Little Hierarchy in the Minimally Specified MSSM

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EWSB in the MSSM

- Requiring EWSB

$$M_Z^2 = -2|\mu|^2 - m_{H_u}^2 - m_{H_d}^2 + \left.\frac{|m_{H_u}^2 - m_{H_d}^2|}{\sqrt{1 - \sin^2(2\beta)}}\right|_{M_Z}$$

$$\Rightarrow M_Z^2 = -1.9\mu_0^2 + 5.9M_{3,0}^2 - 1.2m_{H_u,0}^2 + 1.5m_{\tilde{t},0}^2 - 0.8A_t M_{3,0} + 0.2A_{t,0}^2 + ...$$

- 125 GeV Higgs mass
- Collider limits $\longrightarrow$ $m_{\tilde{t}} \sim$ few TeV

- Naturalness: Large cancelling effects in a fundamental theory are unlikely
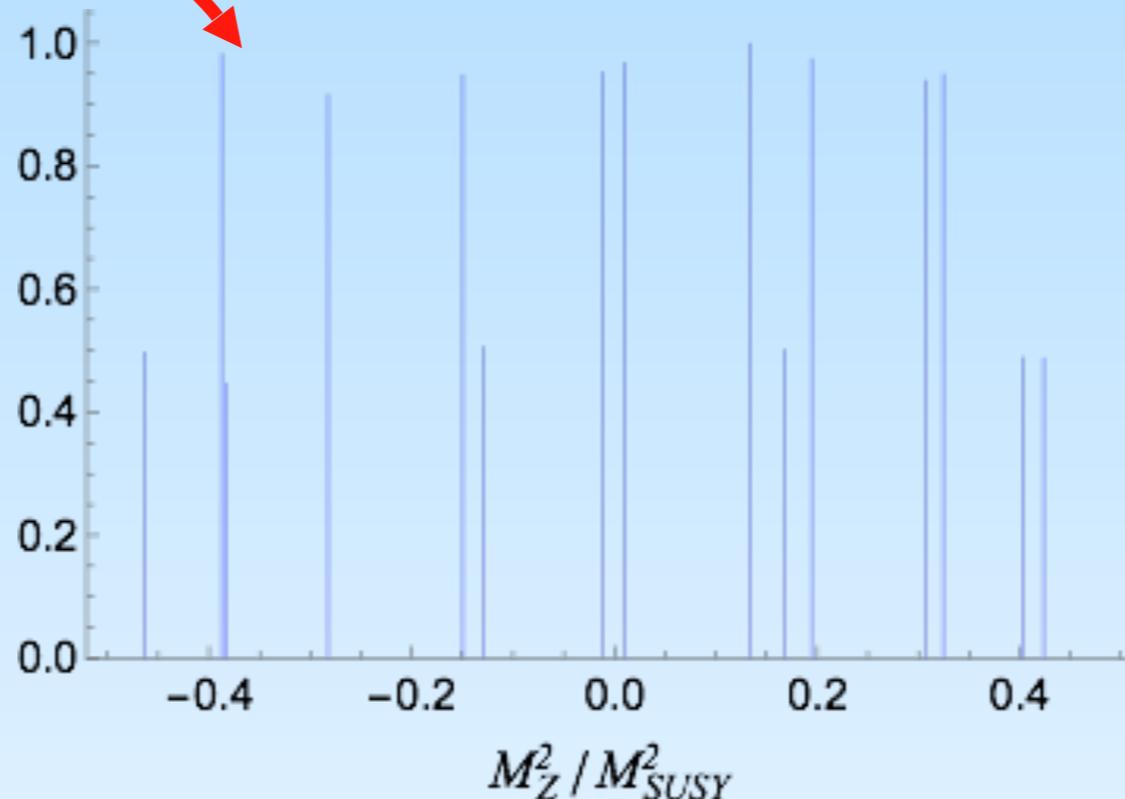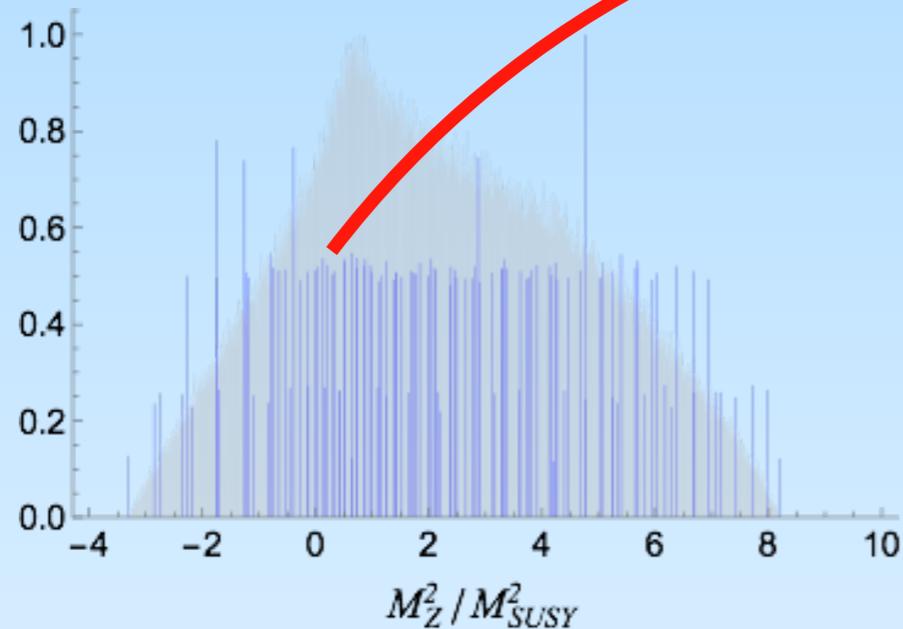
Method of Minimal Specification

★ Different approach to the little hierarchy ★

- Study outcomes of hierarchy between EW and SUSY scales that only depend on specifying parameters with one significant figure.

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

- Allow parameters at the GUT scale to vary as $[0.5, 1.5]M_{SUSY}$ for mass dimension parameters and $[0.5, 1.5]M_{SUSY}^2$ for mass-squared dimension
- Two-loop RGE's, evolve to stop mass
- Automatically avoid accidentally large hierarchy

★ Only specify model parameters by one digit
   For example: $M_{1/2} = 1.2 M_{SUSY}, m_0^2 = 0.8 M_{SUSY}^2$

★ Little hierarchy btw EW and SUSY of factor of 10-30 can be generated in the CMSSM

★ More complex models, non-universal Higgs masses or non-universal gauginos ~300

$$\Rightarrow M_Z^2 = -1.9\mu_0^2 + 5.9 M_{3,0}^2 - 1.2 m_{H_u,0}^2 + 1.5 m_{t,0}^2 - 0.8 A_t M_{3,0} + 0.2 A_{t,0}^2 + ...$$

Simple Scenario - $M_{1/2}, \mu$

$M_{SUSY} = 3TeV$

$\tan\beta = 10$

- Individual outcomes will be shifted if central values slightly different
- Smallest natural outcome guaranteed by minimal specification corresponds to the largest gap size
- Largest gap ~ 0.13 corresponds to hierarchy $M_Z \sim 0.4 M_{SUSY}$
- New parameters scanning at sub-leading levels $10^{-2}, 10^{-3}, 10^{-4}, ..$ will split outcomes e.g.
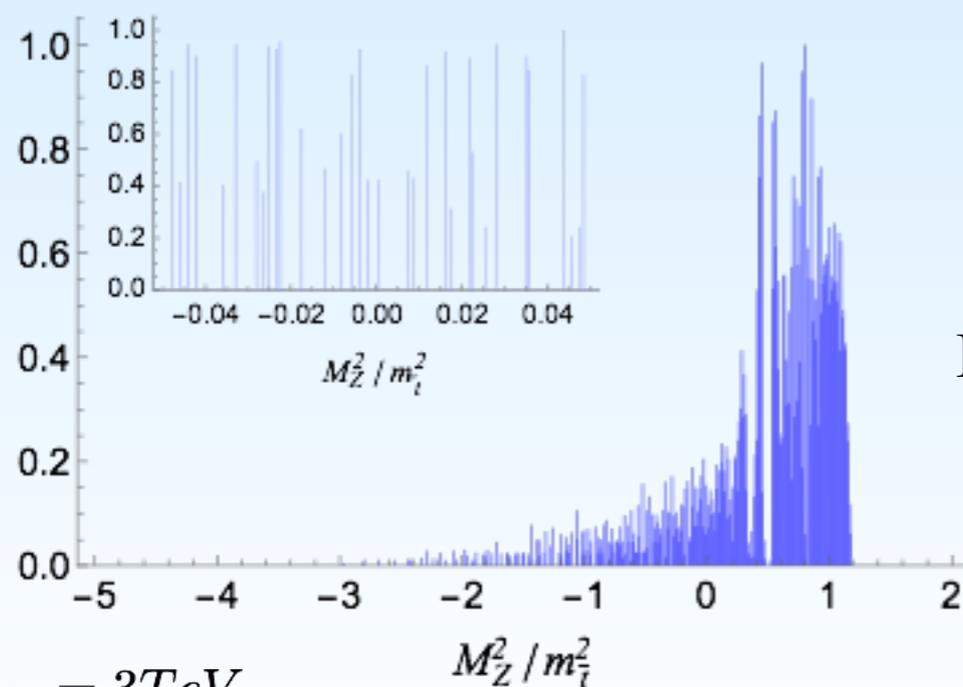
In a model with just two non-zero parameters, conclusions from Minimal Specification reproduce the estimates from traditional approaches (e.g. Barbieri-Giudice)

Results for the CMSSM $\{\mu, M_{1/2}, m_0\} \sim M_{SUSY}$
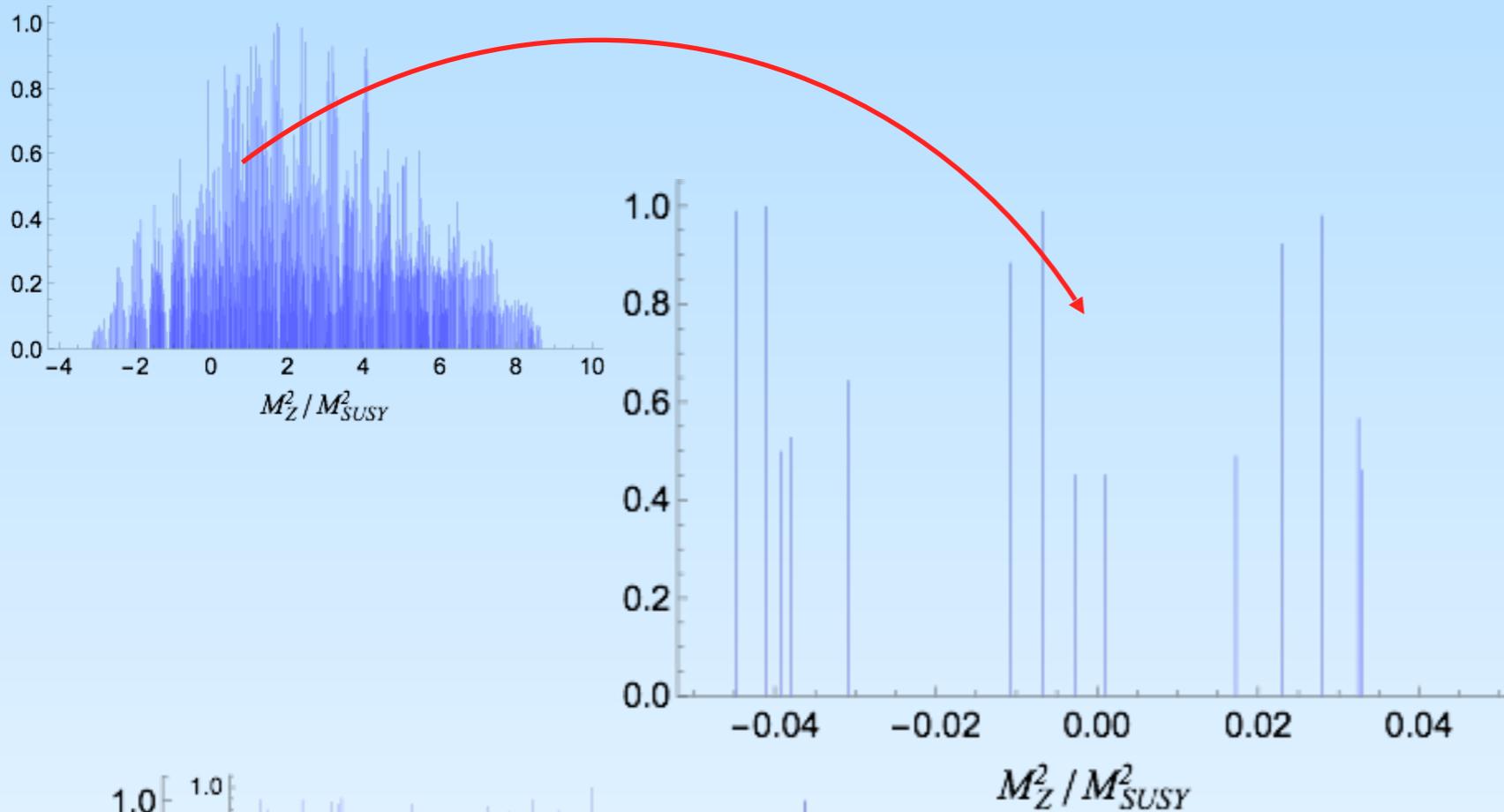
Largest gap ~ 0.02

$$M_Z \gtrsim 0.14 M_{SUSY}$$
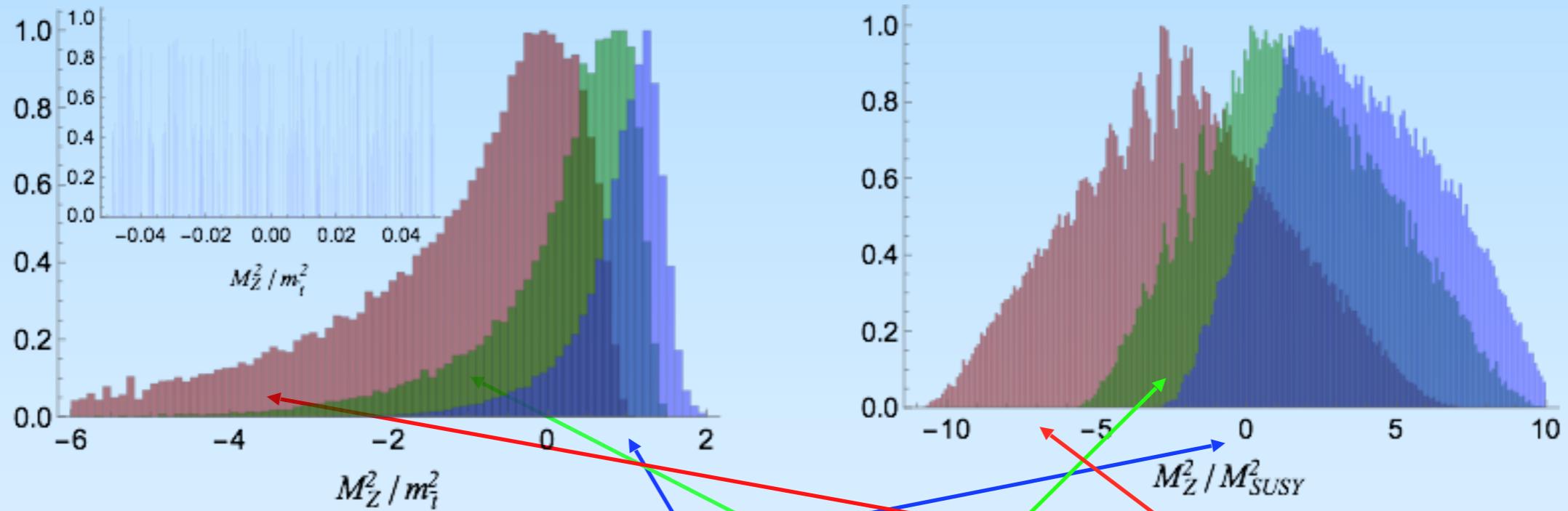
Largest gap ~ 0.008

$$M_Z \gtrsim 0.09 m_{\tilde{t}}$$

In the previous case, largest gap size at this level would have required specifying parameters to two digits. Here, smaller gaps are completely ordinary

$M_{SUSY} = 3 TeV$

$\tan \beta = 10$

CMSSM including $-A_0 \sim M_{SUSY}$

Shifting the central value of μ : $\textcolor{blue}{M_{SUSY}}$, $\textcolor{green}{\sqrt{2}M_{SUSY}}$, $\textcolor{red}{2M_{SUSY}}$

$\Rightarrow$ shifts the position of the peak, but the gap sizes remain

CMSSM$-A_0$: M_Z^2/M_{SUSY}^2 ~0.004

$\qquad\qquad M_Z^2/m_{\tilde{t}}^2 \sim 0.002$

CMSSM$+A_0$: $M_Z^2/M_{SUSY}^2 \sim 0.003$

$\qquad\qquad M_Z^2/m_{\tilde{t}}^2 \sim 0.001$

$M_Z \gtrsim 0.03 m_{\tilde{t}}$
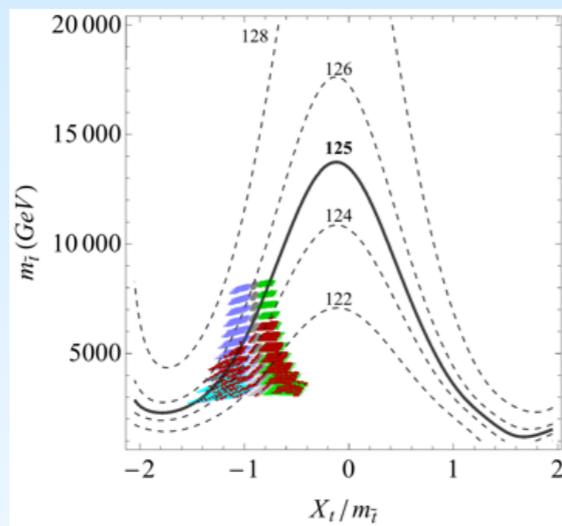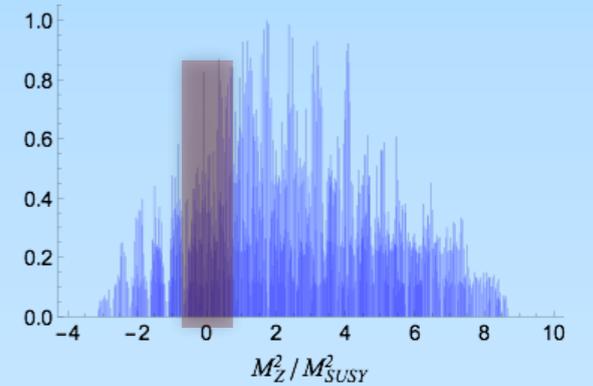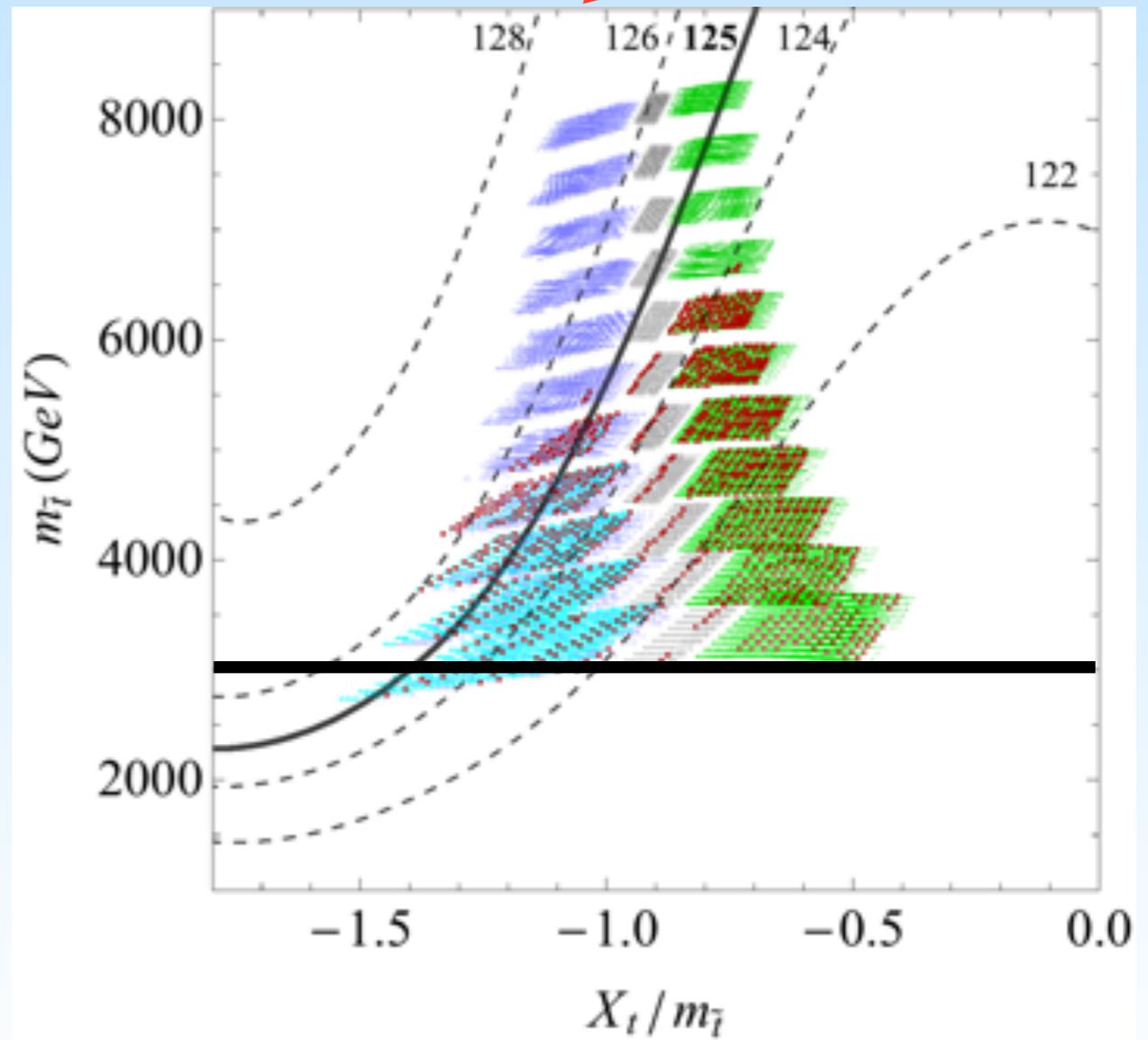
$M_{SUSY} = 3 TeV$

$\tan\beta = 10$

Hierarchy and the Higgs mass

- Comparing hierarchy to Higgs mass shows that only the CMSSM with negative A-terms can lead to sufficiently heavy Higgs boson
- CMSSM $(-A_0, A_0 = 0, +A_0) \rightarrow$ (blue, gray, green)
- Red points correspond to $|M_Z^2/m_{\tilde{t}}^2| < 0.1$
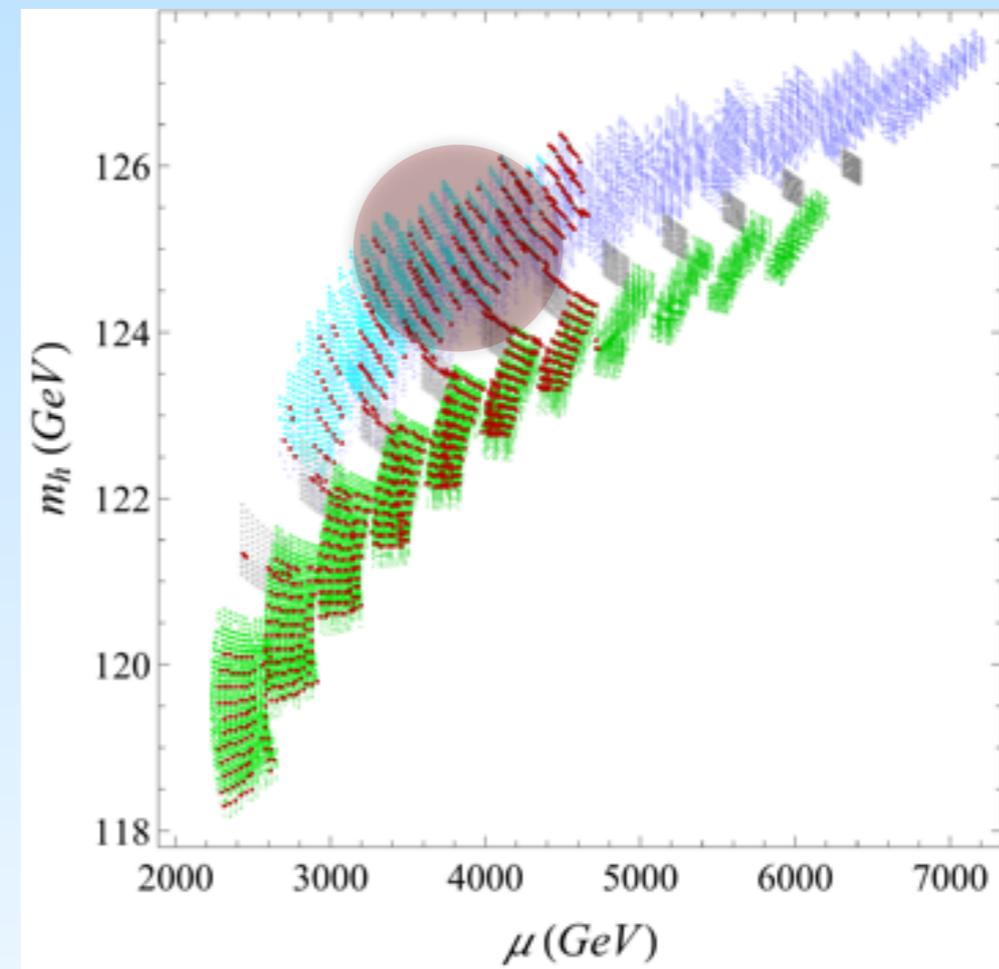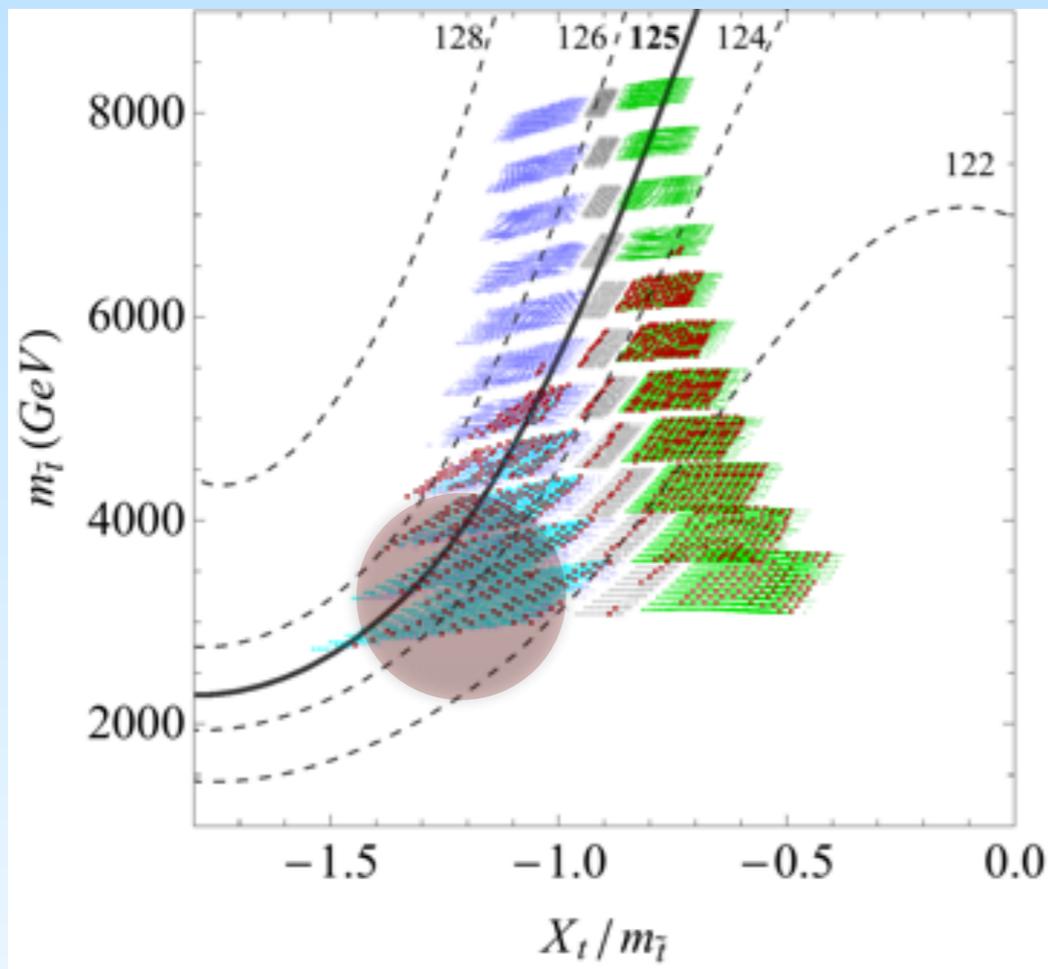

Higgs contours from *FeynHiggs*

$M_{SUSY} = 3 TeV$

$\tan \beta = 10$

Hierarchy and the Higgs mass cont.

$M_{SUSY} = 3 TeV$

$\tan \beta = 10$

Non-universal cases

$$\underline{\{M_{1/2}, \mu, m_0, A_0 = 0, m_{H_u}, m_{H_d}\} \sim M_{SUSY}}$$

$$M_Z^2/M_{SUSY}^2 \sim 4 \times 10^{-4}$$

$$M_Z^2/m_{\tilde{t}}^2 \sim 1.5 \times 10^{-4} \qquad \longrightarrow \qquad M_Z \gtrsim 0.01 m_{\tilde{t}}$$

$$\underline{\{M_{1/2}, \mu, m_0, A_0, m_{H_u}, m_{H_d}\} \sim M_{SUSY}}$$

$$M_Z^2/M_{SUSY}^2 \sim 3 \times 10^{-5}$$

$$M_Z^2/m_{\tilde{t}}^2 \sim 1 \times 10^{-5}$$

$$\underline{\{M_{1/2}, \mu, m_0, -A_0, m_{H_u}, m_{H_d}\} \sim M_{SUSY}}$$

$$M_Z^2/M_{SUSY}^2 \sim 5 \times 10^{-5}$$

$$M_Z^2/m_{\tilde{t}}^2 \sim 3 \times 10^{-5} \qquad \qquad M_Z \gtrsim 0.003 m_{\tilde{t}}$$

$$M_{SUSY} = 3 TeV$$

$$\tan \beta = 10$$

Non-universal gauginos give similar results

Conclusions

- Based on Minimal Specification methodology
  - Allow parameters to vary as $[0.5, 1.5]M_{SUSY}$ for mass dimension parameters and $[0.5, 1.5]M_{SUSY}^2$ for mass-squared dimension, specified by one digit
  - From distribution, interpret largest gap size as smallest naturally occurring outcome. This automatically avoids accidentally large hierarchies and results that depend on precise values
  - CMSSM hierarchy ~ 30
  - CMSSM with negative A-terms can lead to this level of hierarchy with sufficiently heavy higgs boson
  - non-universal models ~300
  - In a general model, parameters scan down to 10^{-6} level

Thanks!