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SUSY Les Houches accord: interfacing SUSY spectrum calculators, decay packages, and event generators

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Abstract: An accord specifying a unique set of conventions for supersymmetric extensions of the Standard Model together with generic file structures for 1) supersymmetric model specifications and input parameters, 2) electroweak scale supersymmetric mass and coupling spectra, and 3) decay tables is presented, to provide a universal interface between spectrum calculation programs, decay packages, and high energy physics event generators.

Keywords: Supersymmetry Phenomenology, Supersymmetric Standard Model, Higgs Physics.

*See http://www.thep.lu.se/~zeiler/slha/ for updates and examples.

Contents

1. Introduction

An increasing number of advanced programs for the calculation of the supersymmetric (SUSY) mass and coupling spectrum are appearing [1]–[5] in step with the more and more refined approaches which are taken in the literature. Furthermore, these programs are often interfaced to specialized decay packages [4, 5] and [6]–[8], relic density calculations [9, 10], and (parton-level) event generators [11]–[18], in themselves fields with a proliferation of philosophies and, consequentially, programs.

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SUSY scenario $\longrightarrow$ Spectrum Calculator $\longrightarrow$ Decay Package $\longrightarrow$ Event Generator

Figure 1: Stages of the interface Accord. By SUSY scenario we not only intend specific SUSY-breaking mechanisms, such as supergravity (SUGRA), gauge mediated SUSY breaking (GMSB), etc., but also more general setups within the Minimal Supersymmetric Standard Model (MSSM).

At present, a small number of specialized interfaces exist between various codes. Such tailor-made interfaces are not easily generalized and are time-consuming to construct and test for each specific implementation. A universal interface would clearly be an advantage here.

However, since the codes involved are not all written in the same programming language, the question naturally arises how to make such an interface work across languages. At present, an inter-language linking solution does not seem to be feasible without introducing at least some dependence on platform (e.g. UNIX variant) and/or compiler. For details on these aspects, see e.g. [19].

At this point, we deem such an interface too fragile to be set loose among the particle physics community. Instead, we advocate a less elegant but more robust solution, exchanging information between FORTRAN and C(++) codes via three ASCII files, one for model input, one for model input plus spectrum output, and one for model input plus spectrum output plus decay information. The detailed structure of these files is described in the sections below. Briefly stated, the purpose of this Accord is thus the following:

1. To present a set of generic definitions for an input/output file structure which provides a universal framework for interfacing SUSY spectrum calculation programs.

2. To present a generic file structure for the transfer of decay information between decay calculation packages and event generators.

Note that different codes may have different implementations of how SUSY Les Houches Accord (SLHA) input/output is *technically* achieved. The details of how to 'switch on' SLHA input/output with a particular program should be described in the manual of that program and are not covered here.

1.1 Using the accord

To interface two or more calculations, the general procedure would be that the user prepares model input parameters together with a set of Standard Model parameters (to be used as low-scale boundary conditions for the spectrum calculation) in an ASCII file, complying with the standard defined in section 3.1 below. At present, only models with the particle spectrum of the MSSM, and with CP and R-parity conserved are included in this standard.

The user then runs a spectrum calculation program with these inputs to obtain the SUSY mass and coupling spectrum at the electroweak (EW) scale. The resulting spectrum is stored, together with a copy of the model input parameters (so that subsequent calculations may be performed consistently), in a new file. Standards for the spectrum file are defined in section 3.2.

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The user may now run some particular decay package to generate a list of decay modes and widths for selected particles, which the decay package saves to a third file, complying with the definitions in section 3.3. Again, a copy of the model input parameters as well as the complete spectrum information is included together with the decay information in this file.

Lastly, the user may instruct a (parton-level) event generator to read in all this information and start generating events. Of course, any of these intermediate steps may be skipped whenever the user does not wish to switch between programs across them, e.g. no decay information is required to be present in the file read by an event generator if the user wishes the event generator to calculate all decay widths itself.

If a general purpose event generator is used, the events will include parton showering and hadronization, whereas if a parton-level generator is used, the events may finally be passed to parton showering and hadronization programs using the already defined Les Houches Accord #1 [20].

2. Conventions

One aspect of supersymmetric calculations that has often given rise to confusion and consequent inconsistencies in the past is the multitude of ways in which the parameters can be, and are being, defined. Hoping to minimize both the extent and impact of such confusion, we have chosen to adopt one specific set of self-consistent conventions for the parameters appearing in this Accord. These conventions are described in the following subsections. As yet, we only consider R-parity and CP conserving scenarios, with the particle spectrum of the MSSM.

Compared to the widely used Gunion and Haber conventions and notation [21], our prescriptions show a few differences. These will be remarked upon in all places where they occur below, with parameters in the notations and conventions of [21] denoted with an explicit superscript: $^{\mathrm{GH}}$.

2.1 Standard model parameters

In general, the SUSY spectrum calculations impose low-scale boundary conditions on the renormalization group equation (RGE) flows to ensure that the theory gives correct predictions for low-energy observables. Thus, experimental measurements of masses and coupling constants at the electroweak scale enter as inputs to the spectrum calculators.

In this Accord, we choose a specific set of low-scale input parameters (block `SMINPUTS` below), letting the electroweak sector be fixed by

1. $\alpha_{\mathrm{em}}(m_Z)^{\overline{\mathrm{MS}}}$: the electromagnetic coupling at the Z pole in the $\overline{\mathrm{MS}}$ scheme with 5 active flavours (see e.g. [22][1]). This coupling is connected to the classical fine structure constant, $\alpha = 1/137.0359895(61)$ [22] by a relation of the form:

$$\alpha_{\mathrm{em}}(m_Z)^{\overline{\mathrm{MS}}} = \frac{\alpha}{1 - \Delta\alpha(m_Z)^{\overline{\mathrm{MS}}}}\,, \tag{2.1}$$

   where $\Delta\alpha(m_Z)^{\overline{\mathrm{MS}}}$ contains the quantum corrections involved in going from the classical limit to the $\overline{\mathrm{MS}}$ value at the scale m_Z.

[1] Note that [22] uses the notation $\widehat{\alpha}(M_Z)$ for this parameter.

2. G_F: the Fermi constant determined from muon decay.

3. m_Z: the Z boson pole mass.

All other electroweak parameters, such as m_W and $\sin^2\theta_W$, should be derived from these inputs if needed.

The strong interaction strength is fixed by $\alpha_s(m_Z)^{\overline{\rm MS}}$ (the five-flavour strong coupling at the scale m_Z in the $\overline{\rm MS}$ scheme), and the third generation Yukawa couplings are obtained from the top and tau pole masses, and from $m_b(m_b)^{\overline{\rm MS}}$, see [22]. The reason we take the running b mass in the $\overline{\rm MS}$ scheme rather than a pole mass definition is that the latter suffers from infra-red sensitivity problems, hence the former is the quantity which can be most accurately related to experimental measurements. If required, relations between running and pole quark masses may be found in [23, 24].

It is also important to note that all presently available experimental determinations of e.g. α_s and the running b mass are based on assuming the Standard Model as the underlying theory, for natural reasons. When extending the field content of the SM to that of the MSSM, the *same* measured results would be obtained for *different* values of these quantities, due to the different underlying field content present in the MSSM. However, since these values are not known before the spectrum has been determined, all parameters contained in block `SMINPUTS` should be the 'ordinary' ones obtained from SM fits, i.e. with no SUSY corrections included. The spectrum calculators themselves are then assumed to convert these parameters into ones appropriate to an MSSM framework.

Finally, while we assume $\overline{\rm MS}$ running quantities with the SM as the underlying theory as input, all running parameters in the *output* of the spectrum calculations are defined in the modified dimensional reduction ($\overline{\rm DR}$) scheme [25, 26, 27], with different spectrum calculators possibly using different prescriptions for the underlying effective field content. More on this in section 2.5.

2.2 Supersymmetric parameters

The chiral superfields of the MSSM have the following $\mathrm{SU}(3)_C \otimes \mathrm{SU}(2)_L \otimes \mathrm{U}(1)_Y$ quantum numbers

$$\begin{aligned} &L:\left(1,2,-\frac{1}{2}\right), \quad \bar{E}:(1,1,1), \qquad Q:\left(3,2,\frac{1}{6}\right), \quad \bar{U}:\left(\bar{3},1,-\frac{2}{3}\right), \\ &\bar{D}:\left(\bar{3},1,\frac{1}{3}\right), \quad H_1:\left(1,2,-\frac{1}{2}\right), \quad H_2:\left(1,2,\frac{1}{2}\right). \end{aligned} \tag{2.2}$$

Then, the superpotential (omitting RPV terms) is written as

$$W = \epsilon_{ab}\left[(Y_E)_{ij} H_1^a L_i^b \bar{E}_j + (Y_D)_{ij} H_1^a Q_i^b \bar{D}_j + (Y_U)_{ij} H_2^b Q_i^a \bar{U}_j - \mu H_1^a H_2^b\right]. \tag{2.3}$$

Throughout this section, we denote $\mathrm{SU}(2)_L$ 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 $\epsilon_{12} = \epsilon^{12} = 1$. Lastly, we will use t, b, τ to denote the $i = j = 3$ entries of mass or coupling matrices (top, bottom and tau).

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The Higgs vacuum expectation values (VEVs) are $\langle H_i^0 \rangle = v_i/\sqrt{2}$, and $\tan\beta = v_2/v_1$. We also use the notation $v = \sqrt{v_1^2 + v_2^2}$. Different choices of renormalization scheme and scale are possible for defining $\tan\beta$. For the input to the spectrum calculators, we adopt by default the commonly encountered definition

$$\tan\beta(m_Z)^{\overline{\rm DR}}, \tag{2.4}$$

i.e. the $\tan\beta$ appearing in block `MINPAR` below is defined as a $\overline{\rm DR}$ running parameter given at the scale m_Z. The optional extended input block `EXTPAR` allows the possibility of using an input definition at a different scale, $\tan\beta(M_{\rm input} \neq m_Z)^{\overline{\rm DR}}$. Lastly, the spectrum calculator may be instructed to write out one or several values of $\tan\beta(Q)^{\overline{\rm DR}}$ at various scales Q_i, see section 2.5 and block `HMIX` below.

The MSSM $\overline{\rm DR}$ gauge couplings (block `GAUGE` below) are: g' (hypercharge gauge coupling in Standard Model normalization), g ($\mathrm{SU}(2)_L$ gauge coupling) and g_3 (QCD gauge coupling).

Our Yukawa matrices, Y_E, Y_D, and Y_U, correspond exactly to $(f)^{\rm GH}$, $(f_1)^{\rm GH}$, and $(f_2)^{\rm GH}$, respectively, in the notation of [21]. For hypercharge, [21] uses $(y)^{\rm GH} \equiv 2Y$, and for the $\mathrm{SU}(2)_L$ singlet leptonic superfield the notation $(\hat{R})^{\rm GH} \equiv \bar{E}$. Finally, for the Higgs vacuum expectation values, we choose the convention in which $\langle H_i^0 \rangle = v_i/\sqrt{2} \equiv (v_i)^{\rm GH}$, so that $v^2 = (v_1^2 + v_2^2) = (246\ \mathrm{GeV})^2$, corresponding to $m_Z^2 = \frac{1}{4}(g'^2 + g^2)(v_1^2 + v_2^2)$, whereas [21] has $(v_1^2 + v_2^2)^{\rm GH} = (174\ \mathrm{GeV})^2$, with $m_Z^2 = \frac{1}{2}(g'^2 + g^2)(v_1^2 + v_2^2)^{\rm GH}$. Otherwise, conventions for the superpotential are identical between this article and [21].[2]

2.3 SUSY breaking parameters

We now tabulate the notation of the soft SUSY breaking parameters. The trilinear scalar interaction potential is

$$V_3 = \epsilon_{ab} \sum_{ij} \left[(T_E)_{ij} H_1^a \tilde{L}_{i_L}^b \tilde{e}_{j_R}^* + (T_D)_{ij} H_1^a \tilde{Q}_{i_L}^b \tilde{d}_{j_R}^* + (T_U)_{ij} H_2^b \tilde{Q}_{i_L}^a \tilde{u}_{j_R}^* \right] + \mathrm{h.c.}, \tag{2.5}$$

where fields with a tilde are the scalar components of the superfield with the identical capital letter. In the literature the T matrices are often decomposed as

$$\frac{T_{ij}}{Y_{ij}} = A_{ij}\,; \qquad (\text{no sum over } i,j)\,, \tag{2.6}$$

where Y are the Yukawa matrices and A the soft supersymmetry breaking trilinear couplings. See also blocks `YE`, `YD`, `YU`, `AE`, `AD`, and `AU` below.

The scalar bilinear SUSY breaking terms are contained in the potential

$$\begin{aligned} V_2 = {} & m_{H_1}^2 H_{1a}^{*} H_1^a + m_{H_2}^2 H_{2a}^{*} H_2^a + \tilde{Q}_{iLa}^{*} (m_{\tilde{Q}}^2)_{ij} \tilde{Q}_{jL}^a + \tilde{L}_{iLa}^{*} (m_{\tilde{L}}^2)_{ij} \tilde{L}_{jL}^a + \\ & + \tilde{u}_{iR} (m_{\tilde{u}}^2)_{ij} \tilde{u}_{jR}^* + \tilde{d}_{iR} (m_{\tilde{d}}^2)_{ij} \tilde{d}_{jR}^* + \tilde{e}_{iR} (m_{\tilde{e}}^2)_{ij} \tilde{e}_{jR}^* - (m_3^2 \epsilon_{ab} H_1^a H_2^b + \mathrm{h.c.})\,. \end{aligned} \tag{2.7}$$

[2] The sign of μ in the original Gunion and Haber article actually disagrees with ours, but that sign was subsequently changed in the erratum to that article, which we here include when giving reference to [21].

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Rather than using m_3^2 itself, below we use the more convenient parameter m_A^2, defined by:

$$m_A^2 = \frac{m_3^2}{\sin\beta\cos\beta}\,, \tag{2.8}$$

which is identical to the pseudoscalar Higgs mass at tree level in our conventions.

Writing the bino as $\tilde{b}$, the unbroken $\mathrm{SU}(2)_L$ gauginos as $\tilde{w}^{A=1,2,3}$, and the gluinos as $\tilde{g}^{X=1...8}$, the gaugino mass terms (appearing in blocks `EXTPAR` and `GAUGE` below) are contained in the lagrangian

$$\mathcal{L}_G = \frac{1}{2}\left(M_1\tilde{b}\tilde{b} + M_2\tilde{w}^A\tilde{w}^A + M_3\tilde{g}^X\tilde{g}^X\right) + \text{h.c.}. \tag{2.9}$$

For the soft trilinear breaking terms above, we use the same sign convention as [21], but with a different normalization and unit $(m_6A_i)^{\mathrm{GH}} \equiv A_i$. For the bilinear breaking terms, we differ only in notation; $(m_i)^{\mathrm{GH}} \equiv m_{H_i}$, $(m_{12})^{\mathrm{GH}} \equiv m_3$, $(M')^{\mathrm{GH}} \equiv M_1$, $(M)^{\mathrm{GH}} \equiv M_2$, $(\lambda')^{\mathrm{GH}} \equiv \tilde{b}$, and $(\lambda^A)^{\mathrm{GH}} \equiv \tilde{w}^A$. Below, it will also be useful to note that we use $\tilde{h}_1 \equiv (\psi^0_{H_1})^{\mathrm{GH}}$ and $\tilde{h}_2 \equiv (\psi^0_{H_2})^{\mathrm{GH}}$ for the higgsinos.

2.4 Mixing matrices

In the following, we describe in detail our conventions for neutralino, chargino, sfermion, and Higgs mixing. For purposes of cross-checking, we include in appendix C expressions for the tree-level mass matrices of neutralinos, charginos, and third generation sfermions, as they appear in the set of conventions adopted here.

More importantly, essentially all SUSY spectrum calculators on the market today work with mass matrices which include higher-order corrections. Consequentially, a formal dependence on the renormalization scheme and scale, and on the external momenta appearing in the corrections, enters the definition of the corresponding mixing matrices. Since, at the moment, no consensus exists on the most convenient definition to use here, the parameters appearing in blocks `NMIX`, `UMIX`, `VMIX`, `STOPMIX`, `SBOTMIX`, `STAUMIX`, and `ALPHA` below should be thought of as 'best choice' solutions, at the discretion of each spectrum calculator. For example, one program may output on-shell parameters (with the external momenta e.g. corresponding to specific particle masses) in these blocks while another may be using $\overline{\mathrm{DR}}$ definitions at certain 'characteristic' scales. For details on specific prescriptions, the manual of the particular spectrum calculator should be consulted.

Nonetheless, for obtaining loop-improved tree-level results, these parameters can normally be used as is. They can also be used for consistent cross section and decay width calculations at higher orders, but then the renormalization prescription employed by the spectrum calculator must match or be consistently matched to that of the intended higher order calculation.

Finally, different spectrum calculators may disagree on the overall sign of one or more rows in a mixing matrix, owing to different diagonalization algorithms. Such differences correspond to a flip of the sign of the eigenvectors in question and do not lead to inconsistencies. Only the relative sign between entries on the same row is physically significant, for processes with interfering amplitudes.

2.4.1 Neutralino mixing

The lagrangian contains the (symmetric) neutralino mass matrix as

$$\mathcal{L}^{\rm mass}_{\tilde{\chi}^0} = -\frac{1}{2}\tilde{\psi}^{0T}\mathcal{M}_{\tilde{\psi}^0}\tilde{\psi}^0 + \text{h.c.}\,, \tag{2.10}$$

in the basis of 2-component spinors $\tilde{\psi}^0 = (-i\tilde{b},\ -i\tilde{w}^3,\ \tilde{h}_1,\ \tilde{h}_2)^T$. We define the unitary 4 by 4 neutralino mixing matrix N (block `NMIX` below), such that:

$$-\frac{1}{2}\tilde{\psi}^{0T}\mathcal{M}_{\tilde{\psi}^0}\tilde{\psi}^0 = -\frac{1}{2}\underbrace{\tilde{\psi}^{0T}N^T}_{\tilde{\chi}^{0T}}\underbrace{N^*\mathcal{M}_{\tilde{\psi}^0}N^\dagger}_{\text{diag}(m_{\tilde{\chi}^0})}\underbrace{N\tilde{\psi}^0}_{\tilde{\chi}^0}\,, \tag{2.11}$$

where the (2-component) neutralinos $\tilde{\chi}^0_i$ are defined such that their absolute masses increase with increasing i. Generically, the resulting mixing matrix N may yield complex entries in the mass matrix, $\text{diag}(m_{\tilde{\chi}^0})_i = m_{\tilde{\chi}^0_i}e^{i\varphi_i}$. If so, we absorb the phase into the definition of the corresponding eigenvector, $\tilde{\chi}^0_i \to \tilde{\chi}^0_i e^{i\varphi_i/2}$, making the mass matrix strictly real:

$$\text{diag}(m_{\tilde{\chi}^0}) \equiv \left[N^*\mathcal{M}_{\tilde{\psi}^0}N^\dagger\right]_{ij} = m_{\tilde{\chi}^0_i}\delta_{ij}\,. \tag{2.12}$$

Note, however, that a special case occurs when CP violation is absent and one or more of the $m_{\tilde{\chi}^0_i}$ turn out to be negative. In this case, we allow for maintaining a strictly real mixing matrix N, instead writing the *signed* mass eigenvalues in the output. Thus, a negative $m_{\tilde{\chi}^0_i}$ in the output implies that the physical field is obtained by the rotation $\tilde{\chi}^0_i \to \tilde{\chi}^0_i e^{i\pi_i/2}$.

Our conventions on this point are slightly different from those used in [21] where the same lagrangian appears but where the diagonalizing matrix $(N)^{\rm GH}$ is chosen such that the elements of the diagonal mass matrix, $(N_D)^{\rm GH}$ (the mass matrix, in the notation of [21]), are *always* real and non-negative, i.e. $(N_D)^{\rm GH} \equiv |\text{diag}(m_{\tilde{\chi}^0})|$, at the price of $(N)^{\rm GH}$ generally being complex-valued also in the absence of CP violation.

2.4.2 Chargino mixing

We make the identification $\tilde{w}^{\pm} = (\tilde{w}^1 \mp i\tilde{w}^2)/\sqrt{2}$ for the charged winos and $\tilde{h}_1^-, \tilde{h}_2^+$ for the charged higgsinos. The lagrangian contains the chargino mass matrix as

$$\mathcal{L}^{\rm mass}_{\tilde{\chi}^+} = -\frac{1}{2}\tilde{\psi}^{-T}\mathcal{M}_{\tilde{\psi}^+}\tilde{\psi}^+ + \text{h.c.}\,, \tag{2.13}$$

in the basis of 2-component spinors $\tilde{\psi}^+ = (-i\tilde{w}^+,\ \tilde{h}_2^+)^T$, $\tilde{\psi}^- = (-i\tilde{w}^-,\ \tilde{h}_1^-)^T$. We define the unitary 2 by 2 chargino mixing matrices, U and V (blocks `UMIX` and `VMIX` below), such that:

$$-\frac{1}{2}\tilde{\psi}^{-T}\mathcal{M}_{\tilde{\psi}^+}\tilde{\psi}^+ = -\frac{1}{2}\underbrace{\tilde{\psi}^{-T}U^T}_{\tilde{\chi}^{-T}}\underbrace{U^*\mathcal{M}_{\tilde{\psi}^+}V^\dagger}_{\text{diag}(m_{\tilde{\chi}^+})}\underbrace{V\tilde{\psi}^+}_{\tilde{\chi}^+}\,, \tag{2.14}$$

where the (2-component) charginos $\tilde{\chi}^+_i$ are defined such that their absolute masses increase with increasing i and such that the mass matrix, $m_{\tilde{\chi}^+_i}$, is strictly real:

$$\text{diag}(m_{\tilde{\chi}^+}) \equiv \left[U\mathcal{M}_{\tilde{\psi}^+}V^T\right]_{ij} = m_{\tilde{\chi}^+_i}\delta_{ij}\,. \tag{2.15}$$

Again, in the absence of CP violation U and V can be chosen strictly real. This choice, as compared to that adopted in [21], shows similar differences as for neutralino mixing.

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2.4.3 Sfermion mixing

At present, we restrict our attention to left-right mixing in the third generation sfermion sector only. The convention we use is, for the interaction eigenstates, that $\tilde{f}_L$ and $\tilde{f}_R$ refer to the $\mathrm{SU}(2)_L$ doublet and singlet superpartners of the fermion $f \in \{t, b, \tau\}$, respectively, and, for the mass eigenstates, that $\tilde{f}_1$ and $\tilde{f}_2$ refer to the lighter and heavier mass eigenstates, respectively. With this choice of basis, the spectrum output (blocks `STOPMIX`, `SBOTMIX`, and `STAUMIX` below) should contain the elements of the following matrix:

$$\begin{pmatrix} \tilde{f}_1 \\ \tilde{f}_2 \end{pmatrix} = \begin{bmatrix} F_{11} & F_{12} \\ F_{21} & F_{22} \end{bmatrix} \begin{pmatrix} \tilde{f}_L \\ \tilde{f}_R \end{pmatrix} , \tag{2.16}$$

whose determinant should be ± 1. We here deliberately avoid notation involving mixing angles, to prevent misunderstandings which could arise due to the different conventions for these angles used in the literature. The mixing matrix elements themselves are unambiguous, apart from the overall signs of rows in the matrices, see above. Note that in [21], the mass eigenstates are *not* necessarily ordered in mass.

2.4.4 Higgs mixing

The conventions for μ, v_1, v_2, v, $\tan\beta$, and m_A^2 were defined above in sections 2.2 and 2.3. The angle α (block `ALPHA`) we define by the rotation matrix:

$$\begin{pmatrix} H^0 \\ h^0 \end{pmatrix} = \begin{bmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{bmatrix} \begin{pmatrix} H_1^0 \\ H_2^0 \end{pmatrix} , \tag{2.17}$$

where H_1^0 and H_2^0 are the CP-even neutral Higgs scalar interaction eigenstates, and h^0 and H^0 the corresponding mass eigenstates (including any higher order corrections present in the spectrum calculation), with $m_{h^0} < m_{H^0}$ by definition. This convention is identical to that of [21].

2.5 Running couplings

In contrast to the effective definitions adopted above for the mixing matrices, we choose to define the parameters which appear in the output blocks `HMIX`, `GAUGE`, `MSOFT`, `AU`, `AD`, `AE`, `YU`, `YD`, and `YE`, as $\overline{\mathrm{DR}}$ running parameters, computed at one or more user-specifiable scales Q_i.

That the $\overline{\mathrm{DR}}$ scheme is adopted for the output of running parameters is simply due to the fact that this scheme substantially simplifies many SUSY calculations (and hence all spectrum calculators use it). However, it does have drawbacks which for some applications are serious. For example, the $\overline{\mathrm{DR}}$ scheme violates mass factorization as used in QCD calculations [28]. For consistent calculation beyond tree-level of processes relying on this factorization, e.g. cross sections at hadron colliders, the $\overline{\mathrm{MS}}$ scheme is the only reasonable choice. At the present level of calculational precision, this is fortunately not an obstacle, since at one loop, a set of parameters calculated in either of the two schemes can be consistently translated into the other [29]. Explicit prescriptions for how to do this are included in appendix B.

Note, however, that different spectrum calculators use different choices for the underlying particle content of the effective theory. The programs SOFTSUSY (v. 1.8), SPHENO (v. 2.1), and SUSPECT (v. 2.2) use the full MSSM spectrum at all scales, whereas in ISAJET (v. 7.69) an alternative prescription is followed, with different particles integrated out of the effective theory at different scales. Whatever the case, these couplings should *not* be used 'as is' in calculations performed in another renormalization scheme or where a different effective field content is assumed. Thus, unfortunately, ensuring consistency of the field content assumed in the effective theory must still be done on a per program basis, though information on the prescription used by a particular spectrum calculator may conveniently be given in block `SPINFO`, when running parameters are provided.

Technically, we treat running parameters in the output in the following manner: since programs outside the spectrum calculation will not normally be able to run parameters with the full spectrum included, or at least less precisely than the spectrum calculators themselves, an option is included in block `MODSEL` below to instruct the spectrum calculator to write out values for each running parameter at a user-defined number of logarithmically spaced scales, i.e. to give output on running parameters at a grid of scales, Q_i, where the lowest point in the grid will normally be $Q_{\text{min}} = m_Z$ and the highest point is user-specifiable. A complementary possibility is to let the spectrum calculator give output for the running couplings at one or more scales equal to specific sparticle masses in the spectrum. This option is also invoked using block `MODSEL`.

Warning: please note that these options are merely intended to *allow* information on running parameters to be passed, if desired. Many of the codes involved will at present not actually make use of this information, even if provided with it.

3. Definitions of the interfaces

In this section, the SUSY Les Houches Accord input and output files are described. We here concentrate on the technical structure only. The reader should consult section 2 for parameter definitions and convention choices.

The following general structure for the SLHA files is proposed:

- All quantities with dimensions of energy (mass) are implicitly understood to be in GeV (GeV/c^2).
- Particles are identified by their PDG particle codes. See appendix A for lists of these, relevant to the MSSM. For a complete listing, see [22, chp. 33].
- The first character of every line is reserved for control and comment statements. Data lines should have the first character empty.
- In general, formatted output should be used for write-out, to avoid "messy-looking" files, while a free format should be used on read-in, to avoid misalignment etc. leading to program crashes.
- Read-in should be performed in a case-insensitive way, again to increase stability.

- The general format for all real numbers is the FORTRAN format E16.8.[3] This large number of digits is used to avoid any possible numerical precision issue, and since it is no more difficult for e.g. the spectrum calculator to write out such a number than a shorter version. For typed input, it merely means that at least 16 spaces are reserved for the number, but e.g. the number `123.456` may be typed in "as is". See also the example files in appendix D.

- A "`#`" mark anywhere means that the rest of the line is intended as a comment to be ignored by the reading program.

- All input and output is divided into sections in the form of named "blocks". A "`BLOCK xxxx`" (with the "`B`" being the first character on the line) marks the beginning of entries belonging to the block named "`xxxx`". E.g. "`BLOCK MASS`" marks that all following lines until the next "`BLOCK`" (or "`DECAY`") statement contain mass values, to be read in a specific format, intrinsic to the `MASS` block. The order of blocks is arbitrary, except that input blocks should always come before output blocks.

- Reading programs should skip over blocks that are not recognized, issuing a warning rather than crashing. Thereby, stability is increased and private blocks can be constructed, for instance `BLOCK MYCODE` could contain some parameters that only the program MyCode (or a special hack of it) needs, but which are not recognized universally.

- A line with a blank first character is a data statement, to be interpreted according to what data the current block contains. Comments and/or descriptions added after the data values, e.g. "` ...# comment`", should always be added, to increase readability of the file for human readers.

- Use of the 'tab' character is dangerous and should be avoided.

Finally, program authors are advised to check that any parameter relations they assume in their codes (implicit or explicit) are either obeyed by the parameters in the files or disabled. As a specific example, take a code that normally would use e.g. the tree-level expression for the stop mixing matrix to compute A_t, given the stop mixing angle (together with a given set of other input parameters). This relation should *not* be used when reading in an SLHA spectrum; there may be (higher-order) contributions included in the spectrum calculation which cannot be absorbed into redefinitions of the tree-level couplings. The reading program should in this case read both the mixing matrix *and* A_t directly from the spectrum file, without assuming any a priori relation between them.

3.1 The model input file

Here, the user sets up his or her calculation, with low-energy boundary conditions and SUSY model parameters. If some or all of the low-energy boundary conditions are not

[3] E16.8: a 16-character wide real number in scientific notation, whereof 8 digits are decimals, e.g. "`-0.12345678E+000`".

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supplied, the spectrum calculator should use its own defaults for those parameters, passing them on to the output file, so that the complete set of parameters that has been used for the calculation is available in the spectrum output. If the spectrum calculator has hard-coded defaults which the user is not allowed to change, the parameters that were *actually used* for the run should be written onto the output file.

The following general structure for the model input file is proposed:

- `BLOCK MODSEL`: Program-independent model switches, e.g. which model of supersymmetry breaking to use.
- `BLOCK SMINPUTS`: Measured values of SM parameters, used as boundary conditions in the spectrum calculation. These are also required for subsequent calculations to be consistent with the spectrum calculation.
- `BLOCK MINPAR`: Input parameters for minimal/default models. No defaults are defined for this block, and so the user must supply all required parameters. If `MINPAR` is not present, then *all* model parameters must be specified explicitly using `EXTPAR` below.
- `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.

See also the example model input file included in appendix D.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. Switches so far defined are:

1: Choice of SUSY breaking model. By default, a minimal type of model will always be assumed. Possible values are:

    0: General MSSM Simulation.

    1: (m)SUGRA model.

    2: (m)GMSB model.

    3: (m)AMSB model.

    4: ...

3: (Default=0) Choice of particle content. This switch is only meant as an example and is not yet implemented in any actual code. Switches defined could be:

    0: MSSM.

    1: NMSSM.

    2: ...

11: (Default=1) Number of points for a logarithmically spaced grid in Q for which the user wants the spectrum calculator to give output for the running parameters.

  1: one copy of each block containing running parameters will be output, at the scale specified by Q_{max} below.

  n > 1: n copies of each block containing running parameters will be output. The smallest scale for the grid is normally m_Z while the maximum scale is set by Q_{max} below.

12: (Default=M_{EWSB}) Q_{max}. The largest Q scale at which to give the running parameters if a grid of output scales for each running parameter block has been requested using the switch above. The default is to give only one copy of each running parameter block, at the scale taken by the spectrum calculator to perform electroweak symmetry breaking. This is often taken to be $Q = M_{\mathrm{EWSB}} \equiv \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$.

21: PDG code for a particle. The running SUSY-breaking mass parameters will be printed out at the pole mass of that particle, in addition to their values at scales given by the grid specified above. Several different entries can be given.

`BLOCK SMINPUTS`

Measured SM parameters, used as boundary conditions for the spectrum calculation and passed to subsequent calculations for consistency. Note that some programs have hard-coded defaults for various of these parameters, hence only a subset may sometimes be available as free inputs. The parameters, as defined in section 2.1, are:

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

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

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

4: m_Z, pole mass.

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

6: m_t, pole mass.

7: m_τ, pole mass.

Please note that $m_b^{\mathrm{pole}} \neq m_b(m_b)^{\overline{\mathrm{MS}}} \neq m_b(m_b)^{\overline{\mathrm{DR}}}$, see discussions in section 2.1 and [23, 24].

`BLOCK MINPAR`

Input parameters for minimal/default SUSY models. The interpretation given to the contents of this block naturally depends on which type of SUSY breaking model has been selected in block `MODSEL`. Below are listed how `MINPAR` should be filled for mSUGRA, mGMSB, and mAMSB models, and for a general MSSM setup. All parameters are understood to be $\overline{\mathrm{DR}}$ parameters given at the input scale, M_{input}, which by default is the unification scale inferred from coupling unification. Alternatively, M_{input} can be given explicitly in block `EXTPAR` below. The only exception is $\tan\beta$ which we define (cf. section 2.2) as a $\overline{\mathrm{DR}}$ parameter at the scale m_Z.

If a non-minimal type of model is desired, these minimal parameter sets may still be used to form the basis for the spectrum calculation, see `EXTPAR` below for details on this.

mSUGRA models.

1: m_0. Common scalar mass.

2: $m_{1/2}$. Common gaugino mass.

3: $\tan\beta$. Ratio of Higgs vacuum expectation, see section 2.2.

4: $\mathrm{sign}(\mu)$. Sign of the bilinear Higgs term in the superpotential.

5: A. Common trilinear coupling.

mGMSB models.

1: Λ. Scale of soft SUSY breaking felt by the low-energy sector.

2: M_{mess}. Overall messenger scale.

3: $\tan\beta$. Ratio of Higgs vacuum expectation values, see section 2.2.

4: $\mathrm{sign}(\mu)$. Sign of the bilinear Higgs term in the superpotential.

5: N_5. Messenger index.

6: c_{grav}. Gravitino mass factor.

mAMSB models.

1: m_0. Common scalar mass term.

2: $m_{3/2}$. Gravitino mass.

3: $\tan\beta$. Ratio of Higgs vacuum expectation values, see section 2.2.

4: $\mathrm{sign}(\mu)$. Sign of the bilinear Higgs term in the superpotential.

Other models.

3: $\tan\beta$. Ratio of Higgs vacuum expectation values, see section 2.2.

No model-specific standards for inputs for models beyond mSUGRA, mGMSB, and mAMSB have yet been defined, apart from the non-universality options available for these models in `EXTPAR` below. However, as long as a code for an alternative SUSY-breaking model adheres to the *output* standards described in the next section, there should be no problems in using it with this interface, as long as $\tan\beta$ is still provided.

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 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 $\overline{\mathrm{DR}}$ scheme.

0: M_{input}. Input scale for 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_{mess}. A special case is when $Q = M_{\mathrm{EWSB}} \equiv \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$ is desired as input scale, since this scale is not known beforehand. This choice can be invoked by giving the special value $M_{\mathrm{input}} = -1$.

Gaugino masses.

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

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

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

Trilinear couplings.

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

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

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

Higgs parameters — either of the parameter sets ($m^2_{H_1}$, $m^2_{H_u}$) or (μ, m^2_A) may be given, but not both.

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

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

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

24: $m^2_A(M_{\mathrm{input}})$. Tree-level pseudoscalar Higgs mass squared.

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

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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: $N_{5,1}$ (GMSB only). $\mathrm{U}(1)_Y$ messenger index.

52: $N_{5,2}$ (GMSB only). $\mathrm{SU}(2)_L$ messenger index.

53: $N_{5,3}$ (GMSB only). $\mathrm{SU}(3)_C$ messenger index.

3.2 The spectrum file

For the MSSM mass and coupling spectrum, the following block names are defined, to be specified further below:

- `BLOCK MASS`: Mass spectrum (pole masses).
- `BLOCK NMIX`: Neutralino mixing matrix.
- `BLOCK UMIX`: Chargino U mixing matrix.
- `BLOCK VMIX`: Chargino V mixing matrix.
- `BLOCK STOPMIX`: Stop mixing matrix.

- `BLOCK SBOTMIX`: Sbottom mixing matrix.
- `BLOCK STAUMIX`: Stau mixing matrix.
- `BLOCK ALPHA`: Higgs mixing angle α.
- `BLOCK HMIX Q= ...`: μ, $\tan\beta$, v, and m_A^2 at scale Q.
- `BLOCK GAUGE Q= ...`: Gauge couplings at scale Q.
- `BLOCK MSOFT Q= ...`: Soft SUSY breaking mass parameters at scale Q.
- `BLOCK AU, AD, AE Q= ...`: Trilinear couplings at scale Q.
- `BLOCK YU, YD, YE Q= ...`: Yukawa couplings at scale Q.
- `BLOCK SPINFO`: Information from the spectrum calculator.

Note that there should always be at least one empty character between the `BLOCK` statement and the block name. For running parameters, an arbitrary number of each block may be written, to provide parameters at a grid of scales Q_i (in the $\overline{\mathrm{DR}}$ scheme). For these blocks, the `Q=` statement should have at least one empty character on both sides. See also the example spectrum file included in appendix D.2.

`BLOCK MASS`

Mass spectrum for sparticles and Higgs bosons, signed pole masses. The standard for each line in the block should correspond to the FORTRAN format

```
(1x,I9,3x,1P,E16.8,0P,3x,'#',1x,A),
```

where the first 9-digit integer should be the PDG code of a particle and the double precision number its mass.

`BLOCK NMIX, UMIX, VMIX, STOPMIX, SBOTMIX, STAUMIX`

Mixing matrices, real parts only (CP violation is not addressed by this Accord at the present stage). The standard should correspond to the FORTRAN format

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

For a generic mixing matrix X, the first two integers in the format represent i and j in X_{ij} respectively, and the double precision number X_{ij} itself. Note that different spectrum calculators may produce different overall signs for rows in these matrices, since an overall sign of an eigenvector does not change physics (see section 2.4 above).

`BLOCK ALPHA`

This block only contains one entry, the Higgs mixing angle α (see definition in section 2.4), written in the format

```
(9x,1P,E16.8,0P,3x,'#',1x,A).
```

BLOCK HMIX Q=...

$\overline{\mathrm{DR}}$ Higgs parameters at the scale Q, cf. sections 2.2 and 2.3. The entries in this block should consist of an index, identifying the particular parameter in the listing below, followed by a double precision number, giving the parameter value. The corresponding FORTRAN format would be

```
(1x,I5,3x,1P,E16.8,0P,3x,'#',1x,A).
```

So far, the following entries are defined:

1: $\mu(Q)$.

2: $\tan\beta(Q)$.

3: $v(Q)$.

4: $m_A^2(Q)$.

BLOCK GAUGE Q= ...

$\overline{\mathrm{DR}}$ gauge couplings at the scale Q, cf. section 2.2. The entries in this block should consist of an index, identifying the parameter in the listing below, the format being equivalent to that of block HMIX above. The parameters are:

1: $g'(Q)$.

2: $g(Q)$.

3: $g_3(Q)$.

BLOCK MSOFT Q= ...

$\overline{\mathrm{DR}}$ soft SUSY breaking mass parameters at the scale Q, cf. eqs. (2.7) and (2.9). The entries in this block should consist of an index, identifying the parameter in the listing below, the format being equivalent to that of block HMIX above and the numbering parallelling that of block EXTPAR. The parameters defined are:

1: $M_1(Q)$.

2: $M_2(Q)$.

3: $M_3(Q)$.

21: $m^2_{H_1}(Q)$.

22: $m^2_{H_2}(Q)$.

31: $m_{\tilde{e}_L}(Q)$.

32: $m_{\tilde{\mu}_L}(Q)$.

33: $m_{\tilde{\tau}_L}(Q)$.

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34: $m_{\tilde{e}_R}(Q)$.

35: $m_{\tilde{\mu}_R}(Q)$.

36: $m_{\tilde{\tau}_R}(Q)$.

41: $m_{\tilde{q}_{1L}}(Q)$.

42: $m_{\tilde{q}_{2L}}(Q)$.

43: $m_{\tilde{q}_{3L}}(Q)$.

44: $m_{\tilde{u}_R}(Q)$.

45: $m_{\tilde{c}_R}(Q)$.

46: $m_{\tilde{t}_R}(Q)$.

47: $m_{\tilde{d}_R}(Q)$.

48: $m_{\tilde{s}_R}(Q)$.

49: $m_{\tilde{b}_R}(Q)$.

`BLOCK AU, AD, AE Q= ...`

$\overline{\mathrm{DR}}$ soft breaking trilinear couplings at the scale Q, cf. eq. (2.5). These blocks are indexed like matrices (formatted like block `NMIX` above). At present, only the (3,3) component of each of these blocks should be given, corresponding to A_t, A_b, and A_τ, respectively. Other non-zero components would in general introduce mixing in the first and second generations, a situtation which cannot be handled by the present Accord. This possibility is, however, left open for future development and/or private extensions.

`BLOCK YU, YD, YE Q= ...`

$\overline{\mathrm{DR}}$ fermion Yukawa couplings at the scale Q, cf. eq. (2.3). These blocks are indexed like matrices (formatted like block `NMIX` above). At present, only the (3,3) component of each of these blocks should be given, corresponding to the top quark, bottom quark, and tau lepton Yukawa couplings, respectively. Comments similar to those for the trilinear couplings above apply.

`BLOCK SPINFO`

Information from spectrum calculator. The program name and version number are obligatory. Optional: warnings and error messages from spectrum calculation, status return codes, regularization and renormalization prescription etc. The format should be

`(1x,I5,3x,A).`

Entries so far defined are:

1: spectrum calculator name (string).

2: spectrum calculator version number (string).

3: If this entry is present, warning(s) were produced by the spectrum calculator. The resulting spectrum may still be OK. The entry should contain a description of the problem (string).

4: If this entry is present, error(s) were produced by the spectrum calculator. The resulting spectrum should not be used. The entry should contain a description of the problem (string).

To illustrate, a certain unlucky choice of input parameters could result in the following form of block `SPINFO`:

```
BLOCK SPINFO
     1 MyRGE
     2 1.0
     3 Charge and colour breaking global minimum
     3 Desired accuracy not quite achieved
     3 LEP2 Higgs bound violated
     4 No radiative electroweak symmetry breaking
     4 Tachyons encountered
```

3.3 The decay file

The decay table for each particle begins with a statement specifying which particle is decaying and its total width, in the format:

```
#         PDG            Width
DECAY   1000021    1.01752300e+00   # gluino decays
```

The first integer is a PDG particle number, specifying the identity of the mother of all subsequent lines until the next `DECAY` or `BLOCK` statement (or end-of-file). The subsequent real number is that particle's total width. The end comment contains a human readable translation of the PDG code.

Every subsequent line contains a decay channel for this mother in the format:

```
#          BR          NDA      ID1       ID2
     4.18313300E-02    2      1000001        -1   # BR(~g -> ~d_L dbar)
     1.55587600E-02    2      2000001        -1   # BR(~g -> ~d_R dbar)
     3.91391000E-02    2      1000002        -2   # BR(~g -> ~u_L ubar)
     1.74358200E-02    2      2000002        -2   # BR(~g -> ~u_R ubar)
...
```

where the first real number is the fraction of the total width (branching fraction) into that particular mode, the first integer is the number of daughters, N, and the N following integers are the PDG codes of the N daughters. The specific FORTRAN formats for the `DECAY` statement and the entries in the decay table are, respectively:

```
('DECAY',1x,I9,3x,1P,E16.8,0P,3x,'#',1x,A),
(3x,1P,E16.8,0P,3x,I2,3x,N(I9,1x),2x,'#',1x,A).
```

A potential pitfall in using these decay tables is how on-shell resonances inside the physical phase space are dealt with. A prime example, which we will use for illustration below, is the top decay, $\mathrm{t} \to W^{+}\mathrm{b} \to \mathrm{q}\bar{\mathrm{q}}'\mathrm{b}$. There are two dangers here that must be consistently dealt with:

1. If both the partial width for $\mathrm{t} \to W^{+}\mathrm{b}$ and for $\mathrm{t} \to \mathrm{q}\bar{\mathrm{q}}'\mathrm{b}$ are written on the file, then the on-shell W part of $\mathrm{t} \to \mathrm{q}\bar{\mathrm{q}}'\mathrm{b}$ will be counted twice. One solution here is to include only the truly off-shell parts in the calculation of partial widths for processes which can occur via seuqences of (lower-order) on-shell splittings. In the example above, the $(1 \to 3)$ partial width $\mathrm{t} \to \mathrm{q}\bar{\mathrm{q}}'\mathrm{b}$ written on the file should thus *not* contain the $(1 \to 2 \otimes 1 \to 2)$ on-shell W contribution.

2. If the on-shell/off-shell rule just described is *not* adhered to, another possible source of error becomes apparent. If the full partial width $\mathrm{t} \to \mathrm{q}\bar{\mathrm{q}}'\mathrm{b}$ (now including the resonant piece) is written in the decay table, the reading program has no immediate way of knowing that there is a resonant W inside. By default, it will most likely use a flat phase space, in the lack of more differential information; hence there would in this example be no W peak in the $\mathrm{q}\bar{\mathrm{q}}'$ invariant mass spectrum. On the other hand, if the rule above *is* adhered to, then the resonant W is not part of the $1 \to 3$ partial width, and a flat phase space is then a reasonable first approximation.

NB: for Majorana particles, modes and charge conjugate modes should both be written on the file, so that the numbers in the first column sum up to 1 for any particle.

At present, this file is thus only capable of transferring integrated information, i.e. partial widths. For a more accurate population of phase space (even when all intermediate states are off-shell), access to differential information is necessary. It should also here be mentioned that several programs include options for letting the partial widths be a function of $\hat{s}$, to account for the resonant shape of the mother. We anticipate that these and other refinements can be included with full backwards compatibility, either by continuing to add information on the same line before the hash mark, or by adding a number of lines beginning with the '+' character for each decay mode in question, where additional information concerning that mode can be given.

The file should also contain a block `DCINFO`, giving information about the decay calculation program and (optionally) exit status. The format and entries of this block are identical to that of block `SPINFO` above.

Note that, if the particle is not known to the reading program, properties such as electric charge, spin, and colour charge could be added on the `DECAY` line. However, for fundamental particles, there is only a limited set of particles for which all programs concerned should know the properties, and for hadrons, the spin is encoded in the last digit of the PDG code while the charge may be calculated from the flavour content which is specified by the 2 or 3 digits preceding the spin digit of the code. Therefore, we do not deem it necessary to adopt a standard for specifying such information at the present time.

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4. Conclusion

The present Accord specifies a unique set of conventions together with ASCII file formats for model input and spectrum output for most commonly investigated supersymmetric models, as well as a decay table file format for use with decay packages.

With respect to the model parameter input file, mSUGRA, mGMSB, and mAMSB scenarios can be handled, with some options for non-universality. However, this should not discourage users desiring to investigate alternative models; the definitions for the spectrum output file are at present capable of handling any CP and R-parity conserving supersymmetric model, with the particle spectrum of the MSSM. Specifically, this includes the so-called SPS points [30].

Also, these definitions are not intended to be static solutions. Great efforts have gone into ensuring that the Accord may accomodate essentially any new model or new twist on an old one with minor modifications required and full backwards compatibility. Planned issues for future extensions of the Accord are, for instance, to include options for R-parity violation and CP violation, and possibly to include definitions for an NMSSM. Topics which are at present only implemented in a few codes, if at all, will be taken up as the need arises. Handling RPV and CPV should require very minor modifications to the existing structure, while the NMSSM, for which there is at present not even general agreement on a unique definition, will require some additional work.

Lastly, while SUSY is perhaps the most studied hypothesis of New Physics, it is by no means the only possible worth investigating. One may well anticipate that similar sources of confusion and misunderstandings as partly motivated this Accord can arise for other New Physics models in the future. In this context, we note that the decay tables defined here are sufficiently general to require little or no modification to encompass other New Physics models, while the rest of the Accord provides a general structure that may be used as a convenient template for future generalisations.

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Code	Name	Code	Name	Code	Name	Code	Name
1	d	11	e^-	21	g		
2	u	12	ν_{e}	22	γ	35	H^0
3	s	13	μ^-	23	Z^0	36	A^0
4	c	14	ν_μ	24	W^+	37	H^+
5	b	15	τ^-	25	h^0		
6	t	16	ν_τ			39	G (graviton)

Table 1: SM fundamental particle codes (+ extended Higgs sector).

Code	Name	Code	Name	Code	Name	Code	Name
1000001	$\tilde{\mathrm{d}}_L$	1000011	$\tilde{\mathrm{e}}_L$	1000021	$\tilde{\mathrm{g}}$		
1000002	$\tilde{\mathrm{u}}_L$	1000012	$\tilde{\nu}_{\mathrm{e}L}$	1000022	$\tilde{\chi}_1^0$	1000035	$\tilde{\chi}_4^0$
1000003	$\tilde{\mathrm{s}}_L$	1000013	$\tilde{\mu}_L$	1000023	$\tilde{\chi}_2^0$		
1000004	$\tilde{\mathrm{c}}_L$	1000014	$\tilde{\nu}_{\mu L}$	1000024	$\tilde{\chi}_1^+$	1000037	$\tilde{\chi}_2^+$
1000005	$\tilde{\mathrm{b}}_1$	1000015	$\tilde{\tau}_1$	1000025	$\tilde{\chi}_3^0$		
1000006	$\tilde{\mathrm{t}}_1$	1000016	$\tilde{\nu}_{\tau L}$			1000039	$\tilde{\mathrm{G}}$ (gravitino)
2000001	$\tilde{\mathrm{d}}_R$	2000011	$\tilde{\mathrm{e}}_R$				
2000002	$\tilde{\mathrm{u}}_R$	2000012	$\tilde{\nu}_{\mathrm{e}R}$				
2000003	$\tilde{\mathrm{s}}_R$	2000013	$\tilde{\mu}_R$				
2000004	$\tilde{\mathrm{c}}_R$	2000014	$\tilde{\nu}_{\mu R}$				
2000005	$\tilde{\mathrm{b}}_2$	2000015	$\tilde{\tau}_2$				
2000006	$\tilde{\mathrm{t}}_2$	2000016	$\tilde{\nu}_{\tau R}$				

Table 2: MSSM sparticle codes.

A. The PDG particle numbering scheme

Listed in the tables 1 and 2 are the PDG codes for the MSSM particle spectrum. Codes for other particles may be found in [22, chp. 33].

B. 1-loop translations from $\overline{\mathrm{DR}}$ to $\overline{\mathrm{MS}}$

All formulae in this appendix are obtained from [29] and are valid for parameters calculated at 1 loop in either of the two schemes.

At the scale μ, the $\overline{\mathrm{MS}}$ gauge coupling of the gauge group G_i (i.e. the coupling appearing in the interaction vertices of the corresponding gauge bosons) is related to the $\overline{\mathrm{DR}}$ one by:

$$g_{i,\overline{\mathrm{MS}}} = g_{i,\overline{\mathrm{DR}}} \left(1 - \frac{g_i^2}{96\pi^2} C(G_i) \right) , \tag{B.1}$$

where the choice of renormalization scheme for g_i in the 1-loop correction piece is irrelevant, since it amounts to a 2-loop effect, and $C(G_i)$ is the quadratic Casimir invariant for the adjoint representation of the gauge group in question.[4]

[4]It should be noted that the couplings of gauginos to scalars are identical to the gauge couplings by

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For the running Yukawa couplings (between the scalar ϕ_i and the two chiral fermions ψ_j and ψ_k), the translation is:

$$Y^{ijk}_{\overline{\rm MS}} = Y^{ijk}_{\overline{\rm DR}} \left(1 + \sum_{a=1}^{3} \frac{g_a^2}{32\pi^2} \left[C_a(r_j) - 2C_a(r_i) + C_a(r_k) \right] \right) , \tag{B.2}$$

where a runs over the SM gauge groups. Note that while the $\overline{\rm DR}$ Yukawas are totally symmetric, this is not the case for the $\overline{\rm MS}$ ones. The same relation can also be used to derive the translation of fermion masses coming from a quadratic term in the superpotential by taking the scalar field as a dummy field with $C(r_i) = 0$ and identifying $C(r_j) = C(r_k)$. This applies e.g. to the Higgs mixing parameter μ.

The soft supersymmetry-breaking parameters differ in the two schemes, too. The relation between the gaugino masses is given by

$$M_{i,\overline{\rm MS}} = M_{i,\overline{\rm DR}} \left(1 + \frac{g_i^2}{16\pi^2} C(G_i) \right) . \tag{B.3}$$

Finally, none of the other supersymmetry-breaking couplings (as written in component rather than superfield notation) differ between the two schemes. In particular, this applies to the soft breaking trilinear couplings and the scalar masses, provided one uses the modified $\overline{\rm DR}$ scheme, as presented in [27].

C. Tree-level mass matrices

The following gives a list of tree-level mass matrices, as they appear in the conventions adopted in this article, see section 2. Note that these expressions *are not* normally the ones used for actual calculations in the spectrum calculators, since most codes on the market today include higher order corrections which are absent below.

The neutralino mass matrix appearing in eq. (2.11) is:

$$\mathcal{M}_{\tilde\psi^0} = \begin{pmatrix} M_1 & 0 & -m_Z \cos\beta \sin\theta_W & m_Z \sin\beta \sin\theta_W \\ 0 & M_2 & m_Z \cos\beta \cos\theta_W & -m_Z \sin\beta \cos\theta_W \\ -m_Z \cos\beta \sin\theta_W & m_Z \cos\beta \cos\theta_W & 0 & -\mu \\ m_Z \sin\beta \sin\theta_W & -m_Z \sin\beta \cos\theta_W & -\mu & 0 \end{pmatrix} , \tag{C.1}$$

and the chargino mass matrix appearing in eq. (2.14):

$$\mathcal{M}_{\tilde\psi^+} = \begin{pmatrix} M_2 & \sqrt{2} m_W \sin\beta \\ \sqrt{2} m_W \cos\beta & \mu \end{pmatrix} . \tag{C.2}$$

For the sfermions, the mixing matrices for $\tilde t$, $\tilde b$, and $\tilde\tau$ respectively, appear in the L-R basis as:

$$\begin{pmatrix} m^2_{\tilde q_{3L}} + m_t^2 + (\frac{1}{2} - \frac{2}{3}\sin^2\theta_W) m_Z^2 \cos 2\beta & m_t \left(A_t - \mu \cot\beta \right) \\ m_t \left(A_t - \mu \cot\beta \right) & m^2_{\tilde t_R} + m_t^2 + \frac{2}{3} \sin^2\theta_W m_Z^2 \cos 2\beta \end{pmatrix} , \tag{C.3}$$

virtue of supersymmetry. This requires the introduction of additional counter terms in the $\overline{\rm MS}$ scheme [29] in order to restore this equality. Analogous additional counter terms arise for the quartic scalar couplings which are related to the Yukawa and gauge couplings due to supersymmetry.

$$\begin{pmatrix} m_{\tilde{q}_{3L}}^2 + m_b^2 - (\frac{1}{2} - \frac{1}{3}\sin^2\theta_W)m_Z^2\cos 2\beta & m_b\,(A_b - \mu\tan\beta) \\ m_b\,(A_b - \mu\tan\beta) & m_{\tilde{b}_R}^2 + m_b^2 - \frac{1}{3}\sin^2\theta_W m_Z^2\cos 2\beta \end{pmatrix}, \tag{C.4}$$

$$\begin{pmatrix} m_{\tilde{\tau}_L}^2 + m_\tau^2 - (\frac{1}{2} - \sin^2\theta_W)m_Z^2\cos 2\beta & m_\tau\,(A_\tau - \mu\tan\beta) \\ m_\tau\,(A_\tau - \mu\tan\beta) & m_{\tilde{\tau}_R}^2 + m_\tau^2 - \sin^2\theta_W m_Z^2\cos 2\beta \end{pmatrix}, \tag{C.5}$$

where we use $m_{\tilde{q}_{3L}}$ to denote the 3$^{\rm rd}$ generation left squark mass.

D. Examples

D.1 Example input file

In the example below, the user has not entered boundary values for the electroweak couplings, nor have the Z and τ masses been supplied. On running, the spectrum calculator should thus use its own defaults for these parameters and pass everything on to the output.

```
# SUSY Les Houches Accord 1.0 - example input file
# Snowmsas point 1a
Block MODSEL  # Select model
     1    1   # sugra
Block SMINPUTS   # Standard Model inputs
     3      0.1172  # alpha_s(MZ) SM MSbar
     5      4.25    # Mb(mb) SM MSbar
     6    174.3     # Mtop(pole)
Block MINPAR  # SUSY breaking input parameters
     3     10.0     # tanb
     4      1.0     # sign(mu)
     1    100.0     # m0
     2    250.0     # m12
     5   -100.0     # A0
```

D.2 Example spectrum file

The spectrum file produced by the above input file should look something like the following:

```
# SUSY Les Houches Accord 1.0 - example spectrum file
# Info from spectrum calculator
Block SPINFO         # Program information
     1   SOFTSUSY    # spectrum calculator
     2   1.8.4       # version number
# Input parameters
Block MODSEL  # Select model
     1    1   # sugra
Block SMINPUTS   # Standard Model inputs
     1    1.27934000e+02   # alpha_em^(-1)(MZ) SM MSbar
     2    1.16637000e-05   # G_Fermi
```

```
     3     1.17200000e-01   # alpha_s(MZ) SM MSbar
     4     9.11876000e+01   # MZ(pole)
     5     4.25000000e+00   # Mb(mb) SM MSbar
     6     1.74300000e+02   # Mtop(pole)
     7     1.77700000e+00   # Mtau(pole)
Block MINPAR  # SUSY breaking input parameters
     1     1.00000000e+02   # m0(MGUT) MSSM DRbar
     2     2.50000000e+02   # m12(MGUT) MSSM DRbar
     3     1.00000000e+01   # tanb(MZ) MSSM DRbar
     4     1.00000000e+00   # sign(mu(MGUT)) MSSM DRbar
     5    -1.00000000e+02   # A0(MGUT) MSSM DRbar
#
# mgut=2.551299875e+16 GeV
Block MASS  # Mass spectrum
# PDG code      mass                 particle
        24      8.02463984e+01   # MW
        25      1.10636832e+02   # h0
        35      4.00874604e+02   # H0
        36      4.00506272e+02   # A0
        37      4.08784776e+02   # H+
   1000001      5.73103437e+02   # ~d_L
   1000002      5.67658152e+02   # ~u_L
   1000003      5.73029886e+02   # ~s_L
   1000004      5.67583798e+02   # ~c_L
   1000005      5.15617364e+02   # ~b_1
   1000006      3.96457239e+02   # ~t_1
   1000011      2.04346872e+02   # ~e_L
   1000012      1.88733599e+02   # ~nue_L
   1000013      2.04344144e+02   # ~mu_L
   1000014      1.88730645e+02   # ~numu_L
   1000015      1.36434250e+02   # ~stau_1
   1000016      1.87868618e+02   # ~nu_tau_L
   1000021      6.09298476e+02   # ~g
   1000022      9.62723703e+01   # ~neutralino(1)
   1000023      1.79383645e+02   # ~neutralino(2)
   1000024      1.78832499e+02   # ~chargino(1)
   1000025     -3.64094094e+02   # ~neutralino(3)
   1000035      3.82627159e+02   # ~neutralino(4)
   1000037      3.82906800e+02   # ~chargino(2)
   2000001      5.46469067e+02   # ~d_R
   2000002      5.47396607e+02   # ~u_R
   2000003      5.46466786e+02   # ~s_R
   2000004      5.47244191e+02   # ~c_R
```

```
   2000005     5.44364792e+02   # ~b_2
   2000006     5.85965936e+02   # ~t_2
   2000011     1.45533727e+02   # ~e_R
   2000013     1.45526066e+02   # ~mu_R
   2000015     2.08212282e+02   # ~stau_2
# Higgs mixing
Block alpha   # Effective Higgs mixing parameter
          -1.13716828e-01   # alpha
Block stopmix  # stop mixing matrix
  1  1     5.37975095e-01   # O_{11}
  1  2     8.42960733e-01   # O_{12}
  2  1     8.42960733e-01   # O_{21}
  2  2    -5.37975095e-01   # O_{22}
Block sbotmix  # sbottom mixing matrix
  1  1     9.47346882e-01   # O_{11}
  1  2     3.20209128e-01   # O_{12}
  2  1    -3.20209128e-01   # O_{21}
  2  2     9.47346882e-01   # O_{22}
Block staumix  # stau mixing matrix
  1  1     2.78399839e-01   # O_{11}
  1  2     9.60465267e-01   # O_{12}
  2  1     9.60465267e-01   # O_{21}
  2  2    -2.78399839e-01   # O_{22}
Block nmix  # neutralino mixing matrix
  1  1     9.86102610e-01   # N_{1,1}
  1  2    -5.46971979e-02   # N_{1,2}
  1  3     1.47526998e-01   # N_{1,3}
  1  4    -5.33445802e-02   # N_{1,4}
  2  1     1.01818619e-01   # N_{2,1}
  2  2     9.43310250e-01   # N_{2,2}
  2  3    -2.73948058e-01   # N_{2,3}
  2  4     1.57325147e-01   # N_{2,4}
  3  1    -6.06211640e-02   # N_{3,1}
  3  2     9.00367885e-02   # N_{3,2}
  3  3     6.95440071e-01   # N_{3,3}
  3  4     7.10339045e-01   # N_{3,4}
  4  1    -1.16446066e-01   # N_{4,1}
  4  2     3.14749686e-01   # N_{4,2}
  4  3     6.47727839e-01   # N_{4,3}
  4  4    -6.83974850e-01   # N_{4,4}
Block Umix  # chargino U mixing matrix
  1  1     9.16207706e-01   # U_{1,1}
  1  2    -4.00703680e-01   # U_{1,2}
```

```
  2  1     4.00703680e-01   # U_{2,1}
  2  2     9.16207706e-01   # U_{2,2}
Block Vmix  # chargino V mixing matrix
  1  1     9.72887524e-01   # V_{1,1}
  1  2    -2.31278762e-01   # V_{1,2}
  2  1     2.31278762e-01   # V_{2,1}
  2  2     9.72887524e-01   # V_{2,2}
Block gauge Q= 4.64649125e+02
     1     3.60872342e-01   # g'(Q)MSSM DRbar
     2     6.46479280e-01   # g(Q)MSSM DRbar
     3     1.09623002e+00   # g3(Q)MSSM DRbar
Block yu Q= 4.64649125e+02
  3  3     8.88194465e-01   # Yt(Q)MSSM DRbar
Block yd Q= 4.64649125e+02
  3  3     1.40135884e-01   # Yb(Q)MSSM DRbar
Block ye Q= 4.64649125e+02
  3  3     9.97405356e-02   # Ytau(Q)MSSM DRbar
Block hmix Q= 4.64649125e+02  # Higgs mixing parameters
     1     3.58660361e+02   # mu(Q)MSSM DRbar
     2     9.75139550e+00   # tan beta(Q)MSSM DRbar
     3     2.44923506e+02   # higgs vev(Q)MSSM DRbar
     4     1.69697051e+04   # mA^2(Q)MSSM DRbar
Block msoft Q=4.64649125e+02 # MSSM DRbar SUSY breaking parameters
     1     1.01353084e+02   # M_1(Q)
     2     1.91513233e+02   # M_2(Q)
     3     5.86951218e+02   # M_3(Q)
    21     3.26601234e+04   # mH1^2(Q)
    22    -1.29761234e+05   # mH2^2(Q)
    31     1.99111011e+02   # meL(Q)
    32     1.99108212e+02   # mmuL(Q)
    33     1.98291304e+02   # mtauL(Q)
    34     1.38808102e+02   # meR(Q)
    35     1.38800070e+02   # mmuR(Q)
    36     1.36441129e+02   # mtauR(Q)
    41     5.51249170e+02   # mqL1(Q)
    42     5.51173571e+02   # mqL2(Q)
    43     4.99839787e+02   # mqL3(Q)
    44     5.29285249e+02   # muR(Q)
    45     5.29130286e+02   # mcR(Q)
    46     4.19025924e+02   # mtR(Q)
    47     5.26529352e+02   # mdR(Q)
    48     5.26527025e+02   # msR(Q)
    49     5.23183913e+02   # mbR(Q)
```

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```
Block au Q= 4.64649125e+02
  3  3    -5.04995511e+02   # At(Q)MSSM DRbar
Block ad Q= 4.64649125e+02
  3  3    -7.97992485e+02   # Ab(Q)MSSM DRbar
Block ae Q= 4.64649125e+02
  3  3    -2.56328558e+02   # Atau(Q)MSSM DRbar
```

D.3 Example decay file

For brevity, the model input and spectrum information is omitted here. See the examples above.

```
# SUSY Les Houches Accord 1.0 - example decay file
# Info from decay package
Block DCINFO          # Program information
     1    SDECAY       # Decay package
     2    1.0          # version number
#         PDG           Width
DECAY   1000021    1.01752300e+00   # gluino decays
#          BR         NDA      ID1       ID2
     4.18313300E-02    2     1000001        -1   # BR(~g -> ~d_L dbar)
     1.55587600E-02    2     2000001        -1   # BR(~g -> ~d_R dbar)
     3.91391000E-02    2     1000002        -2   # BR(~g -> ~u_L ubar)
     1.74358200E-02    2     2000002        -2   # BR(~g -> ~u_R ubar)
     4.18313300E-02    2     1000003        -3   # BR(~g -> ~s_L sbar)
     1.55587600E-02    2     2000003        -3   # BR(~g -> ~s_R sbar)
     3.91391000E-02    2     1000004        -4   # BR(~g -> ~c_L cbar)
     1.74358200E-02    2     2000004        -4   # BR(~g -> ~c_R cbar)
     1.13021900E-01    2     1000005        -5   # BR(~g -> ~b_1 bbar)
     6.30339800E-02    2     2000005        -5   # BR(~g -> ~b_2 bbar)
     9.60140900E-02    2     1000006        -6   # BR(~g -> ~t_1 tbar)
     0.00000000E+00    2     2000006        -6   # BR(~g -> ~t_2 tbar)
     4.18313300E-02    2    -1000001         1   # BR(~g -> ~dbar_L d)
     1.55587600E-02    2    -2000001         1   # BR(~g -> ~dbar_R d)
     3.91391000E-02    2    -1000002         2   # BR(~g -> ~ubar_L u)
     1.74358200E-02    2    -2000002         2   # BR(~g -> ~ubar_R u)
     4.18313300E-02    2    -1000003         3   # BR(~g -> ~sbar_L s)
     1.55587600E-02    2    -2000003         3   # BR(~g -> ~sbar_R s)
     3.91391000E-02    2    -1000004         4   # BR(~g -> ~cbar_L c)
     1.74358200E-02    2    -2000004         4   # BR(~g -> ~cbar_R c)
     1.13021900E-01    2    -1000005         5   # BR(~g -> ~bbar_1 b)
     6.30339800E-02    2    -2000005         5   # BR(~g -> ~bbar_2 b)
     9.60140900E-02    2    -1000006         6   # BR(~g -> ~tbar_1 t)
     0.00000000E+00    2    -2000006         6   # BR(~g -> ~tbar_2 t)
```

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