MadGraph/MadEvent 4 BSM: status and perspectives

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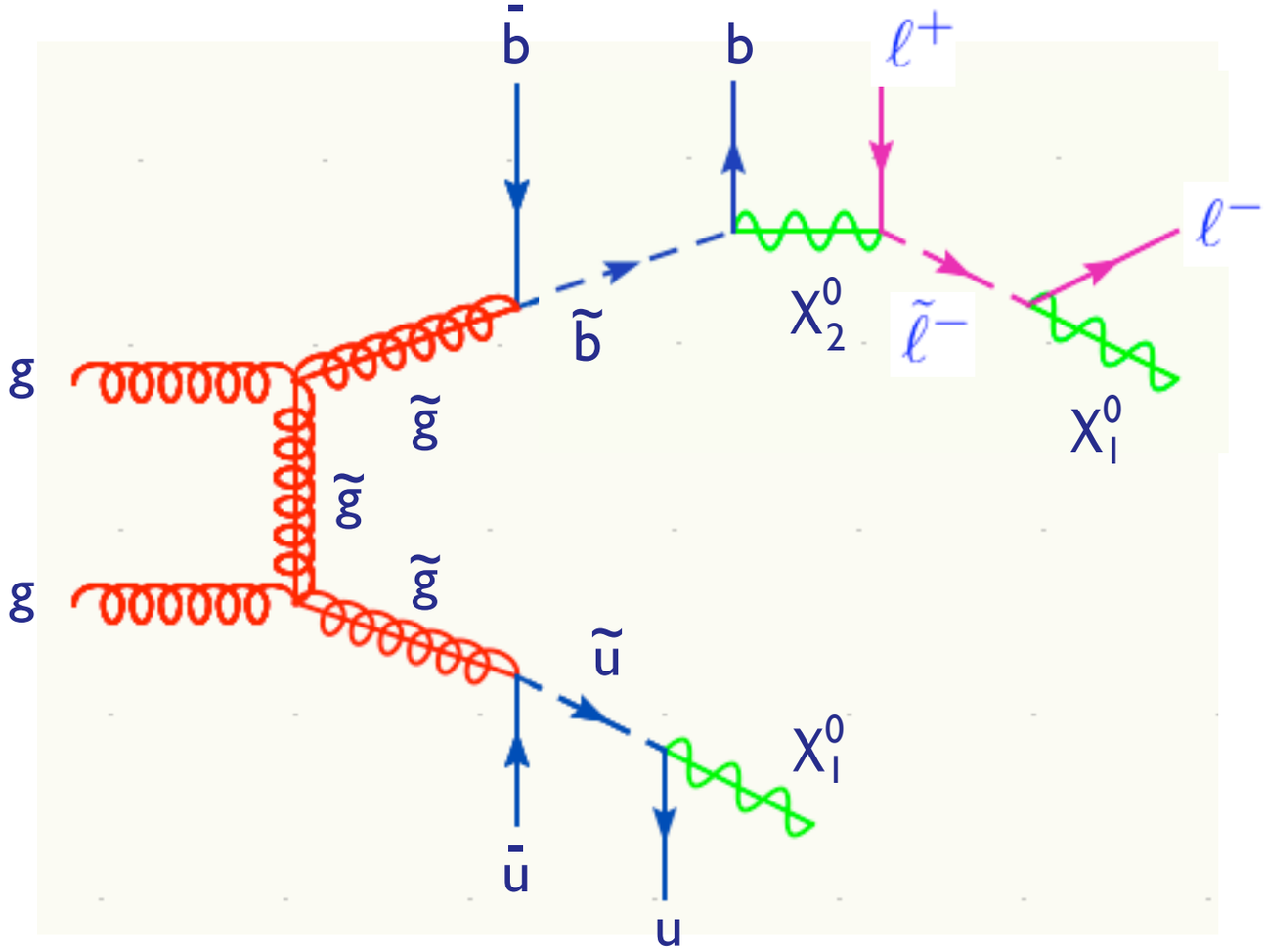
Johan Alwall, Pavel Demin, Simon de Visscher, Rikkert Frederix, Michel Herquet, Tim Stelzer
+ Steve Mrenna, Tilman Plehn, David L. Rainwater,
+ Pierre Artoisenet, Claude Duhr, Olivier Mattelaer,...

+ OUR GOLDEN USERS!!

Outline

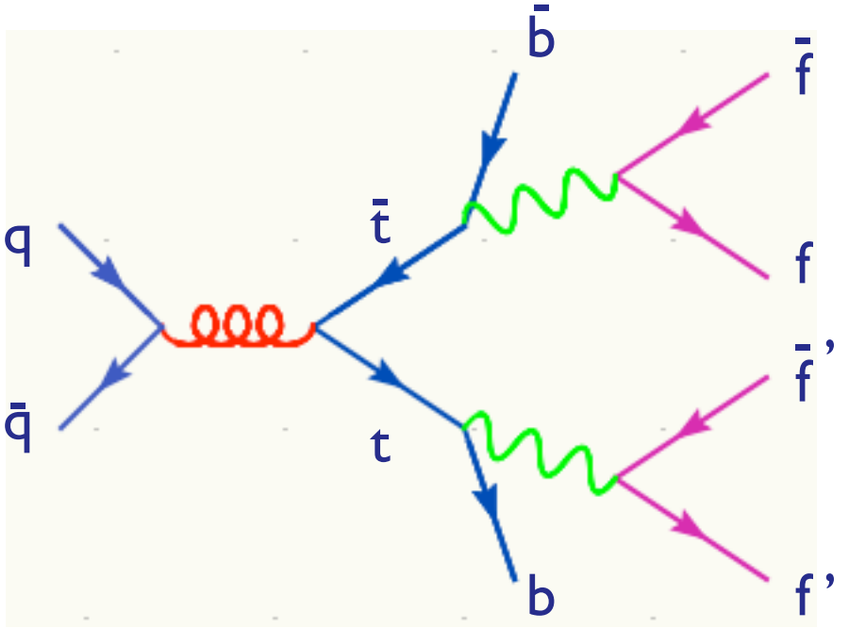
- Motivations
- MG/ME v4 : status and latest developments
- On-going projects and plans
- Discussion

How are we going to discover New Physics?



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

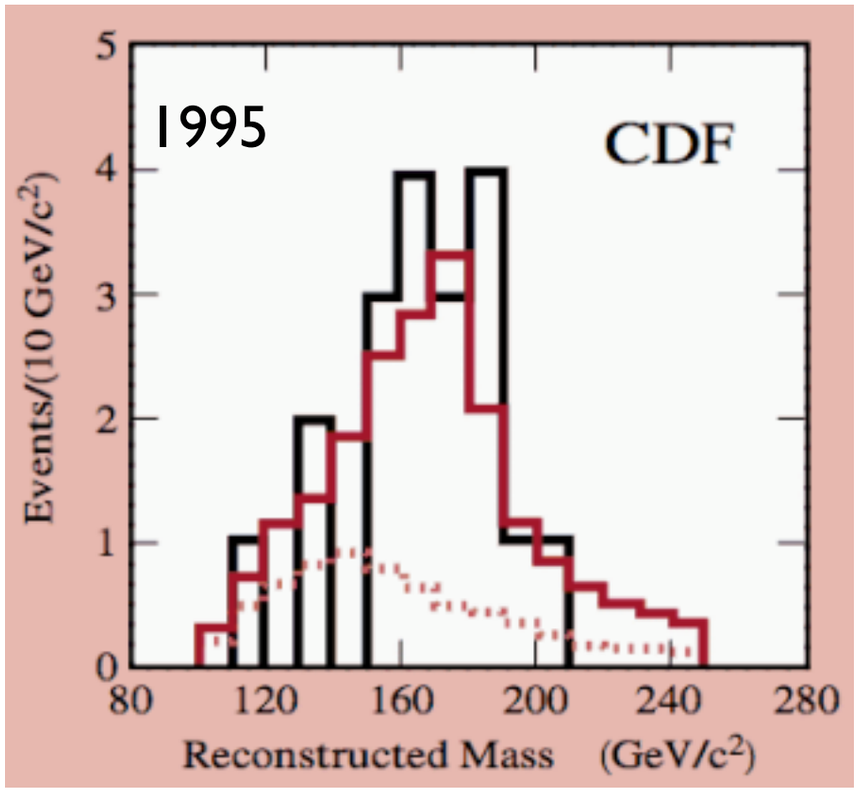
A lesson from the top



How did it go?

0. The only unknown was the top mass!

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



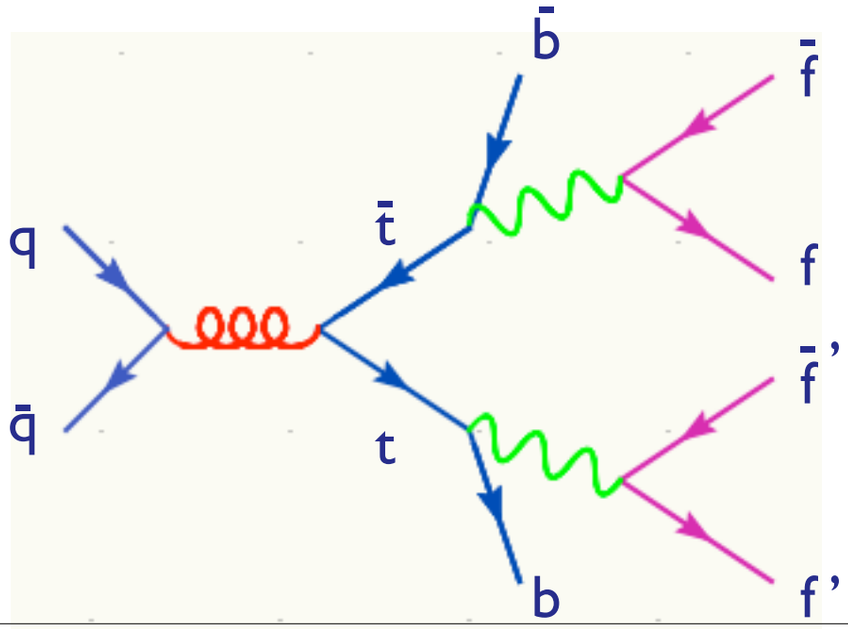
2. Mass reconstruction employed

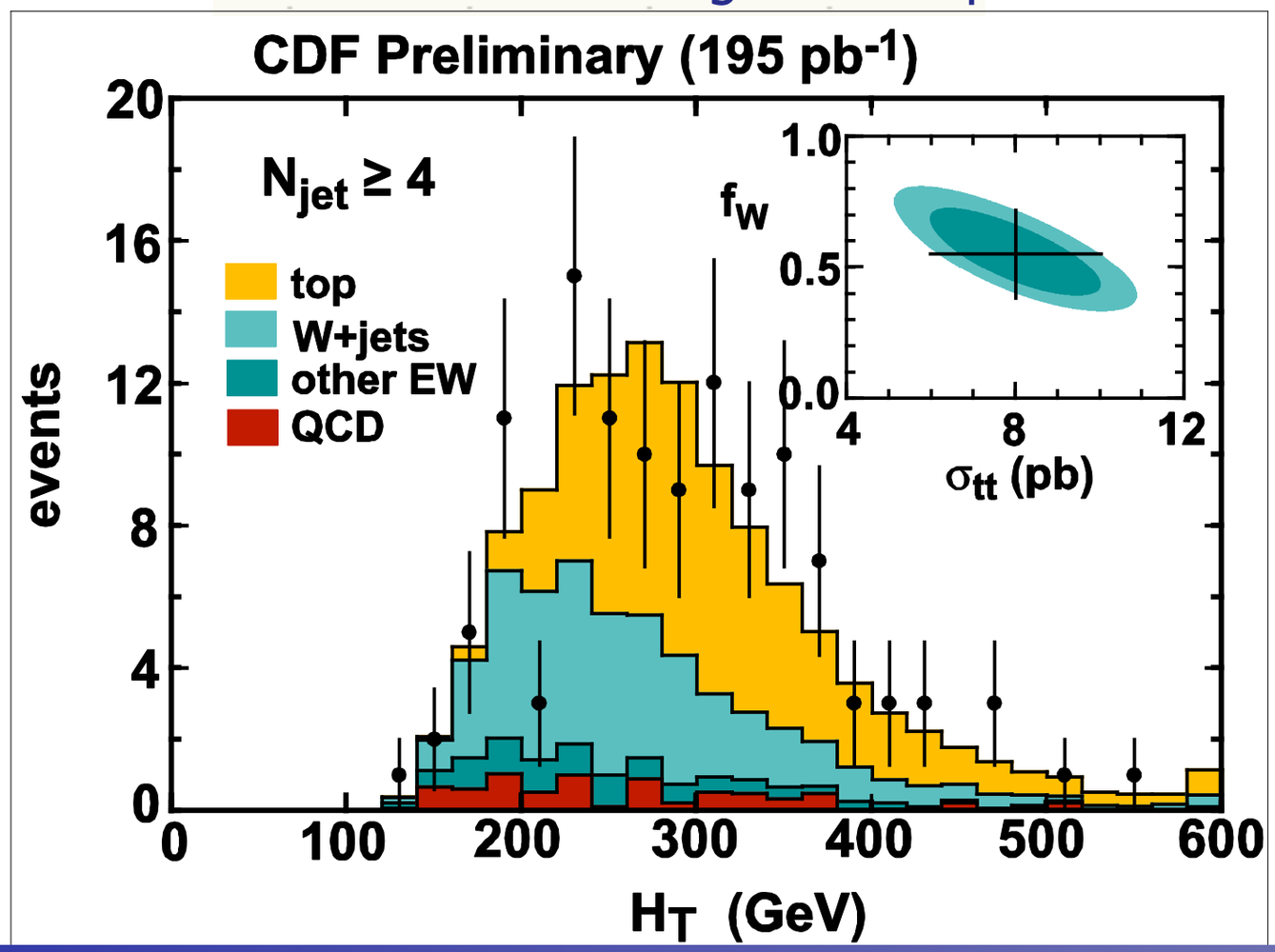
3. Backgrounds estimated via control samples with heavy flavors and also via MC ratio's.

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.

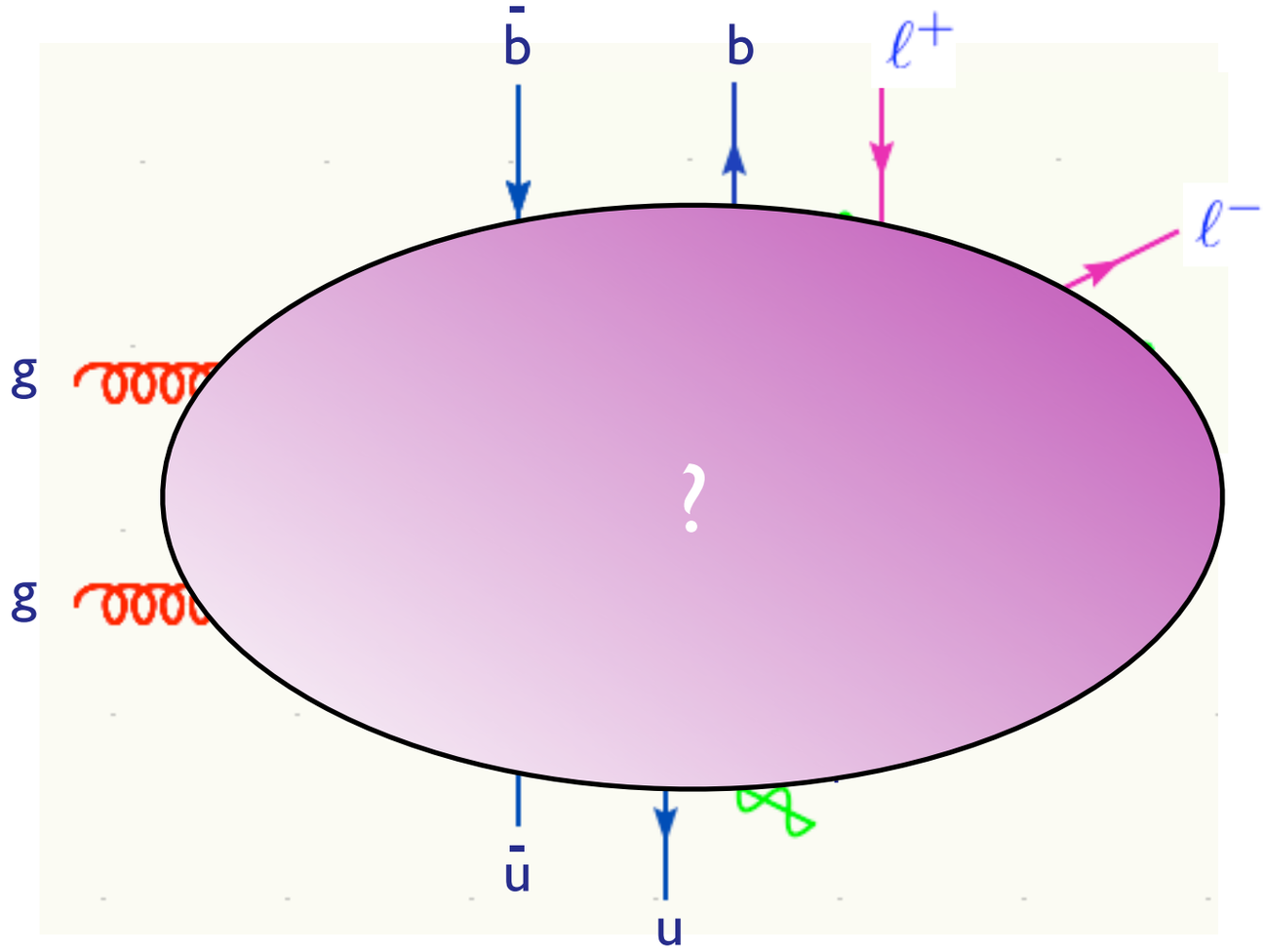
Cleaner and cleaner samples more exclusive studies:

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

Is this strategy directly applicable to new heavy state searches?

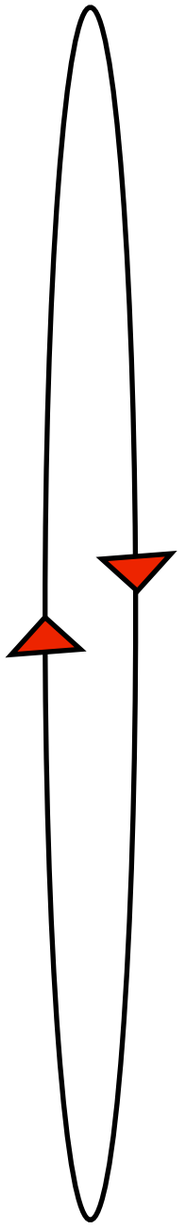
A lesson from the top

Susy inclusive searches are similar but more complicated final states.



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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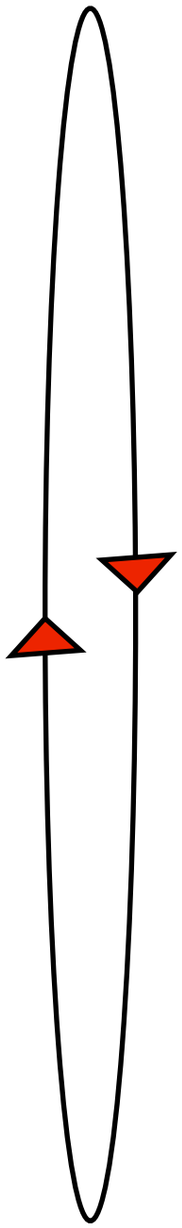

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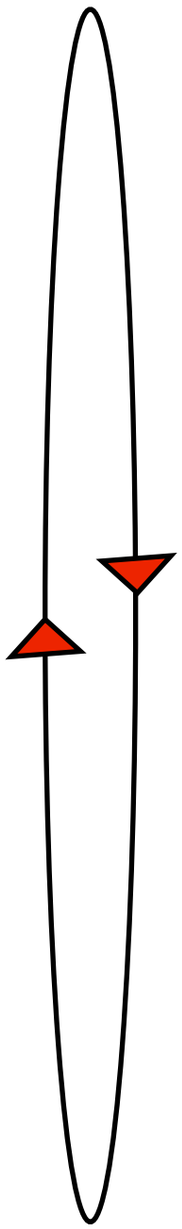

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Off-shell effects, Matrix Element methods

Proposed solution:
MG/ME: A fully flexible platform of matrix element based tools that can be used by both TH and EXP's.

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

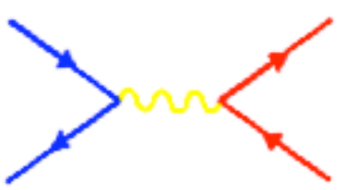
http://madgraph.hep.uiuc.edu/

Center for Particle Physics and Phenomenology - CP3

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

MUSEO STORICO DELLA FISICA E CENTRO STUDI E RICERCHE

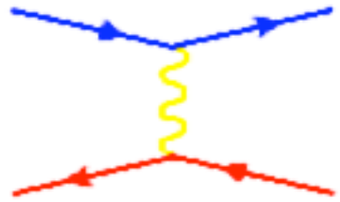
http://madgraph.roma2.infn.it/



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 (+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

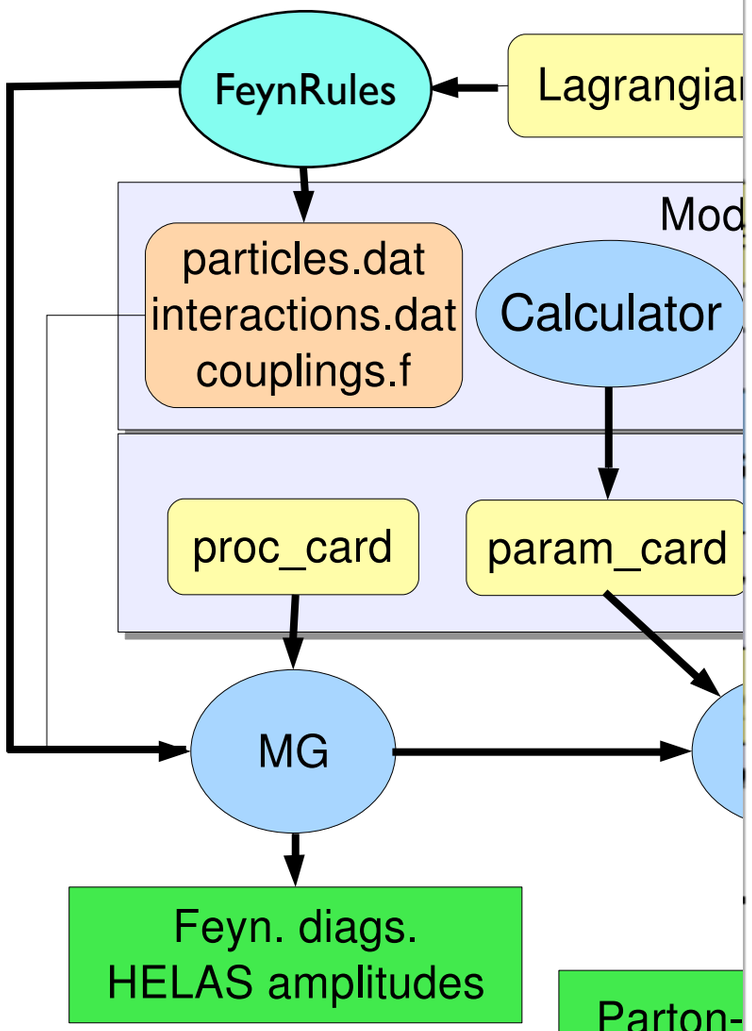
- The new web generation:
  - User requests a process (Ex. pp>tt~jjj) and corresponding code is generated on the fly.
  - User inputs model/parameters/cuts, and code runs in parallel on modest farms.
  - MG/ME Returns cross section, plots, parton-level events.
- Advantages:
  - Reduces overhead to getting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

MadGrap




```
<header>
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#*********************************************************************
#                                                                     *
#                      MadGraph/MadEvent                              *
#                                                                     *
#                     The new web generation                          *
#                                                                     *
#                  http://madgraph.hep.uiuc.edu                       *
#                  http://madgraph.phys.ucl.ac.be                     *
#                  http://madgraph.roma2.infn.it                      *
#                                                                     *
#           CP3 team                      Tim Stelzer                 *
#     Universite de Louvain          University of Illinois           *
#                                                                     *
#*.................................................................*
#                                                                     *
# This file contains all the information necessary to reproduce       *
# the events generated:                                               *
#                                                                     *
# 1. software version                                                 *
# 2. proc_card.dat      : code generation info including model        *
# 3. param_card.dat     : model primary parameters in the LH format   *
# 4. run_card.dat       : running parameters (collider and cuts)      *
# 5. pythia_card.dat    : present only in the pythia event file       *
# 6. pgs_card.dat       : present only in the pgs event file          *
#                                                                     *
#                                                                     *
#*********************************************************************
-->
<MGVersion>
# MG/ME version    : 4.2.5
# madgraph version : 4.2.1
# template version : 2.2.4
# helas version    : 3.2
# model version    : sm_1.1
</MGVersion>
<MGProcCard>
#*********************************************************************
#                      MadGraph/MadEvent                              *
#                  http://madgraph.hep.uiuc.edu                       *
#                                                                     *
#                      proc_card.dat                                  *
#
```

Parton-level
Plots, rootfile, ...

Hadron-level
Plots, rootfile, ...

Reco-level
Plots, rootfile, ...

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]
- NRQCD matrix element generator [P. Artoisenet, FM, T. Stelzer]
- Grid Version [Mad Team]

New models in MG/ME

1. Modify by hand the available models : SM, 2HDM, SUSY, HEFT, TopBSM

☹ touch fortran

☺ start from any implemented model

2. Use the USRMOD framework

☺ no fortran

☹ start from SM

3. NEW: interface to FeynRules
   → C. Duhr's talk

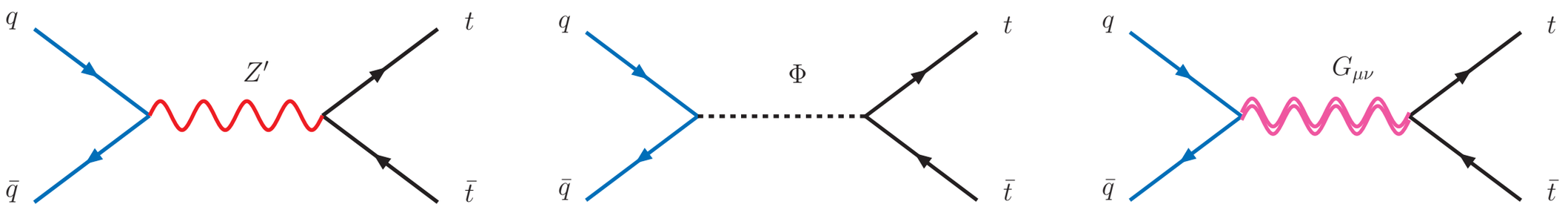
☺!

Current Plan : full validation against the existing models and migration to FeynRules

TopBSM

[R. Frederix, FM,2007]

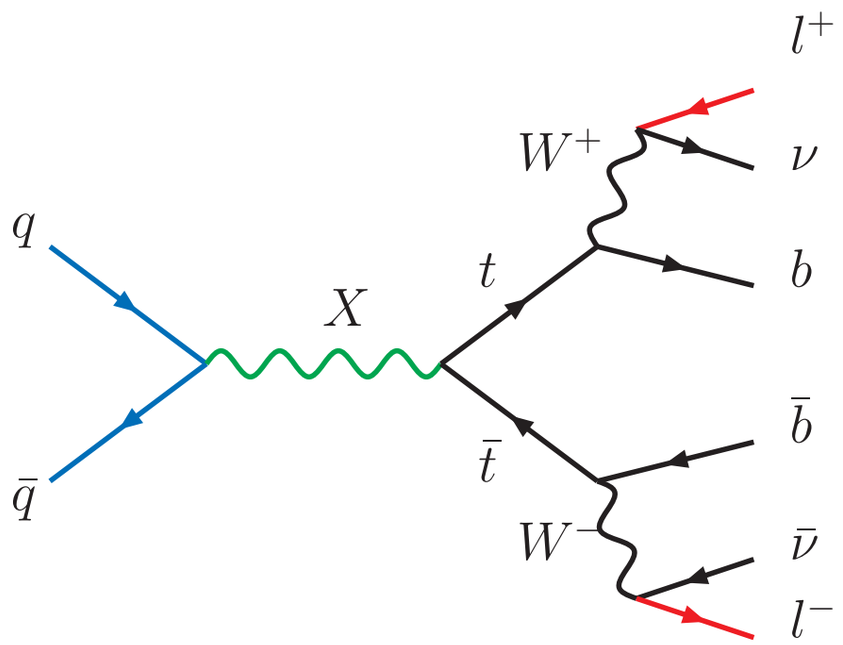
In many scenarios for EWSB new resonances show up, some of which preferably couple to 3rd generation quarks.



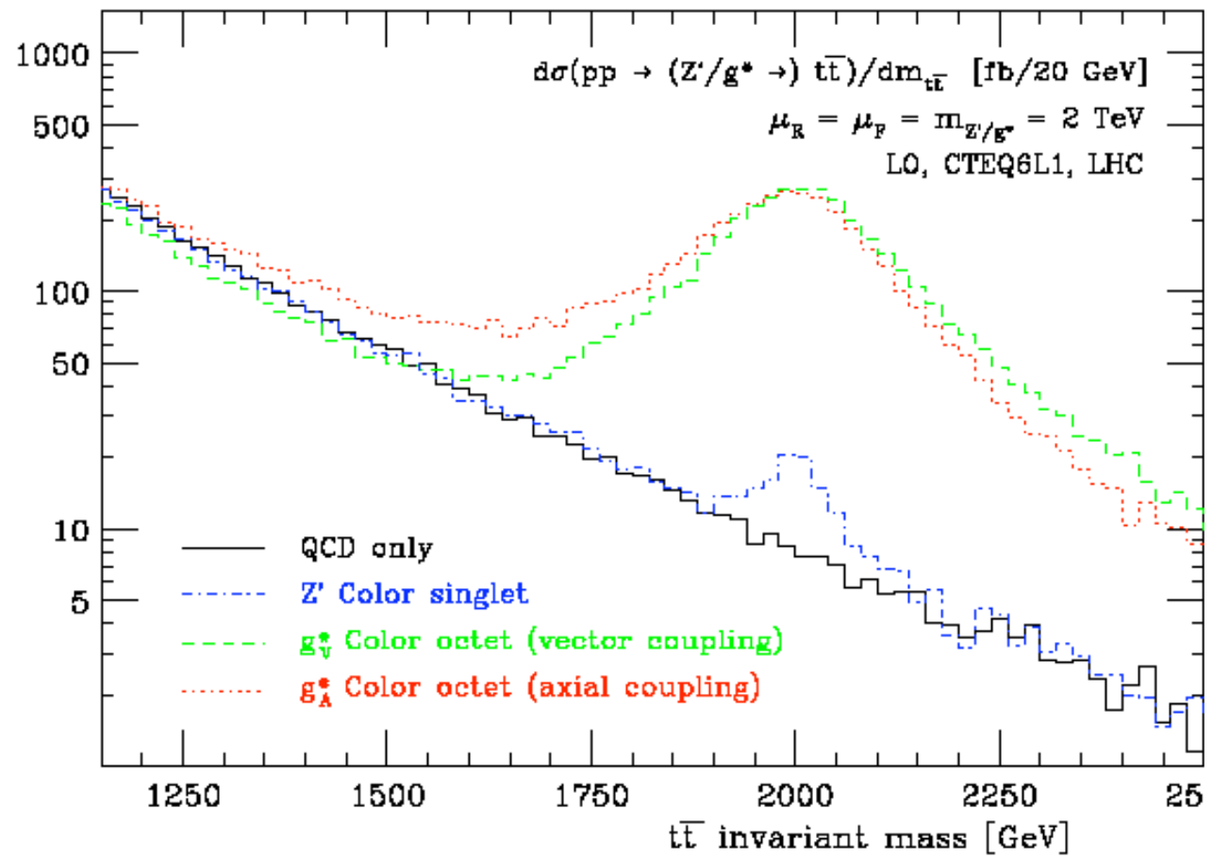
Given the large number of models, in this case is more efficient to adopt a "model independent" search and try to get as much information as possible on the quantum numbers and coupling of the resonance.

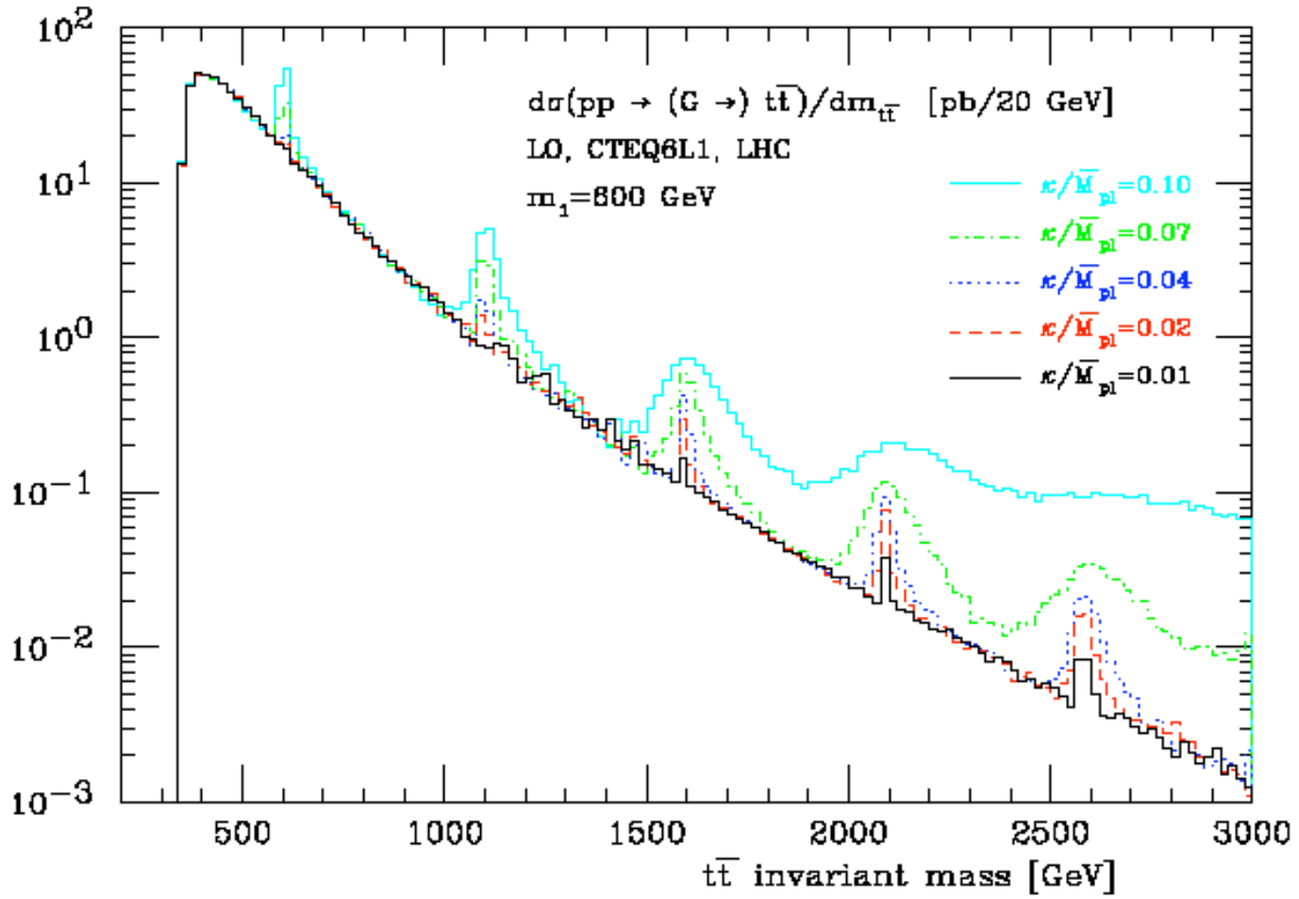
To access the spin of the intermediate resonance spin correlations should be measured.

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.

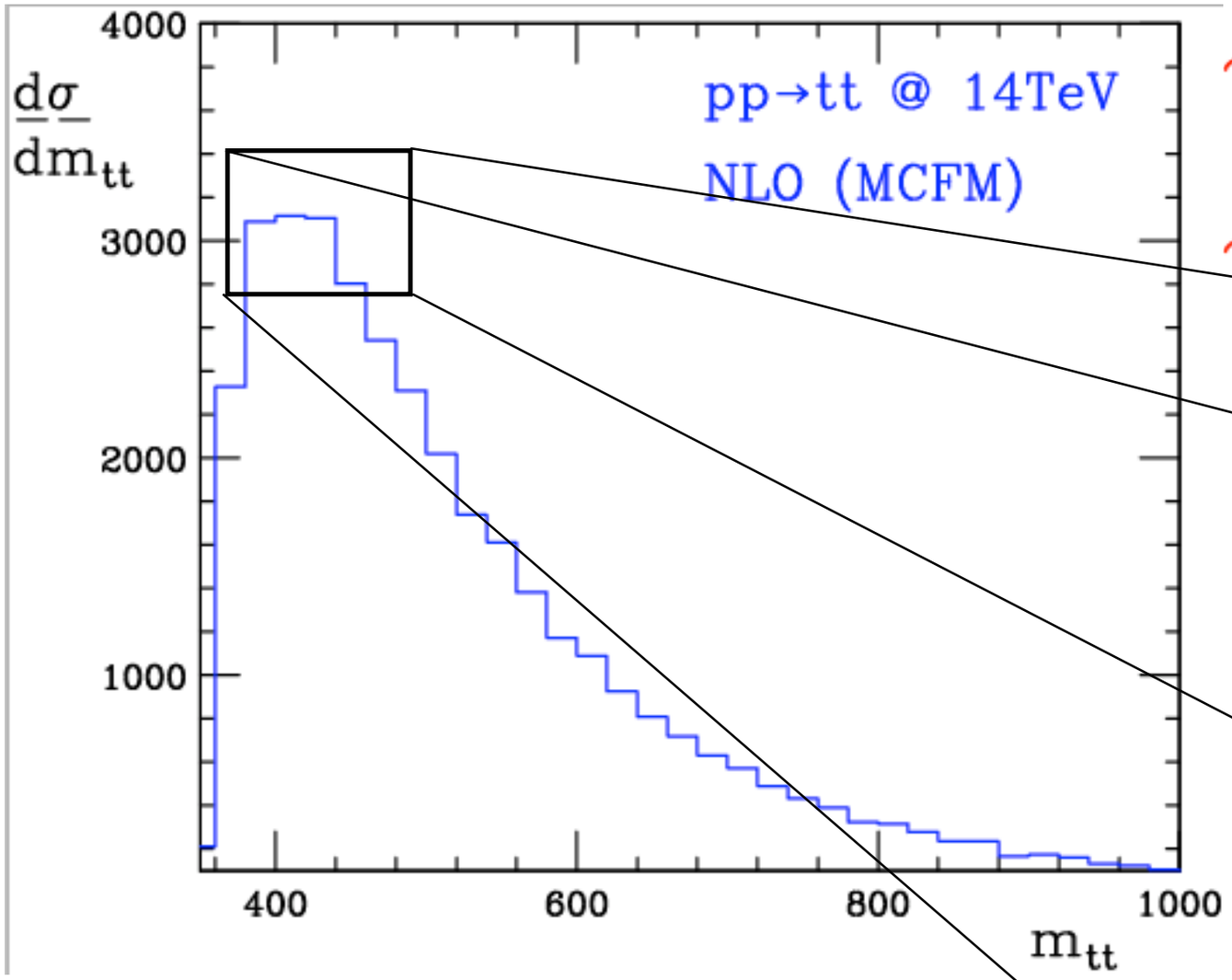


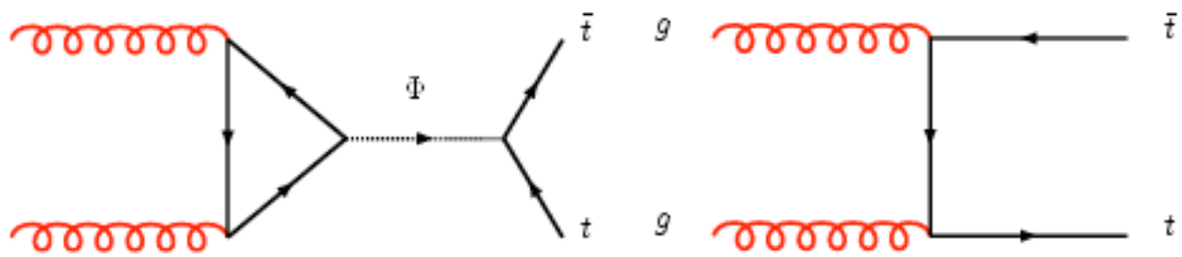
TopBSM : Examples

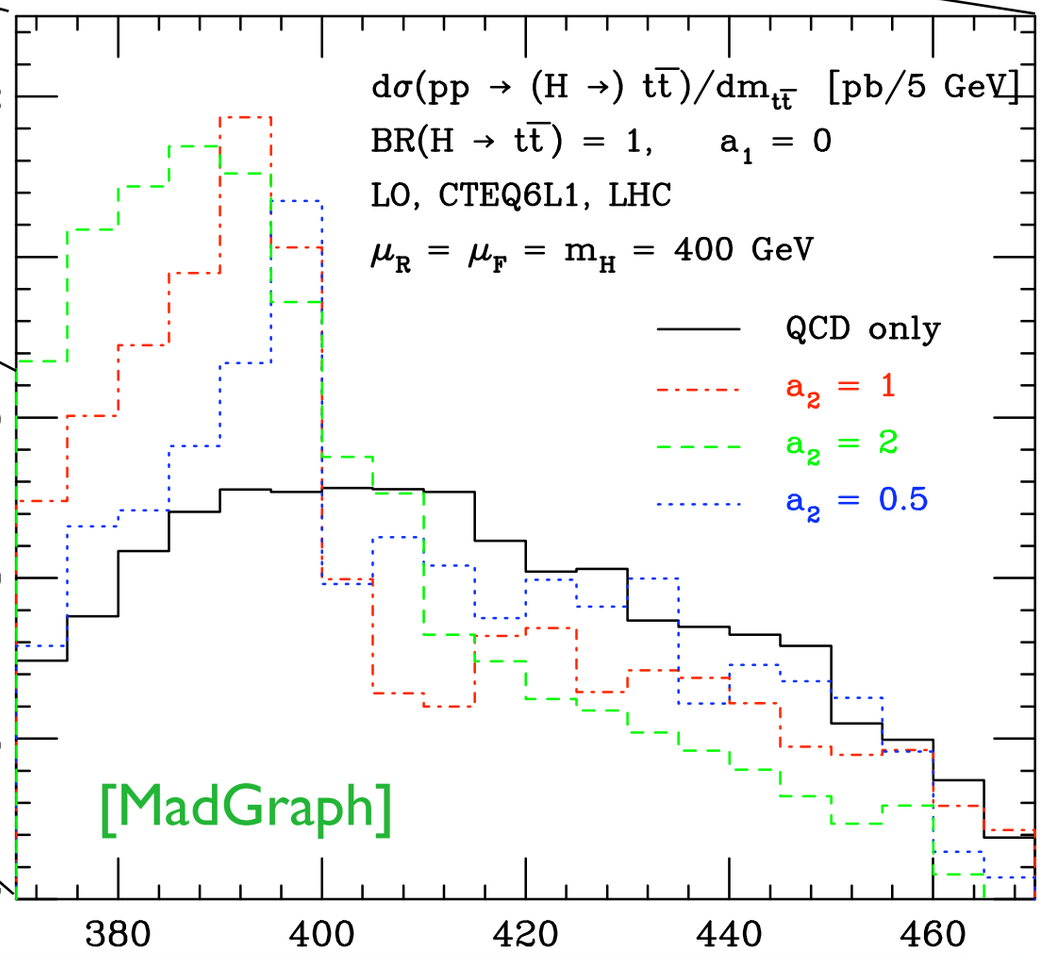




TopBSM: more than just peaks!







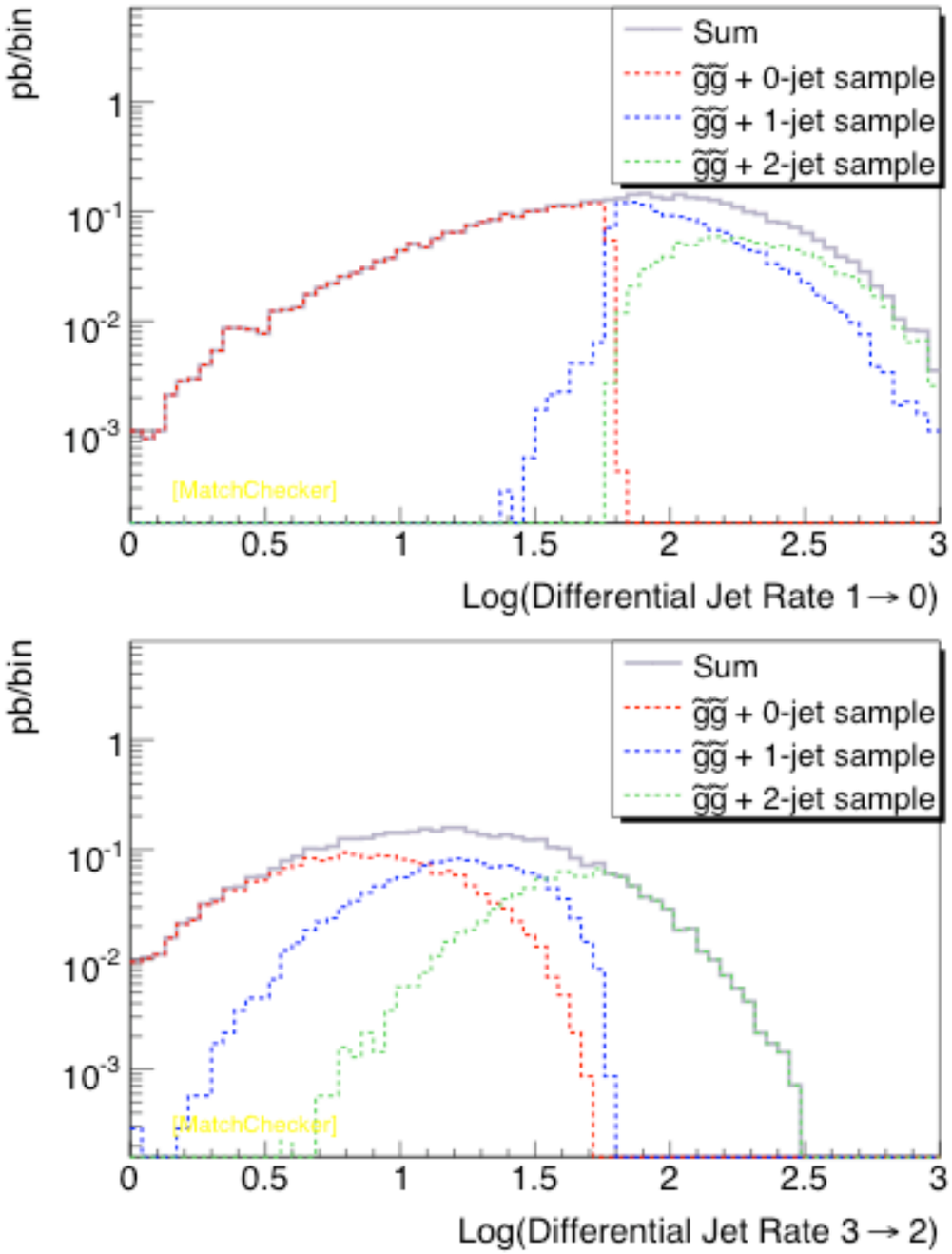
Non-trivial behavior (peak-dip) due to the interference between the signal and the background, only if top width dominated by $\Phi \to tt$. [Dicus, Stange & Willenbrock 1994]

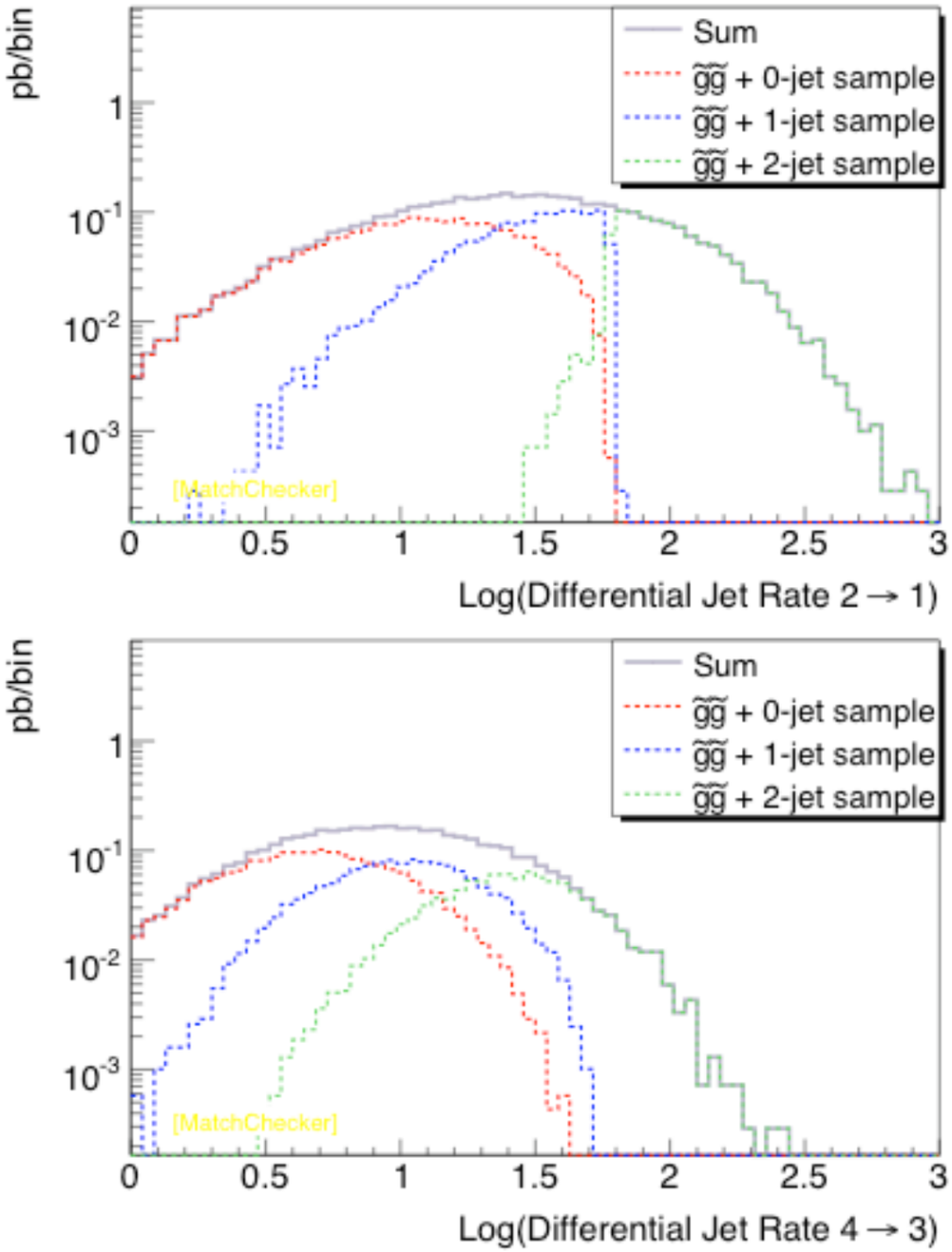
ME/PS merging in MadGraph

- K_T MLM scheme [Mrenna] implemented by J. Alwall.
- Interfaced to Pythia 6 with 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.

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

[Alwall, de Visscher, FM]



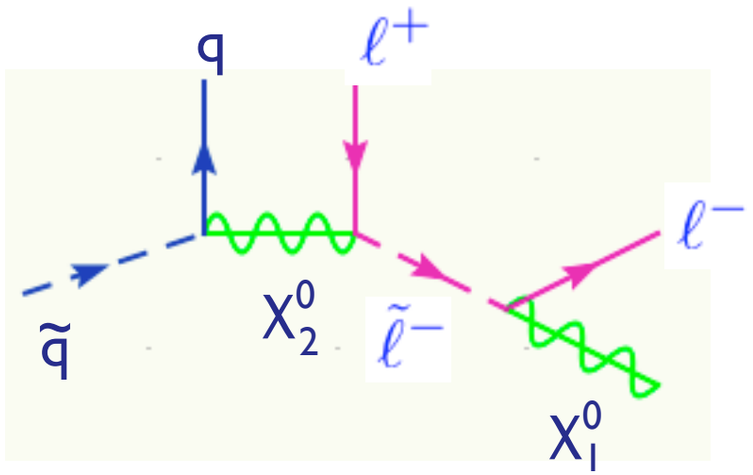


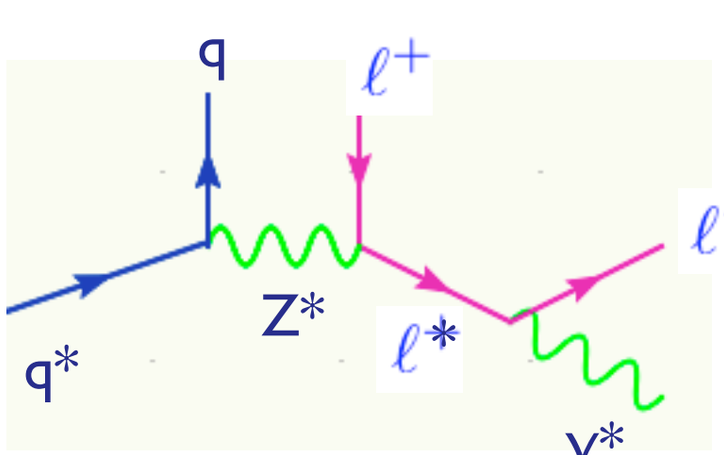
Jet rates are smooth :

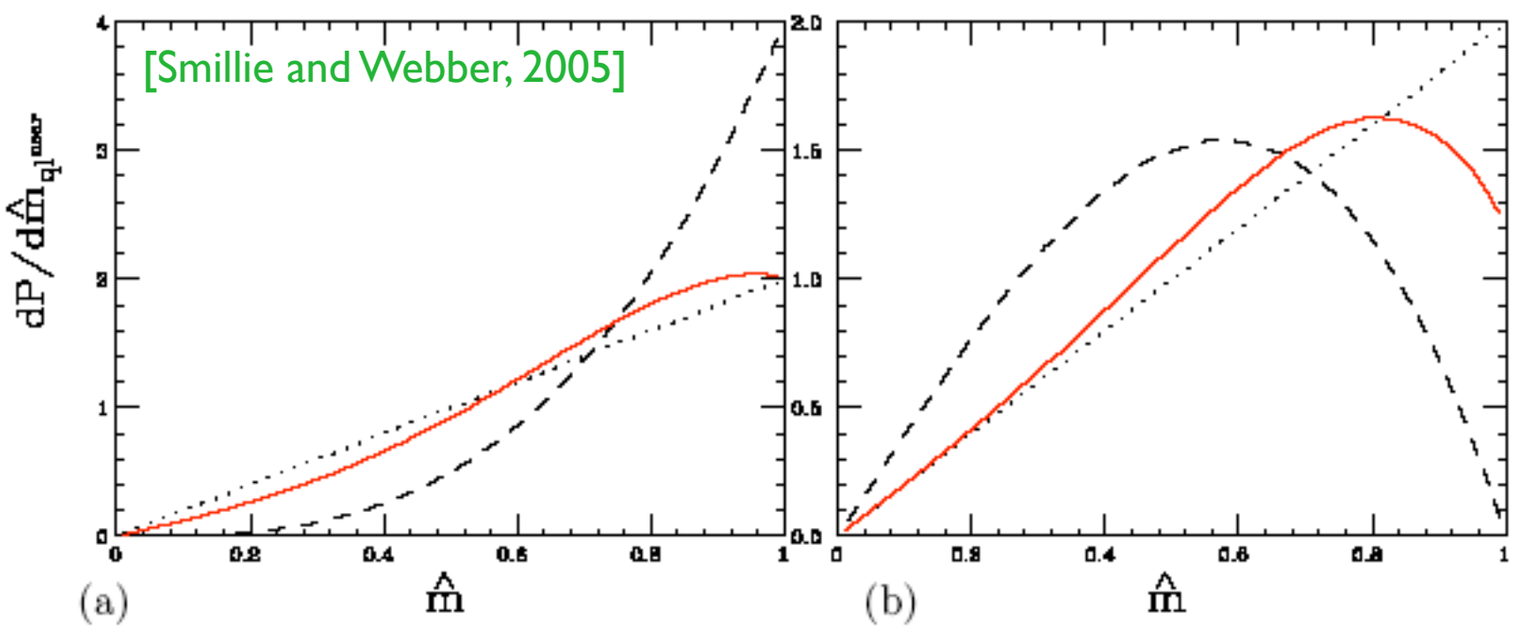
SUSY double counting problem solved by the use of the decay chains!

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

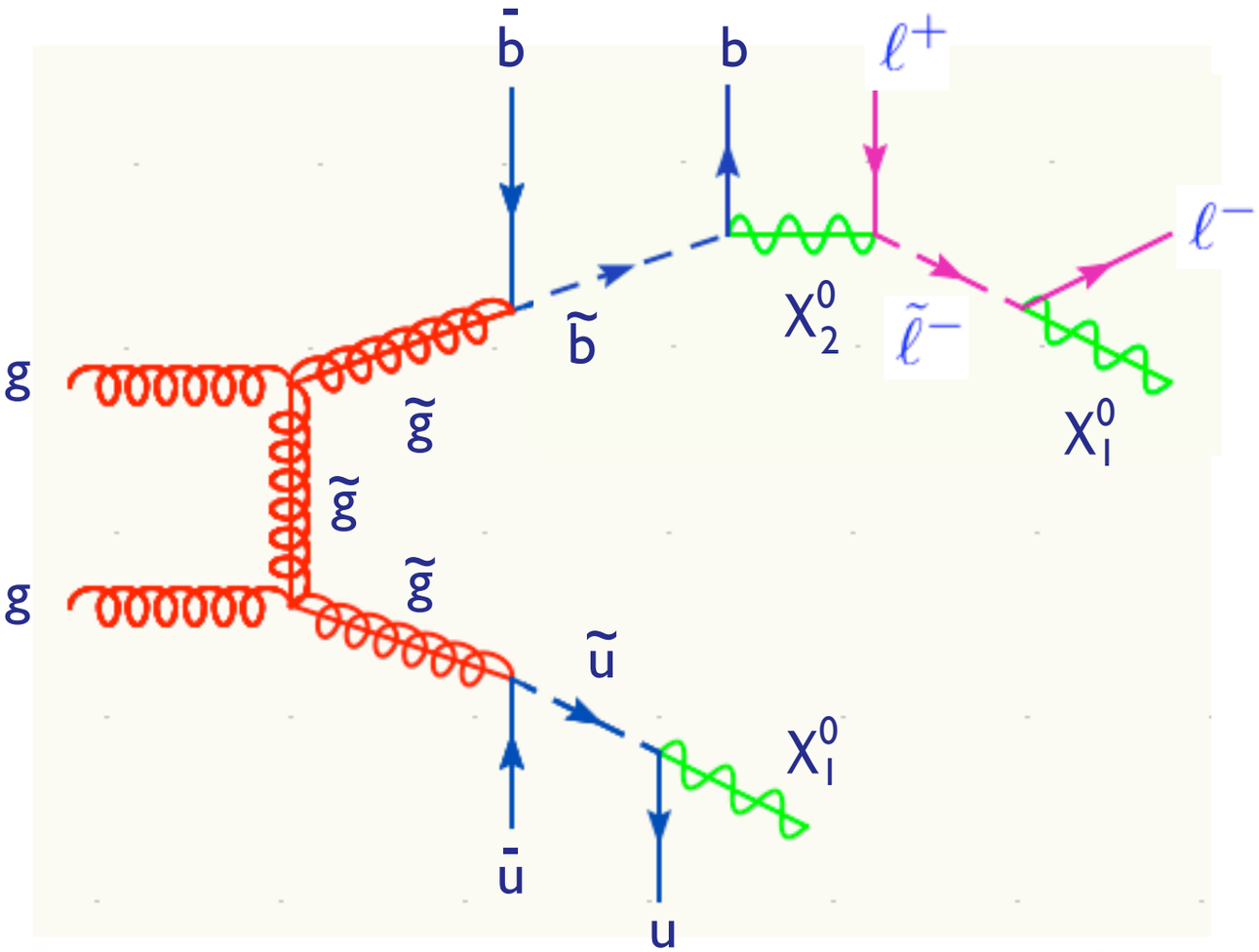
1. production and decay are factorized.
2. Spin is ignored (not in HERWIG)
3. Chains proceed only through $1 \rightarrow 2$ decays.
4. The narrow width approximation is employed.
5. Non-resonant diagrams are ignored.

Flexible ME tools can 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))
```

Conclusions

- LHC poses new challenges to the MC community.
- Kaizen approach.
- MadGraph/MadEvent 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!

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/ME 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