“N”MSSM

Extra Higgs Particles and Their Masses

-ino for gauge particles
s- for fermions

ie gauginos and
sfermions

SUSY

- Hierarchy problem $\delta m_H^2 < m_P^2$
- The Higgs mass can be protected by using chiral symmetry.
- The minimum number of particles to do this is every particle has a scalar partner.

MSSM

- The SM Higgs doublet has 4 degrees of freedom: 3 are absorbed leaving h_0
- The MSSM has 2 Higgs doublets, therefore 8 degrees of freedom: 3 are absorbed leaving $h_0, H_0, A^0, H^{+/-}$

MSSM (continued)

- 2 doublets means 2 vacuum expectation values (VEVs)
- The sum of the VEV's squared is fixed by W and Z masses, but the ratio is not

Higgs Sector Concerns

- μ problem: $\mu H_1 \cdot H_2$
- The μ is either very large, with "convenient" cancellations with SUSY breaking parameters, or both of the variables are around EW/TeV scale

Adding an Extra Singlet

- $h_s S H_1 \cdot H_2$ replaces $\mu H_1 \cdot H_2$ with $\mu = h_s < S >$
- An extra singlet is the NMSSM
- To protect the mass of S, introduce a $U(1)'$ ("N"MSSM) under which Higgs and singlet are charged

Adding an Extra Singlet

- This singlet would contribute a third neutral Higgs (2 more degrees of freedom).
- The three Higgs masses and mixing are analyzed through a 3 x 3 matrix, similar to the 2 Higgs doublet in the MSSM

Terms in Potential

$$V_F = |h_s|^2 \left[|H_1 \cdot H_2|^2 + |S|^2 (|H_1|^2 + |H_2|^2) \right.$$

$$V_D = \frac{G^2}{8} \left(|H_2|^2 - |H_1|^2 \right)^2 + \frac{g_2^2}{2} |H_1^\dagger H_2|^2 + \frac{g_1'^2}{2} \left(Q_1 |H_1|^2 + Q_2 |H_2|^2 + Q_S |S|^2 \right)^2$$

$$V_{soft} = m_1^2 |H_1|^2 + m_2^2 |H_2|^2 + m_S^2 |S|^2 - (A h_s S H_1 \cdot H_2 + h.c.)$$

Mass Matrix

$$(M^2)_{h^0} = \begin{pmatrix} \kappa_1^2 v_1^2 + \frac{A h_s s v_2}{\sqrt{2} v_1} & \kappa_{12} v_1 v_2 - \frac{A h_s s}{\sqrt{2}} & \kappa_{1s} v_1 s - \frac{A h_s v_2}{\sqrt{2}} \\ \kappa_{12} v_1 v_2 - \frac{A h_s s}{\sqrt{2}} & \kappa_2^2 v_2^2 + \frac{A h_s s v_1}{\sqrt{2} v_2} & \kappa_{2s} v_2 s - \frac{A h_s v_1}{\sqrt{2}} \\ \kappa_{1s} v_1 s - \frac{A h_s v_2}{\sqrt{2}} & \kappa_{2s} v_2 s - \frac{A h_s v_1}{\sqrt{2}} & \kappa_s^2 s^2 + \frac{A h_s}{\sqrt{2}} \frac{v_1 v_2}{s} \end{pmatrix}$$

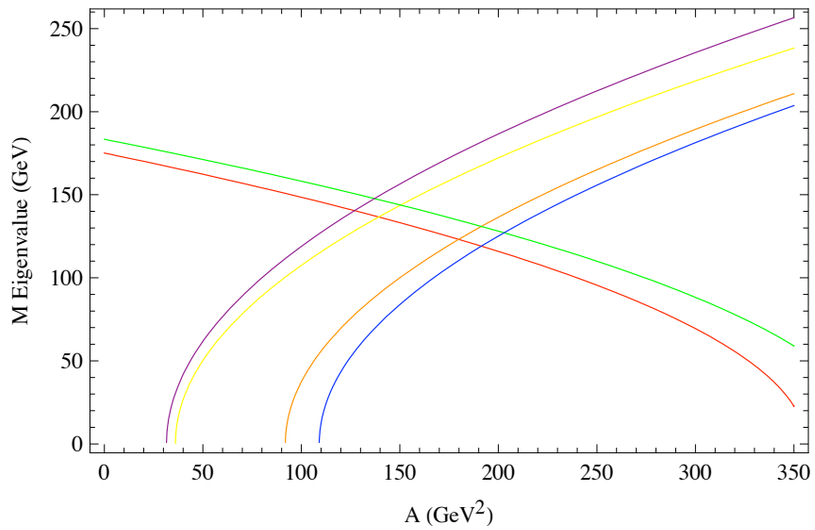
$$\kappa_i^2 = G^2/4 + g'^2_1 Q_i^2 \qquad \kappa_{is} = h_s^2 + g'^2_1 Q_i Q_S$$

$$\kappa_{12} = h_s^2 + g'^2_1 Q_1 Q_2 - G^2/4 \qquad \kappa_s^2 = g'^2_1 Q_S^2$$

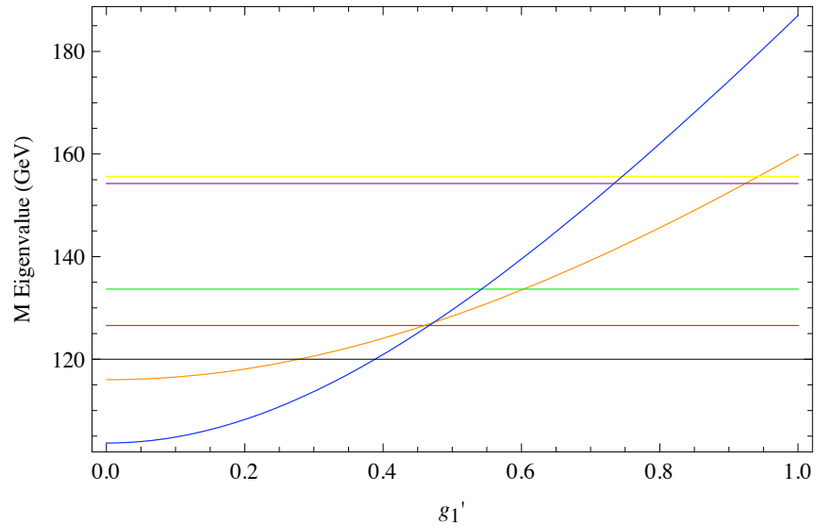
Cases

- This matrix is interesting in various limits
- Suppress the $U(1)'$ at leading order

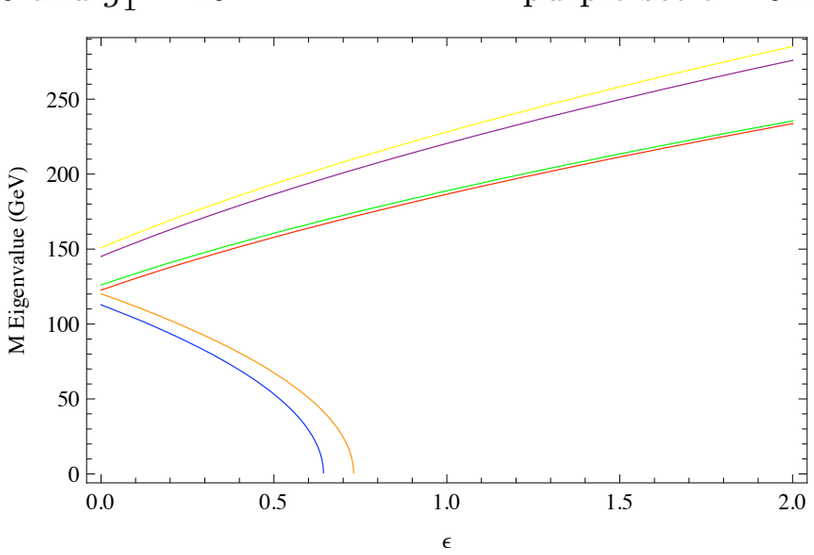
- The first simple case is that $< S >$ is much larger than $< H_1 >$ or $< H_2 >$.
- The second simple case is that they are approximately equal.



(a)A dependence: red, orange and yellow set $\epsilon = 0.05$ and $g_1' = 10^{-3}$, while green, blue and purple set $\epsilon = 0.20$ and $g_1' = 10^{-5}$



(b)g_1' dependence: red, orange and yellow set $\epsilon = 0.05$ and $A = 170GeV^2$, while green, blue and purple set $\epsilon = 0.10$ and $A = 160GeV^2$



(c)ϵ dependence: red, orange and yellow set $g_1' = 10^{-5}$ and $A = 170GeV^2$, while green, blue and purple set $A = 160GeV^2$ and $g_1' = 10^{-3}$

FIG. 3: Perturbed Eigenvalues of Neutral Higgs Matrix in $s > v$ Expansion. $h^0_{(1)}$, $h^0_{(2)}$ and $h^0_{(3)}$ correspond to (red, green), (orange, blue) and (yellow, purple).

Conclusions

- "N"MSSM can give a complicated Higgs sector.
- The effect of a more complicated Higgs sector and the extra $U(1)'$ can be probed at LHC.

References

- Cvetic, M. *et al.* arXiv:hep-ph/9703317v2
- Martin, S. arXiv:hep-ph/9709356v4