Portorož, Slovenia

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Flavored U(1)s

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- Outline

I. Introduction: MFV, global U(1)s, and anomalies

II. U(1) phases and CP violation

III. B violating attractors

IV. Baryonic axions?

V. Conclusion

I. MFV, global U(1)s, anomalies

A. Minimal Flavor Violation

The three generations of quarks/leptons have identical gauge interactions

→ flavor symmetry: $G_F = U(3)^5 = U(3)_Q \times U(3)_U \times U(3)_D \times U(3)_L \times U(3)_E$

Chivukula, Georgi '87

- The only sources of breaking are the Yukawa couplings:

$$\mathcal{L}_{Yukawa} = U Y_u Q H + D Y_d Q H^\dagger + E Y_e L H^\dagger$$

...but artificially invariant if $Y_{u,d} \to g_{U,D} Y_{u,d} g_Q^\dagger$, $Y_e \to g_E Y_e g_L^\dagger$.

(= *spurions*)

- New physics couplings/operators are assumed to be also invariant:

Example: $d_L^I \to d_L^J \gamma^*$ from $\mathcal{O}_\gamma \sim c^{IJ} \bar{Q}^I \gamma_\nu Q^J D_\mu F^{\mu\nu}$

MFV expansion: $c^{IJ} \sim (1 + Y_u^\dagger Y_u + Y_d^\dagger Y_d + \ldots)^{IJ}$

Background values: $v Y_u = m_u V_{CKM}$, $v Y_{d,e} = m_{d,e}$.

D'Ambrosio, et al. '02

B. Flavor symmetry and anomalies

The three generations of quarks/leptons have identical gauge interactions

→ flavor symmetry: $G_F = U(3)^5 = U(3)_Q \times U(3)_U \times U(3)_D \times U(3)_L \times U(3)_E$

But the U(1)s are chiral hence anomalous:

$$\begin{pmatrix} \partial_\mu J_Q^\mu \\ \partial_\mu J_U^\mu \\ \partial_\mu J_D^\mu \\ \partial_\mu J_L^\mu \\ \partial_\mu J_E^\mu \end{pmatrix} = -\frac{N_f}{16\pi^2} \begin{pmatrix} 1 & 3/2 & 1/6 \\ 1/2 & 0 & 4/3 \\ 1/2 & 0 & 1/3 \\ 0 & 1/2 & 1/2 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} g_s^2 G_{\mu\nu}\tilde{G}^{\mu\nu} \\ g^2 W_{\mu\nu}\tilde{W}^{\mu\nu} \\ g'^2 B_{\mu\nu}\tilde{B}^{\mu\nu} \end{pmatrix}$$

B. Flavor symmetry and anomalies

The three generations of quarks/leptons have identical gauge interactions

→ flavor symmetry: $G_F = U(3)^5 = U(3)_Q \times U(3)_U \times U(3)_D \times U(3)_L \times U(3)_E$

But the U(1)s are chiral hence anomalous:

$$\begin{pmatrix} \partial_\mu J_Y^\mu \\ \partial_\mu J_B^\mu \\ \partial_\mu J_L^\mu \\ \partial_\mu J_{PQ}^\mu \\ \partial_\mu J_E^\mu \end{pmatrix} = -\frac{N_f}{16\pi^2} \begin{pmatrix} 0 & 0 & 0 \\ 0 & 1/2 & -1/2 \\ 0 & 1/2 & -1/2 \\ 1 & 0 & 8/3 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} g_s^2 G_{\mu\nu}\tilde{G}^{\mu\nu} \\ g^2 W_{\mu\nu}\tilde{W}^{\mu\nu} \\ g'^2 B_{\mu\nu}\tilde{B}^{\mu\nu} \end{pmatrix}$$

$U(1)_{B-L}$ and $U(1)_Y$ are anomaly-free.

C. Strong but no weak CP puzzle

Could we use these U(1) transformations to get rid of CPV terms:

$$\mathcal{L}_{\not{CP}} = \theta_C \frac{\alpha_S}{8\pi} G_{\mu\nu}\tilde{G}^{\mu\nu} + \theta_L \frac{g^2}{16\pi^2} W_{\mu\nu}\tilde{W}^{\mu\nu} + \theta_Y \frac{g'^2}{16\pi^2} B_{\mu\nu}\tilde{B}^{\mu\nu}$$

with $\theta_C \to \theta_C - N_f(2\alpha_Q + \alpha_U + \alpha_D)$

$$\theta_L \to \theta_L - N_f(3\alpha_Q + \alpha_L)$$

$$\theta_Y \to \theta_Y - N_f(1/3\alpha_Q + 8/3\alpha_U + 2/3\alpha_D + \alpha_L + 2\alpha_E)$$

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$$\mathcal{L}_{\not{CP}} = \theta_C \frac{\alpha_S}{8\pi} G_{\mu\nu}\tilde{G}^{\mu\nu} + \theta_L \frac{g^2}{16\pi^2} W_{\mu\nu}\tilde{W}^{\mu\nu} + \theta_Y \frac{g'^2}{16\pi^2} B_{\mu\nu}\tilde{B}^{\mu\nu}$$

with $\theta_C \to \theta_C - \arg\det \mathbf{Y}_u - \arg\det \mathbf{Y}_d$

$$\theta_L \to \theta_L - N_f(3\alpha_Q + \alpha_L)$$

$$\theta_Y \to \theta_Y + N_f(3\alpha_Q + \alpha_L) - \tfrac{8}{3}\arg\det \mathbf{Y}_u - \tfrac{2}{3}\arg\det \mathbf{Y}_d - 2\arg\det \mathbf{Y}_e$$

But $U(3)^5$ is broken by the Yukawa couplings.

= Three $U(1)$ are fixed to get to $v\mathbf{Y}_u = m_u V_{CKM}$, $v\mathbf{Y}_{d,e} = m_{d,e}$.

$B_{\mu\nu}\tilde{B}^{\mu\nu}$: removed by partial integration.

$W_{\mu\nu}\tilde{W}^{\mu\nu}$: removed thanks to $U(1)_{B+L}$ (choice for $3\alpha_Q + \alpha_L$).

$G_{\mu\nu}\tilde{G}^{\mu\nu}$: cannot be removed → Strong CP puzzle.

D. Flavor-blind multi-fermion transitions

t'Hooft '76

Instantons still induce $U(1)$-breaking but $SU(3)^5$-invariant transitions:

Singlet QCD anomaly:

$$\mathcal{H}_{eff}^{axial} \sim g_{axial}(\varepsilon^{IJK}Q^I Q^J Q^K)^2(\varepsilon^{IJK}U^I U^J U^K)(\varepsilon^{IJK}D^I D^J D^K)$$

→ Mass for the eta prime.

B+L anomaly:

$$\mathcal{H}_{eff}^{B+L} \sim g_{B+L}(\varepsilon^{IJK}Q^I Q^J Q^K)^3(\varepsilon^{IJK}L^I L^J L^K)$$

→ Sphalerons in leptogenesis.

So: MFV should be based on $SU(3)^5$ instead of $U(3)^5$.

Four $U(1)$ are necessarily fixed, only $U(1)_{B-L}$ may remain.

II. U(1) phases and CP-violation

A. U(1) rotations and anomalous CP-violating phases

Flavor-blind anomalous couplings are naturally CP-violating

Singlet QCD anomaly:

$$\mathcal{H}_{eff}^{axial} \sim g_{axial}(\varepsilon^{IJK}Q^I Q^J Q^K)^2(\varepsilon^{IJK}U^I U^J U^K)(\varepsilon^{IJK}D^I D^J D^K)$$

Under $U(1)^5$: $g_{axial} \to |g_{axial}| \exp i(\delta_{axial} + \underbrace{N_f(2\alpha_Q + \alpha_U + \alpha_D)}_{})$

$$= -\arg\det \mathbf{Y}_u - \arg\det \mathbf{Y}_d = \theta_{eff} - \theta_C$$

B+L anomaly:

$$\mathcal{H}_{eff}^{B+L} \sim g_{B+L}(\varepsilon^{IJK}Q^I Q^J Q^K)^3(\varepsilon^{IJK}L^I L^J L^K)$$

Under $U(1)^5$: $g_{B+L} \to |g_{B+L}| \exp i(\delta_{B+L} + \underbrace{N_f(3\alpha_Q + \alpha_L)}_{})$

$$= \theta_L$$

Two additional free and CP-violating parameters in the SM?

B. U(1) rotations and CP-violating B and/or L violating couplings

Simplest ΔB or ΔL operators allowed by the SM flavor structures:

$$SU(3)_Q \xleftrightarrow{\mathrm{Y}_u} SU(3)_U \qquad SU(3)_Q \xleftrightarrow{\mathrm{Y}_d} SU(3)_D \qquad\qquad SU(3)_L \xleftrightarrow{\mathrm{Y}_e} SU(3)_E$$

E.g.: $\varepsilon^{IJK} Q^{\dagger I} (U\mathrm{Y}_u)^J (D\mathrm{Y}_d)^K$ $\qquad$ $\varepsilon^{IJK} L^{\dagger I} L^{\dagger J} (E\mathrm{Y}_e)^K$

$\to \exp iN_f \alpha_Q$ $\qquad$ $\to \exp iN_f \alpha_L$

$$\mathcal{H}_{eff} = \frac{1}{\Lambda^5}\Big[\underbrace{c_1 E L^{\dagger 2} U^3 + c_2 L^{\dagger 3} Q^{\dagger} U^2}_{\Delta B, \Delta L = 1, 3} + \underbrace{c_3 D^4 U^2 + c_4 D^3 U Q^{\dagger 2} + c_5 D^2 Q^{\dagger 4}}_{\Delta B, \Delta L = 2, 0}\Big]$$

can induce proton decay! $\qquad$ can induce neutron oscillations!

B. U(1) rotations and CP-violating B and/or L violating couplings

Simplest ΔB or ΔL operators allowed by the SM flavor structures:

E.g.: $\varepsilon^{IJK} Q^{\dagger I} (U \mathrm{Y}_u)^J (D \mathrm{Y}_d)^K$ $\qquad$ $\varepsilon^{IJK} L^{\dagger I} L^{\dagger J} (E \mathrm{Y}_e)^K$

$\rightarrow \exp i N_f \alpha_Q$ $\qquad$ $\rightarrow \exp i N_f \alpha_L$

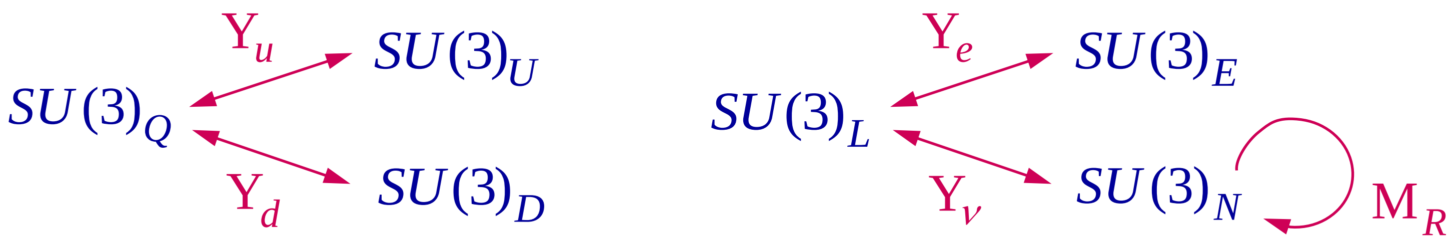
$$\mathcal{H}_{eff} = \frac{1}{\Lambda^5}\Big[\underbrace{c_1 E L^{\dagger 2} U^3 + c_2 L^{\dagger 3} Q^{\dagger} U^2}_{\Delta B, \Delta L = 1, 3} + \underbrace{c_3 D^4 U^2 + c_4 D^3 U Q^{\dagger 2} + c_5 D^2 Q^{\dagger 4}}_{\Delta B, \Delta L = 2, 0}\Big]$$

$\rightarrow \exp i N_f (\alpha_Q + \alpha_L)$ $\qquad$ $\rightarrow \exp i N_f (2\alpha_Q)$

Both classes of operators cannot be made real at the same time.

B. U(1) rotations and CP-violating B and/or L violating couplings

Weinberg operators are naturally CP-violating:



E.g.: $\varepsilon^{IJK} Q^{\dagger I} (U Y_u)^J (D Y_d)^K$ $\qquad$ $\varepsilon^{IJK} L^{\dagger I} (\underbrace{\nu Y_\nu^T M_R^{-1} Y_\nu}_{m_\nu / v} Y_e^\dagger Y_e)^{JK}$

Weinberg '79

$$\mathcal{H}_{eff} = H^2 L (Y_\nu^T M_R^{-1} Y_\nu) L + \frac{1}{\Lambda^2}\left[c_1 LQ^3 + c_2 EU^2 D + c_3 EUQ^{\dagger 2} + c_4 LQD^\dagger U^\dagger \right]$$

$$c_i \to |c_i| \exp i(\delta_i + \underbrace{N_f (3\alpha_Q + \alpha_L)}_{=\theta_L})$$

$\downarrow$

Conventionally fixed: $-2\alpha_L \equiv \arg(Y_\nu^T M_R^{-1} Y_\nu)^{11}$

C. Supersymmetry: MFV for R-parity violating couplings

1. Take the usual seesaw : $-2\alpha_L \equiv \arg(\mathrm{Y}_\nu^T \mathrm{M}_R^{-1} \mathrm{Y}_\nu)^{11}$

2. Get rid of $W_{\mu\nu}\tilde{W}^{\mu\nu} \Rightarrow 3\alpha_Q = \theta_L / N_f - \alpha_L$: All 5 phases fixed!

3. Add $\Delta B = 1$ supersymmetric couplings: $\mathcal{W}_{RPV} = \lambda''^{IJK} U^I D^J D^K$

4. Impose MFV, e.g. $\lambda''^{IJK} = \lambda \varepsilon^{LMN} \mathrm{Y}_u^{IL} \mathrm{Y}_d^{JM} \mathrm{Y}_d^{KN}$ (Holomorphic MFV)

↑ O(1) free parameter

5. The RPV coupling is then CP-violating, even when λ is assumed real:

$$\lambda'' \to |\lambda''| \exp i(\delta_{\lambda''} + N_f \alpha_Q)$$

↑ Small CKM-induced phase

III. B violating attractors

A. Flavored R-parity violation in the MSSM

Nikolidakis, CS '07

$$\mathcal{W}_{RPV} \supset \underbrace{\lambda^{IJK} L^I L^J E^K + \lambda'^{IJK} L^I Q^J D^K}_{\Delta L = 1} + \underbrace{\lambda''^{IJK} U^I D^J D^K}_{\Delta B = 1}$$

Violates selection rules:

$\Delta L = 3$ hierarchies

$\oplus$

$\Delta L = 2$ neutrino mass

$$\lambda'^{IJK} \sim \varepsilon^{ILM} (\underbrace{v \mathrm{Y}_\nu^T \mathrm{M}_R^{-1} \mathrm{Y}_\nu}_{m_\nu / v} \mathrm{Y}_e^\dagger \mathrm{Y}_e)^{LM} \mathrm{Y}_d^{KJ}$$

Yukawa-induced hierarchies:

$$\lambda''^{IJK} \sim \varepsilon^{LJK} (\mathrm{Y}_u \mathrm{Y}_d^\dagger)^{IL}$$

Dominant, breaks $U(1)_D$

$$\lambda''^{IJK} \sim \varepsilon^{LMN} \mathrm{Y}_u^{IL} \mathrm{Y}_d^{JM} \mathrm{Y}_d^{KN}$$

Holomorphic, breaks $U(1)_Q$

A. Flavored R-parity violation in the MSSM

Nikolidakis, CS '07

$$\mathcal{W}_{RPV} \supset \underbrace{\lambda^{IJK} L^I L^J E^K + \lambda'^{IJK} L^I Q^J D^K}_{\Delta L = 1} + \underbrace{\lambda''^{IJK} U^I D^J D^K}_{\Delta B = 1}$$

Violates selection rules:

$\Delta L = 3$ hierarchies

$\oplus$

$\Delta L = 2$ neutrino mass

$$\Rightarrow \begin{cases} \lambda^{IJK} < 10^{-13} \\ \lambda'^{IJK} < 10^{-17} \end{cases}$$

Yukawa-induced hierarchies:

Dominant :

λ''	ds	sb	bd
u	5	5	5
c	4	6	5
t	1	5	4

$x \equiv \mathcal{O}(10^{-x})$

$\tan\beta = 5$

Holomorphic:

Csaki, Grossman, Heidenreich '11

λ''	ds	sb	bd
u	13	8	10
c	10	6	7
t	6	5	6

Proton decay is slow enough even for TeV-scale squark masses!

A. Flavored R-parity violation in the MSSM

Nikolidakis, CS '07

$$\mathcal{W}_{RPV} \supset \underbrace{\lambda^{IJK} L^I L^J E^K + \lambda'^{IJK} L^I Q^J D^K}_{\Delta L = 1} + \underbrace{\lambda''^{IJK} U^I D^J D^K}_{\Delta B = 1}$$

Violates selection rules:

$\Delta L = 3$ hierarchies

$\oplus$

$\Delta L = 2$ neutrino mass

$$\Rightarrow \begin{cases} \lambda^{IJK} < 10^{-12} \\ \lambda'^{IJK} < 10^{-14} \end{cases}$$

Yukawa-induced hierarchies:

Dominant :

λ''	ds	sb	bd
u	4	4	4
c	3	4	4
t	0	3	3

$x \equiv \mathcal{O}(10^{-x})$

$\tan\beta = 50$

Holomorphic:

Csaki, Grossman, Heidenreich '11

λ''	ds	sb	bd
u	11	6	8
c	8	4	5
t	4	3	4

Proton decay is slow enough even for TeV-scale squark masses!

B. Form non-renormalization of holomorphic MFV

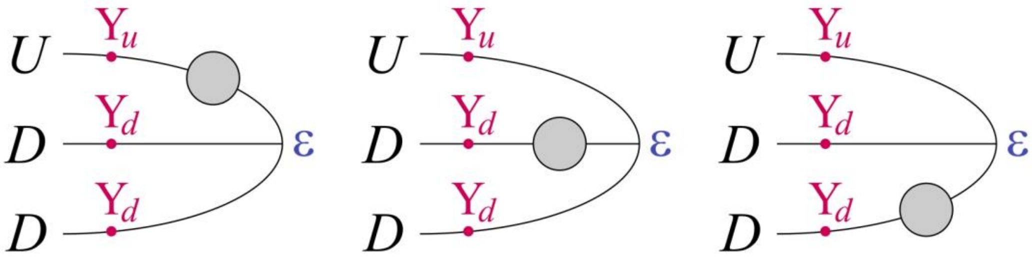
Bernon, CS '14

At the high scale: $\lambda''^{IJK} = \lambda_1 \varepsilon^{LMN} \mathbf{Y}_u^{IL} \mathbf{Y}_d^{JM} \mathbf{Y}_d^{KN}$

At the low scale? $\lambda''^{IJK} = \lambda_1 \varepsilon^{LMN} \mathbf{Y}_u^{IL} \mathbf{Y}_d^{JM} \mathbf{Y}_d^{KN}$

$$+ \lambda_2 \varepsilon^{LMN} (\mathbf{Y}_u \mathbf{Y}_u^\dagger \mathbf{Y}_u)^{IL} \mathbf{Y}_d^{JM} \mathbf{Y}_d^{KN}$$

$$+ \lambda_3 \varepsilon^{LMN} \mathbf{Y}_u^{IL} (\mathbf{Y}_d \mathbf{Y}_u^\dagger \mathbf{Y}_u)^{JM} \mathbf{Y}_d^{KN} + \ldots$$



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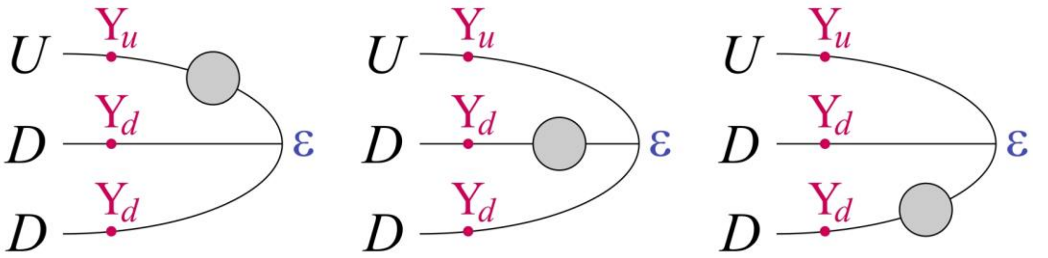
$$+ \lambda_2 \varepsilon^{LMN} (\mathbf{Y}_u \mathbf{Y}_u^\dagger \mathbf{Y}_u)^{IL} \mathbf{Y}_d^{JM} \mathbf{Y}_d^{KN}$$

$$+ \lambda_3 \varepsilon^{LMN} \mathbf{Y}_u^{IL} (\mathbf{Y}_d \mathbf{Y}_u^\dagger \mathbf{Y}_u)^{JM} \mathbf{Y}_d^{KN} + \ldots$$

Actually, these corrections precisely sum up, at all orders



$$\varepsilon^{LJK} A^{LI} \quad + \quad \varepsilon^{ILK} A^{LJ} \quad + \quad \varepsilon^{IJL} A^{LK} = \varepsilon^{IJK} Tr(A)$$

B. Form non-renormalization of holomorphic MFV

Bernon, CS '14

At the high scale: $\lambda''^{IJK} = \lambda_1 \varepsilon^{LMN} \mathbf{Y}_u^{IL} \mathbf{Y}_d^{JM} \mathbf{Y}_d^{KN}$

At the low scale? $\lambda''^{IJK} = \lambda_1 \varepsilon^{LMN} \mathbf{Y}_u^{IL} \mathbf{Y}_d^{JM} \mathbf{Y}_d^{KN}$

$$+ \lambda_2 \varepsilon^{LMN} (\mathbf{Y}_u \mathbf{Y}_u^{\dagger} \mathbf{Y}_u)^{IL} \mathbf{Y}_d^{JM} \mathbf{Y}_d^{KN}$$

$$+ \lambda_3 \varepsilon^{LMN} \mathbf{Y}_u^{IL} (\mathbf{Y}_d \mathbf{Y}_u^{\dagger} \mathbf{Y}_u)^{JM} \mathbf{Y}_d^{KN} + \ldots$$

Actually, these corrections precisely sum up, at all orders,

And holomorphy holds at all scales if it holds at some scale:

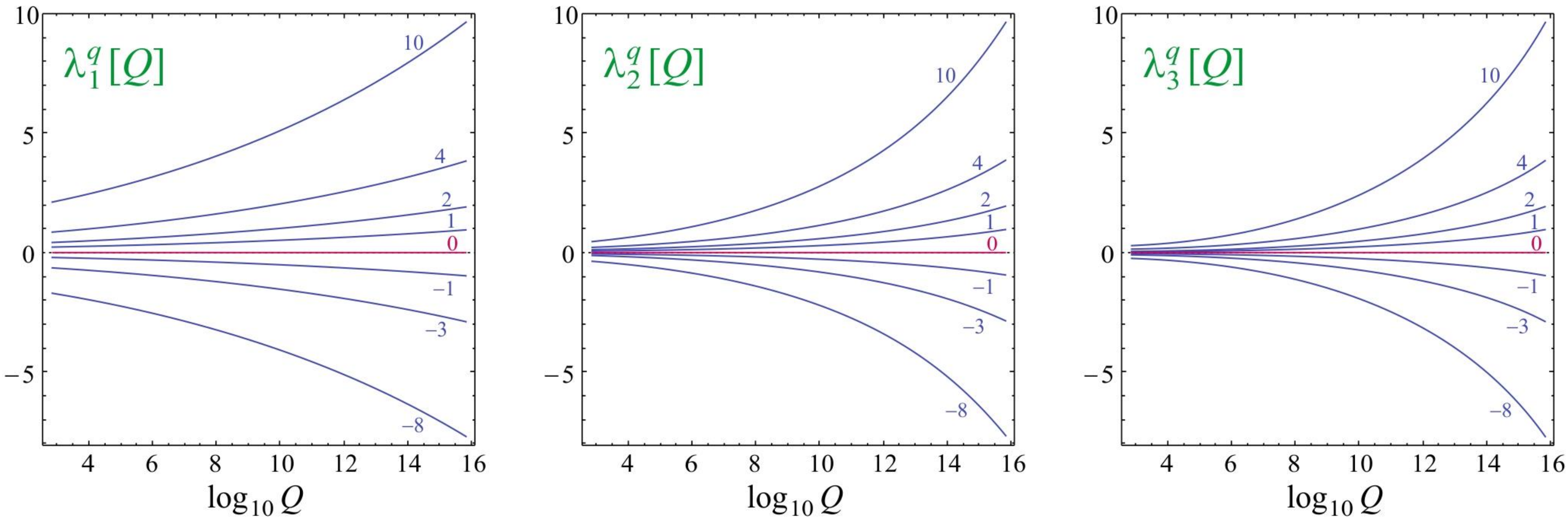
$$\lambda''^{IJK}[t] = \lambda_1[t] \varepsilon^{LMN} \mathbf{Y}_u^{IL}[t] \mathbf{Y}_d^{JM}[t] \mathbf{Y}_d^{KN}[t]$$

$$\frac{d\lambda_1}{dt} = -\lambda_1 (\gamma_{Q^P}^{Q^P} + \gamma_{H_2}^{H_2} + 2\gamma_{H_1}^{H_1})$$

B. Form non-renormalization of holomorphic MFV

Bernon, CS '14

At the high scale: $\lambda''^{IJK} = \lambda_1 \varepsilon^{LMN} \mathbf{Y}_u^{IL} \mathbf{Y}_d^{JM} \mathbf{Y}_d^{KN} + \lambda_2 \varepsilon^{LMN} (\mathbf{Y}_u \mathbf{Y}_u^\dagger \mathbf{Y}_u)^{IL} \mathbf{Y}_d^{JM} \mathbf{Y}_d^{KN} + \lambda_3 \varepsilon^{LMN} \mathbf{Y}_u^{IL} (\mathbf{Y}_d \mathbf{Y}_u^\dagger \mathbf{Y}_u)^{JM} \mathbf{Y}_d^{KN} + \ldots$

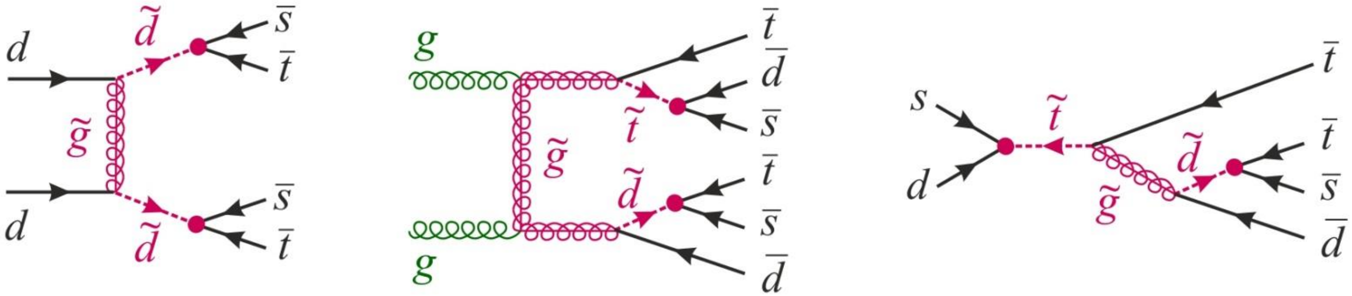


Holomorphy emerges at the low scale whenever only $U(1)_Q$ is broken.

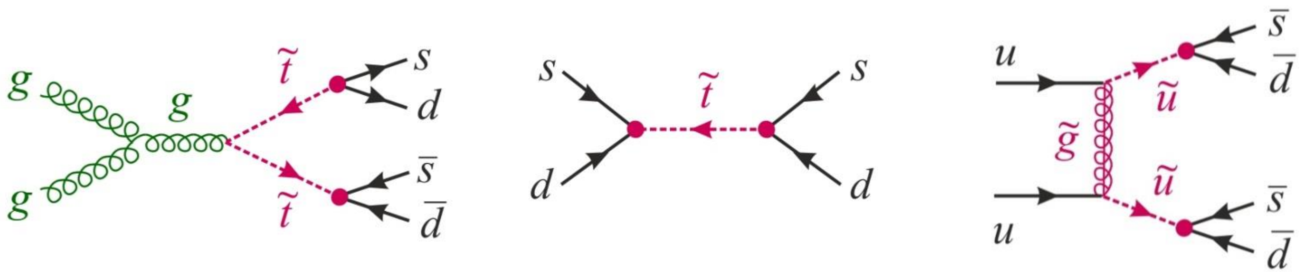
C. Characteristic signatures of the B violating MSSM

Dominant B-violation through $\lambda''_{312} \leq \mathcal{O}(1)$: $\tilde{t}_R d_R s_R,\ t_R \tilde{d}_R s_R,\ t_R d_R \tilde{s}_R$.

- Same sign top pairs → same sign lepton pairs.



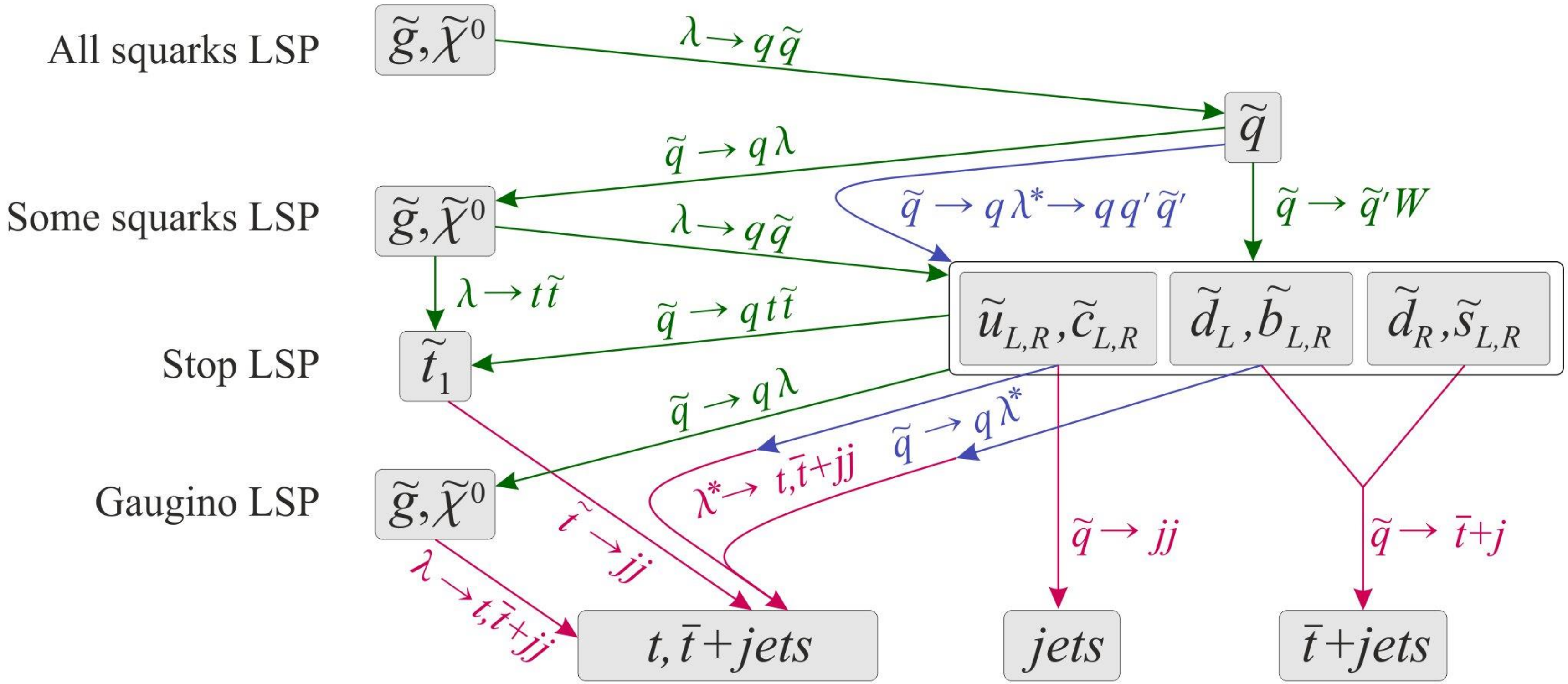
- Dijet resonances from intermediate up-type squarks.



- R-hadrons? Without large mass splitting, sparticles decay too quickly.

C. Characteristic signatures of the B violating MSSM

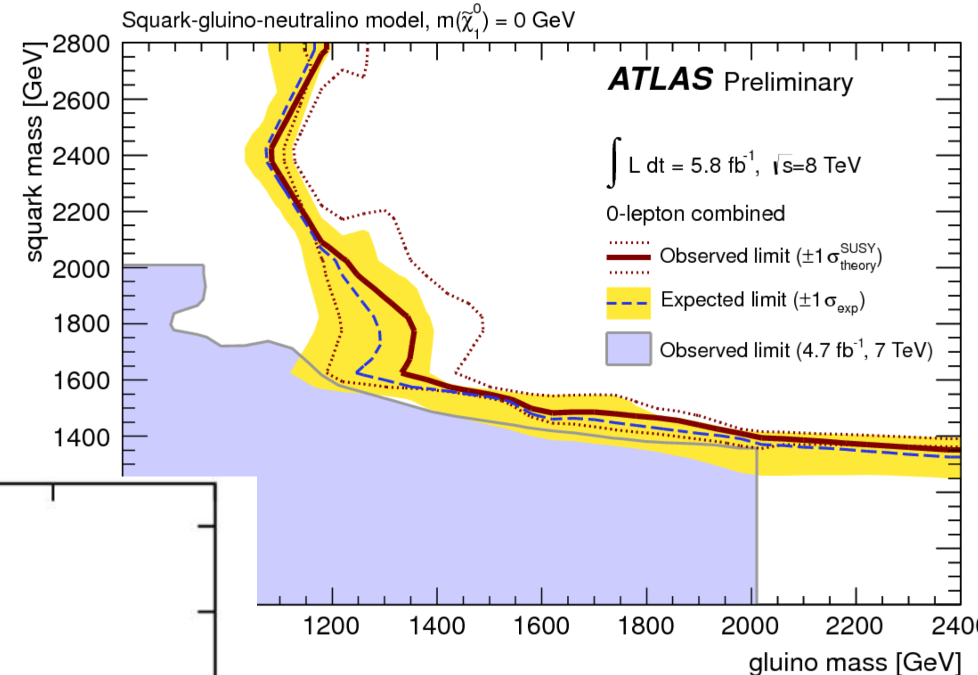
Durieux, CS, '13



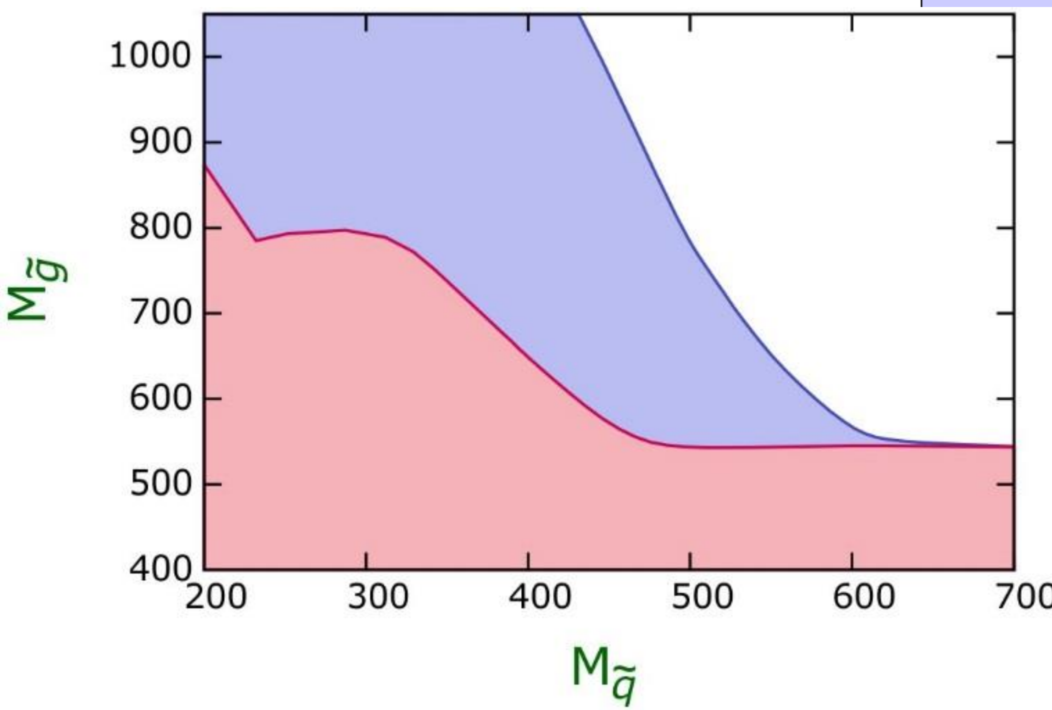
C. Characteristic signatures of the B violating MSSM

Durieux, CS, '13

MSSM with R-parity



(from same sign lepton pairs)

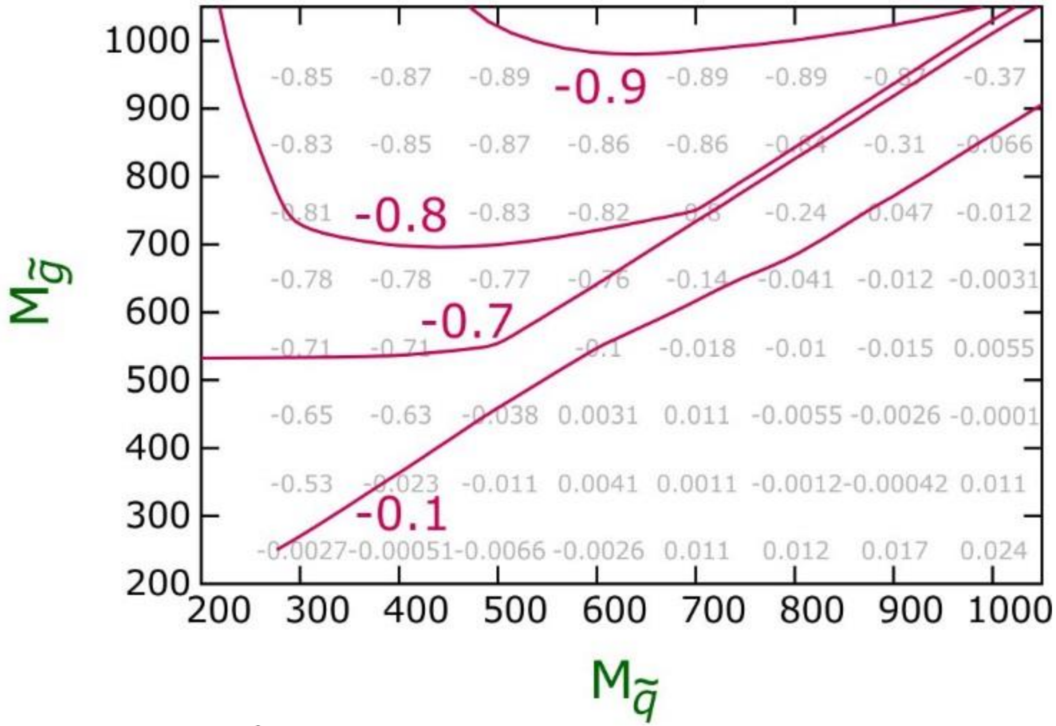


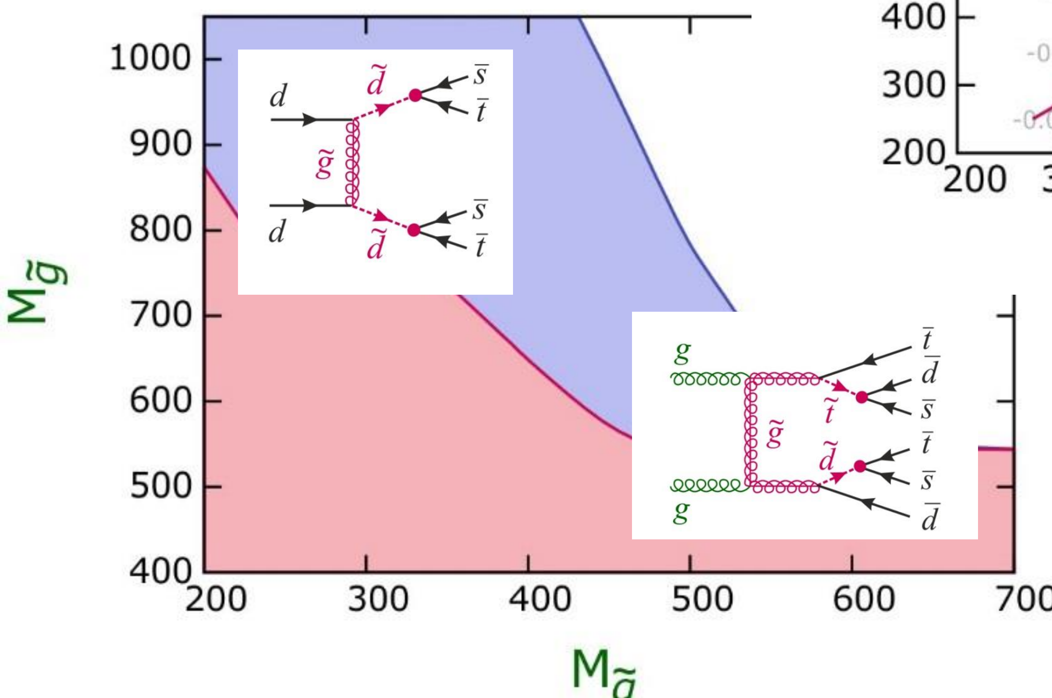
MSSM without R-parity

C. Characteristic signatures of the B violating MSSM

Durieux, CS, ‘13

Lepton charge asymmetry:





MSSM without R-parity

IV. Baryonic Axions?

A. Invisible axion as a solution to the strong CP puzzle

Introduce a new field to spontaneously relax θ_C towards zero.

- Impose $U(1)_{PQ}$ invariance (DFSZ):

$$\mathcal{L} = H_u U \mathrm{Y}_u Q + H_d D \mathrm{Y}_d Q + H_d E \mathrm{Y}_e L + V(H_u, H_d, \phi)$$

$$\supset H_u H_d \phi^2$$

$$e^{iX_u\alpha_{PQ}} \quad e^{-iX_u\alpha_{PQ}} \quad e^{iX_d\alpha_{PQ}} \quad e^{-iX_d\alpha_{PQ}} \quad e^{-i(X_u+X_d)\alpha_{PQ}}$$

- Break $U(1)_{PQ}$ spontaneously → Goldstone boson = axion

- $U(1)_{PQ}$ is a chiral symmetry → explicitly broken by the anomaly.

These (not unique) charges are not always compatible with B violation!

(think about $\lambda''^{IJK} U^I D^J D^K$ in SUSY) Watamura & Yoshimura, '82

B. Could the axion participate in B violating processes?

[Some very preliminary ideas!]

Proton decay to axions?

$$\mathcal{L}_{eff} = \phi \frac{LQQQ}{\Lambda^3} \rightarrow \phi = (v_{PQ} + \eta) e^{ia/v_{PQ}} \rightarrow \mathcal{L}_{eff} = \frac{v_{PQ} LQQQ}{\Lambda^3} + i \frac{aLQQQ}{\Lambda^3}$$

Even with MFV, the scale Λ must be close to v_{PQ}, and the axion should stay invisible.

Supersymmetry? Naively, the couplings could sum up to

$$\mathcal{W}_{eff} = \left(\frac{v_{PQ}}{\Lambda} + i \frac{a}{\Lambda} \right) \lambda''^{IJK} U^I D^J D^K$$

With MFV, proton decay still ok even for large $v_{PQ} / \Lambda \sim 10^5$.

If $m_{\tilde{a}} < m_{p^+}$: $p^+ \rightarrow K^+ \tilde{a} \Rightarrow \Lambda > 10^{3-5}$ TeV.

If $m_{\tilde{a}} > m_{p^+}$: $pp \rightarrow \bar{t} + \tilde{a}$ at the LHC?

Conclusion

1. MFV must allow for B and/or L violation

Since it occurs in the SM → Enforce MFV using $SU(3)^5$ only.

2. Flavor U(1)-breakings are quite automatically CP-violating

In particular, the SM appears to have four CP-violating parameters!

$$\delta_{CKM}\ ,\ \theta_L\ ,\ \theta_C\ ,\ \theta_{eff} = \theta_C - \arg\det \mathbf{Y}_u - \arg\det \mathbf{Y}_d$$

In supersymmetry, RPV should be CP-violating also.

3. In supersymmetry, large B-violation is natural and welcome!

With holomorphy, it even gives a unique IR stable parametrization.

Could a signals in same sign lepton pair searches be around the corner?

4. Axions and B-violation could be intimately linked.