MadGraph

short tutorial on matrix element generation

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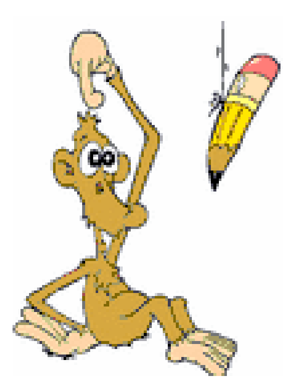
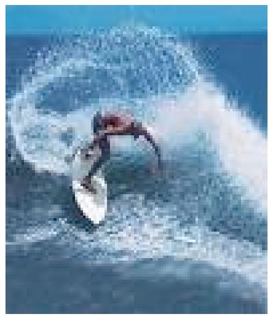
+ Tilman Plehn, David L. Rainwater,
+ Pierre Artoisenet, Claude Duhr, Olivier Mattelaer,...
+ our GOLDEN USERS!!

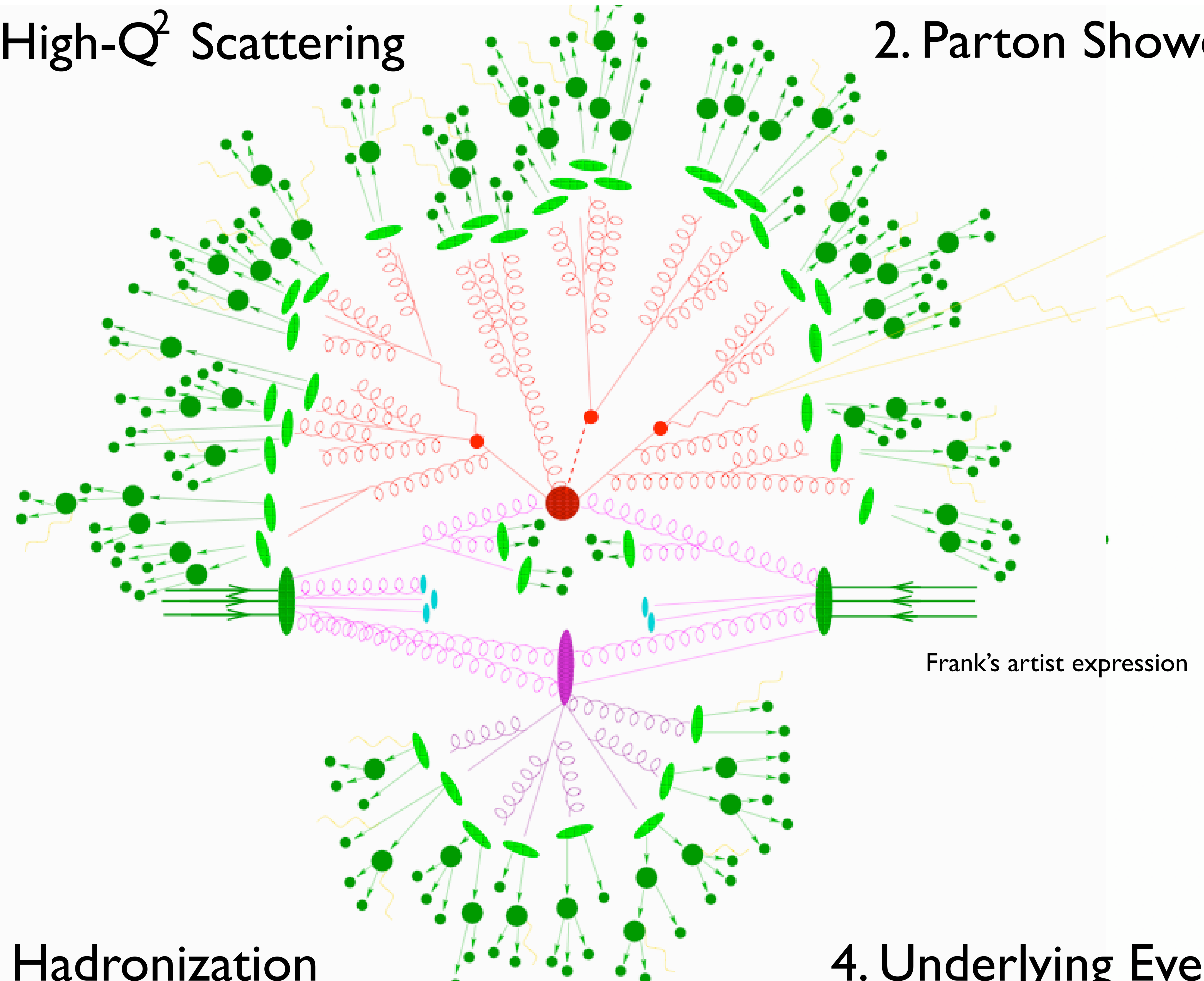
Plan

- MG/ME: overview 15’
- Web generation: physics at the LHC 15’

\+  -  = 

1. High-Q^2 Scattering

2. Parton Shower



Frank's artist expression

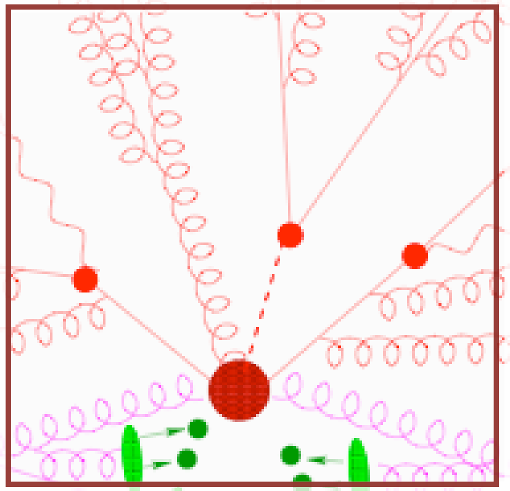
3. Hadronization

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)

What's a matrix-element based generator?

$$\sigma_X = \sum_{a,b} \int_0^1 dx_1 dx_2\, f_a(x_1, \mu_F^2) f_b(x_2, \mu_F^2) \times \hat{\sigma}_{ab \to X}(x_1, x_2, \alpha_S(\mu_R^2), \frac{Q^2}{\mu_F^2}, \frac{Q^2}{\mu_R^2}$$

- Matrix element calculators provide our first estimation of rates for inclusive final states.

- Extra radiation is included: it is described by the PDF's in the initial state and by the definition of a final state parton, which at LO represents all possible final state evolutions.

- Due to the above approximations a cross section at LO can strongly depend on the factorization and renormalization scales.

- Any tree-level calculation for a final state F can be promoted to the exclusive F + X through a shower. However, a naive sum of final states with different jet multiplicities would lead to double counting.

The technical challenges

How do we calculate a LO cross section for 3 jets at the LHC?

I. Identify all subprocesses (gg→ggg, qg→qgg....) in

$$\sigma(pp \to 3j) = \sum_{ijk} \int f_i(x_1) f_j(x_2) \hat{\sigma}(ij \to k_1 k_2 k_3)$$

easy

II. For each one, calculate the amplitude:

$$\mathcal{A}(\{p\},\{h\},\{c\}) = \sum_i D_i$$

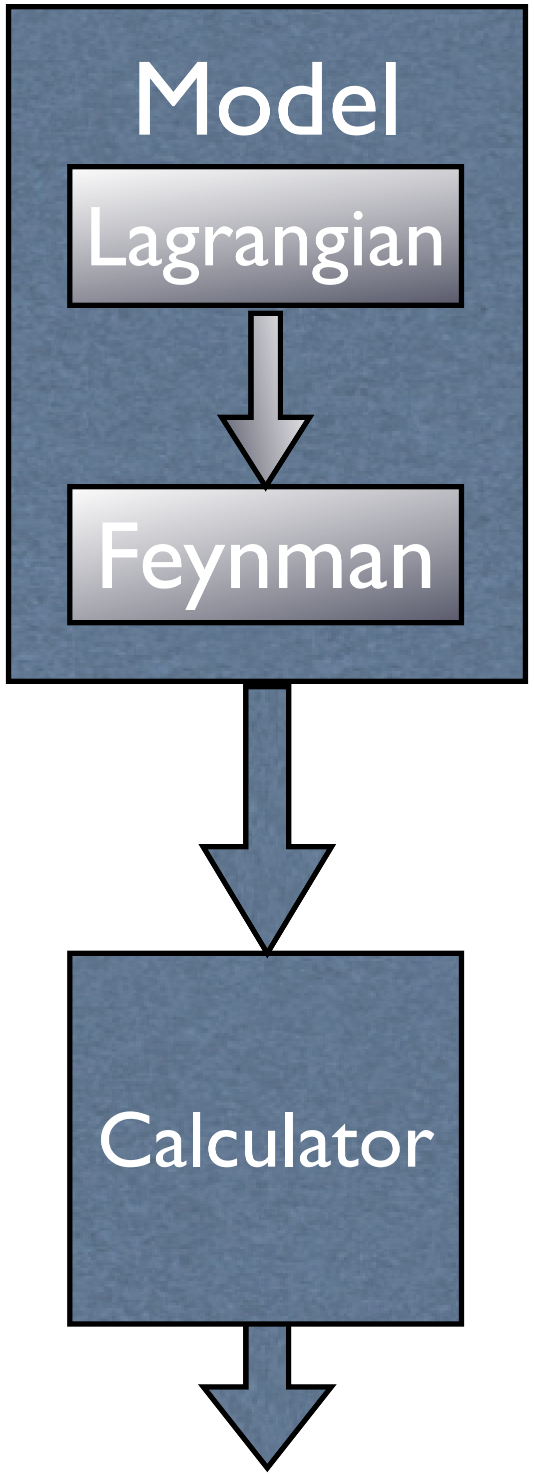
difficult

III. Square the amplitude, sum over spins & color, integrate over the phas
space (D ~ 3n)

$$\hat{\sigma} = \frac{1}{2\hat{s}} \int d\Phi_p \sum_{h,c} |\mathcal{A}|^2$$

very hard

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

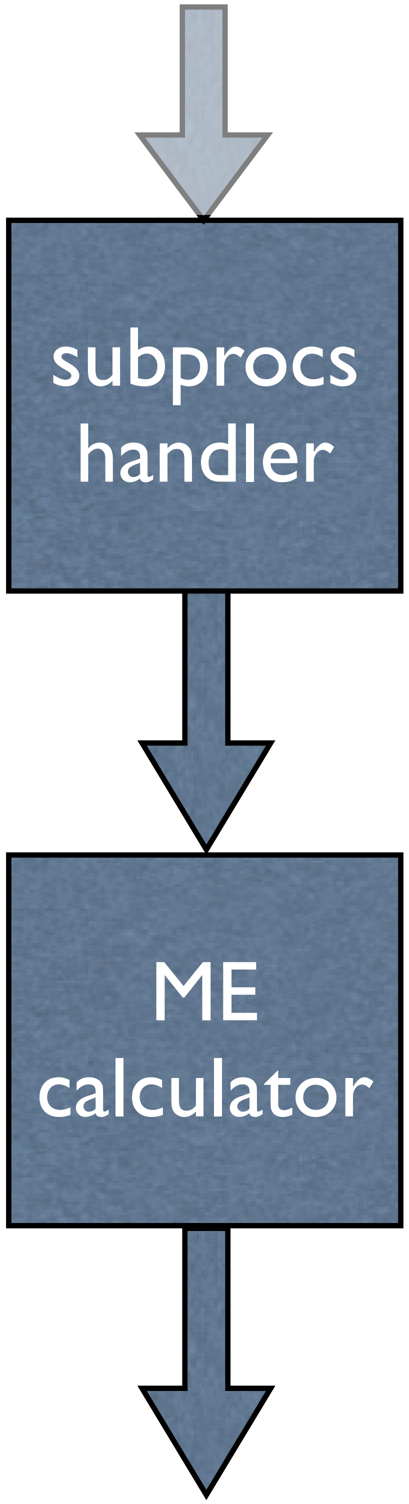
SUSY, Little Higgs, Higgsless, GUT, Extra dimensions (flat, warped, universal,...)

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...

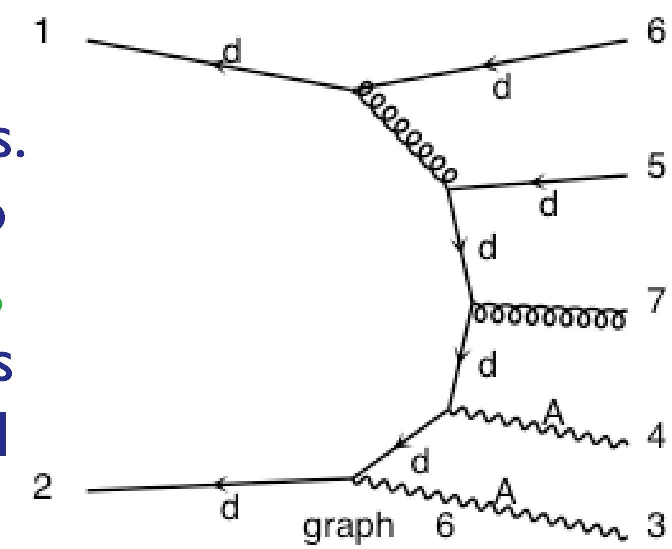
Matrix Element based MC's



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

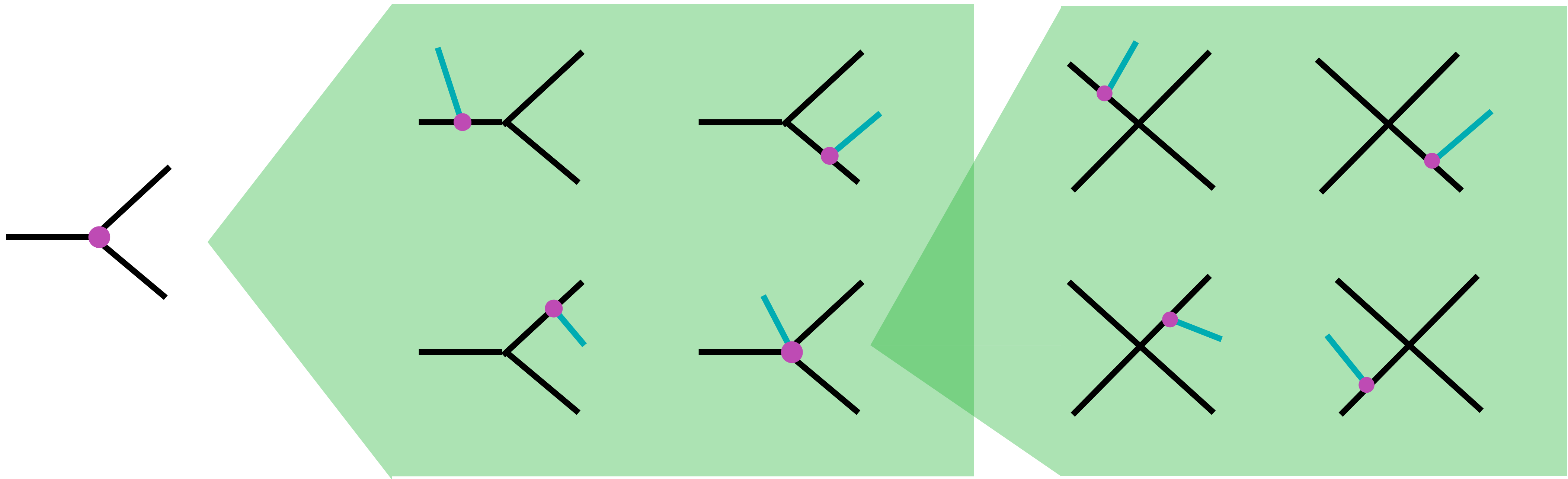
d~ d -> a a u u~ g
d~ d -> a a c c~ g
s~ s -> a a u u~ g
s~ s -> a a c c~ g

<u>Automatically</u> 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

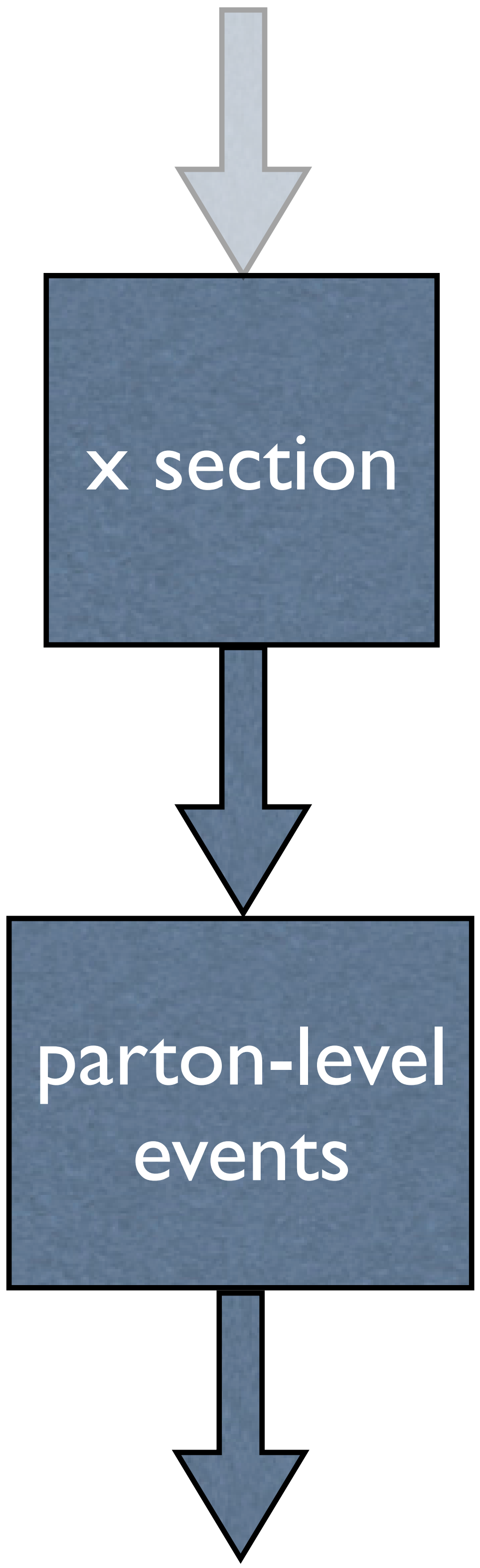


2. Dress the topologies with particles starting from the external particles and checking the existence of the corresponding verteces.

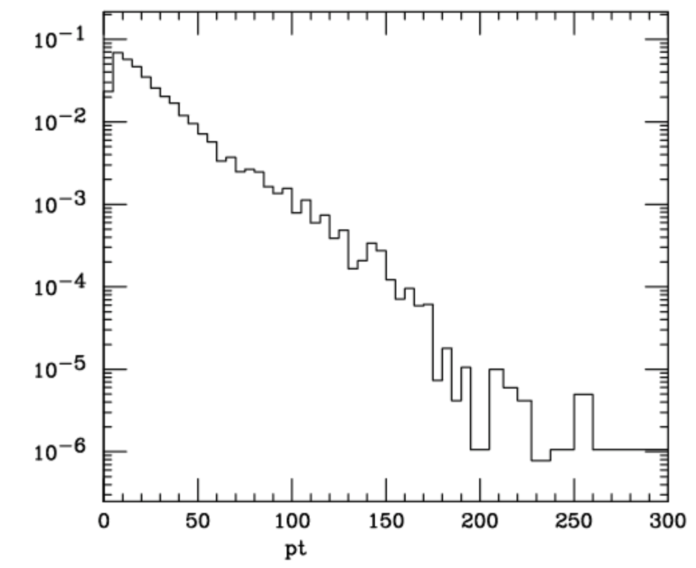
3. Write out a code based on the Feynman rules library.

"Only" a book-keeping problem!

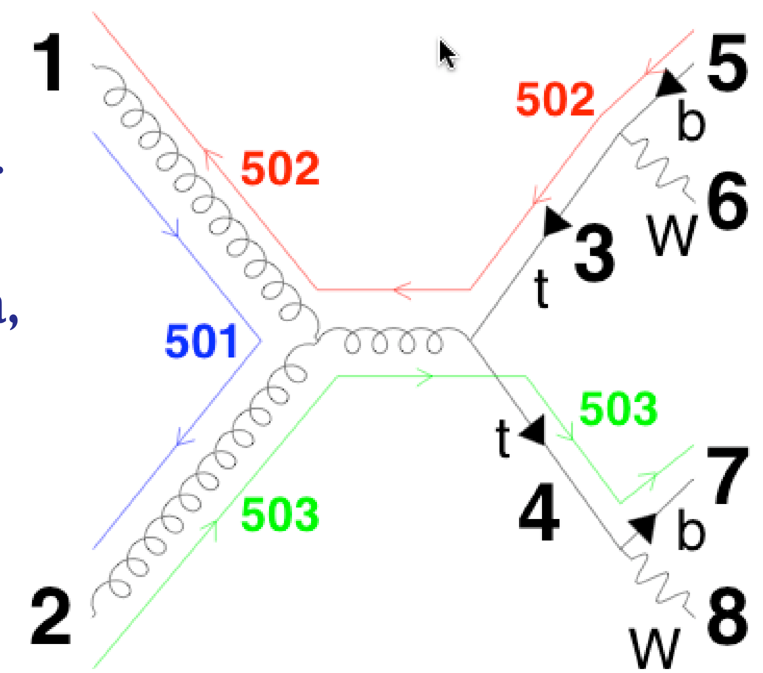
Matrix Element based MC's



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



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.



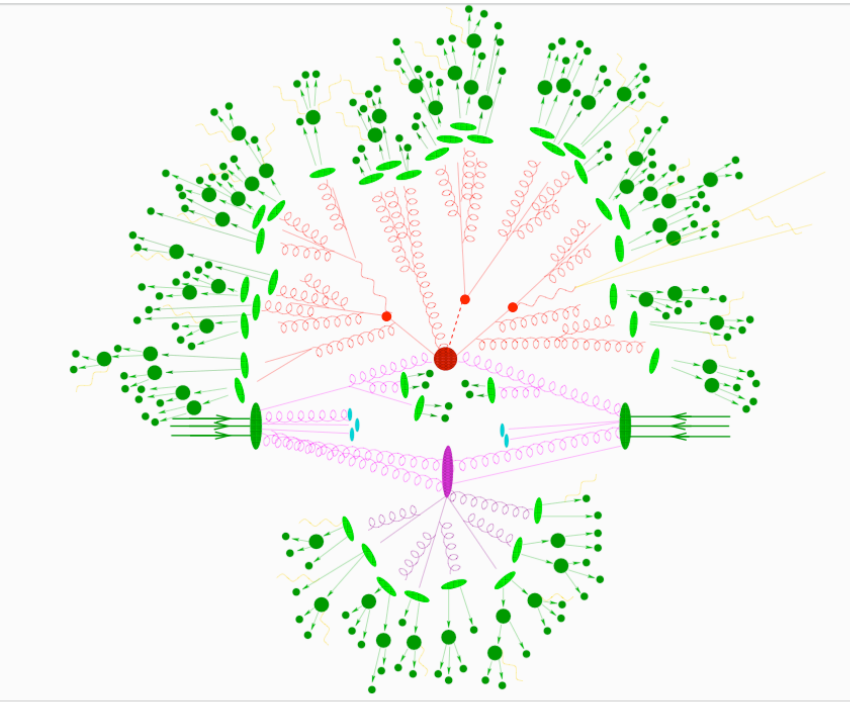
Matrix Element based MC's

Shower & Hadro

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!

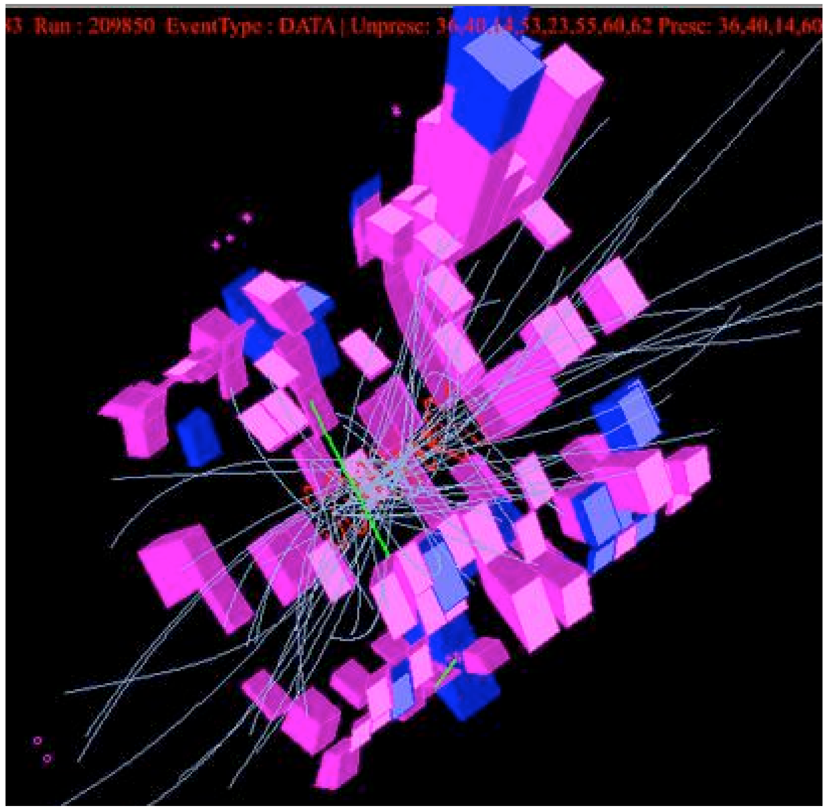


th

exp

Detector simulation & reco

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]

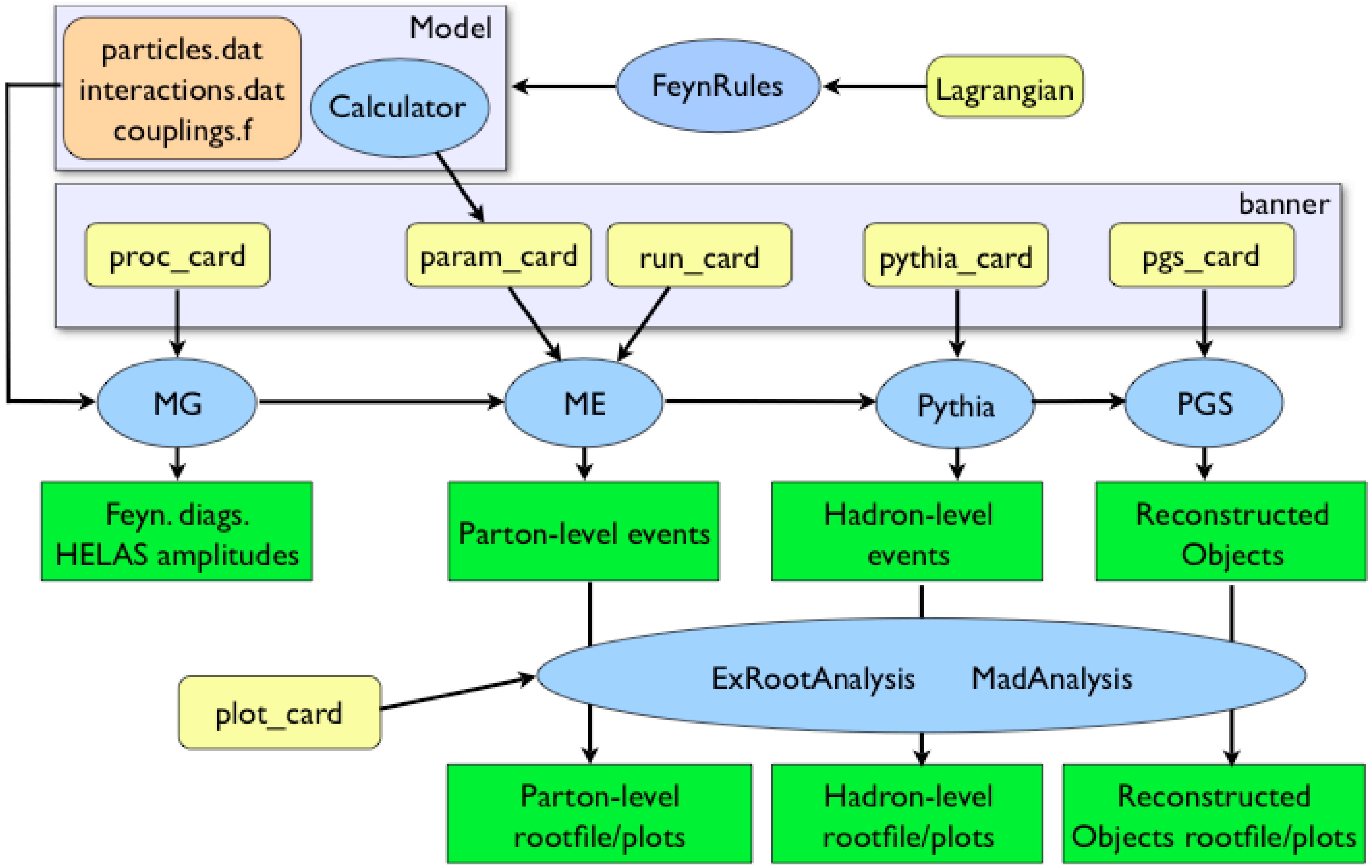
- The new web generation:
  - User requests a process (Ex. pp>tt~jjj) and corresponding code is generated on the fly.
  - User inputs model/parameters/cuts, and code runs in parallel on modest farms.
  - MG/ME Returns cross section, plots, parton-level events.
- Advantages:
  - Reduces overhead to getting 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

High Energy Physics Illinois

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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

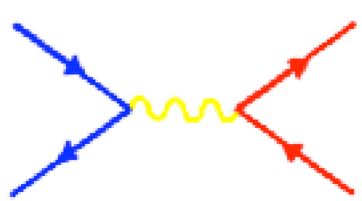
http://madgraph.hep.uiuc.edu/

Center for Particle Physics and Phenomenology - CP3

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

MUSEO STORICO DELLA FISICA E CENTRO STUDI E RICERCHE

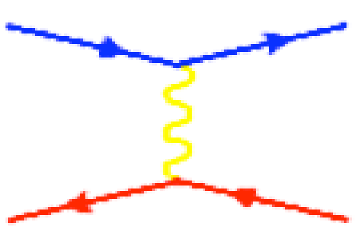
http://madgraph.roma2.infn.it/



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.

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).

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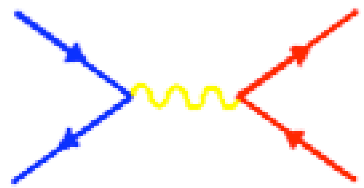
Multi-processes

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

```
#*********************************************************************
#--------------------------------------------------------------------*
# 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                                                  *
```

Web tools



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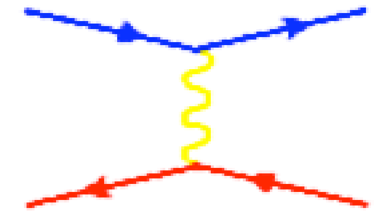


Generate Process | Register | Tools | My Database | Cluster Status | Downloads (needs registration) | Wiki/Docs | Admin

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

MC basics:

from integration to event generation

Calculations of cross section or decay widths involve integrations over high-dimension phase space of very peaked functions:

$$\sigma = \frac{1}{2s}\int |\mathcal{M}|^2 d\Phi(n)$$

$$Dim[\Phi(n)] \sim 3n$$

General and flexible method is needed

Integrals as averages

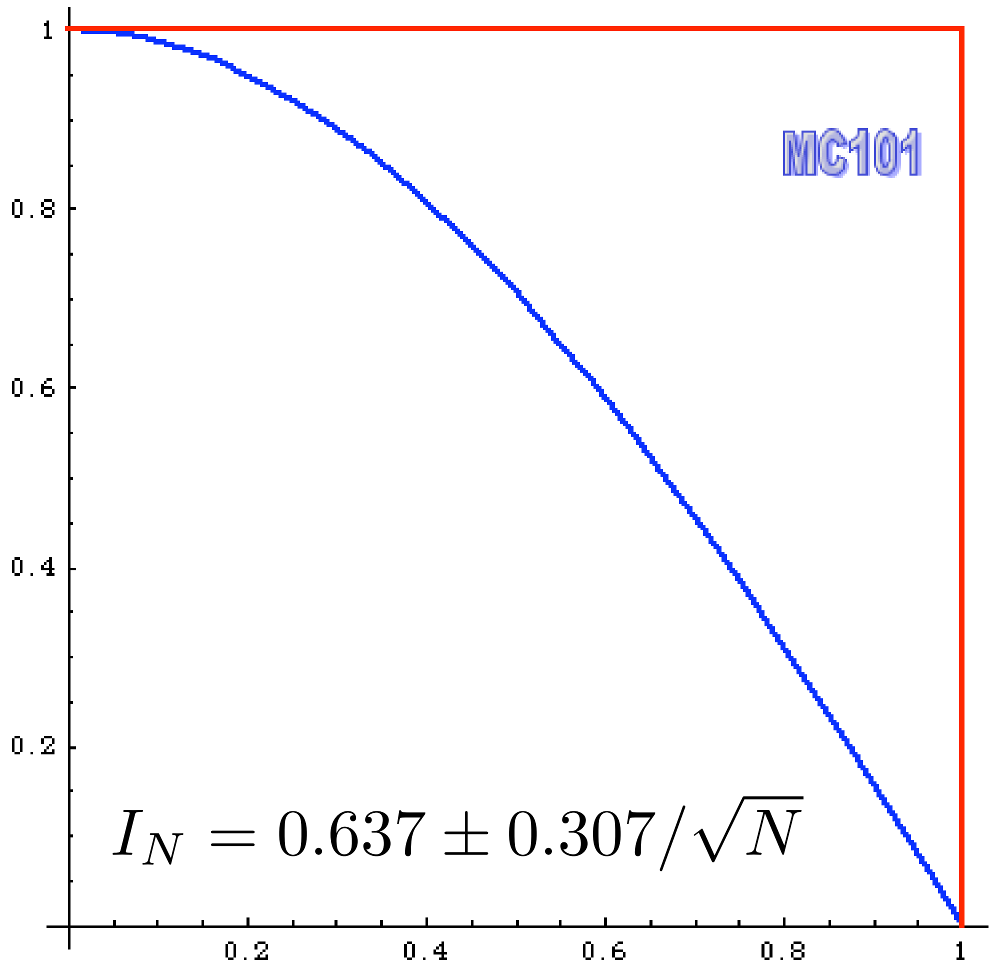
$$I = \int_{x_1}^{x_2} f(x)dx \quad \Rightarrow \quad I_N = (x_2 - x_1)\frac{1}{N}\sum_{i=1}^{N} f(x)$$

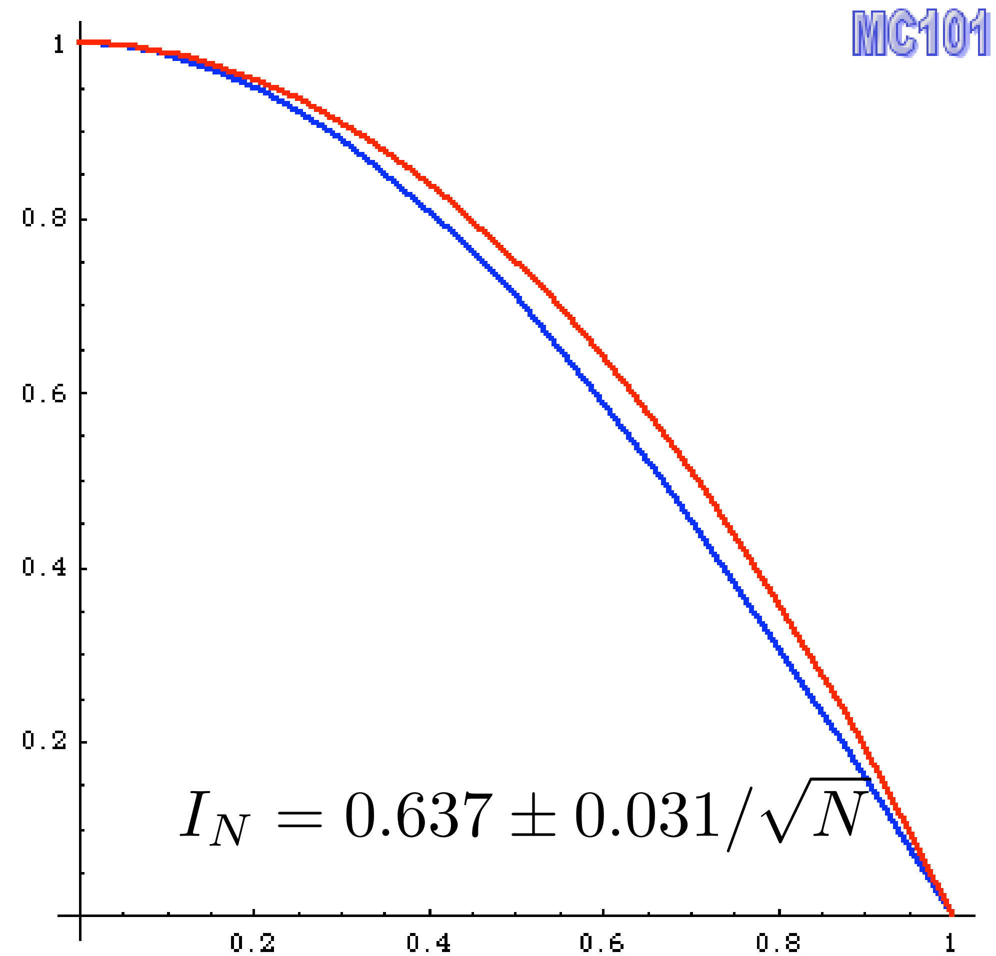
$$V = (x_2 - x_1)\int_{x_1}^{x_2} [f(x)]^2 dx - I^2 \quad \Rightarrow \quad V_N = (x_2 - x_1)^2 \frac{1}{N}\sum_{i=1}^{N} [f(x)]^2 - I_N^2$$

$$I = I_N \pm \sqrt{V_N/N}$$

- ☞ Convergence is slow but it can be estimated easily
- ☞ Error does not depend on # of dimensions!
- ☞ Improvement by minimizing V_N.
- ☞ Optimal/Ideal case: $f(x)=C \Rightarrow V_N=0$

Importance Sampling



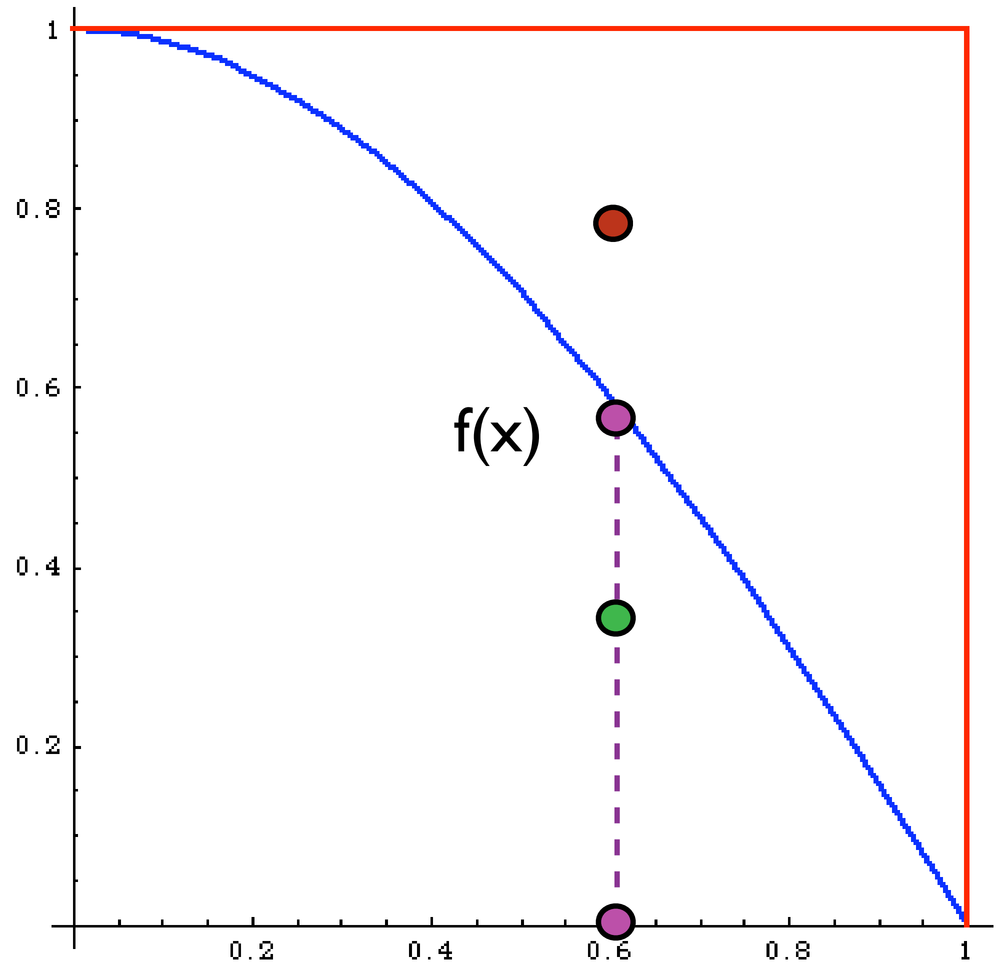


$$I = \int_0^1 dx \cos\frac{\pi}{2}x$$

$$I = \int_0^1 dx(1-x^2)\frac{\cos\frac{\pi}{2}x}{1-x^2}$$

$$= \int_{\xi_1}^{\xi_2} d\xi \frac{\cos\frac{\pi}{2}x[\xi]}{1-x[\xi]^2} \Rightarrow \simeq 1$$

Event generation



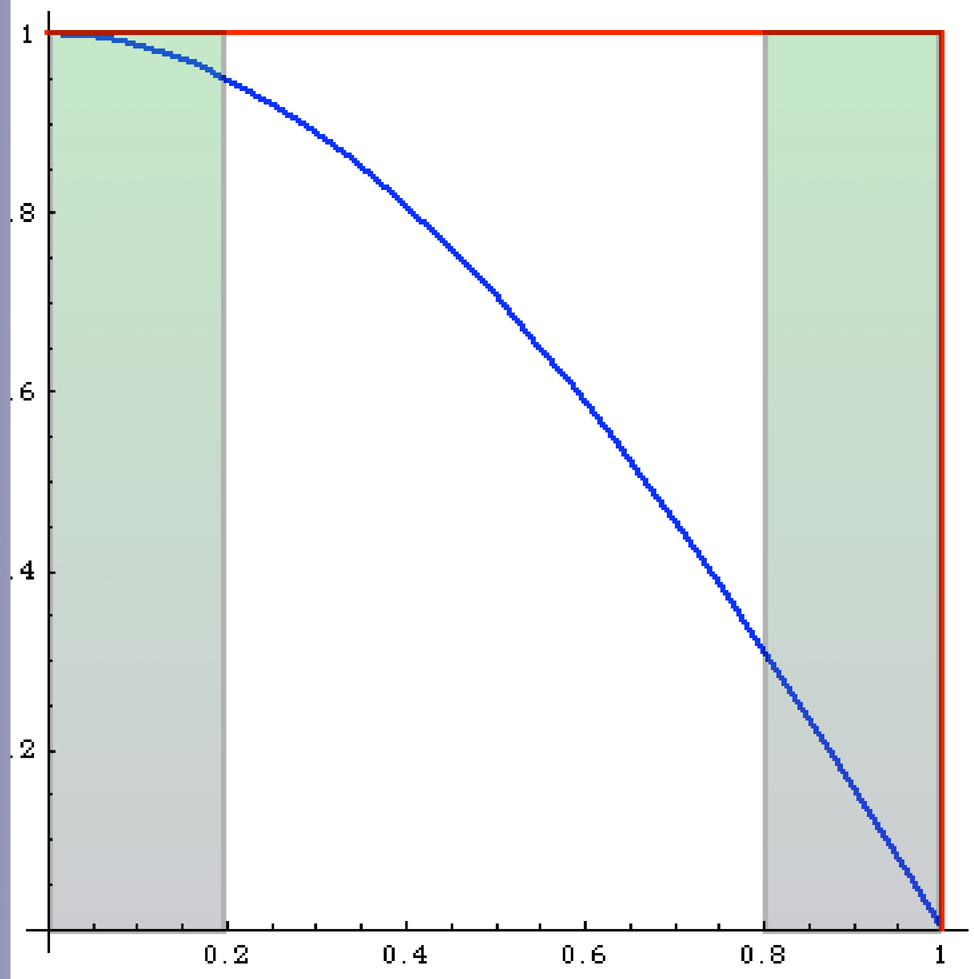
Alternative way

1. pick x
2. calculate f(x)
3. pick 0<y<fmax
4. Compare:
   if f(x)>y accept event,

   else reject it.

$$I = \frac{\text{accepted}}{\text{total tries}} = \text{efficiency}$$

Event generation

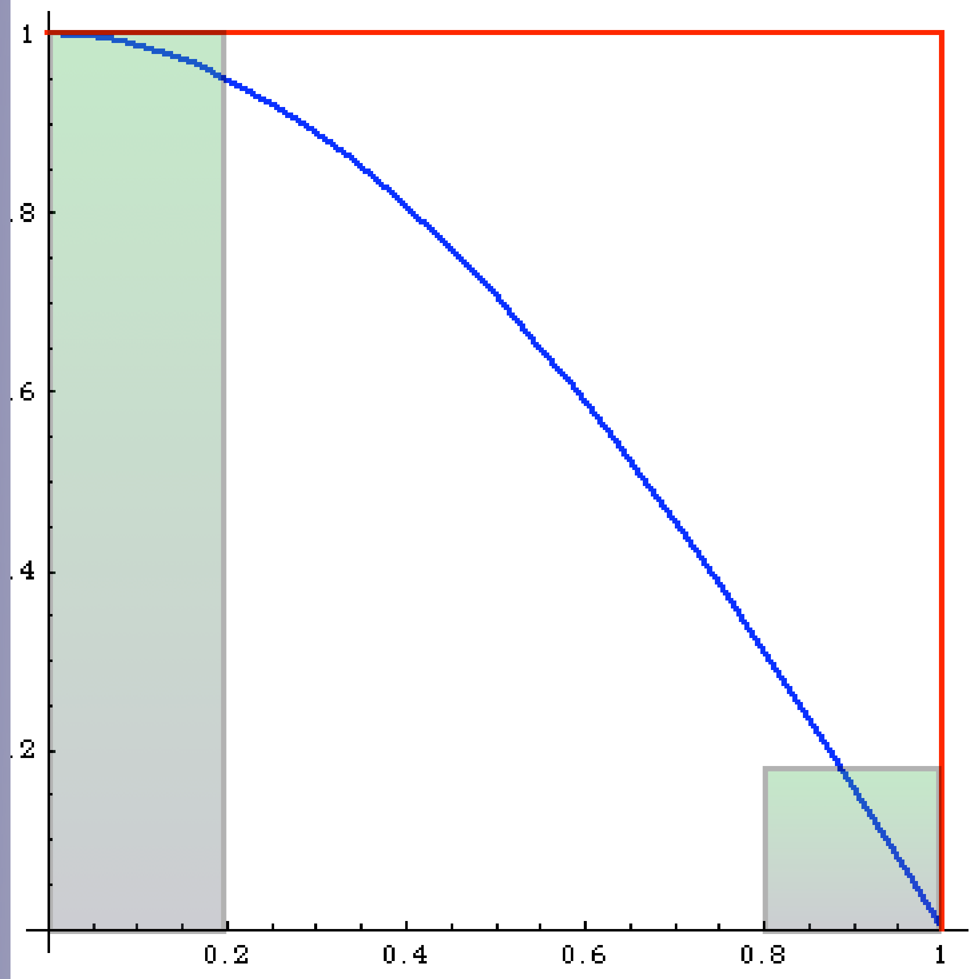


What's the difference?

before:

same # of events in areas of phase space with very different probabilities: events must have different weights

Event generation



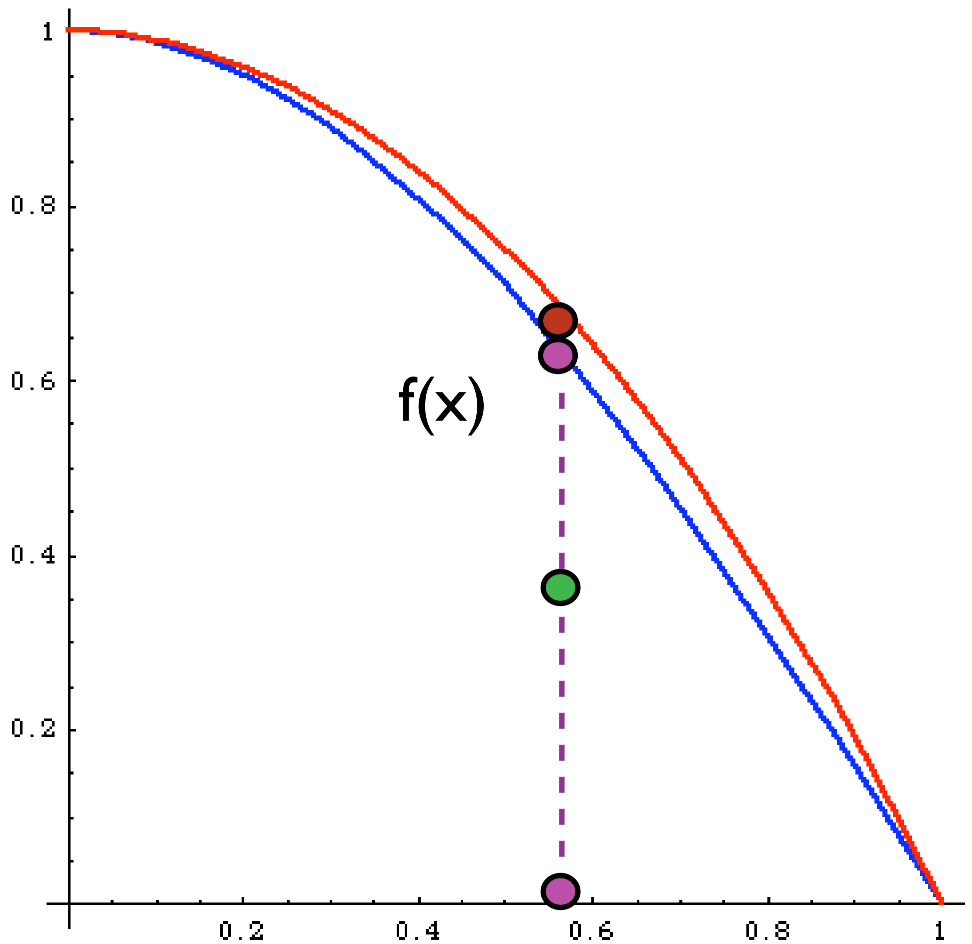
What's the difference?

after:

events is proportional to the probability of areas of phase space:
events have all the same weight ("unweighted")

Events distributed as in Nature

Event generation



Improved

1. pick x distributed as p(x)
2. calculate f(x) and p(x)
3. pick 0<y<1
4. Compare:
   if f(x)>y p(x) accept event,

else reject it.

much better efficiency!!!

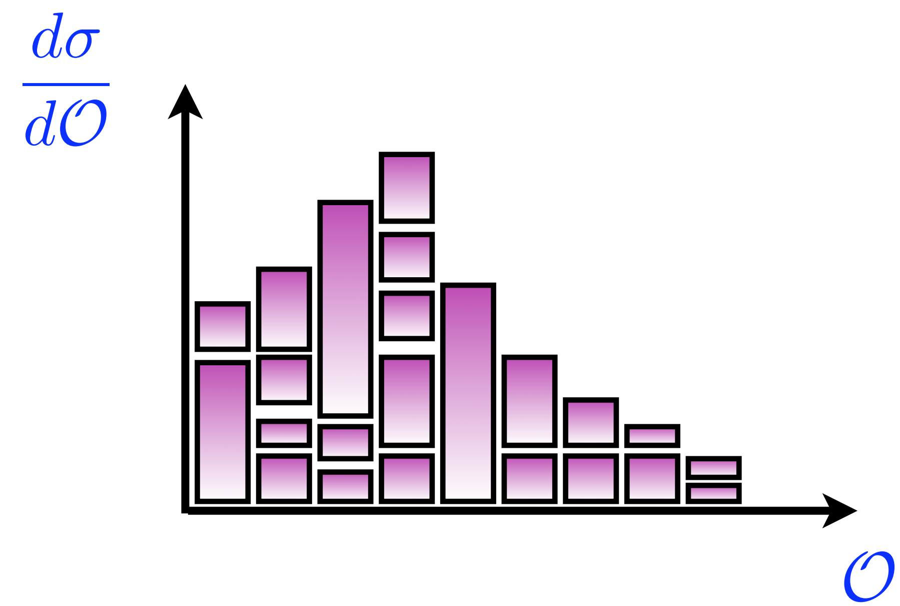
Event generation

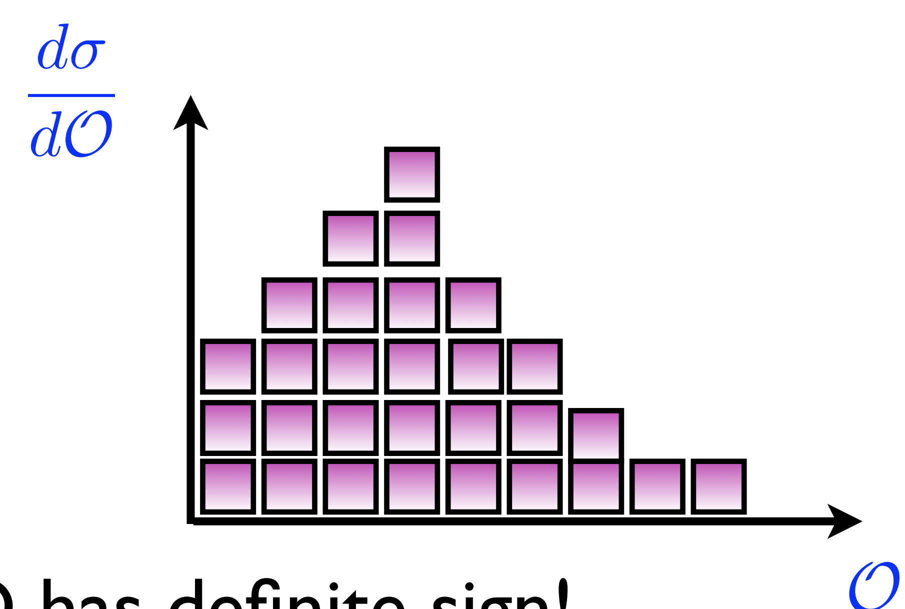
MC integrator

↓

Event generator

← Acceptance-Rejection





☞ This is possible only if $f(x)<\infty$ AND has definite sign!