MonteCarlo's for Top Physics

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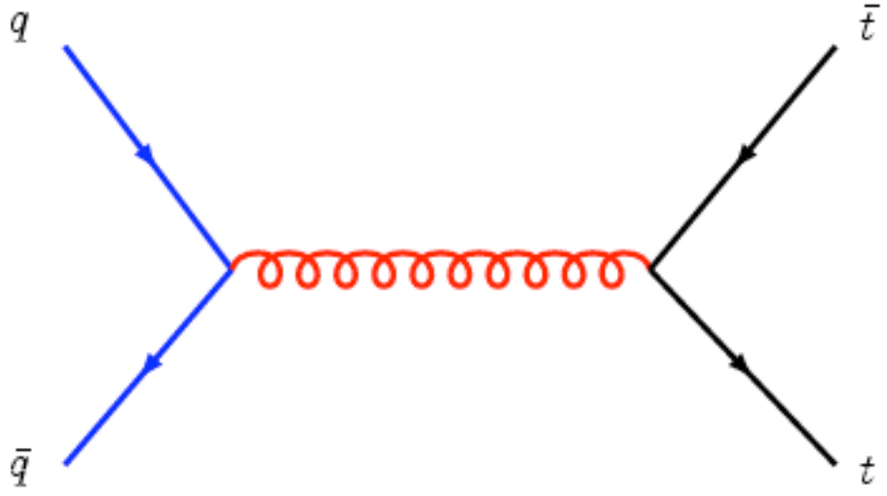
Outline

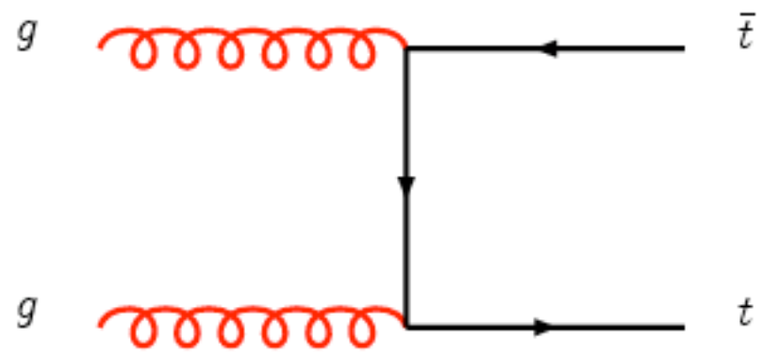
- From top physics to top MC needs
- Inclusive samples w/ matching ME+PS
- A quick look at BSM physics
- Conclusions

From Tevatron to LHC

Tevatron



LHC



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)

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},$\sigma(tt)$,$\sigma(t)$);
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^+....)

TH useful results on top production

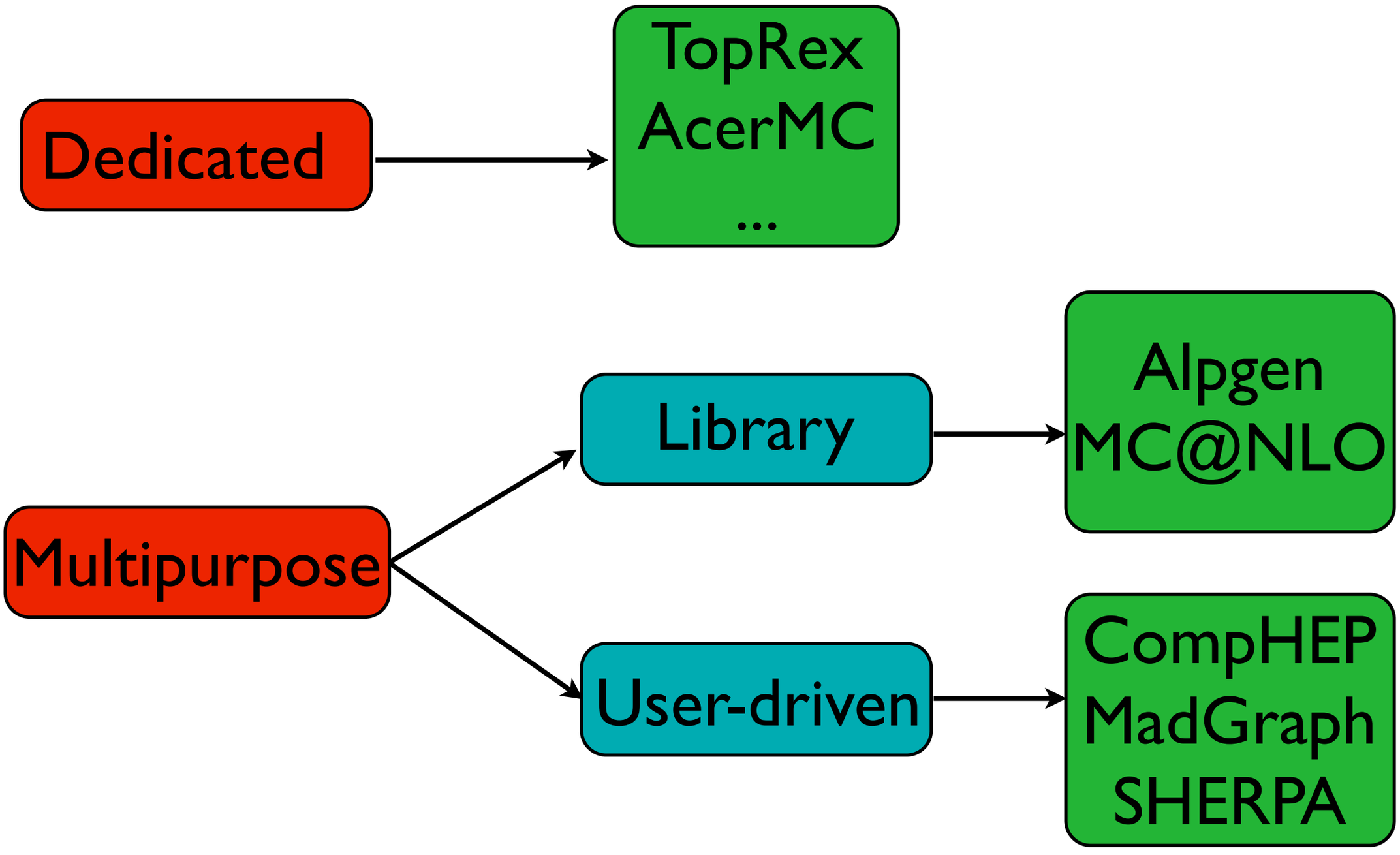
tt signal

- PDF's with systematic uncertainties — CTEQ, MRST, LHAPDF, Giele
- NLO+shower for tt and single top (MC@NLO) — Frixione, et al. 2005-07
- 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

tt as a background

- pp → (b f f') (b f f') : LO matrix element, including all (off-shell) diagrams — Kauer and Zeppenfeld, 2002
- tt+1jet at NLO — Dittmaier, Uwer, Weinzierl, 2007
- tt+jets: ME+Parton Shower — Alpgen; MadEvent; SHERPA...

MC tools for Top physics



MC tools for Top physics

Selected comments:

1. MC@NLO is the best TH tool for SM signal, (tt and single-top, with spin-correlated decays), but it is tied to HERWIG.

2. Alpgen has set the standard for inclusive matched samples tt+jets. Spin correlations are kept. Strictly SM.

3. MadGraph/MadEvent is now interfaced to CMSSW and can produce SM and "any" BSM signal and backgrounds including matched samples tt+jets with Pythia.

Some examples later...

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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

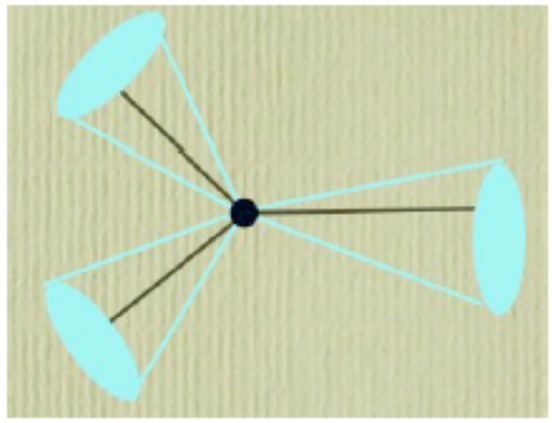
1. hadron-level description
2. resums large logs
3. quantum interference through AA
4. valid when partons are collinear and/or soft
5. nedeed for realistic studies

Approaches are complementary!

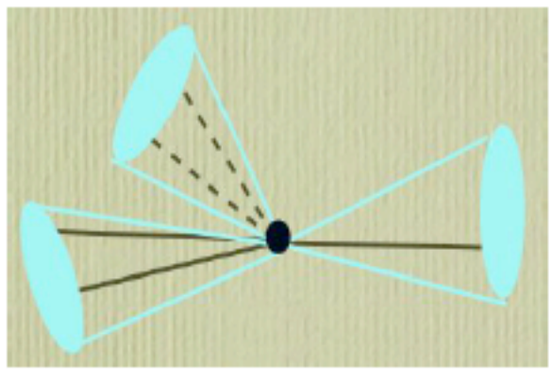
But double-counting has to be avoided!

The matching algorithm

Jet-parton matching

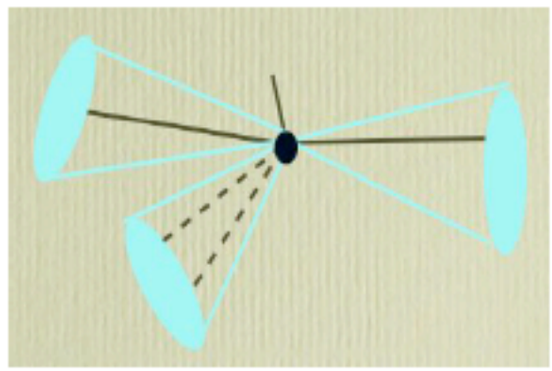


Event matched, $N_{\text{jet}} = N_{\text{part}} = 3$
– Keep event

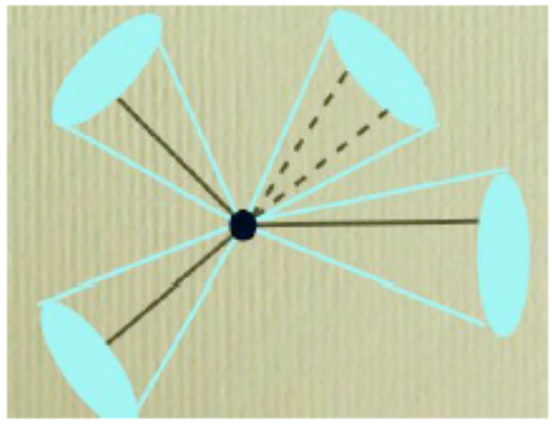


Not matched, $N_{\text{jet}} = N_{\text{part}} = 3$
but $N_{\text{matched}} = 2$ – throw away

Collinear double-log
double counting



Soft single-log double
counting

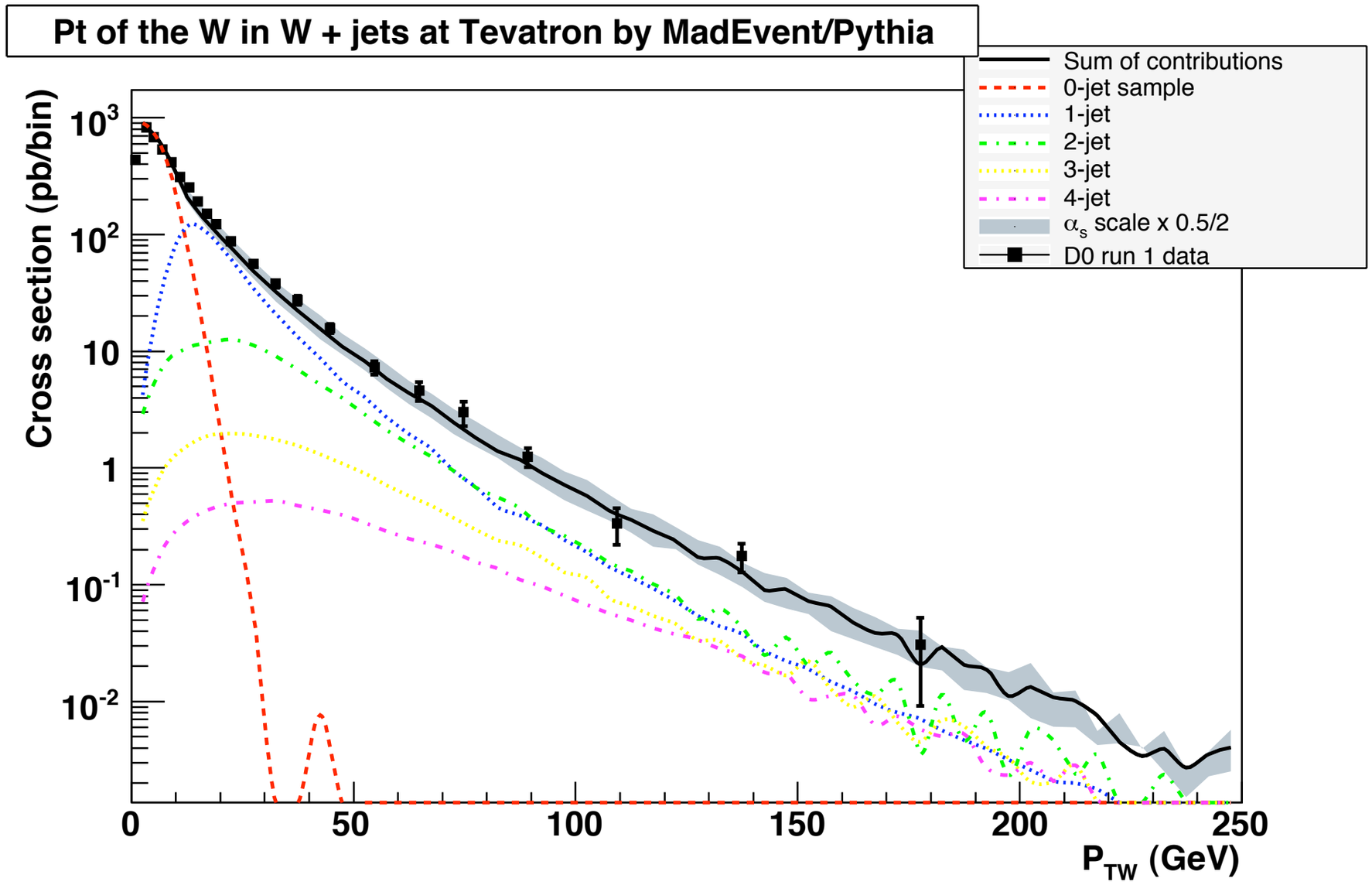


Event matched, but $N_{\text{jet}} > N_{\text{part}}$
– Keep for highest-multiplicity sample only

Solid lines = ME partons Broken lines = PS partons

W+ jets

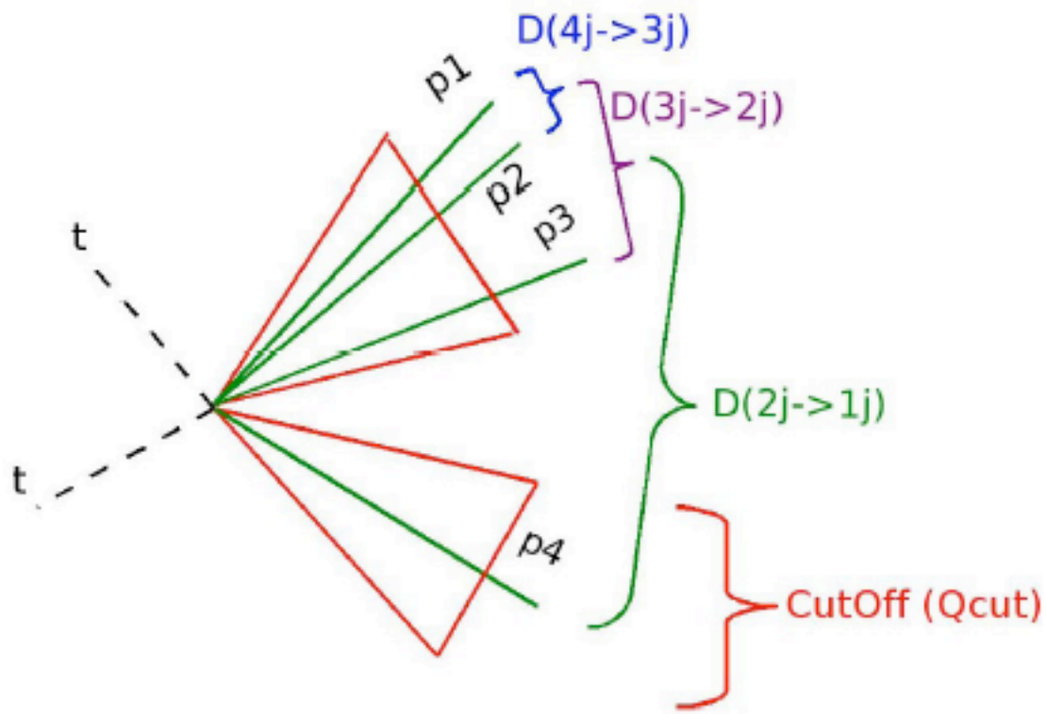
[J. Alwall]



1. The most inclusive observable.
2. All parton multiplicities contribute.
3. Excellent agreement with TeV data (validation)

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.



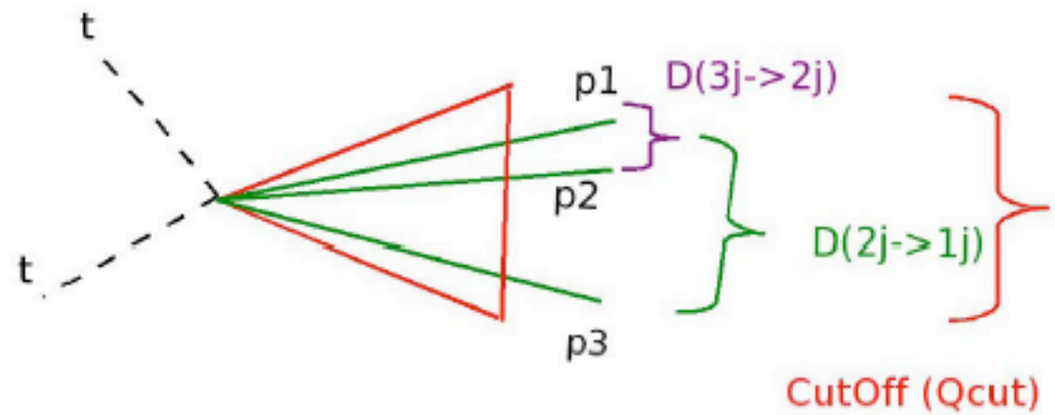
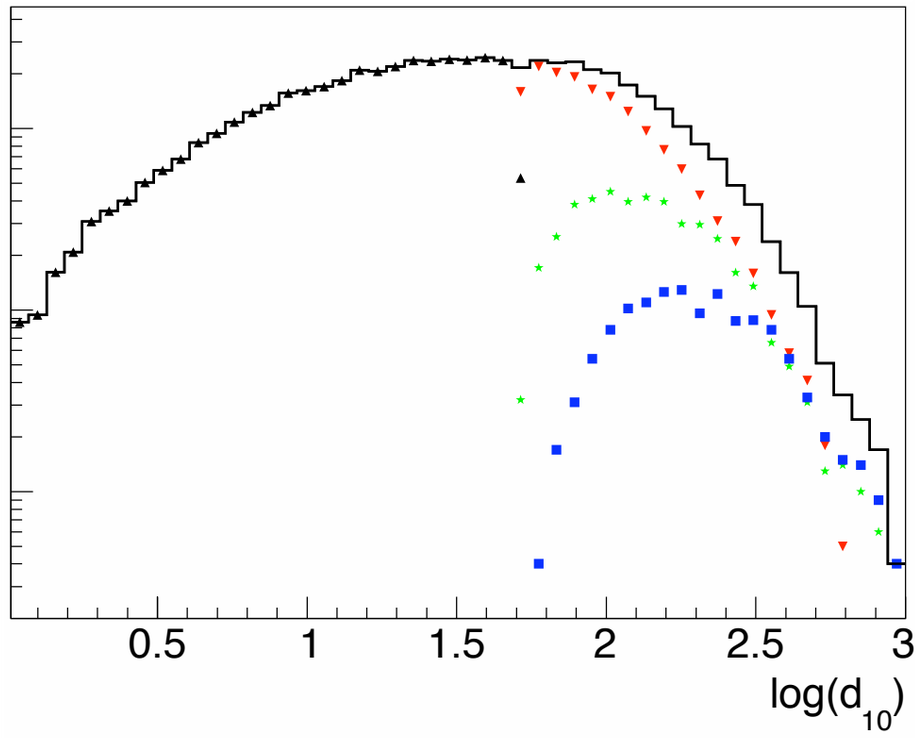


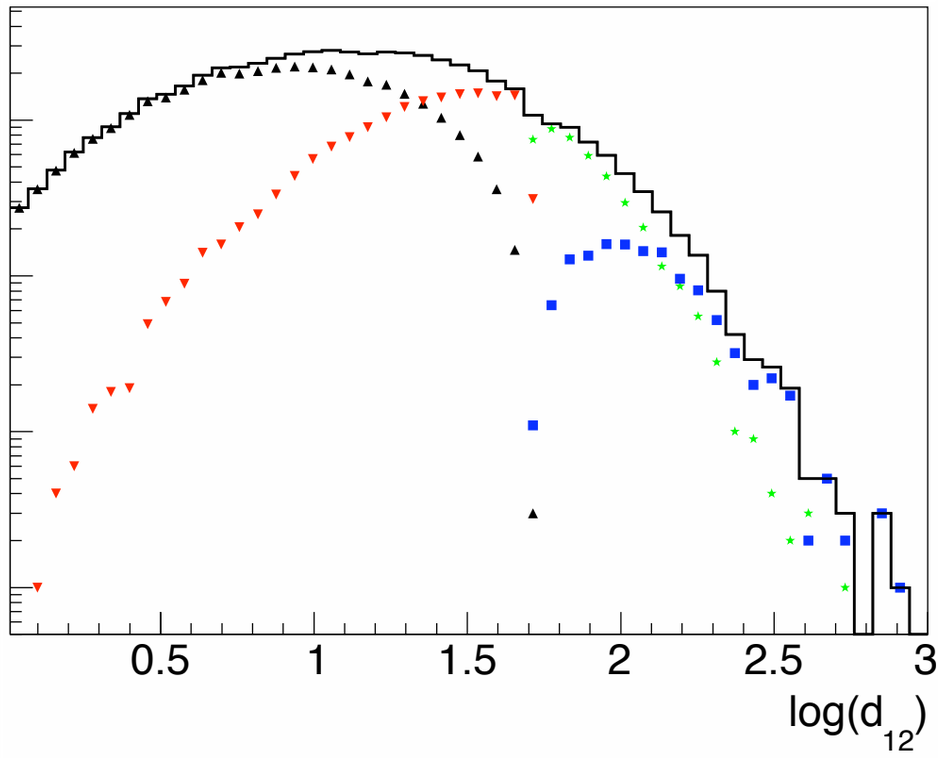
Illustration of a $t\bar{t}+2$ ME partons after (very simplified) showering.
D(2 jets $\rightarrow$ 1 jets)$>$ $Qcut$: **link partons with distance typical of ME-level generation**

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

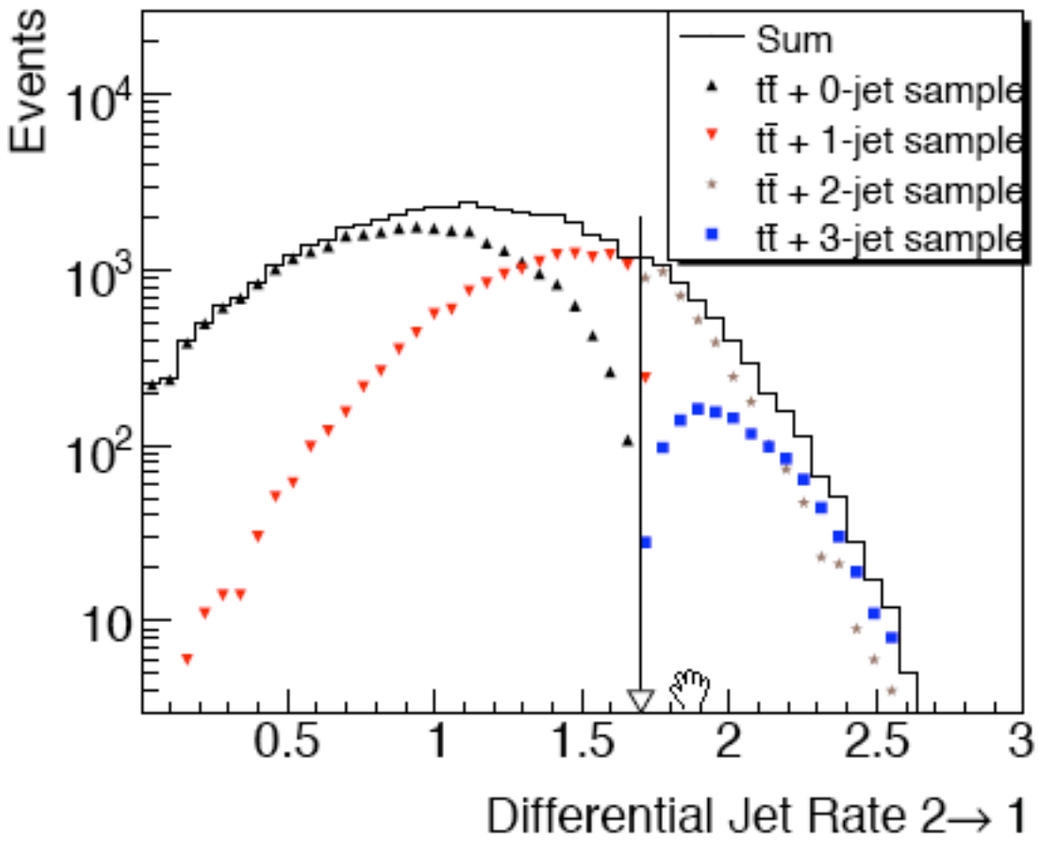
[J. Alwall, S. de Visscher]

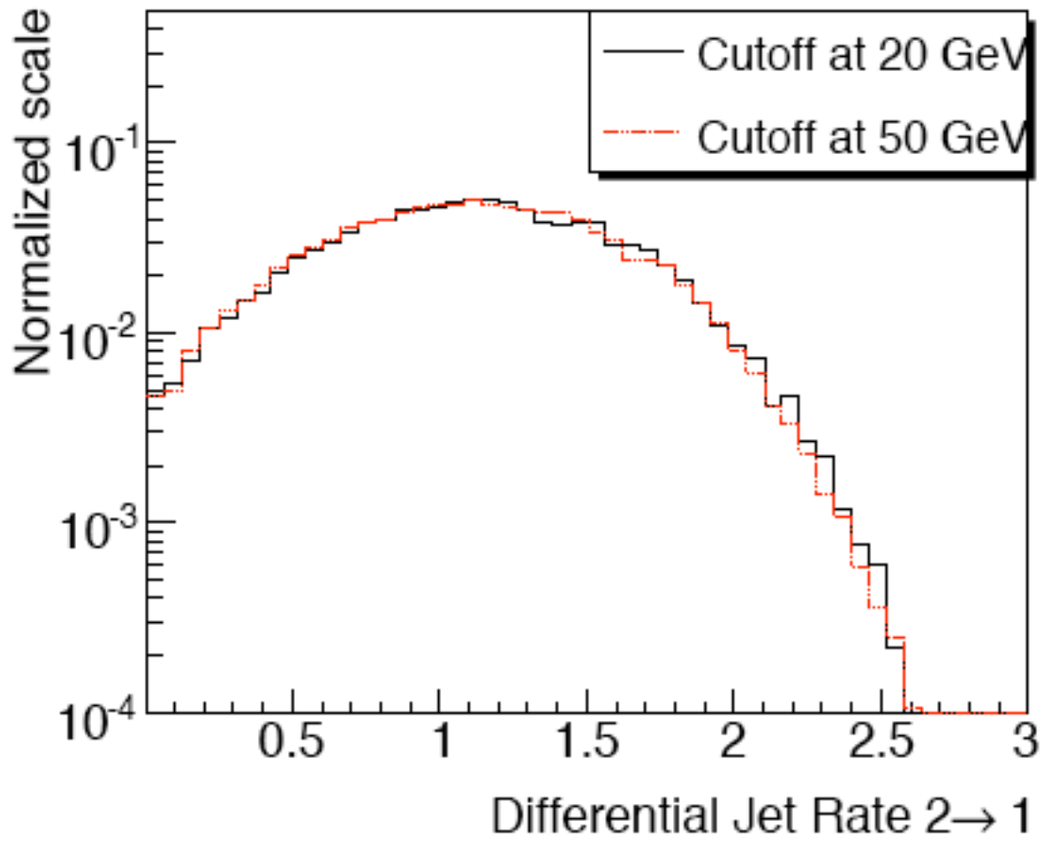




Jet rates are smooth at the cutoff scale

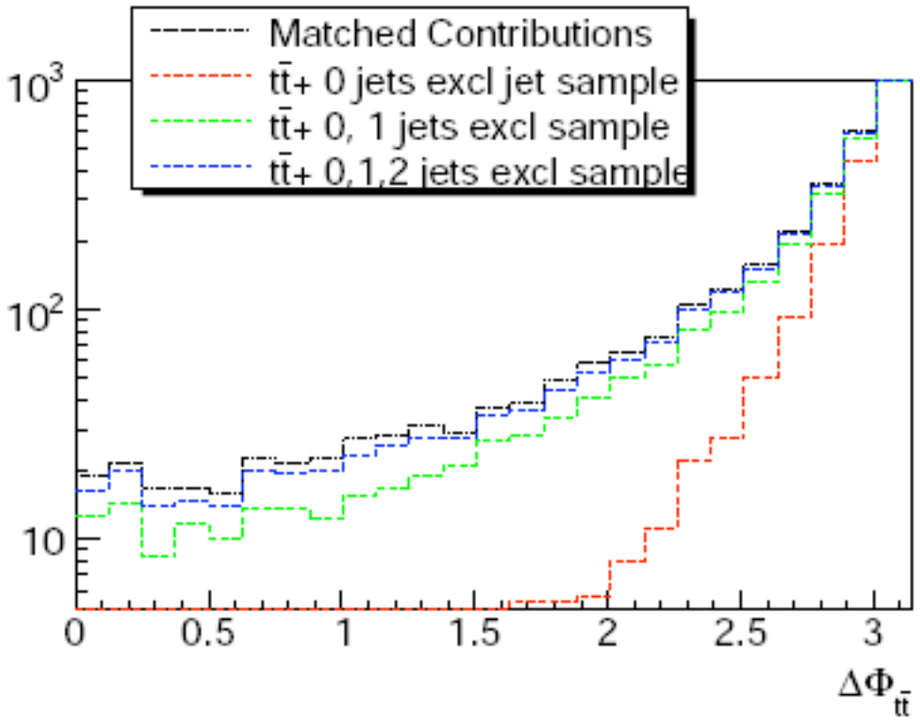
Sanity checks: differential jet rates



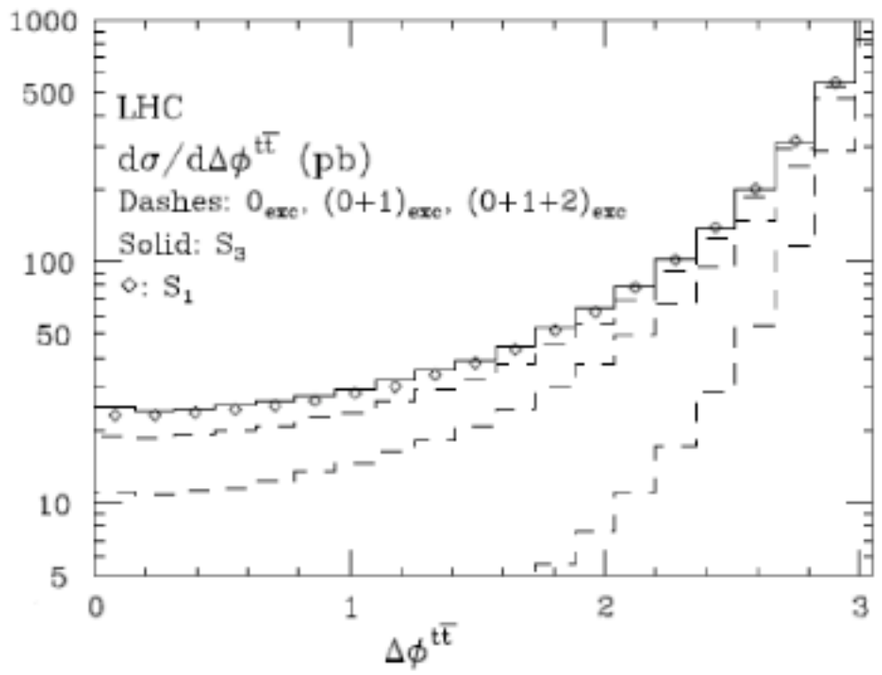


Jet rates are independent of the cutoff scale

Comparisons: ΔΦ(tt)

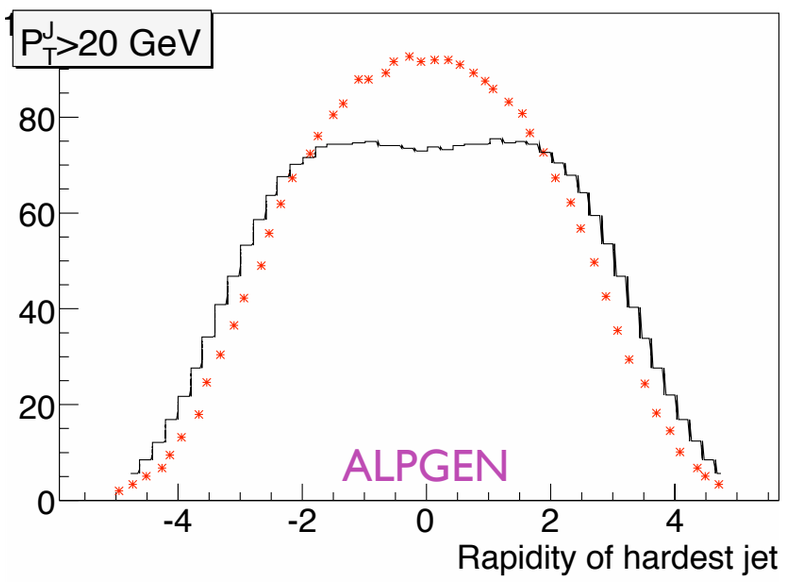


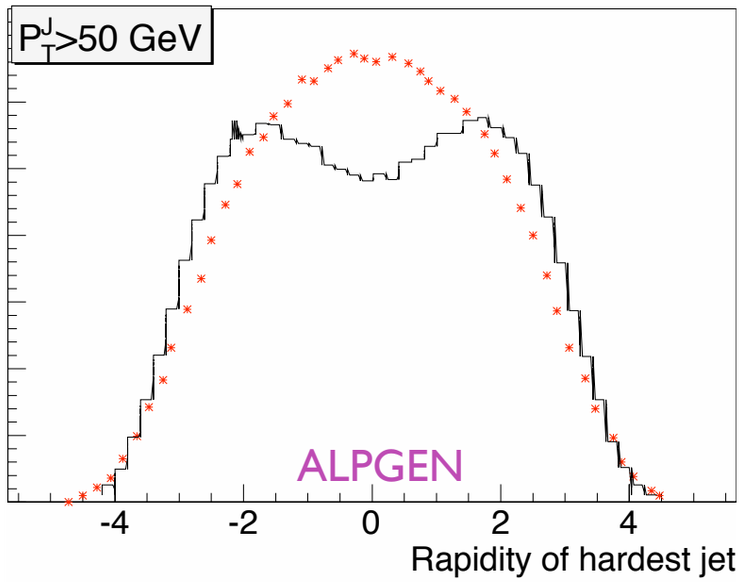
MG/ME with Modified MLM matching, using k_T clustering.

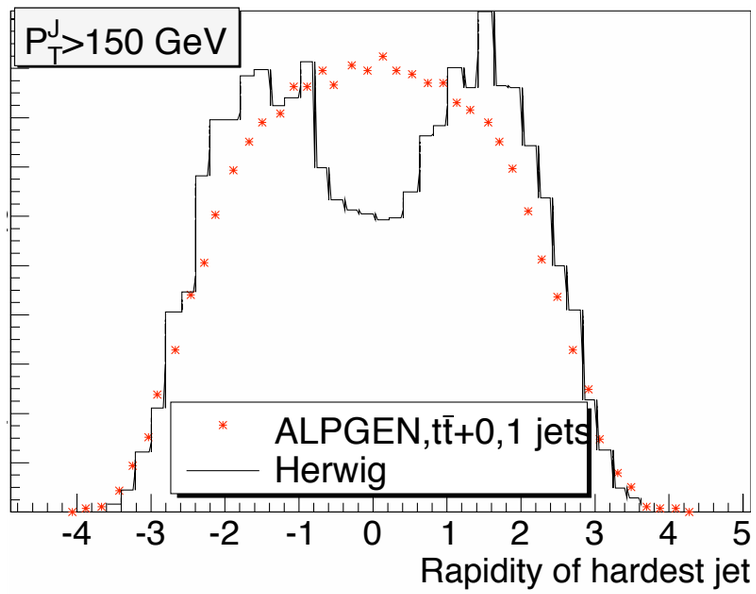


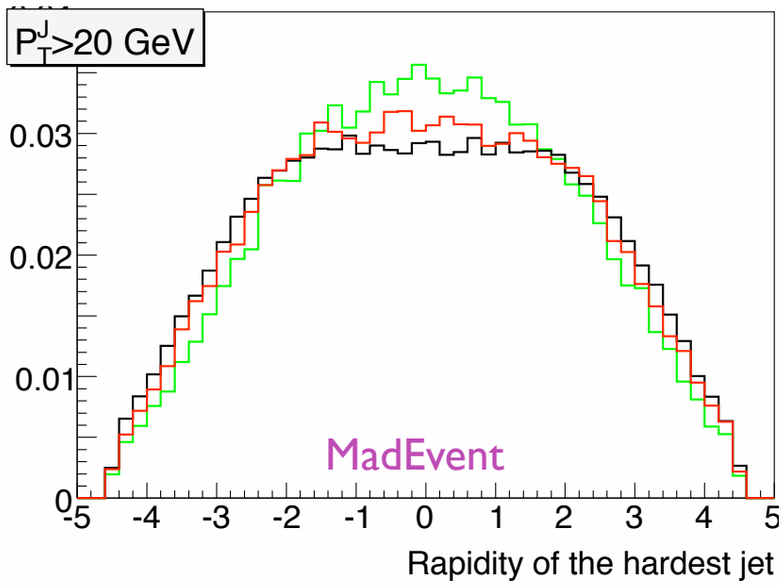
ALPGEN with MLM matching using cone algorithm. (Mangano et *al*: hep-ph/0611129)

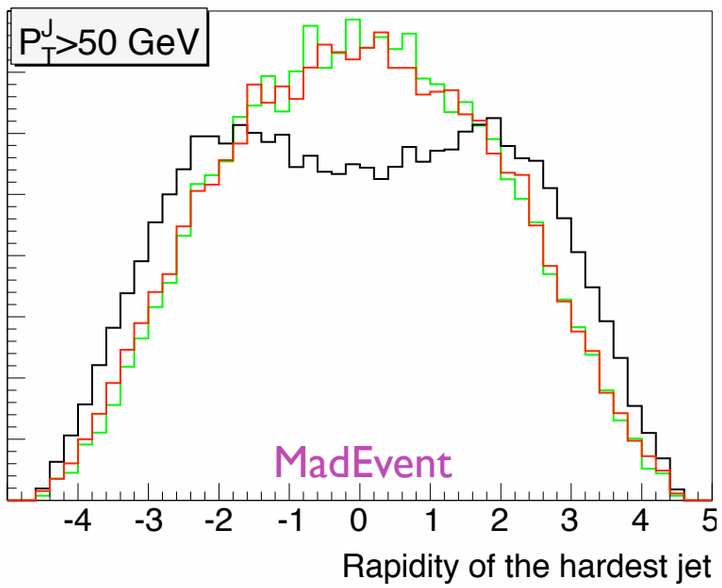
Comparisons: jet rapidity

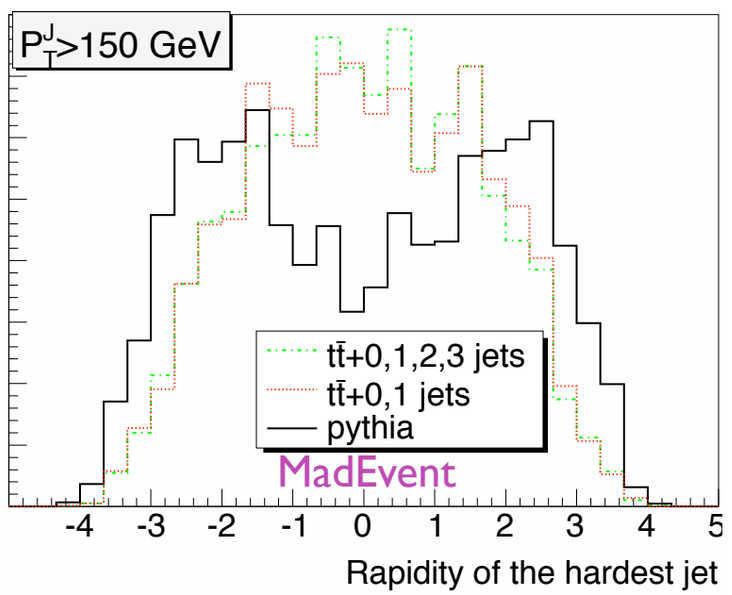












Both Pythia and Herwig seem to develop a (artificial?) deep in the central reapidity region for high-pt jets...

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Simple observation

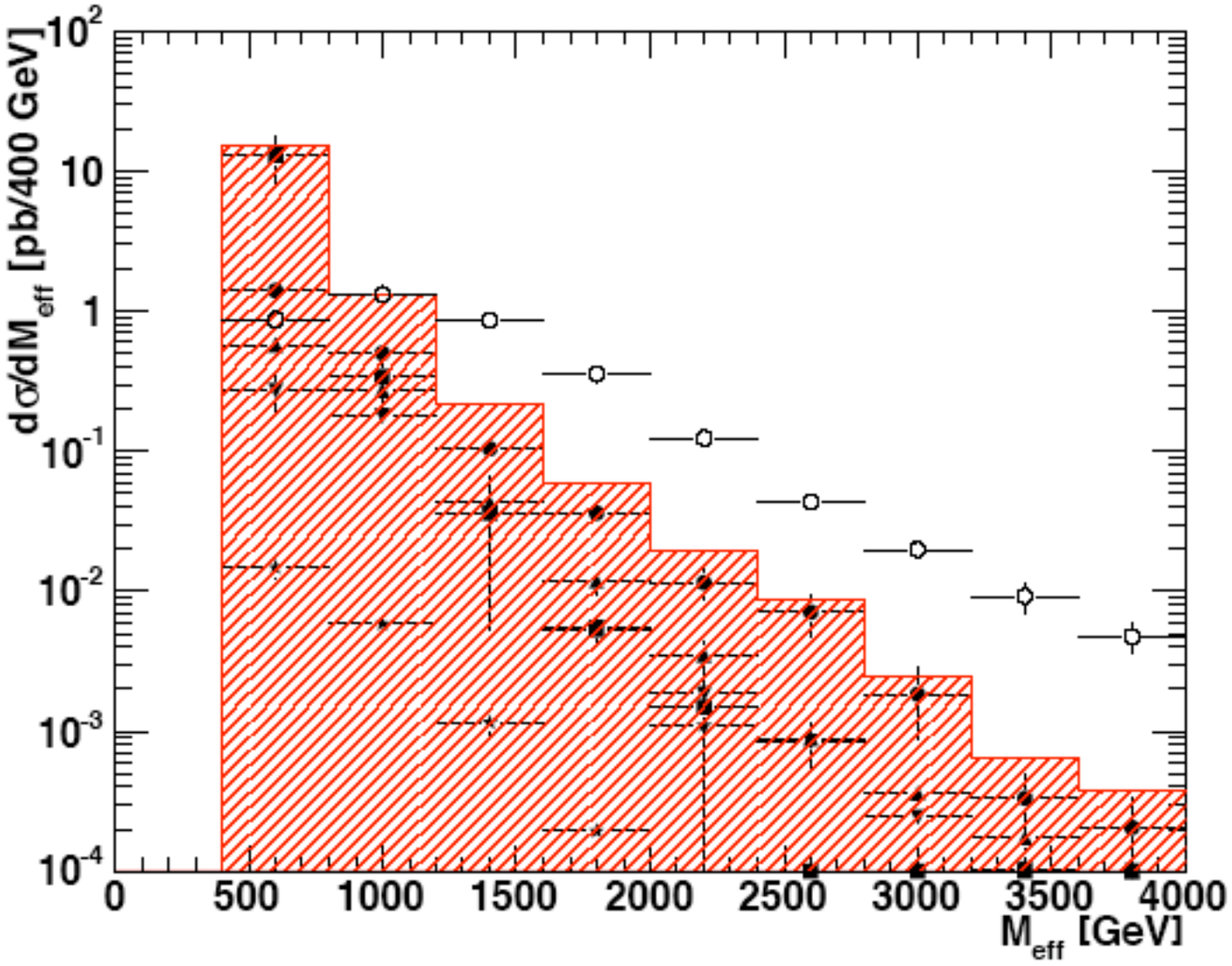
- For new physics associated to top, two approaches are possible:
  top-down and bottom-up
- In the past, these two different strategies needed different MC tools.
- Some of the new MC tools (such as MadGraph or SHERPA) allow to tackle both, including the backgrounds!

SUSY example

[Kraml, Raklev, 2006]

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

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

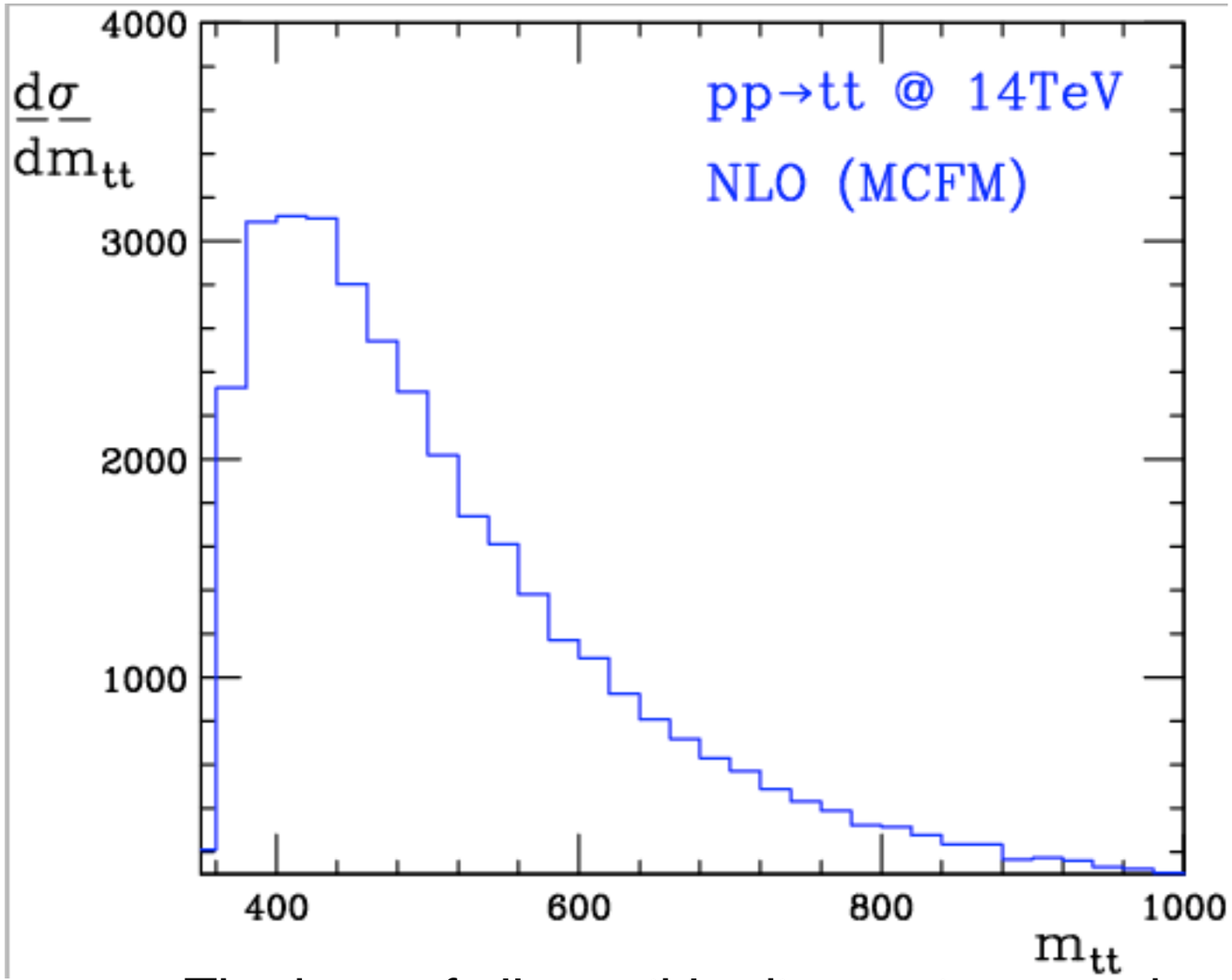


Same-sign top quarks as a signature of light stops.

Very nice, typical SUSY inclusive signature: need for a very good control of the SM backgrounds.

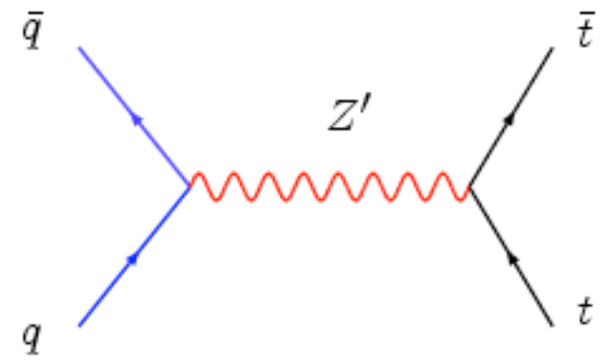
The whole analysis can be performed within one MC (e.g. MadGraph), including matched samples for the backgrounds (on-going).

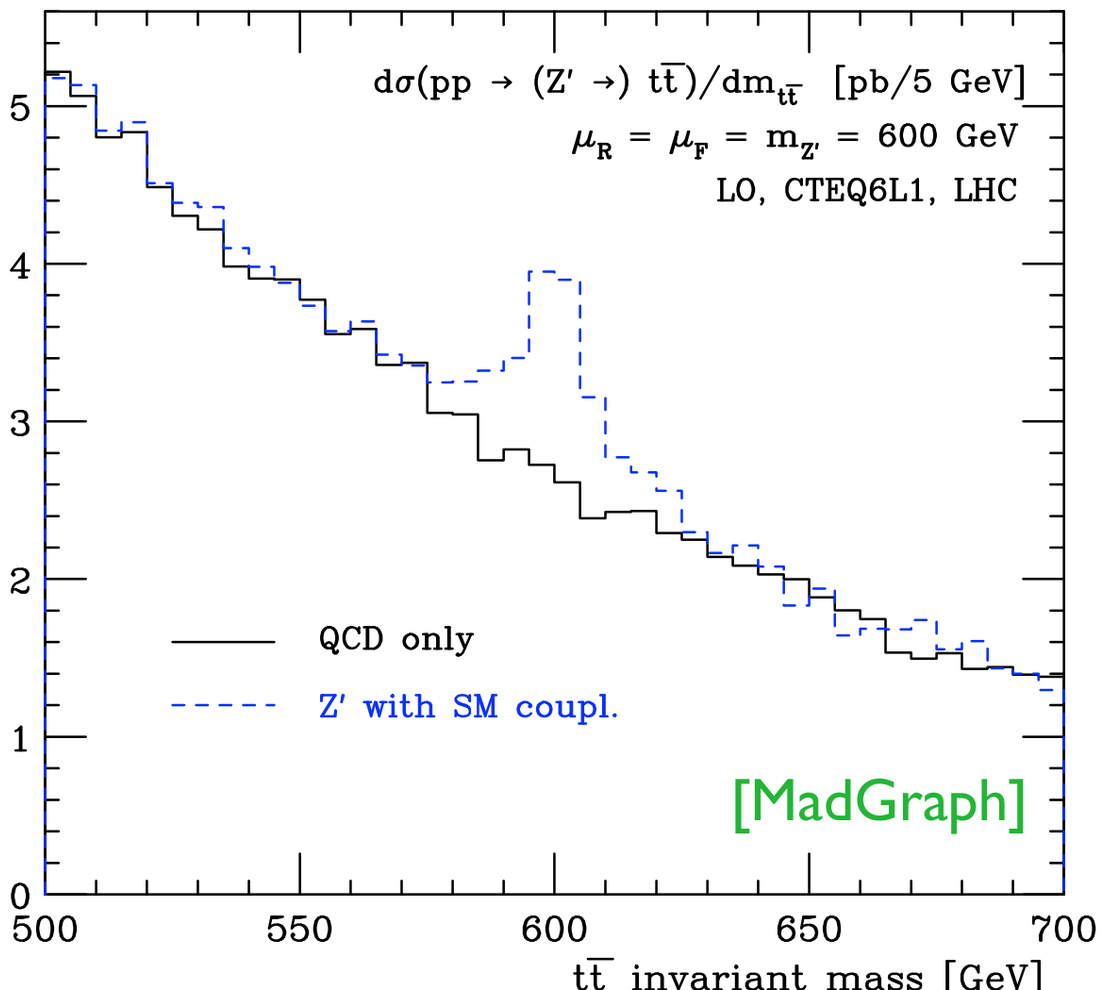
Signature based example: m_{tt} as a BSM physics observatory



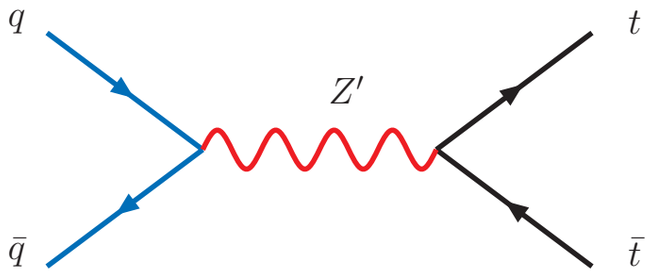
The best of all possible discoveries: a peak in the invariant mass distribution!

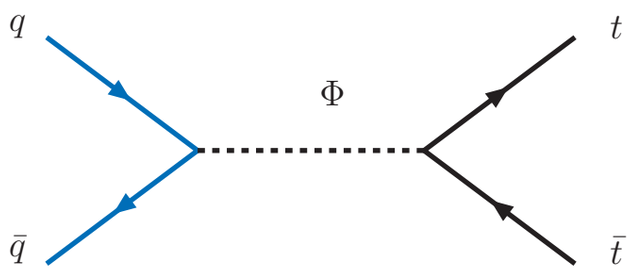
Similar results are obtained if a scalar or a spin2 particle is exchanged. How to distinguish them?

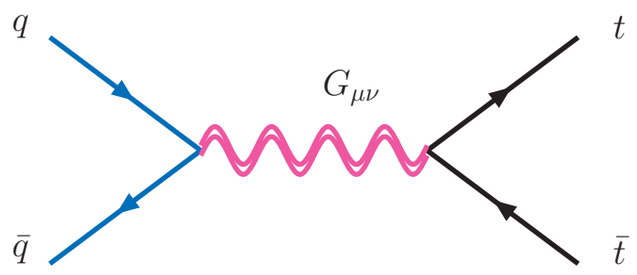




m_{tt} as a BSM physics observatory

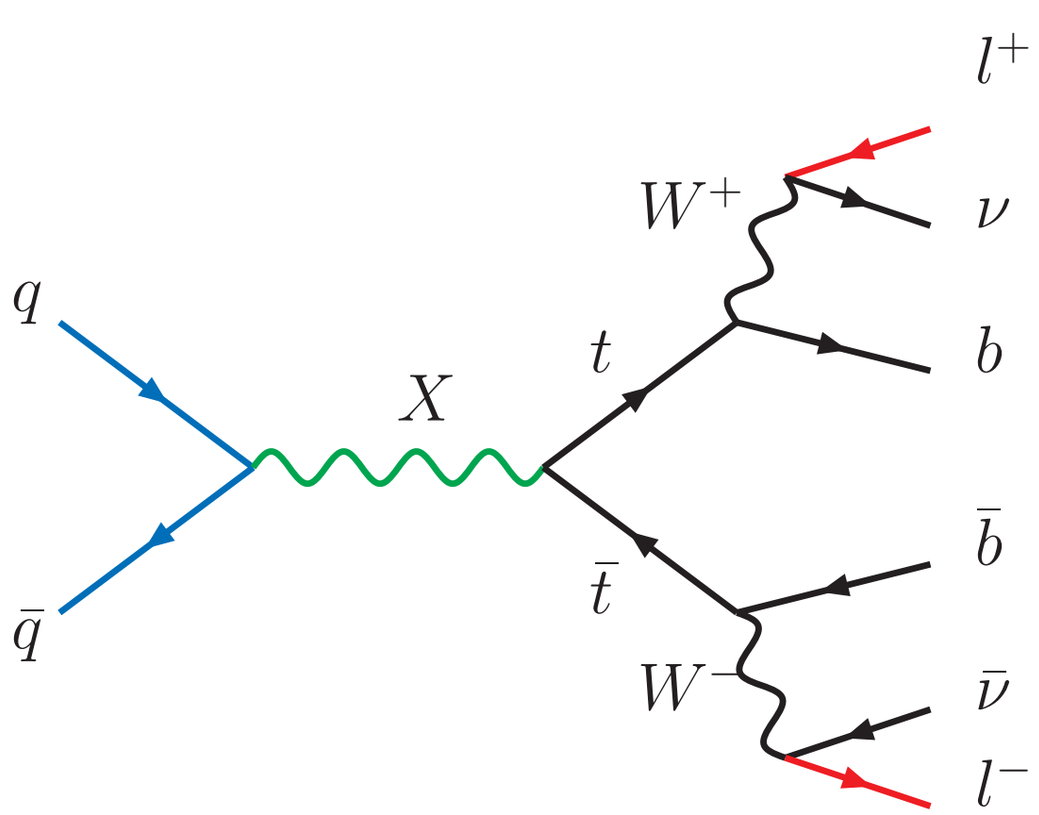




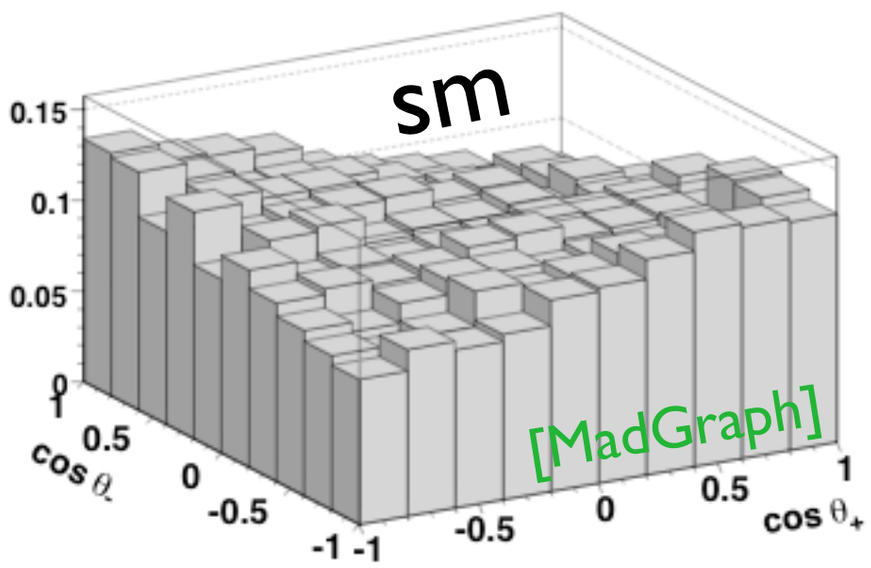


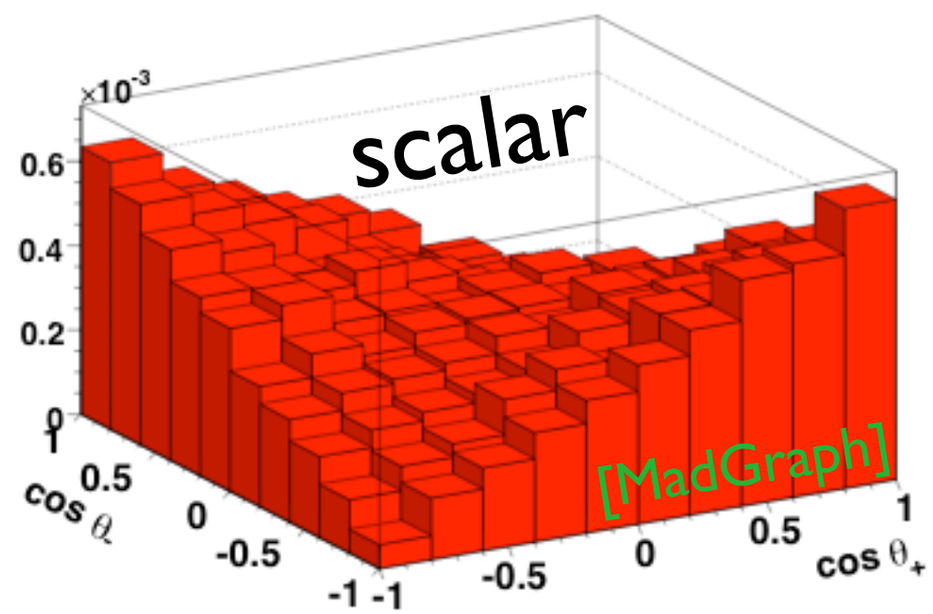
How to extract the spin information about the resonance?

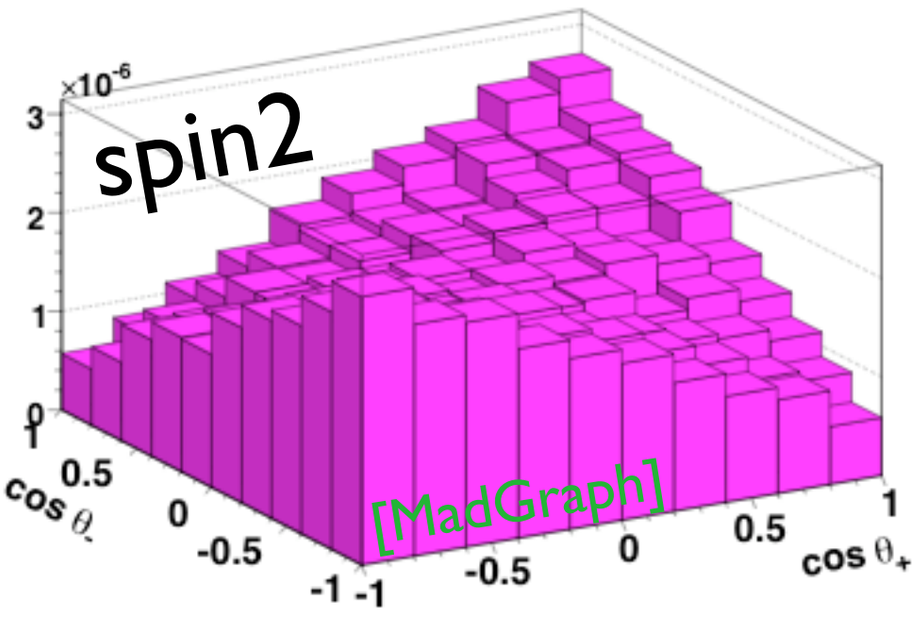
Decay the top's and look at angular correlations between the leptons!

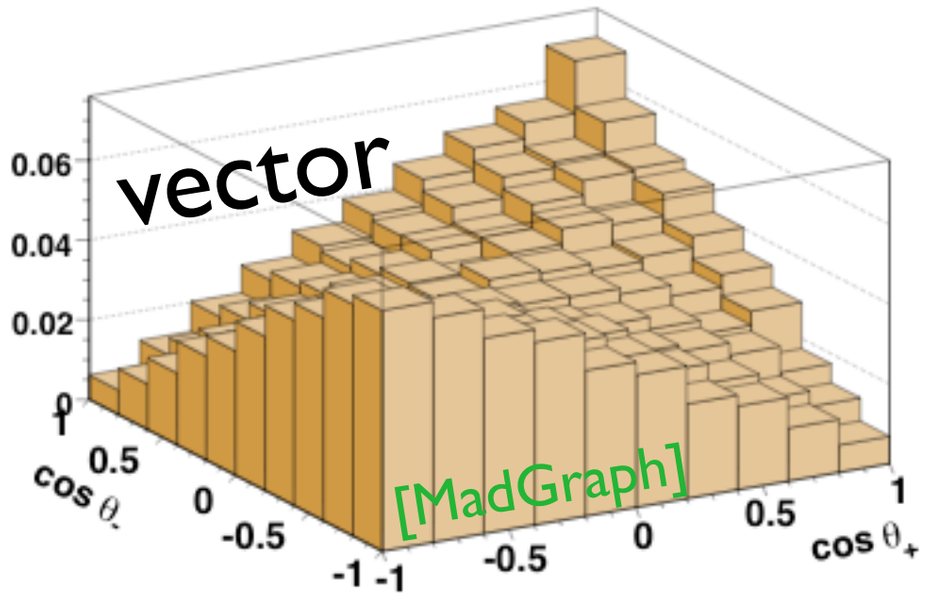


m_{tt} as a BSM physics observatory







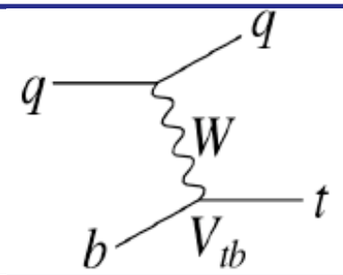
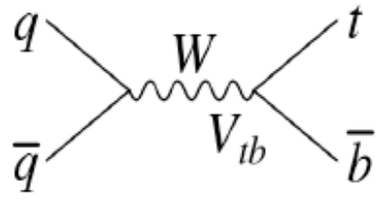
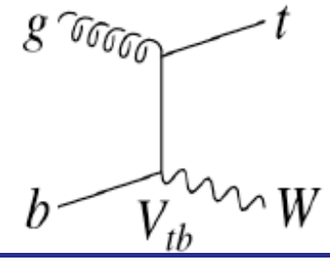


$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta_+ d\cos\theta_-} = \frac{1}{4}\left(1 + \kappa_t \kappa_{\bar{t}} D \cos\theta_- \cos\theta_+\right)$$

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:
  - ⋆ Impressive progress in producing accurate inclusive tt+jets samples with matching, and studies of the associated systematics possible.
  - ⋆ 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...

Single top

Process	Diagram	Accuracy	CTEQ6M, mt=178 GeV,th err≅10% σ (pb)	
			TeV II	LHC
t-channel		NLO Stelzer, Sullivan, Willenbrock '97	1.85	239
s-channel		(N)NLO Smith, Willenbrock '96 Chetyrkin, Steinhauser'01	0.82	9.8
tW		NLO Campbell, Tramontano '05	0.129	64

All signals available in MCFM (Campbell, Ellis) and t- and s-channel also in MC@NLO (Frixione, Laenen, Motylinsky, Webber). Most of the backgrounds are also known at NLO. However, analysis still rely on LO calculations for the heavy-quark fractions in W+jets events (largest background) ⇒ room for improvement.

Comment on the single top MC's

- The only full MC available with a rigourous matching scheme is MC@NLO (with one hard extra parton)
- All other tools available have only an heuristic matching between $qb \rightarrow tq'$ and $qg \rightarrow tbq'$ to describe the b-jet at high pt.
- Extra light jets start mixing s- and t-channel (at NNLO).
- tW is very special ⇒ very special attention

Room for improvement...