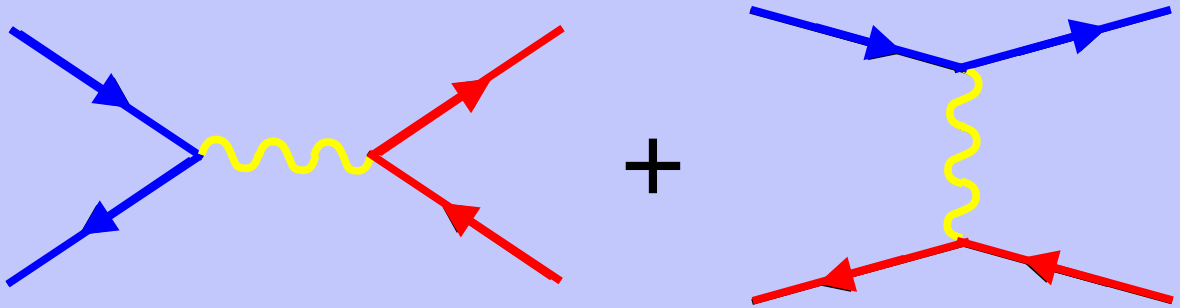
MadGraph + MadEvent



MadGraph/MadEvent Can
Automatically Calculate
1-Loop Cross Sections ?

Not Yet!

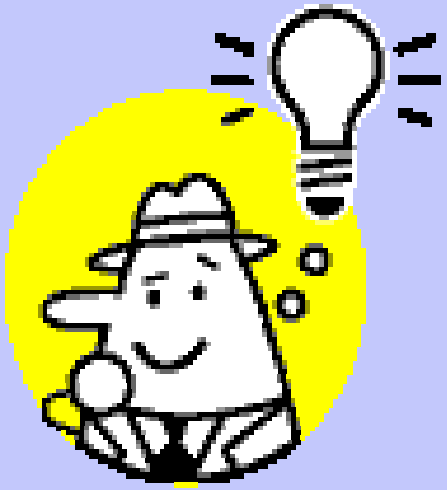
Tim Stelzer
Fabio Maltoni

Outline

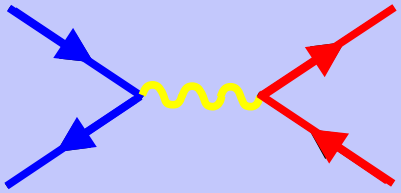
- Why am I here?
- MadGraph
  - Topology Generation
  - Diagram/Amplitude Generation
- MadEvent
  - Single Diagram Enhanced MC

Why Am I Here?

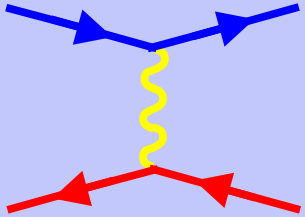
- Currently MadGraph/MadEvent
  - Generates Born Level σ
  - Uses Helicity Amplitudes
  - Generates Color-Connected Amps
  - Efficient Single-Diagram Integration



- Soon it could
  - Subtraction of Reals
  - 1-loop diagrams
  - 1-loop helicity amplitudes??



MadGraph



Matrix Element / Feynman Diagrams

- Inspired by FeynArts.
- Fortran computer program that:
  - Generates fortran helicity code (HELAS) to calculate tree level matrix elements
  - Includes color/symmetry factors
  - Creates postscript file of Feynman diagrams.

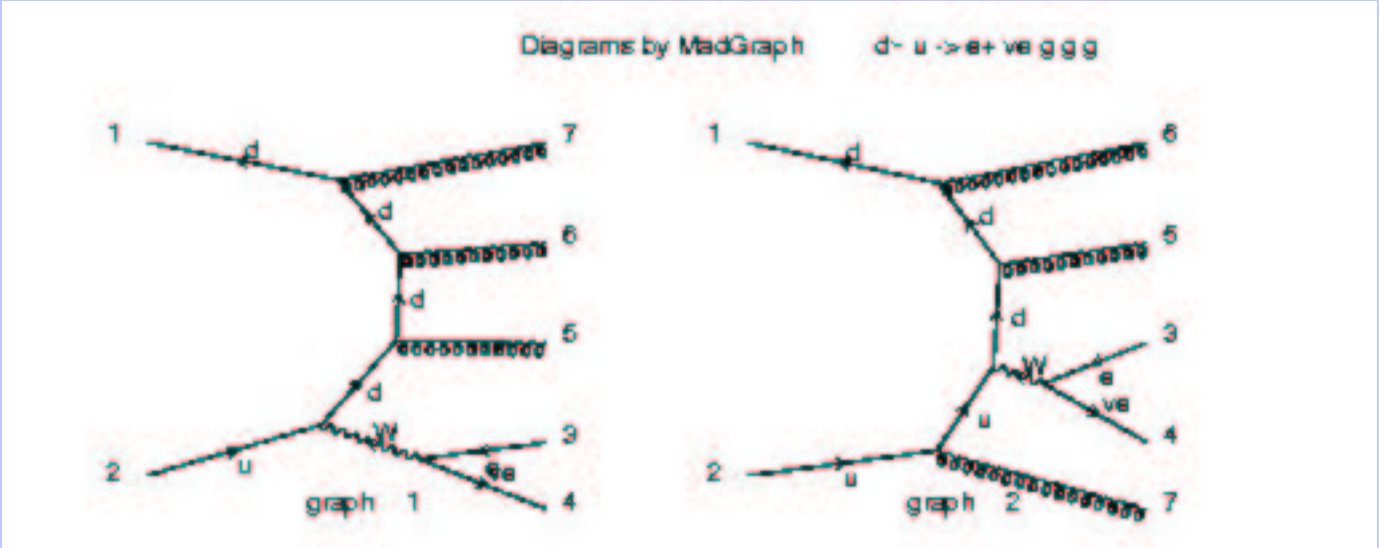
MadGraph Example

pp -> W^+ + 3 jets

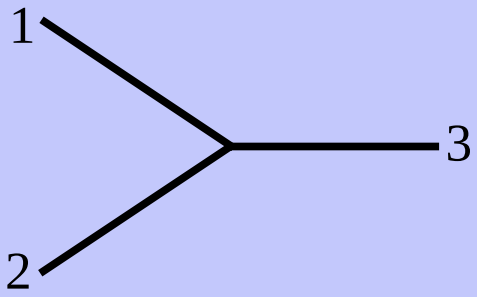
- Enter Process: pp > e+ ve jjj
- Enter QCD Order: 3
- Enter QED Order: 2

  (…… wait 2 minutes)

- Generated 53 sub processes

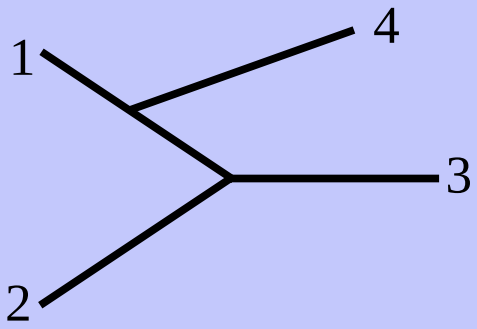


Topologies

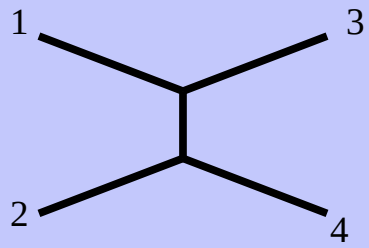


- Start with 3 external line topology
  - Add external line to 1

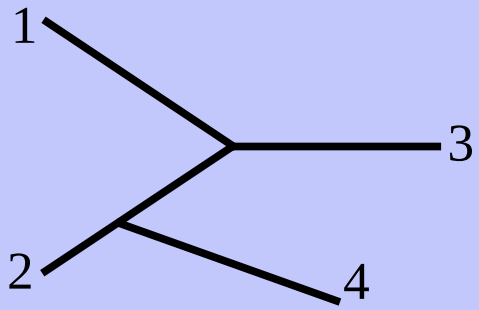
Topologies



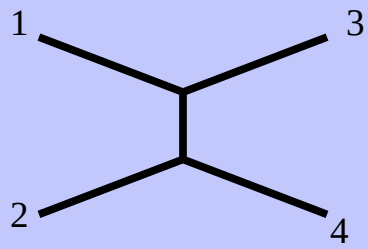
- Start with 3 external line topology
  - Add external line to 1

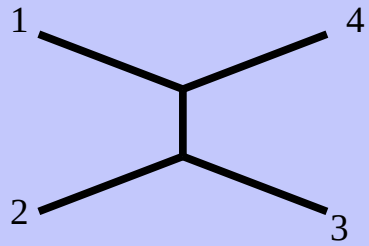


Topologies

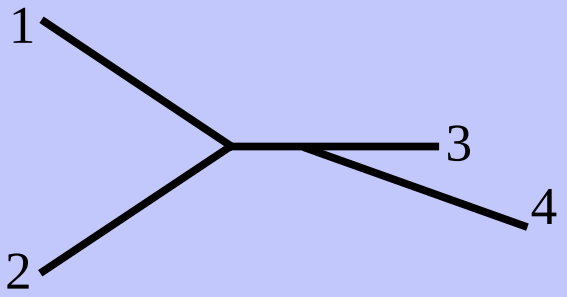


- Start with 3 external line topology
  - Add external line to 1
  - Add external line to 2

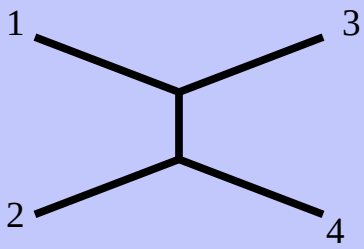


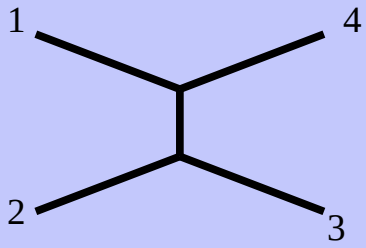


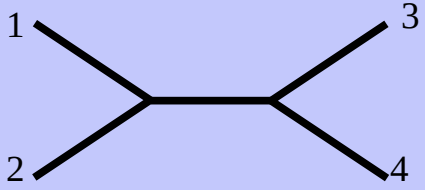
Topologies



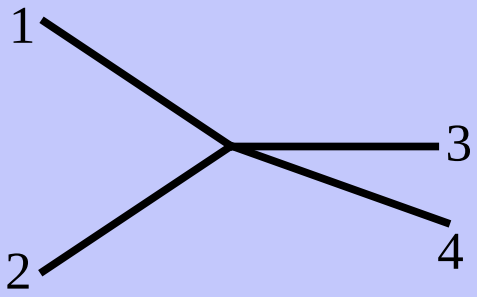
- Start with 3 external line topology
  - Add external line to 1
  - Add external line to 2
  - Add external line to 3



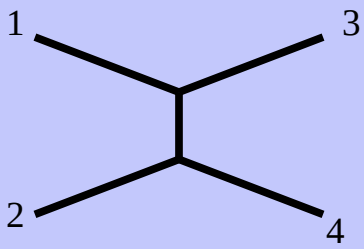


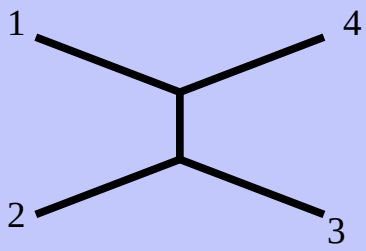


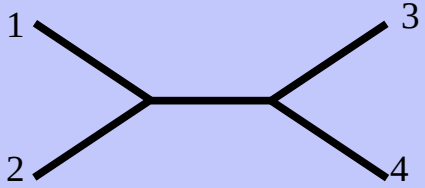
Topologies

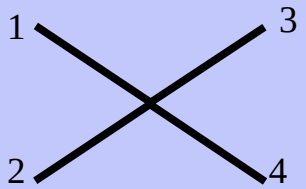


- Start with 3 external line topology
  - Add external line to 1
  - Add external line to 2
  - Add external line to 3
  - Add external line to vertex



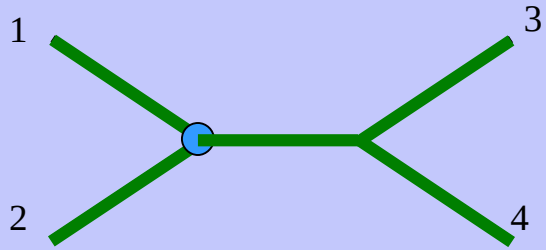






Diagram/Amplitudes

uu~ > uu~



- For each topology
  - Write all external wave functions

    call ixxxxx(p1, ……W1)
    call oxxxxx(p2,……W2)
    call ixxxxx(p3,…..W3)
    call oxxxxx(p4,…W4)
  - Choose vertex w/ only 1 unknown line
  - Determine allowed interactions and write wavefunction.

    call jioxxx(W1,W2, …….W5)
  - Continue until all lines known, write amp.

    call iovxxx(W3,W4,W5, …AMP(1))

Other Elements

- Optimization
- Color factors
- Summing over partons
- Loops?

MADEVENT!

Monte Carlo Integration

$$\int f(\mathrm{x})\,\mathrm{dx} \approx \sum_{i=1,N} f(x_i)\frac{V}{N}$$

- Advantages
  - Large numbers of dimensions
  - Complicated cuts
  - ONLY OPTION
  - Event generation

- Limitations
  - Only works for function f(x) ≈ 1

Adaptive M.C. (VEGAS)

$$\sigma = \int |\, a_1 + a_2 \,|^2 \, \mathrm{d}(PS) = \sum_{i=1,N} \frac{|\, a_1(p_i) + a_2(p_i) \,|^2}{g_i} \frac{V}{N}$$

- Advantages $\int \frac{1}{(x^2+a)} \frac{1}{(y^2+b)} dxdy$
  - Grid adjusts to numerically flatten peaks
  - Flexible
- Limitations $\int \frac{1}{((x-y)^2+a)} dxdy$
  - Adjusting grid takes time
  - Peaks must lie on integration variable

Multi-Channel M.C.

$$\sigma = \int |\, a_1 + a_2 \,|^2 \, \mathrm{d}(PS) = \sum_{i=1,N} \frac{|\, a_1(p_i) + a_2(p_i) \,|^2}{\alpha_1 g_{1i} + \alpha_2 g_{2i}} \frac{V}{N}$$

- Advantages
  - Allows for more complicated peaks
- Limitations
  - Need to calculate all g_i values for each point. (slow)
  - Each phase space channel must be invertible
  - N coupled equations for α_i so only works for small number of channels.

Single Diagram Enhanced

MadEvent

$$\sigma = \int |a_1 + a_2|^2 \, \mathrm{d}(PS) = \int \frac{|a_1 + a_2|^2}{|a_1|^2 + |a_2|^2} |a_1|^2 \, \mathrm{d}(PS) + \int \frac{|a_1 + a_2|^2}{|a_1|^2 + |a_2|^2} |a_2|^2 \, \mathrm{d}(PS)$$

- Key Idea
  - Any single diagram is “easy” to integrate
  - Divide integration into pieces, based on diagrams
- Get N independent integrals
  - Errors add in quadrature so no extra cost
  - No need to calculate “weight” function from other channels.
  - Can optimize # of points for each one independently
  - Parallel in nature
- What about interference?
  - Never creates “new” peaks, so we’re OK

MadEvent Example

Vector Bosons

process	+n jets	order		unit	Tevatron	LHC
		qcd	qed			
e+ ve (e- ve~)	0 1 2 3 4	n	2	pb	758 182 46.6 12.0 3.2	3850 (3450) 1700 (1520) 742 (642) 337 (279) 156 (122)
e+ e-	0 1 2 3 4	n	2	pb	210 46.2 12.6 3.30 0.871	1000 398 179 79.0 35.1
e+ ve (e- ve~) b b~	0 1 2	n+2	2	fb	427 195 73.1	2330 (1770) 2950 (2330) 2600 (1980)
e+e- b b~	0 1 2	n+2	2	fb	165 79.3 28.0	3880 3080 1770
W+W-	0 1 2	n	2	pb	9.28 3.84 1.23	46.3 37.0 25.3
W+ Z (W- Z)	0 1 2	n	2	pb	1.49 0.633 0.209	10.0 (7.25) 10.7 (7.31) 9.15 (6.40)
Z Z	0 1 2	n	2	pb	1.04 0.440 0.133	6.70 4.95 2.97

MadEvent Example

Heavy Quarks and Higgs

process	+n jets	order		unit	Tevatron	LHC
		qcd	qed			
t t~	0 1 2 3	n+2	0	pb	7.67 3.53 1.24 0.385	579 762 660 460
b b~	0 1 2 3	n+2	0	nb	832 113 29.0 6.35	15000 3040 1110 356
t t~ b b~	0 1	n+4	0	fb	14.5 8.21	3890 6440
	0 1	n+2	2	fb	1.14 0.747	336 380
b b~ b b~	0 1	n+4	0	pb	86.1 41.0	4050 546
	0 1	n+2	2	fb	676 428	16100 4090

process	+n jets	order		unit	Tevatron	LHC
		qcd	qed			
h	2 3	n-2	3	fb	157 89.3	1550 1000
t t~ h	0 1 2	n+2	1	fb	7.30 3.14 1.00	545 830 852
W+ h (W- h)	0 1 2 3	n	2	fb	67.9 29.3 9.11 2.34	563 (391) 425 (290) 250 (168) 137 (89)

It Works!!!

- Integrates cross section and generates unweighted events for “any” tree-level processes.
- Advantages
  - Can handle “general” problem
  - Parallel in nature
  - Sub channel numbers help with cuts
- Limitations
  - Still need to adjust grid in some channels.
  - W+5 jets (7,000 diagrams w/ hundreds sub processes)

Conclusions

- MadGraph Could Be Helpful for Automating NLO
- Born cross section
- Real Subtraction
- Automated Integration and Phase Space
- Loop Diagrams