Practical introduction into selected TOOLS for High Energy Physics

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Southampton University & Rutherford Appleton LAB

NExT PhD School

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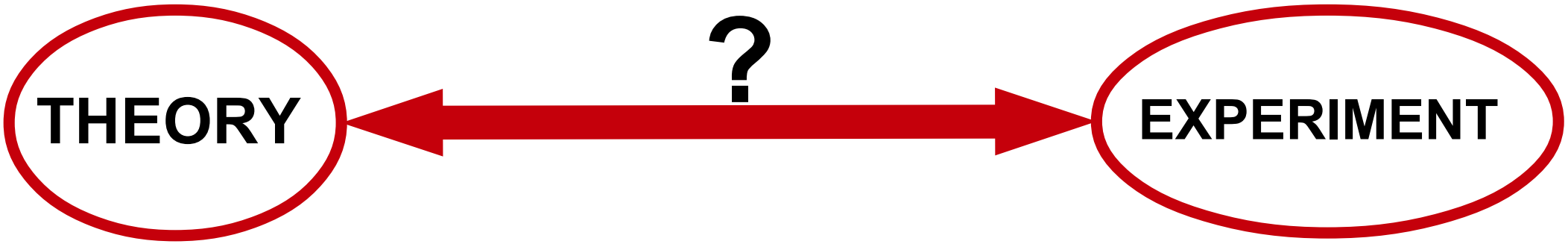
THEORY
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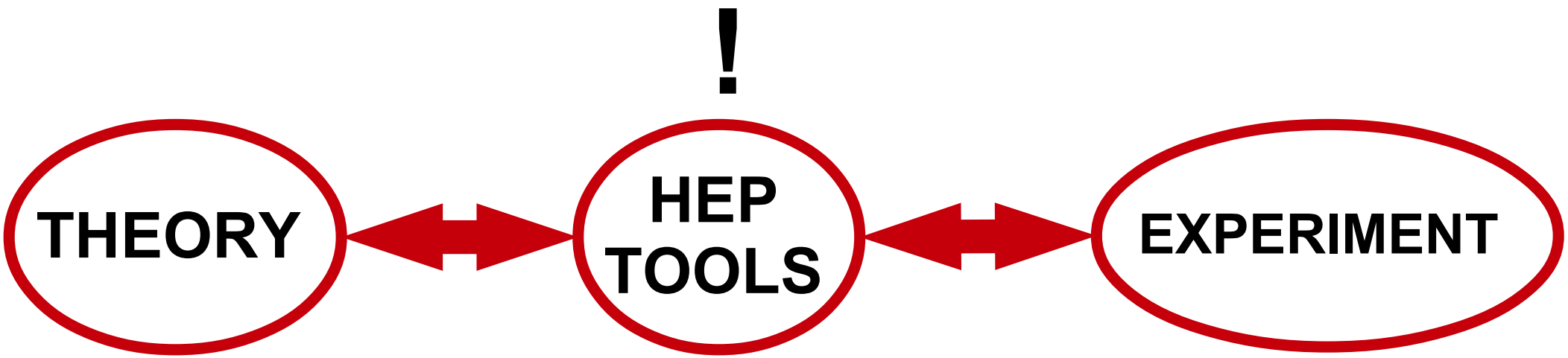
EXPERIMENT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THEORY
HEP
TOOLS
EXPERIMENT

THEORY <–> EXPERIMENT
Connection

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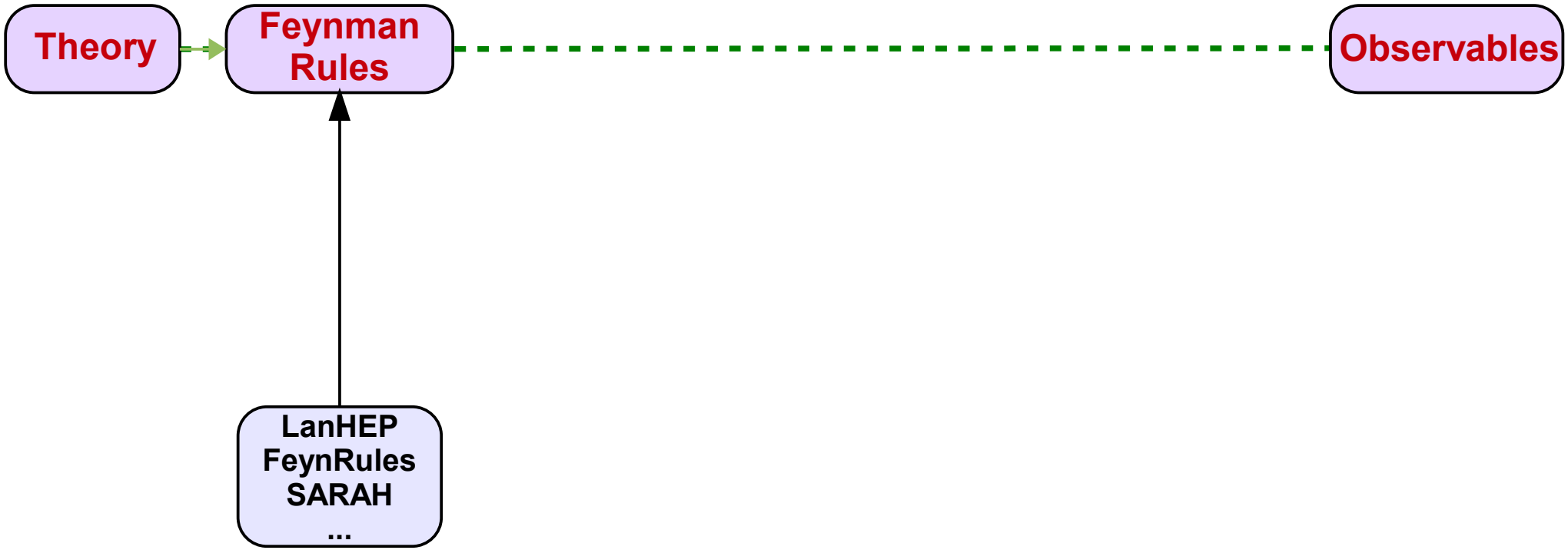

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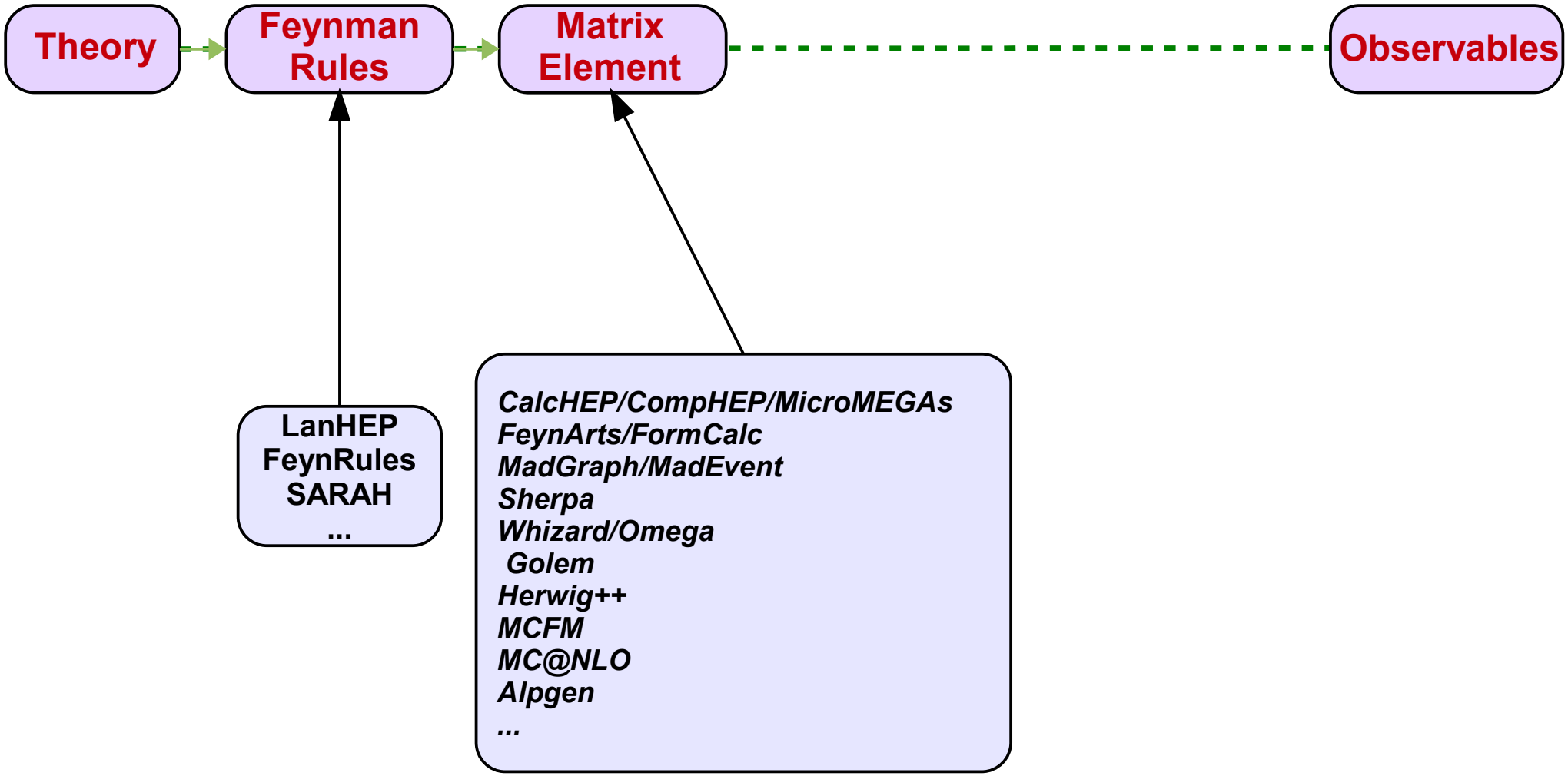

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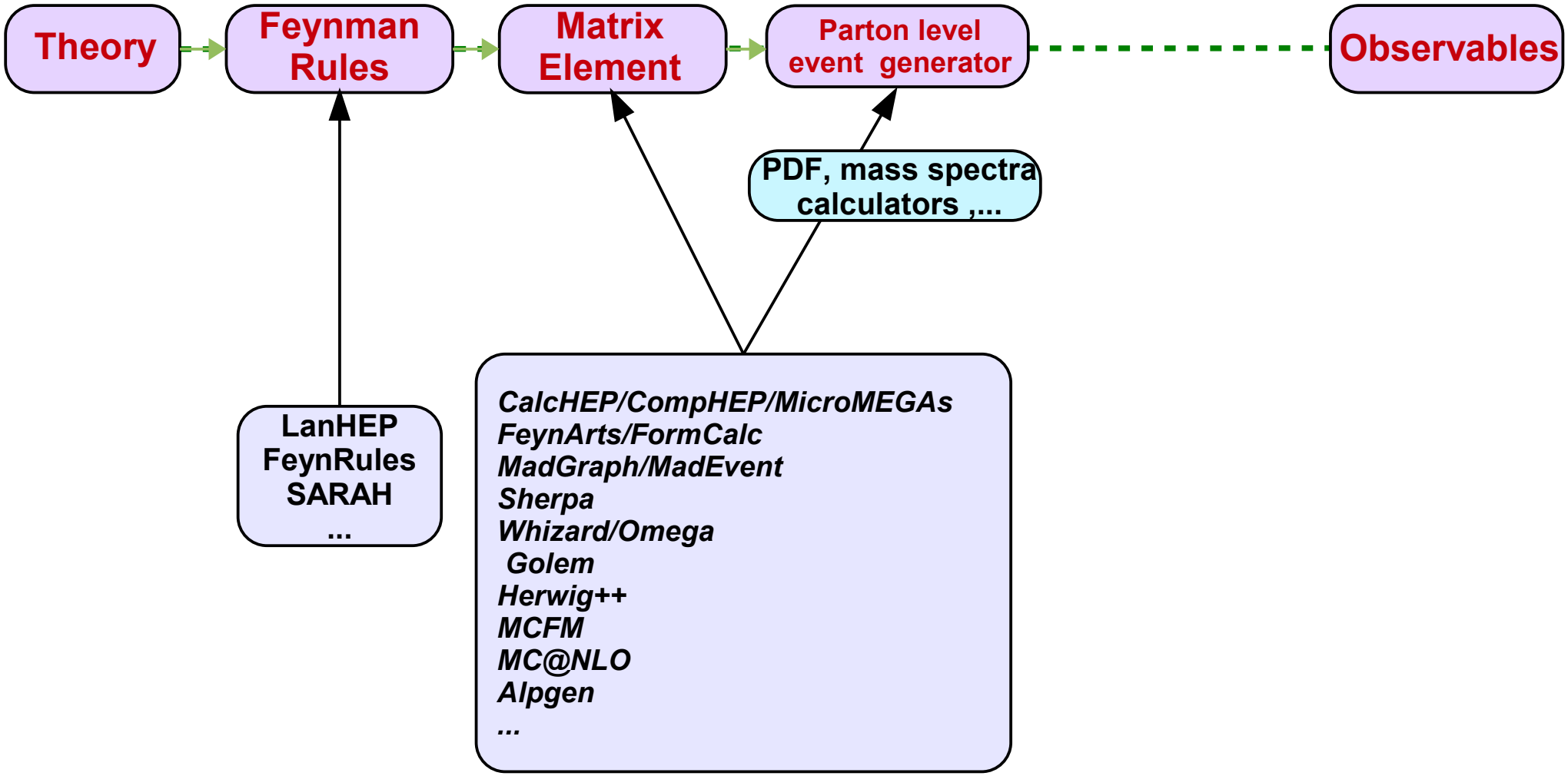

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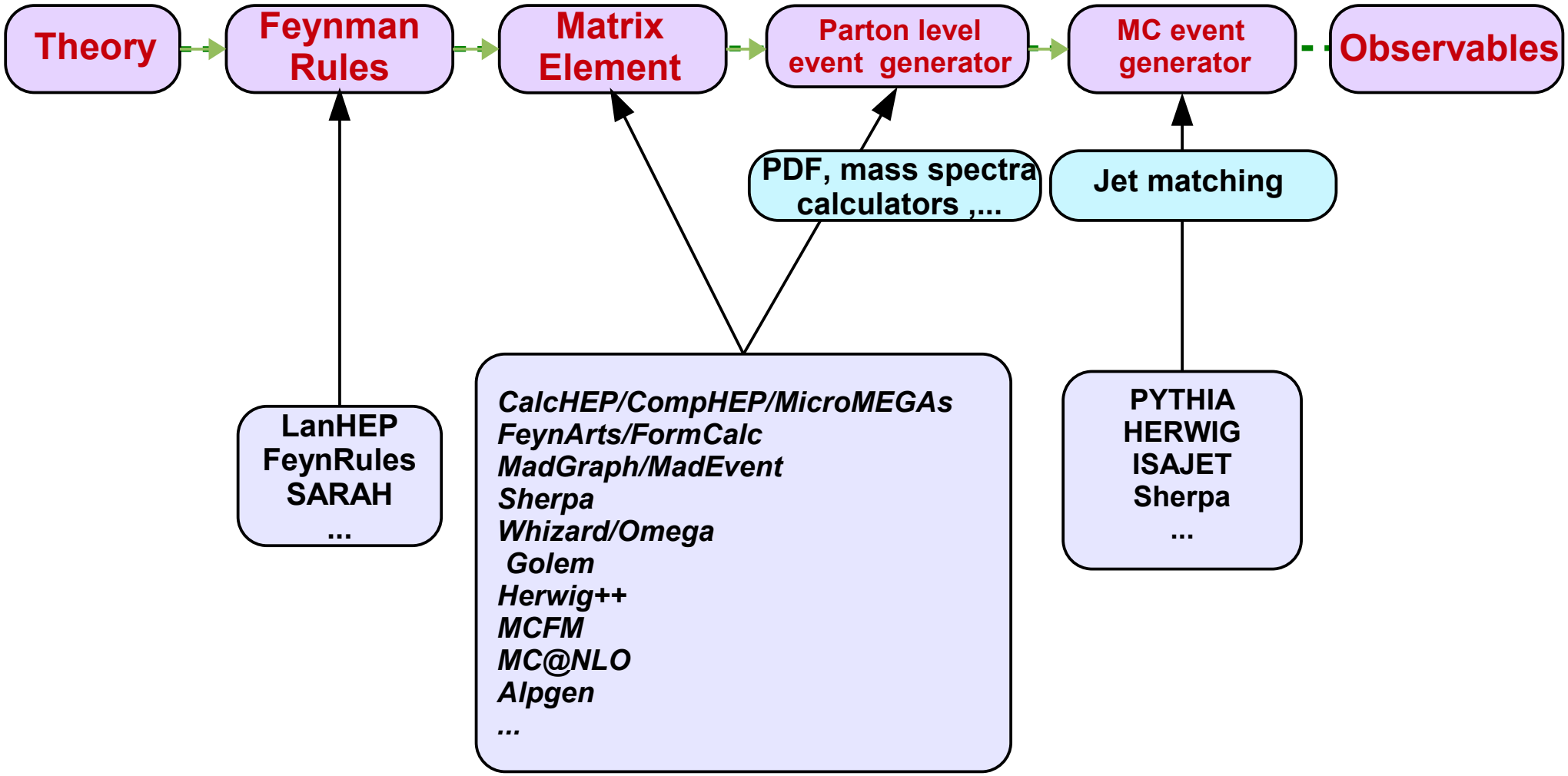

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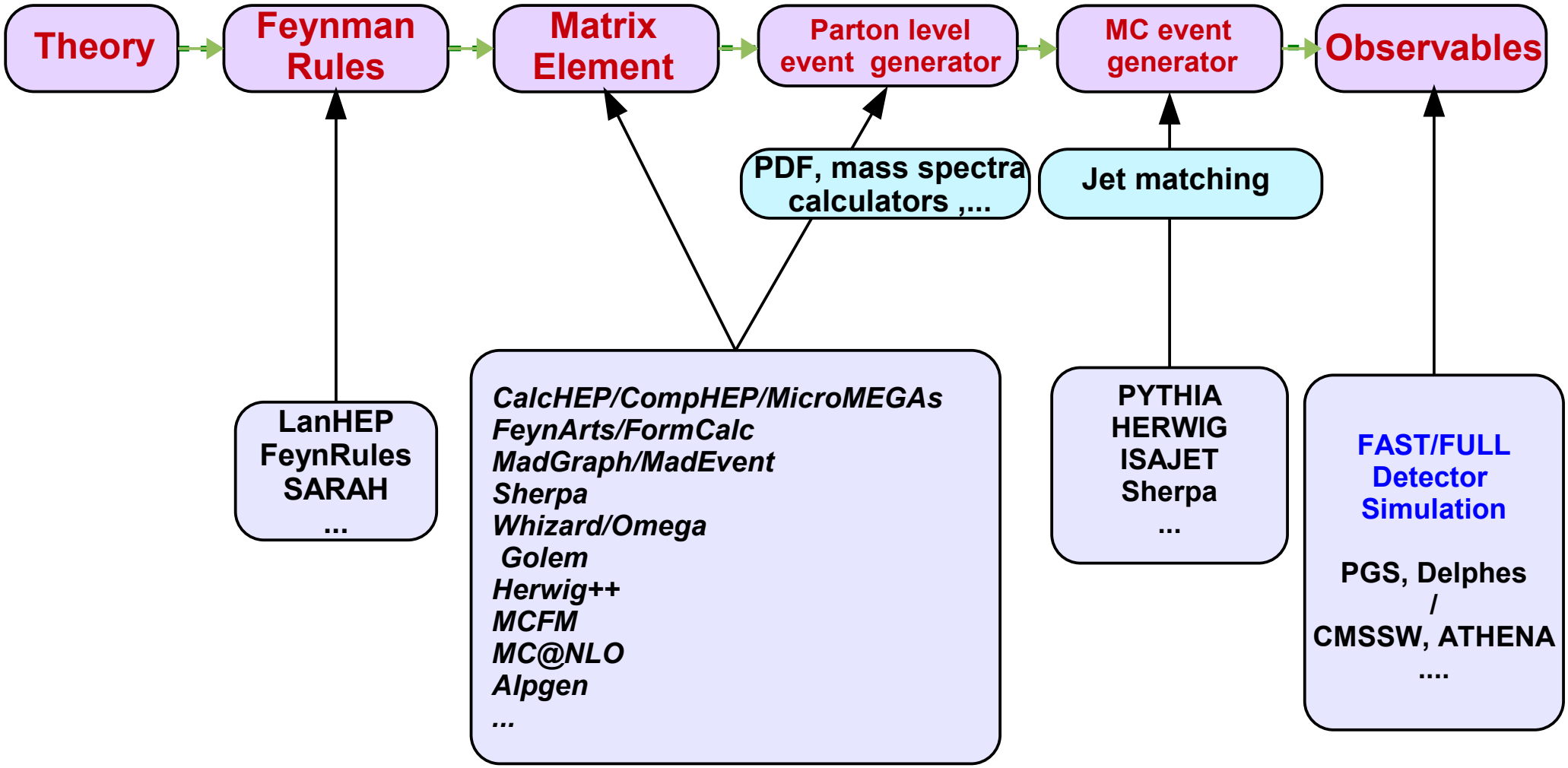

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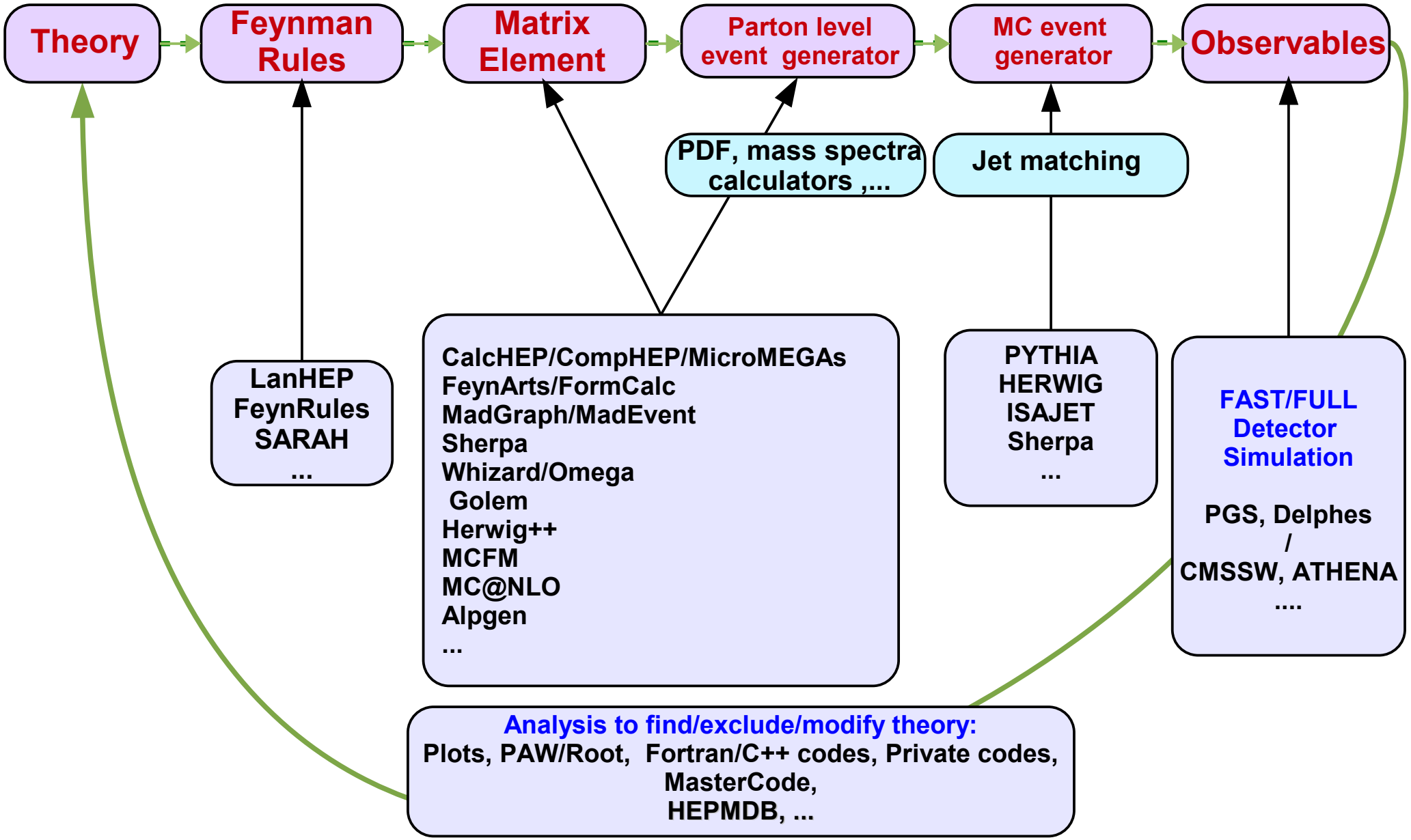

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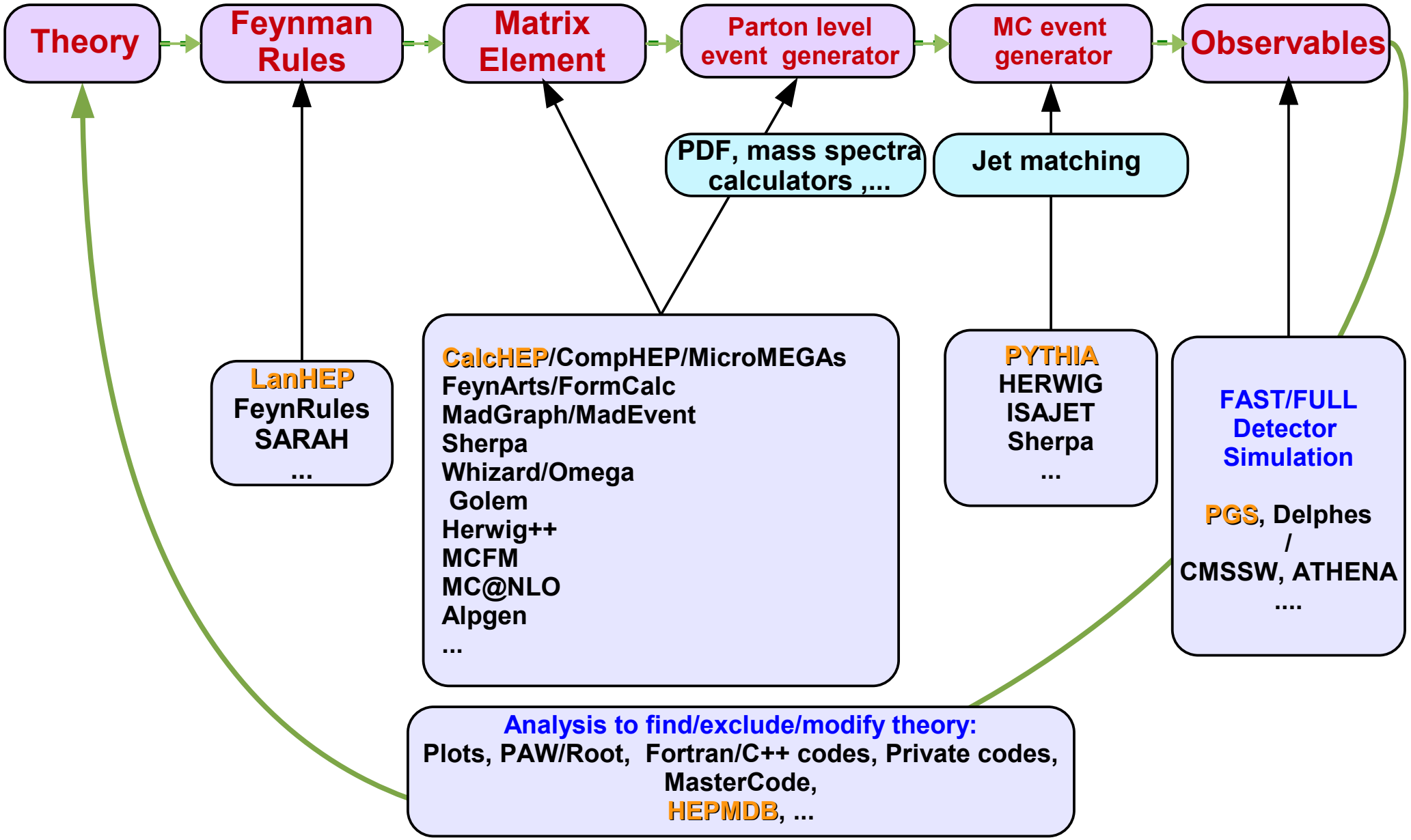

TOOLS repositories

- ***A Repository For Beyond-the-Standard-Model Tools***
  http://www.ippp.dur.ac.uk/montecarlo/BSM/
- ***MC4BSM workshop***
  http://theory.fnal.gov/mc4bsm/

Outline of the course

- **Lecture I:** *Matrix Element Calculations: CalcHEP*
- **Lecture II:** *Model Implementation : LanHEP*
  High Energy Physics Model Database (HEPMDB)
- **Lecture III:** *introduction into PAW & event analysis*
  Examples of the CalcHEP/LanHEP application
- **Lecture IV:** *Beyond the Parton Level: PYTHIA and PGS*
- **Lecture V:** *Advanced topics*

Lecture I:

Introduction into CalcHEP

- *system requirements & linux primer*
- *installation*
- *models and symbolic session*
- *numerical session and kinematical distributions*
- *event generation*
- *CalcHEP Batch Interface*

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

- ***"HEP TOOLS dropbox directory" available at***
  http://www.personal.soton.ac.uk/ab1u06/webpage/hep_tools.html

Prerequisites

- ***basic knowledge of Linux/UNIX***
  - ***See Linux primer in the dropbox (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)***
  - ***Grace/Helas (Fujimoto et al)***
  - ***FeynArts/FeynCalc/FormCalc (Hahn et al)***
  - ***WHIZARD,O'mega (Moretti, Ohl, Reuter)***
  - ***Sherpa (Krauss et al)***

Features/Limitations of CalcHEP

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

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

Features/Limitations of CalcHEP

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

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

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

Authors - Alexander Pukhov, Alexander Belyaev, Neil Christensen

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

General information

Main features, Acknowledgments, News&Bugs, References, Contributions

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Manual

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

HEP computer tools (Lecture by Alexander Belyaev)

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

Code download.

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

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Models:

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

Model database HEPMDB

Related packages on Web:

Packages for model generation: LanHEP, FeynRules, SARAH

RGE and spectrum calculation: SuSpect, Isajet, SoftSUSY, SPheno, CPsuperH, NMSSMTools

Particle widths in MSSM: SUSY-HIT, HDECAY

Parton showers: PYTHIA

Contacts

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

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manual is updated!

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new version and writeup!

arXiv:1207.6082

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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* = 3.4.cpc
- **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)

Exercise#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 "
  is a good sign

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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**

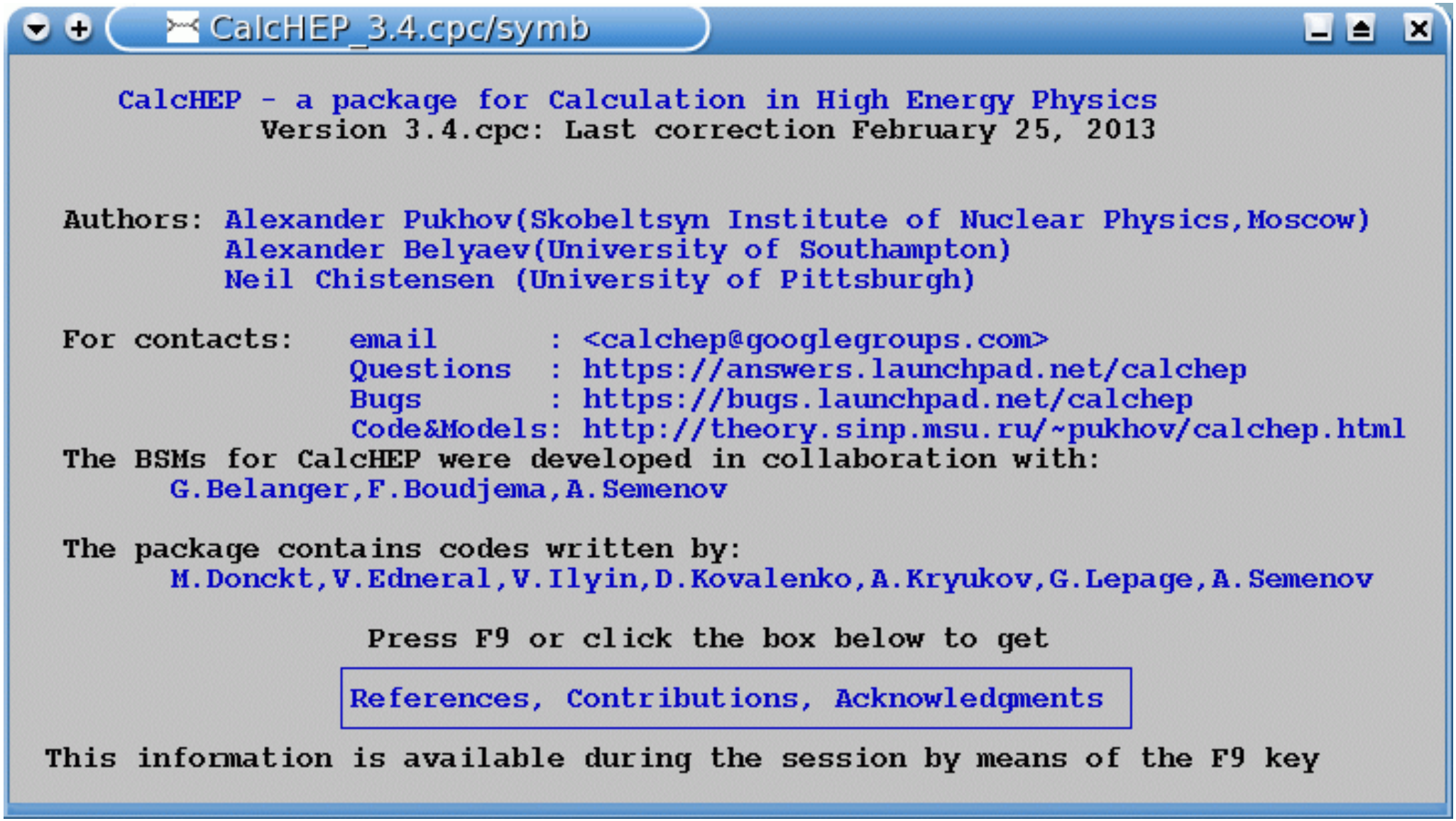
- ***Files:***

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

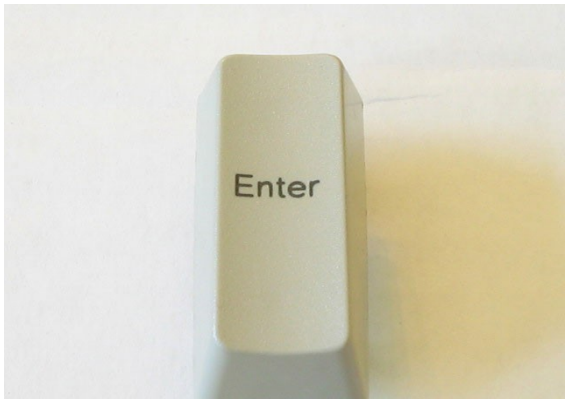
- ***Start:***

./calchep

Starting CalcHEP



Principle KEYS for CalcHEPs GUI

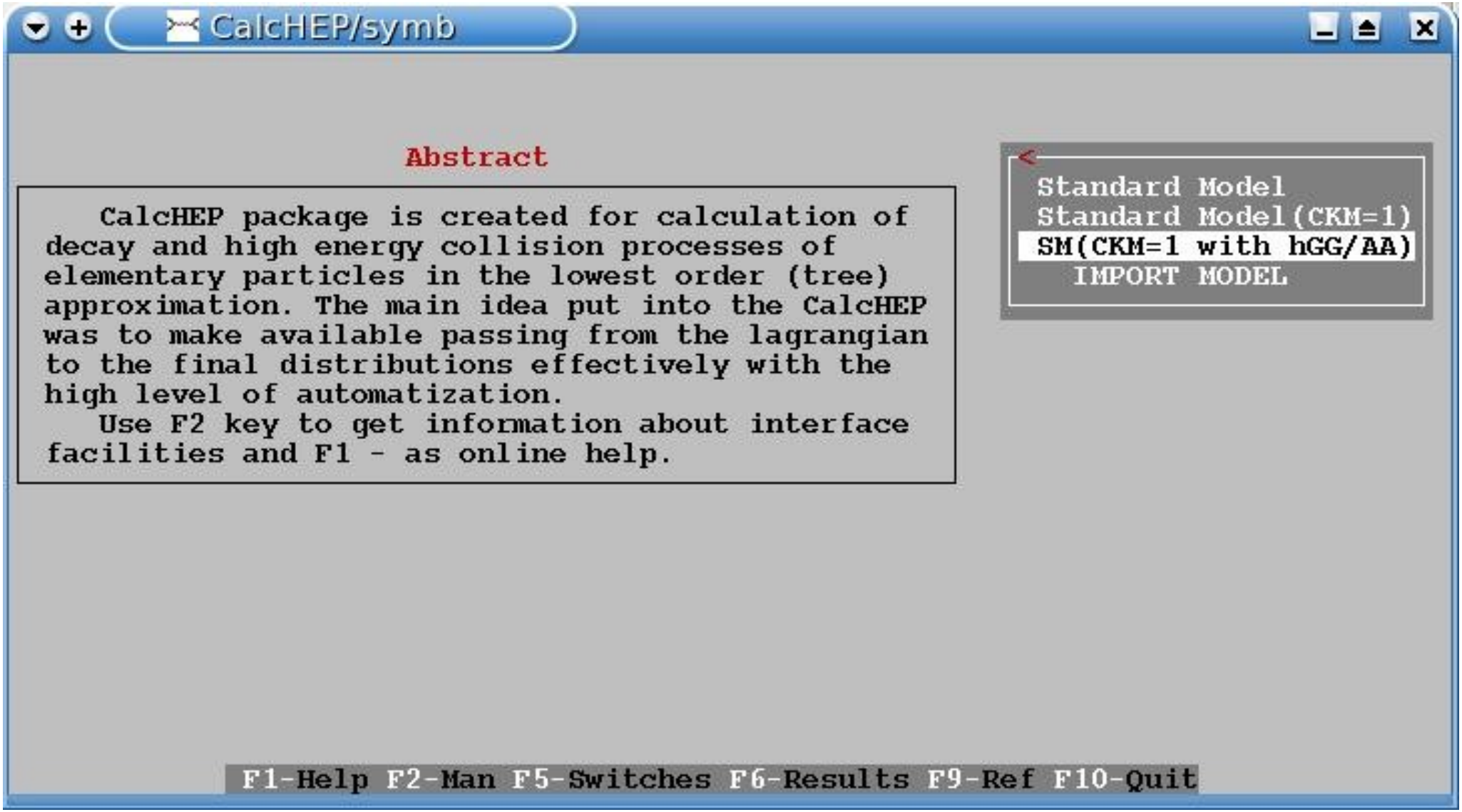


Enter menu selection (forward)

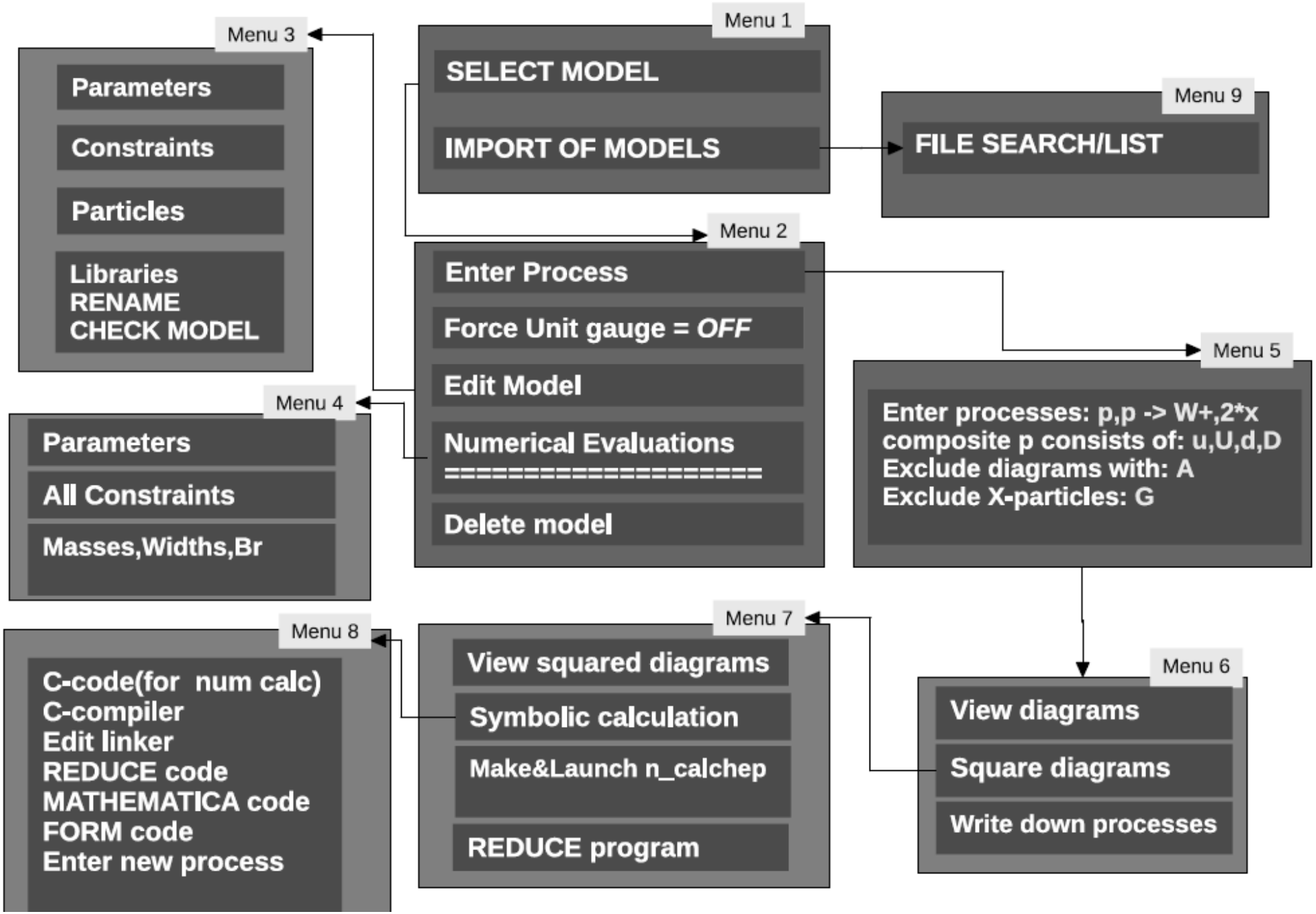
Exit menu selection (back)

Help!

Starting CalcHEP



CalcHEP menu structure: symbolic part



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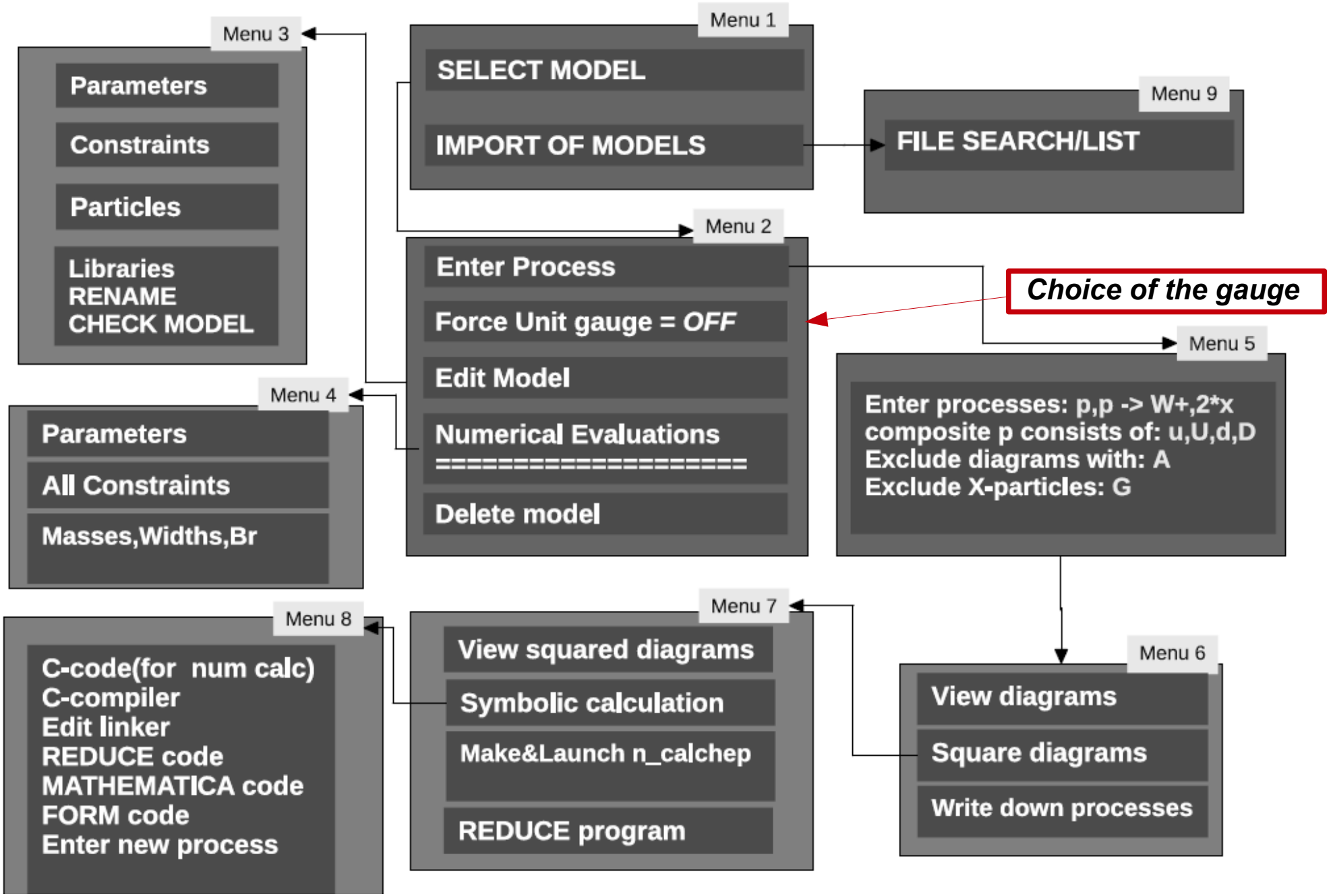
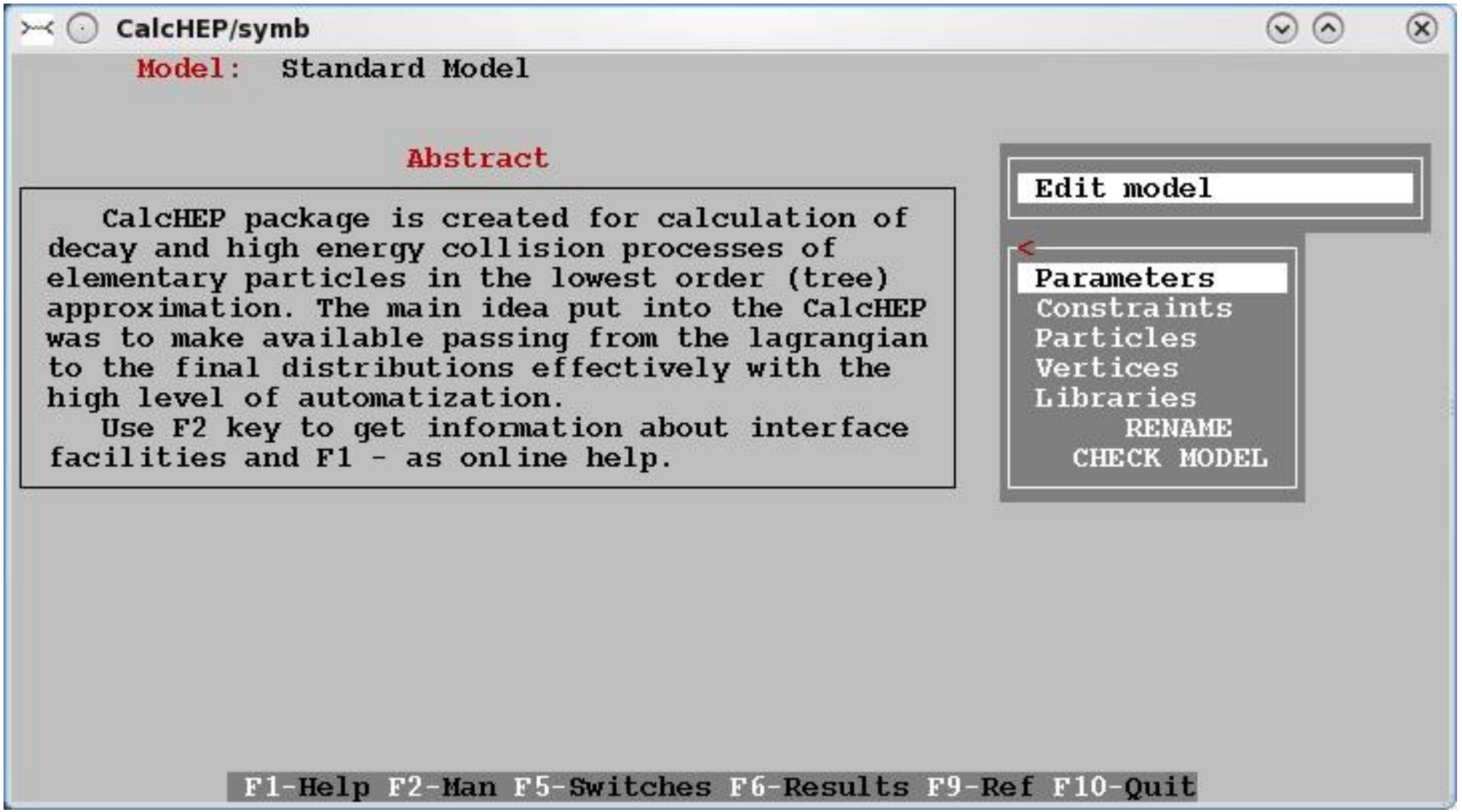


Model Structure

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



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

CalcHEP/symb

Particles

Clr Del Size Read ErrMes

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

F1 F2 Xgoto Ygoto Find Write

Particles: prtcl*xx*.mdl

CalcHEP/symb

Particles

Clr–Del–Size–Read–ErrMes

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

F1–F2–Xgoto–Ygoto–Find–Write

Higgs boson width will be calculated `on the fly`

Independent parameters: varsxx.mdl

CalcHEP_3.4.cpc/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	172.5	t-quark pole mass
MZ	91.188	Z-boson mass
MW	80.385	W-boson mass
Mh	125	higgs mass
wt	1.59	t-quark width (tree level 1->2x)
wZ	2.49444	Z-boson width (tree level 1->2x)
wW	2.08895	W-boson width (tree level 1->2x)

F1-F2-Xgoto-Ygoto-Find-Write

Dependent parameters(constraints): funcxx.mdl

CalcHEP_3.4.cpc/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)
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
LamQCD	initQCD5(alfSMZ,McMc,MbMb,Mtp)	
Mb	MbEff(Q)	
Mt	MtEff(Q)	
Mc	McEff(Q)	

F1-F2-Xgoto-Ygoto-Find-Write

Feynman rules: lgrng*xx*.mdl

CalcHEP/symb

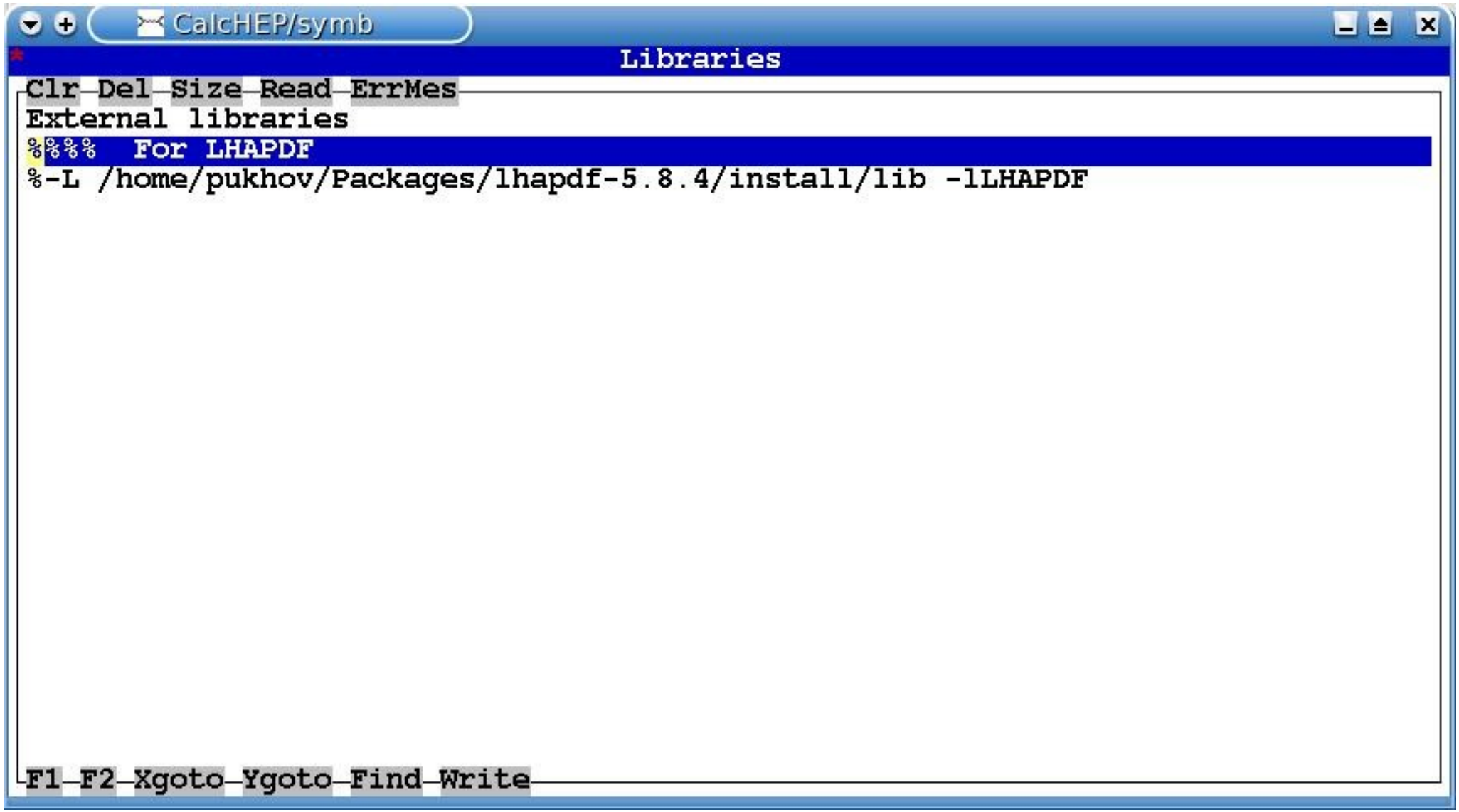
Vertices

Clr Del Size Read ErrMes

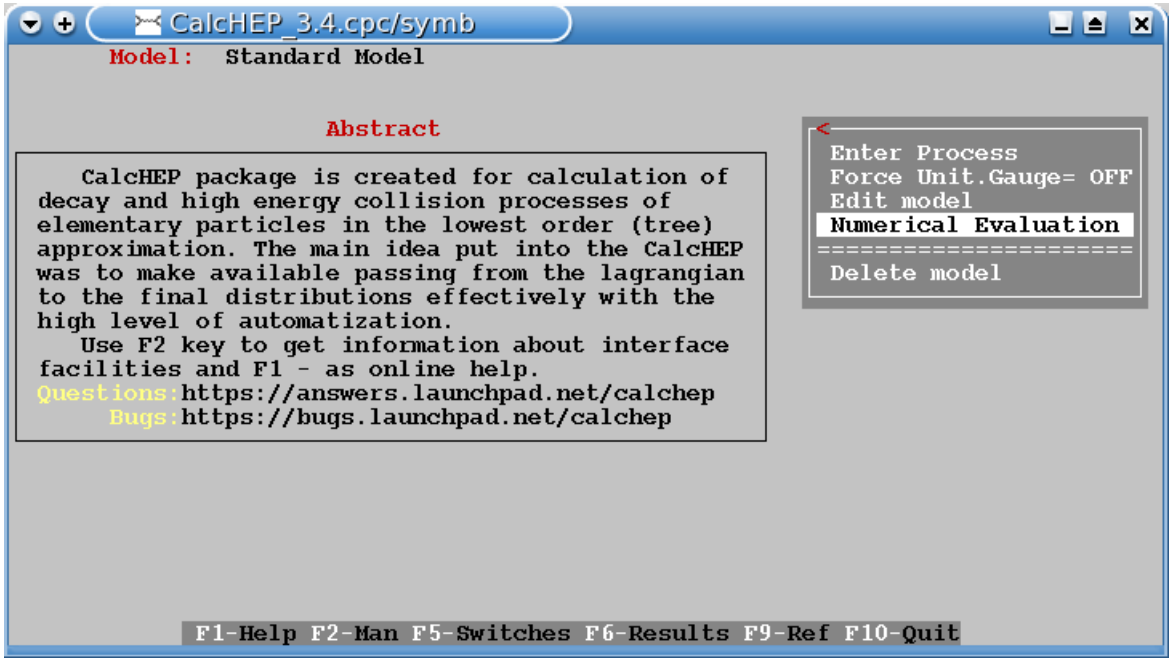
A1	A2	A3	A4	> Factor <|	> Lorentz part
h	W+	W-		EE*MW/SW		m2.m3
h	Z	Z		EE/(SW*CW^ 2)*MW		m2.m3
h	h	h		-(3/2)*EE*Mh^ 2/(MW*SW)		1
h	h	h	h	(-3/4)*(EE*Mh/(MW*SW))^ 2		1
h	h	Z	Z	(1/2)*(EE/(SW*CW))^ 2		m3.m4
h	h	W+	W-	(1/2)*(EE/SW)^ 2		m3.m4
M	m	h		-EE*Mm/(2*MW*SW)		1
L	l	h		-EE*Ml /(2*MW*SW)		1
C	c	h		-EE*Mc/(2*MW*SW)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

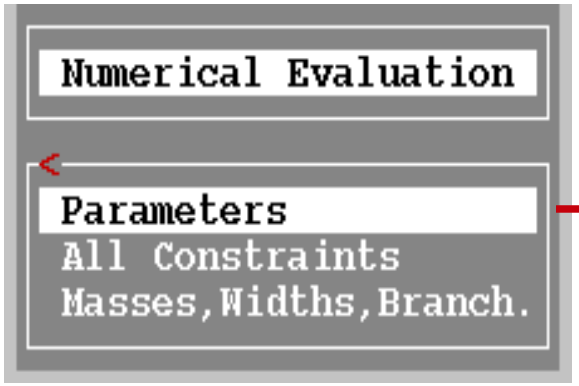
F1 F2 Xgoto Ygoto Find Write

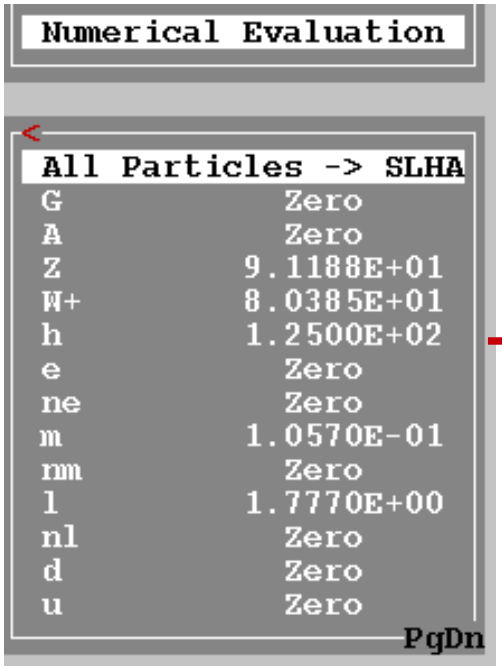
External Libraries: extlib*xx*.mdl



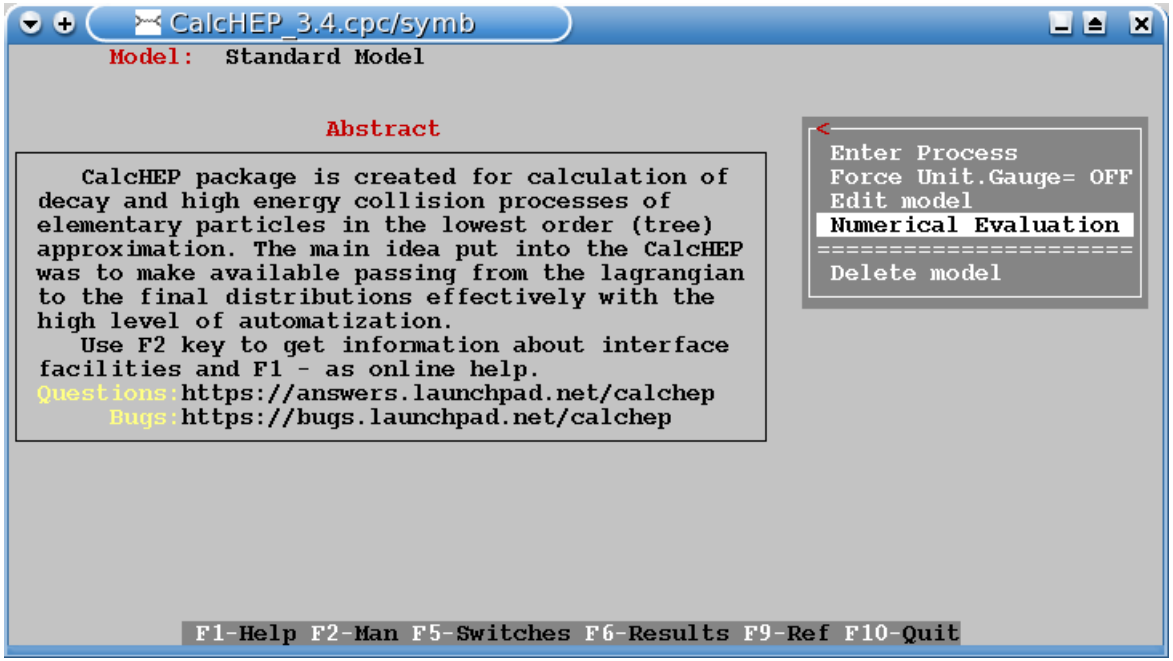
Numerical evaluation of masses & branchings

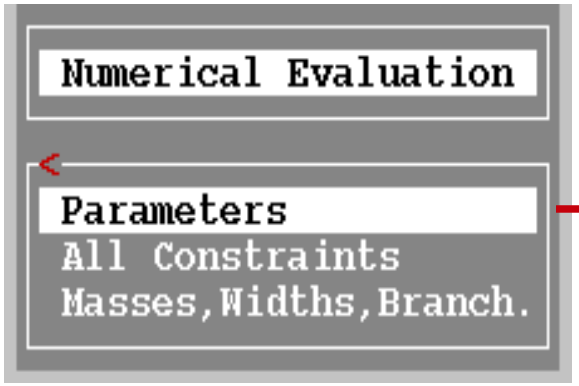


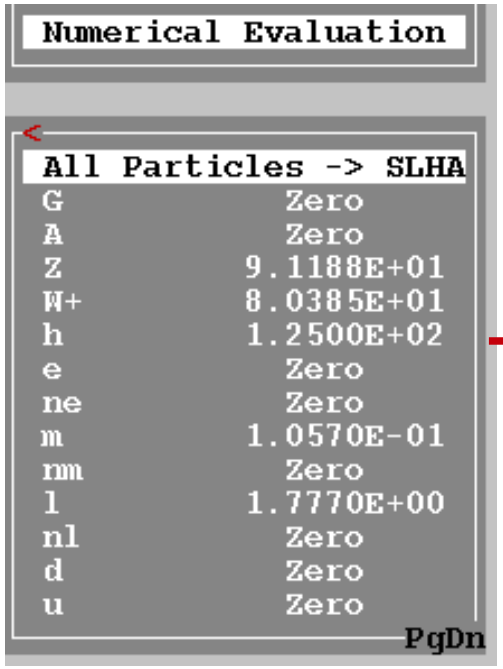




Numerical evaluation of masses & branchings







Exercise#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*

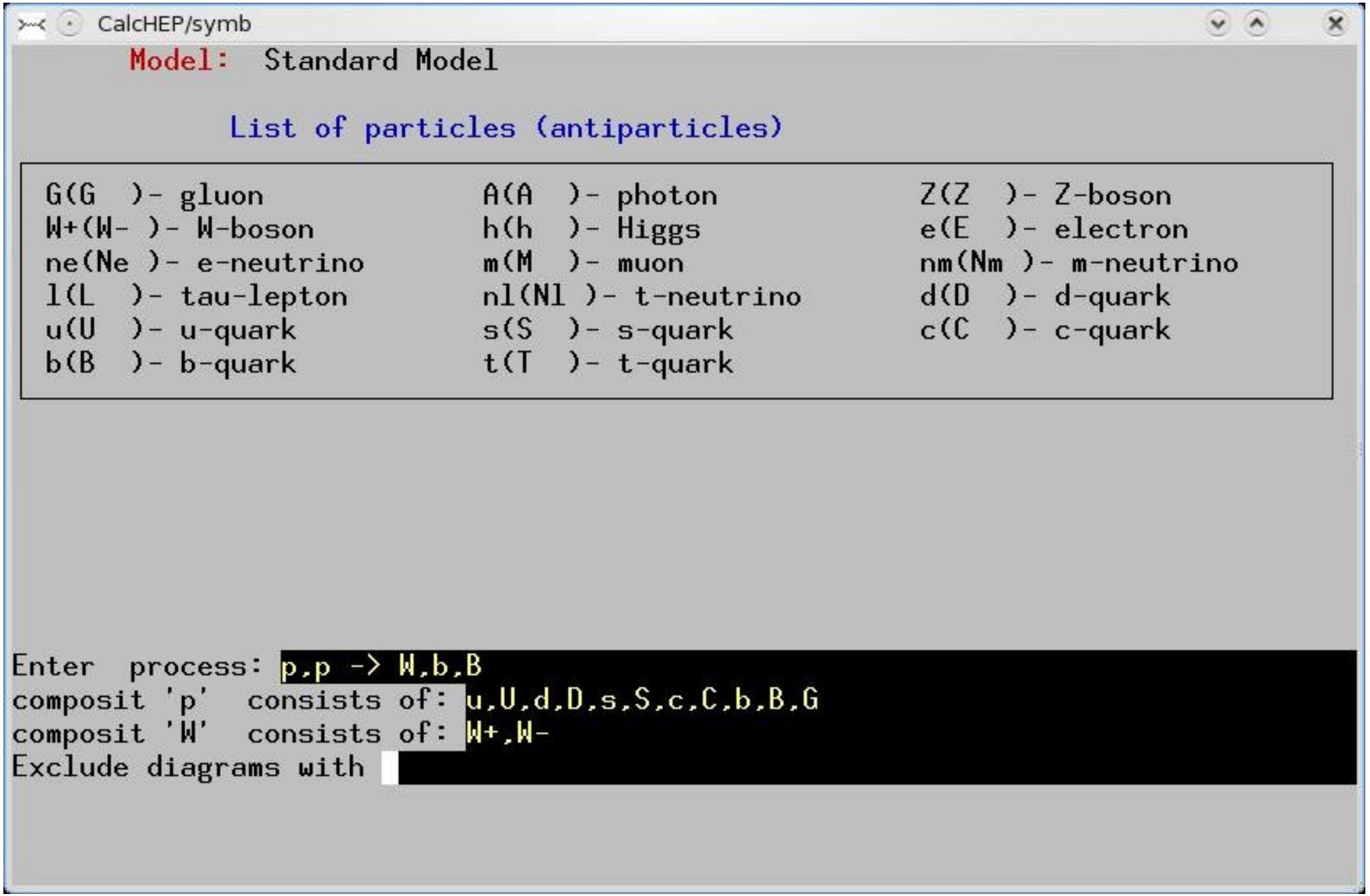
  *'H -> 2*x'*

- *intermediate particles can be non-trivially excluded*

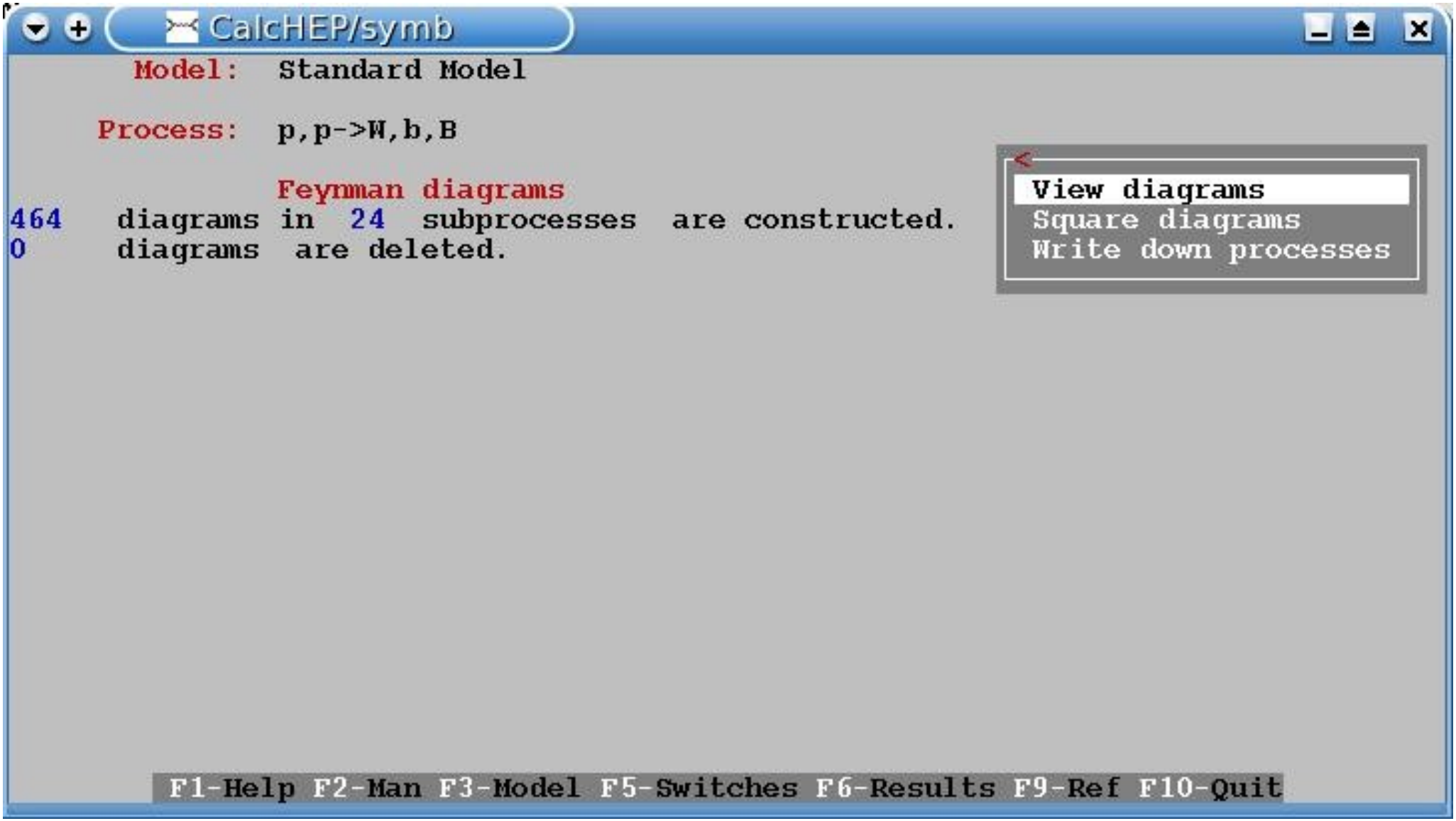
  'W+ > 2, A>1, Z>3'

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

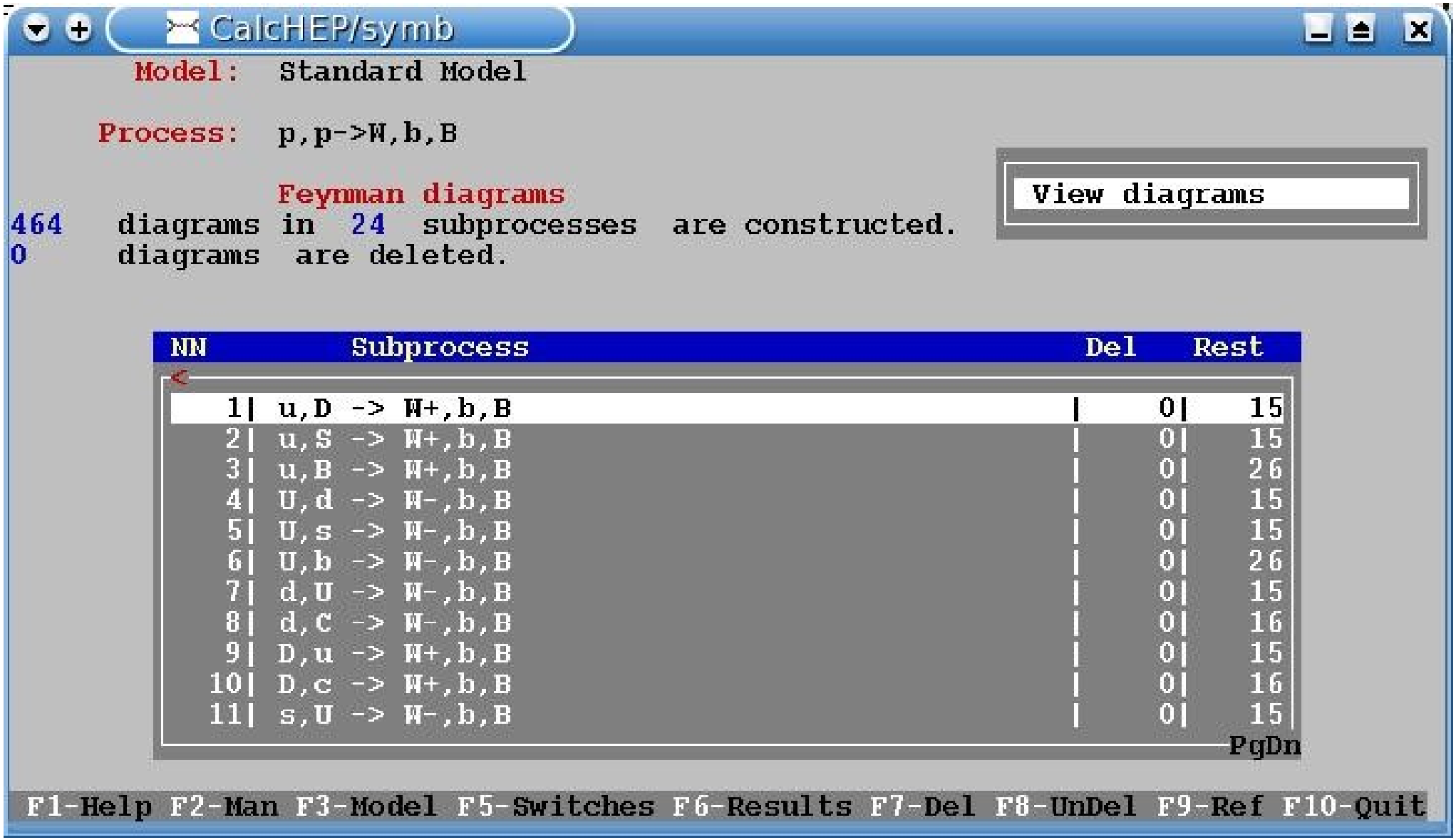
Symbolic session (1)



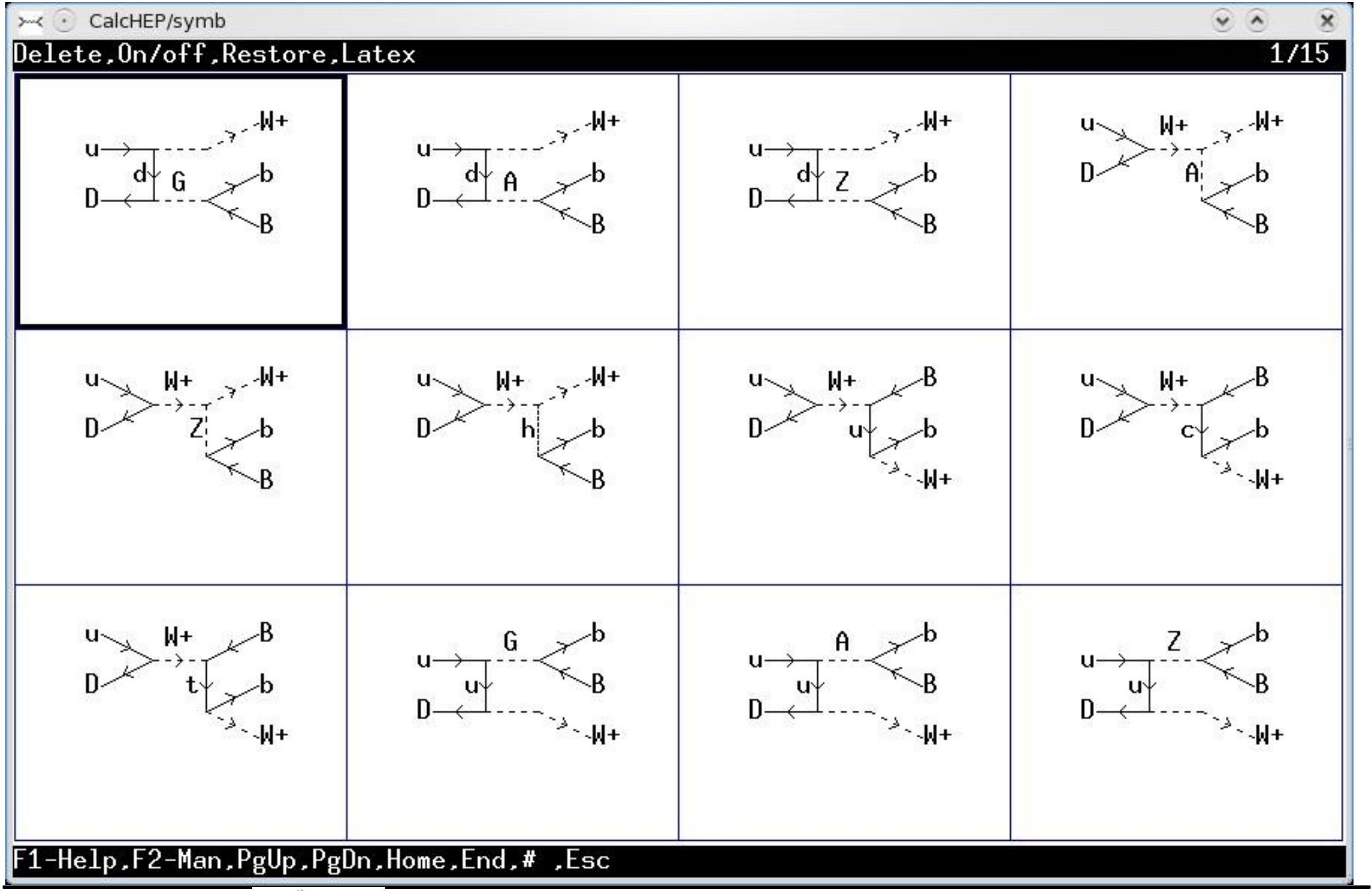
Symbolic session (2)



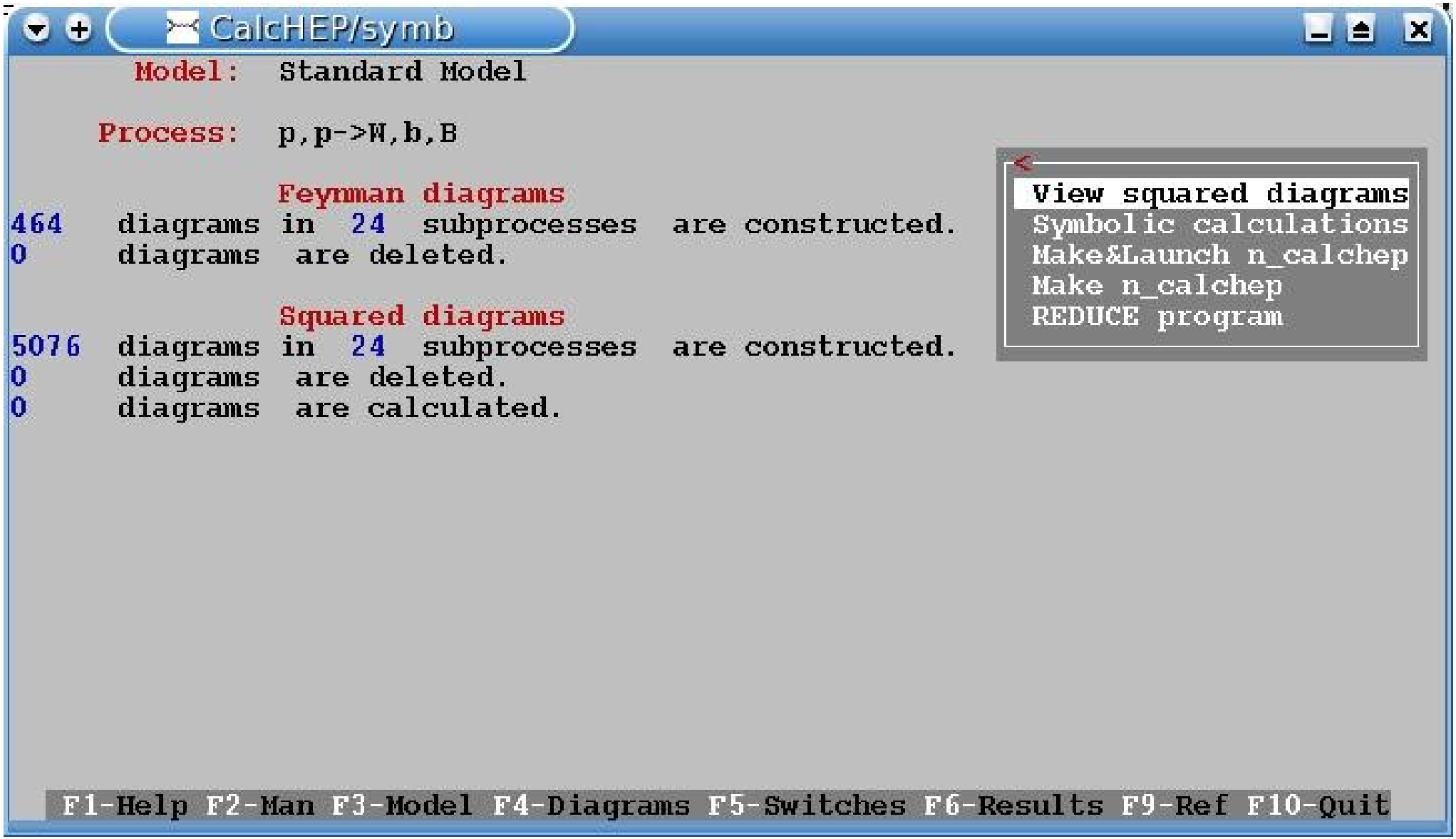
Symbolic session (3)



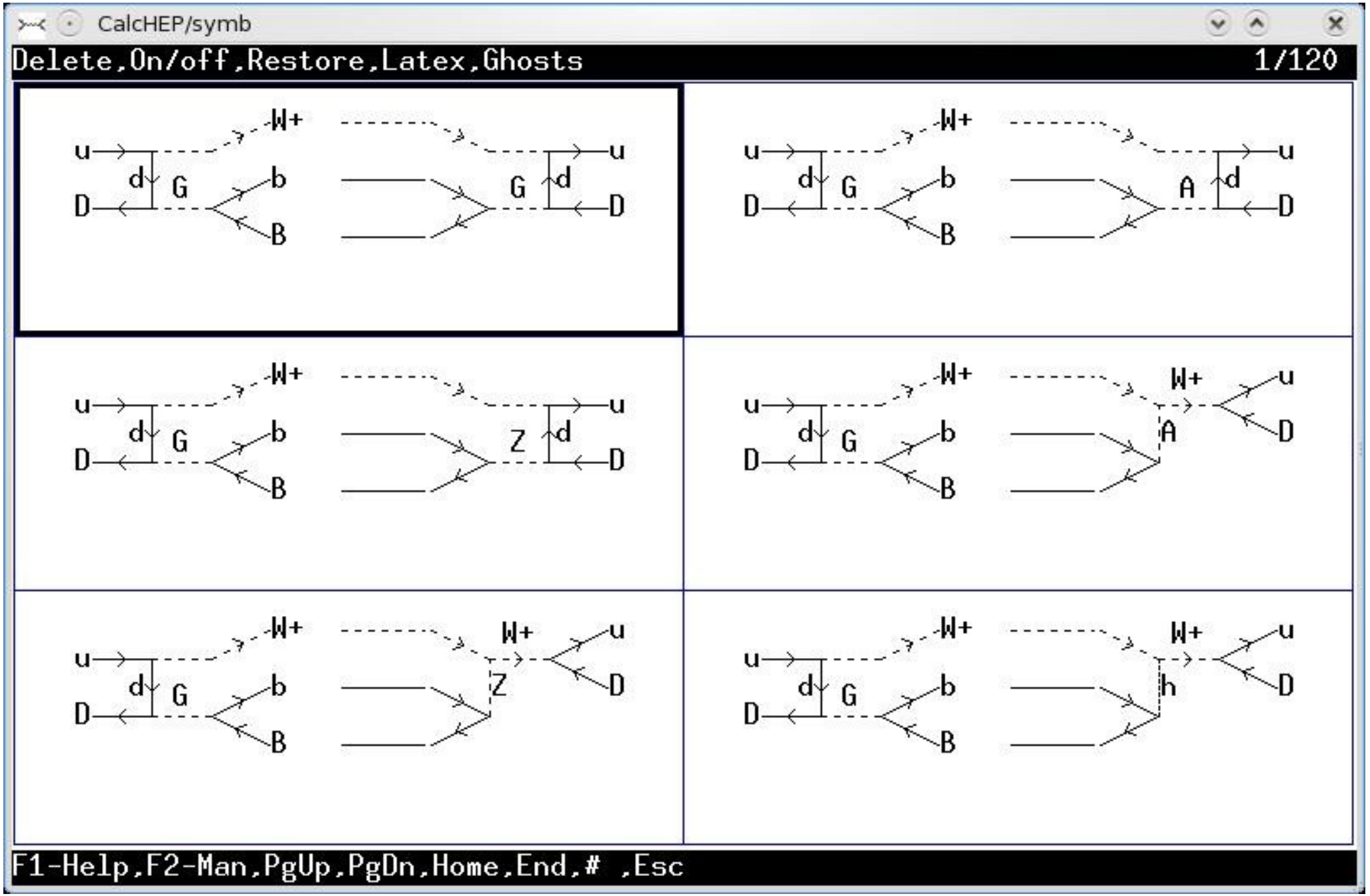
Symbolic session (4)



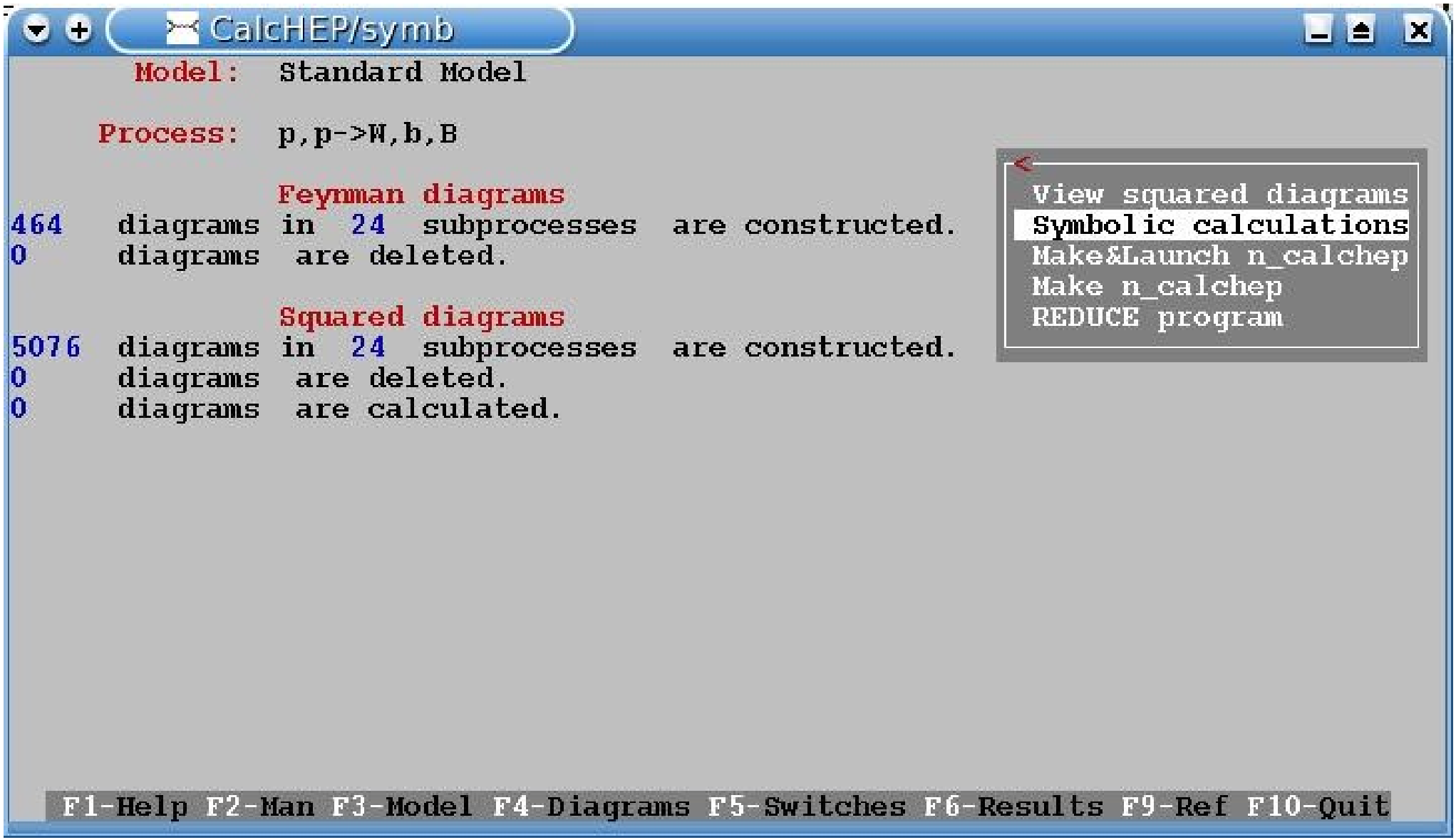
Symbolic session (5)



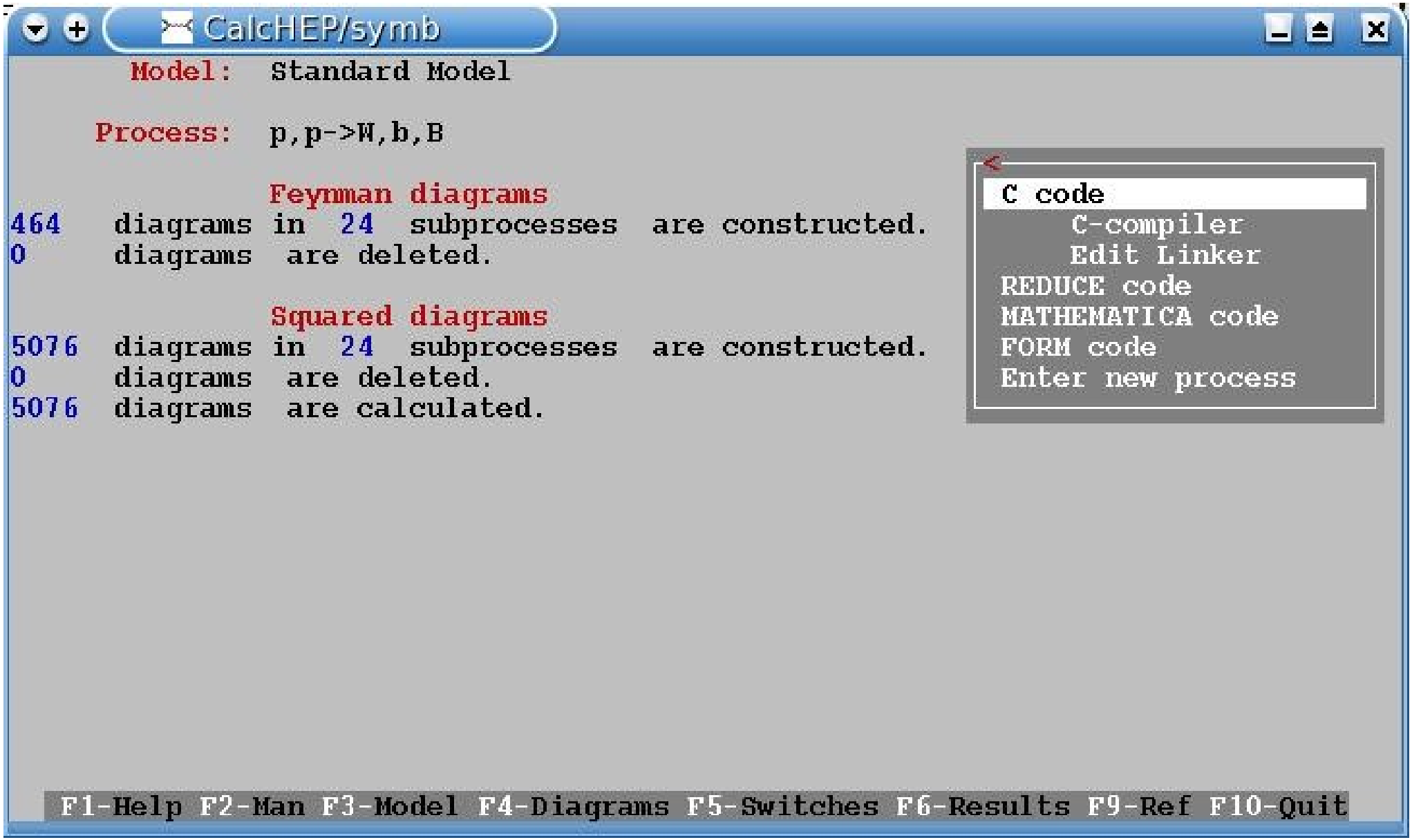
Symbolic session (6)



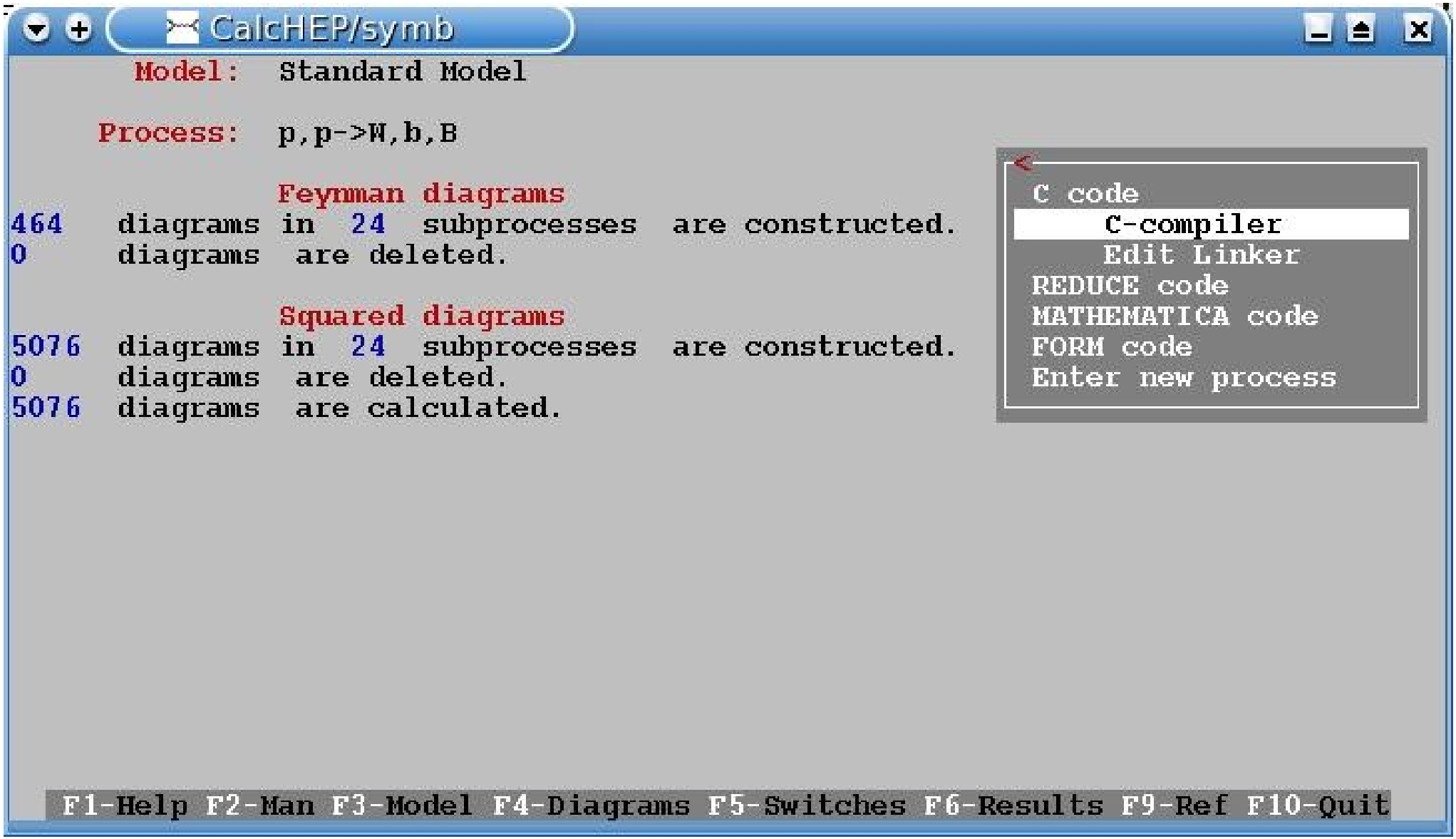
Symbolic session (7)



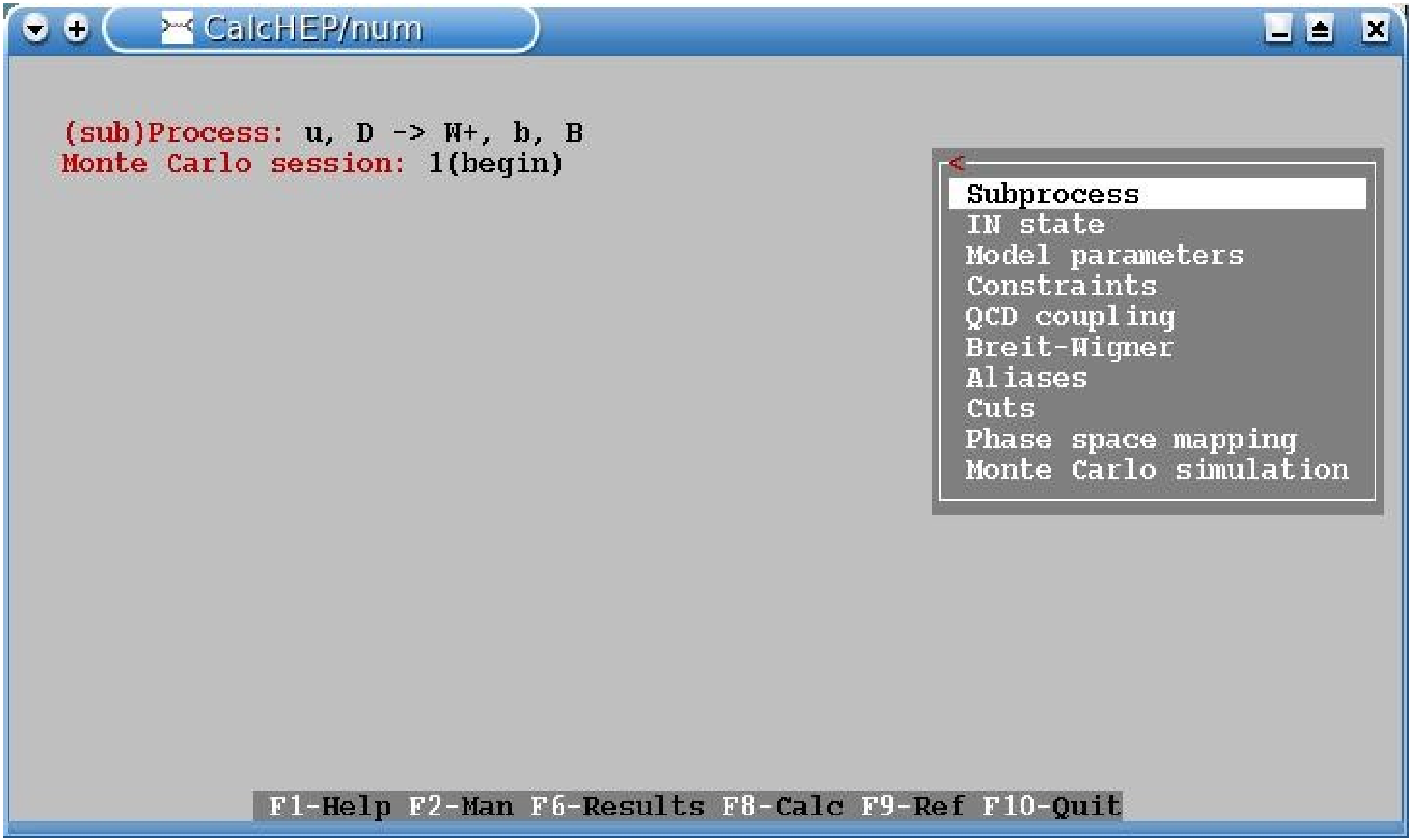
Symbolic session (8)



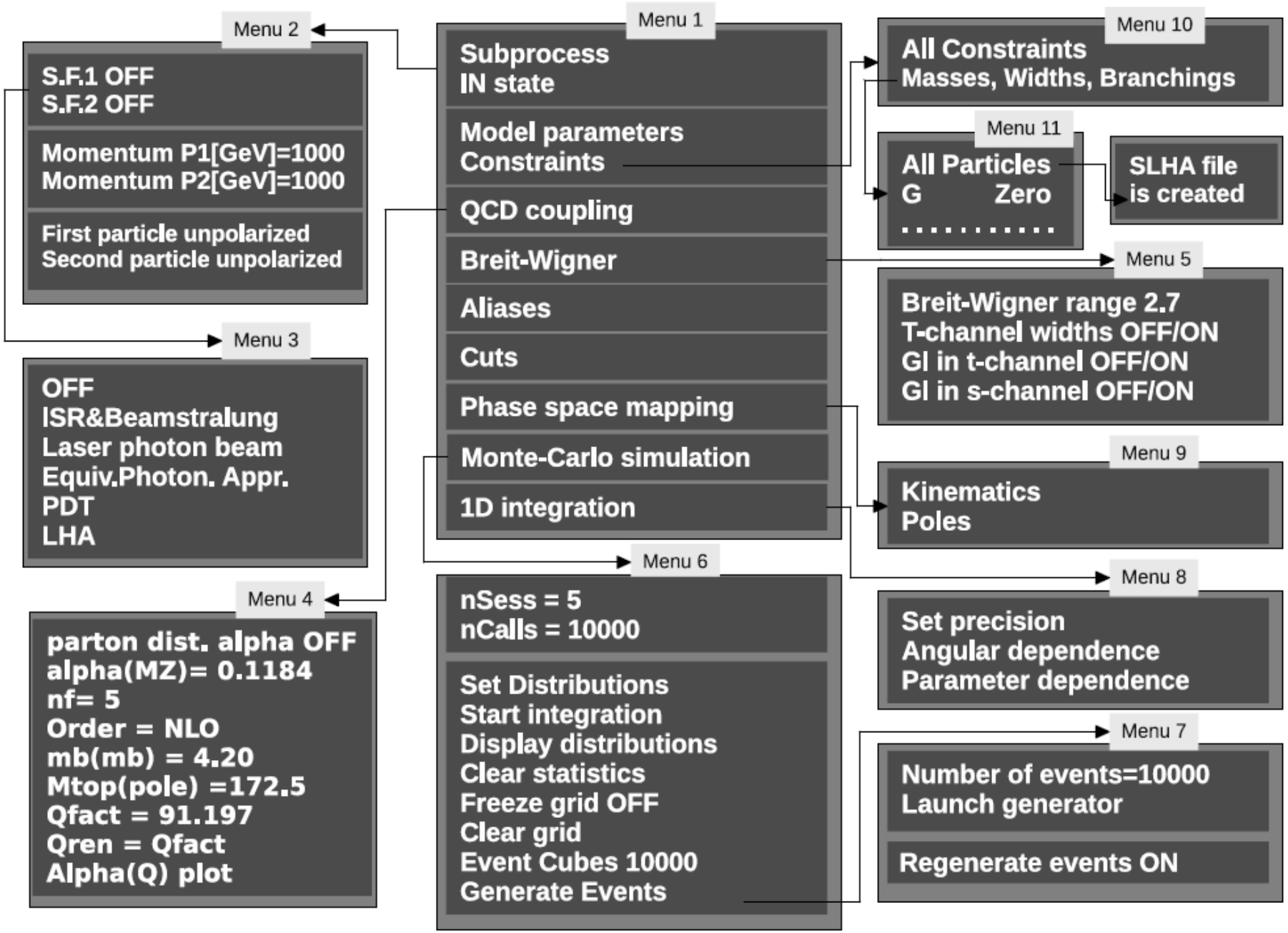
Symbolic session (9)



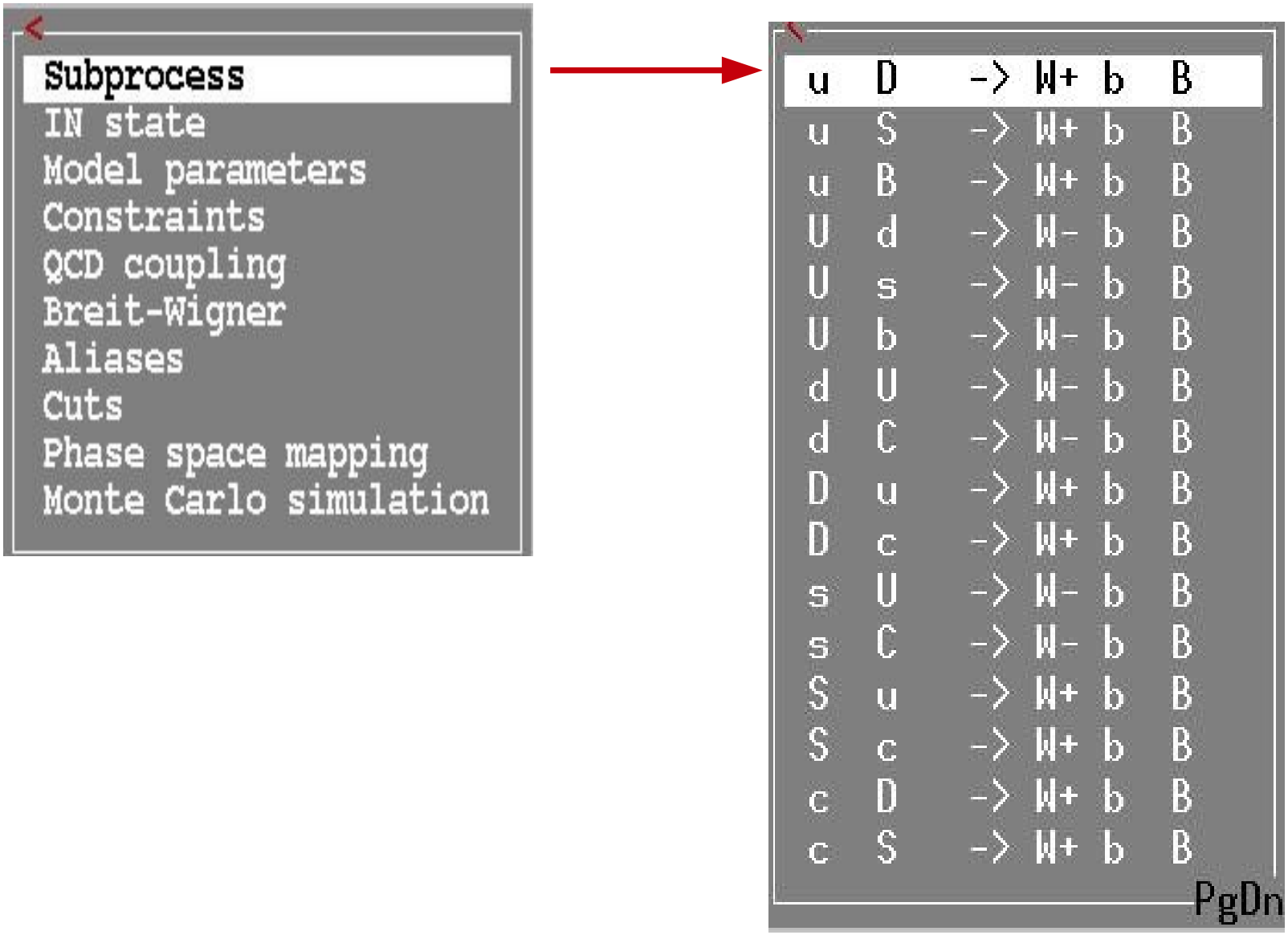
Numerical part of CalcHEP



Menu structure of the numerical part

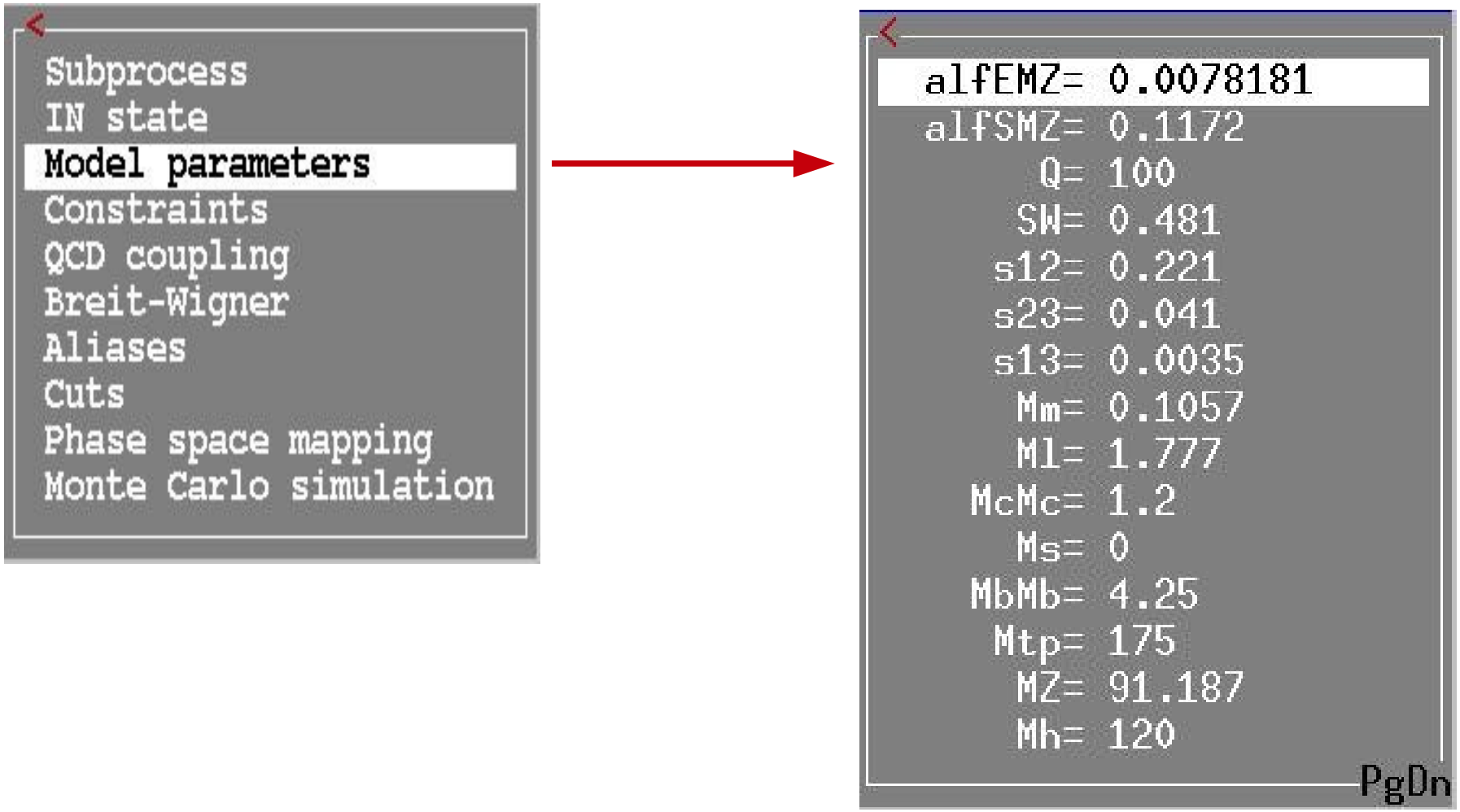


subprocess menu

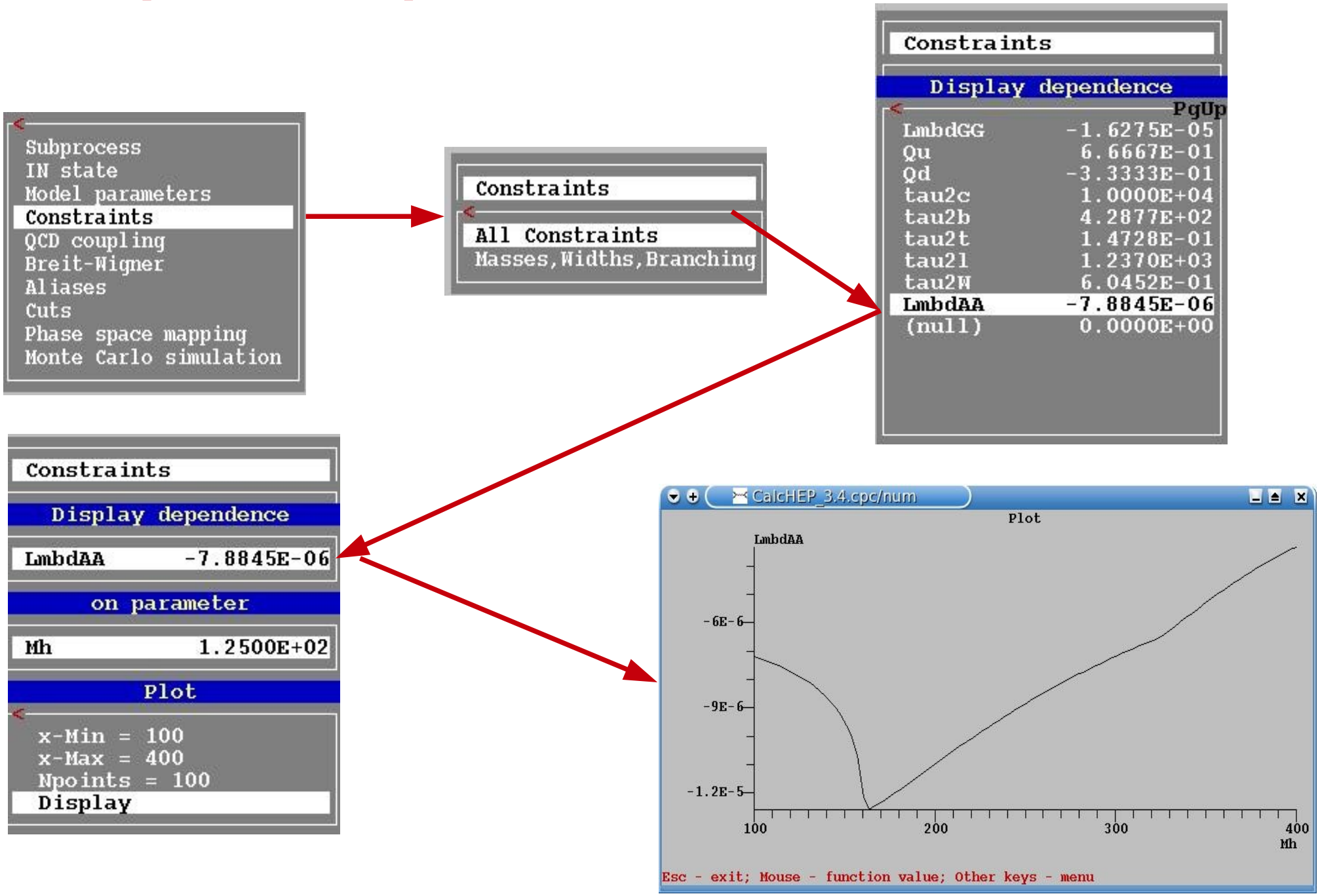


control of the initial states and parton density functions

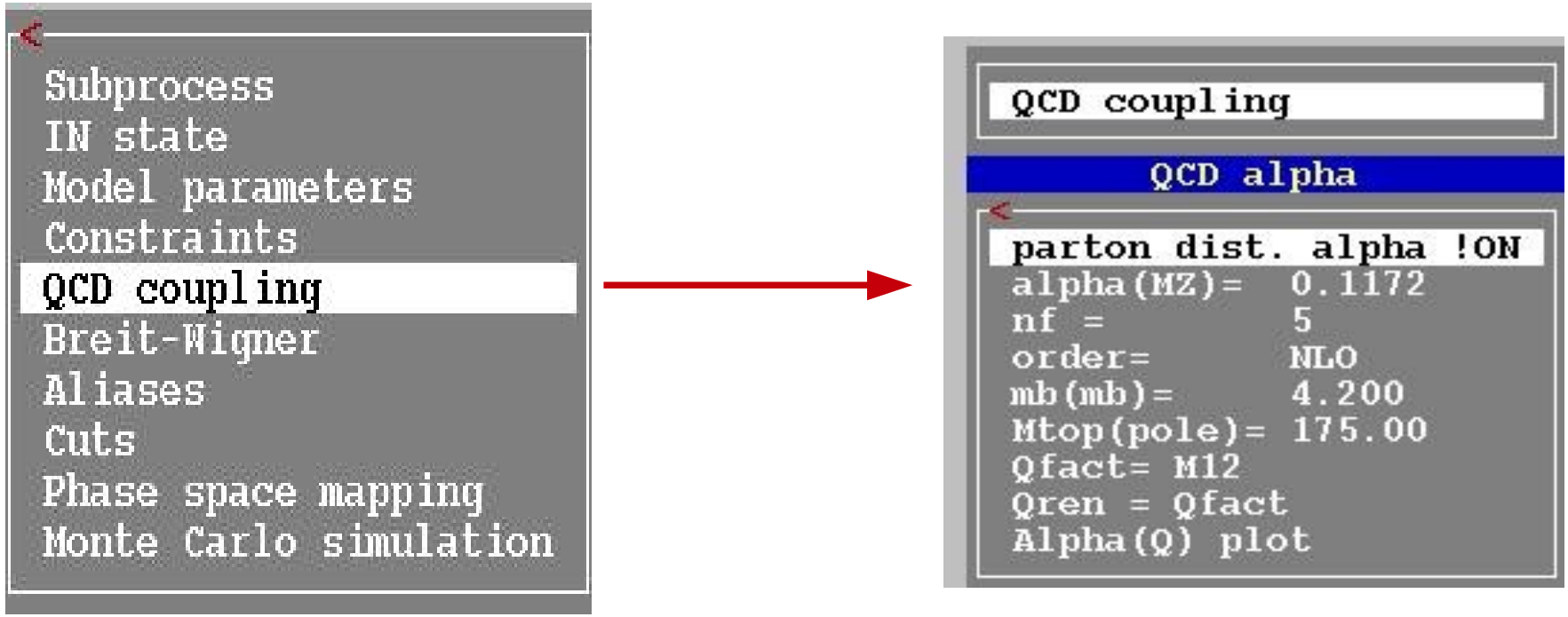
model parameters



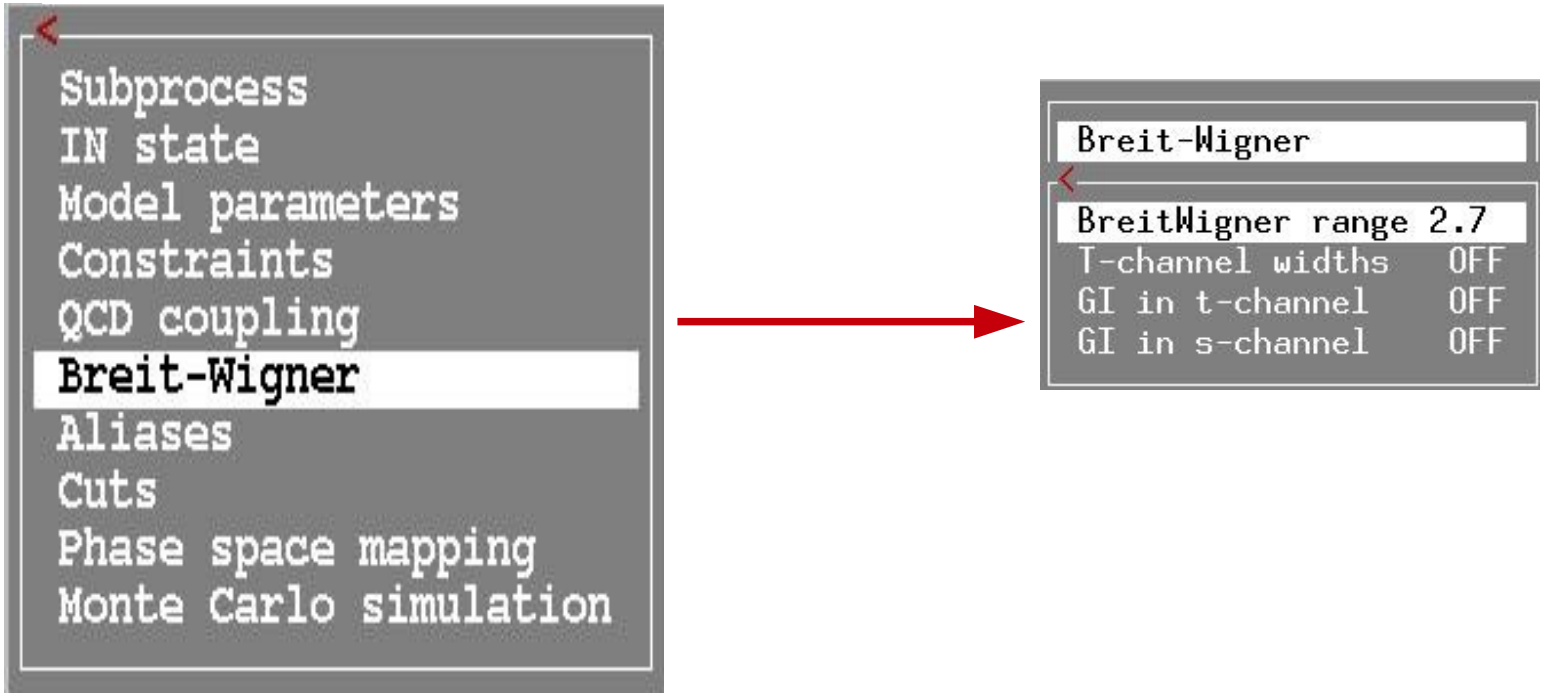
dependent parameters (SM CKM=1 with hGG/AA)



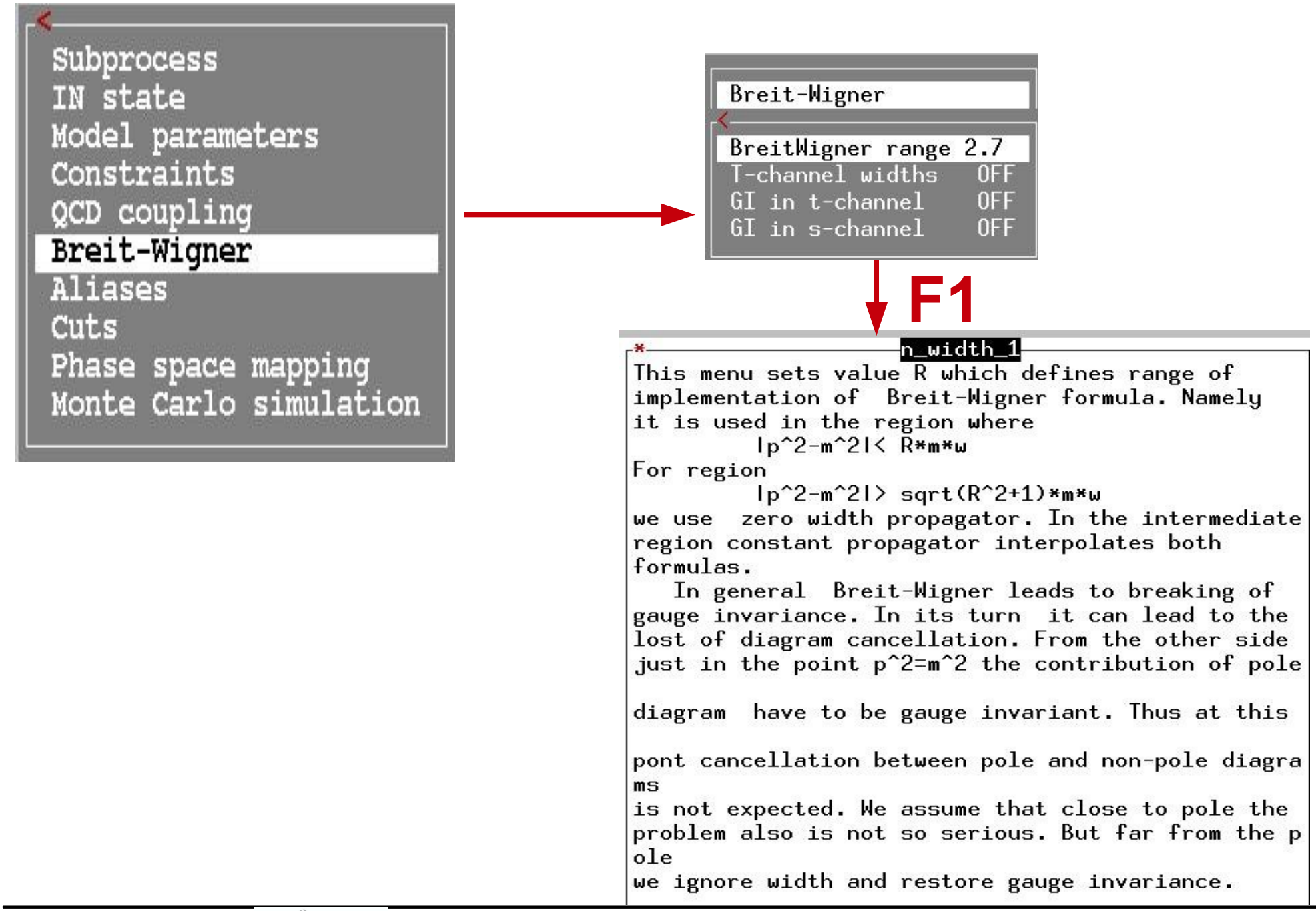
QCD coupling and the scale



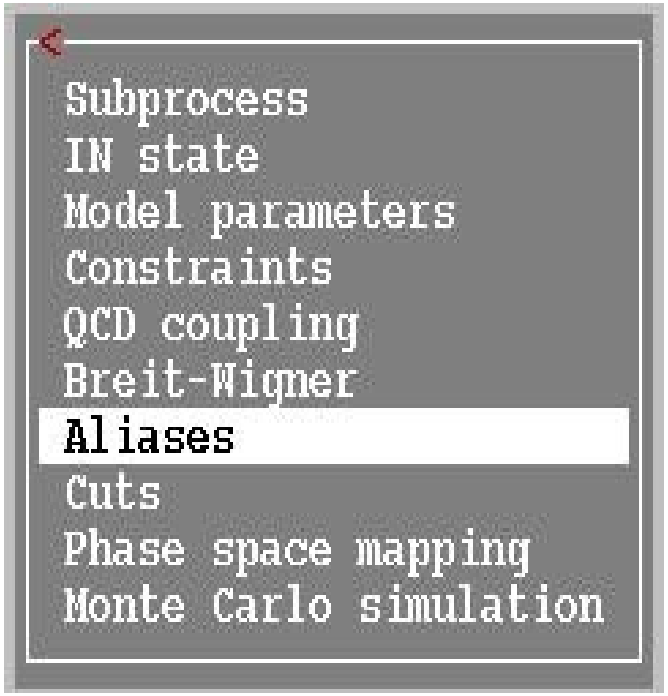
control of resonances

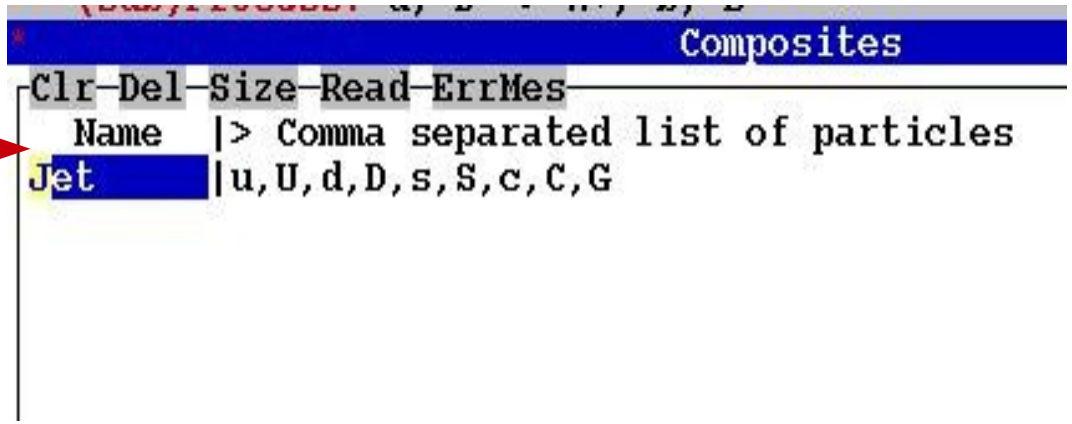


control of resonances

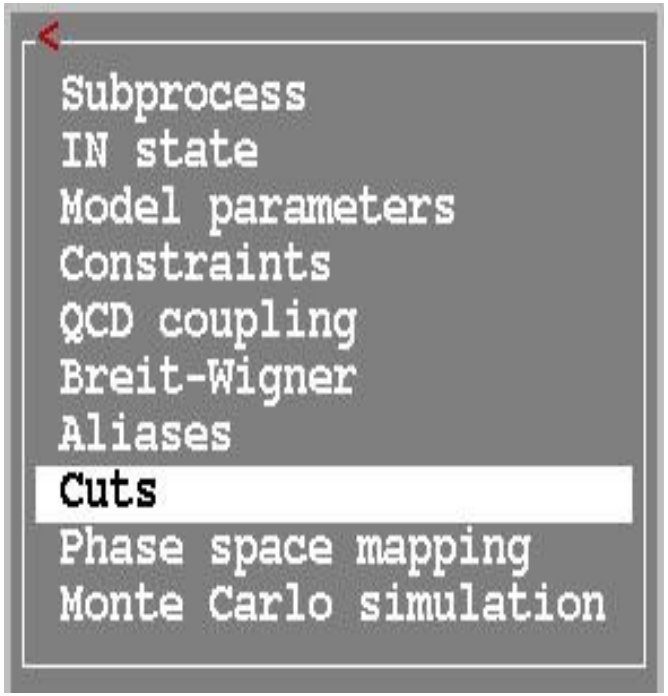


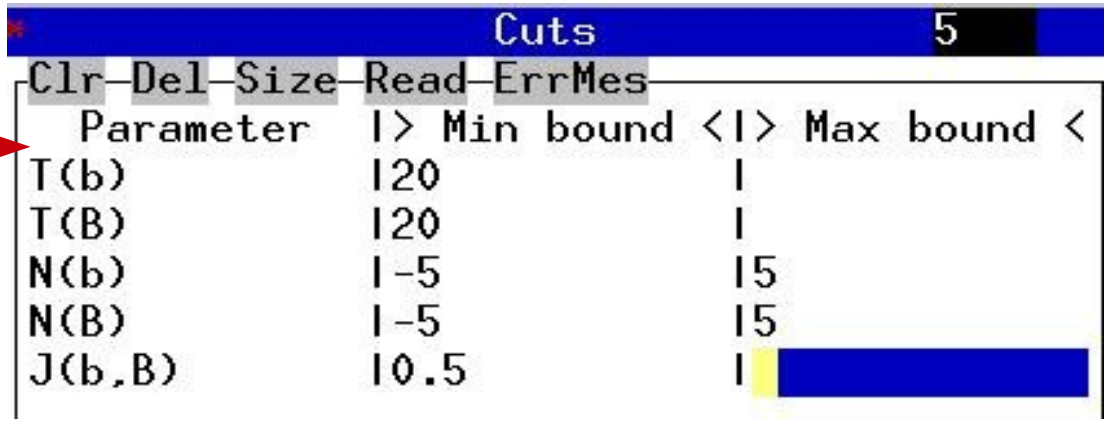
Aliases


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

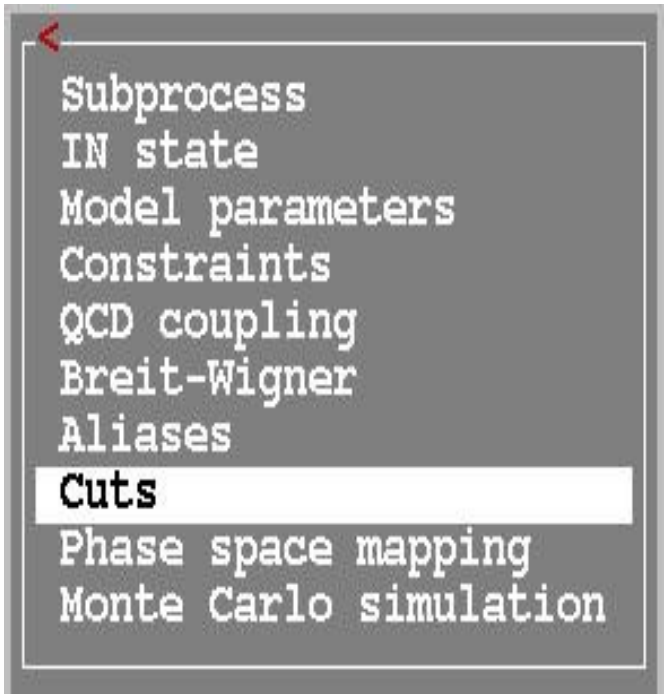

Composites
Clr Del Size Read ErrMes
Name |> Comma separated list of particles
Jet |u,U,d,D,s,S,c,C,G

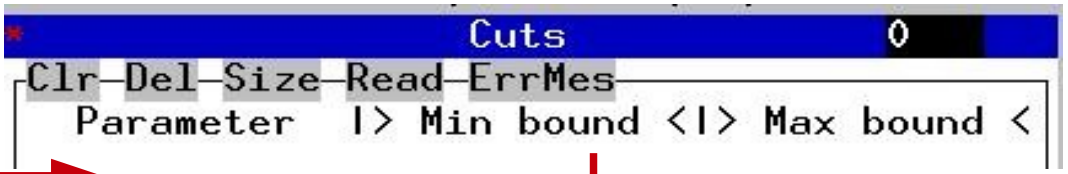
setting kinematical cuts





setting kinematical cuts





F1

n_cut

This table apples cuts on the phase space. A phase space function is described in the first column. Its limits are defined and the second and the third columns. If one of these fields is empty then a one-side cut is applied.

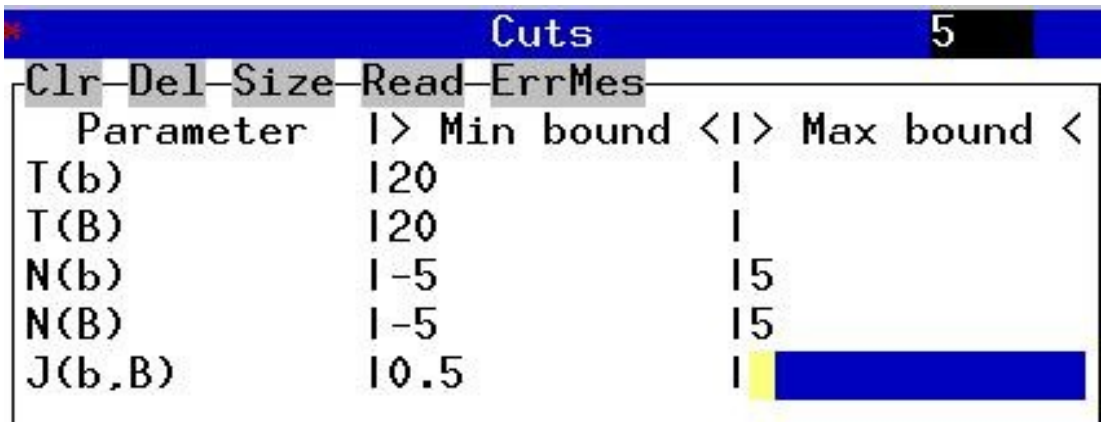
The phase space function is defined by its name which characterize type of cut and a particle list for which the cut is applied.

For example, "T(u)" means transverse momentum of 'u'-quark; T(u,D) means summary transverse momentum of quark pair.

The following cut functions are available:

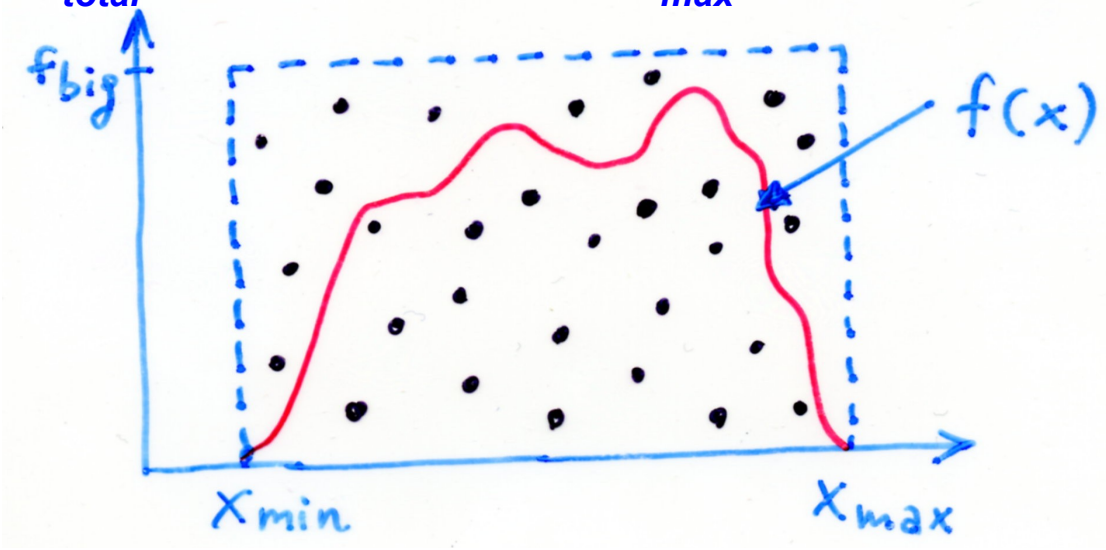
A - Angle in degree units;
C - Cosine of angle;
J - Jet cone angle;
E - Energy of the particle set;
M - Mass of the particle set;
P - Cosine in the rest frame of pair;

PgDn-

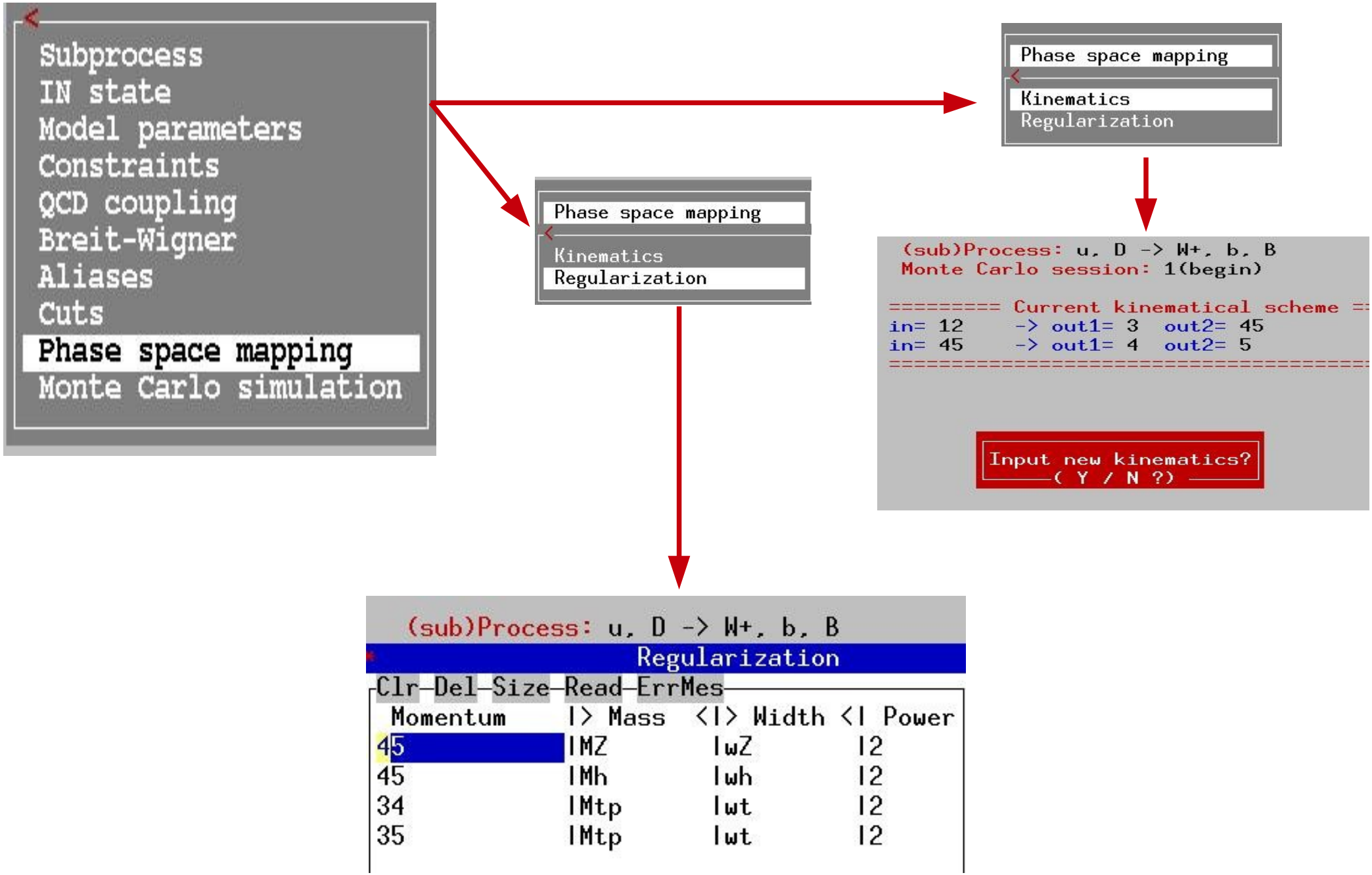


MC inegration and event generation is based on John von Neumann selection-rejection procedure

- *sample u_1=rnd1, u_2=rnd2*
- *$x = x_{min} + (x_{min} - x_{max})\, u_1$*
  $f^* = fmax * u_2$
- *check whether or not f(x) > f**
  - *If this holds, accept x as a realization of f(x)*
  - *if not, reject the value of x and repeat the sampling step*
- *as a results, the x will be generated according to a f(x),*
  $N_{accepted}/N_{total} * (x\_min - xmax) * f_{max}$ = square



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

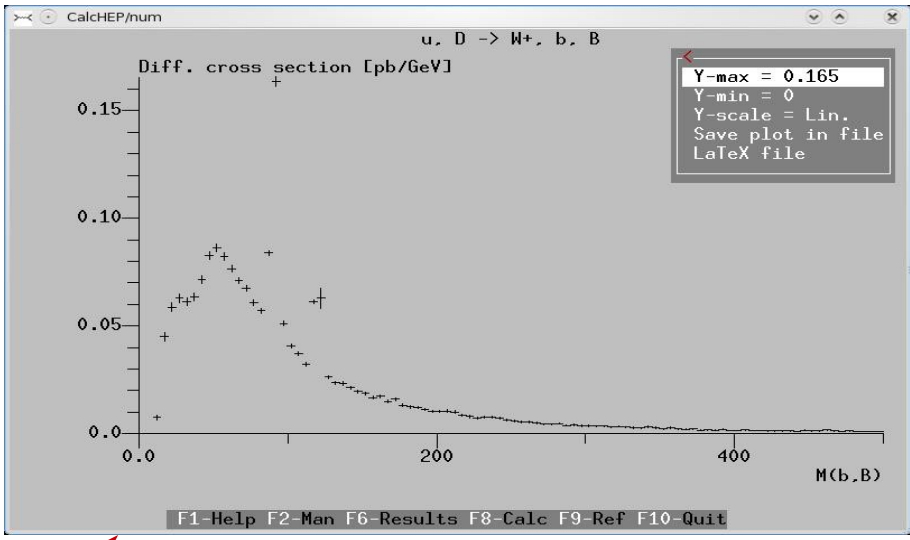
Parameter_1	|> Min_1	<| Max_1	<|Parameter_2	|> Min_2	<| Max_2
T(b)	0	200			
T(B)	0	200			
N(b)	-5	5			
N(B)	-5	5			
M(b,B)	0	500			
M(W+,b)	0	500			
T(b)	0	500	M(b,B)	0	500

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

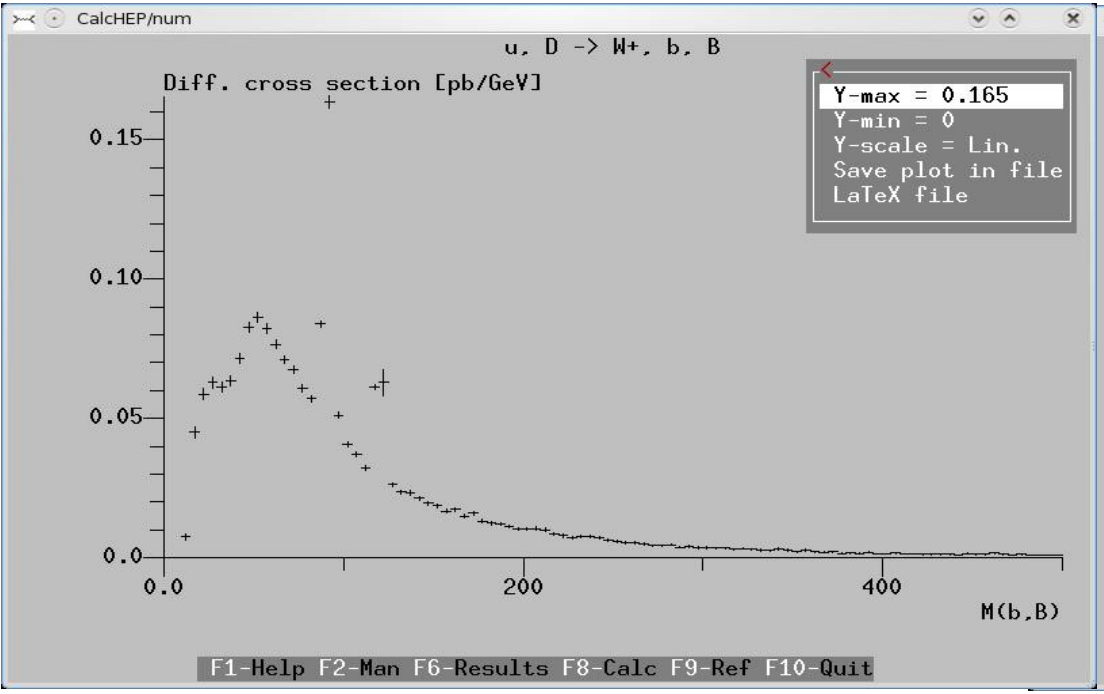
```
(sub)Process: u, D -> W+, b, B
Monte Carlo session: 2(continue)
```

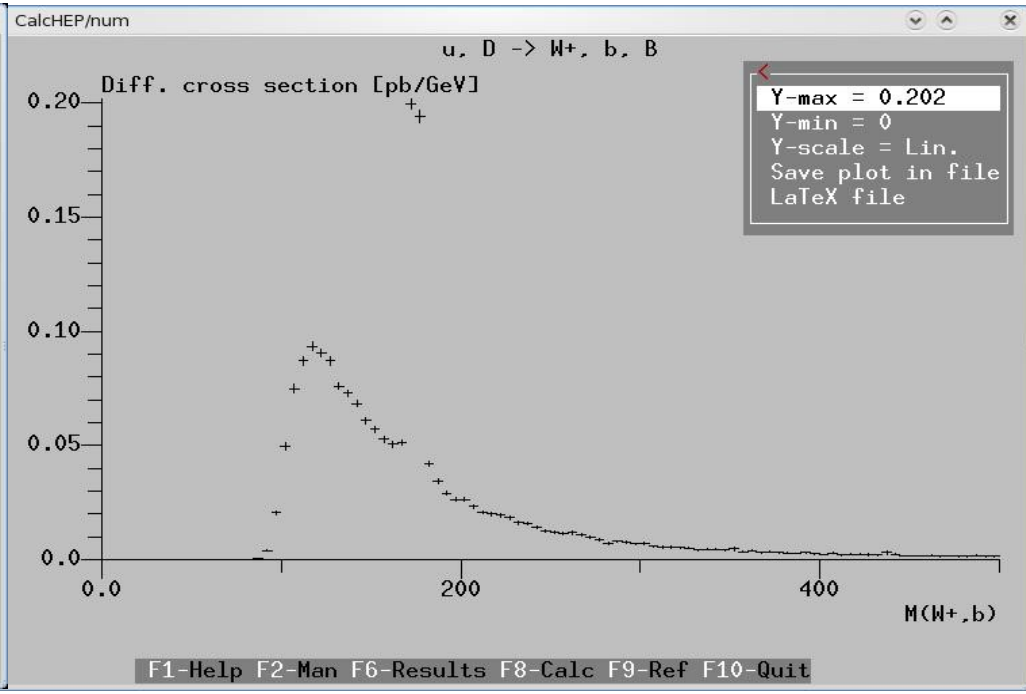
#IT	Cross section [pb]	Error %
6	9.5931E+00	7.10E-01
7	9.5686E+00	6.79E-01
8	9.5669E+00	6.82E-01
9	9.6892E+00	7.93E-01
10	9.6267E+00	7.51E-01
1	9.7757E+00	7.32E-01
clear statistics.		
2	9.6557E+00	6.82E-01
3	9.7464E+00	1.38E+00
4	9.6945E+00	1.05E+00
5	9.7032E+00	7.68E-01
< >	9.7095E+00	3.74E-01

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



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



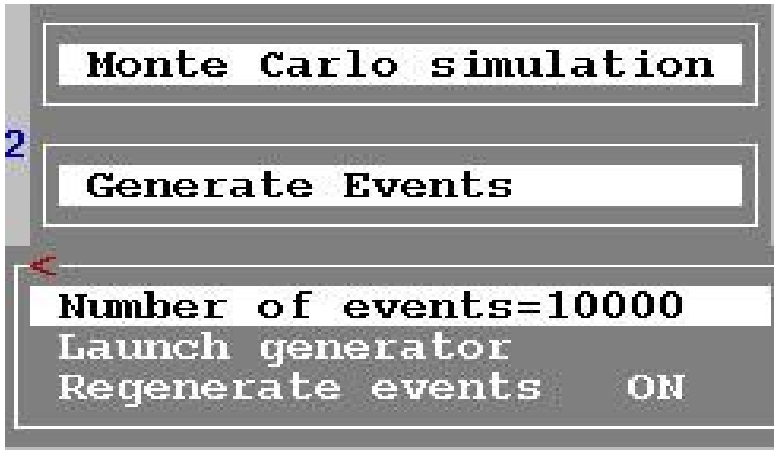


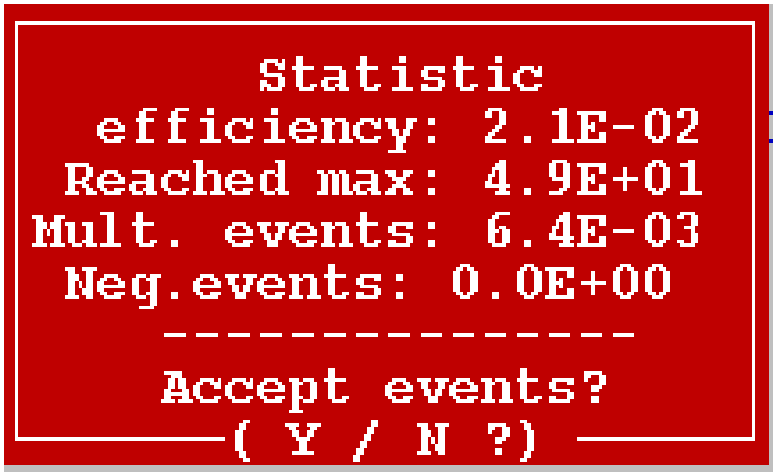
Exercise#4

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 model

```
 ../bin/subproc_cycle 100 1000
#Subprocess 1 ( u, D -> W+, b, B ) Cross section = 3.7118E+00 , 1000 events
#Subprocess 2 ( u, S -> W+, b, B ) Cross section = 1.4038E-01 , 1000 events
#Subprocess 3 ( u, B -> W+, b, B ) Cross section = 6.5581E-05 , 6 events
#Subprocess 4 ( U, d -> W-, b, B ) Cross section = 2.0071E+00 , 1000 events
#Subprocess 5 ( U, s -> W-, b, B ) Cross section = 2.3631E-02 , 1000 events
#Subprocess 6 ( U, b -> W-, b, B ) Cross section = 8.5102E-06 , 0 events
#Subprocess 7 ( d, U -> W-, b, B ) Cross section = 1.9329E+00 , 1000 events
#Subprocess 8 ( d, C -> W-, b, B ) Cross section = 6.1994E-02 , 1000 events
#Subprocess 9 ( D, u -> W+, b, B ) Cross section = 3.7528E+00 , 1000 events
#Subprocess 10 ( D, c -> W+, b, B ) Cross section = 2.1220E-02 , 1000 events
#Subprocess 11 ( s, U -> W-, b, B ) Cross section = 2.6142E-02 , 1000 events
#Subprocess 12 ( s, C -> W-, b, B ) Cross section = 2.4726E-01 , 1000 events
#Subprocess 13 ( S, u -> W+, b, B ) Cross section = 1.4176E-01 , 1000 events
#Subprocess 14 ( S, c -> W+, b, B ) Cross section = 2.4992E-01 , 1000 events
#Subprocess 15 ( c, D -> W+, b, B ) Cross section = 2.1041E-02 , 1000 events
#Subprocess 16 ( c, S -> W+, b, B ) Cross section = 2.4806E-01 , 1000 events
#Subprocess 17 ( c, B -> W+, b, B ) Cross section = 4.9244E-04 , 49 events
#Subprocess 18 ( C, d -> W-, b, B ) Cross section = 6.0969E-02 , 1000 events
#Subprocess 19 ( C, s -> W-, b, B ) Cross section = 2.5407E-01 , 1000 events
#Subprocess 20 ( C, b -> W-, b, B ) Cross section = 4.9473E-04 , 49 events
#Subprocess 21 ( b, U -> W-, b, B ) Cross section = 8.3331E-06 , 0 events
#Subprocess 22 ( b, C -> W-, b, B ) Cross section = 4.9524E-04 , 49 events
#Subprocess 23 ( B, u -> W+, b, B ) Cross section = 6.3592E-05 , 6 events
#Subprocess 24 ( B, c -> W+, b, B ) Cross section = 5.0576E-04 , 50 events
Total Cross Section 12.90318118 [pb]
see details in prt_29 - prt_52 files
```

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 scattering 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***
- ***gen_events***
- ***name_cycle***
- ***pcm_cycle***

Exercise#5
learn how to use:
1) gen_events
2) events2tab
3) plot_view

scripts for numerical session

- ***events2tab***

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

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

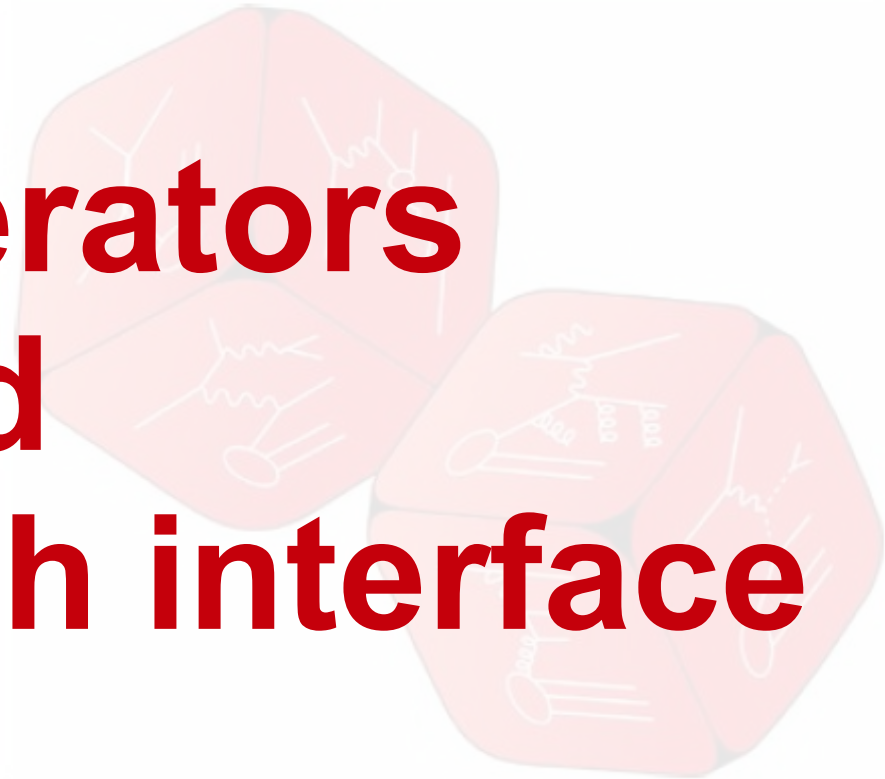
- ***name_cycle***

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

```
../bin/name_cycle Mh 100 10 11
```

scripts above became a part of calchep_batch interface – to be discussed below

MC generators and CalcHEP batch interface



. . . because Einstein was wrong: God does throw dice!

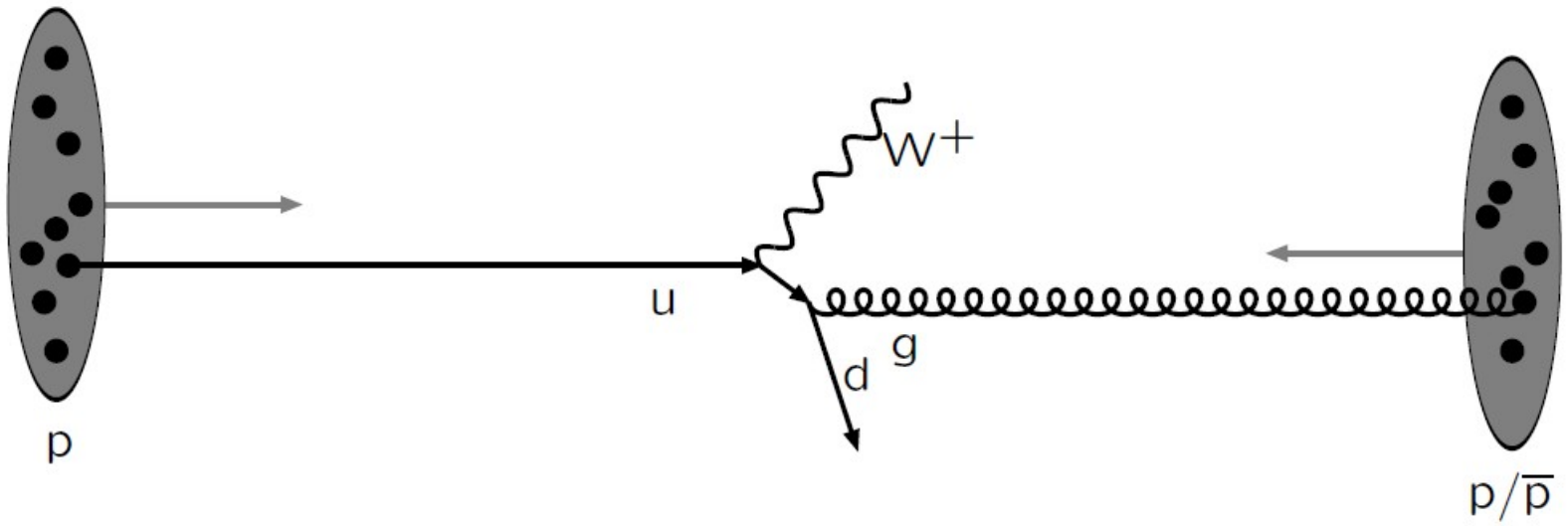
Quantum mechanics: amplitudes $\Longrightarrow$ probabilities

Anything that possibly can happen, will! (but more or less often)

Event Structure

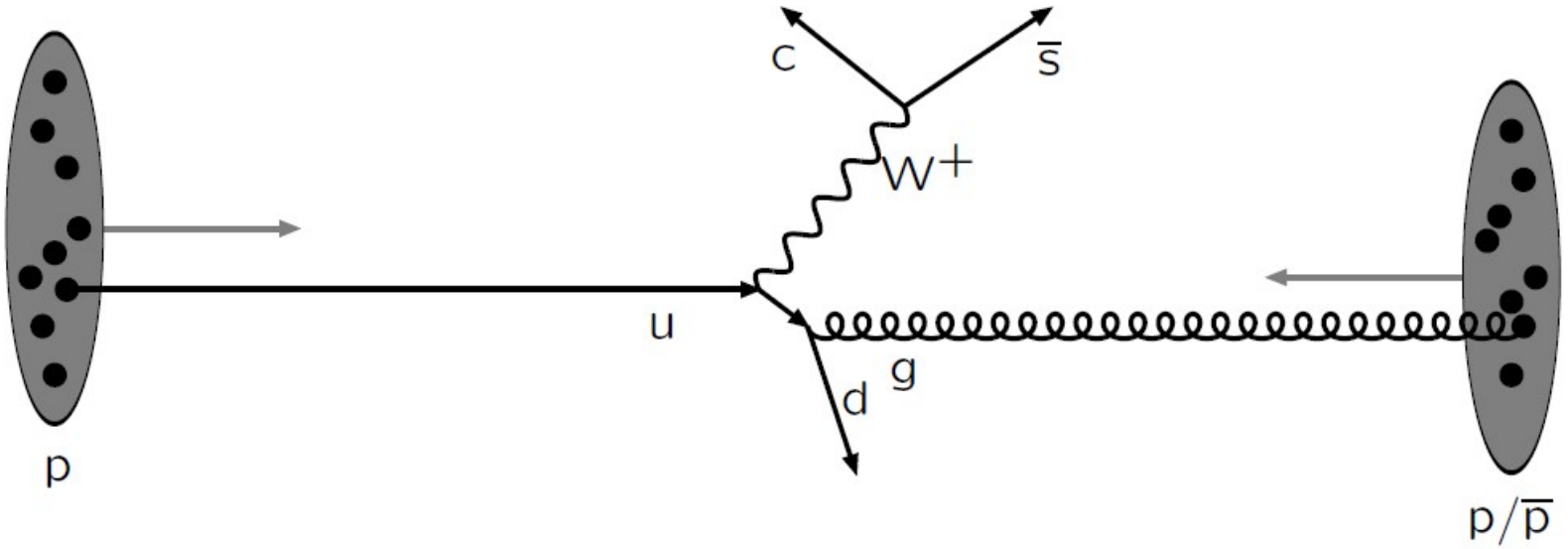
Incoming beams: parton densities

Event Structure



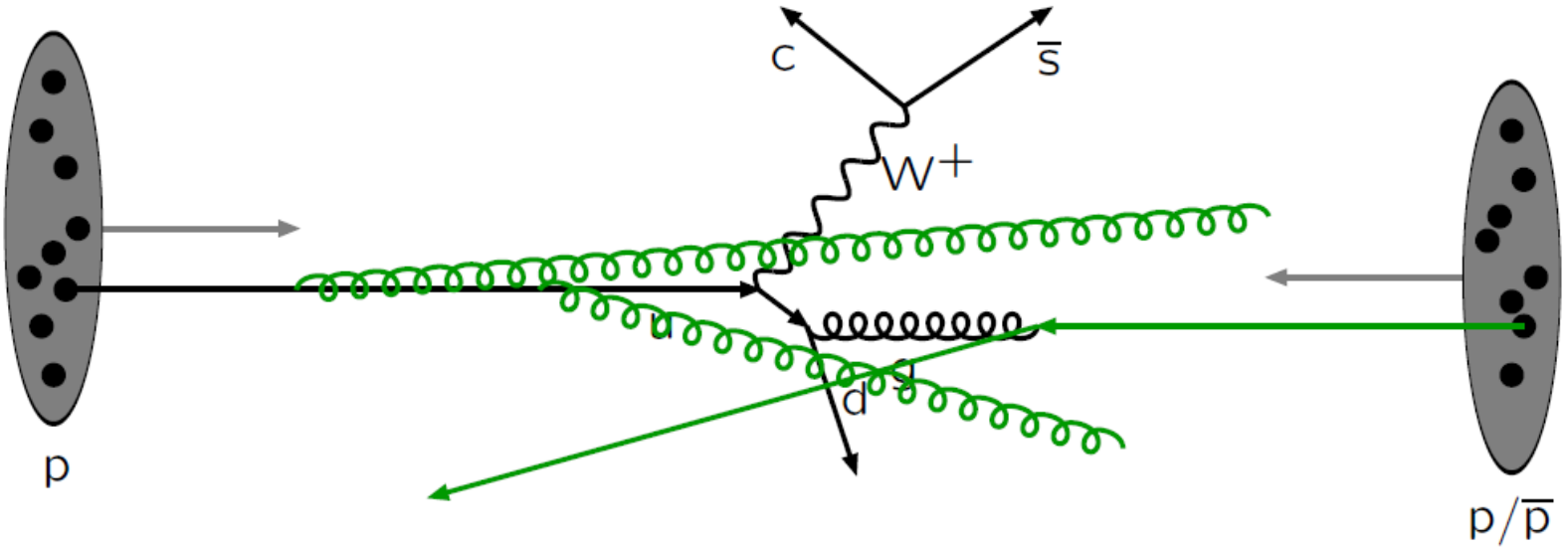
Hard subprocess: described by matrix elements

Event Structure



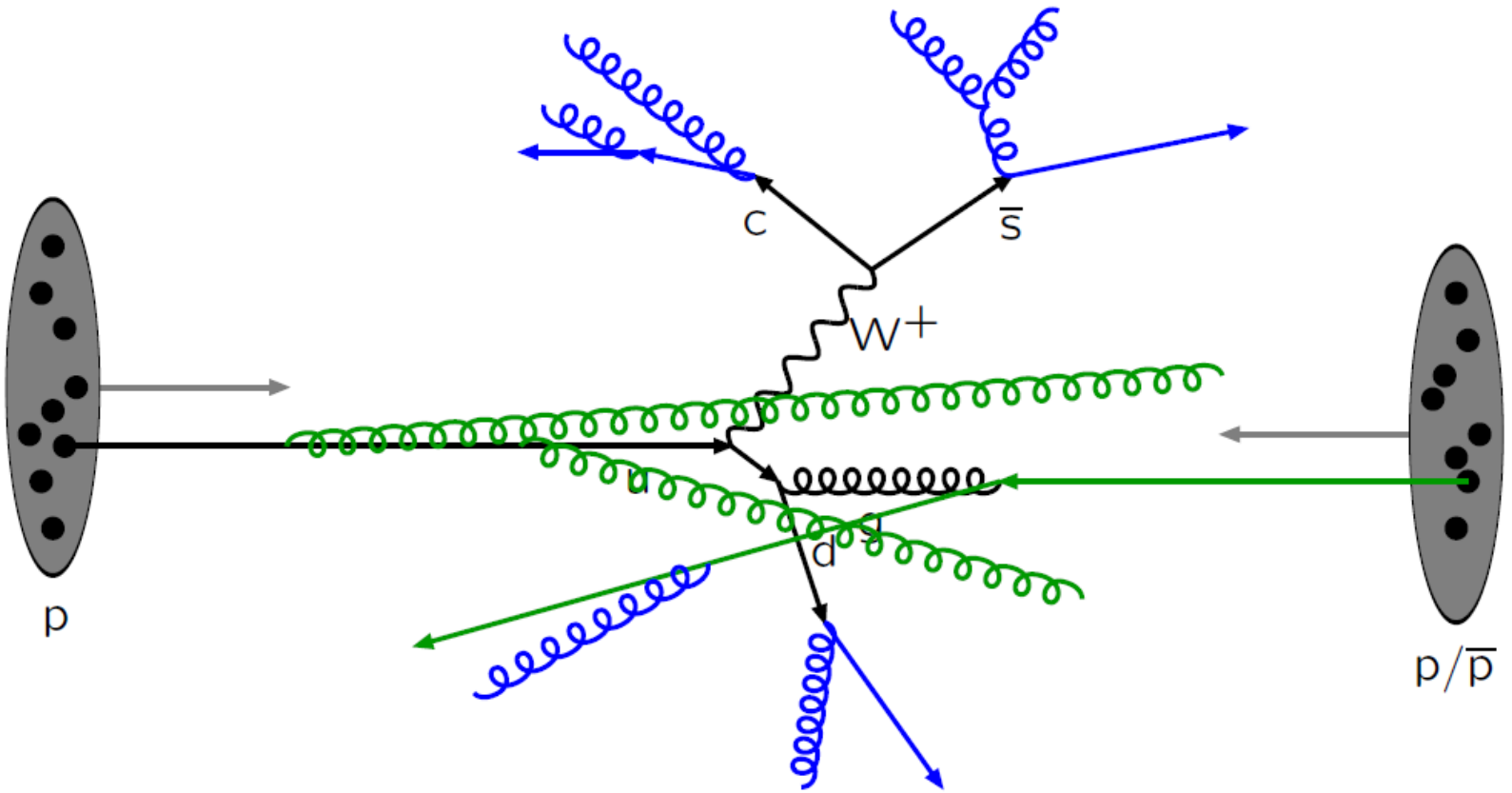
Resonance decays: correlated with hard subprocess

Event Structure



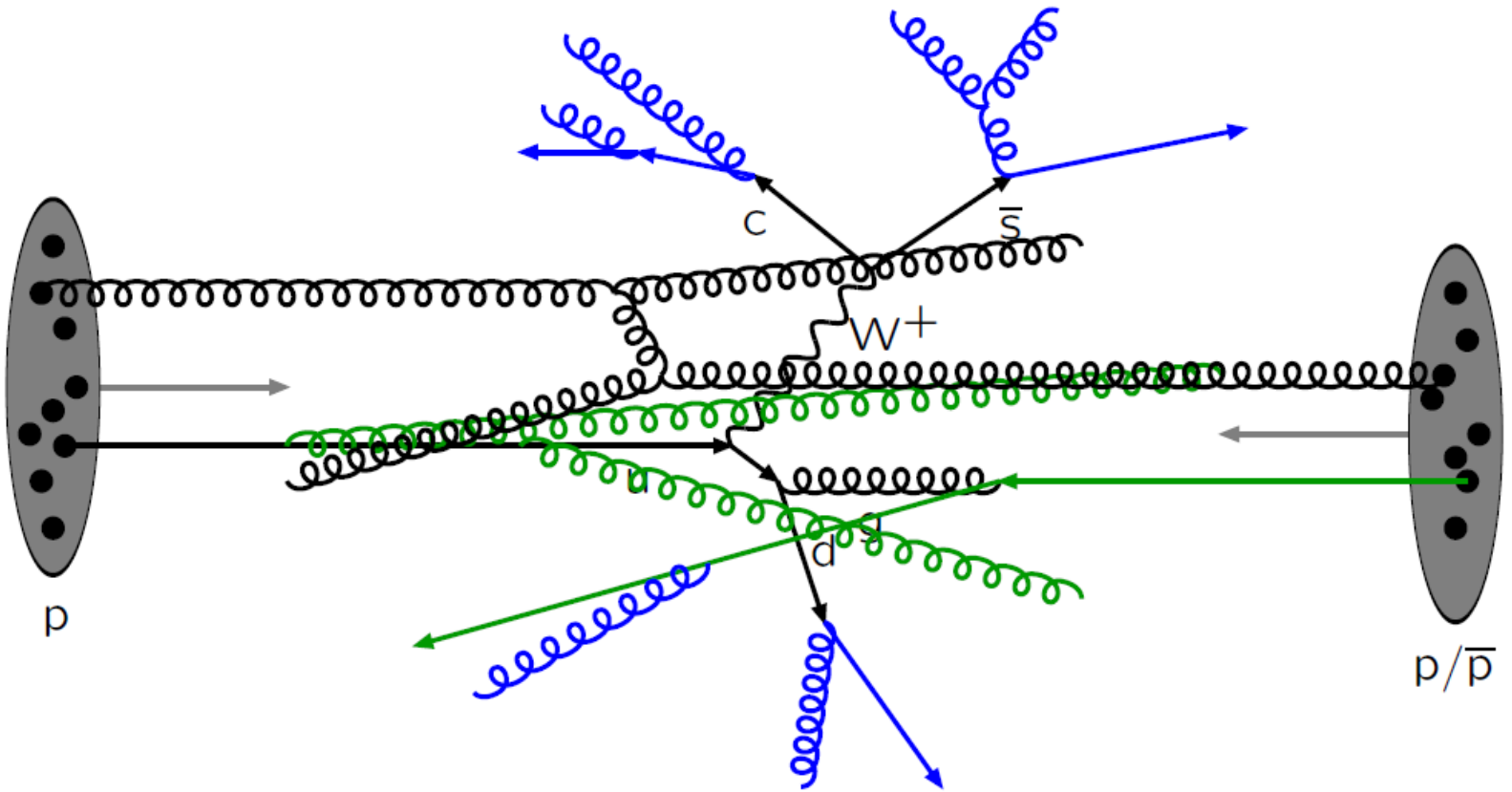
Initial-state radiation: spacelike parton showers

Event Structure



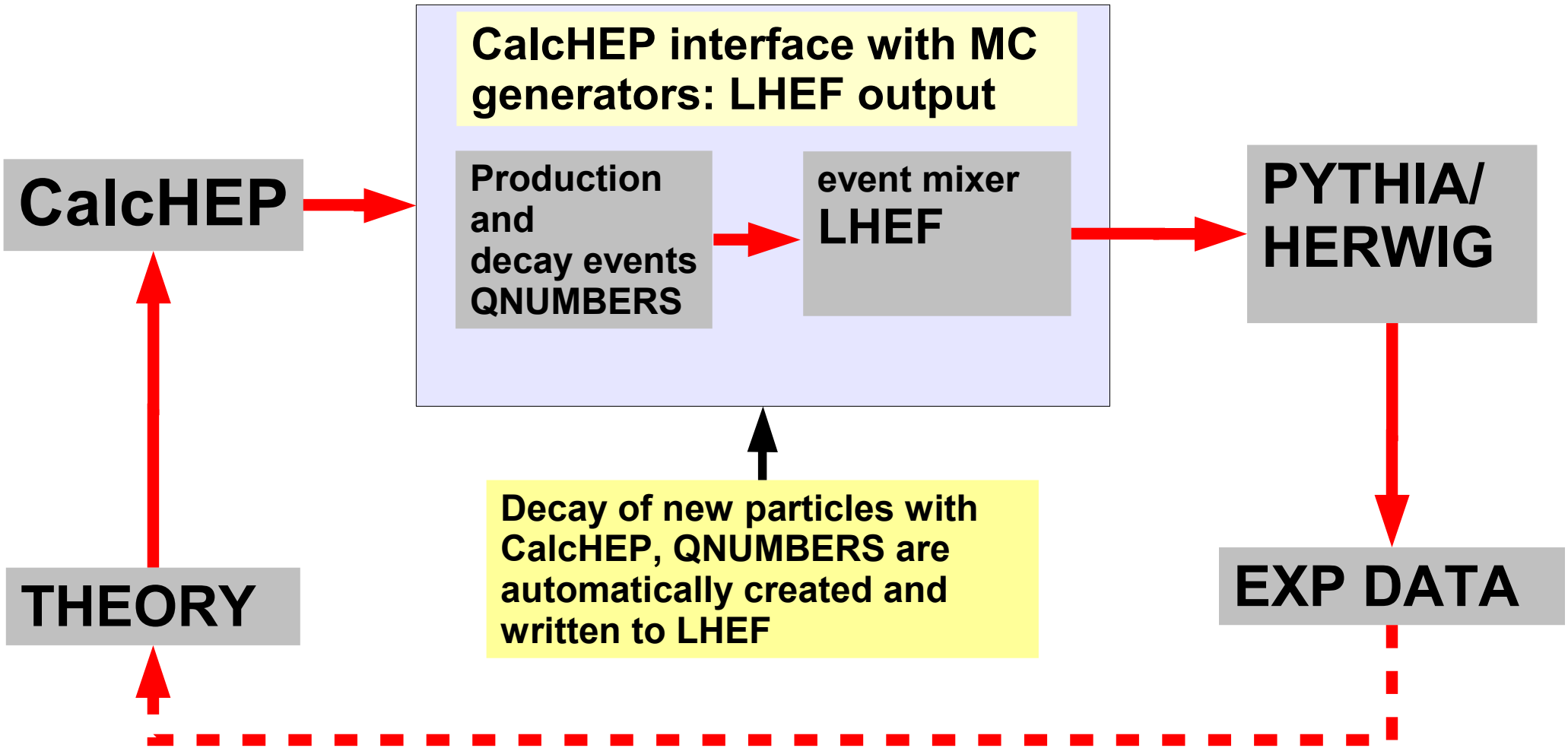
Final-state radiation: timelike parton showers

Event Structure



Multiple parton–parton interactions . . .

Present Status of the CalcHEP



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:~/proj/intro_to_hep_tools/tutorial/work> ./calchep_batch batch_file

calchep_batch version 1.6

Processing batch:
Progress information can be found in the html directory.
Simply open the following link in your browser:
file:///home/belyaev/proj/intro_to_hep_tools/tutorial/work/html/index.html
```

Main Features

- Batch file
- Process library
- Runs
- Combines decays
- Parallelization
- HTML progress

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)

Generating Events

	Finished	Time(hr)
Symbolic	12/12	0.01
σ	3/3	0.07
Events	2/3	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	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	✓	24571	0.00
C,s->W-,b,B	✓	24575	0.00
W+->E,ne	✓	25201	0.00
W+->M,nm	✓	25205	0.00
W-->e,Ne	✓	25339	0.00
W-->m,Nm	✓	25343	0.00
Widths	✓	25477	0.00

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	984.9	0/13	13/13	0.01	1000
Mh=125	970	0/13	13/13	0.01	1000
Mh=130	965.5	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

Standard Model(CKM=1)

Done!

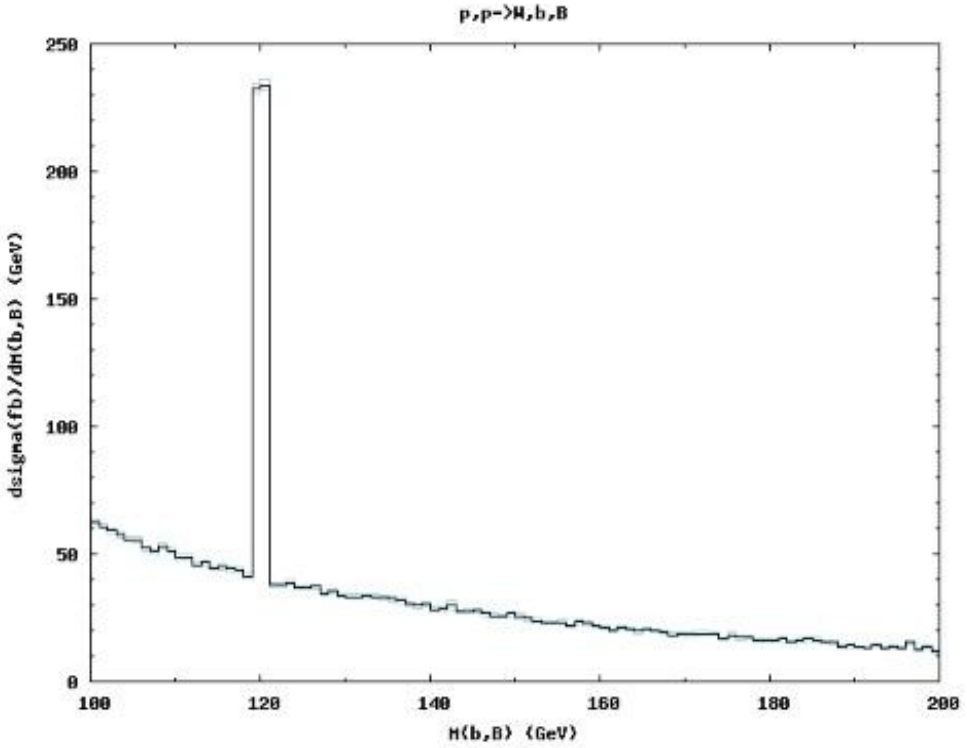
Processes	σ (fb)	Δσ (%)	PID	Time (hr)	N events	Details
u,D->W+,b,B	1319.3	0.46	28597	0.00	382/382	prt_1 session.dat
U,d->W-,b,B	715.68	0.47	28601	0.00	221/221	prt_1 session.dat
d,U->W-,b,B	714.79	0.48	28638	0.00	221/221	prt_1 session.dat
D,u->W+,b,B	1336.1	0.66	28642	0.00	386/386	prt_1 session.dat
s,C->W-,b,B	86.063	0.41	28678	0.00	39/39	prt_1 session.dat
S,c->W+,b,B	86.641	0.4	28682	0.00	39/39	prt_1 session.dat
c,S->W+,b,B	86.338	0.37	28718	0.00	39/39	prt_1 session.dat
C,s->W-,b,B	86.574	0.38	28722	0.00	39/39	prt_1 session.dat
Total	4431.5					

Decays	Γ (GeV)	ΔΓ (%)	PID	Time (hr)	N events	Details
W+->E,ne	0.22349	4.5 x10^{-05}	28758	0.00	5098/5100	prt_1 session.dat

CalcHEP batch interface: numerical results and distributions

Widths		PID	Time (hr)	Details
Widths		28838	0.00	session.dat
Total	984.9		0.01	1000/1000

Distributions



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

Lecture II:

- **Introduction into LanHEP**
  - ***idea***
  - ***installation***
  - ***options***
  - ***Examples***
- **High Energy Physics Model Data Base (HEPMDB)**

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

make clean

Exercise#6
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,
```

Some Format Options for LanHEP output

```
model qed/1.
parameter ee = 0.3133: 'Electric charge'.

prtcformat fullname:
'Full Name   ', name:' p ', aname:' ap', pdg:'  PDG ID',
spin2:'2*spin', mass:' mass ',width:'width ',
color, aux, texname:'>LaTeX(A)<', atexname:'>LaTeX(A+)< ' .

vector A/A:(photon, pdg 22).
spinor e1:(electron, mass me=0.000511, pdg 11).

let F^mu^nu=deriv^mu*A^nu-deriv^nu*A^mu.
lterm -1/4*F**2 + ee*E1*gamma*A*e1.
```

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

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

- ***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.
```

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

Exercise#7

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) - ....
```

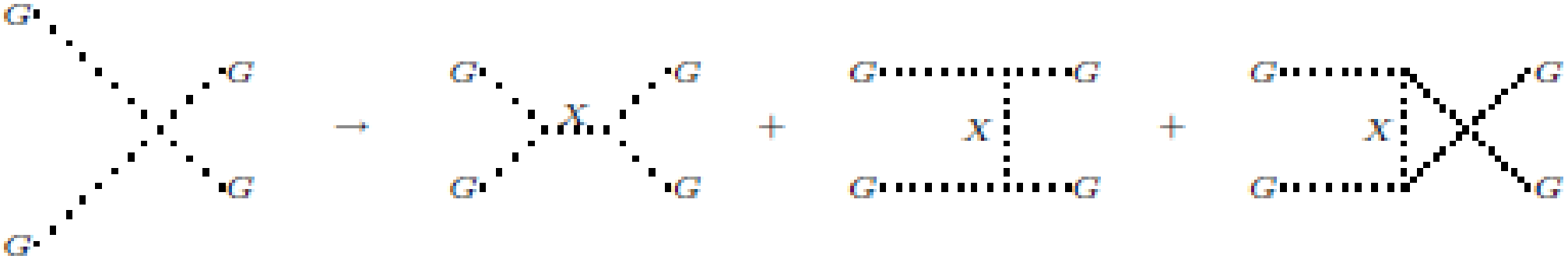
where dfdfc(W,H1) **function** ***evaluates the variational derivative, multiplies it by the conjugate expression and returns the result***

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):*
  - δ_{pq} for two color particles A^1_p and A^2_q
  - λ^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:

http://hep.pa.msu.edu/belyaev/
/proj/intro_to_hep_tools/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.
```

Implementation of SM Lagrangian(5)

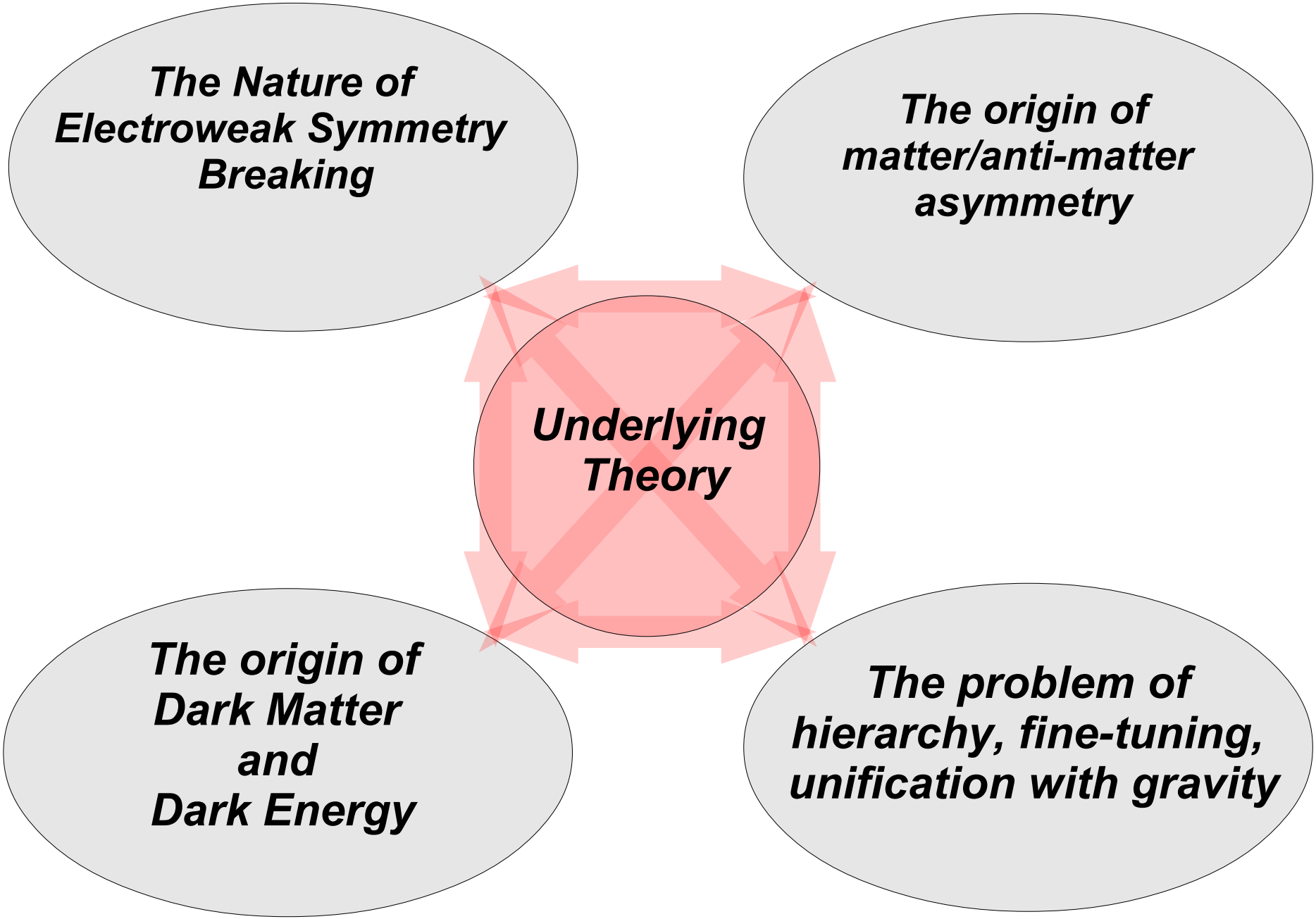
```
% Self-interaction of gauge bosons


lterm -F**2/4   where
        F=deriv^mu*B1^nu-deriv^nu*B1^mu.

lterm -F**2/4  where
        F=deriv^mu*G^nu^a-deriv^nu*G^mu^a+i*GG*f_SU3^a^b^c*G^mu^b*G^nu^c.

lterm -F**2/4  where
F=deriv^mu*WW1^nu^a-deriv^nu*WW1^mu^a -g*eps^a^b^c*WW1^mu^b*WW1^nu^c.
```

Implementation of SM Lagrangian(6)

```
% left fermion interaction with gauge fields


lterm   anti(psi)*gamma*(1-g5)/2*(i*deriv-g*taupm*WW/2-Y*g1*B1)*psi
                where
                        psi=l1,  Y=-1/2;
                        psi=l2,  Y=-1/2;
                        psi=l3,  Y=-1/2;
                        psi=q1a, Y= 1/6;
                        psi=q2a, Y= 1/6;
                        psi=q3a, Y= 1/6.

% right fermion interaction with gauge fields

lterm   anti(psi)*gamma*(1+g5)/2*(i*deriv - Y*g1*B1)*psi
                where
                        psi=e1,Y= -1;
                        psi=e2,Y= -1;
                        psi=e3,Y= -1;
                        psi=u, Y=  2/3;
                        psi=c, Y=  2/3;
                        psi=t, Y=  2/3;
                        psi=d, Y= -1/3;
                        psi=s, Y= -1/3;
                        psi=b, Y= -1/3.


% quark-gluon interaction

lterm  GG*anti(psi)*lambda*gamma*G*psi where
        psi=q1; psi=q2; psi=q3.
```

HEPMDB

What underlying theory should explain?



Promising candidates for underlying theory

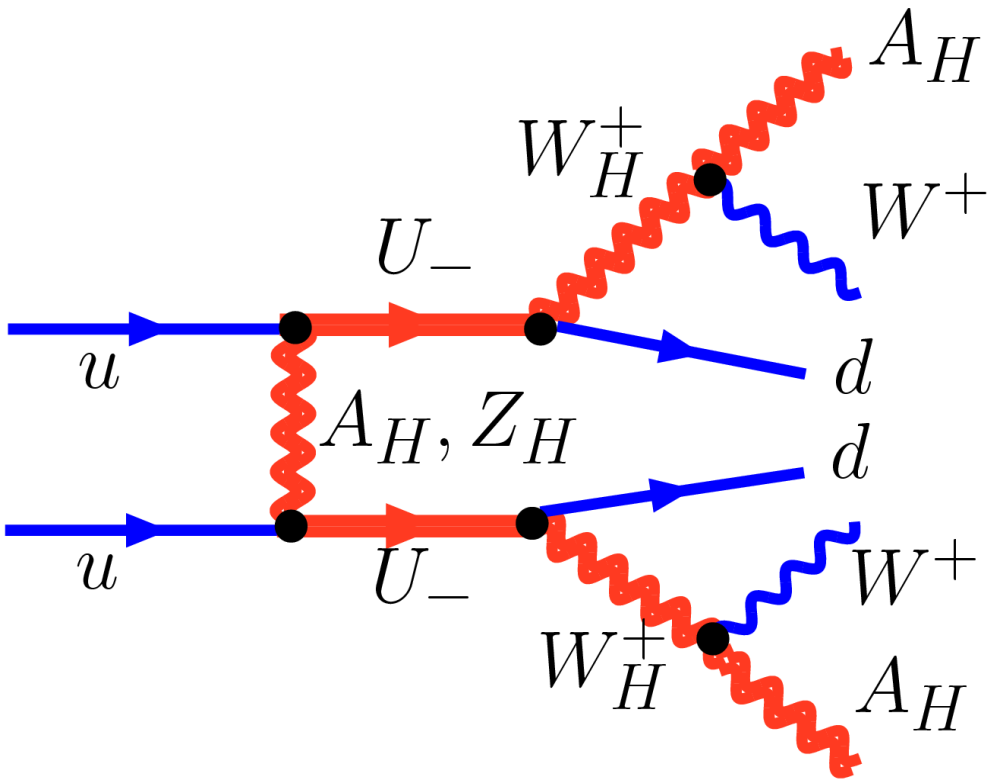
- ***Supersymmetry:***
  - ***cMSSM, MSSM, NMSSM, E_6SSM, ...***
- ***Walking Technicolor***
- ***Extradimensional Models:***
  - ***Universal and Warp extra dimensions***

.....

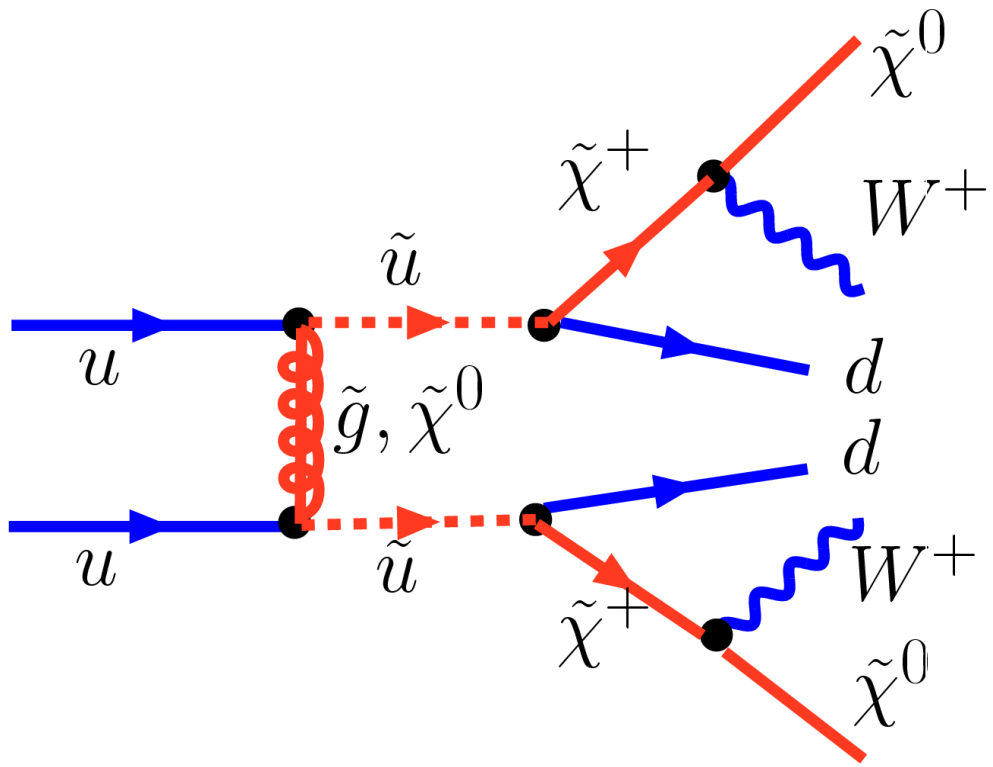
.....

.....

Signatures could look alike

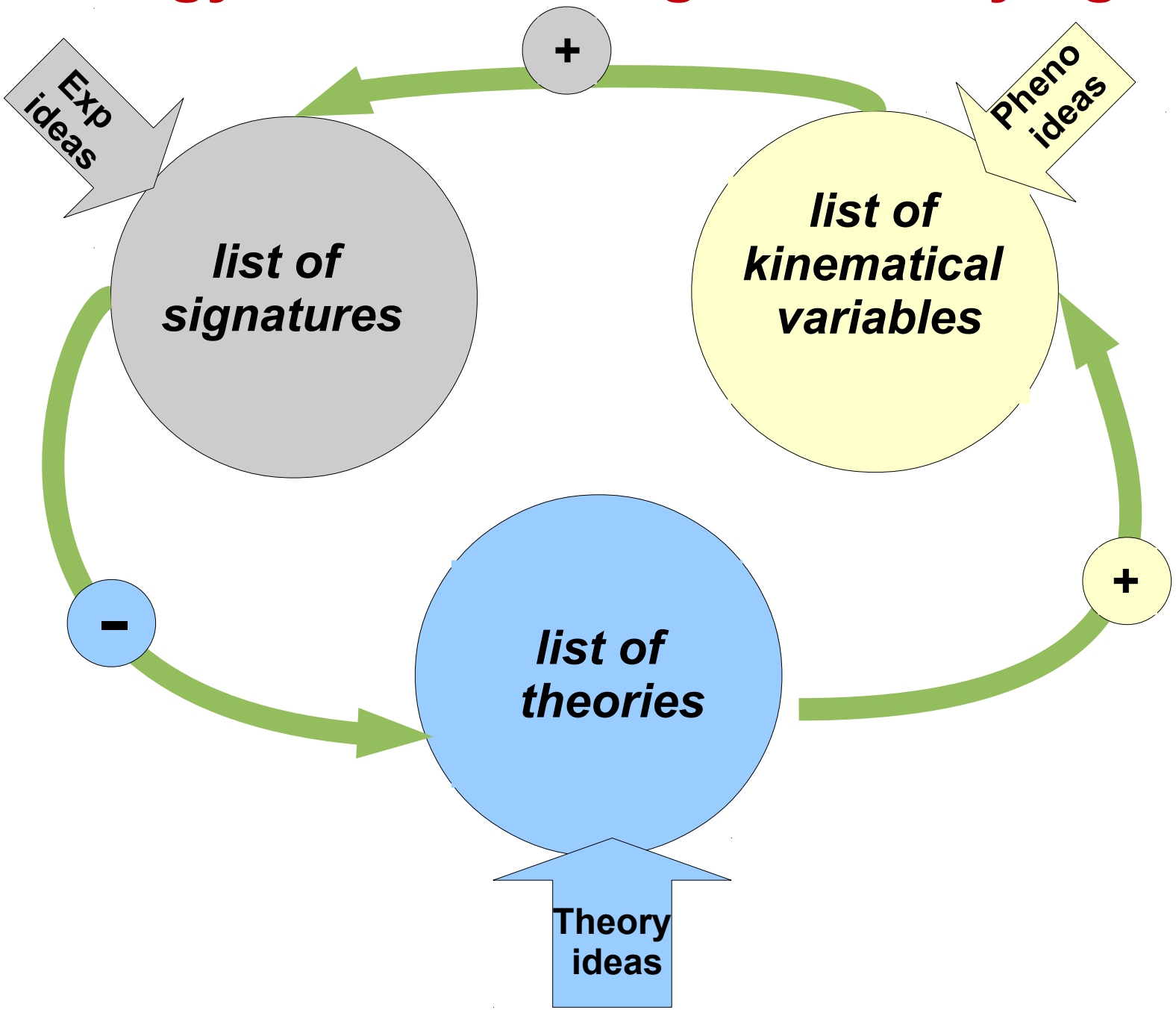


LHT

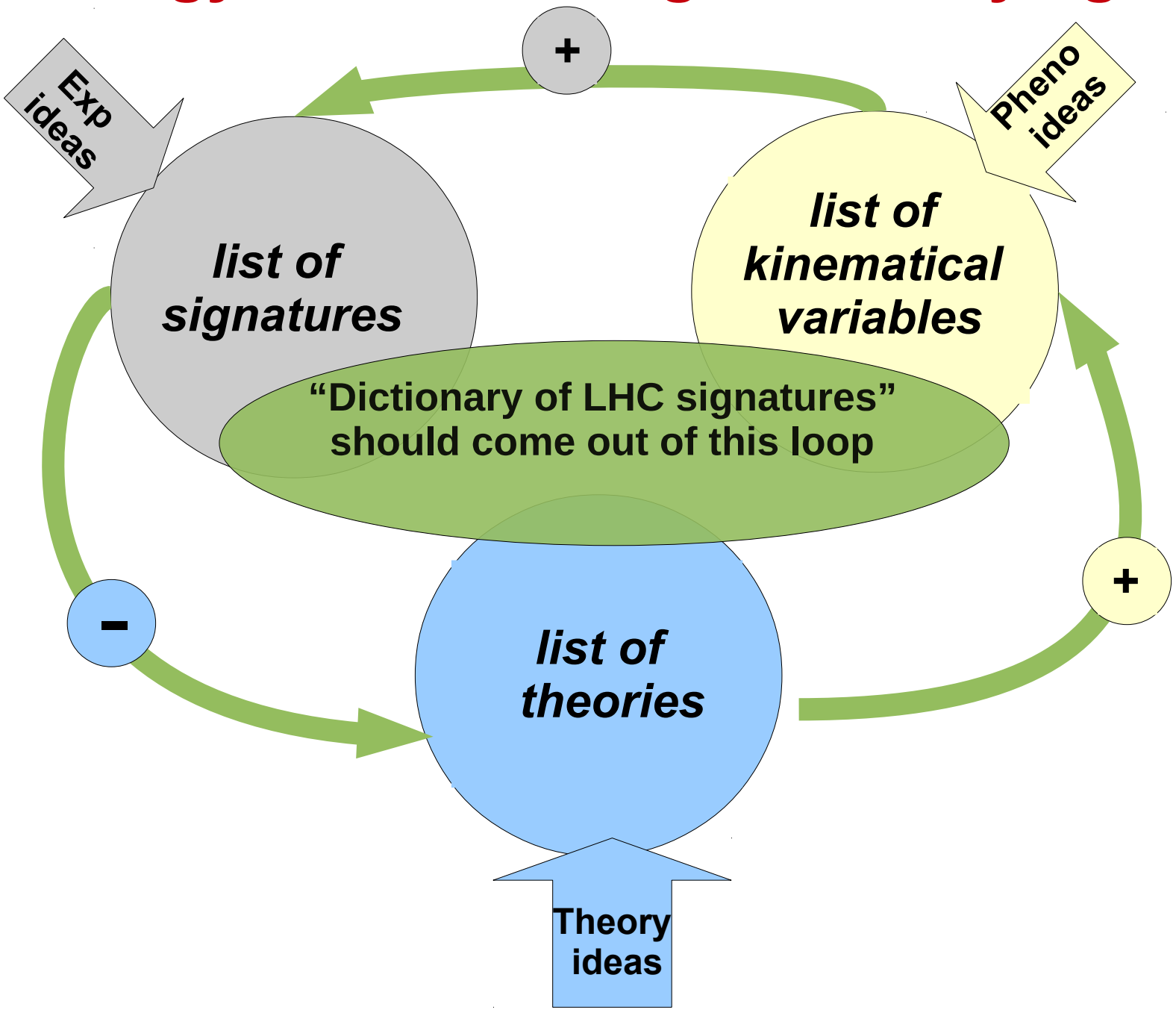


SUSY

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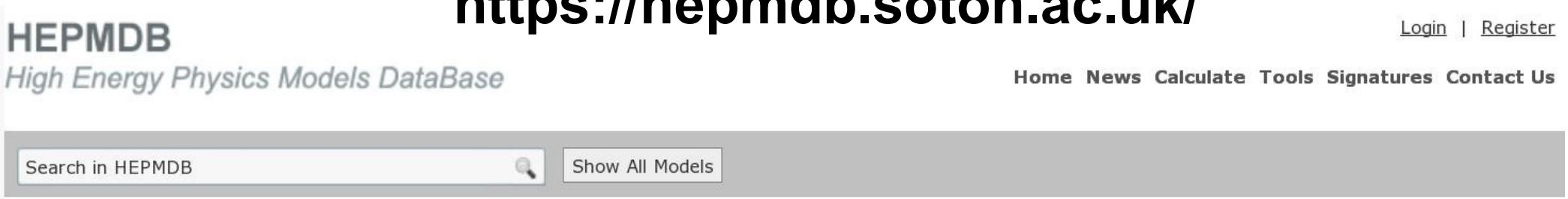
We need dictionary in the form of the Model Database and their Signatures

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.

HEPMDB is also designed for collecting different signatures for its models as well as respective experimental efficiencies. Using this information HEPMDB will be able to compare its BSM model predictions with LHC data which and would allow to discriminate an underlying theory.

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

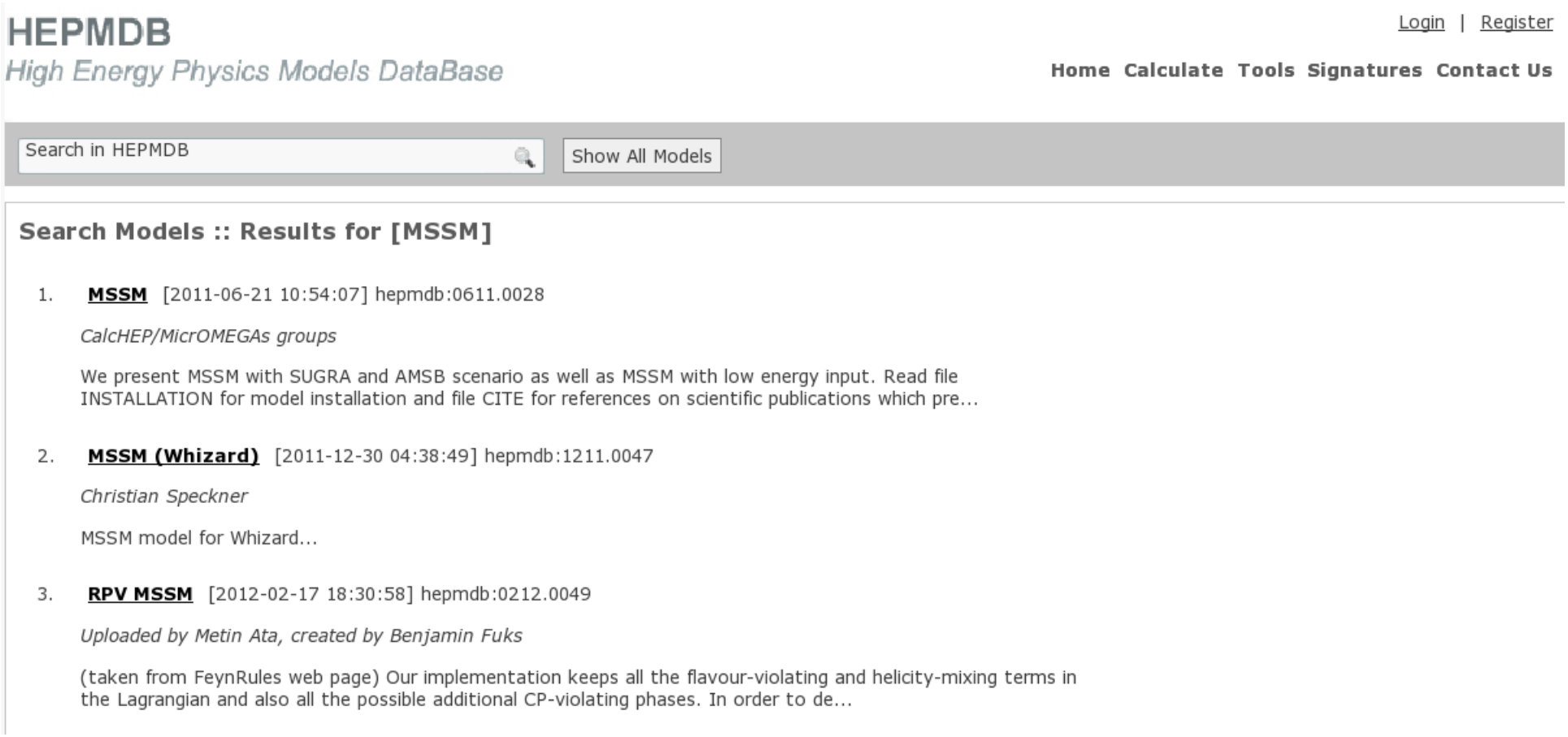
- "Signatures of New Physics at the LHC" web-site
  http://www.lhcnewphysics.org/
  collects various BSM signatures, their classification and related papers

- 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

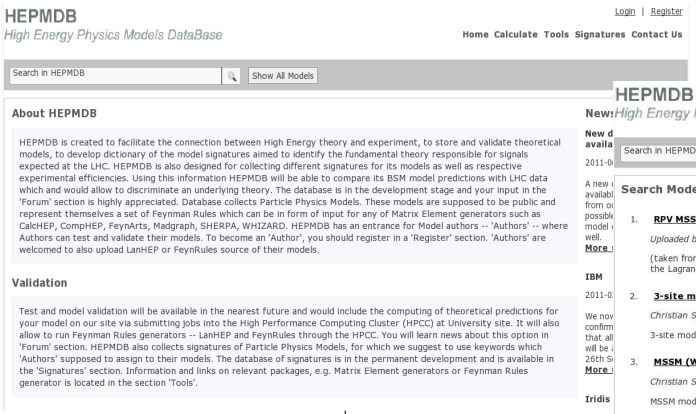
Future prospects for HEPMDB (months scale)

- The LanHEP and FeynRules packages will be added to provide model generation from model sources
- CompHEP package will be added.
- A systematic model validation process will be started and the respective pages will be added.
- The possibility to study events beyond the parton level will be carefully considered, up to detector simulation.
  One concrete possibility would be the chain
  LHE events -> HEPMC events -> FASTSIM events (ROOT format)
  For the FASTSIM package, Delphes seems a promising candidate.
- The structure of the database of signatures will be extended to deal with correlated signatures (i.e., whereby multiple signatures, or lacks thereof, must be accounted for simultaneously)

Future prospects for HEPMDB (~year time scale)

- we plan to install the MicrOMEGAs package for evaluation of the dark matter relic density as well as to provide a possibility for scans of various model parameter spaces.
- Author of other packages/models are welcome to install/upload them
- the format for model predictions consistent with the format for presentation of the LHC data by experimentalists is planned.
- The question about including automatic tools for NLO evaluations is under discussion and will be developed further at the later stages of HEPMDB development.

Tutorial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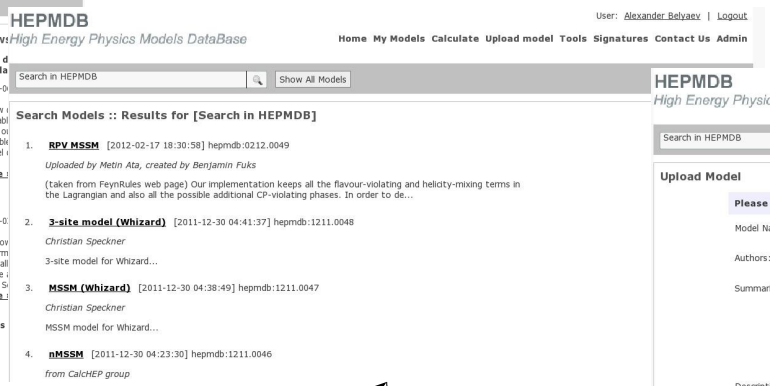
About HEPMDB
HEPMDB is created to facilitate the connection between High Energy theory and experiment, to store and validate theoretical models, to develop dictionary of the model signatures aimed to identify the fundamental theory responsible for signals expected at the LHC. HEPMDB is also designed for collecting different signatures for its models as well as respective experimental efficiencies. Using this information HEPMDB will be able to compare its BSM model predictions with LHC data which and would allow to discriminate an underlying theory. 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
Test and model validation will be available in the nearest future and would include the computing of theoretical predictions for your model on our site via submitting jobs into the High Performance Computing Cluster (HPCC) at University site. It will also allow to run Feynman Rules generators -- LanHEP and FeynRules through the HPCC. You will learn news about this option in 'Forum' section. HEPMDB also collects signatures of Particle Physics Models, for which we suggest to use keywords which 'Authors' supposed to assign to their models. The database of signatures is in the permanent development and is available in the 'Signatures' section. Information and links on relevant packages, e.g. Matrix Element generators or Feynman Rules generator is located in the section 'Tools'.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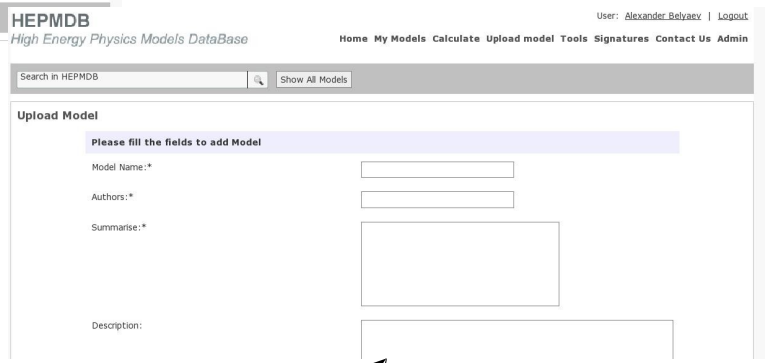
Search in HEPMDB
Show All Models
Search Models :: Results for [Search in HEPMDB]
1. RPV MSSM [2012-02-17 18:30:58] hepmdb:0212.0049
Uploaded by Metin Ata, created by Benjamin Fuks
(taken from FeynRules web page) Our implementation keeps all the flavour-violating and helicity-mixing terms in the Lagrangian and also all the possible additional CP-violating phases. In order to de...
2. 3-site model (Whizard) [2011-12-30 04:41:37] hepmdb:1211.0048
Christian Speckner
3-site model for Whizard...
3. MSSM (Whizard) [2011-12-30 04:38:49] hepmdb:1211.0047
Christian Speckner
MSSM model for Whizard...
4. nMSSM [2011-12-30 04:23:30] hepmdb:1211.0046
from CalcHEP group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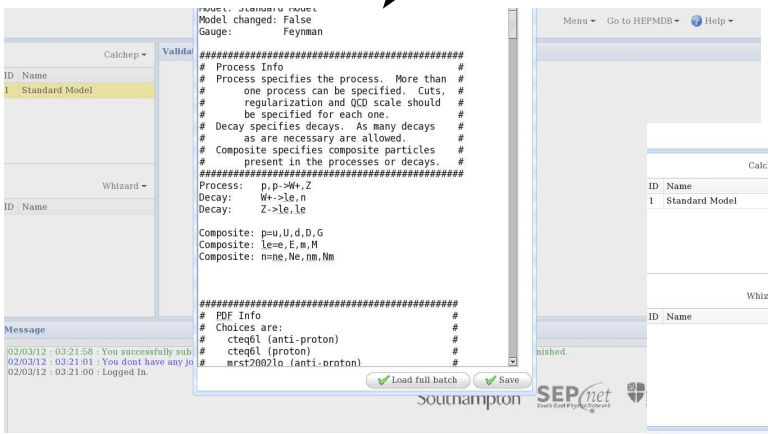
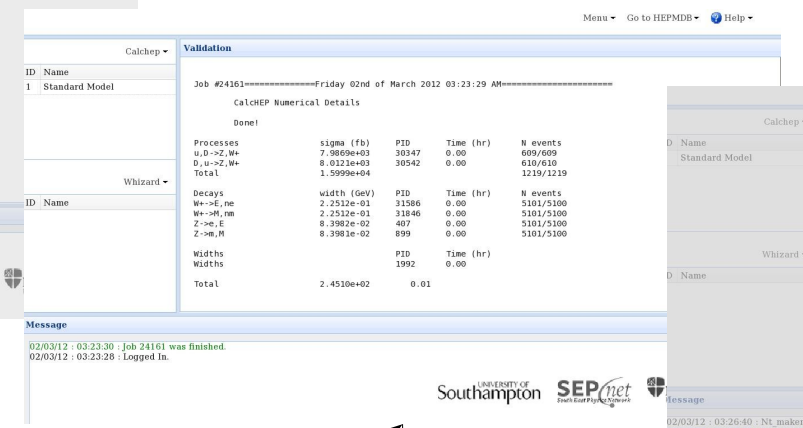
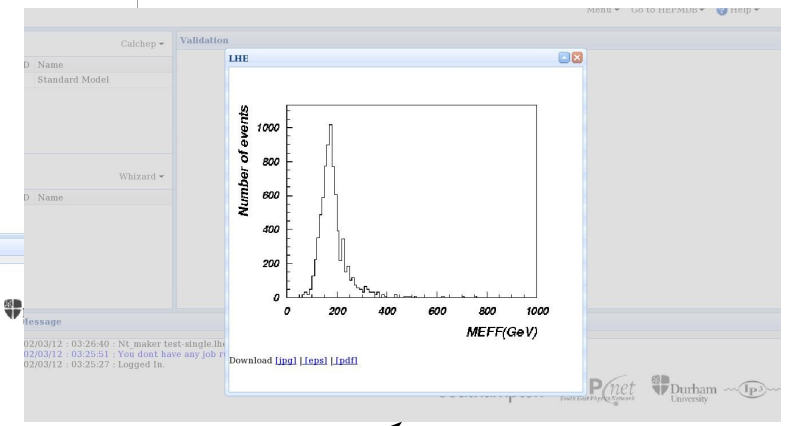
Show All Models
Upload Model
Please fill the fields to add Model
Model Name:*
Authors:*
Summarise:*
Description:


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
Calchep
Whizard
Message


Menu
Go to HEPMDB
Help
Calchep
Validation
Job #24161==========Friday 02nd of March 2012 03:23:29 AM==========
CalcHEP Numerical Details
Done!
Processes sigma (fb) PID Time (hr) N events
u,D->Z,W+ 7.9869e+03 30347 0.00 609/609
D,u->Z,W+ 8.0121e+03 30542 0.00 610/610
Total 1.5999e+04 1219/1219
Decays width (GeV) PID Time (hr) N events
W+->E,ne 2.2512e-01 31586 0.00 5101/5100
W+->M,nm 2.2512e-01 31846 0.00 5101/5100
Z->e,E 8.3982e-02 407 0.00 5101/5100
Z->m,M 8.3981e-02 899 0.00 5101/5100
Widths PID Time (hr)
Widths 1992 0.00
Total 2.4510e+02 0.01
Whizard
Message
02/03/12 : 03:23:30 : Job 24161 was finished.
02/03/12 : 03:23:28 : Logged In.


Validation
LHE
Number of events
MEFF(GeV)
0
200
400
600
800
1000
Download [jpg] [eps] [pdf]

Tutorial

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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.

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 »

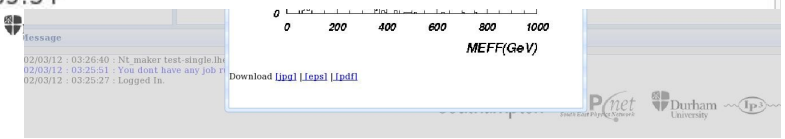
CalcHEP and HEPMDB: practical introduction and tutorial

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

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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

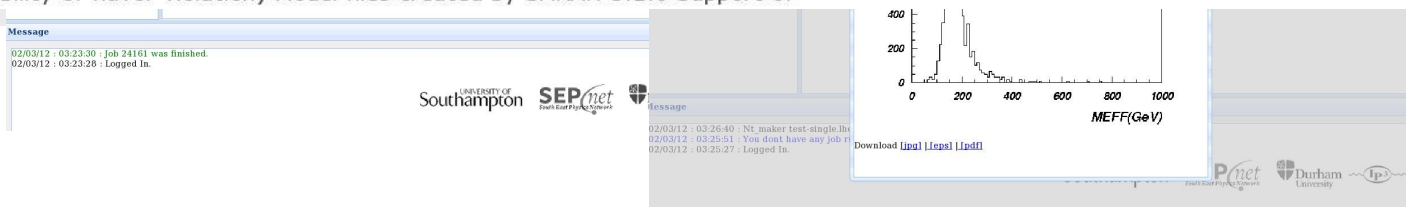
   Florian Staub

   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



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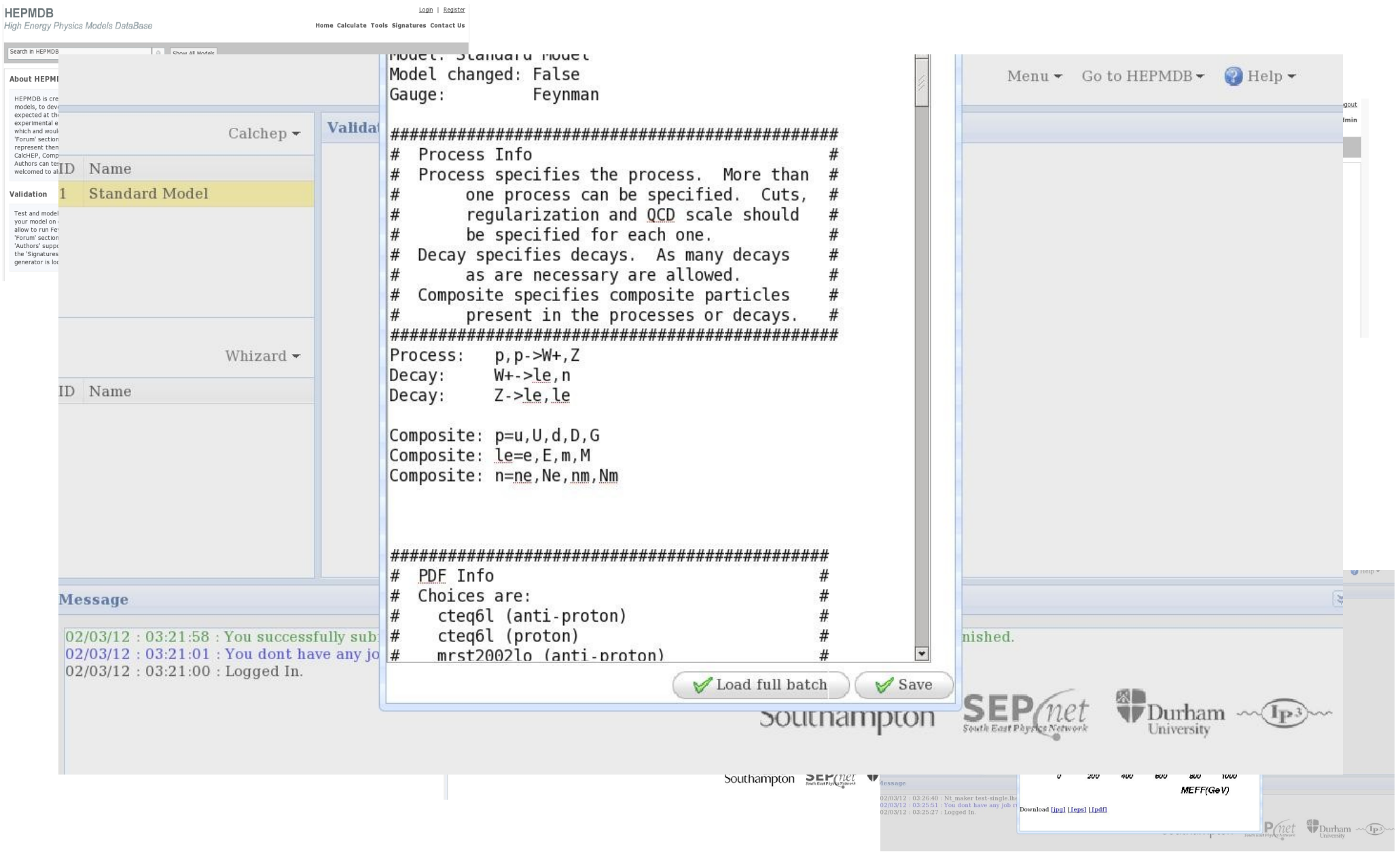
Model Name:*
Authors:*
Summarise:*
Description:
Message
02/03/12 : 03:23:30 : Job 24161 was finished.
02/03/12 : 03:23:28 : Logged In.
Southampton
SEPnet
Durham University

Tutorial


HEPMDB
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Calchep
Whizard
ID Name
1 Standard Model
Menu
Go to HEPMDB
Help
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
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
South East Physics Network
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)
```

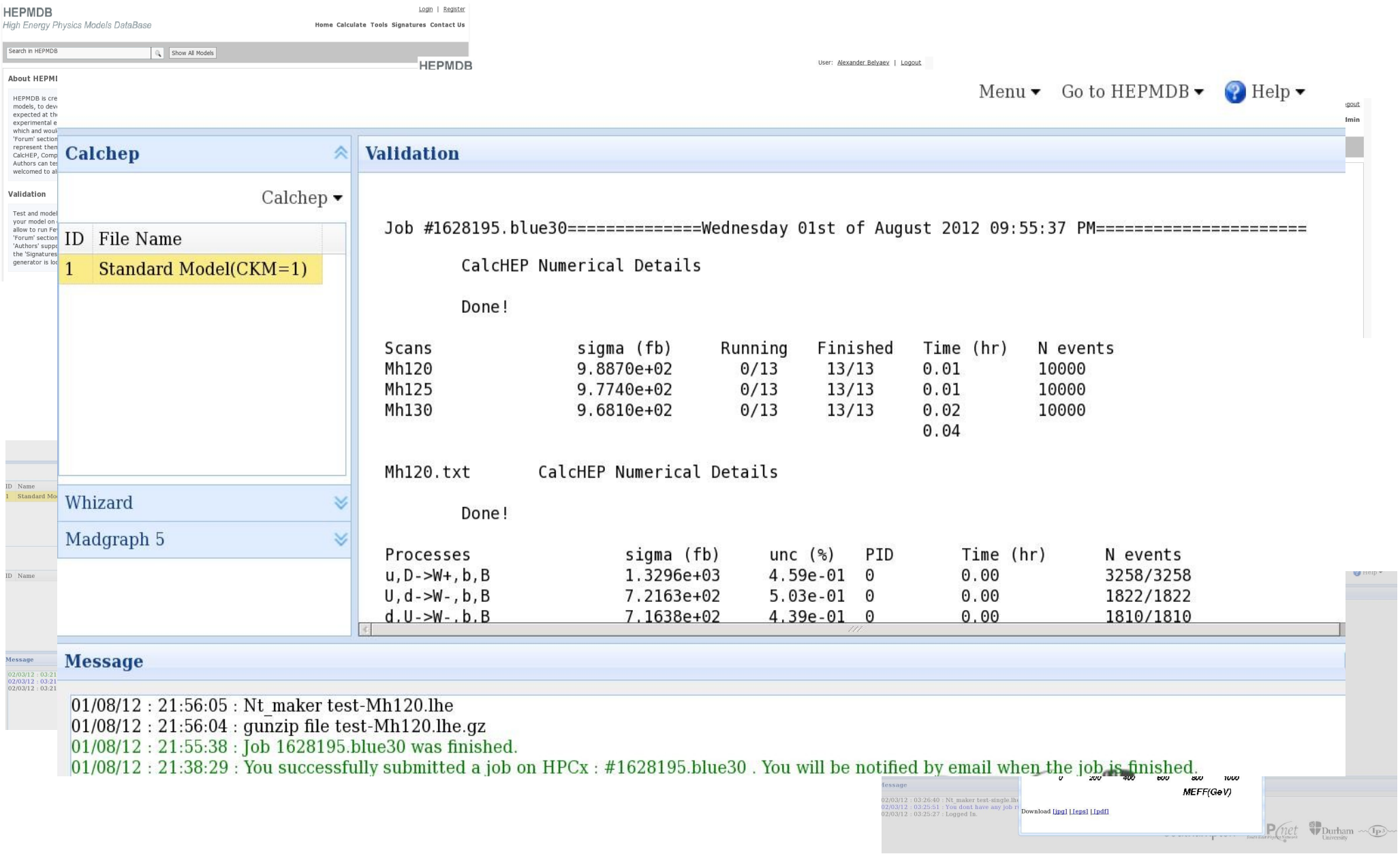
```
Dist parameter:    M(W,jet)
Dist min:          100
Dist max:          200
Dist n bins:       100
Dist title:        p,p->W,b,B
Dist x-title:      M(W,jet) (GeV)

#################################################
#  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)

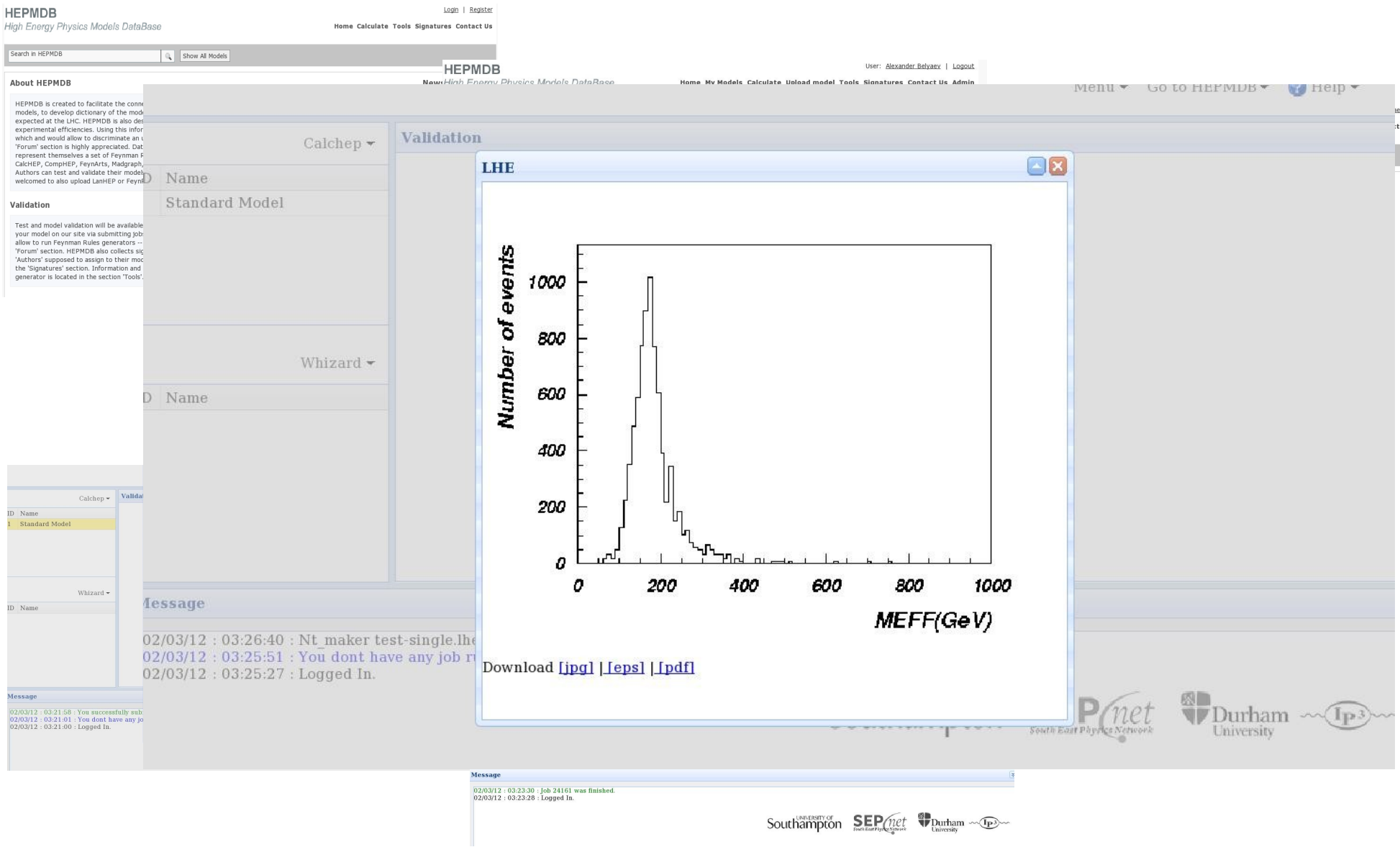
```
################################################
#  Parallelization Info                        #
#  Parallelization method choices:             #
#      local                                   #
#      pbs                                     #
#  Que can be left blank if not required       #
#      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


HEPMDB
High Energy Physics Models DataBase
Login | Register
Home Calculate Tools Signatures Contact Us
Search in HEPMDB
Show All Models
About HEPMDB
Validation
Calchep
Name
Standard Model
Whizard
Name
Validation
LHE
Number of events
1000
800
600
400
200
0
0
200
400
600
800
1000
MEFF(GeV)
Download [jpg] | [eps] | [pdf]
Message
02/03/12 : 03:26:40 : Nt_maker test-single.lhe
02/03/12 : 03:25:51 : You dont have any job r
02/03/12 : 03:25:27 : Logged In.
Message
02/03/12 : 03:23:30 : Job 24161 was finished.
02/03/12 : 03:23:28 : Logged In.
Durham University

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 higgs 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

Lecture III:

- PAW
- Examples of the CalcHEP/LanHEP application

Plotting/Analyzing results with PAW

http://paw.web.cern.ch/paw/tutorial/

- **Installation**
  - ***PAW is the part of the CERN library (CERNLIB)***

    http://cernlib.web.cern.ch/cernlib/download/

Architecture and operating system

- PC Linux Cern i686-slc5-gcc34-opt(Cernlib 2006)(README, compressed tar files, libraries, include files, binaries)
- PC Linux Cern i686-slc5-gcc41-opt(Cernlib 2006)(README, compressed tar files, libraries, include files, binaries)
- PC Linux Cern i686-slc5-gcc43-opt(Cernlib 2006)(README, compressed tar files, libraries, include files, binaries)
- PC Linux Cern x86_64-slc5-gcc34-opt(Cernlib 2006)(README, compressed tar files, libraries, include files, binaries)
- PC Linux Cern x86_64-slc5-gcc41-opt(Cernlib 2006)(README, compressed tar files, libraries, include files, binaries)
- PC Linux Cern x86_64-slc5-gcc43-opt(Cernlib 2006)(README, compressed tar files, libraries, include files, binaries)
- PC Linux Cern slc4_ia32_gcc4(Cernlib 2006)(README, compressed tar files, libraries, include files, binaries)
- PC Linux Cern slc4_amd64_gcc4(Cernlib 2006)(README, compressed tar files, libraries, include files, binaries)
- Apple MacOSX MacIntel_gcc4(Cernlib 2006)(README, compressed tar files, libraries, include files, binaries)
- PC Linux Cern slc3_ia32_gcc344(Cernlib 2005)(README, compressed tar files, libraries, include files, binaries)
- PC Linux Cern slc4_amd64_gcc34(Cernlib 2005)(README, compressed tar files, libraries, include files, binaries)
- PC Linux Cern slc3_ia32_gcc323(Cernlib 2004)(README, compressed tar files, libraries, include files, binaries,)
- PC Linux RH7.3, (RH8); gcc 3.2 (Cernlib 2003)(README, compressed tar files, libraries, binaries, others)
- PC Linux RH10 (RH9); gcc 3.3 (Cernlib 2003)(README, compressed tar files)
- PC Linux RH7.3; gcc 2.95.2(Cernlib 2002)(README, compressed tar files, libraries, binaries, others)
- PC Linux RH7.2(README, compressed tar files, libraries, binaries, others)
- PC Linux RH6.1(README, compressed tar files, libraries, binaries, others)
- SUN Solaris 7(README, compressed tar files, libraries, binaries)
- Tru64 Unix 4.0F(README, compressed tar files, libraries, binaries)
- HP-UX 10.20(README, compressed tar files, libraries, binaries)
- RS/6000 AIX 4.3(README, compressed tar files, libraries, binaries)
- Silicon Graphics IRIX 6.5 (README, compressed tar files, libraries, binaries)
- PC Windows NT/95/98/2000/XP (README, compressed tar files, libraries, binaries)

Plotting/Analyzing results with PAW

http://paw.web.cern.ch/paw/tutorial/

- **Installation**
  - ***PAW is the part of the CERN library (CERNLIB)***
    http://cernlib.web.cern.ch/cernlib/download/
  - *chose your operating system and download* **pawX11** *e.g. from*
    http://cernlib.web.cern.ch/cernlib/download/2003_rh73/bin/
  - ***On MAC, use fink package to install CERNLIB***
- ***Running PAW:*** **paw** ***or*** **pawX11**

```
*****************************************************************
*                                                               *
*            W E L C O M E    to   P A W                       *
*                                                               *
*       Version 2.14/04      12 January 2004                    *
*                                                               *
*****************************************************************
Workstation type (?=HELP) <CR>=1 :
Version 1.29/03 of HIGZ started
*** Using default PAWLOGON file "/home/belyaev/.pawlogon.kumac"

PAW >
```

Parameter space scan in CalcHEP

•`par_scan < data.txt`: This script calculates the cross-sections according to the grid for names and parameters given in `data.txt` file. The format of `data.txt` is

```
name_1  name_2 ... name_N
val_11  val_12 ... val_1N
.........................
val_M1  val_M2 ... val_MN
```

where `name_1  name_2 ... name_N` are the names of independent model parameters , while `val_11 ... val_1N` are the values for the respective parameters to be used for the first calculation and `val_M1 ... val_MN` are the values for these parameters for the last parameter point to be calculated. Note that this script does not sum over the subprocesses (i.e. it will do the calculation only for the subprocess currently chosen in `session.dat`). The results of the calculations are printed to stdout and can be redirected into a file with a command such as

```
par_scan < data.txt > results.txt
```

where `results.txt` is the file where the results should go. The output format repeats the input format but contains one additional column with the results of the calculation.

Plotting/Analyzing results with PAW

http://paw.web.cern.ch/paw/tutorial/ ; paw/paw_manual.pdf

first_example.kumac

- *read vector from file :* **' help vector/read'**

vector/read cs res.out match=/./(2)

vector/read vlist fname [format opt match]

Plotting/Analyzing results with PAW

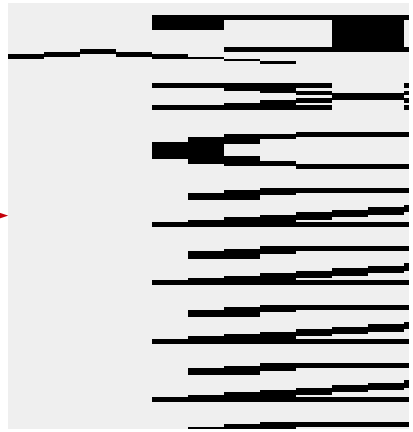
http://paw.web.cern.ch/paw/tutorial/ ; paw/paw_manual.pdf

first_example.kumac

- *read vector from file :* **' help vector/read'**

vector/read cs res.out match=/./(2)

vector/read vlist fname [format opt match]



Plotting/Analyzing results with PAW

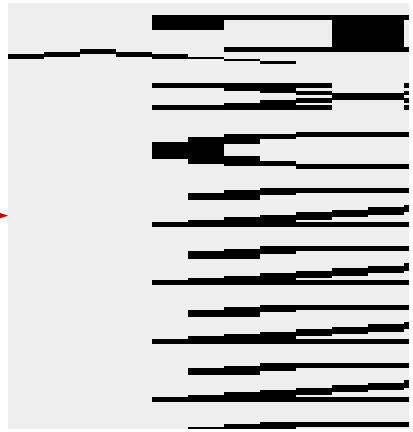
http://paw.web.cern.ch/paw/tutorial/ ; paw/paw_manual.pdf

first_example.kumac

- *read vector from file :'* **help vector/read'**

  vector/read cs res.out match=/./(2)

  vector/read vlist fname [format opt match]



- *create 2d histogram:'* **help 2d'**

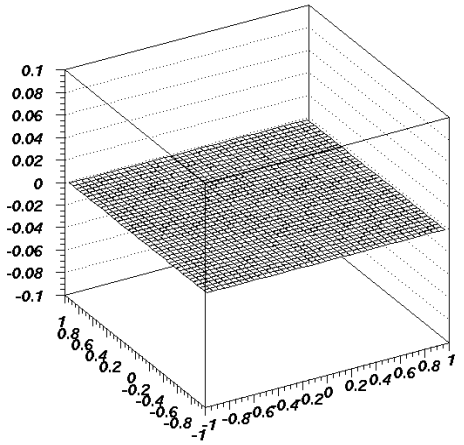
  2d 10 ! 41 -1 1 41 -1 1

  2d id title ncx xmin xmax ncy ymin ymax [valmax]

- *plot 2d histogram:* **' help hi/plo'**

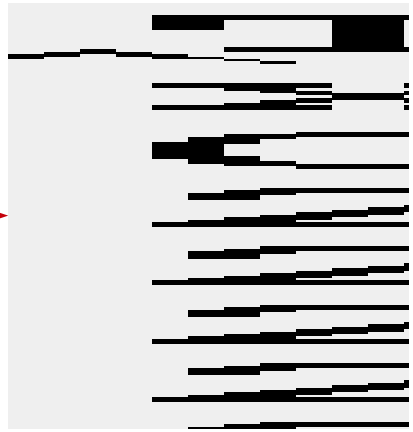
  hi/plo 10 surf

  hi/plot [id chopt]



Plotting/Analyzing results with PAW

http://paw.web.cern.ch/paw/tutorial/ ; paw/paw_manual.pdf



example1.kumac

- *read vector from file :* ' help vector/read'

  vector/read cs res.out match=/./(2)

  vector/read vlist fname [format opt match]

- *create 2d histogram:* ' help 2d'

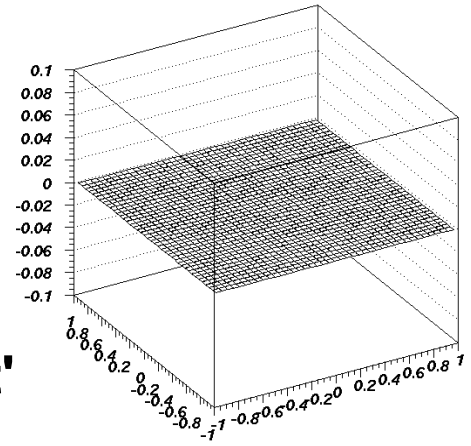
  2d 10 ! 41 -1 1 41 -1 1

  2d id title ncx xmin xmax ncy ymin ymax [valmax]

- *plot 2d histogram:* ' help hi/plo'

  hi/plo 10 surf

  hi/plot [id chopt]

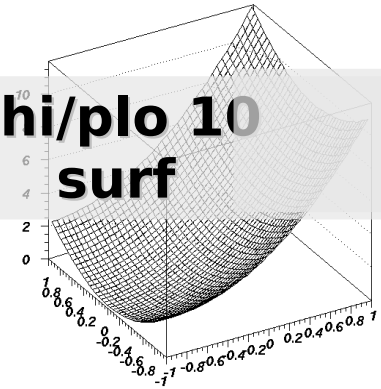


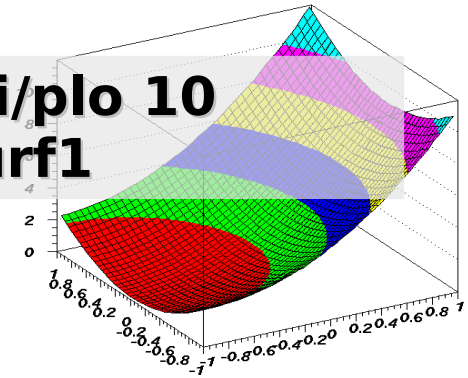
- *put vector contents into histogram* ' help put_vect/cont'

put_vect/contents 10 cs

put_vect/contents id vname

- *plot 2d histogram again*



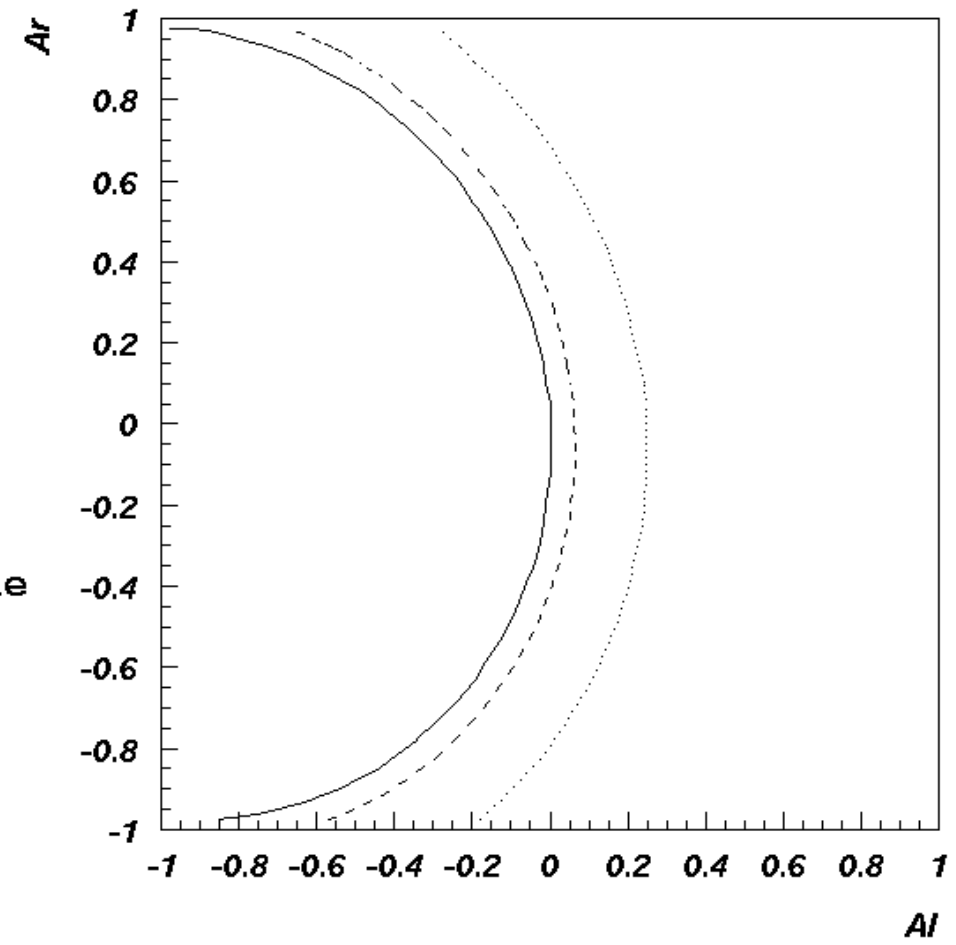


- *axis title*

atitle Al Ar

Plotting/Analyzing results with PAW

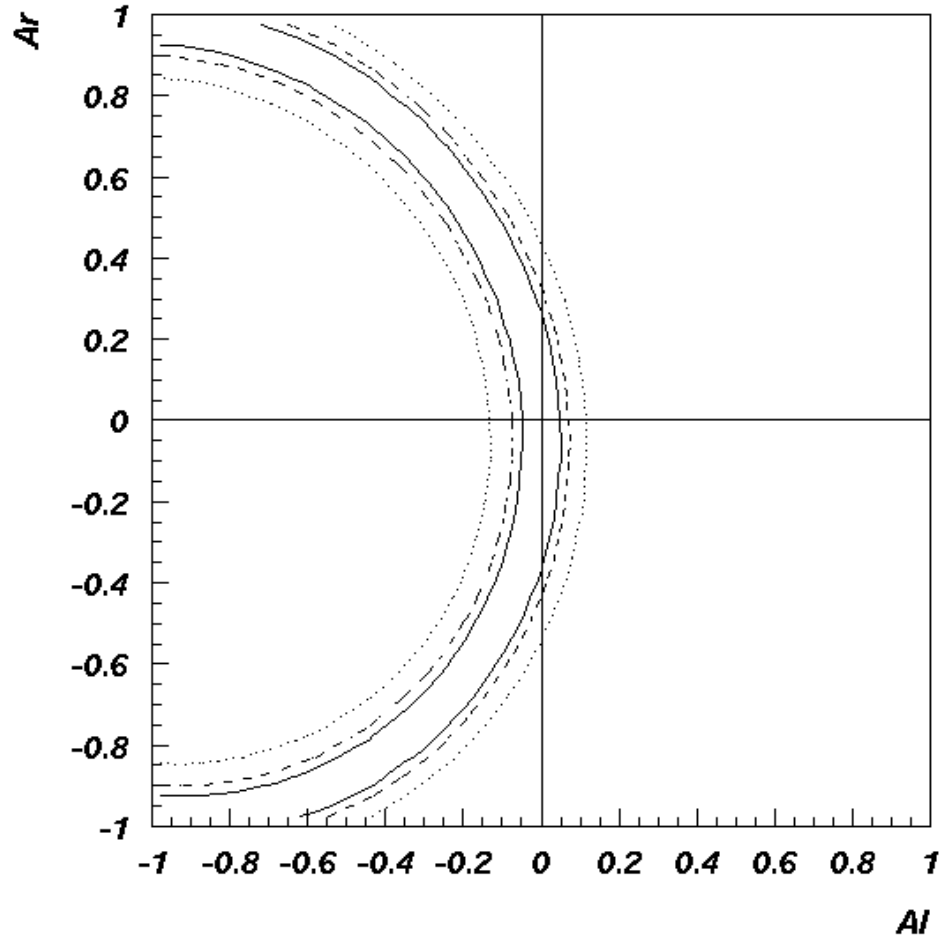
```
*** pause
wait

*** create vector for levels
vec/cre level(3) R 2.3  2.6 3.6

*** let the length of the dash-line in cm
set dash 0.3

*** plot empty histogram
HI/plo 11

*** plot contour levels in superimposed mode
HISTOGRAM/2D_PLOT/CONTOUR 10 3 1s level

*** set axis title (Al,Ar)
atitle  Al Ar

*** write figure into the file
pic/pri cont1.eps
```



Plotting/Analyzing results with PAW

$$\chi^2 = \left(\frac{\sigma_{SM} - \sigma[A_r, A_l]}{\Delta\sigma_{SM}} \right)^2$$

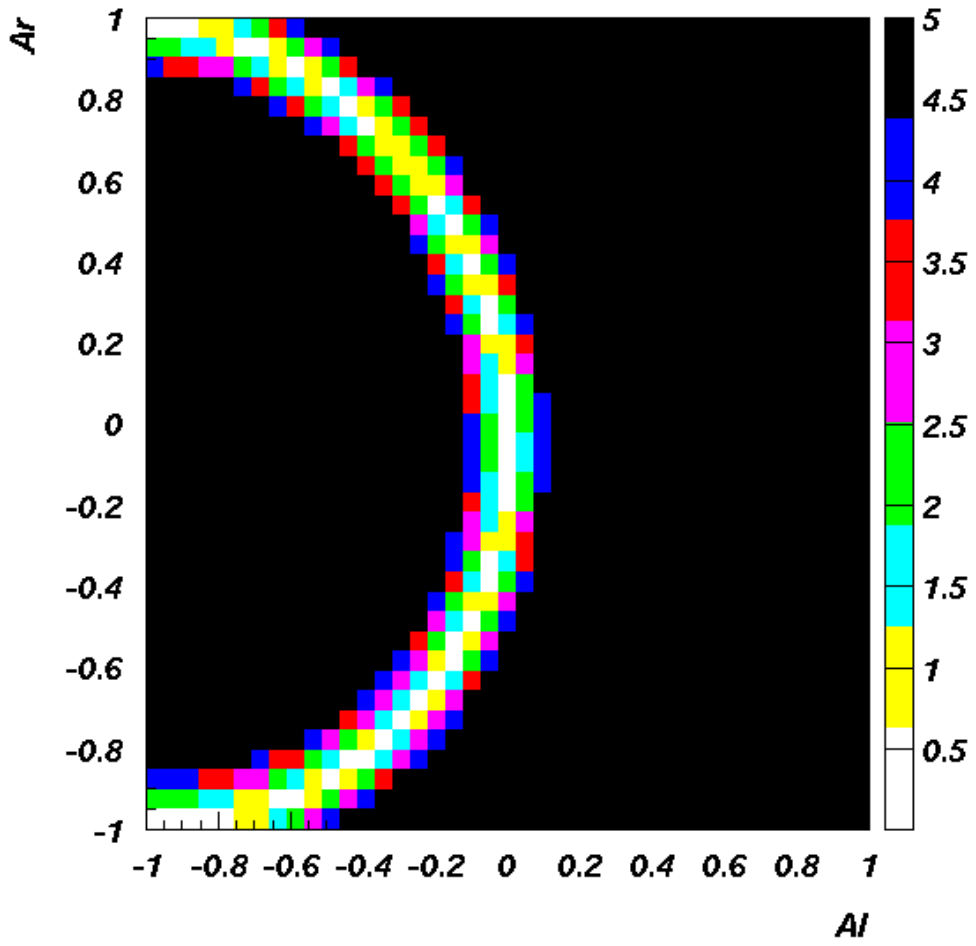
```
*** create vector for chi^2 levels
vec/cre lchi2(3) R 2. 3. 5.

*** construct sqrt(chi^2) vector chi2
*** 2.2929 correcponds to SM value
*** 0.05 is assumed to be the exp error
sigma chi2=sqrt((2.3-cs)**2/(2.3*0.05)**2)

*** put chi2 contents into histogram 11
PUT_VECT/CONTENTS 11 chi2

*** plot contour plots for lchi2 levels
CONTOUR 11 3 1 lchi2

*** set axis title
atitle  Al Ar

*** plot 2 crossing lines
line 0 -1 0 1 ; line -1 0 1 0

*** write picture into the eps file
pic/pri cont2.eps
```



Plotting/Analyzing results with PAW

$$\chi^2 = \left(\frac{\sigma_{SM} - \sigma[A_r, A_l]}{\Delta\sigma_{SM}} \right)^2$$

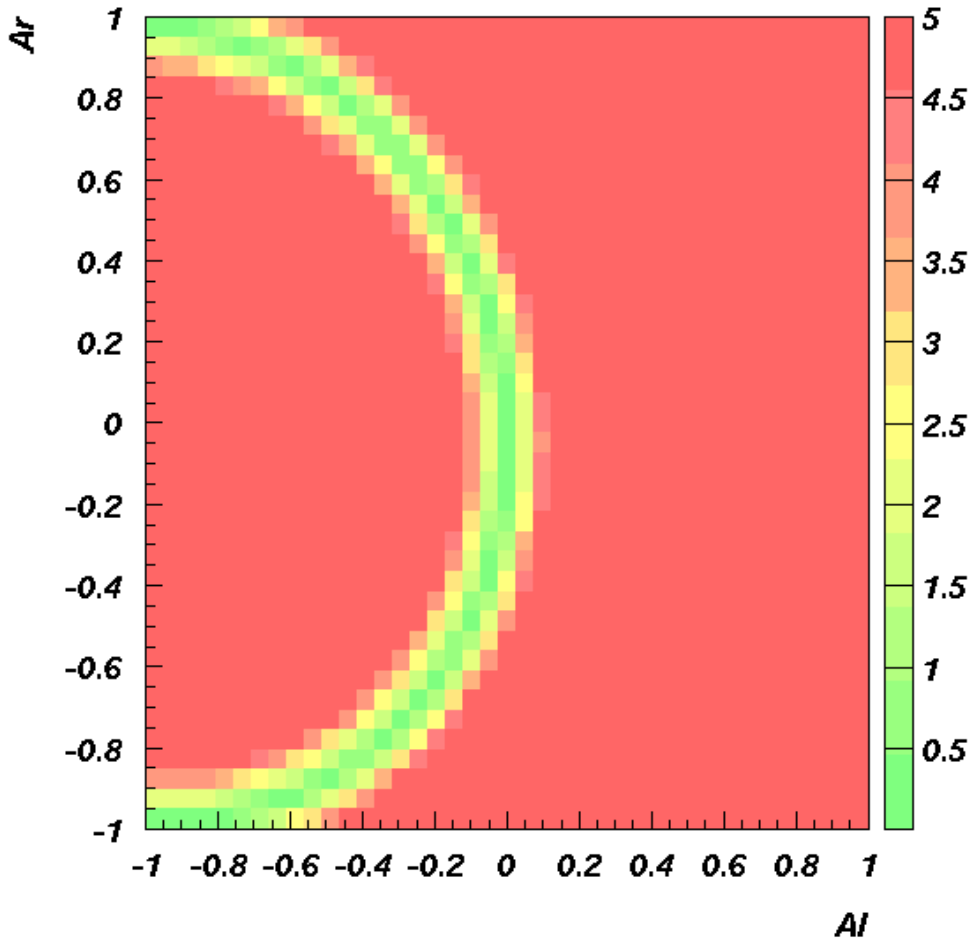
```
*** nicer plotting of chi^2

*** creatre vector chi2n <=5
sigma chi2n=min(5,chi2)

*** reset histogram 11
reset 11

*** read chi2n into hist 11
put_vect/contents 11 chi2n


*** plot nice color chi^2 plot
hi/plo 11 zcol

*** set axis title
atitle  Al Ar

*** write picture into the eps file
pic/pri cont3.eps
```



Plotting/Analyzing results with PAW

```
*** even nicer plotting of chi^2

*** creatre vector chi2n <=5
sigma chi2n=min(5,chi2)

*** reset histogram 11
reset 11

*** read chi2n into hist 11
put_vect/contents 11 chi2n

*** define number of colors
*** (first 7 are conventional ones)
set ncol 18

*** define colors from green -> to red
 color_table 8   0.5     1          0.5
 color_table 9   0.6     1          0.5
 color_table 10  0.7     1          0.5
 color_table 11  0.8     1          0.5
 color_table 12  0.9     1          0.5
 color_table 13  1       1.         0.5
 color_table 14  1       0.9        0.5
 color_table 15  1       0.7        0.5
 color_table 16  1       0.6        0.5
 color_table 17  1       0.5        0.5
 color_table 18  1       0.4        0.4

*** plot nice color chi^2 plot
hi/plo 11 zcol

*** set axis title
atitle  Al Ar

*** write picture into the eps file
pic/pri cont4.eps
```

You can control even color table and mix colors as you want!



Exercise#8
perform χ^2 analysis for B_l, B_r

More systematic introduction into PAW

- take a quick look at tutorial and manual :-)
- start with 'help'!

```
PAW > help

From  /...

 1:    KUIP          Command Processor commands.
 2:    MACRO         Macro Processor commands.
 3:    VECTOR        Vector Processor commands.
 4:    HISTOGRAM     Manipulation of histograms. Interface to the HBOOK package.
 5:    FUNCTION      Operations with Functions. Creation and plotting.
 6:    NTUPLE        Ntuple creation and related operations.
 7:    GRAPHICS      Interface to the graphics packages HPLOT and HIGZ.
 8:    PICTURE       Creation and manipulation of HIGZ pictures.
 9:    ZEBRA         Interfaces to the ZEBRA RZ, FZ and DZ packages.
10:    FORTRAN       Interface to MINUIT, COMIS, SIGMA and FORTRAN Input/Output.
11:    NETWORK       To access files on remote computers.
12:    MLP           Multi-Layer Perceptron (MLP).
13:    OBSOLETE      Obsolete commands

Enter a number ('0'=Top, '\'=one level back, 'Q'=command mode):
```

Vectors and operations

```
Menu /VECTOR

 1:    /VECTOR        Vector Processor commands.

From  /VECTOR/...

 2: * CREATE          Create a vector named VNAME (elements are set to zero).
 3: * LIST            List all vectors (name, dimensions, type).
 4: * DELETE          Delete from memory all vectors in the list VLIST.
 5: * COPY            Copy a vector into another one.
 6: * INPUT           Enter values into a vector from the terminal.
 7: * PRINT           Write to the terminal the content of a vector.
 8: * READ            Enter values into vector(s) from a file.
 9: * WRITE           Write to a file the content of vector(s).
10: * DRAW            Draw vector VNAME (real) interpreting it as a histogram.
11: * HFILL           Fill the existing histogram ID with vector VNAME (real) .
12: * PLOT            Each element of VNAME (real)  is used to fill an histogram
                      which is automatically booked with 100 channels and then
                      plotted.
13: * FIT             Fit a user defined function to the points defined by the
                      two vectors X and Y and the vector of associated errors EY.
14:    OPERATIONS     Simple arithmetic operations between vectors.

Keyword "VECTOR" found in commands:

15: * /KUIP/FUNCTIONS
                      List of all KUIP System Functions.
16: * /HISTOGRAM/GET_VECT
                      Fill a vector from values stored in HBOOK objects.
17: * /HISTOGRAM/PUT_VECT
                      Replace histogram contents with values in a vector.
18: * /GRAPHICS/PRIMITIVES/HIST
                      Draw an histogram defined by arrays X and Y.
```

Vectors and operations

```
* VECTOR/CREATE VNAME [ TYPE VALUES ]

VNAME      C 'Vector name(length)'
TYPE       C 'Vector type' D='R'
VALUES     C 'Value list' D=' ' Separate Vararg

Possible TYPE values are:

 R
 I

Create a vector named VNAME (elements are set to zero).  The dimensions are
taken from the name, for example VEC(20), VEC(3,100), VEC(2,2,10).  Up to 3
dimensions are supported. Dimensions which are not specified are taken to
1, for example VEC(10) ---> VEC(10,1,1) and VEC ---> VEC(1,1,1).  The
vector may be of type Real or Integer.  A vector is filled at the same time
if parameters are given after the TYPE:

 VEC/CREATE V(10) R 1 2 3 4 5 66 77 88 99 111
 VEC/CREATE W(20) R 1 2 3

In the last example only the first three elements are filled.  Vector
elements may be changed later with the command VECTOR/INPUT.

If many equal values have to be entered consecutively, one can specify just
one value and precede it by a repetition factor and an asterisk. Example:

 VEC/CREATE Z(20) R 5*1 2 4*3   --->   VEC/CREATE Z(20) R 1 1 1 1 1 2 3 3 3
3

Enter HELP VECTOR for more information on vector addressing.
```

Vectors and operations

```
* VECTOR/READ VLIST FNAME [ FORMAT OPT MATCH ]

  VLIST      C 'Vector list'
  FNAME      C 'File name' D=' '
  FORMAT     C 'Format' D=' '
  OPT        C 'Options' D='OC'
  MATCH      C 'Matching pattern' D=' '

  Possible OPT values are:

   OC
   O
  ' '
   C

  Enter values into vector(s) from a file.  A format can be specified, e.g.
  FORMAT='F10.5,2X,F10.5', or the free format is used if FORMAT is not
  supplied.
  OPT is used to select between the following options:

   'OC'   file is Opened, read and then Closed (default case)
   'O'    file is Opened and then read (left open for further reading)
   ' '    file is read (already open, left so for further reading)
   'C'    file is read and then Closed (already open)

  If the character 'Z' is present in OPT, the vector elements equal to zero
  after reading are set to the latest non-zero element value (for example
  reading 1 2 3 0 0 4 0 5 will give 1 2 3 3 3 4 4 5).

  MATCH is used to specify a pattern string, restricting the vector filling
  only to the records in the file which verify the pattern. Example of
  patterns:

    /string/      match a string (starting in column 1)
   -/string/      do not match a string (starting in column 1)
    /string/(n)   match a string, starting in column n
    /string/(*)   match a string, starting at any column
```

Histograms and operations

```
Menu /HISTOGRAM

 1:    /HISTOGRAM     Manipulation of histograms. Interface to the HBOOK package.

From   /HISTOGRAM/...

 2: * FILE            Open an HBOOK direct access file.
 3: * LIST            List histograms and Ntuples in the current directory.
 4: * DELETE          Delete histogram/Ntuple ID in Current Directory (memory).
 5: * PLOT            Plot a single histogram or a 2-Dim projection.
 6: * ZOOM            Plot a single histogram between channels ICMIN and ICMAX.
 7: * MANY_PLOTS      Plot one or several 1D histograms into the same plot.
 8: * PROJECT         Fill all booked projections of a 2-Dim histogram.
 9: * COPY            Copy a histogram onto another one.
10: * FIT             Fit a user defined (and parameter dependent) function to a
                      histogram ID (1-Dim or 2-Dim) in the specified range.
11:    2D_PLOT        Plotting of 2-Dim histograms in various formats.
12:    CREATE         Creation ('booking') of HBOOK objects in memory.
13:    HIO            Input/Output operations of histograms.
14:    OPERATIONS     Histogram operations and comparisons.
15:    GET_VECT       Fill a vector from values stored in HBOOK objects.
16:    PUT_VECT       Replace histogram contents with values in a vector.
17:    SET            Set histogram attributes.

Keyword "HISTOGRAM" found in commands:

18: * /FUNCTION/FUN1
                      Create a one dimensional histogram and fill the bins with
                      the values of a (single-valued) function.
19: * /GRAPHICS/PRIMITIVES/HIST
                      Draw an histogram defined by arrays X and Y.
```

Functions and operations

```
List of command(s) for FUNCTION ...

 1: * /HISTOGRAM/OPERATIONS/FUNCTION
                     Associate the function UFUNC with the histogram ID.
 2: * /HISTOGRAM/GET_VECT/FUNCTION
                     Get function associated to histogram ID into vector VNAME.

Menu /FUNCTION

 3:   /FUNCTION      Operations with Functions. Creation and plotting.

From  /FUNCTION/...

 4: * FUN1           Create a one dimensional histogram and fill the bins with
                     the values of a (single-valued) function.
 5: * FUN2           Create a two dimensional histogram and fill the bins with
                     the values of a (two-valued) function.
 6: * DRAW           Draw the function UFUNC in the current ranges specified by
                     the command: RANGE XLOW XUP YLOW YUP ZLOW ZUP and with
                     THETHA and PHI angles specified by the command ANGLE THETA
                     PHI. The number of points to evaluate the function between
                     XLOW, XUP YLOW, YUP, and ZLOW, ZUP can be changed by the
                     command POINTS NPX NPY NPZ.
 7: * PLOT           Plot single-valued function UFUNC between XLOW and XUP.
 8: * POINTS         Change the number of points to be used by FUN/DRAW and
                     FUN/PLOT. Note that the default for NPX is 20 for 3-Dim
                     plots (FUN/DRAW) but it is 100 for 1-Dim plots (FUN/PLOT).
 9: * RANGE          Change the range used by FUN/DRAW.
10: * ANGLE          Change the angle used by FUN/DRAW and HISTO/PLOT.
```

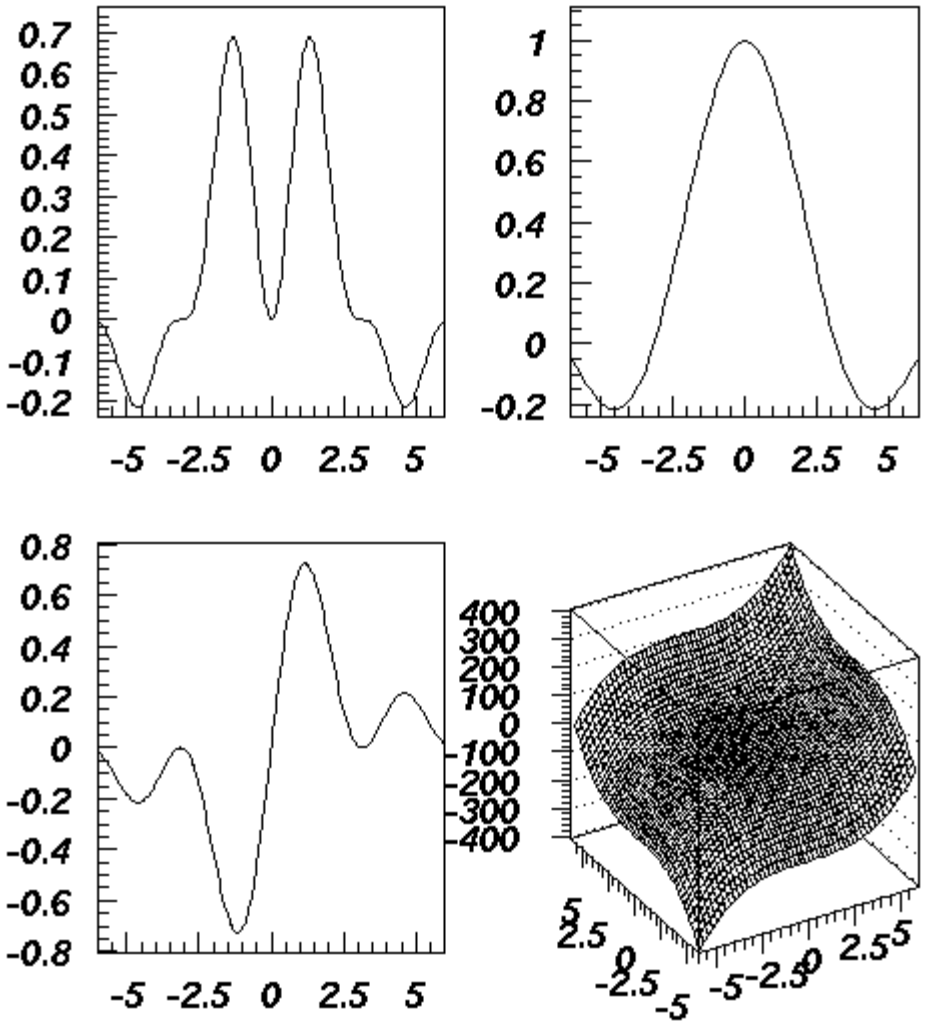
Example of Function Plot

func_plot_example.kumac

```
zone 2 2

mes 'fun/plot sin(x)**3/x -6 6'
fun/plot sin(x)**3/x -6 6
wait

mes 'fun/plot func.f(x) -6 6'
fun/plot func.f(x) -6 6
wait

mes 'func.f77(x) -6 6'
fun/plot func.f77(x) -6 6
wait

mes 'fun2 10 x**3+y**6 50 -6 6 100 -6 6'
fun2 10 x**3+y**3 50 -6 6 50 -6 6
```

```
function func(x)
func=sin(x)/x
return
end
```

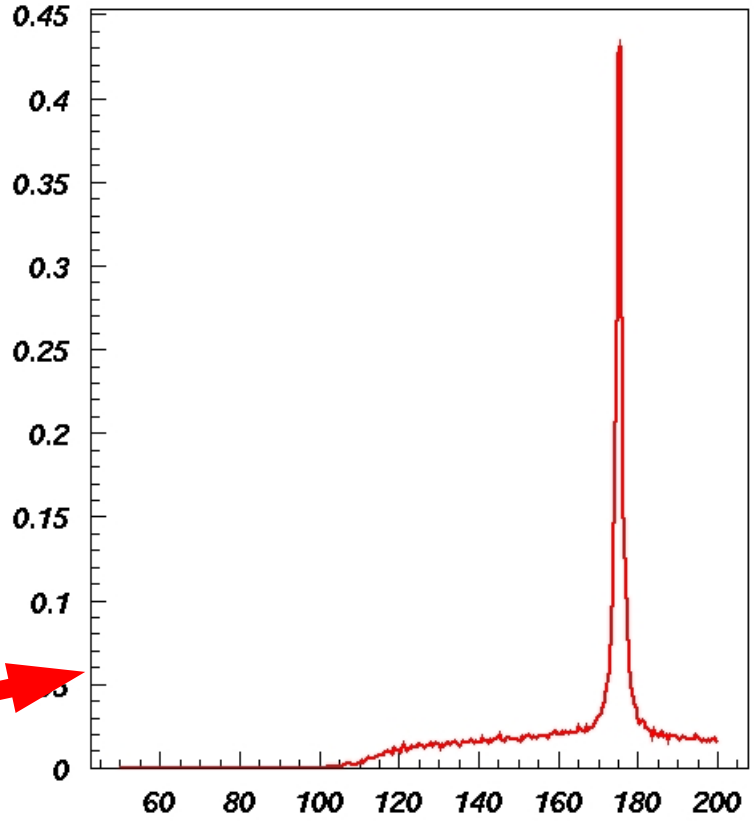
```
function func(x)
DOUBLE PRECISION y
y=dble(x)
func=dsin(y)**2/y
return
end
```



Plotting distribution from CalcHEP with PAW

dist_plot_example.kumac

```
* read in distribution from tab_1.txt
vec/read m34 tab_1.txt MATCH=/./(2) FORMAT='E13.7,20x'

*create x axis
sigma x=array(300,50#200)

* create 1D histogram and define min/max values
1D 10 ! 30 50 200; min 10 0. ; max 10 0.5

* plot histogram as an emty frame
hi/plo 10

* plot curve
graph 300 x m34
```




```
u, D -> W+, b, B
x-axis: "Mass{p3+p4}"  from 50.000000 to 200.000000 N_bins= 300
Diff. cross section [pb/GeV]
0.000000E+00 +/-  0.000000E+00
0.000000E+00 +/-  0.000000E+00
0.000000E+00 +/-  0.000000E+00
0.000000E+00 +/-  0.000000E+00
0.000000E+00 +/-  0.000000E+00
0.000000E+00 +/-  0.000000E+00
0.000000E+00 +/-  0.000000E+00
```

What is the ntuple?

- Suppose one has an event record and each event characterized by N variables
- We would like to create/analyze some distributions according to various selection criteria
- One possibility is to create and fill N histograms on an event-by-event basis. But each time we want to try new cut or variable we should re-create histograms
- Ntuples is the alternative, more generic and powerful way of performing such analysis
- An Ntuple is like a table where the N variables mentioned above are the columns and each event is a row.
- Once ntuple is created, it is easy to make projections of any of the NVAR variables of the events and to change the selection mechanisms, or the binning and so on.

Ntuples and operations

```
Menu /NTUPLE

 1:    /NTUPLE        Ntuple creation and related operations.

From   /NTUPLE/...

 2: * CREATE          Create a Row_Wise_Ntuple. (See below how to create a
                      Column_Wise_Ntuple).
 3: * LIST            List all Ntuples in the Current Directory.
 4: * PRINT           Print a summary about Ntuple IDN.
 5: * HMERGE          Merge HBOOK files containing histograms and/or ntuples.
                      Ntuples are merged and histograms with the same ID are
                      added. The INFILES are merged into a new file OUTFILE. If
                      OUTFILE already exists, it is overwritten.
 6: * DUPLICATE       The structure of Ntuple ID1 is duplicated in a new ntuple
                      ID2.
 7: * RECOVER         To recover Ntuple ID. If the job producing the Ntuple
                      crashed or the header was not stored correctly in the file
                      with HROUT, RECOVER will scan the Ntuple to rebuild the
                      header table and recompute the number of entries. The file
                      on which the Ntuple resides must be open in Update mode.
 8: * SCAN            Scan the entries of an Ntuple subject to user cuts.
 9: * LOOP            Invoke the selection function UWFUNC for each event
                      starting at event IFIRST.
10: * GCUT            Define a graphical cut on a one or two dimensional plot.
11: * PROJECT         Project an Ntuple onto a 1-Dim or 2-Dim histogram,
                      possibly using a selection function or predefined cuts.
12: * READ            Read Ntuple values from the alphanumeric file FNAME with
```

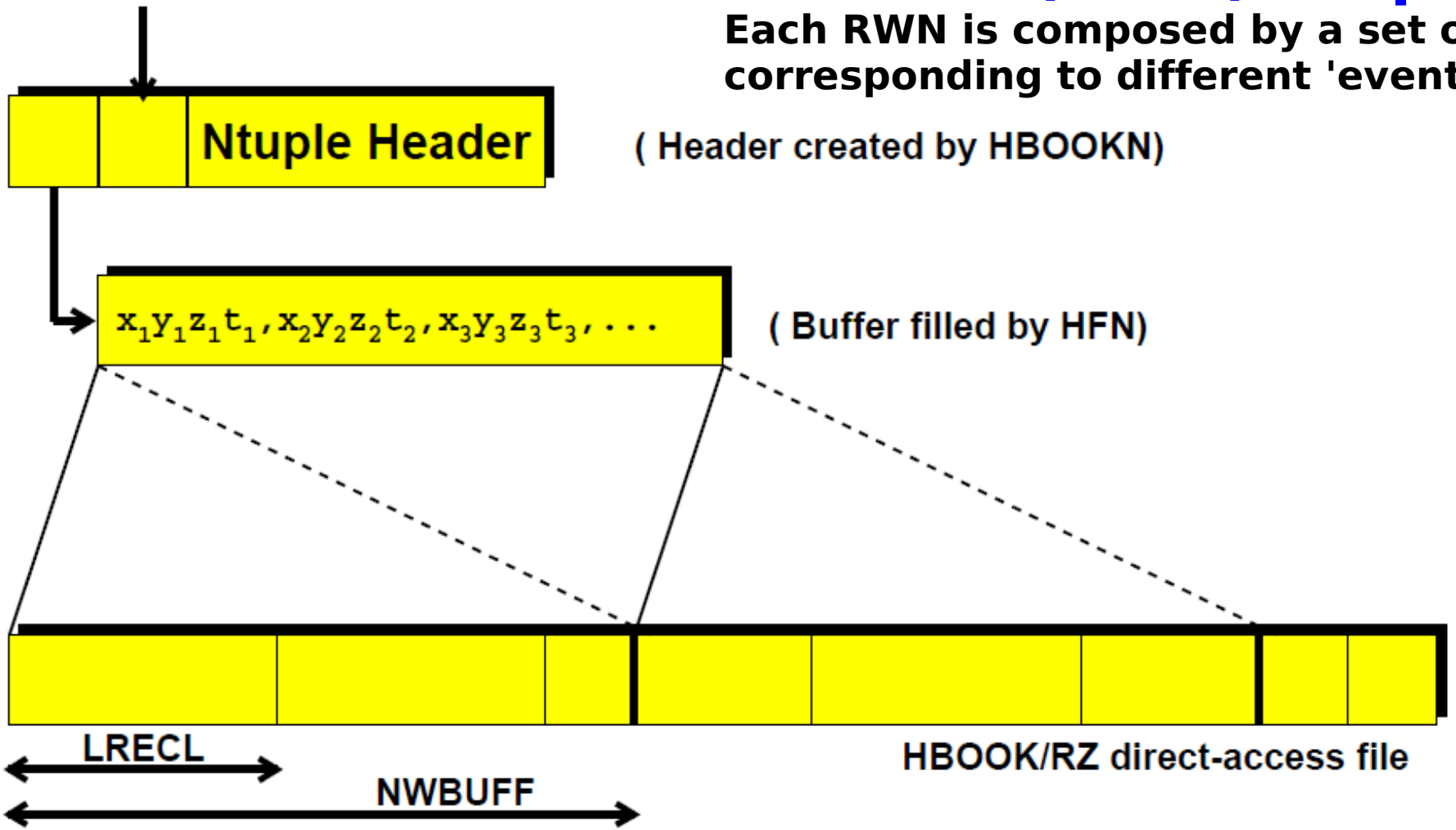
Ntuples and operations

```
13: * PLOT          Project and plot an Ntuple as a (1-Dim or 2-Dim) histogram
                    with automatic binning (ID=1000000), possibly using a
                    selection algorithm. See parameter CHOPT in command
                    HISTO/PLOT to have more details on the possible OPTION.
14: * CHAIN         Using the chain command one can build logical Ntuples of
                    unlimited size.
15: * CUTS          Define the CUTID with the format $nn.
16: * CSELECT       To write selection mechanism as a comment on the picture.
17: * UWFUNC        To generate the FORTRAN skeleton of a selection function
                    or the INCLUDE file with the columns declaration.
18: * LINTRA        Data reduction on Ntuple.
19: * VMEM          Change or show the size of the dynamic memory buffer used
                    to store Ntuple columns during Ntuple analysis. The
                    default is 10 MB. Giving a value of 0 turns the buffer
                    facility off. The upper limit is 128 MB, but be sure you
                    have enough swap space and realize that when the buffer is
                    swapped to disk you loose part of the benefit of the
                    buffer facility (which is to reduce the number of disk
                    accesses). Omitting the argument or specifying -1 will
                    show you the current upper limit and used and free space.
                    Giving -2 shows which columns are currently stored in
                    memory.
20: * DUMP          For the selected events the values of the expressions are
                    printed to the screen (by default) or to a specified file.
                    If the expression is non scalar (e.g. vector) the elements
                    of the vector are separated by a ',' (changed with SEP1).
                    The values of the expressions are separated by a '%'
                    (changed with SEP2).
21: * FLAGS_QP      Set debug options for the Query Processor
22:   MASK
23: * MERGE         Obsolete command use HMERGE.
```

More details on ntuples

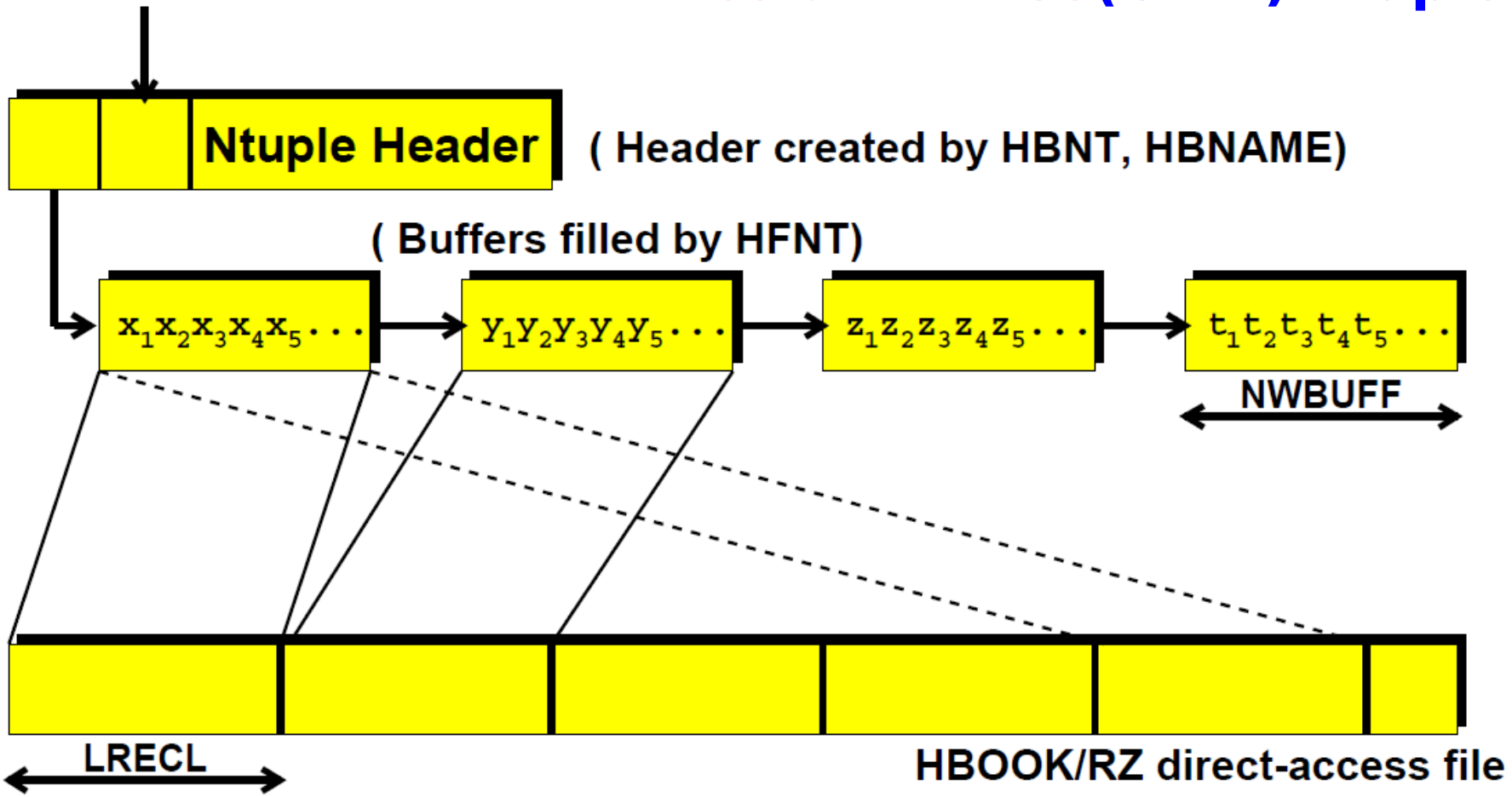
- **Depending on complexity of ntuple structure, there are raw-wise(RWN) and column-wise(CWN) ntuples**
  - **raw-wise(RWN) ntuple**

Each RWN is composed by a set of rows corresponding to different 'events'.



More details on ntuples

- **Depending on complexity of ntuple structure, there are raw-wise(RWN) and column-wise(CWN) ntuples**
  - **column-wise(CWN) ntuple**



Reading in events from CalcHEP into PAW

```
#CalcHEP version 2.4.1
#Type 2 -> 3
#Initial_state
  P1_3=7.000000E+03  P2_3=-7.000000E+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 7.9945520808E+01 3.2588068426E+00 3.2588068426E+00
#Cross_section(Width) 4.539702E+00
#Number_of_events      10000
#Events       P1_3 [Gev]         P2_3 [Gev]         P3_1 [Gev]     QCD SCALE     Color chains
       1   1.9099723613E+03 -1.2214173341E+02  4.9096294384E+01   9.119E+01    (1 4)(5 2)
       1   1.2633868974E+03 -1.3652035094E+01 -7.2512493004E+01   9.119E+01    (1 2)(5 4)
       1   1.7217000671E+02 -4.0911580358E+02  1.5543238585E+02   9.119E+01    (1 4)(5 2)
       1   5.8493602000E+02 -1.0209703443E+02  3.2182656194E+01   9.119E+01    (1 4)(5 2)
```

- ***Step1: define the ntuple and its structure – nt/create***

2->3 process: 2+3x3 = 1 1 columns to read

```
* NTUPLE/CREATE IDN TITLE NVAR CHRZPA NPRIME VARLIST
*
*   IDN         C 'Ntuple Identifier'
*   TITLE       C 'Ntuple title' D=' '
*   NVAR        I 'Number of variables' D=1 R=1:512
*   CHRZPA      C 'RZ path' D=' '
*   NPRIME      I 'Primary allocation' D=1000
*   VARLIST     C 'Names of the NVAR variables' Vararg

NTUPLE/CREATE  10 wbb 11 ! ! p1_3 p2_3 p3_1 p3_2 p3_3 p4_1 p4_2 p4_3 p5_1 p5_2 p5_3
```

Reading in events from CalcHEP into PAW

- ***Step2: read data into ntuple – nt/read***

```
* NTUPLE/READ IDN FNAME [ FORMAT OPT NEVENT MATCH ]

*   IDN          C 'Ntuple Identifier'
*   FNAME        C 'File name'
*   FORMAT       C 'Format' D='*'
*   OPT          C 'Options' D=' '
*   NEVENT       I 'Number of events' D=1000000
*   MATCH        C 'Matching pattern' D=' '

NT/READ 10 events_12.txt    MATCH=/./(13) FORMAT='9X,11E18.10,25X'
```

#Events	P1_3 [Gev]	P2_3 [Gev]	P3_1 [Gev]	P3_2 [Gev]	P3_3 [Gev]
1	1.9099723613E+03	-1.2214173341E+02	4.9096294384E+01	-3.5607712198E+01	-9.7528813138E+01
1	1.2633868974E+03	-1.3652035094E+01	-7.2512493004E+01	4.5054467522E+00	8.9872156911E+02
1	1.7217000671E+02	-4.0911580358E+02	1.5543238585E+02	-1.0720493405E+02	-3.1513524249E+02

- ***Step3: make plots and perform analysis –***

nt/plot nt/cuts nt/project nt/loop nt/chain

Example of ntuple event analysis with paw

- ***See file*** *ntuple_example.kumac*
- *We have signal (ev_1_s.txt) and background (ev_2_b.txt)*

$$u\bar{d}(\bar{d}u) \to W^+ b\bar{b} \text{ events}$$

- ***Let us work out optimal cuts for signal extraction***
- ***Out plan:***
  - ***Read in signal and bacground events into PAW***
  - ***Plots various 1d and 2d distributions***
  - ***Work out 'optimal' kinematical cuts***
- ***Why do we need to do this?***

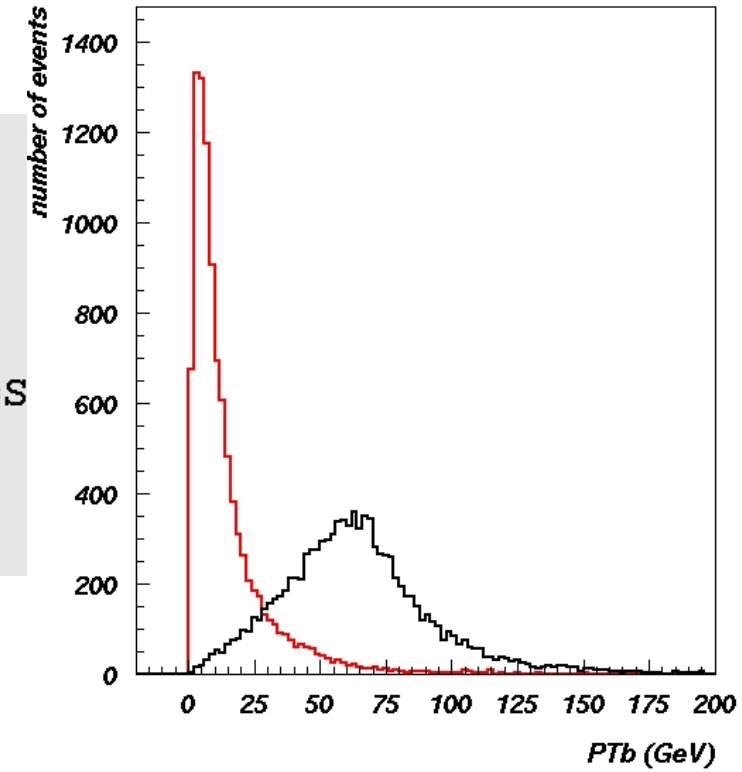
$$\sigma_b \simeq 26 \text{ pb, while } \sigma_s \simeq 0.32 \text{ pb!}$$

Example of ntuple event analysis with paw

file *ntuple.kumac*

```
* creating and reading ntuples for signal and background

NTUPLE/CREATE  10 wbb_s 11 ! ! p1_3 p2_3 p3_1 p3_2 p3_3 p4_1 p4_2 p4_3 p5_1 p5_2 p5_3
NTUPLE/CREATE  20 wbb_b 11 ! ! p1_3 p2_3 p3_1 p3_2 p3_3 p4_1 p4_2 p4_3 p5_1 p5_2 p5_3
NT/READ 10 ev_1_s.txt   MATCH=/./(13) FORMAT='9X,11E18.10,25X'
NT/READ 20 ev_1_b.txt   MATCH=/./(13) FORMAT='9X,11E18.10,25X'
* ==>   9994 events have been read
* ==>   9996 events have been read
```

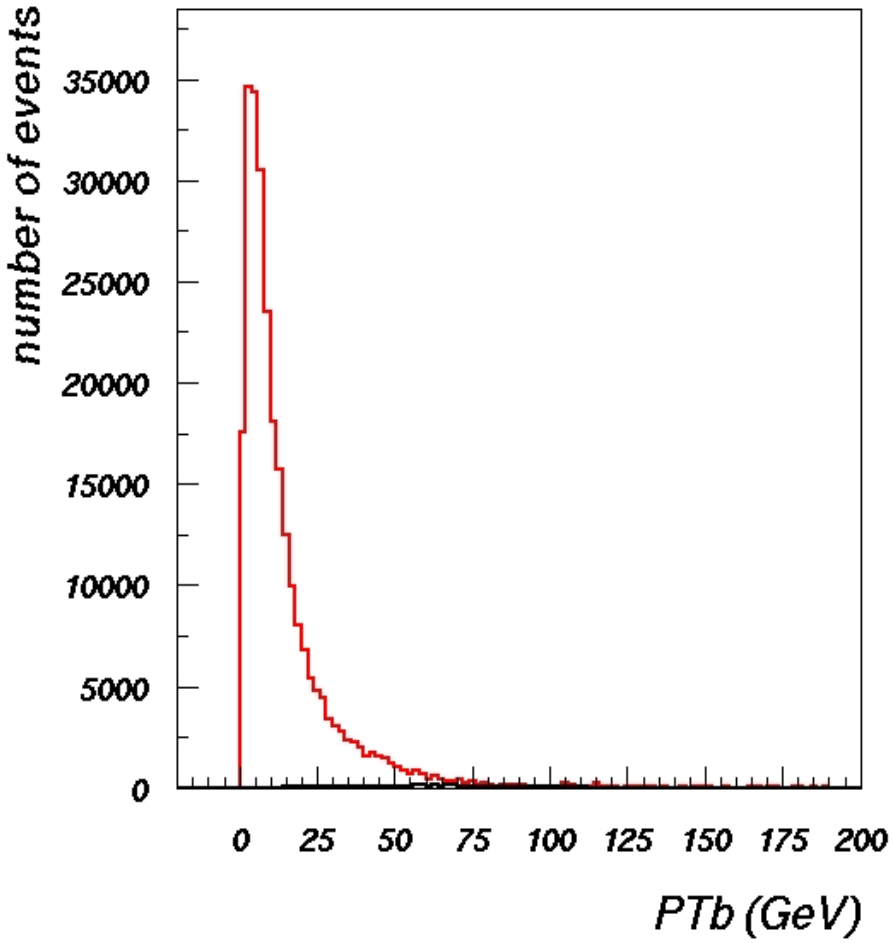
```
*set the line width for the histogram
set hwidt 5

*plot P_T distributions for signal and background

set hcol 2; nt/plo 20.sqrt(p4_1**2+p4_2**2)
set hcol 1; nt/plo 10.sqrt(p4_1**2+p4_2**2)    OPTION=S
atit  'PTb (GeV)' 'number of events'

*pause
wait
```



Example of ntuple event analysis with paw

file *ntuple.kumac*

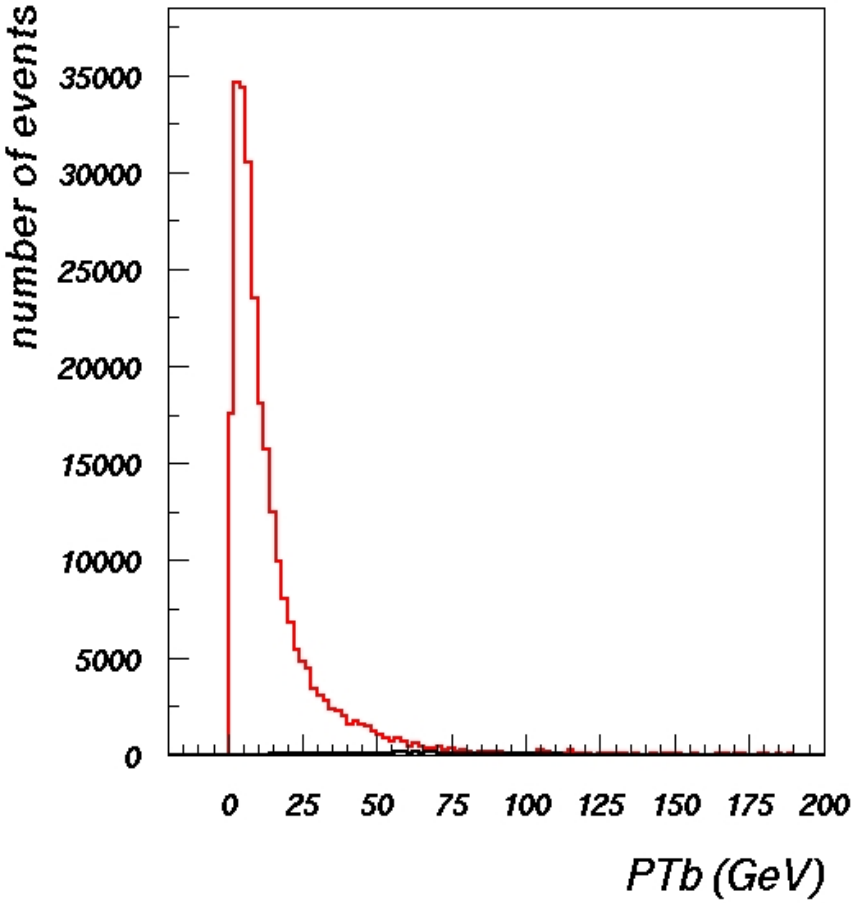
```
*****************************
*plot PT distributions normalized to CS
sigma CSB=26
sigma CSS=0.32
sigma NB=CSB*10000/10000.
sigma NS=CSS*10000/10000.

* set line color to 2(red)
set hcol 2
nt/plo 20.sqrt(p4_1**2+p4_2**2) NB

* set line color to 1(black)
set hcol 1
nt/plo 10.sqrt(p4_1**2+p4_2**2) NS  OPTION=S
atit  'PTb (GeV)' 'number of events'
mess 'EXAMPLE 2'
wait
```



Example of ntuple event analysis with paw

file *ntuple.kumac*

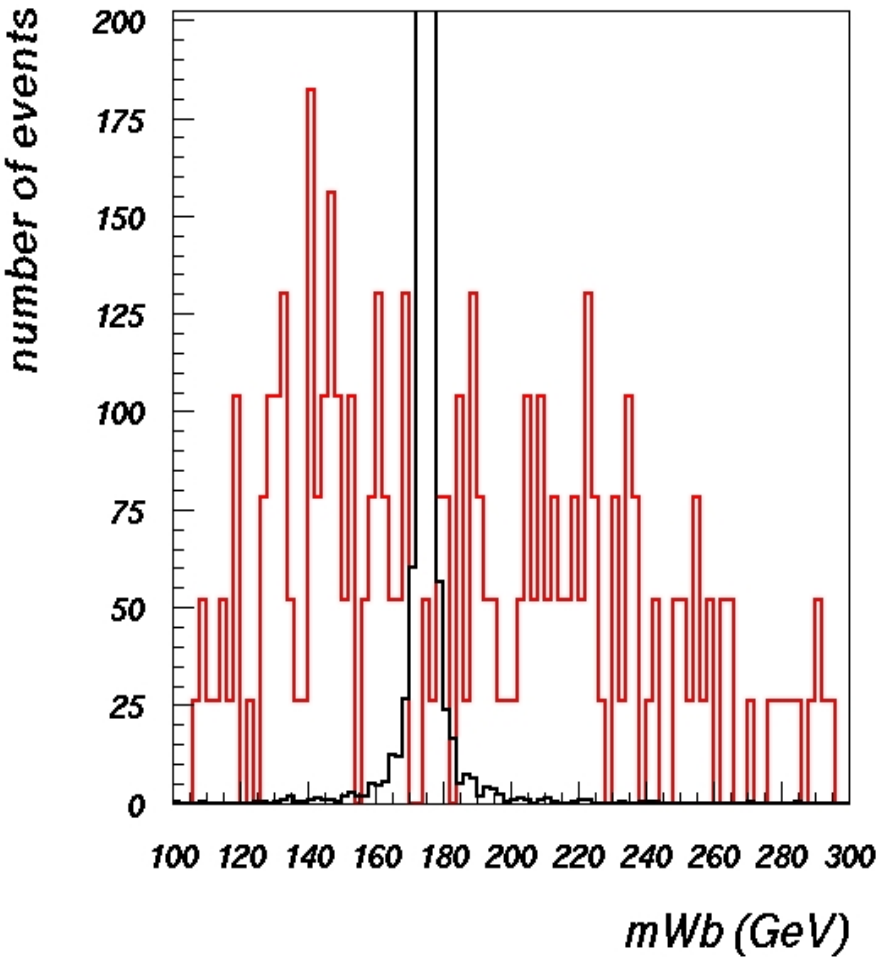
```
*************************************
* creating convenient set
* of variables with UWFUN
* uwfun 10 var.f

* plot various distributions normalized
* number of events
* NB and NS (background and signal)

set hcol 2
nt/plo 20.var.f(4) NB.and.300>var.f(4)>40
set hcol 1

nt/plo 10.var.f(4) NS.and.300>var.f(4)>40  OPTION=S
atit 'PTb (GeV)' 'number of events'
mess 'EXAMPLE 3'
wait
```



Example of ntuple event analysis with paw

file *ntuple.kumac*

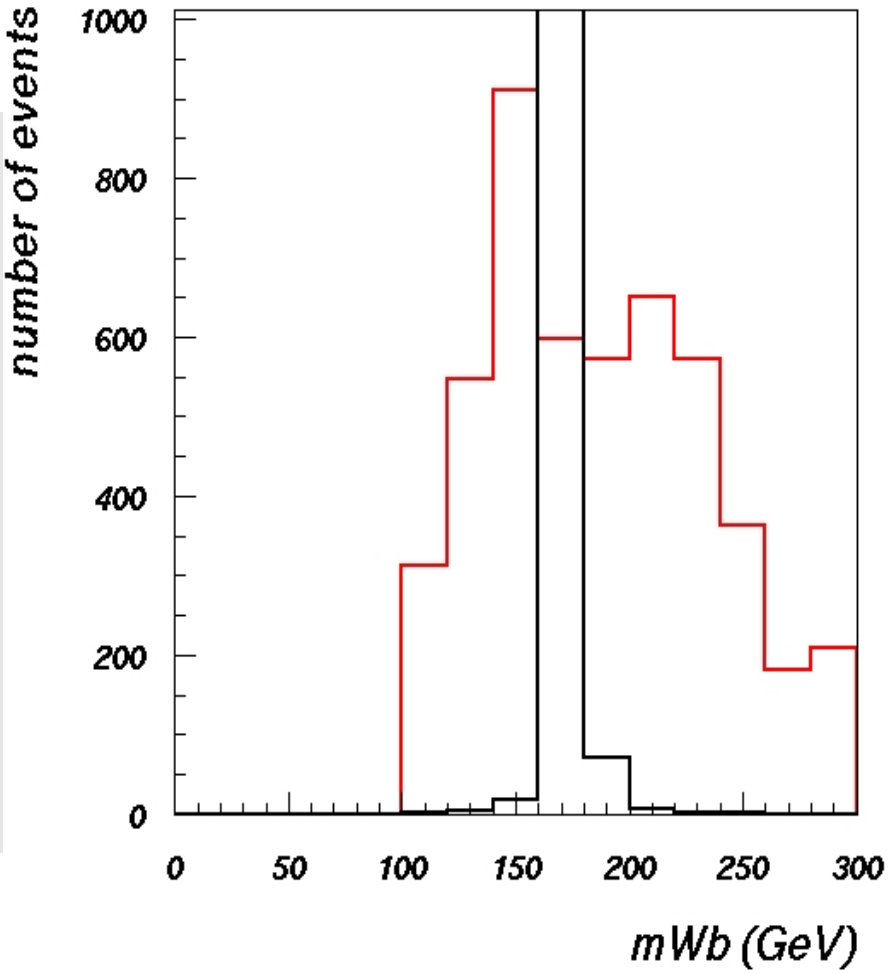
```
************************************
*define various cuts
* var.f(1)  - var.f(5)  PT of particels 1-5
* var.f(nm) invariant mass of (n,m) particles

* separate cuts
CUT $1 var.f(4)>40
CUT $2 var.f(5)>40
CUT $3 var.f(34).lt.300.

* cuts combination
CUT $10 $1.and.$2.and.$3

*plot m34 distribution
*normalized to N events

set hcol 2
nt/plo 20.var.f(34) NB.and.$10

set hcol 1
nt/plo 10.var.f(34) NE.and.$10  OPTION=S

atit  'mWb (GeV)' 'number of events'
```



Example of ntuple event analysis with paw

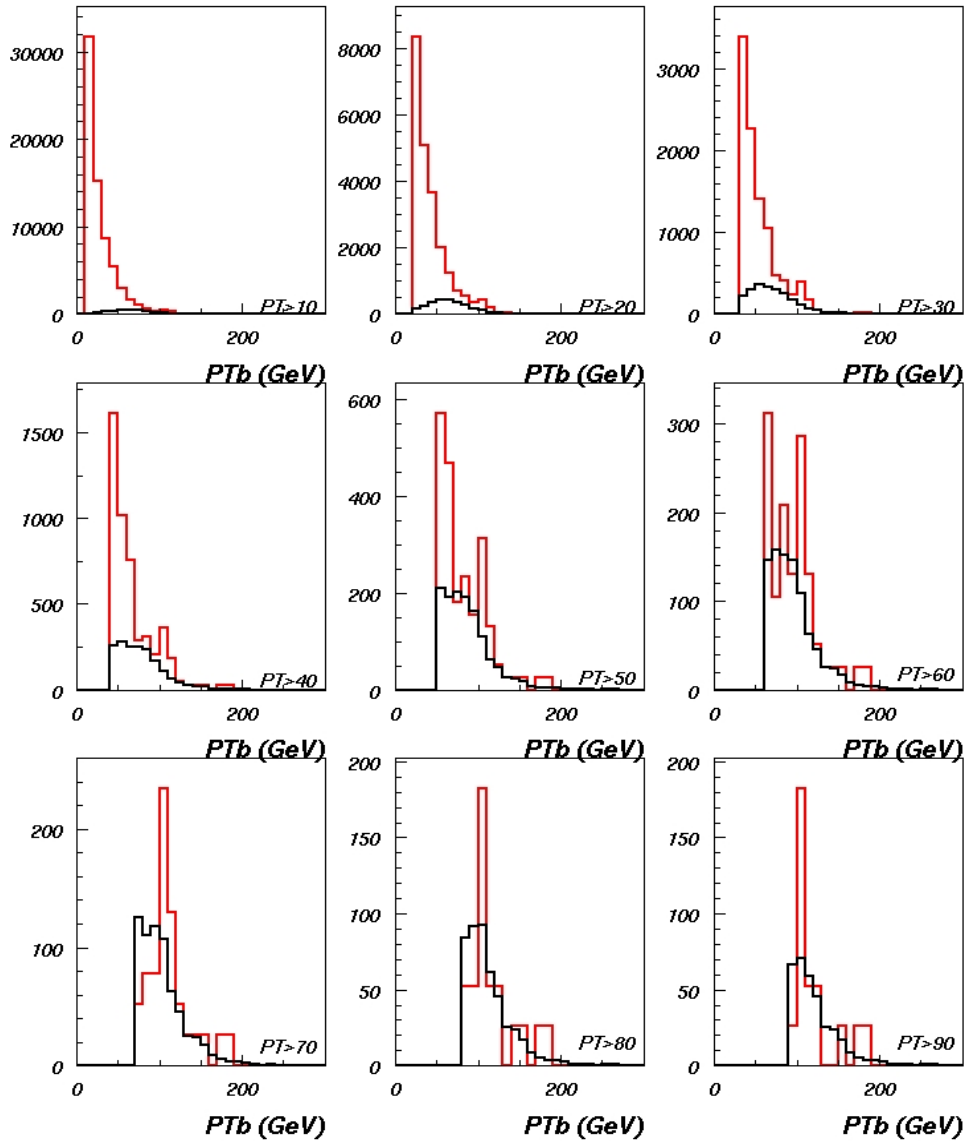
file *ntuple.kumac*

```
*****************************************
*** -> projecting to histograms

* define 1d histogram
1d 50 ! 15 0 300

* use IDH=50 to plot distribution
* within ID=50 histogram

set hcol 2
nt/plo 20.var.f(34) NB.and.$10 IDH=50

set hcol 1
nt/plo 10.var.f(34) NS.and.$10 IDH=50 OPTION=S
atit  'mWb (GeV)' 'number of events'
wait

*****************************************
```



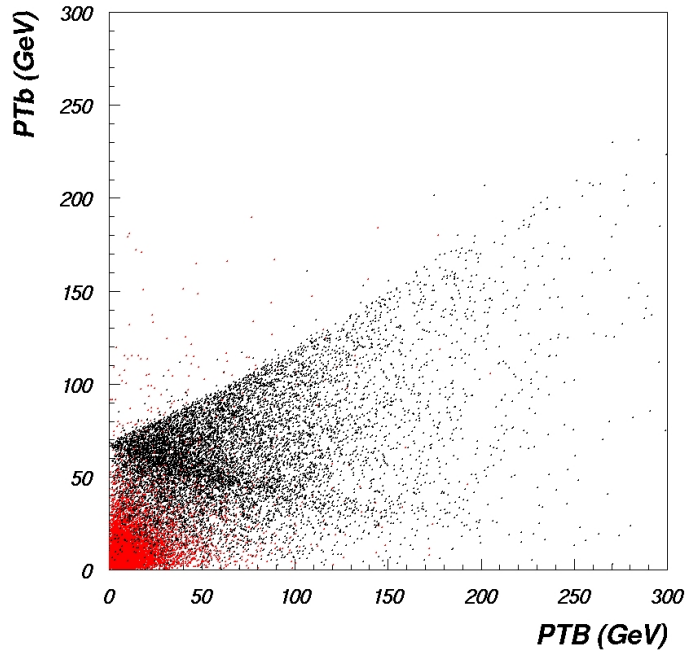
Example of ntuple event analysis with paw

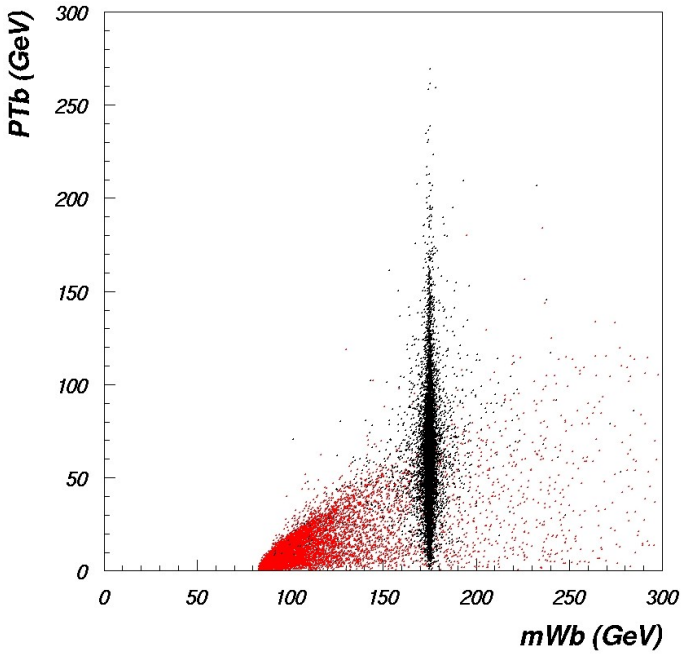
```
*****************************************
* EXAMPLE OF CYCLE PLOTTING WITH
* INCREASING OF PTB CUT

1d 40 ! 30 0 300

*define number of frames per page
*to put all 9 plots from "DO LOOP"
*into 1 page

set ysiz 35
set xsiz 30
ZONE 3 3

*** DO LOOP
DO I=10,90,10
CUT $1 var.f(4)>[I]
CUT $2 var.f(5)>[I]

set hcol 2
nt/plo 20.var.f(4) NB.and.$10 IDH=40

set hcol 1
nt/plo 10.var.f(4) NS.and.$10 IDH=40 OPTION=S

atit  'PTb (GeV)' ' '

*set the size of the text to be printed
set chhe 0.4

* print the cut value
itx 220 1000 PT>[I]
wait
ENDDO
wait
```



Example of ntuple event analysis with paw

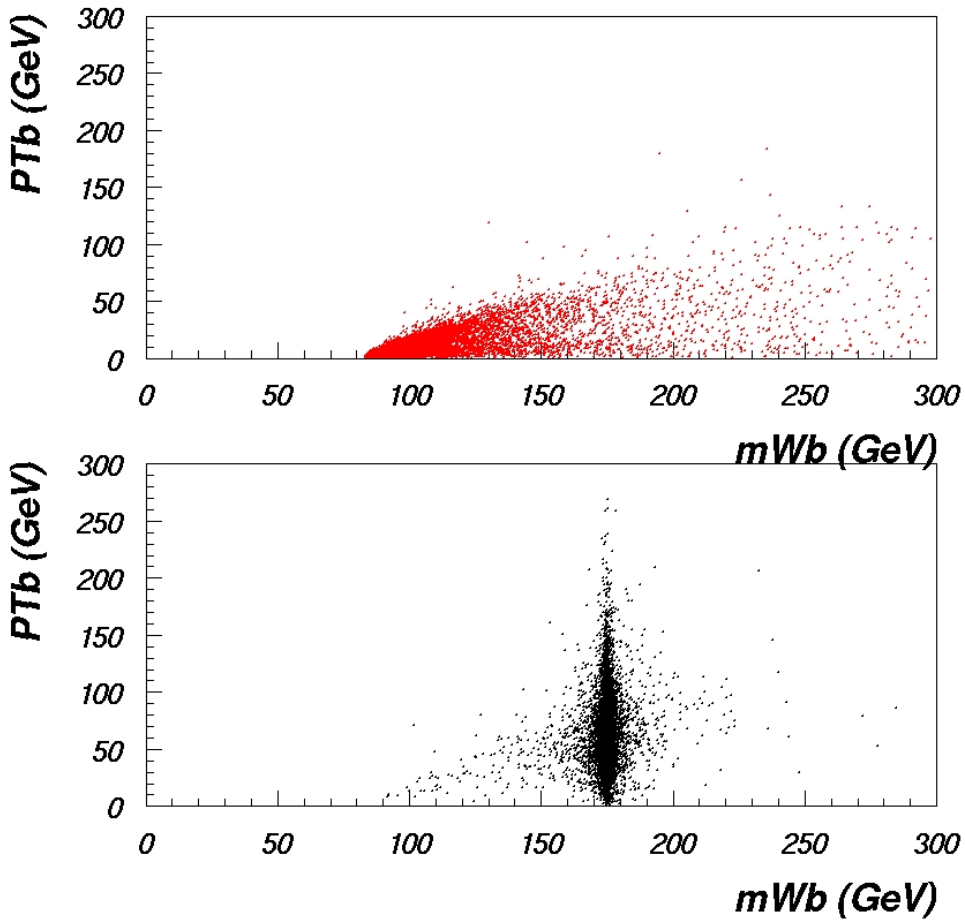
```
**2d plotting*****************
*

* set polymarker type to 8 (solid circle)
set mtyp 8

* set polymarker scale factor
set mscf 0.2

* create 2d histogram
2d 30 ! 30 0 300 30 0 300

*******************************
* plot PT b-bar versus PT b
*******************************
set pmci 2
nt/plo 20.var.f(4)%var.f(5) IDH=30

set pmci 1
nt/plo 10.var.f(4)%var.f(5) IDH=30 OPTION=S
atit 'PTB (GeV)' 'PTb (GeV)'

wait
*******************************
* plot PTb versus  MWb
*******************************
2d 30 ! 30 0 300 30 0 300
set pmci 2
nt/plo 20.var.f(4)%var.f(34) IDH=30

set pmci 1
nt/plo 10.var.f(4)%var.f(34) IDH=30 OPTION=S
atit 'mWb (GeV)' 'PTb (GeV)'
*********************************
```





Example of ntuple event analysis with paw

```
**2d plotting*****************
* plotting 2 plots in one frame
zone 1 2


set pmci 2;
nt/plo 20.var.f(4)%var.f(34)   NB   IDH=30
atit 'mWb (GeV)' 'PTb (GeV)'
set pmci 1
nt/plo 10.var.f(4)%var.f(34)   NS   IDH=30
atit 'mWb (GeV)' 'PTb (GeV)'
mess 'EXAMPLE 9'

*********************************
```



Example of ntuple event analysis with paw

```
*****************************************
** counting number of events  survived cuts*

** define cuts
CUT $1 var.f(4)>40; CUT $2 var.f(5)>40
CUT $3 var.f(34).lt.300.
CUT $10 $1.and.$2.and.$3

** define 1d histogram
1d 50 ! 100 0 300

** project background event into ID=50
nt/pro 50 20.var.f(34) NB.and.$10

** create empty vector
vec/cre m34(100)

** get content of histogram into vector
GET_VECT/CONTENTS 50 m34

** sum m34 contents to get number of back events
sigma back=vsum(m34)

** reset contents of histogram 50
his/oper/reset 50

** make similar operations with signal
nt/pro 50 10.var.f(34) NS.and.$10
GET_VECT/CONTENTS 50 m34
sigma signal=vsum(m34)

** calculate significance
sigma signif=signal/sqrt(back)

** print  number of  signal and back events
vec/print back ; vec/print signal ; vec/print signif
```

```
BACK(1) = 4914
SIGNAL(1) = 1752
SIGNIF(1) = 24.9929
```

Exercise#9

perform signal/background analysis
with PAW for $u\bar{d} \to e^+\nu b\bar{b}$
process starting from CalcHEP

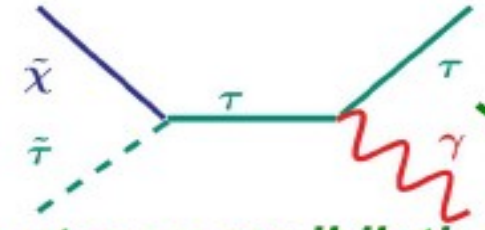
Examples of the CalcHEP application

Dark matter relic density – IsaRed and MicrOmegas

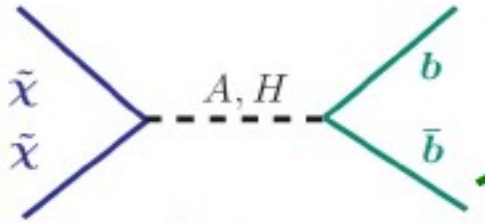
Neutralino relic density in mSUGRA

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

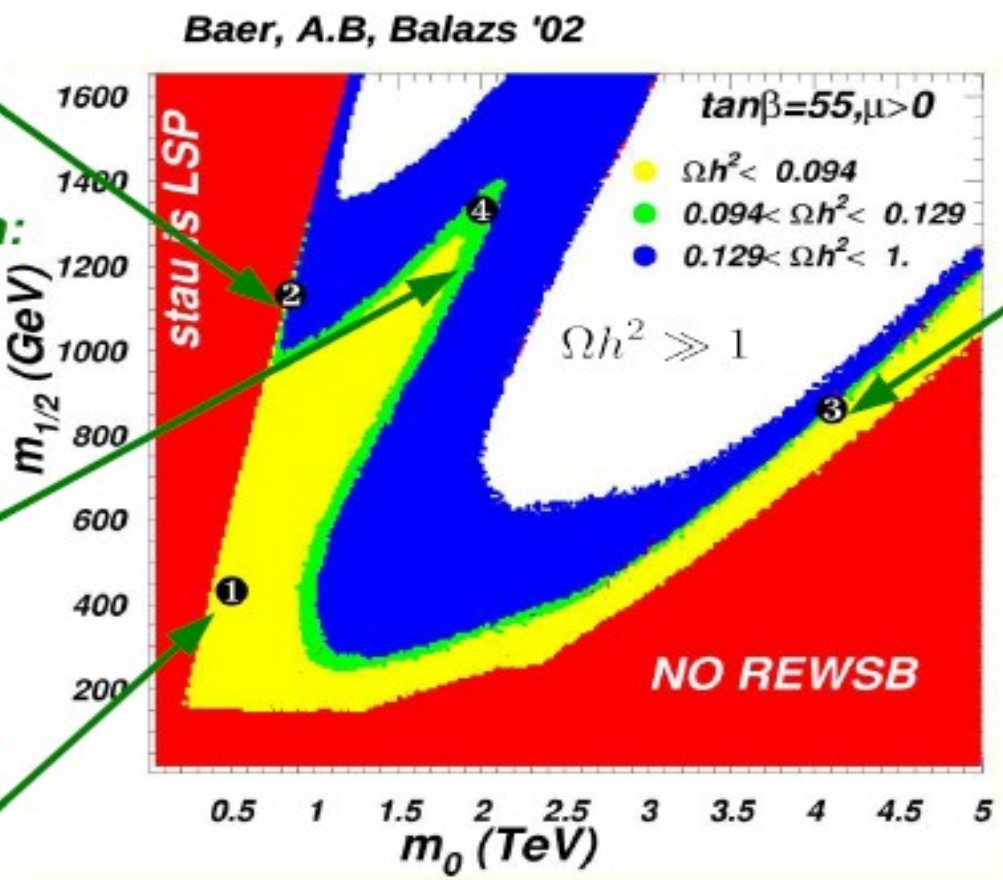
special regions with high σ_A ***are required to get*** $0.094 < \Omega h^2 < 0.129$



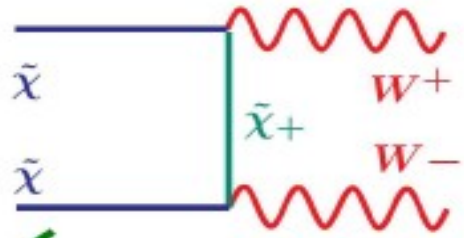
2. stau coannihilation:
degenerate χ and stau



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

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

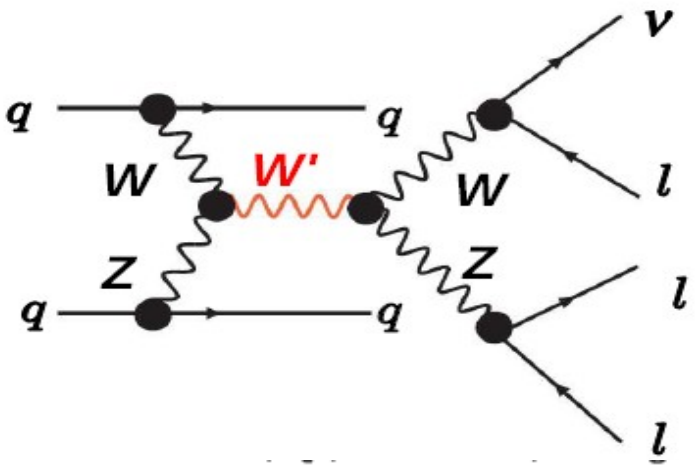
additional regions:
Z/h annihilation
stop coannihilation

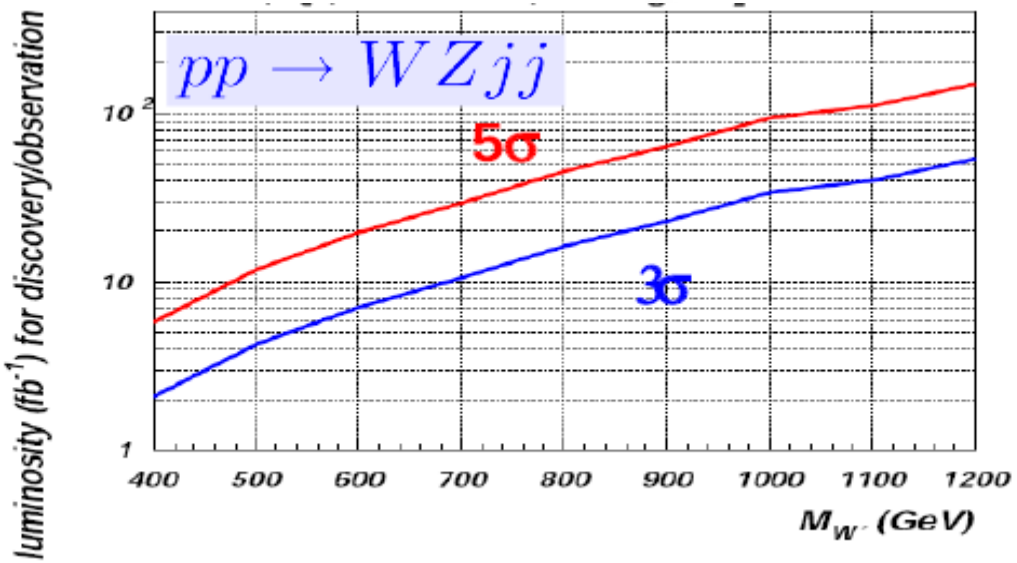
W' 3-lepton signatures from 3-site Higgsless model

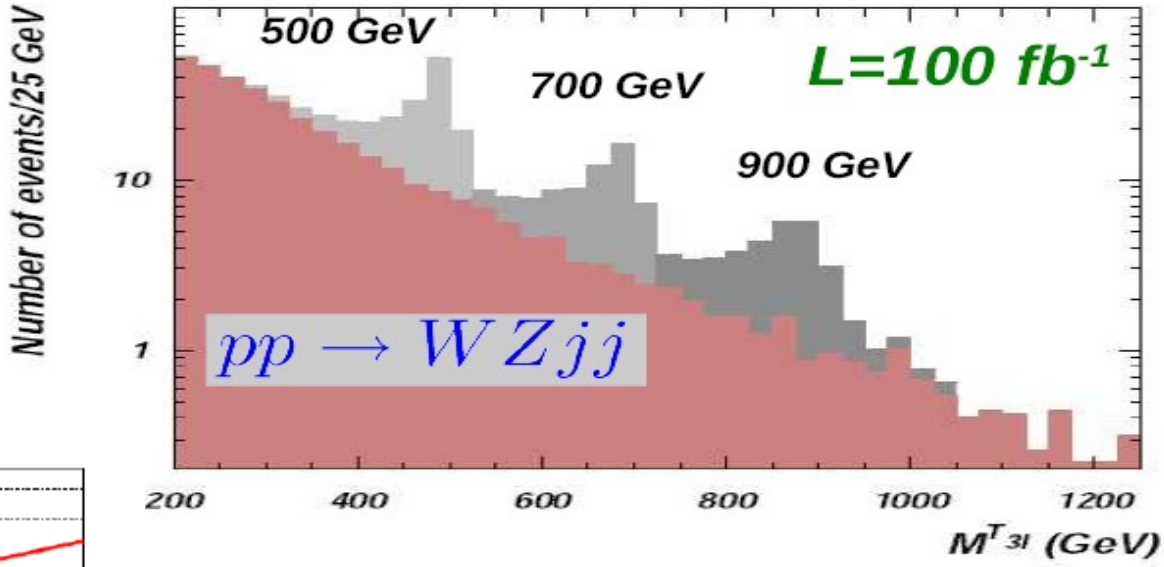
- **CMS: W' 3-lepton signatures from 3-site Higgsless model**

LHC reach for WZ->W' process

[AB, Chivukula, Christensen, He, Kuang, Pukhov, Qi, Simmons, Zhang '07]



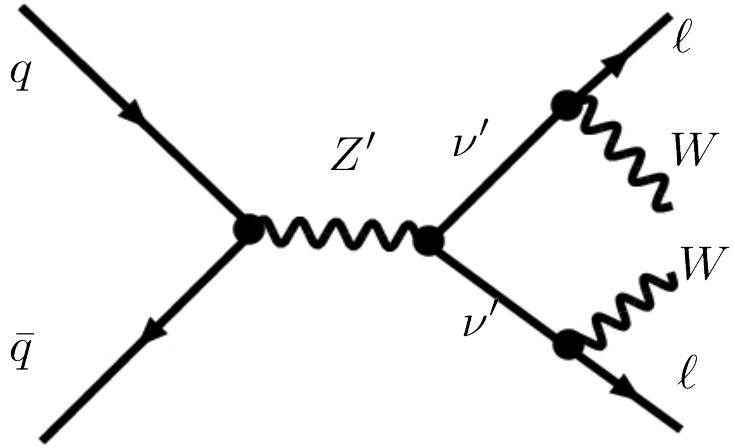


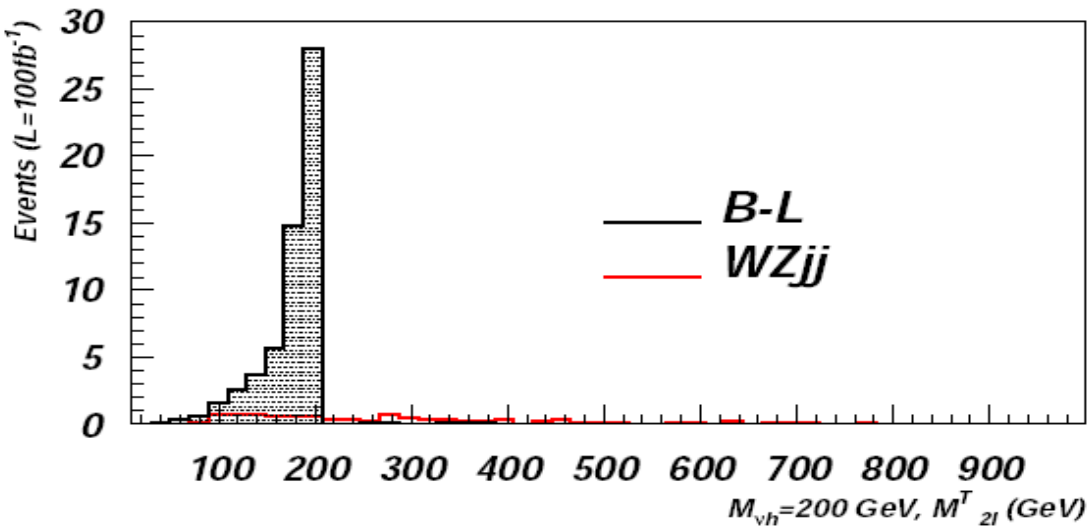


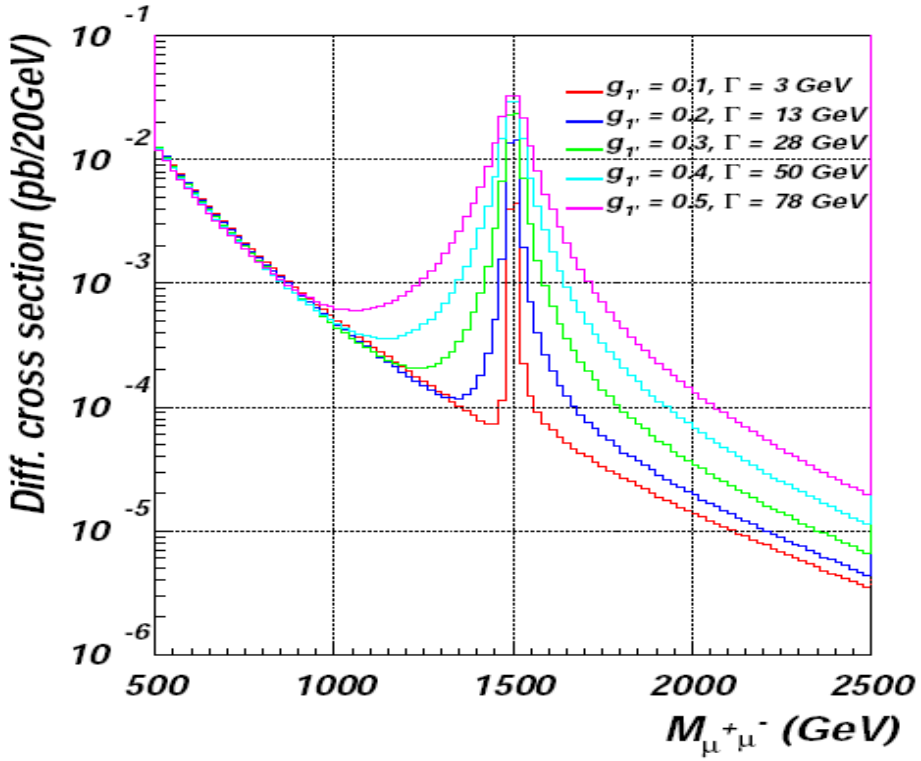
B-L extension of SM

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

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

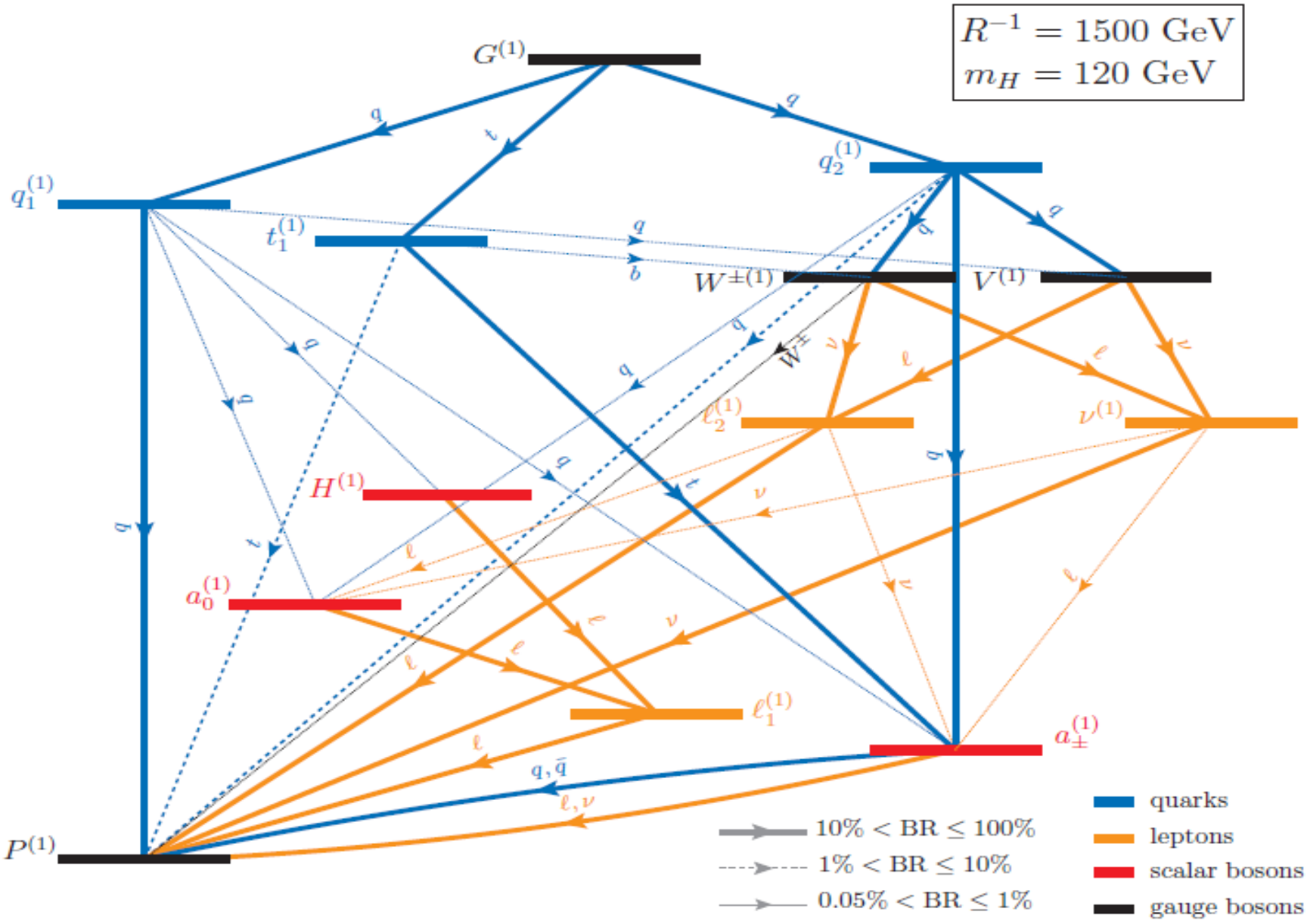






Universal Extra Dimensions

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

Home
Symbolic Results
Numerical Results
Events Library
Process Library
Help

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

Results from calchep_batch

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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	✓

Results from calchep_batch

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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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Help

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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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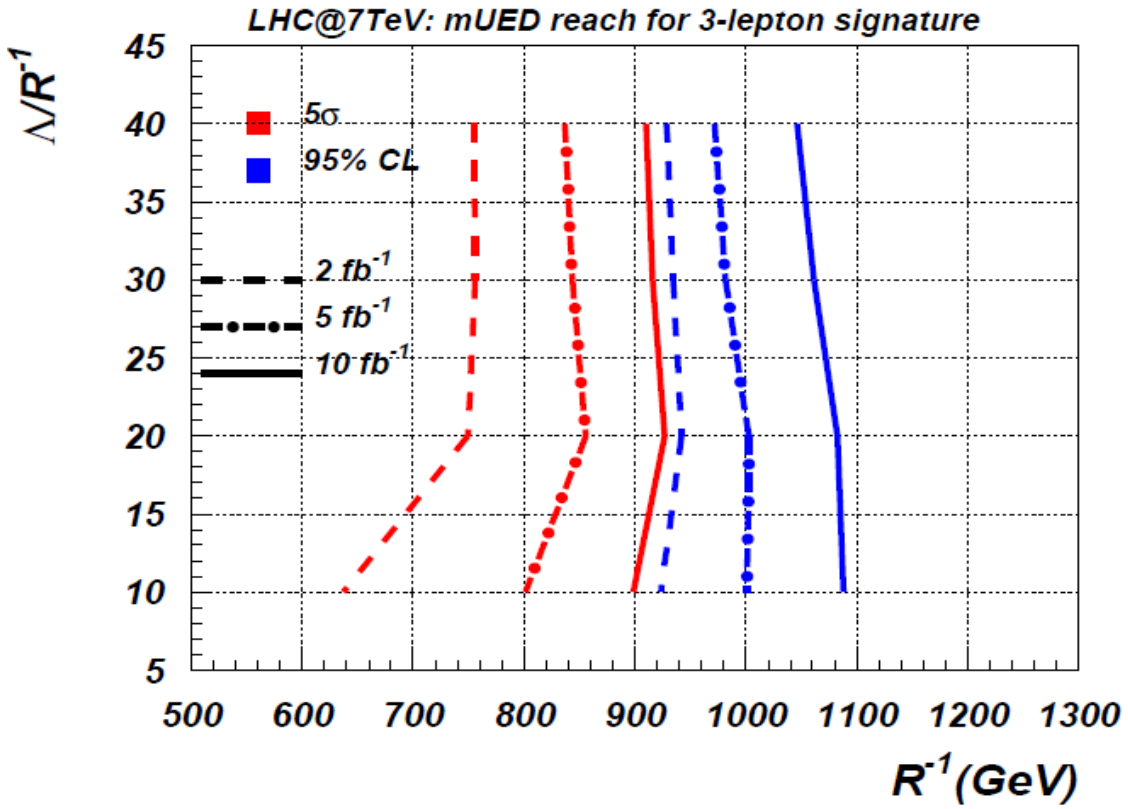
Process Library

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	



Lecture IV

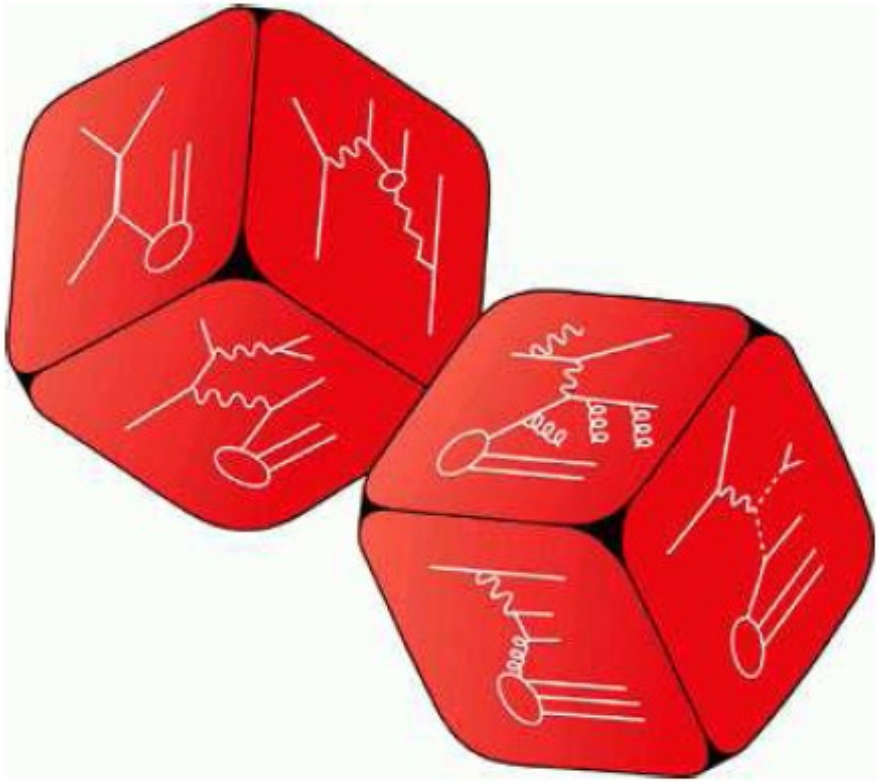
- PYTHIA
- PGS
- link to user-defined process via LHE files

current and general remarks

- Most of you should get more experience with Linux, start with Linux primer!
- Ask more questions, try examples
- Use launchpad to file problems or ask questions – answers will be available to everybody!

- More tools exist – those were of my personal preference
- *Read manuals – they have some more details*
- *Automation tools are powerful but should not blindly trusted (or blamed) - use independent programs to for double check, use limits to check if your results make sense*

A tour to Monte Carlo



. . . because Einstein was wrong: God does throw dice!

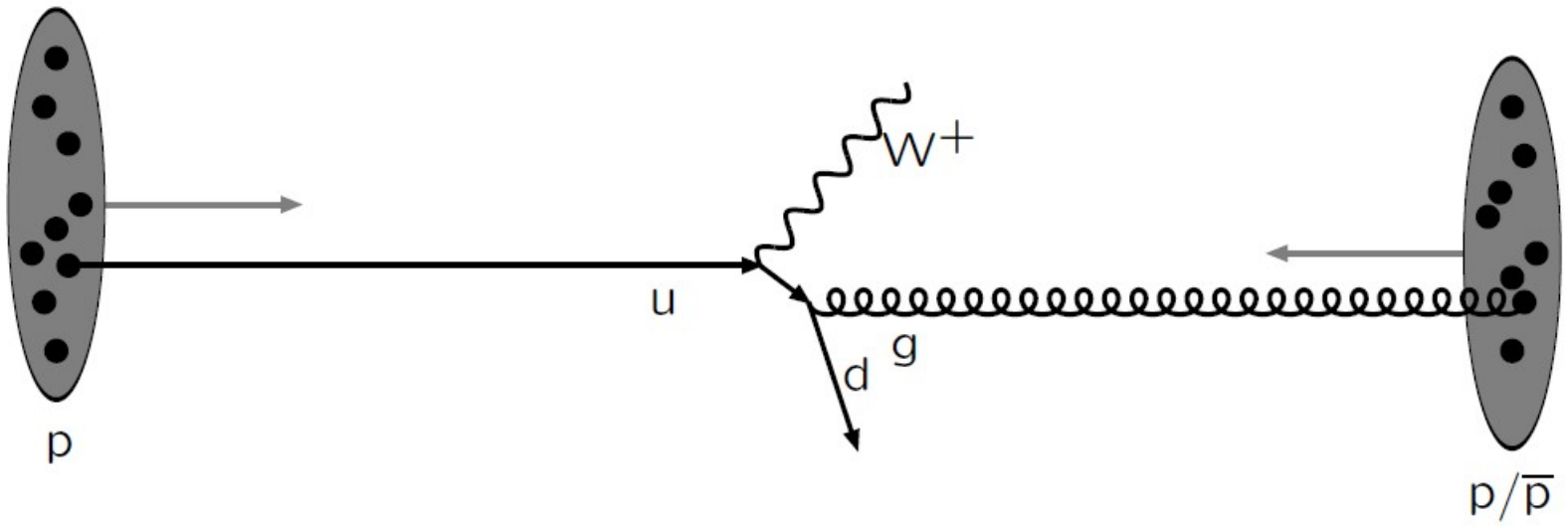
Quantum mechanics: amplitudes $\Longrightarrow$ probabilities

Anything that possibly can happen, will! (but more or less often)

Event Structure

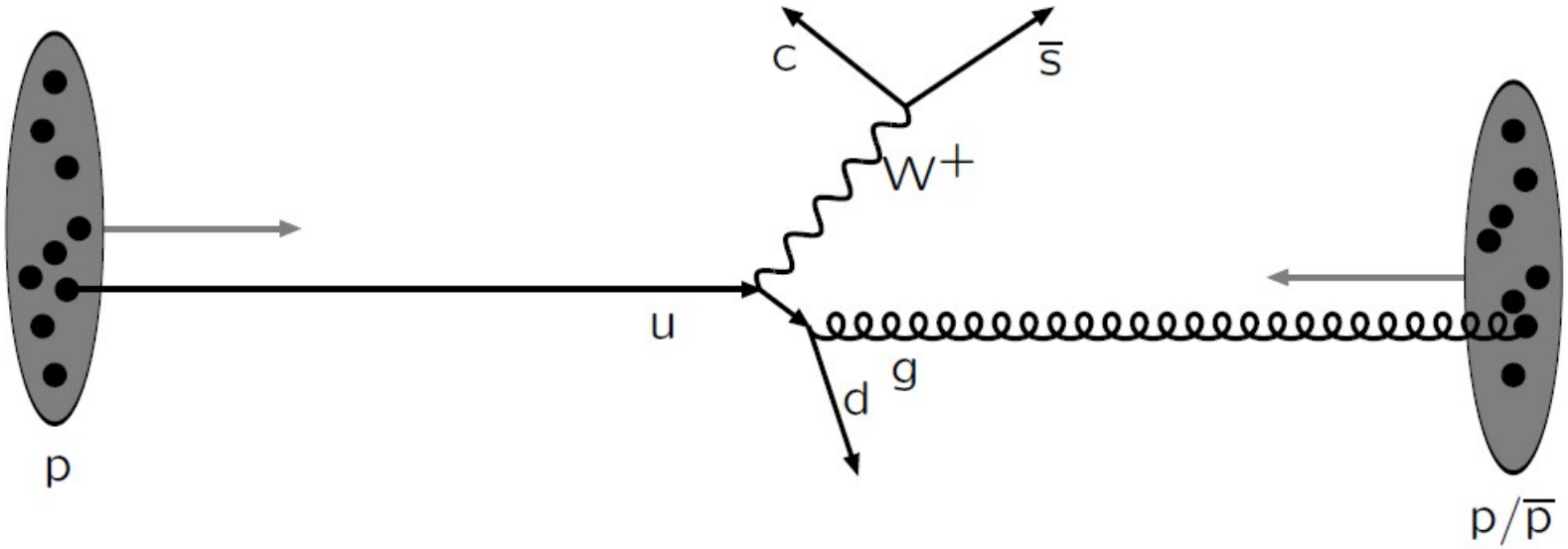
Incoming beams: parton densities

Event Structure



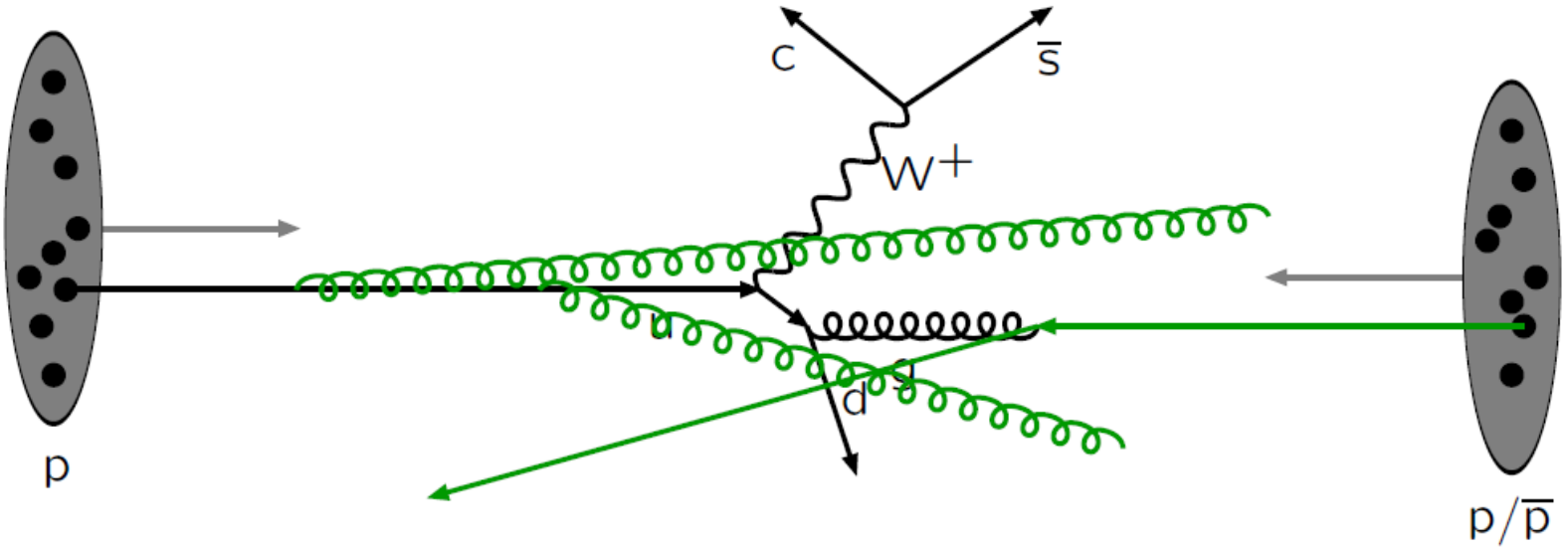
Hard subprocess: described by matrix elements

Event Structure



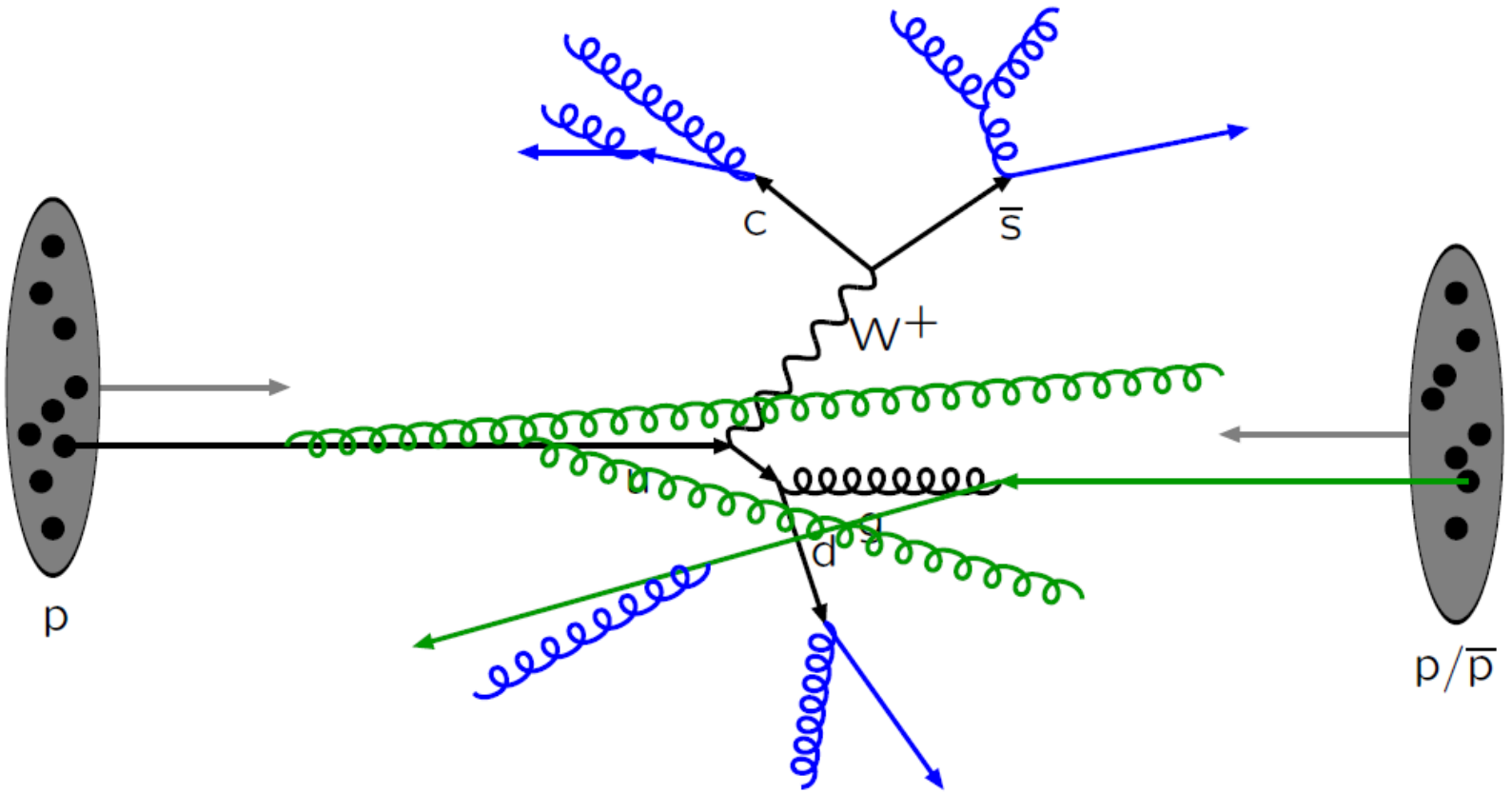
Resonance decays: correlated with hard subprocess

Event Structure



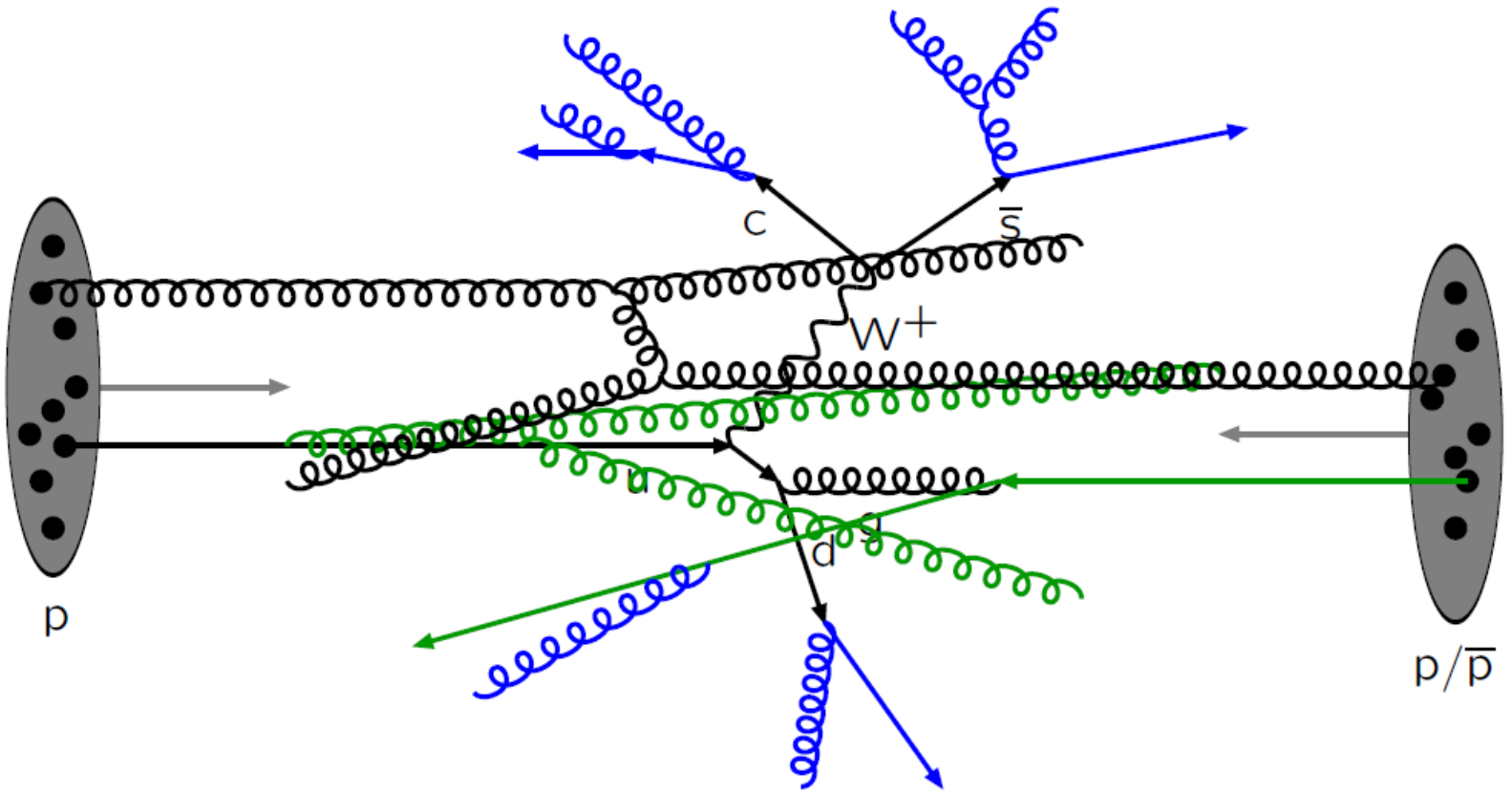
Initial-state radiation: spacelike parton showers

Event Structure



Final-state radiation: timelike parton showers

Event Structure



Multiple parton–parton interactions . . .

Introduction to PYTHIA(1)

http://www.thep.lu.se/~torbjorn/Pythia.html

Introduction

PYTHIA and JETSET are programs for the generation of high-energy physics events, i.e. for the description of collisions at high energies between elementary particles such as e+, e-, p and pbar in various combinations. Together they contain theory and models for a number of physics aspects, including hard and soft interactions, parton distributions, initial and final state parton showers, multiple interactions, fragmentation and decay. They are largely based on original research, but also borrow many formulae and other knowledge from the literature.

The main PYTHIA author is Torbjörn Sjöstrand.

The supersymmetric and technicolor extensions have been implemented by Stephen Mrenna.

Lepton and baryon number violation in Supersymmetry, and a new improved model for multiple interactions, have been implemented by Peter Skands.

Introduction to PYTHIA(2)

http://www.thep.lu.se/~torbjorn/Pythia.html

LUND UNIVERSITY

PYTHIA

Index

Authors

Torbjörn Sjöstrand
Jesper Christiansen
Philip Ilten
Stephen Mrenna
Stefan Prestel
Peter Skands

Recent program versions: PYTHIA 6.4

PYTHIA 6.4 is a direct continuation of 6.3, the transition mainly marked by the appearance of an updated manual. With the release of PYTHIA 8.1 in 2007 it lost its status as the official current version.

Both 6.4 and 8.1 have continued to be maintained in parallel, however, since 8.1 initially was untested and missed some features, and since the transition from existing Fortran applications to new C++ ones requires some planning and effort in the affected experimental community. As 8.1 has matured and gained in acceptance, development efforts have gradually shifted away from 6.4. Bug fixes and new tunes have still been introduced in recent years, but not any new physics features.

On 13 December 2012 development of PYTHIA 6 formally stopped, and plans for winding down support were presented. See official letter here.

While PYTHIA 8.1 in almost all respects can do more and better than the 6.4 versions, there are some areas still missing, notably e p, gamma p and gamma gamma physics. These have not been given the highest priority in the LHC era, so for such application it is still necessary to use PYTHIA 6.4. For all p p, p pbar and e+ e- physics, however, is is now strongly recommended to turn to PYTHIA 8.1.

Latest 6.4 version

Starting with version 6.410 the main repository of PYTHIA subversions has been migrated to the HepForge development platform.

The new PYTHIA 6.4 development area is found **here** . It contains downloads, update notes and example programs, as in the current webpages, but adds new possibilities for bug tracking, wikis and discussions.

At the same time, the monolithic structure, with all Fortran code in a single file, has been replaced with distribution as a gzipped tar-ball. Alternatively SVN can be used.

Latest non-HepForge 6.4 version

The most recent version of the program, before the move to HepForge, is

- The PYTHIA code (6.409)

Getting started with PYTHIA

- *Tutorials*

http://www-cdf.fnal.gov/physics/lectures/pythia_Dec2004.html

- *The latest 6.4 source – see dropbox:* **pythia-6.4.28.f**
- *The main program examples*

Sample main programs

In order to illustrate how to run PYTHIA 6.4, a few sample main programs are collected below. Most are very simple, to help new users get started. No independent documentation is available beyond what is found in each file.

- standard declarations and commonblocks, for easy copying
- the very most trivial test of PYTHIA
- run all existing subprocesses one at a time
- Z0 production at LEP 1

- *Linking and running: this is a FORTRAN package*
  - **f77 -c pythia64*xx*.f**
  - **f77 -o main6*yy*.x main6n.f pythia64*xx*.o**

    (*use* f77,g77 *or* gfortran)

PYTHIA overview(1)

must take a look at video lectures on MC generators – on PYTHIA WWW page!

LUND UNIVERSITY

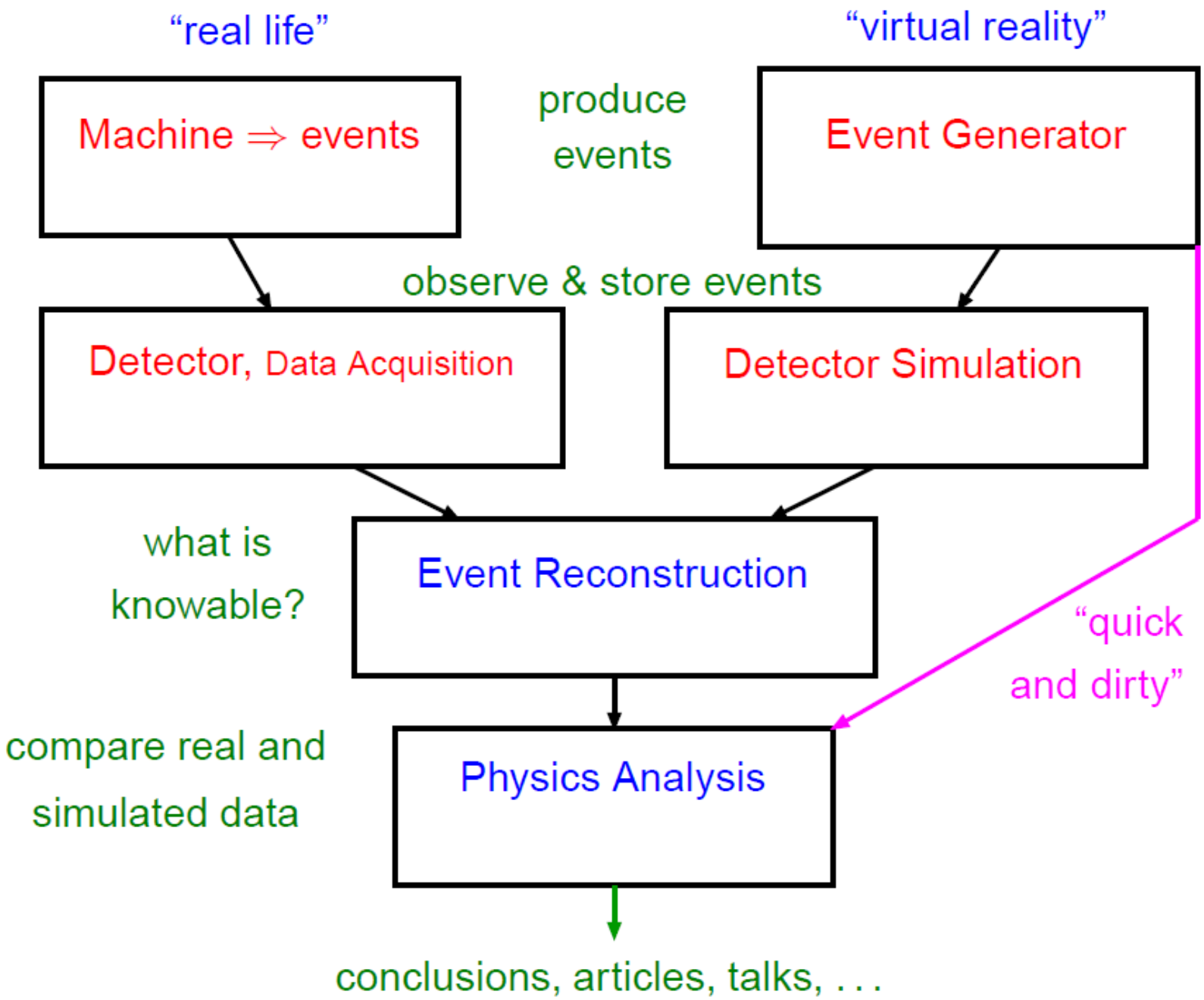
Academic Training Lectures
CERN
4, 5, 6, 7 April 2005

Monte Carlo Generators for the LHC

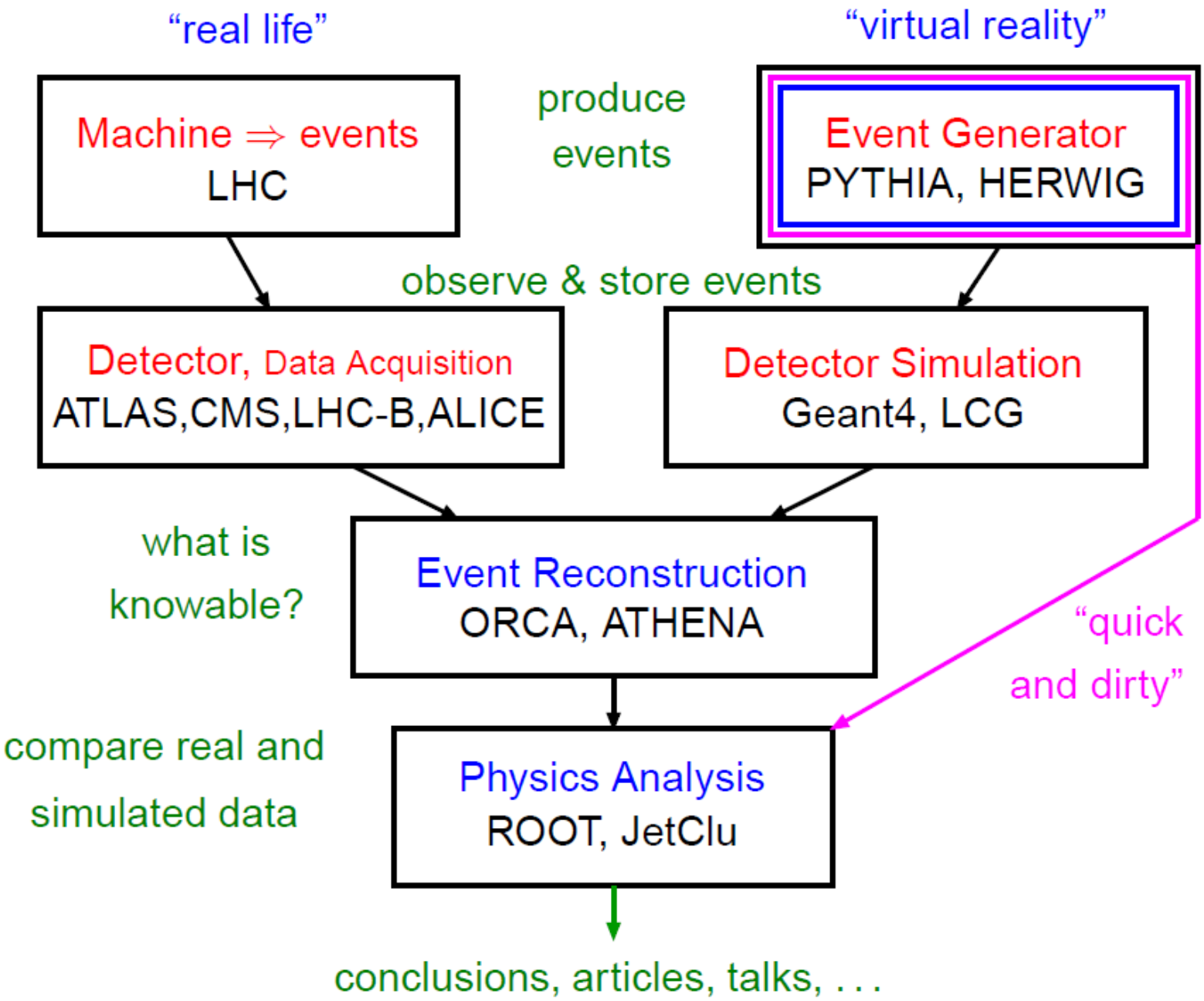
Torbjörn Sjöstrand
CERN and Lund University

1. **(today) Introduction and Overview; Matrix Elements**
2. (Tuesday) Parton Showers; Matching Issues
3. (Wednesday) Multiple Interactions and Beam Remnants
4. (Thursday) Hadronization and Decays; Summary and Outlook

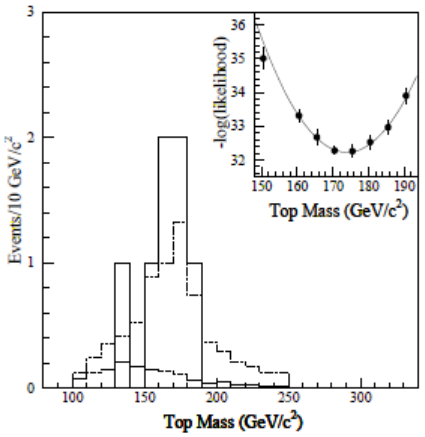
PYTHIA overview(2)



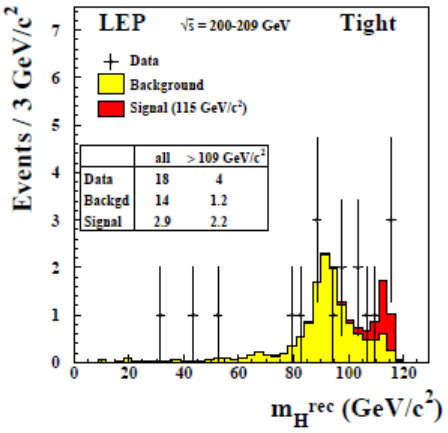
PYTHIA overview(2)



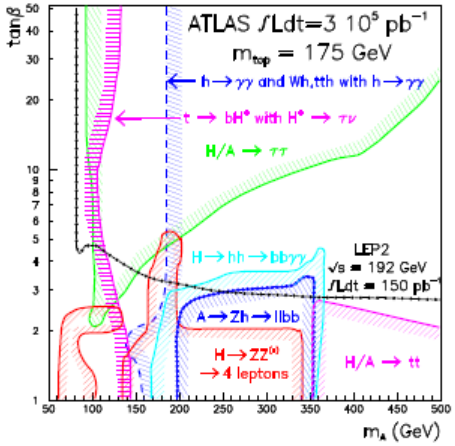
Why generators?



top discovery and mass determination



Higgs (non) discovery



Higgs and supersymmetry exploration

not feasible without generators

- *Allow theoretical and experimental studies of complex multiparticle physics*
- *Analytical tools ca not represent the complexity of the real picture!*
- *Many aspects of **theory-phenomenology-experiment** to be answered:*
  - *from complexity of theoretical picture*
  - *to phenomenological understanding of features and observability of signal over the background*
  - *to understanding/optimization of detector features/requirements, acceptances to observe and study this theory*

PDG Particle Codes

A. Fundamental objects

1	d	11	e^-	21	g					add − sign for antiparticle, where appropriate
2	u	12	ν_e	22	γ	32	Z'^0			
3	s	13	μ^-	23	Z^0	33	Z''^0			
4	c	14	ν_μ	24	W^+	34	W'^+			
5	b	15	τ^-	25	h^0	35	H^0	37	H^+	+ diquarks, SUSY,
6	t	16	ν_τ			36	A^0	39	Graviton	technicolor, . . .

B. Mesons

$100\,|q_1| + 10\,|q_2| + (2s+1)$ with $|q_1| \geq |q_2|$

particle if heaviest quark u, $\bar{s}$, c, $\bar{b}$; else antiparticle

111	π^0	311	K^0	130	K^0_L	221	η^0	411	D^+	431	D_s^+
211	π^+	321	K^+	310	K^0_S	331	η'^0	421	D^0	443	J/ψ

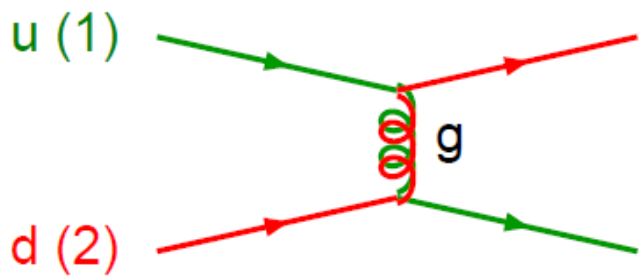
C. Baryons

$1000\,q_1 + 100\,q_2 + 10\,q_3 + (2s+1)$

with $q_1 \geq q_2 \geq q_3$, or Λ-like $q_1 \geq q_3 \geq q_2$

2112	n	3122	Λ^0	2224	Δ^{++}	3214	Σ^{*0}
2212	p	3212	Σ^0	1114	Δ^-	3334	Ω^-

Cross sections and kinematics

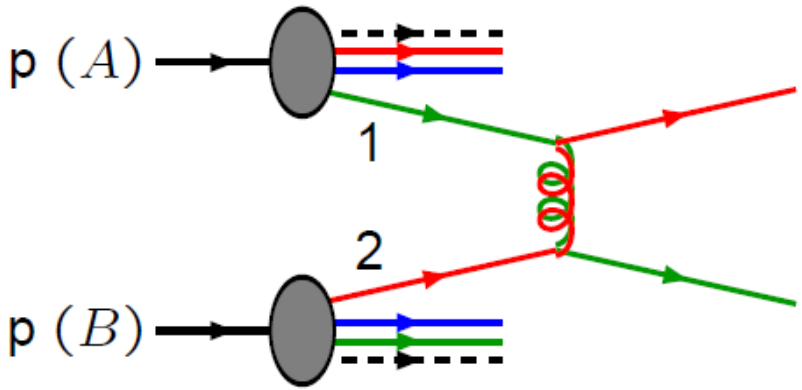


$$\hat{s} = (p_1 + p_2)^2$$

$$\hat{t} = (p_1 - p_3)^2 = -\hat{s}(1 - \cos\hat{\theta})/2$$

$$\hat{u} = (p_1 - p_4)^2 = -\hat{s}(1 + \cos\hat{\theta})/2$$

$$\mathrm{qq}' \to \mathrm{qq}' \quad : \quad \frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}\hat{t}} = \frac{\pi}{\hat{s}^2}\frac{4}{9}\alpha_s^2\frac{\hat{s}^2 + \hat{u}^2}{\hat{t}^2} \qquad (\sim \text{Rutherford})$$



$$s = (p_A + p_B)^2$$

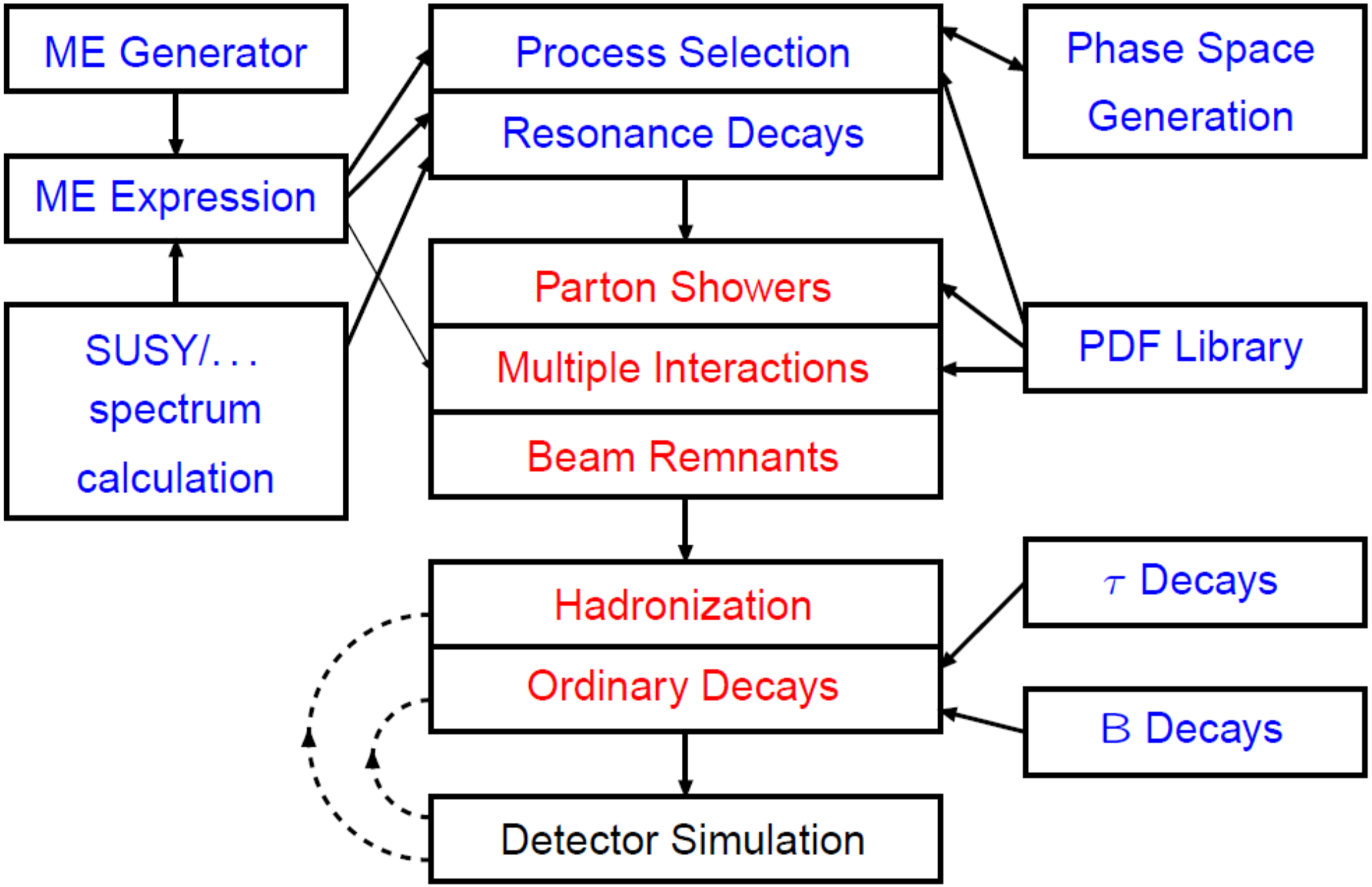
$$x_1 \approx E_1/E_A$$

$$x_2 \approx E_2/E_B$$

$$\hat{s} = x_1 x_2 s$$

$$\sigma = \sum_{i,j} \iiint \mathrm{d}x_1\,\mathrm{d}x_2\,\mathrm{d}\hat{t}\, f_i^{(A)}(x_1, Q^2)\, f_j^{(B)}(x_2, Q^2)\,\frac{\mathrm{d}\hat{\sigma}_{ij}}{\mathrm{d}\hat{t}}$$

Picture of the MC generation



PYTHIA subprocesses(1)

No.	Subprocess
Hard QCD processes:	
11	$f_i f_j \to f_i f_j$
12	$f_i \bar{f}_i \to f_k \bar{f}_k$
13	$f_i \bar{f}_i \to gg$
28	$f_i g \to f_i g$
53	$gg \to f_k \bar{f}_k$
68	$gg \to gg$
Soft QCD processes:	
91	elastic scattering
92	single diffraction (XB)
93	single diffraction (AX)
94	double diffraction
95	low-$p_\perp$ production
Open heavy flavour:	
(also fourth generation)	
81	$f_i \bar{f}_i \to Q_k \bar{Q}_k$
82	$gg \to Q_k \bar{Q}_k$
83	$q_i f_j \to Q_k f_l$

No.	Subprocess
84	$g\gamma \to Q_k \bar{Q}_k$
85	$\gamma\gamma \to F_k \bar{F}_k$
Closed heavy flavour:	
86	$gg \to J/\psi g$
87	$gg \to \chi_{0c} g$
88	$gg \to \chi_{1c} g$
89	$gg \to \chi_{2c} g$
104	$gg \to \chi_{0c}$
105	$gg \to \chi_{2c}$
106	$gg \to J/\psi\gamma$
107	$g\gamma \to J/\psi g$
108	$\gamma\gamma \to J/\psi\gamma$
W/Z production:	
1	$f_i \bar{f}_i \to \gamma^*/Z^0$
2	$f_i \bar{f}_j \to W^\pm$
22	$f_i \bar{f}_i \to Z^0 Z^0$
23	$f_i \bar{f}_j \to Z^0 W^\pm$
25	$f_i \bar{f}_i \to W^+ W^-$
15	$f_i \bar{f}_i \to g Z^0$

No.	Subprocess
16	$f_i \bar{f}_j \to g W^\pm$
30	$f_i g \to f_i Z^0$
31	$f_i g \to f_k W^\pm$
19	$f_i \bar{f}_i \to \gamma Z^0$
20	$f_i \bar{f}_j \to \gamma W^\pm$
35	$f_i \gamma \to f_i Z^0$
36	$f_i \gamma \to f_k W^\pm$
69	$\gamma\gamma \to W^+ W^-$
70	$\gamma W^\pm \to Z^0 W^\pm$
Prompt photons:	
14	$f_i \bar{f}_i \to g\gamma$
18	$f_i \bar{f}_i \to \gamma\gamma$
29	$f_i g \to f_i \gamma$
114	$gg \to \gamma\gamma$
115	$gg \to g\gamma$
Deeply Inel. Scatt.:	
10	$f_i f_j \to f_k f_l$
99	$\gamma^* q \to q$

PYTHIA subprocesses(2)

No.	Subprocess
Photon-induced:	
33	$f_i\gamma \to f_i g$
34	$f_i\gamma \to f_i\gamma$
54	$g\gamma \to f_k\bar{f}_k$
58	$\gamma\gamma \to f_k\bar{f}_k$
131	$f_i\gamma_T^* \to f_i g$
132	$f_i\gamma_L^* \to f_i g$
133	$f_i\gamma_T^* \to f_i\gamma$
134	$f_i\gamma_L^* \to f_i\gamma$
135	$g\gamma_T^* \to f_i\bar{f}_i$
136	$g\gamma_L^* \to f_i\bar{f}_i$
137	$\gamma_T^*\gamma_T^* \to f_i\bar{f}_i$
138	$\gamma_T^*\gamma_L^* \to f_i\bar{f}_i$
139	$\gamma_L^*\gamma_T^* \to f_i\bar{f}_i$
140	$\gamma_L^*\gamma_L^* \to f_i\bar{f}_i$
80	$q_i\gamma \to q_k\pi^\pm$
Light SM Higgs:	
3	$f_i\bar{f}_i \to h^0$
24	$f_i\bar{f}_i \to Z^0h^0$
26	$f_i\bar{f}_j \to W^\pm h^0$

No.	Subprocess
32	$f_i g \to f_i h^0$
102	$gg \to h^0$
103	$\gamma\gamma \to h^0$
110	$f_i\bar{f}_i \to \gamma h^0$
111	$f_i\bar{f}_i \to g h^0$
112	$f_i g \to f_i h^0$
113	$gg \to g h^0$
121	$gg \to Q_k\bar{Q}_k h^0$
122	$q_i\bar{q}_i \to Q_k\bar{Q}_k h^0$
123	$f_i f_j \to f_i f_j h^0$
124	$f_i f_j \to f_k f_l h^0$
Heavy SM Higgs:	
5	$Z^0Z^0 \to h^0$
8	$W^+W^- \to h^0$
71	$Z_L^0Z_L^0 \to Z_L^0Z_L^0$
72	$Z_L^0Z_L^0 \to W_L^+W_L^-$
73	$Z_L^0W_L^\pm \to Z_L^0W_L^\pm$
76	$W_L^+W_L^- \to Z_L^0Z_L^0$
77	$W_L^\pm W_L^\pm \to W_L^\pm W_L^\pm$

No.	Subprocess
BSM Neutral Higgs:	
151	$f_i\bar{f}_i \to H^0$
152	$gg \to H^0$
153	$\gamma\gamma \to H^0$
171	$f_i\bar{f}_i \to Z^0H^0$
172	$f_i\bar{f}_j \to W^\pm H^0$
173	$f_i f_j \to f_i f_j H^0$
174	$f_i f_j \to f_k f_l H^0$
181	$gg \to Q_k\bar{Q}_k H^0$
182	$q_i\bar{q}_i \to Q_k\bar{Q}_k H^0$
183	$f_i\bar{f}_i \to gH^0$
184	$f_i g \to f_i H^0$
185	$gg \to gH^0$
156	$f_i\bar{f}_i \to A^0$
157	$gg \to A^0$
158	$\gamma\gamma \to A^0$
176	$f_i\bar{f}_i \to Z^0A^0$
177	$f_i\bar{f}_j \to W^\pm A^0$
178	$f_i f_j \to f_i f_j A^0$
179	$f_i f_j \to f_k f_l A^0$

PYTHIA subprocesses(3)

No.	Subprocess
186	$gg \to Q_k\overline{Q}_kA^0$
187	$q_i\overline{q}_i \to Q_k\overline{Q}_kA^0$
188	$f_i\overline{f}_i \to gA^0$
189	$f_ig \to f_iA^0$
190	$gg \to gA^0$
Charged Higgs:	
143	$f_i\overline{f}_j \to H^+$
161	$f_ig \to f_kH^+$
Higgs pairs:	
297	$f_i\overline{f}_j \to H^\pm h^0$
298	$f_i\overline{f}_j \to H^\pm H^0$
299	$f_i\overline{f}_i \to A^0h^0$
300	$f_i\overline{f}_i \to A^0H^0$
301	$f_i\overline{f}_i \to H^+H^-$
New gauge bosons:	
141	$f_i\overline{f}_i \to \gamma/Z^0/Z'^0$
142	$f_i\overline{f}_j \to W'^+$
144	$f_i\overline{f}_j \to R$

No.	Subprocess
Technicolor:	
149	$gg \to \eta_{tc}$
191	$f_i\overline{f}_i \to \rho^0_{tc}$
192	$f_i\overline{f}_j \to \rho^+_{tc}$
193	$f_i\overline{f}_i \to \omega^0_{tc}$
194	$f_i\overline{f}_i \to f_k\overline{f}_k$
195	$f_i\overline{f}_j \to f_k\overline{f}_l$
361	$f_i\overline{f}_i \to W^+_LW^-_L$
362	$f_i\overline{f}_i \to W^\pm_L\pi^\mp_{tc}$
363	$f_i\overline{f}_i \to \pi^+_{tc}\pi^-_{tc}$
364	$f_i\overline{f}_i \to \gamma\pi^0_{tc}$
365	$f_i\overline{f}_i \to \gamma\pi'^0_{tc}$
366	$f_i\overline{f}_i \to Z^0\pi^0_{tc}$
367	$f_i\overline{f}_i \to Z^0\pi'^0_{tc}$
368	$f_i\overline{f}_i \to W^\pm\pi^\mp_{tc}$
370	$f_i\overline{f}_j \to W^\pm_LZ^0_L$
371	$f_i\overline{f}_j \to W^\pm_L\pi^0_{tc}$
372	$f_i\overline{f}_j \to \pi^\pm_{tc}Z^0_L$
373	$f_i\overline{f}_j \to \pi^\pm_{tc}\pi^0_{tc}$
374	$f_i\overline{f}_j \to \gamma\pi^\pm_{tc}$

No.	Subprocess
375	$f_i\overline{f}_j \to Z^0\pi^\pm_{tc}$
376	$f_i\overline{f}_j \to W^\pm\pi^0_{tc}$
377	$f_i\overline{f}_j \to W^\pm\pi'^0_{tc}$
381	$q_iq_j \to q_iq_j$
382	$q_i\overline{q}_i \to q_k\overline{q}_k$
383	$q_i\overline{q}_i \to gg$
384	$f_ig \to f_ig$
385	$gg \to q_k\overline{q}_k$
386	$gg \to gg$
387	$f_i\overline{f}_i \to Q_k\overline{Q}_k$
388	$gg \to Q_k\overline{Q}_k$
Compositeness:	
146	$e\gamma \to e^*$
147	$dg \to d^*$
148	$ug \to u^*$
167	$q_iq_j \to d^*q_k$
168	$q_iq_j \to u^*q_k$
169	$q_i\overline{q}_i \to e^\pm e^{*\mp}$
165	$f_i\overline{f}_i(\to \gamma^*/Z^0) \to f_k\overline{f}_k$
166	$f_i\overline{f}_j(\to W^\pm) \to f_k\overline{f}_l$

PYTHIA subprocesses(4)

No.	Subprocess
Leptoquarks:	
145	$q_i \ell_j \to L_Q$
162	$qg \to \ell L_Q$
163	$gg \to L_Q \overline{L}_Q$
164	$q_i \overline{q}_i \to L_Q \overline{L}_Q$
Left–right symmetry:	
341	$\ell_i \ell_j \to H_L^{\pm\pm}$
342	$\ell_i \ell_j \to H_R^{\pm\pm}$
343	$\ell_i^{\pm} \gamma \to H_L^{\pm\pm} e^{\mp}$
344	$\ell_i^{\pm} \gamma \to H_R^{\pm\pm} e^{\mp}$
345	$\ell_i^{\pm} \gamma \to H_L^{\pm\pm} \mu^{\mp}$
346	$\ell_i^{\pm} \gamma \to H_R^{\pm\pm} \mu^{\mp}$
347	$\ell_i^{\pm} \gamma \to H_L^{\pm\pm} \tau^{\mp}$
348	$\ell_i^{\pm} \gamma \to H_R^{\pm\pm} \tau^{\mp}$
349	$f_i \overline{f}_i \to H_L^{++} H_L^{--}$
350	$f_i \overline{f}_i \to H_R^{++} H_R^{--}$
351	$f_i f_j \to f_k f_l H_L^{\pm\pm}$
352	$f_i f_j \to f_k f_l H_R^{\pm\pm}$
353	$f_i \overline{f}_i \to Z_R^0$
354	$f_i \overline{f}_j \to W_R^{\pm}$

No.	Subprocess
Extra Dimensions:	
391	$f\overline{f} \to G^*$
392	$gg \to G^*$
393	$q\overline{q} \to gG^*$
394	$qg \to qG^*$
395	$gg \to gG^*$
SUSY:	
201	$f_i \overline{f}_i \to \tilde{e}_L \tilde{e}_L^*$
202	$f_i \overline{f}_i \to \tilde{e}_R \tilde{e}_R^*$
203	$f_i \overline{f}_i \to \tilde{e}_L \tilde{e}_R^* +$
204	$f_i \overline{f}_i \to \tilde{\mu}_L \tilde{\mu}_L^*$
205	$f_i \overline{f}_i \to \tilde{\mu}_R \tilde{\mu}_R^*$
206	$f_i \overline{f}_i \to \tilde{\mu}_L \tilde{\mu}_R^* +$
207	$f_i \overline{f}_i \to \tilde{\tau}_1 \tilde{\tau}_1^*$
208	$f_i \overline{f}_i \to \tilde{\tau}_2 \tilde{\tau}_2^*$
209	$f_i \overline{f}_i \to \tilde{\tau}_1 \tilde{\tau}_2^* +$
210	$f_i \overline{f}_j \to \tilde{\ell}_L \tilde{\nu}_\ell^* +$
211	$f_i \overline{f}_j \to \tilde{\tau}_1 \tilde{\nu}_\tau^* +$
212	$f_i \overline{f}_j \to \tilde{\tau}_2 \tilde{\nu}_\tau^* +$
213	$f_i \overline{f}_i \to \tilde{\nu}_\ell \tilde{\nu}_\ell^*$

No.	Subprocess
214	$f_i \overline{f}_i \to \tilde{\nu}_\tau \tilde{\nu}_\tau^*$
216	$f_i \overline{f}_i \to \tilde{\chi}_1 \tilde{\chi}_1$
217	$f_i \overline{f}_i \to \tilde{\chi}_2 \tilde{\chi}_2$
218	$f_i \overline{f}_i \to \tilde{\chi}_3 \tilde{\chi}_3$
219	$f_i \overline{f}_i \to \tilde{\chi}_4 \tilde{\chi}_4$
220	$f_i \overline{f}_i \to \tilde{\chi}_1 \tilde{\chi}_2$
221	$f_i \overline{f}_i \to \tilde{\chi}_1 \tilde{\chi}_3$
222	$f_i \overline{f}_i \to \tilde{\chi}_1 \tilde{\chi}_4$
223	$f_i \overline{f}_i \to \tilde{\chi}_2 \tilde{\chi}_3$
224	$f_i \overline{f}_i \to \tilde{\chi}_2 \tilde{\chi}_4$
225	$f_i \overline{f}_i \to \tilde{\chi}_3 \tilde{\chi}_4$
226	$f_i \overline{f}_i \to \tilde{\chi}_1^{\pm} \tilde{\chi}_1^{\mp}$
227	$f_i \overline{f}_i \to \tilde{\chi}_2^{\pm} \tilde{\chi}_2^{\mp}$
228	$f_i \overline{f}_i \to \tilde{\chi}_1^{\pm} \tilde{\chi}_2^{\mp}$
229	$f_i \overline{f}_j \to \tilde{\chi}_1 \tilde{\chi}_1^{\pm}$
230	$f_i \overline{f}_j \to \tilde{\chi}_2 \tilde{\chi}_1^{\pm}$
231	$f_i \overline{f}_j \to \tilde{\chi}_3 \tilde{\chi}_1^{\pm}$
232	$f_i \overline{f}_j \to \tilde{\chi}_4 \tilde{\chi}_1^{\pm}$
233	$f_i \overline{f}_j \to \tilde{\chi}_1 \tilde{\chi}_2^{\pm}$
234	$f_i \overline{f}_j \to \tilde{\chi}_2 \tilde{\chi}_2^{\pm}$

PYTHIA subprocesses(5)

No.	Subprocess
235	$f_i\bar{f}_j \to \tilde{\chi}_3\tilde{\chi}_2^{\pm}$
236	$f_i\bar{f}_j \to \tilde{\chi}_4\tilde{\chi}_2^{\pm}$
237	$f_i\bar{f}_i \to \tilde{g}\tilde{\chi}_1$
238	$f_i\bar{f}_i \to \tilde{g}\tilde{\chi}_2$
239	$f_i\bar{f}_i \to \tilde{g}\tilde{\chi}_3$
240	$f_i\bar{f}_i \to \tilde{g}\tilde{\chi}_4$
241	$f_i\bar{f}_j \to \tilde{g}\tilde{\chi}_1^{\pm}$
242	$f_i\bar{f}_j \to \tilde{g}\tilde{\chi}_2^{\pm}$
243	$f_i\bar{f}_i \to \tilde{g}\tilde{g}$
244	$gg \to \tilde{g}\tilde{g}$
246	$f_i g \to \tilde{q}_{iL}\tilde{\chi}_1$
247	$f_i g \to \tilde{q}_{iR}\tilde{\chi}_1$
248	$f_i g \to \tilde{q}_{iL}\tilde{\chi}_2$
249	$f_i g \to \tilde{q}_{iR}\tilde{\chi}_2$
250	$f_i g \to \tilde{q}_{iL}\tilde{\chi}_3$
251	$f_i g \to \tilde{q}_{iR}\tilde{\chi}_3$
252	$f_i g \to \tilde{q}_{iL}\tilde{\chi}_4$
253	$f_i g \to \tilde{q}_{iR}\tilde{\chi}_4$

No.	Subprocess
254	$f_i g \to \tilde{q}_{jL}\tilde{\chi}_1^{\pm}$
256	$f_i g \to \tilde{q}_{jL}\tilde{\chi}_2^{\pm}$
258	$f_i g \to \tilde{q}_{iL}\tilde{g}$
259	$f_i g \to \tilde{q}_{iR}\tilde{g}$
261	$f_i\bar{f}_i \to \tilde{t}_1\tilde{t}_1^*$
262	$f_i\bar{f}_i \to \tilde{t}_2\tilde{t}_2^*$
263	$f_i\bar{f}_i \to \tilde{t}_1\tilde{t}_2^* +$
264	$gg \to \tilde{t}_1\tilde{t}_1^*$
265	$gg \to \tilde{t}_2\tilde{t}_2^*$
271	$f_i f_j \to \tilde{q}_{iL}\tilde{q}_{jL}$
272	$f_i f_j \to \tilde{q}_{iR}\tilde{q}_{jR}$
273	$f_i f_j \to \tilde{q}_{iL}\tilde{q}_{jR} +$
274	$f_i\bar{f}_j \to \tilde{q}_{iL}\tilde{q}_{jL}^*$
275	$f_i\bar{f}_j \to \tilde{q}_{iR}\tilde{q}_{jR}^*$
276	$f_i\bar{f}_j \to \tilde{q}_{iL}\tilde{q}_{jR}^* +$
277	$f_i\bar{f}_i \to \tilde{q}_{jL}\tilde{q}_{jL}^*$
278	$f_i\bar{f}_i \to \tilde{q}_{jR}\tilde{q}_{jR}^*$
279	$gg \to \tilde{q}_{iL}\tilde{q}_{iL}^*$

No.	Subprocess
280	$gg \to \tilde{q}_{iR}\tilde{q}_{iR}^*$
281	$bq_i \to \tilde{b}_1\tilde{q}_{iL}$
282	$bq_i \to \tilde{b}_2\tilde{q}_{iR}$
283	$bq_i \to \tilde{b}_1\tilde{q}_{iR} + \tilde{b}_2\tilde{q}_{iL}$
284	$b\bar{q}_i \to \tilde{b}_1\tilde{q}_{iL}^*$
285	$b\bar{q}_i \to \tilde{b}_2\tilde{q}_{iR}^*$
286	$b\bar{q}_i \to \tilde{b}_1\tilde{q}_{iR}^* + \tilde{b}_2\tilde{q}_{iL}^*$
287	$f_i\bar{f}_i \to \tilde{b}_1\tilde{b}_1^*$
288	$f_i\bar{f}_i \to \tilde{b}_2\tilde{b}_2^*$
289	$gg \to \tilde{b}_1\tilde{b}_1^*$
290	$gg \to \tilde{b}_2\tilde{b}_2^*$
291	$bb \to \tilde{b}_1\tilde{b}_1$
292	$bb \to \tilde{b}_2\tilde{b}_2$
293	$bb \to \tilde{b}_1\tilde{b}_2$
294	$bg \to \tilde{b}_1\tilde{g}$
295	$bg \to \tilde{b}_2\tilde{g}$
296	$b\bar{b} \to \tilde{b}_1\tilde{b}_2^* +$

Examples

Sample main programs

In order to illustrate how to run PYTHIA 6.4, a few sample main programs are collected below. Most are very simple, to help new users get started. No independent documentation is available beyond what is found in each file.

- standard declarations and commonblocks, for easy copying
- the very most trivial test of PYTHIA
- run all existing subprocesses one at a time
- Z0 production at LEP 1
- study of W mass shift by colour rearrangement at LEP 2
- supersymmetry production at a hadron collider
- leptoquark production at HERA
- technicolor production at the Tevatron
- charged multiplicity in top events at the LHC
- heavy Higgs mass spectrum comparing two running-width schemes
- production of a single top by s-channel W exchange (with tricks)
- jet or minimum bias production by gamma*-p or gamma*-gamma* interactions
- implementation of user-defined external processes according to the Les Houches standard
- comparison of cross sections for q g -> q gamma as external or internal process
- program for e+e- with routines to turn gluinos into stable gluino-hadrons, optionally via stop-hadrons
  and a modified version with unstable gluino-hadrons in hadron colliders
  and ditto, using "PDG-endorsed" codes for R-hadrons
  and production of stable stop-hadrons, also using "PDG-endorsed" codes
- various options for the underlying-event and parton-shower framework, with consistently tuned sets of parameters, updated to the options available starting with PYTHIA 6.402, illustrated by t tbar production at the Tevatron (supersedes the older version)
- example how to use input via the SuSy Les Houches Accord to generate supersymmetric processes, in this case stop1 pair production events at LHC; the run requires an external file with a SuSy spectrum calculated by an external RGE code, like softsusy.spc generated by SoftSusy
- example how to use the interface to FeynHiggs

main63.f (1) : Preamble/Declarations

```
C...A simple skeleton program, illustrating a typical Pythia run:
C...Z0 production at LEP 1.
C...Toy task: compare multiplicity distribution with matrix elements
C...and with parton showers (using same fragmentation parameters).

C-----------------------------------------------------------------

C...Preamble: declarations.

C...All real arithmetic in double precision.
      IMPLICIT DOUBLE PRECISION(A-H, O-Z)
C...Three Pythia functions return integers, so need declaring.
      INTEGER PYK,PYCHGE,PYCOMP

C...EXTERNAL statement links PYDATA on most machines.
      EXTERNAL PYDATA

C...Commonblocks.
C...The event record.
      COMMON/PYJETS/N,NPAD,K(4000,5),P(4000,5),V(4000,5)
C...Parameters.
      COMMON/PYDAT1/MSTU(200),PARU(200),MSTJ(200),PARJ(200)
C...Particle properties + some flavour parameters.
      COMMON/PYDAT2/KCHG(500,4),PMAS(500,4),PARF(2000),VCKM(4,4)
C...Decay information.
      COMMON/PYDAT3/MDCY(500,3),MDME(8000,2),BRAT(8000),KFDP(8000,5)
C...Selection of hard scattering subprocesses.
      COMMON/PYSUBS/MSEL,MSELPD,MSUB(500),KFIN(2,-40:40),CKIN(200)
C...Parameters.
      COMMON/PYPARS/MSTP(200),PARP(200),MSTI(200),PARI(200)
C...Supersymmetry parameters.
      COMMON/PYMSSM/IMSS(0:99),RMSS(0:99)

C-----------------------------------------------------------------
```

main63.f (2): Initialization

```
C-----------------------------------------------------------------------
C...First section: initialization.

C...Main parameters of run: c.m. energy and number of events.
      ECM=91.2D0
C...Select gamma*/Z0 production process.
      MSEL=0
      MSUB(1)=1

C...Initialize.
      CALL PYINIT('CMS','e+','e-',ECM)

C-----------------------------------------------------------------------
```

main63.f (3): Event loop

```
C...Second section: event loop.
      NEV=1000

C...Begin event loop.
      DO 200 IEV=1,NEV
        CALL PYEVNT

C...List first few events.
        IF(IEV.LE.2) THEN
          CALL PYLIST(1)

C...manioulating events with PYEDIT
          CALL PYEDIT(1)
          print *, 'CALL PYEDIT(1)'
          CALL PYLIST(1)

          CALL PYEDIT(2)
          print *, 'CALL PYEDIT(2)'
          CALL PYLIST(1)

          CALL PYEDIT(3)
          print *, 'CALL PYEDIT(3)'
          CALL PYLIST(1)
        ENDIF
C...End event loop.
  200 CONTINUE
C-----------------------------------------------------------------------
```

main63.f (4): Output – cs, statistics etc

```
C...Third section: produce output and end.

C...Cross section table, etc
      print *, 'CALL PYSTAT(1)'
      CALL PYSTAT(1)
      print *, 'CALL PYSTAT(2)'
      CALL PYSTAT(2)
      print *, 'CALL PYSTAT(3)'
      CALL PYSTAT(3)


      END
```

PYTHIA output file(1)

```
**                *......*                    Welcome to the Lund Monte Carlo!   **
**            *:::!!::::::::::::*                                                **
**         *::::::!!::::::::::::::*            PPP  Y   Y TTTTT H   H III   A    **
**       *:::::::!!:::::::::::::::::*          P  P  Y Y    T   H   H  I   A A   **
**     *:::::::::!!:::::::::::::::::::*        PPP    Y     T   HHHHH  I  AAAAA  **
**    *:::::::::!!:::::::::::::::::::*         P      Y     T   H   H  I  A   A  **
**     *:::::::::!!:::::::::::::::::::*!       P      Y     T   H   H III A   A  **
**       *:::::::!!:::::::::::::::::* !!                                          **
**        !! *:::!!:::::::::::::::*    !!       This is PYTHIA version 6.403      **
**        !!     !!* -><- *           !!       Last date of change:  7 Jun 2006  **
**        !!     !!                   !!                                         **
**        !!     !!                   !!       Now is 12 Jun 2006 at 21:22:44    **
**        !!                          !!                                         **
**        !!        lh                !!       Disclaimer: this program comes    **
**        !!                          !!       without any guarantees. Beware    **
**        !!                    hh    !!       of errors and use common sense    **
**        !!    ll                    !!       when interpreting results.        **
**        !!                          !!                                         **
**        !!                          !!       Copyright T. Sjostrand (2006)     **
**                                                                               **
** An archive of program versions and documentation is found on the web:         **
** http://www.thep.lu.se/~torbjorn/Pythia.html                                   **
**                                                                               **
** When you cite this program, the official reference is to the 6.4 manual:      **
** T. Sjostrand, S. Mrenna and P. Skands, JHEP05 (2006) 026                      **
** (LU TP 06-13, FERMILAB-PUB-06-052-CD-T) [hep-ph/0603175].                     **
**                                                                               **
** Also remember that the program, to a large extent, represents original       **
** physics research. Other publications of special relevance to your            **
** studies may therefore deserve separate mention.                               **
**                                                                               **
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**   Fermi National Accelerator Laboratory, MS 234, Batavia, IL 60510, USA;      **
**   phone: + 1 - 630 - 840 - 2556; e-mail: mrenna@fnal.gov                      **
** Author: Peter Skands; Theoretical Physics Department,                         **
**   Fermi National Accelerator Laboratory, MS 106, Batavia, IL 60510, USA;      **
**   phone: + 1 - 630 - 840 - 2270; e-mail: skands@fnal.gov                      **
**                                                                               **
**                                                                               **
```

PYTHIA output file(2)

```
******** PYMAXI: summary of differential cross-section maximum search ********

           ================================================================
           I                                                I               I
           I  ISUB  Subprocess name                         I  Maximum value  I
           I                                                I               I
           ================================================================
           I                                                I               I
           I    1   f + fbar -> gamma*/Z0                   I    5.5811E-04   I
           I                                                I               I
           ================================================================

************************ PYINIT: initialization completed ************************
```

PYTHIA output file(3)

Event listing (summary)

I	particle/jet	KS	KF	orig	p_x	p_y	p_z	E	m
1	!e+!	21	-11	0	0.000	0.000	45.600	45.600	0.001
2	!e-!	21	11	0	0.000	0.000	-45.600	45.600	0.001
3	!e+!	21	-11	1	0.000	0.000	45.600	45.600	0.000
4	!e-!	21	11	2	0.000	0.000	-45.600	45.600	0.000
5	!e+!	21	-11	3	0.000	0.000	45.575	45.575	0.000
6	!e-!	21	11	4	0.000	0.000	-45.600	45.600	0.000
7	!Z0!	21	23	0	0.000	0.000	-0.025	91.175	91.175
8	!d!	21	1	7	11.184	38.550	-21.621	45.593	0.330
9	!dbar!	21	-1	7	-11.183	-38.550	21.596	45.582	0.330
10	(Z0)	11	23	7	0.000	0.000	-0.025	91.175	91.175
11	gamma	1	22	3	0.000	0.000	0.025	0.025	0.000
12	gamma	1	22	1	0.000	0.000	0.000	0.000	0.000
13	gamma	1	22	2	0.000	0.000	0.000	0.000	0.000
14	(d)	A 12	1	8	12.058	35.719	-19.730	42.551	0.330
15	(g)	I 12	21	8	-0.259	0.809	-0.796	1.164	0.000
16	(g)	I 12	21	8	-0.946	0.885	-0.895	1.574	0.000
17	(g)	I 12	21	8	0.180	-0.053	-0.403	0.444	0.000
18	(g)	I 12	21	8	-0.507	-1.075	1.471	1.891	0.000
19	(g)	I 12	21	9	-0.135	0.005	0.002	0.135	0.000
20	(g)	I 12	21	9	-1.124	-0.532	0.305	1.281	0.000
21	(g)	I 12	21	9	-2.742	-8.032	3.310	9.109	0.000
22	(dbar)	V 11	-1	9	-6.525	-27.726	16.710	33.025	0.330

PYTHIA output file(4)

23	(string)	11	92	14	0.000	0.000	-0.025	91.175	91.175
24	(rho-)	11	-213	23	6.454	18.403	-10.603	22.211	0.778
25	(K*+)	11	323	23	3.212	10.704	-5.698	12.578	0.920
26	(K*bar0)	11	-313	23	0.888	5.002	-3.158	6.049	0.900
27	(omega)	11	223	23	0.707	2.000	-0.944	2.438	0.745
28	(omega)	11	223	23	0.466	0.428	-0.533	1.137	0.781
29	pi-	1	-211	23	-0.435	0.044	0.041	0.461	0.140
30	(omega)	11	223	23	-0.126	0.276	0.141	0.830	0.759
31	pi+	1	211	23	0.111	0.155	-0.437	0.497	0.140
32	(rho-)	11	-213	23	-1.256	-0.775	0.796	1.735	0.445
33	(omega)	11	223	23	-1.443	-2.223	0.655	2.840	0.784
34	(Delta0)	11	2114	23	-1.774	-6.236	3.411	7.416	1.151
35	(eta)	11	221	23	-2.334	-7.741	4.380	9.212	0.547
36	(Deltabar+)	11	-1114	23	-4.469	-20.035	11.923	23.770	1.208
37	pi-	1	-211	24	5.724	15.696	-9.207	19.077	0.140
67	gamma	1	22	45	0.000	0.137	-0.068	0.153	0.000
68	gamma	1	22	48	0.084	-0.033	0.002	0.091	0.000
69	gamma	1	22	48	0.001	0.034	0.084	0.091	0.000
70	gamma	1	22	50	-0.136	0.388	-0.077	0.418	0.000
71	gamma	1	22	50	0.033	0.088	-0.023	0.097	0.000
72	gamma	1	22	52	-0.356	-0.187	0.106	0.416	0.000
73	gamma	1	22	52	-0.222	-0.014	0.100	0.243	0.000
74	gamma	1	22	55	-0.260	-0.369	0.048	0.454	0.000
75	gamma	1	22	55	-0.279	-0.345	0.182	0.479	0.000
76	gamma	1	22	60	-0.806	-2.505	1.476	3.018	0.000
77	gamma	1	22	60	-0.331	-1.168	0.776	1.441	0.000
		sum:	0.00		0.000	0.000	0.000	91.200	91.200

PYTHIA output file(7)

```
 CALL PYSTAT(1)
1********* PYSTAT:  Statistics on Number of Events and Cross-sections *********

 ===================================================================================
 I                                  I                                  I             I
 I            Subprocess            I      Number of points            I    Sigma    I
 I                                  I                                  I             I
 I----------------------------------I----------------------------------I    (mb)     I
 I                                  I                                  I             I
 I N:o Type                         I    Generated         Tried       I             I
 I                                  I                                  I             I
 ===================================================================================
 I                                  I                                  I             I
 I   0 All included subprocesses    I         1000          12861      I  4.350E-05 I
 I   1 f + fbar -> gamma*/Z0        I         1000          12861      I  4.350E-05 I
 I                                  I                                  I             I
 ===================================================================================
```

Useful Switches and Parameters(2)

Hard processes —basics

MSEL = 0: pick your wanted set of processes I by MSUB(I) = 1;

MSEL = 1, CKIN(3) > ∼10 : QCD jet production with $p_\perp >$ CKIN(3);
$p_\perp \to 0$ divergence $\Rightarrow$ inconsistencies for small CKIN(3).

MSEL = 1, (CKIN(3) = 0.): "minimum bias", including unitarized jets
but excluding elastic/diffractive;

MSEL = 2, (CKIN(3) = 0.): "minimum bias", including elastic/diffractive.

For s-channel resonances, like $q\bar{q} \to \gamma^*/Z^0 \to \ell^+\ell^-$,
CKIN(1)$< \widehat{m} <$CKIN(2).

For $2 \to 2$ processes, like $qg \to \tilde{q}\tilde{g}$, CKIN(3)$< \hat{p}_\perp <$CKIN(4).
Note: $p_\perp$ changed by showers, so important smearing effects.
The same is true for many other CKIN variables.

Irrespective of smearing, it is consistent to split cross section into
a set of consecutive non-overlapping $\hat{p}_\perp$ (or $\widehat{m}$) bins.

Useful Switches and Parameters(4)

Parton densities and Scales

`MSTP(51)` = **7**: CTEQ 5L parton densities.
`MSTP(51)` = 8: CTEQ 5M1 parton densities (NLO!).
`MSTP(51)` = 4: GRV 94L parton densities.

`MSTP(52)` = 2: link to PDFLIB with `MSTP(51)` = 1000$\times$`NGROUP`+`NSET`;
requires that dummy `PDFSET` and `STRUCTM` routines not linked;
can also be used as interface to LHAPDF

`MSTP(3)` = **2**: set $\Lambda_{\rm QCD}$ value according to the choice of PDF set,
defined for 4 flavours, except FSR showers in resonances ($\approx$ LEP).

`MSTP(3)` = **1**: set $\Lambda_{\rm QCD}$ value by hand separately for
(a) hard interactions, (b) ISR, (c) FSR except resonances,
(d) FSR in resonances, defined for 5 flavours.
`PARP(1)` : $\Lambda_{\rm QCD}$ for hard interaction.

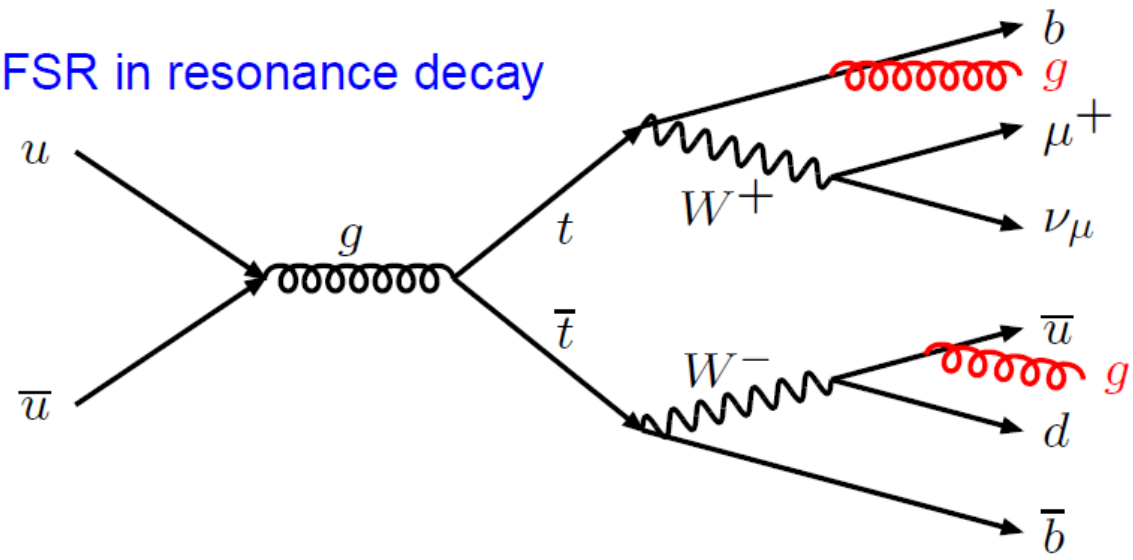
`MSTP(32)` = **8**: the $2 \to 2$ hard interaction process scale
$Q^2 = (m^2_{\perp 3} + m^2_{\perp 4})/2 = p^2_\perp + (m^2_3 + m^2_4)/2$.
`MSTP(32)` = 4: $Q^2 = \hat{s}$ instead.

Useful Switches and Parameters(6)

Final-state showers

MSTP(71) = 0/**1** : master switch off/on.

FSR in resonance decay



$b \to bg$ in top decay
partly constrained
by $Z^0 \to b\overline{b}g$

$W^\pm \to q\overline{q}' =$
$= Z^0 \to q\overline{q}$
to high accuracy

PARJ(81) = **0.29**: Λ_{QCD} for resonance FSR, for 5 flavours,
extreme range would be 0.2 – 0.4.

PARJ(82) = **1.0**: lower invariant-mass cutoff m_{min} for shower evolution.

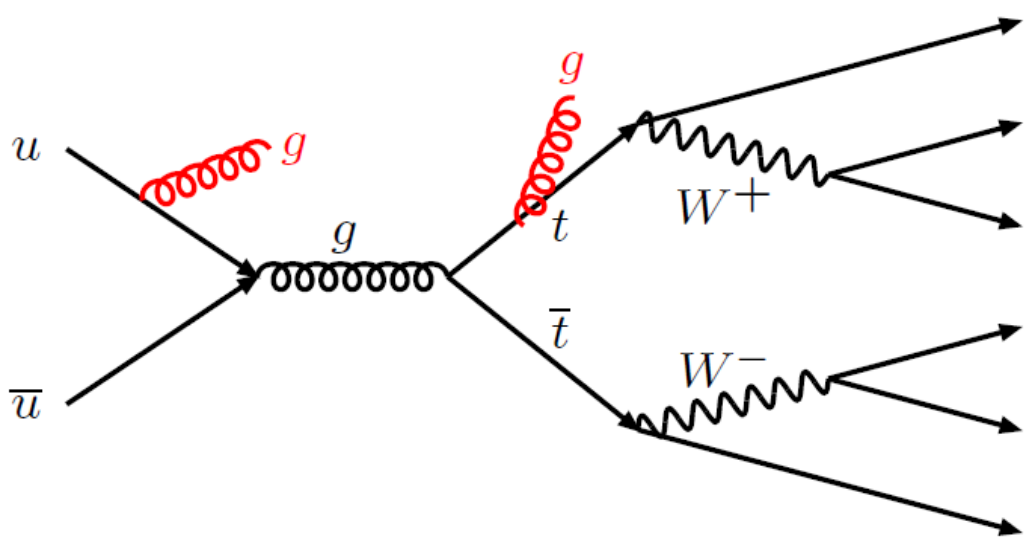
PARP(72) : Λ_{QCD} for non-resonance FSR (e.g. off top *before* decay),
cf. MSTP(3), extreme range would be 0.1 – 0.5.

PARP(71) = **4.**: $Q^2_{\text{shower, max}} =$PARP(71)$\times Q^2_{\text{hard interaction}}$;
$p_\perp^2 \approx z(1-z)m^2 < m^2/4$ motivates default, extreme range 1. – 16.

Useful Switches and Parameters(7)

Initial-state showers (+ interference)

MSTP(61) = 0/**1** : master switch off/on.



MSTP(67) = 0
MSTJ(50) = 0
switch off
destructive
interference
ISR/FSR

PARP(61) : Λ_{QCD} for ISR, cf. MSTP(3), extreme range 0.1 – 0.5.

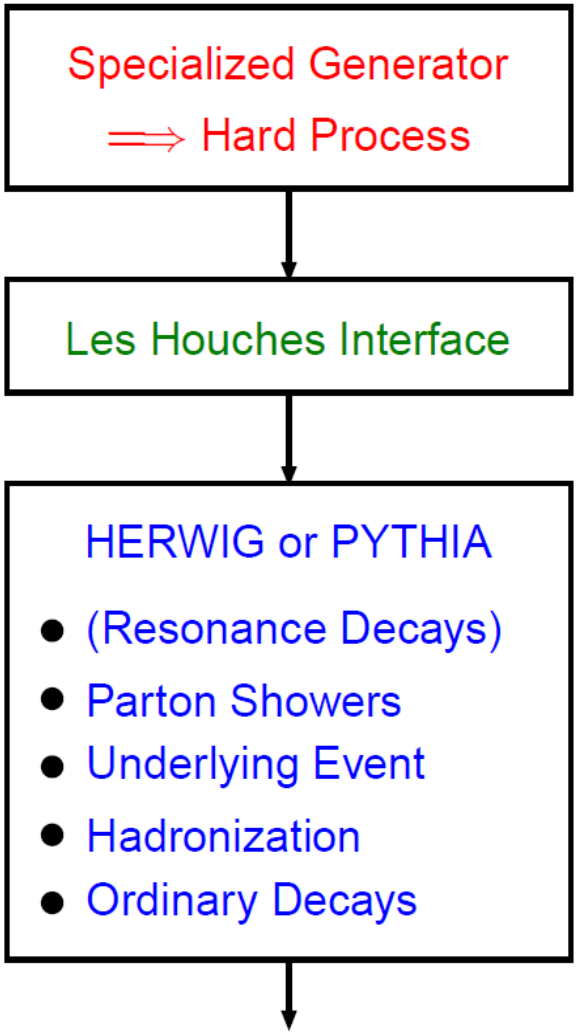
PARP(62) = **1.0** : lower cutoff Q_{min} for shower evolution.

PARP(64) = **1.0** : α_{s} and PDF scale $Q^2 =$PARP(64)$\times p_{\perp}^2$.

PARP(67) = **4.** : $Q^2_{\mathrm{shower,\ max}} =$PARP(67)$\times Q^2_{\mathrm{hard\ interaction}}$;
$p_{\perp}^2 \approx (1-z)m^2$ motivates default > 1, extreme range 1. – 8.

MSTP(68) = **1** : put $Q^2_{\mathrm{shower,\ max}} = s$ for single-resonance production
with ME matching (γ^*/Z^0, $\mathrm{W}^{\pm}$, h^0, ...)

External user process and interface with CalcHEP: Les Houches accord



Some Specialized Generators:

- AcerMC: $t\bar{t}b\bar{b}$, ...
- ALPGEN: $W/Z+ \leq 6j$, $nW + mZ + kH+ \leq 3j$, ...
- AMEGIC++: generic LO
- CompHEP: generic LO
- GRACE+Bases/Spring: generic LO+ some NLO loops
- GR@PPA: $b\bar{b}b\bar{b}$
- MadCUP: $W/Z+ \leq 3j$, $t\bar{t}b\bar{b}$
- MadGraph+HELAS: generic LO
- MCFM: NLO $W/Z+ \leq 2j$, WZ, WH, $H+ \leq 1j$
- O'Mega+WHIZARD: generic LO
- VECBOS: $W/Z+ \leq 4j$

Apologies for all unlisted programs

External user process and interface via events in the Les Houches accord format

Initialization

```
 INTEGER MAXPUP
 PARAMETER (MAXPUP=100)
 INTEGER IDBMUP,PDFGUP,PDFSUP,IDWTUP,NPRUP,LPRUP
 DOUBLE PRECISION EBMUP,XSECUP,XERRUP,XMAXUP
 COMMON/HEPRUP/IDBMUP(2),EBMUP(2),PDFGUP(2),PDFSUP(2),IDWTUP,
&NPRUP,XSECUP(MAXPUP),XERRUP(MAXPUP),XMAXUP(MAXPUP),LPRUP(MAXPUP)
```

IDBMUP: incoming beam particles (PDG codes, $p = 2212$, $\overline{p} = -2212$)

EBMUP: incoming beam energies (GeV)

PDFGUP, PDFSUP: PDFLIB parton distributions (not used by PYTHIA)

IDWTUP: weighting strategy

- = 1: PYTHIA mixes and unweights events, according to known $d\sigma_{max}$
- = 2: PYTHIA mixes and unweights events, according to known σ_{tot}
- = **3**: unit-weight events, given by user, always to be kept
- = 4: weighted events, given by user, always to be kept
- = -1, -2, -3, -4: also allow negative $d\sigma$

NPRUP: number of separate user processes

XSECUP(i): σ_{tot} for each user process

XERRUP(i): error on σ_{tot} for each user process

XMAXUP(i): $d\sigma_{max}$ for each user process

LPRUP(i): integer identifier for each user process

The event

```
 INTEGER MAXNUP
 PARAMETER (MAXNUP=500)
 INTEGER NUP,IDPRUP,IDUP,ISTUP,MOTHUP,ICOLUP
 DOUBLE PRECISION XWGTUP,SCALUP,AQEDUP,AQCDUP,PUP,VTIMUP,SPINUP
 COMMON/HEPEUP/NUP,IDPRUP,XWGTUP,SCALUP,AQEDUP,AQCDUP,
&IDUP(MAXNUP),ISTUP(MAXNUP),MOTHUP(2,MAXNUP),ICOLUP(2,MAXNUP),
&PUP(5,MAXNUP),VTIMUP(MAXNUP),SPINUP(MAXNUP)
```

`IDPRUP`: identity of current process

`XWGTUP`: event weight (meaning depends on `IDWTUP` weighting strategy)

`SCALUP`: scale Q of parton distributions etc.

`AQEDUP`: $\alpha_{\rm em}$ used in event

`AQCDUP`: $\alpha_{\rm S}$ used in event

`NUP`: number of particles in event

`IDUP(i)`: PDG identity code for particle `i`

`ISTUP(i)`: status code ($-1 =$ incoming parton, $1 =$ final-state parton, $2 =$ intermediate resonance with preserved m)

`MOTHUP(j,i)`: position of one or two mothers

`PUP(j,i)`: (p_x, p_y, p_z, E, m)

`VTIMUP(i)`: invariant lifetime $c\tau$

`SPINUP(i)`: spin (helicity) information

Example of the main program to use .lhe file with PYTHIA

```
sasha:~/Dropbox/hep_tools/pythia> more calchep_pythia.f
      IMPLICIT DOUBLE PRECISION(A-H, O-Z)
      IMPLICIT INTEGER(I-N)

      REAL*8 RMSS
      COMMON/PYMSSM/IMSS(0:99),RMSS(0:99)
      SAVE /PYMSSM/
      INTEGER MAXNUP
      PARAMETER (MAXNUP=500)
      COMMON/PYJETS/N,NPAD,K(4000,5),P(4000,5),V(4000,5)
      integer NPAD,NVT
      real*8 parp,pari
      integer MSTP,MSTI
      COMMON/PYPARS/MSTP(200),PARP(200),MSTI(200),PARI(200)

      lun2=12
      mstp(161)=lun2
      mstp(162)=lun2

      NEV=3

      OPEN(lun2, FILE='events.lhe',STATUS='UNKNOWN', FORM='FORMATTED')
      CALL PYINIT('USER',' ',' ',0d0)
      DO 200 NVT=1,NEV
         CALL PYEVNT
*...<<<<<<< USER's routines for analysis should be call here >>>>>>
        call pylist(2)
        IF(NUP.eq.0) then
           print *, 'end of event record', N
        goto 100
      ENDIF
200   CONTINUE
100   CALL PYSTAT(1)
      CLOSE(lun2)
      END
```

Next Step – perform detector simulation – PGS

http://www.physics.ucdavis.edu/~conway/research/software/pgs/pgs4-general.htm

PGS is a simulation of a generic high-energy physics collider detector with a tracking system, electromagnetic and hadronic calorimetry, and muon system. It is designed to take events generated with popular event generators like PYTHIA and HERWIG and produce semi-realistic reconstructed physics objects such as photons, electrons, muons, hadronically decaying taus, and hadronic jets (including b- and charm-tagging). Many basic detector parameters are configurable using a detector parameter file, which includes calorimeter segmentation and resolution, tracking coverage and resolution, and other configurable parameters.

PGS is very simple: for every final state generated particle, a calorimeter energy deposit is simulated, and a track is simulated in the case of long-lived charged particles. From this information, the "high-level" physics objects (photons, electrons, ...) are reconstructed just as in most modern high energy physics experiments.

PGS is designed to be fast. And, that having been said, there are many things that are not simultaed in PGS, including secondary interactions, multiple interactions, z-vertex spread, bremsstrahlung, pair production, decays in flight, magnetic field effects, detector material, and probably other things as well. But it's fast.

PGS is, well, pretty good. Most collider detector analyses suffer most from geometric acceptance and resolution issues, and PGS gets those mostly right. For many analyses you will find (we hope!) that the answer from PGS agrees within a factor of two of the answer you might obtain with a full-fleged detector simulation. In many cases the agreement is much better, of the order of 20%. But, as with any detector simulation, you should always be aware of the limitations and avoid drawing physics conclusions which might depend too much on absolute accuracy. PGS is an excellent tool for prototyping analyses and techniques, but it only goes so far.

Running PGS

hep_tools/pgs/PGS-120611/examples

```
sasha:~/Dropbox/hep_tools/pgs/PGS-120611/examples> more run_pgs

# usage example:
#               run_pgs name.lhe          #events trigger#
#       e.g.    run_pgs zprime.lhe 1000   1


echo $1 file
echo $2 events
echo trigger L$3
#echo detector:$4

olympics --lhe $1 --pythia cards/lhe.pyt        \
         --nev $2 --L$3                         \
         --numToPrint 5                         \
         --logFile  olympics.$1.log             \
         --detector pars/lhc.par                \
          $1.lhco
                                                  _
```

pars/lhc.par

hep_tools/pgs/PGS-120611/examples

lhc.par - /home/belyaev/Dropbox/hep_tools/pgs/PGS-120611/examples/pars/

File Edit Search Preferences Shell Macro Windows Help

/home/belyaev/Dropbox/hep_tools/pgs/PGS-120611/examples/pars/lhc.par 1244 bytes L: 1 C: 0

```
LHC                     ! parameter set name
320                     ! eta cells in calorimeter
200                     ! phi cells in calorimeter
0.0314159               ! eta width of calorimeter cells  |eta| < 5
0.0314159               ! phi width of calorimeter cells
0.0044                  ! electromagnetic calorimeter resolution  cons
0.024                   ! electromagnetic calorimeter resolution * sqr
0.8                     ! hadronic calolrimeter resolution * sqrt(E)
0.2                     ! MET resolution
0.01                    ! calorimeter cell edge crack fraction
cone                    ! jet finding algorithm (cone or ktjet)
5.0                     ! calorimeter trigger cluster finding seed thr
1.0                     ! calorimeter trigger cluster finding shoulder
0.5                     ! calorimeter kt cluster finder cone size (del
2.0                     ! outer radius of tracker (m)
4.0                     ! magnetic field (T)
0.000013                ! sagitta resolution (m)
0.98                    ! track finding efficiency
1.00                    ! minimum track pt (GeV/c)
3.0                     ! tracking eta coverage
3.0                     ! e/gamma eta coverage
2.4                     ! muon eta coverage
2.0                     ! tau eta coverage
```

Output from PGS

hep_tools/pgs/PGS-120611/examples

#	typ	eta	phi	pt	jmas	ntrk	btag	had/em	dum1	dum2
0		1	1							
1	1	0.572	6.165	51.15	0.00	-1.0	0.0	0.00	0.0	0.0
2	4	3.272	3.302	47.82	9.38	6.0	0.0	1.76	0.0	0.0
3	6	0.000	1.381	29.76	0.00	0.0	0.0	0.00	0.0	0.0
0		2	1							
1	1	-0.549	1.904	37.40	0.00	-1.0	0.0	0.00	0.0	0.0
2	4	2.751	3.969	48.24	6.64	7.0	0.0	0.39	0.0	0.0
3	4	2.616	6.252	15.84	1.87	7.0	0.0	3.23	0.0	0.0
4	4	0.487	0.298	7.41	0.00	1.0	0.0	999.00	0.0	0.0
5	6	0.000	6.257	34.36	0.00	0.0	0.0	0.00	0.0	0.0
0		3	1							
1	1	0.689	6.113	46.64	0.00	-1.0	0.0	0.01	0.0	0.0
2	4	-1.435	4.182	23.16	1.55	3.0	0.0	1.30	0.0	0.0
3	4	-0.256	1.529	30.98	3.92	6.0	0.0	2.30	0.0	0.0
4	4	-0.168	3.041	27.38	5.00	11.0	0.0	1.81	0.0	0.0
5	6	0.000	4.216	16.88	0.00	0.0	0.0	0.00	0.0	0.0
0		4	1							
1	1	0.886	0.279	83.88	0.00	-1.0	0.0	0.00	0.0	0.0
2	4	-0.061	3.543	54.68	9.48	12.0	0.0	1.39	0.0	0.0
3	4	-1.960	3.568	8.57	1.23	4.0	0.0	1.18	0.0	0.0
4	6	0.000	1.942	23.37	0.00	0.0	0.0	0.00	0.0	0.0

Lecture V: Advanced topics

- CalcHEP
- LanHEP
- PAW
- PYTHIA&PGS
- HEPMDB

Dropbox: separate dir per subject, all zipped

Alexander Belyaev

- Project
- cern_school_project_belyaev.pdf
- cern_school_project_belyaev.odp
- Dropbox

```
drwxrwxr-x 5 belyaev belyaev      4096 2013-04-12 13:06 calchep/
-rw-rw-r-- 1 belyaev belyaev  12131132 2013-04-12 13:23 calchep.tgz
drwxrwxr-x 2 belyaev belyaev      4096 2013-04-11 23:33 hepmdb/
-rw-rw-r-- 1 belyaev belyaev   2189822 2013-04-12 13:18 hepmdb.tgz
drwxrwxr-x 3 belyaev belyaev      4096 2013-04-09 14:06 lanhep/
-rw-rw-r-- 1 belyaev belyaev   3213756 2013-04-12 13:22 lanhep.tgz
drwxrwxr-x 2 belyaev belyaev      4096 2013-04-12 13:16 Lectures/
-rw-rw-r-- 1 belyaev belyaev  34230318 2013-04-12 13:20 Lectures.tgz
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drwx------ 5 belyaev belyaev      4096 2012-11-27 10:04 pgs/
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drwxrwxr-x 2 belyaev belyaev      4096 2013-04-11 12:04 references/
-rw-rw-r-- 1 belyaev belyaev    492753 2013-04-12 13:24 references.tgz
```
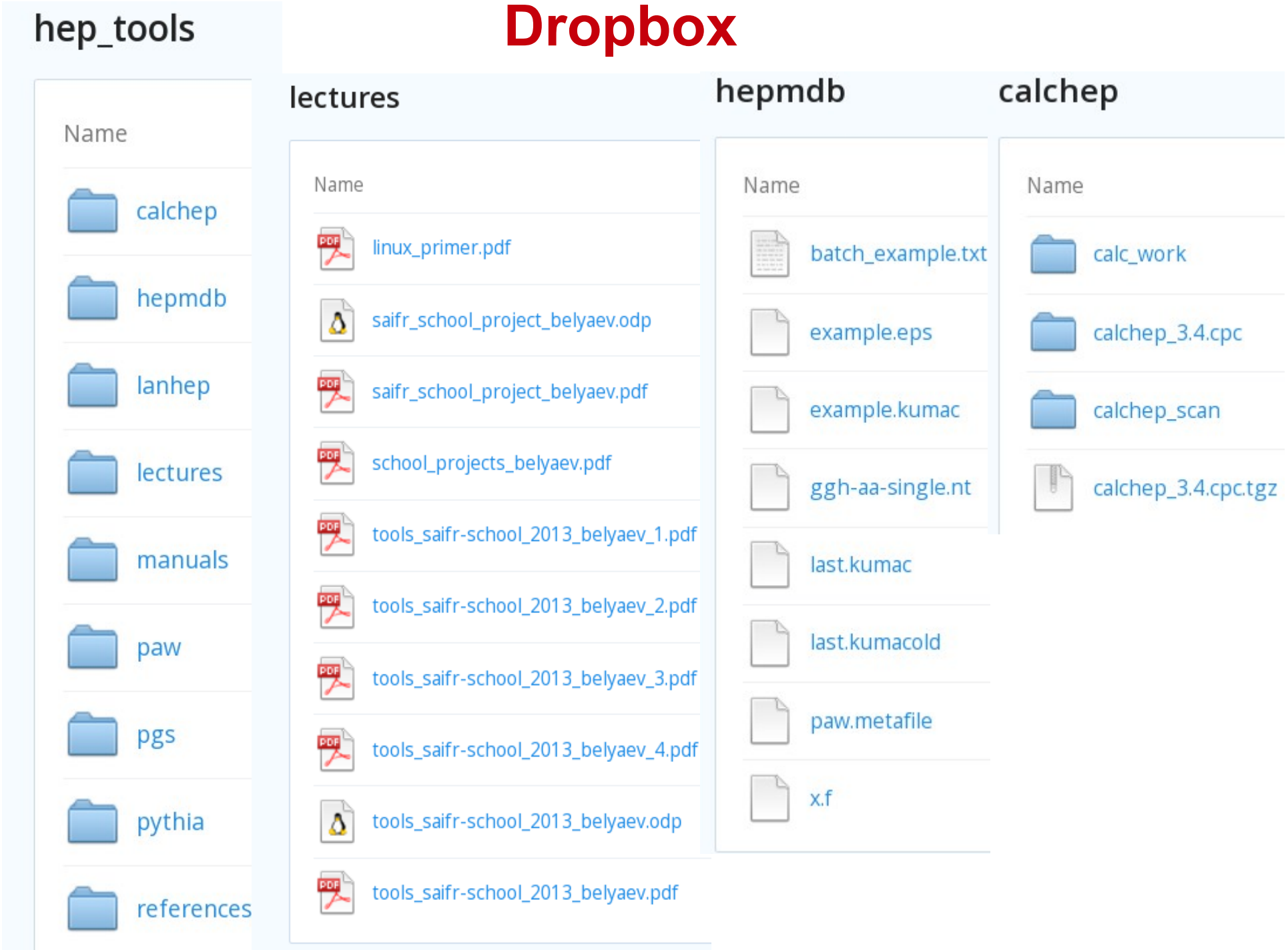

Dropbox

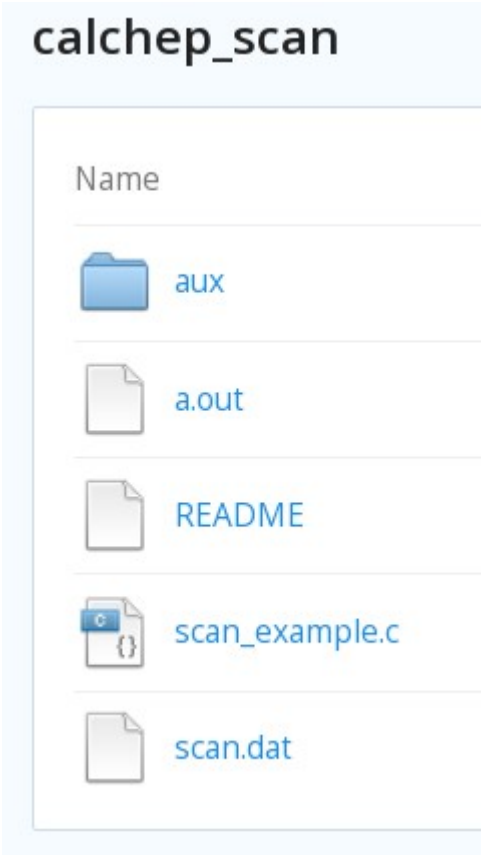

hep_tools
Name
calchep
hepmdb
lanhep
lectures
manuals
paw
pgs
pythia
references
lectures
Name
linux_primer.pdf
saifr_school_project_belyaev.odp
saifr_school_project_belyaev.pdf
school_projects_belyaev.pdf
tools_saifr-school_2013_belyaev_1.pdf
tools_saifr-school_2013_belyaev_2.pdf
tools_saifr-school_2013_belyaev_3.pdf
tools_saifr-school_2013_belyaev_4.pdf
tools_saifr-school_2013_belyaev.odp
tools_saifr-school_2013_belyaev.pdf
hepmdb
Name
batch_example.txt
example.eps
example.kumac
ggh-aa-single.nt
last.kumac
last.kumacold
paw.metafile
x.f
calchep
Name
calc_work
calchep_3.4.cpc
calchep_scan
calchep_3.4.cpc.tgz

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_3.4.cpc/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_3.4.cpc/utile/usrFF.c
- **user-defined propagator**
  (alteration of the existing propagators)
  calchep_3.4.cpc/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;
```

Some 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
- Possiblity to link to GoSam - CalcHEP@NLO is under discussion

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 indicies 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

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

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

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*

```
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.
```

LanHEP

- *Aux field and vertex splitting*
- *Dealing with higher dimensional theories*

PAW

- ***Smearing of Momentum***
- ***var.f file***

What vertices are possible?

What vertices are possible?

Maximum of 4 particles.
No 4-fermion vertices
(unless split with auxiliary field).

What vertices are possible?

Any Lorentz structure you can build with:

pi	Momentum of ith particle.
mi , Mi	1st , 2nd Lorentz index of ith particle.
eps(v1,v2,v3,v4)	Levi-Civita epsilon tensor.
G(5) , G(v)	Dirac gamma matrices.

Why Feynman Gauge?

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For massive vector bosons in unitary gauge:

$$(p^2 - M^2)\Delta_{\mu\nu} = -g_{\mu\nu} + \frac{p_\mu p_\nu}{M^2}$$

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Why Feynman Gauge?

For this reason, Sasha Pukhov chose Feynman gauge:

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Symbolic algebra is also faster in Feynman gauge.

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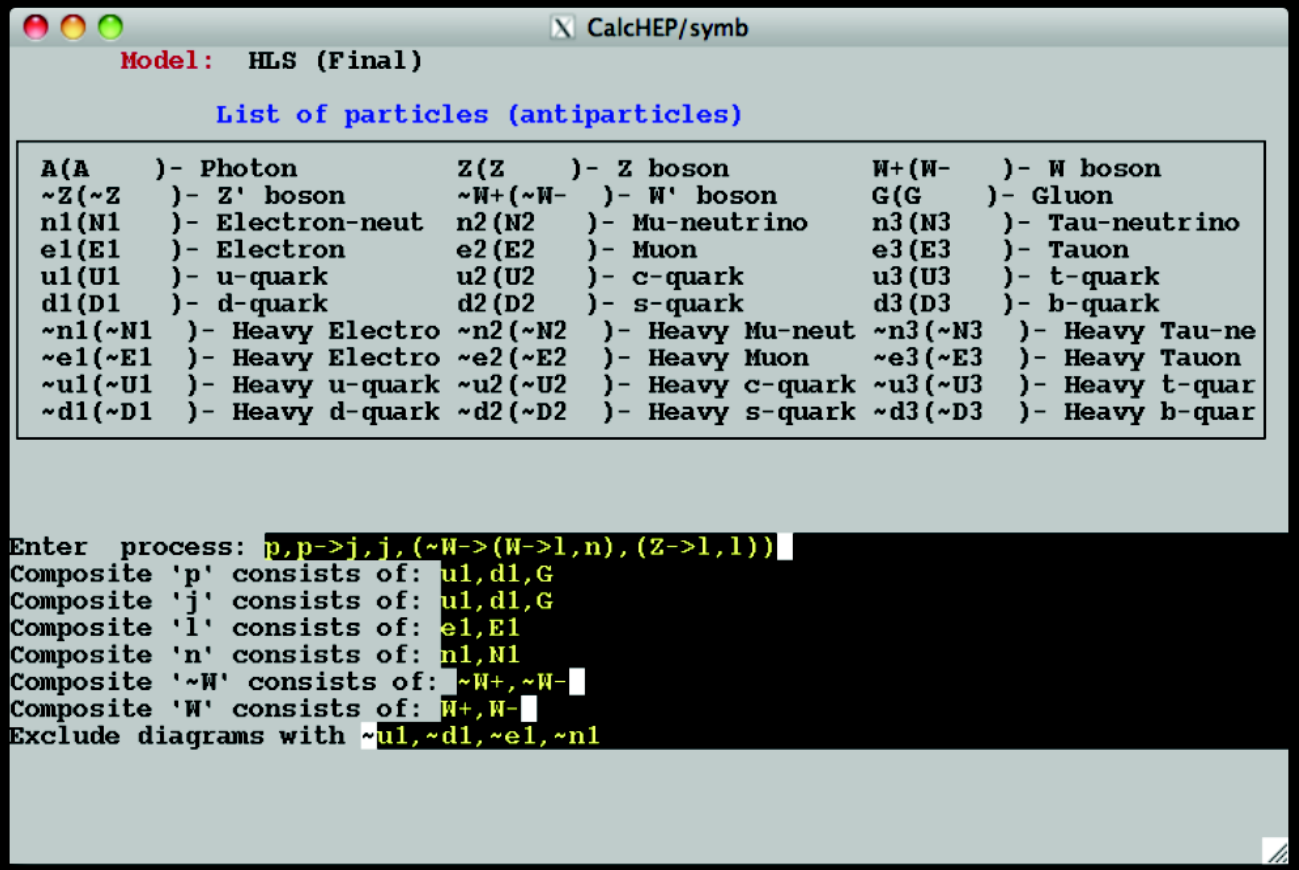
New Developments

New Developments

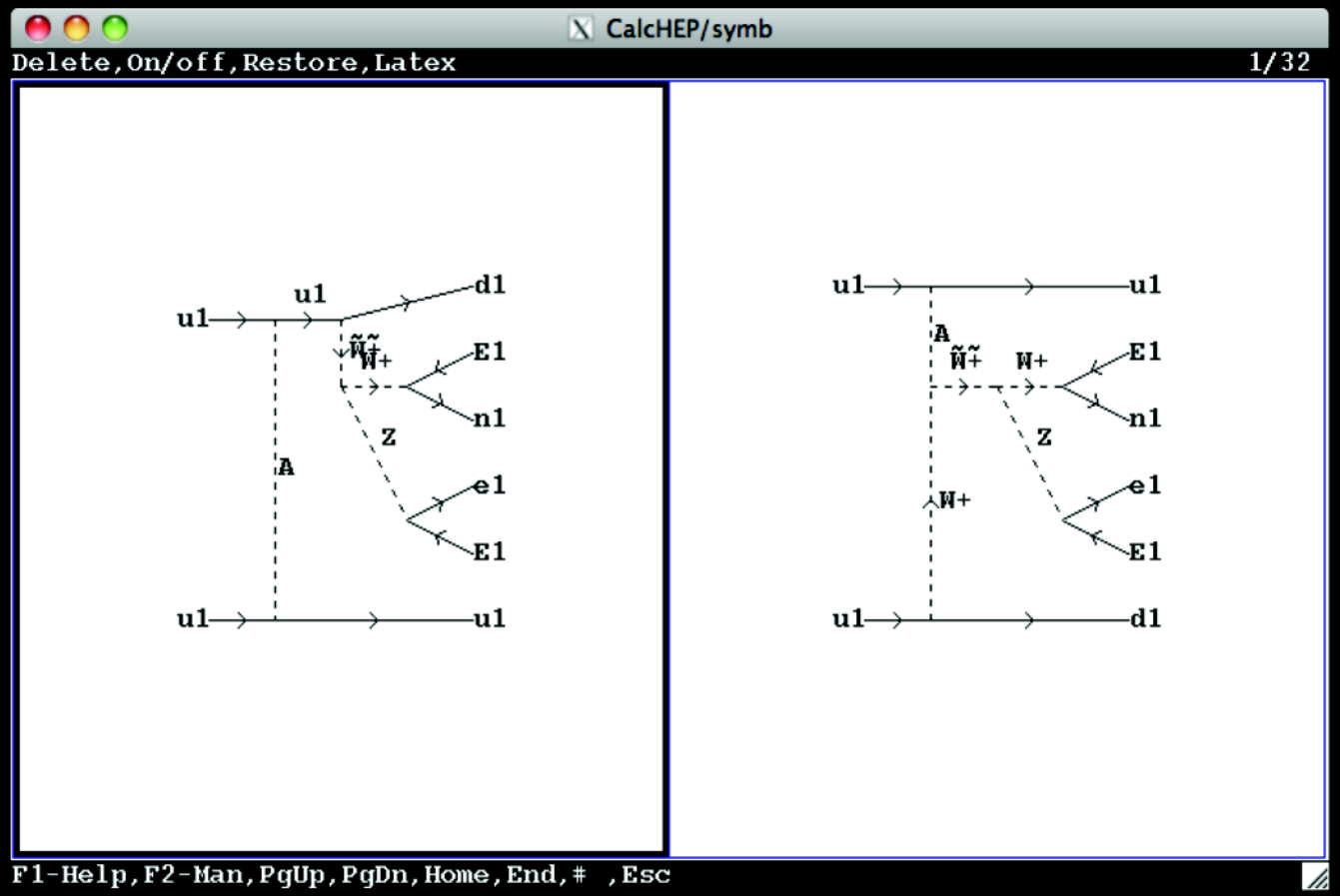
Choose resonant diagrams:

$$p, p \to j, j, (\sim W \to (W \to l, n), (Z \to l, l))$$

New Developments



New Developments



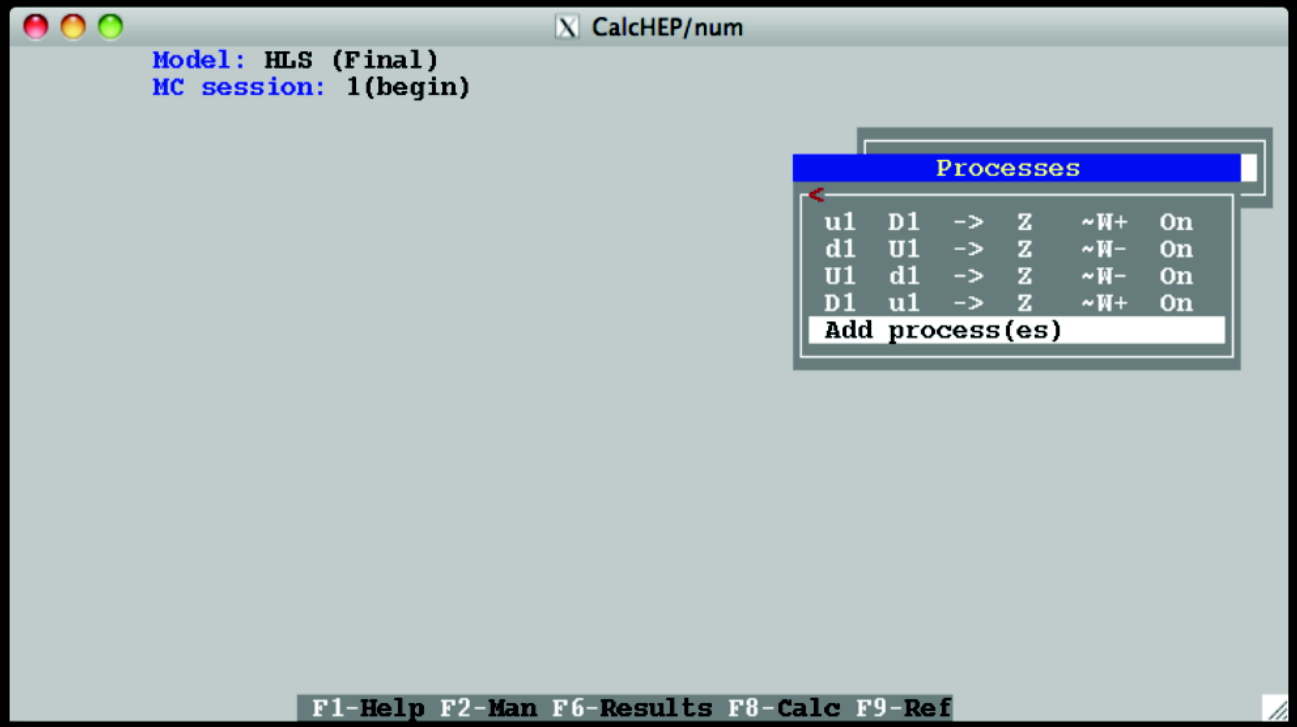
New Developments

New numerical session:

Allows to dynamically generate multiple production and decay processes.

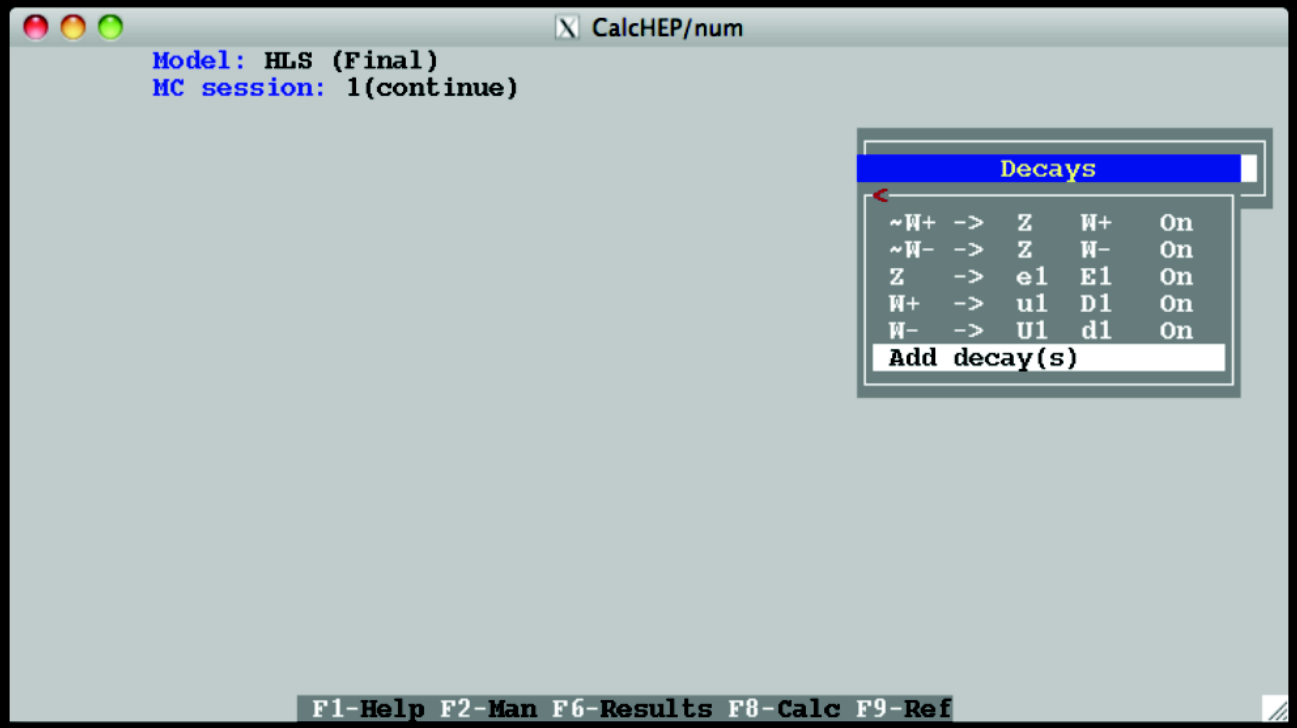
New Developments

New numerical session:



New Developments

New numerical session:



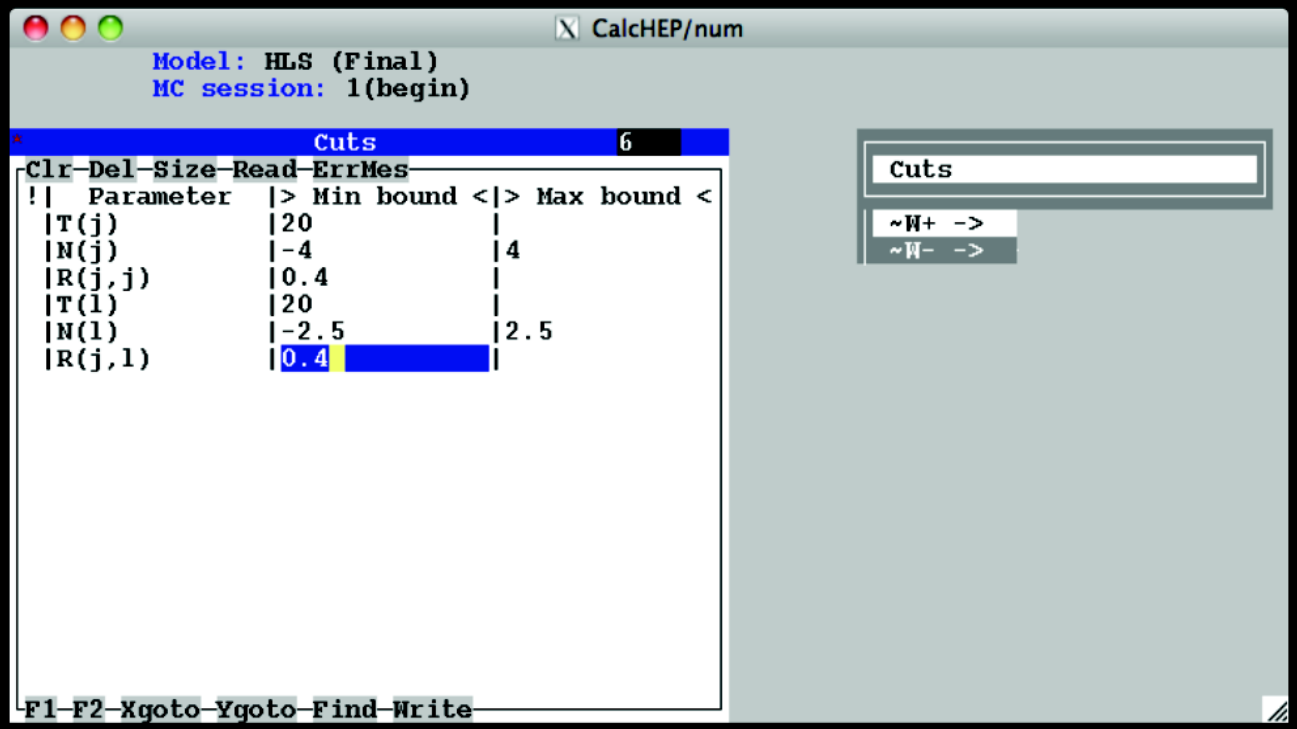
New Developments

New numerical session:

Allows to cut on final states (after decay).

New Developments

New numerical session:



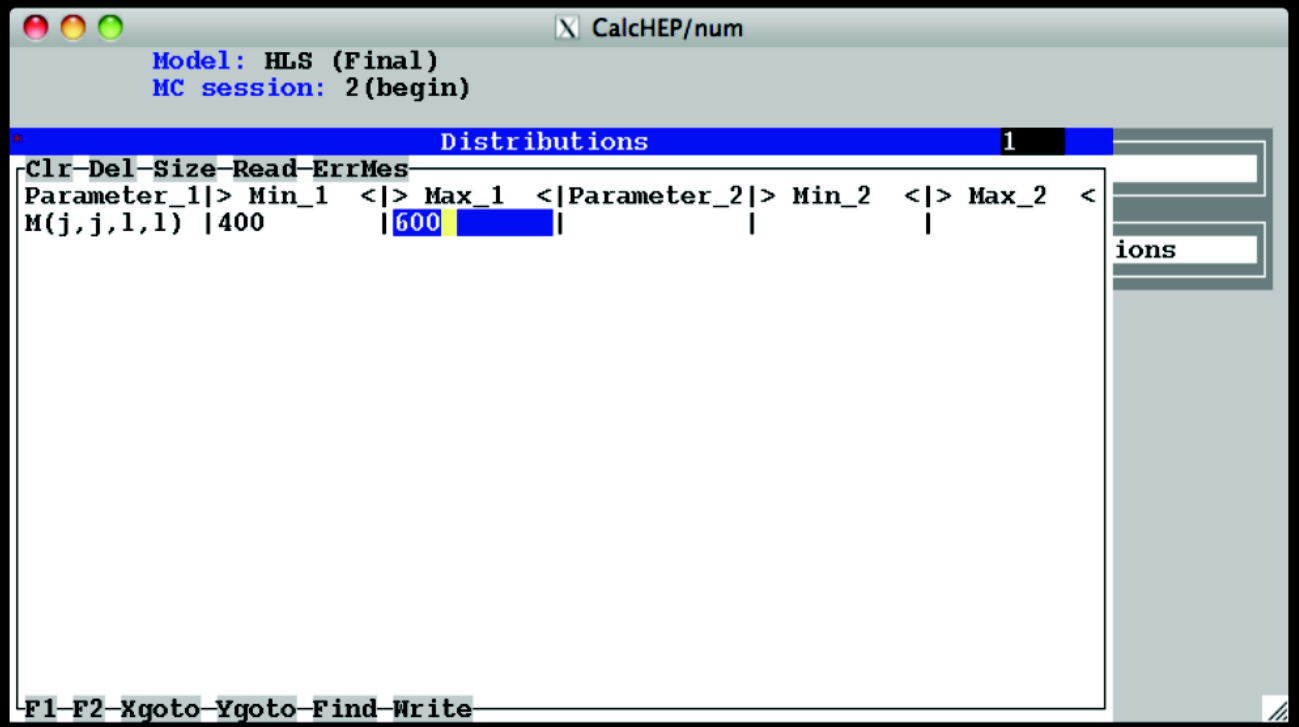
New Developments

New numerical session:

Allows to bin final states (after decay).

New Developments

New numerical session:



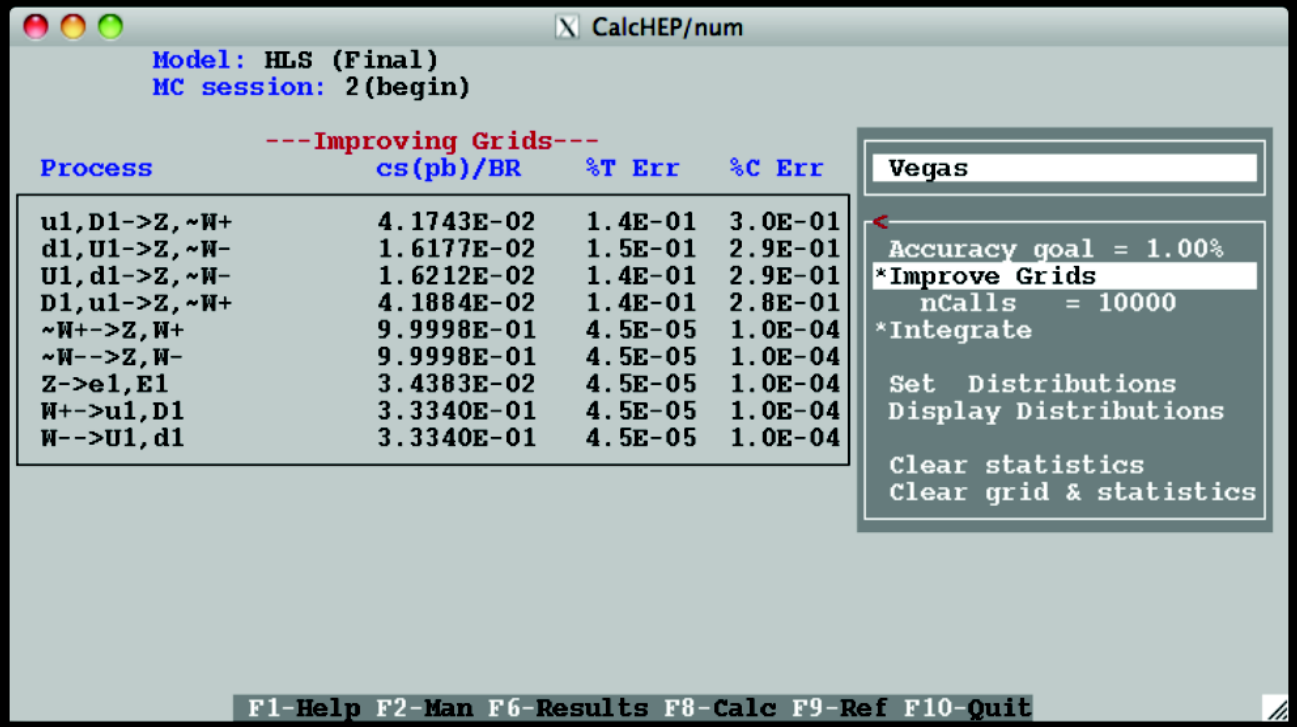
New Developments

New numerical session:

Improves all the grids.

New Developments

New numerical session:



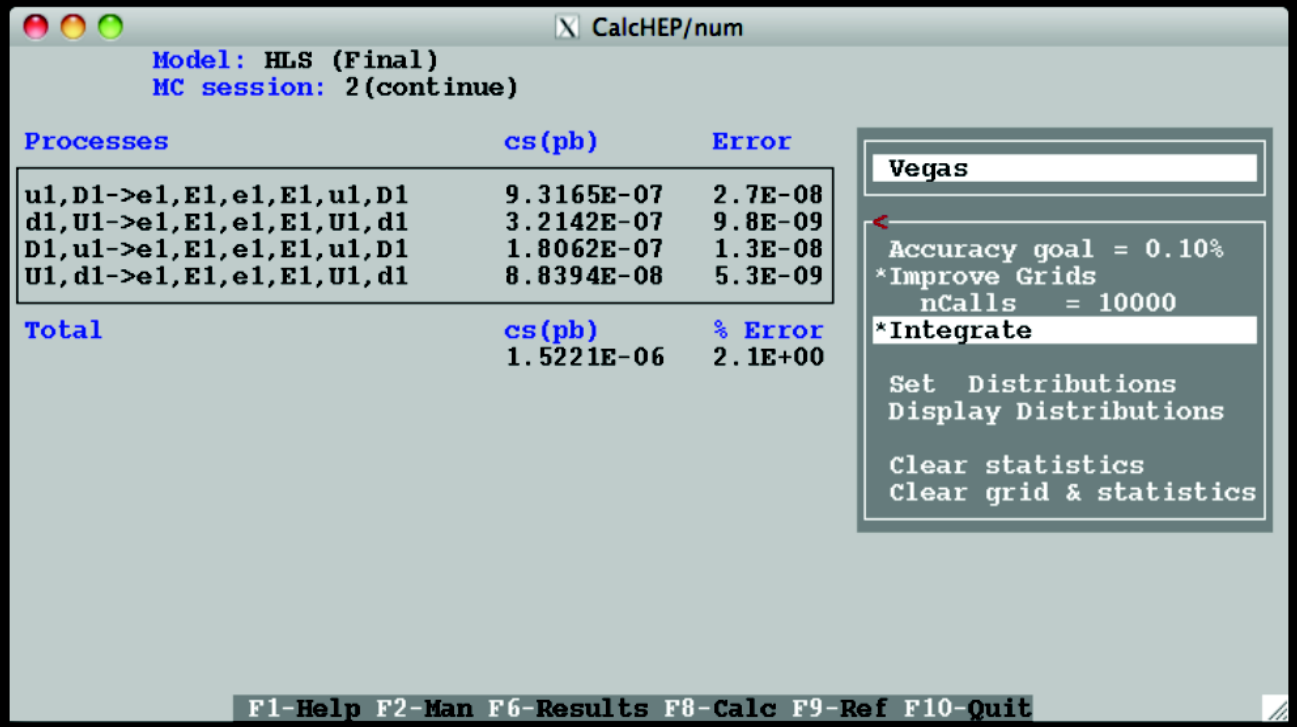
New Developments

New numerical session:

Dynamically connects production and decays.
Sums over subprocesses.

New Developments

New numerical session:



New Developments

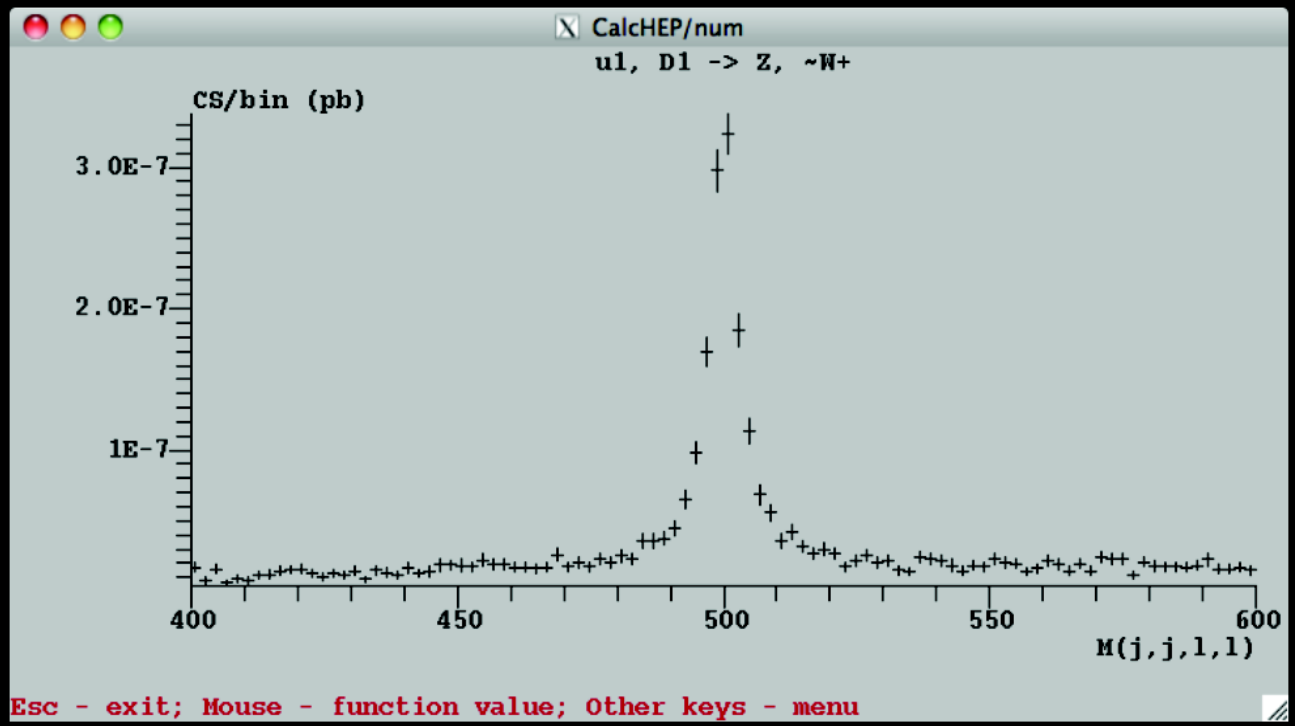
New numerical session:

Cuts final states (after decay).

Bins final states (after decay).

New Developments

New numerical session:



New Developments

New numerical session:

Spends increasingly more time on subprocesses with largest absolute error.