The Particle Physics and Cosmology of SU(4) Heterotic Vacua - the B-L MSSM

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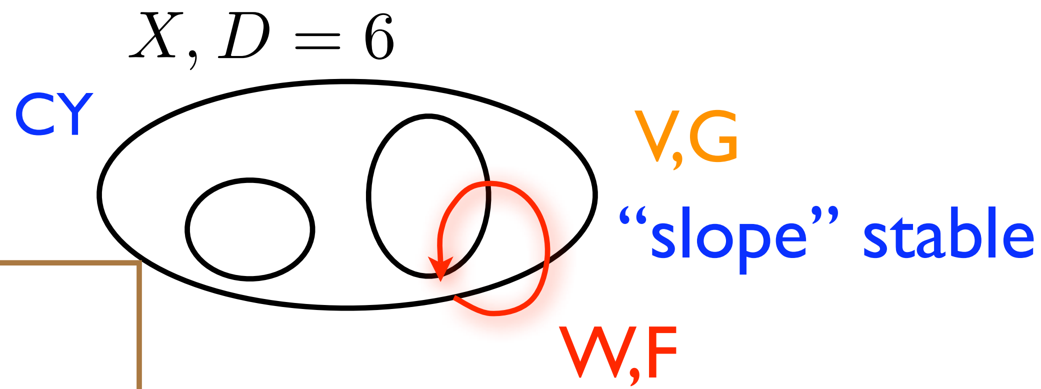
Penn HEP 2010

Smooth Heterotic Compactifications

$D = 10, \quad g_{MN}, \quad A^a_M, E_8$



$\mathbb{R}^4$

$N = 1\ SUSY$

$H = [E_8, G]$

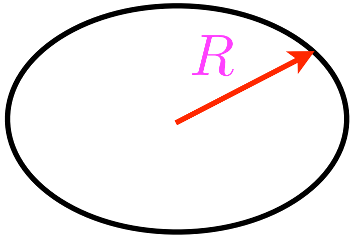
$\mathcal{H} = [H, F]$

$H^1(V)^F \Rightarrow matter$

$H^1(V^*)^F \Rightarrow conjugate\ matter$

$H^1(\wedge^2 V)^F \Rightarrow Higgs$

$H^1(V \otimes V^*)^F \Rightarrow Bundle\ Moduli$



$R^{-1} = M_C \simeq 10^{16}\ GeV$

Heterotic Standard Model

$V \; , G = SU(4)$, $W \; , F = \mathbb{Z}_3 \times \mathbb{Z}_3$

Braun, He, Ovrut, Pantev 2006
Anderson, Gray, He, Lukas 2009

$\mathbb{R}^4$ Theory Gauge Group:

Gauge connection $G = SU(4) \Rightarrow E_8 \rightarrow H = Spin(10)$

Wilson line $F = \mathbb{Z}_3 \times \mathbb{Z}_3 \Rightarrow$

$$Spin(10) \rightarrow \mathcal{H} = SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_{B-L}$$

rank Spin(10)=5 plus F Abelian ⇒ extra gauged $U(1)_{B-L}$.

By construction $U(1)_{B-L}$ is anomaly free. Note that

$$\mathbb{Z}_2 \; (R-\text{parity}) \subset U(1)_{B-L}$$

⇒ no rapid proton decay. But must be spontaneously broken above the scale of weak interactions.

$\mathbb{R}^4$ Theory Spectrum:

$$E_8 \xrightarrow{V} Spin(10) \Rightarrow$$

$$248 = (1, 45) \oplus (4, 16) \oplus (\bar{4}, \bar{16}) \oplus (6, 10) \oplus (15, 1)$$

The Spin(10) spectrum is determined from $n_R = h^1(X, U_R(V))$.

$$Spin(10) \xrightarrow{F} SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_{B-L} \Rightarrow$$

The $3 \times 2 \times 1_Y \times 1_{B-L}$ spectrum is determined from $n_r = (h^1(X, U_R(V)) \otimes \mathbf{R})^{\mathbb{Z}_3 \times \mathbb{Z}_3}$. Tensoring and taking invariant subspace gives 3 families of quarks/leptons each transforming as

$$Q_L = (3, 2, 1, 1), \quad u_R = (\bar{3}, 1, -4, -1), \quad d_R = (\bar{3}, 1, 2, -1)$$

$$L_L = (1, 2, -3, -3), e_R = (1, 1, 6, 3), \qquad \nu_R = (1, 1, 0, 3)$$

under $SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_{B-L}$. Also, 1 pair of Higgs

$$H = (1, 2, 3, 0), \quad \bar{H} = (1, \bar{2}, -3, 0)$$

That is, we get exactly the matter spectrum of the MSSM with 3 right-handed neutrinos! In addition, there are

$n_1 = h^1(X, V \times V^*)^{\mathbb{Z}_3 \times \mathbb{Z}_3} = 13$ vector bundle moduli $\phi = (1,1,0,0)$

Note: In pre-string Spin(10) GUTtheories the gauged $U(1)_{B-L}$ is spontaneously broken by adding multiplets, such as $\mathbf{126}$, which contain $SU(3)_C \times SU(2)_L \times U(1)_Y$ singlets for which

$$3(B-L) = \pm 2, \pm 4, \ldots \quad \Rightarrow \quad U(1)_{B-L} \longrightarrow \mathbb{Z}_2 \ \ (R-parity)$$

Not possible in Spin(10) heterotic strings since $\mathbf{45}, \mathbf{16}, \mathbf{1\bar{6}}, \mathbf{10}, \mathbf{1}$ are the only multiplets in the $\mathbf{248}$ of E_8. The only singlets are ν_R

$$3(B-L) = 1 \quad \Rightarrow \quad U(1)_{B-L} \longrightarrow 1$$

$\Rightarrow$ In SU(4) heterotic vacua must break B-L symmetry via

$$\langle \nu_3 \rangle \neq 0 \quad \text{at low scale}$$

N=1 Supersymmetry Primer

Chiral Superfield: $\Phi \sim (\phi, \quad \psi, \quad F)$ quarks/leptons/Higgs

Vector Superfield: $V \sim (A_\mu, \ \lambda, \ D)$ gauge fields

F and D are "auxiliary fields" which ⇒ potential energy is

$$\mathcal{V} = |F|^2 + \frac{1}{2}D^2$$

where

$$F = \frac{\partial W}{\partial \phi} \ , \quad \text{W holomorphic "superpotential"}$$

$$D = g\phi^\dagger T \phi$$

Supersymmetric Interactions:

The most general superpotential is

$$W = \sum_{i=1}^{3} (\lambda_{u,i} Q_i H u_i + \lambda_{d,i} Q_i \bar{H} d_i + \lambda_{\nu,i} L_i H \nu_i + \lambda_{e,i} L_i \bar{H} e_i) + \mu H \bar{H}$$

Note B-L symmetry forbids dangerous B and L violating terms

$$LLe, \quad LQd, \quad udd$$

Supersymmetry Breaking, the Renormalization Group and the LHC

Soft Supersymmetry Breaking:

Ambroso, Ovrut 2009

N=1 Supersymmetry is spontaneously broken by the moduli during compactification ⇒ soft supersymmetry breaking interactions. The relevant ones are

$$V_{2s} = m_{\nu_3}^2 |\nu_3|^2 + m_H^2 |H|^2 + m_{\bar{H}}^2 |\bar{H}|^2 - (BH\bar{H} + hc) + \ldots$$

$$V_{2f} = \frac{1}{2} M_3 \lambda_3 \lambda_3 + \ldots$$

At the compactification scale $M_C \simeq 10^{16} GeV$ these parameters are fixed by the vacuum values of the moduli. For example

$$m_{\nu_3}^2 = m_{\nu_3}^2(\langle\phi\rangle)$$

Can one compute $\langle\phi\rangle$?

As of yet no complete theory of moduli stabilization. However

- ∗ New theory to stabilize all geometric moduli   Anderson, Gray, Lukas, Ovrut 2010

At a lower scale μ measured by $t = ln(\frac{\mu}{M_C})$ parameters change under the renormalization group. For example

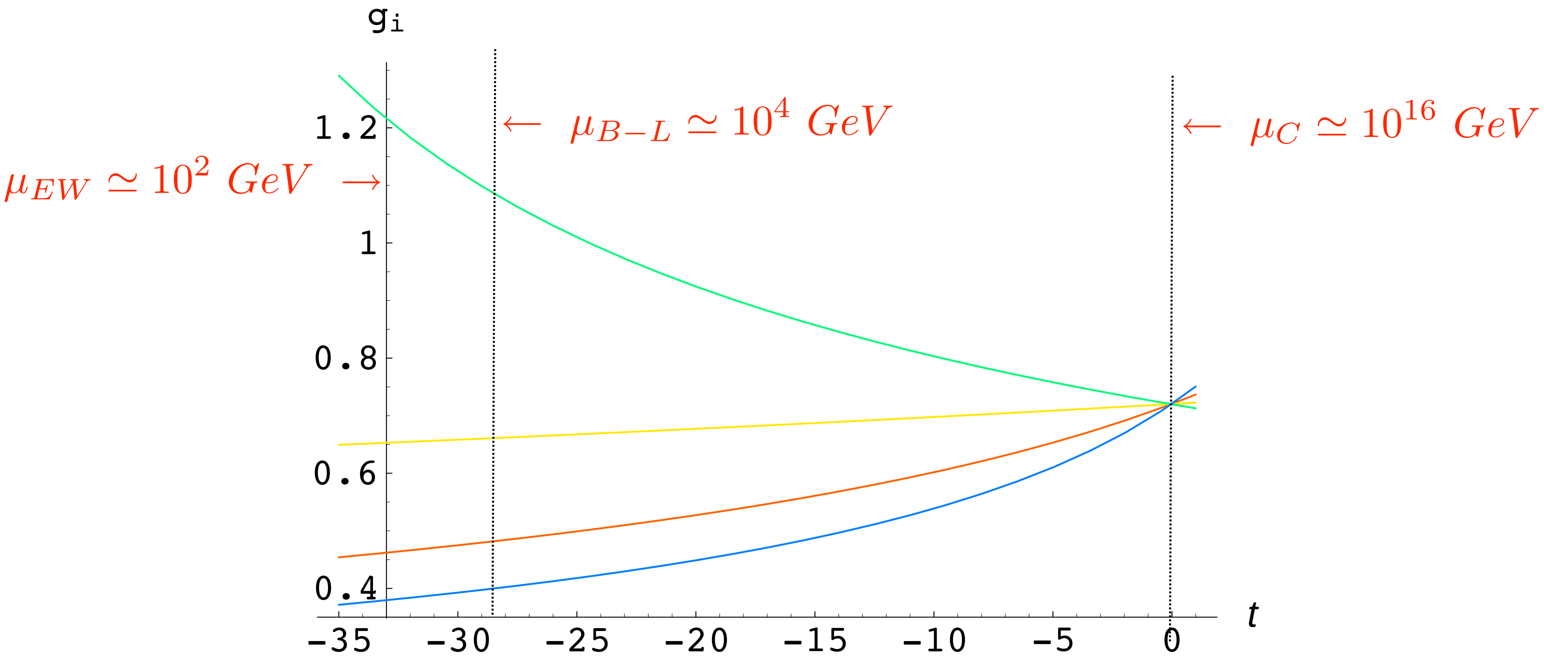


Figure 1: This plot shows the running of the gauge couplings g_1(red), g_2(yellow), g_3(green) and g_4(blue) and their subsequent unification at 2×10^{16} GeV. For this plot, $t = Ln(\mu/(2.2 \times 10^{16}))$.

The renormalization group equation for m_{ν_3} is

$$16\pi^2 \frac{dm^2_{\nu_3}}{dt} \simeq \frac{3}{4} {g_4}^2 \sum_{i=1}^{3} (m^2_{\nu_i} + \dots)$$

Solving the RGEs assuming

$$m_H(0)^2 = m_{\bar{H}}(0)^2, \quad m_{Q_i}(0)^2 = m_{u_j}(0)^2 = m_{d_k}(0)^2$$

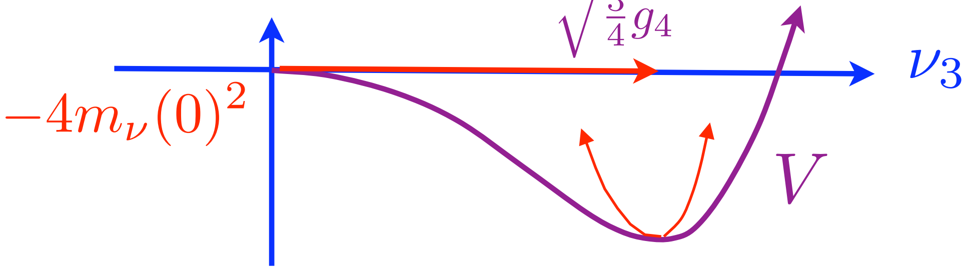
$$m_{L_i}(0)^2 = m_{e_j}(0)^2 \neq m_{\nu_k}(0)^2$$

⇒ at scale $\mu \simeq 10^4 \ GeV \ \Rightarrow \ t_{B-L} \simeq -28.7$

$$m_{\nu_3}(t_{B-L})^2 = m_\nu(0)^2 - 5m_\nu(0)^2 = -4m_\nu(0)^2$$

⇒

$$\langle \nu_3 \rangle = \frac{2m_\nu(0)}{\sqrt{\frac{3}{4}} g_4}$$



The gauged $U(1)_{B-L}$ is spontaneously broken by the third family right-handed sneutrino.

⇒ a B-L vector boson mass of

$$M_{A_{B-L}} = 2\sqrt{2}m_\nu(0)$$

At this scale, no other symmetry is broken.

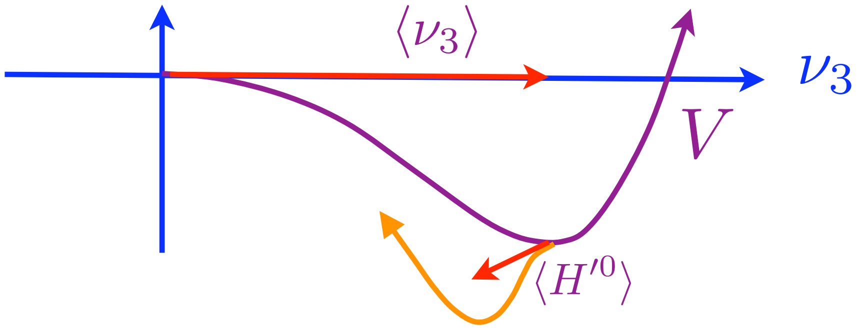
Similarly, at the electroweak scale $\mu \simeq\ 10^2\ GeV\ \Rightarrow\ t_{EW} \simeq -33.2$

$$m_{H'}(t_{EW})^2 \simeq -\frac{\Delta^2}{tan\beta^2}m_H(0)^2 \quad , \quad m_{\bar{H}'}(t_{EW})^2 \simeq m_H(0)^2$$

where $tan\beta = \frac{\langle H\rangle}{\langle\bar{H}\rangle}$ and $0 < \Delta^2 < 1$ is related to $M_3(0)$. ⇒ at t_{EW} electroweak symmetry is broken by the expectation value

$$\langle H'^0\rangle = \frac{2\Delta\ m_H(0)}{tan\beta\sqrt{\frac{3}{5}g_1^2 + g_2^2}}$$

⇒ a Z-boson mass of $M_Z = \frac{\sqrt{2}\Delta\ m_H(0)}{tan\beta} \simeq 91GeV$



It follows that there is a B-L/EW gauge hierarchy. For a “natural” range of parameters we find

$$\mathcal{O}(10) \lesssim \frac{M_{A_{B-L}}}{M_Z} \lesssim \mathcal{O}(100)$$

which is phenomenologically acceptable.

Initial Parameter Space:

With “universality” assumptions such as

$$m_H(0)^2 = m_{\bar{H}}(0)^2, \quad m_{Q_i}(0)^2 = m_{u_j}(0)^2 = m_{d_k}(0)^2$$

and restricting to the third family ⇒ 9 initial parameters.

Fix 5 in middle of B-L radiative breaking regime ⇒ 4 parameters

$$c_q(0)\ \underset{\substack{\uparrow\\ \text{choose}}}{,}\ c_{\nu_3}(0)\ ,\ c_\mu(0)\ \underset{\substack{\uparrow\\ \text{scan}}}{,}\ tan\beta$$

Lower Bounds on Masses:

Derived from data under various scenarios. Example

Search for Neutral MSSM Higgs Bosons at LEP

ALEPH, DELPHI, L3 and OPAL Collaborations
The LEP Working Group for Higgs Boson Searches

hep-ex/0602042

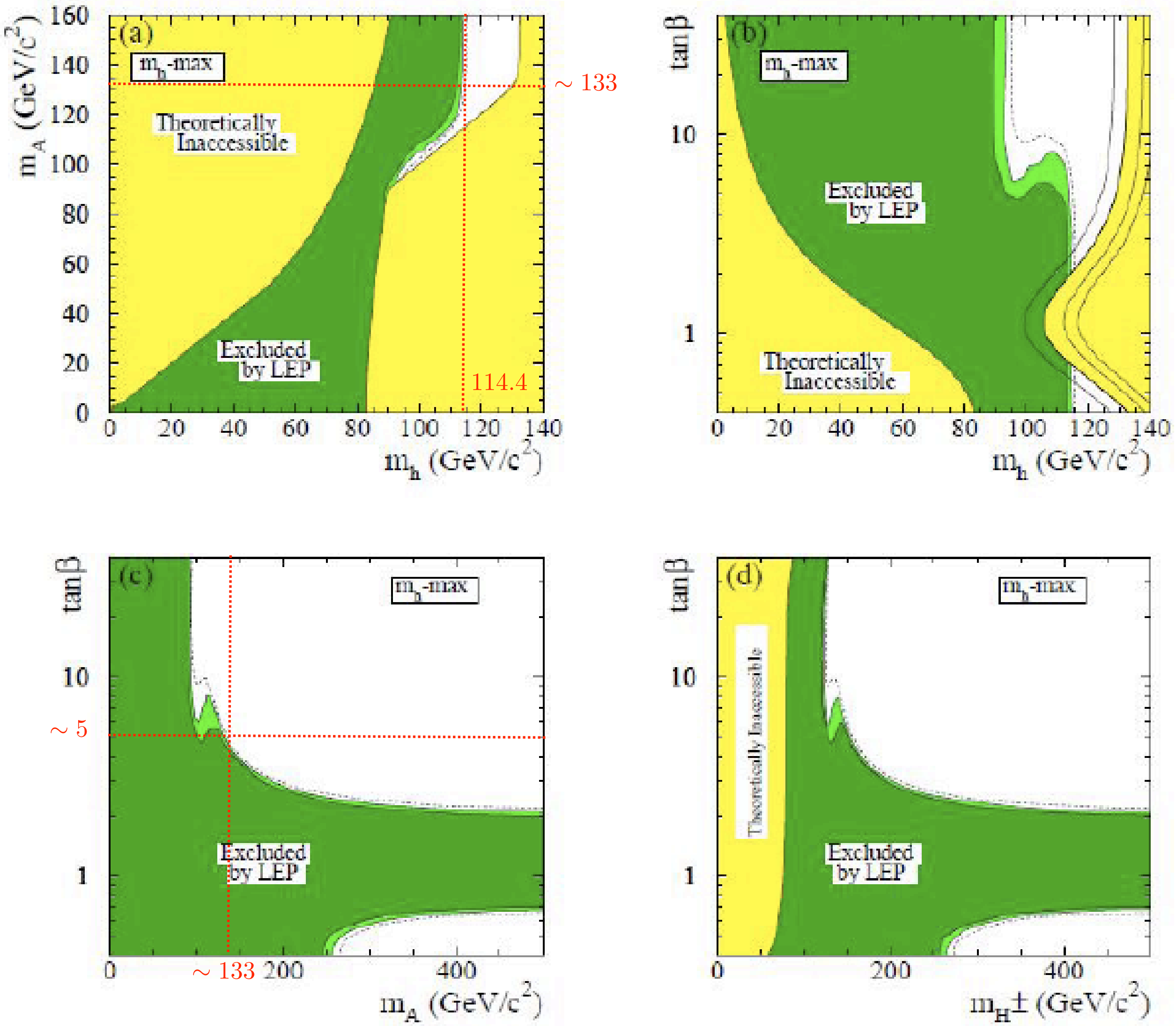
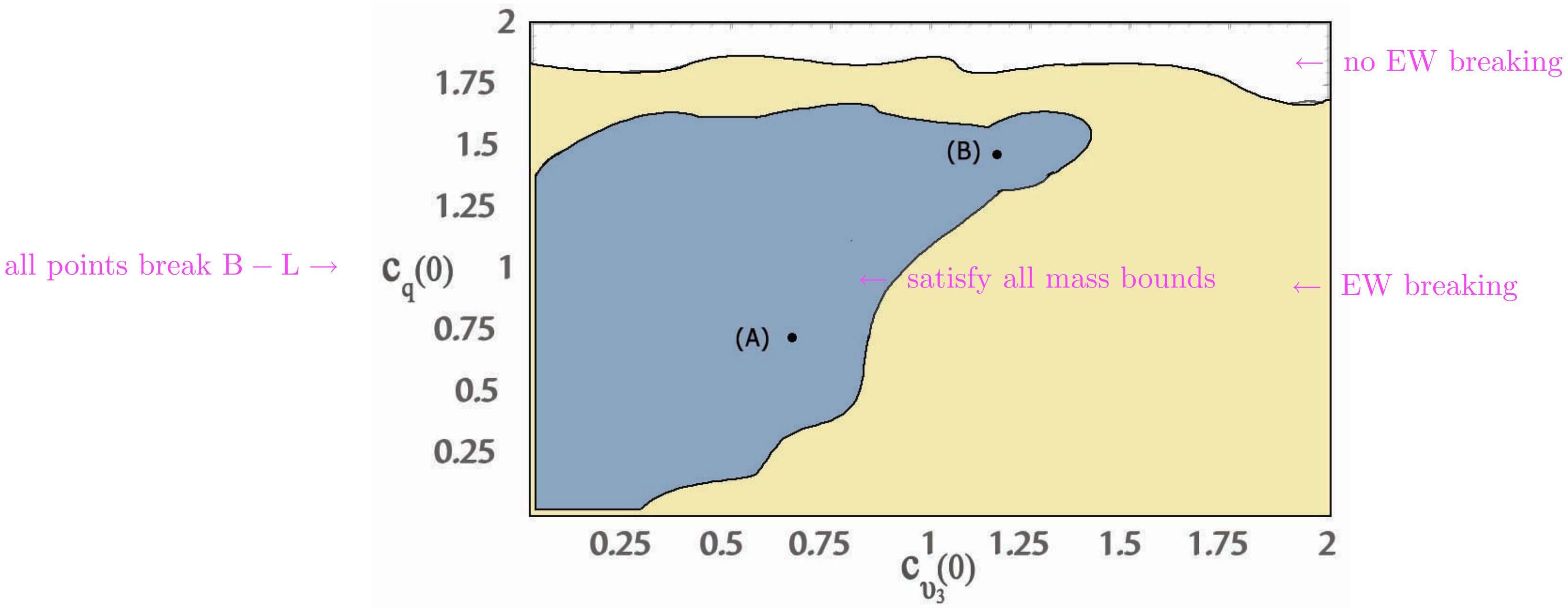


Figure 14: Exclusions at the 95% confidence level (medium-grey or light-green) and at the 99.7% confidence level (dark-grey or dark-green) for the CP conserving, $m_{h^0} - max$ scenario and for $m_t = 174.3$ GeV/c^2. The figure shows the theoretically inaccessible domains (light-grey or yellow) and the regions excluded in this search, in four projections of the MSSM parameters: (a): (m_{h^0}, m_{A^0}); (b): $(m_{h^0}, \tan\beta)$; (c): $(m_{A^0}, \tan\beta)$; (d): $(m_{H^\pm}, \tan\beta)$. The dashed lines indicate the boundaries of the region which are expected to be excluded at 95% confidence level based on Monte Carlo simulations with no signal. In the $(m_{h^0}, \tan\beta)$ projection (plot (b)), the upper boundary of the parameter space is indicated for four values of the top quark mass; from left to right: m_t =169.3, 174.3, 179.3, and 183.0 GeV/c^2.

the stop mixing parameter is set to a large value

All superpartner masses are related through intertwined renormalization group equations. ⇒ Inputting some initial parameters allows one to predict all sparticle and Higgs masses!

For a representative choice of initial parameters $c_q(0)$, $c_{\nu_3}(0)$ the $\mu, tan\beta$ plane can be scanned for the regime consistent with data.



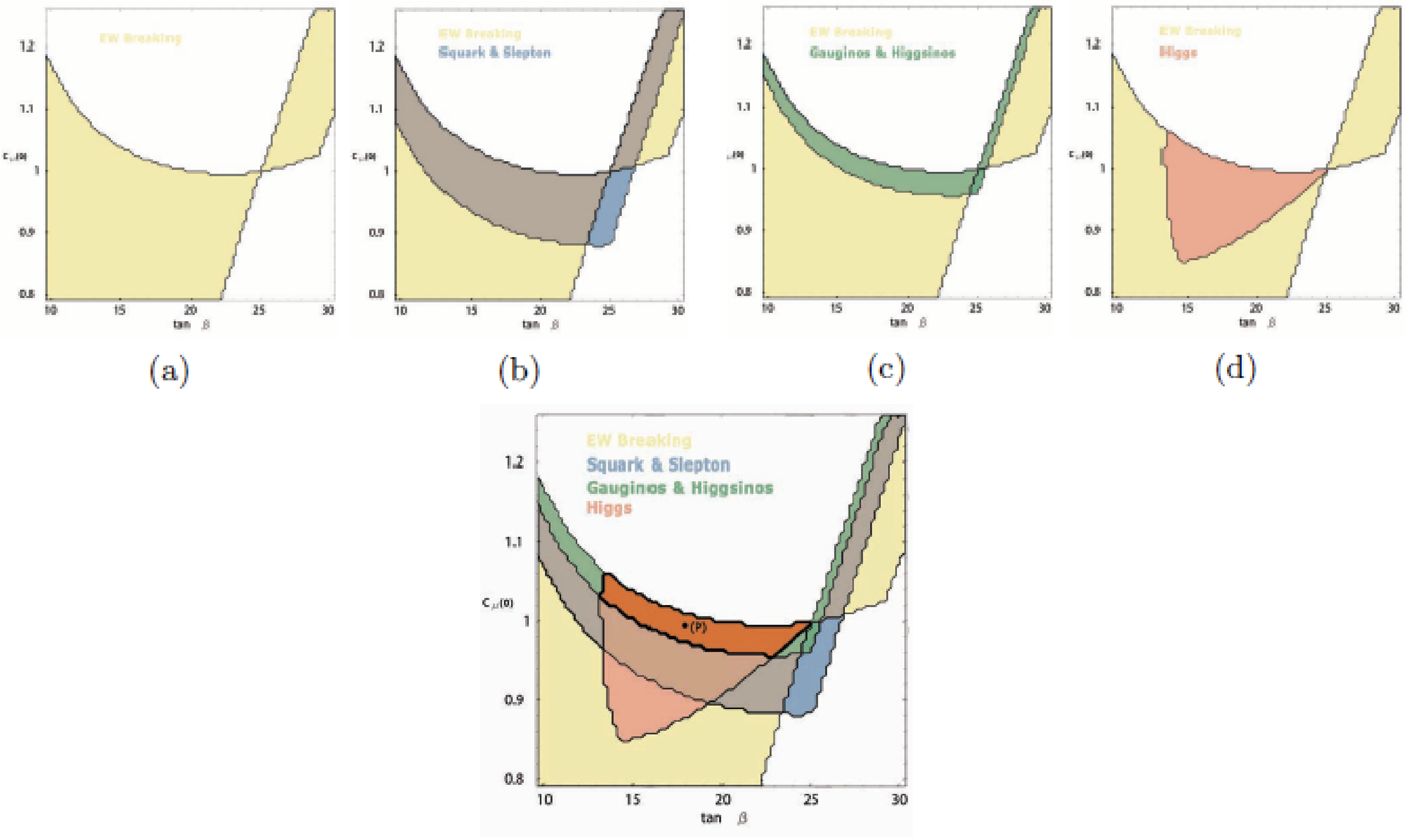
← no EW breaking

all points break B – L →

← satisfy all mass bounds

← EW breaking

Figure 2: A plot of the $c_q(0)$-$c_{\nu_3}(0)$ plane showing physically relevant areas. The yellow and white indicate points whose corresponding $c_\mu(0)$-$\tan\beta$ plane does and does not contain a region of electroweak symmetry breaking respectively. Within the yellow area, the blue shading contains all points whose $c_\mu(0)$-$\tan\beta$ plane has a non-vanishing region satisfying all experimental sparticle and Higgs bounds and for which *all soft susy breaking masses remain positive over the entire scaling range*. (A) and (B) indicate the two points analyzed in detail in the text.



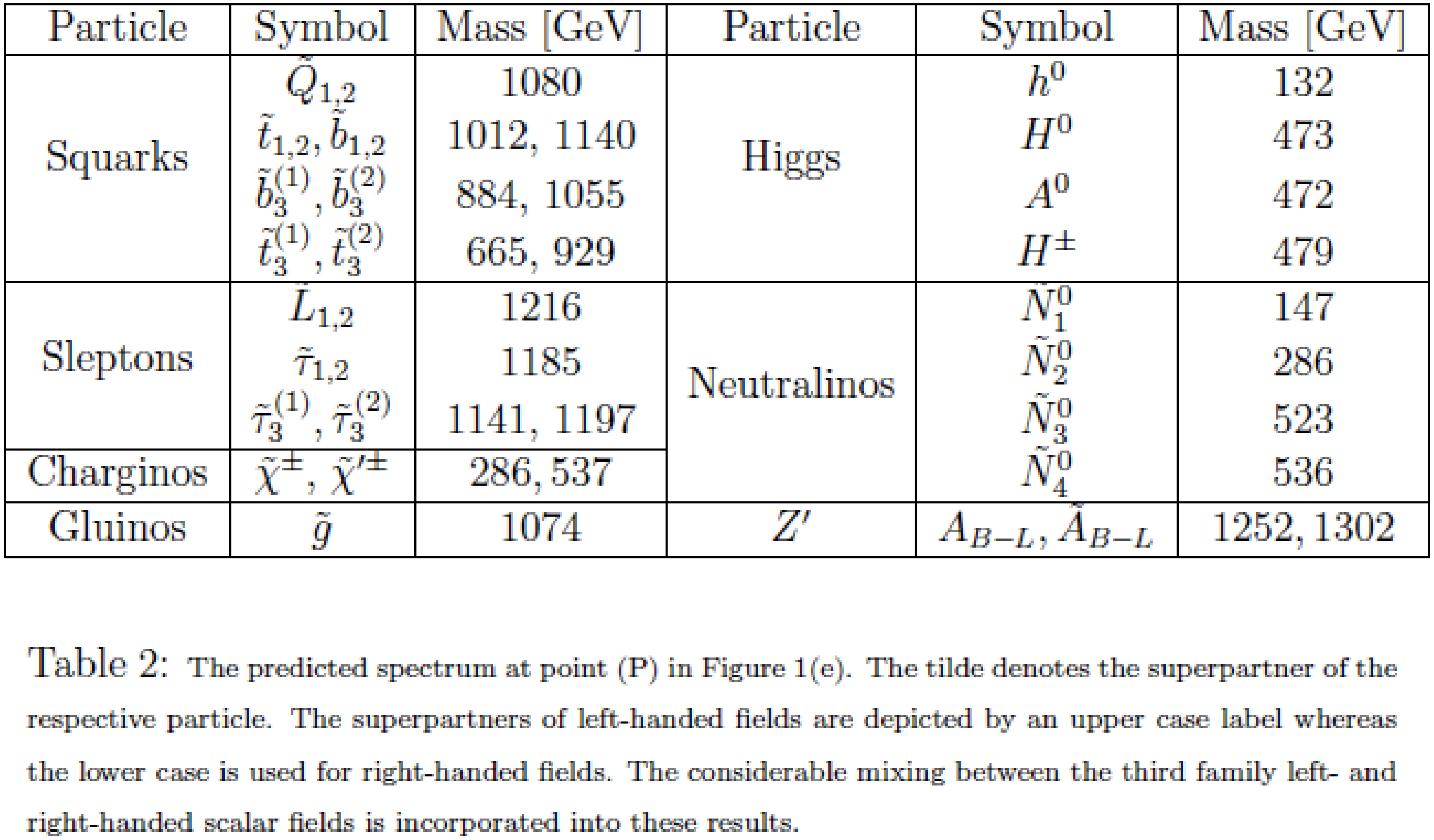
(a) (b) (c) (d)

(e)

point (A)

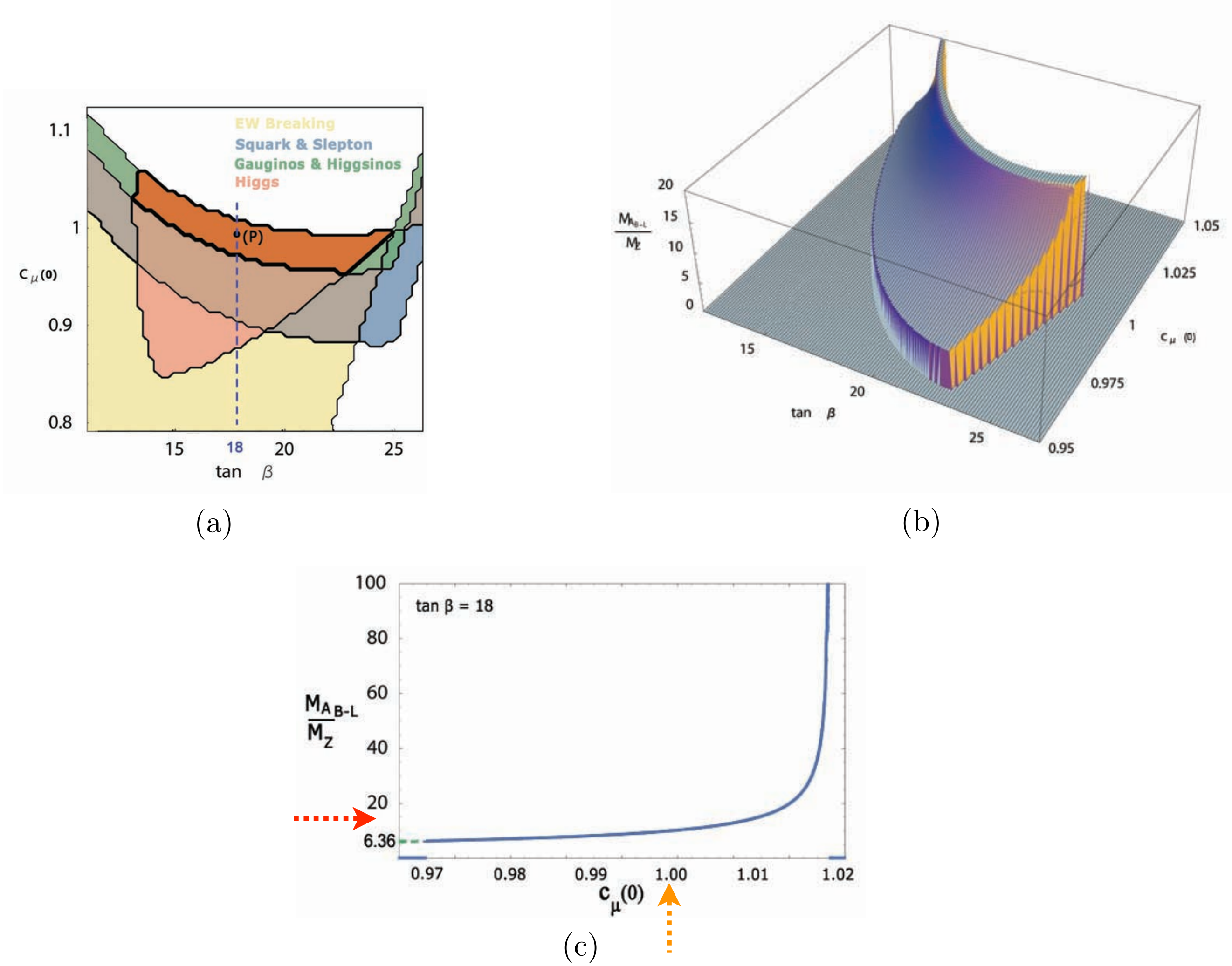
Figure 1: The $c_\mu(0)$-tan β plane corresponding to the point $c_q(0) = 0.75, c_{\nu_3}(0) = 0.75$. The yellow and white regions of (a) indicate where electroweak symmetry is and is not broken respectively. The individual regions satisfying the present experimental bounds for squarks and sleptons, gauginos and Higgs fields are shown in (b),(c) and (d), while their intersection is presented in (e). The dark brown area of (e) is the phenomenologically allowed region where electroweak symmetry is broken and all experimental mass bounds are satisfied. We present our predictions for the sparticle and Higgs masses at point (P).

The predicted sparticle and Higgs masses at point (P) are



Particle	Symbol	Mass [GeV]	Particle	Symbol	Mass [GeV]
Squarks	$\tilde{Q}_{1,2}$	1080	Higgs	h^0	132
	$\tilde{t}_{1,2}, \tilde{b}_{1,2}$	1012, 1140		H^0	473
	$\tilde{b}_3^{(1)}, \tilde{b}_3^{(2)}$	884, 1055		A^0	472
	$\tilde{t}_3^{(1)}, \tilde{t}_3^{(2)}$	665, 929		$H^{\pm}$	479
Sleptons	$\tilde{L}_{1,2}$	1216	Neutralinos	$\tilde{N}_1^0$	147
	$\tilde{\tau}_{1,2}$	1185		$\tilde{N}_2^0$	286
	$\tilde{\tau}_3^{(1)}, \tilde{\tau}_3^{(2)}$	1141, 1197		$\tilde{N}_3^0$	523
Charginos	$\tilde{\chi}^{\pm}, \tilde{\chi}'^{\pm}$	286, 537		$\tilde{N}_4^0$	536
Gluinos	$\tilde{g}$	1074	Z'	$A_{B-L}, \tilde{A}_{B-L}$	1252, 1302

Table 2: The predicted spectrum at point (P) in Figure 1(e). The tilde denotes the superpartner of the respective particle. The superpartners of left-handed fields are depicted by an upper case label whereas the lower case is used for right-handed fields. The considerable mixing between the third family left- and right-handed scalar fields is incorporated into these results.



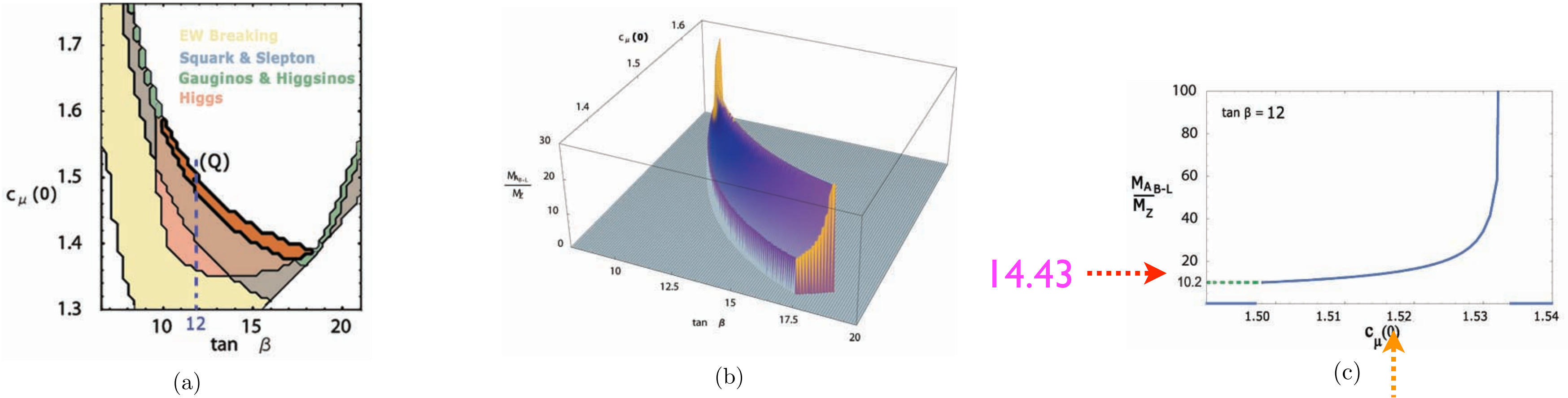
(a)

(b)

(c)

Figure 4: Plot (a) shows the $c_\mu(0)$-$\tan\beta$ plane corresponding to point (A) in Figure 2 with the phenomenologically allowed region indicated in dark brown. The mass spectrum at (P) was presented in Table 2. A plot of the hierarchy M_{B-L}/M_Z over the allowed region is given in (b). Graph (c) shows the hierarchy as a function of $c_\mu(0)$ along the $\tan\beta = 18$ line passing through (P).

- $M_{A_{B-L}}/M_Z = 1252/91 = 13.76$ hierarchy at (P)



(a) (b) (c)

Figure 5: Plot (a) shows the $c_\mu(0)$-$\tan\beta$ plane corresponding to point (B) in Figure 2 with the phenomenologically allowed region indicated in dark brown. The mass spectrum at (Q) was presented in Table 3. A plot of the hierarchy M_{B-L}/M_Z over the allowed region is given in (b). Graph (c) shows the hierarchy as a function of $c_\mu(0)$ along the $\tan\beta = 12$ line passing through (Q).

Particle	Symbol	Mass [GeV]	Particle	Symbol	Mass [GeV]
Squarks	$\tilde{Q}_{1,2}$	850	Higgs	h^0	127
	$\tilde{t}_{1,2}, \tilde{b}_{1,2}$	775, 953		H^0	382
	$\tilde{b}_3^{(1)}, \tilde{b}_3^{(2)}$	670, 915		A^0	381
	$\tilde{t}_3^{(1)}, \tilde{t}_3^{(2)}$	456, 737		$H^\pm$	390
Sleptons	$\tilde{L}_{1,2}$	1255	Neutralinos	$\tilde{N}_1^0$	97
	$\tilde{\tau}_{1,2}$	1237		$\tilde{N}_2^0$	189
	$\tilde{\tau}_3^{(1)}, \tilde{\tau}_3^{(2)}$	1217, 1246		$\tilde{N}_3^0$	499
Charginos	$\tilde{\chi}^\pm, \tilde{\chi}'^\pm$	190, 510		$\tilde{N}_4^0$	509
Gluinos	$\tilde{g}$	712	Z'	$A_{B-L}, \tilde{A}_{B-L}$	1314, 1348

Table 3: The predicted spectrum at point (Q) in Figure 3. The tilde denotes the superpartner of the respective particle. The superpartners of left-handed fields are depicted by an upper case label whereas the lower case is used for right-handed fields. The mixing between the third family left- and right-handed scalar fields is incorporated.

Some $\langle \nu_3 \rangle \neq 0$ Phenomenology:

Ambroso, Ovrut 2009/2010
Barger, Perez, Spinner

(A) Proton Decay

Expanding $\nu_3 = \langle \nu_3 \rangle + \nu_3'$ and diagonalizing the kinetic energy $\Rightarrow$ the superpotential becomes

$$\mathcal{W} = W + \epsilon_3 \sum_{i=1}^{3} \lambda_{e,i} L_3 L_i e_i + \epsilon_3 \sum_{i=1}^{3} \lambda_{d,i} L_3 Q_i d_i \; + 0 \; u_i d_j d_k$$

lepton number violating — baryon number violating

where $\epsilon_3 = \lambda_{\nu_3} \dfrac{\langle \nu_3 \rangle}{\mu}$. The baryon number violating operators can only arise from B-L invariant higher-dimension terms

$$\frac{1}{M_C} \gamma_{ijk} \, \nu_3 u_i d_j d_k \ , \qquad \gamma_{ijk} = -\gamma_{ikj}$$

When $\langle \nu_3 \rangle \neq 0$ these induce

$$\lambda''_{ijk} u_i d_j d_k \ , \qquad \lambda''_{ijk} = \gamma_{ijk} \frac{\langle \nu_3 \rangle}{M_C}$$

Nucleon decay is generated from

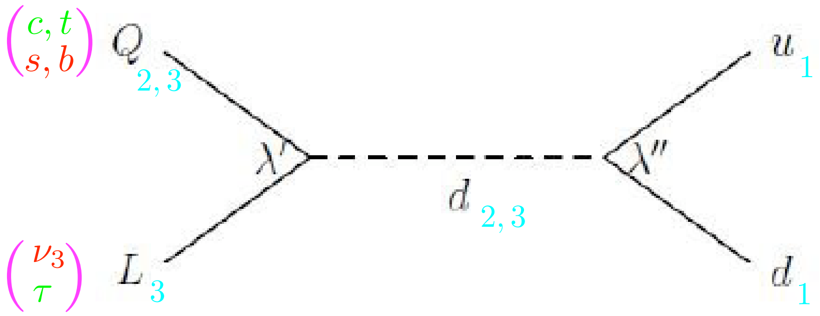


Figure 13: Effective operators generated by the dimension 4 interactions $\lambda'_{ijk}L_iQ_jd_k$ and $\lambda''_{ijk}u_id_jd_k$. When the external fields are light families, these graphs induce nucleon decay. The solid lines represent fermions while the dashed line represents scalar propagators.

For proton decay, the relevant baryon violating operators are

$$\lambda''_{11k}u_1d_1d_k \ , \quad k = 2, 3$$

For the B-L MSSM with $\langle \nu_3 \rangle \neq 0$ the relevant lepton violating terms are

$$\epsilon_3\lambda_{d,k}\overset{\overset{\epsilon}{\downarrow}}{L}_3Q_kd_k \ , \quad k = 2, 3$$

Since the masses of τ^+ and B^+ exceed the proton mass, the only possible decay channel is

$$p \longrightarrow K^+ + \bar{\nu}_3$$

The product of couplings inducing this decay is

$$\lambda'\lambda'' = \epsilon_3 \lambda_{d,2} \gamma_{112} \frac{\langle \nu_3 \rangle}{M_C}$$

This decay will be suppressed below observed bound if

$$\lambda'\lambda'' < \mathcal{O}(10^{-25})$$

For example, evaluating parameters at the point (P) discussed above

and taking $\gamma_{112} \sim \mathcal{O}(1)$ gives

$$\lambda'\lambda'' < 6.89 \times 10^{-16} \lambda_{\nu_3} \quad \Rightarrow \quad \lambda_{\nu_3} \lesssim 10^{-10}$$

- Sufficiently suppresses proton decay

Also

- Consistent with baryogenesis and gravitino dark matter

(B) Neutrino Masses

To compute the neutrino masses, must consider the full neutralino mass matrix. In the basis $(\psi_{N_3}, \psi_{\nu_3}, \lambda_{B-L}, \lambda_Y, \lambda_{W^0}, \tilde{\bar{H}}^0, \tilde{H}^0)$ this is

$\psi_{\nu_3}, \lambda_{B-L}$ mixing

$$\begin{pmatrix} 0 & \lambda_{\nu_3}\langle H\rangle & 0 & 0 & 0 & 0 & \lambda_{\nu_3}\langle\nu_3\rangle \\ \lambda_{\nu_3}\langle H\rangle & 0 & \sqrt{2}g_{B-L}\langle\nu_3\rangle & 0 & 0 & 0 & 0 \\ 0 & \sqrt{2}g_{B-L}\langle\nu_3\rangle & M_4 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & M_1 & 0 & -\frac{g_Y\langle\bar{H}\rangle}{\sqrt{2}} & \frac{g_Y\langle H\rangle}{\sqrt{2}} \\ 0 & 0 & 0 & 0 & M_2 & \frac{g_2\langle\bar{H}\rangle}{\sqrt{2}} & -\frac{g_2\langle H\rangle}{\sqrt{2}} \\ 0 & 0 & 0 & -\frac{g_Y\langle\bar{H}\rangle}{\sqrt{2}} & \frac{g_2\langle\bar{H}\rangle}{\sqrt{2}} & 0 & -\mu \\ \lambda_{\nu_3}\langle\nu_3\rangle & 0 & 0 & \frac{g_Y\langle H\rangle}{\sqrt{2}} & -\frac{g_2\langle H\rangle}{\sqrt{2}} & -\mu & 0 \end{pmatrix}$$

MSSM

Note that terms proportional to the left-handed sneutrino VEV have been dropped since $\langle N_3\rangle \ll \lambda_{\nu_3}\langle\nu_3\rangle$. In the limit $\lambda_{\nu_3} \to 0$, ψ_{N_3} has zero mass and $\psi_{\nu_3}, \lambda_{B-L}$ have diagonal masses

$$m_{\psi_{\nu'_3}} = M_{A_{B-L}}\left(1 - \frac{M_4}{2\sqrt{2}g_{B-L}\langle\nu_3\rangle}\right), m_{\lambda'_{B-L}} = M_{A_{B-L}}\left(1 + \frac{M_4}{2\sqrt{2}g_{B-L}\langle\nu_3\rangle}\right)$$

Note, in the $M_4 \to 0$ supersymmetric limit

$$m_{\psi'_{\nu_3}} = m_{\lambda'_{B-L}} = M_{A_{B-L}}$$

That is, the right-handed neutrino gets a Majorana mass

$$m_{\psi'_{\nu_3}} \simeq \mathcal{O}(M_{A_{B-L}})$$

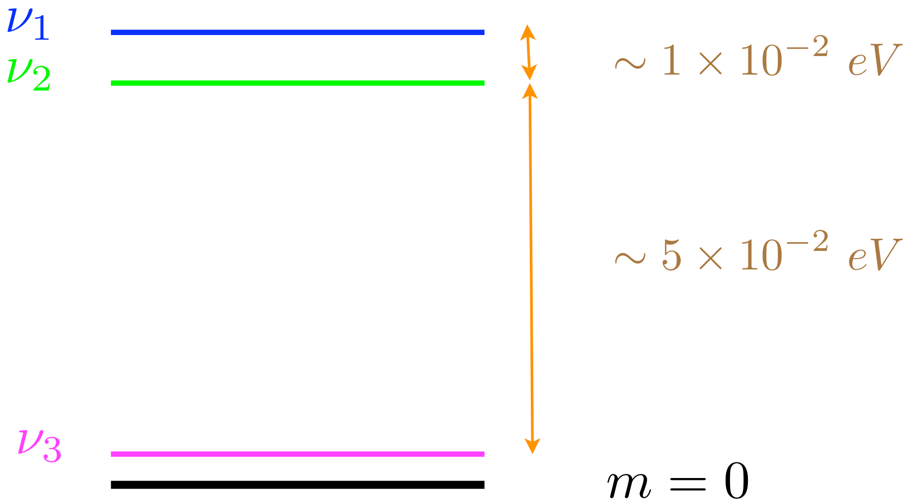
Now turning on $\lambda_{\nu_3} \neq 0$ $\Rightarrow$ left-handed neutrino mass

$$m_{\psi_{N'_3}} \simeq \frac{(\lambda_{\nu_3}\langle\nu_3\rangle)^2}{m_{\tilde{N}^0}}$$

Evaluating at point (P) above and taking $\lambda_{\nu_3} \lesssim 10^{-10}$ to satisfy proton decay bound $\Rightarrow$

$$m_{\psi'_{N_3}} \lesssim 7.2 \times 10^{-7}\ eV$$

This predicts an "inverted" neutrino hierarchy



Some $\langle \nu_3 \rangle \neq 0$ Cosmology:

Ambroso, Ovrut 2009/2010

Gravitino dark matter in R-parity breaking vacua, W. Buchmuller, L. Covi, K. Hamaguchi, A. Ibarra and T. Yanagida, JHEP **0703**, 037 (2007) [arXiv:hep-ph/0702184].

Baryon Asymmetry and Dark Matter

Primordial baryon asymmetry not erased before EW transition requires small lepton number violating terms ⇒

$$\left(\frac{\epsilon_3}{10^{-6}}\right)\left(\frac{\tan\beta}{10}\right) \lesssim 1$$

$$\lambda_{\nu_3} \lesssim 10^{-10}$$

where $\epsilon_3 = \lambda_{\nu_3}\frac{\langle \nu_3 \rangle}{\mu}$. Evaluated, for example, at (P) with

gives

$$\left(\frac{\epsilon_3}{10^{-6}}\right)\left(\frac{\tan\beta}{10}\right) \lesssim 0.933 \times 10^{-3} \ll 1$$

Note that a neutralino is the lightest sparticle in the B-L MSSM. Assuming the gravitino is the LSP and the neutralino the NLSP⇒

gravitino lifetime:

$$\tau_{3/2} \simeq 10^{28} s \left(\frac{\epsilon_3}{10^{-7}}\right)^{-2} \left(\frac{\tan\beta}{10}\right)^{-2} \left(\frac{m_{3/2}}{10\ GeV}\right)^{-3}$$

neutralino lifetime:

$$\tau_{NLSP} \simeq 10^{-9} s \left(\frac{\epsilon_3}{10^{-7}}\right)^{-2} \left(\frac{\tan\beta}{10}\right)^{-2} \left(\frac{m_{\tilde{N}}}{200\ GeV}\right)^{-3}$$

Taking $m_{3/2} \simeq 10^2\ GeV$, the lifetimes evaluated at (P) are

$$\tau_{3/2} \simeq 3.45 \times 10^{28} s \quad , \quad \tau_{NLSP} \simeq 1.77 \times 10^{-6} s$$

The estimated lifetime of the universe is

$$\tau_{\text{universe}} \sim 13.7 \text{ billion years} \simeq 4.32 \times 10^{17} s$$

It follows that in the B-L MSSM

$$\tau_{NLSP} << \tau_{\text{universe}}$$

and

$$\tau_{3/2} >> \tau_{\text{universe}} \Rightarrow \text{gravitino dark matter}$$