Relatively Heavy Higgs Boson From More Generic Gauge Mediation

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JLE, Ibe, Yanagida, arXiv:1108.3437
More Generic Gauge Mediation

Outline

The State of Things

Gauge Mediation

More Generic Gauge Mediation

Lightest Higgs Boson Mass
Should We Still Study SUSY

- Tuning arguments have worked in the past
- Tuning not yet to severe
- Gauge coupling unification is quite suggestive
- SUSY still has viable dark matter candidates
- True killer of the MSSM (Heavy Higgs) seems unlike
Higgs Searches: Pre LHC

- Pre LHC Higgs: Roughly $m_H > 114\text{GeV}$, $m_H \lesssim 600 \text{ GeV}$
- Pre LHC Supersymmetric Higgs: $m_H \lesssim 130 \text{ GeV}$
Higgs Searches at LHC

- LHC is making significant progress
- The Higgs is either Very Heavy or close to LEP bound
- CMS exclusion plot (Atlas similar except 140GeV)

![Graph showing CMS Preliminary, $\sqrt{s} = 7$ TeV, $L_{\text{int}} = 1.1-1.7$ fb$^{-1}$ limits on Higgs boson mass (GeV/c$^2$)].
CMS $H \rightarrow \gamma\gamma$

- CMS sees prominent peek at 140 GeV, mostly in $H \rightarrow \gamma\gamma$
Atlas $H \rightarrow \gamma\gamma$

- Atlas sees no 140 GeV peek in $H \rightarrow \gamma\gamma$
Higgs Searches at LHC: Continued

- Atlas Low Mass exclusion plot
- Atlas believes $m_H = 128$ GeV (Private Conversation)
Higgs Searches at LHC: Continued

- Exclusion confidence levels of SM Higgs
Why Gauge Mediation?

- Softly broken MSSM has many parameters (105 Martin)
  \[ m_i^2, \ M_i, \ A_{ij}, \ B_{ij} \]

- Generic Soft Masses and A terms give FV

- Phenomenology requires
  \[ m_{f_{ij}}^2 \simeq M_f \delta_{ij} \text{ etc.} \]

- Need a well motivated model with no FV
- Minimal gauge mediation also has no CP problem
Conventional Gauge Mediated SUSY Breaking

- Messengers are in GUT consistent representations
- Simplest representation, $5 + \bar{5}$

\[
\Phi = (\Phi_L \ \Phi_C) \quad \bar{\Phi} = (\bar{\Phi}_L \ \bar{\Phi}_C)
\]

- Messenger parity sequesters the messenger sector

\[
\Phi \rightarrow -\Phi \quad \bar{\Phi} \rightarrow -\bar{\Phi}
\]

- Messenger sector couples to a gauge singlet spurion

\[
W_M = Z \bar{\Phi} \Phi \quad Z = M + \theta^2 F
\]
Without Messenger Parity

- Messengers quantum numbers identical to SM fields
- Flavor violating interactions not forbidden

\[ W = \rho_1 \Phi_L Q_L \bar{U}_R + \rho_2 \bar{\Phi}_L Q_L \bar{D}_R + \rho_3 \bar{\Phi}_L L_L \bar{E}_R , \]

- Generic soft masses are generated
- Operators contributing to Proton decay

\[ W = \lambda_1 \Phi_D Q_L Q_L + \lambda_2 \bar{\Phi}_D Q_L L_L , \]

- Messenger parity seems quite necessary
Scalar masses generated at two loops

\[ m_f^2 \sim \left( \frac{g^2}{16\pi^2} \right)^2 \frac{F^2}{M^2} \]
Mass Generation in Gauge Mediation

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- Trilinears at two loops
  \[ \frac{A_t^2}{m_f^2} \sim \frac{g^2}{16\pi^2} \ll 1 \]
Higgs Boson of mGMSB

- $A \simeq 0$ minimal gauge mediation
- One-loop Higgs mass

\[
m_{h^0}^2 \lesssim m_Z^2 \cos^2 2\beta + \frac{3}{4\pi^2} y_t^2 m_t^2 \sin^2 \beta \left( \log \frac{m_t^2}{m_t^2} + \frac{A_t^2}{m_t^2} - \frac{A_t^4}{12m_t^4} \right).
\]

- Larger log enhance term still present
- $A_t$ contribute very little
- $m_H < 120$ GeV even for $m_{\tilde{g}} = 2.5$ TeV
More Generic Gauge Mediation

Are large $A$-terms possible in gauge mediation?

- Messenger parity $\rightarrow$ the Yukawa and messenger sector interact only at the loop level
- SUSY breaking only communicated through gauge fields
- $A_t$ not possible at one-loop

Wish list for more generic gauge mediation

- Messenger Yukawa sector mixing allowed
- No flavor violation
- No proton decay problems
SUSY-Zero and Messenger Higgs Mixing

➢ Gauge mediation without messenger parity

<table>
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<th>$\phi_+$</th>
<th>$H_u$</th>
<th>$H_d$</th>
<th>10</th>
<th>5*</th>
<th>$N_R$</th>
<th>$\Phi$</th>
<th>$\bar{\Phi}$</th>
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<td>$U(1)$</td>
<td>+1</td>
<td>-2</td>
<td>-3</td>
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<td>+2</td>
<td>0</td>
<td>0</td>
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</tbody>
</table>

$$W = g Z \bar{\Phi} \Phi + \frac{\langle \phi_+^2 \rangle}{\Lambda^2} Z \bar{\Phi} H_u ,$$

➢ Negatively charged couplings forbidden by holomorphy

$$W = \rho_1 \Phi_L Q_L \bar{U}_R + \rho_2 \bar{\Phi}_L Q_L \bar{D}_R + \rho_3 \bar{\Phi}_L L_L \bar{E}_R ,$$

|   | +1 | 0 | 1 | 0 | 1 | +2 | 0 | +2 | +1 |

$$W = \lambda_1 \Phi_D Q_L Q_L + \lambda_2 \bar{\Phi}_D Q_L L_L ,$$

|   | +1 | 0 | 1 | 0 | +1 | +2 |
Type-II Gauge Mediation

- Type-II gauge mediation, $H_u$ mixes with messengers
  \[ W = gZ\Phi\Phi' + g'Z\Phi\bar{L}\bar{H}_u + \mu\bar{H}_uH_d + \tilde{y}_{Uij}\bar{H}_uQ_Li\bar{U}_{Rj}, \]

- Rotating, a messenger Yukawa interaction emerges
  \[ W = gZ\Phi\Phi' + \mu H_uH_d + \mu'\Phi\bar{L}H_d + y_{Uij}H_uQ_Li\bar{U}_{Rj} + y'_{Uij}\Phi\bar{L}Q_Li\bar{U}_{Rj}, \]
  \[ y_{Uij} = \frac{g}{\sqrt{g^2 + g'^2}}\tilde{y}_{Uij}, \quad y'_{Uij} = \frac{g'}{\sqrt{g^2 + g'^2}}\tilde{y}_{Uij}. \]

- Type-II has minimal flavor violation (MFV)
- Messenger Higgs mixing suppressed by $\mu'/M$
Tree Level Effects

- Higgs messenger mixing gives tree level Higgs mass

\[ m_{H_d}^2 = -\mu' \frac{F^2}{M^4 - F^2} . \]

- Tree level effects suppressed by messenger scale

\[ H_d \quad \quad \quad H_d^\dagger \]

\[ Z \quad \quad \quad Z^\dagger \]
One-Loop Scalar Masses

- One-loop squark and slepton masses

\[ \delta m_{Q_3}^2 = \frac{1}{2} \delta m_T^2 \approx \frac{8}{3} \left( \frac{\alpha_3}{4\pi} \right)^2 \frac{F^2}{M^2} - \frac{y_t'^2}{48\pi^2} \frac{F^2}{M^2} \frac{F^2}{M^4}, \quad (x \ll 1) \]

- One-loop contribution is negative

- Positive stop mass constraints

\[ \frac{F}{M^2} \ll 2\sqrt{2} \times \frac{\alpha_3}{y_t'} \]
A-Terms in Gauge Mediation

- A-terms from wave function renormalization

\[ A_t = -\frac{3}{32\pi^2} y_t'^2 \frac{F}{M} \frac{1}{x} \log \left( \frac{1 + x}{1 - x} \right) \approx -\frac{3y_t'^2}{16\pi^2} \frac{F}{M} \] (1)
Two-Loop Scalar Masses

Two-loop contribution from wave function renormalization

\[
\delta m^2_{Q_3} = \frac{y_t'^2}{128\pi^4} \left( 3y_t'^2 + 3y_t^2 - \frac{8}{3}g_3^2 - \frac{3}{2}g_2^2 - \frac{13}{30}g_1^2 \right) \frac{F^2}{M^2},
\]

\[
\delta m^2_T = \frac{y_t'^2}{128\pi^4} \left( 6y_t'^2 + 6y_t^2 - \frac{16}{3}g_3^2 - 3g_2^2 - \frac{13}{15}g_1^2 \right) \frac{F^2}{M^2},
\]

\[
\delta m^2_{H_u} = -9 \frac{y_t^2 y_t'^2}{256\pi^4} \frac{F^2}{M^2}.
\]

Two loop contribution important, not suppressed by \( F/M^2 \).

Two loop contribution POSITIVE for most \( y_t' \)

Two-loop > One-loop contribution unless \( F/M^2 \simeq 1 \)
Lightest Higgs Boson Mass

- The Lightest Higgs boson mass in Type-II
  - \( m_{\text{gluino}} = 2.1 \text{ TeV} \)
  - \( \tan \beta = 10 \)
  - \( \text{N}_{\text{Mess}} = 1 \)

- Upper bound on \( x \) from tachyonic stop mass
- Upper bound on \( y'_t \) from tachyonic slepton

\[
\delta \beta m_i^2 \simeq \frac{1}{8\pi^2} \frac{3}{5} Y g_1^2 S_{\text{new}} \propto m_{Q_3}^2 - 2m_T^2
\]

- \( S \) is large and negative because of two-loop contribution
Mass Spectrum of Type-II

- Slepton and squark masses in Type-II

- Third generation squark masses significantly increased
- Left-handed slepton masses decreased
- Right-handed slepton masses increased
Conclusion

- LHC excluded Higgs mass in most of $145 \sim 400$ GeV (95%)
- Some prominent features are emerging
- Vanilla SUSY models have very light Higgs mass
- Using SUSY-zero, Higgs-Messenger mixing possible
- Higgs-Messenger mixing enhances $A$-terms
- Large $A$-terms Give larger Higgs mass