# 1 MSSM benchmarks

The supersymmetric extension of the Standard Model actually has one fewer parameters than the SM itself, since the Higgs self-coupling is not an independent parameter. However, once supersymmetry is broken, as it must be, there is a proliferation of free parameters; the minimal extension has $\mathcal{O}(120)$ new parameters, almost all to do with SUSY breaking. We know from lack of observation of BSM physics that many of these parameters must be small. In addition most models of SUSY breaking predict many of these parameters, or relationships between them. This leads us to analyse simpler subsets of the full 124 dimensional space. One particular, if poorly motivated, example often considered is the CMSSM, or mSUGRA scenario.

In mSUGRA four parameters, usually given at the GUT scale, and one sign are considered: $m_0$ a uniform scalar mass, $m_{1/2}$ the gaugino mass, $A_0$ the scalar trilinear, $\tan\beta$ the ratio of Higgs vevs and $\mathrm{sgn}\,(\mu)$ the sign of the Higgs mu term. From these input values one can evolve the RGEs down to the weak scale at which point the observable spectrum can be evaluated.

One attractive feature of SUSY is that it potentially contains a DM candidate. If the lightest supersymmetric state is electrically neutral (and R-parity is conserved) then the LSP can be the DM. In addition to the weak scale spectrum all weak couplings and mixings can be calculated and this allows one to calculate the relic abundance of the LSP and its cross section to scatter in DM direct detection experiments. Finally, one may also calculate the contribution of SUSY to rare SM processes e.g. $b \to s\gamma$, $g_\mu - 2$.

Even with only four numbers to specify the allowed parameter space is sizeable and hard to visualise. It is often represented as the famous $m_0$-$m_{1/2}$ plots, where $A_0$, $\tan\beta$ and $\mathrm{sgn}\,(\mu)$ are fixed and the allowed parameter space is plotted in the $m_0$-$m_{1/2}$ plane. The constraints typically placed on the model are:

- The Higgs: Requiring the Higgs get a mass consistent with LEP
- Cosmological abundance of DM: $\Omega_\chi h^2 = 0.1 \pm 0.02$
- FCNCs: $BR(b \to s\gamma) = (3.55 \pm 0.38) \times 10^{-4}$ and $BR(B_s \to \mu^+\mu^-) < 1.5 \times 10^{-7}$. The $b \to s\gamma$ constraint favours $\mu > 0$ in mSUGRA.
- Muon anomalous magnetic moment: $a_\mu = (g_\mu - 2)/2$

After these constraints are imposed only a small allowed region is left. The allowed region can further be broken into four general areas

**Bulk region** At low $m_0$ and $m_{1/2}$

**Co-annihilation region** This region is at low $m_0$ where the stau is nearly degenerate with the LSP and the correct DM abundance is achieved through LSP-stau co-annihilation.

**Focus point region** This is the region at large $m_0$ and large $m_{1/2}$ where there is large Higgsino content in the LSP, facilitating LSP annihilation.

**Funnel region** At large $\tan\beta$ a diagonal region opens up where one of the heavy Higgses is approximately twice the LSP mass so that the DM abundance is sufficiently lowered through resonant annihilation.

These features are evident in Figure 1, the green regions are allowed by all constraints and have the correct WMAP DM abundance.

Due to both the complexity of the parameter space and of collider studies it was decided to create a series of "benchmark" points [2] and lines[1]. These are supposed to capture the various features of MSSM parameter space. A few examples are:

1. **SPS 1a(1a') A bulk region point.** $m_0 = 100\text{GeV}\,(70\text{GeV})$, $m_{1/2} = 250\text{GeV}$, $A_0 = -100\text{GeV}\,(-300\text{GeV})$, $\tan\beta = 10$, $\mu > 0$

2. **SPS 2 From the focus point region.** $m_0 = 1450\text{GeV}$, $m_{1/2} = 300\text{GeV}$, $A_0 = 0\text{GeV}$, $\tan\beta = 10$, $\mu > 0$

3. **SPS 3 From the co-annihilation region.** $m_0 = 90\text{GeV}$, $m_{1/2} = 400\text{GeV}$, $A_0 = 0\text{GeV}$, $\tan\beta = 10$, $\mu > 0$

4. **SPS 4 Large $\tan\beta$, affects Higgs phenomenology.** $m_0 = 400\text{GeV}$, $m_{1/2} = 300\text{GeV}$, $A_0 = 0\text{GeV}$, $\tan\beta = 50$, $\mu > 0$

There are many others including points from gauge mediated and anomaly mediated SUSY breaking. Their spectra can be seen in Figures 2, 3 and 4.

The LHC will be most easily able to produce the coloured superpartners, which are often very heavy, and the only real hope for seeing the non-coloured ones, unless they are below $\sim 300\,\text{GeV}$, is through their production in decays of coloured states. The LEMC will be somewhat complementary in that it will be able to produce any superpartner (sleptons, squarks, charginos

[1] These are a one parameter family of solutions that pass through particular benchmark points.

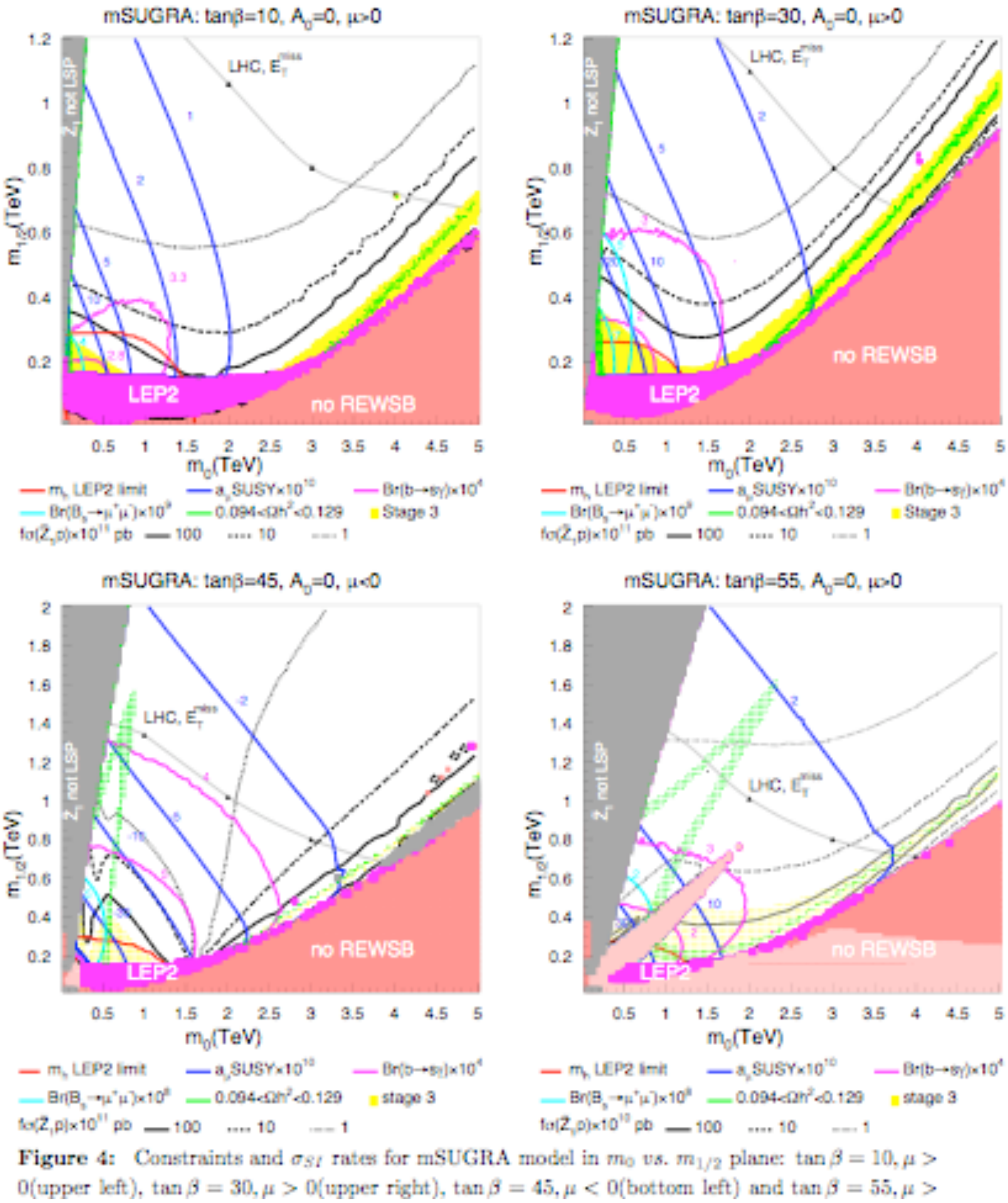


Figure 1: Allowed regions, taken from [3].

and neutralinos) that couples to the $Z$ or photon as long as they are below threshold. However from the figures it is clear that this still often leaves many states out of reach. In addition the gluino can only be made through a loop process. Since the squarks are generally heavier than the sleptons and the stop is typically the lightest squark it is worth thinking about whether the LEMC will have good discovery potential for this heavy state. It can decay in various ways (e.g. $\tilde{t} \rightarrow \tilde{\chi}^0 t$, $\tilde{t} \rightarrow \tilde{\chi}^+ b$) and, although the benchmarks exist, it may be best to proceed by just thinking in a model independent way about signals depending upon its mass and branching rates. CLIC [1] has done analyses for $e^+e^-$ and many of the these may carry over for $\mu^+\mu^-$.

## References


[1] E. Accomando et al. Physics at the clic multi-tev linear collider. 2004.

[2] B. C. Allanach et al. The snowmass points and slopes: Benchmarks for susy searches. 2002.

[3] Howard Baer, Csaba Balazs, Alexander Belyaev, and Jorge O'Farrill. Direct detection of dark matter in supersymmetric models. *JCAP*, 0309:007, 2003.

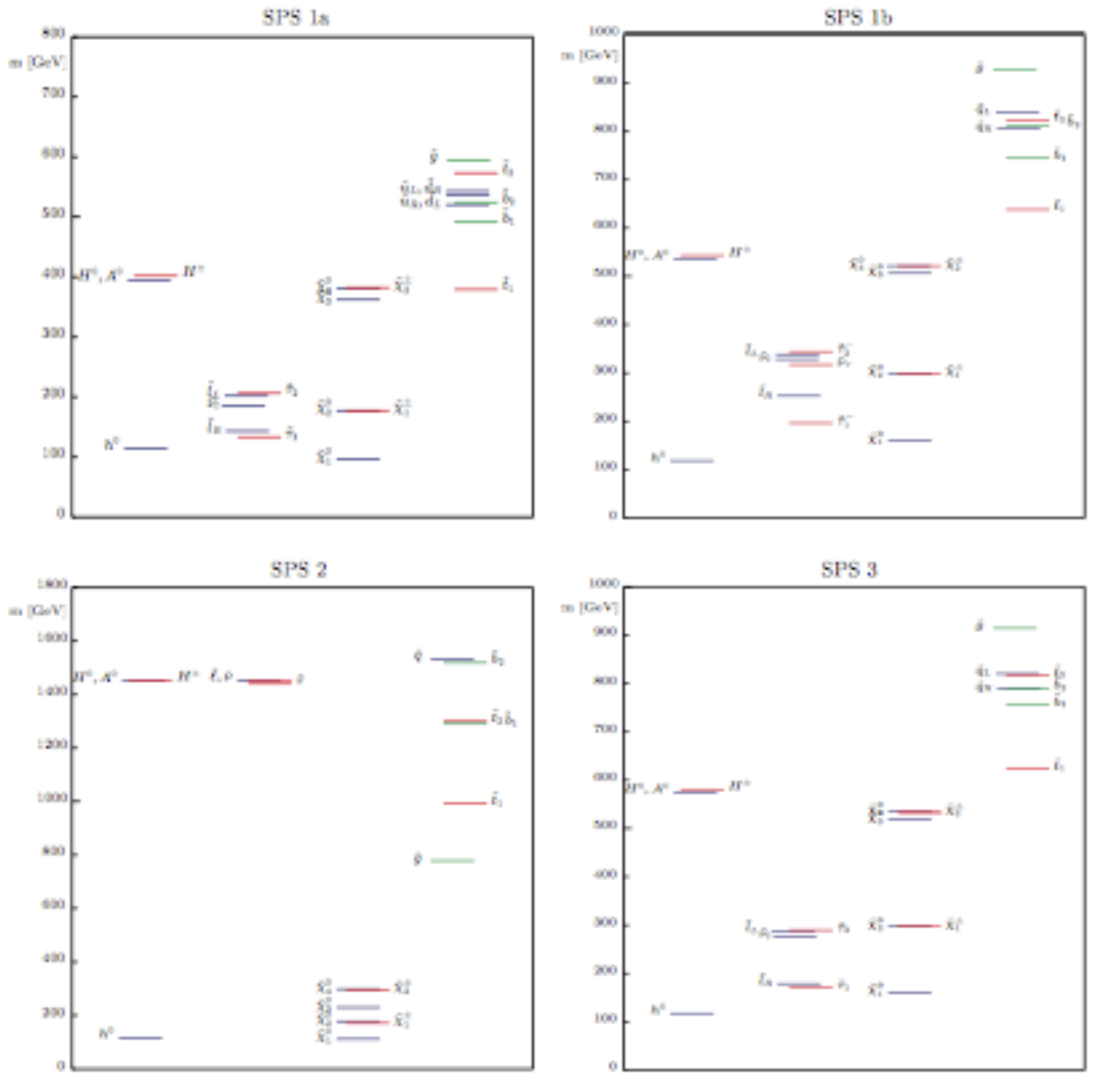


FIG. 1: The SUSY particle spectra for the benchmark points corresponding to SPS 1a, SPS 1b, SPS 2 and SPS 3 as obtained with *ISAJET 7.58* (see Ref. [33]).

Figure 2: Benchmark spectra, taken from [2].

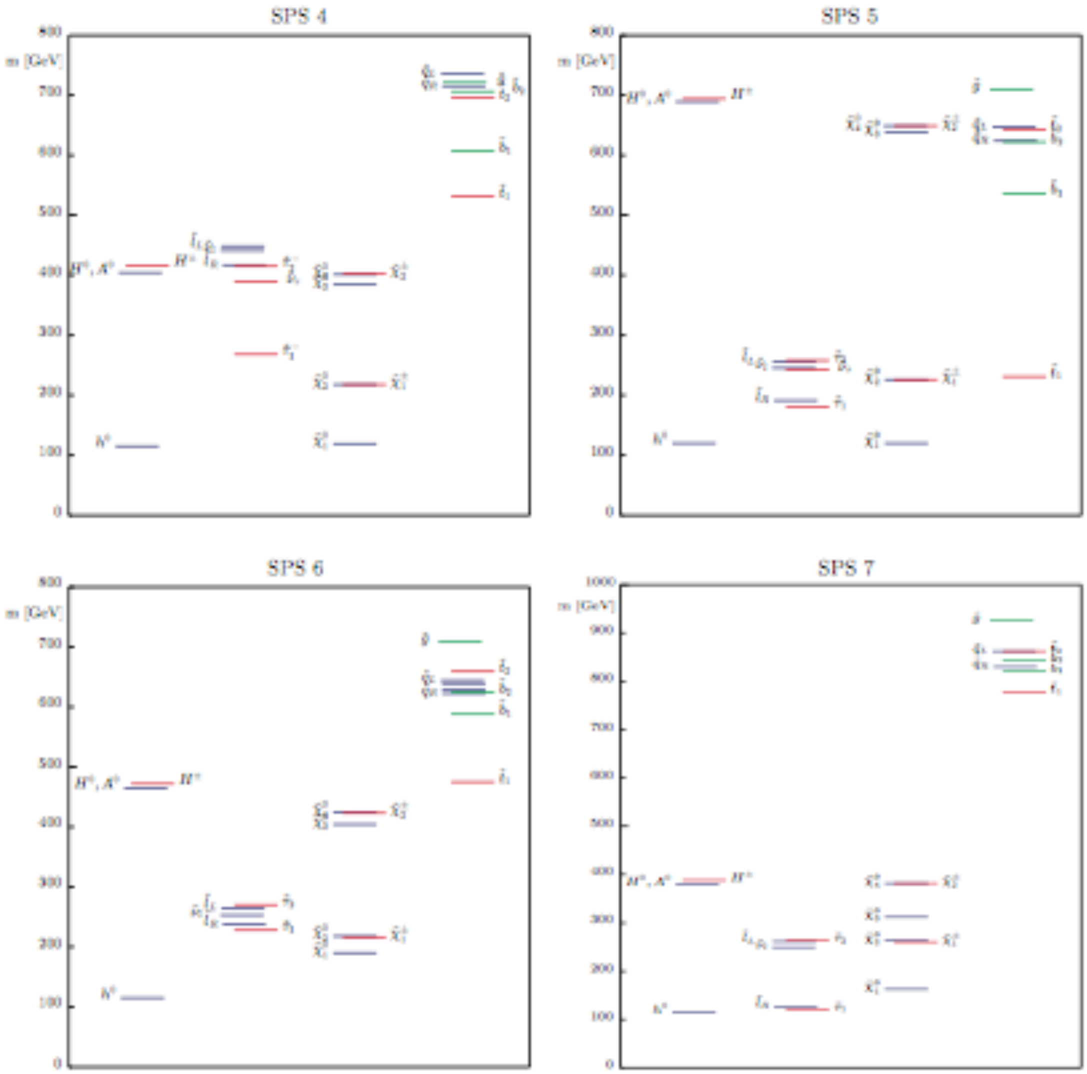


FIG. 2: The SUSY particle spectra for the benchmark points corresponding to SPS 4, SPS 5, SPS 6 and SPS 7 as obtained with *ISAJET 7.58* (see Ref. [33]).

Figure 3: Benchmark spectra, taken from [2].

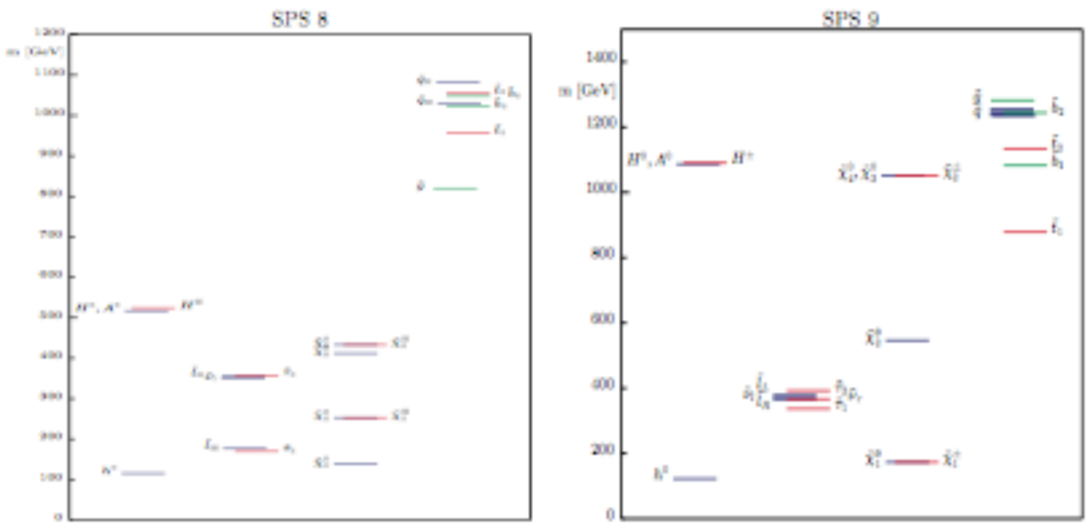


FIG. 3: The SUSY particle spectra for the benchmark points corresponding to SPS 8 and SPS 9 as obtained with *ISAJET 7.58* (see Ref. [33]).

Figure 4: Benchmark spectra, taken from [2].