CalcHEP

Neil Christensen
PITTsburgh Particle physics, Astrophysics and Cosmology Center (PITT PACC),
University of Pittsburgh
in collaboration with
Alexander Belyaev and Alexander Pukhov

Outline

- Code Download & Manual
- Graphical Symbolic Session
- Graphical Numerical Session
- Batch Mode
- Developmental Numerical Session
- Future Developments

Download & Installation

- Download
  - http://theory.sinp.msu.ru/~pukhov/calchep.html
- Setup CalcHEP directory:
  - mkdir physics/CalcHEP
  - cp Downloads/calchep_3.2.7.tar.gz physics/CalcHEP/calchep_3.2.7.tar.gz
- Compile CalcHEP
  - cd physics/CalcHEP
  - tar xvzf calchep_3.2.7.tar.gz
  - cd calchep_3.2.7
  - make
- Start CalcHEP
  - ./mkUsrDir ../ch_3.2.7
  - cd ../ch_3.2.7
  - ./calchep &

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

Authors - Alexander Pukhov, Alexander Belyaev, Neil Christensen

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

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

Manual
calchep_man_2.3.5(ps.gz) (137 pages, 445KB, March 18, 2005)
HEP computer tools (Lecture by Alexander Belyaev)
See also: Dan Green, High Pt physics at hadron colliders (Cambrige University Press)

Codes download.
Licence Installation References&Contributions
CalcHEP code for UNIX: version 3.2 (November 8, 2011)

Models:
MSSM(24.06.2011) NMSSM23(07.05.2011) CPVMSSM(07.05.2011) LeptoQuarks
Universal Extra Dimension Models: 5DSM 6DSM SUSY models for CompHEP By A.Semenov

---

Relative packages on Web:
Packages for model generation: LanHEP FeynRules
RGE and spectrum calculation: SuSpect Isajet SoftSUSY SPheno CPsuperH NMHDecay
Particle widths in MSSM: SDECAY HDECAY
Parton showers: PYTHIA

Email contact: **calchep@googlegroups.com**
Main Page

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Very old!

CalcHEP
Calculator for High Energy Physics
A package for the evaluation of Feynman diagrams, integration over multi-particle phase space, and event generation.

A.Pukhov, A.Belyaev, N.Christensen*

User's manual for version 3.3
(XXXX, 2011)

Based on Pukhov et al, hep-ph/9908288

Graphical User Interface

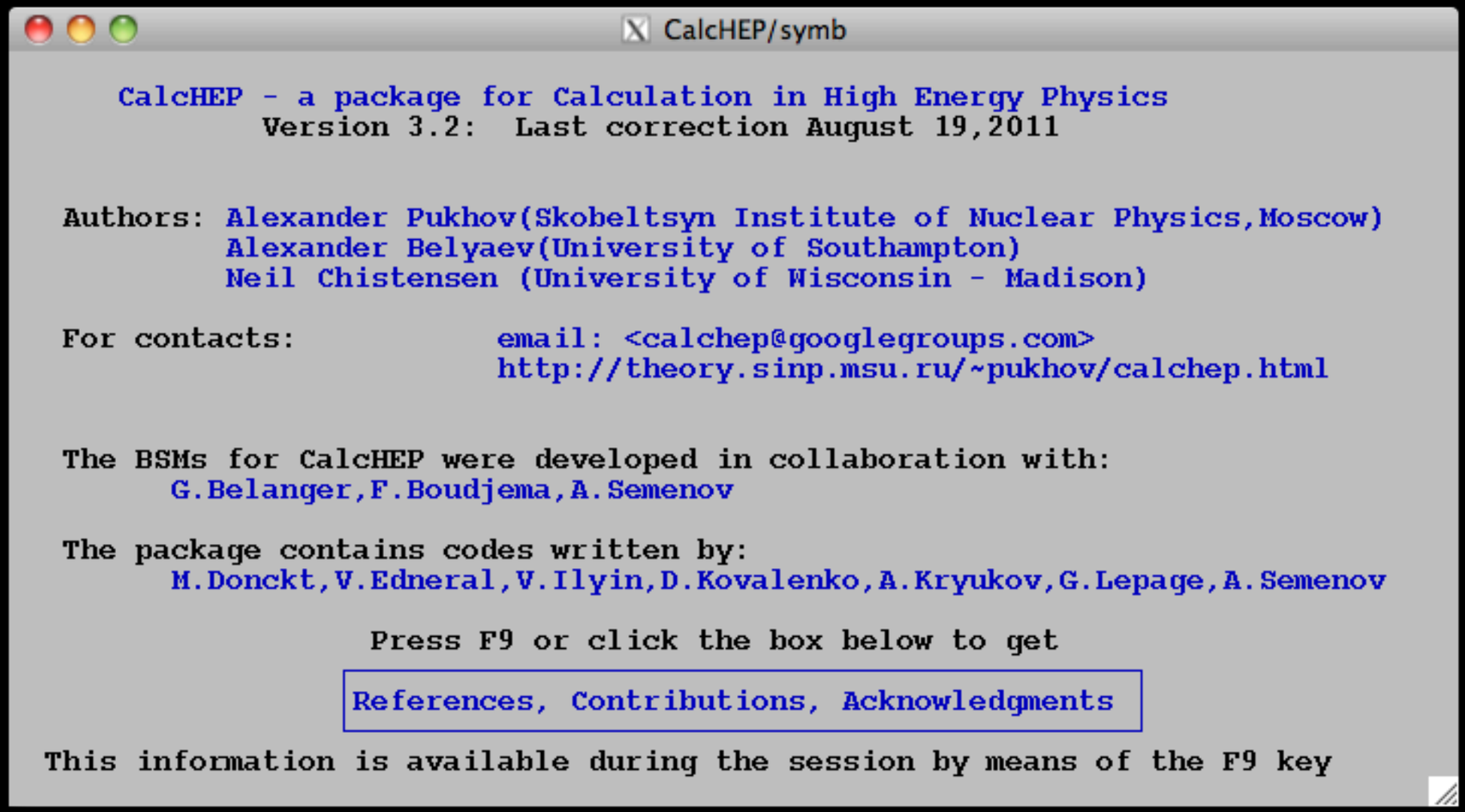
- Import Model.
- Check Model.
- Calculate Widths & Branching Ratios.
- Generate Diagrams.
- Generate Numerical Code for processes.
- Compile Numerical Code for Processes.

Edit Model

- Import Model
- Parameters:
  - Add/remove independent parameters.
  - Change numerical values of independent parameters.
- Constraints:
  - Add/remove dependent parameters.
  - Change expressions for dependent parameters.
- Particles:
  - Add/remove particles.
  - Change properties of particles.
- Vertices:
  - Add/remove vertices.
  - Change coefficient of vertices.
  - Change Lorentz structure of vertices.
- Libraries:
  - Add/remove external code.
  - Add LHAPDF support.
- Check Model

Terminal — bash — 80×24

```
new-host-2:ch_3.2.7 neil$ ./calchep&
```


CalcHEP/symb
CalcHEP - a package for Calculation in High Energy Physics
Version 3.2: Last correction August 19,2011
Authors: Alexander Pukhov(Skobeltsyn Institute of Nuclear Physics,Moscow)
Alexander Belyaev(University of Southampton)
Neil Chistensen (University of Wisconsin - Madison)
For contacts: email: <calchep@googlegroups.com>
http://theory.sinp.msu.ru/~pukhov/calchep.html
The BSMs for CalcHEP were developed in collaboration with:
G.Belanger,F.Boudjema,A.Semenov
The package contains codes written by:
M.Donckt,V.Edneral,V.Ilyin,D.Kovalenko,A.Kryukov,G.Lepage,A.Semenov
Press F9 or click the box below to get
References, Contributions, Acknowledgments
This information is available during the session by means of the F9 key

CalcHEP/symb

Abstract

CalcHEP package is created for calculation of decay and high energy collision processes of elementary particles in the lowest order (tree) approximation. The main idea put into the CalcHEP was to make available passing from the lagrangian to the final distributions effectively with the high level of automatization.

Use F2 key to get information about interface facilities and F1 - as online help.

<

Standard Model

Standard Model(CKM=1)

IMPORT MODEL

F1-Help F2-Man F5-Switches F6-Results F9-Ref F10-Quit

CalcHEP/symb

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<

Standard Model
Standard Model(CKM=1)
IMPORT MODEL

F1-Help F2-Man F5-Switches F6-Results F9-Ref F10-Quit

CalcHEP/symb

File Search: $CALCHEP/*

IMPORT MODEL

CalcHEP/symb

File Search: ~/*

IMPORT MODEL

CalcHEP/symb

File Search: ~/*

Contents of directory

<

.config/
.cups/
.dropbox/
.emacs.d/
.fontconfig/
.fonts/
.foxrc/
.jaxodraw/
.KoalaNext/
.m2/
.netbeans/
.netbeans-registration/
.sherpa/
.ssh/
.subversion/
.texlive2008/
.Trash/
.whizard/

PgDn

IMPORT MODEL

F1-Help F2-Man F5-Switches F6-Results F9-Ref F10-Quit

CalcHEP/symb

File Search: ~/*

Contents of directory

<

PgUp

.Xcode/
bin/
Calibre Library/
Desktop/
Documents/
Downloads/
Dropbox/
Library/
Movies/
Music/
NetBeansProjects/
physics/
Pictures/
programs/
Public/
QtSDK/
Sites/
VirtualBox VMs/

PgDn

IMPORT MODEL

F1-Help F2-Man F5-Switches F6-Results F9-Ref F10-Quit

CalcHEP/symb

File Search: ~/physics/*

IMPORT MODEL

CalcHEP/symb

File Search: ~/physics/*

Contents of directory

IMPORT MODEL

F1-Help F2-Man F5-Switches F6-Results F9-Ref F10-Quit

CalcHEP/symb

File Search: ~/physics/projects/*

IMPORT MODEL

CalcHEP/symb

File Search: ~/physics/projects/MC4BSM-2012/Sandbox/MC4BSM_2012-CH/*

IMPORT MODEL

CalcHEP/symb

File Search: ~/physics/projects/MC4BSM-2012/Sandbox/MC4BSM_2012-CH/

IMPORT MODEL

CalcHEP/symb

IMPORT MODEL

Choose a model

Download all models

MC4BSM_2012 | 1.mdl

F1-Help F2-Man F5-Switches F6-Results F9-Ref F10-Quit

CalcHEP/symb

IMPORT MODEL

Choose a model

MC4BSM_2012 | 1.mdl

Correct name MC4BSM_2012

CalcHEP/symb

IMPORT MODEL

Choose a model

MC4BSM_2012 | 1.mdl

The model is added
Press any key

CalcHEP/symb

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<

Standard Model
Standard Model(CKM=1)
MC4BSM_2012
IMPORT MODEL

F1-Help F2-Man F5-Switches F6-Results F9-Ref F10-Quit

CalcHEP/symb

Model: MC4BSM_2012

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<

Enter Process
Force Unit.Gauge OFF
Edit model
Numerical Evaluation
==========
Delete model

F1-Help F2-Man F5-Switches F6-Results F9-Ref F10-Quit

CalcHEP/symb

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Edit model

<

Parameters
Constraints
Particles
Vertices
Libraries
RENAME
CHECK MODEL

F1-Help F2-Man F5-Switches F6-Results F9-Ref F10-Quit

CalcHEP/symb

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CHECK MODEL

The model is Ok
Press any key

CalcHEP/symb

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F1-Help F2-Man F5-Switches F6-Results F9-Ref F10-Quit

CalcHEP/symb

Parameters 22

Clr Del Size Read ErrMes

Name	Value	> Comment
lam2	1	lam2
lam1p	1	lam1p
lam2p	1	lam2p
GG	1.21977796370	Strong coupling constant This value will be ignored an
MTA	1.777	Mass of tt.
MT	172	Mass of t.
MB	4.7	Mass of b.
MZ	91.1876	Mass of phi.
MH	120	Mass of H.
Muv	500	Mass of uv.
Mev	250	Mass of ev.
%WT	1.50833649	Width of t.
%WZ	2.4952	Width of Z.
%WW	2.085	Width of W.
%WH	0.00575308848	Width of H.
%Wpe1	1	Width of p1.
%Wpe2	1	Width of p2.
%Wuv	1	Width of uv.
%Wev	1	Width of ev.
E	2.71828182845	The base of the natural logarithm.
Pi	3.14159265358	The circumference of a circle divided by the diameter.

F1 F2 Xgoto Ygoto Find Write

CalcHEP/symb

Parameters 24

Clr Del Size Read ErrMes

Name	Value	> Comment
lam2	1	lam2
lam1p	1	lam1p
lam2p	1	lam2p
GG	1.21977796370	Strong coupling constant This value will be ignored an
MTA	1.777	Mass of tt.
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Mev	250	Mass of ev.
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WZ	2.4952	Width of Z.
WW	2.085	Width of W.
%WH	0.00575308848	Width of H.
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%Wpe2	1	Width of p2.
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%Wev	1	Width of ev.
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Constraints
Particles
Vertices
Libraries
RENAME
CHECK MODEL

F1-Help F2-Man F5-Switches F6-Results F9-Ref F10-Quit

CalcHEP/symb

Constraints 30

Clr Del Size Read ErrMes

Name	> Expression
MPe1	pow(2,-0.5)*pow(pow(MM1,2)+pow(MM2,2)-pow(pow(MM1,4)+4*pow(MM12,4)-2*p
MPe2	pow(2,-0.5)*pow(pow(MM1,2)+pow(MM2,2)+pow(pow(MM1,4)+4*pow(MM12,4)-2*p
th	acos(pow(1+(pow(MM12,-4)*pow(-pow(MM1,2)+pow(MM2,2)+pow(4*pow(MM12,4)+
aEW	pow(aEWM1,-1)
MW	pow(pow(MZ,2)/2.+pow(-(aEW*Pi*pow(2,-0.5)*pow(Gf,-1)*pow(MZ,2))+pow(MZ
ee	2*pow(aEW,0.5)*pow(Pi,0.5)
sw2	1-pow(MW,2)*pow(MZ,-2)
cw	pow(1-sw2,0.5)
sw	pow(sw2,0.5)
g1	ee*pow(cw,-1)
gw	ee*pow(sw,-1)
v	2*MW*sw*pow(ee,-1)
lam	(pow(MH,2)*pow(v,-2))/2.
yb	ymb*pow(2,0.5)*pow(v,-1)
yt	ymt*pow(2,0.5)*pow(v,-1)
ytau	ymtau*pow(2,0.5)*pow(v,-1)
muH	pow(lam*pow(v,2),0.5)
x1	-6*lam
x3	-2*lam
x5	-6*lam
x7	-2*lam

F1 F2 Xgoto Ygoto Find Write

CalcHEP/symb

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F1-Help F2-Man F5-Switches F6-Results F9-Ref F10-Quit

CalcHEP/symb

Particles 9

Clr-Del-Size-Read-ErrMes

Full name	A	A+	number	2*spin	mass	width	color	aux	>LaTex(A)<	>
Electron-neut	ve	ve~	12	1	0	0	1		ve	v
Mu-neutrino	vm	vm~	14	1	0	0	1		vm	v
Tau-neutrino	vt	vt~	16	1	0	0	1		vt	v
Electron	e-	e+	11	1	0	0	1		e-	e
Muon	m-	m+	13	1	0	0	1		m-	m
Tau	tt-	tt+	15	1	MTA	0	1		tt-	t
u-quark	u	u~	2	1	0	0	3		u	u
c-quark	c	c~	4	1	0	0	3		c	c
t-quark	t	t~	6	1	MT	!WT	3		t	t
d-quark	d	d~	1	1	0	0	3		d	d
s-quark	s	s~	3	1	0	0	3		s	s
b-quark	b	b~	5	1	MB	0	3		b	b
Photon	A	A	22	2	0	0	1	G	A	A
Z	Z	Z	23	2	MZ	!WZ	1	G	Z	Z
W	W+	W-	24	2	MW	!WW	1	G	W+	W
G	G	G	21	2	0	0	8	G	G	G
H	H	H	25	0	MH	!WH	1		H	H
p1	p1	p1	9000006	0	MPe1	!Wpe1	1		p1	p
p2	p2	p2	9000007	0	MPe2	!Wpe2	1		p2	p
uv	uv	uv~	9000008	1	Muv	!Wuv	3		uv	u
ev	ev	ev~	9000009	1	Mev	!Wev	1		ev	e

F1-F2-Xgoto-Ygoto-Find-Write

CalcHEP/symb

Particles 15

Clr-Del-Size-Read-ErrMes

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Electron	e-	e+	11	1	0	0	1		e-	e
Muon	m-	m+	13	1	0	0	1		m-	m
Tau	tt-	tt+	15	1	MTA	0	1		tt-	t
u-quark	u	u~	2	1	0	0	3		u	u
c-quark	c	c~	4	1	0	0	3		c	c
t-quark	t	t~	6	1	MT	WT	3		t	t
d-quark	d	d~	1	1	0	0	3		d	d
s-quark	s	s~	3	1	0	0	3		s	s
b-quark	b	b~	5	1	MB	0	3		b	b
Photon	A	A	22	2	0	0	1	G	A	A
Z	Z	Z	23	2	MZ	WZ	1	G	Z	Z
W	W+	W-	24	2	MW	WW	1	G	W+	W
G	G	G	21	2	0	0	8	G	G	G
H	H	H	25	0	MH	!WH	1		H	H
p1	p1	p1	9000006	0	MPe1	!Wpe1	1		p1	p
p2	p2	p2	9000007	0	MPe2	!Wpe2	1		p2	p
uv	uv	uv~	9000008	1	Muv	!Wuv	3		uv	u
ev	ev	ev~	9000009	1	Mev	!Wev	1		ev	e

F1-F2-Xgoto-Ygoto-Find-Write

Automatic Widths

- Syntax:
  - !WH (The ! means automatic.)
  - Don't forget to comment the width out of the parameters table.
- What is calculated:
  - For each particle, all $1 \rightarrow 2$ decays that are kinematically open are calculated.
  - If the calculated width is 0, then all $1 \rightarrow 3$ decays that are kinematically open are calculated.
  - If the calculated width is 0, then all $1 \rightarrow 4$ decays that are kinematically open are calculated.

CalcHEP/symb

Model: MC4BSM_2012

Abstract

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Edit model

<

Parameters
Constraints
Particles
Vertices
Libraries
RENAME
CHECK MODEL

F1-Help F2-Man F5-Switches F6-Results F9-Ref F10-Quit

CalcHEP/symb

Vertices 40

Clr Del Size Read ErrMes

A1	A2	A3	A4	> Factor <	> Lorentz part
W-.C	W+.c	H		x55	1
W-.C	W+.c	Z.f		x57	i
A	W-.C	W+.c		x59	p1.m1+p3.m1
W-.C	W+.c	Z		x62	p2.m3+p3.m3
W-.C	Z.c	W+.f		x65	i
W-.C	Z.c	W+		x67	p2.m3+p3.m3
Z.C	W-.c	W+.f		x70	i
Z.C	W-.c	W+		x72	p2.m3+p3.m3
Z.C	W+.c	W-.f		x75	i
Z.C	W+.c	W-		x77	p2.m3+p3.m3
Z.C	Z.c	H		x80	1
G	G.C	G.c		x82	GG*p1.m1+GG*p3.m1
G	G	G		x85	-GG*p1.m2*m1.m3+GG*p1.m3*m1.m2+GG*p2.m1*m2
G	G	G.t		GG*x92	m1.M3*m2.m3-m1.m3*m2.M3
A	ev~	ev		x93	G(m1)
A	uv~	uv		x94	G(m1)
p1	e+	ev		x95	(1-G5)
p2	e+	ev		x96	(1-G5)
p1	u~	uv		x97	(1-G5)
p2	u~	uv		x98	(1-G5)
p1	ev~	e-		x99	(1+G5)
p2	ev~	e-		x100	(1+G5)
p1	uv~	u		x101	(1+G5)
p2	uv~	u		x102	(1+G5)
G	uv~	uv		x103	GG*G(m1)
A	H	W-.f	W+	x104	i*m1.m4
A	Z.f	W-.f	W+	x106	m1.m4
A	W-.f	W+		x108	i*m1.m3
H	W-.f	W+		x110	-i*p1.m3+i*p2.m3
Z.f	W-.f	W+		x113	-p1.m3+p2.m3
A	W+	W-		x116	-m1.m2*p1.m3+m1.m2*p2.m3+m1.m3*p1.m2-m1.m3
A	H	W+.f	W-	x123	i*m1.m4
A	Z.f	W+.f	W-	x125	m1.m4
A	W+.f	W-		x127	i*m1.m3

F1 F2 Xgoto Ygoto Find Write

CalcHEP/symb

Model: MC4BSM_2012

Abstract

CalcHEP package is created for calculation of decay and high energy collision processes of elementary particles in the lowest order (tree) approximation. The main idea put into the CalcHEP was to make available passing from the lagrangian to the final distributions effectively with the high level of automatization.

Use F2 key to get information about interface facilities and F1 - as online help.

Edit model

<

Parameters
Constraints
Particles
Vertices
Libraries
RENAME
CHECK MODEL

CalcHEP/symb

Libraries 14

Clr Del Size Read ErrMes

```
External libraries  and citation                                        <
%This model file was generated by FeynRules version $Revision: 915 $.
%Please cite:
%   arXiv:0806.4194
%   arXiv:0906.2474
%Further information can be found at:
%   http://feynrules.phys.ucl.ac.be
%
%This model implementation was created by:
%   C. Duhr
%Emails:
%   duhrc@itp.phys.ethz.ch
%Model version: 1.0
%Date: 27. 02. 2012
```

F1 F2 Xgoto Ygoto Find Write

CalcHEP/symb

Libraries 14

Clr Del Size Read ErrMes

```
External libraries  and citation                                        <
%This model file was generated by FeynRules version $Revision: 915 $.
%Please cite:
%   arXiv:0806.4194
%   arXiv:0906.2474
%Further information can be found at:
%   http://feynrules.phys.ucl.ac.be
%
%This model implementation was created by:
%   C. Duhr
%Emails:
%   duhrc@itp.phys.ethz.ch
%Model version: 1.0
%Date: 27. 02. 2012
-L/Users/neil/programs/Whizard/lib  -lLHAPDF
```

F1 F2 Xgoto Ygoto Find Write

CalcHEP/symb

Libraries 15

Clr Del Size Read ErrMes

```
External libraries  and citation                                        <
%This model file was generated by FeynRules version $Revision: 915 $.
%Please cite:
%   arXiv:0806.4194
%   arXiv:0906.2474
%Further information can be found at:
%   http://feynrules.phys.ucl.ac.be
%
%This model implementation was created by:
%   C. Duhr
%Emails:
%   duhrc@itp.phys.ethz.ch
%Model version: 1.0
%Date: 27. 02. 2012
-L/Users/neil/programs/Whizard/lib  -lLHAPDF
/Users/neil/physics/CalcHEP/usrfun.c
```

F1 F2 Xgoto Ygoto Find Write

CalcHEP/symb

Model: MC4BSM_2012

Abstract

CalcHEP package is created for calculation of decay and high energy collision processes of elementary particles in the lowest order (tree) approximation. The main idea put into the CalcHEP was to make available passing from the lagrangian to the final distributions effectively with the high level of automatization.

Use F2 key to get information about interface facilities and F1 - as online help.

Edit model

<

Parameters
Constraints
Particles
Vertices
Libraries
RENAME
CHECK MODEL

F1-Help F2-Man F5-Switches F6-Results F9-Ref F10-Quit

CalcHEP/symb

Model: MC4BSM_2012

Abstract

CalcHEP package is created for calculation of decay and high energy collision processes of elementary particles in the lowest order (tree) approximation. The main idea put into the CalcHEP was to make available passing from the lagrangian to the final distributions effectively with the high level of automatization.

Use F2 key to get information about interface facilities and F1 - as online help.

Edit model

Save corrections ?
(Y / N ?)

CalcHEP/symb

Model: MC4BSM_2012

Abstract

CalcHEP package is created for calculation of decay and high energy collision processes of elementary particles in the lowest order (tree) approximation. The main idea put into the CalcHEP was to make available passing from the lagrangian to the final distributions effectively with the high level of automatization.

Use F2 key to get information about interface facilities and F1 - as online help.

<

Enter Process
Force Unit.Gauge OFF
Edit model
Numerical Evaluation
==========
Delete model

F1-Help F2-Man F5-Switches F6-Results F9-Ref F10-Quit

Libraries

- LHAPDF:
  - General PDF's can be used in the numerical session.
  - Will come back to LHAPDF in the numerical session.
- usrfun.c:
  - Any kinematical function can be defined and used in cuts and histograms in the numerical session.
  - Will come back to usrfun.c in the numerical session.
- Dependent parameters:
  - Any code required for the calculation of dependent variables can be linked.

CalcHEP/symb

Model: MC4BSM_2012

Abstract

CalcHEP package is created for calculation of decay and high energy collision processes of elementary particles in the lowest order (tree) approximation. The main idea put into the CalcHEP was to make available passing from the lagrangian to the final distributions effectively with the high level of automatization.

Use F2 key to get information about interface facilities and F1 - as online help.

<

Enter Process
Force Unit.Gauge OFF
Edit model
Numerical Evaluation
==========
Delete model

F1-Help F2-Man F5-Switches F6-Results F9-Ref F10-Quit

CalcHEP/symb

Model: MC4BSM_2012

Abstract

CalcHEP package is created for calculation of decay and high energy collision processes of elementary particles in the lowest order (tree) approximation. The main idea put into the CalcHEP was to make available passing from the lagrangian to the final distributions effectively with the high level of automatization.

Use F2 key to get information about interface facilities and F1 - as online help.

Numerical Evaluation

<

Parameters
All Constraints
Masses,Widths,Branch.

F1-Help F2-Man F5-Switches F6-Results F9-Ref F10-Quit

CalcHEP/symb

Model: MC4BSM_2012

Abstract

CalcHEP package is created for calculation of decay and high energy collision processes of elementary particles in the lowest order (tree) approximation. The main idea put into the CalcHEP was to make available passing from the lagrangian to the final distributions effectively with the high level of automatization.

Use F2 key to get information about interface facilities and F1 - as online help.

Numerical Evaluation

Change Parameter

<

READ_FROM_FILE	
aEWM1	1.2790E+02
Gf	1.1664E-05
aS	1.1840E-01
ymb	4.7000E+00
ymt	1.7200E+02
ymtau	1.7770E+00
MM1	2.0000E+02
MM2	3.0000E+02
MM12	5.0000E+01
lam1	1.0000E+00
lam2	1.0000E+00
lam1p	1.0000E+00
lam2p	1.0000E+00

PgDn

F1-Help F2-Man F5-Switches F6-Results F9-Ref F10-Quit

CalcHEP/symb

Model: MC4BSM_2012

Abstract

CalcHEP package is created for calculation of decay and high energy collision processes of elementary particles in the lowest order (tree) approximation. The main idea put into the CalcHEP was to make available passing from the lagrangian to the final distributions effectively with the high level of automatization.

Use F2 key to get information about interface facilities and F1 - as online help.

Numerical Evaluation

Constraint

Sqrt2	1.4142E+00
MPe1	1.9969E+02
MPe2	3.0021E+02
th	1.5210E+00
aEW	7.8186E-03
MW	7.9824E+01

F1-Help F2-Man F5-Switches F6-Results F9-Ref F10-Quit

CalcHEP/symb

Model: MC4BSM_2012

Abstract

CalcHEP package is created for calculation of decay and high energy collision processes of elementary particles in the lowest order (tree) approximation. The main idea put into the CalcHEP was to make available passing from the lagrangian to the final distributions effectively with the high level of automatization.

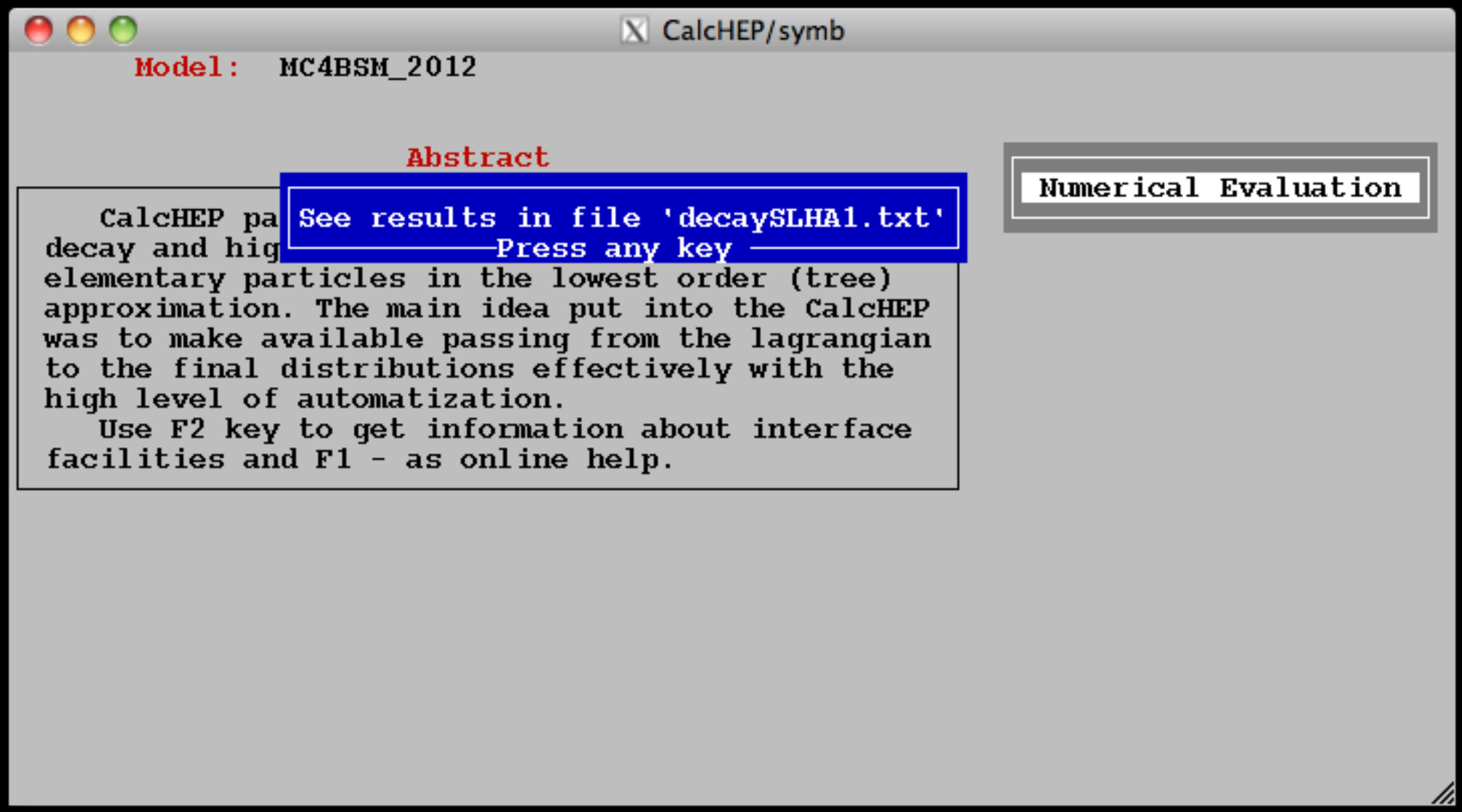
Use F2 key to get information about interface facilities and F1 - as online help.

Numerical Evaluation

ALL PARTICLES	
ve	Zero
vm	Zero
vt	Zero
e-	Zero
m-	Zero
tt-	1.7770E+00
u	Zero
c	Zero
t	1.7200E+02
d	Zero
s	Zero
b	4.7000E+00
A	Zero

PgDn

F1-Help F2-Man F5-Switches F6-Results F9-Ref F10-Quit


CalcHEP/symb
Model: MC4BSM_2012
Abstract
See results in file 'decaySLHA1.txt'
Press any key
CalcHEP pa
decay and hig
elementary particles in the lowest order (tree)
approximation. The main idea put into the CalcHEP
was to make available passing from the lagrangian
to the final distributions effectively with the
high level of automatization.
Use F2 key to get information about interface
facilities and F1 - as online help.
Numerical Evaluation

Terminal — s_calchep — 80×24

s_calchep | bash | bash

```
new-host-2:ch_3.2.7 neil$ ./calchep&
[1] 815
new-host-2:ch_3.2.7 neil$
new-host-2:ch_3.2.7 neil$ sh: ./n_calchep: No such file or directory
PROCESS: t->2*x
PROCESS: Z->2*x
PROCESS: W+->2*x
PROCESS: H->2*x
PROCESS: p1->2*x
asks 2->3 for p1
asks 2->4 for p1
PROCESS: p2->2*x
PROCESS: uv->2*x
PROCESS: ev->2*x

new-host-2:ch_3.2.7 neil$ ls results/
EXTLIBsh       autoprot.h     decaySLHA1.txt proclib_0.a    scale.so
VandP.cc       aux            n_calchep      scale.c        session.dat
new-host-2:ch_3.2.7 neil$ less results/decaySLHA1.txt
new-host-2:ch_3.2.7 neil$
```

Terminal — less — 80×24

less | bash | bash

```
BLOCK ModelParameters # MC4BSM_2012
   1      1.279000E+02 # aEWM1
   2      1.166370E-05 # Gf
   3      1.184000E-01 # aS
   4      4.700000E+00 # ymb
   5      1.720000E+02 # ymt
   6      1.777000E+00 # ymtau
   7      2.000000E+02 # MM1
   8      3.000000E+02 # MM2
   9      5.000000E+01 # MM12
  10      1.000000E+00 # lam1
  11      1.000000E+00 # lam2
  12      1.000000E+00 # lam1p
  13      1.000000E+00 # lam2p
  14      1.777000E+00 # MTA
  15      1.720000E+02 # MT
  16      4.700000E+00 # MB
  17      9.118760E+01 # MZ
  18      1.200000E+02 # MH
  19      5.000000E+02 # Muv
  20      2.500000E+02 # Mev
  21      1.508336E+00 # WT
  22      2.495200E+00 # WZ
results/decaySLHA1.txt
```

Terminal — less — 80×24

less | bash | bash

```
  23      2.085000E+00 # WW
  24      2.718282E+00 # E
  25      3.141593E+00 # Pi
#
BLOCK QNUMBERS 12  # ve
 1  0 # 3*el.charge
 2  1 # 2*spin
 3  1 # color dim
 4  126 # 0={ self-conjugated}
#
BLOCK QNUMBERS 14  # vm
 1  0 # 3*el.charge
 2  1 # 2*spin
 3  1 # color dim
 4  126 # 0={ self-conjugated}
#
BLOCK QNUMBERS 16  # vt
 1  0 # 3*el.charge
 2  1 # 2*spin
 3  1 # color dim
 4  126 # 0={ self-conjugated}
#
BLOCK QNUMBERS 11  # e-
:
```

Terminal — less — 80×24

less | bash | bash

```
 1.111203E-01 2   12 -11  #  ve,e+
 1.111203E-01 2   14 -13  #  vm,m+
 1.110377E-01 2   16 -15  #  vt,tt+
 3.333608E-01 2   2 -1  #  u,d~
 3.333608E-01 2   4 -3  #  c,s~
#
DECAY 25  5.419672E-03 # H
 4.582716E-02 2   15 -15  #  tt-,tt+
 9.541729E-01 2   5 -5  #  b,b~
#
DECAY 9000006  0.000000E+00 # p1
#
DECAY 9000007  1.233917E+00 # p2
 5.000000E-01 2   -11 9000009  #  e+,ev
 5.000000E-01 2   11 -9000009  #  e-,ev~
#
DECAY 9000008  5.400326E+00 # uv
 5.858766E-01 2   2 9000006  #  u,p1
 4.141233E-01 2   2 9000007  #  u,p2
#
DECAY 9000009  2.934454E-01 # ev
 1.000000E+00 2   11 9000006  #  e-,p1
#
(END)
```

CalcHEP/symb

Model: MC4BSM_2012

Abstract

CalcHEP package is created for calculation of decay and high energy collision processes of elementary particles in the lowest order (tree) approximation. The main idea put into the CalcHEP was to make available passing from the lagrangian to the final distributions effectively with the high level of automatization.

Use F2 key to get information about interface facilities and F1 - as online help.

<

Enter Process

Force Unit.Gauge OFF

Edit model

Numerical Evaluation

==========

Delete model

F1-Help F2-Man F5-Switches F6-Results F9-Ref F10-Quit

CalcHEP/symb

Model: MC4BSM_2012

Abstract

CalcHEP package is created for calculation of decay and high energy collision processes of elementary particles in the lowest order (tree) approximation. The main idea put into the CalcHEP was to make available passing from the lagrangian to the final distributions effectively with the high level of automatization.

Use F2 key to get information about interface facilities and F1 - as online help.

<

Enter Process
Force Unit.Gauge OFF
Edit model
Numerical Evaluation
==========
Delete model

F1-Help F2-Man F5-Switches F6-Results F9-Ref F10-Quit

CalcHEP/symb

Model: MC4BSM_2012

List of particles (antiparticles)

ve(ve~)- Electron-neut	vm(vm~)- Mu-neutrino	vt(vt~)- Tau-neutrino
e-(e+)- Electron	m-(m+)- Muon	tt-(tt+)- Tau
u(u~)- u-quark	c(c~)- c-quark	t(t~)- t-quark
d(d~)- d-quark	s(s~)- s-quark	b(b~)- b-quark
A(A)- Photon	Z(Z)- Z	W+(W-)- W
G(G)- G	H(H)- H	p1(p1)- p1
p2(p2)- p2	uv(uv~)- uv	ev(ev~)- ev

Enter process: p,p->p2,p2

CalcHEP/symb

Model: MC4BSM_2012

List of particles (antiparticles)

ve(ve~)- Electron-neut	vm(vm~)- Mu-neutrino	vt(vt~)- Tau-neutrino
e-(e+)- Electron	m-(m+)- Muon	tt-(tt+)- Tau
u(u~)- u-quark	c(c~)- c-quark	t(t~)- t-quark
d(d~)- d-quark	s(s~)- s-quark	b(b~)- b-quark
A(A)- Photon	Z(Z)- Z	W+(W-)- W
G(G)- G	H(H)- H	p1(p1)- p1
p2(p2)- p2	uv(uv~)- uv	ev(ev~)- ev

Enter process: p,p->le,v

CalcHEP/symb

Model: MC4BSM_2012

List of particles (antiparticles)

ve(ve~)- Electron-neut	vm(vm~)- Mu-neutrino	vt(vt~)- Tau-neutrino
e-(e+)- Electron	m-(m+)- Muon	tt-(tt+)- Tau
u(u~)- u-quark	c(c~)- c-quark	t(t~)- t-quark
d(d~)- d-quark	s(s~)- s-quark	b(b~)- b-quark
A(A)- Photon	Z(Z)- Z	W+(W-)- W
G(G)- G	H(H)- H	p1(p1)- p1
p2(p2)- p2	uv(uv~)- uv	ev(ev~)- ev

Enter process: p,p->le,v

CalcHEP/symb

Model: MC4BSM_2012

List of particles (antiparticles)

ve(ve~)- Electron-neut	vm(vm~)- Mu-neutrino	vt(vt~)- Tau-neutrino
e-(e+)- Electron	m-(m+)- Muon	tt-(tt+)- Tau
u(u~)- u-quark	c(c~)- c-quark	t(t~)- t-quark
d(d~)- d-quark	s(s~)- s-quark	b(b~)- b-quark
A(A)- Photon	Z(Z)- Z	W+(W-)- W
G(G)- G	H(H)- H	p1(p1)- p1
p2(p2)- p2	uv(uv~)- uv	ev(ev~)- ev

Enter process: p,p->le,v
composite 'p' consists of: u,u~,d,d~,G
composite 'le' consists of: e+,e-,m+,m-
composite 'v' consists of: ve,ve~,vm,vm~

CalcHEP/symb

Model: MC4BSM_2012

List of particles (antiparticles)

ve(ve~)- Electron-neut	vm(vm~)- Mu-neutrino	vt(vt~)- Tau-neutrino
e-(e+)- Electron	m-(m+)- Muon	tt-(tt+)- Tau
u(u~)- u-quark	c(c~)- c-quark	t(t~)- t-quark
d(d~)- d-quark	s(s~)- s-quark	b(b~)- b-quark
A(A)- Photon	Z(Z)- Z	W+(W-)- W
G(G)- G	H(H)- H	p1(p1)- p1
p2(p2)- p2	uv(uv~)- uv	ev(ev~)- ev

Enter process: p,p->le,v
composite 'p' consists of: u,u~,d,d~,G
composite 'le' consists of: e+,e-,m+,m-
composite 'v' consists of: ve,ve~,vm,vm~
Exclude diagrams with

CalcHEP/symb

Model: MC4BSM_2012

List of particles (antiparticles)

ve(ve~)- Electron-neut	vm(vm~)- Mu-neutrino	vt(vt~)- Tau-neutrino
e-(e+)- Electron	m-(m+)- Muon	tt-(tt+)- Tau
u(u~)- u-quark	c(c~)- c-quark	t(t~)- t-quark
d(d~)- d-quark	s(s~)- s-quark	b(b~)- b-quark
A(A)- Photon	Z(Z)- Z	W+(W-)- W
G(G)- G	H(H)- H	p1(p1)- p1
p2(p2)- p2	uv(uv~)- uv	ev(ev~)- ev

Enter process: p,p->le,v
composite 'p' consists of: u,u~,d,d~,G
composite 'le' consists of: e+,e-,m+,m-
composite 'v' consists of: ve,ve~,vm,vm~
Exclude diagrams with

CalcHEP/symb

```
      Model:   MC4BSM_2012

    Process:   p,p->le,v

               Feynman diagrams
8     diagrams in  8   subprocesses  are constructed.
0     diagrams  are deleted.
```

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

CalcHEP/symb

Model: MC4BSM_2012

Process: p,p->le,v

Feynman diagrams

8 diagrams in 8 subprocesses are constructed.
0 diagrams are deleted.

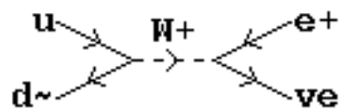
View diagrams

NN	Subprocess	Del	Rest
1	u,d~ -> ve,e+	0	1
2	u,d~ -> vm,m+	0	1
3	u~,d -> ve~,e-	0	1
4	u~,d -> vm~,m-	0	1
5	d,u~ -> ve~,e-	0	1
6	d,u~ -> vm~,m-	0	1
7	d~,u -> ve,e+	0	1
8	d~,u -> vm,m+	0	1

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

CalcHEP/symb

Delete,On/off,Restore,Latex 1/1



F1-Help,F2-Man,PgUp,PgDn,Home,End,# ,Esc

CalcHEP/symb

Model: MC4BSM_2012

Process: p,p->le,v

Feynman diagrams

8 diagrams in 8 subprocesses are constructed.
0 diagrams are deleted.

<

View diagrams
Square diagrams
Write down processes

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

CalcHEP/symb

```
      Model:   MC4BSM_2012

    Process:   p,p->le,v

               Feynman diagrams
8     diagrams in  8   subprocesses  are constructed.
0     diagrams  are deleted.

               Squared diagrams
8     diagrams in  8   subprocesses  are constructed.
0     diagrams  are deleted.
0     diagrams  are calculated.
```

<
View squared diagrams
Symbolic calculations
Make&Launch n_calchep
Make n_calchep
REDUCE program

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

Numerical Session

CalcHEP/num

(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

<
Subprocess
IN state
Model parameters
Constraints
QCD coupling
Breit-Wigner
Aliases
Cuts
Phase space mapping
Monte Carlo simulation
1D intergration

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

CalcHEP/num

```
(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)
```

Subprocess

u	d~	->	ve	e+
u	d~	->	vm	m+
u~	d	->	ve~	e-
u~	d	->	vm~	m-
d	u~	->	ve~	e-
d	u~	->	vm~	m-
d~	u	->	ve	e+
d~	u	->	vm	m+

F1-Help F2-Man F6-Results F8-Calc F9-Ref

CalcHEP/num

(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

<
Subprocess
IN state
Model parameters
Constraints
QCD coupling
Breit-Wigner
Aliases
Cuts
Phase space mapping
Monte Carlo simulation
1D intergration

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

CalcHEP/num

(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

IN state

<

S.F.1: OFF
S.F.2: OFF
First particle momentum[GeV] = 3500
Second particle momentum[GeV] = 3500
First particle unpolarized
Second particle unpolarized

F1-Help F2-Man F6-Results F7-Plot F8-Calc F9-Ref

CalcHEP/num

(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

IN state

S.F.1: OFF

OFF
PDT:
LHA:

F1-Help F2-Man F6-Results F8-Calc F9-Ref

CalcHEP/num

(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

IN state

LHAlib menu

<

GSG961.LHgrid
MRST2004nlo.LHgrid
cteq5l.LHgrid
cteq61-1.LHpdf
cteq61.LHgrid
cteq61.LHpdf
cteq6ll.LHpdf

S.F.1: OFF

F1-Help F2-Man F6-Results F8-Calc F9-Ref

CalcHEP/num

(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

IN state

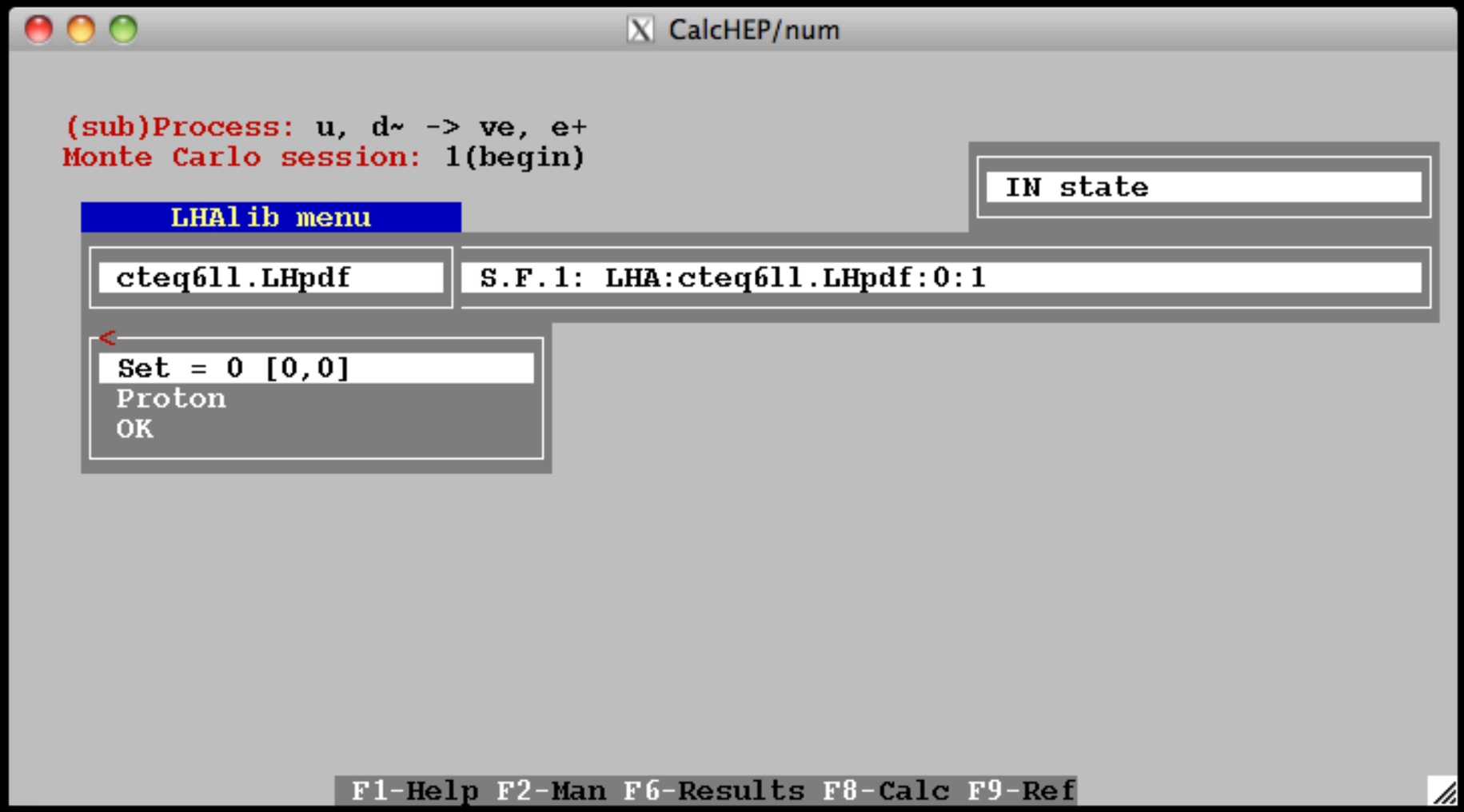
LHAlib menu

<

GSG961.LHgrid
MRST2004nlo.LHgrid
cteq5l.LHgrid
cteq61-1.LHpdf
cteq61.LHgrid
cteq61.LHpdf
cteq6ll.LHpdf

S.F.1: OFF

F1-Help F2-Man F6-Results F8-Calc F9-Ref


CalcHEP/num
(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)
IN state
LHAlib menu
cteq6ll.LHpdf
S.F.1: LHA:cteq6ll.LHpdf:0:1
Set = 0 [0,0]
Proton
OK
F1-Help F2-Man F6-Results F8-Calc F9-Ref

CalcHEP/num

(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

IN state

S.F.1: LHA:cteq6ll.LHpdf:0:1
S.F.2: LHA:cteq6ll.LHpdf:0:1
First particle momentum[GeV] = 4000
Second particle momentum[GeV] = 4000
First particle unpolarized
Second particle unpolarized

F1-Help F2-Man F6-Results F7-Plot F8-Calc F9-Ref

CalcHEP/num

(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

<
Subprocess
IN state
Model parameters
Constraints
QCD coupling
Breit-Wigner
Aliases
Cuts
Phase space mapping
Monte Carlo simulation
1D intergration

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

CalcHEP/num

(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

<
Subprocess
IN state
Model parameters
Constraints
QCD coupling
Breit-Wigner
Aliases
Cuts
Phase space mapping
Monte Carlo simulation
1D intergration

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

CalcHEP/num

```
(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)
```

```
Model parameters
   Change parameter
<
      READ_FROM_FILE
aEWM1          127.9
Gf             1.166e-05
aS             0.1184
ymb            4.7
ymt            172
ymtau          1.777
MM1            200
MM2            300
MM12           50
lam1           1
lam2           1
lam1p          1
lam2p          1
MTA            1.777
                    PgDn
```

F1-Help F2-Man F6-Results F8-Calc F9-Ref

CalcHEP/num

(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

<
Subprocess
IN state
Model parameters
Constraints
QCD coupling
Breit-Wigner
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Phase space mapping
Monte Carlo simulation
1D intergration

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

CalcHEP/num

(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

Constraints
<
All Constraints
Masses,Widths,Branching

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

CalcHEP/num

(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

<
Subprocess
IN state
Model parameters
Constraints
QCD coupling
Breit-Wigner
Aliases
Cuts
Phase space mapping
Monte Carlo simulation
1D intergration

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

CalcHEP/num

(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

QCD coupling

QCD alpha

parton dist. alpha ON
alpha(MZ)= 0.1172
nf = 5
order= NLO
mb(mb)= 4.200
Mtop(pole)= 175.00
Qfact= M12
Qren = Qfact
Alpha(Q) plot

F1-Help F2-Man F6-Results F8-Calc F9-Ref

CalcHEP/num

(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

QCD coupling

QCD alpha

Qren = MZ

Renorm. scale: MZ

CalcHEP/num

(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

QCD coupling

QCD alpha

parton dist. alpha ON
alpha(MZ)= 0.1172
nf = 5
order= NLO
mb(mb)= 4.200
Mtop(pole)= 175.00
Qfact= M12
Qren = MZ
Alpha(Q) plot

F1-Help F2-Man F6-Results F8-Calc F9-Ref

CalcHEP/num

(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

<
Subprocess
IN state
Model parameters
Constraints
QCD coupling
Breit-Wigner
Aliases
Cuts
Phase space mapping
Monte Carlo simulation
1D intergration

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

CalcHEP/num

```
(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)
```

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

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

“GI in s-channel”

- Roughly:
  - Give all terms a common denominator,
    - But when multiplying each squared diagram by a form of 1, only include the width in the denominator.
  - For example, multiply terms without the resonance by:

$$\frac{(p^2 - m^2)^2}{(p^2 - m^2)^2 + (m\Gamma)^2}$$

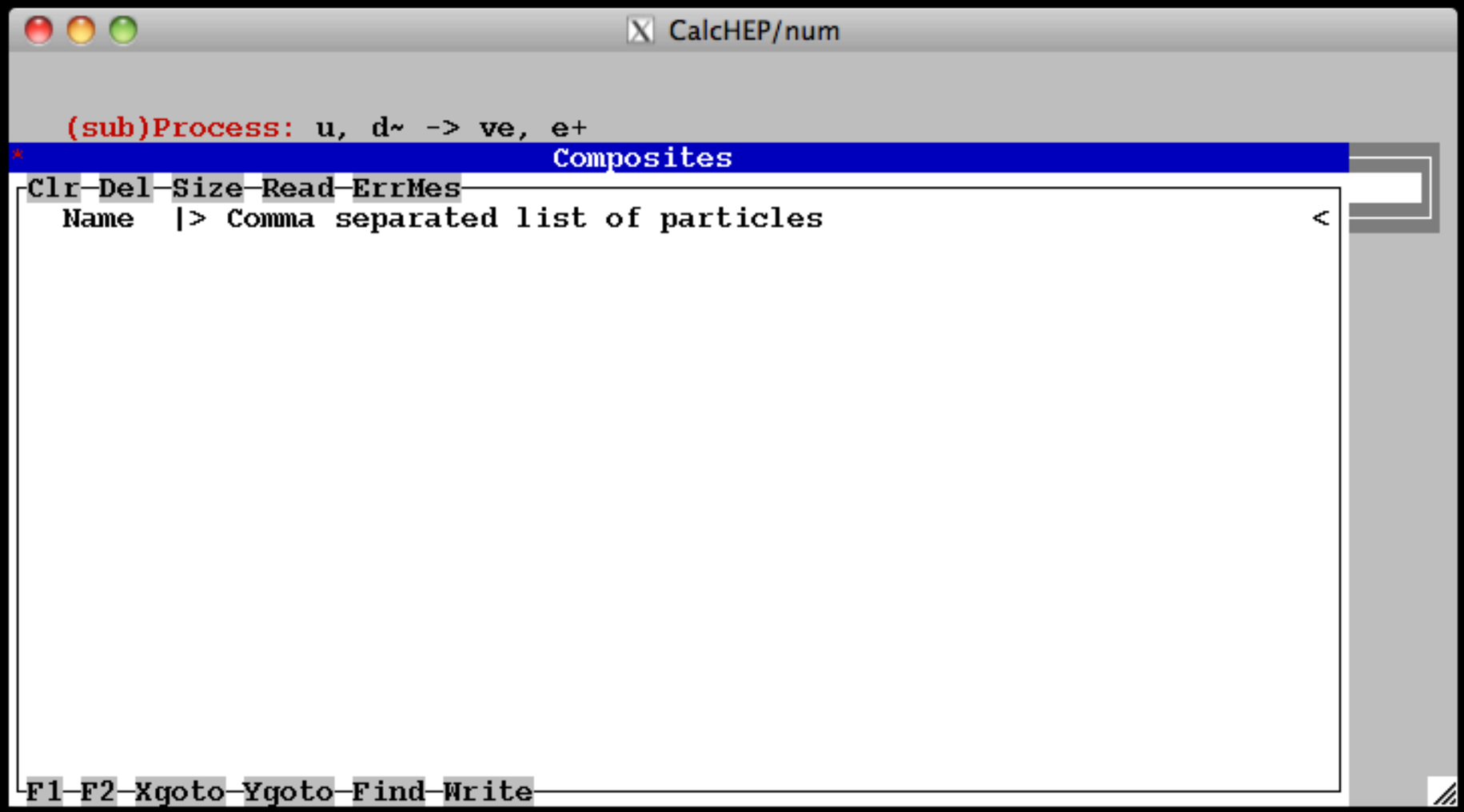
For further details, see: Nucl. Phys. B375 (1992) 3–44, Phys. Lett. B349 (1995) 367–374 and Int. J. Mod. Phys. A11 (1996) 5015–5026.

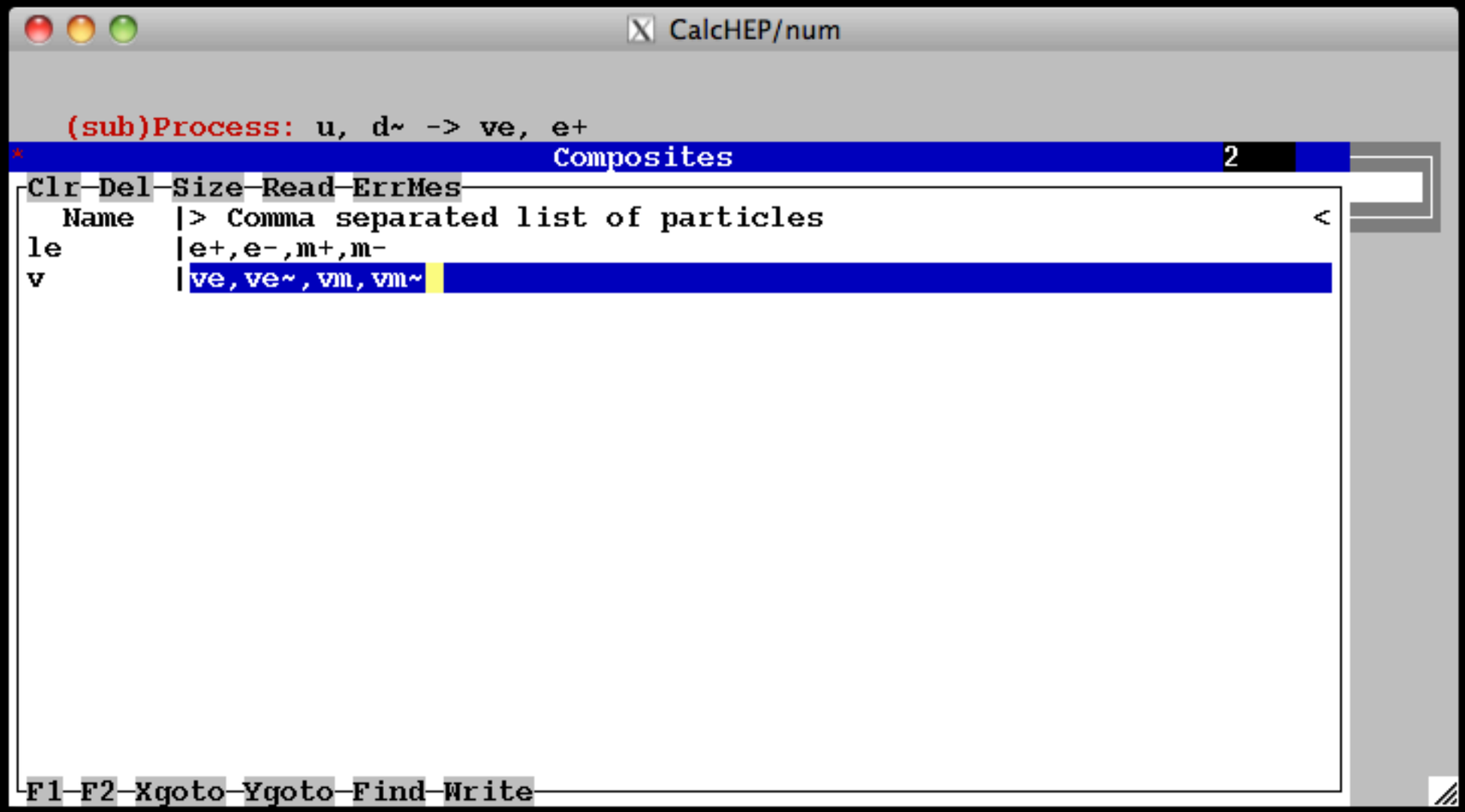
CalcHEP/num

(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

<
Subprocess
IN state
Model parameters
Constraints
QCD coupling
Breit-Wigner
Aliases
Cuts
Phase space mapping
Monte Carlo simulation
1D intergration

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


CalcHEP/num
(sub)Process: u, d~ -> ve, e+
Composites
Clr Del Size Read ErrMes
Name |> Comma separated list of particles
F1 F2 Xgoto Ygoto Find Write


CalcHEP/num
(sub)Process: u, d~ -> ve, e+
Composites
2
Clr Del Size Read ErrMes
Name |> Comma separated list of particles <
le |e+,e-,m+,m-
v |ve,ve~,vm,vm~
F1 F2 Xgoto Ygoto Find Write

CalcHEP/num

(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

<
Subprocess
IN state
Model parameters
Constraints
QCD coupling
Breit-Wigner
Aliases
Cuts
Phase space mapping
Monte Carlo simulation
1D intergration

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

CalcHEP/num

(sub)Process: u, d~ -> ve, e+

Cuts

Clr Del Size Read ErrMes

!| Parameter |> Min bound <|> Max bound <

F1 F2 Xgoto Ygoto Find Write

Cuts

CalcHEP/num

(sub)Process: u, d~ -> ve, e+

Cuts 3

Clr-Del-Size-Read-ErrMes

Parameter	> Min bound <	> Max bound <
T(le)	20	
N(le)	-2.5	2.5
T(v)	20	

F1-F2-Xgoto-Ygoto-Find-Write

Cuts

CalcHEP/num

(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

<
Subprocess
IN state
Model parameters
Constraints
QCD coupling
Breit-Wigner
Aliases
Cuts
Phase space mapping
Monte Carlo simulation
1D intergration

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

CalcHEP/num

(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

Phase space mapping
<
Kinematics
Regularization

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

CalcHEP/num

(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

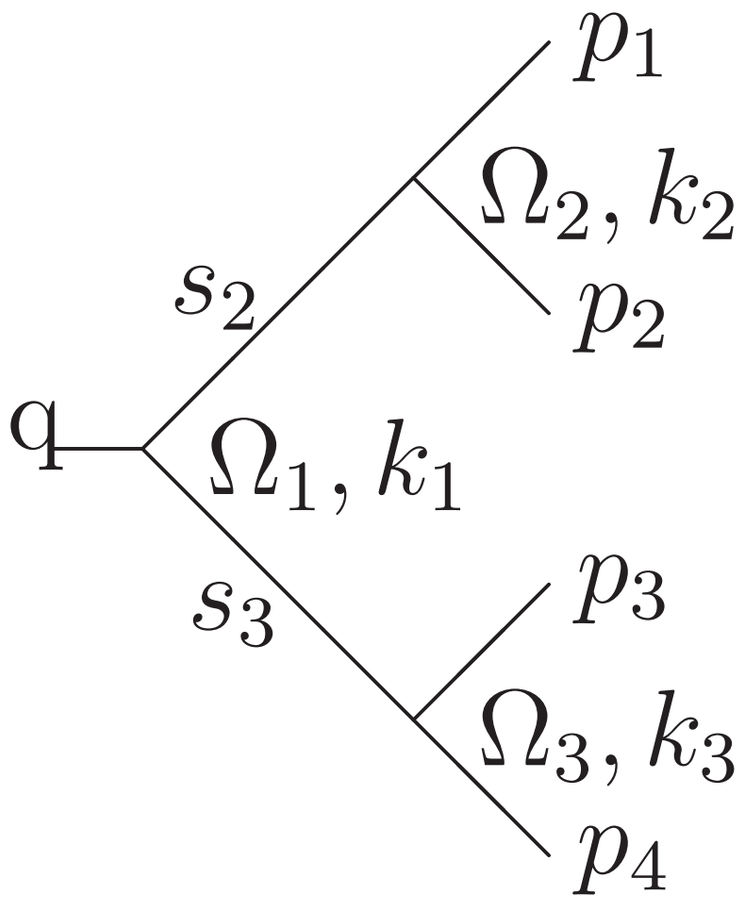
========= Current kinematical scheme =========
in= 12   -> out1= 3 out2= 4
==

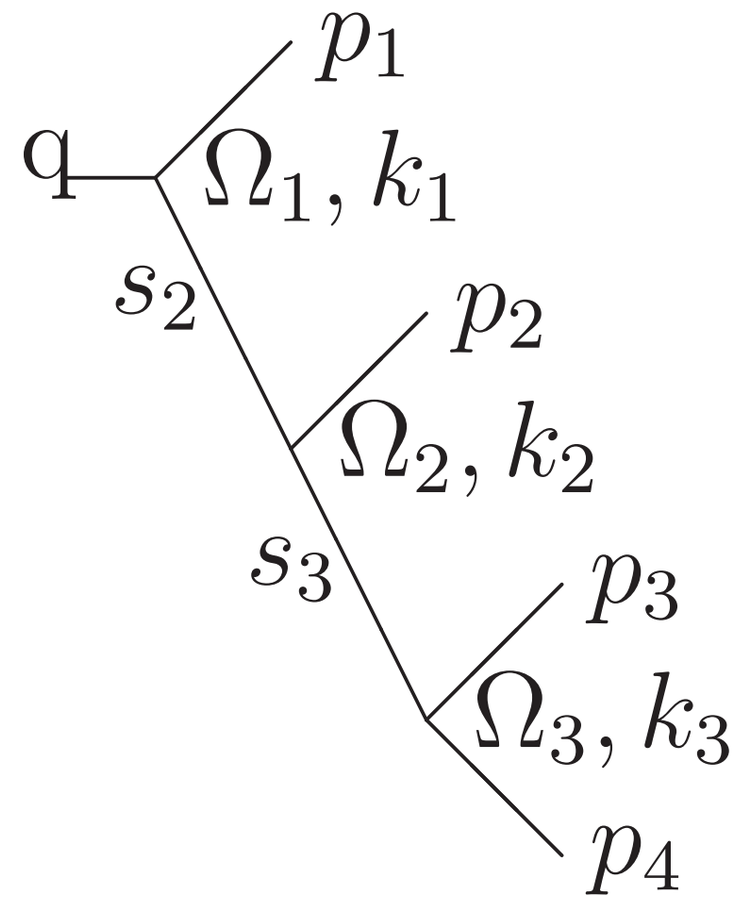
Phase space mapping

Kinematics

Input new kinematics?
(Y / N ?)

Kinematics


p_1
Ω_2, k_2
s_2
p_2
q
Ω_1, k_1
s_3
p_3
Ω_3, k_3
p_4


p_1
q
Ω_1, k_1
s_2
p_2
Ω_2, k_2
s_3
p_3
Ω_3, k_3
p_4

CalcHEP/num

(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

Phase space mapping
<
Kinematics
Regularization

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

CalcHEP/num

(sub)Process: u, d~ -> ve, e+

Regularization

Clr Del Size Read ErrMes

Momentum |> Mass <|> Width <| Power

F1 F2 Xgoto Ygoto Find Write

Phase space mapping

Regularization

CalcHEP/num

(sub)Process: u, d~ -> ve, e+

Regularization

Clr-Del-Size-Read-ErrMes

Momentum	|> Mass <|	|> Width <|	Power
34	|MW	|WW	|2

F1-F2-Xgoto-Ygoto-Find-Write

Phase space mapping

Regularization

Regularization

Basic idea:

The general idea of the integrand smoothing is trivial. Let us need to evaluate

$$\int_a^b F(x)dx \quad , \tag{39}$$

and let $F(x)$ have a peak like $f(x)$, where $f(x)$ is a simple symbolically integrable function in contrast to $F(x)$:

$$g(x) = \int_a^x f(x')dx' \ . \tag{40}$$

Now we may represent the integral (39) as

$$\int_a^b F(x)dx = \int_0^{g(b)} dy \frac{F(g^{-1}(y))}{f(g^{-1}(y))}, \tag{41}$$

where $g^{-1}(y)$ is the inverse function for $g(x)$. The integrand is a smooth function now.

Regularization

Basic idea:

The idea of the branching method is the following. Let $F(x)$ have two peaks, one is similar to $f_1(x)$ and another to $f_2(x)$. $f_1(x)$ and $f_2(x)$ are singular but elementary functions. Then, instead of one integration (39), we could perform two ones:

$$\int F(x)dx = \int \frac{F(x)f_1(x)}{f_1(x)+f_2(x)}dx + \int \frac{F(x)f_2(x)}{f_1(x)+f_2(x)}dx \ , \qquad (42)$$

but now each integration has only a single peak! It is easy to extend this method for an arbitrary number of peaks.

CalcHEP/num

(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

<
Subprocess
IN state
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Breit-Wigner
Aliases
Cuts
Phase space mapping
Monte Carlo simulation
1D intergration

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

CalcHEP/num

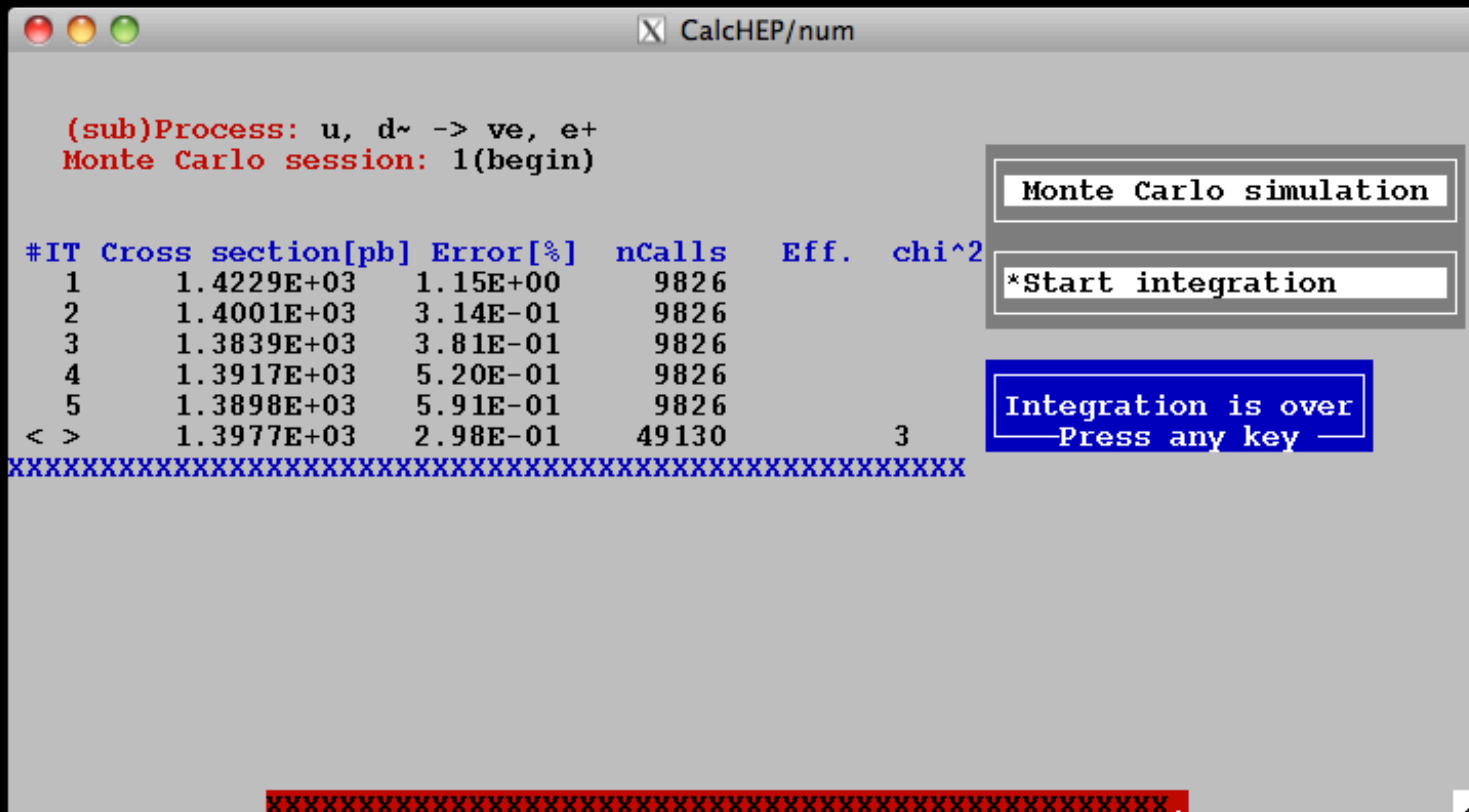
(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

#IT Cross section[pb] Error[%] nCalls Eff. chi^2 <
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

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

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


CalcHEP/num
(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)
#IT Cross section[pb] Error[%] nCalls Eff. chi^2
1 1.4229E+03 1.15E+00 9826
2 1.4001E+03 3.14E-01 9826
3 1.3839E+03 3.81E-01 9826
4 1.3917E+03 5.20E-01 9826
5 1.3898E+03 5.91E-01 9826
< > 1.3977E+03 2.98E-01 49130 3
Monte Carlo simulation
*Start integration
Integration is over
Press any key

CalcHEP/num

(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

#IT	Cross section[pb]	Error[%]	nCalls	Eff.	chi^2
1	1.4229E+03	1.15E+00	9826		
2	1.4001E+03	3.14E-01	9826		
3	1.3839E+03	3.81E-01	9826		
4	1.3917E+03	5.20E-01	9826		
5	1.3898E+03	5.91E-01	9826		
< >	1.3977E+03	2.98E-01	49130		3

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

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

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

CalcHEP/num

(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

#IT	Cross section[pb]	Error[%]	nCalls	Eff.	chi^2
1	1.4229E+03	1.15E+00	9826		
2	1.4001E+03	3.14E-01	9826		
3	1.3839E+03	3.81E-01	9826		
4	1.3917E+03	5.20E-01	9826		
5	1.3898E+03	5.91E-01	9826		
< >	1.3977E+03	2.98E-01	49130		3

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

Monte Carlo simulation

Clear statistic

Old results for integral and distributions are deleted.
Press any key

CalcHEP/num

(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

#IT	Cross section[pb]	Error[%]	nCalls	Eff.	chi^2
1	1.4229E+03	1.15E+00	9826		
2	1.4001E+03	3.14E-01	9826		
3	1.3839E+03	3.81E-01	9826		
4	1.3917E+03	5.20E-01	9826		
5	1.3898E+03	5.91E-01	9826		
< >	1.3977E+03	2.98E-01	49130		3

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

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

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

CalcHEP/num

(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

#IT	Cross section[pb]	Error[%]	nCalls	Eff.	chi^2
1	1.4229E+03	1.15E+00	9826		
2	1.4001E+03	3.14E-01	9826		
3	1.3839E+03	3.81E-01	9826		
4	1.3917E+03	5.20E-01	9826		
5	1.3898E+03	5.91E-01	9826		
< >	1.3977E+03	2.98E-01	49130		3

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

Monte Carlo simulation

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

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

CalcHEP/num

(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

#IT	Cross section[pb]	Error[%]	nCalls	Eff.	chi^2
1	1.4229E+03	1.15E+00	9826		
2	1.4001E+03	3.14E-01	9826		
3	1.3839E+03	3.81E-01	9826		
4	1.3917E+03	5.20E-01	9826		
5	1.3898E+03	5.91E-01	9826		
< >	1.3977E+03	2.98E-01	49130		3

Monte Carlo simulation

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

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

CalcHEP/num

(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

#IT	Cross section[pb]	Error[%]	nCalls	Eff.	chi^2
1	1.4229E+03	1.15E+00	9826		
2	1.4001E+03	3.14E-01	9826		
3	1.3839E+03	3.81E-01	9826		
4	1.3917E+03	5.20E-01	9826		
5	1.3898E+03	5.91E-01	9826		
< >	1.3977E+03	2.98E-01	49130		3

Monte Carlo simulation

nSess = 5
nCalls = 100000
Set Distributions
*Start integration
Display Distributions
Clear statistic
Freeze grid ON
Clear grid
Event Cubes 10000
Generate Events

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

CalcHEP/num

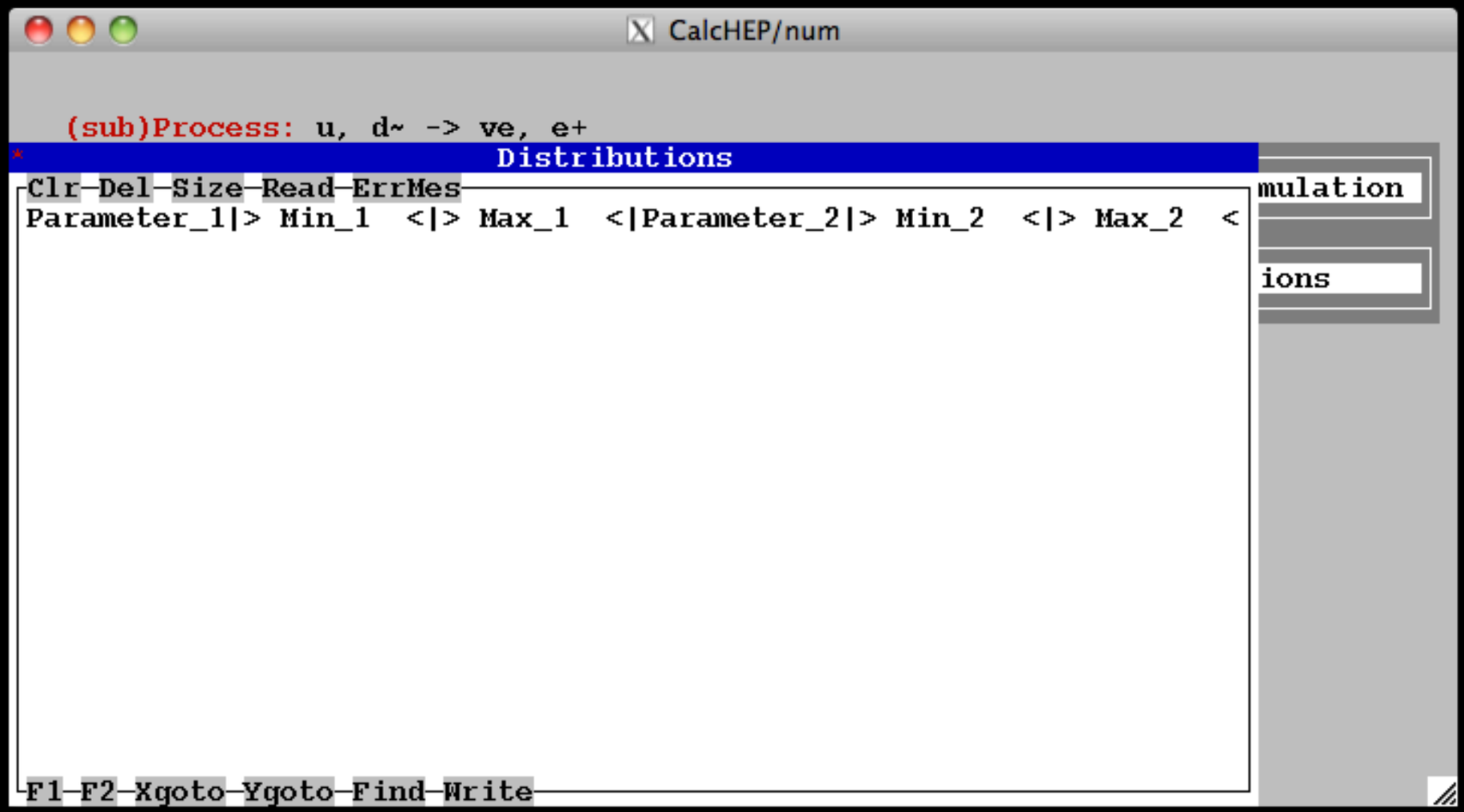
(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

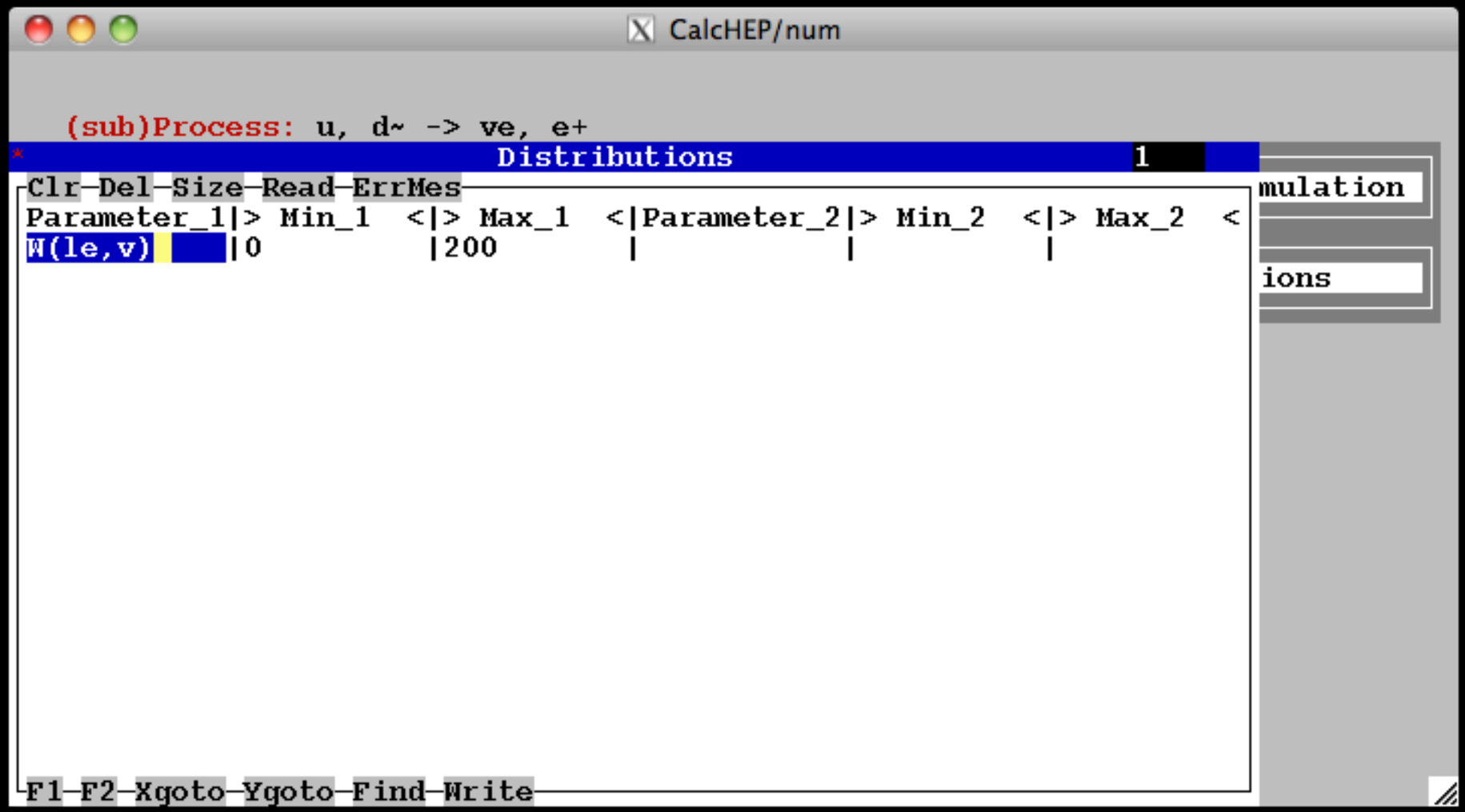
#IT	Cross section[pb]	Error[%]	nCalls	Eff.	chi^2
1	1.4229E+03	1.15E+00	9826		
2	1.4001E+03	3.14E-01	9826		
3	1.3839E+03	3.81E-01	9826		
4	1.3917E+03	5.20E-01	9826		
5	1.3898E+03	5.91E-01	9826		
< >	1.3977E+03	2.98E-01	49130		3

Monte Carlo simulation

nSess = 5
nCalls = 100000
Set Distributions
*Start integration
Display Distributions
Clear statistic
Freeze grid ON
Clear grid
Event Cubes 10000
Generate Events

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


CalcHEP/num
(sub)Process: u, d~ -> ve, e+
Distributions
Clr Del Size Read ErrMes
Parameter_1|> Min_1 <|> Max_1 <|Parameter_2|> Min_2 <|> Max_2 <
mulation
ions
F1 F2 Xgoto Ygoto Find Write


CalcHEP/num
(sub)Process: u, d~ -> ve, e+
Distributions 1
Clr-Del-Size-Read-ErrMes
Parameter_1|> Min_1 <|> Max_1 <|Parameter_2|> Min_2 <|> Max_2 <
W(le,v) |0 |200 | | |
mulation
ions
F1-F2-Xgoto-Ygoto-Find-Write

CalcHEP/num

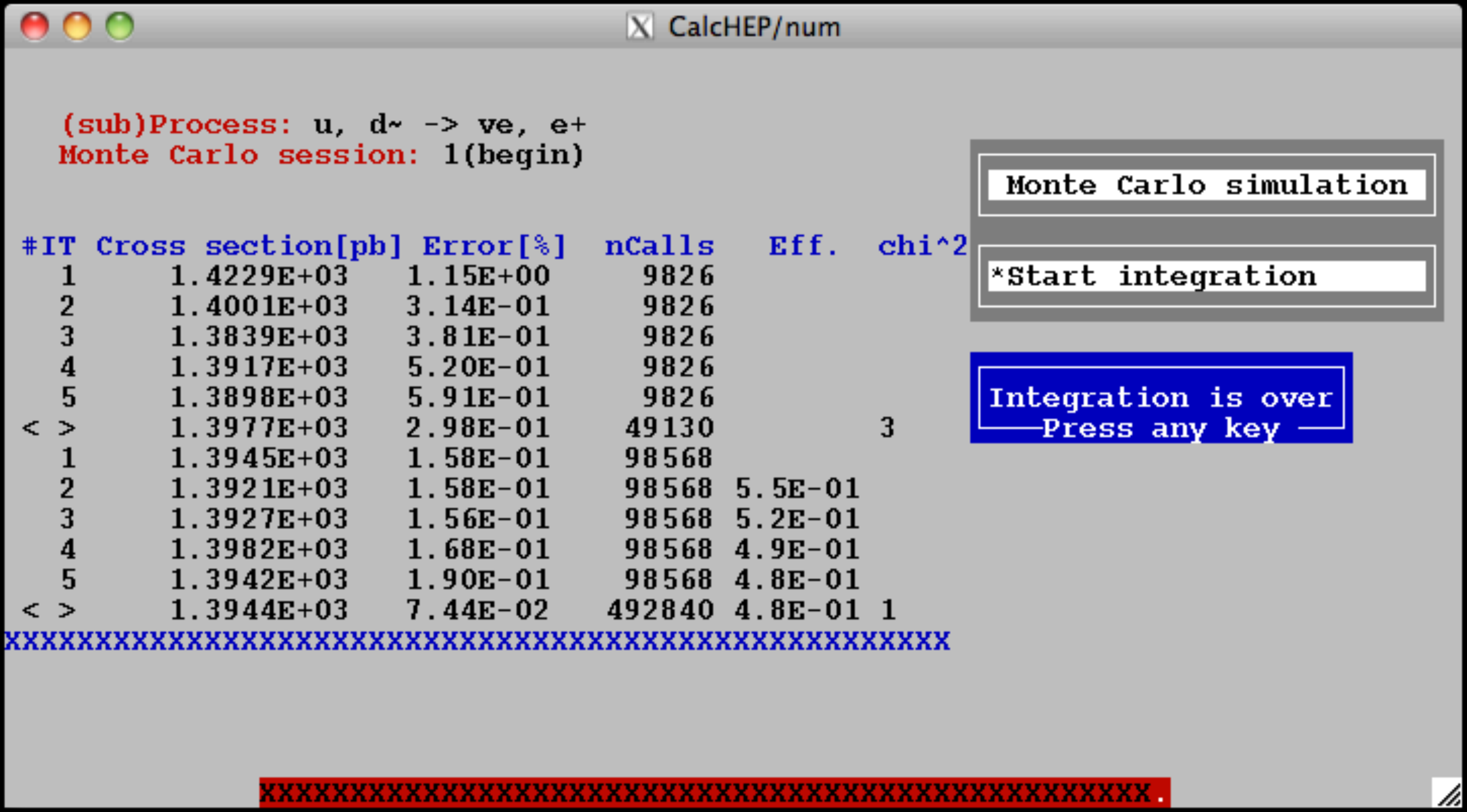
(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

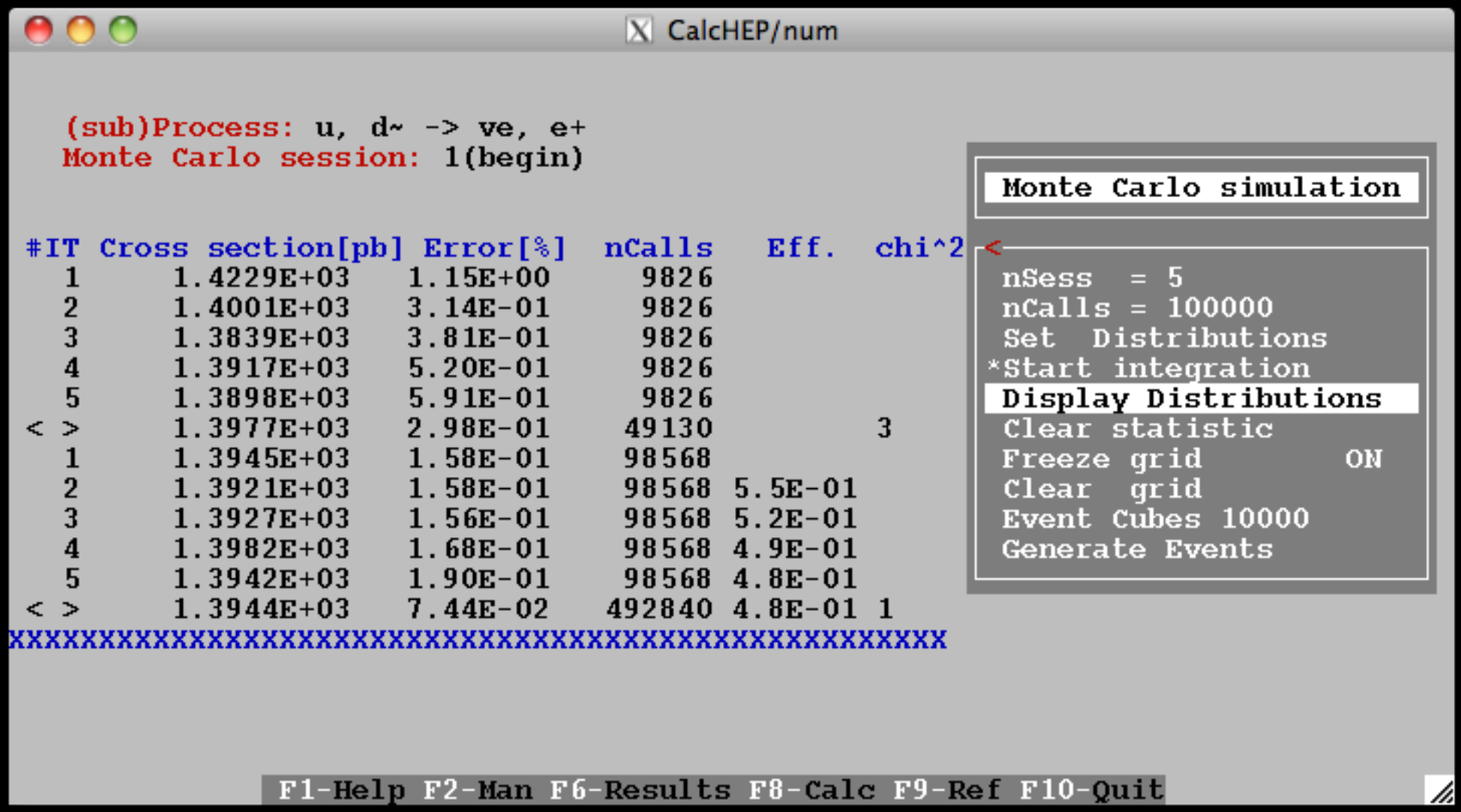
#IT	Cross section[pb]	Error[%]	nCalls	Eff.	chi^2
1	1.4229E+03	1.15E+00	9826		
2	1.4001E+03	3.14E-01	9826		
3	1.3839E+03	3.81E-01	9826		
4	1.3917E+03	5.20E-01	9826		
5	1.3898E+03	5.91E-01	9826		
< >	1.3977E+03	2.98E-01	49130		3

Monte Carlo simulation

nSess = 5
nCalls = 100000
Set Distributions
*Start integration
Display Distributions
Clear statistic
Freeze grid ON
Clear grid
Event Cubes 10000
Generate Events

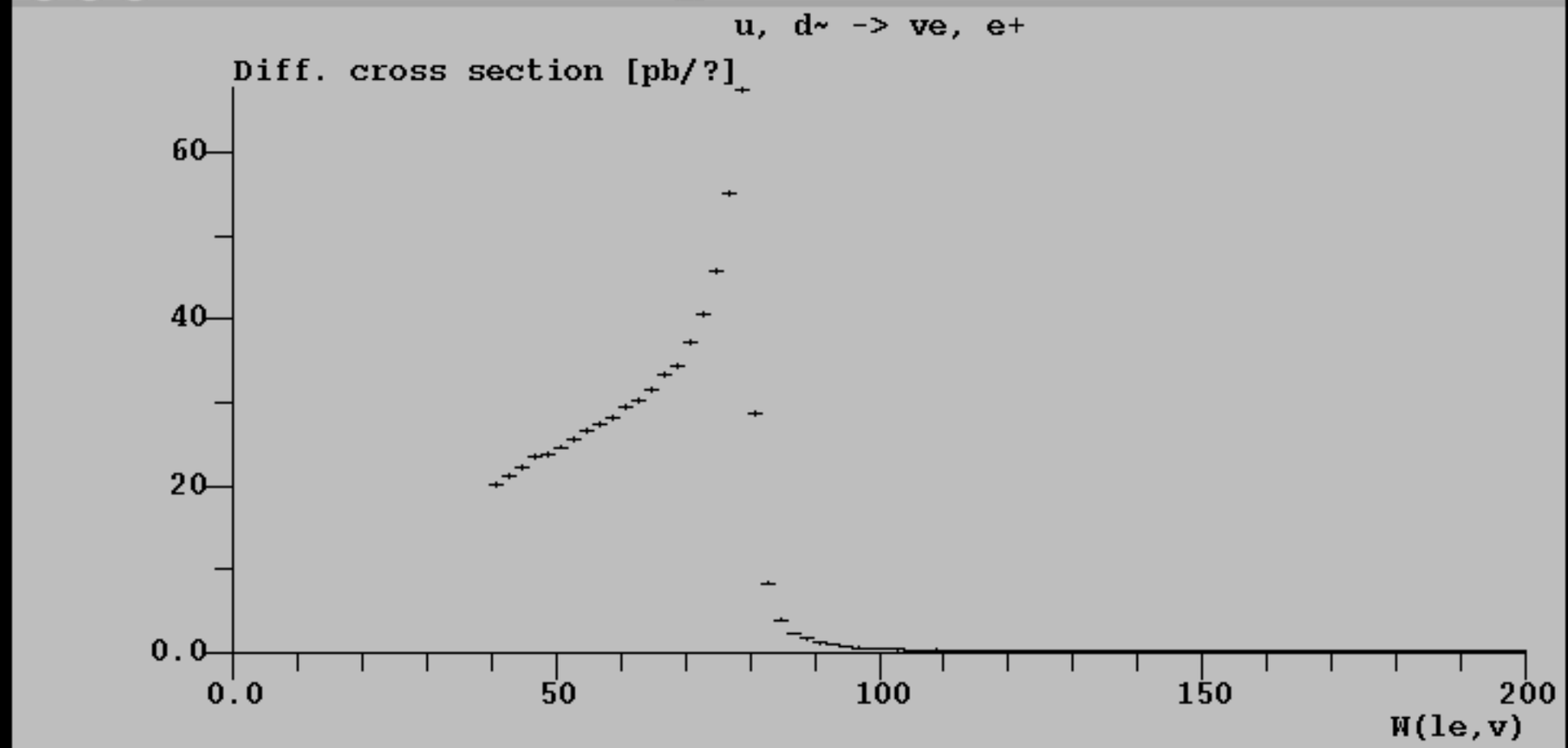
F1-Help F2-Man F6-Results F8-Calc F9-Ref F10-Quit


CalcHEP/num
(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)
#IT Cross section[pb] Error[%] nCalls Eff. chi^2
1 1.4229E+03 1.15E+00 9826
2 1.4001E+03 3.14E-01 9826
3 1.3839E+03 3.81E-01 9826
4 1.3917E+03 5.20E-01 9826
5 1.3898E+03 5.91E-01 9826
< > 1.3977E+03 2.98E-01 49130 3
1 1.3945E+03 1.58E-01 98568
2 1.3921E+03 1.58E-01 98568 5.5E-01
3 1.3927E+03 1.56E-01 98568 5.2E-01
4 1.3982E+03 1.68E-01 98568 4.9E-01
5 1.3942E+03 1.90E-01 98568 4.8E-01
< > 1.3944E+03 7.44E-02 492840 4.8E-01 1
Monte Carlo simulation
*Start integration
Integration is over
Press any key

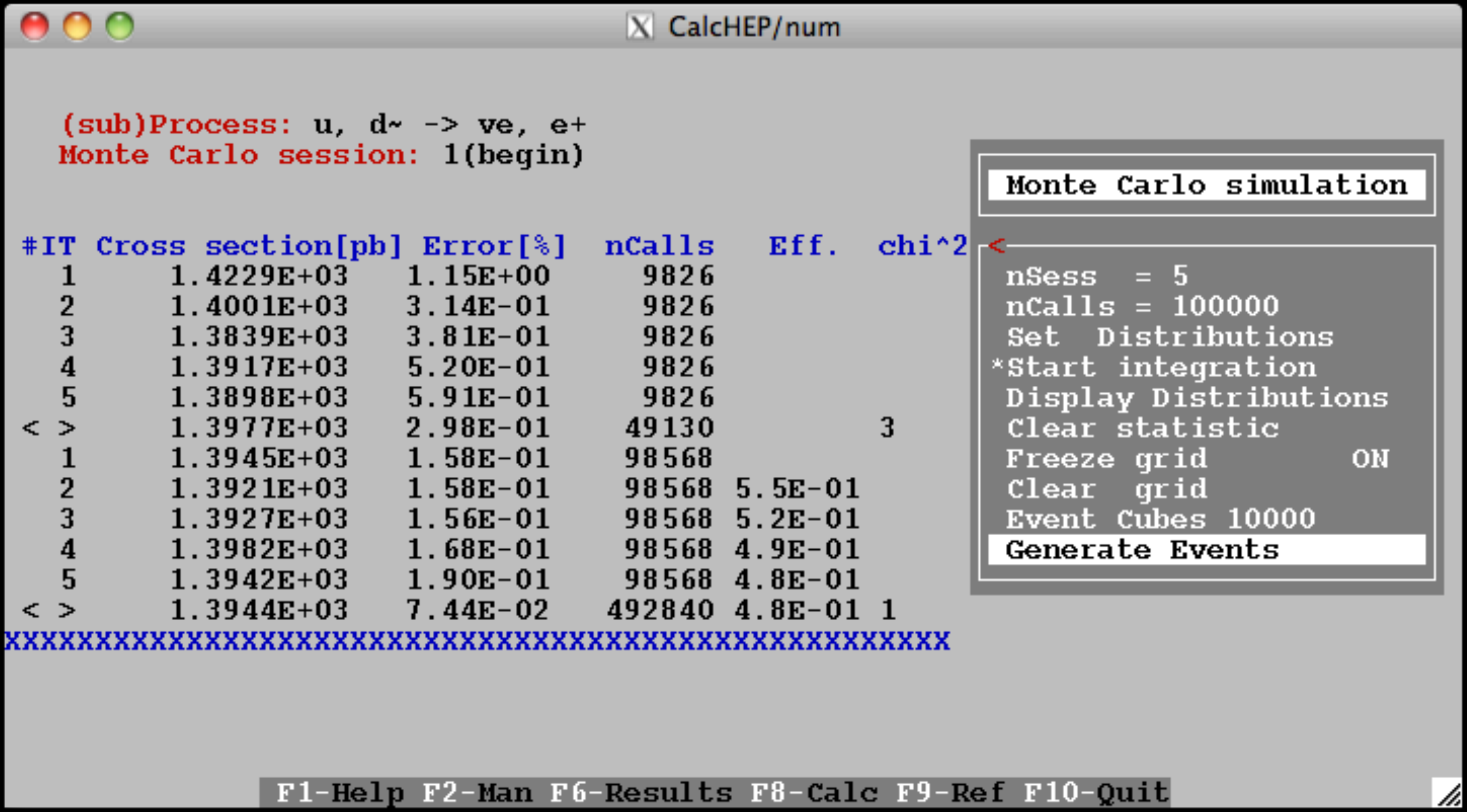

CalcHEP/num
(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)
#IT Cross section[pb] Error[%] nCalls Eff. chi^2
1 1.4229E+03 1.15E+00 9826
2 1.4001E+03 3.14E-01 9826
3 1.3839E+03 3.81E-01 9826
4 1.3917E+03 5.20E-01 9826
5 1.3898E+03 5.91E-01 9826
< > 1.3977E+03 2.98E-01 49130 3
1 1.3945E+03 1.58E-01 98568
2 1.3921E+03 1.58E-01 98568 5.5E-01
3 1.3927E+03 1.56E-01 98568 5.2E-01
4 1.3982E+03 1.68E-01 98568 4.9E-01
5 1.3942E+03 1.90E-01 98568 4.8E-01
< > 1.3944E+03 7.44E-02 492840 4.8E-01 1
Monte Carlo simulation
nSess = 5
nCalls = 100000
Set Distributions
*Start integration
Display Distributions
Clear statistic
Freeze grid ON
Clear grid
Event Cubes 10000
Generate Events
F1-Help F2-Man F6-Results F8-Calc F9-Ref F10-Quit

CalcHEP/num

u, d~ -> ve, e+



Mouse Info: X=4.040E+01 F=2.01E+01+/-3.0E-01
Esc - exit; Mouse - function value; Other keys - menu


CalcHEP/num
(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)
#IT Cross section[pb] Error[%] nCalls Eff. chi^2
1 1.4229E+03 1.15E+00 9826
2 1.4001E+03 3.14E-01 9826
3 1.3839E+03 3.81E-01 9826
4 1.3917E+03 5.20E-01 9826
5 1.3898E+03 5.91E-01 9826
< > 1.3977E+03 2.98E-01 49130 3
1 1.3945E+03 1.58E-01 98568
2 1.3921E+03 1.58E-01 98568 5.5E-01
3 1.3927E+03 1.56E-01 98568 5.2E-01
4 1.3982E+03 1.68E-01 98568 4.9E-01
5 1.3942E+03 1.90E-01 98568 4.8E-01
< > 1.3944E+03 7.44E-02 492840 4.8E-01 1
Monte Carlo simulation
nSess = 5
nCalls = 100000
Set Distributions
*Start integration
Display Distributions
Clear statistic
Freeze grid ON
Clear grid
Event Cubes 10000
Generate Events
F1-Help F2-Man F6-Results F8-Calc F9-Ref F10-Quit

CalcHEP/num

(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)

#IT	Cross section[pb]	Error[%]	nCalls	Eff.	chi^2
1	1.4229E+03	1.15E+00	9826		
2	1.4001E+03	3.14E-01	9826		
3	1.3839E+03	3.81E-01	9826		
4	1.3917E+03	5.20E-01	9826		
5	1.3898E+03	5.91E-01	9826		
< >	1.3977E+03	2.98E-01	49130		3
1	1.3945E+03	1.58E-01	98568		
2	1.3921E+03	1.58E-01	98568	5.5E-01	
3	1.3927E+03	1.56E-01	98568	5.2E-01	
4	1.3982E+03	1.68E-01	98568	4.9E-01	
5	1.3942E+03	1.90E-01	98568	4.8E-01	
< >	1.3944E+03	7.44E-02	492840	4.8E-01	1

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

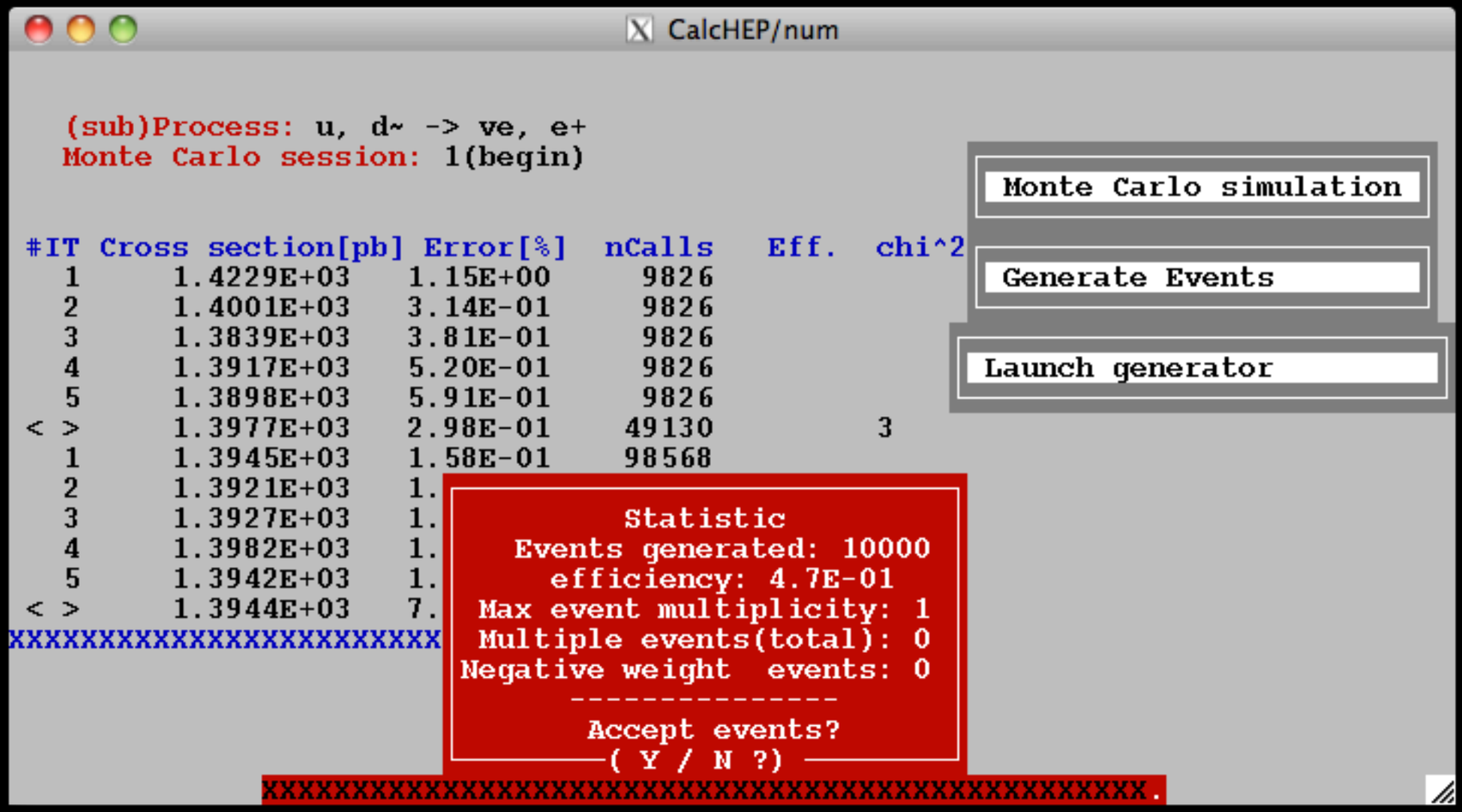
Monte Carlo simulation

Generate Events

<

Number of events=10000
Launch generator
Regenerate events ON

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


CalcHEP/num
(sub)Process: u, d~ -> ve, e+
Monte Carlo session: 1(begin)
#IT Cross section[pb] Error[%] nCalls Eff. chi^2
1 1.4229E+03 1.15E+00 9826
2 1.4001E+03 3.14E-01 9826
3 1.3839E+03 3.81E-01 9826
4 1.3917E+03 5.20E-01 9826
5 1.3898E+03 5.91E-01 9826
< > 1.3977E+03 2.98E-01 49130 3
1 1.3945E+03 1.58E-01 98568
2 1.3921E+03 1.
3 1.3927E+03 1.
4 1.3982E+03 1.
5 1.3942E+03 1.
< > 1.3944E+03 7.
Monte Carlo simulation
Generate Events
Launch generator
Statistic
Events generated: 10000
efficiency: 4.7E-01
Max event multiplicity: 1
Multiple events(total): 0
Negative weight events: 0
Accept events?
(Y / N ?)

Batch Mode

- Batch File:
  - Define processes, parameters, energies, cuts, etc. of run.
- Production + Decay:
  - Production and decay are connected.
  - (Cuts are only applied to production modes.)
  - Final output is in an lhe file.
- Parallelization:
  - Dynamically splits subprocesses and runs them concurrently.
  - Also works with clusters.
- HTML Status:
  - Dynamically writes HTML showing current state.

pp-WPZ

```
########################################
# Model Info
########################################
Model                          :       HLS (Final)
Model changed                  :       False
Gauge                          :       Feynman
```

-:--- **pp-WPZ** Top (18,0) (Fundamental)

Wrote /Users/neil/physics/CalcHEP/ch_2.5.6/pp-WPZ

pp-WPZ

```
Model                          :        HLS (Final)
Model changed                  :        False
Gauge                          :        Feynman

########################################
# Process Info
########################################
Process                :        p,p->~W,Z
Decay                  :        ~W->W,Z
Decay                  :        W->j,j
Decay                  :        Z->l,l
Composite              :        p=u1,U1,d1,D1,G
Composite              :        j=u1,U1,d1,D1,G
Composite              :        ~W=~W+,~W-
Composite              :        W=W+,W-
Composite              :        l=e1,E1,e2,E2
```

-:--- **pp-WPZ** 7% (18,0) (Fundamental)

Wrote /Users/neil/physics/CalcHEP/ch_2.5.6/pp-WPZ

pp-WPZ

```
Composite       :       ~W=~W+,~W-
Composite       :       W=W+,W-
Composite       :       l=e1,E1,e2,E2

########################################
# PDF Info
########################################
pdf1            :       cteq6l (proton)
pdf2            :       cteq6l (proton)

########################################
# Momentum Info
########################################
p1              :       7000
p2              :       7000
```

-:--- **pp-WPZ** Bot (32,0) (Fundamental)

Wrote /Users/neil/physics/CalcHEP/ch_2.5.6/pp-WPZ

pp-WPZ

```
# Momentum Info
#######################################
p1                :       7000
p2                :       7000

#######################################
# Parameter Info
#######################################
Parameter         :       MF=4000
```

-:--- **pp-WPZ** Bot (37,0) (Fundamental)

Wrote /Users/neil/physics/CalcHEP/ch_2.5.6/pp-WPZ

pp-WPZ

```
########################################
Run parameter   :       MWP
Run begin       :       400
Run step size   :       100
Run n steps     :       9

########################################
# Event Info
########################################
Number of events        :       1000
Filename                :       pp-WPZ
```

-:**- pp-WPZ Bot (52,0) (Fundamental)

pp-WPZ

```
# Event Info
########################################
Number of events        :       1000
Filename                :       pp-WPZ

########################################
# Parallelization Info
########################################
Parallelization method  :       local
Max number of cpus      :       2
sleep time              :       3
```

-:--- pp-WPZ Bot (57,24) (Fundamental)

Wrote /Users/neil/physics/CalcHEP/ch_2.5.6/pp-WPZ

pp-WPZ

```
#######################################
Parallelization method  :       local
Max number of cpus      :       2
sleep time              :       3

#######################################
# Vegas Info
#######################################
nSess_1           :       5
nCalls_1          :       10000
nSess_2           :       5
nCalls_2          :       100000
```

-:--- **pp-WPZ** Bot (63,26) (Fundamental)

Terminal — bash — 80×24

```
ip-101-210:ch_2.5.6 neil$ ./calchep_batch pp-WPZ
```

Terminal — perl5.10.0 — 80×24

```
ip-101-210:ch_2.5.6 neil$ ./calchep_batch pp-WPZ


Processing batch:
Progress information can be found in the html directory.
Simply open the following link in your browser:
file:///Users/neil/physics/CalcHEP/ch_2.5.6/html/index.html
You can also view textual progress reports in /Users/neil/physics/CalcHEP/ch_2.5
.6/html/index.txt
        and the other .txt files in the html directory.
Events will be stored in the Events directory.
```

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Symbolic Sessions

HLS (Final)

Processes	Lib	PID	Time(hr)
u1,D1->Z,~W+	✓	13766	0.00
U1,d1->Z,~W-	✓	13768	0.00
d1,U1->Z,~W-	✓	14504	0.00
D1,u1->Z,~W+	✓	14506	0.00
~W+->Z,W+	✓	15242	0.00
~W-->Z,W-	✓	15244	0.00
W+->u1,D1	✓	15370	0.00
W-->U1,d1	✓	15372	0.00
Z->e1,E1	✓	15498	0.00
Z->e2,E2	✓	15500	0.00
Widths	✓	15626	0.01

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Numerical Sessions

HLS (Final)

Calculating Cross Sections

Runs	σ (fb)	Running	Finished	Time (hr)	N events
MWP=400	0	0/4	4/4	0.01	0
MWP=500	0	2/4	2/4	0.01	0
MWP=600	0	0/4	0/4	0.00	0
MWP=700	0	0/4	0/4	0.00	0
MWP=800	0	0/4	0/4	0.00	0
MWP=900	0	0/4	0/4	0.00	0
MWP=1000	0	0/4	0/4	0.00	0
MWP=1100	0	0/4	0/4	0.00	0
MWP=1200	0	0/4	0/4	0.00	0
				0.01	

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Numerical Sessions

HLS (Final)

Calculating Cross Sections

Processes	σ (fb)	PID	Time (hr)	Details	
u1,D1->Z,~W+	17.563	18000	0.00	prt_1	session.dat
U1,d1->Z,~W-	6.5531	18011	0.00	prt_1	session.dat
d1,U1->Z,~W-	0	18046	0.00	prt_1	session.dat
D1,u1->Z,~W+	0	18056	0.00	prt_1	session.dat
Total	24.116		0.01		

Distributions

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Numerical Sessions

HLS (Final)

Calculating Cross Sections

Runs	σ (fb)	Running	Finished	Time (hr)	N events
MWP=400	0	0/4	4/4	0.01	0
MWP=500	0	0/4	4/4	0.01	0
MWP=600	0	0/4	4/4	0.01	0
MWP=700	0	0/4	4/4	0.01	0
MWP=800	0	0/4	4/4	0.01	0
MWP=900	0	0/4	4/4	0.01	0
MWP=1000	0	0/4	4/4	0.01	0
MWP=1100	0	0/4	4/4	0.01	0
MWP=1200	0	2/4	0/4	0.00	0
				0.06	

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Numerical Sessions

HLS (Final)

Generating Events

Runs	σ (fb)	Running	Finished	Time (hr)	N events
MWP=400	0	2/11	4/11	0.00	0
MWP=500	0	0/11	0/11	0.00	0
MWP=600	0	0/11	0/11	0.00	0
MWP=700	0	0/11	0/11	0.00	0
MWP=800	0	0/11	0/11	0.00	0
MWP=900	0	0/11	0/11	0.00	0
MWP=1000	0	0/11	0/11	0.00	0
MWP=1100	0	0/11	0/11	0.00	0
MWP=1200	0	0/11	0/11	0.00	0
				0.00	

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Numerical Sessions

HLS (Final)

Generating Events

Processes	σ (fb)	PID	Time (hr)	N events	Details	
u1,D1->Z,~W+	118.01	19315	0.00	392/392	prt_1	session.dat
U1,d1->Z,~W-	47.412	19325	0.00	157/157	prt_1	session.dat
d1,U1->Z,~W-	47.438	19459	0.00	157/157	prt_1	session.dat
D1,u1->Z,~W+	117.97	19469	0.00	392/392	prt_1	session.dat
Total	330.83			1098/1098		

Decays	Γ (GeV)	PID	Time (hr)	N events	Details	
~W+->Z,W+	2.867	19610	0.00	5101/5100	prt_1	session.dat
~W-->Z,W-	2.867	19625	0.00	5101/5100	prt_1	session.dat
W+->u1,D1	0.70557	19802	0.00	5101/5100	prt_1	session.dat
W-->U1,d1	0.70557	19816	0.00	5101/5100	prt_1	session.dat
Z->e1,E1	0.086807	19994	0.00	5101/5100	prt_1	session.dat
Z->e2,E2	0.086806	20008	0.00	5101/5100	prt_1	session.dat

Widths		PID	Time (hr)		Details
Widths		20186	0.00		session.dat
Total	0		0.01		

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Numerical Sessions

HLS (Final)

Generating Events

Runs	σ (fb)	Running	Finished	Time (hr)	N events
MWP=400	0.5216	0/11	11/11	0.01	1000
MWP=500	0.1831	0/11	11/11	0.01	1000
MWP=600	0	2/11	2/11	0.00	0
MWP=700	0	0/11	0/11	0.00	0
MWP=800	0	0/11	0/11	0.00	0
MWP=900	0	0/11	0/11	0.00	0
MWP=1000	0	0/11	0/11	0.00	0
MWP=1100	0	0/11	0/11	0.00	0
MWP=1200	0	0/11	0/11	0.00	0
				0.02	

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Numerical Sessions

HLS (Final)

Generating Events

Runs	σ (fb)	Running	Finished	Time (hr)	N events
MWP=400	0.5216	0/11	11/11	0.01	1000
MWP=500	0.1831	0/11	11/11	0.01	1000
MWP=600	0.07601	0/11	11/11	0.01	1000
MWP=700	0.03533	0/11	11/11	0.01	1000
MWP=800	0.01781	0/11	11/11	0.01	1000
MWP=900	0.009534	0/11	11/11	0.01	1000
MWP=1000	0	2/11	4/11	0.00	0
MWP=1100	0	0/11	0/11	0.00	0
MWP=1200	0	0/11	0/11	0.00	0
				0.06	

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Numerical Sessions

HLS (Final)

Done!

Runs	σ (fb)	Running	Finished	Time (hr)	N events
MWP=400	0.5216	0/11	11/11	0.01	1000
MWP=500	0.1831	0/11	11/11	0.01	1000
MWP=600	0.07601	0/11	11/11	0.01	1000
MWP=700	0.03533	0/11	11/11	0.01	1000
MWP=800	0.01781	0/11	11/11	0.01	1000
MWP=900	0.009534	0/11	11/11	0.01	1000
MWP=1000	0.005353	0/11	11/11	0.01	1000
MWP=1100	0.003121	0/11	11/11	0.01	1000
MWP=1200	0.001876	0/11	11/11	0.01	1000
				0.08	

Terminal — s_calchep — 80×24

```
ip-101-210:ch_2.5.6 neil$ ls Events/
events.txt          pp-WPZ-MWP1200.lhe pp-WPZ-MWP600.lhe  pp-WPZ-MWP900.lhe
pp-WPZ-MWP1000.lhe pp-WPZ-MWP400.lhe  pp-WPZ-MWP700.lhe  tmp
pp-WPZ-MWP1100.lhe pp-WPZ-MWP500.lhe  pp-WPZ-MWP800.lhe
ip-101-210:ch_2.5.6 neil$
```

Terminal — less — 149×32

```
</event>
<event>
12    1   1.0000000E+00   9.0880000E+02  -1.0000000E+00  -1.0000000E+00
       2   -1    0    0  500    0  0.00000000000E+00  0.00000000000E+00  1.24919161230E+02  1.24919161230E+02  0.00000000000E+00  0.0000E+00  9.0
      -1   -1    0    0    0  500  0.00000000000E+00  0.00000000000E+00 -1.65296074880E+03  1.65296074880E+03  0.00000000000E+00  0.0000E+00  9.0
      23    2    1    2    0    0  1.96743249538E+00 -3.34962100188E+02 -3.68522676850E+02  5.06453095606E+02  9.11876000000E+01  6.6842E-14  9.0
 6000024    2    1    2    0    0 -2.12754895199E+00  3.32615923671E+02 -1.16009205556E+03  1.27192099650E+03  4.00000000000E+02  5.1309E-13  9.0
      11    1    3    3    0    0  4.01749762042E+01 -8.30894807808E+01 -8.81035497527E+01  1.27593597051E+02  0.00000000000E+00  0.0000E+00  9.0
     -11    1    3    3    0    0 -3.82075437089E+01 -2.51872619408E+02 -2.80419127097E+02  3.78859498555E+02  0.00000000000E+00  0.0000E+00  9.0
      23    2    4    4    0    0 -4.70434449331E+00 -6.41200418955E+01 -2.10518779002E+02  2.38866335566E+02  9.11876000000E+01  4.5742E-14  9.0
      24    2    4    4    0    0  2.73691199794E+00  3.99082142084E+02 -9.49000131668E+02  1.03256047881E+03  8.03980000000E+01  1.7452E-13  9.0
      13    1    7    7    0    0 -2.77243188511E+01 -8.01358688379E+01 -1.60444295351E+02  1.81473905599E+02  1.05700000000E-01  0.0000E+00  9.0
     -13    1    7    7    0    0  2.30199743578E+01  1.60158269424E+01 -5.00744836508E+01  5.73924299666E+01  1.05700000000E-01  0.0000E+00  9.0
       2    1    8    8  502    0  1.44275400844E-01  3.93357475279E+02 -9.47769820024E+02  1.02615678915E+03  0.00000000000E+00  0.0000E+00  9.0
      -1    1    8    8    0  502  2.59263659709E+00  5.72466680462E+00 -1.23031164409E+00  6.40368966223E+00  0.00000000000E+00  0.0000E+00  9.0
</event>
<event>
12    1   1.0000000E+00   2.1010000E+03  -1.0000000E+00  -1.0000000E+00
      -1   -1    0    0    0  500  0.00000000000E+00  0.00000000000E+00  3.95828447880E+02  3.95828447880E+02  0.00000000000E+00  0.0000E+00  9.0
       2   -1    0    0  500    0  0.00000000000E+00  0.00000000000E+00 -2.78778201450E+03  2.78778201450E+03  0.00000000000E+00  0.0000E+00  9.0
      23    2    1    2    0    0  3.98720351095E+02 -9.17245455795E+02 -9.53483143105E+02  1.38554245976E+03  9.11876000000E+01  1.6897E-15  9.0
 6000024    2    1    2    0    0 -3.98718386267E+02  9.17491192838E+02 -1.43871557147E+03  1.79825220411E+03  4.00000000000E+02  1.6194E-13  9.0
      13    1    3    3    0    0  3.29927460706E+02 -6.97248883794E+02 -6.84270543232E+02  1.03113254375E+03  1.05700000000E-01  0.0000E+00  9.0
     -13    1    3    3    0    0  6.87928903898E+01 -2.19996572001E+02 -2.69212599873E+02  3.54409916005E+02  1.05700000000E-01  0.0000E+00  9.0
      23    2    4    4    0    0 -2.75178944925E+01  3.20771359936E+02 -6.98020898007E+02  7.74236678561E+02  9.11876000000E+01  1.6327E-14  9.0
      24    2    4    4    0    0 -3.71202456603E+02  5.96474095859E+02 -7.40449525448E+02  1.02383132401E+03  8.03980000000E+01  1.7722E-15  9.0
      13    1    7    7    0    0 -5.91105304205E+01  2.53933594886E+02 -5.57604095217E+02  6.15547450318E+02  1.05700000000E-01  0.0000E+00  9.0
     -13    1    7    7    0    0  3.15926359280E+01  6.68377650497E+01 -1.40416802790E+02  1.58689228242E+02  1.05700000000E-01  0.0000E+00  9.0
       2    1    8    8  502    0 -3.50334928341E+02  5.56940940593E+02 -7.17750454935E+02  9.73695788676E+02  0.00000000000E+00  0.0000E+00  9.0
      -1    1    8    8    0  502 -2.08675282615E+01  3.95331552655E+01 -2.26990705125E+01  5.01355353330E+01  0.00000000000E+00  0.0000E+00  9.0
</event>
:
```

Batch Mode

- Sasha Belyaev has pushed this batch mode to the limit running an E6 MSSM model with ~6000 production + decay modes on thousands of cpus on a pbs cluster, successfully.

In Development

New Numerical Session

- Dynamical Processes and Decays:
  - Dynamically add processes and decays.
  - Code is dynamically generated and linked.
  - Splits processes by order in electric charge (if model is written in the right way).
- Connects Productions and Decays:
  - Dynamically connects production and decay modes.
  - Cuts are applied to final states (after decay).
  - Optionally Breit-Wigner smear resonances.
  - Adds cross sections and distributions (after decay).
  - Works harder on processes with larger absolute errors.
- Parallelized.

CalcHEP/num

Process:

MC session: 1(begin) Model: MC4BSM_2012

<

- Composites
- Final Process
- Production Processes
- Decays
- IN state
- Model parameters
- Constraints
- QCD coupling
- Breit-Wigner
- Cuts
- Phase space mapping
- Detector Smearing
- Vegas
- N threads = 2

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

CalcHEP/num

MC session: 1(begin) Process:
Model: MC4BSM_2012

Composites 3

Clr-Del-Size-Read-ErrMes

Name	> Comma separated list of particles <
p	u,u~,d,d~,G
j	u,u~
l	e+,e-

F1-F2-Xgoto-Ygoto-Find-Write

CalcHEP/num

Process:
MC session: 1(begin) Model: MC4BSM_2012

<
Composites
Final Process
Production Processes
Decays
IN state
Model parameters
Constraints
QCD coupling
Breit-Wigner
Cuts
Phase space mapping
Detector Smearing
Vegas
N threads = 2

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

CalcHEP/num

MC session: 1(begin) Process:
Model: MC4BSM_2012

Particles

```
p = u,u~,d,d~,G
j = u,u~
l = e+,e-

   ve/ve~          vm/vm~          vt/vt~          e-/e+
   m-/m+          tt-/tt+           u/u~           c/c~
    t/t~            d/d~           s/s~           b/b~
    A/A             Z/Z          W+/W-            G/G
    H/H            p1/p1          p2/p2         uv/uv~
  ev/ev~
```

Enter final process:p,p->j,j,l,l,p1,p1

CalcHEP/num

Process: p,p->j,j,l,l,p1,p1
MC session: 1(begin) Model: MC4BSM_2012

<
Composites
Final Process
Production Processes
Decays
IN state
Model parameters
Constraints
QCD coupling
Breit-Wigner
Cuts
Phase space mapping
Detector Smearing
Vegas
N threads = 2

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

CalcHEP/num

Process: p,p->j,j,l,l,p1,p1
MC session: 1(begin) Model: MC4BSM_2012

Particles

```
p = u,u~,d,d~,G
j = u,u~
l = e+,e-

   ve/ve~          vm/vm~          vt/vt~          e-/e+
   m-/m+          tt-/tt+           u/u~           c/c~
    t/t~            d/d~           s/s~           b/b~
    A/A             Z/Z          W+/W-            G/G
    H/H           p1/p1           p2/p2         uv/uv~
  ev/ev~
```

```
Enter process:p,p->uv,uv~
Remove particles:
Highest power of EE:
```

CalcHEP/num

Process: p,p->j,j,l,l,p1,p1
MC session: 1(begin) Model: MC4BSM_2012

Processes	N diags		Status
u,u~->uv,uv~	13	GG^0 x EE^0	Done
u~,u->uv,uv~	13	GG^0 x EE^0	Done
*d,d~->uv,uv~	4	GG^0 x EE^0	Compilation
*d~,d->uv,uv~	4	GG^0 x EE^0	Compilation
G,G->uv,uv~	6	GG^0 x EE^0	Queued

XXXXXXXXXXXXXXXXXXXXress. Calculation in progress.

CalcHEP/num

MC session: 1(begin)

Process: p,p->j,j,l,l,p1,p1
Model: MC4BSM_2012

Processes

u	u~	->	uv	uv~	(GG^0	EE^0)	On
u~	u	->	uv	uv~	(GG^0	EE^0)	On
d	d~	->	uv	uv~	(GG^0	EE^0)	On
d~	d	->	uv	uv~	(GG^0	EE^0)	On
G	G	->	uv	uv~	(GG^0	EE^0)	On

Add process(es)

F1-Help F2-Man F6-Results F8-Calc F9-Ref

CalcHEP/num

Process: p,p->j,j,l,l,p1,p1
MC session: 1(begin) Model: MC4BSM_2012

<
Composites
Final Process
Production Processes
Decays
IN state
Model parameters
Constraints
QCD coupling
Breit-Wigner
Cuts
Phase space mapping
Detector Smearing
Vegas
N threads = 2

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

CalcHEP/num

Process: p,p->j,j,l,l,p1,p1
MC session: 1(begin) Model: MC4BSM_2012

Decays

uv	->	u	p1	On
uv~	->	u~	p1	On
uv	->	u	p2	On
uv~	->	u~	p2	On
p2	->	e+	ev	On
p2	->	e-	ev~	On
ev	->	e-	p1	On
ev~	->	e+	p1	On

Add decay(s)

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

CalcHEP/num

MC session: 1(begin)

Process: p,p->j,j,l,l,p1,p1
Model: MC4BSM_2012

Cuts 7

Clr-Del-Size-Read-ErrMes

Parameter	> Min bound <	> Max bound <
T(j)	20	
N(j)	-4	4
J(j,j)	0.4	
T(l)	20	
N(l)	-2.5	2.5
J(j,l)	0.4	
T(p1,p1)	20	

F1-F2-Xgoto-Ygoto-Find-Write

Cuts

CalcHEP/num

Process: p,p->j,j,l,l,p1,p1
MC session: 1(begin) Model: MC4BSM_2012

---Improving Grids---

Process		cs(pb)/BR	%T Err	%C Err	SqrtN*Err
*u,u~->uv,uv~	(GG^0 EE^0)	1.4155E-01	1.8E-01	2.0E-01	2.0E-01
*u~,u->uv,uv~	(GG^0 EE^0)	1.4239E-01	3.4E-01	3.4E-01	3.4E-01
d,d~->uv,uv~	(GG^0 EE^0)	2.6010E-02	3.5E-01	3.5E-01	3.5E-01
d~,d->uv,uv~	(GG^0 EE^0)	2.5974E-02	4.1E-01	4.1E-01	4.0E-01
G,G->uv,uv~	(GG^0 EE^0)	8.2218E-02	3.9E-01	3.9E-01	3.9E-01
uv->u,p1		5.8588E-01	5.0E-05	1.0E-04	9.9E-05
uv~->u~,p1		5.8588E-01	5.0E-05	1.0E-04	9.9E-05
uv->u,p2		4.1412E-01	5.0E-05	1.0E-04	9.9E-05
uv~->u~,p2		4.1412E-01	5.0E-05	1.0E-04	9.9E-05
p2->e+,ev		5.0000E-01	5.0E-05	1.0E-04	9.9E-05
p2->e-,ev~		5.0000E-01	5.0E-05	1.0E-04	9.9E-05
ev->e-,p1		1.0000E+00	5.0E-05	1.0E-04	9.9E-05
ev~->e+,p1		1.0000E+00	5.0E-05	1.0E-04	9.9E-05

CalcHEP/num

MC session: 1(continue)

Process: p,p->j,j,l,l,p1,p1
Model: MC4BSM_2012

Distributions 1

Clr-Del-Size-Read-ErrMes

Parameter_1	> Min_1	<	> Max_1	<	Parameter_2	> Min_2	<	> Max_2	<
M(1,1)	0		500						

ions

F1-F2-Xgoto-Ygoto-Find-Write

CalcHEP/num

Process: p,p->j,j,l,l,p1,p1
MC session: 1(continue) Model: MC4BSM_2012

	Processes	cs(pb)	Error
	u,u~->u,u~,p1,e-,e+,p1	0.0000E+00	0.0E+00
	d,d~->u,u~,p1,e+,e-,p1	0.0000E+00	0.0E+00
	u~,u->u,p1,u~,e-,e+,p1	0.0000E+00	0.0E+00
	u~,u->u,u~,p1,e+,e-,p1	0.0000E+00	0.0E+00
	u~,u->u,u~,p1,e-,e+,p1	0.0000E+00	0.0E+00
	d~,d->u,p1,u~,e+,e-,p1	0.0000E+00	0.0E+00
	d,d~->u,u~,p1,e-,e+,p1	0.0000E+00	0.0E+00
	d~,d->u,p1,u~,e-,e+,p1	0.0000E+00	0.0E+00
	u,u~->u,p1,u~,e+,e-,p1	0.0000E+00	0.0E+00
	G,G->u,u~,p1,e-,e+,p1	0.0000E+00	0.0E+00
	u,u~->u,p1,u~,e-,e+,p1	0.0000E+00	0.0E+00
	G,G->u,p1,u~,e-,e+,p1	0.0000E+00	0.0E+00
	d,d~->u,p1,u~,e-,e+,p1	0.0000E+00	0.0E+00
	d~,d->u,u~,p1,e+,e-,p1	0.0000E+00	0.0E+00
	u,u~->u,u~,p1,e+,e-,p1	0.0000E+00	0.0E+00
	G,G->u,p1,u~,e+,e-,p1	0.0000E+00	0.0E+00
1	u~,u->u,p1,u~,e+,e-,p1	0.0000E+00	0.0E+00
1	G,G->u,u~,p1,e+,e-,p1	0.0000E+00	0.0E+00
	d,d~->u,p1,u~,e+,e-,p1	0.0000E+00	0.0E+00
	d~,d->u,u~,p1,e-,e+,p1	0.0000E+00	0.0E+00

Total cs(pb) % Error
2

Calculation in progress. Calculation in progress.

CalcHEP/num

Process: p,p->j,j,l,l,p1,p1
MC session: 1(continue) Model: MC4BSM_2012

	Processes	cs(pb)	Error
	u~,u->u,p1,u~,e+,e-,p1	1.1974E-02	6.6E-05
	u,u~->u,u~,p1,e+,e-,p1	1.1713E-02	5.2E-05
	G,G->u,u~,p1,e+,e-,p1	6.9668E-03	5.2E-05
	G,G->u,u~,p1,e-,e+,p1	6.9662E-03	5.5E-05
	d~,d->u,u~,p1,e+,e-,p1	2.1890E-03	1.7E-05
	d,d~->u,u~,p1,e+,e-,p1	0.0000E+00	0.0E+00
1	d,d~->u,p1,u~,e+,e-,p1	0.0000E+00	0.0E+00
	d~,d->u,p1,u~,e-,e+,p1	0.0000E+00	0.0E+00
	u~,u->u,u~,p1,e+,e-,p1	0.0000E+00	0.0E+00
	u~,u->u,p1,u~,e-,e+,p1	0.0000E+00	0.0E+00
	u,u~->u,p1,u~,e+,e-,p1	0.0000E+00	0.0E+00
	d~,d->u,u~,p1,e-,e+,p1	0.0000E+00	0.0E+00
	d~,d->u,p1,u~,e+,e-,p1	0.0000E+00	0.0E+00
	u,u~->u,u~,p1,e-,e+,p1	0.0000E+00	0.0E+00
	d,d~->u,u~,p1,e-,e+,p1	0.0000E+00	0.0E+00
1	G,G->u,p1,u~,e-,e+,p1	0.0000E+00	0.0E+00
	G,G->u,p1,u~,e+,e-,p1	0.0000E+00	0.0E+00
	u,u~->u,p1,u~,e-,e+,p1	0.0000E+00	0.0E+00
	d,d~->u,p1,u~,e-,e+,p1	0.0000E+00	0.0E+00

Total	cs(pb)	% Error
2	3.9809E-02	2.9E-01

Calculation in progress. Calculation in progress.

CalcHEP/num

Process: p,p->j,j,l,l,p1,p1
MC session: 1(continue) Model: MC4BSM_2012

	Processes	cs(pb)	Error
	u~,u->u,p1,u~,e-,e+,p1	1.2186E-02	9.1E-05
	u,u~->u,p1,u~,e-,e+,p1	1.2090E-02	5.3E-05
1	u~,u->u,p1,u~,e+,e-,p1	1.1974E-02	6.6E-05
	u,u~->u,u~,p1,e-,e+,p1	1.1913E-02	6.4E-05
	u~,u->u,u~,p1,e+,e-,p1	1.1847E-02	6.3E-05
	u,u~->u,p1,u~,e+,e-,p1	1.1844E-02	8.9E-05
	u~,u->u,u~,p1,e-,e+,p1	1.1835E-02	8.9E-05
	u,u~->u,u~,p1,e+,e-,p1	1.1713E-02	5.2E-05
	G,G->u,p1,u~,e-,e+,p1	7.1189E-03	5.9E-05
	G,G->u,u~,p1,e-,e+,p1	6.9766E-03	3.8E-05
	G,G->u,u~,p1,e+,e-,p1	6.9668E-03	5.2E-05
	G,G->u,p1,u~,e+,e-,p1	6.9195E-03	5.3E-05
	d,d~->u,u~,p1,e-,e+,p1	2.1992E-03	1.7E-05
	d~,d->u,p1,u~,e-,e+,p1	2.1919E-03	1.2E-05
1	d~,d->u,p1,u~,e+,e-,p1	2.1888E-03	1.6E-05
	d~,d->u,u~,p1,e+,e-,p1	2.1877E-03	9.6E-06
	d~,d->u,u~,p1,e-,e+,p1	2.1856E-03	1.7E-05
	d,d~->u,p1,u~,e-,e+,p1	2.1855E-03	1.7E-05
	d,d~->u,p1,u~,e+,e-,p1	2.1834E-03	1.6E-05
	d,d~->u,u~,p1,e+,e-,p1	2.1650E-03	1.2E-05

Total	cs(pb)	% Error
2	1.4087E-01	1.7E-01

Calculation in progress. Calculation in progress.

CalcHEP/num

MC session: 1(continue)

Process: p,p->j,j,l,l,p1,p1
Model: MC4BSM_2012

Processes	cs(pb)	Error
u,u~->u,p1,u~,e-,e+,p1	1.2068E-02	3.5E-05
u~,u->u,p1,u~,e-,e+,p1	1.1995E-02	4.7E-05
u~,u->u,p1,u~,e+,e-,p1	1.1985E-02	4.7E-05
u,u~->u,p1,u~,e+,e-,p1	1.1929E-02	4.5E-05
u,u~->u,u~,p1,e-,e+,p1	1.1870E-02	4.6E-05
u~,u->u,u~,p1,e-,e+,p1	1.1785E-02	4.1E-05
u~,u->u,u~,p1,e+,e-,p1	1.1768E-02	5.2E-05
u,u~->u,u~,p1,e+,e-,p1	1.1767E-02	3.8E-05
G,G->u,p1,u~,e+,e-,p1	6.9962E-03	3.2E-05
G,G->u,u~,p1,e-,e+,p1	6.9822E-03	2.7E-05
G,G->u,p1,u~,e-,e+,p1	6.9791E-03	2.5E-05
G,G->u,u~,p1,e+,e-,p1	6.9726E-03	2.7E-05
d,d~->u,u~,p1,e-,e+,p1	2.1992E-03	1.7E-05
d~,d->u,u~,p1,e-,e+,p1	2.1975E-03	9.5E-06
d~,d->u,p1,u~,e+,e-,p1	2.1964E-03	9.6E-06
d~,d->u,u~,p1,e+,e-,p1	2.1947E-03	7.4E-06
d~,d->u,p1,u~,e-,e+,p1	2.1915E-03	9.6E-06
d,d~->u,p1,u~,e+,e-,p1	2.1872E-03	1.2E-05
d,d~->u,p1,u~,e-,e+,p1	2.1840E-03	8.3E-06
d,d~->u,u~,p1,e+,e-,p1	2.1664E-03	9.6E-06

Total	cs(pb)	% Error
0	1.4061E-01	1.0E-01

```
<
 Accuracy goal = 0.10%
*Improve Grids
   nMaxIts  = 10
   nCalls   = 10000
*Integrate

 Set  Distributions
 Display Distributions

 Clear statistics
 Clear grid & statistics

 N threads = 2
```

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

CalcHEP/num

MC session: 1(continue)

Process: p,p->j,j,l,l,p1,p1
Model: MC4BSM_2012

Processes	cs(pb)	Error
u,u~->u,p1,u~,e-,e+,p1	1.2068E-02	3.5E-05
u~,u->u,p1,u~,e-,e+,p1	1.1995E-02	4.7E-05
u~,u->u,p1,u~,e+,e-,p1	1.1985E-02	4.7E-05
u,u~->u,p1,u~,e+,e-,p1	1.1929E-02	4.5E-05
u,u~->u,u~,p1,e-,e+,p1	1.1870E-02	4.6E-05
u~,u->u,u~,p1,e-,e+,p1	1.1785E-02	4.1E-05
u~,u->u,u~,p1,e+,e-,p1	1.1768E-02	5.2E-05
u,u~->u,u~,p1,e+,e-,p1	1.1767E-02	3.8E-05
G,G->u,p1,u~,e+,e-,p1	6.9962E-03	3.2E-05
G,G->u,u~,p1,e-,e+,p1	6.9822E-03	2.7E-05
G,G->u,p1,u~,e-,e+,p1	6.9791E-03	2.5E-05
G,G->u,u~,p1,e+,e-,p1	6.9726E-03	2.7E-05
d,d~->u,u~,p1,e-,e+,p1	2.1992E-03	1.7E-05
d~,d->u,u~,p1,e-,e+,p1	2.1975E-03	9.5E-06
d~,d->u,p1,u~,e+,e-,p1	2.1964E-03	9.6E-06
d~,d->u,u~,p1,e+,e-,p1	2.1947E-03	7.4E-06
d~,d->u,p1,u~,e-,e+,p1	2.1915E-03	9.6E-06
d,d~->u,p1,u~,e+,e-,p1	2.1872E-03	1.2E-05
d,d~->u,p1,u~,e-,e+,p1	2.1840E-03	8.3E-06
d,d~->u,u~,p1,e+,e-,p1	2.1664E-03	9.6E-06

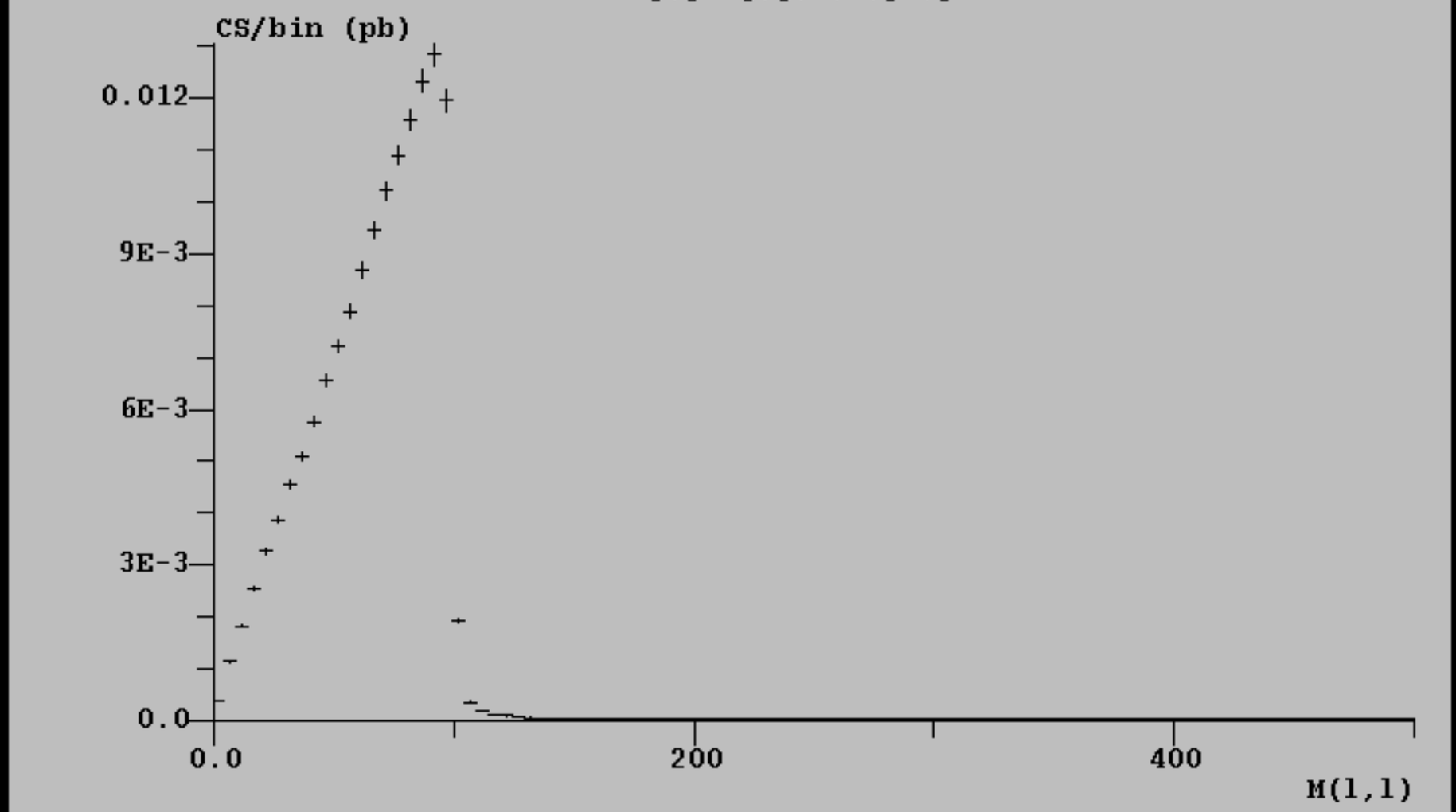
Total	cs(pb)	% Error
0	1.4061E-01	1.0E-01

```
 Accuracy goal = 0.10%
*Improve Grids
   nMaxIts   = 10
   nCalls    = 10000
*Integrate

 Set  Distributions
 Display Distributions

 Clear statistics
 Clear grid & statistics

 N threads = 2
```

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

CalcHEP/num

p,p->j,j,l,l,p1,p1



Esc - exit; Mouse - function value; Other keys - menu

Future

- Helicity amplitudes.
- Spin correlation.
- Jet matching.
- ...

Appendix

Resonant Diagrams

- Specify resonant diagrams:
  - p,p→(~W→(W→j,j),(Z→l,l)),Z→l,l

CalcHEP/symb

Model: HLS (Final)

Abstract

CalcHEP package is created for calculation of decay and high energy collision processes of elementary particles in the lowest order (tree) approximation. The main idea put into the CalcHEP was to make available passing from the lagrangian to the final distributions effectively with the high level of automatization.

Use F2 key to get information about interface facilities and F1 - as online help.

<

Enter Process
Force Unit.Gauge OFF
Create Prod+Dec code
Edit model
Delete model

F1-Help F2-Man F5-Switches F6-Results F9-Ref F10-Quit

CalcHEP/symb

Model: HLS (Final)

List of particles (antiparticles)

A(A)- Photon	Z(Z)- Z boson	W+(W-)- W boson
~Z(~Z)- Z' boson	~W+(~W-)- W' boson	G(G)- Gluon
n1(N1)- Electron-neut	n2(N2)- Mu-neutrino	n3(N3)- Tau-neutrino
e1(E1)- Electron	e2(E2)- Muon	e3(E3)- Tauon
u1(U1)- u-quark	u2(U2)- c-quark	u3(U3)- t-quark
d1(D1)- d-quark	d2(D2)- s-quark	d3(D3)- b-quark
~n1(~N1)- Heavy Electro	~n2(~N2)- Heavy Mu-neut	~n3(~N3)- Heavy Tau-ne
~e1(~E1)- Heavy Electro	~e2(~E2)- Heavy Muon	~e3(~E3)- Heavy Tauon
~u1(~U1)- Heavy u-quark	~u2(~U2)- Heavy c-quark	~u3(~U3)- Heavy t-quar
~d1(~D1)- Heavy d-quark	~d2(~D2)- Heavy s-quark	~d3(~D3)- Heavy b-quar

Enter process: u1,D1->u1,D1,e1,E1,e1,E1

CalcHEP/symb

Model: HLS (Final)

List of particles (antiparticles)

A(A)- Photon	Z(Z)- Z boson	W+(W-)- W boson
~Z(~Z)- Z' boson	~W+(~W-)- W' boson	G(G)- Gluon
n1(N1)- Electron-neut	n2(N2)- Mu-neutrino	n3(N3)- Tau-neutrino
e1(E1)- Electron	e2(E2)- Muon	e3(E3)- Tauon
u1(U1)- u-quark	u2(U2)- c-quark	u3(U3)- t-quark
d1(D1)- d-quark	d2(D2)- s-quark	d3(D3)- b-quark
~n1(~N1)- Heavy Electro	~n2(~N2)- Heavy Mu-neut	~n3(~N3)- Heavy Tau-ne
~e1(~E1)- Heavy Electro	~e2(~E2)- Heavy Muon	~e3(~E3)- Heavy Tauon
~u1(~U1)- Heavy u-quark	~u2(~U2)- Heavy c-quark	~u3(~U3)- Heavy t-quar
~d1(~D1)- Heavy d-quark	~d2(~D2)- Heavy s-quark	~d3(~D3)- Heavy b-quar

Enter process: u1,D1->u1,D1,e1,E1,e1,E1
Exclude diagrams with ~u1,~d1,~e1,~n1

CalcHEP/symb

```
      Model:  HLS (Final)

    Process:  u1,D1->u1,D1,e1,E1,e1,E1

              Feynman diagrams
1906  diagrams in  1   subprocesses  are constructed.
0     diagrams  are deleted.
```

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

CalcHEP/symb

Model: HLS (Final)

Process: u1,D1->u1,D1,e1,E1,e1,E1

Feynman diagrams

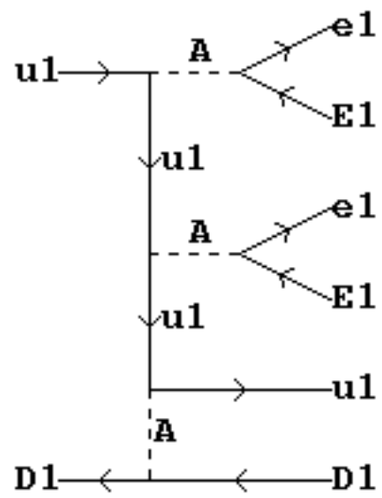
1906 diagrams in 1 subprocesses are constructed.
0 diagrams are deleted.

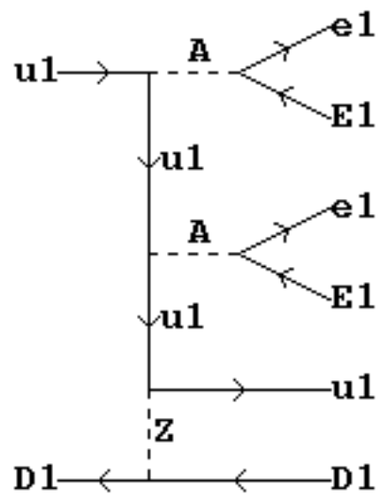
View diagrams
Squaring technique
Write down processes

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

CalcHEP/symb

Delete,On/off,Restore,Latex 1/1906





F1-Help,F2-Man,PgUp,PgDn,Home,End,# ,Esc

CalcHEP/symb

Model: HLS (Final)

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<

Enter Process
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Create Prod+Dec code
Edit model
Delete model

F1-Help F2-Man F5-Switches F6-Results F9-Ref F10-Quit

CalcHEP/symb

Model: HLS (Final)

List of particles (antiparticles)

A(A)- Photon	Z(Z)- Z boson	W+(W-)- W boson
~Z(~Z)- Z' boson	~W+(~W-)- W' boson	G(G)- Gluon
n1(N1)- Electron-neut	n2(N2)- Mu-neutrino	n3(N3)- Tau-neutrino
e1(E1)- Electron	e2(E2)- Muon	e3(E3)- Tauon
u1(U1)- u-quark	u2(U2)- c-quark	u3(U3)- t-quark
d1(D1)- d-quark	d2(D2)- s-quark	d3(D3)- b-quark
~n1(~N1)- Heavy Electro	~n2(~N2)- Heavy Mu-neut	~n3(~N3)- Heavy Tau-ne
~e1(~E1)- Heavy Electro	~e2(~E2)- Heavy Muon	~e3(~E3)- Heavy Tauon
~u1(~U1)- Heavy u-quark	~u2(~U2)- Heavy c-quark	~u3(~U3)- Heavy t-quar
~d1(~D1)- Heavy d-quark	~d2(~D2)- Heavy s-quark	~d3(~D3)- Heavy b-quar

Enter process: u1,D1->(~W+->(W+->u1,D1),(Z->e1,E1)),(Z->e1,E1)

CalcHEP/symb

```
      Model:  HLS (Final)

            List of particles (antiparticles)

 A(A    )- Photon          Z(Z    )- Z boson         W+(W-   )- W boson
 ~Z(~Z   )- Z' boson       ~W+(~W-  )- W' boson       G(G    )- Gluon
 n1(N1   )- Electron-neut  n2(N2   )- Mu-neutrino     n3(N3   )- Tau-neutrino
 e1(E1   )- Electron       e2(E2   )- Muon            e3(E3   )- Tauon
 u1(U1   )- u-quark        u2(U2   )- c-quark         u3(U3   )- t-quark
 d1(D1   )- d-quark        d2(D2   )- s-quark         d3(D3   )- b-quark
 ~n1(~N1  )- Heavy Electro ~n2(~N2  )- Heavy Mu-neut  ~n3(~N3  )- Heavy Tau-ne
 ~e1(~E1  )- Heavy Electro ~e2(~E2  )- Heavy Muon     ~e3(~E3  )- Heavy Tauon
 ~u1(~U1  )- Heavy u-quark ~u2(~U2  )- Heavy c-quark  ~u3(~U3  )- Heavy t-quar
 ~d1(~D1  )- Heavy d-quark ~d2(~D2  )- Heavy s-quark  ~d3(~D3  )- Heavy b-quar


Enter  process: u1,D1->(~W+->(W+->u1,D1),(Z->e1,E1)),(Z->e1,E1)
Exclude diagrams with ~u1,~d1,~e1,~n1
```

CalcHEP/symb

```
      Model:  HLS (Final)

    Process:  u1,D1->(~W+->(W+->u1,D1),(Z->e1,E1)),(Z->e1,E1)

              Feynman diagrams
4     diagrams in  1   subprocesses  are constructed.
0     diagrams  are deleted.
```

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

CalcHEP/symb

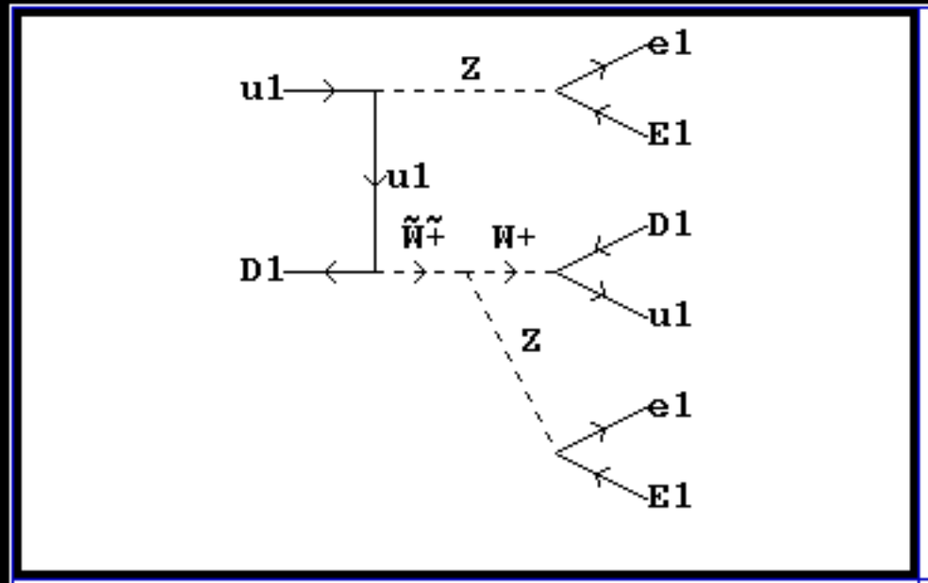
```
      Model:   HLS (Final)

    Process:   u1,D1->(~W+->(W+->u1,D1),(Z->e1,E1)),(Z->e1,E1)

               Feynman diagrams
 4     diagrams in  1   subprocesses  are constructed.
 0     diagrams  are deleted.
```

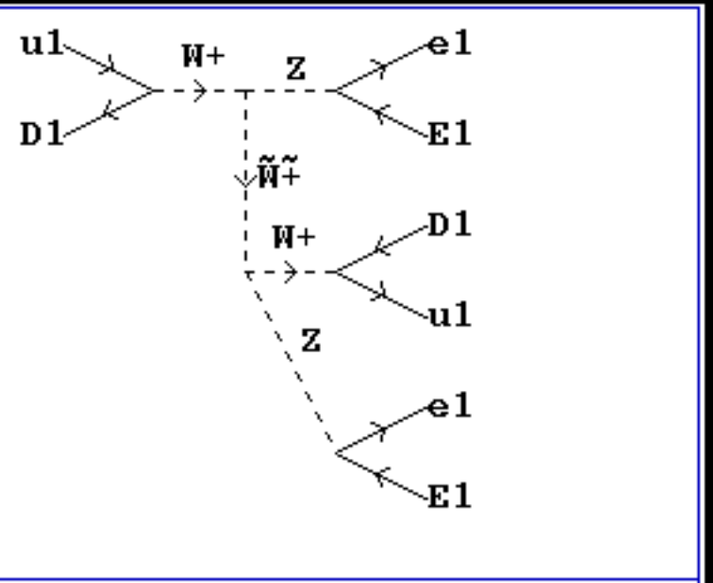
View diagrams
Squaring technique
Write down processes

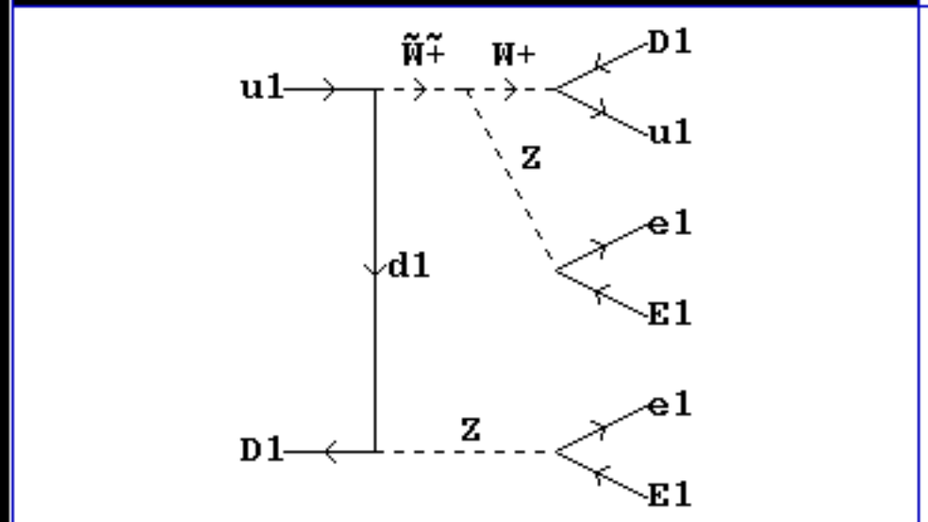
F1-Help F2-Man F3-Model F5-Switches F6-Results F9-Ref F10-Quit

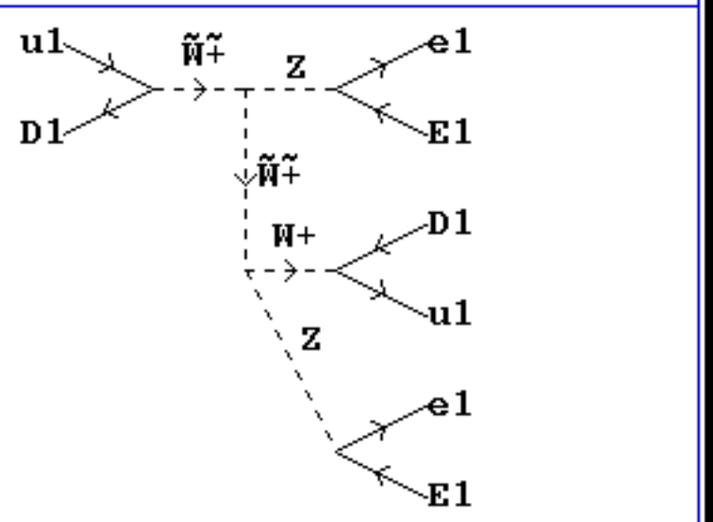
CalcHEP/symb

Delete,On/off,Restore,Latex 1/4









F1-Help,F2-Man,PgUp,PgDn,Home,End,# ,Esc