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CompHEP
Specialized package for automatic calculations of elementary particle decays and collisions [1]

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Abstract

At present time when a new generation of TeV colliders are beginning to operate one needs to calculate cross-sections for a great number of various reactions. Such calculations are united in the framework of the collider physical program, providing definite predictions how to detect the signatures of the new physics and separate them from the background. The CompHEP package was created for calculation of decay and high energy collision processes of elementary particles in the lowest order (tree) approximation. The main idea put into the CompHEP was to make available passing from the lagrangian to the final distributions effectively with the high level of automatization what is extremely needed in collider physics.

1. Introduction

CompHEP project was started in 1989 by group of physicists and programmers from the Institute of Nuclear Physics, Moscow State University. Twelve researchers (P. Baikov, E. Boos, M. Dubinin, H. Eck, V. Edneral, D. Kovalenko, A. Kryukov, A. Pukhov, A. Semenov, S. Shichanin, P. Silaev, A. Taranov) took part in the development of the project coordinated by Dr. V.Ilyin and Prof. V.I.Savrin. The main steps of the CompHEP development are published in Ref.[1]. The project was supported by Russian State Program on High Energy Physics, RFFI (93-02-14428), ISF (M9B000), INTAS (93-1180), Japan Society for the Promotion of Science, Japanese companies KASUMI Co, Ltd and SECOM Co, Ltd. and Royal Society (UK).

[1] The talk given at the Korean Physical Society meeting on October 21, 1994

The first versions of the CompHEP package were written in Turbo Pascal for IBM compatible PC. In 1992 this package was rewritten in the C programming language and now the installation on UNIX workstations is available. At present time there are some versions for different platforms: HP Apollo 9000, IBM RS 6000, DECstation 3000, Sparc station, Silicon Graphics. Adaptations for these platforms were done during the visits of the CompHEP group members in KEK (Japan), Seoul National University (Korea), University "La Sapienza" (Rome, Italy), University of Sao Paulo (Brazil), DESY (Germany).

CompHEP is a menu-driven system with the mixed text/graphical output of information and the context HELP facility. The notations used in CompHEP are very similar to those used in particle physics. The present version has 4 built-in physical models. Two of them are versions of the Standard Model (SU(3)xSU(2)xU(1)) in the unitary and 'tHooft-Feynman gauges. The user can change interaction vertices and model parameters. A creation of a new particle interaction model by the user is possible. In the present version polarizations are not taken into account. Averaging over initial and summing over final polarizations are performed automatically.

The general structure of the CompHEP package is represented in Fig.1. It consists of two parts: the symbolical part and the numerical one. The main tasks solved by the symbolical part are :

1. to select process by specifying *in-* and *out-* particles for decays of $1 \to 2, \ldots, 1 \to 5$ type and collisions of $2 \to 2, \ldots, 2 \to 4$ type;

2. to generate and display Feynman diagrams;

3. to delete some number of diagrams from the further consideration;

4. to generate and display squared Feynman diagrams (corresponding to squared S-matrix elements);

5. to calculate analytical expressions corresponding to squared diagrams with the help of the fast built-in symbolic calculator;

6. to perform numerical calculations for $1 \to 2$ and $2 \to 2$ processes, to show plots of angular distributions and cross sections;

7. to save symbolic results corresponding to the squared diagrams calculated in the REDUCE and MATHEMATICA codes for further symbolical manipulations;

8. to generate the optimized FORTRAN code for the squared matrix elements for further numerical calculations;

The numerical part of the CompHEP package is written in FORTRAN.

It uses the CompHEP FORTRAN output, the BASES&SPRING package [2] for Monte-Carlo integration and event generation. The main tasks solved by the numerical part are :

1. to choose phase space kinematical variables;

2. to introduce kinematical cuts over any squared momentum transfers and squared masses for any groups of outgoing particles;

3. to perform a regularization to remove sharp peaks in the squared matrix elements;

4. to change the BASES parameters for Monte-Carlo integration ;

5. to change numerical values of model parameters;

6. to calculate distributions, cross-sections or particle widths by the Monte-Carlo method;

7. to perform the same intergration taking into account structure function for incoming particles;

8. to generate events and to get histograms simulating the signal in real experiment.

2. Menu system of the CompHEP symbolic part

The CompHEP is a menu-driven system. The user can select a menu position with the help of the ARROW keys. The input of the selected position is performed by pressing the ENTER key. Before pressing ENTER one can press F1 key (HELP) to get information about the selected menu position. To return to the previous level menu one should press the ESC or BACKSPACE keys.

The menu titles of the CompHEP symbolic part are shown in Fig.2.

Menu 1 (models)

This menu gives the user a possibility to select a model of elementary particle interaction.

1. *QED* denotes Quantum Electrodynamics.

2. *Fermi model* denotes QED with the four-fermion weak interaction model. The interaction of fermion currents is implemented through auxiliary particles (W and Z bosons) having constant propagators.

3. *St.model (unit. gauge)* denotes the Standard Model with the electroweak sector in the unitary (physical) gauge and QCD in the Feynman gauge.

4. *St.model (Feyn. gauge)* denotes the Standard Model with the electroweak sector in the 'tHooft - Feynman gauge and QCD in the Feynman gauge;

N E W M O D E L is an option for creating a new physical model. The new model is created as a copy of some old model with some new name. The *Edit model* option of Menu 3 can be used to insert changes. If the user chooses this menu line he will be asked about a new model name and about a template for model. To choose the template the list of the existing models appears.

After a model selection the user gets to Menu 2 for further processing.

Menu 2

1. *Enter process* is an option for entering the process from the keyboard (see Section 4). If the input is correct, CompHEP constructs the corresponding Feynman diagrams and the user enters Menu 4.

2. *Edit model* option allows the user to view and change the current physical model. The user enters Menu 3 to insert changes into model tables.

3. *Delete changes* option removes the model created with the help of the *N E W M O D E L* option from Menu 1 or restores the built-in model if it has been changed with the help of the *Edit model* option.

Menu 3 (edition of models)

A physical model in CompHEP consists of four tables:

1.*Variables* (the list of independent parameters)

2.*Constraints* (the list of dependent parameters)

3.*Particles* (the list of particles)

4.*Lagrangian* (the list of vertices)

By this Menu the user selects a table for changes (see Section 3). After changes the user should press the ESC key to leave this Menu. If the tables are changed the user will be asked:

Save changes Y/N ?

If the user's answer is "N" then the changes will be forgotten. In other case CompHEP checks the new version of the model. If the version is correct it is saved into the user's directory *Models* . Otherwise the message about an error appears on the screen.

Menu 4

1. *Squaring* generates diagrams for squared S-matrix elements.

2. *View diagrams* displays graphic representation of the constructed Feynman diagrams (see Fig. 3). Here the user has a possibility to exclude some

diagrams from further processing.

When squaring is finished Menu 5 is displayed.

Menu 5

1. *View squared diagrams* shows graphic representation of the constructed squared diagrams. Here the user again has a possibility to exclude some diagrams from further processing.

2. *Symbolic calculations* starts symbolic calculations of the squared diagrams generated. In CompHEP the calculation is done by means of the built-in symbolic manipulation package.

3. *Write results* - gives the possibility to write obtained analytical result for squared diagrams on the hard disk in different formats, the corresponding files are placed in the subdirectory RESULTS. This option is available after the symbolic calculation only. Menu 6 for different output formats is displayed.

4. *REDUCE program* generates for each squared diagram a source code in the REDUCE format for the following calculation of the matrix element squared by means of REDUCE. This option can be used to check the build-in symbolic calculator.

5. *Numerical calculator* fulfills numerical calculations for the simplest $1 \to 2$ and $2 \to 2$ processes. Calculated numerical values of widths, distributions or cross sections are displayed on the screen, also angle distributions. In the case of infrared singularities the message *Division by zero* is written. Menu 7 appears for further processing.

6. *Enter new process* returns to the Menu 2 for entering a new collision or decay process.

7. *Interface* gives a possibility to incorporate the CompHEP session with the work of other external packages. The Menu of external packages appears. The first position of this Menu is used to start the numerical part of the CompHEP package (see Section 5). Other positions are free.

Menu 6

1. *FORTRAN code* writes down symbolical results in the directory RESULTS as a FOFTRAN code for further numerical calculations.

2/3. *REDUCE code / MATHEMATICA code* writes down symbolical results in the directory RESULTS as a REDUCE/MATHEMATICA code for further symbolical manipulations.

Menu 7

1. *View/change data* shows the table with parameter names and numerical values on the screen. It gives the user a possibility to change a numerical value for any parameter. After changes one should press ESC to leave the parameter table. The cross section (width) will be recalculated automatically.

2. *Set angular range* (for $2 \to 2$ processes only) allows to set *min* and *max* values for cosine of scattering angle in the center of mass reference system.

3. *Set precision* sets a precision for the numerical calculation.

4. *Angular dependence* allows to draw (also save into the file) the differential cross section as a function of cosine of scattering angle in the center of mass frame. Menu 8 is called for further work.

5. *Parameter dependence* allows one to get distributions for any parameter involved into the process under consideration. For the $1 \to 2$ process the parameter dependence of the width can be displayed. For the $2 \to 2$ process the user can construct plots both for the cross section and for the asymmetry (the forward - backward cross section difference). This selection is realized by Menu 9, the user getting a table to select parameters. Then the user is asked about minimal and maximal values of these parameters and about scales (normal / logarithmical) for parameters. After finishing the calculations the user gets Menu 10.

Menu 8

1. *Show plot* displays on the screen the calculated angular dependence. Two ordinates scales are available: normal and logarithmic ones.

2. *Save results in a file* writes down the calculated angular dependence in a file. The file is created in the RESULTS directory. The message about the file name appears on the screen.

3. *Recalculate* recalculates the differential cross section for a given number of points and with higher precision.

Menu 9 : (see the item 5 in Menu 5)

Menu 10

1. *Show plot* displays on the screen graphical plots for the total cross section (asymmetry) as a function of selected parameter. For positive functions two ordinate scales are available: normal and logarithmic ones.

2. *Save results in a file* writes down the calculated parameter dependence in a file. The file is created in the RESULTS directory. The message about the file name appears on the screen.

3. Physical model structure in CompHEP.

The information about a physical model in CompHEP is stored in four tables. They are

Parameters - the table of independent parameters,

Constraints - the table of dependent parameters,

Particles - the table of particles,

Lagrangian - the table of vertices.

All independent parameters used in calculations are described in the *Parameters* table:

Name	Value	Comment
EE	0.313	electromagnetic coupling constant
GG	1.373	strong coupling constant
SW	0.48	sine of the Weinberg angle
MZ	91.16	Z-boson mass
wZ	2.53	Z-boson width
wW	2.25	W-boson width
...	...	...

Name means the name of the parameter used for a further model definition and a symbolic result representation. *Value* is a numerical value of the parameter used for numerical calculations. *Comment* is a commentary what the corresponding parameter means.

The table *Constraints* describes variables that are functions of parameters:

Name	Expression	Comment
CW	Sqrt(1-SW**2)	cosine of the Weinberg angle
MW	MZ*CW	W boson mass
...	...	...

Here *Name* means the name of a new variable, *Expression* defines a function of independent parameters and dependent variables defined above.

The *Particles* table consists of 8 fields:

Full name	P	aP	2*Spin	Mass	Width	Color	Aux
gluon	G	G	2	0	0	8	G
electron	e1	E1	1	0	0	1	
e-neutrino	n1	N1	1	0	0	1	L
u-quark	u	U	1	0	0	3	
W-boson	W+	W-	2	MW	wW	1	G
Z-boson	Z	Z	2	MZ	wZ	1	G
...	...	...	...	...	...	...	...

Full name denotes the name of the particle. This field is a comment only.

P and *aP* contain designations of the particle and antiparticle correspondingly. If the antiparticle is identical to the particle *aP* must be equal to *P*.

*2*Spin* denotes the doubled spin of the particle. Only 0, 1 and 2 values are available here (scalar, spinor and vector cases).

Mass and *Width* are particle mass and width identifiers. The values of these symbolic parameters have to be entered in the tables *Parameters* or *Constrains*. It is possible to enter zero in these fields.

Color denotes a dimension of the color SU(3) group representation: 3 for quarks, 8 for gluons, 1 for colorless particles.

Aux is a special auxiliary field: *L/R* are marks for left/right massless spinor particles, *G* is a mark for a vector particle to be treated as a gauge field in the 'tHooft - Feynman gauge, asterisk "*" is a mark for a massive particle that will have the constant propagator $\frac{1}{M^2}$. This option is used for implementation of the four-fermion vertex in the Fermi model of electroweak interaction.

Propagators of any particles are generated by CompHEP automatically. CompHEP uses the standard form for scalar, spinor and vector particle propagators. However the field "Aux" provides the user with some possibility to change propagators.

The table *Lagrangian* includes the list of vertices.

A1	A2	A3	A4	Factor	Lorentz part
W+	W-	Z		EE*CW/SW	m1.m2*(p1-p2).m3+m2.m3*(p2-p3).m1 +m3.m1*(p3-p1).m2
N1	e1	W+		EE/(2*Sqrt2*SW)	G(m3)*(1-G5)
E1	n1	W-		EE/(2*Sqrt2*SW)	G(m3)*(1-G5)
U	u	G		GG	G(m3)
...	...	...	...	...	...

The first four fields (A1, A2, A3, A4) contain the names of interacting particles. The last two fields *Factor* and *Lorentz part* define the vertex itself. *Factor* is a scalar factor dependent only on model variables. It can not include summation of terms but only a single term.

Lorentz part depends on model variables, Lorentz momenta (p1, p2, p3 and p4) and Lorentz indices (m1, m2, m3 and m4) corresponding to the particles listed in the first four fields: p1 and m1 for the first particle etc.

Here dot symbol "." is used for a scalar product of Lorentz momenta ($p1.p2 = g_{\mu\nu}p1^{\mu}p2^{\nu}$) or indices ($p1.m1 = p1_{\mu_1}$, $m1.m2 = g_{\mu_1\mu_2}$); G denotes the Dirac's gamma matrix ($G(m3) = \gamma^{\mu_3}$); G5 is the γ^5 matrix ($\gamma^5\gamma^5 = 1$)

The normalization condition is the following. Let S is the action. Then for a three particle vertex

$$\frac{\delta^3 S}{\delta A1_{[m1]}(p1)\delta A2_{[m2]}(p2)\delta A3_{[m3]}(p3)} = (2*\pi)^{-2} * \delta(p1+p2+p3)$$

$$*[\gamma^0] * ColorStructure * Factor * LorentzPart$$

Here *ColorStructure* is a QCD color structure. It is generated automatically from a particle color weight. It is impossible to introduce into the table the 4-gluon vertex explicitly in this way. This vertex (and corresponding diagrams) is generated automatically in some special way during the symbolic calculation of squared diagrams.

Optional γ^0 appears for a vertex with fermions to get a Lorentz covariant object. The Majorana representation for γ-matrix is implied.

4. Entering a process in CompHEP.

After the input of the command *Enter process* of the Menu 2 the list of particles will be shown contained in the model together with the corresponding notation conventions. The notation of an antiparticle is shown in

parenthesis after the notation of a particle. For example in the case of the Standard Model:

A(A) -photon	G(G) -gluon	e1(E1) -electron
n1(N1) -e-neutrino	e2(E2) -muon	n2(N2) -mu-neutrino
e3(E3) -tau	n3(N3) -tau-neutrino	u(U) u-quark
d(D) -d-quark	c(C) c-quark	s(S) s-quark
t(T) t-quark	b(B) b-quark	H(H) -Higgs
W+(W-) W-boson	Z(Z) Z-boson	

In the down part of the screen the prompt **Enter process** appears. The syntax for the input is the following: first *in*-particles separated by comma, then arrow "$->$", and then *out*-particles separated by commas. For example,

Enter process: $u, U -> G, G$

denotes the process of annihilation of u-quark and u-antiquark into two gluons.

One can also construct inclusive processes. For example,

Enter process: $u, U -> G, G, 2 * x$

is the request to construct all processes of annihilation of u-quark and u-antiquark into two gluons and two arbitrary particles.

If the program finds the unknown symbol among the in-particles this symbol is considered as a composite particle. For instance, after the input

Enter process: $e, p -> 3 * x$

the question appears:

Is 'p' a composite particle Y/N ?

If one answers 'Y' he will be prompted to specify the proton structure (list of partons). A possible input is

'p' consists of: u, U, d, D, G

If one enters the collision process (not particle decay) then he will be asked about total energy of colliding particles in the center-of-mass system (in GeV):

Enter Sqrt(S) in GeV: *300*

On the next step the user will be asked if it is necessary to generate diagrams with all possible intermediate (virtual) particles. These restrictions are used to exclude diagrams which are suppressed due to a large particle mass or a small coupling constant or due to some other reasons. For example:

Restrict virtual particles: $W+ < 2$

This particular restriction means that only diagrams with no more than one virtual W-boson will be generated.

Several restrictions separated with commas are allowed.

5. Numerical part of the CompHEP package

This program provides the user a possibility to prepare the CompHEP FORTRAN output for a further numerical integration over phase space and then to carry out this integration in a user-friendly manner. This program provides also an interface with the Monte Carlo integration package BASES and the event generator SPRING.

The user has a possibility to calculate widths for decays or cross sections for collisions. Then one can fill histograms for different distributions. This program does not allow to make a summation over types of *in*- or *out*-particles.

There are two modes of the program run available: interactive and batch ones. In the interactive mode the program is a menu-driven system. The menu titles of the CompHEP numerical part is reproduced in Fig.4. To select the menu position the user should type its number and press the ENTER key. To get HELP about any menu position the user should enter h#, where # is the position number, or h for general help for this menu.

The **Calculation** position of **Main menu** starts a calculation of the cross-section (for collisions) or the width (for decays) by BASES. The program operation is organized as a sequence of work sessions. The session number is displayed and automatically increasing after each sequential Monte Carlo calculation.

After completing the BASES calculation the **Event generator** submenu (the interface with the SPRING program) will appear if the event generator has been switched on in the submenu **MC parameters**:

Event generator menu	
1: Start generator	2: Number of events = 10000
3: View current 'hst' file	

The file hst.# contains the report of the SPRING run with histograms initialized for filling by the user.

Other **Main menu** positions call submenus for setting conditions of the Monte Carlo integration. Below we give a brief description of the submenu titles.

The **IN state** submenu serves for preparing the initial state of collision processes. It is possible:

- to change $\sqrt{s}$ – summary energy of *in*-particles in CMS,
- to switch on a structure function option.

The **Model parameters** submenu allows one to change any physical model parameters involved in the process. New values will be saved in a file.

The **Invariant cuts** submenu allows to introduce kinematical cuts (lower and upper bounds) for arbitrary squared combinations of Lorentz momenta of *in*- and *out*- particles. These cuts are written down in the table. For example:

N	MIN VALUE [GeV**2]	INVARIANT	MAX VALUE [GeV**2]	STATUS
1		(-p1+p3)**2	< -1.000	HARD
2		(-p2+p4)**2	< -1.000	HARD

The **Kinematics** submenu is used for defining integration variables. First one has to choose the necessary number of independent kinematical variables, express all scalar products of particle momenta and other Lorentz vectors (if they are) via these integration variables, evaluate squared matrix element for the current phase space point and multiply squared matrix element by the corresponding Jacobian. This menu allows the user to define kinematics in the most convenient way for the further integration over phase space.

The scheme of kinematical variable selection are fixed in the table. For example:

Decay	In	Out 1	Out 2	Pvect
1	p1+p2	p3	p4+p5	-p1
2	p4+p5	p4	p5	-p2

The **MC parameters** submenu allows the user to change some BASES [2] parameters which are engaged in this program. There are two loops of

the BASES calculation. The first one consists of iterations with adaptation of the grid from iteration to iteration. The second loop includes iterations with the fixed grid to accumulate necessary statistics. So,

Ncall – number of Monte-Carlo sample points for one iteration;

Itmx1 – maximal number of iterations with the grid adaptation (1st loop);

Acc1 – limit for the calculation accuracy in % (1st loop);

Itmx2 – maximal number of iterations with the fixed grid (2nd loop);

Acc2 – limit for the calculation accuracy in % (2nd loop).

Also it is possible to switch on the **Event generator** SPRING and define a number of events to be generated.

The **Regularization** submenu is used to transform integration variables for representing the integrand as a smooth function.

In some cases the matrix element squared has very strong singularities and the Monte Carlo integrators are not efficient enough. The typical example of the singular integration is given by the process

$$\mathsf{e1,A} \to \mathsf{e1,Z,H},$$

with the singularity appearing from the exchange of t-channel electron.

For a reliable evaluation of such singular integrals this program has the special option which can be activated in the menu. Certainly this option is available only if there is the correspondence between singularities and a set of the integration variables. So, to make the regularization it could be necessary to change kinematics.

The introduction of kinematical regularizations speeds up the convergency of the Monte Carlo integration. The invariants over which the regularization is made are written down in the table. For example:

N	INVARIANT	MASS [GeV]	WIDTH [GeV]	STATUS
1	(-p1+p3)**2	0		ON
2	(-p2+p4)**2	0		ON

The **Task formation** submenu provides the following options :

- to collect results of the calculation in the table(s) with any physical parameters as a table argument;
- to prepare the task for batch mode calculation;
- to set default session parameters.

The **View results** submenu allows the user to view any output files containing results of cross section (or width) calculation, a report on the process of MC integration, histograms.

As a result of the calculation for each work session the program creates three output files:

res.#, prt.# and hst.#.

Here # denotes the number of session. The file res.# contains a result of the calculation with a list of model parameters used.

The file prt.# is a copy of the screen report of calculation with list of all parameters (technical and physical ones).

The file hst.# contains filled histograms.

The **User's menu** serves for an implementation of any user's calls. For example, it can provide the interface with the CERN PDF library.

The **Users' functions** subroutine allows the user to implement some functions written by himself in order

- to introduce cuts for any functions of kinematical variables;
- to make convolution of squared matrix elements with any structure functions with account of the running (strong) coupling constant and the momentum transfer scale;
- to save any users' parameters in the file SESSION.DAT when the program is over and to read them from this file when the program starts.

6. Brief review of physical results obtained by means of the CompHEP package

Ten three-body processes in the e^+e^- collisions for a heavy particle production such as Higgs, t-quark, W and Z are calculated in Ref.[3] by two independent computer codes (generated by CompHEP[1] and GRACE[2]).

The results are in an excellent agreement within statistical errors of numerical integration (about 0.5%). This cross-check of numerical results demonstrates that CompHEP and GRACE systems are quite reliable for a theoretical study of processes at future $e^+e^-, e\gamma$ and $\gamma\gamma$ colliders.

Cross sections of the Higgs boson associated production in γe collisions are calculated in Ref.[4] for the $\gamma e \to \nu W H$ and $\gamma e \to e Z H$ processes. Event signatures for Higgs boson production, event separation and background conditions are considered. It is shown that the Higgs boson production process $\gamma e \to \nu W H$ seems very promising for the investigation of gauge cancellations between different diagrams and search for anomalous phenomena (for instance, anomalous Higgs boson interaction vertices).

In the paper[5] the calculations of total cross sections for the W and Z boson production in γe and $\gamma\gamma$ collisions are presented in the 3rd order in electroweak coupling constant at the tree level. They are compared with the estimations obtained by simple approximation methods to see their accuracy for this class of processes. The preliminary physical analysis of obtained results is given.

All tree level diagrams are calculated by means of the CompHEP package for the reaction $\gamma\gamma \to t\bar{t}H$ [6]. It was shown that the reaction is very sensitive to probing the Higgs fermion coupling in TeV energy range.

In the paper[7] the complete tree level calculations for three particle final state production at future $e^+e^-, \gamma e$ and $\gamma\gamma$ colliders are presented. The results obtained with the help of the CompHEP package for total cross sections and other characteristics of processes in the energy range 0.1-2 TeV are summarized and their comparison with the results of other approaches is discussed. In particular the processes of W, Z and H boson production are considered. These reactions are especially interesting in connection with probing new couplings, searching for new particle signals and estimating the most important backgrounds in various experiments.

The possibility of the single and pair excited neutrino production in high energy $e^+e^-, \gamma e$ and $\gamma\gamma$ collisions at linear colliders is studied in Ref.[8]. The integrated cross sections of these subprocesses are calculated in a symbolical form. A special attention is paid to a search for excited neutrino in the $\gamma e \to W, W, e$ process. The lower limits for the compositeness parameter to be available in the experiments at Next Linear Colliders are estimated.

The possibility to detect the Higgs boson signal in the process $e^+e^- \to Z\bar{b}b$ at LEP200 energies is considered in Ref.[9]. The calculations are per-

formed in the tree approximation for a complete set of diagrams. Tree level corrections to the Higgs signal are computed. If the highest possible LEP200 energy is $\sqrt{s} = 190$ GeV the Higgs signal will be very clean for the masses of Higgs up to $\sqrt{s} - M_Z$ about 95 GeV.

In [10] the possibility of Higgs boson signal observation at LEP200 and Next Linear Colliders in the reactions $e^+e^- \to \mu^+\mu^- b\bar{b}$, $e^+e^- \to \nu\bar{\nu}b\bar{b}$, $e^+e^- \to e^+e^- b\bar{b}$ is investigated. Complete tree level calculations for these $2 \to 4$ processes are performed and compared with the various effective $2 \to 2$ body approximations. The accuracy of effective approximations near the thresholds and at different energies are calculated. In some situations it is necessary to introduce nontrivial kinematical cuts in order to separate the signal from the background.

A complete tree-level calculation of the reaction $e^+e^- \to e\nu\bar{t}b$ in the electroweak standard theory in the LEP200 energy range is presented in Ref.[11]. For top quark masses in the range 130 to 190 GeV the cross sections are found to be of the order $10^{-5} - 10^{-6}$pb. Therefore, the number of single top quark events is expected to be negligible even with an integrated luminosity of L=500 pb^{-1}. It is further demonstrated that the Weizsaecker-Williams approximation approaches the accurate cross section calculations reasonably well.

In Ref.[12] the possibilities of search for vector leptoquarks at high energy ep and γp colliders are investigated. The exact analytical expressions are derived for cross sections with the help of CompHEP taking into account possible anomalous couplings of vector leptoquark with gauge bosons. The vector leptoquark search potential at HERA and future ep colliders is discussed in detail.

Different $2 \to 3$ reactions for the Higgs production in association with a vector boson pair at future e^+e^- colliders are calculated in the paper [13] using the amplitude technique and the CompHEP package. A very good agreement of two independent calculations has been found. The paper demonstrates an important point of the CompHEP application for an additional test of results obtained by other methods or computer systems.

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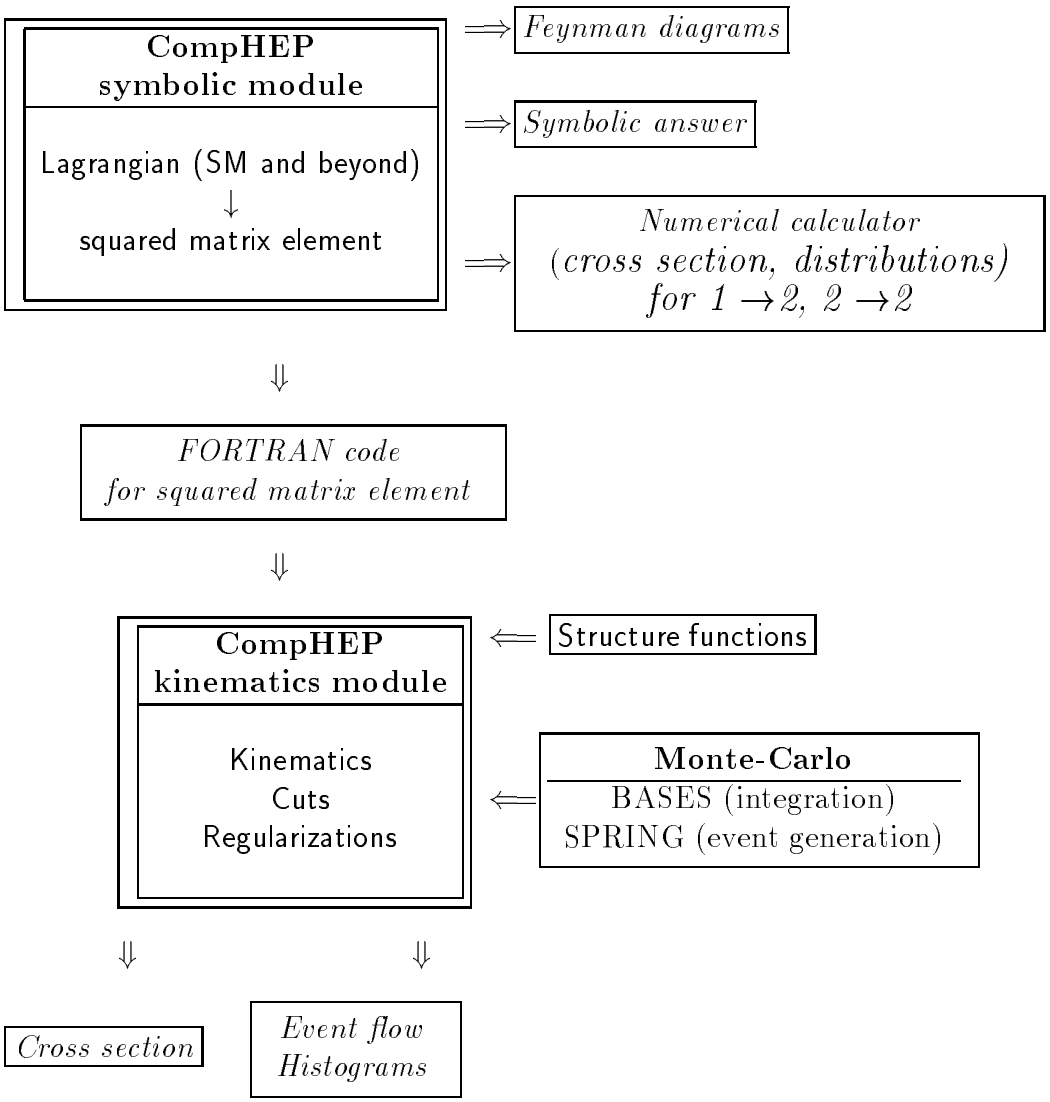

Fig. 1.The general structure of the CompHEP package

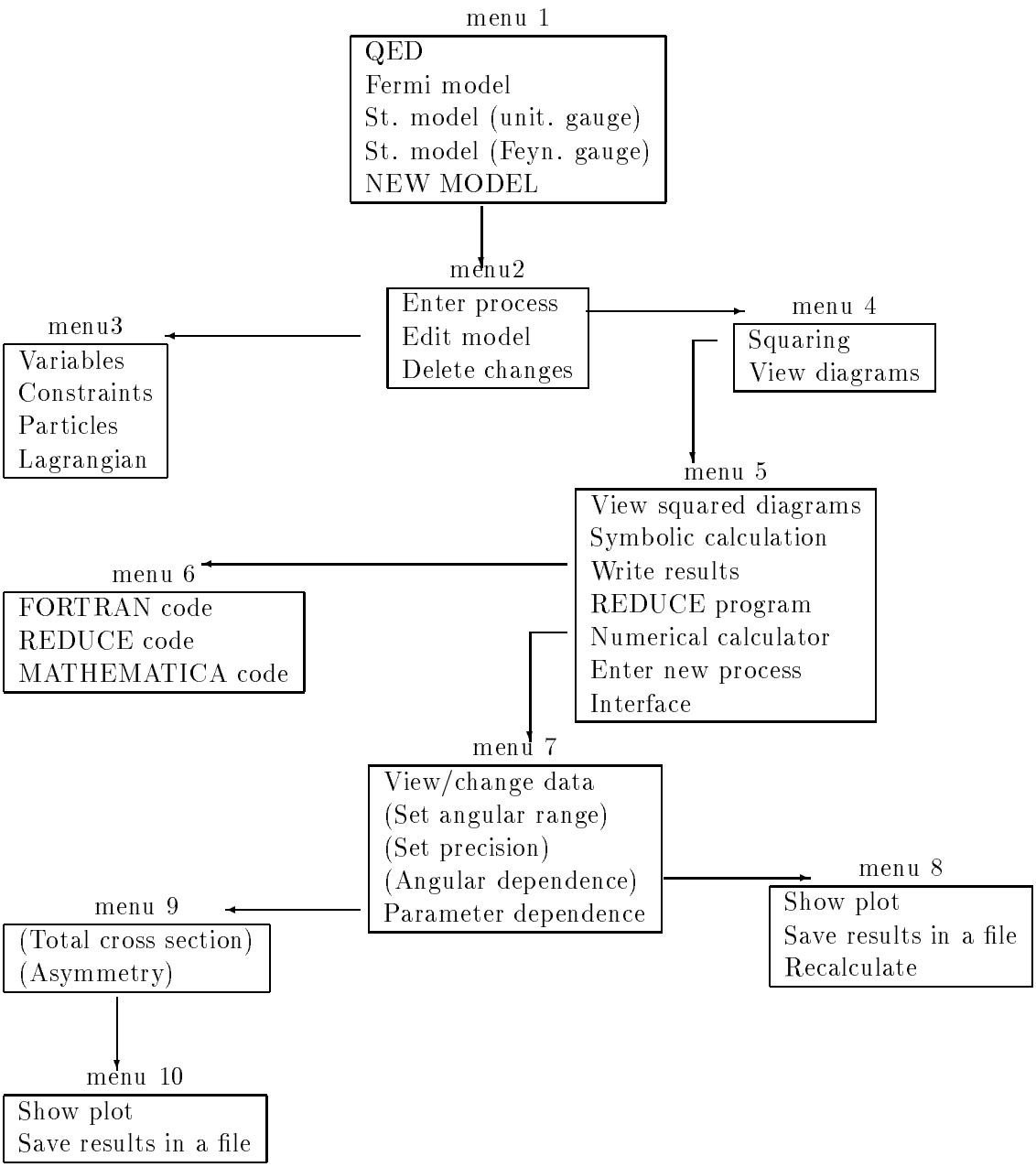

Fig. 2. The menu system for the CompHEP symbolic part

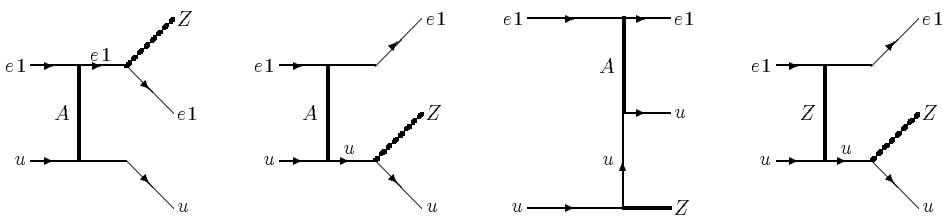

Fig. 3. Diagrams for process $e^-, u -> e^-, u, Z$

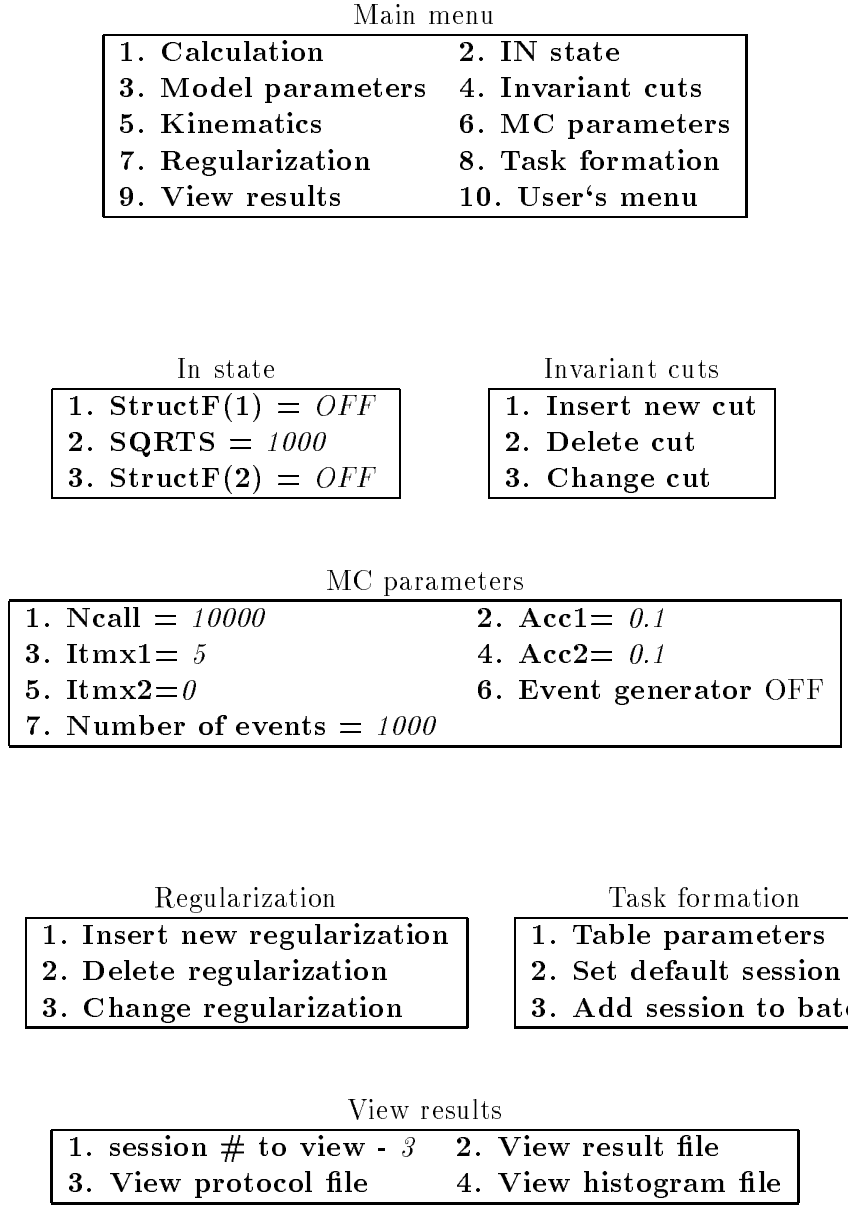

Fig.4 The menu system for the CompHEP numerical part