MonteCarlo's for Top Physics

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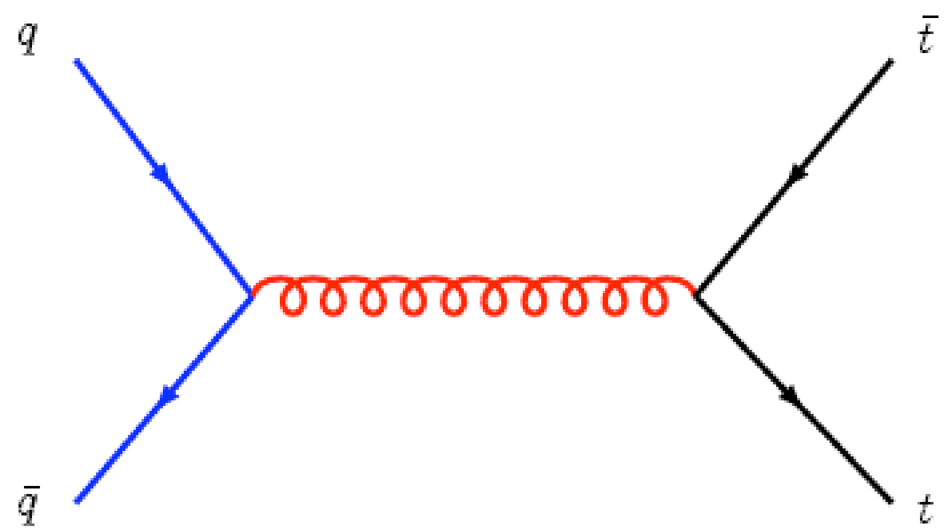
Outline

- From top physics to top MC needs
- Fixed order theoretical results
- New MC approaches
- A quick look at BSM
- Conclusions

From Tevatron to LHC

Tevatron



85% of the total cross section

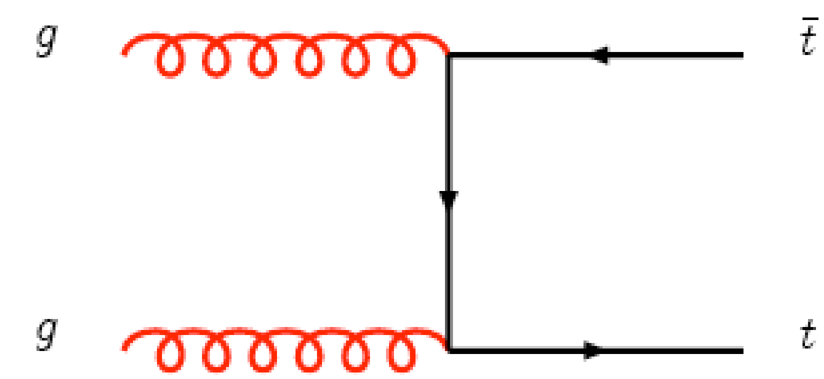
10 tt pairs per day

60% of the time there is extra radiation so that pt(tt)>15 GeV.

tt are produced closed to threshold, in a $^3S_1[8]$ state. Same spin directions. 100% correlated in the off-diagonal basis.

Worry because of the backgrounds: (W+jets, WQ+jets, WW+jets)

LHC



90% of the total cross section

1 tt pair per second

Almost 70% of the time there is extra radiation so that pt(tt)>30 GeV.

tt can be easily produced away from threshold. On threshold they are $^1S_0$ state, with opposite spin directions. No 100% correlation.

Worry because IT is a background!

Top as signal

Our AIM is twofold:

I. Measure all properties (mass, couplings, spin) to establish indirect evidence for SM and BSM physics.

Examples: precision EW and QCD (m_{top},σ(tt),σ(t));
Rare decays and anomalous couplings. CP violation.

II. Use top as direct probe of the EWSB sector and BSM physics

Examples: SM ttH; BSM: Z' and W' resonances; SUSY: tH^+ and $t \rightarrow bH^+$ or stop $\rightarrow t$ X.

Top as background

At the LHC, many measurements will need a good understanding and control of tt events.
A few examples:

- gg→H and qq→Hqq with H→WW
- tt in single top measurements
- tt+jets and ttbb for ttH
- tt+jets and ttW for SUSY searches (gluino pairs, stop pairs, tH^+....)

Fundamental theoretical results on top production

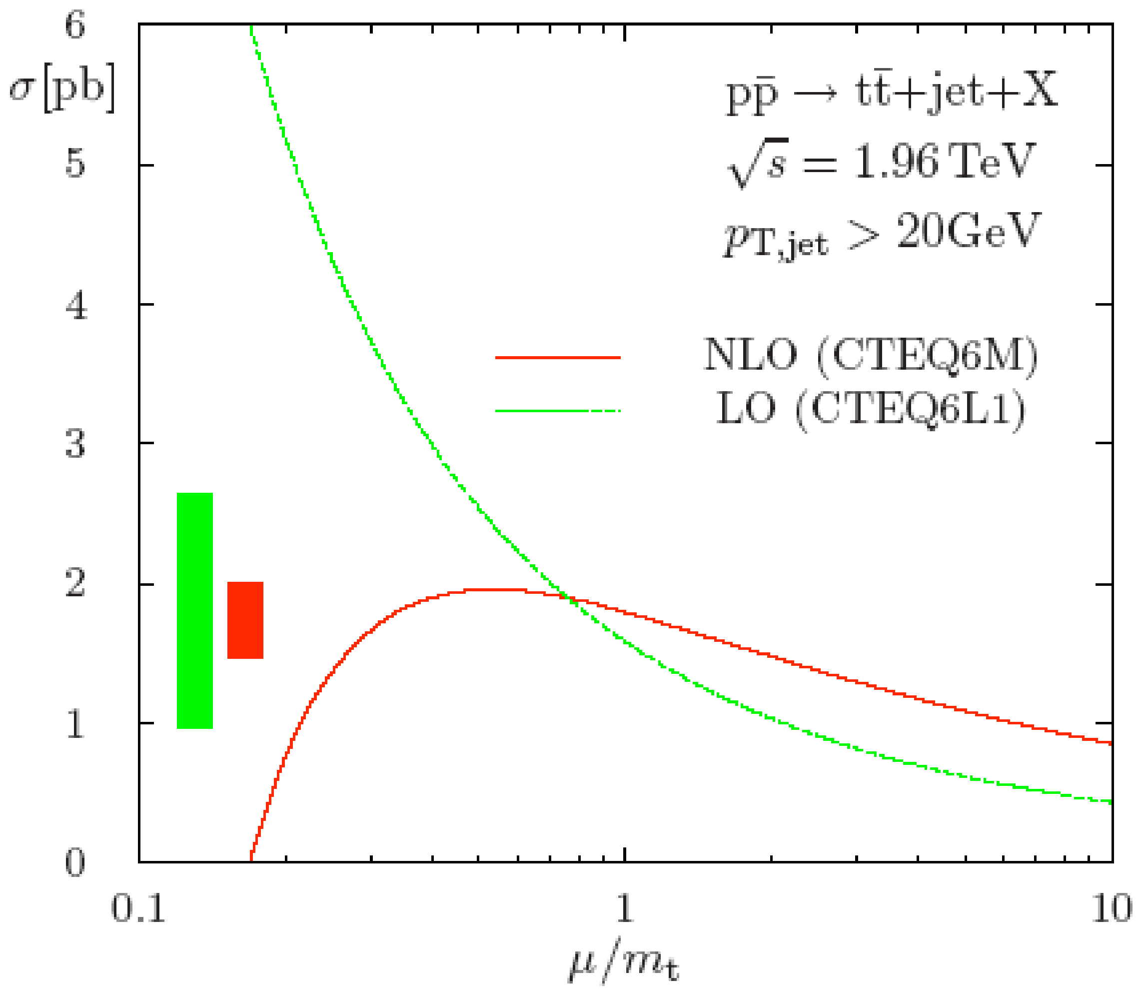
top signal

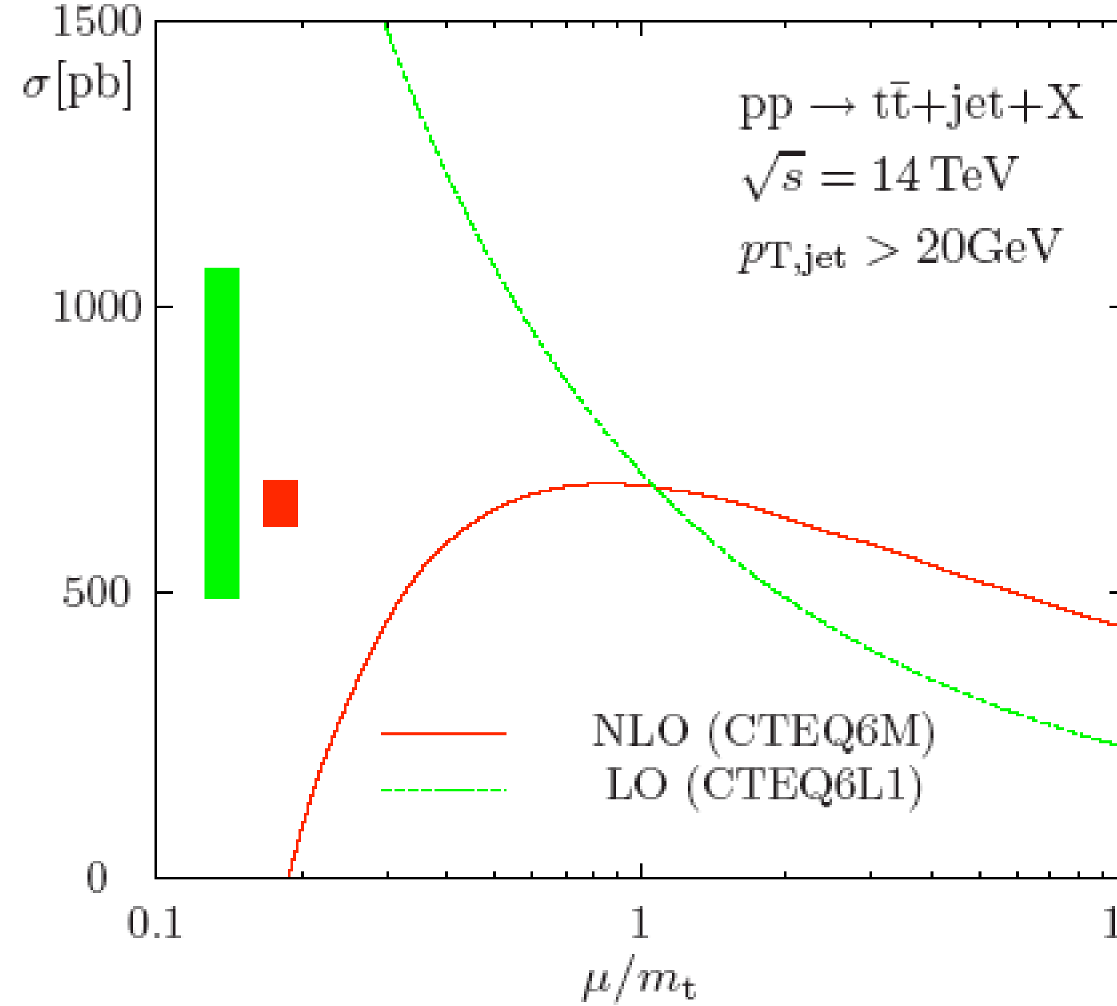
- NLO+shower for tt and single top — Frixione, Frixione, Laenen, Nason, Motylinsky, Ridolfi, Webber 2003-07
- NLO tt w/ spin correlations — Bernreuther, Brandenburg, Si, Uwer, 2004
- NLO single-top's w/ spin correlations — Campbell, Ellis, Tramontano 2004-05; Cao, Schwienhorst, Yuan 2004
- EW corrections to tt and single top — Beenakker, 1994; Kao and Wackeroth, 2000; Kuhn, Scharf, Uwer, 2006; Beccaria et at, 2006
- tt+1jet at NLO — Dittmaier, Uwer, Weinzierl, 2007
- pp $\rightarrow$ (b f f') (b f f') — Kauer and Zeppenfeld, 2002
- tt+jets: ME+Parton Shower — Alpgen; MadEvent; SHERPA...

tt as a background

tt+1jet at NLO

[Dittmaier, Uwer, Weinzierl, 2007]

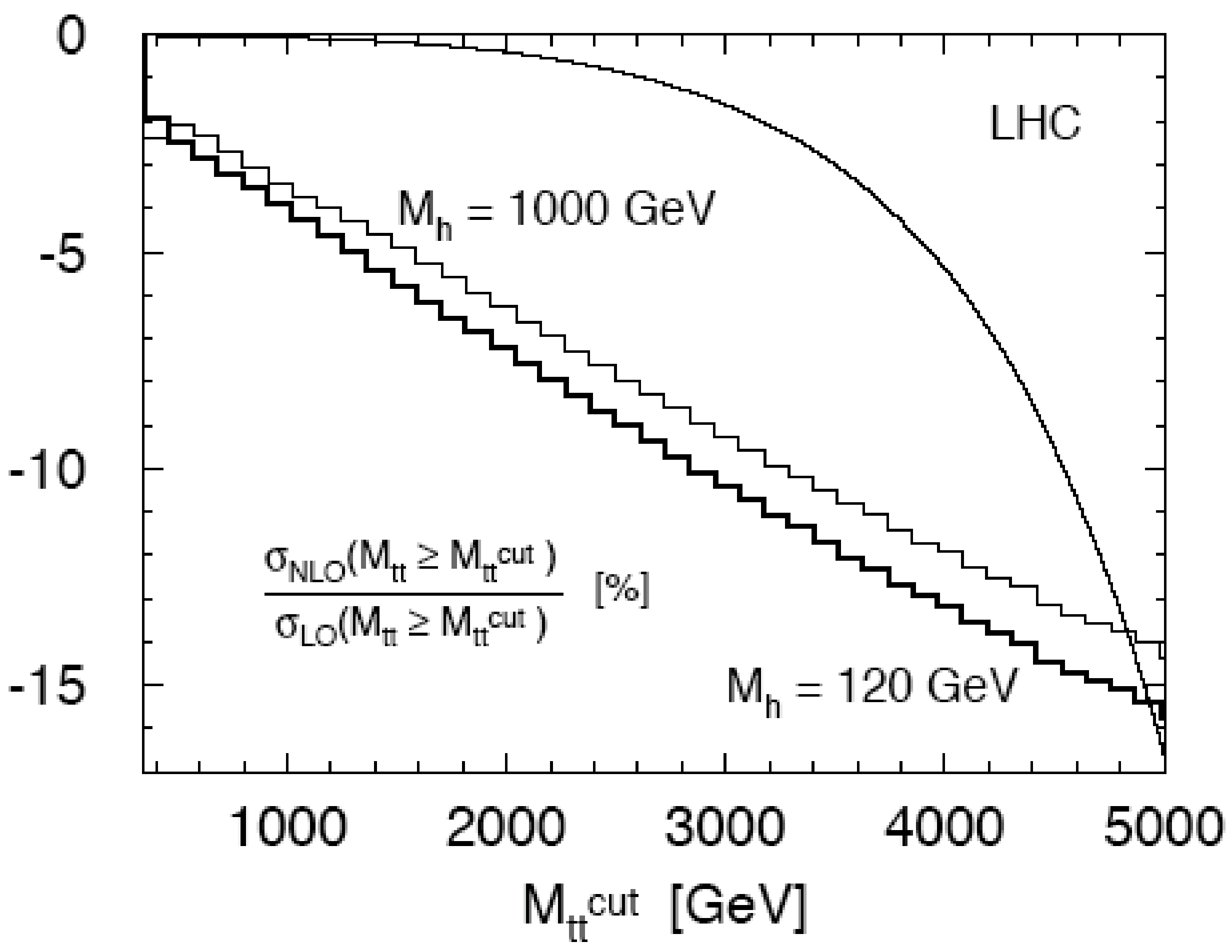


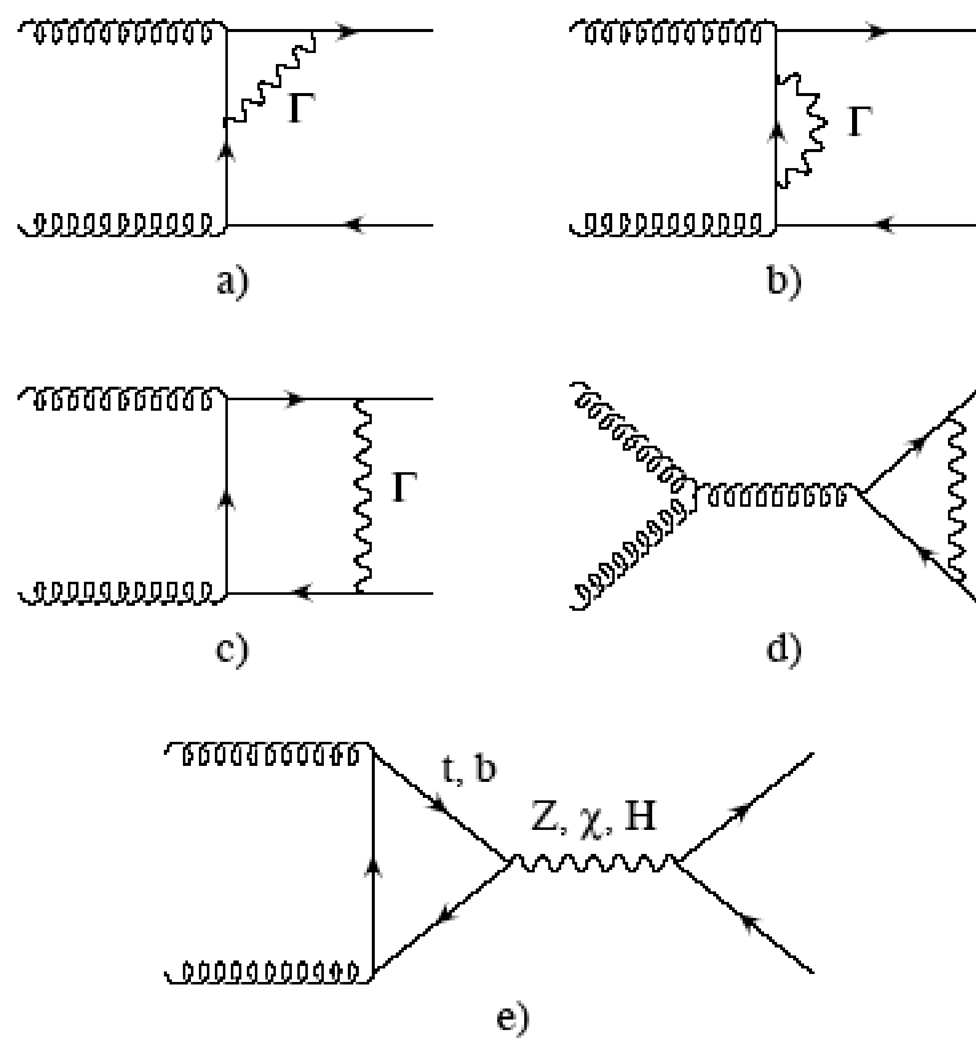


* Impressive state-of-the-art NLO calculation
* Amazing (unexpected?) improvement in the scale dependence
* Distributions eagerly awaited for comparison with ME+PS

ttbar: EW corrections

[Kuhn,Scharf,Uwer, 2006]





* Several groups have by now calculated the contribution from the virtual exchange of electro-weak bosons (W,Z,H,γ)

*The effect on the total cross section is small but it is enhaced at large m_{tt}, up to -10/-15%.

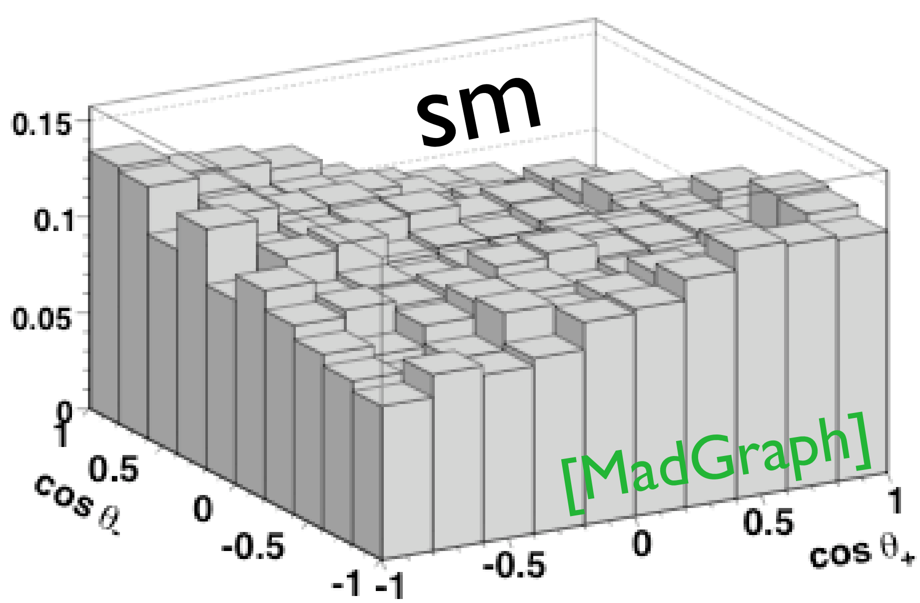
*SUSY could also lead to virtual corrections of similar size, relevant only for high-m_{tt} physics.

ttbar: spin correlations at NLO

[Bernreuther, Brandenburg,Si,Uwer, 2006]

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta_+ d\cos\theta_-} = \frac{1}{4}\left(1 + \kappa_t \kappa_{\bar{t}} D \cos\theta_- \cos\theta_+\right)$$

$$D = \frac{N(\uparrow\uparrow) + N(\downarrow\downarrow) - N(\uparrow\downarrow) - N(\downarrow\uparrow)}{N(\uparrow\uparrow) + N(\downarrow\downarrow) + N(\uparrow\downarrow) + N(\downarrow\uparrow)}$$



$C_x = k_t\, k_t\;\; D$		L–L	L–J	J–J
Tevatron				
C_{hel}	LO	–0.471	–0.240	–0.123
	NLO	–0.352	–0.168	–0.080
C_{beam}	LO	0.928	0.474	0.242
	NLO	0.777	0.370	0.176
C_{off}	LO	0.937	0.478	0.244
	NLO	0.782	0.372	0.177
LHC				
C_{hel}	LO	0.319	0.163	0.083
	NLO	0.326	0.158	0.076

NLO corrections are very small!

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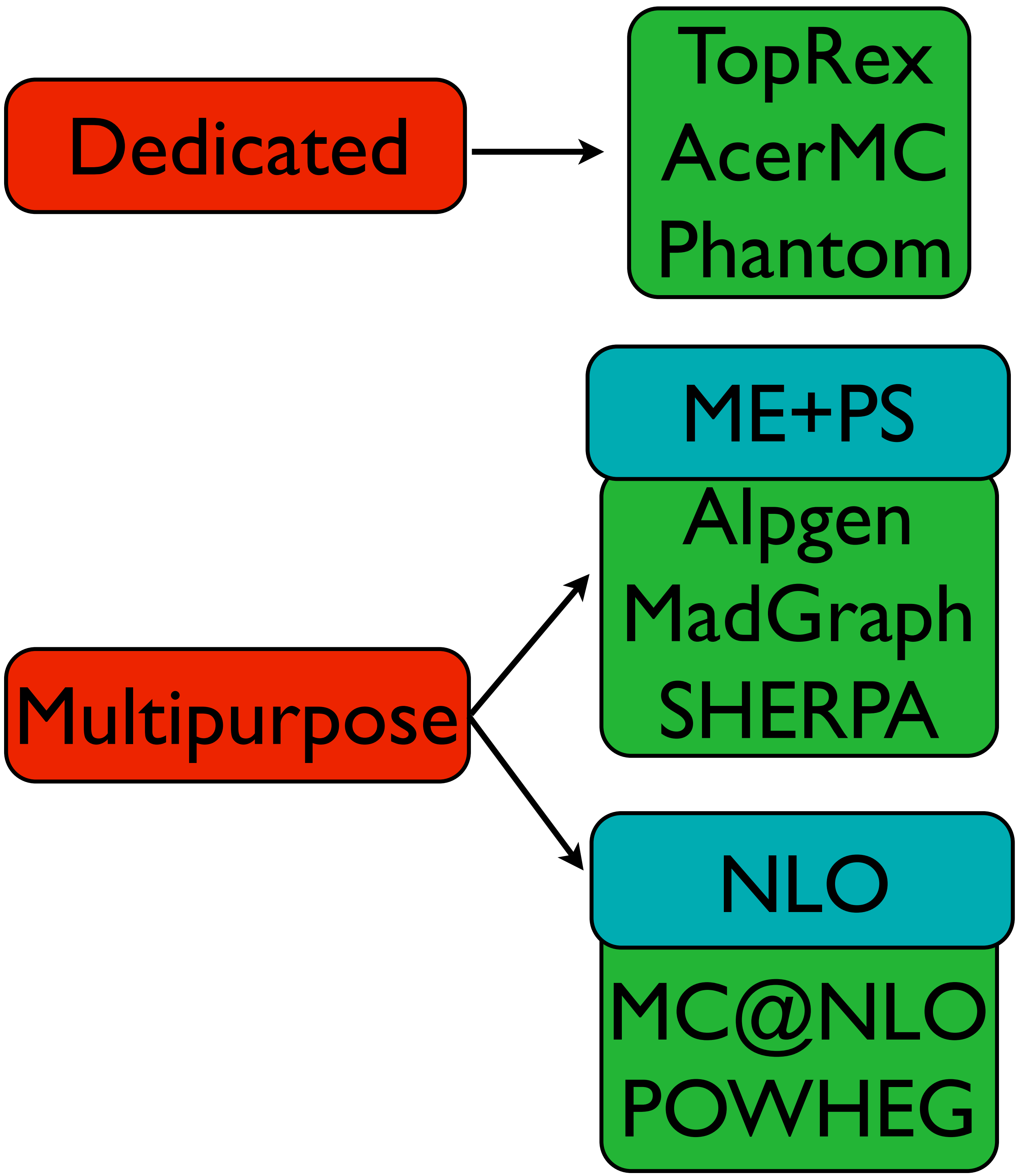
MC tools for SM and BSM top physics



Optimized for a few processes. Limited capabilities but optimal for specific studies. E.g. pp>tt>6f studies.

New generation of multipurpose MC's, matrix element based. Calculations are automatic at tree level. Matching is performed with the parton shower to produce inclusive multi-jet samples. Most codes are also suitable for BSM physics.

Combine NLO accuracy in normalization and shapes of hard radiation with parton shower. "Best" tools when NLO calculation is available (i.e. low jet multiplicity). Current limitation is manual work => small libraries. Only SM.

ME/PS matching

ME

1. parton-level description
2. fixed order calculation
3. quantum interference exact
4. valid when partons are hard and well separated
5. needed for multi-jet description

Shower MC

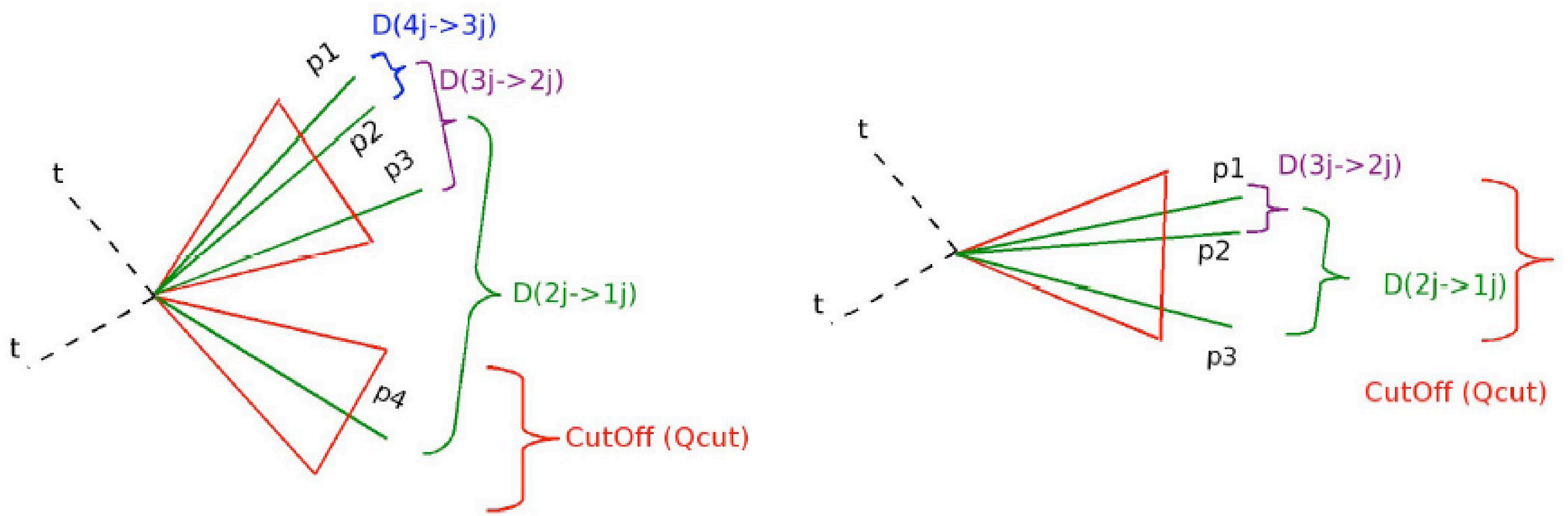
1. hadron-level description
2. resums large logs
3. quantum interference through AA
4. valid when partons are collinear and/or soft
5. nedeed for realistic studies

Approaches are complementary!

But double-counting has to be avoided!

Sanity checks: differential jet rates

Between low-Q^2 and high-Q^2 physics descriptions, transition has to me smooth and independant of $Qcut$ choice! Use differential jet rate to check this!
Def: D(N j$-$ >N-1 j):While clustering partons, maximum distance at which an event switch from a N-jet to a N-1 jet configuration.



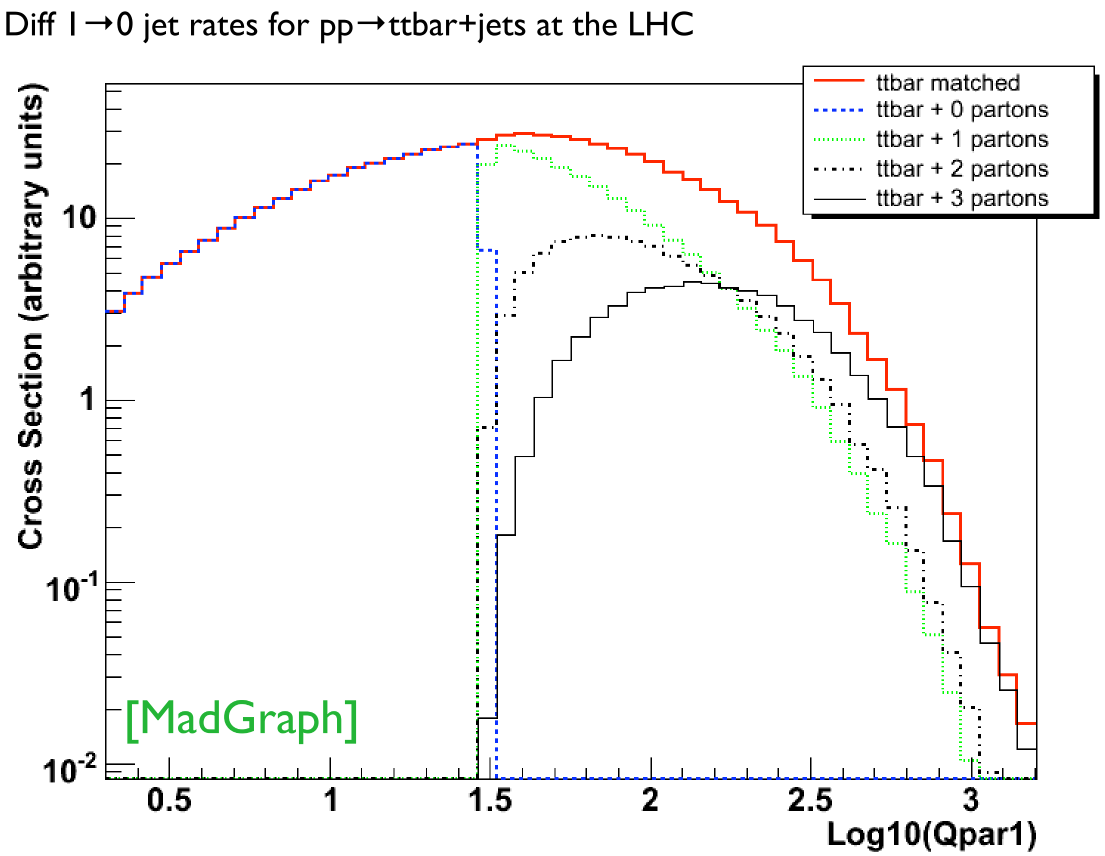
[Simon de Visscher]

Illustration of a $t\bar{t}+2$ ME partons after (very simplified) showering.
D(2 jets $\rightarrow$ 1 jets)> $Qcut$: **link partons with distance typical of ME-level generation**

Illustration of a $t\bar{t}+1$ ME partons after (very simplified) showering.
D(2 jets $\rightarrow$ 1 jets)< $Qcut$: **link partons with distance typical of PS-level generation**

Sanity checks: differential jet rates

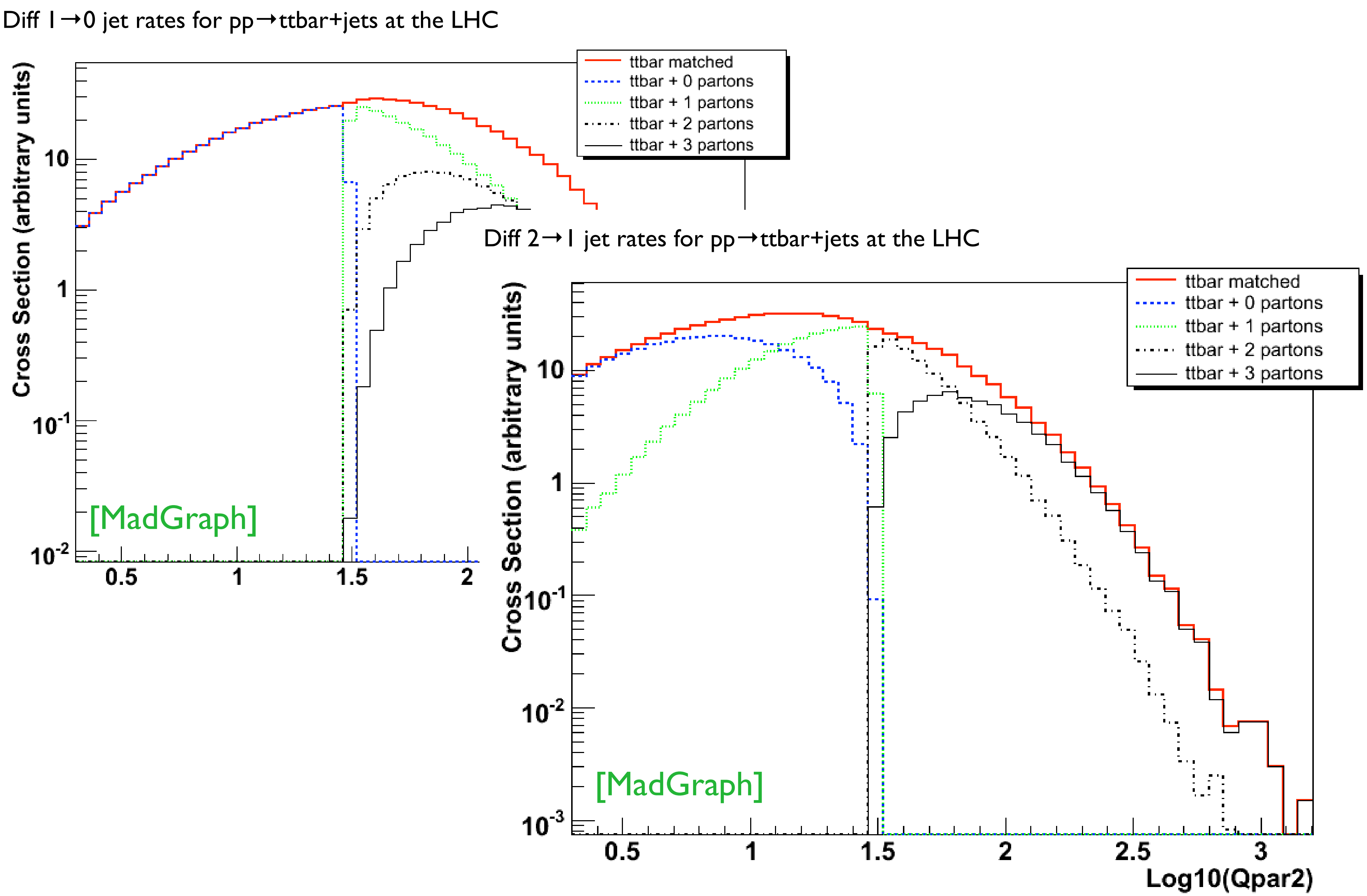
[J. Alwall et al. (MadGraph Coll.)]



Jet rates should be:

* smooth at the cutoff scale
* independent of the cutoff scale

Sanity checks: differential jet rates



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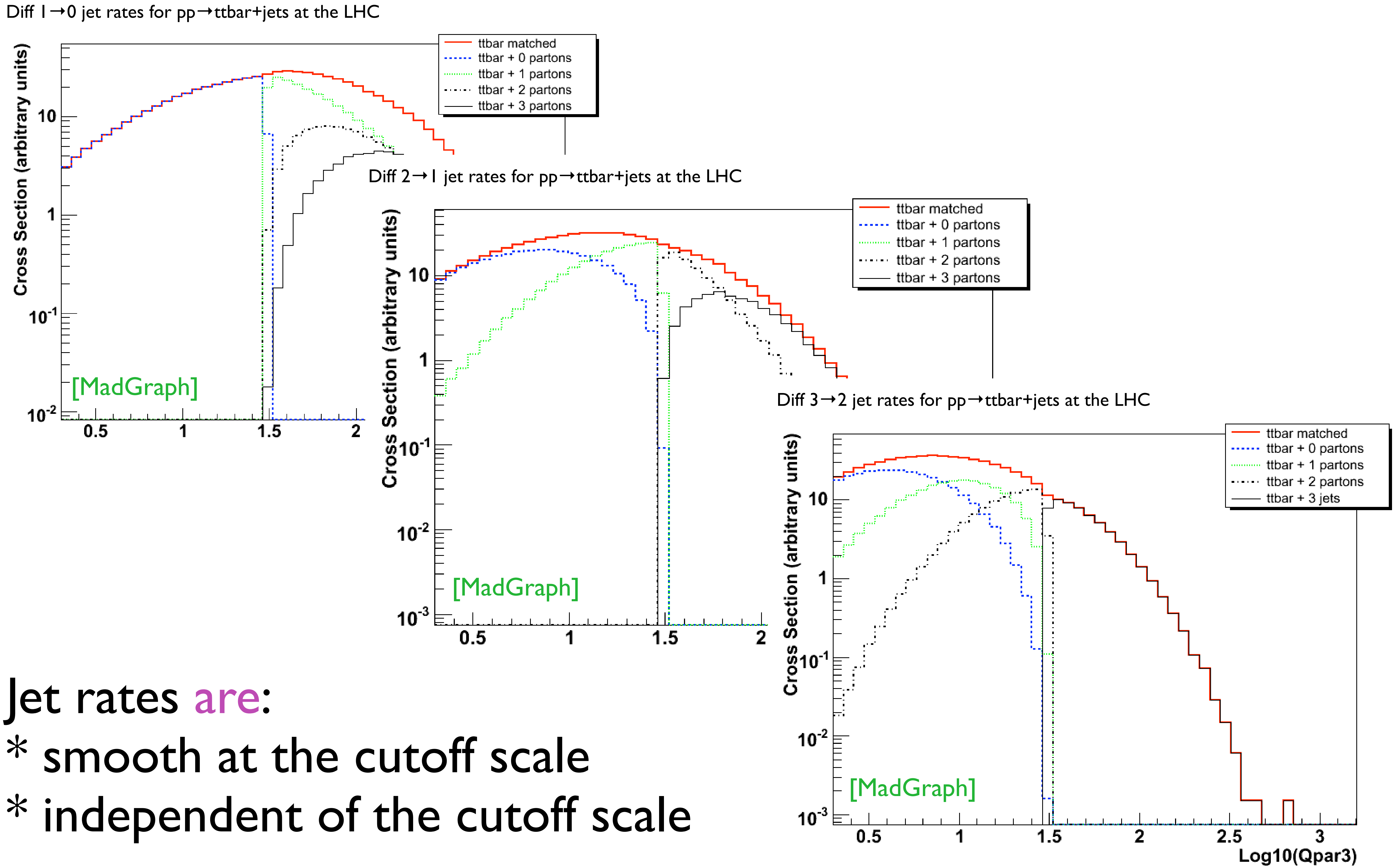


Jet rates are:

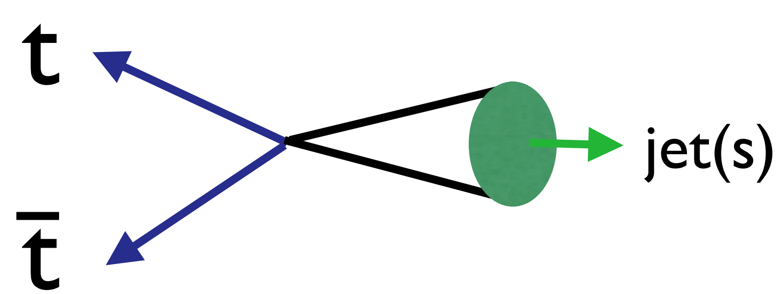
* smooth at the cutoff scale
* independent of the cutoff scale

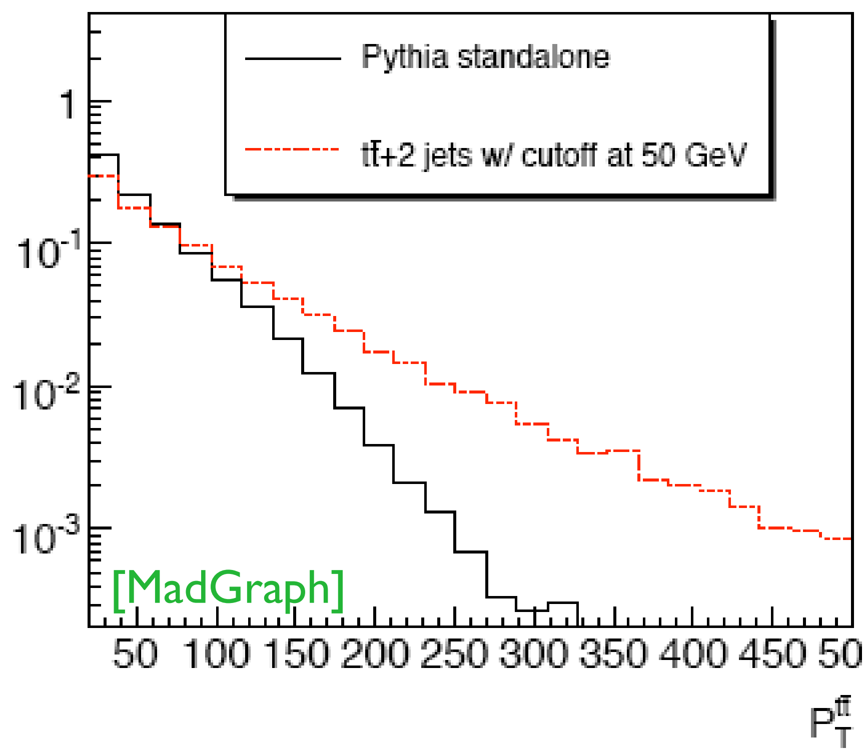
PS alone vs matched samples

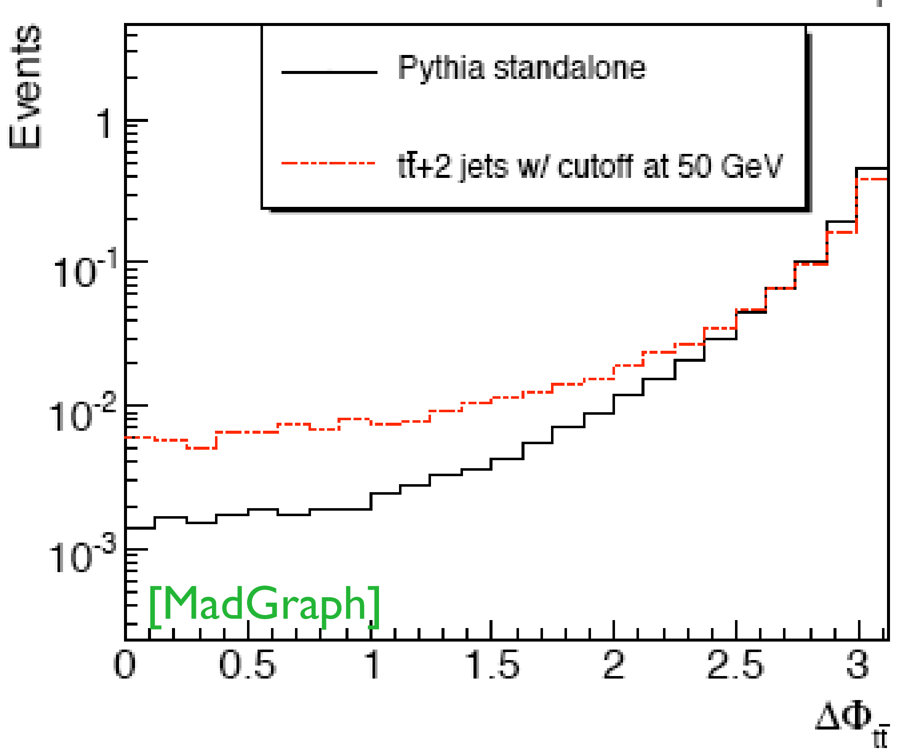
Comparison of key kinematical distributions of extra radiation between:

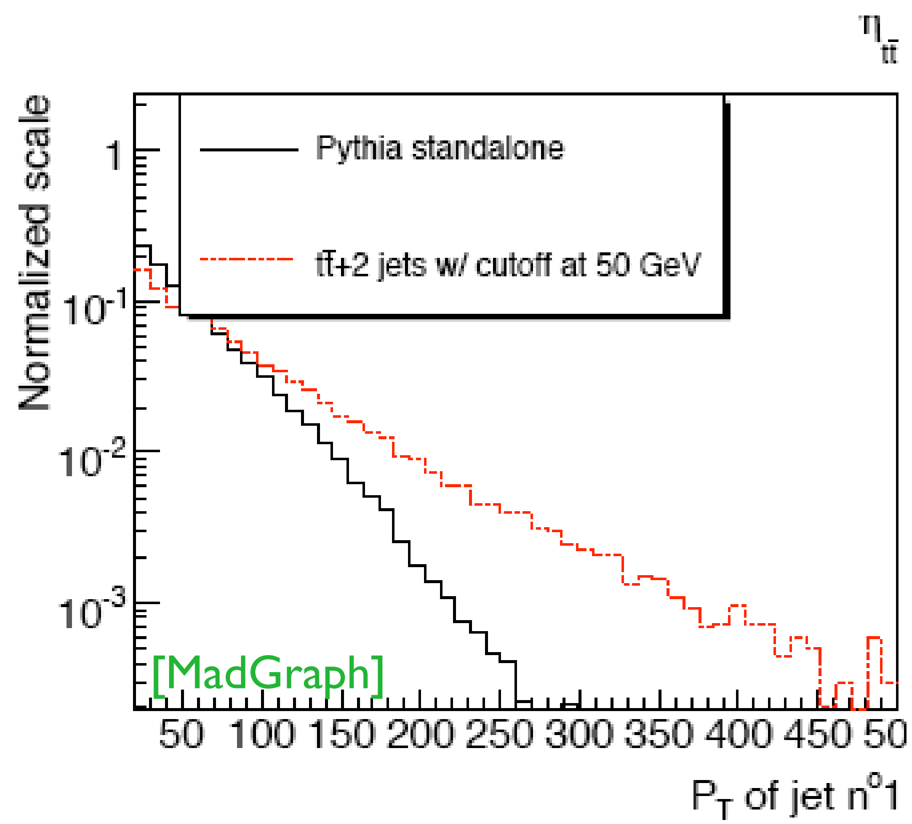
* t tbar + shower (Pythia)

* matched sample of t tbar + 0,1,2 partons with Qcut=50 GeV



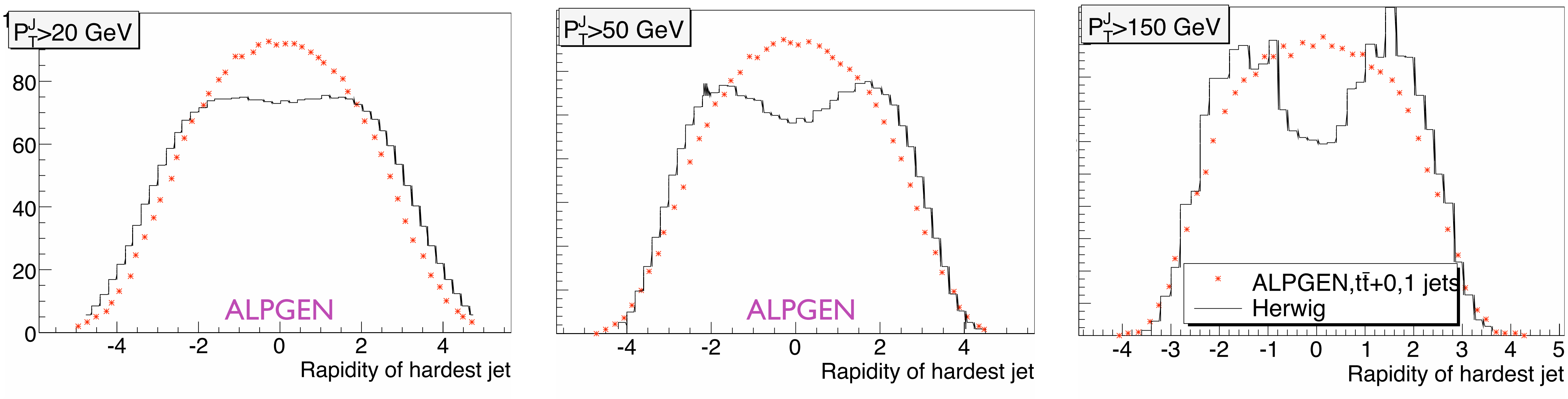




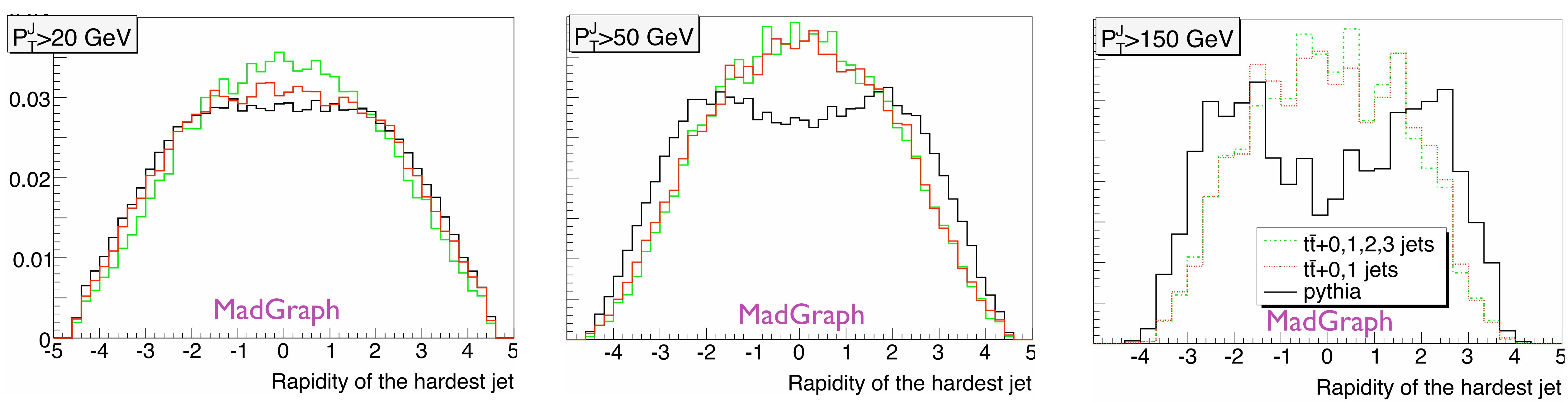


Comparisons: 1st jet rapidity

[Mangano, Moretti, Piccinini, Treccani, 2007]

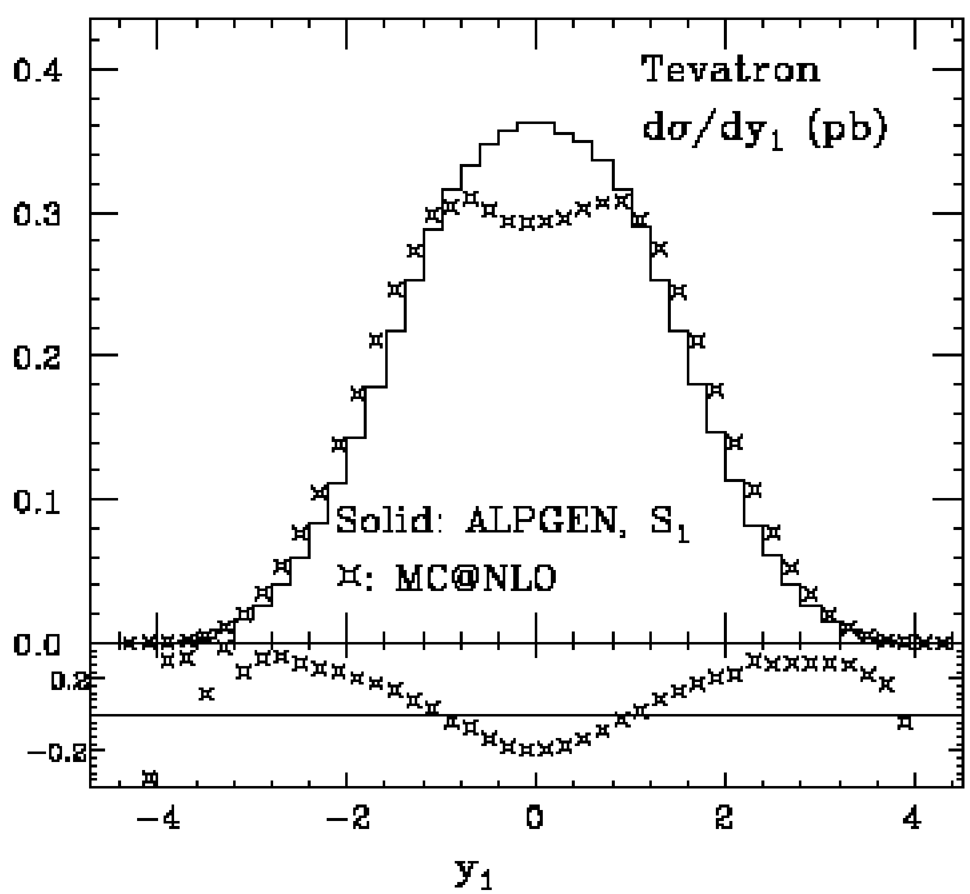


[J. Alwall,et al. (Madgraph Coll.)]



What about MC at NLO approeches?

Comparisons: 1st jet rapidity



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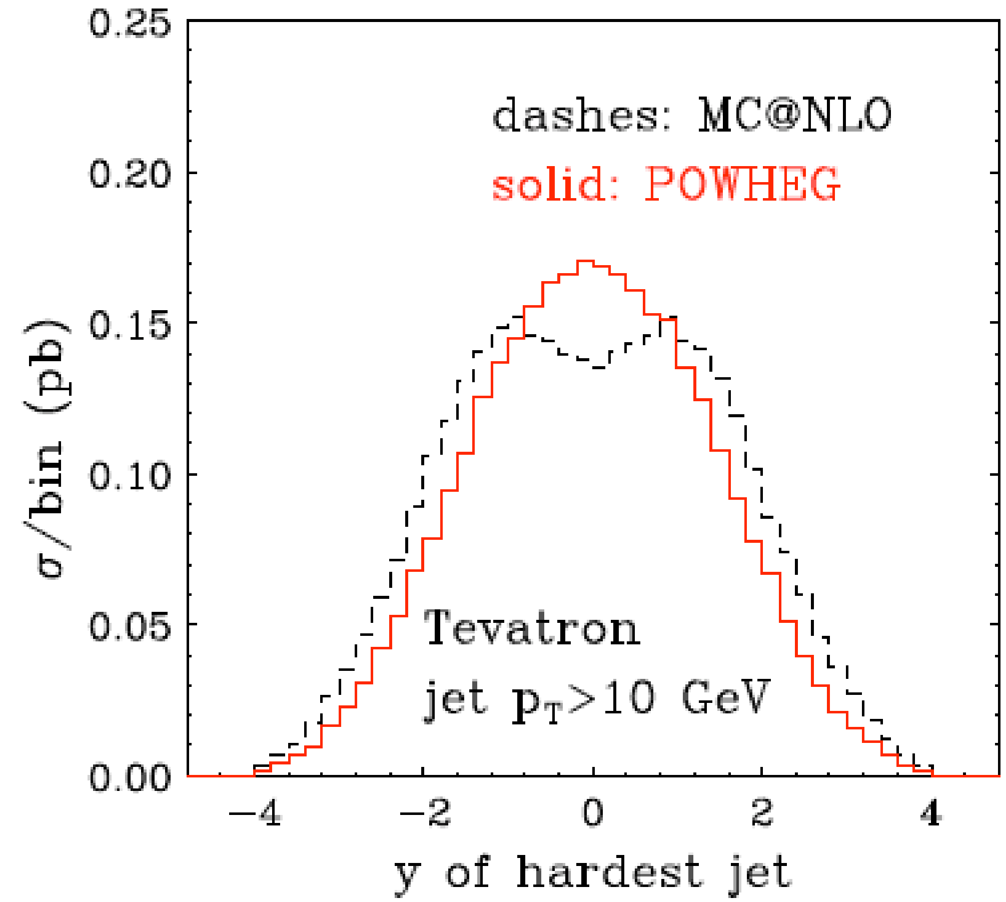

[Frixione, Nason, Ridolfi 2007]

It seems that indeed both Pythia and Herwig develop a deep in the central rapidity region for high-pt jets, which is filled by ME+PS. Hard radiation in MC@NLO is not able to fill it, while POWHEG as a similar behaviour as ME+PS. It will be interesting to see what tt+1jet at NLO predicts...

Still a lot to learn by comparing different approaches!

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Preliminary observation

- For new physics associated to top, two approaches are possible:
  - top-down (e.g. , model parameter scanning)
  - bottom-up (e.g., inverse problem, OSET)
- Different strategies lead to different MC tools.
- Some of the MC tools of the new generation (e.g. MadGraph and SHERPA) allow to tackle both by featuring:

1. Main templates for BSM models available (MSSM, 2HDM, UED,...)
2. Easy implementation of new models (from Feynman rules)
3. Any tree-level process available* (automatic code creation).
4. Multi-jets samples with matching for QCD background (and possibly BSM signals).

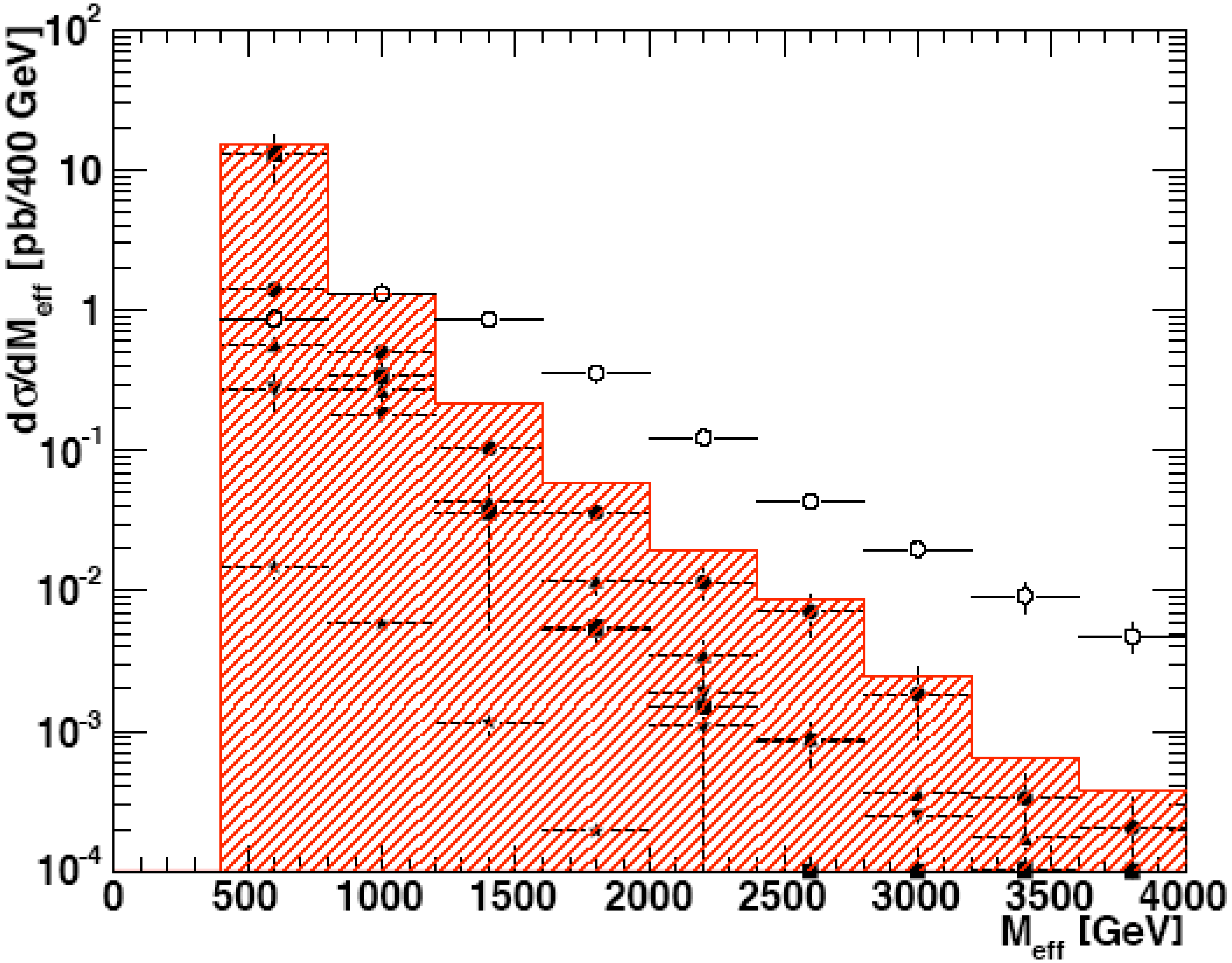
*within reason.

SUSY example

[Kraml, Raklev, 2006]

$$\tilde{g}\tilde{g} \to t\bar{t}\tilde{t}_1\tilde{t}_1^*, tt\tilde{t}_1^*\tilde{t}_1^*, \bar{t}\bar{t}\tilde{t}_1\tilde{t}_1 \qquad m_{\tilde{t}_1} < m_t$$

$$pp \to \tilde{g}\tilde{g} \to bbl^\pm l^\pm + \text{jets} + E^T_{\text{miss}} \qquad \tilde{t} \to c\tilde{\chi}^0_1$$



Same-sign top quarks as a signature of light stops.

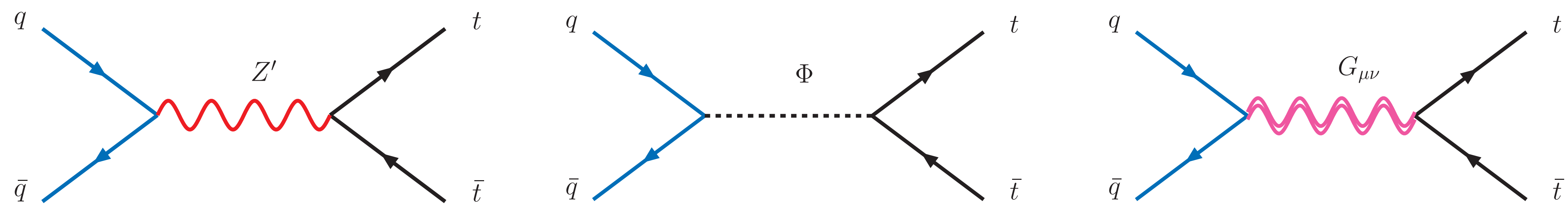
Typical SUSY inclusive signature: need for a very good control of the SM backgrounds (here Pythia).

The whole analysis can be now performed within one MC including matched samples for the backgrounds.

New resonances

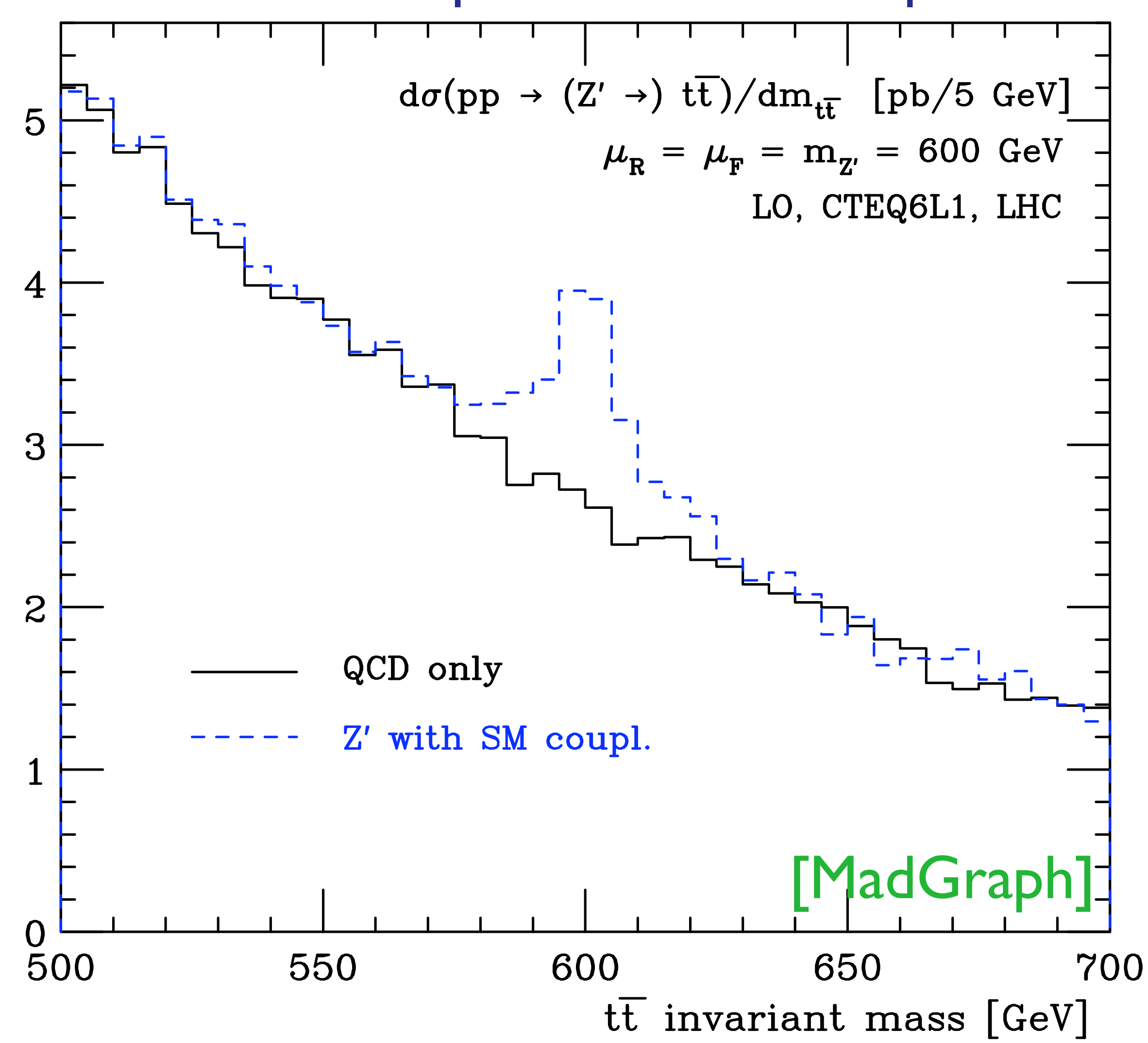
[Alwall, Frederix, FM]

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.

In most cases, one expects a simple peak in the m_{tt} distribution, with no shape difference between different spin resonances.



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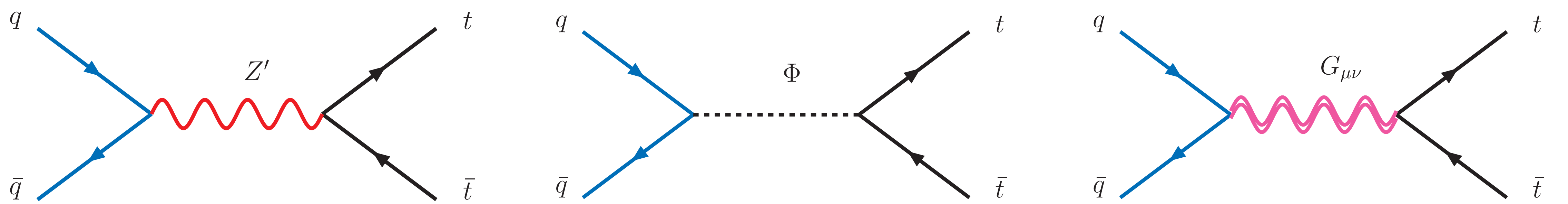
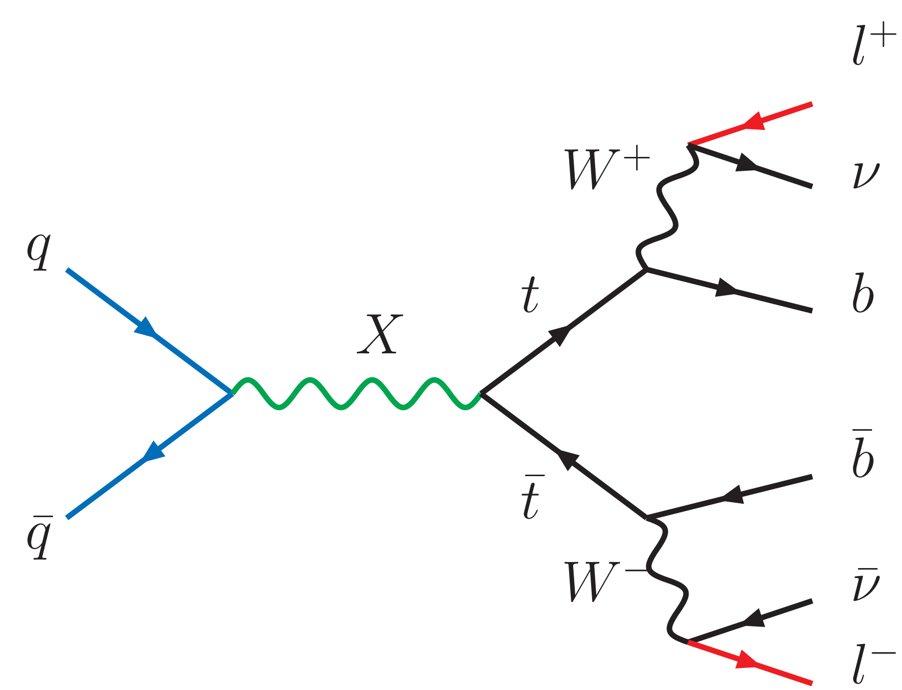


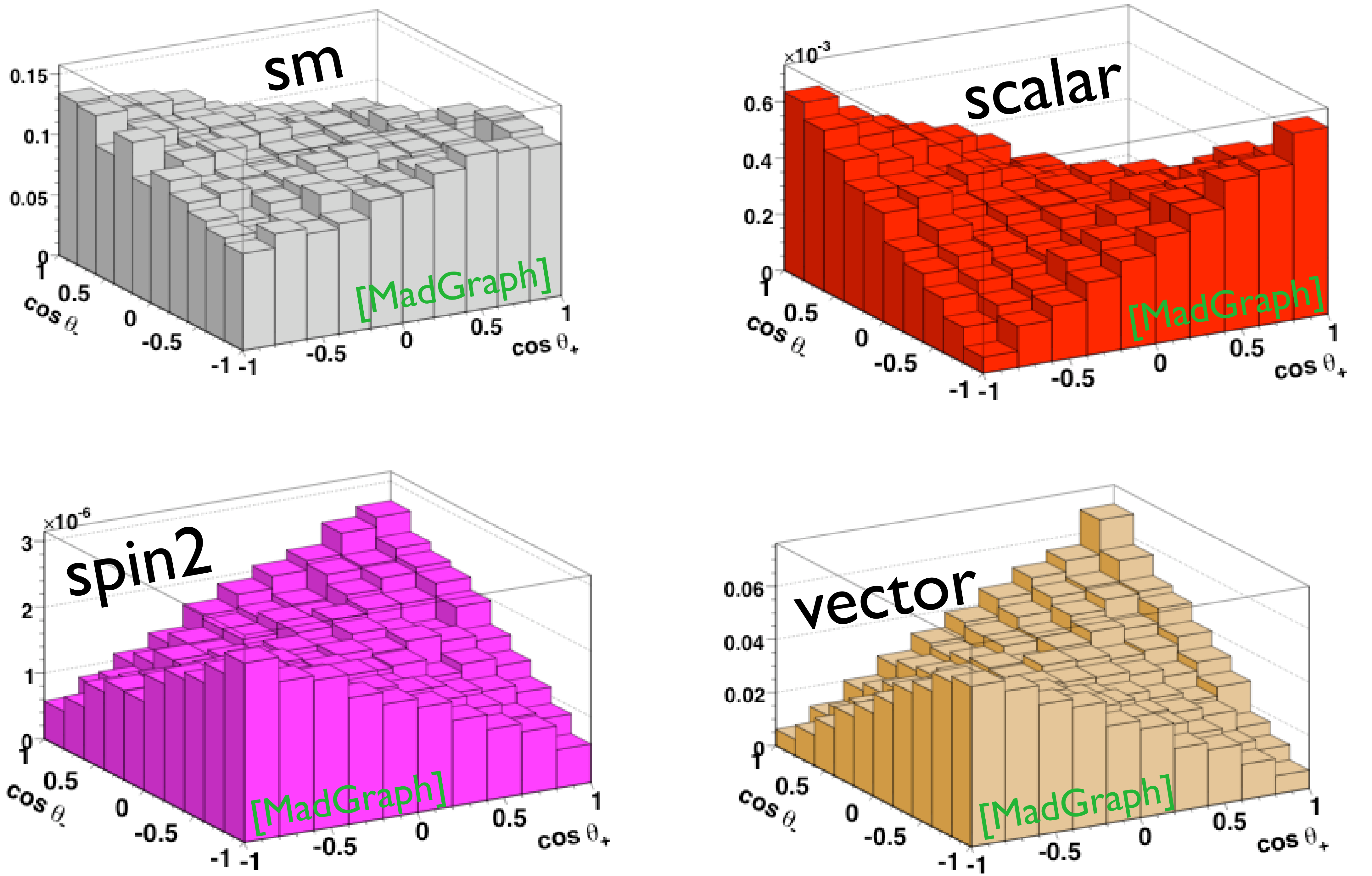
Given the large number of models, in this case is more efficient to adopt a "model independent" search and try to get as much information as possible on the quantum numbers and coupling of the resonance.

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

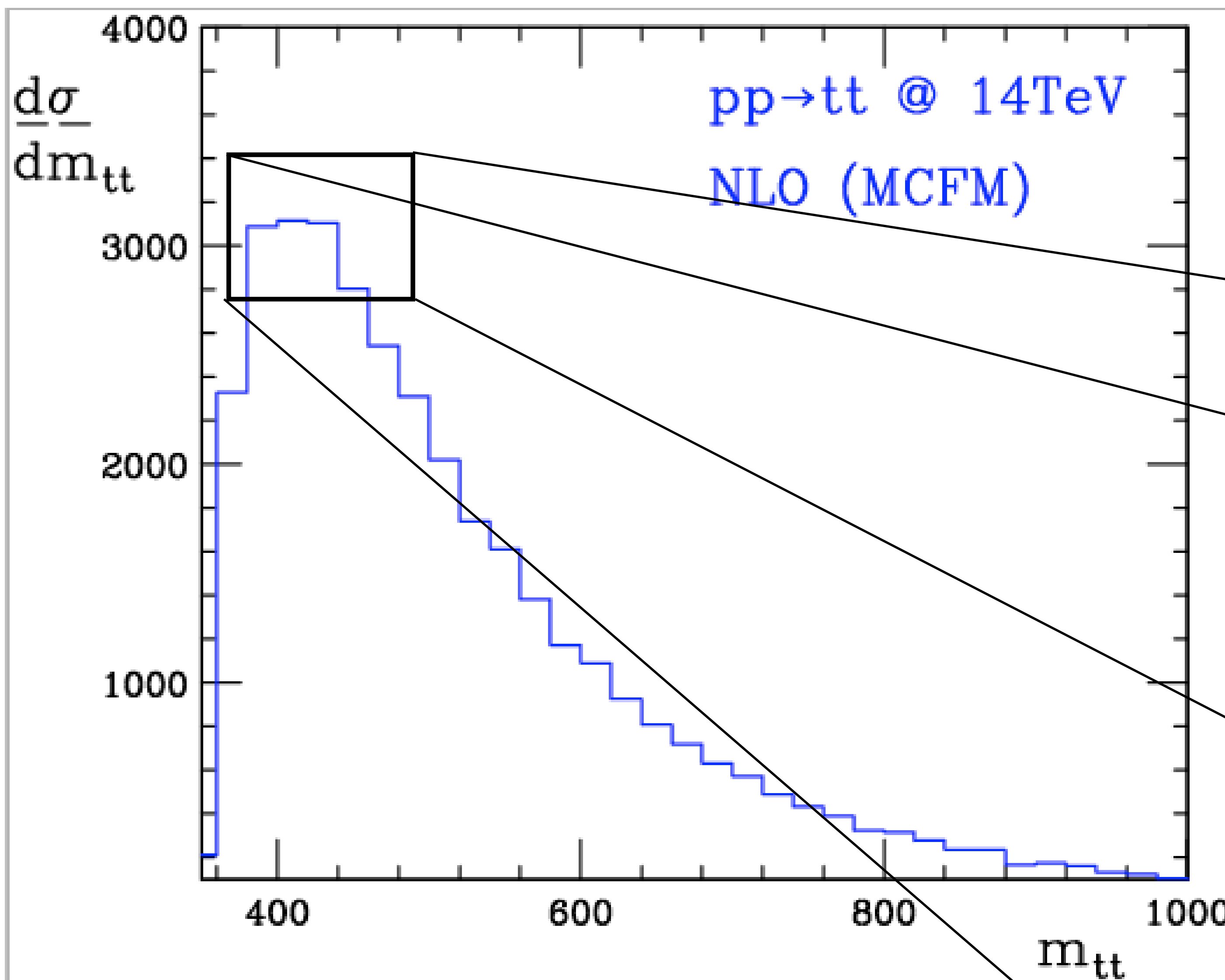
It therefore mandatory for such cases to have MC samples where spin correlations are kept and the full matrix element pp>X>tt>6f is used.

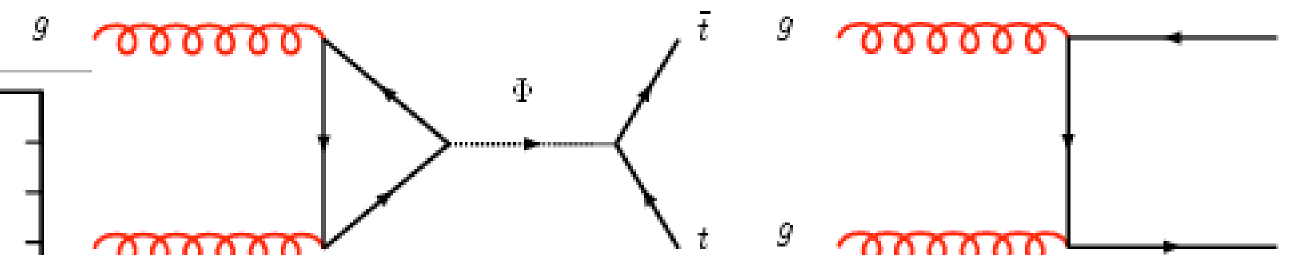


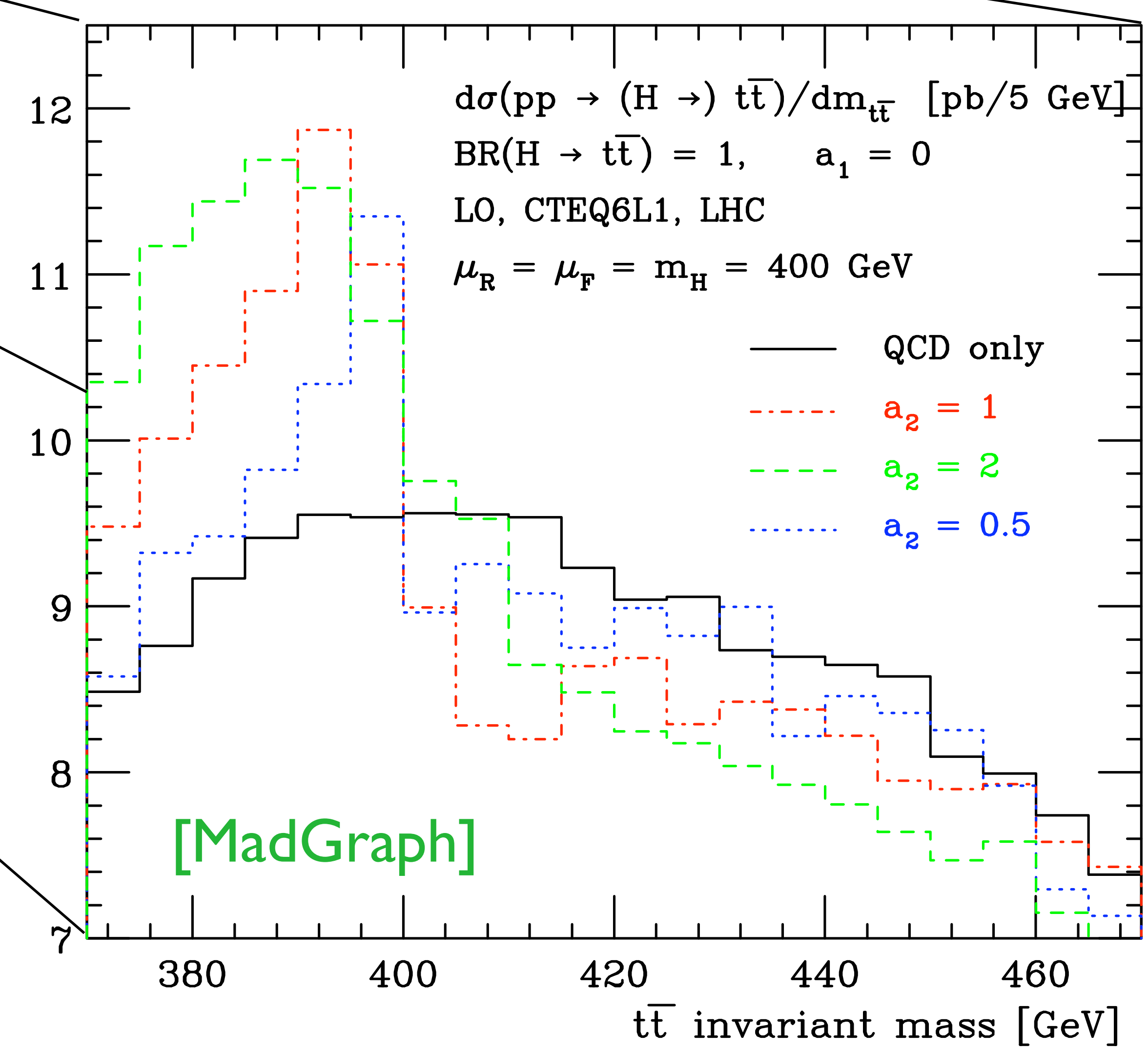
New resonances



New resonances: 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]

Conclusions

- Top is the best known probe of EWSB and fermion mass generation.
- At the LHC top will also be a serious source of backgrounds to New Physics searches.
- New MC tools are available that can provide an accurate description of both signals and backgrounds involving top:
  - ⋆ New parton-level NLO calculations available: ttbar and single top very well known.
  - ⋆ Impressive progress in fixed-order and parton-shower matching both at LO (inclusive tt+jets samples) and NLO (tt in MC@NLO and POWHEG). First systematics comparison available.
  - ⋆ Progress in the simulation of basically any new physics scenario's involving top (MSSM, new resonances, vector-like parterns, anomalous couplings,...)
- New and exciting possibilities of interaction between TH's and EXP's...