CalcHEP — calculator for High Energy Physics

Presented by **Alexander Pukhov**, Daejeon, May 2014

CalcHEP team : **Alexander Belyaev**, **Neil Christensen**.

Related packages:
LanHEP: **Andrew Semenov**
micrOmegas: **Genevieva Belanger, Fawzy Boudjma**

Institutions: **Moscow State University, University of Southampton, University of Pittsburgh JINR(Dubna), LapTh (CNRS)**

Outline

- **Main features**
- **CalcHEP GUI session**

  general structure; automatic width calculation; cuts and distributions
- **New options:** paralleling; QCD color sextets and 333 vertex.
- **Batch interface**

  calcHEP scripts; batch tasks; PC farms
- **Model implementation**

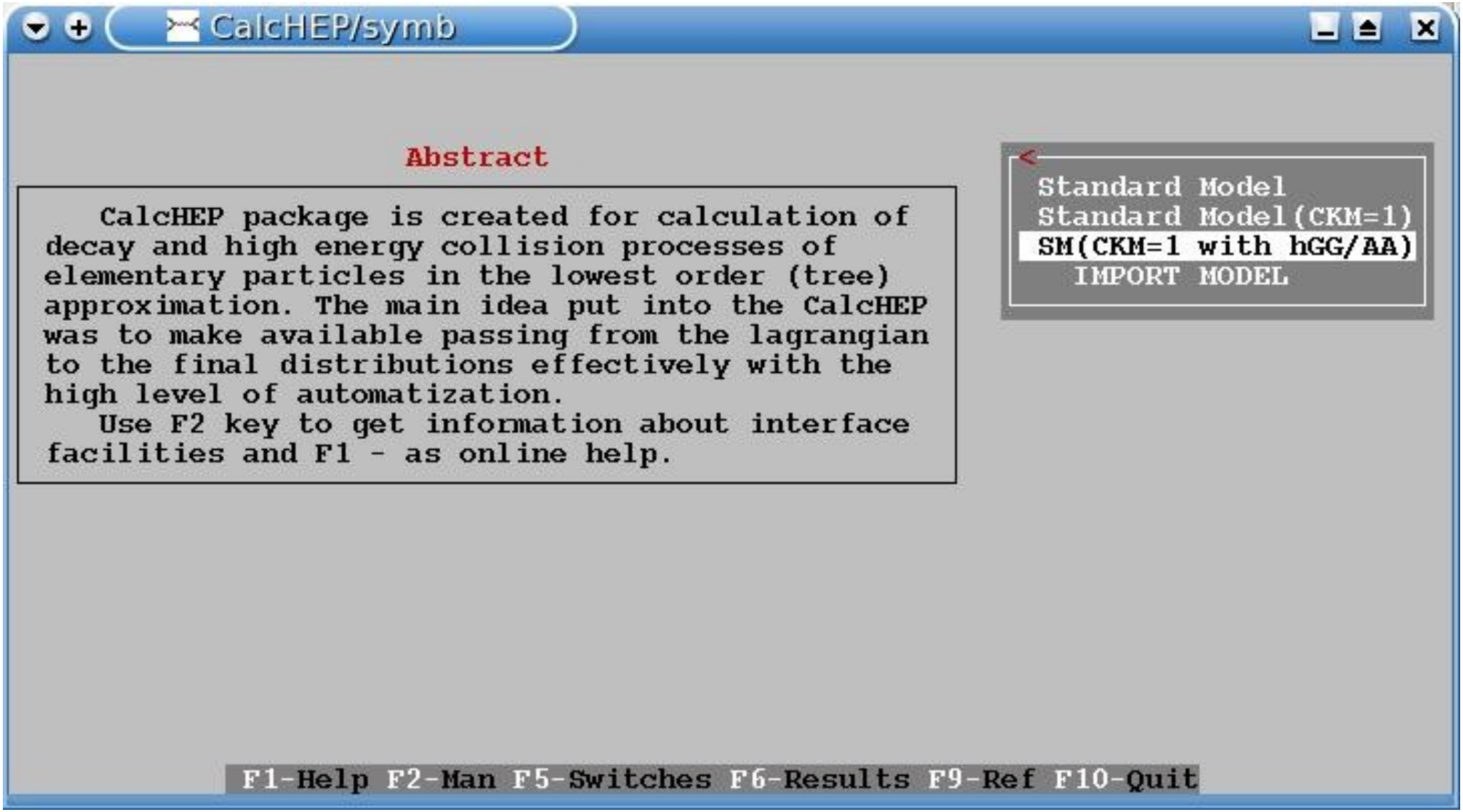
  SLHAplus; loop induced vertexes

  LanHEP; HEPmdb
- **MicrOMEGAS**

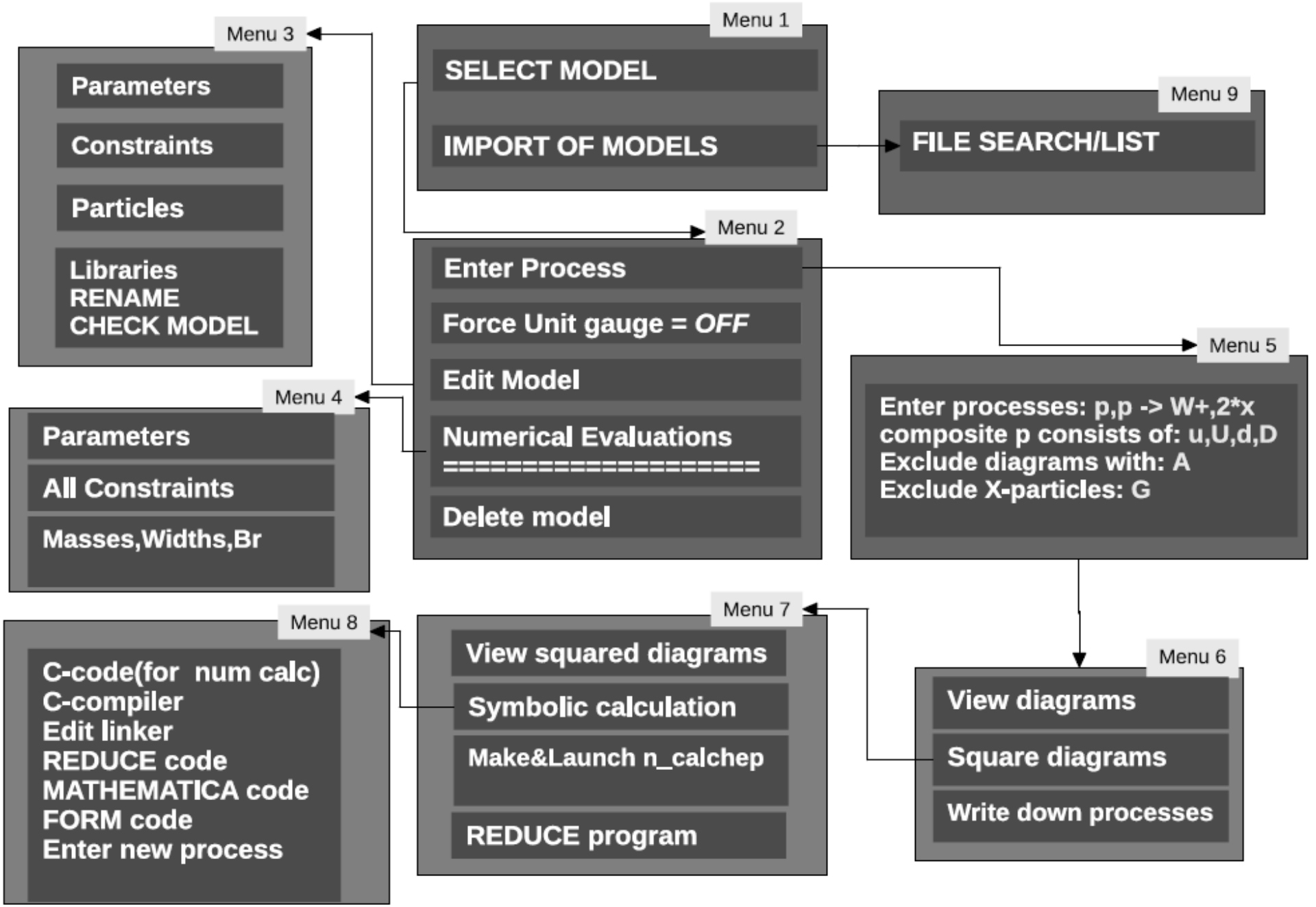
Main features

- **Language C**
- **Symbolic calculation of squared diagrams**. Calchep uses built-in symbolic calculator. Result of calculation can be presented in formats of Reduce, Mathematica, C.
- **Tree level** calculations in Unitary and Feynman gauges. The last one is free of diagram cancellation at high energies.
- **Menu-driven graphical interface** with help facilities. It is easy to start to use CalcHEP for beginners.
- **Run-time generation** of new codes and dynamic linking of generated code. It allows **'on fly' width calculation** including 1->3, 1->4 channels and virtual W/Z contribution.
- **Les Houches Interfaces** events (LEF), structure functions (LHAPDF). SLHA-based interface with spectrum generators (SuSpect, NMSSMTools) and programs for experimental analysis like HiggsBounds[Signals].
- **Paralleling** for symbolic and numerical calculations.
- **Batch interface** for running in PC clusters.

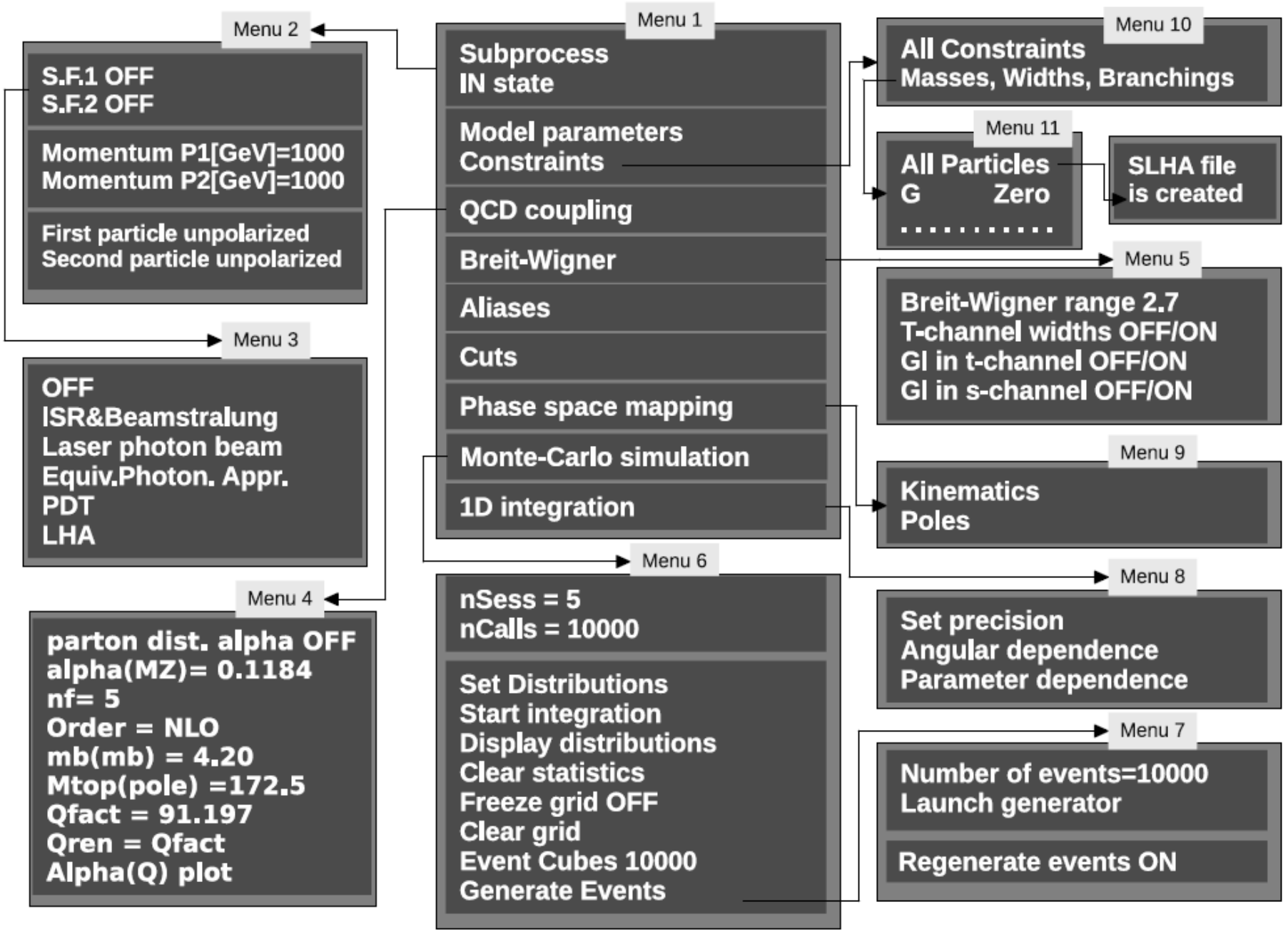
Graphic interface



CalcHEP menu structure: symbolic part



Menu structure of the numerical part

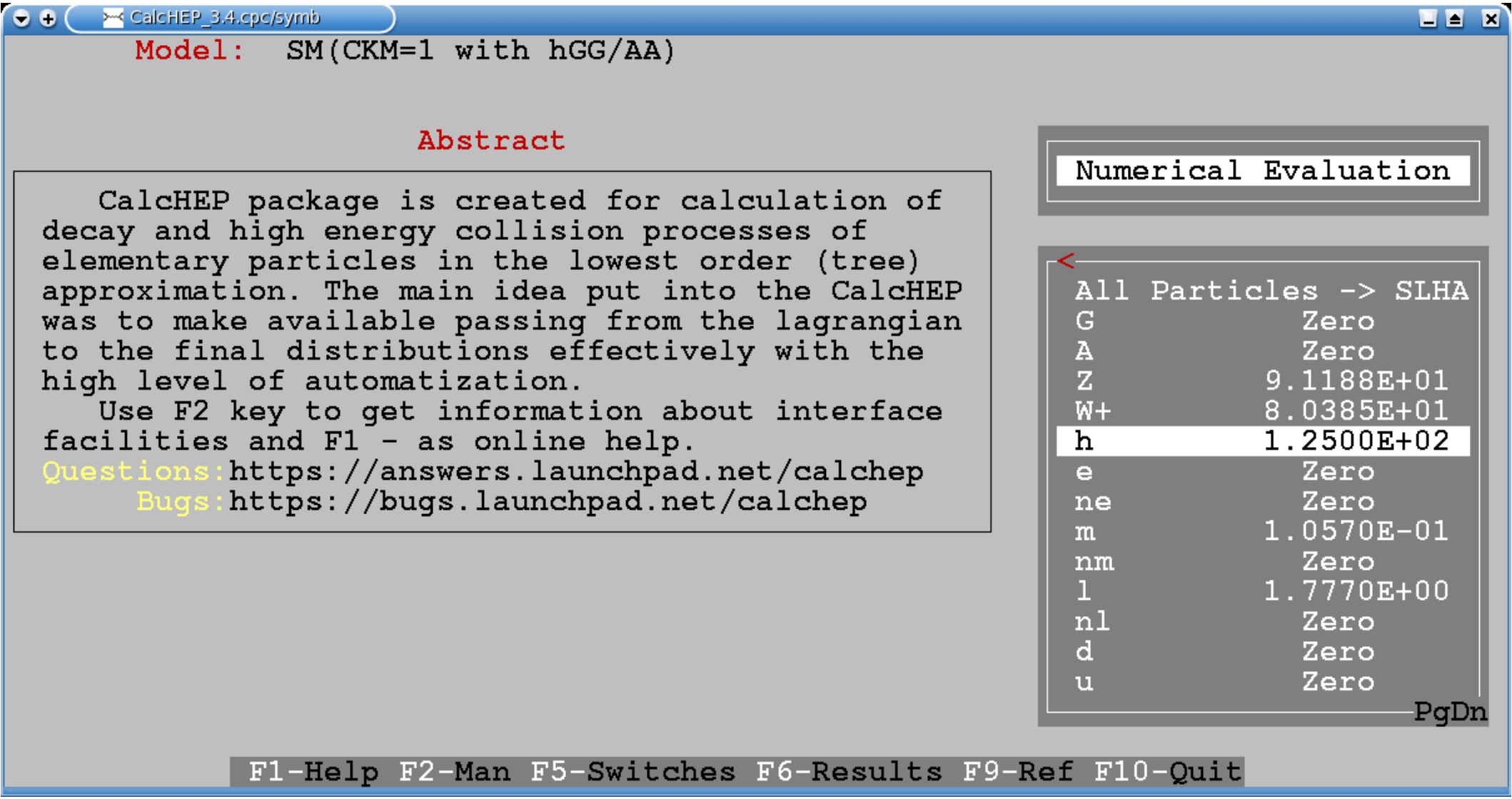


Automatic width calculation

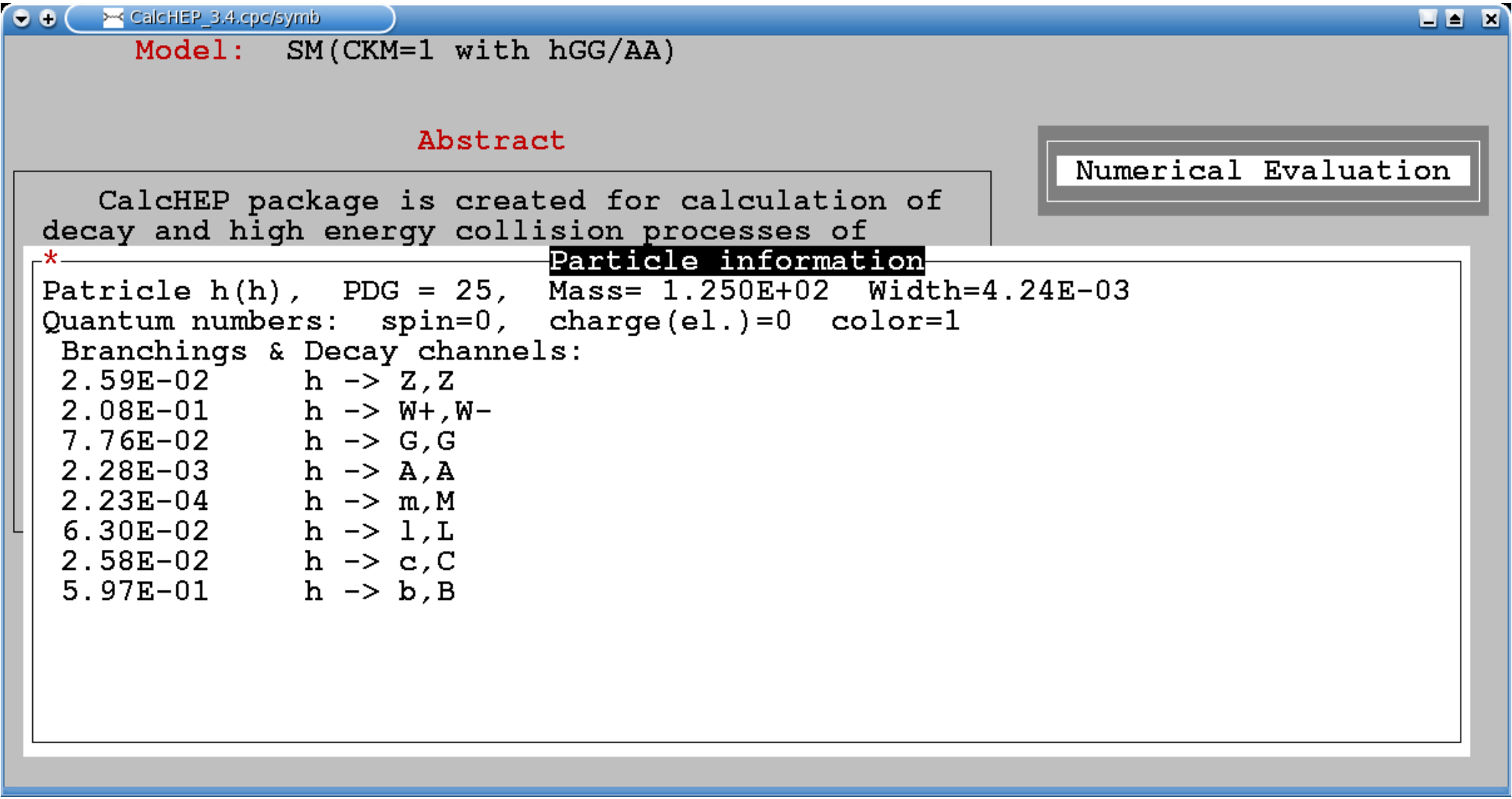
- Code for particle widths are generated and compiled in run time and linked dynamically.
- 1->2, 1->3, 1->4 decays are tested subsequently until open channels are detected.
- To take into account radiation corrections of Higgs decay effective quark masses are used:

  MqEff(Q) ~ MqRun(Q/3) where Q= Higgs Mass
- There is an option to calculate widths for processes with virtual W/Z. CalcHEP a) calculates width of process where W is replaced of e^+,\nu b) takes into account branching; c) takes into account relation between 1->3 and 1->4 widths.
- h->G,G and G->AA can be treated via effective vertexes.
- Quite realistic description of Higgs decay can be obtained by this way. SM and MSSM width and branching where compared with HDECAY

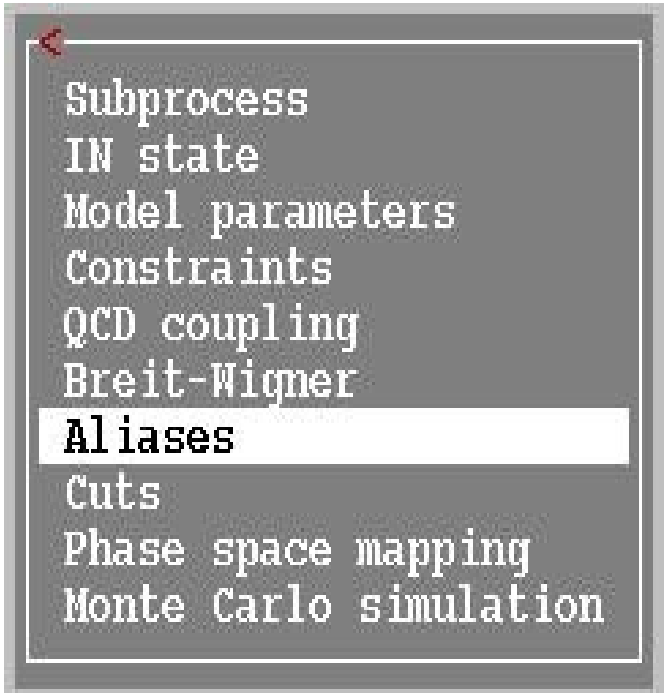
One create *decaySLHA.txt* file which contains quantum numbers, masses, widths, and branching for all particles or to test properties of each particle separately.

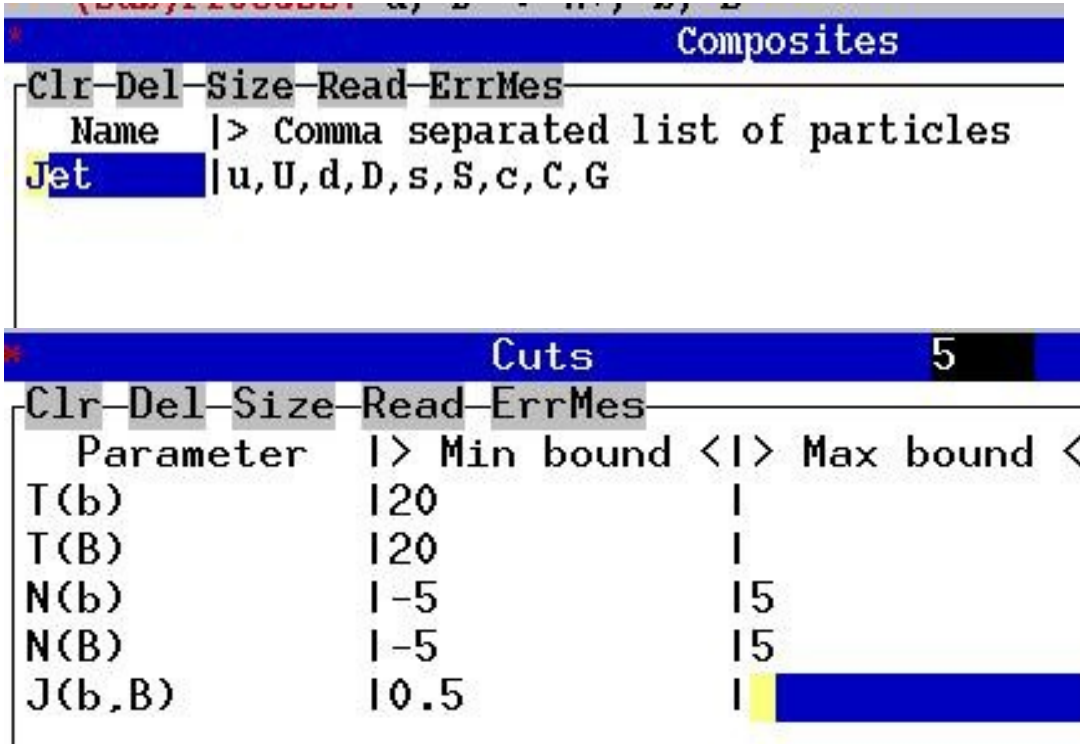


Higgs decay

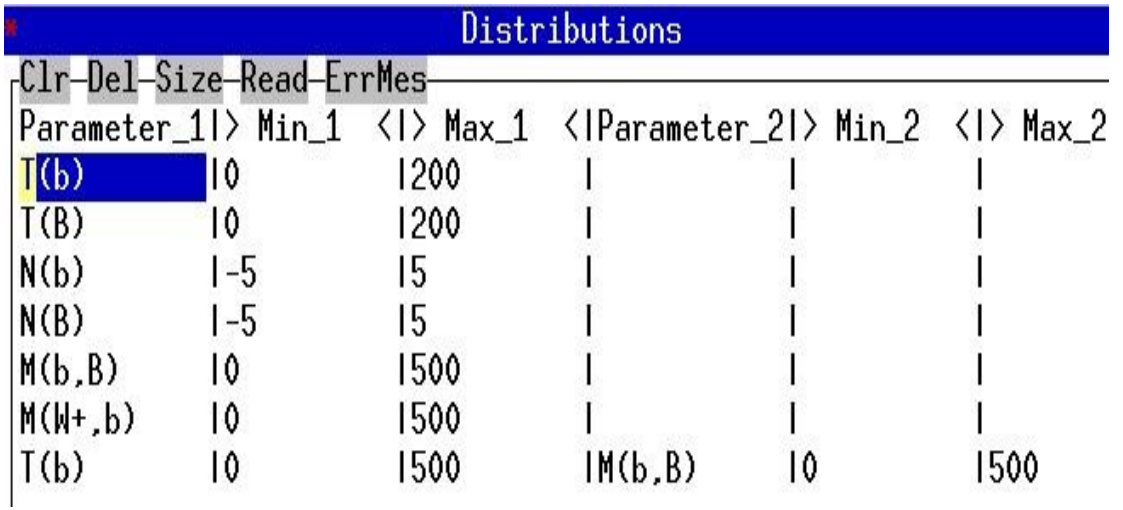

CalcHEP_3.4.cpc/symb
Model: SM(CKM=1 with hGG/AA)
Abstract
CalcHEP package is created for calculation of
decay and high energy collision processes of
Numerical Evaluation
Particle information
Patricle h(h), PDG = 25, Mass= 1.250E+02 Width=4.24E-03
Quantum numbers: spin=0, charge(el.)=0 color=1
Branchings & Decay channels:
2.59E-02 h -> Z,Z
2.08E-01 h -> W+,W-
7.76E-02 h -> G,G
2.28E-03 h -> A,A
2.23E-04 h -> m,M
6.30E-02 h -> l,L
2.58E-02 h -> c,C
5.97E-01 h -> b,B

Aliases, Cuts, Distributions





In case of identical particles constructing distributions h CalcHEP normaly sums all contributions. Also for each function **F** we have **F^** and **F_** which evaluate **max** and **min** values.



List of built-in functions for cuts and distributions.

A - Angle in degree units
C - Cosine of angle
D - Jet separation
min(pT1^2,pT2^2)*(cosh(d_Rapidity)-cos(d_AzimuthAngle))
J - Jet cone angle
E - Energy of the particle set
M - Mass of the particle set
P - Cosine of the angle between the first particle in the list and the direction of boosting of the particle set into the rest frame of the particles set
T - Transverse momentum (P_t) of the particle set
Y - Rapidity of the particle set
N - Pseudo-rapidity of the particle set
Z - Transverse energy

U*user* *user defined function via* ***usrfun(****"user****")***

Recently implemented options

•**Parallelization.** Symbolic calculations are paralleled by **fork().** Compilation of C-codes of squared diagrams is paralleled by **threads** technique. Monte Carlo integration and events generation also are paralleled via **threads.** Thus all steps of CalcHEP calculations are paralleled. By default **N,** the number of processes launched in parallel, is defined by **sysconf.** It accelerates calculations in **N/2** times. **N** can be changed by the user via menu system.

• One can combine power of threading and power of HPC cluster of running job on several nodes.

QCD colors. CalcHEP color package is extended for calculation of processes with color sextets and **333** vertexes.

Color chain basis is constructed from color δ^a_b and ε_{abc} or ε^{abc}. Product of ε_{abc} or ε^{abc} is replaced on δ, thus they never appear simultaneously in basis elements.

There are two ways to expand color amplitude over color chain basis. We can use Nc=3 calculations with non-orthogonal basis or Nc=inf calculations with $\varepsilon_{abc}\,\varepsilon^{abc} = Nc(Nc-1)$.

Integration and generation of events

- Vegas is used for integration and events generation
- First Vegas loop is used for grid adaptation.
- Second Vegas loop is used to get profile of integrand and estimate efficiency of generator
- Modified Vegas used for event generation.
- Parallelization can be switched *ON/OFF*.

To produce event file in LHE format we use command

- event_mixer Lum nEvents directories .....

  It collects all event files disposed in *directories,* mixes collision events, apply decay events, and finaly creates LHE file.

- The *decaySLHA.txt* file is used to define branchings.
- Resulting event file is *event_mixer.lhe*

Batch scripts.

Batch mode in CalcHEP is a GUI mode where a) graphical output is suppressed; b) command line simulates keyboard hits.

n_calchep +blind - GUI session which produces command string

n_calchep -blind **<** command string > repeats the same calculation.

CalcHEP/bin directory contains scripts written in this technique

symbolic calculations: s_blind mkLibstat mkLibshared

setting parameters: set_param set_momenta set_vegas

single session: run_vegas gen_events

cycles: name_cycle pcm_cycle subproc_cycle

cycle over random set of points: par_scan par_scan_sum

There is README file which explains script. Or one call one of them without parameters to get explanation: ./pcm_cycle

- Error, ./pcm_cycle needs 3 numerical parameters
- 1: Initial CM momentum
- 2: Step for momentum
- 3: Number of steps

The **calchep_batch** program

- All steps of calculation can be done in batch mode by one command

  ./calchep_batch <input file>

- Control of calculation can be done via WEB browser. Before calculation the program writes on the screen name of html file.

- One can use parallel calculation of batch task on PS farm.

Example of input file for calchep_batch command

```
Model:        Standard Model(CKM=1)
Model changed: False
Gauge:        Feynman

Process:   p,p->W,b,B
Decay:     W->le,n
Composite: p=u,U,d,D,s,S,c,C,b,B,G
Composite: W=W+,W-
Composite: le=e,E,m,M
Composite: n=ne,Ne,nm,Nm
Composite: jet=u,U,d,D,s,S,c,C,b,B,G

pdf1:      cteq6l (proton)
pdf2:      cteq6l (proton)
p1:        4000
p2:        4000

Run parameter: Mh
Run begin:     120
Run step size: 5
Run n steps:   3

alpha Q :          M45

Cut parameter:    M(b,B)
Cut invert:       False
Cut min:          100

Dist parameter:    M(b,B)
Dist min:          100
Dist max:          200
Dist n bins:       100
Dist title:        p,p->W,b,B
Dist x-title:      M(b,B) (GeV)

Dist parameter:    M(W,jet)
Dist min:          100
Dist max:          200
Dist n bins:       100
Dist title:        p,p->W,b,B
Dist x-title:      M(W,jet) (GeV)

Number of events (per run step): 10000
Filename:                        pp_Wbb_enbb

nSess_1:   5
nCalls_1:  100000
nSess_2:   5
nCalls_2:  100000

#Parallelization method:      local
Parallelization method:      pbs

Max number of nodes:   2
Max number of processes per node: 2
```

Model implementation: SLHAplus

SLHAplus is a library of auxiliary functions used for for model realization. Now it includes

a) **functions for SLHA interface:**

slhaRead(fineName, mode)

slhaVal(BlockName, Scale, N_key_symbols, keys ...)

Example:

```
 Block MASS
  25  125
```

```
Mh=slhaVal("MASS", 0.,1,25)
```

Downloaded SLHA width forbids automatic width calculation

b) **functions for diagonalizing of** mass matrices : i) real symmetric ii) hermitian; iii) complex; iv) complex symmetric.

c) **Passarino-Weltman** functions to construct effective hGG and hAA vertexes.

d) **QCD functions** for running alphaQCD, masses, effective Yukawa couplings.

Model construction: LanHEP program

FeynRules, Sarah, and **LanHEP** can be successfully used for generation of CalcHEP model files.

LanHEP
(http://http://theory.sinp.msu.ru/~semenov/lanhep.html)
is more adapted for CalcHEP.

a) it supports SLHAplus routing for file interface between spectrum generators and matrix element calculators.

b) diagonalizing routines.

c) allows to extract scalar coefficients at different Lorentz structures in vertices of interaction.

Extracting coefficients at hqq and hWW vertices one can a) generate automatically models with effective hGG and hGG interactions; b) make interface with HiggsSignals[Bounds]

Gauge invariance

- It still is a problem for MSSM like models. Options:
  a) tree level masses –> not realistic mass (Higgs) spectrum
  b) couplings restored form masses –> huge couplings appear
  c) Used solution: loop induced Higgs couplings & particles spectrum generated by external program -> slightly broken gauge invariance.
- In NMSSM we use 20 couplings generating by NMSSMTools for Higgs sector.
- Comparing calculations in two gauges in CalcHEP one can estimate the level of the problem.
- Possible solution: in the **sloops** package masses of in/out particles are treated as independent parameters.

- **Finite widths** brake gauge invariance as well.

HEPMDB – model database

https://hepmdb.soton.ac.uk

- *to collect HEP models for various multipurpose Matrix Element generators (tracing the history of the model modifications, and making available all the versions of the model)*
- *to collect models' sources (LanHEP, FeynRules, SARAH)*
- *to allows users* **upload their own models** *and perform evaluation of HEP processes and event generation using the full power of the HPC behind HEPMDB and using* **different** *ME generators installed at HEPMDB as different* **modules**
- *to plot and document various kinematical distributions from generated events in the LHE format*
- *to allow to compare/validate models*
- *to collect predictions and specific features of various models in the form of* **database of signatures** *and perform comparison model predictions with experimental data*

HEPMDB Last year activity: 160 users, ~2K visits from over 60 countries

micrOMEGAs
http://lapth.cnrs.fr/micromegas/

CalcHEP has an option to generate code of matrix elements for other programs. One example of such CalcHEP implementation is micrOMEGAs program created for calculation of Dark Matter observables. It needs matrix elements to calculate cross sections of DM annihilation and its scattering on atomic nuclei. It uses CalcHEP routine

cc = getMEcode(twidth,Gauge, Process, excludeVirtual, excludeOut,lib)
Here lib is a name of shared library which is generated and loaded.

To calculate matrix element **micrOMEGAs** uses

cc->interface->sqme(nsub,GGqcd,momenta,&errode)

To assign variables one can use

assignVal(name,newValue)

sortOddParicles() calculates mass spectrum and constrains. To check mass and widths:
pMass(pName), **pWidth**(pName, decayList)

CalcHEP has similar interface in terms of **ROOT** C++ structures.

micrOMEGAs calculates DM signals:

- **Relic Dark Mater density**. Because of importance of co-annihilation the list of annihilation channels depends on parameters. It was a reason of including dynamic generation of matrix elements in CalcHEP.
- Signals of **direct detection**: DM interaction with atomic nuclei of underground detector.
- Signals on **indirect detection**: Traces of DM annihilation in galactic halo
- **Neutrino telescope** signal: DM annihilation in the center of Sun.

MicrOMEGAs is developing for mutual analysis of DM and collider experiments. In the current moment it is done via ***interface with HiggsBounds[Signals].***

http://theory.npi.msu.su/~pukhov/calchep.html

CalcHEP - a package for calculation of Feynman diagrams and integration over multi-particle phase space.

Authors - Alexander Pukhov, Alexander Belyaev, Neil Christensen

The main idea of CalcHEP is to enable one to go directly from the Lagrangian to the cross sections and distributions effectively, with a high level of automation. The package can be compiled on any Unix platform.

General information

Main features, Acknowledgments News&Bugs References Contributions

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Manual

calchep_man_3.3.6.pdf (manual for version 3.3.6, July 19, 2012)

HEP computer tools (Lecture by Alexander Belyaev)

See also: Dan Green, High Pt physics at hadron colliders (Cambrige University Press)

Code download.

Licence Installation Curent version 3.4.cpc (08.03.2013) Old Versions,

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Models:

MSSM(24.06.2011) NMSSM23(07.05.2011) CPVMSSM(03.05.2012) SUSY models By A.Semenov LeptoQuarks 5DSM 6DSM

Model database HEPMDB

Related packages on Web:

Packages for model generation: LanHEP FeynRules SARAH

RGE and spectrum calculation: SuSpect Isajet SoftSUSY SPheno CPsuperH NMSSMTools

Particle widths in MSSM: SUSY-HIT HDECAY

Parton showers: PYTHIA

Contacts

Email: calchep@googlegroups.com *Launchpad service:* *Ask a question* *File a bug*