MadGraph and CalcHEP

10/5/07
233B

Matthew Buckley

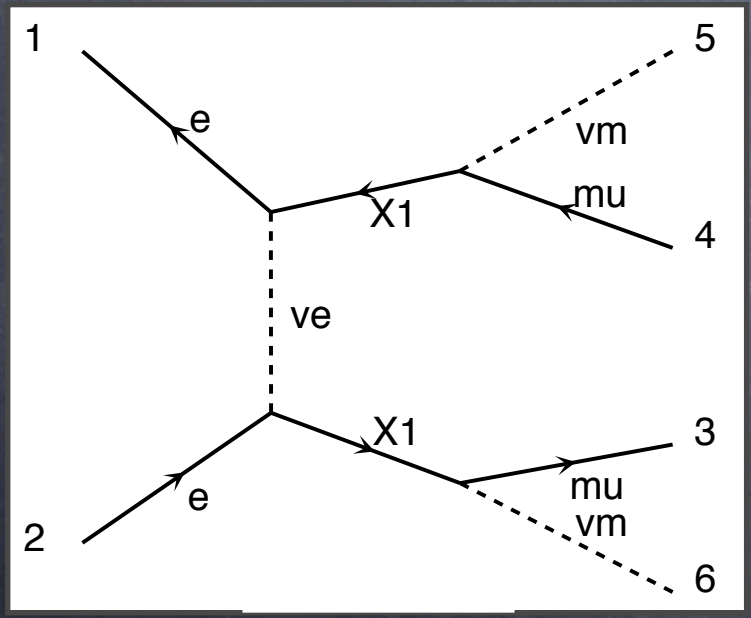
Overview

- MadGraph:
  - Based off of HELAS; sums over individual helicity and polarizations.
  - Must run full Monte-Carlo for all events; multi-particle final states not a problem.
- CalcHEP:
  - Does not include helicity information; does sums over gamma matrices.
  - New interactions entered 'direct' from Lagrangian.
  - Fast for 2-body; full Monte-Carlo for more complicated phase space very slow.

HELAS

(search SPIRES for 'a murayama and t HELAS')

- FORTRAN 77 subroutines that allows explicit construction of spinors, polarization vectors, etc and calculation of matrix elements.




```
DO NW1=-1,1,2
   DO NW2=-1,1,2

      CALL OXXXXX(P1,M2,NW1,+1 , SWINO1)
      CALL IXXXXX(P2,M2,NW2,-1 , SWINO2)
      CALL IOVXXX(SWINO2,SWINO1,J3,G3 , PRODUCTION1)

      CALL HIOXXX(EM,SWINO1,GL,M1,0, NU1)
      CALL IOSXXX(SWINO2,EP,NU1,GR, PRODUCTION2)

      CALL IXXXXX(P1,M2,NW1,+1 , SWINO1)
      CALL OXXXXX(P2,M2,NW2,-1 , SWINO2)
      CALL IOSXXX(SWINO1,MUM,CMISS1,GR , DECAY1)
      CALL IOSXXX(MUP,SWINO2,CMISS2,GL , DECAY2)
      SUSY(NW1,NW2) =DECAY1*DECAY2*
$           (PRODUCTION1+PRODUCTION2)
   END DO
END DO
```

MadGraph

(http://madgraph.hep.uiuc.edu)

- Automatically builds the HELAS code for your process. Includes correct PDFs for pp initial states. Cannot do polarized initial states.
- Model fully editable. However, highly recommended you use a generator (more on this in a minute).
- Cleverly splits phase-space to consider only one singularity at a time.

$$|\mathcal{M}|^2 = \sum_i w_i |\mathcal{M}|^2, \quad \sum_i w_i = 1$$

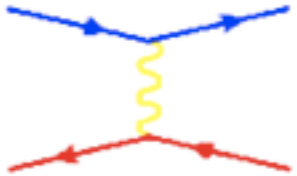
$$w_i = \frac{|\mathcal{M}_i|^2}{\sum_k |\mathcal{M}_k|^2}$$

High Energy Physics Illinois

This material is based upon work supported by the National Science Foundation under Grant No. 0426272.
Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation

MadGraph Version 4

UCL UIUC Fermi
by Fabio Maltoni, Tim Stelzer
and the CP3 Development team



I. Fill the form:

Model: SM — Particle names

Input Process: — Examples

Max QCD Order: 99

Max QED Order: 99

p and j definitions: p=j=d u s c d~ u~ s~ c~ g

sum over leptons: l+ = e+, mu+ ; l- = e-, mu- ; vl = ve, vm ; vl~ = ve~, vm~

Submit

We'll use an offline version of this

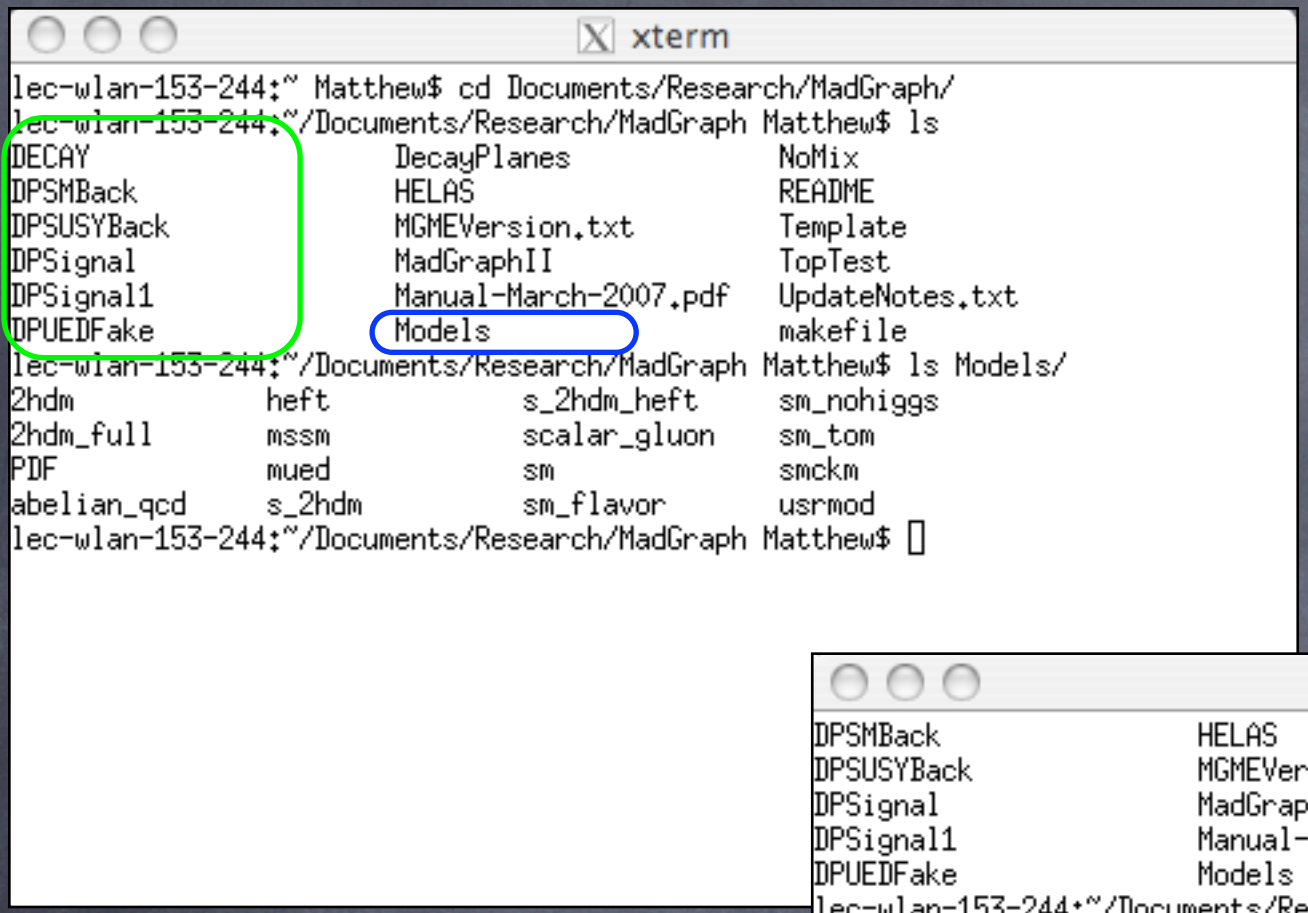
II. Upload the proc_card.dat

Process card examples

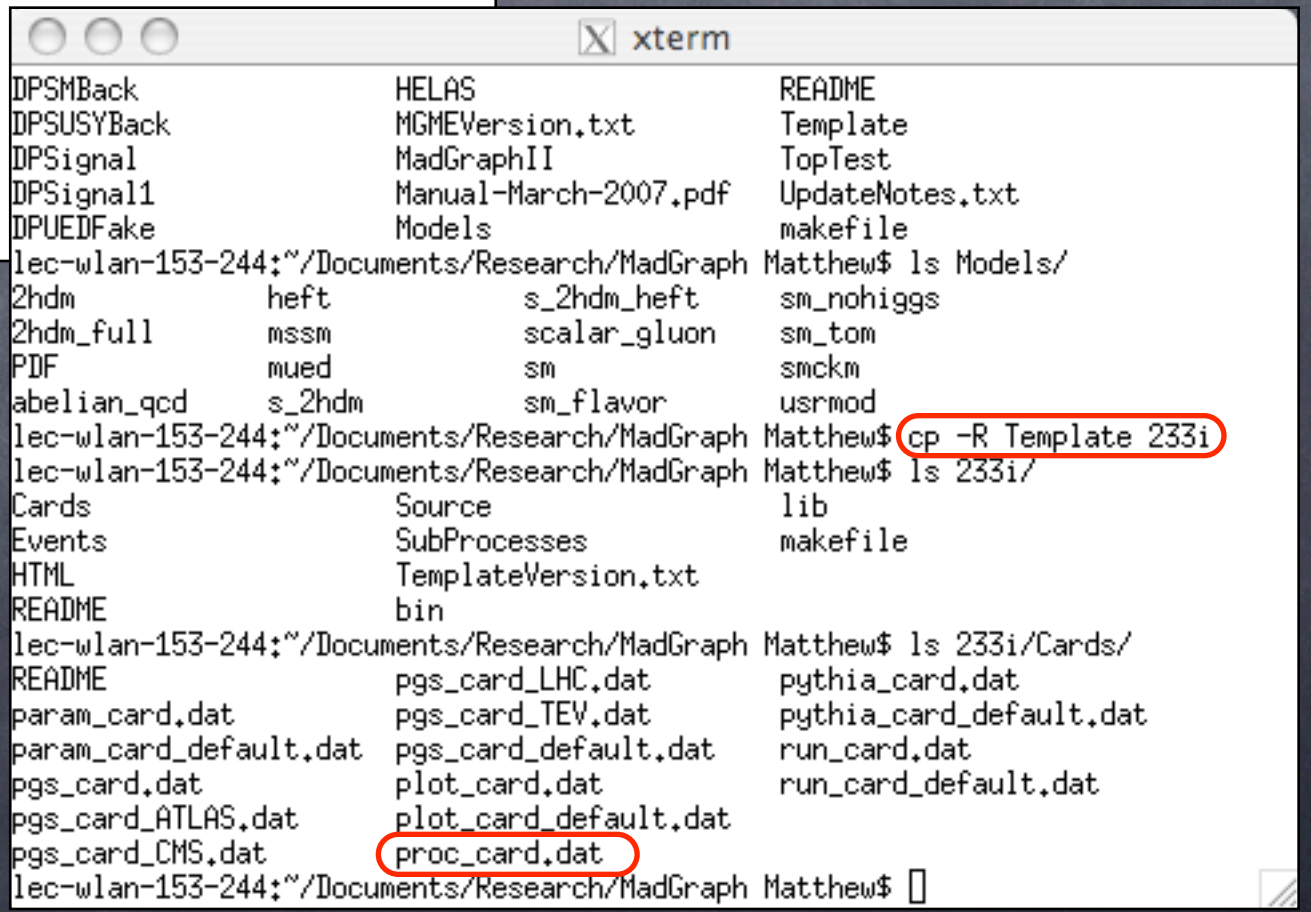
Choose File no file selected and send it to the server.

III. Upload the full banner (all cards are uploaded as the "current" ones)

Choose File no file selected and send it to the server.



Step 1: Create new working directory



Step 2: Edit Cards/proc_card.dat

```
#*********************************************************************
# Begin PROCESS # This is TAG. Do not modify this line

pp>e-ve~   @0        # First Process
QCD=99               # Max QCD couplings
QED=2                # Max QED couplings
end_coup             # End the couplings input

pp>e-ve~j @1         # Second Process
QCD=99               # Max QCD couplings
QED=2                # Max QED couplings
end_coup             # End the couplings input

pp>tt~     @2        # Third Process
QCD=99               # Max QCD couplings
end_coup             # End the couplings input

done                 # this tells MG there are no more procs

# End PROCESS  # This is TAG. Do not modify this line
#*********************************************************************
# Model information                                                  *
#*********************************************************************
# Begin MODEL  # This is TAG. Do not modify this line
sm
# End   MODEL  # This is TAG. Do not modify this line
#*********************************************************************
# Start multiparticle definitions                                    *
#*********************************************************************
# Begin MULTIPARTICLES # This is TAG. Do not modify this line
P uu~dd~ss~cc~g
J uu~dd~ss~cc~g
L+ e+mu+
L- e-mu-
vl vevm
vl~ ve~vm~
# End  MULTIPARTICLES # This is TAG. Do not modify this line
```

Specify initial/final states
QCD/QED couplings
Can enter arbitrary number of Processes.

Don't forget to increment this number

Specifies particle content/couplings
NOT particle masses

Allows specification of particle 'classes'

Simple Example: $e^- e^+ \rightarrow \mu^- \mu^+$

What are the particle names?

Look in Madgraph/Models/sm/particles.dat

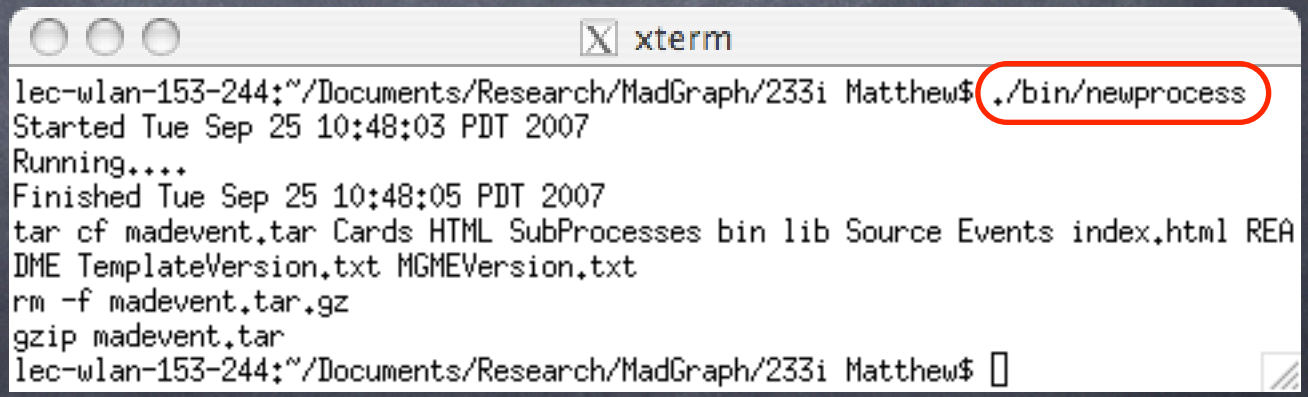
Allowed interactions in MadGraph/Models/sm/interactions.dat

```
#
#       particles_0001_v1.dat
#
#This is a special data file which contains particles of the
#Standard Model. The format for entering new particles is.
#Particle codes taken from  http://pdg.lbl.gov /2000/ montecarlorpp.pdf
#Name anti_Name  Spin    Linetype Mass Width Color Label Model
#xxx   xxxx      SFV      WSDC     str  str  STO    str  PDG code

#
# Quarks
#

d       d~        F        S      ZERO  ZERO    T    d    1
u       u~        F        S      ZERO  ZERO    T    u    2
s       s~        F        S      ZERO  ZERO    T    s    3
c       c~        F        S      ZERO  ZERO    T    c    4
b       b~        F        S      BMASS ZERO    T    b    5
t       t~        F        S      TMASS TWIDTH  T    t    6

#
# Leptons
#

e-      e+        F        S      ZERO  ZERO    S    e    11
mu-     mu+       F        S      ZERO  ZERO    S    mu   13
ta-     ta+       F        S      LMASS ZERO    S    ta   15
ve      ve~       F        S      ZERO  ZERO    S    ve   12
vm      vm~       F        S      ZERO  ZERO    S    vm   14
vt      vt~       F        S      ZERO  ZERO    S    vt   16

#
```

Step 2: Edit Cards/proc_card.dat

```
#*********************************************************************
# Process(es) requested : mg2 input                                  *
#*********************************************************************
# Begin PROCESS # This is TAG. Do not modify this line

e-e+>mu-mu+  @0      # First Process
QCD=0               # Max QCD couplings
QED=2               # Max QED couplings
end_coup            # End the couplings input

done                # this tells MG there are no more procs

# End PROCESS  # This is TAG. Do not modify this line
#*********************************************************************
# Model information                                                  *
#*********************************************************************
# Begin MODEL  # This is TAG. Do not modify this line
sm
# End   MODEL  # This is TAG. Do not modify this line
```

Step 3: Start our new process



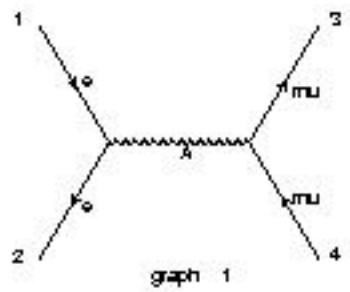
Step 4: Check our results

```
xterm
lec-wlan-153-244:~/Documents/Research/MadGraph/233i Matthew$ open index.html
lec-wlan-153-244:~/Documents/Research/MadGraph/233i Matthew$
```

MadEvent Card for e-e+>mu-mu+

Created: Tue Sep 25 10:48:05 PDT 2007

Process: e-e+>mu-mu+
QCD=0
QED=2
Model: sm



Links	Status
Process Information	Generation Complete
Code Download	Available
On-line Event Generation	Only available from the web
Results and Event Database	No runs available

Notes:

Last Update: Tue Sep 25 10:48:06 PDT 2007

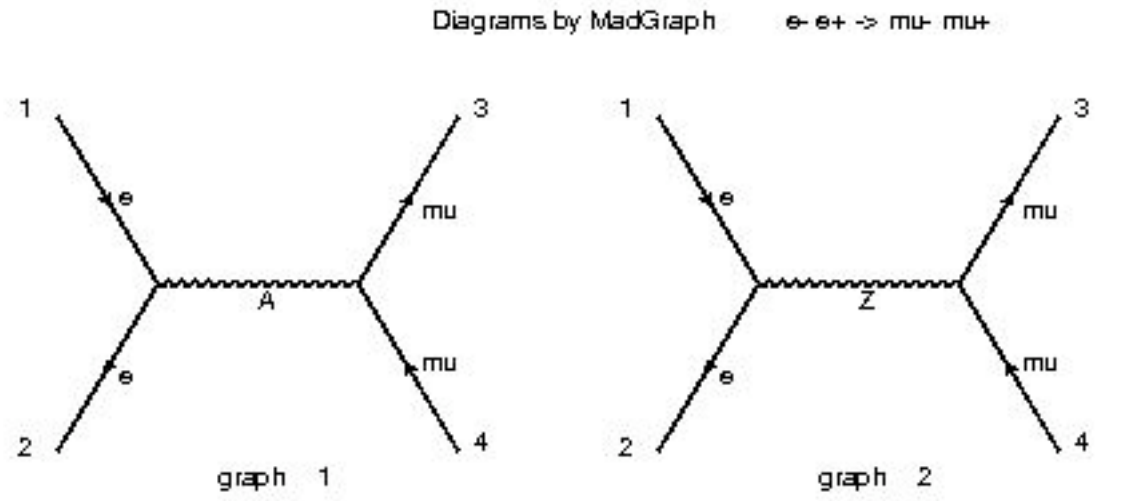
SubProcesses and Feynman diagrams

Directory	# Diagrams	# Subprocesses	FEYNMAN DIAGRAMS		SUBPROCESS
P0e-e+_mu-mu+	2	1	html	postscript	e- e+ -> mu- mu+

proc_log.txt Log file from MadGraph code generation.
proc_card.dat Input file used for code generation.
particles.dat Particles file used for code generation.
interactions.dat Interactions file used for code generation.

Main Page

Postscript Diagrams



Step 5: Edit Cards/ param_card/dat

No changes needed, so...

```
Block MODSEL # Select Model
     0   1   #  0 1 = SM
Block SMINPUTS      # Standard Model inputs
     1         1.32506980E+02   # alpha_em(MZ)(-1) SM MSbar
     2         1.16639000E-05   # G_Fermi
     3         1.18000000E-01   # alpha_s(MZ) SM MSbar
     4         9.11880000E+01   # Z mass (as input parameter)
Block MGSMPARAM      # Standard Model parameters for MadGraph
     1         2.22246533E-01   # sin(theta_W)^2
     2         8.04190000E+01   # W mass (as input parameter)
Block MGYUKAWA     # Yukawa masses m/v=y/sqrt(2)
#     PDG         YMASS
     5         4.70000000E+00   # mbottom for the Yukawa  y_b
     4         1.42000000E+00   # mcharm  for the Yukawa  y_c
     6         1.74300000E+02   # mtop    for the Yukawa  y_t
    15         1.77700000E+00   # mtau    for the Yukawa  y_ta
Block MGCKM     # CKM elements for MadGraph
     1   1     9.75000000E-01   # Vud for Cabibbo matrix
Block MASS      #  Mass spectrum (kinematic masses)
#        PDG        Mass
         5     4.70000000E+00   # bottom   pole mass
         6     1.74300000E+02   # top      pole mass
        15     1.77700000E+00   # tau      mass
        23     9.11880000E+01   # Z        mass
        24     8.04190000E+01   # W        mass
        25     1.20000000E+02   # H        mass
```

WARNING: running ./bin/newprocess overwrites param_card.dat with the card from ../Models/model_name

Step 6: Edit Cards/ run_card.dat

```
#*********************************************************************
# Tag name for the run (one word)                                    *
#*********************************************************************
  'fermi'     = run_tag ! name of the run
#*********************************************************************
# Number of events and rnd seed                                      *
#*********************************************************************
  10000       = nevents ! Number of unweighted events requested
      0       = iseed   ! rnd seed (0=assigned automatically=default))
#*********************************************************************
# Collider type and energy                                           *
#*********************************************************************
      1       = lpp1  ! beam 1 type (0=NO PDF)
      1       = lpp2  ! beam 2 type (0=NO PDF)
   7000       = ebeam1  ! beam 1 energy in GeV
   7000       = ebeam2  ! beam 2 energy in GeV
#*********************************************************************
```

Beam type

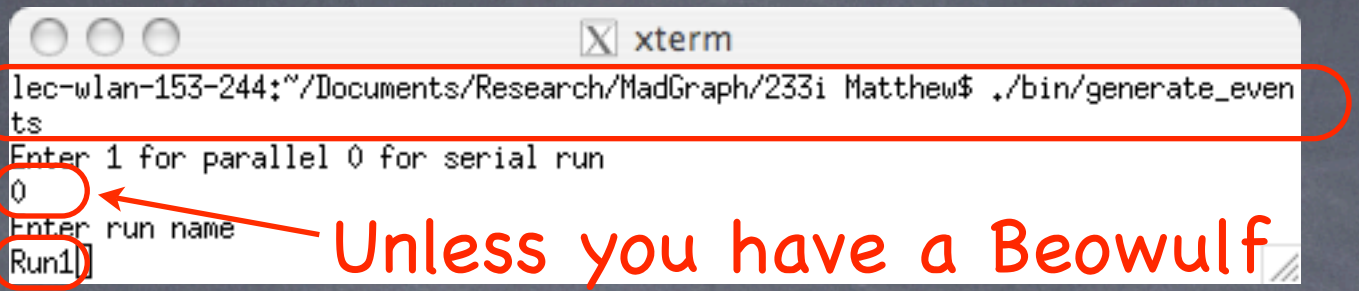
Beam energy

Want electrons at say 100 GeV

```
#*********************************************************************
# Collider type and energy                                           *
#*********************************************************************
      0       = lpp1  ! beam 1 type (0=NO PDF)
      0       = lpp2  ! beam 2 type (0=NO PDF)
    100       = ebeam1  ! beam 1 energy in GeV
    100       = ebeam2  ! beam 2 energy in GeV
#*********************************************************************
```

run_card.dat also includes information on cuts. Ignore for now.

Step 7: Run Monte-Carlo



Unless you have a Beowulf cluster handy

Wait.... then check results from index.html

Links

Process Information

Code Download

On-line Event Generation

Results and Event Database

Available Results

Links	Events	Tag	Run	Collider	Cross section (pb)	Events
results banner	Parton-level LHE	fermi	Run1	e e 100 x 100 GeV	.27830E+01	9965

Main Page

Available Results

Links	Events	Tag	Run	Collider	Cross section (pb)	Events
results banner	Parton-level LHE	fermi	Run1	e e 100 x 100 GeV	.27830E+01	9965

Main Page

2.78 pb cross section

We expected:

$$\frac{86.8 \text{ nb}}{s/\text{GeV}^2} = 2.17 \text{ pb}$$

But remember, this doesn't include right-helicity electrons

Available Results

Links	Events	Tag	Run	Collider	Cross section (pb)	Events
results banner	Parton-level LHE	fermi	Run1	e e 100 x 100 GeV	.27830E+01	9965

Main Page

Results also in Events/ subfolder

Process
sigma= 2783.200± 4.402(fb)

Graph	Cross Sect(fb)	Error(fb)	Events (K)	Eff	Unwgt	Luminosity
Sum	**2783.200**	**4.402**	**64**	**0.4**		
P0e-e+_mu-mu+	2783.200	4.402	64	0.4		5.71

e-e+_mu-mu+
s= 2783.190± 4.403(fb)

Graph	Cross Sect(fb)	Error(fb)	Events (K)	Eff	Unwgt	Luminosity
Sum	**2783.190**	**4.403**	**1276**	**1.8**		
G1	2268.600	4.355	254	1.0	12943	5.71
G2	514.590	0.642	1022	1.3	51236	99.60

$pp \to t\bar{t} \to b\bar{b}\mu\bar{\nu}_\mu jj$

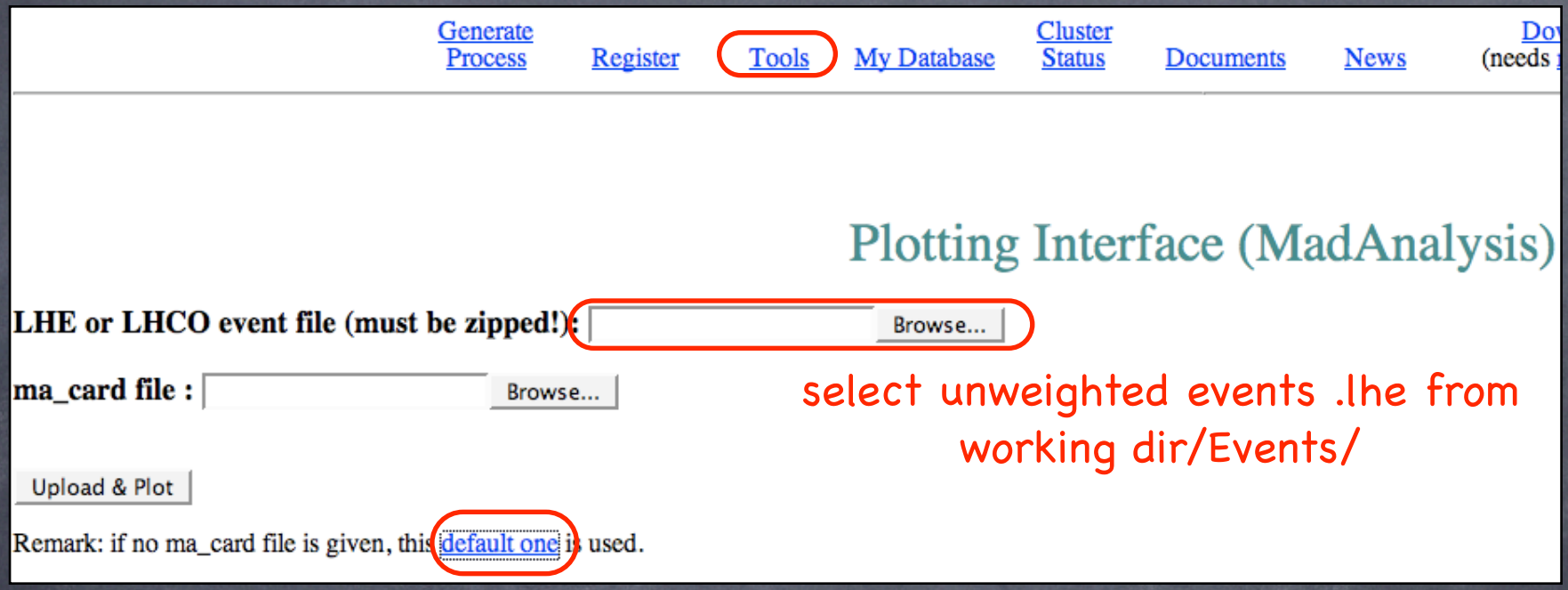
```
#*********************************************************************
# Process(es) requested : mg2 input                                  *
#*********************************************************************
# Begin PROCESS # This is TAG. Do not modify this line

pp>tt~>bb~mu-vm~jj  @0        # First Process
QCD=2               # Max QCD couplings
QED=4               # Max QED cou
end_coup            # End the cou

done                # this tells
```

```
#*********************************************************************
# Collider type and energy                                           *
#*********************************************************************
       1     = lpp1  ! beam 1 type (0=NO PDF)
       1     = lpp2  ! beam 2 type (0=NO PDF)
     500     = ebeam1  ! beam 1 energy in GeV
     500     = ebeam2  ! beam 2 energy in GeV
#*********************************************************************
# PDF CHOICE: this automatically fixes also alpha_s and its evol.    *
#*********************************************************************
 'cteq6l1'    = pdlabel     ! PDF set
#*********************************************************************
```

SubProcesses and Feynman diagrams

Directory	# Diagrams	# Subprocesses	FEYNMAN DIAGRAMS		SUBPROCESS			
P0uxu_bbxmu-vmxudx	1	4	html	postscript	u~ u -> b b~ mu- vm~ u d~	d~ d -> b b~ mu- vm~ u d~	s~ s -> b b~ mu- vm~ u d~	c~ c -> b b~ mu- vm~ u d~
P0uxu_bbxmu-vmxsxc	1	4	html	postscript	u~ u -> b b~ mu- vm~ s~ c	d~ d -> b b~ mu- vm~ s~ c	s~ s -> b b~ mu- vm~ s~ c	c~ c -> b b~ mu- vm~ s~ c
P0uux_bbxmu-vmxudx	1	4	html	postscript	u u~ -> b b~ mu- vm~ u d~	d d~ -> b b~ mu- vm~ u d~	s s~ -> b b~ mu- vm~ u d~	c c~ -> b b~ mu- vm~ u d~
P0uux_bbxmu-vmxsxc	1	4	html	postscript	u u~ -> b b~ mu- vm~ s~ c	d d~ -> b b~ mu- vm~ s~ c	s s~ -> b b~ mu- vm~ s~ c	c c~ -> b b~ mu- vm~ s~ c
P0gg_bbxmu-vmxudx	3	1	html	postscript	g g -> b b~ mu- vm~ u d~			
P0gg_bbxmu-vmxsxc	3	1	html	postscript	g g -> b b~ mu- vm~ s~ c			

MadAnalysis



select unweighted events .lhe from working dir/Events/

Download and modify the ma_card.dat file

ma_card.dat

particle class definitions

cuts for plotting (there are generation cuts in run_card.dat)

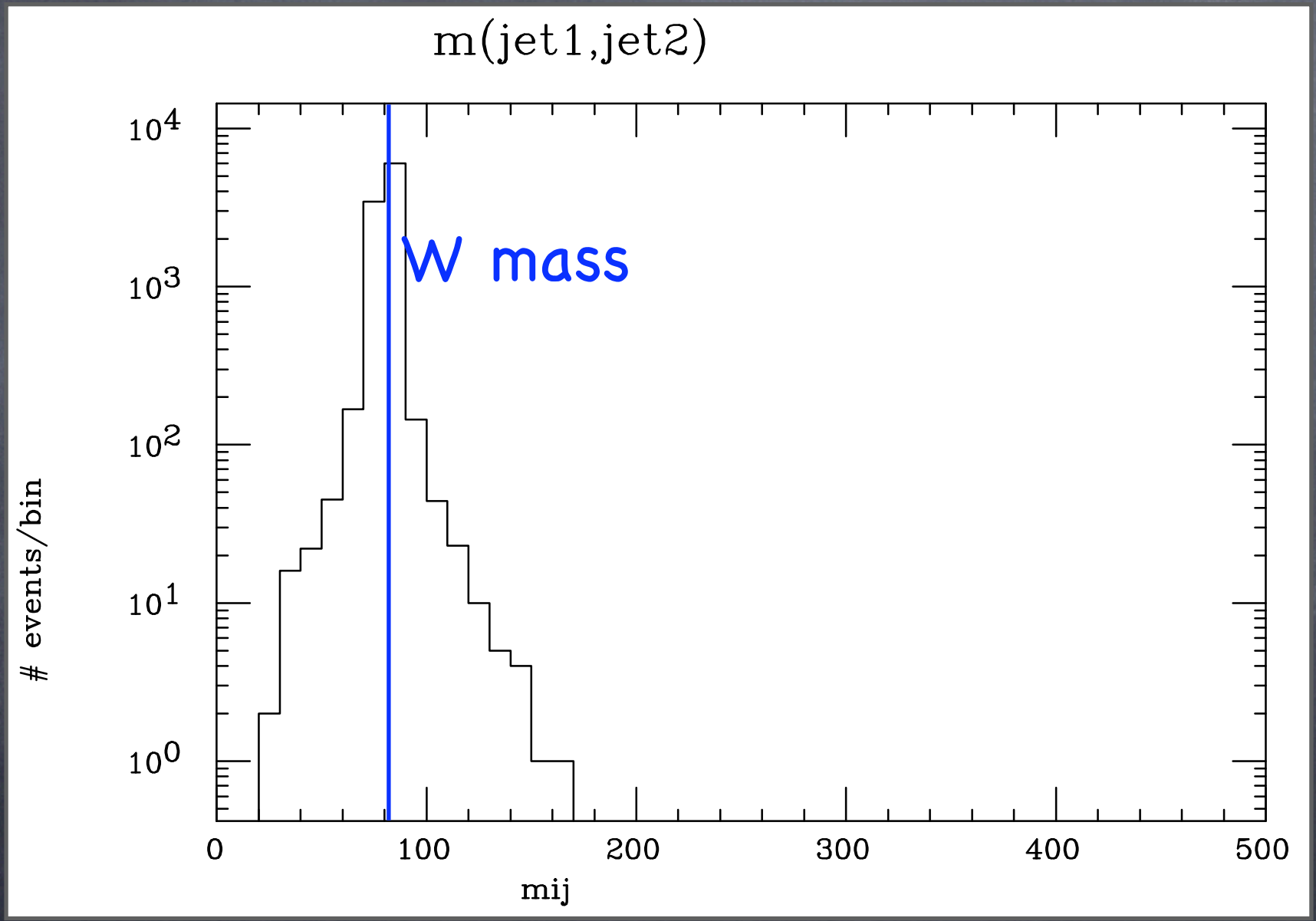
```
#*********************************************************************
# Put here your list of classes
#*********************************************************************
# Do NOT put spaces before class names!
# Begin Classes # This is TAG. Do not modify this line
jet  1 -1 2 -2 3 -3 4 -4 21   # Class number 1
b    5 -5                     # Class number 2
mu+  -13                      # Class number 3
mET  12 -12 14 -14 16 -16     # Missing ET class, name is reserved
# End Classes # This is TAG. Do not modify this line
#*********************************************************************
# Cuts on plotted events
#*********************************************************************
# Modify the cuts and remove the pounds/hashes to apply those cuts
# Do NOT put spaces at the beginning of the following lines!
# Begin Cuts # This is TAG. Do not modify this line
#etmin     2 2 40d0
#etmin     2 1 80d0
#etmin     1 3 20d0
#etmax     2 1 200d0
#ptmin     3 1 0d0
#etmissmin 20d0
#etmissmax 80d0
#etamax    1 1 1d0
#etamax    2 1 2d0
#etamin    2 2 1.5d0
#etamin    2 1 2d0
#mijmax    2 1 2 2 200d0
#mijmin    2 1 2 2 100d0
#X1min     2 1 40d0
#X1max     2 2 50d0
#dRijmin     2 1 2 2 0.7d0
#dRijmax     1 3 2 2 0.7d0
#XY1min    2 2 2 2 20d0
#XYZA2max  2 2 2 2 4 1 5 1 40d0
# End Cuts # This is TAG. Do not modify this line
```

ma_card.dat

```
#*********************************************************************
# Put here the plots that you want
#*********************************************************************
# Do NOT put spaces at the beginning of the following lines!
# Begin PlotDefs # This is TAG. Do not modify this line
pt   1 3   # plot pt for the first three particles in class 1
pt   2 2   # plot pt for the first two particles in class 2
pt   3 3   # plot pt for the first three particles in class 3
pt   4 1   # plot pt for the first particle in class 4
pt   5 1
#e    2 2
y    1 3   # plot rapidity for the first three particles in class 1
y    2 2
y    4 3
eta  2 2   # plot pseudo-rapidity for the first two particles in the second class
#mom  4 1
#costh 5 1
#phi   2 2
#delta_eta 2 2
#delta_eta 4 1
mij  1 4   # use the first four particles in the first class to plot invariant mas
s
mij  2 2   # use the first two from the second class also
#*********************************************************************
# Put here the plot ranges
#*********************************************************************
# Do NOT put spaces at the beginning of the following lines!
# Begin PlotRange # This is TAG. Do not modify this line
pt        4    0  200   # bin size, min value, max value
```

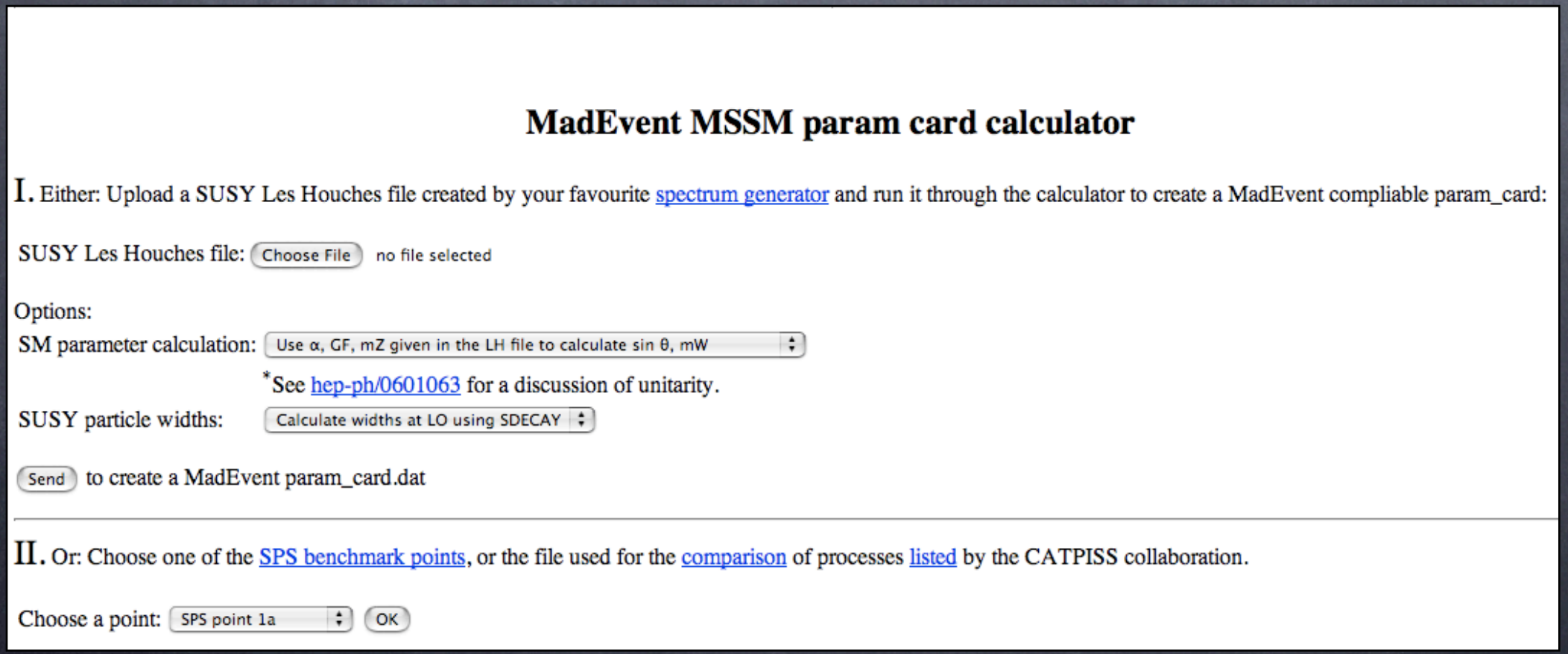
number of particles

class of particles


m(jet1,jet2)
W mass
events/bin
10^4
10^3
10^2
10^1
10^0
0
100
200
300
400
500
mij

BSM Models

Can build your own, or download cards from MadGraph -> Tools -> Calculators



MadEvent MSSM param card calculator

I. Either: Upload a SUSY Les Houches file created by your favourite spectrum generator and run it through the calculator to create a MadEvent compliable param_card:

SUSY Les Houches file: Choose File no file selected

Options:

SM parameter calculation: Use α, GF, mZ given in the LH file to calculate sin θ, mW

*See hep-ph/0601063 for a discussion of unitarity.

SUSY particle widths: Calculate widths at LO using SDECAY

Send to create a MadEvent param_card.dat

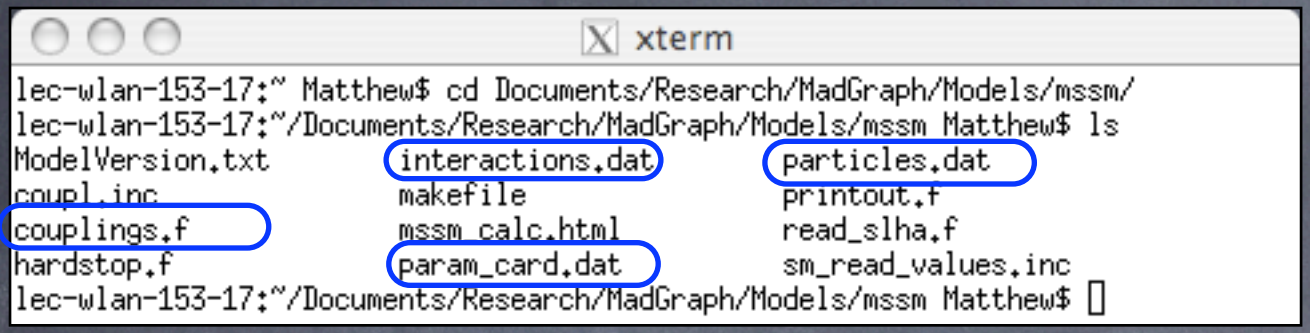
II. Or: Choose one of the SPS benchmark points, or the file used for the comparison of processes listed by the CATPISS collaboration.

Choose a point: SPS point 1a OK

To build your own:

Detailed instructions in Madgraph/Models/usrmod

Look at MSSM for examples



Remember: running ./bin/newprocess with 'mssm' selected in proc_card.dat will replace param_card.dat in working dir. with the card in /Models/mssm (default SPS 1a)

/Models/mssm/ interactions.dat

```
# FFV (qq'W) - diagonal CKM

d u w- GWF QED
s c w- GWF QED
b t w- GWF QED
u d w+ GWF QED
c s w+ GWF QED
t b w+ GWF QED

# FFV (ll'W)

ve  e-  w+ GWF QED
vm  mu- w+ GWF QED
vt  ta- w+ GWF QED
e-  ve  w- GWF QED
mu- vm  w- GWF QED
ta- vt  w- GWF QED

# FFV (gluinos)

go go g GGI QCD

# FFV (weak inos)

n1  n1  z  GZN11 QED
n1  n2  z  GZN12 QED
n1  n3  z  GZN13 QED
n1  n4  z  GZN14 QED
```

def. in couplings.f

param_card.dat (SPS 5)

```
   1000016     2.75385794E+02   # ~nu_tauL
   1000021     9.35267827E+02   # ~g
   1000022     1.60546014E+02   # ~chi_10
   1000023     3.03817792E+02   # ~chi_20
   1000025    -5.26777922E+02   # ~chi_30
   1000035     5.41860077E+02   # ~chi_40
   1000024     3.05822092E+02   # ~chi_1+
   1000037     5.39635061E+02   # ~chi_2+
#
BLOCK NMIX  # Neutralino Mixing Matrix
  1  1     9.94034047E-01   # N_11
  1  2    -2.41961542E-02   # N_12
  1  3     9.88272712E-02   # N_13
  1  4    -3.92941573E-02   # N_14
  2  1     5.07230286E-02   # N_21
  2  2     9.64386004E-01   # N_22
  2  3    -2.18097338E-01   # N_23
  2  4     1.40784803E-01   # N_24
  3  1    -4.03955574E-02   # N_31
  3  2     5.74673223E-02   # N_32
```

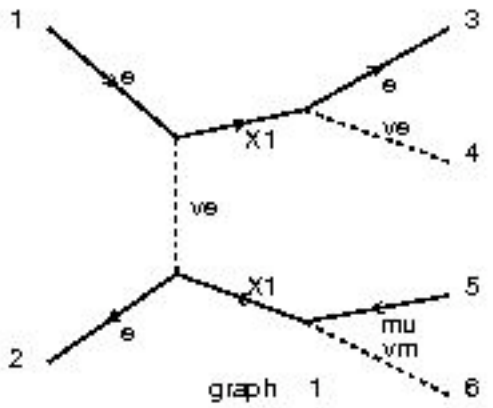
/Models/mssm/particles.dat

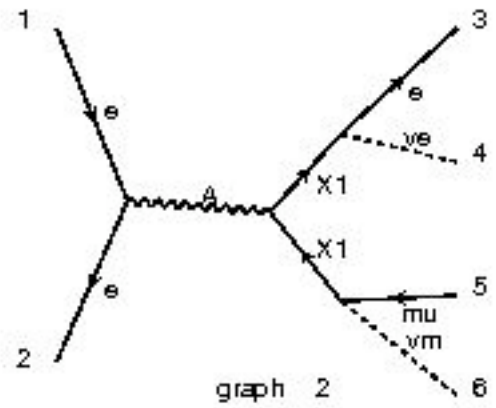
```
dl    dl~   S   D   MDL   WDL   T   dl   1000001
dr    dr~   S   D   MDR   WDR   T   dr   2000001
ul    ul~   S   D   MUL   WUL   T   ul   1000002
ur    ur~   S   D   MUR   WUR   T   ur   2000002
sl    sl~   S   D   MSL   WSL   T   sl   1000003
sr    sr~   S   D   MSR   WSR   T   sr   2000003
```

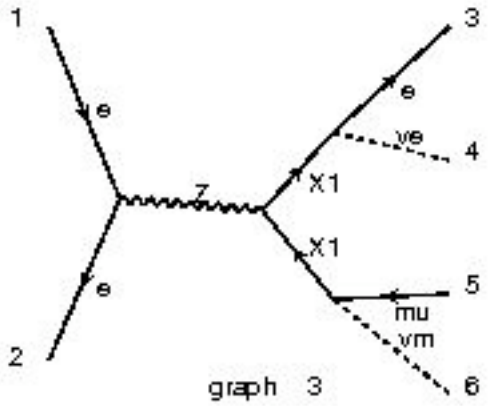
Editing pre-made Models

- Remember, there are relationships between the various parameters in param_card.dat
  - masses, yukawa couplings, neutralino mixing matrices....
  - Changing only 1 or 2 of these can make the model inconsistent.
  - Proceed with caution

Final Example

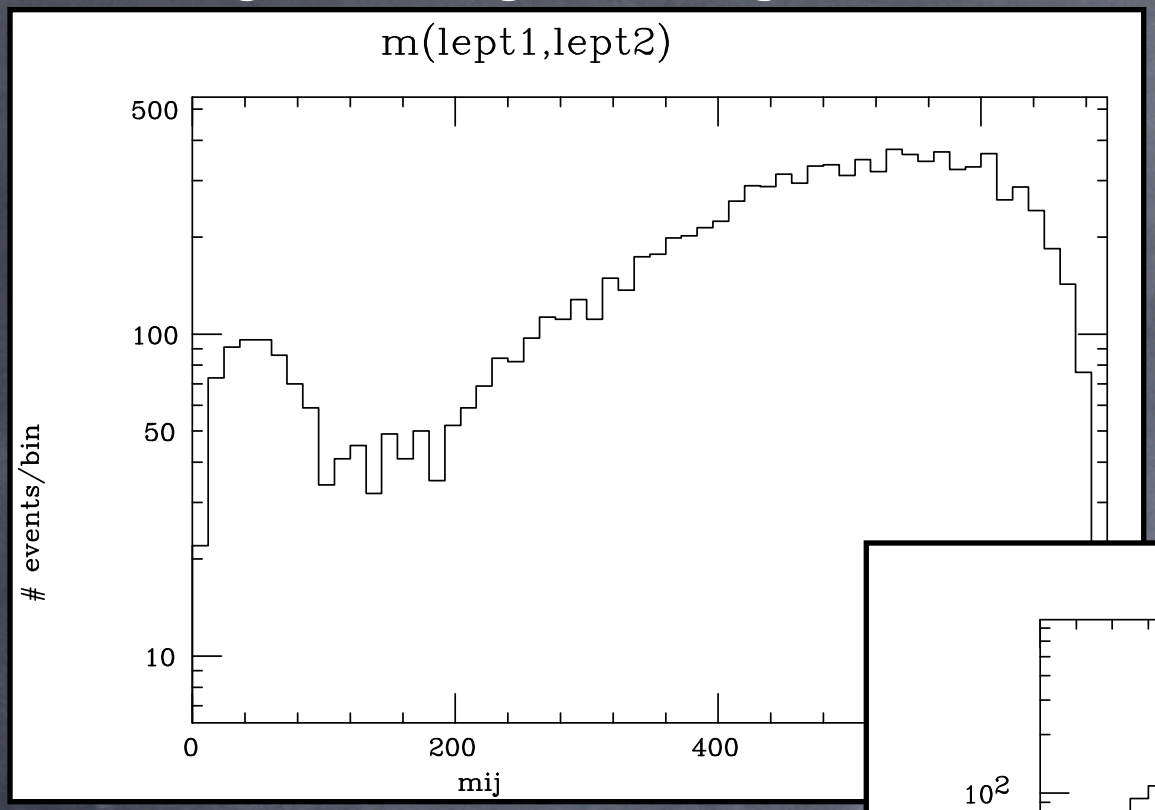




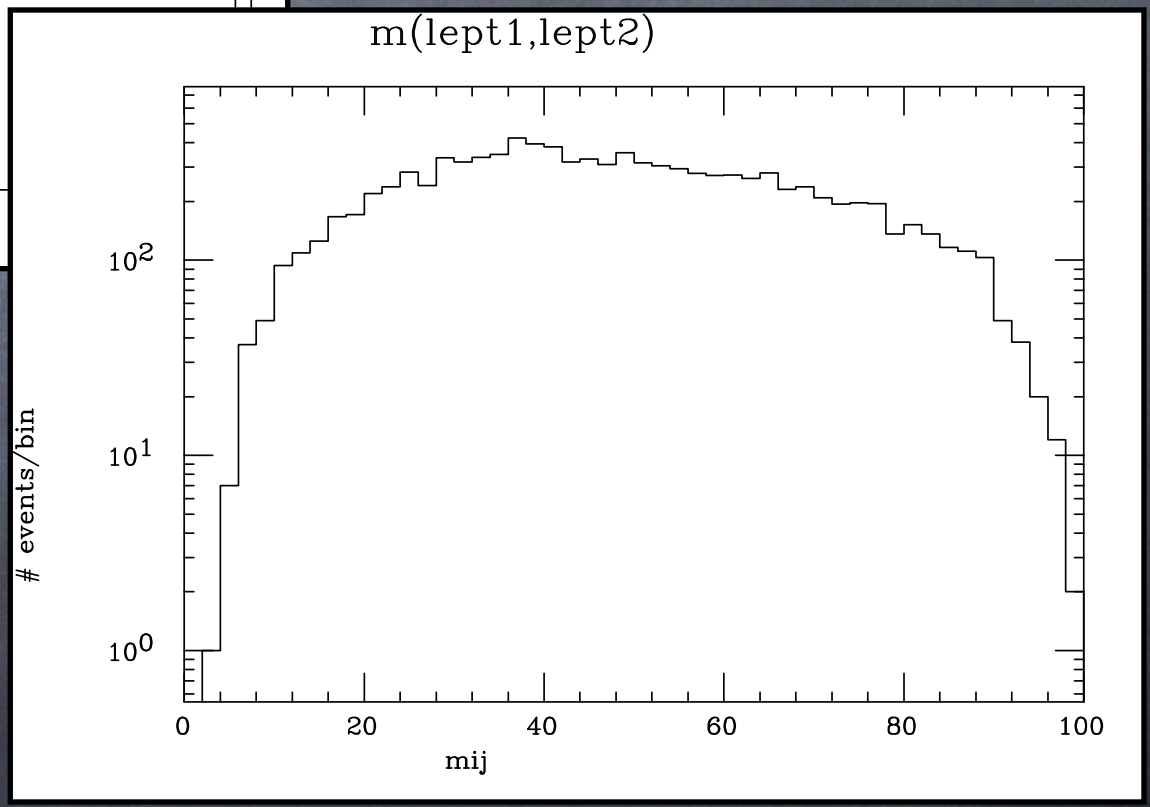



```
#*********************************************************************
# Begin PROCESS # This is TAG. Do not modify this line

e-e+>x1-x1+>e-sve~mu+svm @0       # First Process
QCD=0              # Max QCD couplings
QED=4                # Max QED couplings
end_coup             # End the couplings input

e-e+>w-w+>e-ve~mu+vm @1        # second Process
QCD=0              # Max QCD couplings
QED=4                # Max QED couplings
end_coup             # End the couplings input

done                 # this tells MG there are no more procs
```

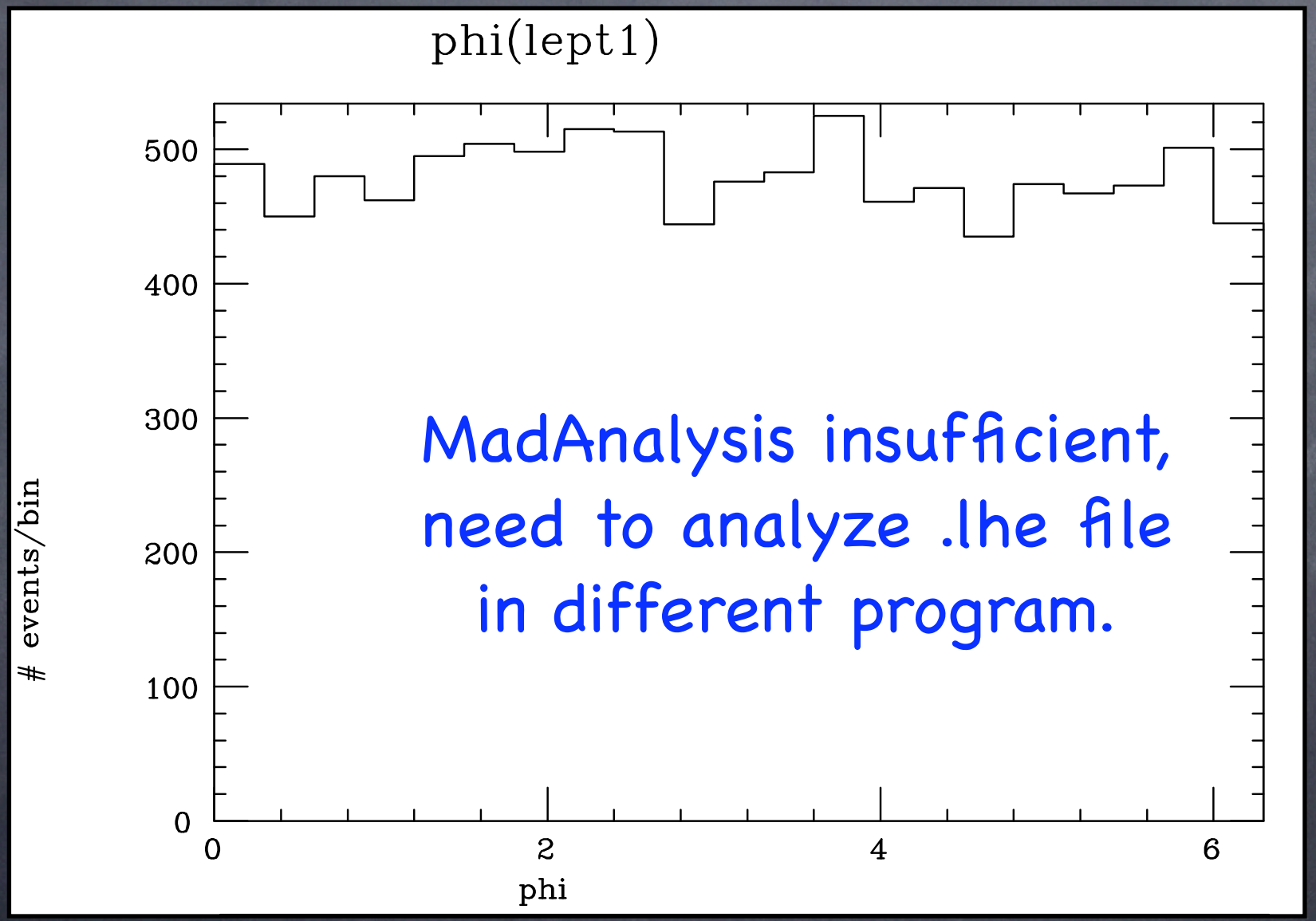
Distinguishing Background:



(700 GeV c.o.m.)

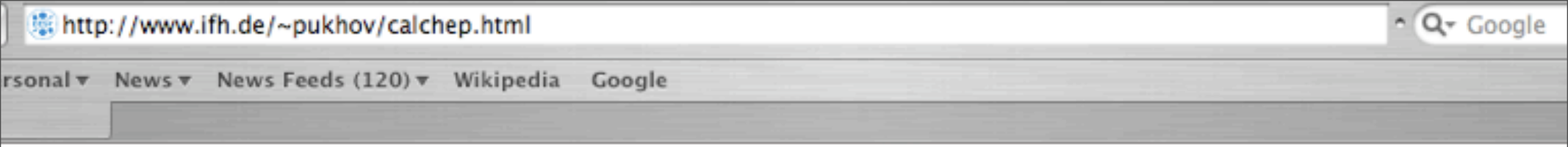


Quantity of Interest:



CalcHEP

- Doesn't calculate individual helicity/ polarizations (not gauge invariant).
  - Instead calculates sums over spins i.e. does Peskin & Schroeder 'trace technology.'
  - # of gamma matrices goes approximately like particle # squared.
- 'Easy' to enter new models, see LanHEP.
- Very fast calculations for small # of particles.
- Used as bases for MicrOmegas, very similar to CompHEP.



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

Author - Alexander Pukhov

alcHEP was to enable one to go directly from the Lagrangian to the cross sections and distributions effectively, with the high leve
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 2.4.5 (December 1 , 2006) version 2.5.j (version under development)

Models:

MSSM(04.08.2006) NMSSM CPVMSSM(04.08.2006) LeptoQuarks

Universal Extra Dimension Models: 5DSM 6DSM

Relative packages on Web:

RGE: SuSpect Isajet SoftSUSY SPheno

Particle widths in MSSM: SDECAY HDECAY

Extentions of MSSM: CPsuperH NMHDecay

Models: LanHEP and SUSY models generated by LanHEP.

Parton showers: PYTHIA

xterm

```
172:~ Matthew$ cd Documents/Research/calchep_2.4.5/
172:~/Documents/Research/calchep_2.4.5 Matthew$ ls
100                             getFlags
CITE                            help
CMessage                        icon
FlagsForMake                    include
FlagsForSh                      launch__n_calchep
INSTALLATION                    ld_n
License.txt                     make__n_calchep
MSSM                            mkUsrDir
MUED                            models
MUED-for-CalcHEP                n_compile
Makefile                        n_calchep.o
SM                              num_c.a
alpha_s.o                       pdfWare
bin                             serv.a
c_source                        setPath
calchep                         sqme_aux.o
calchep.ini                     symb.a
calchep_manual_2.3.5.pdf        utile
dummy.a
172:~/Documents/Research/calchep_2.4.5 Matthew$
```

Run this to set up new working dir.

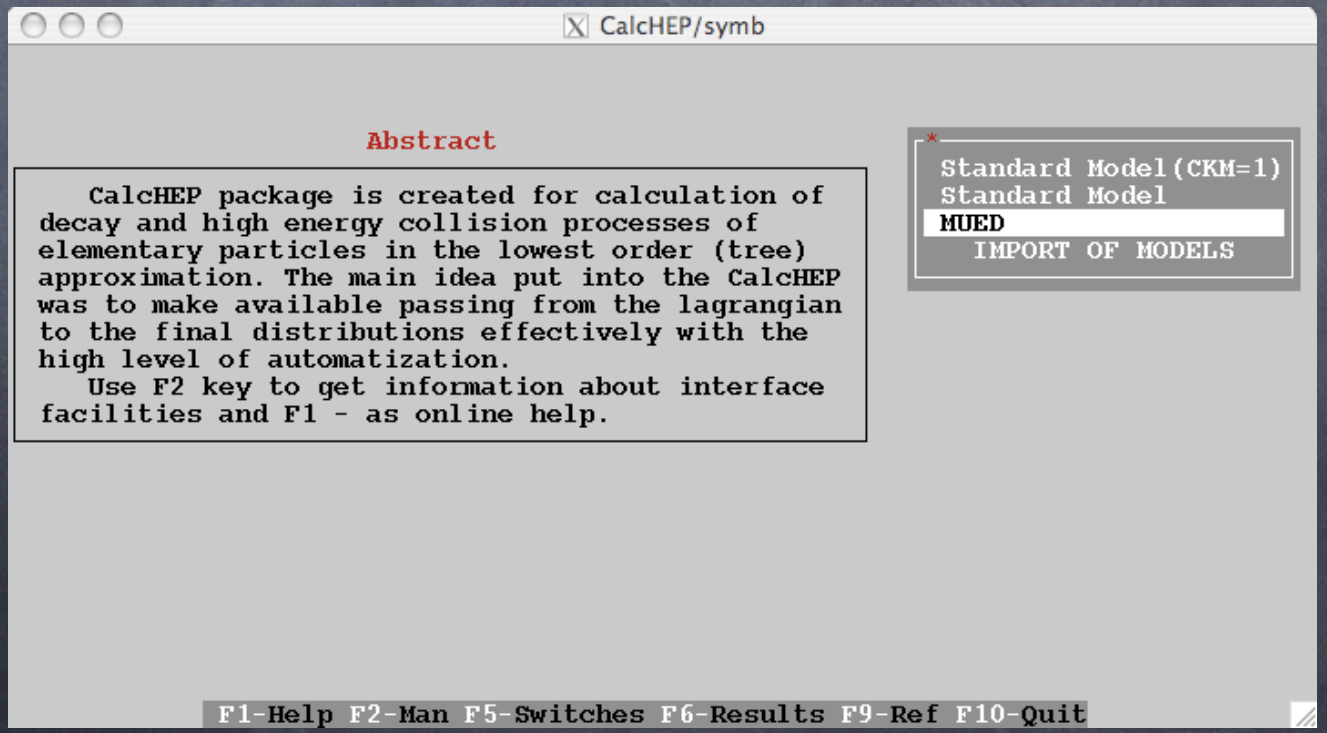
```
172:~/Documents/Research/calchep_2.4.5 Matthew$ cd 233/
172:~/Documents/Research/calchep_2.4.5/233 Matthew$ ls
bin             calchep.ini     results
calchep         models          tmp
172:~/Documents/Research/calchep_2.4.5/233 Matthew$ cd models/
172:~/Documents/Research/calchep_2.4.5/233/models Matthew$ ls
extlib1.mdl     func1.mdl       lgrng1.mdl      prtcls1.mdl     vars1.mdl
extlib2.mdl     func2.mdl       lgrng2.mdl      prtcls2.mdl     vars2.mdl
172:~/Documents/Research/calchep_2.4.5/233/models Matthew$ open lgrng1.mdl
172:~/Documents/Research/calchep_2.4.5/233/models Matthew$
```

```
Standard Model(CKM=1)
 Vertices
A1   |A2   |A3   |A4   |>          Factor              <|>  Lorentz part
G    |G    |G    |     |GG                               |m1.m2*(p1-p2).m3+m2.m3*(p2-p3).m1+m3.m1*(p3-p1).m2
G    |G    |G.t  |     |GG/Sqrt2                         |m1.M3*m2.m3-m1.m3*m2.M3
W+   |W-   |A    |     |-EE                              |m1.m2*(p1-p2).m3+m2.m3*(p2-p3).m1+m3.m1*(p3-p1).m2
W+   |W-   |Z    |     |-EE*CW/SW                        |m1.m2*(p1-p2).m3+m2.m3*(p2-p3).m1+m3.m1*(p3-p1).m2
E    |e    |A    |     |-EE                              |G(m3)
M    |m    |A    |     |-EE                              |G(m3)
```

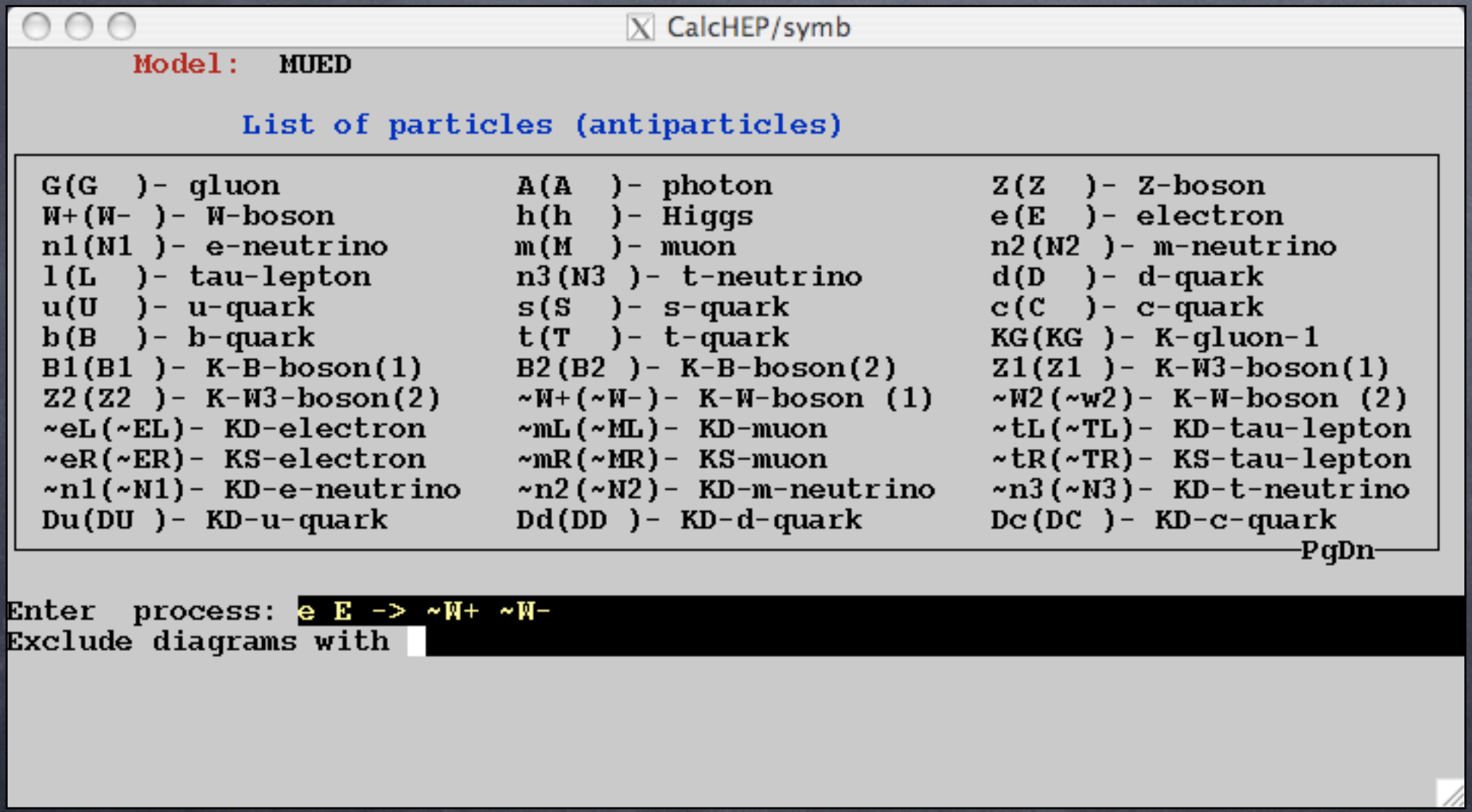
Let's use a predefined model: MUED (from Pukhov website)

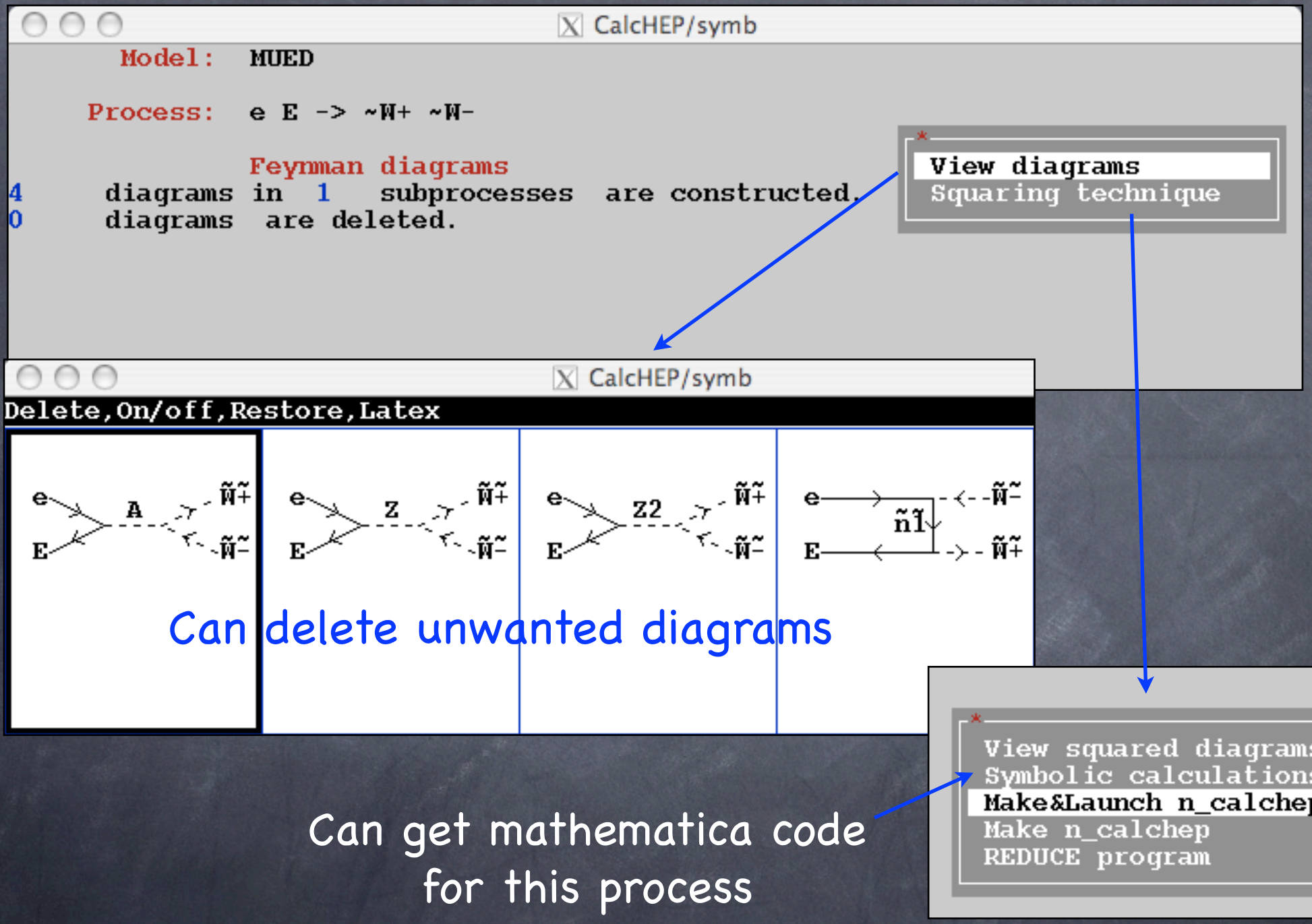
K-gluon-1	KG	KG	1000021	2	MKG	wKG	8		g^1	g^1
K-B-boson(1)	B1	B1	1000022	2	MB1	0	1		B^1	B^1
K-B-boson(2)	B2	B2	3000022	2	MB2	wB2	1		B^2	B^2
K-W3-boson(1)	Z1	Z1	1000023	2	MZ1	wZ1	1		W^1_3	W^1_3
K-W3-boson(2)	Z2	Z2	2000023	2	MZ2	wZ2	1		W^2_3	W^2_3
K-W-boson (1)	~W+	~W-	1000024	2	MW1	wW1	1		W^{1+}	W^{1-}
K-W-boson (2)	~W2	~w2	2000024	2	MW2	wW2	1		W^{2+}	W^{2-}
KD-electron	~eL	~EL	1000011	1	DMe	wDe1	1		E_1^1	\bar{E}^1_1
KD-muon	~mL	~ML	1000013	1	DMm	wDe2	1		E_2^1	\bar{E}^1_2

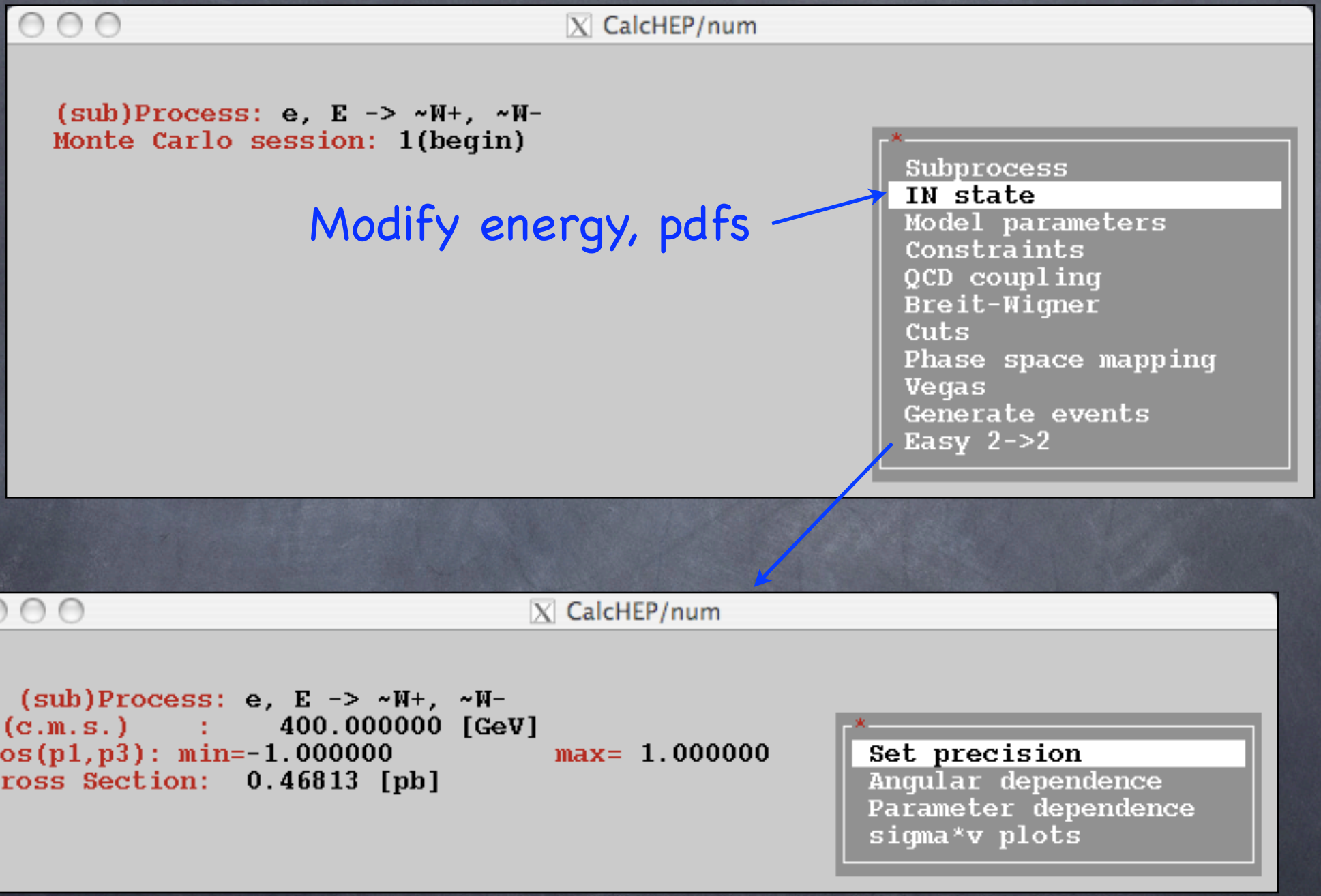
To use, run ./calchep from model's working dir.



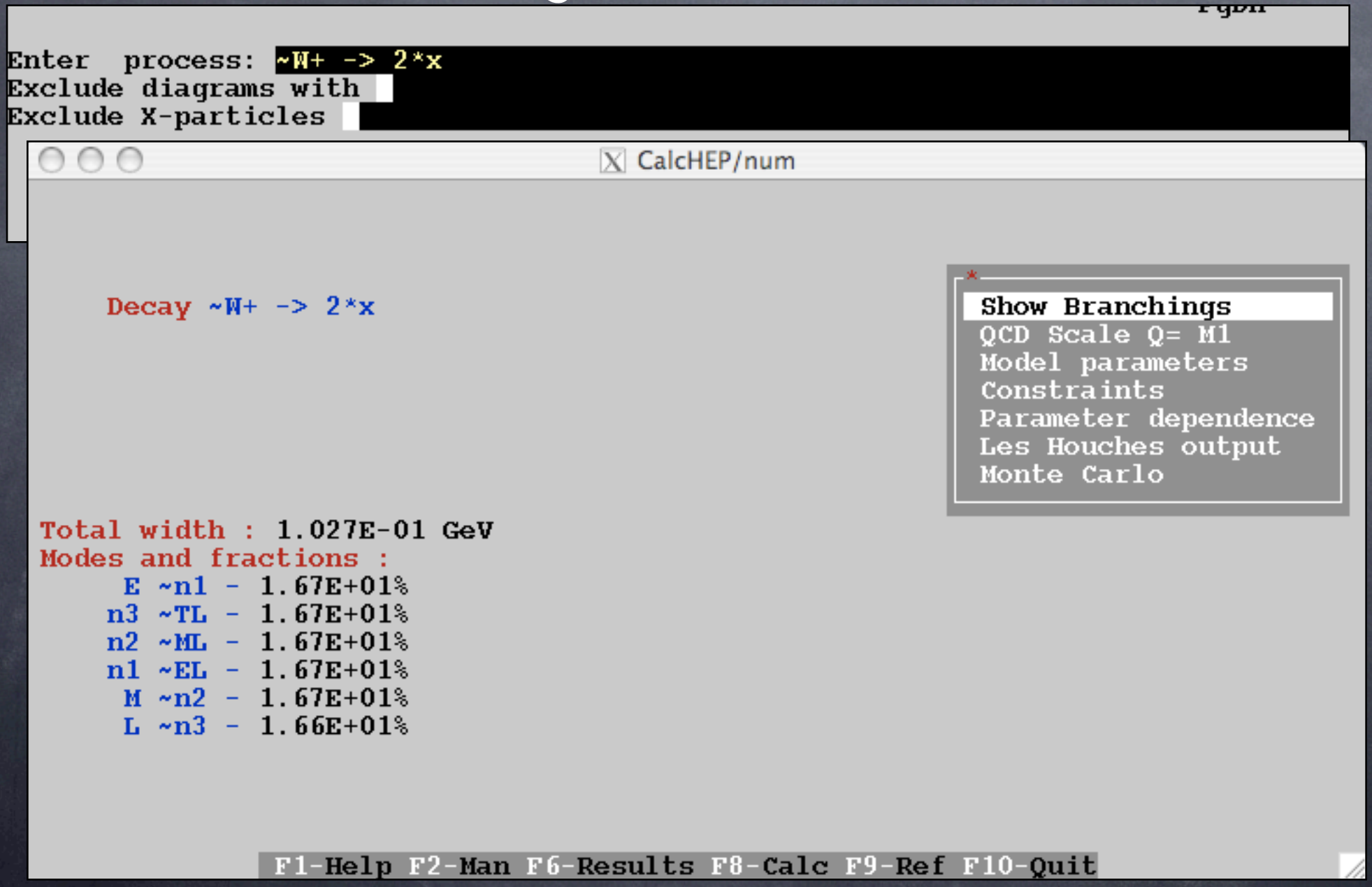
Can edit model parameters, let's skip that and enter a process (from the next window)




CalcHEP/symb
Model: MUED
Process: e E -> ~W+ ~W-
Feynman diagrams
4 diagrams in 1 subprocesses are constructed.
0 diagrams are deleted.
View diagrams
Squaring technique
CalcHEP/symb
Delete,On/off,Restore,Latex
e
E
A
Z
Z2
ñ1
~W+
~W-
Can delete unwanted diagrams
View squared diagrams
Symbolic calculations
Make&Launch n_calchep
Make n_calchep
REDUCE program
Can get mathematica code
for this process


CalcHEP/num
(sub)Process: e, E -> ~W+, ~W-
Monte Carlo session: 1(begin)
Modify energy, pdfs
Subprocess
IN state
Model parameters
Constraints
QCD coupling
Breit-Wigner
Cuts
Phase space mapping
Vegas
Generate events
Easy 2->2
CalcHEP/num
(sub)Process: e, E -> ~W+, ~W-
P(c.m.s.) : 400.000000 [GeV]
Cos(p1,p3): min=-1.000000 max= 1.000000
Cross Section: 0.46813 [pb]
Set precision
Angular dependence
Parameter dependence
sigma*v plots

What else can you do?
widths and branching ratios:



Can't specify intermediate states:

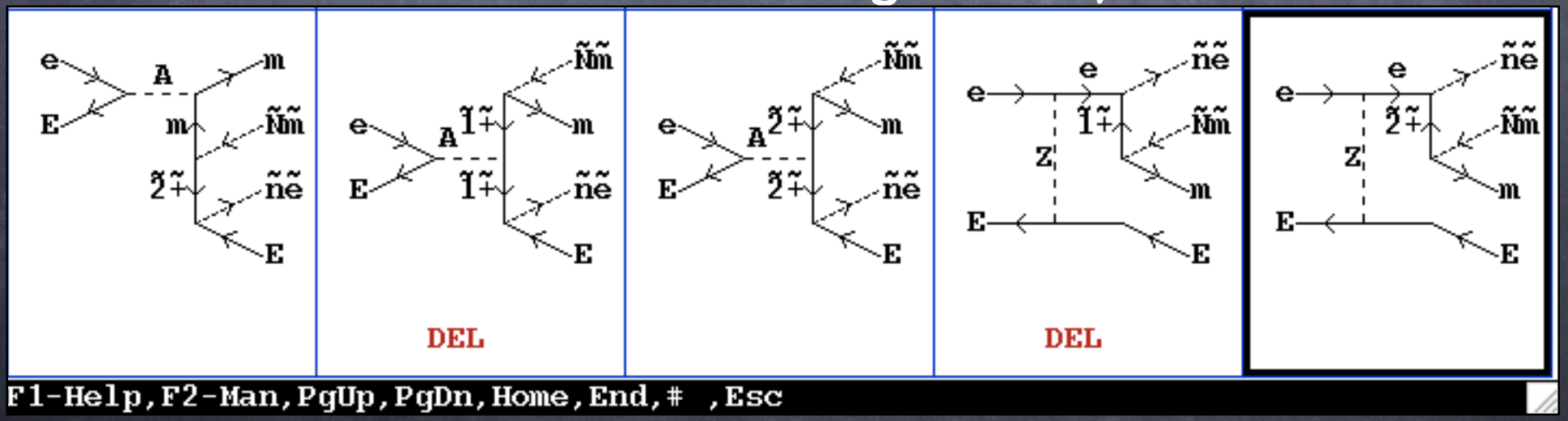
(using MSSM model from Pukhov site)

```
Enter  process: e E -> ~1+ ~1- -> E ~ne m ~Nm
composit '->'  consists of:
```

Can exclude specific particles from appearing:

```
Enter  process: e E -> E ~ne m ~Nm
Exclude diagrams with ~2+,~2-
```

or just delete unwanted diagrams by hand:



Even with just a few diagrams, 4-body states still take a long time to run

Summary

- Two tools for calculating tree-level cross-sections
  - Madgraph:
    - Can perform many-body final state calculations in a reasonable amount of time.
    - Several plotting options for data; outputs results in Les Houches file format.

Summary

- CalcHEP
  - Very quick for 2-2 production or width calculations.
  - Calculation time grows prohibitively long for >2 final states.
  - Straightforward to enter new models, CalcHEP and related CompHEP used as core for several other programs.

Summary

- Showering/Hadronization
  - MadGraph/CalcHEP both work at parton-level.
  - Can 'wrap' Pythia on the output of MadGraph.
  - Getting this right a non-trivial problem, many people working on better approaches.