CalcHEP 2.3: MSSM, structure functions, event generation, batches, and generation of matrix elements for other packages.

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Abstract
CalcHEP is a package for computation of Feynman diagrams and integration over multi-particle phase space. The main idea prescribed into CalcHEP is to make available passing on from Lagrangians to the final distributions effectively with a high level of automation. This article presents new options of CalcHEP available in version 2.3. They are a) MSSM model with different SUGRA scenarios, b) interface with PDFLIB and implementation of new MRST/CTEQ structure functions, c) realization of approach to structure functions for models with diagonal CKM, d) generation of events and interface with PYTHIA, e) calculations in non-interactive (batch) regime, f) generation of code of different matrix elements for other programs, g) many new interface facilities.

1 Introduction
CalcHEP is a package for automatic calculations of elementary particle decay and collision properties in the lowest order of perturbation theory (the tree approximation). CalcHEP is a next development of the CompHEP[1] package which was created by the author together with his colleagues in Skobeltsyn Institute of Nuclear Physics. Other packages created to solve a similar problem are FeynArt[2], GRACE[3], HELAS[4], MADGRAPH[5], PHELAS[6], O’MEGA[7]. See also the review [8].
CalcHEP is a menu-driven system with the context help. The notations used in CalcHEP are very similar to those used in particle physics. The CalcHEP package consists of two parts: symbolic and numerical. The symbolic part produces C codes for a squared matrix element, and they are used in the numerical calculation later on. Menu systems for both parts and relations between them are shown on Fig.1 and Fig.2.

The symbolic part of CalcHEP lets the user:

- select a model of particle interaction and implement some changes in the model. In particular one can choose the package for solution of RGE equations in case of SUGRA models;
- choose a gauge between the physical or t’Hooft-Feynman ones.
- select a process by specifying incoming and outgoing particles for the decays of $1 \rightarrow 2, \ldots, 1 \rightarrow 5$ types and the collisions of $2 \rightarrow 2, \ldots, 2 \rightarrow 4$ types;
- generate Feynman diagrams, display them, and create the corresponding \LaTeX output;
- exclude some diagrams;
- generate and display squared Feynman diagrams;
- calculate analytical expressions corresponding to squared diagrams by using the fast built-in symbolic calculator; There is an additional option to perform the calculations in the leading order of $1/N_c$ expansion.
- save symbolic results corresponding to the squared diagrams calculated in the REDUCE and MATHEMATICA codes for further symbolic manipulations;
- generate the optimized C codes for the squared matrix elements for further numerical calculations;
- launch the compilation of the generated codes and start the corresponding numerical session;
- generate libraries of matrix elements for other packages.

The numerical part of CalcHEP offers to:
• convolute the squared matrix element with structure functions and beam spectra. The PDFLIB, CTEQ, and MRST parton distribution functions, the ISR and Beamstrahlung spectra of electrons, the laser photon spectrum, and the Weizsaecker-Williams photon structure functions are available;

• modify physical parameters (incoming momenta, couplings, masses etc.) involved in the process;

• select the scale parameter for evaluation of the QCD coupling constant and parton structure functions;

• calculate Higgs widths and decay rates taking into account high order QCD loop corrections.

• apply LEP mass limits on MSSM spectrum, as well as calculate $b \to s\gamma$, $B_s \to \mu^+\mu^-$, and $(g-2)_\mu$ constraints.

• apply various kinematic cuts.

• define the kinematic scheme (phase space parameterization) for effective Monte Carlo integration;

• introduce a phase space mapping in order to smooth sharp peaks of a squared matrix element and structure functions;

• perform a Monte Carlo phase space integration by VEGAS;

• generate partonic level events and direct them to PYTHIA

• display distributions in various kinematic variables;

• create the graphical and LaTeX outputs for histograms.

The current version is accompanied with various batch programs which allow to performs all calculations in non-interactive regime.

CalcHEP source codes for Unix and complete manual are disposed on the following Web sites

http://theory.sinp.msu.ru/~pukhov/calchep.html
http://www.ifh.de/~pukhov/calchep.html

In this paper we describe new option of CalcHEP available staring from version 2.3.

A comment about file structure of CalcHEP. We use notation $\text{CALCHEP}^1$ to designate the CalcHEP code disposition on the

$^1$It is up to the user responsibility to define the environment variable CALCHEP to simplify his/her work with CalcHEP. In general it is not needed.
disk space. During installation the user creates another directory, say WORK, intended for user files. WORK contains subdirectories

models/ tmp/ results/ bin/

intended for user’s version of models, temporary files, numerical sessions and CalcHEP commands respectively. Note that bin is just a symbolic link of $CALCHEP/bin/ directory.

WORK/ contains also a startup script command calchep which launches symbolic session $CALCHEP/bin/s_calchep which it its turn realizes work with models, symbolic calculations and the record of the obtained matrix elements into WORK/results. After that calchep calls C-compiler and transforms C-code stored in WORK/results into executable n_calchep disposed in the same place. The last command realises CalcHEP numerical calculations.

2 New service facilities.

Version 2.3 has some new service facilities which simplify interactive sessions and also are necessary to realize some batch commands.

In case of work with CalcHEP tables (model files, cuts, distributions) the following new options are implemented:

a) Search a record in the table, which contains simultaneously several pattens. The search is activated by the ^F key. After that the user has to introduce the pattens separated by commas. This option is convenient for search a vertex in large Lagrangian tables. For example, to find the neutralino - chargino - W vertex one has to specify the pattens as "~o1,~1+,W-". The order of patterns does not matter.

b) Automatic increase of size of some fields in case of long input. This option is needed in batch sessions when program fills tables in blind regime and doesn’t see field boundaries.

c) There is a possibility to move cursor on needed position on the table. This option needs to locate position in the table according to error messages.

d) There is an option to write the contents of given field into the file and read it back. It can be used for implementation of cumbersome vertex of interaction. When the program writes to the file it automatically splits the field on short lines with about 80 symbols in
each line. But when file is read, the end-of-line symbols are ignored.

'Find' option for CalcHEP menus is implemented. Just press 'F' when you are in some menu and specify the needed pattern. This option is convenient for search a record in the long menus like menu of SUSY 'Constraints'. Also it is used in batch calculations to force the program to go to the needed menu position.

Comment and 'force' symbols in model tables. In case of tables of independent and constrained parameters we give the user possibilities to comment the given record or to force the program to include the given parameter in the numerical code. The first option gives a flexibility for model modification. The second one can be used if the user wont to have approach during numerical sessions to some constraints which are not involved in matrix element computation$^2$. To comment and force a variable the symbols '%', and '*' respectively should be disposed before the parameter name. For example, to include the $b \rightarrow s \gamma$ constraint into numerical session mark the corresponding constraint by '*' like

```
| *bsgnlo|bsgnlo(mssm0k)
```

Definition of a model of particle interaction is slightly improved.

a) For each particle we keep its code in Monte Carlo numbering scheme$^{22}$. This code is used for interface with structure functions routines, say CTEQ, and interface with event generation packages like PYTHIA$^{23}$. It allows to organize interface that is not sensitive to name of particles used in CalcHEP.

b) In previous versions it was forbidden to use metric tensor $g_{\mu\nu}$ in vertexes with spinors particles. Instead one had to use the anticommutator of Dirac $\gamma$-matrices. Now this artificial restriction is avoided.

c) CalcHEP works only with vetrices with simple, factored, structure of color indexes. In order to realize vertexes like the four-gluons one it was proposed to use auxiliary tensor fields with color indexes and point like propagators. Now it was recognized that in general case, say for realization of leptoquark interactions, one needs two such fields.

$^2$By default CalcHEP does not include such parameters into numerical sessions.
One of them plays a role of constraint, when the second presents the corresponding Lagrange multiplier. In the current version for each color vector field two tensor auxiliary fields generated automatically.\footnote{The names of these fields are constructed from the name of the mother field by adding the extensions ".t" and ".T".}

**Physical gauge** can be switched on/off via CalcHEP menu. In the previous versions we included any model twice, first time in the \textit{t’Hooft-Feynman} gauge and second time in the \textit{Physical} one. Now we keep only models defined in the \textit{t’Hooft-Feynman} gauge. But if the user sets flag \texttt{Force Unit.gauge}\footnote{See \textit{menu 2} on Fig. 1} in position \textit{ON}, then vertexes with Faddev-Popov ghosts will be ignored and propagators of massive vector particles will be evaluated in the \textit{Physical} gauge.

For \(1 \rightarrow 2\) processes we gives the user an option to use effective masses of \(b\) and \(t\) quarks, which reproduces Higgs widths up to all known QCD loop corrections.

**\(v \ast \sigma\) plot** for \(2 \rightarrow 2\) reactions is available, where \(v\) is relative velocity. This option simplifies the analysis of \(v \rightarrow 0\) limit.

**All histograms** generated during numerical session are stored on disk automatically in files \texttt{distr_\#}, where \# denotes the number of current Monte Carlo session. The \texttt{show_distr} function allows one to see all set of generated distributions and to extract the needed plot. The \texttt{sum_distr} function performs summation of produced distribution. The examples of usage are
\begin{verbatim}
../bin/show_distr distr_1
../bin/sum_distr distr_1 distr_2 distr_3 > distr_sum
\end{verbatim}

The sum is performed only for distributions which are produced in sessions with identical outgoing particle. It can be used for sum over incoming partons.

\footnote{As it was written above the user has approach to CalcHEP executables via \texttt{WORK/bin}. This example demonstrates this option.}
3 MSSM in CalcHEP

This section follows to [9]

3.1 Les Houches Accord for MSSM.

Originally the MSSM in format of CalcHEP/CompHEP notations was realized in [17]. Version of this model with effective Higgs masses evaluated by FeynHiggsFast[12] was presented in [18]. Next step in this business was a development of Les Houches Accord format[16] for MSSM input. This format treats all masses and mixing angles of super-particles as independent input parameters. It is assumed that all these masses and angles should be evaluated by some external program based of original SUSY model. The list of parameters is presented in Table 1. The MSSM in Les Houches format was implemented in framework of the micrOMEGAs project[9]. Current version of CalcHEP uses namely this realization.

Table 1: Les Houches Accord Parameters

| name    | comment               | name    | comment               |
|---------|-----------------------|---------|-----------------------|
| tb      | tangent beta          | MSnl    | τ-sneutrino mass      |
| alpha   | Higgs α angle         | MScL/ | masses of left/right selectrons |
| mu      | Higgs μ parameter     | MSmL/τ | left/right smuon masses |
| Mh      | Mass of light Higgs   | MSI1/2 | masses of light/heavy τ |
| MH3     | Mass of CP-odd Higgs  | MSu1/2 | masses of left/right u-squarks |
| MIH     | Mass of Heavy Higgs   | MSs1/2 | masses of left/right s-squarks |
| MHc     | Mass of charged Higgs | MSst1/2 | masses of light/heavy τ |
| Al      | \( \tilde{t} \) trilinear coupling | MSdL/2 | masses of left/right d-squarks |
| Am      | \( \tilde{μ} \) trilinear coupling | MScL/2 | masses of left/right c-squarks |
| Ab      | \( \tilde{b} \) trilinear coupling | MSbL/2 | masses of light/heavy b-squarks |
| At      | \( \tilde{t} \) trilinear coupling | Zniij  | i=1,...,4; j=1,...,4; neutralino mixing |
| MNEi    | i=1,2,3,4; neutralino masses | Zuij  | i=1,2;j=1,2; chargino U mixing |
| MC(1/2) | light/heavy chargino masses | Zviij  | i=1,2;j=1,2; chargino V mixing |
| MSG     | mass of gluino        | Zlj    | i=1,2;j=1,2; \( \tilde{τ} \) mixing |
| MSne    | \( \tilde{e} \)-sneutrino mass | Ztij    | i=1,2;j=1,2; \( \tilde{t} \) mixing matrix |
| MSnm    | \( \tilde{μ} \)-sneutrino mass | Zbij   | i=1,2;j=1,2; \( \tilde{b} \) mixing matrix |

We have to note that MSSM with general Les Houches Accord
input brakes the $SU(2)$ gauge invariance which leads to gauge dependence of produced results. The implementation of large loop corrections to Higgs masses is done in gauge invariant manner[18]. So, the problem is caused by corrections for masses of s-particles only. In general the gauge dependence should be an order of loop corrections, because it caused by partial implementation of them. Nevertheless, in some special cases, when gauge invariance is responsible for mutual cancellations of diagrams, its lost can be dangerous.

One can check the gauge dependence by comparing results produced in Unitary gauge against results of t’Hooft-Feynman one. In case of calculation of relic neutralino density[9] in was detected that the gauge dependence is less than 2%, that is smaller than expected value of loop corrections. It looks like even for LHC energies small breaking of gauge invariance initiated by the *Les Houches Accord* is not a problem. But this point is not absolutely clear.

After each numerical session the file with MSSM parameters written in the Les Houches Accord format appears on the disk. The file name is *slha_#.txt*, where # denotes the session number. It can be used for interface with other packages, for example, PYTHIA.

### 3.2 Parameters of MSSM.

The CalcHEP package contains two versions of MSSM. They are identical at the level of *Les Houches Accord*, but have different parameter interface. In one case parameters are specified at low energies, whereas in the second case all soft SUSY breaking terms are specified at GUT (about $10^{19}$GeV) scale. In the second case one can significantly decrease the number of parameters assuming some scenario of Supersymmetry breaking. All these parameters in the CalcHEP notations are presented in the Table 2. Note that there is a small difference between parameter sets used at low and high scales.

The first model is *ewsbMSSM*. Masses and mixing angles are evaluated by the function included in *Constraints* model table,

\[
\text{suspectEWSBc(smOk, tb, MG1, MG2, MG3, Am, A1, At, Ab, MH3, mu, M11, M13, Mr1, Mr3, Mq1, Mq3, Mu1, Mu3, Md1, Md3, LC)}
\]

The parameters are assumed to be given at Electroweak Symmetry Breaking scale $Q = \sqrt{MS1 \cdot MS2}$. Besides the parameters presented at Table 2 it contains auxiliary parameter *smOk* included for
Table 2: Set of MSSM parameters. Parameters used at the GUT scale only are marked with #, whereas parameters used only at the EWSB scale are marked with *. Index i numerates generations.

| name   | comment               | name   | comment                      |
|--------|-----------------------|--------|------------------------------|
| tb     | tangent beta          | $M_{l_i}$ | Left-handed slepton masses   |
| $A_{t}$ | $t$ trilinear coupling | $M_{r_i}$ | Right-handed selectron masses|
| $A_{b}$ | $b$ trilinear coupling | $M_{q_i}$ | Left-handed squark masses    |
| $A_{l}$ | $\tilde{\tau}$ trilinear coupling | $M_{u_i}$ | Right-handed u-squark masses |
| $A_{m}$ | $\tilde{\mu}$ trilinear coupling | $M_{d_i}$ | Right-handed d-squark masses |
| $M_{G1}$ | U(1) Gaugino mass     | *$M_{H3}$ | Mass of Pseudoscalar Higgs    |
| $M_{G2}$ | SU(2) Gaugino mass    | *$\mu$  | Higgs $\mu$ parameter        |
| $M_{G3}$ | SU(3) Gaugino mass    | #$M_{H_{u}}$ | Mass of first Higgs doublet  |
| #$\text{sgn}(\mu)$ | sign of $\mu$ at low scales | #$M_{H_{d}}$ | Mass of second Higgs doublet |

technical purposes and parameter $L C$ that switches on ($L C > 0$) calculation of loop correction for $s$-particles. This calculation is realized by means of SuSpect package[11]. The loop corrections to Higgs masses are always included and their calculation also is supported by SuSpect. It is assumed that MSSM parameters describing first two generations are identical, so only parameters corresponding to the first and third generations are included into the list.

The second model, sugraMSSM, has the GUT scale input motivated by Super-Gravity SUSY breaking scenario. Here mass spectrum is calculated by the function

\[
\text{suspectSUGRAc}(\text{smOk},tb,MG1,MG2,MG3,A1,At,Ab,\text{sgn},Hu,Hd,Ml1,Ml3,Mr1,Mr3,Mq1,Mq3,Mu1,Mu3,Md1,Md3)
\]

The current sugraMSSM model files realize the minimal SUGRA scenario where

\[
A1 = At = Ab = a_0
\]
\[
MG1 = MG2 = MG3 = m_{1/2}
\]
\[
Hu = Hd = Ml1 = Ml3 = Mr1 = Mr3 = Mq1 = Mq3 = Mu1 = Mu3 = Md1 = Md3 = m_0
\]

So, there are only 4 new parameters\(^6\), namely, $tb, a_0, m_0, m_{1/2}$ and

\(^6\)for some reason in CalcHEP notations $m_0$ and $m_{1/2}$ presented as $m\text{Zero}$ and $m\text{hf}$ correspondingly.
\( sgn = sgn(\mu) \) which should be \( \pm 1 \). The user can easily constructs the non-minimal sugra model moving some parameters from the list of Constraints to the list of Variables. An analyze of relic density and other constraints if framework of non-minimal SUGRA was done in [10].

By default we use the SuSpect[11] codes for solution of the Renorm-Group Equations which connect the GUT scale parameters with low energy ones. For other possibilities see the next section.

Both, the solution of RGE and the calculation of corrections to Higgs masses, depend on QCD sector of SM, which is not known with good precision. The corresponding parameters are \( M_{b\bar{b}} \) - scale invariant b-quark mass \( M_{b}(M_{b}) \); \( M_{t\bar{t}} \) - pole mass of t-quark; \( \alpha_{SMZ} \) - strong coupling constant at \( M_{Z} \). From the other side actual b and t-quarks masses are described by free parameters \( M_{b} \) and \( M_{t} \). In general case, the correct implementation of these masses depends on the problem under consideration. Say, for treating of Higgs decays one has to use running masses at the corresponding scale, but if these quarks appear as s-channel resonances, then the pole masses should be used. In the same manner, the strong coupling which appears in QCD vertexes is not defined through the \( \alpha_{SMZ} \).

### 3.3 Isajet, SoftSusy, and SPHENO in CalcHEP.

For the sugraMSSM model CalcHEP supports interface with with all modern RGE packages SuSpect[11], Isajet[13], SoftSusy[14], and SPHENO[15]. SuSpect is default one. To use another package one has to replace \texttt{suspectSUGRAc} on \texttt{isajetSUGRAc}, \texttt{sphenoSUGRAc}, or \texttt{softSusySUGRAc} respectively. These functions already presented in the Constraints table but are commented.

For the ewsbMSSM model we support SuSpect and Isajet. In order to use Isajet for calculations masses of Higgs and super particles replace the \texttt{suspectEWSBc} presented in list of constraints on \texttt{isajetEWSBc} one. This function also is presented and commented.

After model modification one has to check installation of the corresponding package and to organize its link with CalcHEP. In case of

\(^{7}\alpha_{s}\) in matrix elements depends on the used parton structure function or is driven by Menu 4 of Fig.2
Isajet the library `libilsajet.a` should be passed to CalcHEP linker. See Section 8.

Interface with Spheno and SoftSusy is realized via independent call of the corresponding program. Parameters are passed via files written in framework of Les Houches Accord. The destination of the package is detected in runtime via environment variables `SPHENO/SOFTSUSY`. These variables have to be defined by the user in a proper way. Note, that definition depends slightly on the type of your command interpreter. For example, if you have SoftSusy installed in subdirectory `softsusy_1.9` of your home directory then define

```
# for sh, bash, ..
# for csh, tcsh, ..
SOFTSUSY=$HOME/softsusy_1.9
setenv SOFTSUSY ~/softsusy_1.9
export SOFTSUSY
```

One can add this instruction into startup file of your Unix session (like `.bashrc` or `.cshrc`), or include it in the CalcHEP startup file `WORK/calchep`. In the last case it should be done in the `sh` format and will work only when numerical session is launched under the symbolic one.

### 3.4 MSSM constraints.

There are several experimental constraints which allow to exclude some regions of MSSM parameter space. The references on experimental results, discussion of theoretical uncertainties and details of realization of corresponding functions see in [10], [9]. The numbers presented below follow to [10].

There is a LEP2 limit on the mass of light Higgs. To check it the user can control the $M_h$ constrained parameter which presents this mass. In case of heavy pseudoscalar Higgs $M_h > 114.4$ GeV. In general case taking into account theoretical and experimental uncertainties we have $M_h > 111$ GeV.

To check the LEP limits for other MSSM masses see the `LEPlim` constrained parameter. `LEPlim=0` means that all constraints are satisfied. In general case

$$LEPlim = l(x_1^+ + 2l(\tilde{\nu}_e) + 4l(\tilde{\nu}_\mu) + 8l(\tilde{\nu}_\tau) + 16l(\tilde{e}_R) + 32l(\tilde{\mu}_R) + 64l(\tilde{\tau}_1)),$$

where function $l()$ returns 1 if the mass limit for the corresponding particle is broken are 0 otherwise.
The \textit{drho} variable presents the $\Delta \rho$ value which describes the MSSM corrections to electroweak observables. It contains stop/sbotom contributions, as well as the two-loop QCD corrections due to gluon exchange and the corrections due to gluino exchange in the heavy gluino limit. Precise measurements allow to set $\Delta \rho < 2 \cdot 10^{-3}$.

\textit{gmuon} presents value of supersymmetric contribution to anomalous magnetic moment of muon. At 3$\sigma$ level $5.1 \cdot 10^{-10} < \text{gmuon} < 64.1 \cdot 10^{-10}$

\textit{bsgndo} returns the branching ratio for $b \rightarrow s \gamma$. See details of calculation in [9]. Taking into account noticeable theoretical uncertainty of SM contribution one can set limits $2.25 \cdot 10^{-4} < \text{bsgndo} < 4.43 \cdot 10^{-4}$

\textit{bsmumu} presents branching ratio $B_s \rightarrow \mu^+ \mu^-$. According to CDF measurements $\text{bsmumu} < 9 \cdot 10^{-6}$. The SM contribution is in 3 order of magnitude smaller.

These constrains were initially written for the micrOMEGAs package. See details in [9] and [10]. It was demonstrated that the most strong constraint on MSSM parameters follows from astrophysics measurements of Dark Matter if it is treated as a relict density of neutralinos. For relic density calculations see the micrOMEGAs package based on matrix elements generated by CalcHEP.

### 3.5 Problem of widths for Higgs and s-particles.

In the current realization of MSSM the widths of Higgs and s-particles are presented as free parameters. In principle they can be easily calculated in a parallel CalcHEP session. The code of such auxiliary session can be attached to the main code of cross section calculation in spirit of Section 7. This idea was realized in the version of CalcHEP included in the micrOMEGAs [9] package. But such option is not realized automatically for any model yet.

In the current version we pass to the user the widths calculated by Isajet or Spheno. To realize such option one has to comment width variables included in the list of free model parameters and uncomment them in the list of constrained parameters. Of course, one has to replace default SuSpect code used for RGE solution and loop correction on Isajet or Spheno one\textsuperscript{8}.

\textsuperscript{8}For the \texttt{ewsbMSSM} Spheno is not supported.
4 QCD parton distributions

Below we describe two accesses to QCD parton distributions supported in CalcHEP. The first of them is a link of CERN PDF library. The second one is based on the special format of Particle Distribution Tables elaborated in the CalcHEP project. The second way allows to implement easily all modern CTEQ/MSRT parton distributions. In both cases, by default, the $\alpha_s$ coupling that was used in the parton distribution is applied to matrix elements\(^9\). For both realizations of parton distributions the user has to specify only incoming particle(proton/anti-proton) and identifier of the set. The sort of parton is detected automatically according to the Monte-Carlo numeration defined in CalcHEP particle tables. We also support special $d'(x)$, $s'(x)$ distributions that describe quark densities in the models with diagonal CKM matrix. See Section (4.3).

4.1 PDFLIB distributions

In order to include the PDFLIB[29] distributions into the CalcHEP list one has to pass the corresponding libraries to CalcHEP linker. Then the distributions of PDFLIB will automatically appear in CalcHEP numerical session compiled after such modification. While PDFLIB is not passes to linker, CalcHEP uses dummy version of this library. This trick allows to install CalcHEP on computer where CERNLIB is not available.

The technical aspects of attaching of new codes to CalcHEP numerical sessions are explained in Section 8. Note, that one can attach any QCD parton distributions to CalcHEP numerical session just presenting its code in PDFLIB format and passing them to the CalcHEP linker instead of PDFLIB.

PDFLIB distributions for parton in nuclei are not supported yet.

4.2 CTEQ and MRST parton distributions

Both CTEQ and MRST groups store information about parton distributions in two-dimensional tables and interpolate these tables. CalcHEP has its own file format for parton tables but uses interpolation procedures of CTEQ and MRST. Thus CalcHEP produces exactly the

\(^9\)But there is a possibility to specify $\alpha_s$ independently.
same results as original CTEQ/MRST functions. The information about interpolation procedure is stored in CalcHEP tables and is detected automatically.

Besides of parton distributions CalcHEP tables contain data for \( \alpha_s(q) \) which correspond to the given parton set and this function is used by default in matrix elements.

The files containing parton distributions must have the "pdt" extension. \texttt{n_calchep} searches such files in the directories "$\text{CALCHEP/pdTables}$", ".../", and "./". Usually the last two directories are the user's working directory and its sub-directory \texttt{results}.

"$\text{CALCHEP/pdTables}$" contains the following parton sets: CTEQ5M, CTEQ6L, CTEQ6M [19] and mrstlo2002, mrst2002nlo, [20]

We pass to the user the routines which transform CTEQ and MRST data files into the CalcHEP format. By means of them the user can add other distribution to the list. The sources of these routines are stored in the $\text{CALCHEP/utile}$ directory. In case of CTEQ the compilation instruction is

\[
\text{cc} \; -o \; \text{cteq2pdt} \; \text{cteq2pdt.c} \; \text{alpha.c} \; -l\text{m}
\]

For compilation one also needs the \texttt{alpha.h} file disposed in the same directory \texttt{utile}. The usage is

\[
./\text{cteq2pdt} < \text{cteq\_file.tbl} > \text{calchep\_file.pdt}
\]

for example

\[
./\text{cteq2pdt} < \text{cteq6m.tbl} > \text{cteq6m.pdt}
\]

The name of \texttt{pdt} file doesn't play a role. The \texttt{cteq2pdt} routine can be applied to any CTEQ4, CTEQ5, CTEQ6 file. It automatically detects version of structure function and \( \alpha_s \) formula.

In the case of MRST files the corresponding compilation instruction is

\[
\text{cc} \; -o \; \text{mrst2pdt} \; \text{mrst2pdt.c} \; \text{alpha.c} \; -l\text{m}
\]

The usage is

\[
./\text{mrst2pdt} \; \text{name} < \text{mrst\_file.dat} > \text{calchep\_file.pdt}
\]

or

\[
./\text{mrst2pdt} \; \text{name} \; \text{nf} \; \text{order} \; \alpha(MZ) < \text{mrst\_file.dat} > \text{calchep\_file.pdt}
\]

For example

\[
./\text{mrst2pdt} \; \text{mrst2002nlo} \; 5 \; \text{nlo} \; 0.1197 \; <\text{mrst2002nlo.dat}>\text{mrstnlo.pdt}
\]

The number of parameters is increased in comparing with CTEQ case, because MRST tables don't contain the complete information. Note that \texttt{name} is the identifier of distribution that you will see in CalcHEP menu. If the last three parameters are not specified then \( \alpha_s \) will not
be included in the table. See MRST documentation to find the proper parameters. For simple checks of pdt files one can use the checkpdt program. The source of this program is stored in $CALCHEP/utile. Compilation instruction is

```bash
c -o checkpdt checkpdt.c -I$CALCHEP/c_source/num/include \ $CALCHEP/c_source/num/pdt.c -lm
```

The usage

```
./checkpdt file.pdt parton x q
```

where parton is a parton number according to Monte Carlo numbering scheme. This program writes on the screen the corresponding parton density and $\alpha_s(q)$. See code checkpdt.c to create more extended test.

### 4.3 $d'(x)$ and $s'(x)$ -parton distributions.

One can expect a noticeable reduction of number of diagrams in the models where quark mixing is absent and, so, CKM matrix is diagonal. Note that the mixing between the first two generations and the third one is characterized by value about 0.04 which has appeared in cross sections in power 2. So, it can be omitted until this mixing itself is not a point of investigations. Also for high energy physics one can neglect masses of quarks of first two generations. Under this assumptions one can perform Cabibbo rotation in space of down quarks $d, s \rightarrow d', s'$ and get Lagrangian free of mixing.

But the quark mixing being removed from vertices re-appears in parton distributions. From mathematical point of view the parton distribution is a quadratic form which is diagonal in the basis of quark mass eigenstates. After Cabibbo rotation this form contains non-diagonal elements.

\[
\begin{pmatrix}
d(x) & 0 \\
0 & s(x)
\end{pmatrix} = \begin{pmatrix}
d'(x) \cos^2 \Theta_c + s'(x) \sin^2 \Theta_c & \frac{1}{2} \sin 2\Theta_c (d'(x) - s'(x)) \\
-\frac{1}{2} \sin 2\Theta_c (d'(x) - s'(x)) & d'(x) \sin^2 \Theta_c + s'(x) \cos^2 \Theta_c
\end{pmatrix}
\]

It means that now cross section contains products of amplitude initiated by $s'$ on conjugated amplitude initiated by $d'$ quark. Now we explain how one can bypass this inconvenience.

---

10nf=5 always, the order is included in the file name.
For the processes without incoming down (anti)quarks, the problem is absent because for these partons the distribution form is still diagonal. For the processes without incoming up (anti)quarks we can solve the problem applying Cabibbo rotation for up quarks. Thus, actually
\[ d'(x) = d(x), \quad s'(x) = s(x) \]
In both these cases we have matrix elements without mixing and with standard structure functions.

At last we have processes with both up and one down quarks in initial state. Here more fine treatment is needed. At formal level one can perform again Cabibbo rotation, say, for down quarks and get matrix element without mixing in vertices. But in this particular case regarding the squared diagrams one can note that the squared matrix elements corresponding to non-diagonal reactions are zero because of absence of mixing in vertexes and in the up quarks parton structure functions. So, only diagonal elements of parton density matrix will contribute and they can be described by effective densities
\[ d'(x) = d(x) \cos^2 \Theta_c + s(x) \sin^2 \Theta_c \]
\[ s'(x) = d(x) \sin^2 \Theta_c + s(x) \cos^2 \Theta_c \]

CalcHEP uses 'free' Monte-Carlo codes 81 and 83 for \( d' \) and \( s' \) quarks correspondingly. In case of CERN PDFLIB and CalcHEP PDT distribution the \( d'(x) \) and \( s'(x) \) function are evaluated automatically according to \( d(x), s(x) \) sorts of both incoming partons.

In the current version of CalcHEP package this \( d'(x) \) and \( s'(x) \) quarks are used in the SUSY models. A version of the Standard Model with diagonal CKM matrix is stored in directory $\text{CALCHEP/models}^+$. The similar technique based on flavor summation was presented in [28]. It allows even more economical presentation of squared matrix elements, but used non-factored representation of parton distributions.

5 Generation of events and interface with PYTHIA.

5.1 The algorithm.

CalcHEP generates events according to the Von Neumann algorithm. See [22], p.202. Let the probability density \( f(x) \) is smaller than some
easily generated function $F(x)^{11}$. Then one can generate $x$ according to distribution $F(x)$ and accept this event with probability $f(x)/F(x)$. This procedure is repeated in cycle until the needed number of events is generated.

To built $F(x)$ CalcHEP divides the space volume on large number of sub-cubes and in each sub-cube sets $F(x)$ a constant which equals to max $f(x)$. CalcHEP has two strategies of detecting the corresponding maxima. First one is a random search. The program generates random points in each sub-cube and tests $f(x)$ in these points. The second one is a search by the simplex method [21]. Preliminary random search is desirable to define a good start point for the simplex method. The number of calls for random search and the number of steps for simplex search are defined by the user.

In general, the detected maxima are lower than the true ones. To satisfy the inequality

$$f(x) \leq F(x)$$

the function $F(x)$ based on the detected maxima can be multiplied by some factor, say 2. Of course, it decreases the efficiency of the generator just on the same factor. Nevertheless, in some sub-cubes were the variance of the function is large this factor may be not enough. If CalcHEP finds a point $x$ where $f(x) > F(x)$ it accompany point with an integer weight $w$. This weight is the integral part of $f(x)/F(x)$ plus one with the probability equal to the fraction part of $f(x)/F(x)$. From view point of calculation of various distributions one event with integer weight $w$ should be treated as $w$ independent events with identical parameters. But for the evaluation of statistical uncertainties a more careful treatment is needed.

### 5.2 Work of generator

The procedure of event generation consists of two steps. The first step is a preparation (initialization) of generator (*Menu 7*). The second step is itself a generation of events (*Menu 8*). Note that the efficiency of generator should be better if the user preliminary launches VEGAS to construct an appropriate grid on the phase space.

---

11 We assume $f(x)$ and $F(x)$ are not normalized.
Preparation of generator. On this step we divide the integration volume on several sub-cubes and find the maximum of the distribution function in each sub-cube. The user has to define the number of Sub-cubes, numbers of the calls of the function for the Random search of maximum and number of steps for the search by the Simplex method.

The larger number of Sub-cubes, the more efficiency of the generator, but the more time for preparation of generator is needed. The preliminary Vegas run provides the user an estimation of the needed time.

The preparation of generator is finished by the message which gives estimation of efficiency of the generator prepared.

Work of generator. Before launching the generator the user has to specify the needed Number of events. In order to reduce the number of multiple events one can multiply the detected maxima by some factor. It should be done by means the second function of Menu 8. If in spite of it CalcHEP meets a point $x$ where the distribution function exceeds the estimated maximum, then the multiple event is generated. In this point the program can look for a new maximum by means of the simplex method starting from the point $x$. The number of steps is defined by the third menu function. One can set this number zero to prevent this search.

When the needed number of events are generated, CalcHEP writes on the screen the message which informs the user about the efficiency of the generator and the number of multiple events. The user can accept the generated set of events or refuse them.

The generator improves itself during each run by means of the improving the maxima estimation in sub-cubes. If nevertheless generator works badly, the user has to return to Menu 7.

The generated events are written in the text format into the file results/events#.txt where # means the session number. Format of this file is described in the Manual.

5.3 Usage of events, interface with PYTHIA.

We present simple routine events2tab which constructs different distribution based on generated events. Format of the call is

```
../../bin/events2tab Variable Min Max Nbin <events.txt > tab.txt
```
Here \textit{Variable} is the name of parameter which distribution you would like to get. The permitted names for \textit{Variable} are described in Manuals. \textit{Min}, \textit{Max} present boundaries of distribution, and \textit{Nbin} $\leq 300$ is the number of bins.

We also present routines which support interface with PYTHIA. The interface is done according to [30] and [31].

The interface programs are written in C and stored in the file \$CALCHEP/utile/event2pyth.c

We suppose that the \textit{main} file will be written in Fortran. An example is presented in \$CALCHEP/utile/callPYTH.f

The main program must be started from initialization routine

\begin{verbatim}
NEVMAX= initEvents(eventFile)
\end{verbatim}

which opens the \textit{eventFile} generated by CalcHEP and reads its header. The return value is the number of events stored in the \textit{eventFile}. Note that one has to remove dummy \texttt{SUBROUTINE UPINIT} and \texttt{SUBROUTINE UPEVNT} from the PYTHIA code before link with CalcHEP interface program. Working versions of these routines are disposed in \texttt{callPYTH.f} and \texttt{event2pyth.c} respectively.

In case of MSSM process one has to pass the corresponding models parameters to PYTHIA. For PYTHIA 6.3 it can be done in framework of Les Houches Accord. Our \texttt{main} \texttt{callPYTH.f} contains an example of realization of such interface. Indeed version 6.3 now is under developing and the current version 6.2 has not such interface. One can 'improve' PYTHIA 6.2 to solve this problem. Namely code for reading the Les Houches Accord file (written by Peter Skands for version 6.3) is disposed in

\$CALCHEP/utile/pyslha.f

To activate this routines one has to add the corresponding call to PYTHIA code. In current version \texttt{pythia6225.f} one has to modify \texttt{SUBROUTINE PYMSIN}, inserting after label 120 the following code

\begin{verbatim}
C...Read spectrum from SLHA file.
    IF (IMSSM.EQ.11.AND.IMSS(21).NE.0) THEN
      CALL PYSLHA(1,0,IFAIL)
    ENDIF
\end{verbatim}

The executable \texttt{a.out} presenting CalcHEP-PYTHIA 6.2 interface can be compiled, for instance, by
cc -c event2pyth.c
f77 callPYTH.f event2pyth.o pyslha.f pythia6225.f

And for the CalcHEP-PYTHIA_6.3 case
cc -c event2pyth.c
f77 callPYTH.f event2pyth.o pythia6225.f

6 Non-interactive sessions

6.1 General concept
CalcHEP was created for calculations in the interactive regime. But it is also important to have an option to perform long-time calculations in the non-interactive, batch, mode. Also there are a lot of requests for organization of various cycles of numerical calculation when user’s control on each step is not needed. It is a challenge to support all such kind of needs in the interactive package and create a comfortable service for it. This is realised in the batch session [26]. Instead of keyboard, the program reads signals that simulates the keyboard hits. This idea can be applied to any interactive program driven by the keyboard. In general, the realization of this idea is quite easy. It’s enough to lock all routines that write on the screen and modify one routine which reads the keyboard signals. It is assumed that anyway all results of calculations are stored in some output files and, thus, they are accessible in the same manner after both interactive and batch sessions.

This way is not free of problems. Let us list some of them:
a) Sometime interactive program contains branching and chooses the way by the dialog with the user. For example, CalcHEP writes informative and dialog messages. The first one waits for ”Press any key”, the second one expects Yes/No answer on some question to branch the program execution. In the batch mode all informative messages are ignored, the dialog ones get the answer Yes automatically. So, these dialog messages should be organized in a proper way to support the main stream of operation.
b) The entry point of the program can depend on the previous session. In this case blind simulation of keyboard can be crazy. We meet this problem in symbolic part of the package. See below.
c) Wrong input can’t be fixed in batch mode. So, the program must be terminated with some error code that informs the user about problems.
d) Some menus depend on the physical problem under the consideration. For example, one doesn’t know a’priori the position of $t$-quark mass in model parameters menu. This problem is solved by means of the Find menu facility which gives us a possibility to find menu record depending on its text label.

Thus, some improvements should be done in interactive programs in order to use them in batch mode. Usually these changes also are welcome for the interactive mode.

In the CalcHEP case the sequence of signals is passed to the program as a parameter. A special parameters, -blind has to precede it as a flag of batch regime. Thus, the batch call is realized like

\[ \texttt{s\_calchep \ -blind "STRING"} \]
\[ \texttt{n\_calchep \ -blind "STRING"} \]

Surely, the task of generating of correct STRING looks like an interactive session with closed eyes. But in the CalcHEP root directory the user can find several Unix scripts which contains inside blind calls for most typical tasks. Parameters of these scripts are substituted into the preliminary prepared sequences of commands, that allows to adapt the program to user requests.

In principle, the whole scope of problems can be solved in the batch mode. Also the user can perform all needed setting in the interactive mode and after that launch the batch one. This way combines the advantages of screen and batch modes.

Below we present the CalcHEP batch command available and explain how the user can write new ones.

### 6.2 Batches for symbolic calculations

The command

- **s\_blind nModel Process nOutput**

performs symbolic calculation for \textit{Process} in framework of the model \textit{nModel} and writes down results in the format according to the \textit{nOutput} parameter. \textit{nModel} and \textit{nOutput} are numbers which specify the chosen models and output format according to items of Menu 1 and Menu 7 of Fig.1 respectively. \textit{Process} must be enclosed into the quotation marks. For example,
performs symbolic calculation in the framework of the Standard Model and writes results in the C notations. \texttt{s\_blind} has to be launched from user \textit{WORK} directory like \texttt{calchep}.

Because \texttt{s\_calchep} has different entry points \texttt{s\_blind} preliminary removes all \texttt{tmp/*} and \texttt{results/*} files to start from the beginning.

The program of this kind is used in \cite{25} for runtime generation of numerical code for various matrix elements.

6.3 Batches for numerical calculations

The programs presented here are disposed in the \$\texttt{CALCHEP/bin} subdirectory which in its turn is linked to user working directory. They should be launched from the user’s subdirectory \textit{results} like \texttt{n\_calchep}. So the format of call is

\texttt{../bin/<batch> <Parameters>}

Being launched without parameters they inform the user about needed ones.

- \texttt{run\_vegas it1 N1 it2 N2}
  launches the Monte Carlo Vegas session. In general case it launches \texttt{it1} Vegas sessions with \texttt{N1} integrand calls for each session, after that it initiates the ”Clear statistics” menu function which forces the program to forget the obtained results and launches \texttt{it2} Vegas sessions with \texttt{N2} integrand calls. Usually two loops are desirable because in the beginning the integration grid is not adapted to the integrand jet. If \texttt{it1}=0 or \texttt{N1}=0, only the second Vegas loop is launched removing the previous results. If \texttt{it2}=0 or \texttt{N2}=0, only the first Vegas loop is launched with keeping the previous results.

- \texttt{set\_momenta p1 p2}
  changes momenta of incoming particles. This function needs two arguments, the values of incoming momenta.

- \texttt{set\_param name value [... name value]}

- \texttt{set\_param File}
  changes numerical values of variables. There are two forms of its usage. First form is self-explanatory. In the second case it is assumed that \textit{File} contains two columns, namely, \textit{name} and \textit{value}.

- \texttt{pcm\_cycle pcm0 step N it1 N1 it2 N2}
  organizes a cycle for calculation of total cross section for different values of particles momenta in the center-of-mass frame. \texttt{pcm0} is
the initial value of momentum, \textit{step} is a step of the scanning and \(N\) is a number of steps. The \texttt{it1 N1 it2 N2} parameters are passed to \texttt{run_vegas}. Result of calculation is stored in \texttt{pcm.tab.#1.#2} file where \#1 and \#2 are the ordering numbers of the first and the last numerical sessions.

- \texttt{name\_cycle name val0 step N it1 N1 it2 N2}
  
  organizes a cycle for calculation of total cross section for different values of the \textit{name} parameter. \texttt{val0} is the initial value of parameter, \textit{step} is a step of the scanning and \(N\) is a number of steps. The \texttt{it1 N1 it2 N2} parameters are passed to \texttt{run_vegas}. Result of calculation is stored in \texttt{name.tab.#1.#2} file where \#1 and \#2 are the ordering numbers of the first and the last numerical sessions.

- \texttt{subproc\_cycle it1 N1 it2 N2}
  
  performs a cycle over all subprocesses generated. The \texttt{it1 N1 it2 N2} parameters are passed to \texttt{run_vegas}.

  It is assumed that all subprocesses have identical sets of outgoing particles. In this case one can choose the same reasonable cuts, regularization and histograms for all subprocesses. The total cross section is displayed on the screen. If histograms are specified, then their sums will be stored in \texttt{dist.#1.#2} file. The user can display them on the screen by the \texttt{disp\_dist} command like all other distributions.

- \texttt{prep\_gen sub\_cubes Random\_search Simplex\_search}
  
  prepares event generator. The parameters correspond to menu 7 Fig.2.

- \texttt{gen\_events N\_events new\_max}
  
  generates \(N\) events. Result is written in \texttt{events.#} file. The parameters correspond to menu 8 Fig.2.

  In case of error in the execution the error code can be displayed by

  \texttt{echo $?}  

  The list of possible error codes is presented in theCalcHEP manual.

6.4 How to write new batch.

There is a tool for writing the command symbols for the “-blind” mode. If one launches \texttt{s(n)_calchep} with the \texttt{+blind} flag, then the program works in the interactive mode, but simulating all features of batch mode. After the end of the session the appropriated line of commands will be written on the screen. For example, let one start

\texttt{n_calchep +blind},
go to Vegas menu, set number of vegas iteration 3, specify number of calls for each iteration 4444, start Vegas, and finish the session. The line obtained should be:

"\[[[\[344440\]],

were ‘3’ and ‘4444’ fragments corresponding to Vegas setting. One can modify it, a little, to get an universal Unix command for Vegas launching with parameters defined as arguments of the command:

\texttt{n\_calcheap -blind }\[[[\[S1S20\]],

It just one of the pieces of \texttt{run\_vegas} presented above.

The cording of keyboard signals is organized by the following way. All alphabetic character and digits are written naturally. The special keys, in general, are coded by 2-positions hexadecimal numbers with the preceding symbol ”\". For example, the ‘Tab’ key is coded as ”\"08”. In order to simplify the reading and the modification of symbol sequence we use the following short codes for basic special keys:

\begin{itemize}
  \item \texttt{[}': Down Arrow
  \item \texttt{\{}': Enter key
  \item \texttt{]}': Escape key
  \item \texttt{]}': Up Arrow key
\end{itemize}

Now one can understand the example presented above. Note, the ‘0’ in the end of the string appeared because the session was finished by pressing ‘0’ that works like F10, which in its turn calls the ‘Quit’ function.

This is a way how the user can create various batches without an intervention into the C programming. Good Luck!

7 CalcHEP as a generator of matrix elements for other packages

In general one can use C-codes of matrix elements generated by CalcHEP in other programs. CalcHEP manual contains full explanation of format of generated routines. Also we present a simple example \texttt{\$CALCHEP/utile/main\_22.c}, which demonstrates the usage of generated codes for $2 \to 2$ reactions. The compilation instruction launched from the directory \texttt{results}, where C-codes for some $2 \to 2$ process are generated should be

\texttt{cc -I\$CALCHEP/include \$CALCHEP/utile/main\_22.c }\backslash
We foresee a possibility to combine in one project several matrix elements produced by CalcHEP. The names of routines generated by CalcHEP are finished by the the postfix "_ext", which can be replaced on other one to avoid name conflicts. Also we have organized one structure interface_ext, which contains all interface routine, so the user can change the code for matrix element by means of one operation.

The command

```bash
../bin/mkLibstat postfix
```

started from the results directory replaces "ext" on your postfix, compiles all routines and transforms them into proclib_postfix.a library which is ready to by included into other packages.

The similar command

```bash
../bin/mkLibldl postfix
```

created the shared proclib_postfix.so library that can be loaded dynamically in run time.

There is a very attractive possibility to generates and link automatically new matrix elements when they becomes needed. New codes can be generated by a command like s_blind described in Section 6.2, compiled by mkLibldl and dynamically loaded by the standard dlopen routine.

This approach was realized in the micrOMEGAs[25, 9] project were numerous co-annihilation processes potentially needed for calculation of neutralino relic density are added to the package in runtime depending on mass relations between super particles.

**8 Loading of additional codes in CalcHEP.**

There are several cases when facilities of CalcHEP numerical session can be enhanced by implementation of addition codes. They are a) CERN PDFLIB parton distributions (Section 4.1), b) user functions for distributions and cuts, c) constraints for new models.

User’s startup file calchep contains definition of environment variable EXTLIB, whose contents is passed to the routine which creates n_calchep. Default it is defined as

```
EXTLIB="$CALCHEP/susylib.a"
```
and passes to linker the library of SUSY constraints and *SuSpect* RGE codes. If the user would like to add CERN PDFLIB, he has to modify EXTLIB like

```
EXTLIB="/CALCHEP/susylib.a -L/cern/pro/lib -lpdflib804 \ 
    -lmathlib -lpacklib"
```

Here we assume that CERNLIB is disposed in its *standard* place. To add *Isajet* RGE code disposed, say, in user’s directory *isajet*, the needed modification is

```
EXTLIB="/CALCHEP/susylib.a $HOME/isajet/libisajet.a"
```

Depending on switches used for *Isajet* compilation, may be, one needs to add CERN *mathlib* too.

If one implements new model in CalcHEP which has addition constraints, the library of these constraints can be attached to n_calchep by the same manner. It should be a library of functions written in C with arguments and returned values of type *double*.

Other useful possibility is the implementation of the *usrfun* routine which should be a function written in C with argument of the "char *" type and returning *double*. Then the user can construct the family of cuts and distributions named like $Uxxx$, where "xxx" will be passed to *usrfun* as an identifier of the function. In the Manual it is explained how one can pass momenta of particles to such function.

We have to note that anyway CalcHEP passed to linker dummy libraries for PDFLIB and *usrfun()* function. $EXTLIB$ is substituted in list of objects for linking before these dummy libraries. So n_calchep will be linked successfully, does not matter it gets or not the true objects.

### 9 Contributions and References

In general, references depend on which path of the package is used.

The kernel of the package was written by Alexander Pukhov, cite

A.Pukhov et al, Preprint INP MSU 98-41/542,arXiv:hep-ph/9908288

or the current paper.

Interface with different RGE codes as well as $(g-2)\mu$, $b\rightarrow s\gamma$, and $B_s\rightarrow \mu^+\mu^-$ constraints were written by microMEGAs team. If you use it, please, cite
The default RGE code included into the package is SuSpect (version 2.3). If you use it, please cite

A. Djouadi, J.-L. Kneur and G. Moultaka,
Preprint PM-02-39, CERN-TH-2002-325, arXiv:hep-ph/0211331.

The package contains some codes written by CompHEP group people. They are included in the CalcHEP package with permission of the authors:

V. Ilyin : num/4_vector.c, num/strfun/sf_epa.c, num/strfun/sf_lsr.c
D. Kovalenko: num/kinintp.c, num/regfunal.c
A. Kryukov : symb/colorf.c, chep_crt/edittab.c
V. Edneral : symb/diagram/diaprins.c, symb/diagram/drawdiag.c,
               chep_crt/crt.c
A. Semenov : chep_crt/xwin/X11_crt0.c

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Pictures and figures

Figure 1: Menu scheme for the symbolic session
Figure 2: Menu scheme for the numerical session