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.

\[
\begin{align*}
\text{e} & \rightarrow \text{X1} & \text{mu} & \rightarrow \text{ve} & \text{X1} & \rightarrow \text{vm} \\
\text{e} & \rightarrow \text{X1} & \text{mu} & \rightarrow \text{vm} & \text{e} & \rightarrow \text{X1} & \text{mu} & \rightarrow \text{vm} & \text{e} & \rightarrow \text{X1} & \text{mu} & \rightarrow \text{vm} & \text{e} & \rightarrow \text{X1} & \text{mu} & \rightarrow \text{vm} \\
\text{DO NW1=-1,1,2} \\
\text{DO NW2=-1,1,2} \\
\text{CALL \textit{OXxxxx}(P1,M2,NW1,+1, SWINO1)} \\
\text{CALL \textit{IXxxxx}(P2,M2,NW2,-1, SWINO2)} \\
\text{CALL \textit{IOvxxxx}(SWINO2,SWINO1,J3,G3, PRODUCTION1)} \\
\text{CALL \textit{Hioxxxx}(EM,SWINO1,GL,M1,0, NU1)} \\
\text{CALL \textit{IOsxxxx}(SWINO2,EP,NU1,GR, PRODUCTION2)} \\
\text{CALL \textit{IXxxxx}(P1,M2,NW1,+1, SWINO1)} \\
\text{CALL \textit{OXxxxx}(P2,M2,NW2,-1, SWINO2)} \\
\text{CALL \textit{IOsxxxx}(SWINO1,MUM,CMISS1,GR, DECAY1)} \\
\text{CALL \textit{IOsxxxx}(SWINO2,CMISS2,GL, DECAY2)} \\
\text{SUSY(NW1,NW2) = DECAY1*DECAY2*} \\
\text{(PRODUCTION1+PRODUCTION2)} \\
\end{align*}
\]
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.

\[
|M|^2 = \sum_i w_i |M_i|^2, \quad \sum_i w_i = 1
\]

\[
w_i = \frac{|M_i|^2}{\sum_k |M_k|^2}
\]
We’ll use an offline version of this
Step 1: Create new working directory

Step 2: Edit Cards/proc_card.dat
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
Step 2: Edit Cards/proc_card.dat

Step 3: Start our new process
Step 4: Check our results

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**

<table>
<thead>
<tr>
<th>Directory</th>
<th># Diagrams</th>
<th># Subprocesses</th>
<th>FEYNMAN DIAGRAMS</th>
<th>SUBPROCESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>P0e^{-}e^{+}mu^{-}mu^{+}</td>
<td>2</td>
<td>1</td>
<td>html</td>
<td>postscript</td>
</tr>
</tbody>
</table>

- **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**

![Postscript Diagrams](image_url)
Step 5: Edit Cards/param_card/dat

<table>
<thead>
<tr>
<th>Block MODSEL</th>
<th># Select Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Block SMINPUTS</th>
<th># Standard Model inputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.32506980E+02</td>
</tr>
<tr>
<td>2</td>
<td>1.16639000E-05</td>
</tr>
<tr>
<td>3</td>
<td>1.18000000E-01</td>
</tr>
<tr>
<td>4</td>
<td>9.11880000E+01</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Block MGSPARAM</th>
<th># Standard Model parameters for MadGraph</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.22246533E-01</td>
</tr>
<tr>
<td>2</td>
<td>8.04190000E+01</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Block MGYUKAWA</th>
<th># Yukawa masses m/v=y/sqrt(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>4.70000000E+00</td>
</tr>
<tr>
<td>4</td>
<td>1.42000000E+00</td>
</tr>
<tr>
<td>6</td>
<td>1.74300000E+02</td>
</tr>
<tr>
<td>15</td>
<td>1.77700000E+00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Block MGCKM</th>
<th># CKM elements for MadGraph</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9.75000000E-01</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Block MASS</th>
<th># Mass spectrum (kinematic masses)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>4.70000000E+00</td>
</tr>
<tr>
<td>6</td>
<td>1.74300000E+02</td>
</tr>
<tr>
<td>15</td>
<td>1.77700000E+00</td>
</tr>
<tr>
<td>23</td>
<td>9.11880000E+01</td>
</tr>
<tr>
<td>24</td>
<td>8.04190000E+01</td>
</tr>
<tr>
<td>25</td>
<td>1.20000000E+02</td>
</tr>
</tbody>
</table>

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

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
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

<table>
<thead>
<tr>
<th>Links</th>
<th>Events</th>
<th>Tag</th>
<th>Run</th>
<th>Collider</th>
<th>Cross section (pb)</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>results banner</td>
<td>Parton-level</td>
<td>LHE</td>
<td>fermi</td>
<td>Run1</td>
<td>e-e 100 x 100 GeV</td>
<td>.27830E+01</td>
</tr>
</tbody>
</table>

### Process

**$\sigma = 2783.200 \pm 4.402 (fb)$**

<table>
<thead>
<tr>
<th>Graph</th>
<th>Cross Sect(fb)</th>
<th>Error(fb)</th>
<th>Events (K)</th>
<th>Eff</th>
<th>Unwgt</th>
<th>Luminosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sum</td>
<td>2783.200</td>
<td>4.402</td>
<td>64</td>
<td>0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P0e-e_+\ mu-mu+$</td>
<td>2783.200</td>
<td>4.402</td>
<td>64</td>
<td>0.4</td>
<td></td>
<td>5.71</td>
</tr>
</tbody>
</table>

**$e-e+_\ mu-mu+$**

**$s = 2783.190 \pm 4.403 (fb)$**

<table>
<thead>
<tr>
<th>Graph</th>
<th>Cross Sect(fb)</th>
<th>Error(fb)</th>
<th>Events (K)</th>
<th>Eff</th>
<th>Unwgt</th>
<th>Luminosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sum</td>
<td>2783.190</td>
<td>4.403</td>
<td>1276</td>
<td>1.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G1</td>
<td>2268.600</td>
<td>4.355</td>
<td>254</td>
<td>1.0</td>
<td>12943</td>
<td>5.71</td>
</tr>
<tr>
<td>G2</td>
<td>514.590</td>
<td>0.642</td>
<td>1022</td>
<td>1.3</td>
<td>51236</td>
<td>99.60</td>
</tr>
</tbody>
</table>
\[
pp \rightarrow t\bar{t} \rightarrow b\bar{b}\mu\bar{\nu}_\mujj
\]

---

**SubProcesses and Feynman diagrams**

<table>
<thead>
<tr>
<th>Directory</th>
<th># Diagrams</th>
<th># Subprocesses</th>
<th>FEYNMAN DIAGRAMS</th>
<th>SUBPROCESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>P0uxu_hbxmu-vmxudx</td>
<td>1</td>
<td>4</td>
<td>html</td>
<td></td>
</tr>
<tr>
<td>P0uxu_hbxmu-vmxsxc</td>
<td>1</td>
<td>4</td>
<td>html</td>
<td></td>
</tr>
<tr>
<td>P0uxu_hbxmu-vmxudx</td>
<td>1</td>
<td>4</td>
<td>html</td>
<td></td>
</tr>
<tr>
<td>P0uxu_hbxmu-vmxsxc</td>
<td>1</td>
<td>4</td>
<td>html</td>
<td></td>
</tr>
<tr>
<td>P0gg_hbxmu-vmxudx</td>
<td>3</td>
<td>1</td>
<td>html</td>
<td></td>
</tr>
<tr>
<td>P0gg_hbxmu-vmxsxc</td>
<td>3</td>
<td>1</td>
<td>html</td>
<td></td>
</tr>
</tbody>
</table>
Download and modify the ma_card.dat file

select unweighted events .lhe from working dir/Events/

MadAnalysis
# ma_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
#etmax 1 1 1d0
#etamax 2 1 2d0
#etamin 2 2 1.5d0
#etamin 2 1 2d0
#mijmax 2 1 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 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
et 5 1  # plot pseudo-rapidity for the first three particles in class 1
et 6 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 mass
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
$m(jet1,jet2)$

$W$ mass
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 $\alpha$, GF, $m_Z$ given in the LH file to calculate $\sin 0$, $m_W$
  - 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 CATPSS 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

def. in couplings.f

param_card.dat (SPS 5)

/Models/mssm/particles.dat
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:

- $m(\text{lept1, lept2})$

(700 GeV c.o.m.)
Quantity of Interest:

MadAnalysis insufficient, need to analyze the file in different program.
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

calcHEP was to enable one to go directly from the Lagrangian to the cross sections and distributions effectively, with the high level of any Unix platform.

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

Manual
- calchepr_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
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
- Extensons of MSSM: CPsuperH, NMHDecay
- Models: LanHEP and SUSY models generated by LanHEP.
- Parton showers: PYTHIA
Run this to set up new working dir.
Let’s use a predefined model: MUED (from Pukhov website)

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)

<table>
<thead>
<tr>
<th>G(G)</th>
<th>A(A)</th>
<th>Z(Z)</th>
<th>e(E)</th>
<th>n2(N2)</th>
<th>d(D)</th>
<th>c(C)</th>
<th>KG(KG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- gluon</td>
<td>- photon</td>
<td>- Z-boson</td>
<td>- electron</td>
<td>- m-neutrino</td>
<td>- d-quark</td>
<td>- c-quark</td>
<td>- K-gluon-1</td>
</tr>
<tr>
<td>W+(W-)</td>
<td>h(h)</td>
<td>n3(N3)</td>
<td>n2(N2)</td>
<td>t(N1)</td>
<td>t-neutrino</td>
<td>m(M)</td>
<td>muon</td>
</tr>
<tr>
<td>- W-boson</td>
<td>Higgs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>l(L)</td>
<td>n3(N3)</td>
<td>d(D)</td>
<td>c(C)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- tau-lepton</td>
<td>- t-neutrino</td>
<td>- d-quark</td>
<td>- c-quark</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>u(U)</td>
<td>s(S)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- u-quark</td>
<td>- s-quark</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b(B)</td>
<td>t(T)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- b-quark</td>
<td>- t-quark</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B1(B1)</td>
<td>B2(B2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- K-B-boson(1)</td>
<td>- K-B-boson(2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z2(Z2)</td>
<td>Z1(Z1)</td>
<td>Z2(\sim Z2)</td>
<td>Z1(\sim Z1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- K-W3-boson(2)</td>
<td>- K-W3-boson(1)</td>
<td>- K-W-boson(2)</td>
<td>- K-W-boson(1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>eL(\sim eL)</td>
<td>mL(\sim mL)</td>
<td>tL(\sim tL)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- KD-electron</td>
<td>- KD-muon</td>
<td>- KD-tau-lepton</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>eR(\sim eR)</td>
<td>mR(\sim mR)</td>
<td>tR(\sim tR)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- KS-electron</td>
<td>- KS-muon</td>
<td>- KS-tau-lepton</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n1(\sim n1)</td>
<td>n2(\sim n2)</td>
<td>n3(\sim n3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- KD-e-neutrino</td>
<td>- KD-m-neutrino</td>
<td>- KD-t-neutrino</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Du(DU)</td>
<td>Dd-DD</td>
<td>Dc(DC)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- KD-u-quark</td>
<td>- KD-d-quark</td>
<td>- KD-c-quark</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Enter process: \textbf{e E -> \sim W+ \sim W-}

Exclude diagrams with \_\_\_
Can delete unwanted diagrams

Can get mathematica code for this process
(sub)Process: e, E → ~W+, ~W−
Monte Carlo session: 1(begin)

Modify energy, pdfs

(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]
What else can you do?

widths and branching ratios:

```
Enter process: ~W+ -> 2*x
Exclude diagrams with [ ]
Exclude X-particles [ ]
```

```
Decay ~W+ -> 2*x
```

Total width : 1.027E-01 GeV
Modes and fractions :
  E ~n1 - 1.67E+01%
  n3 ~TL - 1.67E+01%
  n2 ~ML - 1.67E+01%
  n1 ~EL - 1.67E+01%
  M ~n2 - 1.67E+01%
  L ~n3 - 1.66E+01%

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: $e \to E \to \sim 1^+ \sim 1^- \to E \sim ne m \sim \tilde{N}m$
composit '->' consists of: 

Can exclude specific particles from appearing:

Enter process: $e \to E \sim ne m \sim \tilde{N}m$
Exclude diagrams with $\sim 2^+, \sim 2^-$

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.