

MadGraph and CalcHEP

10/5/07

233B

Matthew Buckley

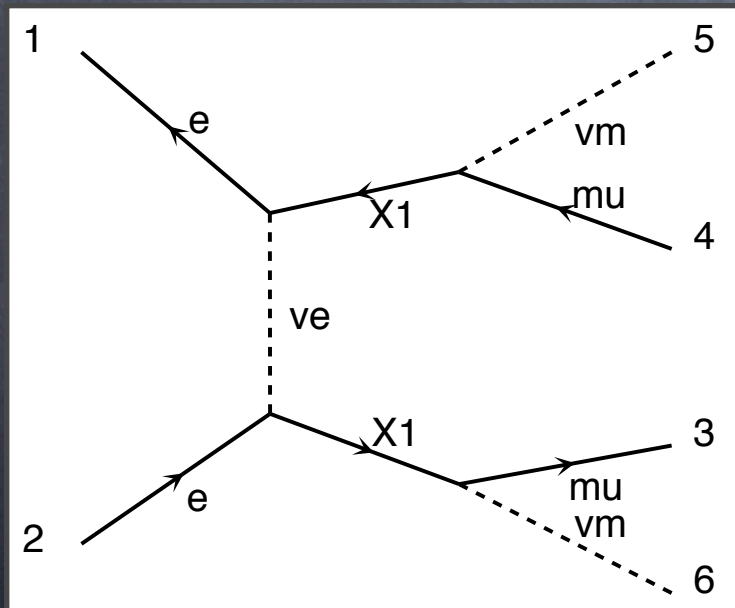
Overview

- 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 † 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 , SWIN01)
    CALL IXXXXX(P2,M2,NW2,-1 , SWIN02)
    CALL IOVXXX(SWIN02,SWIN01,J3,G3 , PRODUCTION1)

    CALL HIOXXX(EM,SWIN01,GL,M1,0, NU1)
    CALL IOSXXX(SWIN02,EP,NU1,GR, PRODUCTION2)

    CALL IXXXXX(P1,M2,NW1,+1 , SWIN01)
    CALL OXXXXX(P2,M2,NW2,-1 , SWIN02)
    CALL IOSXXX(SWIN01,MUM,CMISS1,GR , DECAY1)
    CALL IOSXXX(MUP,SWIN02,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.

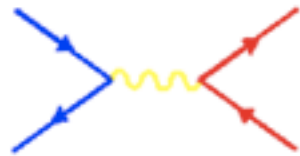
$$|\mathcal{M}|^2 = \sum_i w_i |\mathcal{M}_i|^2, \quad \sum_i w_i = 1$$

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



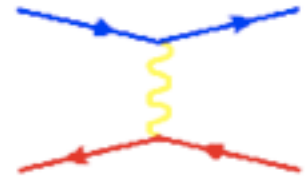
This material is based upon work supported by the National Science Foundation under Grant No. 0426272.

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](#)



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I. Fill the form:

Model: [Particle names](#)

Input Process: [Examples](#)

Max QCD Order:

Max QED Order:

p and j definitions:

sum over leptons:

We'll use an offline version of this

II. Upload the proc_card.dat

[Process card examples](#)

no file selected and it to the server.

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

no file selected and it to the server.

```
xterm
lec-wlan-153-244:~ Matthew$ cd Documents/Research/MadGraph/
lec-wlan-153-244:~/Documents/Research/MadGraph Matthew$ ls
DECAY          DecayPlanes   NoMix
DPSMBack       HELAS         README
DPSUSYBack     MGMEVersion.txt Template
DPSignal       MadGraphII    TopTest
DPSignal1      Manual-March-2007.pdf UpdateNotes.txt
DPUEDFake      Models        makefile
lec-wlan-153-244:~/Documents/Research/MadGraph Matthew$ ls Models/
2hdm          heft          s_2hdm_heft   sm_nohiggs
2hdm_full     mssm          scalar_gluon  sm_tom
PDF           mued          sm             smckm
abelian_qcd   s_2hdm        sm_flavor     usrmod
lec-wlan-153-244:~/Documents/Research/MadGraph Matthew$
```

Step 1: Create new working directory

```
xterm
DPSMBack       HELAS         README
DPSUSYBack     MGMEVersion.txt Template
DPSignal       MadGraphII    TopTest
DPSignal1      Manual-March-2007.pdf UpdateNotes.txt
DPUEDFake      Models        makefile
lec-wlan-153-244:~/Documents/Research/MadGraph Matthew$ ls Models/
2hdm          heft          s_2hdm_heft   sm_nohiggs
2hdm_full     mssm          scalar_gluon  sm_tom
PDF           mued          sm             smckm
abelian_qcd   s_2hdm        sm_flavor     usrmod
lec-wlan-153-244:~/Documents/Research/MadGraph Matthew$ cp -R Template 233i
lec-wlan-153-244:~/Documents/Research/MadGraph Matthew$ ls 233i/
Cards          Source        lib
Events         SubProcesses  makefile
HTML           TemplateVersion.txt
README         bin
lec-wlan-153-244:~/Documents/Research/MadGraph Matthew$ ls 233i/Cards/
README          pgs_card_LHC.dat   pythia_card.dat
param_card.dat  pgs_card_TEV.dat  pythia_card_default.dat
param_card_default.dat pgs_card_default.dat run_card.dat
pgs_card.dat    plot_card.dat      run_card_default.dat
pgs_card_ATLAS.dat plot_card_default.dat
pgs_card_CMS.dat proc_card.dat
lec-wlan-153-244:~/Documents/Research/MadGraph Matthew$
```

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/ montecarlohpp.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

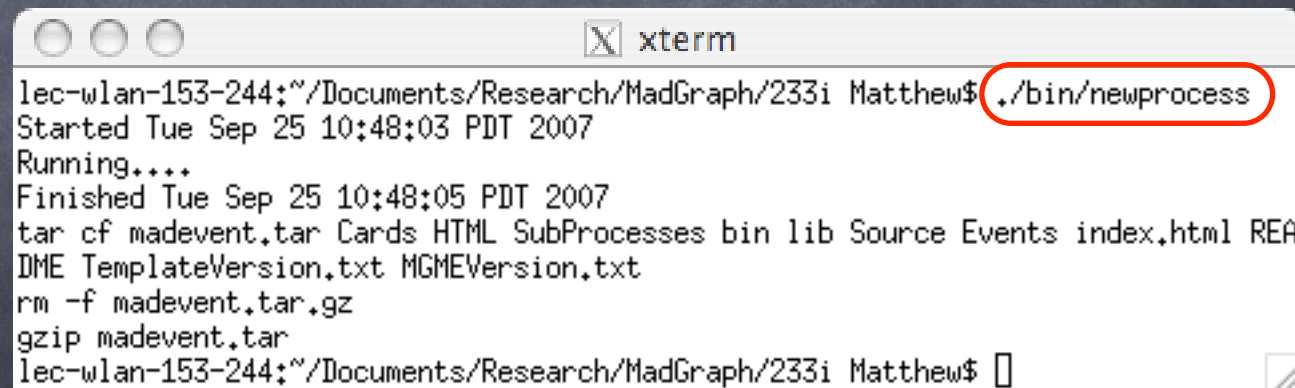
#
# Leptons
#
e- e+ F S ZERO ZERO S e 11
mu- mu+ F S ZERO ZERO S mu 13
ta- ta+ F S LMASS ZERO S ta 15
ve ve~ F S ZERO ZERO S ve 12
vm vm~ F S ZERO ZERO S vm 14
vt vt~ F S ZERO ZERO S vt 16

#
```

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



```
lec-wlan-153-244:~/Documents/Research/MadGraph/233i Matthew$ ./bin/newprocess  
Started Tue Sep 25 10:48:03 PDT 2007  
Running....  
Finished Tue Sep 25 10:48:05 PDT 2007  
tar cf madevent.tar Cards HTML SubProcesses bin lib Source Events index.html REA  
DME TemplateVersion.txt MGMEVersion.txt  
rm -f madevent.tar.gz  
gzip madevent.tar  
lec-wlan-153-244:~/Documents/Research/MadGraph/233i Matthew$ []
```

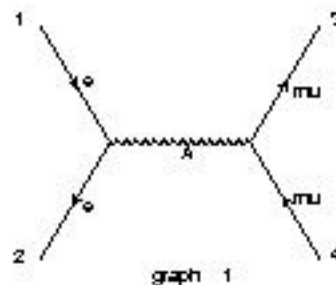
Step 4: Check our results

```
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

[Process Information](#)

[Code Download](#)

[On-line Event Generation](#)

[Results and Event Database](#)

Status

Generation Complete

Available

[Only available from the web](#)

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.

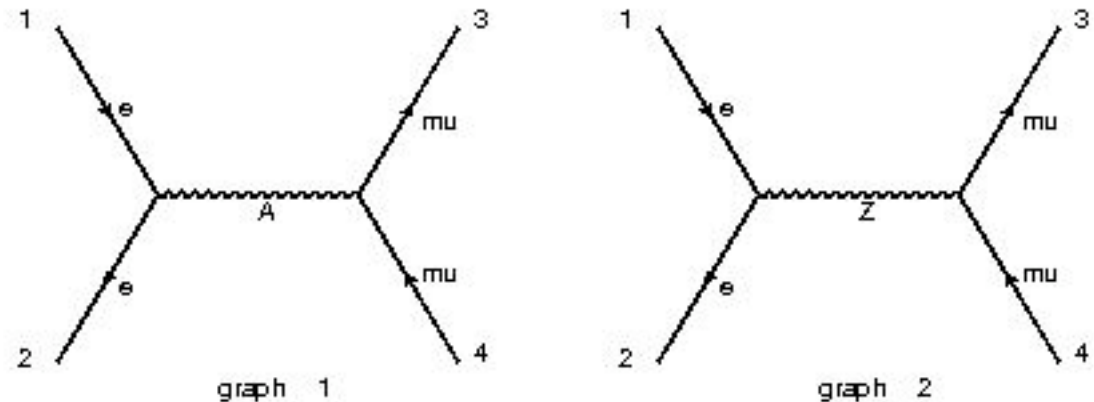
[particles.dat](#) Particles file used for code generation.

[interactions.dat](#) Interactions file used for code generation.

[Main Page](#)

[Postscript Diagrams](#)

Diagrams by MadGraph e- e+ -> mu- mu+



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

Want electrons at
say 100 GeV

```
#####  
# 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

```
#####  
# 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

```
lec-wlan-153-244:~/Documents/Research/MadGraph/233i Matthew$ ./bin/generate_events
Enter 1 for parallel 0 for serial run
0
Enter run name
Run1
```

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	ee 100 x 100 GeV	.27830E+01	9965

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Available Results

Links	Events	Tag	Run	Collider	Cross section (pb)	Events
results banner	Parton-level LHE	fermi	Run1	ee 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

$\sigma = 2783.200 \pm 4.402(\text{fb})$

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+](#)

$\sigma = 2783.190 \pm 4.403(\text{fb})$

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

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

```

*****
# 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 couplings
end_coup # End the couplings

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			
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-vmxsc	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-vmxsc	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-vmxsc	3	1	html	postscript	g g -> b b~ mu- vm~ s~ c			

MadAnalysis

[Generate Process](#) [Register](#) [Tools](#) [My Database](#) [Cluster Status](#) [Documents](#) [News](#) [Do...](#) (needs ...)

Plotting Interface (MadAnalysis)

LHE or LHCO event file (must be zipped!):

ma_card file :

Remark: if no ma_card file is given, this [default one](#) is used.

select unweighted events .lhe from working dir/Events/

Download and modify the ma_card.dat file

ma_card.dat

particle class
definitions

```
#####
# 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/hashs 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
```

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

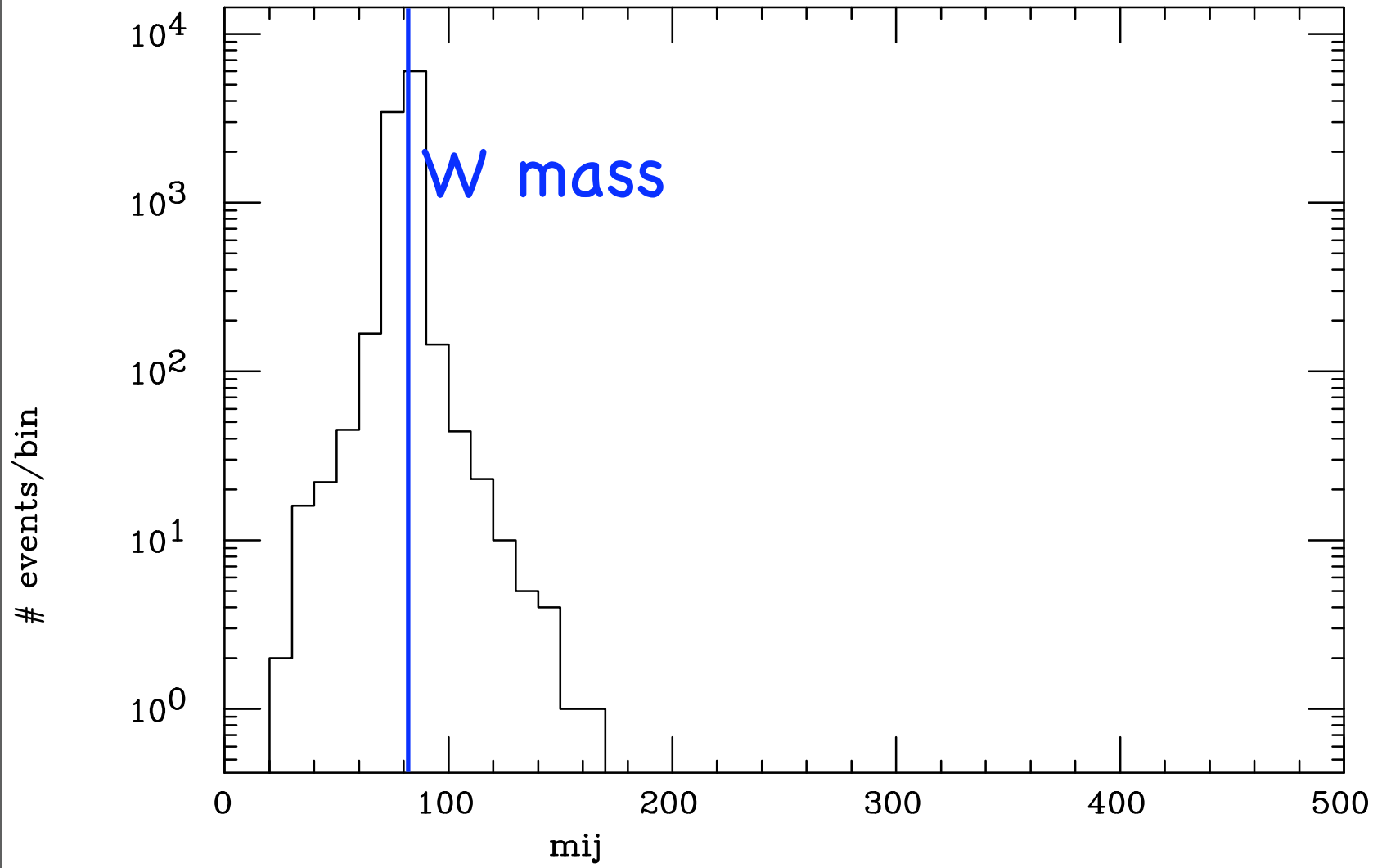
ma_card.dat

```
#####
# 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

$m(\text{jet1}, \text{jet2})$



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 compliant param_card:

SUSY Les Houches file: no file selected

Options:

SM parameter calculation:

*See [hep-ph/0601063](#) for a discussion of unitarity.

SUSY particle widths:

to create a MadEvent param_card.dat

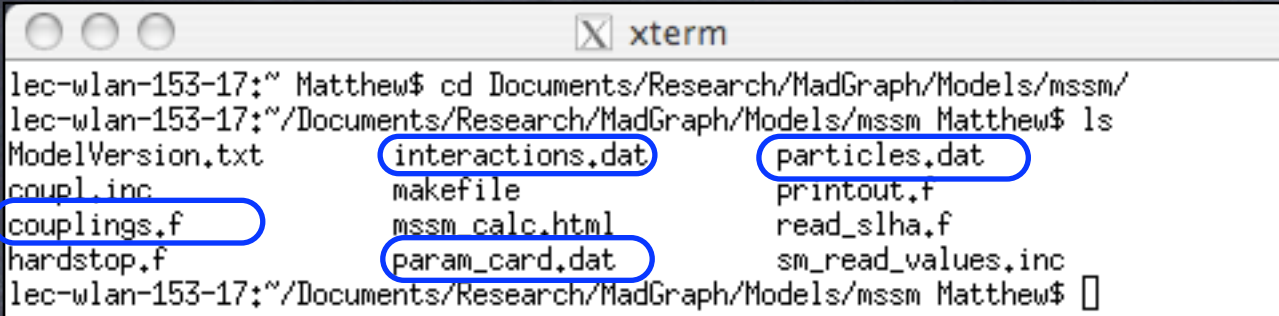
II. Or: Choose one of the [SPS benchmark points](#), or the file used for the [comparison](#) of processes [listed](#) by the CATPISS collaboration.

Choose a point:

To build your own:

Detailed instructions in Madgraph/Models/usrmod

Look at MSSM for examples



```
lec-wlan-153-17:~ Matthew$ cd Documents/Research/MadGraph/Models/mssm/
lec-wlan-153-17:~/Documents/Research/MadGraph/Models/mssm Matthew$ ls
ModelVersion.txt      interactions.dat      particles.dat
coupl.inc             makefile            printout.f
couplings.f           mssm_calc.html     read_slha.f
hardstop.f           param_card.dat      sm_read_values.inc
lec-wlan-153-17:~/Documents/Research/MadGraph/Models/mssm Matthew$
```

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
```

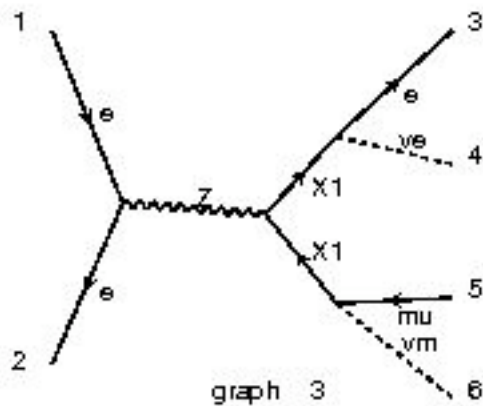
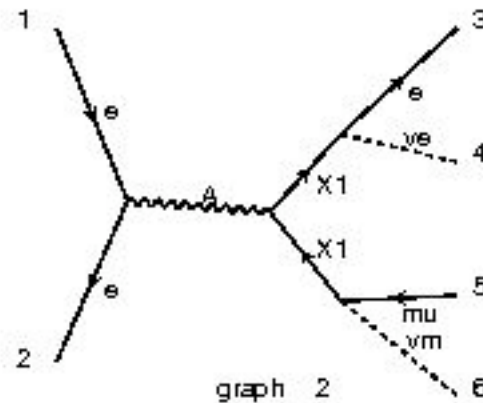
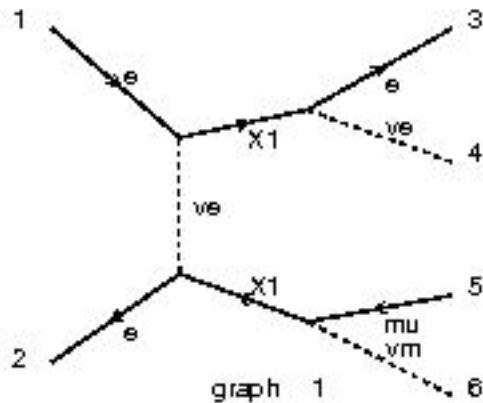
/Models/mssm/particles.dat

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

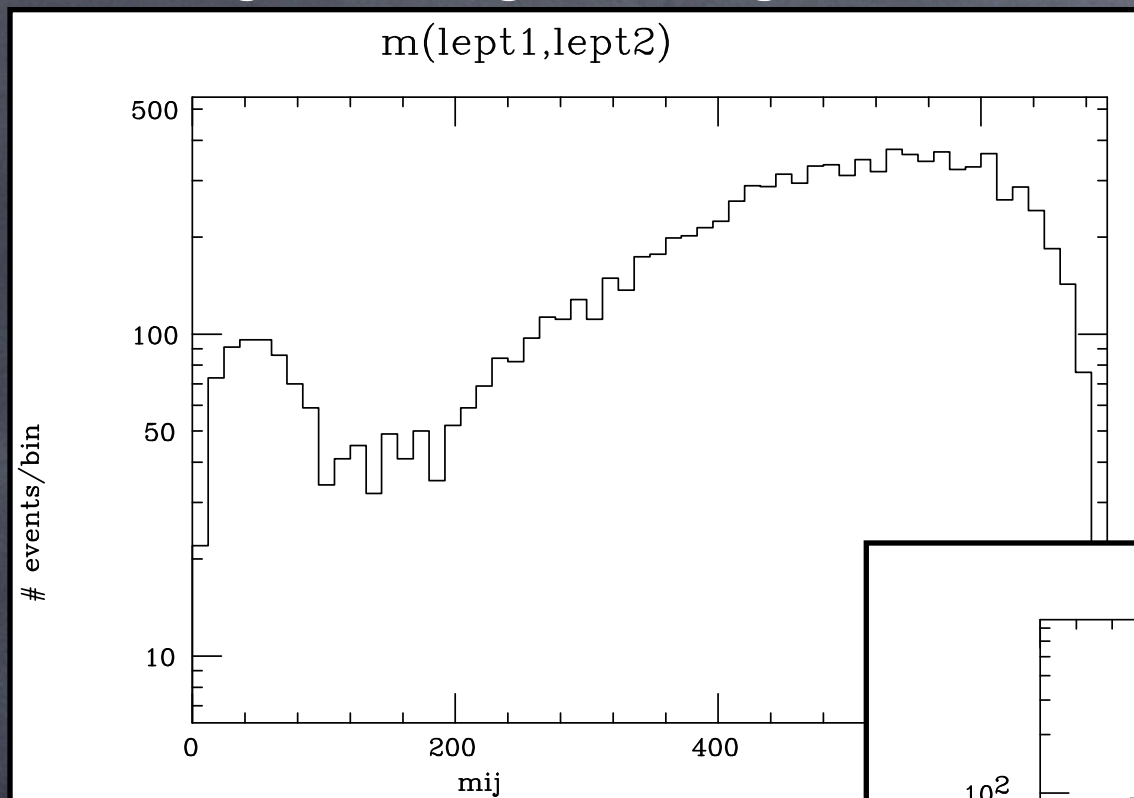
e-e->x1-x1->e-sve~mu+svm @0      # First Process
QCD=0                            # Max QCD couplings
QED=4                             # Max QED couplings
end_coup                          # End the couplings input

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

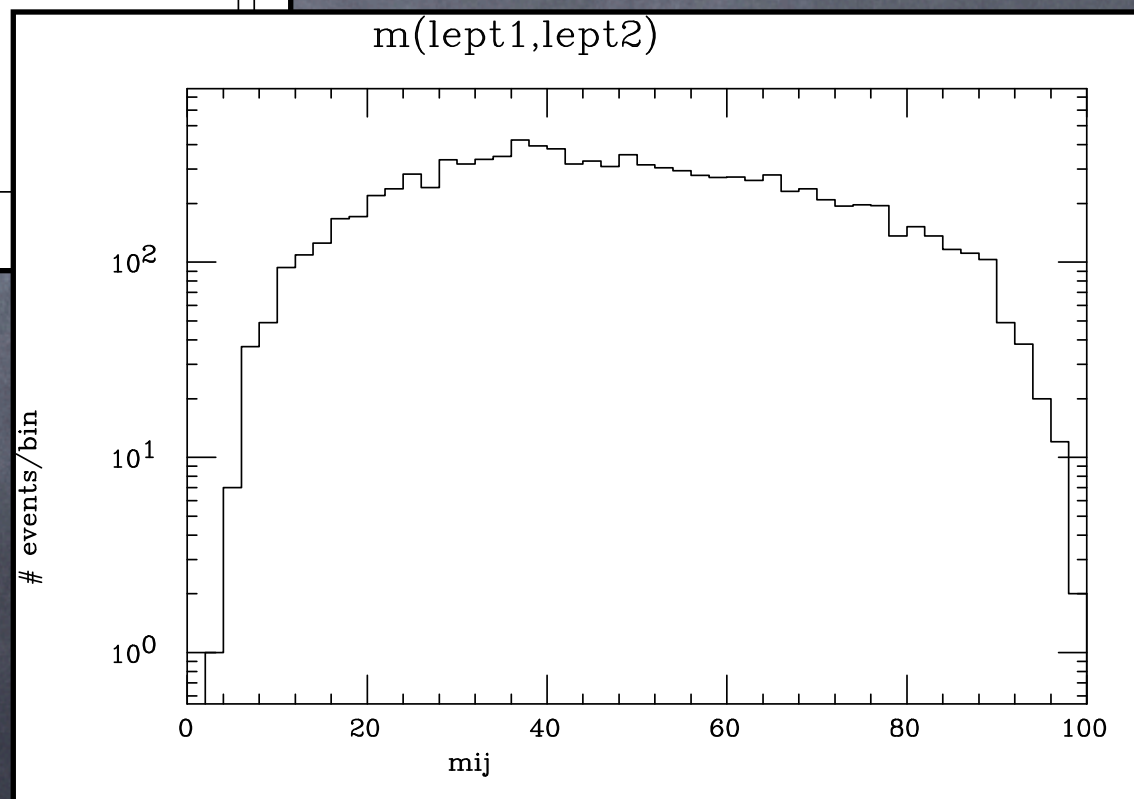
done                               # this tells MG there are no more procs

```

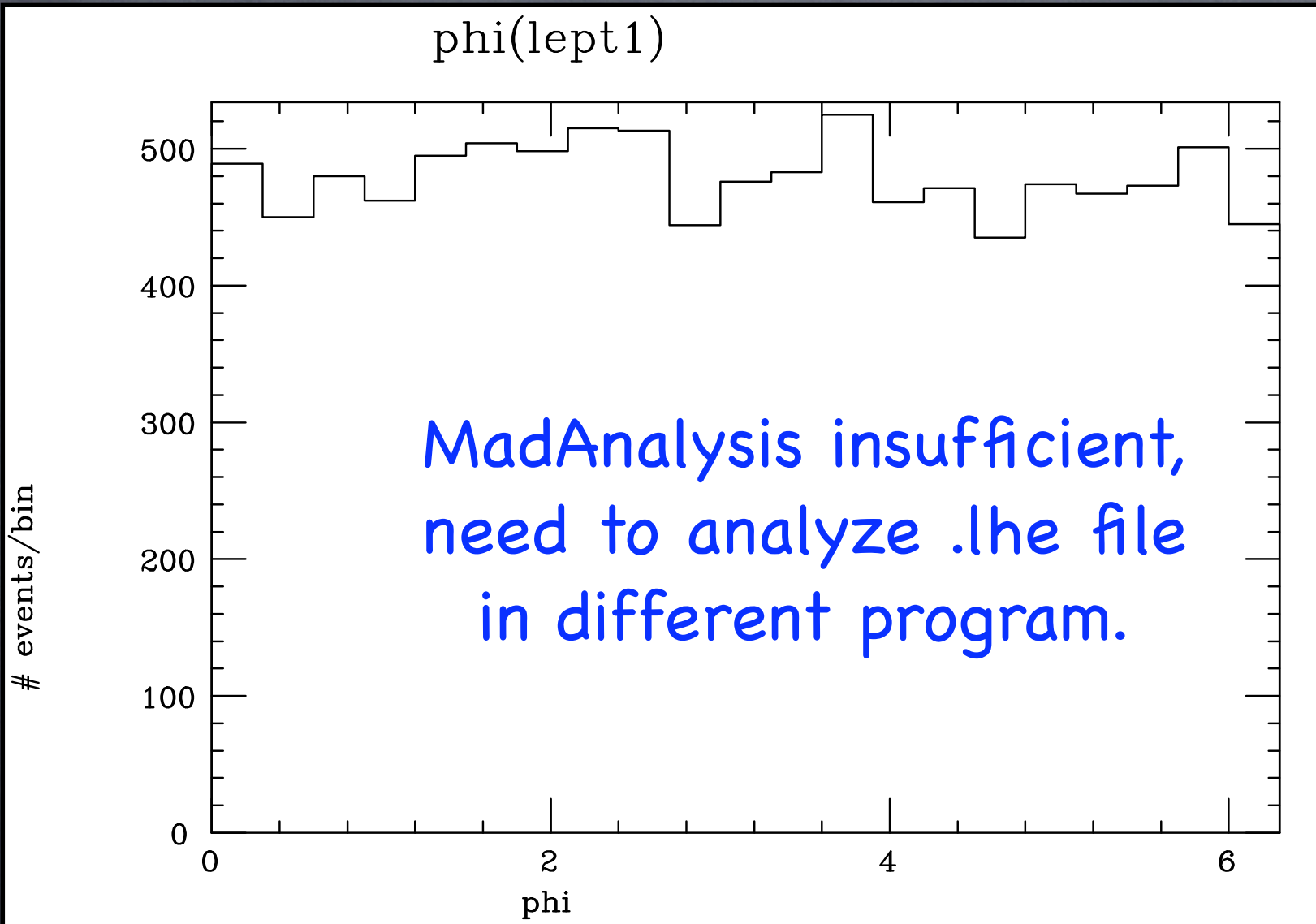
Distinguishing Background:



(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.

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

Author - Alexander Pukhov

CalHEP was to enable one to go directly from the Lagrangian to the cross sections and distributions effectively, with the high level 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](#) (Cambridge University Press)

Codes download.

- [Licence](#)
- [Installation](#)
- [References&Contributions](#)

CalHEP 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](#)

Extensions 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_comp
Makefile            n_calchep.o
SM                  num_c.a
alpha_s.o           n_calchep.o
bin                 serv.a
c_source            setPath
calchep             sqm_aux.o
calchep.ini         symb.a
calchep_manual_2.3.5.pdf
dummy.a            utile
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$

```

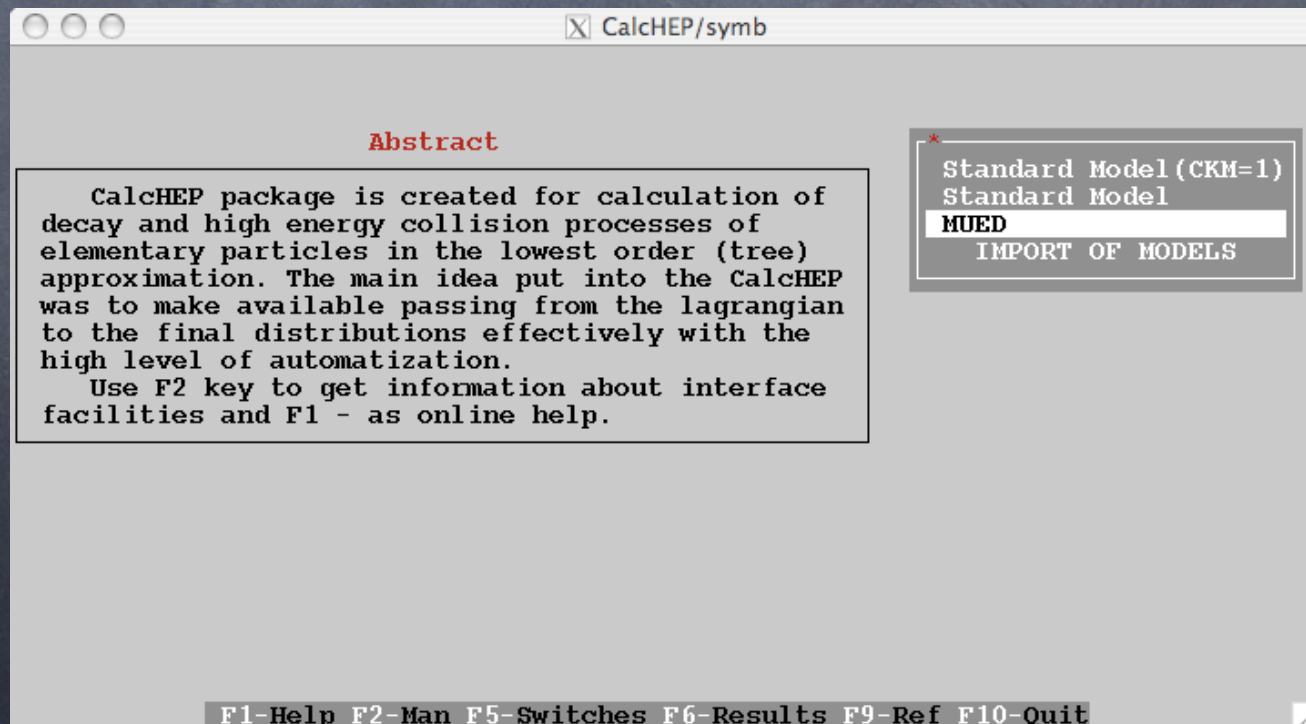
Standard Model(CKM=1)

Vertices					Factor	<l> Lorentz part
A1	IA2	IA3	IA4	>	IGG	$ m1.m2*(p1-p2).m3+m2.m3*(p2-p3).m1+m3.m1*(p3-p1).m2$
G	IG	IG.t		IGG/Sqrt2		$ m1.M3*m2.m3-m1.m3*m2.M3$
W+	IW-	IA		I-EE		$ m1.m2*(p1-p2).m3+m2.m3*(p2-p3).m1+m3.m1*(p3-p1).m2$
W+	IW-	IZ		I-EE*CW/SW		$ m1.m2*(p1-p2).m3+m2.m3*(p2-p3).m1+m3.m1*(p3-p1).m2$
l	le	IA		I-EE		IG(m3)
M	lm	IA		I-EE		IG(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

List of particles (antiparticles)

G(G)- gluon	A(A)- photon	Z(Z)- Z-boson
W+(W-)- W-boson	h(h)- Higgs	e(E)- electron
n1(N1)- e-neutrino	m(M)- muon	n2(N2)- m-neutrino
l(L)- tau-lepton	n3(N3)- t-neutrino	d(D)- d-quark
u(U)- u-quark	s(S)- s-quark	c(C)- c-quark
b(B)- b-quark	t(T)- t-quark	KG(KG)- K-gluon-1
B1(B1)- K-B-boson(1)	B2(B2)- K-B-boson(2)	Z1(Z1)- K-W3-boson(1)
Z2(Z2)- K-W3-boson(2)	~W+(~W-)- K-W-boson (1)	~W2(~w2)- K-W-boson (2)
~eL(~EL)- KD-electron	~mL(~ML)- KD-muon	~tL(~TL)- KD-tau-lepton
~eR(~ER)- KS-electron	~mR(~MR)- KS-muon	~tR(~TR)- KS-tau-lepton
~n1(~N1)- KD-e-neutrino	~n2(~N2)- KD-m-neutrino	~n3(~N3)- KD-t-neutrino
Du(DU)- KD-u-quark	Dd(DD)- KD-d-quark	Dc(DC)- KD-c-quark

PgDn

Enter process: e E -> ~W+ ~W-

Exclude diagrams with

Model: MUED

Process: $e E \rightarrow \tilde{W}^+ \tilde{W}^-$

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

View diagrams
 Squaring technique

CalcHEP/symb

Delete, On/off, Restore, Latex

--	--	--	--

Can delete unwanted diagrams

Can get mathematica code for this process

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

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:

Enter process: $\sim W^+ \rightarrow 2^* x$
Exclude diagrams with
Exclude X-particles

Decay $\sim W^+ \rightarrow 2^* x$

Total width : 1.027E-01 GeV
Modes and fractions :

E	$\sim n1$	-	1.67E+01%
n3	$\sim TL$	-	1.67E+01%
n2	$\sim ML$	-	1.67E+01%
n1	$\sim EL$	-	1.67E+01%
M	$\sim n2$	-	1.67E+01%
L	$\sim n3$	-	1.66E+01%

Show Branchings
QCD Scale $Q = M1$
Model parameters
Constraints
Parameter dependence
Les Houches output
Monte Carlo

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

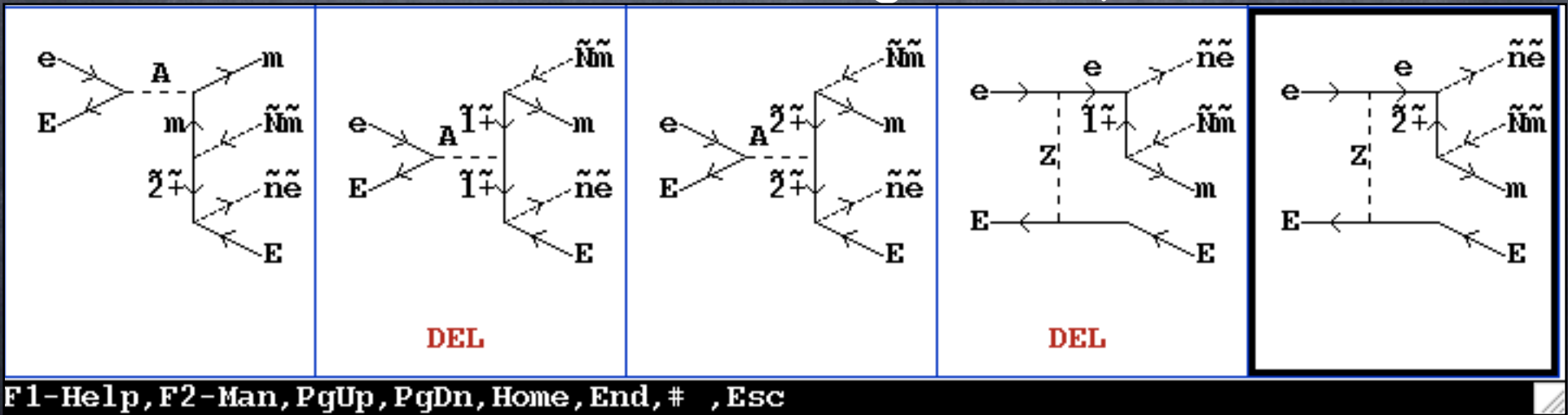
Can't specify intermediate states:
 (using MSSM model from Pukhov site)

```
Enter process: e E -> ~l+ ~l- -> 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.