Top Physics with MadGraph/MadEvent

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& CERN - theory devision

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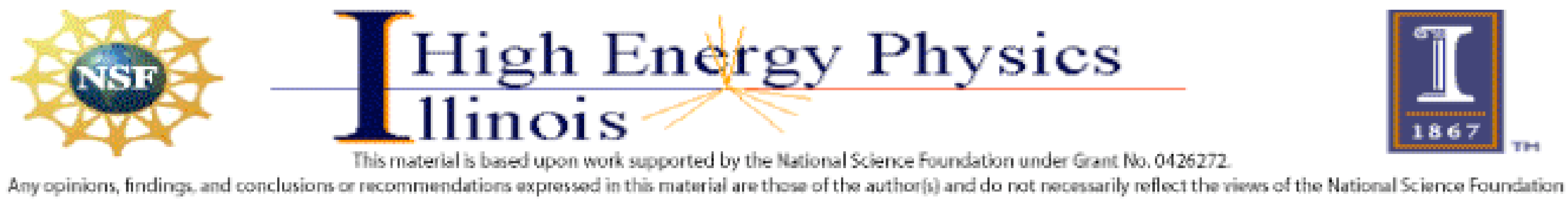
+ Steve Mrenna, Tilman Plehn, David L. Rainwater,
+ Pierre Artoisenet, Claude Duhr, Nicolas Greiner...

+ OUR GOLDEN USERS!!

What is MadGraph/MadEvent (MG/ME)?

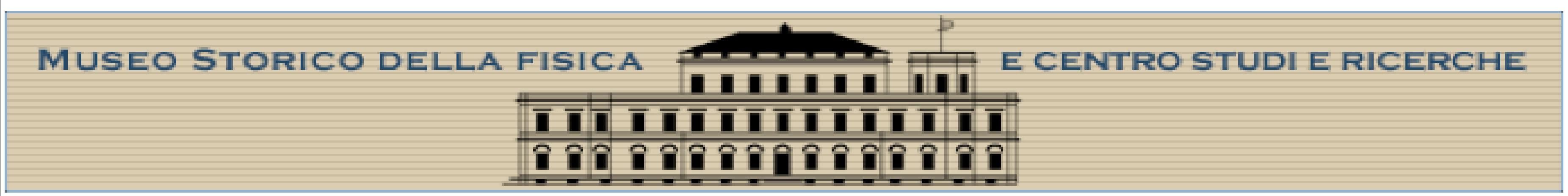
- MG/MEv4 is a user-driven, matrix element based, tree-level event generator
- Multi-process: Signal and background generation simultaneously
- Web server interface from which the simulation itself can be done on-line or off-line
- With MG/ME and its tools/interfaces, the full simulation chain from hard scale physics to detector simulation is available within one framework

MadGraph on the Web

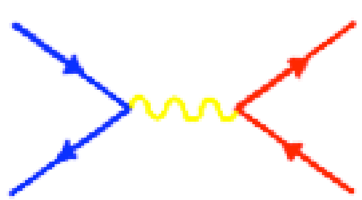


http://madgraph.hep.uiuc.edu/

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



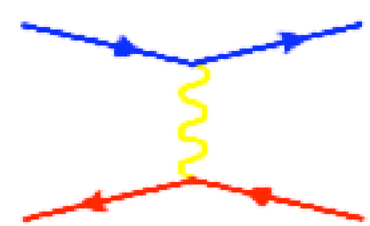
http://madgraph.roma2.infn.it/



MadGraph Version 4

UCL UIUC Fermi

by the MG/ME Development team

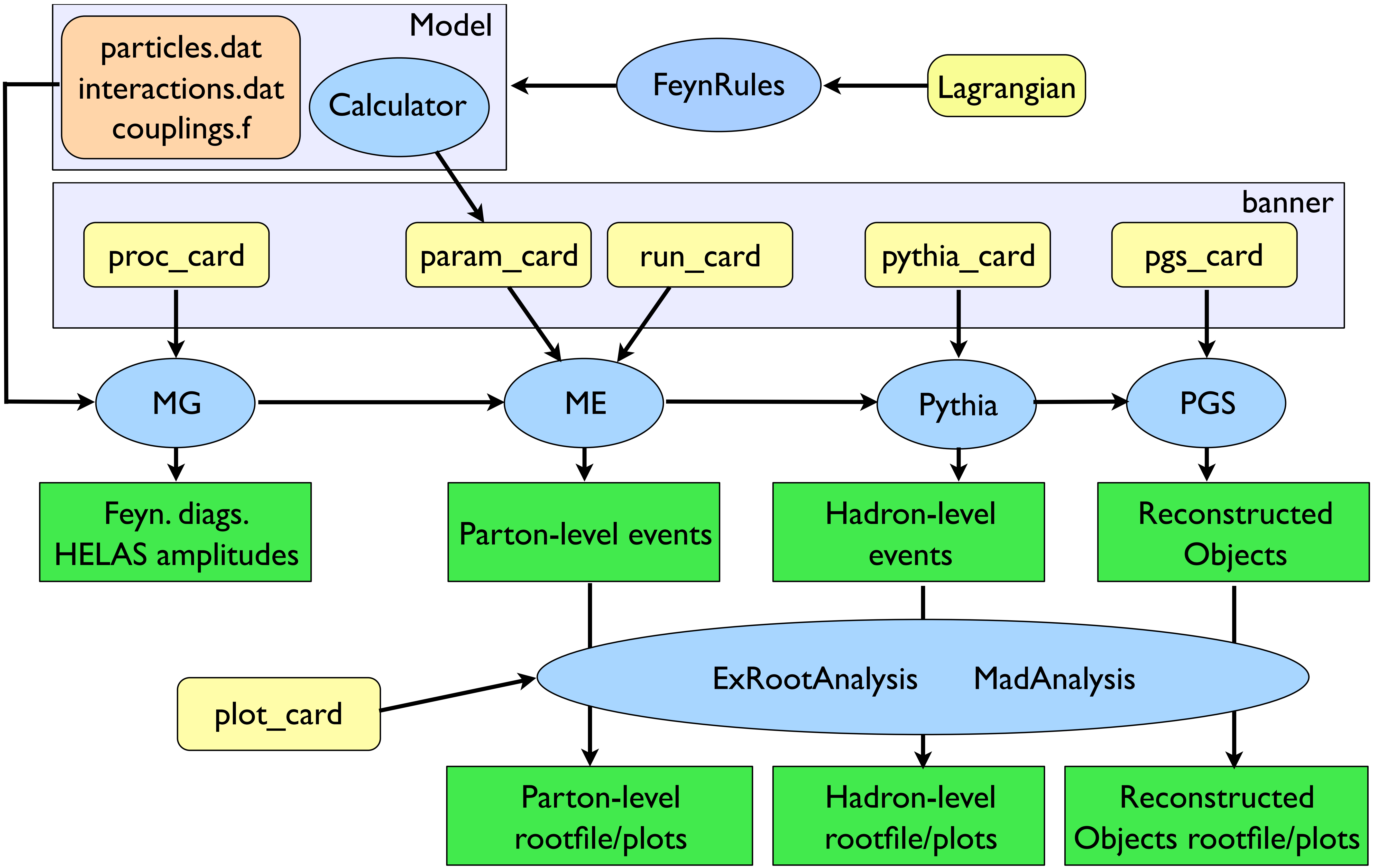


Generate Process | Register | Tools | My Database | Cluster Status | Downloads (needs registration) | Wiki/Docs | Admin

Three medium size clusters public access (+1 private cluster). ~1500 registered users.

Thanks to: D. Lesny, L. Nelson (UIUC), F. Chalier, T. Keutgen (UCL), R. Ammendola, N. Tantalo (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, with MadDipole for NLO comp.
- 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
- Detailed process specification
- MadWeight: automatic reweighting of experimental events
- Analysis platforms: ExRootAnalysis, MadAnalysis and MatchChecker

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Process specification

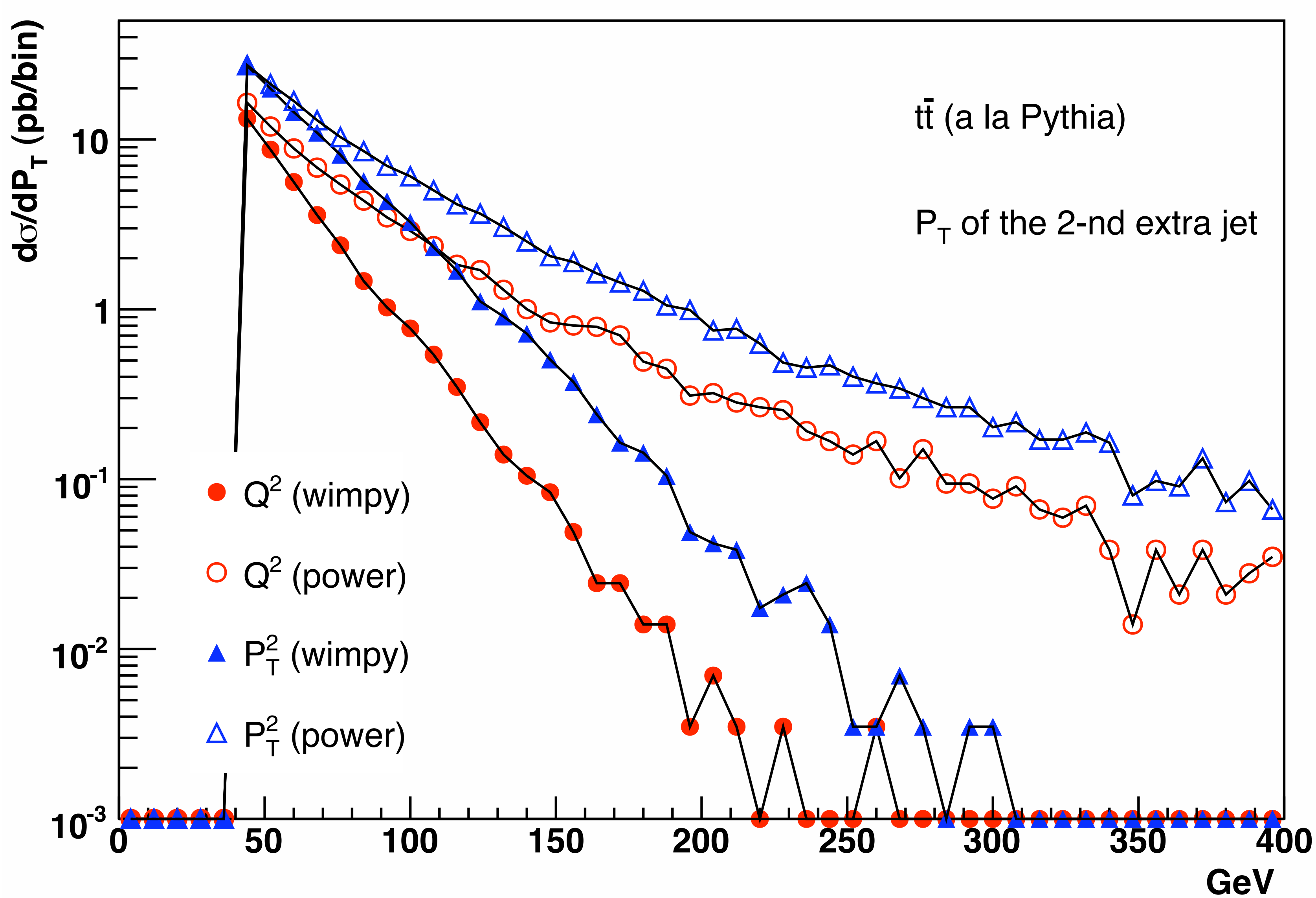
- Specify the process in the proc_card.dat (or use the box online)
  - Use "/" to exclude particles and ">" to specify intermediate states (s- or t-channel)
    - e.g. "pp > tt~ > bb~W+W- / Z a"
  - Specify the full decay chain by using "(... > ...)". This improves generation time by quite a lot! Works up to 8 final state particles
    - e.g. "pp > (t > b (W+ > e+ ve)) (t~ > b~ (W- > mu- vm~))"
  - Use "$" to exclude s-channel resonances (Only gauge invariant in NWA!)
    - e.g. "pp > bb~W+W- $ t~" for W associated single top + b, without ttbar contributions
  - Use "[...]" for quarkonium production
    - e.g. "gg > g cc~[3S11]" for gg>g+charmonium with S=1, L=0, J=1, c=1 (J/Psi production via a color-singlet transition).

Matching ME and PS

- K_T MLM scheme implemented by J. Alwall.
- Interfaced to (fortran) Pythia, with Q^2 and pt^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 (e.g. gluino/squark)
- Interfaces with Pythia8 and Herwig++ are through standard LHEF and not yet available with merging.

PS alone vs Matched Sample

- A parton shower like Pythia is by construction a highly tuneable tool. Consider for instance the pt distribution of the 2nd extra jet in ttbar events with different settings:



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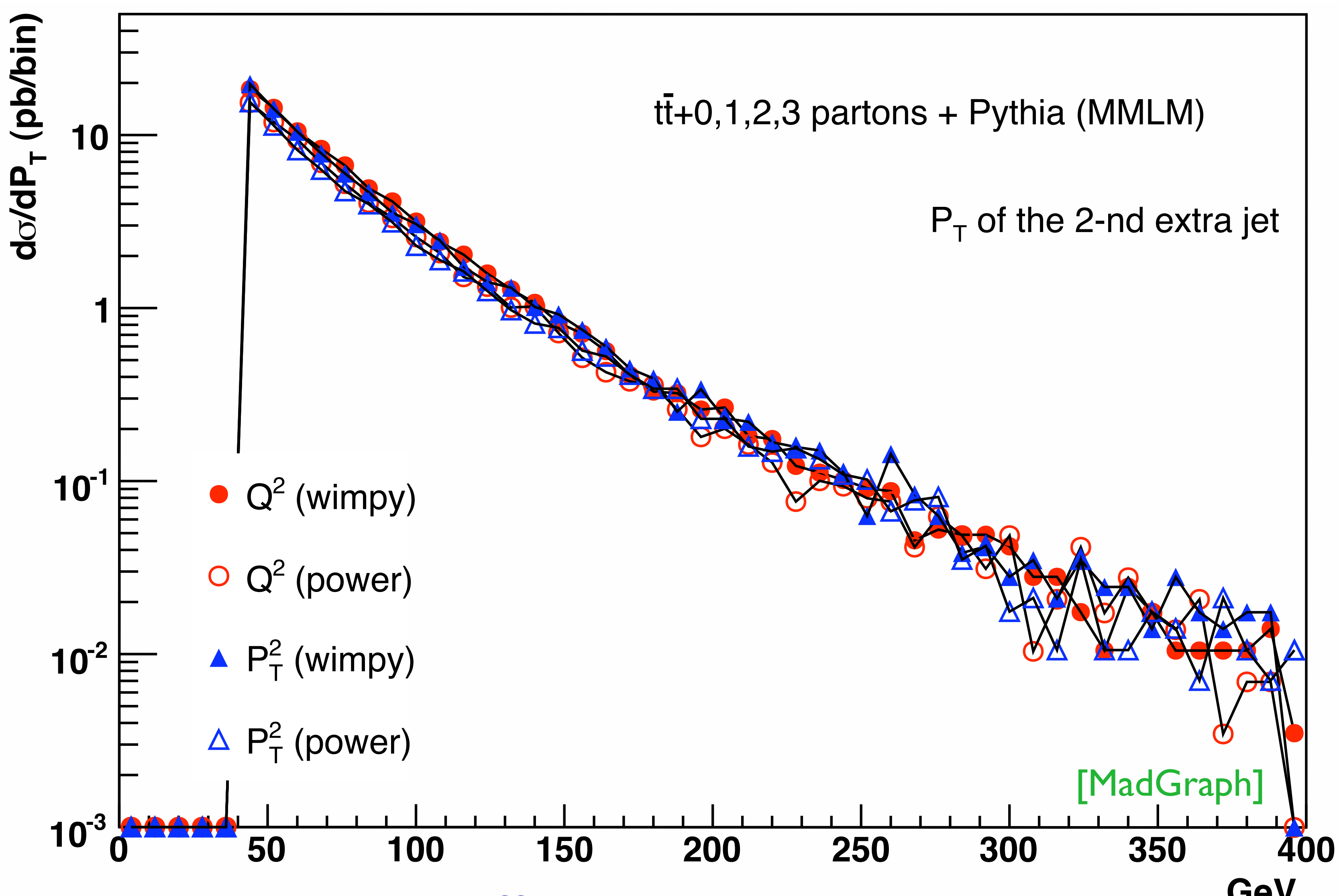
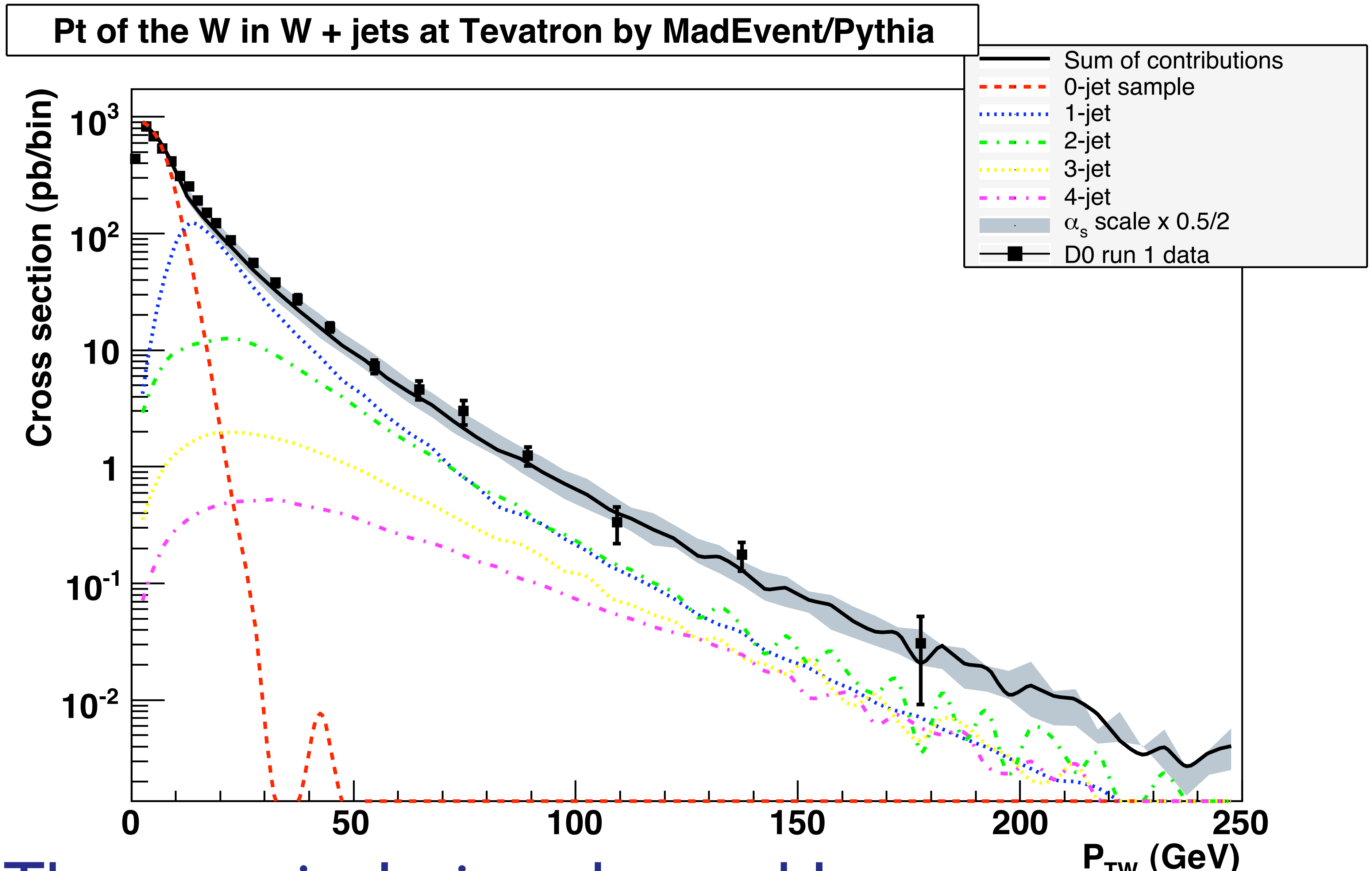


In matched samples these differences are irrelevant since the high pt behavior is described by the matrix element.
Uncertainties in the matching itself are not shown.

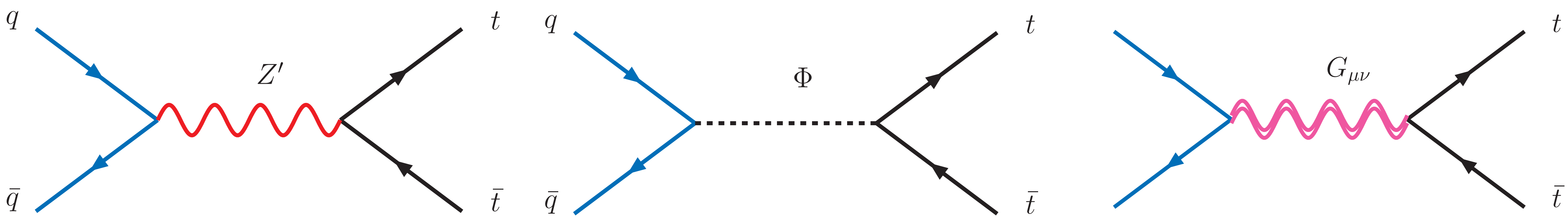
It's working!



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

TopBSM: New Physics in ttbar production

[RF, F. Maltoni] arXiv:0712.2355



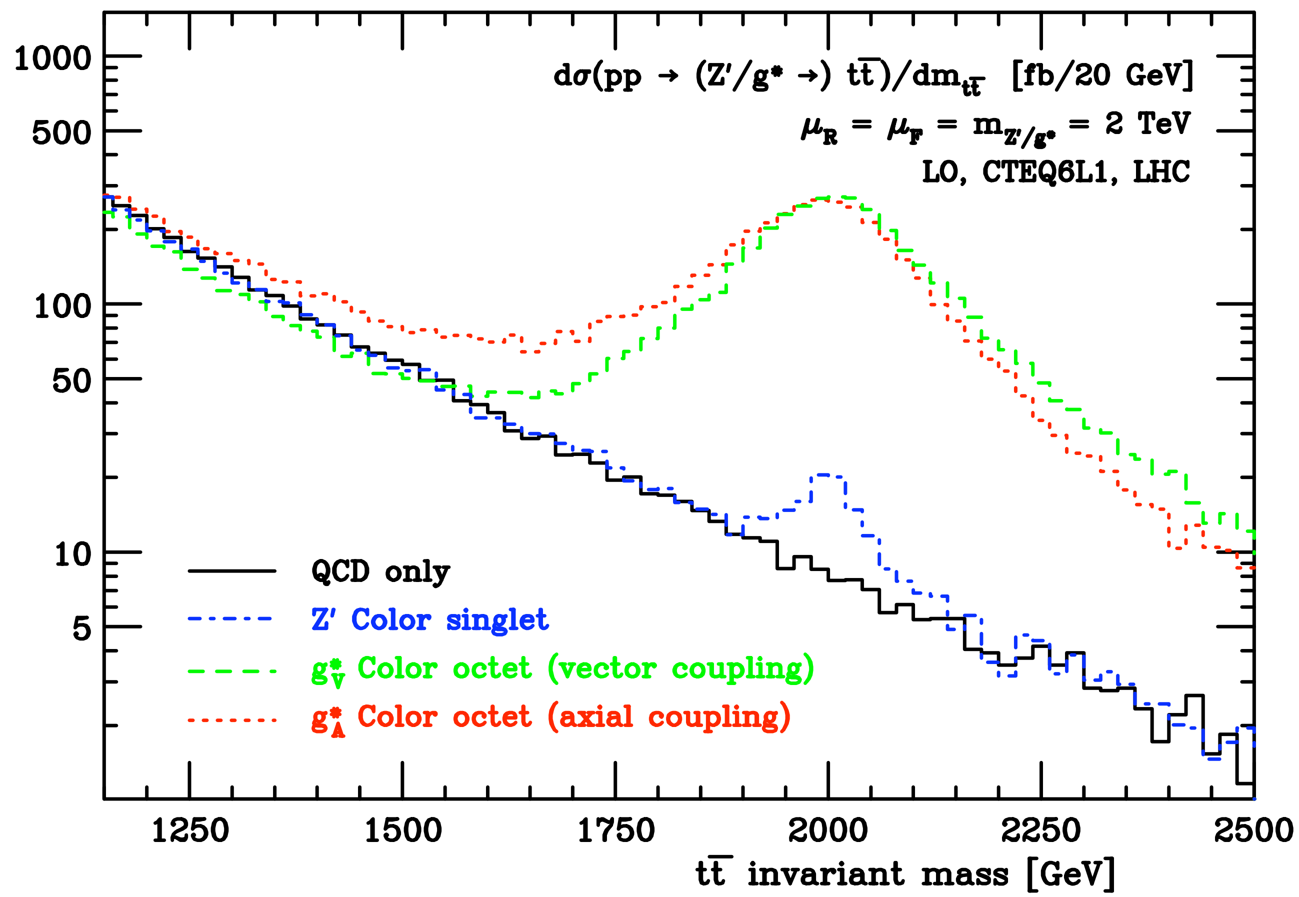
- In the topBSM model general resonances are added to the SM that couple to top quarks.

  These resonances can describe a large variety of models: Two-Higgs doublet models to extra dimensions and many more, by tuning the couplings and the masses of the resonances.

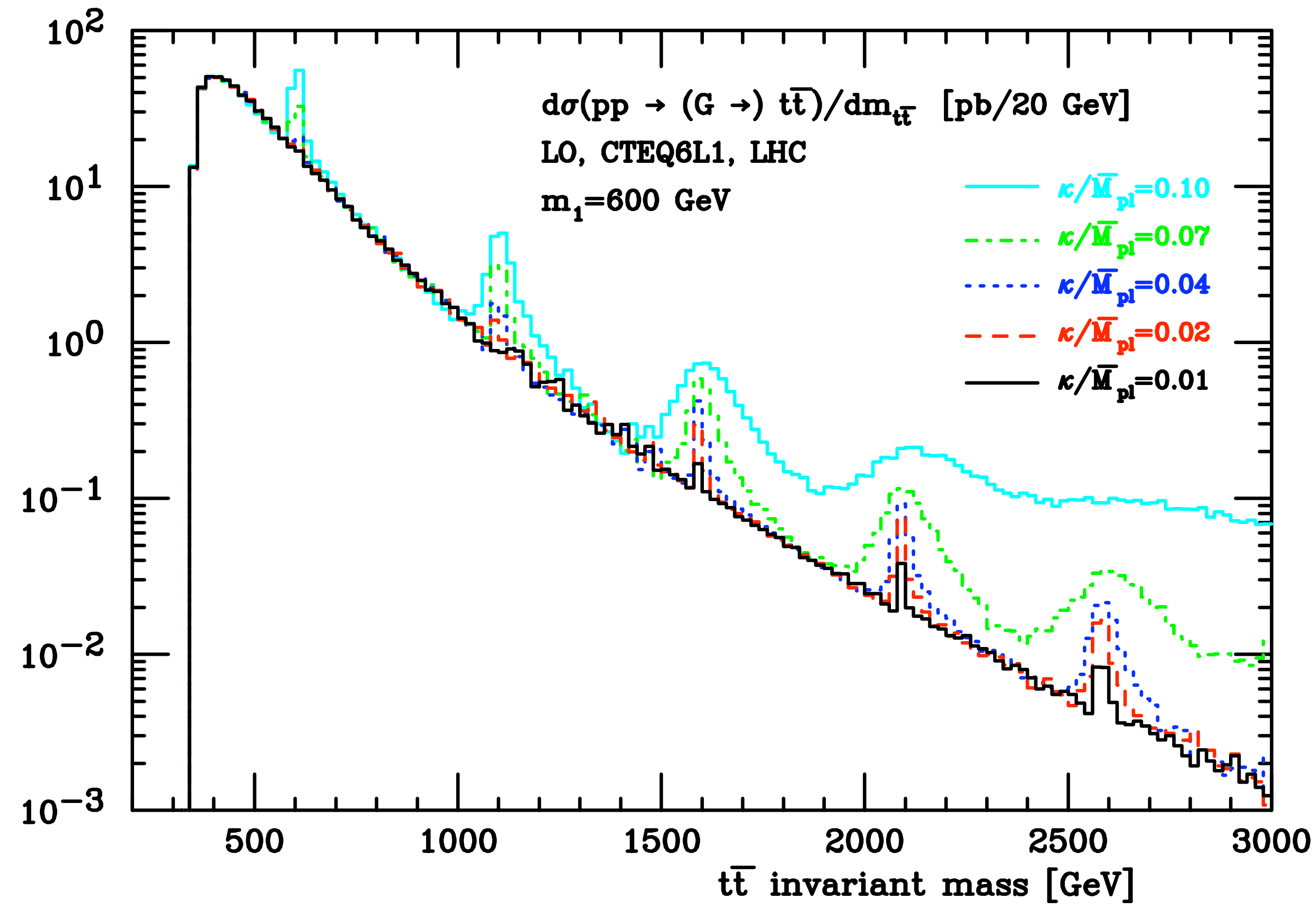
- In this way general resonances in ttbar events can be analyzed

TopBSM: ttbar invariant mass

[RF, F. Maltoni] arXiv:0712.2355



Spin-1



Spin-2

"Only" for discovery of the resonance. To determine properties more involved variables are needed

TopBSM: Spin Determination

[RF, F. Maltoni] arXiv:0712.2355

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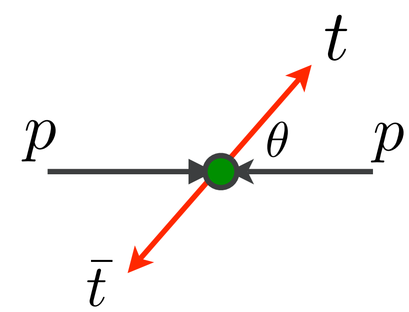
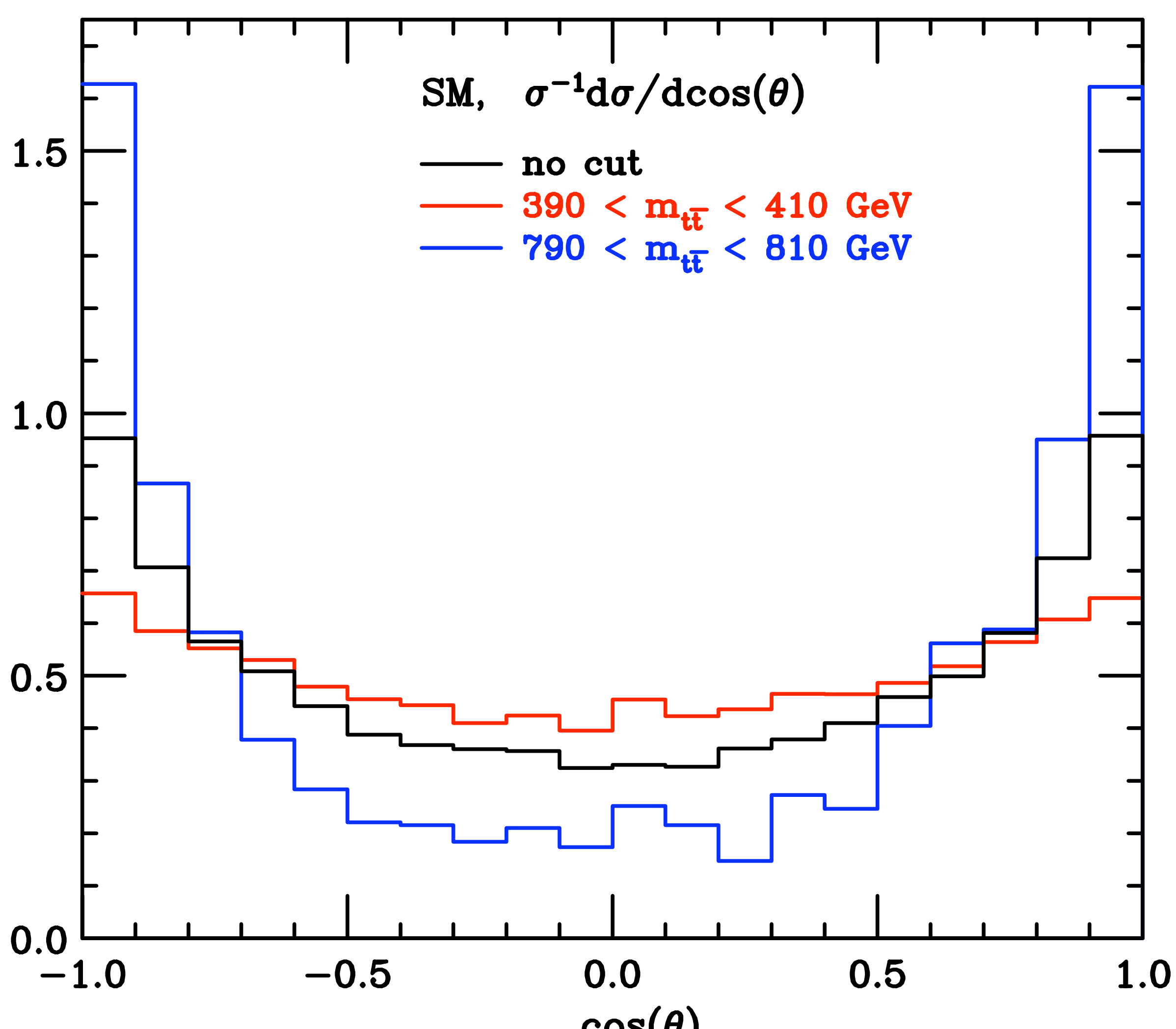
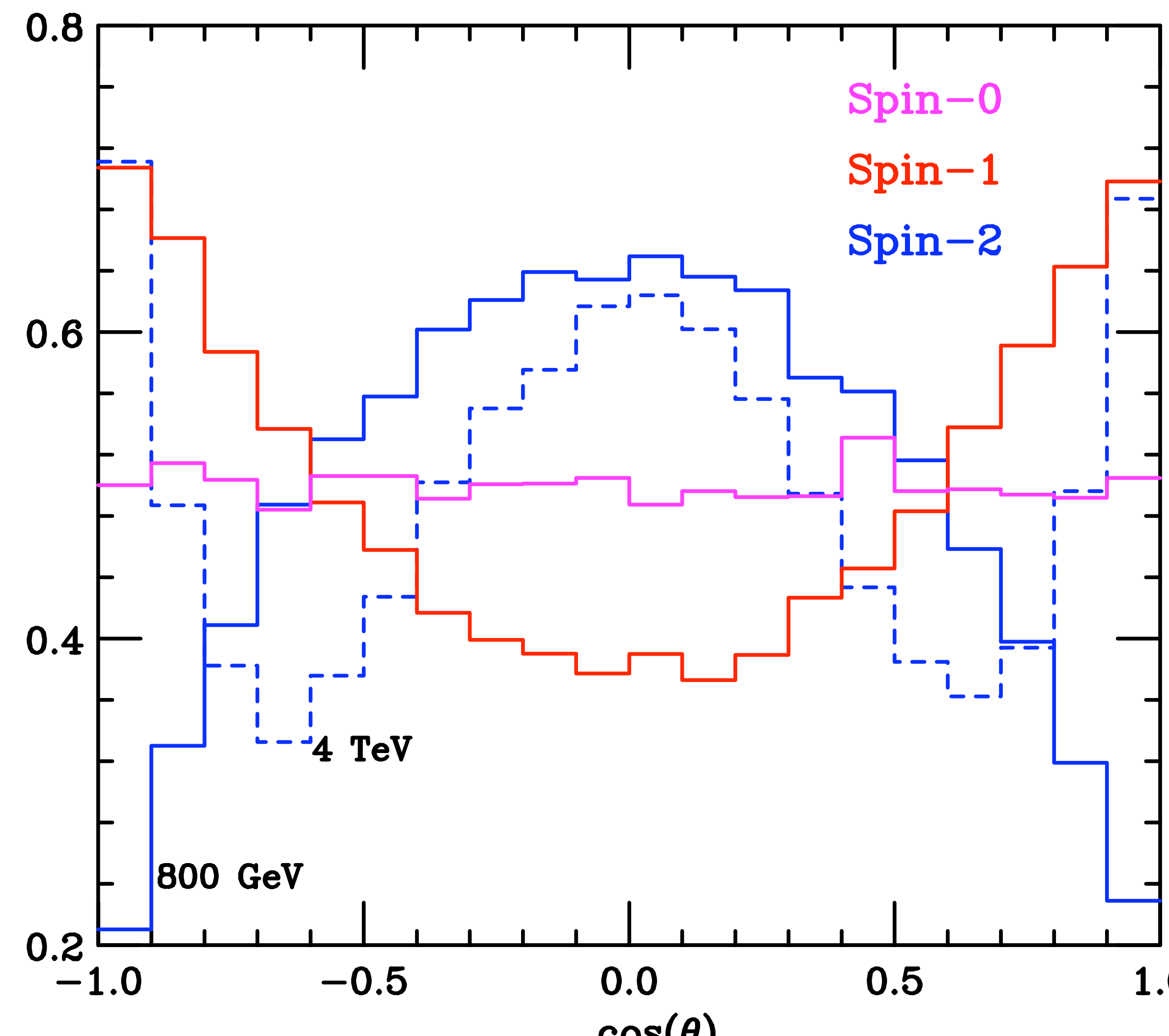
By measuring the Collins-Soper angle information about the spin structure of the resonance can be obtained



SM



BSM



TopBSM: Spin correlations

[RF, F. Maltoni] arXiv:0712.2355

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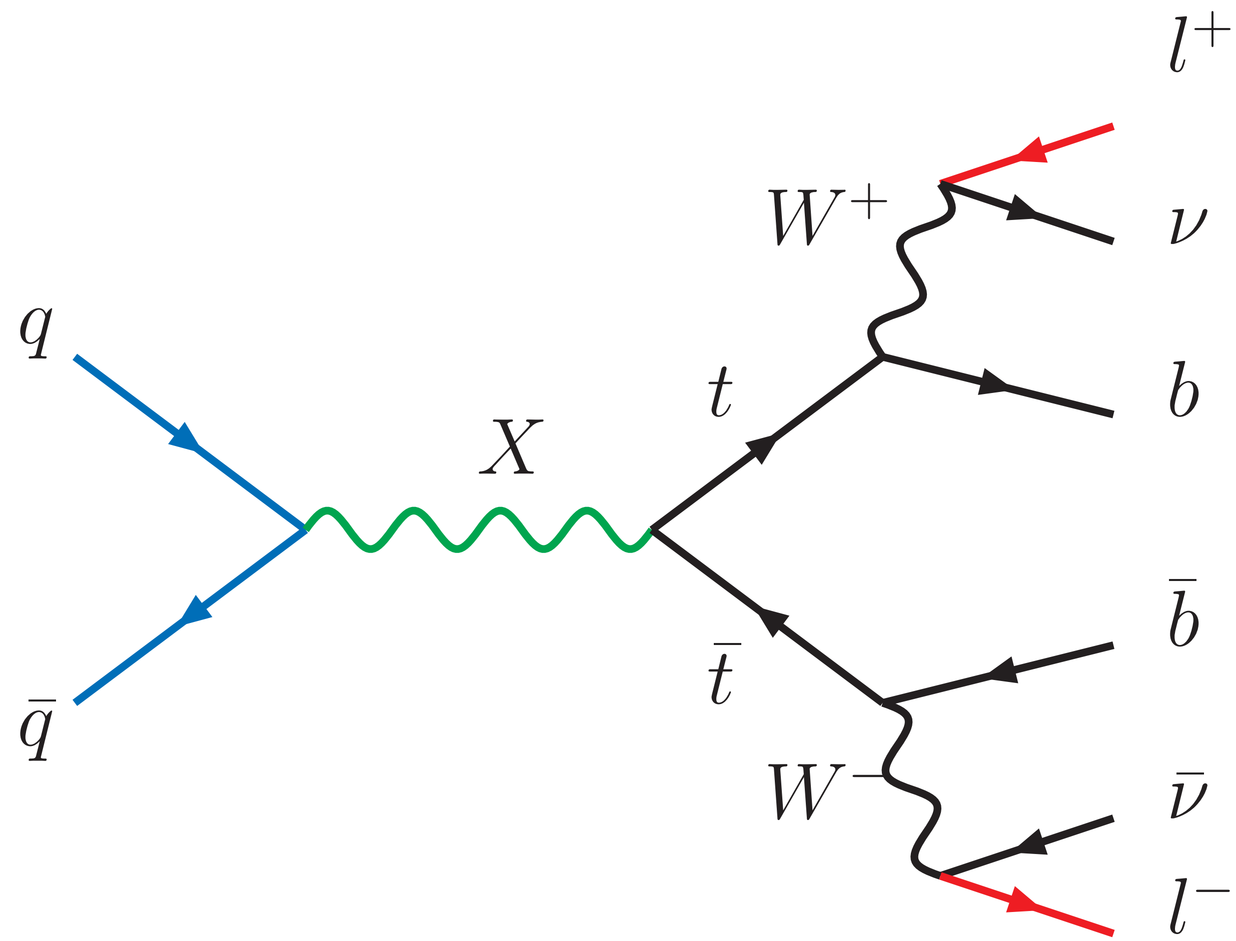
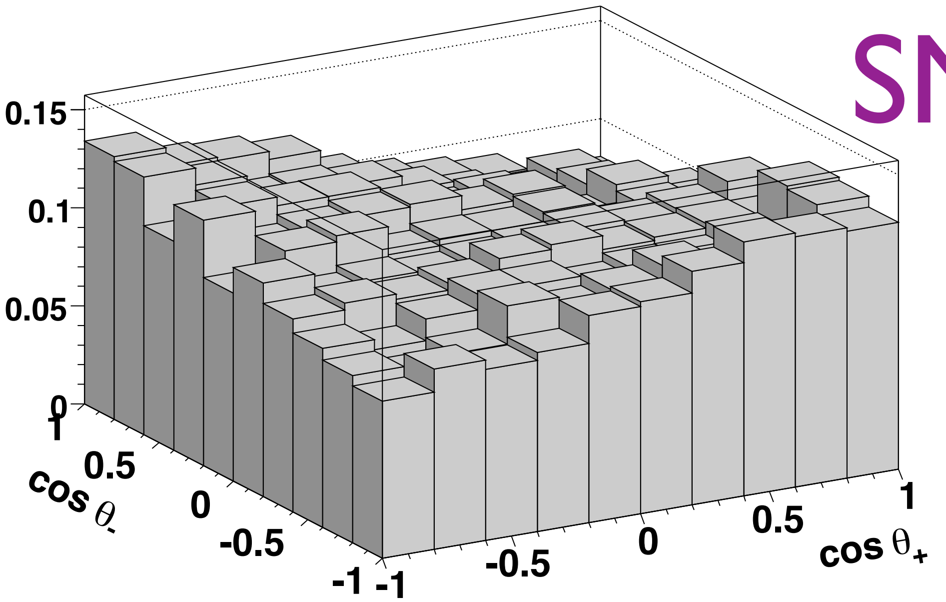
- To access the properties (CP or coupling structure) of resonances full matrix elements that describe the final state particles are needed.
- For example: to determine the coupling structure of a Spin-1 resonance in ttbar production the full 2→6 need to be generated.



TopBSM: Spin correlations

[RF, F. Maltoni] arXiv:0712.2355

$$\frac{1}{\sigma}\frac{d^2\sigma}{d\cos\theta_+ d\cos\theta_-} = \frac{1}{4}\left(1 - A\cos\theta_+\cos\theta_- + b_+\cos\theta_+ + b_-\cos\theta_-\right)$$



SM

Angle between l^+ in top rest-frame and top in top pair rest-frame

Angle between l^- in anti-top rest-frame and anti-top in top pair rest-frame

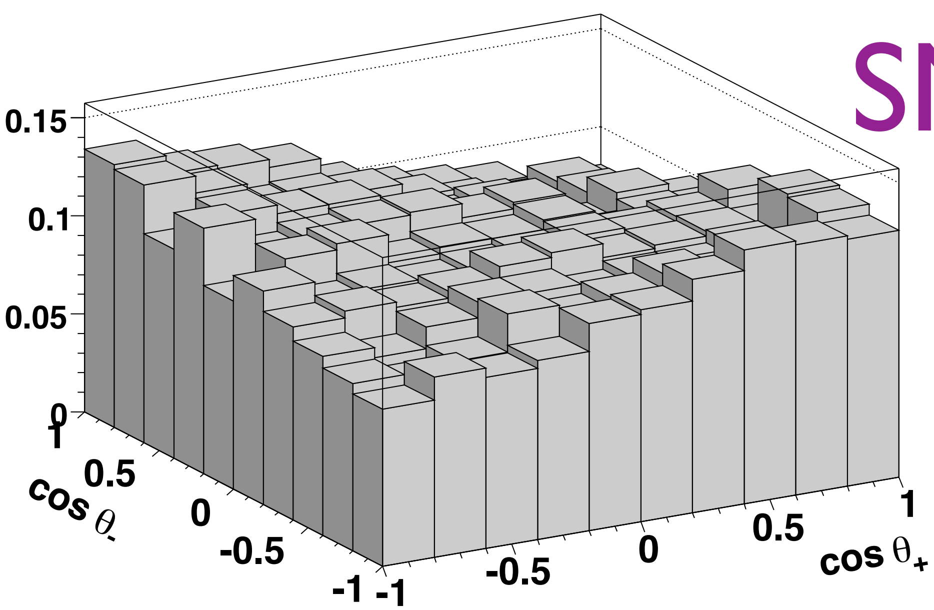
Example: Spin-1

TopBSM: Spin correlations

[RF, F. Maltoni]
arXiv:0712.2355

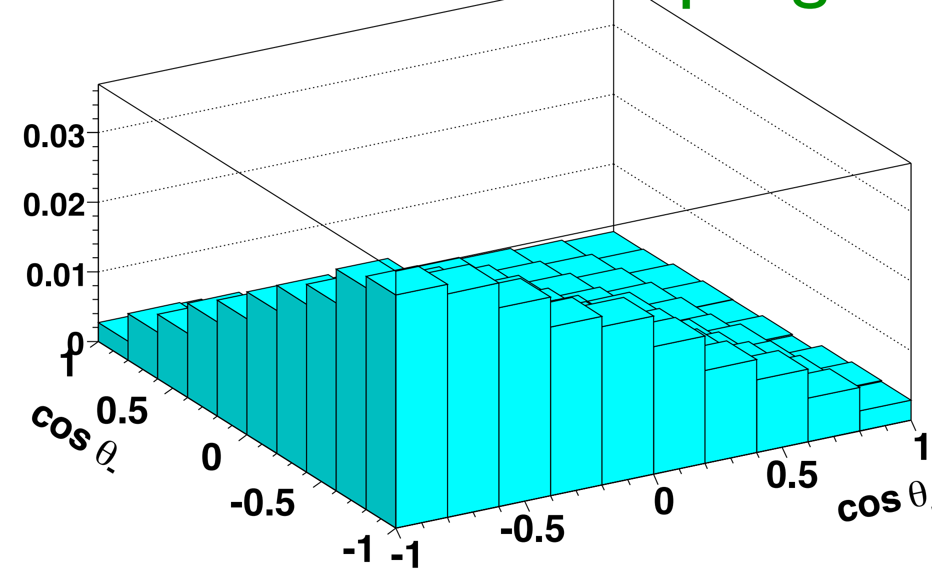
$$\frac{1}{\sigma}\frac{d^2\sigma}{d\cos\theta_+ d\cos\theta_-} = \frac{1}{4}\Big(1 - A\cos\theta_+\cos\theta_- + b_+\cos\theta_+ + b_-\cos\theta_-\Big)$$

SM

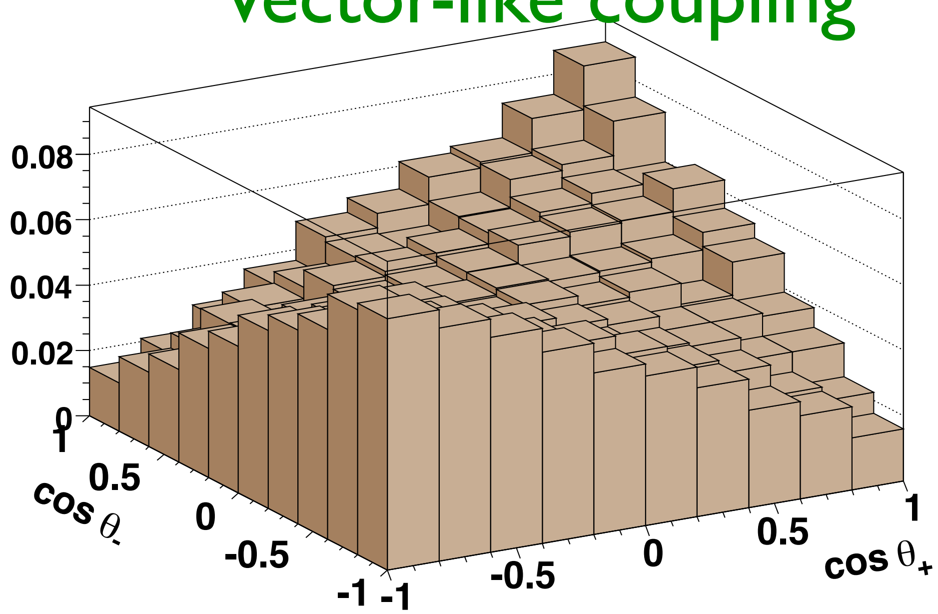


Spin-1

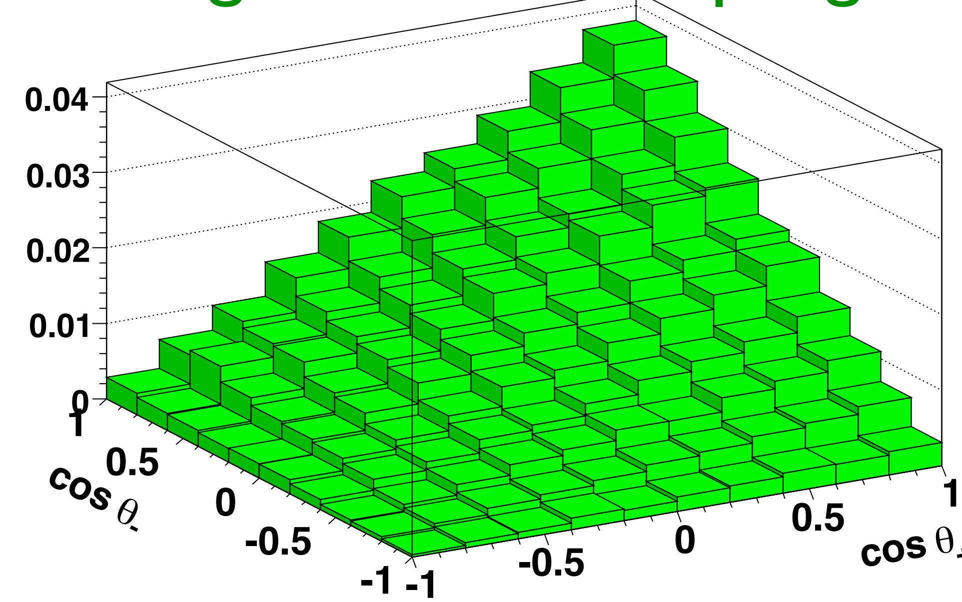
Left-handed coupling



Vector-like coupling



Right-handed coupling



MadWeight

[P. Artoisenet, V. Lemaître, F. Maltoni, O. Mattelaer]

- Tool to find matrix element weight of experimental events for (almost) any process in any model: Matrix Element Method.
- Use all information in the events to determine a parameter

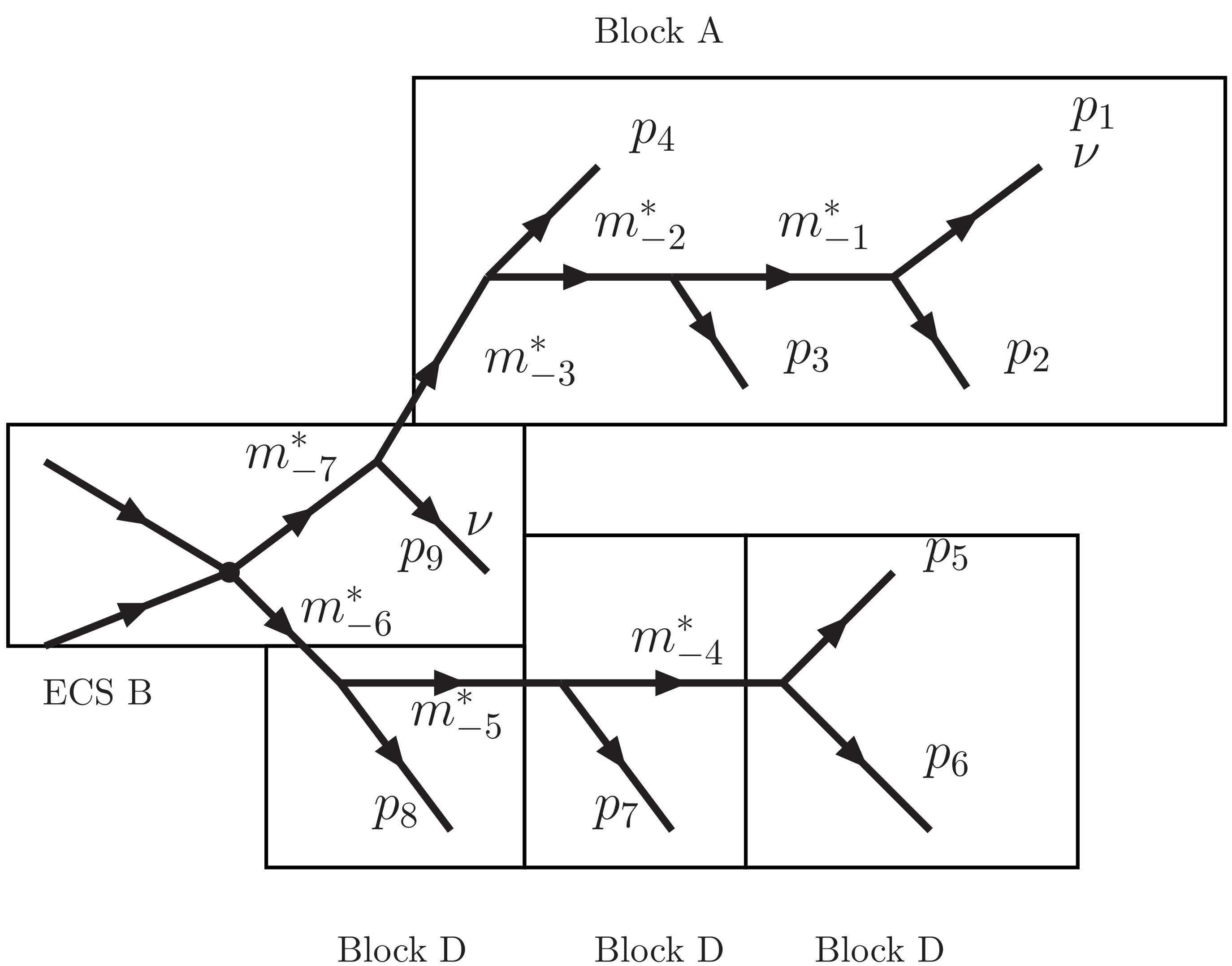
$$P(\boldsymbol{x},\alpha) = \frac{1}{\sigma_\alpha}\int d\phi(\boldsymbol{y})|M_\alpha|^2(\boldsymbol{y})dq_1 dq_2 f_1(q_1)f_2(q_2)W(\boldsymbol{x},\boldsymbol{y})$$

- Transfer function *W(x,y)* accounts for the evolution from parton level event *y* to the reconstructed event in the detector *x*
  - Many more "peaks" in the integration then matrix element alone. Need for efficient integration routines

MadWeight: PS integration

[P. Artoisenet, V. Lemaître, F. Maltoni, O. Mattelaer]

- Phase space integration using automatic (analytic) changes of variables to align with peaks

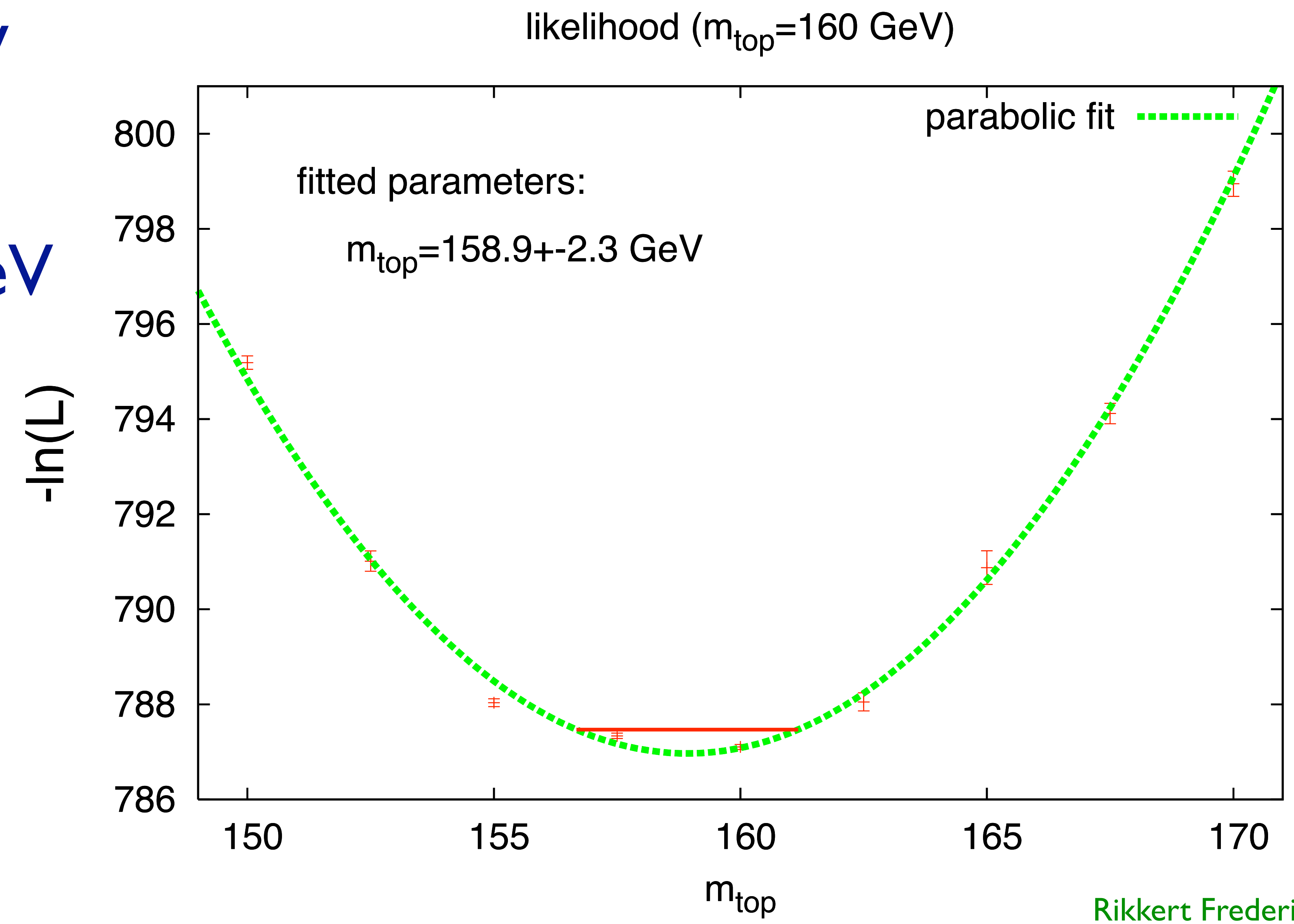


This leads to an efficient integration over the matrix elements and the transfer functions

MadWeight: Example

[P. Artoisenet, V. Lemaître, F. Maltoni, O. Mattelaer]

- Measurement of the top-quark mass in the semi-leptonic channel
- 20 Monte-Carlo events (MG/ME/Pyhtia/PGS)
- Input: m_t = 160 GeV
- Output:
  m_t = 158.9 ± 2.3 GeV



MadDipole

[RF, T. Gehrmann, N. Greiner; JHEP 0809:122, 2008]

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

- First step to automatic NLO with MadGraph/MadEvent
  - Various groups are focussing on the automatization of the loop diagrams, e.g.:
    - CutTools [G. Ossola, C.G. Papadopoulos, R. Pittau]
    - BlackHat [C. Berger et al.]
    - Rocket [W. Giele, G. Zanderighi]
    - GOLEM [T. Binoth et al.]
- Automatization of the Real contributions also needed

MadDipole

[RF, T. Gehrmann, N. Greiner; JHEP 0809:122, 2008]

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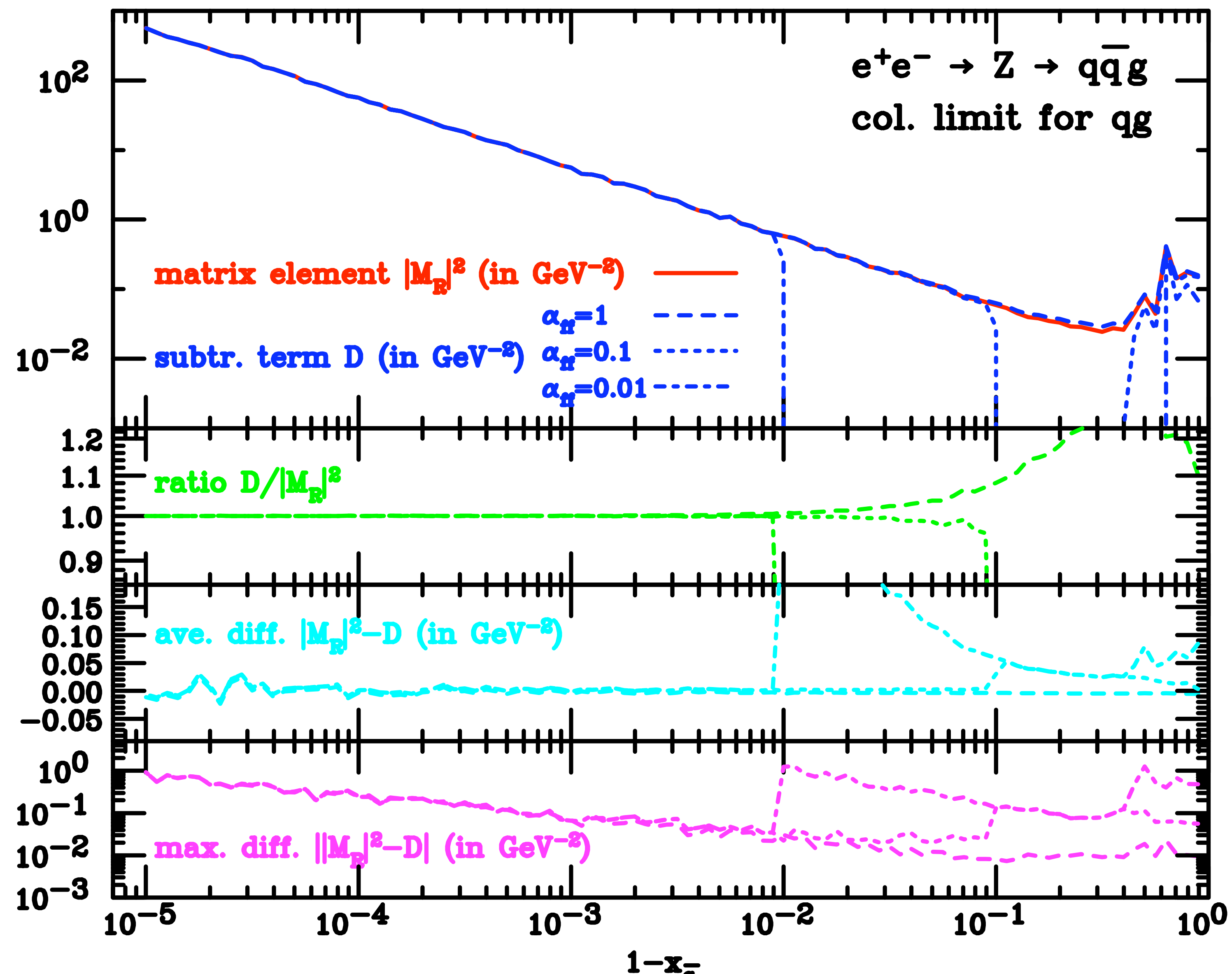
- Goal: Automatic Dipole Subtraction for any NLO calculation
  - Catani-Seymour subtraction scheme
  - Reals & subtraction terms for the reals and virtuals
  - Including "alpha" dependence to restrict dipoles to divergent regions of the phase-space
  - Both for SM and BSM
  - Compatible with MG StandAlone

MadDipole

[RF, T. Gehrmann, N. Greiner; JHEP 0809:122, 2008]

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

- Subtraction is working
- alpha dependence clearly visible
  - Extensive testing against MCFM
- Next steps:
  - do the subtraction terms for the virtuals
  - and the phase space integration



Summary

- MadGraph/MadEvent is a versatile Monte Carlo tool
  - Matching between ME and PS available
  - Many BSM physics models available.
    “Model-independent” topBSM available for top studies
  - MadWeight for Matrix Element Method
  - MadDipole as a first step to NLO

See also the three operational cluster at
http://madgraph.phys.ucl.ac.be
http://madgraph.hep.uiuc.edu
http://madgraph.roma2.infn.it