Flavour in the Era of the LHC, CERN, MAy 15-17 2006

Discussion on the SUSY Les Houches Accord 2 project

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RPV, CPV, FLV, NMSSM, THEORY ERRORS,

CROSS SECTIONS, GENERAL BSM RESONANCES, …

Outline

- SLHA1 – brief overview
- SLHA2:
  - SUSY CONVENTIONS – HOW TO GENERALISE?
    - Model definition
    - MSSM w/ Flavour Violation
    - MSSM w/ R-parity Violation
    - MSSM w/ CP Violation (?)
    - NMSSM (?)
  - CROSS SECTIONS AND THEORY ERRORS
  - OTHER EXTENSIONS
    - Well-defined mixing Matrices
    - General BSM Resonances - QNUMBERS

SUSY Les Houches Accord v1

SUSY MODEL —input→ **SPECTRUM CALCULATOR** —spectrum→ **MC EVENT GEN / XS CALCULATOR**

SUSY MODEL:
- ✓MSSM
- ✓SUGRA
- ✓GMSB
- ✓AMSB
- ☒NMSSM
- ☒RPV
- ☒CPV
- ☒FLV
- …

SPECTRUM CALCULATOR:
- CPSUPERH
- ✓FEYNHIGGS
- ✓ISASUSY
- ✓NMHDECAY
- ✓SOFTSUSY
- ✓SPHENO
- ✓SUSPECT
- …

MC EVENT GEN / XS CALCULATOR:
- ✓CALC/COMPHEP
- AF'S SLEPTONS
- GRACE
- HERWIG (++)
- ISAJET
- ✓PROSPINO
- ✓PYTHIA
- ✓SHERPA
- ✓SMADGRAPH
- SUSYGEN
- ✓WHIZARD
- …

SPECTRUM CALCULATOR —spectrum→ **CDM PACKAGE**:
- MICRΩS✓
- DARKSUSY
- NEUTDRIVER
- PLATON (?)

SPECTRUM CALCULATOR —spc→ **DECAY PACKAGE** —spc+dec→ MC EVENT GEN / XS CALCULATOR

DECAY PACKAGE:
- ✓FEYNHIGGS
- ✓FCHDECAY
- HDECAY
- ✓NMHDECAY
- ✓SDECAY
- ✓SPHENO

FITTERS: FITTINO✓, SFITTER✓

+ F77 I/O Library by T.✓ Hahn (now also SLHA2)

Example SLHA Spectrum

```
Block SPINFO          # Program information
     1    SOFTSUSY    # spectrum calculator
     2    1.9.1       # version number
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)MSbar
     4     9.11876000e+01   # MZ(pole)
     5     4.25000000e+00   # Mb(mb)
     6     1.74300000e+02   # Mtop(pole)
     7     1.77700000e+00   # Mtau(pole)
Block MINPAR  # SUSY breaking input parameters
     3     1.00000000e+01   # tanb
     4     1.00000000e+00   # sign(mu)
     1     1.00000000e+02   # m0
     2     2.50000000e+02   # m12
     5    -1.00000000e+02   # A0
# Low energy data in SOFTSUSY: MIXING=-1 TOLERANCE=1.000
# mgut=2.45916471e+16 GeV
Block MASS   # Mass spectrum
#PDG code        mass                  particle
        24     8.04191121e+01    # MW
        25     1.10762378e+02    # h0
        35     4.00599584e+02    # H0
        36     4.00231463e+02    # A0
        37     4.08513284e+02    # H+
   1000001     5.72700955e+02    # ~d_L
   1000002     5.67251814e+02    # ~u_L
   1000003     5.72700955e+02    # ~s_L
   1000004     5.67251814e+02    # ~c_L
   1000005     5.15211952e+02    # ~b_1
   1000006     3.95920984e+02    # ~t_1
   1000011     2.04276615e+02    # ~e_L
   1000012     1.88657729e+02    # ~nue_L
   1000013     2.04276615e+02    # ~mu_L
   1000014     1.88657729e+02    # ~numu_L
   1000015     1.36227147e+02    # ~stau_1
   1000016     1.87773326e+02    # ~nu_tau_L
   1000021     6.07604198e+02    # ~g
   1000022     9.72852615e+01    # ~neutralino(1)
   1000023     1.80961862e+02    # ~neutralino(2)
   1000024     1.80378828e+02    # ~chargino(1)
   1000025    -3.64435115e+02    # ~neutralino(3)
```

```
Block nmix  # neutralino mixing matrix
  1  1     9.86066377e-01   # N_{1,1}
  1  2    -5.46292061e-02   # N_{1,2}
  1  3     1.47649927e-01   # N_{1,3}
  1  4    -5.37424305e-02   # N_{1,4}
  2  1     1.02062420e-01   # N_{2,1}
  2  2     9.42721210e-01   # N_{2,2}
  2  3    -2.74985600e-01   # N_{2,3}
  2  4     1.58880154e-01   # N_{2,4}
  3  1    -6.04575099e-02   # N_{3,1}
  3  2     8.97030908e-02   # N_{3,2}
  3  3     6.95501068e-01   # N_{3,3}
  3  4     7.10335491e-01   # N_{3,4}
  4  1    -1.16624405e-01   # N_{4,1}
  4  2     3.16616055e-01   # N_{4,2}
  4  3     6.47194471e-01   # N_{4,3}
  4  4    -6.83587843e-01   # N_{4,4}
Block Umix  # chargino U mixing matrix
  1  1     9.15531658e-01   # U_{1,1}
  1  2    -4.02245924e-01   # U_{1,2}
  2  1     4.02245924e-01   # U_{2,1}
  2  2     9.15531658e-01   # U_{2,2}
Block Vmix  # chargino V mixing matrix
  1  1     9.72345994e-01   # V_{1,1}
  1  2    -2.33545003e-01   # V_{1,2}
  2  1     2.33545003e-01   # V_{2,1}
  2  2     9.72345994e-01   # V_{2,2}
Block gauge Q= 4.64231969e+02
     1     3.60968173e-01   # g'(Q)MSSM DRbar
     2     6.46474399e-01   # g(Q)MSSM DRbar
     3     1.09626470e+00   # g3(Q)MSSM DRbar
Block yu Q= 4.64231969e+02
  3  3     8.89731484e-01   # Yt(Q)MSSM DRbar
Block yd Q= 4.64231969e+02
  3  3     1.39732269e-01   # Yb(Q)MSSM DRbar
Block ye Q= 4.64231969e+02
  3  3     1.00914051e-01   # Ytau(Q)MSSM DRbar
Block hmix Q= 4.64231969e+02  # Higgs mixing parameters
     1     3.58339654e+02   # mu(Q)MSSM DRbar
     2     9.75145219e+00   # tan beta(Q)MSSM DRbar
     3     2.44923803e+02   # higgs vev(Q)MSSM DRbar
     4     1.67100152e+05   # mA^2(Q)MSSM DRbar
Block msoft Q=4.64231969e+02 # MSSM DRbar SUSY breaking
     1     1.01439997e+02   # M_1(Q)
     2     1.91579315e+02   # M_2(Q)
     3     5.86586195e+02   # M_3(Q)
    21     3.23914077e+04   # mH1^2(Q)
```

How to Generalise? MSSM

2. Superpotential (at scale Q (normally M_{GUT}) in DRbar)

RPV

CPV

FLV

$$W = \epsilon_{ab}\left[(Y_E)_{ij} H_1^a L_i^b \bar{E}_j + (Y_D)_{ij} H_1^a Q_i^b \bar{D}_j + (Y_U)_{ij} H_2^b Q_i^a \bar{U}_j + \frac{1}{2}\lambda_{ijk} L_i^a L_j^b E_k + \lambda'_{ijk} L_i^a Q_j^b D_k - \epsilon_i L_i^a H_2^b - \mu H_1^a H_2^b\right] + \frac{1}{2}\lambda''_{ijk} U_i D_j D_k$$

3. SUSY Breaking Terms (at scale Q in DRbar)

$$V_3 = \epsilon_{ab}\sum_{ij}\left[(T_E)_{ij} H_1^a \tilde{L}_{i_L}^b \tilde{e}_{j_R}^* + (T_D)_{ij} H_1^a \tilde{Q}_{i_L}^b \tilde{d}_{j_R}^* - (T_U)_{ij} H_2^b \tilde{Q}_{i_L}^a \tilde{u}_{j_R}^* + \frac{1}{2}(T_\lambda)_{ijk} \tilde{L}_{i_L}^a \tilde{L}_{j_L}^b \tilde{e}_{k_R}^* + (T_{\lambda'})_{ijk} \tilde{L}_i^a \tilde{Q}_j^b \tilde{d}_{k_R}^*\right] + \frac{1}{2}(T_{\lambda''})_{ijk} \tilde{u}_{i_R}^* \tilde{d}_{j_R}^* \tilde{d}_{k_R}^* + h.c.$$

$$V_2 = m_{H_1}^2 H_{1a}^* H_1^a + m_{H_2}^2 H_{2a}^* H_2^a + \tilde{Q}_{i_La}^* (m_{\tilde{Q}}^2)_{ij} \tilde{Q}_{j_L}^a + \tilde{L}_{i_La}^* (m_{\tilde{L}}^2)_{ij} \tilde{L}_{j_L}^a + \tilde{u}_{i_R} (m_{\tilde{u}}^2)_{ij} \tilde{u}_{j_R}^* + \tilde{d}_{i_R} (m_{\tilde{d}}^2)_{ij} \tilde{d}_{j_R}^* + \tilde{e}_{i_R} (m_{\tilde{e}}^2)_{ij} \tilde{e}_{j_R}^* - \epsilon_{ab}(m_3^2 H_1^a H_2^b + D_i L_i^a H_2^b + m_{L_iH} L_i^a H_1^b + h.c.)\ .$$

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

How to Generalise? Model Definition

- <u>Additions</u> to global switches in block **MODSEL**:

  3) Choice of particle content
  - **0:** MSSM (default)
  - **1:** NMSSM ←

  4) R-parity violation
  - **0:** R-parity conserved (default)
  - **1:** R-parity violated

  5) CP violation
  - **0:** CP conserved (default)
  - **1:** CP violated but only by CKM phase
  - **2:** CP violated, general phases allowed

  6) Flavour violation ←
  - **0:** No (SUSY) flavour violation (default)
  - **1:** Flavour violated

Q: Is one model sufficient for NMSSM, nMSSM, MNMSSM, …

In principle the models are qualitatively different, but still … same particle content?

Q: Is this adequate?

NB: For SLHA2 we are keeping RPV, CPV, and FLV ~ separate

How to Generalise? FLV

- **SUPER-CKM BASIS:**
  - defined as basis in which quark Yukawas, in DRbar, are diagonal
  - NB: lepton mixing not treated yet (though see RPV).
- **INPUT**
  - **VCKMIN**: V_{CKM} in PDG parametrisation (SM MSbar at M_Z).
  - **SMINPUTS**: Include $m_{u,d,s}(2\text{GeV})^{MSbar}$ and $m_c(m_c)^{MSbar}$
  - NB: no explicit proposal yet for input of non-diagonal soft SUSY-breaking trilinear and bilinear terms, e.g. **MSQ2IN**, **MSU2IN**, **MSD2IN?**
- **LAGRANGIAN PARAMETERS** (all DRbar at scale **Q**) :
  - Yukawas: Super-CKM basis → always diagonal (but same blocks as SLHA1)
  - **VCKM** and bilinear SUSY-breaking **MSQ2**, **MSU2**, **MSD2** matrices
  - Matrices are symmetric: Give **only** i<j entries of M_{ij}? ← see next:: (Jaume)
  - Or entire matrix i ≤ j ? (i=j already in EXTPAR → inconsistencies?)
  - Hermiticity ➔ MSQ2(i,j)=MSQ2(j,i)* → keep these matrices real?

How to Generalise? FLV

- **EW SCALE MIXING**:
  - **USQMIX**: 6x6 up-squark mixing in super-CKM basis
  - **DSQMIX**: 6x6 down-squark mixing in super-CKM basis
- Problem: which quark is which? Enumeration of mass eigenstates.
- **(from Jaume):** *"Particle codes: we have taken the following convention: squarks ordered in growing mass, the PDG codes for squarks are used:"*

FCHDECAY
fchdecay.googlepages.com

Down squarks: PDG code	Up squarks: PDG Code
1000001 d_1	1000002 u_1
1000003 d_2	1000004 u_2
1000005 d_3	1000006 u_3
2000001 d_4	2000002 u_4
2000003 d_5	2000004 u_5
2000005 d_6	2000006 u_6

Main Issue:
PDG (no-mixing limit):

1000001 d_L	1000002 u_L
1000003 s_L	1000004 c_L
1000005 b_1	1000006 t_1
2000001 d_R	2000002 u_R
2000003 s_R	2000004 c_R
2000005 b_2	2000006 t_2

How to Generalise? RPV

- **INPUT**
  - New input blocks for all RPV superpotential parameters, soft-breaking parameters, and sneutrino vevs (prefix "**RV**" and suffix "**IN**")
- **LAGRANGIAN PARAMETERS** (DRbar at scale **Q**) :
  - New output blocks for all RPV parameters (prefix "**RV**")
- **POLE MASSES**
  - "new" sneutrinos:
  - **1000017, 1000018,1000019**
- **EW SCALE MIXING:**
  - **RVNMIX**: 7x7 neutralino/neutrino
  - **RVHMIX**: 5x5 CP-even H/sneutrino
  - **RVAMIX**: 5x5 CP-odd H/sneutrino
  - **RVLMIX**: 8x8 Charged H/slepton
  - **RVUMIX, RVVMIX**: 5x5 chargino/lepton

Input block	Output block	data
RVLAMBDAIN	RVLAMBDA	$i\ j\ k\ \lambda_{ijk}$
RVLAMBDAPIN	RVLAMBDAP	$i\ j\ k\ \lambda'_{ijk}$
RVLAMBDAPPIN	RVLAMBDAPP	$i\ j\ k\ \lambda''_{ijk}$
RVKAPPAIN	RVKAPPA	$i\ \kappa_i$
RVAIN	RVA	$i\ j\ k\ A_{ijk}$
RVAPIN	RVAP	$i\ j\ k\ A'_{ijk}$
RVAPPIN	RVAPP	$i\ j\ k\ A''_{ijk}$
RVDIN	RVD	$i\ D_i$
RVSNVEVIN	RVSNVEV	$i\ v_i$
RVMLH1SQIN	RVMLH1SQ	$i\ m^2_{\tilde{L}_i H_1}$

example… →

How to Generalise? RPV

- Mixing Example: Charged colour-singlet fermions

Flavour basis

e^+	= e^+ flavour eigenstate
mu^+	= mu^+ -”-
tau^+	= tau^+ -”-
-i $\sim w^+$	= charged wino
$\sim h2^+$	= charged higgsino (up-type)

Mass basis (PDG numbers), strictly mass-ordered:

-11 (e^+)	= lightest state (regardless of composition!)
-13 (mu^+)	= 2nd lightest
-15 (tau^+)	= 3rd lightest
1000027 ($chi1^+$)	= …
1000037 ($chi2^+$)	= heaviest charged colour-singlet fermion

NB: currently using U,V mixing etc for each sector separately and not “Super-MNS” for leptons/Higgses. Need to discuss?

How to Generalise? CPV

- **SIMPLEST WAY**
  - Add prefix "**IM**" to already existing SLHA1 blocks
  - E.g. in input: **IMEXTPAR**; in output: **IMNMIX** etc …
  - Not completely general, but useful starting point
- **MORE GENERAL**
  - Add prefix "**IM**" to new SLHA2 blocks (supersede SLHA1 if present)
- **EW SCALE MIXING:**
  - **CVHMIX**: 4x4 neutral Higgs (CP-even & CP-odd) mixing
  - **IMCVHMIX**: imaginary parts
  - Charged Higgs mixing (2x2) not yet agreed upon

How to Generalise? NMSSM

Cf. NMHDecay,
Ellwanger, Gunion, Hugonie

2. **Superpotential** (at scale Q (normally M_{GUT}) in DRbar) **NMSSM**

$$W = W_{MSSM} + \lambda \epsilon_{ab} S H_1^a H_2^b + \frac{\kappa}{3} S^3$$

(usually with μ_{MSSM}=0)

3. **SUSY Breaking Terms** (at scale Q in DRbar)

$$V_3 = V_{3,MSSM} + (\epsilon_{ab} \lambda A_\lambda S H_1^a H_2^b + h.c.) + \frac{\kappa}{3} A_\kappa S^3,$$

$$V_2 = V_{2,MSSM} + m_S^2 S^2$$

EXTPAR:
61) lambda
62) kappa
63) A_lambda
64) A_kappa
65) mu_eff=lambda<S>

4. **Physical Spectrum**

- 3 H^0 (PDG: 25,35,45), 2 A^0 (PDG: 36, 46), 5χ^0 (PDG: 1000045)
- Mixing: **NMHMIX** **NMAMIX** **NMNMIX**

See also MicrOMEGAs & CalcHEP
+ Interface to PYTHIA

Cross Sections & Theory Errors

NB: Not included in current LH status report

- Theory Errors
  - Introduce (unphysical) input variables corresponding to variations within theoretical uncertainty -> range of spectra. (Similar in spririt to error PDF's)
  - Calculation of observables from spectrum → +/- errors on computed variables
- Cross Sections used by fit programs **Fittino, Sfitter**
  - Templated in SPheno. Collecting experiences now.

These (and more?) to be included in journal writeup

Including (possibility for) well-defined mixing matrices

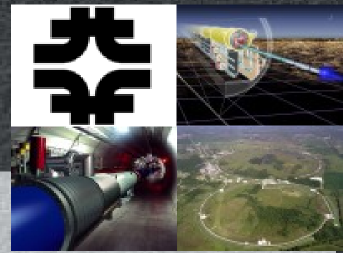
- **In SLHA1**, exact definition of mixing matrices was "left up to RGE program" (since the only thing we could agree on was not to agree …)
  - **Read the individual manual**
    - DRbar at some scale m? ($m^2_{SUSY} = m_{t1}m_{t2}$, $m = (m_h + m_H)/2$, …)
    - On-shell ?
    - Etc …
  - **Not a huge problem**
    - DRbar Lagrangian parameters also given
    - → can always construct desired mixing structure

- **Still**, would be nice to have possibility for exact definition
  - Include option for giving DRbar mixing matrices at scale Q:

e.g. BLOCK NMIX Q=…	or	BLOCK DRNMIX Q=…
		BLOCK NMIXDR Q=…

MC4BSM Workshop

Monte Carlo Tools for Beyond-the-Standard-Model Physics. March 20-21 2006. Fermilab



- **MC4BSM:** first workshop to focus explicitly on tools for non-SUSY BSM:
  - Survey what is available: communication + feedback
  - Identify promising models and start to fill up the gaps
  - Streamlining the process of going from models to events

- **One question that came up:**
  - Successive resonance decays of general new physics resonances?
  - Can be done with SLHA decay tables, just add basic information about particle
  - → **Proposal for SLHA2. BLOCK QNUMBERS (or PARTICLE?)**

```
BLOCK QNUMBERS 1234567 # new_guy PDG=1234567
        1 0  # 3 times electric charge
        2 2  # number of spin states (2S+1)
        3 1  # colour rep (1: singlet, 3: triplet, 8: octet)
        4 0  # Particle/Antiparticle distinction (0=own anti)
BLOCK MASS  # Mass Spectrum
   1234567  3.1415926535E+02  # new_guy
DECAY   1234567   1.000000E+00 # new_guy width
   1.0000E-00 2       22       22 # Br(new_guy -> gamma gamma)
```

- (→ Already used to interface CalcHEP, NMHDecay, and PYTHIA, for the NMSSM)

Outlook

- 'Conceptual Design Report' for SLHA2 in Les Houches BSM Proceedings, hep-ph/0602198 concerns core SLHA2 conventions.
- More extensive writeup to follow in 2006. To discuss:
  - Flavour in the Era of the LHC, CERN, May 15-17, 2006 (flavour)
  - Tools 2006, Annecy, Jun 26-28, 2006
  - MC4LHC, CERN, Jul 17-26, 2006
  - MC4BSM, Gainesville, FL, Winter 06/07
- See also Les Houches BSM tools repository: http://www.ippp.dur.ac.uk/montecarlo/BSM

Work 1

$$W_{MSSM} = \epsilon_{ab}\left[(Y_E)_{ij} H_1^a L_i^b E_j + (Y_D)_{ij} H_1^a Q_i^b D_j + (Y_U)_{ij} H_2^b Q_i^a U_j - \mu H_1^a H_2^b\right]$$

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

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

$$L_G = \frac{1}{2}\left(M_1 \tilde{b}\tilde{b} + M_2 \tilde{w}^A \tilde{w}^A + M_3 \tilde{g}^X \tilde{g}^X\right) + h.c. :$$

Work 2

$$W = \epsilon_{ab}\Big[(Y_E)_{ij} H_1^a L_i^b \bar{E}_j + (Y_D)_{ij} H_1^a Q_i^b \bar{D}_j + (Y_U)_{ij} H_2^b Q_i^a \bar{U}_j + \frac{1}{2}\lambda_{ijk} L_i^a L_j^b E_k + \lambda'_{ijk} L_i^a Q_j^b D_k - \epsilon_i L_i^a H_2^b - \mu H_1^a H_2^b\Big] + \frac{1}{2}\lambda''_{ijk} U_i D_j D_k$$

$$V_3 = \epsilon_{ab} \sum_{ij} \Big[(T_E)_{ij} H_1^a \tilde{L}_{iL}^b \tilde{e}_{jR}^* + (T_D)_{ij} H_1^a \tilde{Q}_{iL}^b \tilde{d}_{jR}^* + (T_U)_{ij} H_2^b \tilde{Q}_{iL}^a \tilde{u}_{jR}^* + \frac{1}{2}(T_\lambda)_{ijk} \tilde{L}_{iL}^a \tilde{L}_{jL}^b \tilde{e}_{kR}^* + (T_{\lambda'})_{ijk} \tilde{L}_i^a \tilde{Q}_j^b \tilde{d}_{kR}^* \Big] + \frac{1}{2}(T_{\lambda''})_{ijk} \tilde{u}_{iR}^* \tilde{d}_{jR}^* \tilde{d}_{kR}^* + h.c.$$

$$V_2 = m_{H_1}^2 H_{1a}^* H_1^a + m_{H_2}^2 H_{2a}^* H_2^a + \tilde{Q}_{iLa}^* (m_{\tilde{Q}}^2)_{ij} \tilde{Q}_{jL}^a + \tilde{L}_{iLa}^* (m_{\tilde{L}}^2)_{ij} \tilde{L}_{jL}^a + \tilde{u}_{iR} (m_{\tilde{u}}^2)_{ij} \tilde{u}_{jR}^* + \tilde{d}_{iR} (m_{\tilde{d}}^2)_{ij} \tilde{d}_{jR}^* + \tilde{e}_{iR} (m_{\tilde{e}}^2)_{ij} \tilde{e}_{jR}^* - \epsilon_{ab}(m_3^2 H_1^a H_2^b + D_i L_i^a H_2^b + m_{L_iH} L_i^a H_1^b + h.c.) .$$

$$L_G = \frac{1}{2}\left(M_1 \tilde{b}\tilde{b} + M_2 \tilde{w}^A \tilde{w}^A + M_3 \tilde{g}^X \tilde{g}^X \right) + h.c. .$$

Work 3

$$W = W_{MSSM} + \lambda \epsilon_{ab} S H_1^a H_2^b + \frac{\kappa}{3} S^3$$

$$V_3 = V_{3,MSSM} + (\epsilon_{ab} \lambda A_\lambda S H_1^a H_2^b + h.c.) + \frac{\kappa}{3} A_\kappa S^3,$$

$$V_2 = V_{2,MSSM} + m_S^2 S^2$$

Conclusions

Tough conditions call for good tools! We will be ready for NMSSM, CPV, RPV, FLV, …

Then all we need is a signal …

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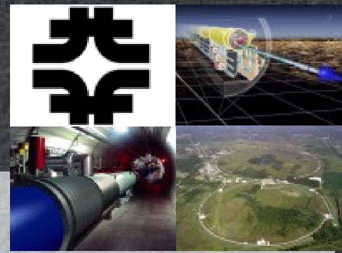

- Many new models of New Physics emerged over last few years:
  - e.g. Extra Dimensions, new technicolor-like models, Higgsless, Little Higgs, gauge and/or matter extensions to MSSM, ...
  - Many of these imply qualitatively new phenomenological signatures
  - The rest imply a possible experimental confusion with existing models

• MSSM has been useful benchmark scenario to test experimental and phenomenological strategies for a long time

– Now increasing focus on non-MSSM signatures + how we could get confused

–Many advanced tools exist to study all aspects of MSSM phenomenology in detail (dark matter, electroweak precision, cross sections, decay widths, NLO, spin correllations, event generators, …) + most use SUSY Les Houches Accord (now being extended to CPV, RPV, FLV, NMSSM)

– For non-MSSM BSM much fewer / less sophisticated tools

The SLHA1 Conventions

1. **Experimental boundary conditions**
   - "SM" gauge couplings and Yukawas (measured)
   - → "MSSM" couplings and Yukawas (not the same, since different field content → different quantum corrections)

2. **Superpotential** (at scale Q (normally M_{GUT}) in DRbar)

1

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

3. **SUSY Breaking Terms** (at scale Q in DRbar)

A

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

m_0

$$V_2 = m_{H_1}^2 H_{1a}^{*} H_1^a + m_{H_2}^2 H_{2a}^{*} H_2^a + \tilde{Q}_{i_L a}^{*}(m_{\tilde{Q}}^2)_{ij}\tilde{Q}_{j_L}^a + \tilde{L}_{i_L a}^{*}(m_{\tilde{L}}^2)_{ij}\tilde{L}_{j_L}^a +$$

m_A

$$\tilde{u}_{iR}(m_{\tilde{u}}^2)_{ij}\tilde{u}_{jR}^* + \tilde{d}_{iR}(m_{\tilde{d}}^2)_{ij}\tilde{d}_{jR}^* + \tilde{e}_{iR}(m_{\tilde{e}}^2)_{ij}\tilde{e}_{jR}^* - (m_3^2\epsilon_{ab}H_1^a H_2^b + h.c.)\ .$$

$M_{\frac{1}{2}}$

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