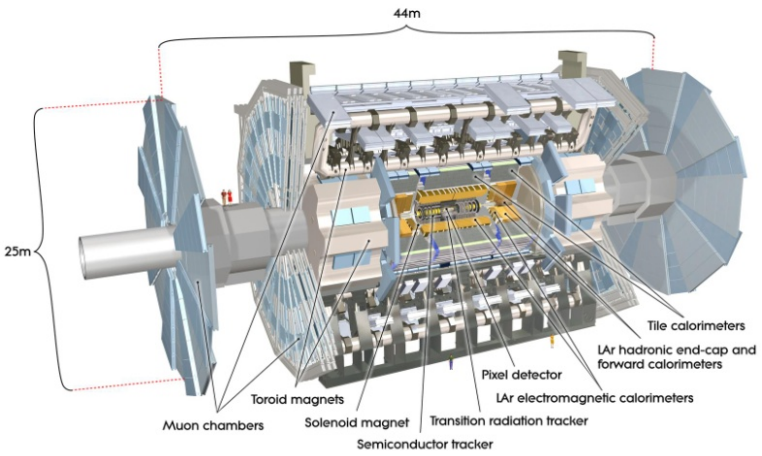
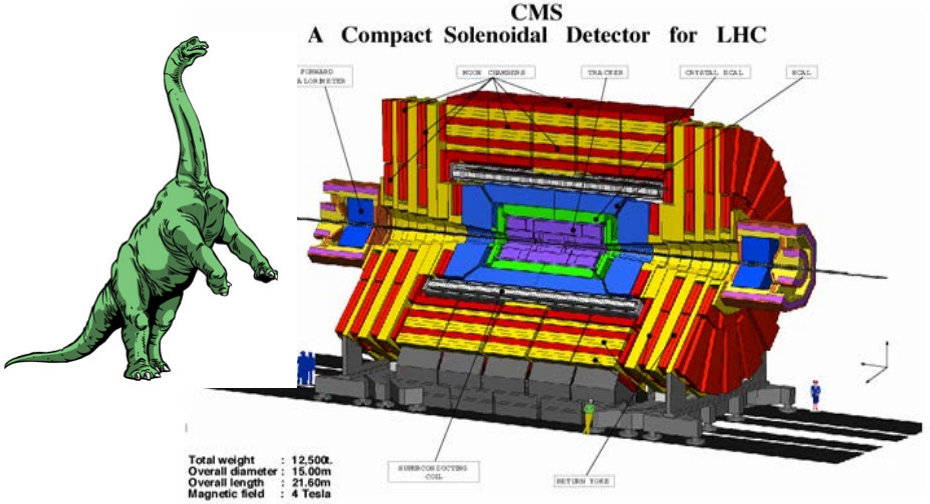
SUSY w/o Prejudice @ LHC-7 /8





1206.4321 & 1206.5800 7/6/12

SLAC NATIONAL ACCELERATOR LABORATORY

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

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

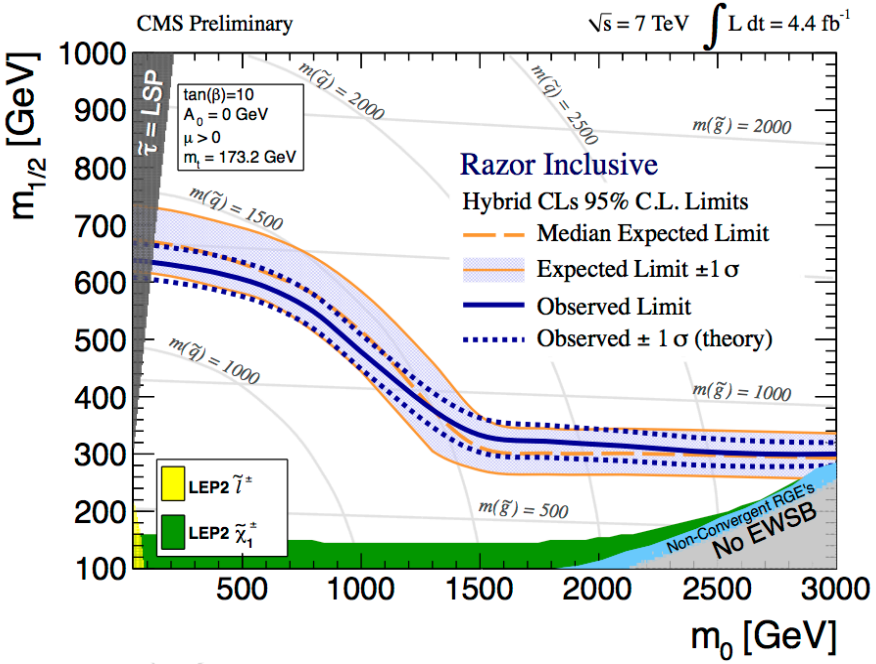
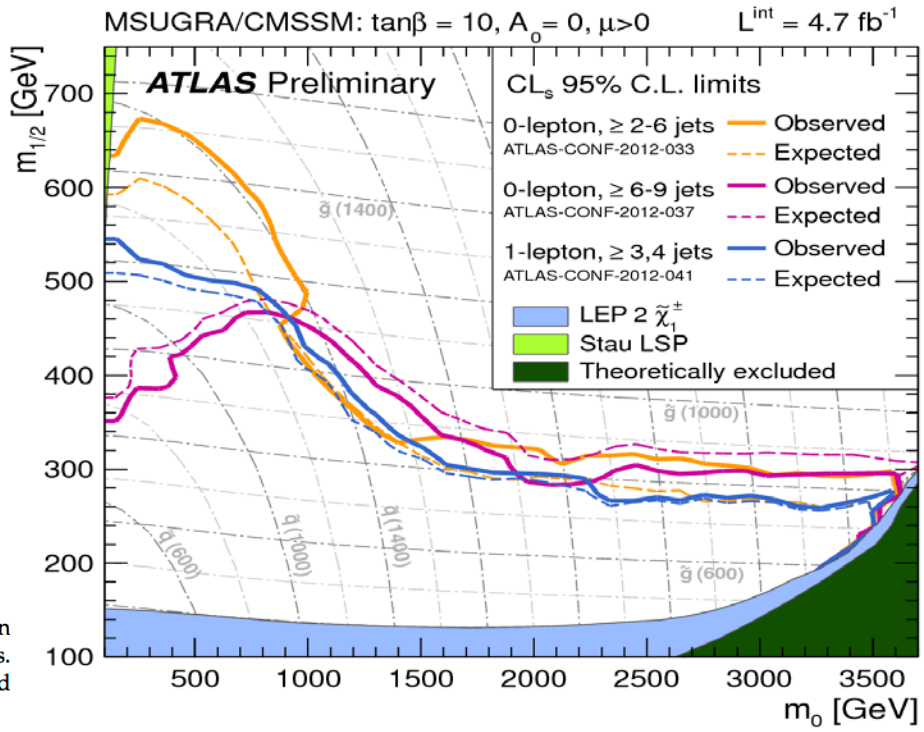


Figure 10: Observed (solid curve) and median expected (dot-dashed curve) 95% CL limits in the $(m_0, m_{1/2})$ CMSSM plane with $\tan\beta = 10$, $A_0 = 0$, $\mathrm{sgn}(\mu) = +1$ from the razor analysis. The $\pm$ one standard deviation equivalent variations in the uncertainties are shown as a band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



pMSSM Analysis Assumptions

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 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!

Two New pMSSM Scans: Neutralino & Gravitino LSPs

(via SOFTSUSY +SuSpect + FeynHiggs+)

$100\ \text{GeV} \leq m_{Le1,2,3} \leq 4\ \text{TeV}$

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

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

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

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

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

→→ 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

ATLAS MET Analyses @ 7 & 8 TeV

- The first step in exploring the parameter space is to apply the SUSY MET searches
- We follow the ATLAS analysis suite 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 [4/6]	0.36%	1.61%
nj1l [8/3]	0.81%	2.64%
nj2l [5]	0.16%	0.22%***
flavor/ml	(in progress)	(ditto)
(sub)total	6.73%	23.28%

→ nj0l is by far dominant in these searches

*** In this case, we extrapolated 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 $\sqrt{s}$ = 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 RATIOS of the expected backgrounds in each signal region at 7 & 8 TeV and use them 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

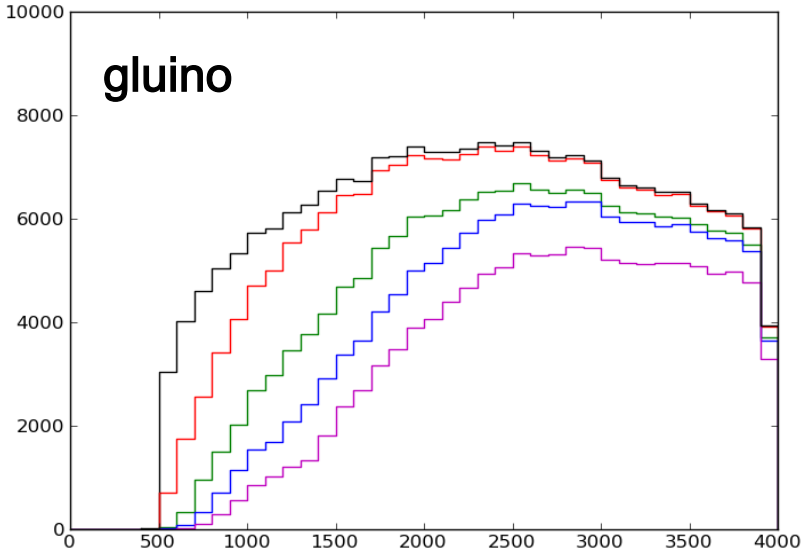
- Not too surprisingly, the gain in pMSSM coverage going to 8 TeV is substantial due to the increases in σ's. nj0l continues to dominate :

	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++	0.35%	0.38%
flavor/ml	(in progress)	(ditto)
(sub)total	32.75%	45.13%

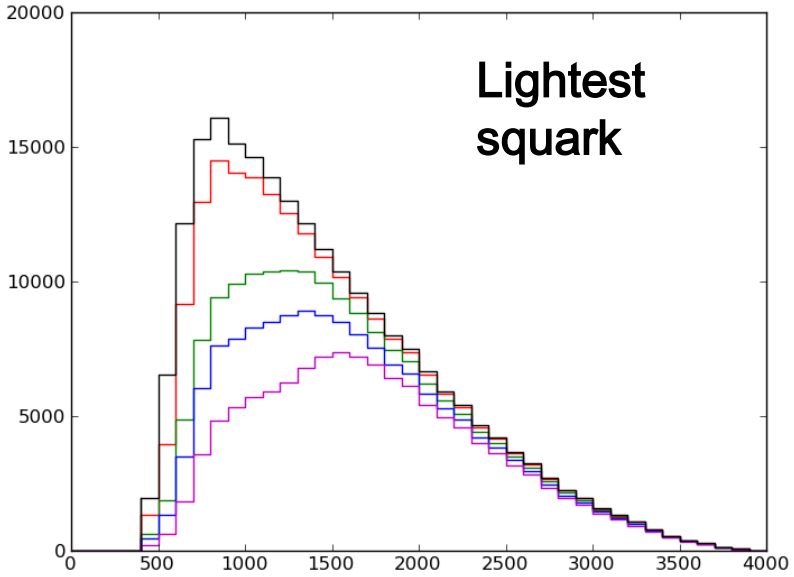
** extrapolated from ~5 fb^{-1} analysis ++ extrapolated from ~1 fb^{-1} analysis

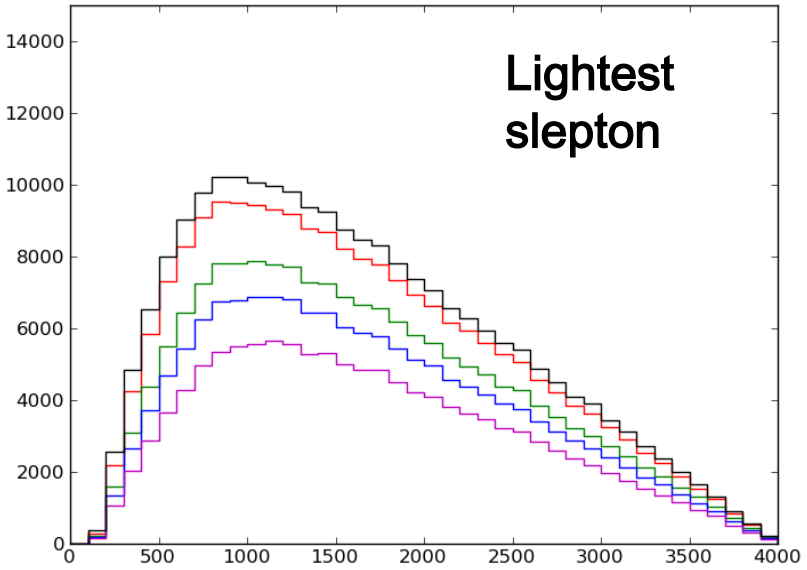
- √s=13-14TeV is needed for more complete coverage

How does the pMSSM respond to negative searches ?

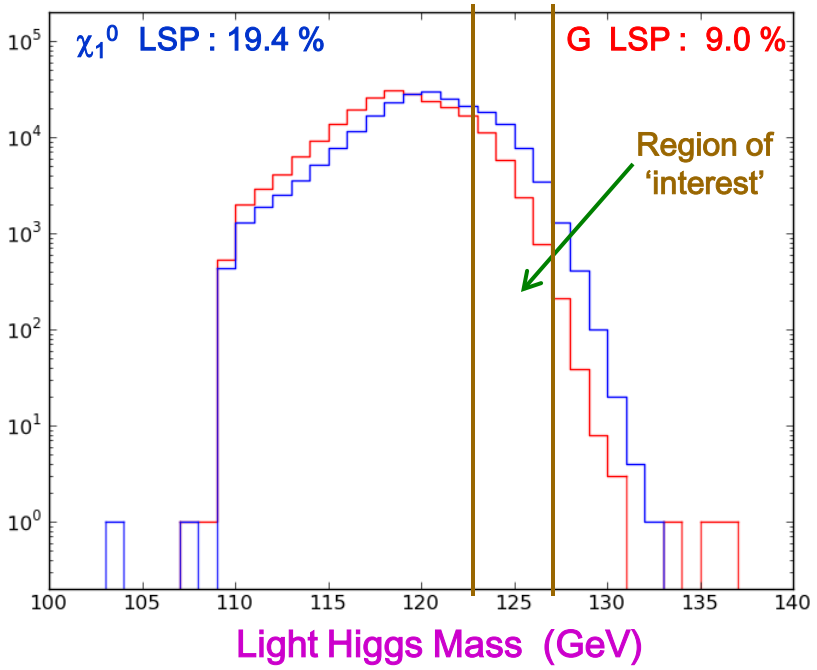


Note that colored sparticles get heavier, i.e., the distributions peak at higher masses as the searches progress but color singlets distributions are just rescaled downward

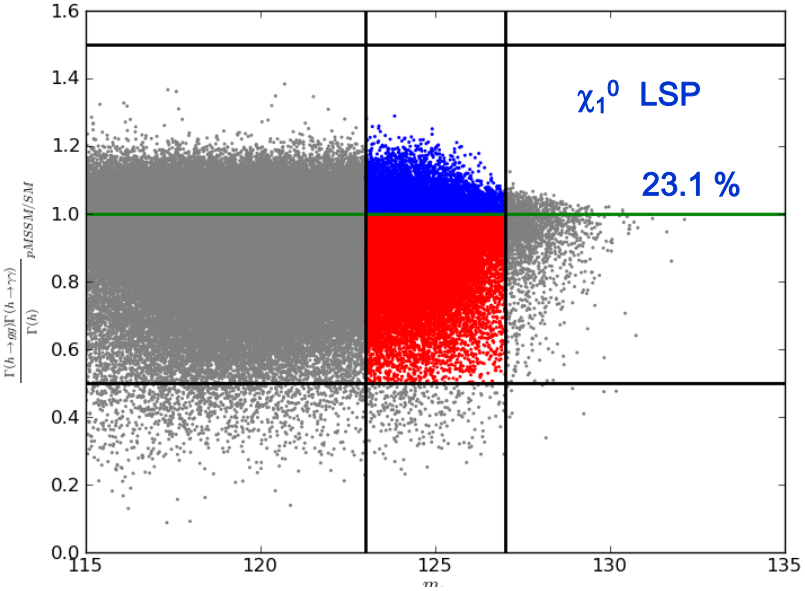


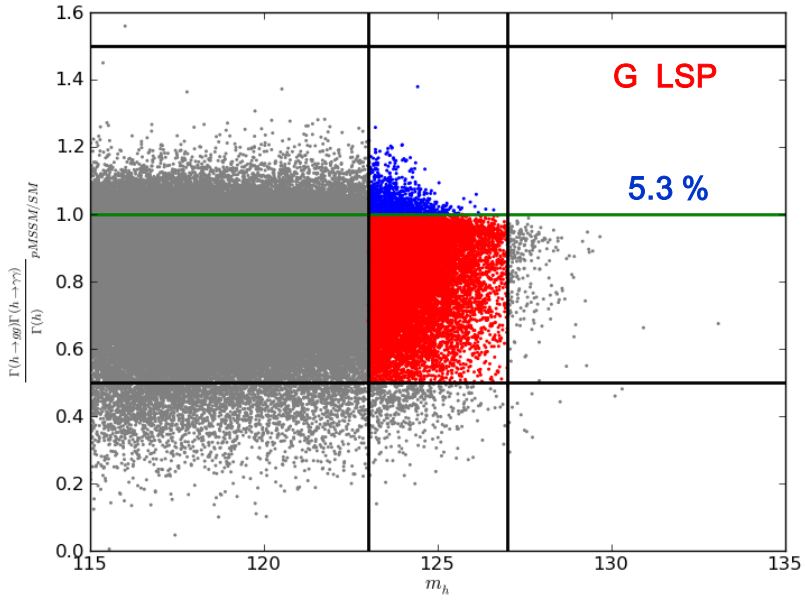


Distribution of Predicted Higgs Masses



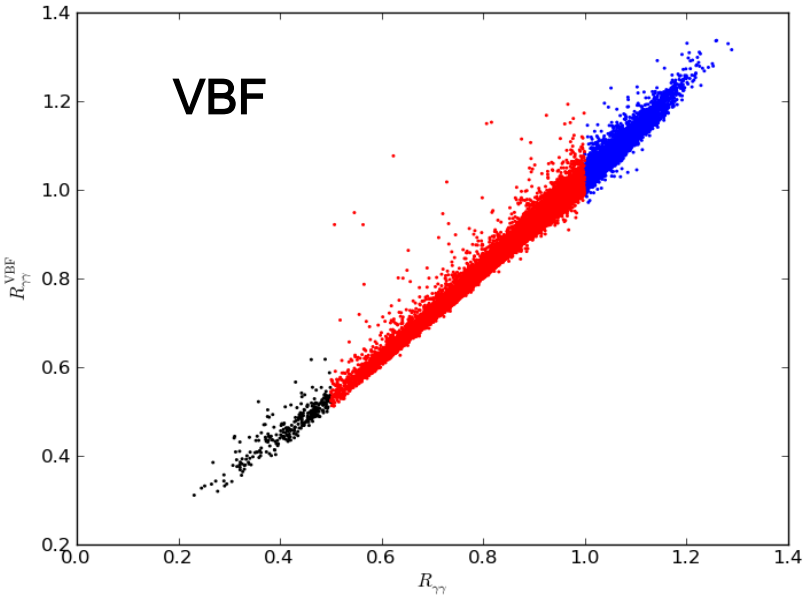
$R_{\gamma\gamma}$

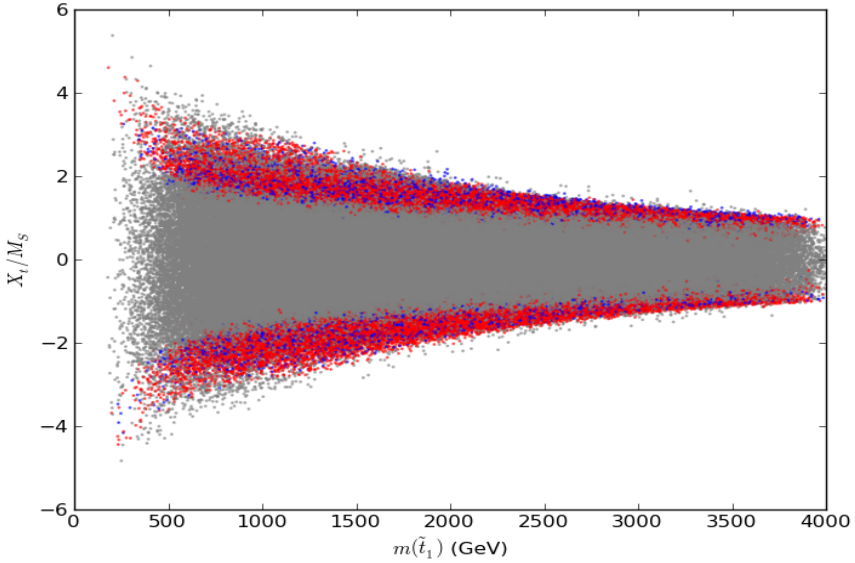


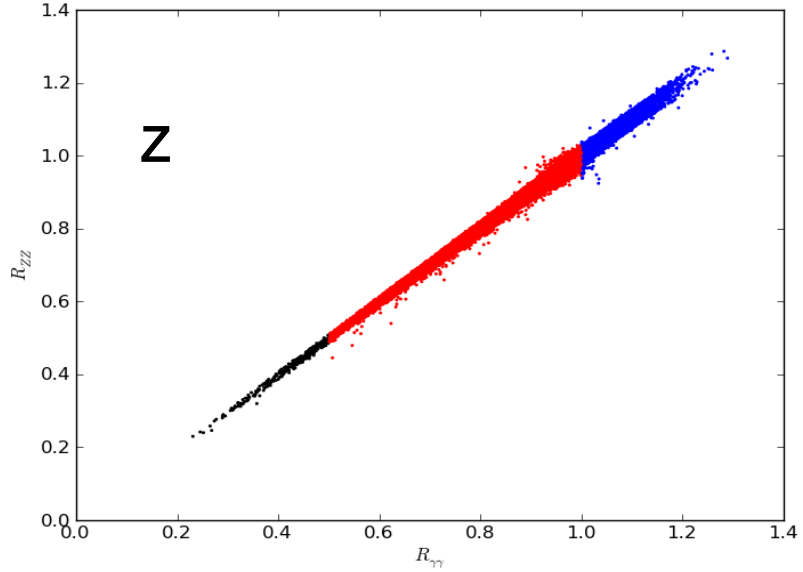


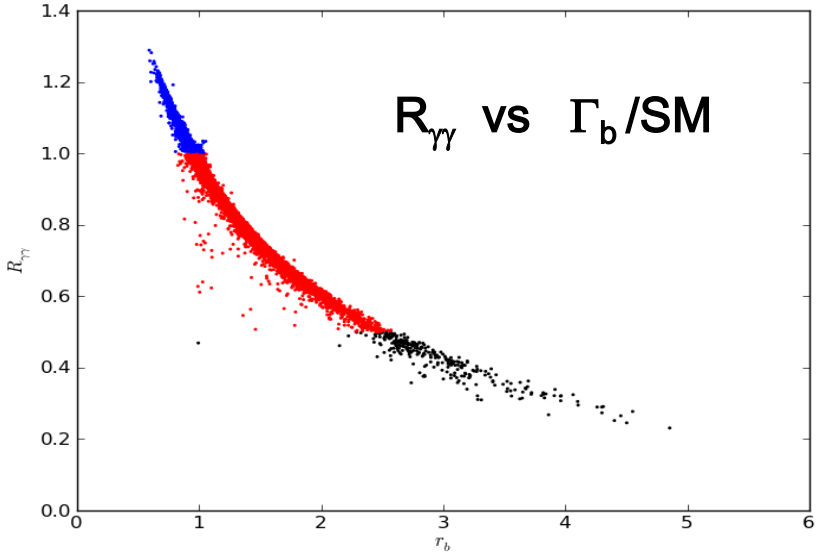
The two different model sets lead to qualitatively similar yet quantitatively very different predictions…

χ_1^0 LSP

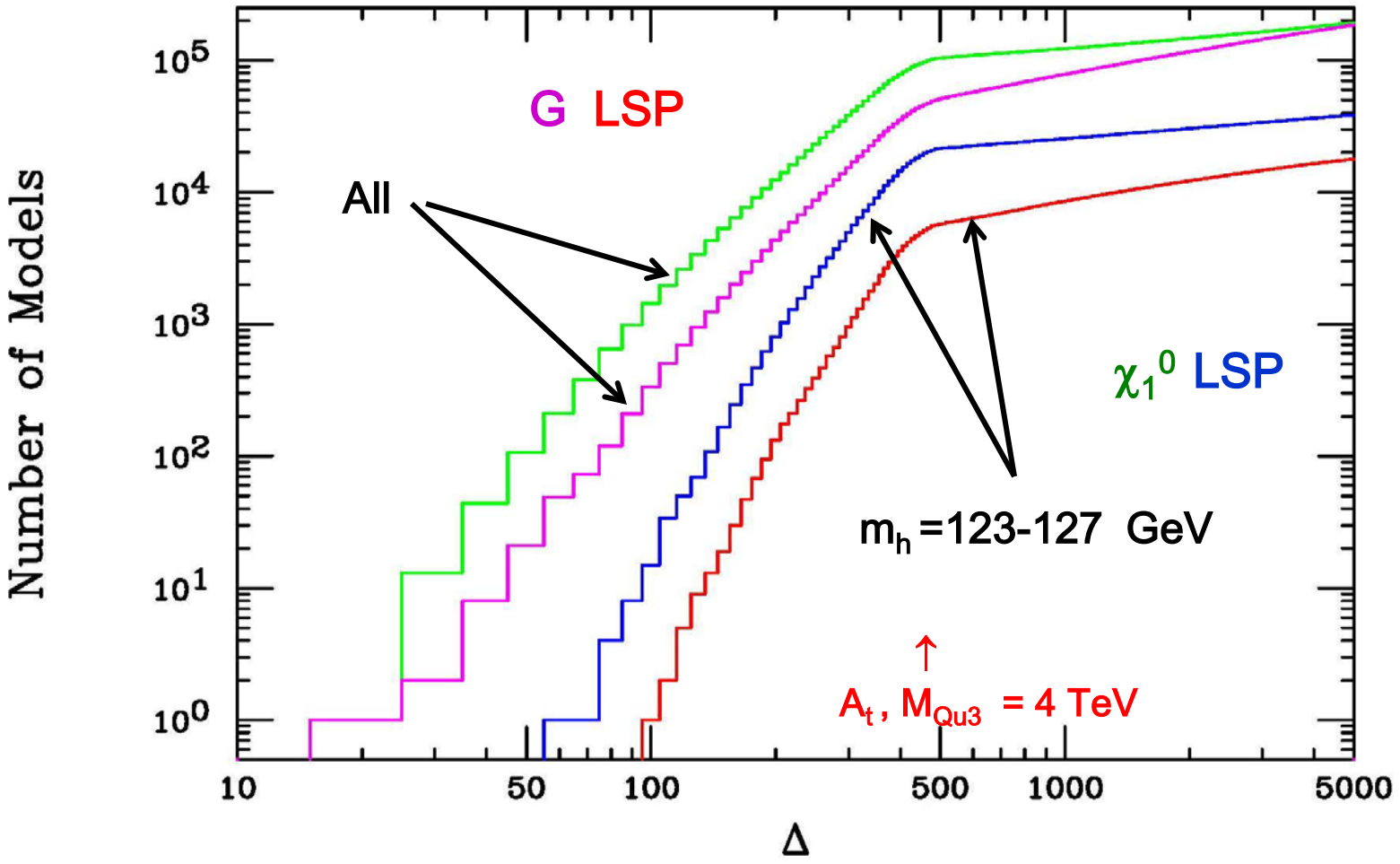

VBF
$R_{\gamma\gamma}^{\rm VBF}$
$R_{\gamma\gamma}$


X_t/M_S
$m(\tilde{t}_1)$ (GeV)


Z
R_{ZZ}
$R_{\gamma\gamma}$

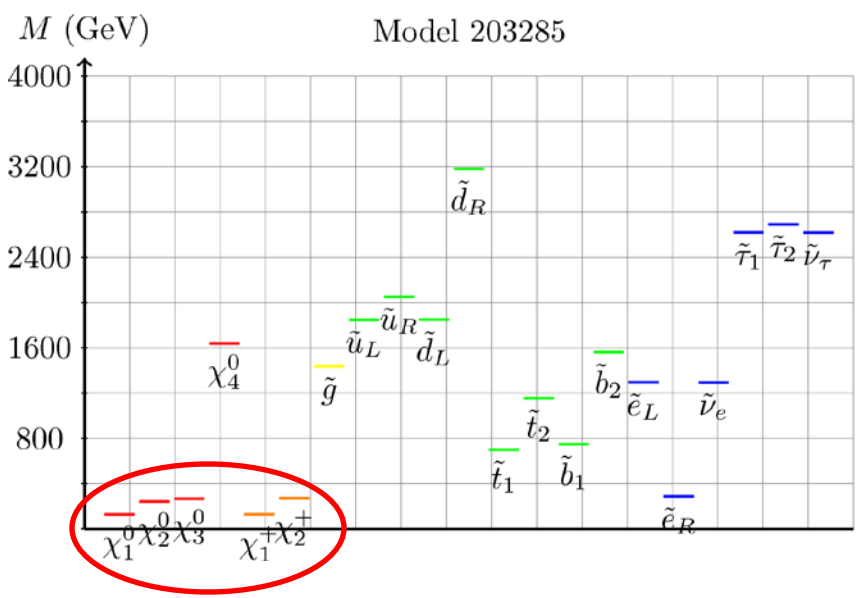

$R_{\gamma\gamma}$ vs Γ_b/SM
$R_{\gamma\gamma}$
r_b

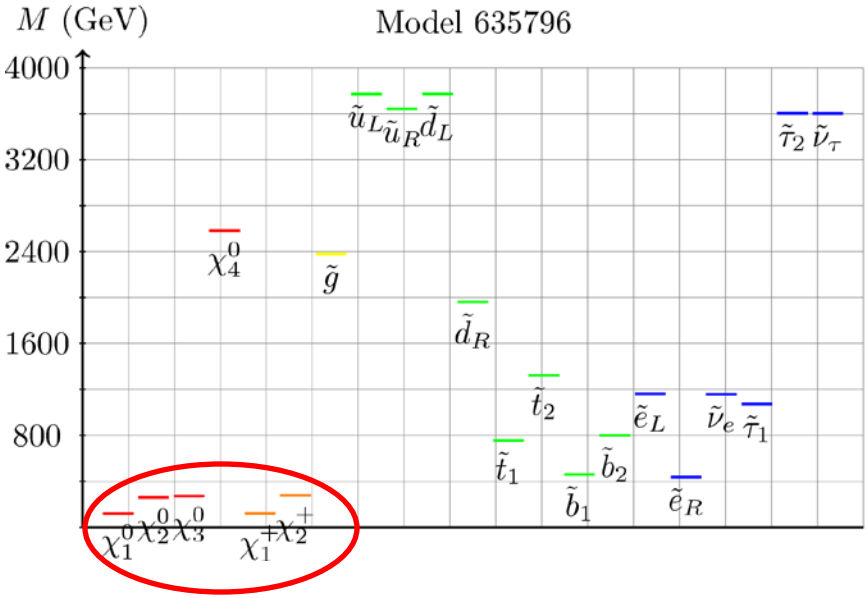
Fine-tuning in the pMSSM

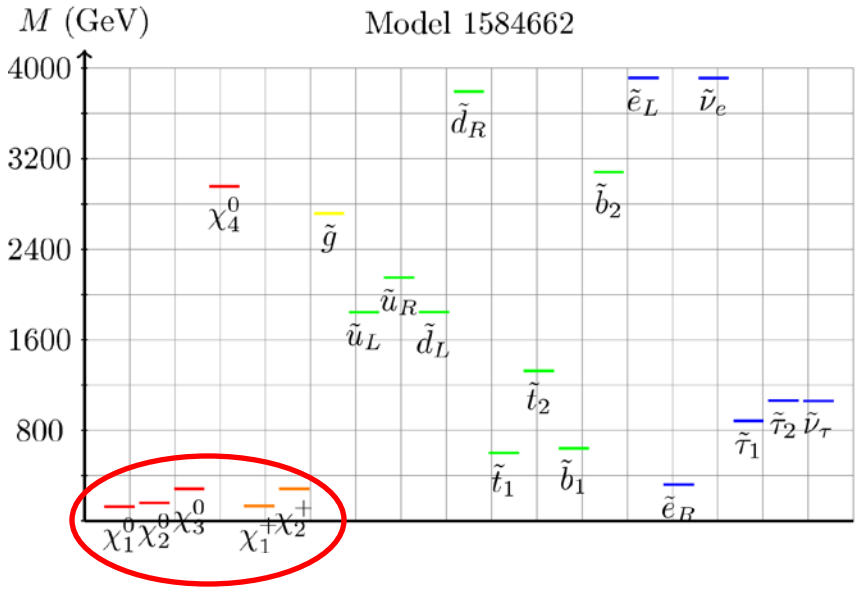


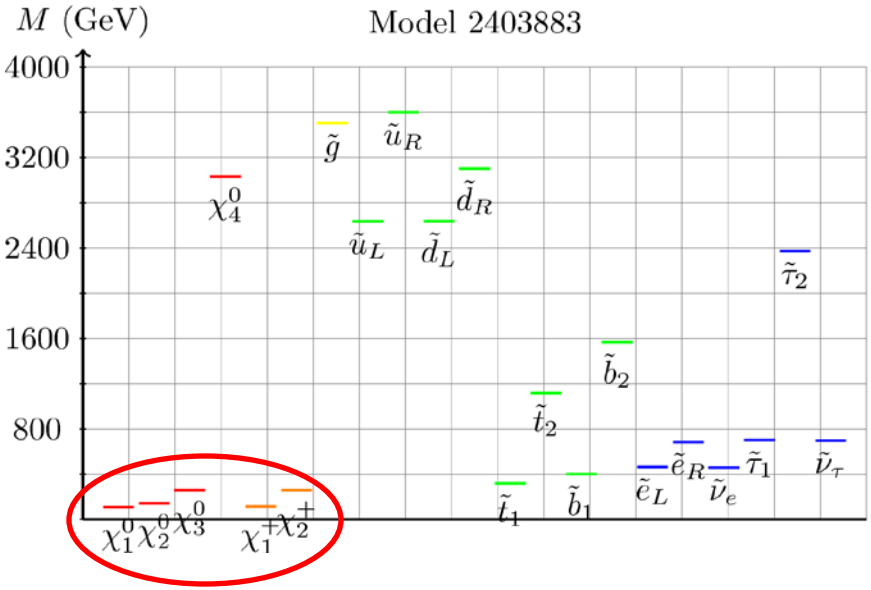
- The ~125GeV Higgs mass removes many of the models with the lowest FT values

Sample Low-FT Model Spectra



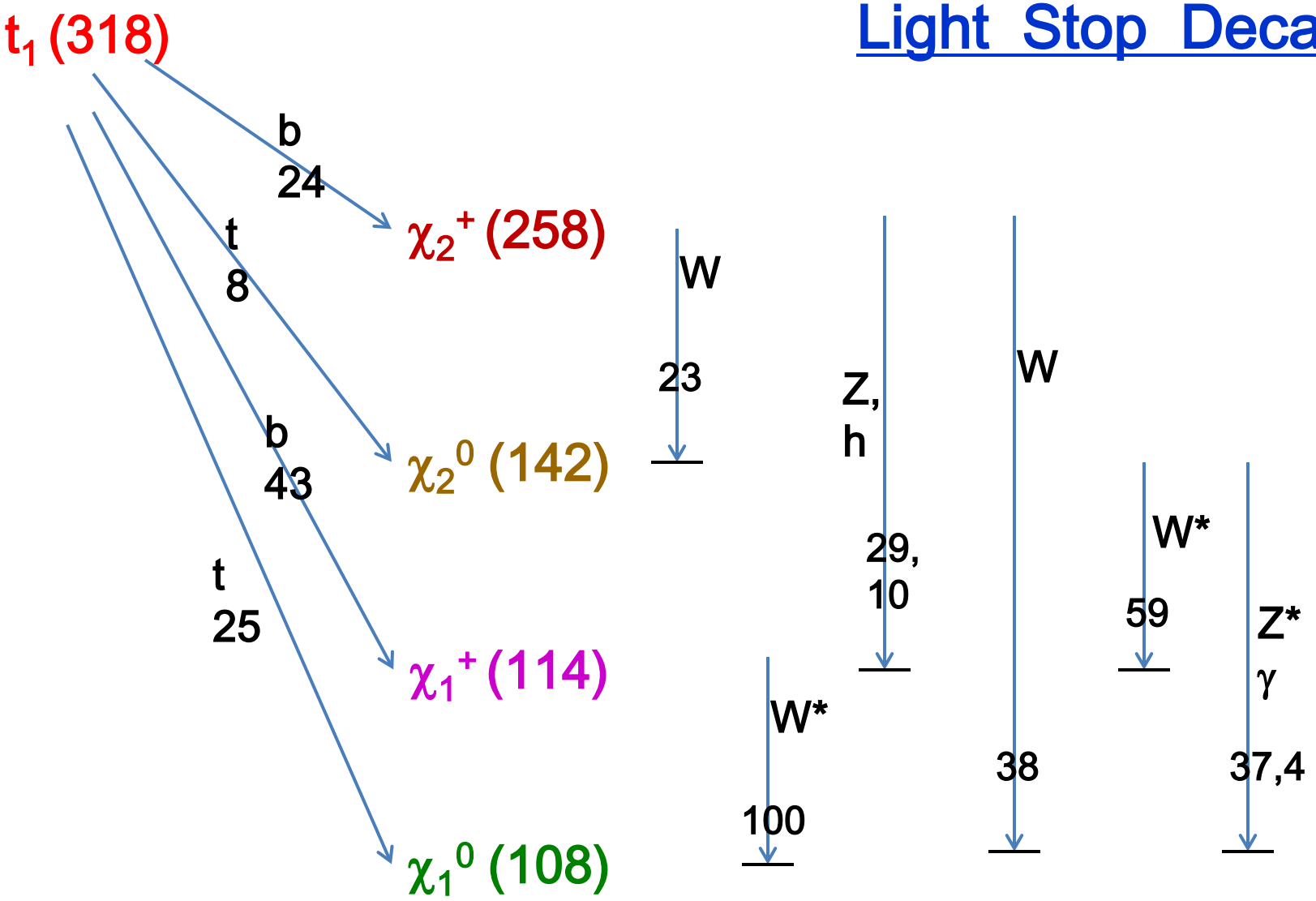




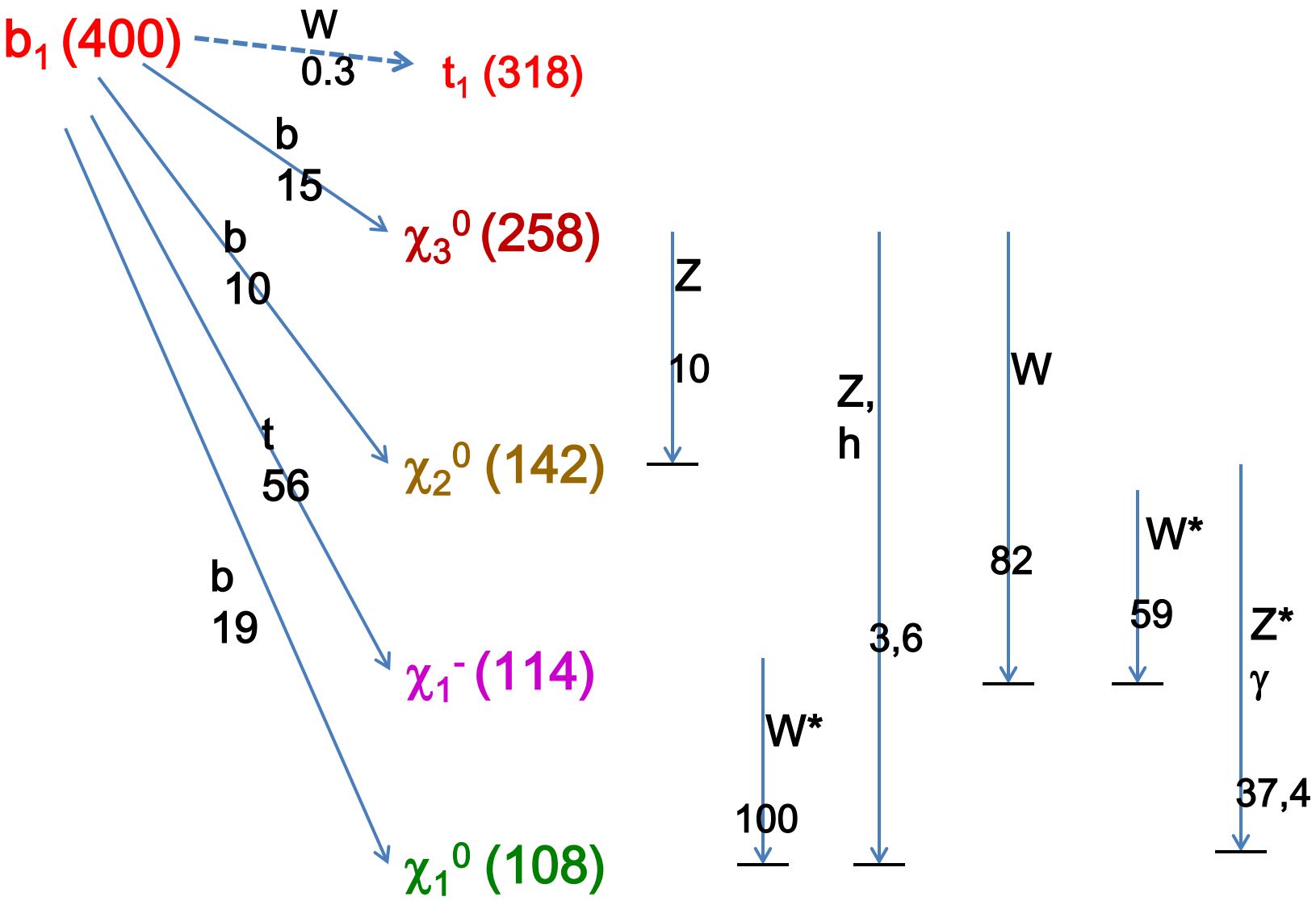


An Example :
#2403883 w/ FT=56.3

Light Stop Decays



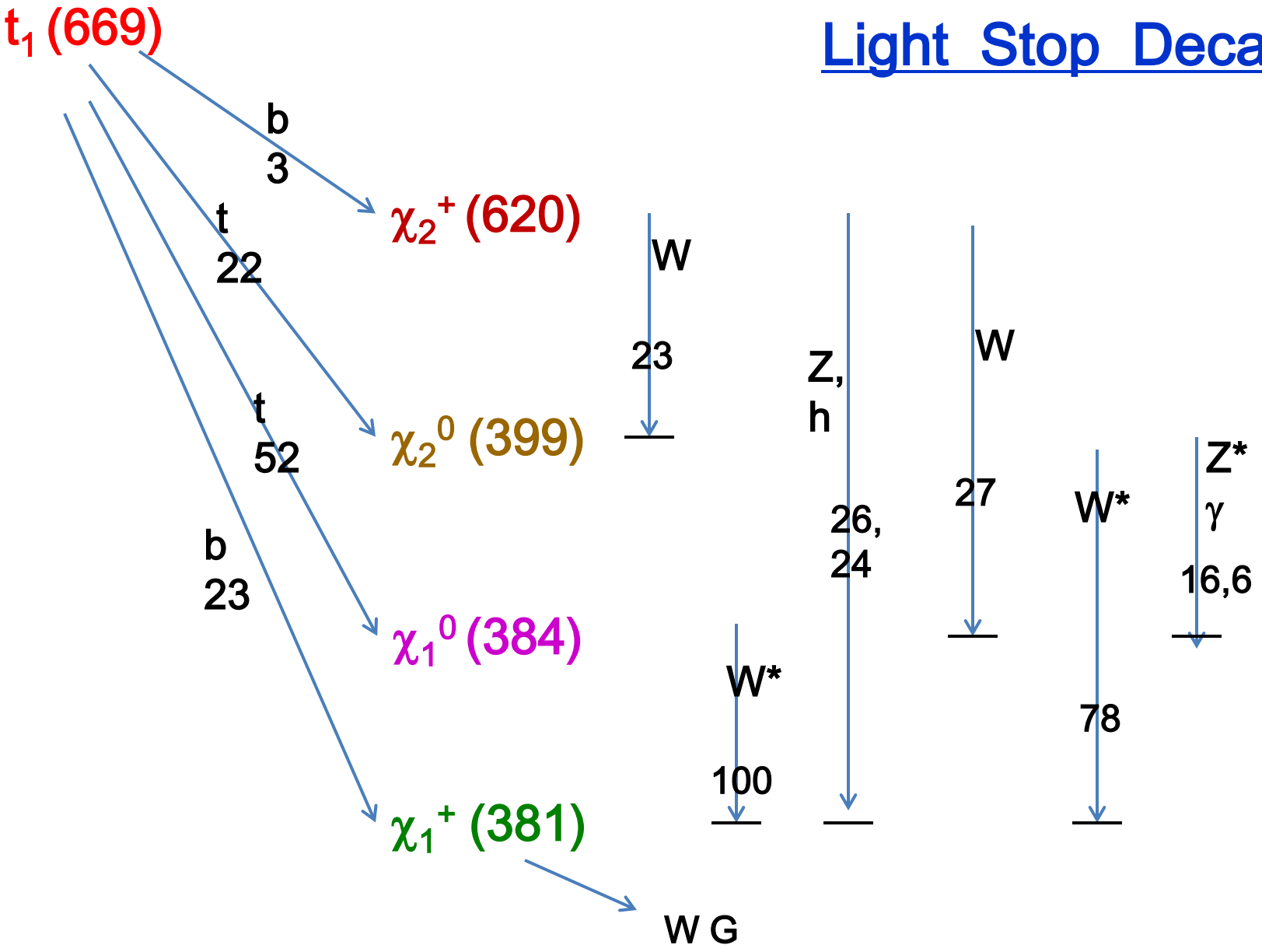
Light Sbottom Decays

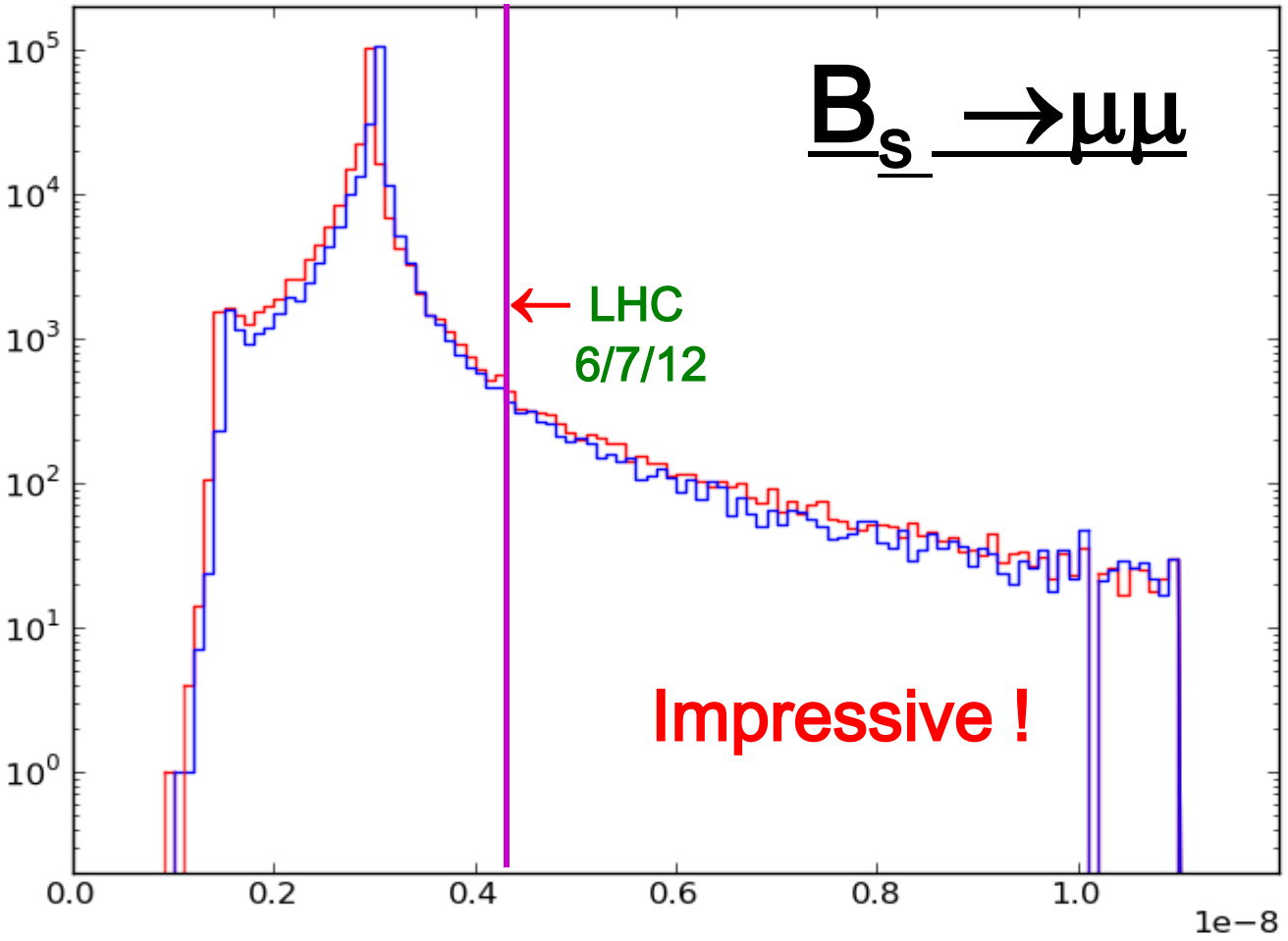


(w/ these BFs the ATLAS 2b-jet + MET search would exclude this b_1 below ~240 GeV)

Light Stop Decays

An Example :
#146314G w/ FT=87.6





- The LHCb 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 ARE important !

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
- Going to 8 TeV will be a significant step in model coverage
- Higgs results will play a critical role in all future studies
- Low FT models have similar features & could be tough to find
- We look forward to more 8 TeV results !

[*Jason is inquiring about the job of sheriff*]

Jason McCullough: Well, gentlemen, I think it's only fair to tell you that I'd only be interested in this job on a temporary basis.

Henry Jackson: Oh?

Jason McCullough: Well, you see, actually I was on my way to Australia when I heard about your gold strike and I decided to, uh, travel through here and see if I couldn't pick myself up a little stake.

Thomas Devery: What do you want to go to Australia for?

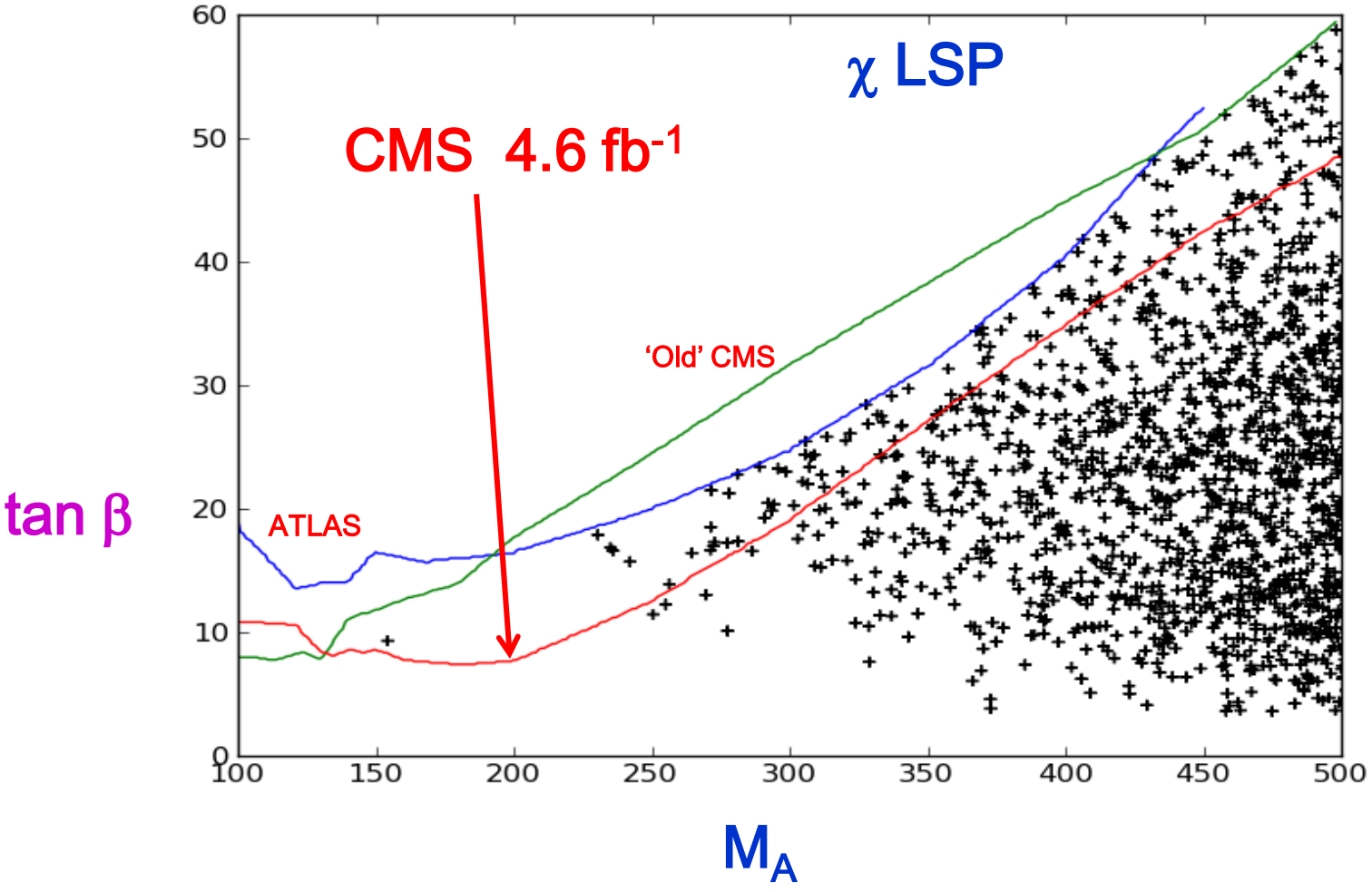
Jason McCullough: Well, it's the last of the frontier country. Thought I might like to do a little pioneering.

Fred Johnson: I thought this was frontier country and we was pioneers.

Henry Jackson: So did I.

BACKUPS

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

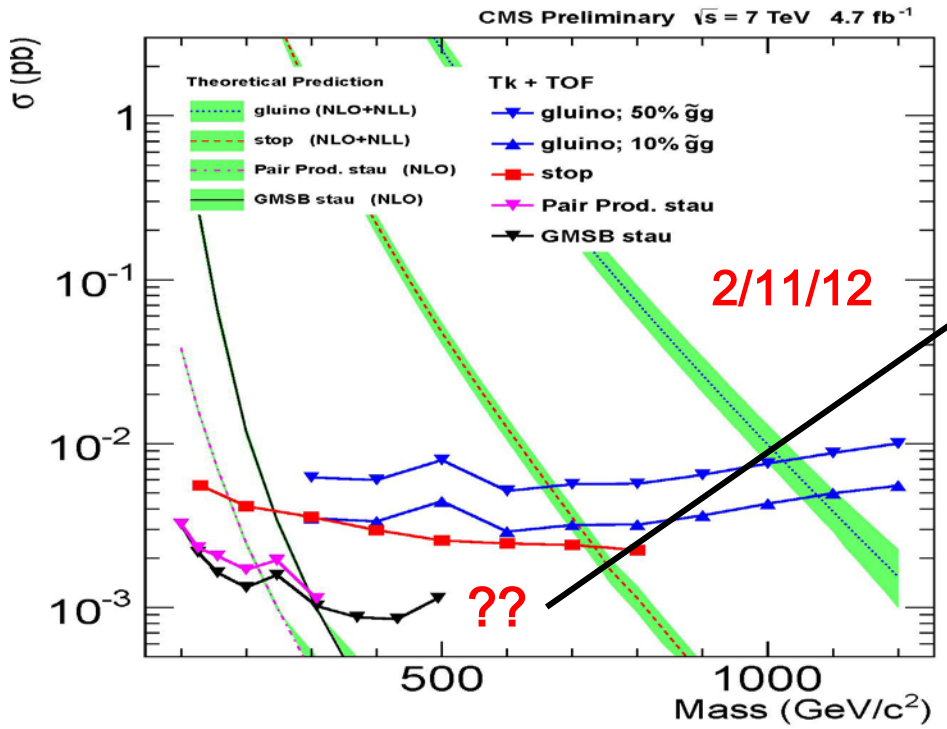


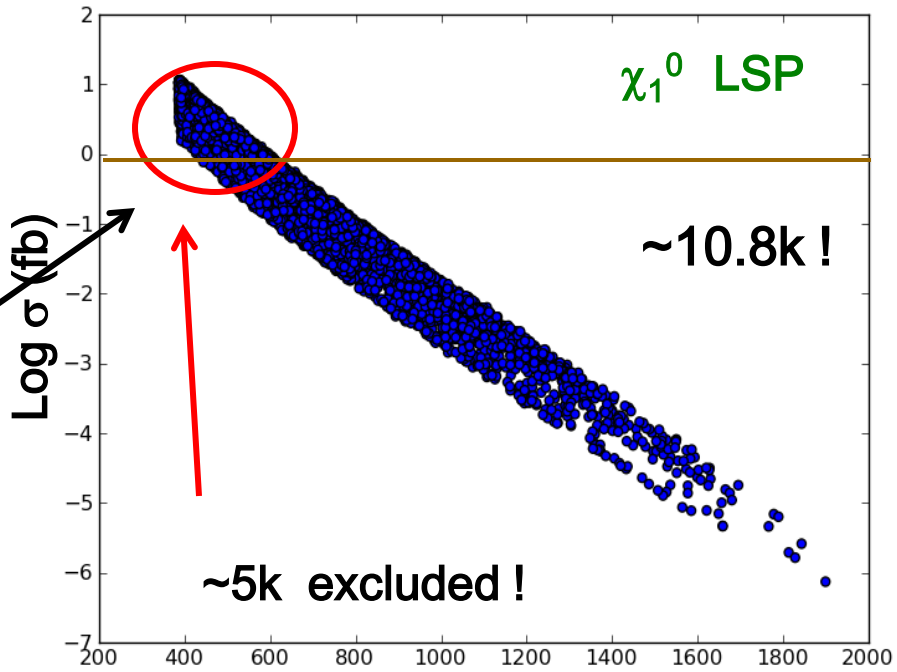
As in the case of $B_s \rightarrow\mu\mu$, improvement in non-MET searches impact the pMSSM analyses… 160(164) models removed from the χ (G) LSP set…

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 :





SM Background Generation @√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

Some Constraints

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

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

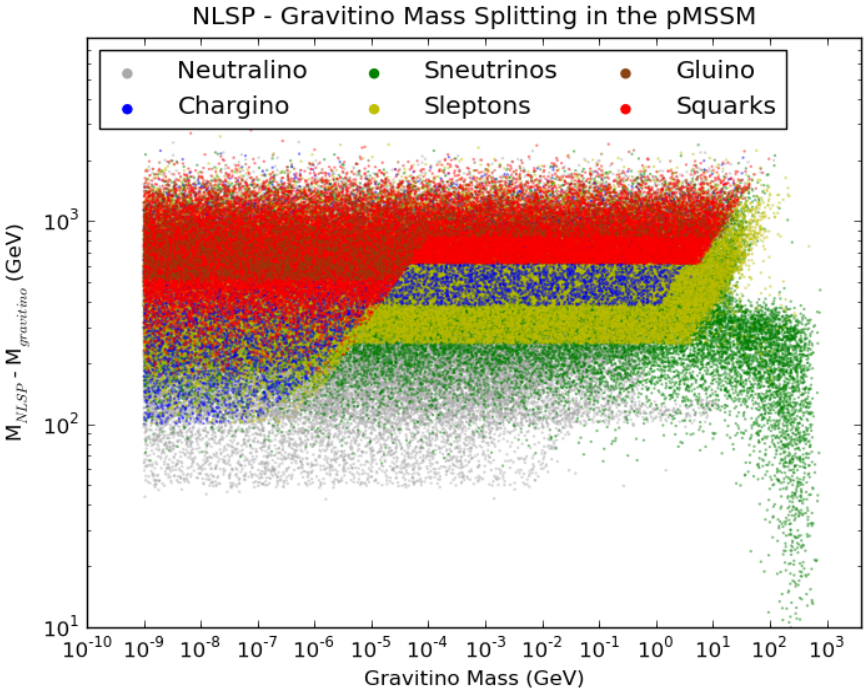
- BBN energy deposition for gravitinos
- Relic ν's & diffuse photon bounds

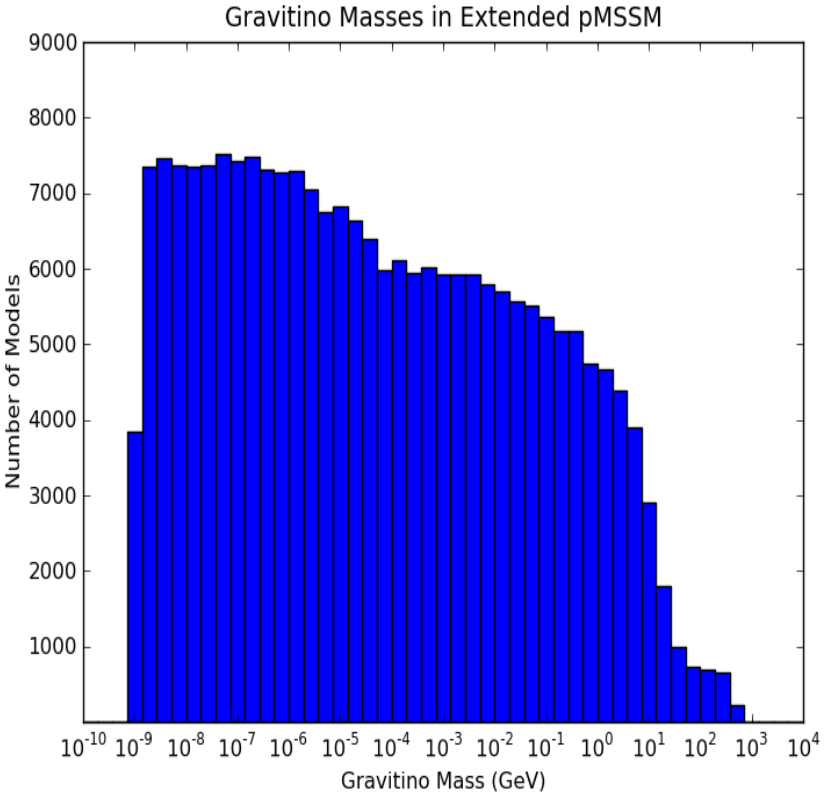
- No tachyons or color/charge breaking minima
- Stable vacua only

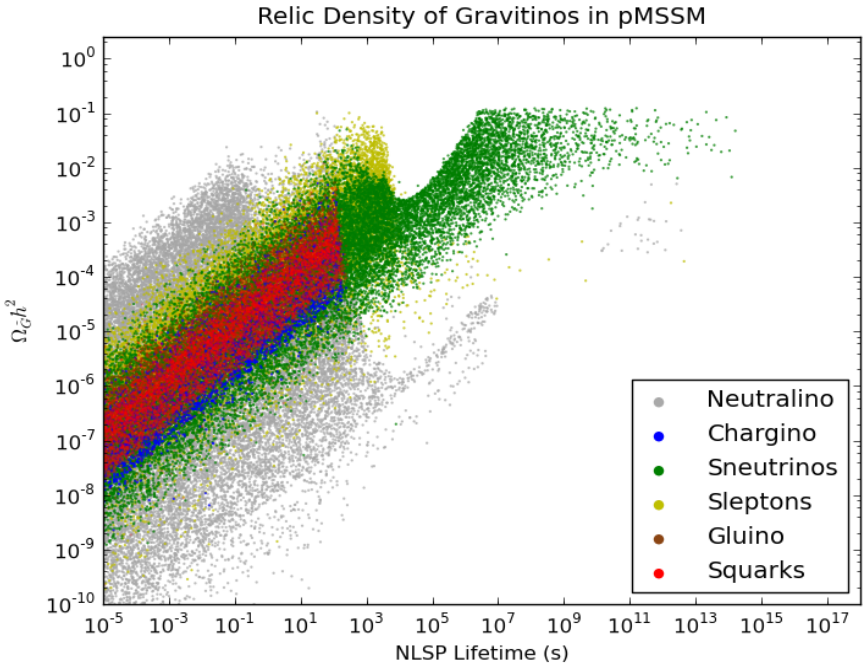
Some New Features

- 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 & 5-body decays for gluinos, t_1 & $\chi_1^{\pm}$

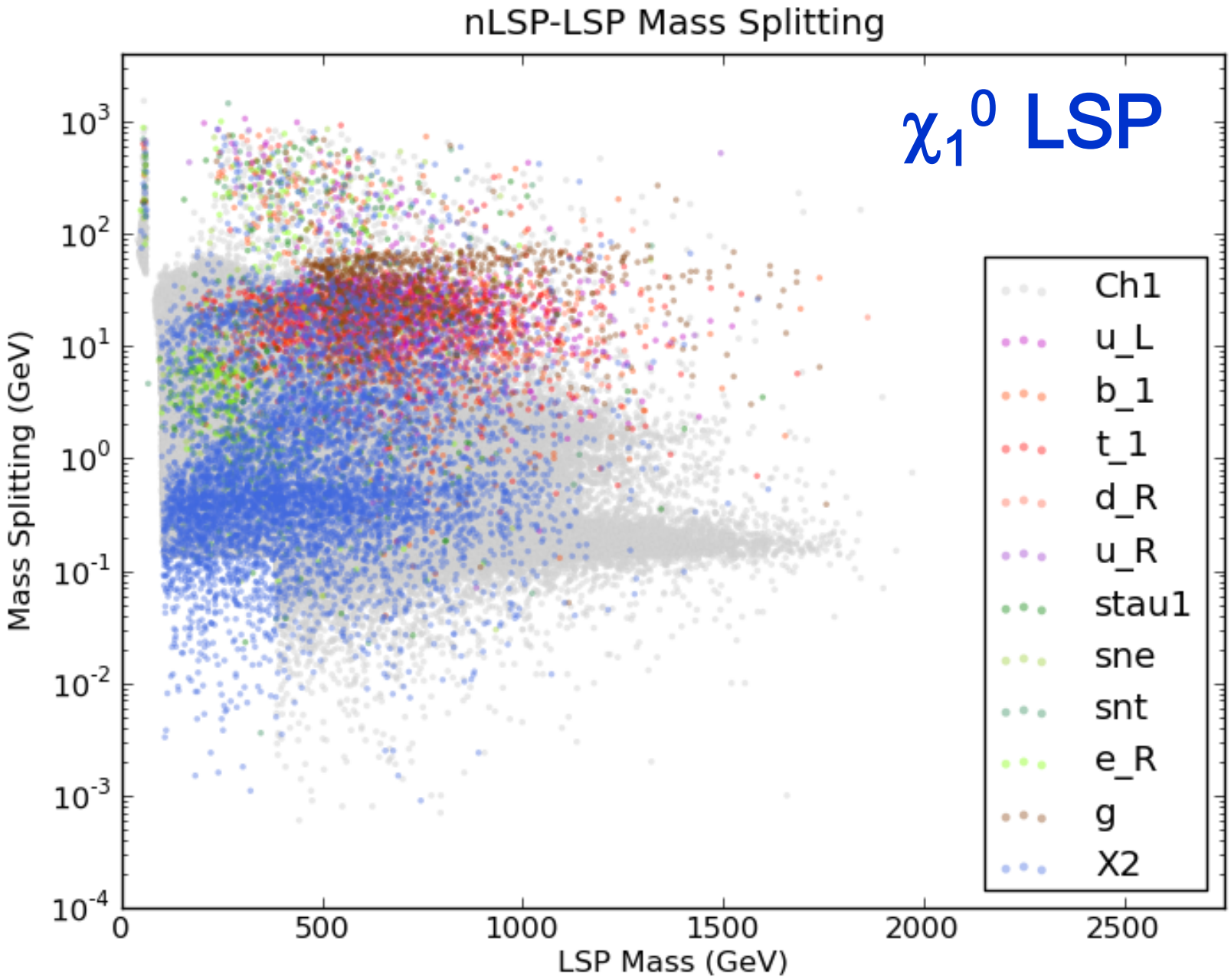
  $\rightarrow$ NNLSPs can be detector stable
- For NLSP decays to G, add all 3- & 4-body modes w/ BBN relevant lifetimes (~10^{-4} to 10^{14} sec) via MadGraph
- Calculate NLSP density using Micromegas & rescale to the gravitino mass
- Use lifetime & BF info for NLSPs from modified SUSY-Hit & check the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

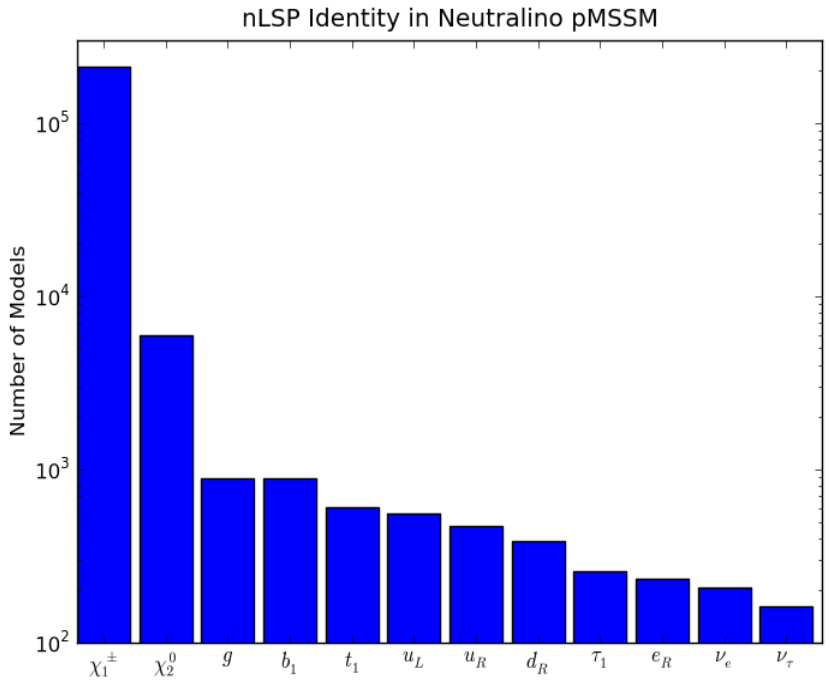


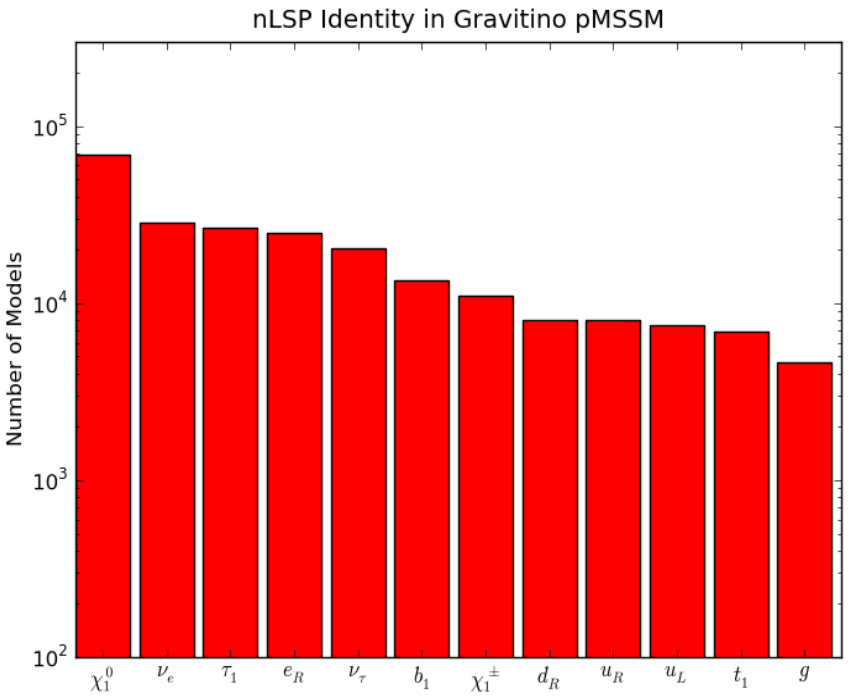




Some properties of the gravitino & the NLSP in the gravitino model set


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





- 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)
- The lightest neutralino plays an important role in either model set

Electroweak Content of χ_1^0

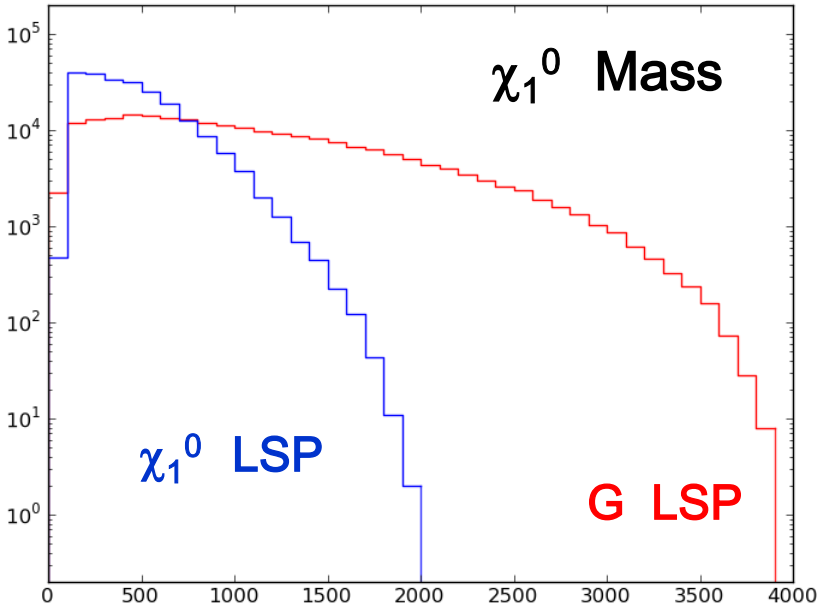
Lightest Neutralino	Definition	Neutralino LSP	Gravitino LSP
Bino	$\|N_{11}\|^2 > 0.95$	0.024	0.313
Mostly Bino	$0.80 < \|N_{11}\|^2 < 0.95$	0.002	0.012
Wino	$\|N_{12}\|^2 > 0.95$	0.546	0.296
Mostly Wino	$0.80 < \|N_{12}\|^2 < 0.95$	0.022	0.019
Higgsino	$\|N_{13}\|^2 + \|N_{14}\|^2 > 0.95$	0.340	0.296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

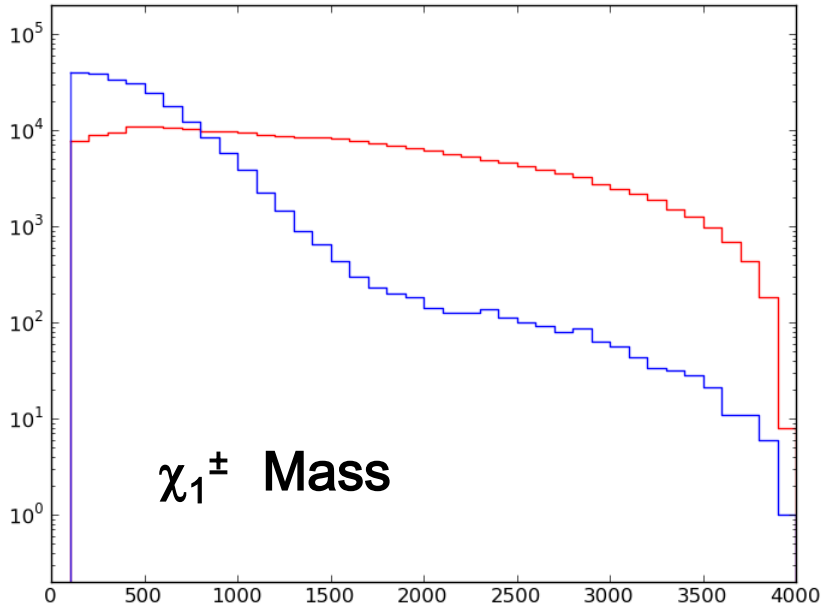
With most of the neutralino parameters ~ 1 TeV the mass & electroweak eigenstates are generally quite close !

- 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..

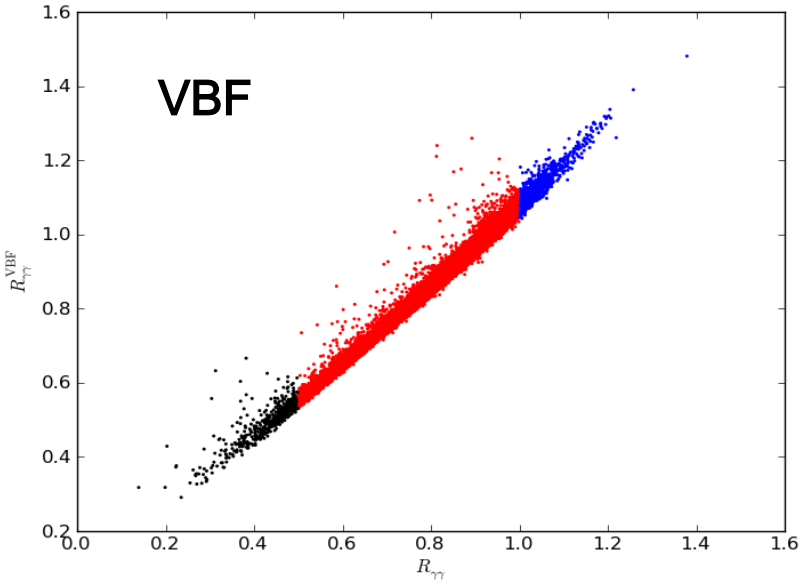
- E.g., since the lightest neutralino is at best the NLSP in the G scan, its mass distribution must now extend to larger values

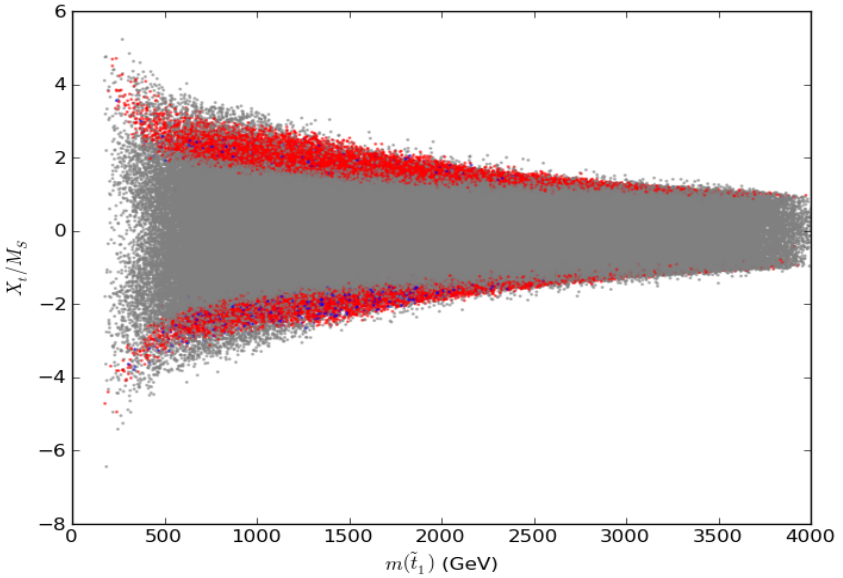
- Other sparticle masses are less influenced due to scan ranges

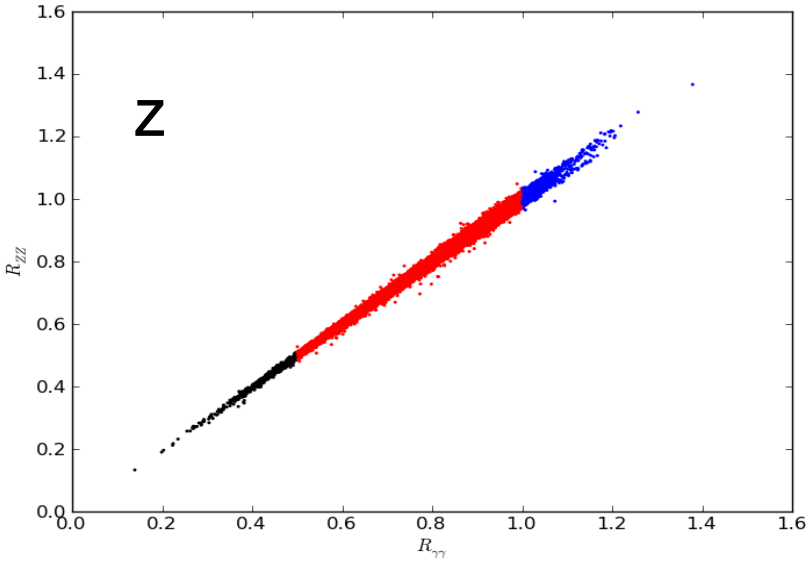


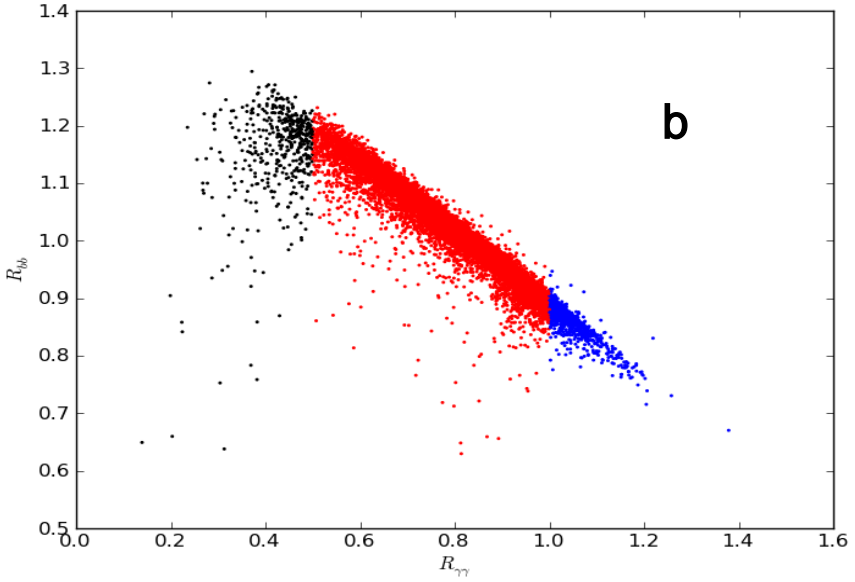


G LSP


VBF
$R_{\gamma\gamma}^{\rm VBF}$
$R_{\gamma\gamma}$


X_t/M_S
$m(\tilde{t}_1)$ (GeV)


Z
R_{ZZ}
$R_{\gamma\gamma}$


b
R_{bb}
$R_{\gamma\gamma}$