# SUSY Les Houches Accord 2

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### A bstract

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 rst SLHA to include various generalisations: the minimal supersymmetric standard model with violation of CP, R-parity, and avour, as well as the simplest next-to-minimalmodel.

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# 1 Introduction

Supersym m etric (SUSY) extensions of the Standard M odel rank am ong the m ost prom ising and well-explored scenarios for New Physics at the TeV scale. Given the long history of supersym m etry and the num ber of people working in the eld, several di erent conventions for de ning supersym m etric theories have been proposed over the years, m any of which have com e into w idespread 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 de ned, a translation can always be m ade between two sets of conventions.

However, the proliferation of conventions does have some disadvantages. Results obtained by di erent 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 rst 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 de nes a set of conventions for supersymmetric models together with a common interface between codes. Them ost 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 M odel 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).

M onte-C arb event generators [20{28], which calculate cross sections through explicit statistical simulation of high-energy particle collisions. By including resonance decays, parton show ering, hadronisation, and underlying-event e ects, fully exclusive nal states can be studied, and, for instance, detector simulations interfaced.

SUSY and CKM thing program s  $[29{32}]$  which tm odel 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 form at, 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 dealw ith, 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 m ind. Some recent public codes [6,7,17,18,34{38} are either in - plementing 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), avour 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 eld content is augmented by a gauge-singlet chiral super eld) which we shall collectively label by the acronym NMSSM.

R ather 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 in plem entation in program s, 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 avour violation, we shall work in the Super-CKM/PMNS basis, as de ned in sections 4.1 and 4.2. For the NMSSM, we de ne one catch-allm odel and extend the SLHA1 m ixing only to include the new states, with CP, R-parity, and avour still assumed conserved.

To make the interface independent of program ming languages, com pilers, platform setc, the SLHA1 is based on the transfer of three di erent ASCII les (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 im plem entation 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 fram ework 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] in plicitly. For instance, all dimensionful parameters quoted in the present paper are assumed to be in the appropriate power of G eV, all angles are in radians, and the output form ats for SLHA2 data BLOCKs 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 rst publication, a few useful extensions to the SLHA1 have been identied. These are collected here for reference and are independent of the more general SUSY models discussed in subsequent sections. (A lso note the recent proposal for a joint SLHA + LHEF form at 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 input) de ned in [1].

Secondly, to allow fordi erent parameters to be de ned at di erent scales (e.g., de ned at M  $_{\rm EW SB}$ , the remaining parameters de ned at M  $_{\rm input}$ ) we introduce a new optional block QEXTPAR which, if present, overrides the default MINPAR and EXTPAR scale choices for specic parameters, as de ned below.

W hile 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 de ned in EXTPAR and QEXTPAR in the SLHA2 are thus (repeating unchanged EXTPAR entries for completeness):

# BLOCK EXTPAR

O ptional input parameters for non-m inim al/non-universal models. This block may be entirely absent from the input le, in which case a m inim altype of the selected SUSY breaking model will be used. When block EXTPAR is present, the starting point is still a m inim al model with parameters as given in MINPAR [1] but with each value present in EXTPAR replacing the m inim alm odel 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 DR scheme.

## Input scale

0 : M input. Input scale for EXTPAR entries in SUGRA, AM SB, and general M SSM models. If absent, the GUT scale derived from gauge unication will be used as input scale. Note that this parameter has no e ect in GM SB scenarios where the input scale by de nition is identical to the messenger scale, M mess. A special case is when  $Q = M_{EW SB} = \frac{p_{m t_1} m_{t_2}}{m_{t_1} m_{t_2}}$  is desired as input scale, since this scale is not known beforehand. This choice can be invoked by giving the special value M input = 1. To de ne an alternative input scale for one or more speci c parameters, see OEXTPAR below.

### Gaugino Masses

- 1 :  $M_1(M_{input})$ .  $U(1)_Y$  gaugino (Bino) m ass.
- 2 :  $M_2$  ( $M_{input}$ ). SU (2)<sub>L</sub> gaugino (W ino) mass.
- 3 :  $M_3$  ( $M_{input}$ ). SU (3)<sub>c</sub> gaugino (gluino) m ass.

#### Trilinear Couplings

- 11 : At(M input). Top trilinear coupling.
- 12 : A<sub>b</sub>(M<sub>input</sub>). Bottom trilinear coupling.
- 13 : A (M input). Tau trilinear coupling.

#### Higgs Param eters

| Only one of the parameter sets  $(m_{H_1}^2, m_{H_2}^2)$ ,  $(m_A^2)$ ,  $(m_A^0)$ , or  $(m_{H^+})$  should be given, they merely represent di erent ways of specifying the same parameters.

- 21 :  $m_{H_1}^2$  (M input). Down type H iggs m ass squared.
- 22 :  $m_{H_2}^2$  (M input). Up type H iggs m ass squared.
- 23 : (M<sub>input</sub>). param eter.
- 24 :  $m_A^2$  (M <sub>input</sub>). Tree{ level pseudoscalar H iggs m ass parameter squared, as de ned in [1].

- 25 : tan (M  $_{input}$ ). If present, this value of tan overrides the one in MINPAR, and the input scale is taken as M  $_{input}$  rather than m  $_{z}$ .
- 26 :  $m_{A^0}$ . P seudoscalar H iggs polem ass. M ay be given instead of  $m_A^2$  (M input).
- 27 :  $m_{H^+}$ . Charged Higgs pole mass. May be given instead of  $m_A^2$  (M input).

### Sferm ion M asses

- 31 : m<sub>et</sub> (M<sub>input</sub>). Left 1<sup>st</sup>gen. scalar lepton mass.
- 32 : m ~, (M input). Left 2<sup>nd</sup> gen. scalar lepton m ass.
- 33 : m <sub>~t</sub> (M <sub>input</sub>). Left 3<sup>rd</sup>gen.scalar lepton m ass.
- 34 : m <sub>e<sub>R</sub></sub> (M <sub>input</sub>). R ight scalar electron m ass.
- 35 : m ~ (M input). Right scalar m uon m ass.
- 36 :  $m_{r_{R}}$  (M input). R ight scalar tau m ass.
- 41 : m <sub>gui</sub> (M <sub>input</sub>). Left 1<sup>st</sup>gen. scalar quark m ass.
- 42 : m quit (M input). Left 2<sup>nd</sup>gen. scalar quark m ass.
- 43 : m <sub>cat</sub> (M <sub>input</sub>). Left 3<sup>rd</sup>gen. scalar quark m ass.
- 44 :  $m_{\alpha_R}$  (M input). R ight scalar up m ass.
- 45 : m c. (M input). Right scalar charm mass.
- 46 : m <sub>fp</sub> (M input). R ight scalar top m ass.
- 47 : m <sub>dr</sub> (M <sub>input</sub>). R ight scalar down m ass.
- 48 :  $m_{s_{R}}$  (M input). R ight scalar strange m ass.
- 49 : m <sub>b</sub> (M <sub>input</sub>). R ight scalar bottom m ass.

### 0 ther Extensions

51	: N $_1$ (G M SB only). U (1) $_{\rm Y}$ m essenger index (de ned as in ref.[51]).
52	: N $_2$ (G M SB only). SU (2) $_{\!\rm L}$ m essenger index (de ned as in ref. [51]).
53	: N $_3$ (GMSB only). SU (3) <sub>c</sub> messenger index (de ned as in ref. [51]).

# BLOCK QEXTPAR

O ptional alternative input scales for speci c param eters. This block should norm ally be absent, in which case the default input scale or M <sub>input</sub> (see EXTPAR 0) will be used for all param eters. We stress that most codes cannot be expected to allow for multiple arbitrary scale choices, so the relevant m anual and output should be carefully checked to make sure the desired behaviour is obtained. Currently de ned 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 :  $Q_A$ , . Input scale for charged slepton trilinear couplings.
- 21 :  $Q_{m_{H_1}^2}$ . Input scale for  $m_{H_1}^2$ .
- 22 :  $Q_{m_{H_2}^2}$ . Input scale for  $m_{H_2}^2$ .
- 23 : Q . Input scale for .
- 24 :  $Q_{m_{\lambda}^2}$  . Input scale for  $m_{\lambda}^2$  , as de ned in [1].
- 25 :  $Q_{tan}$  . Input scale for tan .
- 31  $: Q_{m_{\star}}$  . Input scale for all left-handed slepton m ass term s.
- 34 :  $Q_{m}$  . Input scale for all right-handed slepton m ass term s.
- 41 :  $Q_{m_{q_r}}$  . Input scale for all left-handed squark mass term s.
- 44 :  $Q_{m_{w_{p}}}$  . Input scale for all right-handed up-type squark mass term s.
- 47 :  $Q_{m_x}$  . Input scale for all right-handed down-type squark mass term s.

# 3 M odel Selection

To de ne the general properties of the model, we propose to introduce global switches in the SLHA1 model de nition block MODSEL, as follows. Note that the switches de ned 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 num ber, specifying the option or value chosen:

- 3 : (Default=0) Choice of particle content. Switches de ned are:
  - 0 : M SSM . This corresponds to SLHA1.
  - 1 : NM SSM . The blocks de ned in section 5 should be present.
- 4 : (Default= 0) R -parity violation. Switches de ned are:
  - 0 : R-parity conserved. This corresponds to the SLHA1.
  - 1 : R-parity violated. The blocks de ned in section 4.2 should be present.
- 5 : (Default=0) CP violation. Switches de ned 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. C om pletely general CP phases allowed. Im aginary 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 avour violation, im aginary parts of the blocks de ned in section 4.1 should be given, again with the pre x IM, which supersede the corresponding entries in IMEXTPAR.
- 6 : (Default=0) F lavour violation. Switches de ned are:
  - 0 : No (SUSY) avour violation. This corresponds to the SLHA1.
  - 1 : Quark avour is violated. The blocks de ned in section 4.1 should be present.
  - 2 : Lepton avour is violated. The blocks de ned in section 4.1 should be present.
  - 3 : Lepton and quark avour is violated. The blocks de ned in section 4.1 should be present.

# 4 GeneralM SSM

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

Speci cally, the chiral super elds of the M SSM have the following SU  $(3)_{\rm C}$   $\,$  SU  $(2)_{\rm L}$  U  $(1)_{\rm Y}$  quantum numbers

L: 
$$(1;2; \frac{1}{2});$$
 E:  $(1;1;1);$  Q:  $(3;2;\frac{1}{6});$  U:  $(3;1; \frac{2}{3});$   
D:  $(3;1;\frac{1}{3});$  H<sub>1</sub>:  $(1;2; \frac{1}{2});$  H<sub>2</sub>:  $(1;2;\frac{1}{2});$  (1)

the superpotential (om itting RPV term s, see section 4.2) is written as

$$W_{MSSM} = {}_{ab}{}^{II}(Y_{E})_{ij}H_{1}^{a}L_{i}^{b}E_{j} + (Y_{D})_{ij}H_{1}^{a}Q_{i}^{b}D_{j} + (Y_{U})_{ij}H_{2}^{b}Q_{i}^{a}U_{j} + H_{1}^{a}H_{2}^{b} ; (2)$$

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

$$V_{3} = \sum_{ab}^{X \ h} (T_{E})_{ij} H_{1}^{a} \Gamma_{i_{L}}^{b} e_{j_{R}} + (T_{D})_{ij} H_{1}^{a} \mathcal{Q}_{i_{L}}^{b} \tilde{d}_{j_{R}} + (T_{U})_{ij} H_{2}^{b} \mathcal{Q}_{i_{L}}^{a} u_{j_{R}}^{1} + h \pi;; \quad (3)$$

$$V_{2} = m_{H_{1}}^{2} H_{1a} H_{1}^{a} + m_{H_{2}}^{2} H_{2a} H_{2}^{a} + Q_{i_{L}a} (m_{Q}^{2})_{ij} Q_{j_{L}}^{a} + L_{i_{L}a} (m_{L}^{2})_{ij} L_{j_{L}}^{a} + \alpha_{i_{R}} (m_{d}^{2})_{ij} d_{j_{R}}^{a} + e_{i_{R}} (m_{e}^{2})_{ij} e_{j_{R}} (m_{3}^{2})_{ab} H_{1}^{a} H_{2}^{b} + h c:); \qquad (4)$$

where a tilde over the sym bol for a quark or lepton super eld denotes its scalar component (note however that we de ne, e.g.,  $u_R$  as the scalar component of U). Throughout this section, we denote SU(2)<sub>L</sub> 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. <sub>ab</sub> is the totally antisym metric tensor, with  $_{12} = {}^{12} = 1$ .

### 4.1 Flavour V iolation

#### 4.1.1 The quark sector and the super-CKM basis

W ithin the MSSM there are in general new sources of avour violation arising from a possible m isalignment of quarks and squarks in avour space. The severe experimental constraints on avour violation have no direct explanation in the structure of the unconstrained MSSM which leads to the well-known supersymmetric avour 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. A ctually, once the electroweak symmetry is broken, a rotation in avour space

$$D^{\circ} = V_d D$$
;  $U^{\circ} = V_u U$ ;  $D^{\circ} = U_d D$ ;  $U^{\circ} = U_u U$ ; (5)

of all matter super elds in the (s)quark superpotential

$$W_{Q} = {}_{ab}{}^{h} (Y_{D})_{ij} H_{1}^{a} Q_{i}^{bo} D_{j}^{o} + (Y_{U})_{ij} H_{2}^{b} Q_{i}^{ao} U_{j}^{o}$$
(6)

brings ferm ions from the interaction eigenstate basis  $fd_L^\circ$ ; $u_L^\circ$ ; $d_R^\circ$ ; $u_R^\circ$ g to their mass eigenstate basis  $fd_L$ ; $u_L$ ; $d_R$ ; $u_R$ g:

$$d_{\rm L}^{\rm o} = V_{\rm d} d_{\rm L}$$
;  $u_{\rm L}^{\rm o} = V_{\rm u} u_{\rm L}$ ;  $d_{\rm R}^{\rm o} = U_{\rm d} d_{\rm R}$ ;  $u_{\rm R}^{\rm o} = U_{\rm u} u_{\rm R}$ ; (7)

and the scalar superpartners to the basis  $f\tilde{d}_L; \mathfrak{a}_L; \tilde{d}_R; \mathfrak{a}_R g$ . Through this rotation, the Yukawa matrices  $Y_D$  and  $Y_U$  are reduced to their diagonal form  $\hat{Y_D}$  and  $\hat{Y_U}$ :

$$(\hat{Y}_{D})_{ii} = (U_{d}^{Y}Y_{D}^{T}V_{d})_{ii} = \frac{p}{2}\frac{m_{di}}{v_{1}}; \qquad (\hat{Y}_{U})_{ii} = (U_{u}^{Y}Y_{U}^{T}V_{u})_{ii} = \frac{p}{2}\frac{m_{ui}}{v_{2}}: \qquad (8)$$

Tree-level m ixing term s am ong quarks of di erent generations are due to the m isalignm ent of  $V_d$  and  $V_u$ , expressed via the CKM m atrix

$$V_{CKM} = V_u^y V_d ; \qquad (9)$$

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

In the super-CKM basis the 6  $\,$  6 m assmatrices for the up-type and down-type squarks are dened as

$$L_{\mathfrak{q}}^{\mathrm{mass}} = \qquad {}_{\mathrm{u}}^{\mathrm{y}} \mathrm{M}_{\mathrm{tr} \mathrm{u}}^{2} \qquad {}_{\mathrm{d}}^{\mathrm{y}} \mathrm{M}_{\mathrm{d} \mathrm{d}}^{2} \mathbf{d}; \qquad (10)$$

where  $u = (\mathfrak{a}_{L};\mathfrak{c}_{L};\mathfrak{t}_{L};\mathfrak{a}_{R};\mathfrak{c}_{R};\mathfrak{t}_{R})^{T}$  and  $d = (\mathfrak{d}_{L};\mathfrak{s}_{L};\mathfrak{d}_{R};\mathfrak{s}_{R};\mathfrak{b}_{R})^{T}$ . We diagonalise the squark mass matrices via 6 6 unitary matrices  $R_{u,rl}$ , such that  $R_{u,rl} M_{u,rl}^{2} R_{u,rl}^{Y}$  are diagonal matrices with increasing mass squared values. The avour-mixed mass matrices read:

$$M_{u}^{2} = \begin{pmatrix} 0 \\ V_{CKM} \\ m_{Q}^{2} \\ V_{CKM} \\ m_{Q}^{2} \\ V_{CKM}^{2} \\ m_{u}^{2} \\$$

$$M_{\alpha}^{2} = \begin{pmatrix} 0 & m_{\alpha}^{2} + m_{d}^{2} + D_{dLL} & \frac{y_{1}}{p_{2}} \hat{T}_{D}^{Y} & m_{d} \tan \\ 0 & m_{\alpha}^{2} + m_{d}^{2} + D_{dRR} & A \end{pmatrix}$$
(12)

In the equations above we introduced the 3 3 m atrices

$$\mathfrak{m}_{\varphi}^{2} \quad V_{d}^{y}\mathfrak{m}_{\varphi}^{2}V_{d}; \quad \mathfrak{m}_{\varkappa}^{2} \quad U_{u}^{y}\mathfrak{m}_{\varkappa}^{2^{T}}U_{u}; \quad \mathfrak{m}_{d}^{2} \quad U_{d}^{y}\mathfrak{m}_{d}^{2^{T}}U_{d};$$
(13)

$$\hat{\mathbf{T}}_{U} \quad U_{u}^{Y} \mathbf{T}_{U}^{T} \mathbf{V}_{u}; \quad \hat{\mathbf{T}}_{D} \quad U_{d}^{Y} \mathbf{T}_{D}^{T} \mathbf{V}_{d}; \qquad (14)$$

where the un-hatted m ass m atrices m  $^2_{Q,\mu,pl}$  and trilinear interaction m atrices  $T_{U,p}$  are given in the interaction basis.

The matrices m  $_{\rm u,d}$  are the diagonal up-type and down-type quark m asses and D  $_{\rm f\,LL\,\,RR}$  are the D-term s given by:

$$D_{fLLRR} = \cos 2 m_Z^2 T_f^3 Q_f \sin^2 w l_3; \qquad (15)$$

which are also avour 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<sup>c</sup>. Note that the up-type and down-type squark mass matrices in eqs. (11) and (12) cannot be simultaneously avour-diagonal unless  $m_g^2$  is avour-universal (i.e., proportional to the identity in avour space).

#### 4.1.2 The lepton sector and the super-PM NS basis

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

N eutrino oscillation data have provided a strong indication that neutrinos have m asses and that there are avour-changing charged currents in the leptonic sector. One popular m odel to produce such e ects is the see saw m echanism, where right-handed neutrinos have both M a jorana m asses as well as Y ukaw a couplings with the left-handed leptons W hen the heavy neutrinos are integrated out of the e ective eld theory, one is left with three light approxim ately left-handed neutrinos which are identified with the ones observed experim entally. There are other m odels of neutrino m asses, for example involving SU (2) H iggs triplets, that, once the triplets have been integrated out, also lead to e ective M a jorana m asses for the neutrinos. Here, we cover all cases that lead to a low energy e ective eld theory with M a jorana neutrino m asses and one sneutrino per family. In term s of this low energy e ective theory, the lepton m ixing phenom enon is analogous to the quark m ixing case and so we adapt the conventions de ned above to the leptonic case.

A fler electroweak symmetry breaking, the neutrino sector of the MSSM contains the Lagrangian pieces (in 2{component notation)

$$L = \frac{1}{2} {}^{\circ T} (m) {}^{\circ} + h c;; \qquad (16)$$

where m is a 3 3 symmetric matrix. The interaction eigenstate basis neutrino elds  $^{\circ}$  are related to the mass eigenstate ones by

$$^{\circ} = V \quad ; \tag{17}$$

reducing the mass matrix m to its diagonal form m

$$(\mathbf{m})_{ii} = (\mathbf{V}^{\mathrm{T}}\mathbf{m} \ \mathbf{V})_{ii} = \mathbf{m}_{i} :$$
(18)

The charged lepton elds have a 3 3 Yukawa coupling matrix de ned in the (s)lepton superpotential

$$W_{E} = {}_{ab}(Y_{E})_{ij}H_{1}^{a}L_{i}^{bo}E_{j}^{o}; \qquad (19)$$

where the charged lepton interaction eigenstates  $fe_L^o; e_R^o g$  are related to the m ass eigenstates  $fe_L; e_R; g$  by

$$e_{\rm L}^{\circ} = V_{\rm e}e_{\rm L}$$
 and  $e_{\rm R}^{\circ} = U_{\rm e}e_{\rm R}$ : (20)

The equivalent diagonalised charged lepton Yukawa matrix is

$$(\hat{Y}_{E})_{ii} = (U_{e}^{Y}Y_{E}^{T}V_{e})_{ii} = \frac{p}{2}\frac{m}{2}\frac{m}{v_{1}}$$
 : (21)

Lepton  ${\tt m}$  ixing in the charged current interaction can then be characterised by the PM NS  ${\tt m}$  atrix

$$U_{PM NS} = V_e^{Y} V ; \qquad (22)$$

which is proportional to the tree-level  $e_{Li j}W$  and  $e_{Ri j}H$  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<sup>1</sup>

$$L_{1}^{mass} = {}_{e}^{Y}M {}_{e}^{2} {}_{e} {}^{Y}M {}_{\sim}^{2} ; \qquad (23)$$

 $^1 {\rm W}$  e here neglect the possible term  $~^{\rm T} {\rm M}^{^{\wedge} 2}_{~ \sim}$  .

where  $= (\sim_e; \sim \sim)^T$  and  $_e = (\otimes_L; \sim_L; \sim_L; \otimes_R; \sim_R; \sim_R)^T$ . M  $_e^2$  is the 6 6 m atrix

$$M_{e}^{2} = \begin{pmatrix} 0 & m_{E}^{2} + m_{e}^{2} + D_{eLL} & \frac{y_{1}}{2} \hat{T}_{E}^{y} & m_{e} \tan \end{pmatrix}$$

$$M_{e}^{2} = \begin{pmatrix} 0 & 1 & 1 & 1 \\ \frac{y_{1}}{2} \hat{T}_{E}^{z} & m_{e} \tan \end{pmatrix}$$

$$M_{e}^{2} + m_{e}^{2} + D_{eRR}$$

$$(24)$$

and M  $^2_{\sim}$  is the 3 3 m atrix

$$M_{\sim}^{2} = U_{PM NS}^{Y} \hat{m}_{L}^{2} U_{PM NS} + D_{LL}; \qquad (25)$$

where D  $_{\rm eLL}$  and D  $_{\rm LL}$  are given in eq.(15). In the equations above we introduced the 3  $\,$  3 m atrices

$$\hat{\mathbf{m}}_{\mathrm{L}}^{2} = \mathbf{V}_{\mathrm{e}}^{\mathrm{y}} \mathbf{m}_{\mathrm{L}}^{2} \mathbf{V}_{\mathrm{e}}; \quad \hat{\mathbf{m}}_{\mathrm{e}}^{2} = \mathbf{U}_{\mathrm{e}}^{\mathrm{y}} \mathbf{m}_{\mathrm{e}}^{2^{\mathrm{T}}} \mathbf{U}_{\mathrm{e}}; \qquad (26)$$

$$\hat{\mathbf{T}}_{\mathrm{E}} = \mathbf{U}_{\mathrm{e}}^{\mathrm{Y}} \mathbf{T}_{\mathrm{E}}^{\mathrm{T}} \mathbf{V}_{\mathrm{e}}; \qquad (27)$$

where the un-hatted m ass matrices m $^2_{L,p}$  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  $R_e$ ; respectively. Thus,  $R_e$ ;  $M^2_{e,r}R_e^y$ ; 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 le, we propose to use de nitions in the modiled dimensional reduction ( $\overline{DR}$ ) scheme. The basis is the super-CKM /PMNS basis as de ned above, that is the one in which the Yukawa couplings of the SM fermions, given in the  $\overline{DR}$  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  $\overline{DR}$  scheme.

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

By default, all input SUSY parameters are given at the scale M<sub>input</sub> as de ned in the SLHA1 block EXTPAR (see above). In principle, advanced codes may also allow for separate input scales for the sferm ion mass matrices and trilinear couplings, via the block QEXTPAR de ned above, but we emphasise that this should be regarded as non-standard.

For the SM input parameters, we take the Particle D ata G roup (PDG) de nition: lepton m asses are all on-shell. The light quark m asses m  $_{\rm urls}$  are given at 2 G eV, and the heavy quark m asses are given as m  $_{\rm c}$  (m  $_{\rm c}$ )<sup>MS</sup>, m  $_{\rm b}$  (m  $_{\rm b}$ )<sup>MS</sup> and m  $_{\rm t}^{\rm on \ shell}$ . The latter two quantities are already in the SLHA1. The others are added to SMINPUTS in the following m anner (repeating the SLHA1 parameters for convenience):

- 1 :  $\frac{1}{em} (m_Z)^{\overline{MS}}$ . Inverse electrom agnetic coupling at the Z pole in the  $\overline{MS}$  scheme (with 5 active avours).
- 2 :  $G_F$  . Ferm i constant (in units of G eV <sup>2</sup>).

- 3 :  ${}_{s}(m_{Z})^{\overline{MS}}$ . Strong coupling at the Z pole in the  $\overline{MS}$  scheme (with 5 active avours).
- 4 :  $m_z$  , pole m ass.
- 5 :  $m_{\rm b}(m_{\rm b})^{\overline{\rm MS}}$ . b quark running m ass in the  $\overline{\rm MS}$  scheme.
- 6 : m<sub>t</sub>, pole m ass.
- 7 :m ,polemass.
- 8 :  $m_3$ , pole mass.
- 11 :  $m_e$ , pole m ass.
- 12 :  $m_1$ , pole mass.
- 13 :m ,polemass.
- 14 :  $m_2$ , pole m ass.
- 21 :  $m_d (2 \text{ GeV})^{\overline{MS}}$ . d quark running m ass in the  $\overline{MS}$  scheme.
- 22 :  $m_u (2 \text{ GeV})^{\overline{MS}}$ . u quark running mass in the  $\overline{MS}$  scheme.
- 23 :  $m_s (2 \text{ GeV})^{\overline{MS}}$ . s quark running m ass in the  $\overline{MS}$  scheme.
- 24 :  $(m_c)^{\overline{MS}}$ . c quark running m ass in the  $\overline{MS}$  scheme.

The FORTRAN form at is the same as that of SMINPUTS in SLHA1 [1].

 $V_{CKM}$ : the input CKM matrix in the W olfenstein parameterisation<sup>2</sup>, in the block VCKMIN. Note that present CKM studies do not precisely de ne a renormalisation scheme for this matrix since the electroweak electroweak is that renormalise it are highly suppressed and generally neglected. We therefore assume that the CKM elements given by PDG (or by UTF it [31] and CKMFitter [32], the main collaborations that extract the CKM parameters) refer to SM  $\overline{MS}$  quantities de ned at  $Q = m_z$ , to avoid any possible ambiguity. VCKMIN should have the following entries

1 : 2 : A 3 : 4 :

The FORTRAN form at is the same as that of SMINPUTS above.

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

- 1 :  $_{12}$  (the solar angle)
- 2 : <sub>23</sub> (the atm ospheric m ixing angle)

 $<sup>^2</sup>$  For the W olfenstein parameters we use the PDG de nition, eq.(11.4) of [52], which is exact to all orders in .

- 3 : 13 (currently only has an upper bound)
- 4 :  $_{13}$  (the D irac CP-violating phase)
- 5 :  $_1$  (the rst M a prana CP-violating phase)
- 6 :  $_2$  (the second CP-violating M a prana phase)

The FORTRAN form at is the same as that of SMINPUTS above. Majorana phases have no e ect on neutrino oscillations. However, they have physical consequences in the case of, for example, 0 decay of nuclei.

 $(\mathfrak{m}_{\mathcal{G}}^2)_{ij}^{\overline{PR}}$ ,  $(\mathfrak{m}_{\mathfrak{a}}^2)_{ij}^{\overline{PR}}$ ,  $(\mathfrak{m}_{\mathcal{G}}^2)_{ij}^{\overline{PR}}$ ,  $(\mathfrak{m}_{\mathfrak{a}}^2)_{ij}^{\overline{PR}}$ ; the squark and slepton soft SUSY – breaking m asses at the input scale in the super-CKM /PMNS basis, as de ned above. They will be given in the new blocks MSQ2IN, MSU2IN, MSD2IN, MSL2IN, MSE2IN, with the FORTRAN form at

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

where the rst two integers in the form at correspond to i and j and the double precision number to the softmass 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.

 $(\hat{\Gamma}_U)_{ij}^{\overline{PR}}$ ,  $(\hat{T}_D)_{ij}^{\overline{PR}}$ , and  $(\hat{T}_E)_{ij}^{\overline{PR}}$ : 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 form at as the soft mass matrices above. If diagonal entries are present these supersede the A parameters specied in the SLHA1 block EXTPAR [1].

For the output, the pole m assess are given in block MASS as in SLHA1 (note, how ever, that som e PDG numbers have di erent assignments in SLHA2, see below) and the  $\overline{DR}$  and m ixing parameters as follows:

 $(\mathfrak{m}_{\mathcal{Q}}^{2})_{ij}^{\overline{DR}}$ ,  $(\mathfrak{m}_{\mathfrak{u}}^{2})_{ij}^{\overline{DR}}$ ,  $(\mathfrak{m}_{\mathfrak{L}}^{2})_{ij}^{\overline{DR}}$ ,  $(\mathfrak{m}_{\mathfrak{L}}^{2})_{ij}^{\overline{DR}}$ ; the squark and slepton soft SUSY – breaking masses at scale Q in the super-CKM /PMNS basis. W ill be given in the new blocks MSQ2 Q=..., MSU2 Q=..., MSD2 Q=..., MSL2 Q=..., MSE2 Q=..., with form ats as the corresponding input blocks MSX2IN above.

 $(\hat{\Gamma}_U)_{ij}^{\overline{PR}}$ ,  $(\hat{T}_D)_{ij}^{\overline{PR}}$ , and  $(\hat{T}_E)_{ij}^{\overline{PR}}$ : 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].

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

The entries of the DR CKM matrix at the scale Q. The real and imaginary parts are given in VCKM Q=..., respectively. The form at 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 DR PMNS matrix at the scale Q. The real and imaginary parts are given in UPMNS Q=... and IMUPMNS Q=..., respectively, with entries de ned as for the  $V_{CKM}$  output blocks above.

The squark and slepton masses and mixing matrices should be dened as in the existing SLHA1, e.g. extending the t, b and ~ mixing matrices to the 6 6 case. More speci cally, the new blocks  $R_u = USQMIX R_d = DSQMIX$ ,  $R_e = SELMIX$  and the 3 3 matrix for R = SNUMIX specify the composition of the mass eigenstates in terms of the super-CKM /PMNS basis states according to the following denitions:



N ote! 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 neardegenerate 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 de ne separate PDG codes and m ixing matrices for the scalar and pseudoscalar sneutrinos, as follows:

If present, SNSMIX and SNAMIX supersede SNUMIX.

## 4.2 R - Parity V iolation

Wewrite the R-parity violating superpotential in the interaction basis as

$$W_{RPV} = ab \frac{1}{2} ijk L_{i}^{a} L_{j}^{b} E_{k} + 0 ijk L_{i}^{a} Q_{j}^{bx} D_{kx} iL_{i}^{a} H_{2}^{b} + \frac{1}{2} ijk xyz U_{i}^{x} D_{j}^{y} D_{k}^{z}; \qquad (34)$$

where  $x_i y_i z = 1_i :::; 3$  are fundam ental SU (3)<sub>c</sub> indices and  $_{xyz}$  is the totally antisymm etric tensor in 3 dimensions with  $_{123} = +1$ . In eq. (34),  $_{ijk}$ ;  $_{ijk}^{0}$  and  $_{i}$  break lepton number, whereas  $_{ijk}^{0}$  violate baryon number. To ensure proton stability, either lepton number conservation or baryon number conservation is usually still assumed, resulting in either  $_{ijk} = _{ijk}^{0} = _{i} = 0$  or  $_{ijk}^{0} = 0$  for all  $i_i j_i k = 1_i 2_i 3$ .

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

$$V_{3RPV} = _{ab} \frac{1}{2} (T)_{ijk} \tilde{\Gamma}^{a}_{iL} \tilde{\Gamma}^{b}_{jL} \mathbf{e}_{kR} + (T^{0})_{ijk} \tilde{\Gamma}^{a}_{iL} \mathcal{Q}^{b}_{jL} \tilde{d}_{kR} + \frac{1}{2} (T^{0})_{ijk} _{xyz} \mathfrak{v}^{x}_{iR} \tilde{d}^{y}_{jR} \tilde{d}^{z}_{kR} + h \mathfrak{k}: :$$
(35)

Note that we do not factor out the couplings (e.g. as in  $T_{ijk} = _{ijk}$  A  $_{ijk}$ ) in order to avoid potential problems with  $_{ijk} = 0$  but  $T_{ijk} \in 0$ . 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

$$V_{2RPV} = {}_{ab}D_{i}\Gamma^{a}_{iL}H^{b}_{2} + \Gamma^{y}_{iaL}m^{2}_{\Gamma_{i}H_{1}}H^{a}_{1} + hc::$$
(36)

W hen lepton number is not conserved the sneutrinos may acquire vacuum expectation values (VEVs) $_{q}h_{\overset{\sim}{q};;i}$  v<sub>e; ;</sub> = 2. The SLHA1 de ned the VEV v, which at tree level is equal to  $2m_{z} = g^{2} + g^{0^{2}}$  246 GeV; this is now generalised to

$$v = \sqrt[q]{v_1^2 + v_2^2 + v_e^2 + v^2 + v^2} :$$
(37)

The addition of sneutrino VEV s allows for various di erent de nitions of tan , but we here choose to keep the SLHA1 de nition tan  $v_2=v_1$ .

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

Firstly, the d-quark m ass m atrices are given by

$$p_{\underline{j}} = (Y_D)_{ij} V_1 + {}^{0}_{kij} V_k :$$
 (38)

where  $v_k$  are the sneutrino VEVs. Secondly, in the lepton number violating case, the PMNS matrix can only be dened 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 de niteness, and to keep the changes with respect to the R-parity conserving case as limited as possible, we de net the super-CKM basis as the one where the Yukawa couplings  $Y_D$  and  $Y_U$  are diagonal. The PMNS basis is de ned as the basis where  $Y_E$  is diagonal and the loop-induced neutrino mass matrix is diagonalised. In this way one obtains a uniquely de ned set of parameters:

ijk 
$$rstV rstV_{esj}U_{etk}^{Y}$$
; (39)

$$_{jk}^{0} \qquad {}_{rst}^{0} V_{rsj} U_{drsj}^{V}$$
; (40)

where the ferm ion mixing matrices are de ned in section 4.1. The Lagrangian for the quark-slepton interactions then takes the following form :

$$L = \int_{ijk}^{0} \gamma_{i} d_{Rk} d_{Lj} + \int_{rsk}^{0} U_{PM NS,ri}^{y} V_{CKM,sj}^{y} \mathcal{L}_{i} d_{Rk} u_{Lj} + hc::$$
(43)

Sim ilarly 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 de ne:

$$\hat{\mathbf{m}}_{\mathbf{L}_{i}\mathbf{H}_{1}}^{2} \quad \mathbf{V}_{e,ir}^{\mathbf{y}} \hat{\mathbf{m}}_{\mathbf{L}_{r}\mathbf{H}_{1}}^{2} :$$

$$(44)$$

#### 4.2.1 Input/Output Blocks

A sm entioned above, we use the super-CKM /PMNS basis throughout, for both superpotential and soft SUSY-breaking terms. This applies to both input and output<sup>3</sup>. The naming convention for input blocks is BLOCK RV#IN, where the '#' character represents the name

 $<sup>^{3}</sup>$ A code m ay 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 super elds entering eqs. (39){(42).

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

Default inputs for all R-parity violating couplings are zero. The inputs are given at scale M  $_{input}$ , as described in SLHA1 (again, if no M  $_{input}$  is given, the GUT scale is assumed), and follow the output form at given below (with the om ission of Q= ...). In addition, the known ferm ion m asses should be given in SMINPUTS as de ned in section 4.1.3.

The dimensionless super-CKM/PMNS couplings  $^{0}_{ijk}$ ,  $^{0}_{ijk}$ , and  $^{00}_{ijk}$  are given in BLOCK RVLAMLLE, RVLAMLQD, RVLAMUDD Q= ... respectively. The output standard should correspond to the FORTRAN form at

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

where the st three integers in the form at correspond to i, j, and k and the double precision num ber is the coupling.

 $\hat{T}_{ijk}$ ,  $\hat{T}_{ijk}^0$ , and  $\hat{T}_{ijk}^{0}$  are given in BLOCK RVTLLE, RVTLQD, RVTUDD Q= ... in the same form at as for the  $\hat{}$  couplings above.

The bilinear superpotential and soft SUSY-breaking term s  $\hat{D}_i$ , and  $\hat{m}_{E_iH_1}^2$  and the sneutrino VEVs are given in BLOCK RVKAPPA, RVD, RVM2LH1, RVSNVEV Q= ... respectively, in the form at

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

The input and output blocks for R-parity violating couplings are sum marised in Tab.1. A s for the R-conserving M SSM, the bilinear term s (both SU SY-breaking and SU SY-respecting ones, including) and the VEV s 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  $m_{H_1}^2$  and  $m_{H_2}^2$  or and  $m_A^2$ . 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. Speci cally, of the last 4 blocks only 3 are independent. One block is determined by minim ising 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 M ixing

In general, the neutrinos m ix with the neutralinos. This requires a change in the denition of the 4 d neutralino m ixing matrix N to a 7 7 matrix. The Lagrangian contains the (symmetric) neutrino/neutralino m ass matrix as

$$L_{\sim^{0}}^{\max} = \frac{1}{2} \sim^{0T} M_{\sim^{0}} \sim^{0} + h \mathfrak{x}; ; \qquad (45)$$

in the basis of 2{component spinors  $\sim^0 = (e; ; ; ib; iw^3; \tilde{h}_1; \tilde{h}_2)^T$ . We de ne the unitary 7 7 neutrino/neutralino mixing matrix N (block RVNMIX), such that:

$$\frac{1}{2} \sim^{0T} M \sim_{0} \sim^{0} = \frac{1}{2} | \underbrace{-}_{\sim^{0T}}^{OT} N | \underbrace{N}_{z} M | \underbrace{-}_{z} N | \underbrace{N}_{z} M | \underbrace{-}_{z} N | \underbrace{-}$$

Input block 0 utput block		data			
RVLAMLLEIN RVLAMLLE		ijk î <sub>ijk</sub>			
RVLAMLQDIN	RVLAMLQD	ijk <sup>^0</sup> <sub>ijk</sub>			
RVLAMUDDIN	RVLAMUDD	ijk <sup>^</sup> @			
RVTLLEIN	RVTLLE	ijk Î <sub>ijk</sub>			
RVTLQDIN	RVTLQD	ijk T̂ <sub>ijk</sub>			
RVTUDDIN	RVTUDD	ijk Î <sup>m</sup> <sub>ijk</sub>			
NB:One of t	he follow ing RV.	$\ldots$ IN blocks m ust be left out:			
(w)	hich one up to u	iser and RGE code)			
RVKAPPAIN	RVKAPPA	i^ <sub>i</sub>			
RVDIN	RVD	iD <sub>i</sub>			
RVSNVEVIN	RVSNVEV	i V <sub>i</sub>			
RVM2LH1IN	RVM2LH1	$im^2_{\Gamma_1H_1}$			

Table 1: Sum m ary of R-parity violating SLHA2 data blocks. All param eters are given in the Super-CKM /PMNS basis. Only 3 out of the last 4 blocks are independent. W hich block to leave out of the input is in principle up to the user, with the caveat that a given spectrum calculator m ay not accept all combinations. See text for a precise de nition of the form at.

where the 7 (2{component) generalised neutrinos  $\sim^0 = (_1; ...; _7)^T$  are de ned 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).

N ote! although these codes are norm ally associated with names that imply a specic avour content, such as code 12 being <sub>e</sub> and so forth, it would be exceedingly complicated to maintain such a correspondence in the context of completely generalmixing, hence we do not make any such association here. The avour content of each state, i.e., of each PDG number, is in general only de ned by its corresponding entries in the mixing matrix RVNMIX. Note, however, that the avour basis is ordered so as to reproduce the usual associations in the trivial case (modulo the unknown avour 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 m inus sign may be removed by phase transformations on  $\sim_1^0$  is 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 de  $ne^4$ 

$$L_{*}^{\max} = {}^{T}M_{*} + h \mathfrak{x};; \qquad (47)$$

in the basis of 2 {com ponent spinors  $\sim = (e_L; L; L; i \neq j = (h_1)^T, \gamma^+ = (e_R; R; R; R; I \neq j = 1)^T$ , where  $\Psi = (\Psi^1 = \Psi^2) = 2$ . Note that in the lim it of no RPV the lepton elds are mass

 $<sup>^{4}</sup>$ N ote that the absence of a factor 1=2 on the rh.s. of eq. (47) corrects and supersedes the published version of this paper.

eigenstates.

We de ne the unitary 5  $\,$  5 charged ferm ion m ixing matrices U ;V , blocks RVUMIX, RVVMIX, such that:

The generalised charged leptons ~  $(e_1;e_2;e_3;e_4;e_5)$  are four-component D irac ferm ions, and the left-handed and right-handed parts of  $e_i$  are the two-component ferm ions  $_i$  and  $_i^+$ , respectively. They are dened 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. A s for neutralino mixing, the avour content of each state is in no way in plied by its PDG number, but is <u>only</u> dened by its entries in RVUMIX and RVVMIX. Note, how ever, that the avour 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 eld while codes 1000024 and 1000037 pertain to the opposite charge. The components of ~ in \PDG notation" would thus be (11,13,15,-1000024,-1000037). In the lim it of CP conservation, U and V are chosen to be real by default.

R-parity violation via lepton number violation in plies that the sneutrinos can mix with the Higgs bosons. In the limit of CP conservation the CP-even (-odd) Higgs bosons mix with real (in aginary) parts of the sneutrinos. We write the neutral scalars as  $^{0}$   $\frac{P}{2Re}$  (H $_{1}^{0}$ ;H $_{2}^{0}$ ;~;~;~;~)<sup>T</sup>, with the mass term

$$L = \frac{1}{2} {}^{0^{T}}M {}^{2}{}_{0} {}^{0}; \qquad (49)$$

where M  $^{2}_{0}$  is a 5 5 symmetric mass matrix. We denot the orthogonal 5 5 mixing matrix (block RVHMIX) by

$${}^{0^{\mathrm{T}}}\mathrm{M} {}^{2}{}_{0} {}^{0} = {}^{0^{\mathrm{T}}} {}^{\mathbb{Q}}_{[-\{z_{-}\}]} {}^{\mathbb{Q}}_{[-\{z_{-}\}]} {}^{\mathbb{Q}}_{[-\{z_{-}\}]} {}^{\mathbb{Q}}_{[+\{z_{-}\}]} {}^{\mathbb{Q}}_{[+\{z_{-}\}]} {}^{\mathbb{Q}}_{[-\{z_{-}\}]} {}^{\mathbb{Q}}_{[$$

where  ${}^{0}$   $(h_{1}^{0};h_{2}^{0};h_{3}^{0};h_{4}^{0};h_{5}^{0})$  are the neutral scalar m ass eigenstates in strictly increasing m ass order (that is, we use the label h for any neutral scalar m ass eigenstate, regardless of whether it is m ore \H iggs-like" or \sneutrino-like"). The states are num bered sequentially by the PDG codes (25,35,1000012,1000014,1000016), regardless of avour content. The sam e convention will be followed below for the neutral pseudoscalars and the charged scalars.

Wew rite the neutral pseudo-scalars as  ${}^{0} P_{2}m^{n} (H_{1}^{0}; H_{2}^{0}; \sim_{e}; \sim; \sim)^{T}^{o}$ , with the mass term

$$L = \frac{1}{2} {}^{0T} M {}^{2} {}_{0} {}^{0} ; \qquad (51)$$

where M  $^{2}_{0}$  is a 5 5 symmetric mass matrix. We denote the 4 5 mixing matrix (block RVAMIX) by

$${}^{\text{OT}} M {}^{2}{}_{0} {}^{0} = {}^{\text{OT}} \mathcal{Q}^{\text{T}} \mathcal{Q} \mathcal{Q}^{\text{T}} \mathcal{Q}^{\text{T}} \mathcal{Q}^{\text{T}} \mathcal{Q}^{\text{T}} \mathcal{Q}^{\text{T}} \mathcal$$

where  $^{0}$  (A<sup>0</sup><sub>1</sub>;A<sup>0</sup><sub>2</sub>;A<sup>0</sup><sub>3</sub>;A<sup>0</sup><sub>4</sub>) are the pseudoscalar m ass eigenstates, again in strictly increasing m ass order. The states are numbered sequentially by the PDG codes (36,1000017, 1000018,1000019), regardless of avour composition. The Goldstone boson G<sup>0</sup> (the \5th component") has been explicitly left out and the 4 rows of @ form a set of orthonorm al vectors.

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

The charged sleptons and charged Higgs bosons also m ix in the 8  $\,$  8 m ass squared m atrix M  $^2\,$  by a 7  $\,$  8 m atrix C (block RVLMIX):

$$L = (H_{1}; H_{2}^{+}; e_{L_{1}}; e_{R_{1}})C^{Y}CM^{2}C^{Y}CM^{2}H_{1}^{+}C_{R_{1}}^{H_{1}}G_{R_{1}}^{H_{2}}G_{R_{1}}^{H_{$$

where i; j;k;l 2 f1;2;3g, ; 2 f1;:::;6g and  $^{+} = {}^{y}$  (h<sub>1</sub><sup>+</sup>;h<sub>2</sub><sup>+</sup>;h<sub>3</sub><sup>+</sup>;h<sub>4</sub><sup>+</sup>;h<sub>5</sub><sup>+</sup>;h<sub>6</sub><sup>+</sup>;h<sub>7</sub><sup>+</sup>); these states are num bered sequentially by the PDG codes (37,1000011,1000013,1000015, 2000011,2000013,2000015), regardless of avour composition. The G oldstone boson G  $^{+}$ (the \8th component") has been explicitly left out and the 7 rows of C form a set of orthonorm alvectors.

R -parity violation m ay also generate contributions to dow n-squark m ixing via additional left-right m ixing term s,

$$\frac{1}{p} v_1 \hat{T}_{D,ij}^{Y} \qquad m_{d,i} \tan_{ij} + \frac{v_k}{p} \hat{T}_{0,kij}^{Y}$$
(54)

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

### 4.3 CP V iolation

W hen adding CP violation to the M SSM m odel parameters and m ixing m atrices (for a recent review see, e.g., the CPN SH report [44]), the SLHA1 blocks are understood to contain the real parts of the relevant parameters. The imaginary parts should be provided w ith exactly the same form at, in a separate block of the same name but prefaced by IM. The defaults for all imaginary parameters w ill be zero. Thus, for example, BLOCK IMAU, IMAD, IMAE, Q= ... would describe the imaginary parts of the trilinear soft SU SY -breaking scalar couplings. For input, BLOCK IMEXTPAR m ay be used to provide the relevant in aginary parts of soft SU SY -breaking inputs. In cases where the de nitions of the current paper supersede the SLHA1 input and output blocks, com pletely equivalent statem ents apply.

O ne special case is the parameter. W hen the real part of is given in EXTPAR 23, the im aginary part should be given in IMEXTPAR 23, as above. How ever, when j jis determined by the conditions for electrow eak symmetry breaking, only the phase ' is taken as an input parameter. In this case, SLHA 2 generalises the entry MINPAR 4 to contain the cosine of

the phase (as opposed to just sign() 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(). CP violated:cos' = Ref g=j j.

### BLOCK IMMINPAR

4 :CP conserved:n/a. CP violated:sin ' = Im f g=j j.

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

When CP symmetry is broken, quantum corrections cause mixing between the CPeven and CP-odd Higgs states. Writing the neutral scalar interaction eigenstates as  $^{0}$  $\overline{2}(\text{RefH}_{1}^{0}\text{g}; \text{RefH}_{2}^{0}\text{g}; \text{Im fH}_{1}^{0}\text{g}; \text{Im fH}_{2}^{0}\text{g})^{T}$  we dene the 3 4 mixing matrix S (blocks CVHMIX and IMCVHMIX) by

$${}^{0^{\mathrm{T}}}\mathrm{M} {}^{2}{}_{0} {}^{0} = {}^{0^{\mathrm{T}}}\mathrm{S}^{\mathrm{T}} \mathrm{S} \mathrm{M} {}^{2}{}_{0}\mathrm{S}^{\mathrm{Y}} \mathrm{S} {}^{0}{}_{0} \mathrm{I}_{\{\mathrm{Z}_{-}\}} \mathrm{I}_{\{\mathrm{Z}_{-}\}} \mathrm{I}_{\{\mathrm{Z}_{-}\}} \mathrm{I}_{\{\mathrm{Z}_{-}\}} \mathrm{I}_{\{\mathrm{Z}_{-}\}} \mathrm{I}_{0} \mathrm{I}_{\{\mathrm{Z}_{-}\}} \mathrm{I}_{0} \mathrm{I}_{\{\mathrm{Z}_{-}\}} \mathrm{I}_{0} \mathrm{I}_{\{\mathrm{Z}_{-}\}} \mathrm{I}_{0} \mathrm{I}_{\{\mathrm{Z}_{-}\}} \mathrm{I}_{0} \mathrm{I}_{\mathrm{Z}} \mathrm{I}_{0} \mathrm{I}_{0} \mathrm{I}_{\mathrm{Z}} \mathrm{I}_{0} \mathrm{I}$$

where  $(h_1^0; h_2^0; h_3^0)^T$  are the mass eigenstates; these states are numbered sequentially by the PDG codes (25,35,36), regardless of avour 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 com parison, in the literature, the projecting-out of the G oldstone boson is often done as a separate step, by rst perform ing a rotation by the angle . (This is, for instance, the prescription followed by CP super H [13]). In such an approach, our matrix S would be decom posed as:

$$S^{0} = {}^{0}_{e} O_{3 3} {}^{1}_{o} {}^{0}_{A} {}^{1}_{e} {}^{0}_{B} {}^{0}_{A} {}^{0}_{A} {}^{0}_{B} {}^{0}_{A} {}^{$$

where  $O_{3}_{3}$  gives the decomposition of the three physical mass eigenstates in terms of the intermediate basis  $\sim^{0} = (2RefH_{1}^{0}g; 2RefH_{2}^{0}g; A_{tree}^{0})^{T}$ , with  $A_{tree}^{0}$  denoting the tree-level MSSM non-Goldstone pseudoscalar mass eigenstate. Note that a simple rotation by

su ces 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 as part of the rst step. In this case, our matrix S would be decom posed as:

$$S^{0} = {}^{0}_{e} R_{3} {}^{0}_{a} {}^{0}_{e} {}^{0}_{a} {}^{0}_{e} {}^{0}_{a} {}^{0}$$

with de ned as them ixing angle in the CP-even H iggs sector at tree-level and R<sub>3</sub> giving the decomposition of the three physical mass eigenstates in terms of the intermediate basis  $^{0} = (h^{0}; H^{0}; A^{0})_{tree}^{T}$ , that is in terms of the the tree-level mass eigenstates. In order to translate between S and R<sub>3</sub>, the tree-level angle would thus also be needed. This should be given in the SLHA1 output BLOCK ALPHA:

### BLOCK ALPHA

CP conserved: ; precise de nition up to spectrum calculator, see SLHA1. CP violated:  $_{tree}$ . M ust 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 realmatrices. One or more mass eigenvalues may then have an apparent negative sign, which can be removed by a phase transformation on  $\sim_i$  as explained in SLHA1 [1]. When going to CPV, the reason for introducing the negative mass convention in the rst place, namely maintaining the mixing matrices strictly real, disappears. We therefore here take all masses real and positive, with N, U, and V com plex. This does lead to a nom inal 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 unam biguously which convention to follow.

# 5 The Next-to-M in im al Supersymmetric SM

The rst question to be addressed in de ning universal conventions for the next-to-m inim al supersymmetric standard model is just what eld content and which couplings this name should apply to. The eld content is already fairly well agreed upon; we shall here de ne the next-to-m inimal case as having exactly the eld content of the M SSM with the addition of one gauge-singlet chiral super eld. As to couplings and parameterisations, several de nitions exist in the literature (for a recent review see, e.g., the CPN SH report [45]). R ather 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 di erent com binations of couplings to zero. For the time being, however, we do specialise to the SLHA1-like case without CP violation, R-parity violation, or avour violation. Below, we shall use the acronym NM SSM for this class of m odels, but we emphasise that we understand it to relate to eld content only, and not to the presence or absence of speci c couplings.

### 5.1 Conventions

Wewrite them ost general CP conserving NM SSM superpotential as (extending the notation of SLHA1):

$$W_{NMSSM} = W_{MSSM}$$
 ab  $SH_1^{a}H_2^{b} + \frac{1}{3}S^3 + \frac{1}{2}^{0}S^2 + {}_{F}S$ ; (58)

where  $W_{MSSM}$  is the MSSM superpotential, eq. (2). A non-zero in combination with a VEV hSi of the singlet generates a contribution to the elective term  $_{e} = hSi + ,$ where the MSSM term is normally assumed to be zero in NMSSM constructions, yielding  $_{e} = hSi$ . The sign of the term in eq. (58) coincides with the one in [16,37] where the Higgs doublet super elds appear in opposite order. The remaining terms represent a general cubic potential for the singlet; is dimensionless, <sup>0</sup> has dimension of mass<sup>5</sup>, and  $_{F}$  has dimension of mass squared. The soft SUSY-breaking terms relevant to the NMSSM are

$$V_{\text{soft}} = V_{2M SSM} + V_{3M SSM} + m_{S}^{2} \mathcal{F}^{2} \mathcal{F} + (a_{ab} A SH_{1}^{a}H_{2}^{b} + \frac{1}{3} A S^{3} + \frac{1}{2}m_{S}^{02}S^{2} + SS + h\epsilon;);$$
(59)

where  $V_{iM SSM}$  are the MSSM soft terms de ned in eqs. (3) and (4), and we have introduced the notation  $m_S^{(2)} = B^{(0)}$ .

At tree level, there are thus 15 parameters (in addition to  $m_z$  which was the sum of the squared H iggs VEVs) that are relevant for the H iggs sector of the R-parity and CP-conserving NM SSM :

$$\tan ; ; m_{H_1}^2; m_{H_2}^2; m_3^2; ; ; A ; A ; ^0; m_S^{02}; F ; S; hSi; m_S^2:$$
(60)

The minim isation of the elective potential in poses 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 \sw itched o ". However, since  $= m_3^2 = {}^0 = m_S^{02} = {}_F = {}_S = 0$  in the majority of phenom enological constructions, for convenience we also allow for a six-parameter speci cation in terms of the reduced parameter list:

$$\tan ; m_{H_1}^2; m_{H_2}^2; ; ; A ; A ; hSi; m_S^2 :$$
(61)

 $<sup>^{5}</sup>$ N ote that the factors 1=2 in front of the  $^{0}$  and m  $^{0}_{s}$  term s in eqs. (58) and (59), respectively, correct and supersede the published version of this paper.

To sum marise, 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,  $m_3^2$ ,  $^0$ ,  $m_S^2$ ,  $_F$ , and  $_F$ , will be assumed to be zero; in both cases the 3 unspecied parameters (as, e.g.,  $m_{H_1}^2$ ,  $m_{H_2}^2$ , and  $m_S^2$ ) are assumed to be determined by the minimization of the elective potential.

# 5.2 Input/Output B locks

Firstly, as described above in section 3, BLOCK MODSEL should contain the switch 3 with value 1, corresponding to the choice of the NM SSM 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 should either be given in MINPAR entry 3 (default) or EXTPAR entry 25 (user-de ned input scale), as in SLHA1. If 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  $m_3^2 = (\cos \sin \beta)$ , 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 de nition in terms of  $m_3^2$  and cos sin unchanged, we maintain an econom ical and straightforward correspondence between the two cases.

Further, new entries in BLOCK EXTPAR have been de ned for the NM SSM speci c input param eters, as follows. As in the SLHA1, these param eters are all given at the common scale M <sub>input</sub>, 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 specic to the NM SSM (in addition to the entries de ned in section 2)

- 61 : (M<sub>input</sub>). Superpotential trilinear Higgs SH<sub>2</sub>H<sub>1</sub> coupling.
- 62 : (M input). Superpotential cubic S coupling.
- 63 : A (M  $_{input}$ ). Soft trilinear H iggs SH  $_2$ H  $_1$  coupling.
- 64 : A (M input). Soft cubic S coupling.
- 65 : hSi(M<sub>input</sub>). Vacuum expectation value of the singlet (scaled by ).
- 66 : <sub>F</sub> (M input). Superpotential linear S coupling.
- 67 : <sub>S</sub> (M input). Soft linear S coupling.
- 68 : <sup>0</sup>(M<sub>input</sub>). Superpotential quadratic S coupling.
- 69 :  $m_{S}^{(2)}$  (M<sub>input</sub>). Soft quadratic S coupling (som et in es denoted  ${}^{0}B^{0}$ ).
- 70 :  $m_{\rm S}^2$  (M input). Soft singlet m ass squared.

Im portant note: only 12 of the param eters listed in eq. (60) should be given as input at any one time (including explicit zeroes for param eters desired \sw itched o "), the remaining ones being determ ined by the minim isation of the elective potential. Which combinations to accept is left up to the individual spectrum calculator programs. A lternatively, for minim alm odels, 6 param eters 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 parameter and corresponding soft term) are maintained, which allows, in principle, for non-zero values for both and hSi. The reason for choosing hSi rather than hSi as input parameter 65 is that it allows more easily to recover the MSSM limit , ! 0, hSi! 1 with hSi xed.

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

#### BLOCK NMSSMRUN Q=...

O utput parameters specic to the NM SSM, given in the  $\overline{DR}$  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 specic scale. See corresponding entries in EXTPAR above for de nitions.

1	: $(Q)^{DR}$ .
2	: (Q) $\overline{P^R}$ .
3	: A (Q) <sup><math>\overline{DR}</math></sup> .
4	: A (Q) <sup><math>DR</math></sup> .
5	: $hSi(Q)^{\overline{DR}}$ .
6	: $_{\rm F}$ (Q) <sup>DR</sup> .
7	: $_{\rm S}$ (Q) <sup>DR</sup> .
8	: ${}^{0}(Q)^{\overline{DR}}$ .
9	: m $_{\rm S}^{\rm O2}$ (Q ) $\overline{^{\rm DR}}$ .
10	: $m_{\rm S}^2$ (Q) <sup>DR</sup> .

### 5.3 Particle M ixing

In the CP-conserving NM SSM, the CP-even interaction eigenstates are  $\begin{bmatrix} p & n \\ 2R & e \end{bmatrix}^n (H_1^0; H_2^0; S)^T$ . We denot the orthogonal 3 mixing matrix S (block NMHMIX) by

$${}^{0T}M {}^{2}{}_{0} {}^{0} = {}^{0T}S^{T}S^{T}SM {}^{2}{}_{0}S^{T}S^{0} \\ | - \{z_{-}\} | - \{z_{-}\}$$

where  ${}^{0}$  (h<sub>1</sub><sup>0</sup>; h<sub>2</sub><sup>0</sup>; h<sub>3</sub><sup>0</sup>) are the m ass eigenstates ordered in m ass. These states are num bered sequentially by the PDG codes (25, 35, 45). The form at of BLOCK NMHMIX is the same as for the m ixing m atrices in SLHA1.

In the MSSM limit (, ! 0, and parameters such that  $h_3^0$  RefSg) the elements of the rst 2 sub-matrix of S<sub>ii</sub> are related to the MSSM angle as

In the CP-odd sector the interaction eigenstates are  ${}^{0} = {}^{p} - {}^{n} (H_{1}^{0}; H_{2}^{0}; S)^{T}$ . We denothe 2 3 m ixing matrix P (block NMAMIX) by

$${}^{\text{OT}} M {}^{2} {}_{0} {}^{0} = {}^{\text{OT}} P^{\text{T}} P M {}^{2} {}_{0} P^{\text{T}} P^{\text{O}} \\ | - \{z_{-}\} | - \{z$$

where  $^{0}$  (A<sup>0</sup><sub>1</sub>;A<sup>0</sup><sub>2</sub>) are the mass eigenstates ordered in mass. These states are num bered sequentially by the PDG codes (36,46). The G oldstone boson G<sup>0</sup> (the \3rd com ponent") 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 NM SSM requires a change in the de nition of the 4 4 neutralino m ixing m atrix N to a 5 5 m atrix. The Lagrangian contains the (sym m etric) neutralino m ass m atrix as

$$L_{\nu^{0}}^{\text{mass}} = \frac{1}{2} \sim^{0T} M_{\nu^{0}} \sim^{0} + h \mathfrak{x};$$
 (64)

in the basis of  $2\{\text{com ponent spinors}^{\sim 0} = (iB; iw^3; H_1; H_2; s)^T$ . We de ne the unitary 5 5 neutralino mixing matrix N (block NMNMIX), such that:

$$\frac{1}{2} \sim^{0T} M \sim_{0} \sim^{0} = \frac{1}{2} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} N M M | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} N M | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{T} | \underbrace{- \left\{ z \atop z \\ - \right\}}^{$$

where the 5 (2(com ponent) neutralinos  $\sim_i$  are dened such that the absolute value of their masses increase with i. As in SLHA1, our convention is that N be a realmatrix. One or more mass eigenvalues may then have an apparent negative sign, which can be removed by a phase transformation on  $\sim_i$ . 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 M SSM spectrum and coupling information in one form or another. This had several advantages: there was a high motivation from program authors to produce and in plem ent the accord accurately and quickly, and perhaps m ore importantly, the SLHA1 was tested \in anger" in diverse situations as it was being written.

We nd ourselves in a slightly di erent situation in terms of the SLHA2. There are currently few programs that utilize information in any of the NMSSM or CP-violating, R-parity violating, or non-trivial avour violating MSSM scenarios. Thus we do not have the bene t of comprehensive simultaneous testing of the proposed accord and the strong motivation that was present for implementation and writing of the original one. W hat we do have are the lessons learned in connection with the SLHA1 itself, and also several almost-nished codes which are now awaiting the nalisation of SLHA2 in order to publish their rst o cial 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 agreem ents reached within this paper constitute a practical solution that will prove useful for SUSY particle phenom enology in the future.

# A cknow ledgem ents

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# A PDG Codes and Extensions

Scalar Q uarks

The existing PDG nom enclature for (s)particle names is based on the limit of the MSSM in which CP, R-parity, and avour are conserved. Several of the mass eigenstates are therefore labeled to indicate de nite R, CP, and/or avour 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 avour violation, R-parity violation, CP violation, and the NM SSM. In the tables below, we sum marise the PDG numbers and suggested labels relevant to each distinct scenario, for squarks (Tab.2), charged colour-singlet ferm ions (Tab.3), neutral colour-singlet ferm ions (Tab.4), charged colour-singlet scalars (Tab.5), and neutral colour-singlet scalars (Tab.6), respectively. Note that these extensions are not o cially endorsed by the PDG at this tim e. Codes for other particles can be found in [52, dp. 33].

								-
FLV	No	Yes	No	Νο	Yes	Yes	Z	
RPV	No	No	Yes	No	Yes	No	S M	
CPV	Νo	Νo	Νo	Yes	Νo	Yes	SM	
1000001	$\widetilde{d_{L}}$	đĩ	$\widetilde{d_1}$	dĭ	đĩ	đĩ	đĩ	
1000002	$\mathfrak{B}_{\mathrm{L}}$	₿1	₿1	$\mathfrak{A}_{\mathrm{L}}$	₿1	₿1	$\mathtt{t}_{\mathrm{L}}$	
1000003	$\mathbf{S}_{\mathrm{L}}$	đ <sub>2</sub>	$\tilde{d}_2$	$\mathbf{S}_{\mathrm{L}}$	đ <sub>2</sub>	đ <sub>2</sub>	$S_{\rm L}$	
1000004	$c_{\rm L}$	₽2	₿2	CL	₽2	₽2	CL	
1000005	$\tilde{D}_{l}$	đ <sub>3</sub>	đ <sub>3</sub>	$\tilde{b}_1$	đ <sub>3</sub>	đ <sub>3</sub>	$\tilde{D}_{l}$	
1000006	ť,	₿3	₿3	ť	₿3	₿3	ť	
2000001	$\widetilde{d_{\mathbb{R}}}$	đĩ <sub>4</sub>	đ <sub>4</sub>	$\widetilde{d_{\mathrm{R}}}$	đĩ <sub>4</sub>	đĩ <sub>4</sub>	$\widetilde{d}_{\mathbb{R}}$	
2000002	₽R	<b>t</b> 4	<b>t</b> 4	₽R	<b>t</b> 4	<b>t</b> 4	₿ ₽	
2000003	$\mathbf{S}_{\mathrm{R}}$	$\widetilde{d}_5$	$\tilde{d}_5$	$\mathbf{S}_{\mathrm{R}}$	$\widetilde{d_5}$	$\widetilde{d}_5$	$\mathbf{S}_{\mathrm{R}}$	
2000004	$c_{R}$	₿5	₿5	$c_{R}$	₿5	₿5	C <sub>R</sub>	
2000005	$\tilde{D}_2$	$\widetilde{d_6}$	$\widetilde{d_6}$	$\tilde{D}_2$	$\widetilde{d_6}$	$\widetilde{d_6}$	$\tilde{b}_2$	
2000006	t	the state	tt <sub>6</sub>	t	the state	the state	to	

Table 2: Particle codes and corresponding labels for squarks. The labels in the rst column correspond to the current PDG nom enclature.

Charged Leptons and Charginos

FLV	No	Yes	Νο	No	Yes	Yes	NI
RPV	No	No	Yes	Νο	Yes	Νo	S S S
CPV	Νο	No	ΝO	Yes	No	Yes	SM
11	е	е	e <sub>1</sub>	е	e <sub>1</sub>	е	е
					-		
13			e <sub>2</sub>		e <sub>2</sub>		
13 15			e <sub>2</sub> e <sub>3</sub>		e <sub>2</sub> e <sub>3</sub>		
13 15 1000024	~1	~1	$e_2$ $e_3$ $e_4^+$	~1+	$e_2$ $e_3$ $e_4^+$	~_1^+	~_1^+

Table 3: Particle codes and corresponding labels for charged colour-singlet ferm ions. The labels in the rst column correspond to the current PDG nom enclature. Note that, for historical reasons, codes 11, 13, and 15 pertain to negatively charged elds while codes 1000024 and 1000037 pertain to the opposite charge.

Ne	Neutrinos and Neutralinos										
	FLV	No	Yes	No	No	Yes	Yes	Z			
	RPV	Νo	No	Yes	No	Yes	Νο	M SS			
	CPV	No	No	No	Yes	No	Yes	M			
	12	е	1	1	e	1	1	е			
	14		2	2		2	2				
	16		3	3		3	3				
	1000022	$\sim_{1}^{0}$	~10	4	$\sim_{1}^{0}$	4	~_1	$\sim^{0}_{1}$			
	1000023	$\sim^{0}_{2}$	$\sim^{0}_{2}$	5	$\sim^{0}_{2}$	5	$\sim^{0}_{2}$	$\sim^{0}_{2}$			
	1000025	~_3	~_3	6	~30	6	~30	~_3^0			
	1000035	$\sim^{0}_{4}$	$\sim^{0}_{4}$	7	$\sim^{0}_{4}$	7	$\sim^{0}_{4}$	$\sim^{0}_{4}$			
	1000045	—	_	_	—	—	—	~_5			

Table 4: Particle codes and corresponding labels for neutral colour-singlet ferm ions. The labels in the rst column correspond to the current PDG nom enclature.

# Charged Higgs Boson and Charged Scalar Leptons

FLV	Νο	Yes	Νo	Νο	Yes	Yes	NN
RPV	Νο	No	Yes	Νο	Yes	Νο	N N
CPV	Νο	NO	Νο	Yes	No	Yes	3M
37	H +	H +	$h_1^+$	H +	$h_1^+$	Н +	H +
1000011	$e_{\rm L}^+$	$e_1^+$	$h_2^+$	$e_{\rm L}^+$	$h_2^+$	$e_1^+$	$e_{\rm L}^+$
1000013	$\sim^+_{L}$	$e_2^+$	$h_3^+$	$\sim^+_{\rm L}$	$h_3^+$	$e_2^+$	$\sim^+_{L}$
1000015	~1	$e_3^+$	$h_4^+$	~1	$h_4^+$	$e_3^+$	~1
2000011	$e_{R}^{+}$	$e_4^+$	$h_5^+$	$e_{R}^{+}$	$h_5^+$	$e_4^+$	$e_{R}^{+}$
2000013	$\sim^+_{\mathbb{R}}$	$e_5^+$	$h_6^+$	$\sim^+_R$	$h_6^+$	$e_5^+$	$\sim^+_R$
2000015	~2+	$e_6^+$	$h_7^+$	~2+	$h_7^+$	$e_6^+$	~2+

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

Neutral Higgs Bosons and Scalar Neutrinos

FLV	Νο	Yes	No	No	Yes	Yes	ΝM
RPV	ΝΟ	ΝO	Yes	Νο	Yes	ΝΟ	N N
CPV	ΝΟ	No	No	Yes	NO	Yes	M
25	$h^0$	h <sup>0</sup>	$h_1^0$	$h_1^0$	$h_1^0$	$h_1^0$	$h_1^0$
35	H <sup>0</sup>	H <sup>0</sup>	$h_2^0$	$h_2^0$	$h_2^0$	$h_2^0$	$h_2^0$
36	A <sup>0</sup>	A <sup>0</sup>	A 1 0	$h_3^0$	A 1	$h_3^0$	A 1 0
45	-	-	-	_	-	_	$h_3^0$
46	-	-	_	_	-	-	$A_2^0$
1000012	~eL	~1 (~1s)	$h_3^0$	$\sim_{e_{L}}$	$h_3^0$	~1	~eL
1000014	~	~2 (~2S)	$h_4^0$	~	$h_4^0$	~2	~
1000016	~ _	~3 (~3S)	$h_5^0$	~ _	$h_5^0$	~3	~ _
1000017	-	(~ <sub>1A</sub> )	$A_2^0$	_	$A_2^0$	-	-
1000018	-	(~ <sub>2A</sub> )	A 3	_	A 3	-	-
1000019	-	(~ <sub>3A</sub> )	A 4	_	A 4	-	-

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

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