Computation Tools for High Energy Physics and cosmology.

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MicrOMEGAs,
A code for calculation of Dark Matter signals in Beyond Standard Models

https://lapth.cnrs.fr/micromegas

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General features and purpose

- MicrOMEGAs is based on CalcHEP package

https://theory.sinp.msu.ru/~pukhov/calchep.html

which is intended for calculation of cross sections and particle decay widths in generic model of particle interaction.

- MicrOMEGAs is able to calculate relic density of DM, signals of direct and indirect DM detection.
- Micromegas contains/imports external packages for model construction, calculation of particle spectra, testing of collider signals.
- Operation system Linux or Darwin (Mac)
- User's code language is C or C++

Downloading of micrOMEGAs package

micrOMEGAs site

http://lapth.in2p3.fr/micromegas

Click *Download and Install* *(left -top part of the screen)*
And then *DOWNLOAD* *(right-top part of the screen)*
The name of received file should be

micromegas_5.2.10.tgz

Unpack it by **tar -xvzf micromegas_5.2.10.tgz**

It should create directory **micromegas_5.2.10/** which occupies about 180 Mb of disk space. You will need more disk space after compilation of specific models and generation of matrix elements .

Compilation of micromegas code consists of 3 steps.

1) Compilation of CalcHEP and main micrOMEGAs routines
2) Compilation of code for given model of particle interaction.
3) Runtime compilation of external packages and matrix elements.

File structure of micrOMEGAs package.

micromegas_5.2.10/ main directory

CalcHEP_src/ generator of matrix elements
sources/ micrOMEGAs own codes
man/ description of micrOMEGAs routines
manual_5.2.pdf
include/ micromegas.h & micromegas_aux.h
lib/ for generated libraries
Packages/
SuSpect_2.41 NMSSMTools_4.7.1 CpsuperH2.3,
LoopTools-2.1 LanHEP

model directories:

MSSM/
NMSSM/ Next-to-Minimal SuSy Model
CPVMSSM/ MSSM with complex parameters
IDM/ Inert doublet model
LHM/ Little Higgs Model
Z3IDM/ Inert doublet and singlet, Z^3 symmetry
Z4IDSM/ Inert doublet and singlet, Z^4 symmetry

Structure of MODEL directory

main.c[pp] file with *main* program for given model

Makefile supports compilation of C and C++ user codes

lib/

- ***.c, .F,cpp** source codes of specific model routines
- **Makefile** called automatically to generate
- **alib.a** compiled library

work/ CalcHEP working directory intended for matrix element generation

- **models/** model in CALCHEP format: **vars1.mdl** **func1.mdl** **prtcls1.mdl** **lgrng1.mdl**
- **so_generated/** directory to store automatically generated matrix elements
- **./calchep** launch interactive CalcHEP session

Structure of main.c file

main.c, main.cpp files in micrOMEGAs model directories consist of several independent blocks enclosed into

```
#ifdef XXXXX
   .....................
#endif
```

In the top of main.c the user can switch on/off any of this block via corresponding *#define* instruction at the top of file

```
#define MASSES_INFO                 // Display information about mass spectrum
#define CONSTRAINTS                 //   Display B->s,gamma, Bs->mu,mu,
#define LILITH                      //  Test of  Higgs properties
#define HIGGSBOUNDS
#define OMEGA                       // Calculate relic density
#define INDIRECT_DETECTION          // Signals of DM annihilation in galaxy hallo
//#define RESET_FORMFACTORS         // Redefinition of  Form Factors and other parameters
#define CDM_NUCLEON                 // Calculate amplitudes and cross-sections for  CDM-
                                       nucleon  collisions
//#define CDM_NUCLEUS               // Calculate number of events for 1kg*day and recoil
                                    //  energy distribution  for various nuclei
#define NEUTRINO                    // neutrino telescope
#define  DECAY                      // particle width and decay branching
#define  CROSS_SECTIONS             // calculate cross sections
```

The main.c files from all model directories are similar and call the same micrOMEGAs routines.

Special requirement for compilation

a) **gfortran.** Mac users has to pay attention on C-Fortran compatibility.

b) **X11 develop package** (file /usr/include/X11/*.h):
Needed for Graphic User Interface in CalcHEP and plot facilities of micrOMEGAs. One can **ignore** this requirement or install

libX11-devel for Fedora/Scientific, old Mac
Xquartz (https://www.xquartz.org) , new Mac
libX11-dev for Ubuntu/Debian [old Ubunty]
libx11-dev for Ubuntu/Debian [new Ubunty]
xorg-x11-devel for SUSE

c) SMODELS external package requires **python 3.0** or later

Compilation of micrOMEGAs routines

To compile CalcHEP and main micrOMEGAs routines one has to call

make

In micrOMEGAS directory. Compiler flags are stored here

CalcHEP_src/FlagsForSh

Any model directory contains main.c & Makefile

Command

make

generates executable

./main

In general

make main=*my_main.c*

generates executable file

./my_main

Default main.c codes generate executable which needs one argument, the name of file with input parameters. For instance

./main data1.par

Run time compilation of matrix elements

If micrOMEGAs needs matrix element for some process, or structure of model vertex, it calls CalcHEP for matrix element generation. Code of matrix element/vertex is compiled, presented as a shared library and stored in directory

MODEL/work/so_generated.

User sees the message on the screen

PROCESS: <name of process>

Or

VERTEX : < name of vertex>

Information about vertices is used to compile effective loop induced Higgs-photon and Higgs-gluon vertices.

Shared library is loaded dynamically in run time

Each shared libraries generated only one time.

If model of interaction is changed, then shared library is recompiled automatically

Dark Matter in micrOMEGAs models.

Discrete symmetry.

MicrOMEGAs assumes a discrete symmetry which is responsible for stability of Dark Matter. For instance, it could be a Z_2 symmetry which divides all particles in two classes, odd and even, say R-parity in MSSM. The lightest odd particle is stable and can be treated as DM.

For micrOMEGAs odd particles are particles whose name started with tilde "~". For example, ~X,~H3,~H+ in IDM.

In case of Z_4 symmetry internal charge for DM particles can be +/- 1 or 2. DM1- the lightest particle with charge 1 is always stable. But the lightest particle with charge 2 in stable if its mass less then the mass of 2 DM1 particles. One can also construct a model with complex symmetry like $Z_2 \times Z_3$ which always has 2 DM particles.

MicrOMEGAs can work with models with 2DM classes which are marked by "~" and "~~"

Example: Inert Doublet Model

Inert Doublet model contains two SU(2)*U(1) doublets

$$H_1 = \begin{pmatrix} 0 \\ <v> + h/\sqrt{2} \end{pmatrix} \quad , \quad H_2 = \begin{pmatrix} \tilde{H}+ \\ (\tilde{X} + i \cdot \tilde{H}3)/\sqrt{2} \end{pmatrix}$$

The Lagrangian contains only *even* powers of H_2 doublet

$$L = (SM\ terms) + D^{\mu} H_2^* D_{\mu} H_2$$

$$-\mu^2 H_2^2 - \lambda_2 H_2^4 - \lambda_3 H_1^2 H_2^2 - \lambda_4 |H_1^* H_2|^2 - \lambda_5 Re[(H_1^* H_2)^2]$$

Because of symmetry $H_2 \to -H_2$ the lightest of $\tilde{H}^+,\ \tilde{X},\ \tilde{H}3$ is stable

Parameters $\mu,\ \lambda_3,\ \lambda_4$ can be expressed in terms of masses

New couplings are λ_2 , $\lambda_L = \lambda_3 + \lambda_4 + \lambda_5$

See details in **arXiv:1106.1719**

vars1.mdl: Free parameters of the model.

```
Inert Doublet Model
 Variables
 Name | Value      |>  Comment                                  <|
EE    |0.31333     |Electromagnetic coupling constant
SW    |0.474       |sin of the Weinberg angle
MZ    |91.187      |Mass of Z
MHX   |111         |Mass of Inert Doublet Higgs
MH3   |222         |Mass of CP-odd Higgs
MHC   |333         |Mass of charged Higgs
LaL   |0.01        |Coupling in Inert Sector
.................................
```

func1.mdl: Constrained parameter of the model.

```
Inert Doublet
 Constraints
 Name   |> Expression
CW      |sqrt(1-SW^2)
MW      |MZ*CW
Mb      |MbEff(Q)
Mc      |McEff(Q)
mu2     |MHX^2-laL*(2*MW/EE*SW)^2
la3     |2*(MHC^2-mu2)/(2*MW/EE*SW)^2
la5     |(MHX^2-MH3^2)/(2*MW/EE*SW)^2
```

prtcls1.mdl: Particles of the model

List fo particles presented in file MODEL/work/models/prtcls1.mdl

Full Name	P	aP	number	spin2	mass	width	color	aux	> LaTeX(A)
photon	A	A	22	2	0	0	1	G	A
Z boson	Z	Z	23	2	MZ	!wZ	1	G	Z
gluon	G	G	21	2	0	0	8	G	G
W boson	W+	W-	24	2	MW	!wW	1	G	W^+
neutrino	n1	N1	12	1	0	0	1	L	\nu^e
electron	e1	E1	11	1	0	0	1		e
mu-neutrino	n2	N2	14	1	0	0	1	L	\nu^\mu
muon	e2	E2	13	1	Mm	0	1		\mu
tau-neutrino	n3	N3	16	1	0	0	1	L	\nu^\tau
tau-lepton	e3	E3	15	1	Mt	0	1		\tau
u-quark	u	U	2	1	0	0	3		u
d-quark	d	D	1	1	0	0	3		d
c-quark	c	C	4	1	Mc	0	3		c
s-quark	s	S	3	1	Ms	0	3		s
t-quark	t	T	6	1	Mtop	wtop	3		t
b-quark	b	B	5	1	Mb	0	3		b
Higgs	h	h	25	0	Mh	!wh	1		h
odd Higgs	~H3	~H3	36	0	MH3	!wH3	1		(H3)
Charged Higgs	~H+	~H-	37	0	MHC	!wHC	1		(H+)
second Higgs	~X	~X	35	0	MHX	!wHX	1		(X)

Names of particles of odd sector start with tilde ~

lgrng1.mdl: Feynman rules

```
Inert Dublet
 Lagrangian
P1 |P2 |P3 |P4 |>   Factor          <|> dLagrangian/ dA(p1) dA(p2)dA(p3)
A  |W+ |W- |   |-EE                  |m3.p2*m1.m2-m1.p2*m2.m3- …...
A  |~H+|~H-|   |EE                   |m1.p3-m1.p2
B  |b  |A  |   |EE/3                 |G(m3)
B  |b  |G  |   |GG                   |G(m3)
B  |b  |Z  |   |-EE/(12*CW*SW)       |4*SW^2*G(m3)-3*G(m3)*(1-G5)
B  |b  |h  |   |-EE*Mb/(2*MW*SW)     |1
B  |t  |W- |   |-EE*Sqrt2/(4*SW)     |G(m3)*(1-G5)
W+ |W- |~X |~X |EE^2/(2*SW^2)        |m1.m2
h  |~X |~X |   |-2*MW*SW/EE          |la3+la4+la5
Z  |Z  |~X |~X |EE^2/(2*CW2*SW^2)    |m1.m2
   …..............
```

p – momentum, m – Lorentz index

Example of micrOMEGAs session for IDM

./main data1.par

```
VERTEX: W- W+ h
VERTEX: L l h
VERTEX: C c h
VERTEX: T t h
VERTEX: B b h
VERTEX: ~H- ~H+ h

Dark matter candidate is '~X' with spin=0/2

=== MASSES OF HIGGS AND ODD PARTICLES: ===
Higgs masses and widths
PROCESS: h->2*x
PROCESS: W+->2*x
PROCESS: Z->2*x
PROCESS: h->W-,E,ne
Delete diagrams with W+<1
PROCESS: h->Z,ne,Ne
Delete diagrams with Z<1
     h   125.00 3.97E-03

Masses of odd sector Particles:
~X   : MHX   =   600.0 || ~H3  : MH3   =   601.0 || ~H+  : MHC   =   604.0

LILITH(DB15.09):  -2*log(L): 25.96; -2*log(L_reference): 0.00; ndf: 38; p-value: 9.31E-01
```

Continue

==== Calculation of relic density =====
PROCESS: ~X,~X ->AllEven,1*x{A,Z,G,W+,W-,ne,Ne,e,E,nm,Nm,m,M,nl,Nl,l,L,u,U,.....
PROCESS: ~H3,~X ->AllEven,1*x{A,Z,G,W+,W-,ne,Ne,e,E,nm,Nm,m,M,nl,Nl,l,L,u,U,...
PROCESS: ~H3,~H3->AllEven,1*x{A,Z,G,W+,W-,ne,Ne,e,E,nm,Nm,m,M,nl,Nl,l,L,...
.....

Xf=2.62e+01 Omega=1.13e-01
# Channels which contribute to 1/(omega) more than 1%.
# Relative contributions in % are displayed
21% ~X ~X ->W+ W-
14% ~X ~X ->Z Z
11% ~H3 ~H3 ->W+ W-
9% ~H+ ~H- ->W+ W-
7% ~H3 ~H3 ->Z Z
6% ~H+ ~X ->A W+
5% ~H3 ~H+ ->A W+
4% ~H+ ~H- ->A A
4% ~H3 ~H+ ->Z W+
3% ~H+ ~X ->Z W+
3% ~H+ ~H- ->A Z
2% ~H+ ~H- ->Z Z
2% ~H+ ~X ->W+ h
1% ~H+ ~H- ->h h

```
==== Indirect detection =======
 annihilation cross section 6.18E-26 cm^3/s
 contribution of processes
  ~X,~X -> W+ W-       6.01E-01
  ~X,~X -> Z Z         3.99E-01
sigmav=6.18E-26[cm^3/s]
Photon flux  for angle of sight f=0.10[rad]
and spherical region described by cone with angle 0.10[rad]
Photon flux = 9.37E-16[cm^2 s GeV]^{-1} for E=300.0[GeV]
Positron flux  =  1.04E-13[cm^2 sr s GeV]^{-1} for E=300.0[GeV]
Antiproton flux  =  5.91E-13[cm^2 sr s GeV]^{-1} for E=300.0[GeV]


==== Calculation of CDM-nucleons amplitudes  =====
PROCESS: QUARKS,~X->QUARKS,~X{u,U,d,D,c,C,s,S,t,T,b,B
Delete diagrams with _S0_!=1,_V5_,A
CDM[antiCDM]-nucleon micrOMEGAs amplitudes:
proton:  SI  1.497E-11 [1.497E-11]  SD  0.000E+00 [0.000E+00]
neutron: SI  1.512E-11 [1.512E-11]  SD  0.000E+00 [0.000E+00]
CDM[antiCDM]-nucleon cross sections[pb]:
 proton  SI 9.767E-14 [9.767E-14] SD 0.000E+00 [0.000E+00]
 neutron SI 9.962E-14 [9.962E-14] SD 0.000E+00 [0.000E+00]
==============Neutrino Telescope=======  for  Sun
 E>1.0E+00 GeV neutrino/anti-neutrino fluxes   1.81E+01/2.05E+01 [1/Year/km^2]
IceCube22 exclusion confidence level = 1.29E-07%
 E>1.0E+00 GeV Upward muon flux    2.337E-07 [1/Year/km^2]
 E>1.0E+00 GeV Contained muon flux 6.999E-07 [1/Year/km^3]
```

Main functions of micrOMEGAs

Free model parameters. .

assignValW(*name,value*) assigns new value to parameter.

For example

assignValW("MHX",600)

Function to download set of parameters:

readVar(*fileName***)**

Structure of file has to be

name value [# comment]

For instance, in case of IDM

```
laL      0.001    # coupling
MHX      600      # inert sector Higgs
 Mh      125      # SM Higgs mass
la2      0.01     # coupling
MHC      604      # mass of charged Higgs
MH3      601      # mass of CP odd Higgs
```

Checking of constrained models parameters

After assignment of parameters one has to call

sortOddParticles(outText);

which calculates constrained parameters and finds DM particle[s]. In case of error in calculation of constrained parameter this routine returns error code and *outText* contains the name of parameter which can not be calculated.

In case of success sortOddParticles detects the lightest odd particle[s]

CDM1 [CDM2] and their masses

Mcdm1 [Mcdm2, Mcdm=min(Mcdm1,Mcdm2)]

Values of constrained parameters can be obtained by

findValW(*name*)

Masses of particles can be obtained by

pMass(*name*)

Calculation of DM relic density for 1 DM case

darkOmega(&Xf,fast,Beps) uses Runge-Kutta to solve

$$\frac{dY}{ds} = \frac{< v\sigma >}{3H}(Y^2 - Y_{eq}^2)$$

Returns Ωh^2

fast =*1* *for fast* calculation: Gauss n-point integration with separation of s-channel poles

0 for precise calculation , Simpson adaptive integration

-1 for very precise Simpson adaptive integration with separation of s-channel poles

Beps removes co-annihilation if

$$exp(\frac{2M_{cdm} - M_1 - M_2}{T}) < Beps$$

X_f =Mcdm/T_f , where $Y(T_f) = 2.5\ Y_{eq}(T_f)$ defines freeze-out temperature

printChannels(Xf, Beps, cut,prc,file) print out main annihilation channels and their contributions to 1/ Ωh^2

21% ~X ~X → W+ W-
14% ~X ~X → Z Z
11% ~H3 ~H3 → W+ W-
9% ~H+ ~H- → W+ W-

Direct Detection

To predict results of direct detection experiment in a given model we have to calculate cross sections of DM – nuclei elastic scattering. Velocities of DM particles in halo of Milky Way are about orbital velocities of stars ~0.001c. So, we calculate elastic cross sections in v=0 limit.
Feynman rules give us

DM - quarks cross section

Then using nucleon form factors we get

DM - nucleon scattering cross section

Then using nucleus form factors we get

DM -nucleus cross section

In the last step we perform recasting of Direct Detection experiments to make conclusion about validity of the model.

There are Spin Independent (scalar) and Spin Dependent (spin flip) cross section. Even (particle ↔ antiparticle) and odd cross sections.

Nucleon amplitudes and cross sections in micrOMEGAs

nucleonAmplitudes(name_of_DM ,pA0,pA5,nA0,nA5);
Output: *pA0,pA5,nA0,nA5* – 2 dimension arrays
Proton
pA0[even SI, odd SI] pA5[even SD, odd SD]
Neutron
nA0[even SI, odd SI] nA5[even SD, odd SD]

Then DM-nucleon cross section in [pb] units are

$\sigma_{si} = C*A^2$ $\sigma_{SD} = 3*C*A^2$ where $C=4/\pi*3.89E8*(M_N*M_{dm}/(M_N+M_{dm)})^2$

CDM[antiCDM]-nucleon micrOMEGAs amplitudes:

proton: SI 1.497E-11 [1.497E-11] SD 0.000E+00 [0.000E+00]
neutron: SI 1.512E-11 [1.512E-11] SD 0.000E+00 [0.000E+00]

micrOMEGAs function for nuclei

nucleusRecoil(
  f, - velocity distribution f(v[km/s]) normalized by $\int_0^\infty f(v)dv = 1$
  A, - atomic number
  Z, - nucleus charge
  J, - number of spin states
  Sxx, - SD formfactors
  dNdE - recoil energy distribution stored in array
)

dNdERecoil(E[keV],dNdE) interpolates dNdE table and gives spectrum in 1/keV/kg/day units

For example:

```
nEvents=nucleusRecoil(Maxwell,73,Z_Ge,J_Ge73,SxxGe73,dNdE);
          Result depends on global parameter
 rhoDM    0.3[GeV/cm^3] Dark Matter density at Rsun
 Vrot     220[km/s]     Galaxy rotation velocity at Rsun
 Vearth   225[km/s]     Galaxy velocity of the Earth
 Vesc                   Escape velocity at Rsun
```

Comparison with DD experiments

α = 1-C.L. can be obtained by

DD_pval(expCode, fv,&expName)

expCode can include

XENON1T_2018, DarkSide_2018, PICO_2019, CRSST_2019

For example

allExp=XENON1T_2018 | DarkSide_2018 | PICO_2019 | CRSST_2019

expName – the name of experiment that leads to the strongest exclusion

arXiv:0803.2360 [hep-ph]

arXiv:2003.08621 [hep-ph]

Indirect detection in micrOMEGAs

Indirect detection -detection of photons, positrons and antiprotons signal obtained in result of DM annihilation in Galactic Hallo.

For various spectra we use NZ=250 dimention arrays and interpolation function for them is SpectdNdE(E,spectArr)
One can use displayPlot to see and compare different spectra.

vsigma=calcSpectrum(key,Sg,Se,Sp,Sne,Snm,Snl,&err)
Calculates vσ cross section in cm^3/sec units for DM annihilation photon Sg, positron Se, antiprotons Sp, and neutrino Sne,Snm,Snl contain spectra for DM-DM annihilation
Here the avarage over DM,DM/antiDM is done. PYTHIA 6.4 was used for hadronisation of primary annihilation channels.

Meaning of key parameter: 1-takes into account W/Z polarization
2-include gammas from 2->2+gamma
4-print cross sections

loopGamma

For all implemented models we have
DM,DM-> photon, photon and DM,DM -> photon, Z
loop induced signals. These signals are not compiled automatically in run-time but generated in advance by means of FormCalc.

One has to uncomment
//#define LoopGAMMA
to force micrOMEGAs to calculate point like gamma signal.
Function loopGamma(&vcs_gz,&vcs_gg) calculates annihilation rates vcs_gz and vcs_gg [cm^3/s]. For example for IDM model with data1.par

```
Gamma ray lines:
E=5.97E+02[GeV]  vcs(Z,A)= 1.58E-28[cm^3/s], flux=4.91E-14[cm^2 s]^{-1}
E=6.00E+02[GeV]  vcs(A,A)= 5.37E-29[cm^3/s], flux=3.33E-14[cm^2 s]^{-1}
```

Calculated cross sections can be compared with experiments for search of single lines in photon spectrum

The loopGamma function is not available automatically for models implemented by the user.

Halo profile

DM distribuion is defined by DM density at Sun, parameter rhoDM and halo profile. By default micrOMEGAs uses Zhao profile

$$F_{halo}(r) = \left(\frac{R_\odot}{r}\right)^\gamma \left(\frac{r_c^\alpha + R_\odot^\alpha}{r_c^\alpha + r^\alpha}\right)^{\frac{\beta-\gamma}{\alpha}}$$

with alpha=1, beta=3 rc=20kpc.

setProfileZhao(α,β,γ,rc) change these parameters.

setHaloProfile(F) allows to substitute any profile presented by function F(r)

The command **setHaloProfile(hProfileZhao)** sets back the Zhao profile

Photon flux

gammaFluxTab(fi,dfi,sigmav,Sg,Sobs)
fi is the angle between the line of sight and the center of the galaxy,
dfi is half the cone angle which characterizes the detector resolution (the solid angle is $2\pi(1-\cos(df\ i))$,
sigmav is the annihilation cross section,
Sg - photon spectrum at point of annihilation
Sobs is tabulated photon flux

SpectdNdE(E,Sobs)

gives resulting photon flux in [1/(GeV cm^2 s)] units

gammaFlux(fi,dfi,vcs_gz))
gammaFlux(fi,dfi,2*vcs_gg)
 return corresponding fluxes for loop induced processes

Antiproton and positron fluxes

- **posiFluxTab**(Emin,sigmav, Se, Sobs)

- **pbarFluxTab**(Emin,sigmav, Sp, Sobs)

The same style as for photons. But depends on propagation parameters

```
K_dif     | 0.0112| kpc^2/Myr |The normalized diffusion coefficient
L_dif     |  4    | kpc       | Vertical size of the Halo diffu
Delta_dif| 0.7    |           |Slope of the diffusion coefficient
Tau_dif   | 10^16 |   s       |Electron energy loss time
Vc_dif    | 0     |  km/s     |Convective Galactic wind
```

And finally

solarModulation(Phi, mass, stellarTab, earthTab)

allows to take into account solar modulation effect.

Here Phi potential [MeV], mass is mass of particle,

stellarTab flux before modulation

earthTab flux after modulation.

E-print 1004.1092[hep-ph]

Neutrino telescope

micrOMEGAs uses direct detection module to calculate number of DM captured by Sun/Earth.

Captured DM is concentrated in the center of Sun/Earth and neutrino produced in result of DM annihilation can be detected by neutrino telescope experiment (IceCube, Super-Kamiokande, Baksan).

DM annihilation inside of Sun/Earth is different from annihilation in vacuum. Also there are effects of propagation and oscilation.

For flux of resulting muon neutrinos micrOMEGAs uses tables obtained by WimpSim package: J. Edso et.al arXiv 0709.3898
Or
PPPC4DMnu: M. Cirelli, et.al. arXiv 1312.6408

Agreement between two sets is not very good.

MicrOMEGAs routine basicNuSpectra reads these tables depending on
WIMPSIM flag
WIMPSIM=1 for WimpSIm
WIMPSIN=0 for PPPC4DMnu

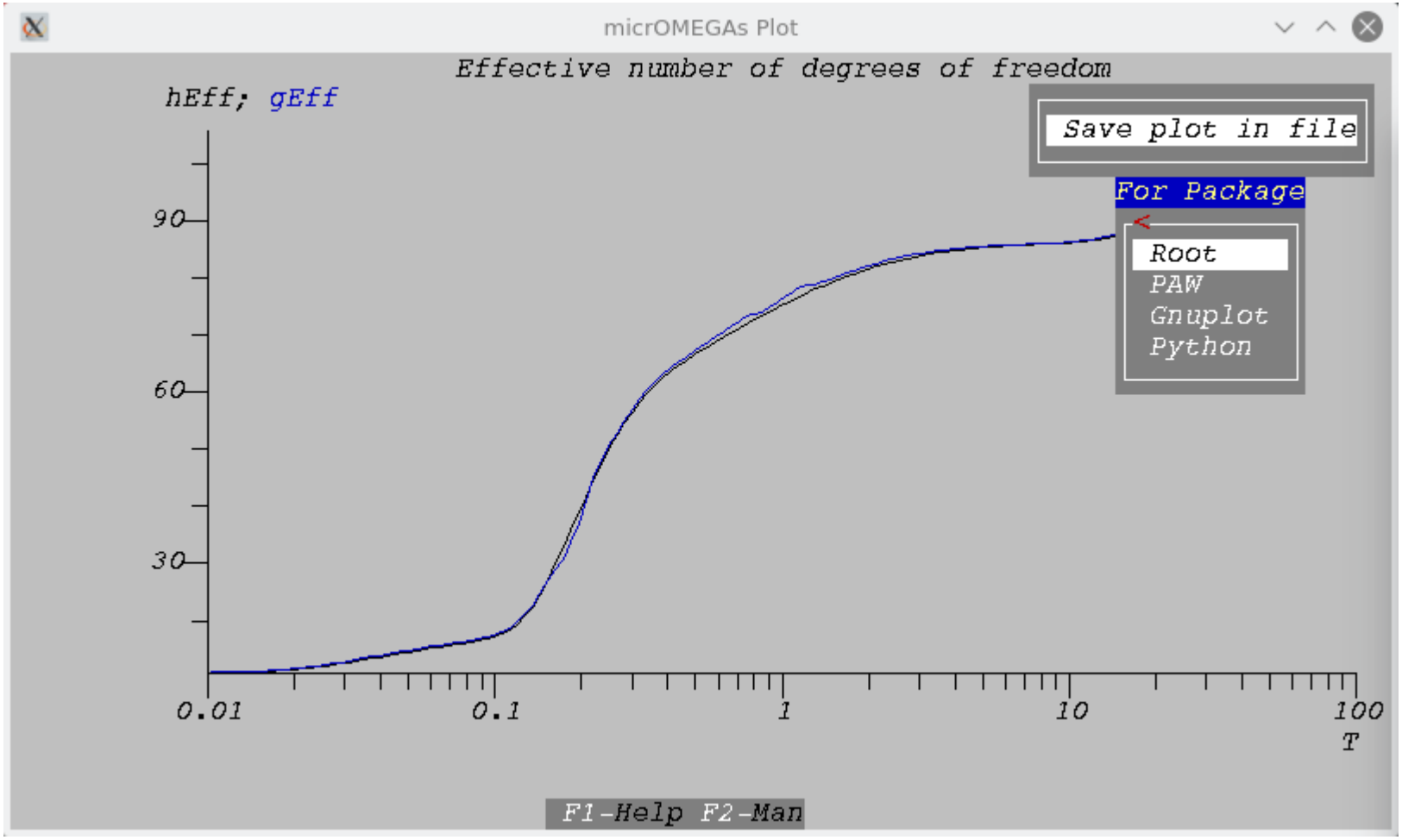
Plots

displayPlot(title,xName,xMin,xMax,lScale, N, …)

displays several curves/histograms on one plot.
xName is the name of a variable,
xMin,xMax are the lower and upper limits.
If lScale != 0, a logarithmic scale is used for the x axis.
N is the number of curves/histograms to display.
After the parameter N, displayPlot expects N × 4 parameters, where each tetrad can contain

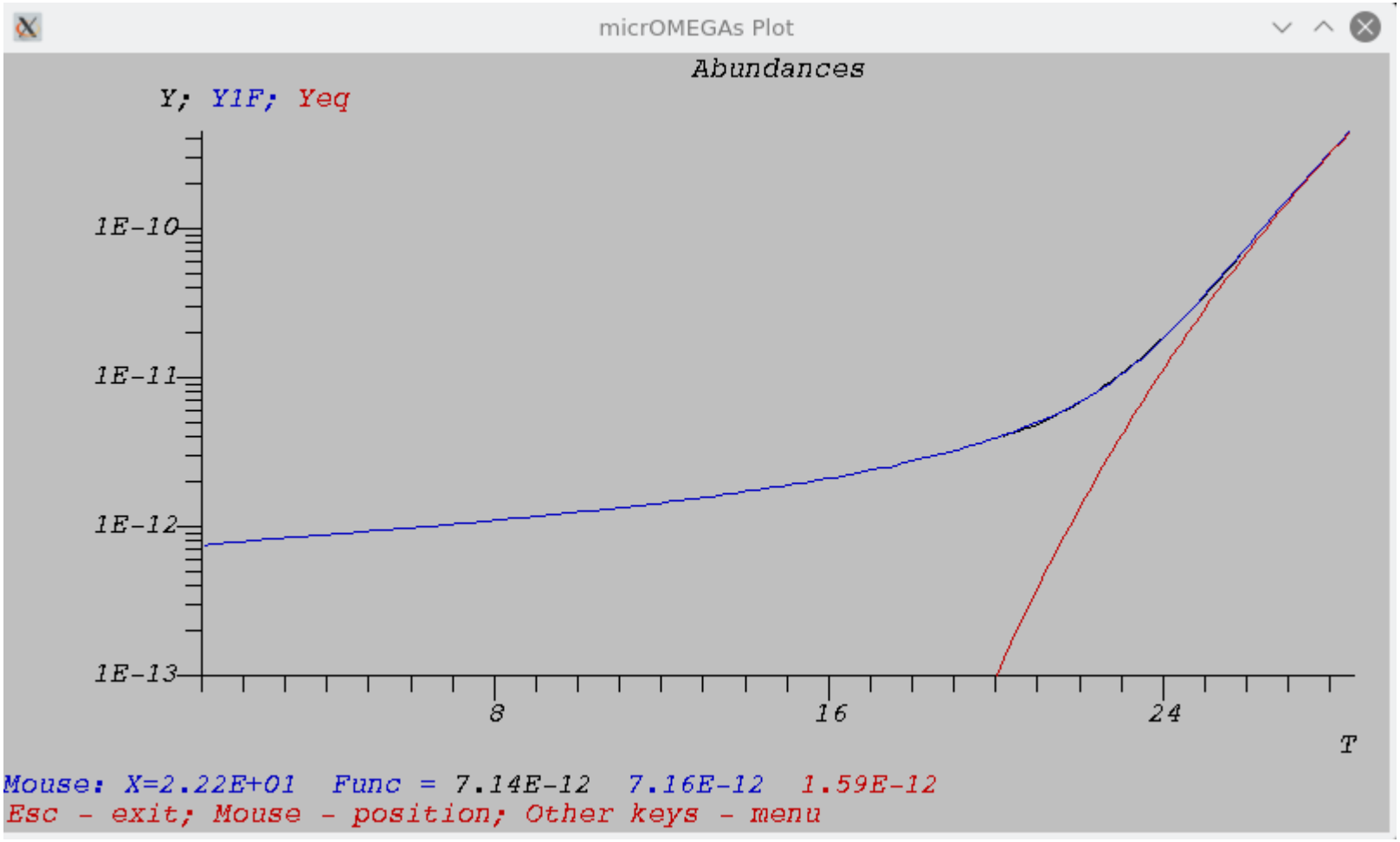
1) test label of curve
2) dimension of array or 0 for functions
3) array of data or a function
4) array of error, or address of function arguments, or NULL

Plots: hEff(T), gEff(T)



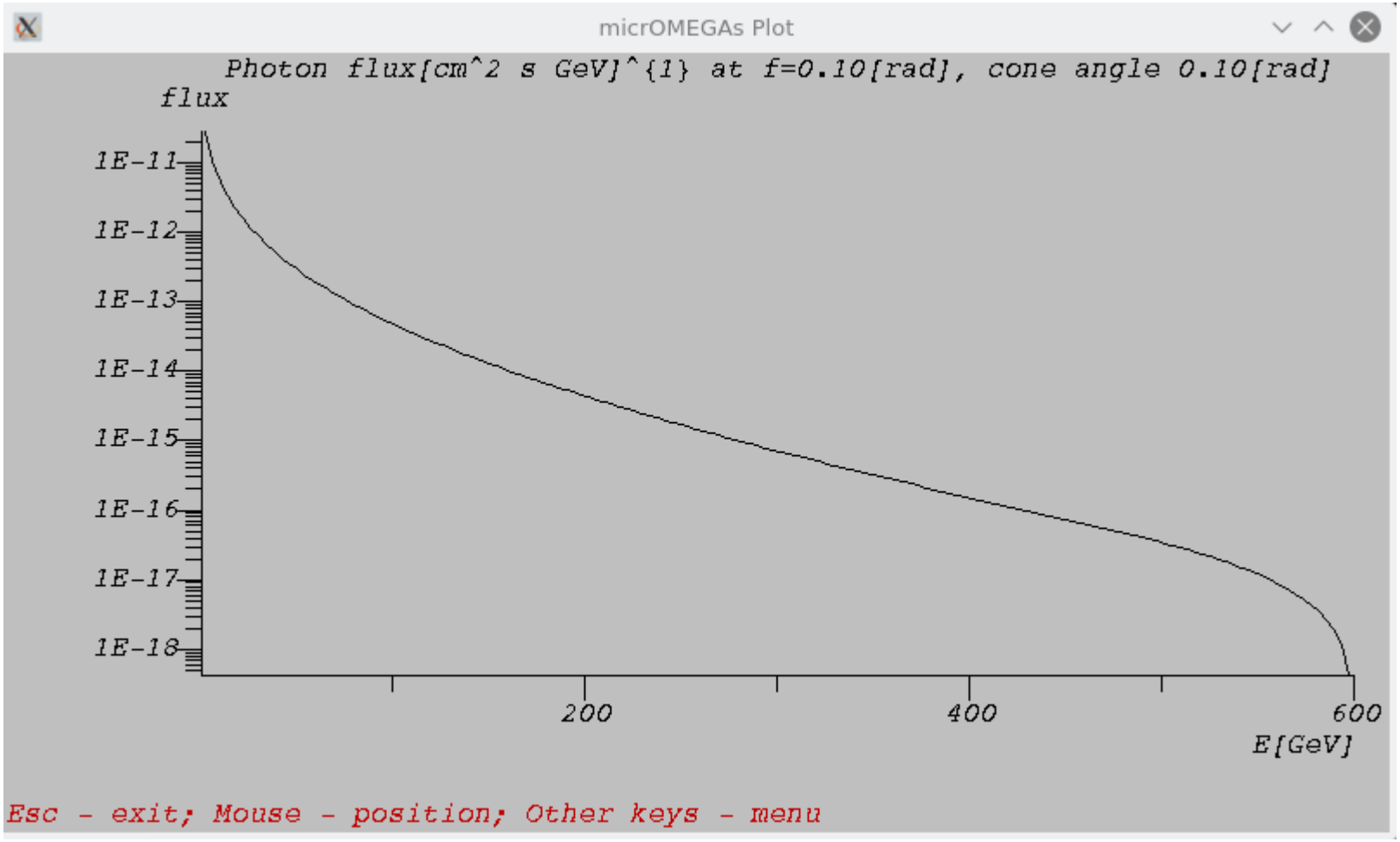
displayPlot("Effective number of degrees of freedom","T",0.01,100, 1,2, "hEff",0,hEff,NULL, "gEff",0,gEff,NULL);

Plots: Abundance Y(T), Y1F(T),Yeq(T)




```
displayPlot("Abundances","T",   1,Tstart,  0,3,
"Y",0,YF,NULL,          // obtained by darkOmega
"Y1F",0,Y1F,NULL,     // obtained by darkOmega2
"Yeq",0,Yeq,NULL);    //  equilibrium abandance
```

Plots: Photon spectrum SpectdNdE(E,Flux)



displayPlot(txt,"E[GeV]",Emin,Mcdm,0,1,"flux",0,SpectdNdE,Flux);

Here Flux is presented by array

External Packages

Directory Packages in intended for extermal packages

MicrOMEGAs contains several packages which are used for calculation of loop-improved particles spectra in MSSM-like models.

1) SuSpect – for MSSM, 2) NMSSMTools for NMSSM,
3) CpsuperH -for MSSM with complex parameters

Also micrOMEGAs contains LoopTools used for DM,DM→ A,A and Lilith for testing Higgs physics.

Several packages are downloaded automatically when the user calls corresponding functions:

HiggsBounds & HiggsSignals - experimental constraints on Higgs
SMODELS – LHC constraints on new particles
SPheno & SoftSUSY - particles spectra of MSSM
SuperIso – flavour physics constraints.

SLHAplus[arXiv 1008.0181]: Tools for reading SLHA files

As a rule external packages use SLHA format: hep-ph/0311123, 0801.0045

Routines **slhaRead, slhaVal (read) openAppend, aPrintF (write)**

File with particle spectrum	**CalcHEP model file**
BLOCK MASS # Mass spectrum	**slhaRead**(file_name, mode)
# PDG Code mass particle	
25 1.15137179E+02 # neutral Higgs	Mh | **slhaVal**("MASS",0,1,25)
37 1.48428409E+03 # charged Higgs	MHC | **slhaVal**("MASS",0,1,37)
BLOCK NMIX # Neutralino Mixing Matrix	
1 1 9.98499129E-01 # Zn11	Zn12 | **slhaVal**("NMIX",0,2,1,2)
1 2 -1.54392008E-02 # Zn12	

Example: SUGRA with SuSpect

```
open  |openAppend("suspect2_lha.in")
input1|aPrintF("Block MODSEL  # Select model\n  1  1   # SUGRA\n")
input2|aPrintF("Block SMINPUTS\n 5 %E#mb(mb)\n 6 %E#mt(pole)\n",MbMb,Mtp)
input3|aPrintF("BLOCK MINPAR\n 1 %E #m0\n 2 %E #m1/2\n ",Mzero,Mhalf)
input4|aPrintF("3 %E #tb\n 4 %E #sign(mu)\n 5 %E #A0\n",tb,sgn,A0)
sys   |System("$CALCHEP/../Packages/SuSpect_2.41/suspect2.exe")
rd    |slhaRead("suspect2_lha.out",0) % mode=4 do not read decays
Mh    |slhaVal("MASS", 0 , 1 , 25)
```

SLHAplus updated

Now people use SLHA format more widely than it was proposed by Peter Skands. micrOMEGAs SLHA package was updated correspondingly. For example

```
Block HiggsBoundsResults
#CHANNELTYPE 1: channel with the highest statistical sensitivity
 1  1        328                                                    # channel id
 1  2          1                                                     # HBresult
 1  3   0.7269279334500290                                         # obsratio
 1  4          1                                                     # ncombined
 1  5   ||(p p)->h+..., h=1 where h is SM-like (CMS-PAS-HIG-12-008)|| # channel
```

```
slhaSTRFormat("HiggsBoundsResults","1 5 ||%[^|]||", channal);
```

```
Block FOBS # Flavour observables
# ParentPDG type value       q   NDA ID1 ID2 ID3 ... comment
    5     1   2.95061156e-04  0     2   3  22       # BR(b->s gamma)
  521     4   8.35442304e-02  0     2 313  22       # Delta0(B->K* gamma)
  531     1   3.24270419e-09  0     2  13 -13       # BR(B_s->mu+ mu-)
```

```
Bsg= slhaValFormat("FOBS", 0., "5 1 %E 0 2 3 22")
```

Implementation of new models in micrOMEGAs

• The command

./newProject *MODEL*

launched from the root micrOMEGAs directory creates the directory *MODEL*, which contains all files needed to run micrOMEGAs (for example main.c) with the exception of the new model files.

• The new model files in the CalcHEP format should then be included in the sub-directory MODEL/work/models. The files needed are

vars1.mdl, func1.mdl, prtcls1.mdl, lgrng1.mdl extlib1.mdl

Simple example:

./newProject IDMcopy
cp IDM/work/models/*1.mdl IDMcopy/work/models
cp IDM/*.dat IDMcopy

It should work!

Implementation of new models:
Generation of model files in CalcHEP Format

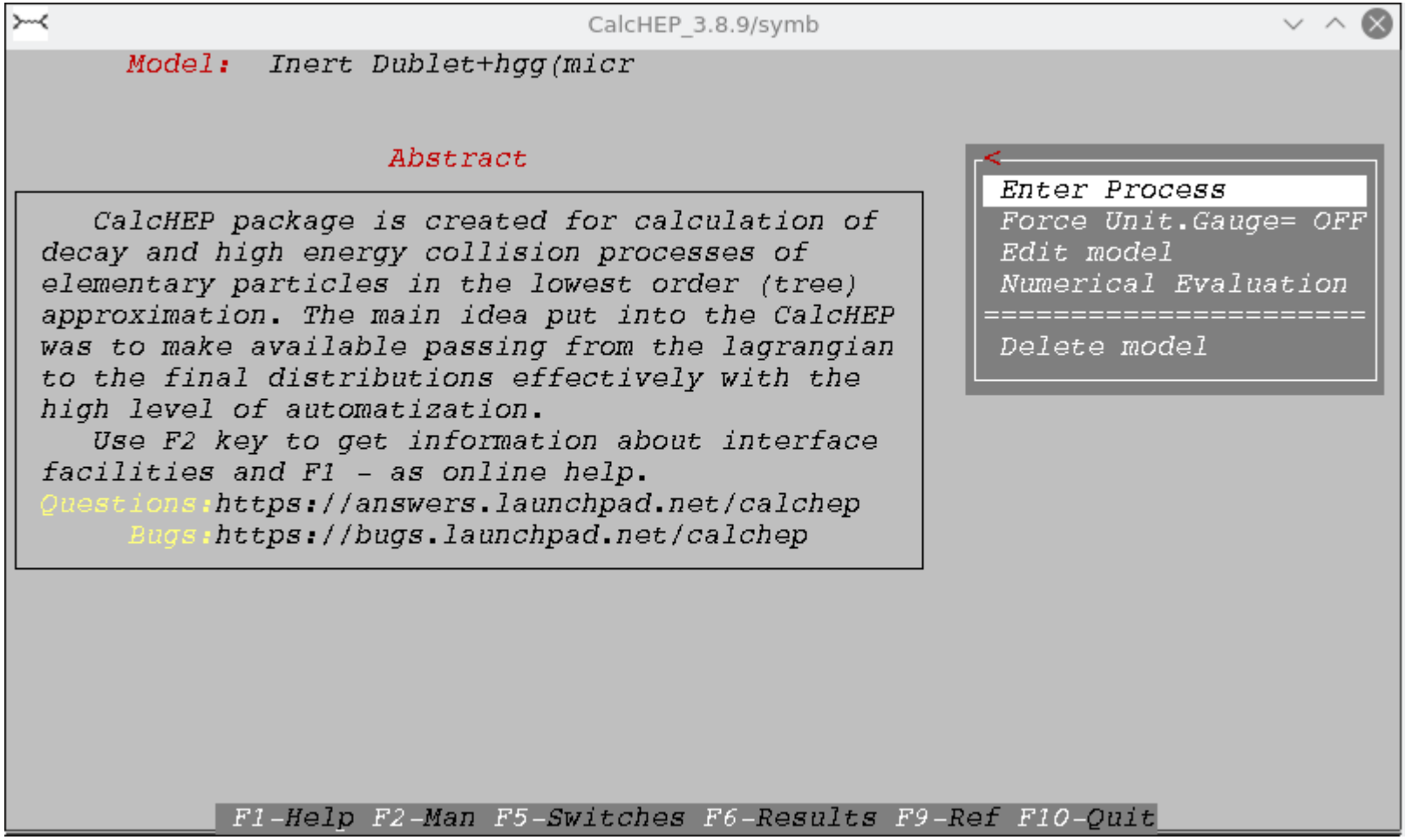
Model files can be created by mean of
LanHEP , FeynRules, Sarah

LanHEP [E-print 1412.5016] is included in micrOMEGAs package.
Each model directory contains lanhep subdirectory with source files and with Makefile which calls LanHEP.
See LanHEP manual
micromegas_X.Y/Packages/LanHEP/manual/man31.pdf

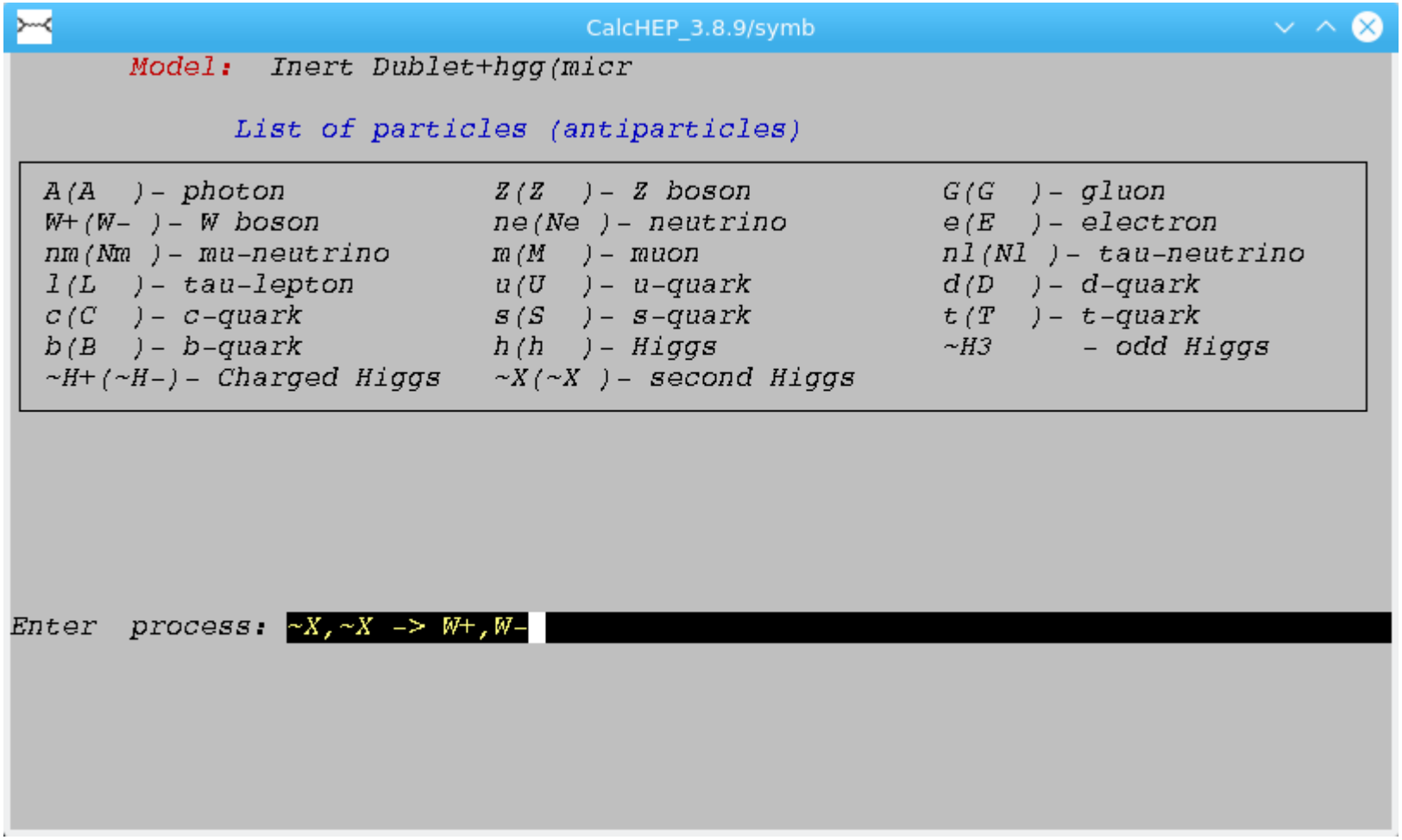
Follow examples presented in any micrOMEGAs model.
The simplest one is in IDM/lanhep

The command **make** launched from the Model directory checks the model and stops with error code if model files do not correspond to CalcHEP requirements.
The user can go to work directory, launch ./calchep and use menu line
CHECK MODEL

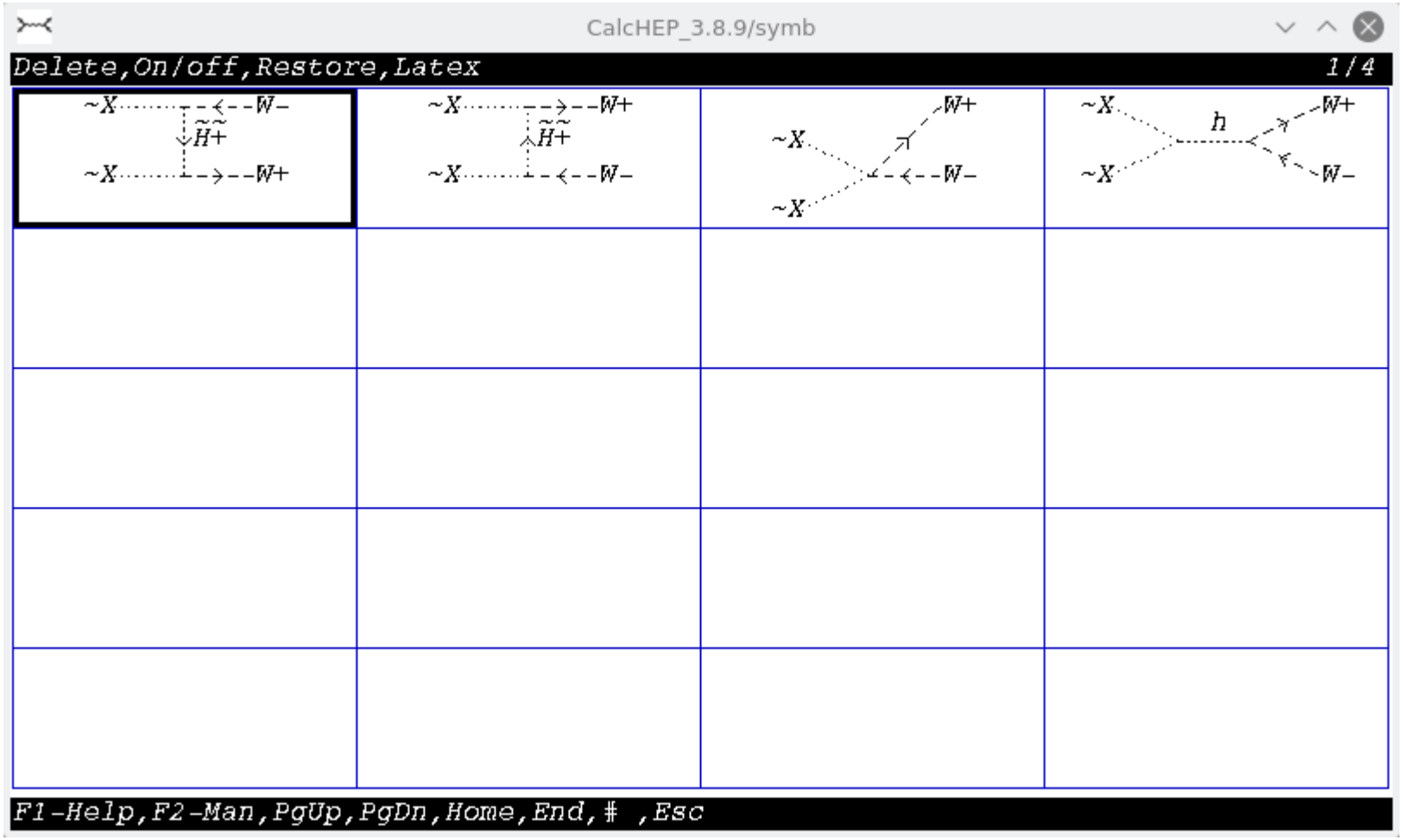
CalcHEP GUI sessions



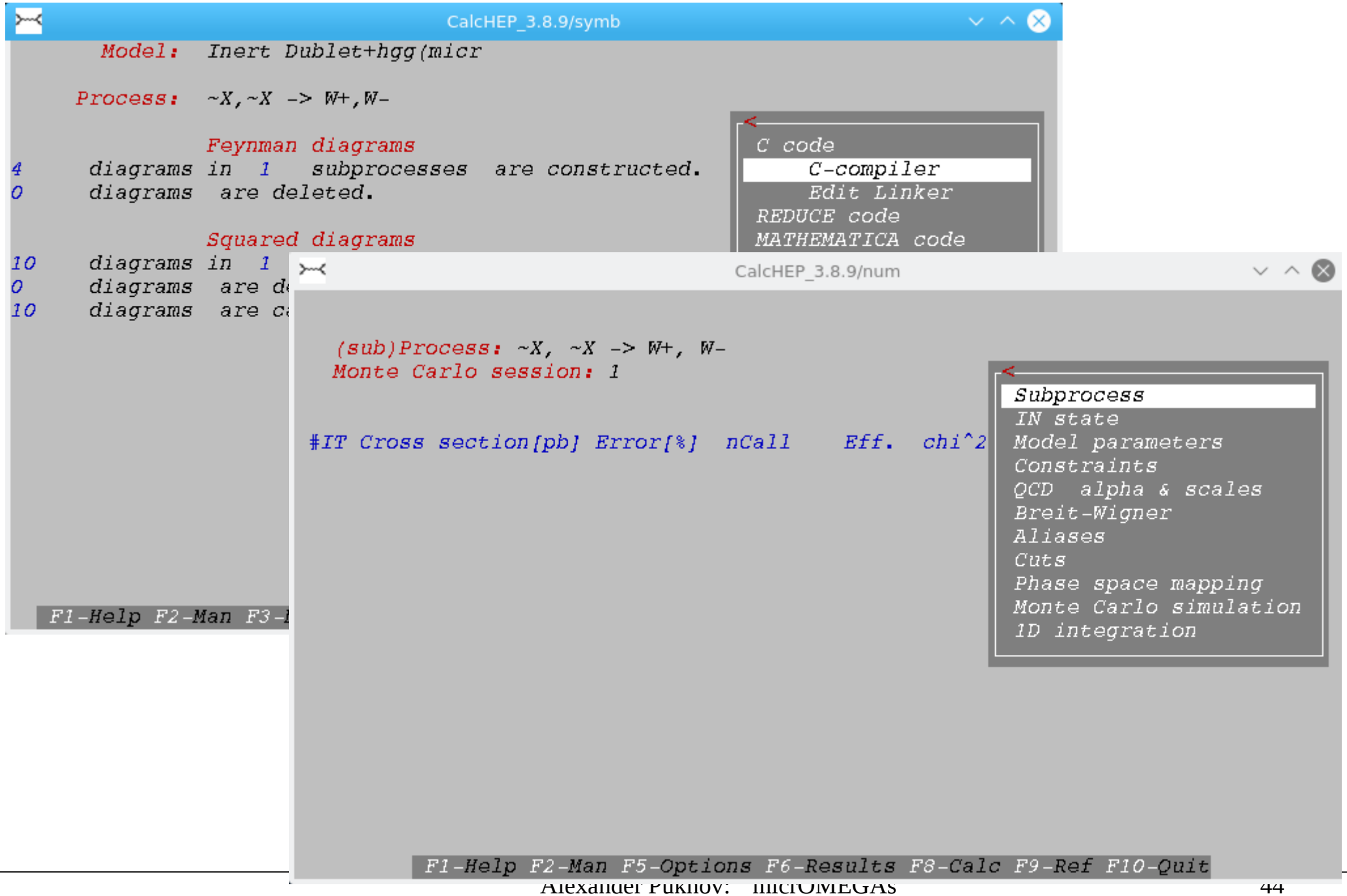
CalcHEP: Enter process



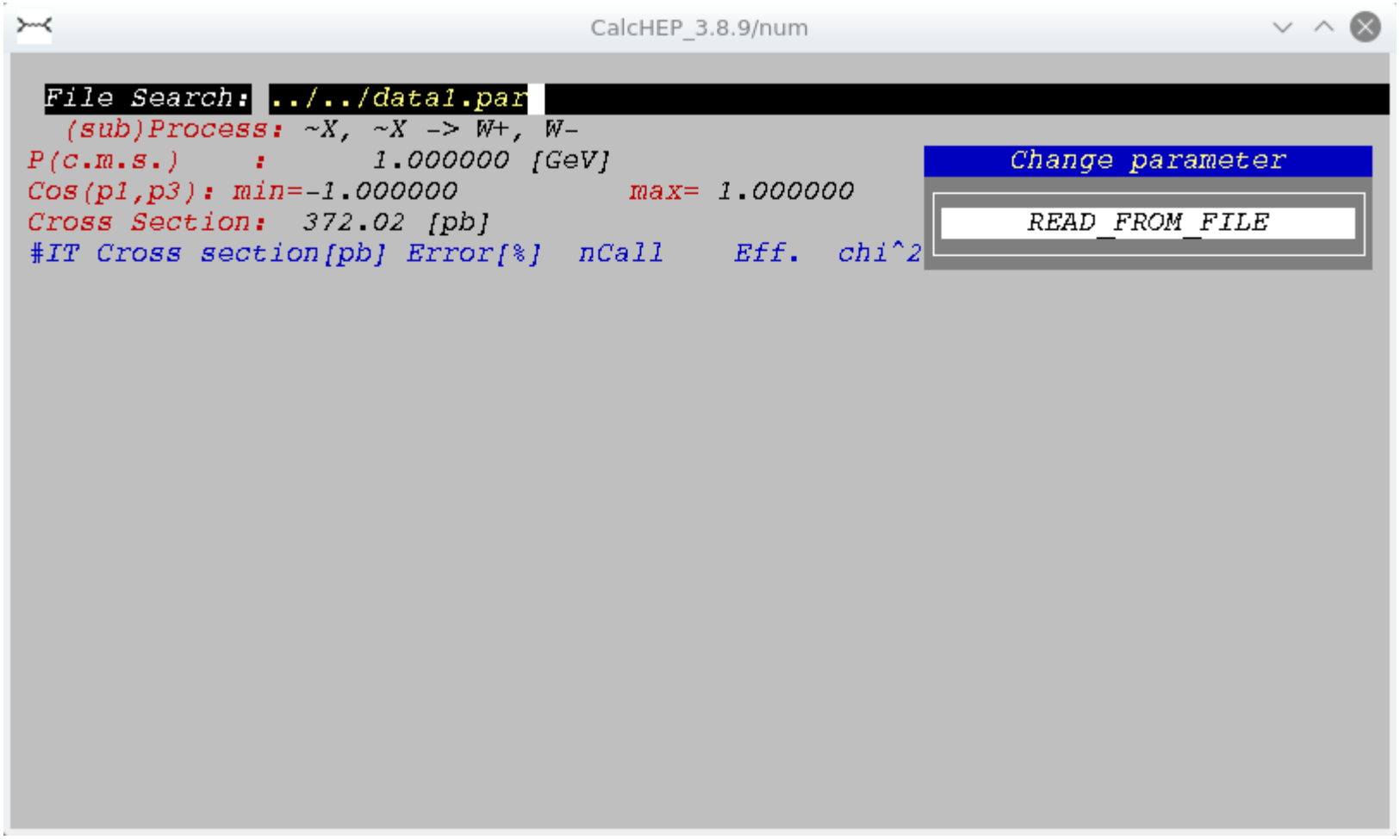
CalcHEP: diagrams



CalcHEP: compilation



CalcHEP: parameters



CalcHEP: v*sigma