FERMILAB-PUB-07-036-T,
CERN-PH-TH/2007-148,DAMTP-2007-76,
Edinburgh 2007/31, KEK-TH-1170,LAPTH-1204/07,
LPT-ORSAY-07-81, SHEP-07-13, SLAC-PUB-12765.

SUSY Les Houches Accord 2

B.C. Allanach[1], C. Balázs[2], G. Bélanger[3], M. Bernhardt[4], F. Boudjema[3], D. Choudhury[5], K. Desch[4], U. Ellwanger[6], P. Gambino[7], R. Godbole[8], T. Goto[9], J. Guasch[10], M. Guchait[11], T. Hahn[12], S. Heinemeyer[13], C. Hugonie[14], T. Hurth[15,16], S. Kraml[15,17], S. Kreiss[18], J. Lykken[19], F. Moortgat[20], S. Moretti[6,21], S. Peñaranda[22], T. Plehn[18], W. Porod[23], A. Pukhov[24], P. Richardson[15,25], M. Schumacher[26], L. Silvestrini[27], P. Skands[15,19*], P. Slavich[3,15], M. Spira[28], G. Weiglein[25], P. Wienemann[4]

Abstract

The Supersymmetry Les Houches Accord (SLHA) provides a universal set of conventions for conveying spectral and decay information for supersymmetry analysis problems in high energy physics. Here, we propose extensions of the conventions of the first SLHA to include various generalisations: the minimal supersymmetric standard model with violation of CP, R-parity, and flavour, as well as the simplest next-to-minimal model.

1 *DAMTP, CMS, University of Cambridge, Wilberforce Road, Cambridge, CB3 0WA, United Kingdom*
2 *School of Physics, Monash University, Melbourne VIC 3800, Australia*
3 *LAPTH, CNRS, UMR 5108, Chemin de Bellevue BP110, F-74941, Annecy-le-Vieux, France*
4 *University of Bonn, Physics Institute, Nussallee 12, D-53115 Bonn, Germany*
5 *Harish Chandra Research Institute, Chhatnag Road, Jhunsi, Allahabad 211019, India*
6 *Laboratoire de Physique Théorique, Université de Paris Sud XI, Bât. 210, F-91405, Orsay, France*
7 *Università di Torino and INFN, sez. di Torino, 10125 Torino, Italy*
8 *Indian Institute of Science, Center for Theoretical Studies, Bangalore 560012, Karnataka, India*
9 *Theory Group, IPNS, KEK, Tsukuba, 305-0801, Japan*
10 *Universitat de Barcelona, Dept. de Fisica Fonamental, Diagonal 647, E-08028 Barcelona, Spain*
11 *Tata Institute for Fundamental Research, Homi Bhabha Road, Mumbai, India*
12 *MPI, Werner Heisenberg Inst., Föhringer Ring 6, D-80805 Munich, Germany*
13 *IFCA (CSIC–UC), Avda. de los Castros s/n, 39005 Santander, Spain*
14 *LPTA, Université Montpellier II, F-34095 Montpellier, Cedex 5, France*
15 *CERN, Department of Physics, Theory Unit, CH-1211, Geneva 23, Switzerland*
16 *SLAC, Stanford University, Stanford, CA 94309, USA*
17 *Laboratoire de Physique Subatomique et de Cosmologie (LPSC), UJF Grenoble 1, CNRS/IN2P3, 53 Avenue des Martyrs, F-38026 Grenoble, France*
18 *The University of Edinburgh, School of Physics, James Clerk Maxwell Building, King's Buildings, Mayfield Road, Edinburgh EH9 3JZ, United Kingdom*
19 *Theoretical Physics, Fermilab, P.O. Box 500, Batavia, IL 60510-0500, USA*

*Corresponding author: Peter Skands (peter.skands@cern.ch), CERN PH-TH, Geneva 23, CH-1211, Switzerland; tlph: +41-2276-72447; see `http://home.fnal.gov/~skands/slha/` for updates and examples.

20 ETH Zurich, CH-8093 Zurich, Switzerland
21 University of Southampton, School of Physics and Astronomy, Highfield, Southampton S017 1BJ, United Kingdom
22 Departamento de Física Teórica, Universidad de Zaragoza, E-50009, Zaragoza, Spain
23 Institut für Theoretische Physik und Astrophysik, Universität Würzburg, 97074 Würzburg, Germany
24 Skobeltsyn Inst. of Nuclear Physics, Moscow State Univ., Moscow 119991, Russia
25 Durham University Inst. for Particle Physics Phenomenology Ogden Centre for Fundamental Physics South Road Durham DH1 3LE, United Kingdom
26 Univ. Göttingen, Inst. für Theoretische Physik, Friedreich-Hund-Platz 1, D-37077 Göttingen, Germany
27 Univ. degli Studi di Roma, La Sapienza, Dipt. di Fisica G. Marconi, Piazzale Aldo Moro 2, I-00185 Rome, Italy
28 Paul Scherrer Institute, 5232 Villigen PSI, Switzerland

Contents

1 Introduction

Supersymmetric (SUSY) extensions of the Standard Model rank among the most promising and well-explored scenarios for New Physics at the TeV scale. Given the long history of supersymmetry and the number of people working in the field, several different conventions for defining supersymmetric theories have been proposed over the years, many of which have come into widespread use. At present, therefore, no unique set of conventions prevails. In principle, this is not a problem. As long as everything is clearly and consistently defined, a translation can always be made between two sets of conventions.

However, the proliferation of conventions does have some disadvantages. Results obtained by different authors or computer codes are not always directly comparable. Hence, if author/code A wishes to use the results of author/code B in a calculation, a consistency check of all the relevant conventions and any necessary translations must first be made – a tedious and error-prone task.

To deal with this problem, and to create a more transparent situation for non-experts, the original SUSY Les Houches Accord (SLHA1) was proposed [1]. This accord uniquely defines a set of conventions for supersymmetric models together with a common interface between codes. The most essential fact is not what the conventions are in detail (they largely resemble those of [2]), but that they are consistent and unambiguous, hence reducing the problem of translating between conventions to a linear, rather than a factorial, dependence on the number of codes involved. At present, these codes can be categorised roughly as follows (see [3, 4] for a review and on-line repository):

- Spectrum calculators [5–8], which calculate the supersymmetric mass and coupling spectrum, assuming some (given or derived) SUSY-breaking terms and a matching to known data on the Standard Model parameters.

- Observables calculators [9–19]; packages which calculate one or more of the following: collider production cross sections (cross section calculators), decay partial widths (decay packages), relic dark matter density (dark matter packages), and indirect/precision observables, such as rare decay branching ratios or Higgs/electroweak observables (constraint packages).

- Monte-Carlo event generators [20–28], which calculate cross sections through explicit statistical simulation of high-energy particle collisions. By including resonance decays, parton showering, hadronisation, and underlying-event effects, fully exclusive final states can be studied, and, for instance, detector simulations interfaced.

- SUSY and CKM fitting programs [29–32] which fit model parameters to collider-type data.

At the time of writing, the SLHA1 has already, to a large extent, obliterated the need for separately coded (and maintained and debugged) interfaces between many of these codes. Moreover, it has provided users with input and output in a common format, which is more readily comparable and transferable. Finally, the SLHA convention choices are also being

adapted for other tasks, such as the SPA project [33]. We believe, therefore, that the SLHA project has been useful, solving a problem that, for experts, is trivial but frequently occurring and tedious to deal with, and which, for non-experts, is an unnecessary headache.

However, SLHA1 was designed exclusively with the MSSM with real parameters and R-parity conservation in mind. Some recent public codes [6, 7, 17, 18, 34–38] are either implementing extensions to this base model or are anticipating such extensions. It therefore seems prudent at this time to consider how to extend SLHA1 to deal with more general supersymmetric theories. In particular, we will consider R-parity violation (RPV), flavour violation (FLV), and CP-violating (CPV) phases in the minimal supersymmetric standard model (MSSM). We will also consider next-to-minimal models (i.e., models in which the MSSM field content is augmented by a gauge-singlet chiral superfield) which we shall collectively label by the acronym NMSSM.

Rather than giving exhaustive historical references for all concepts used in this article, we provide a list of useful and pedagogical reviews to whose contents and references in turn we refer. For the various topics treated in the article, these reviews are:

- SUSY [39],
- FLV [40],
- Neutrinos [41],
- RPV [42, 43],
- CPV [44],
- NMSSM [45],
- SUSY Tools [3, 4].

There is clearly some tension between the desirable goals of generality of the models, ease of implementation in programs, and practicality for users. A completely general accord would be useless in practice if it was so complicated that no one would implement it. We have agreed on the following for SLHA2: for the MSSM, we will here restrict our attention to *either* CPV or RPV, but not both. For RPV and flavour violation, we shall work in the Super-CKM/PMNS basis, as defined in sections 4.1 and 4.2. For the NMSSM, we define one catch-all model and extend the SLHA1 mixing only to include the new states, with CP, R-parity, and flavour still assumed conserved.

To make the interface independent of programming languages, compilers, platforms etc, the SLHA1 is based on the transfer of three different ASCII files (or potentially a character string containing identical ASCII information): one for model input, one for spectrum calculator output, and one for decay calculator output. We believe that the advantage of implementation independence outweighs the disadvantage of codes using SLHA1 having to parse input. Indeed, there are tools to assist with this task [46–48].

Care was taken in SLHA1 to provide a framework for the MSSM that could easily be extended to the cases listed above. The conventions and switches described here are designed to be a *superset* of those of the original SLHA1 and so, unless explicitly mentioned in

the text, we will assume the conventions of the original accord [1] implicitly. For instance, all dimensionful parameters quoted in the present paper are assumed to be in the appropriate power of GeV, all angles are in radians, and the output formats for SLHA2 data `BLOCK`s follow those of SLHA1. In a few cases it will be necessary to replace the original conventions. This is clearly remarked upon in all places where it occurs, and the SLHA2 conventions then supersede the SLHA1 ones.

2 Extensions of SLHA1

Since its first publication, a few useful extensions to the SLHA1 have been identified. These are collected here for reference and are independent of the more general SUSY models discussed in subsequent sections. (Also note the recent proposal for a joint SLHA+LHEF format for BSM event generation [49, 50].)

Firstly, we introduce additional optional entries in the SLHA1 block `EXTPAR` to allow for using either the A^0 or H^+ pole masses as input instead of the parameter $m_A^2(M_{\rm input})$ defined in [1].

Secondly, to allow for different parameters to be defined at different scales (e.g., μ defined at $M_{\rm EWSB}$, the remaining parameters defined at $M_{\rm input}$) we introduce a new optional block `QEXTPAR` which, if present, overrides the default `MINPAR` and `EXTPAR` scale choices for specific parameters, as defined below.

While there is no obligation on codes to implement these extensions, we perceive it as useful that the accord allows for them, enabling a wider range of input parameter sets to be considered. The entries defined in `EXTPAR` and `QEXTPAR` in the SLHA2 are thus (repeating unchanged `EXTPAR` entries for completeness):

`BLOCK EXTPAR`

Optional input parameters for non-minimal/non-universal models. This block may be entirely absent from the input file, in which case a minimal type of the selected SUSY breaking model will be used. When block `EXTPAR` is present, the starting point is still a minimal model with parameters as given in `MINPAR` [1] but with each value present in `EXTPAR` replacing the minimal model value of that parameter, as applicable. If `MINPAR` is not present, then *all* model parameters must be specified explicitly using `EXTPAR`. All scale-dependent parameters are understood to be given in the $\overline{\rm DR}$ scheme.

Input scale

0 : $M_{\rm input}$. Input scale for `EXTPAR` entries in SUGRA, AMSB, and general MSSM models. If absent, the GUT scale derived from gauge unification will be used as input scale. Note that this parameter has no effect in GMSB scenarios where the input scale by definition is identical to the messenger scale, $M_{\rm mess}$. A special case is when $Q = M_{\rm EWSB} \equiv \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$ is desired as input scale, since this scale is not known beforehand. This choice can be invoked by giving the special value $M_{\rm input} = -1$. To define an alternative input scale for one or more specific parameters, see `QEXTPAR` below.

Gaugino Masses

1 : $M_1(M_{\rm input})$. $U(1)_Y$ gaugino (Bino) mass.

2 : $M_2(M_{\rm input})$. $SU(2)_L$ gaugino (Wino) mass.

3 : $M_3(M_{\rm input})$. $SU(3)_C$ gaugino (gluino) mass.

Trilinear Couplings

11 : $A_t(M_{\rm input})$. Top trilinear coupling.

12 : $A_b(M_{\rm input})$. Bottom trilinear coupling.

13 : $A_\tau(M_{\rm input})$. Tau trilinear coupling.

Higgs Parameters
— Only one of the parameter sets ($m^2_{H_1}$, $m^2_{H_2}$), (μ, m^2_A), ($\mu, m_{\rm A^0}$), or ($\mu, m_{\rm H^+}$) should be given, they merely represent different ways of specifying the same parameters.

21 : $m^2_{H_1}(M_{\rm input})$. Down type Higgs mass squared.

22 : $m^2_{H_2}(M_{\rm input})$. Up type Higgs mass squared.

23 : $\mu(M_{\rm input})$. μ parameter.

24 : $m^2_A(M_{\rm input})$. Tree–level pseudoscalar Higgs mass parameter squared, as defined in [1].

25 : $\tan\beta(M_{\rm input})$. If present, this value of $\tan\beta$ overrides the one in MINPAR, and the input scale is taken as $M_{\rm input}$ rather than m_Z.

26 : $m_{\rm A^0}$. Pseudoscalar Higgs pole mass. May be given instead of $m_A^2(M_{\rm input})$.

27 : $m_{\rm H^+}$. Charged Higgs pole mass. May be given instead of $m_A^2(M_{\rm input})$.

Sfermion Masses

31 : $m_{\tilde{e}_L}(M_{\rm input})$. Left 1$^{\rm st}$gen. scalar lepton mass.

32 : $m_{\tilde{\mu}_L}(M_{\rm input})$. Left 2$^{\rm nd}$gen. scalar lepton mass.

33 : $m_{\tilde{\tau}_L}(M_{\rm input})$. Left 3$^{\rm rd}$gen. scalar lepton mass.

34 : $m_{\tilde{e}_R}(M_{\rm input})$. Right scalar electron mass.

35 : $m_{\tilde{\mu}_R}(M_{\rm input})$. Right scalar muon mass.

36 : $m_{\tilde{\tau}_R}(M_{\rm input})$. Right scalar tau mass.

41 : $m_{\tilde{q}_{1L}}(M_{\rm input})$. Left 1$^{\rm st}$gen. scalar quark mass.

42 : $m_{\tilde{q}_{2L}}(M_{\rm input})$. Left 2$^{\rm nd}$gen. scalar quark mass.

43 : $m_{\tilde{q}_{3L}}(M_{\rm input})$. Left 3$^{\rm rd}$gen. scalar quark mass.

44 : $m_{\tilde{u}_R}(M_{\rm input})$. Right scalar up mass.

45 : $m_{\tilde{c}_R}(M_{\rm input})$. Right scalar charm mass.

46 : $m_{\tilde{t}_R}(M_{\rm input})$. Right scalar top mass.

47 : $m_{\tilde{d}_R}(M_{\rm input})$. Right scalar down mass.

48 : $m_{\tilde{s}_R}(M_{\rm input})$. Right scalar strange mass.

49 : $m_{\tilde{b}_R}(M_{\rm input})$. Right scalar bottom mass.

Other Extensions

51 : N_1 (GMSB only). $U(1)_Y$ messenger index (defined as in ref. [51]).

52 : N_2 (GMSB only). $SU(2)_L$ messenger index (defined as in ref. [51]).

53 : N_3 (GMSB only). $SU(3)_C$ messenger index (defined as in ref. [51]).

BLOCK QEXTPAR

Optional alternative input scales for specific parameters. This block should normally be absent, in which case the default input scale or $M_{\rm input}$ (see EXTPAR 0) will be used for all parameters. We stress that most codes cannot be expected to allow for multiple arbitrary scale choices, so the relevant manual and output should be carefully checked to make sure the desired behaviour is obtained. Currently defined entries are:

1 : Q_{M_1}. Input scale for M_1.

2 : Q_{M_2}. Input scale for M_2.

3 : Q_{M_3}. Input scale for M_3.

11 : Q_{A_u}. Input scale for up-type squark trilinear couplings.

12 : Q_{A_d}. Input scale for down-type squark trilinear couplings.

13 : Q_{A_ℓ}. Input scale for charged slepton trilinear couplings.

21 : $Q_{m^2_{H_1}}$. Input scale for $m^2_{H_1}$.

22 : $Q_{m^2_{H_2}}$. Input scale for $m^2_{H_2}$.

23 : Q_μ. Input scale for μ.

24 : $Q_{m^2_A}$. Input scale for m^2_A, as defined in [1].

25 : $Q_{\tan\beta}$. Input scale for $\tan\beta$.

31 : $Q_{m_{\tilde{\ell}_L}}$. Input scale for all left-handed slepton mass terms.

34 : $Q_{m_{\tilde{\ell}_R}}$. Input scale for all right-handed slepton mass terms.

41 : $Q_{m_{\tilde{q}_L}}$. Input scale for all left-handed squark mass terms.

44 : $Q_{m_{\tilde{u}_R}}$. Input scale for all right-handed up-type squark mass terms.

47 : $Q_{m_{\tilde{d}_R}}$. Input scale for all right-handed down-type squark mass terms.

3 Model Selection

To define the general properties of the model, we propose to introduce global switches in the SLHA1 model definition block MODSEL, as follows. Note that the switches defined here are in addition to the ones in [1].

BLOCK MODSEL

Switches and options for model selection. The entries in this block should consist of an index, identifying the particular switch in the listing below, followed by another integer or real number, specifying the option or value chosen:

3 : (Default=0) Choice of particle content. Switches defined are:
- 0 : MSSM. This corresponds to SLHA1.
- 1 : NMSSM. The blocks defined in section 5 should be present.

4 : (Default=0) R-parity violation. Switches defined are:
- 0 : R-parity conserved. This corresponds to the SLHA1.
- 1 : R-parity violated. The blocks defined in section 4.2 should be present.

5 : (Default=0) CP violation. Switches defined are:
- 0 : CP is conserved. No information even on the CKM phase is used. This corresponds to the SLHA1.
- 1 : CP is violated, but only by the standard CKM phase. All other phases are assumed zero.
- 2 : CP is violated. Completely general CP phases allowed. Imaginary parts corresponding to the entries in the SLHA1 block `EXTPAR` can be given in `IMEXTPAR` (together with the CKM phase). In the case of additional SUSY flavour violation, imaginary parts of the blocks defined in section 4.1 should be given, again with the prefix `IM`, which supersede the corresponding entries in `IMEXTPAR`.

6 : (Default=0) Flavour violation. Switches defined are:
- 0 : No (SUSY) flavour violation. This corresponds to the SLHA1.
- 1 : Quark flavour is violated. The blocks defined in section 4.1 should be present.
- 2 : Lepton flavour is violated. The blocks defined in section 4.1 should be present.
- 3 : Lepton and quark flavour is violated. The blocks defined in section 4.1 should be present.

4 General MSSM

For convenience, we here repeat the definitions of the field content, superpotential and soft SUSY-breaking potential of the MSSM in the notation of [1].

Specifically, the chiral superfields of the MSSM have the following $SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$ quantum numbers

$$\begin{array}{llllll} L: & (1,2,-\frac{1}{2}), & \bar{E}: & (1,1,1), & Q: (3,2,\frac{1}{6}), & \bar{U}: (\bar{3},1,-\frac{2}{3}), \\ \bar{D}: & (\bar{3},1,\frac{1}{3}), & H_1: & (1,2,-\frac{1}{2}), & H_2: (1,2,\frac{1}{2}) \ , & \end{array} \tag{1}$$

the superpotential (omitting RPV terms, see section 4.2) is written as

$$W_{MSSM} \ = \ \epsilon_{ab} \left[(Y_E)_{ij} H_1^a L_i^b \bar{E}_j + (Y_D)_{ij} H_1^a Q_i^b \bar{D}_j + (Y_U)_{ij} H_2^b Q_i^a \bar{U}_j - \mu H_1^a H_2^b \right] \ , \tag{2}$$

and the trilinear and bilinear soft SUSY-breaking potentials V_3 and V_2 are

$$V_3 = \epsilon_{ab} \sum_{ij} \left[(T_E)_{ij} H_1^a \tilde{L}^b_{i_L} \tilde{e}^*_{j_R} + (T_D)_{ij} H_1^a \tilde{Q}^b_{i_L} \tilde{d}^*_{j_R} + (T_U)_{ij} H_2^b \tilde{Q}^a_{i_L} \tilde{u}^*_{j_R} \right] + \text{h.c.} \,, \tag{3}$$

$$\begin{aligned} V_2 = {} & m^2_{H_1} H^*_{1\,a} H^a_1 + m^2_{H_2} H^*_{2\,a} H^a_2 + \tilde{Q}^*_{i_L a} (m^2_{\tilde{Q}})_{ij} \tilde{Q}^a_{j_L} + \tilde{L}^*_{i_L a} (m^2_{\tilde{L}})_{ij} \tilde{L}^a_{j_L} + \\ & \tilde{u}_{i_R} (m^2_{\tilde{u}})_{ij} \tilde{u}^*_{j_R} + \tilde{d}_{i_R} (m^2_{\tilde{d}})_{ij} \tilde{d}^*_{j_R} + \tilde{e}_{i_R} (m^2_{\tilde{e}})_{ij} \tilde{e}^*_{j_R} - (m^2_3 \epsilon_{ab} H^a_1 H^b_2 + \text{h.c.}) \,, \end{aligned} \tag{4}$$

where a tilde over the symbol for a quark or lepton superfield denotes its scalar component (note however that we define, e.g., $\tilde{u}^*_R$ as the scalar component of $\bar{U}$). Throughout this section, we denote $SU(2)_L$ fundamental representation indices by $a, b = 1, 2$ and generation indices by $i, j = 1, 2, 3$. Colour indices are everywhere suppressed, since only trivial contractions are involved. ϵ_{ab} is the totally antisymmetric tensor, with $\epsilon_{12} = \epsilon^{12} = 1$.

4.1 Flavour Violation

4.1.1 The quark sector and the super-CKM basis

Within the MSSM there are in general new sources of flavour violation arising from a possible misalignment of quarks and squarks in flavour space. The severe experimental constraints on flavour violation have no direct explanation in the structure of the unconstrained MSSM which leads to the well-known supersymmetric flavour problem.

The Super-CKM basis of the squarks is very useful in this context because in that basis only physically measurable parameters are present. In the Super-CKM basis the quark mass matrix is diagonal and the squarks are rotated in parallel to their superpartners. Actually, once the electroweak symmetry is broken, a rotation in flavour space

$$D^{\,o} \;=\; V_d \, D \,, \qquad U^{\,o} \;=\; V_u \, U \,, \qquad \bar{D}^o = \; U^*_d \, \bar{D} \,, \qquad \bar{U}^o = \; U^*_u \, \bar{U} \,, \tag{5}$$

of all matter superfields in the (s)quark superpotential

$$W_Q \;=\; \epsilon_{ab} \left[(Y_D)_{ij} \, H^a_1 Q^{b\,o}_i \bar{D}^{\,o}_j + (Y_U)_{ij} \, H^b_2 Q^{a\,o}_i \bar{U}^{\,o}_j \right] \tag{6}$$

brings fermions from the interaction eigenstate basis $\{d^o_L, u^o_L, d^o_R, u^o_R\}$ to their mass eigenstate basis $\{d_L, u_L, d_R, u_R\}$:

$$d^o_L = V_d d_L \,, \qquad u^o_L = V_u u_L \,, \qquad d^o_R = U_d d_R \,, \qquad u^o_R = U_u u_R \,, \tag{7}$$

and the scalar superpartners to the basis $\{\tilde{d}_L, \tilde{u}_L, \tilde{d}_R, \tilde{u}_R\}$. Through this rotation, the Yukawa matrices Y_D and Y_U are reduced to their diagonal form $\hat{Y}_D$ and $\hat{Y}_U$:

$$(\hat{Y}_D)_{ii} = (U^\dagger_d Y^T_D V_d)_{ii} = \sqrt{2} \frac{m_{d\,i}}{v_1} \,, \qquad (\hat{Y}_U)_{ii} = (U^\dagger_u Y^T_U V_u)_{ii} = \sqrt{2} \frac{m_{u\,i}}{v_2} \,. \tag{8}$$

Tree-level mixing terms among quarks of different generations are due to the misalignment of V_d and V_u, expressed via the CKM matrix

$$V_{\text{CKM}} = V^\dagger_u V_d \,, \tag{9}$$

which is proportional to the tree-level $\bar{u}_{Li} d_{Lj} W^+$, $\bar{u}_{Li} d_{Rj} H^+$, and $\bar{u}_{Ri} d_{Lj} H^+$ couplings ($i, j = 1, 2, 3$). This is also true for the supersymmetric counterparts of these vertices, in the limit of unbroken supersymmetry.

In the super-CKM basis the 6×6 mass matrices for the up-type and down-type squarks are defined as

$$\mathcal{L}_{\tilde{q}}^{\text{mass}} = -\Phi_u^\dagger \mathcal{M}_{\tilde{u}}^2 \Phi_u - \Phi_d^\dagger \mathcal{M}_{\tilde{d}}^2 \Phi_d \,, \tag{10}$$

where $\Phi_u = (\tilde{u}_L, \tilde{c}_L, \tilde{t}_L, \tilde{u}_R, \tilde{c}_R, \tilde{t}_R)^T$ and $\Phi_d = (\tilde{d}_L, \tilde{s}_L, \tilde{b}_L, \tilde{d}_R, \tilde{s}_R, \tilde{b}_R)^T$. We diagonalise the squark mass matrices via 6×6 unitary matrices $R_{u,d}$, such that $R_{u,d}\, \mathcal{M}^2_{\tilde{u},\tilde{d}}\, R^\dagger_{u,d}$ are diagonal matrices with increasing mass squared values. The flavour-mixed mass matrices read:

$$\mathcal{M}_{\tilde{u}}^2 = \begin{pmatrix} V_{\text{CKM}}\, \hat{m}^2_{\tilde{Q}}\, V^\dagger_{\text{CKM}} + m_u^2 + D_{u\,LL} & \frac{v_2}{\sqrt{2}} \hat{T}_U^\dagger - \mu m_u \cot\beta \\ \frac{v_2}{\sqrt{2}} \hat{T}_U - \mu^* m_u \cot\beta & \hat{m}^2_{\tilde{u}} + m_u^2 + D_{u\,RR} \end{pmatrix} , \tag{11}$$

$$\mathcal{M}_{\tilde{d}}^2 = \begin{pmatrix} \hat{m}^2_{\tilde{Q}} + m_d^2 + D_{d\,LL} & \frac{v_1}{\sqrt{2}} \hat{T}_D^\dagger - \mu m_d \tan\beta \\ \frac{v_1}{\sqrt{2}} \hat{T}_D - \mu^* m_d \tan\beta & \hat{m}^2_{\tilde{d}} + m_d^2 + D_{d\,RR} \end{pmatrix} . \tag{12}$$

In the equations above we introduced the 3×3 matrices

$$\hat{m}^2_{\tilde{Q}} \equiv V_d^\dagger\, m^2_{\tilde{Q}}\, V_d \,, \quad \hat{m}^2_{\tilde{u}} \equiv U_u^\dagger\, m^{2\,T}_{\tilde{u}}\, U_u \,, \quad \hat{m}^2_{\tilde{d}} \equiv U_d^\dagger\, m^{2\,T}_{\tilde{d}}\, U_d \,, \tag{13}$$

$$\hat{T}_U \equiv U_u^\dagger\, T_U^T\, V_u \,, \quad \hat{T}_D \equiv U_d^\dagger\, T_D^T\, V_d \,, \tag{14}$$

where the un-hatted mass matrices $m^2_{Q,u,d}$ and trilinear interaction matrices $T_{U,D}$ are given in the interaction basis.

The matrices $m_{u,d}$ are the diagonal up-type and down-type quark masses and $D_{f\,LL,RR}$ are the D-terms given by:

$$D_{f\,LL,RR} = \cos 2\beta\, m_Z^2 \left(T_f^3 - Q_f \sin^2\theta_W \right) \mathbb{1}_3 \,, \tag{15}$$

which are also flavour diagonal. Here, Q_f is the electric charge of the left-handed chiral supermultiplet to which the squark belongs, i.e., it is $2/3$ for U and $-2/3$ for U^c. Note that the up-type and down-type squark mass matrices in eqs. (11) and (12) cannot be simultaneously flavour-diagonal unless $\hat{m}^2_{\tilde{Q}}$ is flavour-universal (i.e., proportional to the identity in flavour space).

4.1.2 The lepton sector and the super-PMNS basis

For the lepton sector, we adopt a super-PMNS basis, as defined in this section.

Neutrino oscillation data have provided a strong indication that neutrinos have masses and that there are flavour-changing charged currents in the leptonic sector. One popular model to produce such effects is the see-saw mechanism, where right-handed neutrinos have both Majorana masses as well as Yukawa couplings with the left-handed leptons.When the heavy neutrinos are integrated out of the effective field theory, one is left with three light approximately left-handed neutrinos which are identified with the ones observed experimentally. There are other models of neutrino masses, for example involving SU(2) Higgs

triplets, that, once the triplets have been integrated out, also lead to effective Majorana masses for the neutrinos. Here, we cover all cases that lead to a low energy effective field theory with Majorana neutrino masses and one sneutrino per family. In terms of this low energy effective theory, the lepton mixing phenomenon is analogous to the quark mixing case and so we adapt the conventions defined above to the leptonic case.

After electroweak symmetry breaking, the neutrino sector of the MSSM contains the Lagrangian pieces (in 2–component notation)

$$\mathcal{L} = -\frac{1}{2}\nu^{oT}(m_\nu)\nu^o + \text{h.c.}, \tag{16}$$

where m_ν is a 3×3 symmetric matrix. The interaction eigenstate basis neutrino fields ν^o are related to the mass eigenstate ones ν by

$$\nu^o = V_\nu \nu, \tag{17}$$

reducing the mass matrix m_ν to its diagonal form $\hat{m}_\nu$

$$(\hat{m}_\nu)_{ii} = (V_\nu^T m_\nu V_\nu)_{ii} = m_{\nu_i}. \tag{18}$$

The charged lepton fields have a 3×3 Yukawa coupling matrix defined in the (s)lepton superpotential

$$W_E = \epsilon_{ab}(Y_E)_{ij} H_1^a L_i^{bo} \bar{E}_j^o, \tag{19}$$

where the charged lepton interaction eigenstates $\{e_L^o, e_R^o\}$ are related to the mass eigenstates $\{e_L, e_R, \}$ by

$$e_L^o = V_e e_L \qquad \text{and} \qquad e_R^o = U_e e_R. \tag{20}$$

The equivalent diagonalised charged lepton Yukawa matrix is

$$(\hat{Y}_E)_{ii} = (U_e^\dagger Y_E^T V_e)_{ii} = \sqrt{2}\frac{m_{ei}}{v_1} \quad . \tag{21}$$

Lepton mixing in the charged current interaction can then be characterised by the PMNS matrix

$$U_{PMNS} = V_e^\dagger V_\nu \ , \tag{22}$$

which is proportional to the tree-level $\bar{e}_{Li}\nu_j W^-$ and $\bar{e}_{Ri}\nu_j H^-$ couplings ($i, j = 1, 2, 3$). This is also true for the supersymmetric counterparts of these vertices, in the limit of unbroken supersymmetry.

Rotating the interaction eigenstates of the sleptons identically to their leptonic counterparts, we obtain the super-PMNS basis for the charged sleptons and the sneutrinos, described by the Lagrangian[1]

$$\mathcal{L}_{\tilde{l}}^{mass} = -\Phi_e^\dagger \mathcal{M}_{\tilde{e}}^2 \Phi_e - \Phi_\nu^\dagger \mathcal{M}_{\tilde{\nu}}^2 \Phi_\nu, \tag{23}$$

[1]We here neglect the possible term $\Phi_\nu^T \hat{\mathcal{M}}_{\tilde{\nu}}^2 \Phi_\nu$.

where $\Phi_\nu = (\tilde{\nu}_e, \tilde{\nu}_\mu, \tilde{\nu}_\tau)^T$ and $\Phi_e = (\tilde{e}_L, \tilde{\mu}_L, \tilde{\tau}_L, \tilde{e}_R, \tilde{\mu}_R, \tilde{\tau}_R)^T$. $\mathcal{M}^2_{\tilde{e}}$ is the 6×6 matrix

$$\mathcal{M}^2_{\tilde{e}} = \begin{pmatrix} \hat{m}^2_{\tilde{L}} + m^2_e + D_{eLL} & \frac{v_1}{\sqrt{2}}\hat{T}^\dagger_E - \mu m_e \tan\beta \\ \frac{v_1}{\sqrt{2}}\hat{T}_E - \mu^* m_e \tan\beta & \hat{m}^2_{\tilde{e}} + m^2_e + D_{eRR} \end{pmatrix} , \tag{24}$$

and $\mathcal{M}^2_{\tilde{\nu}}$ is the 3×3 matrix

$$\mathcal{M}^2_{\tilde{\nu}} = U^\dagger_{PMNS}\, \hat{m}^2_{\tilde{L}}\, U_{PMNS} + D_{\nu LL}, \tag{25}$$

where D_{eLL} and $D_{\nu LL}$ are given in eq. (15). In the equations above we introduced the 3×3 matrices

$$\hat{m}^2_{\tilde{L}} \equiv V^\dagger_e\, m^2_{\tilde{L}}\, V_e\,, \quad \hat{m}^2_{\tilde{e}} \equiv U^\dagger_e\, m^{2^T}_{\tilde{e}}\, U_e\,, \tag{26}$$

$$\hat{T}_E \equiv U^\dagger_e\, T^T_E\, V_e\,, \tag{27}$$

where the un-hatted mass matrices $m^2_{L,e}$ and the trilinear interaction matrix T_E are given in the interaction basis. We diagonalise the charged slepton and sneutrino mass matrices via the unitary 6×6 and 3×3 matrices $R_{e,\nu}$ respectively. Thus, $R_{e,\nu}\mathcal{M}^2_{\tilde{e},\tilde{\nu}}R^\dagger_{e,\nu}$ are diagonal with increasing entries toward the bottom right of each matrix.

4.1.3 Explicit proposal for SLHA2

As in the SLHA1 [1], for all running parameters in the output of the spectrum file, we propose to use definitions in the modified dimensional reduction ($\overline{\rm DR}$) scheme. The basis is the super-CKM/PMNS basis as defined above, that is the one in which the Yukawa couplings of the SM fermions, given in the $\overline{\rm DR}$ scheme, are diagonal. Note that the masses and vacuum expectation values (VEVs) in eqs. (8), (18), and (21) must thus also be the running ones in the $\overline{\rm DR}$ scheme.

The input for an explicit implementation in a spectrum calculator consists of the following information:

- By default, all input SUSY parameters are given at the scale $M_{\rm input}$ as defined in the SLHA1 block `EXTPAR` (see above). In principle, advanced codes may also allow for separate input scales for the sfermion mass matrices and trilinear couplings, via the block `QEXTPAR` defined above, but we emphasise that this should be regarded as non-standard.

- For the SM input parameters, we take the Particle Data Group (PDG) definition: lepton masses are all on-shell. The light quark masses $m_{u,d,s}$ are given at 2 GeV, and the heavy quark masses are given as $m_c(m_c)^{\overline{\rm MS}}$, $m_b(m_b)^{\overline{\rm MS}}$ and $m_t^{\rm on-shell}$. The latter two quantities are already in the SLHA1. The others are added to `SMINPUTS` in the following manner (repeating the SLHA1 parameters for convenience):

  `1` : $\alpha^{-1}_{\rm em}(m_Z)^{\overline{\rm MS}}$. Inverse electromagnetic coupling at the Z pole in the $\overline{\rm MS}$ scheme (with 5 active flavours).

  `2` : G_F. Fermi constant (in units of GeV^{-2}).

3 : $\alpha_s(m_Z)^{\overline{\rm MS}}$. Strong coupling at the Z pole in the $\overline{\rm MS}$ scheme (with 5 active flavours).

4 : m_Z, pole mass.

5 : $m_b(m_b)^{\overline{\rm MS}}$. b quark running mass in the $\overline{\rm MS}$ scheme.

6 : m_t, pole mass.

7 : m_τ, pole mass.

8 : m_{ν_3}, pole mass.

11 : $m_{\rm e}$, pole mass.

12 : m_{ν_1}, pole mass.

13 : m_μ, pole mass.

14 : m_{ν_2}, pole mass.

21 : $m_d(2\ {\rm GeV})^{\overline{\rm MS}}$. d quark running mass in the $\overline{\rm MS}$ scheme.

22 : $m_u(2\ {\rm GeV})^{\overline{\rm MS}}$. u quark running mass in the $\overline{\rm MS}$ scheme.

23 : $m_s(2\ {\rm GeV})^{\overline{\rm MS}}$. s quark running mass in the $\overline{\rm MS}$ scheme.

24 : $m_c(m_c)^{\overline{\rm MS}}$. c quark running mass in the $\overline{\rm MS}$ scheme.

The FORTRAN format is the same as that of `SMINPUTS` in SLHA1 [1].

- $V_{\rm CKM}$: the input CKM matrix in the Wolfenstein parameterisation[2], in the block `VCKMIN`. Note that present CKM studies do not precisely define a renormalisation scheme for this matrix since the electroweak effects that renormalise it are highly suppressed and generally neglected. We therefore assume that the CKM elements given by PDG (or by UTFit [31] and CKMFitter [32], the main collaborations that extract the CKM parameters) refer to SM $\overline{\rm MS}$ quantities defined at $Q = m_Z$, to avoid any possible ambiguity. `VCKMIN` should have the following entries

  1 : λ

  2 : A

  3 : $\bar\rho$

  4 : $\bar\eta$

  The FORTRAN format is the same as that of `SMINPUTS` above.

- $U_{\rm PMNS}$: the input PMNS matrix, in the block `UPMNSIN`. It should have the PDG parameterisation in terms of rotation angles [52] (all in radians):

  1 : $\bar\theta_{12}$ (the solar angle)

  2 : $\bar\theta_{23}$ (the atmospheric mixing angle)

[2]For the Wolfenstein parameters we use the PDG definition, eq.(11.4) of [52], which is exact to all orders in λ.

3 : $\bar{\theta}_{13}$ (currently only has an upper bound)

4 : $\bar{\delta}_{13}$ (the Dirac CP-violating phase)

5 : α_1 (the first Majorana CP-violating phase)

6 : α_2 (the second CP-violating Majorana phase)

The FORTRAN format is the same as that of `SMINPUTS` above. Majorana phases have no effect on neutrino oscillations. However, they have physical consequences in the case of, for example, $\beta\beta0\nu$ decay of nuclei.

- $(\hat{m}^2_{\tilde{Q}})^{\overline{\rm DR}}_{ij}$, $(\hat{m}^2_{\tilde{u}})^{\overline{\rm DR}}_{ij}$, $(\hat{m}^2_{\tilde{d}})^{\overline{\rm DR}}_{ij}$, $(\hat{m}^2_{\tilde{L}})^{\overline{\rm DR}}_{ij}$, $(\hat{m}^2_{\tilde{e}})^{\overline{\rm DR}}_{ij}$: the squark and slepton soft SUSY-breaking masses at the input scale in the super-CKM/PMNS basis, as defined above. They will be given in the new blocks `MSQ2IN`, `MSU2IN`, `MSD2IN`, `MSL2IN`, `MSE2IN`, with the FORTRAN format

  ```
  (1x,I2,1x,I2,3x,1P,E16.8,0P,3x,'#',1x,A).
  ```

  where the first two integers in the format correspond to i and j and the double precision number to the soft mass squared. Only the "upper triangle" of these matrices should be given. If diagonal entries are present, these supersede the parameters in the SLHA1 block `EXTPAR`.

- $(\hat{T}_U)^{\overline{\rm DR}}_{ij}$, $(\hat{T}_D)^{\overline{\rm DR}}_{ij}$, and $(\hat{T}_E)^{\overline{\rm DR}}_{ij}$: the squark and slepton soft SUSY-breaking trilinear couplings at the input scale in the super-CKM/PMNS basis. They will be given in the new blocks `TUIN`, `TDIN`, `TEIN`, in the same format as the soft mass matrices above. If diagonal entries are present these supersede the A parameters specified in the SLHA1 block `EXTPAR` [1].

For the output, the pole masses are given in block `MASS` as in SLHA1 (note, however, that some PDG numbers have different assignments in SLHA2, see below) and the $\overline{\rm DR}$ and mixing parameters as follows:

- $(\hat{m}^2_{\tilde{Q}})^{\overline{\rm DR}}_{ij}$, $(\hat{m}^2_{\tilde{u}})^{\overline{\rm DR}}_{ij}$, $(\hat{m}^2_{\tilde{d}})^{\overline{\rm DR}}_{ij}$, $(\hat{m}^2_{\tilde{L}})^{\overline{\rm DR}}_{ij}$, $(\hat{m}^2_{\tilde{e}})^{\overline{\rm DR}}_{ij}$: the squark and slepton soft SUSY-breaking masses at scale Q in the super-CKM/PMNS basis. Will be given in the new blocks `MSQ2 Q=...`, `MSU2 Q=...`, `MSD2 Q=...`, `MSL2 Q=...`, `MSE2 Q=...`, with formats as the corresponding input blocks `MSX2IN` above.

- $(\hat{T}_U)^{\overline{\rm DR}}_{ij}$, $(\hat{T}_D)^{\overline{\rm DR}}_{ij}$, and $(\hat{T}_E)^{\overline{\rm DR}}_{ij}$: The squark and slepton soft SUSY-breaking trilinear couplings in the super-CKM/PMNS basis. Given in the new blocks `TU Q=...`, `TD Q=...`, `TE Q=...`, which supersede the SLHA1 blocks `AD`, `AU`, and `AE`, see [1].

- $(\hat{Y}_U)^{\overline{\rm DR}}_{ii}$, $(\hat{Y}_D)^{\overline{\rm DR}}_{ii}$, $(\hat{Y}_E)^{\overline{\rm DR}}_{ii}$: the diagonal $\overline{\rm DR}$ Yukawas in the super-CKM/PMNS basis, with $\hat{Y}$ defined by eqs. (8) and (21), at the scale Q. Given in the SLHA1 blocks `YU Q=...`, `YD Q=...`, `YE Q=...`, see [1]. Note that although the SLHA1 blocks provide for off-diagonal elements, only the diagonal ones will be relevant here, due to the CKM/PMNS rotation.

- The entries of the $\overline{\rm DR}$ CKM matrix at the scale Q. The real and imaginary parts are given in `VCKM Q=...` and `IMVCKM Q=...`, respectively. The format of the individual entries is the same as for mixing matrices in the SLHA1. Note that the complete matrix should be output, i.e., all entries should be included.

- The entries of the $\overline{\rm DR}$ PMNS matrix at the scale Q. The real and imaginary parts are given in `UPMNS Q=...` and `IMUPMNS Q=...`, respectively, with entries defined as for the V_{CKM} output blocks above.

- The squark and slepton masses and mixing matrices should be defined as in the existing SLHA1, e.g. extending the $\tilde{t}$, $\tilde{b}$ and $\tilde{\tau}$ mixing matrices to the 6×6 case. More specifically, the new blocks R_u =`USQMIX` R_d =`DSQMIX`, R_e =`SELMIX` and the 3×3 matrix for R_ν =`SNUMIX` specify the composition of the mass eigenstates in terms of the super-CKM/PMNS basis states according to the following definitions:

$$\begin{pmatrix} 1000001 \\ 1000003 \\ 1000005 \\ 2000001 \\ 2000003 \\ 2000005 \end{pmatrix} = \begin{pmatrix} \tilde{d}_1 \\ \tilde{d}_2 \\ \tilde{d}_3 \\ \tilde{d}_4 \\ \tilde{d}_5 \\ \tilde{d}_6 \end{pmatrix}_{\rm mass-ordered} = \texttt{DSQMIX}_{ij} \begin{pmatrix} \tilde{d}_L \\ \tilde{s}_L \\ \tilde{b}_L \\ \tilde{d}_R \\ \tilde{s}_R \\ \tilde{b}_R \end{pmatrix}_{\rm super-CKM} , \tag{28}$$

$$\begin{pmatrix} 1000002 \\ 1000004 \\ 1000006 \\ 2000002 \\ 2000004 \\ 2000006 \end{pmatrix} = \begin{pmatrix} \tilde{u}_1 \\ \tilde{u}_2 \\ \tilde{u}_3 \\ \tilde{u}_4 \\ \tilde{u}_5 \\ \tilde{u}_6 \end{pmatrix}_{\rm mass-ordered} = \texttt{USQMIX}_{ij} \begin{pmatrix} \tilde{u}_L \\ \tilde{c}_L \\ \tilde{t}_L \\ \tilde{u}_R \\ \tilde{c}_R \\ \tilde{t}_R \end{pmatrix}_{\rm super-CKM} . \tag{29}$$

$$\begin{pmatrix} 1000011 \\ 1000013 \\ 1000015 \\ 2000011 \\ 2000013 \\ 2000015 \end{pmatrix} = \begin{pmatrix} \tilde{e}_1 \\ \tilde{e}_2 \\ \tilde{e}_3 \\ \tilde{e}_4 \\ \tilde{e}_5 \\ \tilde{e}_6 \end{pmatrix}_{\rm mass-ordered} = \texttt{SELMIX}_{ij} \begin{pmatrix} \tilde{e}_L \\ \tilde{\mu}_L \\ \tilde{\tau}_L \\ \tilde{e}_R \\ \tilde{\mu}_R \\ \tilde{\tau}_R \end{pmatrix}_{\rm super-PMNS} , \tag{30}$$

$$\begin{pmatrix} 1000012 \\ 1000014 \\ 1000016 \end{pmatrix} = \begin{pmatrix} \tilde{\nu}_1 \\ \tilde{\nu}_2 \\ \tilde{\nu}_3 \end{pmatrix}_{\rm mass-ordered} = \texttt{SNUMIX}_{ij} \begin{pmatrix} \tilde{\nu}_e \\ \tilde{\nu}_\mu \\ \tilde{\nu}_\tau \end{pmatrix}_{\rm super-PMNS} . \tag{31}$$

Note! A potential for inconsistency arises if the masses and mixings are not calculated in the same way, e.g. if radiatively corrected masses are used with tree-level mixing matrices. In this case, it is possible that the radiative corrections to the masses shift the mass ordering relative to the tree-level. This is especially relevant when near-degenerate masses occur in the spectrum and/or when the radiative corrections are large. In these cases, explicit care must be taken especially by the program writing

the spectrum, but also by the one reading it, to properly arrange the rows in the order of the mass spectrum actually used.

- **Optionally**, we allow for the possibility of the scalar and pseudoscalar components of the sneutrinos to be treated separately. In this case, we define separate PDG codes and mixing matrices for the scalar and pseudoscalar sneutrinos, as follows:

$$\begin{pmatrix} 1000012 \\ 1000014 \\ 1000016 \end{pmatrix} = \begin{pmatrix} \tilde{\nu}_{1S} \\ \tilde{\nu}_{2S} \\ \tilde{\nu}_{3S} \end{pmatrix}_{\rm mass-ordered} = \texttt{SNSMIX}_{ij} \begin{pmatrix} \sqrt{2}{\rm Re}\left\{\tilde{\nu}_e\right\} \\ \sqrt{2}{\rm Re}\left\{\tilde{\nu}_\mu\right\} \\ \sqrt{2}{\rm Re}\left\{\tilde{\nu}_\tau\right\} \end{pmatrix}_{\rm super-PMNS} , \tag{32}$$

$$\begin{pmatrix} 1000017 \\ 1000018 \\ 1000019 \end{pmatrix} = \begin{pmatrix} \tilde{\nu}_{1A} \\ \tilde{\nu}_{2A} \\ \tilde{\nu}_{3A} \end{pmatrix}_{\rm mass-ordered} = \texttt{SNAMIX}_{ij} \begin{pmatrix} \sqrt{2}{\rm Im}\left\{\tilde{\nu}_e\right\} \\ \sqrt{2}{\rm Im}\left\{\tilde{\nu}_\mu\right\} \\ \sqrt{2}{\rm Im}\left\{\tilde{\nu}_\tau\right\} \end{pmatrix}_{\rm super-PMNS} . \tag{33}$$

  If present, `SNSMIX` and `SNAMIX` supersede `SNUMIX`.

4.2 R-Parity Violation

We write the R-parity violating superpotential in the interaction basis as

$$\begin{aligned} W_{\rm RPV} &= \epsilon_{ab}\left[\frac{1}{2}\lambda_{ijk}L_i^a L_j^b \bar{E}_k + \lambda'_{ijk}L_i^a Q_j^{bx}\bar{D}_{kx} - \kappa_i L_i^a H_2^b\right] \\ &\quad + \frac{1}{2}\lambda''_{ijk}\epsilon_{xyz}\bar{U}_i^x \bar{D}_j^y \bar{D}_k^z, \end{aligned} \tag{34}$$

where $x, y, z = 1, \ldots, 3$ are fundamental ${\rm SU}(3)_C$ indices and ϵ_{xyz} is the totally antisymmetric tensor in 3 dimensions with $\epsilon_{123} = +1$. In eq. (34), $\lambda_{ijk}, \lambda'_{ijk}$ and κ_i break lepton number, whereas λ''_{ijk} violate baryon number. To ensure proton stability, either lepton number conservation or baryon number conservation is usually still assumed, resulting in either $\lambda_{ijk} = \lambda'_{ijk} = \kappa_i = 0$ or $\lambda''_{ijk} = 0$ for all $i, j, k = 1, 2, 3$.

The trilinear R-parity violating terms in the soft SUSY-breaking potential are

$$\begin{aligned} V_{3,\rm RPV} &= \epsilon_{ab}\left[\frac{1}{2}(T)_{ijk}\tilde{L}_{iL}^a \tilde{L}_{jL}^b \tilde{e}_{kR}^* + (T')_{ijk}\tilde{L}_{iL}^a \tilde{Q}_{jL}^b \tilde{d}_{kR}^*\right] \\ &\quad + \frac{1}{2}(T'')_{ijk}\epsilon_{xyz}\tilde{u}_{iR}^{x*}\tilde{d}_{jR}^{y*}\tilde{d}_{kR}^{z*} + {\rm h.c.} \quad . \end{aligned} \tag{35}$$

Note that we do not factor out the λ couplings (e.g. as in $T_{ijk}/\lambda_{ijk} \equiv A_{\lambda,ijk}$) in order to avoid potential problems with $\lambda_{ijk} = 0$ but $T_{ijk} \neq 0$. This usage is consistent with the convention for the R-conserving sector elsewhere in this report.

The bilinear R-parity violating soft terms (all lepton number violating) are

$$V_{2,\rm RPV} = -\epsilon_{ab}D_i\tilde{L}_{iL}^a H_2^b + \tilde{L}_{iaL}^\dagger m^2_{\tilde{L}_i H_1} H_1^a + {\rm h.c.} \; . \tag{36}$$

When lepton number is not conserved the sneutrinos may acquire vacuum expectation values (VEVs) $\langle\tilde{\nu}_{e,\mu,\tau}\rangle \equiv v_{e,\mu,\tau}/\sqrt{2}$. The SLHA1 defined the VEV v, which at tree level is equal to $2m_Z/\sqrt{g^2+g'^2} \sim 246$ GeV; this is now generalised to

$$v = \sqrt{v_1^2 + v_2^2 + v_{\rm e}^2 + v_\mu^2 + v_\tau^2} \; . \tag{37}$$

The addition of sneutrino VEVs allows for various different definitions of $\tan\beta$, but we here choose to keep the SLHA1 definition $\tan\beta = v_2/v_1$.

For input/output, we use the super-CKM/PMNS basis throughout, as defined in section 4.1 with the following considerations specific to the R-parity violating case.

Firstly, the d-quark mass matrices are given by

$$\sqrt{2}(m_d)_{ij} = (Y_D)_{ij} v_1 + \lambda'_{kij} v_k \ . \tag{38}$$

where v_k are the sneutrino VEVs. Secondly, in the lepton number violating case, the PMNS matrix can only be defined consistently by taking into account the 1-loop contributions induced by the lepton-number violating couplings (see, e.g., [43]). We here restrict our attention to scenarios in which there are no right-handed neutrinos and, thus, neutrino masses are generated solely by the lepton number violating couplings. In this case, the PMNS matrix is not an independent input but an output.

For definiteness, and to keep the changes with respect to the R-parity conserving case as limited as possible, we define the super-CKM basis as the one where the Yukawa couplings Y_D and Y_U are diagonal. The PMNS basis is defined as the basis where Y_E is diagonal and the loop-induced neutrino mass matrix is diagonalised. In this way one obtains a uniquely defined set of parameters:

$$\hat{\lambda}_{ijk} \equiv \lambda_{rst} V_{\nu,ri} V_{e,sj} U^\dagger_{e,tk} \ , \tag{39}$$

$$\hat{\lambda}'_{ijk} \equiv \lambda'_{rst} V_{\nu,ri} V_{d,sj} U^\dagger_{d,tk} \ , \tag{40}$$

$$\hat{\kappa}_i \equiv \kappa_r V_{e,ri} \ , \tag{41}$$

$$\hat{\lambda}''_{ijk} \equiv \lambda''_{rst} U^\dagger_{u,ri} U^\dagger_{d,sj} U^\dagger_{d,tk} \ , \tag{42}$$

where the fermion mixing matrices are defined in section 4.1. The Lagrangian for the quark-slepton interactions then takes the following form:

$$\mathcal{L} = -\hat{\lambda}'_{ijk} \tilde{\nu}_i \bar{d}_{Rk} d_{Lj} + \hat{\lambda}'_{rsk} U^\dagger_{PMNS,ri} V^\dagger_{CKM,sj} \tilde{l}_{L,i} \bar{d}_{Rk} u_{Lj} + \text{h.c.} \ . \tag{43}$$

Similarly one obtains the soft SUSY breaking couplings in this basis by replacing the superpotential quantities in eqs. (39)–(42) by the corresponding soft SUSY breaking couplings. In addition we define:

$$\hat{m}^2_{\tilde{L}_i H_1} \equiv V^\dagger_{e,ir} m^2_{\tilde{L}_r H_1} \ . \tag{44}$$

4.2.1 Input/Output Blocks

As mentioned above, we use the super-CKM/PMNS basis throughout, for both superpotential and soft SUSY-breaking terms. This applies to both input and output[3]. The naming convention for input blocks is `BLOCK RV#IN`, where the '`#`' character represents the name

[3]A code may need to convert internally the parameters to the interaction basis. In this case it must supply – or take as additional inputs – the individual rotation matrices of quark and lepton superfields entering eqs. (39)–(42).

of the relevant output block given below (thus, for example, the "LLE" couplings in the super-PMNS basis, $\hat{\lambda}_{ijk}$, would be given in `BLOCK RVLAMLLEIN`).

Default inputs for all R-parity violating couplings are zero. The inputs are given at scale $M_{\rm input}$, as described in SLHA1 (again, if no $M_{\rm input}$ is given, the GUT scale is assumed), and follow the output format given below (with the omission of `Q= ...`). In addition, the known fermion masses should be given in `SMINPUTS` as defined in section 4.1.3.

The dimensionless super-CKM/PMNS couplings $\hat{\lambda}_{ijk}$, $\hat{\lambda}'_{ijk}$, and $\hat{\lambda}''_{ijk}$ are given in `BLOCK RVLAMLLE, RVLAMLQD, RVLAMUDD Q= ...` respectively. The output standard should correspond to the FORTRAN format

```
(1x,I2,1x,I2,1x,I2,3x,1P,E16.8,0P,3x,'#',1x,A) .
```

where the first three integers in the format correspond to i, j, and k and the double precision number is the coupling.

$\hat{T}_{ijk}$, $\hat{T}'_{ijk}$, and $\hat{T}''_{ijk}$ are given in `BLOCK RVTLLE, RVTLQD, RVTUDD Q= ...` in the same format as for the $\hat{\lambda}$ couplings above.

The bilinear superpotential and soft SUSY-breaking terms $\hat{\kappa}_i$, $\hat{D}_i$, and $\hat{m}^2_{\tilde{L}_i H_1}$ and the sneutrino VEVs are given in `BLOCK RVKAPPA, RVD, RVM2LH1, RVSNVEV Q= ...` respectively, in the format

```
(1x,I2,3x,1P,E16.8,0P,3x,'#',1x,A) .
```

The input and output blocks for R-parity violating couplings are summarised in Tab. 1. As for the R-conserving MSSM, the bilinear terms (both SUSY-breaking and SUSY-respecting ones, including μ) and the VEVs are not independent parameters. They become related by the condition of electroweak symmetry breaking. Thus, in the SLHA1, one had the possibility *either* to specify $m^2_{H_1}$ and $m^2_{H_2}$ *or* μ and m^2_A. This carries over to the RPV case, where not all the parameters in the input blocks `RV...IN` in Tab. 1 can be given simultaneously. Specifically, of the last 4 blocks only 3 are independent. One block is determined by minimising the Higgs-sneutrino potential. We do not here insist on a particular choice for which of `RVKAPPAIN`, `RVDIN`, `RVSNVEVIN`, and `RVM2LH1IN` to leave out, but leave it up to the spectrum calculators to accept one or more combinations.

4.2.2 Particle Mixing

In general, the neutrinos mix with the neutralinos. This requires a change in the definition of the 4×4 neutralino mixing matrix N to a 7×7 matrix. The Lagrangian contains the (symmetric) neutrino/neutralino mass matrix as

$$\mathcal{L}^{\rm mass}_{\tilde{\chi}^0} = -\frac{1}{2}\tilde{\psi}^{0T}\mathcal{M}_{\tilde{\psi}^0}\tilde{\psi}^0 + \text{h.c.}\ , \tag{45}$$

in the basis of 2–component spinors $\tilde{\psi}^0 = (\nu_e, \nu_\mu, \nu_\tau, -i\tilde{b}, -i\tilde{w}^3, \tilde{h}_1, \tilde{h}_2)^T$. We define the unitary 7×7 neutrino/neutralino mixing matrix N (block `RVNMIX`), such that:

$$-\frac{1}{2}\tilde{\psi}^{0T}\mathcal{M}_{\tilde{\psi}^0}\tilde{\psi}^0 = -\frac{1}{2}\underbrace{\tilde{\psi}^{0T}N^T}_{\tilde{\chi}^{0T}}\underbrace{N^*\mathcal{M}_{\tilde{\psi}^0}N^\dagger}_{\text{diag}(m_{\tilde{\chi}^0})}\underbrace{N\tilde{\psi}^0}_{\tilde{\chi}^0}\ , \tag{46}$$

Input block	Output block	data
RVLAMLLEIN	RVLAMLLE	$i\ j\ k\ \hat{\lambda}_{ijk}$
RVLAMLQDIN	RVLAMLQD	$i\ j\ k\ \hat{\lambda}'_{ijk}$
RVLAMUDDIN	RVLAMUDD	$i\ j\ k\ \hat{\lambda}''_{ijk}$
RVTLLEIN	RVTLLE	$i\ j\ k\ \hat{T}_{ijk}$
RVTLQDIN	RVTLQD	$i\ j\ k\ \hat{T}'_{ijk}$
RVTUDDIN	RVTUDD	$i\ j\ k\ \hat{T}''_{ijk}$
NB: One of the following RV...IN blocks must be left out: (which one up to user and RGE code)		
RVKAPPAIN	RVKAPPA	$i\ \hat{\kappa}_i$
RVDIN	RVD	$i\ \hat{D}_i$
RVSNVEVIN	RVSNVEV	$i\ v_i$
RVM2LH1IN	RVM2LH1	$i\ \hat{m}^2_{\tilde{L}_i H_1}$

Table 1: Summary of R-parity violating SLHA2 data blocks. All parameters are given in the Super-CKM/PMNS basis. Only 3 out of the last 4 blocks are independent. Which block to leave out of the input is in principle up to the user, with the caveat that a given spectrum calculator may not accept all combinations. See text for a precise definition of the format.

where the 7 (2–component) generalised neutrinos $\tilde{\chi}^0 = (\nu_1, ..., \nu_7)^T$ are defined strictly mass-ordered, i.e., with the 1^{st},2^{nd},3^{rd} lightest corresponding to the mass entries for the PDG codes 12, 14, and 16, and the four heaviest to the PDG codes 1000022, 1000023, 1000025, and 1000035 (see also appendix A).

Note! although these codes are normally associated with names that imply a specific flavour content, such as code 12 being $\nu_{\rm e}$ and so forth, it would be exceedingly complicated to maintain such a correspondence in the context of completely general mixing, hence we do not make any such association here. The flavour content of each state, i.e., of each PDG number, is in general only defined by its corresponding entries in the mixing matrix RVNMIX. Note, however, that the flavour basis is ordered so as to reproduce the usual associations in the trivial case (modulo the unknown flavour composition of the neutrino mass eigenstates).

In the limit of CP conservation, the default convention is that N be a real matrix and one or more of the mass eigenstates may have an apparent negative mass. The minus sign may be removed by phase transformations on $\tilde{\chi}^0_i \equiv \nu_i$ as explained in SLHA1 [1].

Charginos and charged leptons may also mix in the case of L-violation. In a similar spirit to the neutralino mixing, we define[4]

$$\mathcal{L}^{\rm mass}_{\tilde{\chi}^+} = -\tilde{\psi}^{-T}\mathcal{M}_{\tilde{\psi}^+}\tilde{\psi}^+ + \text{h.c.}\ , \tag{47}$$

in the basis of 2–component spinors $\tilde{\psi}^- = (e_L, \mu_L, \tau_L, -i\tilde{w}^-, \tilde{h}^-_1)^T$, $\tilde{\psi}^+ = (\bar{e}_R, \bar{\mu}_R, \bar{\tau}_R, -i\tilde{w}^+, \tilde{h}^+_2)^T$, where $\tilde{w}^\pm = (\tilde{w}^1 \mp \tilde{w}^2)/\sqrt{2}$. Note that in the limit of no RPV the lepton fields are mass

[4]Note that the absence of a factor 1/2 on the r.h.s. of eq. (47) corrects and supersedes the published version of this paper.

eigenstates.

We define the unitary 5×5 charged fermion mixing matrices U, V, blocks `RVUMIX`, `RVVMIX`, such that:

$$-\tilde{\psi}^{-T}\mathcal{M}_{\tilde{\psi}^+}\tilde{\psi}^+ = -\underbrace{\tilde{\psi}^{-T}U^T}_{\kappa^{-T}}\underbrace{U^*\mathcal{M}_{\tilde{\psi}^+}V^\dagger}_{\mathrm{diag}(m_{\tilde{\chi}^+})}\underbrace{V\tilde{\psi}^+}_{\kappa^+} \ . \tag{48}$$

The generalised charged leptons $\tilde{\chi}^- \equiv (e_1, e_2, e_3, e_4, e_5)$ are four-component Dirac fermions, and the left-handed and right-handed parts of e_i are the two-component fermions κ_i^- and $\bar{\kappa}_i^+$, respectively. They are defined as strictly mass ordered, i.e., with the 3 lightest states corresponding to the PDG codes `11`, `13`, and `15`, and the two heaviest to the codes `1000024`, `1000037`. As for neutralino mixing, the flavour content of each state is in no way implied by its PDG number, but is only defined by its entries in `RVUMIX` and `RVVMIX`. Note, however, that the flavour basis is ordered so as to reproduce the usual associations in the trivial case. For historical reasons, codes `11`, `13`, and `15` pertain to the negatively charged field while codes `1000024` and `1000037` pertain to the opposite charge. The components of $\tilde{\chi}^-$ in "PDG notation" would thus be `(11,13,15,-1000024,-1000037)`. In the limit of CP conservation, U and V are chosen to be real by default.

R-parity violation via lepton number violation implies that the sneutrinos can mix with the Higgs bosons. In the limit of CP conservation the CP-even (-odd) Higgs bosons mix with real (imaginary) parts of the sneutrinos. We write the neutral scalars as $\phi^0 \equiv \sqrt{2}\mathrm{Re}\left\{(H_1^0, H_2^0, \tilde{\nu}_e, \tilde{\nu}_\mu, \tilde{\nu}_\tau)^T\right\}$, with the mass term

$$\mathcal{L} = -\frac{1}{2}\phi^{0T}\mathcal{M}^2_{\phi^0}\phi^0 \ , \tag{49}$$

where $\mathcal{M}^2_{\phi^0}$ is a 5×5 symmetric mass matrix. We define the orthogonal 5×5 mixing matrix $\aleph$ (block `RVHMIX`) by

$$-\phi^{0T}\mathcal{M}^2_{\phi^0}\phi^0 = -\underbrace{\phi^{0T}\aleph^T}_{\Phi^{0T}}\underbrace{\aleph\mathcal{M}^2_{\phi^0}\aleph^T}_{\mathrm{diag}(m^2_{\Phi^0})}\underbrace{\aleph\phi^0}_{\Phi^0} \ , \tag{50}$$

where $\Phi^0 \equiv (h_1^0, h_2^0, h_3^0, h_4^0, h_5^0)$ are the neutral scalar mass eigenstates in strictly increasing mass order (that is, we use the label h for any neutral scalar mass eigenstate, regardless of whether it is more "Higgs-like" or "sneutrino-like"). The states are numbered sequentially by the PDG codes `(25,35,1000012,1000014,1000016)`, regardless of flavour content. The same convention will be followed below for the neutral pseudoscalars and the charged scalars.

We write the neutral pseudo-scalars as $\bar{\phi}^0 \equiv \sqrt{2}\mathrm{Im}\left\{(H_1^0, H_2^0, \tilde{\nu}_e, \tilde{\nu}_\mu, \tilde{\nu}_\tau)^T\right\}$, with the mass term

$$\mathcal{L} = -\frac{1}{2}\bar{\phi}^{0T}\mathcal{M}^2_{\bar{\phi}^0}\bar{\phi}^0 \ , \tag{51}$$

where $\mathcal{M}^2_{\bar{\phi}^0}$ is a 5×5 symmetric mass matrix. We define the 4×5 mixing matrix $\bar{\aleph}$ (block `RVAMIX`) by

$$-\bar{\phi}^{0T}\mathcal{M}^2_{\bar{\phi}^0}\bar{\phi}^0 = -\underbrace{\bar{\phi}^{0T}\bar{\aleph}^T}_{\bar{\Phi}^{0T}}\underbrace{\bar{\aleph}\mathcal{M}^2_{\bar{\phi}^0}\bar{\aleph}^T}_{\mathrm{diag}(m^2_{\bar{\Phi}^0})}\underbrace{\bar{\aleph}\bar{\phi}^0}_{\bar{\Phi}^0} \ , \tag{52}$$

where $\bar{\Phi}^0 \equiv (A_1^0, A_2^0, A_3^0, A_4^0)$ are the pseudoscalar mass eigenstates, again in strictly increasing mass order. The states are numbered sequentially by the PDG codes `(36,1000017, 1000018,1000019)`, regardless of flavour composition. The Goldstone boson G^0 (the "5th component") has been explicitly left out and the 4 rows of $\bar{\aleph}$ form a set of orthonormal vectors.

If the blocks `RVHMIX, RVAMIX` are present, they *supersede* the SLHA1 `ALPHA` variable/block.

The charged sleptons and charged Higgs bosons also mix in the 8×8 mass squared matrix $\mathcal{M}^2_{\phi^\pm}$ by a 7×8 matrix C (block `RVLMIX`):

$$\mathcal{L} = -\underbrace{(H_1^{-*}, H_2^+, \tilde{e}^*_{L_i}, \tilde{e}^*_{R_j})C^\dagger}_{\Phi^+} \underbrace{C\mathcal{M}^2_{\phi^\pm}C^\dagger}_{\mathrm{diag}(\mathcal{M}^2_{\Phi^\pm})} C \begin{pmatrix} H_1^- \\ H_2^{+*} \\ \tilde{e}_{L_k} \\ \tilde{e}_{R_l} \end{pmatrix} , \tag{53}$$

where $i,j,k,l \in \{1,2,3\}$, $\alpha,\beta \in \{1,\ldots,6\}$ and $\Phi^+ = \Phi^{-\dagger} \equiv (h_1^+, h_2^+, h_3^+, h_4^+, h_5^+, h_6^+, h_7^+)$; these states are numbered sequentially by the PDG codes `(37,1000011,1000013,1000015, 2000011,2000013,2000015)`, regardless of flavour composition. The Goldstone boson G^+ (the "8th component") has been explicitly left out and the 7 rows of C form a set of orthonormal vectors.

R-parity violation may also generate contributions to down-squark mixing via additional left-right mixing terms,

$$\frac{1}{\sqrt{2}} v_1 \hat{T}^\dagger_{D,ij} - \mu m_{d,i} \tan\beta \delta_{ij} + \frac{v_k}{\sqrt{2}} \hat{T}^\dagger_{\lambda',kij} \tag{54}$$

where v_k are the sneutrino vevs. However, this only mixes the six down-type squarks amongst themselves and so is identical to the effects of flavour mixing. This is covered in section 4.1 (along with other forms of flavour mixing).

4.3 CP Violation

When adding CP violation to the MSSM model parameters and mixing matrices (for a recent review see, e.g., the CPNSH report [44]), the SLHA1 blocks are understood to contain the real parts of the relevant parameters. The imaginary parts should be provided with exactly the same format, in a separate block of the same name but prefaced by `IM`. The defaults for all imaginary parameters will be zero. Thus, for example, `BLOCK IMAU, IMAD, IMAE, Q= ...` would describe the imaginary parts of the trilinear soft SUSY-breaking scalar couplings. For input, `BLOCK IMEXTPAR` may be used to provide the relevant imaginary parts of soft SUSY-breaking inputs. In cases where the definitions of the current paper supersede the SLHA1 input and output blocks, completely equivalent statements apply.

One special case is the μ parameter. When the real part of μ is given in `EXTPAR 23`, the imaginary part should be given in `IMEXTPAR 23`, as above. However, when $|\mu|$ is determined by the conditions for electroweak symmetry breaking, only the phase φ_μ is taken as an input parameter. In this case, SLHA2 generalises the entry `MINPAR 4` to contain the cosine of

the phase (as opposed to just sign(μ) in SLHA1), and we further introduce a new block `IMMINPAR` whose entry `4` gives the sine of the phase, that is:

`BLOCK MINPAR`

`4` : CP conserved: sign(μ).
CP violated: $\cos\varphi_\mu = \mathrm{Re}\{\mu\}/|\mu|$.

`BLOCK IMMINPAR`

`4` : CP conserved: n/a.
CP violated: $\sin\varphi_\mu = \mathrm{Im}\{\mu\}/|\mu|$.

Note that $\cos\varphi_\mu$ coincides with sign(μ) in the CP-conserving case.

When CP symmetry is broken, quantum corrections cause mixing between the CP-even and CP-odd Higgs states. Writing the neutral scalar interaction eigenstates as $\phi^0 \equiv \sqrt{2}(\mathrm{Re}\{H_1^0\}, \mathrm{Re}\{H_2^0\}, \mathrm{Im}\{H_1^0\}, \mathrm{Im}\{H_2^0\})^T$ we define the 3×4 mixing matrix S (blocks `CVHMIX` and `IMCVHMIX`) by

$$-\phi^{0T}\mathcal{M}^2_{\phi^0}\phi^0 = -\underbrace{\phi^{0T}S^T}_{\Phi^{0T}}\underbrace{S^*\mathcal{M}^2_{\phi^0}S^\dagger}_{\mathrm{diag}(m^2_{\Phi^0})}\underbrace{S\phi^0}_{\Phi^0}\ , \tag{55}$$

where $\Phi^0 \equiv (h_1^0, h_2^0, h_3^0)^T$ are the mass eigenstates; these states are numbered sequentially by the PDG codes `(25,35,36)`, regardless of flavour composition. That is, even though the PDG reserves code `36` for the CP-odd state, we do not maintain such a labelling here, nor one that reduces to it. This means one does have to exercise some caution when taking the CP conserving limit.

The matrix S thus gives the decomposition of the three physical mass eigenstates in terms of the four interaction eigenstates, all in one go, with the Goldstone boson G^0 explicitly projected out and the 3 rows of S forming a set of orthonormal vectors.

For comparison, in the literature, the projecting-out of the Goldstone boson is often done as a separate step, by first performing a rotation by the angle β. (This is, for instance, the prescription followed by CPsuperH [13]). In such an approach, our matrix S would be decomposed as:

$$S\phi^0 = \begin{pmatrix} & & 0 \\ \mathcal{O}_{3\times 3} & & 0 \\ & & 0 \end{pmatrix} \underbrace{\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -\sin\beta & \cos\beta \\ 0 & 0 & \cos\beta & \sin\beta \end{pmatrix}\phi^0}_{(\sqrt{2}\mathrm{Re}\{H_1^0\},\sqrt{2}\mathrm{Re}\{H_2^0\},A^0_{\mathrm{tree}},G^0_{\mathrm{tree}})^T}\ , \tag{56}$$

where $\mathcal{O}_{3\times 3}$ gives the decomposition of the three physical mass eigenstates in terms of the intermediate basis $\tilde{\phi}^0 = (\sqrt{2}\mathrm{Re}\{H_1^0\}, \sqrt{2}\mathrm{Re}\{H_2^0\}, A^0_{\mathrm{tree}})^T$, with A^0_{tree} denoting the tree-level MSSM non-Goldstone pseudoscalar mass eigenstate. Note that a simple rotation by

β suffices to translate between the two conventions, so whichever is the more practical can easily be used.

A second alternative convention,e.g. adopted by FeynHiggs [11, 38], is to also rotate the CP-even states by the angle α as part of the first step. In this case, our matrix S would be decomposed as:

$$S\phi^0 = \begin{pmatrix} \mathcal{R}_{3\times3} & \begin{matrix}0\\0\\0\end{matrix} \\ \end{pmatrix} \underbrace{\begin{pmatrix} -\sin\alpha & \cos\alpha & 0 & 0 \\ \cos\alpha & \sin\alpha & 0 & 0 \\ 0 & 0 & -\sin\beta & \cos\beta \\ 0 & 0 & \cos\beta & \sin\beta \end{pmatrix}}_{(h^0,H^0,A^0,G^0)^T_{\rm tree}} \phi^0 \ , \tag{57}$$

with α defined as the mixing angle in the CP-even Higgs sector at tree-level and $\mathcal{R}_{3\times3}$ giving the decomposition of the three physical mass eigenstates in terms of the intermediate basis $\tilde{\Phi}^0 = (h^0, H^0, A^0)^T_{\rm tree}$, that is in terms of the the tree-level mass eigenstates. In order to translate between S and $\mathcal{R}_{3\times3}$, the tree-level angle α would thus also be needed. This should be given in the SLHA1 output `BLOCK ALPHA`:

`BLOCK ALPHA`

> CP conserved: α; precise definition up to spectrum calculator, see SLHA1.
> CP violated: $\alpha_{\rm tree}$. Must be accompanied by the matrix S, as described above, in the blocks `CVHMIX` and `IMCVHMIX`.

For the neutralino and chargino mixing matrices, the default convention in SLHA1 (and hence for the CP conserving case) is that they be real matrices. One or more mass eigenvalues may then have an apparent negative sign, which can be removed by a phase transformation on $\tilde{\chi}_i$ as explained in SLHA1 [1]. When going to CPV, the reason for introducing the negative-mass convention in the first place, namely maintaining the mixing matrices strictly real, disappears. We therefore here take all masses real and positive, with N, U, and V complex. This does lead to a nominal dissimilarity with SLHA1 in the limit of vanishing CP violation, but we note that the explicit CPV switch in `MODSEL` can be used to decide unambiguously which convention to follow.

5 The Next-to-Minimal Supersymmetric SM

The first question to be addressed in defining universal conventions for the next-to-minimal supersymmetric standard model is just what field content and which couplings this name should apply to. The field content is already fairly well agreed upon; we shall here define the next-to-minimal case as having exactly the field content of the MSSM with the addition of one gauge-singlet chiral superfield. As to couplings and parameterisations, several definitions exist in the literature (for a recent review see, e.g., the CPNSH report [45]). Rather than adopting a particular one, or treating each special case separately, below we choose instead to work at the most general level. Any particular special case can then be

obtained by setting different combinations of couplings to zero. For the time being, however, we do specialise to the SLHA1-like case without CP violation, R-parity violation, or flavour violation. Below, we shall use the acronym NMSSM for this class of models, but we emphasise that we understand it to relate to field content only, and not to the presence or absence of specific couplings.

5.1 Conventions

We write the most general CP conserving NMSSM superpotential as (extending the notation of SLHA1):

$$W_{NMSSM} = W_{MSSM} - \epsilon_{ab}\lambda S H_1^a H_2^b + \frac{1}{3}\kappa S^3 + \frac{1}{2}\mu' S^2 + \xi_F S \ , \tag{58}$$

where W_{MSSM} is the MSSM superpotential, eq. (2). A non-zero λ in combination with a VEV $\langle S \rangle$ of the singlet generates a contribution to the effective μ term $\mu_{\rm eff} = \lambda \langle S \rangle + \mu$, where the MSSM μ term is normally assumed to be zero in NMSSM constructions, yielding $\mu_{\rm eff} = \lambda \langle S \rangle$. The sign of the λ term in eq. (58) coincides with the one in [16, 37] where the Higgs doublet superfields appear in opposite order. The remaining terms represent a general cubic potential for the singlet; κ is dimensionless, μ' has dimension of mass[5], and ξ_F has dimension of mass squared. The soft SUSY-breaking terms relevant to the NMSSM are

$$V_{\rm soft} = V_{2,MSSM} + V_{3,MSSM} + m_{\rm S}^2 |S|^2 + (-\epsilon_{ab}\lambda A_\lambda S H_1^a H_2^b + \frac{1}{3}\kappa A_\kappa S^3 + \frac{1}{2} m_S'^2 S^2 + \xi_S S + \text{h.c.}) \ , \tag{59}$$

where $V_{i,MSSM}$ are the MSSM soft terms defined in eqs. (3) and (4), and we have introduced the notation $m_S'^2 \equiv B'\mu'$.

At tree level, there are thus 15 parameters (in addition to m_Z which fixes the sum of the squared Higgs VEVs) that are relevant for the Higgs sector of the R-parity and CP-conserving NMSSM:

$$\tan\beta, \ \mu, \ m_{H_1}^2, \ m_{H_2}^2, \ m_3^2, \ \lambda, \ \kappa, \ A_\lambda, \ A_\kappa, \ \mu', \ m_S'^2, \ \xi_F, \ \xi_S, \ \lambda \langle S \rangle \, , \ m_S^2 \ . \tag{60}$$

The minimisation of the effective potential imposes 3 conditions on these parameters, such that only 12 of them can be considered independent. We leave it up to each spectrum calculator to decide on which combinations to accept. For the purpose of this accord, we note only that to specify a general model exactly 12 parameters from eq. (60) should be provided in the input, including explicit zeroes for parameters desired "switched off". However, since $\mu = m_3^2 = \mu' = m_S'^2 = \xi_F = \xi_S = 0$ in the majority of phenomenological constructions, for convenience we also allow for a six-parameter specification in terms of the reduced parameter list:

$$\tan\beta, \ m_{H_1}^2, \ m_{H_2}^2, \ \lambda, \ \kappa, \ A_\lambda, \ A_\kappa, \ \lambda \langle S \rangle \, , \ m_S^2 \ . \tag{61}$$

[5]Note that the factors 1/2 in front of the μ' and m'_S terms in eqs. (58) and (59), respectively, correct and supersede the published version of this paper.

To summarise, in addition to m_Z, the input to the accord should contain either 12 parameters from the list given in eq. (60), including zeroes for parameters not present in the desired model, or it should contain 6 parameters from the list in eq. (61), in which case the remaining 6 "non-standard" parameters, μ, m_3^2, μ', $m_S'^2$, ξ_F, and ξ_F, will be assumed to be zero; in both cases the 3 unspecified parameters (as, e.g., $m_{H_1}^2$, $m_{H_2}^2$, and m_S^2) are assumed to be determined by the minimisation of the effective potential.

5.2 Input/Output Blocks

Firstly, as described above in section 3, `BLOCK MODSEL` should contain the switch 3 with value 1, corresponding to the choice of the NMSSM particle content.

Secondly, for the parameters that are also present in the MSSM, we re-use the corresponding SLHA1 entries. That is, m_Z should be given in `SMINPUTS` entry `4` and $m_{H_1}^2, m_{H_2}^2$ can be given in the `EXTPAR` entries `21` and `22`. $\tan\beta$ should either be given in `MINPAR` entry 3 (default) or `EXTPAR` entry 25 (user-defined input scale), as in SLHA1. If μ should be desired non-zero, it can be given in `EXTPAR` entry `23`. The corresponding soft parameter m_3^2 can be given in `EXTPAR` entry `24`, in the form $m_3^2/(\cos\beta\sin\beta)$, see [1]. The notation m_A^2 that was used for that parameter in the SLHA1 is no longer relevant in the NMSSM context, but by keeping the definition in terms of m_3^2 and $\cos\beta\sin\beta$ unchanged, we maintain an economical and straightforward correspondence between the two cases.

Further, new entries in `BLOCK EXTPAR` have been defined for the NMSSM specific input parameters, as follows. As in the SLHA1, these parameters are all given at the common scale $M_{\rm input}$, which can either be left up to the spectrum calculator or given explicitly using `EXTPAR 0` or `QEXTPAR` (see section 2):

```
BLOCK EXTPAR
```

Input parameters specific to the NMSSM (in addition to the entries defined in section 2)

`61` : $\lambda(M_{\rm input})$. Superpotential trilinear Higgs SH_2H_1 coupling.

`62` : $\kappa(M_{\rm input})$. Superpotential cubic S coupling.

`63` : $A_\lambda(M_{\rm input})$. Soft trilinear Higgs SH_2H_1 coupling.

`64` : $A_\kappa(M_{\rm input})$. Soft cubic S coupling.

`65` : $\lambda\langle S\rangle(M_{\rm input})$. Vacuum expectation value of the singlet (scaled by λ).

`66` : $\xi_F(M_{\rm input})$. Superpotential linear S coupling.

`67` : $\xi_S(M_{\rm input})$. Soft linear S coupling.

`68` : $\mu'(M_{\rm input})$. Superpotential quadratic S coupling.

`69` : $m_S'^2(M_{\rm input})$. Soft quadratic S coupling (sometimes denoted $\mu' B'$).

`70` : $m_S^2(M_{\rm input})$. Soft singlet mass squared.

Important note: only 12 of the parameters listed in eq. (60) should be given as input at any one time (including explicit zeroes for parameters desired "switched off"), the remaining ones being determined by the minimisation of the effective potential. Which combinations to accept is left up to the individual spectrum calculator programs. Alternatively, for minimal models, 6 parameters of those listed in eq. (61) should be given.

For non-zero values, signs can be either positive or negative. As noted above, the meaning of the already existing entries `EXTPAR 23` and `24` (the MSSM μ parameter and corresponding soft term) are maintained, which allows, in principle, for non-zero values for both μ and $\langle S \rangle$. The reason for choosing $\lambda \langle S \rangle$ rather than $\langle S \rangle$ as input parameter 65 is that it allows more easily to recover the MSSM limit λ, $\kappa \to 0$, $\langle S \rangle \to \infty$ with $\lambda \langle S \rangle$ fixed.

In the spectrum output, running NMSSM parameters corresponding to the `EXTPAR` entries above can be given in the block `NMSSMRUN Q=...`:

`BLOCK NMSSMRUN Q=...`

Output parameters specific to the NMSSM, given in the $\overline{\rm DR}$ scheme, at the scale Q. As in the SLHA1, several of these blocks may be given simultaneously in the output, each then corresponding to a specific scale. See corresponding entries in `EXTPAR` above for definitions.

`1`	: $\lambda(Q)^{\overline{\rm DR}}$.
`2`	: $\kappa(Q)^{\overline{\rm DR}}$.
`3`	: $A_\lambda(Q)^{\overline{\rm DR}}$.
`4`	: $A_\kappa(Q)^{\overline{\rm DR}}$.
`5`	: $\lambda \langle S \rangle (Q)^{\overline{\rm DR}}$.
`6`	: $\xi_F(Q)^{\overline{\rm DR}}$.
`7`	: $\xi_S(Q)^{\overline{\rm DR}}$.
`8`	: $\mu'(Q)^{\overline{\rm DR}}$.
`9`	: $m'^2_S(Q)^{\overline{\rm DR}}$.
`10`	: $m^2_S(Q)^{\overline{\rm DR}}$.

5.3 Particle Mixing

In the CP-conserving NMSSM, the CP-even interaction eigenstates are $\phi^0 \equiv \sqrt{2}\mathrm{Re}\left\{(H^0_1, H^0_2, S)^T\right\}$. We define the orthogonal 3×3 mixing matrix S (block `NMHMIX`) by

$$-\phi^{0T}\mathcal{M}^2_{\phi^0}\phi^0 = -\underbrace{\phi^{0T}S^T}_{\Phi^{0T}}\underbrace{S\mathcal{M}^2_{\phi^0}S^T}_{\mathrm{diag}(m^2_{\Phi^0})}\underbrace{S\phi^0}_{\Phi^0} \ , \tag{62}$$

where $\Phi^0 \equiv (h_1^0, h_2^0, h_3^0)$ are the mass eigenstates ordered in mass. These states are numbered sequentially by the PDG codes `(25,35,45)`. The format of `BLOCK NMHMIX` is the same as for the mixing matrices in SLHA1.

In the MSSM limit (λ, $\kappa \to 0$, and parameters such that $h_3^0 \sim \mathrm{Re}\{S\}$) the elements of the first 2×2 sub-matrix of S_{ij} are related to the MSSM angle α as

$$\begin{aligned} S_{11} &\sim -\sin\alpha \ , & S_{21} &\sim \cos\alpha \ , \\ S_{12} &\sim \cos\alpha \ , & S_{22} &\sim \sin\alpha \ . \end{aligned}$$

In the CP-odd sector the interaction eigenstates are $\bar{\phi}^0 \equiv \sqrt{2}\mathrm{Im}\left\{(H_1^0, H_2^0, S)^T\right\}$. We define the 2×3 mixing matrix P (block `NMAMIX`) by

$$-\bar{\phi}^{0T}\mathcal{M}^2_{\bar{\phi}^0}\bar{\phi}^0 = -\underbrace{\bar{\phi}^{0T}P^T}_{\bar{\Phi}^{0T}}\underbrace{P\mathcal{M}^2_{\bar{\phi}^0}P^T}_{\mathrm{diag}(m^2_{\bar{\Phi}^0})}\underbrace{P\bar{\phi}^0}_{\bar{\Phi}^0} \ , \tag{63}$$

where $\bar{\Phi}^0 \equiv (A_1^0, A_2^0)$ are the mass eigenstates ordered in mass. These states are numbered sequentially by the PDG codes `(36,46)`. The Goldstone boson G^0 (the "3rd component") has been explicitly left out and the 2 rows of P form a set of orthonormal vectors. An updated version `NMSSMTools` [37] will follow these conventions.

If `NMHMIX, NMAMIX` blocks are present, they *supersede* the SLHA1 `ALPHA` variable/block.

The neutralino sector of the NMSSM requires a change in the definition of the 4×4 neutralino mixing matrix N to a 5×5 matrix. The Lagrangian contains the (symmetric) neutralino mass matrix as

$$\mathcal{L}^{\mathrm{mass}}_{\tilde{\chi}^0} = -\frac{1}{2}\tilde{\psi}^{0T}\mathcal{M}_{\tilde{\psi}^0}\tilde{\psi}^0 + \mathrm{h.c.} \ , \tag{64}$$

in the basis of 2–component spinors $\tilde{\psi}^0 = (-i\tilde{b},\, -i\tilde{w}^3,\, \tilde{h}_1,\, \tilde{h}_2,\, \tilde{s})^T$. We define the unitary 5×5 neutralino mixing matrix N (block `NMNMIX`), such that:

$$-\frac{1}{2}\tilde{\psi}^{0T}\mathcal{M}_{\tilde{\psi}^0}\tilde{\psi}^0 = -\frac{1}{2}\underbrace{\tilde{\psi}^{0T}N^T}_{\tilde{\chi}^{0T}}\underbrace{N^*\mathcal{M}_{\tilde{\psi}^0}N^\dagger}_{\mathrm{diag}(m_{\tilde{\chi}^0})}\underbrace{N\tilde{\psi}^0}_{\tilde{\chi}^0} \ , \tag{65}$$

where the 5 (2–component) neutralinos $\tilde{\chi}_i$ are defined such that the absolute value of their masses increase with i. As in SLHA1, our convention is that N be a real matrix. One or more mass eigenvalues may then have an apparent negative sign, which can be removed by a phase transformation on $\tilde{\chi}_i$. The states are numbered sequentially by the PDG codes `(1000022,1000023,1000025,1000035,1000045)`.

6 Conclusion and Outlook

At the time of writing of the SLHA1, a large number of computer codes already existed which used MSSM spectrum and coupling information in one form or another. This had several advantages: there was a high motivation from program authors to produce and

implement the accord accurately and quickly, and perhaps more importantly, the SLHA1 was tested "in anger" in diverse situations as it was being written.

We find ourselves in a slightly different situation in terms of the SLHA2. There are currently few programs that utilise information in any of the NMSSM or CP-violating, R-parity violating, or non-trivial flavour violating MSSM scenarios. Thus we do not have the benefit of comprehensive simultaneous testing of the proposed accord and the strong motivation that was present for implementation and writing of the original one. What we do have are the lessons learned in connection with the SLHA1 itself, and also several almost-finished codes which are now awaiting the finalisation of SLHA2 in order to publish their first official releases. Concrete tests involving several of these were thus possible in connection with this writeup.

We have adhered to the principle of backward compatibility wherever feasible. We therefore expect that the conventions and agreements reached within this paper constitute a practical solution that will prove useful for SUSY particle phenomenology in the future.

Acknowledgements

The majority of the agreements and conventions contained herein resulted from the workshops "Physics at TeV Colliders", Les Houches, France, 2005 [53] and 2007, and "Flavour in the Era of the LHC", CERN, 2005–2006. We also thank W. Hollik for useful discussions at "Tools for SUSY and the New Physics", Annecy-le-Vieux, France, 2006.

BCA and WP would like to thank enTapP 2005, Valencia, Spain, 2005 for hospitality offered during working discussions of this project. SM thanks The Royal Society (London, UK) for partial financial support in the form of a 'Conference Grant' to attend the workshop "Physics at TeV Colliders", Les Houches, France, 2007.

This work has been partially supported by STFC and by Fermi Research Alliance, LLC, under Contract No. DE-AC02-07CH11359 with the United States Department of Energy. SP is supported by a Spanish MCyT Ramon y Cajal contract. WP is supported by the German Ministry of Education and Research (BMBF) under contract 05HT6WWA. The work of TG is supported in part by the Grant-in-Aid for Science Research, Ministry of Education, Culture, Sports, Science and Technology, Japan, No. 16081211. PG is supported by MIUR under contract 2004021808-009. The work of MS is supported in part by the Swiss Bundesamt für Bildung und Wissenschaft. The work of AP was supported in part by GDRI-ACPP of CNRS and by grant RFBR-08-02-00856-a of the Russian Foundation for Basic Research. JG, PG, T. Hahn, SH, SP, and WP are supported in part by the European Community's Marie-Curie Research Training Network under contract MRTN-CT-2006-035505 'Tools and Precision Calculations for Physics Discoveries at Colliders' and PS is supported by contract MRTN-CT-2006-035606 'MCnet'.

A PDG Codes and Extensions

The existing PDG nomenclature for (s)particle names is based on the limit of the MSSM in which CP, R-parity, and flavour are conserved. Several of the mass eigenstates are therefore labeled to indicate definite R, CP, and/or flavour quantum numbers. When the corresponding symmetries are broken, such a labeling becomes misleading. Throughout this paper we have adopted the convention of assigning a common label to all states which carry identical conserved quantum numbers in the given model. We then re-use the existing PDG codes for those states, arranged in strictly increasing mass order.

This implies that, while the PDG numbers remain unaltered, their labels change, depending on which scenario is considered. The PDG codes and labels are discussed in detail in the individual sections on flavour violation, R-parity violation, CP violation, and the NMSSM. In the tables below, we summarise the PDG numbers and suggested labels relevant to each distinct scenario, for squarks (Tab. 2), charged colour-singlet fermions (Tab. 3), neutral colour-singlet fermions (Tab. 4), charged colour-singlet scalars (Tab. 5), and neutral colour-singlet scalars (Tab. 6), respectively. Note that these extensions are not officially endorsed by the PDG at this time. Codes for other particles can be found in [52, chp. 33].

Scalar Quarks

FLV	No	Yes	No	No	Yes	Yes	NMSSM
RPV	No	No	Yes	No	Yes	No	
CPV	No	No	No	Yes	No	Yes	
1000001	$\tilde{d}_L$	$\tilde{d}_1$	$\tilde{d}_1$	$\tilde{d}_L$	$\tilde{d}_1$	$\tilde{d}_1$	$\tilde{d}_L$
1000002	$\tilde{u}_L$	$\tilde{u}_1$	$\tilde{u}_1$	$\tilde{u}_L$	$\tilde{u}_1$	$\tilde{u}_1$	$\tilde{u}_L$
1000003	$\tilde{s}_L$	$\tilde{d}_2$	$\tilde{d}_2$	$\tilde{s}_L$	$\tilde{d}_2$	$\tilde{d}_2$	$\tilde{s}_L$
1000004	$\tilde{c}_L$	$\tilde{u}_2$	$\tilde{u}_2$	$\tilde{c}_L$	$\tilde{u}_2$	$\tilde{u}_2$	$\tilde{c}_L$
1000005	$\tilde{b}_1$	$\tilde{d}_3$	$\tilde{d}_3$	$\tilde{b}_1$	$\tilde{d}_3$	$\tilde{d}_3$	$\tilde{b}_1$
1000006	$\tilde{t}_1$	$\tilde{u}_3$	$\tilde{u}_3$	$\tilde{t}_1$	$\tilde{u}_3$	$\tilde{u}_3$	$\tilde{t}_1$
2000001	$\tilde{d}_R$	$\tilde{d}_4$	$\tilde{d}_4$	$\tilde{d}_R$	$\tilde{d}_4$	$\tilde{d}_4$	$\tilde{d}_R$
2000002	$\tilde{u}_R$	$\tilde{u}_4$	$\tilde{u}_4$	$\tilde{u}_R$	$\tilde{u}_4$	$\tilde{u}_4$	$\tilde{u}_R$
2000003	$\tilde{s}_R$	$\tilde{d}_5$	$\tilde{d}_5$	$\tilde{s}_R$	$\tilde{d}_5$	$\tilde{d}_5$	$\tilde{s}_R$
2000004	$\tilde{c}_R$	$\tilde{u}_5$	$\tilde{u}_5$	$\tilde{c}_R$	$\tilde{u}_5$	$\tilde{u}_5$	$\tilde{c}_R$
2000005	$\tilde{b}_2$	$\tilde{d}_6$	$\tilde{d}_6$	$\tilde{b}_2$	$\tilde{d}_6$	$\tilde{d}_6$	$\tilde{b}_2$
2000006	$\tilde{t}_2$	$\tilde{u}_6$	$\tilde{u}_6$	$\tilde{t}_2$	$\tilde{u}_6$	$\tilde{u}_6$	$\tilde{t}_2$

Table 2: Particle codes and corresponding labels for squarks. The labels in the first column correspond to the current PDG nomenclature.

Charged Leptons and Charginos

FLV	No	Yes	No	No	Yes	Yes	NMSSM
RPV	No	No	Yes	No	Yes	No	
CPV	No	No	No	Yes	No	Yes	
11	e^-	e^-	e_1^-	e^-	e_1^-	e^-	e^-
13	μ^-	μ^-	e_2^-	μ^-	e_2^-	μ^-	μ^-
15	τ^-	τ^-	e_3^-	τ^-	e_3^-	τ^-	τ^-
1000024	$\tilde{\chi}_1^+$	$\tilde{\chi}_1^+$	e_4^+	$\tilde{\chi}_1^+$	e_4^+	$\tilde{\chi}_1^+$	$\tilde{\chi}_1^+$
1000037	$\tilde{\chi}_2^+$	$\tilde{\chi}_2^+$	e_5^+	$\tilde{\chi}_2^+$	e_5^+	$\tilde{\chi}_2^+$	$\tilde{\chi}_2^+$

Table 3: Particle codes and corresponding labels for charged colour-singlet fermions. The labels in the first column correspond to the current PDG nomenclature. Note that, for historical reasons, codes `11`, `13`, and `15` pertain to negatively charged fields while codes `1000024` and `1000037` pertain to the opposite charge.

Neutrinos and Neutralinos

FLV	No	Yes	No	No	Yes	Yes	NMSSM
RPV	No	No	Yes	No	Yes	No	
CPV	No	No	No	Yes	No	Yes	
12	ν_e	ν_1	ν_1	ν_e	ν_1	ν_1	ν_e
14	ν_μ	ν_2	ν_2	ν_μ	ν_2	ν_2	ν_μ
16	ν_τ	ν_3	ν_3	ν_τ	ν_3	ν_3	ν_τ
1000022	$\tilde{\chi}_1^0$	$\tilde{\chi}_1^0$	ν_4	$\tilde{\chi}_1^0$	ν_4	$\tilde{\chi}_1^0$	$\tilde{\chi}_1^0$
1000023	$\tilde{\chi}_2^0$	$\tilde{\chi}_2^0$	ν_5	$\tilde{\chi}_2^0$	ν_5	$\tilde{\chi}_2^0$	$\tilde{\chi}_2^0$
1000025	$\tilde{\chi}_3^0$	$\tilde{\chi}_3^0$	ν_6	$\tilde{\chi}_3^0$	ν_6	$\tilde{\chi}_3^0$	$\tilde{\chi}_3^0$
1000035	$\tilde{\chi}_4^0$	$\tilde{\chi}_4^0$	ν_7	$\tilde{\chi}_4^0$	ν_7	$\tilde{\chi}_4^0$	$\tilde{\chi}_4^0$
1000045	-	-	-	-	-	-	$\tilde{\chi}_5^0$

Table 4: Particle codes and corresponding labels for neutral colour-singlet fermions. The labels in the first column correspond to the current PDG nomenclature.

Charged Higgs Boson and Charged Scalar Leptons

FLV	No	Yes	No	No	Yes	Yes	NMSSM
RPV	No	No	Yes	No	Yes	No	
CPV	No	No	No	Yes	No	Yes	
37	H^+	H^+	h_1^+	H^+	h_1^+	H^+	H^+
1000011	$\tilde{e}_L^+$	$\tilde{e}_1^+$	h_2^+	$\tilde{e}_L^+$	h_2^+	$\tilde{e}_1^+$	$\tilde{e}_L^+$
1000013	$\tilde{\mu}_L^+$	$\tilde{e}_2^+$	h_3^+	$\tilde{\mu}_L^+$	h_3^+	$\tilde{e}_2^+$	$\tilde{\mu}_L^+$
1000015	$\tilde{\tau}_1^+$	$\tilde{e}_3^+$	h_4^+	$\tilde{\tau}_1^+$	h_4^+	$\tilde{e}_3^+$	$\tilde{\tau}_1^+$
2000011	$\tilde{e}_R^+$	$\tilde{e}_4^+$	h_5^+	$\tilde{e}_R^+$	h_5^+	$\tilde{e}_4^+$	$\tilde{e}_R^+$
2000013	$\tilde{\mu}_R^+$	$\tilde{e}_5^+$	h_6^+	$\tilde{\mu}_R^+$	h_6^+	$\tilde{e}_5^+$	$\tilde{\mu}_R^+$
2000015	$\tilde{\tau}_2^+$	$\tilde{e}_6^+$	h_7^+	$\tilde{\tau}_2^+$	h_7^+	$\tilde{e}_6^+$	$\tilde{\tau}_2^+$

Table 5: Particle codes and corresponding labels for charged colour-singlet scalars. The labels in the first column correspond to the current PDG nomenclature.

Neutral Higgs Bosons and Scalar Neutrinos

FLV	No	Yes	No	No	Yes	Yes	NMSSM
RPV	No	No	Yes	No	Yes	No	
CPV	No	No	No	Yes	No	Yes	
25	h^0	h^0	h_1^0	h_1^0	h_1^0	h_1^0	h_1^0
35	H^0	H^0	h_2^0	h_2^0	h_2^0	h_2^0	h_2^0
36	A^0	A^0	A_1^0	h_3^0	A_1^0	h_3^0	A_1^0
45	-	-	-	-	-	-	h_3^0
46	-	-	-	-	-	-	A_2^0
1000012	$\tilde{\nu}_{e_L}$	$\tilde{\nu}_1$ $(\tilde{\nu}_{1S})$	h_3^0	$\tilde{\nu}_{e_L}$	h_3^0	$\tilde{\nu}_1$	$\tilde{\nu}_{e_L}$
1000014	$\tilde{\nu}_{\mu_L}$	$\tilde{\nu}_2$ $(\tilde{\nu}_{2S})$	h_4^0	$\tilde{\nu}_{\mu_L}$	h_4^0	$\tilde{\nu}_2$	$\tilde{\nu}_{\mu_L}$
1000016	$\tilde{\nu}_{\tau_L}$	$\tilde{\nu}_3$ $(\tilde{\nu}_{3S})$	h_5^0	$\tilde{\nu}_{\tau_L}$	h_5^0	$\tilde{\nu}_3$	$\tilde{\nu}_{\tau_L}$
1000017	-	$(\tilde{\nu}_{1A})$	A_2^0	-	A_2^0	-	-
1000018	-	$(\tilde{\nu}_{2A})$	A_3^0	-	A_3^0	-	-
1000019	-	$(\tilde{\nu}_{3A})$	A_4^0	-	A_4^0	-	-

Table 6: Particle codes and corresponding labels for neutral colour-singlet scalars. The labels in the first column correspond to the current PDG nomenclature. The labels in parenthesis denote the optional separation of sneutrinos into separate scalar and pseudoscalar components.

References

[1] Skands, P. et al., JHEP **07** (2004) 036, (See also Les Houches 'Physics at TeV Colliders 2003' Beyond the Standard Model Working Group: Summary report, hep-ph/0402295).

[2] Chung, D. J. H. et al., Phys. Rept. **407** (2005) 1.

[3] Allanach, B. C., Eur. Phys. J. **C59** (2009) 427.

[4] Skands, P. et al., A repository for Beyond-the-Standard-Model tools, FERMILAB-CONF-05-521-T. In Les Houches 'Physics at TeV Colliders 2005' BSM Working Group: Summary report, hep-ph/0602198. See `http://www.ippp.dur.ac.uk/montecarlo/BSM/`.

[5] Baer, H., Paige, F. E., Protopopescu, S. D., and Tata, X., (1999), hep-ph/0001086.

[6] Allanach, B. C., Comput. Phys. Commun. **143** (2002) 305.

[7] Porod, W., Comput. Phys. Commun. **153** (2003) 275.

[8] Djouadi, A., Kneur, J.-L., and Moultaka, G., Comput. Phys. Commun. **176** (2007) 426.

[9] Beenakker, W., Höpker, R., and Spira, M., (1996), hep-ph/9611232.

[10] Djouadi, A., Kalinowski, J., and Spira, M., Comput. Phys. Commun. **108** (1998) 56.

[11] Heinemeyer, S., Hollik, W., and Weiglein, G., Comput. Phys. Commun. **124** (2000) 76, see `www.feynhiggs.de`.

[12] Mühlleitner, M., Djouadi, A., and Mambrini, Y., Comput. Phys. Commun. **168** (2005) 46.

[13] Lee, J. S. et al., Comput. Phys. Commun. **156** (2004) 283.

[14] Bélanger, G., Boudjema, F., Pukhov, A., and Semenov, A., Comput. Phys. Commun. **174** (2006) 577.

[15] Gondolo, P. et al., JCAP **0407** (2004) 008.

[16] Ellwanger, U., Gunion, J. F., and Hugonie, C., JHEP **02** (2005) 066.

[17] Béjar, S. and Guasch, J., FCHDECAY: A program to compute Higgs bosons flavour changing neutral current decays, see `http://fchdecay.googlepages.com`.

[18] Degrassi, G., Gambino, P., and Slavich, P., Comput. Phys. Commun. **179** (2008) 759.

[19] Mahmoudi, F., Comput. Phys. Commun. **178** (2008) 745.

[20] Corcella, G. et al., JHEP **01** (2001) 010.

[21] Moretti, S., Odagiri, K., Richardson, P., Seymour, M. H., and Webber, B. R., JHEP **04** (2002) 028.

[22] Sjöstrand, T., Mrenna, S., and Skands, P., JHEP **05** (2006) 026.

[23] Mrenna, S., Comput. Phys. Commun. **101** (1997) 232.

[24] Hagiwara, K. et al., Phys. Rev. **D73** (2006) 055005.

[25] Katsanevas, S. and Morawitz, P., Comput. Phys. Commun. **112** (1998) 227.

[26] Reuter, J. et al., (2005), hep-ph/0512012.

[27] Cho, G. C. et al., Phys. Rev. **D73** (2006) 054002.

[28] Kilian, W., Ohl, T., and Reuter, J., (2007), arXiv:0708.4233 [hep-ph].

[29] Bechtle, P., Desch, K., and Wienemann, P., Comput. Phys. Commun. **174** (2006) 47.

[30] Lafaye, R., Plehn, T., and Zerwas, D., (2004), hep-ph/0404282.

[31] Ciuchini, M. et al., JHEP **07** (2001) 013.

[32] Charles, J. et al., Eur. Phys. J. **C41** (2005) 1.

[33] Aguilar-Saavedra, J. A. et al., Eur. Phys. J. **C46** (2006) 43.

[34] Dreiner, H. K., Richardson, P., and Seymour, M. H., JHEP **04** (2000) 008.

[35] Skands, P. Z., Eur. Phys. J. **C23** (2002) 173.

[36] Sjöstrand, T. and Skands, P. Z., Nucl. Phys. **B659** (2003) 243.

[37] Ellwanger, U. and Hugonie, C., Comput. Phys. Commun. **175** (2006) 290.

[38] Frank, M. et al., JHEP **02** (2007) 047.

[39] Martin, S. P., (1997), hep-ph/9709356.

[40] Misiak, M., Pokorski, S., and Rosiek, J., Adv. Ser. Direct. High Energy Phys. **15** (1998) 795.

[41] Gonzalez-Garcia, M. C. and Maltoni, M., Phys. Rept. **460** (2008) 1.

[42] Barbier, R. et al., Phys. Rept. **420** (2005) 1.

[43] Hirsch, M., Diaz, M. A., Porod, W., Romao, J. C., and Valle, J. W. F., Phys. Rev. **D62** (2000) 113008.

[44] Boonekamp, M. et al., in Workshop on CP studies and non-standard Higgs physics, hep-ph/0608079, 2006.

[45] Baffioni, S. et al., in Workshop on CP studies and non-standard Higgs physics, hep-ph/0608079, 2006.

[46] Hahn, T., (2004), hep-ph/0408283.

[47] Hahn, T., (2006), hep-ph/0605049.

[48] Kreiss, S., work in progress. See `http://www.svenkreiss.com/SLHAio`.

[49] Alwall, J. et al., Comput. Phys. Commun. **176** (2007) 300.

[50] Alwall, J. et al., (2007), arXiv:0712.3311 [hep-ph].

[51] Martin, S. P., Phys. Rev. **D55** (1997) 3177.

[52] Yao, W. M. et al., J. Phys. **G33** (2006) 1.

[53] Allanach, B. C. et al., Les Houches 2005 BSM working group: Summary report, hep-ph/0602198, 2006.