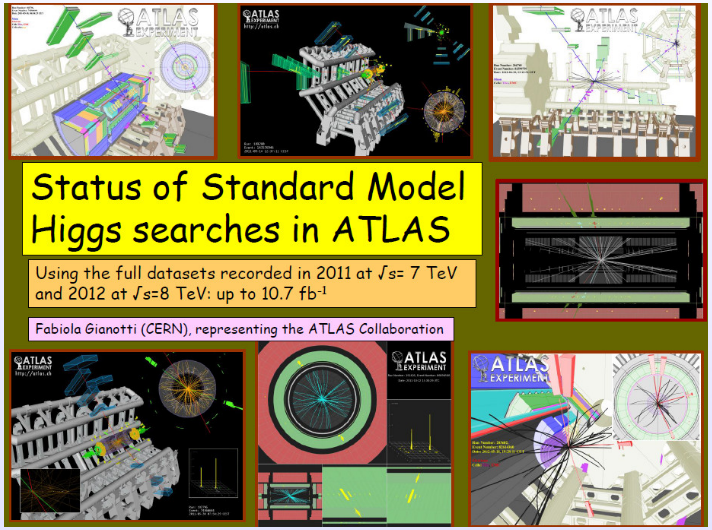
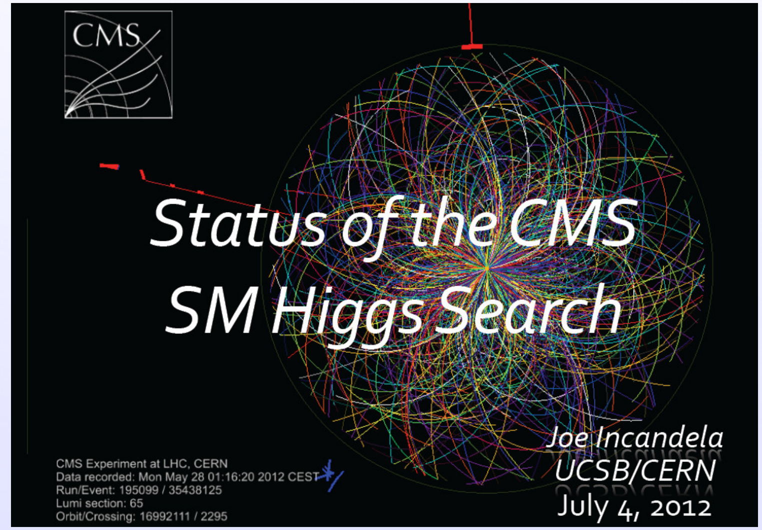
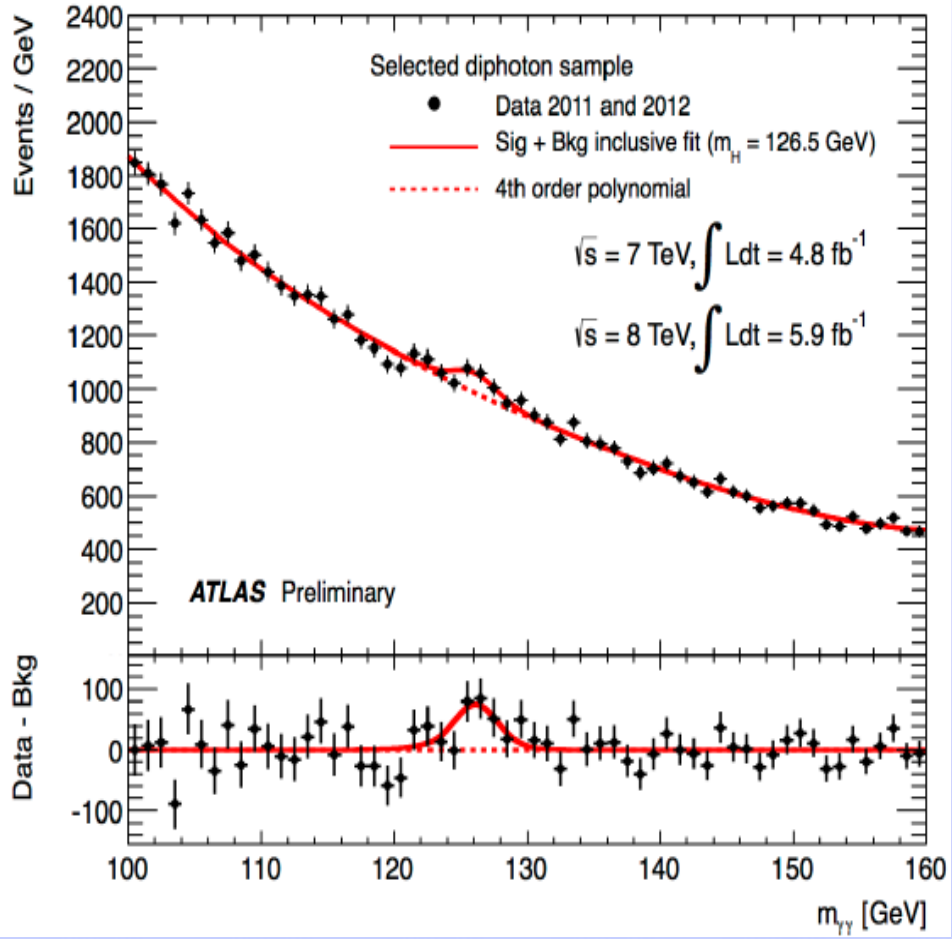
Higgs Properties in the pMSSM

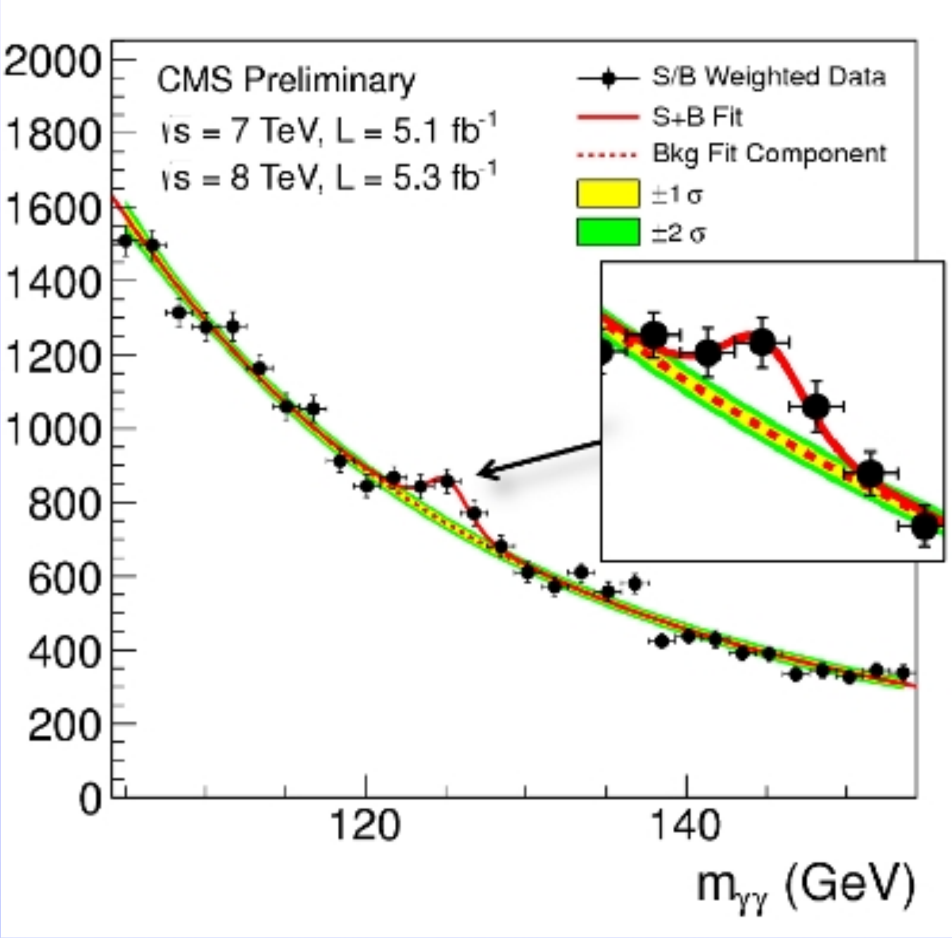




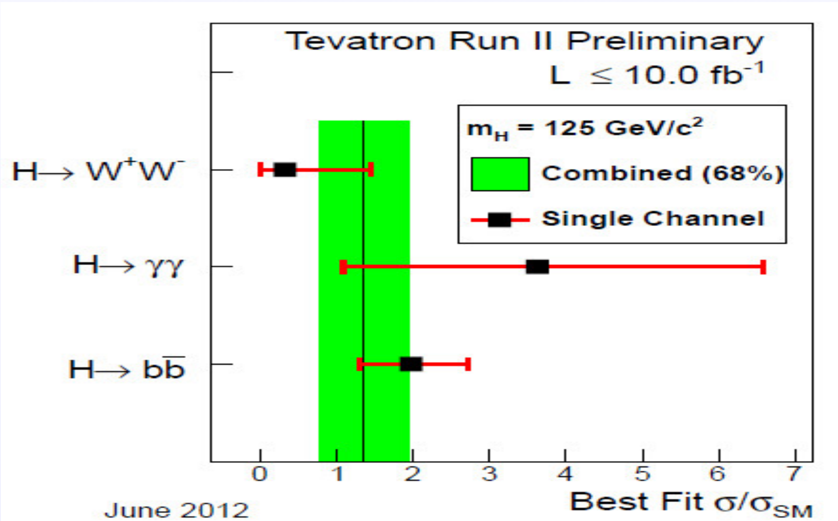
Cahill-Rowley, JLH, Hoeche, Ismail, Rizzo 1206.4321, 1206.5800, 1210.ASAP

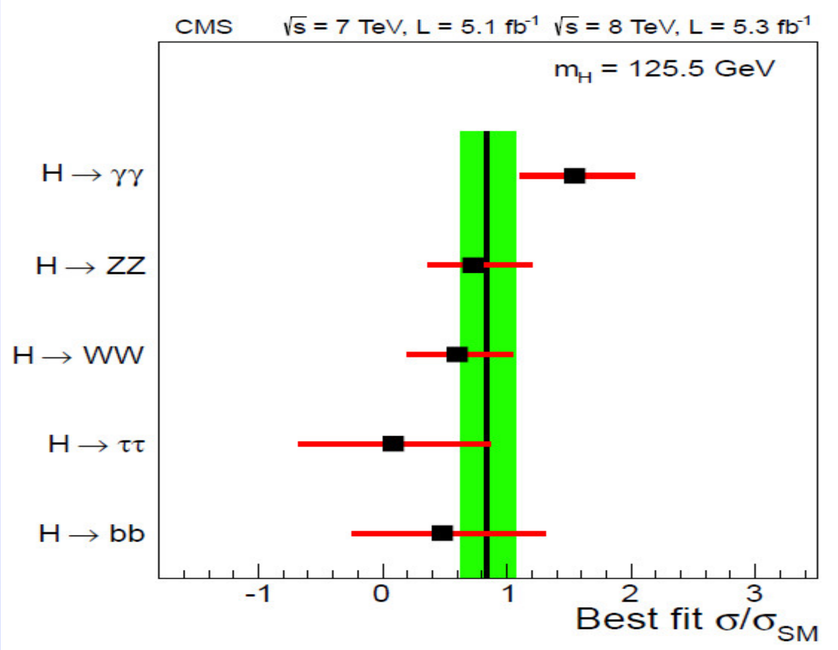
Our Shiny-New Higgs-like Boson!



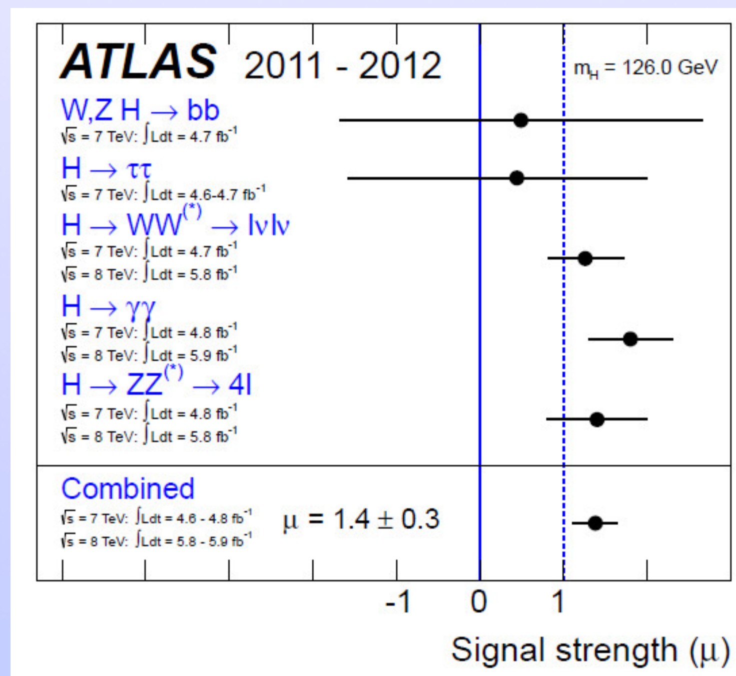


Generally the Higgs is SM-like…so far…





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.




ZERO
The Clifford pentads
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.
It is not higgs.
http://arXiv:physics/030201
(a meson, probably).

The pMSSM Model Framework

- The phenomenological MSSM (pMSSM)
  - Most general CP-conserving MSSM
  - Minimal Flavor Violation, First 2 sfermion generations are degenerate w/ negligible Yukawas
  - No GUT, SUSY-breaking assumptions!
  - 19 real, weak-scale parameters

    scalars:

    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}

    gauginos: M_1, M_2, M_3

    tri-linear couplings: A_b, A_t, A_τ

    Higgs/Higgsino: μ, M_A, $\tan\beta$

Study of the pMSSM (Neutralino/Gravitino LSP)

Scan with Linear Priors

Perform large scan over Parameters

$100 \text{ GeV} \leq m_{sfermions} \leq 4 \text{ TeV}$

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

$400 \text{ GeV} \leq M_3 \leq 4 \text{ TeV}$

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

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

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

$(1 \text{ ev} \leq m_G \leq 1 \text{ GeV})$ (log prior)

Subject these points to Constraints from:

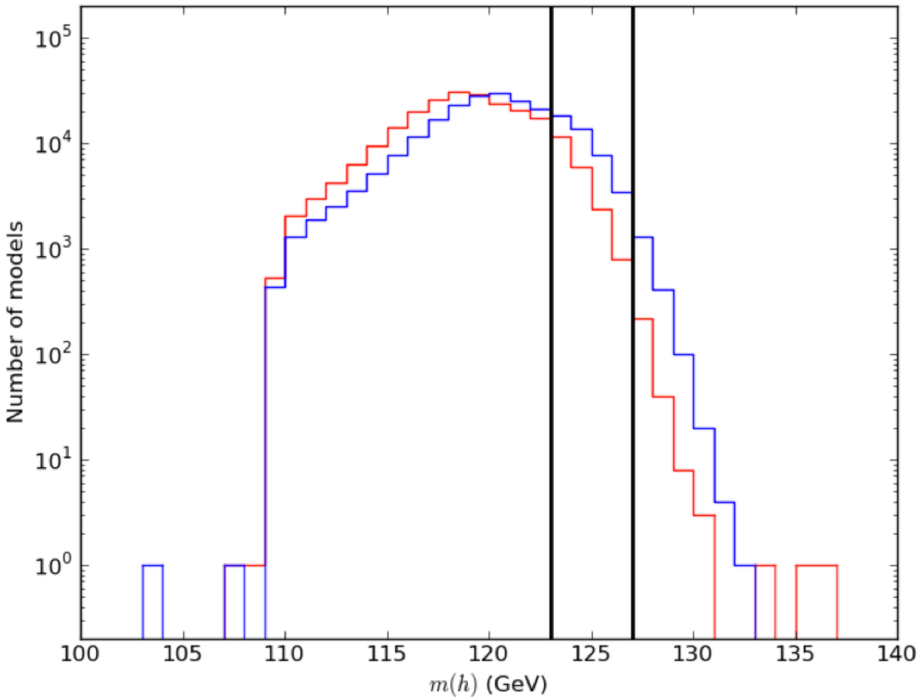
- Flavor physics
- EW precision measurements
- Collider searches
- Cosmology

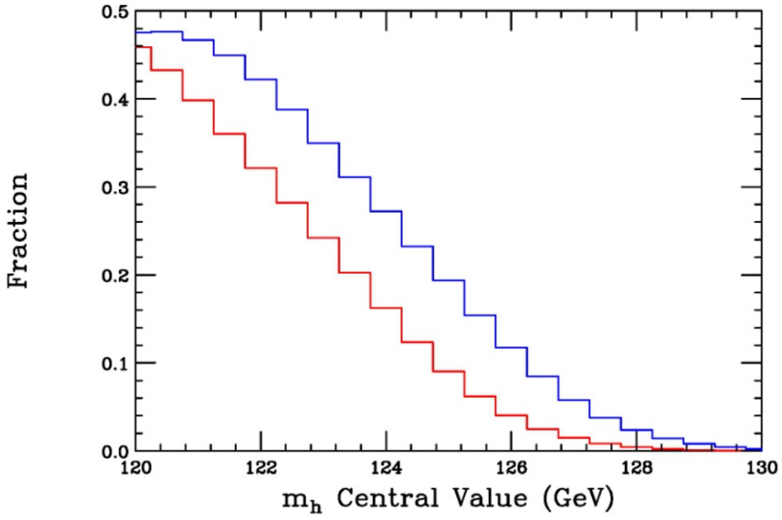
~225,000 models survive constraints for each LSP type!

Predictions for Lightest Higgs Mass in the pMSSM

Models consistent with EW Precision, B Physics, Cosmology, and Collider data

Neutralino LSP
Gravitino LSP





The SUSY Higgs Sector

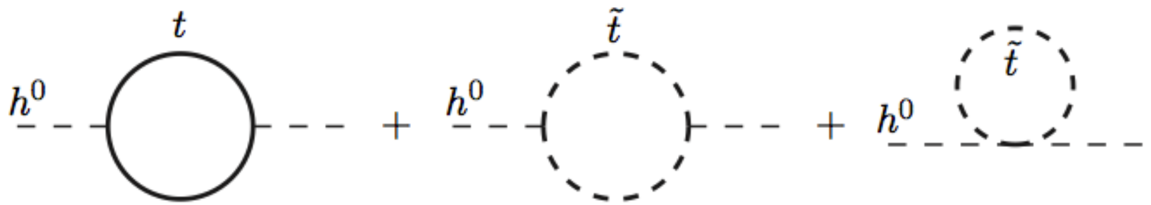
- SUSY Higgs sector: h^0, H^0, $H^\pm$, A^0
- 2 free parameters in the Higgs potential: very predictive at tree-level!

$$M_Z^2 = -2\mu^2 + 2\,\frac{m_{H_d}^2 - t_\beta^2\, m_{H_u}^2}{t_\beta^2 - 1}$$

$$m_{h^0} < m_Z |\cos(2\beta)|$$

- Radiative corrections are important!

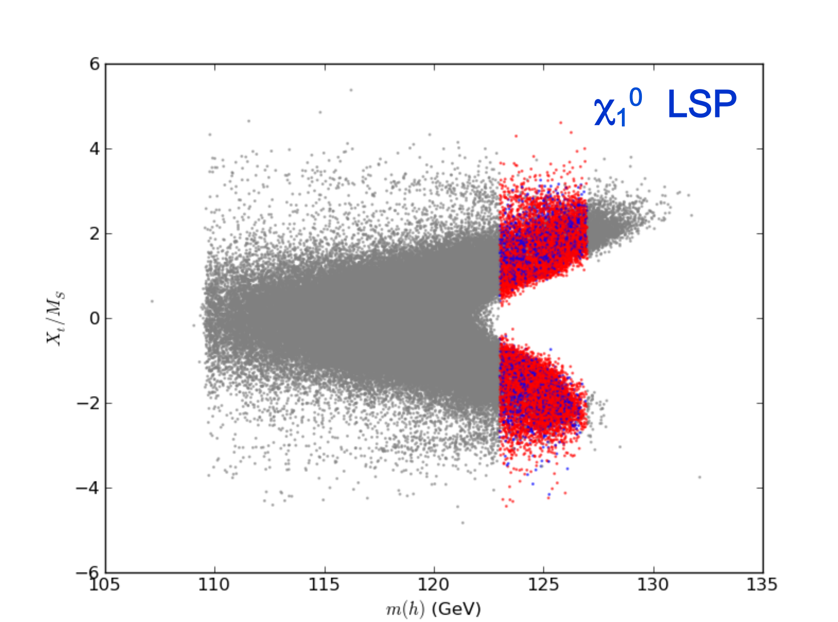
$$\Delta(m_{h^0}^2) =$$

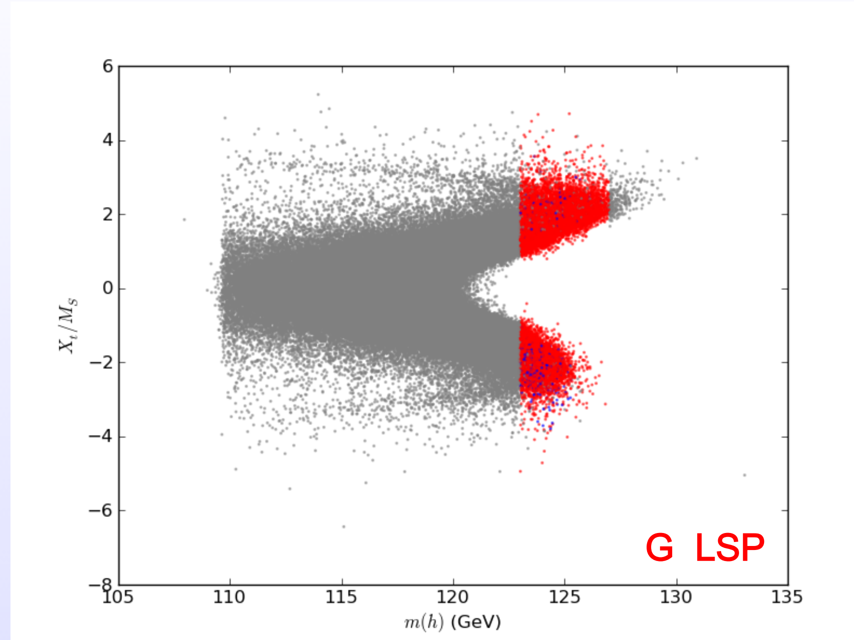


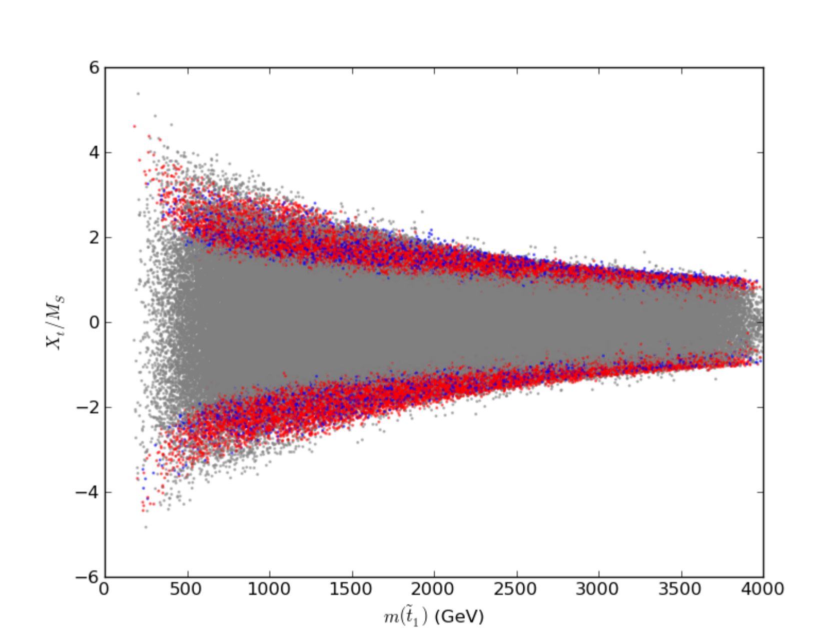
Higgs mass is very senistive in particular to the lightest stop mass

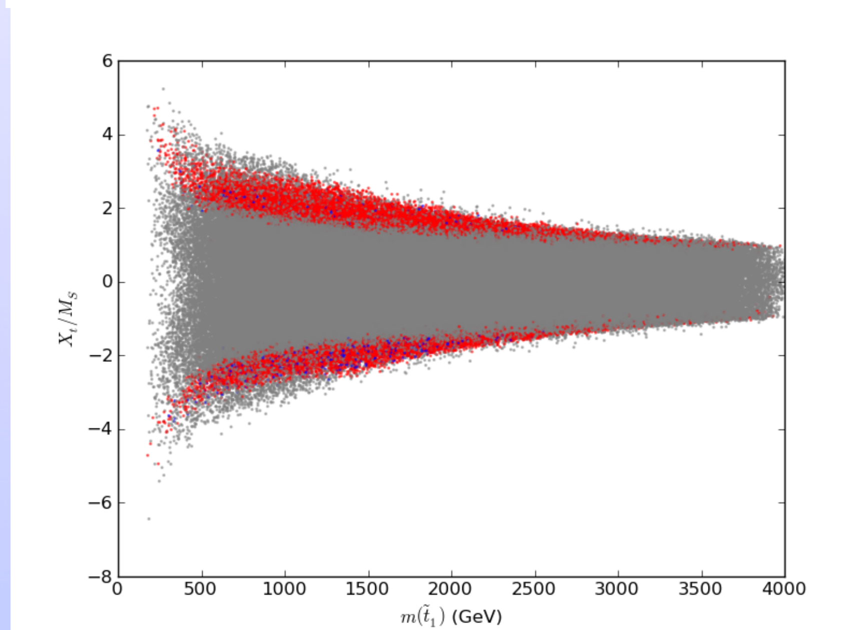
$$m_{h^0}^2 = m_Z^2\cos^2(2\beta) + \frac{3}{4\pi^2}\sin^2\beta\, y_t^2 \Big[m_t^2 \ln\left(m_{\tilde{t}_1} m_{\tilde{t}_2}/m_t^2\right) + c_{\tilde{t}}^2 s_{\tilde{t}}^2 (m_{\tilde{t}_2}^2 - m_{\tilde{t}_1}^2)\ln(m_{\tilde{t}_2}^2/m_{\tilde{t}_1}^2)$$
$$+ c_{\tilde{t}}^4 s_{\tilde{t}}^4 \Big\{ (m_{\tilde{t}_2}^2 - m_{\tilde{t}_1}^2)^2 - \frac{1}{2}(m_{\tilde{t}_2}^4 - m_{\tilde{t}_1}^4)\ln(m_{\tilde{t}_2}^2/m_{\tilde{t}_1}^2) \Big\} / m_t^2 \Big].$$

Special parameter regions needed for the126 GeV Higgs





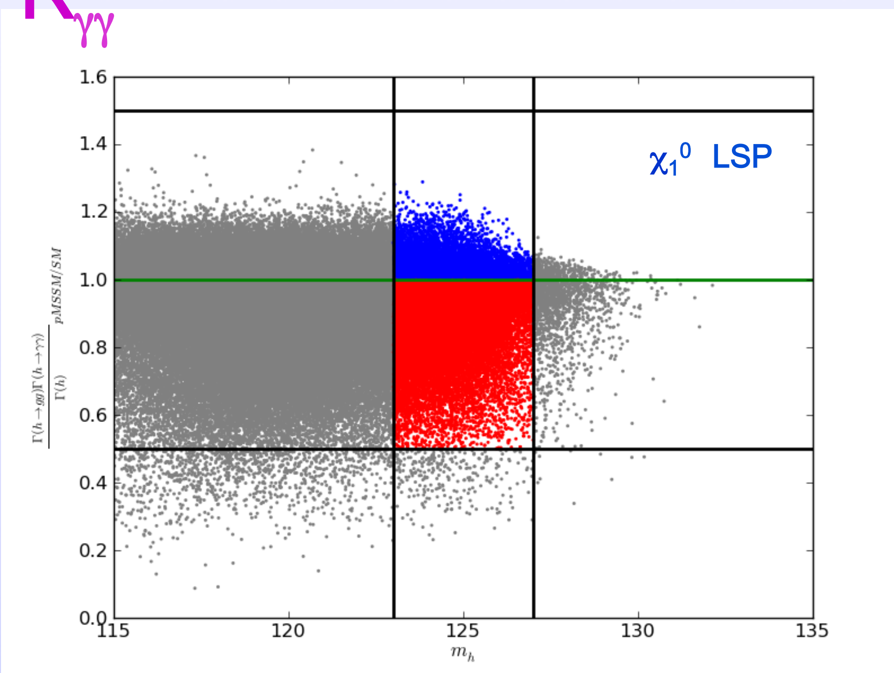


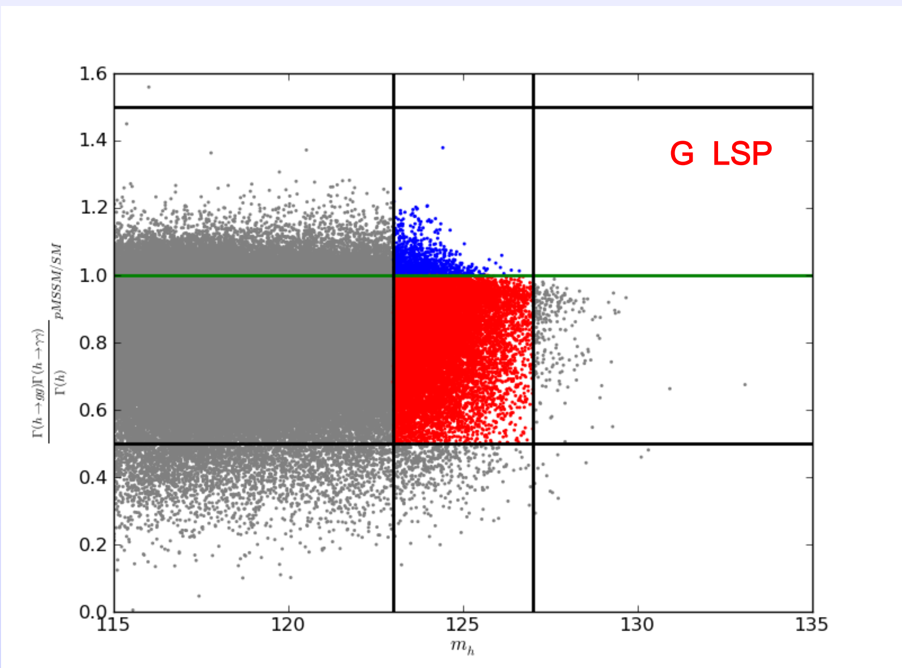


Higgs Properties

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

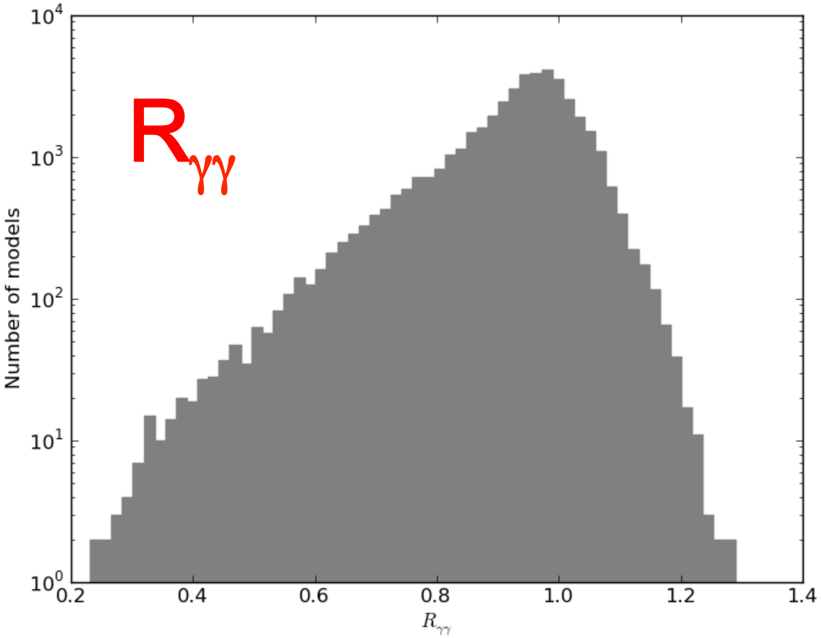
$R_{\gamma\gamma}$



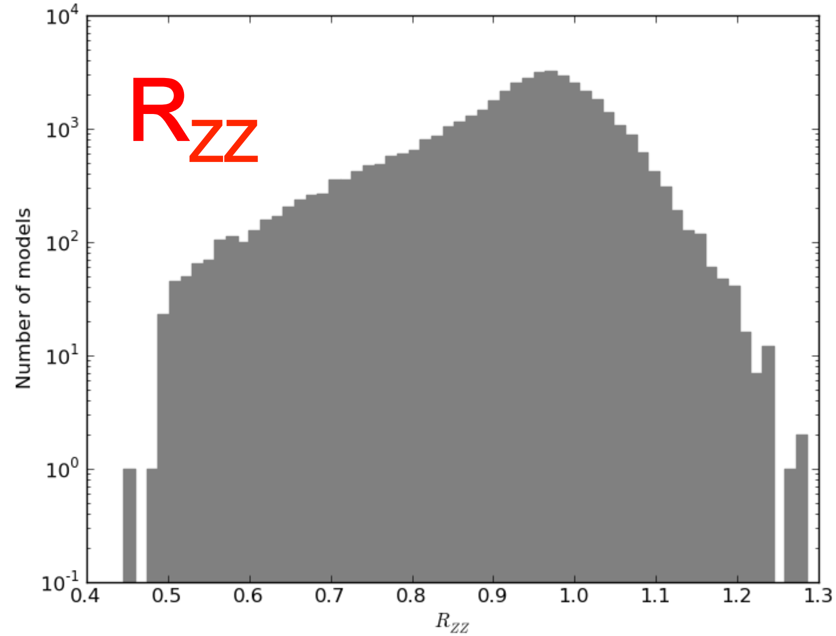


The two different model sets lead to qualitatively similar yet quantitatively very different predictions…

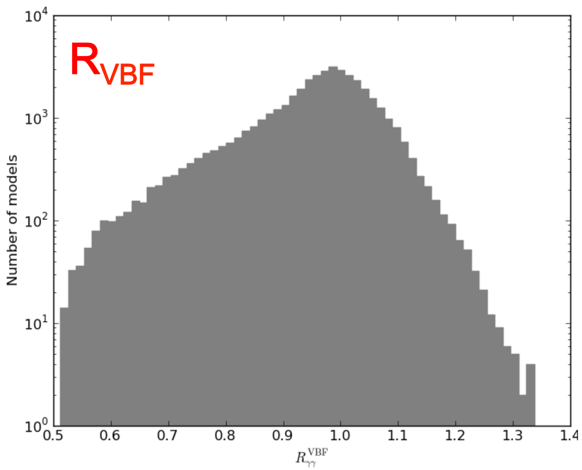
χ_1^0 LSP



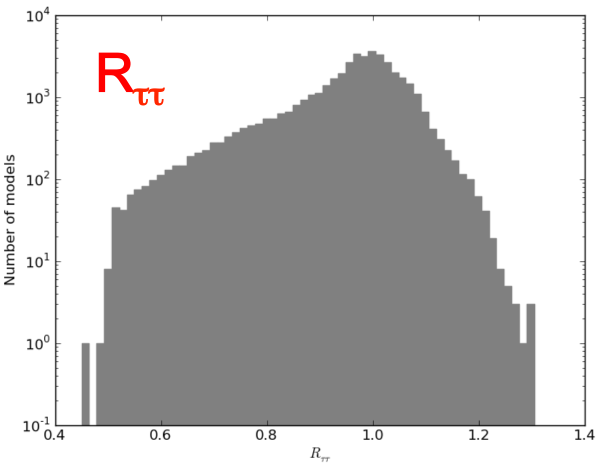
$R_{\gamma\gamma}$
Number of models
10^0 10^1 10^2 10^3 10^4
0.2 0.4 0.6 0.8 1.0 1.2 1.4
$R_{\gamma\gamma}$



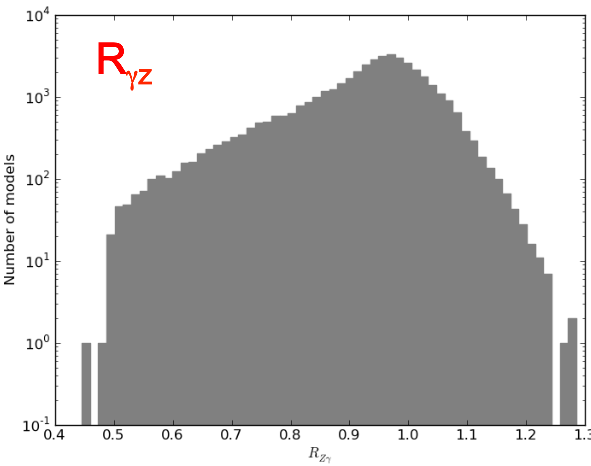
R_{ZZ}
Number of models
10^{-1} 10^0 10^1 10^2 10^3 10^4
0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3
R_{ZZ}



R_{VBF}
Number of models
10^0 10^1 10^2 10^3 10^4
0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4
$R_{\gamma\gamma}^{VBF}$



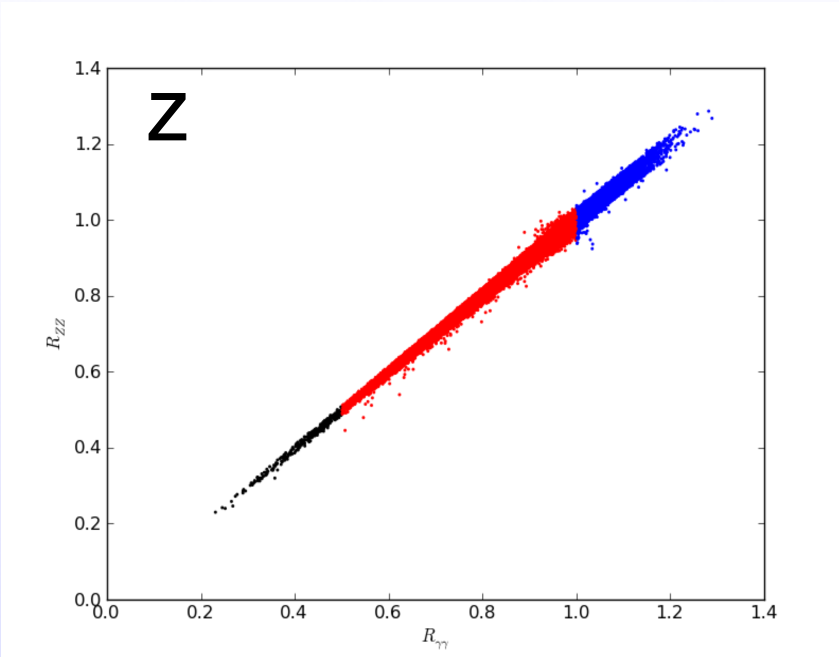
$R_{\tau\tau}$
Number of models
10^{-1} 10^0 10^1 10^2 10^3 10^4
0.4 0.6 0.8 1.0 1.2 1.4
$R_{\tau\tau}$

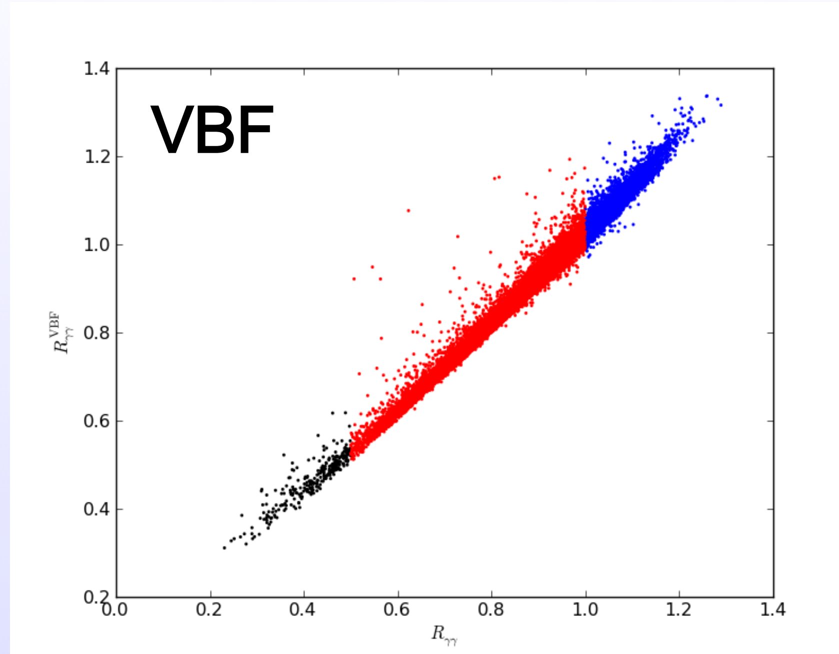


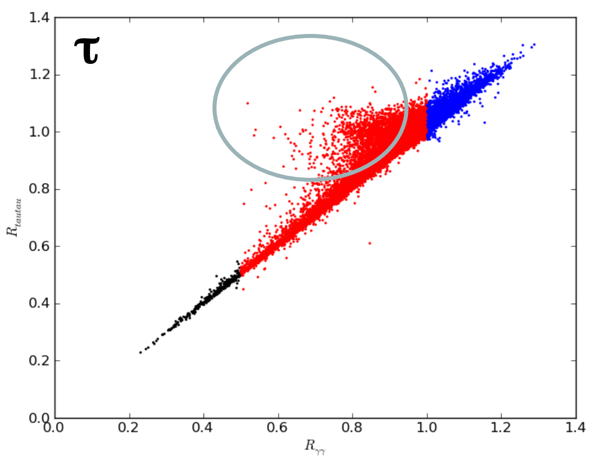
$R_{\gamma Z}$
Number of models
10^{-1} 10^0 10^1 10^2 10^3 10^4
0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3
$R_{Z\gamma}$

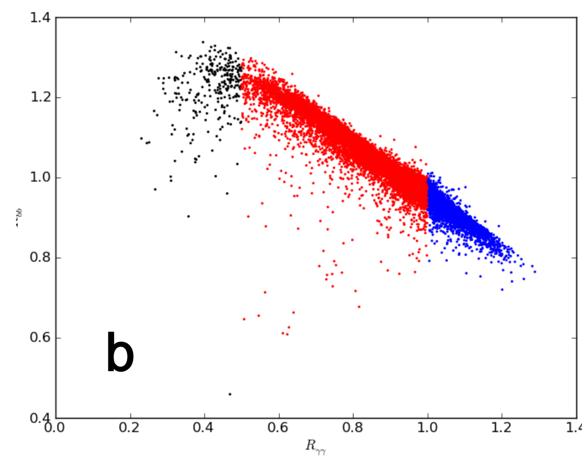
χ_1^0 LSP

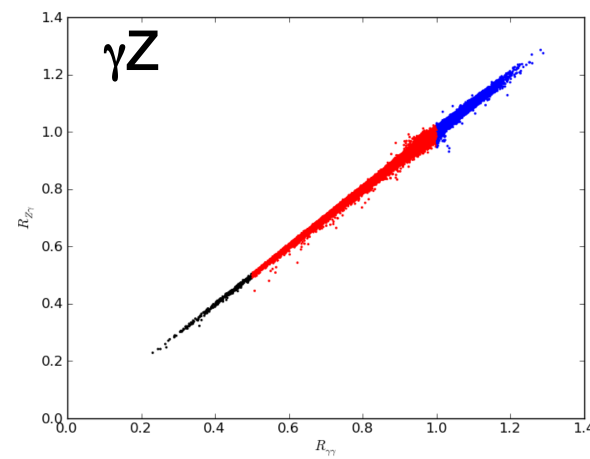
Very Highly Correlated !







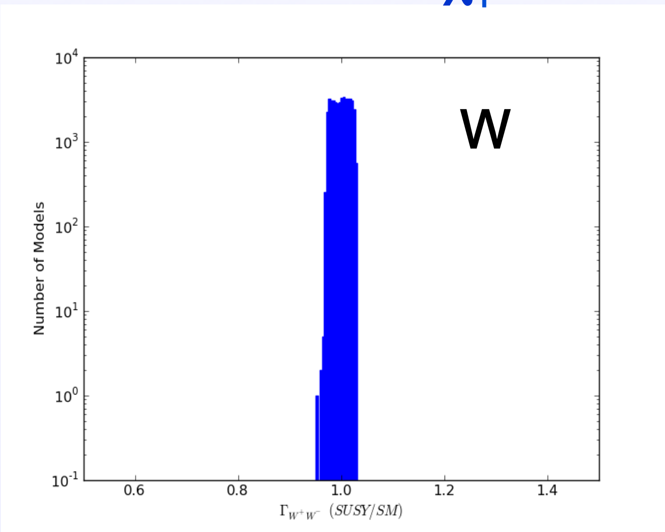


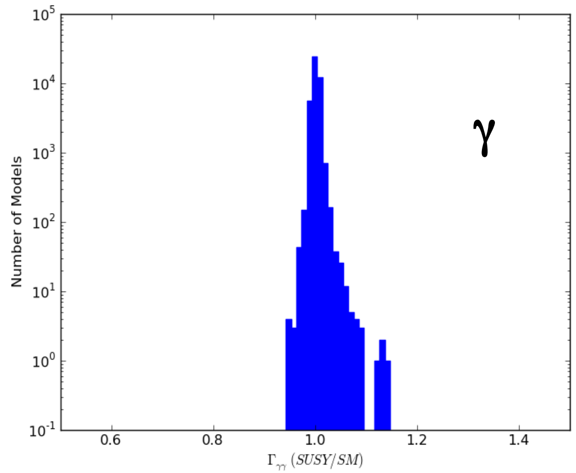


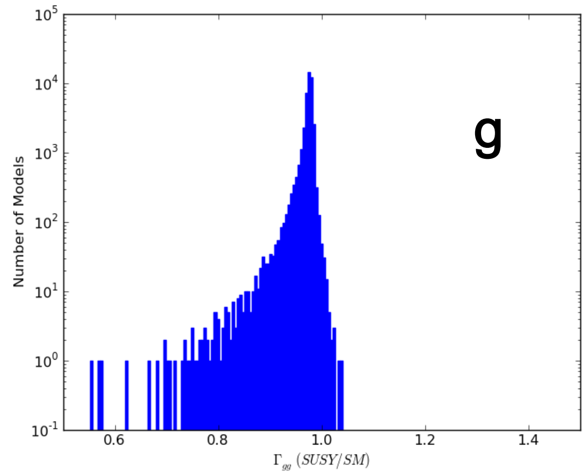
Examination of Partial Widths

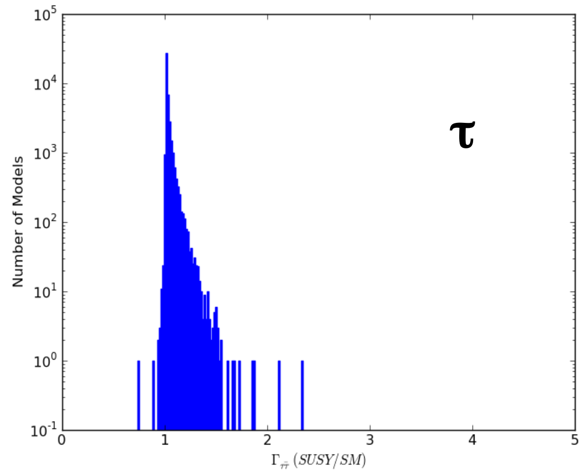
χ_1^0 LSP

- Most partial widths are close to their SM values due to decoupling
- for both LSP model sets we get highly peaked $r=\Gamma / \Gamma_{SM}$ distributions (here for the neutralino model set)
- Precision ILC measurements could Select pMSSM parameters





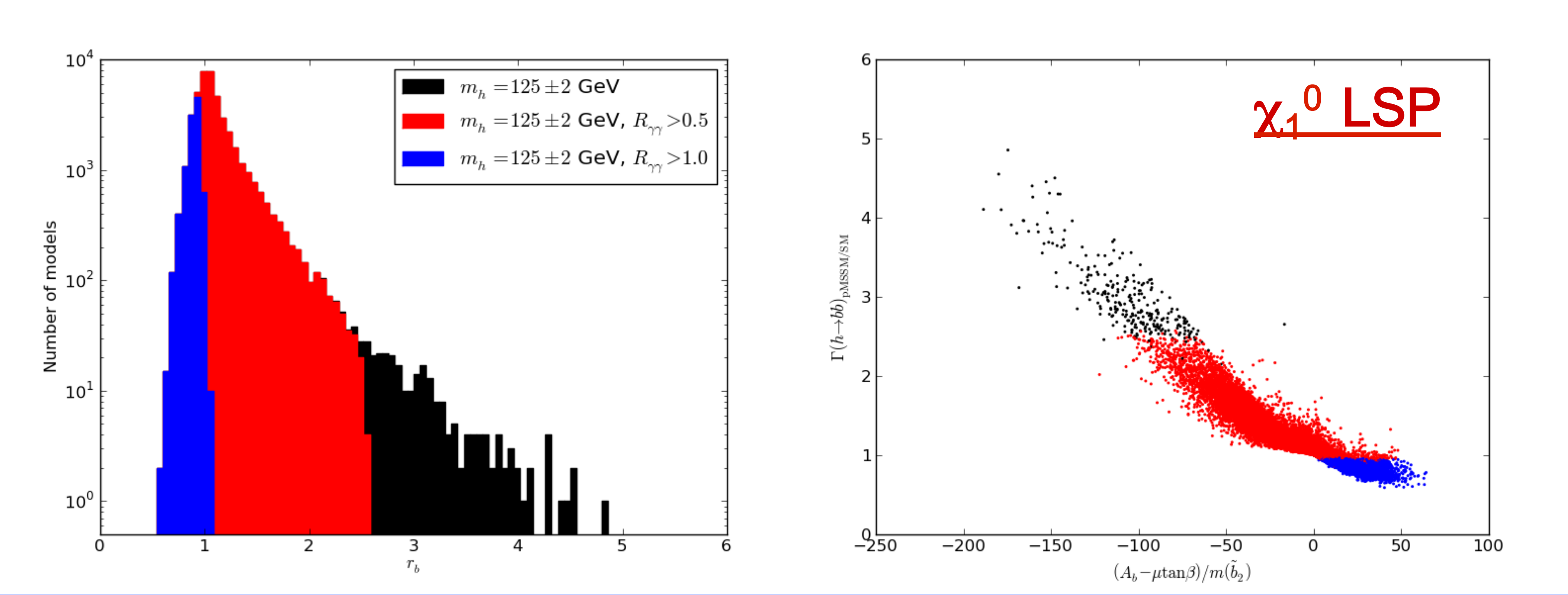




h→bb is quite different…

- 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

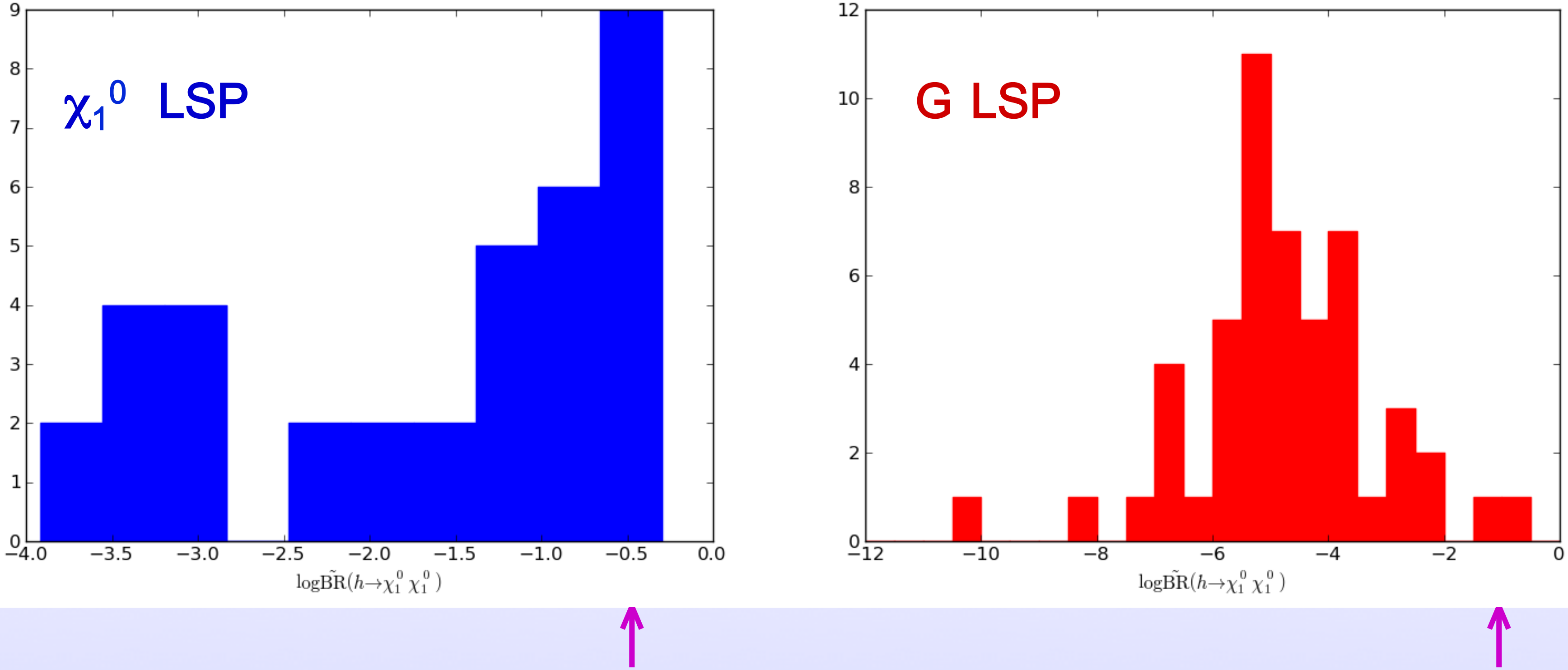


Non-SM Higgs decays

- 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 $h \to$ invisible BF > 10% & in one case it's $\approx$ 50%

- 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 lower BF in this mode. Only 1/51 models lead to a BF > 1% (19%).



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.

Naturalness Criterion

Standard prescription to compute fine-tuning:

- Take mass relation w/ radiative corrections

$$M_Z^2 = -2\mu^2 + 2\,\frac{m_{H_d}^2 - t_\beta^2\, m_{H_u}^2}{t_\beta^2 - 1}$$ + higher order

- Compute dependence on each SUSY parameter, p_i

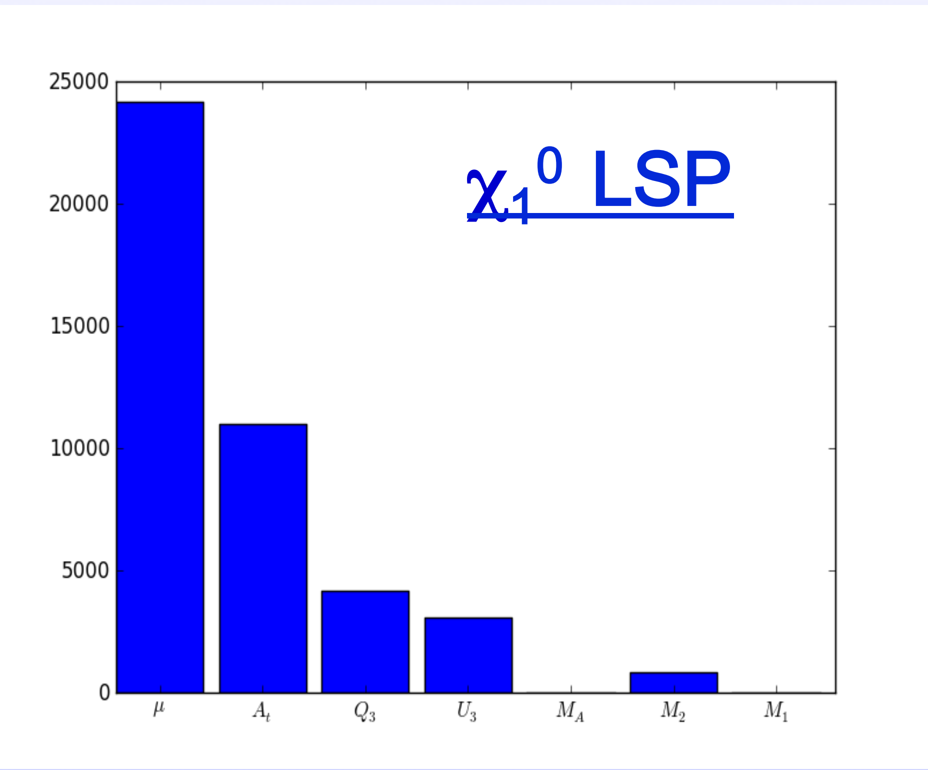
$$Z_i = \frac{\partial(\log M_Z^2)}{\partial(\log p_i)} = \frac{p_i}{M_Z^2}\,\frac{\partial M_Z^2}{\partial p_i}$$

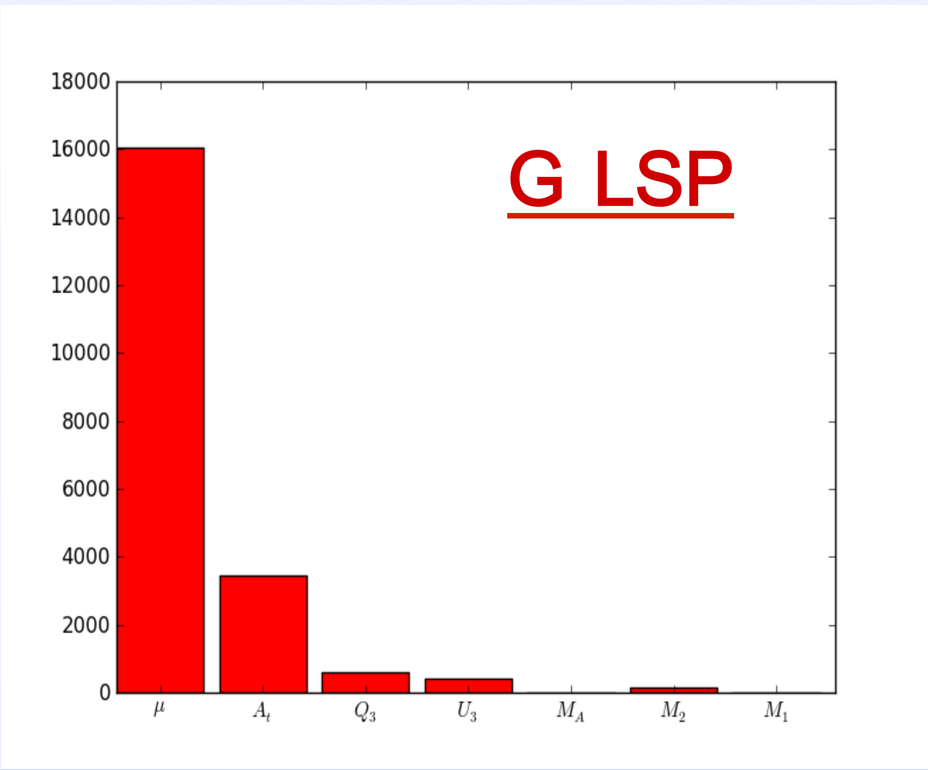
- Overall fine-tuning of model given by

  $\Delta = \max|Z_i|$

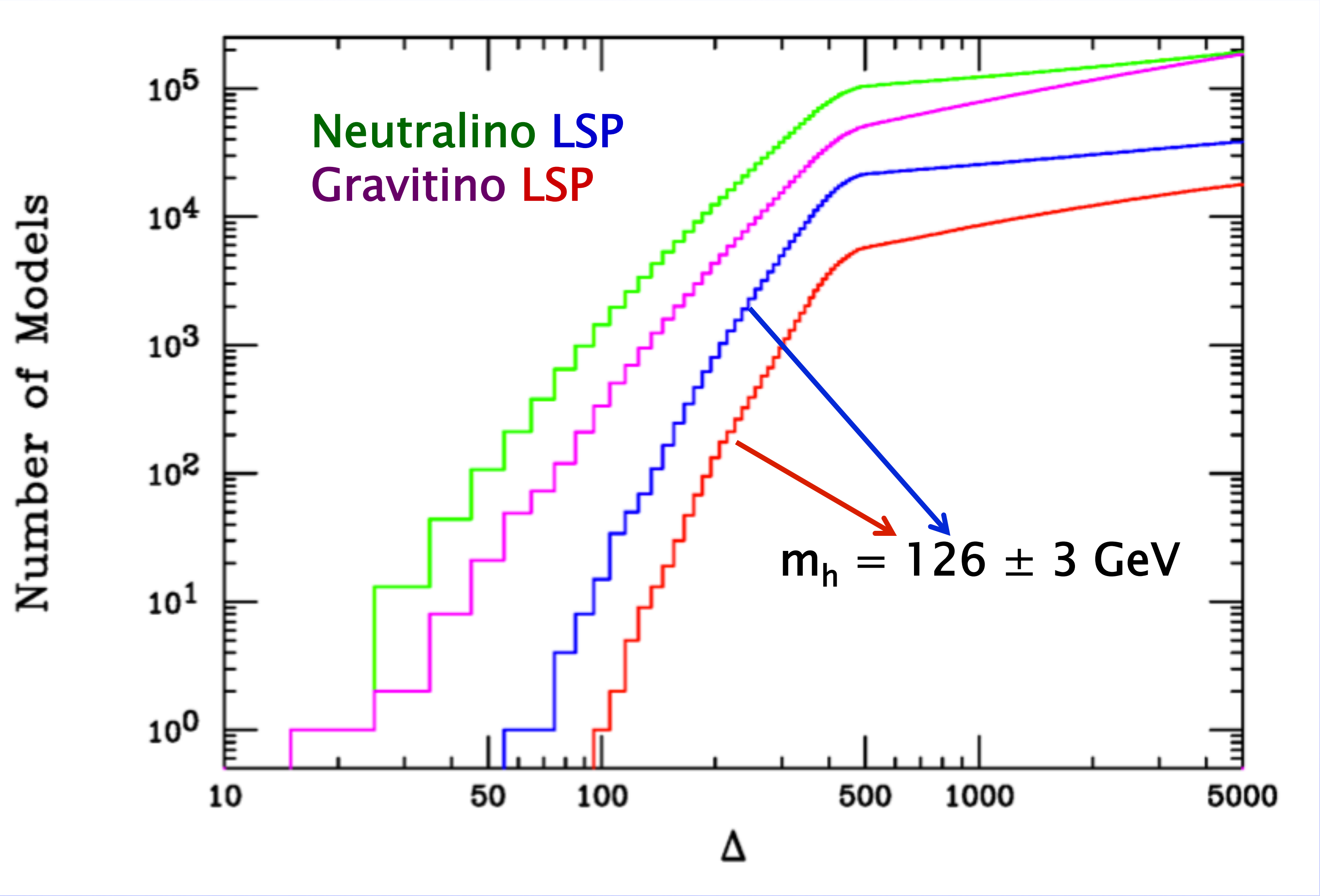
Barbieri, Giudice
Kasahara, Freese, Gondolo

Dominant FT Contributors

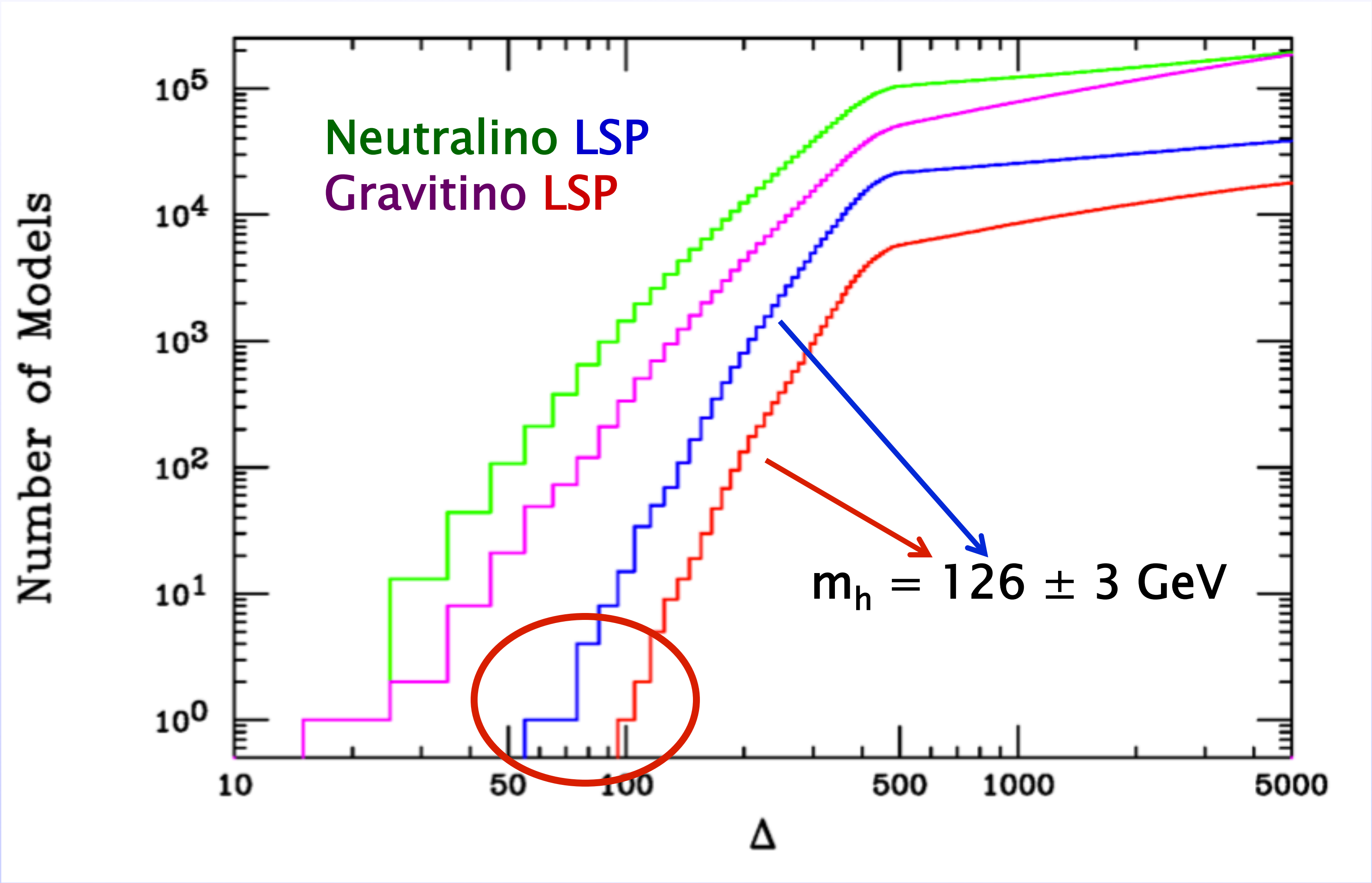




Fine-Tuning in the pMSSM

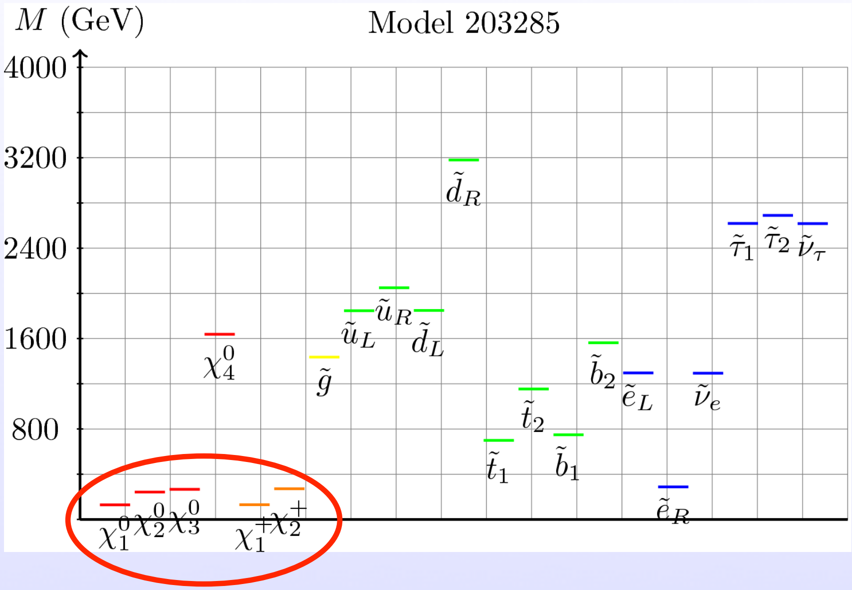


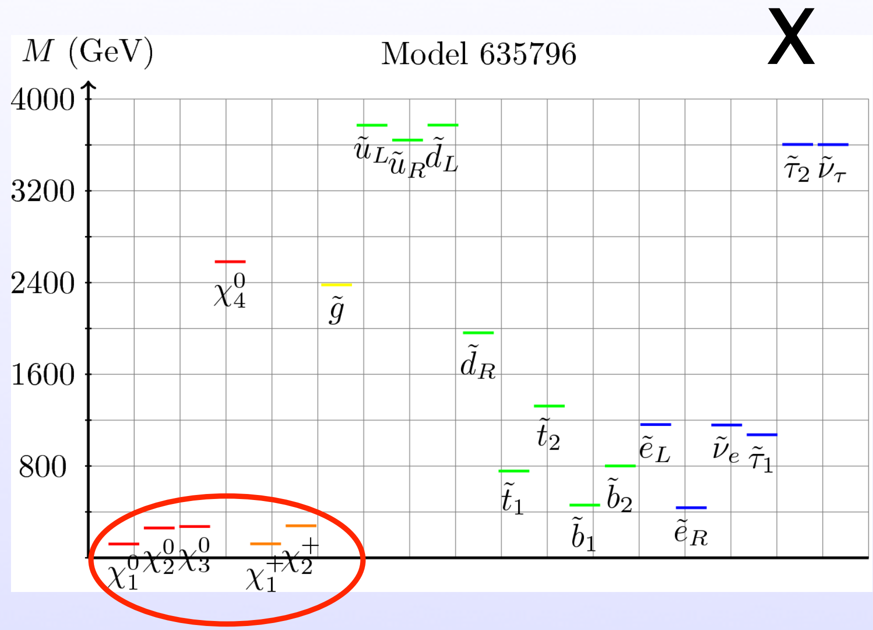
Fine-Tuning in the pMSSM

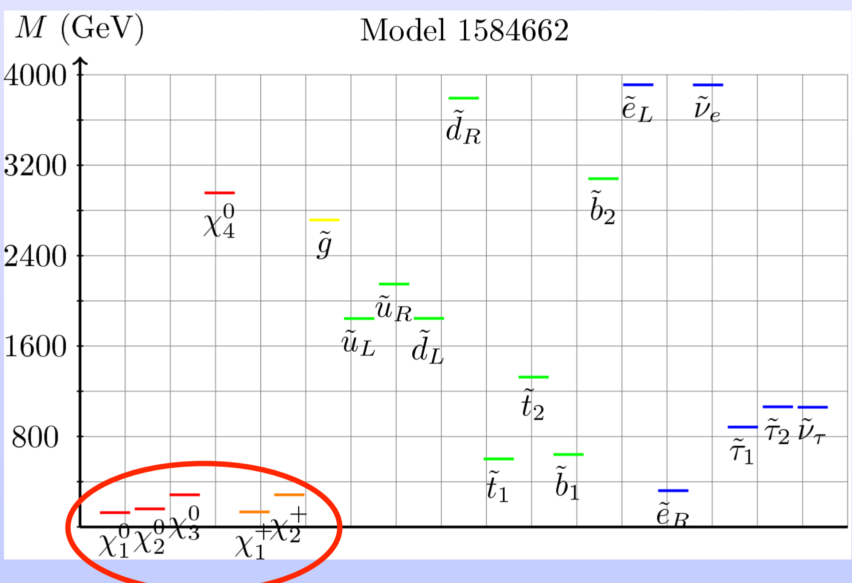


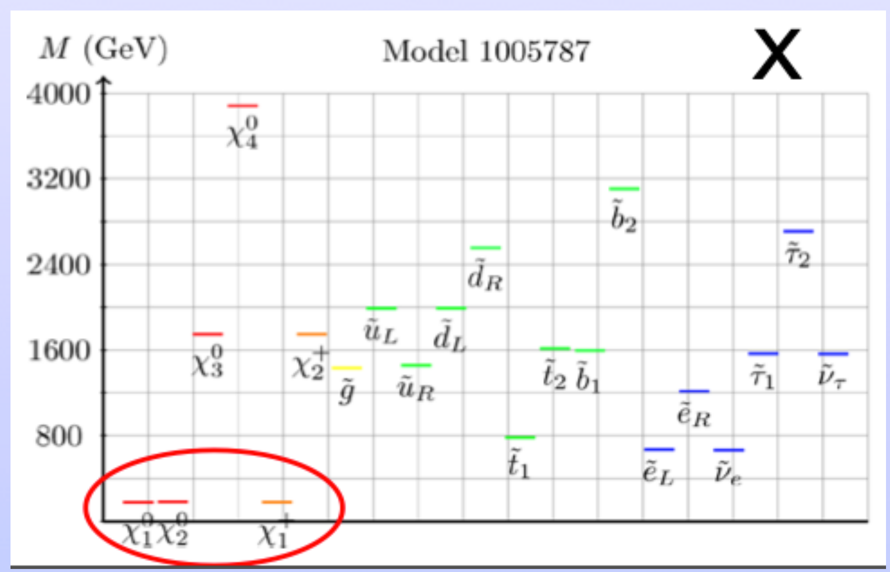
13 + 1 models with $\Delta < 100$,
4+1 of these are excluded by the LHC

Low Fine-Tuning Model Spectra I

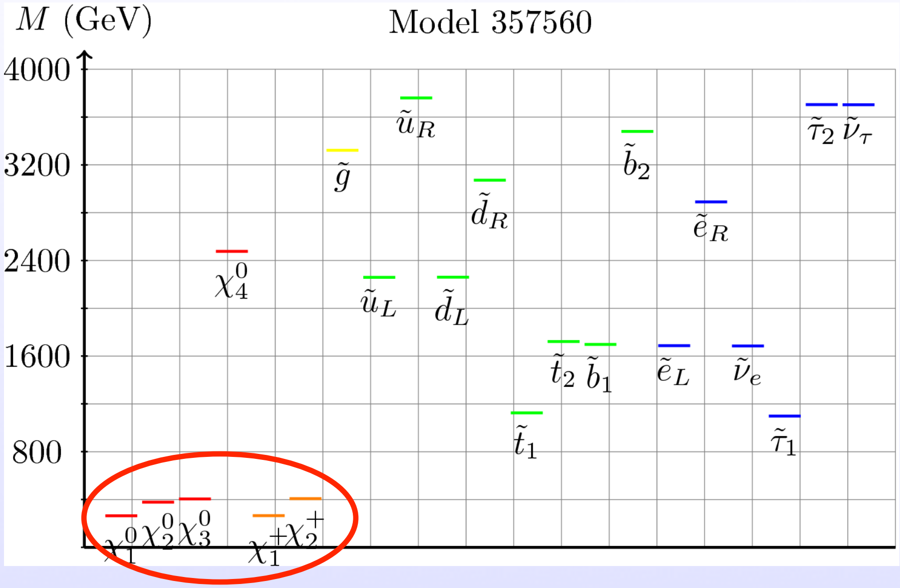


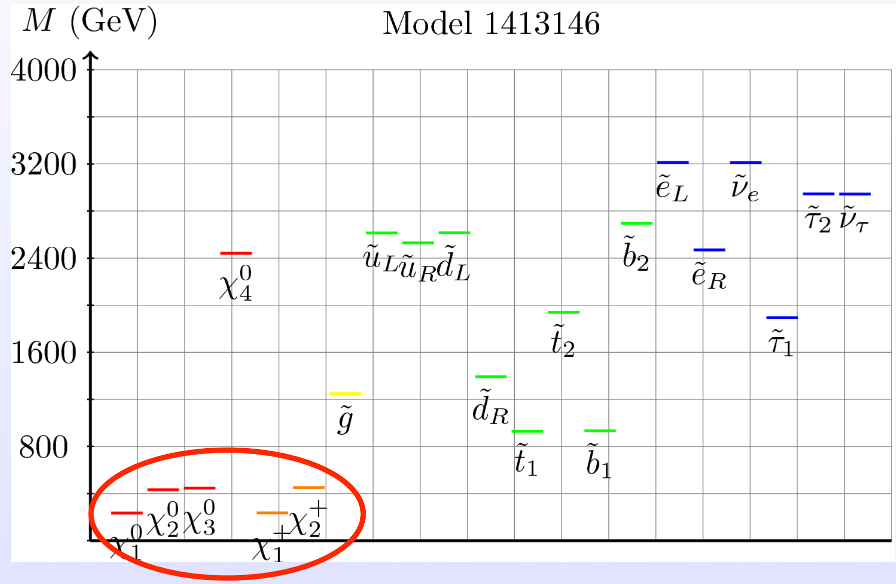


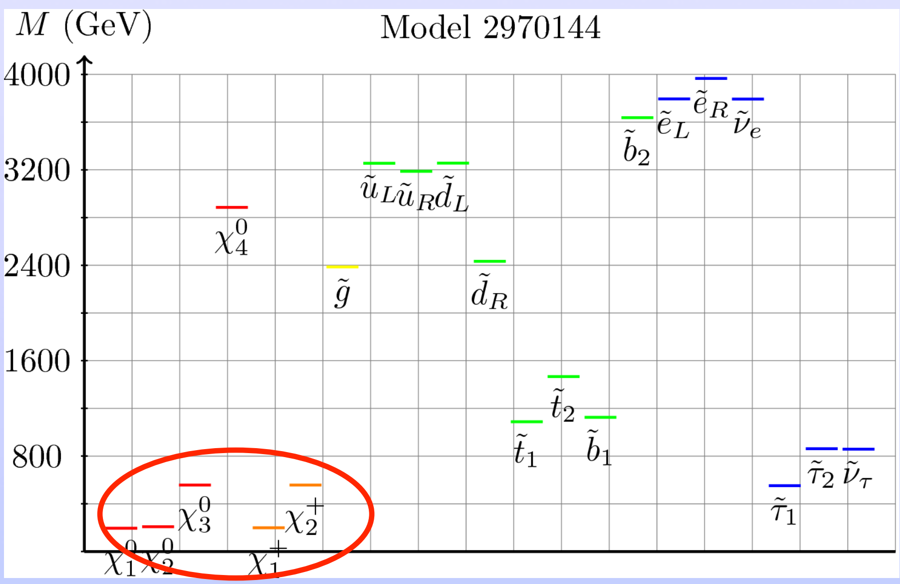


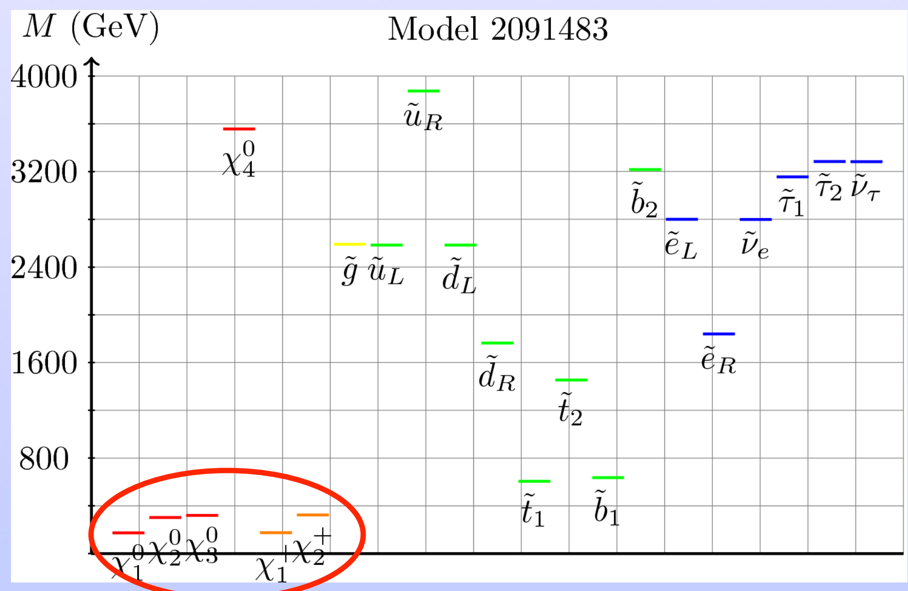


Low Fine-Tuning Model Spectra II

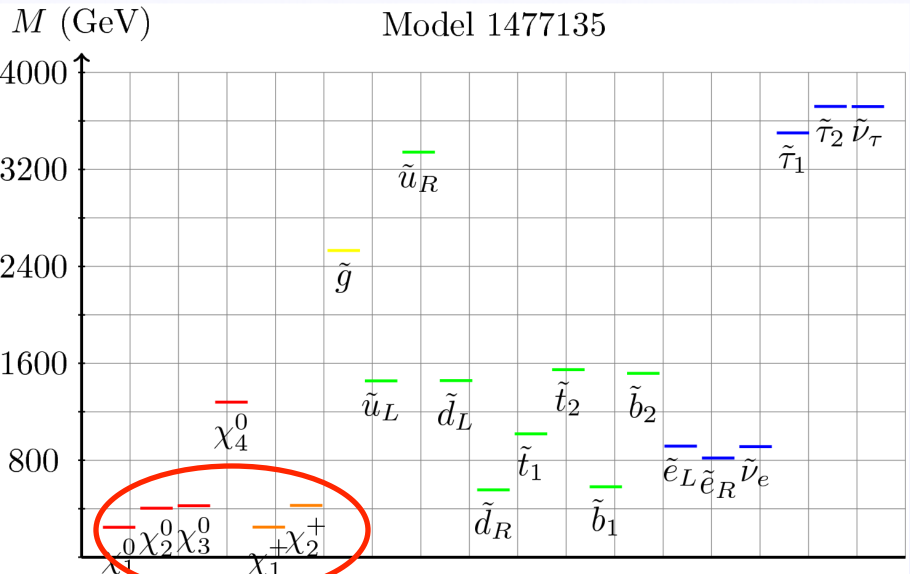


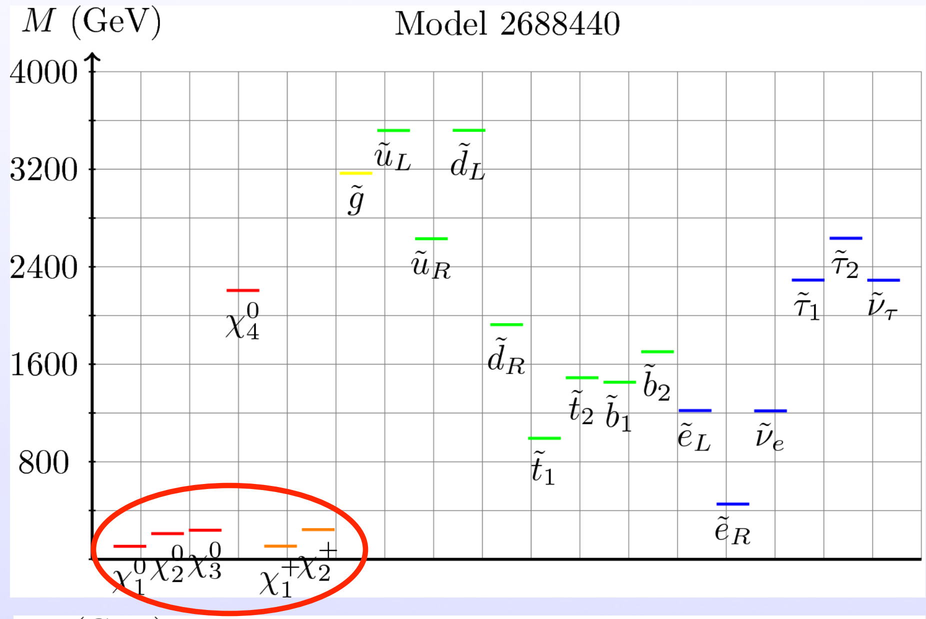


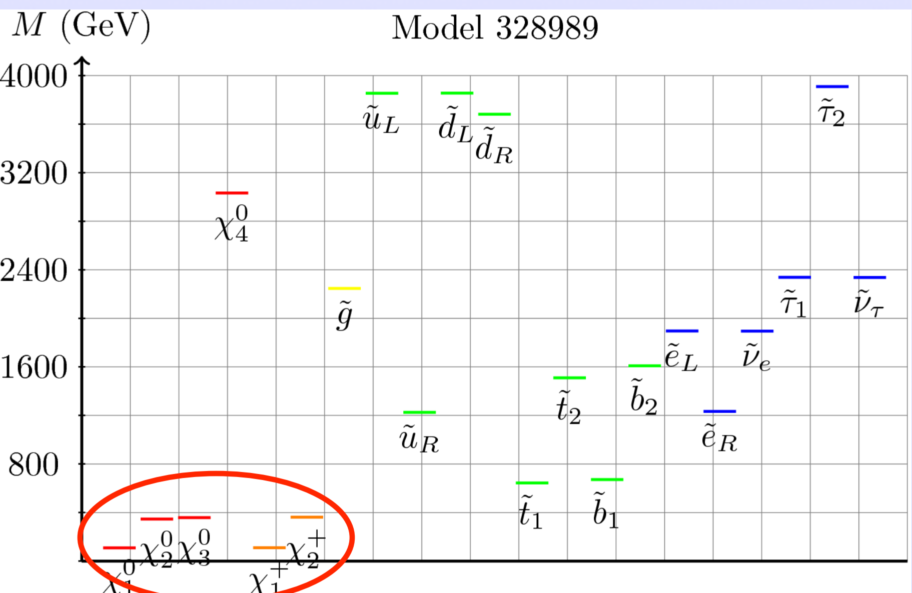


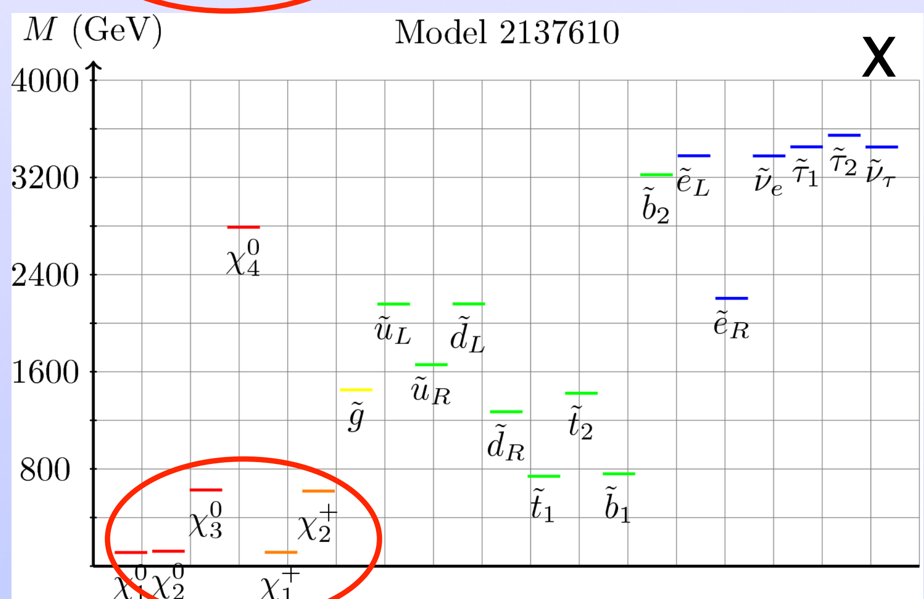


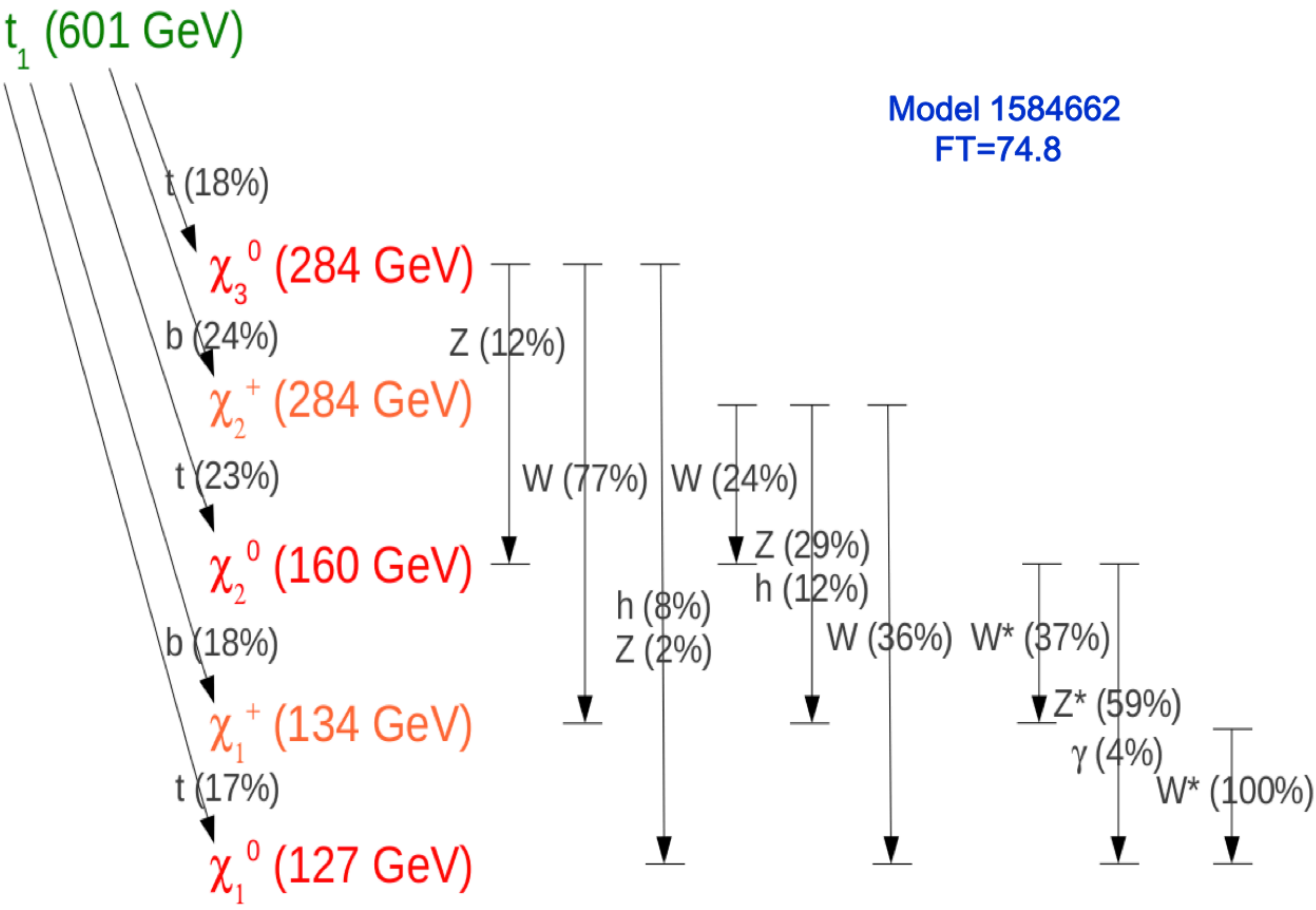
Low Fine-Tuning Model Spectra III

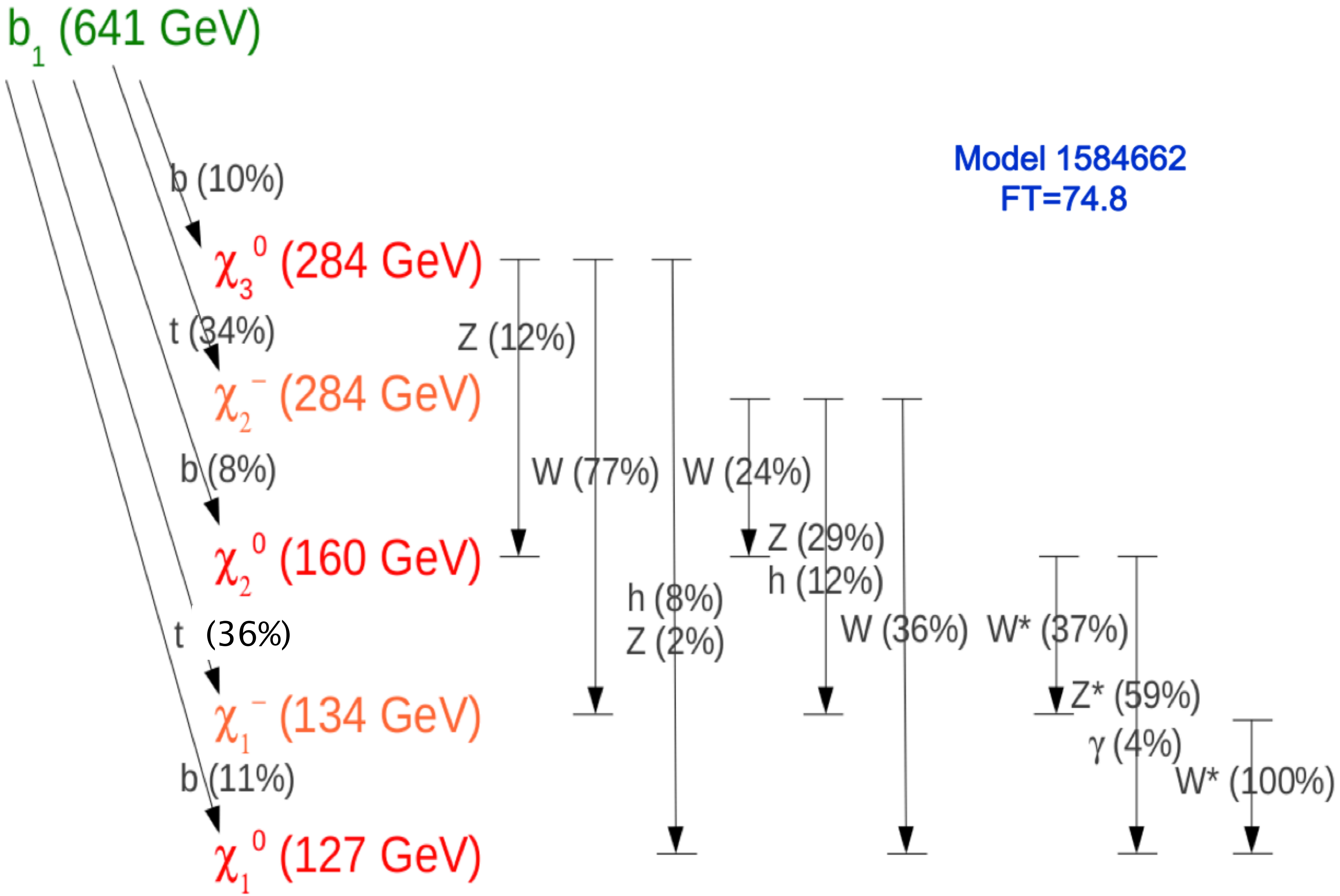









t1 (601 GeV)
Model 1584662
FT=74.8
t (18%)
χ3 0 (284 GeV)
b (24%)
Z (12%)
χ2 + (284 GeV)
t (23%)
W (77%)
W (24%)
Z (29%)
χ2 0 (160 GeV)
h (12%)
h (8%)
Z (2%)
b (18%)
W (36%)
W* (37%)
Z* (59%)
χ1 + (134 GeV)
γ (4%)
t (17%)
W* (100%)
χ1 0 (127 GeV)



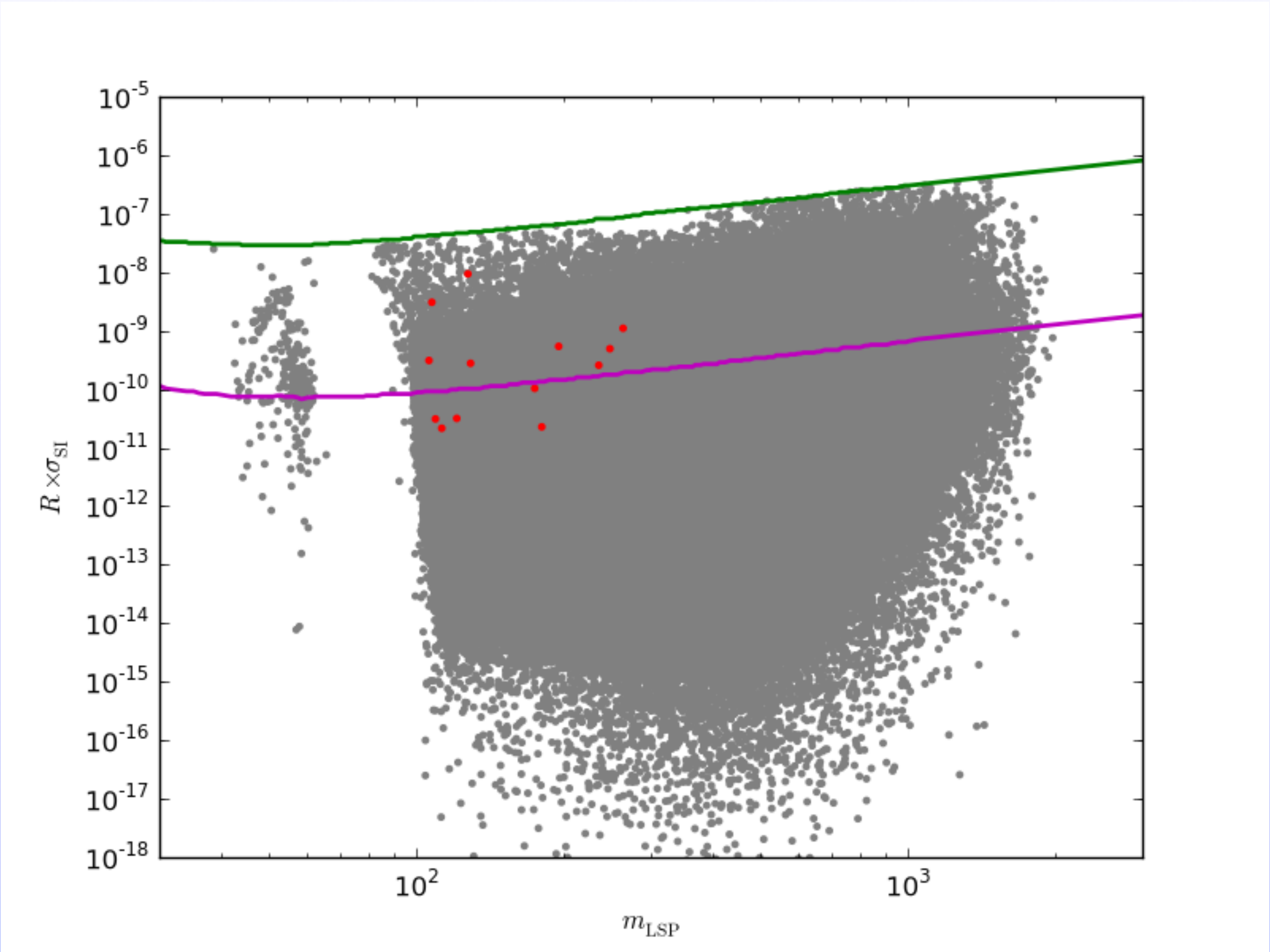
b_1 (641 GeV)
Model 1584662
FT=74.8
b (10%)
χ_3^0 (284 GeV)
t (34%)
χ_2^- (284 GeV)
b (8%)
χ_2^0 (160 GeV)
t (36%)
χ_1^- (134 GeV)
b (11%)
χ_1^0 (127 GeV)
Z (12%)
W (77%)
W (24%)
Z (29%)
h (12%)
h (8%)
Z (2%)
W (36%)
W* (37%)
Z* (59%)
γ (4%)
W* (100%)

Conclusions

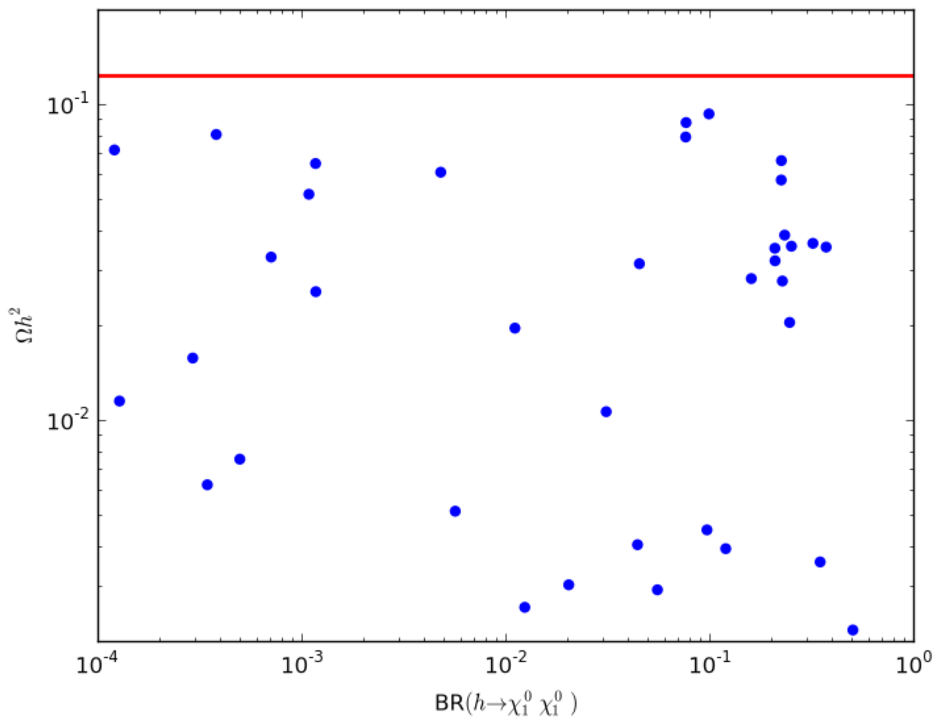
- Relatively easy to accommodate 125/6 Higgs in the pMSSM
  - Selects region of stop mixing
- Higgs branching fractions are correlated
  - Lower bb predicted
  - Lower $\tau\tau$ difficult
- Reasonable fine-tuning ~1% is possible
  - Selects region of parameter space
  - Light stop/sbottom
  - Very light and compressed EW-ino sector: Tailor-made for the ILC!

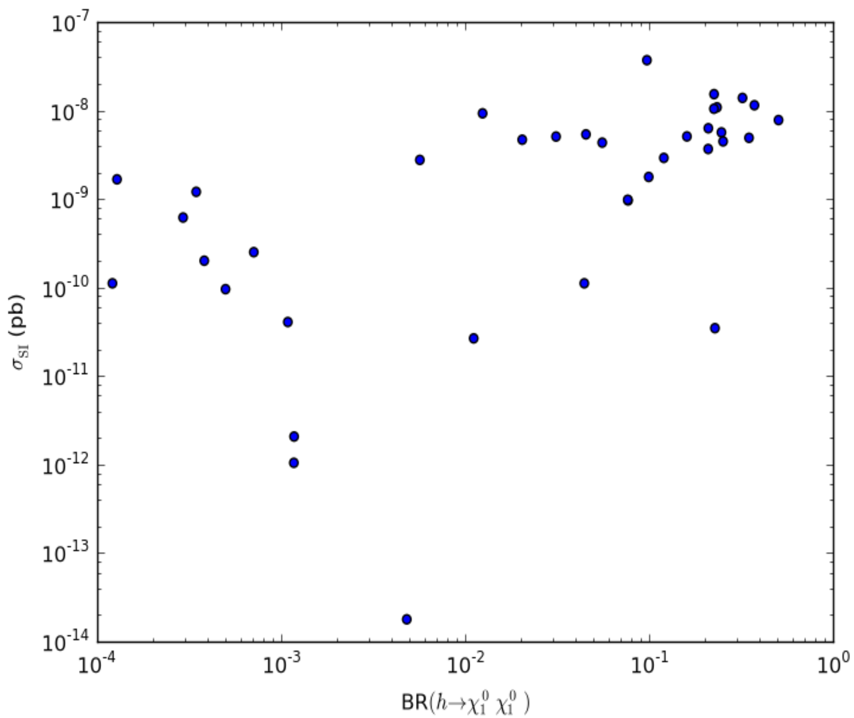
Backup

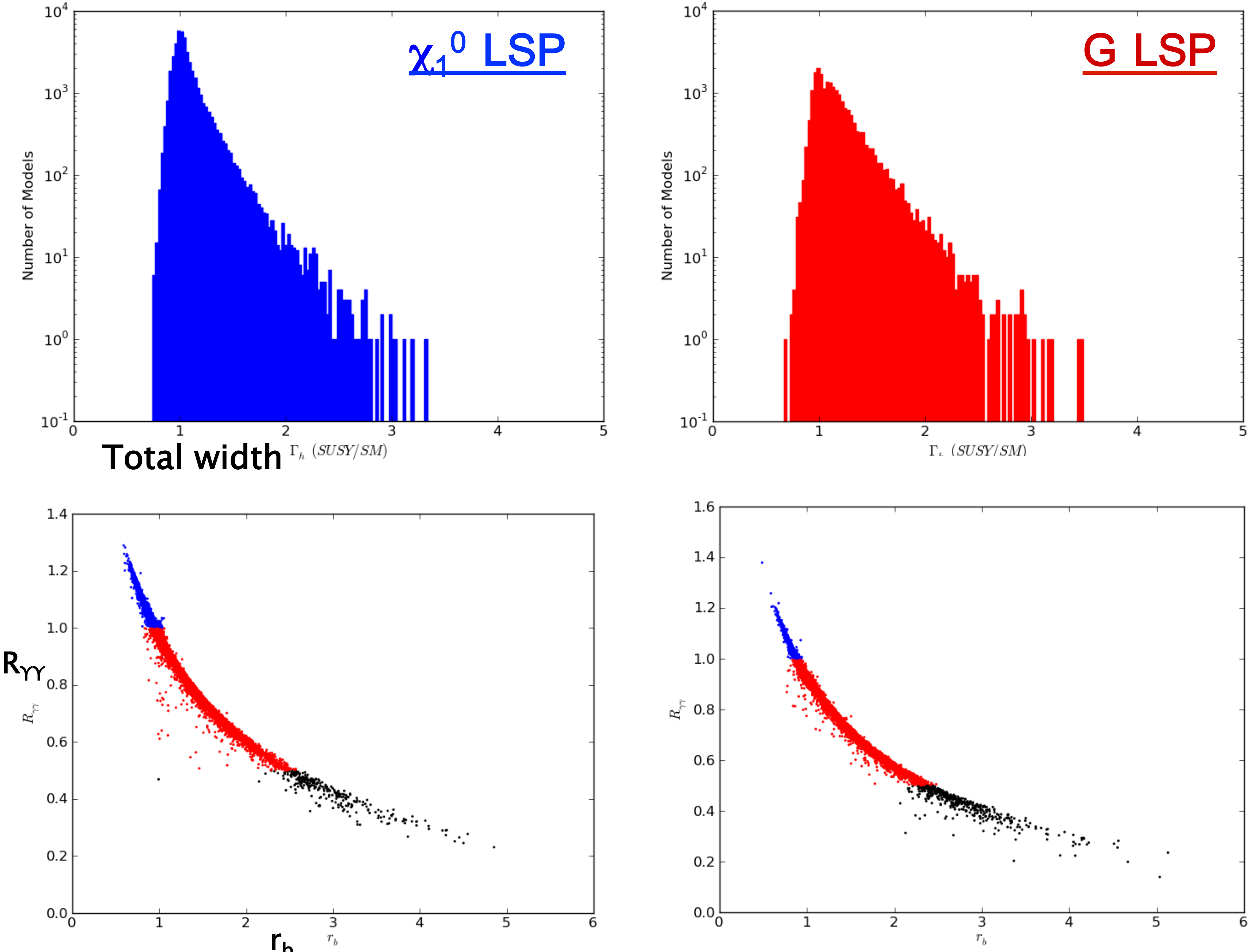
Direct Detection of Dark Matter



Astrophysical Properties of Invisible Higgs Models

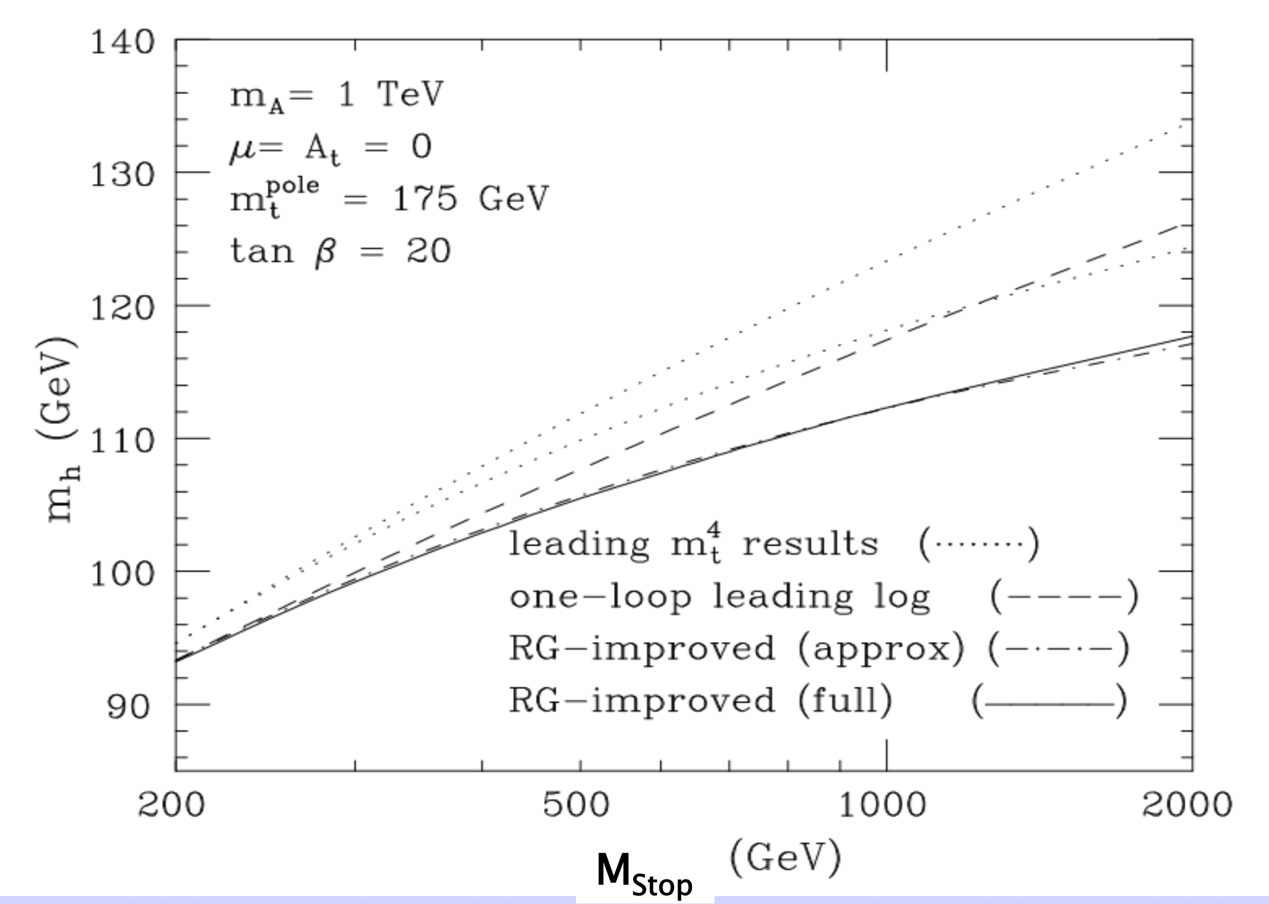






χ1⁰ LSP
G LSP
Number of Models
Number of Models
Total width
Γh (SUSY/SM)
Γh (SUSY/SM)
Rγγ
Rγγ
Rγγ
rb
rb
rb

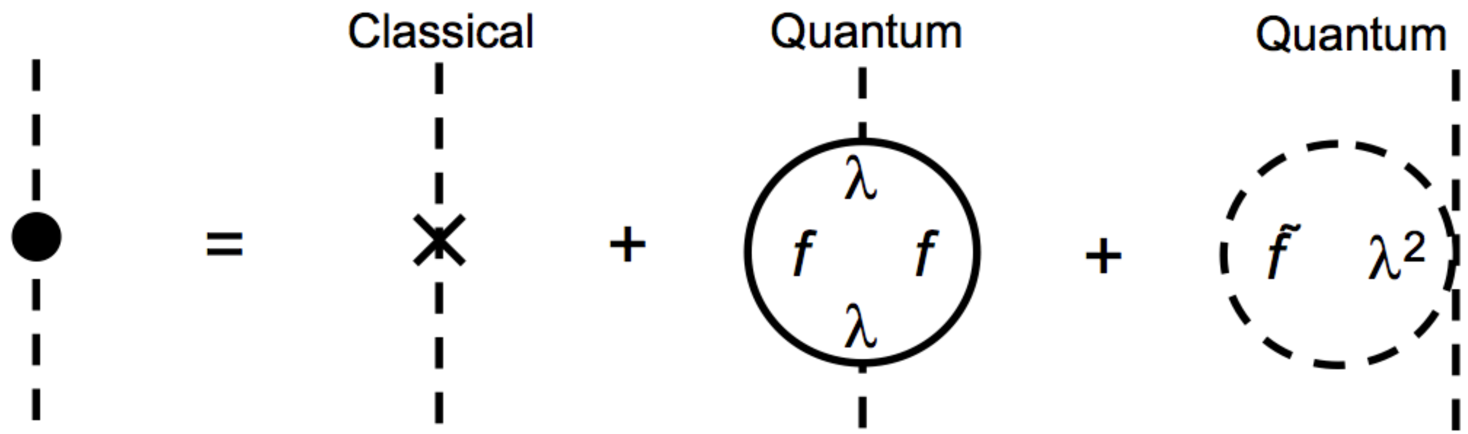
The SUSY Higgs Sector



Haber, Hempfling

A heavy h^0 needs a heavy stop-squark $\tilde{t}_1$

Supersymmetry and Naturalness

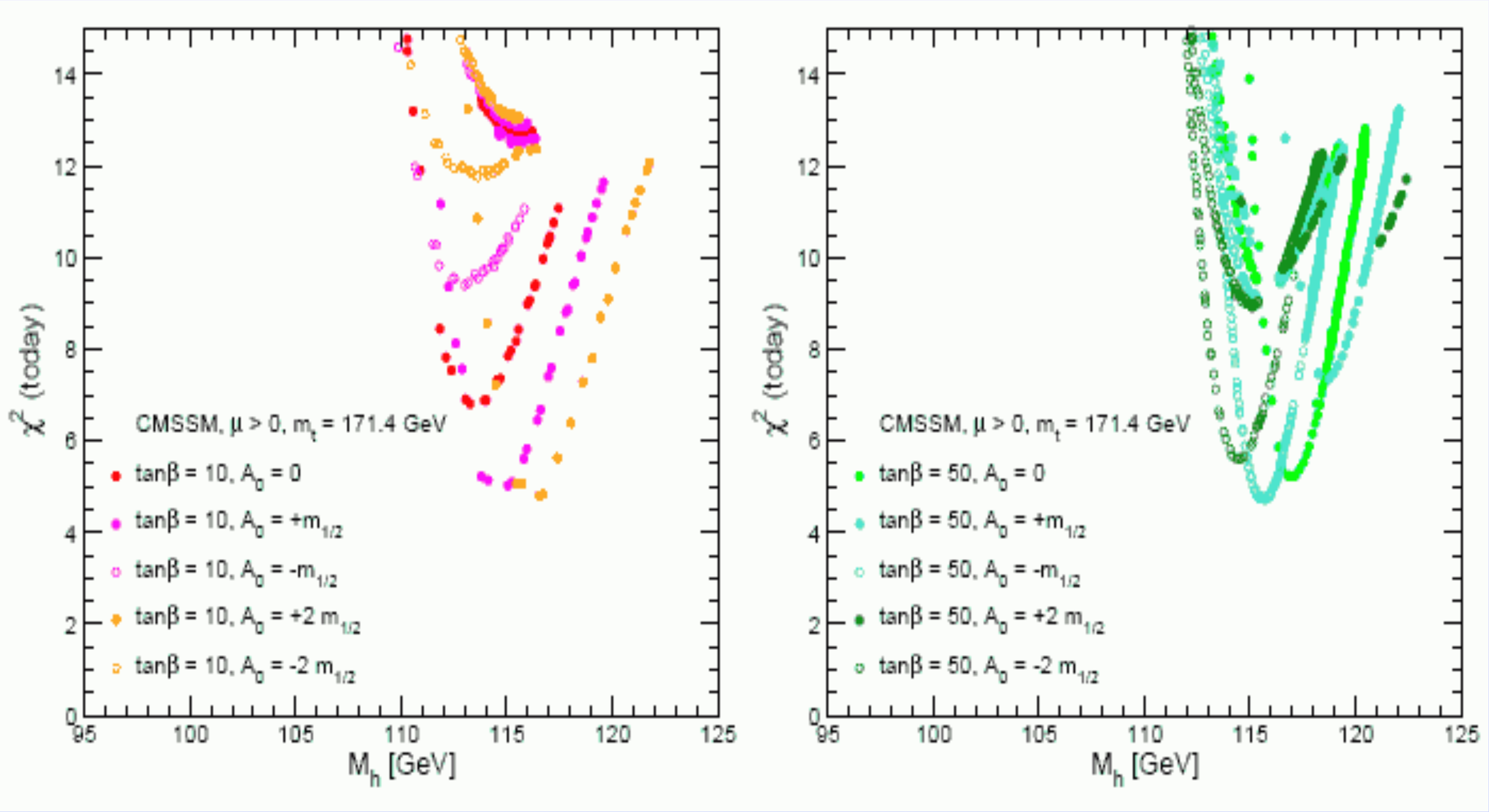


$$m_h^2 = (m_h^2)_0 \underbrace{- \frac{1}{16\pi^2}\lambda^2\Lambda^2 + \frac{1}{16\pi^2}\lambda^2\Lambda^2}_{+\ \frac{1}{16\pi^2}\lambda^2 (m_{\tilde{f}}^2 - m_f^2)\ \ln(\Lambda/m_h)}$$

The hierarchy problem needs a light stop-squark $\tilde{t}_1$

Predictions for Lightest Higgs Mass in the CMSSM

- χ^2 fit to EW, Flavor, Collider, Cosmology global data set



Ellis etal arXiv:0706.0652

Anderson & Castano
hep-ph/9409419

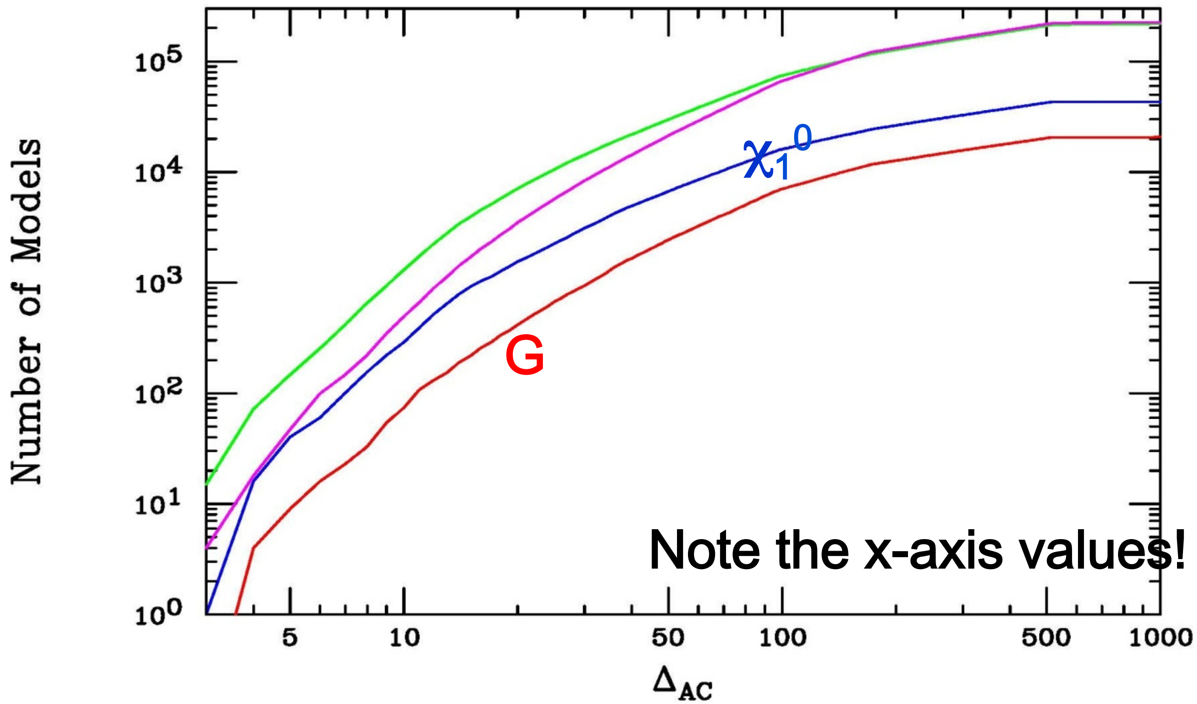
FT from parameter a is $\gamma = c/\bar{c}.$

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)

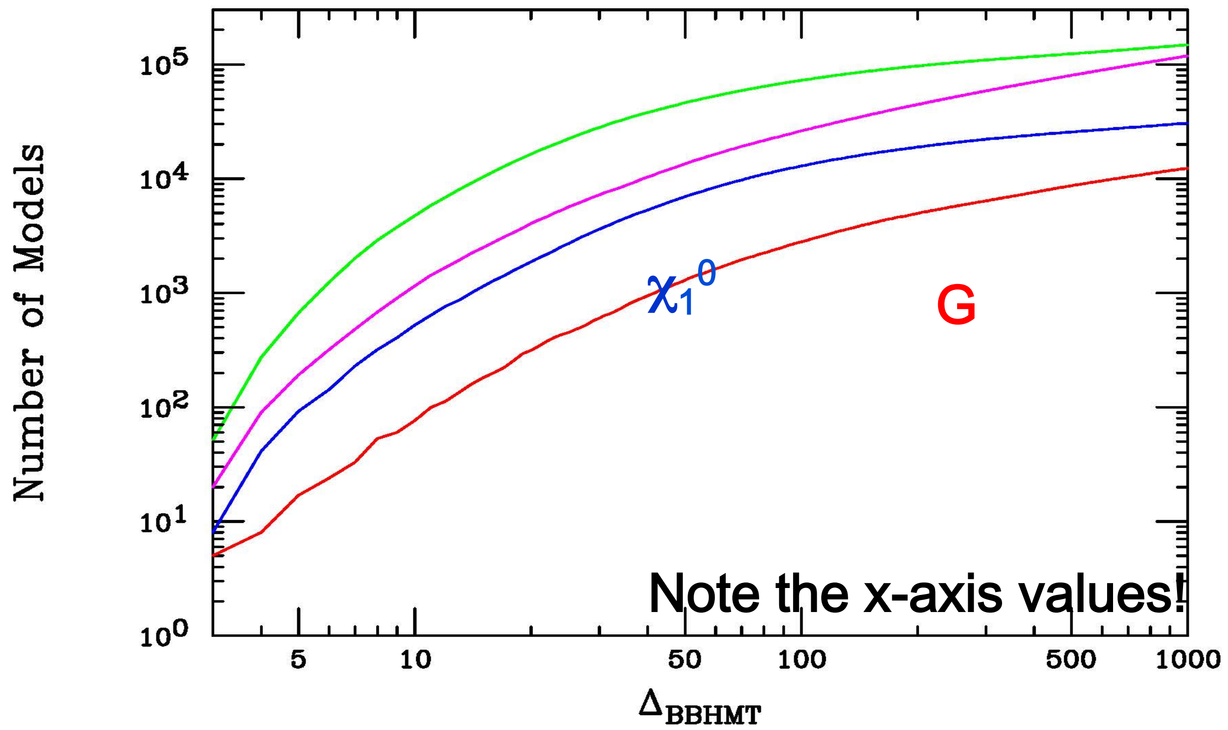


Note the x-axis values!

Caveat: there are other possible measures of EW FT…

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

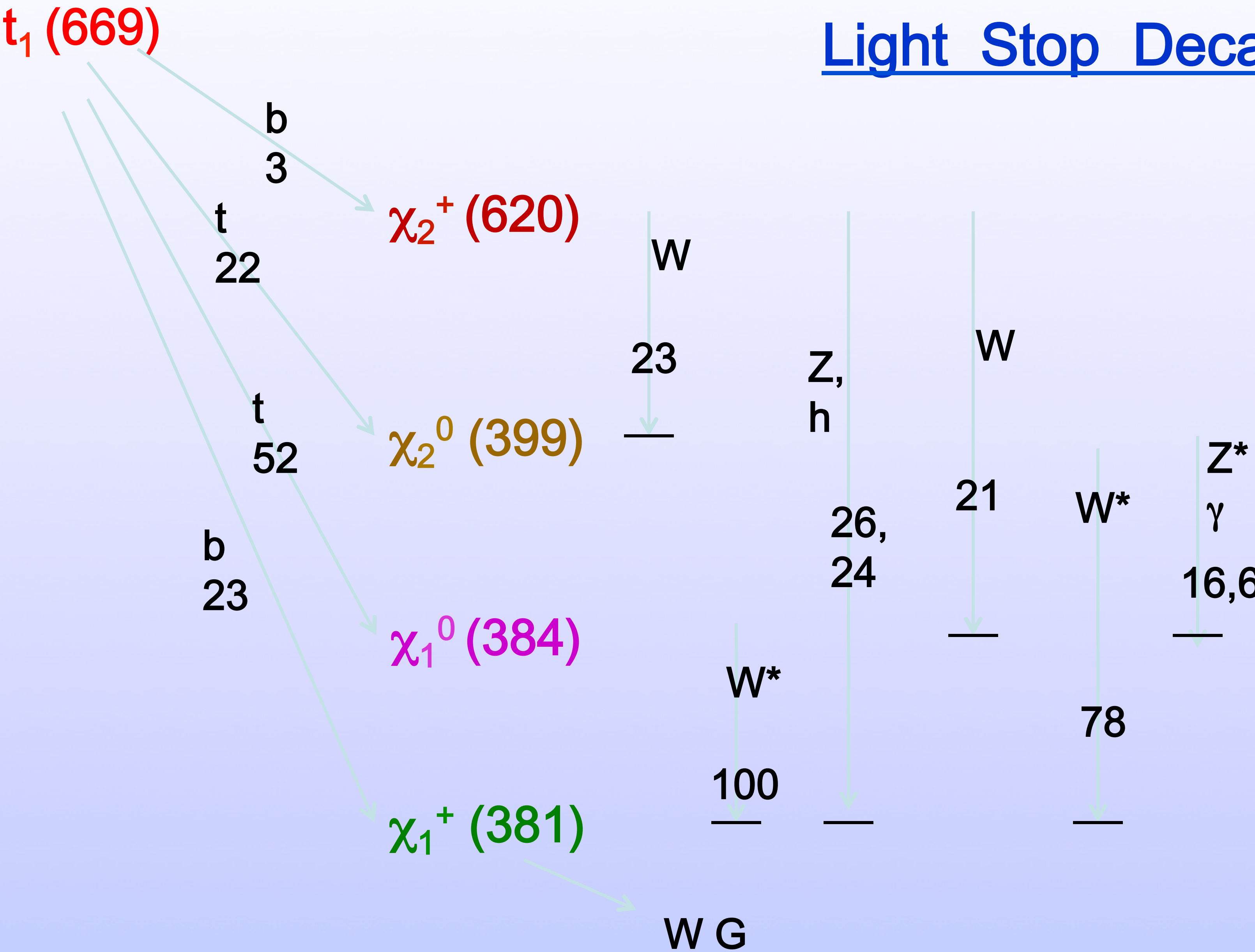
Just require RC's (the Σ's) to be smaller than the LHS ..this is the so-called minimal or 'vanilla' constraints. Then



Baer etal, 1207.3343

An Example :
#146314G w/ FT=95.9

Light Stop Decays



An Example :

#2592398 w/ FT_{BBHMT} =6.6

Light Stop Decays