1 NMSSM

1.1 Introduction

In the NMSSM one adds a gauge singlet N to the MSSM fields. One may distinguish two extreme versions of the NMSSM:

(i) The "General NMSSM" is defined by the following superpotential:

$$W = -\mu H_1 H_2 + \lambda N H_1 H_2 - \frac{k}{3} N^3 + \frac{1}{2}\mu' N^2 + \mu'' N + \ldots \tag{1}$$

This version, which reduces to the MSSM in the limit that the N field is removed, clearly does not have a $\mathbb{Z}_3$ symmetry and hence there are no domain walls. There may be tadpole corrections to the linear N term in SUGRA models. But in models of dynamical SUSY breaking there is no such problem.

(ii) The "Constrained NMSSM" is defined by equation 1 with $\mu = \mu' = \mu'' = 0$, plus the constraints of gauge coupling unification and universal soft SUSY-breaking parameters imposed at the unification scale $M_X \approx 10^{16}$ GeV. In this version the superpotential only involves trilinear terms, and clearly we can choose it either to have a $\mathbb{Z}_3$ symmetry which protects it against supergravity tadpoles but causes a domain wall problem, or else to have tiny explicit $\mathbb{Z}_3$ violation which avoids the domain walls but leaves us with no explanation for the stability of the hierarchy.

1.2 Higgs Bosons

The gauge singlet N contains a complex scalar component, which may be decomposed into a real CP-even neutral singlet Higgs boson, and an imaginary CP-odd neutral singlet Higgs boson. These two extra neutral Higgs bosons may mix with the neutral Higgs bosons of the MSSM of the same CP. In the limit that there is no mixing the extra Higgs bosons are undetectable since they are gauge singlets. However mixing yields two CP-odd Higgs bosons, plus three CP-even Higgs bosons (one more in each CP sector than in the MSSM) plus of course the usual charged Higgs bosons which are largely unaffected by the presence of the extra singlets (except that the mass of the charged Higgses may be reduced to zero). Although there are more neutral Higgs bosons, they are more difficult to produce due to their couplings being diluted due to the mixing with the singlet. Nevertheless singlet dilution is the smoking gun of the NMSSM and the LC is the ideal machine to look for it.

2 Constrained NMSSM

In the MSSM limit of the NMSSM (characterised by large singlet VEV, and small dimensionless singlet couplings) the gauge singlets decouple making them almost impossible to detect. This is the case in the Constrained NMSSM, for example. (see PRD52(1995)4183). In this model the allowed parameter space is always close to the MSSM limit, so one is looking for very slight deviations from MSSM couplings in the neutral Higgs sector. An important exception is when, by chance, a singlet Higgs becomes degenerate with an MSSM Higgs of the same CP. Then the two states will mix, leading to unmistakable diluted Higgs couplings (see PRD52(1995)4183).

3 General NMSSM

In this model we are typically not in the MSSM limit and the two extra neutral Higgs bosons readily mix with their respective CP MSSM cousins, leading to the phenomenon of "singlet dilution" even when the masses of the states are not degenerate.

3.1 Effects of Singlet Dilution

3.1.1 The Bound

It is well known that the upper bound on the mass of the lightest CP-even Higgs boson may be higher in the NMSSM than the MSSM (PRD49 (1994) 2435). In fact it may be substantially higher (i.e. higher than 150 GeV) if the cut-off scale of new physics is reduced below the GUT scale.

Now suppose we believe in GUTs, so that the bound is around 150 GeV. But suppose that the lightest CP-even Higgs boson is predominantly singlet so it is unobservable, then it turns out that the bound applies to the second lightest CP-even Higgs boson – so the bound is a useful concept in the NMSSM.

A LC will be able to set a limit on the bound even in the worst possible scenario that the singlets mix maximally with the MSSM Higgs making them most difficult to detect. How this is done for LEP2 is explained in PRD53(1996)4049, and a similar procedure may be followed at a LC.

3.1.2 m_A-$\tan\beta$ plane

For a given value of λ it is possible to obtain excluded regions in the m_A-$\tan\beta$ plane, in a rather similar way to those of the MSSM (PRD53(1996)4049). The excluded regions are almost non-existent after LEP2, in the case of large λ, due to singlet dilution. However a LC should be able to make impressive in-roads in this plane.

3.1.3 Decay Couplings

The couplings of the neutral Higgs to quarks are also subject to dilution (PRD52(1995)4183).

3.1.4 Trilinear Higgs couplings and Rare Decays

Dilution will also affect these (not yet studied) leading possibly to rare decays of Higgs bosons to singlets.

4 Parameter Space

Suppose that the smoking gun of singlet dilution is discovered. What next? The next task is to determine what type of NMSSM one is up against, and then determine the parameters of the model. For the general NMSSM there are a lot of free parameters, and life will be very difficult. For an unconstrained model but involving only trilinear couplings some progress has been made (PRD49 (1994) 2435), but the parameter space is still a nightmare. Life is easier in this case in the constrained NMSSM, but this model is likely to look very similar to the MSSM. One may hope for an accidental degeneracy of a singlet with an MSSM state as mentioned, or failing this one may hope that high precision measurements of MSSM couplings will lead to discrepancies.

For a completely general NMSSM, there has been no attempt to study the whole parameter space, and one could make a start at Snowmass.

4.1 Collider Phenomenology

4.1.1 LHC

The task of the LHC is to count the Higgs bosons. If there are more neutral Higgs bosons than in the MSSM then the NMSSM is immediately in business.

Specific tasks: production cross-sections for all neutral Higgs bosons with the modified couplings.

4.2 LC

The LC will be able to systematically search for Higgs bosons with diluted couplings as discussed above.

Specific tasks: see above.

4.3 Muon colliders

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