Collider phenomenology with CalcHEP

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OUTLINE

location of this talk

http://www.hep.phys.soton.ac.uk/~belyaev/proj/talks/dubna_calchep_2009.pdf

- ***Introduction into CalcHEP***
  - ***models and symbolic session***
  - ***numerical session and kinematical distributions***
  - ***event generation***
- ***Introduction to LanHEP***
  - ***automatic generation of Feynman rules from the Lagrangian***
- ***Beyond the parton level simulation***
  - ***event simulation using PYTHIA***
  - ***CalcHEP – PYTHIA interface and simulation of new Physics Processes***
- ***CalcHEP Batch Interface and various applications***

Practical points

- ***The WEB page of CalcHEP***
  http://theory.npi.msu.su/~pukhov/calchep.html

- ***e-mail for your questions/remarks***
  calchep@googlegroups.com , a.belyaev@soton.ac.uk

- ***some useful Manuals***
  http://www.hep.phys.soton.ac.uk/~belyaev/manual

- ***exercises***
  for those who wants to practice and start using CalcHEP rightaway

Exercise#xx

Introduction to CalcHEP

- ***Author(s)***
  - ***Alexander Pukhov***

    (AB and Neil Christensen have joined the project in 2009)
- ***Idea***
  - ***The effective study of HEP phenomenology passing at high level of automation from your favorite model to physical observables such as decay width, branching ratios, cross sections kinematic distributions, ...***

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- ***Analogous packages*** ***(matrix element generators)***

  http://www.ippp.dur.ac.uk/montecarlo/BSM/
  http://www-theory.lbl.gov/tools/
  - ***CompHEP (Boos et al)***
  - ***MadGraph/MadEvent (Maltoni, Stelzer)***
  - ***Grace/Helas (Fujimoto et al)***
  - ***FeynArts/FeynCalc/FormCalc (Hahn et al)***
  - ***WHIZARD,O'mega (Moretti, Ohl, Reuter)***
  - ***Sherpa (Krauss et al)***

Features/Limitations of CalcHEP

- ***Can evaluate any decay and scattering processes within any (user defined) model!***

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- ***Squared Matrix Element calculation***
  - ***no spin information for outgoing particles – spin averaged amplitude***

Features/Limitations of CalcHEP

- ***Can evaluate any decay and scattering processes within any (user defined) model!***

- ***Tree-level processes***
- ***Squared Matrix Element calculation***
  - ***no spin information for outgoing particles – spin averaged amplitude***
- ***Limit on number of external legs (involved particles) and number of diagrams***
  - ***official limit – 8 , unofficial – none***
  - ***limit is set from the practical point of view:***
    - 2 → 6 (1→7) set the essential time/memory limit
    - number of diagrams ~ 500 set the disk space and time limit

Quick start with CalcHEP: practical notes on the installation

- ***Download code, read manual and compile***
  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 in CalcHEP was to enable one to go directly from the Lagrangian to the cross sections and distributions effectively, with the high level of automation. The package can be compiled on any Unix platform.

General information
- Main facilities , - Old Versions , - Acknowledgments - News&Bugs

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Manual
- calchep_man_2.3.5(ps.gz) (137 pages, 445KB, March 18, 2005)
- HEP computer tools (Lecture by Alexander Belyaev)

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

Codes download.
- Licence - Installation - References&Contributions

CalcHEP code for UNIX: - version 2.5.3 (March 23 , 2009) - version 2.6.a (version under development)

Quick start with CalcHEP: practical notes on the installation

- ***Download code, read manual and compile***
  http://theory.npi.msu.su/~pukhov/calchep.html
  - **tar -zxvf calchep_2.*x.x*.tgz**
  - **cd calchep_2.*x.x***
  - **make**

  the currrent version is 2.*x.x* = 2.*5.4*
- **Create work directory**
  - **From calchep_2.*x.x* directory:**

  ./mkUsrDir *../calc_work*
- **Supported operating system**
  - **Linux, IRIX, IRIX64, HP-UX, OSF1, SunOS, Darwin, CYGWIN**

  (see *getFlags* file)

Exercise#1: Install CalcHEP

Starting CalcHEP

- **cd ../calc_work**

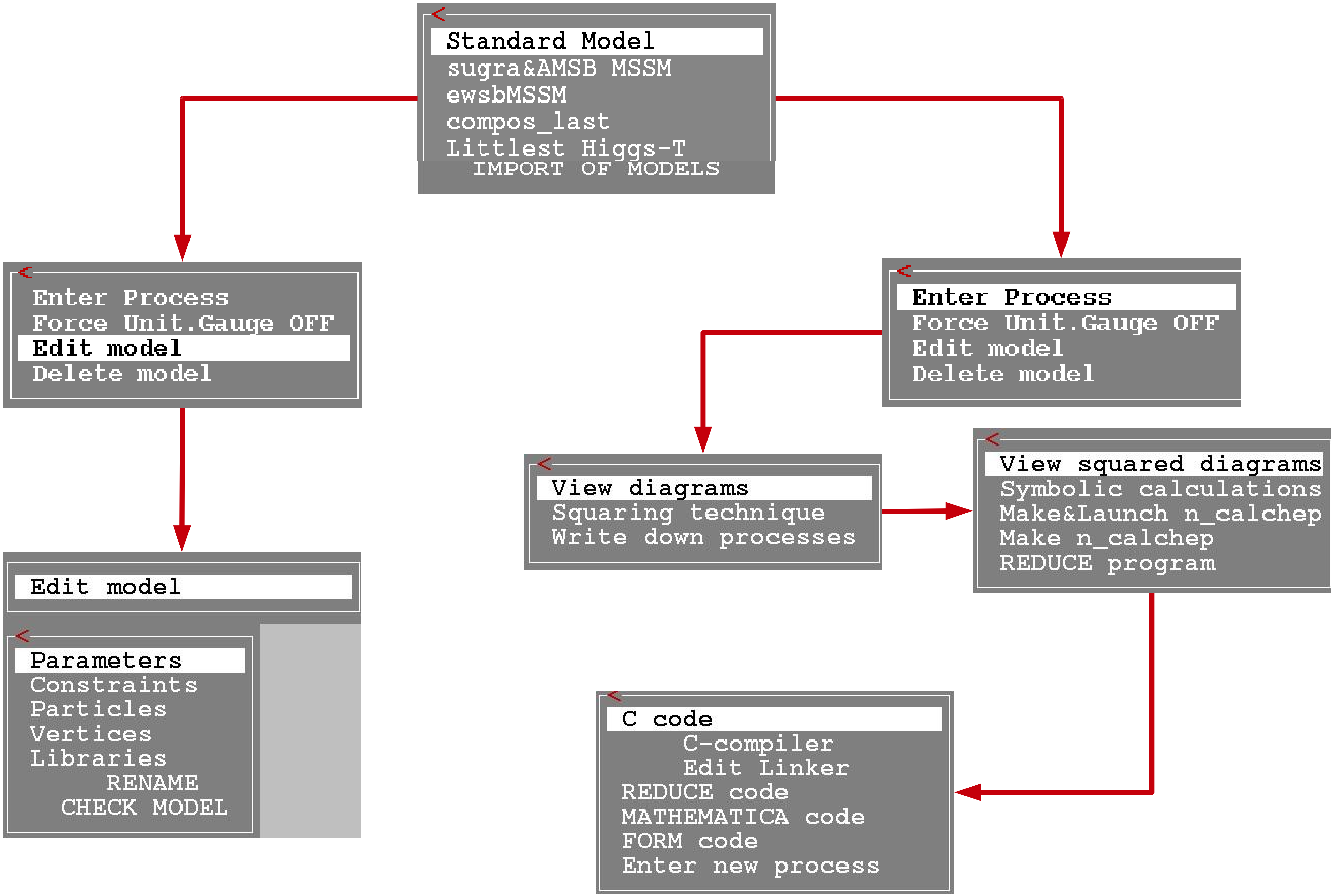
- ***Files:***

bin -> .... /calchep_2.x.x/bin
calchep
calchep_batch
calchep.ini
models/
results/
tmp/

- ***Start:***

./calchep

CalcHEP menu structure: symbolic part



Model: prtcl*xx*.mdl

CalcHEP/symb

Particles

Clr-Del-Size-Read-ErrMes

Full name	A	A+	number	2*spin	mass	width	color	aux	>LaTex(A)<	>LaTeX(A+) <
gluon	G	G	21	2	0	0	8	G	g	g
photon	A	A	22	2	0	0	1	G	\gamma	\gamma
Z-boson	Z	Z	23	2	MZ	wZ	1	G	Z	Z
W-boson	W+	W-	24	2	MW	wW	1	G	W^+	W^-
Higgs	h	h	25	0	Mh	!wh	1		h	h
electron	e	E	11	1	0	0	1		e^-	e^+
e-neutrino	ne	Ne	12	1	0	0	1	L	\nu_e	\bar{\nu}_e
muon	m	M	13	1	Mm	0	1		\mu^-	\mu^+
m-neutrino	nm	Nm	14	1	0	0	1	L	\nu_\mu	\bar{\nu}_\mu
tau-lepton	l	L	15	1	Ml	0	1		\tau^-	\tau^-
t-neutrino	nl	Nl	16	1	0	0	1	L	\nu_\tau	\bar{\nu}_\tau
d-quark	d	D	1	1	0	0	3		d	\bar{d}
u-quark	u	U	2	1	0	0	3		u	\bar{u}
s-quark	s	S	3	1	Ms	0	3		s	\bar{s}
c-quark	c	C	4	1	Mc	0	3		c	\bar{c}
b-quark	b	B	5	1	Mb	0	3		b	\bar{b}
t-quark	t	T	6	1	Mt	wt	3		t	\bar{t}

F1-F2-Xgoto-Ygoto-Find-Write

Model: vars*xx*.mdl

CalcHEP/symb

Parameters 1

Clr Del Size Read ErrMes

Name	Value	> Comment
alfEMZ	0.0078180608	MS-BAR electromagnetic alpha(MZ)
alfSMZ	0.1172	Srtong alpha(MZ) for running mass calculation
Q	100	scale for running mass calculation
GG	1.238	Running Strong coupling. The given value doesn't matter.
SW	0.481	MS-BAR sine of the electroweak mixing angle
s12	0.221	Parameter of C-K-M matrix (PDG96)
s23	0.041	Parameter of C-K-M matrix (PDG96)
s13	0.0035	Parameter of C-K-M matrix (PDG96)
Mm	0.1057	muon mass
Ml	1.777	tau-lepton mass
McMc	1.2	Mc(Mc)
Ms	0	s-quark mass (pole mass, PDG96)
MbMb	4.25	Mb(Mb)
Mtp	175	t-quark pole mass
MZ	91.187	Z-boson mass
Mh	120	higgs mass
wt	1.59	t-quark width (tree level 1->2x)
wZ	2.49444	Z-boson width (tree level 1->2x)
wW	2.08895	W-boson width (tree level 1->2x)

F1 F2 Xgoto Ygoto Find Write

Model: funcxx.mdl

```
CalcHEP/symb
                              Constraints
Clr-Del-Size-Read-ErrMes
 Name    |> Expression                                              <
EE       |sqrt(16*atan(1.)*alfEMZ)       % electromagnetic constant
CW       |sqrt(1-SW^ 2)                  % cos of the Weinberg angle
MW       |MZ*CW                          % W-boson  mass
c12      |sqrt(1-s12^ 2)                 % parameter  of C-K-M matrix
c23      |sqrt(1-s23^ 2)                 % parameter  of C-K-M matrix
c13      |sqrt(1-s13^ 2)                 % parameter  of C-K-M matrix
Vud      |c12*c13                        % C-K-M matrix element
Vus      |s12*c13                        % C-K-M matrix element
Vub      |s13                            % C-K-M matrix element
Vcd      |-s12*c23-c12*s23*s13           % C-K-M matrix element
Vcs      |c12*c23-s12*s23*s13            % C-K-M matrix element
Vcb      |s23*c13                        % C-K-M matrix element
Vtd      |s12*s23-c12*c23*s13            % C-K-M matrix element
Vts      |-c12*s23-s12*c23*s13           % C-K-M matrix element
Vtb      |c23*c13                        % C-K-M matrix element
qcdOk    |initQCD(alfSMZ,McMc,MbMb,Mtp)
 Mb      |MbEff(Q)*one(qcdOk)
 Mt      |MtEff(Q)*one(qcdOk)
 Mc      |McEff(Q)*one(qcdOk)

F1-F2-Xgoto-Ygoto-Find-Write
```

Model: lgrngxx.mdl

CalcHEP/symb

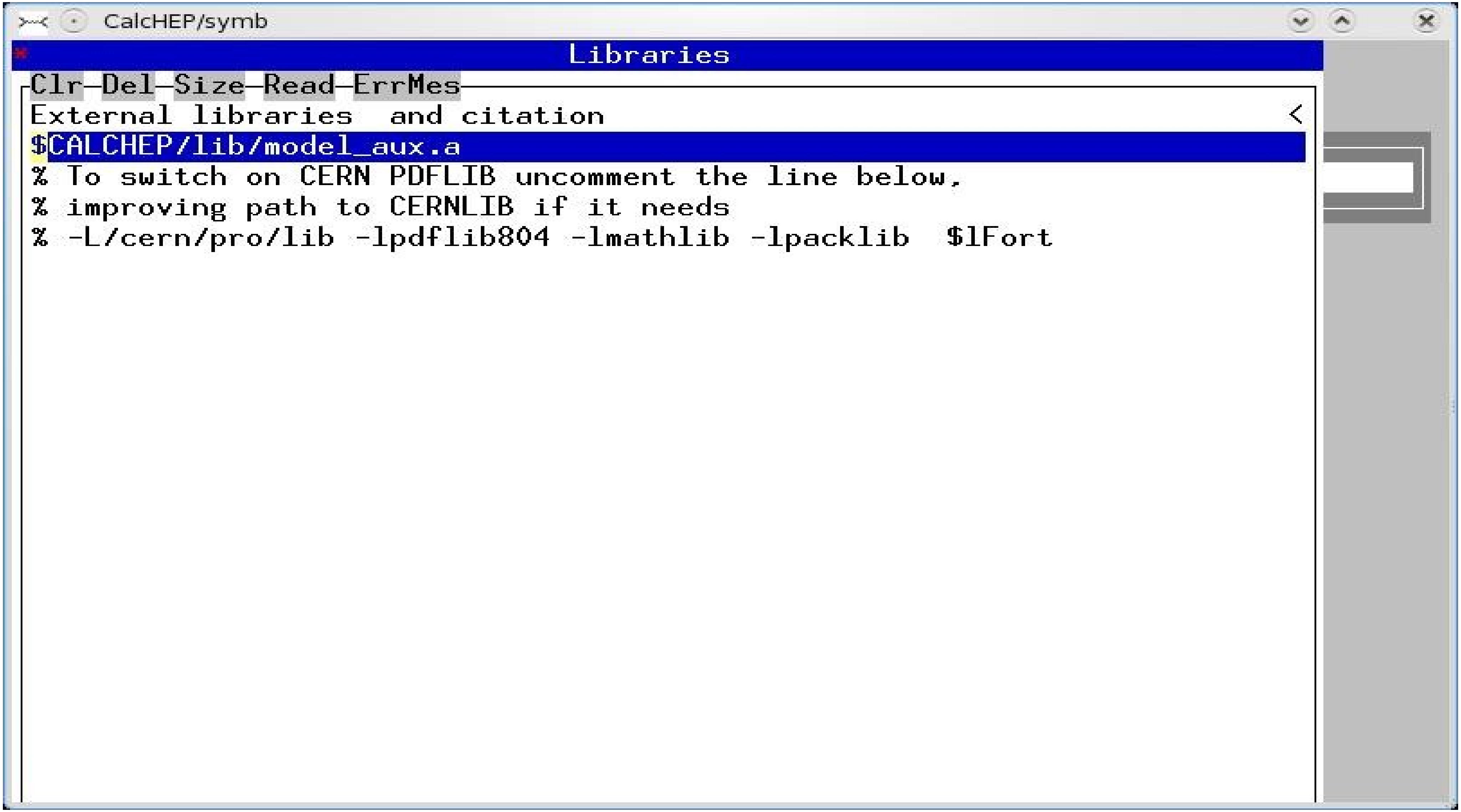
Vertices

Clr Del Size Read ErrMes

A1	A2	A3	A4	> Factor <	> Lorentz part
h	Z	Z		EE/(SW*CW^ 2)*MW	m2.m3
h	h	h		-(3/2)*EE*Mh^ 2/(MW*SW)	1
h	h	h	h	(-3/4)*(EE*Mh/(MW*SW))^ 2	1
h	h	Z	Z	(1/2)*(EE/(SW*CW))^ 2	m3.m4
h	h	W+	W-	(1/2)*(EE/SW)^ 2	m3.m4
M	m	h		-EE*Mm/(2*MW*SW)	1
L	l	h		-EE*Ml /(2*MW*SW)	1
C	c	h		-EE*Mc/(2*MW*SW)	1
S	s	h		-EE*Ms/(2*MW*SW)	1
B	b	h		-EE*Mb/(2*MW*SW)	1
T	t	h		-EE*Mt /(2*MW*SW)	1
E	e	A		-EE	G(m3)
M	m	A		-EE	G(m3)
L	l	A		-EE	G(m3)
Ne	e	W+		EE/(2*Sqrt2*SW)	G(m3)*(1-G5)
Nm	m	W+		EE/(2*Sqrt2*SW)	G(m3)*(1-G5)
Nl	l	W+		EE/(2*Sqrt2*SW)	G(m3)*(1-G5)
E	ne	W-		EE/(2*Sqrt2*SW)	G(m3)*(1-G5)
M	nm	W-		EE/(2*Sqrt2*SW)	G(m3)*(1-G5)
L	nl	W-		EE/(2*Sqrt2*SW)	G(m3)*(1-G5)
E	e	Z		-EE/(4*SW*CW)	G(m3)*(1-G5)-4*(SW^ 2)*G(m3)
M	m	Z		-EE/(4*SW*CW)	G(m3)*(1-G5)-4*(SW^ 2)*G(m3)
L	l	Z		-EE/(4*SW*CW)	G(m3)*(1-G5)-4*(SW^ 2)*G(m3)
Ne	ne	Z		EE/(4*SW*CW)	G(m3)*(1-G5)

F1 F2 Xgoto Ygoto Find Write

Model: extlib*xx*.mdl



Details of symbolic session

The syntax for the input is: `P1[,P2] -> P3,P4 [,...,[N*x]]`

- 'P1'..'P4' are particle names, N is a number of particles
- hadron/composite particle scattering

  'p,p->W+,b,B'

  unknown particle are assumed to be composite:

  'p' consists of **u,U,d,D,s,S,c,C,b,B,G**
- wild cards/names for outgoing particles

  'H -> 2*x'
- intermediate particles can be non-trivially excluded

  'W+ > 2, A>1, Z>3'
- particle width can be calculated 'on-fly'

  '!wtop' , i.e. '!' symbol should be used in the prt table
- particles spin

  0, 1/2, 1, 3/2, 2

Exercise#2
calculate SM Higgs boson Decay width and branching ratios as a function of Higgs boson mass

Principle KEYS for CalcHEPs GUI

Enter menu selection (forward)

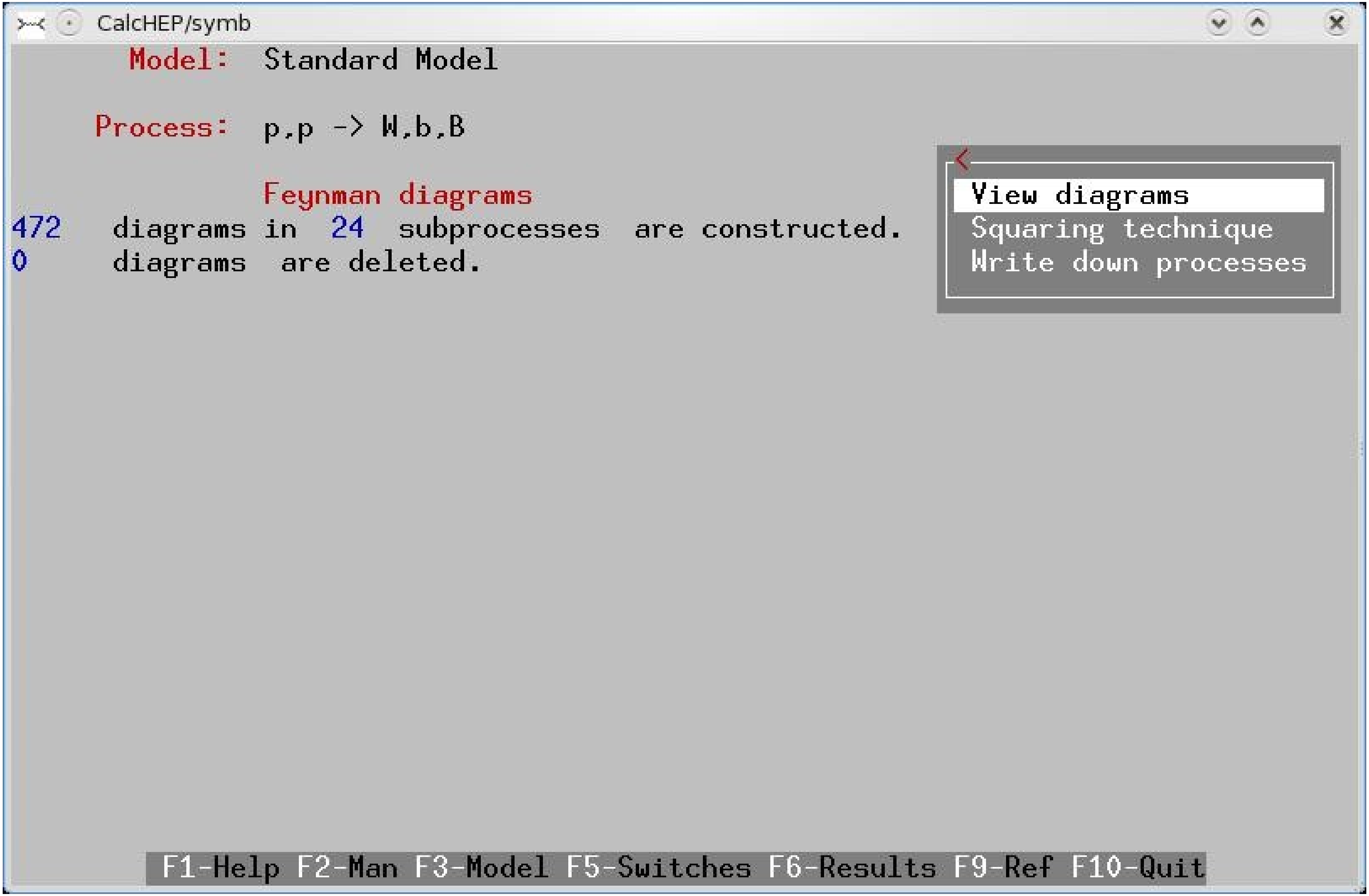
Exit menu selection (back)

Help!

Example of the symbolic calculation

```
CalcHEP/symb
      Model:  Standard Model

          List of particles (antiparticles)

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

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

Example of the symbolic calculation



Example of the symbolic calculation

CalcHEP/symb

Model: Standard Model

Process: p,p -> W,b,B

Feynman diagrams

472 diagrams in 24 subprocesses are constructed.
0 diagrams are deleted.

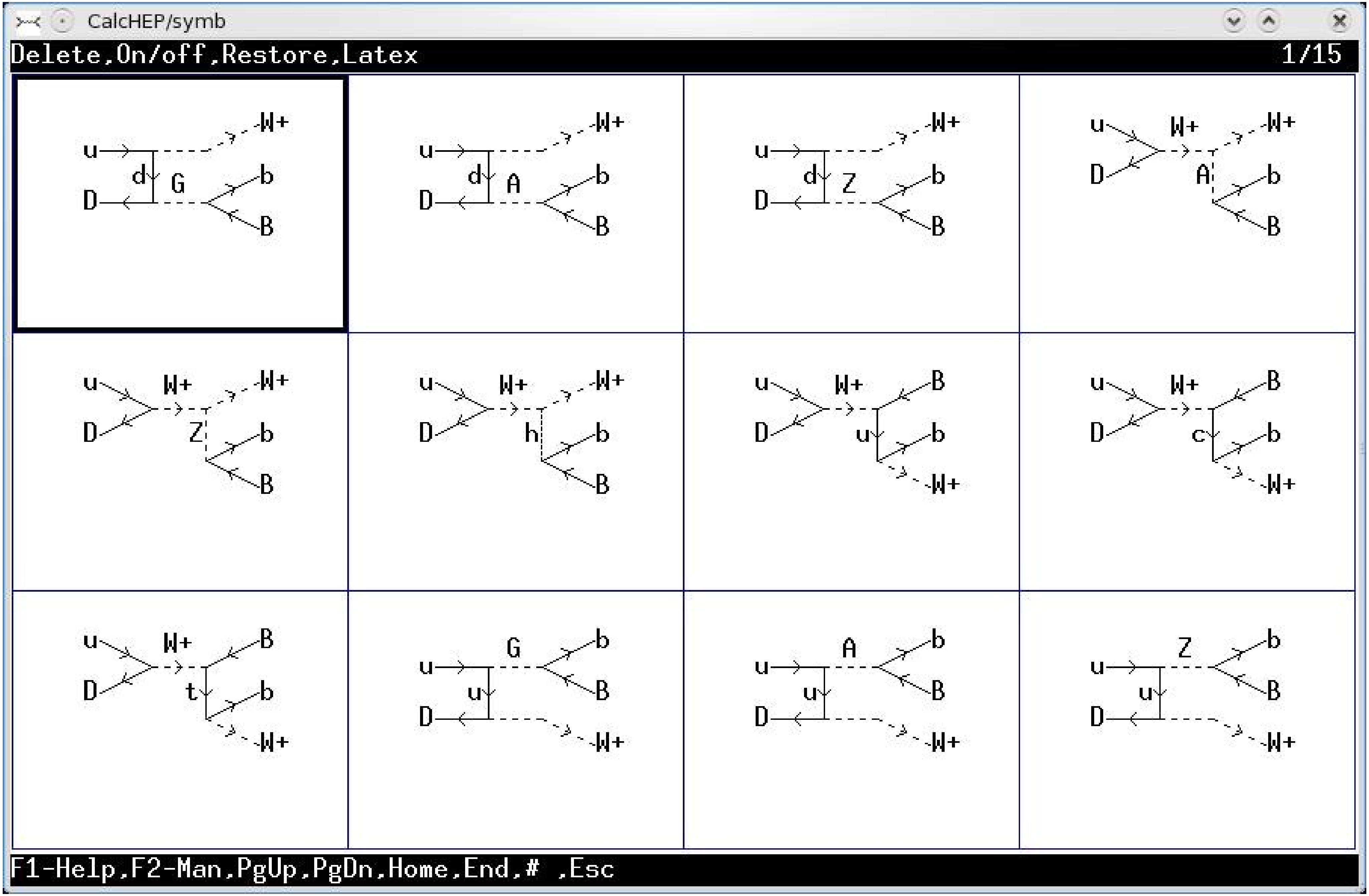
View diagrams

NN	Subprocess	Del	Rest
1	u,D -> W+,b,B	0	15
2	u,S -> W+,b,B	0	16
3	u,B -> W+,b,B	0	26
4	U,d -> W-,b,B	0	15
5	U,s -> W-,b,B	0	16
6	U,b -> W-,b,B	0	26
7	d,U -> W-,b,B	0	15
8	d,C -> W-,b,B	0	16
9	D,u -> W+,b,B	0	15
10	D,c -> W+,b,B	0	16
11	s,U -> W-,b,B	0	16

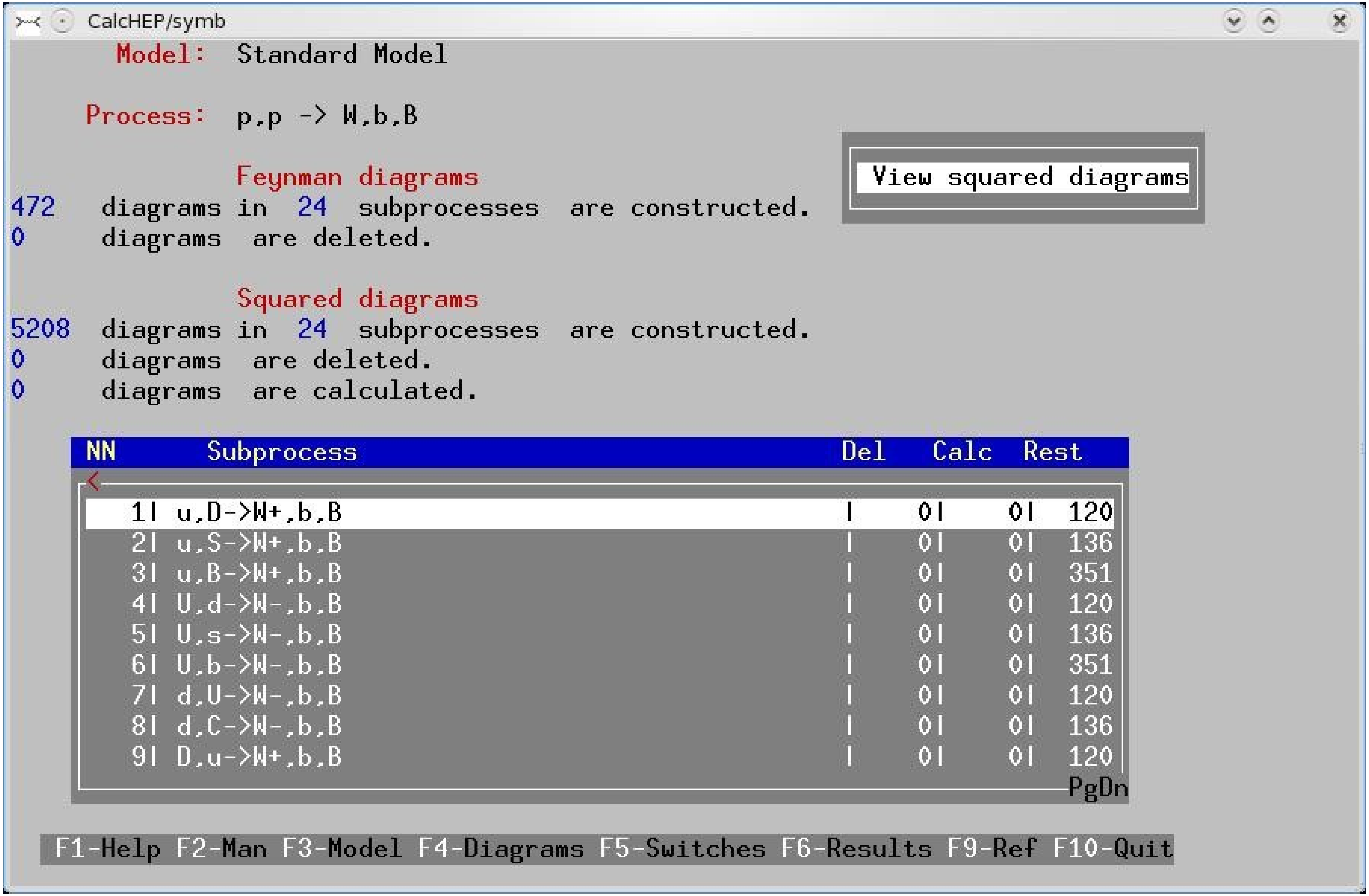
PgDn

F1-Help F2-Man F3-Model F5-Switches F6-Results F7-Del F8-UnDel F9-Ref F10-Quit

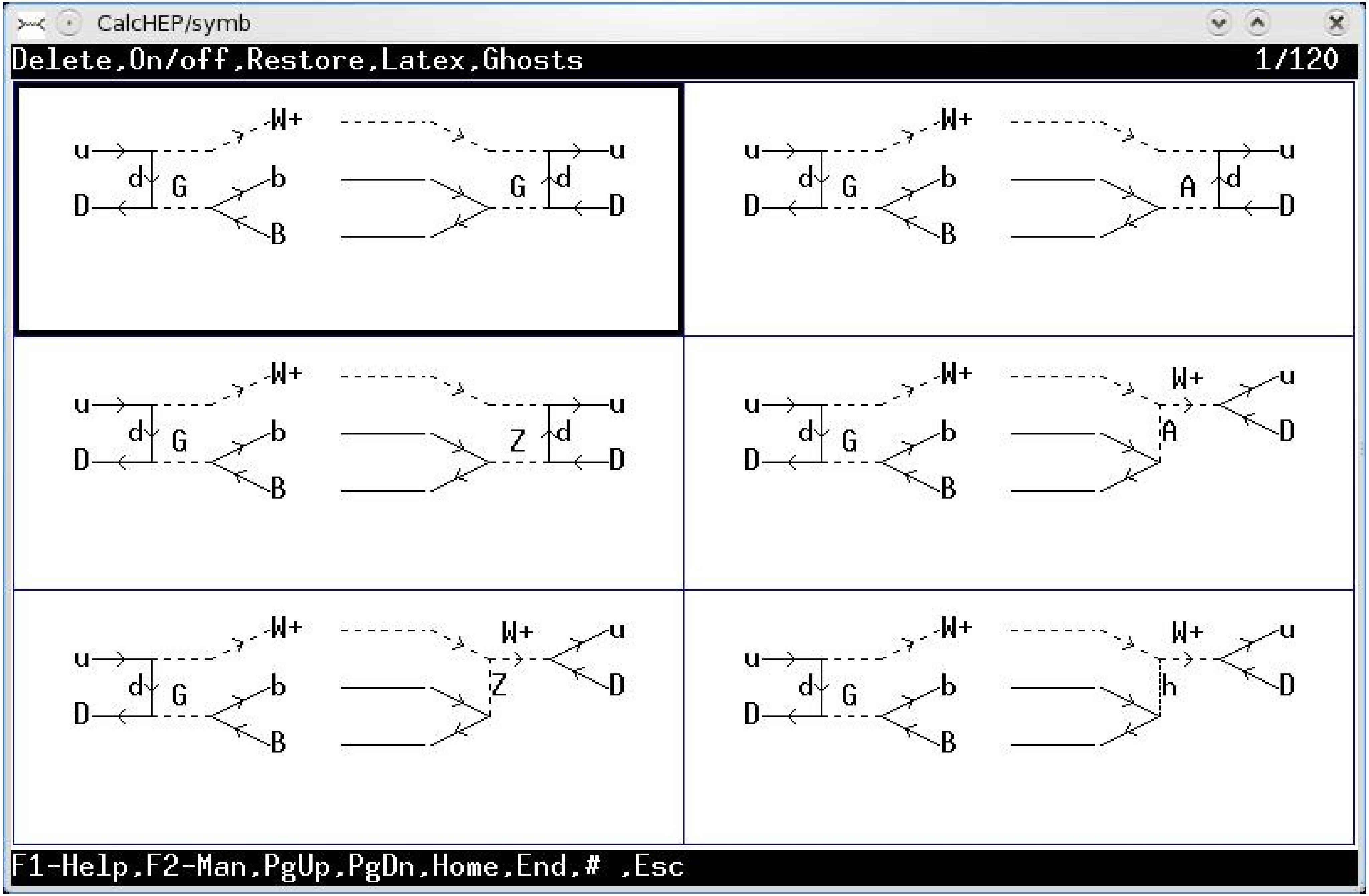
Example of the symbolic calculation



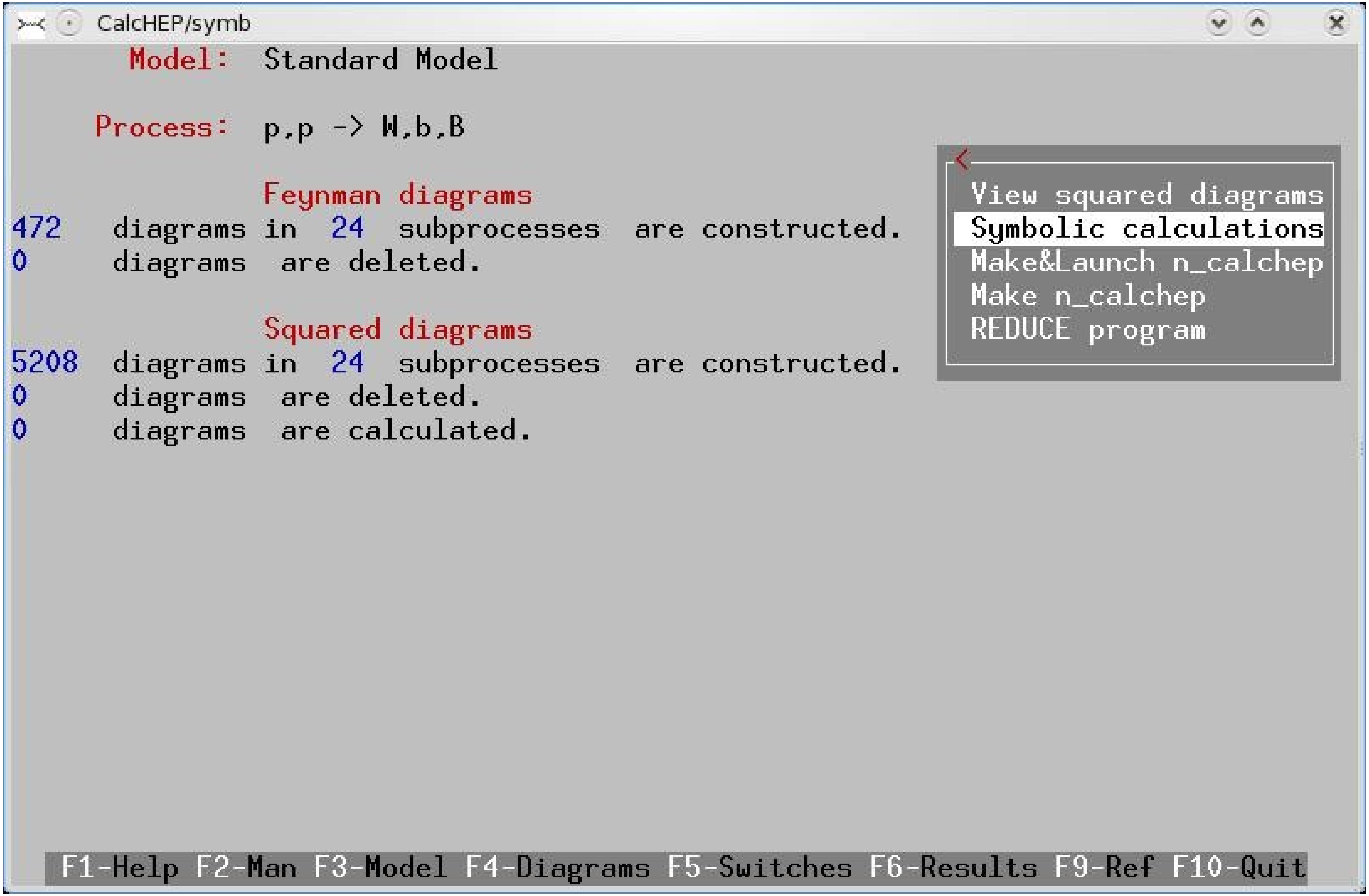
Example of the symbolic calculation



Example of the symbolic calculation



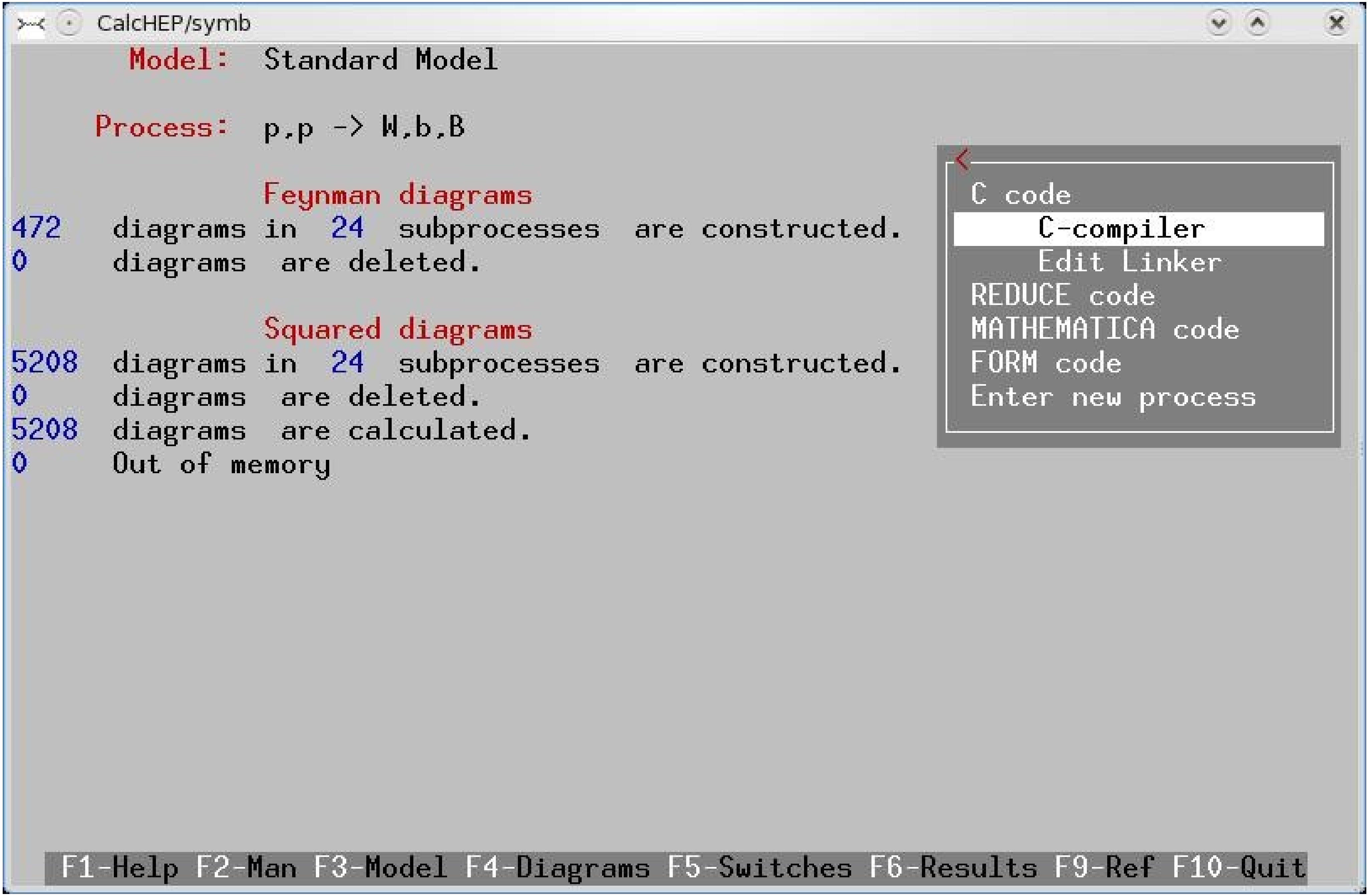
Example of the symbolic calculation



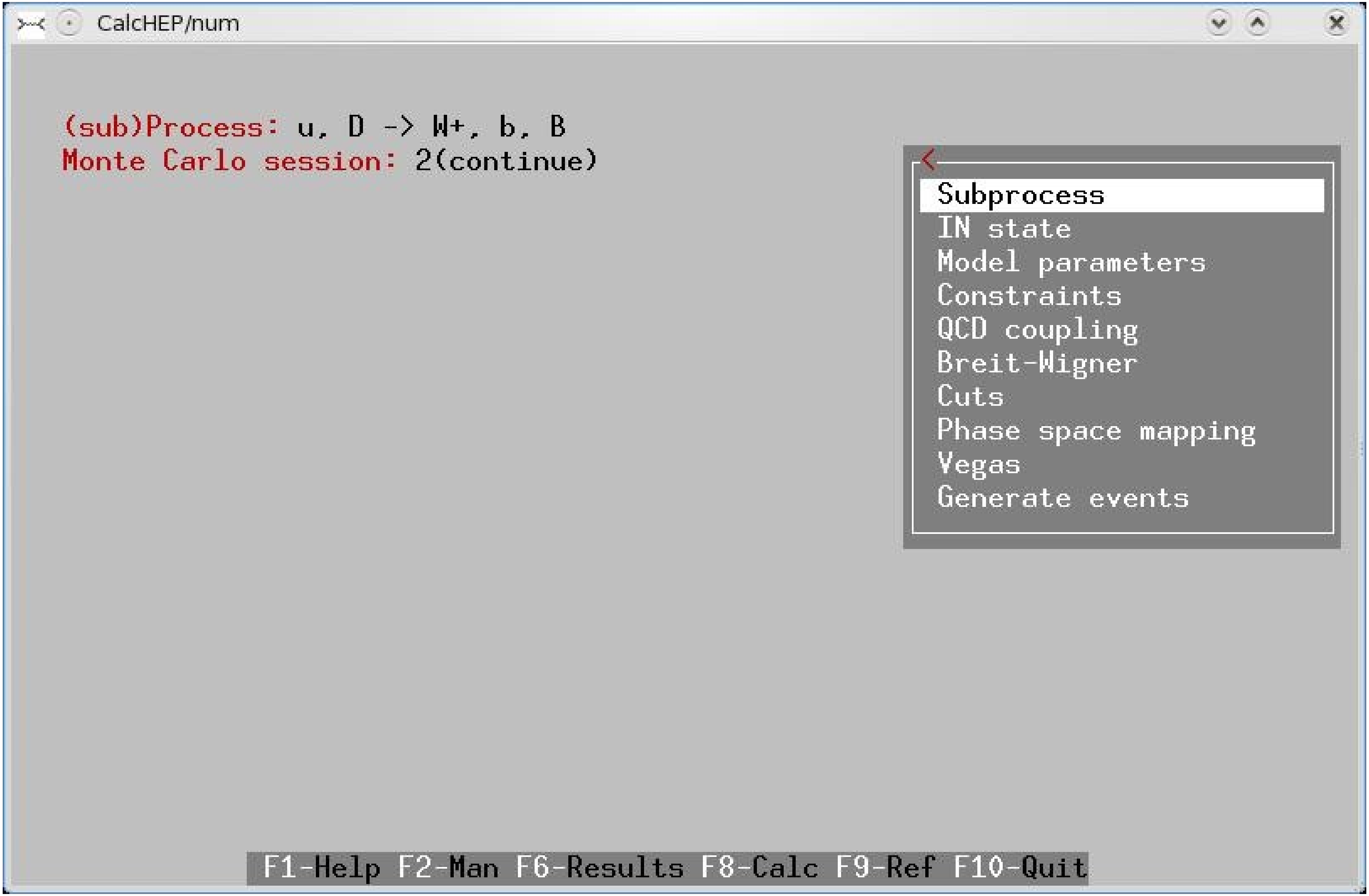
Example of the symbolic calculation

```
CalcHEP/symb

     Model:   Standard Model

   Process:   p,p -> W,b,B

              Feynman diagrams
472   diagrams in  24  subprocesses  are constructed.
0     diagrams  are deleted.

              Squared diagrams
5208  diagrams in  24  subprocesses  are constructed.
0     diagrams  are deleted.
5208  diagrams  are calculated.
0     Out of memory

 C code
     C-compiler
     Edit Linker
 REDUCE code
 MATHEMATICA code
 FORM code
 Enter new process

F1-Help F2-Man F3-Model F4-Diagrams F5-Switches F6-Results F9-Ref F10-Quit
```

Example of the symbolic calculation



Numerical part of CalcHEP



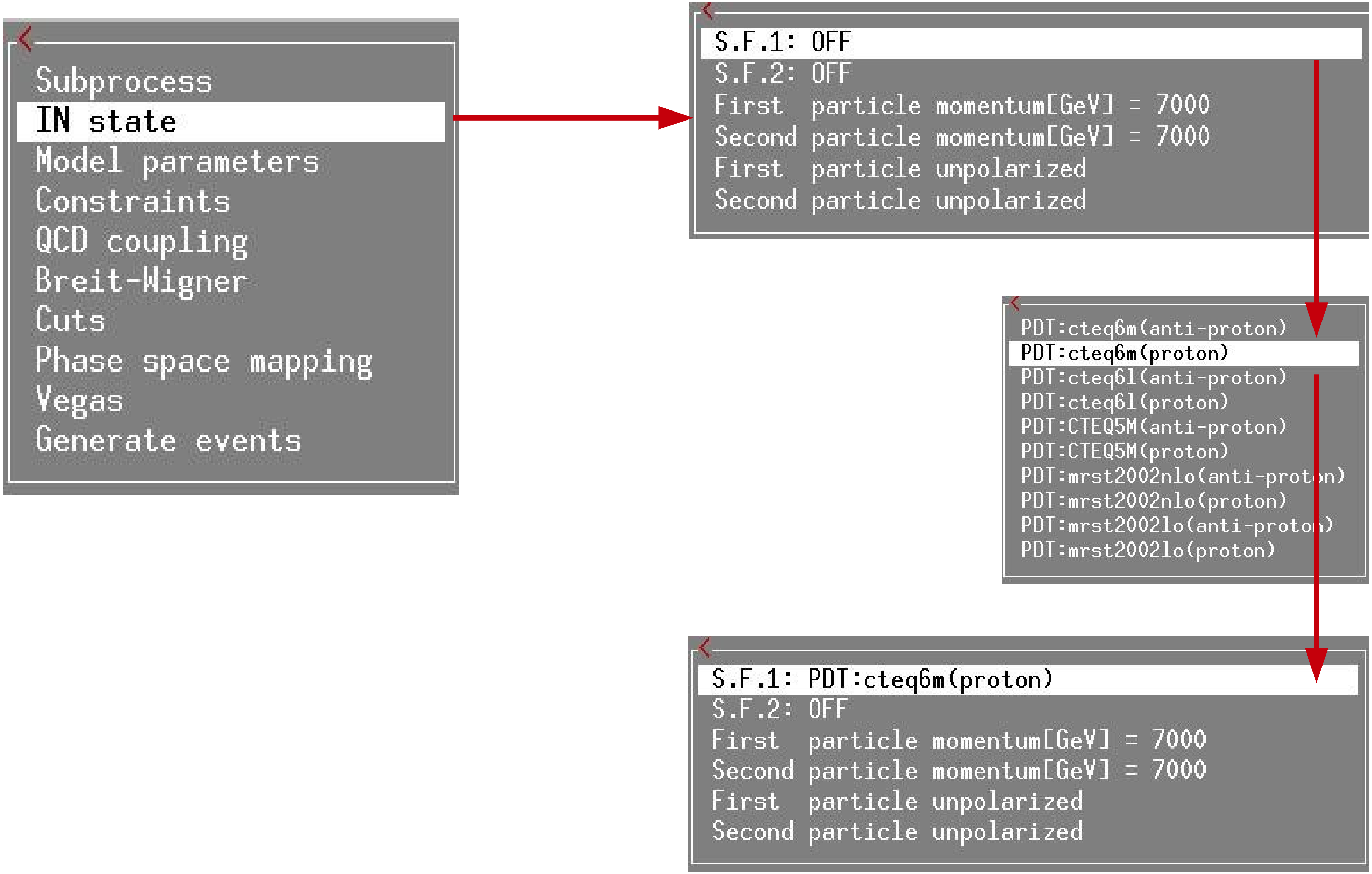
subprocess menu

- Subprocess
- IN state
- Model parameters
- Constraints
- QCD coupling
- Breit-Wigner
- Cuts
- Phase space mapping
- Vegas
- Generate events

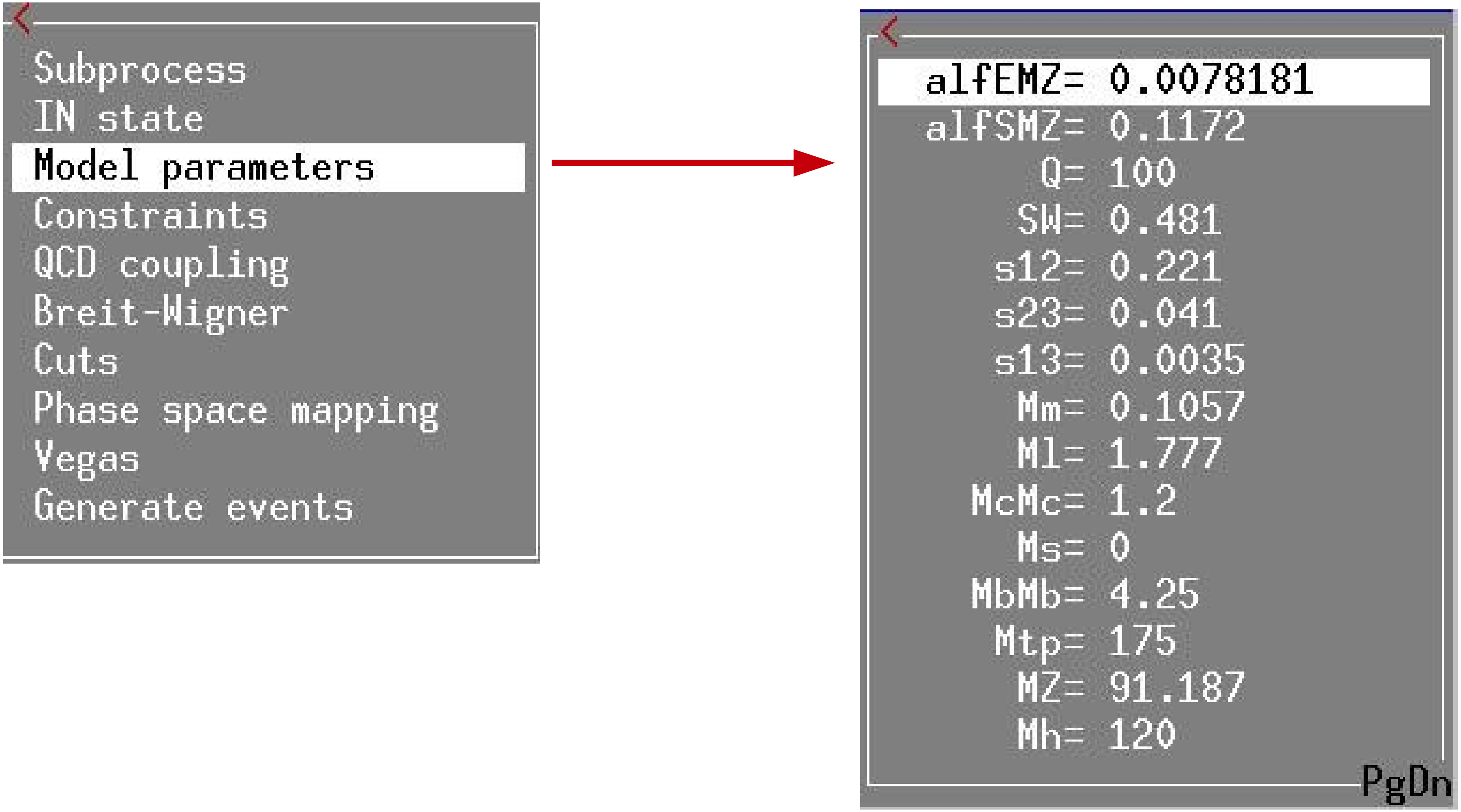
u	D	->	W+	b	B
u	S	->	W+	b	B
u	B	->	W+	b	B
U	d	->	W-	b	B
U	s	->	W-	b	B
U	b	->	W-	b	B
d	U	->	W-	b	B
d	C	->	W-	b	B
D	u	->	W+	b	B
D	c	->	W+	b	B
s	U	->	W-	b	B
s	C	->	W-	b	B
S	u	->	W+	b	B
S	c	->	W+	b	B
c	D	->	W+	b	B
c	S	->	W+	b	B

PgDn

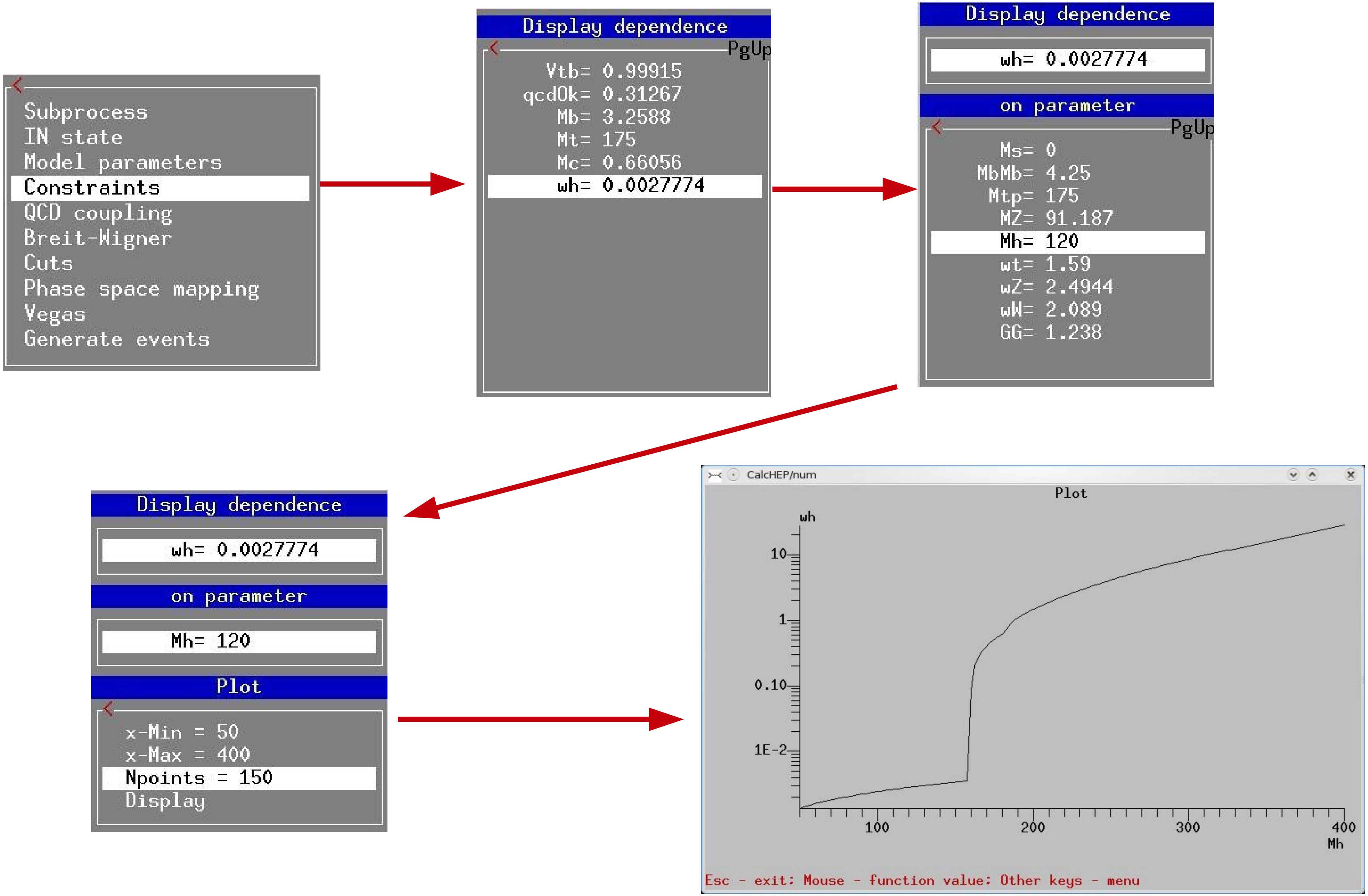
control of the initial states and parton density functions



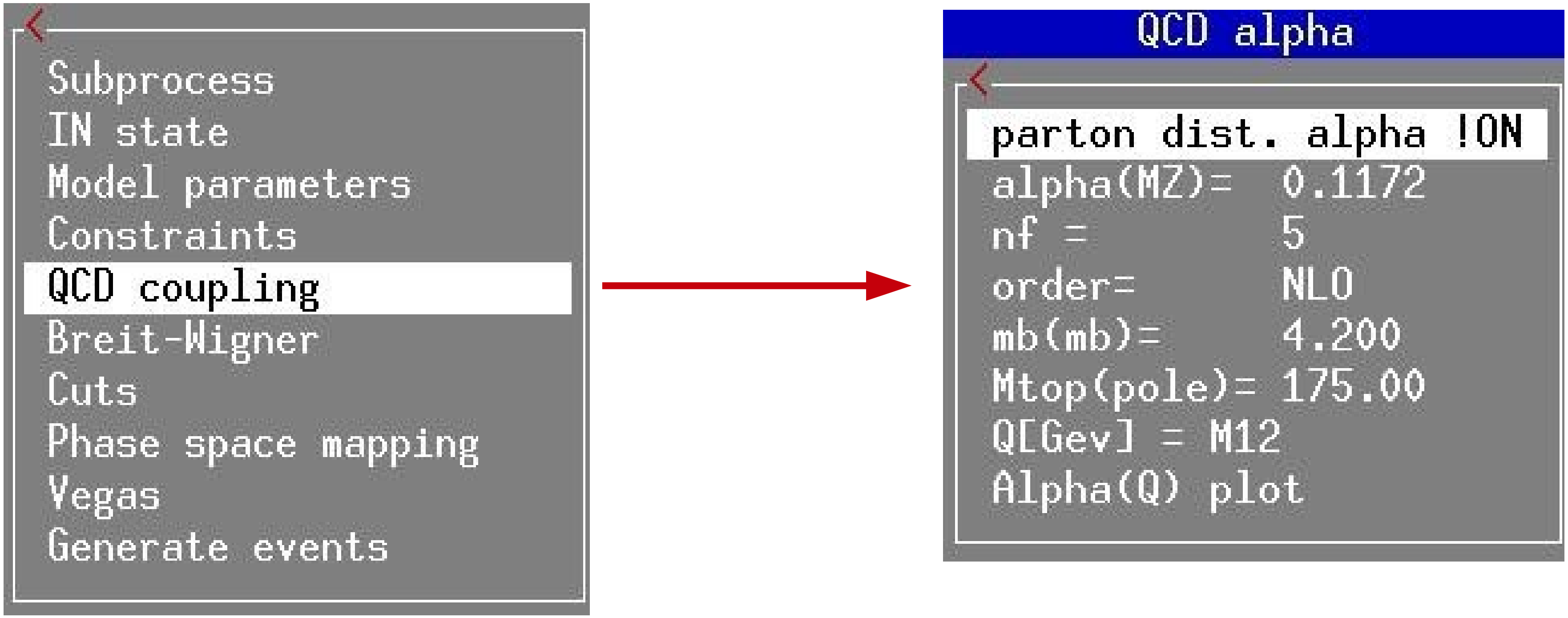
model parameters



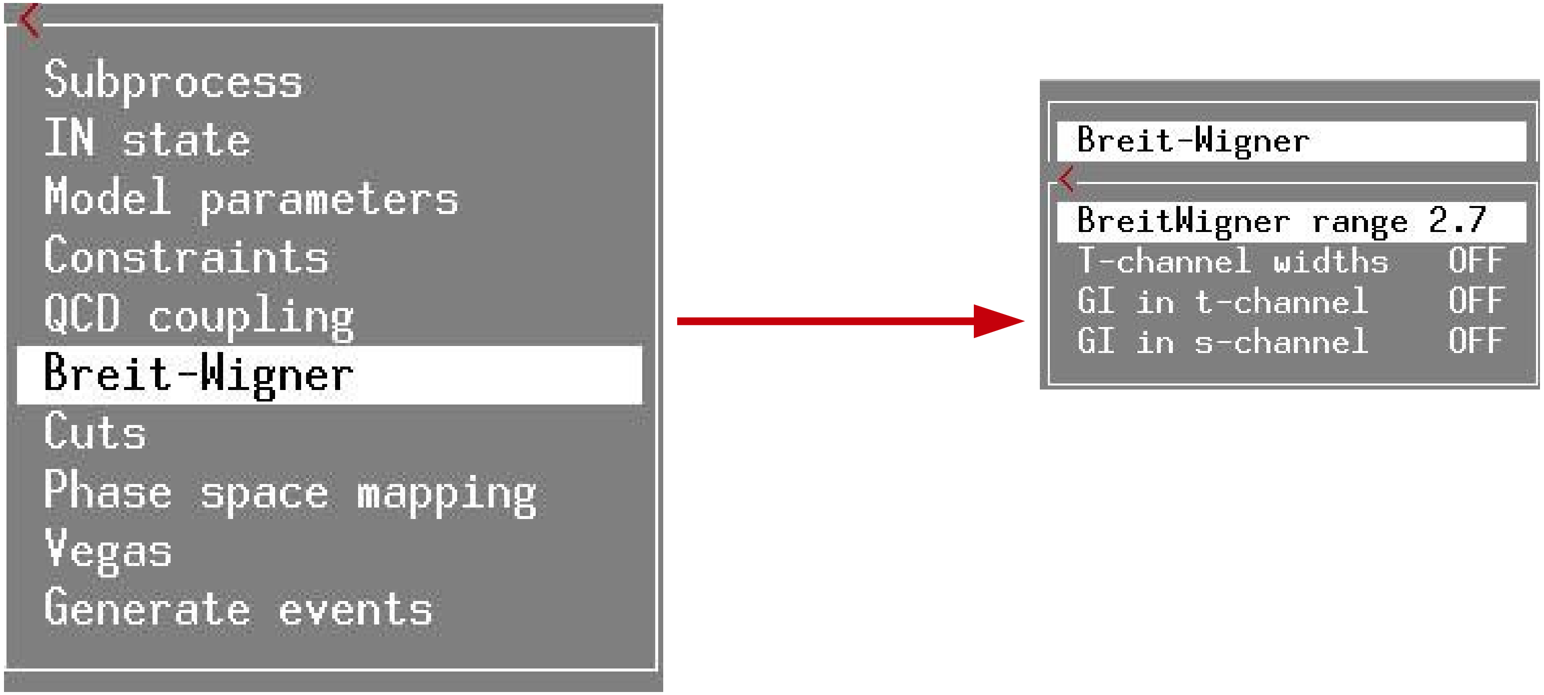
dependent parameters



QCD coupling and the scale



control of resonances



control of resonances

```
Subprocess
IN state
Model parameters
Constraints
QCD coupling
Breit-Wigner
Cuts
Phase space mapping
Vegas
Generate events
```

```
Breit-Wigner

BreitWigner range 2.7
T-channel widths    OFF
GI in t-channel     OFF
GI in s-channel     OFF
```

F1

```
n_width_1
This menu sets value R which defines range of
implementation of  Breit-Wigner formula. Namely
it is used in the region where
         |p^2-m^2|< R*m*w
For region
         |p^2-m^2|> sqrt(R^2+1)*m*w
we use  zero width propagator. In the intermediate
region constant propagator interpolates both
formulas.
   In general  Breit-Wigner leads to breaking of
gauge invariance. In its turn  it can lead to the
lost of diagram cancellation. From the other side
just in the point p^2=m^2 the contribution of pole

diagram  have to be gauge invariant. Thus at this

pont cancellation between pole and non-pole diagra
ms
is not expected. We assume that close to pole the
problem also is not so serious. But far from the p
ole
we ignore width and restore gauge invariance.
```

setting kinematical cuts

- Subprocess
- IN state
- Model parameters
- Constraints
- QCD coupling
- Breit-Wigner
- **Cuts**
- Phase space mapping
- Vegas
- Generate events

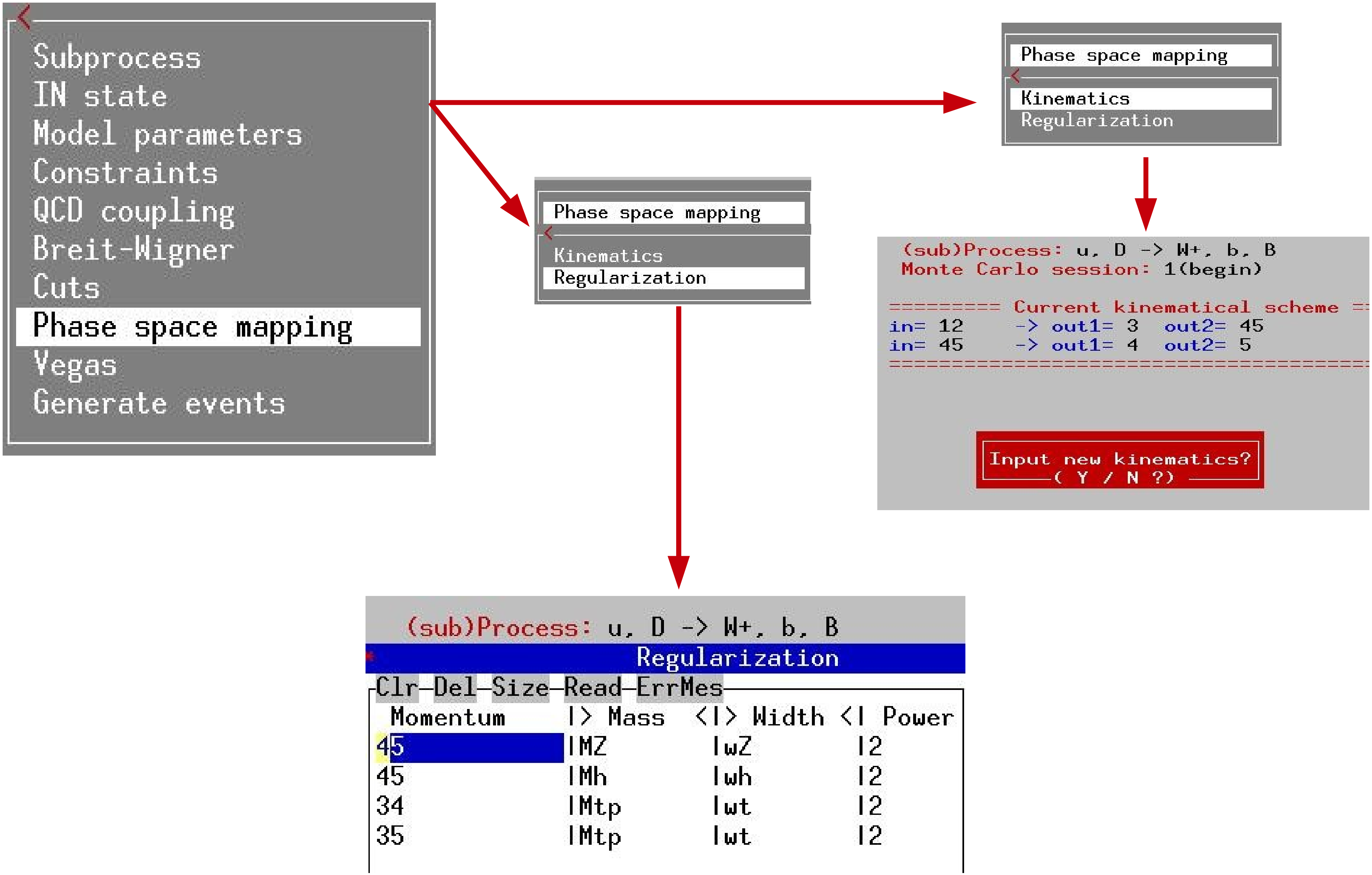
```
                    Cuts                          0
Clr-Del-Size-Read-ErrMes
   Parameter    |> Min bound <|> Max bound <
```

F1

```
n_cut
 This table  apples cuts on the phase space. A phase space function
is described in the first column. Its limits are defined and the second
and the third columns. If one of these fields is empty then a one-side
cut is applied.
 The phase space function is defined by its name which characterize
type of cut and a particle list for which the cut is applied.
For example, "T(u)" means  transverse momentum  of 'u'-quark;
T(u,D) means summary transverse momentum of quark pair.
The following  cut functions are available:
 A  - Angle  in degree units;
 C  - Cosine of angle;
 J  - Jet cone angle;
 E  - Energy of the particle set;
 M  - Mass of the particle set;
 P  - Cosine in the rest frame of pair;
                                                                  PgDn
```

```
                    Cuts                          5
Clr-Del-Size-Read-ErrMes
   Parameter    |> Min bound <|> Max bound <
T(b)            |20            |
T(B)            |20            |
N(b)            |-5            |5
N(B)            |-5            |5
J(b,B)          |0.5           |
```

phase-space mapping



integration over the phase space

```
Subprocess
IN state
Model parameters
Constraints
QCD coupling
Breit-Wigner
Cuts
Phase space mapping
Vegas
Generate events
```

```
Vegas

nSess_1   = 5
nCalls_1 = 100000
nSess_2   = 5
nCalls_2 = 100000
Set  Distributions
*Start integration
Display Distributions
Clear statistic
Freeze grid          OFF
Clear  grid
```

Distributions

Clr-Del-Size-Read-ErrMes

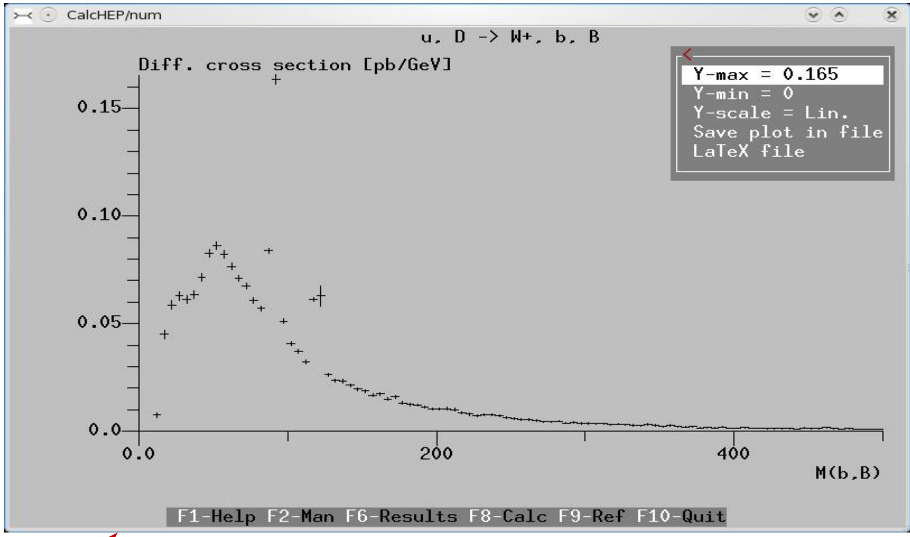
Parameter_1	Min_1	Max_1	Parameter_2	Min_2	Max_2
T(b)	0	200			
T(B)	0	200			
N(b)	-5	5			
N(B)	-5	5			
M(b,B)	0	500			
M(W+,b)	0	500			
T(b)	0	500	M(b,B)	0	500

```
Vegas

nSess_1   = 5
nCalls_1 = 100000
nSess_2   = 5
nCalls_2 = 100000
Set  Distributions
*Start integration
Display Distributions
Clear statistic
Freeze grid          OFF
Clear  grid
```

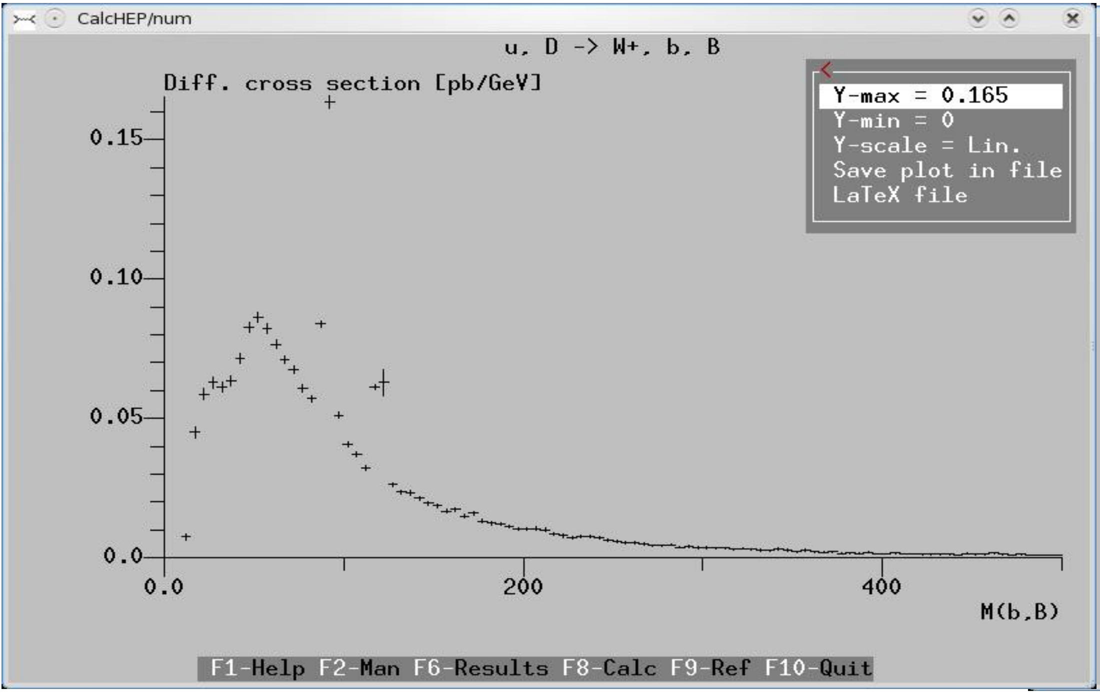
(sub)Process: u, D -> W+, b, B
Monte Carlo session: 2(continue)

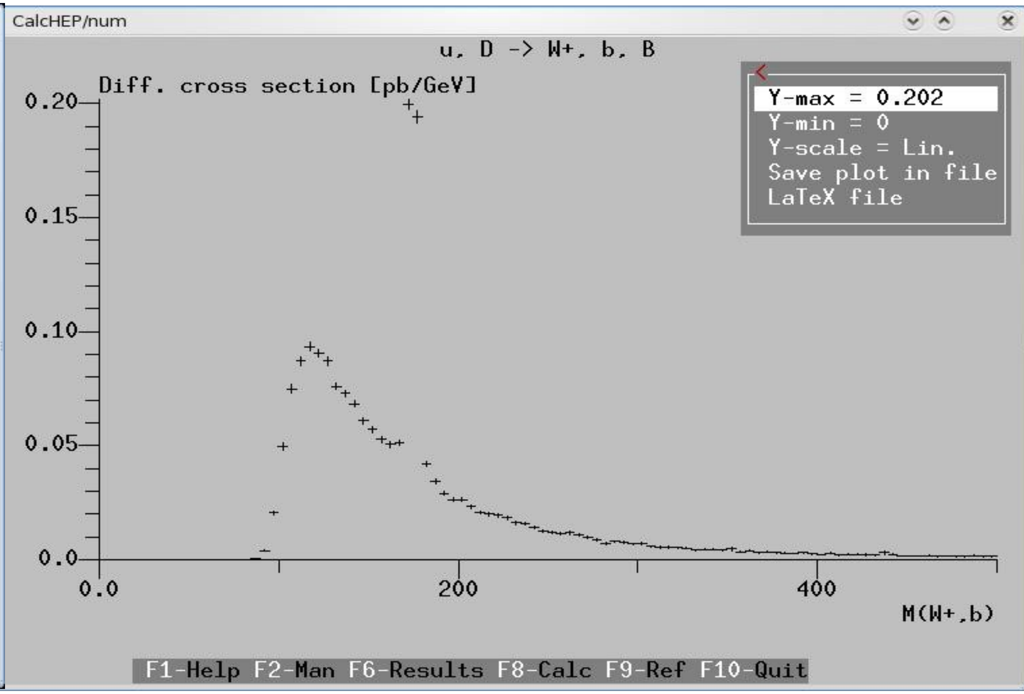
#IT	Cross section [pb]	Error %
6	9.5931E+00	7.10E-01
7	9.5686E+00	6.79E-01
8	9.5669E+00	6.82E-01
9	9.6892E+00	7.93E-01
10	9.6267E+00	7.51E-01
1	9.7757E+00	7.32E-01
clear statistics.		
2	9.6557E+00	6.82E-01
3	9.7464E+00	1.38E+00
4	9.6945E+00	1.05E+00
5	9.7032E+00	7.68E-01
< >	9.7095E+00	3.74E-01

```
nSess_1   = 5
nCalls_1 = 100000
nSess_2   = 5
nCalls_2 = 100000
Set  Distributions
*Start integration
Display Distributions
Clear statistic
Freeze grid          OFF
Clear  grid
```



Resulting M_{bb} and M_{Wtb} kinematical distributions



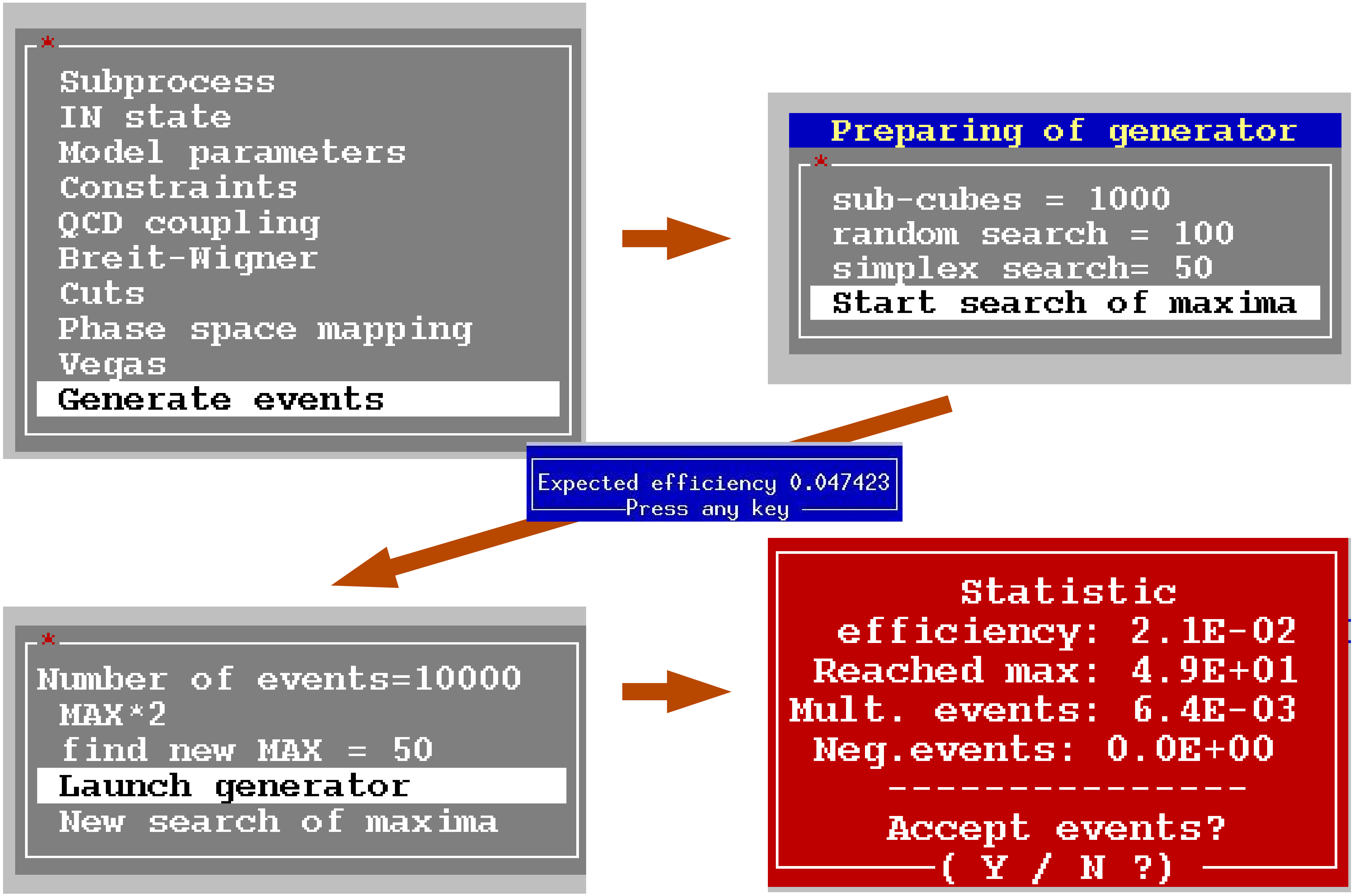


Exercise#3

1. Calculate WbB production rates at Tevatron and LHC for PT b-jet > 20 GeV, b-Jet separation > 0.5, max pseudorapidity < 3

2. Plot bb- and Wb invariant mass distributions for PT b-jet > 20 GeV and PT b-jet > 40 GeV

generation of events



GUI gives user a full control of details of symbolic/numerical session. Is there automation of calculation involving many sub-processes?

there are several useful scripts which run various loops and aimed to make a calculation easy

- ***cycle over subprocesses***
  - ***exit from the numerical session***
  - **cd results**
  - **../bin/subproc_cycle** ***lumi nmax***

requires 2 parameters:

1. luminosity

2. max number of events per process

e.g.

../bin/subproc_cycle 1000 100000

running subproc_cycle for SM model

```
../bin/subproc_cycle 0 0
#Subprocess 1 ( u, D -> W+, b, B ) Cross section = 9.6364E+00 , 0 events
#Subprocess 2 ( u, S -> W+, b, B ) Cross section = 4.0808E-01 , 0 events
#Subprocess 3 ( u, B -> W+, b, B ) Cross section = 2.3490E-04 , 0 events
#Subprocess 4 ( U, d -> W-, b, B ) Cross section = 5.7795E+00 , 0 events
#Subprocess 5 ( U, s -> W-, b, B ) Cross section = 1.0253E-01 , 0 events
#Subprocess 6 ( U, b -> W-, b, B ) Cross section = 4.3181E-05 , 0 events
#Subprocess 7 ( d, U -> W-, b, B ) Cross section = 5.8270E+00 , 0 events
#Subprocess 8 ( d, C -> W-, b, B ) Cross section = 2.1421E-01 , 0 events
#Subprocess 9 ( D, u -> W+, b, B ) Cross section = 9.5470E+00 , 0 events
#Subprocess 10 ( D, c -> W+, b, B ) Cross section = 9.1056E-02 , 0 events
#Subprocess 11 ( s, U -> W-, b, B ) Cross section = 1.0383E-01 , 0 events
#Subprocess 12 ( s, C -> W-, b, B ) Cross section = 1.2694E+00 , 0 events
#Subprocess 13 ( S, u -> W+, b, B ) Cross section = 4.1026E-01 , 0 events
#Subprocess 14 ( S, c -> W+, b, B ) Cross section = 1.2333E+00 , 0 events
#Subprocess 15 ( c, D -> W+, b, B ) Cross section = 9.3773E-02 , 0 events
#Subprocess 16 ( c, S -> W+, b, B ) Cross section = 1.2480E+00 , 0 events
#Subprocess 17 ( c, B -> W+, b, B ) Cross section = 3.4475E-03 , 0 events
#Subprocess 18 ( C, d -> W-, b, B ) Cross section = 2.1469E-01 , 0 events
#Subprocess 19 ( C, s -> W-, b, B ) Cross section = 1.2651E+00 , 0 events
#Subprocess 20 ( C, b -> W-, b, B ) Cross section = 3.4542E-03 , 0 events
#Subprocess 21 ( b, U -> W-, b, B ) Cross section = 4.3722E-05 , 0 events
#Subprocess 22 ( b, C -> W-, b, B ) Cross section = 3.3992E-03 , 0 events
#Subprocess 23 ( B, u -> W+, b, B ) Cross section = 2.3111E-04 , 0 events
#Subprocess 24 ( B, c -> W+, b, B ) Cross section = 3.4543E-03 , 0 events
Sum of distributions is stored in file distr_7_30
Total Cross Section 37.45843711 [pb]
see details in prt_7 - prt_30 files
```

running subproc_cycle for SM(CKM=1) model

```
../bin/subproc_cycle 0 0
#Subprocess 1 ( u, D -> W+, b, B ) Cross section = 9.8549E+00 , 0 events
#Subprocess 2 ( U, d -> W-, b, B ) Cross section = 5.6112E+00 , 0 events
#Subprocess 3 ( d, U -> W-, b, B ) Cross section = 5.6156E+00 , 0 events
#Subprocess 4 ( D, u -> W+, b, B ) Cross section = 9.9153E+00 , 0 events
#Subprocess 5 ( s, C -> W-, b, B ) Cross section = 1.5792E+00 , 0 events
#Subprocess 6 ( S, c -> W+, b, B ) Cross section = 1.3757E+00 , 0 events
#Subprocess 7 ( c, S -> W+, b, B ) Cross section = 1.3475E+00 , 0 events
#Subprocess 8 ( C, s -> W-, b, B ) Cross section = 1.6218E+00 , 0 events
Sum of distributions is stored in file distr_1_8
Total Cross Section 36.9212 [pb]
```

Note the d- and s- quarks IDs

```
d-quark        |d   |D   |81       |1      |0      |0      |3     |     |d
u-quark        |u   |U   |2        |1      |0      |0      |3     |     |u
s-quark        |s   |S   |83       |1      |0      |0      |3     |     |s
```

For SM(CKM=1) model PDF of d- and s- quarks is redefined

Accessing your results

- ***results are stored in "results" directory***
- ***output files:***
  - **n_calchep** — ***numerical module***
  - **prt_*nn*** — ***protocol***
  - **distr_*nn_mm*** — ***summed distributions***
  - **distr_*nn*** — ***individual distribution***
  - **events_*nn.txt*** — ***events file***
  - **list_prc.txt** — ***list of processes***
  - **qnumbers** — ***qnumbers – PYTHIA input with new prt definitions***
  - **session.dat** — ***current session status – format is similar to*** **prt_*nn*** ***one***
- ***for every new process the "results" directory is offered to be renamed or removed***

protocol prt_*nn*

```
    CalcHEP kinematics module
 The session parameters:

#Subprocess 1 ( u, D -> W+, b, B )
#Session_number 1
#Initial_state  inP1=7.000000E+03  inP2=7.000000E+03
 Polarizations= { 0.000000E+00  0.000000E+00 }
  StrFun1="PDT:cteq6m(proton)" 2212
  StrFun2="PDT:cteq6m(proton)" 2212

#Physical_Parameters
    alfEMZ = 7.818060999999999E-03
    alfSMZ = 1.172000000000000E-01
............................................
............................................
#Cuts
*** Table ***
 Cuts
  Parameter   |> Min bound <|> Max bound <|
T(b)          |20           |
T(B)          |20           |
............................................
............................................
#Regularization
*** Table ***
 Regularization
 Momentum     |> Mass  <|> Width <| Power|
45            |MZ       |wZ       |2
45            |Mh       |wh       |2
............................................
............................................
#END
===================================
 #IT  Cross section [pb]  Error %    nCall   chi**2
  1      2.0373E+00       3.30E+01    20000
  2      8.6164E+00       2.86E+01    20000
............................................
............................................
```

useful scripts for numerical session

see calchep_2.x.x/bin/ directory

- ***subproc_cycle*** ***../bin/subproc_cycle 1000 100000***
- ***sum_distr*** ***../bin/sum_distr distr_2 distr_3 > distr_sum***
- ***show_distr*** ***../bin/show_distr distr_sum***
- ***tab_view*** ***../bin/tab_view < tab_1.txt***
- ***events2tab***
- ***gen_events***
- ***name_cycle***
- ***pcm_cycle***

Exercise#4
learn how to use:
1) gen_events
2) events2tab
3) tab_view

scripts for numerical session

- ***events2tab***

Parameters:
1- name of variable,
2- minimum limit,
3- maximum limit,
4- number of bins(<=300).
File with events must be passed to input.

../bin/events2tab "T(b)" 1 100 200 < events_1.txt >tab.txt
../bin/tab_view < tab.txt

- ***name_cycle***

1: Name of parameter
2: Initial value
3: Step
4: Number of steps

../bin/name_cycle Mh 100 10 11

scripts above became a part of calchep_batch interface – to be discussed in the following lecture(s)