

CalcHEP

Developments

Neil Christensen

University of Wisconsin - Madison

Supported by NSF, grant number PHY-0705682.

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:

p_i	Momentum of i th particle.
m_i, M_i	1st, 2nd Lorentz index of i th particle.
$\text{eps}(v_1, v_2, v_3, v_4)$	Levi-Civita epsilon tensor.
$G(5), G(v)$	Dirac gamma matrices.

Why Feynman Gauge?

Why Feynman Gauge?

For massive vector bosons in unitary gauge:

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

Why Feynman Gauge?

For massive vector bosons in unitary gauge:

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

Contributes to very fast energy growth at high energies which is canceled in a gauge invariant theory.

Why Feynman Gauge?

For massive vector bosons in unitary gauge:

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

Cancelation of large terms can lead to a loss of precision.

Why Feynman Gauge?

For this reason, Sasha Pukhov chose Feynman gauge:

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

Why Feynman Gauge?

For this reason, Sasha Pukhov chose Feynman gauge:

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

Symbolic algebra
is also faster in
Feynman gauge.

Why Ghosts?

Why Ghosts?

For a massive vector boson:

$$\sum \epsilon_{\mu}^* \epsilon_{\nu} = -g_{\mu\nu} + \frac{p_{\mu} p_{\nu}}{M^2}$$

Why Ghosts?

For a massive vector boson:

$$\sum \epsilon_{\mu}^* \epsilon_{\nu} = -g_{\mu\nu} + \frac{p_{\mu} p_{\nu}}{M^2}$$

Contributes to very fast energy growth at high energies which is canceled in a gauge invariant theory.

Why Ghosts?

For a massive vector boson:

$$\sum \epsilon_{\mu}^* \epsilon_{\nu} = -g_{\mu\nu} + \frac{p_{\mu} p_{\nu}}{M^2}$$

Cancelation of large terms can lead to a loss of precision.

Why Ghosts?

For this reason, Sasha Pukhov chose:

$$\sum \epsilon_{\mu}^* \epsilon_{\nu} \longrightarrow -g_{\mu\nu}$$

But,

Why Ghosts?

For this reason, Sasha Pukhov chose:

$$\sum \epsilon_{\mu}^* \epsilon_{\nu} \longrightarrow -g_{\mu\nu}$$

But, need ghosts and Goldstones
in external states
to cancel unphysical polarizations.

New Developments

New Developments

Choose resonant diagrams:

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

New Developments

```
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: p,p->j,j,(~W->(W->l,n),(Z->l,l))
Composite 'p' consists of: u1,d1,G
Composite 'j' consists of: u1,d1,G
Composite 'l' consists of: e1,E1
Composite 'n' consists of: n1,N1
Composite '~W' consists of: ~W+,~W-
Composite 'W' consists of: W+,W-
Exclude diagrams with ~u1,~d1,~e1,~n1
```

New Developments

CalcHEP/symb

Delete, On/off, Restore, Latex 1/32

The image displays two Feynman diagrams side-by-side, illustrating particle interactions. Both diagrams feature a horizontal line representing a $u1$ quark. In the left diagram, a dashed line labeled A (gluon) branches off from the $u1$ line. A W^+ boson is produced, which then decays into $E1$ and $n1$. Another Z boson is produced, which decays into $e1$ and $E1$. The right diagram shows a similar setup, but the W^+ boson decays into $E1$ and $n1$, and the Z boson decays into $e1$ and $E1$. The $u1$ line continues to the right, ending at $u1$ in the left diagram and $d1$ in the right diagram.

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

New Developments

New numerical session:

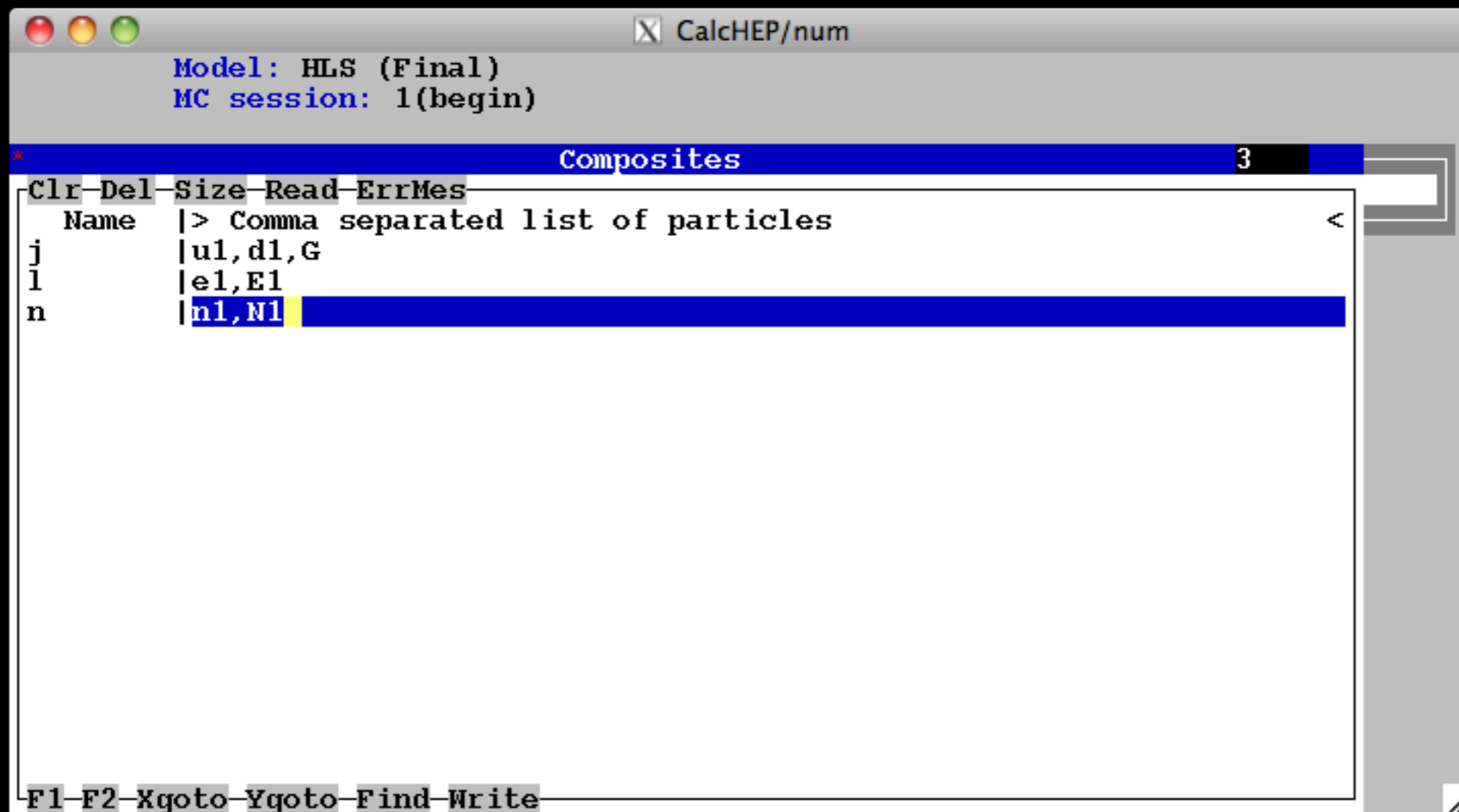
New Developments

New numerical session:

Allows general definition of “composites”.

New Developments

New numerical session:



The screenshot shows a window titled "CalcHEP/num" with a menu bar and a text area. The text area contains the following information:

```
Model: HLS (Final)
MC session: 1(begin)
```

Clr	Del	Size	Read	ErrMes	
					Composites 3
					Name > Comma separated list of particles <
j					u1,d1,G
l					e1,E1
n					n1,N1

At the bottom of the window, there is a menu bar with the following items: F1, F2, Xgoto, Ygoto, Find, Write.

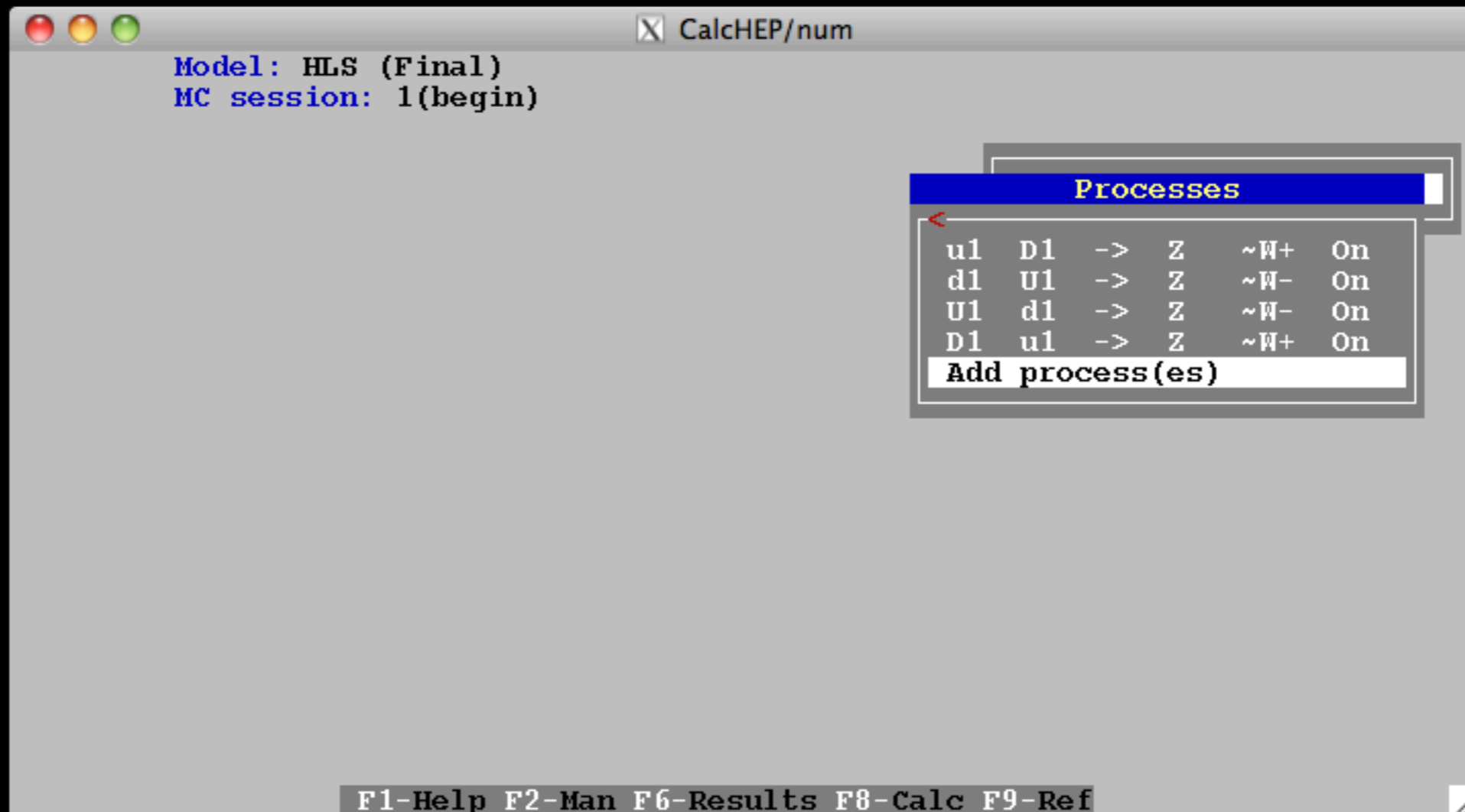
New Developments

New numerical session:

Allows to dynamically generate multiple production and decay processes.

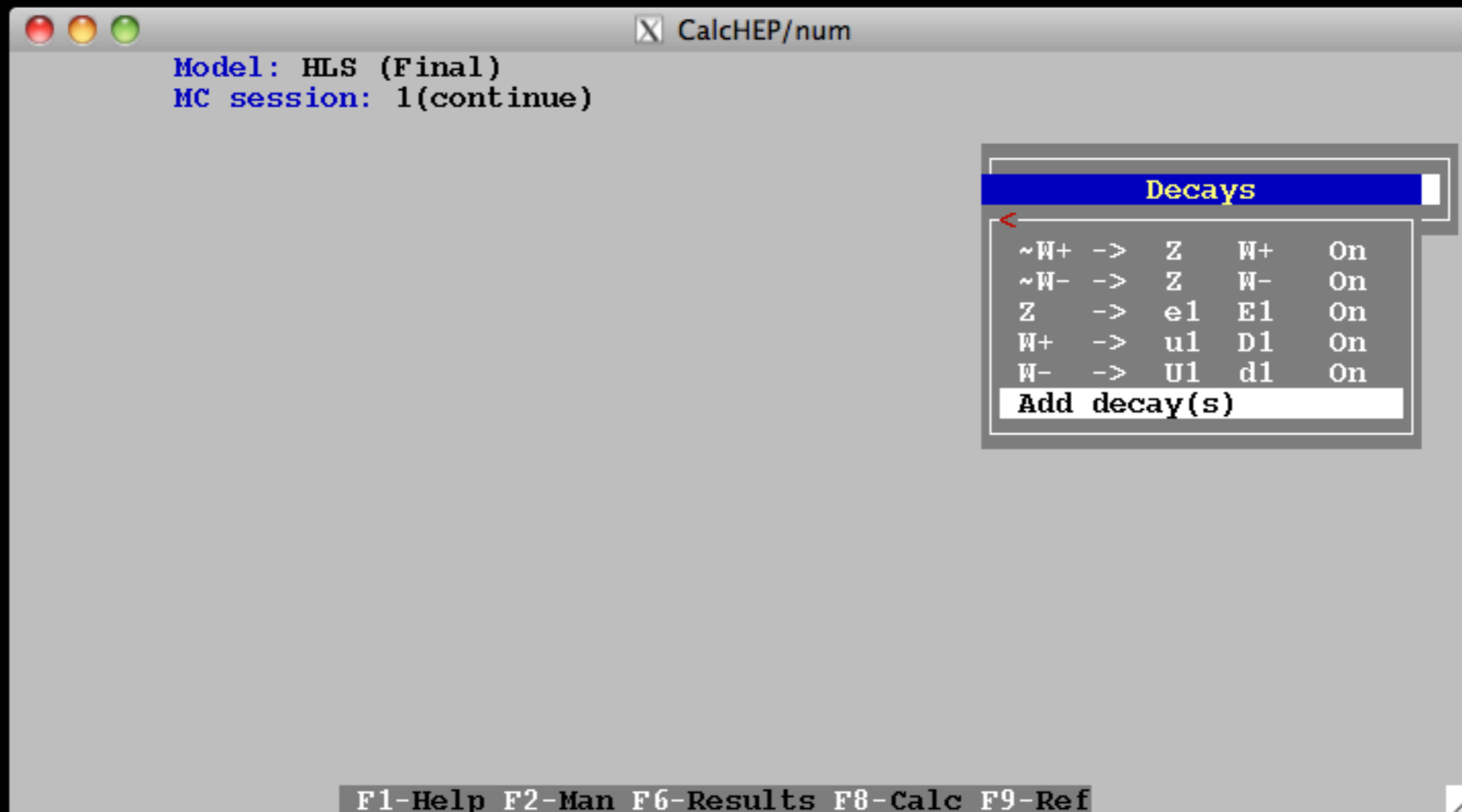
New Developments

New numerical session:



New Developments

New numerical session:



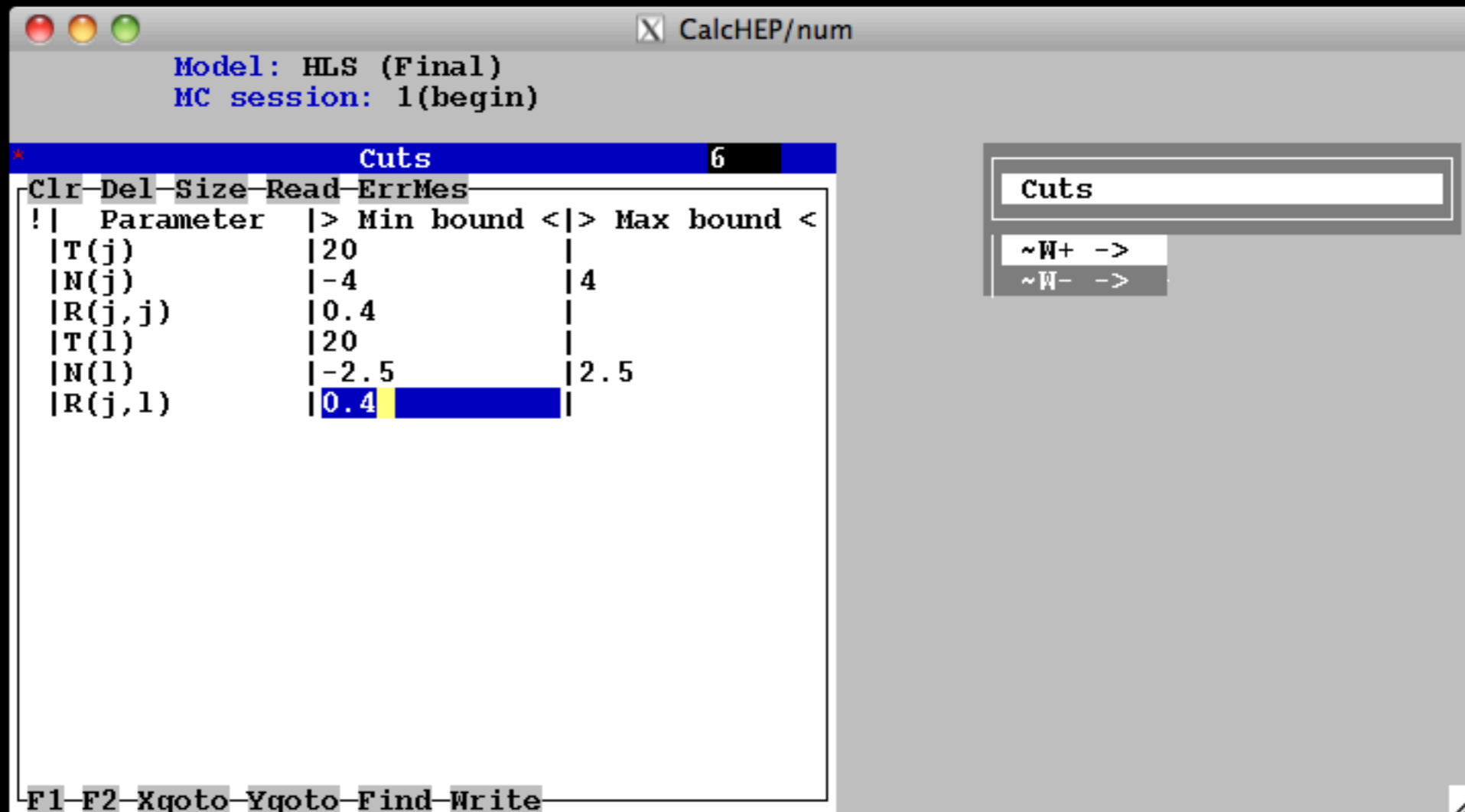
New Developments

New numerical session:

Allows to cut on final states (after decay).

New Developments

New numerical session:



The screenshot shows the CalcHEP/num software interface. At the top, it displays "Model: HLS (Final)" and "MC session: 1(begin)". A window titled "Cuts" is open, showing a table of parameters and their bounds. The table has columns for "Parameter", "Min bound", and "Max bound". The parameters listed are T(j), N(j), R(j,j), T(1), N(1), and R(j,1). The values for the bounds are: T(j) [20,], N(j) [-4, 4], R(j,j) [0.4,], T(1) [20,], N(1) [-2.5, 2.5], and R(j,1) [0.4,]. The value 0.4 in the R(j,1) row is highlighted in blue. To the right of the table, there are two buttons labeled "~W+ ->" and "~W- ->". At the bottom of the window, there is a menu bar with options: F1, F2, Xgoto, Ygoto, Find, Write.

Parameter	Min bound	Max bound
T(j)	20	
N(j)	-4	4
R(j,j)	0.4	
T(1)	20	
N(1)	-2.5	2.5
R(j,1)	0.4	

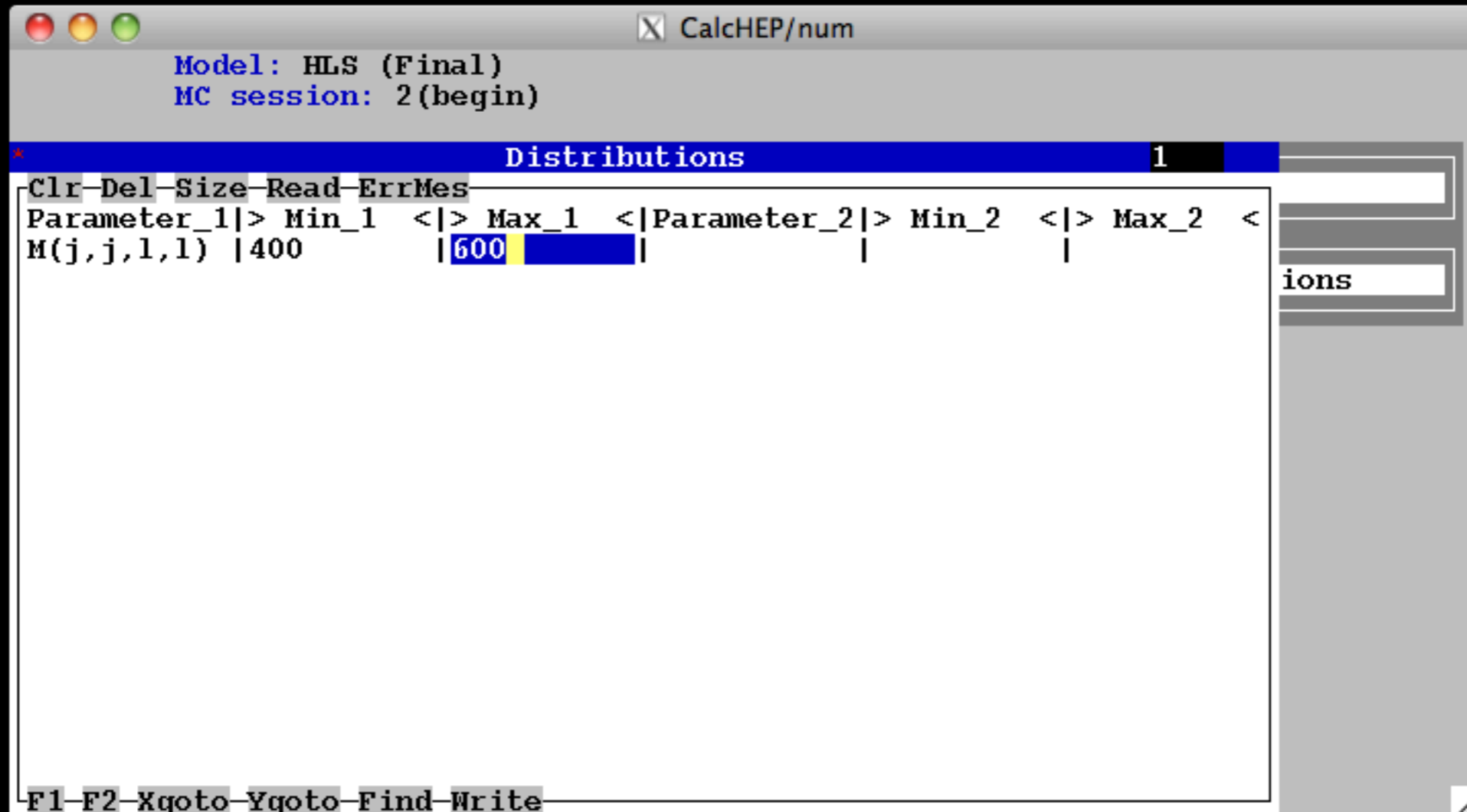
New Developments

New numerical session:

Allows to bin final states (after decay).

New Developments

New numerical session:



The screenshot shows a window titled "CalcHEP/num" with a menu bar and a main content area. The menu bar includes "Model: HLS (Final)" and "MC session: 2(begin)". The main content area is titled "Distributions" and contains a table with columns for "Parameter_1", "Min_1", "Max_1", "Parameter_2", "Min_2", and "Max_2". The first row of data is "M(j,j,1,1) | 400 | 600 |", where "600" is highlighted in blue. The table is partially obscured by a sidebar on the right with a button labeled "ions". At the bottom of the window, there is a menu bar with options "F1", "F2", "Xgoto", "Ygoto", "Find", and "Write".

```
Model: HLS (Final)
MC session: 2(begin)

Distributions 1
+-----+-----+-----+-----+-----+-----+
|Clr|Del|Size|Read|ErrMes|
+-----+-----+-----+-----+-----+
|Parameter_1|> Min_1 <|> Max_1 <|Parameter_2|> Min_2 <|> Max_2 <|
|M(j,j,1,1) |400 |600 |
+-----+-----+-----+-----+-----+

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

New Developments

New numerical session:

Improves all the grids.

New Developments

New numerical session:

Model: HLS (Final)
MC session: 2 (begin)

---Improving Grids---

Process	cs(pb)/BR	%T Err	%C Err
u1,D1->Z,~W+	4.1743E-02	1.4E-01	3.0E-01
d1,U1->Z,~W-	1.6177E-02	1.5E-01	2.9E-01
U1,d1->Z,~W-	1.6212E-02	1.4E-01	2.9E-01
D1,u1->Z,~W+	4.1884E-02	1.4E-01	2.8E-01
~W+->Z,W+	9.9998E-01	4.5E-05	1.0E-04
~W-->Z,W-	9.9998E-01	4.5E-05	1.0E-04
Z->e1,E1	3.4383E-02	4.5E-05	1.0E-04
W+->u1,D1	3.3340E-01	4.5E-05	1.0E-04
W-->U1,d1	3.3340E-01	4.5E-05	1.0E-04

Vegas

Accuracy goal = 1.00%

*Improve Grids
nCalls = 10000

*Integrate

Set Distributions
Display Distributions

Clear statistics
Clear grid & statistics

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

New Developments

New numerical session:

Dynamically connects production and decays.

Sums over subprocesses.

New Developments

New numerical session:

Model: HLS (Final)
MC session: 2 (continue)

Processes	cs (pb)	Error
u1,D1->e1,E1,e1,E1,u1,D1	9.3165E-07	2.7E-08
d1,U1->e1,E1,e1,E1,U1,d1	3.2142E-07	9.8E-09
D1,u1->e1,E1,e1,E1,u1,D1	1.8062E-07	1.3E-08
U1,d1->e1,E1,e1,E1,U1,d1	8.8394E-08	5.3E-09
Total	cs (pb)	% Error
	1.5221E-06	2.1E+00

Vegas

< Accuracy goal = 0.10%
*Improve Grids
nCalls = 10000

***Integrate**

Set Distributions
Display Distributions

Clear statistics
Clear grid & statistics

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

New Developments

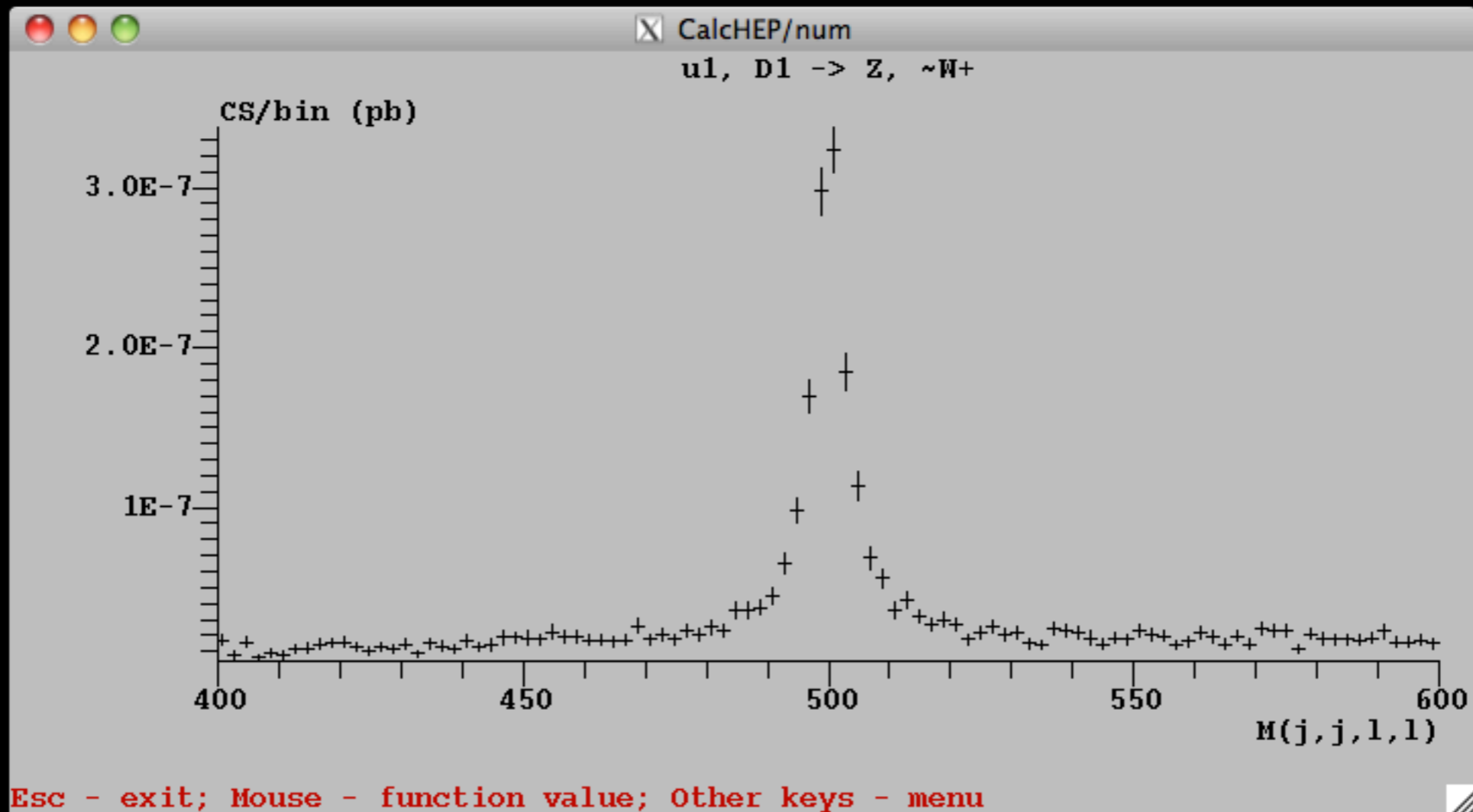
New numerical session:

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.

New Developments

New numerical session:

Future : Write events (after decay).

CH Wish List for FeynRules

CH Wish List for FeynRules

I am already very happy with it.

CH Wish List for FeynRules

Stability:

Automated validations run for each stable version and subversion.

Think about how to improve the code that is present as well as tack on new modules.

CH Wish List for FeynRules

Complex Parameters:

CH only allows real parameters.

Perhaps a general routine which splits complex parameters into real and imaginary parts?
(Christian?)

CH Wish List for FeynRules

4 Color Adjoint Vertices:

In CH, this must be done via auxiliary fields.

Can this be automated?

Sasha's Wish List for FeynRules

Template for batch mode.

Example how to run in batch mode.

My Wish List for FeynRules

More Warnings:

Lots of questions from users where they do something wrong in FR. Can we think about more detailed warnings?

E.g. Definitions- \rightarrow { $\phi \rightarrow (v+h)/\text{Sqrt}[2]$ }
is not allowed.

My Wish List for FeynRules

Easier Model Implementation:

Although much easier,
implementing a new model is still coding.
Let's bring it to the "masses".

Java interface? (Started..)

My Wish List for FeynRules

FeynRules 2011

Possibly emphasize physics goals which requires technology rather than emphasizing technology?

E.g. Working Group 1 : Implement model Y including spin $3/2$ particle X (which is currently impossible for FeynRules) and study the LHC phenomenology, finishing with a paper.