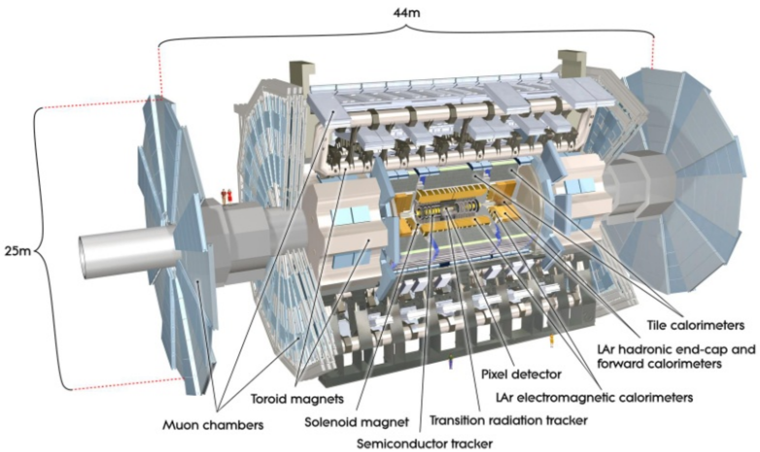
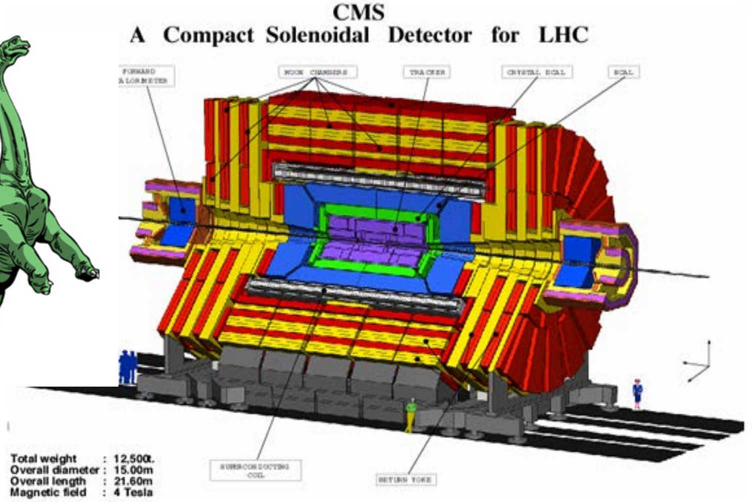
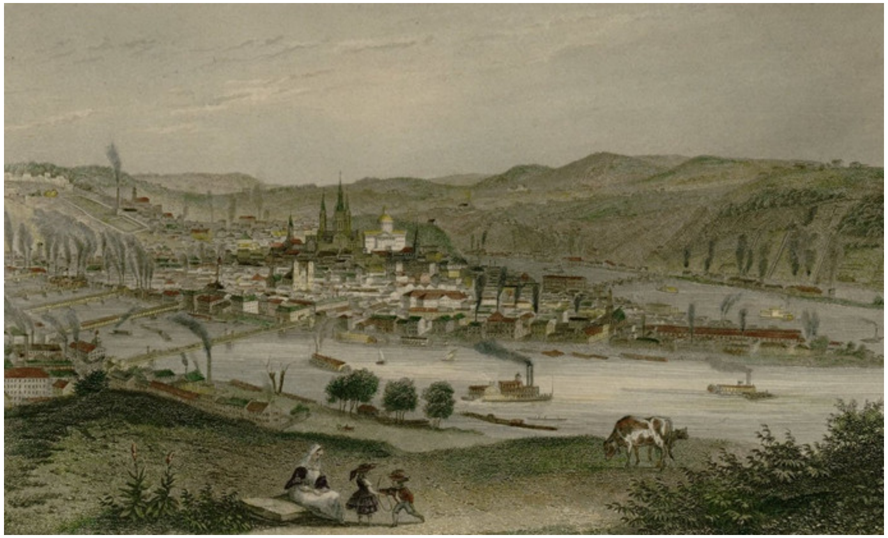
# SUSY w/o Prejudice @ LHC-7 /8 : Part I



5/7/12

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

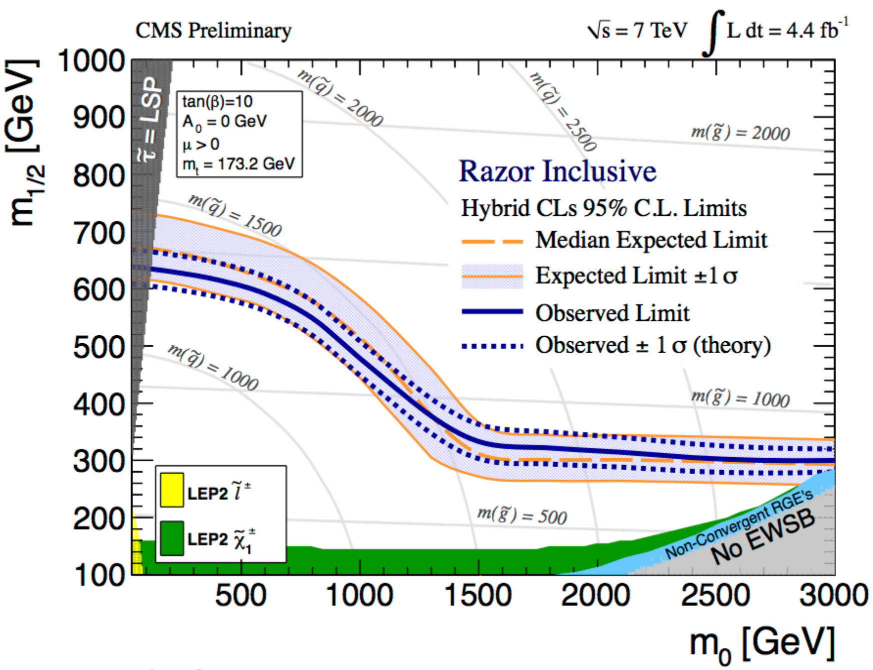
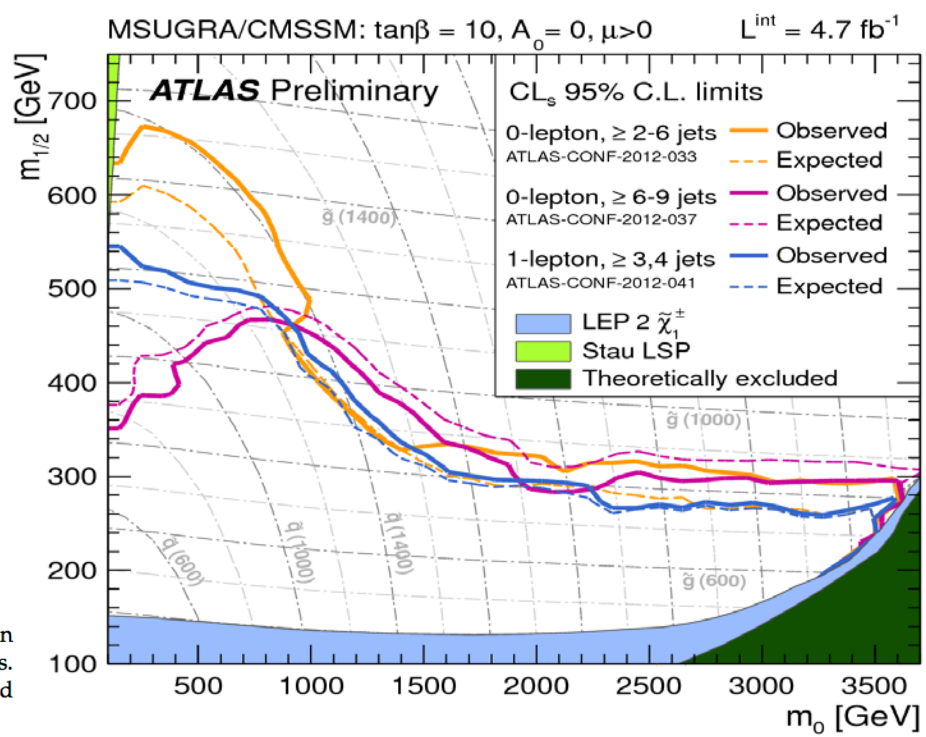




Figure 10: Observed (solid curve) and median expected (dot-dashed curve) 95% CL limits in the $(m_0, m_{1/2})$ CMSSM plane with $\tan\beta = 10$, $A_0 = 0$, $\text{sgn}(\mu) = +1$ from the razor analysis. The ± one standard deviation equivalent variations in the uncertainties are shown as a band around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



# 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+)

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

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

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

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

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

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

→→ 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

# Some Constraints

- $\Delta\rho$ / W-mass
- $b \to s\, \gamma$
- $\Delta(g-2)_\mu$
- $\Gamma(Z \to$ 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

- BBN energy deposition for gravitinos
- Relic $\nu$'s & diffuse photon bounds

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

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

- 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, $t_1$ & $\chi_1^{\pm}$

→ NNLSPs can be detector stable

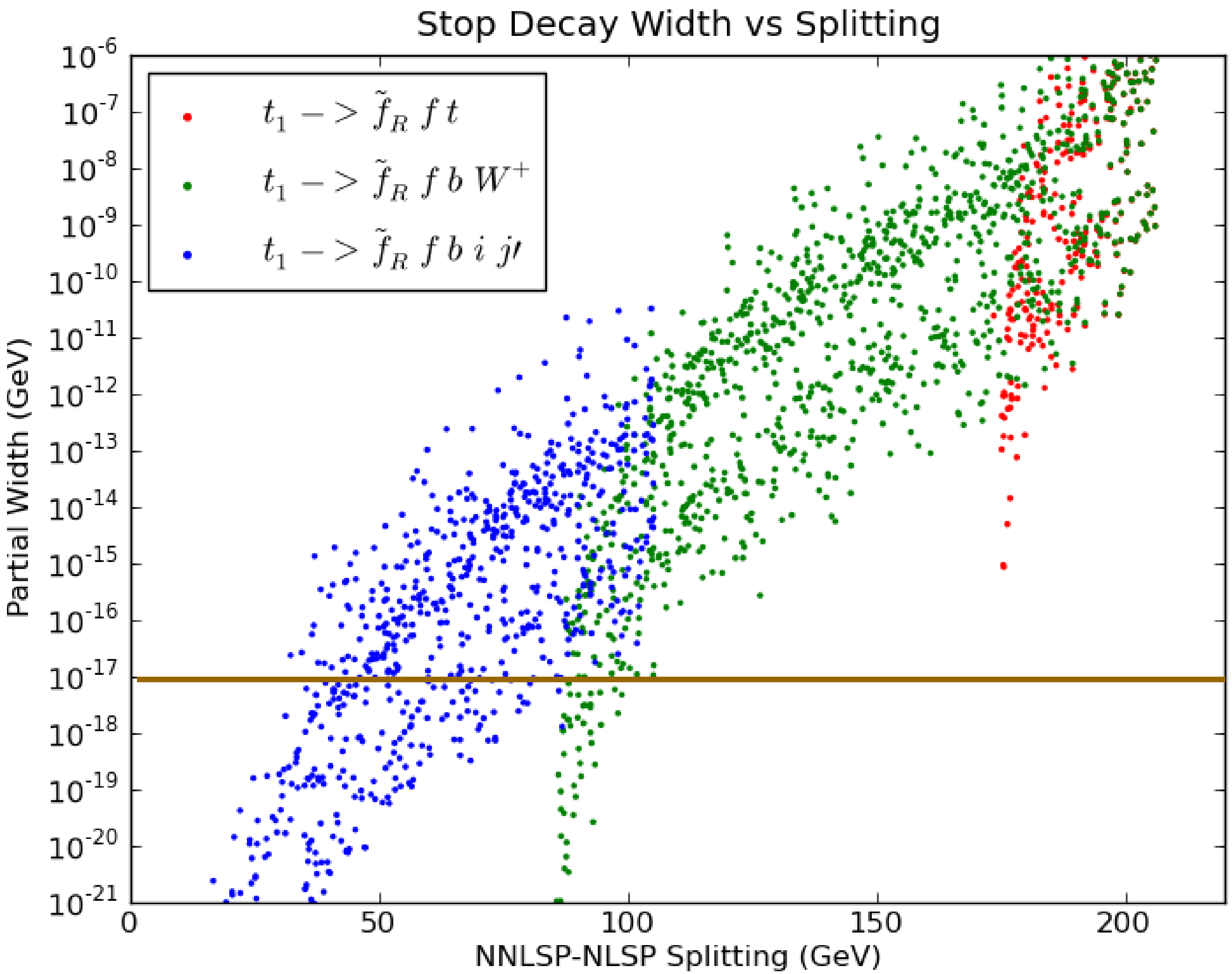
- For NLSP decays to G, add all 3- & 4-body modes w/ BBN relevant lifetimes ($\sim 10^{-4}$ to $10^{14}$ sec) via MadGraph

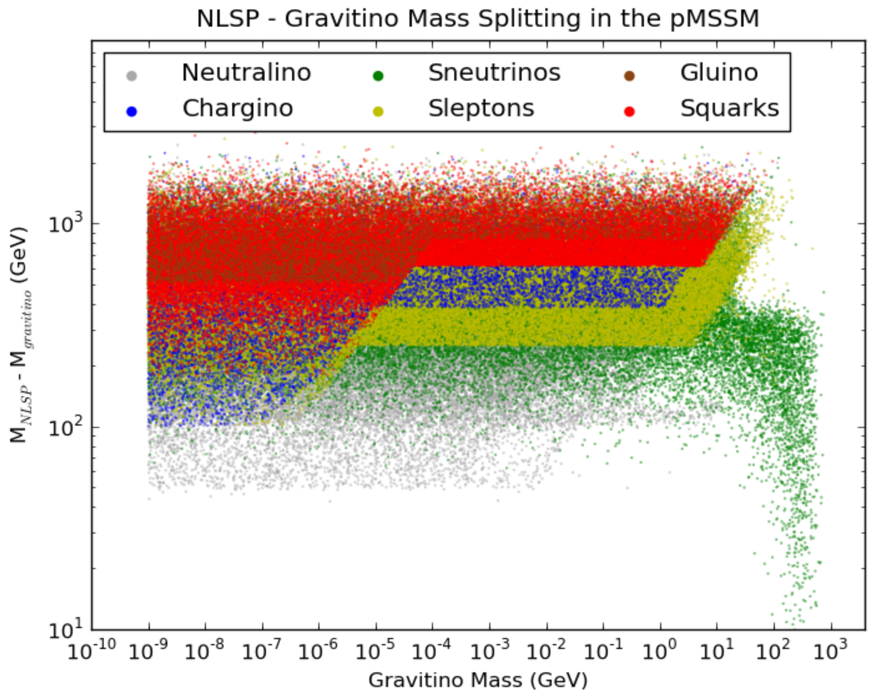
- Calculate NLSP density using Micromegas & rescale to the gravitino mass

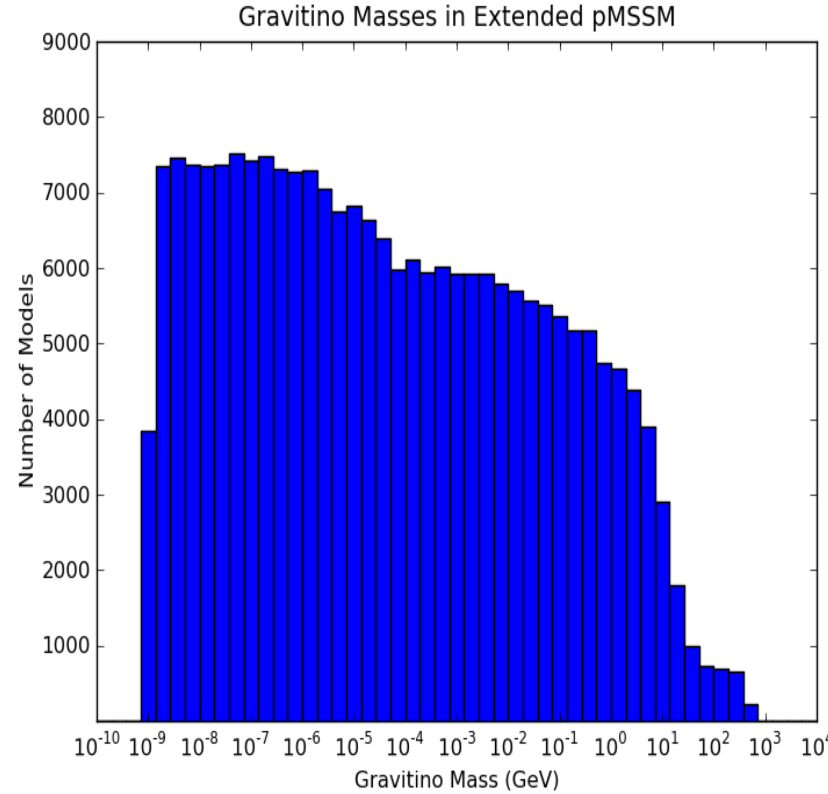
- Use lifetime & BF info for NLSPs from modified SUSY-Hit & check the constraints on EM or hadronic energy deposition during BBN

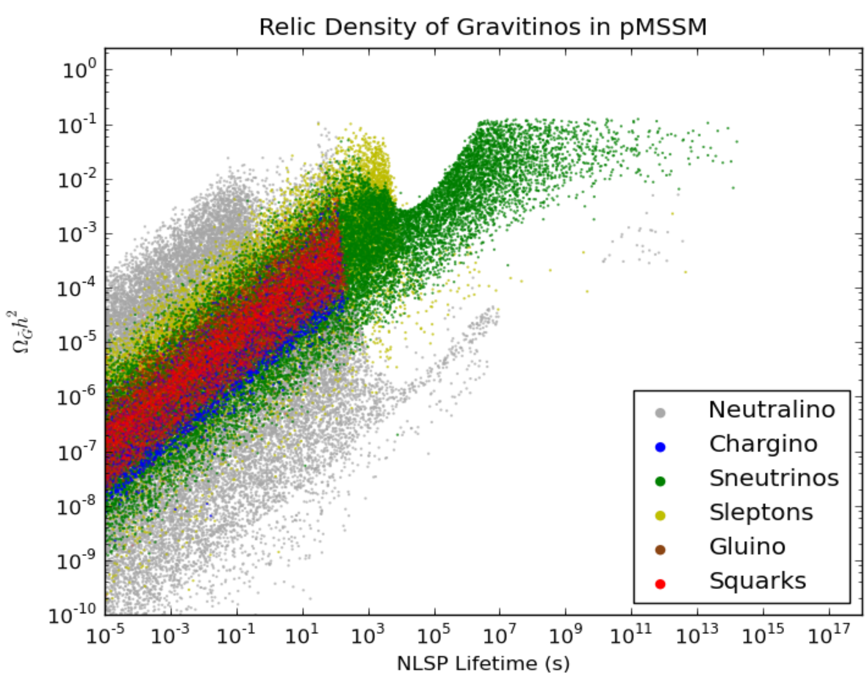
- Add constraints from the cosmo relic ν & diffuse photon fluxes

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

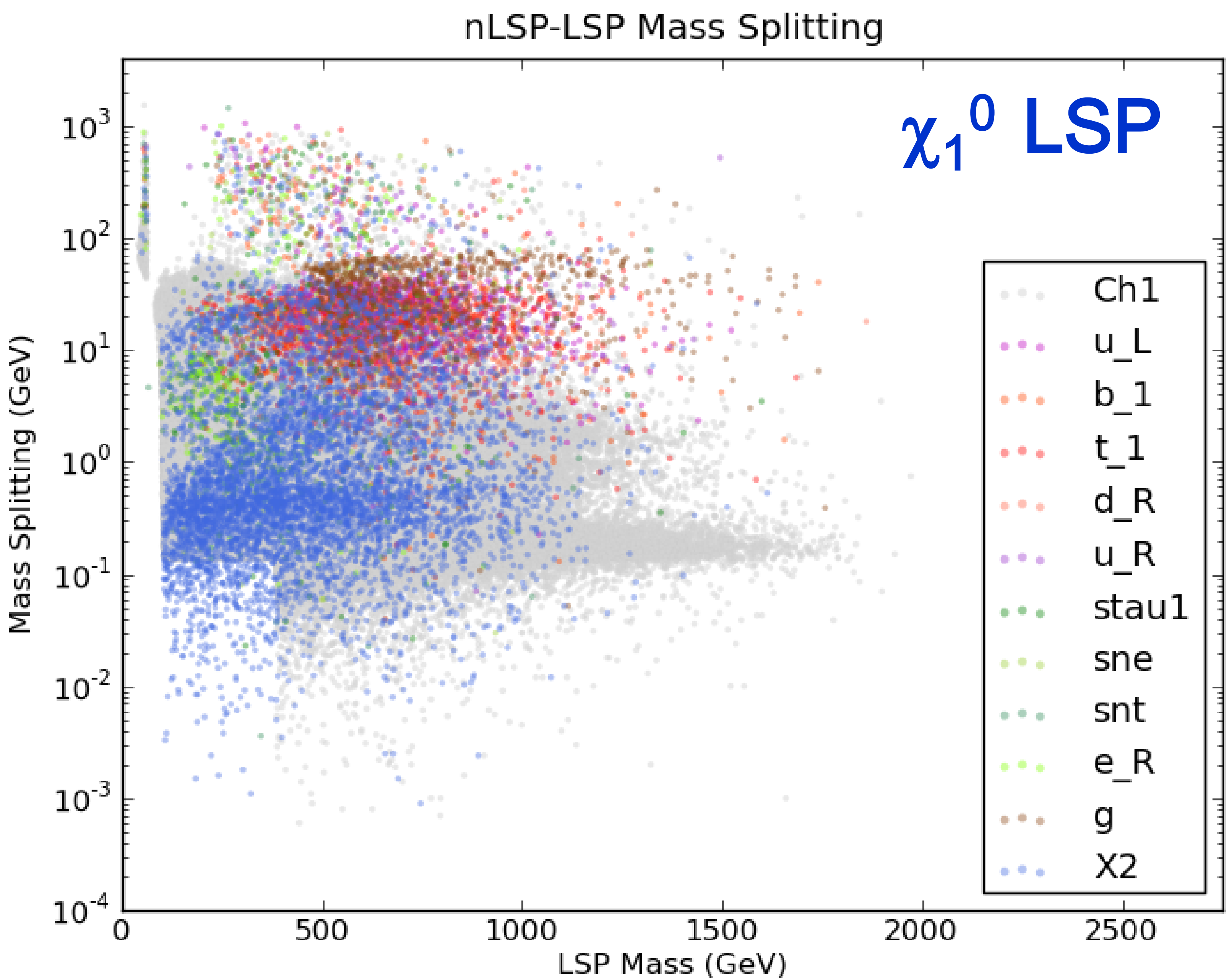


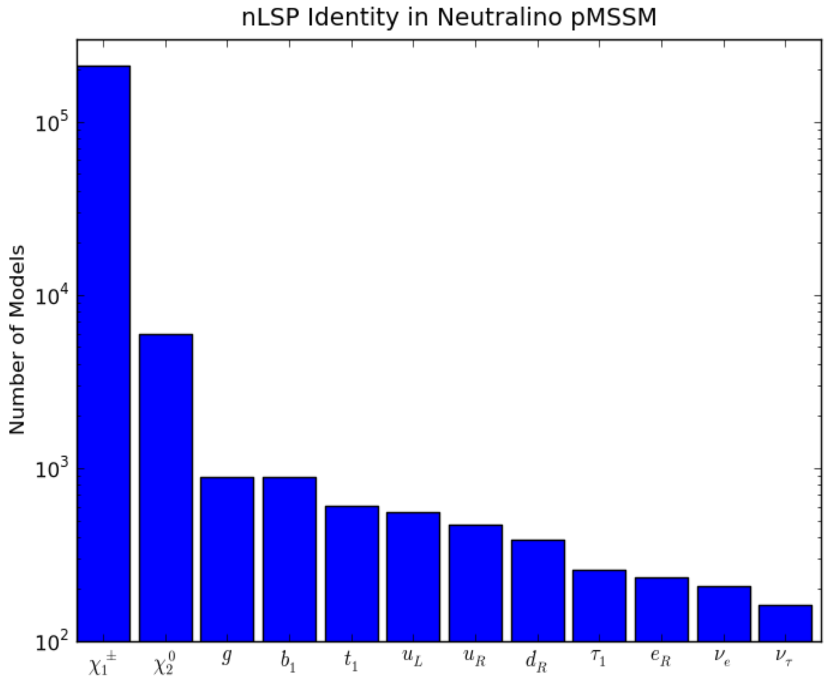


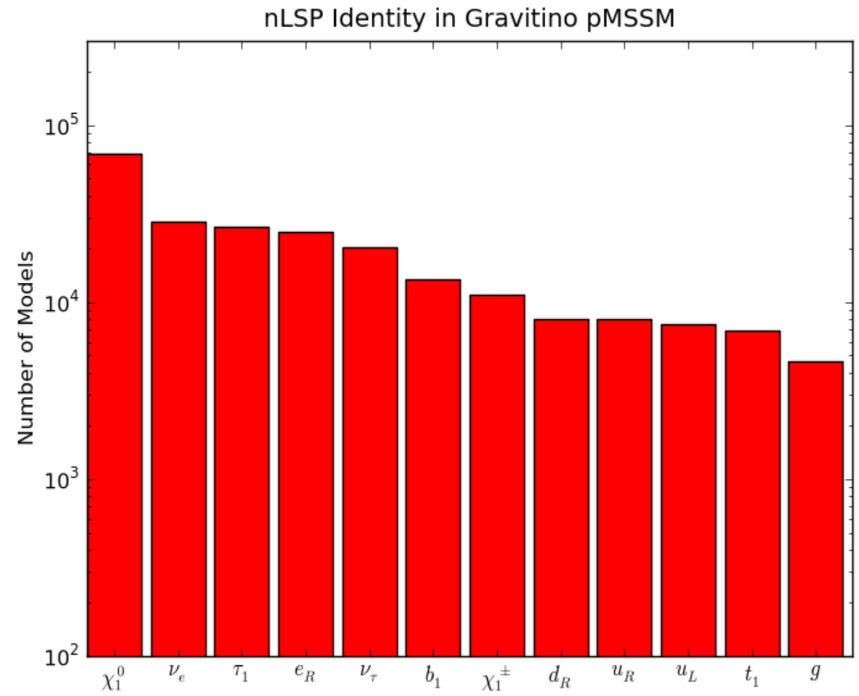




**Some properties of the gravitino & the NLSP in the gravitino model set**


nLSP-LSP Mass Splitting
$\chi_1^0$ 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 $\chi_1^0$

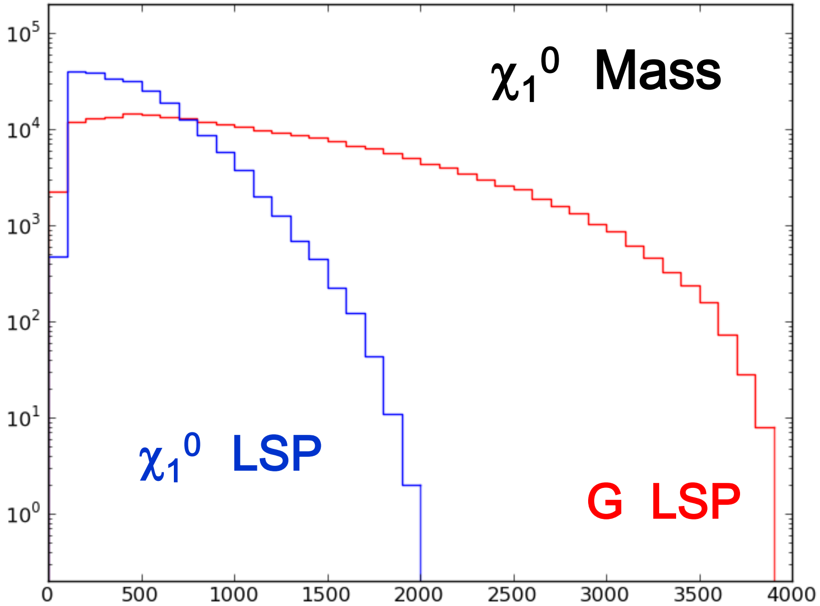
| Lightest Neutralino | Definition | Neutralino LSP | Gravitino LSP |
|---|---|---|---|
| Bino | $\|N_{11}\|^2 > 0.95$ | 0.024 | 0.313 |
| Mostly Bino | $0.80 < \|N_{11}\|^2 < 0.95$ | 0.002 | 0.012 |
| Wino | $\|N_{12}\|^2 > 0.95$ | 0.546 | 0.296 |
| Mostly Wino | $0.80 < \|N_{12}\|^2 < 0.95$ | 0.022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

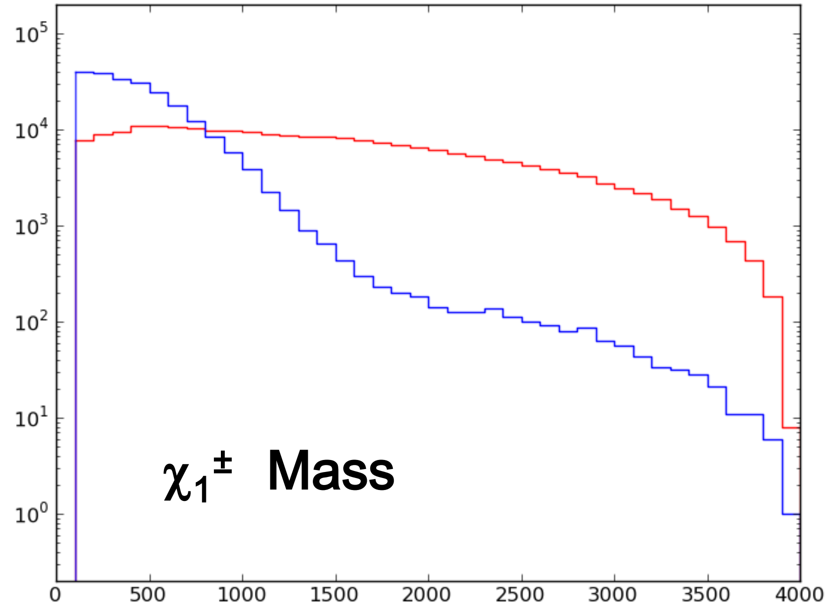
With most of the neutralino parameters ~ 1 TeV the mass & electroweak eigenstates are generally quite close !

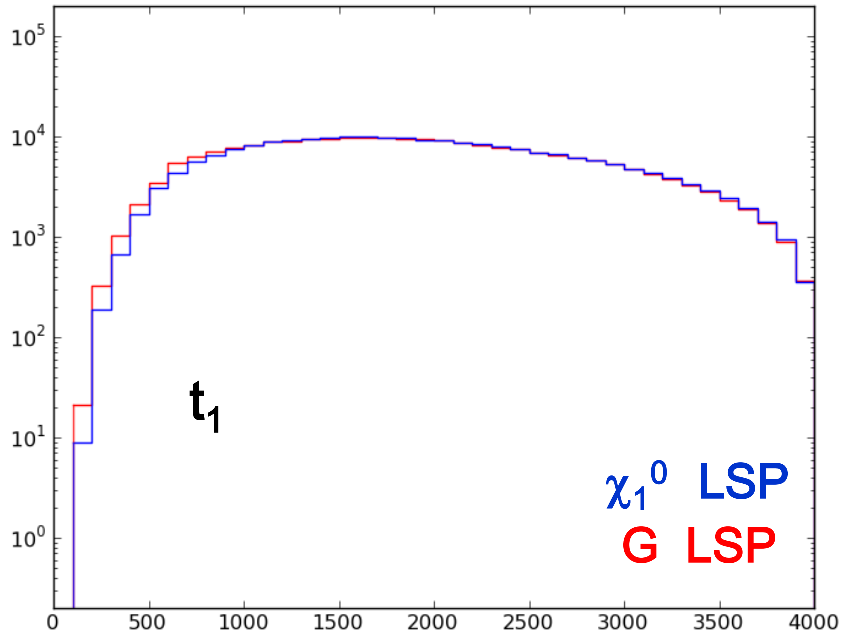
- The mass spectra of the MSSM fields are (indirectly) influenced by the nature of the LSP, i.e., the fact that G can be VERY light whereas $\chi_1^0$ must be > ~ 10's of GeV in the scan..

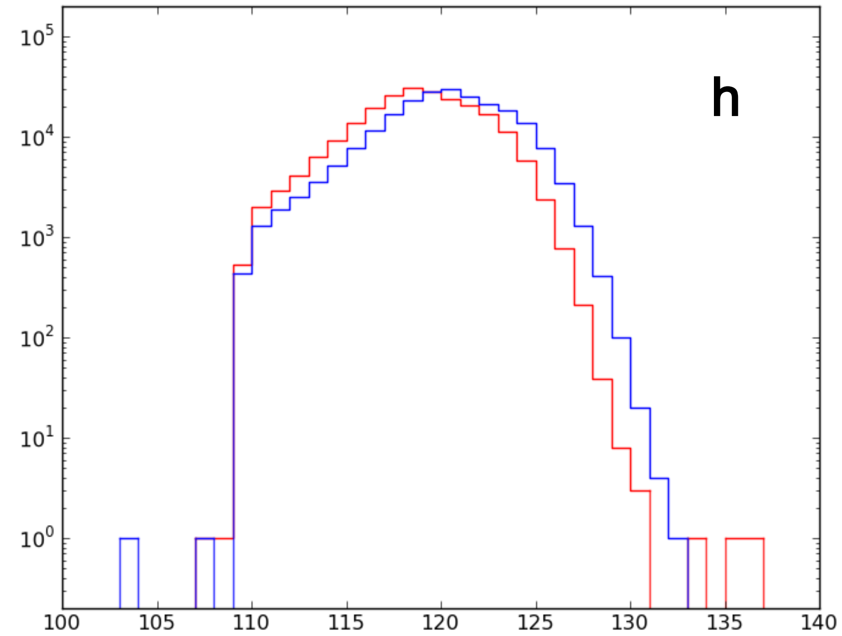
- E.g., since the lightest neutralino is at best the NLSP in the G scan, its mass distribution must now extend to larger values

- Other sparticle masses are less influenced due to scan ranges



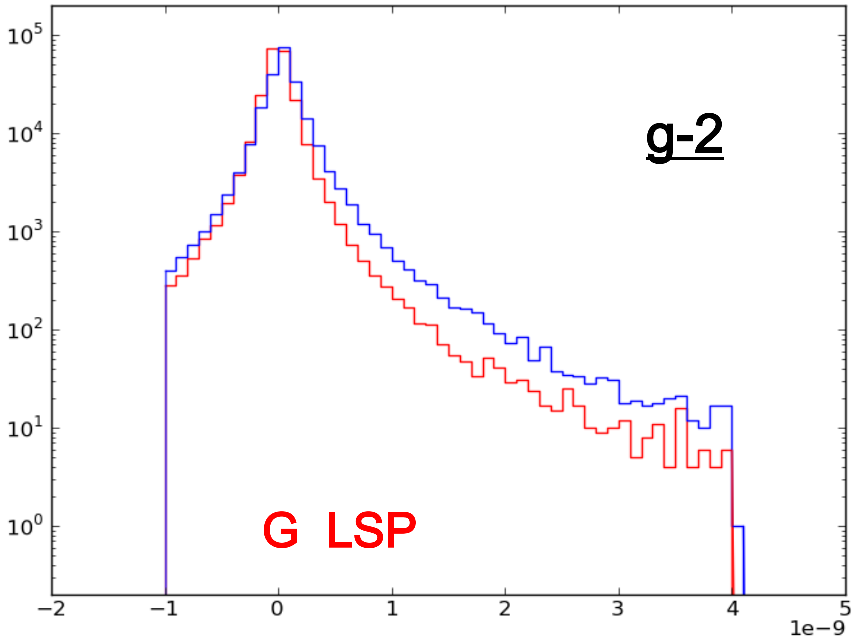



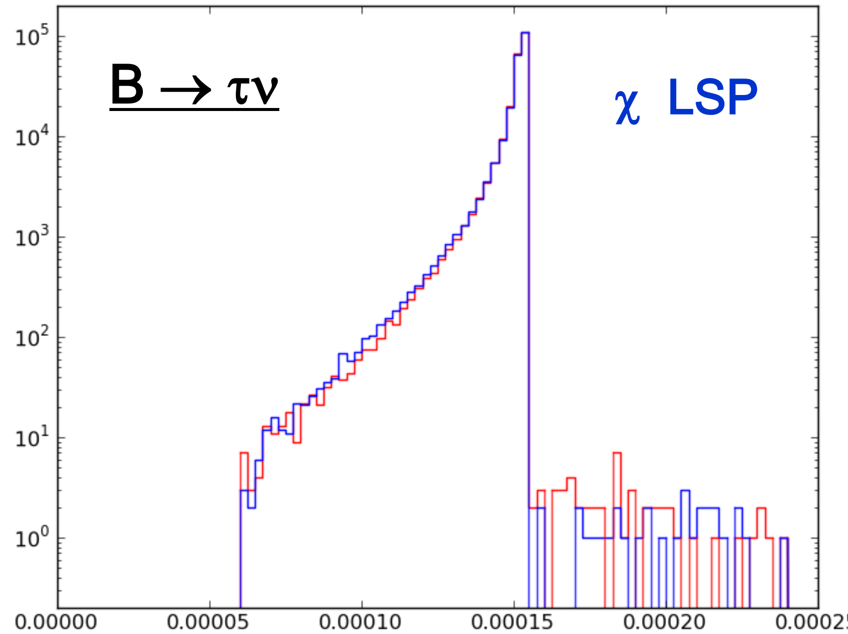


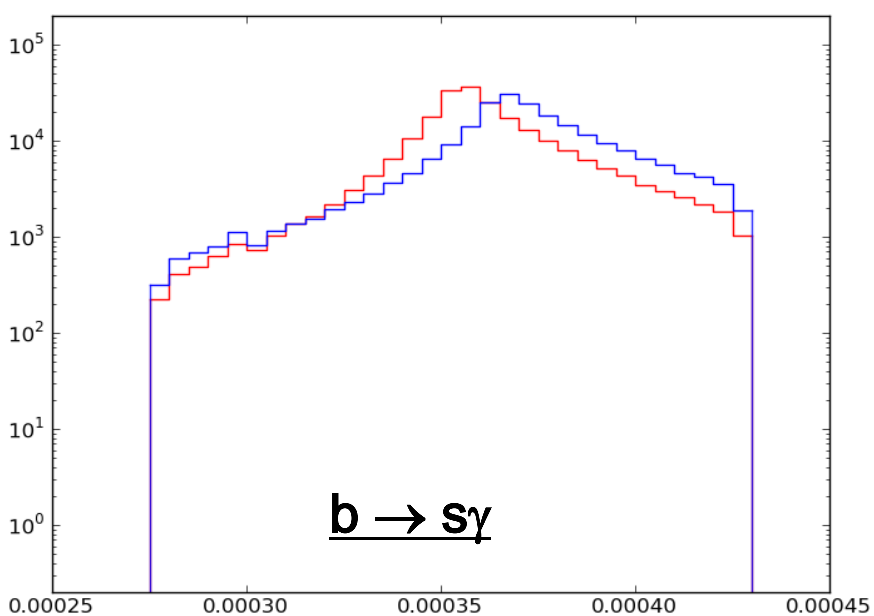




- Although the h mass itself is not part of the scan, the slightly different mass specta in the G scan contribute, via loops, to a somewhat lighter Higgs

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



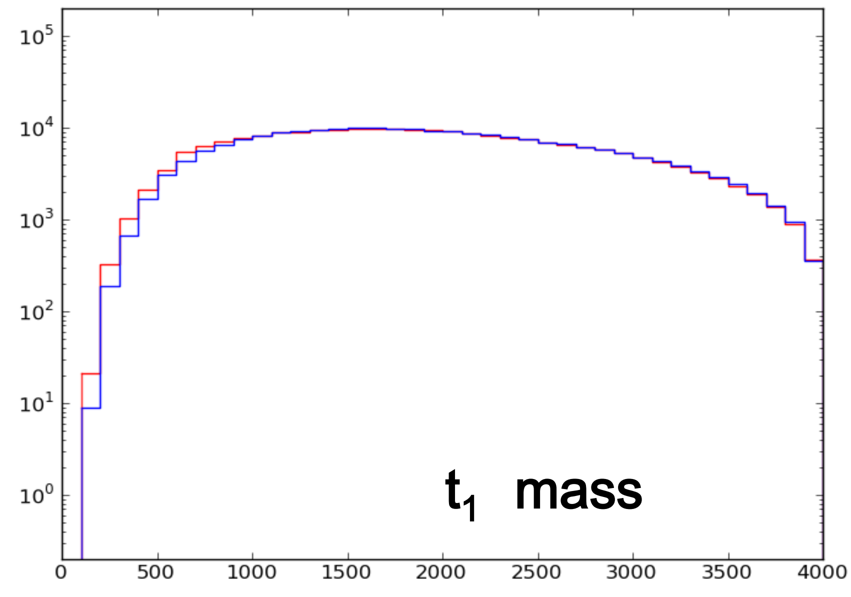

- Overall, these are quite minor differences . The important differences for LHC searches are the nature of the LSP & ID of the NLSP

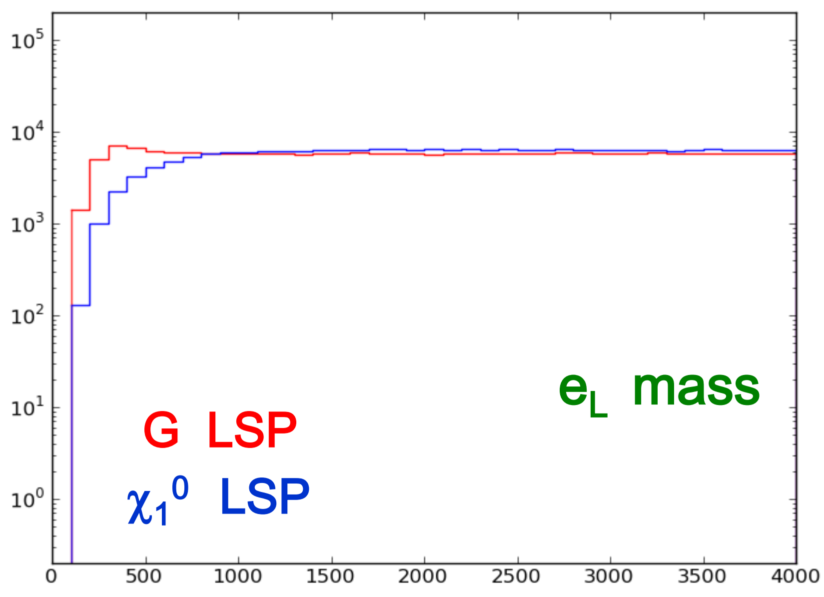
→ Now that you've seen a bit about how these model sets are generated & some of their properties, Ahmed will now tell you about some of the implications of these model sets for physics at the LHC.

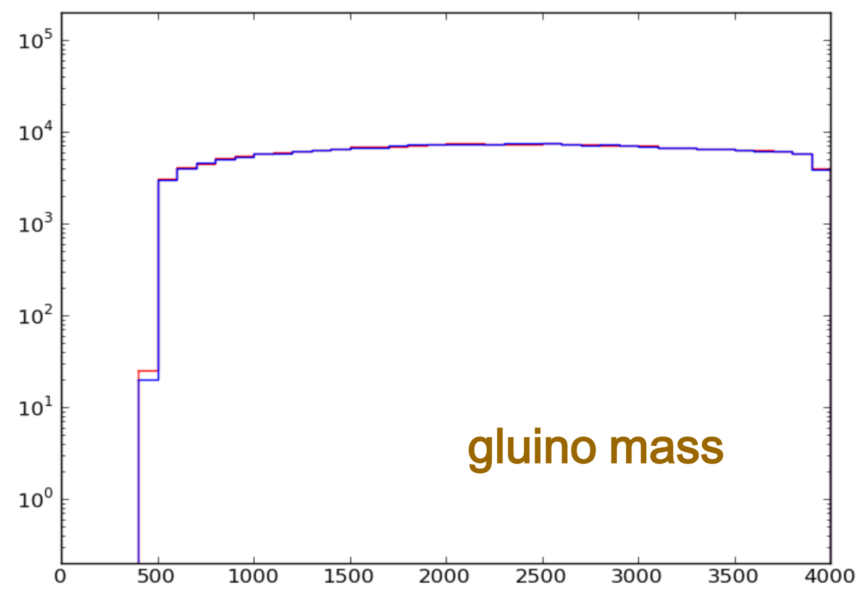
# BACKUPS

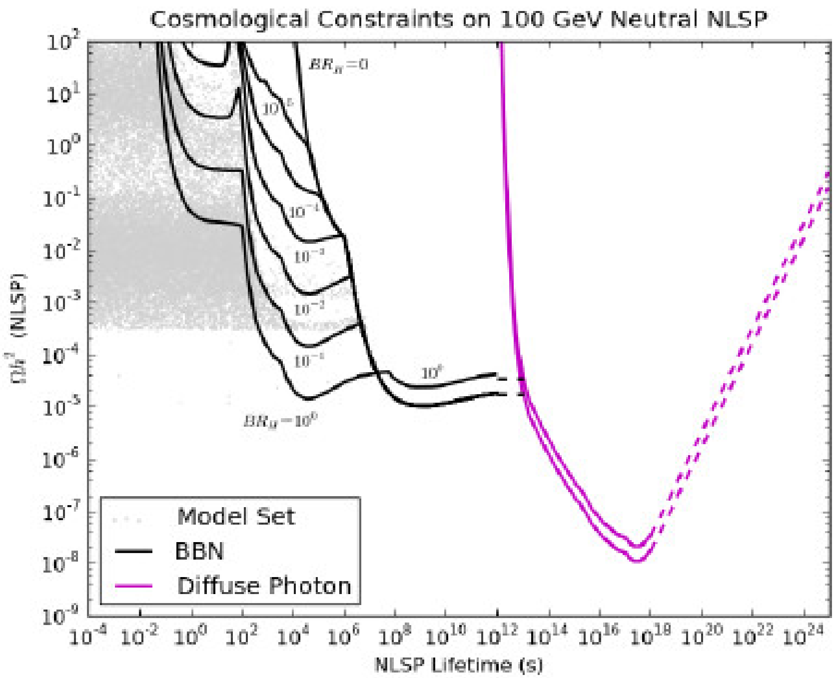
- Mass distributions for sparticles that are restricted to be >400 GeV will be less affected than those that must be >100 GeV by the choice of LSP.

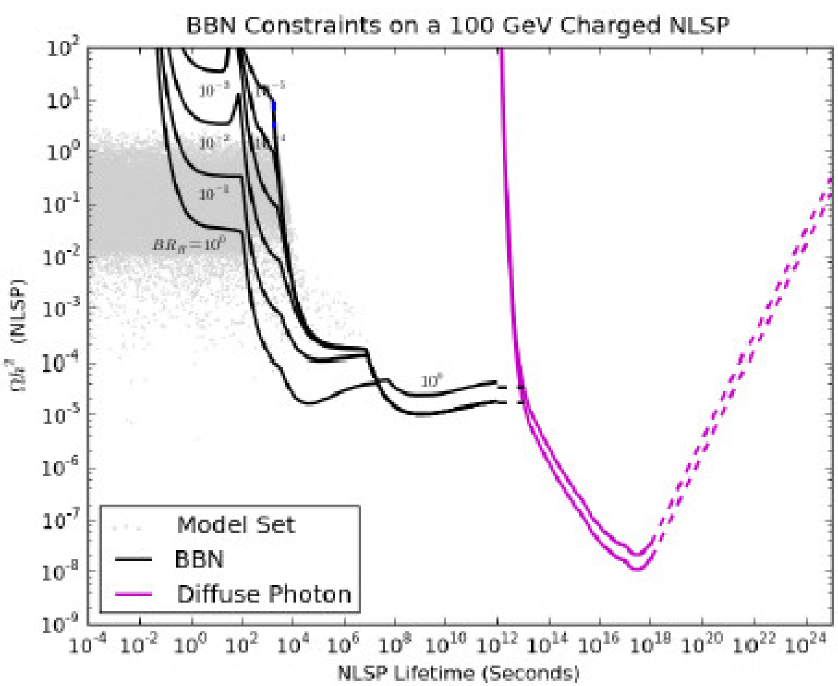
- However, some of these small spectrum shifts can & do influence other observables….





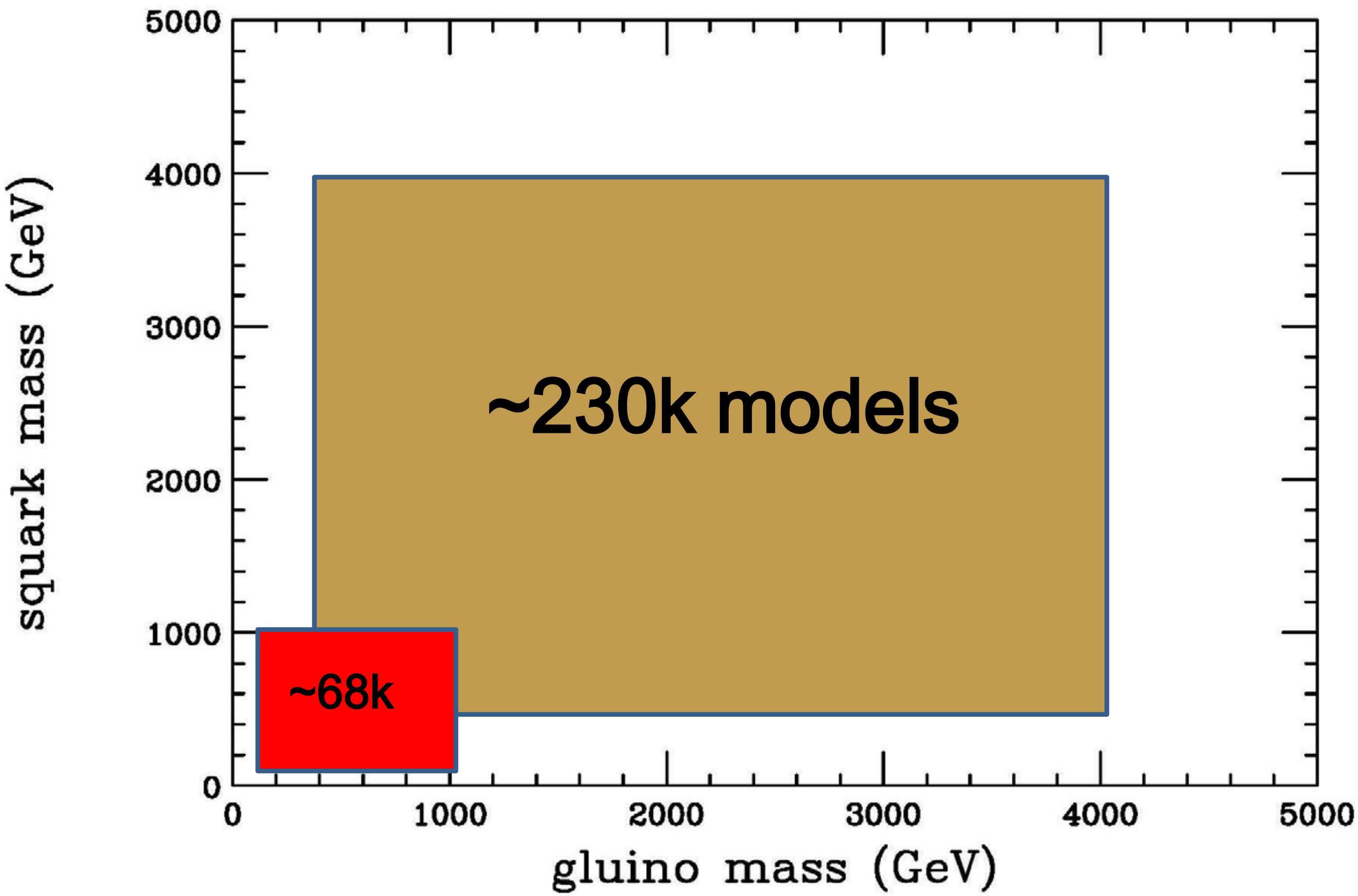

## Sample constraints from BBN and diffuse $\gamma$'s for different hadronic branching fractions of the NLSP

## Shaded areas show where our gravitino models live

We follow :

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

# A much larger volume needs to be explored…




…. for both gravitino and neutralino LSPs

# $\chi_1^0$ LSP DM Observables