SUSY in the Light of B Physics and Electroweak Precision Observables

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Abstract. Indirect information about the possible scale of supersymmetry (SUSY) breaking can be obtained from the comparison of precisely measured observables (and also of exclusion limits) with accurate theory predictions incorporating SUSY loop corrections. Recent results are reviewed obtained from a combined analysis of the most sensitive electroweak precision observables (EWPO), $M_W$, $\sin^2 \theta_{\text{eff}}$, $\Gamma_Z$, $(g - 2)_\mu$ and $M_t$, and B-physics observables (BPO), BR($b \to s\gamma$), BR($B_s \to \mu^+\mu^-$), BR($B_u \to \tau \nu_\tau$) and $\Delta M_{B_s}$. Assuming that the lightest supersymmetric particle (LSP) provides the cold dark matter density preferred by WMAP and other cosmological data, $\chi^2$ fits are performed to the parameters of the constrained minimal supersymmetric extension of the Standard Model (CMSSM), in which the SUSY-breaking parameters are universal at the GUT scale, and the non-universal Higgs model (NUHM), in which this constraint is relaxed for the soft SUSY-breaking contributions to the Higgs masses. Within the CMSSM indirect bounds on the mass of the lightest $CP$-even Higgs boson are derived.

PACS. 12.60.Jv Supersymmetric models – 12.15.Lk Electroweak radiative corrections

1 Introduction

Phenomenological analyses of supersymmetry (SUSY) often make simplifying assumptions that drastically reduce the dimensionality of the parameter space of the minimal supersymmetric extension of the Standard Model (MSSM). One assumption that is frequently employed is that (at least some of) the soft SUSY-breaking parameters are universal at some high input scale, before renormalisation. One model based on this simplification is the constrained MSSM (CMSSM), in which all the soft SUSY-breaking scalar masses $m_0$ are assumed to be universal at the GUT scale, as are the soft SUSY-breaking gaugino masses $m_{1/2}$ and trilinear couplings $A_0$. The assumption that squarks and sleptons with the same gauge quantum numbers have the same masses is motivated by the absence of identified supersymmetric contributions to flavour-changing neutral interactions and rare decays. Universality between squarks and sleptons with different gauge interactions may be motivated by some GUT scenarios [1]. However, the universality of the soft SUSY-breaking contributions to the Higgs scalar masses is less motivated, and is relaxed in the non-universal Higgs model (NUHM) [2,3,4].

In Ref. [5] a combined $\chi^2$ analysis has been performed of electroweak precision observables (EWPO), going beyond previous such analyses [6,7] (see also Ref. [8]), and of B-physics observables (BPO), including some that have not been included before in comprehensive analyses of the SUSY parameter space (see, however, Ref. [9]). The set of EWPO included in the analysis of Ref. [5] are the $W$ boson mass $M_W$, the effective leptonic weak mixing angle $\sin^2 \theta_{\text{eff}}$, the total $Z$ boson width $\Gamma_Z$ (using for these three observables the recent theory predictions obtained in Refs. [10,11]), the anomalous magnetic moment of the muon $(g - 2)_\mu$ (based on Refs. [12,13], see Ref. [14] for recent reviews), and the mass of the lightest MSSM Higgs boson $M_h$ obtained from the program FeynHiggs [15,16,17]. In addition, four BPO are included: the branching ratios BR($b \to s\gamma$) (based on the results of Ref. [18]), incorporating also the latest SM corrections provided in Ref. [19]), BR($B_s \to \mu^+\mu^-$) (based on results from Ref. [20], which are in good agreement with Ref. [21]) and BR($B_u \to \tau \nu_\tau$) (based on Ref. [22]), and the $B_s$ mass mixing parameter $\Delta M_{B_s}$ (based on Ref. [22]).

For the evaluation of the BPO minimal flavor violation (MFV) at the electroweak scale is assumed. Non-minimal flavor violation (NMFV) effects can be induced by RGE running from the high scale, see e.g. Ref. [23], that may amount to $\sim 10\%$ of the SUSY corrections. These additional contributions are neglected in the present analysis.

For each observable, the $\chi^2$ function is constructed including both theoretical and experimental systematic uncertainties, as well as statistical errors [5]. The analysis is carried out in the CMSSM and the NUHM, taking into account the fact that the cold dark matter density is known from astrophysics and cosmology with an uncertainty smaller than 10 % [24], effectively reducing the dimensionality of the parameter space by one. The combined $\chi^2$ function for the EWPO and the BPO is investigated in the CMSSM and the NUHM.
For the CMSSM furthermore indirect constraints on the lightest Higgs-boson mass, $M_h$, are discussed.

### 2 CMSSM analysis including EWPO and BPO

In Fig. 1 we show for the CMSSM the combined $\chi^2$ values for the EWPO and BPO, computed as described in Ref. [5], for $\tan \beta = 10$ (upper panel) and $\tan \beta = 50$ (lower panel). We see that the global minimum of $\chi^2 \sim 4.5$ for both values of $\tan \beta$. This is quite a good fit for the number of experimental observables being fitted. There is a slight tension between the EWPO, which show a preference for small $m_{1/2}$, and the BPO, which do not exhibit this behaviour, see Ref. [5] for a more detailed discussion. For both values of $\tan \beta$, the focus-point region is disfavoured by comparison with the non-universality of the two Higgs mass parameters.

The NUHM has two more parameters in addition to those of the CMSSM. They characterise the degree of non-universality of the two Higgs mass parameters. After imposing the electroweak vacuum conditions the two parameters can be traded for $M_A$ and $\mu$. It has been pointed out in Refs. [5, 29] that $m_{1/2}$ or $\mu$ can be varied such that (essentially) the whole $(M_A, \tan \beta)$ plane is compatible with the WMAP constraint on the dark matter relic density.

Fig. 2 shows the combined EWPO and BPO $\chi^2$ function for a $(M_A, \tan \beta)$ plane in the NUHM (called plane P1 in Refs. [5, 29]) with $m_0 = 800$ GeV and $\mu = 1000$ GeV, where $m_{1/2}$ is chosen to vary across the plane so as to maintain the WMAP relationship with

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**Fig. 1.** The combined $\chi^2$ function for the electroweak observables $M_W$, $\sin^2 \theta_W$, $\Gamma_Z$, $(g-2)_\mu$, $M_h$, and the $b$-physics observables $\text{BR}(b \rightarrow s\gamma)$, $\text{BR}(B_s \rightarrow \mu^+ \mu^-)$, $\text{BR}(B_d \rightarrow \tau\nu)$ and $\Delta M_{B_s}$, evaluated in the CMSSM for $\tan \beta = 10$ (upper plot) and $\tan \beta = 50$ (lower plot) for various discrete values of $\mu_0$. We use $m_t = 171.4 \pm 2.1$ GeV and $m_b(m_b) = 4.25 \pm 0.11$ GeV, and $m_0$ is chosen to yield the central value of the cold dark matter density indicated by WMAP and other observations for the central values of $m_t$ and $m_b$.**
The best-fit point in this example has $M_A \sim 440$ GeV and $\tan \beta \sim 50$. It has $\chi^2 = 7.1$, which is slightly worse than the CMSSM fits in Fig. 1. We also display the $\Delta \chi^2 = 2.30$ and $4.61$ contours, which would correspond to the $68\%$ and $95\%$ C.L. contours in the $(M_A, \tan \beta)$ plane if the overall likelihood distribution, $\mathcal{L} \propto e^{-\chi^2/2}$, was Gaussian. This is clearly only roughly the case in this analysis, but these contours nevertheless give interesting indications on the preferred region in the $(M_A, \tan \beta)$ plane. No results are shown in the upper right corner of the plane (with high $M_A$ and high $\tan \beta$) because there the relic density is low compared to the preferred WMAP value. The lower left portion of the plane is missing because of the finite resolution of our scan.

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