AN NMSSM WITHOUT DOMAIN WALLS *

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We consider the Higgs sector in an extension of the MSSM involving an extra $U(1)'$ gauge symmetry and SM singlet $U(1)'$ charged scalars, in which the effective $\mu$ parameter is decoupled from the $Z'$ mass. There are large mixings between Higgs doublets and singlets, significantly affecting the Higgs spectrum, production cross sections, decay modes, exclusion limits, and allowed parameter ranges. Scalars considerably lighter than 114 GeV are allowed, and the range $\tan\beta \sim 1$ is both allowed and theoretically favored. We concentrate on the lighter (least model dependent) Higgs particles with significant $SU(2)$-doublet components to their wave functions, for the case of no explicit $CP$ violation in the Higgs sector. We consider their spectra, including the dominant radiative corrections to their masses in the large $t$ mass limit; production cross sections and exclusion limits at LEP and a future linear collider; and decay properties.\(^1\)

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1. Introduction

The superpotential for the MSSM contains the supersymmetric mass term $\mu H_2H_1$. The minimization condition for the MSSM scalar potential relates $\mu$ to $M_Z$ and soft SUSY breaking parameters. However, $\mu$ is an input-scale parameter and therefore should have a value $O(M_{Pl})$ or $O(M_{GUT})$. This has led to a widespread belief that the MSSM must be extended at very high energies to include a mechanism which relates $\mu$ to the SUSY breaking mechanism.\textsuperscript{2} The simplest extension\textsuperscript{3} adds a single scalar singlet with the superpotential $\lambda S H_u H_d + k S^3$, which is able to solve the $\mu$ problem at the expense of requiring a $Z_3$ discrete symmetry to forbid a $\mu S S^2$ term which would re-introduce the $\mu$ problem. It has been criticized because it would create domain walls in the early universe. Additionally, in many string constructions (e.g., heterotic and intersecting brane) superpotential terms are typically off-diagonal in the fields, which disallows the $kS^3$ term. Thus we are led to consider larger models that may be derived from string constructions involving a non-anomalous $U(1)'$.

$U(1)'$ models involve a standard model singlet field $S$ which yields an effective $\mu$ parameter $h(S)$, where the superpotential includes the term $hS H_2 H_1$, thus solving the $\mu$ problem.\textsuperscript{5} $S$ will be charged under the $U(1)'$, so that its expectation value also gives mass to the new $Z'$ gauge boson. The extended gauge symmetry forbids an elementary $\mu$ term as well as terms like $S^a$ in the superpotential (the role of the $S^3$ term in generating quartic terms in the potential is played by $D$ terms and possibly off-diagonal superpotential terms involving additional standard model singlets).

In this talk I explore the extended Higgs sector in a particular $U(1)'$ model using a bottom-up approach involving several standard model singlet fields\textsuperscript{4}. This model has the advantage that it somewhat decouples the effective $\mu$ parameter from the $Z'$ mass, and leads naturally to a sufficiently heavy $Z'$. We make the assumption that any fermionic matter necessary to cancel anomalies also receives a mass at the $U(1)'$ breaking scale and is decoupled from physics that will be visible at the LHC. We expect that the generic features will be representative of a wider class of constructions.

2. The Model

The model we consider, first introduced in \textsuperscript{4}, has the superpotential:

$$W = hSH_2H_1 + \lambda S_1 S_2 S_3 + W_{MSSM}$$

(1)
S, S₁, S₂, and S₃ are standard model singlets, but are charged under an extra $U(1)'$ gauge symmetry. The model is such that the potential has an $F$ and $D$-flat direction in the limit $\lambda \to 0$, allowing a large (TeV scale) $Z'$ mass for small $\lambda$. The use of an $S$ field different from the $S_i$ in the first term allows a decoupling of $M_{Z'}$ from the effective $\mu$.

The superpotential $W$ leads to the $F$-term scalar potential:

$$V_F = h^2 (|H_2|^2 |H_1|^2 + |S|^2 |H_2|^2 + |S|^2 |H_1|^2) + \lambda^2 (|S_1|^2 |S_2|^2 + |S_2|^2 |S_3|^2 + |S_3|^2 |S_1|^2).$$

(2)

The $D$-term potential is:

$$V_D = \frac{G^2}{8} (|H_2|^2 - |H_1|^2)^2 + \frac{1}{2} g_{Z'}^2 \left( Q_S |S|^2 + Q_{H_1} |H_1|^2 + Q_{H_2} |H_2|^2 + \sum_{i=1}^{3} Q_{S_i} |S_i|^2 \right)^2,$$

where $G^2 = g_1^2 + g_2^2 = g_3^2 / \cos^2 \theta_W$; $g_1$, $g_2$, and $g_{Z'}$ are the coupling constants for $U(1)$, $SU(2)$ and $U(1)'$, respectively, and $\theta_W$ is the weak angle. $Q_\phi$ is the $U(1)'$ charge of the field $\phi$. We will take $g_{Z'} \sim \sqrt{5/3} g_1$ (motivated by gauge unification) for definiteness.

We do not specify a SUSY breaking mechanism but rather parameterize the breaking with the soft terms

$$V_{soft} = m_{H_1}^2 |H_1|^2 + m_{H_2}^2 |H_2|^2 + m_S^2 |S|^2 + \sum_{i=1}^{3} m_{S_i}^2 |S_i|^2$$

$$- (A_h h S H_1 H_2 + A_\lambda \lambda S_1 S_2 S_3 + \text{H.C.})$$

$$+ (m_{S_1 S_1}^2 S S_1 + m_{S_2 S_2}^2 S S_2 + \text{H.C.})$$

(4)

The last two terms are necessary to break two unwanted global $U(1)$ symmetries, and require $Q_{S_1} = Q_{S_2} = -Q_S$. The potential $V = V_F + V_D + V_{soft}$ was studied in 4, where it was shown that for appropriate parameter ranges it is free of unwanted runaway directions and has an appropriate minimum.

3. Higgs sector and electroweak symmetry breaking

The Higgs sector for this model contains 6 CP-even scalars and 4 CP-odd scalars, which we label $H_1 \ldots H_6$ and $A_1 \ldots A_4$, respectively, in order of increasing mass. We compute the six CP-even scalar masses including the dominant 1-loop contribution coming from the top/stop loop. We scan over vacuum expectation values such that the three singlets $S_1$, $S_2$, and $S_3$ typically have larger vevs than the other three fields.
A scan of parameter space indicates that there is a significant region with light $H$ and/or light $A$, able to escape experimental detection at LEP2 because of its small mixing with the MSSM Higgs doublets. In Fig. 1 we present the cross section for the Higgsstrahlung process $e^+e^- \rightarrow ZH$ for the lightest 3 CP-even states, and the $ZZH$ coupling of the heaviest states relative to the Standard Model. One can see that $20 \text{GeV} < m_{H_1} < 200 \text{GeV}$ is allowed, and the heaviest states are decoupled from the $Z$.

Decays of the Higgses in this model can be very unlike the MSSM, with $H \rightarrow A_1 A_1$ and $H \rightarrow \chi^0 \chi^0$ dominating if they are kinematically allowed due to new $U(1)'$ D-term and singlet F-term contributions. In addition $H \rightarrow W^+ W^-$ can be kinematically allowed. Further phenomenological analysis including $HA$ production, $H$ and $A$ decay modes, and gauginos will be presented in Ref. 1.

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