Practical introduction into CalcHEP

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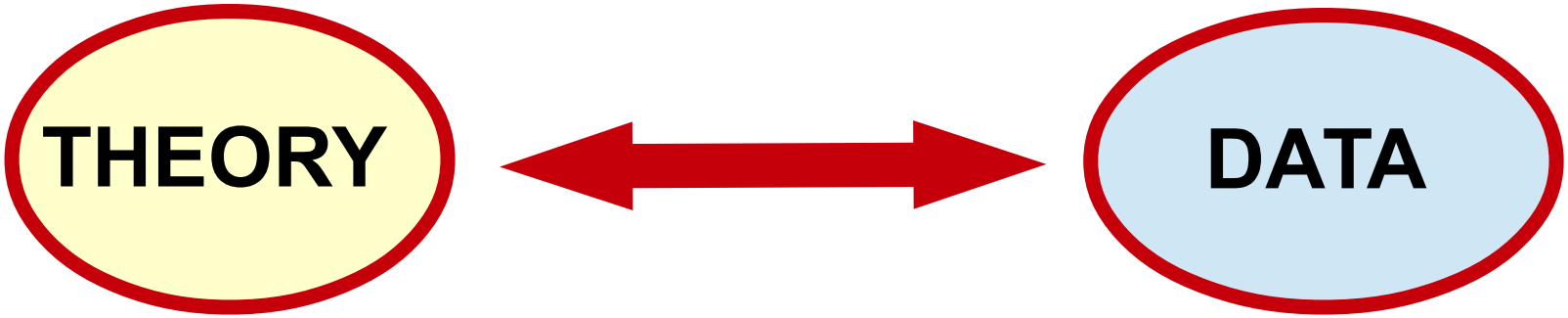
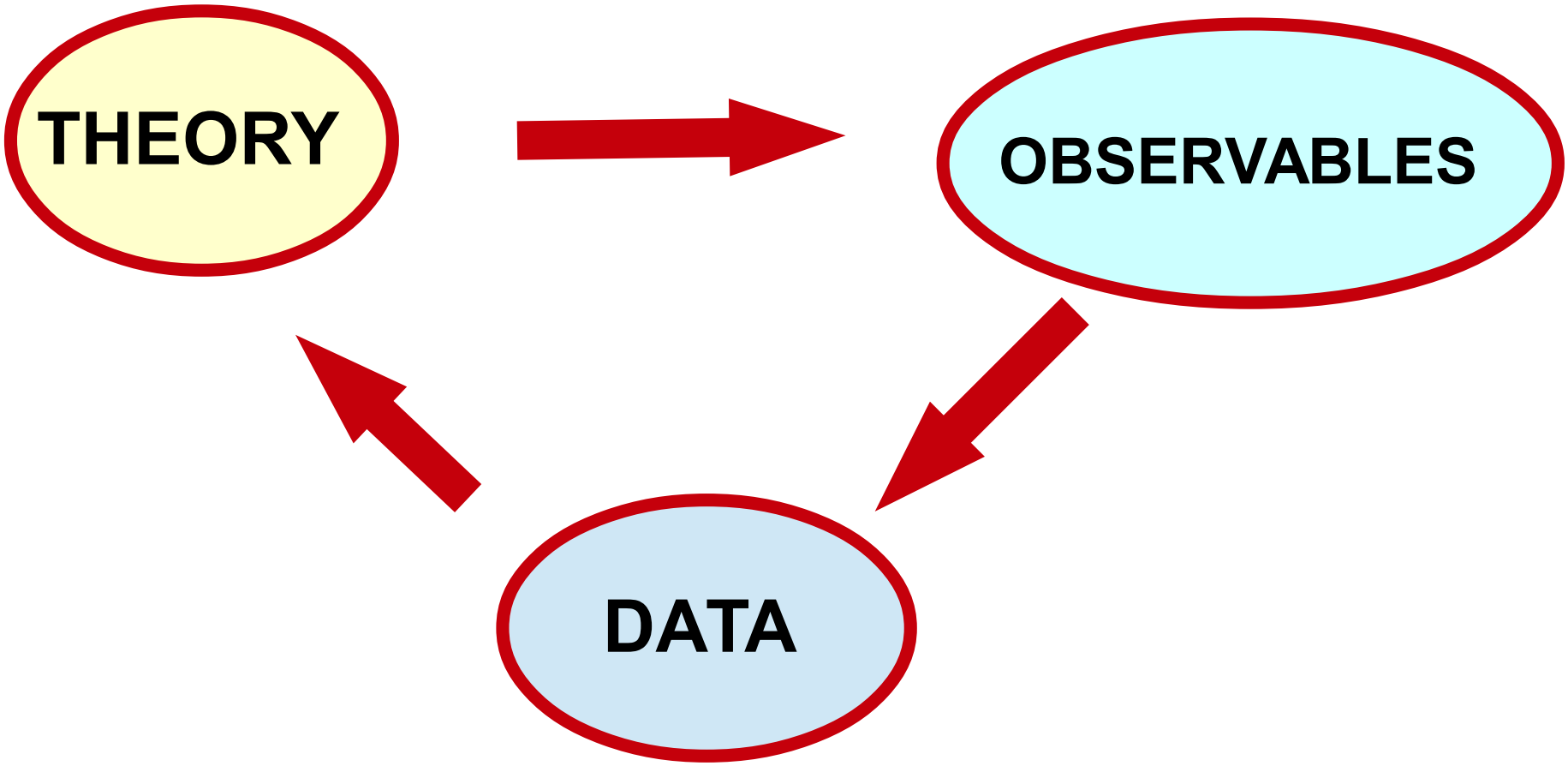
Dartmouth-TRIUMF-University of Washington High-Energy Physics/Cosmology Tools Bootcamp

23-27 October 2017

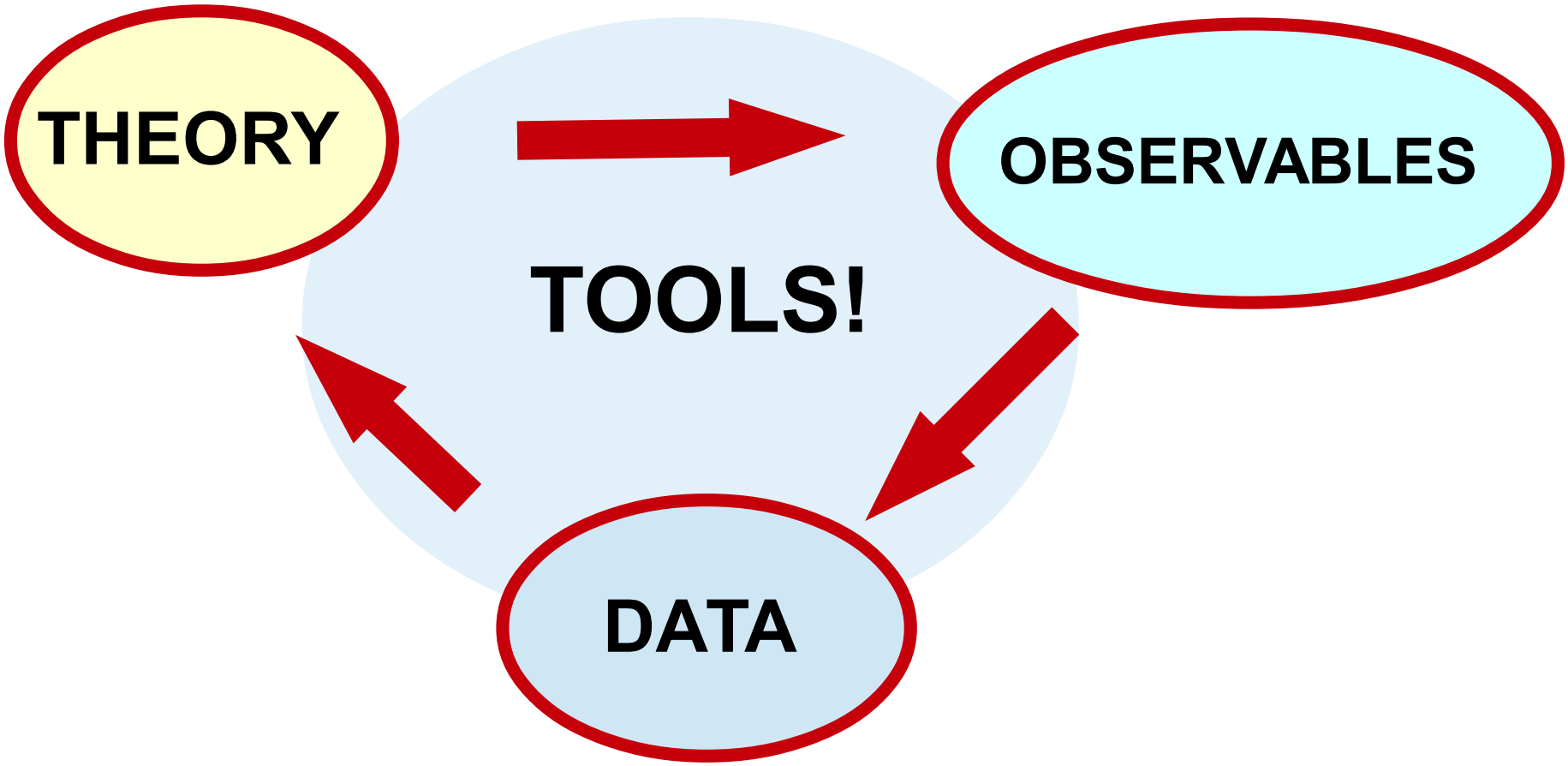
To test theory we need
theory ↔ data link
which is actually a non-trivial story



theory ↔ data requires observables to be compared with data



theory ↔ data requires observables to be compared with data and we need TOOLS to do this!



Tools for theory → observables link

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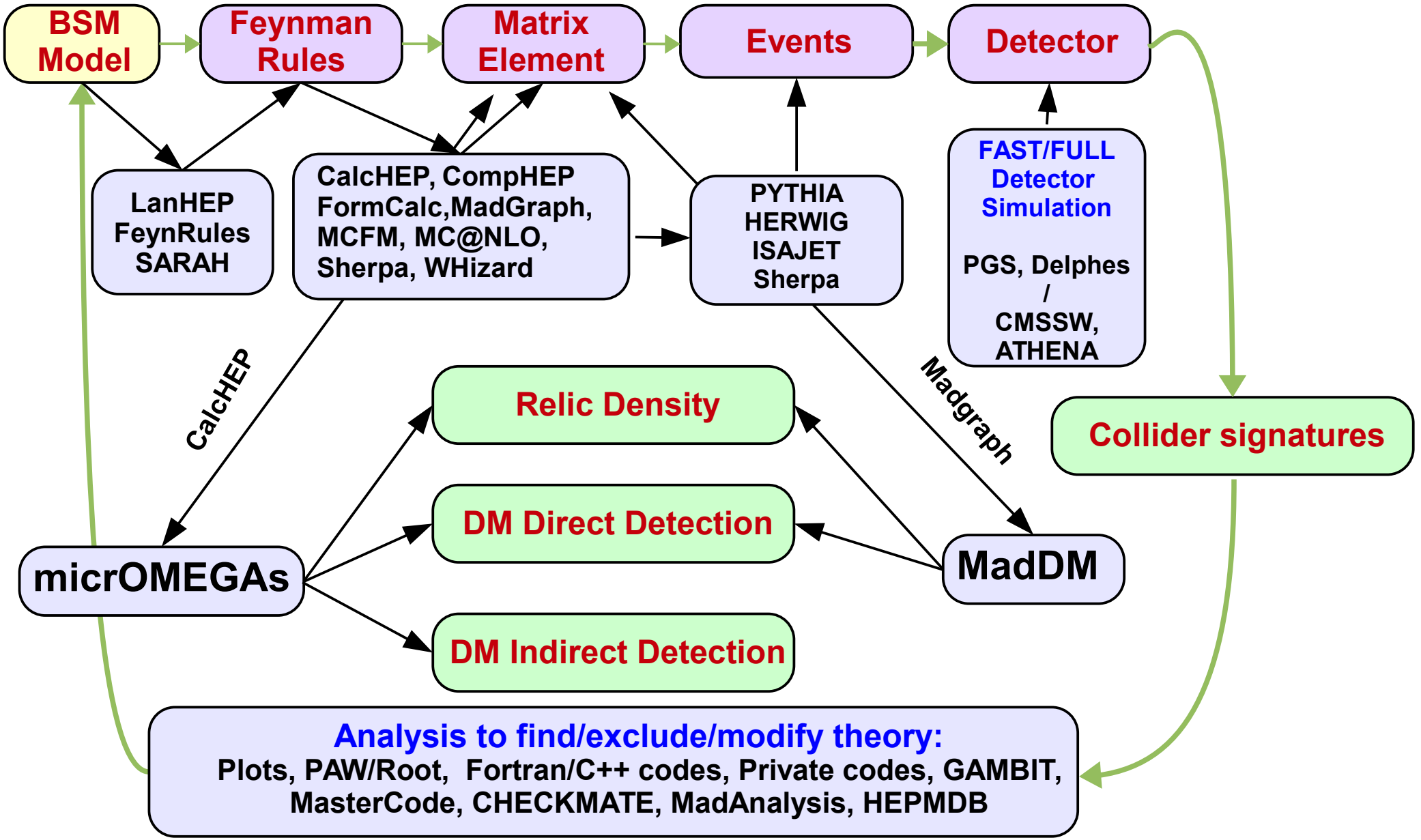

- ***Do ask*** *questions* ***during*** *the lecture*

- *There are* ***exercises (ex#)*** *for you which will be able to do during this course*

Lecture I:

Introduction into CalcHEP

- *system requirements & linux primer*
- *installation*
- *models and symbolic session*

Lecture II:

Introduction into CalcHEP

- *numerical session and kinematical distributions*
- *event generation*
- *CalcHEP Batch Interface*

Lecture III:

- LanHEP
- HEPMDB
- PhenoData
- advanced topics

Web page & contacts

- ***The WEB page of CalcHEP***
  http://theory.npi.msu.su/~pukhov/calchep.html
  arXiv:1207.6082

- ***e-mails***
  calchep@googlegroups.com
  a.belyaev@soton.ac.uk

Prerequisites

- ***basic knowledge of Linux/UNIX***
  - ***See Linux primer – linux_primer.pdf (thanks to Elena Vataga)***

Getting Started with Linux

UNIVERSITY OF Southampton

Navigating the Linux Filesystem

The Linux filesystem is a tree-like hierarchy of directories and files.

- *When you first login to a Linux machine, you find yourself in your home directory.*
- *A path is a way you need to follow in the tree structure to reach a given file. An absolute path name is one beginning with the "/" character. A relative path is a path relative to your working directory*

Command	Description
pwd	"Print Working Directory". Shows the current location in the directory tree
cd *dir*	Change the current directory to *dir* Ex: `cd /user/src/redhat`
cd .. **cd -** **cd**	Move one directory up Return to previous directory Return to your home directory
ls	List all files in the current directory

Command	Description
tree	List contents of directories in a tree-like format

Working with Files and Directories

Command	Description
mkdir	Make directory
rmdir	Remove an empty directory
cp *source dest* **cp -p** ...	Copy a file Copy a file, preserving its attributes like mode, ownership, timestamps
mv *source dest*	Move a file to a new location or rename it.
rm **rm -r**	Delete a file Remove directories and their contents recursively

Command	Description
less	More sophisticated version of more (can scroll backwards and has many more options)
dos2unix	the program that converts plain text files in DOS/MAC format to UNIX format

Getting Help

1. Help on most Linux commands is build into the commands themselves:

   `$ ls --help`

2. The best source of information for most commands is the online manual pages, known as "man pages" for short:

   `$ man ls`

   - *To search for a particular word within a man page, type "/word". To quite from a man page just type the "q" key.*

3. Sometimes you might not remember the name of Linux command and you need to search for

- ***gcc compiler***
- ***gfortran compiler***

CalcHEP

was born as a CompHEP in 1989: MGU-89-63/140

- **Author(s)**
  - **Alexander Pukhov, AB, Neil Christensen**

    (AB and Neil Christensen have joined the project in 2009)
    http://theory.npi.msu.su/~pukhov/calchep.html
- **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, parton-level events, ...**
- **Analogous packages (matrix element generators)**
  http://www.ippp.dur.ac.uk/montecarlo/BSM/
  - **CompHEP (Boos et al)**
  - **MadGraph/MadEvent (Maltoni, Stelzer et al)**
  - **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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- 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 the time limit

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 Publications&Lectures 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 Current version 3.6.30(updated 21.09.2017) New Options Archive

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Models:
MSSM_10.14(15.10.2014) NMSSM_8.15(25.08.2015) CPVMSSM_10.14(16.10.2014) 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

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new options and writeup!

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Connected to launchpad system

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_3.*x.x*.tgz**
  - **cd calchep_3.*x.x***
  - **make**

    the current version is 3.*x.x* = 3.6.30
- **Create work directory**
  - **From calchep_3.*x.x* directory (e.g. ../calc_work)**

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

    (see *getFlags* file)

ex#1: Install CalcHEP

Compilation, potential problem and its solution

- **To compile the CalcHEP source code you need:**
  C compiler, the X11 graphics library and the X11 include files
  "CalcHEP is compiled successfully and can be started "
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- **Compilation for High Precision Calculations**
  - **Intel C compiler has a _Quad type, -D QUAD has to be added to FlagsForSh as**
    CFLAGS="-D_QUAD_ -fPIC -fsigned-char -Qoption,cpp,--extended_float_type"

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    CFLAGS="-D_QUAD_ -fPIC -fsigned-char -Qoption,cpp,--extended_float_type"
- **Potential problem in compilation**
  - **The most frequent compilation problem is due to the absence of the X11 include files; CalcHEP still compiles, however, it only runs in non-interactive mode ./calchep will give**

    Error: You have launched the interactive session for a version of CalcHEP that has been compiled without the X11 library. Presumably, the X11 development package is not installed on your computer.
  - **the following additional package should be install to run CalcHEP in GUI mode**
    - **libX11-devel for Fedora/Scientific, Darwin(MAC)**
    - **libX11-dev for Ubuntu/Debian**
    - **xorg-x11-devel for SUSE**

Starting CalcHEP

- **cd ../calc_work**

- ***Files:***

bin -> ..... /calchep_3.x.x/bin
calchep
calchep_batch
calchep.ini
models/
results/
tmp/

- ***Start:***

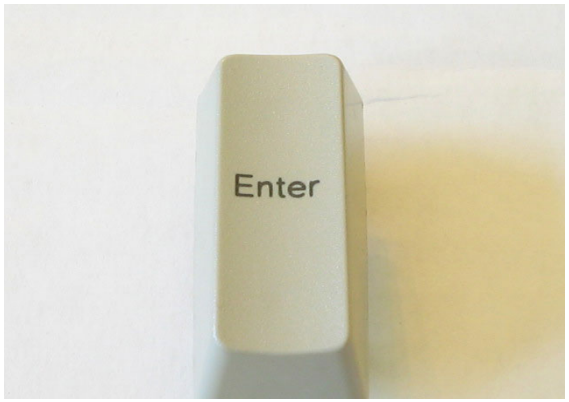
./calchep

Starting CalcHEP

CalcHEP_3.6.30/symb

```
   CalcHEP - a package for Calculation in High Energy Physics
           Version 3.6.30: Last correction September 21, 2017


 Authors: Alexander Pukhov(Skobeltsyn Institute of Nuclear Physics,Moscow)
          Alexander Belyaev(University of Southampton)
          Neil Chistensen (University of Pittsburgh)

 For contacts:    email       : <calchep@googlegroups.com>
                  Questions   : https://answers.launchpad.net/calchep
                  Bugs        : https://bugs.launchpad.net/calchep
                  Code&Models: http://theory.sinp.msu.ru/~pukhov/calchep.html
 The BSMs for CalcHEP were developed in collaboration with:
       G.Belanger,F.Boudjema,A.Semenov

 The package contains codes written by:
       M.Donckt,V.Edneral,V.Ilyin,D.Kovalenko,A.Kryukov,G.Lepage,A.Semenov

                  Press F9 or click the box below to get

                 References, Contributions, Acknowledgments

This information is available during the session by means of the F9 key
```

Principle KEYS for CalcHEPs GUI

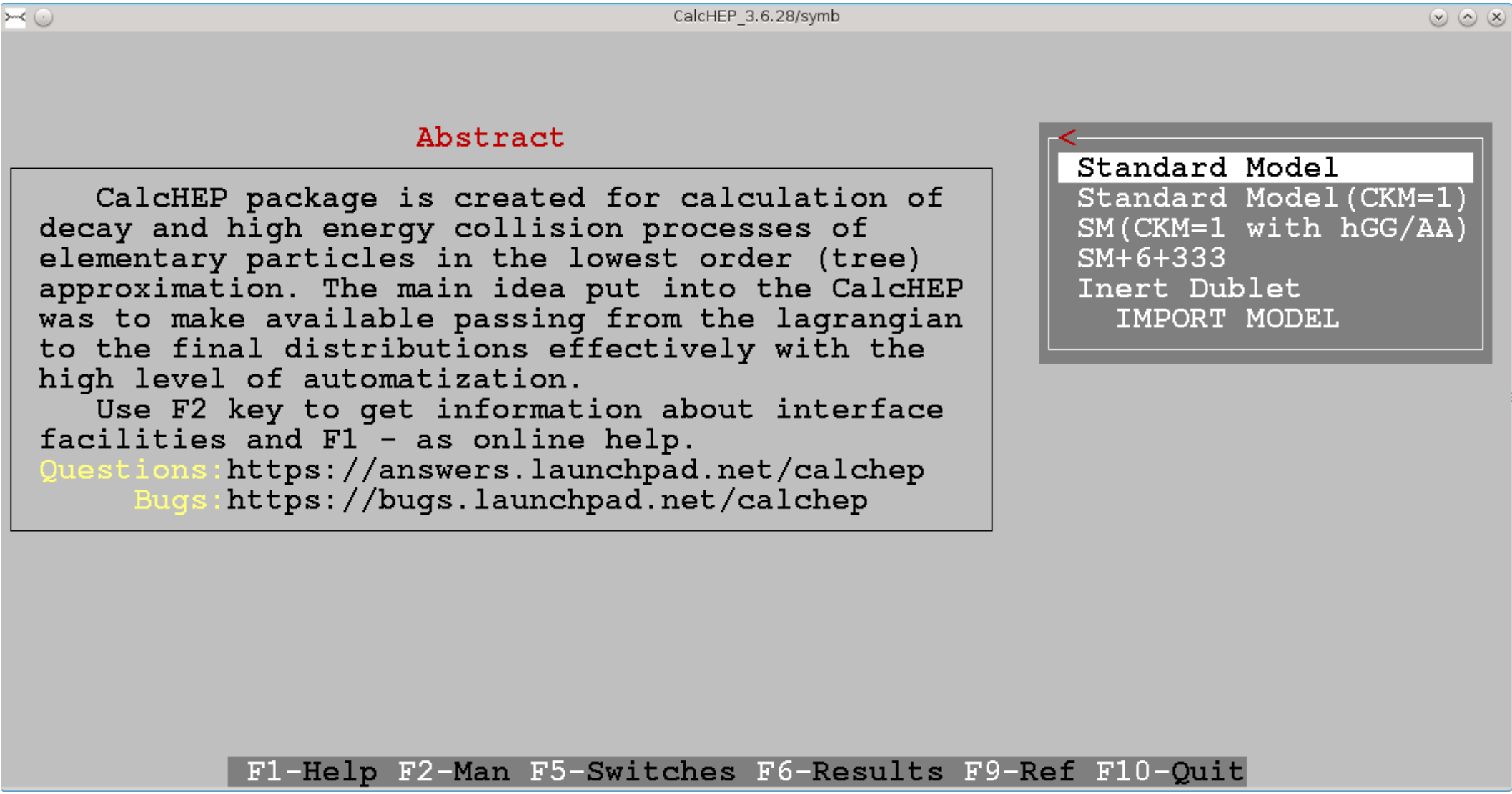


Enter menu selection (forward)

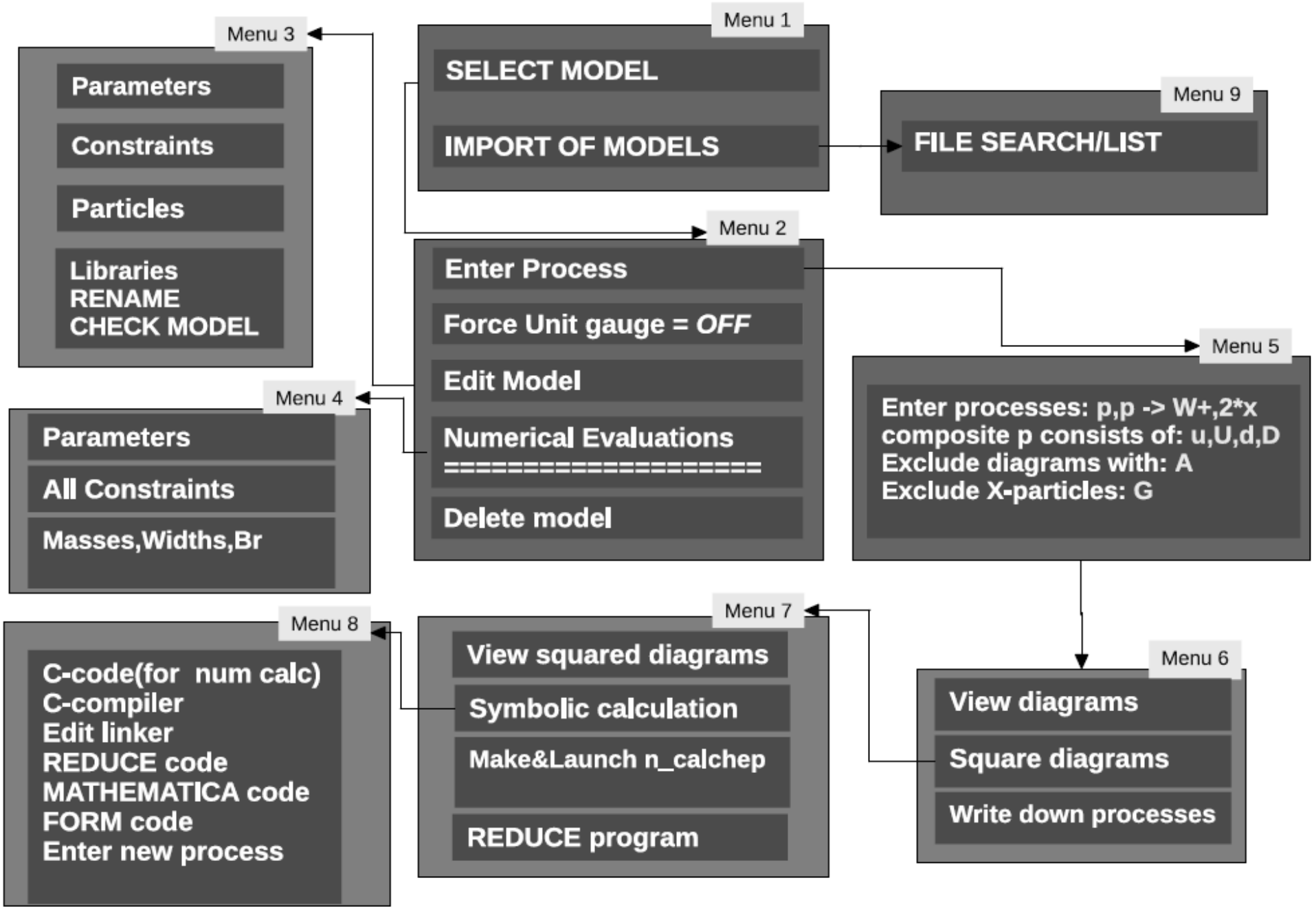
Exit menu selection (back)

Help!

Starting CalcHEP



CalcHEP menu structure: symbolic part



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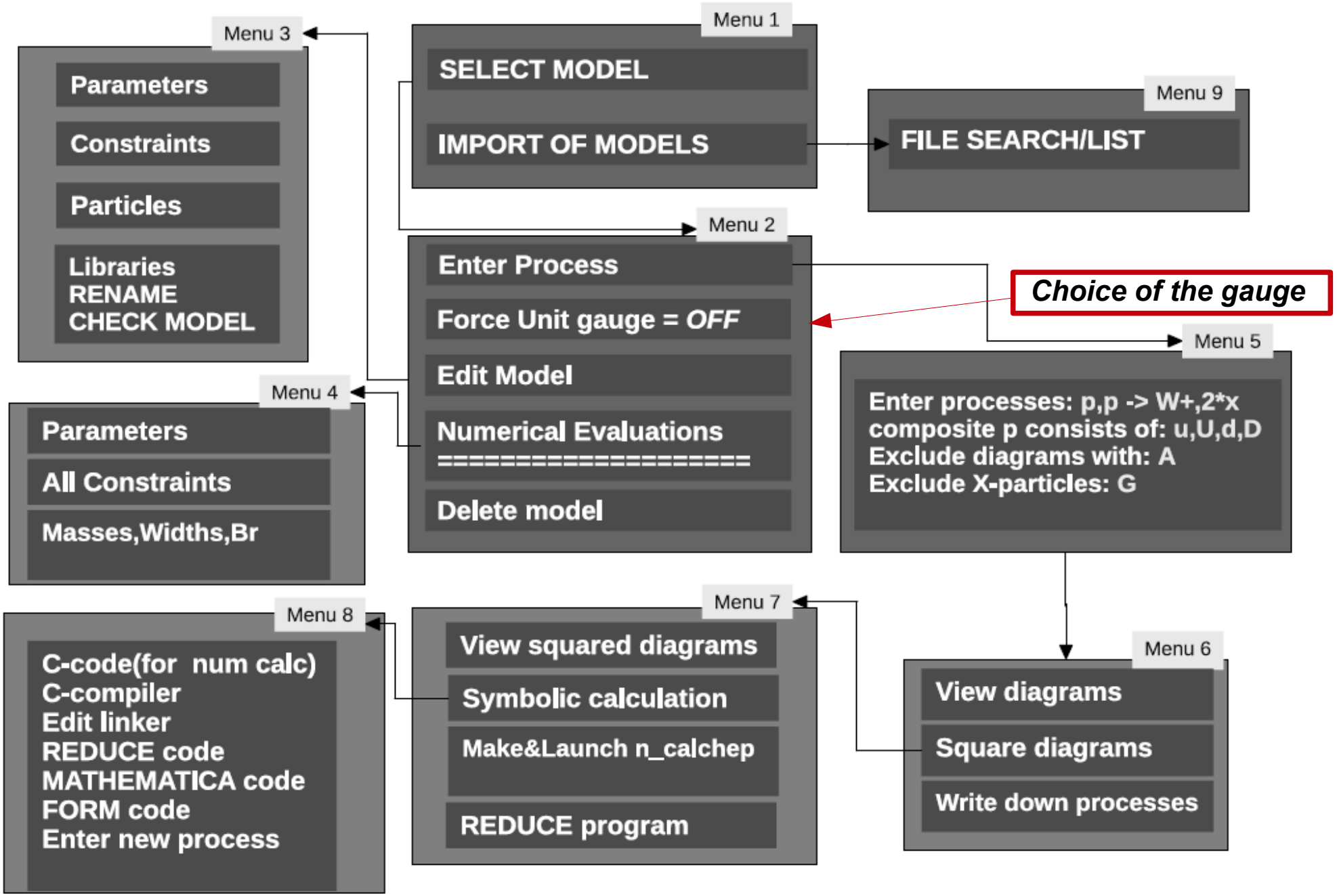
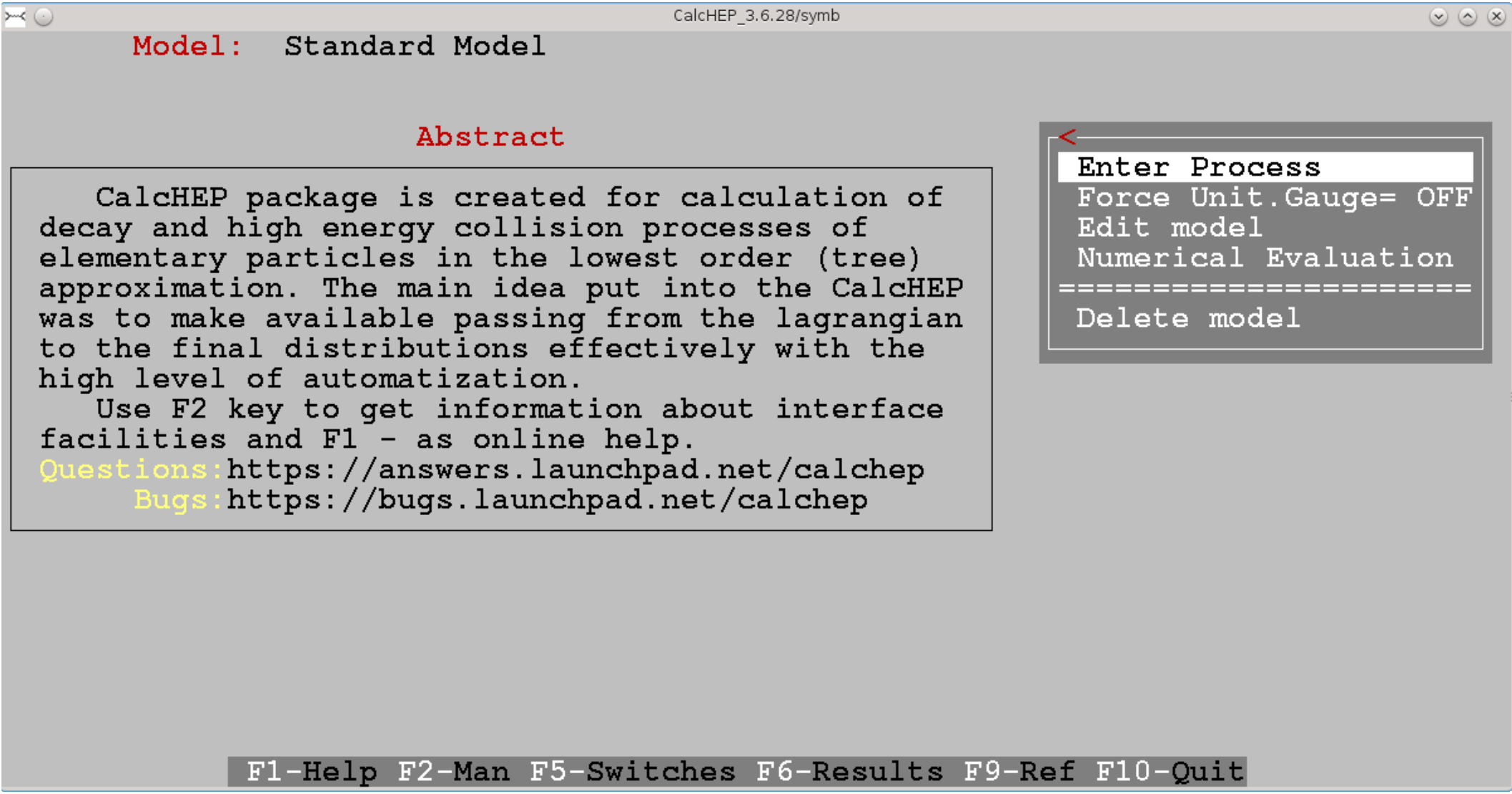


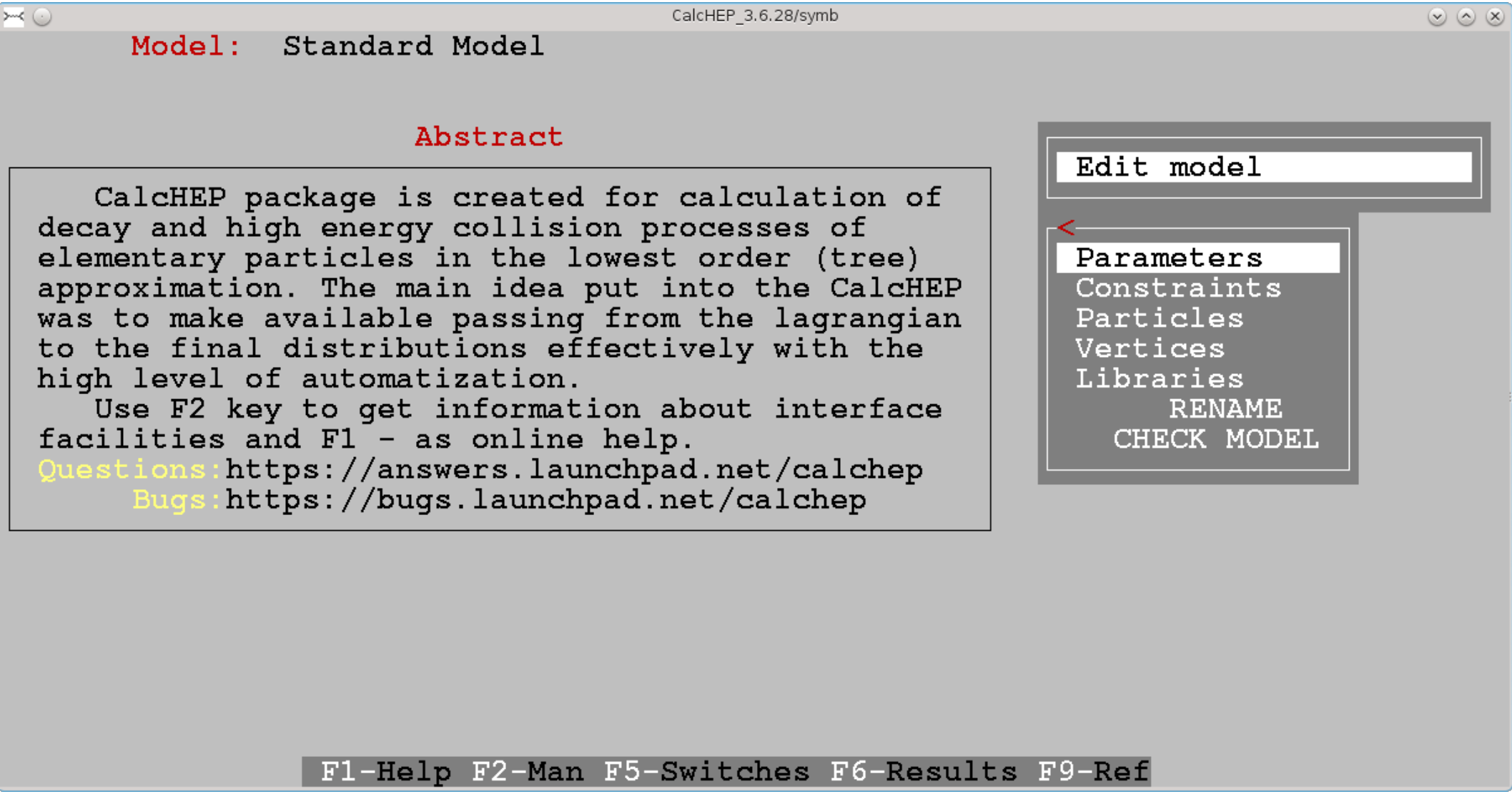
Initial Menu after the model choice

Choose your gauge ***Enter Process***
Edit Model ***Numerical Evaluation***



The Model Structure

Parameters ***Constraints***
Particles ***Vertices***



Particles: prtcl*xx*.mdl (spins 0,1/2,1,3/2,2)

CalcHEP_3.6.28/symb

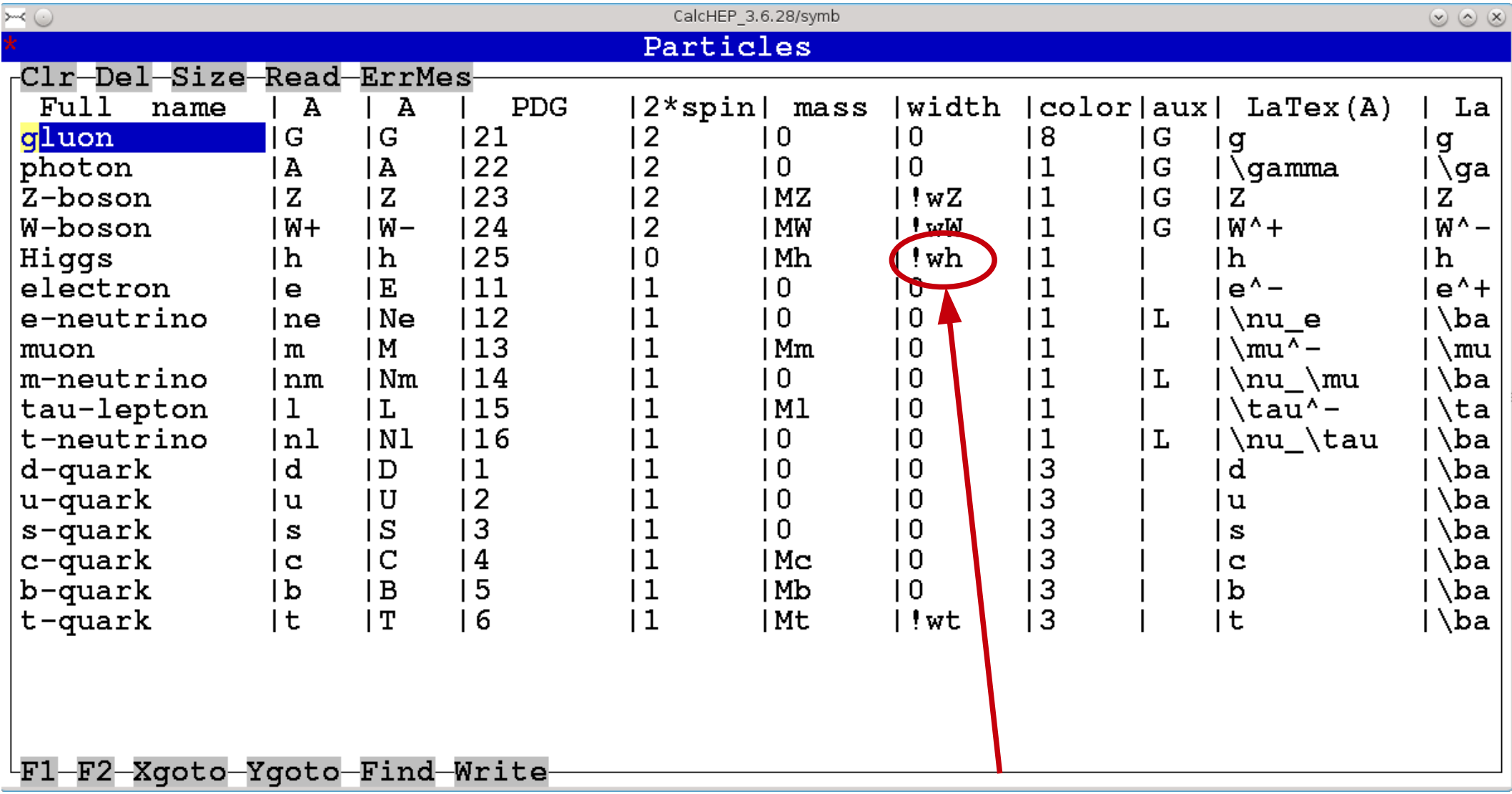
Particles

Clr Del Size Read ErrMes

Full name	A	A	PDG	2*spin	mass	width	color	aux	LaTex(A)	La
gluon	G	G	21	2	0	0	8	G	g	g
photon	A	A	22	2	0	0	1	G	\gamma	\ga
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	\ba
muon	m	M	13	1	Mm	0	1		\mu^-	\mu
m-neutrino	nm	Nm	14	1	0	0	1	L	\nu_\mu	\ba
tau-lepton	l	L	15	1	Ml	0	1		\tau^-	\ta
t-neutrino	nl	Nl	16	1	0	0	1	L	\nu_\tau	\ba
d-quark	d	D	1	1	0	0	3		d	\ba
u-quark	u	U	2	1	0	0	3		u	\ba
s-quark	s	S	3	1	0	0	3		s	\ba
c-quark	c	C	4	1	Mc	0	3		c	\ba
b-quark	b	B	5	1	Mb	0	3		b	\ba
t-quark	t	T	6	1	Mt	!wt	3		t	\ba

F1 F2 Xgoto Ygoto Find Write

Particles: prtcl*xx*.mdl



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photon	A	A	22	2	0	0	1	G	\gamma	\ga
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	\ba
muon	m	M	13	1	Mm	0	1		\mu^-	\mu
m-neutrino	nm	Nm	14	1	0	0	1	L	\nu_\mu	\ba
tau-lepton	l	L	15	1	Ml	0	1		\tau^-	\ta
t-neutrino	nl	Nl	16	1	0	0	1	L	\nu_\tau	\ba
d-quark	d	D	1	1	0	0	3		d	\ba
u-quark	u	U	2	1	0	0	3		u	\ba
s-quark	s	S	3	1	0	0	3		s	\ba
c-quark	c	C	4	1	Mc	0	3		c	\ba
b-quark	b	B	5	1	Mb	0	3		b	\ba
t-quark	t	T	6	1	Mt	!wt	3		t	\ba

Higgs boson width will be calculated `on the fly`

Independent parameters: varsxx.mdl

CalcHEP_3.6.28/symb

Parameters

Clr Del Size Read ErrMes

Name	Value	Comment
EE	0.31343	elecromagnetic constant
alfSMZ	0.1184	Srtong alpha(MZ) for running mass calculation
Q	100	scale for running mass calculation
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)
MbMb	4.25	Mb(Mb)
Mtp	173.07	t-quark pole mass
MZ	91.189	Z-boson mass
MW	80.385	W-boson mass
Mh	125	higgs mass

F1 F2 Xgoto Ygoto Find Write

Dependent parameters(constraints): funcxx.mdl

CalcHEP_3.6.28/symb

Constraints

Clr Del Size Read ErrMes

Name	Expression	
CW	MW/MZ	% on-shell cos of the Weinberg angle
SW	sqrt(1-CW^2)	% sin of the Weinberg angle
GF	EE^2/(2*SW*MW)^2/Sqrt2	% Fermi constant (not used below)
LamQCD	initQCD5(alfSMZ,McMc,MbMb,Mtp)	
Mb	MbEff(Q)	
Mt	MtEff(Q)	
Mc	McEff(Q)	
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

F1 F2 Xgoto Ygoto Find Write

Feynman rules: lgrng*xx*.mdl

CalcHEP_3.6.28/symb

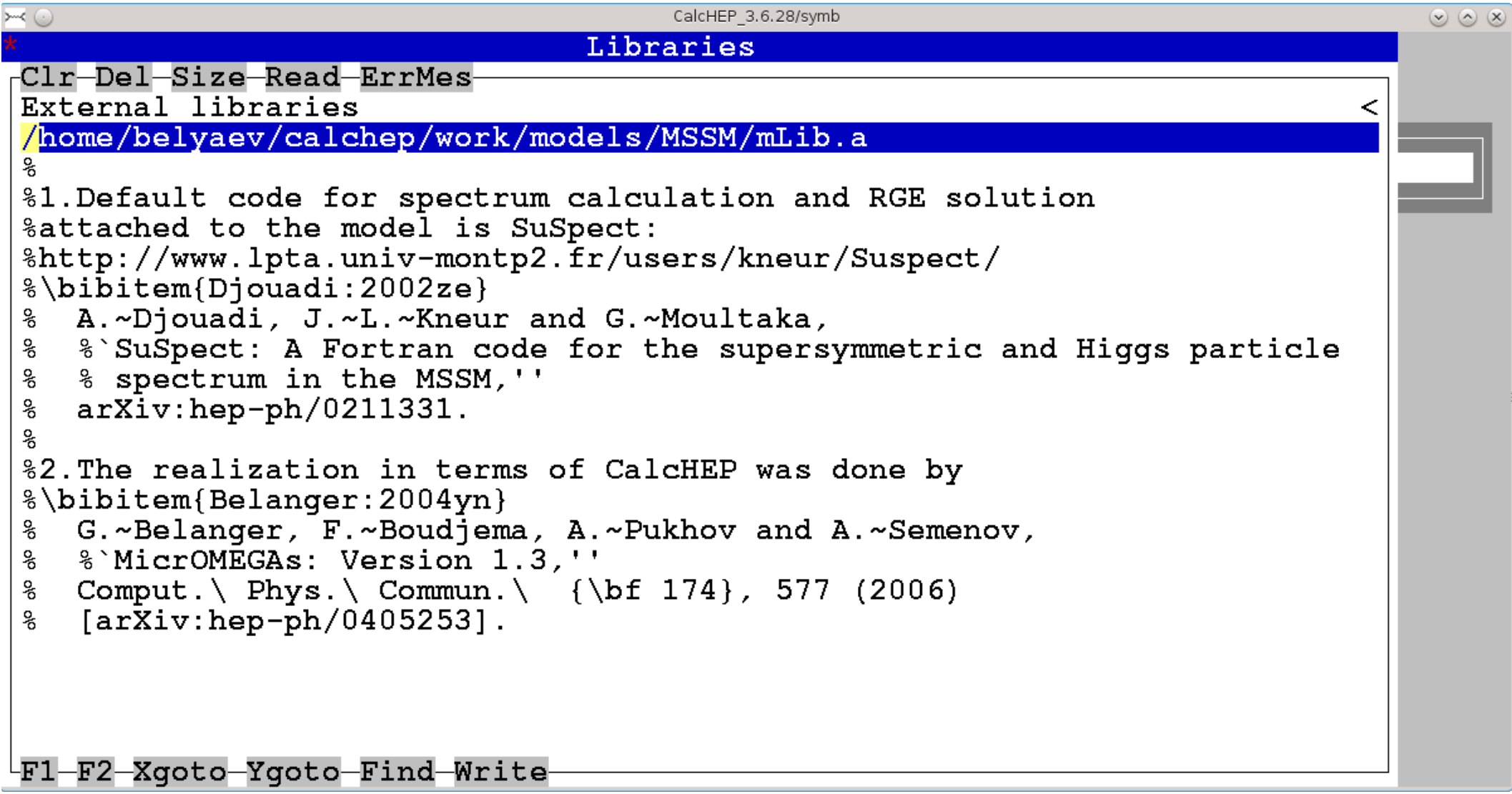
Vertices 26

Clr	Del	Size	Read	ErrMes			
A1	A2	A3	A4		Factor	Lorentz part	
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)*	
M	m	Z			-EE/(4*SW*CW)	G(m3)*(1-G5)-4*(SW^ 2)*	
L	l	Z			-EE/(4*SW*CW)	G(m3)*(1-G5)-4*(SW^ 2)*	
Ne	ne	Z			EE/(4*SW*CW)	G(m3)*(1-G5)	
Nm	nm	Z			EE/(4*SW*CW)	G(m3)*(1-G5)	
Nl	nl	Z			EE/(4*SW*CW)	G(m3)*(1-G5)	
U	u	A			(2/3)*EE	G(m3)	
D	d	A			(-1/3)*EE	G(m3)	
C	c	A			(2/3)*EE	G(m3)	
S	s	A			(-1/3)*EE	G(m3)	
B	b	A			(-1/3)*EE	G(m3)	
T	t	A			(2/3)*EE	G(m3)	
U	u	Z			-EE/(12*SW*CW)	-3*G(m3)*(1-G5)+8*(SW^	
D	d	Z			-EE/(12*SW*CW)	+3*G(m3)*(1-G5)-4*(SW^	

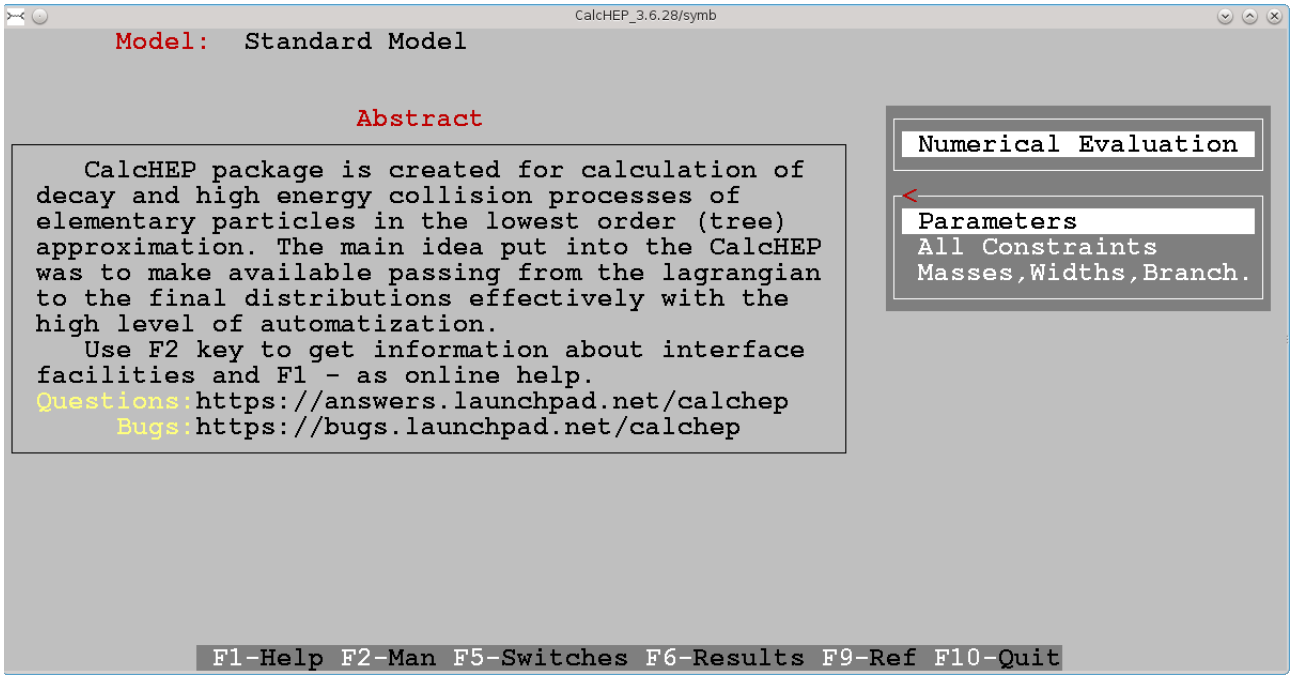
F1 F2 Xgoto Ygoto Find Write

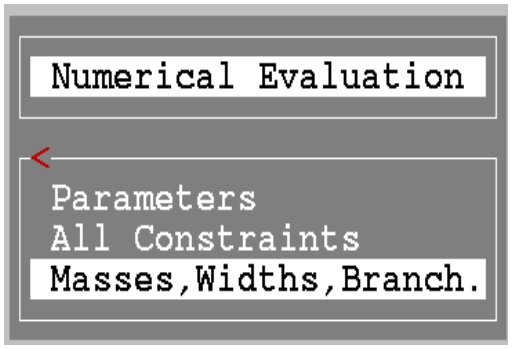
External Libraries: extlib*xx*.mdl

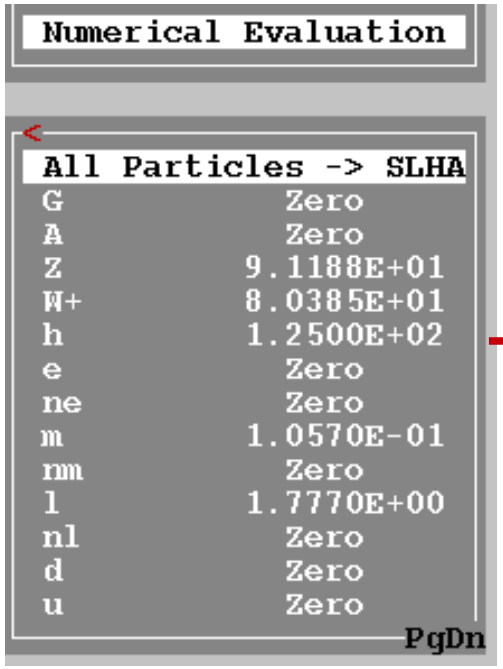
Typically is empty for simple models but can be used for any library which helps to build complicated model. E.g. mass spectra calculator for SUSY (involving RGE solutions etc)



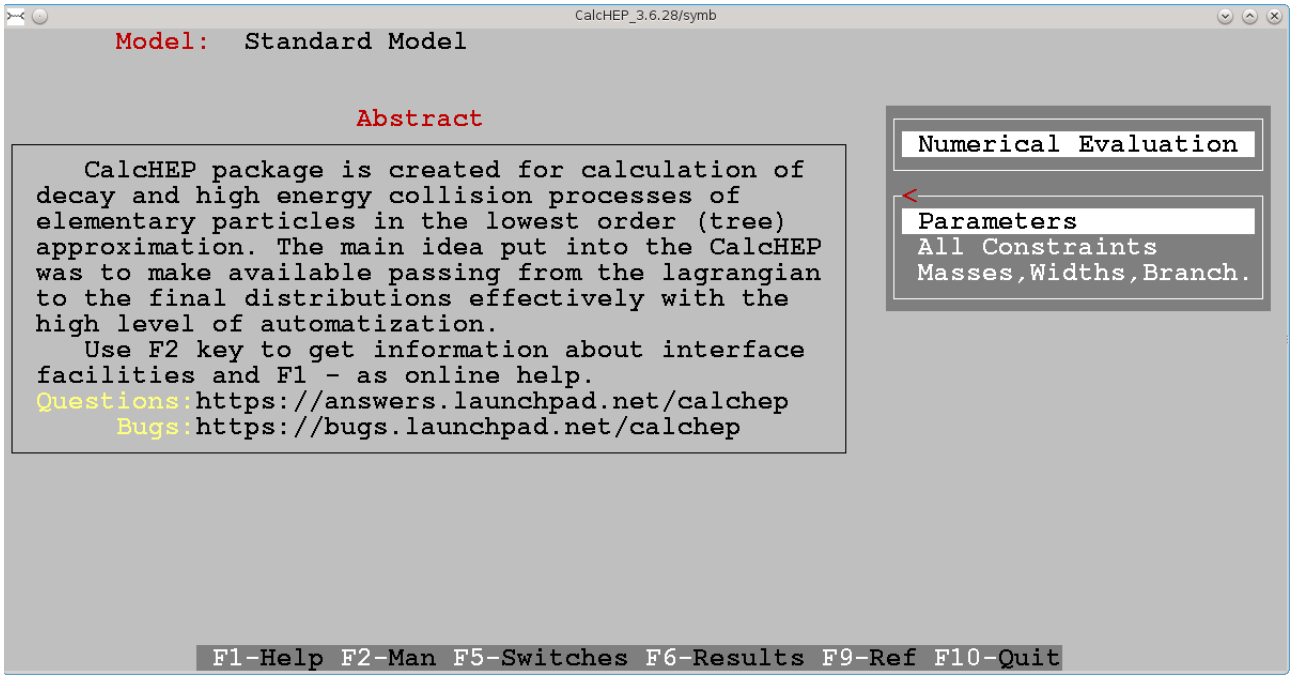
Numerical evaluation of masses & branchings

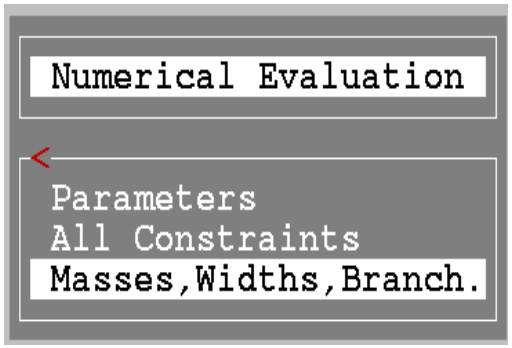


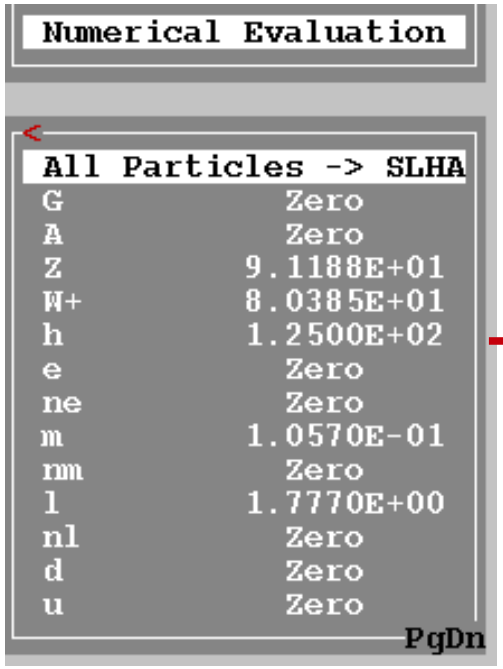




Numerical evaluation of masses & branchings







ex#2: Find the SM particles spectrum and Br ratios

Details of symbolic session

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

- **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**

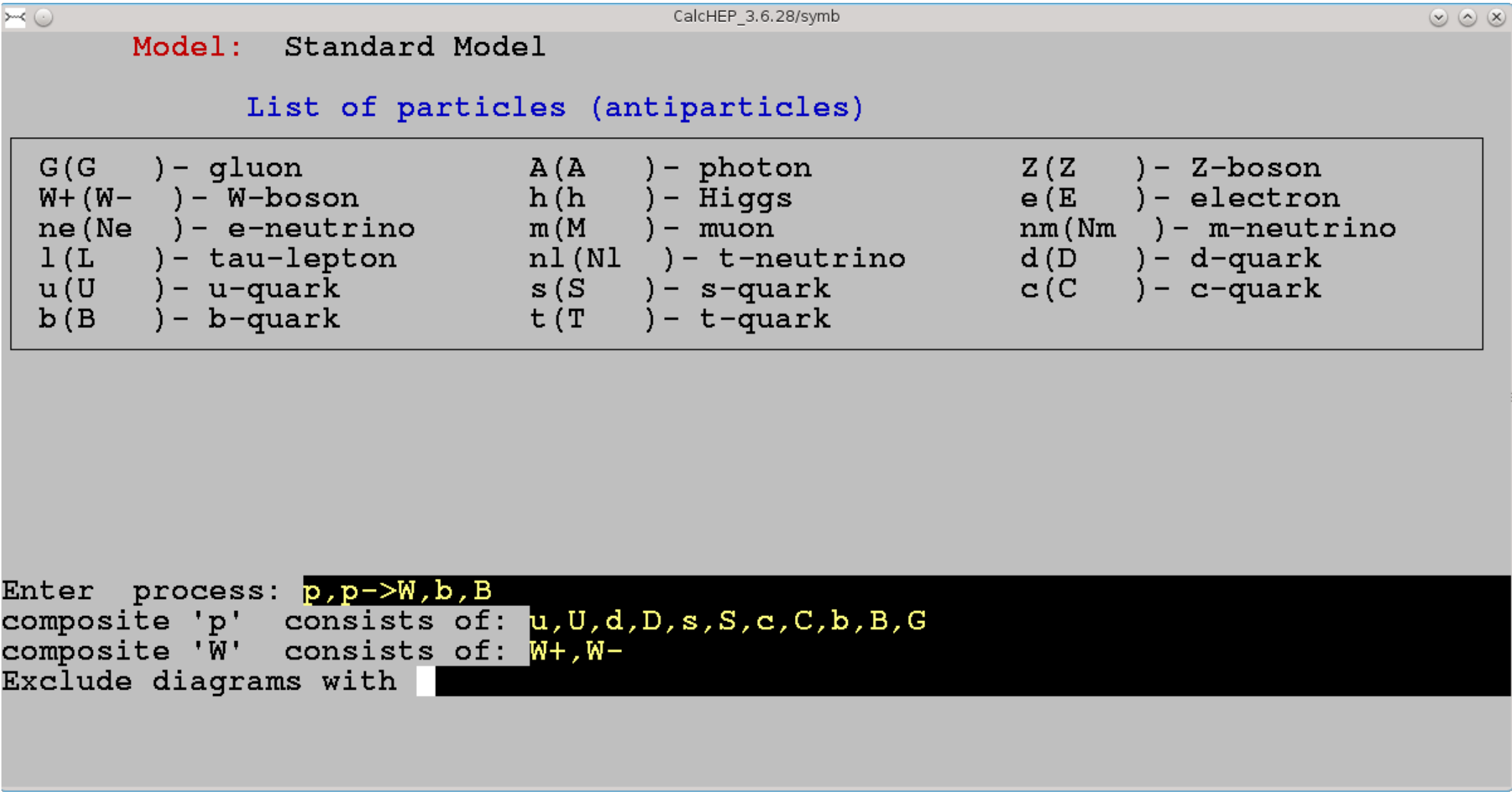
  'H -> 2*x'

- **intermediate particles can be non-trivially excluded**

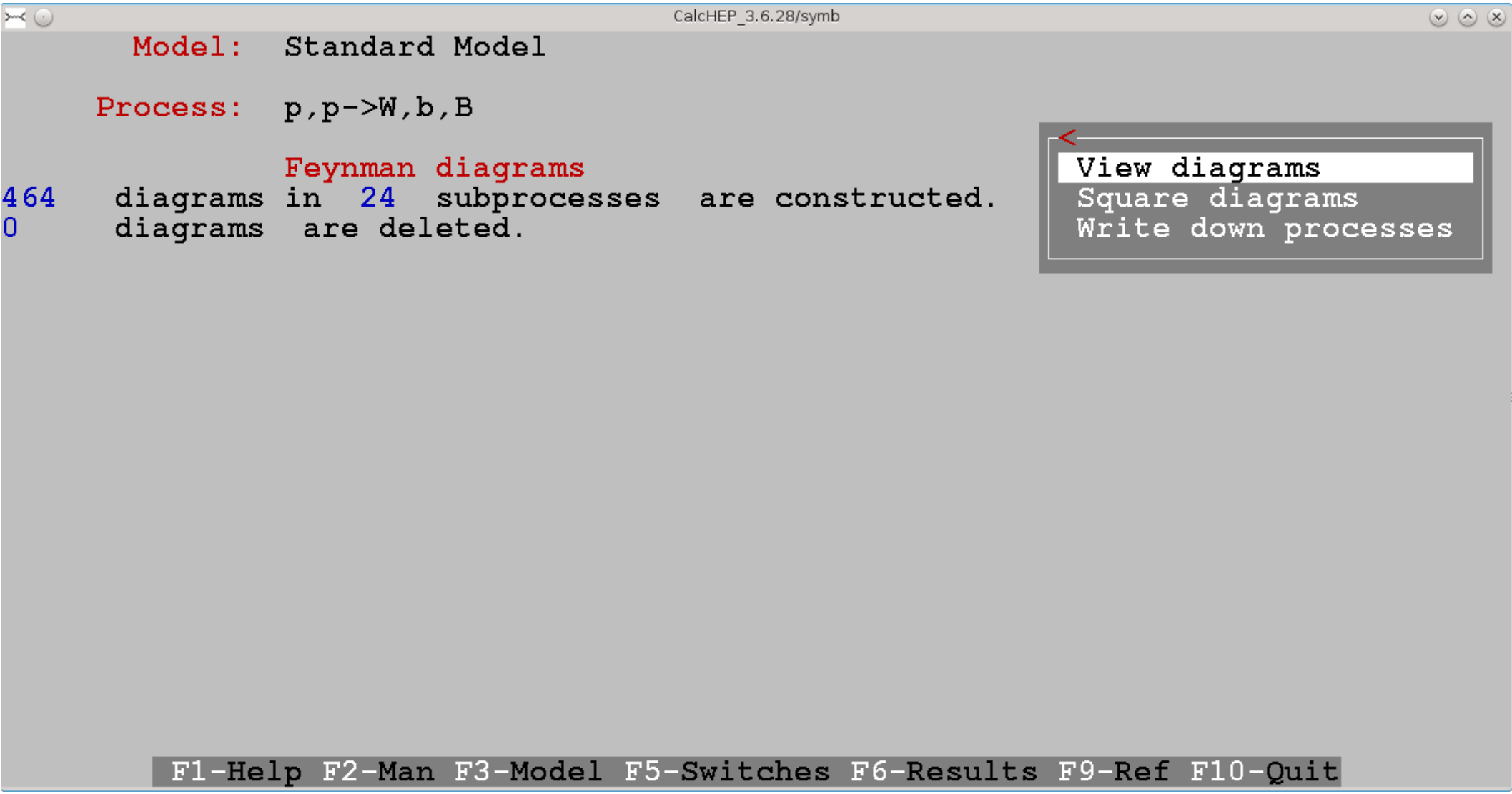
  'W+ > 2, A>1, Z>3'

ex#3: Evaluate SM Higgs total widths and Br ratios as a function of its mass in the 100-500 GeV range

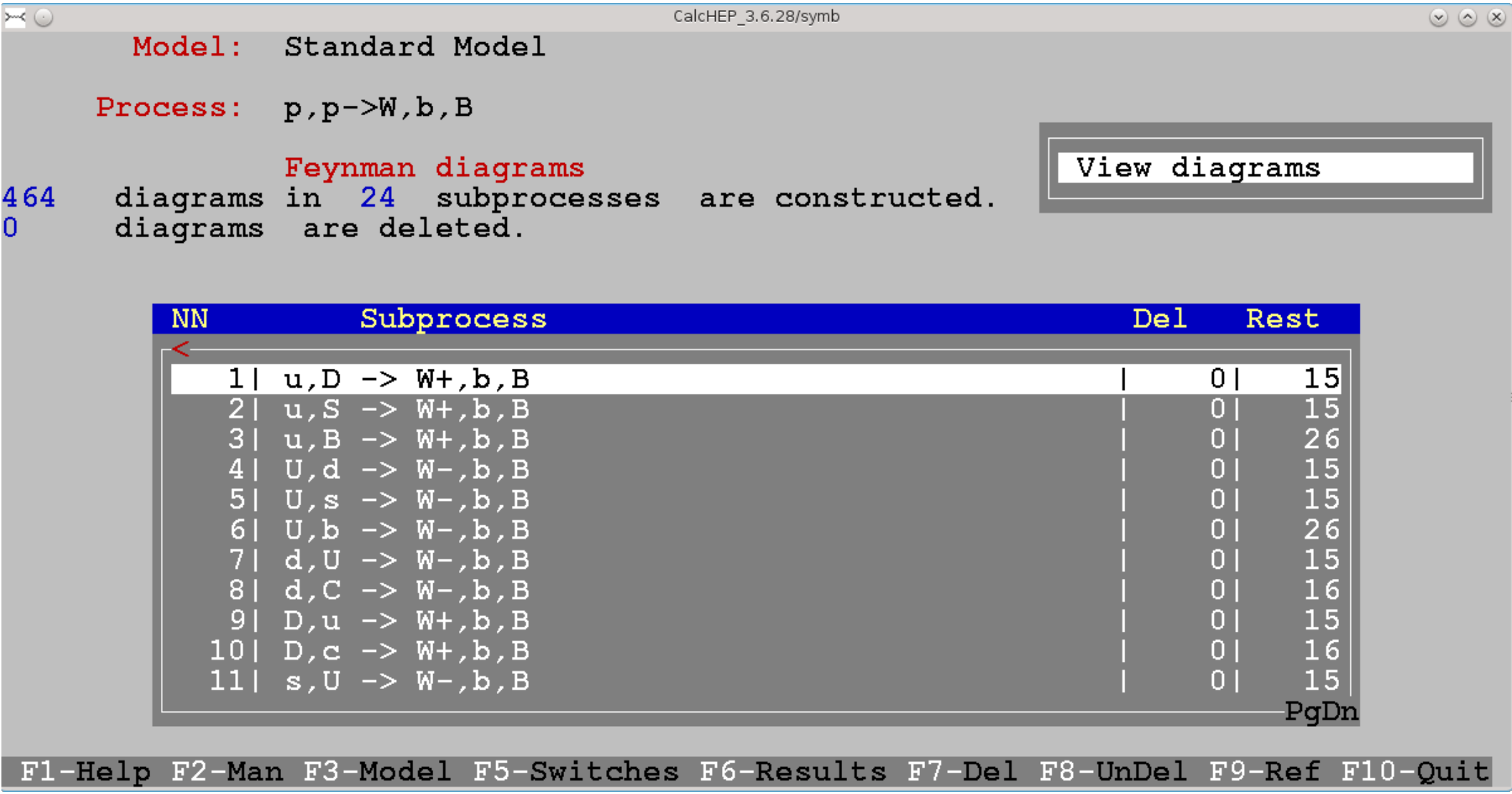
Symbolic session (1)



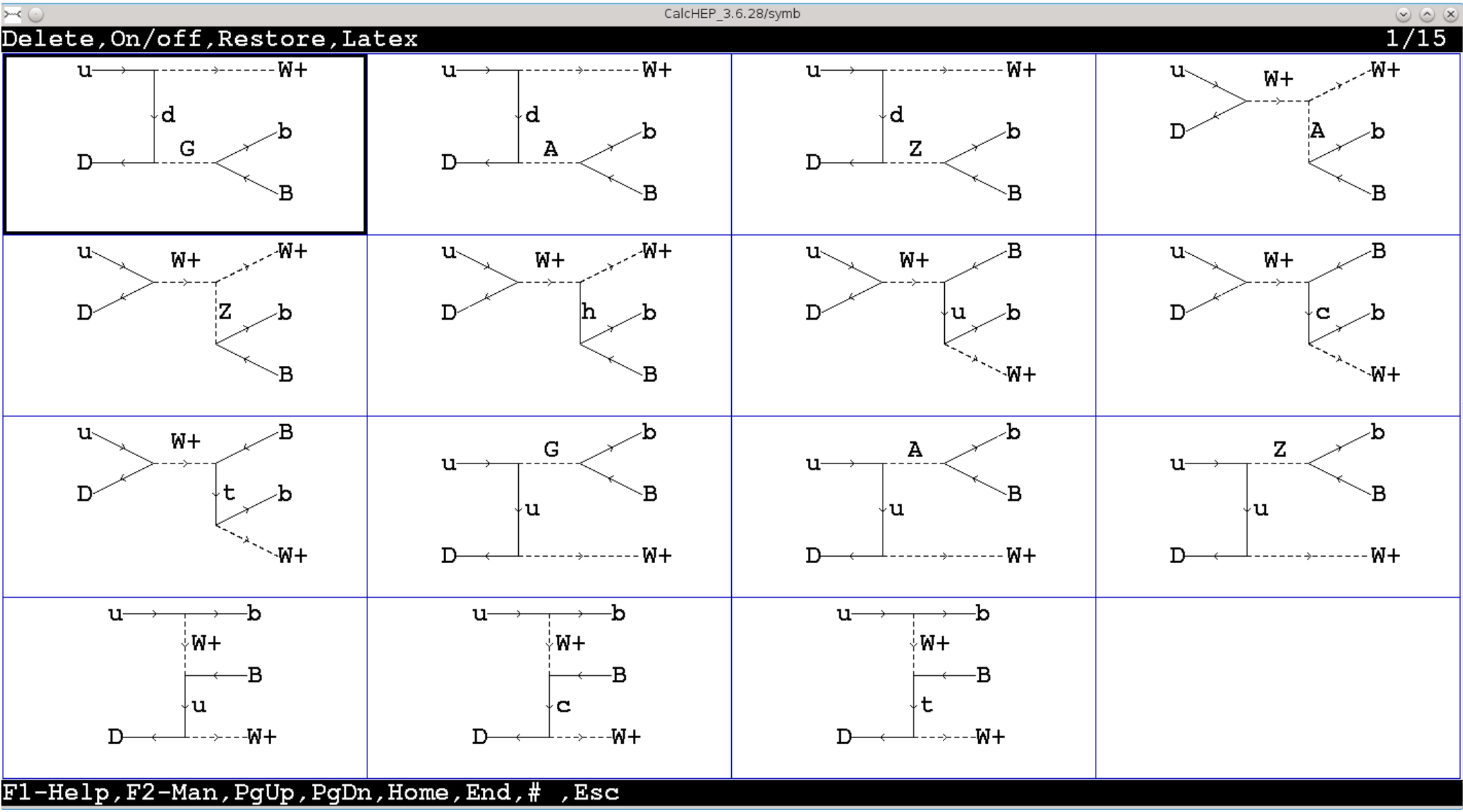
Symbolic session (2)



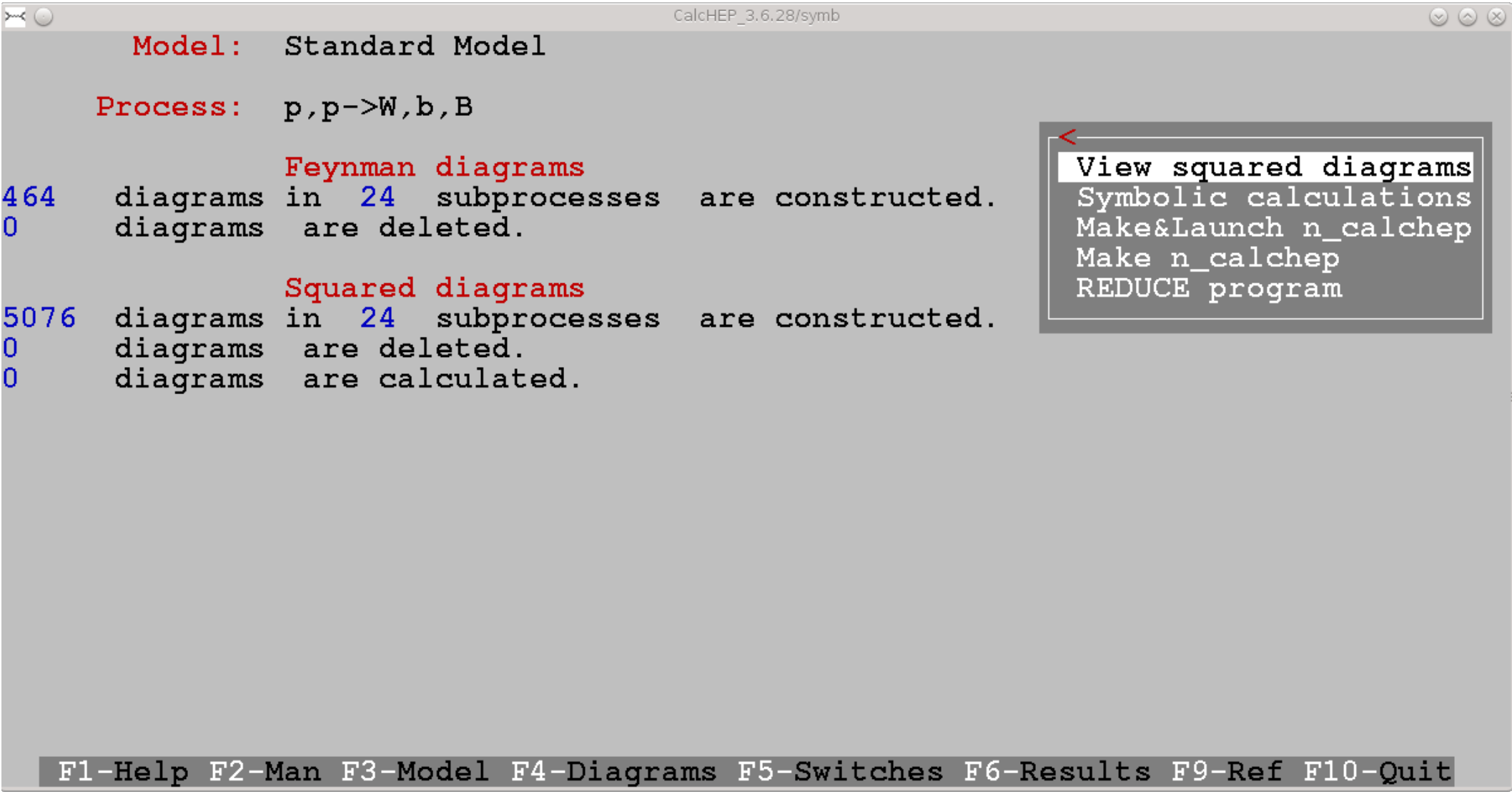
Symbolic session (3)



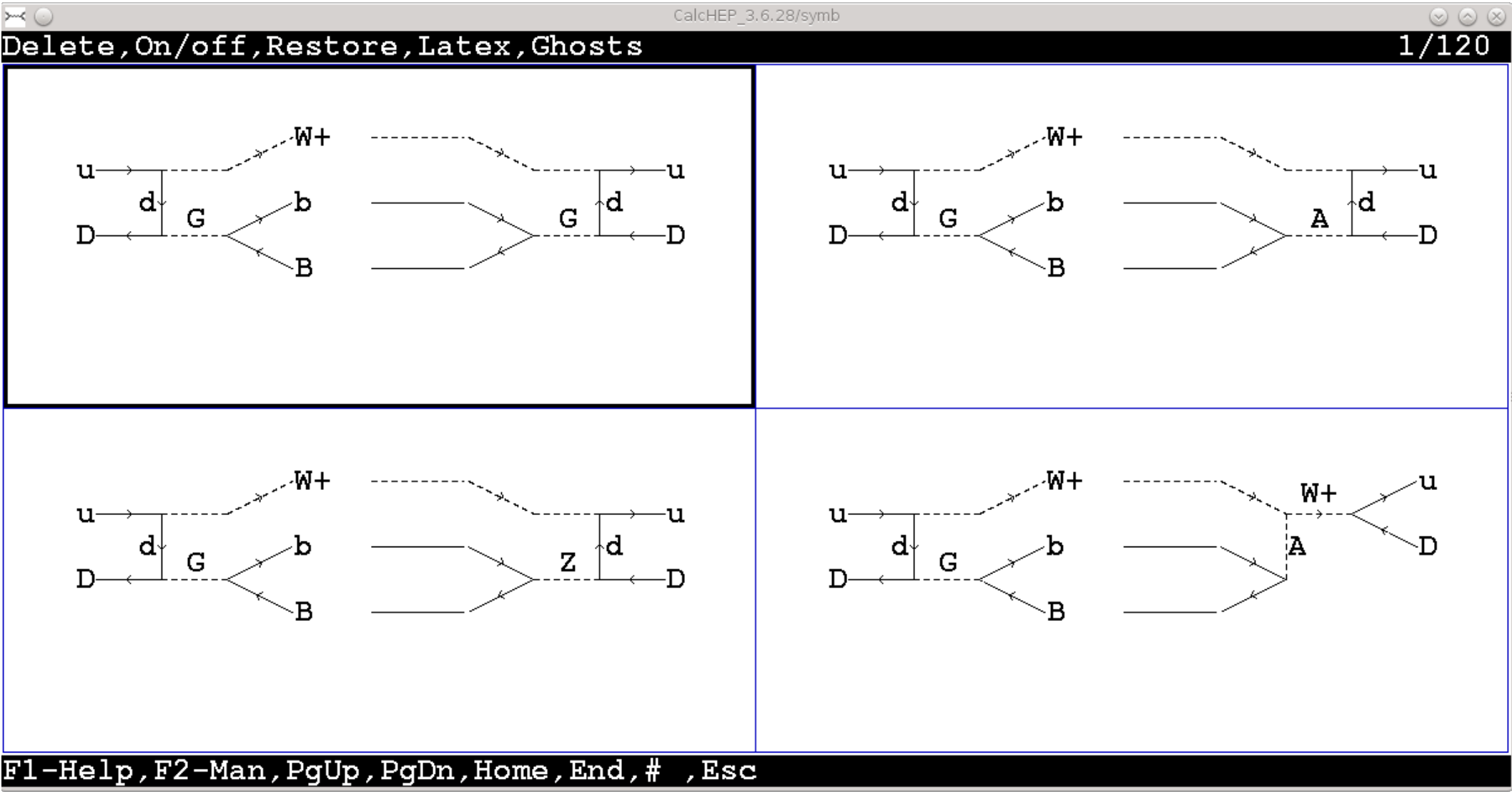
Symbolic session (4)



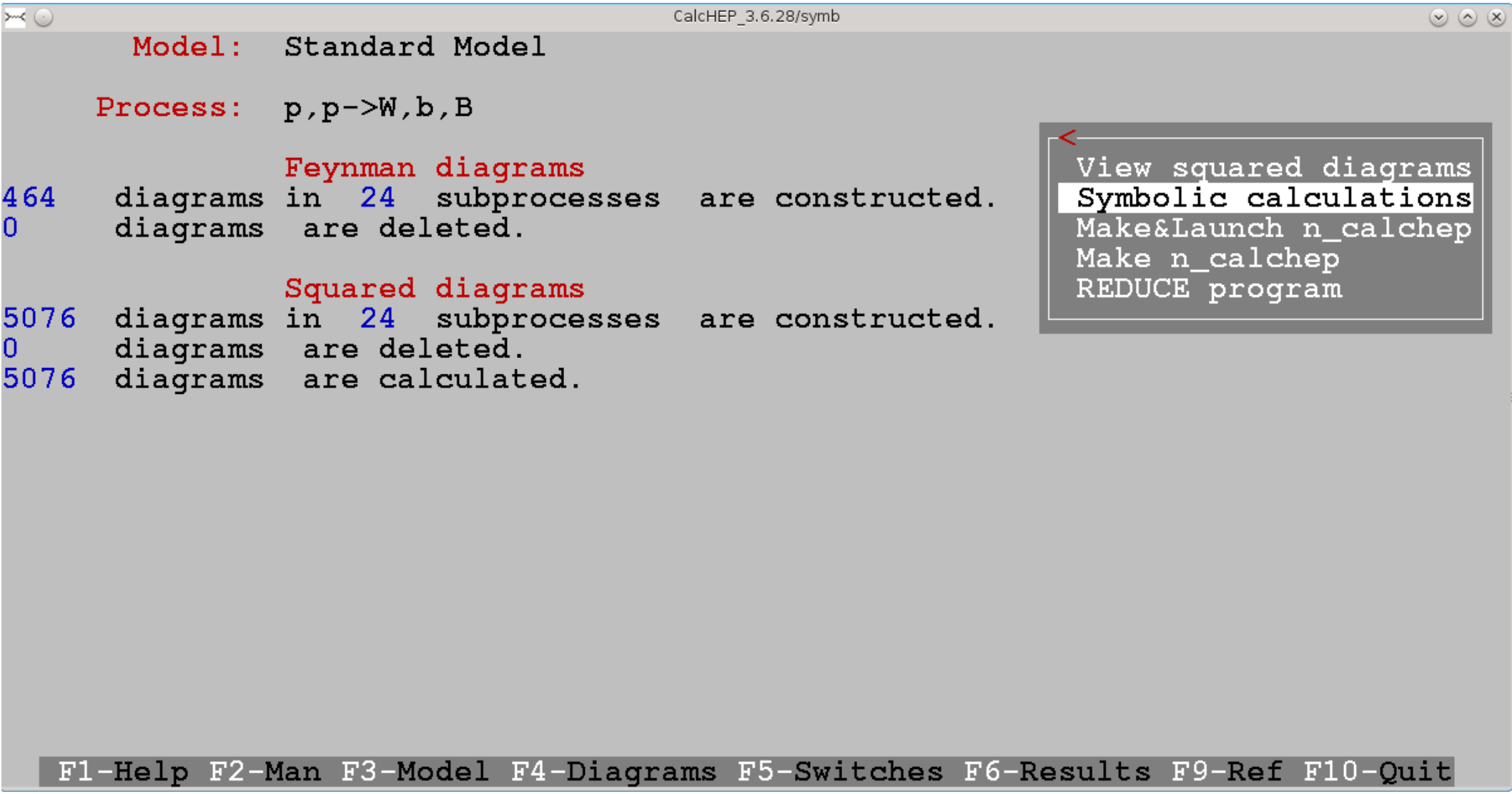
Symbolic session (5)



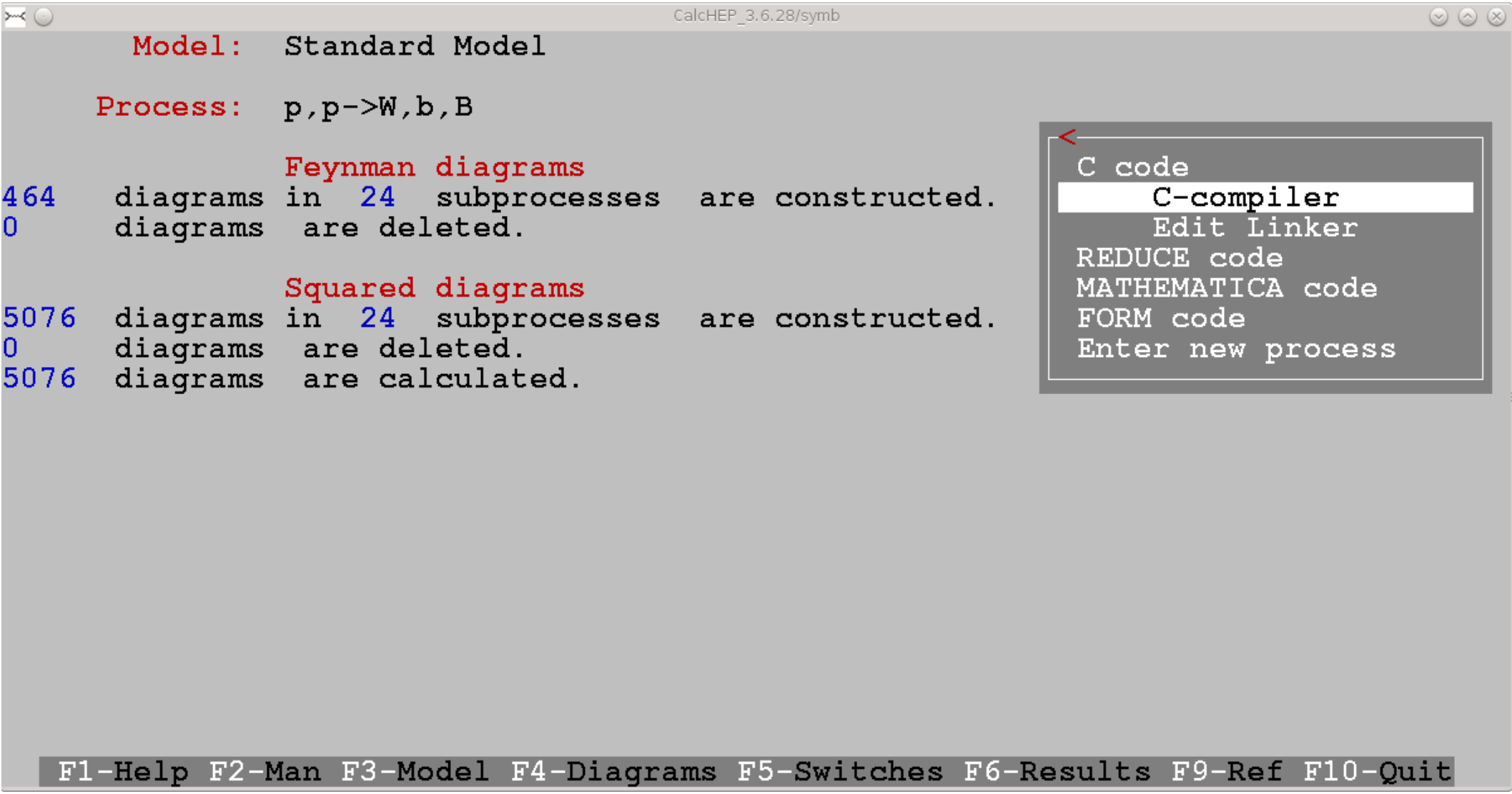
Symbolic session (6)



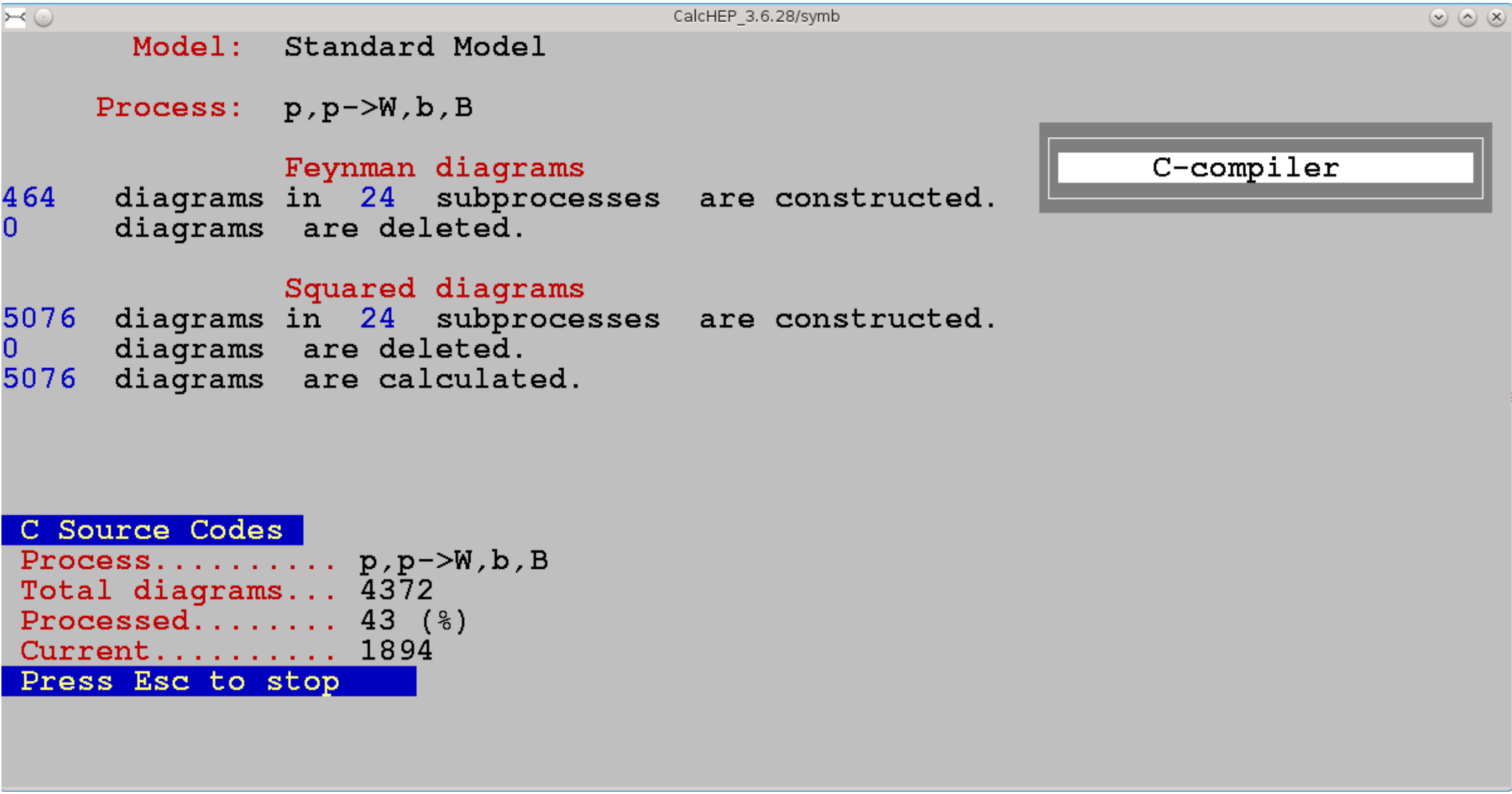
Symbolic session (7)



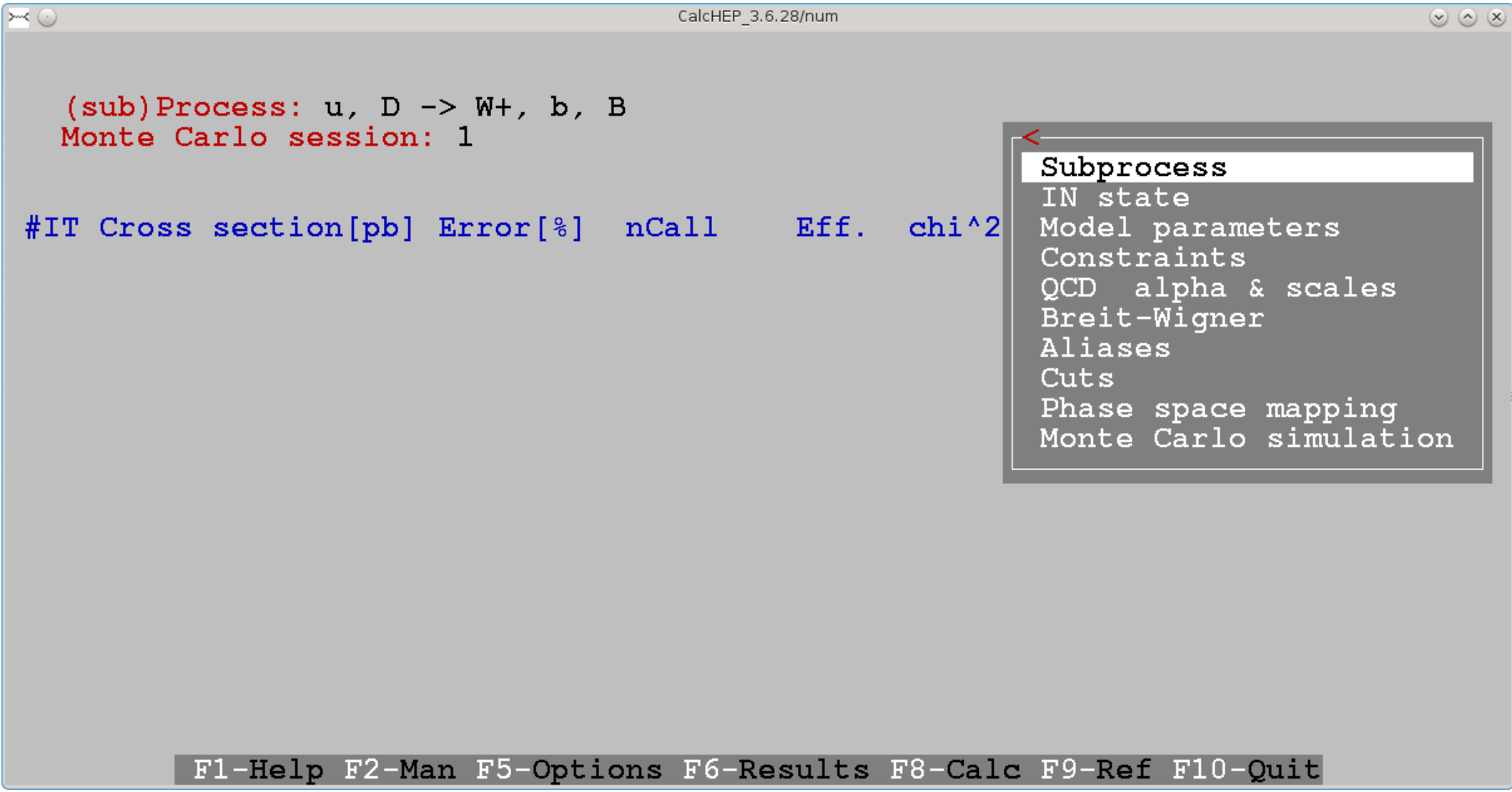
Symbolic session (8)



Symbolic session (9)



Numerical part of CalcHEP

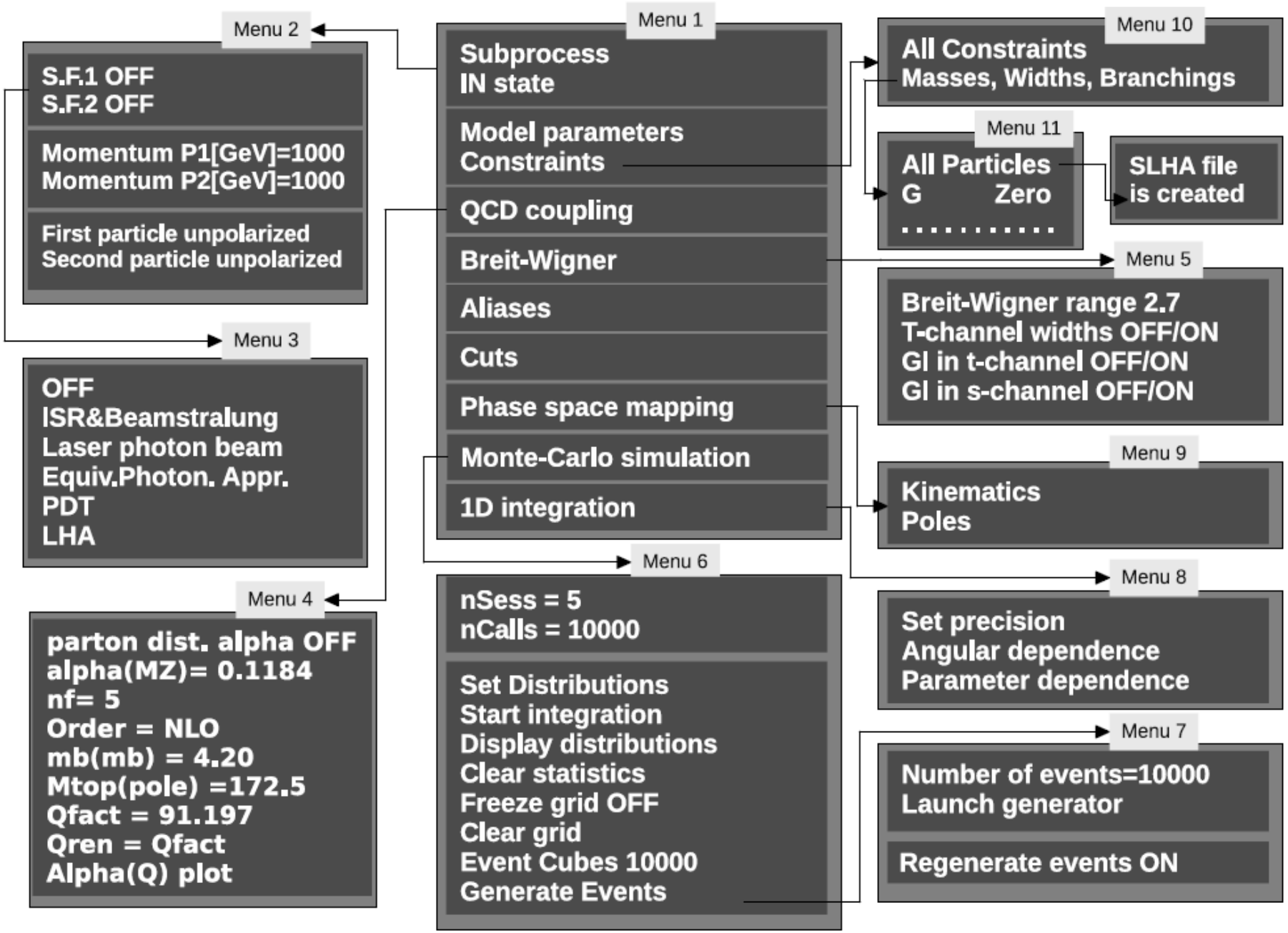


Lecture II:

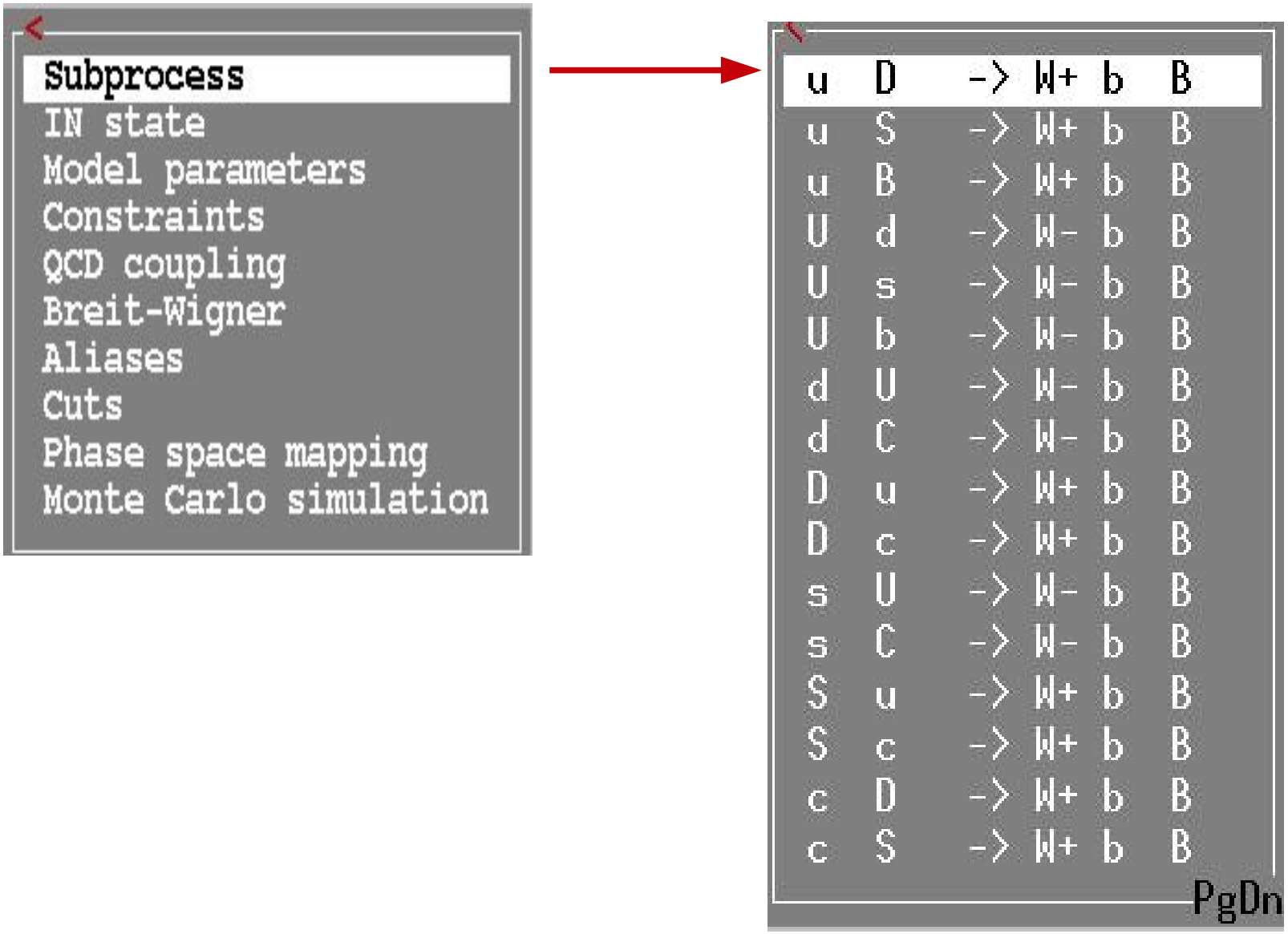
Introduction into CalcHEP

- *numerical session and kinematical distributions*
- *event generation*
- *CalcHEP Batch Interface*

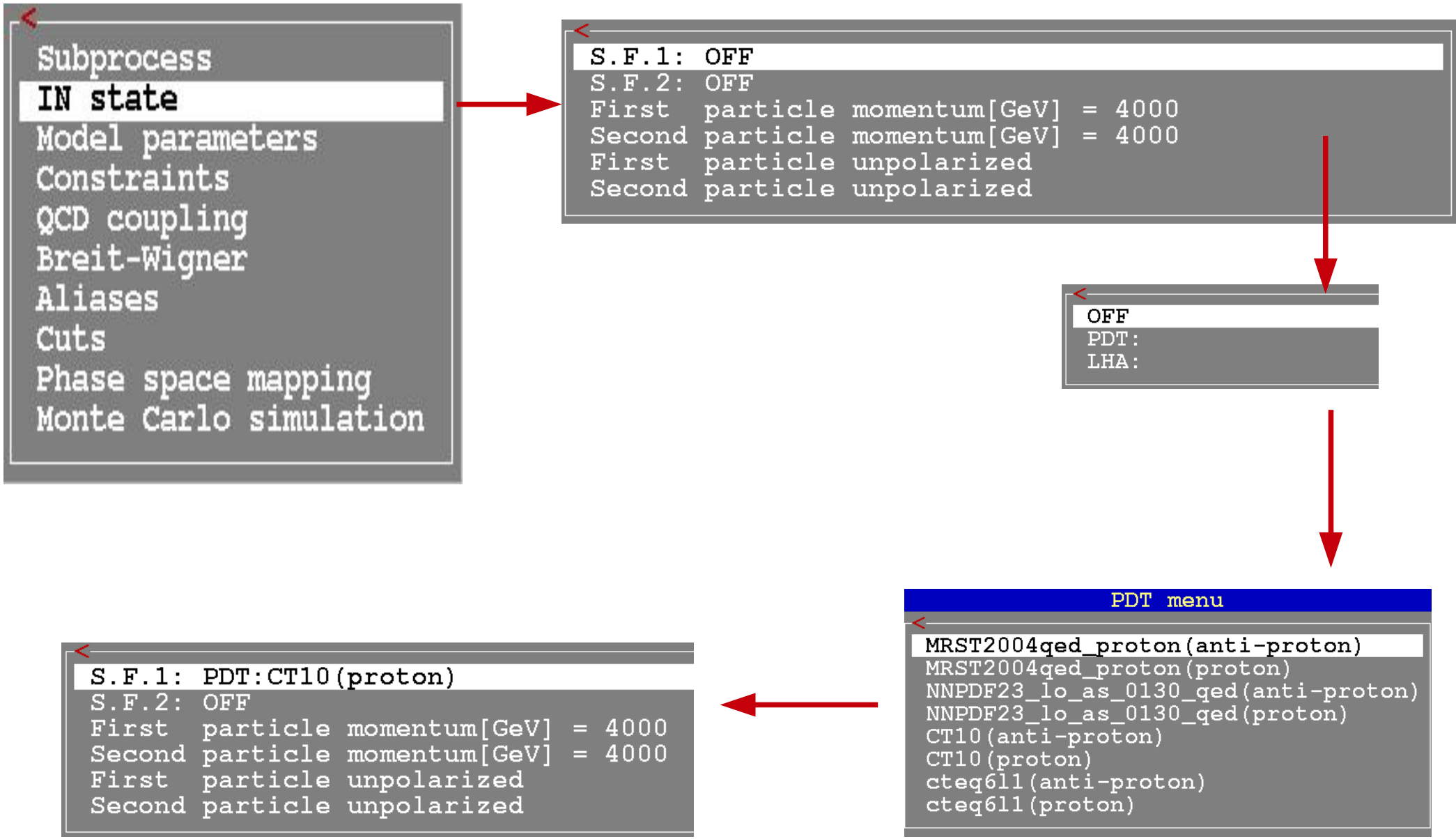
Menu structure of the numerical part



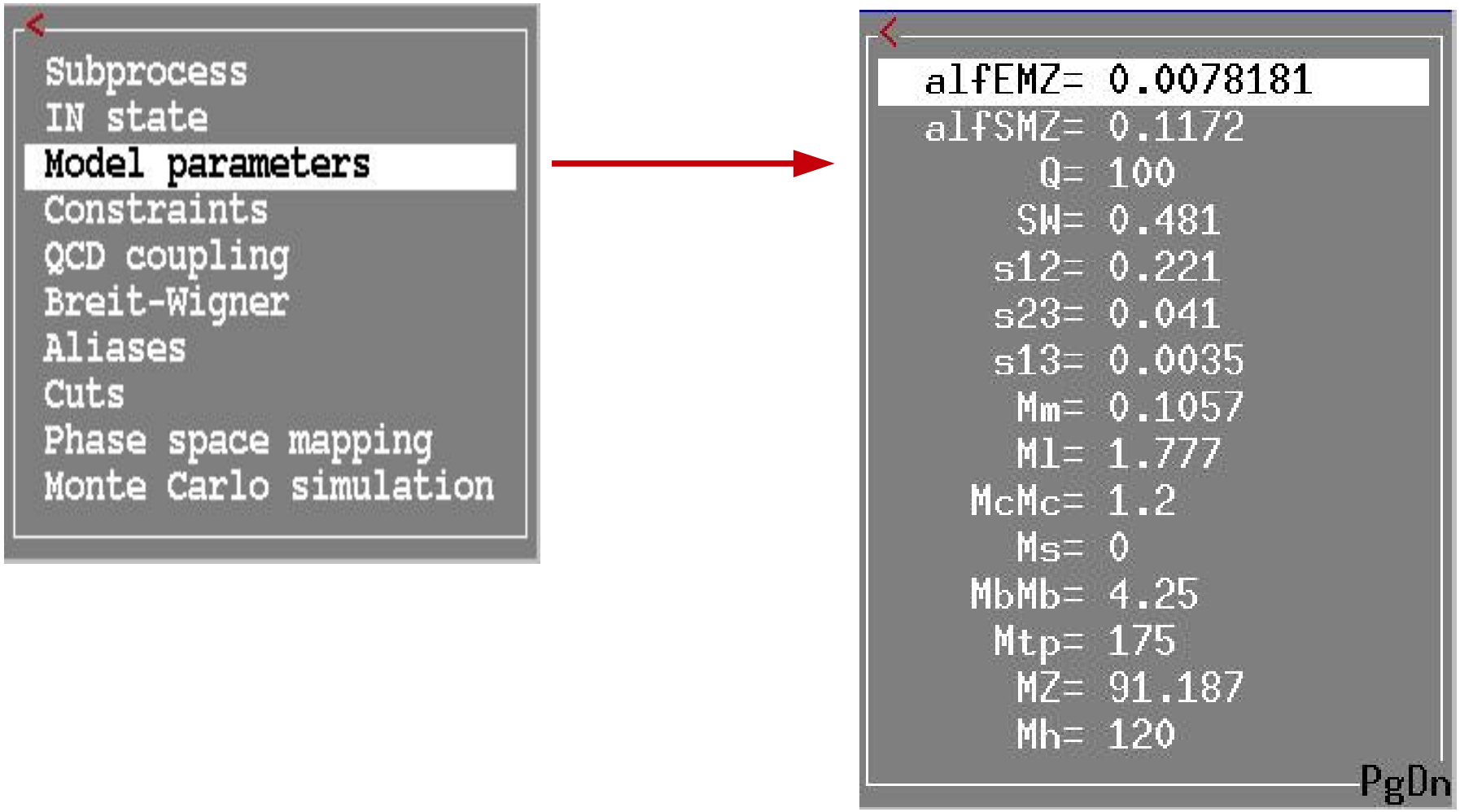
subprocess menu



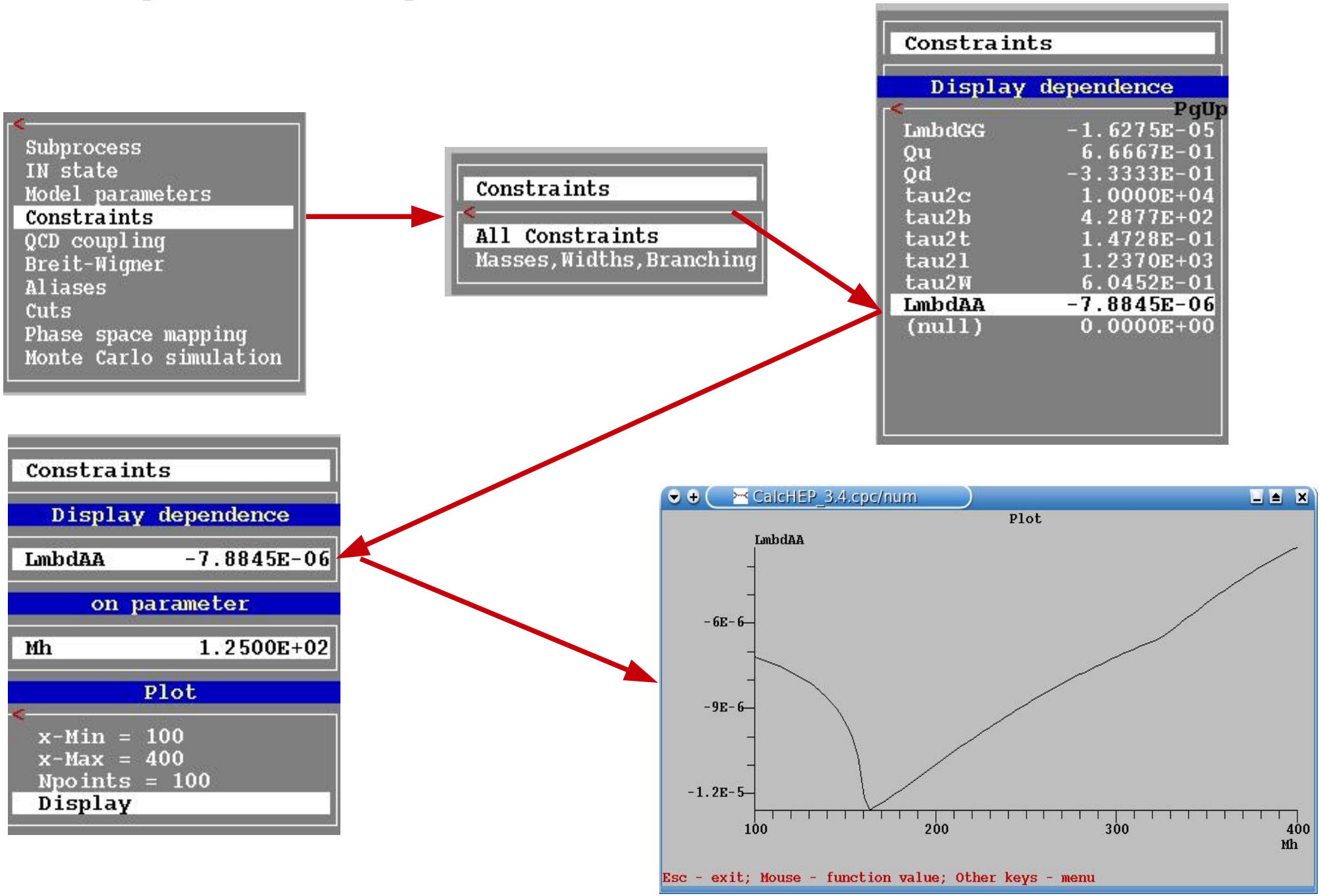
control of the initial states and parton density functions



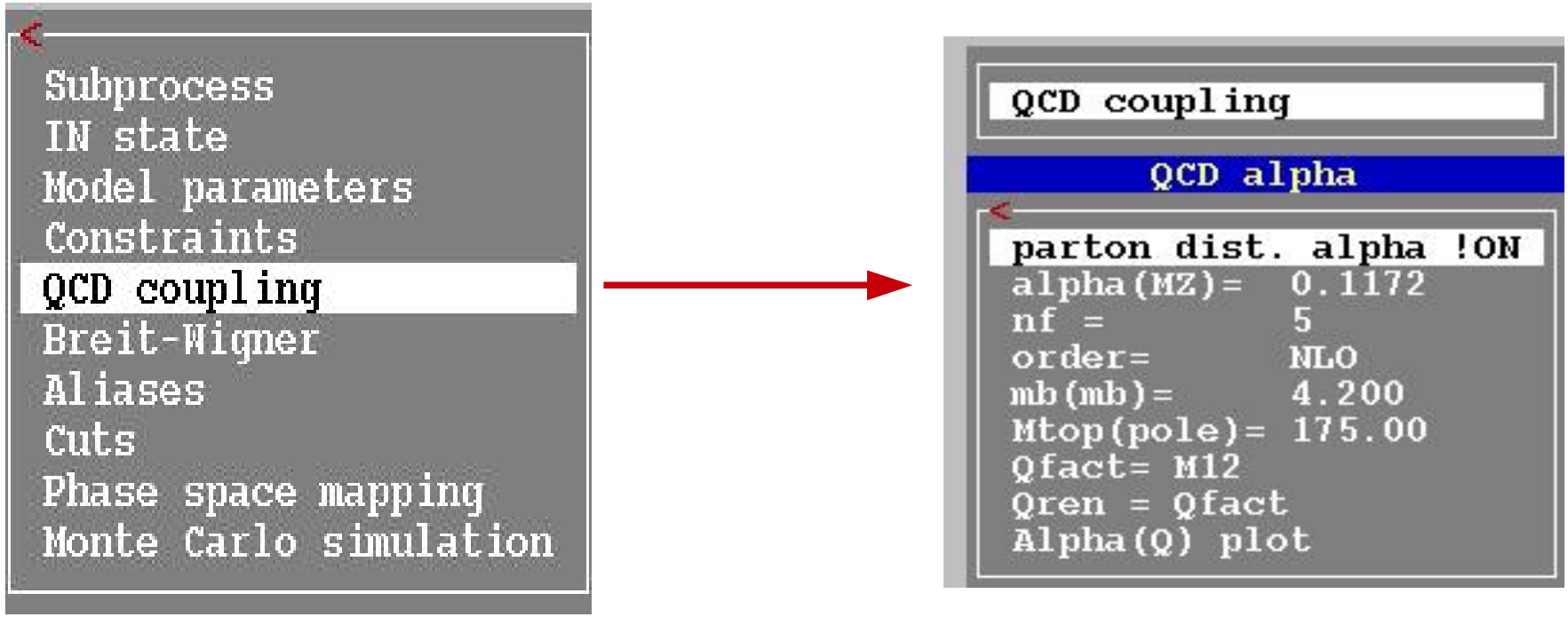
model parameters



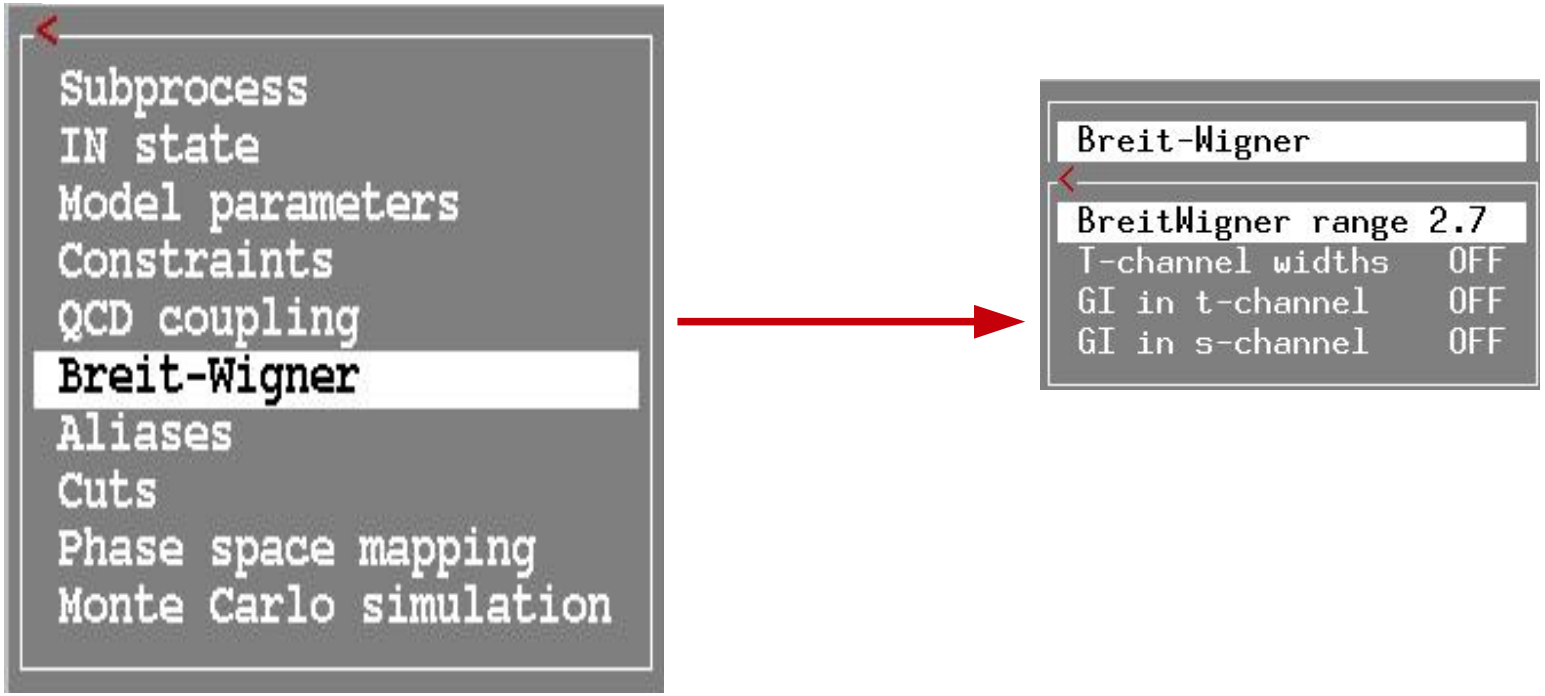
dependent parameters (SM CKM=1 with hGG/AA)



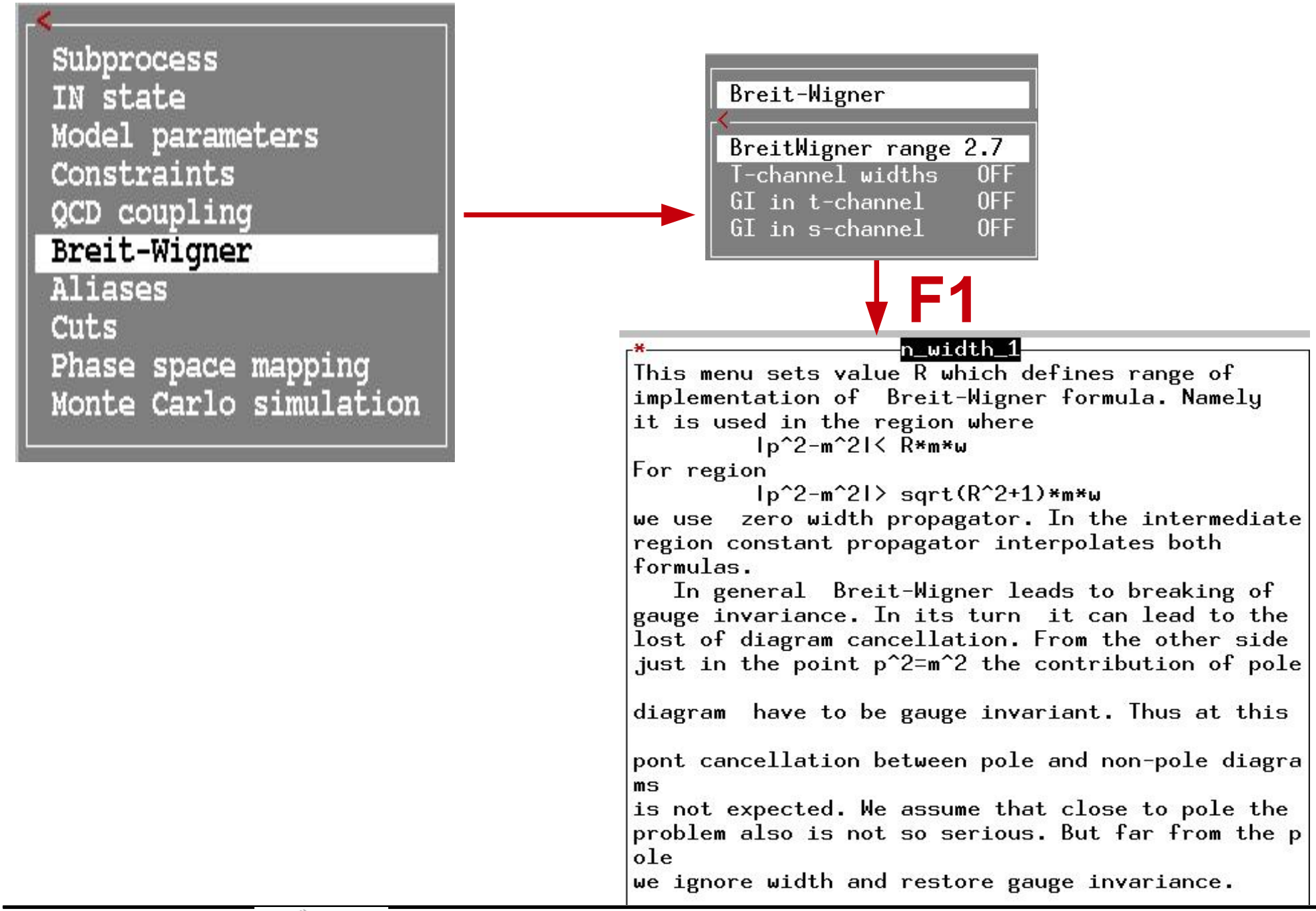
QCD coupling and the scale



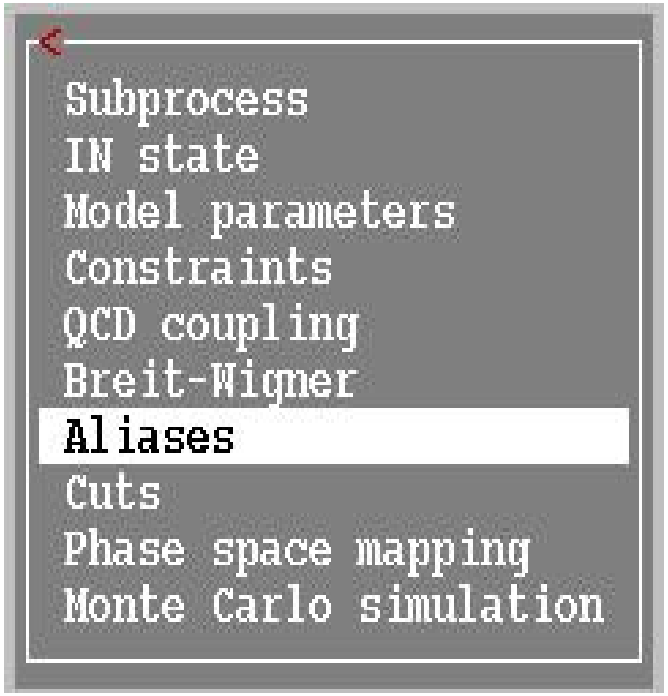
control of resonances

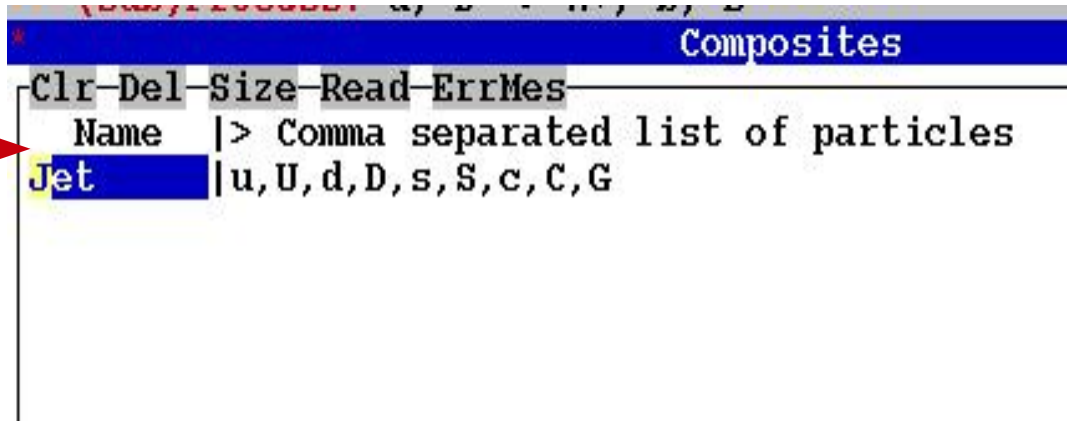


control of resonances

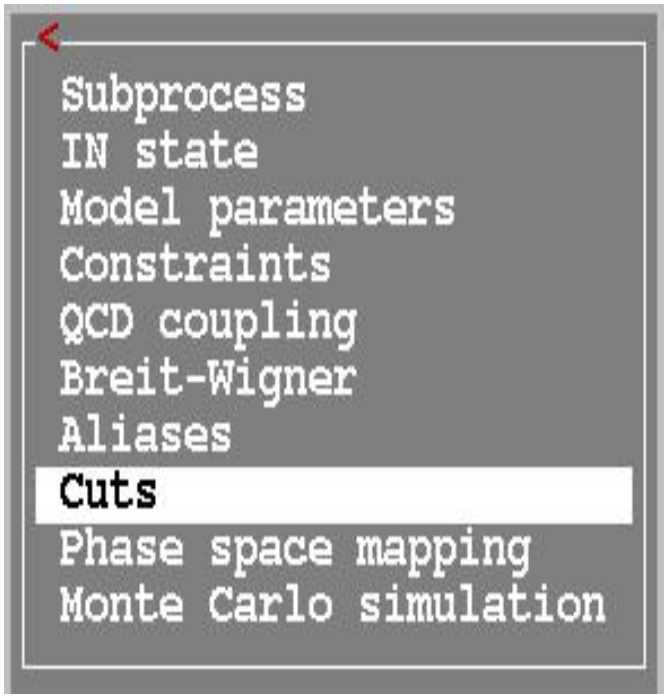


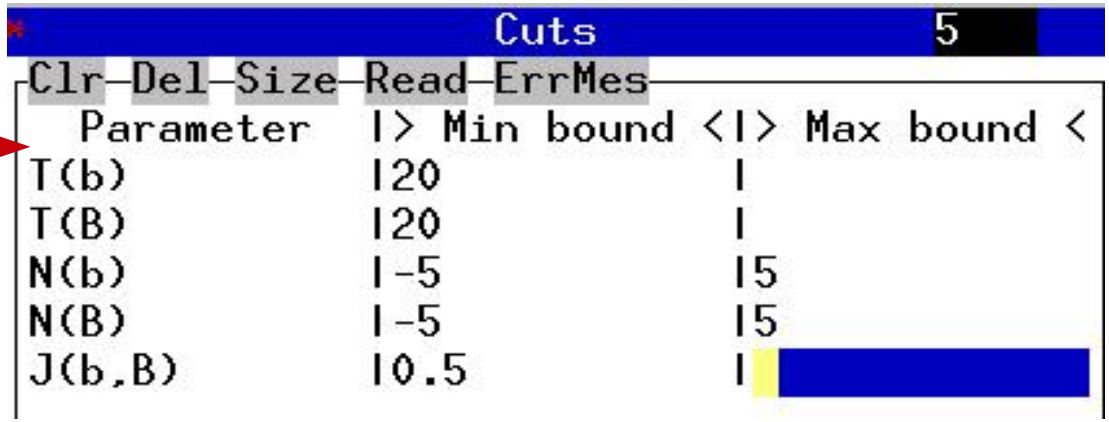
Aliases


Subprocess
IN state
Model parameters
Constraints
QCD coupling
Breit-Wigner
Aliases
Cuts
Phase space mapping
Monte Carlo simulation

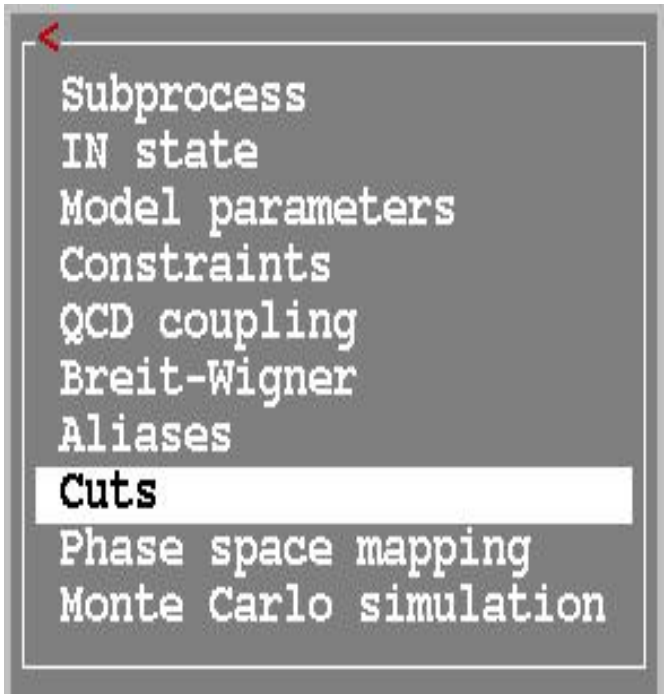

Composites
Clr-Del-Size-Read-ErrMes
Name |> Comma separated list of particles
Jet |u,U,d,D,s,S,c,C,G

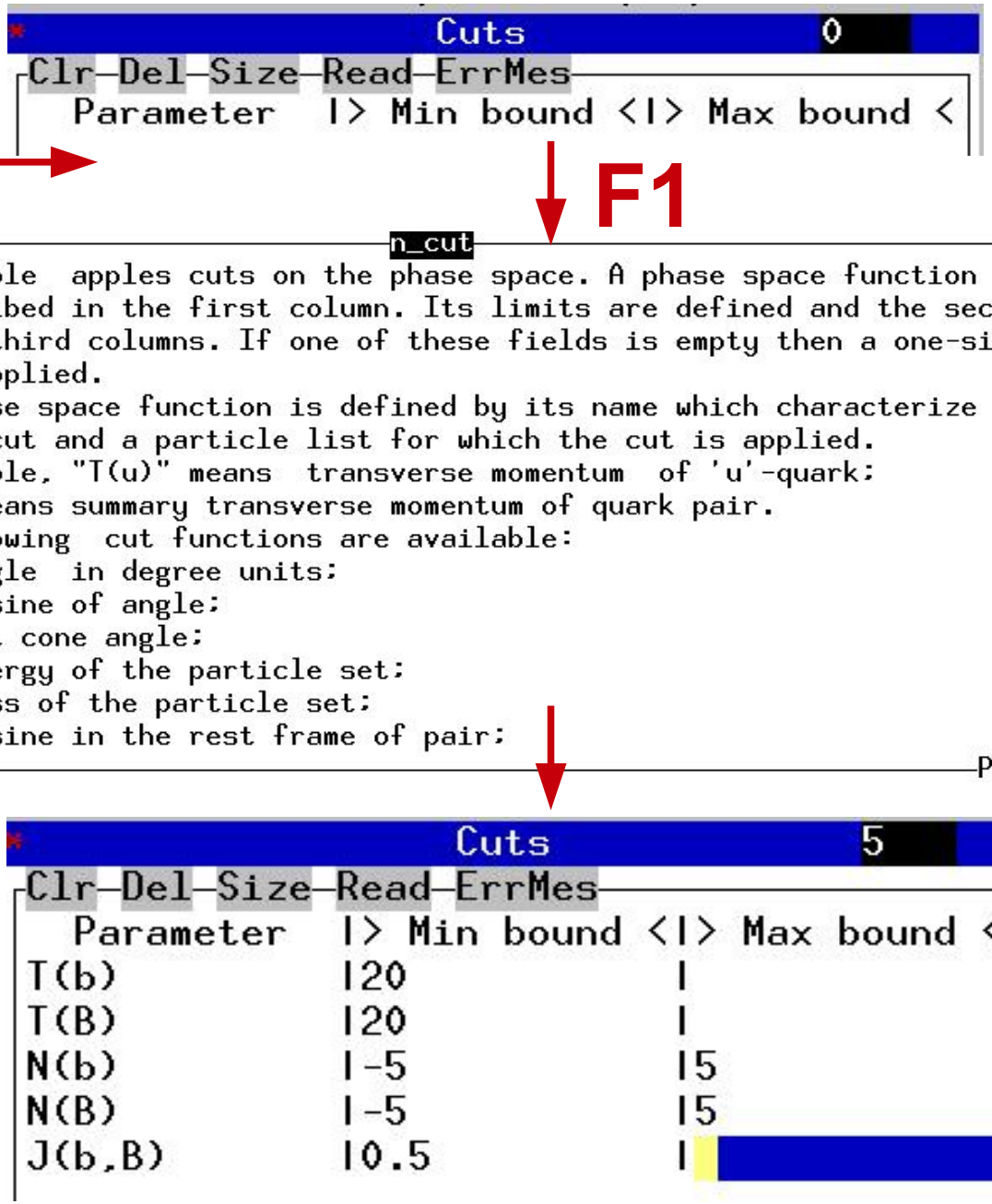
setting kinematical cuts



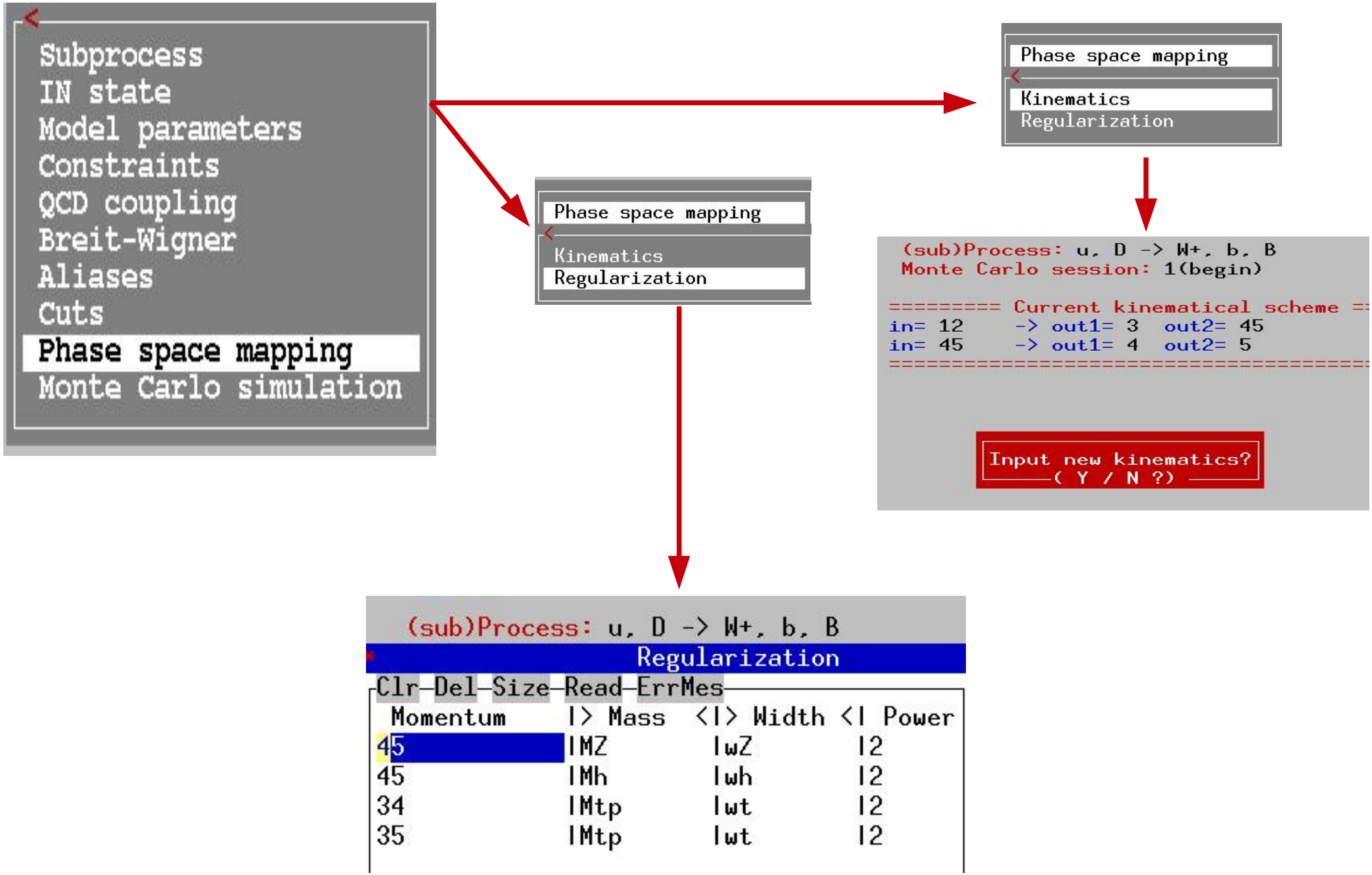


setting kinematical cuts





phase-space mapping



integration over the phase space

```
Subprocess
IN state
Model parameters
Constraints
QCD coupling
Breit-Wigner
Aliases
Cuts
Phase space mapping
Monte Carlo simulation
```

```
Monte Carlo simulation
nSess  = 5
nCalls = 10000
Set  Distributions
*Start integration
Display Distributions
Clear statistic
Freeze grid          OFF
Clear  grid
Event Cubes 10000
Generate Events
```

Distributions

Clr	Del	Size	Read	ErrMes

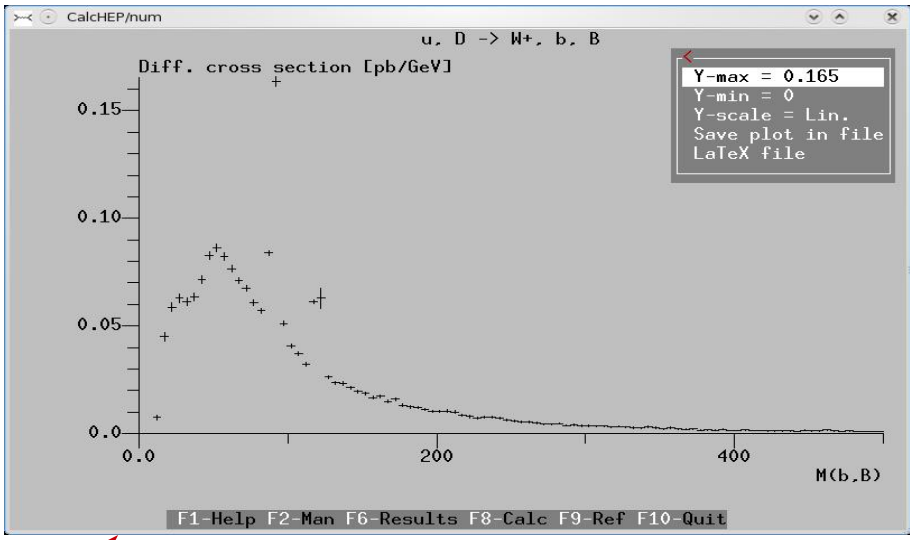
Parameter_1	I> Min_1	<I> Max_1	<IParameter_2	I> Min_2	<I> Max_2
T(b)	0	200			
T(B)	0	200			
N(b)	-5	5			
N(B)	-5	5			
M(b,B)	0	500			
M(W+,b)	0	500			
T(b)	0	500	M(b,B)	0	500

```
nSess  = 5
nCalls = 10000
Set  Distributions
*Start integration
Display Distributions
Clear statistic
Freeze grid          OFF
Clear  grid
Event Cubes 10000
Generate Events
```

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

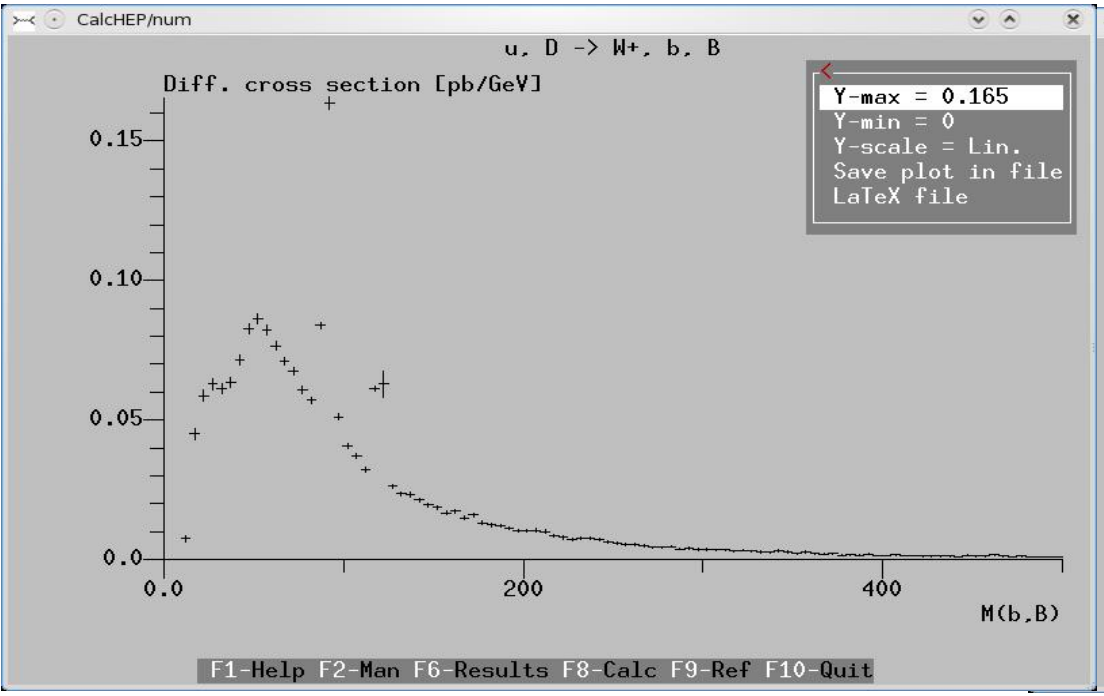
#IT	Cross section [pb]	Error %
6	9.5931E+00	7.10E-01
7	9.5686E+00	6.79E-01
8	9.5669E+00	6.82E-01
9	9.6892E+00	7.93E-01
10	9.6267E+00	7.51E-01
1	9.7757E+00	7.32E-01
clear statistics.		
2	9.6557E+00	6.82E-01
3	9.7464E+00	1.38E+00
4	9.6945E+00	1.05E+00
5	9.7032E+00	7.68E-01
< >	9.7095E+00	3.74E-01

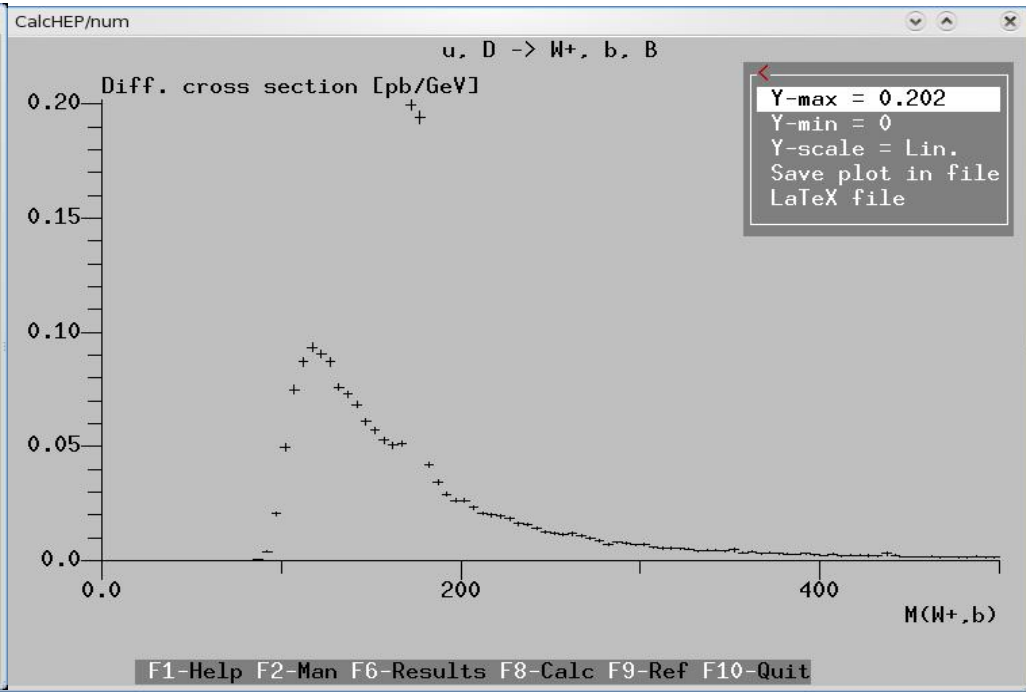
```
nSess  = 5
nCalls = 10000
Set  Distributions
*Start integration
Display Distributions
Clear statistic
Freeze grid          OFF
Clear  grid
Event Cubes 10000
Generate Events
```



The accuracy and the stability of the cross section indicate that you can trust your results

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

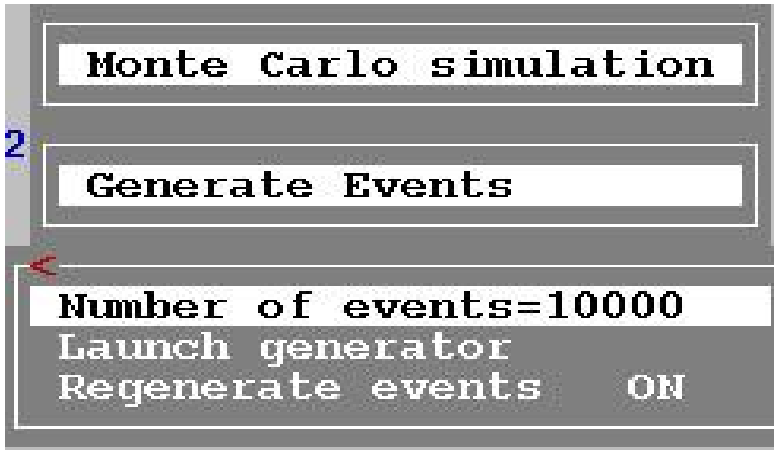


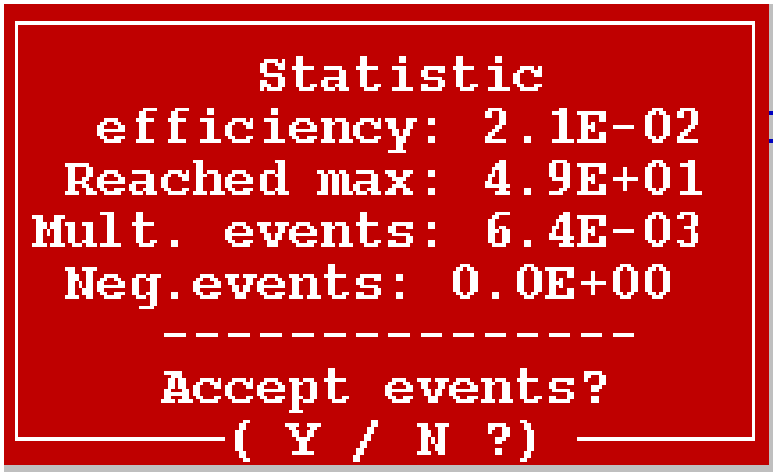


ex#4

1. Calculate WbB production rates at the 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

events generations





File with events in the native CalcHEP format

events_1.txt - /home/belyaev/Dropbox/hep_tools/calchep/calc_work/pp_Wbb_example/

File Edit Search Preferences Shell Macro Windows Help

/home/belyaev/Dropbox/hep_tools/calchep/calc_work/pp_Wbb_example/events_1.txt 243603 bytes L: 1 C: 0

```
#CalcHEP  3.4.cpc
#Type 2 -> 3
#Initial_state
  P1_3=4.000000E+03  P2_3=-4.000000E+03
  StrFun1="PDT:cteq6m(proton)" 2212
  StrFun2="PDT:cteq6m(proton)" 2212
#PROCESS   2(u) -1(D) -> 24(W+) 5(b) -5(B)
#MASSES  0.0000000000E+00 0.0000000000E+00 8.0385000000E+01 3.2414139578E+00 3.2414139578E+00
#Cross_section(Width) 6.473084E+01
#Number_of_events       1000
#Events       P1_3 [Gev]         P2_3 [Gev]         P3_1 [Gev]         P3_2 [Gev]         P3_3 [Gev]         P4
       1   7.0828325272E+02 -3.8182148276E+00 -5.8685533663E+00  2.4810106784E+00  6.8128552155E+02  1.995
       1   1.5237718262E+02 -2.5952742306E+01  1.1734367441E+01 -2.1669699291E+01  5.6645397996E+01  4.499
       1   7.2370755716E+02 -3.3186893665E+00 -3.4449322581E+00 -5.1815667765E+00  5.8508268207E+02 -3.584
       1   2.6295673814E+02 -1.1370528114E+01  8.9463043464E+00 -3.4258266547E+00  2.2732569389E+02 -9.675
       1   5.7099697940E+02 -3.3943984194E+01  7.2879879961E+00 -2.3531627752E+01  1.9857446272E+01 -8.750
       1   3.6709401207E+02 -2.4124155464E+01 -4.8101350483E+00  6.6698730251E+01  2.0295672218E+02 -4.597
       1   3.7196555447E+01 -4.1553021555E+02 -3.1735918986E+00  2.8330641675E-01 -6.6745521993E+00  4.343
       1   4.0543944850E+01 -1.1104274125E+02 -8.2903700266E+00 -4.3292277920E+00 -9.0241583360E-01  6.562
       1   4.0084952687E+02 -1.0215920577E+01  1.1427574950E+01  2.6016502364E+00  3.8645254998E+02 -4.666
       1   2.2620009412E+01 -1.2387066011E+02 -5.0869818859E+00  1.1389105773E+01 -7.1200204784E+01  1.176
       1   7.2046251695E+02 -2.1091178466E+01 -1.4887347954E+01  8.1292985197E+01  5.8742582956E+02 -5.134
       1   6.8661185459E+01 -8.3534206530E+01 -5.5091602956E+00 -1.7099072377E+01  4.1559702536E+01  2.604
       1   1.5145483971E+03 -3.1164597600E+00 -7.8325298677E+00  3.6606202670E+01  1.2782056265E+03  1.074
```

GUI gives user a full control of details of symbolic/numerical session.

To sum over the sub-processes one should use **scripts**

there are several scripts which run various loops to facilitate calculation

- ***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

You should run it from results dir where the n_calchep binary is!

running subproc_cycle for SM CKM=1 model

```
../bin/subproc_cycle 100 1000
#Subprocess 1 ( u, D -> W+, b, B ) Cross section = 3.9103E+00 , 1000 events
#Subprocess 2 ( U, d -> W-, b, B ) Cross section = 2.0301E+00 , 1000 events
#Subprocess 3 ( d, U -> W-, b, B ) Cross section = 2.0992E+00 , 1000 events
#Subprocess 4 ( D, u -> W+, b, B ) Cross section = 3.9088E+00 , 1000 events
#Subprocess 5 ( s, C -> W-, b, B ) Cross section = 2.6165E-01 , 1000 events
#Subprocess 6 ( S, c -> W+, b, B ) Cross section = 2.6151E-01 , 1000 events
#Subprocess 7 ( c, S -> W+, b, B ) Cross section = 2.6073E-01 , 1000 events
#Subprocess 8 ( C, s -> W-, b, B ) Cross section = 2.5592E-01 , 1000 events
Total Cross Section 12.98821 [pb]
see details in prt_37 - prt_44 files
```

- **bunch of events_*nn.txt* *event files are created,***
  so how do we combine them?

We need Events in LHE format to talk to MC generators!

- **bin/event_mixer** ***Luminosity[1/fb] nevents event_dirs***

mixes subprocesses and connects production and decay events

```
bin/event_mixer  10 1000 pp_wbb w_2x
9.327E+00  -total cross section[pb]
3265     -maximum number of events
```

- ***the output is*** **event_mixer.lhe** ***file***

```
<LesHouchesEvents version="1.0">
<!--
File generated with CalcHEP-PYTHIA interface
-->
<header>
<slha>
</slha>
</header>
<init>
  2212  2212  7.00000006860E+03  7.00000006860E+03    -1    -1    -1    -1     3     1
  1.16593335502E+01  0.00000000000E+00  1.00000000000E+00   1
</init>
<event>
 7    1   1.0000000E+00   2.8420000E+02  -1.0000000E+00  -1.0000000E+00
       -3   -1    0    0    0  501  0.00000000000E+00  0.00000000000E+00  1.54424456520E+02
        4   -1    0    0  500    0  0.00000000000E+00  0.00000000000E+00 -1.30792414700E+02
       24    2    1    2    0    0 -9.99292465447E+01 -1.63668803915E+01 -6.48692987742E+01
        5    1    1    2  500    0  7.34149473360E+01  2.15593961832E+01  4.23390519202E+01
       -5    1    1    2    0  501  2.65142992097E+01 -5.19251579179E+00  4.61622886720E+01
      -11    1    3    3    0    0 -7.19345413730E+01  7.47572186340E-01 -8.03452022142E+01
       12    1    3    3    0    0 -2.79947051718E+01 -1.71144525779E+01  1.54759034400E+01
</event>
```

Accessing all 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 = 7.8180609999999E-03
    alfSMZ = 1.1720000000000E-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_x.x.x/bin/ directory and README file!

- 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
- plot_view ../bin/plot_view < tab_1.txt
- events2tab
- lhe2tab
- gen_events
- name_cycle
- pcm_cycle
- par_scan

ex#5
produce LHE file
and use lhe2tab
to produce
distributions

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 – will be discussed below

the most general scan with

par_scan

- Usage:
  $CALCHEP/bin/par_scan < data_file

- Data file structure:

```
# Comments following the '#' symbol
par_name_1  par_name_2 ...   par_name_N & fun_name_1  fun_name_2 ...
  val11       val12    ....    val1N
  val21       val12    ....    val1N
.........................
```

- where par_name_i present free parameters of the models. Among them one also can write momenta of incoming particles as momentum1 and momentum2.
- fun_name_i is the name of constrained parameter which will be presented in output file
- Output file has the same structure as input plus calculated numerical values for constrained parameters, and an additional column for evaluated cross section with statistical error
- If you are not interested in the prt_# files you can clean it using
  $CALCHEP/bin/par_scan clean < data_file

CalcHEP batch interface

CalcHEP batch interface: all results in one shot

```
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
#######################################
```

```
#######################################
Kinematics :      12 -> 3, 45
Kinematics :      45 -> 4 , 5
Regularization momentum:1: 45
Regularization mass:1:     Mh
Regularization width:1:    wh
Regularization power:1:    2
#######################################
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)
#######################################
Number of events (per run step): 1000
Filename:                        test
#######################################
Parallelization method:      local
Max number of cpus:          2
sleep time:                  3
#######################################
nSess_1:   5
nCalls_1:  100000
nSess_2:   5
nCalls_2:  100000
```

CalcHEP batch interface: running and monitoring

```
sasha:~/calchep/work> ./calchep_batch

Main usage: "./calchep_batch batch_file_name"
    An example batch file  can be seen in:
    file:///home/belyaev/calchep/calchep_last/utile/batch_file

Help files can be created with the command:
    "./calchep_batch -help".

The files and directories created by the batch script can
    be removed with the command: "./calchep_batch -clean".
    This will remove the Events, Processes and html directories.
```

```
sasha:~/calchep/work> ./calchep_batch batch_file

calchep_batch version 1.38

Processing batch:
Progress information can be found in the html directory.
Simply open the following link in your browser:
file:///home/belyaev/calchep/work/html/index.html
You can also view textual progress reports in /home/belyaev/calchep/work/html/index.txt
        and the other .txt files in the html directory.
Events will be stored in the batch_results directory.
```

CalcHEP batch interface: monitoring the progress

Home
Symbolic Results
Numerical Results
Events Library
Process Library
Help

Thank you for using CalcHEP!
Please cite arXiv:1207.6082

CalcHEP Batch Details

Standard Model(CKM=1)

Done!

	Finished	Time(hr)
Symbolic	12/12	0.00
σ	3/3	0.03
Events	3/3	0.01

CalcHEP batch interface:
monitoring details of the symbolic section

Home
Symbolic Results
Numerical Results
Events Library
Process Library
Help

Thank you for using CalcHEP!
Please cite
arXiv:1207.6082

Symbolic Sessions

Standard Model(CKM=1)

Processes	Removes	Lib	PID	Time(hr)
u,D->W+,b,B	✓			
U,d->W-,b,B	✓			
d,U->W-,b,B	✓			
D,u->W+,b,B	✓			
s,C->W-,b,B	✓			
S,c->W+,b,B	✓			
c,S->W+,b,B	✓			
C,s->W-,b,B	✓			
W+->E,ne	✓			
W+->M,nm	✓			
W-->e,Ne	✓			
W-->m,Nm	✓			
Widths	✓			

CalcHEP batch interface: monitoring results of the numerical session

Home
Symbolic Results
Numerical Results
Events Library
Process Library
Help

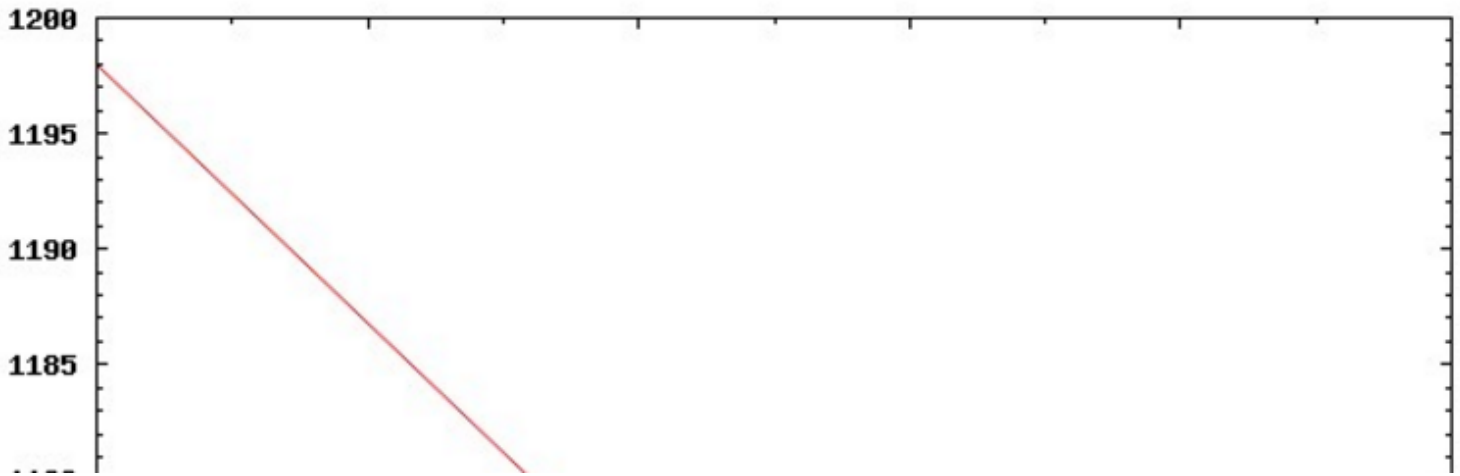
Thank you for using CalcHEP!
Please cite arXiv:1207.6082

Numerical Sessions

Standard Model(CKM=1)

Done!

Scans	σ (fb)	Running	Finished	Time (hr)	N events
Mh=120	1198	0/13	13/13	0.01	1000
Mh=125	1170	0/13	13/13	0.01	1000
Mh=130	1157	0/13	13/13	0.01	1000
				0.03	



CalcHEP batch interface: details of the numerical session

Home
Symbolic Results
Numerical Results
Events Library
Process Library
Help

Thank you for using CalcHEP!
Please cite arXiv:1207.6082

Numerical Sessions

Standard Model(CKM=1)

Done!

Processes	σ (fb)	Δσ (%)	PID	Time (hr)	N events	Details	
u,D->W+,b,B	1582.1	0.53	28919	0.00	383/382	prt_1	session.dat
U,d->W-,b,B	837.97	0.41	28923	0.00	218/217	prt_1	session.dat
d,U->W-,b,B	838.94	0.49	28928	0.00	218/217	prt_1	session.dat
D,u->W+,b,B	1621.4	2.7	28935	0.00	390/389	prt_1	session.dat
s,C->W-,b,B	111.07	0.41	28942	0.00	41/40	prt_1	session.dat
S,c->W+,b,B	111.15	0.38	28947	0.00	41/40	prt_1	session.dat
c,S->W+,b,B	111.5	0.46	28955	0.00	41/40	prt_1	session.dat
C,s->W-,b,B	111.76	0.41	28962	0.00	41/40	prt_1	session.dat
Total	5325.9	0.85					

Decays	Γ (GeV)	ΔΓ (%)	PID	Time (hr)	N events	Details	
W+->E,ne	0.23493	0	29144	0.00	5099/5100	prt_1	session.dat
W+->M,nm	0.23493	0	29148	0.00	5099/5100	prt_1	session.dat

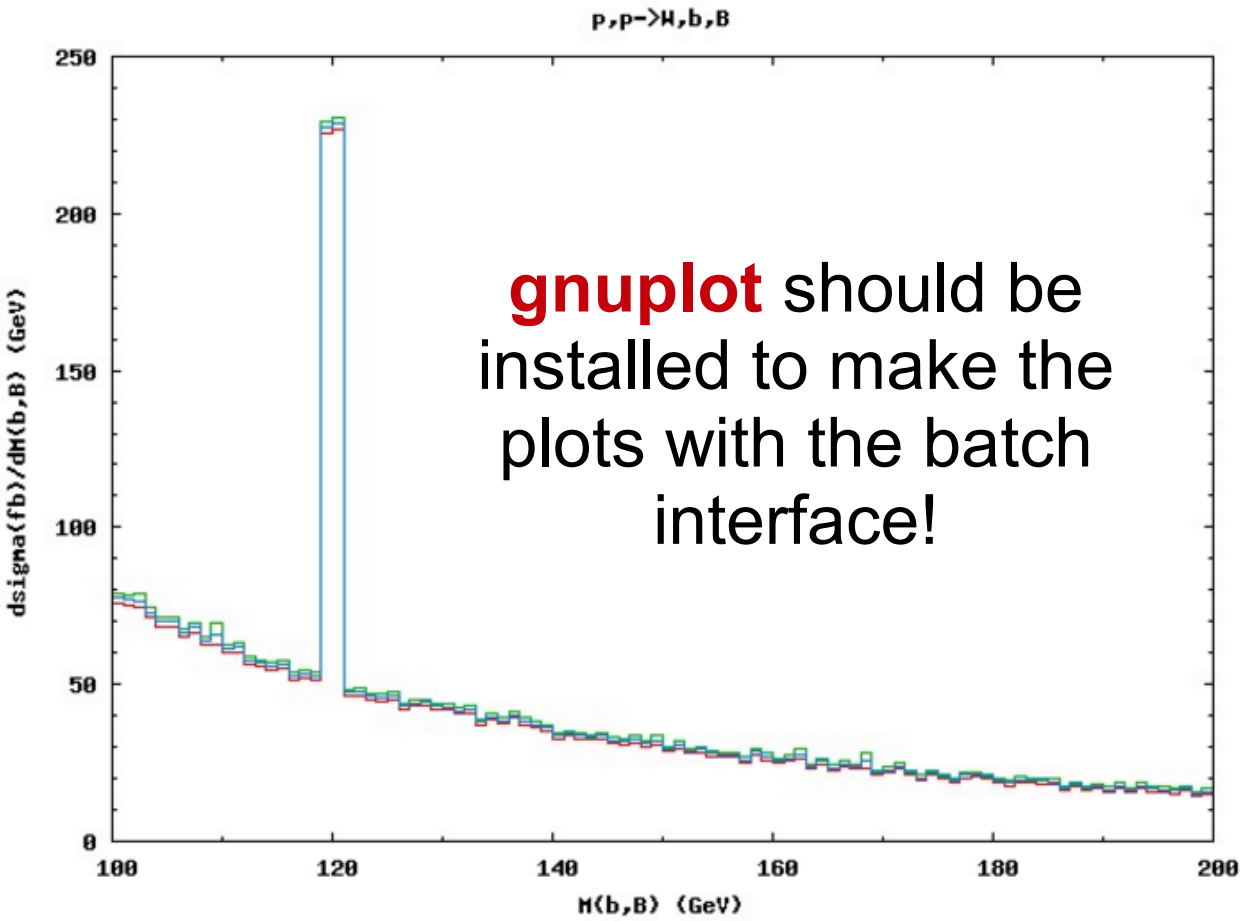
CalcHEP batch interface:
numerical results and distributions

Home
Symbolic Results
Numerical Results
Events Library
Process Library
Help

Thank you for using CalcHEP!
Please cite arXiv:1207.6082

Widths		PID	Time (hr)	Details
Widths		29167	0.00	session.dat
Total	1198		0.01	1000/1000

Distributions



ex#6: *using calchep_batch evaluate complete cross section for pp-> Wbb process with the same cuts as for ex#4*

gnuplot should be installed to make the plots with the batch interface!

CalcHEP batch interface:
access to your results

- results are located in **batch_results** folder
- ***.lhe.gz** : LHE event files
- ***.jpg** : figures
- ***.distr** : files with distributions which cab be used to re-produce plots using **$CALCHEP/bin/show_distr**
- ***.tgz** : zipped html folder with all numerical details, .txt and .html files of the batch run

CalcHEP batch interface:
some additional features/tricks

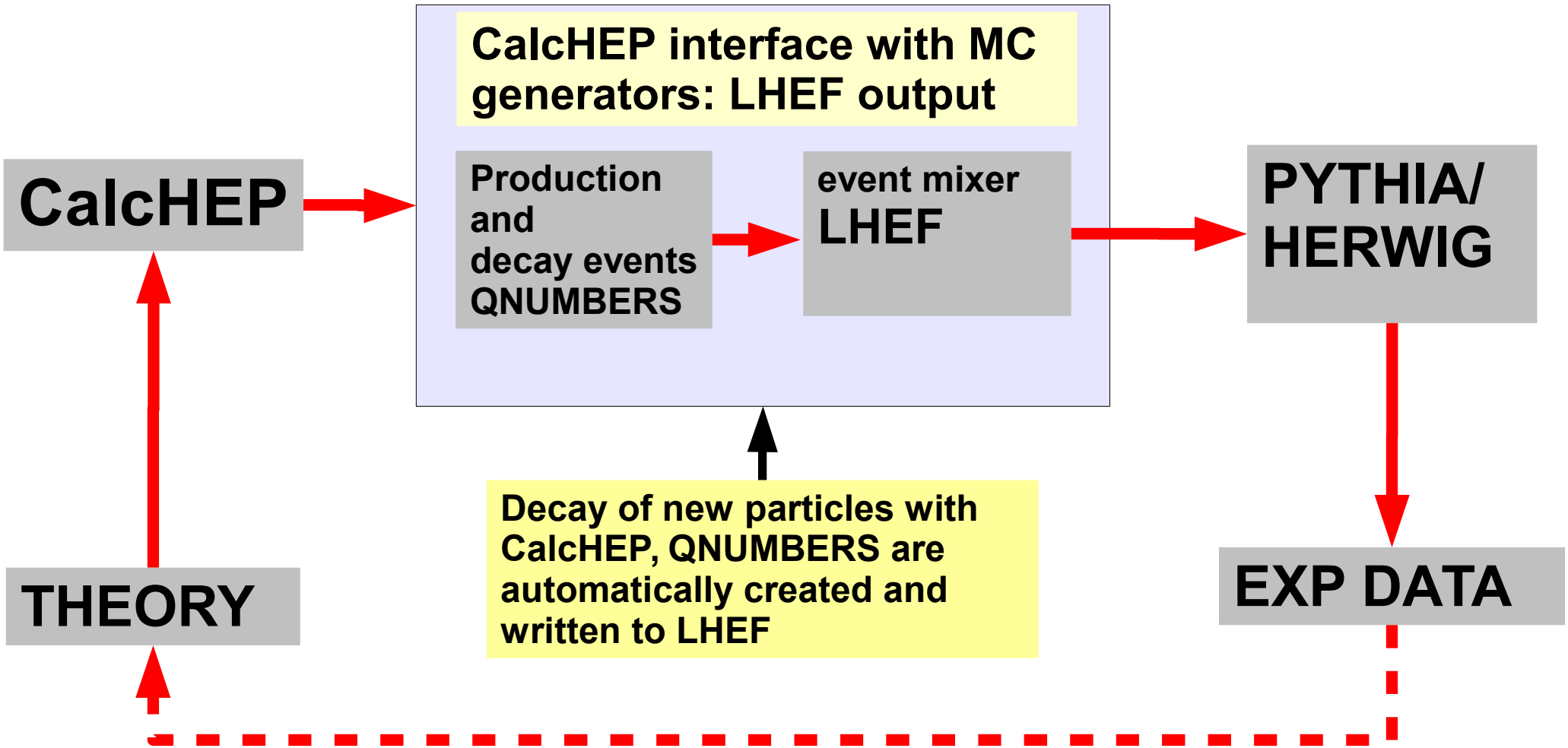
- see https://answers.launchpad.net/calchep
  for many “tricky” questions/answers
- scanning over the collider energy

  Run parameter: rtS
  Run begin: 7
  Run step size: 1
  Run n steps: 2

  p1: 1000*rtS/2
  p2: 1000*rtS/2

  rtS here is some “fake” parameter
- you can use “fake” parameter only if you define it as a loop parameter
  - It can be used in the cut statement (assigning cut to the symbol)
  - It can be assigned to the parameter model – this way you can run use complicated scan

CalcHEP interface to MC generators via Events in the LHE format



Lecture III:

- LanHEP
- HEPMDB
- PhenoData
- advanced topics

Introduction to LanHEP package

Author: *Andrei Semenov*

http://theory.sinp.msu.ru/~semenov/lanhep.html

LanHEP software package

Overview

The LanHEP program for Feynman rules generation in momentum representation is presented. It reads the Lagrangian written in the compact form close to one used in publications. It means that Lagrangian terms can be written with summation over indices of broken symmetries and using special symbols for complicated expressions, such as covariant derivative and strength tensor for gauge fields. The output is Feynman rules in terms of physical fields and independent parameters. This output can be written in LaTeX format and in the form of CompHEP model files, which allows one to start calculations of processes in the new physical model. Although this job is rather straightforward and can be done manually, it requires careful calculations and in the modern theories with many particles and vertices can lead to errors and misprints. The program allows one to introduce into CompHEP new gauge theories as well as various anomalous terms.

Installation

To install LanHEP on your computer, you should get the archive file (see below) and unpack it. The archive contains the C source files. To create the executable file lhep , type 'make`. When the LanHEP is complied, remove source files by typing 'make clean`. The archive also contains the directory mdl with startup file and examples for several physical models. Add the directory containing LanHEP to your PATH environment variable. Than LanHEP can be started from any other directory, it can find automatically files from the mdl directory.

Online Manual version 2.0

Introduction to LanHEP package

V3.17 arXiv:0805.0555

This is the program for Feynman rules generation in momentum space

- **Example for QED**

$$\mathcal{L}_{QED} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \bar{e}\gamma^{\mu}(i\partial_{\mu} + g_e A_{\mu})e - m\bar{e}e, \qquad \mathcal{L}_{GF} = -\frac{1}{2}(\partial_{\mu}A^{\mu})^2$$

```
model QED/1.
parameter ge=0.31333:'elementary electric charge'.
spinor e1/E1:(electron, mass me=0.000511).
vector A/A:(photon).
let F^mu^nu=deriv^nu*A^mu-deriv^mu*A^nu.
lterm -1/4*(F^mu^nu)**2 - 1/2*(deriv^mu*A^mu)**2.
lterm E1*(i*gamma*deriv-me)*e1.
lterm ge*E1*gamma*A*e1.
```

Fields in the vertex	Variational derivative of Lagrangian by fields
$E1_a \quad e1_b \quad A_\mu$	$ee \cdot \gamma^{\mu}_{ab}$

LanHEP installation

http://theory.sinp.msu.ru/~semenov/lanhep.html

tar -zxvf lhep*xxx*.tar.gz

cd lhep*xxx*

make

ex#7
install LanHEP

Running LanHEP

- **cd mdl**
- ***../lhep -ca stand.mdl***

File sm_tex processed, 0 sec.

File stand.mdl processed, 1 sec.

Default options are in calchep.rc file

```
% Definitions specific for CalcHEP format of Feynman rules.

external_func(creal,1).
external_func(cimag,1).
external_func(cabs,1).

prtcformat fullname: 'Full   Name     ',
           name:' P ', aname:' aP', pdg:'  number  ',
           spin2,mass,width, color, aux, texname: ' LaTeX(A)       ',
           atexname:'  LateX(A+)          '.

prtcproperty pdg:(A=22, Z=23, 'W+'=24, G=21,
                  d=1, u=2, s=3, c=4, b=5, t=6,
                  ne=12, nm=14, nl=16,
                  e=11, m=13, l=15,
                  n1=12, n2=14, n3=16,
                  e1=11, e2=13, e3=15,
  ~ne=1000012, ~nm=1000014, ~nl=1000016,
  ~e1=1000011, ~m1=1000013, ~l1=1000015,
  ~e2=2000011, ~m2=2000013, ~l2=2000015,
  ~eL=1000011, ~mL=1000013,
  ~eR=2000011, ~mR=2000013,
```

Features of LanHEP

- it reads Lagrangian written in the form close to one used in publications and transforms it into momenta space
- it writes Feynman rules in the form of four tables in CompHEP format as well as tables in LaTeX format
- LanHEP expands expression and combines similar terms user can define the substitution rules, it allows to define multiplets, and their components
- user can write Lagrangian terms with Lorentz and multiplet indices explicitly or omit indices (all or some of them)
- LanHEP performs explicit summation over the indices in Lagrangian terms, if the corresponding components for multiplets and matrices are introduced
- it allows user to introduce vertices with 4 fermions and 4 colored particles (such vertices can't be introduced directly in CompHEP) by means of auxiliary field with constant propagator
- it also can check whether the set of introduced vertices satisfies the electric charge conservation law
- many more features: see manual(!) – using superpotential formalism, check for BRST invariance, two-component notation for fermions, ...

QCD as the next example

- **Gauge interactions** $L_{YM} = -\frac{1}{4} F^{a\mu\nu} F^a_{\mu\nu},$

where $F^a_{\mu\nu} = \partial_\mu G^a_\nu - \partial_\nu G^a_\mu - g_s f^{abc} G^b_\mu G^c_\nu,\ G^a_\mu(x)$

- **Quark kinetic term** $L_F = \bar{q}_i \gamma^\mu \partial_\mu q_i + g_s \lambda^a_{ij} \bar{q}_i \gamma^\mu q_j G^c_\mu,$

- **Gauge fixing term and Fadeev-Popov ghost term**

$$\mathcal{L}_{GF} = -\frac{1}{2}(\partial_\mu G^\mu_a)^2 + i g_s f^{abc} \bar{c}^a G^b_\mu \partial^\mu c^c,$$

```
model QCD/2.
parameter gg=1.117:'Strong coupling'.
spinor q/Q:(quark, mass mq=0.01, color c3).
vector G/G:(gluon, color c8, gauge).
let F^mu^nu^a = deriv^nu*G^mu^a - deriv^mu*G^nu^a -
          gg*f_SU3^a^b^c*G^mu^b*G^nu^c.
lterm -F**2/4-(deriv*G)**2/2.
lterm Q*(i*gamma*deriv+mq)*q.
lterm i*gg*f_SU3*ccghost(G)*G*deriv*ghost(G).
lterm gg*Q*gamma*lambda*G*q.
```

QCD Feynman rules generated by LanHEP in LaTeX format

Fields in the vertex	Variational derivative of Lagrangian by fields
$G_{\mu p}\ G.C_q\ G.c_r$	$-gg\cdot p_3^{\mu} f_{pqr}$
$Q_{ap}\ q_{bq}\ G_{\mu r}$	$gg\cdot\gamma_{ab}^{\mu}\lambda_{pq}^{r}$
$G_{\mu p}\ G_{\nu q}\ G_{\rho r}$	$ggf_{pqr}(p_3^{\nu}g^{\mu\rho}-p_2^{\rho}g^{\mu\nu}-p_3^{\mu}g^{\nu\rho}+p_1^{\rho}g^{\mu\nu}+p_2^{\mu}g^{\nu\rho}-p_1^{\nu}g^{\mu\rho})$
$G_{\mu p}\ G_{\nu q}\ G_{\rho r}\ G_{\sigma s}$	$gg^2(g^{\mu\rho}g^{\nu\sigma}f_{pqt}f_{rst}-g^{\mu\sigma}g^{\nu\rho}f_{pqt}f_{rst}+g^{\mu\nu}g^{\rho\sigma}f_{prt}f_{qst}$
	$+g^{\mu\nu}g^{\rho\sigma}f_{pst}f_{qrt}-g^{\mu\sigma}g^{\nu\rho}f_{prt}f_{qst}-g^{\mu\rho}g^{\nu\sigma}f_{pst}f_{qrt})$

Syntax of LanHEP

- ***The LanHEP input file is the sequence of statements, each starts with a special identifier (such as parameter, lterm, etc) and ends with the full-stop '.' symbol. Statement can occupy several lines***
- ***Identifiers:*** ***Indentfiers are the names of particles, parameters etc.***
- ***Constants:*** ***integers, floating point numbers, strings***
- ***Comments:*** '%' ,'/*' ... '*/'
- ***Order of the indices of the objects (default):***

```
[spinor, color c3, color c8, vector]
```

- ***declaring new groups:***

```
group color:SU(3).
repres color:(c3/c3b,c8).
```

- ***parameters***

parameter *name*=*value*:*comment*.

- ***particles***

scalar *P/aP*:(*options*).
spinor *P/aP*:(*options*).
vector *P/aP*:(*options*).

Syntax of LanHEP

- ***Specials*** gamma, gamma5, moment, deriv, lambda, f_SU3
  declaring new specials: special *name*:(*islist*).

- ***Orthogonal matrice*** OrthMatrix($\{\{a_{11}, a_{12}\}, \{a_{21}, a_{22}\}\}$).

- ***Including files*** read *file*. or use *file*. (no multiple reading)

- ***Checking electric charge conservation*** SetEM(*photon*, *param*).

- ***Running LanHEP*** lhep *filename options*

  -OutDir *directory* Set the directory for output files

  -InDir *directory* Set the directory where to search files

  -tex LanHEP generates LaTeX files

  -frc If -tex option is set, forces LanHEP to split 4-fermion and 4-color vertices just as it is made for CompHEP files.

  -texLines *num* Set number of lines in LaTeX tables

  -texLineLength *num* Controls width of the Lagrangian

Default groups and specials in LanHEP

- **See** mdl/lhep.rc

```
special gamma:(spinor,cspinor,vector).
special gamma5:(spinor,cspinor).
special '(1+gamma5)/2':(spinor,cspinor), '(1-gamma5)/2':
(spinor,cspinor).
special moment:(vector).
special '__moment__start__':(vector), '__moment__end__'.
special epsv:(vector,vector,vector,vector).
group color:SU(3).
repres color:(c3/c3b,c8).
SetDefIndex(spinor,color c3, color c8, vector).
special lambda:(color c3, color c3b, color c8).
special f_SU3:(color c8, color c8, color c8).
special d_SU3:(color c8, color c8, color c8).
special eps_c3: (color c3,  color c3,  color c3),
       eps_c3b:(color c3b, color c3b, color c3b).
let deriv=-i*moment.
let tau1={{0,1},{1,0}}, tau2={{0,i},{-i,0}}, tau3={{1,0},{0,-1}}.
```

user-defined model

$$\bar{b}_{ap} \quad t_{bq} \quad W^{-}{}_{\mu} \quad \Big| \; -\frac{1}{4}\frac{e\cdot\sqrt{2}\cdot Vtb}{s_w}\cdot(1-\gamma^5)_{cb}\delta_{pq}\gamma^{\mu}_{ac}$$

- ***Let us add left and right anomalous couplings to WtB interaction: Ar and Al***

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%% anomalous WtB interactions Ar and Al
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

parameter Ar,Al.
let PR=(1+gamma5)/2, PL=(1-gamma5)/2.

lterm   -g/Sqrt2*
         (Ar*anti(t)*'W+'*gamma*PR*b  + Al*anti(t)*'W+'*gamma*PL*b)
       + AddHermConj.
```

$$-\frac{1}{4}\frac{e\cdot\sqrt{2}}{s_w}\delta_{pq}\gamma^{\mu}_{ac}(Vtb\cdot(1-\gamma^5)_{cb}+Ar\cdot(1+\gamma^5)_{cb}+Al\cdot(1-\gamma^5)_{cb})$$

ex#8

implement $\sigma^{\mu\nu}$ anomalous terms B_l, B_r

Using the superpotential formalism in the MSSM and its extensions

- ***Superpotential – a polynomial W depending on scalar fields A_i***
- ***The most general form of the MSSM superpotential which does not violate gauge invariance and the SM conservation laws is:***

$$W = \mu\epsilon_{ij}H_i^1H_j^2 + \epsilon_{ij}Y_l^{IJ}H_i^1L_j^IR^J + \epsilon_{ij}Y_d^{IJ}H_i^1Q_j^ID^J + \epsilon_{ij}Y_u^{IJ}H_i^2Q_j^IU^J$$

which in LanHEP notation will take a form

```
keep_lets W.
let W=eps*(mu*H1*H2+ml*H1*L*R+md*H1*Q*D+mu*H2*Q*U).
```

Where H1, H2, L, R, Q, U, D ***should be defined above as doublets and singlets in terms of scalar particles.***

keep_lets ***statement substitution of*** H1, H2, L, R, Q, U, D **in terms of their components**

Using the superpotential formalism in the MSSM and its extensions

- ***Yuakawa interactions are given by***

$$-\frac{1}{2}\left(\frac{\partial^2 W}{\partial A_i \partial A_j}\Psi_i\Psi_j + H.c.\right)$$

which in the LanHEP language will take form

```
lterm - df(W,H1,H2)*fH1*fH2 - ...   + AddHermConj.
```

where fH1, fH2 ***should be defined above as fermionic partners of corresponding multiples, e.g.***

```
let f_h1 = { Zn31*up(~o1)+Zn32*up(~o2)+Zn33*up(~o3)+Zn34*up(~o4),
             Zm21*up('~1-')+Zm22*up('~2-') }.
```

Using the superpotential formalism in the MSSM and its extensions

- ***FF* term from scalar supersymmetric potential***

$$V = \frac{1}{2} D^a D^a + F_i^\star F_i \quad \textit{where} \quad F_i = \partial W / \partial A_i$$

in LanHEP notation will take a form

```
lterm - df(W,H1)*df(Wc,H1c) - ....
```

where Wc ***should be decleared above as the conjugate superpotential***

FF* term can be introduced even in shorter way as

```
lterm - dfdfc(W,H1) - ....
```

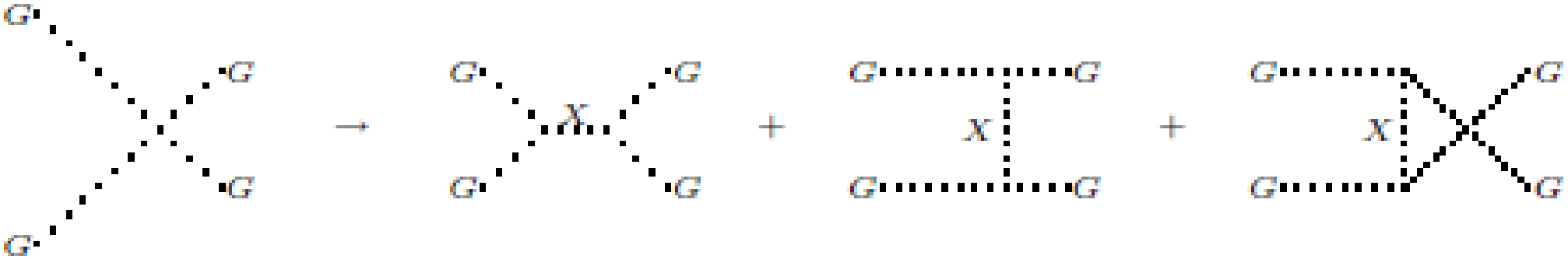
where dfdfc(W,H1) **function** ***evaluates the variational derivative, multiplies it by the conjugate expression and returns the result***

Vertices with color particles in CalcHEP

- *The CalcHEP Lagrangian tables do not describe explicitly the color structure of a vertex.*
- *If color particles are present in the vertex, the following implicit contractions are assumed (p, q, r are color indices):*
  - $\pm_{pq}$ for two color particles A^1_p and A^2_q
  - $\lrcorner^r_{pq}$ for three particles, which are color triplet, antitriplet and octet
  - f^{pqr} for three color octets $f^{pqr} G^p_\mu G^q_\nu G^r_\lambda$
  - ***There are no other color structures in CalcHEP***

Vertices with color particles in CalcHEP

- *4-gluon vertex can be split it into 3-legs vertices* $f^{pqr} G^q_\mu G^r_\nu X^p_{\mu\nu}$



- *Here the field* $X^p_{\mu\nu}$ *is a Lorenz tensor and color octet, and this field has constant propagator.*
- *If gluon name in CalcHEP is 'G', the name 'G.t' is used for this tensor particle; its indices are denoted as 'm_' and 'M_'*
  ('_' is the number of the particle in table item).

Vertices

Clr	Del	Size	Read	ErrMes			
A1	|A2	|A3	|A4	|>	Factor	<|>	Lorentz part
G	|G	|G	|	|GG			|m1.m2*(p1-p2).m3+m2.m3*(p2-p3).m1+m3.m1*(p3-p1).m2
G	|G	|G.t	|	|GG/Sqrt2			|m1.M3*m2.m3-m1.m3*m2.M3

Vertices with color particles in LanHEP

- *The splitting of vertex with 4 colored particle into 3-particles vertices is done by LanHEP automatically: each vertex containing 4 color particles is split to 2 vertices which are joined by automatically generated auxiliary field*
- *option SplitCol1=N.*
  where N is a number:
  - *-1 remove all vertices with 4 color particles from Lagrangian;*
  - *0 turn off multiplet level vertices splitting;*
  - *1 allows vertices splitting with 4 color multiplets;*
  - *2 allows vertices splitting with any 4 scalar multiplets except Higgs*
- *option SplitCol2=N.*
  - *where N is a number:*
  - *0 disable vertex level splitting;*
  - *1 enable vertex level splitting (only for vertices with 4 color particles).*
- *the default value is 2 for SplitCol1 and 1 for SplitCol2*

Implementation of SM Lagrangian(1)

Location of LanHEP model files:

lanhep/mdl/stand.mdl

```
%
% Standard Model - unitary and t'Hooft-Feynman gauges.
%

keys gauge_fixing=Feynman.

do_if gauge_fixing==Feynman.
    model 'Stand. Model (Feyn. gauge)'/6.
do_else_if gauge_fixing==unitary.
    model 'Stand. Model (un. gauge)'/5.
do_else.
    write('Error: the key "gauge" should be either "Feynman" or "unitary".').
    quit.
end_if.
```

Implementation of SM Lagrangian(2)

- ***Parameters definition***

```
let g5=gamma5.
use sm_tex.

parameter  EE  = 0.31333 : 'Electromagnetic coupling constant (<->1/128)',
           GG  = 1.117   : 'Strong coupling constant (Z point)  (PDG-94)',
           SW  = 0.4740  : 'sin of the Weinberg angle (PDG-94,"on-shell")',
           s12 = 0.221   : 'Parameter of C-K-M matrix (PDG-94)',
           s23 = 0.040   : 'Parameter of C-K-M matrix (PDG-94)',
           s13 = 0.0035  : 'Parameter of C-K-M matrix (PDG-94)'.

parameter  CW  = sqrt(1-SW**2) : 'cos of the Weinberg angle'.

parameter  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'.

parameter  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'.

OrthMatrix( { {Vud,Vus,Vub}, {Vcd,Vcs,Vcb}, {Vtd,Vts,Vtb}} ).
```

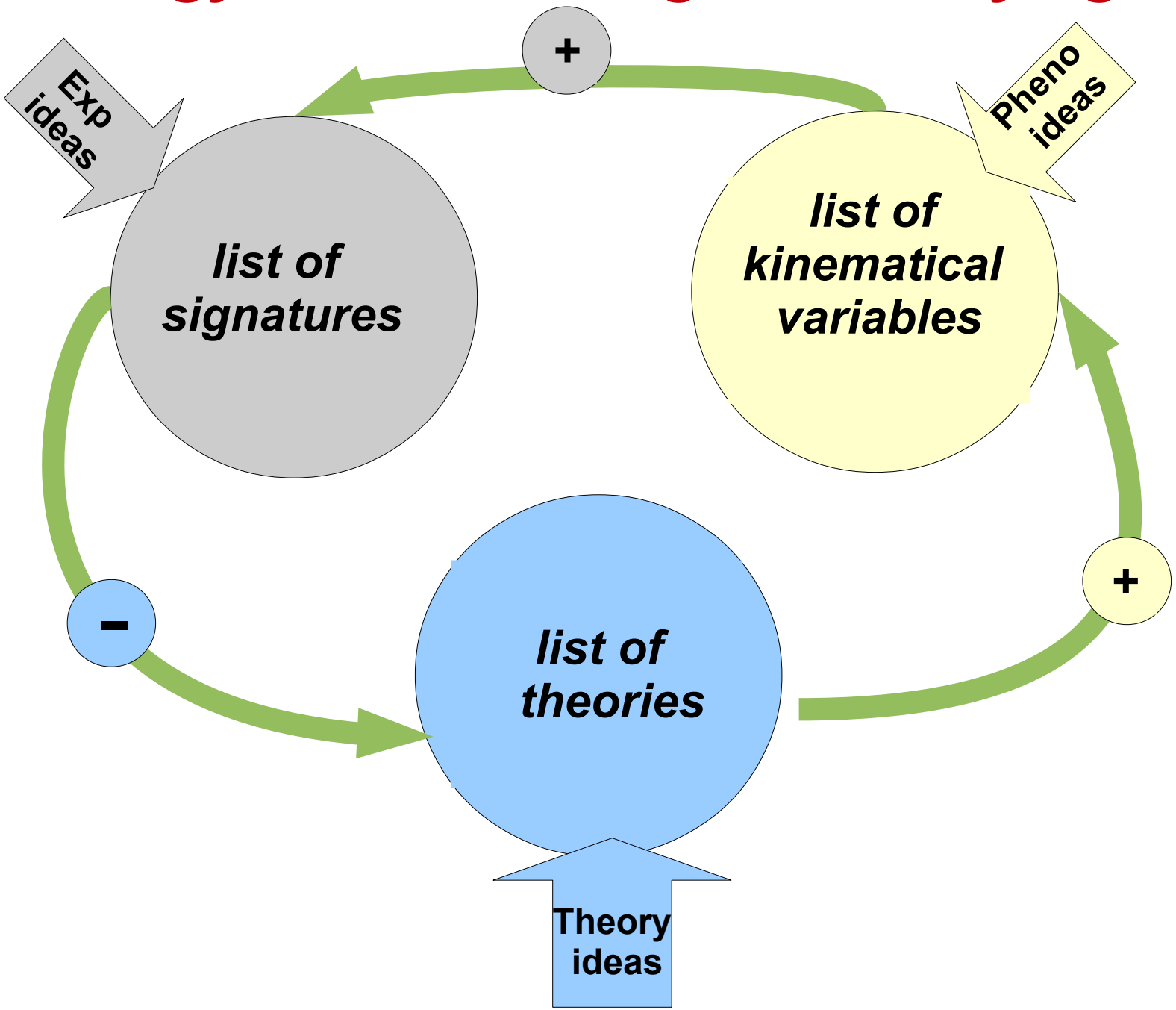
Implementation of SM Lagrangian(4)

- ***Definition of mixings and doublets***

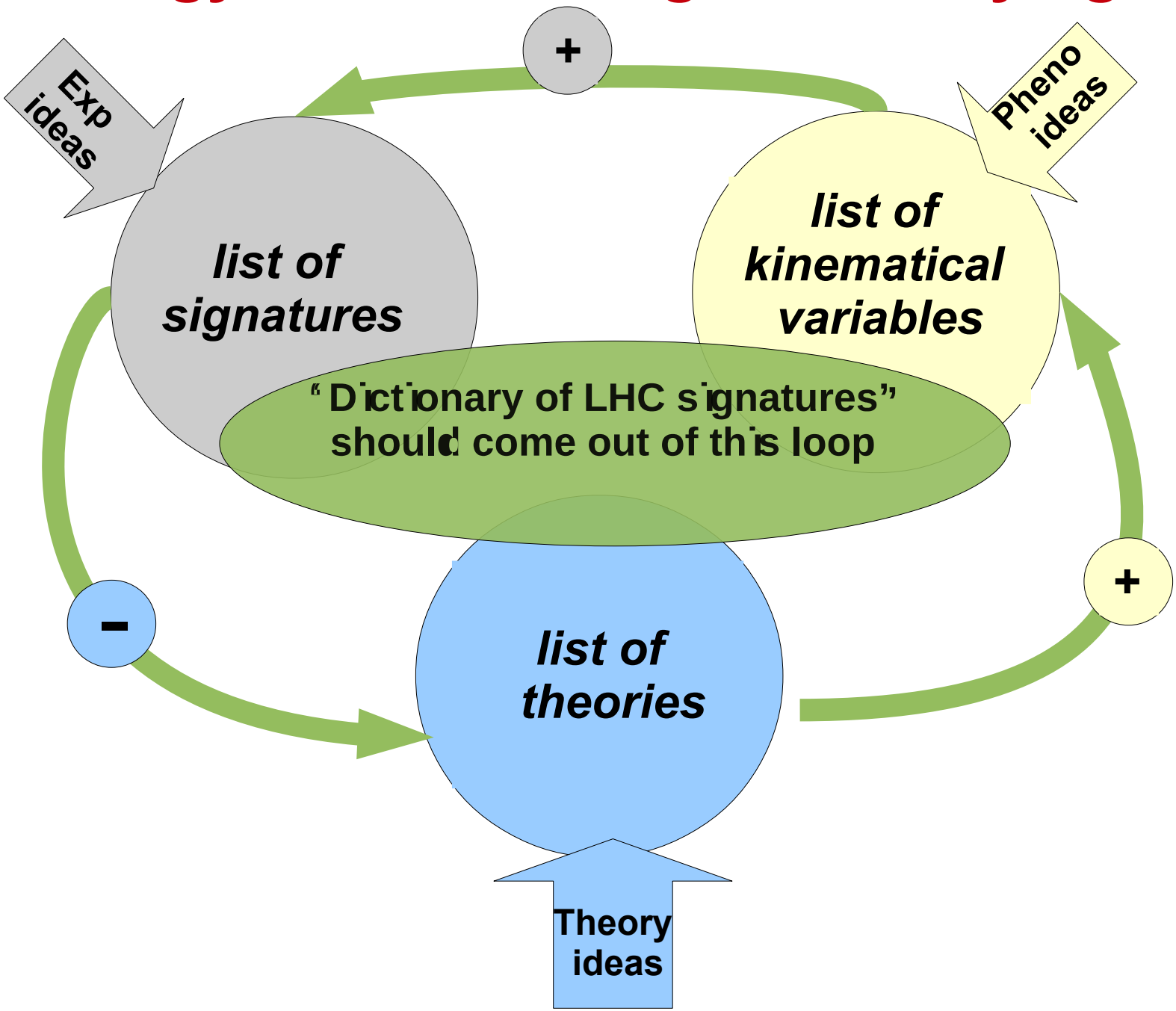
```
let l1={n1,e1}, L1={N1,E1}.
let l2={n2,e2}, L2={N2,E2}.
let l3={n3,e3}, L3={N3,E3}.

let q1={u,d}, Q1={U,D}, q1a={u,Vud*d+Vus*s+Vub*b}, Q1a={U,Vud*D+Vus*S+Vub*B}.
let q2={c,s}, Q2={C,S}, q2a={c,Vcd*d+Vcs*s+Vcb*b}, Q2a={C,Vcd*D+Vcs*S+Vcb*B}.
let q3={t,b}, Q3={T,B}, q3a={t,Vtd*d+Vts*s+Vtb*b}, Q3a={T,Vtd*D+Vts*S+Vtb*B}.

let B1= -SW*Z+CW*A, W3=CW*Z+SW*A, W1=('W+'+'W-')/Sqrt2,
        W2 = i*('W+'-'W-')/Sqrt2.

do_if gauge_fixing==Feynman.

let gh1 = ('W+.c'+'W-.c')/Sqrt2, gh2= i*('W+.c'-'W-.c')/Sqrt2,
                gh3= CW*'Z.c'+SW*'A.c', gh={gh1,gh2,gh3}.

let Gh1 = ('W+.C'+'W-.C')/Sqrt2, Gh2=i*('W+.C'-'W-.C')/Sqrt2,
                Gh3= CW*'Z.C'+SW*'A.C', Gh={Gh1,Gh2,Gh3}.

end_if.

let WW1 = {W1,  W2 , W3}, WW = {'W+',W3,'W-'}.

let g=EE/SW, g1=EE/CW.
```

HEPMDB

The strategy for delineating of underlying theory



The strategy for delineating of underlying theory



First Steps towards "Dictionary"

AB, Asesh Datta, A. De Roeck Rohini Godbole, Bruce Mellado, Andreas Nyffeler, Chara Petridou, D.P. Roy, Pramana 72:229-238,2009. e-Print: arXiv:0806.2838 [hep-ph]

Variables		SUSY (MSSM)	LHT	UED
Spin		heavy partners differ in spin by 1/2	heavy partners have the same spin, no heavy gluon	heavy partners have the same spin
Higher level modes		NO heavy partners	NO heavy partners	YES heavy partners
$N_{l^+l^+}/N_{l^-l^-}$		$R_{SUSY} < R_{LHT}$	R_{LHT}	$R_{UED} \simeq R_{LHT}$
SS leptons rates		from several channels: SS heavy fermions, Majorana fermions	only from SS heavy fermions	only from SS heavy fermions
$R = \frac{N(\not{E}_T + jets)}{N(l's + \not{E}_T + \text{jets})}$		R_{SUSY}	$R_{\text{LHT}} < R_{\text{SUSY}}$	R_{UED} to be studied
b-jet multiplicity		enhanced (FP)	not enhanced	not enhanced
Single heavy top		NO	YES	YES via KK2 decay
polarization effects	$tt + \not{E}_T$	to be studied	to be studied	to be studied
	$\tau\tau + \not{E}_T$	to be studied	to be studied	to be studied
Direct DM detection rate		high (FP) low (coann)	low (Bino-like LTP)	typically low for γ_1(5D) DM [22] typically high for γ_H(6D) DM [22]

It was realised that
“Dictionary of the LHC Signatures”
in the form of various tables is not enough to accommodate all models and their signatures

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We need dictionary in the form of the Model Database and their Signatures

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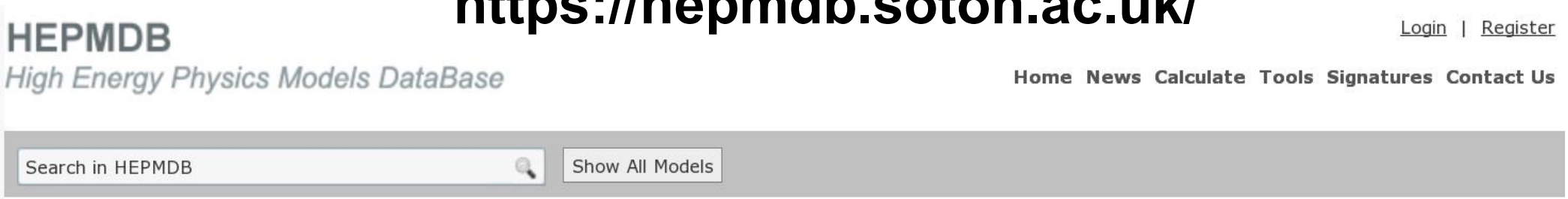
We need dictionary in the form of the Model Database and their Signatures

High Energy Physics Model Database [HEPMDB]

High Energy Physics Model Database

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



About HEPMDB

HEPMDB is created to facilitate the connection between High Energy theory and experiment, to store and validate theoretical models, to develop dictionary of the model signatures aimed to identify the fundamental theory responsible for signals expected at the LHC.

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The database is in the development stage and your input in the 'Forum' section is highly appreciated. Database collects Particle Physics Models. These models are supposed to be public and represent themselves a set of Feynman Rules which can be in form of input for any of Matrix Element generators such as CalcHEP, CompHEP, FeynArts, Madgraph, SHERPA, WHIZARD. HEPMDB has an entrance for Model authors -- 'Authors' -- where Authors can test and validate their models.

To become an 'Author', you should register in a 'Register' section. 'Authors' are welcomed to also upload LanHEP or FeynRules source of their models.

Validation

News

CalcHEP and HEPMDB: practical introduction and tutorial

2012-05-03 23:13:13

CalcHEP and HEPMDB: practical introduction and tutorial will take place at CERN https://indico.cern.ch/conferenceDisplay.py?confId=189668
More »

LHAPDF package is added

2012-03-25 12:55:34

LHAPDF is installed at HEPMDB and can be used now. To use LHAPDF installed at HEPMDB with CalcHEP models one should add -L$HOME/lhapdf/lib/ -lLHAPDF line to your extlibN.mdl file. P.S. All news about HEPMDB like this one will be sent to all users registered at HEPMDB (they also should have an option not to receive these news if they want)
More »

Miniworkshop on High Energy Physics Model Database (HEPMDB)

2012-05-03 23:15:00

Miniworkshop on High Energy Physics Model Database (HEPMDB).
At IPPP at Durham we have a one-day mini-workshop on High Energy Physics Model Database (HEPMDB). The schedule and registration are available at http://indico.cern.ch/event/hepmdb

High Energy Physics Model Database

- **Developed at Southampton with support from IPPP, Durham**
  as a result of ideas discussed in the context of the "Dictionary of LHC signatures", at the FeynRules workshop (April, 2010) and at the Mini-Workshop on Dynamical Symmetry Breaking models and tools (July 2010)
- **Further developed at the Les Houches Workshop, June 2011**

High Energy Physics Model Database – HEPMDB. Towards decoding of the underlying theory at the LHC.

arXiv:1203.1488 (the last section of the Les Houches 2011 proceedings)

Maksym Bondarenko[1], Alexander Belyaev[1,2], Lorenzo Basso[1,2,3], Edward Boos[4], Vyacheslav Bunichev[4], R. Sekhar Chivukula[5], Neil D. Christensen[6], Simon Cox[7], Albert De Roeck[8], Stefano Moretti[1,2], Alexander Pukhov[4], Sezen Sekmen[8], Andrei Semenov[9], Elizabeth H. Simmons[5], Claire Shepherd-Themistocleous[2], Christian Speckner[3]

Abstract

We present here the first stage of development of the High Energy Physics Model Data-Base (HEPMDB) which is already a convenient centralized storage environment for HEP models, and can accommodate, via web interface to the HPC cluster, the validation of models, evaluation of LHC predictions and event generation-simulation chain. The ultimate goal of HEPMDB is perform an effective LHC data interpretation isolating the most successful theory for explaining the LHC observations.

Aims of the HEPMDB (1)

- *to collect HEP models for various multipurpose Matrix Element (ME) generators like CalcHEP, CompHEP, FeynArts, MadGraph/MadEvent, AMEGIC ++/COMIX within SHERPA and WHIZARD.*
  Under "HEP models" we denote the set of particles, Feynman rules and parameters written in the format specific for a given package
- *to collect models' sources which can be used in the HEPMDB to generate HEP models for various ME generators using FeynRules or LanHEP which automate the process of generating Feynman Rules, particle spectra, etc..*
  For the moment, FeynRules supports formats for CompHEP, CalcHEP, FeynArts, GoSam, MadGraph/MadEvent, SHERPA and WHIZARD Currently LanHEP works with CalcHEP, CompHEP, FeynArts and GoSam. Also, the latest LanHEP version 3.15 has an option under testing of outputting the model in UFO format which provides a way to interface it with MadGraph/MadEvent
- to allows users upload their models and perform evaluation of HEP processes and event generation for their own models using the full power of the High Performance Computing (HPC) cluster behind the HEPMDB.
  This is one of the very powerful features of the HEPMDB: it provides a web interface to various ME generators which can then also be run directly on the HPC cluster. This way, users can preform calculations for any model from HEPMDB avoiding problems related to installing the actual software, which can sometimes be quite cumbersome

Aims of HEPMDB (2)

- to plot and document various kinematical distributions from generated events in the LHE format
- to allow to compare predictions from models generated from LanHEP and FeynRules
- to collect predictions and specific features of various models in the form of database of signatures and perform comparison of various model predictions with experimental data (to be developed)

  There are a lot of different aspects related to this problem. This task includes a comprehensive development of a database of signatures as well as development of the format of presentation of these signatures. This format will be consistent with the format which will be used by the experimentalists for the presentation of the LHC data, discussed in the context of the "Les Houches Recommendations for the Presentation of LHC Results" activity.
- to trace the history of the model modifications, and makes available all the versions of the model

  Through this application, we stress the importance of reproducibility of the results coming from HEPMDB or from a particular model downloaded from HEPMDB.

Sounding similar but qualitatively different related projects

- “Database of Numerical HEP scattering cross sections”
  http://durpdg.dur.ac.uk/HEPDATA/REAC
  collects various particle scattering process which are connected to experimental searches of different reactions

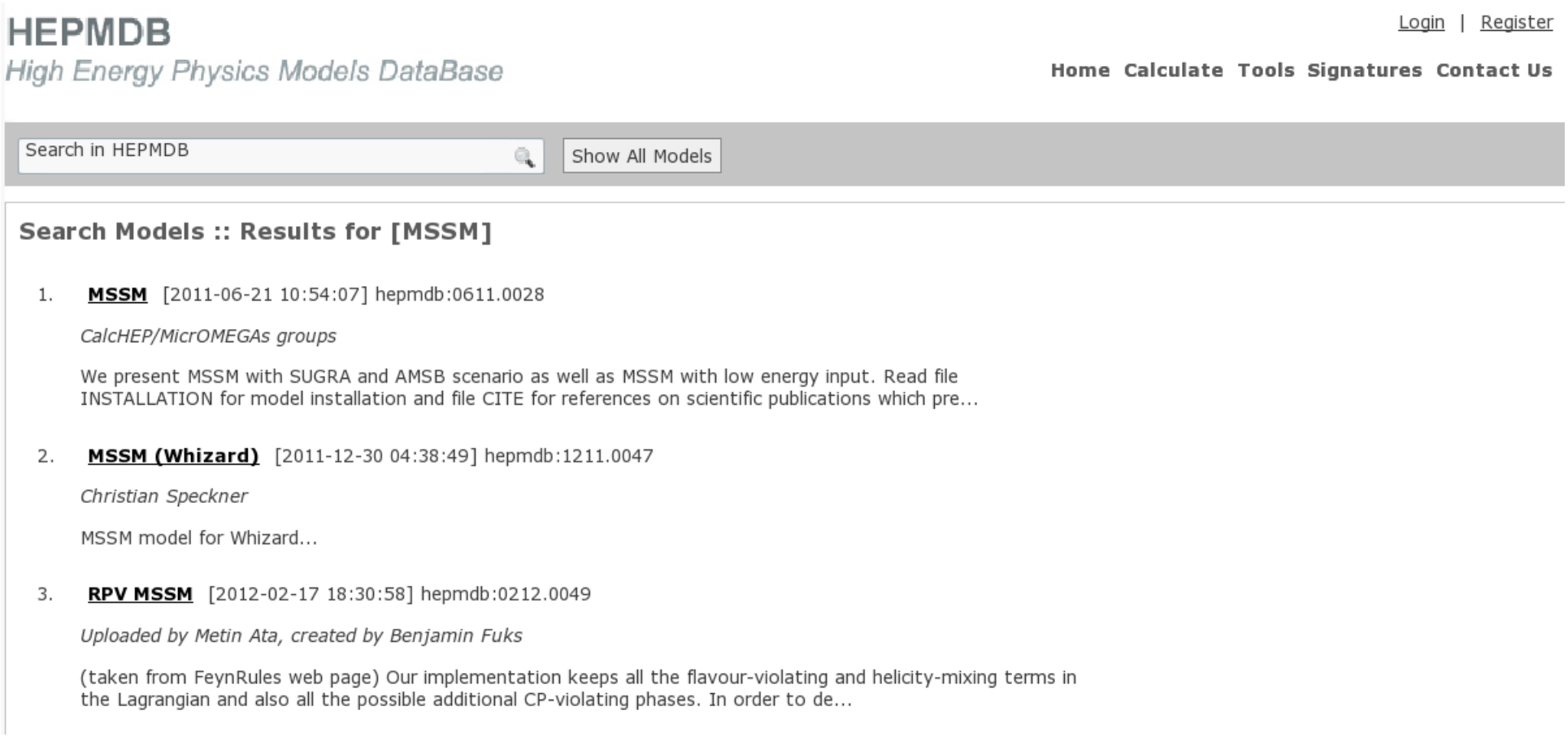
- “Signatures of New Physics at the LHC” web-site
  http://www.lhcnewphysics.org/
  collects various BSM signatures, their classification and related papers

- FeynRules and models database
  http://feynrules.irmp.ucl.ac.be
  collects various models implemented into FeynRules and have an effective way to validate them

- **HEPMDB can effectively collaborate with all projects above!**

The current status of HEPMDB (1)

- Allows to search and download an existing HEP model. The search engine checks patterns in the fields:
  Model, Authors, References, Abstract, Signatures and Information



The current status of HEPMDB (2)

- one can upload a new model (upon user registration). The model can be uploaded in the format of any ME generator. Also, a user can upload the model source in FeynRules or LanHEP formats, allows to keep model privately!

Model : MSSM

http://hepmdb.soton.ac.uk/hepmdb:0611.0028

Authors

CalcHEP/MicrOMEGAs groups

Added By

Alexander Belyaev

References

G.~Belanger, F.~Boudjema, A.~Pukhov and A.~Semenov, Comput. Phys. Commun. 174, 577 (2006)[arXiv:hep-ph/0405253]
A.~Djouadi, J.~L.~Kneur and G.~Moultaka, arXiv:hep-ph/0211331

Abstract

Updated MSSM model for CalcHEP is uploaded (bug for SC constant in the file with dependences is corrected)

Information

We present MSSM with SUGRA and AMSB scenario as well as MSSM with low energy input. Read file INSTALLATION for model installation and file CITE for references on scientific publications which present realization of the model.

Tools

CalcHEP [model]

Model History

2011-12-02 15:01:19
2011-10-14 13:40:10

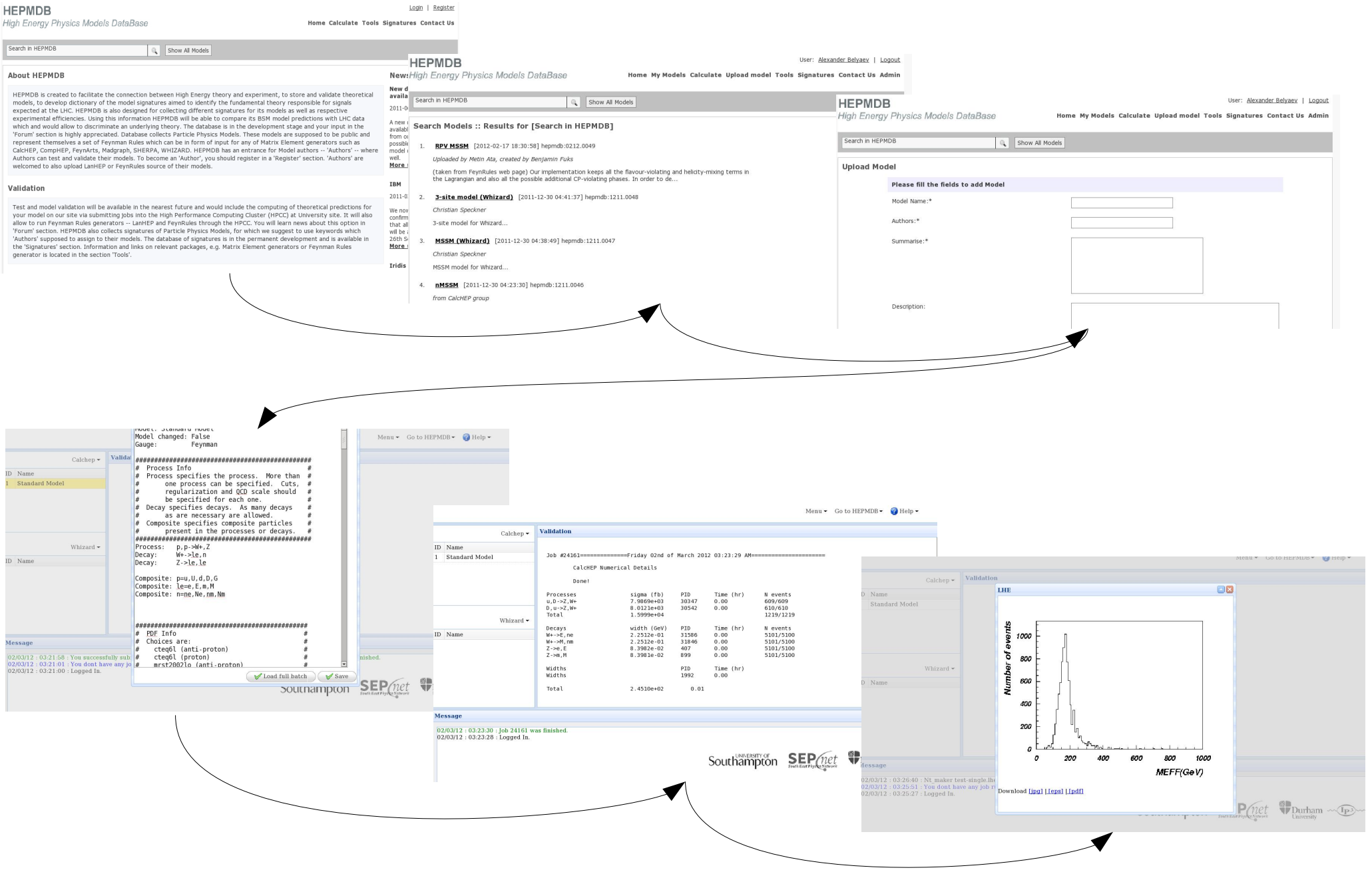
Download Model File | Validate Model on HPCx | Edit Model

Reviews

The current status of HEPMDB (3)

- allows to the evaluate cross sections for user-defined processes for the chosen model and produce a respective LHE file with generated parton-level events. This file is becomes available for download once the process is finished (user will receive an e-mail notification on this)
  Currently, the HEPMDB allows the user to perform these calculations (using the HPC) for CalcHEP, WHIZARD and MadGRAPH 5
- produces ntuple files and allows to plot various kinematical distributions
- allows to update/add features and respective signatures specific to each model.
  These features and signatures can be used in the future to distinguish the model from others and connect it to the LHC signatures.
- keeps track of the model changes, providing reproducibility for the results obtained with previous versions of the models uploaded to HEPMDB
- allows to collect feedback/remarks on particular model from users in Review section

Tutorial


HEPMDB
High Energy Physics Models DataBase
Home Calculate Tools Signatures Contact Us
About HEPMDB
Validation
Search Models :: Results for [Search in HEPMDB]
Upload Model
Please fill the fields to add Model
Model Name:*
Authors:*
Summarise:*
Description:
Load full batch
Save
Validation
Message
LHE
Number of events
MEFF(GeV)

Tutorial

HEPMDB

High Energy Physics Models DataBase

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Search in HEPMDB | Show All Models

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News

We suffered a failure of the Iridis cooling system earlier this morning

2012-07-10 18:52:13

We suffered a failure of the Iridis cooling system earlier this morning, which led to temperatures in the data centre rising very rapidly. We do not expect to be able o resume a batch service until after lunch.
More »

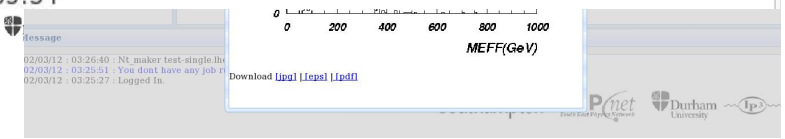
CalcHEP and HEPMDB: practical introduction and tutorial

2012-05-03 23:13:13

CalcHEP and HEPMDB: practical introduction and tutorial will take place at CERN https://indico.cern.ch/conferenceDisplay.py?confId=189668
More »

LHAPDF package is added

2012-03-25 12:55:34



Tutorial

HEPMDB
High Energy Physics Models DataBase

Login | Register

Home News Calculate Tools Signatures Wiki Contact Us

Search in HEPMDB

Show All Models

Search Models :: Results for [MSSM]

1. **MSSM** [2011-06-21 10:54:07] hepmdb:0611.0028

   CalcHEP/MicrOMEGAs groups

   We present MSSM with SUGRA and AMSB scenario as well as MSSM with low energy input. Read file INSTALLATION for model installation and file CITE for references on scientific publications which pre...

2. **MSSM with bilinear R-Parity violation** [2011-11-17 20:00:51] hepmdb:1111.0036

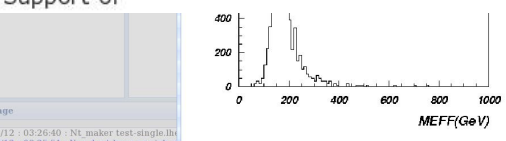
   Florian Staub

   The MSSM with bilinear R-Parity violating terms in the superpotential and for the soft-breaking terms. Model files created by SARAH 3.1.0 Support of SLHA+ functionality to read spectrum files...

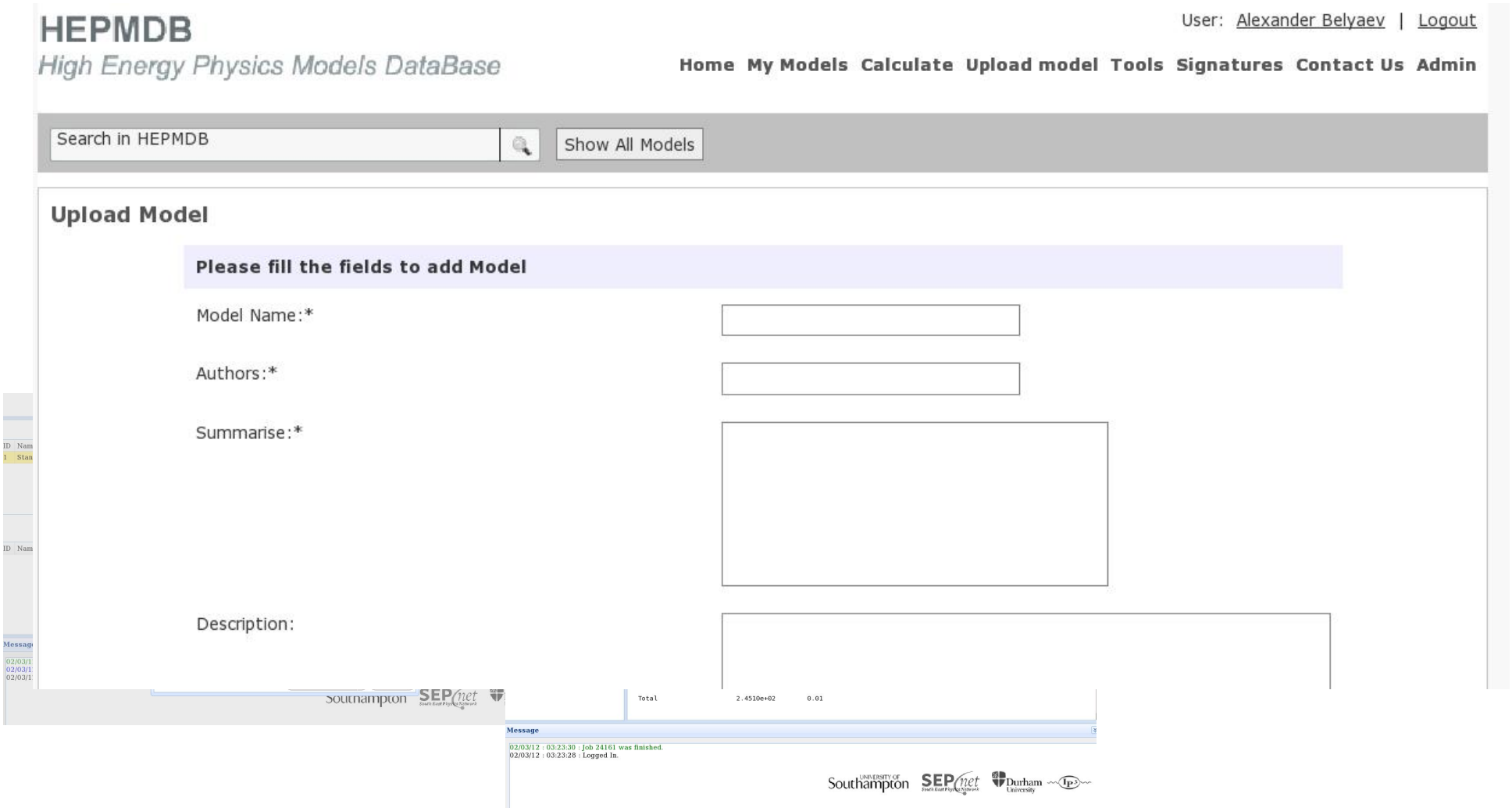
3. **TMSSM** [2011-11-17 20:06:23] hepmdb:1111.0037

   Florian Staub

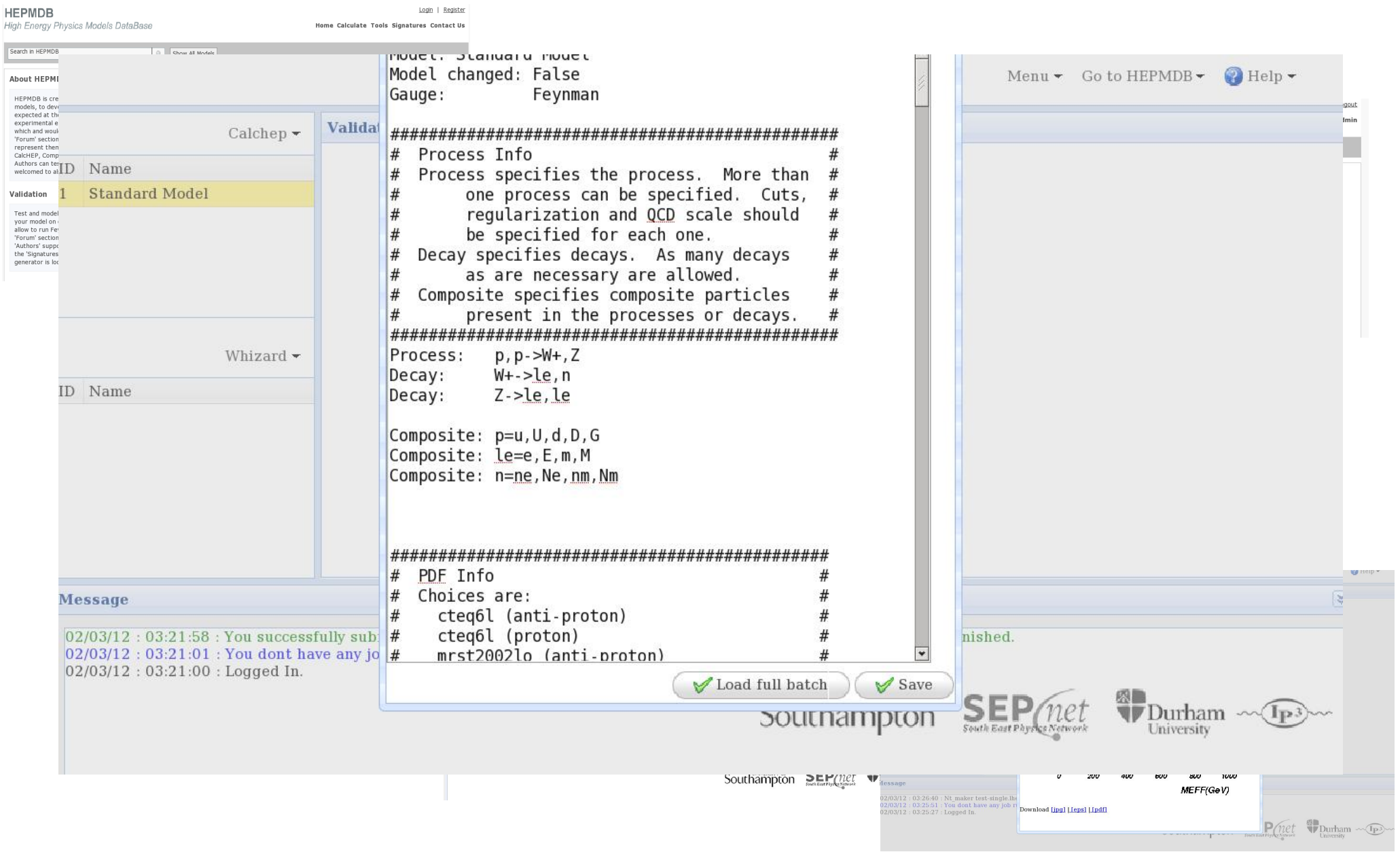
   Triplet extended MSSM (including possibility of flavor violation) Model files created by SARAH 3.1.0 Support of



Tutorial


HEPMDB
High Energy Physics Models DataBase
User: Alexander Belyaev | Logout
Home My Models Calculate Upload model Tools Signatures Contact Us Admin
Search in HEPMDB
Show All Models
Upload Model
Please fill the fields to add Model
Model Name:*
Authors:*
Summarise:*
Description:
Total 2.4510e+02 0.01
Message
02/03/12 : 03:23:30 : Job 24161 was finished.
02/03/12 : 03:23:28 : Logged In.
Southampton
SEPnet
Durham University

Tutorial


HEPMDB
High Energy Physics Models DataBase
Home Calculate Tools Signatures Contact Us
Calchep
ID Name
1 Standard Model
Whizard
Model changed: False
Gauge: Feynman
Process Info
Process specifies the process. More than one process can be specified. Cuts, regularization and QCD scale should be specified for each one.
Decay specifies decays. As many decays as are necessary are allowed.
Composite specifies composite particles present in the processes or decays.
Process: p,p->W+,Z
Decay: W+->le,n
Decay: Z->le,le
Composite: p=u,U,d,D,G
Composite: le=e,E,m,M
Composite: n=ne,Ne,nm,Nm
PDF Info
Choices are:
cteq6l (anti-proton)
cteq6l (proton)
mrst2002lo (anti-proton)
Load full batch
Save
Menu
Go to HEPMDB
Help
Message
02/03/12 : 03:21:58 : You successfully sub
02/03/12 : 03:21:01 : You dont have any jo
02/03/12 : 03:21:00 : Logged In.
Southampton
SEPnet
Durham University
MEFF(GeV)

Batch file in details(1)

```
################################################
#  batch_file for CalcHEP                      #
#  It has to be launched via                   #
#          ./calchep_batch batch_file          #
#  Lines beginning with # are ignored.         #
################################################

################################################
#  Model Info                                  #
#  Model is the exact model name.              #
#  Model changed specifies whether a change    #
#       was made to the model files.  Changes  #
#       to the numerical values of external    #
#       parameters is ok.  Other changes       #
#       require that the process library be    #
#       recreated.  Values are True or False.  #
#  Gauge specifies gauge.  Choices are         #
#       Feynman or unitary.                    #
################################################
Model:         Standard Model(CKM=1)
Model changed: False
Gauge:         Feynman

################################################
#  Process Info                                #
#  Process specifies the process.  More than   #
#       one process can be specified.  Cuts,   #
#       regularization and QCD scale should    #
#       be specified for each one.             #
#  Decay specifies decays.  As many decays     #
#       as are necessary are allowed.          #
#  Composite specifies composite particles     #
#       present in the processes or decays.    #
################################################
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



################################################
#  PDF Info                                     #
#  Choices are:                                 #
#    cteq6l (anti-proton)                       #
#    cteq6l (proton)                            #
#    mrst2002lo (anti-proton)                   #
#    mrst2002lo (proton)                        #
#    cteq6m (anti-proton)                       #
#    cteq6m (proton)                            #
#    cteq5m (anti-proton)                       #
#    cteq5m (proton)                            #
#    mrst2002nlo (anti-proton)                  #
#    mrst2002nlo (proton)                       #
#    ISR                                        #
#    ISR & Beamstrahlung                        #
#    Equiv. Photon                              #
#    Laser photons                              #
#    Proton Photon                              #
#    OFF                                       #
#                                               #
#  ISR and Beamstrahlung are only available     #
#    for electrons and positrons, while the     #
#    others are available for protons and       #
#    antiprotons.                               #
#    Default pdf: OFF                          #
#  Bunch x+y sizes (nm)                         #
#    Ignored unless ISR & Beam chosen.          #
#    Default: 560                               #
#  Bunch length (mm)                            #
#    Ignored unless ISR & Beam chosen.          #
```

Batch file in details(2)

```
#    Default: 0.4                                  #
#  Number of particles                             #
#    Ignored unless ISR & Beam chosen.             #
#    Default: 2E+10                                #
#  Default Beamstrahlung parameters                #
#    correspond roughly with ILC.                  #
#                                                  #
#  Equiv. Photon, Laser photons and                #
#    Proton Photon are available for               #
#    photons.                                      #
#    Default pdf: OFF                             #
#  Photon particle                                 #
#    Ignored unless Equiv. Photon chosen.          #
#    Choices are: mu^-,e^-,e^+,mu^+                #
#    Default: e^+                                  #
#  |Q|max                                          #
#    Ignored unless Equiv. Photon chosen.          #
#    Default: 100                                  #
#  Incoming particle mass                          #
#    Ignored unless Proton Photon chosen.          #
#    Default: 0.938                                #
#  Incoming particle charge                        #
#    Ignored unless Proton Photon chosen.          #
#    Choices are: 1,-1                             #
#    Default: 1                                    #
#  |Q^2|max                                        #
#    Ignored unless Proton Photon chosen.          #
#    Default: 2                                    #
#  Pt cut of outgoing proton                       #
#    Ignored unless Proton Photon chosen.          #
#    Default: 0.1                                  #
################################################
pdf1:      cteq6l (proton)
pdf2:      cteq6l (proton)
```

```
#Bunch x+y sizes (nm)      : 202500
#Bunch length (mm)         : 10
#Number of particles       : 5E+11

#Photon particle           : e^-
#|Q|max                    : 250
#Incoming particle mass    : 0.938
#Incoming particle charge  : -1
#|Q^2|max                  : 2.0
#Pt cut of outgoing proton : 0.15

################################################
#  Momentum Info                               #
#    in GeV                                    #
################################################
p1:        4000
p2:        4000

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

################################################
#  Run Info                                    #
#  Masses and Energies are in GeV              #
#  More than one run can be specified at       #
#     the same time.                           #
################################################
Run parameter: Mh
Run begin:     120
Run step size: 5
Run n steps:   3
```

Batch file in details(3)

```
################################################
#  QCD Running Info                            #
#  As in the gui:                              #
#  parton dist. alpha                          #
#     default: ON                              #
#  alpha(MZ)                                   #
#     default: 0.1172                          #
#  alpha nf                                    #
#     default: 5                               #
#  alpha order                                 #
#     choices: LO, NLO, NNLO                   #
#     default: NLO                             #
#  mb(mb)                                      #
#     default: 4.2                             #
#  Mtop(pole)                                  #
#     default: 175                             #
#  alpha Q                                     #
#     Must be in terms of the final state      #
#     particles.                               #
#     default: M12                             #
#     :n: specifies which process.             #
#     : means to apply to all processes.       #
################################################
#parton dist. alpha: ON
#alpha(MZ):          0.118
#alpha nf:           5
#alpha order:        NLO
#mb(mb):             4
#Mtop(pole):         174

#alpha Q :1:         M34
#alpha Q :2:         M45
alpha Q :            M45
```

```
################################################
#  Cut Info                                    #
#  Must be in terms of the (production mode)   #
#     final state particles.                   #
#     :n: specifies which process.             #
#     : means to apply to all processes.       #
################################################

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

Cut parameter:    J(jet,jet)
Cut invert:       False
Cut min:          0.5
Cut max:

Cut parameter:    T(jet)
Cut invert:       False
Cut min:          20
Cut max:

Cut parameter:    N(jet)
Cut invert:       False
Cut min:         -2.5
Cut max:          2.5



################################################
#  Kinematics Info                             #
#  Must be exactly as in CH.                   #
#     Comment out to use the CH defaults.      #
#     :n: specifies which process.             #
#     : means to apply to all processes.       #
################################################
```

Batch file in details(4)

```
#Kinematics :1:    12 -> 34 , 56
#Kinematics :1:    34 -> 3 , 4
#Kinematics :1:    56 -> 5 , 6

Kinematics :      12 -> 3, 45
Kinematics :      45 -> 4 , 5



################################################
#  Regularization Info                         #
#  Must be in terms of the final state         #
#     particles.                               #
#     :n: specifies which process.             #
#     : means to apply to all processes.       #
################################################
Regularization momentum:1: 45
Regularization mass:1:     Mh
Regularization width:1:    wh
Regularization power:1:    2


################################################
#  Distribution Info                           #
#  Only 1 dimensional distributions are        #
#     currently supported.                     #
#  Dist n bins should be one of:               #
#     300, 150, 100, 75, 60, 50, 30, 25,       #
#     20, 15, 12, 10, 6, 5, 4, 3, 2            #
#  Dist title and Dist x-title should be       #
#     plain text.                              #
################################################
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)
```

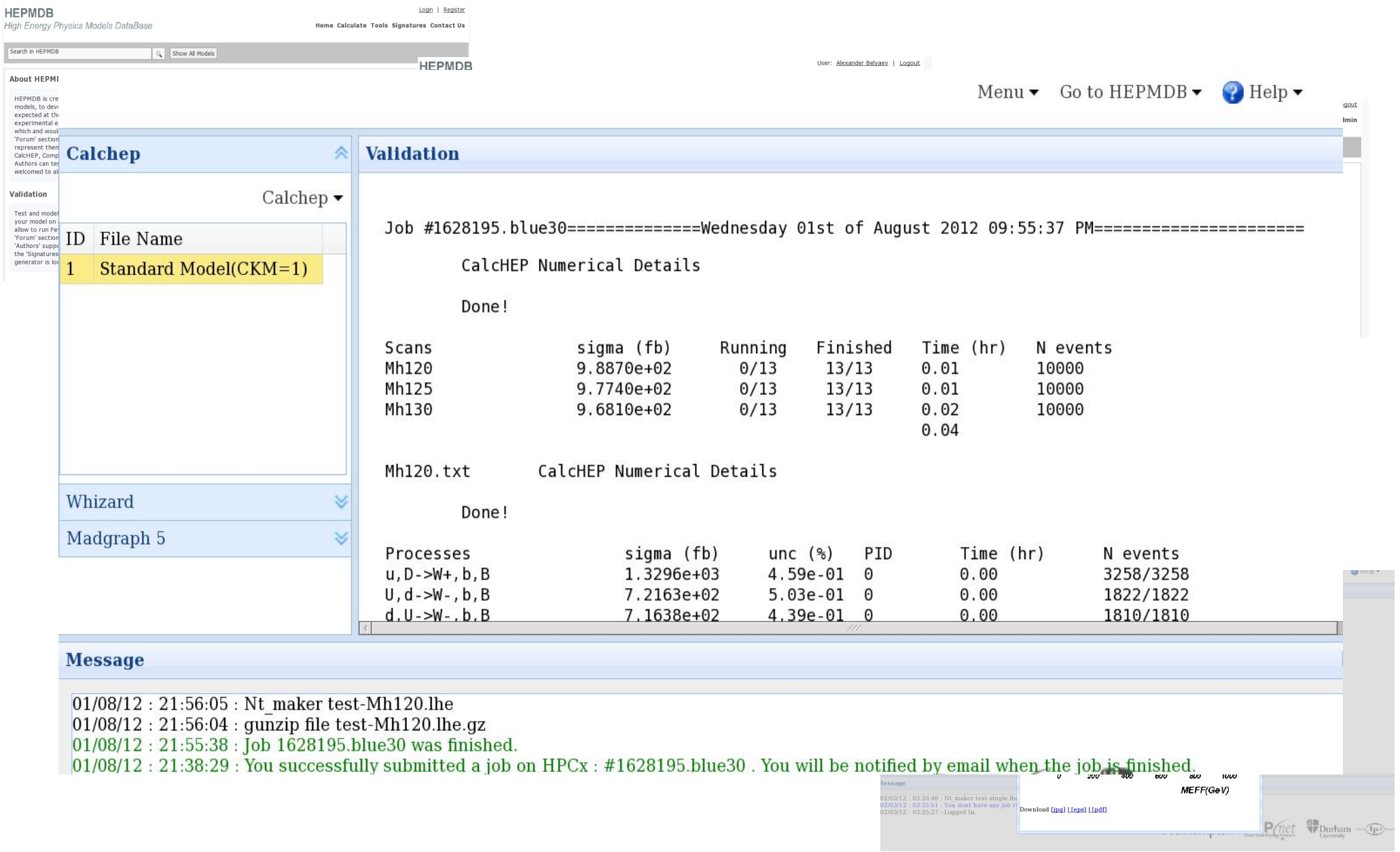
```
Dist parameter:    M(W,jet)
Dist min:          100
Dist max:          200
Dist n bins:       100
Dist title:        p,p->W,b,B
Dist x-title:      M(W,jet) (GeV)

################################################
#  Events Generation                           #
#  Number of events determines how many        #
#       events to produce for each run.        #
#  Filename is the name used for the event     #
#       files.  If no parameter is run over    #
#       then, -Single.lhe is appended.  If     #
#       a parameter is run over then its       #
#       value will be appended as in           #
#       pp-WW-MW400.lhe.                       #
#  NTuple determines whether PAW ntuples       #
#       are created.  This only works if       #
#       nt_maker is properly compiled and      #
#       in the bin directory.                  #
#       Choices are True or False.             #
#  Cleanup determines whether the              #
#       individual event files are removed     #
#       after they are combined.               #
#       Default: True                          #
################################################
Number of events (per run step): 1000
Filename:                        test
NTuple:                          False
Cleanup:                         False
```

Batch file in details(5)

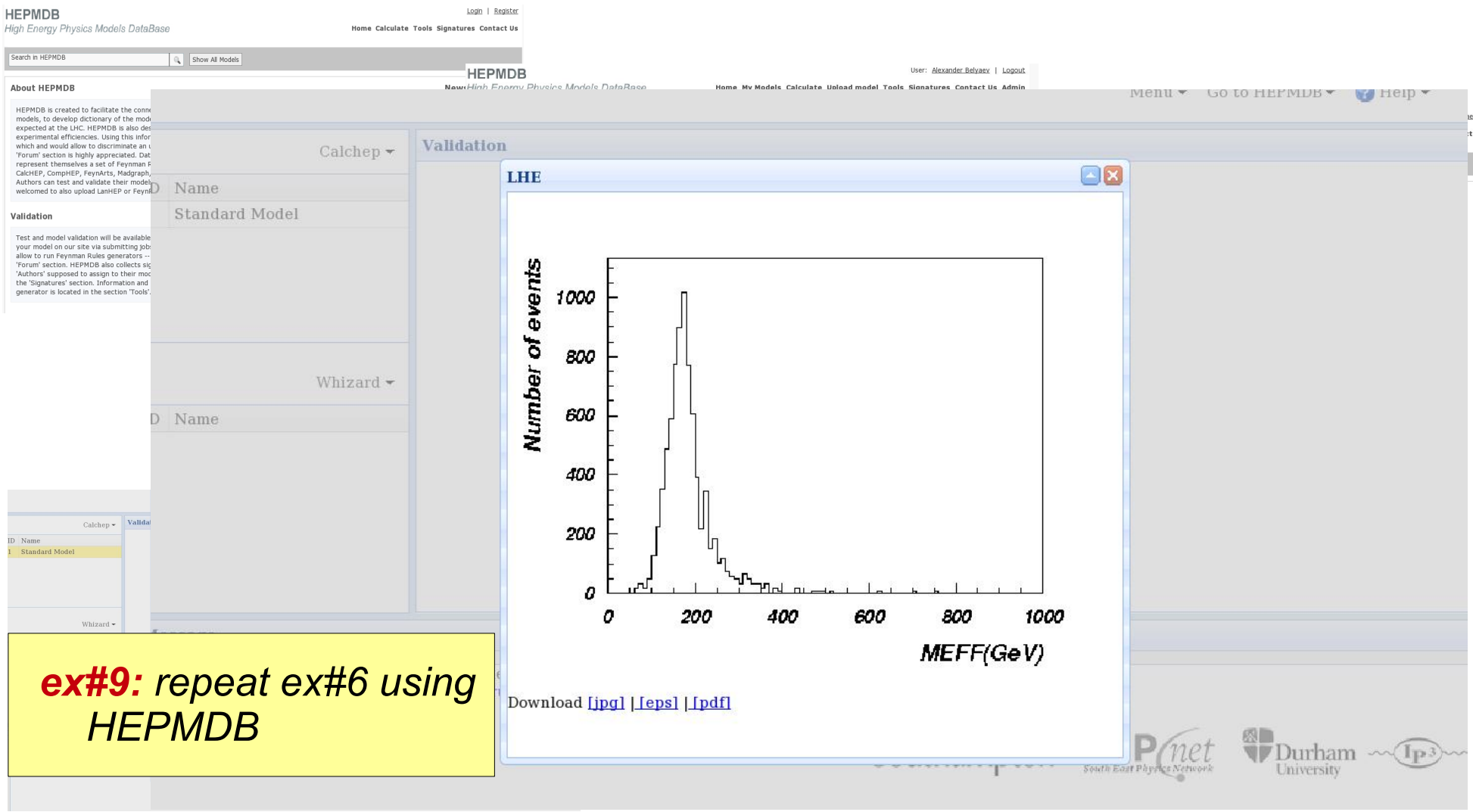
```
################################################
#  Parallelization Info                        #
#  Parallelization method choices:             #
#      local                                   #
#      pbs                                     #
#  Que can be left blank if not required       #
#      on your pbs cluster.                    #
#  Walltime should be the number               #
#      of hours necessary for each job.        #
#      Leave blank if your pbs cluster does    #
#      not require this and will let a         #
#      job run until it is finished.           #
#  Memory is the amount of memory required     #
#      for each job in gb.  Leave blank        #
#      if not required on your cluster.        #
#  email is only used on the pbs cluster       #
#      if you want it to inform you of         #
#      problems. email is currently ignored.   #
#  sleep time determines how often the         #
#      script updates (in seconds)             #
#      while waiting for processes to finish.  #
#  nice level is used for the CH jobs in       #
#      local mode and combining events in      #
#      all modes.                              #
#      default: 19                             #
################################################
Parallelization method:      local
#Que:                         brody_main
#Walltime:                    0.15
#Memory:                      1
#email:                       name@address
Max number of cpus:          2
sleep time:                  3
nice level :                 19
```

```
################################################
#  Vegas                                       #
#  The variables are the same as in the gui.   #
#  If commented out, the default values        #
#      are used.                               #
#                                              #
#  nSess_1 : number of the 1st sessions        #
#     default: 5                               #
#  nCalls_1 : number of calls per 1st sessions#
#     default: 10000                           #
#  nSess_2 : number of the 2nd sessions        #
#     default: 0                               #
#  nCalls_2 : number of calls per 2nd sessions#
#     default: 10000                           #
################################################
nSess_1:   5
nCalls_1:  100000
nSess_2:   5
nCalls_2:  100000


################################################
#  Event Generator                             #
#  The variables are the same as in the gui.   #
#  If commented out, the default values        #
#      are used.                               #
#                                              #
#  sub-cubes:                                  #
#     default: 1000                            #
#  random search:                              #
#     default: 100                             #
#  simplex search:                             #
#     default: 50                              #
#                                              #
#  MAX*N: integer to multiply max by           #
#     default: 2                               #
#  find new MAX:                               #
#     default: 100                             #
################################################
#sub-cubes:      100000
#random search:  100
#simplex search: 50

#MAX*N:          2
#find new MAX:   100
```

Tutorial


HEPMDB
High Energy Physics Models DataBase
Login | Register
Home Calculate Tools Signatures Contact Us
Search in HEPMDB
Show All Models
HEPMDB
User: Alexander Belyaev | Logout
Menu
Go to HEPMDB
Help
Calchep
Calchep
ID File Name
1 Standard Model(CKM=1)
Whizard
Madgraph 5
Validation
Job #1628195.blue30==========Wednesday 01st of August 2012 09:55:37 PM==========
CalcHEP Numerical Details
Done!
Scans sigma (fb) Running Finished Time (hr) N events
Mh120 9.8870e+02 0/13 13/13 0.01 10000
Mh125 9.7740e+02 0/13 13/13 0.01 10000
Mh130 9.6810e+02 0/13 13/13 0.02 10000
0.04
Mh120.txt CalcHEP Numerical Details
Done!
Processes sigma (fb) unc (%) PID Time (hr) N events
u,D->W+,b,B 1.3296e+03 4.59e-01 0 0.00 3258/3258
U,d->W-,b,B 7.2163e+02 5.03e-01 0 0.00 1822/1822
d,U->W-,b,B 7.1638e+02 4.39e-01 0 0.00 1810/1810
Message
01/08/12 : 21:56:05 : Nt_maker test-Mh120.lhe
01/08/12 : 21:56:04 : gunzip file test-Mh120.lhe.gz
01/08/12 : 21:55:38 : Job 1628195.blue30 was finished.
01/08/12 : 21:38:29 : You successfully submitted a job on HPCx : #1628195.blue30 . You will be notified by email when the job is finished.
MEFF(GeV)

Tutorial



ex#9: *repeat ex#6 using HEPMDB*

Example of models created for CalcHEP

- **SM + extensions**
  - SM
  - B-L symmetric Z' with heavy Majorana neutrinos
  - SM + Z'
  - general 2 Higgs doublet model
  - 4th generation
  - Excited fermions
  - Model with contact interactions
  - Standard Model + anomalous gauge boson couplings
  - Model of strongly int EW sector
    (5 & 6 dim operators involving Sigma field)
- **SUSY**
  - constraint MSSM
  - general MSSM, with 124 free parameters
  - NMSSM
  - RPVMSSM
  - left-right symmetric MSSM
  - MSSM with CP violation
  - E6MSSM
- **Extra dimensions**
  - 5D UED with 2KK layers
  - 6D UED with 2KK layers
  - ADD = ADD
  - RS = Randall Sundrum
- **Leptoquarks**
  - Complete LQ model
    SU(3)xSU(1)xU(1) vector&scalar
- **Technicolor & Higgsless**
  - Minimal walking technicolor
  - TC with DM
  - 3-site model
  - Hidden Local symmetry model
  - 4SM = general 4-site model
- **Little Higgs**
  - Littlest higss model with T-parity
  - LHT + T-parity violation

Models at FeynRules web-site

Standard Model	The SM implementation of FeynRules, included into the distribution of the FeynRules package.
Simple extensions of the SM (10)	Several models based on the SM that include one or more additional particles, like a 4th generation, a second Higgs doublet or additional colored scalars.
Supersymmetric Models (4)	Various supersymmetric extensions of the SM, including the MSSM, the NMSSM and many more.
Extra-dimensional Models (4)	Extensions of the SM including KK excitations of the SM particles.
Strongly coupled and effective field theories (4)	Including Technicolor, Little Higgs, as well as SM higher-dimensional operators.
Miscellaneous (0)	

Remarks on collecting models at HEPMDB

- *there are numerous model implementations exist (FeynRules team, LanHEP/CalcHEP/CompHEP teams, private implementations)*
- *they are highly complementary and useful*
- *HEPMDB is the natural place to accommodate all of them (also allows to keep model privately, controlled by Public/Private option On/Off!)*

Summary on HEPMDB

- HEPMDB is already a convenient centralized storage environment for HEP models. Via web interface to the HPC cluster (12 cores per user) it allows to evaluate the LHC predictions and event generation-simulation chain

- Your relevant packages can be installed at HEPMDB!

- we hope that starting from the present stage, HEPMDB development will be boosted further via involvement of the HEP community
  (via direct involvement into HEPMDB, via various projects involving HEPMDB, via numerous comments/requests for HEPMDB features)

- we hope also that in the near future the HEPMDB will become a powerful tool for isolation of the most successful theory for explaining the LHC data

PhenoData

- spin-off the **PhenoData**
  hepmdb.soton.ac.uk/phenodata
- stores data (digitized curves from figures, tables etc) from those HEP papers which did not provide data in arXiv or HEPData, and to avoid duplication of work of HEP researchers on digitizing plots.
- has an easy search interface and paper identification via arXiv, DOI or preprint numbers. PhenoData is not intended to be a replication of any existing archive
- Has batch upload mode

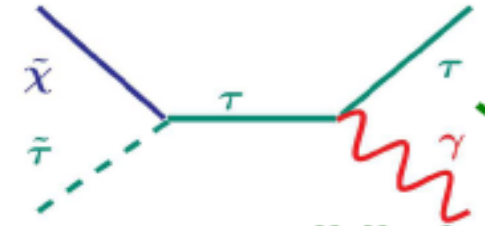
Example of the HEP Tools application

Dark matter relic density – IsaRed and MicrOmegas

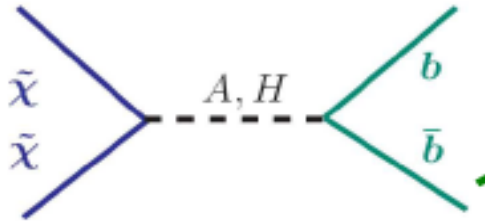
Neutralino relic density in mSUGRA

most of the parameter space is ruled out! $\Omega h^2 \gg 1$

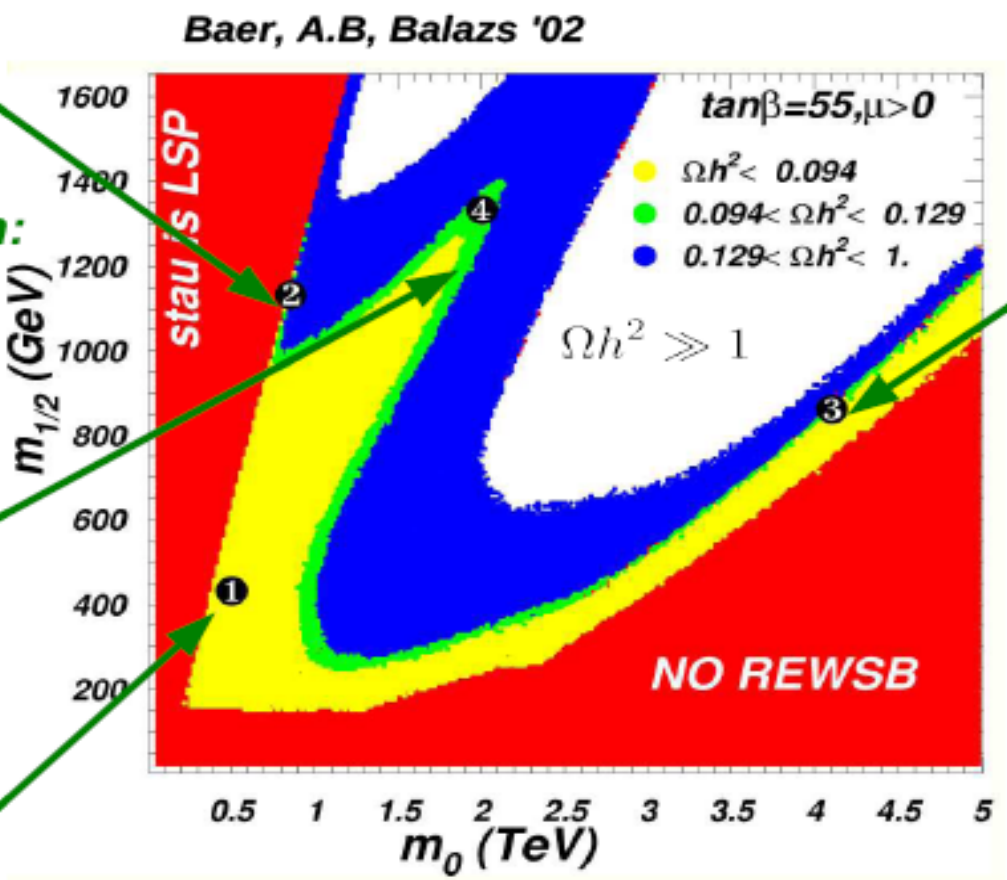
special regions with high σ_A ***are required to get*** $0.094 < \Omega h^2 < 0.129$



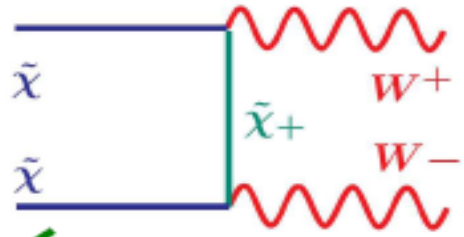
2. stau coannihilation:
degenerate χ ***and stau***



4. funnel: ***(large tanβ) annihilation via A, H***



1. bulk region: ***light sfermions***



3. focus point:
mixed neutralino, low μ, importance of higgsino-wino component

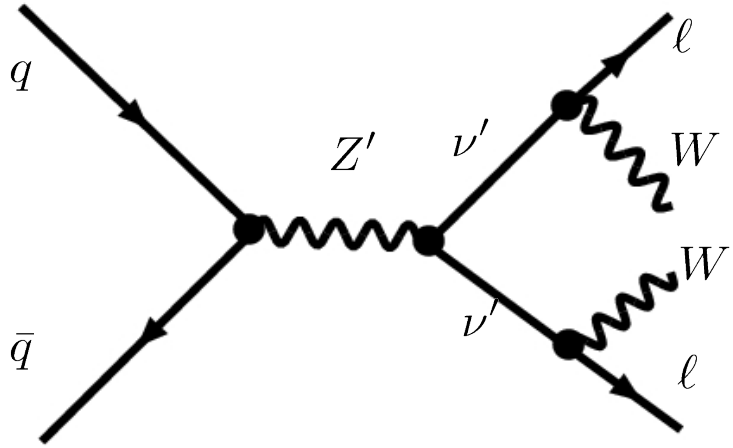
$\mu^2 + M_Z^2/2 \approx -\varepsilon m_0^2 + 2m_{1/2}^2$

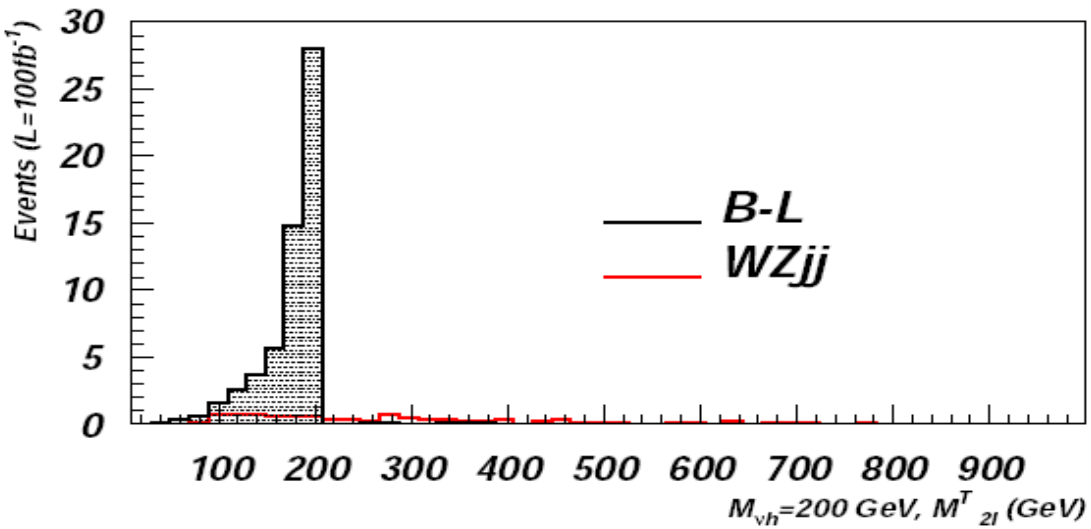
additional regions:
Z/h annihilation
stop coannihilation

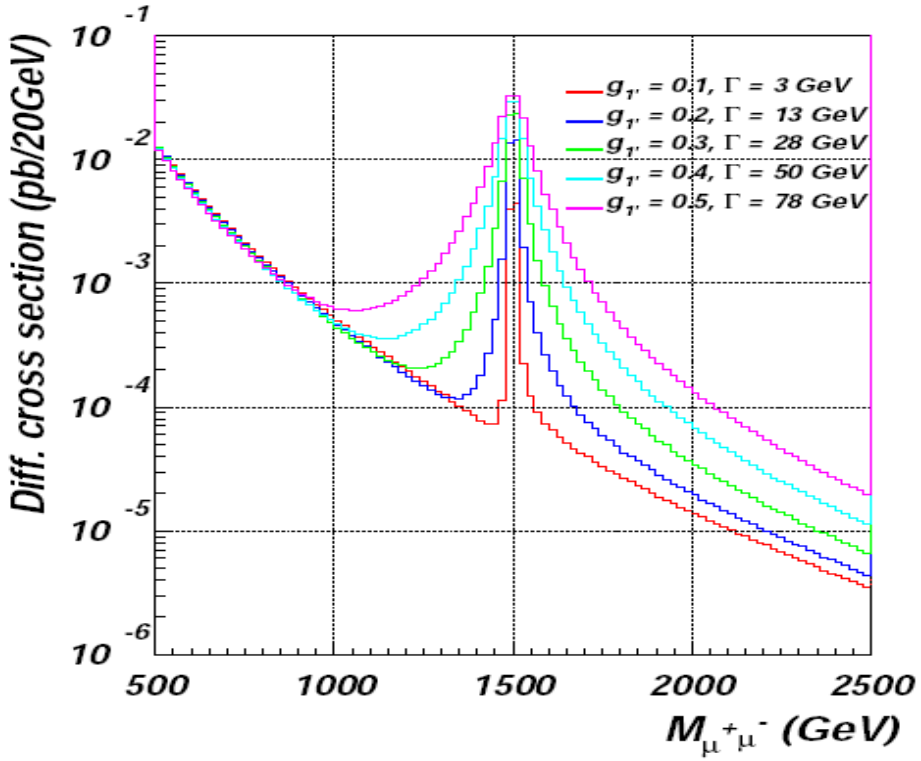
B-L extension of SM

Extra U(1)' : Z', heavy long leaving neutrino

(in collaboration with S. Moretti, L. Basso, C. Shepherd)

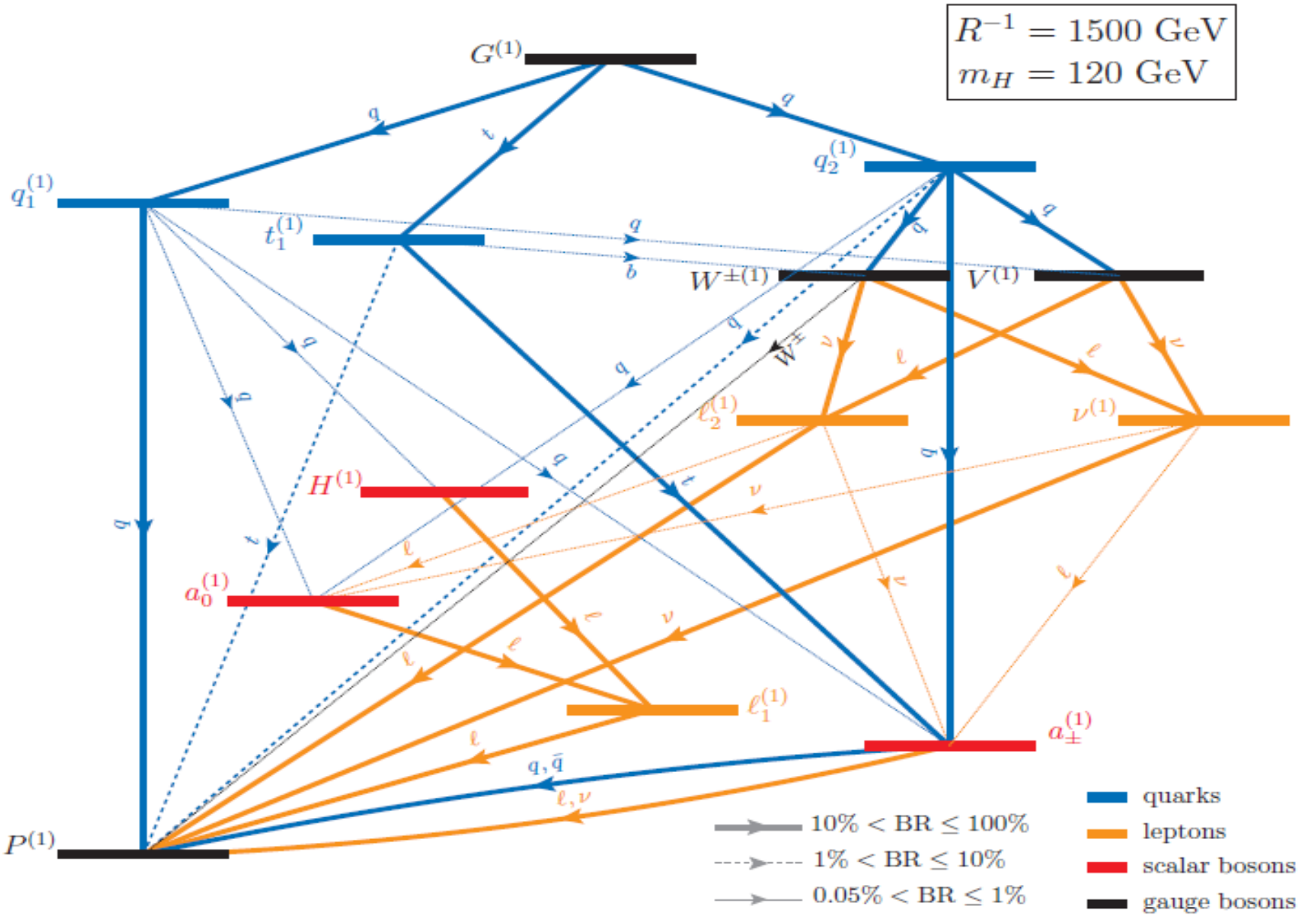






Universal Extra Dimensions

hep-ph/1212.4858 ***In collaboration with M.Brown, J.M. Moreno, C. Papineau***



Universal Extra Dimensions

- **Set up of the production and decay processes with the calchep_batch**

```
Process: p,p->y2,y2
Process: p,p->y3,y3
Process: p,p->y2,y3

Decay: y1->2*x
Decay: y2->2*x
Decay: y3->2*x
Decay: y4->2*x
Decay: y5->2*x
Decay: y6->2*x
Decay: y7->2*x
Decay: y8->2*x

Composite: p=u,U,d,D,s,S,c,C,b,B,G
Composite: y1=~G_1
Composite: y2=~d1_1,~u1_1,~s1_1,~c1_1,~b1_1,~t1_1,~d2_1,~u2_1,~s2_1,~c2_1,~b2_1,~t2_1
Composite: y3=~D1_1,~U1_1,~S1_1,~C1_1,~B1_1,~T1_1,~D2_1,~U2_1,~S2_1,~C2_1,~B2_1,~T2_1
Composite: y4=Z,W+,W-,t,T,H
Composite: y5=~P_1,~V_1,~W+_1,~W-_1
Composite: y6=~e1_1,~e2_1,~n1_1,~mu1_1,~mu2_1,~n2_1,~tau1_1,~tau2_1,~n3_1
Composite: y7=~E1_1,~E2_1,~N1_1,~Mu1_1,~Mu2_1,~N2_1,~Tau1_1,~Tau2_1,~N3_1
Composite: y8=~H_1,~a0_1,~a+_1,~a-_1
```

- **Scan in 2D space with the calchep_batch**

```
################################################
#  Run Info                                    #
#  Masses and Energies are in GeV              #
#  More than one run can be specified at       #
#     the same time.                           #
################################################
Run parameter: invR
Run begin:     600
Run step size: 200
Run n steps:   4
Run parameter: nL
Run begin:     10
Run step size: 10
Run n steps:   4
```

Results from calchep_batch

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Process Library
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Thank you for using CalcHEP!
Please cite arXiv:0000.0000

CalcHEP Batch Details

MUED-Chloe-2KK

Done!

	Finished	Time(hr)
Symbolic	6498/6498	0.00
σ	4/4	3.29
Events	4/4	7.30

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Symbolic Sessions

MUED-Chloe-2KK

Processes	Lib PID Time(hr)
u,u->~u1_1,~u1_1	✓
u,u->~u1_1,~u2_1	✓
u,u->~u2_1,~u2_1	✓
u,d->~d1_1,~u1_1	✓
u,d->~d1_1,~c1_1	✓
u,d->~d1_1,~t1_1	✓
u,d->~d1_1,~u2_1	✓
u,d->~d1_1,~c2_1	✓

.....~ 6k subprocesses .....

~a-_1->N1,~e2_1	✓
~a-_1->N1,~e1_1	✓
~a-_1->H,~W-_1	✓
~a-_1->Z,~W-_1	✓
~a-_1->A,~W-_1	✓
~a-_1->W-,~V_1	✓
~a-_1->W-,~P_1	✓
Widths	✓

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Numerical Sessions

MUED-Chloe-2KK

Done!

Runs	σ (fb)	Running	Finished	Time (hr)	N events
invR=600 LR=40	5126	0/6499	6499/6499	20.68	50000
invR=800 LR=40	809.2	0/6499	6499/6499	28.52	50000
invR=1000 LR=40	151.2	0/6499	6499/6499	24.66	50000
invR=1200 LR=40	30.29	0/6499	6499/6499	21.86	50000
				95.72	

Results from calchep_batch

Numerical Sessions

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MUED-Chloe-2KK

Done!

Processes	σ (fb)	PID	Time (hr)	N events	Details
u,u->~u1_1,~u1_1	497.36	19766	0.00	5196/5196	prt_1 session.dat
u,u->~u1_1,~u2_1	696.28	19769	0.00	7202/7202	prt_1 session.dat
u,u->~u2_1,~u2_1	550.46	19775	0.00	5734/5734	prt_1 session.dat
u,d->~d1_1,~u1_1	212.45	19781	0.00	2297/2297	prt_1 session.dat

.....~ 6k subprocesses .....

~a-_1->N1,~e1_1	1.3688 x10^{-14}	14954	0.00	255000/254999	prt_1 session.dat
~a-_1->H,~W-_1	0	14991	0.00	0/254999	prt_1 session.dat
~a-_1->Z,~W-_1	0	15098	0.00	0/254999	prt_1 session.dat
~a-_1->A,~W-_1	0	15172	0.00	0/254999	prt_1 session.dat
~a-_1->W-,~V_1	0	18314	0.00	0/254999	prt_1 session.dat
~a-_1->W-,~P_1	0	18320	0.00	0/254999	prt_1 session.dat

Widths		PID	Time (hr)	Details
Widths		18342	0.00	session.dat
Total	5126		20.68	

Results from calchep_batch

CalcHEP Events Library

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Symbolic Results
Numerical Results
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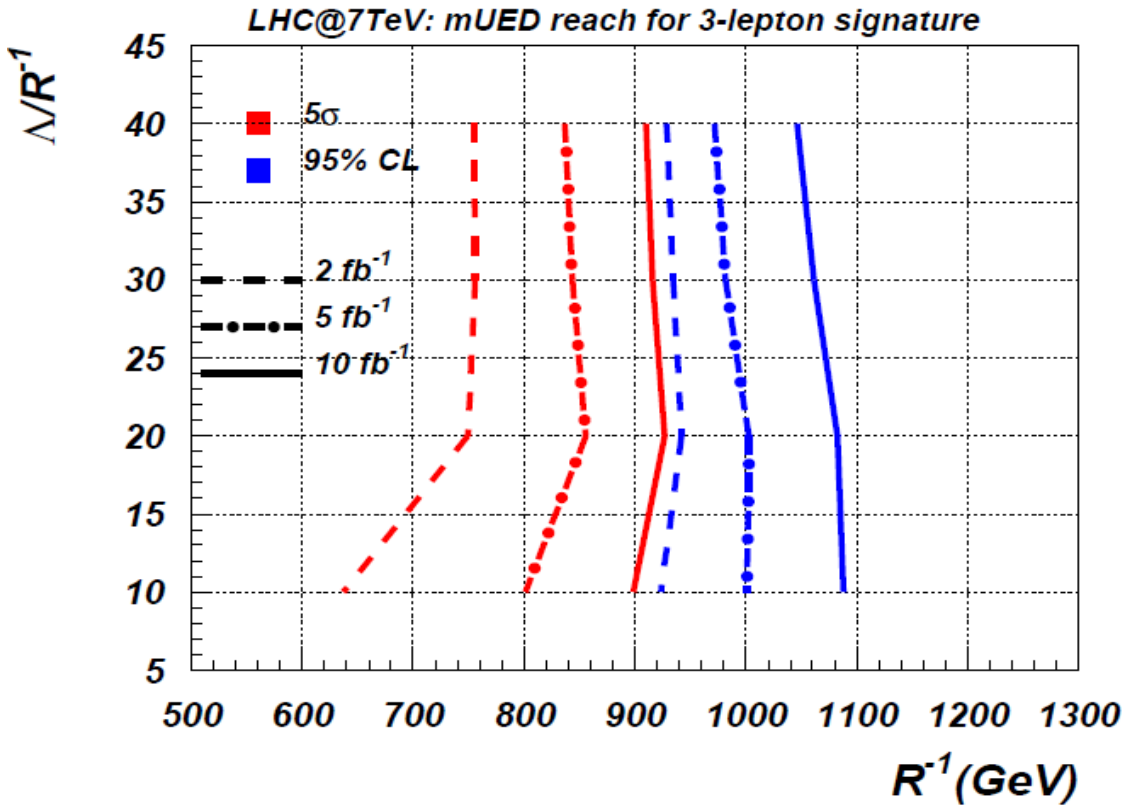
Process Library

Date	LHE	plain Ntuple
Tue Mar 27 23:06:39 2012	Q1Q1_MH120_8tev-invR1000LR40.lhe	
Wed Mar 28 00:32:40 2012	Q1Q1_MH120_8tev-invR1200LR40.lhe	
Tue Mar 27 19:42:27 2012	Q1Q1_MH120_8tev-invR600LR40.lhe	
Tue Mar 27 21:34:29 2012	Q1Q1_MH120_8tev-invR800LR40.lhe	



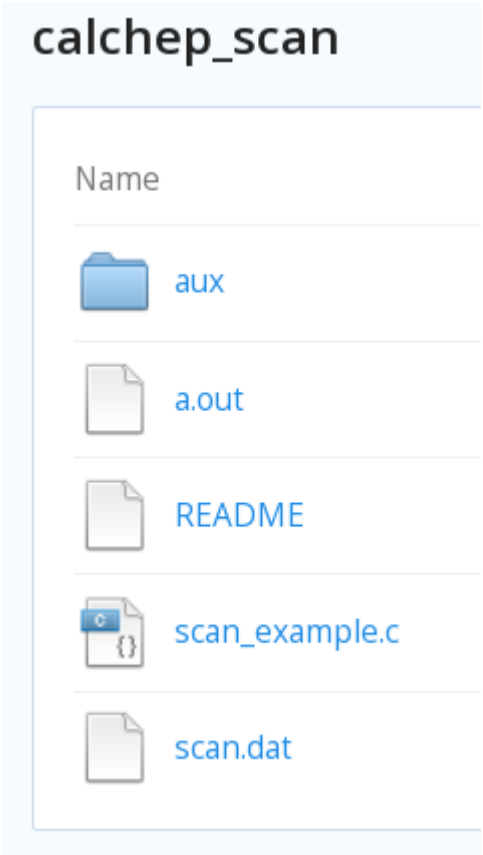
Advanced Topics

CalcHEP

- ***CalcHEP as a matrix element generator for other packages***
  Example/template is in the **hep_tools/calchep/calchep_scan**
  - compilation/linking

$CALCHEP/bin/make_main [-o<exe_name>] <C source codes and libraries>

  - README



CalcHEP

scan_example.c

```
#include<math.h>
#include<stdio.h>
#include<unistd.h>
#include<sys/stat.h>
#include<sys/types.h>
#include <dlfcn.h>
#include <sys/wait.h>
#include"num_in.h"
#include"num_out.h"
#include"VandP.h"
#include"dynamic_cs.h"
#include"rootDir.h"
#include <time.h>

int main(void)
{ int err,i;

        /* INTPUT PARAMETERS (to scan over) */
     double Mh,   Mhmin=110,       Mhmax=150;

        /* OUTPUT PARAMETERS */
     // Higgs decay branching ratios
     double  wh,braa;
txtList branchings;

//set model dir here
char mdldir[] = "models";

 // Set model number and number of points to collect, mdlnr is your model number
int mdlnr=3, npoints=50;

//a model to switch between to reset values when reloading
 setModel(mdldir , mdlnr );
```

CalcHEP

scan_example.c

```
/*****************************************************************************/
 srand (time(NULL)); //this is used to seed the random number by the system time

 if (remove("scan.dat") == -1)
        perror("Error in deleting a file");

 FILE *file;
 file = fopen("scan.dat","a+"); /* apend file (add text to
                                   a file or create a file if it does not exist.*/
 // Writing parameter names at first line to keep track of columns:
 //input parameters (1)
 //output parameters (3)
 fprintf(file,"Mh\t\twh\t\tbraa\n");
 fclose(file); /*done with header of file*/

 /*** Starting randomizing loop ***/
 for (i = 1; i <= npoints; i++){

 /********** generate random values for variables **********/
 Mh      = Mhmin+(double) random()/RAND_MAX*(Mhmax-Mhmin);

 /* Have to reset model every time, otherwise widths are not recalculated */
 setModel(mdldir , mdlnr );

 /******* assign variable values ********/
 /* the string is the calchep var name */
 err=assignValW("Mh", Mh);

 // Calculation of public constraints
 err=calcMainFunc();
```

CalcHEP

scan_example.c

```
 if(err!=0) {
          printf("Can not calculate constrained parameter
%s\n",varNames[err]);i--;
 }
 else {
                // if the point survives the constraints collect more output
values:
                // width and branchings of a particle
                wh      = pWidth("h",&branchings);
                braa    = findBr(branchings,"A,A");

                // write values to file
                file  = fopen("scan.dat","a+");
                //input parameters
                fprintf(file,"%f\t",Mh);
                //output parameters
                fprintf(file,"%f\t%e\n",wh,braa);
                fclose(file);
 }

 }// *** end of rand loop ***

   return 0;
}
```

CalcHEP

$CALCHEP/bin/make_main scan_example.c
a.out
more scan.dat

Mh	wh	braa
135.996838	0.006698	2.099067e-03
116.973931	0.003420	2.160684e-03
132.554627	0.005675	2.198545e-03
127.711034	0.004660	2.271069e-03
130.134697	0.005117	2.244877e-03
115.663777	0.003326	2.126571e-03
111.244676	0.003048	2.000407e-03
139.144130	0.007952	1.977188e-03
123.835785	0.004091	2.271298e-03
139.866680	0.008296	1.945347e-03
112.663815	0.003139	2.037072e-03
123.800804	0.004087	2.271076e-03

- **One can perform a powerful scan of parameter space, Br's, cross sections, ...**

CalcHEP

- **user-defined cuts**
  $CALCHEP/utile/usrfun.c

```
// Example: UMT(p1,p2) function which calculates transfer mass of 2 particles,
// for instance    UMT(e,Ne) - gives transverce mass of electron and neutrino.

double usrfun(char * name, int nIn, int nOut, double * pvect,char**pName,int*pCode)
{    char p1[10],p2[10];    // for 2 particles in MT(p1,p2)
     int i,j;
     double sum=0;

     if(name==strstr(name,"MT("))    // name is started from "MT("
     {  //read p1&p2
        int np=sscanf(name+3,"%[^,],%[^)]",p1,p2);
        for(i=nIn;i<nIn+nOut;i++)
        {  if(strcmp(p1,p2)==0) j=i+1;     /* if  p1==p2 */ else j=nIn;
           for(  ;j<nIn+nOut;j++)
           if(strcmp(p1,pName[i])==0 &&  strcmp(p2,pName[j])==0)
           //find position of particles
           { double * q1=pvect+4*i, *q2=pvect+4*j;
             double Et1=sqrt(fabs(q1[0]*q1[0] - q1[3]*q1[3]) );
             // transvers energy of the first particle
             double Et2=sqrt(fabs(q2[0]*q2[0] - q2[3]*q2[3]) );
             // transvers energy of the second particle
             sum+=sqrt( (Et1+Et2)*(Et1+Et2) -(q1[1]+q2[1])*(q1[1]+q2[1]) - (q1[
); // sqrt(E^2-PL^2)
           }
        }
     }  else { printf("Not defined user function %s\n",name); exit(2);}

     return sum;
}
```

CalcHEP

- **user-defined form-factor**
  $CALCHEP/utile/usrFF.c
- **user-defined propagator**
  (alteration of the existing propagators)
  $CALCHEP/c_source/num/sqme_aux.c

```
Q1[i]=dmass[i]*dmass[i]-sqrMom(nin,Qtxt[i],momenta);
if(dwidth[i])
{  REAL w,w2, q2=Q1[i]*Q1[i];
    w=dmass[i]*dwidth[i];
    w2=w*w;
    if(q2>BWrange2*w2) {if(q2<(BWrange2+1)*w2) q2=(BWrange2+1) *w2; w2=0; }
    Q2[i]=1/(q2+w2);
    Q0[i]=Q2[i]*Q1[i]*Q1[i];
    Q1[i]*=Q2[i];
} else
{  if((Q1[i]>0? Q1[i]:-Q1[i]) < 10*s0max) err=2;
    if(!Q1[i]) Q1[i]=s0max;
    Q1[i]=1/Q1[i];
    Q2[i]=Q1[i]*Q1[i];
    Q0[i]=1;
}
}
return err;
```

New/recent features of CalcHEP

- ***Default composites and saving of input***

```
Enter process:  p*,p* -> ~o1,~o1,p*
```

CalcHEP automatically substitutes 'p*' contents in the input line

```
composite  'p*' consists of:  G,u,U,d,D,s,S,c,C,b,B
```

In the same manner at first call of numerical session one gets default table

```
                Composites
Name   |> Comma separated list of particles
p*     |G,d,u,U,D,s,S,c,C,b,B
```

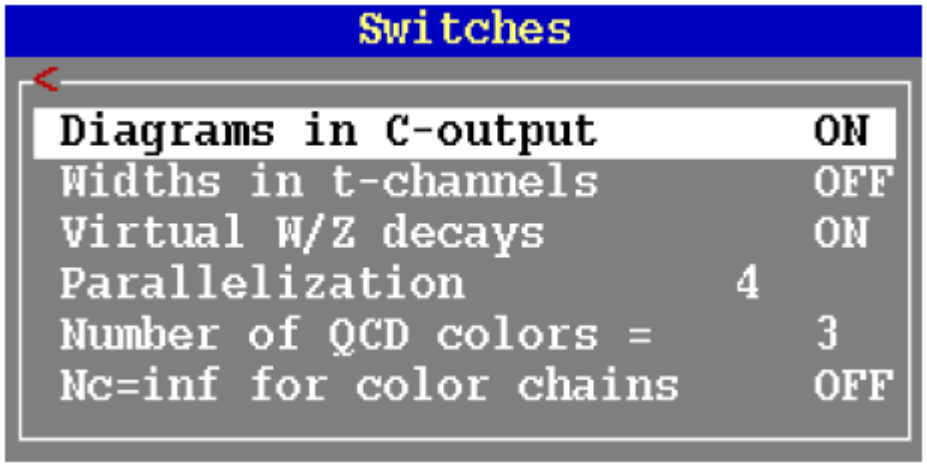
and recommended Cuts

```
                Cuts
!| Parameter | Min bound    | Max bound
%| T(p*)     | 50           |
%|J(p*,p*)   | 0.5          |
```

New/recent features of CalcHEP

- ***Parallel calculations***

Program	Method
symbolic calculation of diagram	fork
writing of C-code	fork
compilation of C-code	not implemented
Vegas MC integration	threads
Generation of unweighted events	threads



New/recent features of CalcHEP

- ***Parallel calculations***
  - ***PBS mode***

```
Parallelization method:      pbs
Walltime : 5
Memory   : 4
email:       name@address
Max number of processes per node: 16
Max number of cpus:      10
```

  - ***local mode***

```
Parallelization method:  local
Max number of processes per node: 1
Max number of cpus:      16
```

New/recent features of CalcHEP

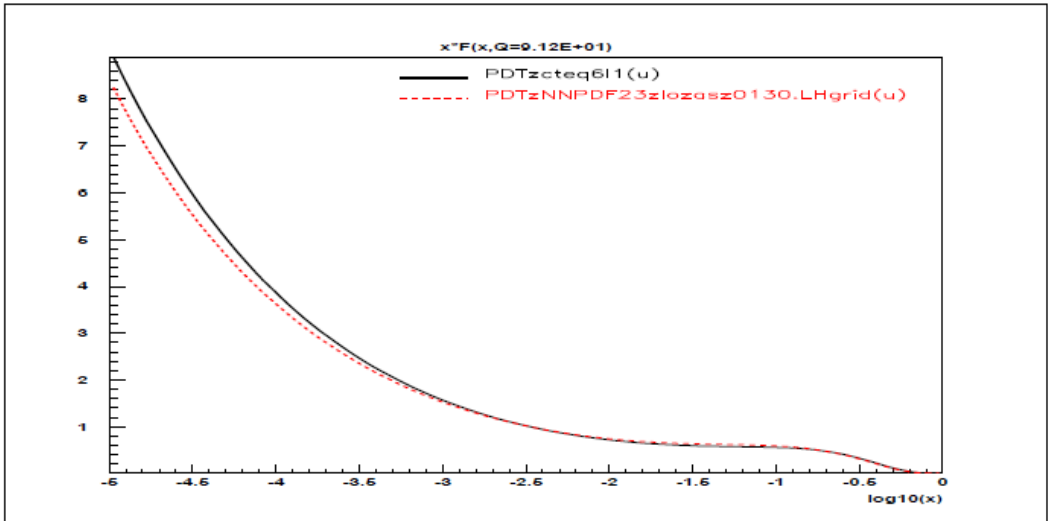
- ***New colour particles and vertices***

P1	P2	P3	color structure
3_a	$\bar{3}^b$		δ^a_b
6_{ab}	$\bar{6}^{cd}$		$(\delta^c_a\delta^d_b + \delta^d_a\delta^c_b)/2$
8_α	8_β		$\delta^{\alpha\beta}$
3_a	3_b	3_c	ϵ^{abc}
$\bar{3}^a$	$\bar{3}^b$	$\bar{3}^c$	$\bar{\epsilon}_{abc}$
8_α	8_β	8_γ	$-if^{\alpha\beta\gamma}$
3_a	$\bar{3}_b$	8_γ	$\tau^{\gamma\,a}_{\ b}$
6_{ab}	$\bar{6}^{cd}$	8_γ	$(\tau^{\gamma\,a}_{\ c}\delta^b_d + \tau^{\gamma\,a}_{\ d}\delta^b_c + \tau^{\gamma\,b}_{\ d}\delta^a_c + \tau^{\gamma\,b}_{\ c}\delta^a_d)/2$
6_{ab}	$\bar{3}^c$	$\bar{3}^d$	$(\delta^a_c\delta^b_d + \delta^a_d\delta^b_c)/2$
$\bar{6}^{ab}$	3_c	3_d	$(\delta^c_a\delta^d_b + \delta^d_a\delta^c_b)/2$

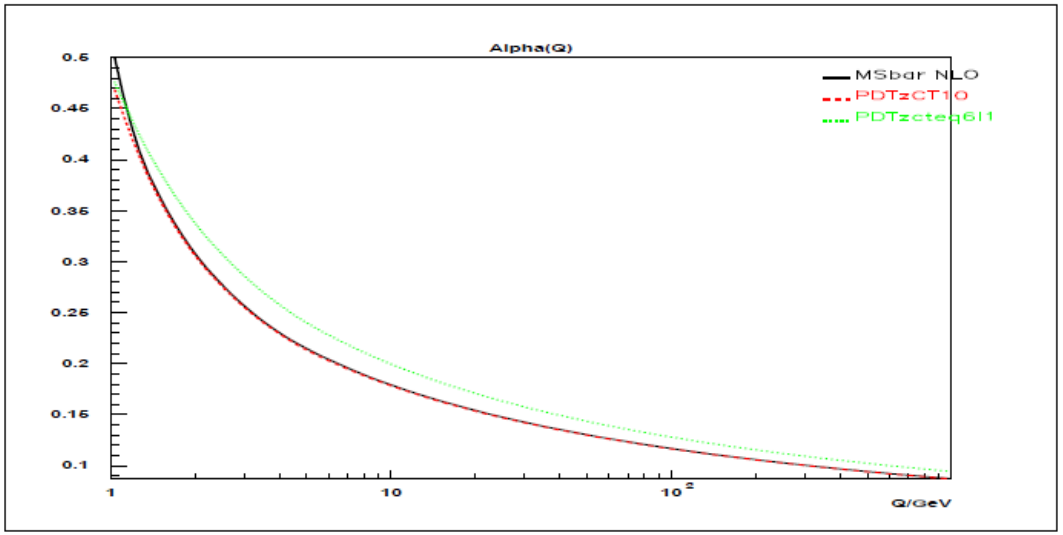
New/recent features of CalcHEP

- ***PDFs and visualisation***

```
PDF plots
x-Min = 1.000E-05
x-Max = 1.000E+00
q-Min = 1.500E+00
q-Max = 1.000E+04
Npoints = 100
q0      = 91.19GeV
x0      = 1.00E-01
log scale argument ON
Display plot x*F(x)
Display plot   F(x)
Display plot   F(Q)
both PDF1&PDF2    ON
```




```
QCD alpha
parton dist. alpha pdf1
alpha(MZ)=  0.1184
nf =        5
order=      NLO
mb(mb)=     4.200
Mtop(pole)= 173.00
Alpha(Q) plot
Qren = M12
Qpdf1= Qren
Qpdf2= Qpdf1
Qshow= Qren
```



New/recent features of CalcHEP

- ***Connection to Delphes***

  LHE → CheckMate2
  - No intermediate HEPMC files
  - PYTHIA8, can control it via cards
  - Delphes3, can control it via cards
  - Produces root files
  - Can use CM statistical analysis routines and check the signal exclusio
  - One can produce muldi-dim scan at HEPMDB and direct lhe files to CM2

Highlights of the CalcHEP

- Convenient graphical interface
- Calculates particle widths 'on the fly'
- Allows to edit diagrams as well as squared diagrams – important for the dedicated interference studies
- Easy to modify an existing model (GUI) or to implement the new one (LanHEP, FeynRules)
- Powerful batch interface – connects numerous production and decay processes
- Allows to perform multidimensional scan of the the parameter space and produce LHE files in one run
- Adopted to HPC cluster (installed at HEPMDB – next lecture)
- Many more – see an updated manual

Outlook

- ME matching: for 1,2,..3 jets ME's
- Connection production and decay without loss of the polarization info
- Helicity amplitude method is on the way

LanHEP

- ***Index order***
  SetDefIndex(spinor, color c3, color c8, vector).
- ***Example: implementation of***

$$\mathcal{O}_{tW} = \bar{q}\sigma_{\mu\nu}\tau^i t\tilde{\phi}W_i^{\mu\nu}$$

interactions

- ***Let statements:***

  You should write explicitly all indices in the let statement or hide them all!

```
parameter ftW=0.
parameter Lam=1000.

let sigma^i^j^mu^nu=
i*(gamma^i^k^mu*gamma^k^j^nu - gamma^i^k^nu*gamma^k^j^mu)/2.
let phitilde = i*tau2*PP.
```

LanHEP

- tau indicies are not in the default order, so they should be shown explicitly

$$\mathcal{O}_{tW} = \bar{q}\sigma_{\mu\nu}\tau^i t\tilde{\phi}W_i^{\mu\nu}$$

SetDefIndex(spinor, color c3, color c8, vector).

```
lterm ftW/Lam**2*(Q3^i*sigma^mu^nu*tau^i^j^a*t)*phitilde^j*F^mu^nu^a
where
F^mu^nu^a=deriv^mu*WW1^nu^a-deriv^nu*WW1^mu^a
+ AddHermConj.
```

- or, alternatively one can add index 2 in the default order and write **lterm** in compact way

```
SetDefIndex(spinor, color c3, color c8, vector, wild 2).

lterm ftW/Lam**2*Q3*sigma^mu^nu*tau^a*phitilde*t*F^a^mu^nu
+ AddHermConj
where
F^a^mu^nu=deriv^mu*WW1^nu^a-deriv^nu*WW1^mu^a.
```

Final remarks

- most of you should get more experience with Linux – will save your time and bring more confidence
- ask more questions, go through all exercises
- use launchpad to file problems or ask questions – answers will be available to everybody!

- more tools exist – those are of my personal preference
- *read manuals – they have much more details*
- ***automation tools are powerful but should not be blindly trusted or blamed! :***

  use independent programs to for double check, use limits to check if your results make sense