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Université
catholique
de Louvain



MadGraph/MadEvent for BSM

Rikkert Frederix

Center for Particle Physics and Phenomenology

Université Catholique de Louvain

Johan Alwall, Pavel Demin, Simon de Visscher, Michel Herquet, Fabio Maltoni, 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

What is MadGraph/MadEvent?

- MG/MEv4 is a user-driven, matrix element based, tree-level event generator
- Both for SM as well as BSM
- Web server interface from which the simulation itself can be done on-line or off-line
- With MG/ME and its tools/interfaces, the full simulation chain from hard scale physics to detector simulation is available within one framework



The MG/ME philosophy

- Fill the gap between theorists and experimentalists
 - Easy to implement new models
 - Easy to interface to hadronization/detector simulation



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 - Efficiently generate events for (basically) any process
 - Signal but also multi-particle backgrounds

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 - Signal but also multi-particle backgrounds
- Web based event generation
 - Code runs in parallel on our farms
 - Centralized maintenance
 - Personal process database for each user

Why tree-level?

- Most of the current collider pheno is done at tree-level both at the theoretical and (even more) at experimental level.
- Experiments need fully exclusive descriptions.
- MC at NLO are very impressive achievements, but currently limited to a small set of key SM processes.



Why tree-level?

Always the fastest way,

very often the most accurate way,

sometimes the only way,

to bring ideas to life and
test them in the experiments!



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In other words,
“tree-level is nirvana”[®]!



MadGraph on the Web



I 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/>

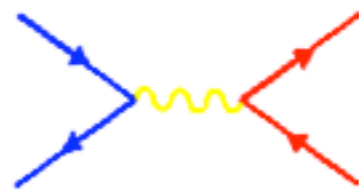


<http://madgraph.phys.ucl.ac.be/>

MUSEO STORICO DELLA FISICA E CENTRO STUDI E RICERCHE



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



[Generate Process](#)

[Register](#)

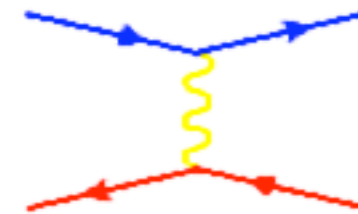
[Tools](#)

MadGraph Version 4
UCL UIUC Fermi
by the [MG/ME Development team](#)

[My Database](#)

[Cluster Status](#)

[Downloads](#)
(needs [registration](#))

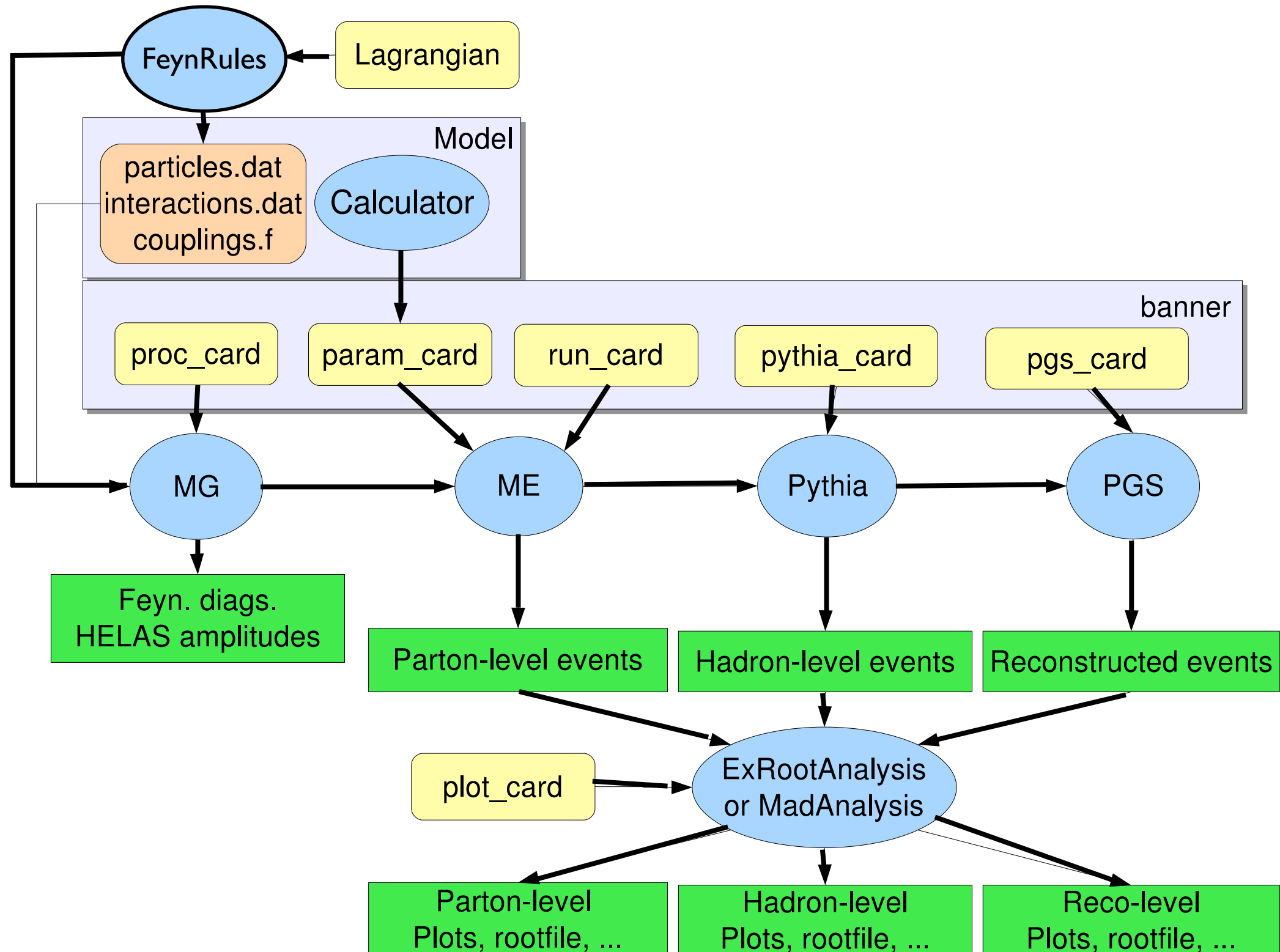


[Wiki/Docs](#)

[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. Tantalò (RM2)

MG/ME flow chart



Features

- Complete web simulation: MadEvent → Pythia → PGS, with personal web databases
- Multi-processes in single code & generation
- Standalone version for theorists
- New complete models: SM, HEFT, MSSM, 2HDM, TopBSM, ...
- Easy new model implementation: USRMOD & interface to FeynRules
- 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
- Decay chains specifications
- Decay width calculator
- Analysis platforms: ExRootAnalysis, MadAnalysis and MatchChecker



New models in MG/ME

I. Modify by hand the available models : SM, 2HDM, MSSM, HEFT, TopBSM, ...

☹ touch fortran

☺ start from any implemented model



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2. Use the USRMOD framework

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3. NEW: interface to FeynRules

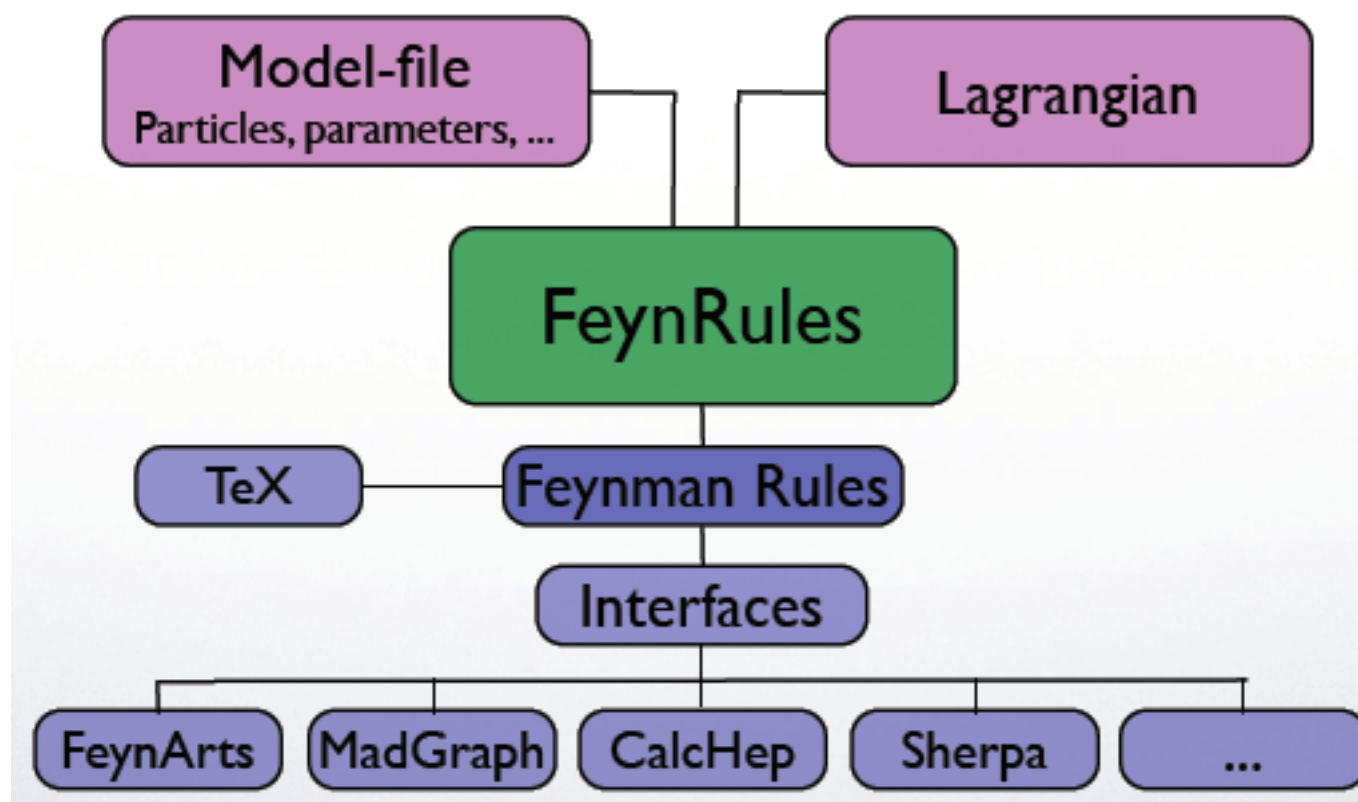
☺ !

FeynRules

[C. Duhr, N. Christensen +
MC collaborators]

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

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



- Get Feynman Rules for 'any' possible Lagrangian
- Only limited Mathematica knowledge required; interfaces take care of fortran/C++ code

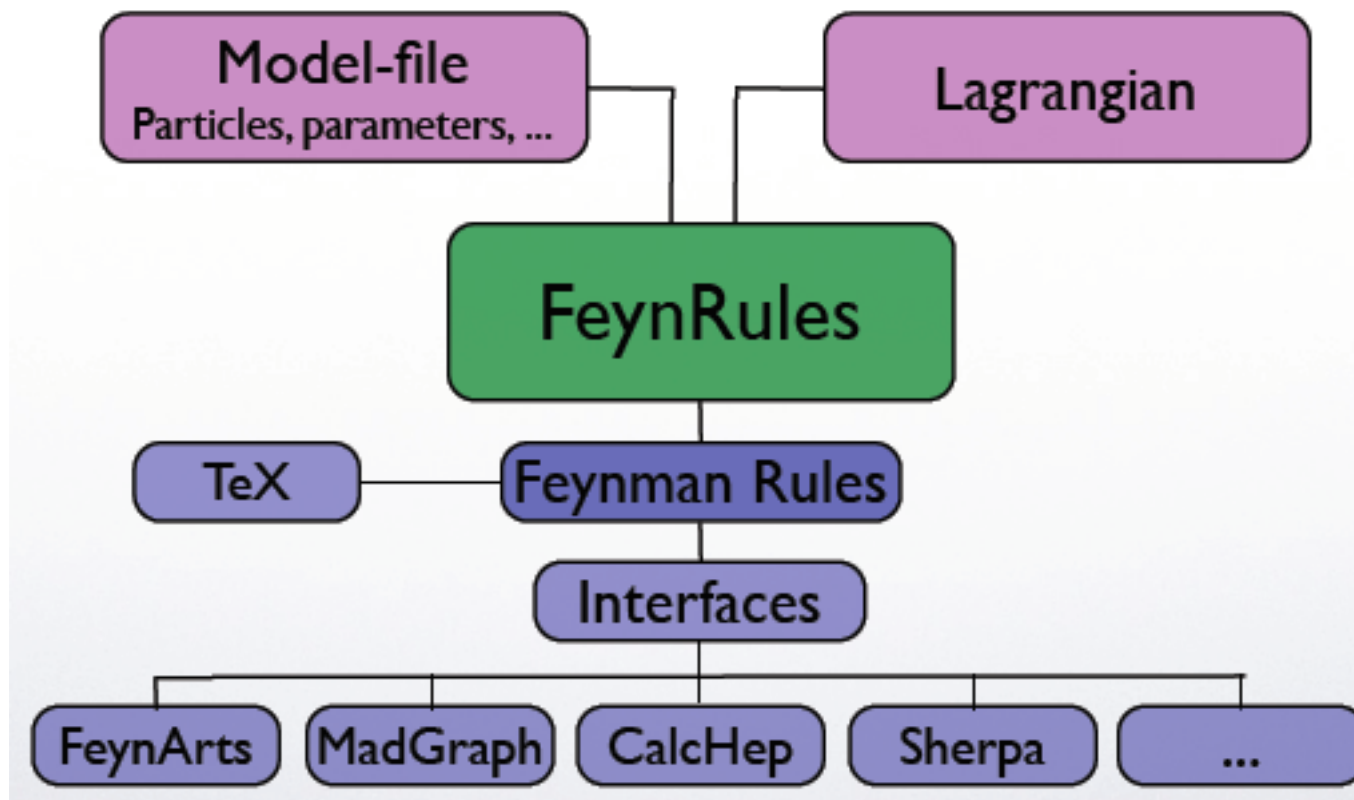
wikipage at europa.fyma.ucl.ac.be/feynrules

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



$$k \left(-2 m_\psi \bar{\psi} \psi + \frac{3}{4} i \partial_\mu (\tilde{\phi}) \bar{\psi}^\dagger \cdot \gamma^\mu \cdot \psi + \frac{3}{2} \bar{\psi} \phi (i \bar{\psi}^\dagger \cdot \gamma^\mu \cdot \partial_\mu (\psi) - g \bar{\psi}^\dagger \cdot \gamma^\mu \cdot T^a \cdot \psi G_{\mu a}) + \frac{1}{2} \left(\frac{1}{2} i (\partial_\mu (h_{\nu\nu}) - \partial_\nu (h_{\mu\nu})) \bar{\psi}^\dagger \cdot \gamma^\mu \cdot \psi - m_\psi \bar{\psi}^\dagger \cdot \psi h_{\mu\mu} + (i \bar{\psi}^\dagger \cdot \gamma^\mu \cdot \partial_\nu (\psi) - g \bar{\psi}^\dagger \cdot \gamma^\mu \cdot T^a \cdot \psi G_{\nu a}) (h_{\rho\rho} \eta_{\mu\nu} - h_{\mu\nu}) \right) \right)$$

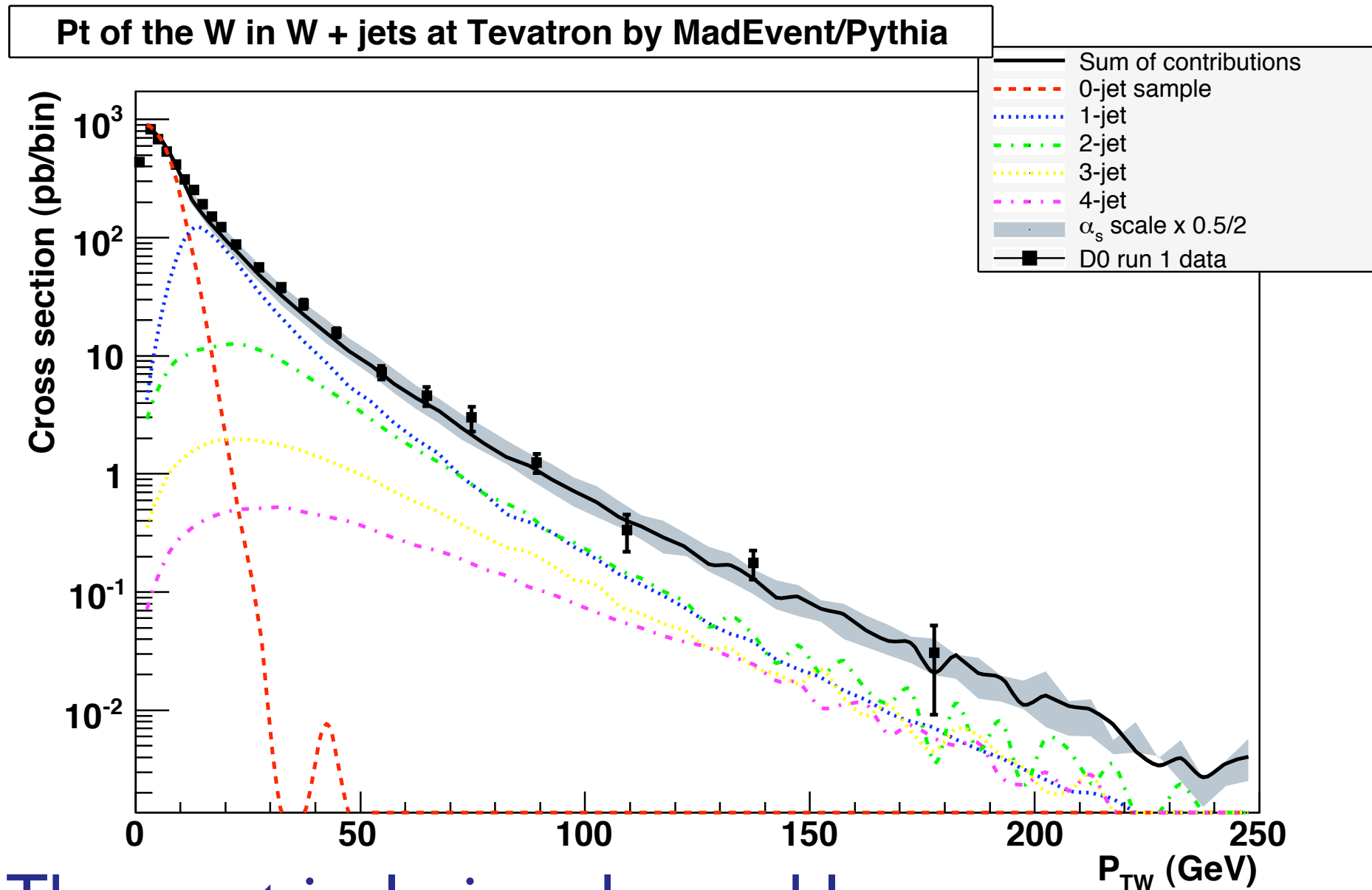
wiki page at europa.fyma.ucl.ac.be/feynrules

Merging ME and PS

a.k.a. Matching

- K_T MLM scheme [Mrenna] implemented by J.Alwall.
- Interfaced to (fortran) Pythia, 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, inclusive jets, ...
- Merging in BSM Physics samples available.
- New merging with Pythia pt^2 ordered shower under study [Alwall]
- Interfaces with Pythia8 and Herwig++ are through standard LHEF and not yet available with merging.

Merging



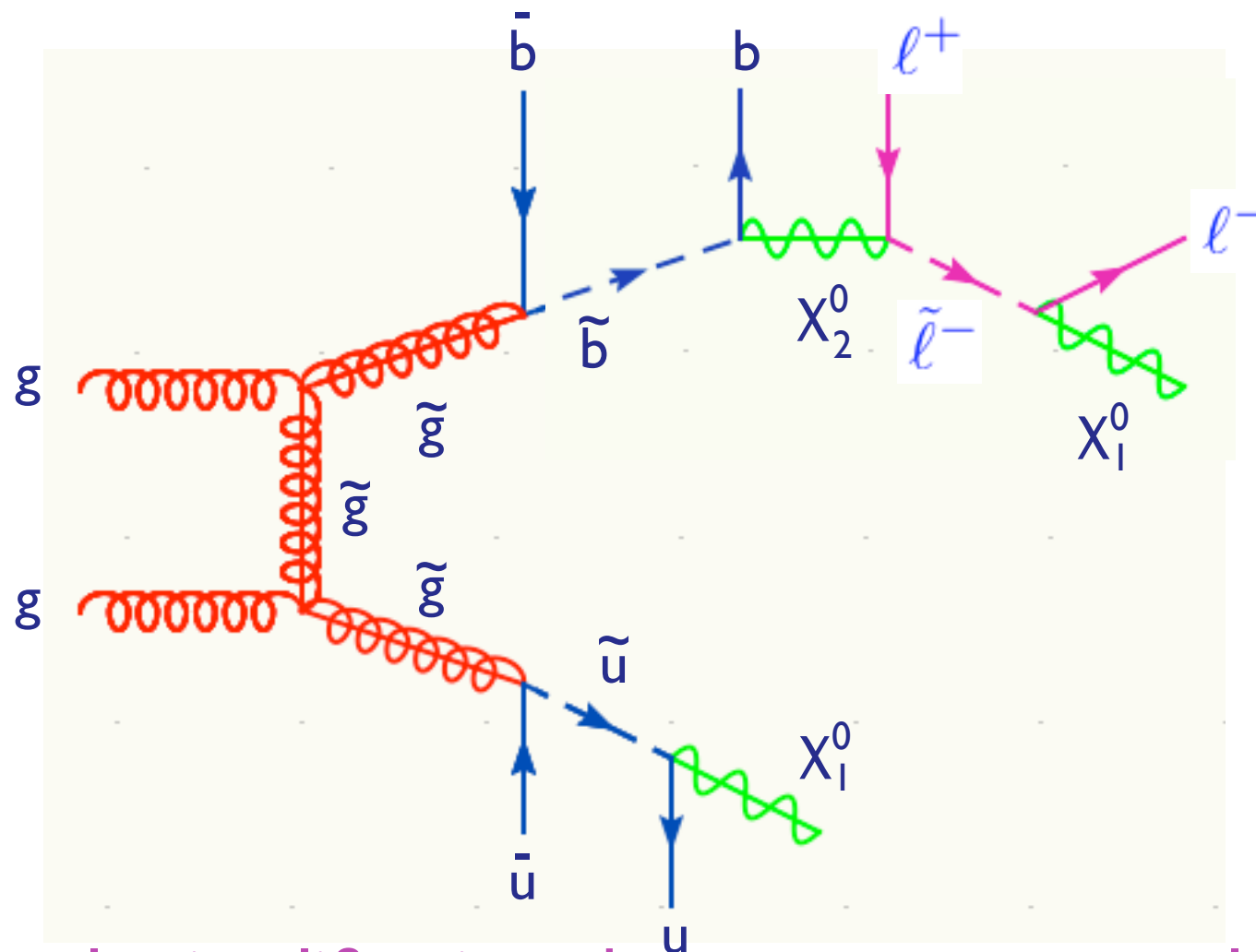
- The most inclusive observable
- All parton multiplicities contribute
- Excellent agreement with TeV data (validation)

Decay Chains

$$gg \rightarrow (g \rightarrow u \bar{u}) (g \rightarrow b \bar{b}) (b \rightarrow \mu^+ \mu^-)$$

[J. Alwall, T. Stelzer]

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 $1 \rightarrow 2$ decays.
4. Resonances have BW.
5. Non-resonant contributions can be systematically included only where relevant.

Example simplification: the process can exactly factorized in

$$gg \rightarrow (g \rightarrow u \bar{u}) (g \rightarrow b \bar{b})$$





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

$$u \bar{u} \rightarrow u \bar{u}$$

$$b \bar{b} \rightarrow b \bar{b} (\mu^+ \mu^- \rightarrow \mu^+ \mu^-)$$

[Maede and Reece, 2007]

Coming soon

- MadWeight: a General approach to Matrix Element techniques
[P.Artoisenet, V. Lemaître, F. Maltoni, O. Mattelaer] 
→ See Olivier's talk tomorrow
- Event generation for quarkonium
[P.Artoisenet, F. Maltoni, T. Stelzer] 
- Automated dipole subtraction
[RF, N. Greiner] 
- MG for the GRID
[J.Alwall, S. de Visscher, P. Demin, RF, F. Maltoni, T. Stelzer] 
- ...

Dipole subtraction



[RF, N. Greiner]

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

- Goal: Automatic Dipole Subtraction for the reals of any NLO calculation
 - Both for SM and BSM
 - Catani-Seymour subtraction scheme
 - Also compatible with MG StandAlone
- Alpha version working!

MG on the grid



[J. Alwall, S. de Visscher, P. Demin,
R.F. Maltoni, T. Stelzer]

- 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 random number seed
 2. the number of events requested

Conclusions

- MadGraph/MadEvent is an event generator that is:
 - Multi purpose, new models are easy to implement
 - Complete, interfaces from model to detector simulation
 - User friendly, due to the web interface
 - Fast, thanks to the cluster oriented structure
 - Open, everybody can contribute!

See also the three operational cluster at

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

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

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



Back-up Slides



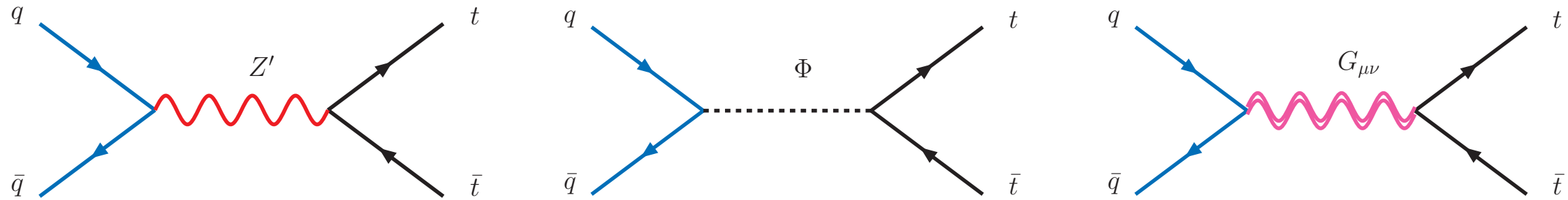
MadGraph standalone: a tool for theorists

- “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).

TopBSM

[RF, F. Maltoni, 2007]

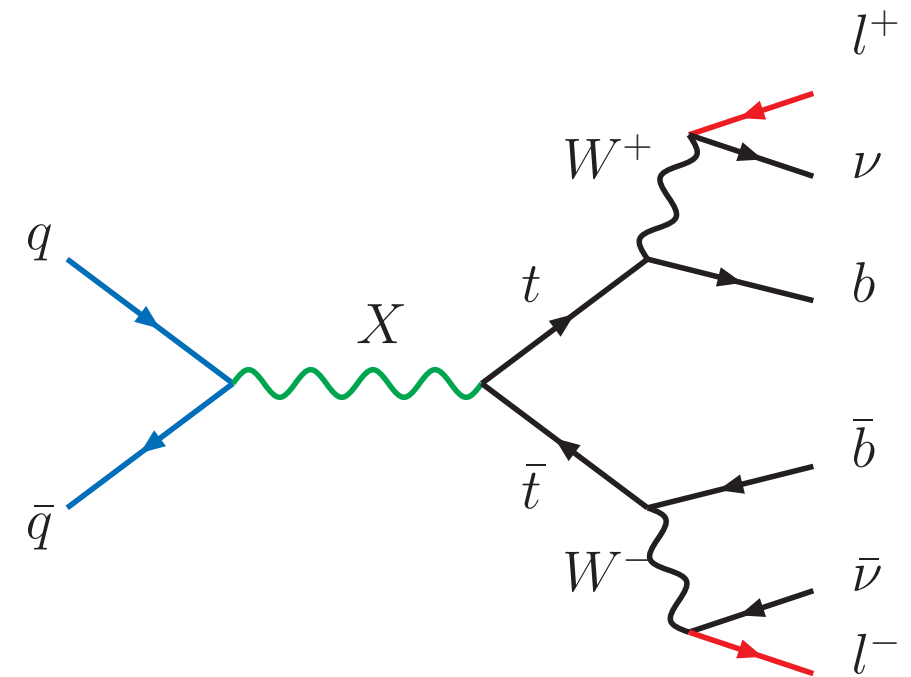
In many scenarios for EWSB new resonances show up, some of which preferably couple to 3rd generation quarks.



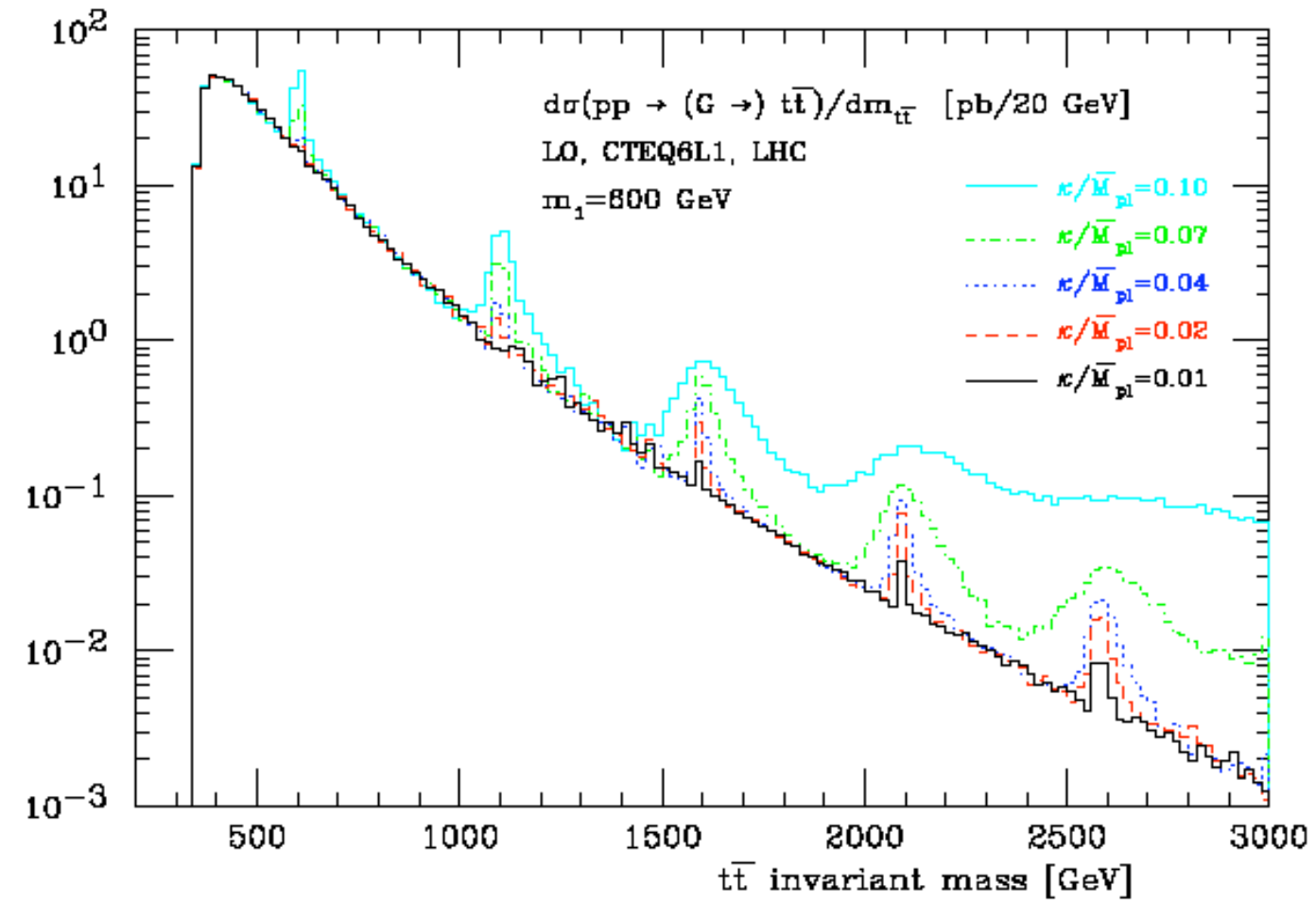
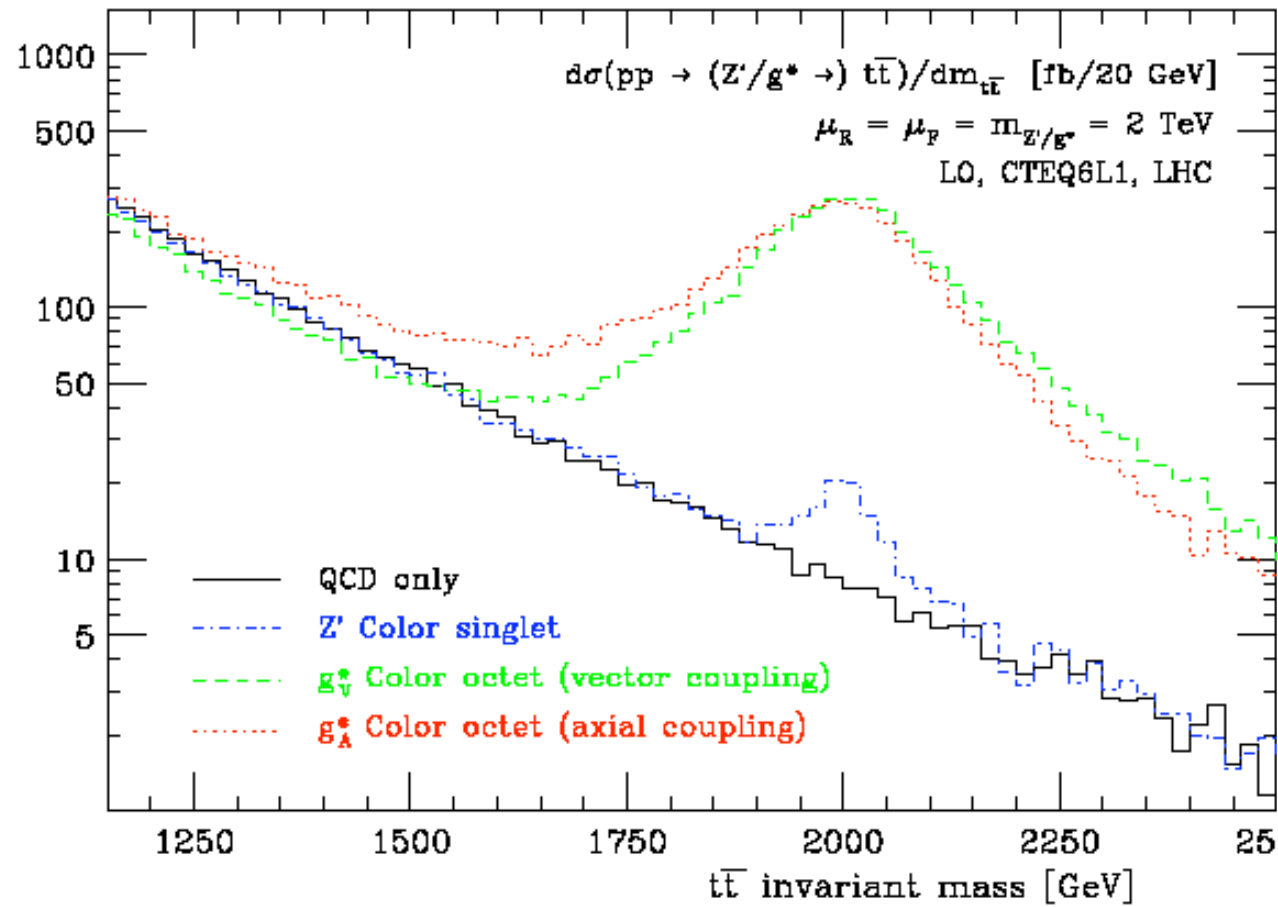
Given the large number of models, in this case is more efficient to adopt a “model independent” search and try to get as much information as possible on the quantum numbers and coupling of the resonance.

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

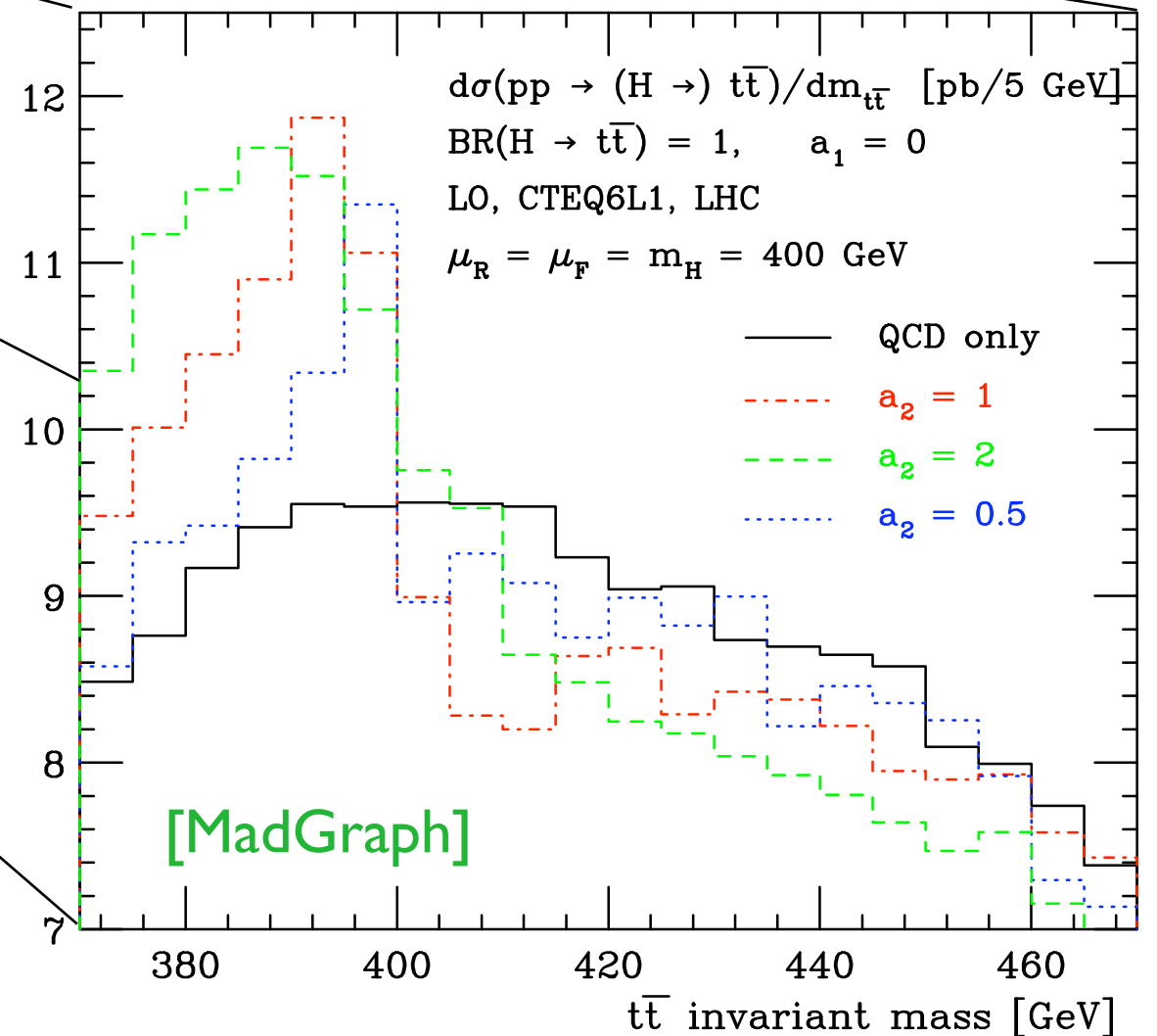
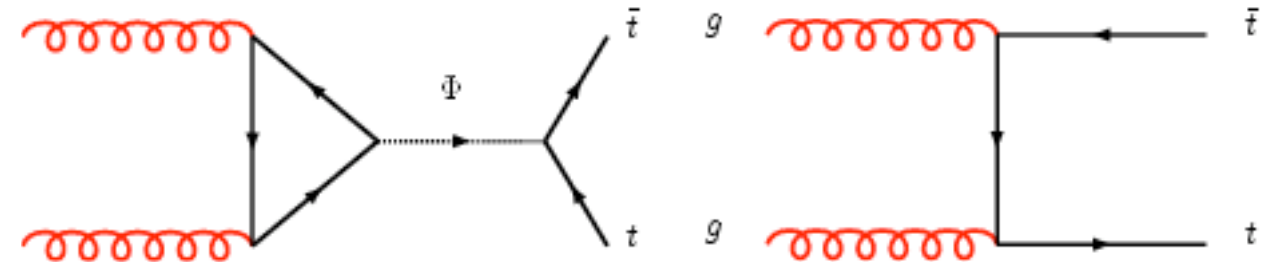
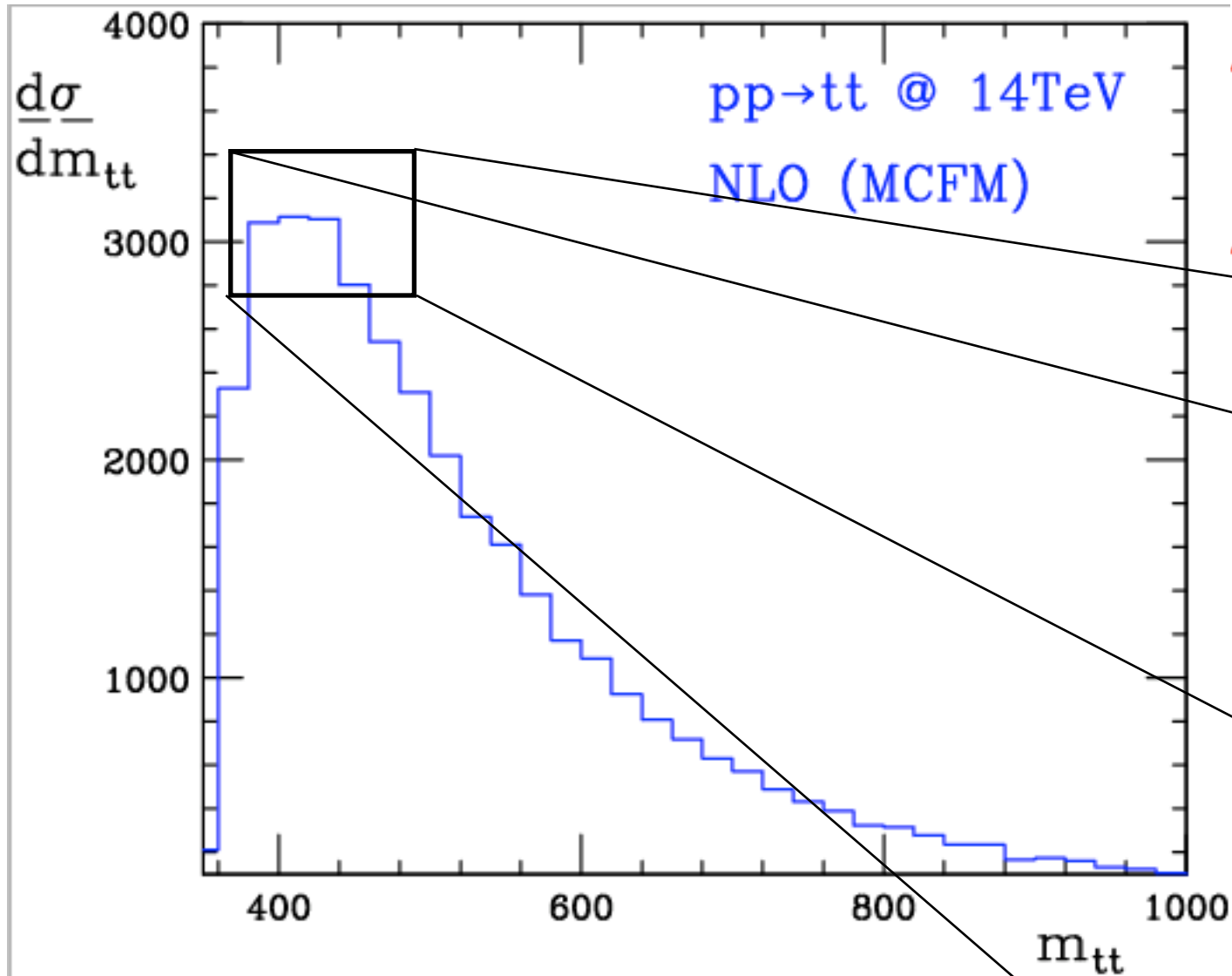
It therefore mandatory for such cases to have MC samples where spin correlations are kept and the full matrix element $\langle pp | X | tt \rangle$ is used.



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 $\Phi \rightarrow t\bar{t}$. [Dicus, Stange & Willenbrock 1994]