MadGraph

a first hands-on tutorial

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

Plan

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- The Big picture 30’

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- MG/ME: overview 30’

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- Web generation: physics at the LHC 60’

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[from M.L. Mangano, 2008]

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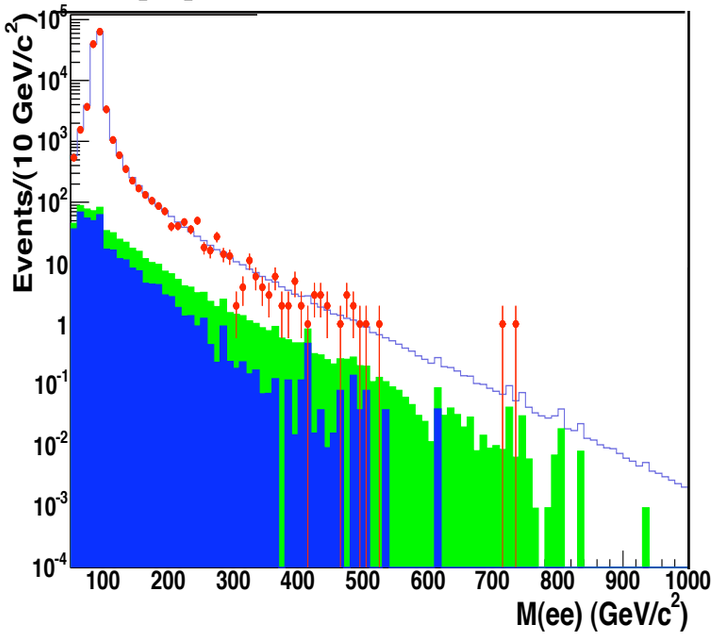

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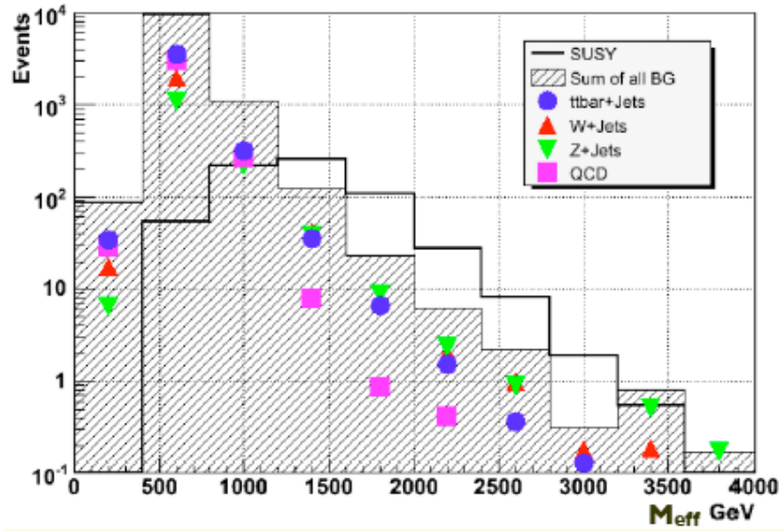

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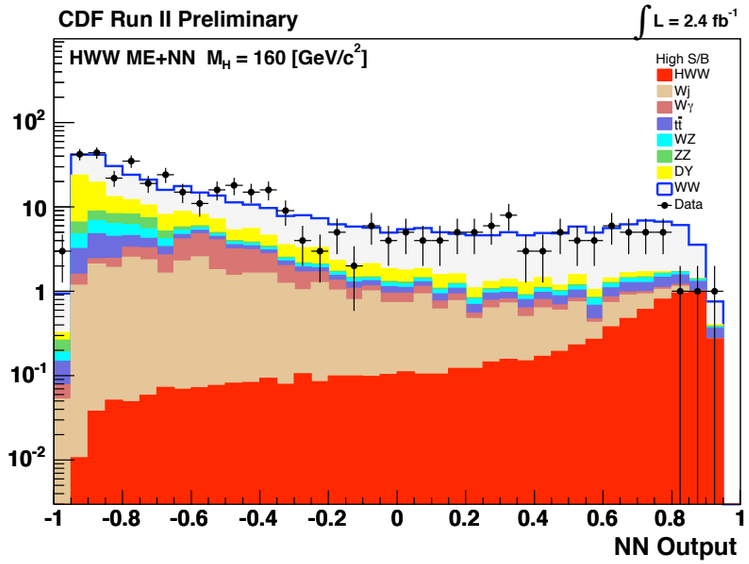

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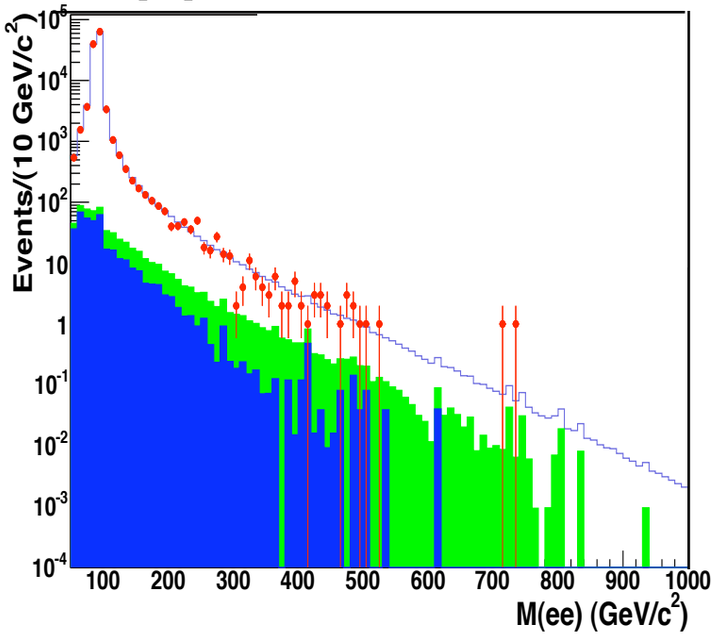

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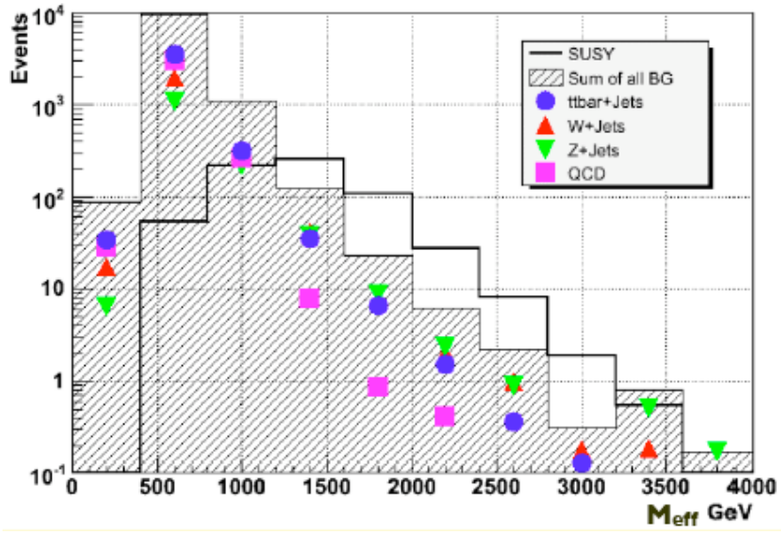

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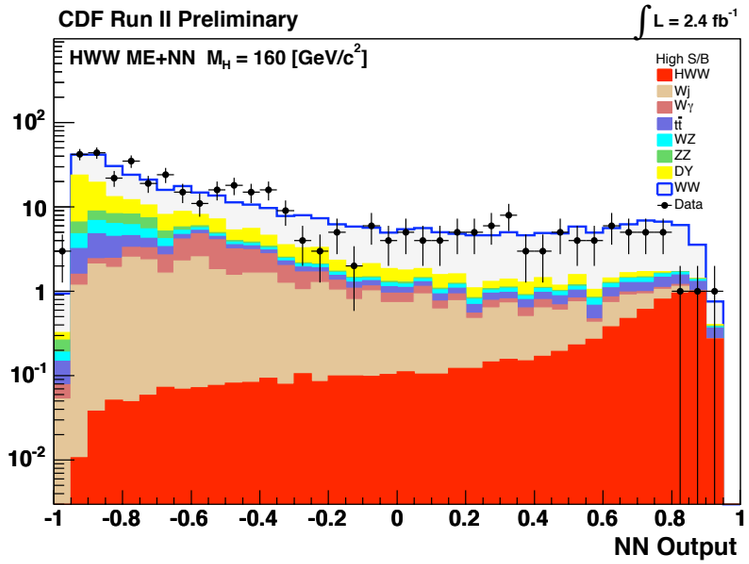

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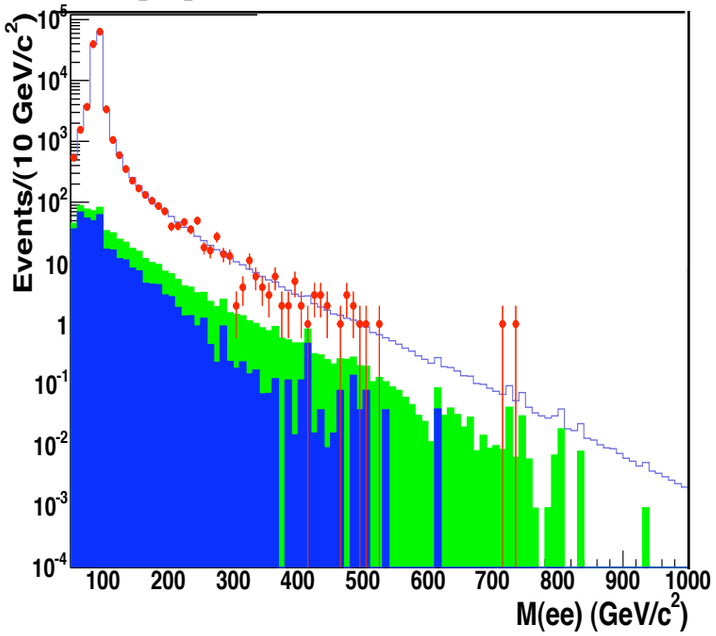

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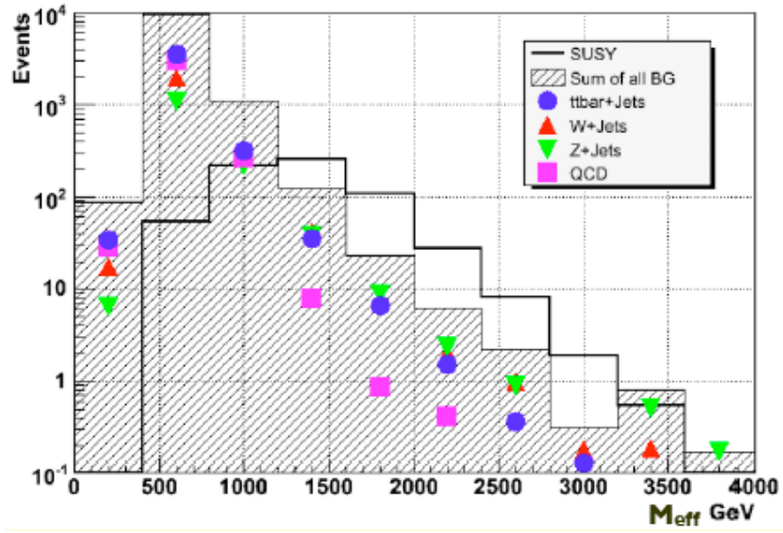

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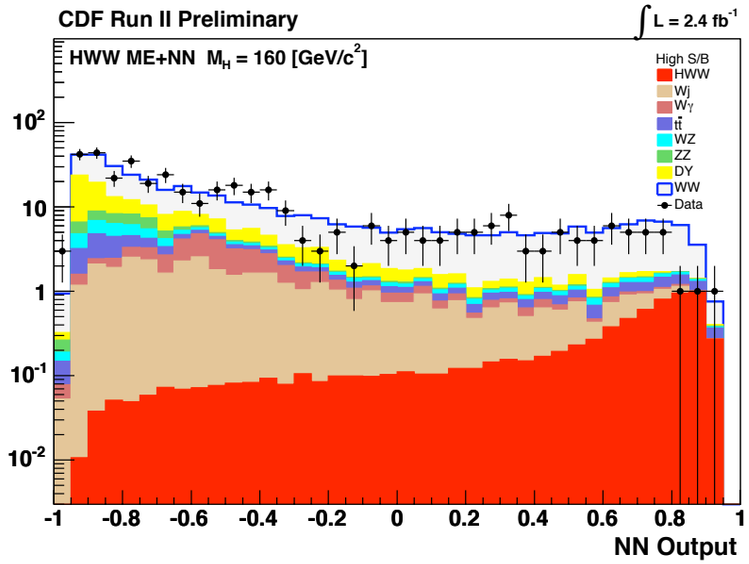

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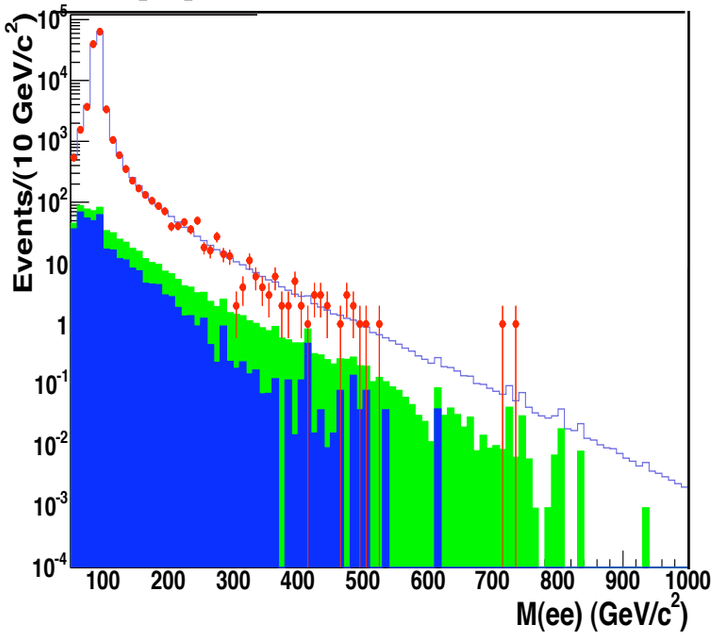

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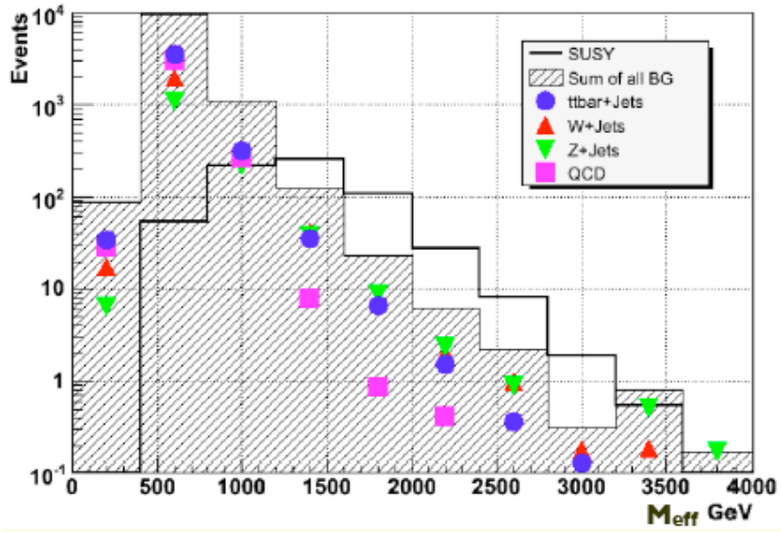

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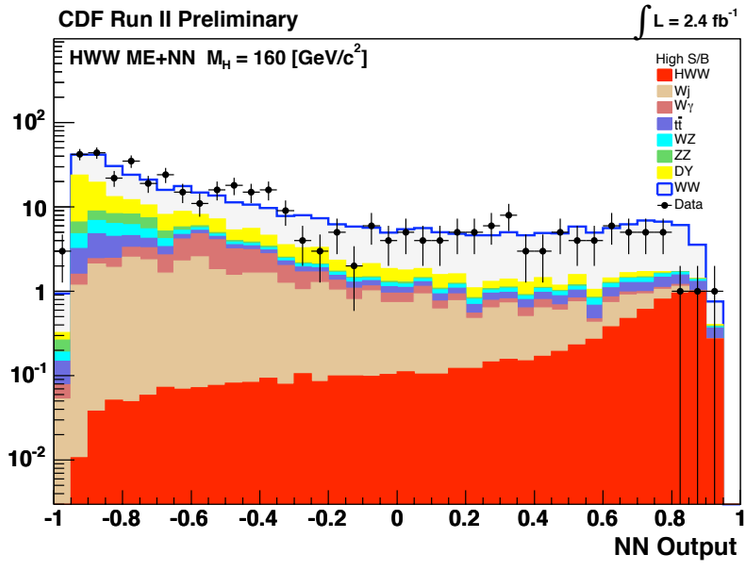

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Background normalization and shapes known very well. Interplay with the best theoretical predictions (via MC) and data.

A new challenge

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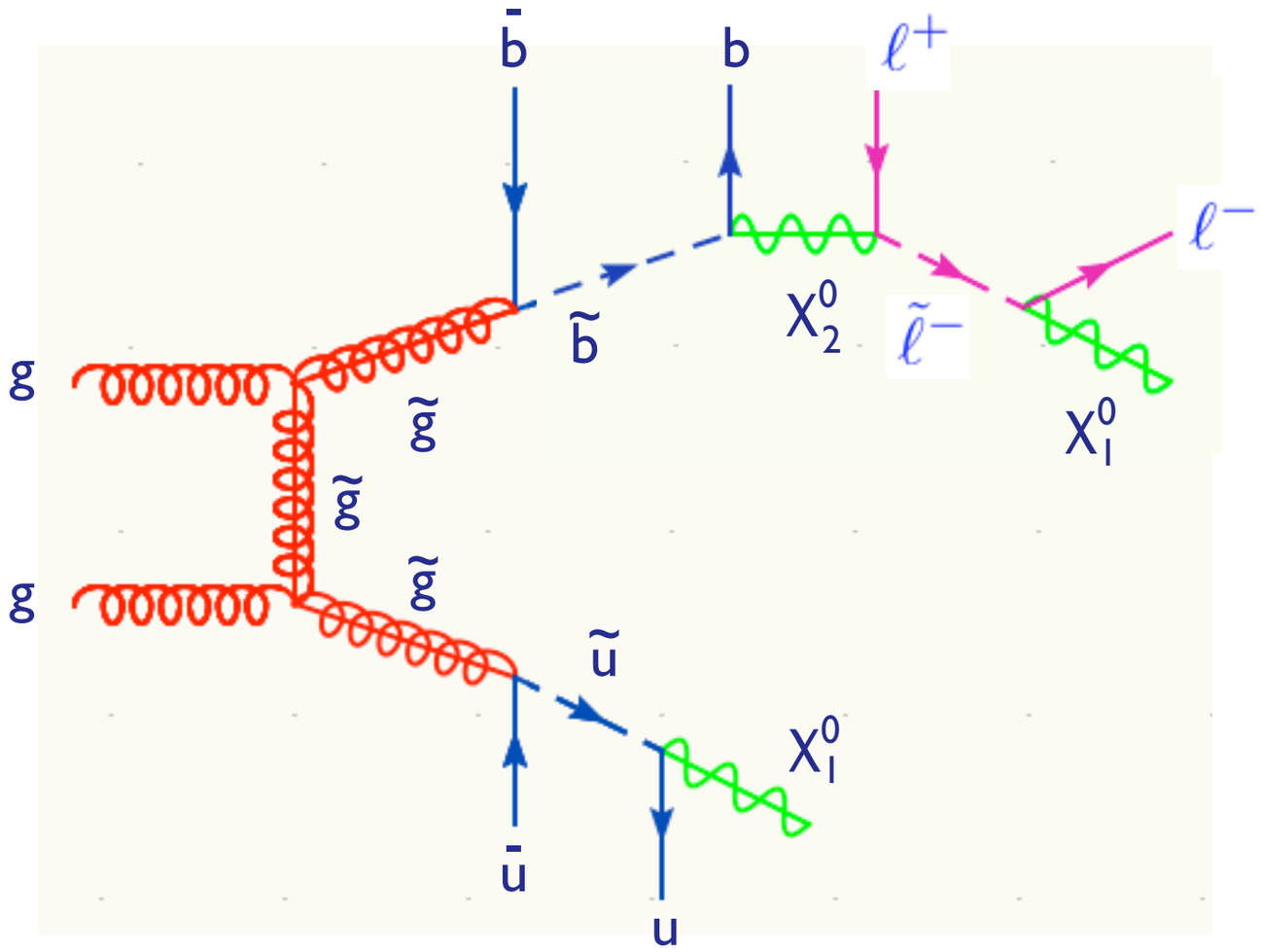

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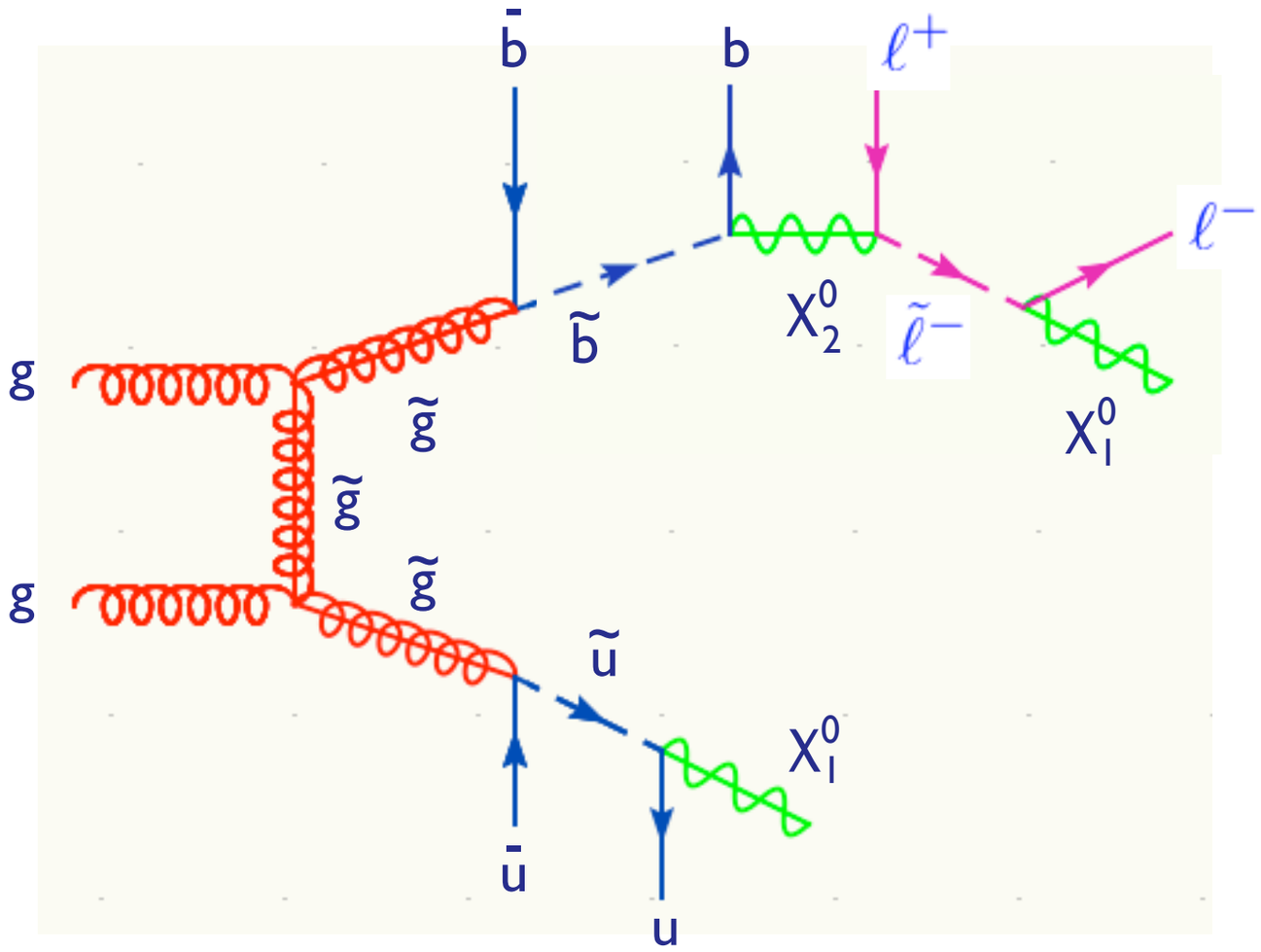

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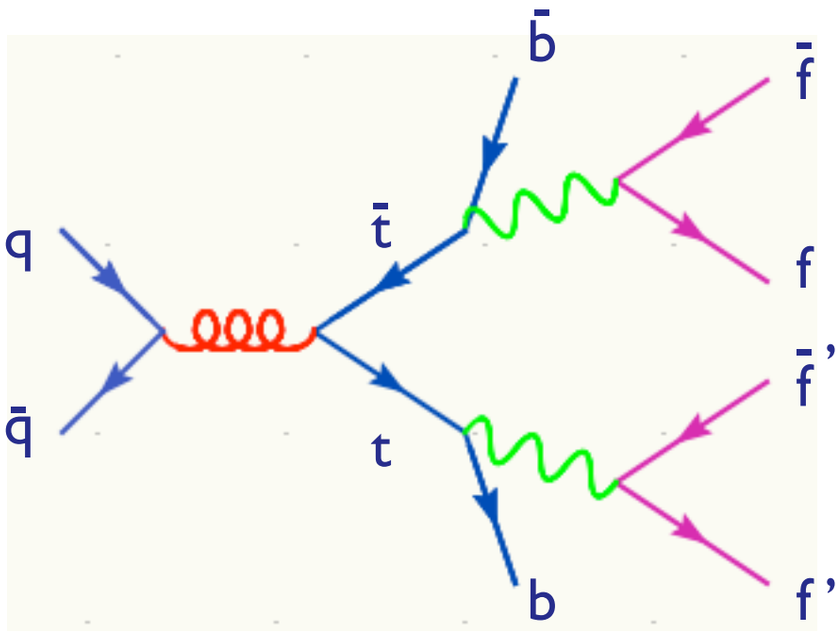

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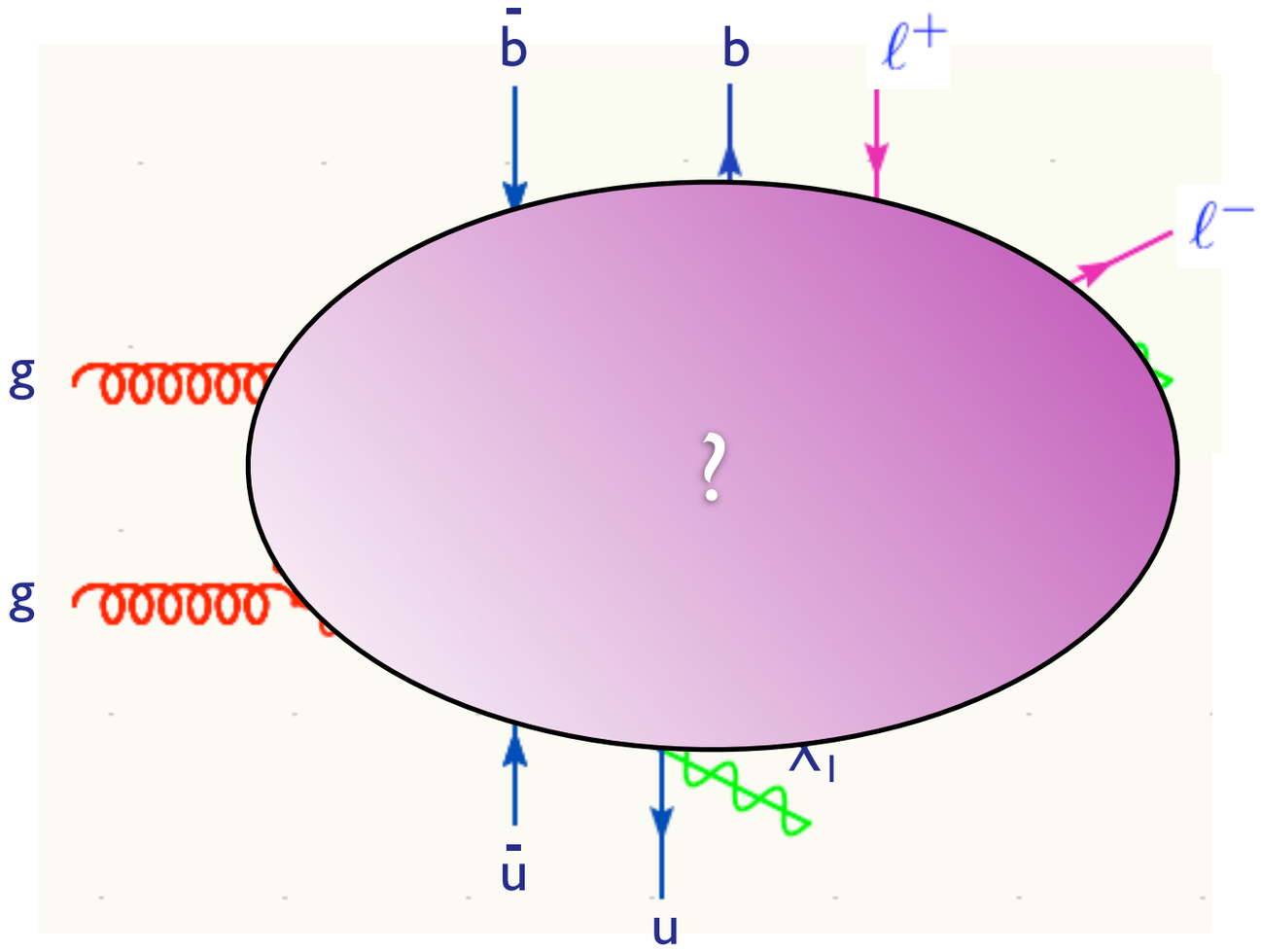

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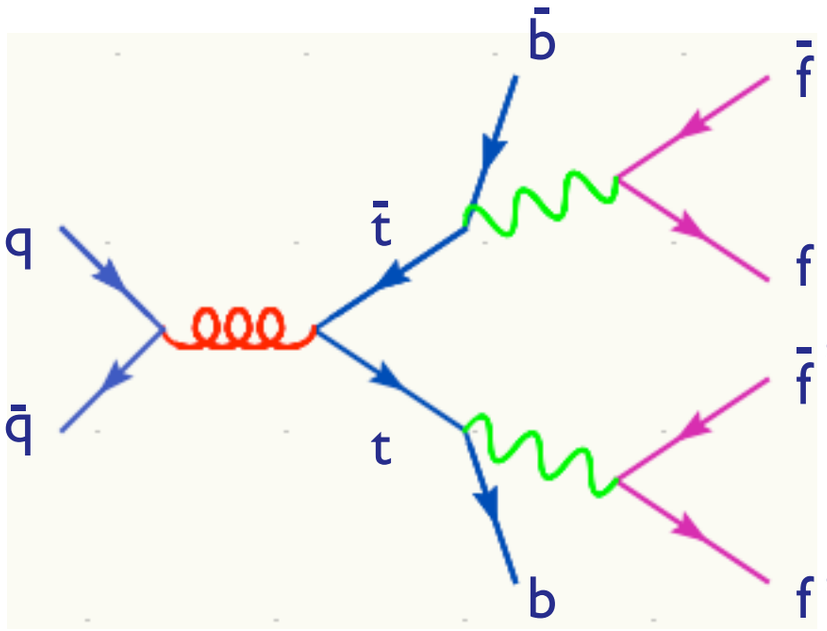

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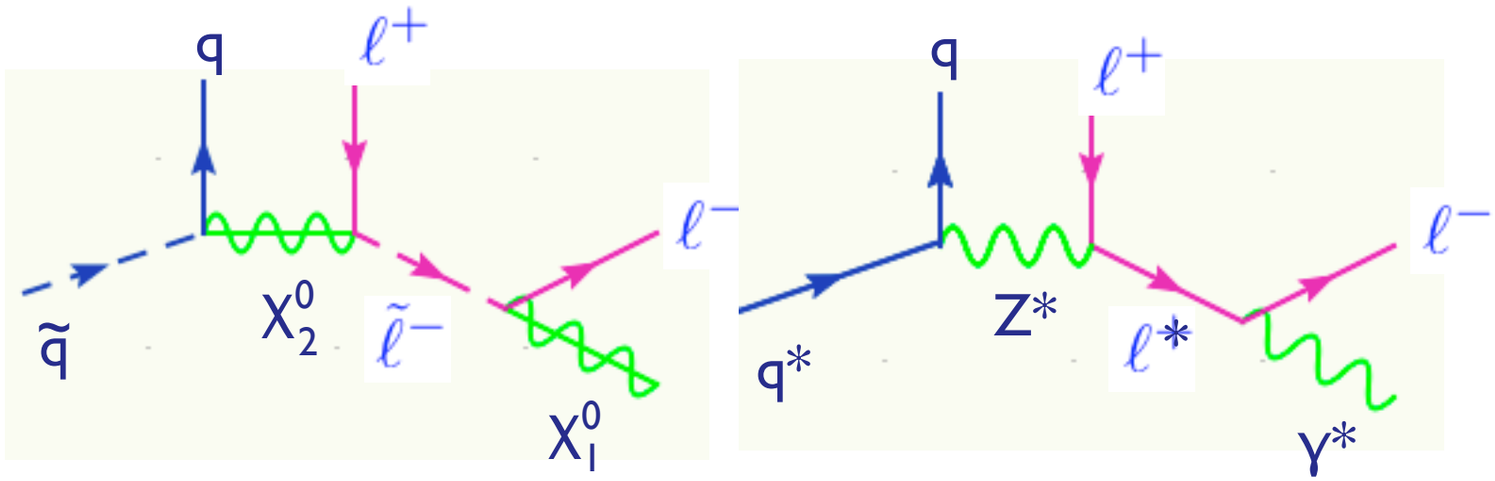
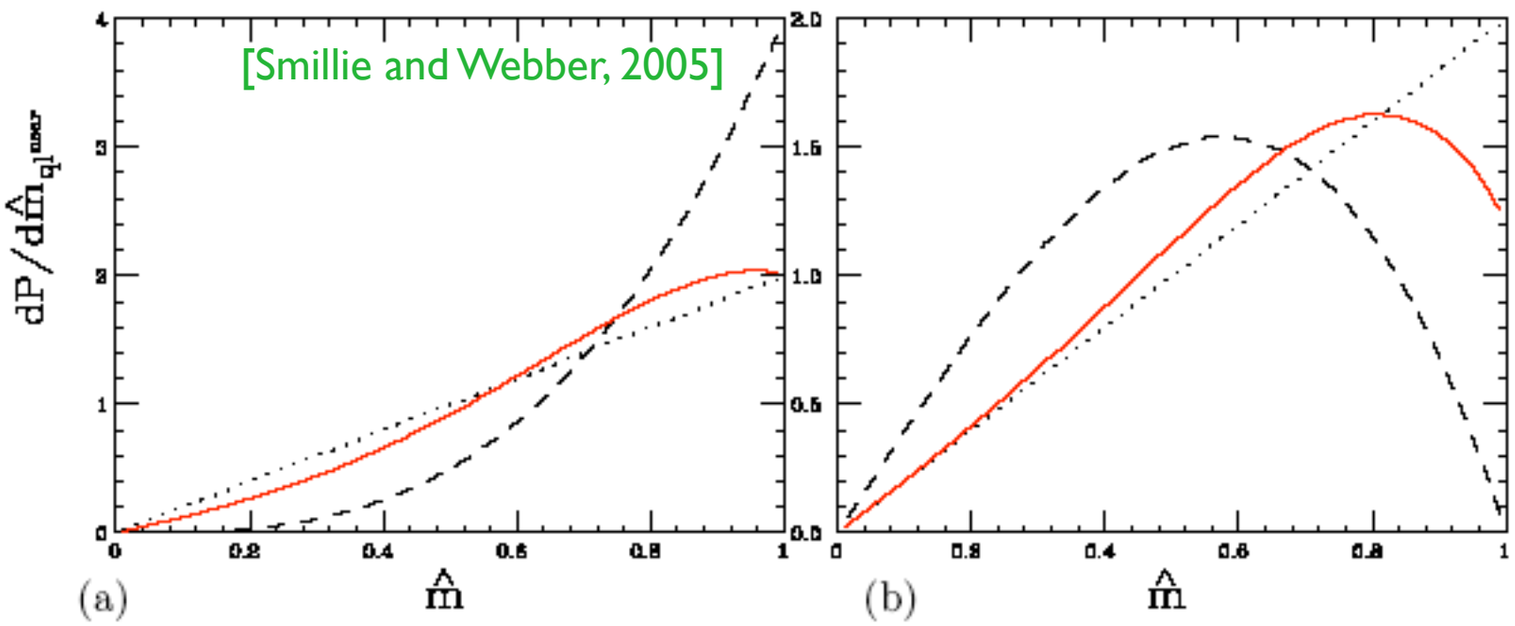
Example: SUSY vs UED

Information on the mass of the intermediate states can be obtained through the study of kinemetical edges. The shape of the edges can give information on the spin of the intermediate states. Compare for instance SUSY and UED:



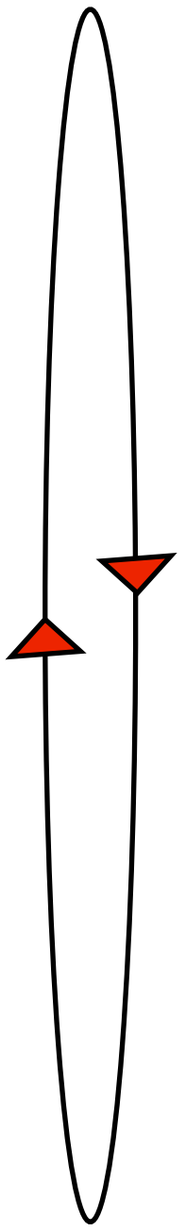


Beware that most of the MC's make some of or all the following simplifications:

1. production and decay are factorized.
2. Spin is ignored.
3. Chains proceed only through 1→2 decays.
4. The narrow width approximation is employed.
5. Non-resonant diagrams are ignored.

Flexible and powerful ME tools are needed to check and in case go beyond the above approximations!

The path towards discoveries



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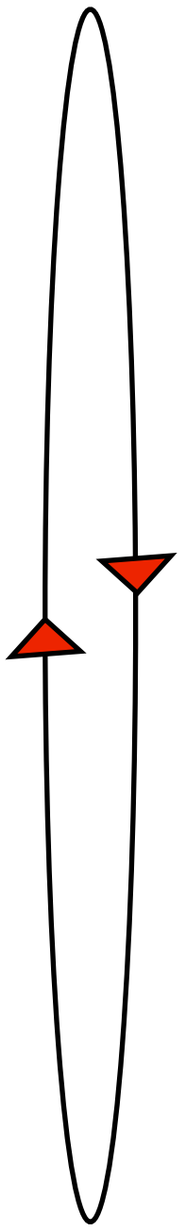

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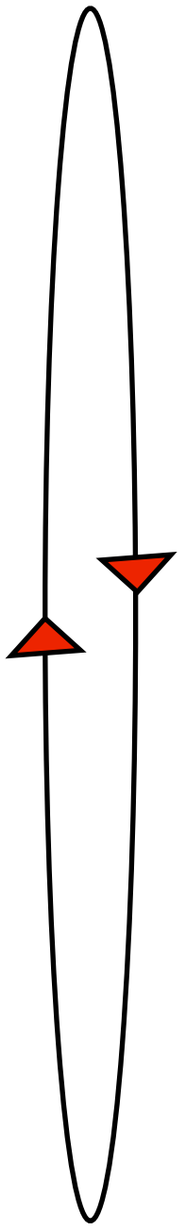

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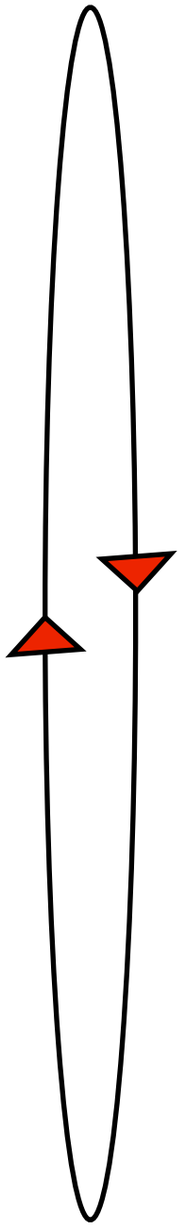

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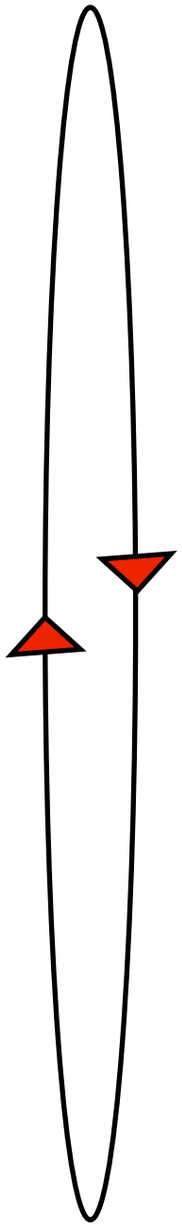

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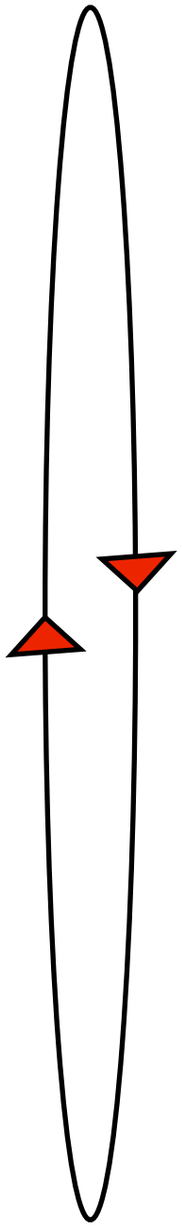

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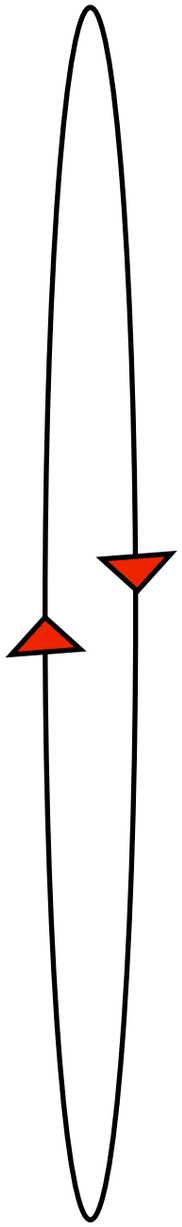

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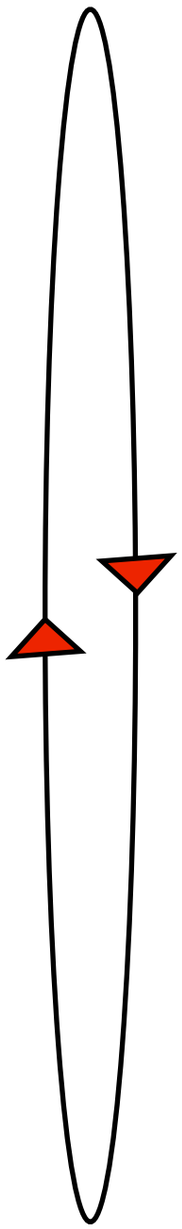

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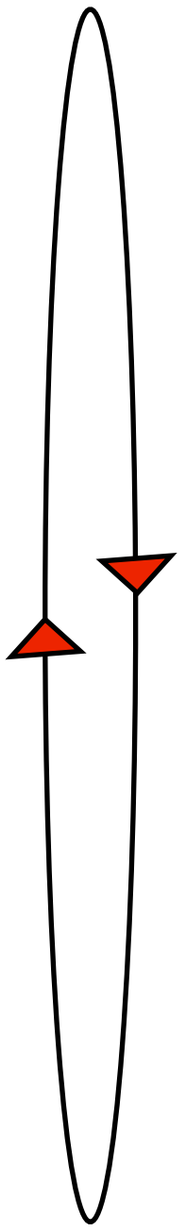

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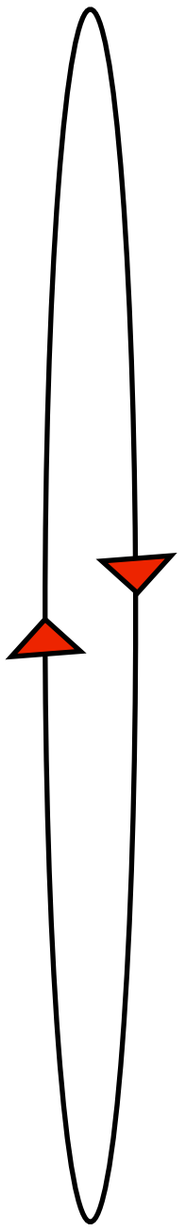

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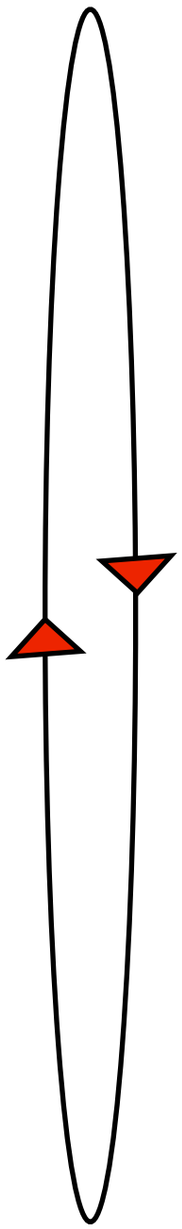

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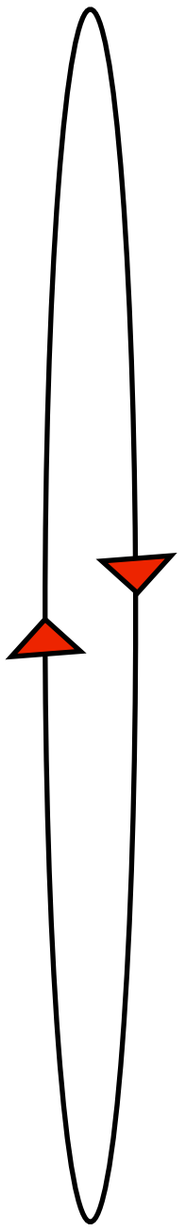

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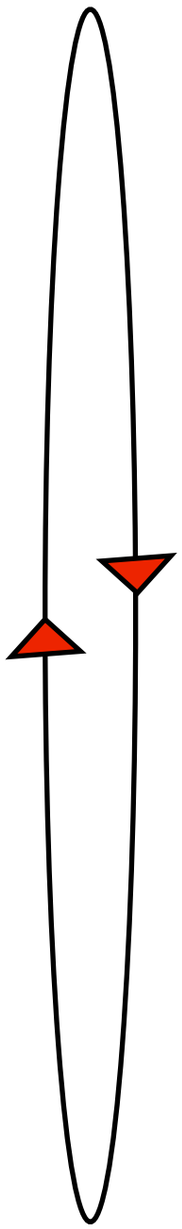

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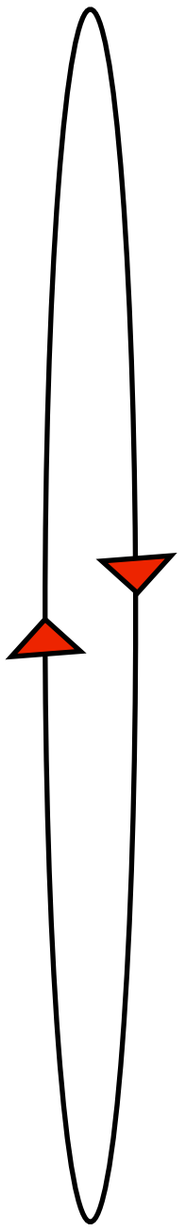

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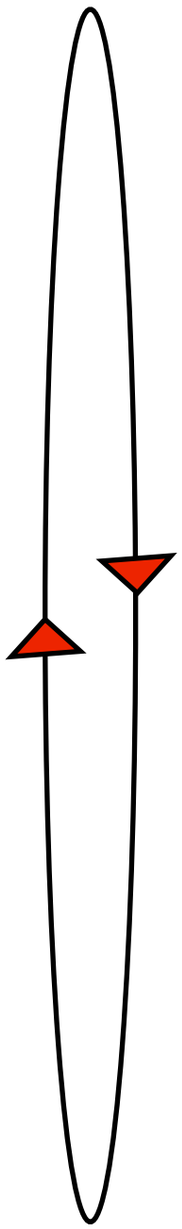

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Off-shell effects, Matrix Element methods, Global fits (Ex: Sfitter)

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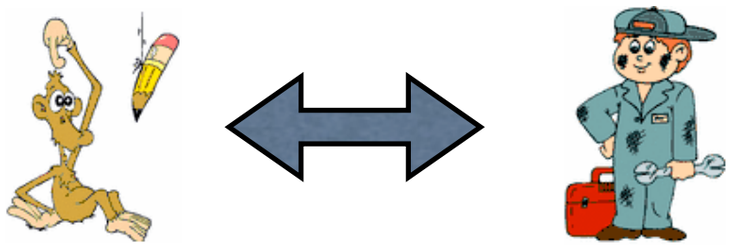
2. A plethora of BSM proposals exist to be compared with data. It will be essential to have an efficient, validated MC framework for theorists to communicate with experimentalits their idea (and viceversa).



A Roadmap (with roadblocks) for BSM @ the LHC

TH

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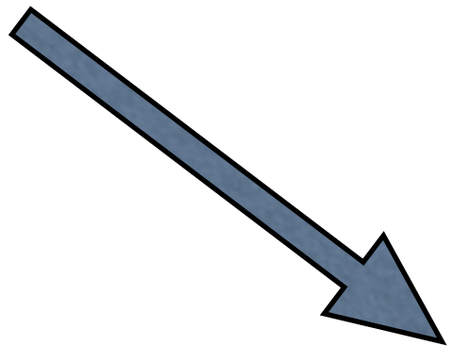

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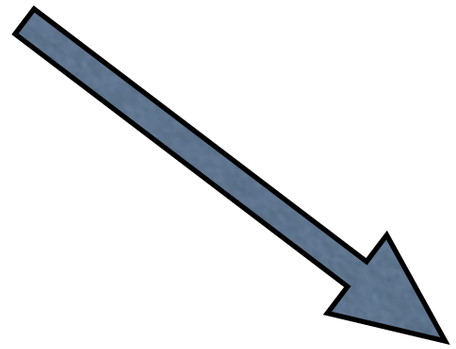


Data

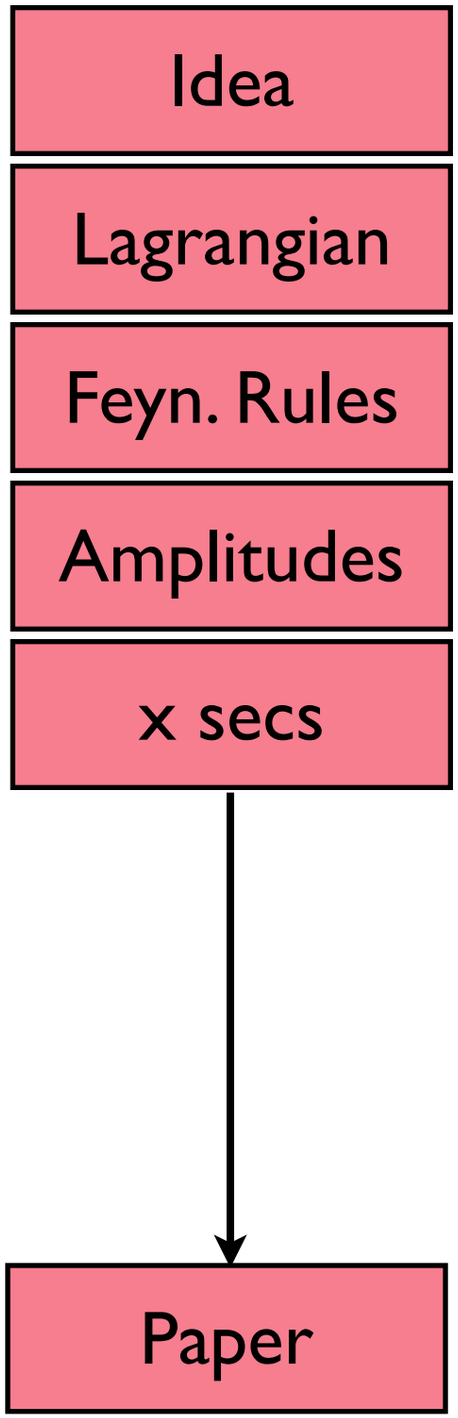
A Roadmap (with roadblocks) for BSM @ the LHC

TH

Idea

A Roadmap (with roadblocks) for BSM @ the LHC

TH



A Roadmap (with roadblocks) for BSM @ the LHC

TH PHENO

Idea

Lagrangian

Feyn. Rules

Amplitudes

x secs

Paper

A Roadmap (with roadblocks) for BSM @ the LHC

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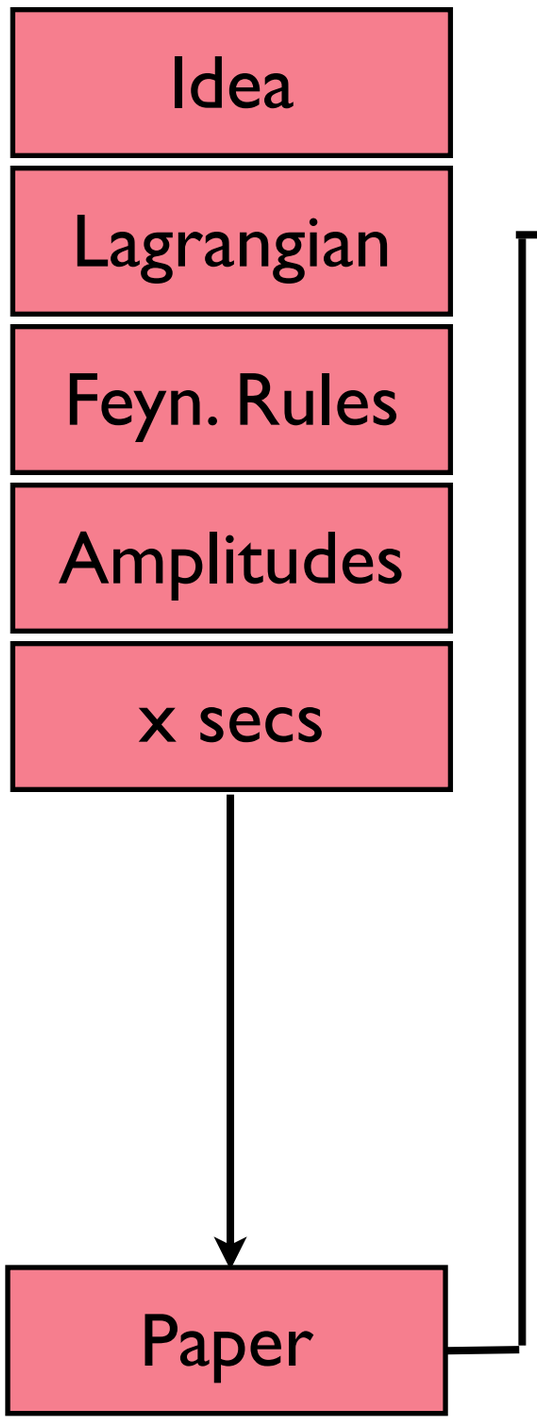

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PS+Hadr

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A Roadmap (with roadblocks) for BSM @ the LHC

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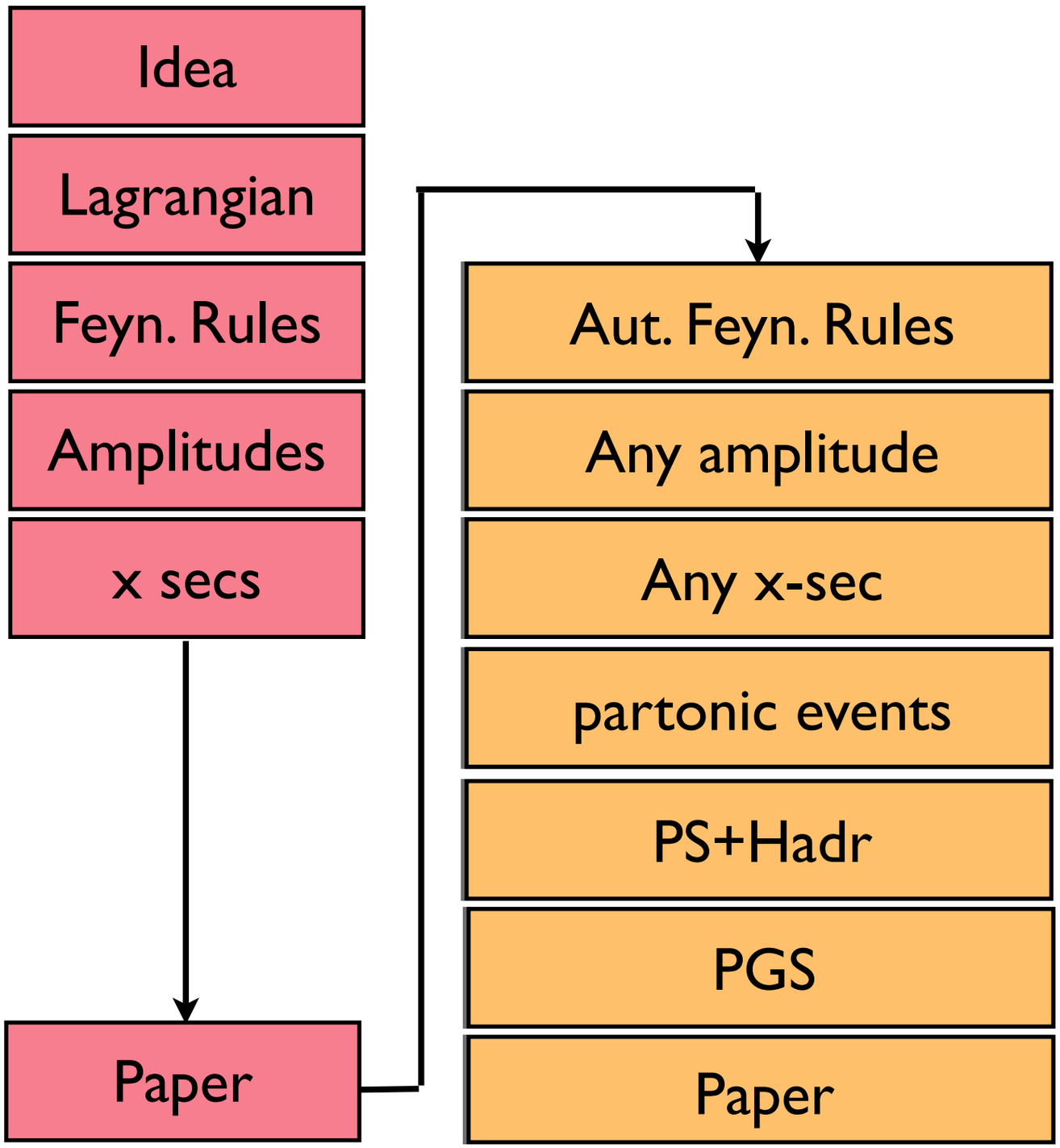

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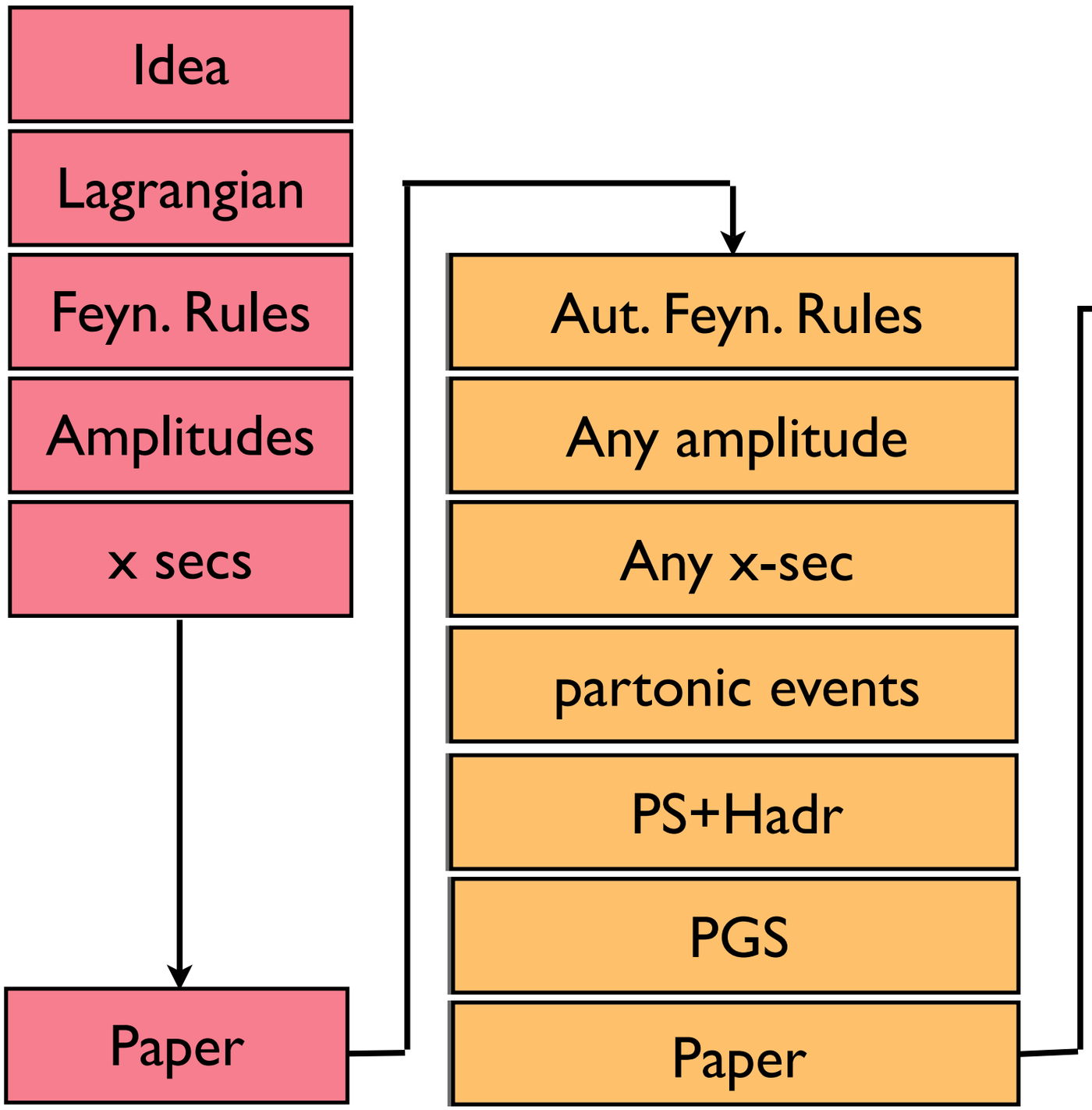

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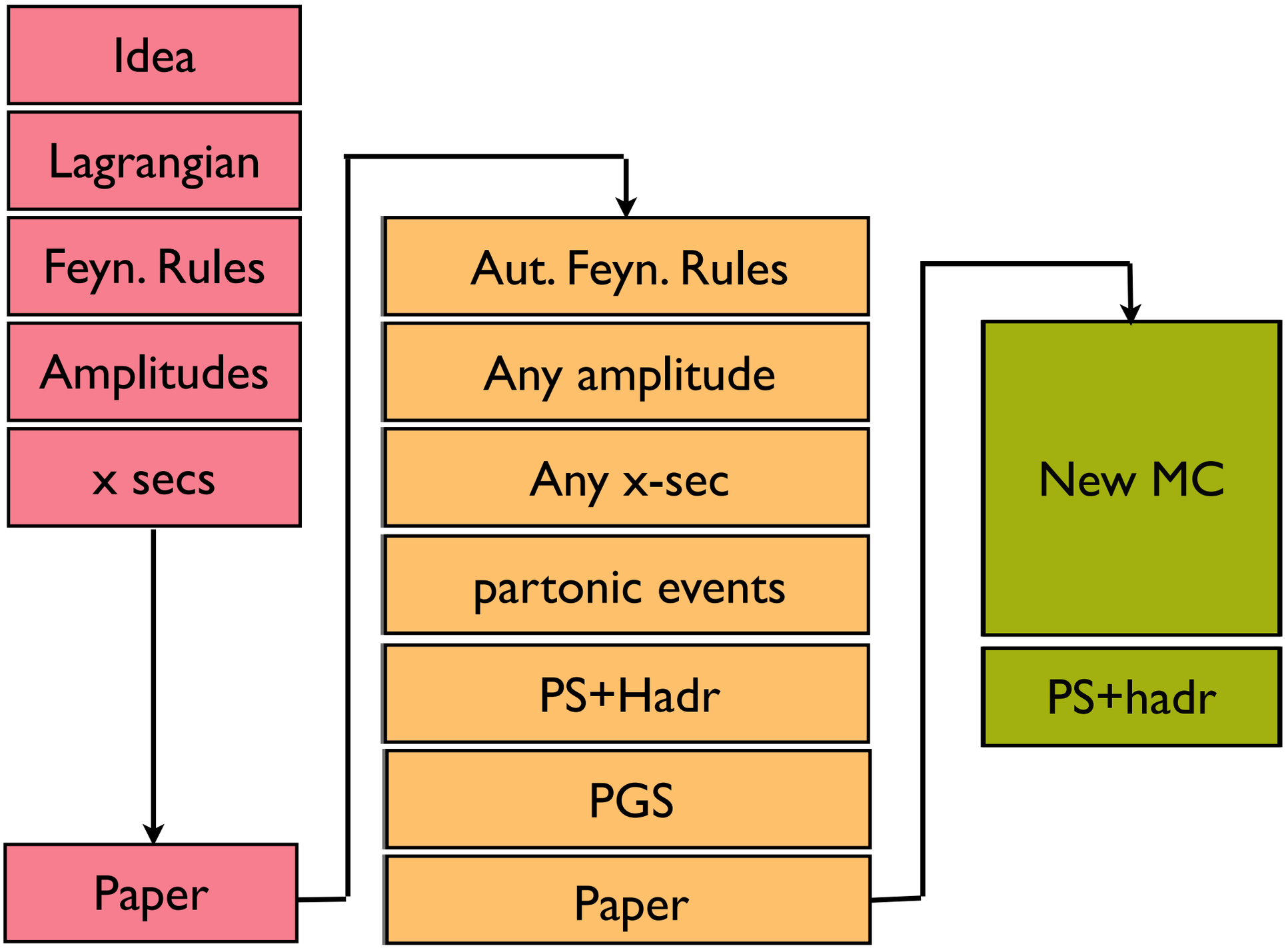

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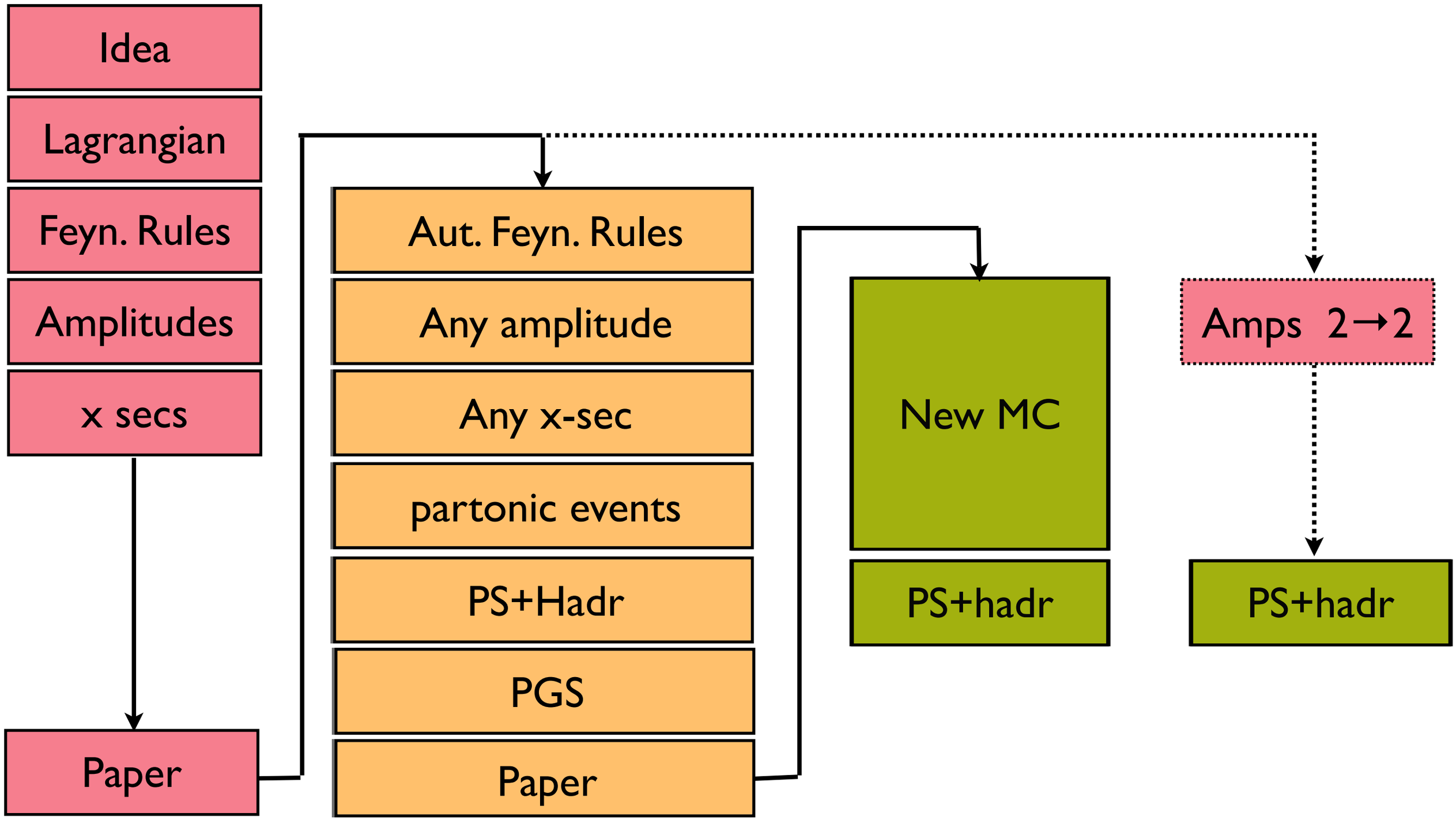

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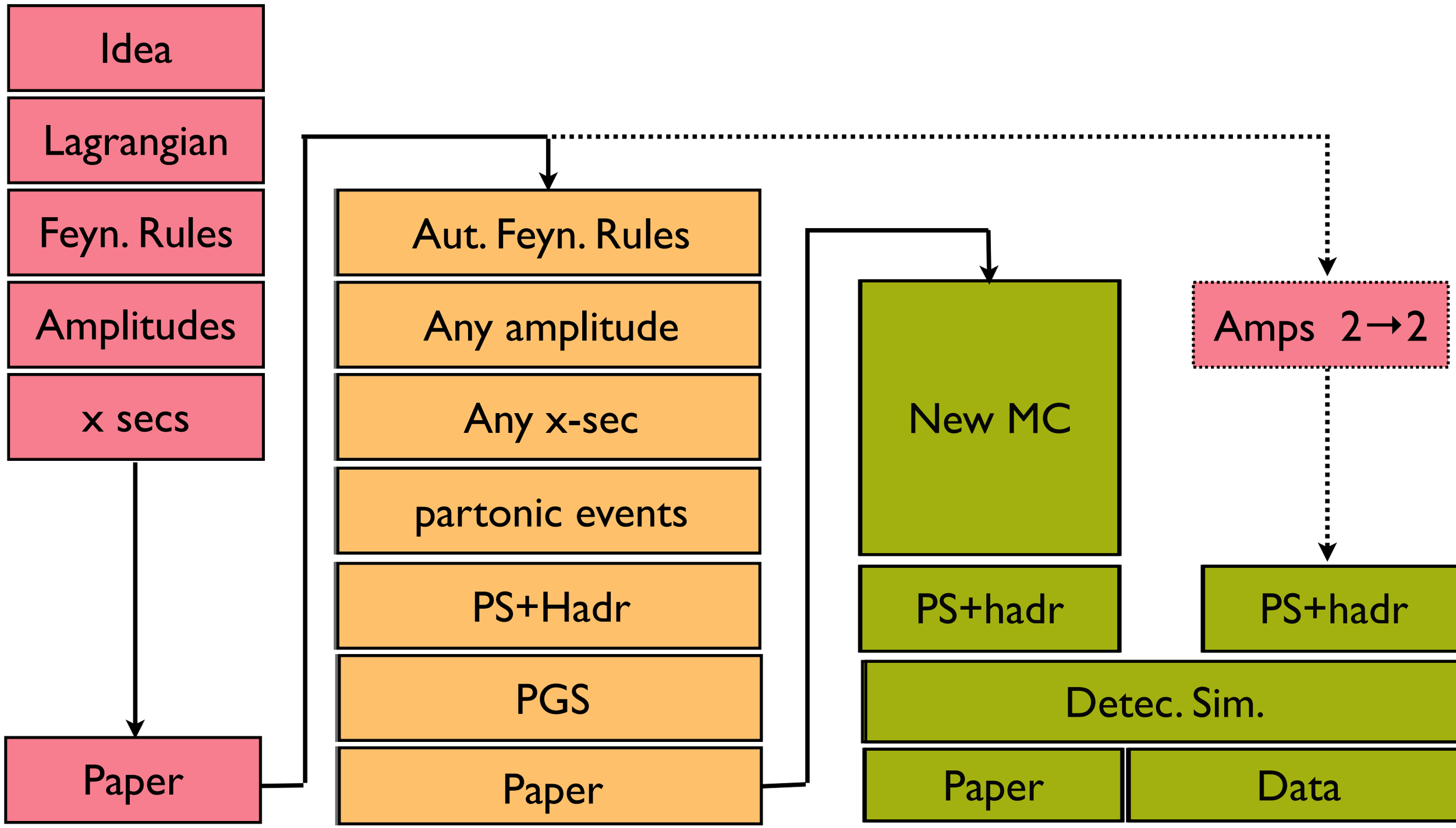

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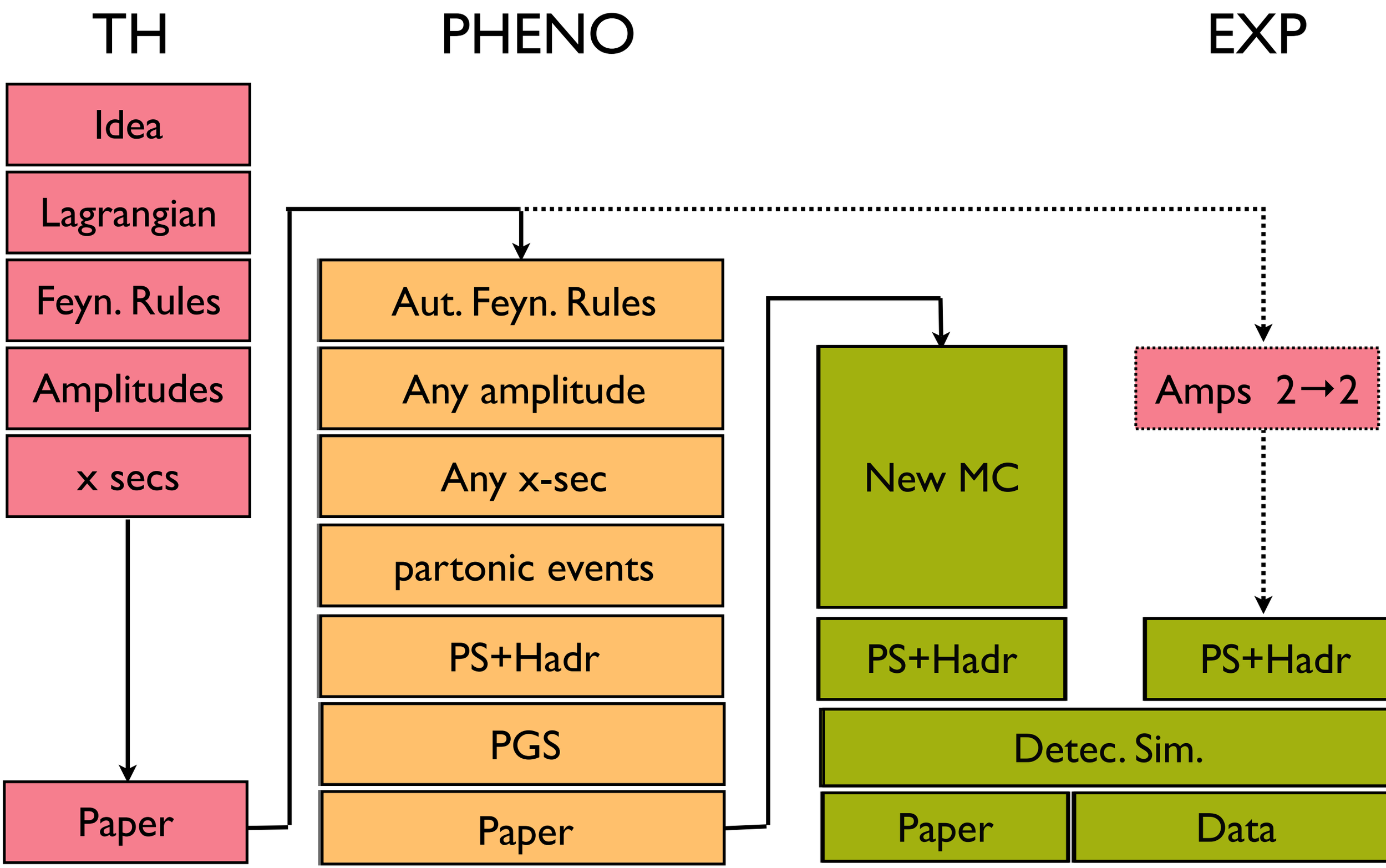

A Roadmap (with roadblocks) for BSM @ the LHC

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A Roadmap for BSM @ the LHC

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Data

- One path for all
- Physics and software validations streamlined
- Robust and efficient Th/Exp communication
- It works top-down and bottom-up

A Roadmap for BSM @ the LHC

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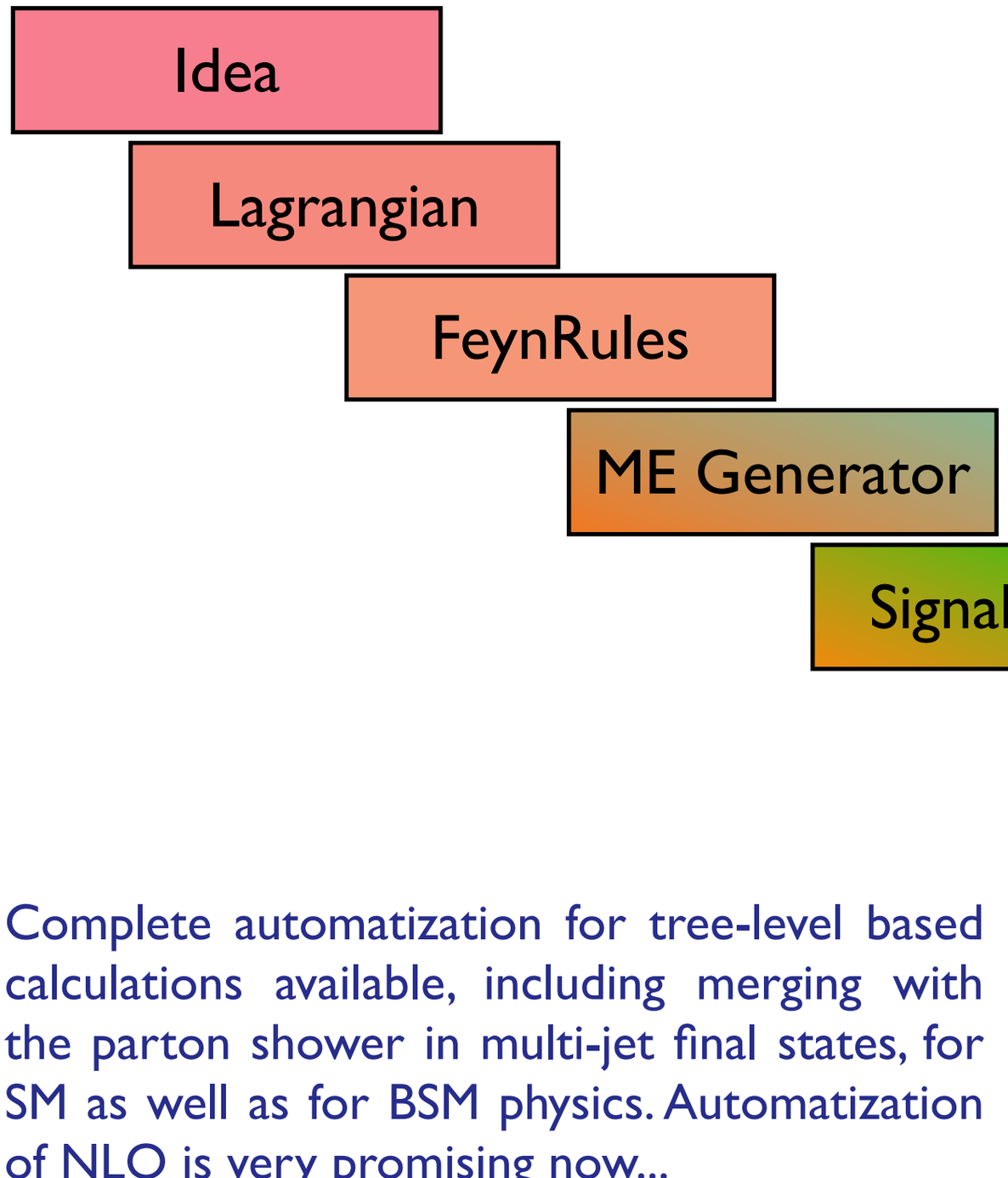
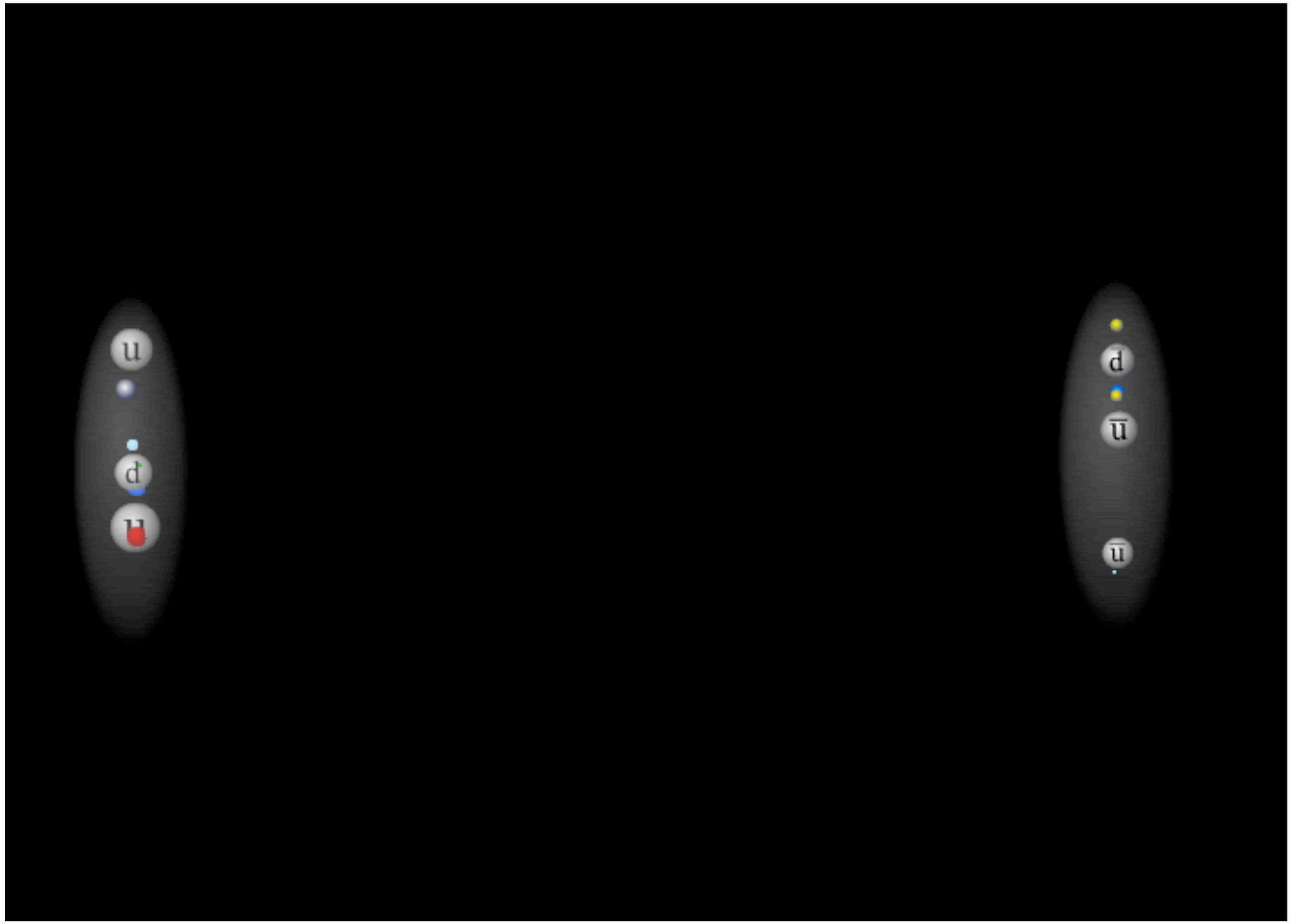
EXP



- One path for all
- Physics and software validations streamlined
- Robust and efficient Th/Exp communication
- It works top-down and bottom-up

Complete automatization for tree-level based calculations available, including merging with the parton shower in multi-jet final states, for SM as well as for BSM physics. Automatization of NLO is very promising now...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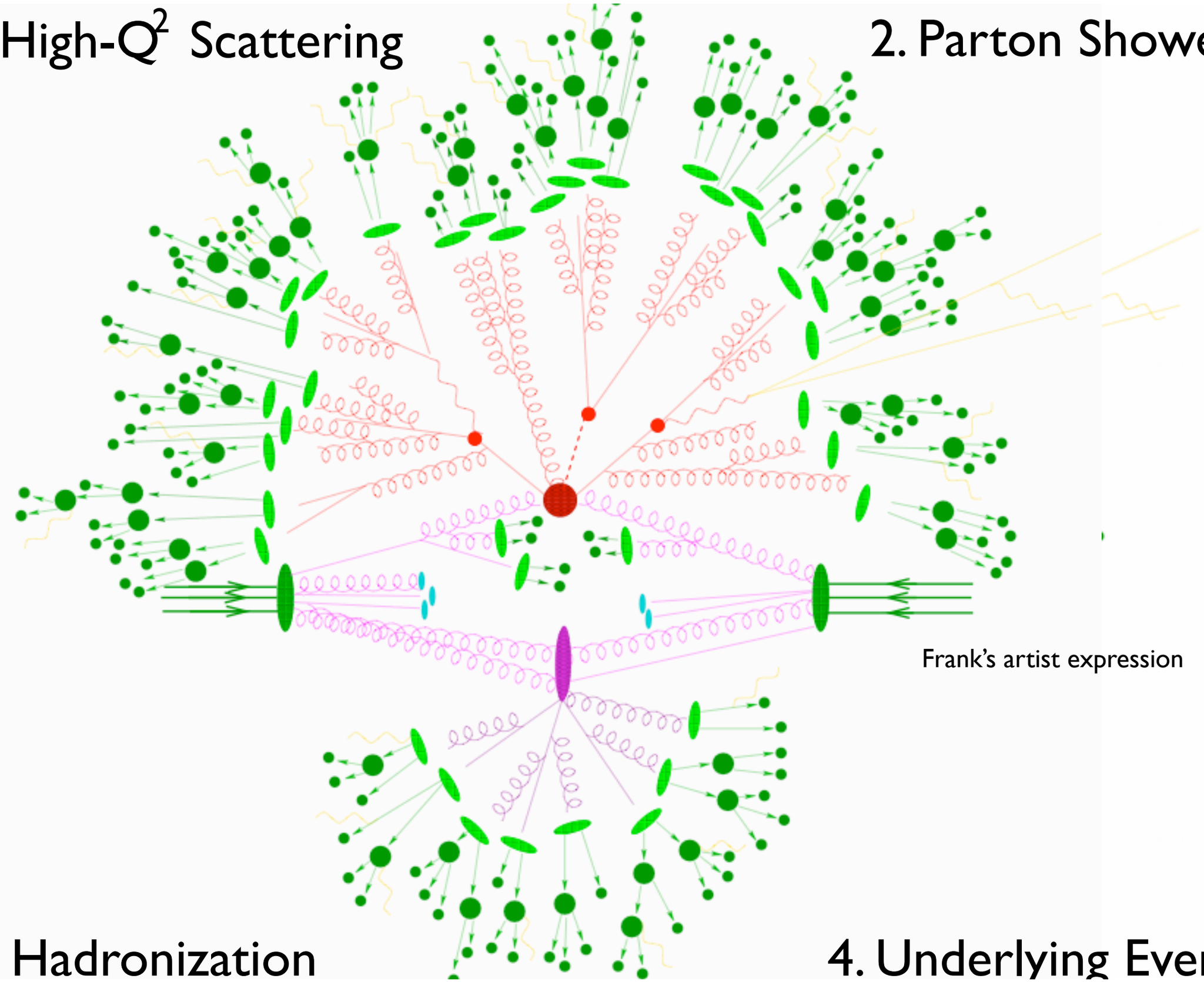
1. High-Q^2 Scattering

2. Parton Shower



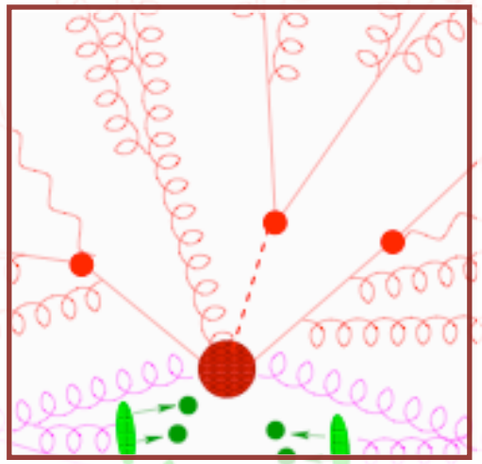
Frank's artist expression

3. Hadronization

4. Underlying Event

1. High-Q^2 Scattering

2. Parton Shower



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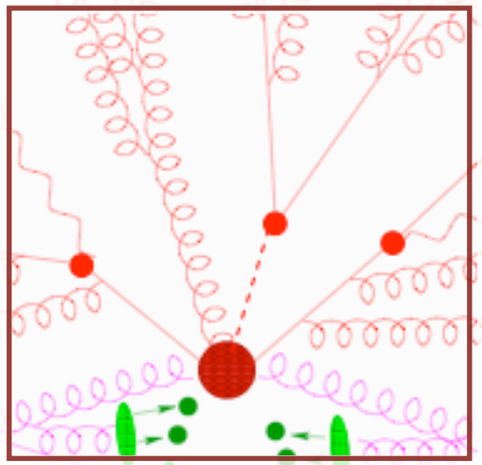
☞ where new physics lies



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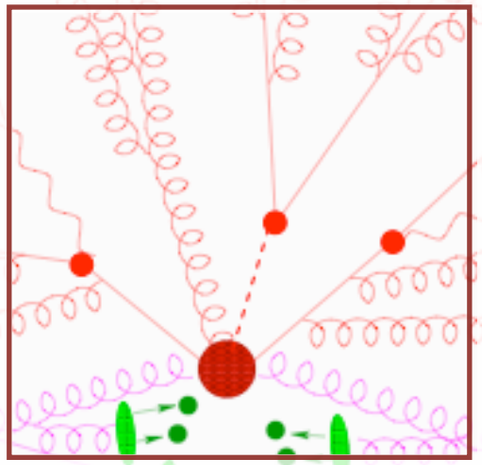

☞ process dependent

3. Hadronization

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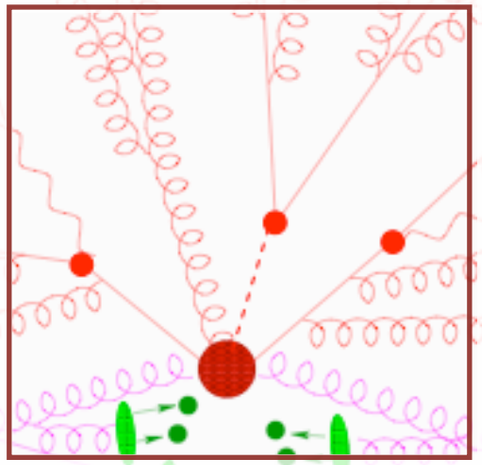

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☞ first principles description

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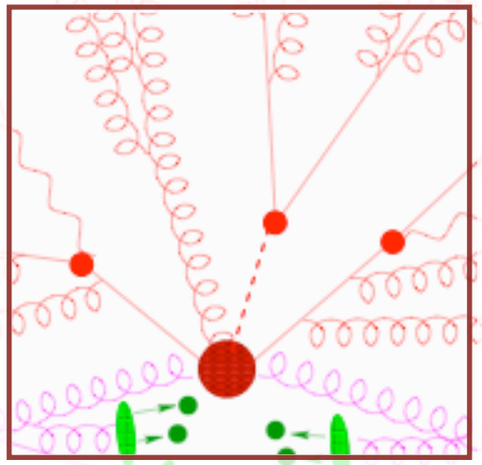

☞ process dependent

☞ 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?

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

- 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?

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

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

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

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

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

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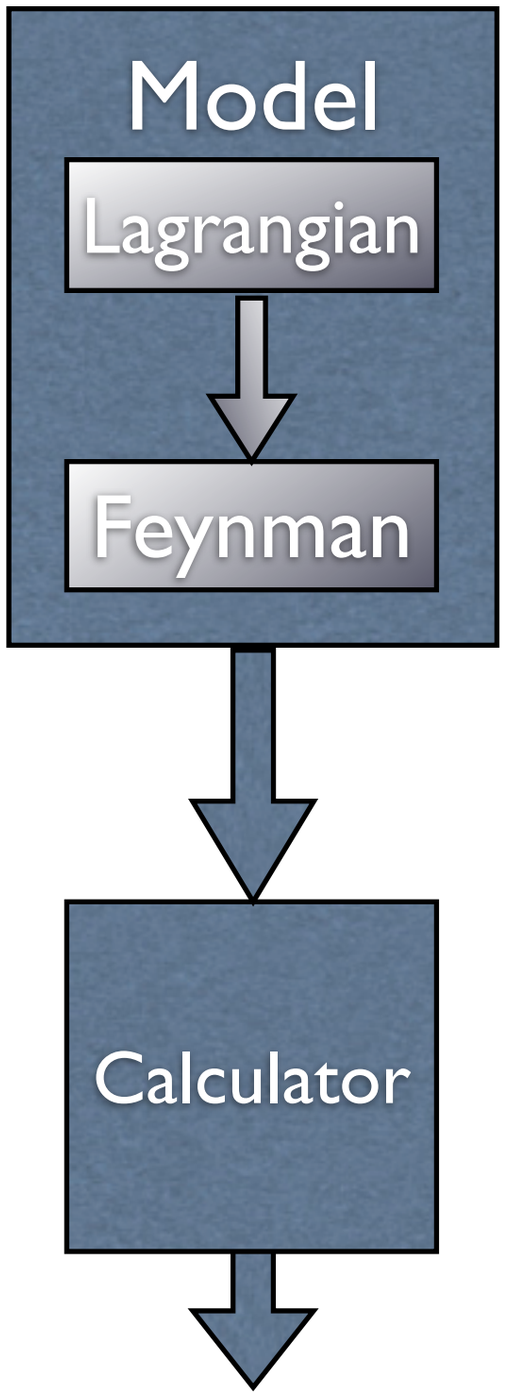
very hard

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

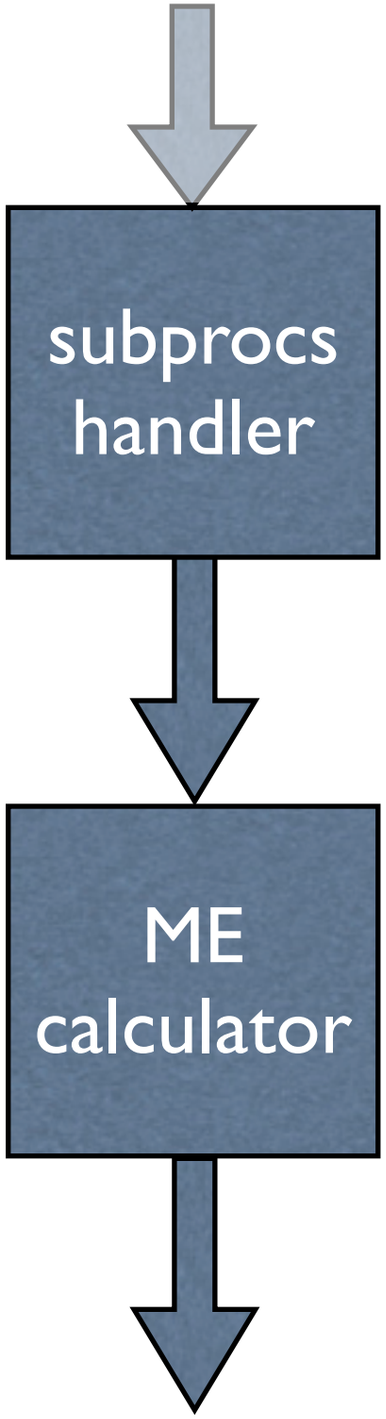
SUSY, Little Higgs, Higgsless, GUT, Extra dimensions (flat, warped, universal,...)

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...

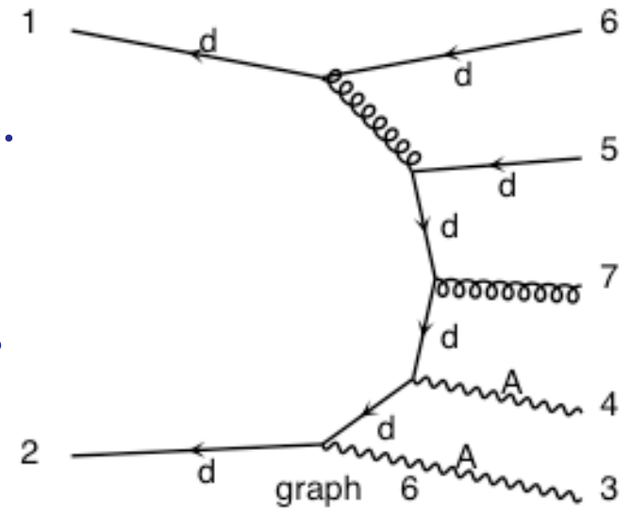
Matrix Element based MC's



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

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].



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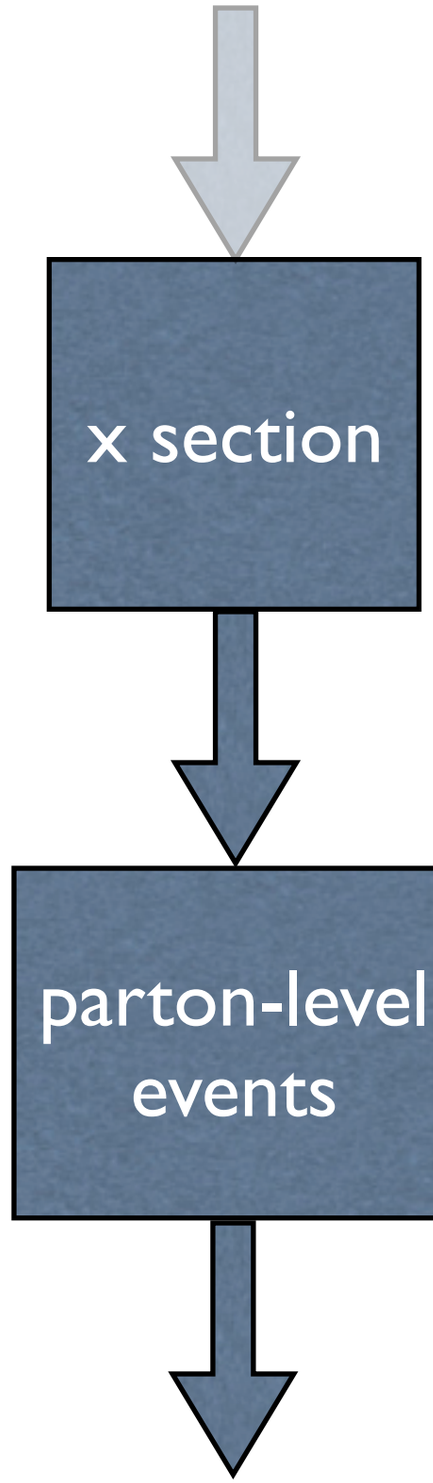
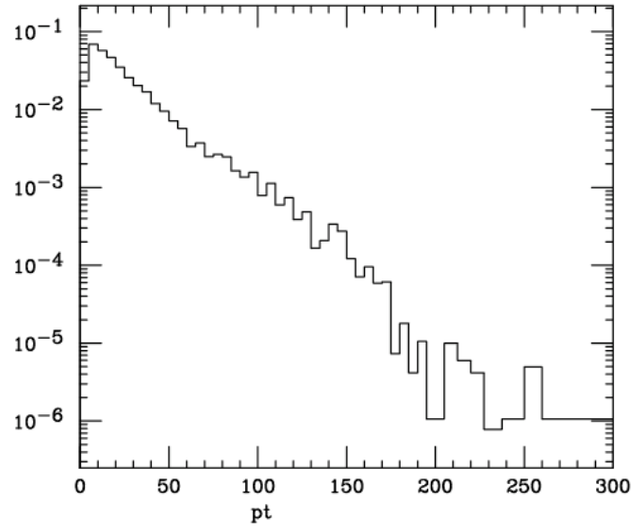
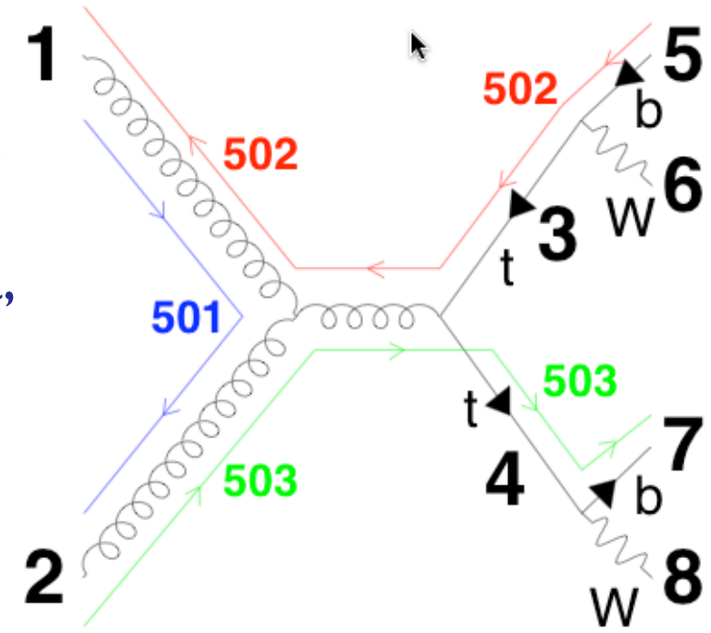


Integrate the matrix element over the phase space using a multi-channel technique and using parton-level cuts.



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.



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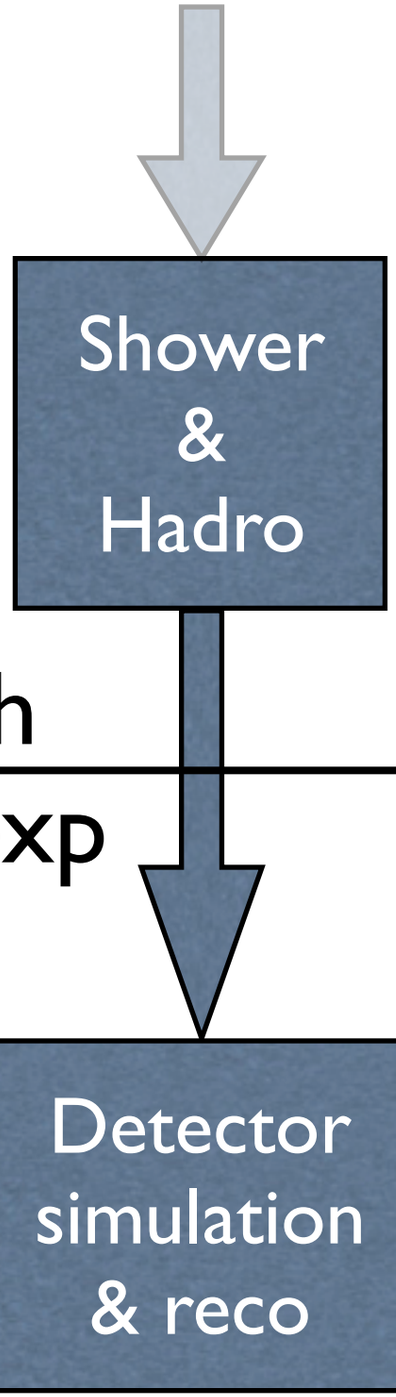
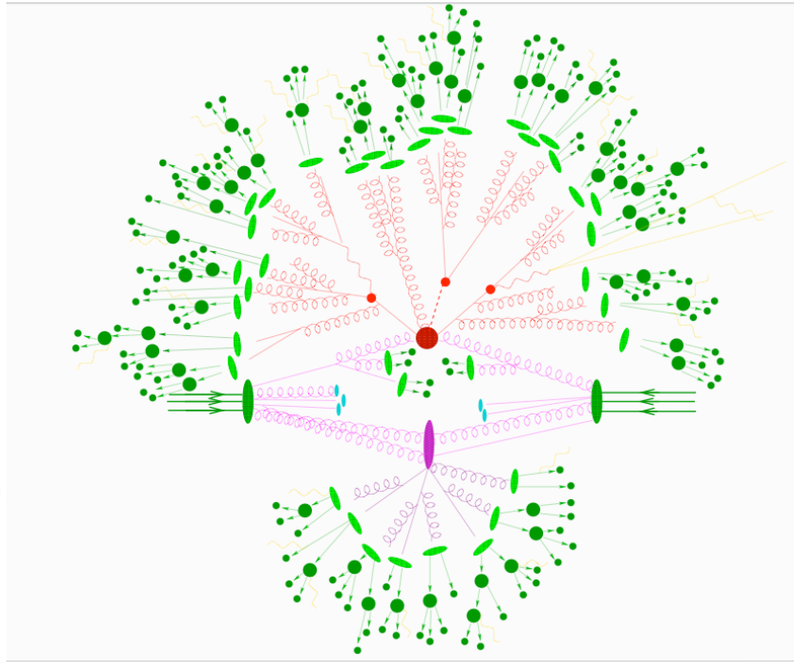


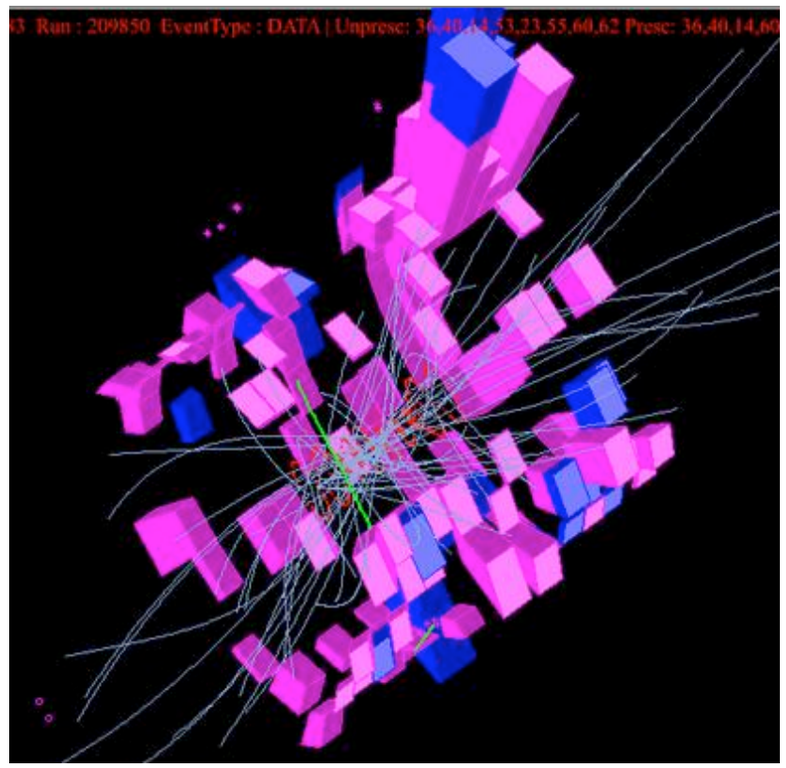
Events in the LH format are passed to the showering and hadronization⇒

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]

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- 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.

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  - 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!

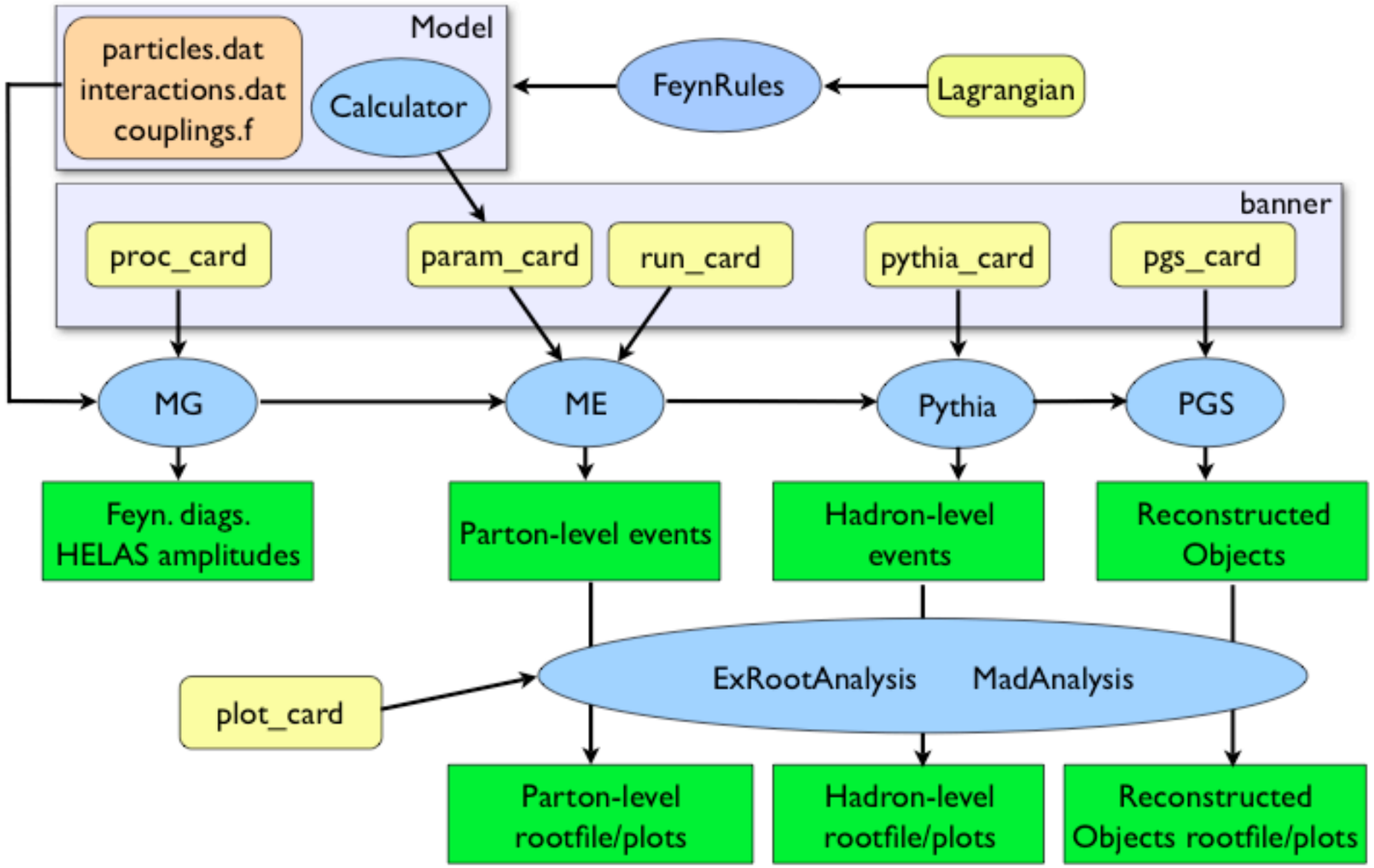
MadGraph/MadEvent v4

[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

This material is based upon work supported by the National Science Foundation under Grant No. 0426272.
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/

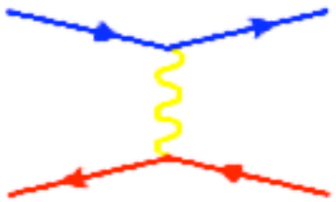
http://madgraph.phys.ucl.ac.be/

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

Let's plug ... & play!

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MadGraph advanced features

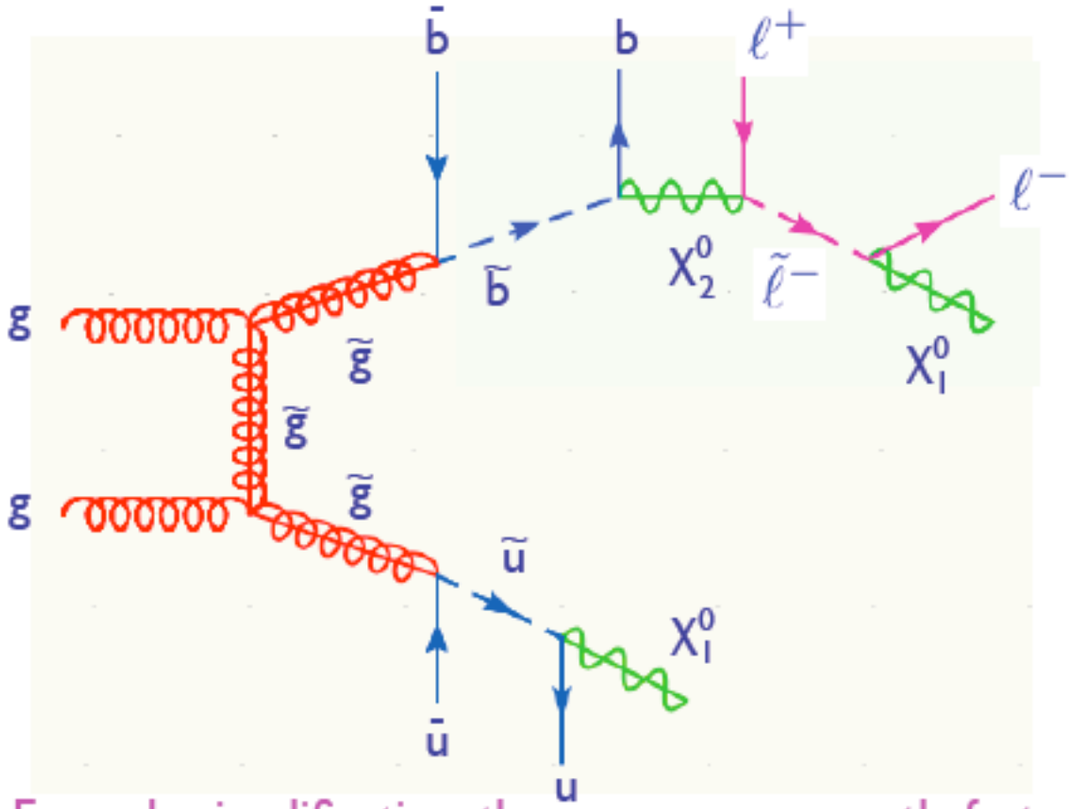
- Latest information available at the Wiki page
- Examples : decay rates, multiprocesses, decay chains,..
- Tools and Calculators
- Full expert/developer's package downloadable
- Standalone
- MadWeight
- New physics models : FeynRules and USERMOD

Let's play advanced!

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))
```

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

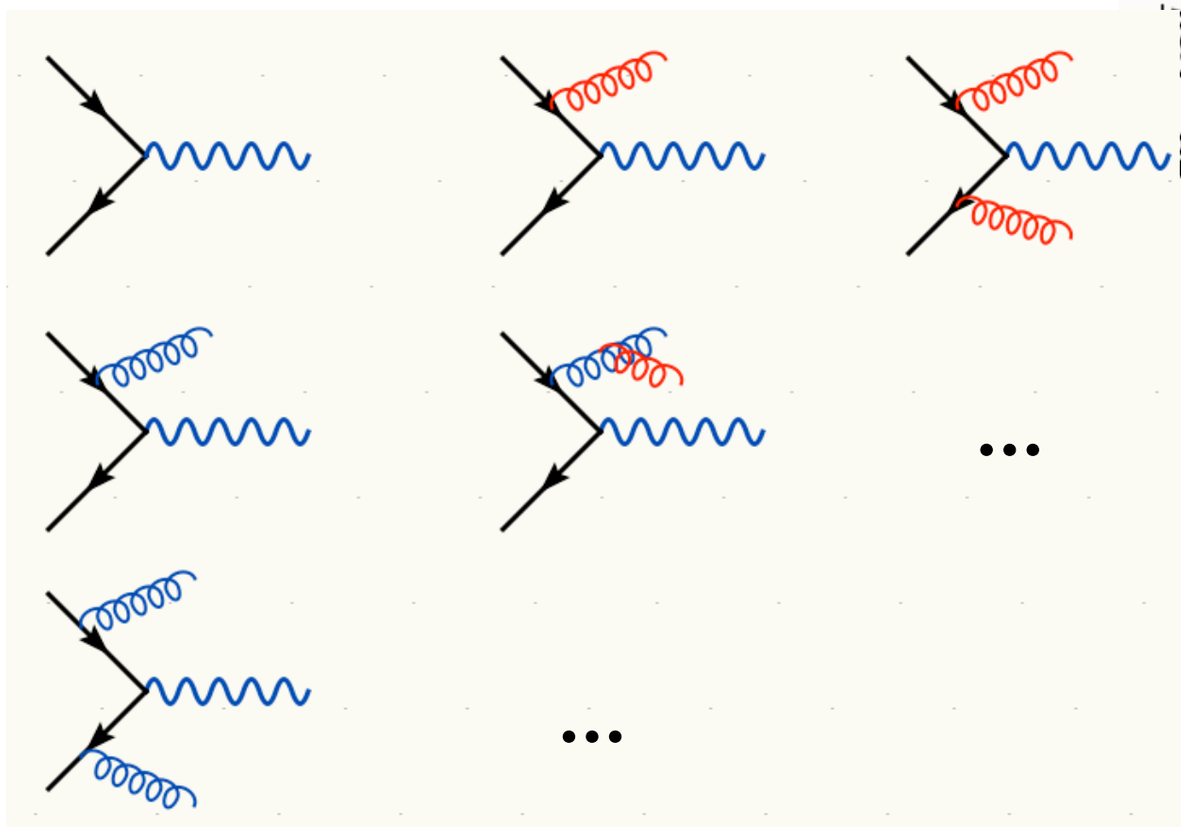
```
#*********************************************************************
#-------------------------------------------------------------------*
# Process(es) requested : mg2 input                                 *
#-------------------------------------------------------------------*
# Begin PROCESS # 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                                                 *
```

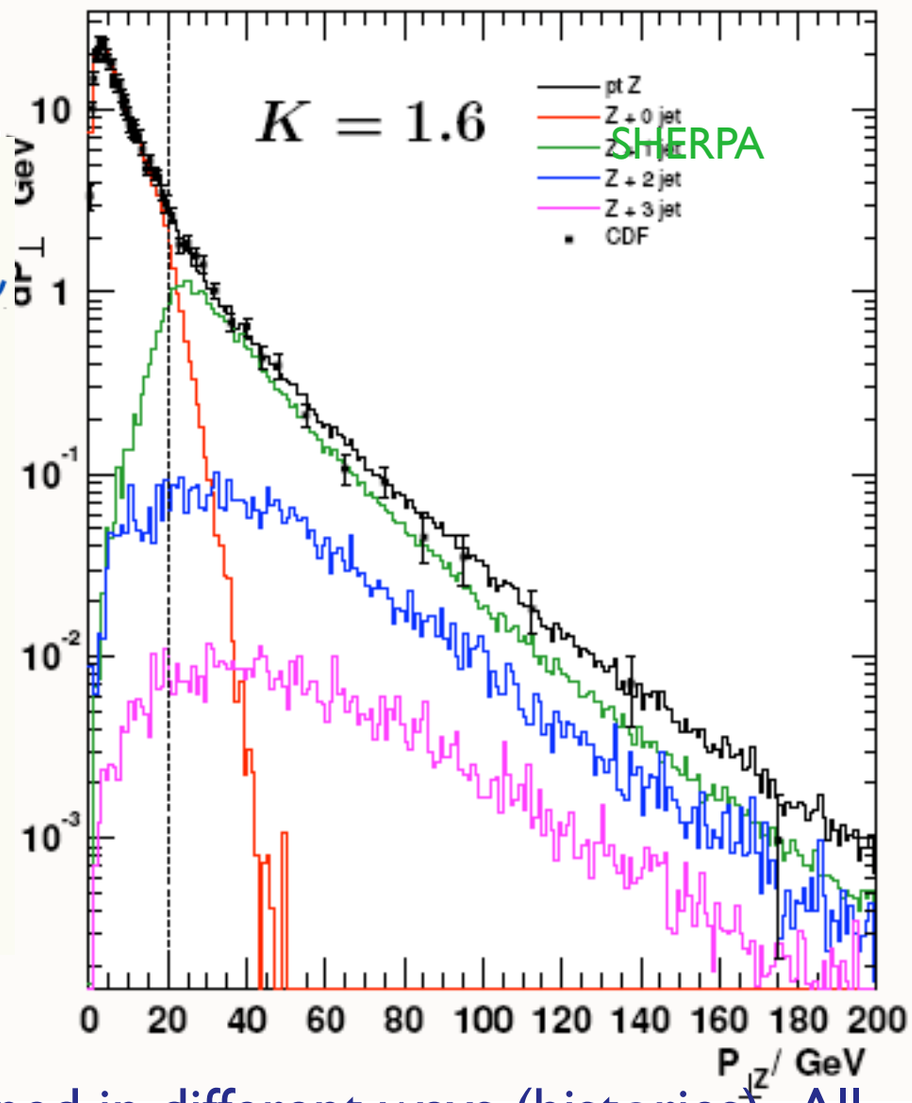
Merging fixed order with PS

[Mangano]
[Catani, Krauss, Kuhn, Webber]

PS →

ME ↓

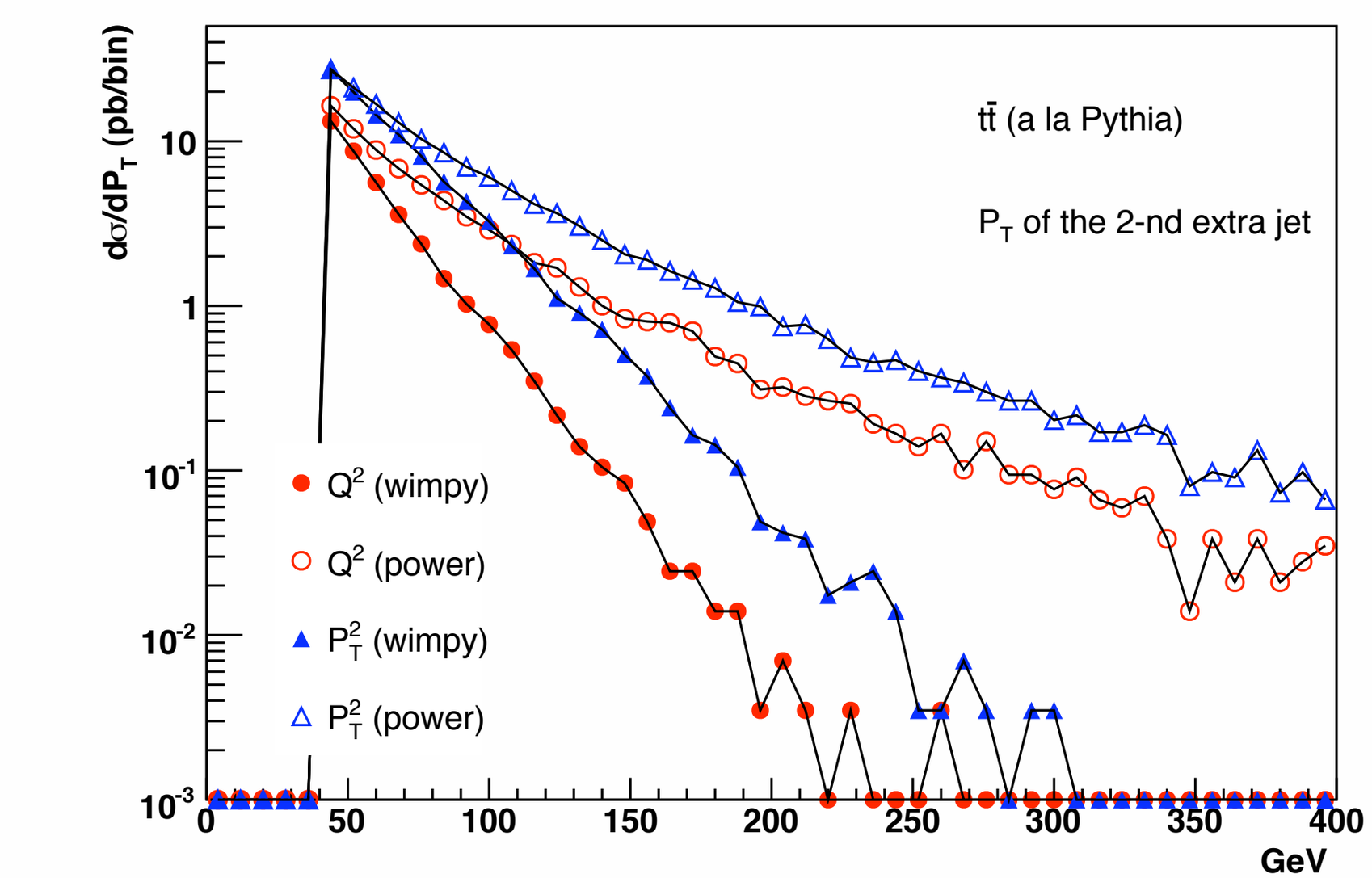




Double counting of configurations that can be obtained in different ways (histories). All the matching algorithms (CKKW, MLM,...) apply criteria to select only one possibility based on the hardness of the partons. As the result events are exclusive and can be added together into an inclusive sample. Distributions are accurate but overall normalization still "arbitrary".

PS alone vs matched samples

A MC shower produces inclusive samples covering all phase space. However, there are regions of the phase space (ex. high pt tails) which cannot be described well by the log enhanced (shower) terms in the QCD expansion and lead to ambiguities. Consider for instance the high-pt distribution of the second jet in ttbar events:



In a matched sample these differences are irrelevant since the behaviour at high pt is dominated by the matrix element. LO+LL is more reliable. (Matching uncertaintes not shown.)

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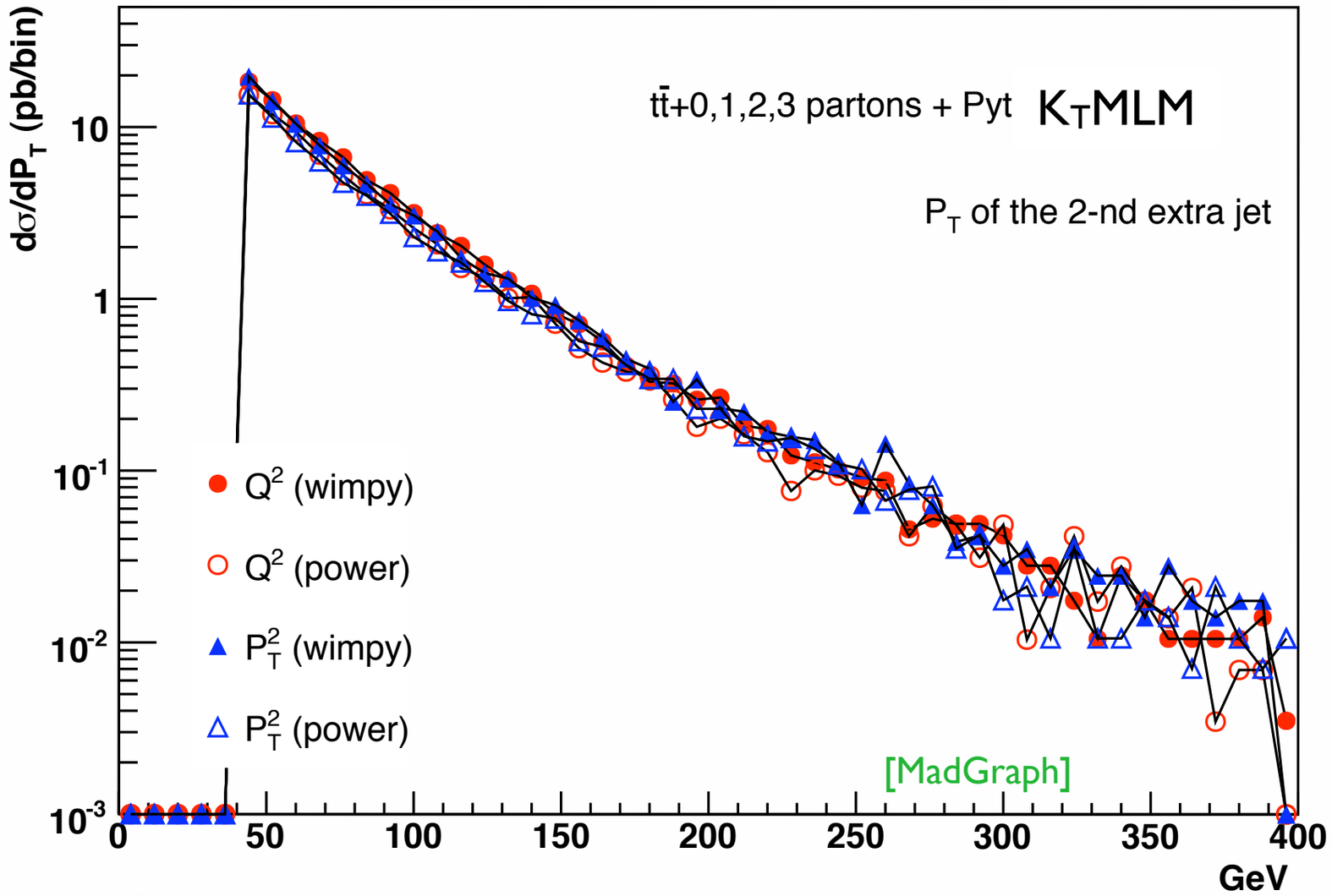

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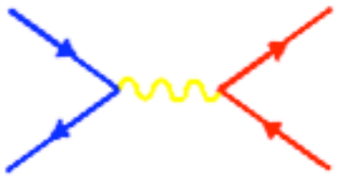
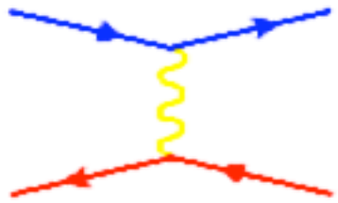
Web tools



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

Online MadGraph/MadEvent related tools

Calculators

Plotting Interface (ExRootAnalysis)

Plotting Interface (MadAnalysis)

Decay Interface

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

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

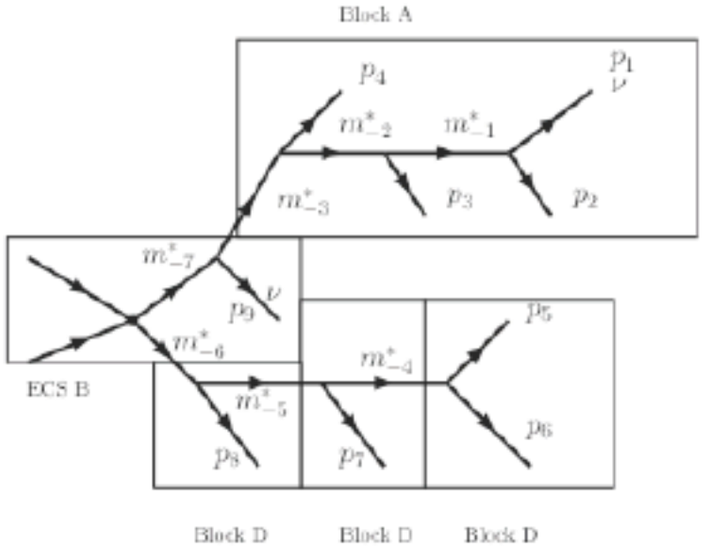
4. Install topdrawer :

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

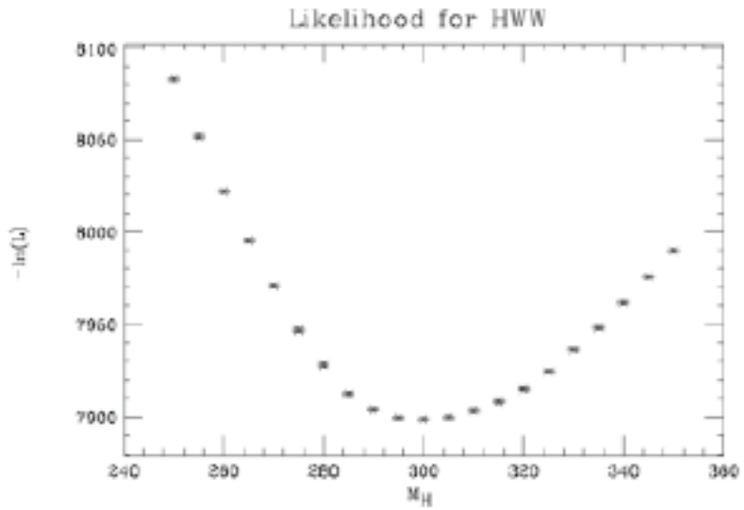
Matrix element methods

[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



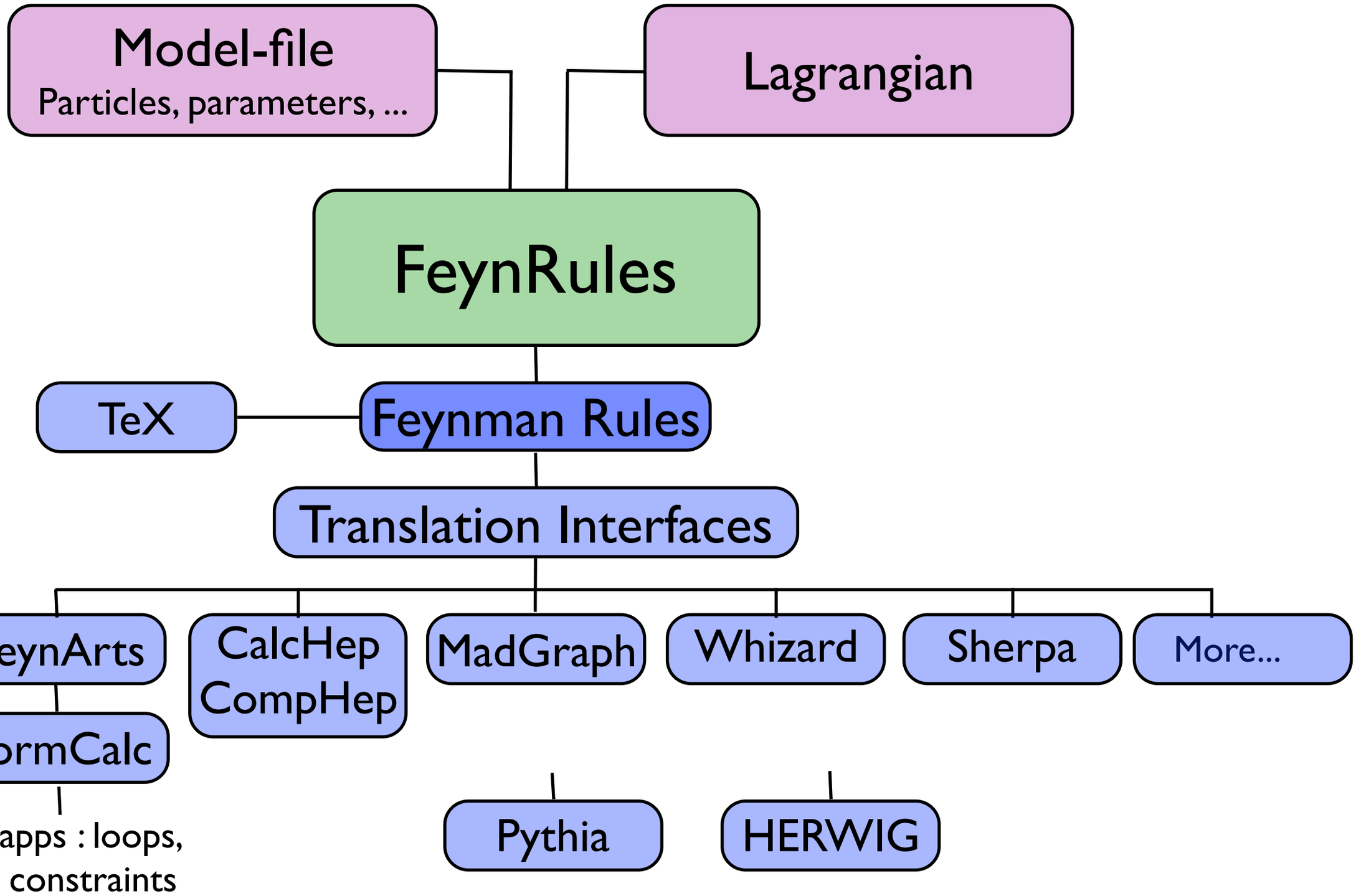
Find likelihood for model parameters (here Higgs mass in $h \to WW$)

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

code available on demand

FeynRules

[Christensen, Duhr, 2008; Christensen, Duhr, Fuks, et al., 2009]



NLO computations

MadDipole: [Frederix, Gerhmann,Greiner, 2008]

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

- 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

MadFKS: [Frederix, Frixione, Maltoni, Stelzer, 2009]

- FKS fully implemented including PS integration
- "Only" virtuals need to be provided

A look into the future

MadGraph 5 : alpha version coming soon!

Automatic NLOwPS in SM and BSM....

A look into the future

MadGraph 5 : alpha version coming soon!

Main points:

* New Matrix Element generator engine in Python
* Full flexibility for New Physics implementation through FeynRules
* Loops... NLO computations for SM and BSM!

Automatic NLOwPS in SM and BSM....