# Benchmark Point Suggestions

S.F. King, M. Muhlleitner, R. Nevzorov and K. Walz

## 1 The benchmark Points

The benchmarks which we propose are based on Ref. [1]. We work in the $Z_3$ invariant NMSSM. All points are compatible with low-energy constraints, the relic density (upper bound) and the Higgs data.

### 1.1 Benchmark Point 1488 $\equiv$ BP7_P1

The bencmark point 1488 is characterized by all Higgs bosons being rather light, so that they should be discovered at LHC13 or the scenario be excluded:

$$\begin{array}{lll} H_2 \equiv h & \text{SM-like} & M_h = 124.4 \text{ GeV} \\ H_1 \equiv H_s & \text{singlet-like} & M_{H_s} = 95.6 \text{ GeV} \\ A_1 \equiv A_s & \text{singlet-like} & M_{A_s} = 108 \text{ GeV} \\ H_3 \equiv H & \text{doublet-like} & M_H = 299 \text{ GeV} \\ A_2 \equiv A & \text{SM-like} & M_A = 298 \text{ GeV} . \end{array} \tag{1.1}$$

The benchmark point 1488 is taken from a scan over a subspace of the NMSSM parameter space, which we call natural NMSSM. The features of this subspace are:

$$0.6 \le \lambda \le 0.7 \,, \quad -0.3 \le \kappa \le 0.3 \,, \quad 1.5 \le \tan\beta \le 2.5 \,, \quad 100 \text{ GeV } \le |\mu_{\text{eff}}| \le 185 \text{ GeV} \,. \tag{1.2}$$

Here the second lightest Higgs $H_2$ is SM-like. We will call it $h$ in the following. The two heavy Higgs bosons $H_3$ and $A_2$, called $H$ and $A$ in the following, are doublet-like. The light pseudocscalar $A_1$, called $A_s$ in the following, is singlet-like. The light scalar $H_1$, called $H_s$ in the following, is singlet-like. The mass scale of the heavy Higgs bosons is set by

$$M_H \approx M_A \approx M_{H^\pm} \approx \mu_{\text{eff}} \tan\beta \,. \tag{1.3}$$

In this natural NMSSM the almost degenerate heavy CP-even, CP-odd and charged Higgs bosons have masses below about 530 GeV, so that they are still light enough to be observed at LHC13. Due to substantial mixing, because of the large $\lambda$, between the SM-like Higgs state and the singlet dominated CP-even state the production cross sections of the lightest and the second lightest CP-even Higgs states are in general large enough to produce these particles. Otherwise the almost singlet-like non-SM CP-even Higgs boson can be produced through the decays of the heavier Higgs states, because of the large $\lambda$. The same holds for the singlet domnated CP-odd Higgs state.

The natural NMSSM should hence in general be accessible, so that it may be constrained at LHC13.

## 1.2 Benchmark Point $A2 \equiv$ BP7_P2

The benchmark point A2 allows for Higgs-to-Higgs and Higgs-to-gauge-Higgs decays.

It is part of the benchmarks resulting from a scan over the NMSSM parameter space with the aim to find Higgs-to-Higgs decay scenarios: Higgs decays into Higgs pairs that subsequently decay into SM particles,

$$\sigma(gg \to \phi_i) \times \mathrm{BR}(\phi_i \to \phi_j \phi_k) \times \mathrm{BR}(\phi_j \to XX) \times \mathrm{BR}(\phi_k \to YY) \tag{1.4}$$

are interesting for the discovery of the heavier Higgs boson $\phi_i$ provided its production cross section is large enough and the branching ratio into the lighter Higgs pair dominates over its branching ratios into the SM final states. For the lighter Higgs bosons $\phi_j$ and $\phi_k$ this production mechanism becomes interesting in case their direct production is strongly suppressed due to them being very singlet-like. Furthermore, Higgs-to-Higgs decays are interesting in themselves as they give access to the trilinear Higgs self-couplings, which can then be used to reconstruct the Higgs potential as the last step in the experimental verification of the Higgs mechanism.

The features of A2 are an overall light spectrum with

$$\begin{array}{lll} H_2 \equiv h & \text{SM-like} & M_h = 124.9 \text{ GeV} \\ H_1 \equiv H_s & \text{singlet-like} & M_{H_s} = 98 \text{ GeV} \\ A_1 \equiv A_s & \text{singlet-like} & M_{A_s} = 78 \text{ GeV} \\ H_3 \equiv H & \text{doublet-like} & M_H = 327 \text{ GeV} \\ A_2 \equiv A & \text{SM-like} & M_A = 326 \text{ GeV} . \end{array} \tag{1.5}$$

More information on the input values and the rates for the SM-like Higgs are given in Table 1.

The final states that we can have are $4b$, $2b2\tau$ $4\tau$, $bb\gamma\gamma$, $bbWW$, $llbb$ and many more. See Table on the twiki page.

| **A.2 (Point ID 2212)** | **Scenario** | | |
|---|---|---|---|
| $M_{H_s}, M_h, M_H$ | 98 GeV | 124.9 GeV | 327 GeV |
| $M_{A_s}, M_A$ | 78 GeV | 326 GeV | |
| $\lvert S_{H_1 h_s}\rvert^2, \lvert P_{A_1 a_s}\rvert^2$ | 0.89 | 0.96 | |
| $\mu_{\tau\tau}$, $\mu_{bb}$ | 1.05 | 0.93 | |
| $\mu_{ZZ}$, $\mu_{WW}$, $\mu_{\gamma\gamma}$ | 0.86 | 0.87 | 0.90 |
| $\tan\beta$, $\lambda$, $\kappa$ | 1.62 | 0.56 | 0.12 |
| $A_\lambda$, $A_\kappa$, $\mu_{\text{eff}}$ | -274.7 GeV | -21.5 GeV | -147.0 GeV |
| $A_t$, $A_b$, $A_\tau$ | 2964 GeV | -988 GeV | 1621 GeV |
| $M_1$, $M_2$, $M_3$ | 755.9 GeV | 646.7 GeV | 2424.9 GeV |
| $M_{Q_3} = M_{t_R}$, $M_{b_R}$ | 2461 GeV | 2452 GeV | 3 TeV |
| $M_{L_3} = M_{\tau_R}$, $M_{\text{SUSY}}$ | 1623.0 GeV | 3 TeV | |

Table 1: The parameters defining scenario A.2, together with the Higgs boson masses, singlet components and reduced signal rates of $h$.

## References

[1] S. F. King, M. Mhlleitner, R. Nevzorov and K. Walz, Phys. Rev. D **90** (2014) 9, 095014 [arXiv:1408.1120 [hep-ph]].