MadGraph/MadEvent: status e prospettive

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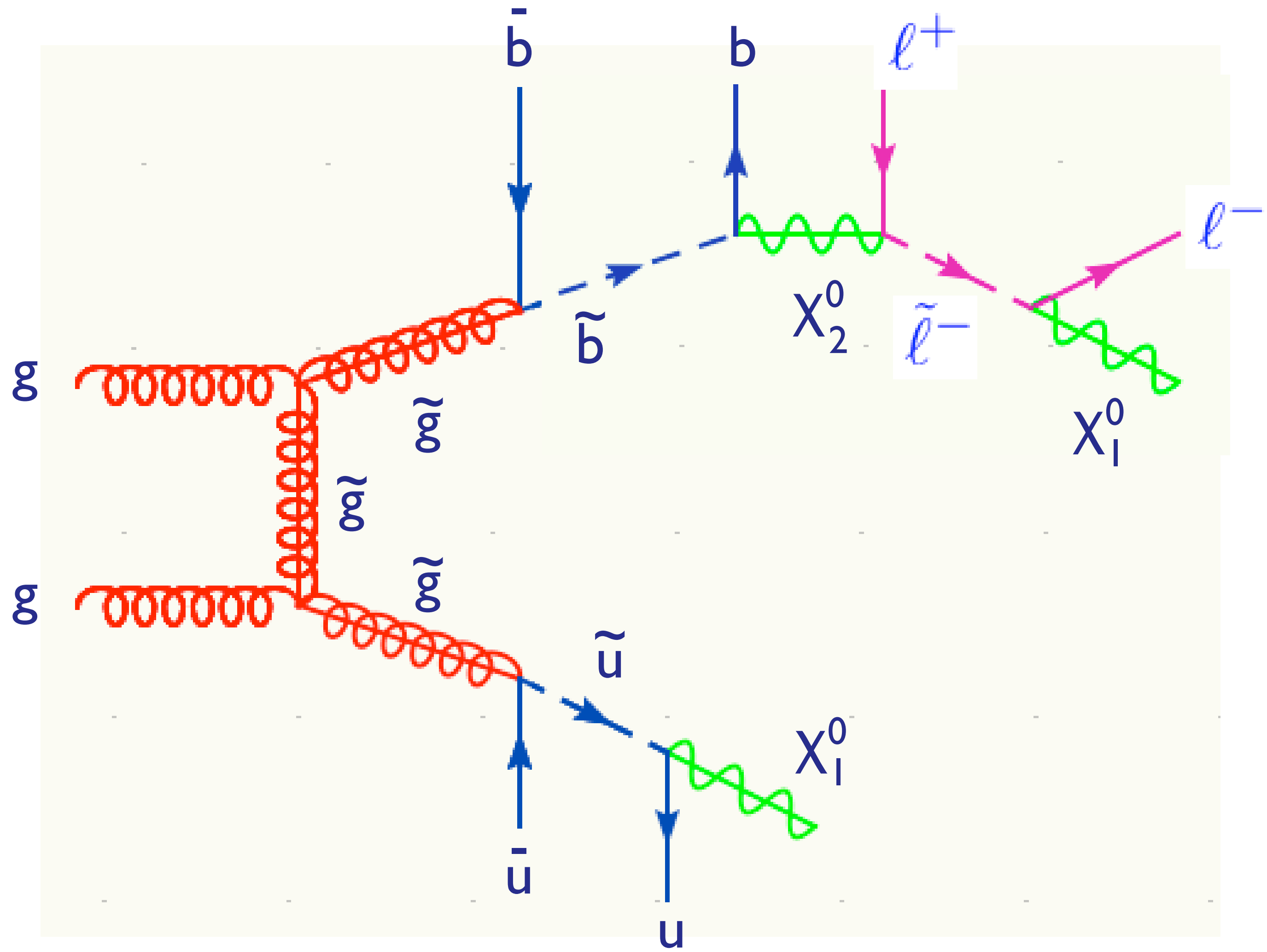
per il team

Johan Alwall, Pavel Demin, Simon de Visscher, Rikkert Frederix, Michel Herquet, Tim Stelzer
+ Steve Mrenna, Tilman Plehn, David L. Rainwater,
+ Pierre Artoisenet, Claude Duhr, Olivier Mattenlaer,...

Outline

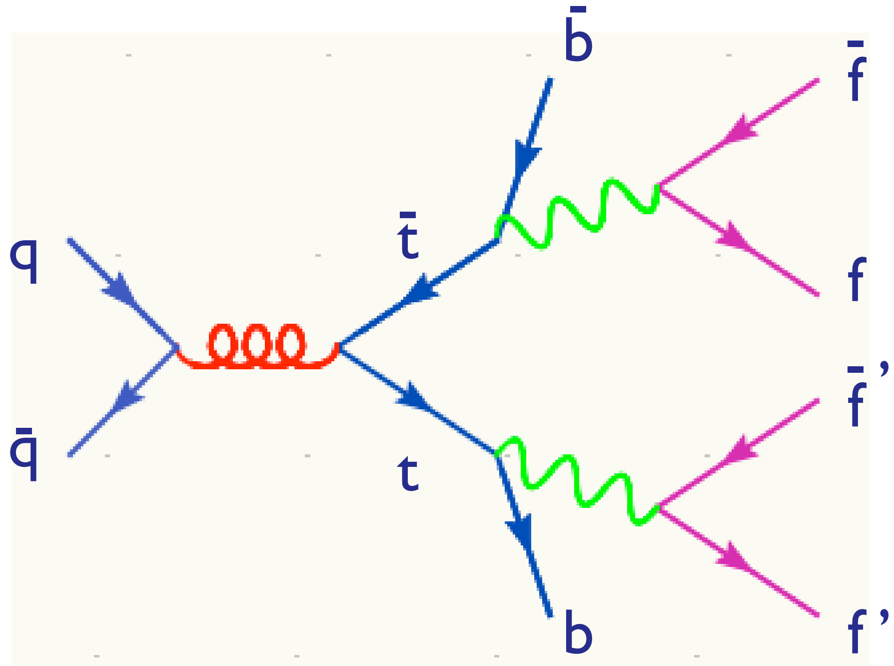
- Motivations
- MG/ME v4 : status and latest developments
- On-going projects and plans
- Discussion

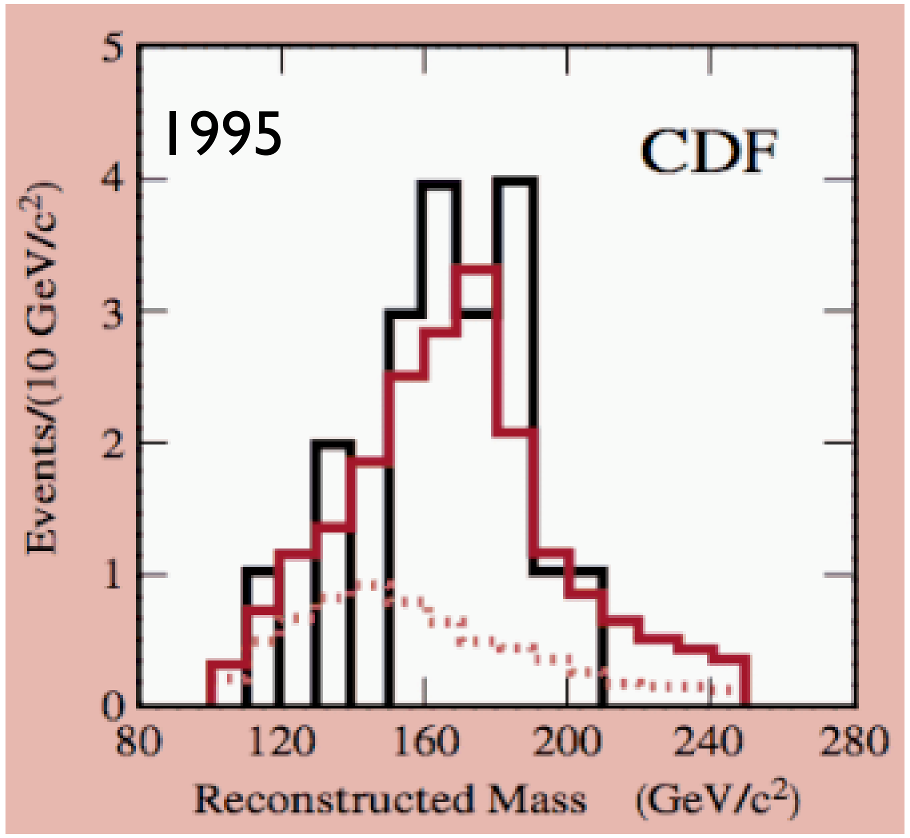
How are we going to discover New Physics?



Heavy states decaying in jets and leptons and $\not{E}_T$.

A lesson from the top





How did it go?

0. The only unknown was the top mass!

1. The experimentally easiest channel for triggering/ reconstruction/background-control was chosen.

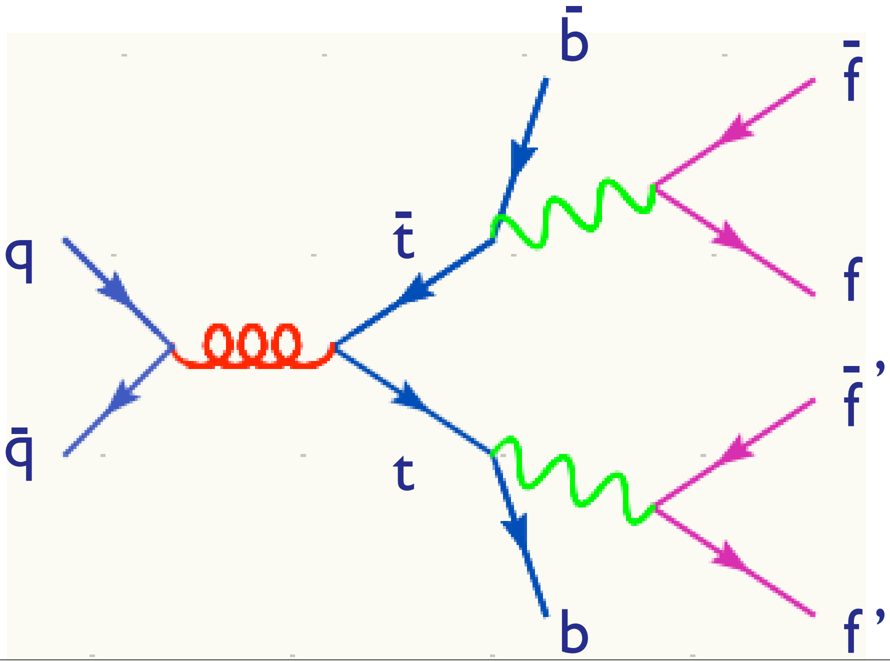
2. Mass reconstruction employed

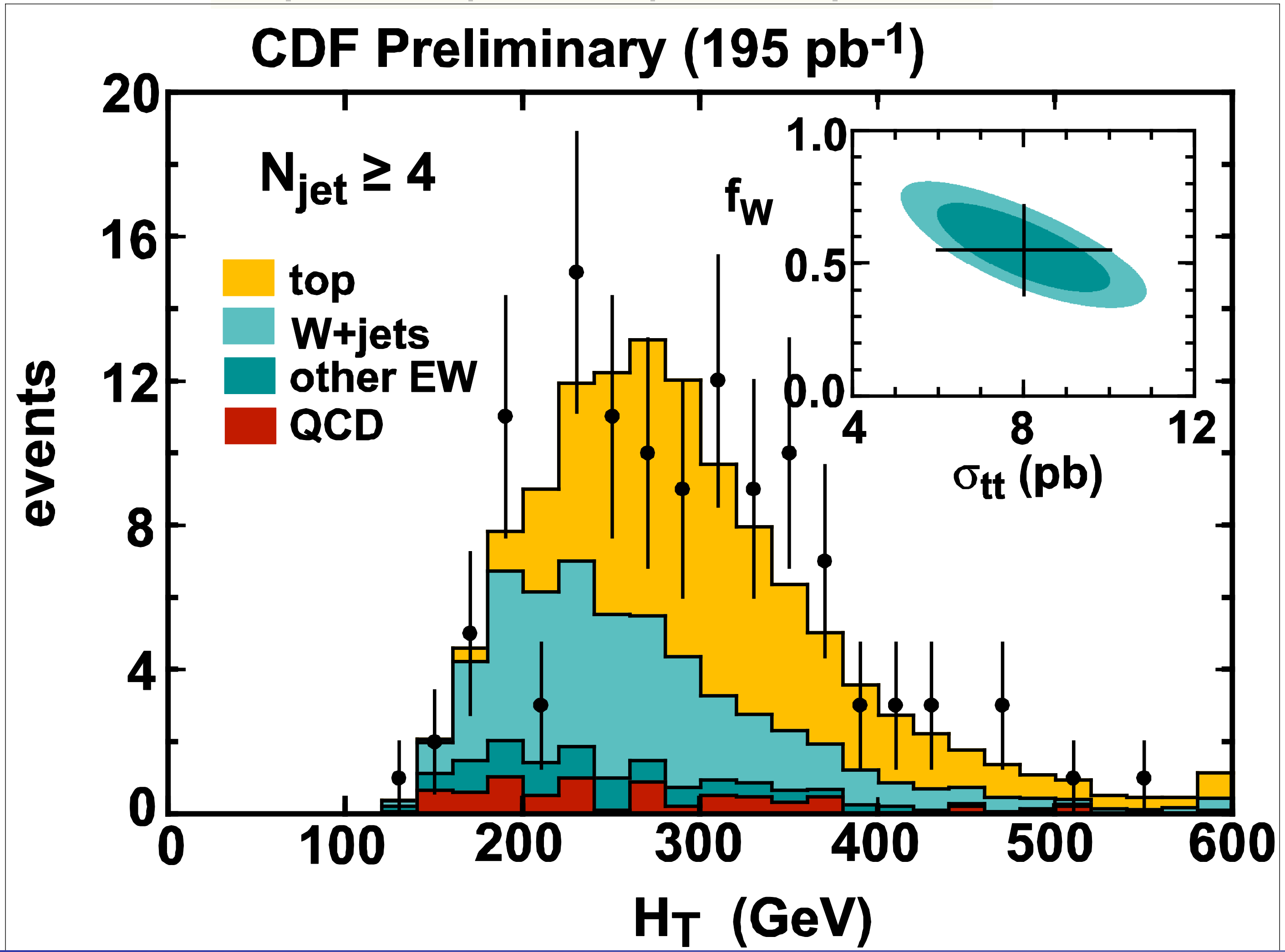
3. Backgrounds estimated via control samples with heavy flavors and also via MC ratio's.

4. Number of events consistent with the cross section expectation from QCD

Handful of events was enough!

A lesson from the top





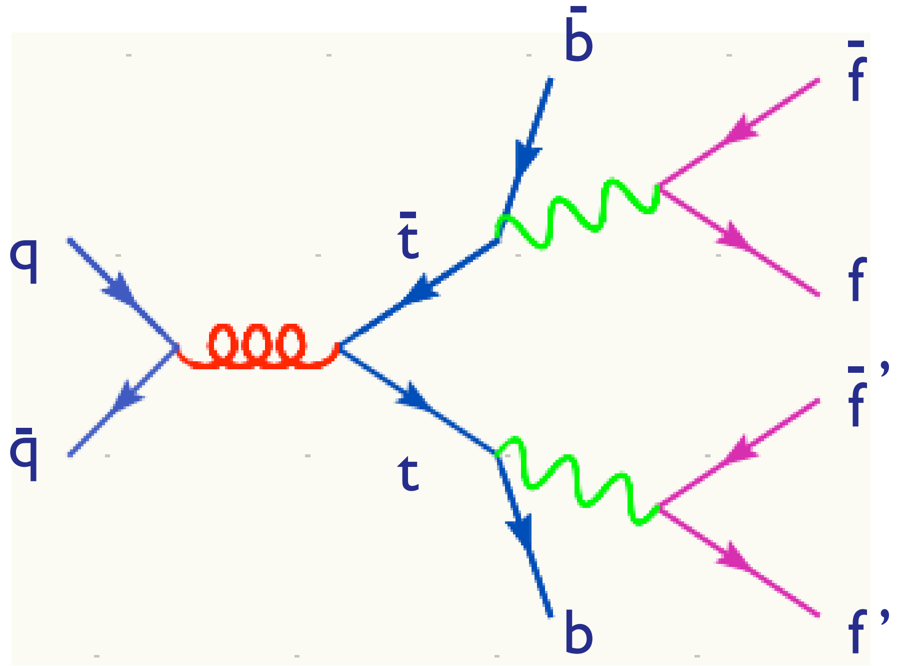
Immediately confirmed in Run II, also by the most inclusive measurements, H_T.

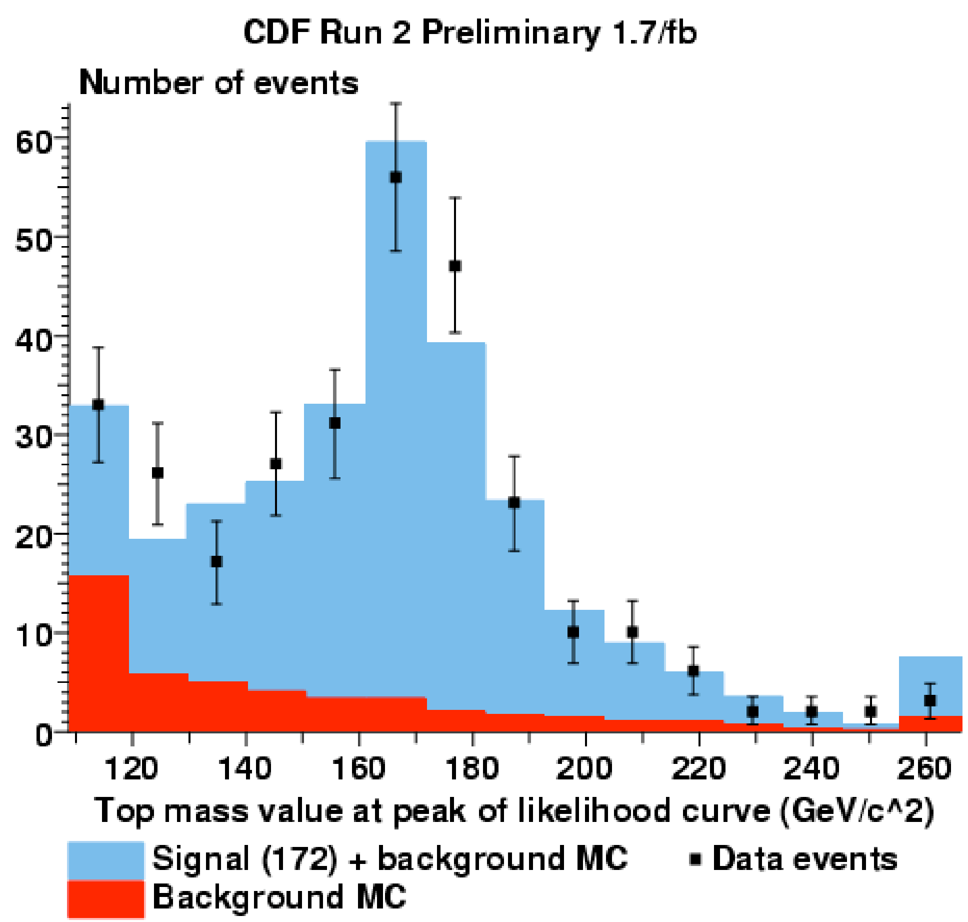
Other channels start to be considered as the statistics increases to have a consistent picture.

Cleaner and cleaner samples more exclusive studies:

1. W Polarization
2. BR’s ratio’s
3. Top Quark charge
4. Differential m_{tt} distribution
5. Search for new physics!!

A lesson from the top





Summary:

1. More than15-year long story

2. At all stages MC's played a role.

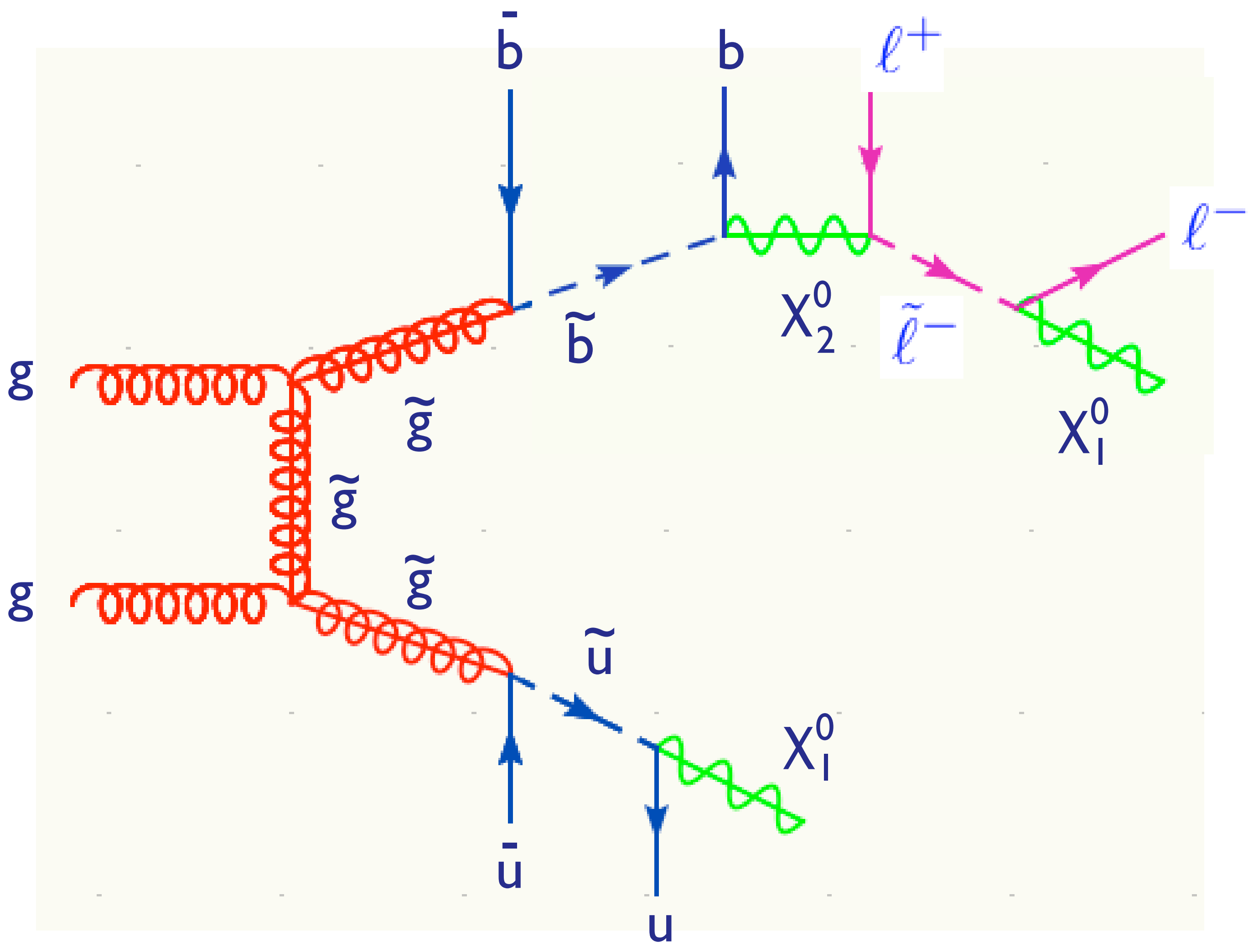
3. Now all studies, including the mass measurements, are strongly based on our simulation tools, i.e., matrix element methods.

More sophisticated analysis need more sophisticated MC's...

Is this strategy directly applicable to new heavy state searches?

A lesson from the top

Susy inclusive searches are similar but more complicated final states.



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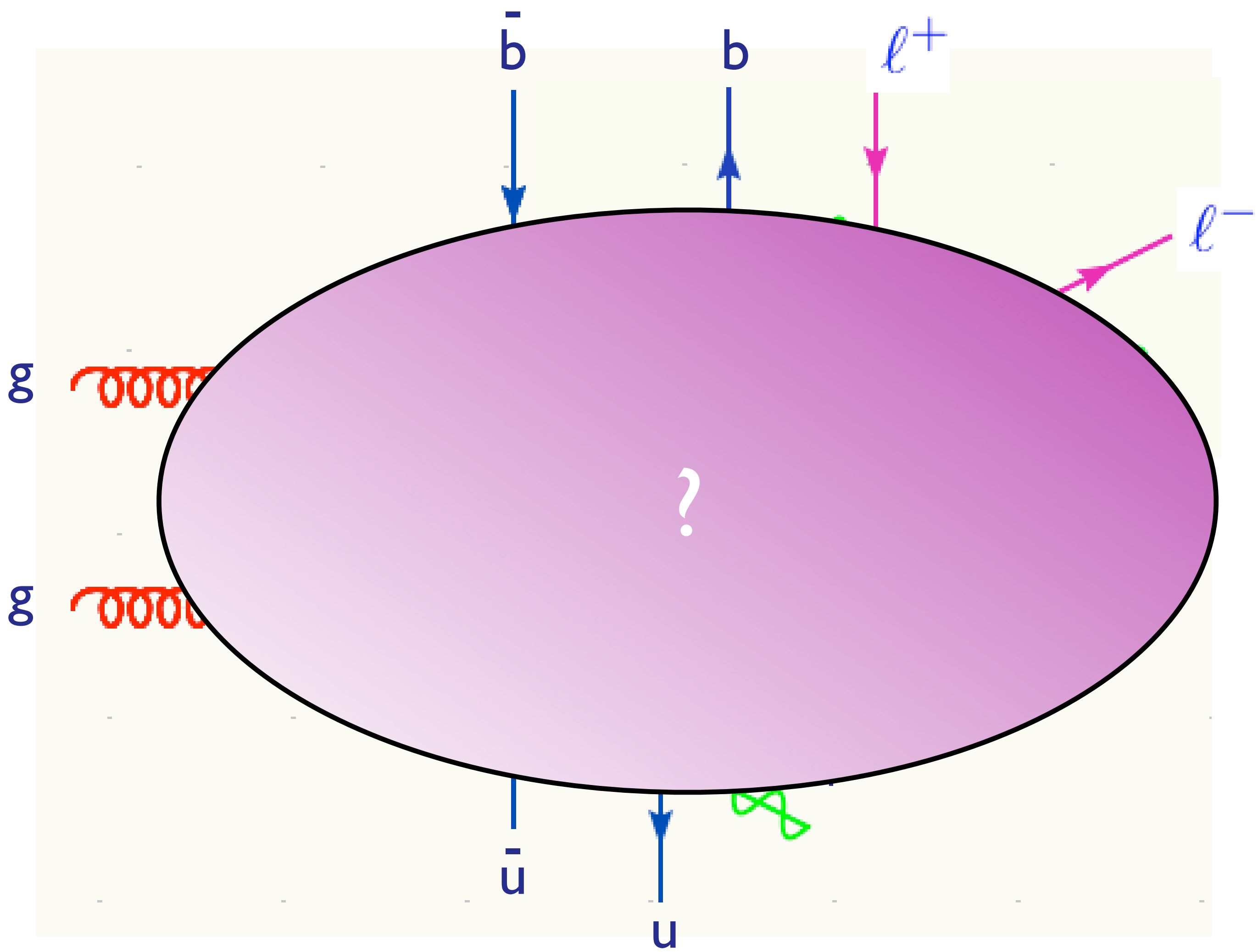
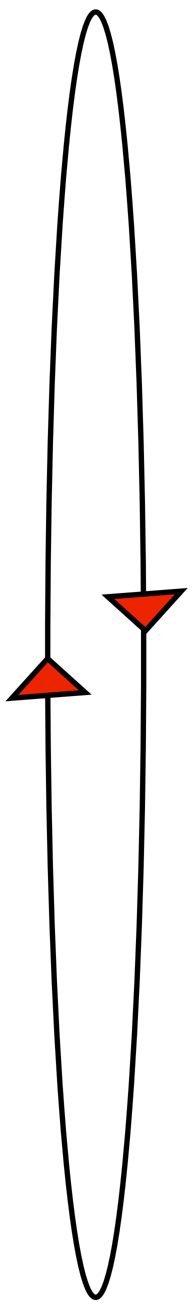


The main difference is that we don't know what to expect!!

A minimal strategy for BSM & Tools



1. Find excess(es) over SM backgrounds

Fully exclusive description for rich and energetic final states (multi-jets + EW and QCD particles (W,Z, photon,b,t).
Flexible MC to be validated and tuned to control samples.
Accurate predictions (NLO,NNLO) for standard candles SM cross sections (with final state acceptance)

2. Identify a finite set of coarse models compatible with the excess(es).

Inverse problem tools (Ex: OSET)

3. Look for "predicted excesses" in other channels.

Simulation of any BSM signature: from models to events in an easy and fast way.

4. Refine

Accurate predictions for cross sections of selected models (Ex: SUSY) to identify couplings.
Accurate predictions for primary couplings (Ex: spectra calculators).

5. Perform more detailed studies to measure mass spectrum, quantum numbers, couplings.

Accurate ME based description for final state distributions which keeps all the relevant information (Ex. decay chain with spin).

6. Refine

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

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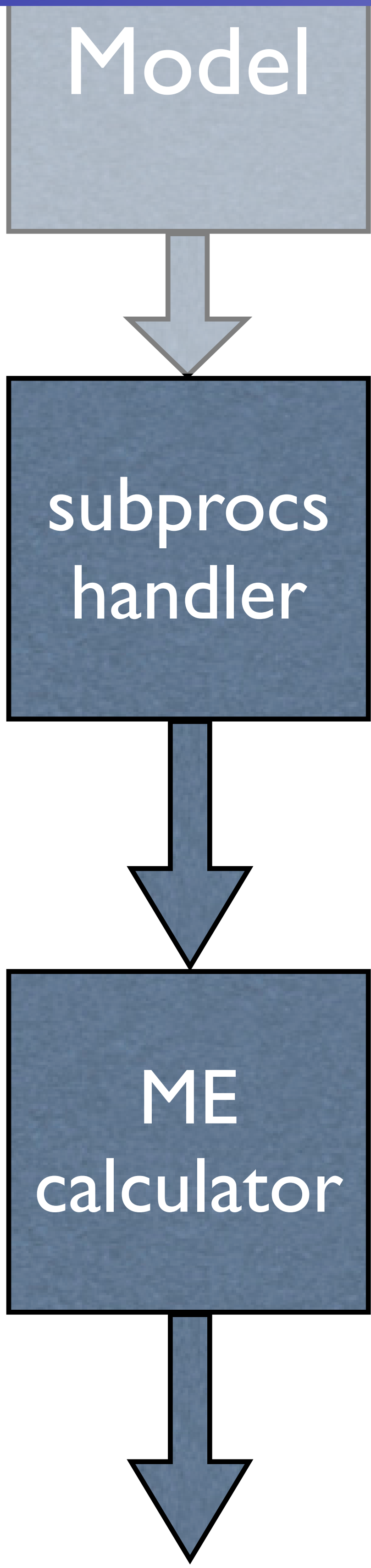
Off-shell effects, Matrix Element methods

Solution:
A fully flexible platform of matrix element based tools that can be used by both TH and EXP's.

General structure

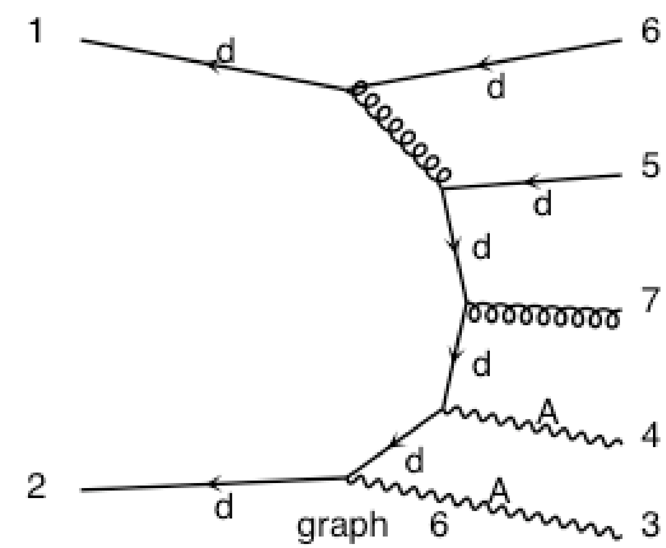


Includes all possible subprocess leading to a given multi-jet final state automatically or manually (done once for all)

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 with many partons in the final state.

Most use Feynman diagrams w/ tricks to reduce the factorial growth, others have recursive relations to reduce the complexity to exponential. ☺



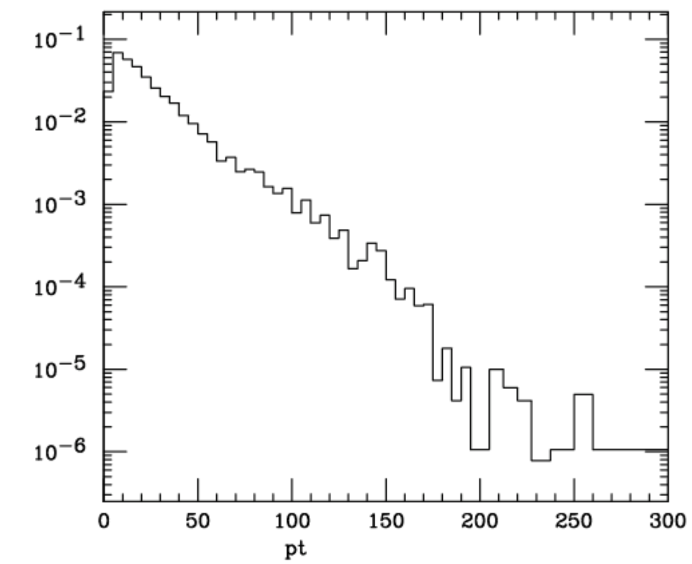
$$\mathcal{A}(\{p\},\{h\},\{c\}) = \sum_i D_i$$

General structure

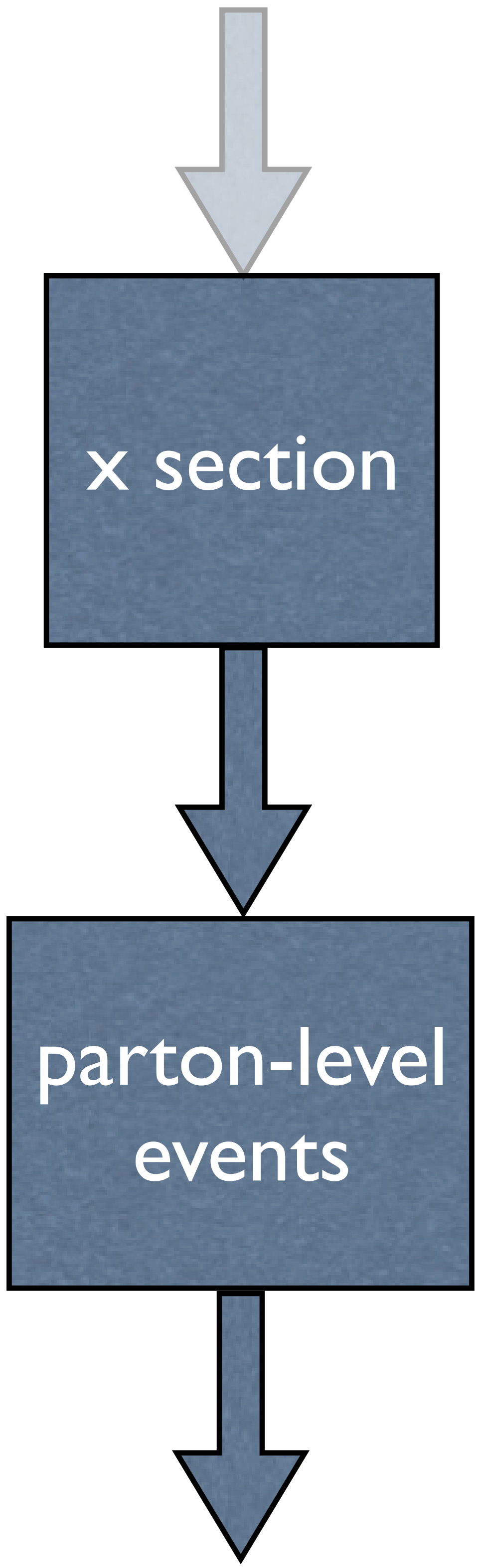
x section

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

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



General structure



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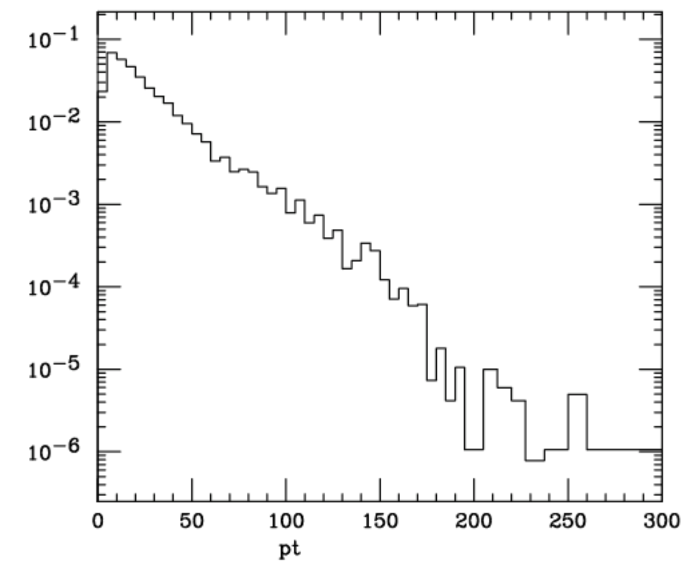
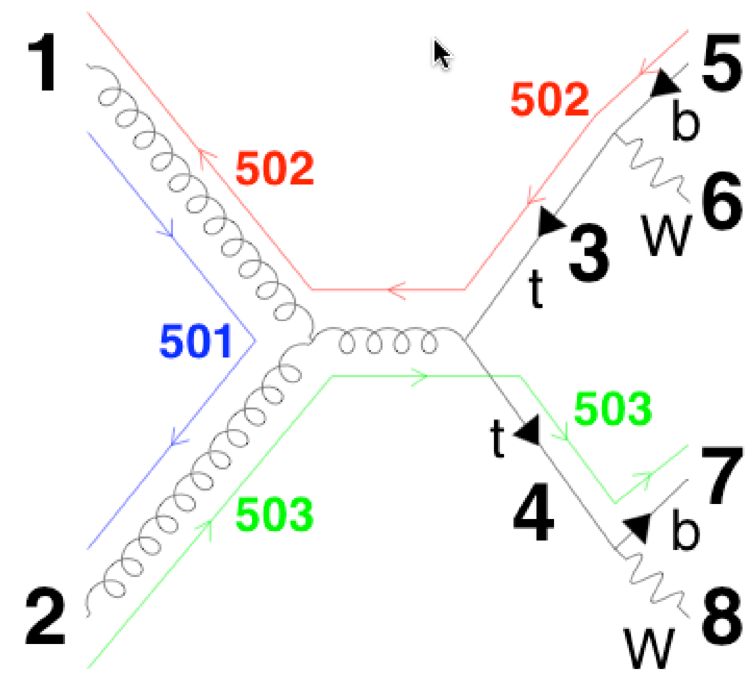
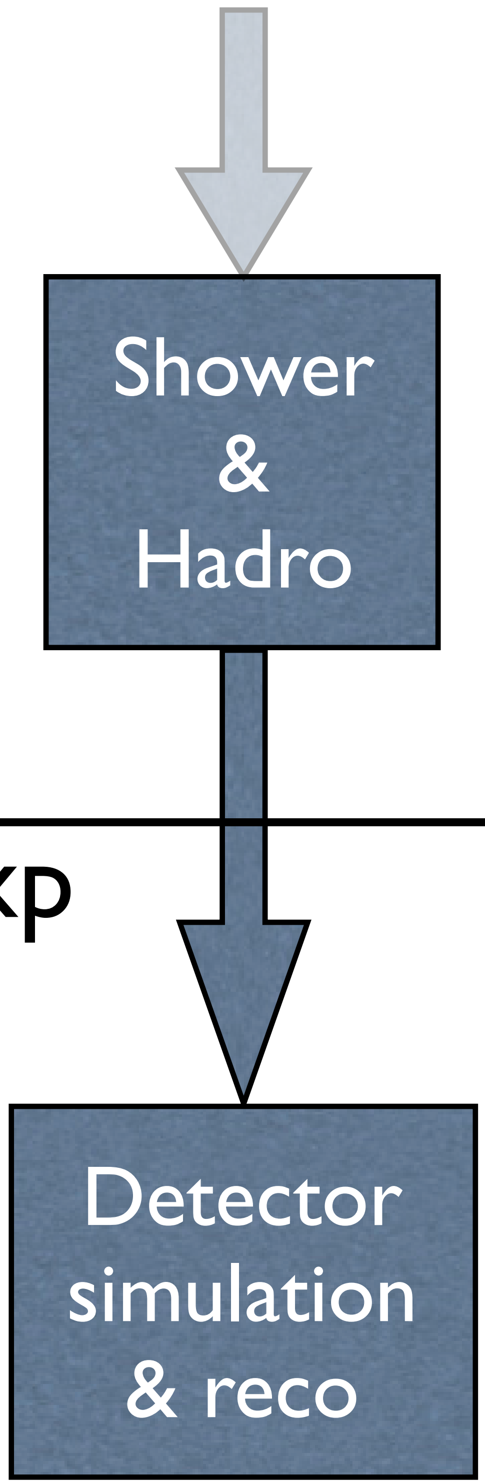
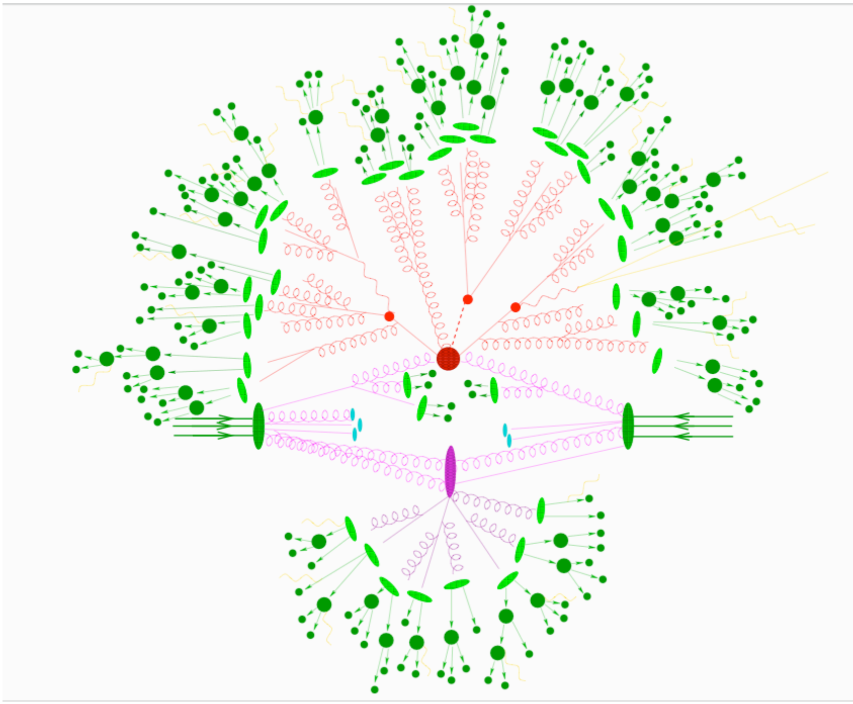


Events are obtained by unweighting. These are at the parton-level. Information on particle id, momenta, spin, color and mother-daugther is given in the Les Houches format.



General structure



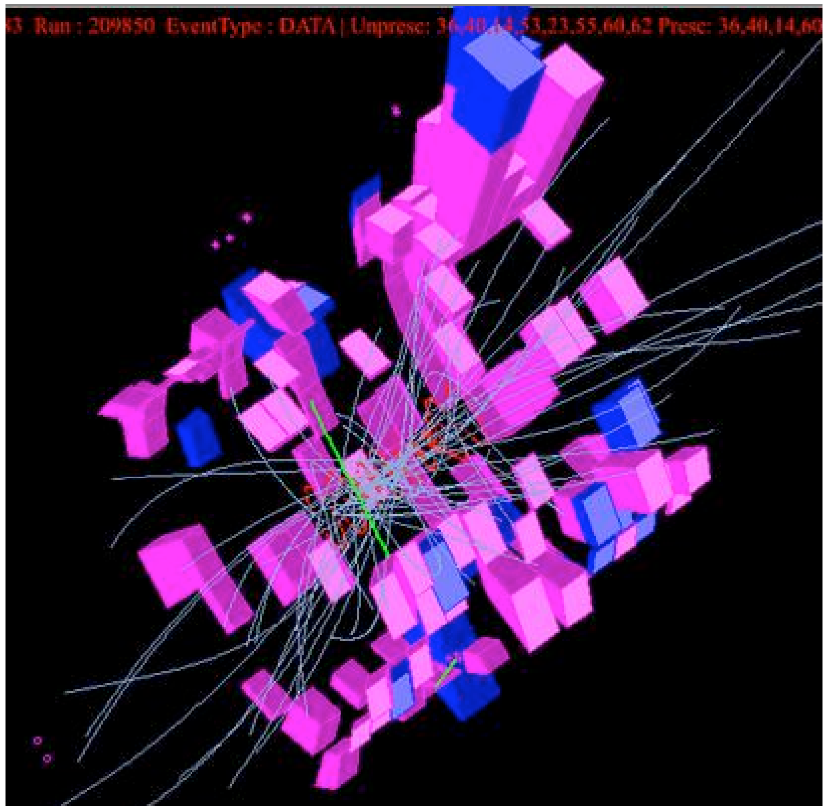


Events in the LH format are passed to the showering and hadronization⇒

high multiplicity hadron-level events

th

exp



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

New generation of ME based MC's

Multipurpose MC's, matrix element based. Matrix element creation is automatic or semi-automatic at tree level. Matching (when available) performed with the parton shower to produce inclusive multi-jet samples. Some codes are also suitable for BSM physics.

Code	Comments
Alpgen	Extendable library of procs. SM only. Optimized for multi-particle events. ME/PS matching a la MLM.
CompHep/CalcHEP	User's driven. Several models available and easy to insert new ones. No ME/PS matching. Squared amplitudes.
HELAC	User's driven. SM only. ME/PS matching a la MLM.
MadGraph	User's driven. Web based. Several models available and easy to insert new ones. ME/PS matching a la MLM.
SHERPA	User's driven. Several models available. Full showering and hadronization. ME/PS matching a la CKKW.

Apart from SHERPA, which provides its own PS, all other ME codes need to be interfaced to a PS (Pythia or HERWIG). This is true also for NLO codes (MC@NLO and POWEG).

MadGraph on the Web

NSF

High Energy Physics Illinois

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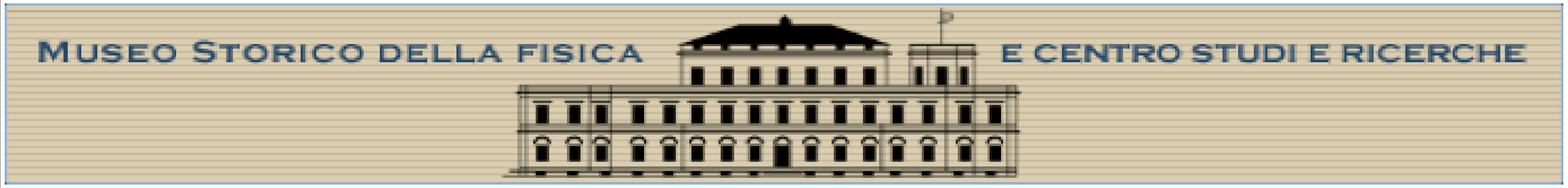
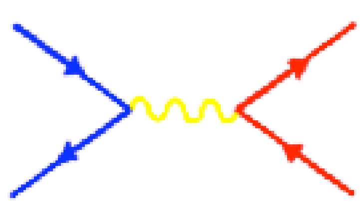
Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation

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

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



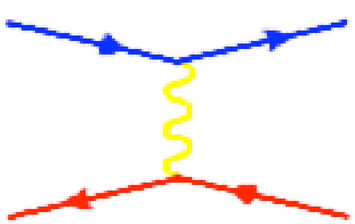
http://madgraph.roma2.infn.it/



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 (+1 private cluster). ~1500 registered users.

Thanks to: D. Lesny, L. Nelson (UIUC), F. Chalier, T. Kuegten (UCL), R. Ammendola, N. Tantalo (RM2)

Madgraph/MadEvent

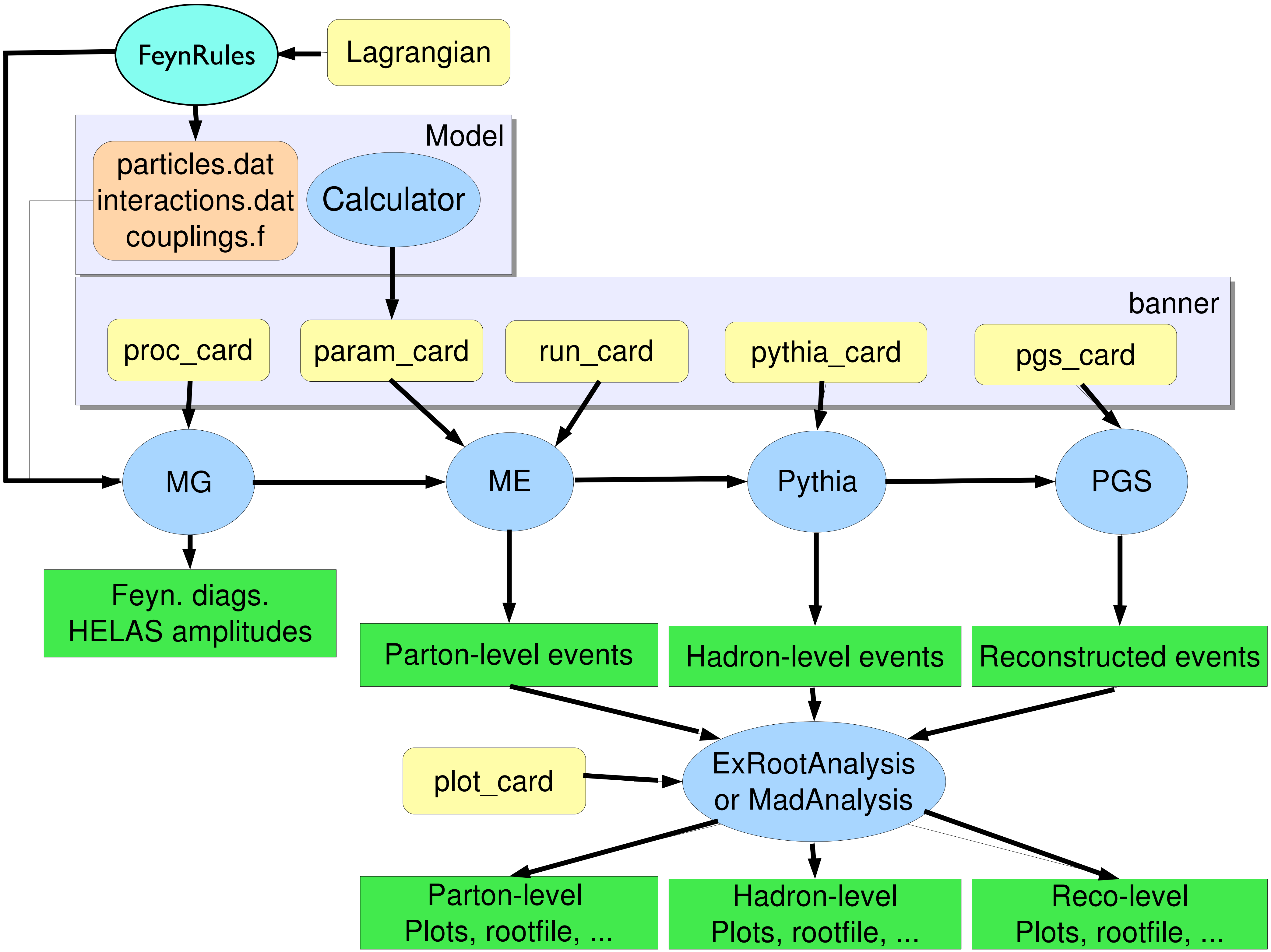
- The new web generation:
  - User requests a process (Ex. pp>tt~jjj) and corresponding code is generated on the fly.
  - User inputs model/parameters/cuts, and code runs in parallel on modest farms.
  - Returns cross section, plots, parton-level events.
- Advantages:
  - Reduces overhead to getting 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 web simulation : MadEvent → Pythia → PGS
- Multi-processes in single code & generation
- Standalone version for theorists
- New complete models : SM, HEFT, MSSM,2HDM
- USRMOD : New Models implementation
- 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
- Analysis platforms: ExRootAnalysis and MadAnalysis

MadGraph/MadEvent v4 Flow



MadGraph/MadEvent v4 : recent developments

- Web staged simulation : LHEF → Pythia → PGS [J. Alwall et al.]
- MatchChecker [S. de Visscher]
- TopBSM [R. Frederix, FM]
- Decay width calculator [J. Alwall]
- Decay chains specifications [J. Alwall, T. Stelzer]
- Grid Version [Mad Team]
- NRQCD matrix element generator [P. Artoisenet, FM, T. Stelzer]

Models in MadGraph

Previously:

- Standard Model

Now:

- MSSM
- General 2HDM: CPV, type I,II,... & Calculator
- Higgs EFT

particles.dat

```
#Name anti_Name   Spin    Linetype Mass Width Color Label Model
#xxx   xxxx       SFV      WSDC     str   str  STO    str  PDG code

#
# Quarks
#

d        d~        F         S      ZERO  ZERO    T     d     1
u        u~        F         S      ZERO  ZERO    T     u     2
s        s~        F         S      ZERO  ZERO    T     s     3
c        c~        F         S      ZERO  ZERO    T     c     4
b        b~        F         S      BMASS ZERO    T     b     5
t        t~        F         S      TMASS TWIDTH  T     t     6
```

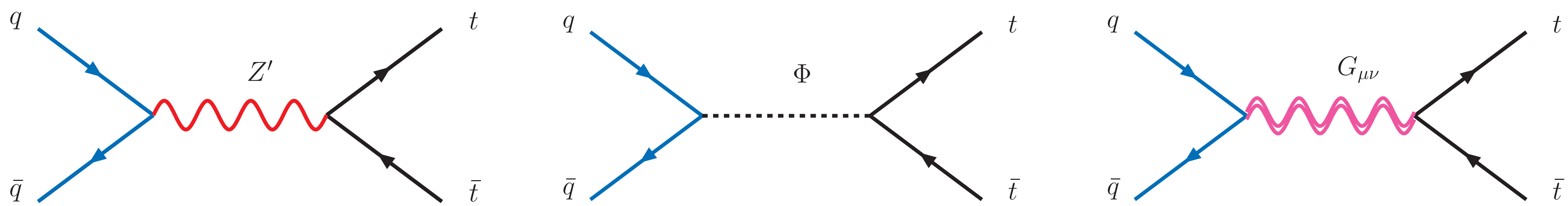
interactions.dat

```
#
# QCD interactions
#

d d g GG QCD
u u g GG QCD
s s g GG QCD
c c g GG QCD
b b g GG QCD
t t g GG QCD

g g g G  QCD
```

+ General framework for user-defined models

TopBSM

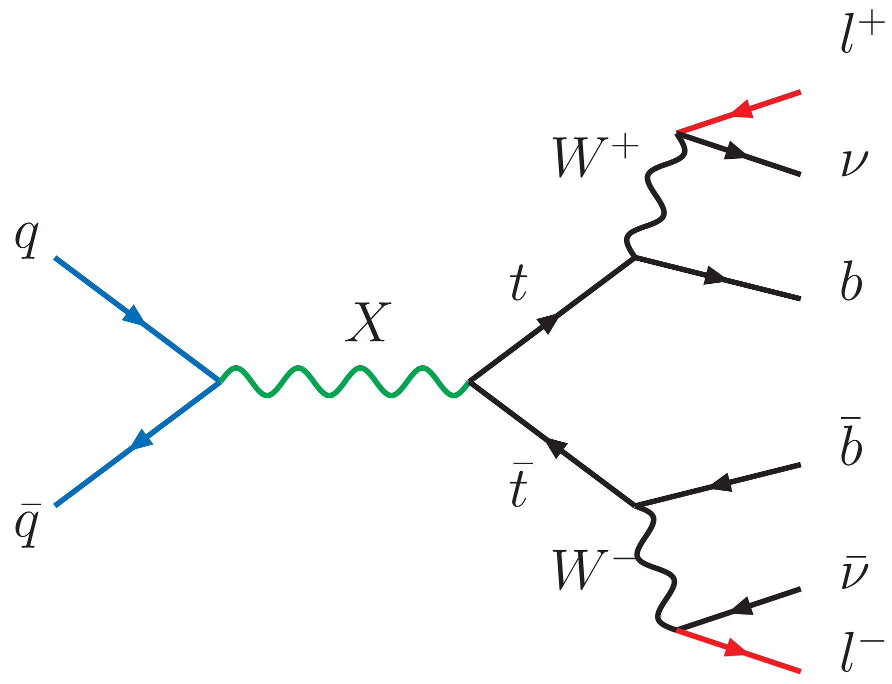
In many scenarios for EWSB new resonances show up, some of which preferably couple to 3rd generation quarks.



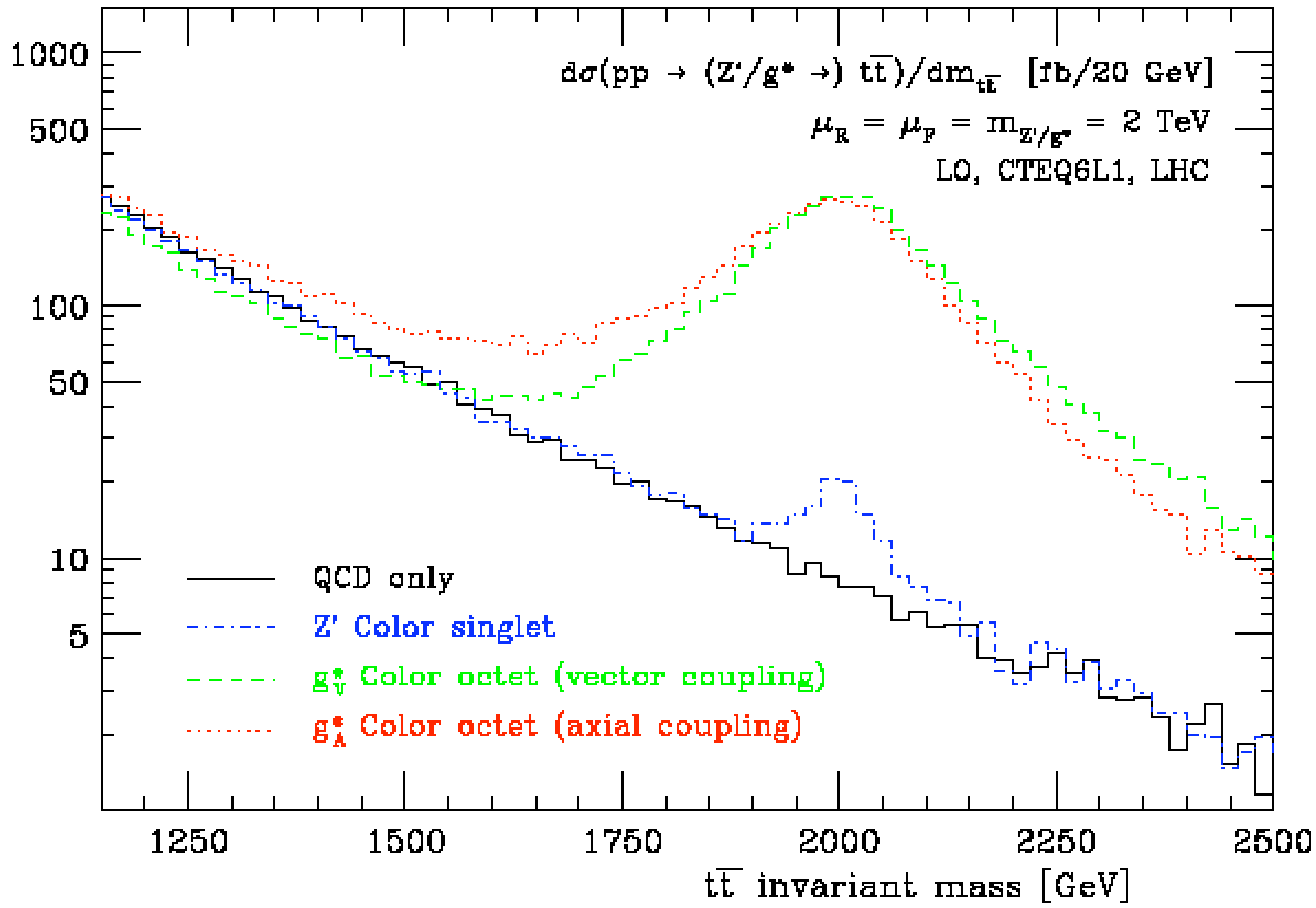
Given the large number of models, in this case is more efficient to adopt a “model independent” search and try to get as much information as possible on the quantum numbers and coupling of the resonance.

To access the spin of the intermediate resonance spin correlations should be measured.

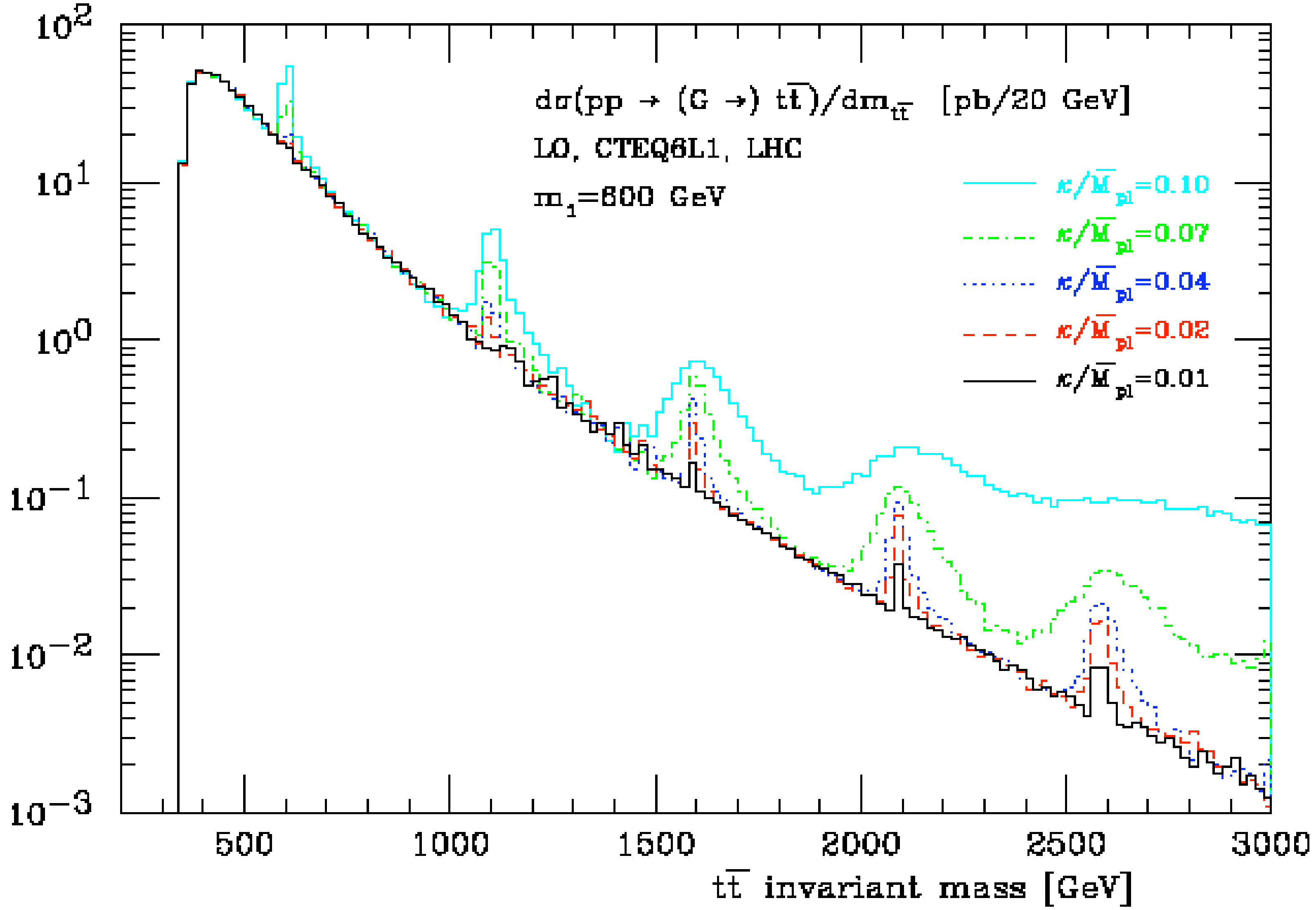
It therefore mandatory for such cases to have MC samples where spin correlations are kept and the full matrix element pp>X>tt>6f is used.



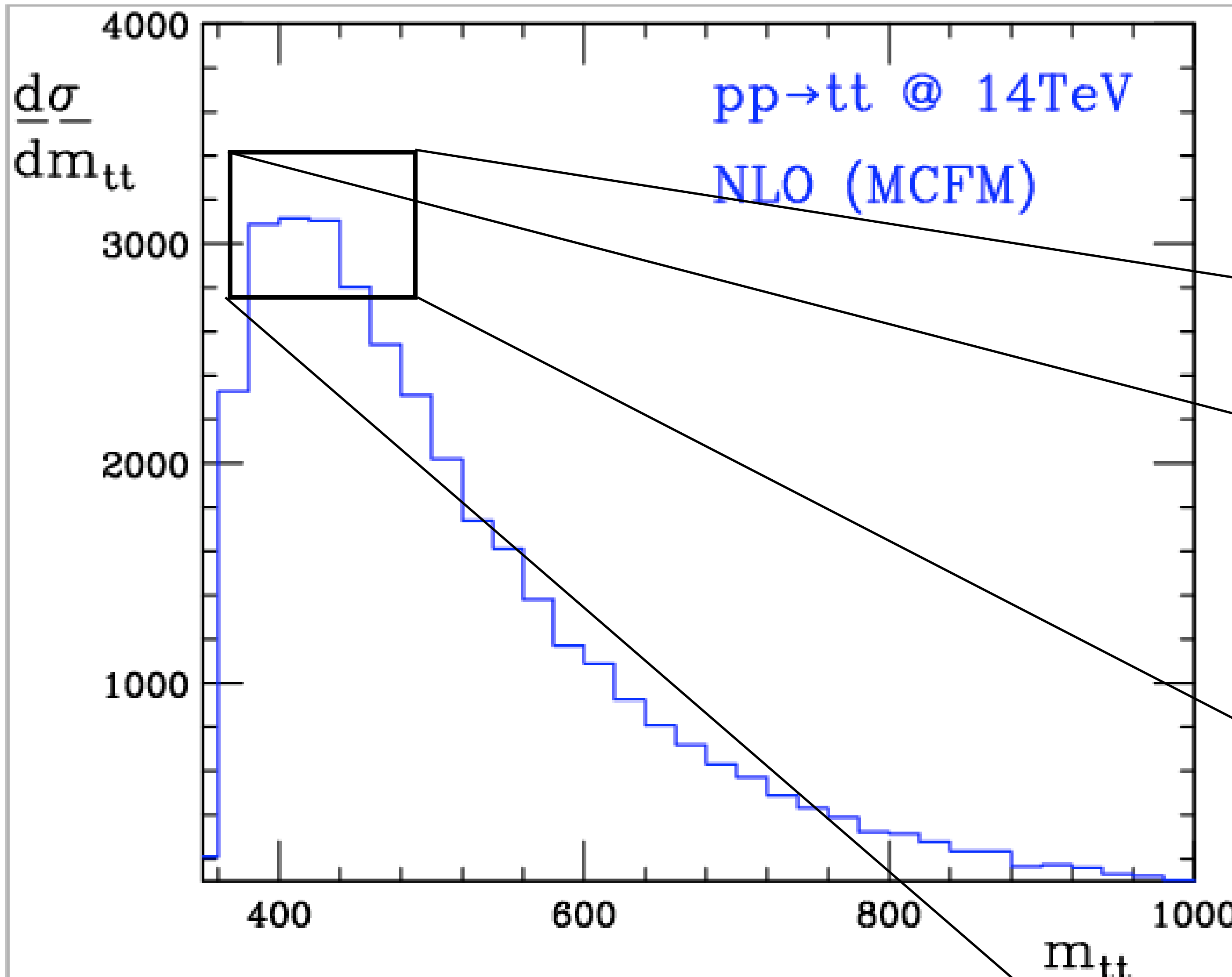
TopBSM : vector resonances

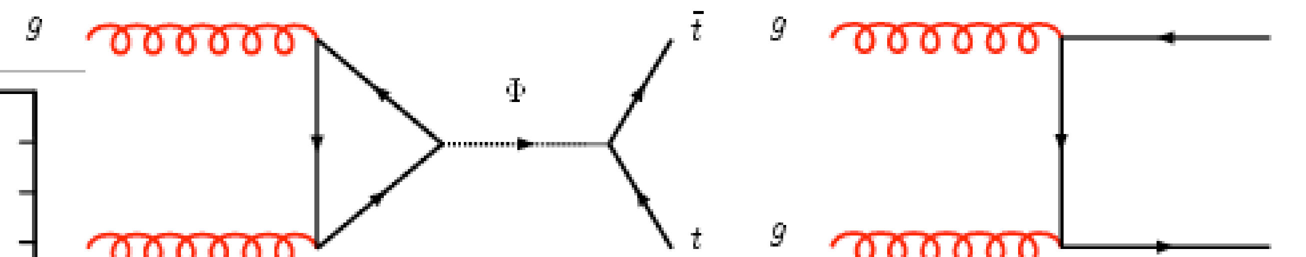


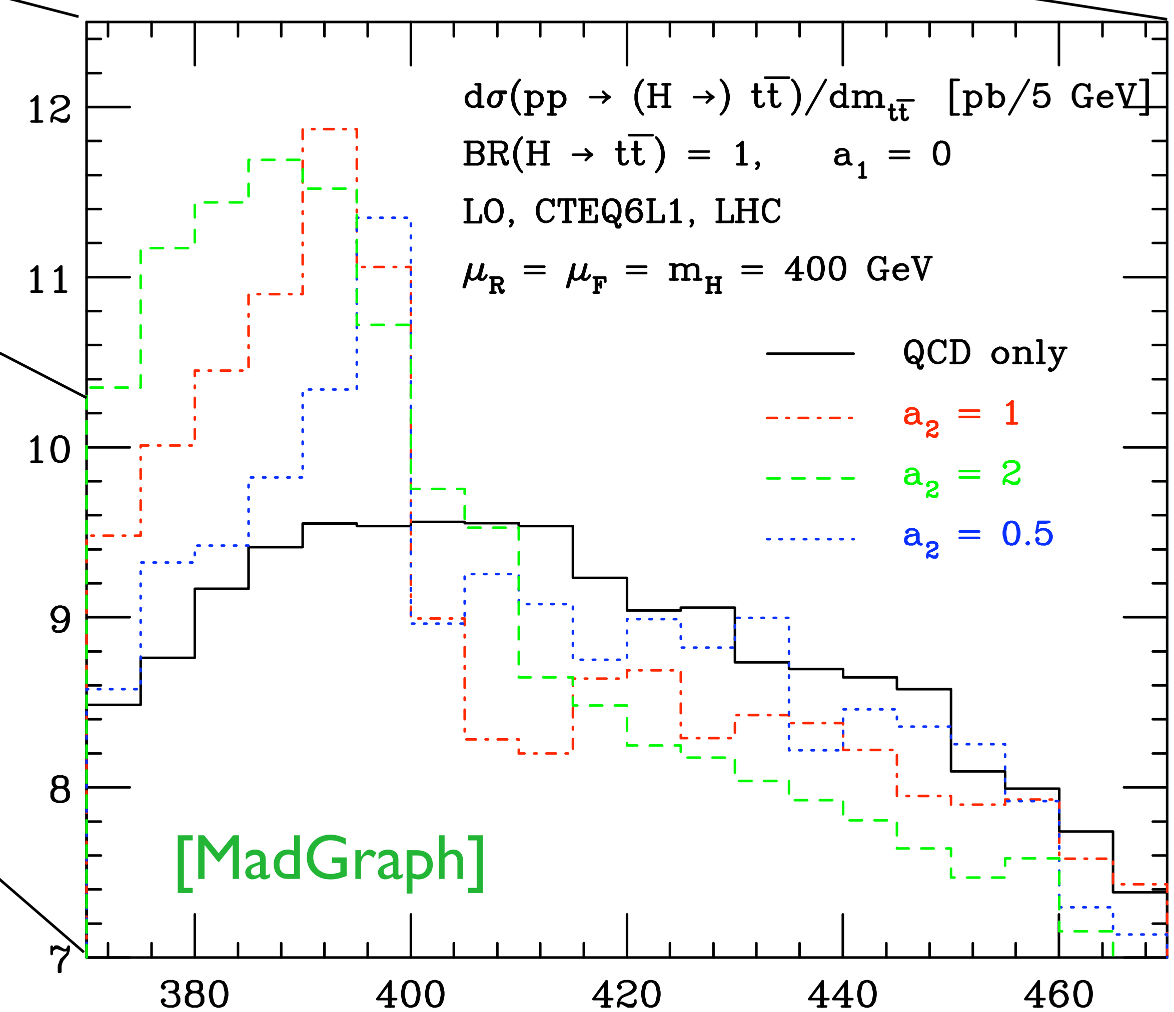
TopBSM : RS gravitons



TopBSM: more than just peaks!







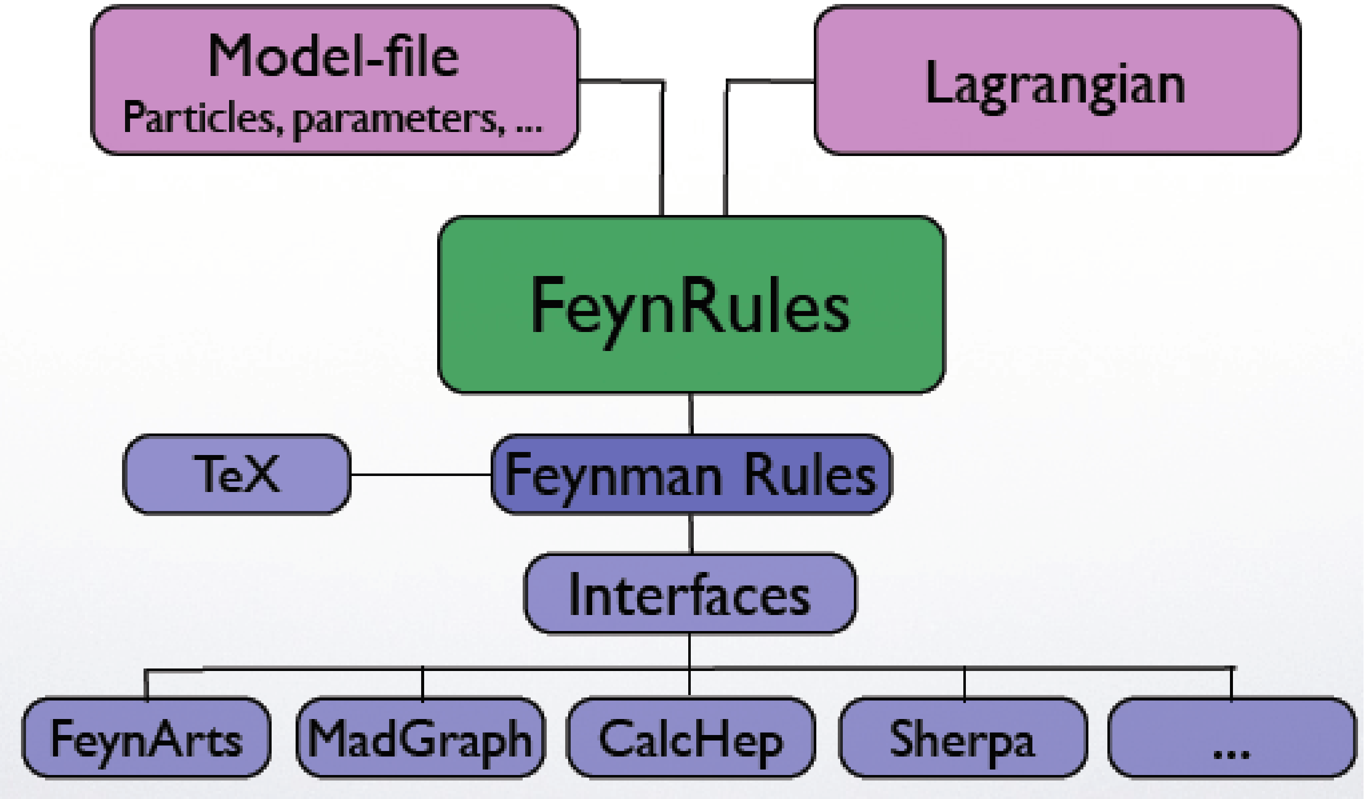
Non-trivial behavior (peak-dip) due to the interference between the signal and the background, only if top width dominated by Φ→tt. [Dicus, Stange & Willenbrock 1994]

Spin-off : FeynRules

[C. Duhr + MC collaborators]

A new tool to extract Feynman rules and couplings directly from the Lagrangian and effortless implement in any MC.

Mathematica package where Lagragians for new models can be developed and studied at the TH level and then passed to full fledged MC for the LHC.



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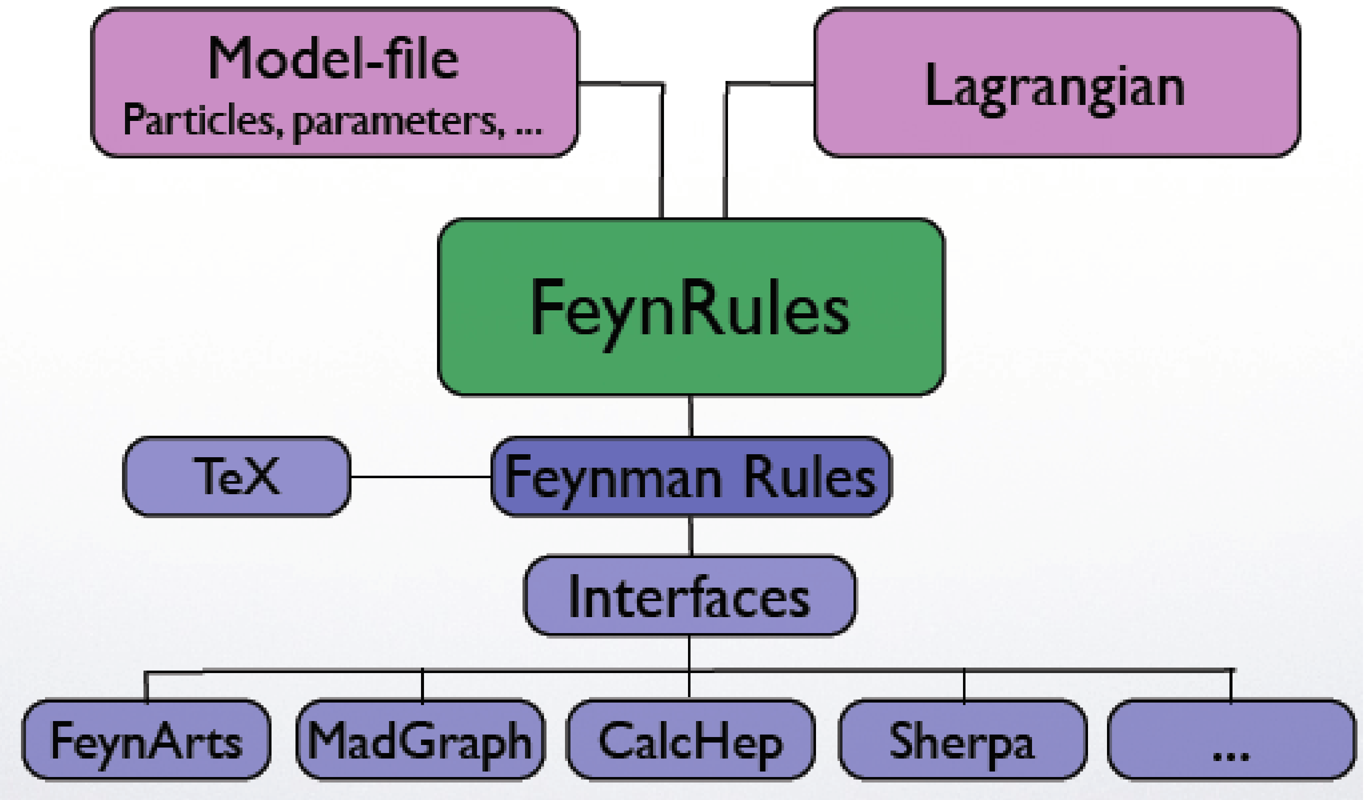


$$\kappa^{-1}\mathcal{L}_{\mathrm{F}}^{\vec{n}}(\kappa) = \frac{1}{2}\Big[(\tilde{h}^{\vec{n}}\eta^{\mu\nu} - \tilde{h}^{\mu\nu,\vec{n}})\bar{\psi}i\gamma_\mu D_\nu\psi - m_\psi\tilde{h}^{\vec{n}}\bar{\psi}\psi + \frac{1}{2}\bar{\psi}i\gamma^\mu(\partial_\mu\tilde{h}^{\vec{n}} - \partial^\nu\tilde{h}^{\vec{n}}_{\mu\nu})\psi\Big] + \frac{3\omega}{2}\tilde{\phi}^{\vec{n}}\bar{\psi}i\gamma^\mu D_\mu\psi - 2\omega m_\psi\tilde{\phi}^{\vec{n}}\bar{\psi}\psi + \frac{3\omega}{4}\partial_\mu\tilde{\phi}^{\vec{n}}\bar{\psi}i\gamma^\mu\psi$$

$$k\Big(-2\,\mathrm{mpsi\ om}\,\phi\,\psi^\dagger.\psi + \frac{3}{4}\,i\,\mathrm{om}\,\partial_\mu(\phi)\,\psi^\dagger.\gamma^\mu.\psi + \frac{3}{2}\,\mathrm{om}\,\phi\big(i\,\psi^\dagger.\gamma^\mu.\partial_\mu(\psi) - g\,\psi^\dagger.\gamma^\mu.T^a.\psi\,G_{\mu,a}\big) + \frac{1}{2}\Big(\frac{1}{2}\,i\big(\partial_\mu(h_{\nu,\nu}) - \partial_\nu(h_{\mu,\nu})\big)\,\psi^\dagger.\gamma^\mu.\psi - \mathrm{mpsi}\,\psi^\dagger.\psi\,h_{\mu,\mu} + \big(i\,\psi^\dagger.\gamma^\mu.\partial_\nu(\psi) - g\,\psi^\dagger.\gamma^\mu.T^a.\psi\,G_{\nu,a}\big)\big(h_{\rho,\rho}\,\eta_{\mu,\nu} - h_{\mu,\nu}\big)\Big)\Big)$$

Nice example of community answer to a widespread need. Official release at MC4BSM.

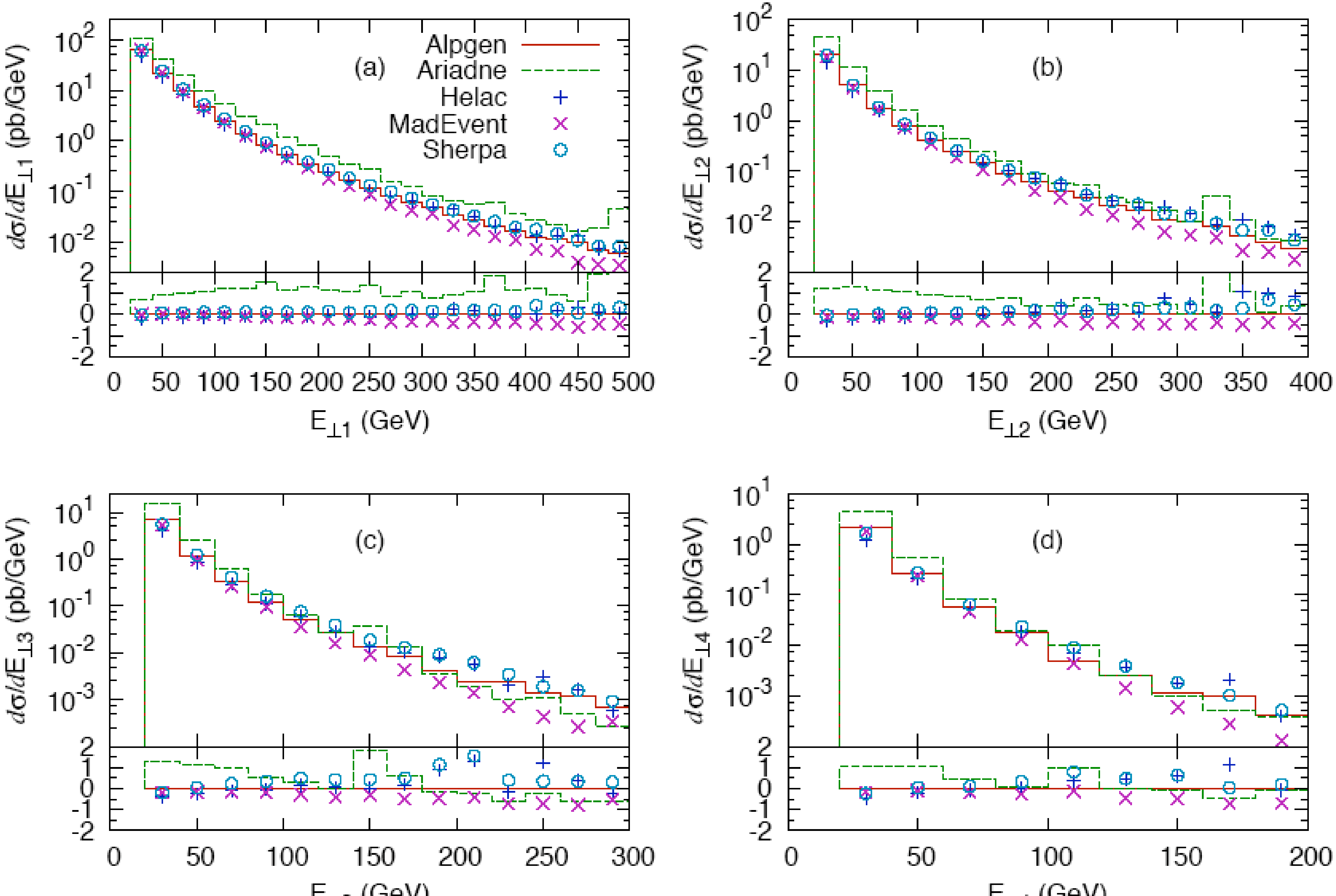
ME/PS merging in MadGraph

- K_T MLM scheme [Mrenna] implemented by J. Alwall.
- Interfaced to (fortran) Pythia, both Q^2 ordered showers.
- Extensively validated in V+jets (data and comparison [arXiv:0706.2569]) and now also in VV+jets, tt+jets, h+jets and inclusive jets.
- Matching in New Physics samples available.
- New matching with Pythia pt^2 ordered shower under study [Alwall]
- Interfaces with Pythia8 and Herwig++ are through standard LHEF and not yet available with matching.

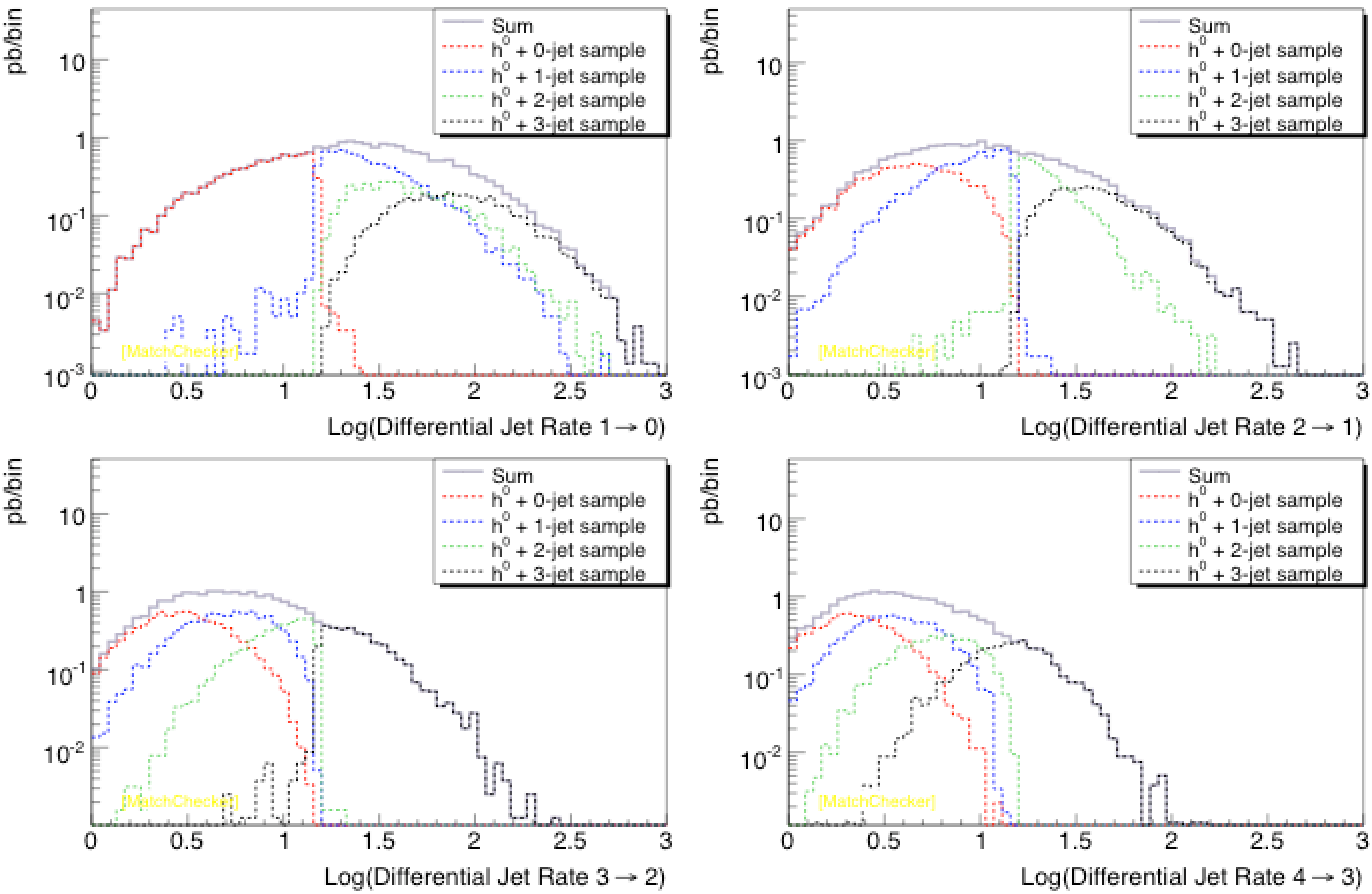
W+ jets: first comparison!

$W^{\pm}$ + jets comparison plots: Jet E_T for LHC

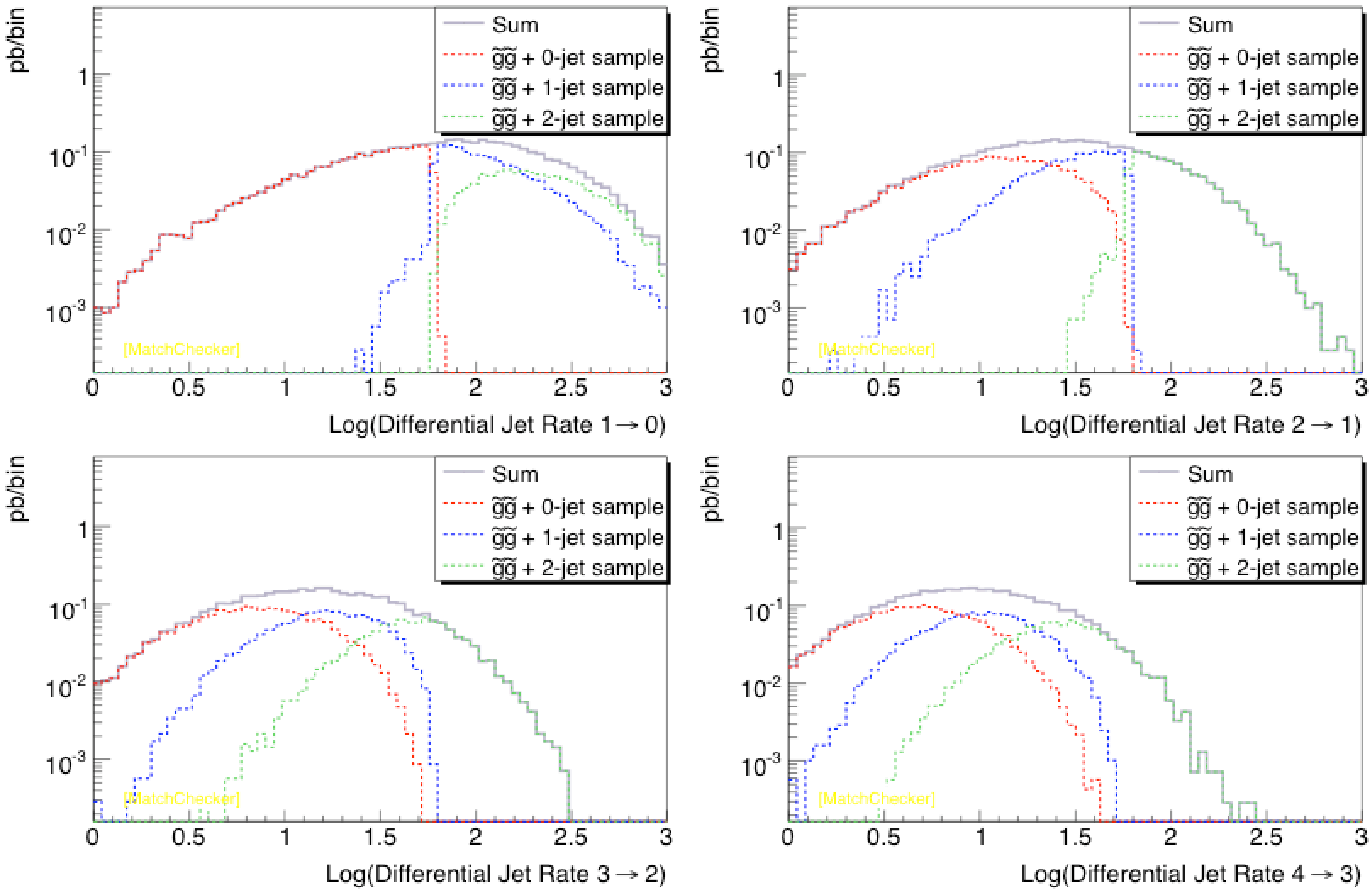
[J. Alwall et al., arXiv:0706.2569]



Example of validation : H+jets



$\tilde{g}\tilde{g}$ + jets: inclusive sample validation plots



Jet rates are smooth :
SUSY double counting problem solved by the use of the decay chains!

Coming soon

- FeynRules : a Mathematica based program to extract Feynman rules and couplings directly from the Lagrangian + interfaces to MC (MadGraph, SHERPA, CalcHEP,...) and to FeynArts.
  [C. Duhr + MC collaborators]
- MadWeight: a General approach to Matrix Element techniques
  [P. Artoisenet, V. Lemaitre, FM, O. Mattelaer]
- Event generation for quarkonium
  [P.Artoisenet, FM, Stelzer]
  I II
- Tools for NLO
- ....
- MG Samples for the LHC

Conclusions

- LHC poses new challenges to the MC community.
- Continuous developments and ongoing projects.
- MadGraph/MadEvent approach is focused towards:
  - Building a community :
    - Web based : public clusters with personal DB's, Twiki, open CVS repository.
    - Support to spin-offs, independent projects, and custom MC needs (Ex: BRIDGE, FeynRules, NLO, BSM implementations, ...)
  - Providing a fully-fledged platform for physics studies at colliders :
    - Complete (staged) simulation chain with interfaces to PS via web + Grid version
    - SM and BSM : signal and backgrounds (including multi-jet samples with ME/PS merg.)
    - TH and EXP tools : StandAlone, ExRootAnalysis, MatchChecker, MadWeight,...

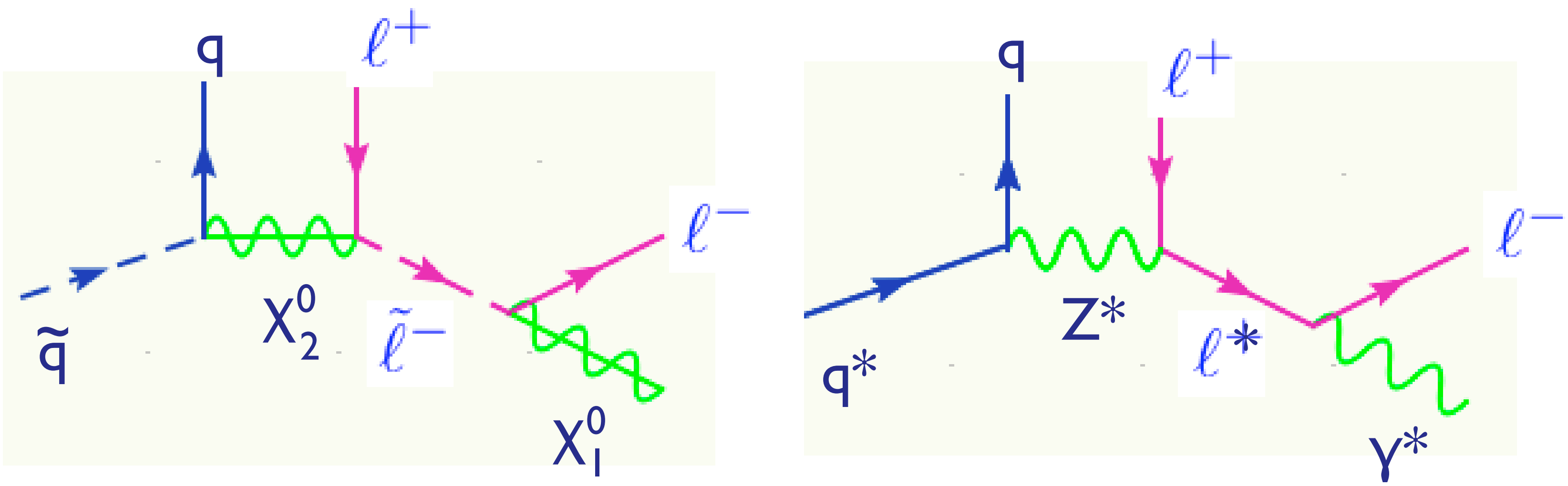
Conclusions

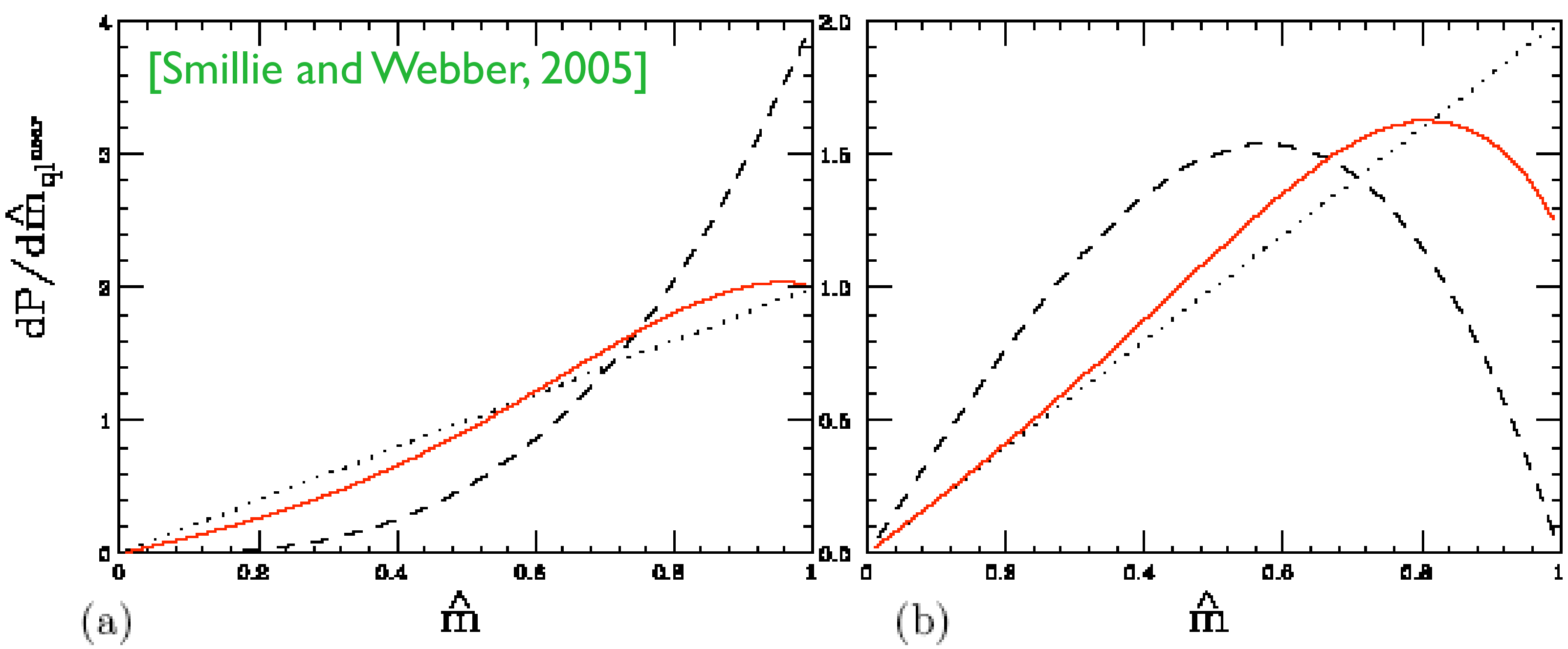
- LHC poses new challenges to the MC community.
- Continuous developments and ongoing projects.
- MadGraph/MadEvent approach is focused towards:
  - Building a community :
    - Web based : public clusters with personal DB's, Twiki, open CVS repository.
    - Support to spin-offs, independent projects, and custom MC needs (Ex: BRIDGE, FeynRules, NLO, BSM implementations, ...)
  - Providing a fully-fledged platform for physics studies at colliders :
    - Complete (staged) simulation chain with interfaces to PS via web + Grid version
    - SM and BSM : signal and backgrounds (including multi-jet samples with ME/PS merg.)
    - TH and EXP tools : StandAlone, ExRootAnalysis, MatchChecker, MadWeight,...

ANY HELP, FEEDBACK, IDEA, SUGGESTIONS,..., ALWAYS WELCOME!

SUSY vs UED

New heavy states tend to decay into lower mass new states, leading to long decay chains, up to the lightest neutral particle (stable is R-parity like is conserved).
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:

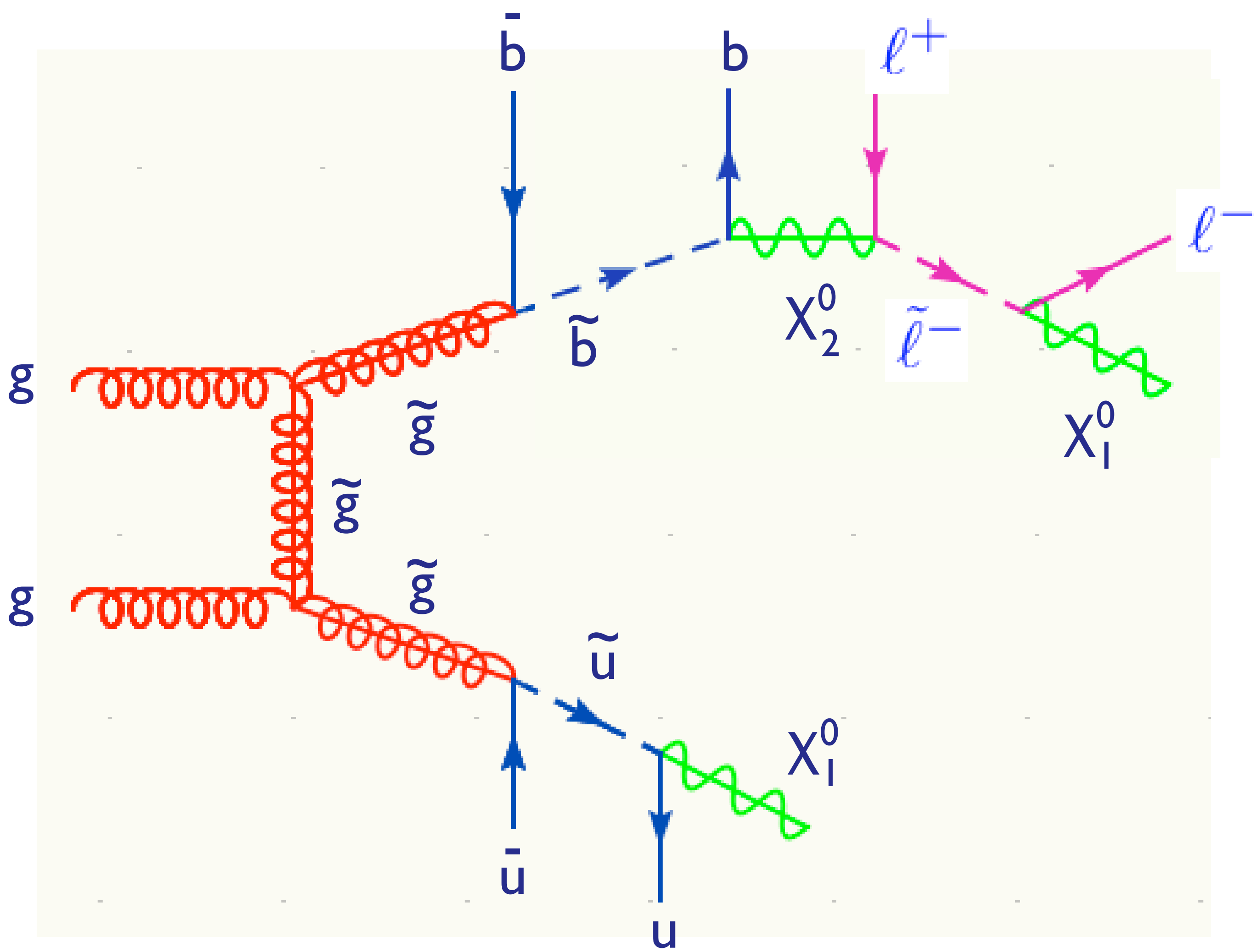
1. production and decay are factorized.
2. Spin is ignored.
3. Chains proceed only through 1→2 decays.
4. The narrow width approximation is employed.
5. Non-resonant diagrams are ignored.

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

Decay chains in MadGraph

[J. Alwall, T. Stelzer]

```
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))
```

LHC Samples and Codes

We have proposed to provide a set of samples and codes for key SM and BSM processes at the LHC.

For each process we plan to provide:

1. Small-size (~1M) parton-level and hadron level (Pythia) sample.
2. Associated (frozen) code for large scale production over the grid.

The samples and the associated codes would be therefore:

a. validated by the MC authors

b. used by experimentalists as a reference for massive productions and full simulations

c. used by theorists for more realistic proto-analysis (w/ PGS)

QCD Jets

Process	Stars	Couplings	Phase space region	Matching	Banner	Event files	Remarks
jets (2)	2	QCD only	pt(at least 1)>X or pt(at least 2)>Y or pt (at least 3)>Z or pt (at least 4)>K	0,1,2,3,4+			light jets are u,d,c,s,g; Need to veto the first gluon splitting into bb in the PS
bb~ + jets	1	QCD only	pt(at least 1)>X or pt(at least 2)>Y or pt (at least 3)>Z or pt (at least 4)>K	0,1,2,3+			massive b; Need to veto the first gluon splitting into bb in the PS
bb~ bb~+ jets	1	QCD only	pt(at least 1)>X or pt(at least 2)>Y or pt (at least 3)>Z or pt (at least 4)>K	0,1+			massive b

Vector Boson(s)

Process	Stars	Couplings	Phase space region	Matching	Banner	Event files	Remarks
W (-> l v)+ jets	3	EW=2 + QCD	all	0,1,2,3,4+			W=W+,W- ; l=(e,mu,tau)
Z /a* (-> l+l-)+ jets	3	EW=2 + QCD	m(l+l-)>50 GeV	0,1,2,3,4+			photon is included ; l=(e,mu,tau)
Z (-> vv)+ jets	2	EW=2 + QCD	pt(Z)>50 GeV	0,1,2,3,4+			
V (-> l l')+ QQ~ + jets	1	EW=2+QCD	all	0,1,2+			V=W+,W-,Z ; l=(e,mu,tau,v), (Z->vv included) Q=b
a + jets	1	EW=1 + QCD	pt(a)>20 GeV, abs(eta(a))<2.5, DeltaR(a,jet)>0.3	0,1,2,3,4+			photon
a + QQ~ + jets	1	EW=1 + QCD	pt(a)>20 GeV, abs(eta(a))<2.5, DeltaR(a,jet)>0.3	0,1,2+			photon; Q=b
VV(-> 4l)+ jets	3	EW=2+QCD	all	0,1+			V=W+,W-,Z l=(e,mu,tau,v)
VV (-> 4l) + QQ~	1	EW=1 + QCD	all	no			V=W+,W-,Z l=(e,mu,tau,v), Q=b
aV(-> 2l)+ jets	1	EW=2+QCD	all	0,1+			V=W+,W-,Z l=(e,mu,tau,v)
a a + jets	1	EW=2+QCD	pt(a)>20 GeV, abs(eta(a))<2.5, DeltaR(a,jet)>0.3	0,1,2+			photon
a a + QQ~ + jets	1	EW=1 + QCD	pt(a)>20 GeV, abs(eta(a))<2.5, DeltaR(a,jet)>0.3	no			photon; Q=b
V V V	3	EW=3	all	no			V=W+,W-,Z
a a a	3	EW=3	pt(a)>20 GeV, abs(eta(a))<2.5, DeltaR(a,jet)>0.3	no			

Top

Process	Stars	Couplings	Phase space region	Matching	Banner	Event files	Remarks
tt + jets	3	QCD only	all	0,1,2,3+			top decays into everything. Done with DECAY
tt + bb~	3	QCD only	all	no			top decays into everything. Done with DECAY
tjb	3	EW=2, QCD=1	all	no			t-channel, b massive, no top decay
tj	3	EW=2, QCD=0	all	no			t-channel, no top decay
tb	3	EW=2, QCD=0	all	no			s-channel, b massive, no top decay
tW	3	EW=2, QCD=1	all	no			tW-channel, no top decay
tWb	3	EW=2, QCD=2	all	no			tW-channel, b-massive, doub-res diagram subtraction, no top decay

Higgs

Process	Stars	Couplings	Phase space region	Matching	Banner	Event files	Remarks
Higgs + jets	2	QCD only	all	0,1,2,3+			HEFT, mh=120,140,160,180,200
Higgs + 2 jets	3	EW only	all	no matching			mh=120,140,160,180,200
tt~ + Higgs	3	QCD=2,EW=1	all	no			mh=120
V (-> l l') + Higgs + jets	2	EW=3 + QCD	all	0,1,2			

MG on the grid

- Usual MG code creation from the web.
- Usual selection of parameters by cards.
- Run in a special mode (on a single machine or over the web cluster) and obtain a gridpack.tar.gz .
- This is a ready-to-go package, "optimized" for the specific process and settings, to be run on a single machine, whose only inputs are:

1. the rnd seed
2. the number of events requested