MadGraph

one hour tutorial on matrix element generation

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+ Tilman Plehn, David L. Rainwater,

+ Pierre Artoisenet, Claude Duhr, Olivier Mattelaer,...

+ our GOLDEN USERS!!

Plan

- MG/ME: overview 15’
- Web generation: physics at the LHC 15’
- ME advanced features 15’
- Fun with the advanced features 15’

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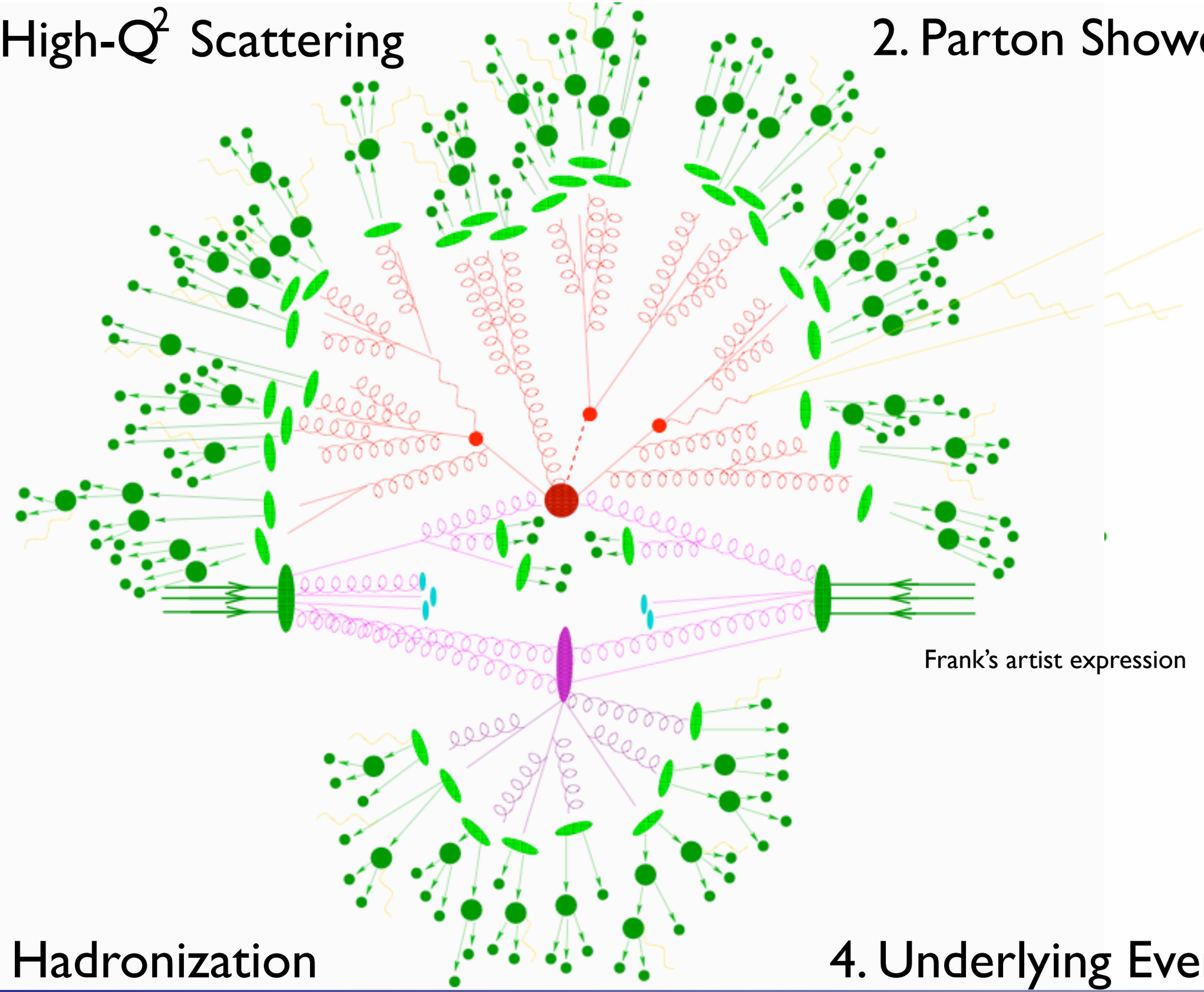
1. High-Q^2 Scattering

2. Parton Shower



Frank's artist expression

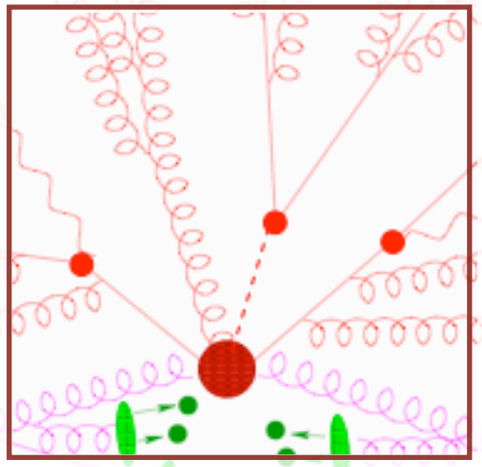
3. Hadronization

4. Underlying Event

1. High-Q^2 Scattering

2. Parton Shower

☞ where new physics lies



☞ process dependent

☞ first principles description

☞ it can be systematically improved

3. Hadronization

4. Underlying Event

My Charge: Tree-level matrix element generators

What are they useful for?

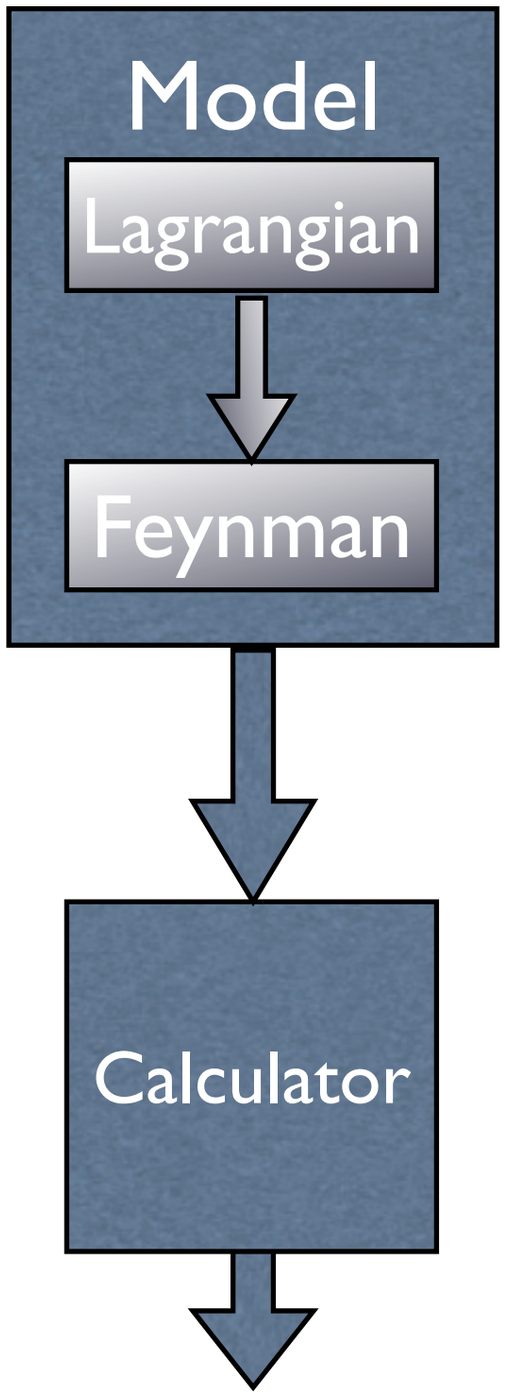
1. Easy and fast cross sections and decay widths calculators

2. Embedded in multipurpose SM and BSM MonteCarlo's

3. Allow numerical checks of analytic calculations (e.g., Reals in NLO and NNLO calculations)

4. Advanced analysis methods (Matrix Elements)

Matrix Element based MC's



Les Houches interface

Invent a model, renormalizable or not, with new physics. Write the Lagrangian and get the Feynman Rules.

The particles content, the type of interactions and the analytic form of the couplings in the Feynman rules define the model at tree level.

Interfaced to FeynRules

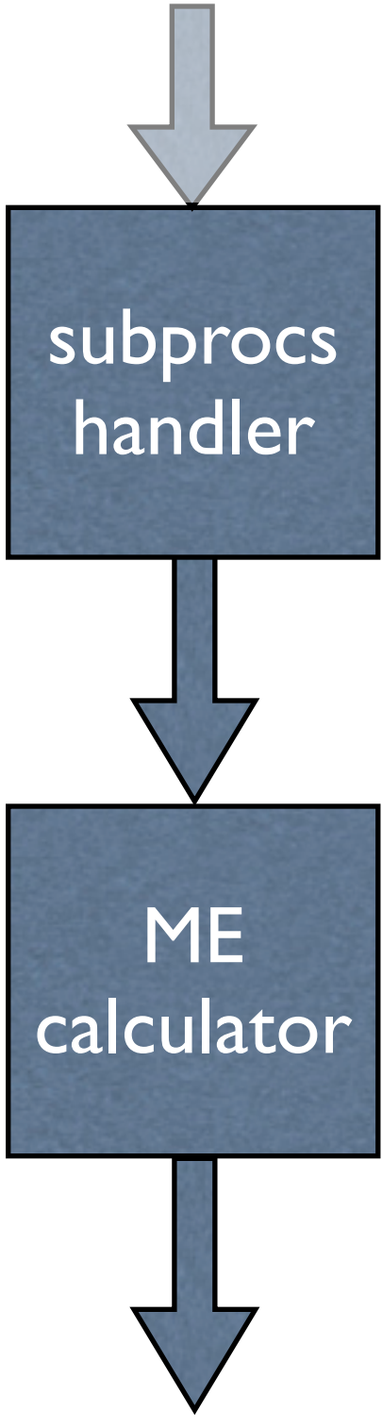
SUSY, Little Higgs, Higgsless, GUT, Extra dimensions (flat, warped, universal,...)

Parameters Calculator.
Given the "primary" couplings, all relevant quantities are calculated: masses, widths and the values of the couplings in the Feynman rules.

Caution: tree-level relations have to be satisfied to avoid gauge violations and/or wrong branching ratios.

FeynHiggs, ISAJET, NMHDecay, SOFTSUSY, SPHENO, SUSPECT, SDECAY...

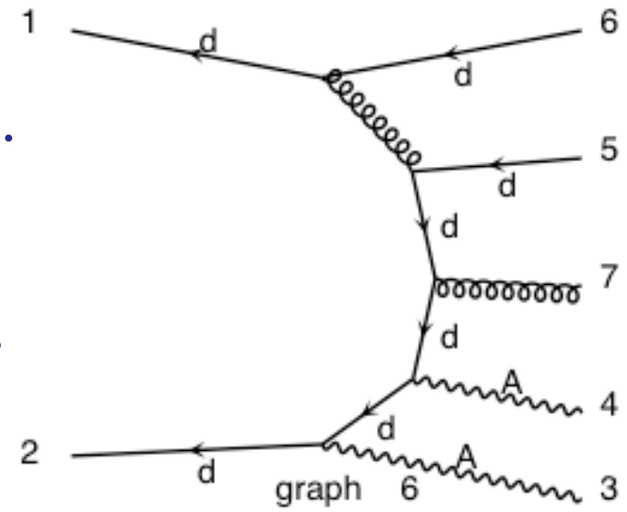
Matrix Element based MC's



Includes all possible subprocess leading to a given multi-jet final state automatically

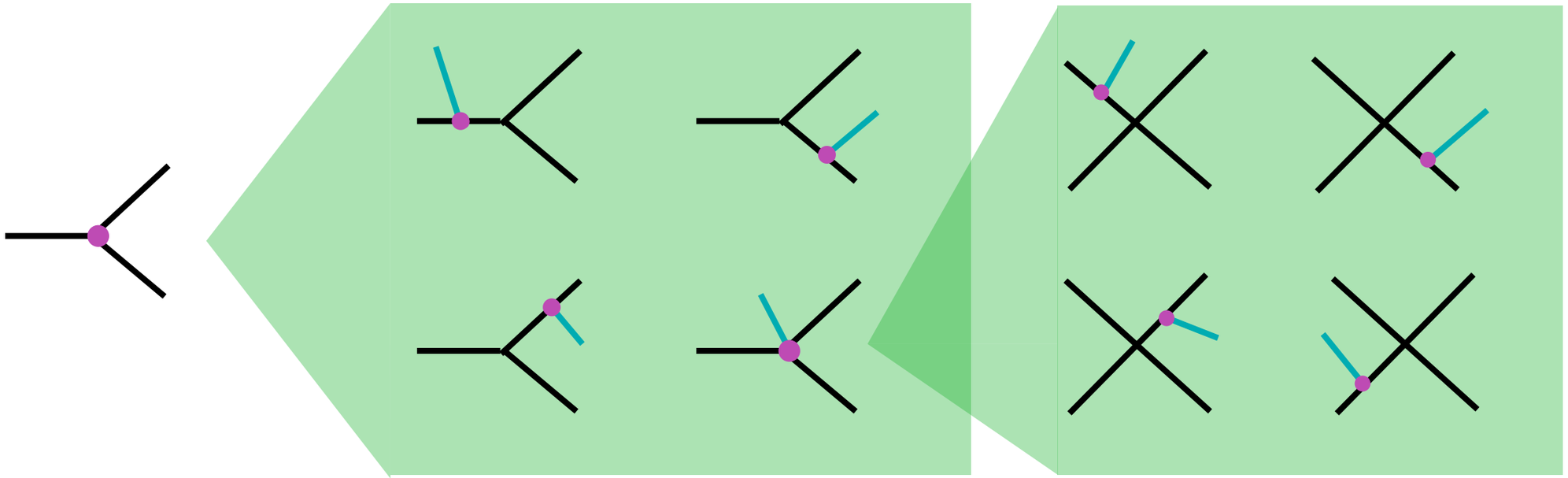
d~ d -> a a u u~ g
d~ d -> a a c c~ g
s~ s -> a a u u~ g
s~ s -> a a c c~ g

Automatically generates a code to calculate |M|^2 for arbitrary processes. Most use Feynman diagrams w/ tricks to reduce the factorial growth [MadGraph, SHERPA], others have recursive relations to reduce the complexity to exponential [Alpgen, HELAC, Comix].



How are the diagrams generated?

1. Generate the topologies



2. Dress the topologies with particles starting from the external particles and checking the existence of the corresponding verteces.

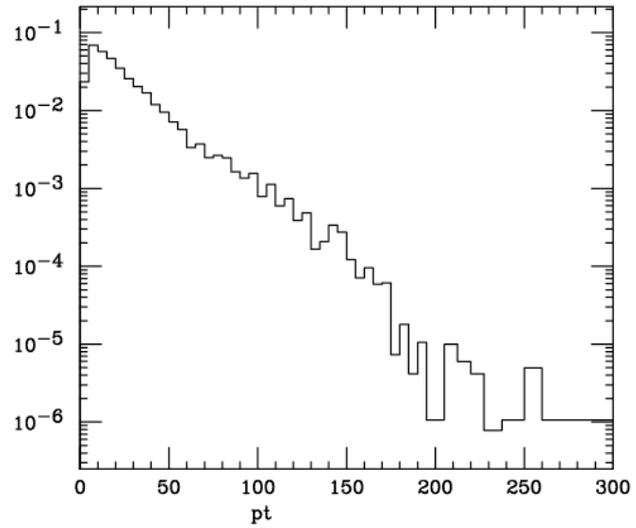
3. Write out a code based on the Feynman rules library.

"Only" a book-keeping problem!

Matrix Element based MC's

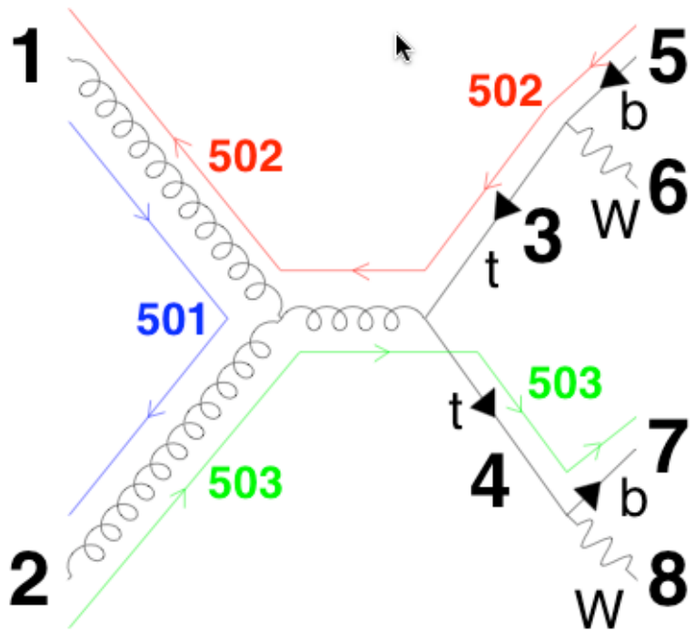
x section

Integrate the matrix element over the phase space using a multi-channel technique and using parton-level cuts.

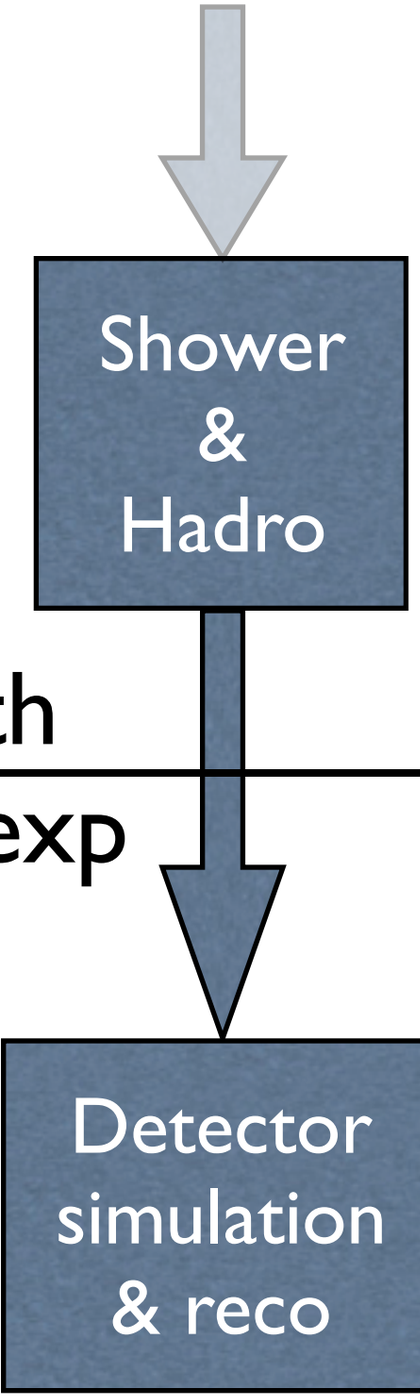


parton-level events

Events are obtained by unweighting. These are at the parton-level. Information on particle id, momenta, spin, color and mother-daugther is given in the Les Houches format.



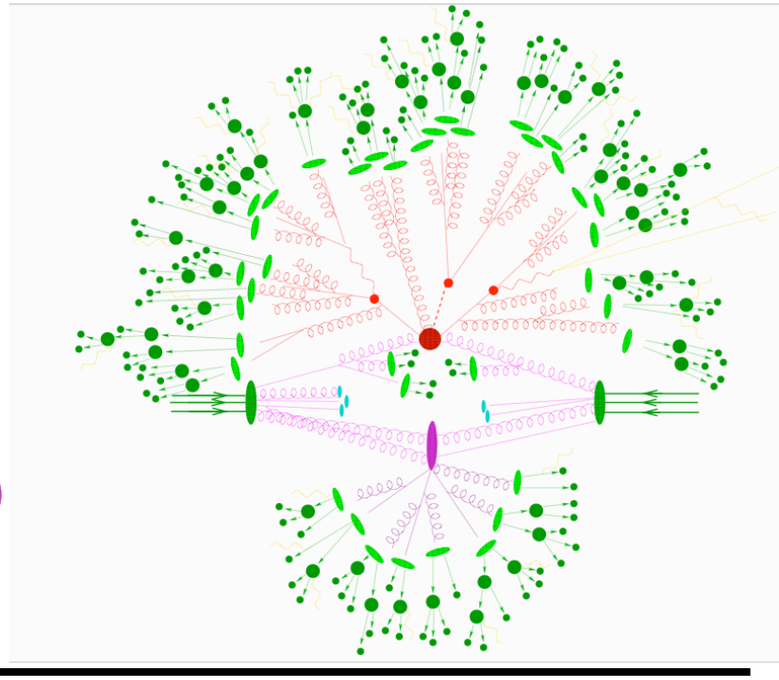
Matrix Element based MC's



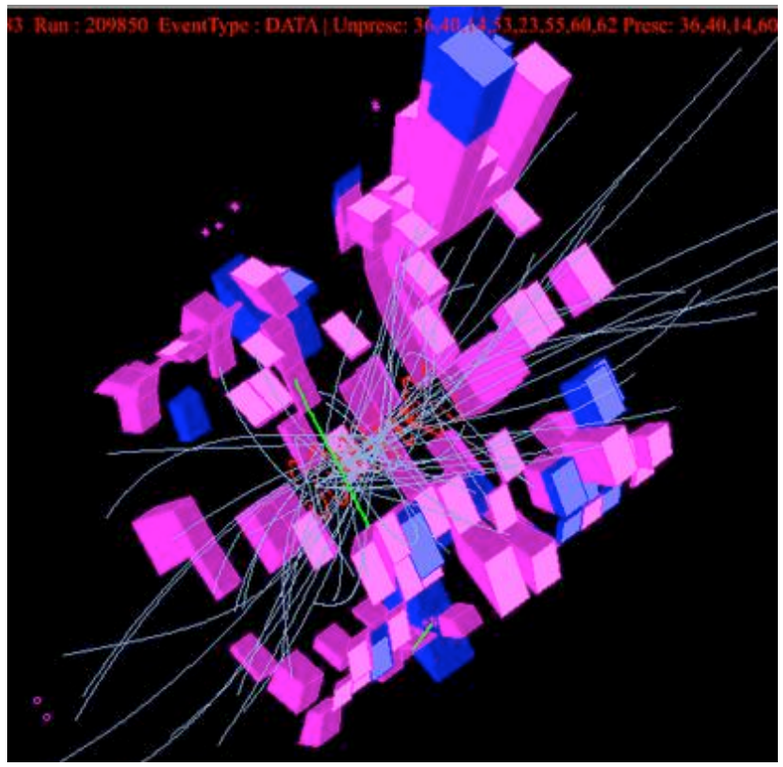
Events in the LH format are passed to the showering and hadronization⇒

high multiplicity hadron-level events

Parton-Jet merging (MLM or CKKW) happens here!



Events in stdhep format are passed through fast or full simulation, and physical objects (leptons, photons, jet, b-jets, taus) are reconstructed.



MadGraph/MadEvent v4

[J. Alwall et al., arXiv:0706.2334]

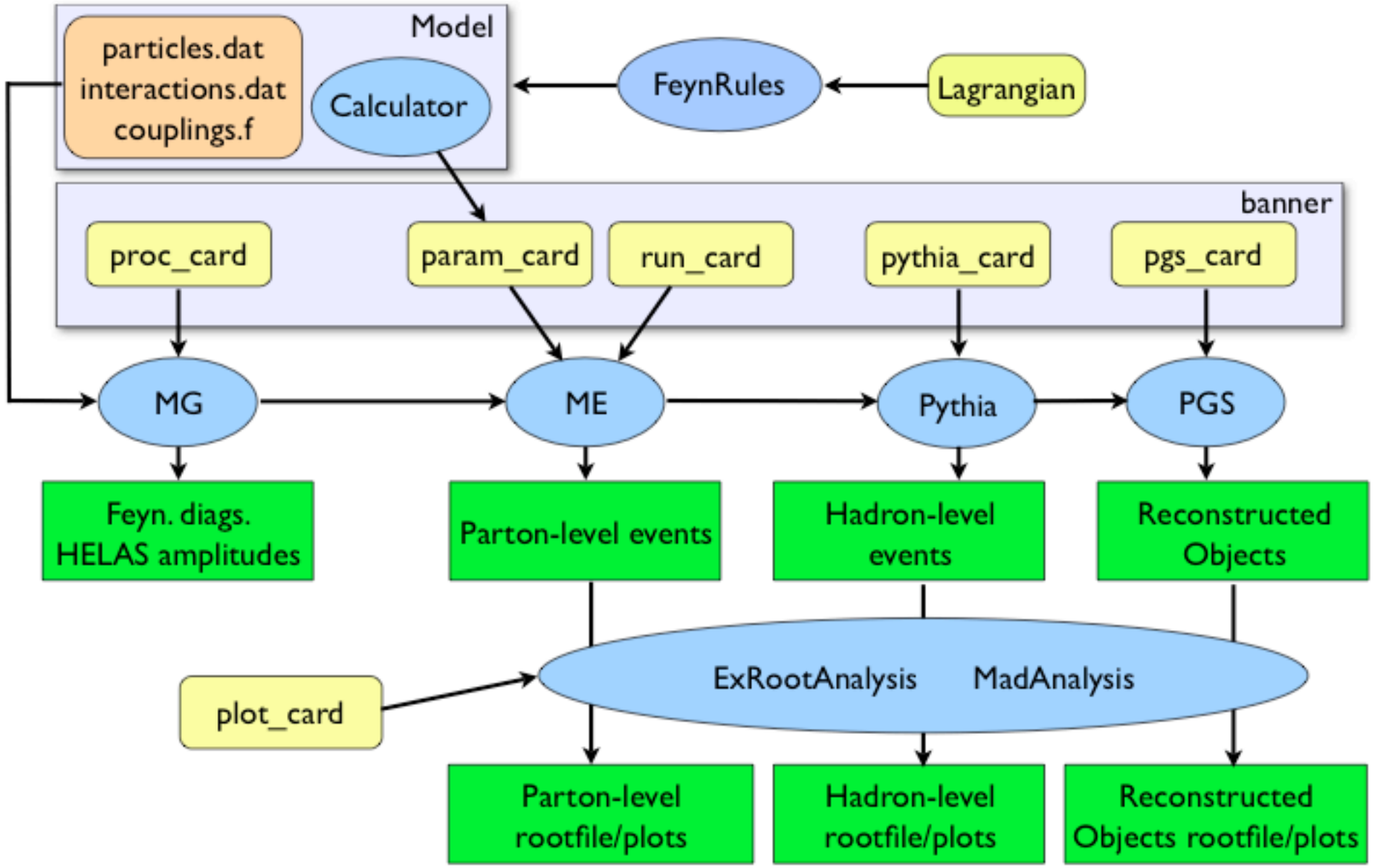
- The new web generation:
  - User requests a process (Ex. pp>tt~jjj) and corresponding code is generated on the fly.
  - User inputs model/parameters/cuts, and code runs in parallel on modest farms.
  - MG/ME Returns cross section, plots, parton-level events.
- Advantages:
  - Reduces overhead to getting results
  - Events can easily be shared/stored
  - Quick response to user requests and to new ideas!
- Limitations:
  - Optimization on single procs limited by generality
  - Tree-level amplitudes based on Feynman diagrams

MadGraph/MadEvent v4

[J. Alwall et al., arXiv:0706.2334]

- Personal web databases
- Complete simulation on the web: MadEvent → Pythia → PGS
- Multi-processes in single code & generation
- Cross section and decay width calculations
- Standalone version for theorists
- New complete models : SM, HEFT, MSSM,2HDM
- USRMOD & interface to FeynRules: New Models implementation
- Les Houches Accord (LHEF) for parton-level event files and Les Houches Accord 2 for model parameters
- Merging w/ Parton Showers (k_T a la MLM) w/ Pythia

FlowChart


Model
particles.dat
interactions.dat
couplings.f
Calculator
FeynRules
Lagrangian
banner
proc_card
param_card
run_card
pythia_card
pgs_card
MG
ME
Pythia
PGS
Feyn. diags.
HELAS amplitudes
Parton-level events
Hadron-level
events
Reconstructed
Objects
plot_card
ExRootAnalysis
MadAnalysis
Parton-level
rootfile/plots
Hadron-level
rootfile/plots
Reconstructed
Objects rootfile/plots

MadGraph on the Web

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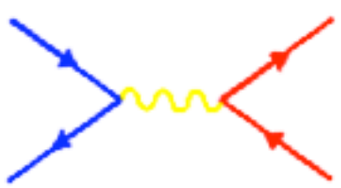
Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation

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

http://madgraph.phys.ucl.ac.be/

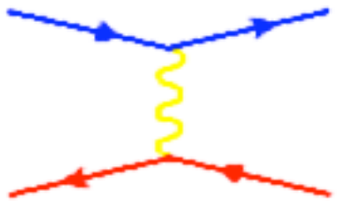
http://madgraph.roma2.infn.it/



MadGraph Version 4

UCL UIUC Fermi

by the MG/ME Development team



Generate Process | Register | Tools | My Database | Cluster Status | Downloads (needs registration) | Wiki/Docs | Admin

Three medium size clusters public access (+private clusters). ~1500 registered users.

Showroom

Movie 1

Movie 2

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

Let's plug ... & play!

1. Register at madgraph.hep.uiuc.edu

2. t tbar production: pp>tt~>bb~mu+ e- ve~ vm (or fully hadronic:pp>tt~>bb~jjjj).

3. t tbar + Higgs : pp>h>tt~bb~ (QCD=2,QED=2). Generate the background pp>tt~bb~ (QCD=99,QED=0) and put a min cut on the m(bb)=100 GeV.

4. Single top + Higgs: pp>tHj (QCD=0, QED=3,j=gudsc, p=gudscb). Show that there is a large negative interference between the diagrams.

5. gg>h: pp>h>mu+ e- ve~ vm (HEFT,QED). Generate the background, pp>W+W-> mu+ e- ve~ vm/h (QCD=0,QED=4). Use different Higgs masses (mh=120,mh=170). Identify a smart discriminating variable among those plotted automatically.

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MadGraph advanced features

- Latest information available at the Wiki page
- Examples : decay rates, multiprocesses, decay chains,..
- Tools and Calculators
- Full expert/developer's package downloadable
- Standalone
- MadWeight
- New physics models : FeynRules and USERMOD

Let's play advanced!

Multi-processes

http://madgraph.phys.ucl.ac.be/EXAMPLES/Cards/proc_card_2.dat

http://madgraph.phys.ucl.ac.be/EXAMPLES/Cards/proc_card_2.dat

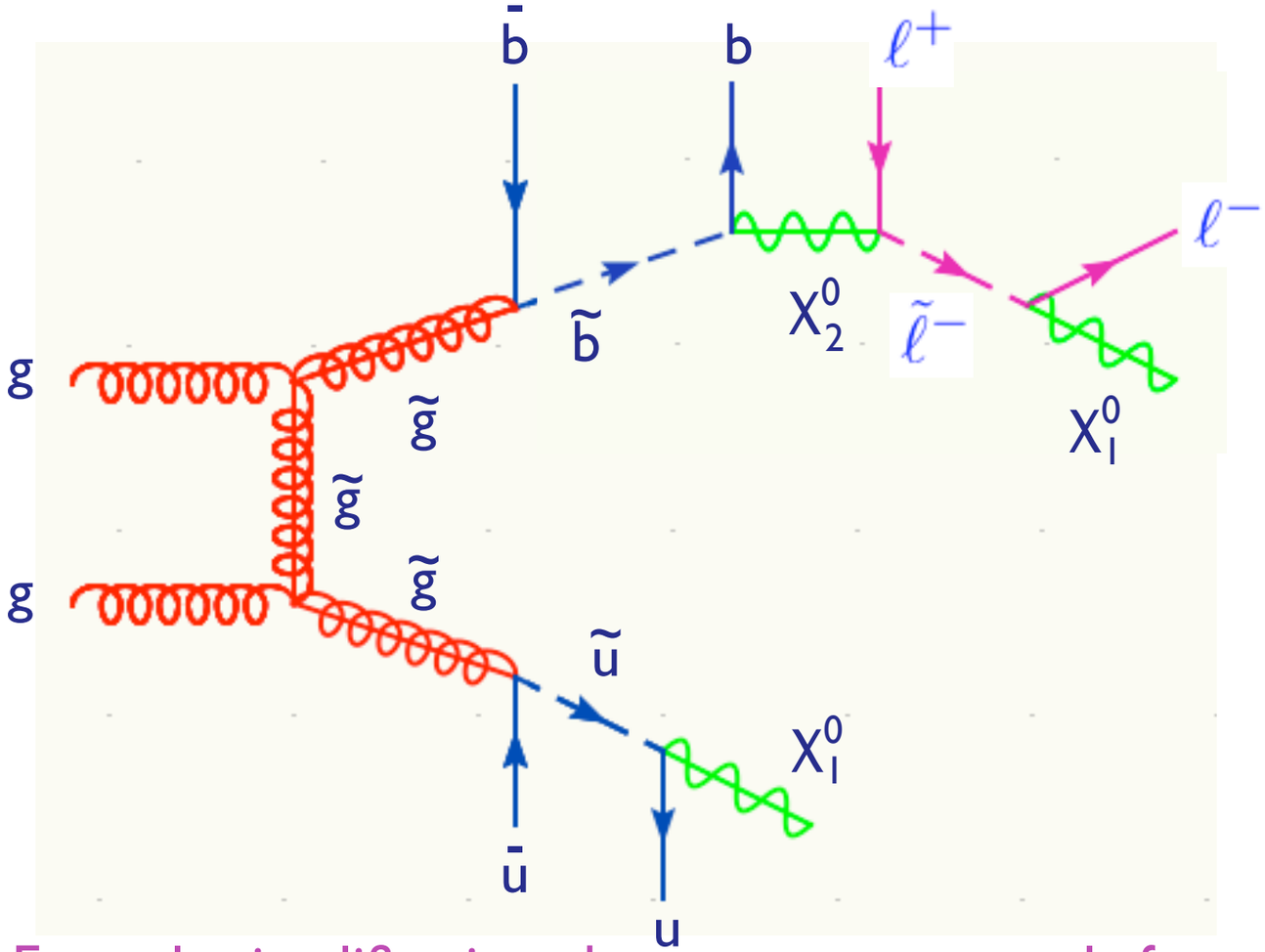
SPINS Java Homepage | Dictionary.com | Free Online Translator | CP3 | Il Blog di Beppe Grillo | sole24radio

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

pp>h>tt~bb~ @1     # First Process: signal for tt~h
QCD=2              # Max QCD couplings
QED=2              # Max QED couplings
end_coup           # no more couplings for this proc

pp>tt~bb~   @2     # Second Process: QCD background tt~bb~
QCD=99             # Max QCD couplings
QED=0              # Max QED couplings
end_coup           # no more couplings for this proc

pp>tt~bb~/h @3     # First Process: EW background  tt~bb~
QCD=2              # Max QCD couplings
QED=2              # Max QED couplings
end_coup           # no more couplings for this proc

done               # Write 'done' to tell MG to stop

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

Decay chains

[Alwall and Stelzer,2007]

```
gg >(go>u~(ul > u n1 ))(go>b~(b1>(b(n2>mu+(mul- >mu- n1)))))
```



In this case:

1. Full matrix element is obtained which includes correlations between production and decays.
2. Spin of the intermediate states is kept.
3. One can go beyond 1→2 decays.
4. Resonances have BW.
5. Non-resonant contributions can be systematically included only where relevant.

Example simplification: the process can exactly factorized in

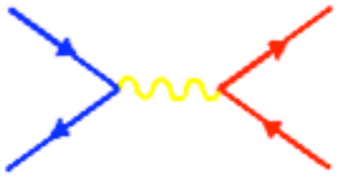
```
gg >(go>u~ul)(go>b~b1)
```

where the squarks can be decayed at the event level, for example by BRIDGE

[Maede and Reece,2007]

```
ul > u n1
b1 > b(n2>mu+(mul- >mu- n1))
```

Web tools



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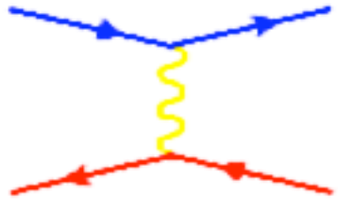

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Online MadGraph/MadEvent related tools

Calculators

Plotting Interface (ExRootAnalysis)

Plotting Interface (MadAnalysis)

Decay Interface

Installing the MG/ME & analysis routines:

1. Get the full thing:

wget http://madgraph.phys.ucl.ac.be/Downloads/MG_ME_V4.2.11.tar.gz;
tar zxvf MG_ME_V4.2.11.tar.gz;
cd MG_ME_V4.2.11

2. Get a very simple LHE and LHCO event analyzer:

wget http://madgraph.phys.ucl.ac.be/Downloads/MadAnalysis_V1.0.7.tar.gz;
tar zxvf MadAnalysis_V1.0.7.tar.gz

3. make

4. Install topdrawer :

cd MadAnalysis; wget http://madgraph.phys.ucl.ac.be/Downloads/td.tgz

MadGraph Standalone

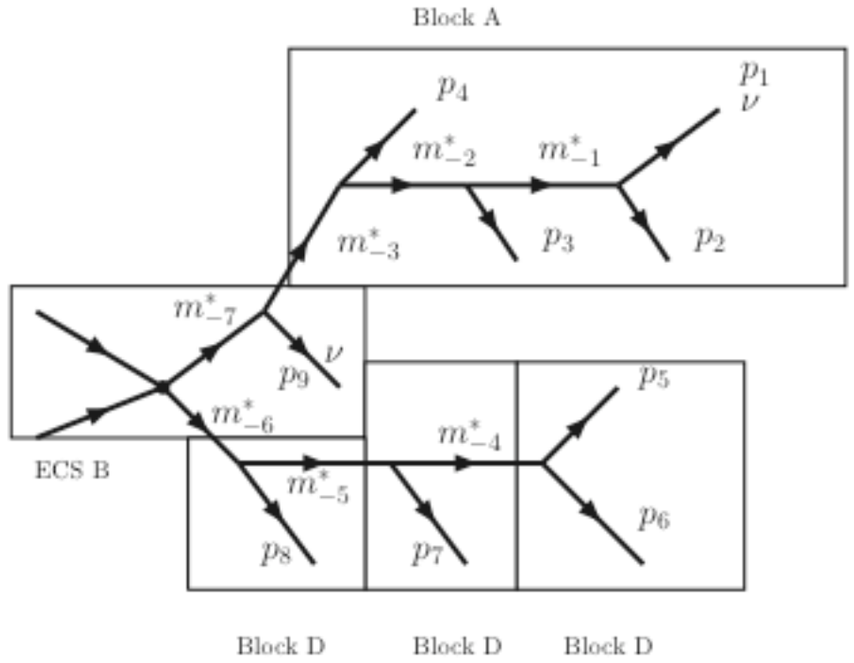
- "Naked" Matrix elements can be also generated to be EXPORTED to any other ME MC or used in higher order computations.
- Matrix elements can be tested point-by-point in phase space AUTOMATICALLY for ANY process.
- Model and parameters are included in a small library (easy to compare different model implementations).

http://cp3wks05.fynu.ucl.ac.be/twiki/bin/view/Software/StandAlone

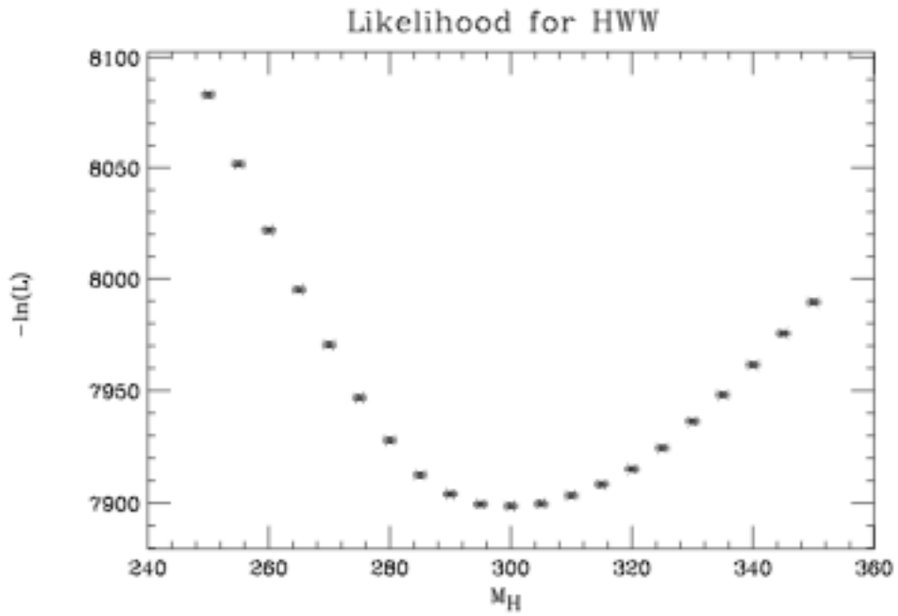
Matrix element methods

[Artoisenet, Lemaitre, FM, Mattelaer]

- Tool to find matrix element weight of experimental events for (almost) any process in any model.



Phase space integration using automatic change of variables to align with peaks



Find likelihood for model parameters (here Higgs mass in $h \to WW$)

http://cp3wks05.fynu.ucl.ac.be/twiki/bin/view/Software/MadWeight

code available on demand

Automatic dipole subtraction

[Frederix, Greiner, in progress]

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

- Goal: Automatic Dipole Subtraction for any NLO calculation
  - Catani-Seymour subtraction scheme
  - Reals & subtraction terms for the reals and virtuals
  - Both for SM and BSM
  - Compatible with MG StandAlone
- Beta version working!

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one hour tutorial on matrix element generation

Thanks for your attention
and your feedback!

Q&A

- Max particles in the final state

  - It depends on the process type. Max number of jets is 4. Max number of particles in general is 8. We are adding the decay chain feature which will allow to select (gauge invariant) subclasses of diagrams leading to higher multiplicities. In any case presently there is a maximum number of 10^4 diagrams per process allowed.

- Is it possible to have e^+ e^- polarized beams in the initial state?

  - Yes. There is now an option available in the run_card.dat

- How do I generate signal and background together from the web?

  - Use the upload proc_card.dat option in the generate process web page. Look at the process card examples.

Q&A

- How long does it take to generate events?
  - It strongly depends on the process and on how many subprocesses there are. Simple 2→2,3,4 processes might take up to several. Multi-jet final state can take several hours. This means that care and responsability is needed when requests are sent to the clusters. Time = $ ....
- How do I make my own plots?
  - You can use the web tool. Or you can use Root by exploiting the root files created on the web. Or MadAnalysis which produces ASCII files in the topdrawer format (easily importable in gnuplot). This last option is very flexible and very easy.
- Is it possible to make scans of parameters space of a model?
  - Yes. You dowload the MG/ME code and write a simple script, starting for example from bin/multi_run. Using a calculator, you can prepare the corresponding cards (param_card_xx.dat) and then feed them one after the other, by saving the results.

Q&A

- qqq
  - aaa
- qqq
  - aaa
- qqq
  - aaa