The current state of SUSY/CompHEP package

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Abstract

The CompHEP software package allows to study the elementary particles decays and collisions with high level of automation. Arbitrary processes can be calculated starting from the set of vertices prescribed by given physical model. This note desribes the details of the Minimal Supersymmetric Standard Model (MSSM) and some extensions implementation in CompHEP package. The notation for the particles and parameters of the MSSM and it's extensions are given.

1 Introduction

The CompHEP package [1] has been designed in the INP MSU. It allows the physicist to generate automatically the Feynman diagrams for a process of collision or decay of elementary particles starting from Feynman rules. Than CompHEP makes symbolic calculation of the squared matrix element and numeric integration over multiparticle phase space for the physical process. The goal of the SUSY/CompHEP package is to develop the description of MSSM (and some of it's extensions) in terms of CompHEP tables describing the physical model. It opens the way to calculate automatically the processes of collisions and decays involving supersymmetric particles.

We have used the LanHEP software package [2] to generate the Feynman rules for the MSSM Lagrangian. The Lanhep allows to write the Lagrangian in terms of initial fields (multiplets) before $SU(2) \times U(1)$ symmetry breaking which makes the description compact. Also the 2-component spinors and the superpotential notation is used, which make the LanHEP model close to formulas in textbooks. The LanHEP output the Feynman rules in CompHEP format (LaTeX output is also available).

The full comparision of generated Feynman rules with ones listed in publications [3, 4] is performed. Many MSSM processes were successfully compared with SPYTHIA and ISASUSY programs (slepton and squarks pair production, chargino and neutralino pair production, gluino production, stops production).

The MSSM model files for CompHEP are available on WWW:
`http://theory.npi.msu.su/~semenov/mssm.html`

2 MSSM notation in CompHEP

The minimal supersymmetric extension of the Standard Model includes the following particles:

The CompHEP notation for the particles in MSSM are the following (we denote by `P/aP` the particle/antiparticle combination):

- `A, W+/W-, Z, G` — the gauge bosons: γ, $W^{\pm}$, Z, g;
- `u/U, d/D, s/S, c/C, b/B, t/T` — the quarks: u, d, s, c, b, t;
- `e1/E1, e2/E2, e3/E3, n1/N1, n2/N2, n3/N3` — the leptons: e, μ, τ, ν_e, ν_μ, ν_τ;
- `h, H, H+/H-, H3` — the Higgs bosons: h^0, H^0, $H^{\pm}$, A^0;
- `~u1/~U1, ~d1/~D1` — the left squarks of the 1st generation: $\widetilde{u_L}$, $\widetilde{d_L}$;
- `~u2/~U2, ~d2/~D2` — the right squarks of the 1st generation: $\widetilde{u_R}$, $\widetilde{d_R}$;
- `~s1/~S1, ~s2/~S2` — the light $\widetilde{s_1}$ and the heavy $\widetilde{s_2}$ s-squarks;
- `~c1/~C1, ~c2/~C2` — the light $\widetilde{c_1}$ and the heavy $\widetilde{c_2}$ c-squarks;
- `~t1/~T1, ~t2/~T2` — top squarks, the light $\widetilde{t_1}$ and the heavy $\widetilde{t_2}$;

- `~b1/~B1, ~b2/~B2` — bottom squarks, the light $\widetilde{b}_1$ and the heavy $\widetilde{b}_2$;
- `~e1/~E1, ~e4/~E4` — left selectron $\widetilde{e_L}$ and the right selectron $\widetilde{e_L}$;
- `~e2/~E2, ~e5/~E5` — the smuons, the light $\widetilde{\mu_1}$ and the heavy $\widetilde{\mu_2}$;
- `~e3/~E3, ~e6/~E6` — the light stau $\widetilde{\tau}_1$ and the heavy stau $\widetilde{\tau}_2$;
- `~n1/~N1, ~n2/~N2, ~n3/~N3` — sneutrino $\widetilde{\nu}_e$, $\widetilde{\nu_\mu}$, $\widetilde{\nu}_\tau$;
- `~1+/~1-, ~2+/~2-` — chargino $\widetilde{\chi_1^\pm}$, $\widetilde{\chi_2^\pm}$;
- `~o1, ~o2, ~o3, ~o4` — neutralino $\widetilde{\chi}_1^0$, $\widetilde{\chi}_2^0$, $\widetilde{\chi}_3^0$, $\widetilde{\chi}_4^0$.

Note that we take into account the mixing of squarks of the 2nd generation. The effect of this mixing is proportional to the s and c quarks masses, and even though these masses are small, neglecting these mixings leads to the spoiling of the gauge invariance.

The MSSM implementation in CompHEP has the following independent parameters which can be set and changed by user:

- `tb` – tanβ, the ratio of the vacuum expectation values of the Higgs doublets;
- `MH3` — the mass of the CP-odd Higgs boson M_{H_A};
- `hx` — μ, the higgsino mass parameter;
- `MG1, MG2, MG3` — the masses of $U(1)$, $SU(2)$, $SU(3)$ gauginos;
- `Ml1, Ml2, Ml3` — the left slepton doublet masses for the 3 generations;
- `Mr1, Mr2, Mr3` — the right slepton singlet masses;
- `Mq1, Mq2, Mq3` — the left squarks doublet masses;
- `Mu1, Mu2, Mu3` — the right up squarks singlet masses;
- `Md1, Md2, Md3` — the right down squarks singlet masses; `At, Ab, Atau` — the soft trilinear couplings for stops, sbottoms, staus.

The Rosiek's notation for trilinear soft couplings `us3, ds2, ls3` was used in early MSSM/CompHEP implementations. Now we use the notation corresponding to ISASUSY package.

There is a number of parameters representing particle width. In the current version these parameters are set by user. These parameters can be important in case of s-channel resonant production of the particle.

- `wC1, wC2` — the widths of two charginos;
- `wNE2, wNE3, wNE4` — the widths of three neutralinos (except the lightest one);
- `wSG` — the width of gluino;
- `wSe1, wSe2, wSmu1, wSmu2, wStau1, wStau2` — the widths of charged sleptons;
- `wSne, wSnmu, wSntau` — the widths of sneutrinos;
- `wSu1, wSu2, wSd1, wSd2, wSs1, wSs2, wSc1, wSc2, wSbot1, wSbot2, wStop1, wStop2` — the widths of squarks;
- `wh` — width of light CP-even Higgs;
- `wHh` — width of heavy CP-even Higgs;
- `wHc` — width of charged Higgs;

- wH3 — width of CP-odd Higgs.

The masses of the MSSM particles are calculated using the mass parameters of the soft SUSY breaking terms. So, these parameters can not be changed directly, and they are listed in the 'Constrains' menu. Only the mass of CP-odd Higgs MH3 and the gluino mass MG3 are set directly.

- MC1, MC2 — the masses of the two charginos;
- MNE1, MNE2, MNE3, MNE4 — the masses of the four neutralinos;
- MSe1, MSe2, MSmu1, MSmu2, MStau1, MStau2 — the masses of charged sleptons;
- MSne, MSnmu, MSntau — the masses of sneutrinos;
- MSu1, MSu2, MSd1, MSd2, MSs1, MSs2, MSc1, MSc2, MSbot1, MSbot2, MStop1, MStop2 — the masses of squarks;
- Mh — mass of light CP-even Higgs;
- MHH — the mass of heavy CP-even Higgs;
- MHc — the mass of charged Higgs.

3 Radiative corrections to Higgs masses

It is well known that the masses of Higgs bosons in the MSSM are significantly shifted by the radiative corrections. There are several techniques to compute the corrections to Higgs masses, one of them is exploiting the general 2 Higgs doublet model potential (see [5] and references herein). We use the effective Higgs potential wich is an extension of MSSM potential:

$$\begin{aligned} V_{eff} &= m_{11}^2(H_1H_1^*) + m_{22}^2(H_2H_2^*) - [m_{12}^2(\epsilon H_1H_2) + h.c.] \\ &+\frac{1}{2}\Big[\frac{1}{4}(g^2+g'^2)+\lambda_1\Big](H_1H_1^*)^2 + \frac{1}{2}\Big[\frac{1}{4}(g^2+g'^2)+\lambda_2\Big](H_2H_2^*)^2 \\ &+\Big[\frac{1}{4}(g^2-g'^2)+\lambda_3\Big](H_1H_1^*)(H_2H_2^*) + \Big[-\frac{1}{2}g^2+\lambda_4\Big](\epsilon H_1H_2)(\epsilon H_1^*H_2^*) \\ &+\big(\lambda_5(\epsilon H_1H_2)^2 + \big[\lambda_6(H_1H_1^*)+\lambda_7(H_2H_2^*)\big](\epsilon H_1H_2) + h.c.\big) \end{aligned} \quad (1)$$

The case of all λ_i being zero corresponds to the original MSSM potential.

Here the parameters m_{11}^2, m_{22}^2 can be fixed by the condition of potencial minimization (see [5]). Then, the parameter m_{12}^2 can be fixed if we choose M_A as independent variable.

This potential shifts the masses of Higgs bosons and CP-even Higgs mixing angle α. Besides that, it contributes to the Higgs interaction vertices.

Analytical formulae for λ_i given in [6] are implemented in CompHEP. The formulae include two-loop leading log corrections and take into account top, bottom Yukawa (and strong gauge) couplings, and squark mixing effects. The parameters of CompHEP:

CompHEP name	[6] notation	meaning
Msusy	M_{SUSY}	SUSY scale ($\sim$ square average of squark masses)
hg3	g_3	$SU(3)$ coupling at the M_t scale
hMtop	$m_t(M_t)$	top mass at the M_t scale
hMbot	$m_b(M_t)$	bottom mass at the M_t scale
At, Ab	A_t, A_b	top and bottom trilinear couplings

Many authors use different approaches to calculate Higgs masses, involving diagrammatic calculation rather than effective potential and RGE. So, many articles and computer programs calculate only the CP-even Higgs masses rather than full λ_i set. This relates in particular to the FeynHiggs package. Note that such prescription bounds only several parameters of 7, and we have to deal with λ's to keep gauge invariance.

As a simplest solution in the case when the Higgs masses are given, we can derive the values for $\lambda_{1,2,3,4}$ assuming that M_H, M_h, $M_{H\pm}$ and α are independent variables. This technique allow to use within CompHEP the diagrammatic methods of Higgs mass computation, in particular, `FeynHiggs` program.

Now there are three possible modes of Higgs masses calculation in MSSM/CompHEP:

- λ_i are prescribed by user directly
- analytical formulae taken from [6]
- λ_i are evaluated from the output of `FeynHiggsFast` package.

The default option is making use of `FeynHiggsFast` package.

4 SUGRA and GMSB models

The number of the independent parameters in MSSM can be reduced by implication of SUGRA or GMSB models. More specific, the parameters of soft SUSY breaking terms (gaugino masses M_1, M_2, M_3, sparticle masses M_L, M_R, M_Q ..., trilinear couplings A_t, A_b, A_τ are computed from just several parameters.

Now it is possible to use ISASUSY package, which includes SUGRA and GMSB models. This package is used to calculate soft SUSY breaking parameters mentioned above. The masses of the particles are calculated by CompHEP from the very formulae as used in unconstrained MSSM. In particular, masses of CP-even Higgs particles are calculated by `FeynHiggs` package, while ISASUSY gives the mass of CP-odd Higgs

SUGRA option:

CompHEP notation	parameters
`tb`	ratio of vaccum expectation value
`suM0`	M_0 – common mass for scalars
`suMHF`	$M_{1/2}$ common mass for fermions
`suA0`	A_0 commen trilinear coupling
`suMU`	`sign`(μ) - sign of higgsino mass parameter
`suMODE`	choose the mSUGRA model (see ISASUSY manual)

GMSB option:

CompHEP notation	parameters
`tb`	ratio of vaccum expectation value
`gmLAM`	Λ parameter
`gmMES`	M_{MES} paramerer
`gmN5`	N_5 dimension
`gmMU`	`sign`(μ) - sign of higgsino mass parameter
`gmMODE`	choose the GMSB model (currently 1 only)

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