Physics setup

DarkSUSY 4.2
(pre-release, trunk @ rev 231)

DarkSUSY day, Stockholm, June 16, 2008

Supersymmetric models

- Input parameters at EW scale (MSSM), or
- Input parameters at GUT scale (mSUGRA)
- Higgs sector with FeynHiggs
- Higgs decay widths from Hdecay
- mSUGRA interfaces: ISASUGRA
- Les Houches Accord 2 currently being implemented

SUSY model setup

We work in the framework of the minimal $N = 1$ supersymmetric extension of the standard model defined by, besides the particle content and gauge couplings required by supersymmetry, the superpotential

$$W = \epsilon_{ij}\left(-\hat{\mathbf{e}}_R^*\mathbf{Y}_E\hat{\mathbf{l}}_L^i\hat{H}_1^j - \hat{\mathbf{d}}_R^*\mathbf{Y}_D\hat{\mathbf{q}}_L^i\hat{H}_1^j + \hat{\mathbf{u}}_R^*\mathbf{Y}_U\hat{\mathbf{q}}_L^i\hat{H}_2^j - \mu\hat{H}_1^i\hat{H}_2^j\right) \tag{2}$$

and the soft supersymmetry-breaking potential

$$\begin{aligned} V_{\rm soft} \;=\;& \epsilon_{ij}\left(-\tilde{\mathbf{e}}_R^*\mathbf{A}_E\mathbf{Y}_E\tilde{\mathbf{l}}_L^iH_1^j - \tilde{\mathbf{d}}_R^*\mathbf{A}_D\mathbf{Y}_D\tilde{\mathbf{q}}_L^iH_1^j + \tilde{\mathbf{u}}_R^*\mathbf{A}_U\mathbf{Y}_U\tilde{\mathbf{q}}_L^iH_2^j - B\mu H_1^iH_2^j + \text{h.c.}\right) \\ & + H_1^{i*}m_1^2H_1^i + H_2^{i*}m_2^2H_2^i \\ & + \tilde{\mathbf{q}}_L^{i*}\mathbf{M}_Q^2\tilde{\mathbf{q}}_L^i + \tilde{\mathbf{l}}_L^{i*}\mathbf{M}_L^2\tilde{\mathbf{l}}_L^i + \tilde{\mathbf{u}}_R^*\mathbf{M}_U^2\tilde{\mathbf{u}}_R + \tilde{\mathbf{d}}_R^*\mathbf{M}_D^2\tilde{\mathbf{d}}_R + \tilde{\mathbf{e}}_R^*\mathbf{M}_E^2\tilde{\mathbf{e}}_R \\ & + \frac{1}{2}M_1\tilde{B}\tilde{B} + \frac{1}{2}M_2\left(\tilde{W}^3\tilde{W}^3 + 2\tilde{W}^+\tilde{W}^-\right) + \frac{1}{2}M_3\tilde{g}\tilde{g}. \end{aligned} \tag{3}$$

Here i and j are SU(2) indices ($\epsilon_{12} = +1$), $\mathbf{Y}$'s, $\mathbf{A}$'s and $\mathbf{M}$'s are 3×3 matrices in generation space, and the other boldface letter are vectors in generation space.

Neutralinos

$$\tilde{\chi}_i^0 = N_{i1}\tilde{B} + N_{i2}\tilde{W}^3 + N_{i3}\tilde{H}_1^0 + N_{i4}\tilde{H}_2^0.$$

$$\mathcal{M}_{\tilde{\chi}^0_{1,2,3,4}} = \begin{pmatrix} M_1 & 0 & -m_Z s_W c_\beta & +m_Z s_W s_\beta \\ 0 & M_2 & +m_Z c_W c_\beta & -m_Z c_W s_\beta \\ -m_Z s_W c_\beta & +m_Z c_W c_\beta & \delta_{33} & -\mu \\ +m_Z s_W s_\beta & -m_Z c_W s_\beta & -\mu & \delta_{44} \end{pmatrix} ;$$

Charginos

$$\mathcal{M}_{\tilde{\chi}^{\pm}} = \begin{pmatrix} M_2 & \sqrt{2} m_W \sin\beta \\ \sqrt{2} m_W \cos\beta & \mu \end{pmatrix},$$

$$\begin{aligned} \tilde{\chi}_i^- &= U_{i1} \tilde{W}^- + U_{i2} \tilde{H}_1^-, \\ \tilde{\chi}_i^+ &= V_{i1} \tilde{W}^+ + V_{i2} \tilde{H}_1^+. \end{aligned}$$

Squarks and sleptons

We then obtain the general 6×6 $\tilde{u}$- and $\tilde{d}$-squark mass matrices:

$$\mathcal{M}^2_{\tilde{u}} = \begin{pmatrix} \mathbf{M}_Q^2 + \mathbf{m}_u^\dagger \mathbf{m}_u + D^u_{LL}\mathbf{1} & \mathbf{m}_u^\dagger(\mathbf{A}_U^\dagger - \mu^* \cot\beta) \\ (\mathbf{A}_U - \mu\cot\beta)\mathbf{m}_u & \mathbf{M}_U^2 + \mathbf{m}_u\mathbf{m}_u^\dagger + D^u_{RR}\mathbf{1} \end{pmatrix}, \tag{26.10}$$

$$\mathcal{M}^2_{\tilde{d}} = \begin{pmatrix} \mathbf{K}^\dagger\mathbf{M}_Q^2\mathbf{K} + \mathbf{m}_d \mathbf{m}_d^\dagger + D^d_{LL}\mathbf{1} & \mathbf{m}_d^\dagger(\mathbf{A}_D^\dagger - \mu^* \tan\beta) \\ (\mathbf{A}_D - \mu\tan\beta)\mathbf{m}_d & \mathbf{M}_D^2 + \mathbf{m}_d^\dagger\mathbf{m}_d + D^d_{RR}\mathbf{1} \end{pmatrix}, \tag{26.11}$$

and the general sneutrino and charged slepton mass matrices

$$\mathcal{M}^2_{\tilde{\nu}} = \mathbf{M}_L^2 + D^\nu_{LL}\mathbf{1} \tag{26.12}$$

$$\mathcal{M}^2_{\tilde{e}} = \begin{pmatrix} \mathbf{M}_L^2 + \mathbf{m}_e \mathbf{m}_e^\dagger + D^e_{LL}\mathbf{1} & \mathbf{m}_e^\dagger(\mathbf{A}_E^\dagger - \mu^* \tan\beta) \\ (\mathbf{A}_E - \mu\tan\beta)\mathbf{m}_e & \mathbf{M}_E^2 + \mathbf{m}_e^\dagger\mathbf{m}_e + D^e_{RR}\mathbf{1} \end{pmatrix}. \tag{26.13}$$

Here

$$D^f_{LL} = m_Z^2 \cos 2\beta (T_{3f} - e_f \sin^2\theta_w), \tag{26.14}$$

$$D^f_{RR} = m_Z^2 \cos 2\beta e_f \sin^2\theta_w. \tag{26.15}$$

In the chosen basis, $\mathbf{m}_u = \mathrm{diag}(m_\mathrm{u}, m_\mathrm{c}, m_\mathrm{t})$, $\mathbf{m}_d = \mathrm{diag}(m_\mathrm{d}, m_\mathrm{s}, m_\mathrm{b})$ and $\mathbf{m}_e = \mathrm{diag}(m_e, m_\mu, m_\tau)$.

CKM mixing

We follow the conventions of the particle data group [32] and put the mixing in the left-handed d-quark fields, so that the definition of the Cabibbo-Kobayashi-Maskawa matrix is $\mathbf{K} = \mathbf{V}_1\mathbf{V}_2^\dagger$, where $\mathbf{V}_1$ ($\mathbf{V}_2$) rotates the interaction left-handed u-quark (d-quark) fields to mass eigenstates. For

In low-energy phenomenological MSSM, we usually assume:

$$\begin{aligned}
\mathbf{A}_U &= \mathrm{diag}(0,0,A_t) \\
\mathbf{A}_D &= \mathrm{diag}(0,0,A_b) \\
\mathbf{A}_E &= 0 \\
\mathbf{M}_Q &= \mathbf{M}_U = \mathbf{M}_D = \mathbf{M}_E = \mathbf{M}_L = m_0\mathbf{1}.
\end{aligned}$$

$$\begin{aligned}
M_1 &= \tfrac{5}{3}\tan^2\theta_w M_2 \simeq 0.5 M_2, \\
M_2 &= \frac{\alpha_{ew}}{\sin^2\theta_w\alpha_s} M_3 \simeq 0.3 M_3.
\end{aligned}$$

Note, however, that this specific choice is not needed by DarkSUSY, more general models are possible.

mSUGRA

- One can also set these low-energy parameters with an external program, like ISASUGRA e.g.
- For consistency, in that case we use the spectrum calculation by that external program and just transfer these values to DarkSUSY

Other masses

- Higgs masses are calculated with FeynHiggs
- Higgs decay widths are calculated with HDecay.

Routines

- dsgive_model: sets an MSSM-7 model
- dsgive_model13: sets an MSSM-13 model
- dsgive_model_isasugra: sets an mSUGRA model

Typical program

call dsinit

[make general settings]

[determine your model parameters your way]

call dsgive_model [or equivalent]

call dssusy [or equivalent]- to set up DarkSUSY for that model

[then calculate what you want]

Generality of expressions

- We try to be as general as possible when including new physics, but it is hard to be overly general all the time
- Hence, most of our expressions and setups in DarkSUSY are more general than typical use would indicate
- We will here summarize where general forms are OK and not

General forms

- The sfermion mass parameters can be general 3x3 (real) matrices, even if some other parts of the code (e.g. annihilation cross sections) rely on them at least being diagonal
- No GUT relation needs to be assumed for M_1, M_2 and M_3.

Complex parameters

- All input parameters are currently real, (MSSM-63) but many of our expressions are general enough to go complex (e.g. all vertices are already complex)
- In future versions, we expect to make most (all?) of our input parameters complex to get to MSSM-124.