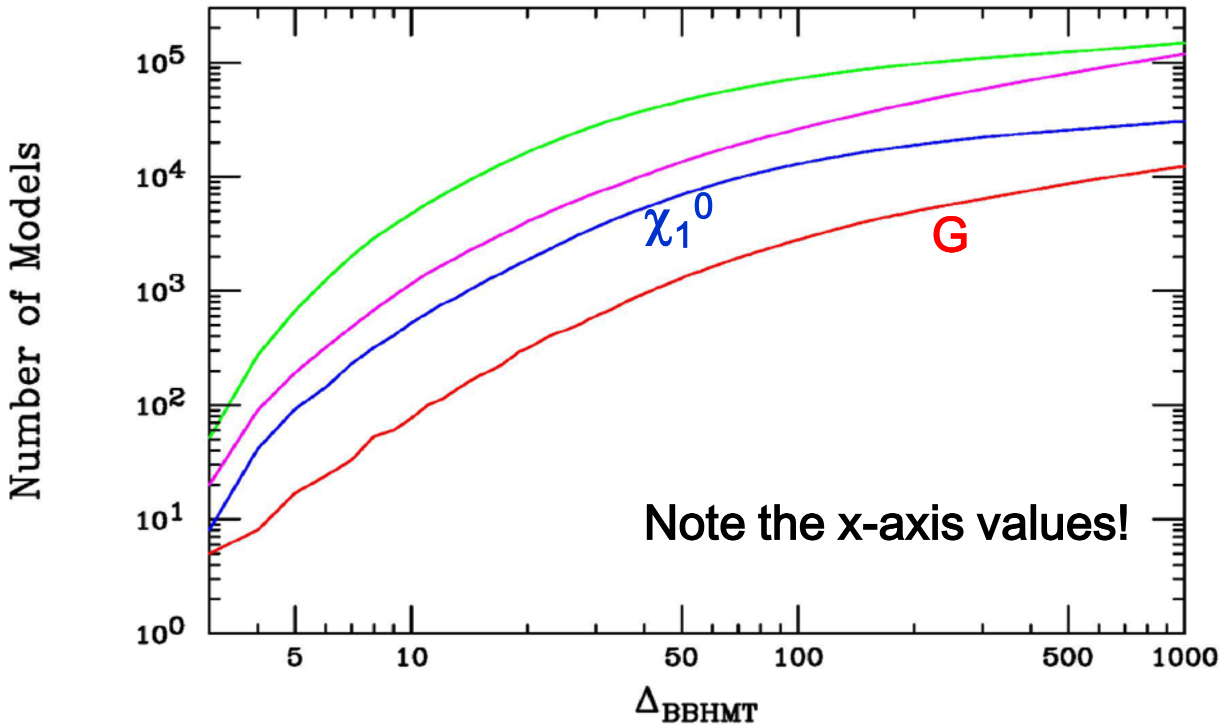
- So let's examine some sample spectra & look for some common features…

- But first… an aside: we note that there are 'alternative measures' of FT proposals that yield more optimistic results

Caveat: there are other possible measures of EW FT…

$$\frac{m_Z^2}{2} = \frac{(m_{H_d}^2 + \Sigma_d^d) - (m_{H_u}^2 + \Sigma_u^u)\tan^2\beta}{(\tan^2\beta - 1)} + \mu^2$$

Just require RC's (the Σ's) to be smaller than the LHS ..this is the so-called minimal or 'vanilla' constraints. Then



Baer etal, 1207.3343

Anderson & Castano
hep-ph/9409419

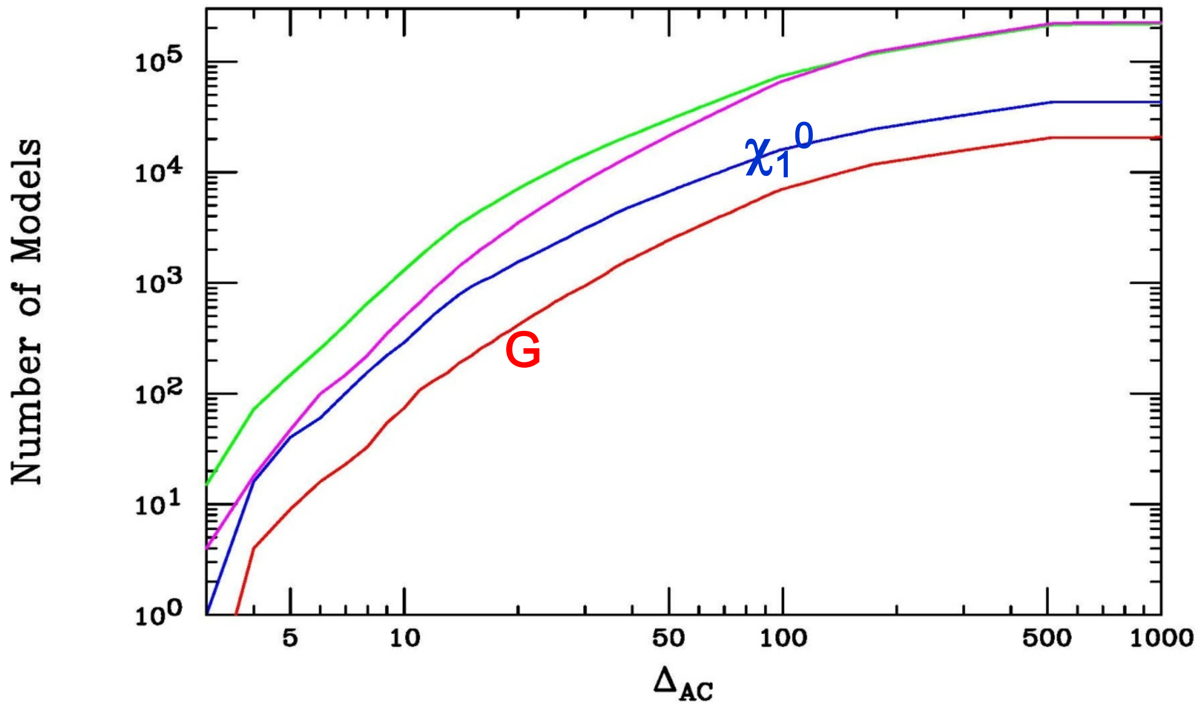
FT from parameter a is $\gamma = c/\bar{c}$.

This definition of $\bar{c}$ corresponds to

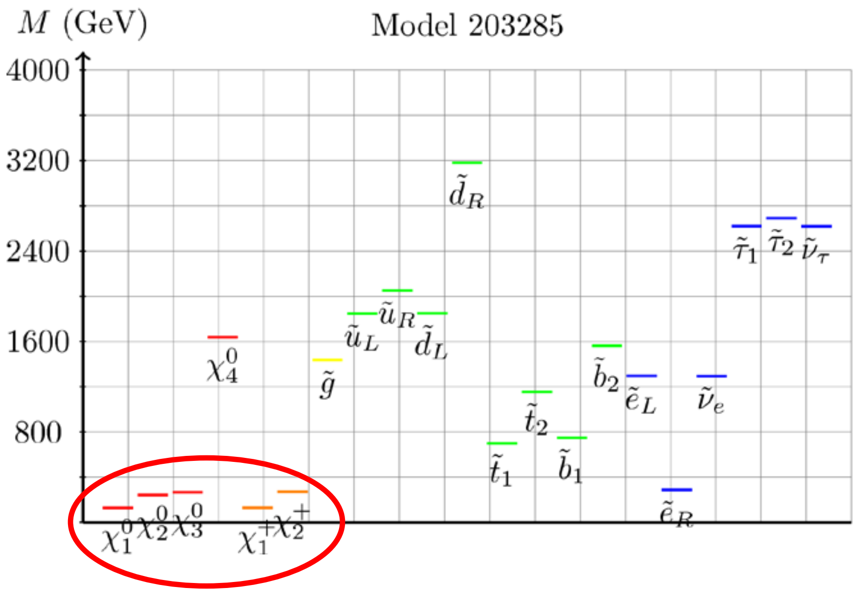
$$\bar{c}^{-1} = \frac{\int da\, a f(a) c(X;a)^{-1}}{a f(a) \int da}$$

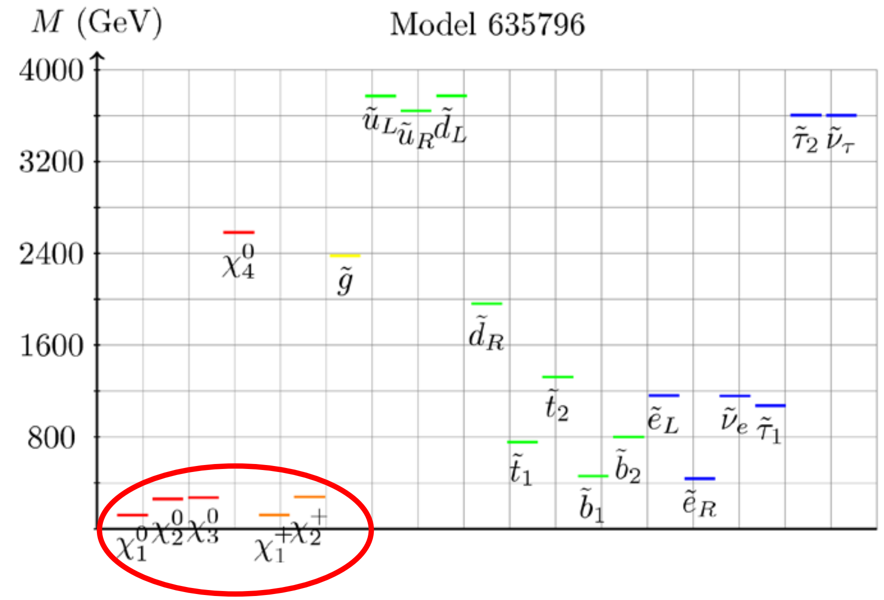
How sensitive is, e.g., M_Z to variations of parameter, a, in a given model M compared to the entire set of models from which M was drawn?

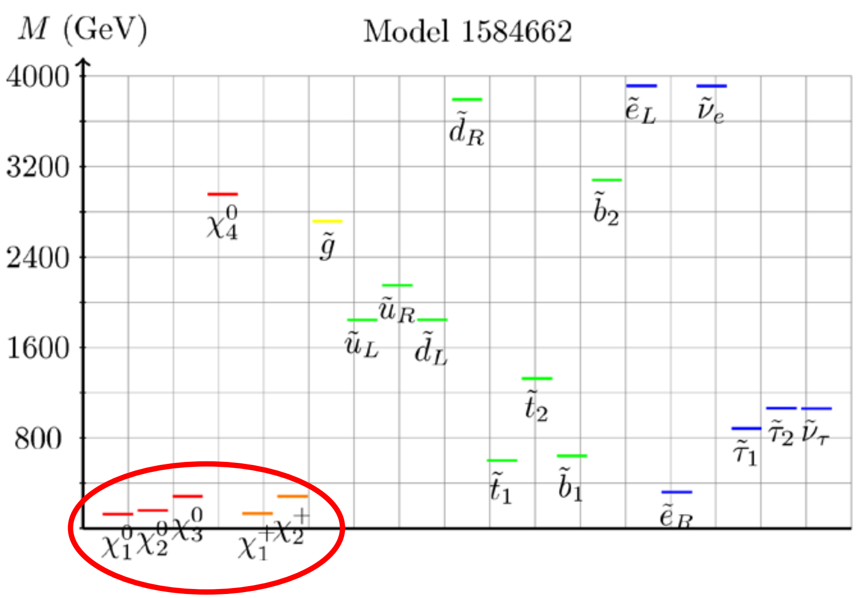
where c is the usual BG result & f is the distribution of the parameter a within the full model set (here taken to be flat as generated)

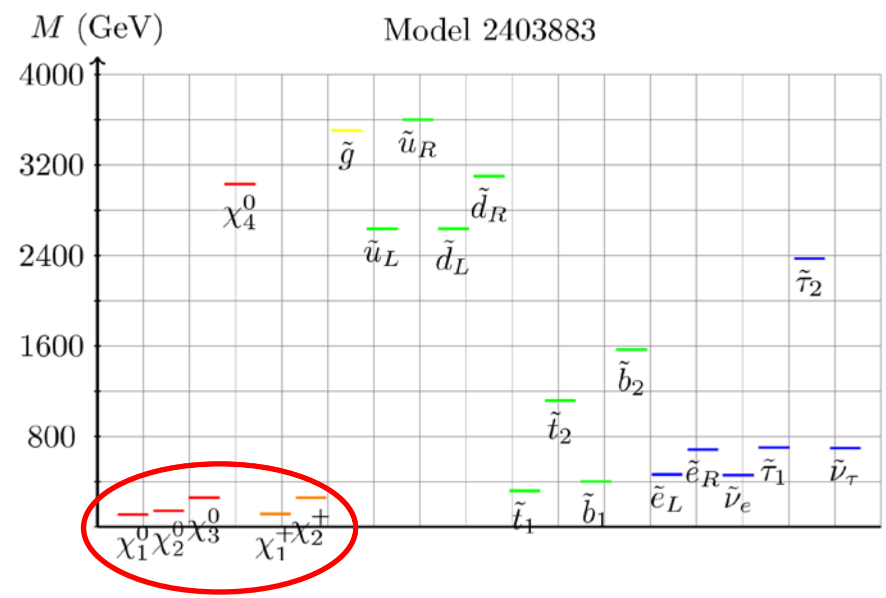


The Better Models & Their Natures

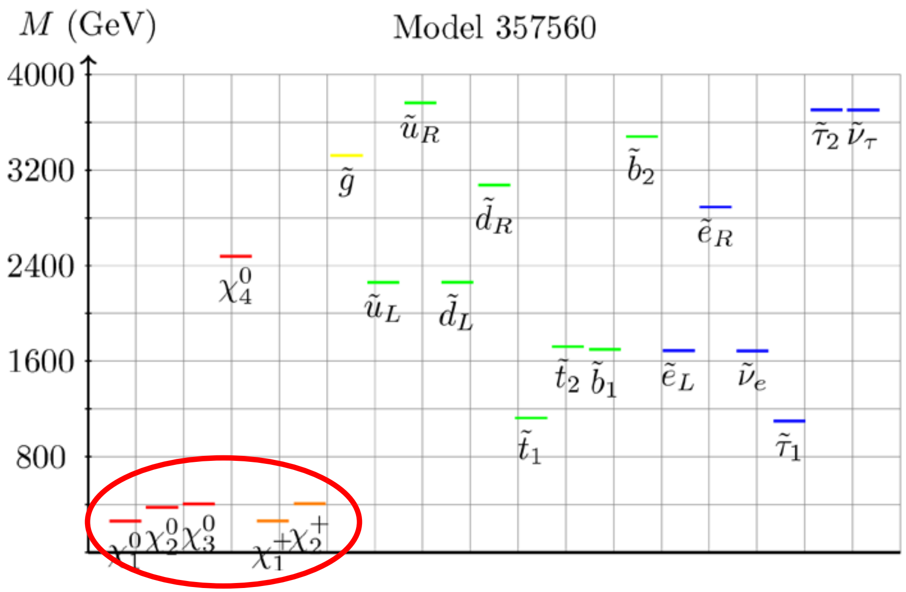


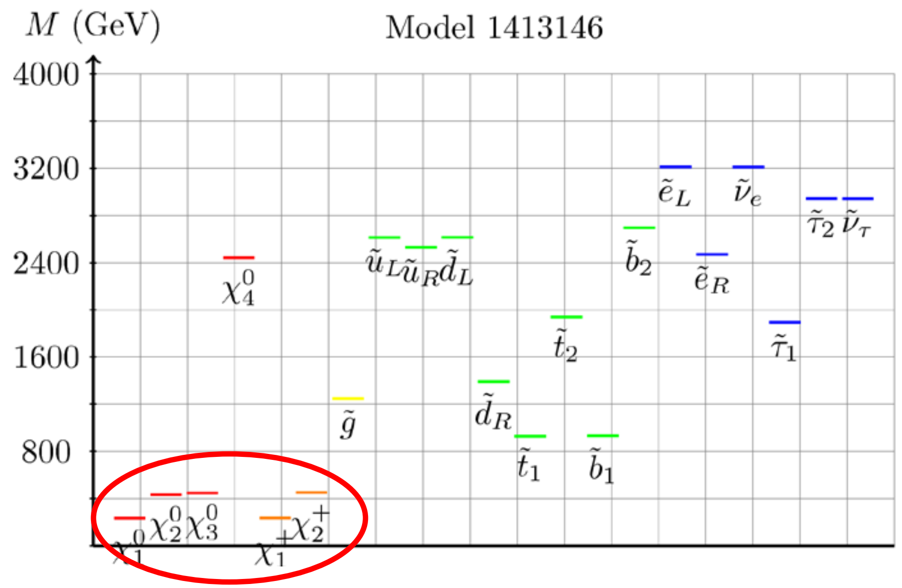


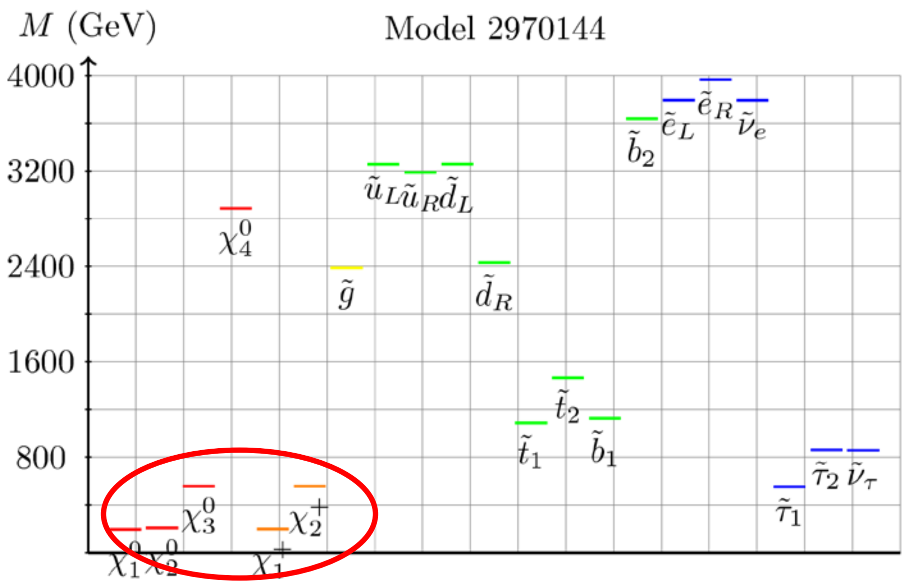


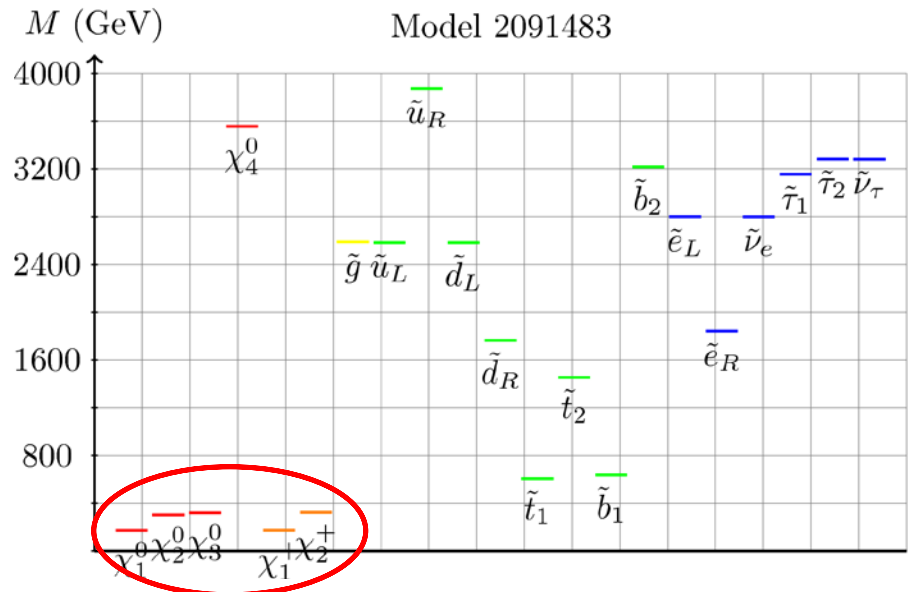


The Better Models & Their Natures II

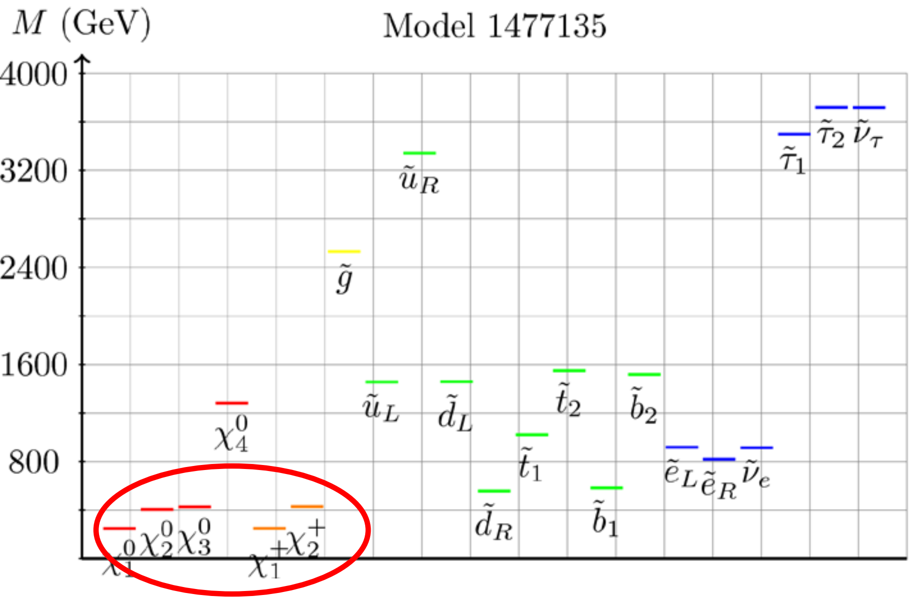


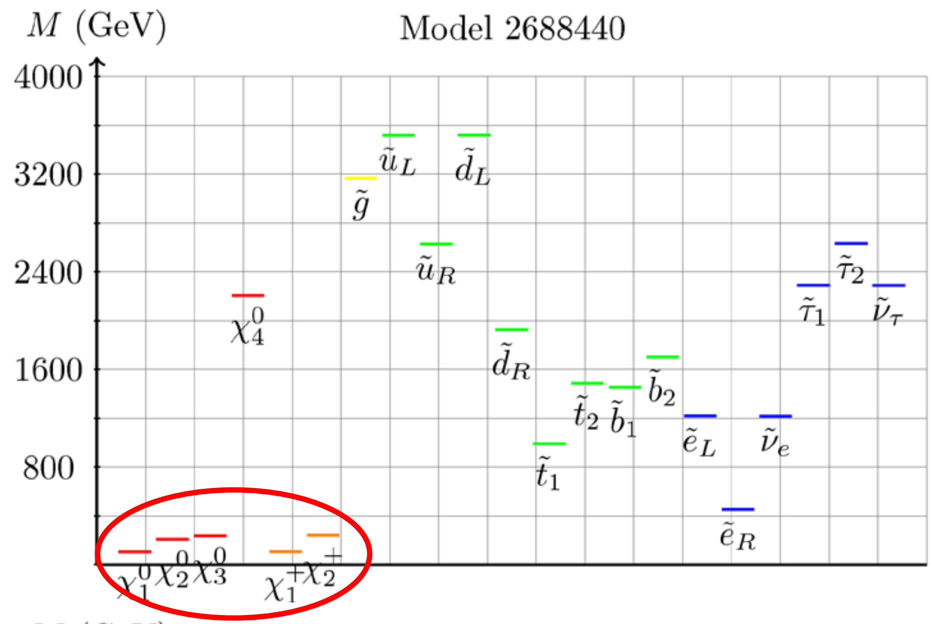


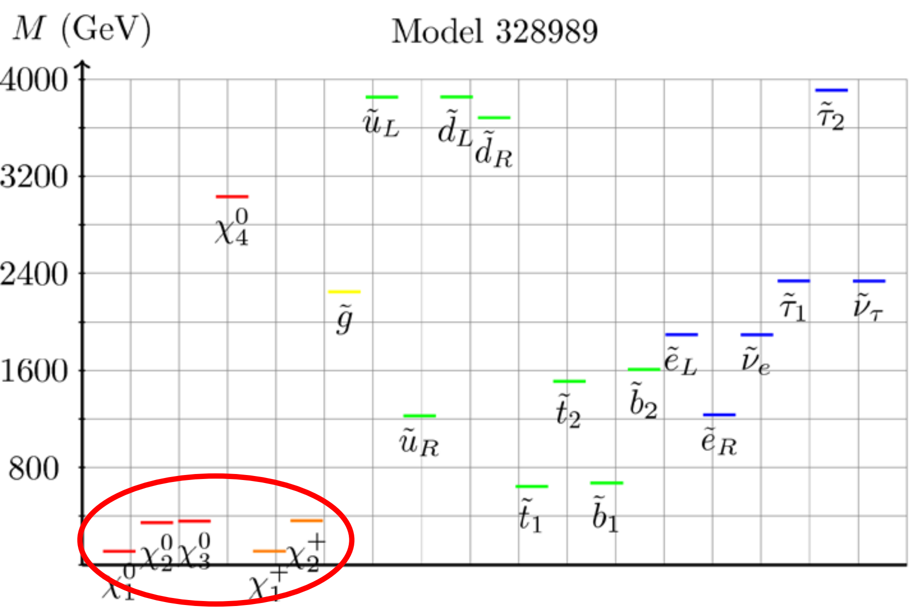


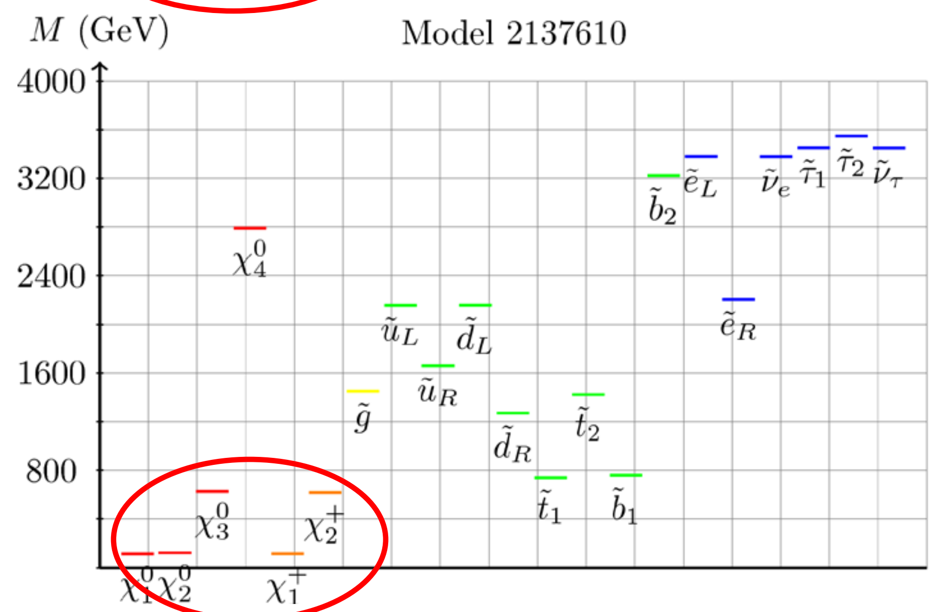


The Better Models & Their Natures III



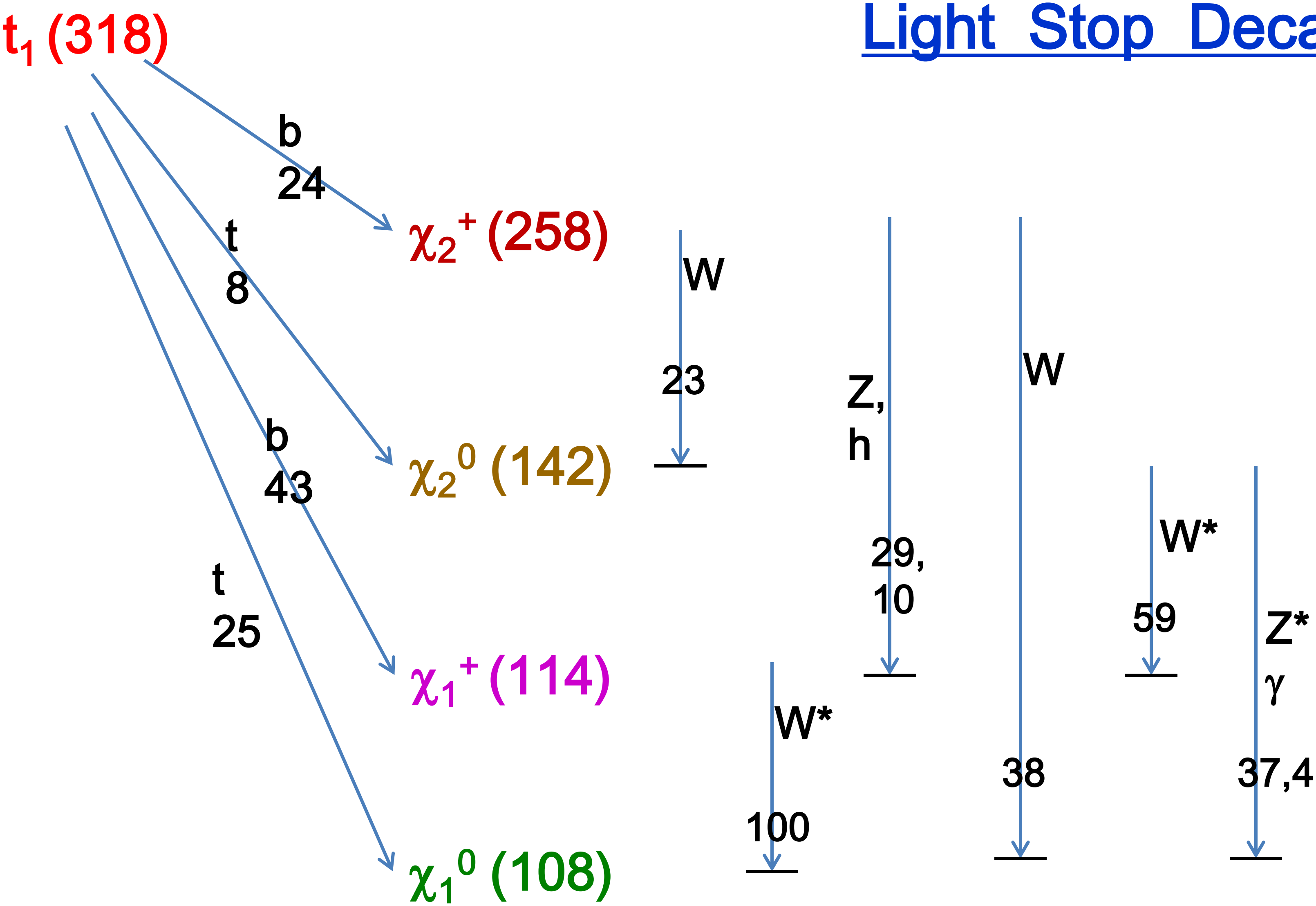




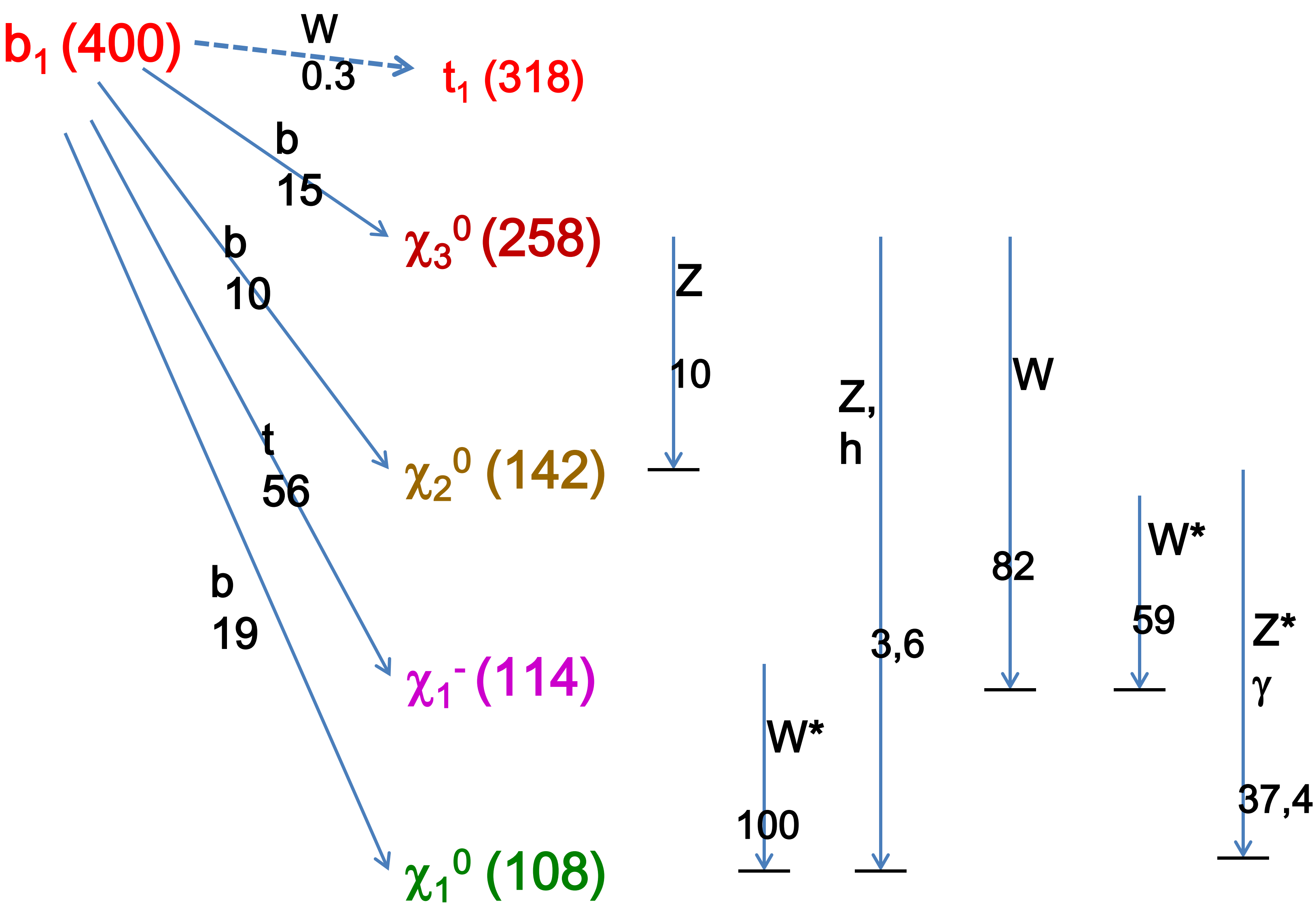


An ‘easy’ example :
#2403883 w/ FT=56.3

Light Stop Decays



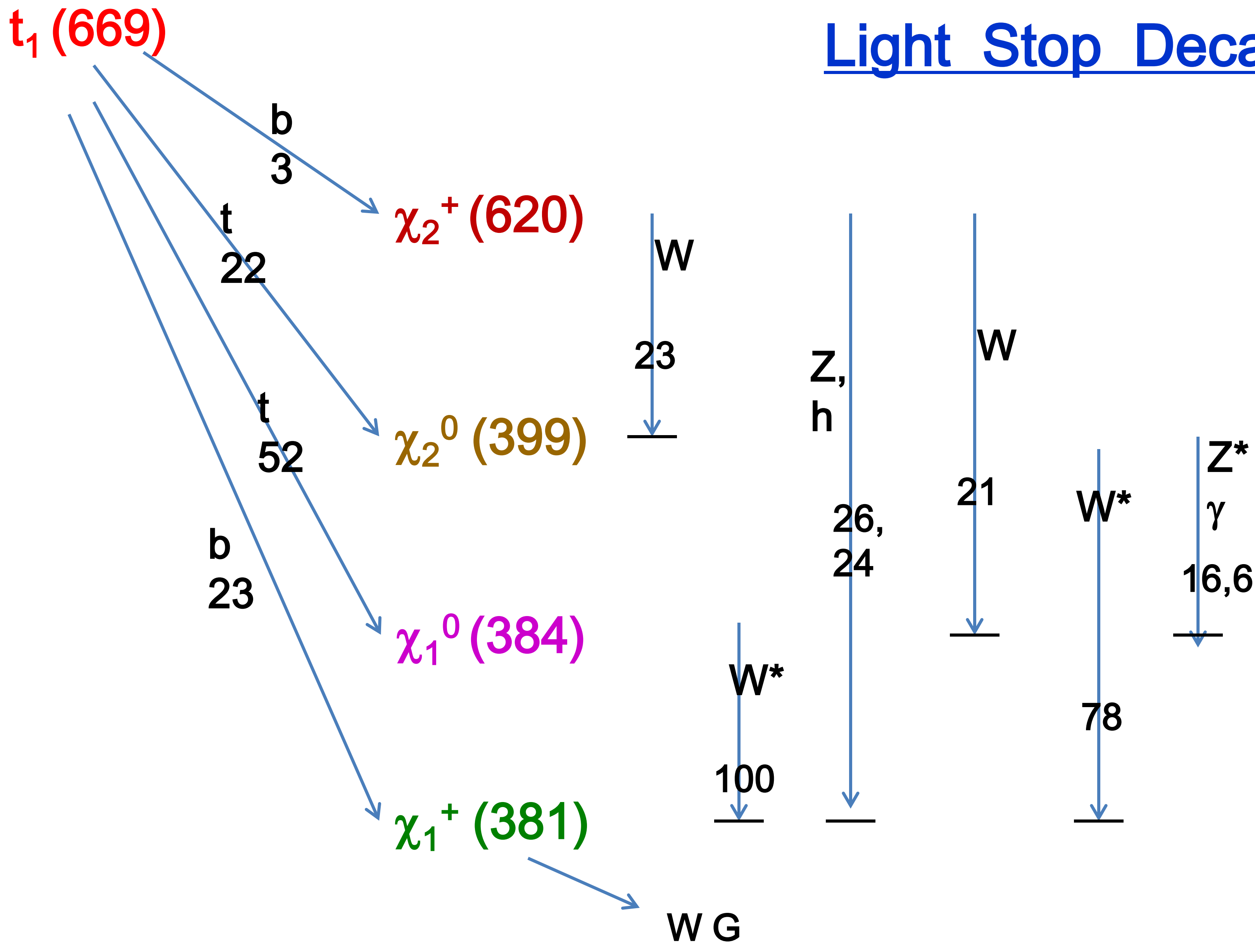
Light Sbottom Decays



This SPECIFIC model is now excluded by bjet+MET & light stop searches..but no others

An Example :
#146314G w/ FT=95.9

Light Stop Decays



Backing off to FT=120, what do we learn ?

- → 5 G models… Those gravitino LSP models have winos & Higgsino below the stop w/ the NLSP being the lightest neutralino or chargino quite similar to the neutralino cases.

- → 50 χ models… of which 32 survive the 7/8 TeV ATLAS MET searches ~10% of these models have all the EWK-inos below the stop/sbottom…the heaviest EWK-ino is the bino.

- These results further verify the patterns seen in the original 13(1) models

Summary & Conclusions

- The pMSSM with either neutralino or gravitino LSPs shows a wide range of very interesting properties. The gravitino case has not been explored until now & may yield some unexpected results

- LHC searches, both with & w/o MET, are cutting into these two model parameter spaces

- SUSY signals can populate a very large variety of search channels all of which must be examined to cover the pMSSM parameter space

- As $\sqrt{s}$ increases some SUSY models may be by-passed

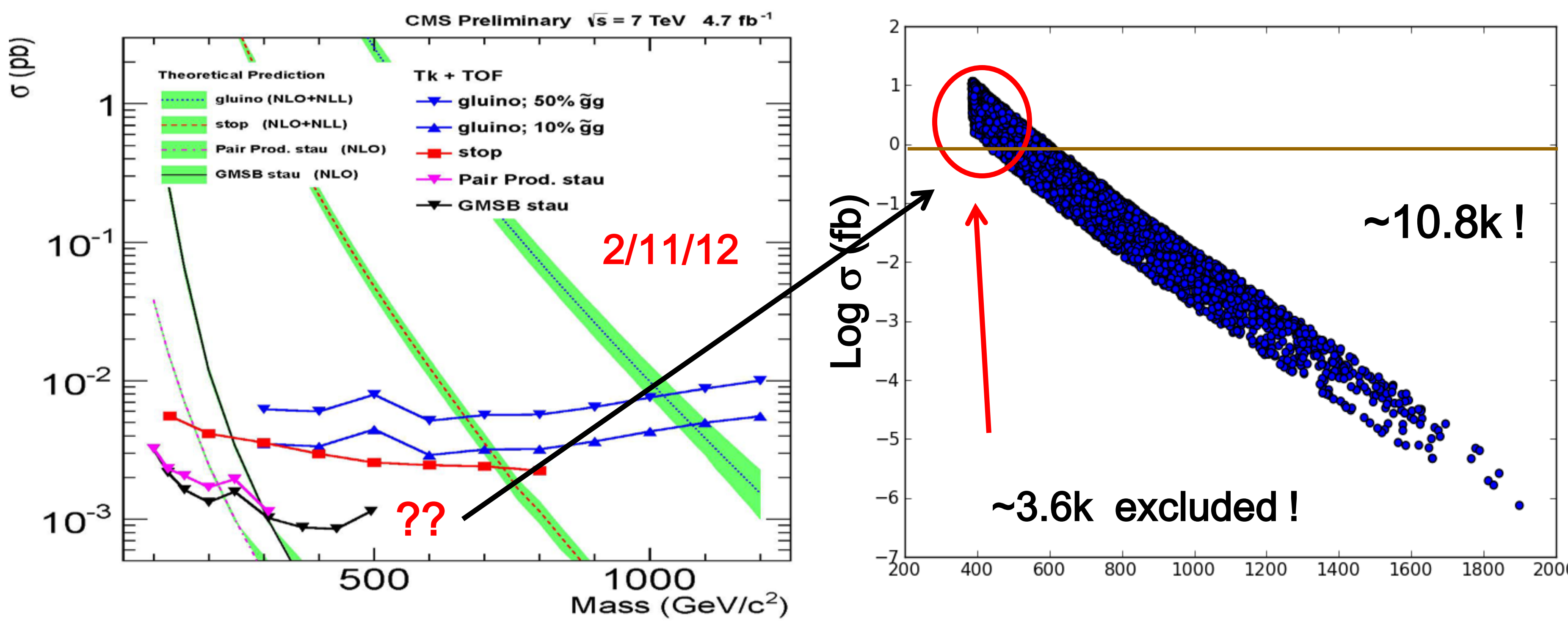
Summary & Conclusions II

- Going to 8 TeV with all analyses and full luminosity will be a significant step in model coverage
- Multiple searches are necessary to maximize parameter space coverage
- Higgs results will now play a critical role in all future studies & may dominate constraints on pMSSM parameter space
- Low FT models have similar features & could be tough to find
- We're looking forward to more 8 TeV results !

BACKUPS

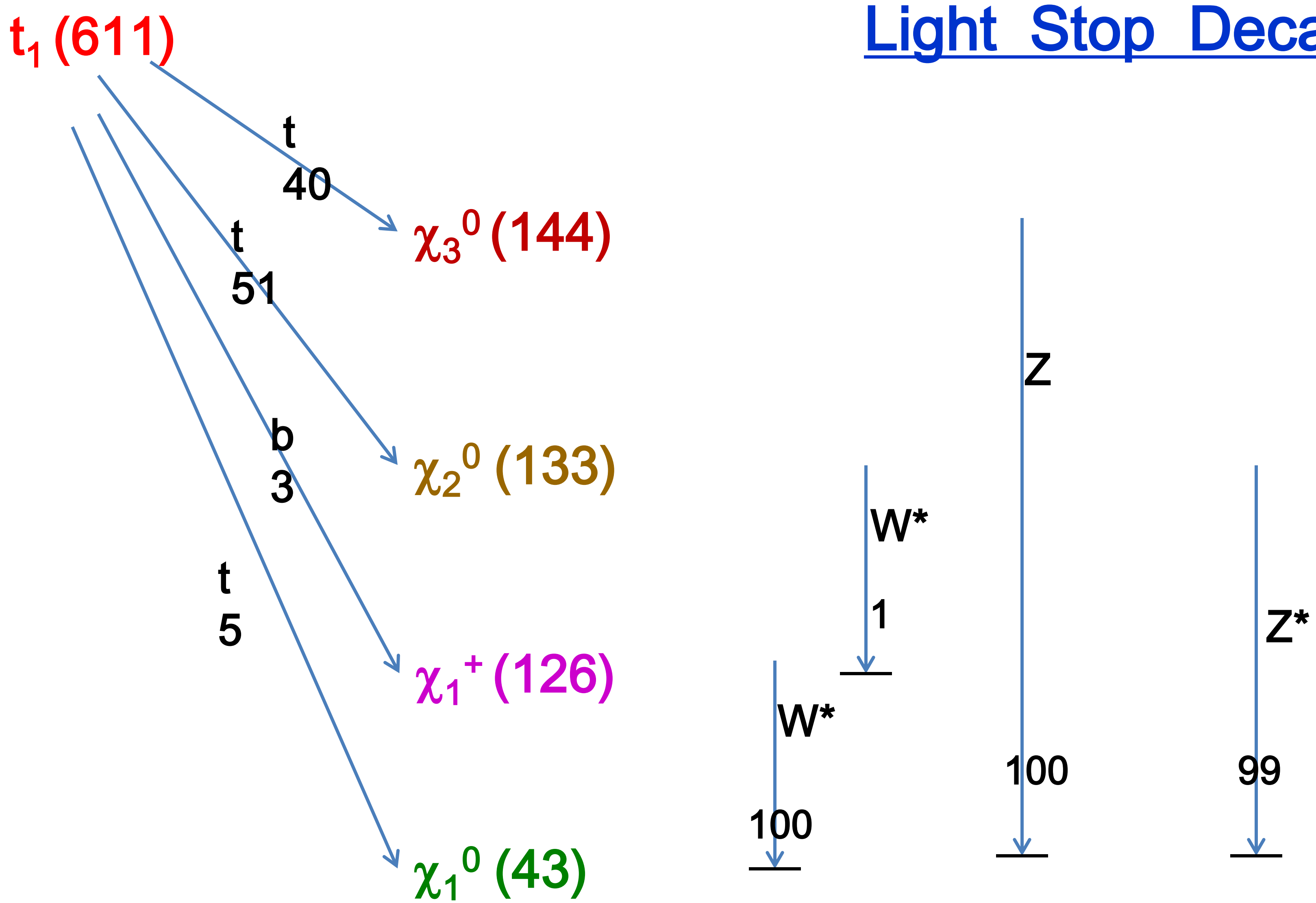
Detector Stable Charginos

- Searches for stable and/or long-lived sparticles can be quite powerful for both χ_1^0 or G LSP sets
- E.g., detector-stable charginos are quite common in χ_1^0 LSP models & extend out to large masses :

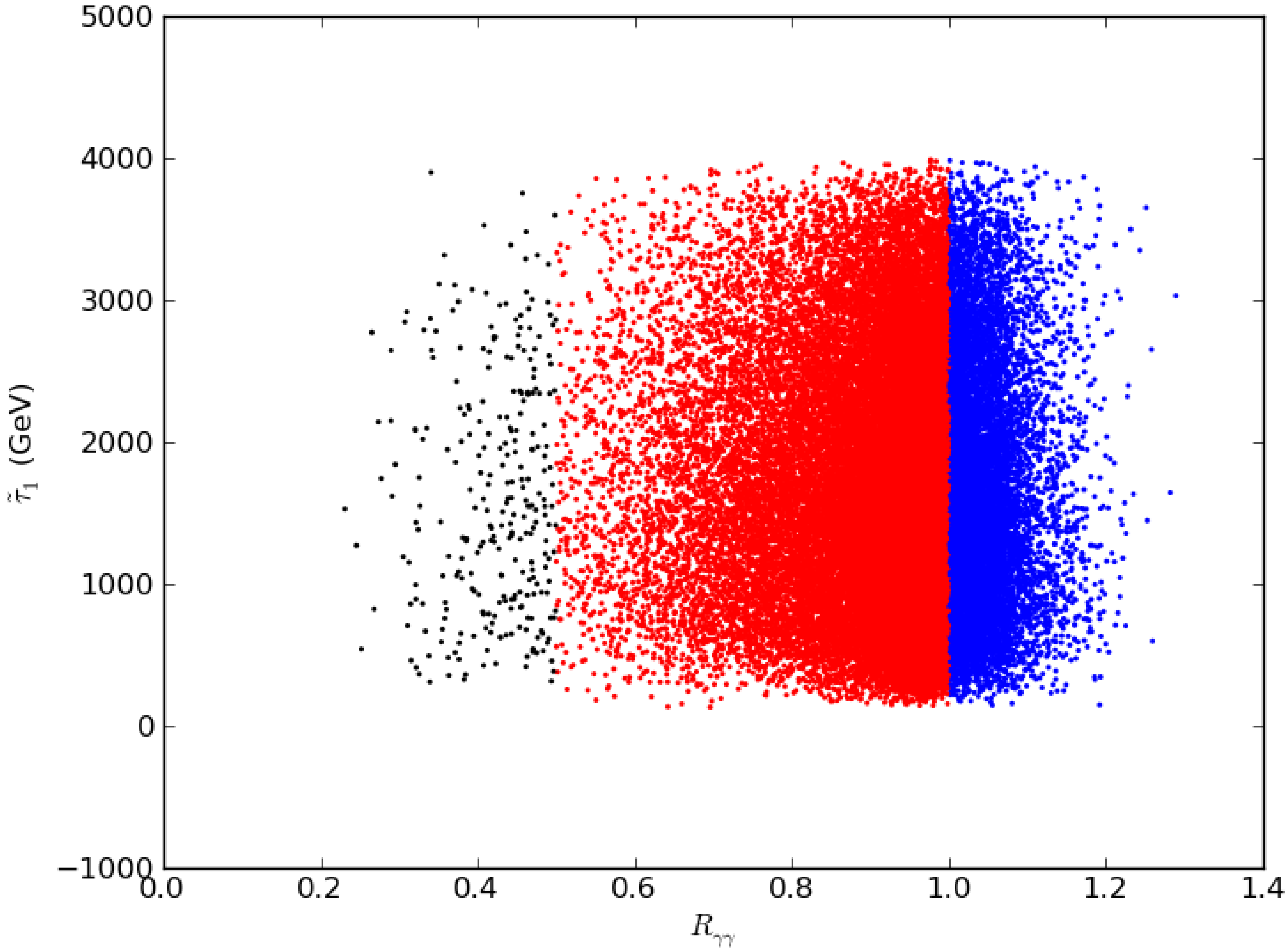


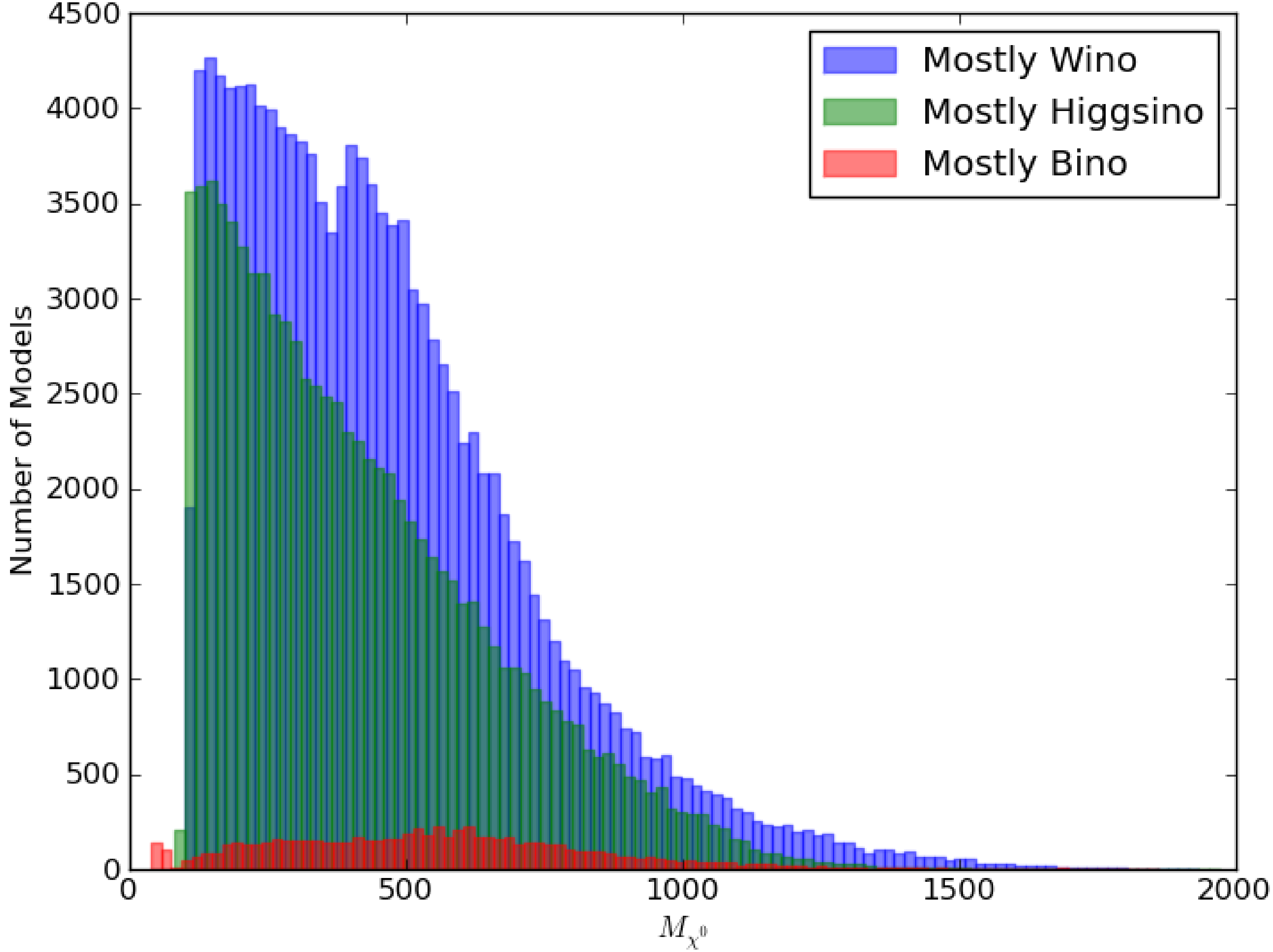
An Example :
#2592398 w/ FT_{BBHMT} =6.6

Light Stop Decays



No significant correlation between the lightest stau mass and $R_{\gamma\gamma}$





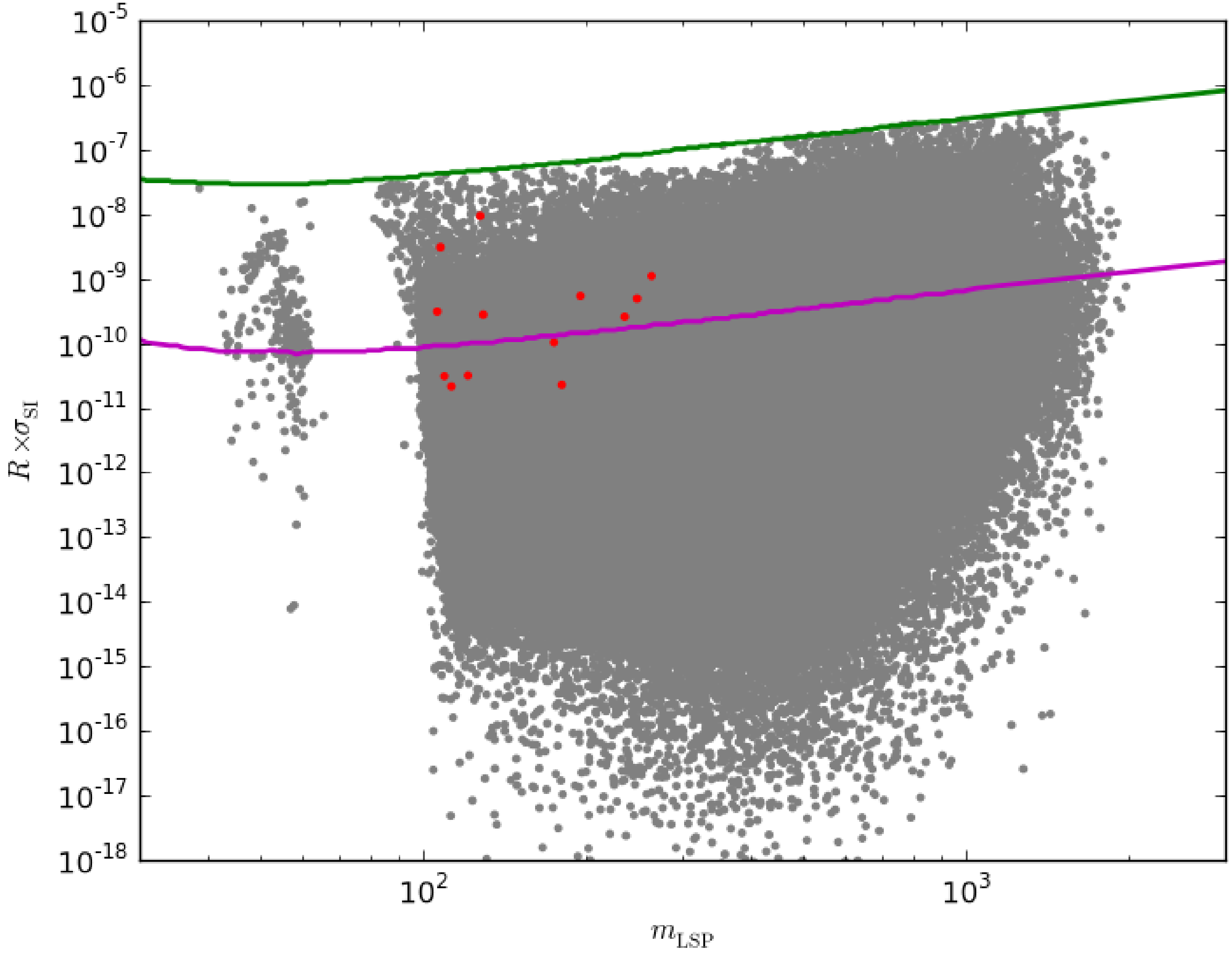
Mostly Wino
Mostly Higgsino
Mostly Bino
Number of Models
M_{χ^0}
0
500
1000
1500
2000
2500
3000
3500
4000
4500

FT Gluino Mass Constraint

$$Z_{M_3}^{NLL} = \frac{2\alpha_s X^2}{(3\pi^3)(t_\beta^2 - 1)} \frac{M_3}{M_Z^2} \left[-y_b^2(2M_3 - A_b) + t_\beta^2 y_t^2 (2M_3 - A_t) \right]$$

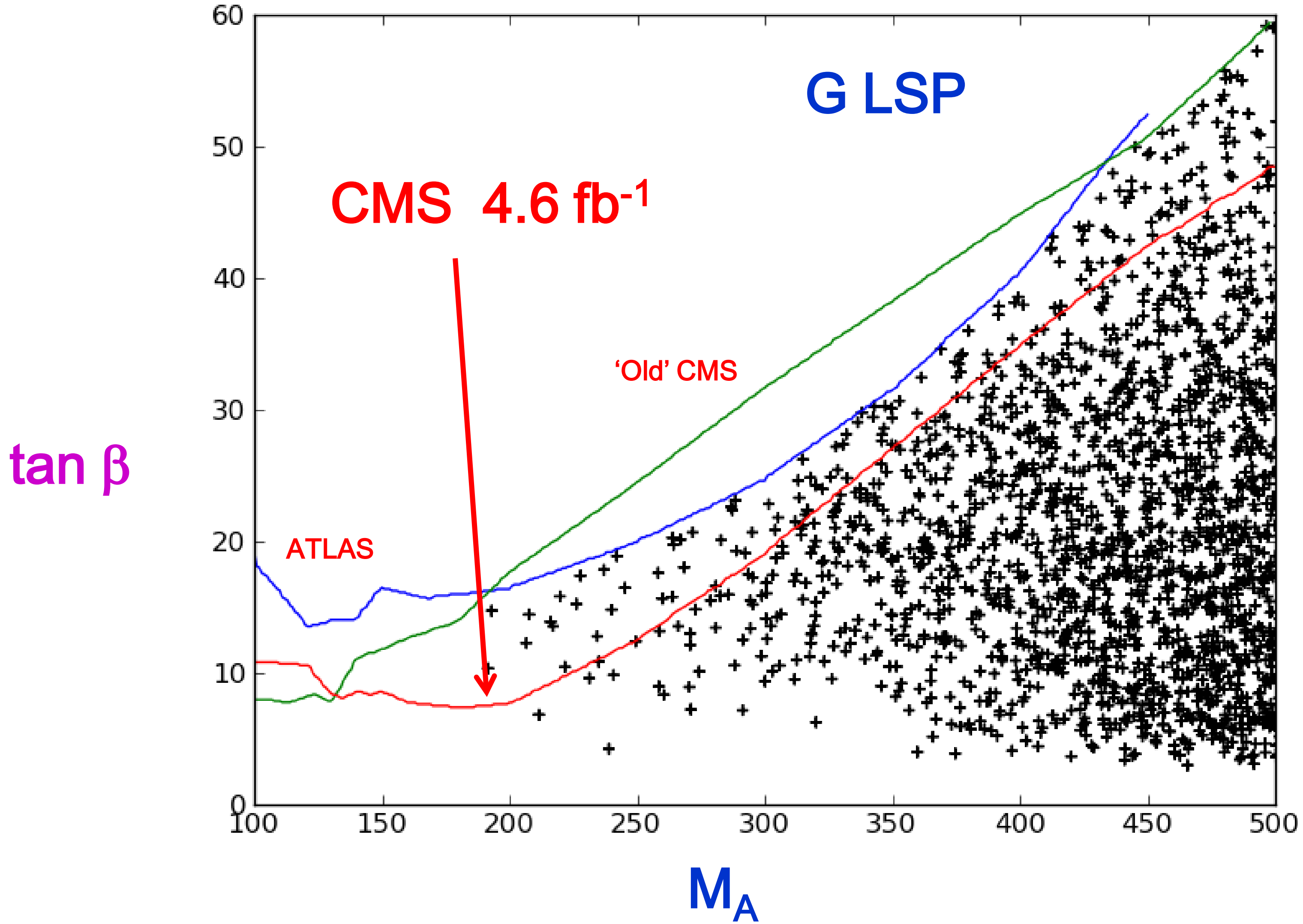
For large $t_\beta^2 >> 1$ & with $(y_b / t_\beta y_t)^2 << 1$ we get

$\approx 1.16\ M_3 (2M_3 - A_t) / \text{TeV}^2 <\ \sim 56$ since $M_3, |A_t| < 4$ TeV



10-5
10-6
10-7
10-8
10-9
10-10
10-11
10-12
10-13
10-14
10-15
10-16
10-17
10-18
$R \times \sigma_{\rm SI}$
10^2
10^3
$m_{\rm LSP}$

Impact of A,H →ττ Searches



The 19(20) Parameter pMSSM

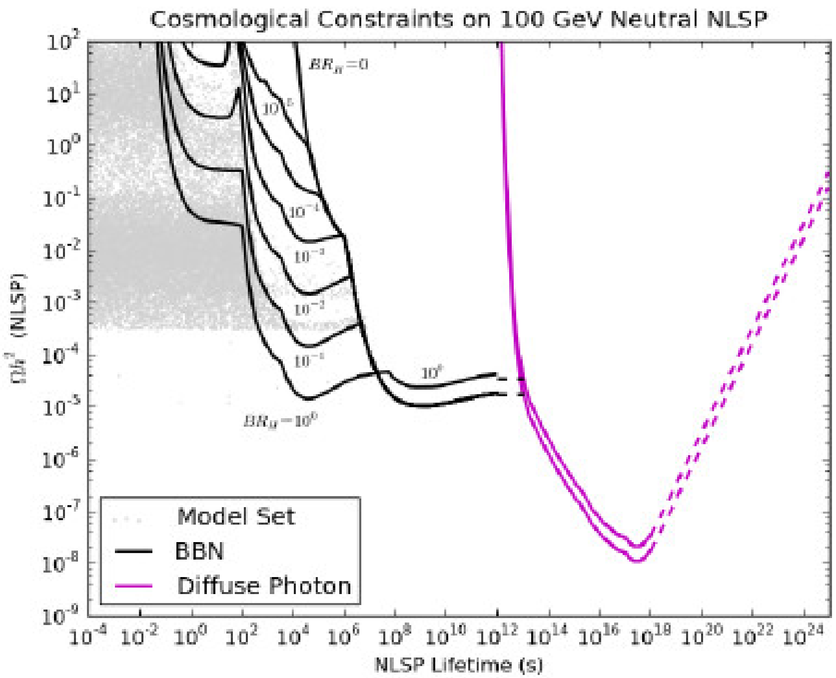
10 sfermion masses: m_{Q_1}, m_{Q_3}, m_{u_1}, m_{d_1}, m_{u_3}, m_{d_3}, m_{L_1}, m_{L_3}, m_{e_1}, m_{e_3}

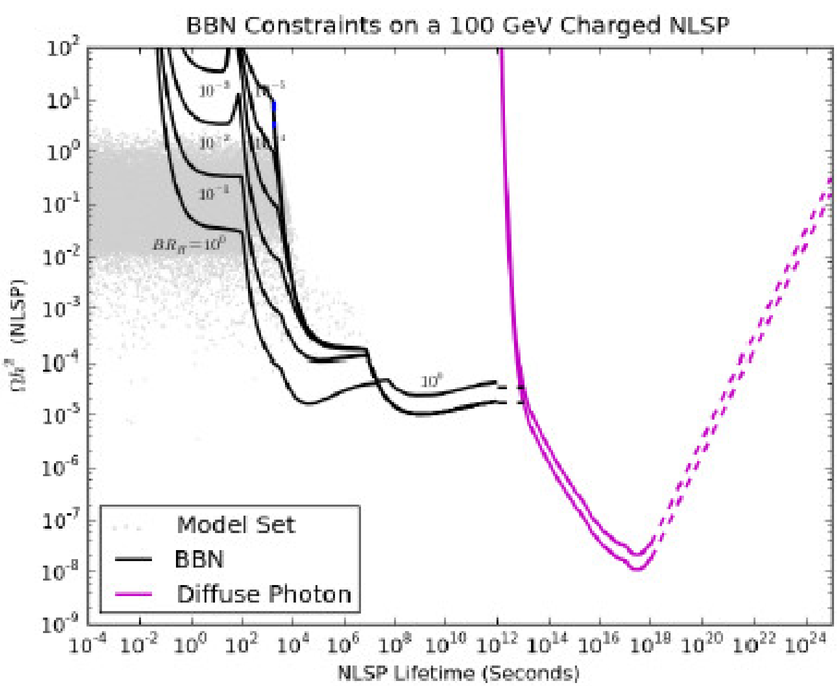
3 gaugino masses: M_1, M_2, M_3

3 tri-linear couplings: A_b, A_t, A_τ

3 Higgs/Higgsino: μ, M_A, $\tan\beta$

→→ (+ 1 gravitino mass : $m_{3/2}$)





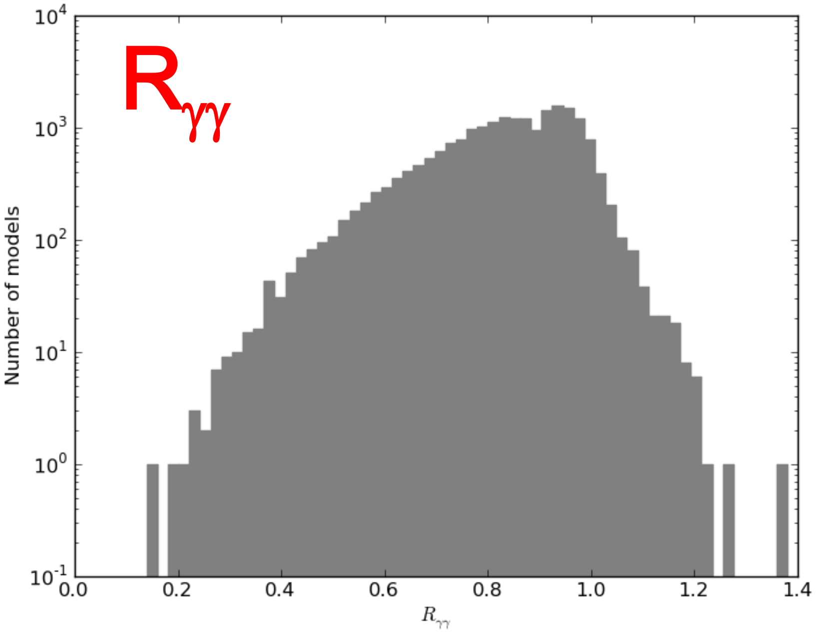
Sample constraints from BBN and diffuse γ's for different hadronic branching fractions of the NLSP

Shaded areas show where our gravitino models live

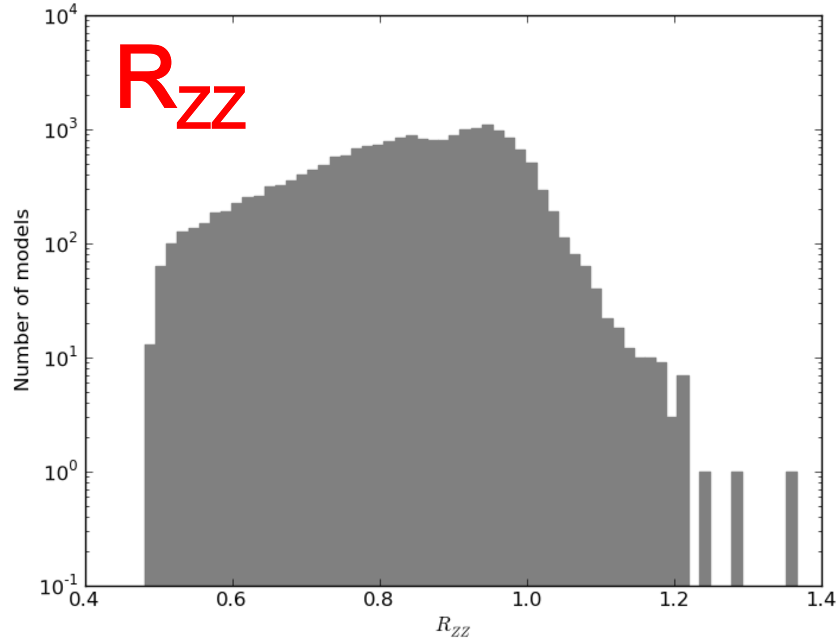
We follow :

Jedamzik;
Kusakabe et al.;
Kanazaki et al.;
Kribs and Rothstein;
.....

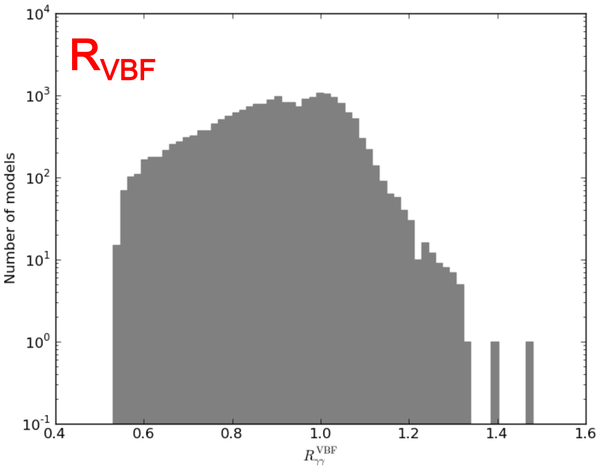
G LSP



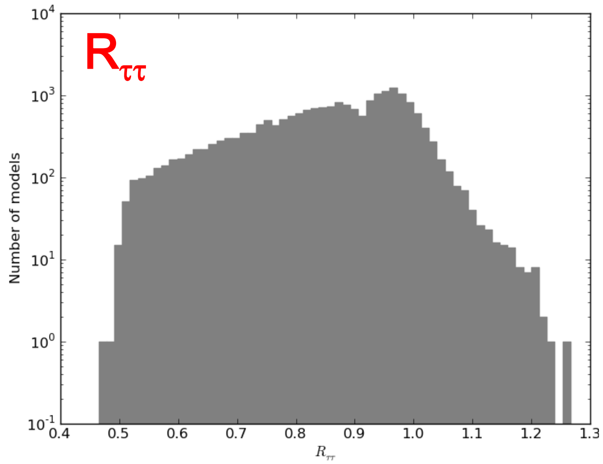
$R_{\gamma\gamma}$
Number of models
$R_{\gamma\gamma}$



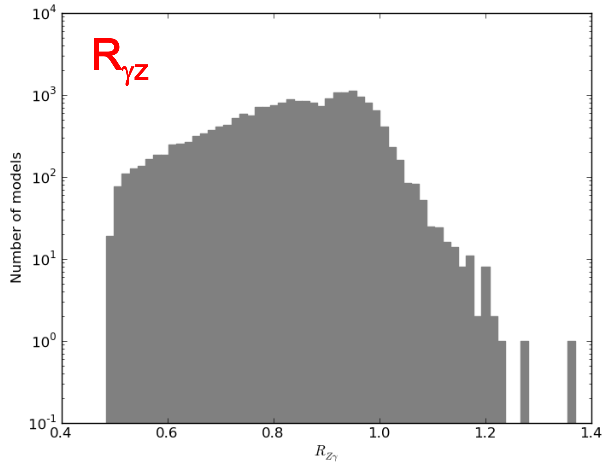
R_{ZZ}
Number of models
R_{ZZ}



R_{VBF}
Number of models
$R_{\gamma\gamma}^{VBF}$



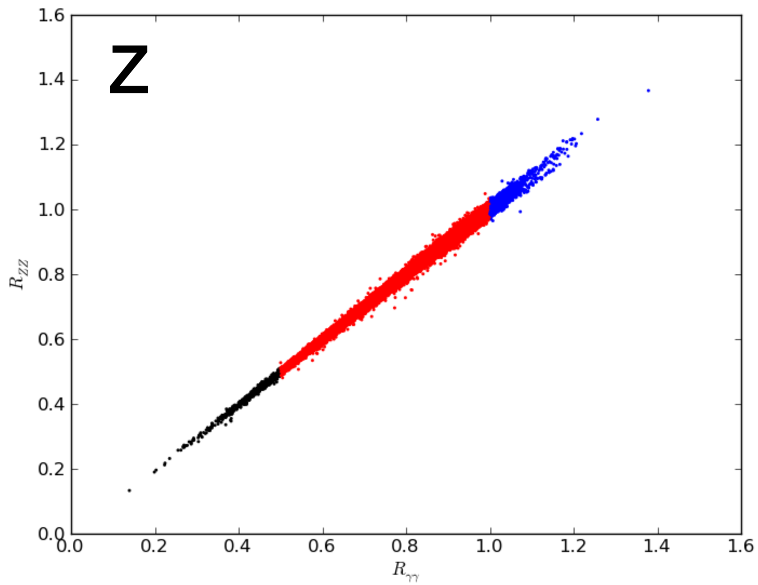
$R_{\tau\tau}$
Number of models
$R_{\tau\tau}$

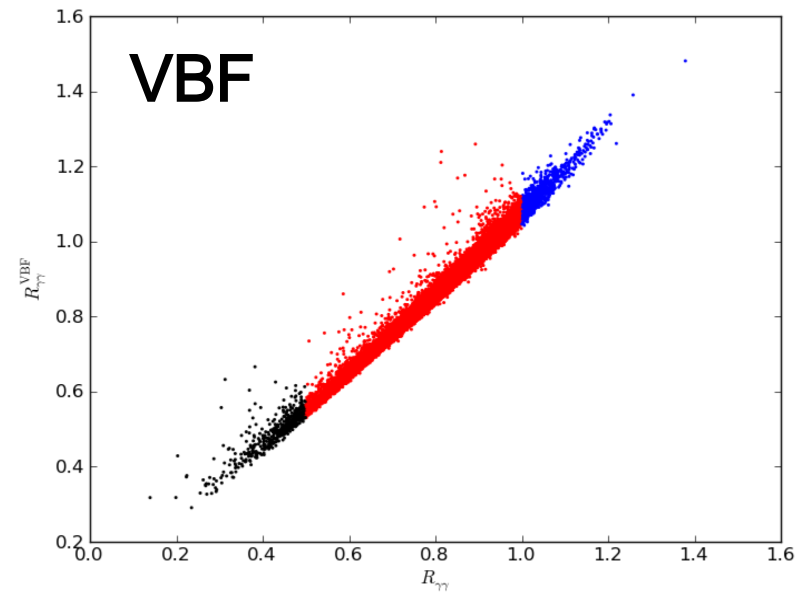


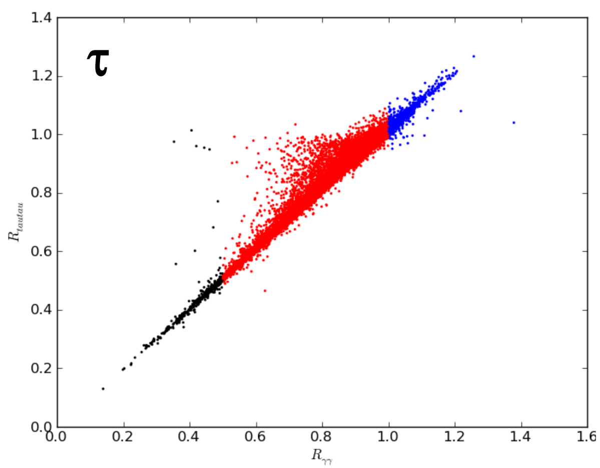
$R_{\gamma Z}$
Number of models
$R_{Z\gamma}$

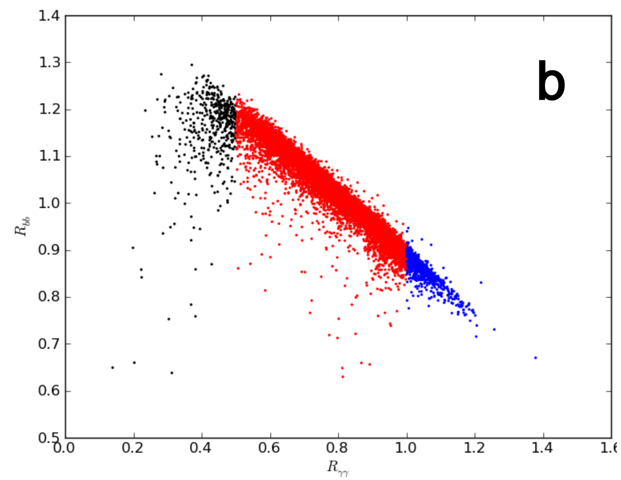
G LSP

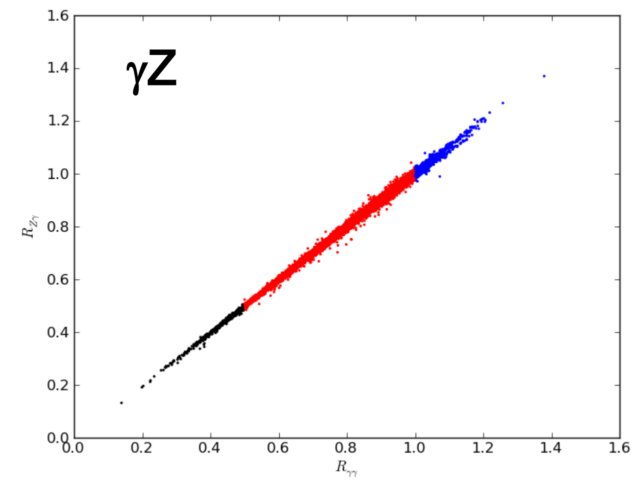
Very Highly Correlated !





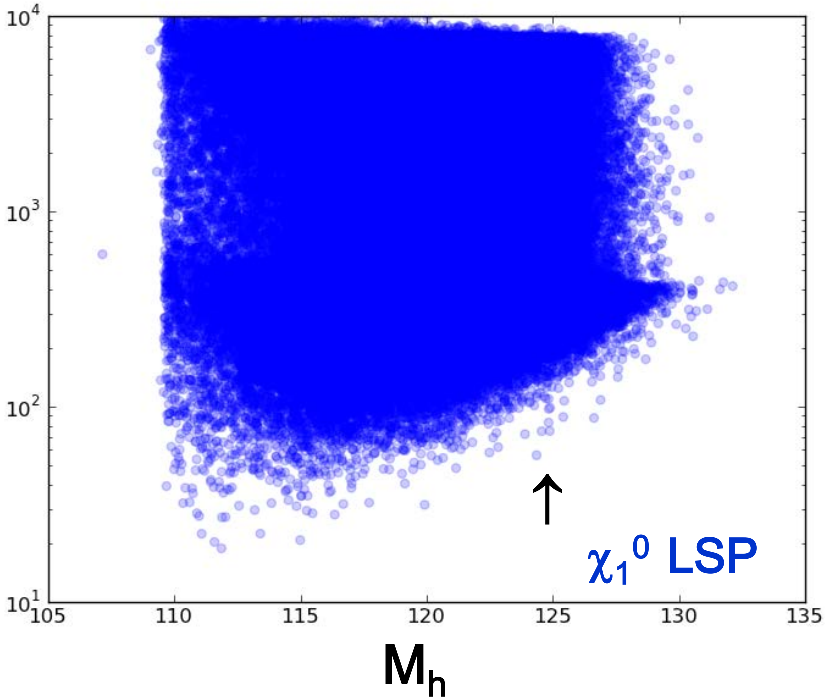


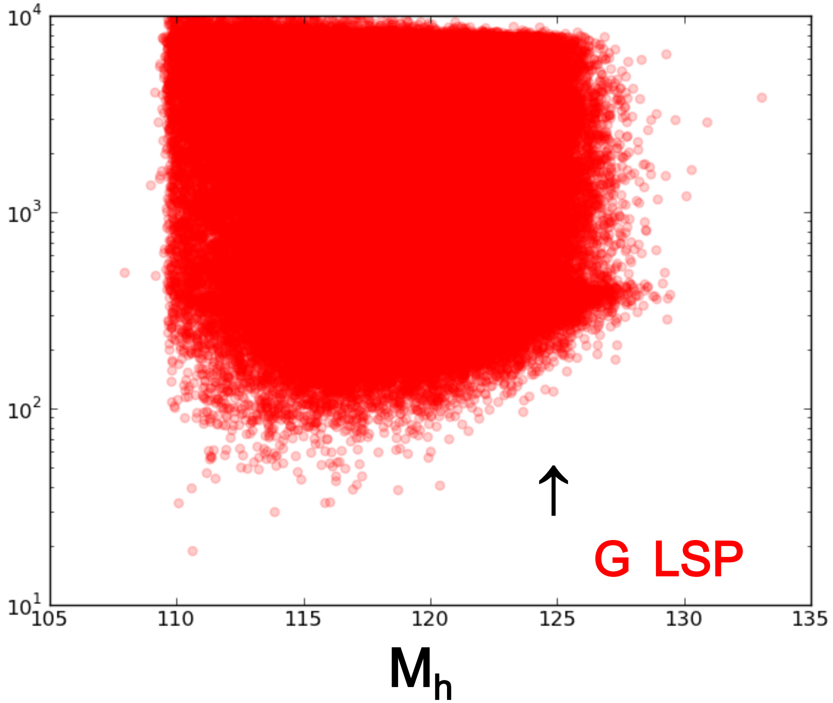




FT vs. Higgs mass distributions for both model sets

Δ



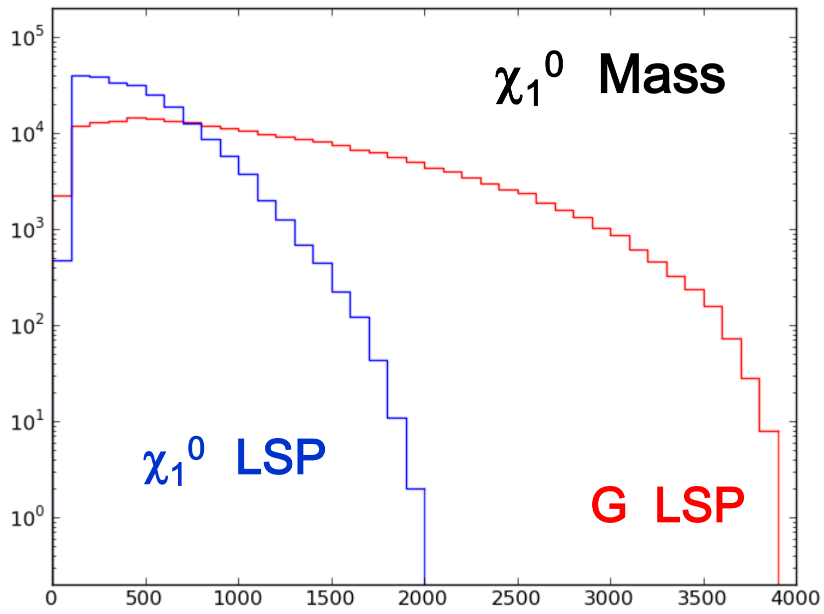


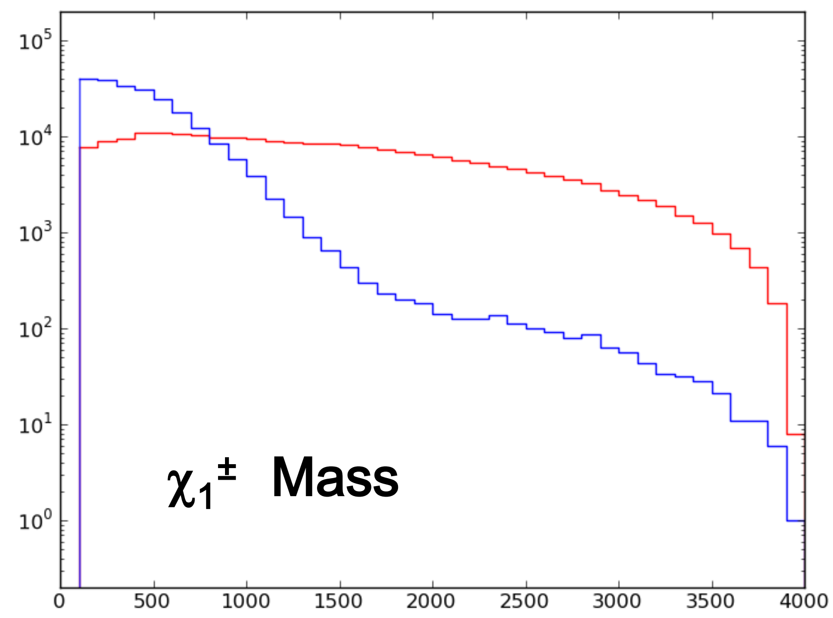
As is well-known, FT prefers lighter Higgs masses. Overall the G LSP models, on average, have slightly more FT than do χ LSP models.

- The mass spectra of the MSSM fields are (indirectly) influenced by the nature of the LSP, i.e., the fact that G can be VERY light whereas χ_1^0 must be > ~ 10's of GeV in the scan..

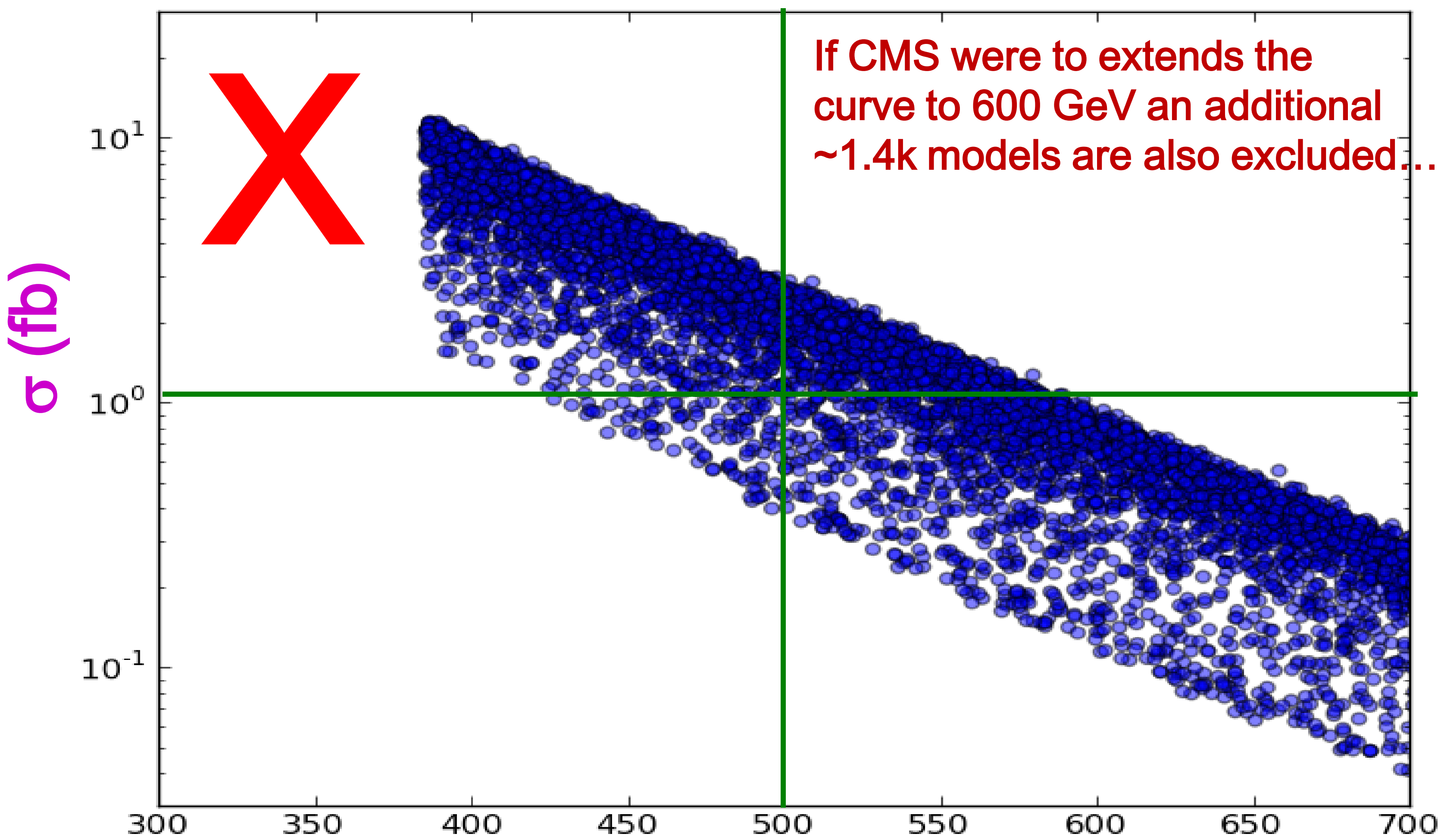
- E.g., since the lightest neutralino is at best the NLSP in the G scan, its mass distribution must now extend to larger values

- Other sparticle masses are less influenced due to scan ranges

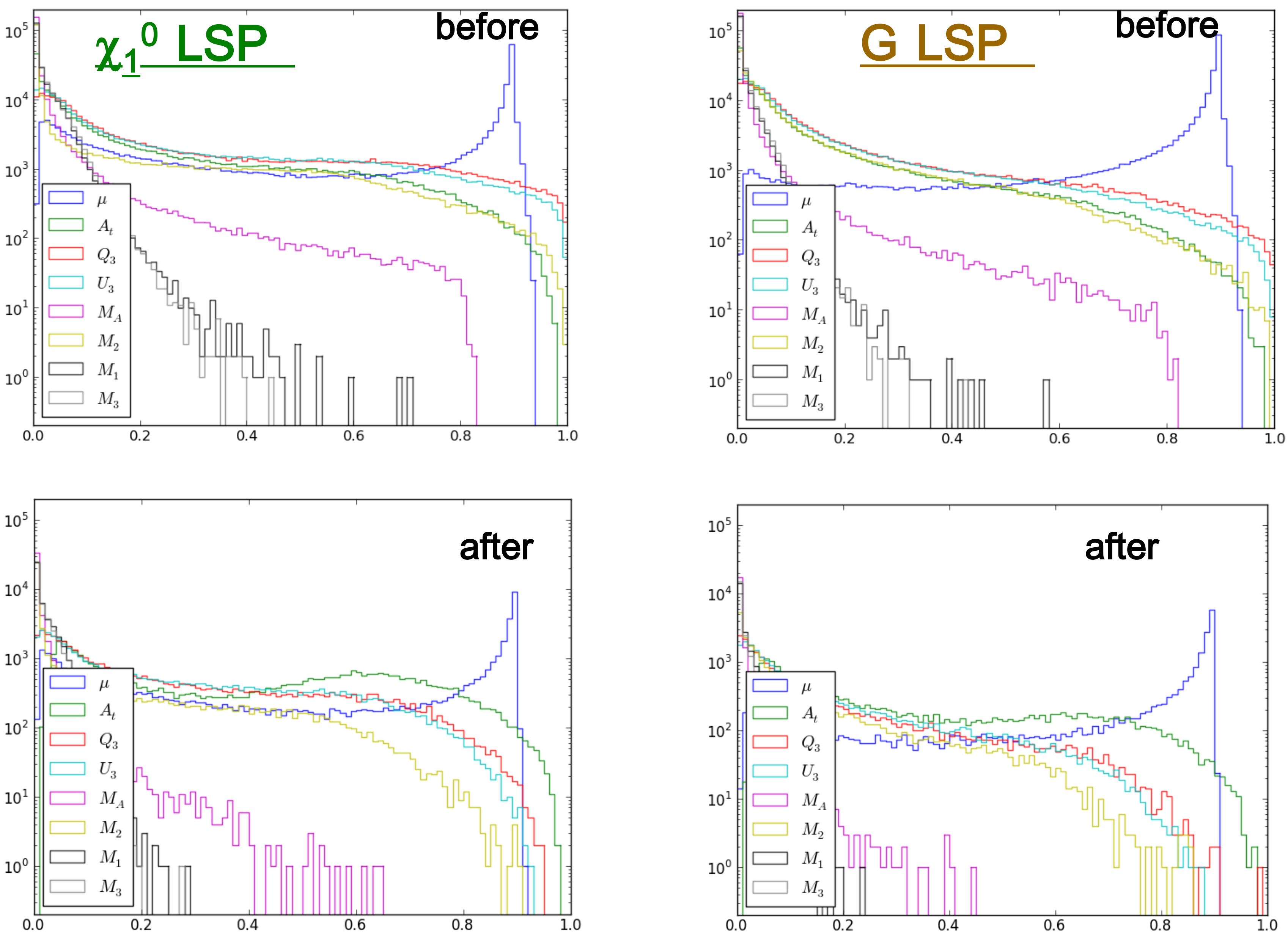


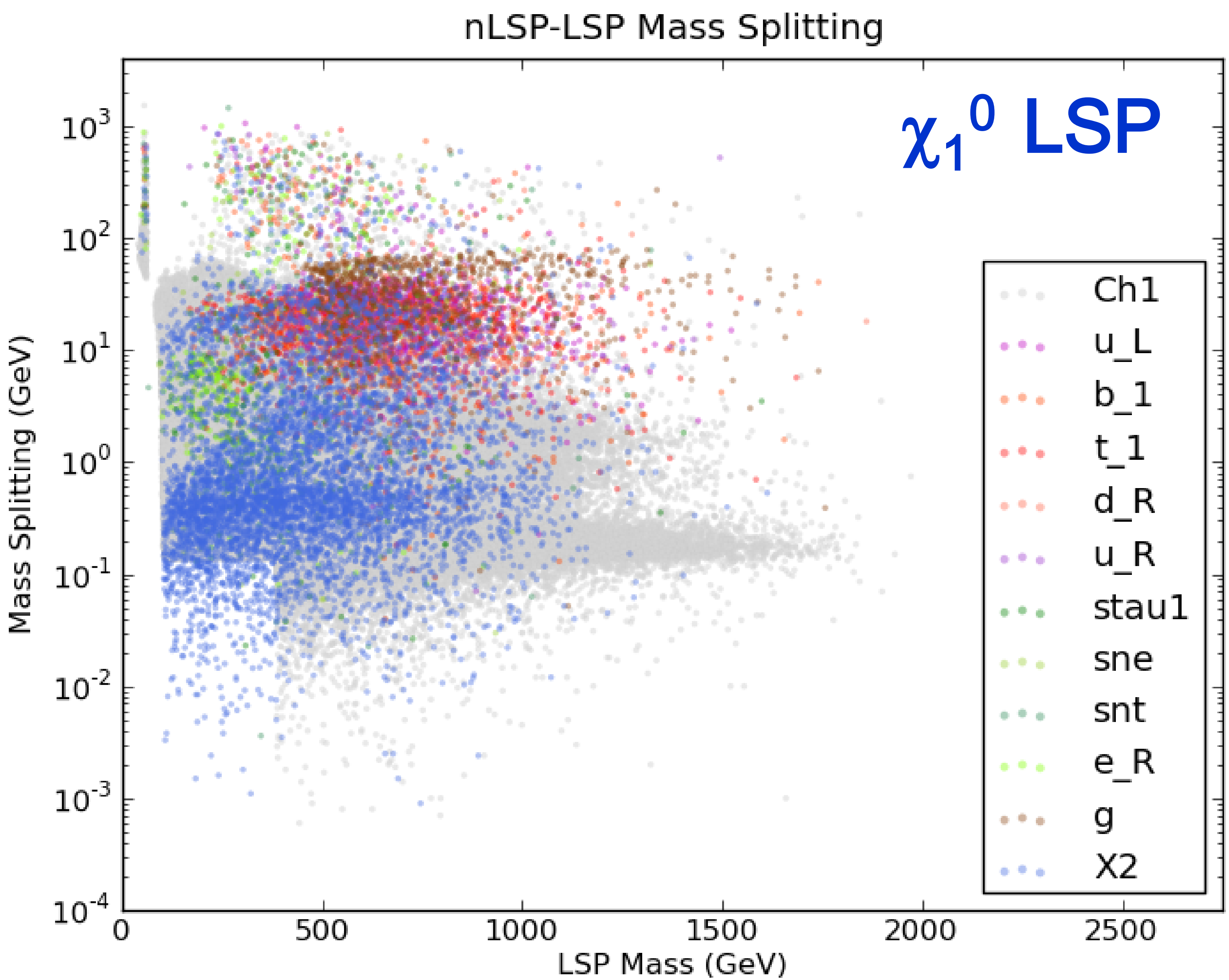


• 3581 (!!) models (conservatively) are removed by stable particle searches w/ ~ 5 fb^{-1} @ 7 TeV



Fractional Contribution to FT





nLSP-LSP Mass Splitting
χ_1^0 LSP
Mass Splitting (GeV)
LSP Mass (GeV)
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
500
1000
1500
2000
2500
Ch1
u_L
b_1
t_1
d_R
u_R
stau1
sne
snt
e_R
g
X2