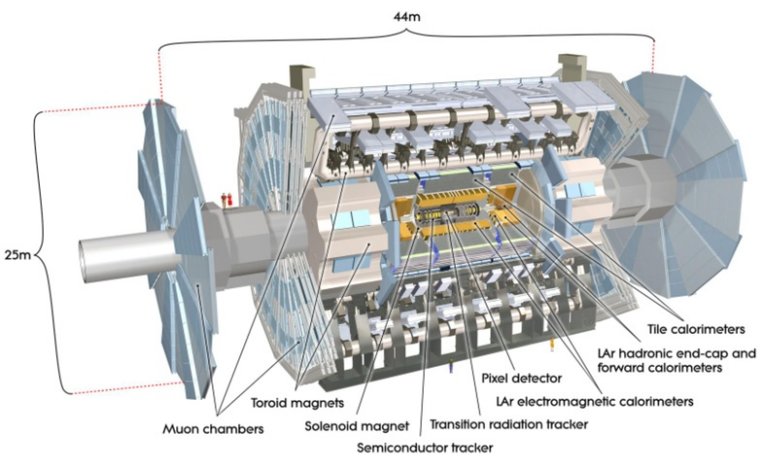
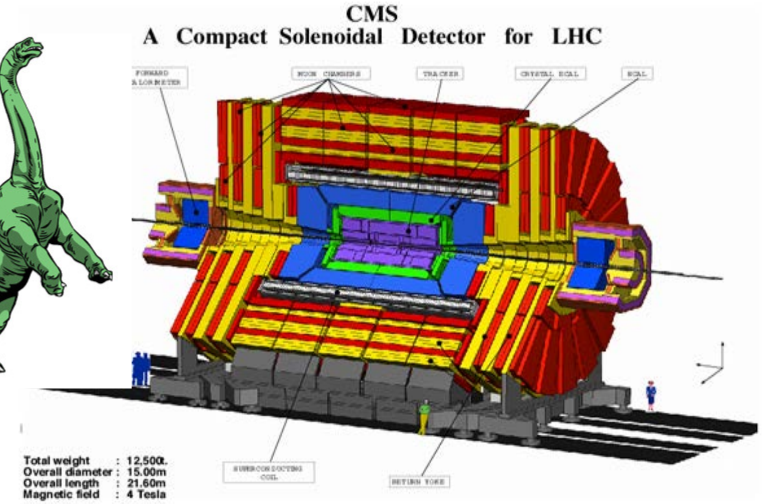
SUSY w/o Prejudice @ LHC-7 & -8





3/29/12

NATIONAL ACCELERATOR LABORATORY

J.L. Hewett, S. Hoeche, A. Ismail, T.G.R., M. W. Rowley

Searches for SUSY @ the LHC keep going and going but have not found any signals (yet)…

However they ARE eating into a lot of the model parameter space…

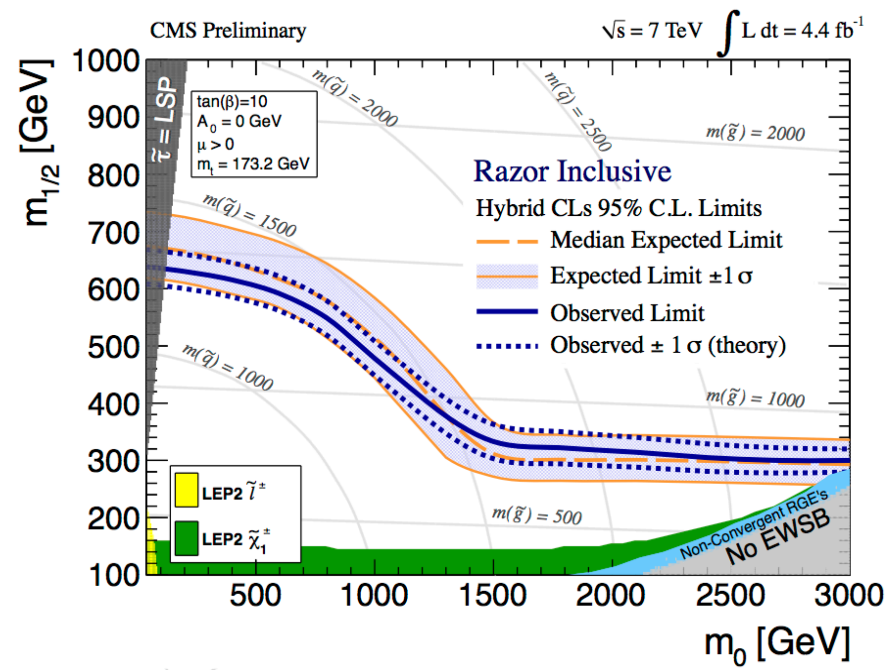
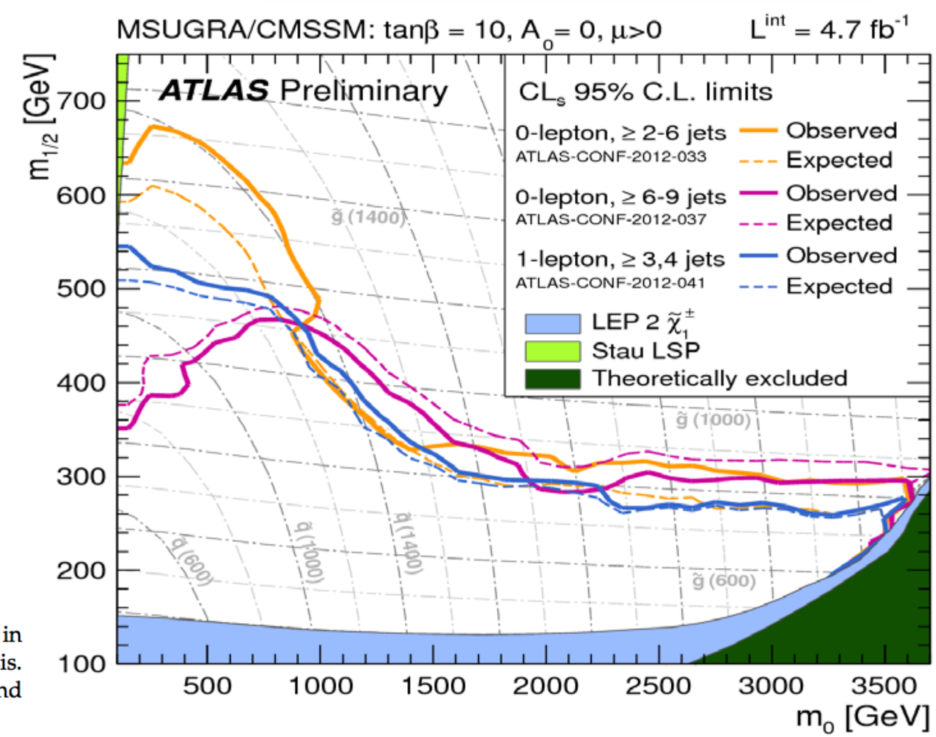


Figure 10: Observed (solid curve) and median expected (dot-dashed curve) 95% CL limits in the $(m_0, m_{1/2})$ CMSSM plane with $\tan\beta = 10$, $A_0 = 0$, $\mathrm{sgn}(\mu) = +1$ from the razor analysis. The ± one standard deviation equivalent variations in the uncertainties are shown as a band around the median expected limit.



Two New pMSSM Scans: Neutralino & Gravitino LSPs

(via SOFTSUSY +SuSpect + FeynHiggs)

$100 \text{ GeV} \leq m_{Ll1,2,3} \leq 4 \text{ TeV}$

$400 \text{ GeV} \leq m_{Qud1,2} \leq 4 \text{ TeV}$ $\quad$ $200 \text{ GeV} \leq m_{Qud3} \leq 4 \text{ TeV}$

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

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

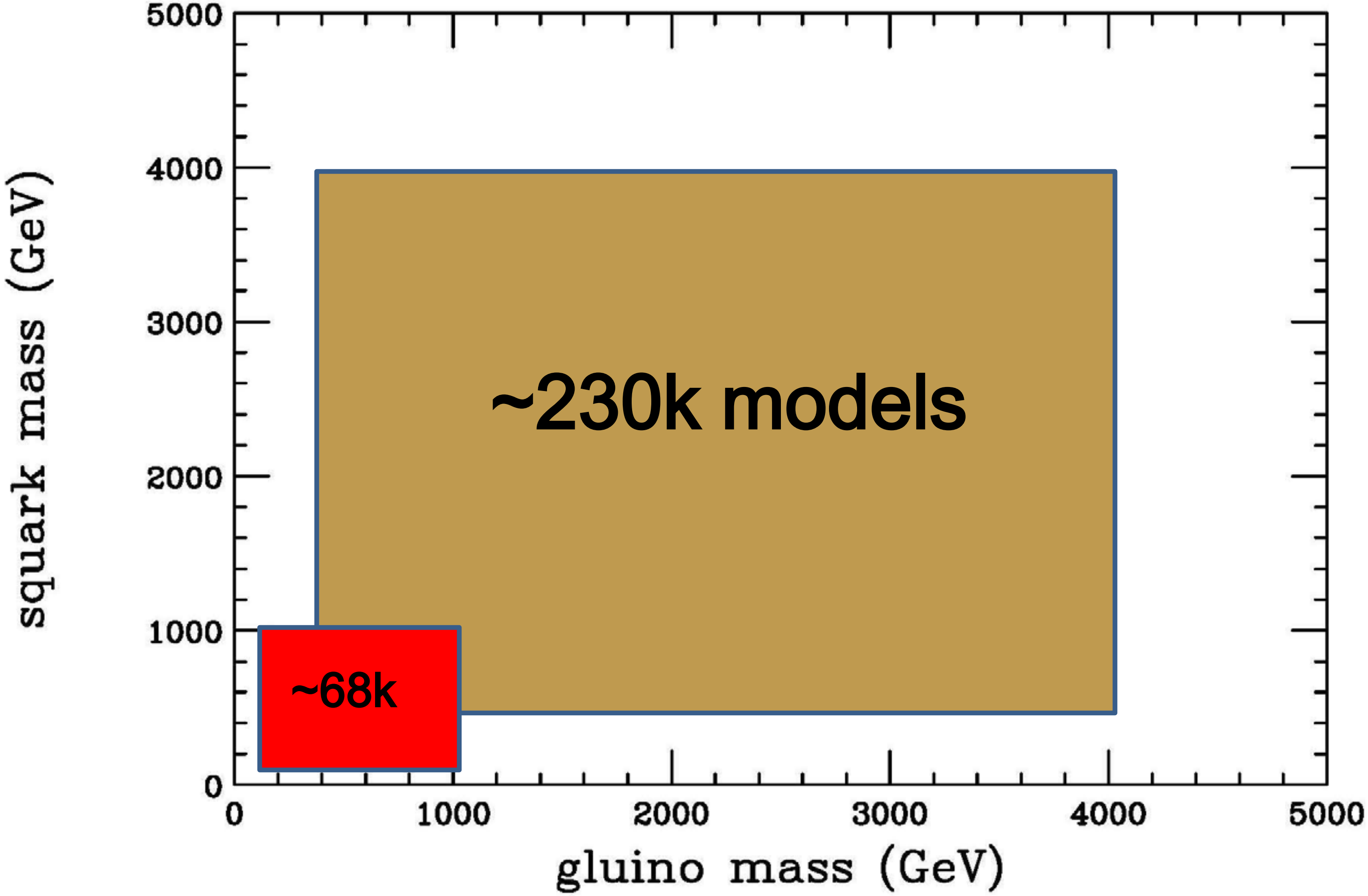
$100 \text{ GeV} \leq M_A \leq 4 \text{ TeV}$

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

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

- Apply all the usual non-LHC + all LHC non-MET constraints (as of 12/1/2011) . Additional complexities occur, eg, BBN constraints for the gravitino LSP case

A much larger volume needs to be explored…



…. for both gravitino and neutralino LSPs

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

- This is NOT generalized GMSB.. We make NO assumptions except that the gravitino is the LSP..it could be light ~1 ev or it could be heavy ~ 1 TeV ! Anybody can be the NLSP.

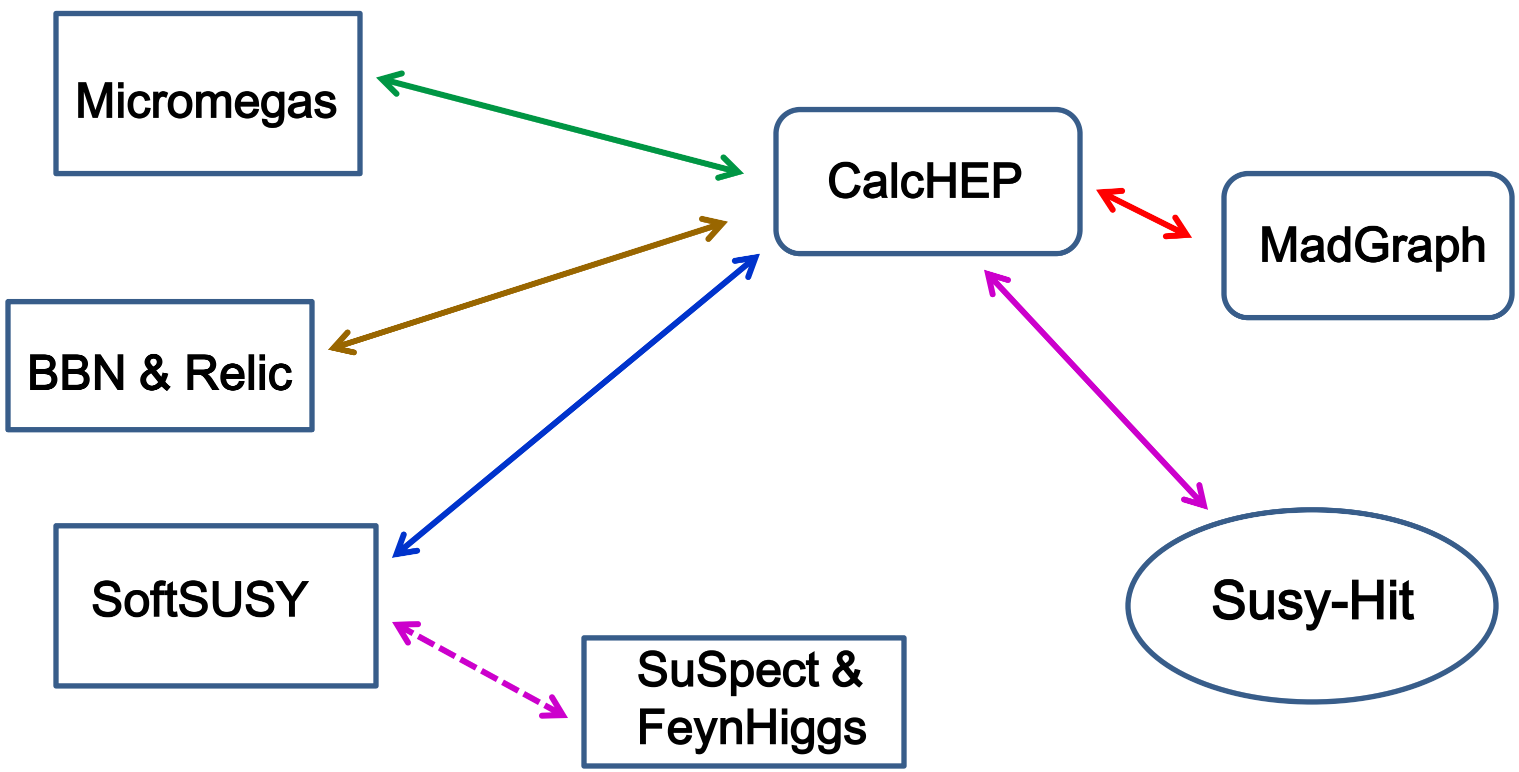
- A big issue is BBN… NLSPs in this scenario tend to be long lived & their decays will inject hadronic &/or EM energy into the early universe, possibly disrupting BBN

- Lots of NEW code needed, e.g., generalize all NLSP/NNLSP decays to the case of arbitrary gravitino mass .. Existing codes inadequate !

- Reminder: No DD or ID constraints for G LSP models

Some of the (MANY) Changes & Additions

- Decays to G's can no longer be performed in the Goldstino limit so all possible NLSP decay modes involving G's need to be recalculated …



- For non-G decays (e.g., for the NNLSP $\rightarrow$ NLSP) add all 3-body sparticle decays not in SUSY-Hit via CalcHEP

- Add relevant 4-body decays for gluinos, t_1 & $\chi_1^{\pm}$

- Add 5-body decays of t_1 via RH-sfermions

$\rightarrow$ All sparticles w/ masses larger than $m_{bottom} + m_{NLSP}$ now have complete decay tables for collider & BBN studies . NNLSPs can be detector stable

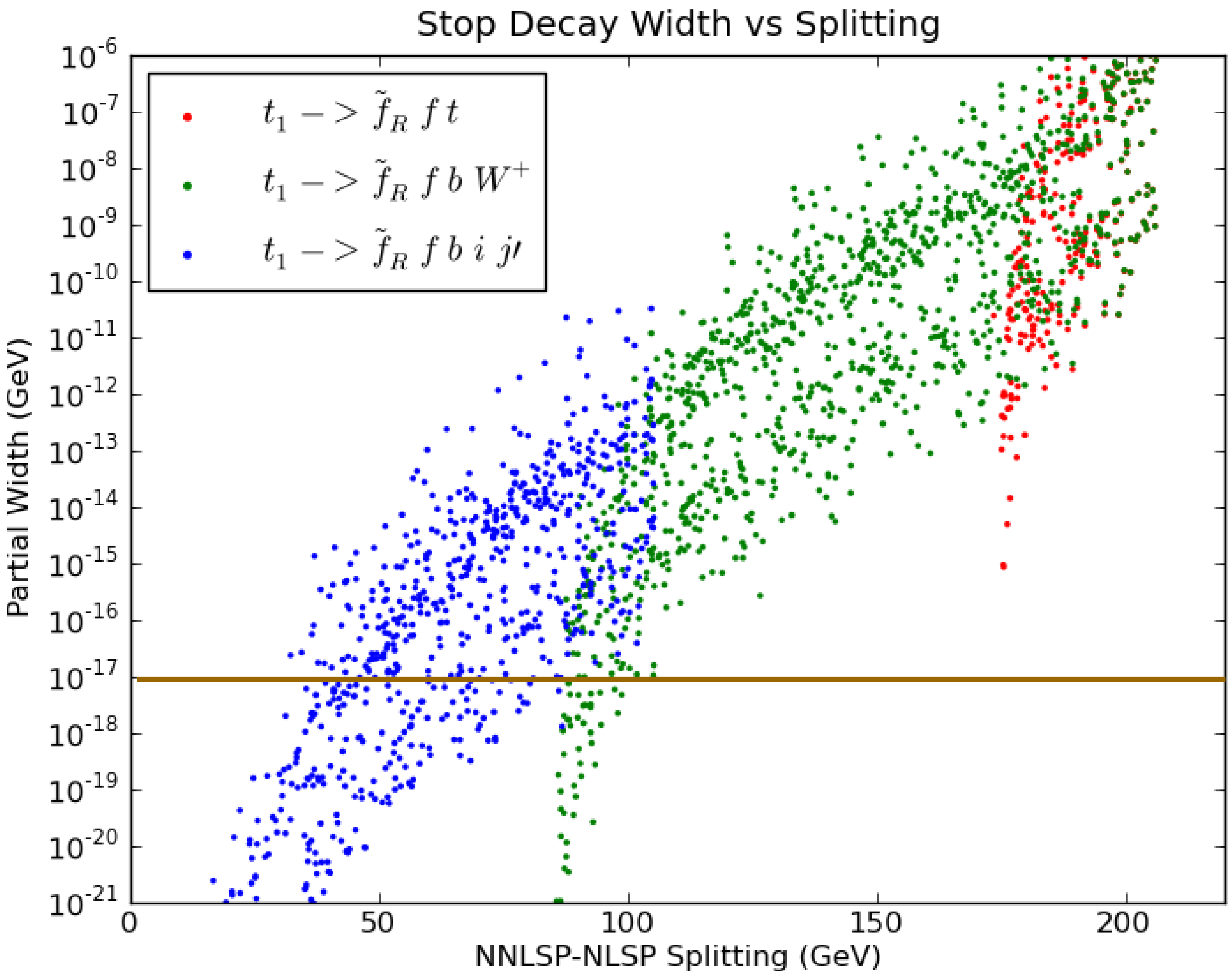
- For NLSP decays to G, add all 3- & 4-body modes w/ BBN relevant lifetimes (~10^{-4} to 10^{14} sec) via MadGraph

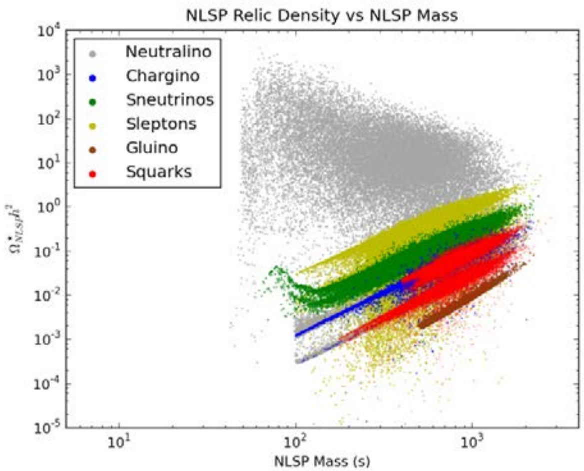
- Calculate NLSP density using Micromegas & rescale to the gravitino mass

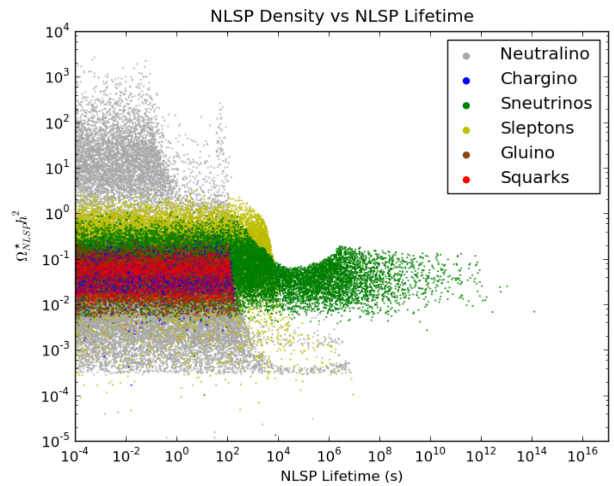
- Use lifetime & BF info for NLSPs from modified SUSY-Hit & check the constraints on EM or hadronic energy deposition during BBN

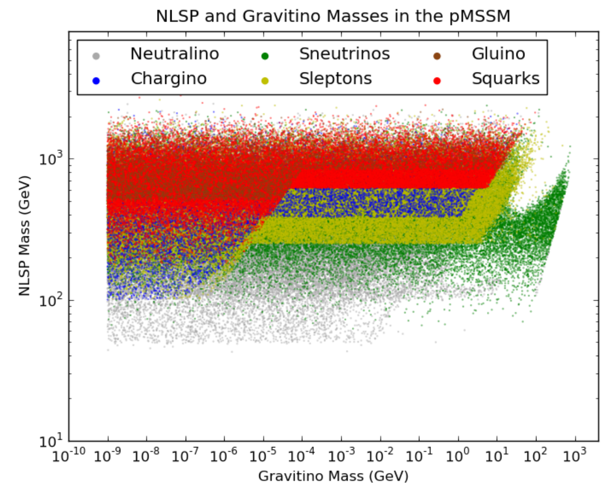
- Add constraints from the cosmo relic ν & diffuse photon fluxes

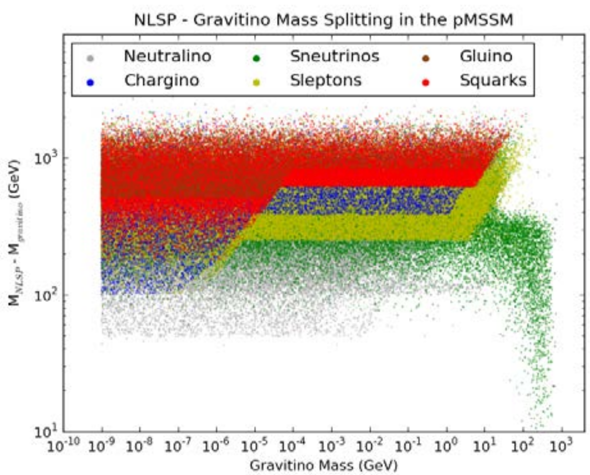
E.g., even if t_1 is the NNLSP it may STILL be detector stable



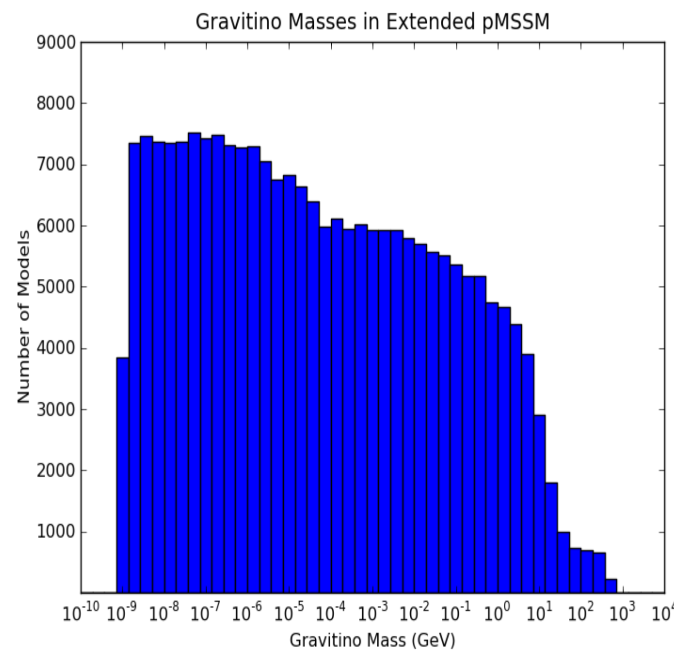


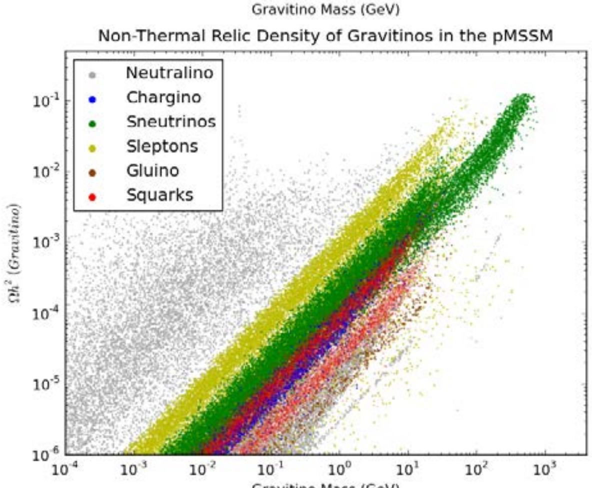




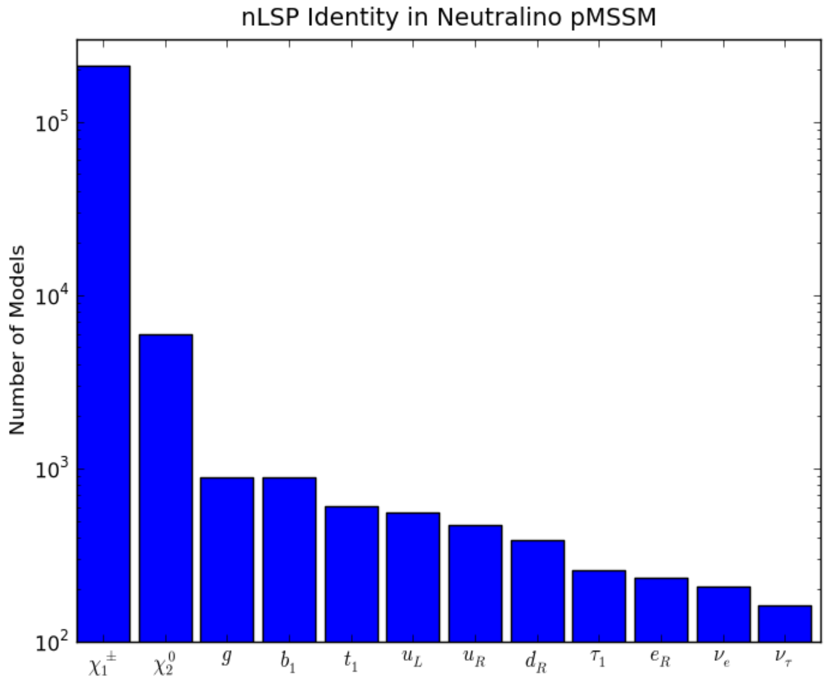


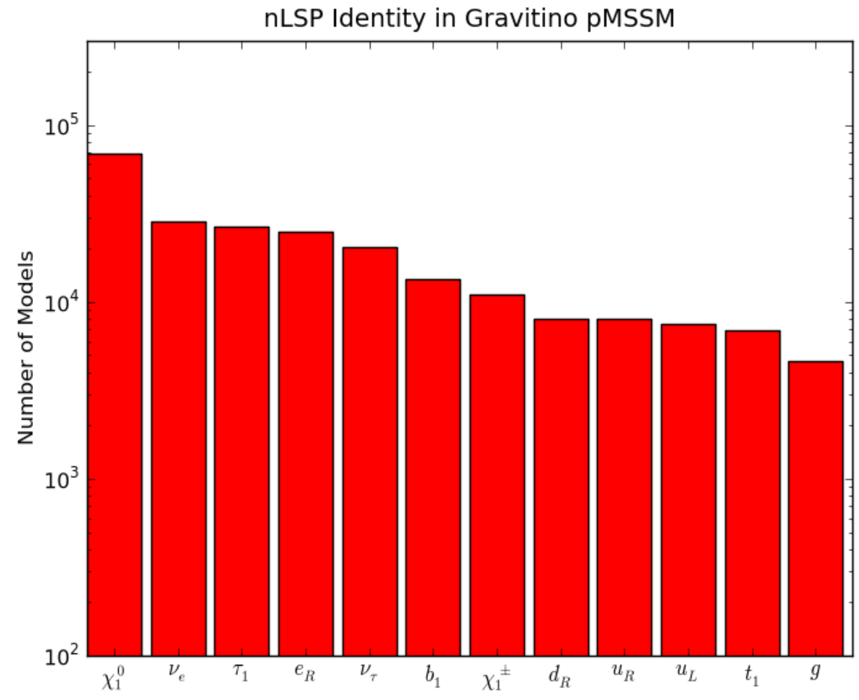
Some properties of the gravitino LSP models





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



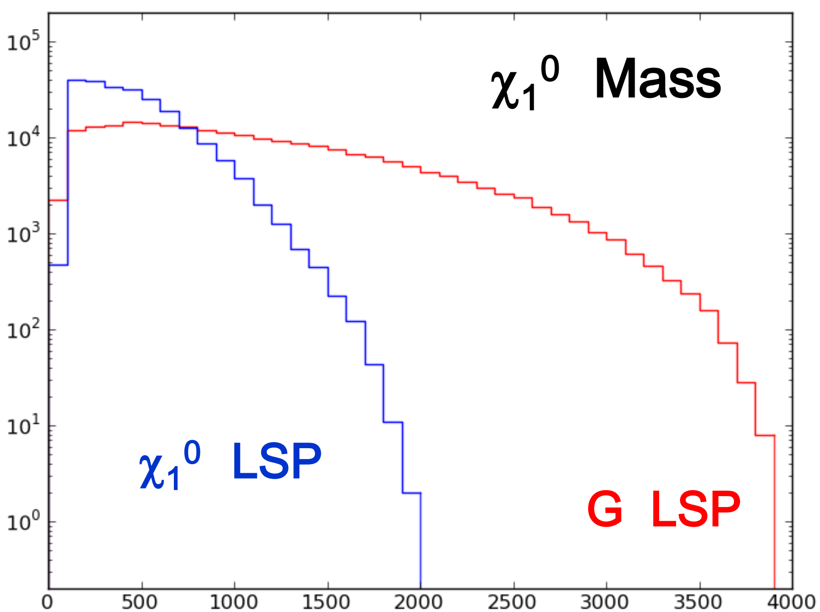


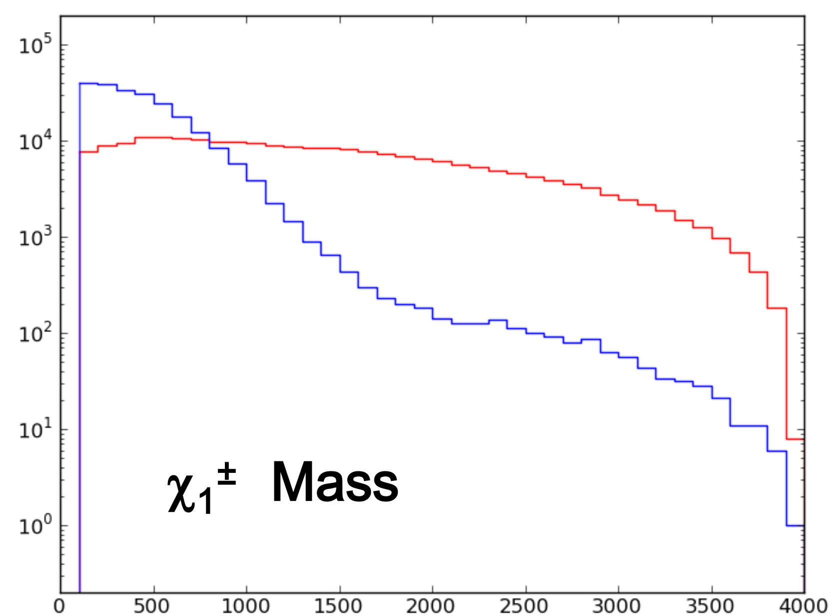
- The likelihood of various NLSP identities is very strongly dependent on the LSP choice
- This can have a potentially large influence on LHC SUSY searches (apart from, e.g., additional cascades)

- 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





ATLAS MET Analyses @ 7 & 8 TeV

- The first step in exploring the parameter space of either pMSSM model set is to apply the SUSY MET searches
- As is our tradition, we follow the ATLAS analyses as closely as possible & we began w/ the χ model set
- At ~1 fb^{-1} this is 'relatively straightforward' as all the data & numerous benchmark model results exist that we can test/validate against. Only partial ~5 fb^{-1} results available.
- We combine the various analyses signal regions (as ATLAS does) into : nj0l, multi-j, nj1l, nj2l (+ multi-l & HF) and we quote the coverage for each as well as the combined result.. 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 [5/6]	0.36%	1.61%
nj1l [8/3]	0.79%	2.64%
nj2l [5]	0.15%	0.20%***
flavor	(in progress)	(ditto)
(sub)total	6.73%	23.27%

→ nj0l is by far dominant in these searches

*** In this case, we extrapolate to ~5 fb^{-1}, since results have not yet been released. 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}

- Our analyses can be updated when more data is available

(Preliminary) Extrapolation to √s = 8 TeV

- The extrapolation here is greater than for ~1 → ~5 fb^{-1} @ 7 TeV
- First pass: assume the cuts & analyses are as for 7 TeV & the number of observed events equals the expected backgrounds in each SR.
- However, we need to know the backgrounds for 8 TeV !
- Rescale ATLAS 7 TeV backgrounds? How? Use MC to determine the RATIO of the expected backgrounds in each signal region at 7 & 8 TeV as transfer factors
- When low statistics becomes an issue we closely follow ATLAS' approach using the sideband 'ABCD' method & then rescale the control regions
- Of course we still need to generate the relevant SM MC backgrounds

SM Background Generation @$\sqrt{s}$=7 & 8 TeV

- Z/W$^{\pm}$ + (0-4) j
- WW/ZZ + (0-2)j
- tt-bar + (0-2)j
- single t +(0-2)j
- QCD up to 6 jets

↔ ME + PS, weighted evts

~ 1 TB

w/ Sherpa

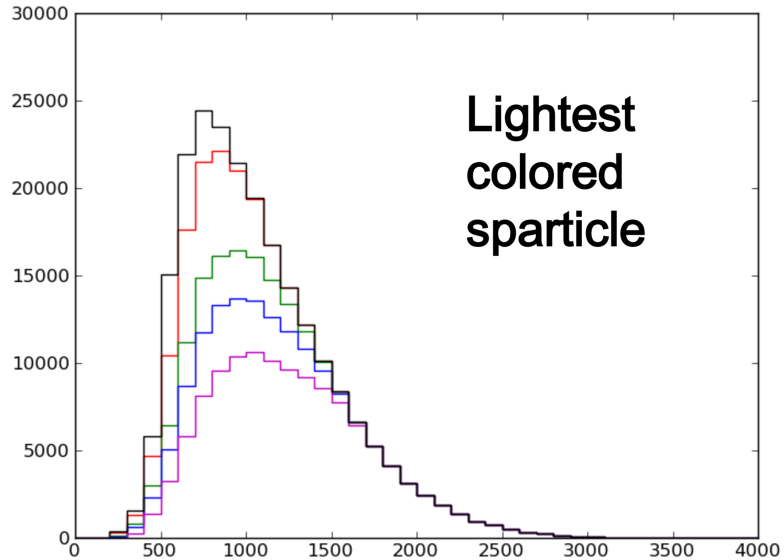
- Not too surprisingly, the gain in pMSSM coverage going to 8 TeV is substantial due to the increases in σ's. nj0l continues to dominate :

	8 TeV 5 fb^{-1}	8 TeV 20 fb^{-1}
nj0l**	32.70%	45.11%
multi-j**	6.26%	7.35%
nj1l**	1.41%	1.53%
nj2l++	0.34%	0.37%
flavor	(in progress)	(ditto)
(sub)total	32.75%	45.13%

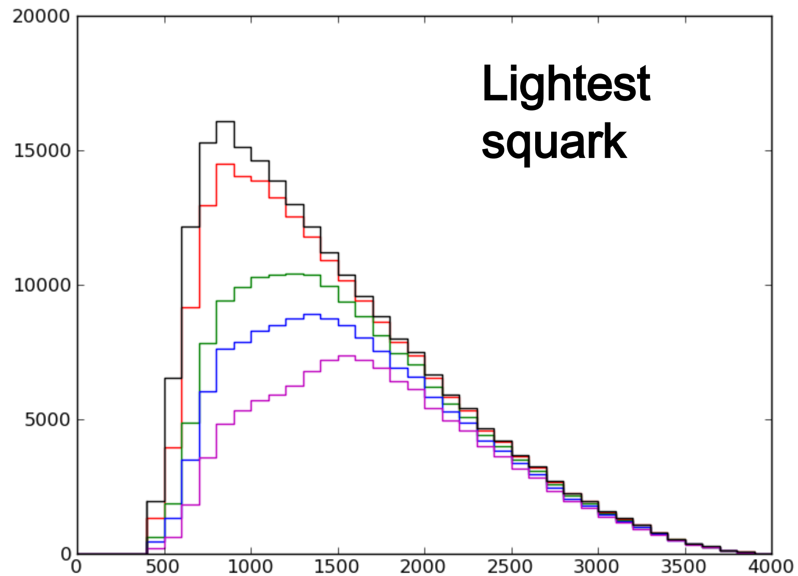
** extrapolated from ~5 fb^{-1} analysis ++ extrapolated from ~1 fb^{-1} analysis

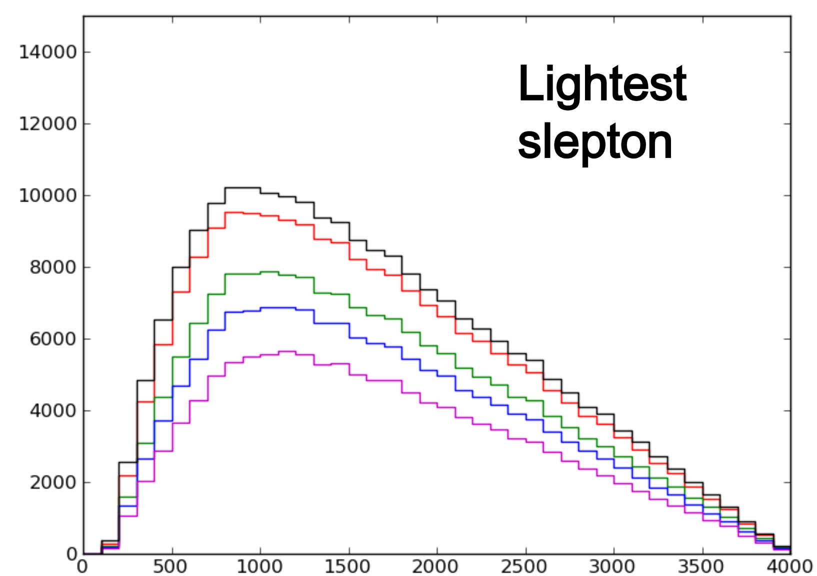
- $\sqrt{s}$=13-14TeV is needed for more complete coverage

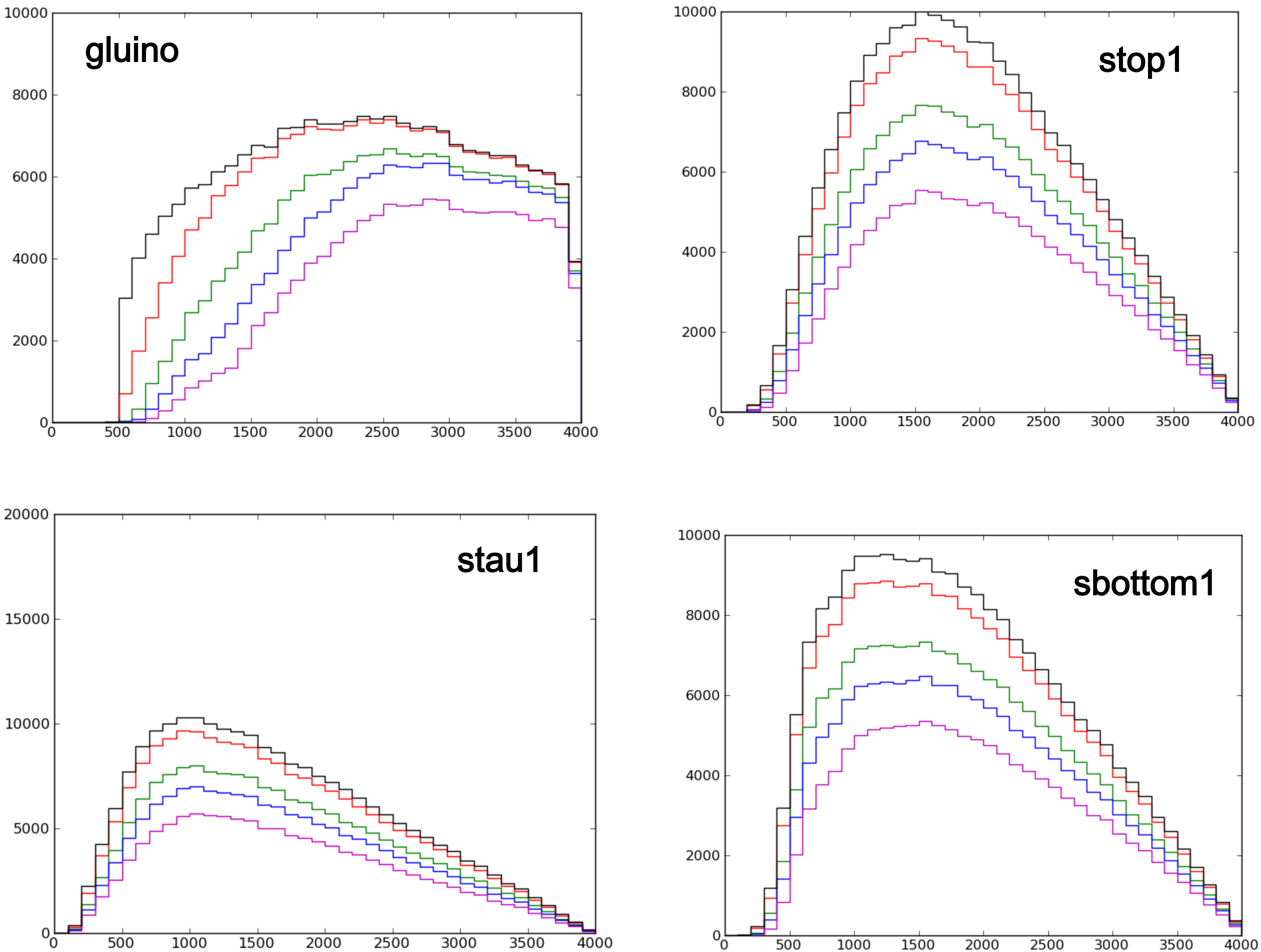
How does the pMSSM respond to negative searches ?



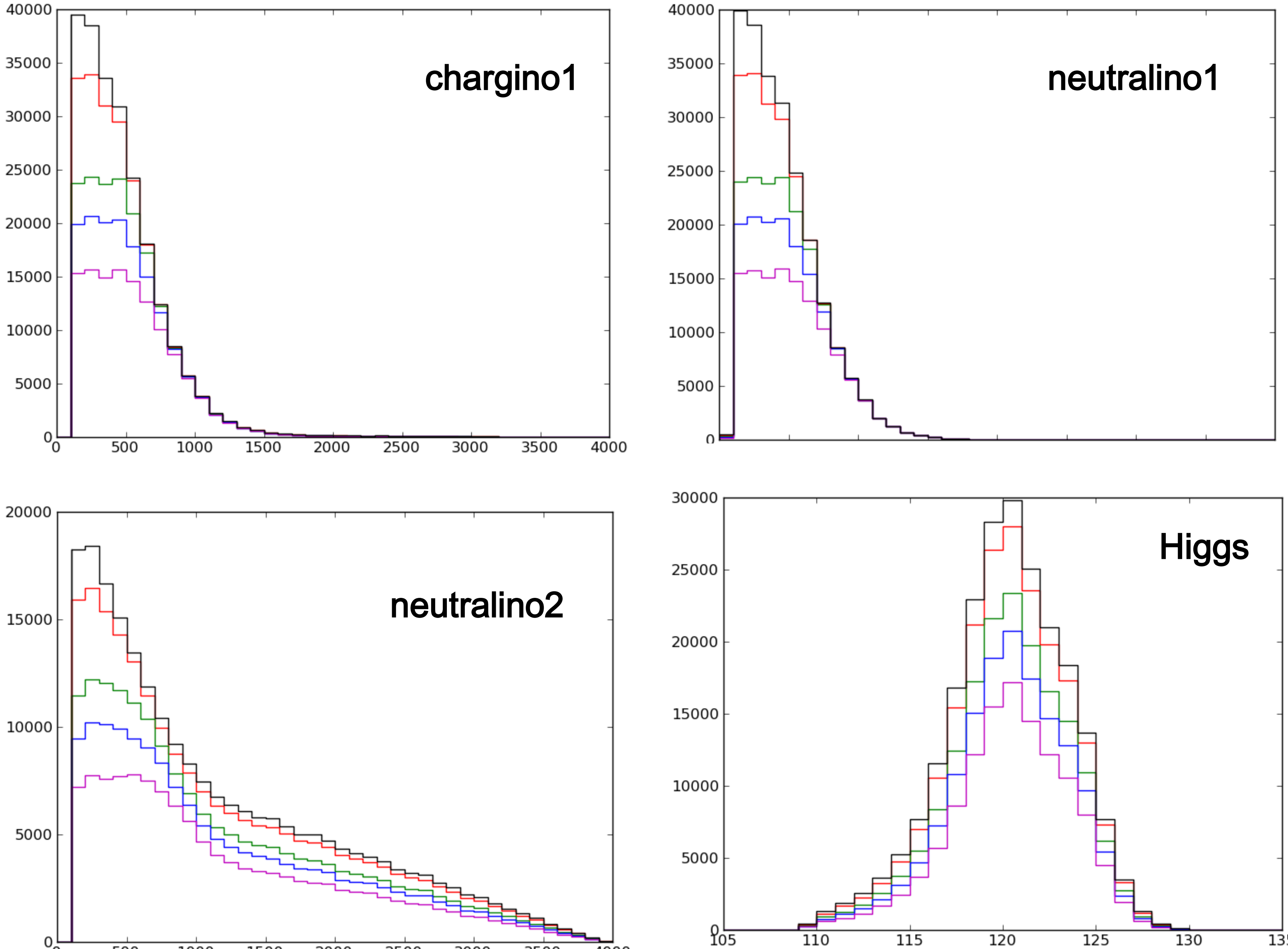
Note that colored sparticles get heavier, i.e., the distributions peak at higher masses as the searches progress but color singlets distributions are just seen to be rescaled downward

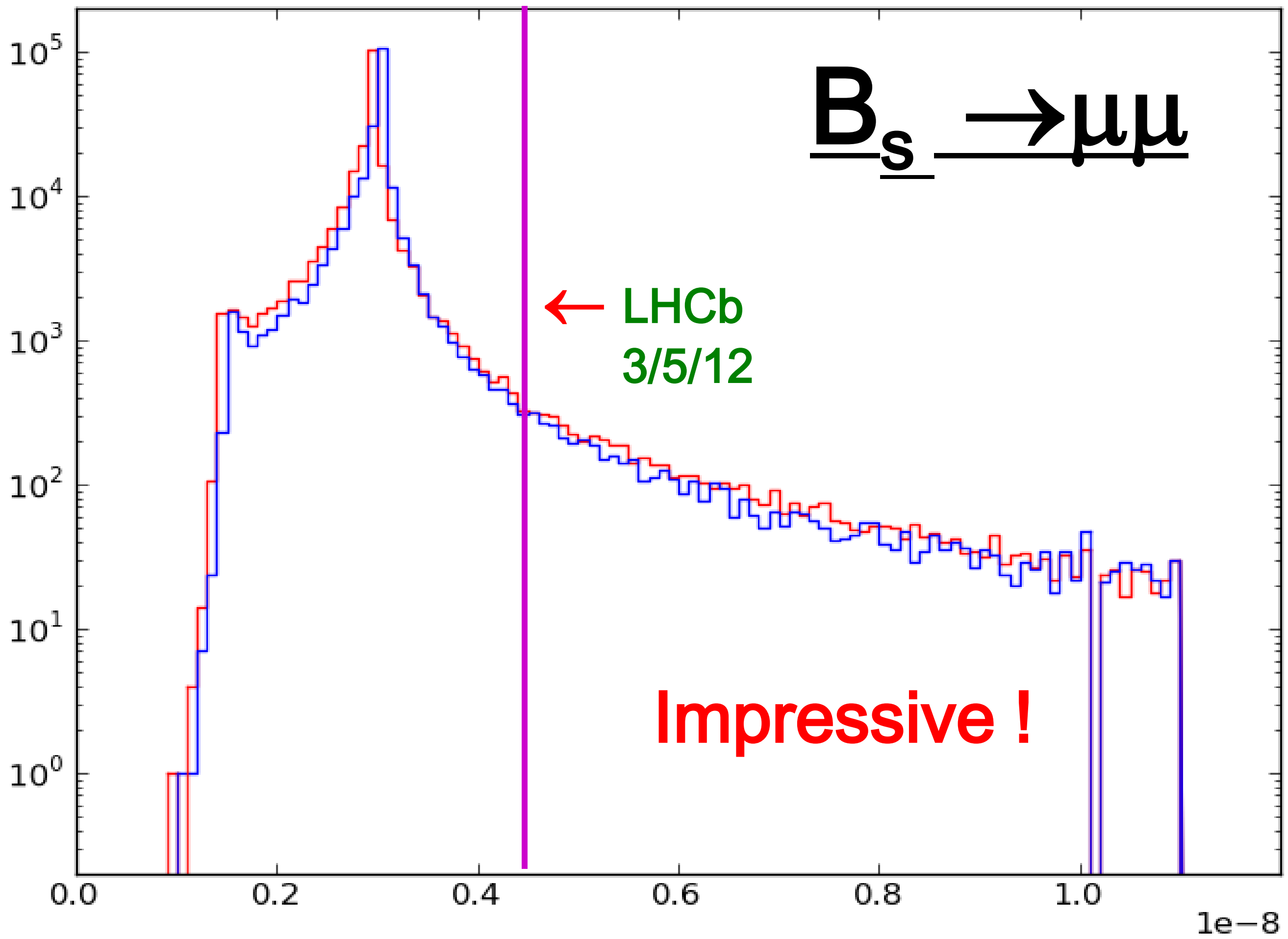






gluino
stop1
stau1
sbottom1

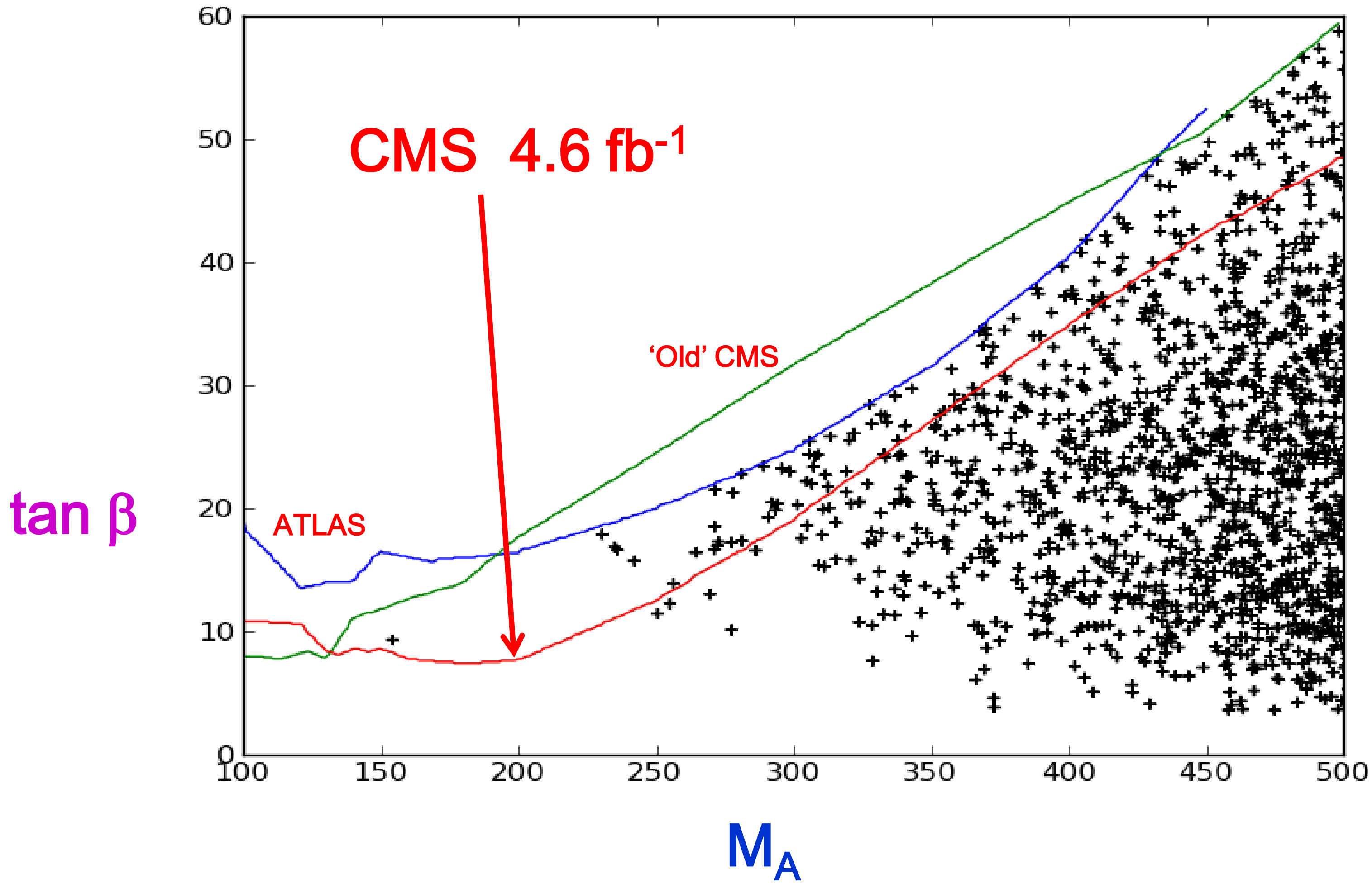

chargino1
neutralino1
neutralino2
Higgs
40000
35000
30000
25000
20000
15000
10000
5000
0
500
1000
1500
2000
2500
3000
3500
4000
105
110
115
120
125
130
135



- LHCb result removes a total of 4899 (5884) models in the neutralino (G) LSP model set …

- non-MET searches REALLY ARE important !

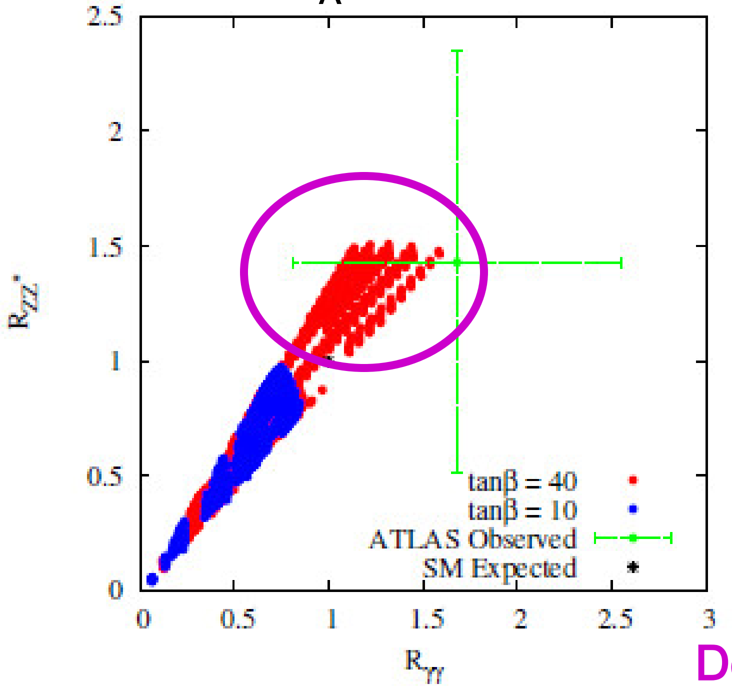
Impact of A,H $\rightarrow\tau\tau$ Searches



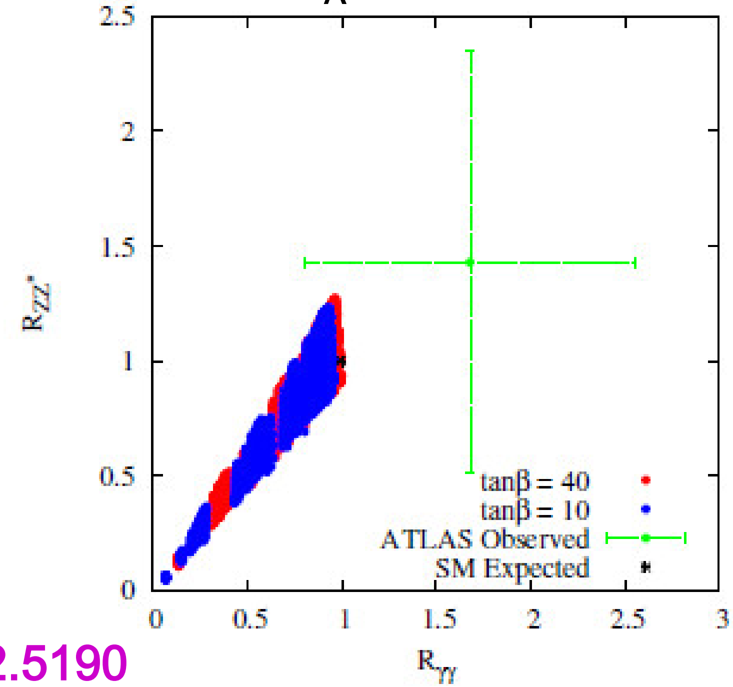
As in the case of $B_s \rightarrow\mu\mu$, improvement in non-MET searches impact the pMSSM analyses… 160 models removed from the neutralino LSP set…

…for example Higgs properties in the MSSM...

M_A =300 GeV



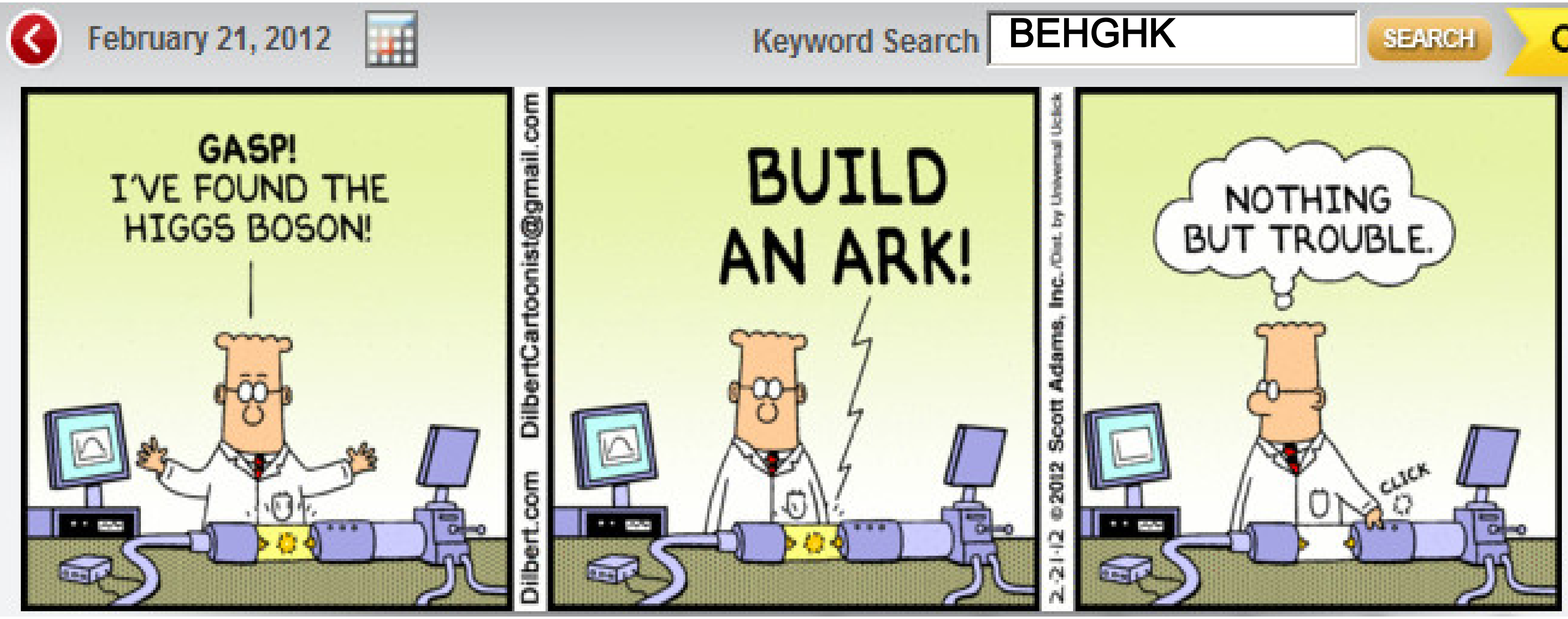
M_A = 1 TeV



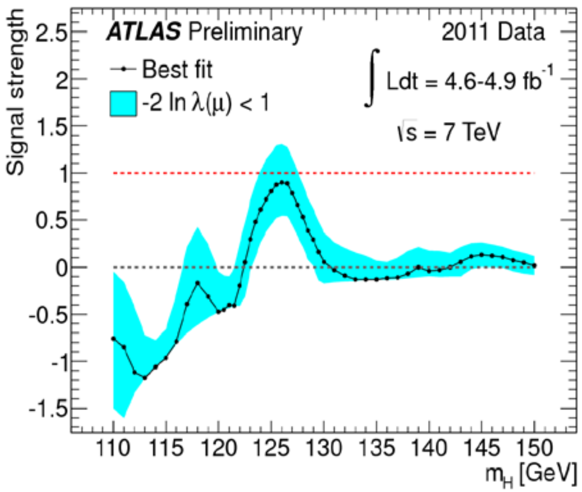
Desai etal. 1202.5190

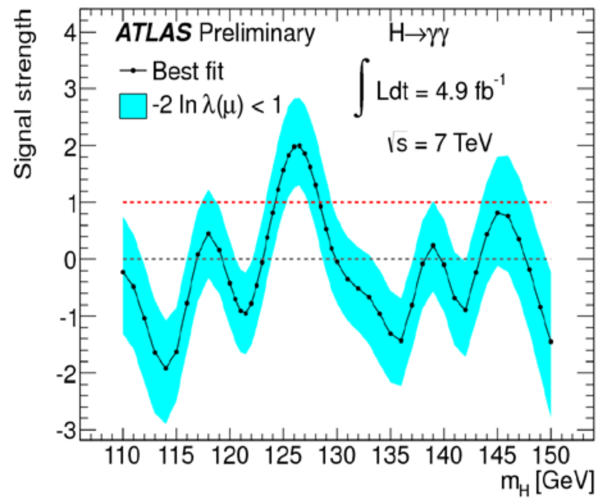
Low M_A & large tan β can enhance h signal rates…however this parameter range is excluded by b-physics & H,A $\to\tau\tau$ searches !

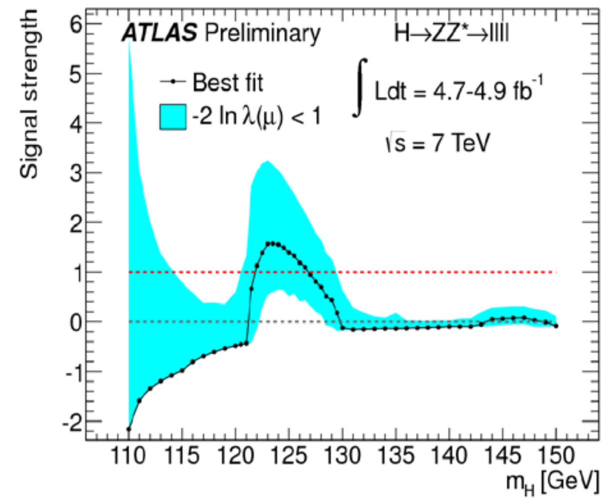
Impact of LHC SM Higgs Searches



..or what will a Higgs at ~125 GeV tell us

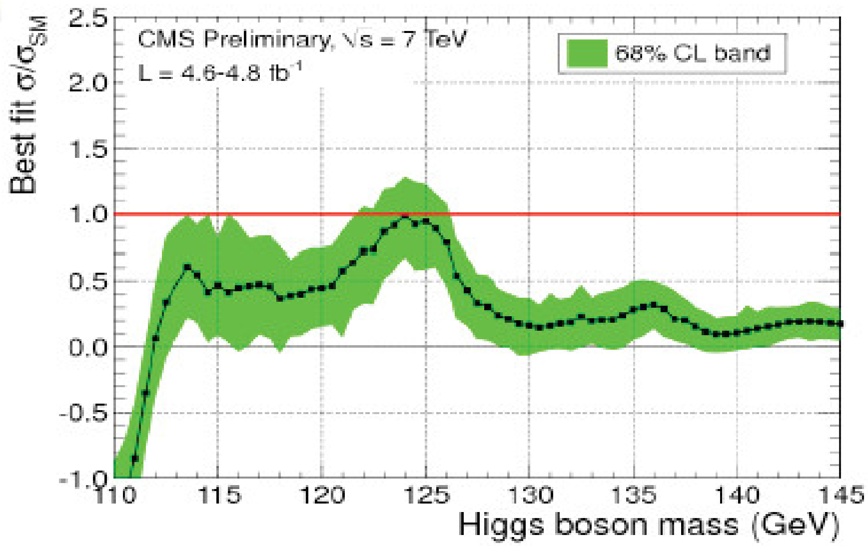




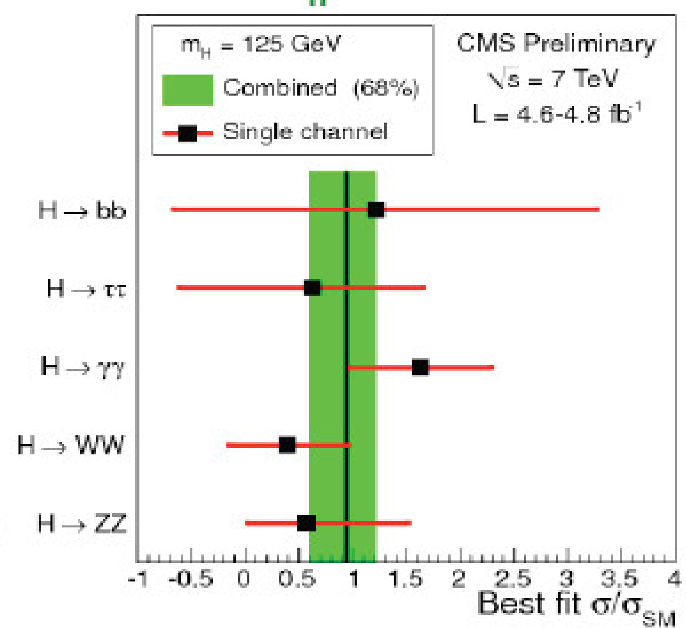


"Generally" living up to ~SM expectations…**

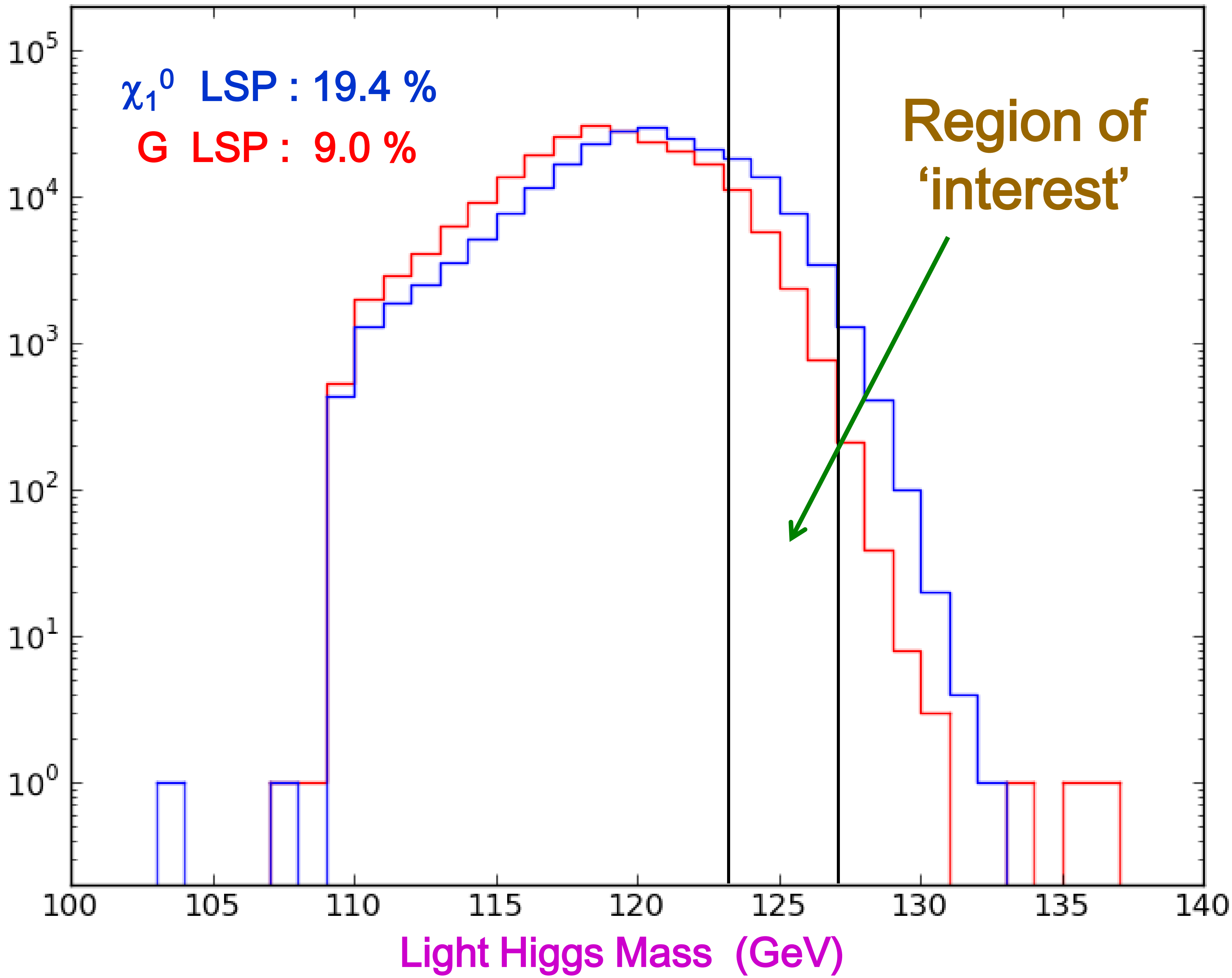
** see however, e.g., 1203.4254



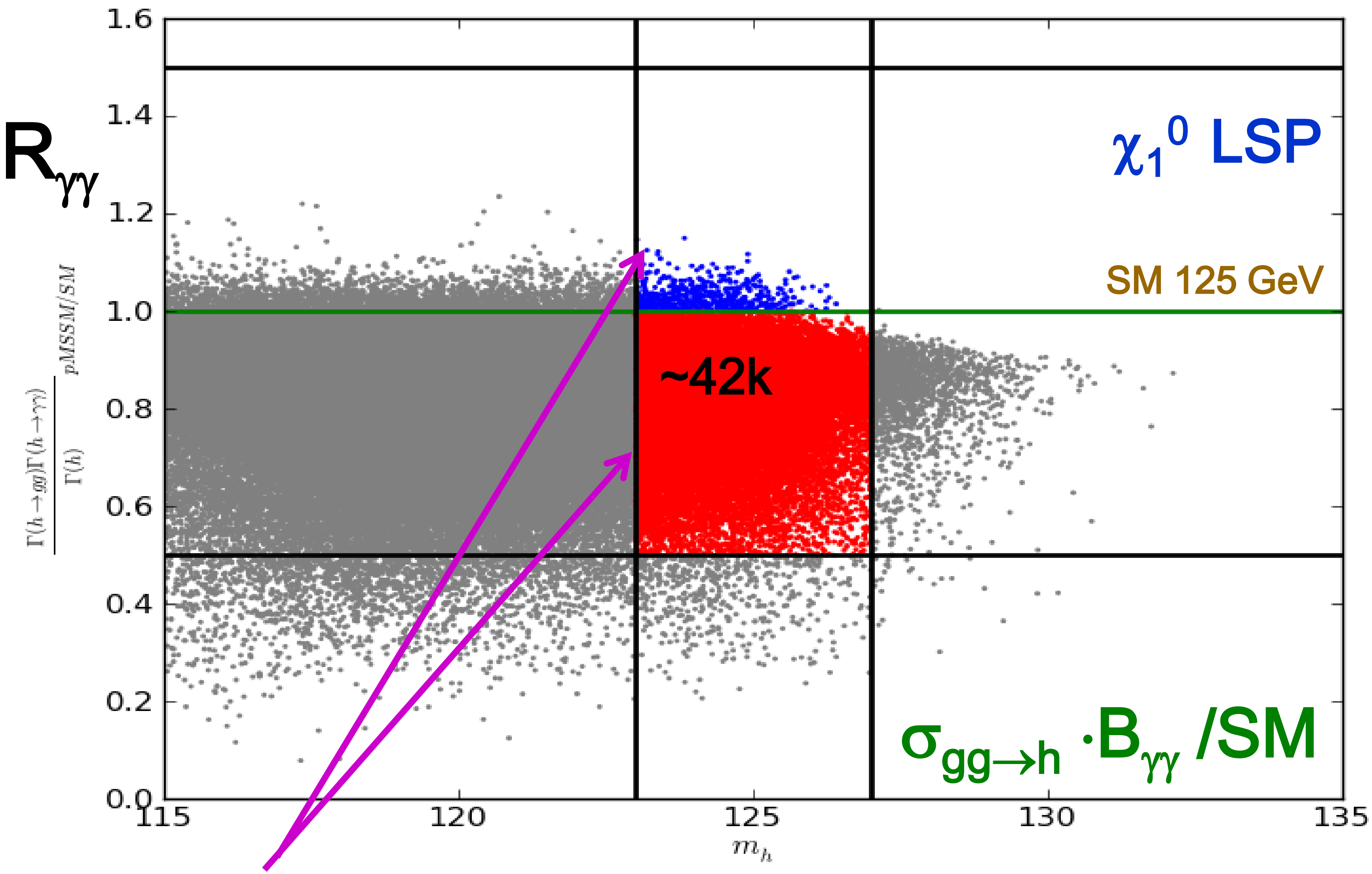
Comparison of channels for M_H=125 GeV



Distribution of Predicted Higgs Masses

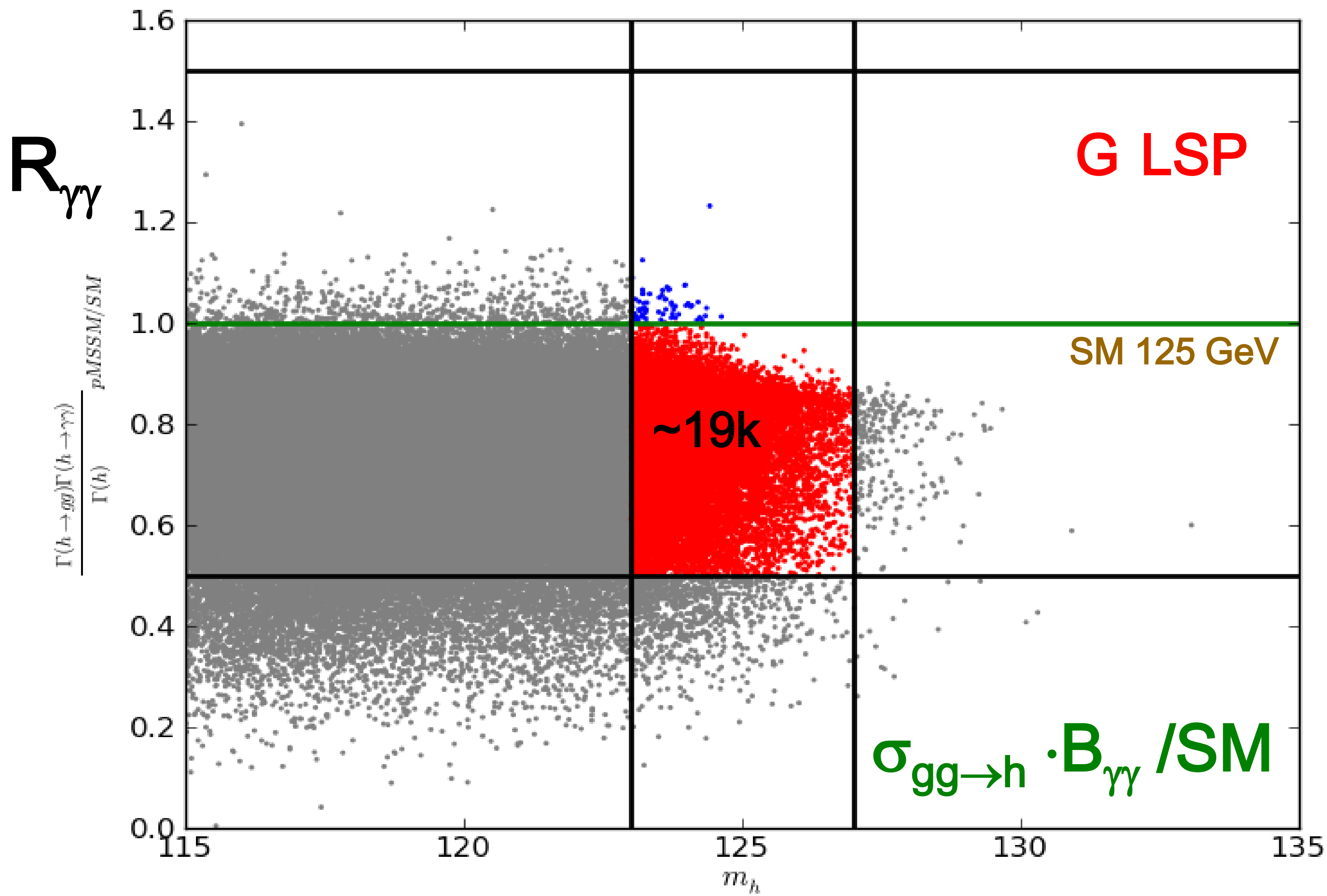


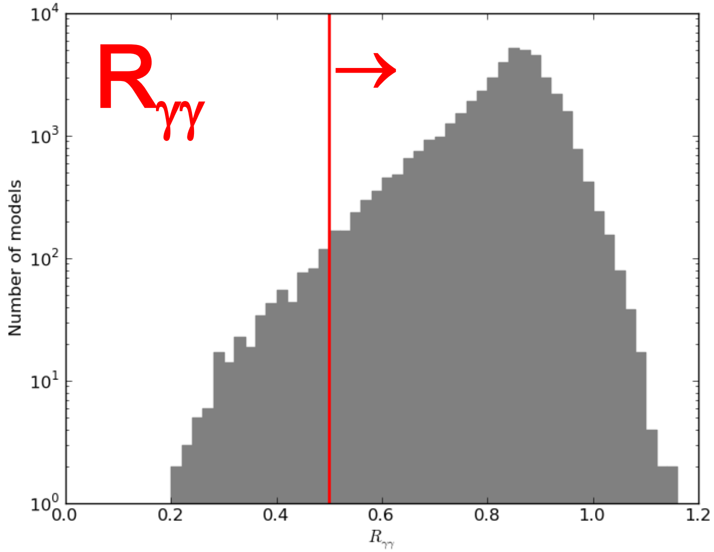
Impact of LHC SM Higgs Searches

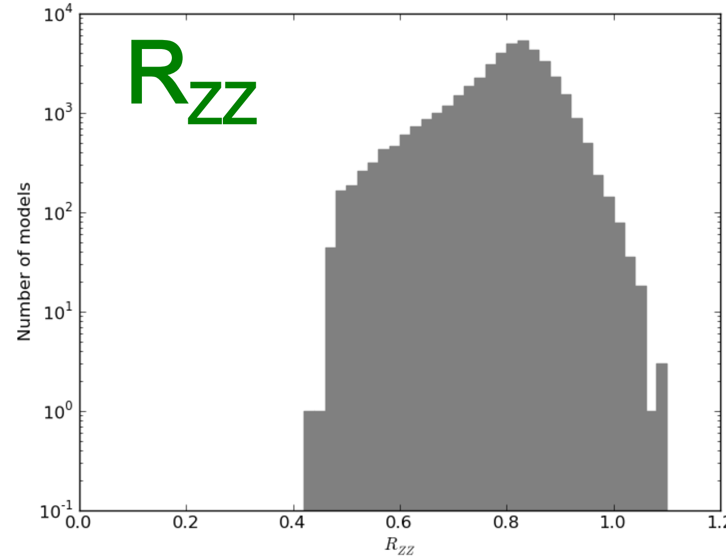


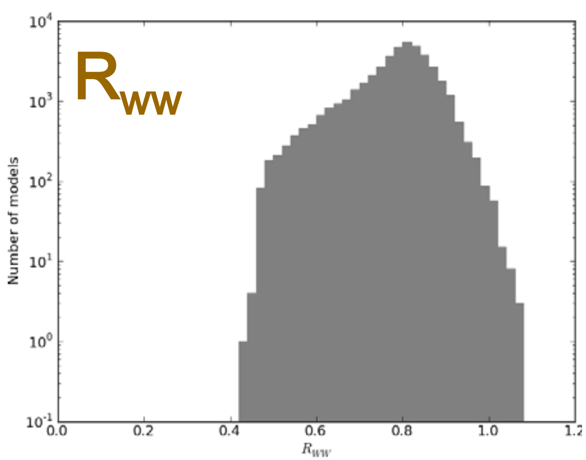
Regions of 'Interest' → Few models larger than the SM

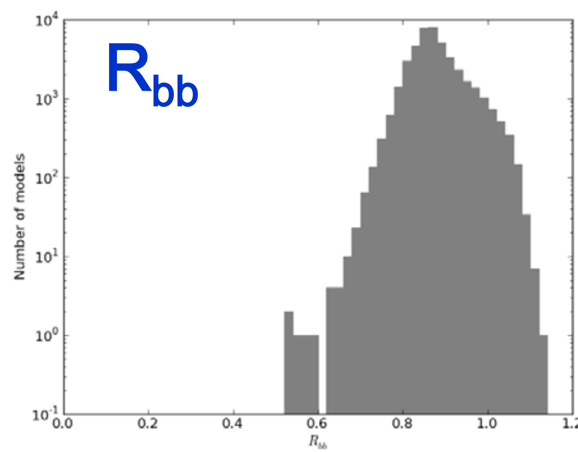
Impact of LHC SM Higgs Searches

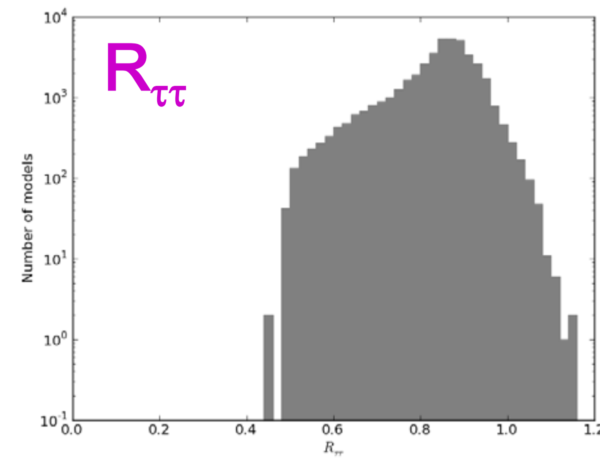






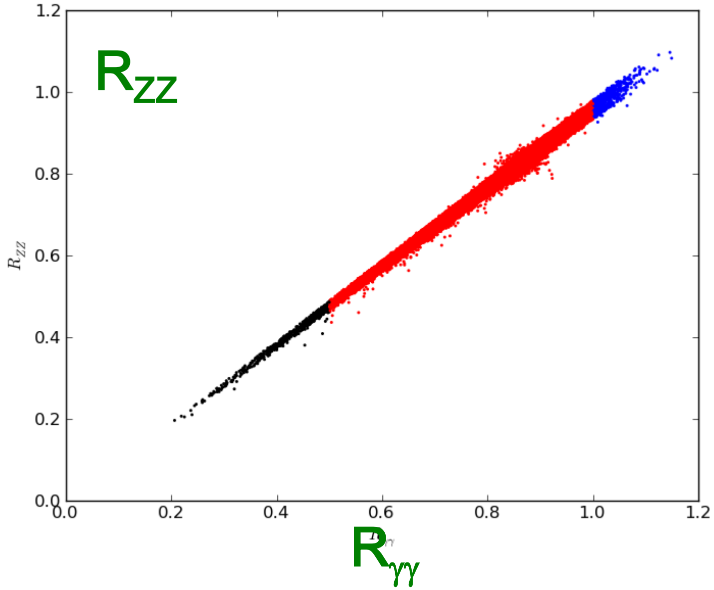


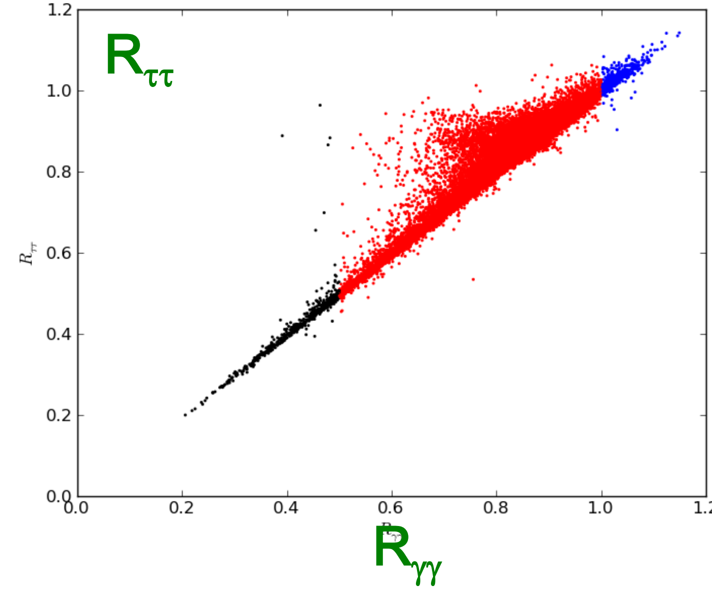




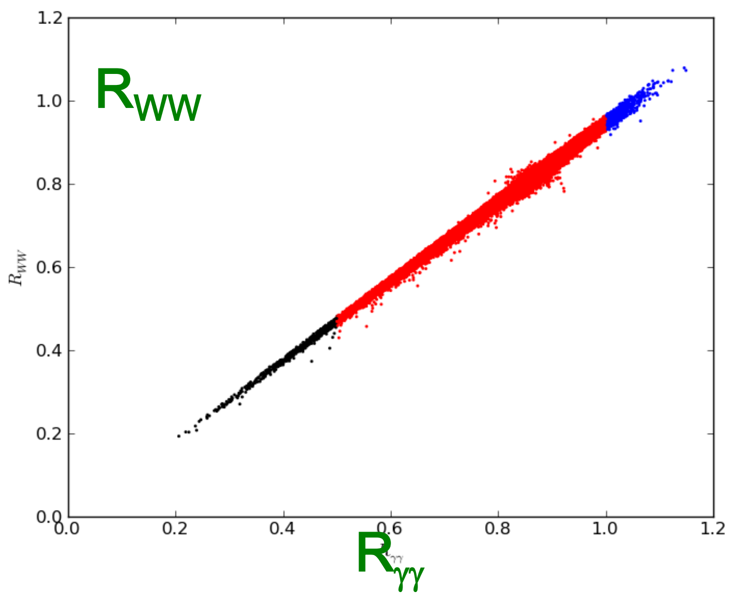
R_{XX} distributions for m_h = 125 ±2 GeV

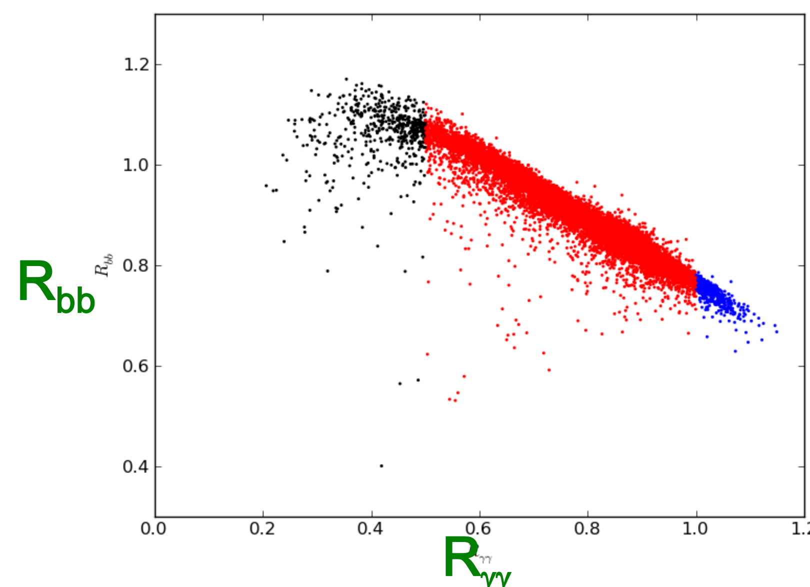
χ_1^0 LSP

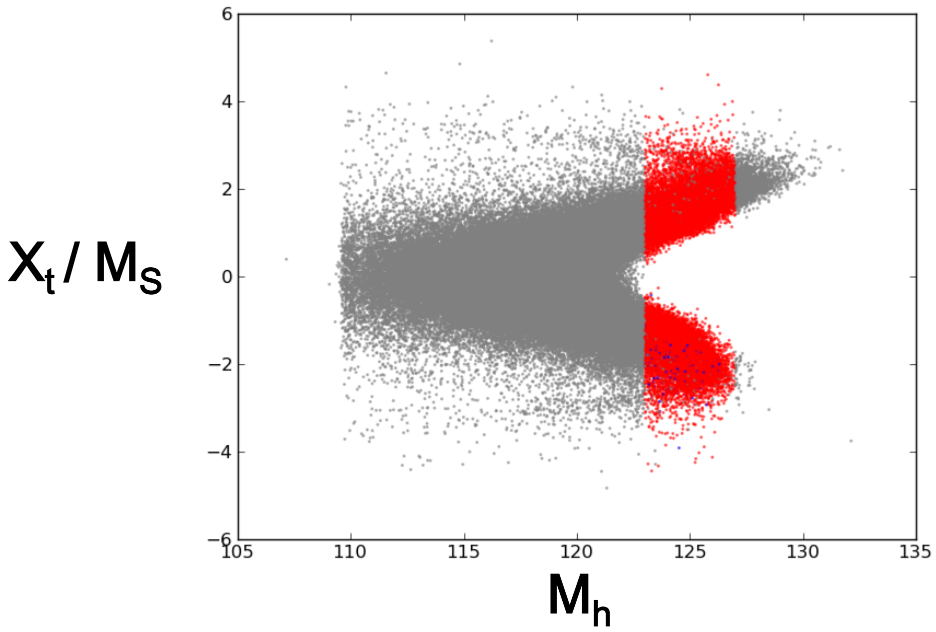




$R_{\gamma\gamma}$ vs R_{XX} for m_h = 125 ±2 GeV χ_1^0 LSP

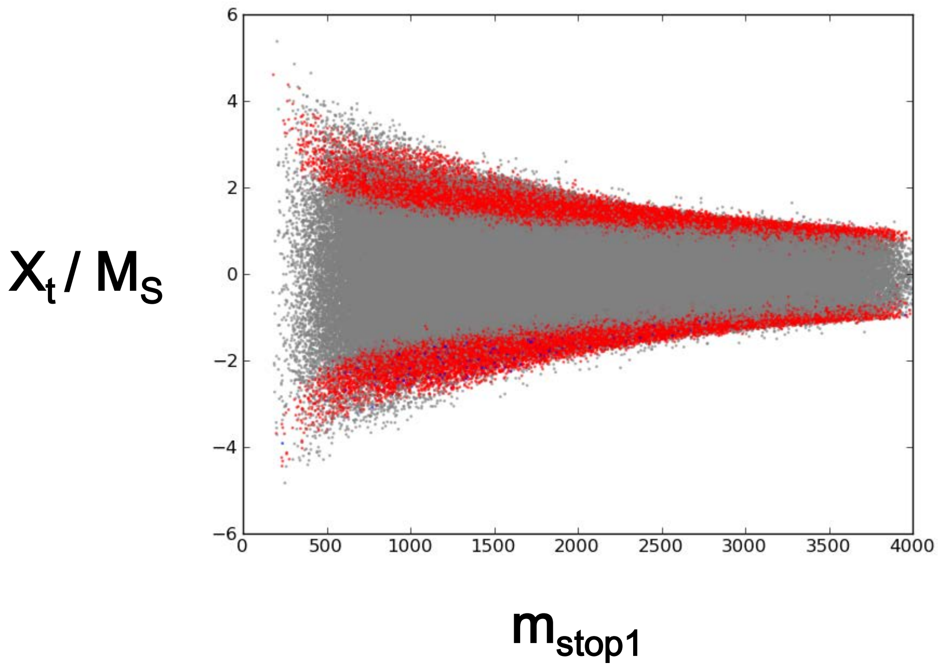






$$X_t = A_t - \mu/t_\beta$$

$$M_S^2 = m_{stop1} \cdot m_{stop2}$$



The blue points seem to prefer negative values of X_t . $Stop_1$ masses down to ~300 GeV or even less are still found for large X_t / M_s

Fine-tuning in the pMSSM

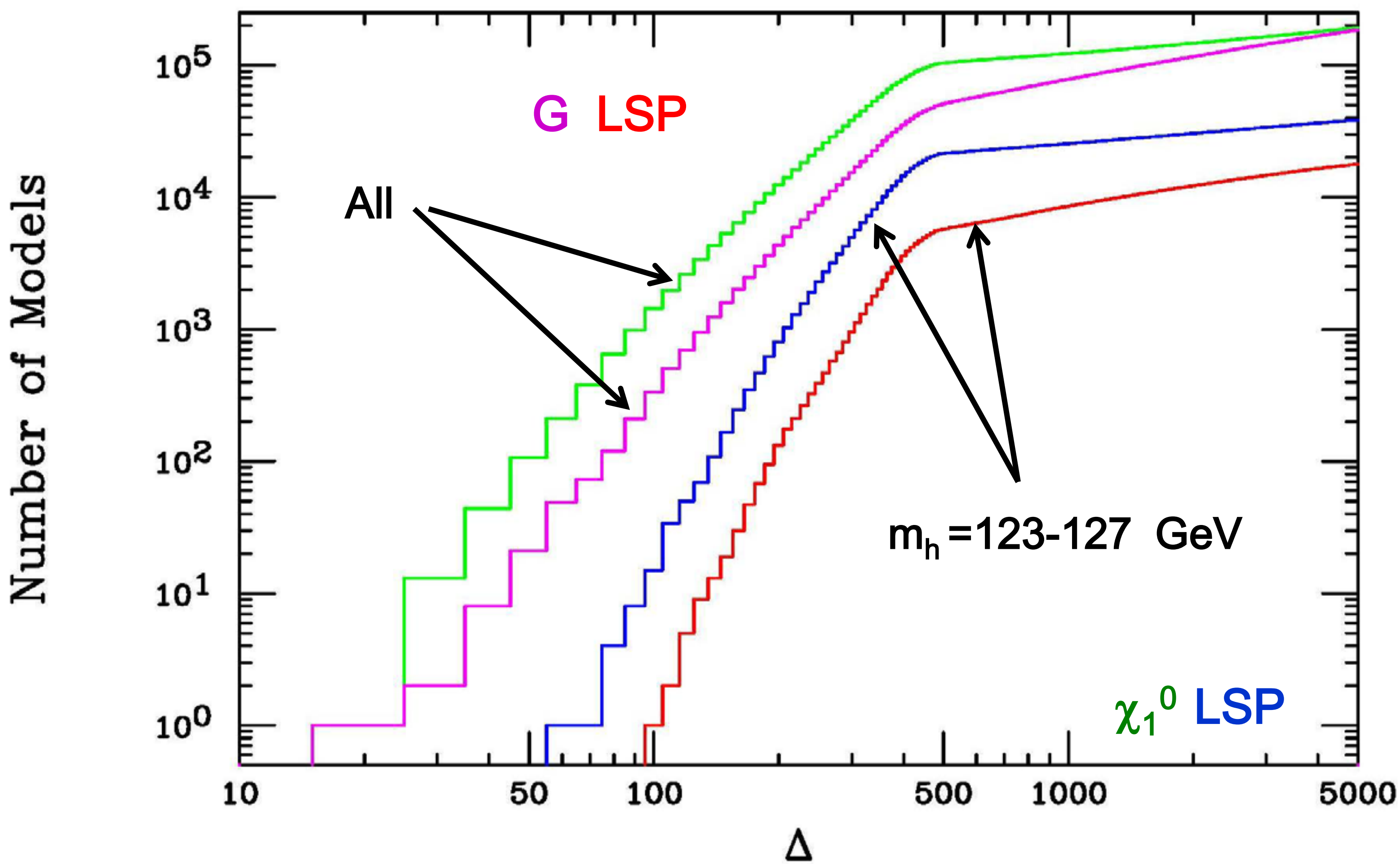
- m_h =123-127 GeV in the MSSM requires large stop masses and/or mixings which then $\rightarrow$ significant FT expected

- 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 FT approach of Ellis et.al. + Barbieri & Giudice :

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

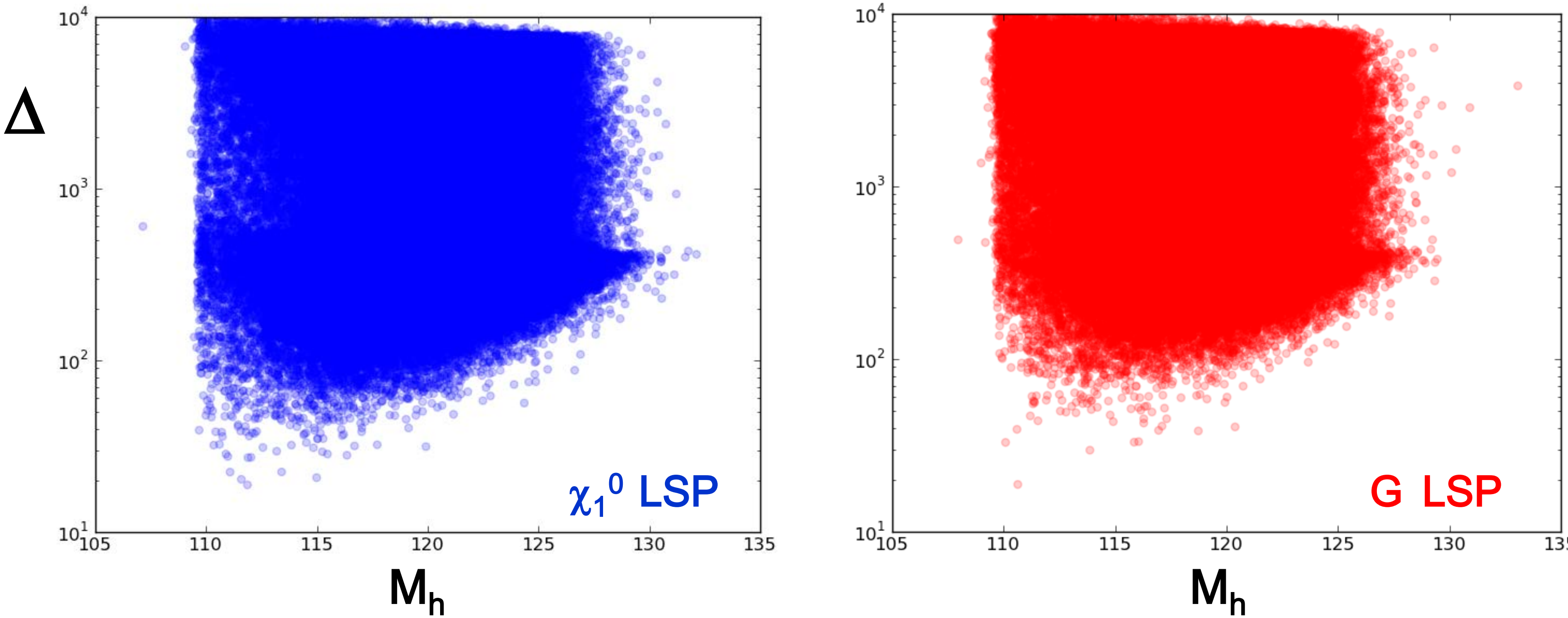
- Specifically we ask for the number of models with Δ less than a specific value…

Fine-tuning in the pMSSM



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

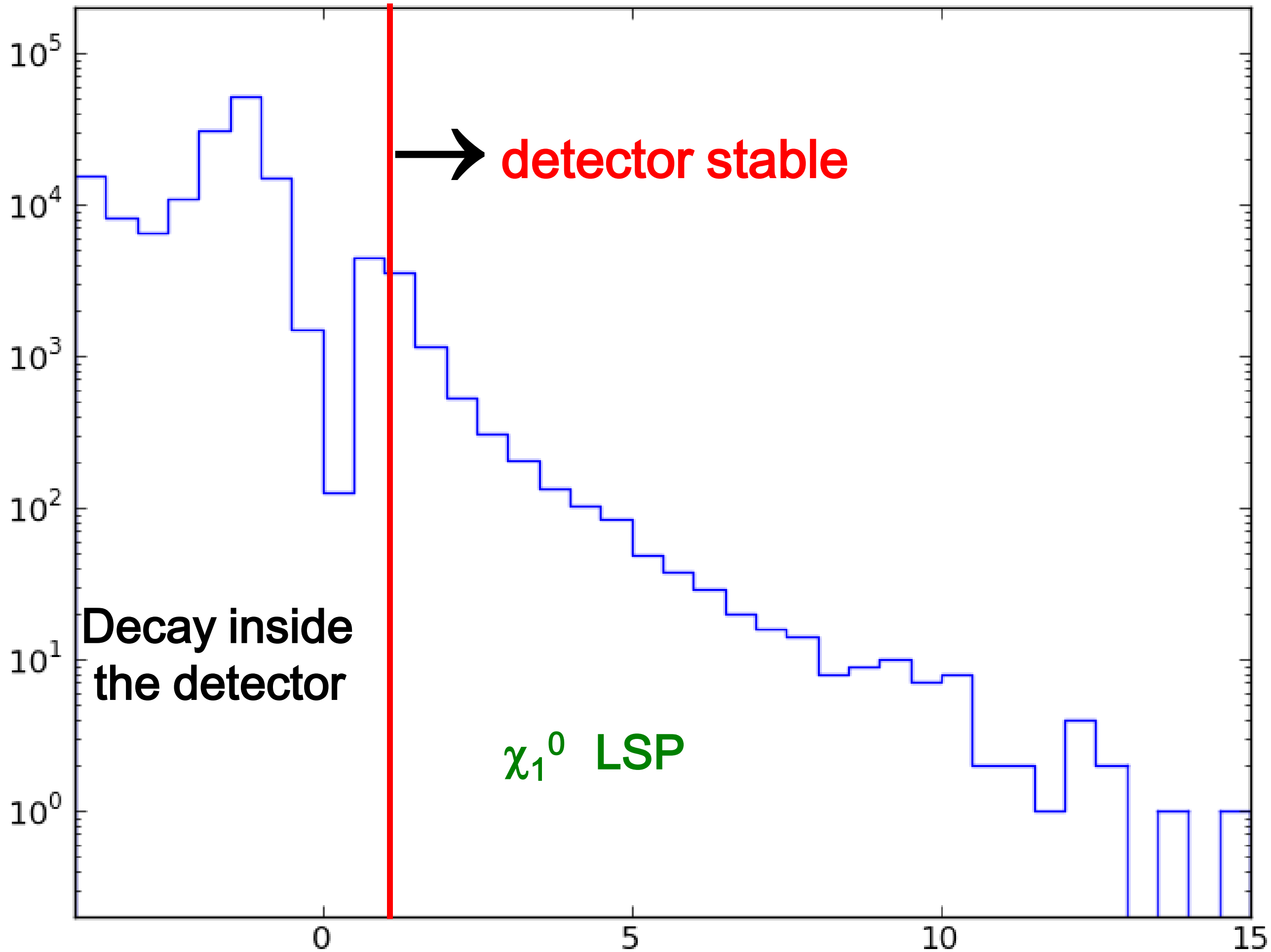
FT vs. Higgs mass distributions for both model sets



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.

Long-Lived Sparticles: The Chargino Example

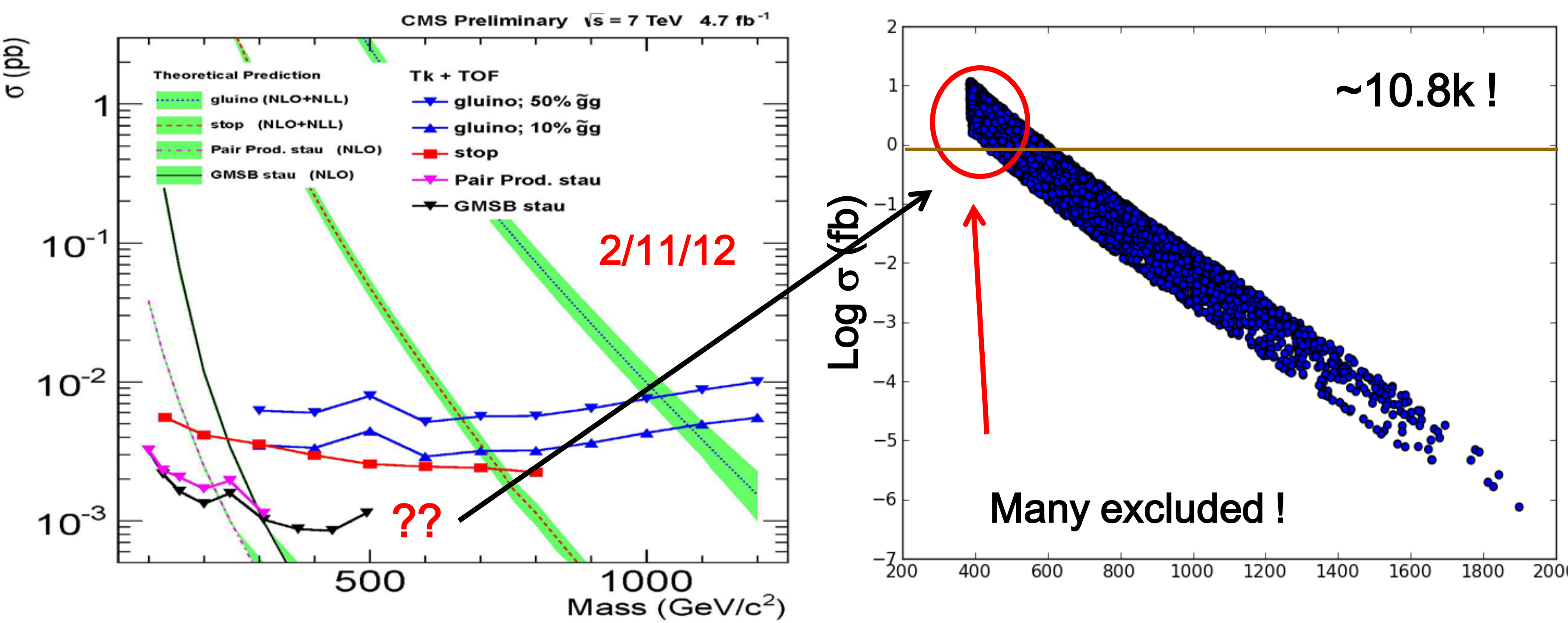
Most LSPs are nearly pure wino or Higgsino



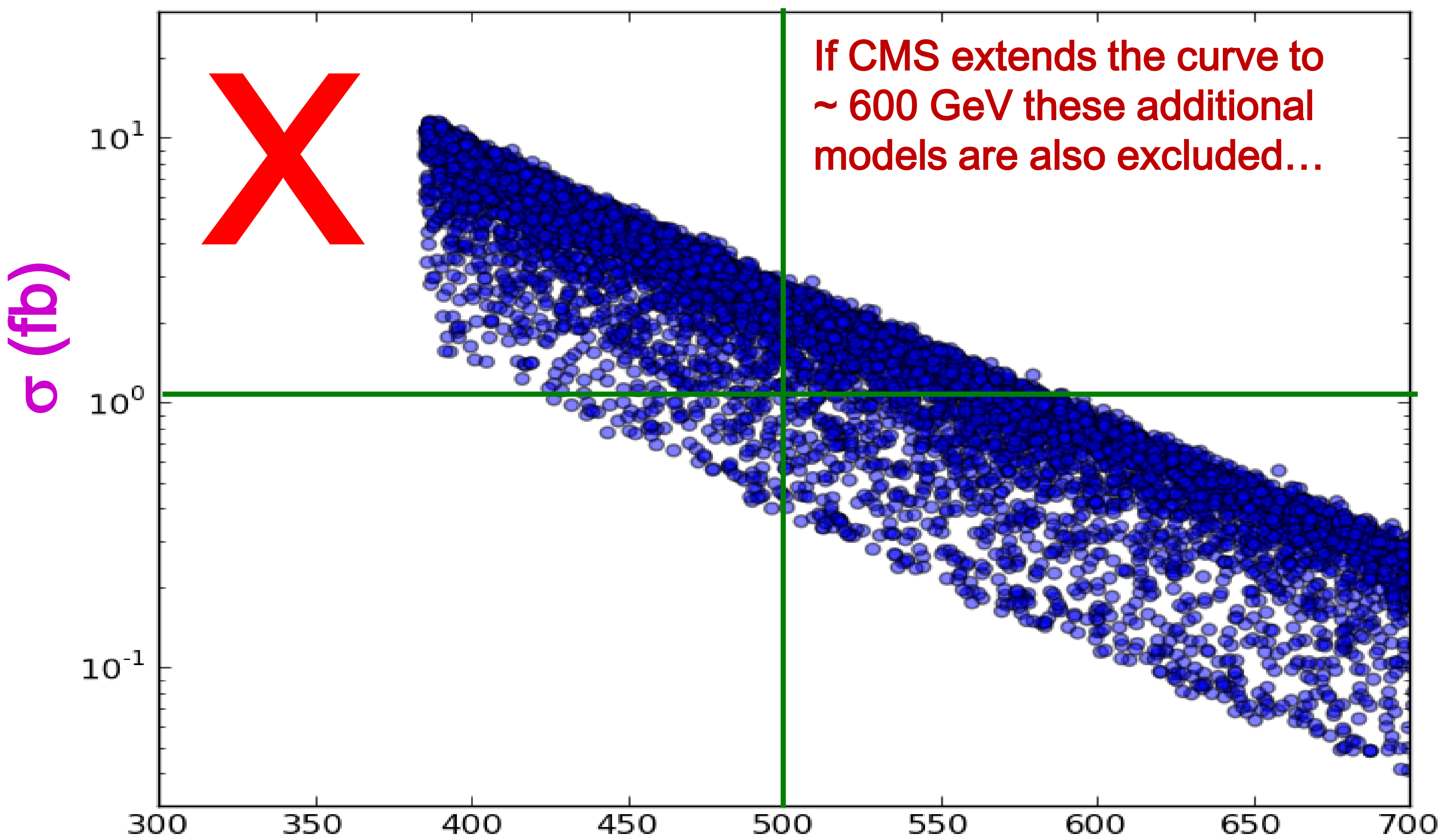
Log (un-boosted chargino decay length in meters)

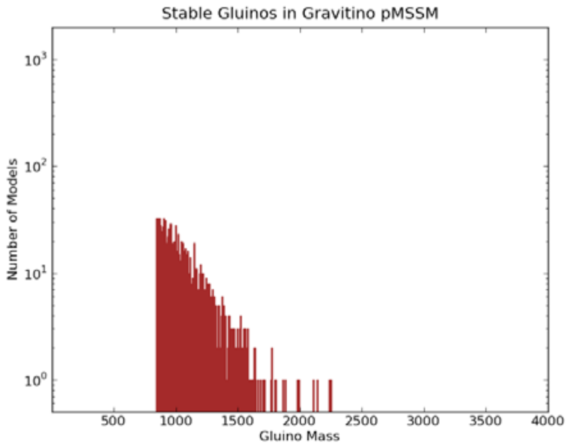
Detector Stable Charginos

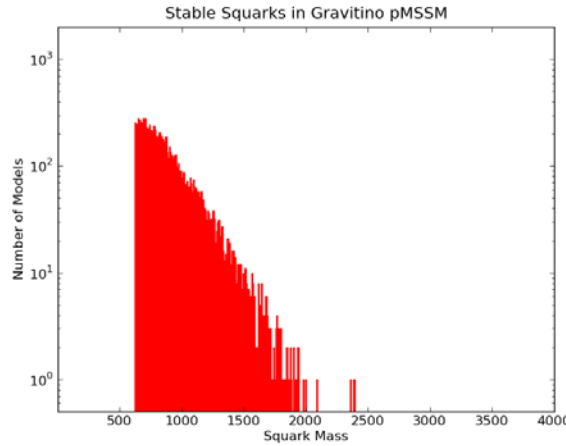
- Searches for stable and/or long-lived sparticles can be quite powerful for both χ_1^0 or G LSP sets
- E.g., detector-stable charginos are quite common in χ_1^0 LSP models & extend out to large masses :

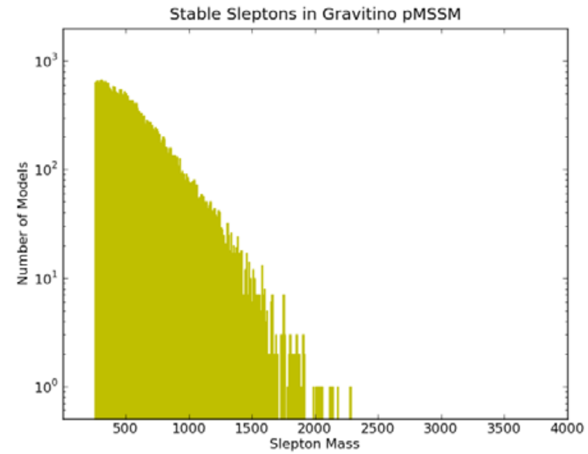


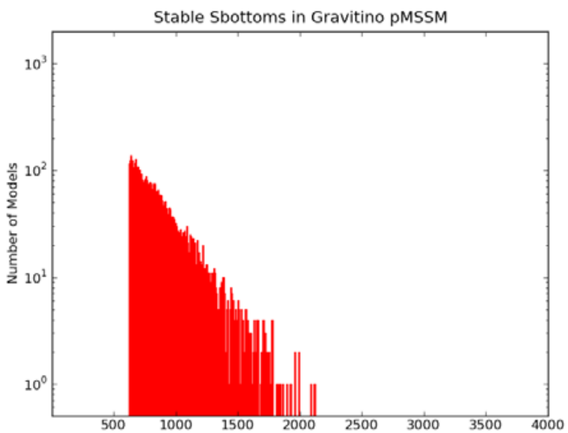
- 3581 (!!) models (conservatively) are removed by stable particle searches w/ ~ 5 fb^{-1} @ 7 TeV





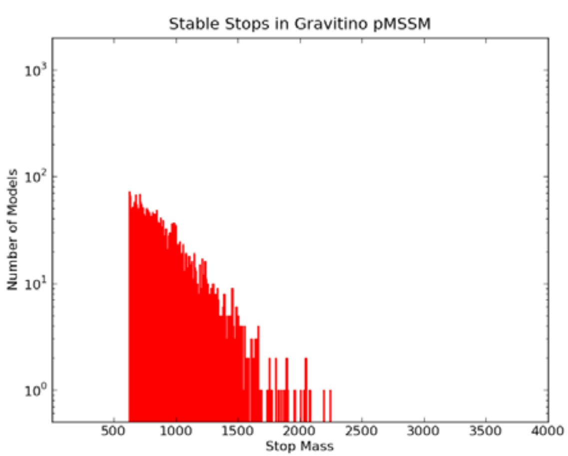


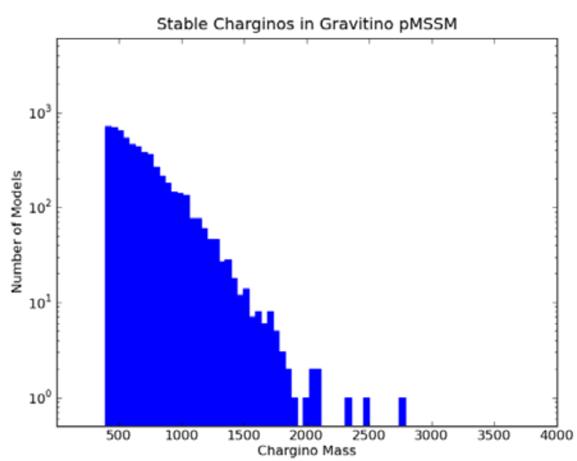




Gravitino LSP scenarios produce many models with detector-stable charged/colored sparticles over a very wide range of masses & species.

Specialized searches are required in some cases & to cover decays inside the detector (not shown here). This is work now in progress.





Summary & Conclusions

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

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

- Going to 8 TeV will be a significant step in model coverage

- Higgs results will play a critical role in all future studies

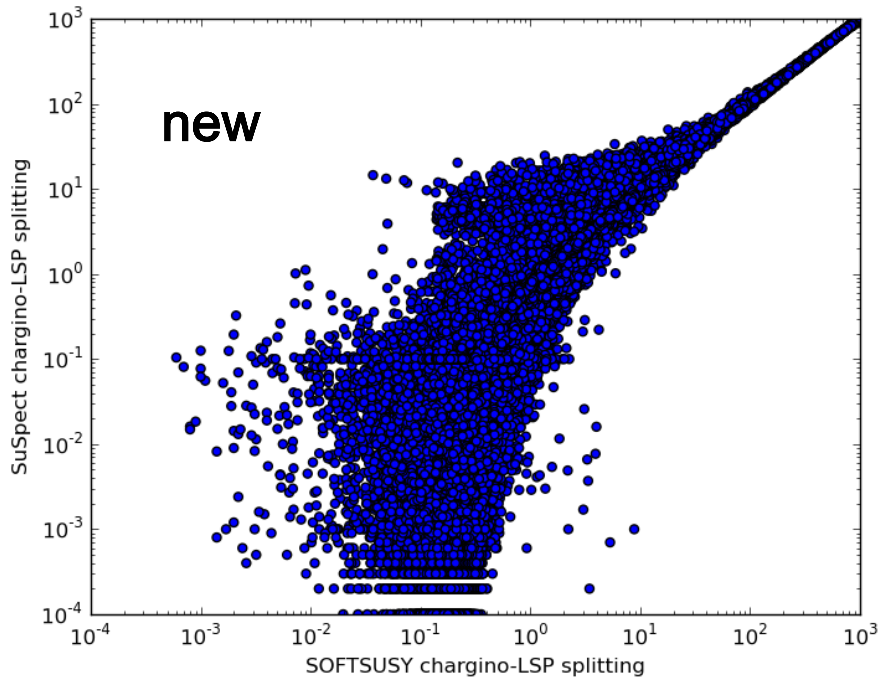
- We look forward to the 8 TeV results in July -- ¡ ɹǝpu∩ uʍoᗡ

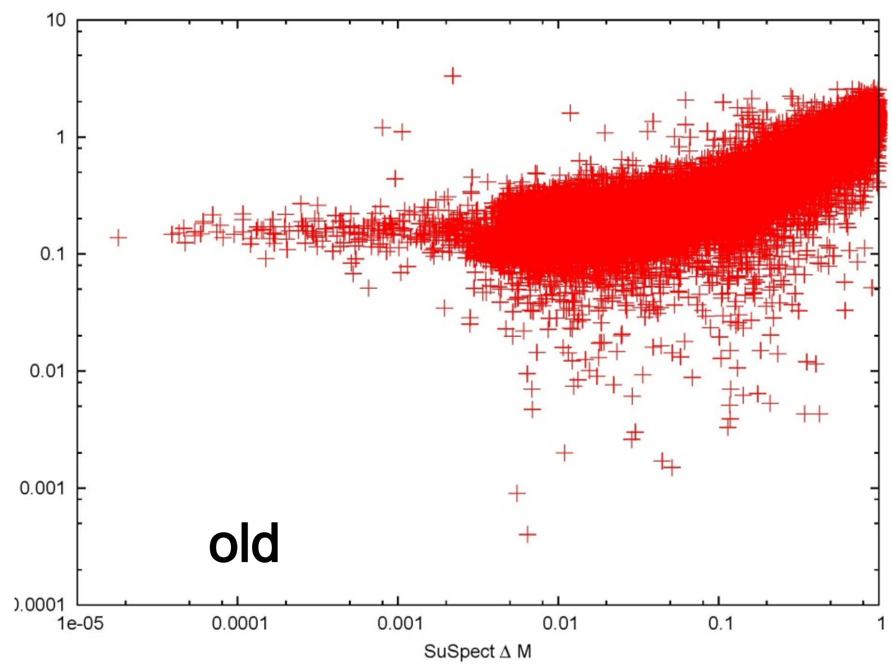
“Take a look at this everyone - it just could be the signature we’ve been looking for!”

BACKUPS

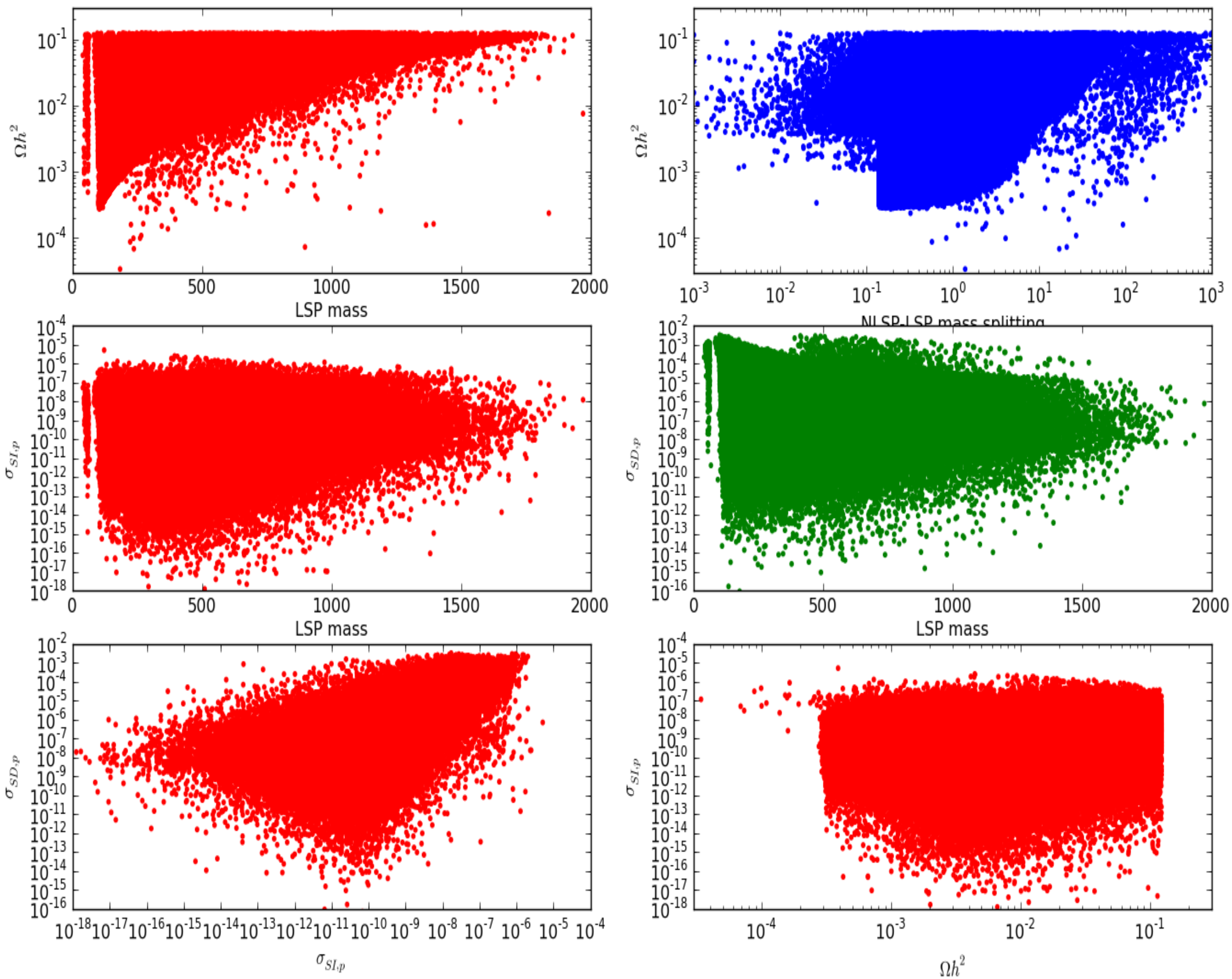
Stable Chargino Spectrum Generator Issues

- The issue still remains as to just how many pMSSM models will lead to long lived charginos. Although the number is always large SuSpect predicts more degeneracies than does SOFTSUSY, i.e., it depends how & which RCs are included





χ_1^0 LSP DM Observables



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, $\tan\beta$

$\rightarrow\rightarrow$ (1 gravitino mass : $m_{3/2}$)

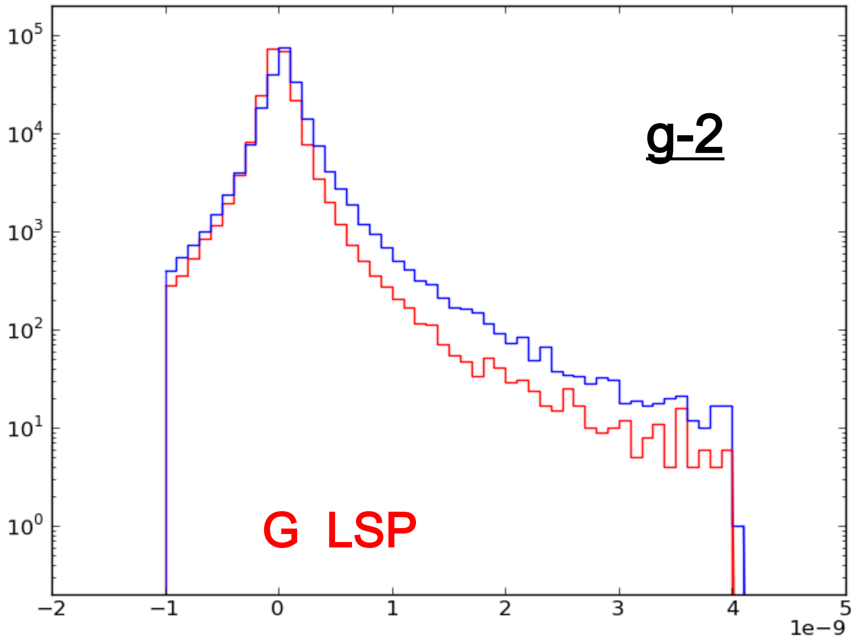
Choose the ranges of these parameters & how they're selected

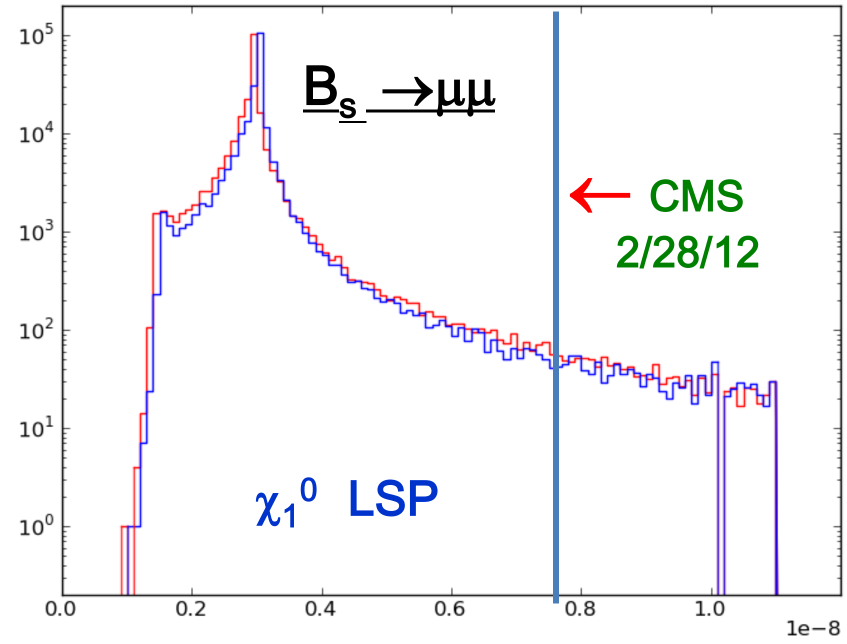
Scan: look for points in this space satisfying all existing data & then study their signatures @ the LHC & elsewhere.. NO FITS!

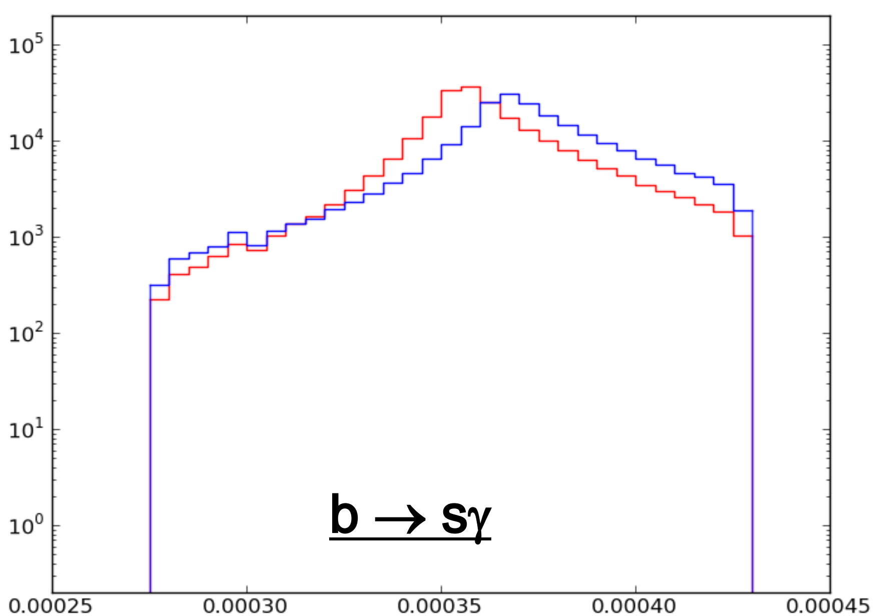
Electroweak Content of χ_1^0

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 !

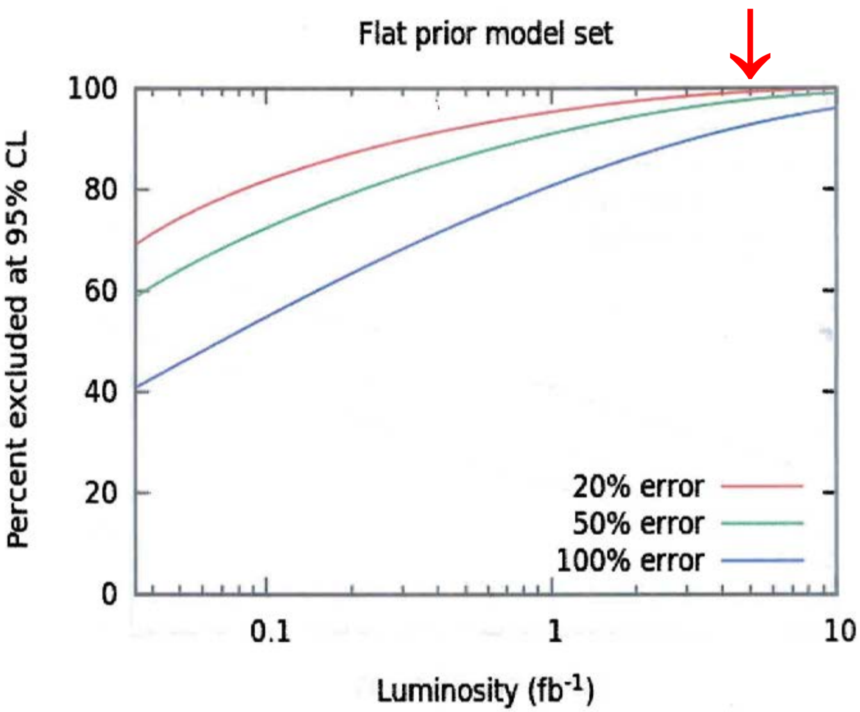


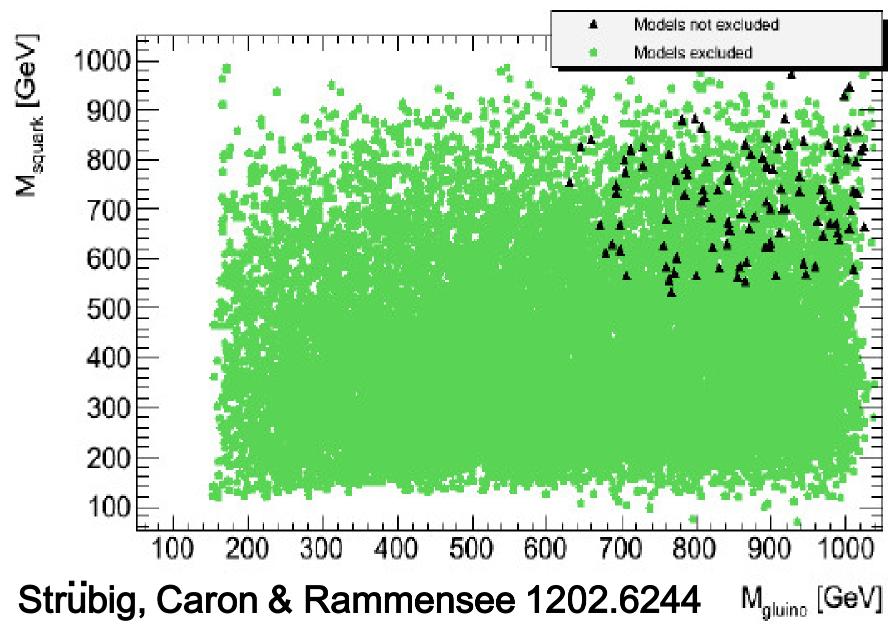




- Overall, these are quite minor differences . The important differences are the LSP itself & the NLSP
- CMS update kills 1041(1143) models in the neutralino (G) LSP set

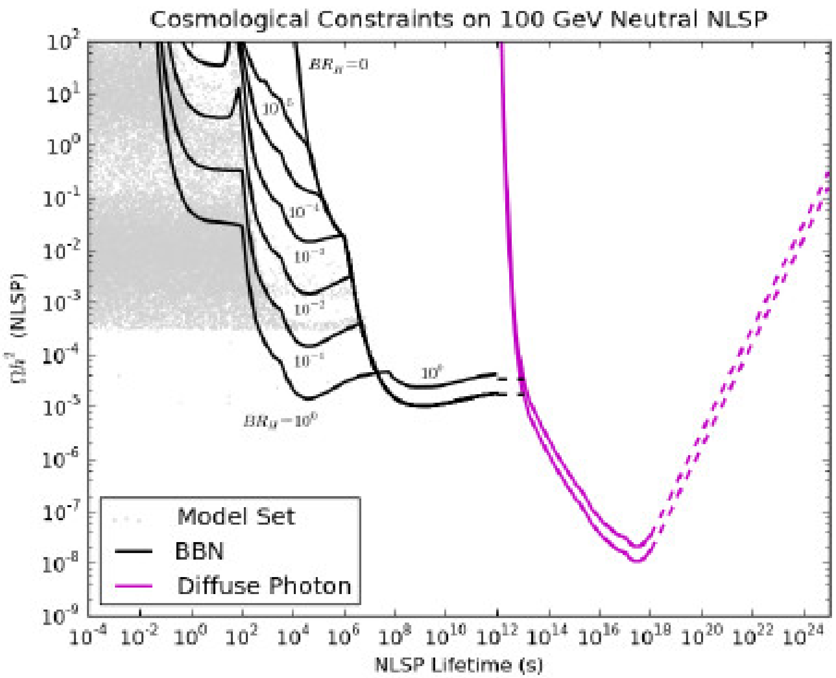
- ATLAS & CMS have 'done a number' on squark & gluinos below ~ 0.8-1 TeV - - even in the pMSSM scenario :

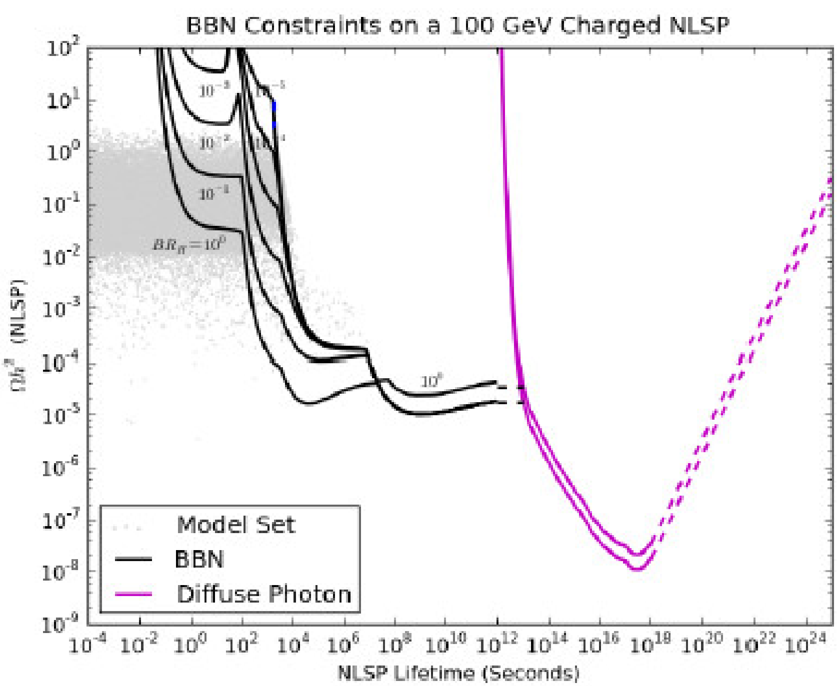




Strübig, Caron & Rammensee 1202.6244

- At most, only ~1% of our old ~68k pMSSM model set w/ sparticle masses below 1 TeV now survive. They're 'dead but still walking' …
  → New pMSSM models needed!





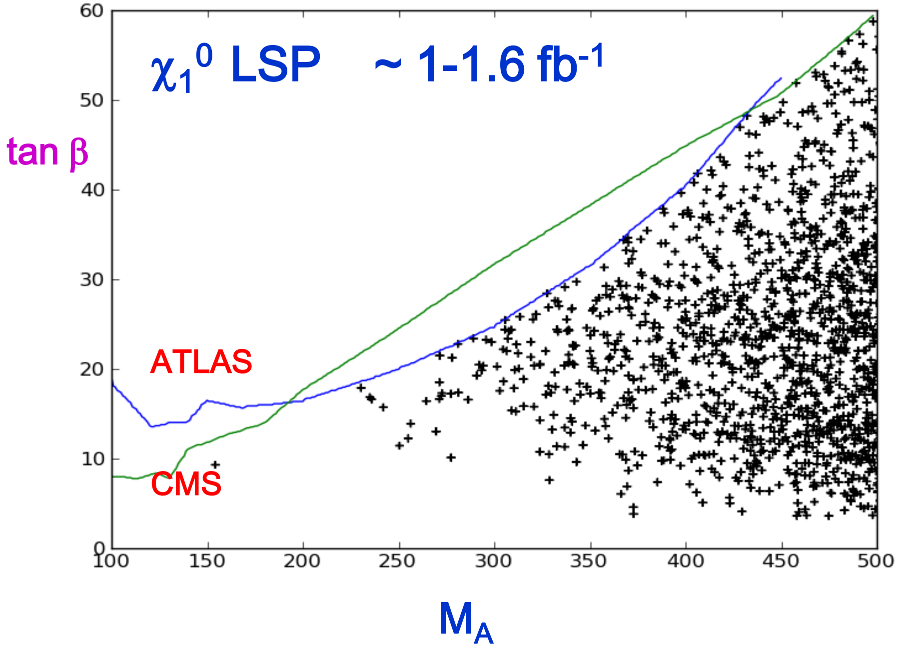
Sample constraints from BBN and diffuse γ's for different hadronic branching fractions of the NLSP

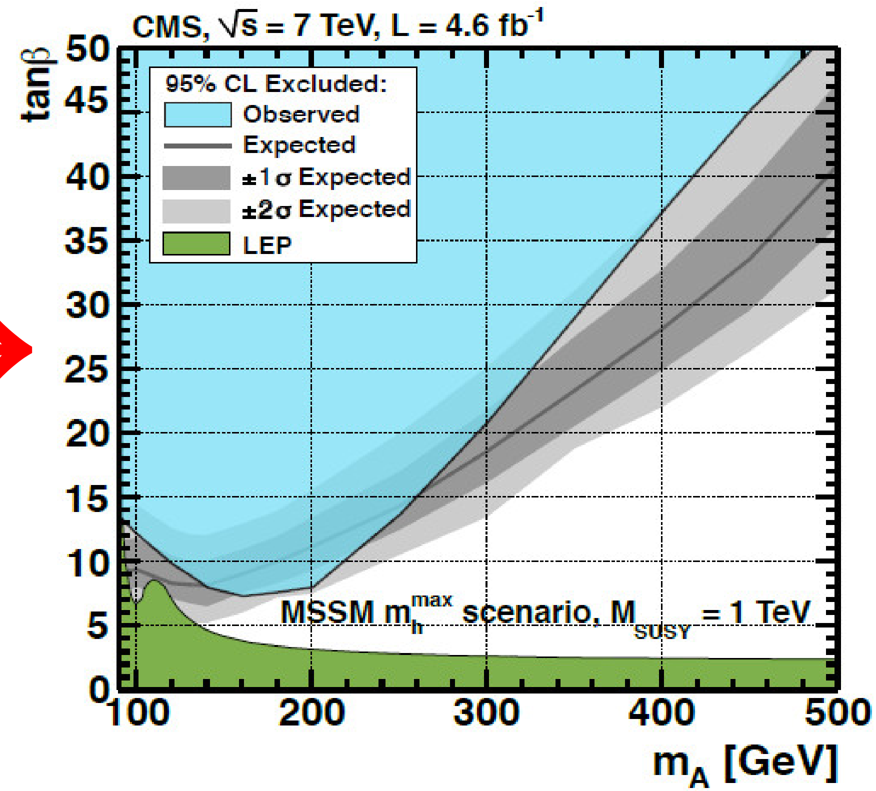
Shaded areas show where our gravitino models live

We follow :

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

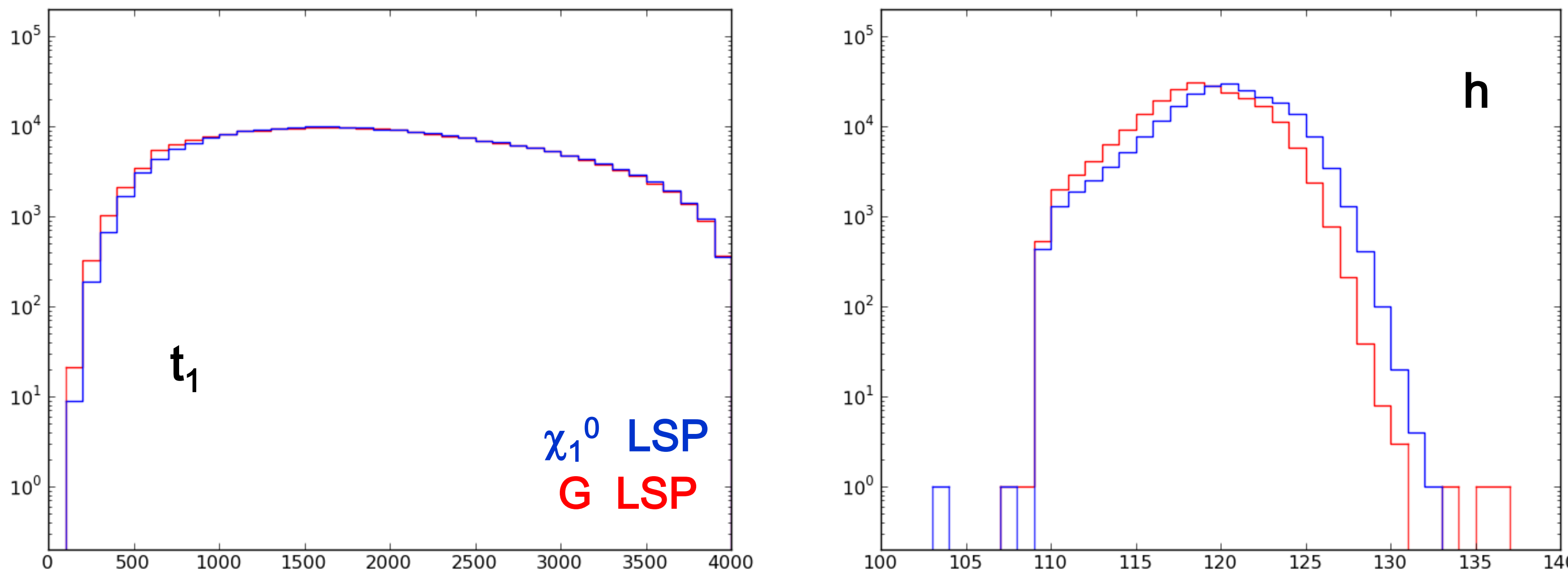
Impact of A,H $\rightarrow \tau\tau$ Searches





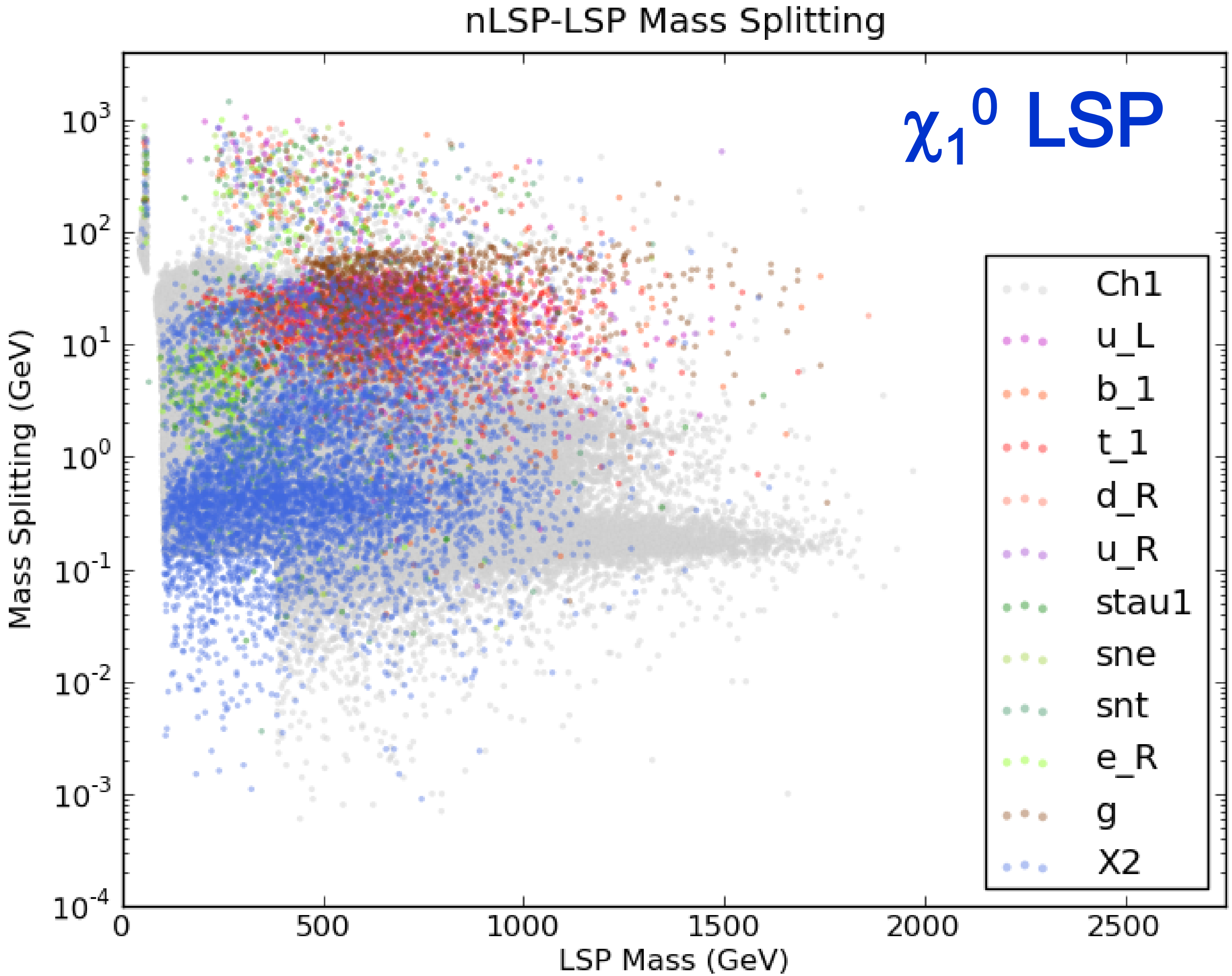
Increased lumi enhances coverage of the M_A - tan β plane

→ These searches have important impact other parts of the pMSSM..



- Although the h mass itself is not part of the scan, the slightly different mass specta in the G scan contribute, via loops, to a somewhat lighter Higgs

- Some other observables show similar size effects but are not really very different in the two model sets


nLSP-LSP Mass Splitting
χ1 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