Discovering SUSY in the first LHC run

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We analyze the potential of the first LHC physics run, assuming 1 fb^{-1} at $\sqrt{s} = 7$ TeV, to discover Supersymmetry (SUSY). The results are based on SUSY parameter fits following a frequentist approach. They include the experimental constraints from electroweak precision data, $(g-2)_\mu$, B physics and cosmological data. The two SUSY models under consideration are the constrained MSSM (CMSSM) with universal soft supersymmetry-breaking mass parameters, and a model with common non-universal Higgs mass parameters in the superpotential (NUHM1). We find that large parts of the regions preferred at the 68% C.L. are accessible to early LHC running.

1 Introduction

One of the main tasks of the LHC is to search for physics beyond the Standard Model (SM), where Supersymmetry (SUSY) is one of the favored ideas. The first physics run of the LHC is currently ongoing at $\sqrt{s} = 7$ TeV, aiming for 1 fb^{-1} until the end of 2011. Here we review the results from frequentist analyses [1, 2] of the parameter spaces of the constrained minimal supersymmetric extension of the Standard Model (CMSSM) — in which the soft SUSY-breaking scalar and gaugino masses are each constrained to universal values m_0 and $m_{1/2}$, respectively — and the NUHM1 — in which the soft SUSY-breaking contributions to the Higgs masses are allowed to have a different but common value. Both models have a common trilinear coupling A_0 at the GUT scale and $\tan\beta$ (the ratio of the two vacuum expectation values) as a low-energy input. A detailed list of references on the subject of frequentist (and bayesian) analyses can be found in Ref. [1].

2 Details of the fits

The results obtained in Refs. [1, 2] include various experimental results: B-physics observables (such as rates for $\mathrm{BR}(b \to s\gamma)$ and $\mathrm{BR}(B_u \to \tau\nu_\tau)$, and the upper limit on $\mathrm{BR}(B_s \to \mu^+\mu^-)$) as well as K-physics observables, precision electroweak data (such as the W boson mass and the anomalous magnetic moment of the muon, $(g-2)_\mu$), the bound on the lightest MSSM Higgs boson mass, M_h, and the cold dark matter (CDM) density (as inferred from astrophysical and cosmological data) assuming that this is dominated by the relic density of the lightest neutralino, $\Omega_\chi h^2$.

The fit is performed by using a global χ^2 likelihood function, which combines all theoretical

predictions with experimental constraints:

$$\chi^2 = \sum_i^N \frac{(C_i - P_i)^2}{\sigma(C_i)^2 + \sigma(P_i)^2} + \sum_i^M \frac{(f_{\mathrm{SM}_i}^{\mathrm{obs}} - f_{\mathrm{SM}_i}^{\mathrm{fit}})^2}{\sigma(f_{\mathrm{SM}_i})^2}$$
$$+ \chi^2(M_h) + \chi^2(\mathrm{BR}(B_s \to \mu\mu)) + \chi^2(\text{SUSY search limits}) \qquad (1)$$

Here N is the number of observables studied, C_i represents an experimentally measured value (constraint), and each P_i defines a prediction for the corresponding constraint that depends on the supersymmetric parameters. The experimental uncertainty, $\sigma(C_i)$, of each measurement is taken to be both statistically and systematically independent of the corresponding theoretical uncertainty, $\sigma(P_i)$, in its prediction. We denote by $\chi^2(M_h)$ and $\chi^2(\mathrm{BR}(B_s \to \mu\mu))$ the χ^2 contributions from two measurements for which only one-sided bounds are available so far. Similarly, we include the lower limits from the direct searches for SUSY particles at LEP [3] as one-sided limits, denoted by "χ^2(SUSY search limits)" in Eq. (1). The experimental constraints used in our analyses are listed in Table 1 of Ref. [1]. Our statistical treatment of the CMSSM and NUHM1 makes use of a large sample of points (about 2.5×10^7) in the SUSY parameter spaces obtained with the Markov Chain Monte Carlo (MCMC) technique. Our analysis is entirely frequentist, and avoids any ambiguity associated with the choices of Bayesian priors.

The main computer code for our evaluations is the `MasterCode` [1,2,4–6], which includes the following theoretical codes. For the RGE running of the soft SUSY-breaking parameters, it uses `SoftSUSY` [7], which is combined consistently with the codes used for the various low-energy observables: `FeynHiggs` [8–11] is used for the evaluation of the Higgs masses and a_μ^{SUSY} (see also [12,13]), for the other electroweak precision data we have included a code based on [14,15], `SuFla` [16,17] and `SuperIso` [18,19] are used for flavor-related observables, and for dark-matter-related observables `MicrOMEGAs` [20] and `DarkSUSY` [21] are included. In the combination of the various codes, `MasterCode` makes extensive use of the SUSY Les Houches Accord [22,23].

3 SUSY discovery potential of the first LHC run

For the parameters of the best-fit CMSSM point we find $m_0 = 60$ GeV, $m_{1/2} = 310$ GeV, $A_0 = 130$ GeV, $\tan\beta = 11$ and $\mu = 400$ GeV, yielding the overall $\chi^2/\mathrm{N_{dof}} = 20.6/19$ (36% probability) and nominally $M_h = 114.2$ GeV. The corresponding parameters of the best-fit NUHM1 point are $m_0 = 150$ GeV, $m_{1/2} = 270$ GeV, $A_0 = -1300$ GeV, $\tan\beta = 11$ and $m_{h_1}^2 = m_{h_2}^2 = -1.2 \times 10^6$ GeV^2 or, equivalently, $\mu = 1140$ GeV, yielding $\chi^2 = 18.4$ (corresponding to a similar fit probability as in the CMSSM) and $M_h = 120.7$ GeV.

In Fig. 1 we display the best-fit value and the 68% and 95% likelihood contours for the CMSSM (upper plot) and the NUHM1 (lower plot) in the $(m_0, m_{1/2})$ plane, obtained as described above from a fit taking into account all experimental constraints. We also show exclusion contours for the hadronic search mode (jets plus missing energy) at CMS. The green (light gray) solid line shows the 95% C.L. exclusion contour for CMS for 1 fb^{-1} at $\sqrt{s} = 7$ TeV [24]. The black solid line shows the corresponding results for only 0.1 fb^{-1}. (Similar results hold for ATLAS.) One can see that with 1 fb^{-1} the best-fit points can be tested, together with a sizable part of the whole 68% C.L. preferred regions. In the case of the NUHM1 (lower plot) nearly the whole 68% C.L. region could be probed.

In conclusion, if the CMSSM or the NUHM1 (or a very similar SUSY model) were realized in nature, the first LHC physics run at $\sqrt{s} = 7$ TeV until the end of 2011 could reveal already

first signals of SUSY. On the other hand, no indication of SUSY-like signatures would already severely restrict these (kind of) GUT based models.

4   Acknowledgments

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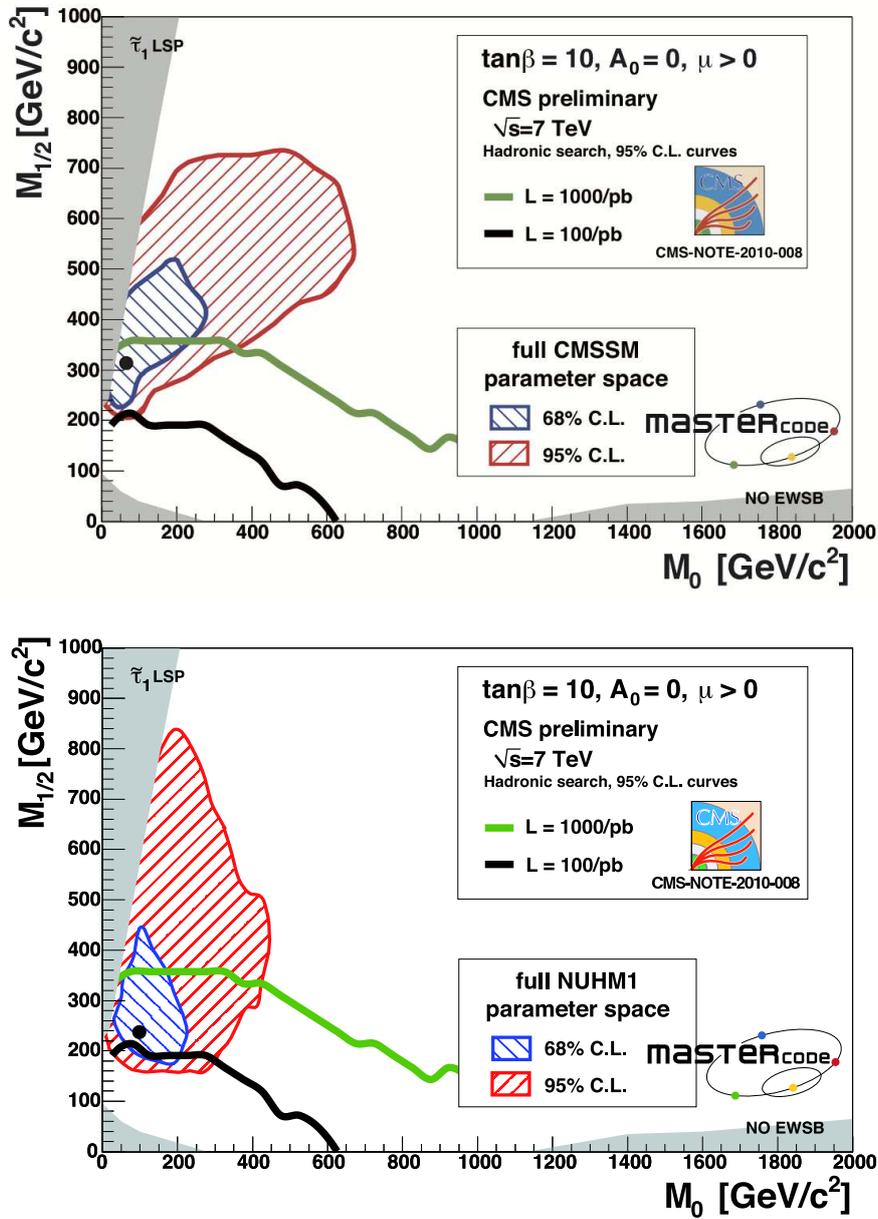
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Figure 1: The $(m_0, m_{1/2})$ plane in the CMSSM (upper plot) and the NUHM1 (lower plot). The dark shaded area at low m_0 and high $m_{1/2}$ is excluded due to a scalar tau LSP, the light shaded areas at low $m_{1/2}$ do not exhibit electroweak symmetry breaking. Shown in both plots are the best-fit point, indicated by a filled circle, and the 68 (95)% C.L. contours from our fit as dark gray/blue (light gray/red) overlays, scanned over all $\tan\beta$ and A_0 values. The 95% C.L. exclusion curves (hadronic search channel) at CMS with 1 (0.1) fb^{-1} at 7 TeV center-of-mass energy is shown as green/light gray (black) solid curve.