The Higgs Sector and Fine-Tuning in the pMSSM

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Matthew Cahill-Rowley, JoAnne Hewett, AI, Tom Rizzo, 1206.5800

Outline

- pMSSM model set generation
- A 125 GeV Higgs
- Fine-tuning
- Outlook

The pMSSM

- Scan over large SUSY parameter space, searching for experimentally viable spectra
- The full MSSM has 105 new free parameters, many of which are very strongly constrained by flavor data
- Minimal flavor violation decreases scan dimensionality without losing much generality
- Take sparticle mass matrices to be flavor diagonal, with first two generations degenerate
- No new sources of CP violation

The pMSSM

- Together, these assumptions leave us with the 19 free parameters of the *phenomenological MSSM*
- M_1, M_2, M_3, μ, $\tan\beta$, M_A, $q_{1,3}$, $u_{1,3}$, $d_{1,3}$, $l_{1,3}$, $e_{1,3}$, $A_{t,b,\tau}$
- Can also add gravitino, with mass $m_{3/2}$
- Generate random points in this parameter space, and test vs. experimental constraints
- Investigate properties of resulting models
  (Cahill-Rowley, Hewett, Hoeche, Al, Rizzo, 1206.4321)

Parameter scan ranges

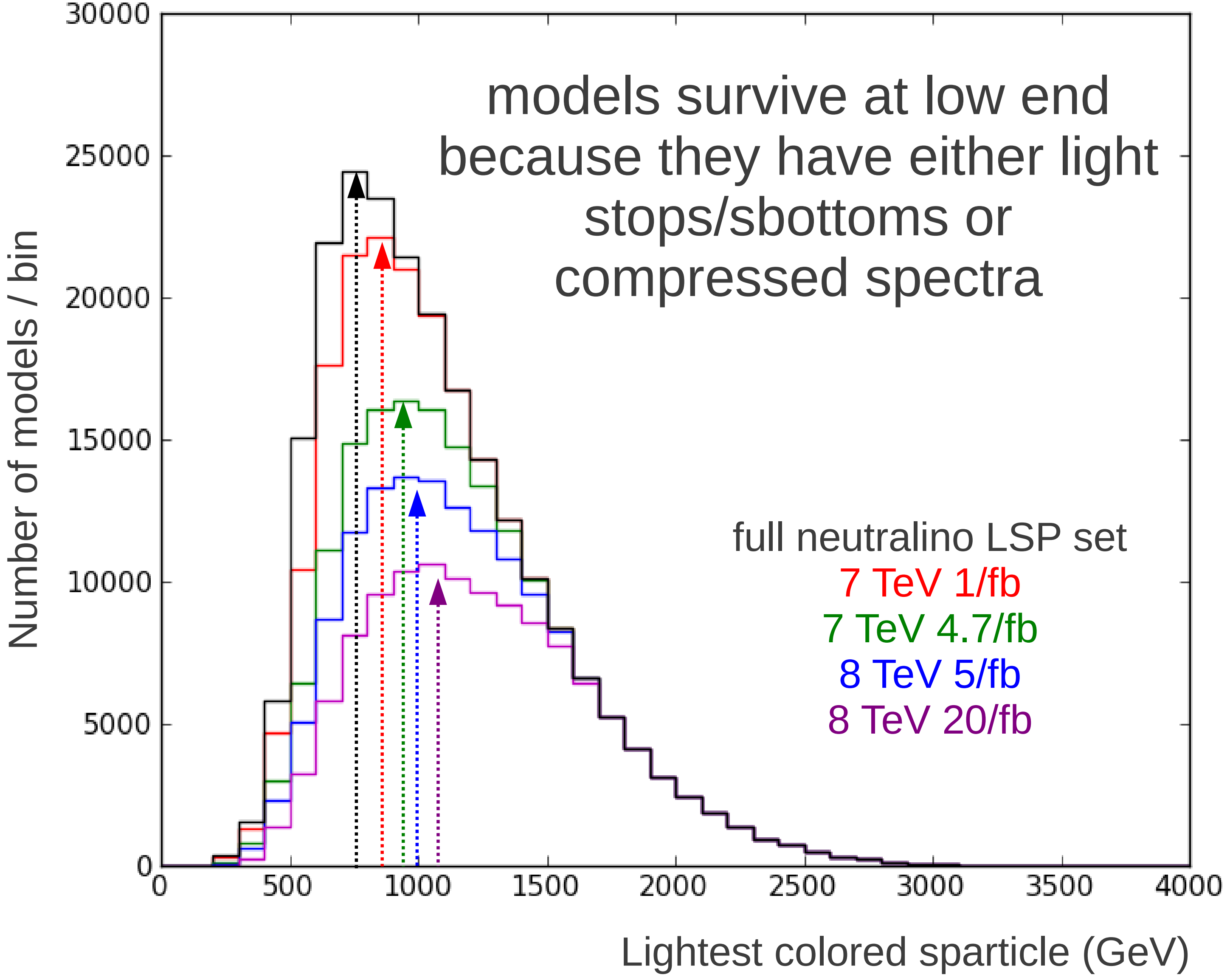
- 50 GeV ≤ $|M_1|$ ≤ 4 TeV
- 100 GeV ≤ $|M_2, \mu|$ ≤ 4 TeV
- 400 GeV ≤ M_3 ≤ 4 TeV
- 1 ≤ $\tan\beta$ ≤ 60
- 1 eV ≤ $m_{3/2}$ ≤ 1 TeV (log prior)
- 100 GeV ≤ M_A, l, e ≤ 4 TeV
- 400 GeV ≤ q_1, u_1, d_1 ≤ 4 TeV
- 200 GeV ≤ q_3, u_3, d_3 ≤ 4 TeV
- $|A_{t,b,\tau}|$ ≤ 4 TeV

Bottom-up approach: thermal gravitino production *not* considered (low reheating temperature, additional source of entropy in early universe) in gravitino LSP model set

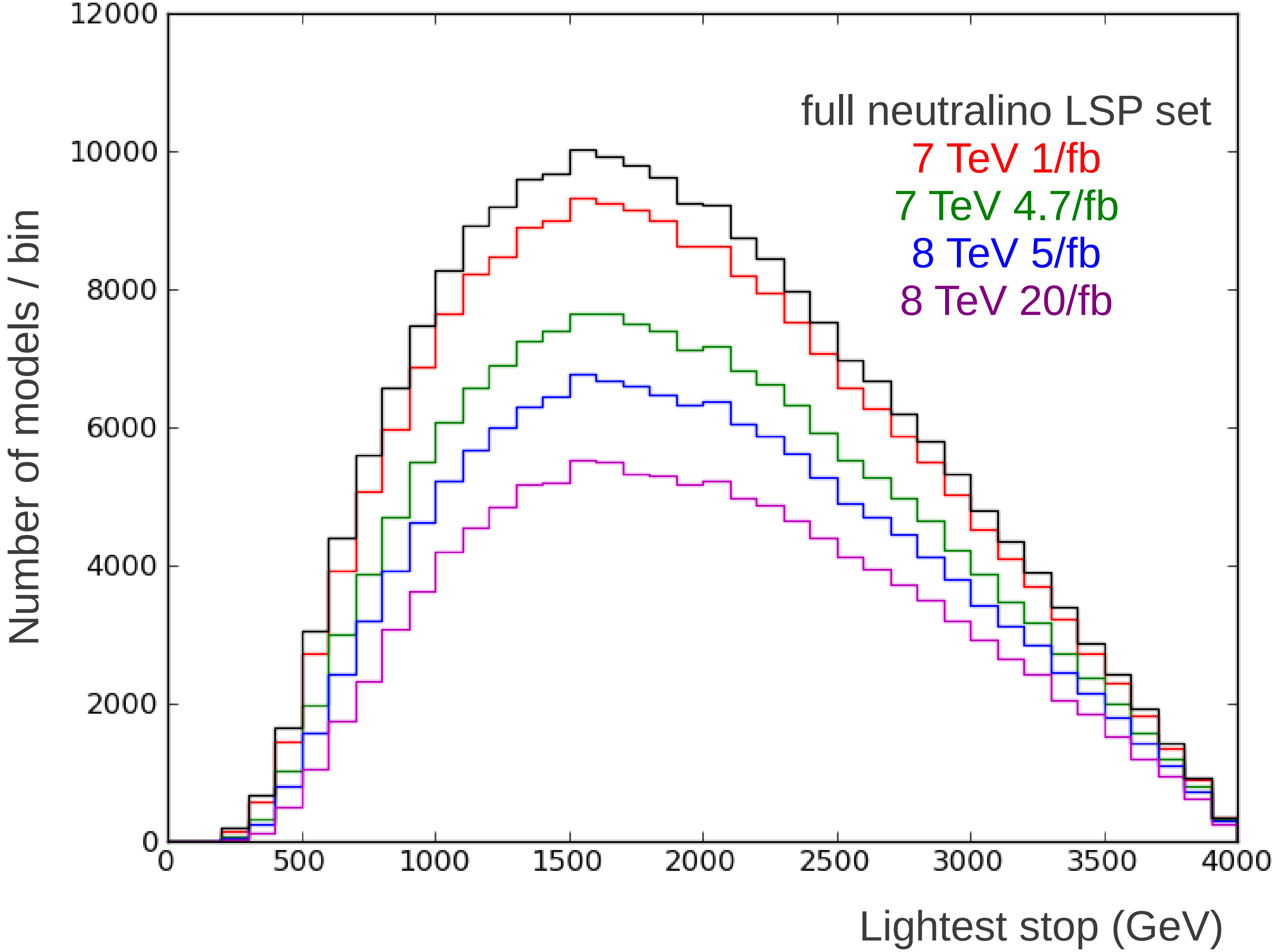
Model set generation

- Generate spectra for $3 \cdot 10^6$ ($7 \cdot 10^5$) points in 19 (20) dimensional pMSSM parameter space with SOFTSUSY, compare with SuSpect, decay with SDECAY/HDECAY/MadGraph/CalcHEP
- Throw away models with tachyons, color/charge breaking minima, unbounded scalar potentials
- Require lightest neutralino (gravitino) to be LSP, and impose upper bound on its thermal relic density (scaled NLSP relic density)
- Check against DM direct detection (cosmology), precision, and flavor measurements
- All charged sparticles > 100 GeV
- Impose LHC stable particle, $\phi \to \tau\tau$ constraints as of 12/2011
- $2 \cdot 10^5$ models left in each set

ATLAS MET searches

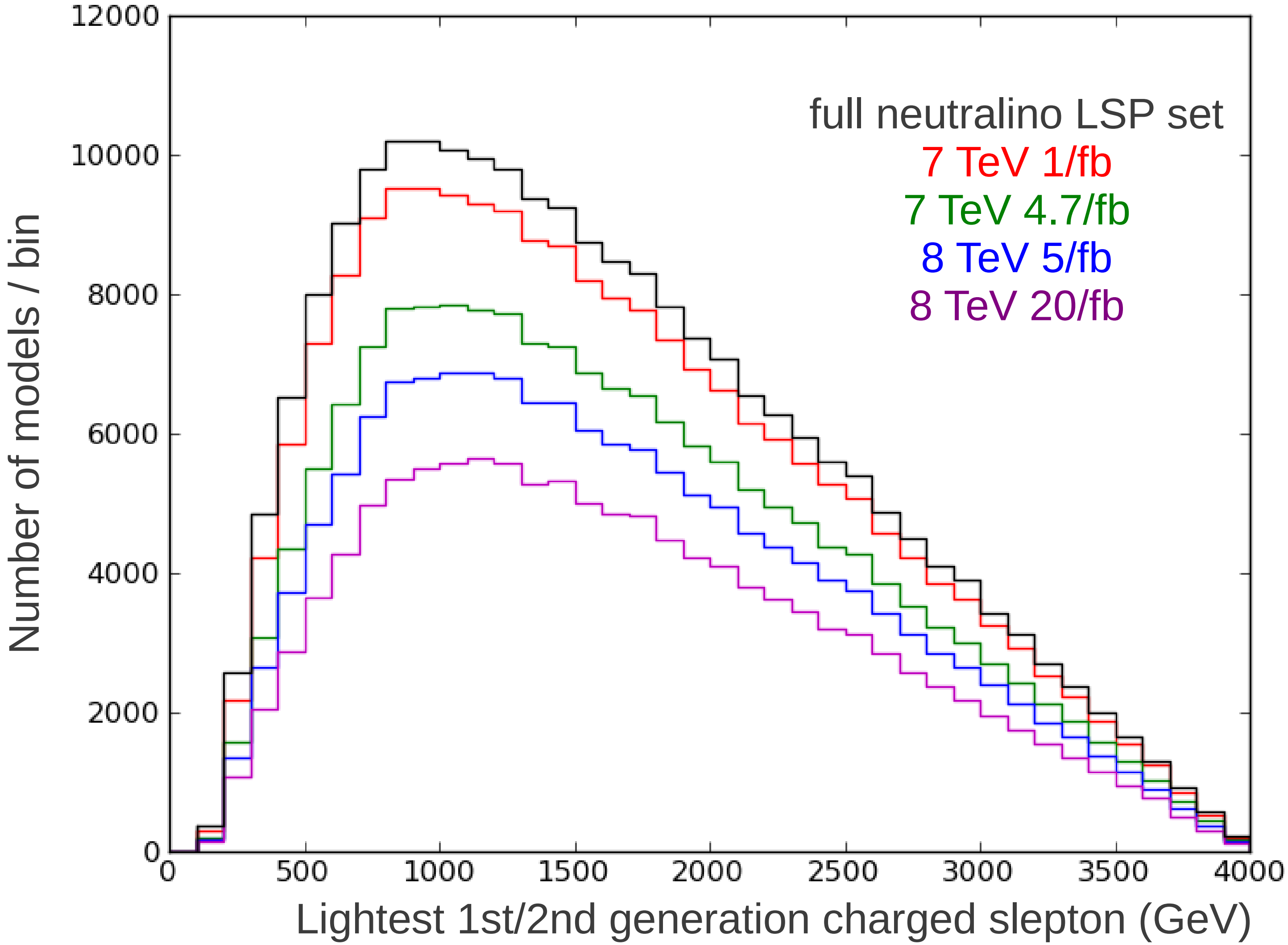


ATLAS MET searches



searches involving b-jets will constrain light 3rd generation squarks

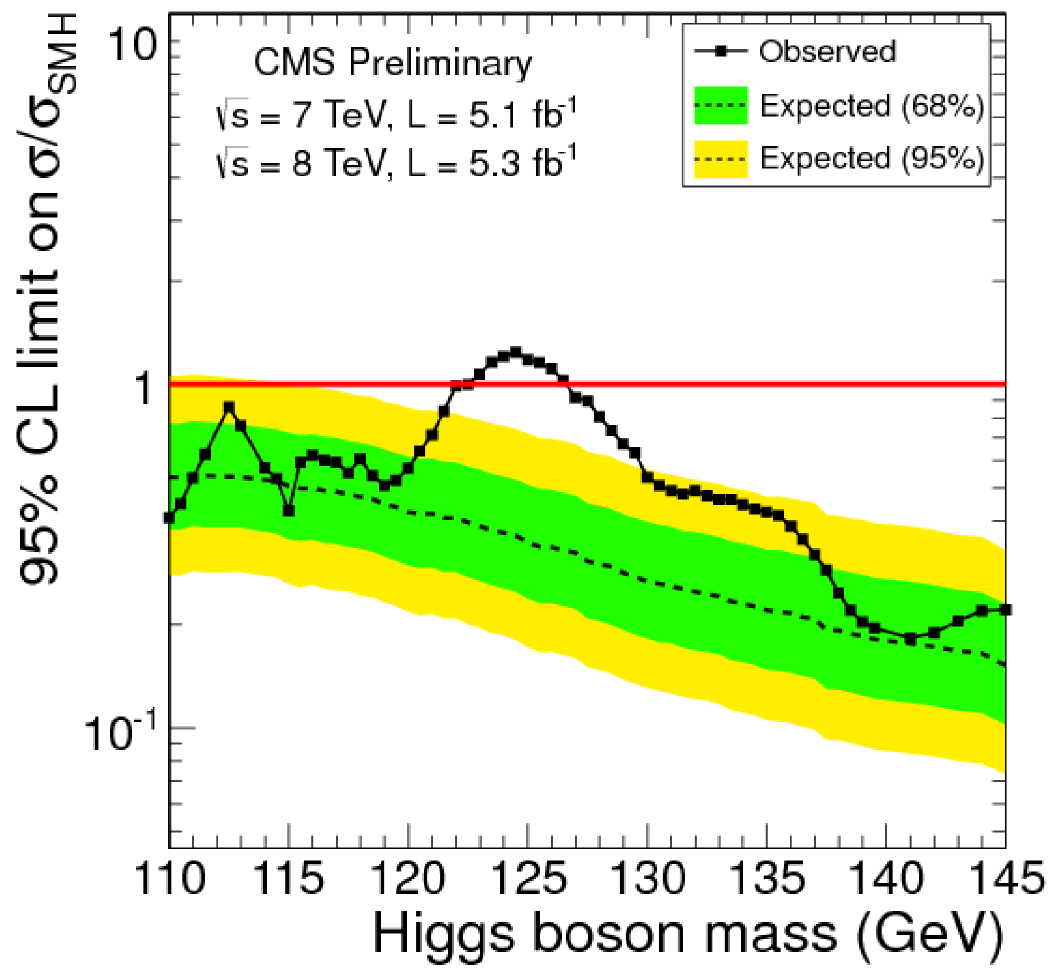
ATLAS MET searches



still room for light uncolored sparticles

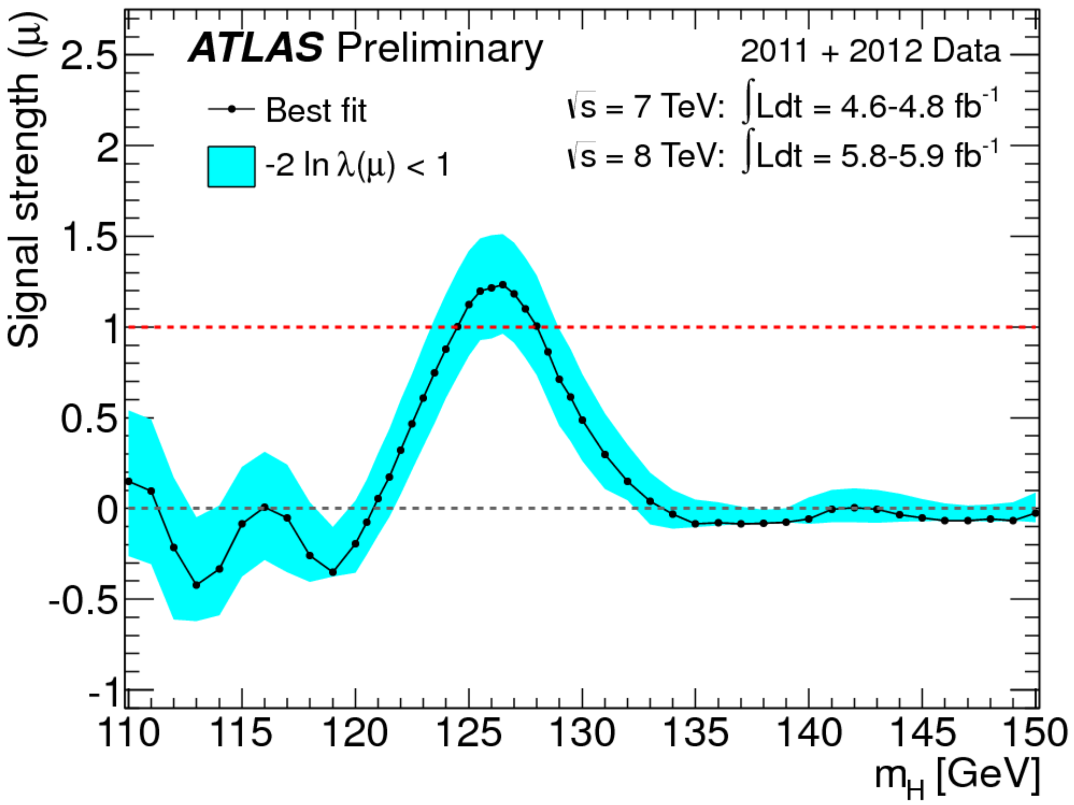
A 125 GeV Higgs

- Higgs-like particle seen near 125 GeV by both ATLAS and CMS
- Greatest significance obtained from diphoton channel
- Can we easily obtain such a Higgs in the pMSSM?

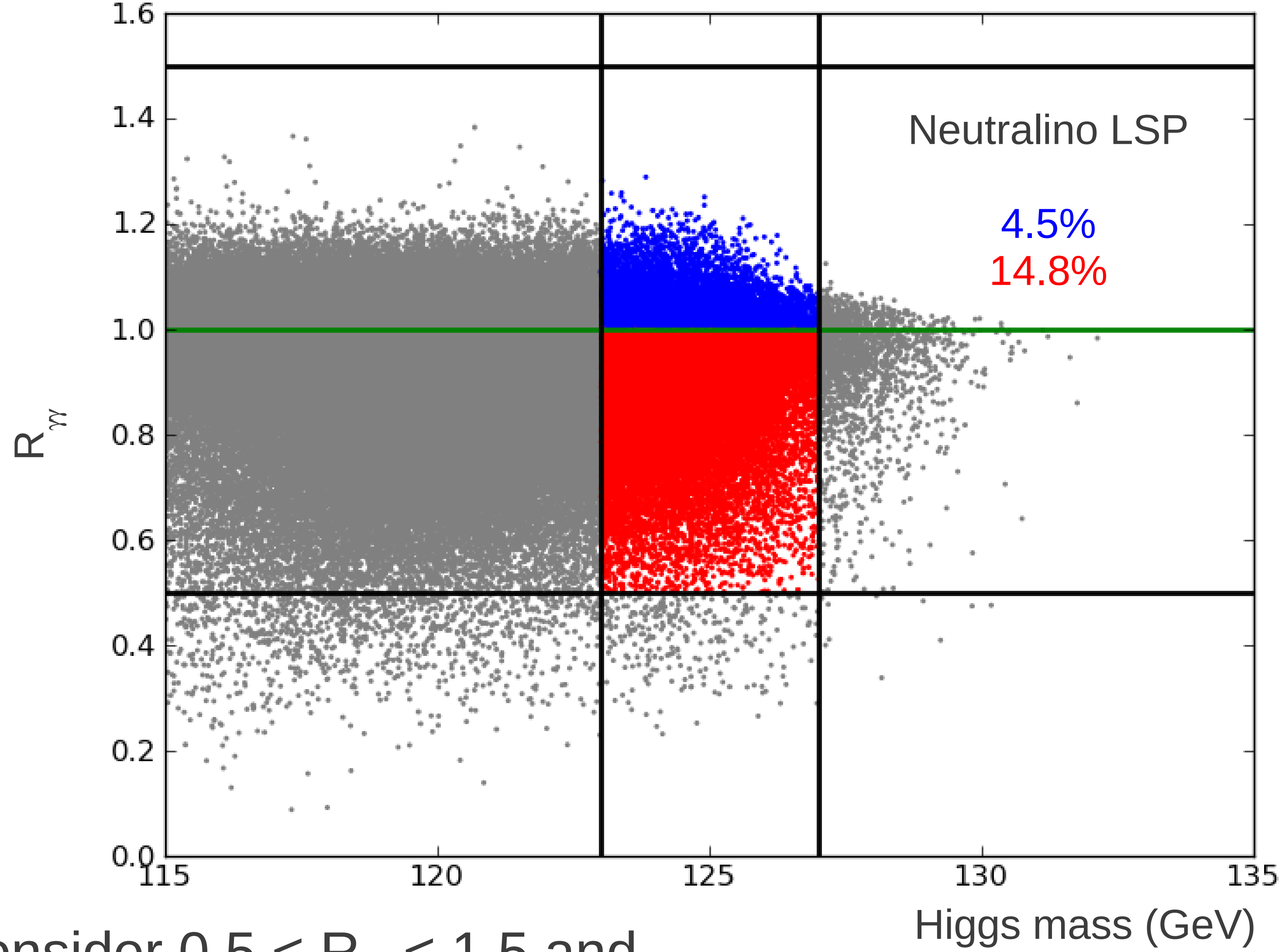


A 125 GeV Higgs

- We calculate $\sigma(gg \to h \to \gamma\gamma)_{\text{pMSSM/SM}}$ in the narrow width approximation and call the ratio $R_{\gamma\gamma}$
- Can do same for any other mode $h \to XX$ to obtain R_{XX}



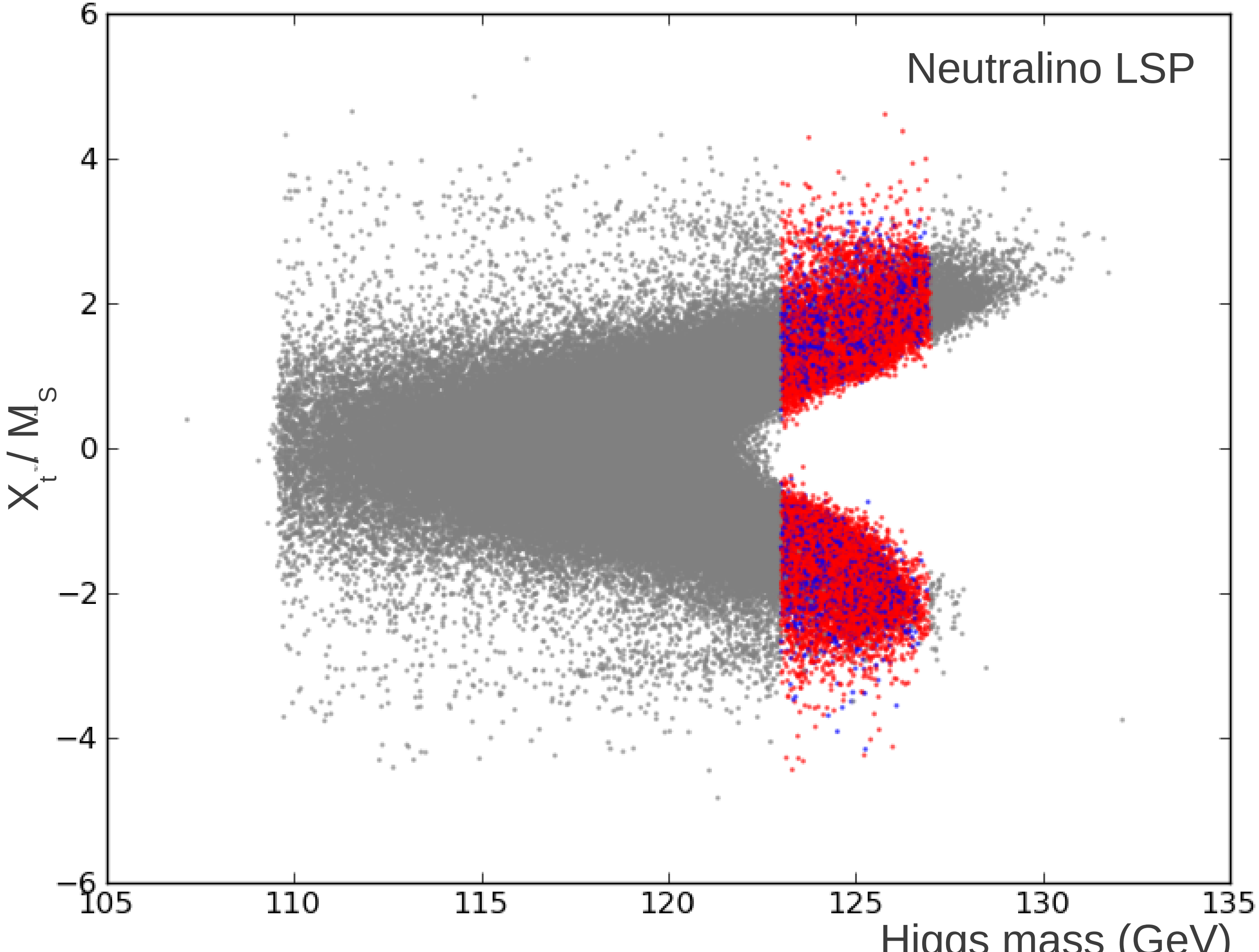
$h \to \gamma\gamma$ in the pMSSM



We consider $0.5 < R_{\gamma\gamma} < 1.5$ and

$123 \text{ GeV} < m_h < 127 \text{ GeV}$

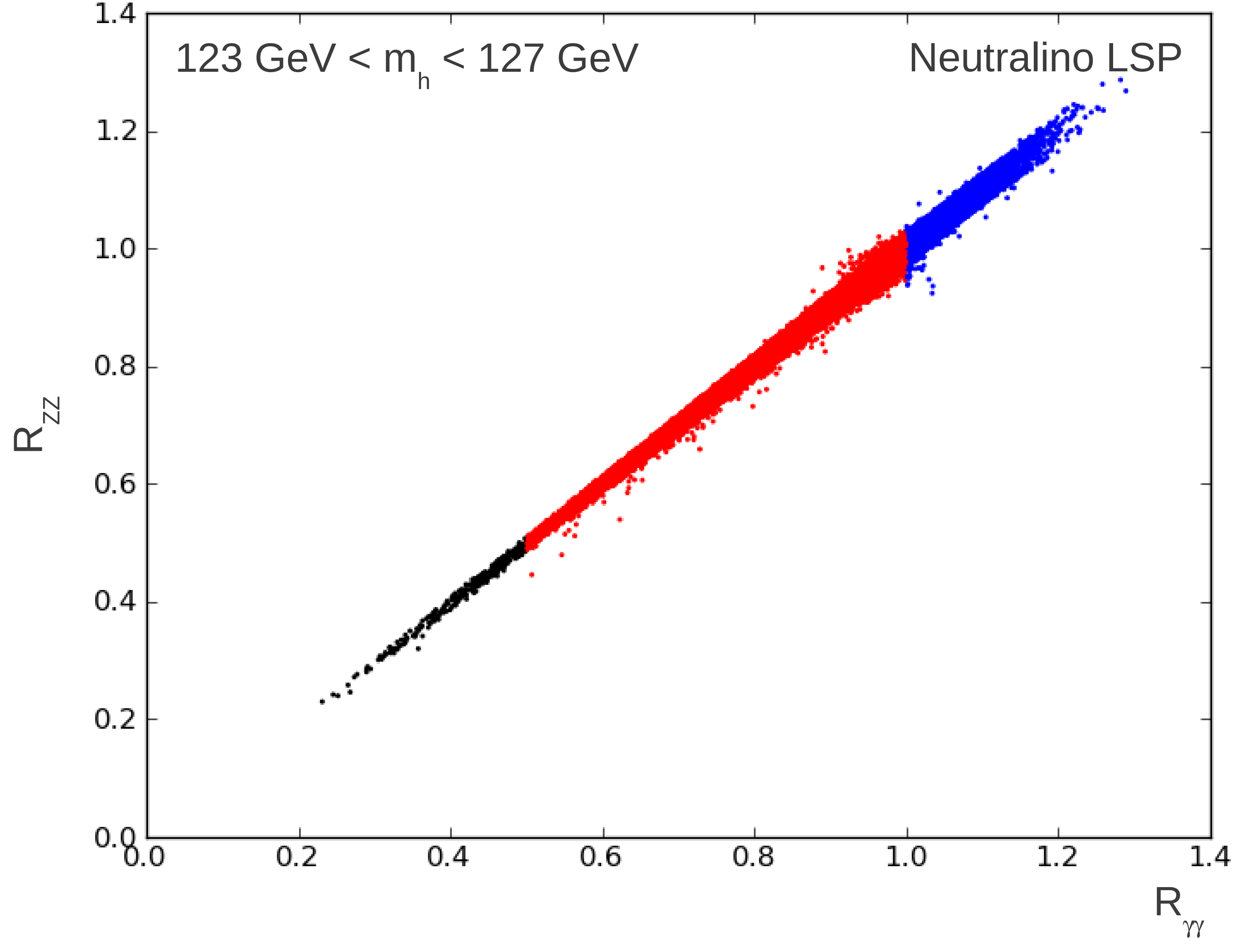
A 125 GeV Higgs



To get heavy Higgs, need large stop mixing $X_t = A_t - \mu \cot \beta$

Maximal mixing when $X_t = \sqrt{6}\, m_t$

125 GeV Higgs at the LHC

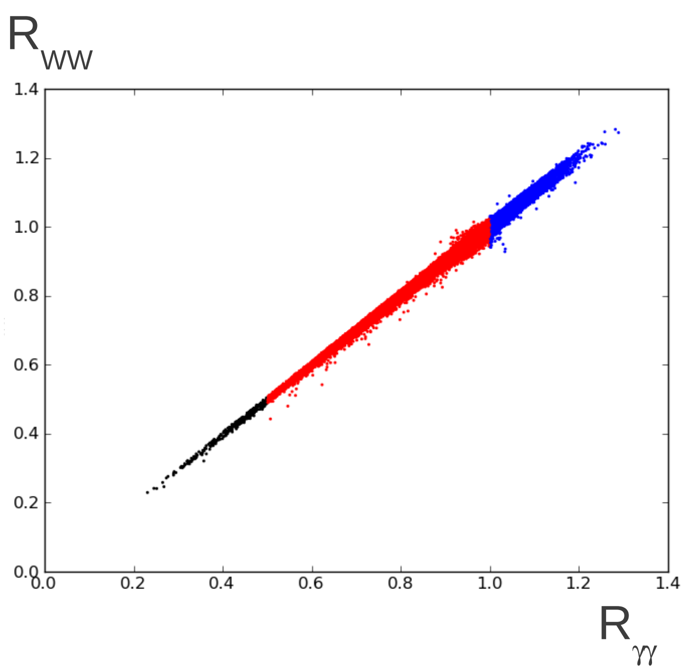


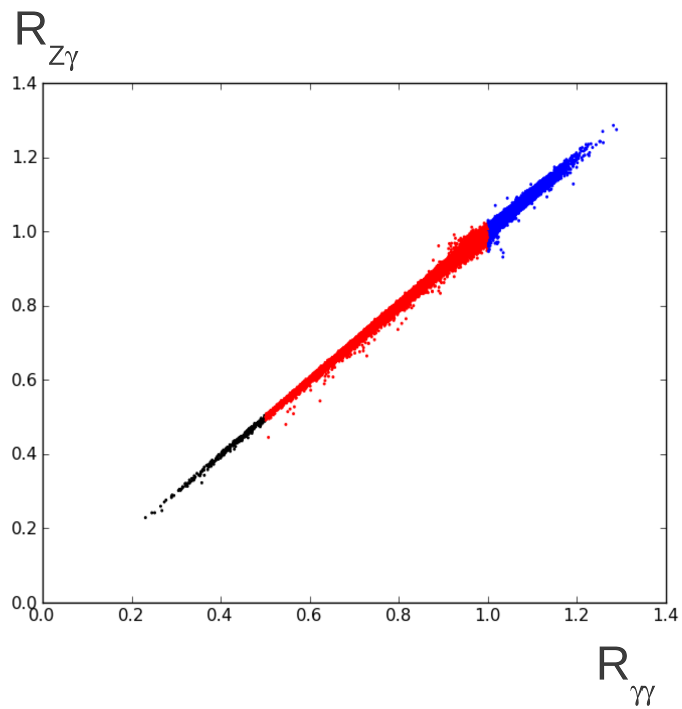
Numbers of h → γγ events, h → ZZ events correlated!
Happens because all models are ~decoupled

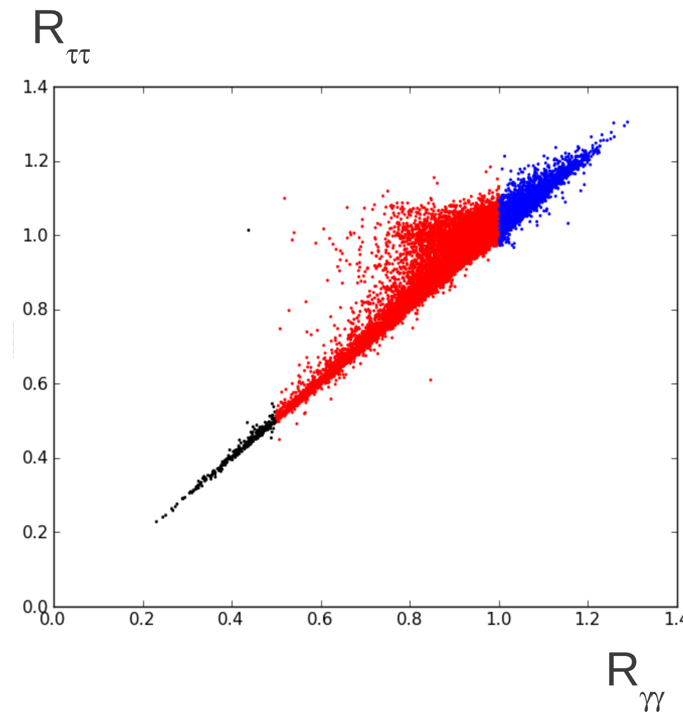
125 GeV Higgs at the LHC

Neutralino LSP

123 GeV < m_h < 127 GeV

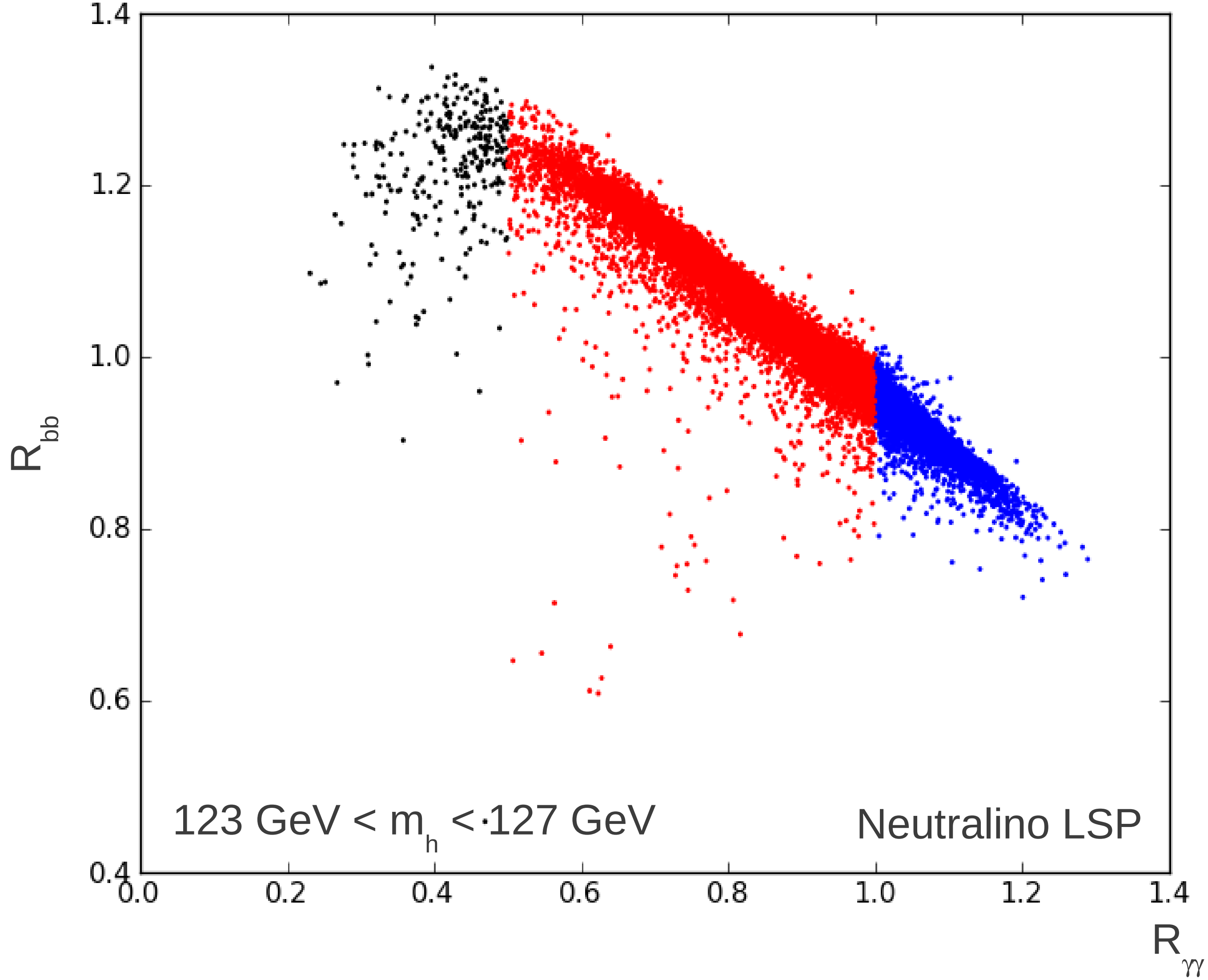






Other modes behave the same way because of decoupling

125 GeV Higgs at the LHC



bb production is anti-correlated with other decay modes

Fine-tuning

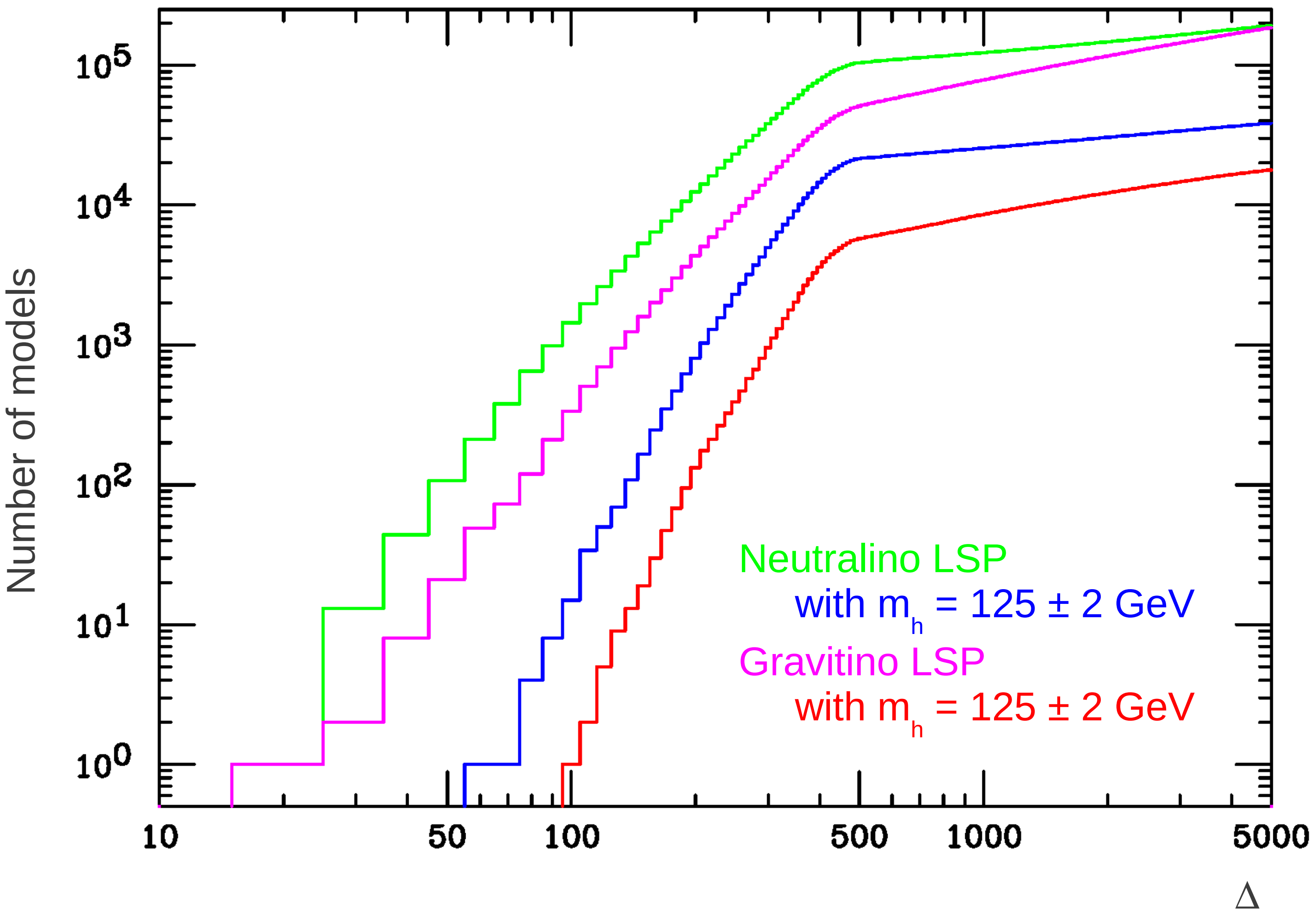
- Measure sensitivity of electroweak symmetry breaking scale to each pMSSM parameter p_i

  Barbieri and Giudice, Nucl.Phys. B306 (1988) 63

$$m_Z^2 = \frac{|m_{H_d}^2 - m_{H_u}^2|}{\sqrt{1-\sin^2(2\beta)}} - m_{H_u}^2 - m_{H_d}^2 - 2|\mu|^2$$

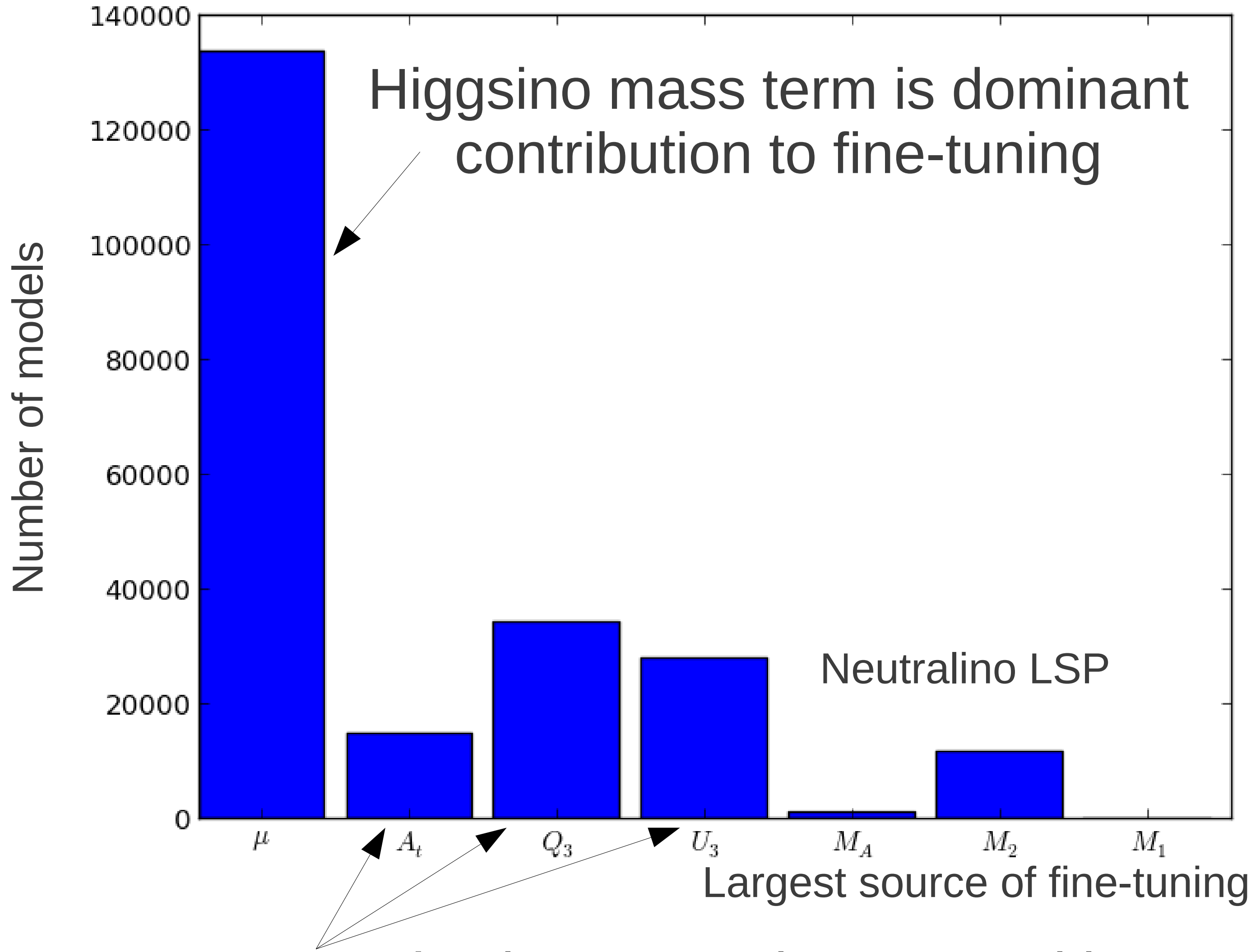
- $A_i = \partial(\log M_Z^2) / \partial(\log p_i)$, $1 \le i \le 19$
- Most sensitive to μ and stop mass parameters, but gluino mass enters at higher order
- Take maximum of all A_i to get fine-tuning Δ

Fine-tuning



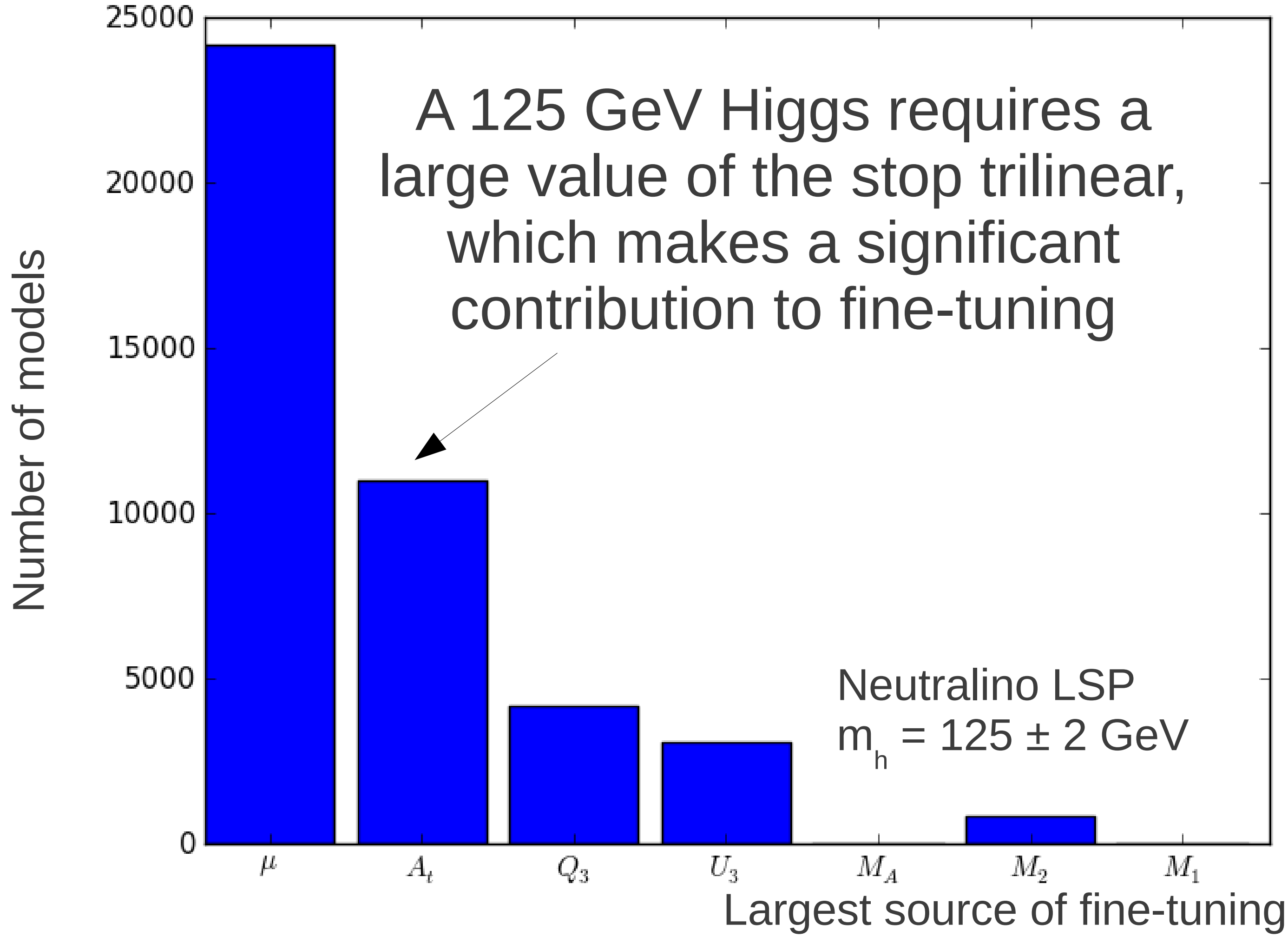
models with Higgs near 125 GeV
are more fine-tuned

Sources of fine-tuning



Stop mass terms also important, but even with strong coupling, loop-induced gluino contribution is less than wino FT

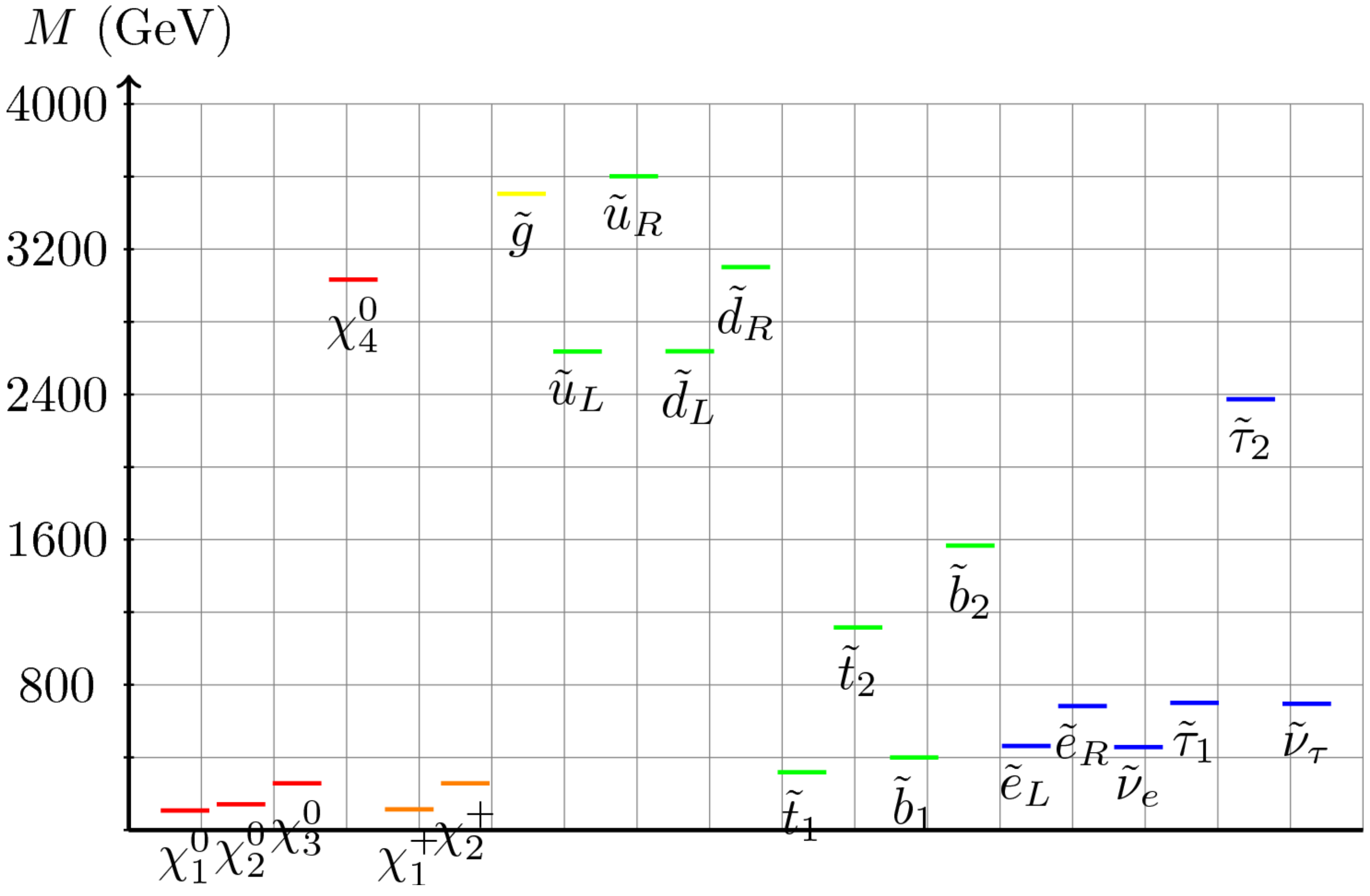
Sources of fine-tuning



Features of models with low FT

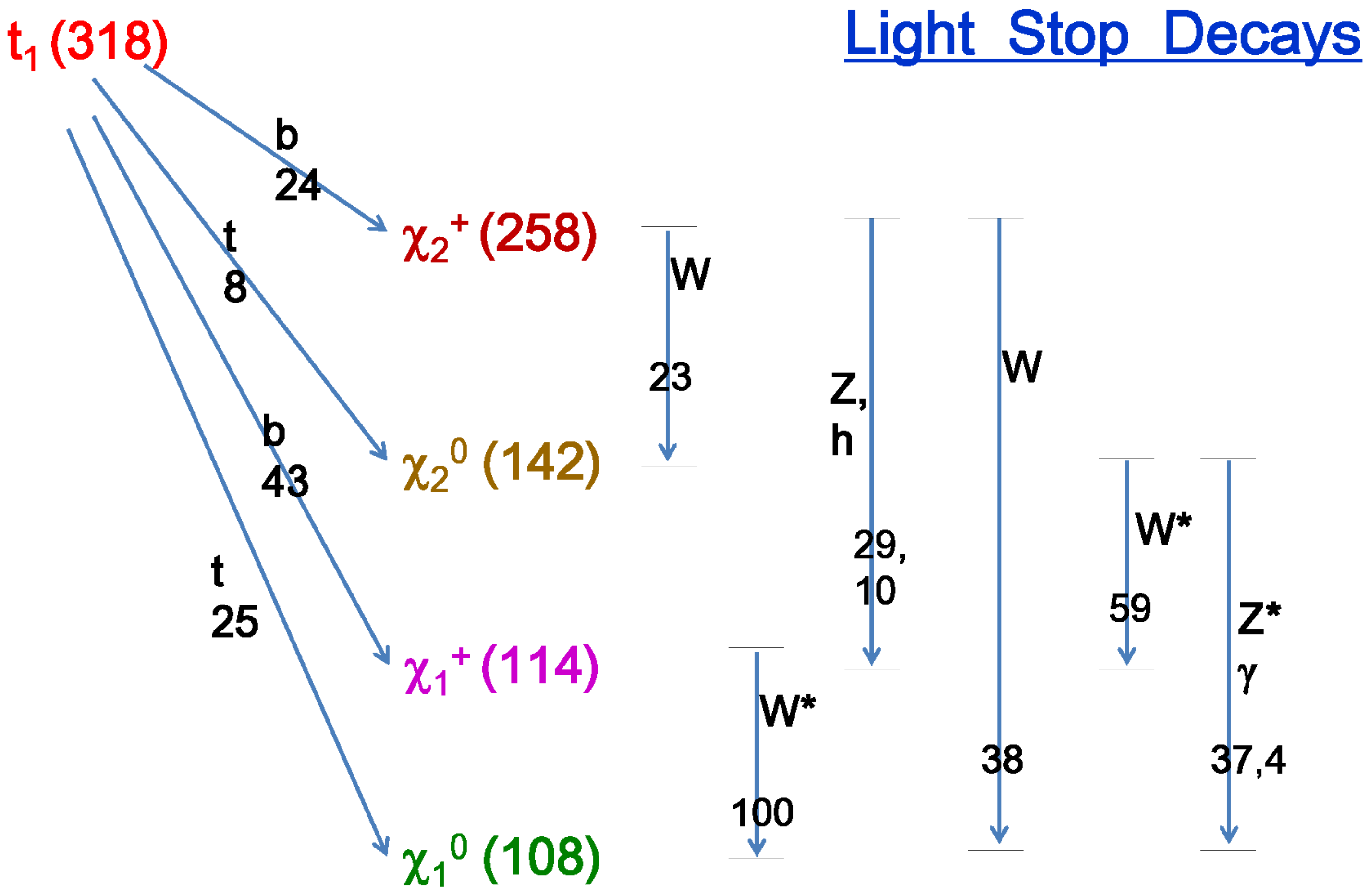
- Look at models with $\Delta < 100$, Higgs near 125 GeV, and passing all existing constraints
- 13 (0) such models in neutralino (gravitino) LSP model set; 33 (5) for $\Delta < 120$
- Light higgsinos, usually light winos
- Light 3rd generation squarks, heavy 1st/2nd generation squarks
- Gluino is not really constrained at this level of fine-tuning

Sample spectrum

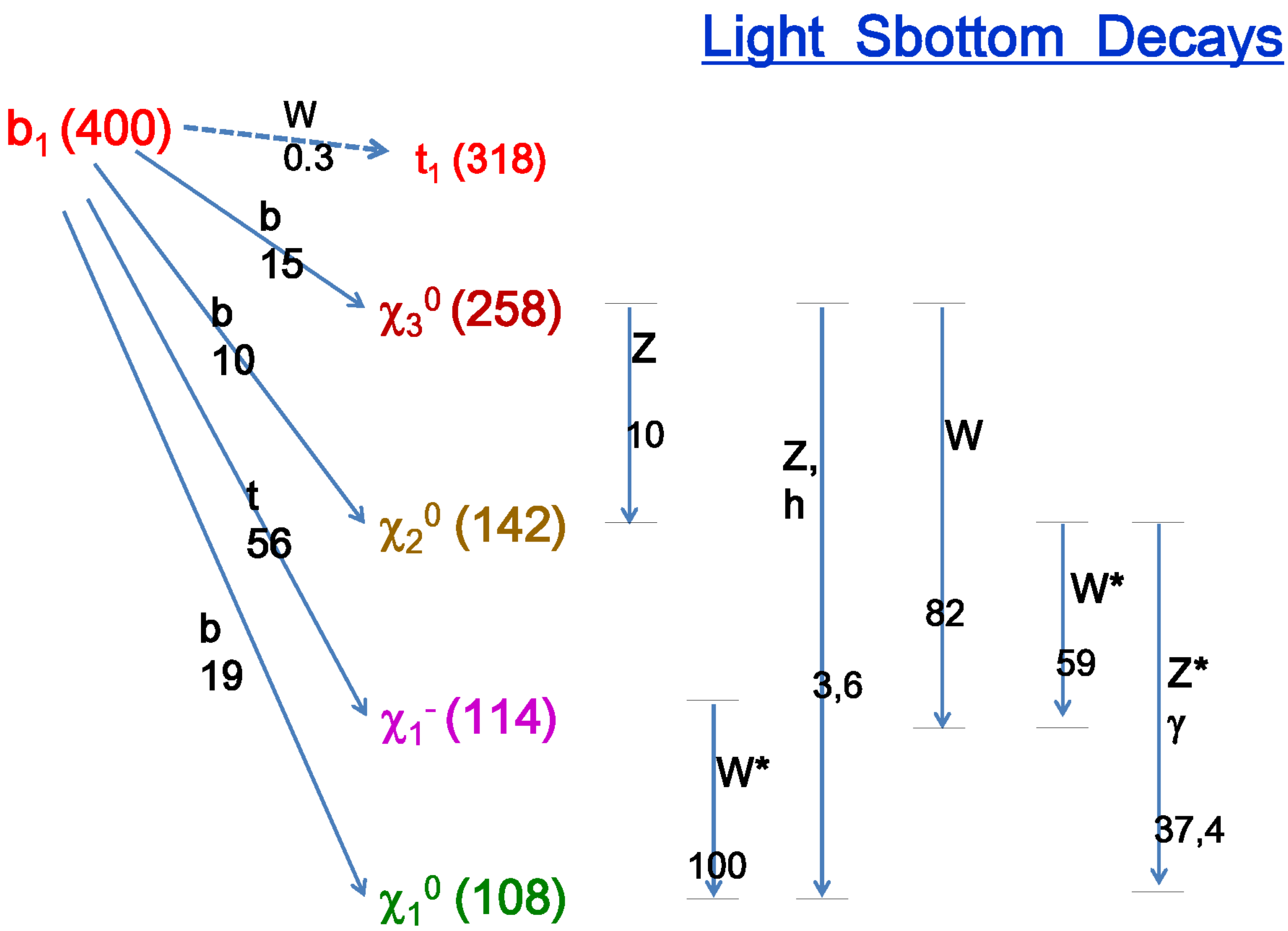


Many possible cascades for light stops and sbottoms

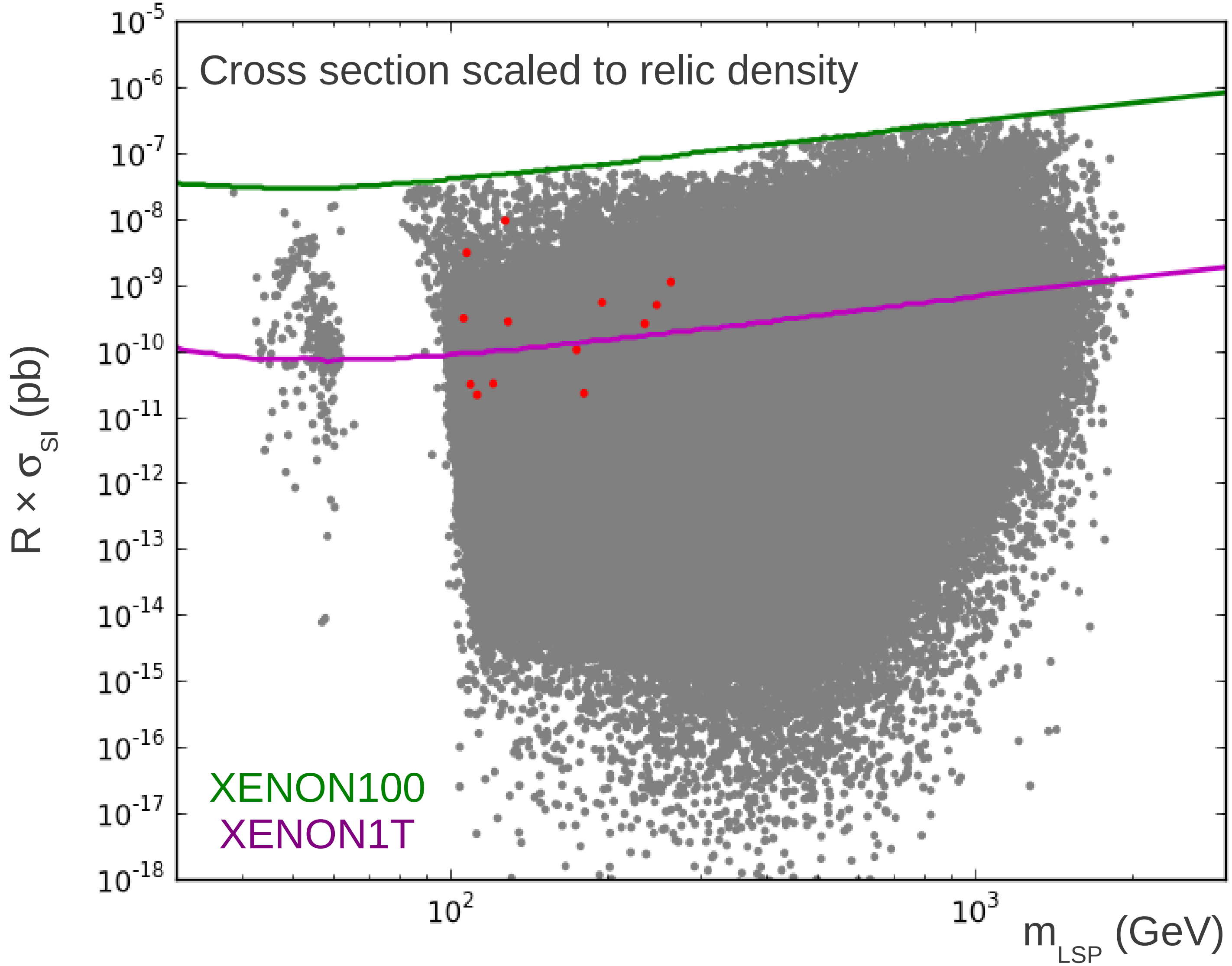
Sample spectrum



Sample spectrum



Features of models with low FT



Low FT models will be probed by upcoming XENON results

Outlook

- The pMSSM allows us to investigate complete, realistic supersymmetric spectra at the LHC and beyond
- 125 GeV Higgs production cross sections vary depending on final state, and are sensitive to hbb coupling
- Light stops in viable low FT models are generically hard to see due to higgsino cascades; to be probed eventually by direct detection, but good to see new search strategies being developed for LHC

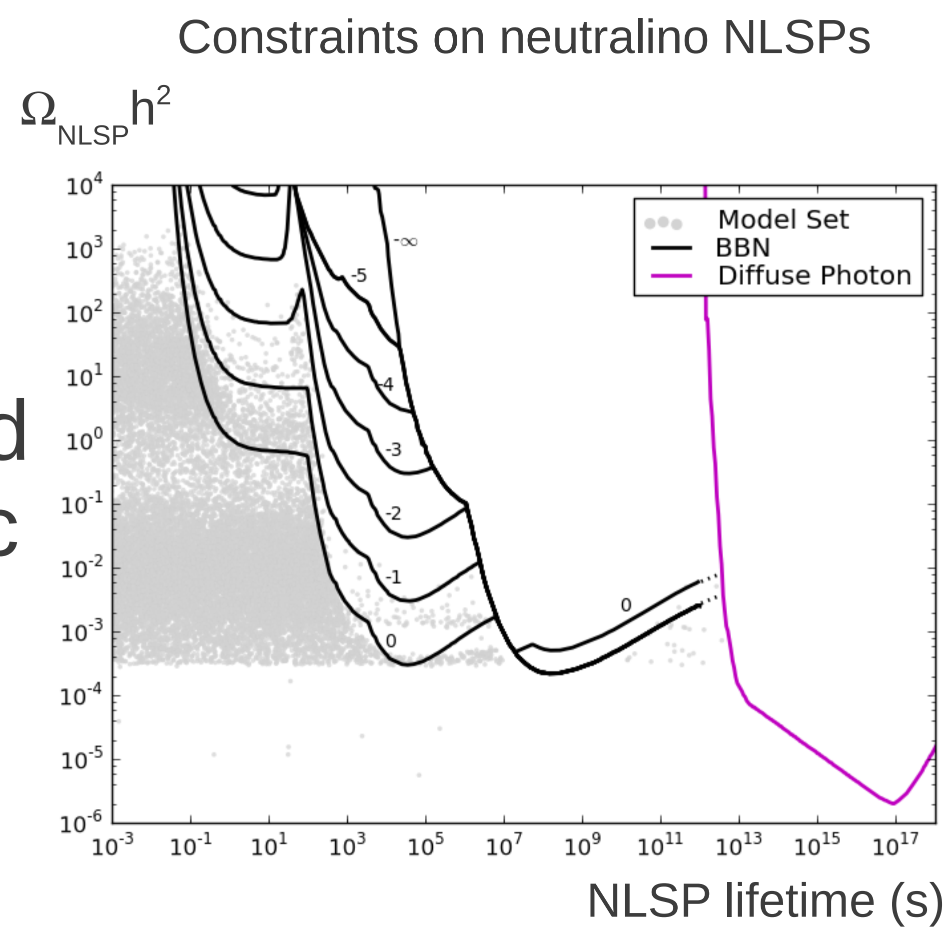
Backup

Gravitino LSP cosmology

- No assumptions about early universe gravitino cosmology, e.g. reheating temperature or entropy production
- NLSP freezes out later
- Assume NLSP reaches its thermal relic density, and consider out-of-equilibrium decays to gravitino
- Gravitino LSP has very weak couplings, so no dark matter detection constraints
- However, for a gravitino LSP, the NLSP can be very long-lived

Gravitino LSP cosmology

- NLSP lifetimes between 10^{-2} and 10^{5} s can affect BBN if decay products are hadronic
- For lifetimes from 10^{5} s to 10^{12} s, BBN is affected even for electromagnetic energy injection
- Diffuse photon constraints become applicable for longer lifetimes

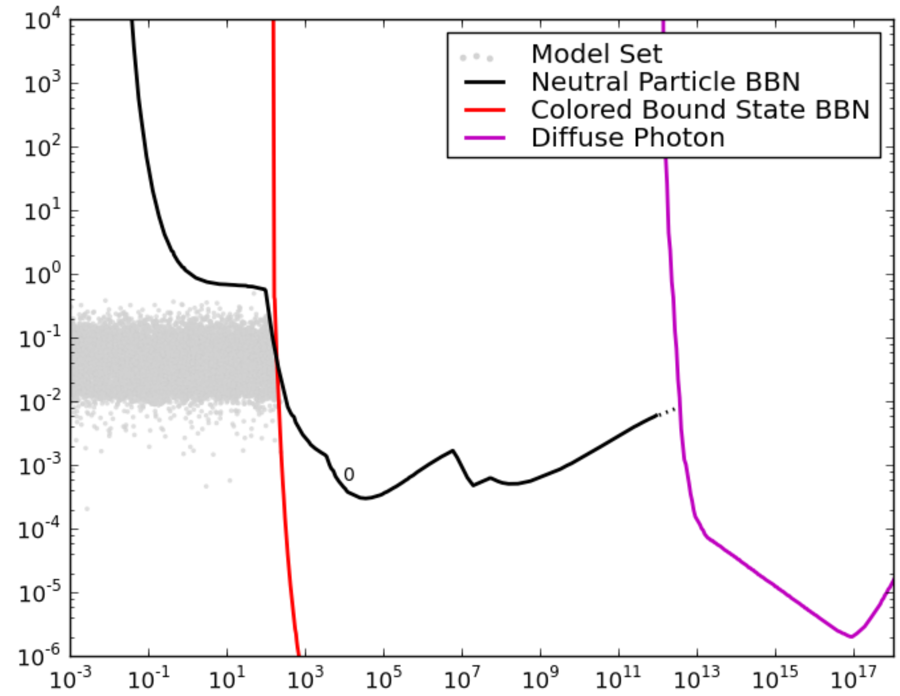


Gravitino LSP cosmology

- Charged NLSPs living longer than 10^3 s can form bound states, modifying the rates of nuclear reactions and affecting BBN
- Colored NLSPs form bound states even earlier; any such NLSPs living longer than ~200 s ruin BBN

Constraints on colored NLSPs

$\Omega_{NLSP}h^2$

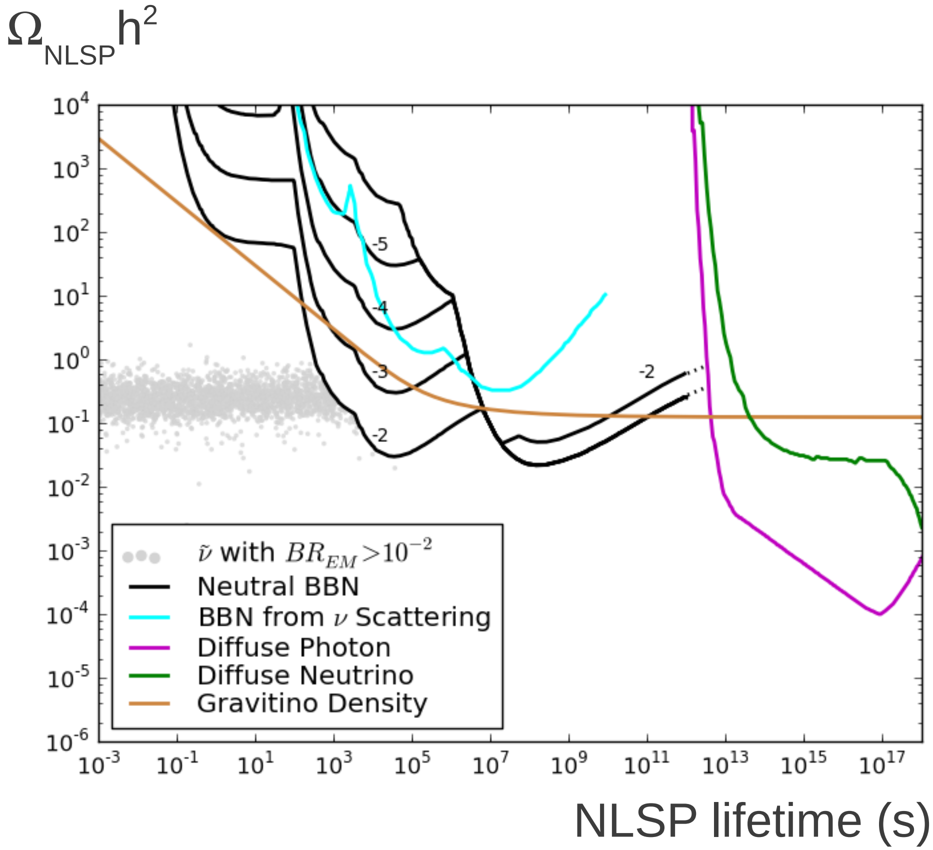


NLSP lifetime (s)

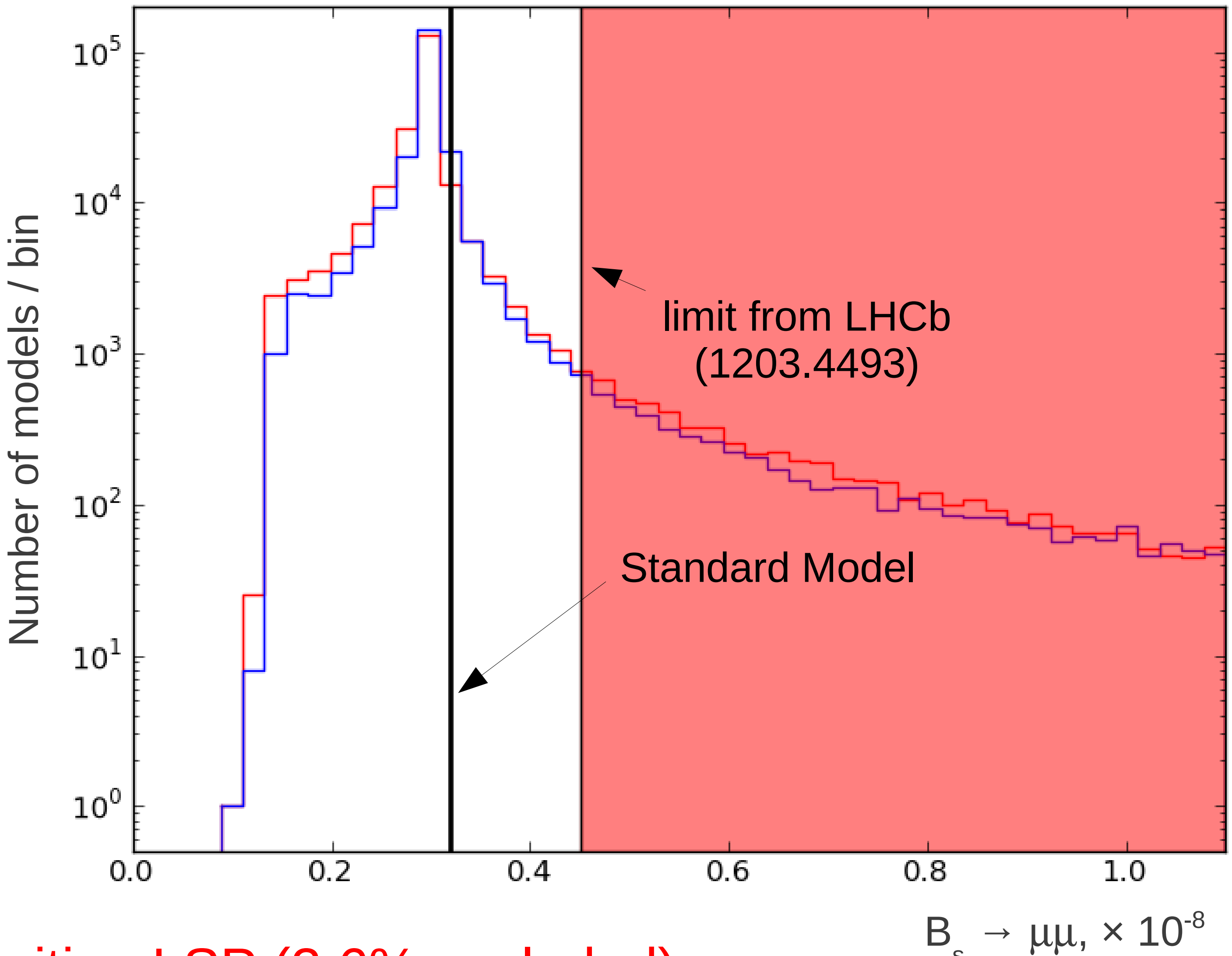
Gravitino LSP cosmology

- Sneutrino NLSPs have small branching ratios for decays that produce visible SM particles
- Neutrinos resulting from sneutrino NLSP decays can also scatter off leptons, giving leptons/mesons that affect BBN
- Diffuse photon/neutrino flux for longer lifetimes

Constraints on sneutrino NLSPs

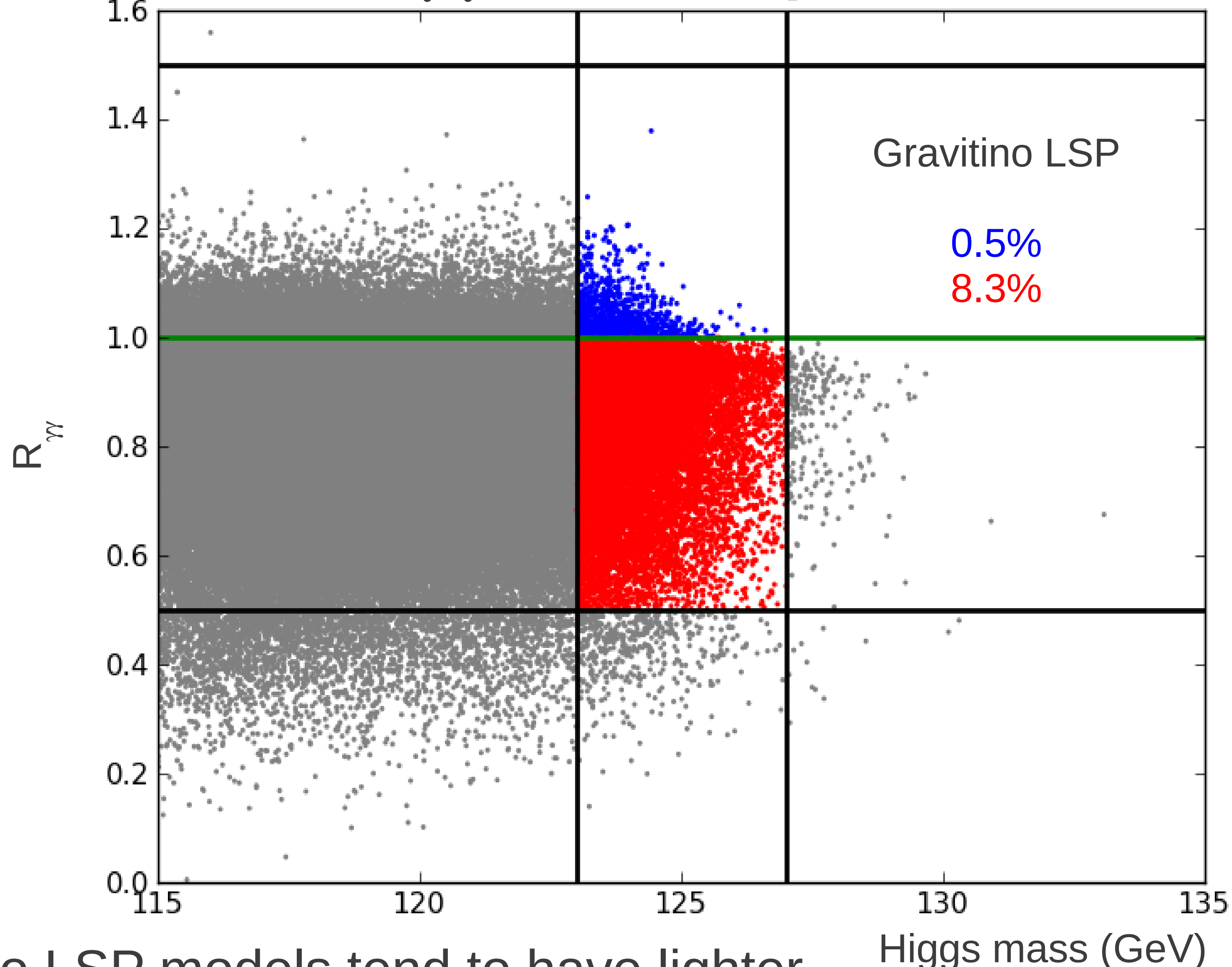


Non-MET searches



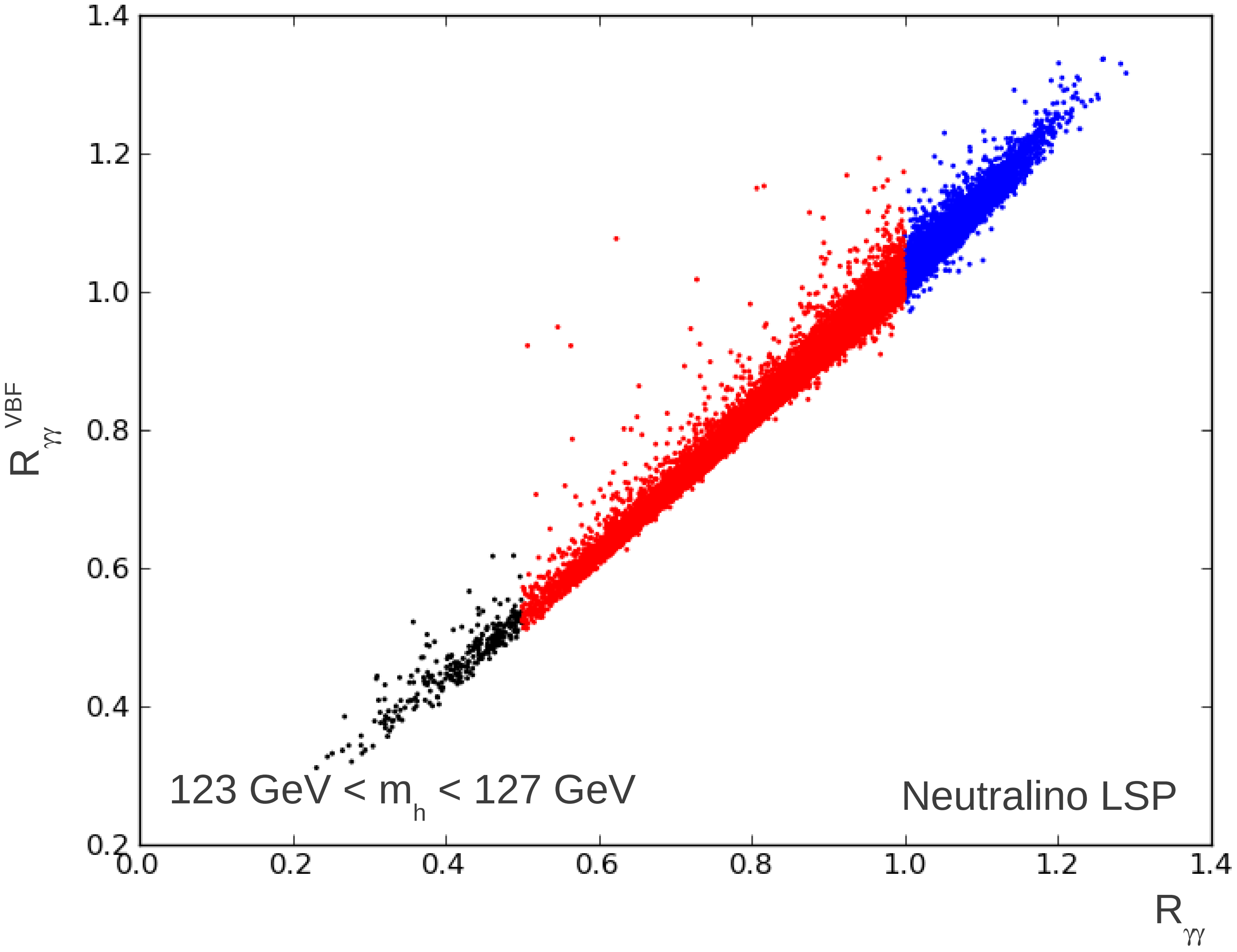
gravitino LSP (2.6% excluded)
neutralino LSP (2.2% excluded)

h → γγ in the pMSSM



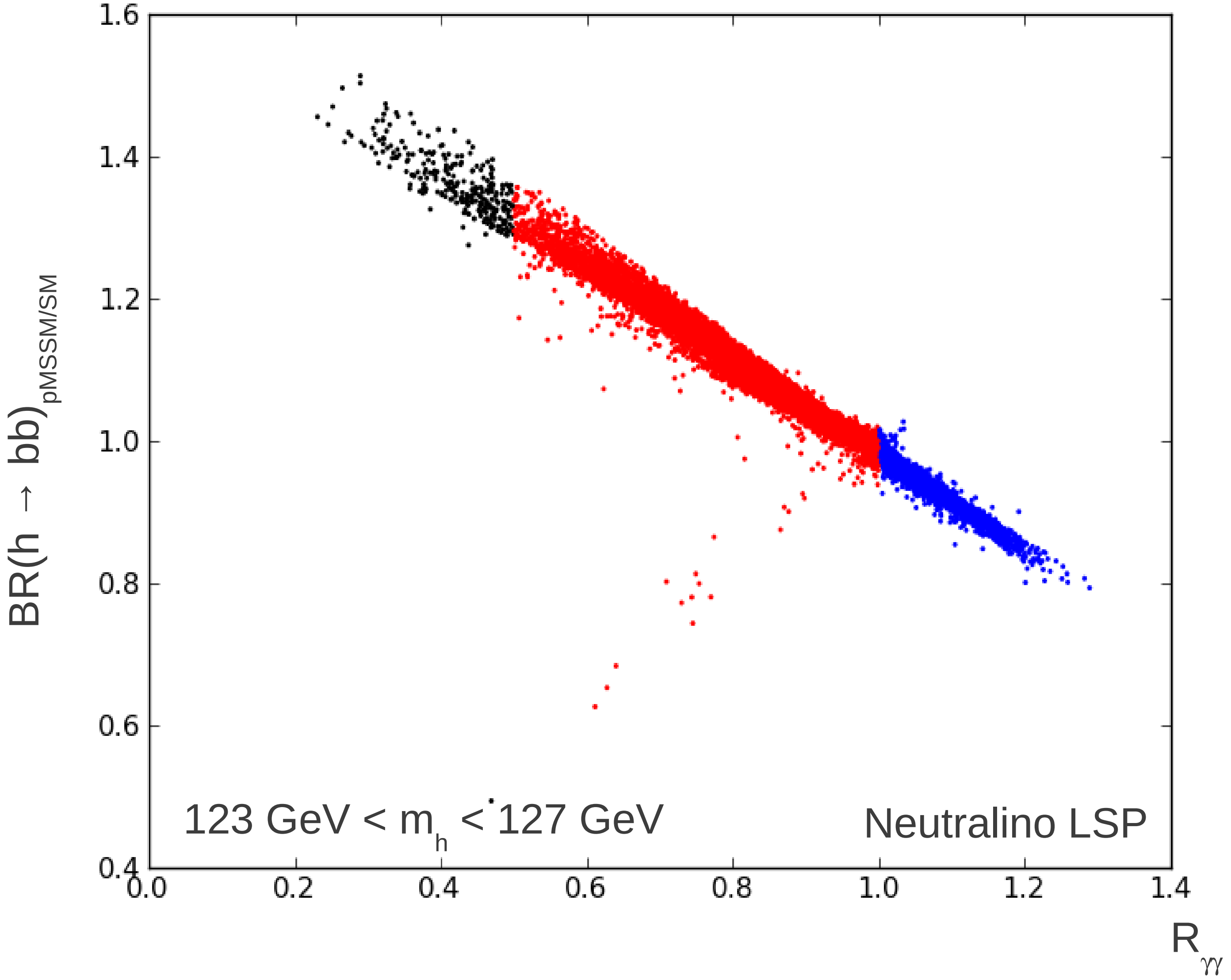
Gravitino LSP models tend to have lighter Higgses, but 125 GeV still quite viable

125 GeV Higgs at the LHC



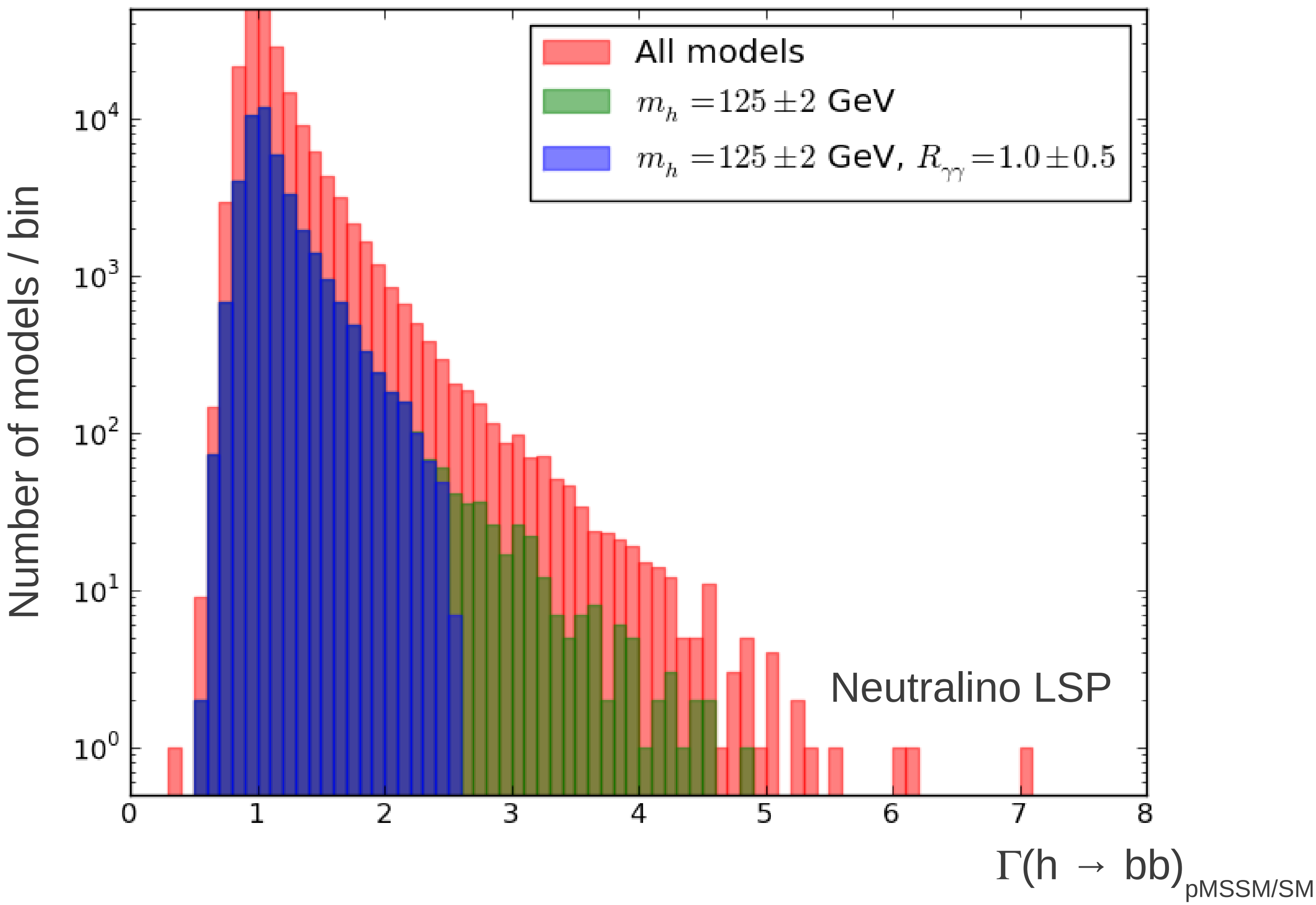
Can also look at vector boson fusion production WW → h → γγ

125 GeV Higgs at the LHC



BR for h → bb is anticorrelated with expected γγ production

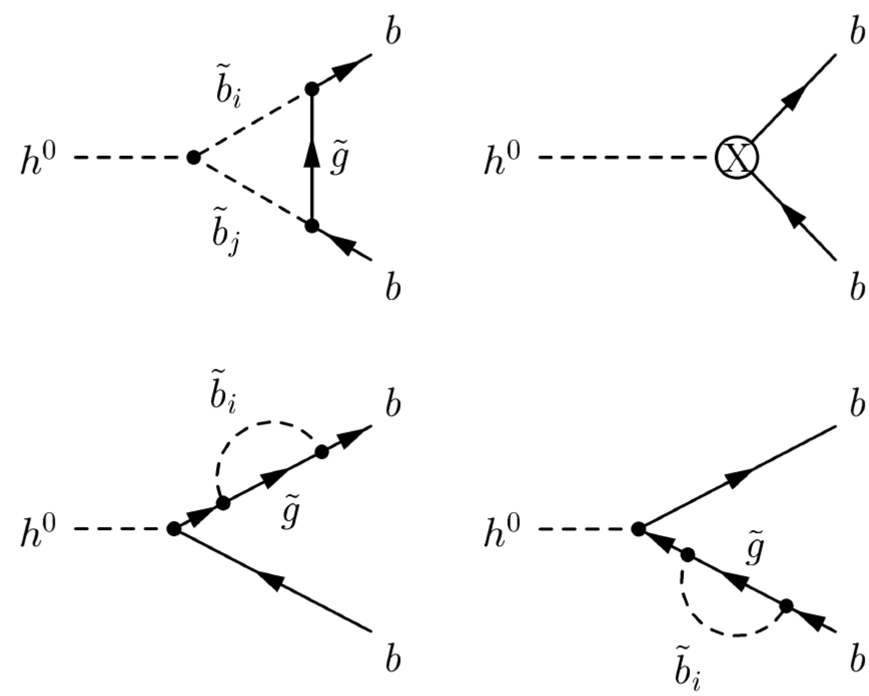
125 GeV Higgs at the LHC



SUSY corrections to bb width reduce other branching ratios!

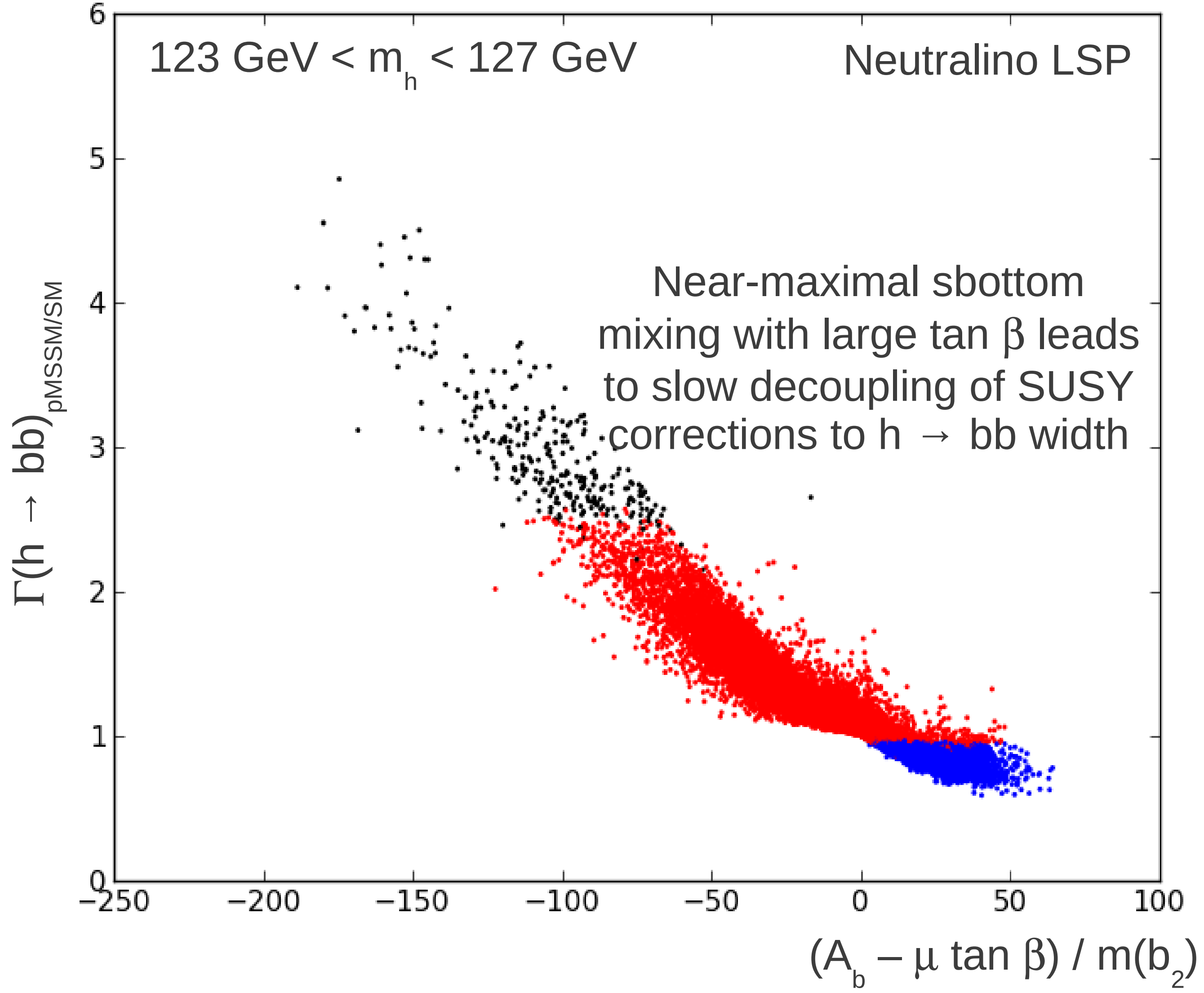
$h \rightarrow bb$ decoupling

- $\Gamma = \Gamma_0(1 + 2\ \delta g^{QCD} / g + 2\ \delta g^{SQCD} / g)$
- In certain limits, the SUSY corrections decouple very slowly, and can remain large for heavy sparticles
- These corrections push up bb width, decreasing all other BR accordingly

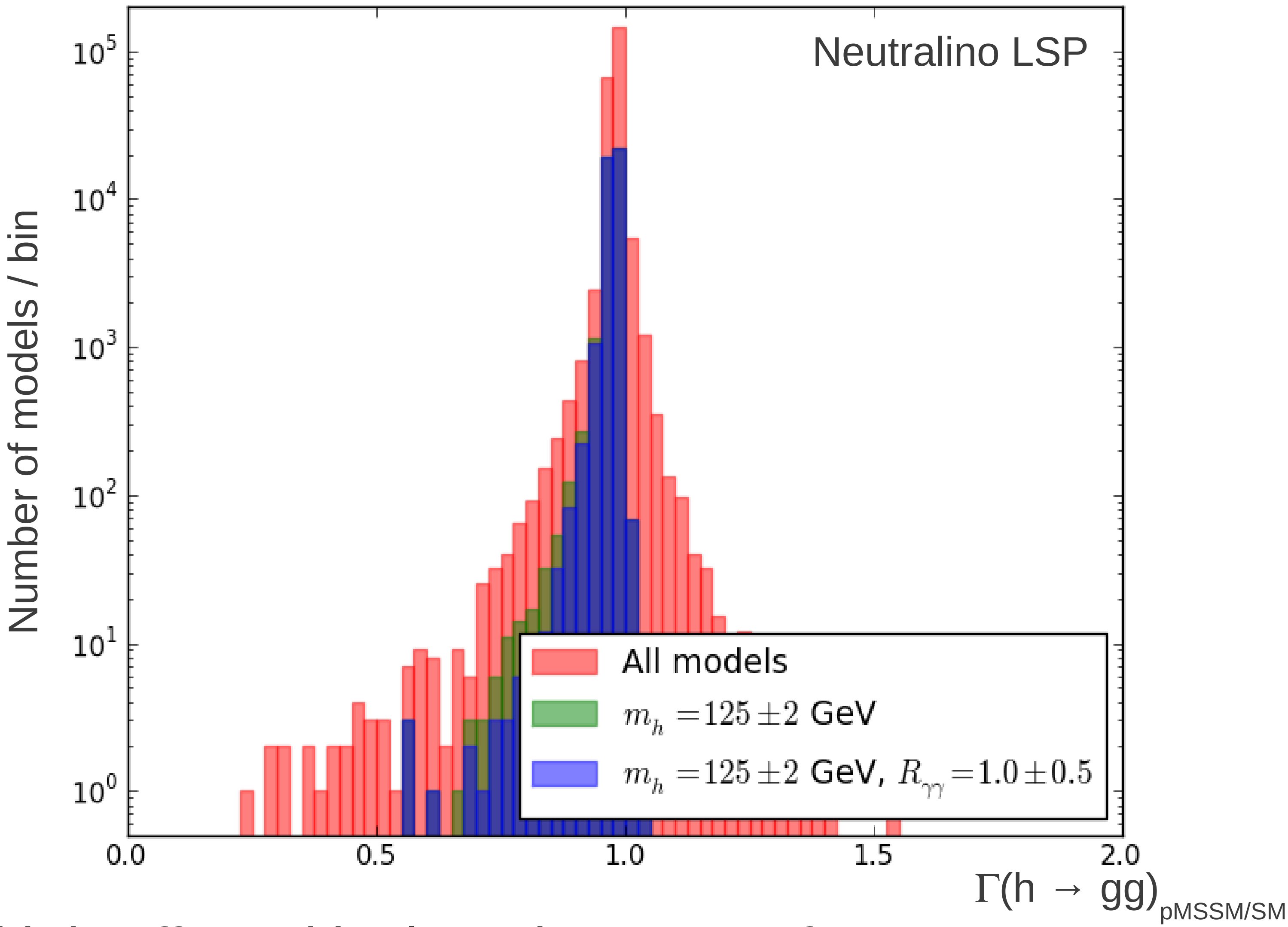


Haber et al., hep-ph/0007006

h → bb decoupling

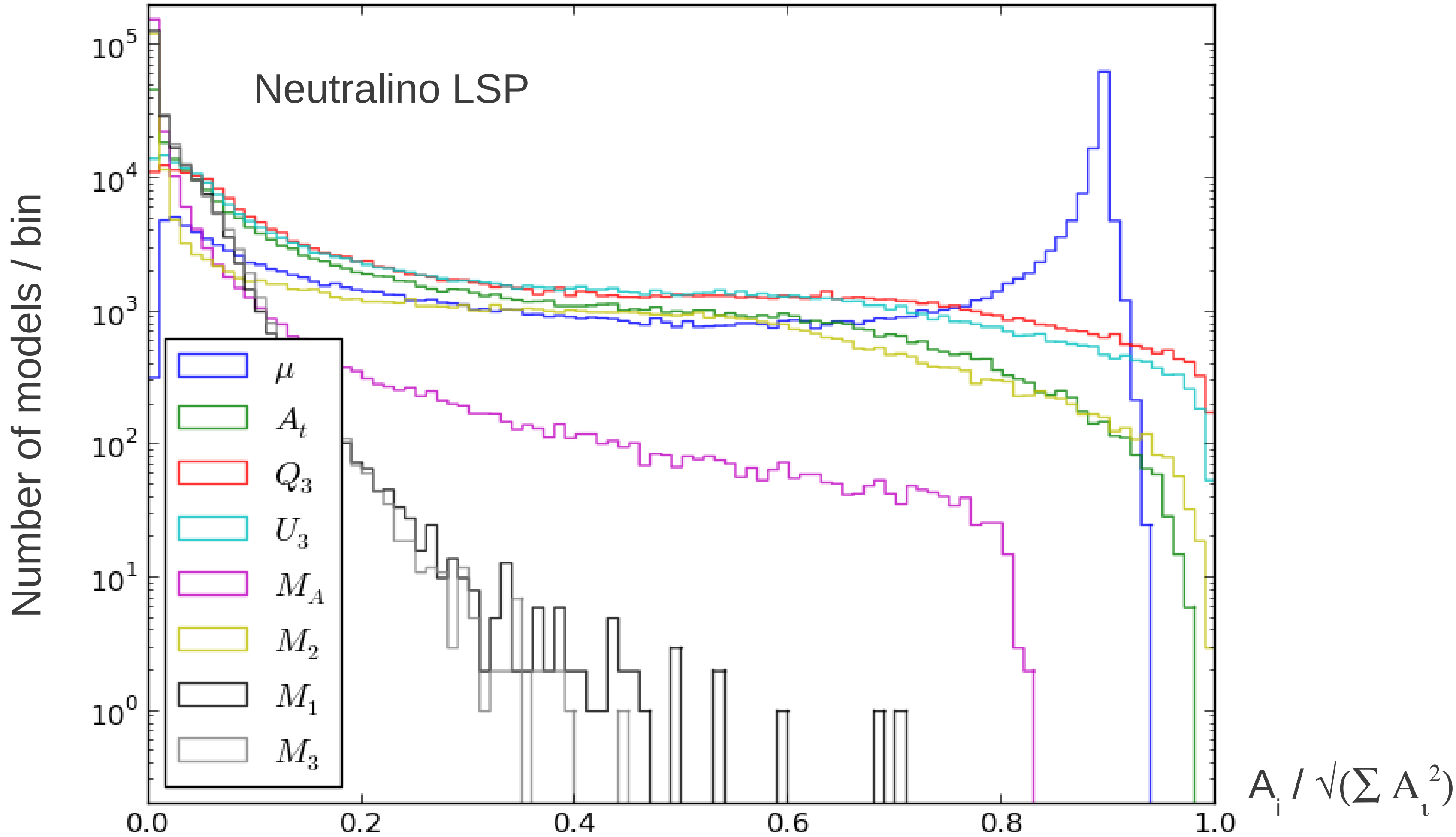


125 GeV Higgs at the LHC



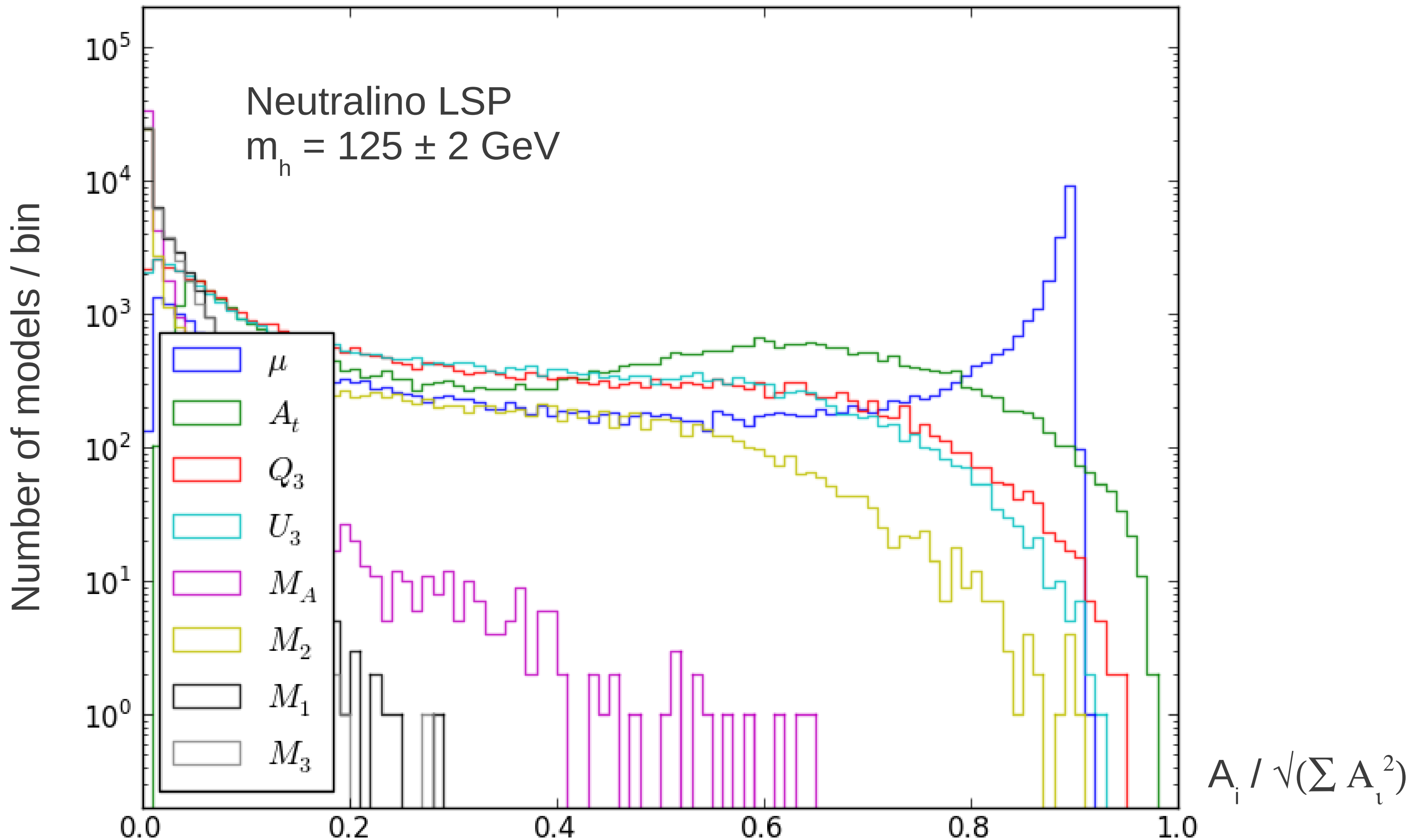
gg width is affected by less than ~25% for models with Higgs near 125 GeV

Sources of fine-tuning



Can also examine relative contributions of each parameter to FT

Sources of fine-tuning



μ contributes over half of the fine-tuning in 56% (50%) of the neutralino LSP model set before (after) making the Higgs mass cut $m_h = 125 \pm 2$ GeV

More sample spectra