We discuss two novel possibilities in Higgs physics. The first is that, by adding a real Higgs triplet to the Standard Model, it is possible for the lightest Higgs boson to be as heavy as 500 GeV without any fine tuning. The second, somewhat orthogonal, possibility concerns the MSSM with explicit CP violation. This model is known to permit a light Higgs boson with mass below 50 GeV which may have avoided detection at LEP and may also avoid detection at the Tevatron and LHC. We suggest that diffraction may provide the key to excluding or observing such a Higgs.

1 Introduction

Precise data from LEP, SLC and Tevatron imply a light Higgs boson when interpreted within the Standard Model, i.e. $m_h = 81^{+52}_{-33}$ GeV, and similar conclusions also apply in the simplest supersymmetric extensions. It is natural to ask how general this situation is. In this talk, we focus upon two quite different extensions to the Standard Model which avoid the more usual constraints on the Higgs mass. In the first case, we consider adding an additional real Higgs triplet to the Standard Model with the effect that the lightest Higgs could be as heavy as 500 GeV. The model is notable in that there is no severe fine tuning and no problem with unwanted phenomenology. Moreover, the argument allowing a heavier Higgs is essentially tree-level. In Section 3, we turn to the MSSM with explicit CP violation. CP violation in the Higgs sector can lead to a situation where the lightest Higgs is lighter even than the direct search limit for a Standard Model Higgs. We suggest that diffractive scattering may provide a means for discovering or excluding such a Higgs.

2 Triplet Higgs

The model consists of adding a real hypercharge zero Higgs triplet $(H)$ to the Standard Model doublet $(\Phi)$, i.e.

$$
\mathcal{L}(\Phi, H) = (D_\mu \Phi)^\dagger (D^\mu \Phi) + \frac{1}{4} (D_\mu H)^\dagger (D^\mu H) - V(\Phi, H),
$$

$$
V(\Phi, H) = \mu_1^2 \Phi^\dagger \Phi + \frac{i}{2} \mu_2^2 H^\dagger H
+ \lambda_1 (\Phi^\dagger \Phi)^2 + \frac{i}{4} \lambda_2 (H^\dagger H)^2
+ \frac{i}{4} \lambda_3 (\Phi^\dagger \Phi)(H^\dagger H) + \lambda_4 v H_\Phi \Phi^\dagger \sigma^i \Phi.
$$

Defining $\tan \beta$ to be the ratio of the triplet to doublet vacuum expectation values then, for non-zero $\beta$, this model violates custodial symmetry, i.e.

$$
\rho \equiv \frac{m_W^2}{m_{Z'}^2} = \frac{1}{\cos^2 \beta} \neq 1.
$$

Usually this tree-level deviation of $\rho$ from unity is regarded as an unpallatable feature of the model. However it is precisely this symmetry breaking which allows the lightest Higgs to be
Figure 1: Ellipse encloses the region allowed by data. Curves show results in the Triplet Model for various values of $\beta$ and various doublet Higgs masses. $\beta = 0$ is the Standard Model curve and the reference Higgs mass is 100 GeV. Figure from Forshaw, Ross and White.

much heavier than in the Standard Model. By giving the triplet a non-zero vacuum expectation value, one is in effect making a positive tree-level contribution to the $T$-parameter, and this is enough to allow a heavier Higgs.

This positive contribution to $T$ can be traced back to the use of the muon decay constant in the precision electroweak fits. Equation (2) effectively induces a small shift in the $W$ mass, and this feeds back, via $G_\mu$, into the measured observables. The correction can be represented as a positive contribution to the oblique parameter $T$, i.e. $\alpha \Delta T \approx \beta^2$. In Figure 1, we show the familiar ellipse in the $S-T$ plane. The interior of the ellipse is allowed by the precision data and the curve corresponding to $\beta = 0$ is the Standard Model result for various Higgs masses, clearly in this case the Higgs should be light. For non-zero $\beta$, the Standard Model curve is shifted upwards thereby allowing the lightest Higgs to be much heavier.

Some additional comments are in order. Firstly, since the triplet has no hypercharge it does not contribute to the oblique parameter $S$. Secondly, the genuine quantum corrections to $T$ are naturally small since, for small mixing $\beta$, the charged and neutral members of the triplet have small mass splitting. In other words, quantum corrections are, to a first approximation, negligible. Note also that $\beta$ does not need to be particularly small in order to accommodate the data. Thirdly, we mention that a study of the mass spectrum in the triplet model and the RG flow of the scalar couplings has recently been completed. Finally, one should note that there are other ways to avoid a light Higgs. In the case that there are no new light particles seen at the LHC, decisive information could well come from even more precise measurements of the $Z$ boson.

We now leave behind the triplet model and shift focus to the opposite extreme of a Higgs which may be even lighter than suggested by the Standard Model.

3 CP violating light Higgs

The possibility of CP violation in the Higgs sector of the MSSM occurs quite naturally as a result of radiative effects induced by explicit CP violation in the third generation of squarks. Moreover, it has been established that the lightest Higgs boson could be much lighter than the direct search limit, obtained assuming the Standard Model, due to a severely weakened coupling to the $Z$ boson. We refer to Carena et al and references therein for more details.

This is illustrated in Figure 2 where we are particularly interested in the upper two plots which have large CP violating phases. In these plots one should focus upon the unexcluded...
windows (light grey) at low to intermediate $\tan \beta$ \(^{a}\) and $m_h < 50$ GeV. Note also that it may be difficult to exclude these regions using conventional search channels at either the Tevatron or LHC\(^8\).

Fortunately, it is possible that such light Higgs bosons may be visible in diffractive scattering events at hadron colliders via the process $p + p \rightarrow p + H + p$, illustrated in Figure 3. The Higgs boson is produced centrally and the incoming hadrons remain intact, deflecting through small angles. In our calculation of the rate, we follow closely the approach of Khoze, Martin and Ryskin\(^{10}\); more details can be found in our paper\(^{11}\). We would like to stress that a higher statistics measurement of the central production of jets at the Tevatron than has been obtained so far\(^{12}\) should provide a good test of the underlying theoretical framework. Such a measurement should be possible in the near future.

In Figure 4 we show the resulting total cross-section for $p + p \rightarrow p + H + p$ as a function of Higgs mass at both Tevatron and LHC energies. The SUSY parameters are chosen to cover the unexcluded windows of Figure 2. Note that for masses below 30 GeV, there may even be sufficient rate to make exploration at the Tevatron a possibility. Certainly these light Higgses ought to be produced in abundance at the LHC.

Although we have not yet performed a detailed study of the background, there are good

\(^{a}\)Note that $\beta$ here is not the same as that in Section 2.
reasons to expect that it should be possible to isolate these diffractive events. The light Higgses are expected to decay to $b$-quarks and the corresponding QCD background will be suppressed by a selection rule which favours the production of $0^+$ states in diffraction (although this rule will become less effective for lower Higgs masses). Moreover, a resolution of order 1 GeV on the mass of the central system may be possible at the LHC with the installation of suitable final state proton detectors\cite{13}.

In summary, it may well be that central production will provide a unique and valuable tool to complement more traditional search strategies for new physics. To exploit this opportunity requires that suitable detectors be installed to measure the momenta of the final state protons.

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