CALCHEP

Introduction to CalcHep

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Where to get information ?

- Web Page: https://theory.sinp.msu.ru/~pukhov/calchep.html
- More detailed Tutorial (Alexander Belyaev):

  https://indico.cern.ch/event/656211/contributions/2756825/attachments/1547486/2429259/calchep_tools_bootcamp_belyaev.pdf
- Models BSM (HEPMDB):

  https://hepmdb.soton.ac.uk/

  Many models available! (need registration)

Installation I

Any Linux distribution (Here I'll assume Ubuntu 18.04)

1. Install cernlib (not essential, but we will need it later)

```
sudo apt-get install -y cernlib
```

2. Install library libx11-dev

```
sudo apt-get install -y libx11-dev
```

3. Download, unzip and compile the code

```
tar -zxvf  calchep_3.x.x.tgz
cd calchep_3.x.x.tgz
make
```

Installation II

4. Create a directory for CalcHep working sessions

```
./mkWORKDir <path>/<directory_name>
```

It is possible to create many working directories in different locations.

5. Check the working directory: `ls`

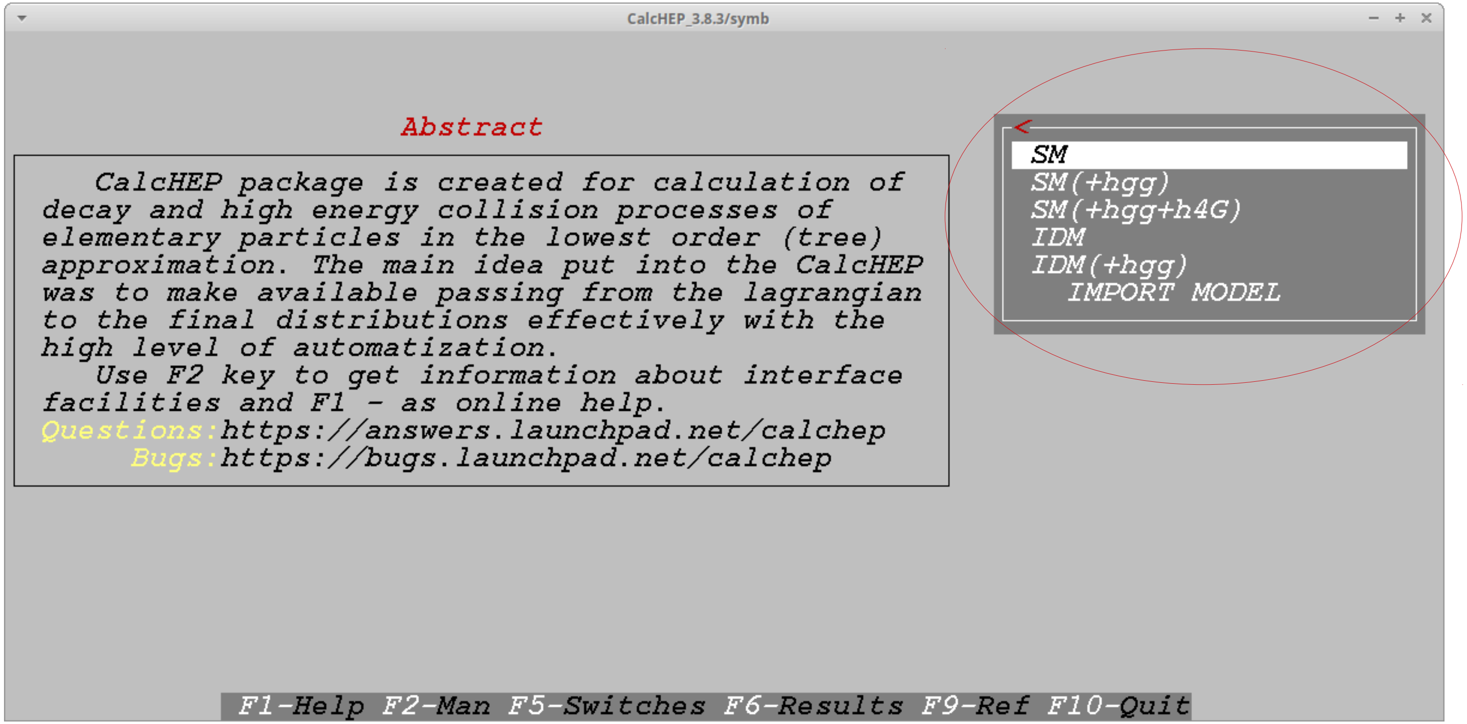
```
batch_results
bin
calchep
calchep_batch
models
results
```

The executables are marked as green.

Starting CalcHep

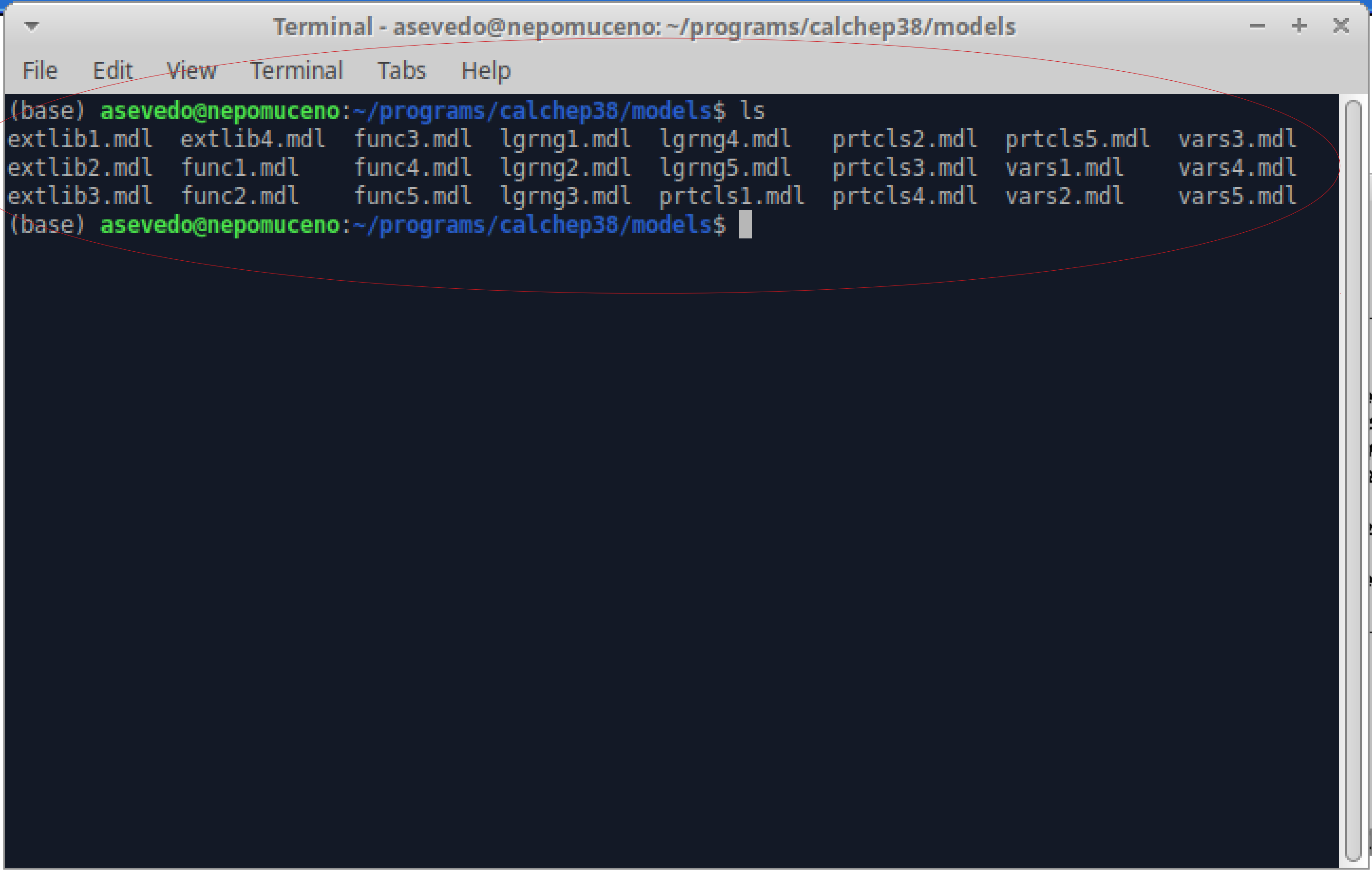
From the working directory, do:

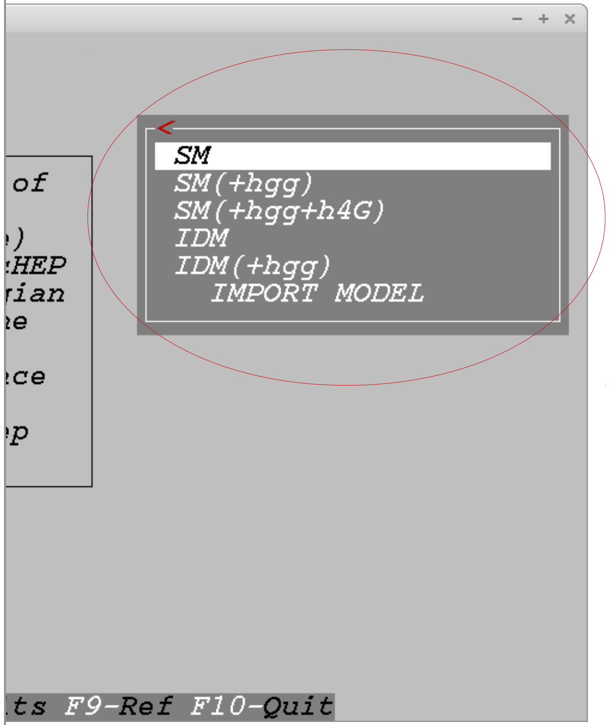
```
./calchep &
```



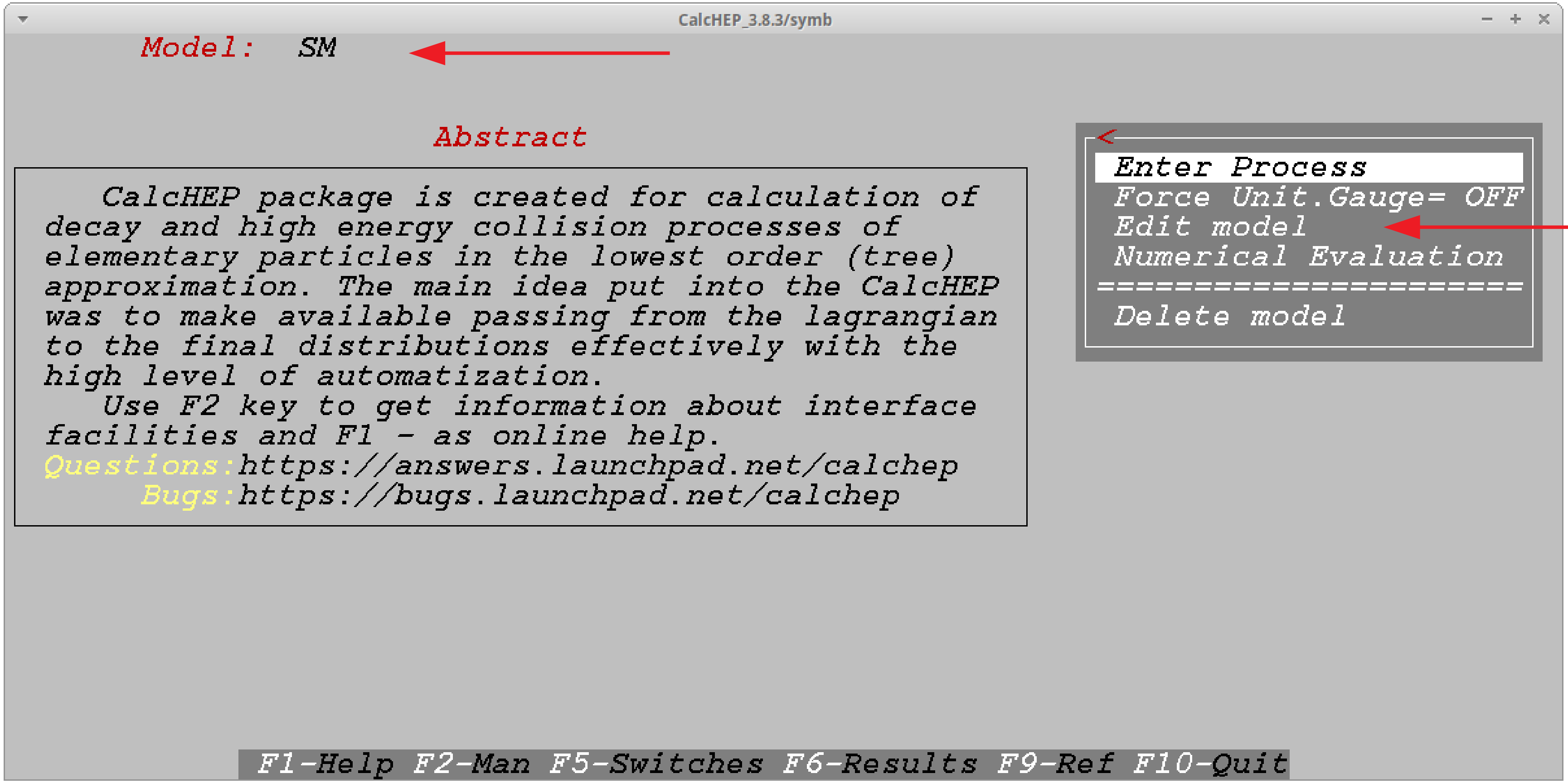
Models

Starting CalcHep

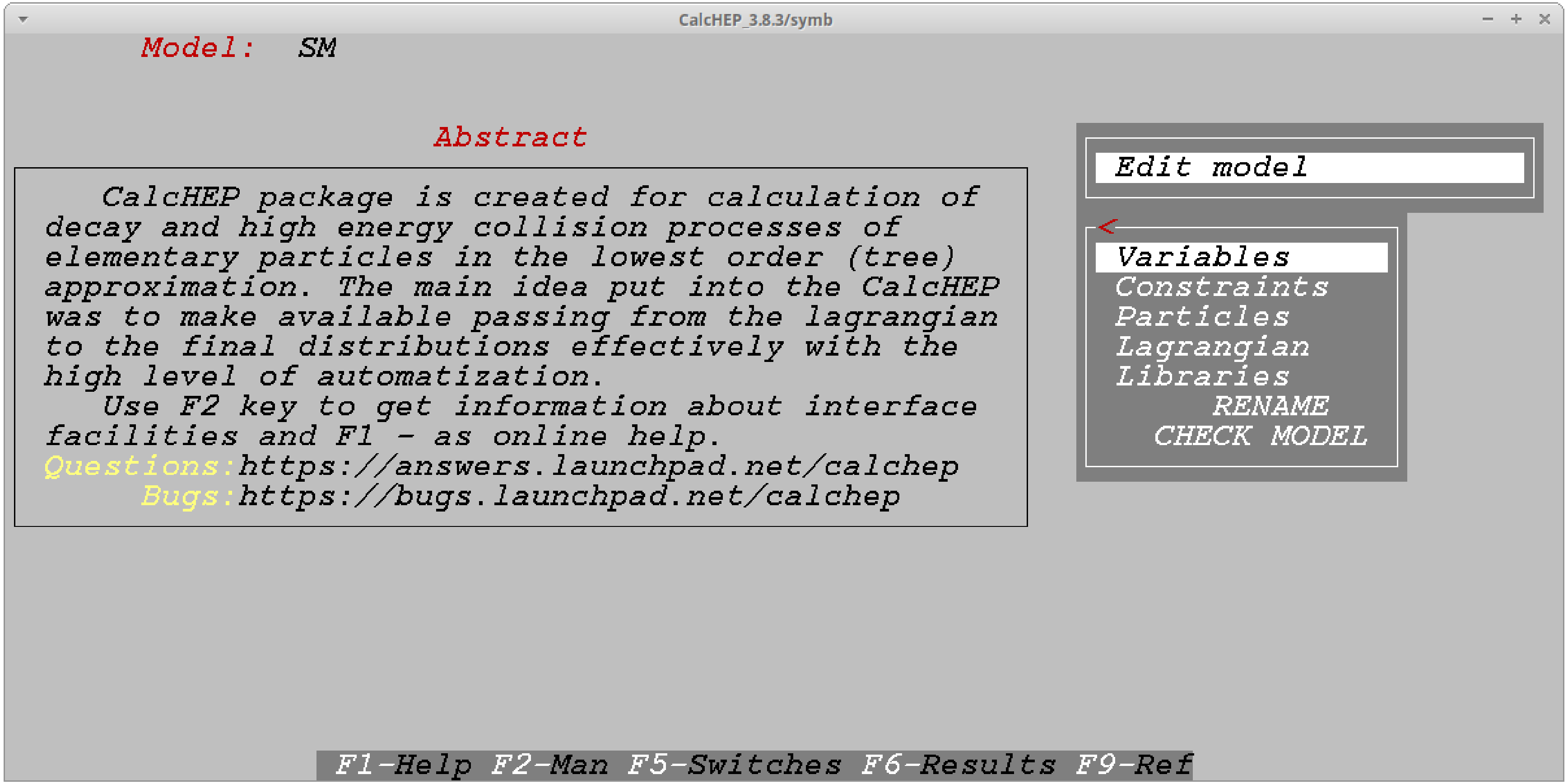




Initial Menu



Models Structure



Variables

CalcHEP_3.8.3/symb

Variables

Clr Del Size Read ErrMes

Name	Value	Comment
EE	0.31333	Electromagnetic coupling constant (<->1/128)
GG	1.117	Strong coupling constant (Z point) (PDG-94)
SW	0.474	sin of the Weinberg angle 0.474 - "on-shell",4
Q	100	Scale of effective running masses
MW	80.385	W boson mass
Mtp	172.5	Top quark pole mass
McMc	1.23	Mc(Mc) MS-BAR
MbMb	4.25	Mb(Mb) MS-BAR
alphaSMZ	0.1184	Srtong alpha(MZ)
Ml	1.777	mass of tau-lepton
Mh	125	mass of Higgs

F1 F2 Xgoto Ygoto Find Write

Constraints

CalcHEP_3.8.3/symb

Constraints

Clr Del Size Read ErrMes

```
 Name   |> Expression
CW      |sqrt(1-SW^2) % cos of the Weinberg angle
GF      |EE^2/(2*SW*MW)^2/Sqrt2 %  experimental value 1.166E-5 [1/GeV^2]
MZ      |MW/CW % Z boson mass
LamQCD  |initQCD5(alphaSMZ, McMc, MbMb, Mtp)
Mb      |MbEff(Q)
Mc      |McEff(Q)
Ms      |MqEff(0.096, Q) % s-quark effective mass  via 2MeV running one
B00000  |1-2*SW^2
B00001  |1-4*SW^2+4*SW^4
```

F1 F2 Xgoto Ygoto Find Write

Particles

CalcHEP_3.8.3/symb

Particles

Clr Del Size Read ErrMes

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	ne	Ne	12	1	0	0	1	L	\nu^e
electron	e	E	11	1	0	0	1		e
mu-neutrino	nm	Nm	14	1	0	0	1	L	\nu^\mu
muon	m	M	13	1	0	0	1		\mu
tau-neutrino	nl	Nl	16	1	0	0	1	L	\nu^\tau
tau-lepton	l	L	15	1	Ml	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	Mtp	!wt	3		t
b-quark	b	B	5	1	Mb	0	3		b
Higgs	h	h	25	0	Mh	!wh	1		h

F1 F2 Xgoto Ygoto Find Write

Width automatically calculated.

Lagrangian

CalcHEP_3.8.3/symb

Lagrangian 29

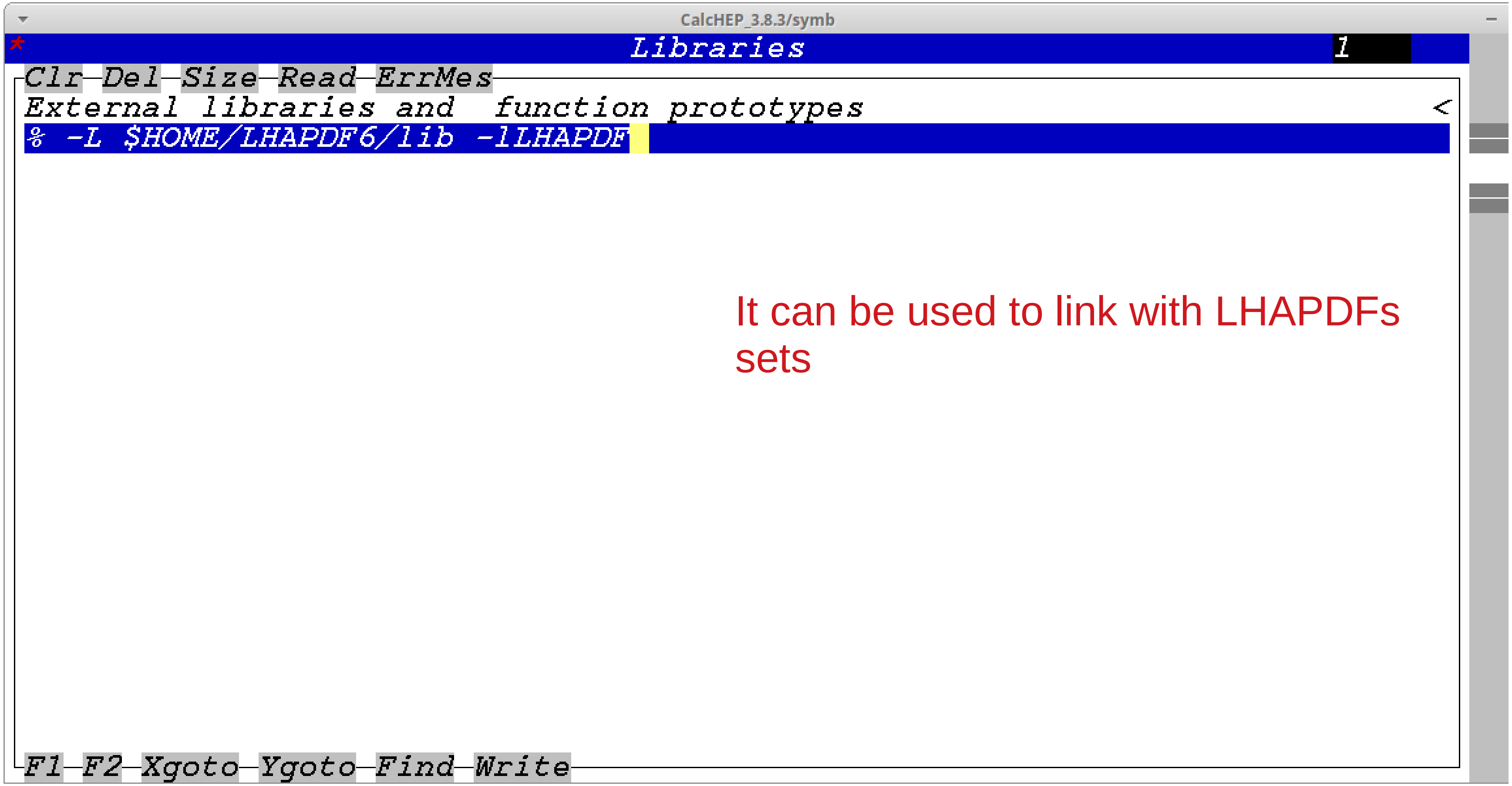
Clr Del Size Read ErrMes

P1	P2	P3	P4	> Factor	</> d
C	c	h		-EE*Mc/(2*MW*SW)	1
C	s	W+		EE*Sqrt2/(4*SW)	G(m
C	s	W+.f		-i*EE*Sqrt2/(4*MW*SW)	Ms*
D	d	A		-EE/3	G(m
D	d	G		GG	G(m
D	d	Z		EE/(12*CW*SW)	4*S
D	u	W-		EE*Sqrt2/(4*SW)	G(m
E	e	A		-EE	G(m
E	e	Z		EE/(4*CW*SW)	4*S
E	ne	W-		EE*Sqrt2/(4*SW)	G(m
G	G	G		GG	m2.
G.C	G.c	G		GG	m3.
L	l	A		-EE	G(m
L	l	Z		EE/(4*CW*SW)	4*S
L	l	Z.f		i*EE*Ml/(2*MW*SW)	G5
L	l	h		-EE*Ml/(2*MW*SW)	1
L	nl	W-		EE*Sqrt2/(4*SW)	G(m
L	nl	W-.f		i*EE*Ml*Sqrt2/(4*MW*SW)	(1-
M	m	A		-EE	G(m
M	m	Z		EE/(4*CW*SW)	4*S
M	nm	W-		EE*Sqrt2/(4*SW)	G(m

F1 F2 Xgoto Ygoto Find Write

$$L = \frac{e}{\sin\theta_W \cos\theta_W} J_Z^{\mu} Z_{\mu}$$

Libraries

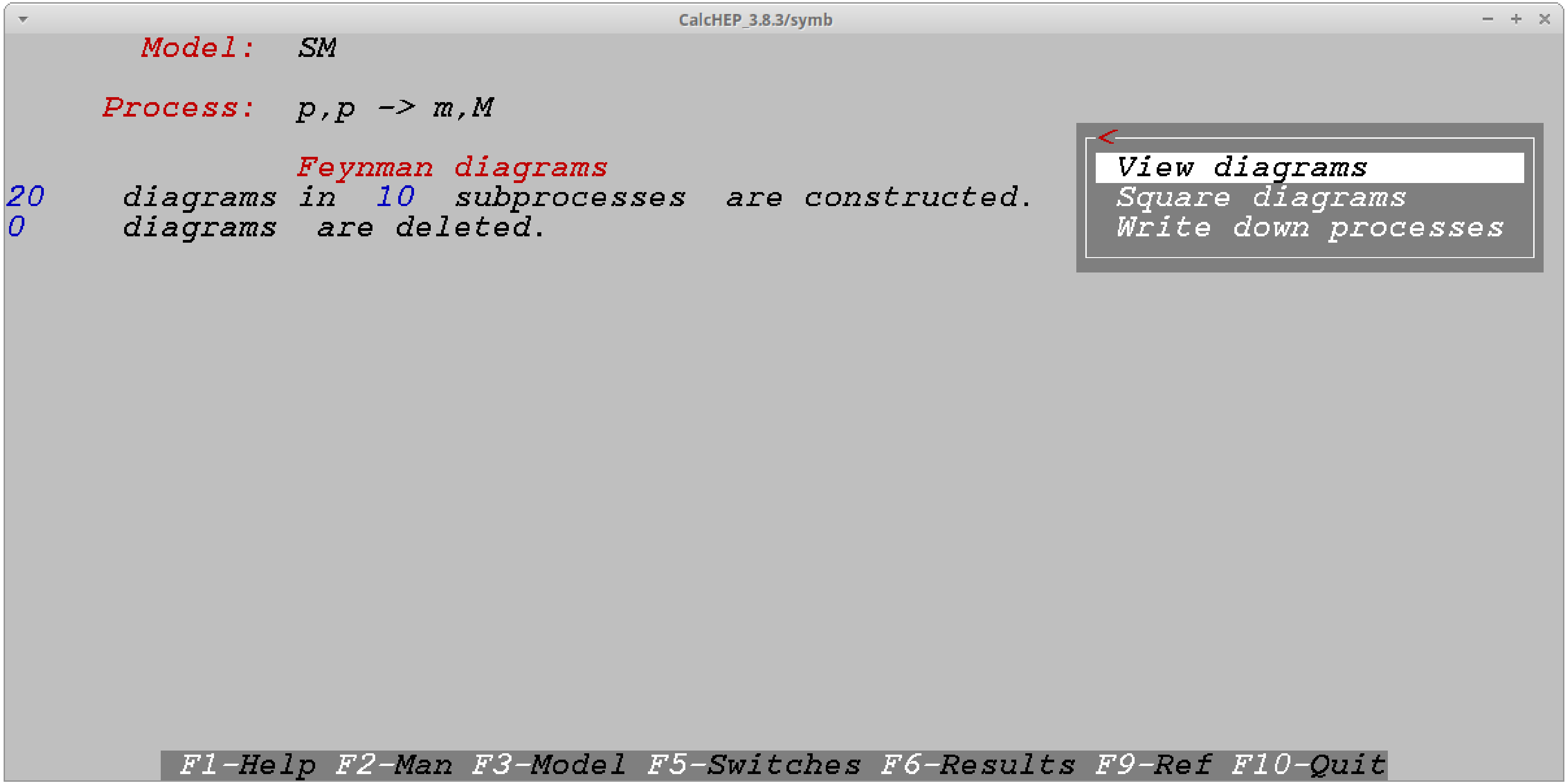


It can be used to link with LHAPDFs sets

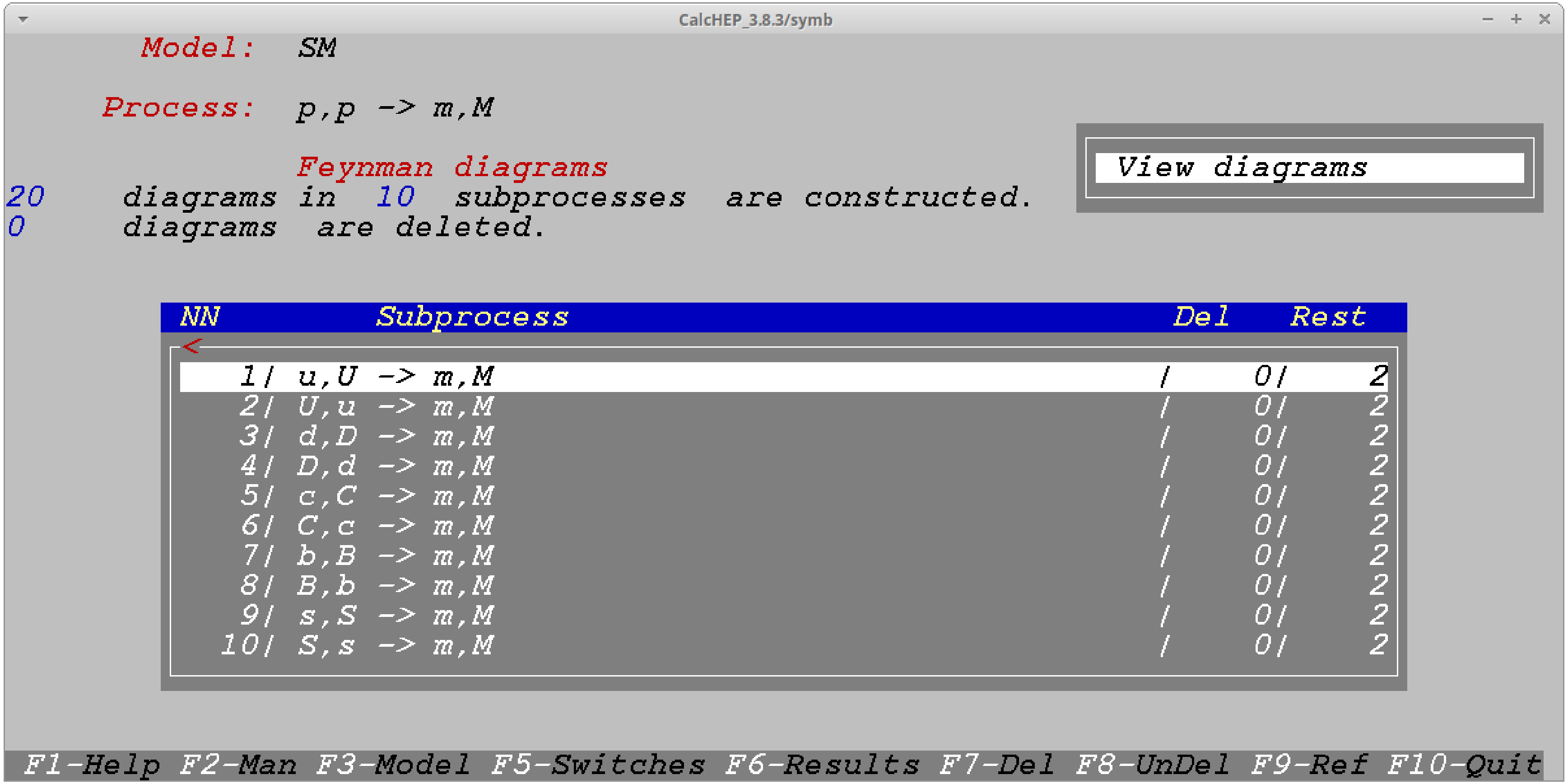
Enter Process

```
CalcHEP_3.8.3/symb
        Model:   SM

              List of particles (antiparticles)

  A(A   )- photon             Z(Z   )- Z boson          G(G   )- gluon
  W+(W-  )- W boson           ne(Ne  )- neutrino        e(E   )- electron
  nm(Nm  )- mu-neutrino       m(M   )- muon             nl(Nl  )- tau-neutrino
  l(L   )- tau-lepton         u(U   )- u-quark          d(D   )- d-quark
  c(C   )- c-quark            s(S   )- s-quark          t(T   )- t-quark
  b(B   )- b-quark            h(h   )- Higgs

Enter  process: p,p -> m,M
composite 'p'  consists of: u,U,d,D,c,C,b,B,s,S,G
Exclude diagrams with
```

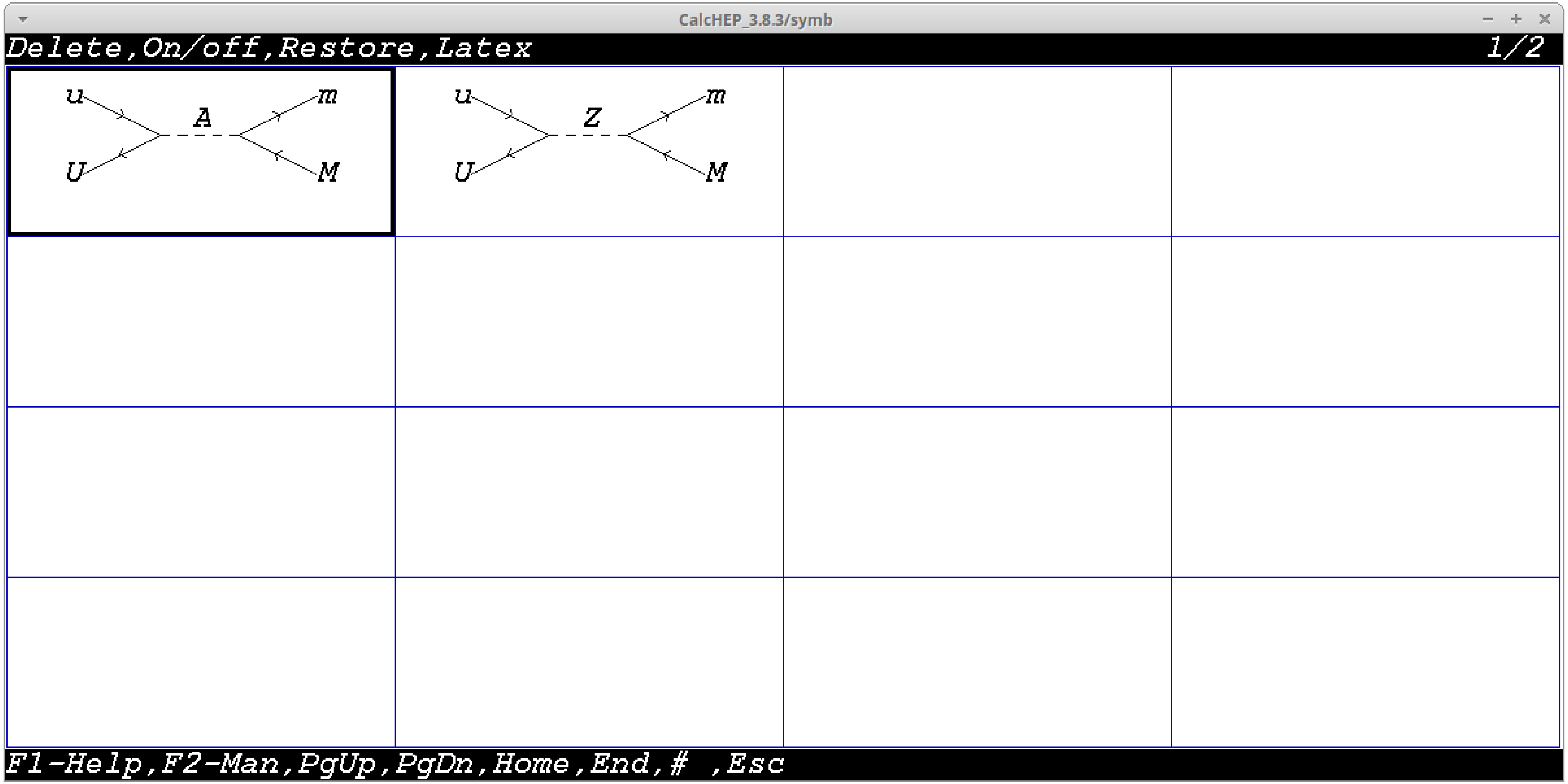
Enter Process



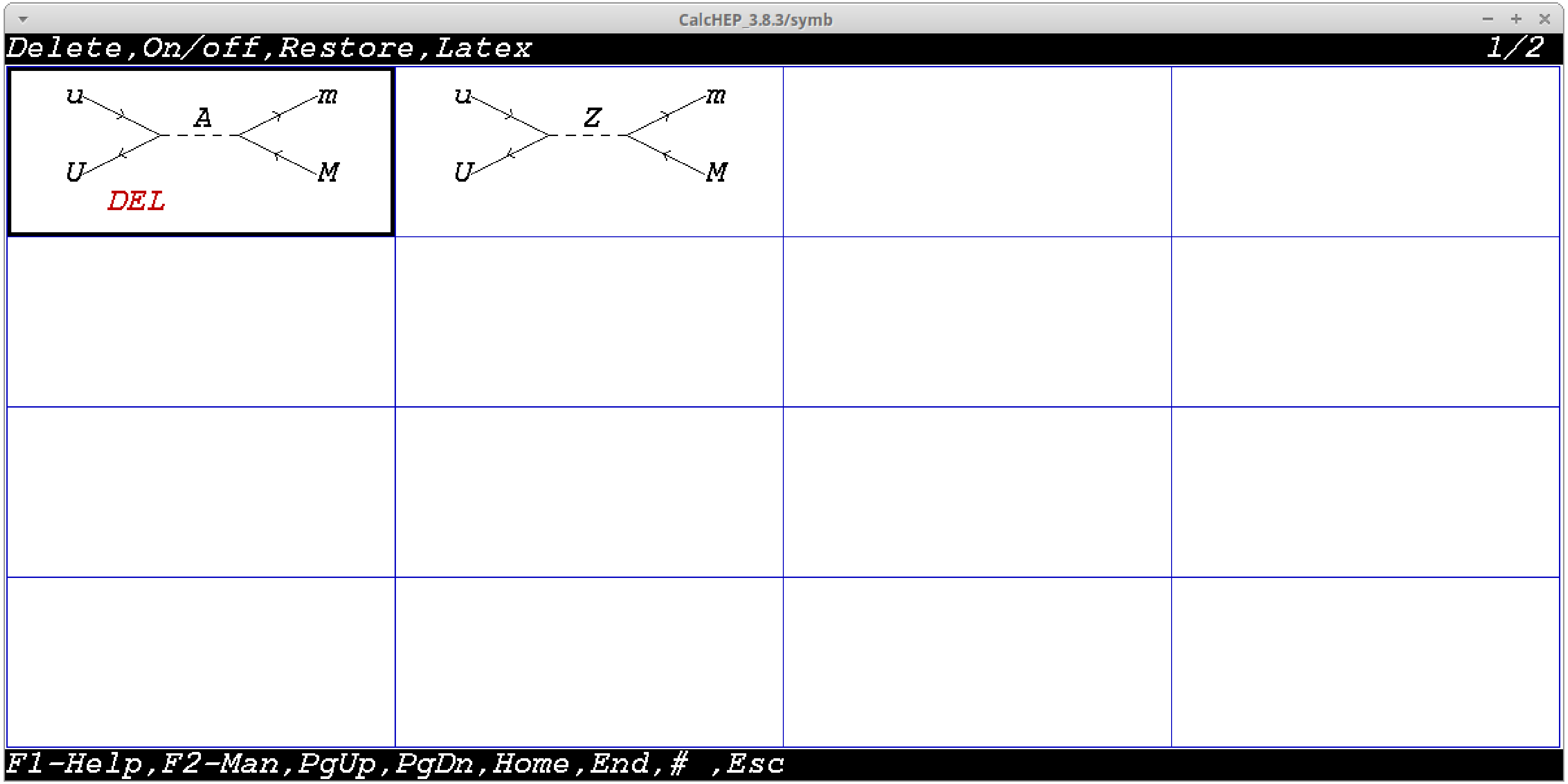
Enter Process



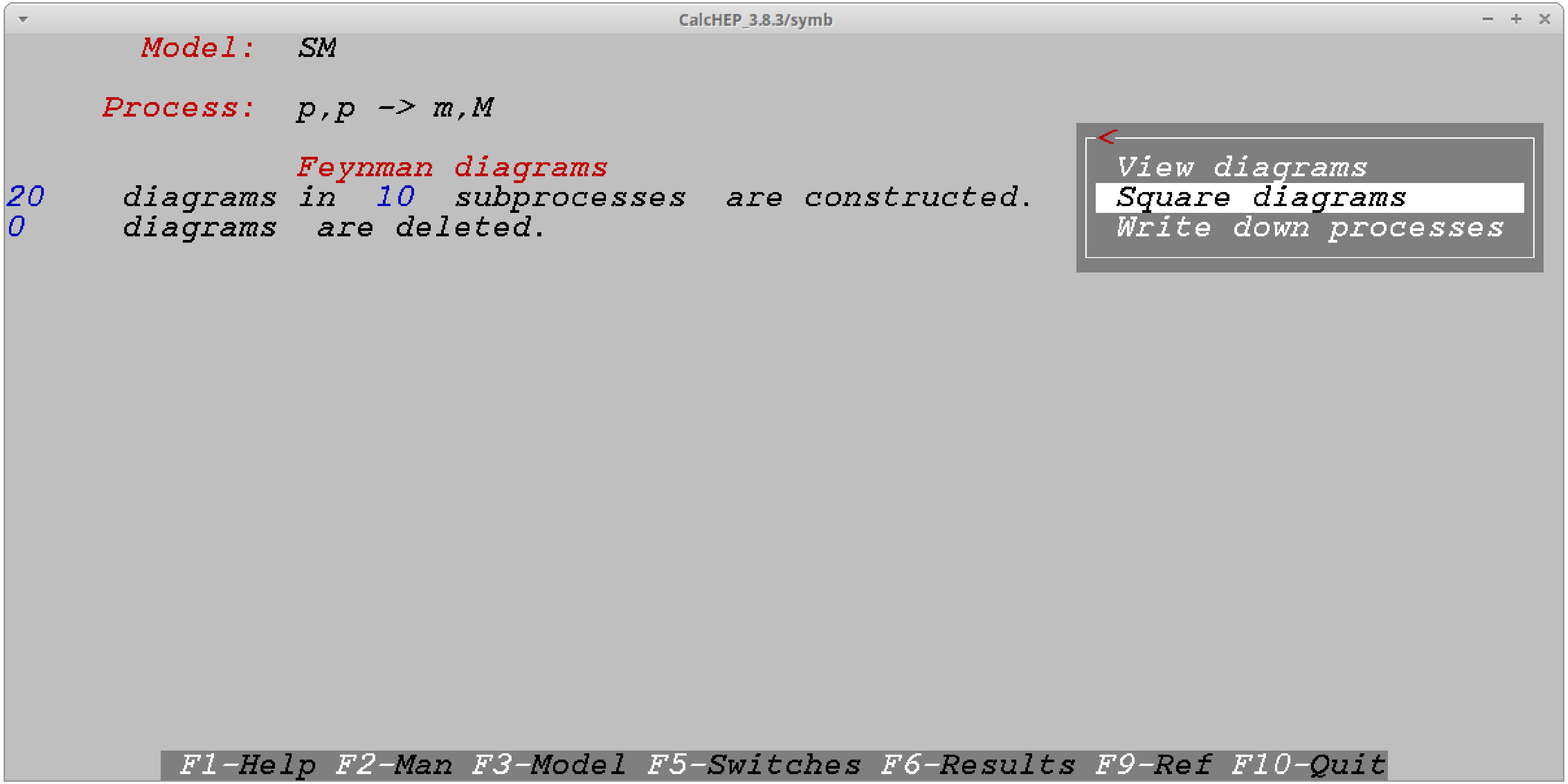
Enter Process



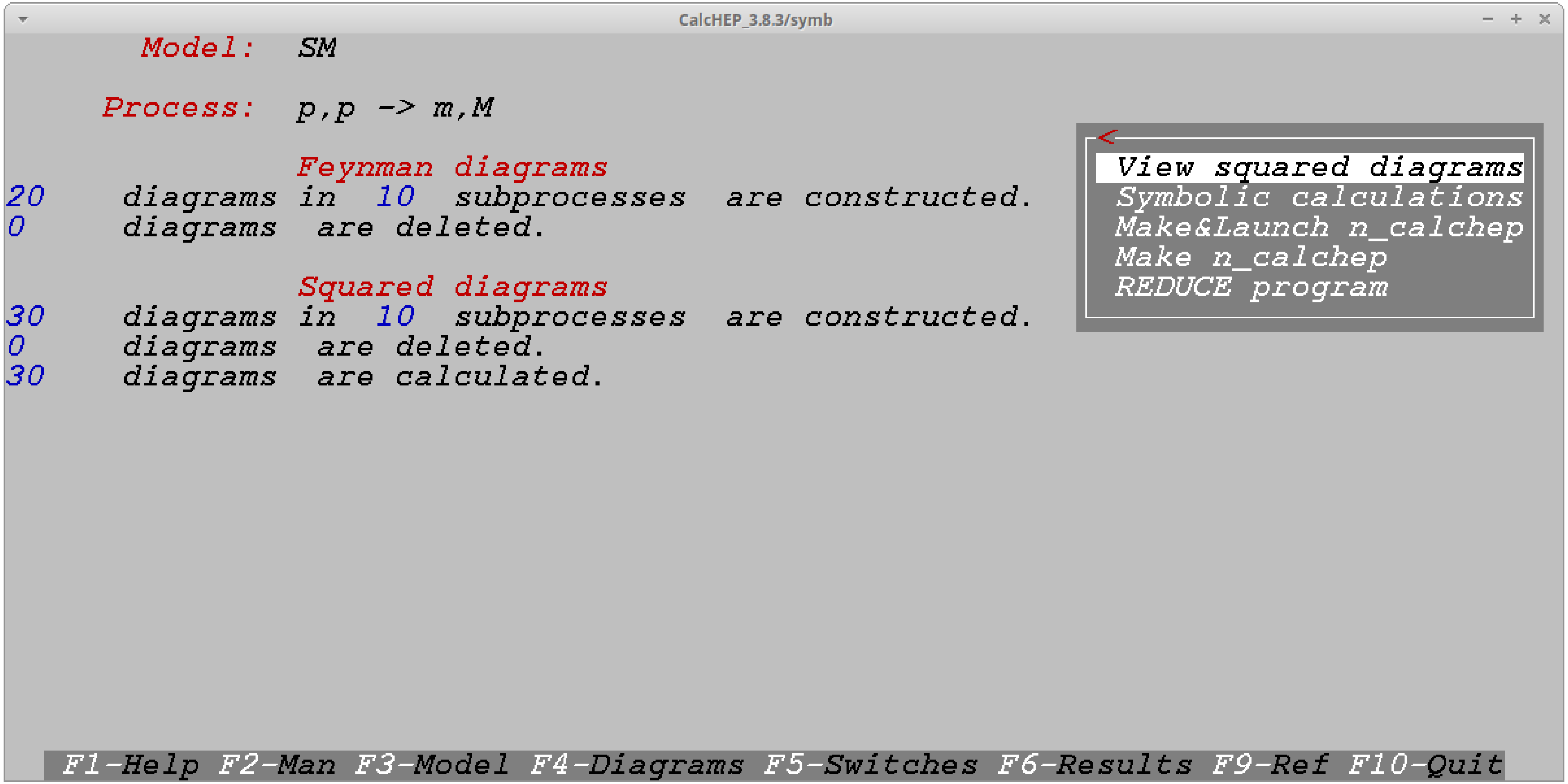
Enter Process



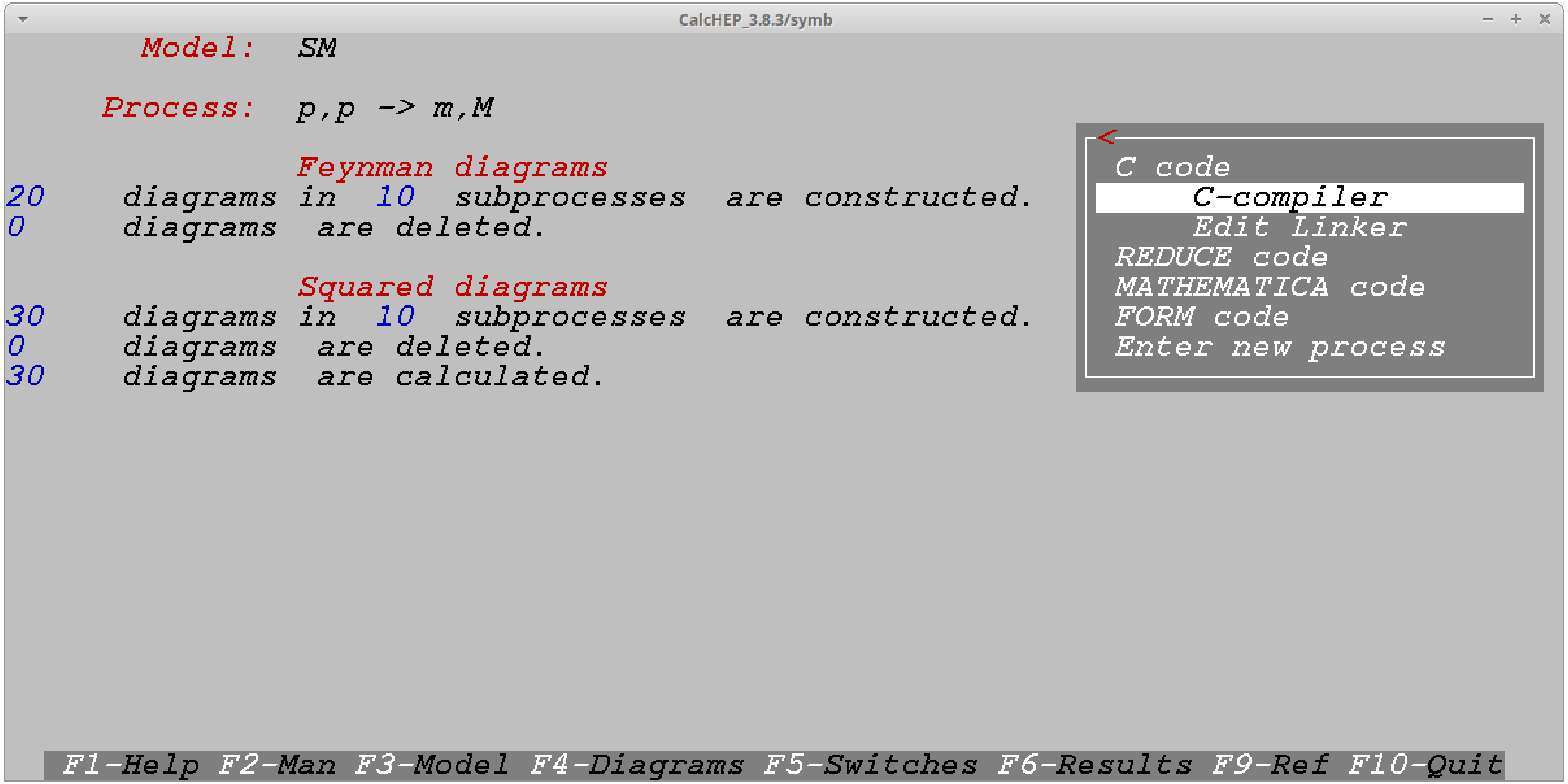
Square Diagrams



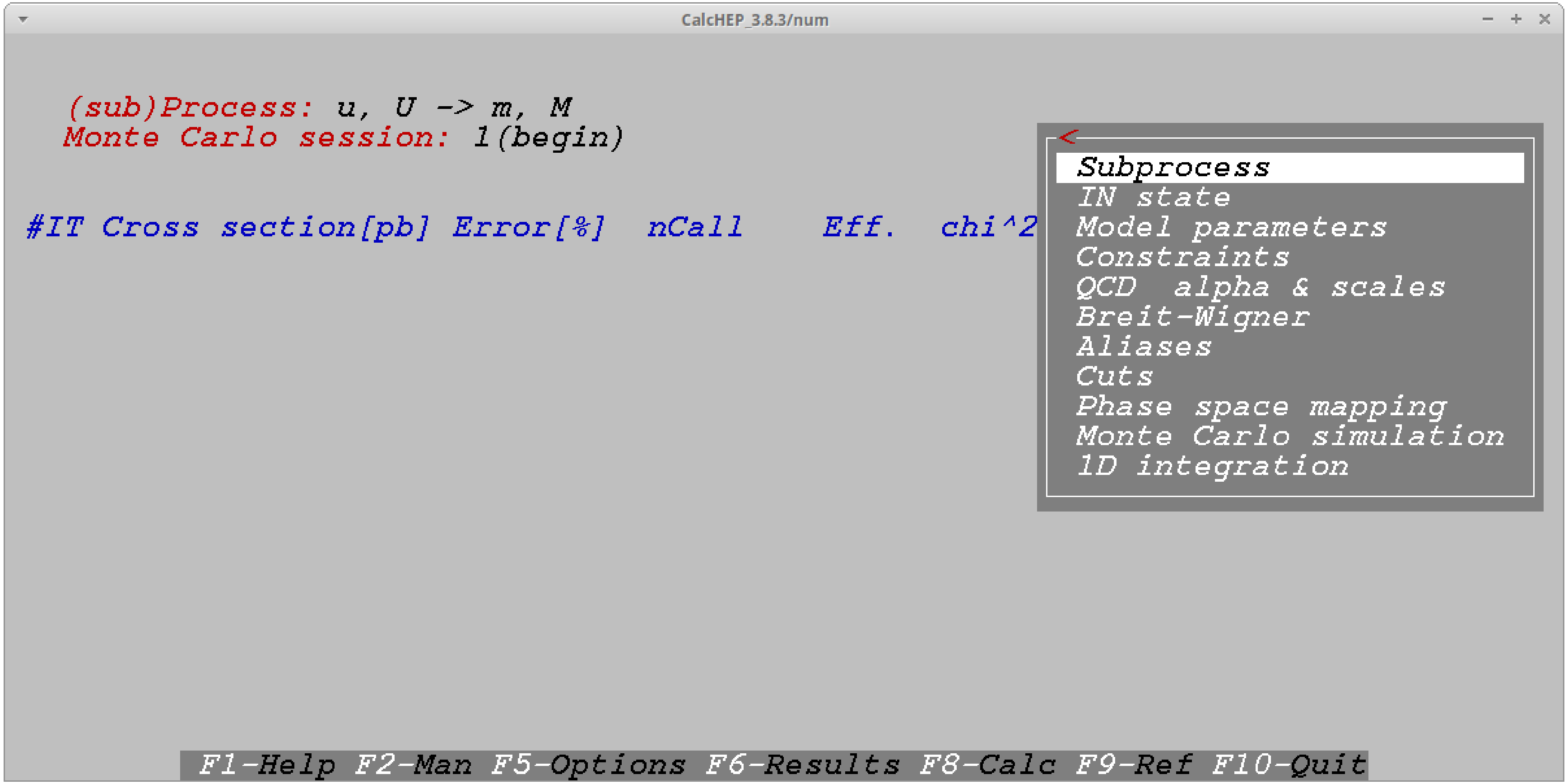
Symbolic Calculation



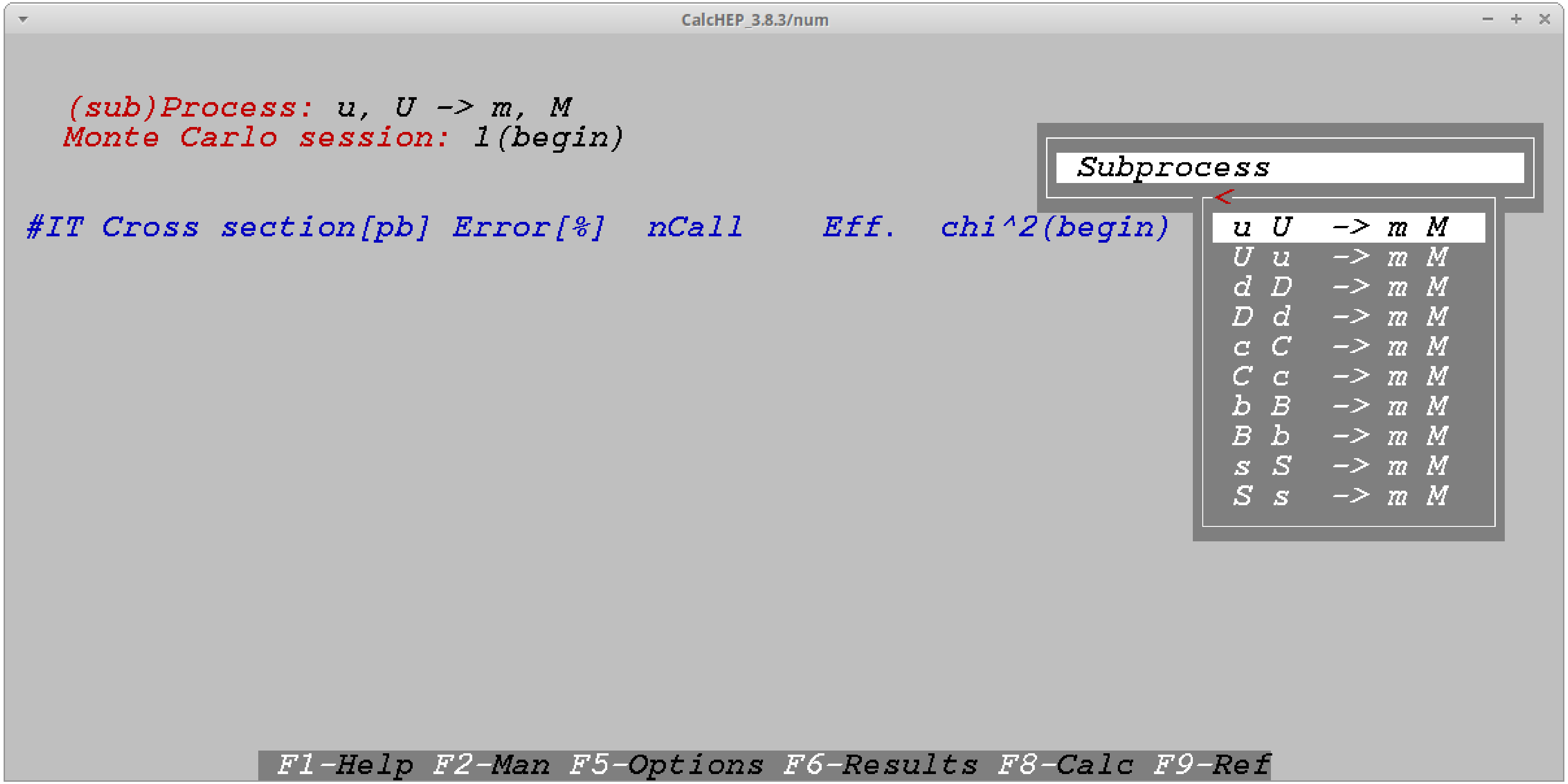
Symbolic Calculation



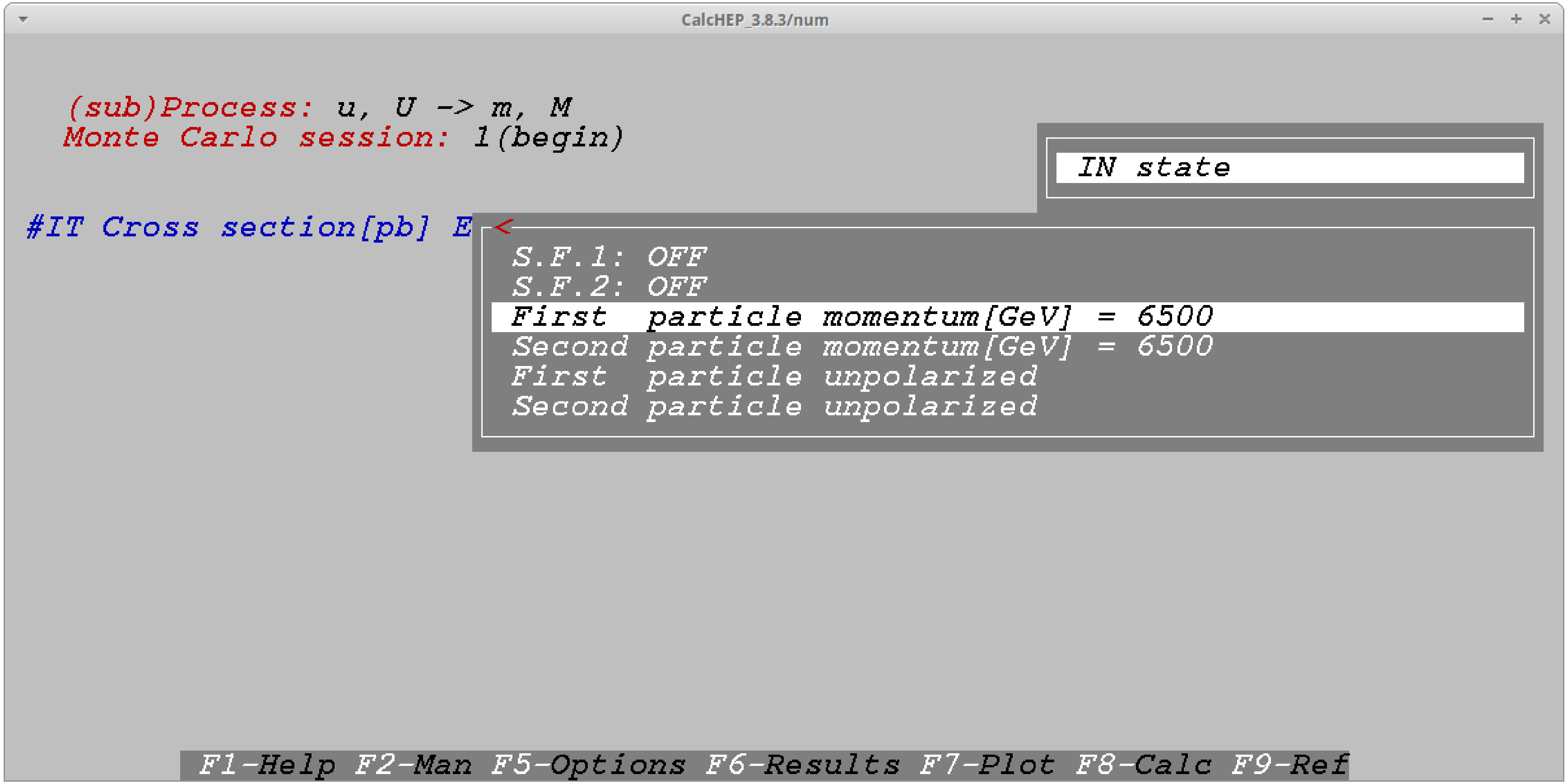
Numerical Calculation



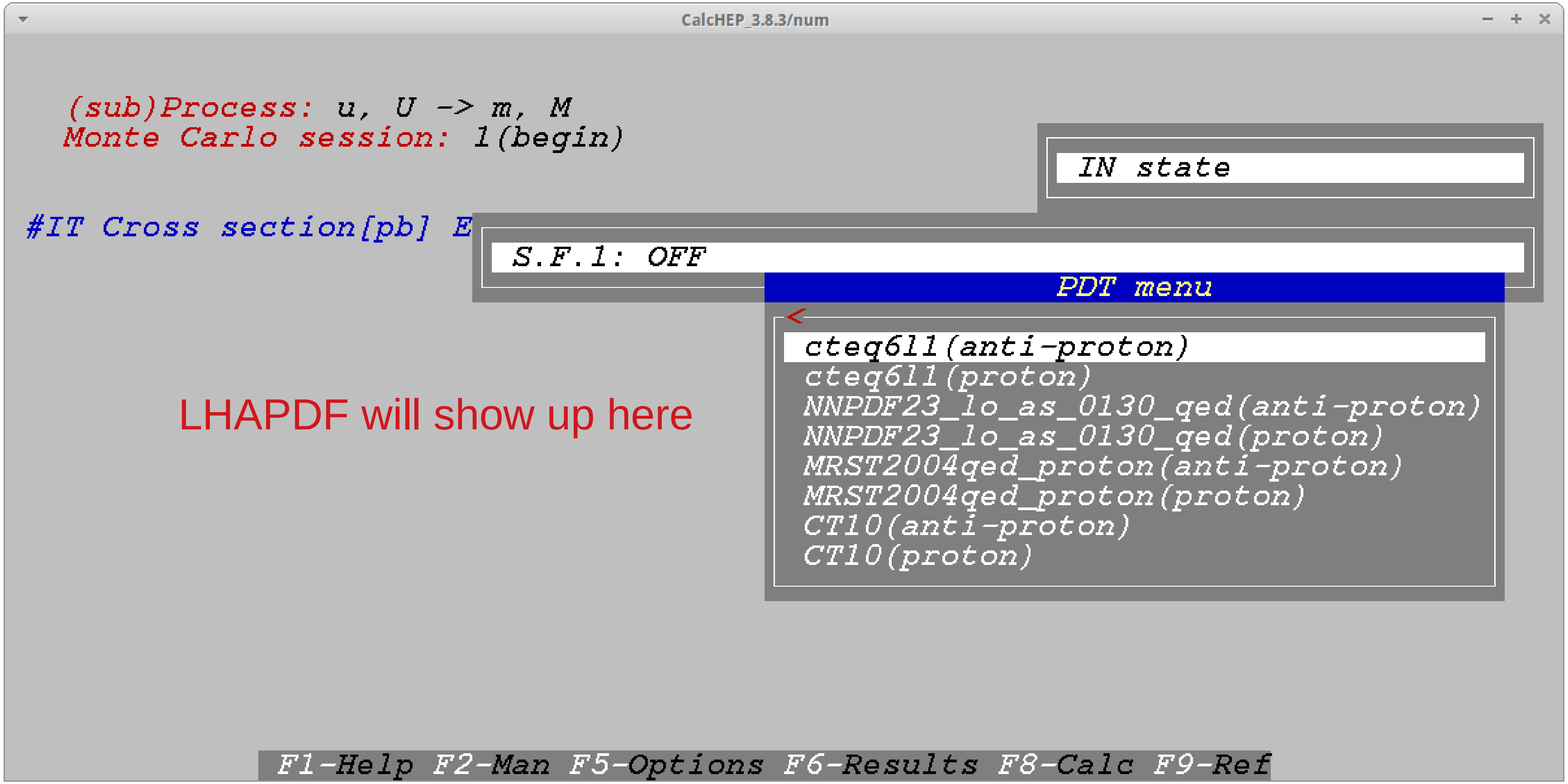
Numerical Calculation



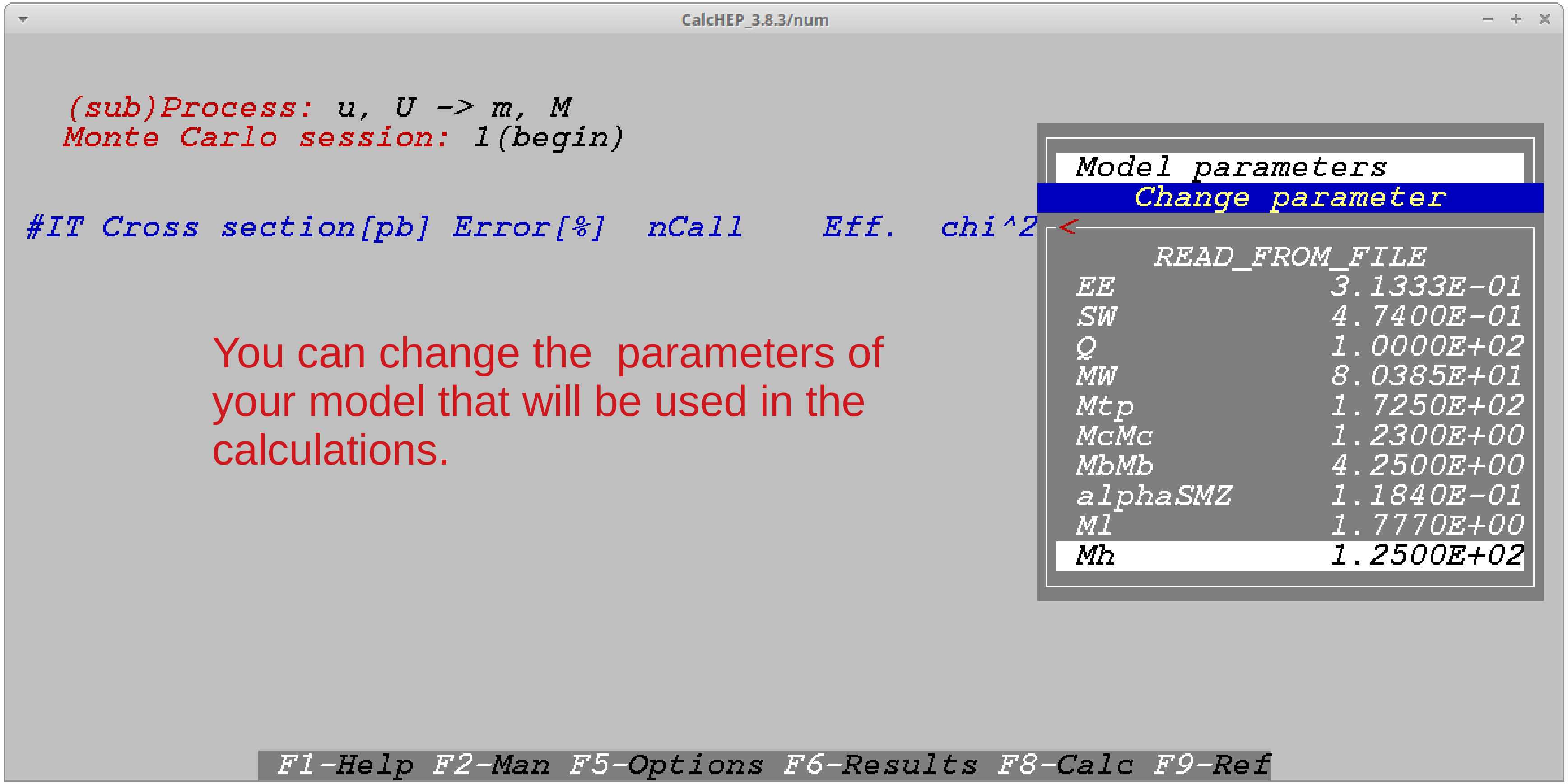
Numerical Calculation



Numerical Calculation

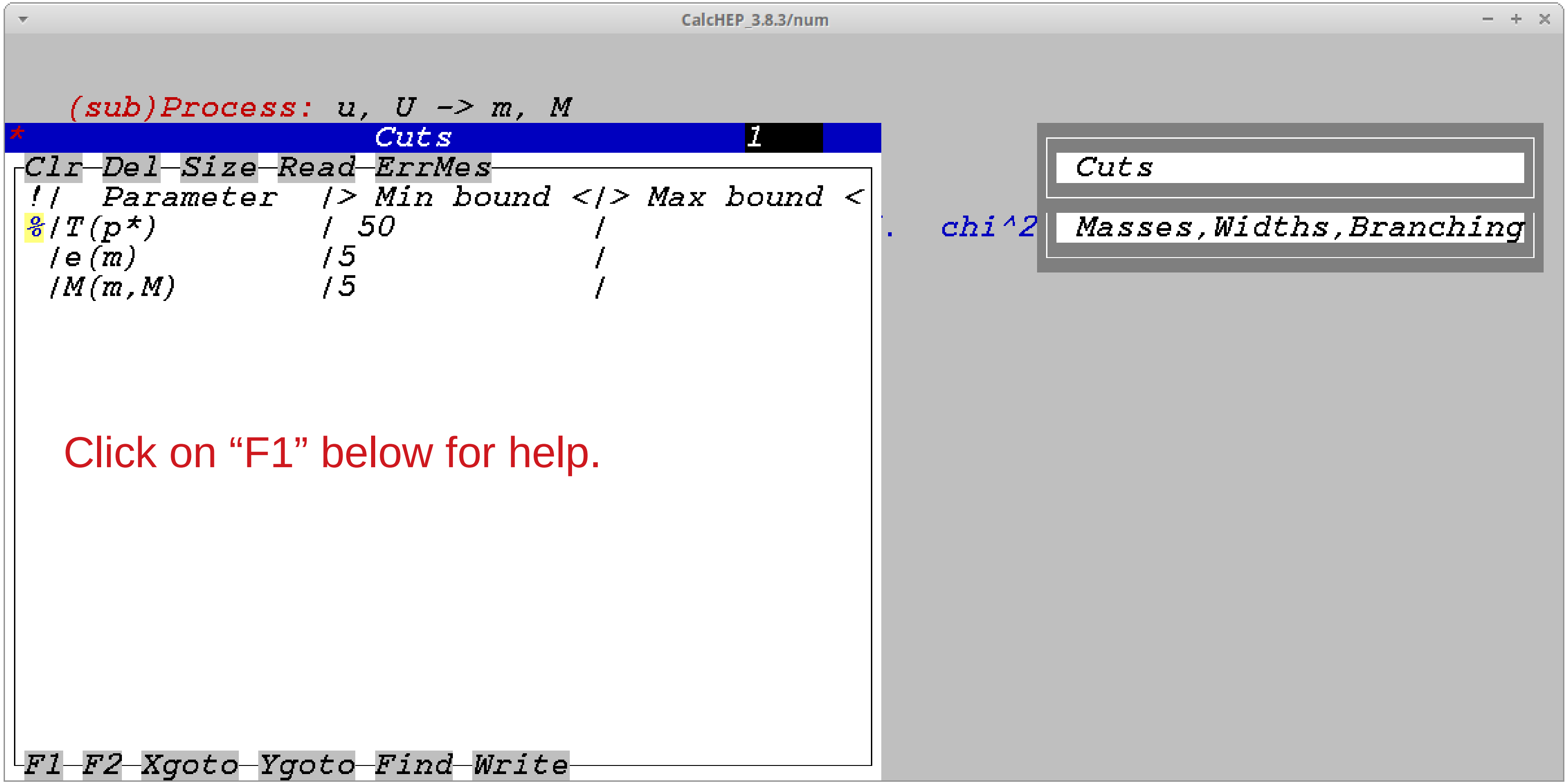


Numerical Calculation



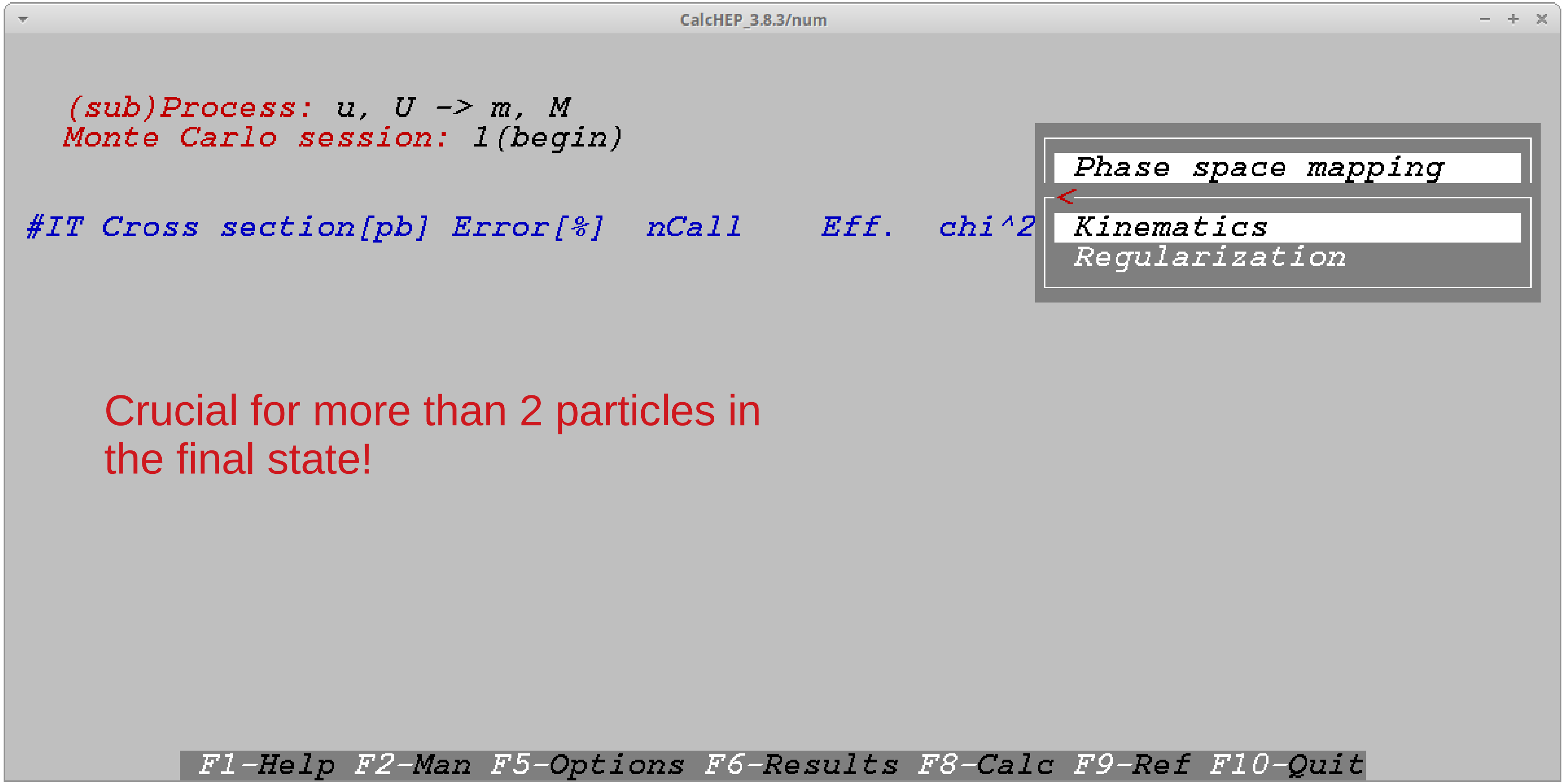
You can change the parameters of your model that will be used in the calculations.

Numerical Calculation



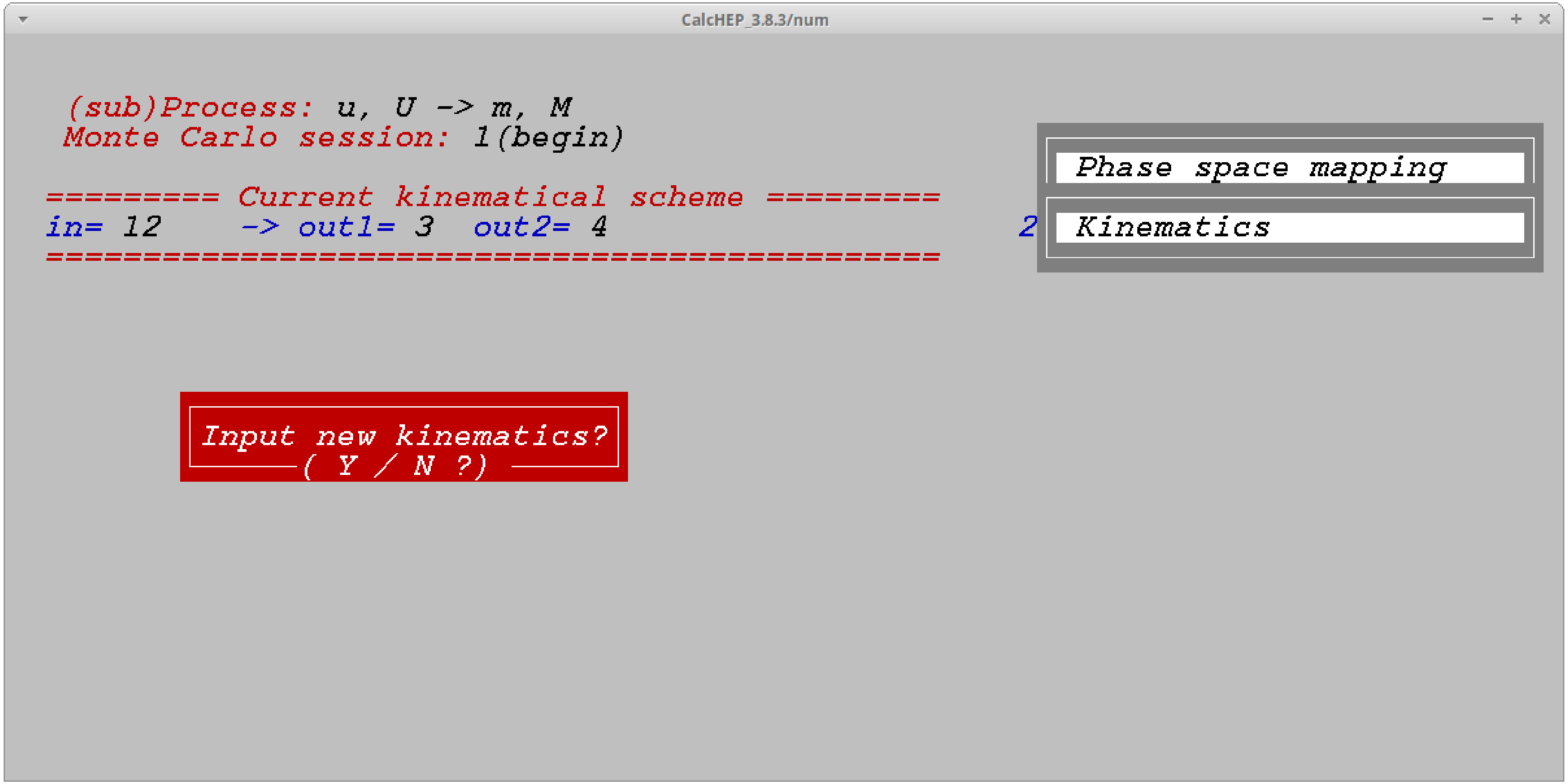
Click on “F1” below for help.

Numerical Calculation



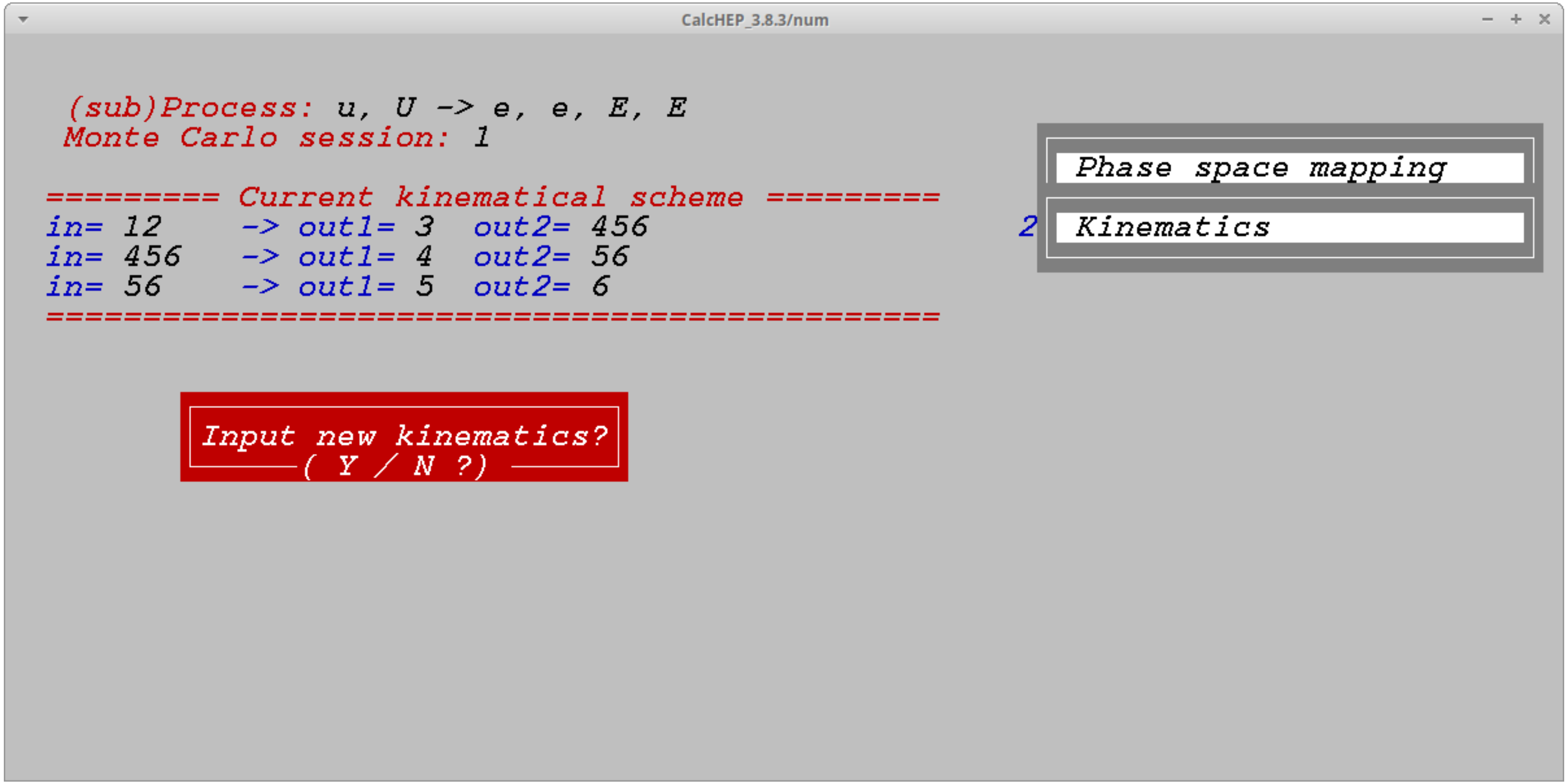
Crucial for more than 2 particles in the final state!

Numerical Calculation



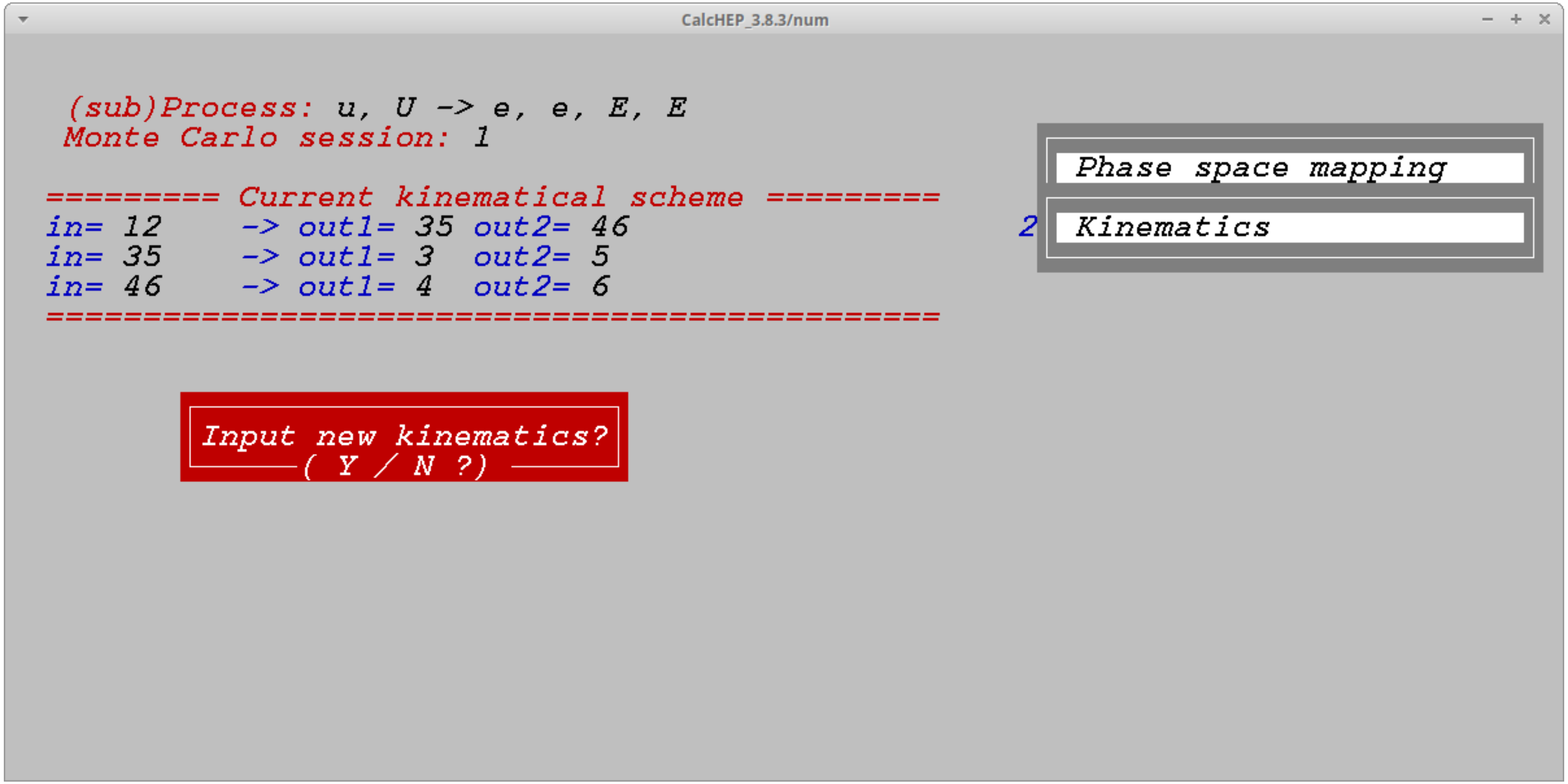
Numerical Calculation

Consider the process *pp* → *ZZ* → 4e

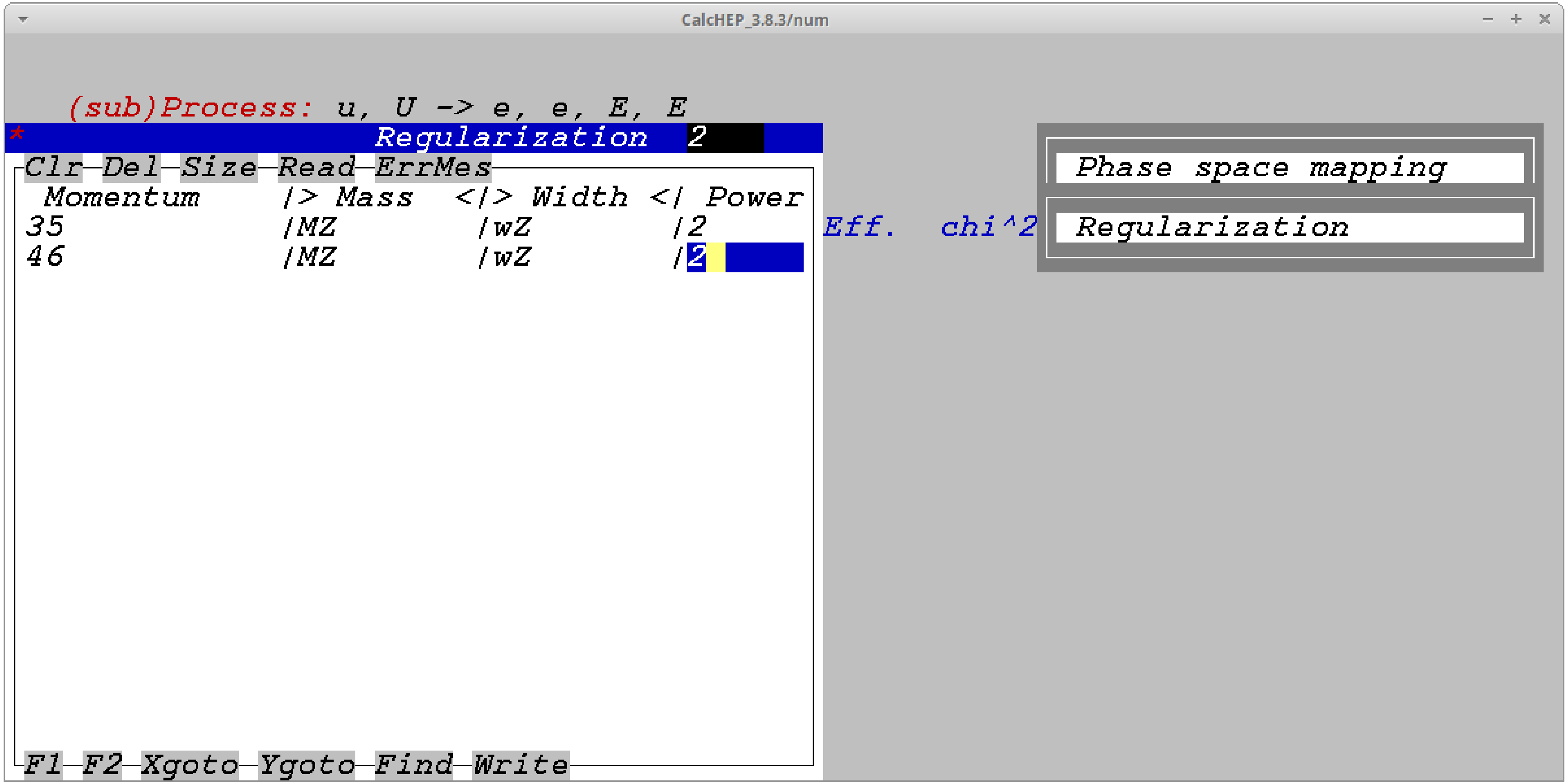


Numerical Calculation

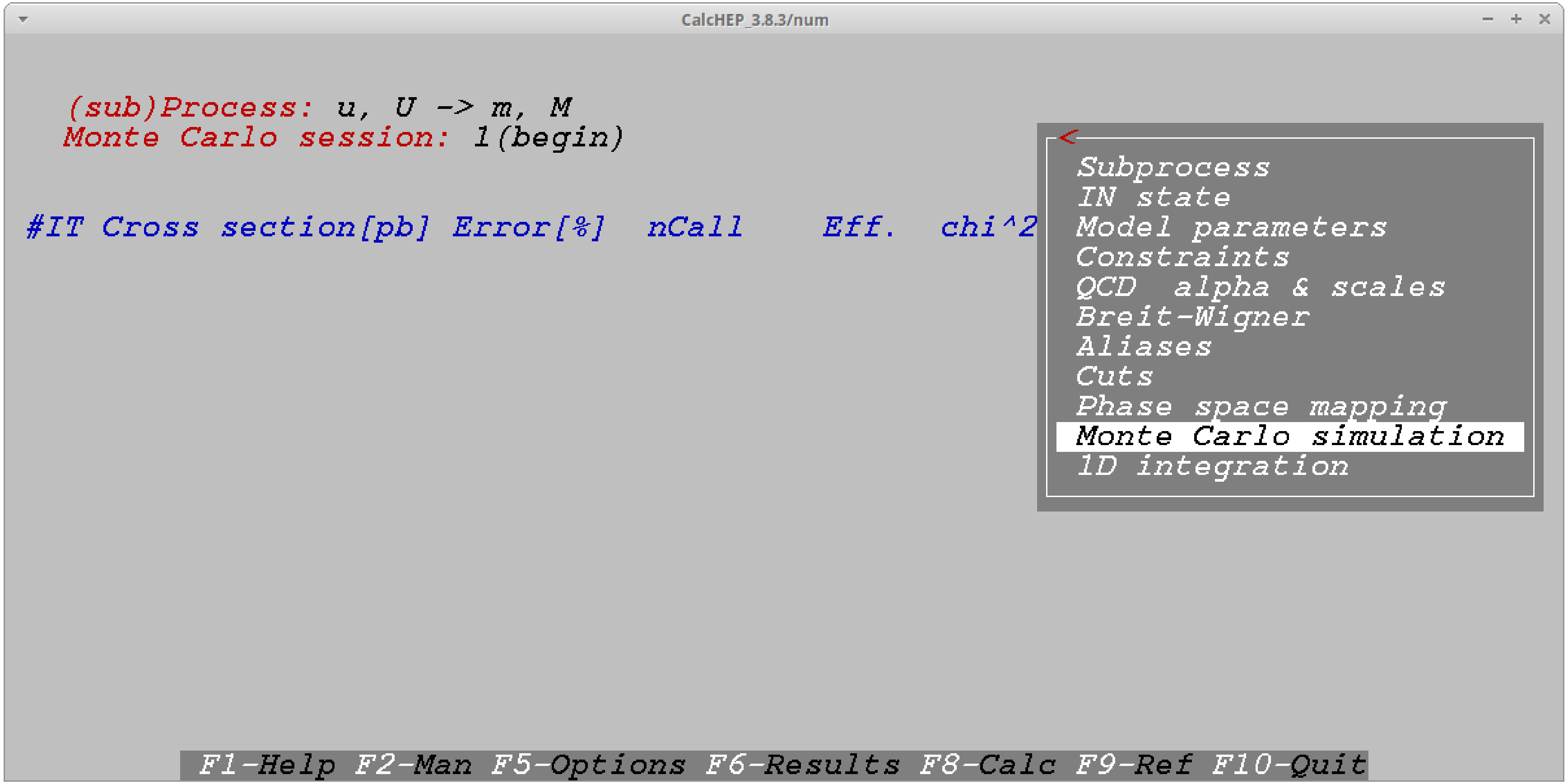
Consider the process *pp* → *ZZ* → 4*e*



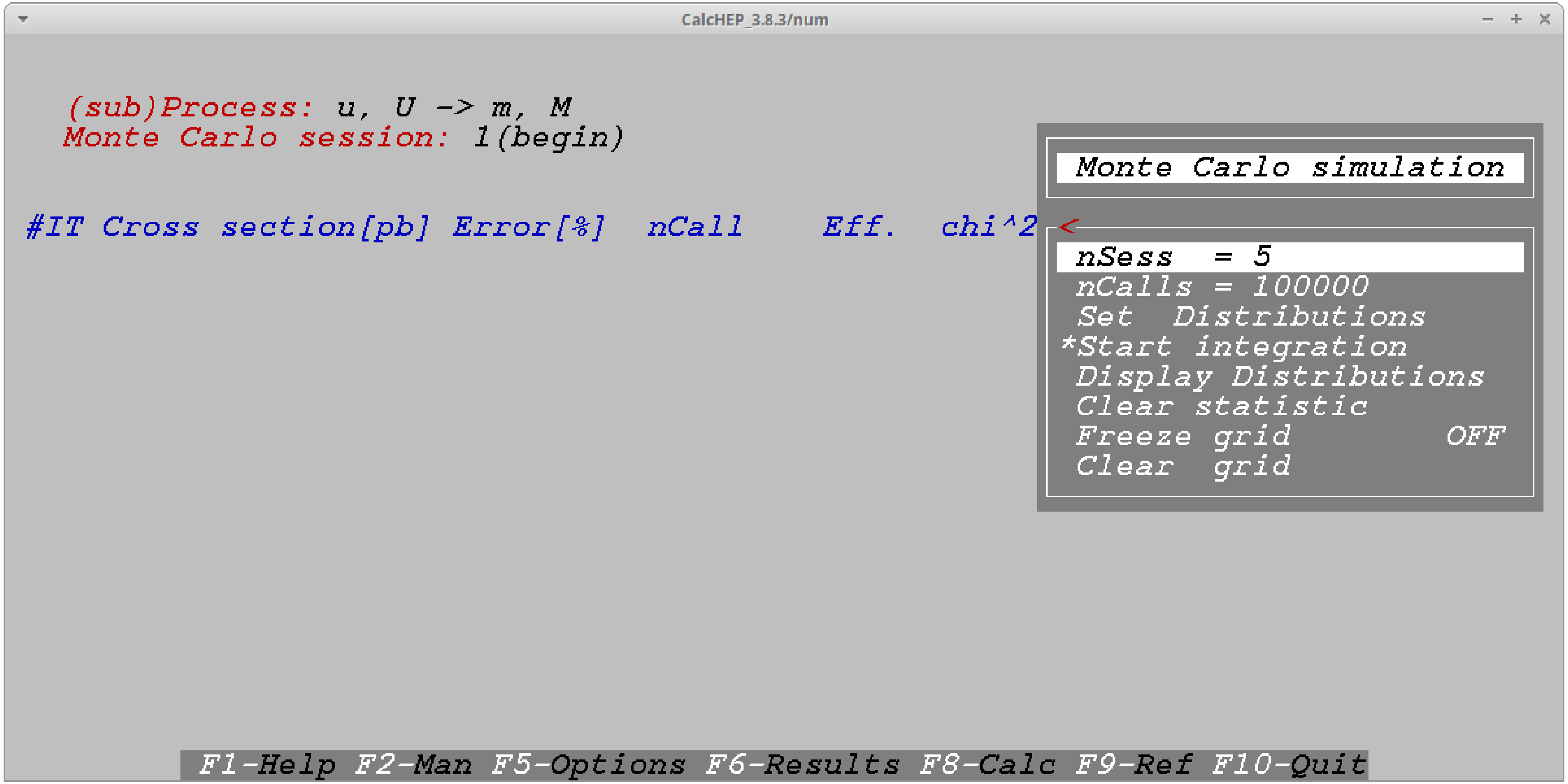
Numerical Calculation



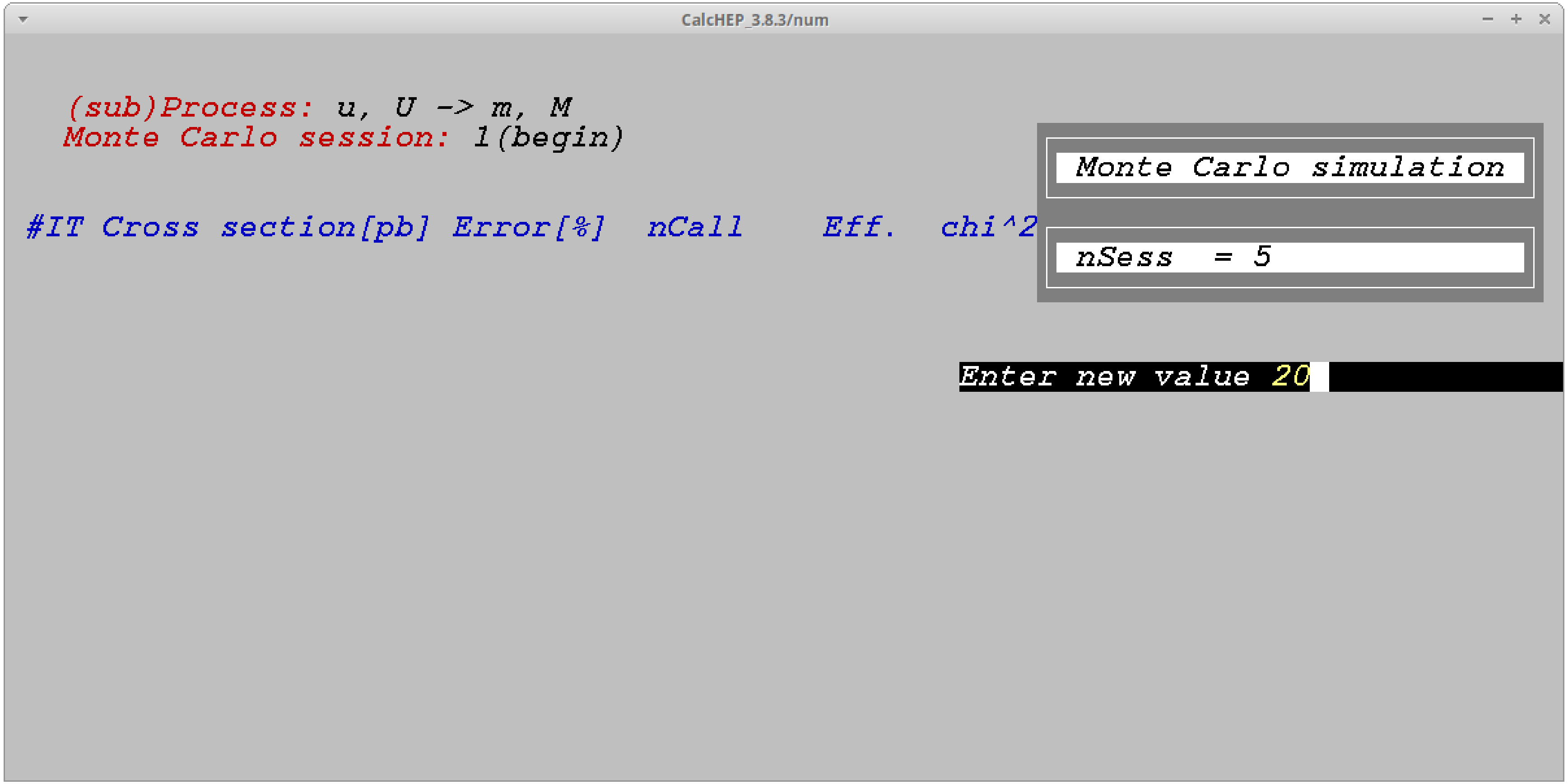
Numerical Calculation



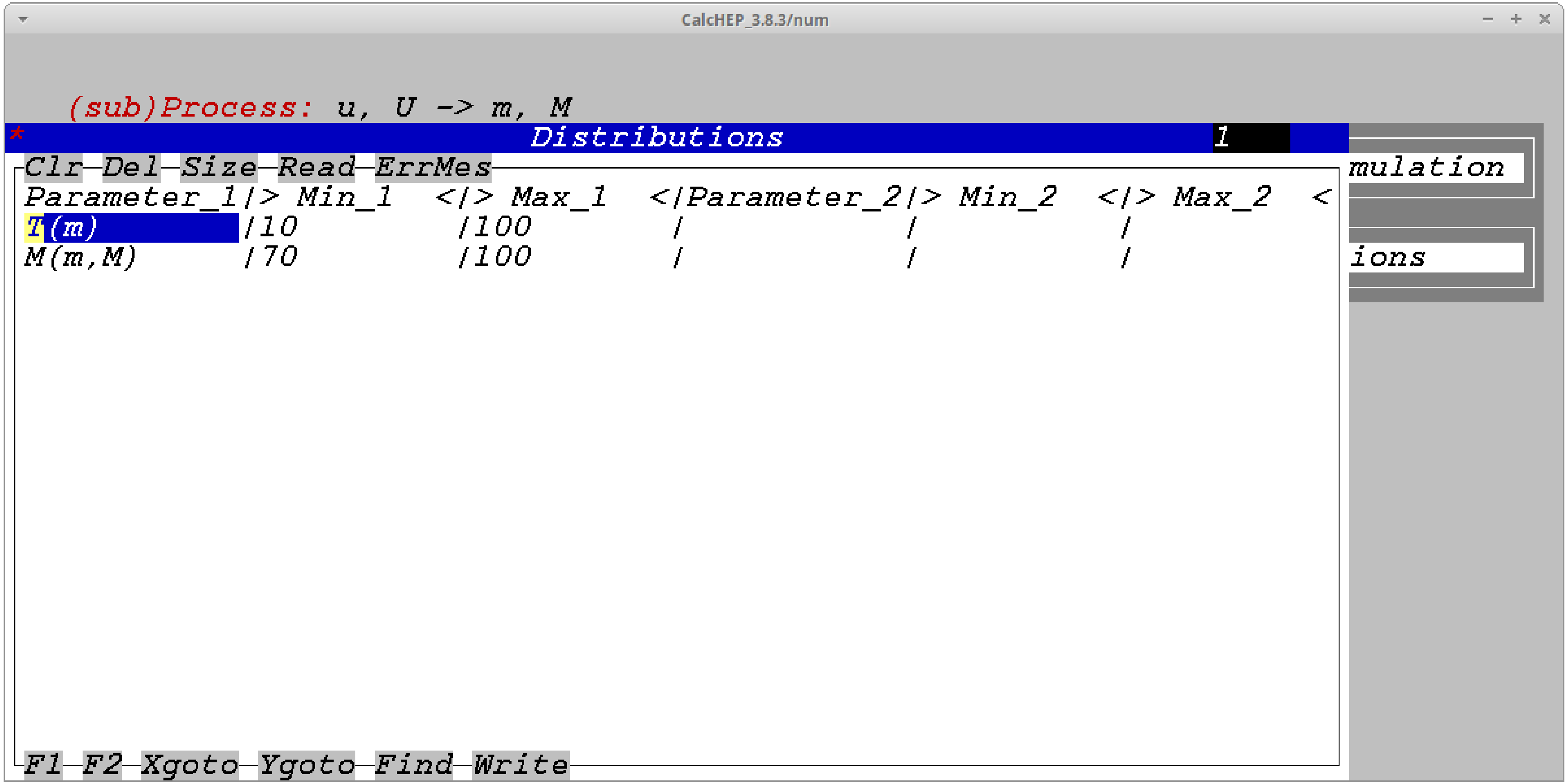
Numerical Calculation



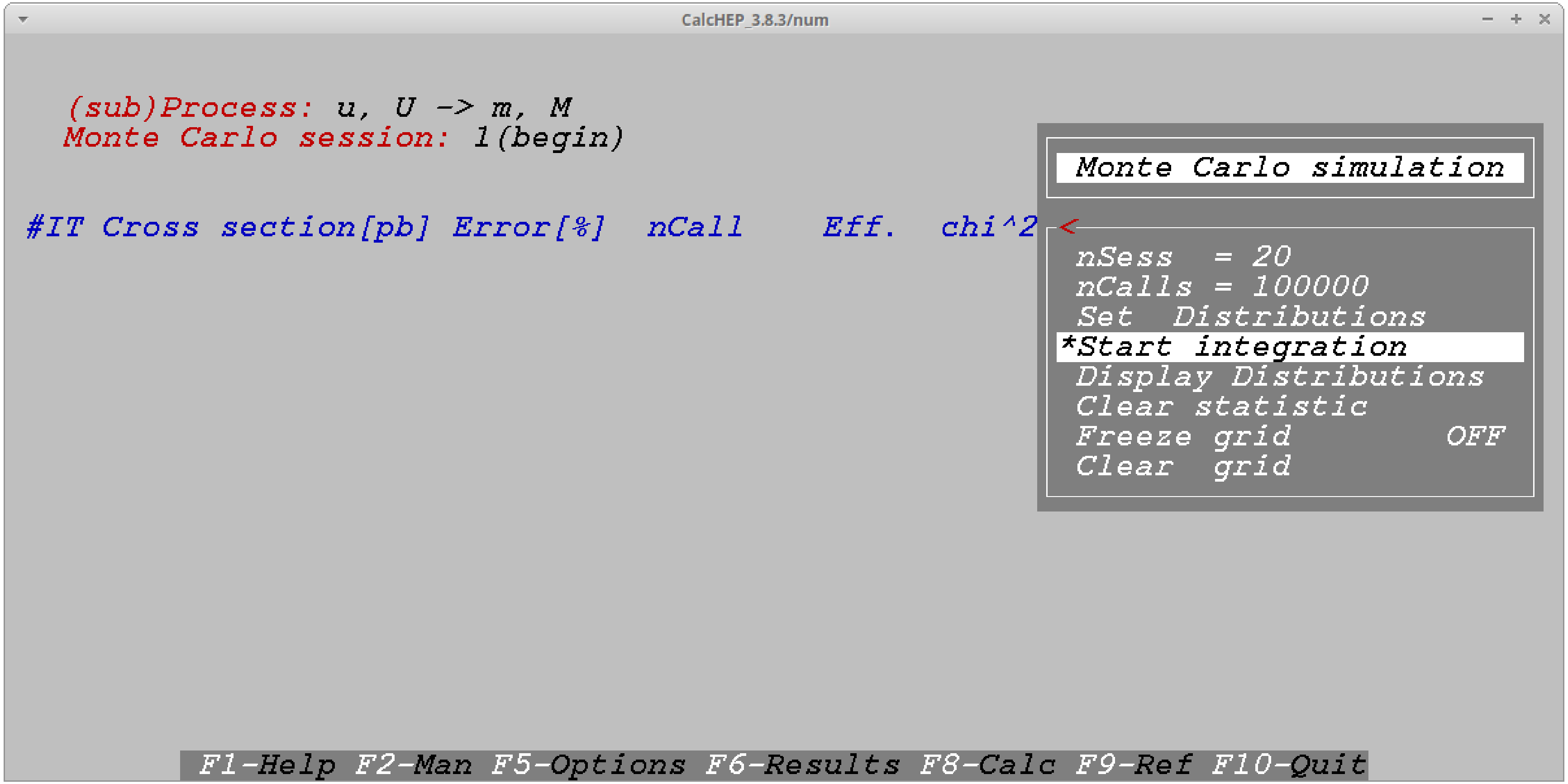
Numerical Calculation



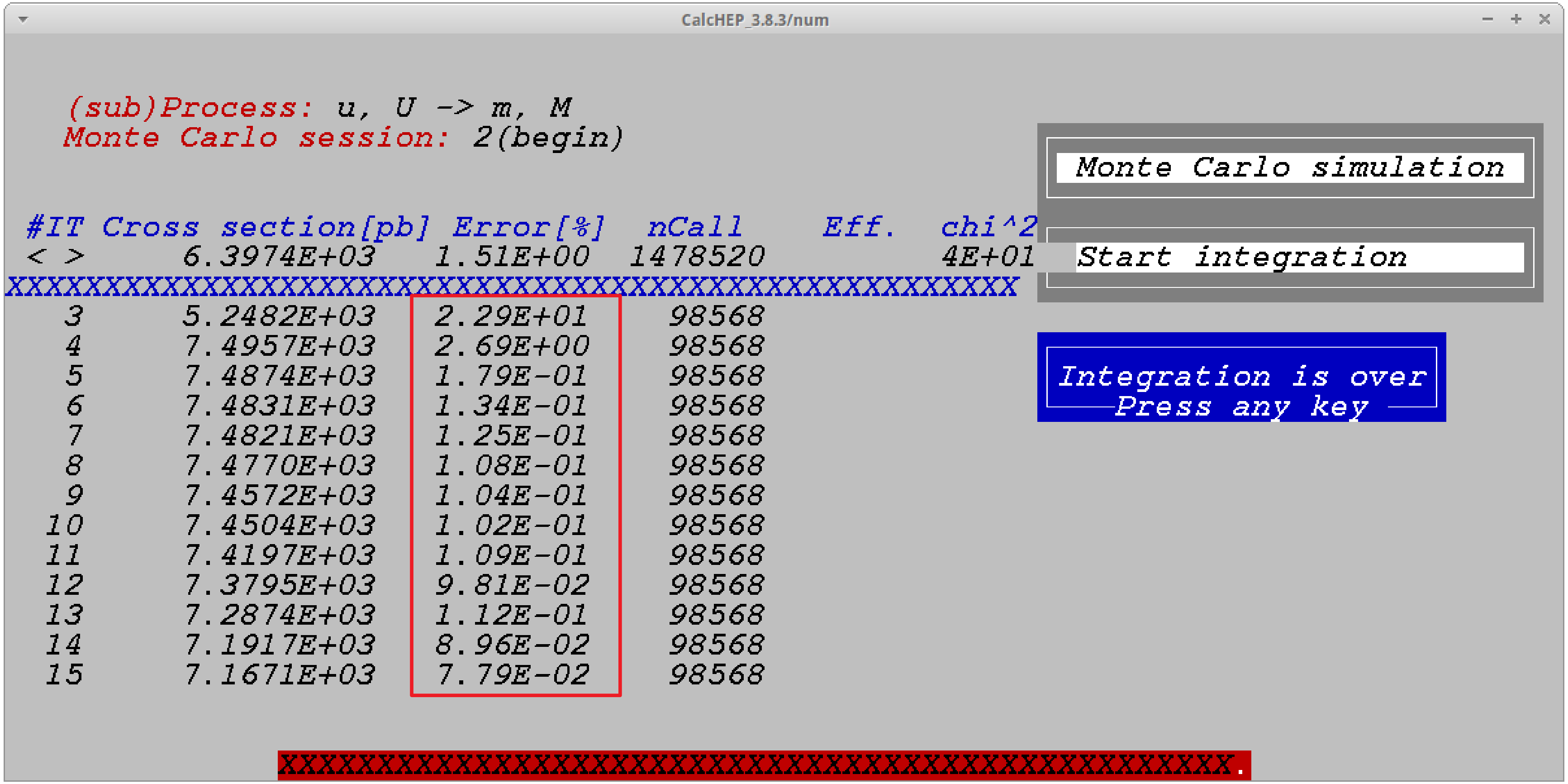
Numerical Calculation



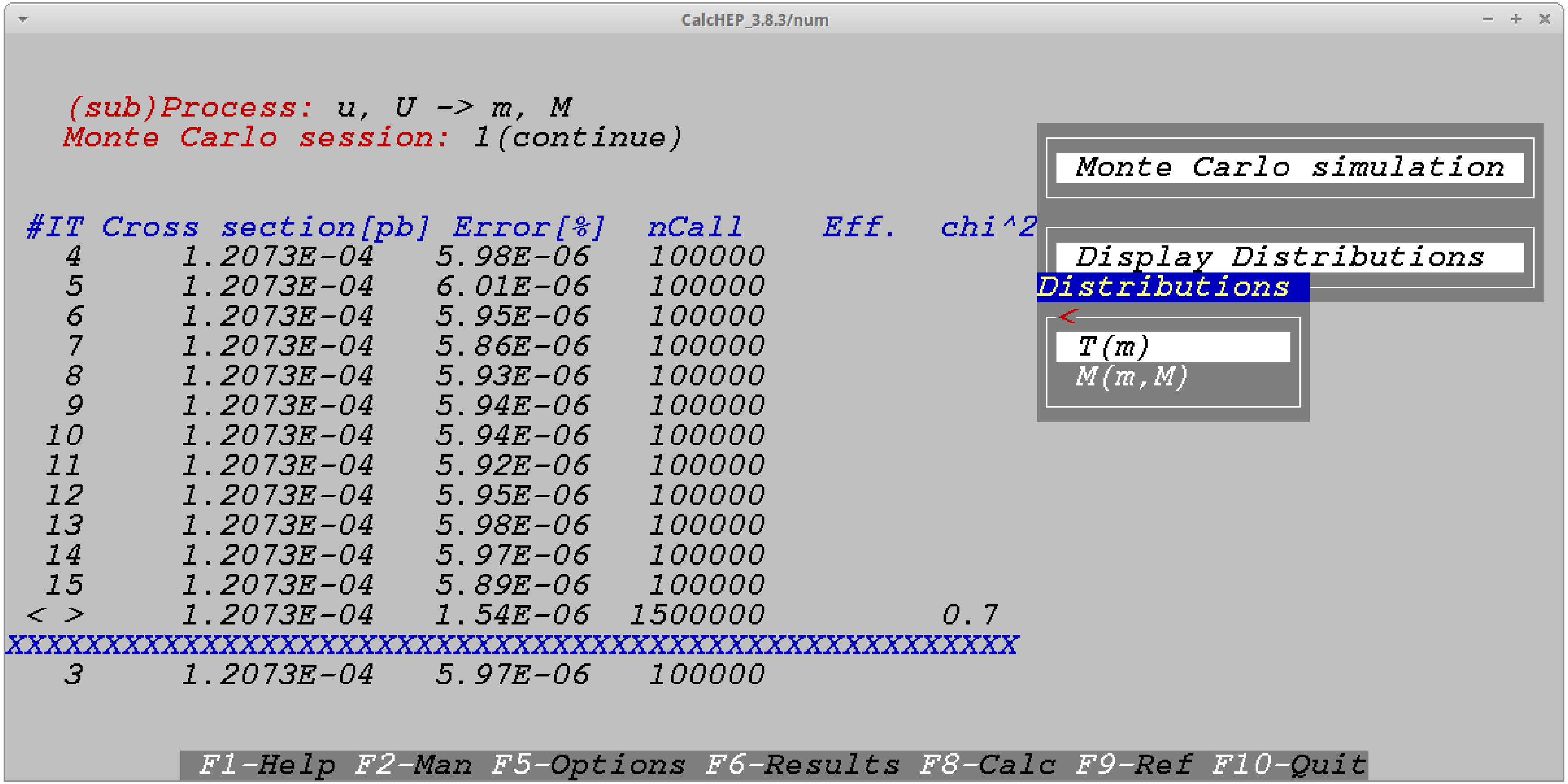
Numerical Calculation



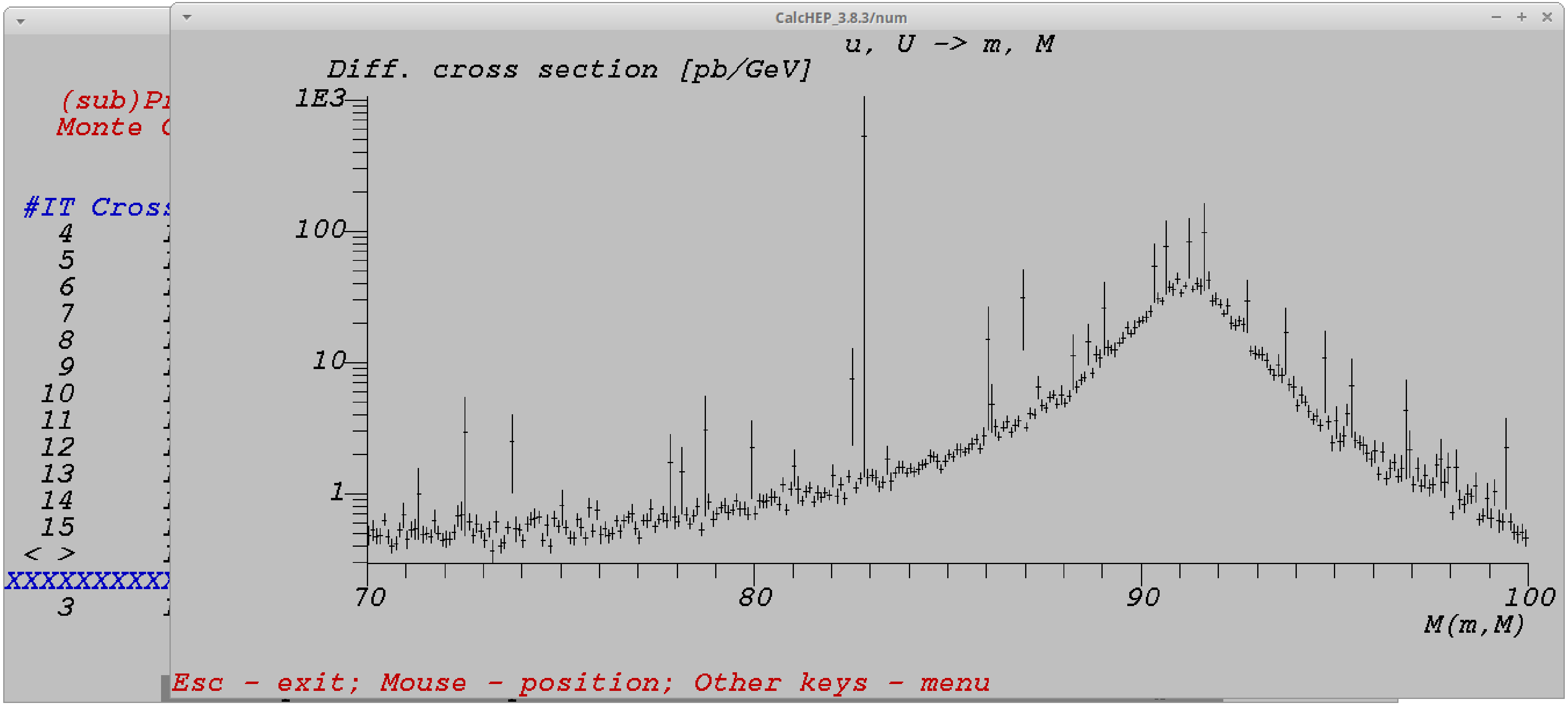
Numerical Calculation



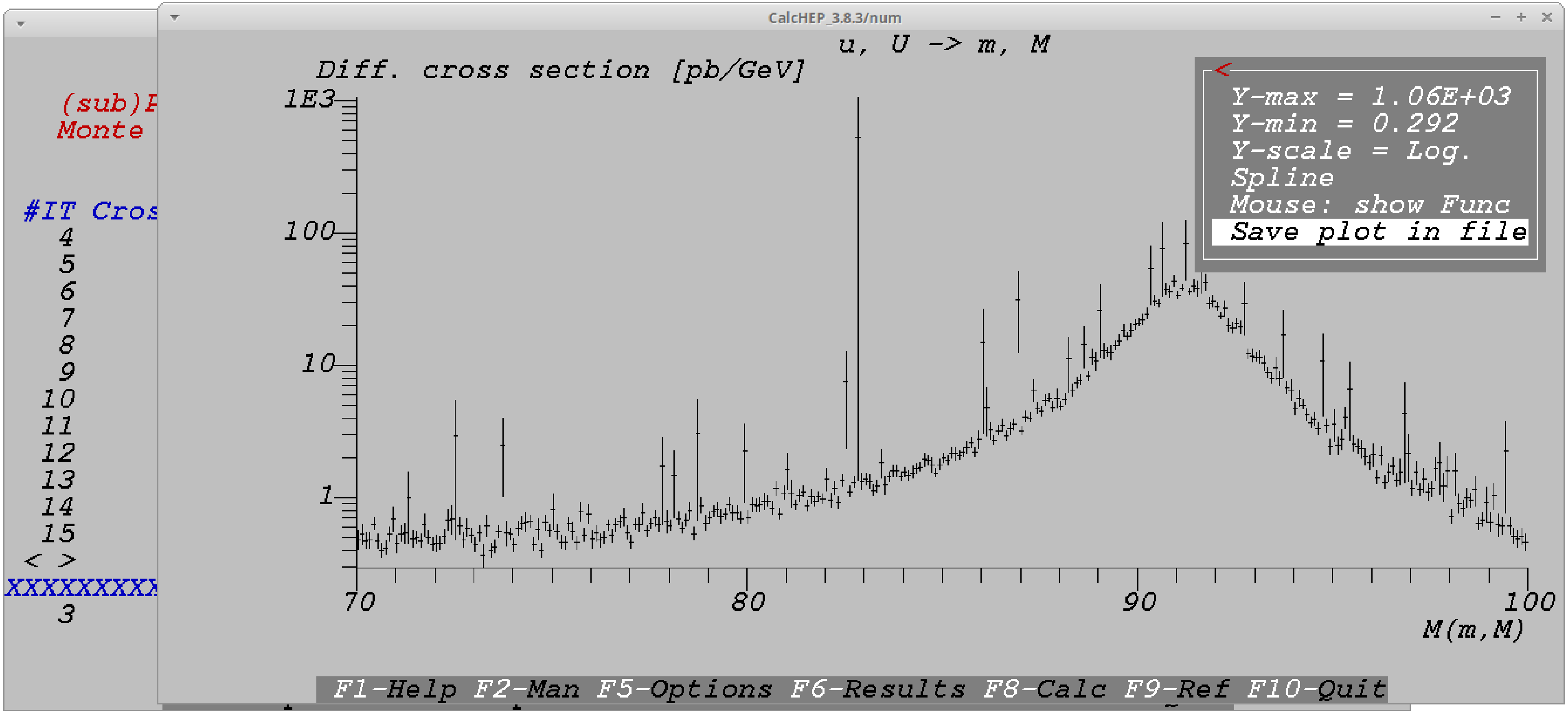
Numerical Calculation



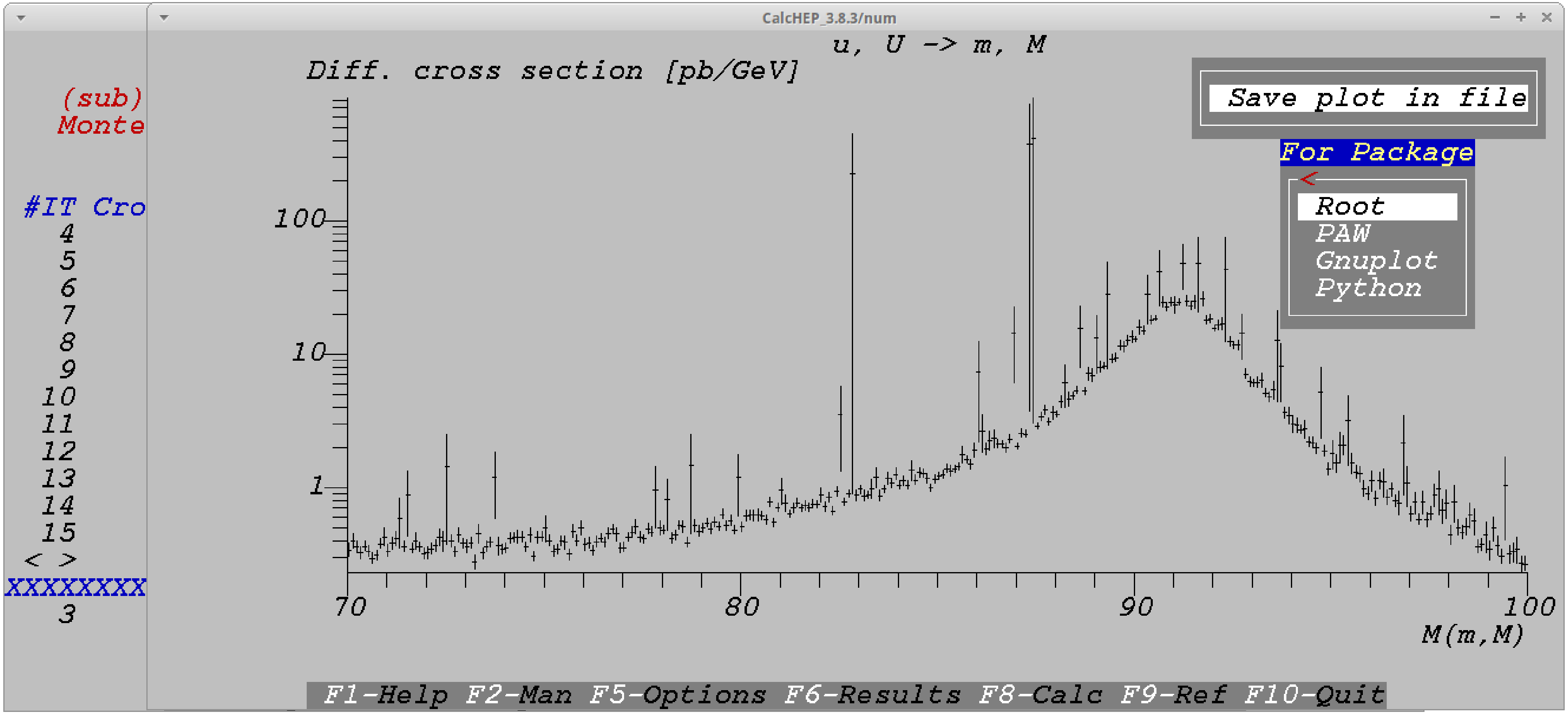
Numerical Calculation



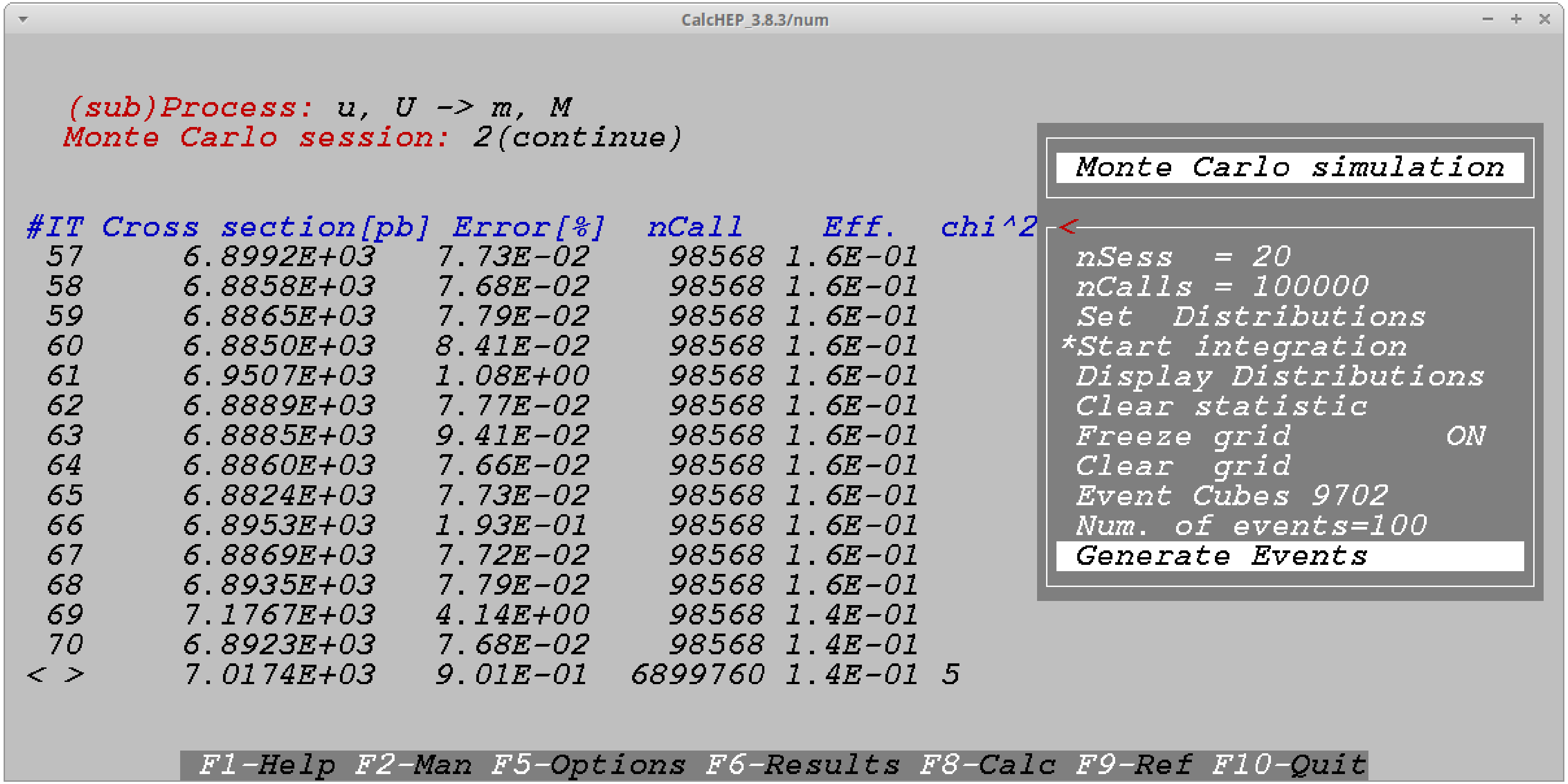
Numerical Calculation



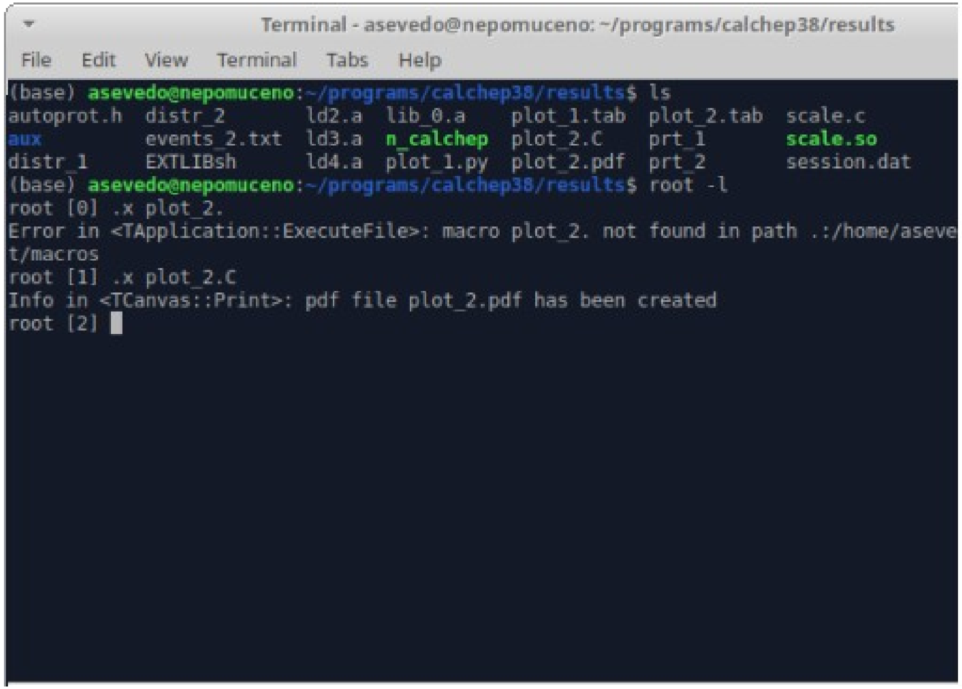
Numerical Calculation

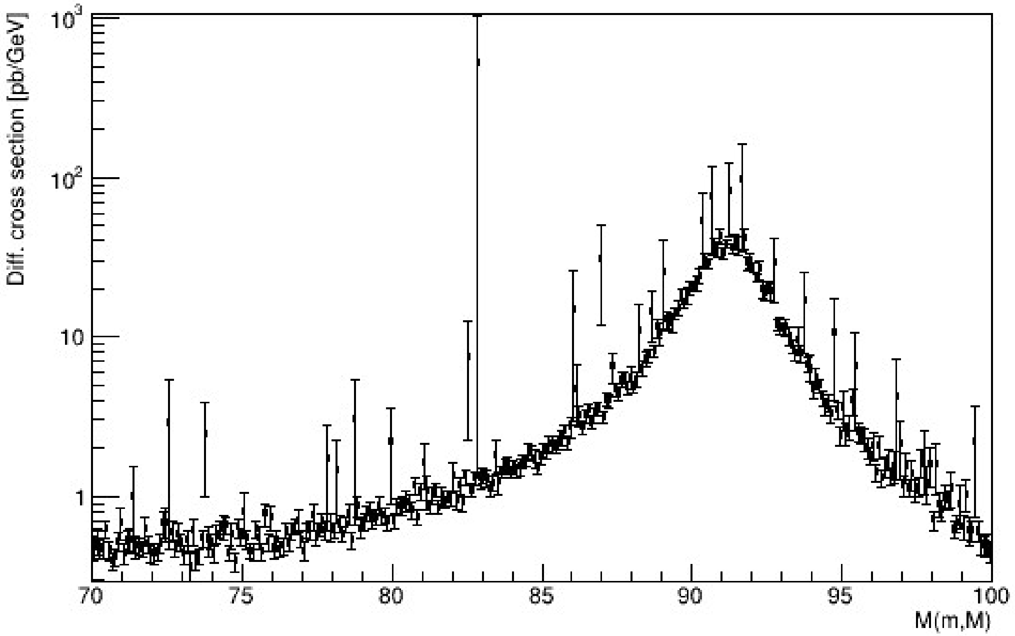


Numerical Calculation



Numerical Calculation – Results



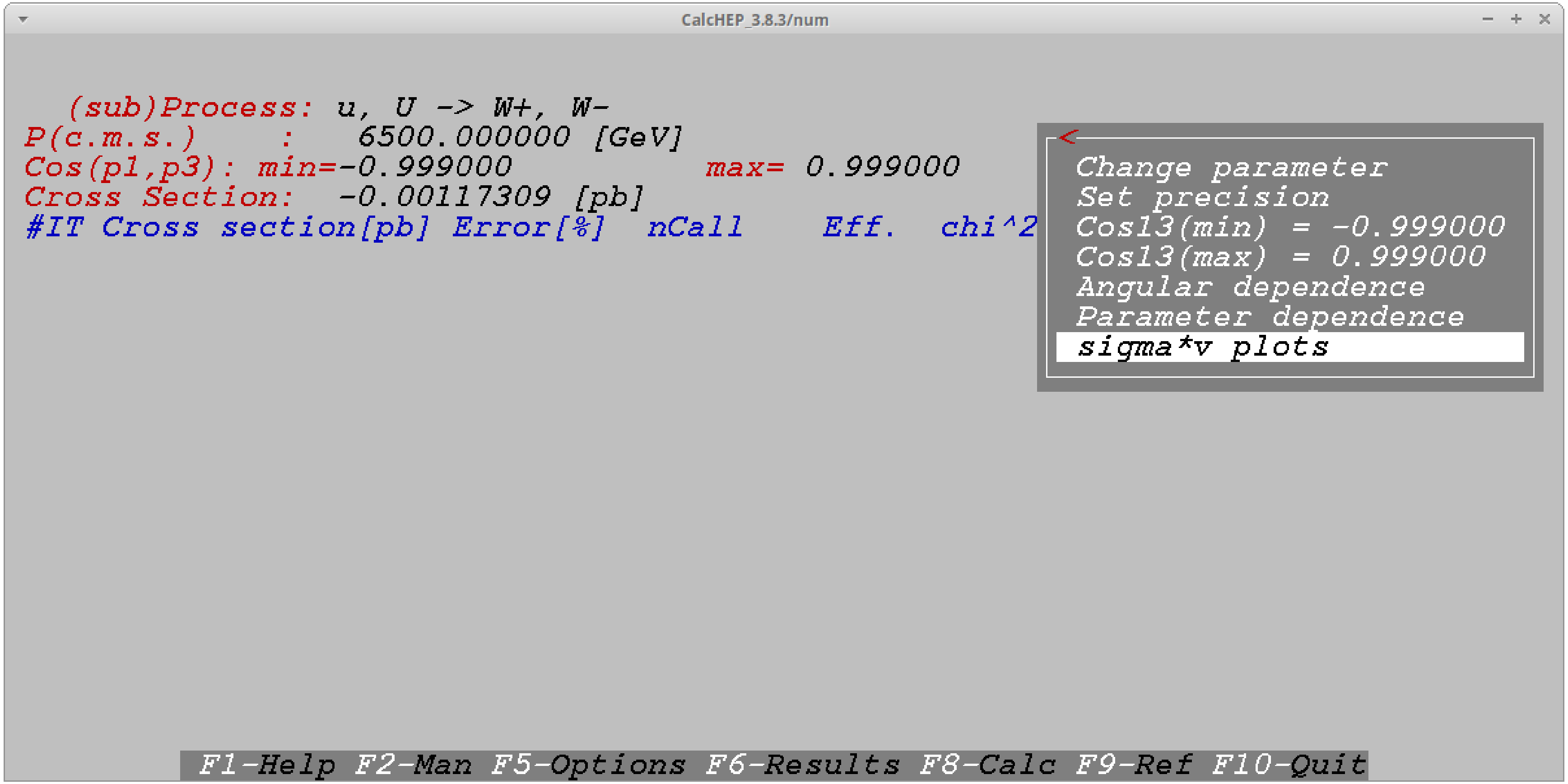


Useful for validation

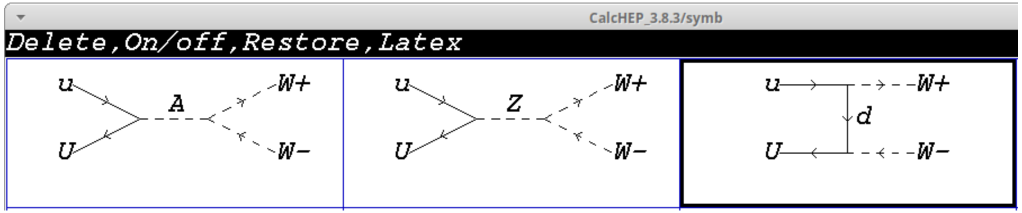
Numerical Calculation

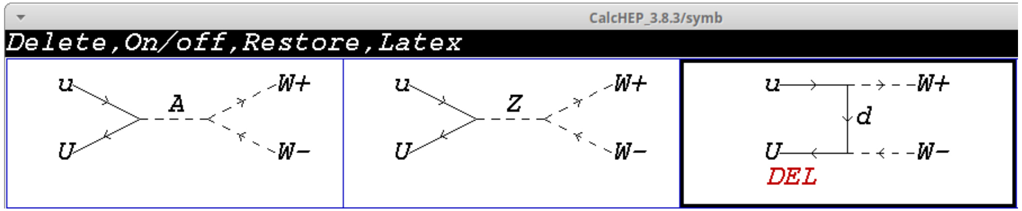
```
CalcHEP_3.8.3/num

 (sub)Process: u, U -> W+, W-
 Monte Carlo session: 1(begin)

#IT Cross section[pb] Error[%]  nCall    Eff.   chi^2

                                              Subprocess
                                              IN state
                                              Model parameters
                                              Constraints
                                              QCD  alpha & scales
                                              Breit-Wigner
                                              Aliases
                                              Cuts
                                              Phase space mapping
                                              Monte Carlo simulation
                                              1D integration

 F1-Help F2-Man F5-Options F6-Results F8-Calc F9-Ref F10-Quit
```

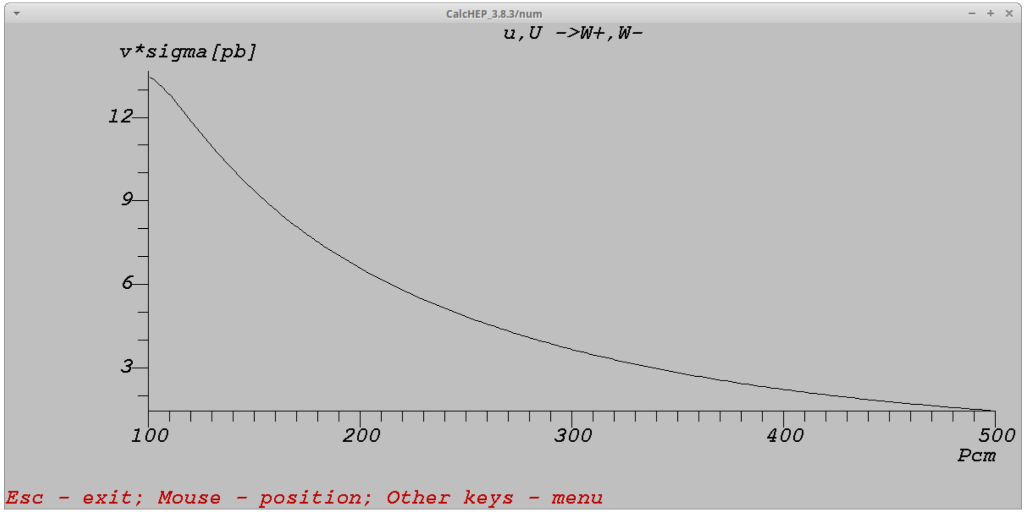
Numerical Calculation

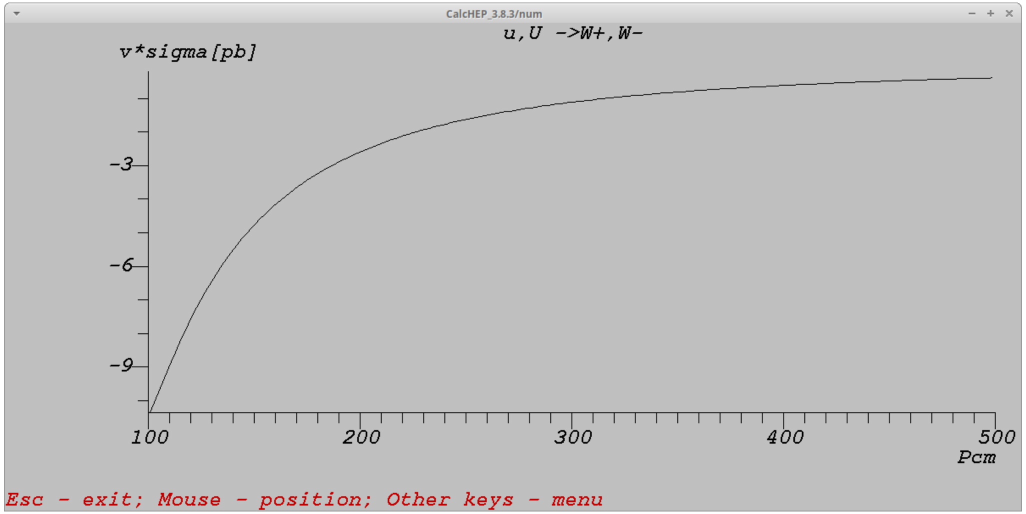


Numerical Calculation



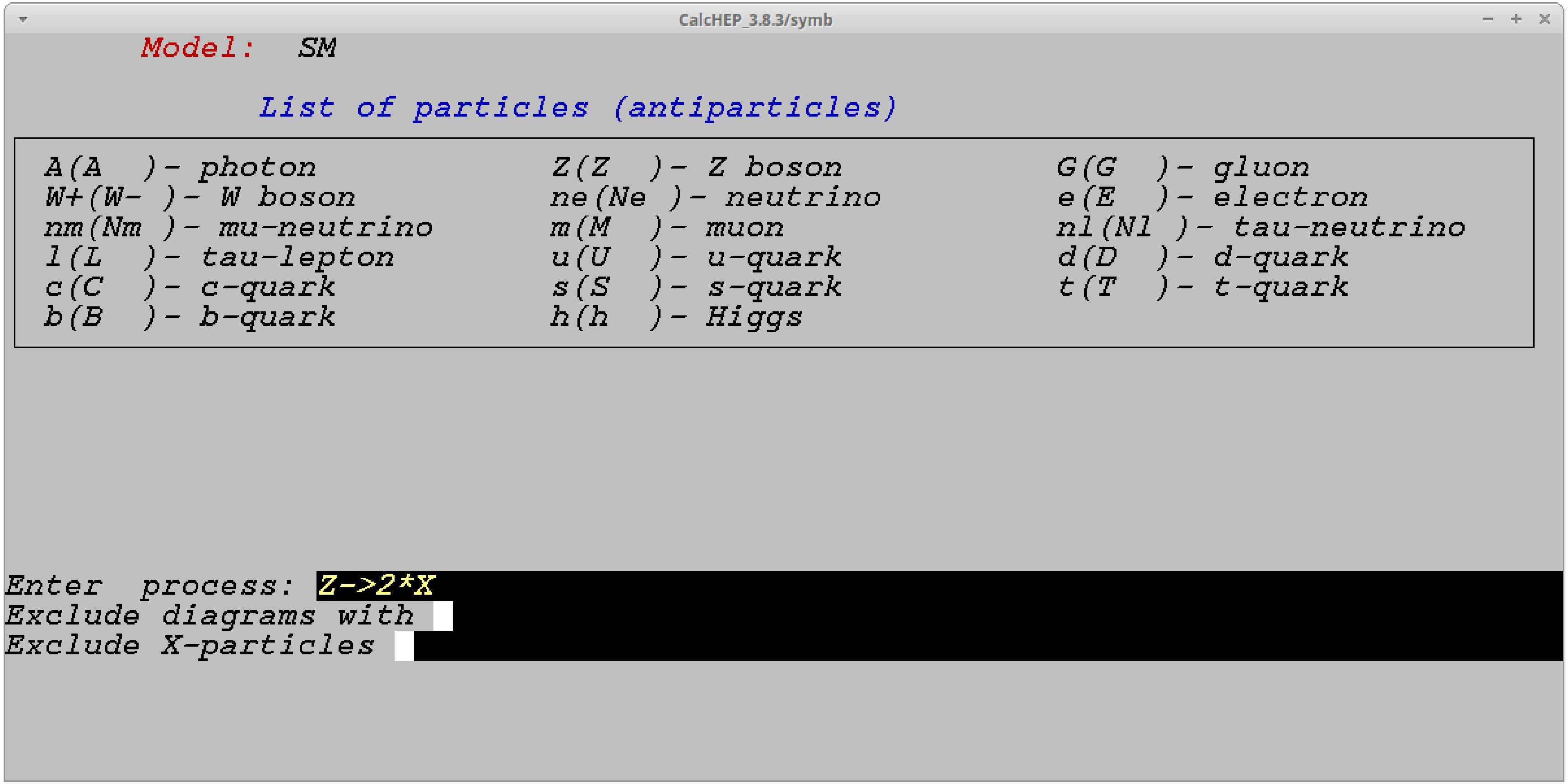






Always check the unitarity of your model!

Decays



CalcHEP_3.8.3/symb
Model: SM
List of particles (antiparticles)
A(A)- photon
W+(W-)- W boson
nm(Nm)- mu-neutrino
l(L)- tau-lepton
c(C)- c-quark
b(B)- b-quark
Z(Z)- Z boson
ne(Ne)- neutrino
m(M)- muon
u(U)- u-quark
s(S)- s-quark
h(h)- Higgs
G(G)- gluon
e(E)- electron
nl(Nl)- tau-neutrino
d(D)- d-quark
t(T)- t-quark
Enter process: Z->2*X
Exclude diagrams with
Exclude X-particles

Batch Calculation

The CalcHep GUI is very useful to understand and validate your model, but obliviously it is not effective for “production mode”. What if you want to calculate cross-sections and generate thousands of events considering different model parameters (for instance, varying the mass of a resonance) ?

For this task, CalcHep has a very powerful **batch mode calculation**. From a single batch file, we can set all the parameters needed to perform the calculations. The progress of the calculations can be check via a html file.

Batch File

```
##################################
#  Model Info
##################################
Model:         B-L (Full fast)
Model changed: False
Gauge:         Unitary

##################################
#  Process Info                  #
##################################

Process:   p,p->m,M
Composite: p=u,U,d,D,s,S,c,C,b,B,G
Remove: Z,A,H1,H2
```

```
#  PDF Info
#pdf1:     LHA:cteq6ll.LHpdf:0:1
#pdf2:     LHA:cteq6ll.LHpdf:0:1

pdf1:      cteq6l1 (proton)
pdf2:      cteq6l1 (proton)

#  Momentum Info in GeV
p1:        6500
p2:        6500

# Parameter Info
# Masses and Energies are in GeV
#Parameter: EE=0.31
#Parameter: MZp=5000
```

Batch File

```
#  Run Info                              #
# Masses and Energies are in GeV
# More than one run can be specified at
# the same time.
Run parameter: MZp
Run begin:     1000
Run step size: 500
Run n steps:   3

#Run parameter: g1p
#Run begin:     0.2
#Run step size: 0.1
#Run n steps:   10
```

```
####### QCD Running Info
####################################
##################
#parton dist. alpha: ON
#alpha(MZ):          0.118
#alpha Q :1:         M34
#alpha Q :2:         M45
alpha Q :            M12
```

Batch File

#Cuts info
Cut parameter: n(m)
Cut invert: False
Cut min: -100
Cut max: 100

Cut parameter: n(M)
Cut invert: False
Cut min: -100
Cut max: 100

Cut parameter: M(m,M)
Cut invert: False
Cut min: 50
Cut max:

Kinematics and Regularization

Kinematics : 12 -> 3,4

Regularization momentum: 34
Regularization mass: MZp
Regularization width: wZp
Regularization power: 2

Batch File

#Distribution
#Need gnplot installed

Dist parameter: M(m,M)
Dist min: 400
Dist max: 3000
Dist n bins: 150
Dist title: p,p->m,M
Dist x-title: M(m,M) (GeV)

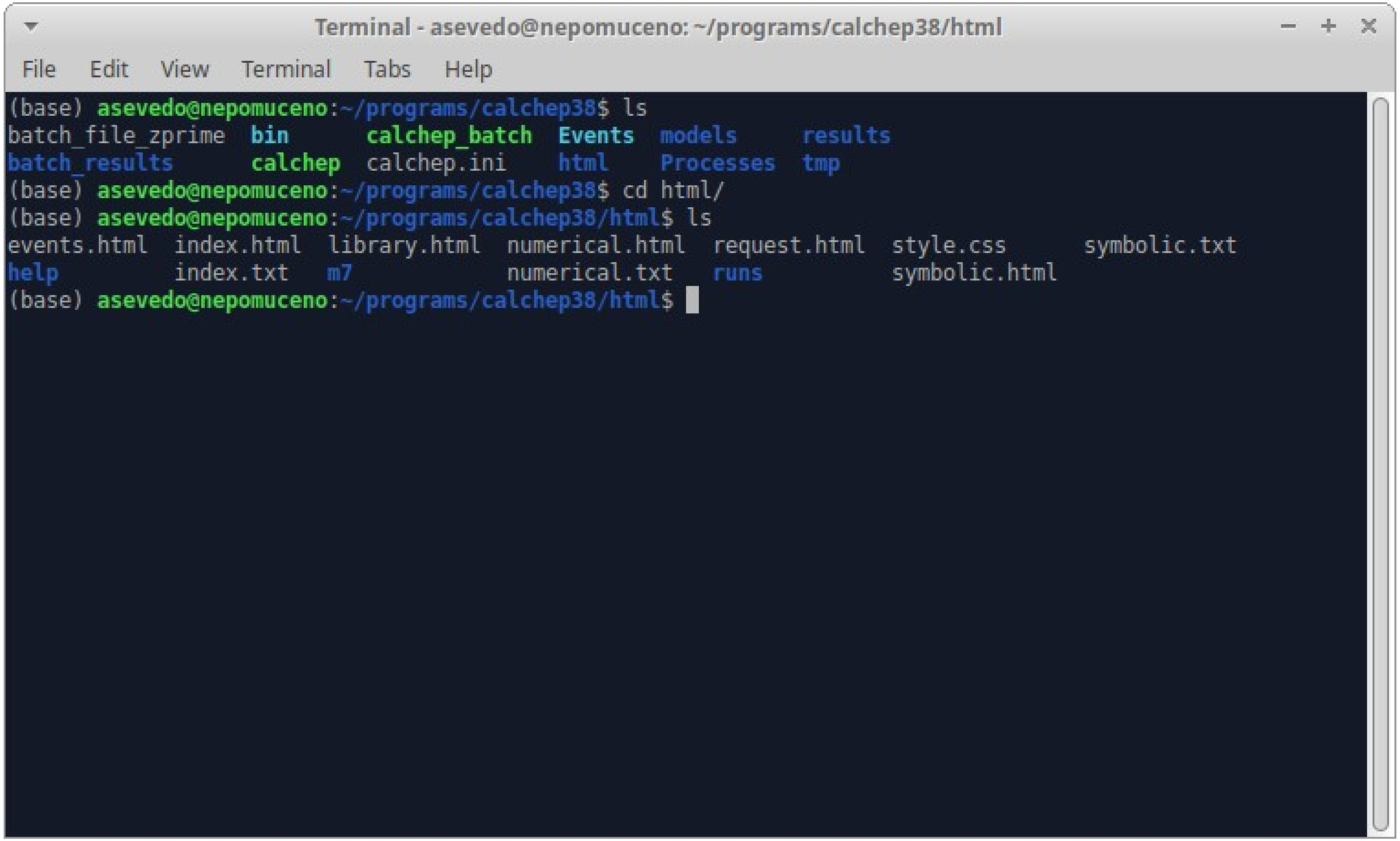
Event generation and Vegas

Number of events (per run step): **1000**
Filename: zprime_mm_events
NTuple: True

#Vegas
nSess_1: 20
nCalls_1: 100000
nSess_2: 20
nCalls_2: 100000

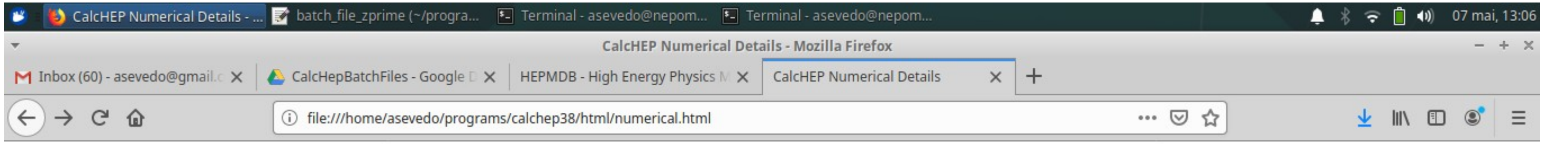
Run you batch file: `./calchep_batch batch_file`

Batch Results



In your work directory, you will find the “html” folder, where you can find “numerical.html” file.

Batch Results



Numerical Sessions

B-L (Full fast)

Calculating Cross Sections

Home
Symbolic Results
Numerical Results
Events Library
Process Library
Help

Thank you for using CalcHEP! Please cite arXiv:1207.6082

Scans	σ (fb)	Running	Finished	Time (hr)	N events			
MZp=1000	76.464	0/10	10/10	0.05		0/10	10/10	0.05
MZp=1500	12.353	0/10	10/10	0.05		0/10	10/10	0.05
MZp=2000	2.862	1/10	6/10	0.03		1/10	6/10	0.03
				0.14				

Remember to clear your web browser cache if the plots are not updating properly. Also, remember to refresh your browser if you started a new run.

Batch Results

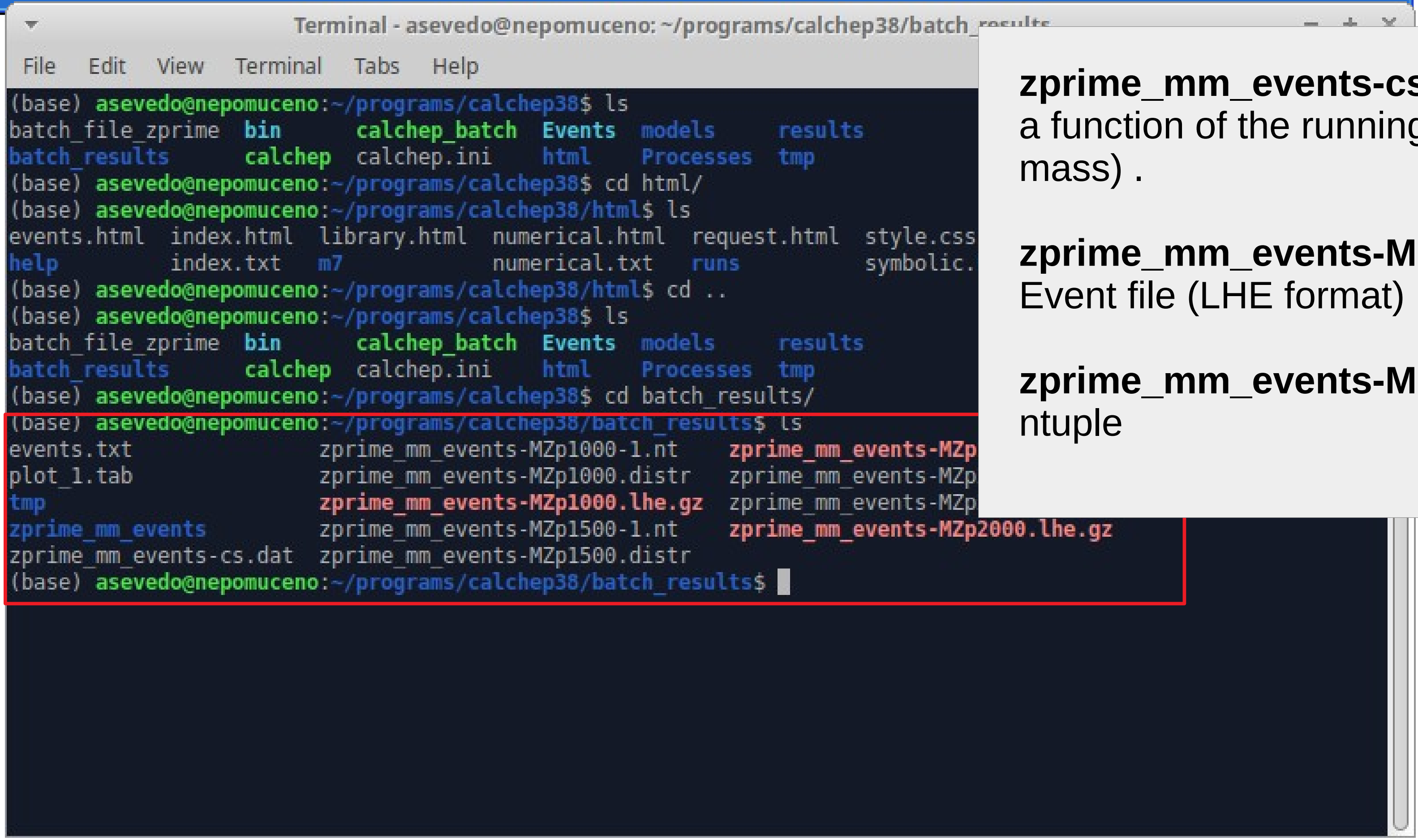
Terminal - asevedo@nepomuceno: ~/programs/calchep38/batch_results

File Edit View Terminal Tabs Help

Rotate

```
(base) asevedo@nepomuceno:~/programs/calchep38$ ls
batch_file_zprime  bin      calchep_batch  Events  models     results
batch_results      calchep  calchep.ini    html    Processes  tmp
(base) asevedo@nepomuceno:~/programs/calchep38$ cd html/
(base) asevedo@nepomuceno:~/programs/calchep38/html$ ls
events.html  index.html  library.html  numerical.html  request.html  style.css      symbolic.txt
help         index.txt   m7            numerical.txt   runs          symbolic.html
(base) asevedo@nepomuceno:~/programs/calchep38/html$ cd ..
(base) asevedo@nepomuceno:~/programs/calchep38$ ls
batch_file_zprime  bin      calchep_batch  Events  models     results
batch_results      calchep  calchep.ini    html    Processes  tmp
(base) asevedo@nepomuceno:~/programs/calchep38$ cd batch_results/
(base) asevedo@nepomuceno:~/programs/calchep38/batch_results$ ls
events.txt                zprime_mm_events-MZp1000-1.nt     zprime_mm_events-MZp1500.lhe.gz
plot_1.tab                zprime_mm_events-MZp1000.distr    zprime_mm_events-MZp2000-1.nt
tmp                       zprime_mm_events-MZp1000.lhe.gz   zprime_mm_events-MZp2000.distr
zprime_mm_events          zprime_mm_events-MZp1500-1.nt     zprime_mm_events-MZp2000.lhe.gz
zprime_mm_events-cs.dat   zprime_mm_events-MZp1500.distr
(base) asevedo@nepomuceno:~/programs/calchep38/batch_results$
```

Batch Results



zprime_mm_events-cs.dat – xsec as a function of the running parameter (Z' mass) .

zprime_mm_events-Mzp*.lhe.gz – Event file (LHE format)

zprime_mm_events-Mzp*.nt – PAW ntuple

Analyze Event File

In order to produce the PAW ntuple file, we need the “nt_maker” script in the $CALCHEP/“bin” directory (see backup slides on how to produce it).

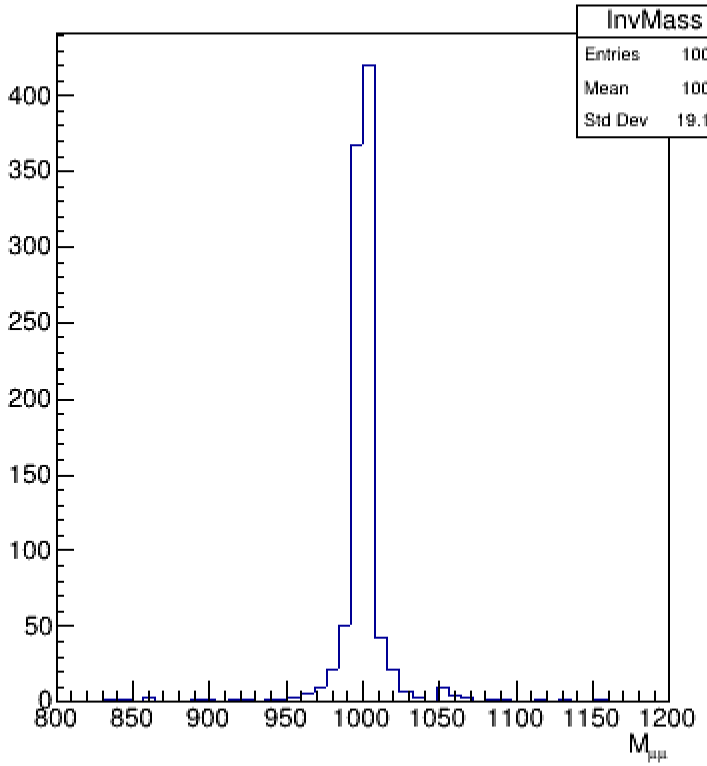
We can use h2root to convert PAW hbook to a ROOT file:

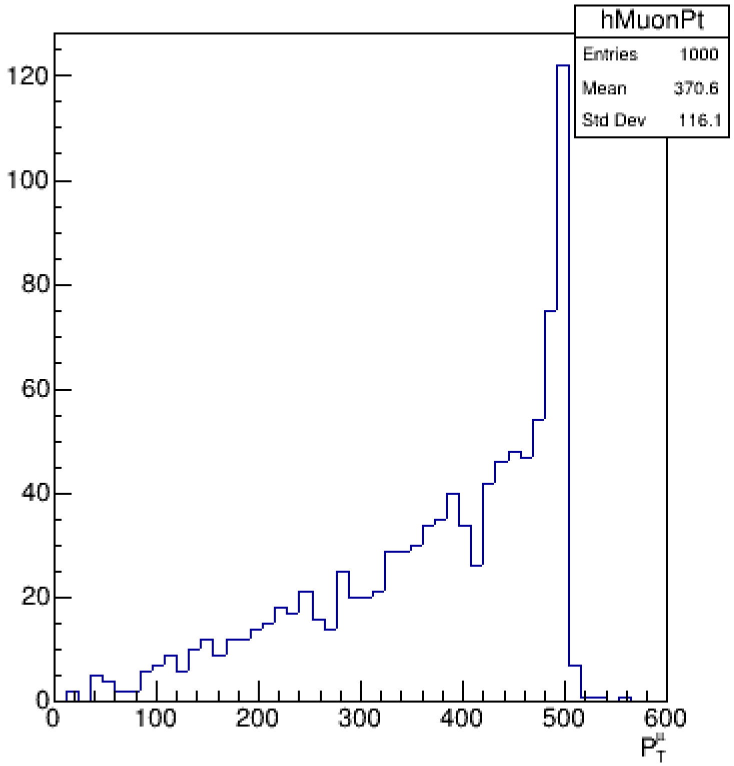
```
h2root zprime_mm_events-MZp1000-1.nt zprime_mm_Mzp1000.root
```

The root file has the Xsec and the four-momenta of the particles. It can be analyzed using the ROOT **TLorentzVector** class (see example attached).

The LHE file can also be red with a Python script. See backup slides for details.

Analyze Event File - Example





Try Yourself!

1. Download the model “Minimal Zp models” from HEPMDB
2. Put the model files in the “models” directory (do not forget to rename the files!)
3. Calculate the cross-section for the various sub-process of the process $pp \rightarrow Z' \rightarrow \mu+ \mu-$. Remove the contributions from the photon and Z bosons and from the scalars H1 and H2 in order to estimate the contribution from Z’ only.
4. Check unitary (using 1D integration option to plot Xsec versus certer-of-mass energy).
5. Check how the Z’ width vary with its mass.
6. Calculate the Xsec for the above process using different Z’ mass in batch mode. Generate events.
7. Using the root ntuple from the LHE event file, plot individual muons pseudorapidity, transverse momentum, muon pair rapidity and muon pair invariant mass.

Getting Help

- Visit CalcHep web page (see slide 2)
- Browse through many Q&A in “Questions for CalcHEP”:
  https://answers.launchpad.net/calchep
- Ask the most powerful answering machine in the world (Google)
- You can also ask me: asevedo@gmail.com

Backup Slide I

Producing the script “nt_maker” when compile CalcHep

1. Assuming that you have version 3.8.3, go to directory **calchep_3.8.3/c_source/mix_events** and open the file “MakeFile”.

2. Include the path to the CERN library files. Example:
CERN=/usr/lib/x86_64-linux-gnu/

3. Compile CalcHep (see slide 3). The script will be in “bin” directory.

Backup Slide II

We can use Python to read a LHE Event file. There is a Python module for that.

Check the link below:

https://pypi.org/project/lhereader/

Backup Slide III

We can use LanHep to implement models in CalcHep. Check this video tutorial:

https://www.youtube.com/watch?v=3dydCI44ZYE&feature=youtu.be&fbclid=IwAR2IHSVfv9TLxWVxdXVockJuXJpySgNMkrw_Z757v7YSU_h71eu_0QBgMwE