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L a n H E P —

a package for automatic generation
of Feynman rules in field theory

Version 2.0

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LanHEP — a package for automatic generation of Feynman rules in field theory. Version 2.0

Abstract. The LanHEP program for Feynman rules generation in momentum representation is presented. It reads the Lagrangian written in a compact form, close to the one used in publications. It means that Lagrangian terms can be written with summation over indices of broken symmetries and using special symbols for complicated expressions, such as covariant derivative and strength tensor for gauge fields. The output is Feynman rules in terms of physical fields and independent parameters. This output can be written in LaTeX format and in the form of CompHEP model files, which allows one to start calculations of processes in the new physical model. Although this job is rather straightforward and can be done manually, it requires careful calculations and in modern theories with many particles and vertices, such as supersymmetric models, can lead to errors and misprints. The program allows one to introduce into CompHEP new gauge theories as well as various anomalous terms.

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Introduction

LanHEP has been designed as part of the CompHEP package [1], a software for automatic calculations in high energy physics. CompHEP allows symbolic computation of the matrix element squared of any process with up to 6 incoming and outgoing particles for a given physical model (i.e. a model defined by a set of Feynman rules as a table of vertices in the momentum representation) and then numerical calculation of cross-sections and various distributions.

The main purpose of the new option given by LanHEP is to easily introduce new models. LanHEP makes possible the generation of Feynman rules for propagators and vertices in momentum representation starting from the Lagrangian defined by a user in some simple format very similar to canonical coordinate representation. The user should prepare a text file with description of all Lagrangian terms in the format close to the form used in standard publications. Of course, the user has to describe all particles and parameters appearing in Lagrangian terms.

The main LanHEP features are:

- LanHEP expands expression and combines similar terms;
- it performs the Fourier transformation by replacing derivatives with momenta of particles;
- it writes Feynman rules in the form of four tables in CompHEP format as well as tables in LaTeX format;
- user can define the substitution rules, for example for covariant derivative;
- it is possible to define multiplets, and (if necessary) their components;
- user can write Lagrangian terms with Lorentz and multiplet indices explicitly or omit indices (all or some of them);
- LanHEP performs explicit summation over the indices in the Lagrangian, if the corresponding components for multiplets and matrices are introduced;
- several tests can be applied to check the correctness of the Lagrangian;
- supersymmetric theories can be described using superpotential formalism;
- BRST invariance of the Lagrangian can be tested, and ghost interaction can be constructed;
- LanHEP allows the user to introduce vertices with 4 fermions or 4 colored particles (such vertices can't be introduced directly in CompHEP) by means of auxiliary field with constant propagator;

The LanHEP software is written in C programming language. The first version [2] was released in August 1996.

1 Getting started with LanHEP

1.1 QED

We start with a simple exercise, illustrating the main ideas and features of LanHEP. The first physical model is Quantum Electrodynamics.

The QED Lagrangian is

$$\mathcal{L}_{QED} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \bar{e}\gamma^{\mu}(i\partial_{\mu} + g_e A_{\mu})e - m\bar{e}e$$

```
model QED/1.
parameter ee=0.31333:'elementary electric charge'.
spinor e1/E1:(electron, mass me=0.000511).
vector A/A:(photon).
let F^mu^nu=deriv^mu*A^nu-deriv^nu*A^mu.
lterm -1/4*(F^mu^nu)**2 - 1/2*(deriv^mu*A^mu)**2.
lterm E1*(i*gamma*deriv+me)*e1.
lterm ee*E1*gamma*A*e1.
```

Figure 1: LanHEP input file for the generation of QED Feynman rules

and the gauge fixing term in Feynman gauge has the form

$$\mathcal{L}_{GF} = -\frac{1}{2}(\partial_\mu A^\mu)^2.$$

Here $e(x)$ is the spinor electron-positron field, m is the electron mass, $A_\mu(x)$ is the vector photon field, $F^{\mu\nu} = \partial_\mu A^\nu - \partial_\nu A^\mu$, and g_e is the elementary electric charge.

The LanHEP input file to generate the Feynman rules for QED is shown in Fig. 1.

First of all, the input file consists of statements. Each statement begins with one of the reserved keywords and ends by a full-stop '.' symbol.

First line says that this is a model with the name `QED` and number 1. This information is supplied for CompHEP, the name `QED` will be displayed in its list of models. In CompHEP package each model is described by four files: 'varsN.mdl', 'funcN.mdl', 'prtclsN.mdl', 'lgrngnN.mdl' , where N is the very number specified in the `model` statement.

The `model` statement stands first in the input file. If this statement is absent, LanHEP does not generate the four standard CompHEP files, but just builds the model and prints a diagnostic, if errors are found.

The second line in the input file contains declaration of the model parameter, denoting elementary electric charge g_e as `ee`. For each parameter used in the model one should declare its numeric value and an optional comment (it is also used in CompHEP menus).

The next two lines declare particles. Statement names `spinor, vector` correspond to the particle spin. So, we declare electron denoted by `e1` (the corresponding antiparticle name is `E1`) and photon denoted by `A` (with antiparticle name being `A`, since the antiparticle for photon is identical to particle).

After the particle name we give in brackets some options. The first one is the full name of the particle, used in CompHEP; the second option declares the mass of this particle.

The `let` statement in the next line declares the substitution rule for symbol `F`.

Predefined name `deriv`, which is reserved for the derivative $\frac{\partial}{\partial x}$, will be replaced after the Fourier transformation by the momentum of the particle multiplied by $-i$.

The rest of the lines describe terms in the Lagrangian. Here the reserved name `gamma` denotes Dirac's γ-matrices.

One can see that the indices are written separated with the caret symbol '^'. Note that in the last two lines we have omitted indices. It means that LanHEP restores omitted indices automatically. Really, one can type the last term in the full format:

```
lterm ee*E1^a*gamma^a^b^mu*A^mu*e1^b.
```

It corresponds to $g_e \bar{e}_a \gamma^\mu_{ab} e_b A_\mu$ with all indices written. Note that the order of objects in the monomial is important to restore indices automatically.

1.2 QCD

Now let us consider the case of Quantum Chromodynamics. The Lagrangian for the gluon fields reads

$$L_{YM} = -\frac{1}{4} F^{a\mu\nu} F^a_{\mu\nu},$$

where

$$F^a_{\mu\nu} = \partial_\mu G^a_\nu - \partial_\nu G^a_\mu - g_s f^{abc} G^b_\mu G^c_\nu,$$

$G^a_\mu(x)$ is the gluon field, g_s is the strong coupling constant and f^{abc} are purely imaginary structure constants of the $SU(3)$ color group.

The quark kinetic term and its interaction with the gluon has the form

$$L_F = \bar{q}_i \gamma^\mu \partial_\mu q_i + g_s \lambda^a_{ij} \bar{q}_i \gamma^\mu q_j G^c_\mu,$$

where λ^a_{ij} are Gell-Mann matrices.

Gauge fixing terms in Feynman gauge together with the corresponding Faddev-Popov ghost term are

$$-\frac{1}{2}(\partial_\mu G^\mu_a)^2 + i g_s f^{abc} \bar{c}^a G^b_\mu \partial^\mu c^c,$$

where $(c, \bar{c})$ are unphysical ghost fields.

The corresponding LanHEP input file is shown in Fig. 2.

```
model QCD/2.
parameter gg=1.117:'Strong coupling'.
spinor q/Q:(quark, mass mq=0.01, color c3).
vector G/G:(gluon, color c8, gauge).
let F^mu^nu^a = deriv^nu*G^mu^a - deriv^mu*G^nu^a -
     gg*f_SU3^a^b^c*G^mu^b*G^nu^c.
lterm -F**2/4-(deriv*G)**2/2.
lterm Q*(i*gamma*deriv+mq)*q.
lterm i*gg*f_SU3*ccghost(G)*G*deriv*ghost(G).
lterm gg*Q*gamma*lambda*G*q.
```

Figure 2: Input file for the generation of QCD Feynman rules

Table 1: QCD Feynman rules generated by LanHEP in LaTeX output format

Fields in the vertex				Variational derivative of Lagrangian by fields
$G_{\mu p}$	$\bar{\eta}^G_q$	$\eta^G{}_r$		$-g_s p_3^\mu f_{pqr}$
$\bar{q}_{ap}$	q_{bq}	$G_{\mu r}$		$g_s \gamma^\mu_{ab} \lambda^r_{pq}$
$G_{\mu p}$	$G_{\nu q}$	$G_{\rho r}$		$g_s f_{pqr}(p_3^\nu g^{\mu\rho} - p_2^\rho g^{\mu\nu} - p_3^\mu g^{\nu\rho} + p_1^\rho g^{\mu\nu} + p_2^\mu g^{\nu\rho} - p_1^\nu g^{\mu\rho})$
$G_{\mu p}$	$G_{\nu q}$	$G_{\rho r}$	$G_{\sigma s}$	$g_s^2(g^{\mu\rho} g^{\nu\sigma} f_{pqt} f_{rst} - g^{\mu\sigma} g^{\nu\rho} f_{pqt} f_{rst} + g^{\mu\nu} g^{\rho\sigma} f_{prt} f_{qst}$
				$+g^{\mu\nu} g^{\rho\sigma} f_{pst} f_{qrt} - g^{\mu\sigma} g^{\nu\rho} f_{prt} f_{qst} - g^{\mu\rho} g^{\nu\sigma} f_{pst} f_{qrt})$

Since QCD uses objects with color indices, one has to declare the indices of these objects. There are three types of color indices supported by LanHEP. These types are referred as `color c3` (color triplets), `color c3b` (color antitriplets), and `color c8` (color octets). One can see that `color c3` index type appears among the options in the quark `q` declaration, and the `color c8` one in the gluon `G` declaration. Antiquark `Q` has got color index of type `color c3b` as antiparticle to quark. LanHEP allows contraction of an index of type `color c3` only with another index of type `color c3b`, and two indices of type `color c8`. Of course, in Lagrangian terms each index has to be contracted with its partner, since Lagrangian has to be a scalar.

LanHEP allows also to use in the Lagrangian terms a predefined symbol `lambda` with the three indices of types `color c3, color c3b, color c8` corresponding to Gell-Mann λ-matrices. Symbol `f_SU3` denotes the structure constant f^{abc} of color $SU(3)$ group (all three indices have the type `color c8`).

Option `gauge` in the declaration of `G` allows to use names `ghost(G)` and `ccghost(G)` for the ghost fields c and $\bar{c}$ in Lagrangian terms and in `let` statements.

Table 1 shows Feynman rules generated by LanHEP in LaTeX format after processing the input file presented in Fig. 2. Four gluon vertex rule is indicated in the last line. Note that the output in CompHEP format has no 4-gluon vertex explicitly; it is expressed effectively through 3-leg vertices by a constant propagator of some auxiliary field (see section 9 for more details).

1.3 Higgs sector of the Standard Model

```
model Higgs/1.
parameter EE = 0.31333 :  'Electromagnetic coupling constant',
      SW = 0.4740 :  'sin of the Weinberg angle (PDG-94)',
      CW = Sqrt(1-SW**2) :  'cos of the Weinberg angle'.
let g=EE/SW, g1=EE/CW.

vector A/A: (photon, gauge),
      Z/Z:('Z boson', mass MZ = 91.187, gauge),
      'W+'/'W-':  ('W boson', mass MW = MZ*CW, gauge).
scalar H/H:(Higgs, mass MH = 200, width wH = 1.461).

let B = -SW*Z+CW*A.
let W = {'W+', CW*Z+SW*A, 'W-'}.
let phi = { -i*gsb('W+'), (vev(2*MW/EE*SW)+H+i*gsb(Z))/Sqrt2 },
      Phi = anti(phi).

lterm -2*lambda*(phi*anti(phi)-v**2/2)**2 where
           lambda=(g*MH/MW)**2/16, v=2*MW*SW/EE.
let D^a^b^mu =(deriv^mu+i*g1/2*B^mu)*delta(2)^a^b
           +i*g/2*taupm^a^b^c*W^mu^c,
      Dc^a^b^mu=(deriv^mu-i*g1/2*B^mu)*delta(2)^a^b
           -i*g/2*taupm^a^b^c*anti(W)^mu^c.
lterm D^a^b^mu*phi^b*Dc^a^c^mu*Phi^c.
```

Figure 3: Input file for the Higgs sector of the Standard Model

The third example illustrates using the multiplets in the framework of LanHEP. Let us consider the Higgs sector of the Standard Model. The Higgs doublet can be defined as

$$\Phi = \left(\begin{array}{c} -iW_f^+ \\ (\frac{2M_W}{es_s} + H + iZ_f)/\sqrt{2} \end{array} \right),$$

where s_w is the sinus of the weak angle, H is the Higgs field, Z_f and $W_f^\pm$ are goldstone bosons corresponding to Z and $W^\pm$ gauge fields. The self-interaction of Higgs field read as

$$\mathcal{L}_H = -2\lambda(\Phi\Phi^* - v^2/2)^2,$$

Table 2: LanHEP output: Feynman rules for Higgs self-interaction

Fields in the vertex	Variational derivative of Lagrangian by fields
$H \quad H \quad H$	$-\frac{3}{2}\frac{eMH^2}{M_W s_w}$
$H \quad W_F^+ \quad W_F^-$	$-\frac{1}{2}\frac{eMH^2}{M_W s_w}$
$H \quad Z_F \quad Z_F$	$-\frac{1}{2}\frac{eMH^2}{M_W s_w}$
$H \quad H \quad H \quad H$	$-\frac{3}{4}\frac{e^2MH^2}{M_W{}^2 s_w{}^2}$
$H \quad H \quad W_F^+ \quad W_F^-$	$-\frac{1}{4}\frac{e^2MH^2}{M_W{}^2 s_w{}^2}$
$H \quad H \quad Z_F \quad Z_F$	$-\frac{1}{4}\frac{e^2MH^2}{M_W{}^2 s_w{}^2}$
$W_F^+ \quad W_F^+ \quad W_F^- \quad W_F^-$	$-\frac{1}{2}\frac{e^2MH^2}{M_W{}^2 s_w{}^2}$
$W_F^+ \quad W_F^- \quad Z_F \quad Z_F$	$-\frac{1}{4}\frac{e^2MH^2}{M_W{}^2 s_w{}^2}$
$Z_F \quad Z_F \quad Z_F \quad Z_F$	$-\frac{3}{4}\frac{e^2MH^2}{M_W{}^2 s_w{}^2}$

where $\lambda = (gM_H/M_W)^2/16$, and the vaccuum expectation value $v = 2M_W/g$ (here and below $g = e/s_w$, $g' = e/c_w$.)

The gauge interaction of a Higgs doublet is given by the term $(D_\mu\Phi)(D^\mu\Phi)^*$, where

$$D_\mu = \partial_\mu + ig'B_\mu/2 + ig\vec{\tau}\vec{W}_\mu.$$

Here B is $U(1)$ singlet and W is $SU(2)$ triplet,

$$B_\mu = -s_w Z_\mu + c_w A_\mu, \qquad W_\mu^a = \begin{pmatrix} W_\mu^+ \\ c_w Z_\mu + s_w A_\mu \\ W_\mu^- \end{pmatrix},$$

and $\vec{\tau}$ is the vector (τ^+, τ^3, τ^-).

The above model can be represented by the LanHEP code shown in Table 3.

New features in this example include the definition of special symbols for coupling constants g, g', gauge and Higgs fields, and the covariant derivative by means of `let` statement. Note that in the declaration for the fields we have used dummy indices (vector and isospin). The multiplets are defined by the components in the curly brackets.

Note that the option `gauge` in the declaration of gauge fields allows to use the name `gsb(Z)` and `gsb('W+')` for the goldstone bosons.

2 Structure of LanHEP input file

The LanHEP input file is the sequence of statements, each starts with a special identifier (such as `parameter,` `lterm` etc) and ends with the full-stop '.' symbol. Statement can occupy several lines in the input file.

This section is aimed to clarify the syntax of LanHEP input files, i.e. the structure of the statements.

2.1 Constants and identifiers

First of all, each word in any statement is either an *identifier* or a *constant.*

Indentfiers are the names of particles, parameters etc. Examples of identifiers from the previous section are particle names

Table 3: LanHEP output: Feynman rules for Higgs gauge interaction

Fields in the vertex	Variational derivative of Lagrangian by fields
$A_\mu \quad W^+{}_\nu \quad W^-_F$	$ieM_W g^{\mu\nu}$
$A_\mu \quad W^+_F \quad W^-{}_\nu$	$-ieM_W g^{\mu\nu}$
$A_\mu \quad W^+_F \quad W^-_F$	$-e(p_2^\mu - p_3^\mu)$
$H \quad W^+{}_\mu \quad W^-{}_\nu$	$\frac{eM_W}{s_w} g^{\mu\nu}$
$H \quad W^+{}_\mu \quad W^-_F$	$-\frac{1}{2}\frac{ie}{s_w}(p_1^\mu - p_3^\mu)$
$H \quad W^+_F \quad W^-{}_\mu$	$\frac{1}{2}\frac{ie}{s_w}(p_2^\mu - p_1^\mu)$
$H \quad Z_\mu \quad Z_\nu$	$\frac{eM_W}{{c_w}^2 s_w} g^{\mu\nu}$
$H \quad Z_\mu \quad Z_F$	$-\frac{1}{2}\frac{ie}{c_w s_w}(p_1^\mu - p_3^\mu)$
$W^+{}_\mu \quad W^-_F \quad Z_\nu$	$-\frac{ieM_W s_w}{c_w} g^{\mu\nu}$
$W^+{}_\mu \quad W^-_F \quad Z_F$	$\frac{1}{2}\frac{e}{s_w}(p_3^\mu - p_2^\mu)$
$W^+_F \quad W^-{}_\mu \quad Z_\nu$	$\frac{ieM_W s_w}{c_w} g^{\mu\nu}$
$W^+_F \quad W^-{}_\mu \quad Z_F$	$\frac{1}{2}\frac{e}{s_w}(p_1^\mu - p_3^\mu)$
$W^+_F \quad W^-_F \quad Z_\mu$	$-\frac{1}{2}\frac{(1-2{s_w}^2)e}{c_w s_w}(p_1^\mu - p_2^\mu)$
$A_\mu \quad A_\nu \quad W^+_F \quad W^-_F$	$2e^2 g^{\mu\nu}$
$A_\mu \quad H \quad W^+{}_\nu \quad W^-_F$	$\frac{1}{2}\frac{ie^2}{s_w} g^{\mu\nu}$
$A_\mu \quad H \quad W^+_F \quad W^-{}_\nu$	$-\frac{1}{2}\frac{ie^2}{s_w} g^{\mu\nu}$
$A_\mu \quad W^+{}_\nu \quad W^-_F \quad Z_F$	$-\frac{1}{2}\frac{e^2}{s_w} g^{\mu\nu}$
$A_\mu \quad W^+_F \quad W^-{}_\nu \quad Z_F$	$-\frac{1}{2}\frac{e^2}{s_w} g^{\mu\nu}$
$A_\mu \quad W^+_F \quad W^-_F \quad Z_\nu$	$\frac{(1-2{s_w}^2)e^2}{c_w s_w} g^{\mu\nu}$
$H \quad H \quad W^+{}_\mu \quad W^-{}_\nu$	$\frac{1}{2}\frac{e^2}{{s_w}^2} g^{\mu\nu}$
$H \quad H \quad Z_\mu \quad Z_\nu$	$\frac{1}{2}\frac{e^2}{{c_w}^2 {s_w}^2} g^{\mu\nu}$
$H \quad W^+{}_\mu \quad W^-_F \quad Z_\nu$	$-\frac{1}{2}\frac{ie^2}{c_w} g^{\mu\nu}$
$H \quad W^+_F \quad W^-{}_\mu \quad Z_\nu$	$\frac{1}{2}\frac{ie^2}{c_w} g^{\mu\nu}$
$W^+{}_\mu \quad W^+_F \quad W^-{}_\nu \quad W^-_F$	$\frac{1}{2}\frac{e^2}{{s_w}^2} g^{\mu\nu}$
$W^+{}_\mu \quad W^-{}_\nu \quad Z_F \quad Z_F$	$\frac{1}{2}\frac{e^2}{{s_w}^2} g^{\mu\nu}$
$W^+{}_\mu \quad W^-_F \quad Z_\nu \quad Z_F$	$\frac{1}{2}\frac{e^2}{c_w} g^{\mu\nu}$
$W^+_F \quad W^-{}_\mu \quad Z_\nu \quad Z_F$	$\frac{1}{2}\frac{e^2}{c_w} g^{\mu\nu}$
$W^+_F \quad W^-_F \quad Z_\mu \quad Z_\nu$	$\frac{1}{2}\frac{(1-2{s_w}^2)^2 e^2}{{c_w}^2 {s_w}^2} g^{\mu\nu}$
$Z_\mu \quad Z_\nu \quad Z_F \quad Z_F$	$\frac{1}{2}\frac{e^2}{{c_w}^2 {s_w}^2} g^{\mu\nu}$

```
e1 E1 A q Q G
```

The first word in each statement is also an identifier, defining the function which this statement performs. The identifiers are usually combinations of letters and digits starting with a letter. If an identifier does not respect this rule, it should be quoted. For example, the names of $W^{\pm}$ bosons must be written as `'W+'` and `'W-'`, since they contain '+' and '−' symbols.

Constants can be classified as

- *integers*: they consist of optional sign followed by one or more decimal digits, such as

  ```
  0   1   -1   123   -98765
  ```

  Integers can appear in Lagrangian terms, parameter definition and in other expressions.

- *Floating point numbers* include optional sign, several decimal digits of mantissa with an embedded period (decimal point) with at least one digit before and after the period, and optional exponent. The exponent, if present, consist of letter `E` or `e` followed by an optional sign and one or more decimal digits. Valid examples of floating point numbers are

  ```
  1.0   -1.0   0.000511   5.11e-4
  ```

  Floating point numbers are used only as parameter values (coupling constants, particle masses etc). They can not be explicitly used in Lagrangian terms.

- *String constants* may include arbitrary symbols. They are used as comments in parameter statements, full particle names in the declaration of a particle, etc. Examples from the previous section are

  ```
  electron
  photon
  ```

  If a string constant contains any character besides letters and digits or does not begin with a letter, it should be quoted. For example, the comments in QED and QCD input files (see previous section) contain blank spaces, so they are quoted:

  ```
  'elementary electric charge'
  'Strong coupling'
  ```

2.2 Comments

User can include comments into the LanHEP input file in two ways. First, symbol `'%'` denotes the comment till the end of current line. Second way allows one to comment any number of lines by putting a part of input file between `'/*'` (begin of comment) and `'*/'` (end of comment) symbols.

2.3 Including files

LanHEP allows the user to divide the input file into several files. To include the file *file*, the user should use the statement

`read` *file*.

The standard extension '`.mdl`' of the file name may be omitted in this statement.

Another way to include a file is provided by the `use` statement as

`use` *file*.

The `use` statement reads the `file` only once, next appearances of this statement with the same argument do nothing. This function prevents multiple reading of the same file. This form can be used mainly to include some standard modules, such as declaration of Standard Model particles to be used for writing some extensions of this model.

2.4 Conditional processing of the model

Let us consider the LanHEP input files for the Standard Model with both the t'Hooft-Feynman and unitary gauges. It is clear that these input files differ by several lines only — the declaration of gauge bosons and Higgs doublet. It is more convenient to have only one model definition file. In this case the conditional statements are necessary. LanHEP allows the user to define several *keys*, and use these keys to branch among several variants of the model. The keys have to be declared by the `keys` statement:

`keys` *name1=value1, name2=value2, ...* .

Then one can use the conditional statements:

```
do_if key==value1.
      actions1
do_else_if key==value2.
      actions2
do_else_if key==value3.
      ...
do_else.
      default actions
end_if.
```

The statements `do_else_if` and `do_else` are not obligatory. The value of the key is a number or symbolic string. An example of using these statement in the Standard model may read:

```
keys Gauge=unitary.

do_if Gauge==Feynman.
vector Z/Z:('Z-boson',mass MZ = 91.187, width wZ = 2.502, gauge).
do_else_if Gauge==unitary.
vector Z/Z:('Z-boson',mass MZ = 91.187, width wZ = 2.502).
do_else.
write('Error:  key Gauge must be either Feynman or unitary').
quit.
end_if.
```

Thus, to change the choice of gauge fixing in the generated Feynman rules it is enough to modify one word in the input file. There is another way, to set the key value from the command line at the launch of LanHEP:

`lhep -key Gauge=Feynman` *filename*.

If the value of key is set from the command line at the program launch, the value for this key in the `keys` statement is ignored.

3 Objects in the expressions for Lagrangian terms

Each symbol which may appear in algebraic expressions (names of parameters, fields, etc) has a fixed order of indices and their types. If this object is used in any expression, one should write its indices in the same order as they were defined when the object has been declared.

Besides the types of indices corresponding to the color $SU(3)$ group: `color c3` (color triplet), `color c3b` (color antitriplet) and `color c8` (color octet) described in the previous example, there are default types of indices for Lorentz group: `vector`, `spinor` and `cspinor` (antispinor). User can also declare new types of indices corresponding to the symmetries other than color

$SU(3)$ group. In this case any object (say, particle) may have indices related to this new group. This possibility will be described in Section 8.

If an index appears twice in some monomial of an expression, LanHEP assumes summation over this index. Types of such indices must allow the contraction, i.e. they should be one of the pairs: `spinor` and `cspinor`, two `vector`, `color c3` and `color c3b`, two `color c8`.

In general the following objects are available to appear in the expressions for a Lagrangian: integers and identifiers of parameters, particles, specials, let-substitutions and arrays.

There are also predefined symbols `i`, denoting imaginary unit i ($i^2 = -1$) and `Sqrt2`, which is a parameter with value $\sqrt{2}$.

3.1 Parameters

Parameters are scalar objects (i.e. they have no indices). Parameters denote coupling constants, masses and widths of particles, etc. To introduce a new parameter one should use the `parameter` statement, which has the generic form

`parameter` *name*`=`*value*`:`*comment*.

- *name* is an identifier of newly created parameter.
- *value* is an integer or floating point number or an expression. One can use previously declared parameters and integers joined by standard arithmetical operators `'+'`, `'-'`, `'*'`, `'/'`, and `'**'` (power).
- *comment* is an optional comment to clarify the meaning of parameter, it is used in CompHEP help windows. Comment has to be a string constant, so if it contains blank spaces or other special characters, it must be quoted (see Section 3).

In the extression for parameters one can use functions `sqrt, pow, sin, asin, cos, acos, tan, atan, atan2, fabs` (same as in C programming language). One can add new functions through the use of the statement

`external_func(`*function*, *arity*`)`.

Arity is the number of arguments of the function. If this function is absent in the standard C library, it should be written in C and added to the library file `usrlib.a` in the CompHEP working directory.

3.2 Particles

Particles are objects to denote physical particles. They may have indices. It is possible to use three statements to declare a new particle, at the same time the second and the third statements define the corresponding Lorentz index:

`scalar` *P*/*aP*`:(`*options*`)`.
`spinor` *P*/*aP*`:(`*options*`)`.
`vector` *P*/*aP*`:(`*options*`)`.

P and *aP* are identifiers of particle and antiparticle. In the case of truly neutral particles (when antiparticle is identical to the particle itself) one should use the form *P*/*P* with identical names for particle and antiparticle.

It is possible to write only the particle name, e.g.

`scalar` *P*`:(`*options*`)`.

In this case the name of corresponding antiparticle is generated automatically. It satisfies the usual CompHEP convention, when the name of antiparticle differs from particle by altering the case of the first letter. So for electron name `e1` automatically generated antiparticle name will be `E1`. If the name contains symbol '+' it is replaced by '–' and vice versa.

The *option* is comma-separated list of options for a declared particle, and it may include the following items:

- the first element in this list must be the full name of the particle, (e.g. `electron` and `photon` in our example.) Full name is a string constant, so it should be quoted if it contains blanks, etc.
- `mass` *param=value* defines the mass of the particle. Here *param* is an identifier of a new parameter, which is used to denote the mass; *value* is its value, it has the same syntax as in the `parameter` statement, comment for this new parameter being generated automatically. If this option omitted, the mass is assumed to be zero.
- `width` *param=value* declares the width of the particle. It has the same syntax as for `mass` option.
- *itype* is a type of index of some symmetry; one can use default index types for color $SU(3)$ group (see QCD example in Section 2). It is possible to use user-defined index types (see Section 8) and Lorentz group indices `vector, spinor, cspinor`.
- `left` or `right` says that the massless spinor particle is an eigenstate of $(1-\gamma^5)/2$ or $(1+\gamma^5)/2$ projectors, so this fermion is left-handed or right-handed.
- `gauge` declares the vector particle as a gauge boson. This option generates the corresponding ghosts and goldstone bosons names for the named particle (see below).

When a particle name is used in any expression (in Lagrangian terms), one should remember that the first index is either a vector or a spinor (if this particle is not a Lorentz scalar). Then the indices follow in the same order as index types in the *options* list. So, in the case of quark declaration (see the QCD example) the first index is spinor, and the second one is color triplet.

There are several functions taking particle name as an argument which can be used in algebraic expressions. These functions are replaced with auxiliary particle names, which are generated automatically.

- Ghost field names in gauge theories are generated by the functions `ghost(`*name*`)` $\to$ `'`*name*`.c'` and `ccghost(`*name*`)` $\to$ `'`*name*`.C'` (see for instance Table 1). Here and below *name* is the name of the corresponding gauge boson.
- Goldstone boson field name in the t'Hooft-Feynman gauge is generated by the function `gsb(`*name*`)` $\to$ `'`*name*`.f'`.
- The function `anti(`*name*`)` generates antiparticle name for the particle *name*.
- The name for a charge conjugate spinor particle $\psi^c = C\bar{\psi}^T$ is generated by the function `cc(`*name*`)` $\to$ `'`*name*`.c'`. Charge conjugate fermion has the same indices types and ordering, however index of `spinor` type is replaced by the index type `cspinor` and vice versa.
- `vev(`*expr*`)` is used in the Lagrangian for vacuum expectation values. Function `vev` ensures that `deriv*vev(`*expr*`)` is zero. In other words, `vev` function forces LanHEP to treat *expr* as a scalar particle which will be replaced by *expr* in Feynman rules.

3.3 Specials

Besides parameters and particles other indexed such as γ-matrices, group structure constants, etc may appear in the Lagrangian terms. We refer such objects as *specials*.

Predefined specials of the Lorentz group are:

- `gamma` stands for the γ^μ-matrices. It has three indices of `spinor, cspinor` and `vector` types.
- `gamma5` denotes γ^5 matrix. It has two indices of `spinor` and `cspinor` types.
- `moment` has one index of `vector` type. At the stage of Feynman rules generation this symbol is replaced by the particle moment.
- `deriv` is replaced by $-ip_\mu$, where p_μ is the particle moment. It has one `vector` index. Note that `deriv*A*B` means $(\partial A)B$, not $\partial(AB)$.
- For the derivative of a product, `derivp(`*expr*`)` can be used. `derivp(A*B)` is equivalent to `deriv*A*B+A*deriv*B`.

Specials of the color $SU(3)$ group are:

- `lambda` denotes Gell-Mann λ-matrices. It has three indices: `color c3, color c3b` and `color c8`.
- `f_SU3` is the $SU(3)$ structure constant. It has three indices of `color c8` type.
- `eps_c3` and `eps_c3b` are antisymmetric tensors. The first has 3 indices of the type `color c3`, and the second 3 `color c3b` indices.

Note that for specials the order of indices types is fixed.

Users can declare new specials with the help of a facility defined in Section 8 to introduce user-defined indices types.

3.4 Let-substitutions

LanHEP allows the user to introduce new symbols and then substitute them in Lagrangian terms by some expressions. Substitution has the generic form

`let` *name*`=`*expr*.

where *name* is the identifier of newly defined object. The expression has the same structure as those in Lagrangian terms, however here expression may have free (non-contracted) indices.

Typical example of using a substitution rule is a definition of the QED covariant derivative as

```
let Deriv^mu=deriv^mu + i*ee*A^mu.
```

corresponding to $D_\mu = \partial_\mu + ig_e A_\mu$.

More complicated example is the declaration $\sigma^{\mu\nu} \equiv i(\gamma^\mu\gamma^\nu - \gamma^\nu\gamma^\mu)/2$ matrices:

```
let sigma^a^b^mu^nu = i*(gamma^a^c^mu*gamma^c^b^nu
                        - gamma^a^c^nu*gamma^c^b^mu)/2.
```

Note that the order of indices types of new symbol is fixed by the declaration. So, first two indices of `sigma` after this declaration are spinor and antispinor, third and fourth are vector indices.

3.5 Arrays

LanHEP allows to define components of indexed objects. In this case, contraction of indices will be performed as an explicit sum of products of the corresponding components.

An object with explicit components has to be written as

{*expr1, expr2 ..., exprN* }^*i*

where expressions correspond to components. All indices of components (if present) have to be written at the each component, and the index numbering components has to be written after closing curly bracket. Of course, all the components must have the same types of free (non-contracted) indices.

Arrays are usually applied for the definition of multiplets and matrices corresponding to broken symmetries.

Typical example of arrays usage is a declaration of electron-neutrino isospin doublet `l1` (and antidoublet `L1`)

```
let l1^a^I = { n1^a, e1^a}^I, L1^a^I = { N1^a, E1^a}^I.
```

Here we suppose that `n1` was declared as the spinor particle (neutrino), with the antiparticle name `N1`.

Note that the functions `anti` and `cc` can be applied also to the multiplets, so the construction

```
let l1^a^I = { n1^a, e1^a}^I, L1^a^I = anti(l1)^a^I.
```

is possible.

Matrices can be represented as arrays which have other arrays as components. However, it is more convenient to declare them with dummy indices, see Section 5.4 (the same is correct for multiplets also).

It is possible also to use arrays directly in the Lagrangian, rather than only in the declaration of let-substitution.

When LanHEP is launched, it has already declared some frequently used matrices. They are:

- `tau1, tau2, tau3` are τ-matrices τ_1, τ_2, τ_3:

$$\tau^1 = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}, \quad \tau^2 = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}, \quad \tau^3 = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix};$$

- `tau` is a vector $\vec{\tau} = (\tau_1, \tau_2, \tau_3)$;
- `taup` and `taum` are matrices $\tau^{\pm} = (\tau^1 \pm i\tau^2)/\sqrt{2}$;
- `taupm` is a vector (τ^+, τ^3, τ^-);
- `eps` is the antisymmetrical tensor ε ($\varepsilon^{123} = 1$);
- `Tau1, Tau2, Tau3` are generators of $SU(2)$ group adjoint representation (3-dimensional analog of τ-matrices) T^1, T^2, T^3 with commutative relations $[T_i, T_j] = -i\epsilon_{ijk}T_k$:

$$T^1 = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & -1 & 0 \\ -1 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix}, \quad T^2 = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & i & 0 \\ -i & 0 & -i \\ 0 & i & 0 \end{pmatrix}, \quad T^3 = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -1 \end{pmatrix};$$

- `Taup` and `Taum` corresponds to $T^{\pm} = (T^1 \pm iT^2)/\sqrt{2}$;
- `Taupm` is a vector $\vec{T} = (T^+, T^3, T^-)$.

3.6 Two-component notation for fermions

It is possible to write the Lagrangian using two-component notation for fermions. The connection between two-component and four-component notations is summarized by the following relations:

$$\psi = \begin{pmatrix} \xi \\ \bar\eta \end{pmatrix}, \qquad \psi^c = \begin{pmatrix} \eta \\ \bar\xi \end{pmatrix}, \qquad \bar\psi = \begin{pmatrix} \eta \\ \bar\xi \end{pmatrix}^T, \qquad \bar\psi^c = \begin{pmatrix} \xi \\ \bar\eta \end{pmatrix}^T.$$

If the user has declared a spinor particle `p` (with antiparticle `P`), the LanHEP notation for its components is:

$\xi \rightarrow$ `up(p)`
$\bar\eta \rightarrow$ `down(p)`
$\eta \rightarrow$ `up(cc(p))` *or* `up(P)`
$\bar\xi \rightarrow$ `down(cc(p))` *or* `down(P)`

To use the four-vector $\bar\sigma^\mu$ one should use the statement

```
special sigma:(spinor2,spinor2,vector).
```

Note that the `sigma` object is not defined by default, thus the above statement is required. It is possible also to use another name instead of `sigma` (this object can be recognized by LanHEP by the types of its indices).

LanHEP uses the following rules to convert the two-component fermions to four-component ones (we use $P_{R,L} = (1 \pm \gamma^5)/2$):

$\eta_1\xi_2 = \bar\psi_1 P_L \psi_2$	`up(P1)*up(p2)`	$\rightarrow$	`P1*(1-gamma5)/2*p2`
$\bar\eta_1\bar\xi_2 = \bar\psi_1 P_R \psi_2$	`down(P1)*down(p2)`	$\rightarrow$	`P1*(1+gamma5)/2*p2`
$\xi_1\xi_2 = \bar\psi_1^c P_L \psi_2$	`up(p1)*up(p2)`	$\rightarrow$	`cc(p1)*(1-gamma5)/2*p2`
$\bar\xi_1\bar\xi_2 = \bar\psi_1 P_R \psi_2^c$	`down(P1)*down(P2)`	$\rightarrow$	`P1*(1+gamma5)/2*cc(P2)`
$\xi_1\eta_2 = \bar\psi_1^c P_L \psi_2^c$	`up(p1)*up(P2)`	$\rightarrow$	`cc(p1)*(1-gamma5)/2*cc(P2)`
$\bar\xi_1\bar\eta_2 = \bar\psi_1^c P_R \psi_2^c$	`down(p1)*down(P2)`	$\rightarrow$	`cc(p1)*(1+gamma5)/2*cc(P2)`
$\eta_1\eta_2 = \bar\psi_1 P_L \psi_2^c$	`up(P1)*up(P2)`	$\rightarrow$	`P1*(1-gamma5)/2*cc(P2)`
$\bar\eta_1\bar\eta_2 = \bar\psi_1^c P_R \psi_2$	`down(p1)*down(p2)`	$\rightarrow$	`cc(p1)*(1+gamma5)/2*p2`
$\bar\xi_1\sigma^\mu\xi_2 = \bar\psi_1\gamma^\mu P_L \psi_2$	`down(P1)*sigma*up(p2)`	$\rightarrow$	`P1*gamma*(1-gamma5)/2*p2`
$\bar\eta_1\sigma^\mu\eta_2 = \bar\psi_1^c\gamma^\mu P_L \psi_2^c$	`down(p1)*sigma*up(P2)`	$\rightarrow$	`cc(p1)*gamma*(1-gamma5)/2*cc(P2)`

4 Lagrangian expressions

When all parameters and particles necessary for the introduction of a (physical) model are declared, one can enter Lagrangian terms with the help of the `lterm` statement:

`lterm` *expr*.

Elementary objects of expression are integers, identifiers of parameters, particles, specials, let-substitutions, and arrays.

These elementary objects can be combined by the usual arithmetic operators as

- *expr1+expr2* (addition),
- *expr1–expr2* (subtraction),
- *expr1*expr2* (product),
- *expr1/expr2* (fraction; here *expr2* must be a product of integers and parameters),

- *expr1**N* (*N*th power of *expr1*; *N* must be an integer).

One can use brackets '(' and ')' to force the precedence of operators. Note, that indices can follow only elementary objects symbols, i.e. if `A1` and `A2` were declared as two vector particles then valid expression for their sum is `A1^mu+A2^mu`, rather than `(A1+A2)^mu`.

4.1 Where-substitutions

More general form of expressions involves *where-substitutions*:

expr `where` *subst*.

In the simple form *subst* is *name*=*repl* or several constructions of this type separated by comma ','. In the form of such kind each instance of identifier *name* in *expr* is replaced by *repl*.

Note that in contrast to let-substitutions, where-substitution does not create a new object. LanHEP simply replaces *name* by *repl*, and then processes the resulting expression. It means in particular that *name* can not have indices, although it can denote an object with indices:

```
lterm F**2 where F=deriv^mu*A^nu-deriv^nu*A^mu.
```

is equivalent to

```
lterm (deriv^mu*A^nu-deriv^nu*A^mu)**2.
```

The substitution rule introduced by the keyword `where` is active only within the current `lterm` statement.

More general form of where-substitution allows to use several *name*=*repl* substitution rules separated by semicolon ';'. In this case *expr* will be replaced by the sum of expressions; each term in this sum is produced by applying one of the substitution rules from semicolon-separated list to the expression *expr*. This form is useful for writing the Lagrangian where many particles have a similar interaction.

For example, if `u,d,s,c,b,t` are declared as quark names, their interaction with the gluon may read as

```
lterm gg*anti(psi)*gamma*lambda*G*psi where
          psi=u; psi=d; psi=s; psi=c; psi=b; psi=t.
```

The equivalent form is

```
lterm gg*U*gamma*lambda*G*u + gg*D*gamma*lambda*G*d +
      gg*C*gamma*lambda*G*c + gg*S*gamma*lambda*G*s +
      gg*T*gamma*lambda*G*t + gg*B*gamma*lambda*G*b.
```

Where-substitution can also be used in `let` statement. In this case one should use brackets:

`let` *lsub=(expr* `where` *wsub=expr1)*.

4.2 Adding Hermitian conjugate terms

It is possible to generate hermitian conjugate terms automatically by putting the symbol `AddHermConj` to `lterm` statement:

`lterm` *expr* `+ AddHermConj.`

Continuing the former example, one can write:

```
lterm a*H*H*h + b*H**3 + AddHermConj.
```

Note, that the symbol `AddHermConj` adds the hermitian conjugate expressions to all terms in the `lterm` statement. It means in particular that in the statement

```
lterm expr1 + (expr2 + AddHermConj).
```

the conjugate terms are added to both *expr1* and *expr2*. Thus, one should not place self-conjugate terms in the `lterm` statement where `AddHermConj` present (or one should supply these terms with 1/2 factor).

4.3 Using the superpotential formalism in the MSSM and its extensions

In supersymmetric models (in particular, in the Minimal Supersymmetric Standard Model (MSSM) [3]) one makes use of the superpotential — a polynomial W depending on scalar fields A_i (superpotential also can be defined in terms of superfields, we do not consider this case). Then, there is the contribution to the Lagrangian: Yukawa terms in the form

$$-\frac{1}{2}\left(\frac{\partial^2 W}{\partial A_i \partial A_j}\Psi_i\Psi_j + H.c.\right)$$

and $F_i^* F_i$ terms, where $F_i = \partial W/\partial A_i$ (for more details, see [3] and references therein).

To use this formalism in LanHEP, one should define first the multiplets of matter fields and then define the superpotential through the let-substitution statement. The example of the MSSM with a single generation may read:

```
keep_lets W.
let W=eps*(mu*H1*H2+ml*H1*L*R+md*H1*Q*D+mu*H2*Q*U).
```

Here symbols `H1, H2, L, R, Q, U, D` are defined somewhere else as doublets and singlets in terms of scalar particles.

Note that before the definition of `W` this symbol should appear in the `keep_lets` statement. It is necessary to notify LanHEP that let-substitutions (multiplets) at the definition of `W` should not be expanded. Without this statement, the representation used by LanHEP for `W` will not contain symbols of multiplets but only the particles which were used at multiplets definition.

Since `W` was declared in the `keep_lets` statement and contains the symbols of multiplets, one can evaluate the variational derivative of `W` by one or two multiplets, e.g. `df(W,H1)` or `df(W,H1,L)`. Thus the Yukawa terms may be written:

```
lterm - df(W,H1,H2)*fH1*fH2 - ...  + AddHermConj.
```

Here `fH1, fH2` are fermionic partners of corresponding multiplets.

To introduce the $F_i^* F_i$ terms one needs to declare the conjugate superpotential, e.g. `Wc`, and write:

```
lterm - df(W,H1)*df(Wc,H1c) - ....
```

A better way is to use the function `dfdfc(W,H1)` instead:

```
lterm - dfdfc(W,H1) - ....
```

The function evaluates the variational derivative, multiply it by the conjugate expression and returns the result. Moreover, it can introduce auxiliary fields to split vertices with 4 color particles (in the case of CompHEP output); see Section 9 for more details.

4.4 Generation of counterterms

Ultraviolet divergencies in renormalized quantum field theories are compensated by renormalization of wave functions $\phi_i \to \phi_i(1+\delta z_i)$, masses $M_i \to M_i + \delta M_i$, charges $e_i \to e_i + \delta e_i$, and may be some other Lagrangian constants. Such transformation of the Lagrangian assumes changes in the Feynman rules. In particular vertices are changed due to the appearence of new terms — *counterterms*. It is possible to treat this transformation at 1-loop level by means of LanHEP package.

The statement

`transform` *obj* `->` *expr*.

forces LanHEP to substitute symbol of a parameter or a particle, *obj*, by the expression *expr* when this object appears in the Lagrangian expressions of the Lagrangian.

For example, if the electric charge e in QED is renormalized than the statement

```
transform e -> e+d_e.
```

makes LanHEP substitute each occurence of `e` symbol in further expressions by `e+d_e`. Of course, `e` and `d_e` should be declared as parameters before this statement.

The `transform` statement is very similar to the `let` statement and uses the same syntax for expression *expr*. It has however two advantages. First, one does not need to introduce new name for transformed parameter or field. Second, if one has the LanHEP file for some physical model, it is enough to add counterterms statements into the input file just after the statements declaring parameters and particles.

In 1-loop approximation renormalization parameters appear in expressions only at first power, i.e. $\delta Z_i \delta Z_j = 0$, where δZ_i means all renormalization parameters (δe_i, δM_i, δz_i, ...). This should be done with the help of the following statement

`infinitesimal` *d_Z1, d_Z2, ..., d_Zn.*

It declares that a monomial should be omitted if it contains more than one of parameters *d_Z1, d_Z2, ..., d_Zn.*

An example for QED model with renormalization reads as:

```
parameter e = 0.3133:  'Electric charge'.
vector A/A:photon.
spinor e1/E1:(electron, mass me=0.000511).
parameter d_e, d_me, d_e1, d_A.
infinitesimal d_e, d_me, d_e1, d_A.
transform e -> e*(1+d_e), me -> me+d_me,
      A -> A*(1+d_A),
      e1 -> e1 + d_e1*e1,
      E1 -> E1 + d_e1*E1.
lterm e*E1*(i*gamma*deriv+gamma*A+me)*e1.
```

4.5 Constructing the ghost Lagrangian

The ghost Lagrangian can be constructed by means of the BRST formalism. To use it, the user should first declare the BRST transformations for fields (see Section 6.4).

The gauge-fixing Lagrangian reads as:

$$\mathcal{L}_{GF} = G^- G^+ + \frac{1}{2}|G^Z|^2 + \frac{1}{2}|G^\gamma|^2,$$

where G^i $(i = \pm, \gamma, Z)$ are gauge-fixing functions. The ghost Lagrangian ensures the BRST invariance of the entire Lagrangian and can be written as ([7])

$$\mathcal{L}_{Gh} = -\bar{c}^i \delta_{BRST} G^i + \delta_{BRST} \tilde{\mathcal{L}}_{Gh}.$$

where $\delta_{BRST} \tilde{\mathcal{L}}_{Gh}$ is an overall function, which is BRST-invariant.

So, for the photon and $G^\gamma = (\partial \cdot A)$, the LanHEP code for gauge-fixing and ghost terms reads as:

```
let G_A = deriv*A.
lterm -G_A**2/2.
lterm -'A.C'*brst(G_A).
```

Here the `brst` function is used to get BRST-transformation of the specified expression.

The inverse BRST transformation can also be used. One can declare the transformations for the fields by means of `brsti_transform`. The function `brsti(`*expr*`)` can be used in `lterm` statements.

5 Omitting indices

Physicists usually do not write all possible indices in the Lagrangian terms. LanHEP also allows a user to omit indices. This feature can simplify the introduction of the expressions and makes them more readable. Compare two possible forms:

```
lterm E1^a*gamma^a^b^mu*A^mu*e1^b.
```

corresponding to $g_e \bar{e}_a(x) \gamma^\mu_{ab} e_b(x) A_\mu(x)$, and

```
lterm E1*gamma^mu*e1*A^mu.
```

corresponding to $g_e \bar{e}(x) \gamma^\mu e(x) A_\mu(x))$. Furthermore, while physicists usually write vector indices explicitly in the formulas, in LanHEP vector indices also can be omitted:

```
lterm -i*ee*E1*gamma*e1*A.
```

Generally speaking, when the user omits indices in the expressions, LanHEP faces two problems: which indices were omitted and how to contract indices.

5.1 Restoring the omitted indices

When the indexed object is declared the corresponding set of indices is assumed. Thus, if the quark `q` is declared as

```
spinor q:('some quark', color c3).
```

its first index is spinor and the second one belongs to the `color c3` type. If both indices are omitted in some expression, LanHEP generates them in the correspondence to order (`spinor, color c3`). However, if only one index is written, for example in the form `q^a`, LanHEP has to recognize whether the index `a` is of `color c3` or of `spinor` types.

To solve this problem LanHEP looks up the *list of indices omitting order*. By default this list is set to

```
[spinor, color c3, color c8, vector]
```

The algorithm to restore omitted indices is the following. First, LanHEP assumes that user has omitted indices which belong to the first type (and corresponding antitype) from this list. Continuing the consideration of our example with particle `q` one can see that since this particle is declared having one `spinor` index (the first type in the list) LanHEP checks whether the number of indices declared for this object without `spinor` index equals the number of indices written explicitly by user. In our example (when user has written `q^a`) this is true. In the following LanHEP concludes that the user omitted the `spinor` index and that explicitly written index is of `color c3` type.

In other cases, when the supposition fails if the user has omitted indices of the first type in the *list of indices omitting order*, LanHEP goes to the second step. It assumes that user has omitted indices of first two types from this list. If this assumption also fails, LanHEP assumes that the user has omitted indices of first three types in the list and so on. At each step LanHEP subtracts the number of indices of these types assumed to be omitted from the full number of indices declared for the object, and checks whether this number of resting indices equals the number of explicitly written indices. If LanHEP fails when the *list of indices omitting order* is completed, error message is returned by the program.

Note that if the user would like to omit indices of some type, he must omit all indices of this type (and antitype) as well as the indices of all types which precede in the *list of indices omitting order*.

For example, if object `Y` is declared with one `spinor`, two `vector` and three `color c8` indices, than

- the form `Y^a^b^c^d^e^f` means that the user wrote all the indices explicitly;
- the form `Y^a^b^c^d^e` means that the user omitted `spinor` index and wrote `vector` and `color c8` ones;
- the form `Y^a^b` means that the user omitted `spinor` and `color c8` indices and wrote only two `vector` ones;
- the form `Y` means that the user omitted all indices;
- all other forms, involving different number of written indices, are incorrect.

One can say that indices should be omitted in the direct correspondence with abrupting the *list of indices omitting order* from left to right.

One could change the *list of indices omitting order types* by the statement `SetDefIndex`. For example, for default setting it looks like

```
SetDefIndex(spinor, color c3, color c8, vector).
```

Each argument in the list is a type of index.

5.2 Contraction of restored indices

A dummy index can be contracted only with some another dummy index. LanHEP expands the expression and restores indices in each monomial. LanHEP reads objects in the monomial from the left to the right and checks whether the restored indices are present. If such index appears LanHEP seeks for the restored index of the appropriate type at the next objects. Note, that the program does not check whether the object with the first restored index has another restored index of the appropriate type. Thus, if `F` is declared as let-substitution for the strength tensor of electromagnetic field (with two vector indices) then expression `F*F` (as well as `F**2`) after processing dummy indices turns to the implied form `F^mu^nu*F^mu^nu` rather than `F^mu^mu*F^nu^nu`.

This algorithm makes the contractions to be sensitive to the order of objects in the monomial. Let us look again at the QED example. Expression `E1*gamma*A*e1` (as well as `A*e1*gamma*E1`) leads to correct result where the vector index of photon is contracted with the same index of γ-matrix, spinor index of electron is contracted with antispinor index of γ-matrix and antispinor index of positron is contracted with spinor index of γ-matrix. However the expression `E1*e1*A*gamma` leads to the wrong form `E1^a*e1^a*A^mu*gamma^b^c^mu`, because the first antispinor index after the electron belongs to positron. Spinor indices of `gamma` stay free (non-contracted) since no more objects with appropriate indices (so, LanHEP will report an error since Lagrangian term is not a scalar).

Note, that in the vertex with two γ-matrices the situation is more ambiguous. Let's look at the term corresponding to the electron anomalous magnetic moment $\bar{e}(x)(\gamma^\mu\gamma^\nu - \gamma^\nu\gamma^\mu)e(x)F_{\mu\nu}$. The correct LanHEP expression is

```
e1*(gamma^mu*gamma^nu - gamma^nu*gamma^mu)*E1*F^mu^nu
```

Here vector indices can't be omitted, since it lead to the contraction of vector indices of γ-matrices. One can see also that the form

```
e1*E1*(gamma^mu*gamma^nu - gamma^nu*gamma^mu)*F^mu^nu
```

will correspond to the expression $\bar{e}(x)e(x)Sp(\gamma^\mu\gamma^\nu)F_{\mu\nu}$. Here LanHEP has got scalar Lorentz-invariant expression in the Lagrangian term, so it has no reason to report an error.

These examples mean that the user should clearly realize how the indices will be restored and contracted, or (s)he has to write all indices explicitly.

5.3 Let-substitutions

Another problem arises when the dummy indices stay free, this is the case for the `let` statement. LanHEP allows only two ways to avoid ambiguity in the order of indices types: either user specifies all the indices at the name of new symbol and free indices in the corresponding expression, or he should omit all free indices.

In the latter case the order of indices types is defined following the order of free dummy indices in the first monomial of the expression. For example if `A1` and `A2` are vectors and `c1` and `c2` are spinors, the statement

```
let d=A1*c1+c2*A2.
```

declares a new object `d` with two indices, the first is a vector index and the second is a spinor index according to their order in the monomial `A1*c1`. Of course, each monomial in the expression must have the same types of free indices.

5.4 Arrays

The usage of arrays with dummy indices allows us to define matrices conveniently. For example, the declaration of τ-matrices (defined in Section 3.5) can be written as

```
let tau1 = {{0, 1}, { 1, 0}}.
let tau2 = {{0, i}, {-i, 0}}.
let tau3 = {{1, 0}, { 0,-1}}.
```

One can see that in such way of declaration a matrix is written "column by column".

The declaration of objects with three 'explicit' indices can be done using the objects already defined. For example, when τ-matrices are defined as before, it is easy to define the vector $\vec{\tau} \equiv (\tau_1, \tau_2, \tau_3)$ as

```
let tau = {tau1, tau2, tau3}.
```

The object tau has three indices, first pair selects the element of the matrix, while the matrix itself is selected by the third index, i.e. `tau^i^j^a` corresponds to τ^a_{ij}.

On the other hand, the declaration of structure constants of a group is more complicated. Declaring such an object one should bear in mind that omitting indices implies that in a sequence of components the second index of an object is changed after the full cycle of the first index, the third index is changed after the full cycle of the second one, etc. For example, a declaration of the antisymmetrical tensor ε^{abc} can read as

```
let eps = {{{0,0,0}, {0,0,-1}, {0,1,0}},
           {{0,0,1}, {0,0,0}, {-1,0,0}},
           {{0,-1,0}, {1,0,0}, {0,0,0}}}.
```

One can easily see that the components are listed here in the following order:

$\varepsilon^{111}, \varepsilon^{211}, \varepsilon^{311}, \varepsilon^{121}, \varepsilon^{221}, \varepsilon^{321}, \varepsilon^{131}, \ \ldots \ \varepsilon^{233}, \varepsilon^{333}.$

The declaration of more complex objects such as $SU(3)$ structure constants can be made in the same way.

6 Checking the correctness of the model

6.1 Checking electric charge conservation

LanHEP can check whether the introduced vertices satisfy electric charge conservation law. This option is available, if the user declares some parameter to denote elementary electric charge (say, ee in QED example), and than indicate, which particle is a photon by the statement

SetEM(*photon*, *param*).

So, in example of Section 1 this statement could be

```
SetEM(A,ee).
```

Electric charge of each particle is determined by analyzing its interaction with the photon. LanHEP checks whether the sum of electric charges of particles in each vertex equals zero.

6.2 Testing Hermitian conjugate terms

LanHEP is able to check the correctness of the hermitian conjugate terms in the Lagrangian. To do this, user should use the statement:

```
CheckHerm.
```

For example, let us consider the following (physically meaningless) input file, where a charged scalar field is declared and cubic terms are introduced:

```
scalar h/H.
parameter a,b,c.
lterm a*(h*h*H+H*H*h)+b*h*h*H+c*H*H*h + h**3.
CheckHerm.
```

The output of LanHEP is the following (here 2 is the symmetry factor):

```
CheckHerm: vertex (h, h, h): conjugate (H, H, H) not found.
CheckHerm: inconsistent conjugate vertices:
    (H, h, h)              (H, H, h)
      2*a          <->        2*a
      2*b          <->    (not found)
   (not found)     <->        2*c
```

If the conjugate vertex is not found, a warning message is printed. If both vertices are present but they are inconsistent, more detailed output is provided. For each couple of the incorrect vertices LanHEP outputs 3 kinds of monomials: 1) those which are found in both vertices (these monomials are correctly conjugated), 2) the monomials found only in first vertex, and 3) the monomials found only in the second vertex.

6.3 Probing the kinetic and mass terms of the Lagrangian

When LanHEP is used to generate CompHEP model files, the information about particles propagators is taken from the particle declaration, where particle mass and width (for Breit-Wigner's propagators) are provided. Thus, the user is not obliged to supply kinetic and mass terms in `lterm` statements. Even if these terms are written, they do not affect the CompHEP output. LanHEP allows user to examine whether the mass sector of the Lagrangian is consistent. To do this, use the statement

```
CheckMasses.
```

This statement must be put after all `lterm` statements of the input file.

When the `CheckMasses` statement is used, LanHEP creates the file named `masses.chk` (in the directory where LanHEP was started). This file contains warning messages if some inconsistencies are found:

- missing or incorrect kinetic term;
- mass terms with mass different from the value specified at the particle declaration;
- off-diagonal mass terms.

Note that in more involved models like the MSSM the masses could depend on other parameters and LanHEP is not able to prove that expressions in actual mass matrix and in parameters declared to be the masses of particles are identical. Moreover, it is often impossible to express the masses as formulas written in terms of independent parameters. For this reason LanHEP evaluates the expressions appearing in the mass sector numerically (based on the parameter values specified by the user).

It is typical for the MSSM that some fields are rotated by unitary matrices to diagonalize mass terms. In some cases, values of mixing matrices elements can not be expressed by formulas and need to be evaluated numerically. LanHEP can recognize the mixing matrix if the elements of this matrix were used in `OrthMatrix` statement. LanHEP restores and prints the mass original matrix before fields rotation by mixing matrix.

6.4 Checking BRST invariance

LanHEP can check the BRST invariance (see the reviews in [5, 6]) of the Lagrangian. First, the user should declare the BRST transformations for the fields in the model by means of `brst_transform` statement:

`brst_transform` *field* `->` *expression*.

For example, the BRST transformation for the photon $\delta A_\mu = \partial_\mu c^A + ie(W^+_\mu c^- - W^-_\mu c^+)$ can be prescribed by the statement:

```
brst_transform A -> deriv*'A.c'+i*EE*('W+'*'W-.c'-'W-'*'W+.c').
```

The file 'sm_brst.mdl' in LanHEP distribution contains the code for gauge and Higgs fields transformation corresponding to the CompHEP implementation of the Standard model.

Since the transformations are defined, the statement

```
CheckBRST.
```

enables the BRST transformation for Lagrangian terms (so it should be placed before the first `lterm` statement). The output is CompHEP or LaTeX file. Certainly, if the Lagrangian is correct, the output files are empty. However some expressions identical to zero could be not simplified and remain in the output.

6.5 Extracting vertices

New statement allows to extract a class of vertices into separate file. This feature is useful in checking large models with thousands of vertices, such as the MSSM. The statement has the form

`SelectVertices(`*file, vlist* `).`

Here *file* is a file name to output selected vertices, and *vlist* determines the class of vertices. The pattern *vlist* may have two possible formats.

In the first format *vlist* is a list of particles:

`[`*P1, P2, P3, ... Pn* `]`

All vertices consisting only of the listed particles *P1, P2,...* are extracted. For example, the pattern

```
[A, Z, 'W+', 'W-', e1, E1, n1, N1]
```

selects vertices of leptons of first generation interaction with gauge fields and the self-interaction of gauge fields (we used here particles notation of CompHEP).

The second format reads

`[`*P11/P12../P1n, P21/.../P2m, ...* `]`

Here are several groups of particles, each group is joined by slash '/' symbol. Selected vertices have the number of legs equal to the number of groups in the list, each leg in the vertex corresponds to one group. For example,

```
[e1/E1/n1/N1, e1/E1/n1/N1, A/Z/'W+'/'W-']
```

selects vertices with two legs corresponding to leptons, third leg is gauge boson. Thus, this pattern extracts vertices of leptons interactions with gauge bosons. Note that the vertices of gauge bosons interaction are not selected in this case. If a group consists of one particle, it must be typed twice to enable second format (e.g. `[P1/P1, P2/P2, P3/P3]` for the vertex consisting of particles `P1, P2, P3`.

It is possible to specify some options in `SelectVertices` statement. The `WithAnti` option adds antiparticle names for each particle in the list (in the first format) or in the each group (in the second format. The `Delete` option removes selected vertices from the LanHEP's internal vertices list, so these vertices are not written in output file `lgrng`N`.mdl (lgrng`N`.tex)`. This could be useful if `SelectVertices` statements are supposed to distribute all vertices which should be in the model, than some 'unexpected' vertices can be found in output `lgrng`N`.mdl` file.

An example of lepton-gauge vertices selection could read as

```
SelectVertices( 'lept-gauge.mdl', [e1/n1, e1/n1, A/Z/'W+'], WithAnti, Delete).
```

7 Simplifying the expression for vertices

7.1 Orthogonal matrices

If some parameters appear to be the elements of the orthogonal matrix such as quark mixing Cabbibo-Kobayashi-Maskava matrix, one should declare them by the statement

OrthMatrix($\{\{a_{11}, a_{12}, a_{13}\}, \{a_{21}, a_{22}, a_{23}\}, \{a_{31}, a_{32}, a_{33}\}\}$).

where a_{ij} denote the parameters. Such a declaration permits LanHEP to reduce expressions which contain these parameters by taking into account the properties of the orthogonal matrices.

Note that this statement has no relation to the arrays; it just declares that these parameters a_{ij} satisfy the correspondent relations. Of course, one can declare further a matrix with these parameters as components by means of the `let` statement.

7.2 Reducing trigonometric expressions

Some physical models, such as the MSSM and general Two Higgs Doublet Model [4], involve large expressions built up of trigonometric functions. In particlular, after the diagonalization of the Lagrangian in the Higgs sector, in the models mentioned above two angles, α and β, are introduced, thus the Lagrangian may be written in LanHEP notation using the following definitions:

```
parameter sa=0.5:'sinus alpha',
          ca=Sqrt(1-sa**2):'cosine alpha'.
parameter sb=0.9:'sinus beta',
          cb=Sqrt(1-sb**2):'cosine beta'.
```

One can find in the output expressions like `sa*cb+ca*sb` $= \sin(\alpha+\beta)$ and much more complicated ones. To simplify the output and make it more readable the user can define new parameters, for example:

```
parameter sapb=sa*cb+ca*sb:'sin(a+b)'.
```

In order to force LanHEP to substitute the expression `sa*cb+ca*sb` by the parameter `sapb`, one should use the statement

```
SetAngle(sa*cb+ca*sb=sapb).
```

It is possible also to substitute an expressions by any polynomial involving paramters, for example,

```
SetAngle((sa*cb+ca*sb)**2+(sa*cb-ca*sb)**2=sapb**2+samb**2).
```

where `samb` should be previously declared as a parameter. Note, that LanHEP expands both expressions before setting the substitution rule. The left-hand side expression can also contain symbols defined by `let` statement. In the Lagrangian expressions LanHEP expresses powers of cosines, `ca**`N and `cb**`N through sines using recursively the formula $\cos^N\alpha = \cos^{N-2}(1-\sin^2\alpha)$ to combine all similar terms. The same procedure is performed for the left-hand side expression in `SetAngle` statement.

If the substitution for one angle combination is defined, LanHEP offers to define the other ones for expressions consisting of parameters used in previous `SetAngle` statements. In our example, for all expressions consisting of parameters `ca, cb, sa, sb`, the following message is printed (e.g. for $\cos(\alpha+\beta)$):

```
Warning: undefined angle combination; use:
         SetAngle(ca*cb-sa*sb=aa000).
```

Here aa000 is an automatically generated parameter. The message is printed only once for each expression. This feature is disabled by default; to enable producing these messages, one should issue the statement

```
option UndefAngleComb=1.
```

7.3 Heuristics for trigonometric expressions

LanHEP can apply several heuristic algorithms to simplify these expressions. For each angle α, the user should declare parameters for $\sin\alpha$, $\cos\alpha$, $\sin 2\alpha$, $\cos 2\alpha$, $\tan\alpha$. Than one should use the angle statement:

```
angle sin=p1, cos=p2, sin2=p3, cos2=p4, tan=p5, texname=name.
```

Here *pN* — parameter identifiers, *name* — LaTeX name for angle, it is used to generate automatically LaTeX names for trigonometric functions of this angle if these names are not set explicitly by SetTexName statement. This statement should immediately follow the declaration of the parameters for $\sin\alpha$ and $\cos\alpha$. Only the sin and cos options are obligatory. Other parameters (i.e. $\sin 2\alpha$, $\cos 2\alpha$, $\tan\alpha$) should be declared if these parameters are defined before $\sin\alpha$ and $\cos\alpha$. If the former parameters will be declared in terms of latter ones, they are recognized automatically and they need not appear in angle statements.

For example, the declaration for trigonometric functions of β angle in MSSM may read:

```
parameter tb=2.52:'Tangent beta'.
parameter sb=tb/Sqrt(1+tb**2):'Sinus beta'.
parameter cb=Sqrt(1-sb**2):'Cosine beta'.

angle sin=sb, cos=cb, tan=tb, texname='\\beta'.

parameter s2b=2*sb*cb:'Sinus 2 beta'.
parameter c2b=cb**2-sb**2:'Cosine 2 beta'.
```

Here the parameters s2b and c2b are recognized automatically by LanHEP as $\sin 2\alpha$ and $\cos 2\alpha$ since they are declared in terms of sa, ca parameters.

For a couple of angles (α, β in this example) the user should declare the parameters for $\sin(\alpha+\beta)$, $\cos(\alpha+\beta)$, $\sin(\alpha-\beta)$, and $\cos(\alpha-\beta)$ to allow using all implemented heuristics:

```
parameter sapb=sa*cb+ca*sb :  'sin(a+b)'.
parameter samb=sa*cb-ca*sb :  'sin(a-b)'.
parameter capb=ca*cb-sa*sb :  'cos(a+b)'.
parameter camb=ca*cb+sa*sb :  'cos(a-b)'.
```

These parameters are recognized as trigonometric functions automatically, by analysis of the right-side expressions.

It is possible to control the usage of heuristics by the statement:

```
option SmartAngleComb=N.
```

where N is a number:

0 heuristics are switched off;

1 heuristics are switched on (by default);

2 same as 1, prints the generated substitution rule if the simplified expressions consists of more than 3 monomials;

3 same as 1, prints all generated substitution rule.

4 same as 1, prints all generated substitution rule and some intermediate expressions (debug mode).

The substitution rules are printed as `SetAngle` statement and can be used for manual improvement of expressions.

7.4 LaTeX output

LanHEP generates LaTeX output instead of CompHEP model files if the user set `-tex` in the command line to start LanHEP. Three files are produced: 'vars$N$.tex', 'prtcls$N$.tex' and 'lgrng$N$.tex'. The first file contains names of parameter used in physical model and their values. The second file describes the particles, together with propagators derived from the vertices.

The last file lists introduced vertices. LanHEP uses Greek letters μ, ν, ρ... for vector indices, letters a, b, c... for spinor ones and p, q, r... for color indices (and for indices of other groups, if they were defined).

It is possible to inscribe names for particles and parameters to use them in LaTeX output. It can be done by the statement

`SetTexName([` *ident=texname, ...* `]).`

Here *ident* is an identifier of particle or parameter, and *texname* is string constant containing LaTeX command. Note, that for introducing backslash '\' in quoted string constant one should type it twice: '\\'.

For example, if one has declared neutrino with name `n1` (and name for antineutrino `N1`) than the statement

```
SetTexName([n1='\\nu^e', N1='\\bar{\\nu}^e']).
```

makes LanHEP to use symbols ν^e and $\bar{\nu}^e$ for neutrino and antineutrino in LaTeX tables.

8 Declaration of new index types and indexed objects

8.1 Declaring new groups

Index type is defined by two keywords[1]: *group name* and *representation name*. Thus, color triplet index type `color c3` has group name `color` and representation name `c3`.

LanHEP allows user to introduce new group names by the `group` statement:

`group` *gname*.

Here *gname* is a string constant, which becomes the name of newly declared group.

Representation names for each group name must be declared by the statement

`repres` *gname*`:(`*rlist*`)`

where *rlist* is a comma-separated list of representation names declaration for the already declared group name *gname*. Each such declaration has the form either *rname* or *rname*/*crname*. In the first case index which belongs to the *gname rname* type can be contracted with another index of the same type; in the second case index of *gname rname* type can be contracted only with an index of *gname crname* type.

For example, definition for color $SU(3)$ group with fundamental, conjugate fundamental and adjoint representations looks like:

[1]The exception is Lorentz group, corresponding indices types are defined by a single keyword.

```
group color:SU(3).
repres color:(c3/c3b,c8).
```

So, three index types can be used: `color c3, color c3b, color c8`. The contraction of these indices is allowed by pairs (`color c3, color c3b`) and (`color c8, color c8`) indices.

8.2 Declaring new specials

Specials with indices of user-defined types can be declared by means of `special` statement:

`special` *name*`:(`*ilist*`).`

Here *name* is the name of new symbol, and *ilist* is a comma-separated list of indices types. For example, Gell-Mann matrices can be defined as (although color group and its indices types are already defined):

```
special lambda:(color c3, color c3b, color c8).
```

To define Dirac's γ-matrices one can use the command

```
special gamma:(spinor, cspinor, vector).
```

8.3 Arrays

Array, i.e. the object with explicit components, can also have the user-defined type of index. In this case generic form of such object is

{ *expr1, expr2 ... ,exprN ; itype* }

where N expressions *expr1 ... exprN* of N components are separated by comma, and *itype* is an optional index type. If *itype* is omitted LanHEP uses default group name `wild` and index type `wild` N, where N is a number of components in the array.

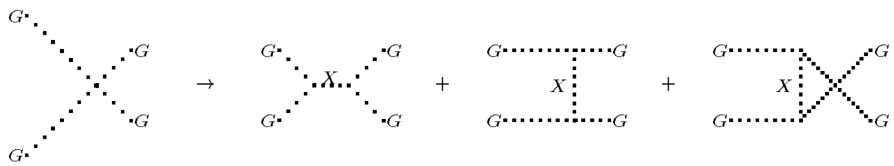
9 Splitting the vertices with 4 colored particles

The CompHEP Lagrangian tables do not describe explicitly the color structure of a vertex. If color particles are present in the vertex, the following implicit contractions are assumed (supposing p, q, r are color indices of particles in the vertex):

- δ_{pq} for two color particles A^1_p, A^2_q;
- λ^r_{pq} for three particles, which are color triplet, antitriplet and octet;
- f^{pqr} for three color octets.

Other color structures are forbidden in CompHEP.

So, to introduce the 4-gluon vertex $f^{pqr}G^q_\mu G^r_\nu f^{pst}G^s_\mu G^t_\nu$ one should split this 4-legs vertex into 3-legs vertices $f^{pqr}G^q_\mu G^r_\nu X^p_{\mu\nu}$:



Here the field $X^p_{\mu\nu}$ is a Lorenz tensor and color octet, and this field has constant propagator. If gluon name in CompHEP is 'G', the name 'G.t' is used for this tensor particle; its indices denoted as 'm_' and 'M_' ('_' is the number of the particle in table item).

The described transformation is performed by LanHEP automatically and transparently for the user. Each vertex containing 4 color particles is split to 2 vertices which are joined by an automatically generated auxiliary field.

The same technique is applied in the MSSM where more vertices with 4 color particles appear: vertices with 2 gluons and 2 squarks and vertices with 4 squarks. However, the large amount of vertices with 4 squarks requires many auxiliary fields, which can easily break CompHEP limitations on the particles number. It is possible however to reduce significantly the number of vertices and auxiliary fields if one introduce auxiliary fields at the level of multiplets.

The vertices with 4 squarks come from DD and F^*F terms. For example, there is the term $\frac{1}{2}D^a_G D^a_G$ in the Lagrangian,

$$D^a_G = g_s(Q^*_i \lambda^a Q_i + D^* \lambda^a D + D^* \lambda^a D),$$

where Q, D, U are squarks multiplets, and λ is Gell-Mann matrix. Instead of evaluating this expression and that splitting all vertices independently, one can introduce one color octet auxiliary field ξ^a and write this Lagrangian term as $D^a_G \xi^a$.

Other DD terms contain both color and colorless particles. Thus, the term $D^i_A D^i_A$ with

$$D^i_A = g_1(Q^* T^i Q + L^* T^i L + H^*_1 T^i H_1 + H^*_2 T^i H_2),$$

can be represented as

$$g_1(Q^*T^iQ)\xi^i + g_1^2(Q^*T^iQ)(L^*T^iL + H_1^*T^iH_1 + H_2^*T^iH_2) + g_1^2(L^*T^iL + H_1^*T^iH_1 + H_2^*T^iH_2)^2$$

where ξ^i is the triplet of auxiliary fields. This terms can also be written in the another form:

$$g_1(Q^*T^iQ + L^*T^iL)\xi^i + g_1^2(Q^*T^iQ + L^*T^iL)(H_1^*T^iH_1 + H_2^*T^iH_2) + g_1^2(H_1^*T^iH_1 + H_2^*T^iH_2)^2,$$

where all vertices with 4 scalars (except vertices with Higgs particles) are splitted. Although the latter splitting is not obligatory, it can reduce significantly the amount of vertices.

The similar technique is applicable to the F^*F terms, with the transformation $F^*_i F_i \to F^*_i \xi^*_i + F_i \xi_i$.

Thus, we distinguish two types of vertices splitting: splitting at multiplet level and splitting at vertices level. Note that splitting the vertices with two gluons and two squarks must be done at vertices level after combining the similar terms, otherwise they would contain the elements of squark mixing matrices.

The vertices splitting at multiplet level is implemented in LanHEP mainly for MSSM needs. The first case refers to DD terms. The user should declare several let-substitutions and then put in `lterm` statement the squared sum:

```
let a1=g*Q*tau*q/2,
    a2=g*L*tau*l/2,
    a3=g*H1*tau*h1/2,
    a4=g*H2*tau*h2/2.
lterm - ( a1 + a2 + a3 + a4 ) ** 2 / 2.
```

In this case LanHEP looks for the square of the sum of several let-substitution symbols, each containing two color or merely scalar particles. If such expression is found, it is replaced as in the previous formulas.

The vertices splitting in F^*F terms is performed by `dfdfc` function (see previous section). After taking the variational derivative the monomials with two color or scalar particles (except

Higgs ones) are multiplied by auxiliary fields, thus mediating the vertices with 4 color (scalar) particles.

The multiplet level vertices splitting is controlled by the statement

`option SplitCol1=`N.

where N is a number:

- -1 remove all vertices with 4 color particles from Lagrangian;
- 0 turn off multiplet level vertices splitting;
- 1 allows vertices splitting with 4 color multiplets;
- 2 allows vertices splitting with any 4 scalar multiplets except Higgs ones (more generally, any multiplets containing vev's).

The value of this option can be set to different values before executing different `lterm` statements.

The vertices level splitting is performed after combining similar terms of the Lagrangian. This splitting can be controlled by the statement

`option SplitCol2=`N.

where N is a number:

- 0 disable vertex level splitting;
- 1 enable vertex level splitting (only for vertices with 4 color particles).

For CompHEP output, the default value is 2 for `SplitCol1` and 1 for `SplitCol2`. For LaTeX output, default value is 0 for both options.

10 Installation

To install LanHEP on your computer, you should get the archive file from the WWW-page `http://theory.sinp.msu.ru/~semenov/lanhep.html`. Unpack the archive:

```
gunzip lhep2000.tar.gz
tar xf lhep2000.tar
```

The archive contains the directory `lanhep` with C source files. If you do not have gcc compiler, you should tune the makefile, change 'gcc' to the compiler which you have. To create the executable file (called `lhep`), go to `lanhep` directory and type

```
make
```

When LanHEP is complied, remove the source files by typing

```
make clean
```

The archive also contains the subdirectory `mdl` with startup file and examples for several physical models. Add the directory containing LanHEP to your *PATH* environment variable. Then LanHEP can be started from any other directory, it can find automatically files in the `mdl` directory.

11 Running LanHEP and the command line options

As mentioned above, LanHEP can read the model description from the input file prepared by the user. To start LanHEP write the command

`lhep` *filename options*

where the possible *options* are described in the next section. If the *filename* is omitted, LanHEP prints it's prompt and waits for the keyboard input. In the last case, user's input is copied into the file `lhep.log` and can be inspected in the following. To finish the work with LanHEP, type '`quit.`' or simply press `^D` (or `^Z` at MS DOS computers).

11.1 Options

Possible options, which can be used in the command line to start LanHEP are:

`-OutDir` *directory* Set the directory where output files will be placed.

`-InDir` *directory* Set the default directory where to search files, which included by `read` and `use` statements.

`-tex` LanHEP generates LaTeX files instead of CompHEP model tables.

`-frc` If `-tex` option is set, forces LanHEP to split 4-fermion and 4-color vertices just as it is made for CompHEP files.

`-texLines` *num* Set number of lines in LaTeX tables to *num*. After the specified number of lines, LanHEP continues writing current table on the next page of LaTeX the output. Default value is 40.

`-texLineLength` *num* Controls width of the Lagrangian table. Default value is 35, user can vary table width by changing this parameter.

`-nocdot` removes \cdot commands between the parameters symbols in the LaTeX output. This option is useful when all parameters have prescribed LaTeX names.

`-c4` produces the output files for CompHEP version 4x.xx, which has slightly different format than 3x.xx.

`-allvrt` produces CompHEP-like ouput with all vertices of the Lagrangian, including 1-leg and 2-leg ones which contribute to the mass matrix. Vertices with more than 4 legs are also in the output (this is not supported by CompHEP now).

`-evl` *num* For the lengthly expression in a vertex (more then *num* monomials) an auxiliary variable is generated, and the expression is stored in the parameters table. This allows to increase significantly the speed of symbolic calculation of the matrix element by CompHEP. *num=2* is recommended.

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