Top Physics with MadGraph/MadEvent

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Johan Alwall, Pavel Demin, Simon de Visscher, Michel Herquet, Fabio Maltoni, Olivier Mattelaer, Tim Stelzer
+ Steve Mrenna, Tilman Plehn, David L. Rainwater,
+ Pierre Artoisenet, Claude Duhr, Nicolas Greiner...

+ OUR GOLDEN USERS!!
What is MadGraph/MadEvent (MG/ME)?

• MG/MEv4 is a user-driven, matrix element based, tree-level event generator

• Multi-process: Signal and background generation simultaneously

• Web server interface from which the simulation itself can be done on-line or off-line

• With MG/ME and its tools/interfaces, the full simulation chain from hard scale physics to detector simulation is available within one framework
MadGraph on the Web

Three medium size clusters public access (+1 private cluster). ~1500 registered users.
Thanks to: D. Lesny, L. Nelson (UIUC), F. Chalier, T. Keutgen (UCL), R. Ammendola, N. Tantalo (RM2)

Top physics workshop @ Grenoble, October 24, 2008

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MG/ME flow chart

Model
- particles.dat
- interactions.dat
- couplings.f

Calculator
- proc_card
- param_card
- run_card

FeynRules
- pythia_card
- pgs_card

Lagrangian

MG
- Feyn. diags.
- HELAS amplitudes

ME
- Parton-level events

Pythia
- Hadron-level events

PGS
- Reconstructed Objects

ExRootAnalysis

MadAnalysis
- Parton-level rootfile/plots
- Hadron-level rootfile/plots
- Reconstructed Objects rootfile/plots
Features

• Complete web simulation: MadEvent $\rightarrow$ Pythia $\rightarrow$ PGS, with personal web databases

• Multi-processes in single code & generation

• Standalone version for theorists, with MadDipole for NLO comp.

• New complete models: SM, HEFT, MSSM, 2HDM, TopBSM

• Easy new model implementation: USRMOD & interface to FeynRules

• Les Houches Accord (LHEF) for parton-level event files & Les Houches Accord 2 for model parameters

• Merging w/ Parton Showers ($k_T$ a la MLM) w/ Pythia

• Detailed process specification

• MadWeight: automatic reweighting of experimental events

• Analysis platforms: ExRootAnalysis, MadAnalysis and MatchChecker
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Process specification

- Specify the process in the `proc_card.dat` (or use the box online)
  - Use “/” to exclude particles and “>” to specify intermediate states (s- or t-channel)
    - e.g. “pp > tt~ > bb~W+W- / Z a”
  - Specify the full decay chain by using “( ... > ... )”. This improves generation time by quite a lot! Works up to 8 final state particles
    - e.g. “pp > (t > b (W+ > e+ ve)) (t~ > b~ (W- > mu- vm~))”
  - Use “$” to exclude s-channel resonances (Only gauge invariant in NWA!)
    - e.g. “pp > bb~W+W- $ t~” for W associated single top + b, without ttbar contributions
- Use “[ ... ]” for quarkonium production
  - e.g. “gg > g cc~[3S11]” for gg>g+charmonium with S=1, L=0, J=1, c=1 (J/Psi production via a color-singlet transition).
Matching ME and PS

- $K_T$ MLM scheme implemented by J. Alwall.
- Interfaced to (fortran) Pythia, with $Q^2$ and $pt^2$ ordered showers.
- Extensively validated in $V+$jets (data and comparison [arXiv:0706.2569]) and now also in $VV+$jets, $tt+$jets, $h+$jets, inclusive jets, ...
- Merging in BSM Physics samples available (e.g. gluino/squark)
- Interfaces with Pythia8 and Herwig++ are through standard LHEF and not yet available with merging.
PS alone vs Matched Sample

• A parton shower like Pythia is by construction a highly tuneable tool. Consider for instance the pt distribution of the 2nd extra jet in ttbar events with different settings:
PS alone vs Matched Sample

- A parton shower like Pythia is by construction a highly tuneable tool. Consider for instance the pt distribution of the 2nd extra jet in ttbar events with different settings:

In matched samples these differences are irrelevant since the high pt behavior is described by the matrix element. Uncertainties in the matching itself are not shown.
It’s working!

- The most inclusive observable
- All parton multiplicities contribute
- Excellent agreement with TeV data (validation)
In the topBSM model general resonances are added to the SM that couple to top quarks. These resonances can describe a large variety of models: Two-Higgs doublet models to extra dimensions and many more, by tuning the couplings and the masses of the resonances.

In this way general resonances in ttbar events can be analyzed.
TopBSM: ttbar invariant mass

Spin-1

“Only” for discovery of the resonance. To determine properties more involved variables are needed

Spin-2

[RF, F. Maltoni]
arXiv:0712.2355
TopBSM: Spin Determination

By measuring the Collins-Soper angle information about the spin structure of the resonance can be obtained.

SM

BSM

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[RF, F. Maltoni]
arXiv:0712.2355
TopBSM: Spin correlations

- To access the properties (CP or coupling structure) of resonances full matrix elements that describe the final state particles are needed.
- For example: to determine the coupling structure of a Spin-1 resonance in $t\bar{t}$bar production the full $2 \rightarrow 6$ need to be generated.
TopBSM: Spin correlations

\[
\frac{1}{\sigma} \frac{d^2 \sigma}{d \cos \theta_+ d \cos \theta_-} = \frac{1}{4} \left( 1 - A \cos \theta_+ \cos \theta_- + b_+ \cos \theta_+ + b_- \cos \theta_- \right)
\]

- Angle between \( l^+ \) in top rest-frame and top in top pair rest-frame
- Angle between \( l^- \) in anti-top rest-frame and anti-top in top pair rest-frame

Example: Spin-1

[RF, F. Maltoni] arXiv:0712.2355
TopBSM: Spin correlations

$$\frac{1}{\sigma} \frac{d^2\sigma}{d\cos\theta_+ d\cos\theta_-} = \frac{1}{4} \left( 1 - A \cos\theta_+ \cos\theta_- + b_+ \cos\theta_+ + b_- \cos\theta_- \right)$$

Left-handed coupling

SM

Spin-1

Vector-like coupling

Right-handed coupling

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MadWeight

[P. Artoisenet, V. Lemaître, F. Maltoni, O. Mattelaer]

- Tool to find matrix element weight of experimental events for (almost) any process in any model: Matrix Element Method.
- Use all information in the events to determine a parameter

\[ P(x, \alpha) = \frac{1}{\sigma_\alpha} \int d\phi(y) |M_\alpha|^2(y)dq_1dq_2f_1(q_1)f_2(q_2)W(x, y) \]

- Transfer function \( W(x, y) \) accounts for the evolution from parton level event \( y \) to the reconstructed event in the detector \( x \)
- Many more “peaks” in the integration then matrix element alone. Need for efficient integration routines
MadWeight: PS integration

[P. Artoisenet, V. Lemaître, F. Maltoni, O. Mattelaer]

• Phase space integration using automatic (analytic) changes of variables to align with peaks

This leads to an efficient integration over the matrix elements and the transfer functions.
**MadWeight: Example**

[P. Artoisenet, V. Lemaître, F. Maltoni, O. Mattelaer]

- Measurement of the top-quark mass in the semi-leptonic channel
- 20 Monte-Carlo events (MG/ME/Pyhtia/PGS)
- Input: $m_t = 160$ GeV
- Output: $m_t = 158.9 \pm 2.3$ GeV
MadDipole

\[ \sigma^{\text{NLO}} = \int_{m+1} d^{(4)} \sigma^R - d^{(4)} \sigma^A \]
\[ + \int_m \left[ \int_{\text{loop}} d^{(d)} \sigma^V + \int_1 d^{(d)} \sigma^A \right] \]
\[ \epsilon=0 \]

- First step to automatic NLO with MadGraph/MadEvent
- Various groups are focusing on the automatization of the loop diagrams, e.g.:
  - CutTools [G. Ossola, C.G. Papadopoulos, R. Pittau]
  - BlackHat [C. Berger et al.]
  - Rocket [W. Giele, G. Zanderighi]
  - GOLEM [T. Binoth et al.]
- Automatization of the Real contributions also needed

\[ \sigma_{\text{NLO}} = \int_{m+1} [d^{(4)} \sigma^R - d^{(4)} \sigma^A] + \int_m \left[ \int_{\text{loop}} d^{(d)} \sigma^V + \int_1 d^{(d)} \sigma^A \right] \epsilon=0 \]
MadDipole

\[ \sigma_{NLO} = \int_{m+1} [d^{(4)} \sigma^R - d^{(4)} \sigma^A] + \int_{m} \left[ \int_{\text{loop}} d^{(d)} \sigma^V + \int_{1} d^{(d)} \sigma^A \right] \epsilon=0 \]

- Goal: Automatic Dipole Subtraction for any NLO calculation
- Catani-Seymour subtraction scheme
- Reals & subtraction terms for the reals and virtuals
- Including “alpha” dependence to restrict dipoles to divergent regions of the phase-space
- Both for SM and BSM
- Compatible with MG StandAlone

[RF; T. Gehrmann, N. Greiner; JHEP 0809:122, 2008]
• Subtraction is working
• alpha dependence clearly visible
  • Extensive testing against MCFM
• Next steps:
  • do the subtraction terms for the virtuals
  • and the phase space integration
Summary

- MadGraph/MadEvent is a versatile Monte Carlo tool
- Matching between ME and PS available
- Many BSM physics models available. “Model-independent” topBSM available for top studies
- MadWeight for Matrix Element Method
- MadDipole as a first step to NLO

See also the three operational cluster at

http://madgraph.phys.ucl.ac.be
http://madgraph.hep.uiuc.edu
http://madgraph.roma2.infn.it