SUSY Les Houches Accord Status and planned extensions (+ other projects)

Preliminary report on Les Houches ('05) discussions

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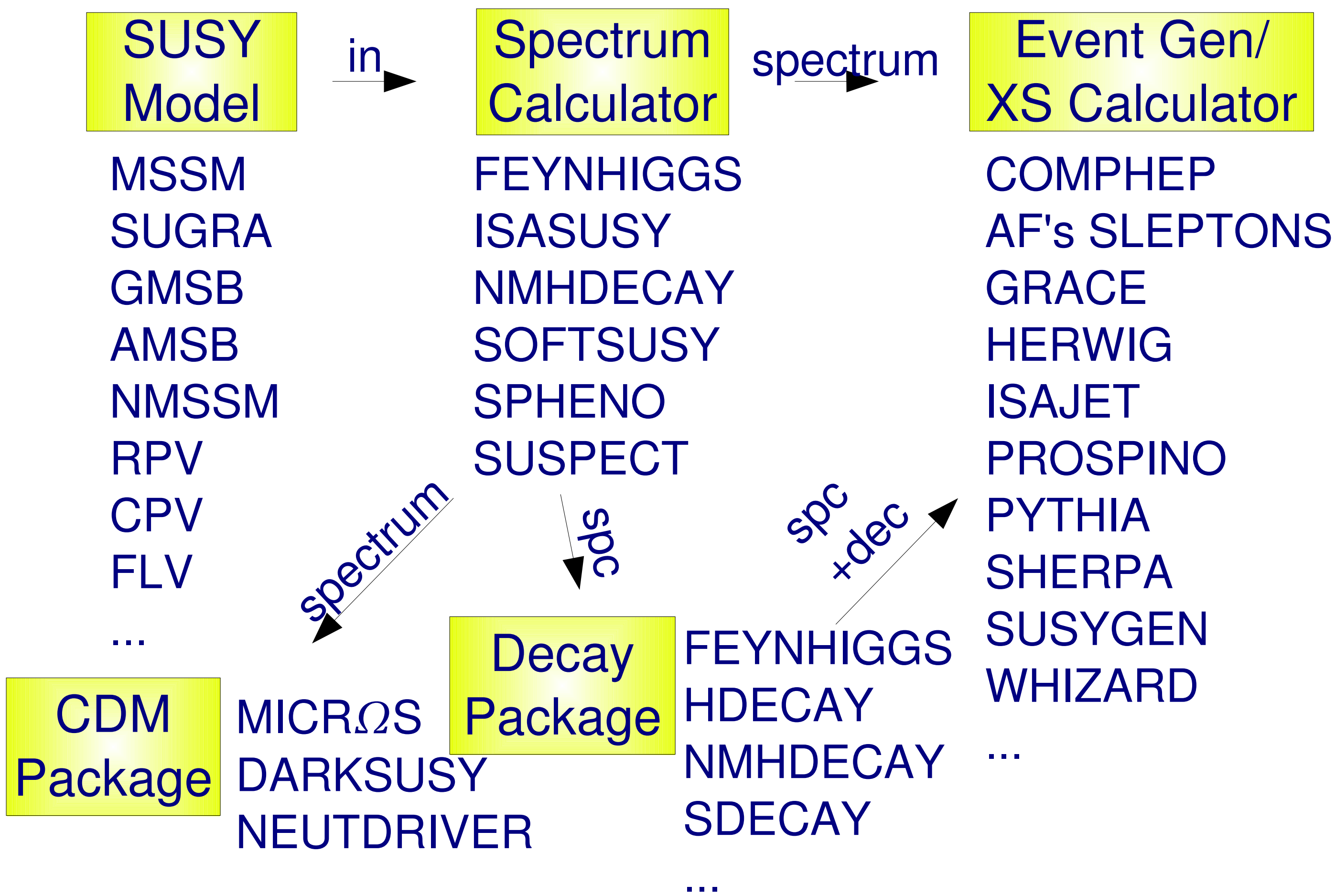
SUSY Les Houches Accord

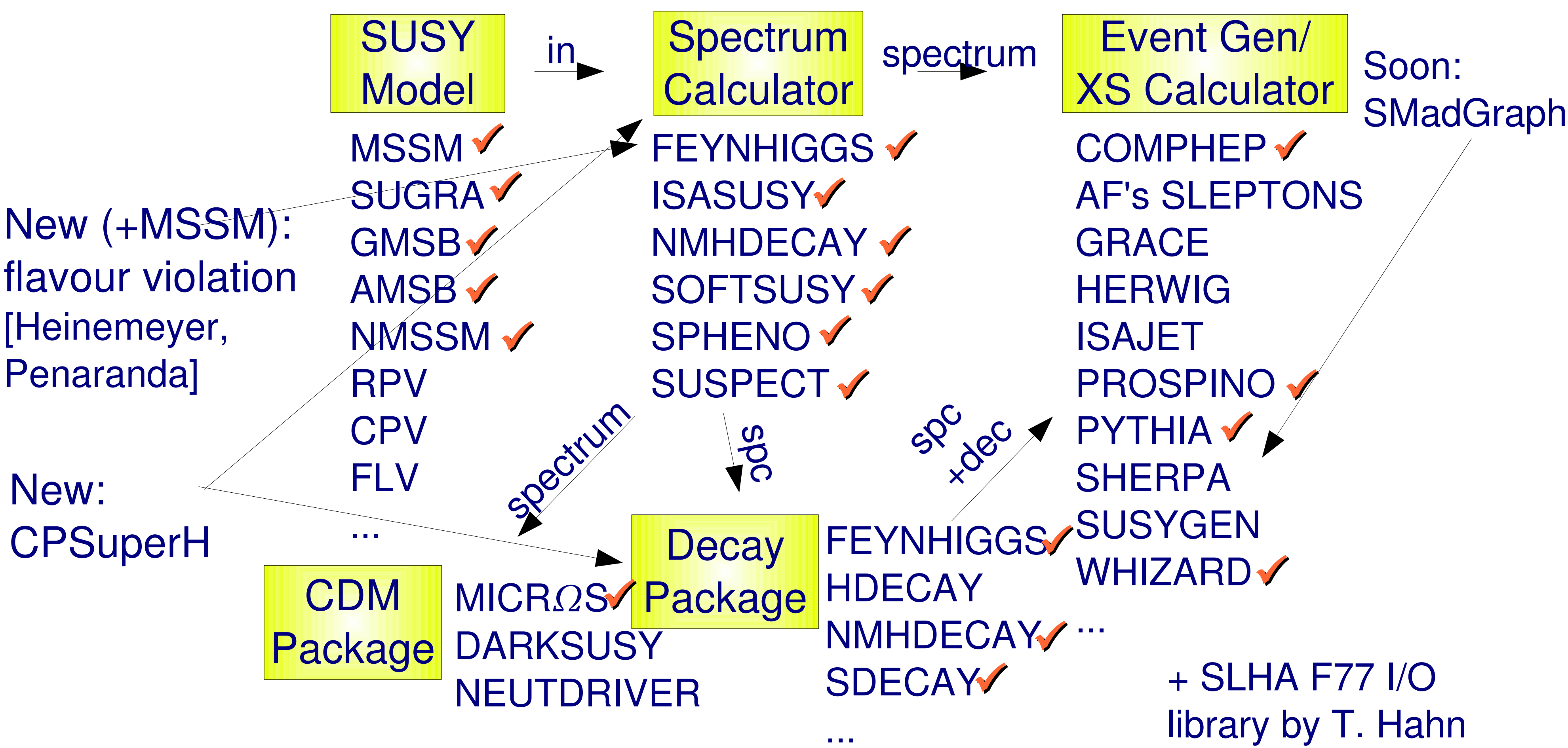
- LH '03: *many* tools -> need to unify -> Accord.



SUSY Les Houches Accord

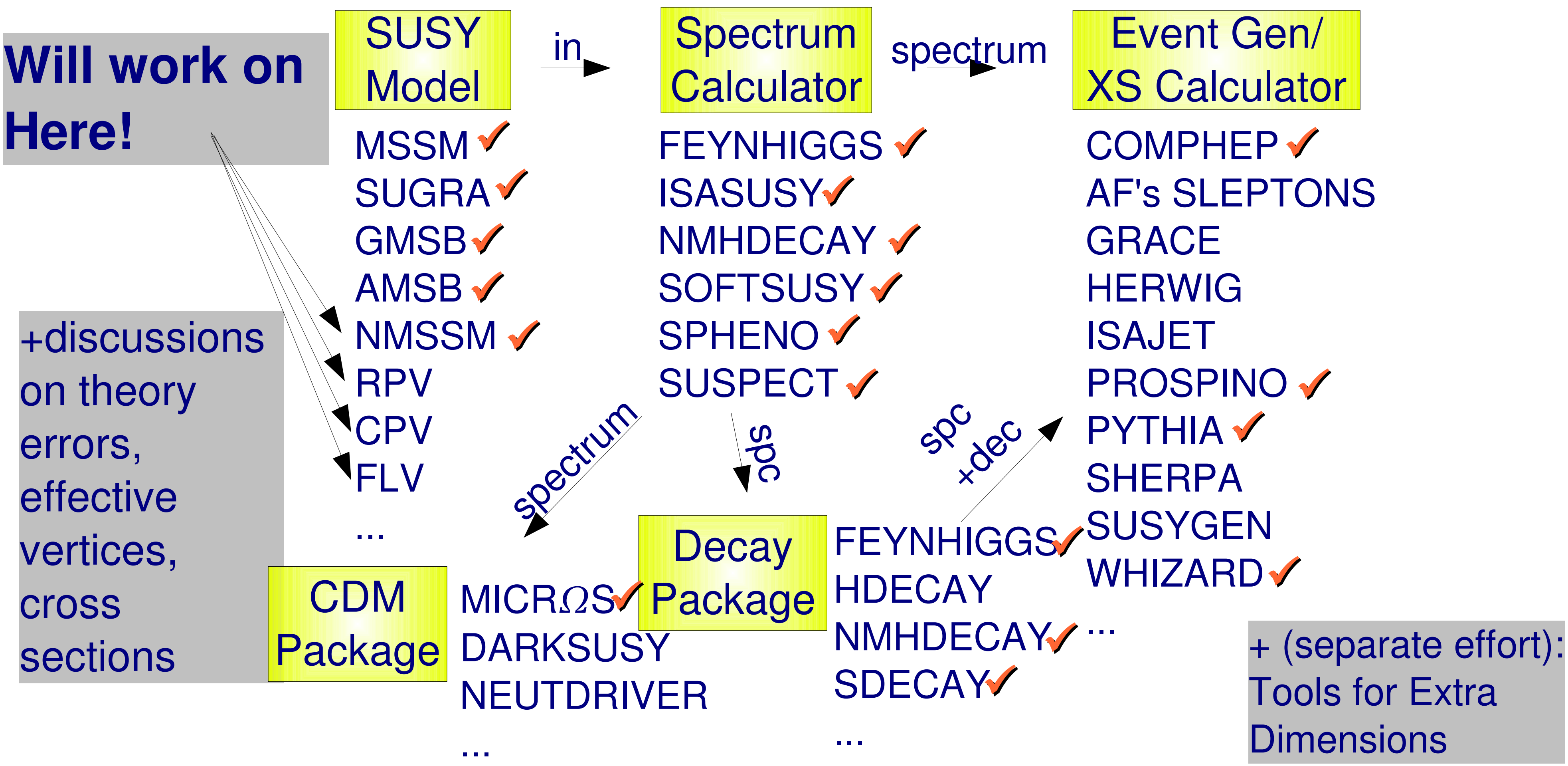
- LH '03: *many* tools -> need to unify -> Accord.

-> JHEP 07(2004)036 [hep-ph/0311123]



SUSY Les Houches Accord

- LH '03: *many* tools -> need to unify -> Accord.
- LH '05: CPV, RPV, FLV, NMSSM, ...



Conventions & Consistency

What is needed to 'specify' a SUSY model?

1. Specify experimental boundary conditions.

   "SM" gauge couplings g_i^{SM} & Yukawas Y_{ijk}^{SM} ('measured')
   $\rightarrow$ "MSSM" couplings g_i and Yukawas Y_{ijk} (not the same, since different field content $\rightarrow$ different quantum corrections).

2. Define the Superpotential.

   Y_{ijk}, μ (+ RPV/NMSSM terms) (HO: at scale Q, e.g. in $\overline{\mathrm{DR}}$ scheme) $\rightarrow W$.

3. Define the SUSY breaking terms.

   Soft breaking gaugino masses M_i, scalar masses m_{ij}, b_{ij}, and trilinear A_{ijk} terms (HO: at scale Q, e.g. in $\overline{\mathrm{DR}}$ scheme).

4. Work out the physical spectrum.

   Pole masses (for kinematics), and couplings (for ME's), incl. mass $\leftrightarrow$ current eigenstate transl., and for HO calcs all def in a useful and well–defined renormalization scheme/scale.

Conventions & Consistency

1. Experimental Boundary Conditions

$\alpha_{\mathrm{em}}(m_{\mathrm{Z}})^{\overline{\mathrm{MS}}}$	$\frac{\alpha}{1-\Delta\alpha(m_{\mathrm{Z}})^{\overline{\mathrm{MS}}}}$
G_F	The Fermi constant determined from μ decay
m_{Z}	The Z boson pole mass
$\alpha_s(m_{\mathrm{Z}})^{\overline{\mathrm{MS}}}$	The 5–flavour $\overline{\mathrm{MS}}$ strong coupling at m_{Z}
$m_{\mathrm{b}}(m_{\mathrm{b}})^{\overline{\mathrm{MS}}}$	The $\overline{\mathrm{MS}}$ b quark running mass at m_{b}
m_{t}	Top pole mass
m_τ	Tau pole mass

Note: no SUSY corrections here!

Conventions & Consistency

2. & 3. Defining the SUSY Model

$\mathrm{sgn}(\mu)$	$W_\mu = \epsilon_{ab}\left[-\mu H_1^a H_2^b\right], (\epsilon_{12}=1)$
$\tan\beta(m_Z)^{\overline{\mathrm{DR}}}$	v_2/v_1 (can also be given at $Q \neq m_Z$)
$V_3(M_{\mathrm{input}})$	$\epsilon_{ab}\sum_{ij}\Big[(T_E)_{ij}H_1^a\tilde{L}_{i_L}^b\tilde{e}_{j_R}^* + (T_D)_{ij}H_1^a\tilde{Q}_{i_L}^b\tilde{d}_{j_R}^* + (T_U)_{ij}H_2^b\tilde{Q}_{i_L}^a\tilde{u}_{j_R}^*\Big] + \mathrm{h.c.},\ A_{ij} = T_{ij}/Y_{ij}$
$V_2(M_{\mathrm{input}})$	$m_{H_j}^2 H_{j\,a}^* H_j^a + \tilde{Q}_{i_L a}^*(m_{\tilde{Q}}^2)_{ij}\tilde{Q}_{j_L}^a + \tilde{L}_{i_L a}^*(m_{\tilde{L}}^2)_{ij}\tilde{L}_{j_L}^a + \tilde{q}_{i_R}(m_{\tilde{q}}^2)_{ij}\tilde{q}_{j_R}^* + \tilde{e}_{i_R}(m_{\tilde{e}}^2)_{ij}\tilde{e}_{j_R}^* - (m_3^2\epsilon_{ab}H_1^a H_2^b + \mathrm{h.c.})$ ∘ Either $(m_{H_1}^2, m_{H_2}^2)$ or $(\mu, m_A^2 = \frac{m_3^2}{\sin\beta\cos\beta})$
$\mathcal{L}_G(M_{\mathrm{input}})$	$\frac{1}{2}\left(M_1\tilde{b}\tilde{b} + M_2\tilde{w}^A\tilde{w}^A + M_3\tilde{g}^X\tilde{g}^X\right) + \mathrm{h.c.}$

Conventions & Consistency

2. & 3. Defining the SUSY Model

$\Longrightarrow$ Now all parameters unambiguously defined. E.g. for the neutralino sector, with $\tilde\psi^{0T} = (-i\tilde b, -i\tilde w^0, \tilde h_1^0, \tilde h_2^0)^T$:

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

At tree level:

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

Generically complex entries $\mathrm{diag}(m_{\tilde\chi^0})_i = m_{\tilde\chi_i^0}e^{i\varphi_i}$, phases removed by redef. $\tilde\chi_i^0 \to \tilde\chi_i^0 e^{i\varphi_i/2} \to$ real positive masses.

Conventions & Consistency

4. Communicating the Spectrum: $\overline{\mathrm{DR}}$ parameters

- Firstly, copies of all the input parameters, for consistency (e.g. so next calculation uses same m_{t}).
- Secondly, all the (non-input) sparticle and Higgs boson pole masses, also e.g. m_{W}.
- Thirdly, all the Lagrangian parameters at given scale(s) Q_i in the $\overline{\mathrm{DR}}$ scheme.
- Fourthly, (less well defined) mixing matrices, for loop-improved tree–level calculations.

Conventions & Consistency

4. Communicating the Spectrum: $\overline{\mathrm{DR}}$ parameters

$W(Q_i)^{\overline{\mathrm{DR}}}$	$\epsilon_{ab}\left[(Y_E)_{ij}H_1^aL_i^b\bar{E}_j + (Y_D)_{ij}H_1^aQ_i^b\bar{D}_j + (Y_U)_{ij}H_2^bQ_i^a\bar{U}_j - \mu H_1^aH_2^b\right]$
$\tan\beta(Q_i)^{\overline{\mathrm{DR}}}$	v_2/v_1
$g_j(Q_i)^{\overline{\mathrm{DR}}}$	g', g, and g_3: gauge couplings
$A_j(Q_i)^{\overline{\mathrm{DR}}}$	Soft breaking trilinear couplings
$v_j(Q_i)^{\overline{\mathrm{DR}}}$	$\sqrt{2}\langle H_j^0\rangle$, so $v^2 = (v_1^2 + v_2^2) = (246\ \mathrm{GeV})^2$
$M_j(Q_i)^{\overline{\mathrm{DR}}}$	Soft breaking gaugino masses
$m_j(Q_i)^{\overline{\mathrm{DR}}}$	Soft breaking sfermion masses
$m_A(Q_i)^{\overline{\mathrm{DR}}}$	Running A mass.

In v1 writeup / In v2 writeup (& JHEP): JHEP 0407:036,2004

Conventions & Consistency

3. Communicating the Spectrum: mixing matrices

- mixing angles avoided, matrix elements given instead.

$$T = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} = \begin{pmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{pmatrix}$$

- No consensus on best 'scheme' $\rightarrow$

  Effective 'best choice' definitions, at the discretion of each spectrum calculator.

E.g. α: Diagonalizes loop–corrected mass matrices, but not a $\overline{\mathrm{DR}}$ or $\overline{\mathrm{MS}}$ parameter. Still, not scale independent. On–shell scheme has scale fixed by renormalization conditions, and external propagators still carry some momentum, which momentum?

Example SLHA spectrum

```
# SUSY Les Houches Accord 1.0
# Example spectrum file - Snowmass point 1a
Block SPINFO          # Program information
     1    SOFTSUSY    # spectrum calculator
     2    1.8.4       # version number
Block MODSEL  # Select model
     1    1   # sugra
Block MINPAR  # Input parameters
     1    1.000000000e+02   # m0
     2    2.500000000e+02   # m12
     3    1.000000000e+01   # tanb
     4    1.000000000e+00   # sign(mu)
     5   -1.000000000e+02   # A0
Block SMINPUTS # SM parameters
     1    1.279340000e+02   # 1/alpha(MZ)[MSbar]
     2    1.166370000e-05   # Gmu [GeV**-2]
     3    1.172000000e-01   # alphas(MZ)[MSbar]
     4    9.118760000e+01   # Z pole mass
     5    4.250000000e+00   # mb(mb)[MSbar]
     6    1.743000000e+02   # t pole mass
     7    1.777000000e+00   # tau pole mas
Block MASS   # Mass spectrum (pole masses)
         24     8.024639840e+01   # W
         25     1.106368320e+02   # h0
         35     4.008746040e+02   # H0
         36     4.005062720e+02   # A0
         37     4.087847760e+02   # H+
    1000001     5.537379281e+02   # sd(L)
    1000002     5.480648005e+02   # su(L)
    1000003     5.536689385e+02   # ss(L)
    1000004     5.479950083e+02   # sc(L)
    1000005     4.990864878e+02   # sb(1)
    1000006     3.866681125e+02   # st(1)
    1000011     2.005077001e+02   # se(L)
    1000012     1.844822029e+02   # snue(L)
    1000013     2.005050044e+02   # smu(L)
    1000014     1.844792730e+02   # snumu(L)
    1000015     1.339969762e+02   # stau(1)
    1000016     1.836242253e+02   # snu(tau(L))
    1000021     5.934756712e+02   # gluino
    1000022     9.701573617e+01   # neutralino(1)
    1000023     1.788864799e+02   # neutralino(2)
    1000024     1.782649096e+02   # chargino(1)
```

```
    1000025    -3.536102287e+02   # neutralino(3)
    1000035     3.733417082e+02   # neutralino(4)
    1000037     3.736128390e+02   # chargino(2)
    2000001     5.269676664e+02   # sd(R)
    2000002     5.311251030e+02   # su(R)
    2000003     5.269652151e+02   # ss(R)
    2000004     5.309795680e+02   # sc(R)
    2000005     5.257115262e+02   # sb(2)
    2000006     5.704560875e+02   # st(2)
    2000011     1.430886701e+02   # se(R)
    2000013     1.430810123e+02   # smu(R)
    2000015     2.043832731e+02   # stau(2)
Block alpha # Effective Higgs mixing angle alph
         -1.146864127e-01   # alpha
Block hmix Q= 4.520624648e+02   # DRbar Higgs mi
     1     3.439934743e+02   # mu
Block stopmix   # stop mixing matrix
  1  1     5.443784304e-01   # O(1,1)
  1  2     8.388397490e-01   # O(1,2)
  2  1     8.388397490e-01   # O(2,1)
  2  2    -5.443784304e-01   # O(2,2)
Block sbotmix   # sbottom mixing matrix
  1  1     9.355024721e-01   # O(1,1)
  1  2     3.533201449e-01   # O(1,2)
  2  1    -3.533201449e-01   # O(2,1)
  2  2     9.355024721e-01   # O(2,2)
Block staumix   # stau mixing matrix
  1  1     2.810947184e-01   # O(1,1)
  1  2     9.596800297e-01   # O(1,2)
  2  1     9.596800297e-01   # O(2,1)
  2  2    -2.810947184e-01   # O(2,2)
# Gaugino-higgsino mixing
Block nmix   # neutralino mixing matrix
  1  1     9.849417415e-01   # N(1,1)
  1  2    -5.795970738e-02   # N(1,2)
  1  3     1.526931274e-01   # N(1,3)
  1  4    -5.670314904e-02   # N(1,4)
  2  1     1.090115410e-01   # N(2,1)
  2  2     9.374300545e-01   # N(2,2)
  2  3    -2.852021039e-01   # N(2,3)
  2  4     1.673354023e-01   # N(2,4)
...
```

Conclusions from Durham Meeting

We have agreed to: Conserve colour, charge, and spin!

- $\rightarrow$ add (optional) new LARGE mixing blocks which in principle can deal with all possible consequences of CPV, RPV, etc. (normally will be block-diagonal to a large extent.)
- Include (option for) giving either effective (loop-improved) mixing matrices OR mixing in $\overline{\mathrm{DR}}$ scheme at a given scale.
- Include imaginary parts in new mixing structure.
- Conventions for NMSSM adopted, for CPV underway.
- Theory errors: highly non-trivial issue. Sub-group organised by K. Desch & W. Porod to investigate solutions.
- Cross sections: even more thorny issue. No general concensus yet — but strong interest from SPA project for e^+e^- case.

Session tuesday 11:00

Topics discussed at Les Houches '05

- Input:
  - CPV:
    - Im{} of AU, AD, AE, M1, M2, M3, mu (not Yukawas)
  - RPV:
    - Superpotential terms: WLLE, WLQD, WUDD, WLH
    - Soft terms: ALLE, ALQD, AUDD, BLH
  - FLV:
    - Diagonal soft entries in EXTPAR -> Matrices: MQ2, MU2, MD2, ML2, ME2 (complex)

Topics discussed at Les Houches '05

- CPV -> mass degeneracy between Real and Imaginary sneutrinos split -> need separate PDG codes for Imaginary sneutrinos: 1000017, 1000018, 1000019 ??
- For new mixing structure, need unique enumerations of
  - mass eigenstate basis
  - flavour/current eigenstate basis
- (General: definitions should reduce intuitively to case of CP, RP etc conserving MSSM.)

Mass and Flavour bases

(proposals)

- General mixing (mass <-> flavour) between:
  - Charged colour-singlet fermions (charged leptons, charginos)
  - Neutral colour-singlet fermions (neutrinos, neutralinos)
  - Charged colour-singlet scalars (sleptons, H+)
  - Neutral colour-singlet scalars (sneutrinos, h0, H0, A0)
  - Colour triplet up-type scalars (all generations)
  - Colour triplet down-type scalars (all generations)
  - So far quark sector not discussed.

Mass and Flavour bases

(proposals)

- Charged colour-singlet fermions

mixing matrix:
m_i = U_ij f_j

Flavour basis

e+	= e+ flavour eigenstate
mu+	= mu+ -”-
tau+	= tau+ -”-
-i ~w+	= charged wino
~h2+	= charged higgsino (up-type)

Mass basis (PDG codes), ordered to reduce to “normal” case:

-11 (e+)	= state that has biggest component of e+		
-13 (mu+)	=	-”-	mu+
-15 (tau+)	=	-”-	tau+
1000027 (chi1+)	= lightest chargino-like state		
1000037 (chi2+)	= heaviest chargino-like state		

NB: Mass basis ordered by **flavour content**, not by increasing mass!

Mass and Flavour bases
(proposals)

mixing matrix:
m_i = U_ij f_j

- Neutral colour-singlet fermions

Flavour basis

nu_e	= nu_e flavour eigenstate
nu_mu	= nu_mu -”-
nu_tau	= nu_tau -”-
-i ~b	= bino
-i ~w3	= neutral wino
~h1	= neutral higgsino 1 (down-type)
~h2	= neutral higgsino 2 (up-type)

Mass basis (PDG codes), ordered to reduce to “normal” case:

12 (nu_e)	= state that has biggest component of nu_e
14 (nu_mu)	= -”- nu_mu
16 (nu_tau)	= -”- nu_tau
1000022 (chi1)	= lightest neutralino-like state
1000023 (chi2)	= 2nd lightest neutralino-like state
1000025 (chi3)	= 3rd lightest neutralino-like state
1000035 (chi4)	= 4th lightest neutralino-like state

Mass and Flavour bases

(proposals)

mixing matrix:
m_i = U_ij f_j

- Charged colour-singlet scalars

Flavour basis

~eL+	= ~eL+ flavour eigenstate
~eR+	= ~eL+ flavour eigenstate
~muL+	= ~muL+ -”-
~muR+	= ~muR+ -”-
~tauL+	= ~tauL+ -”-
~tauR+	= ~tauR+ -”-
H+	= charged Higgs

Mass basis (PDG codes), ordered to reduce to “normal” case:

1000011 (~eL+)	= state that has biggest component of ~eL+
2000011 (~eR+)	= state that has biggest component of ~eR+
1000013 (~muL+)	= -”- ~muL+
2000013 (~muR+)	= -”- ~muR+
1000015 (~tau1+)	= lightest stau-like mass eigenstate
2000015 (~tau2+)	= heaviest stau-like mass eigenstate
37 (H+)	= state that has biggest component of H+

Mass and Flavour bases

(proposals)

- Neutral colour-singlet scalars

mixing matrix:
m_i = U_ij f_j

Flavour basis

h1	= CP-even higgs 1 (down-type)
h2	= CP-even higgs 2 (up-type)
a0	= CP-odd higgs
Re{~nu_[e,mu,tau]L}	= CP-even ~nu_L flavour states (e,mu,tau)
Im{~nu_[e,mu,tau]L}	= CP-odd ~nu_L flavour states (e,mu,tau)

Mass basis (PDG codes), ordered to reduce to “normal” case:

25 (h0)	= lightest dominantly CP-even higgs-like state ?
35 (H0)	= heaviest dominantly CP-even higgs-like state ?
36 (A0)	= state that has biggest component of a0 ?
1000012 (~nu_eL)	= ?
1000014 (~nu_muL)	= ?
1000016 (~nu_tauL)	= ?
1000017	= ?
1000018	= ?
1000019	= ?

Mass and Flavour bases

(proposals)

- Squarks:
  - Similar to uncoloured sectors.
  - Ie not Super-CKM or similar. (CKM-like matrix can always be derived from more elementary mass <-> flavour map.)
  - Input from flavour discussion? Wishes, pitfalls?

mixing matrix:
m_i = U_ij f_j

Other projects - 1/3

- Tools for **Extra Dimensions**
  - Introduce, review, and collect a repository of available tools. (Top of wishlist presented by de Roeck)
  - Validating, esp private and semi-public tools
  - Towards standardization & benchmarks?
  - Cross sections, Dark Matter (MicrOmegas)
  - UED in Sdecay?
  - Large final states (RS CompHEP <-> MadGraph)

[Ferrag, Muanza, Kraml, de Roeck, Przysiezniak-Frey, Azuelos, Skands, Grojean, Miakov?, Karim, Belanger, Pukhov, Semenov, Savant, Giacomo, Pape, Balazs,Dominici, Kazana, Lykken, Matchev?, Alemany, Besancon, Dobrescu, Gustavo, Eduardo,]

Other projects - 2/3

- Event Generator(s) for **NMSSM**
  - NMSSM in NMHDecay, CalcHEP, MicrOmegas
  - + Being implemented in SPheno
  - Still no working event generator
  - Aim here to establish chain:
    - Scattering by CompHEP -> Les Houches event files
    - Decay tables by CompHEP, NMHDecay, Spheno
    - Event file + decay tables read by PYTHIA -> events
    - (+ validate against existing HERWIG and PYTHIA hacks)

Hugonie, Skands, Moretti, Kraml, Zerwas, Heinemeyer, Weiglein, Pukhov, Belanger, Porod

Other projects - 3/3

- Event Generator(s) for **CPV**
  - Complex neutralino + chargino mixing in PYTHIA, but rarely used -> validate? (still, spin correllations missing)
  - Spheno, SHERPA, CompHEP intrinsically complex, but CPV never yet really studied.
  - FeynHiggs & CPSuperH do CPV.
  - Status of Susygen not clear.
  - CPnSH project (cf Kraml) -> tools needed, but so far no major initiatives at Les Houches.

Kraml, Heinemeyer, Weiglein, Mrenna, Schumacher,Richardson, Schumann, Pukhov, Porod