

# SUSY WITH BROKEN BARYON NUMBER: HIGGS AND THE LHC

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Sogee Spinner – SISSA

**arXiv:1204.4458** – J. Arnold, P. Fileviez Perez, B. Fornal, S.S.

And earlier:

**arXiv:1002.1754** - P. Fileviez Perez, M. Wise

**arXiv:1106.0343** - P. Fileviez Perez, M. Wise

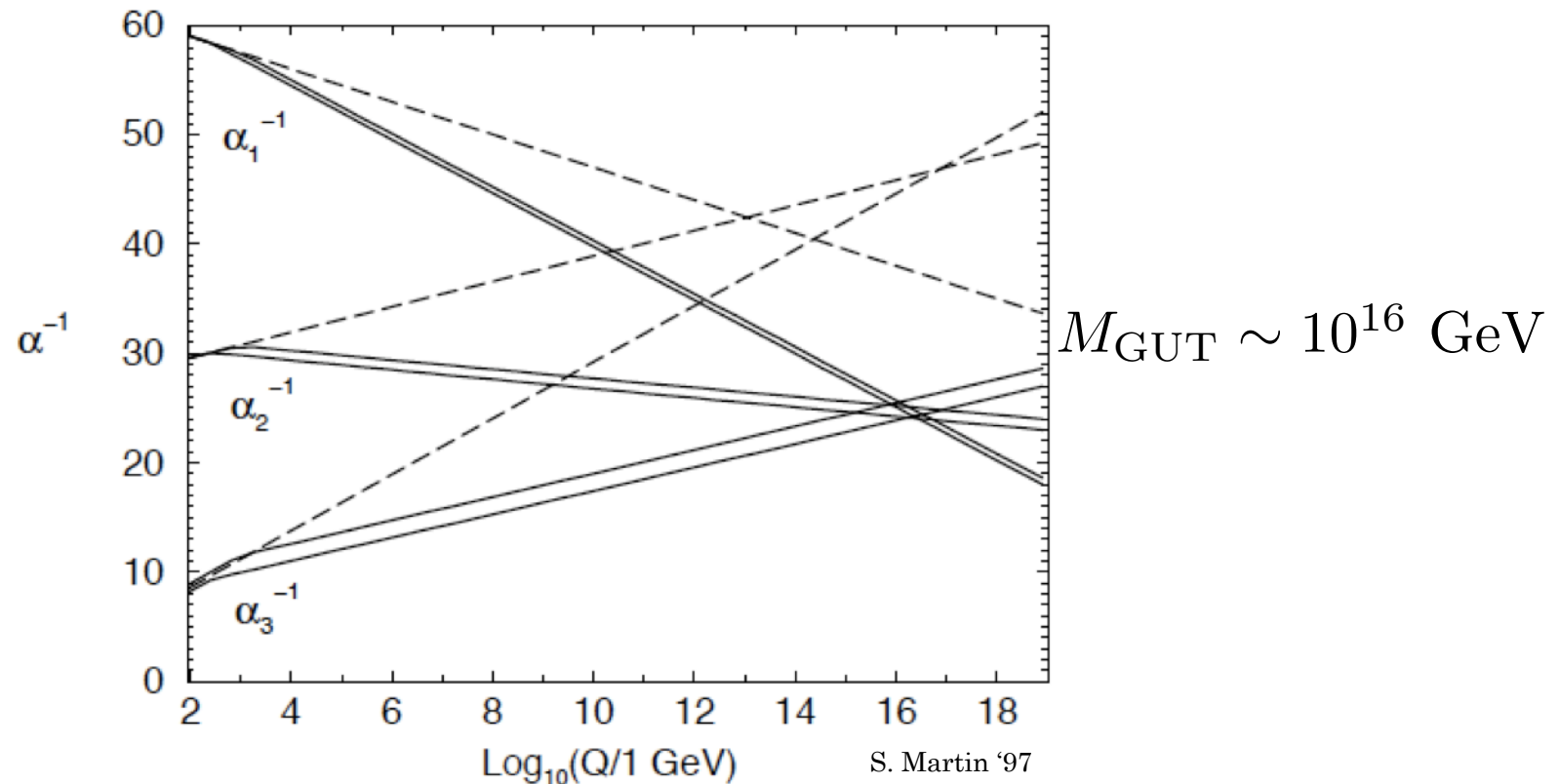
**arXiv:1201.1501** - P. Fileviez Perez

# INTRO: LIFE IN THE DESERT



# BEYOND THE EW (AND SUSY) SCALE

- GUT – A *clue* about higher scales:



- GUT  $\rightarrow$  proton decay, reinforces:  $M_{\text{GUT}} \gtrsim 10^{16} \text{ GeV}$ 
  - Very strong bounds:  $\tau_p > 10^{33} \text{ years!}$

# SUSY AND PROTON DECAY

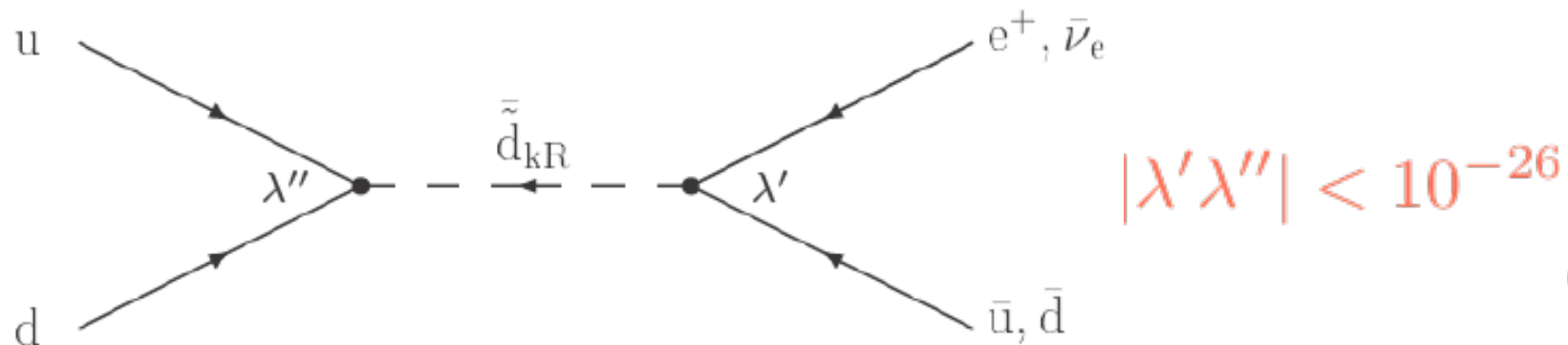
- Gauge invariance allows tree-level proton decay.
  - No accidental  $B - L$  symmetry as in SM:

$$W = W_{\text{MSSM}} + W_?$$

$$W_{\text{MSSM}} = Y_U Q H_u u^c + Y_d Q H_d d^c + Y_E L H_d e^c + \mu H_u H_d$$

Lepton number violation:  $W_{\Delta L=1} = \lambda' Q L d^c + \lambda L L e^c + \mu' H_u L$

Baryon number violation:  $W_{\Delta B=1} = \lambda'' u^c d^c d^c$



# R-PARITY?

- Discrete (*ad hoc*) symmetry:  $R_P = (-1)^{3(B-L)+2S}$
- $R_P$  subgroup of  $U(1)_{B-L}$  - many models of gauged  $B-L$ :
  - Consistent with  $SO(10)$  unification

## Minimal Supersymmetric B-L

V. Barger, P. Fileviez Perez, S.S. PRL '09

- Gauged  $U(1)_{B-L}$ , MSSM + 3 right-handed  $\nu$ 
  - No new Higgs! VEV of sneutrino breaks  $B-L$

### ○ Predictive:

- |                      |                           |   |
|----------------------|---------------------------|---|
| ○ TeV $Z'$           | ○ Two light sterile $\nu$ | Mohapatra PRL '86;<br>Ghosh, Senjanovic, Zhang PLB '10;<br>V. Barger, P. Fileviez Perez, S.S. PLB '10 |
| ○ R-parity violation | ○ Gravitino dark matter?  |   |
| ○ No tree-level BNV  | ○ Radiative B-L breaking  | Ambroso, Ovrut JHEP '09 (Strings)   |

# PROTON DECAY BEYOND TREE-LEVEL

- Despite R-parity or  $B-L$ :

$$W_{\text{NR}} \supset \frac{\gamma}{M} QQQ L$$

- If  $\gamma \sim 1$ :  $M > 10^{17}$  GeV

- Similar term in SM:

$$\mathcal{L}_{\text{NR}} \supset \frac{\gamma}{M_{\text{SM}}^2} QQQ L$$

- Less severe:  $\gamma \sim 1$ :  $M_{\text{SM}} > 10^{15}$  GeV

It all hints at a Desert – from the TeV to GUT scale

$W^\pm Z^0$

$SO(10)?$

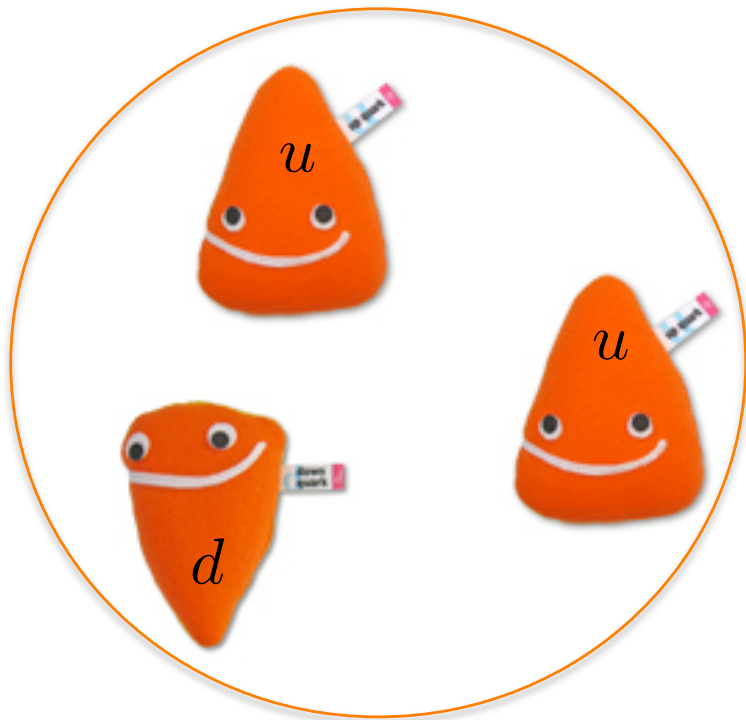


## A DIFFERENT PARADIGM

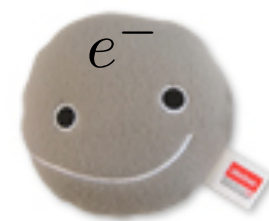
- Gauge Baryon and Lepton number (not B-L)
  - Inconsistent with traditional unification
- However, for  $\Delta B \neq 1$  or  $\Delta L \neq 1$ :
  - Proton is safe
  - No need for a desert
  - Can even break B and L at the TeV scale!!!
  - Different models are possible



# GAUGING BARYON AND LEPTON NUMBERS



Proton





# CANCELING ANOMALIES

- Both B and L intro new anomalies

$$SU(2)^2 \times U(1)_B : \underset{Q}{3} \times \underset{?}{3} \times \frac{1}{3} + 3\mathcal{A}_B = 0 \quad \Rightarrow \quad \mathcal{A}_B = -1$$

$$SU(2)_L^2 \times U(1)_L : \underset{L}{3} \times \underset{?}{1} + \mathcal{A}_L = 0 \quad \Rightarrow \quad \mathcal{A}_L = -3$$

- Fix both and others by introducing a new family:

- $B_4 = \mathcal{A}_B = -1$

- $L_4 = \mathcal{A}_L = -3$

- New quarks constrained by LHC, intro 2 new families

- Vector-like under SM – mass  $\sim$  scale of B breaking

- $B_4; \quad B_5 = -(1 + B_4)$

- $L_4; \quad L_5 = -(3 + L_4)$

# BARYON NUMBER AND SUSY

- B Higgs sector - model dependent
- Intro:  $S_B$  and  $\bar{S}_B$ 
  - Vector-like mass for new quarks – avoid bounds on new families

$$W = S_B Q_4 Q_5^c$$

$$B(S_B) = B_4 + B_5 = B_4 + -(1 + B_4) = -1$$

- VEV of  $S_B$  and  $\bar{S}_B$  : VEV proportional to soft masses
  - TeV scale  $Z_B$
- Important consequence for SUSY pheno:

$$W \supset \frac{A}{M} u^c d^c d^c S_B \quad \langle S_B \rangle \neq 0 \quad \longrightarrow \quad \text{BNV and RPV}$$

# BARYON NUMBER VIOLATION

- $\lambda'' = \frac{\langle S_B \rangle}{M}$
- No washout of baryon asymmetry requires

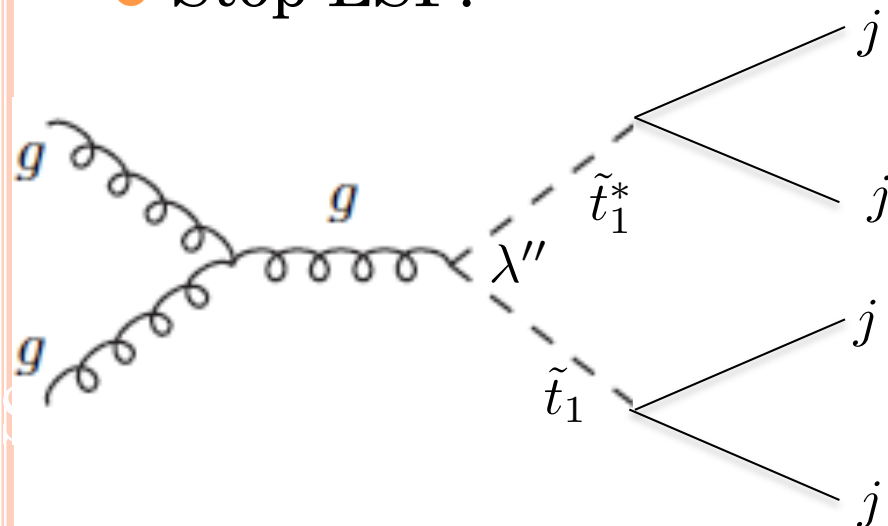
$$\lambda'' < 5 \times 10^{-7} \left( \frac{m_{\tilde{q}}}{1 \text{ TeV}} \right)^{\frac{1}{2}}$$

- Possible LSPs and decays:

$$\begin{aligned} \chi^0 &\rightarrow jjj & \tilde{q} &\rightarrow jj \\ \tilde{g} &\rightarrow jjj & \tilde{\ell} &\rightarrow \ell jjj \end{aligned}$$

Large background for SUSY:  
Completely changes SUSY  
bounds!

- Stop LSP:



$$L(\tilde{q}_i \rightarrow q_j q_k) > 1 \text{ mm} \left( \frac{10^2 \text{ GeV}}{M_{\tilde{q}}} \right) \left( \frac{10^{-7}}{\lambda''} \right)^2$$

- Forms bound states, possibly displaced vertices

Also considered in Csaki's talk

# LEPTON NUMBER AND NEUTRINO MASSES

- L Higgs sector:  $\Delta L = 1$  inconsistent with  $\Delta B = 1$ 
  - If  $\Delta L = 2$ , facilitate type I seesaw:

- Intro:  $\bar{S}_L$  and  $S_L$ ;  $L(\bar{S}_L, S_L) = \pm 2$

$$W \supset f_{ii} \bar{S}_L \nu_i^c \nu_i^c \quad \langle \bar{S}_L \rangle \neq 0 \quad \longrightarrow \quad \begin{pmatrix} \nu & \nu^c \\ 0 & m_{\text{Dirac}} \\ m_{\text{Dirac}} & f \langle \bar{S}_L \rangle \end{pmatrix}$$

$$m_\nu \sim \frac{m_{\text{Dirac}}^2}{f \langle \bar{S}_L \rangle} \quad m_{\text{Dirac}} = v Y_\nu; \quad Y_\nu \lesssim 10^{-5}$$

- VEV of  $\bar{S}_L$  and  $S_L$ : must be proportional to SUSY scale
  - TeV scale  $Z_L$

# NEW FERMIONS

- New quarks acquire mass through:

$$m_{q_{4,5}} \sim \langle S_B \rangle$$

- Don't mix with lighter families because of B number

- New leptons acquire mass from MSSM-Higgs:

$$m_{e_4} = \frac{v_d}{\sqrt{2}} Y_{e_4} \gtrsim 100 \text{ GeV}$$

- Taking Yukawa couplings perturbative

$$\tan \beta < 6$$

- Fifth generation with opposite SM-charges:

$$m_{e_5} = \frac{v_u}{\sqrt{2}} Y_{e_5}$$

## B, L AND THE HIGGS AT THE LHC



## NEW LEPTONS CONTRIBUTE TO HIGGS MASS:

$$\Delta m_h^2(\text{MSSM}) \sim \frac{3m_t^4}{2\sqrt{2}\pi^2} \frac{G_F}{\sin^2 \beta} \ln \frac{m_{\tilde{t}_1}^2 m_{\tilde{t}_2}^2}{m_t^4}$$



$$\Delta m_h^2(\text{MSSM}) + \Delta m_h^2(\text{MSSM})[3m_t^4 \rightarrow m_{e_5}^4 \dots]$$

$W^\pm$   
 $Z^0$   
SUSY?

# NEW LEPTONS CONTRIBUTE TO HIGGS MASS:

**Scan:**

$$m_{\tilde{Q}_3}, m_{\tilde{t}_c}, m_{\tilde{b}_c} = 200..2000 \text{ GeV}$$

$$m_{\nu_4} = m_{\nu_5} = 90 \text{ GeV}; \quad m_{e_4} = m_{e_5} = 100 \text{ GeV}$$

$$X_t = -4.4 \text{ TeV}$$

$$\tan \beta = 2.6$$

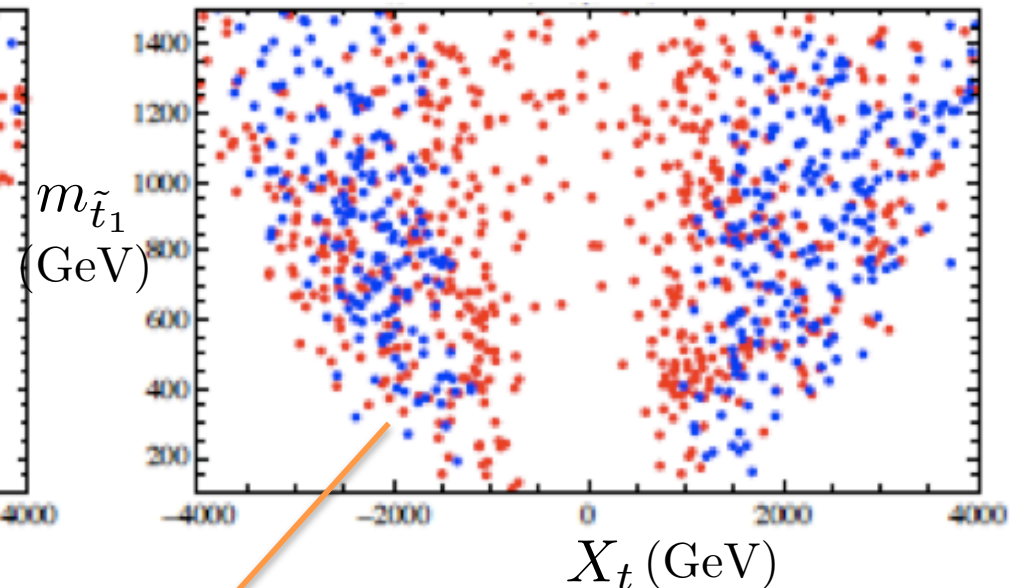
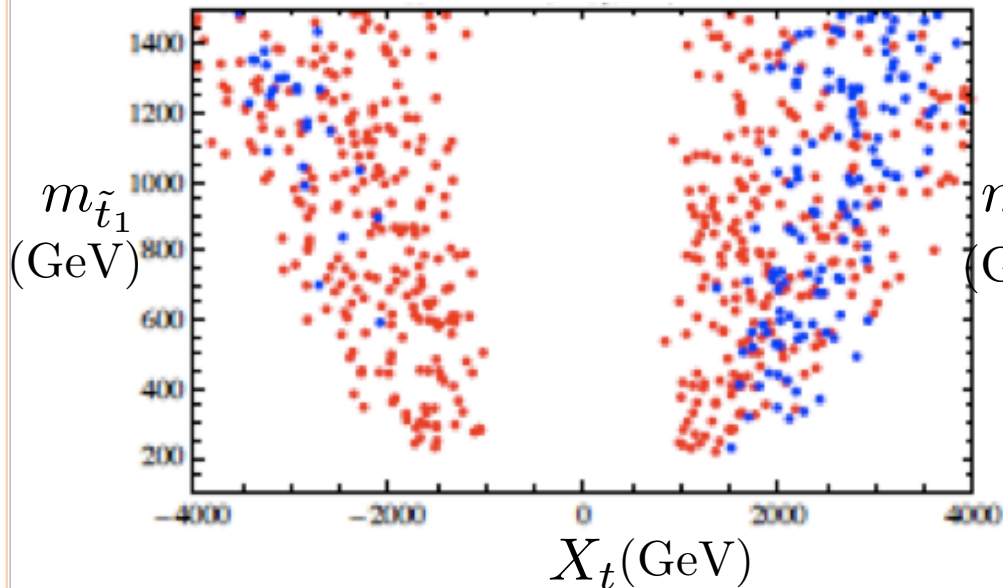
●  $m_h = 115..122 \text{ GeV}$

●  $m_h = 122..128 \text{ GeV}$

FeynHiggs – 2 loop Higgs mass

MSSM

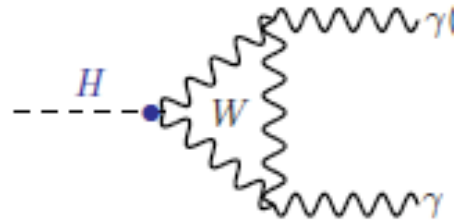
BLMSSM



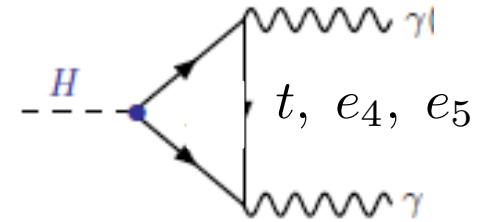
Stop LSP with RPV decays



# NEW LEPTONS AND RADIATIVE HIGGS DECAY:



$$\mathcal{A}_W \sim 8.1$$

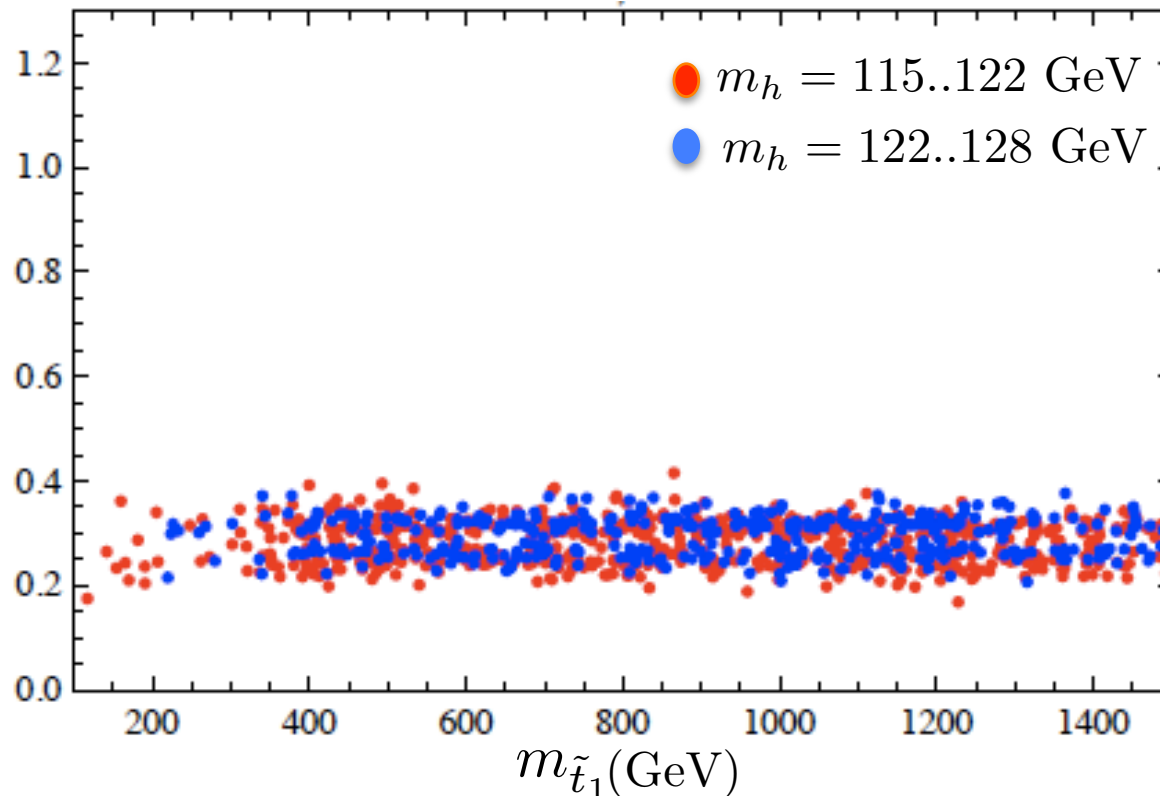


Fermions decrease cancel W loop

$$\mathcal{A}_t \sim -1.8$$

$$\mathcal{A}_{e_4, e_5} \sim -1.4$$

$$\frac{\Gamma_{h \rightarrow \gamma\gamma}^{\text{BLMSSM}}}{\Gamma_{h \rightarrow \gamma\gamma}^{\text{MSSM}}}$$



If  $\gamma\gamma$  channel  
verified rule out  
this model!

(modifications through mixing  
possible similar to P. Schwaller)

# CONCLUSION

- A desert-less paradigm
  - Gauge Baryon and Lepton number
    - Both can be broken at a TeV!
- B and L violation:
  - Type I seesaw
  - BNV  $\lambda''$ , changes SUSY bounds light stop possible
- Anomaly cancellation requires new families
  - New leptons can increase Higgs mass
  - Also reduce  $h \rightarrow \gamma\gamma$ , can be ruled out soon!