Top & New physics with MadGraph

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Contents

- Introduction to MadGraph/MadEvent
- Example: BSM physics in top pair invariant mass
    - theoretical uncertainties
    - top mass
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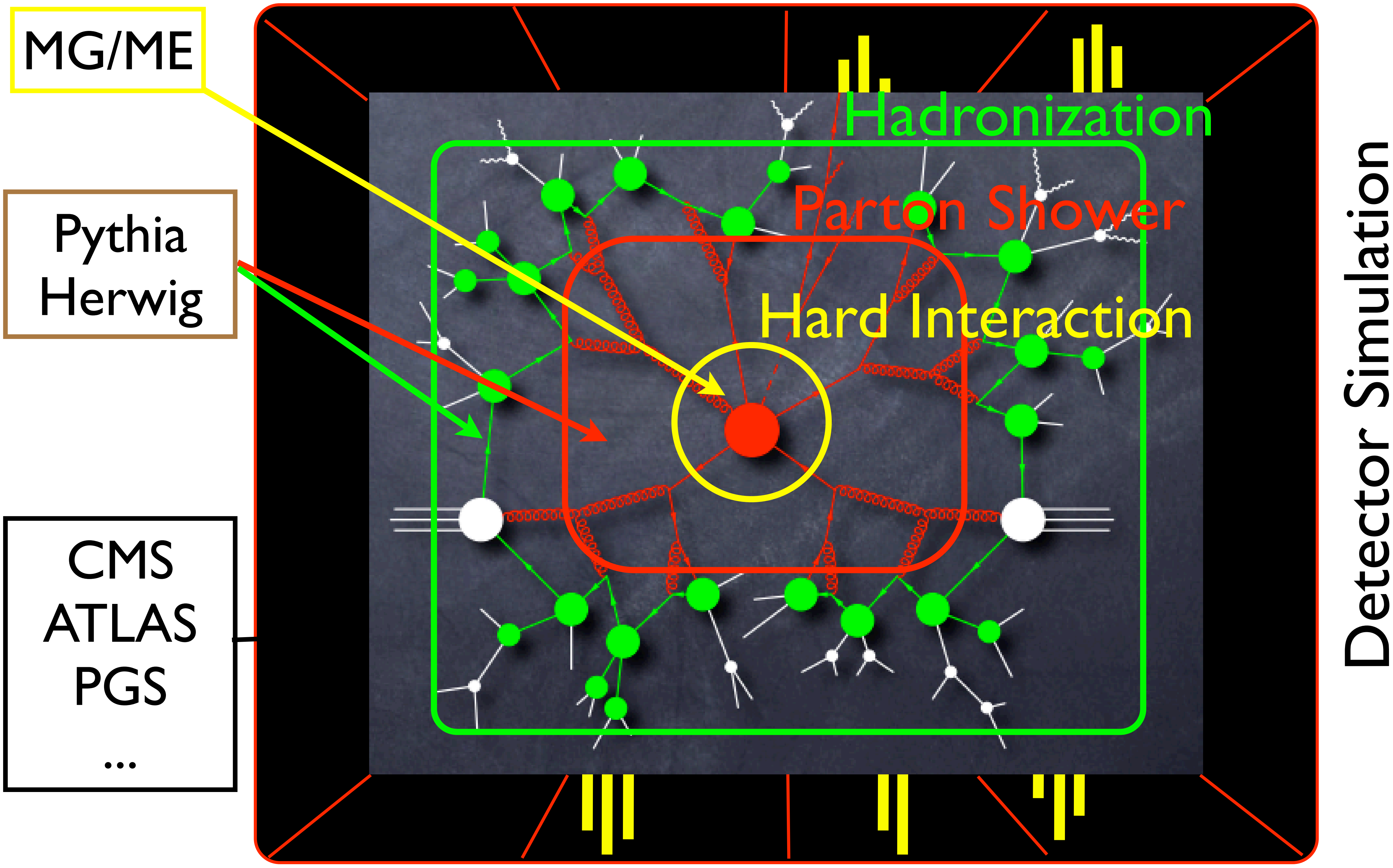
- Conclusions

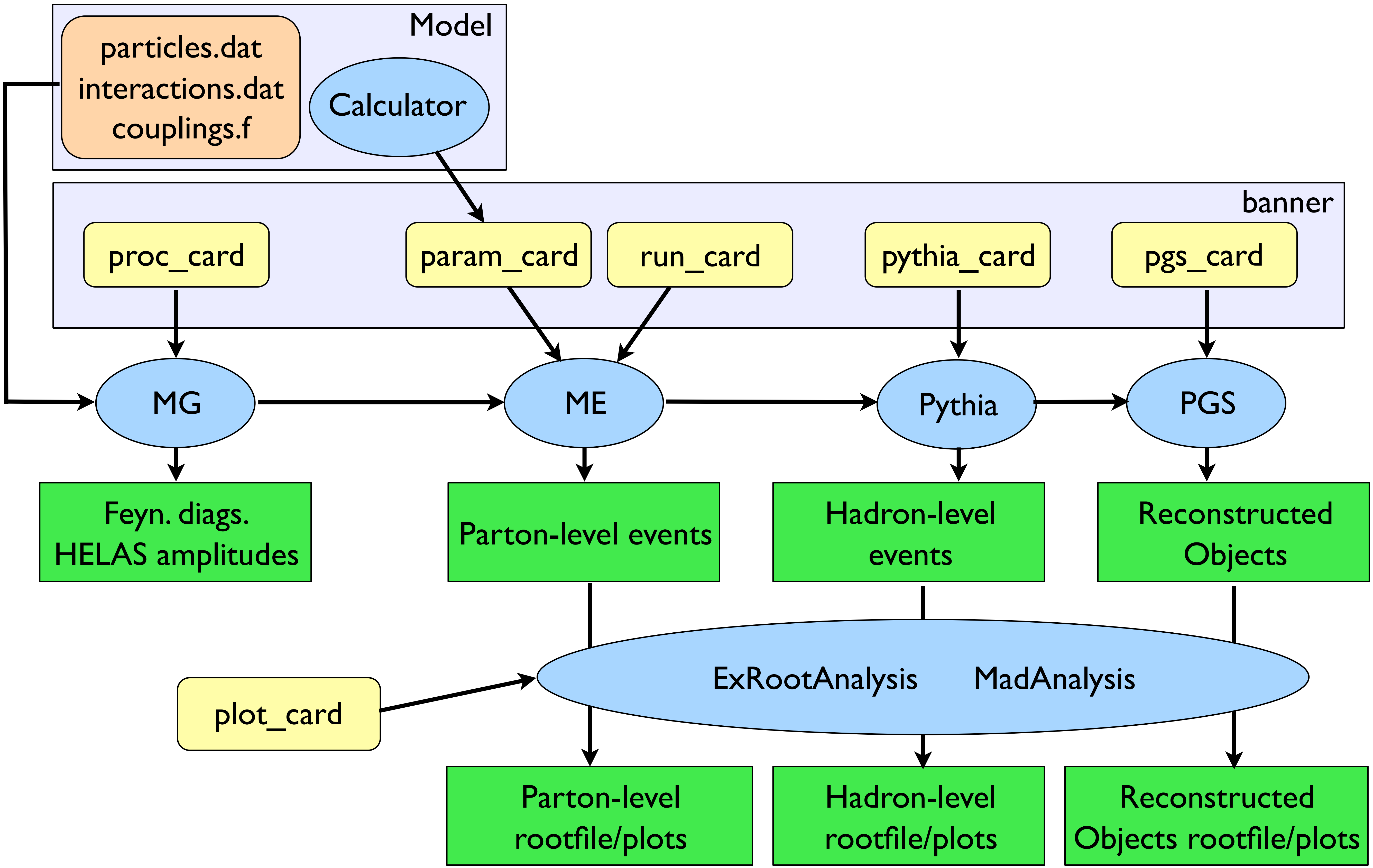
Introduction to MadGraph/MadEvent

- MG/MEv4 is a user-driven, matrix element based, 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 Big Picture



Flow Chart



Model
particles.dat
interactions.dat
couplings.f
Calculator
banner
proc_card
param_card
run_card
pythia_card
pgs_card
MG
ME
Pythia
PGS
Feyn. diags.
HELAS amplitudes
Parton-level events
Hadron-level events
Reconstructed Objects
ExRootAnalysis
MadAnalysis
plot_card
Parton-level rootfile/plots
Hadron-level rootfile/plots
Reconstructed Objects rootfile/plots

MG/ME Features

- Helicity amplitudes, based on HELAS
- Efficient (i.e. parallel) phase space integration ('multi-channel' based on Feynman diagrams)
- It complies with the Les Houches Accord standards, w.r.t. the model parameters and event files
- Matching between Matrix Elements & Parton Shower
- Structure is model independent
- Easy to implement and validate new models
- Open development community

Matching

J. Alwall

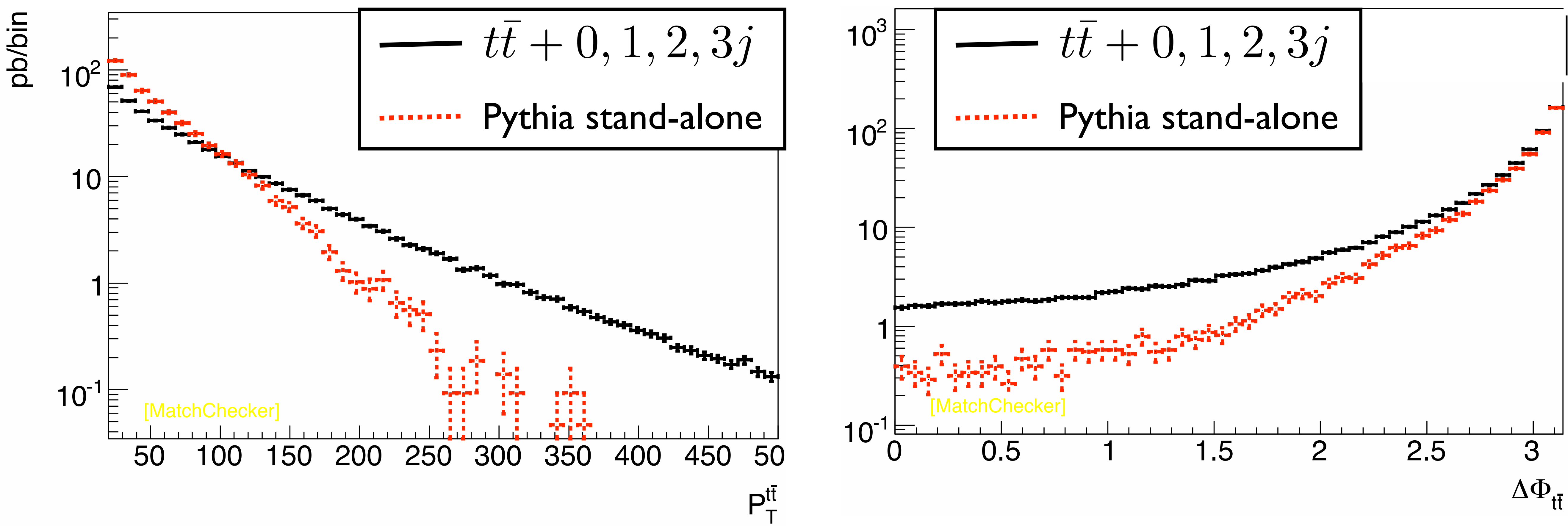
Matrix Element	Parton Shower
1. Parton-level description	1. Hadron-level description
2. Fixed order calculation	2. Resums large logs
3. Exact quantum interference	3. quantum interference through AA
4. Valid for hard and well separated partons	4. Valid when partons are soft and/or collinear
5. Needed for multi-jet description	5. Needed for realistic studies

Matrix element and Parton Shower approaches are complementary.

We have to combine them without double-counting.

MadGraph uses MLM matching with $k_\perp$ jet algorithm

Matching
in top pair production



Matching scheme is universal.
Already tested and validated for:

$Z,\ W^{\pm},\ ZZ,\ W^{+}W^{-},\ \tilde{q}\tilde{g},\ t'\bar{t}',\ t\bar{t}h,\ \ldots$

Models

- SM
  - HiggsEFT (Effective couplings between Higgs and gluons/photons)
- MSSM (CP & R-parity conserving)
- Generic 2HDM (Completely general 2 Higgs doublet model, incl. FCNC and CP violation)
- User Model -- General framework to include user-defined models

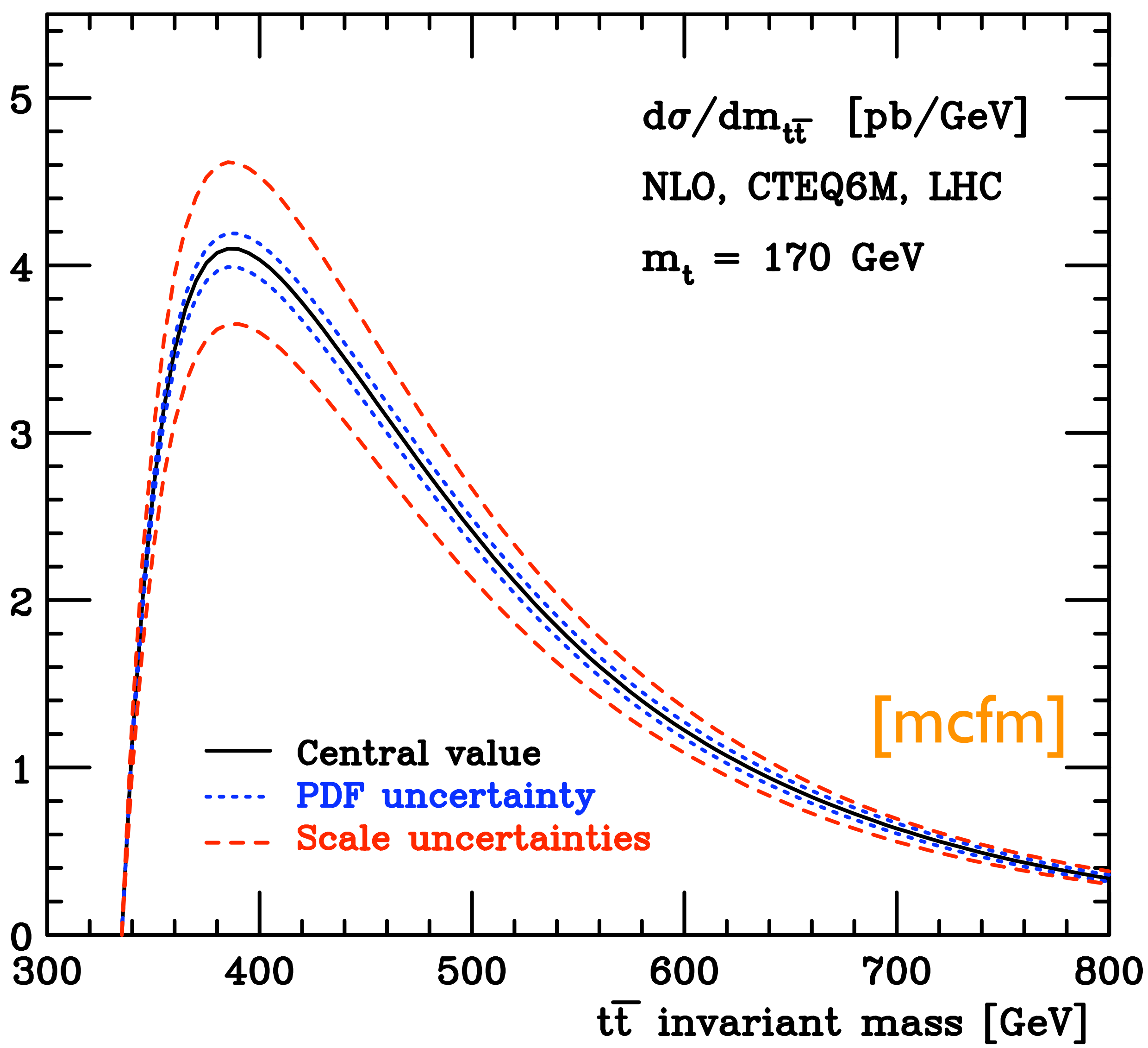
BSM physics

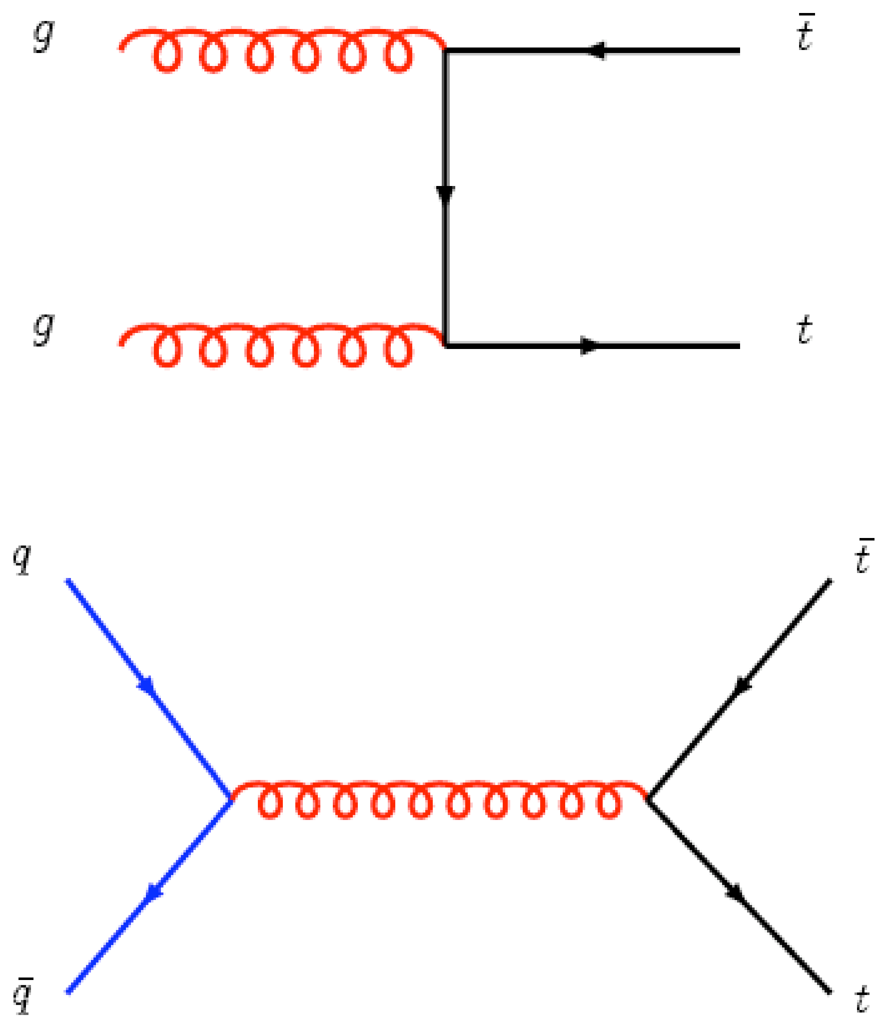
- For new physics associated to top, two approaches are possible:
  - top-down (e.g., model parameter scanning)
  - bottom-up (e.g., inverse problem)
- Let's focus on the bottom-up approach

Bottom-up approach

- Define/choose a variable
- Theory uncertainties
- Effects from BSM (in ‘model independent way’) on this variable
- Use more info, like spin correlations, to be able to discriminate between BSM physics

Top pair invariant mass





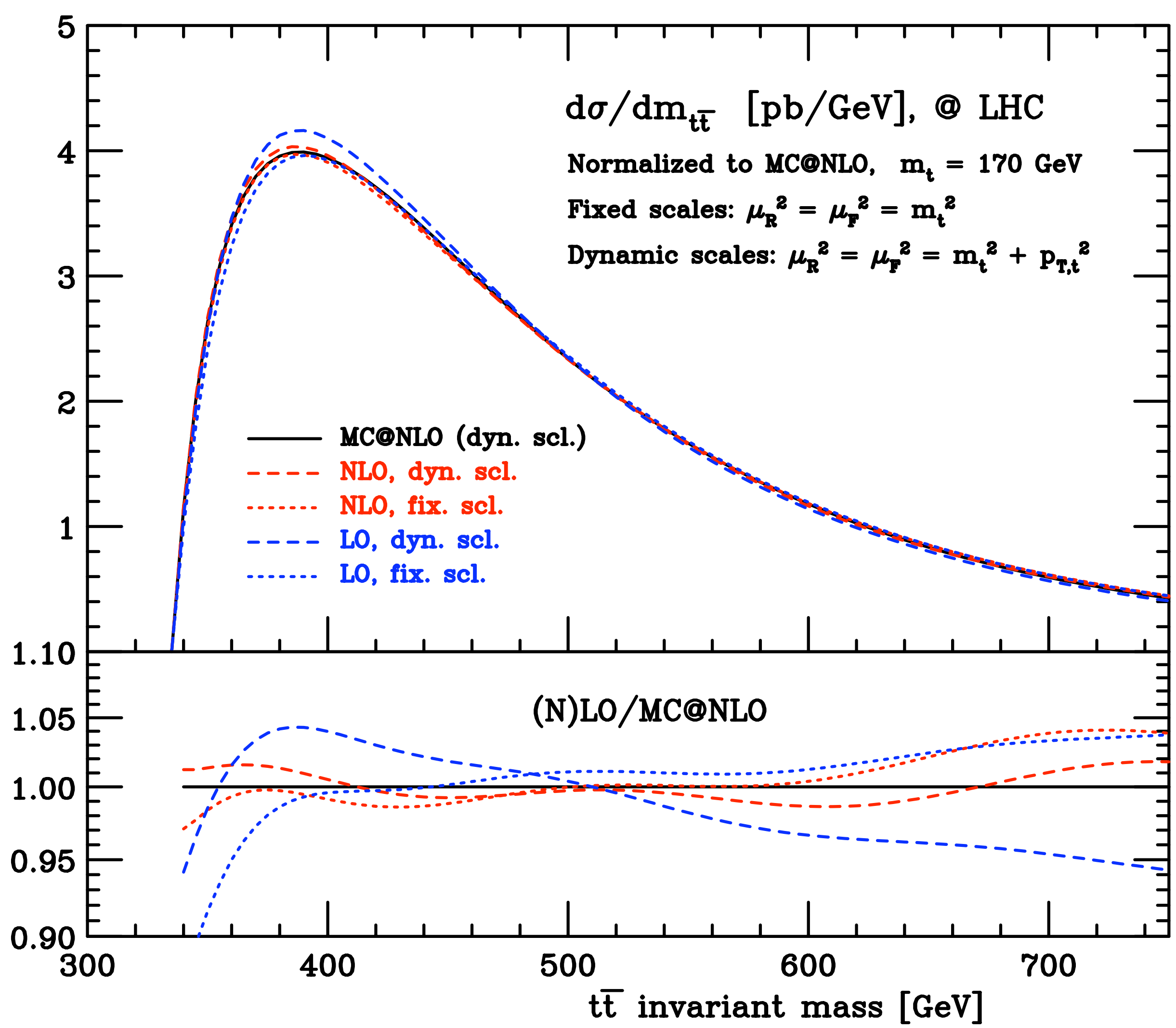
NLO: Mangano, Nason & Ridolfi 1992

Incl. spin corr.: Bernreuther, Brandenburg, Si & Uwer 2001

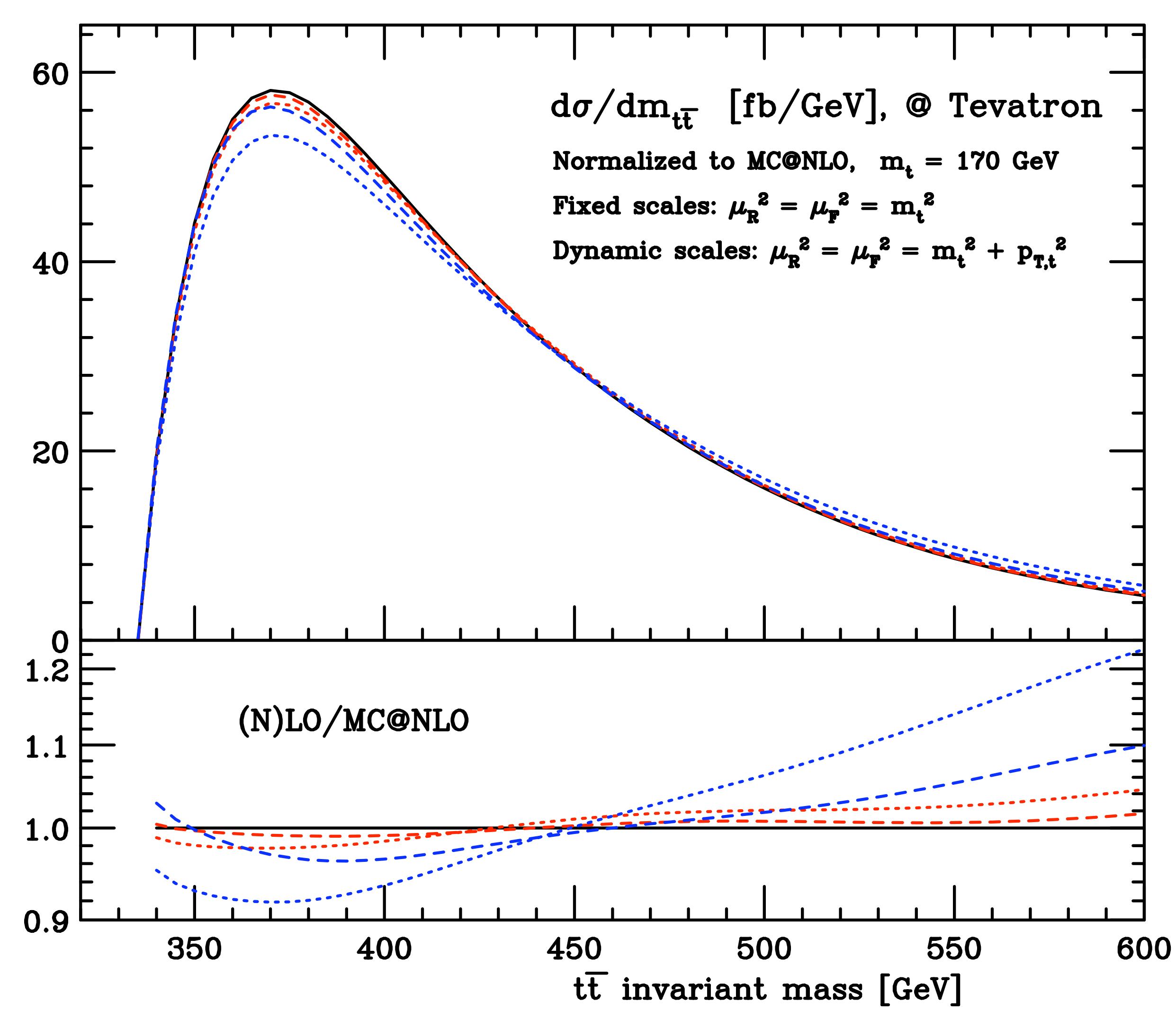
NLL: Bonciani, Catani, Mangano & Nason 1998

LO vs NLO

This distribution is known at NLO. So we should use a MC at NLO for event generation.
What are the differences between LO and NLO?

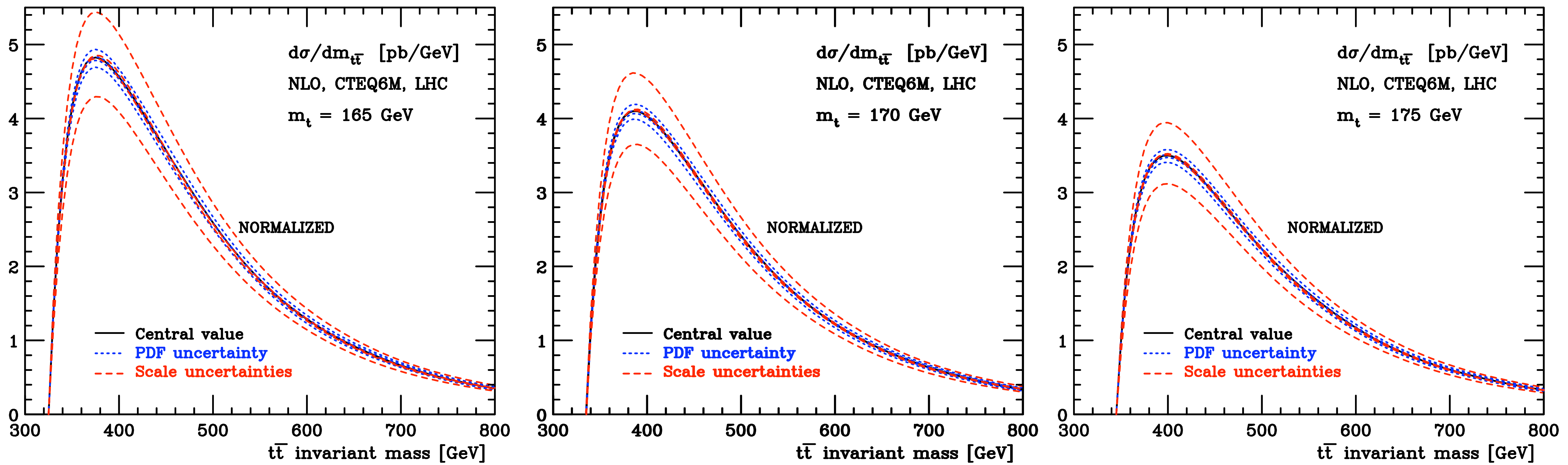


LHC



Tevatron

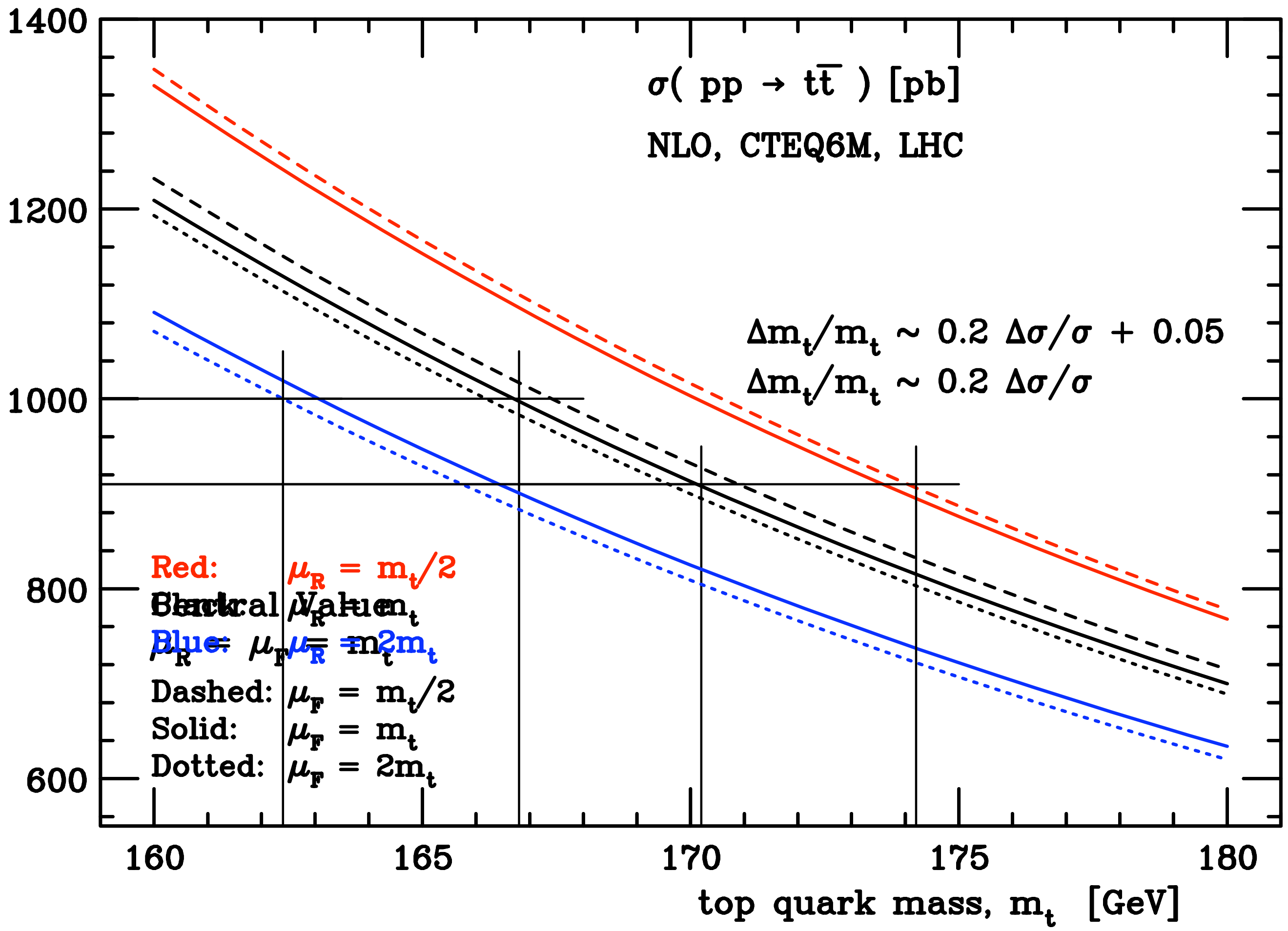
Theoretical uncertainties
in top pair invariant mass



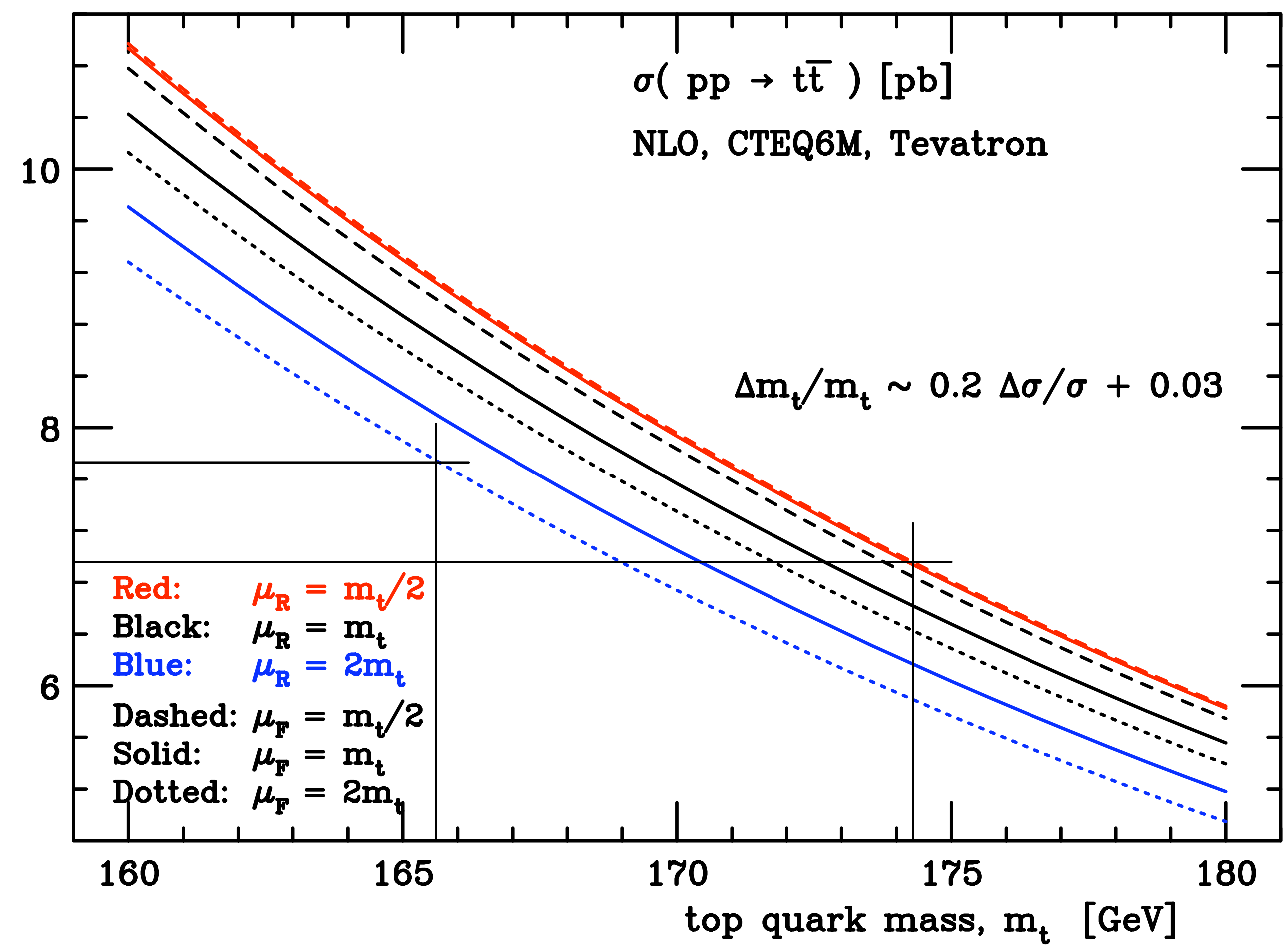
m_t=165 GeV m_t=170 GeV m_t=175 GeV

Shape is under good control, normalization uncertainty is large.
Study moments to compare distributions!

Top mass
from zeroth moment (cross section)



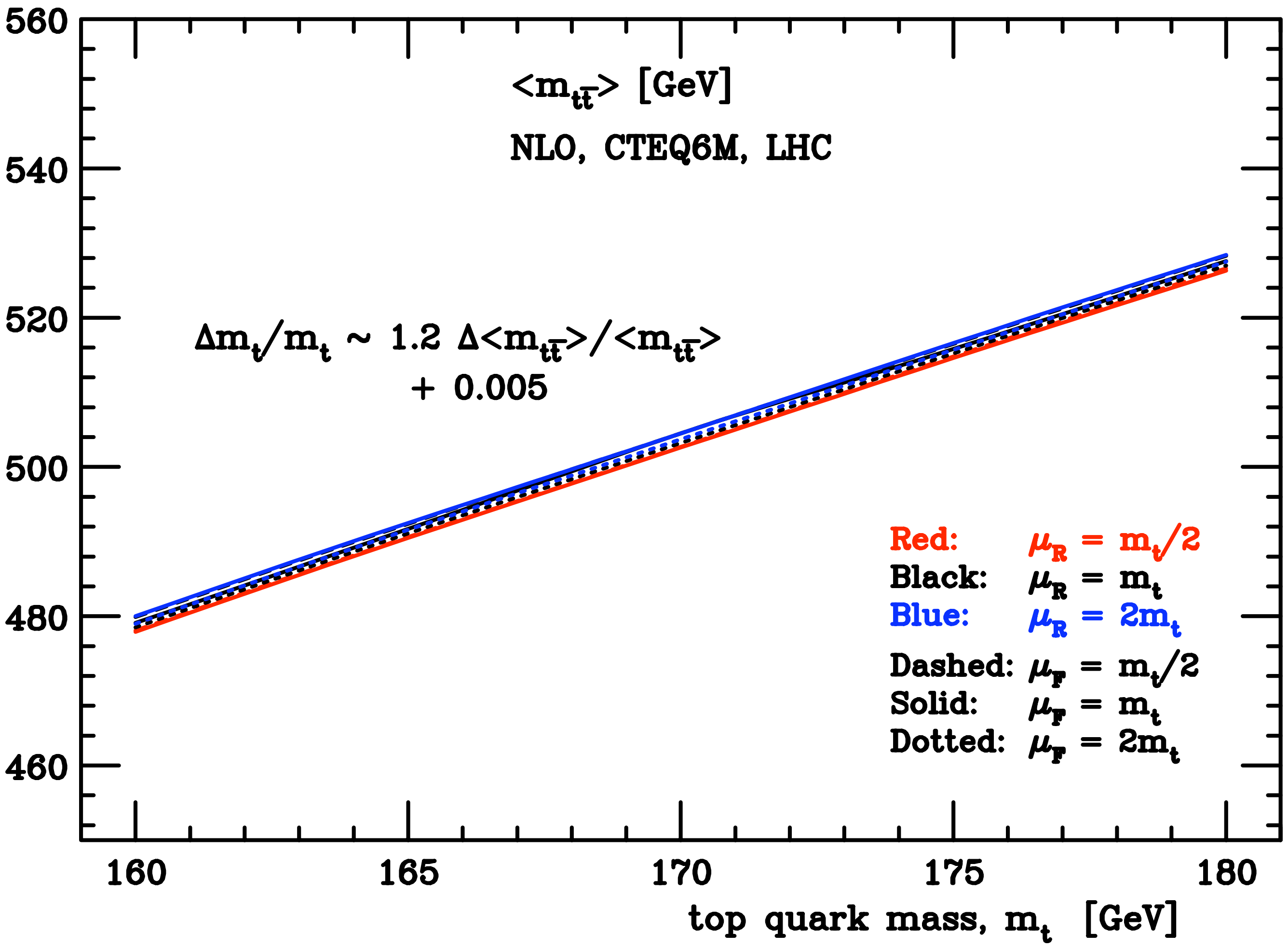
LHC



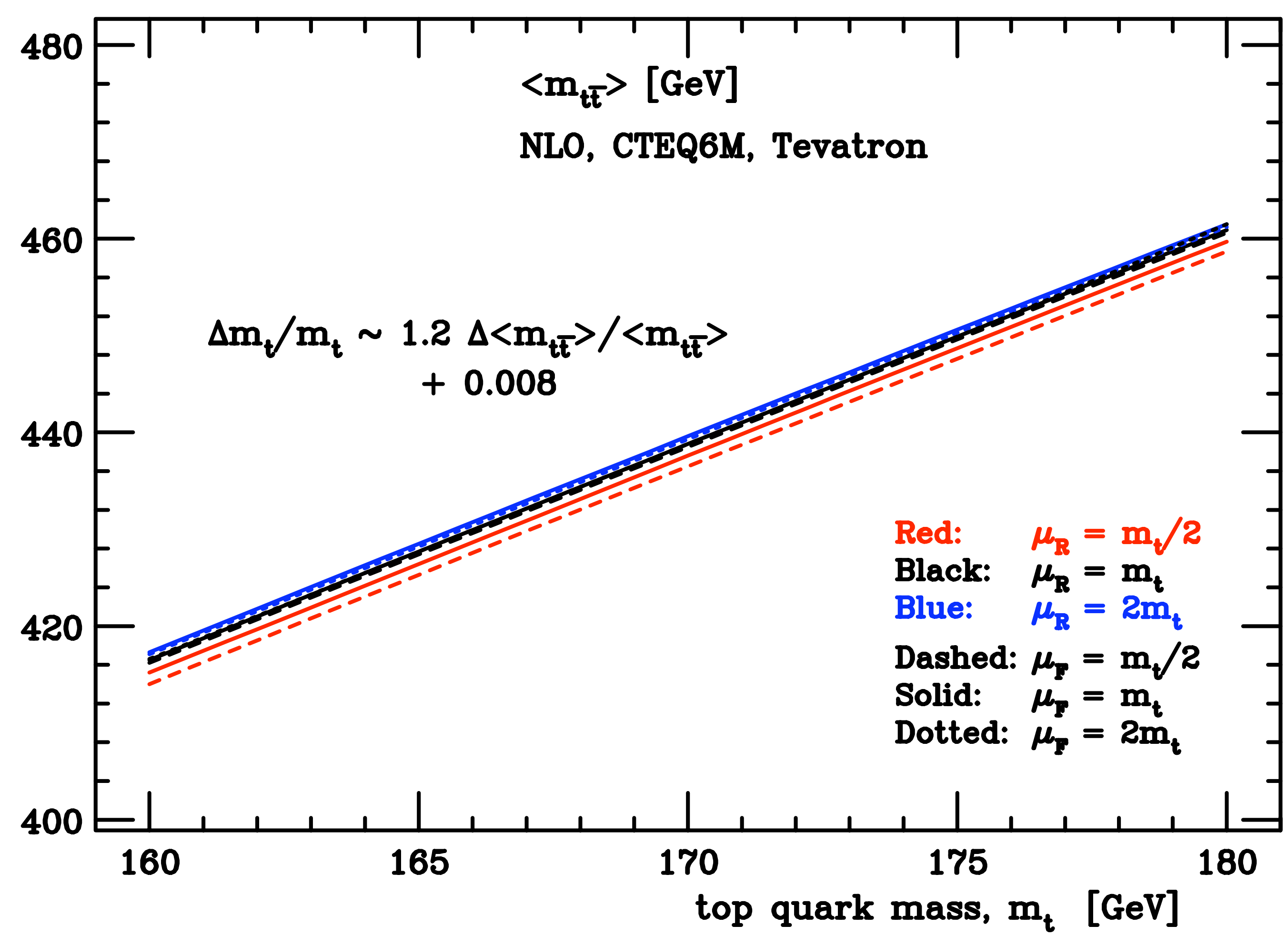
Tevatron

Top mass
from the average value for $m_{t\bar{t}}$

$$\langle m_{t\bar{t}} \rangle = \int \mathrm{d}m_{t\bar{t}}\; m_{t\bar{t}} \frac{\partial \sigma}{\partial m_{t\bar{t}}}\Big|_{\mathrm{norm.}}$$



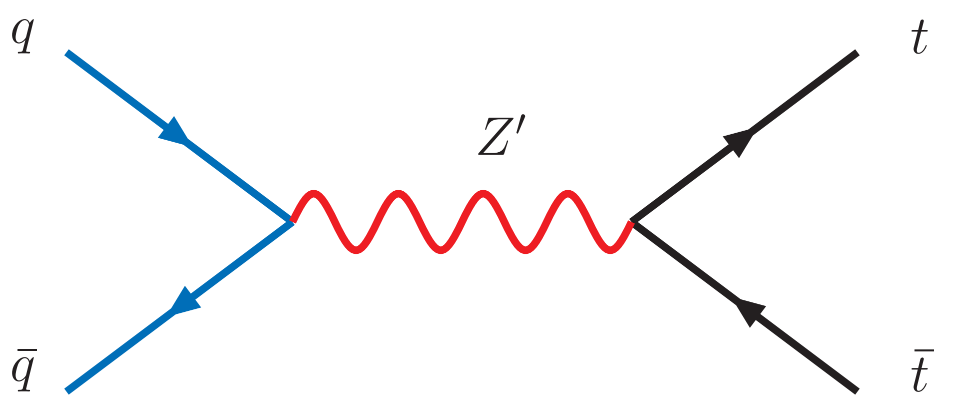
LHC

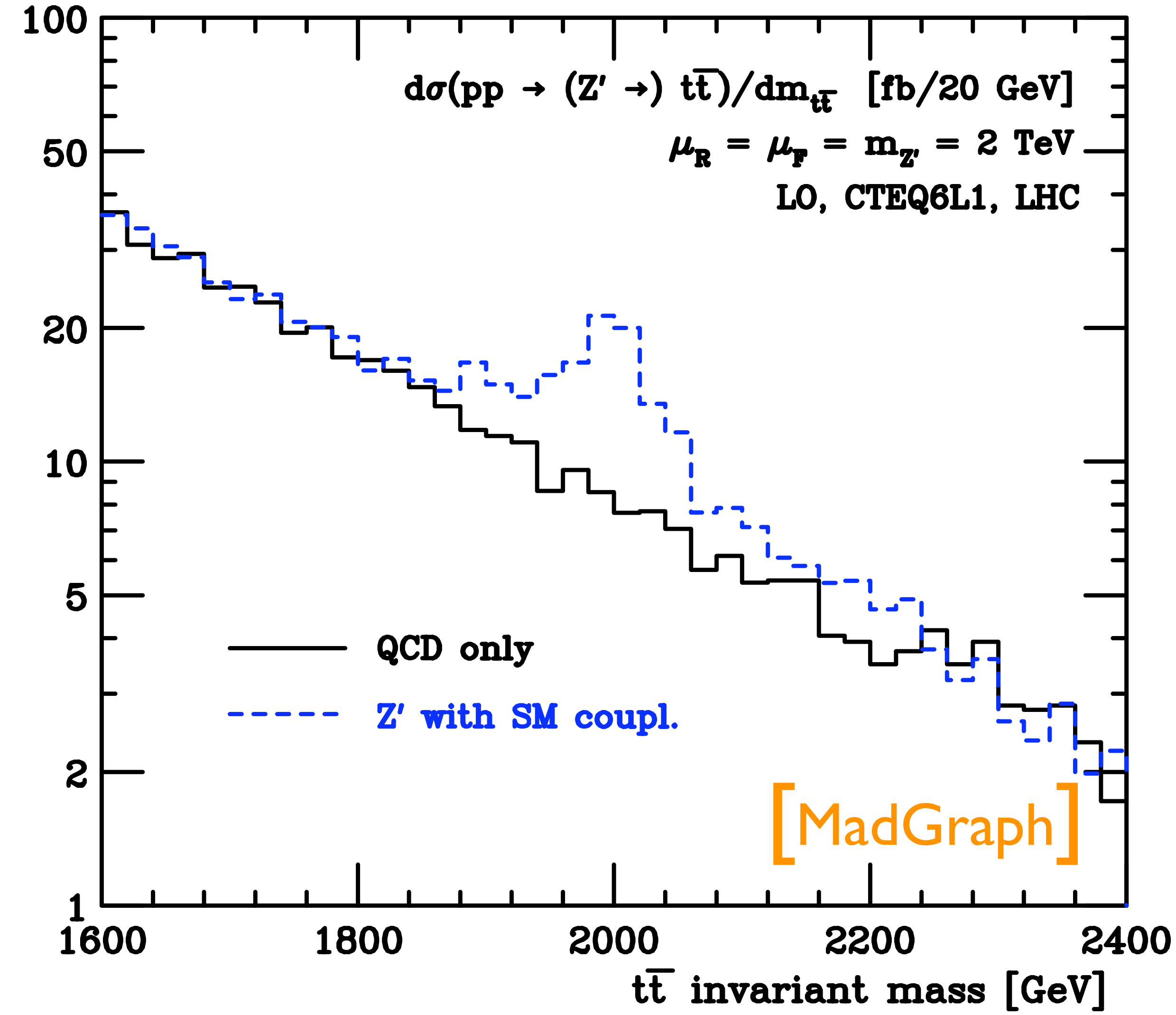


Tevatron

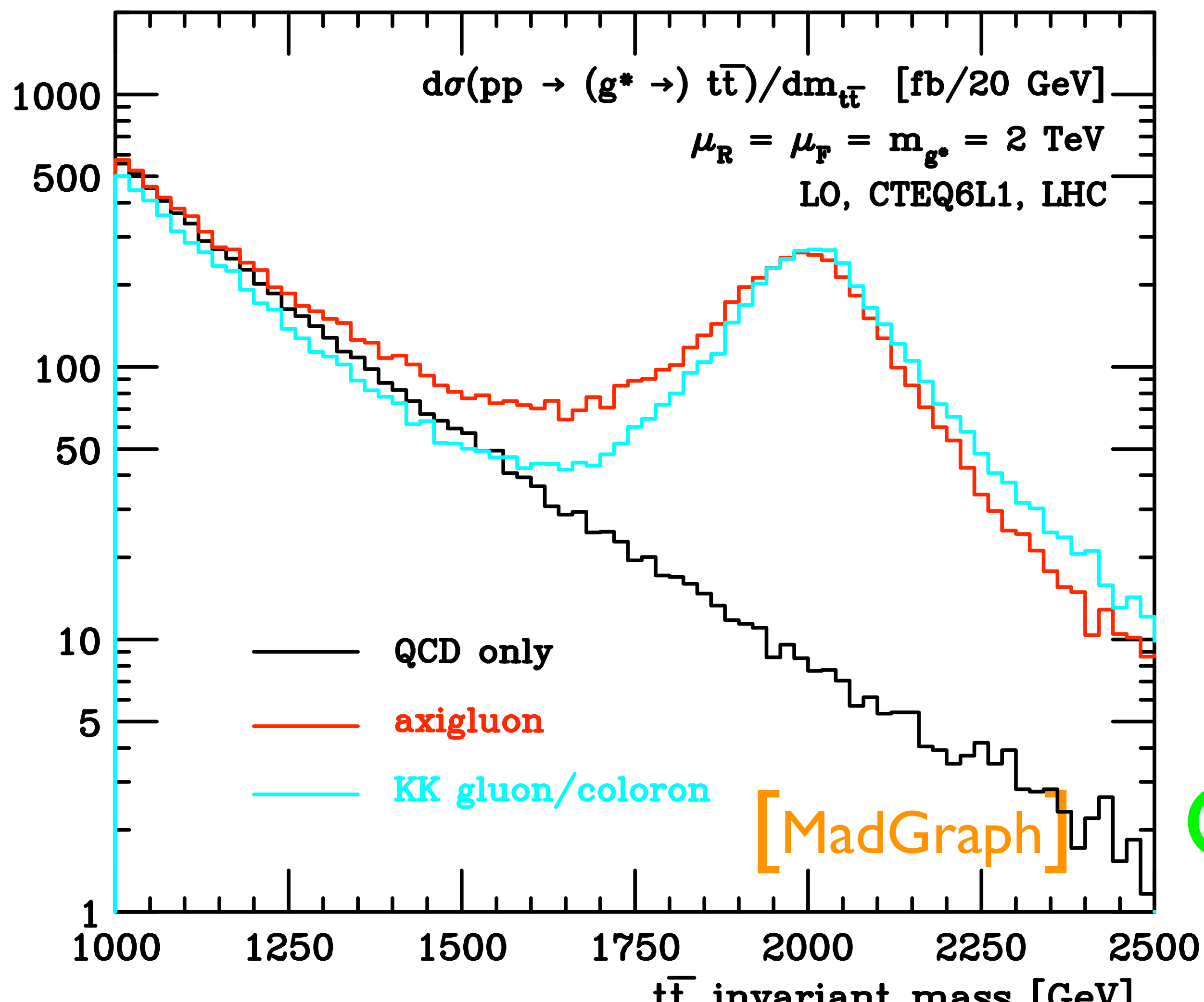
BSM resonances in top pair production at the LHC

Spin-1 resonance





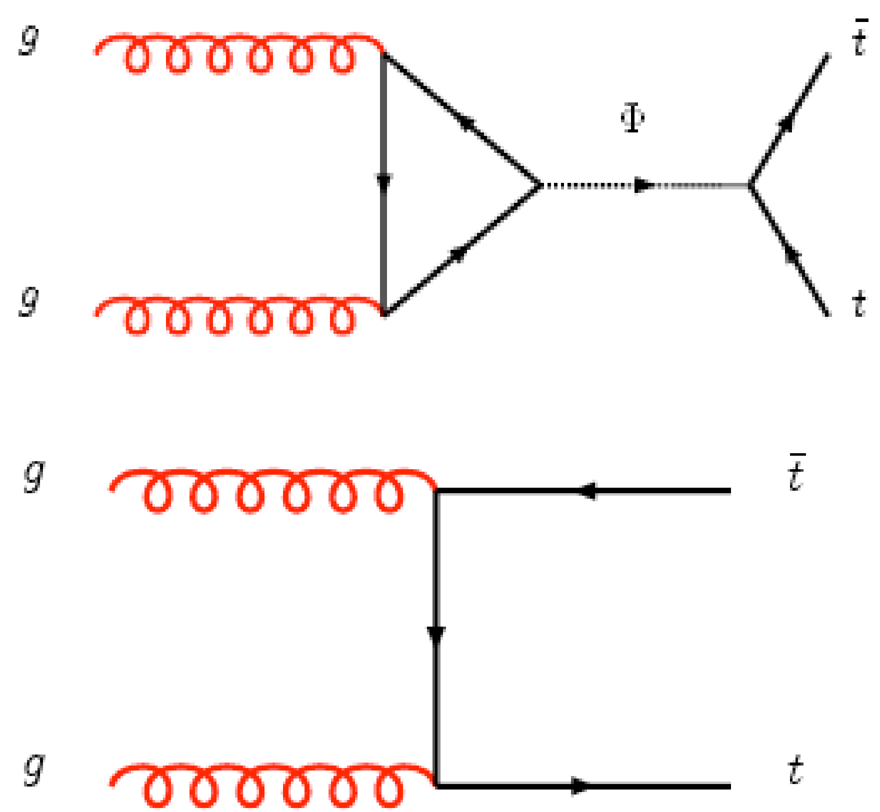
Color singlet

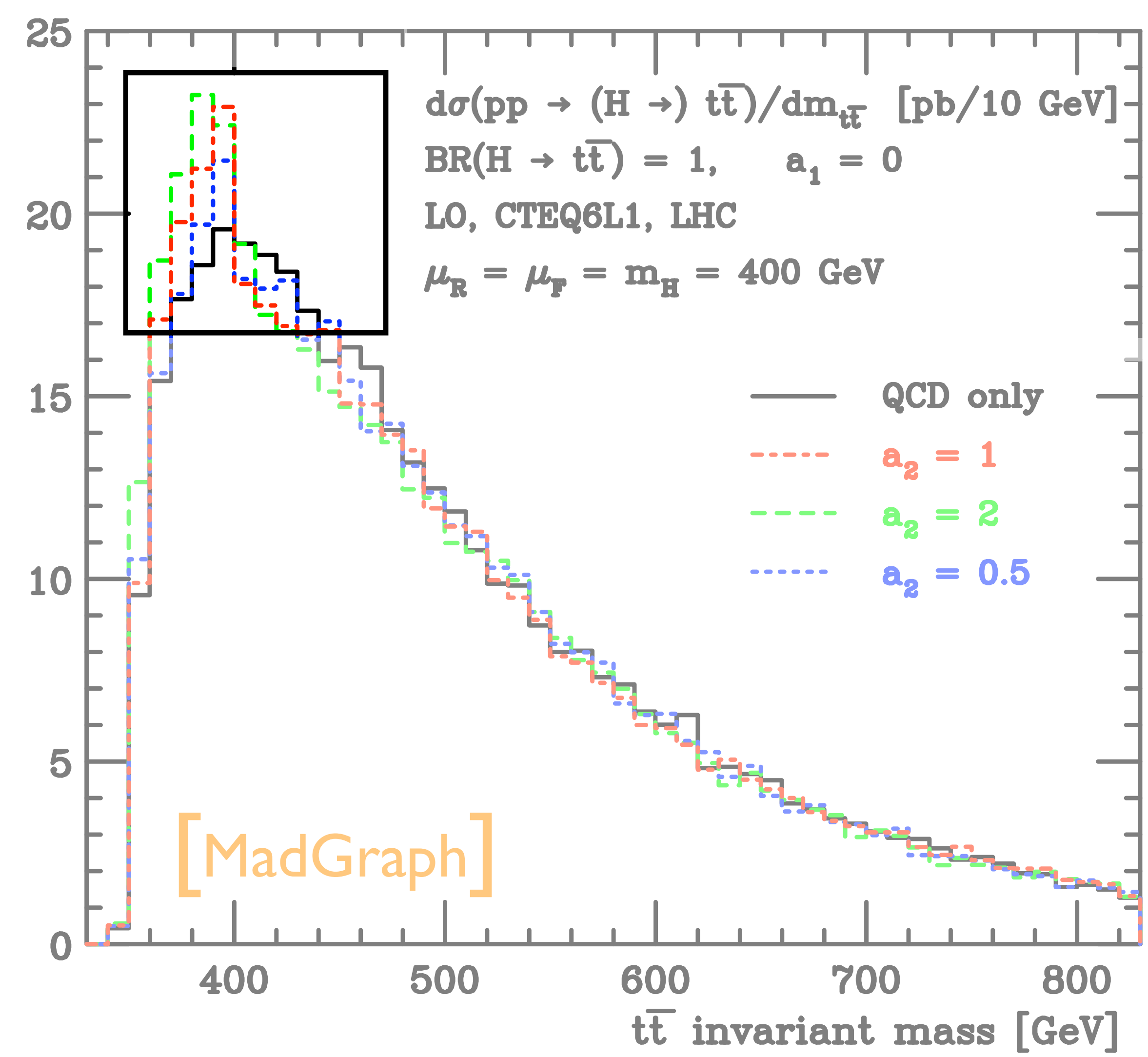


Color octet

Review by T. Rizzo 2007

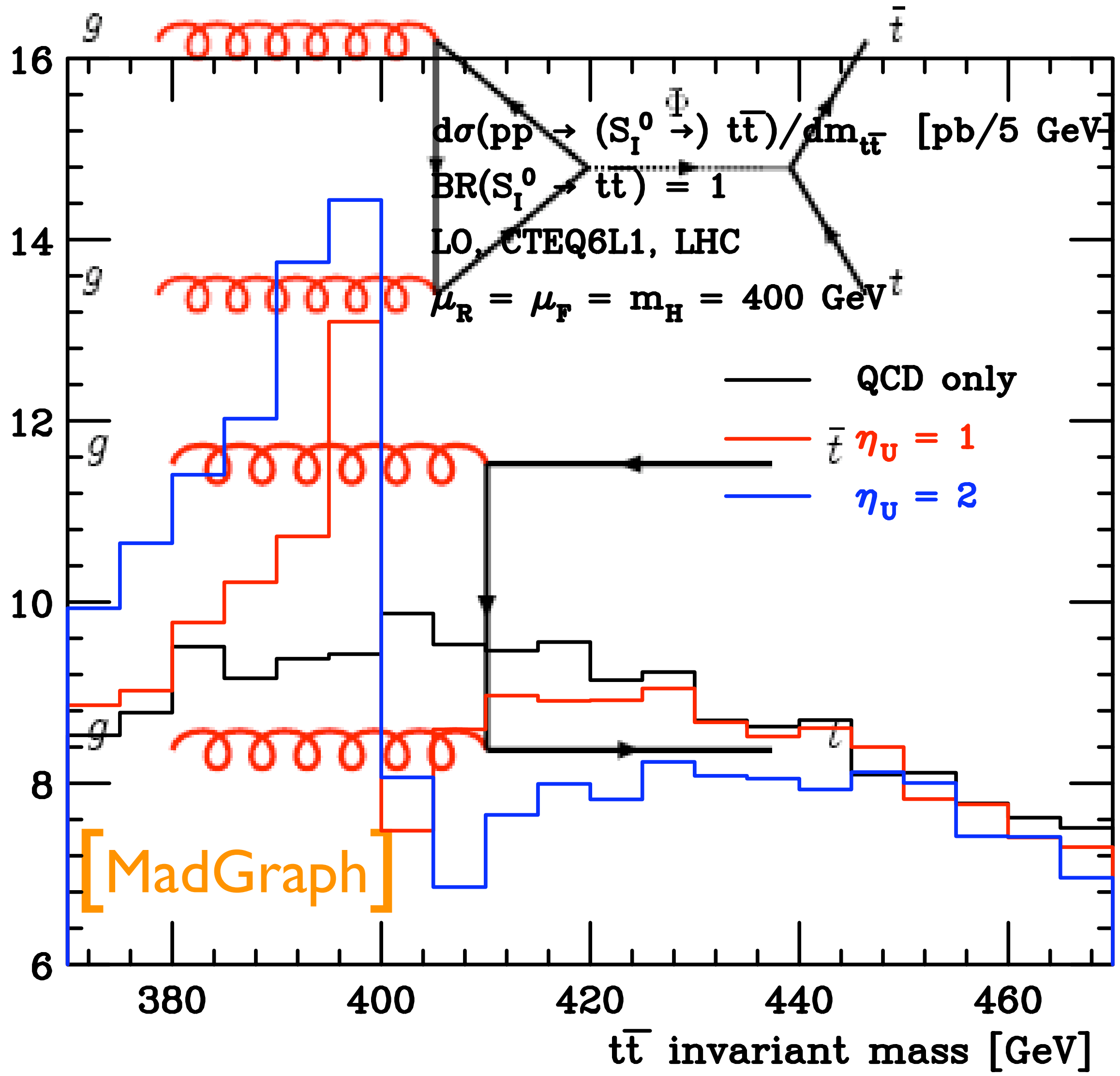
Spin-0 resonance

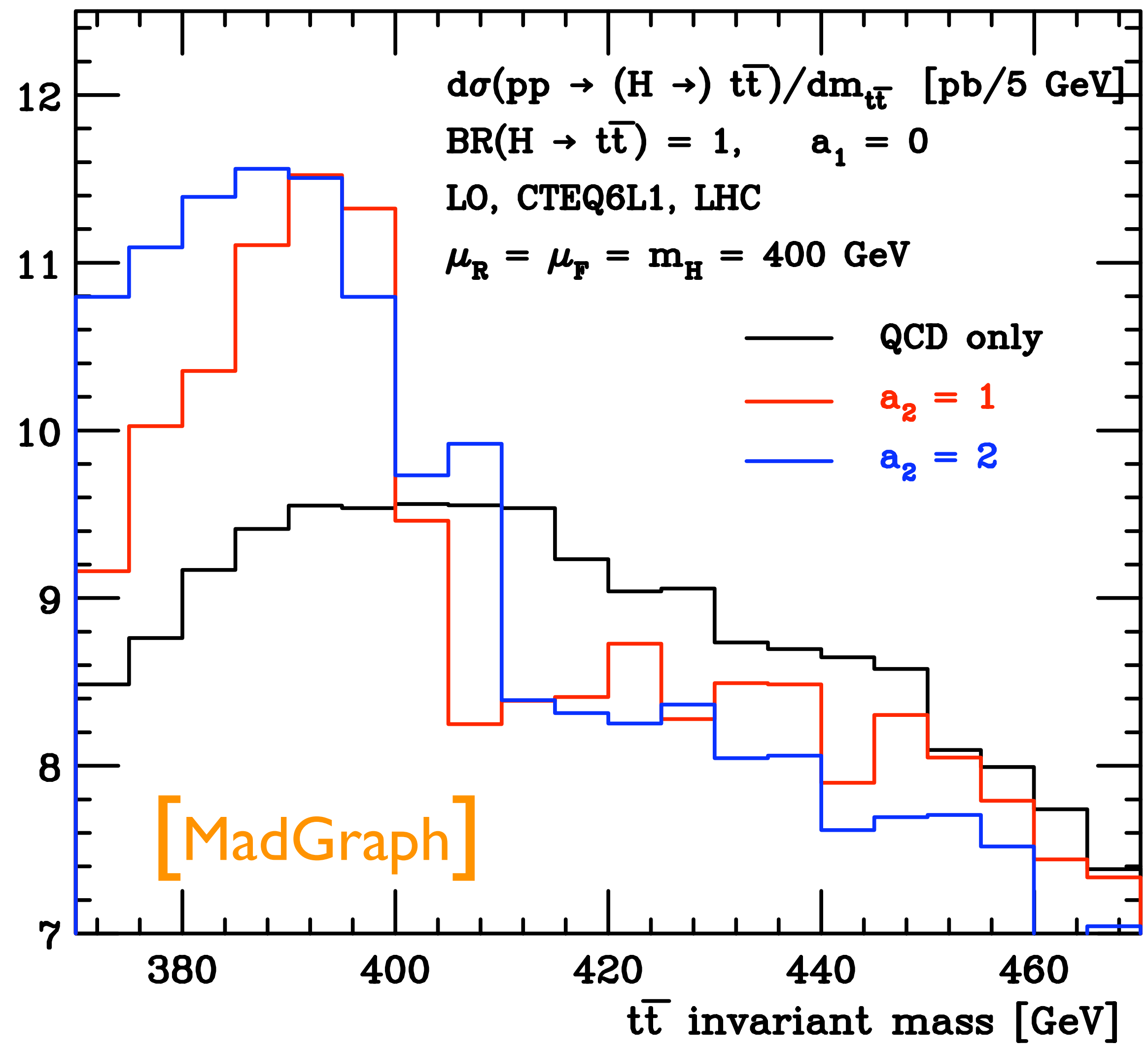




Gaemers & Hoogeveen 1984
Dicus, Stange & Willenbrock 1994

Spin-0 resonance





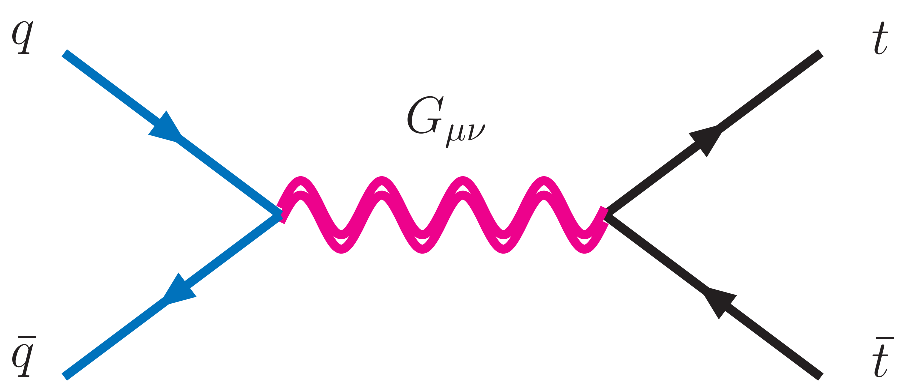
Pseudo-scalar, Color octet

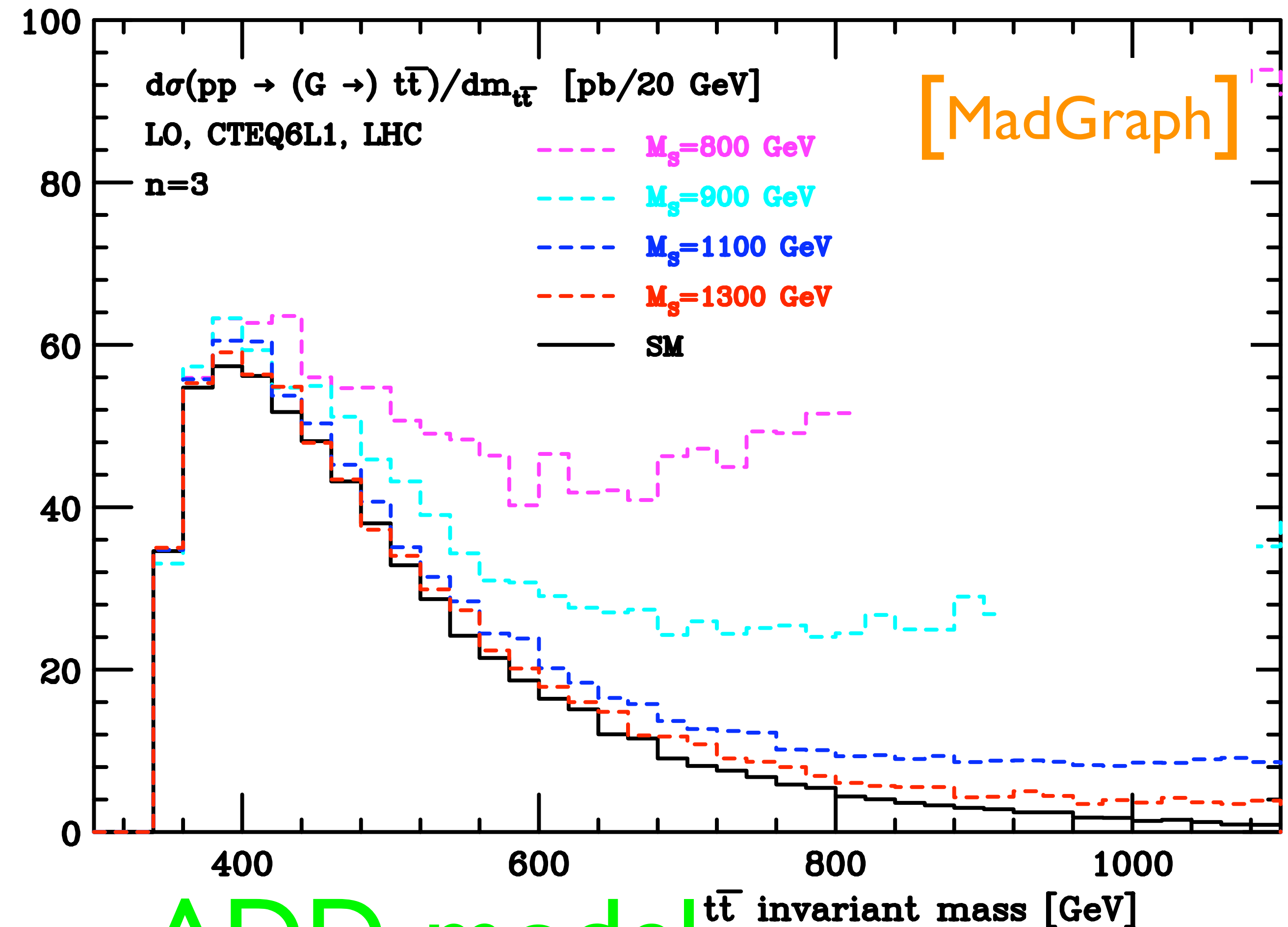
Manohar & Wise 2006
Gresham & Wise 2007

Pseudo-scalar, Color singlet

Gaemers & Hoogeveen 1984
Dicus, Stange & Willenbrock 1994

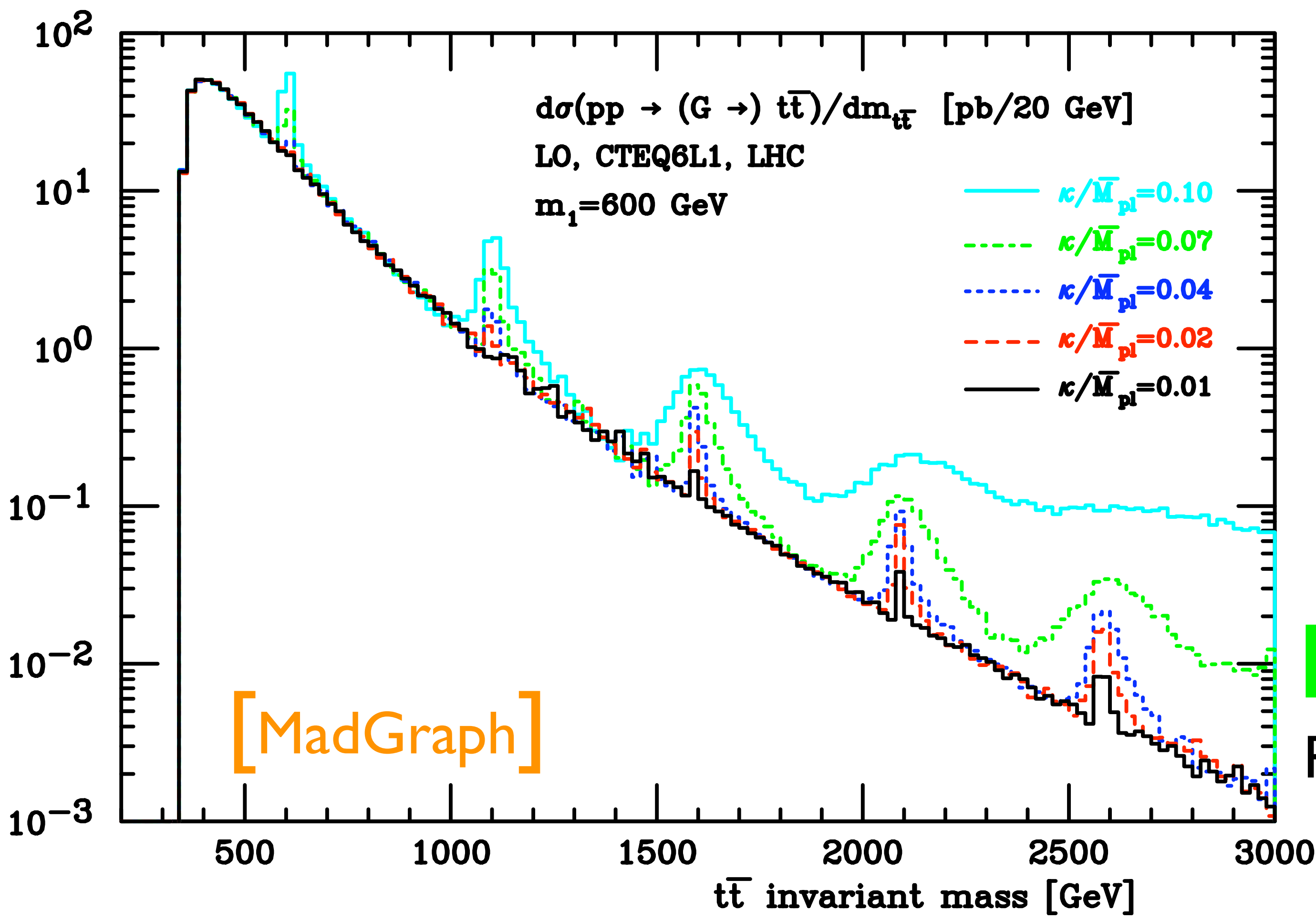
Spin-2 resonance





ADD-model

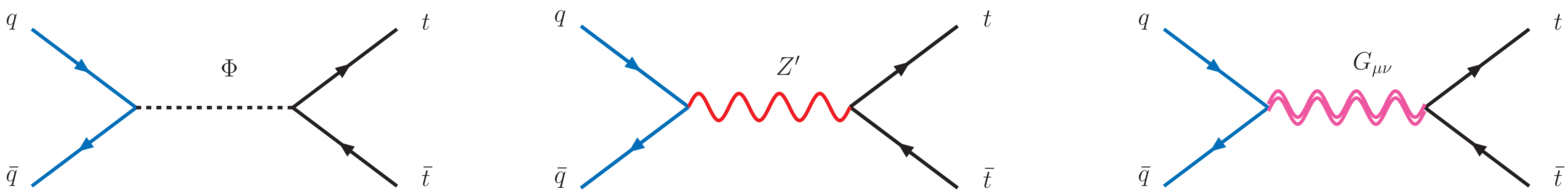
Arkani-Hamed, Dimopoulos & Dvali 1998



RS-model

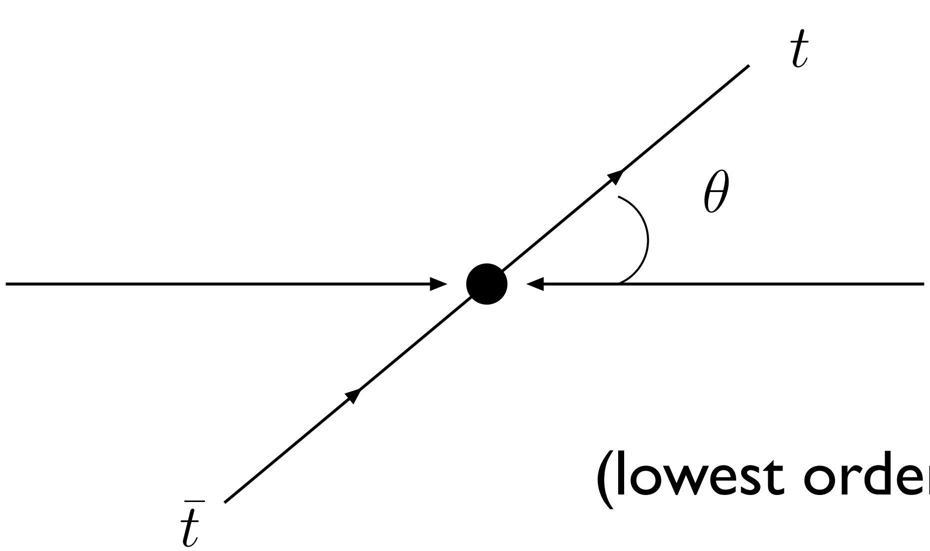
Randall & Sundrum 1999

Spin correlations
from top directions



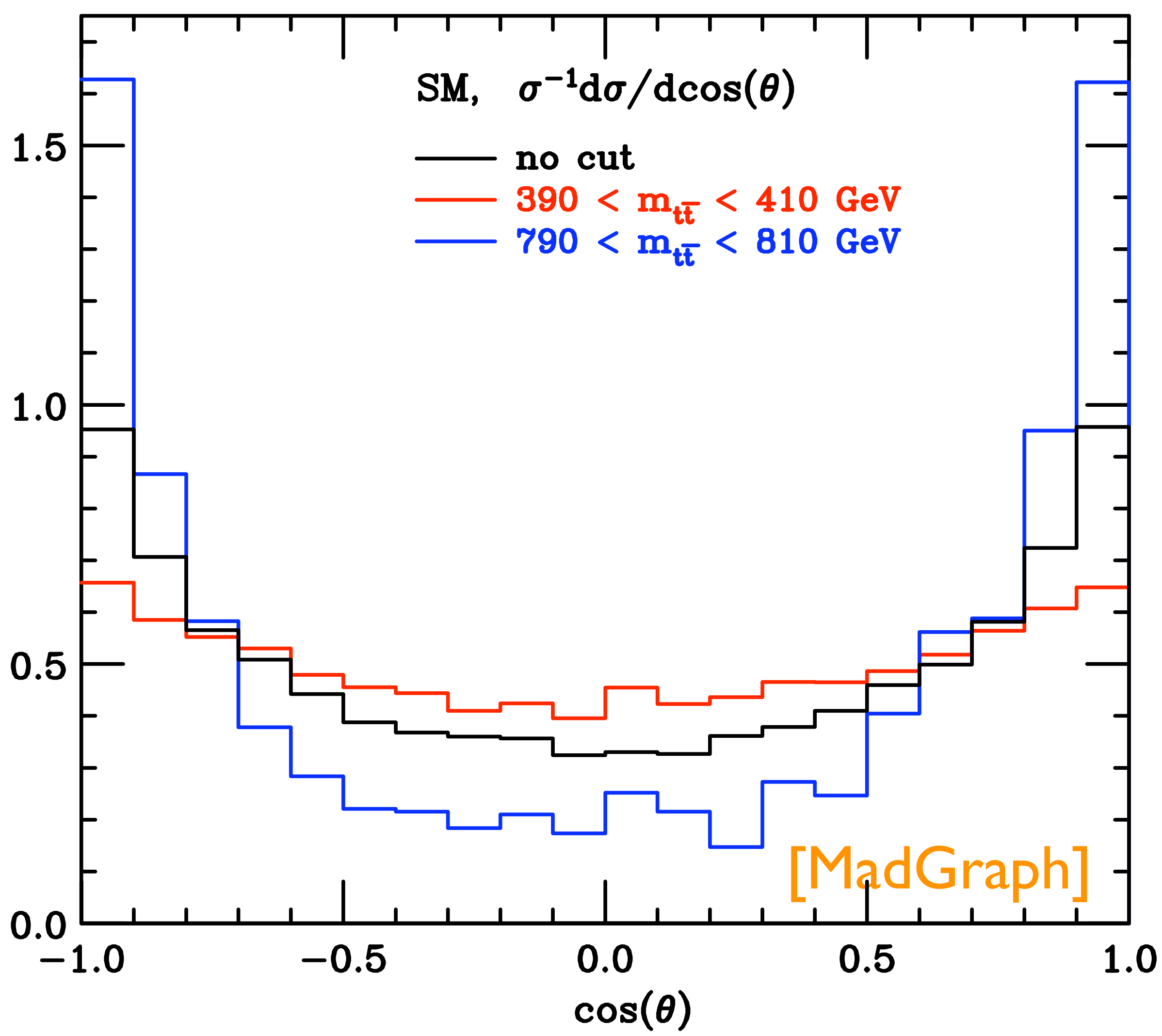
How to extract the spin information about the resonance?

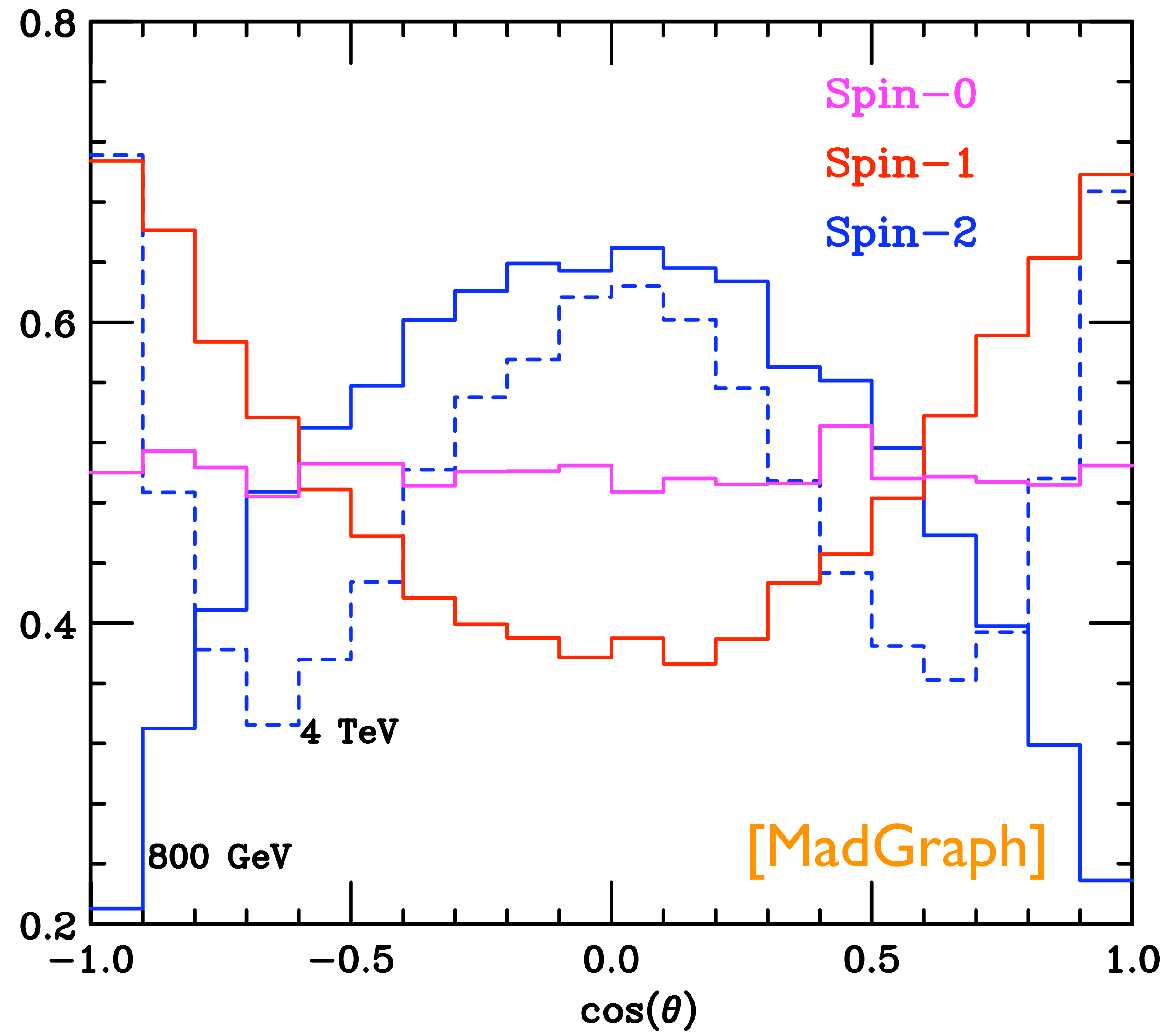
Measure the Collins-Soper angle:



(lowest order)

Collins-Soper angle
in top pair production





LHC

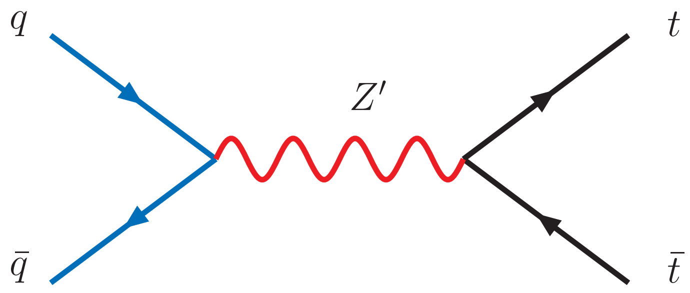
Conclusions

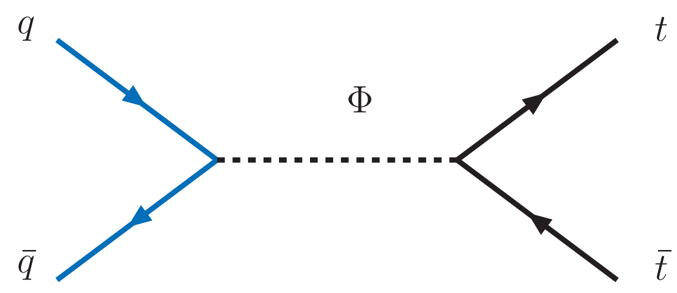
- MadGraph/MadEvent is an event generator that is:
  - Multi purpose, new models are easy to implement
  - Complete, interfaces from model to detector simulation
  - User friendly, due to the web interface
  - Fast, thanks to the cluster oriented structure
  - Open, everybody can contribute!

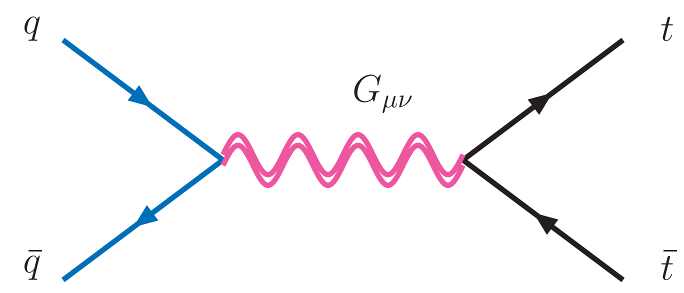
See also the three operational cluster at
http://madgraph.phys.ucl.ac.be
http://madgraph.hep.uiuc.edu
http://madgraph.roma2.infn.it

Back-up slides

Spin correlations from top decays

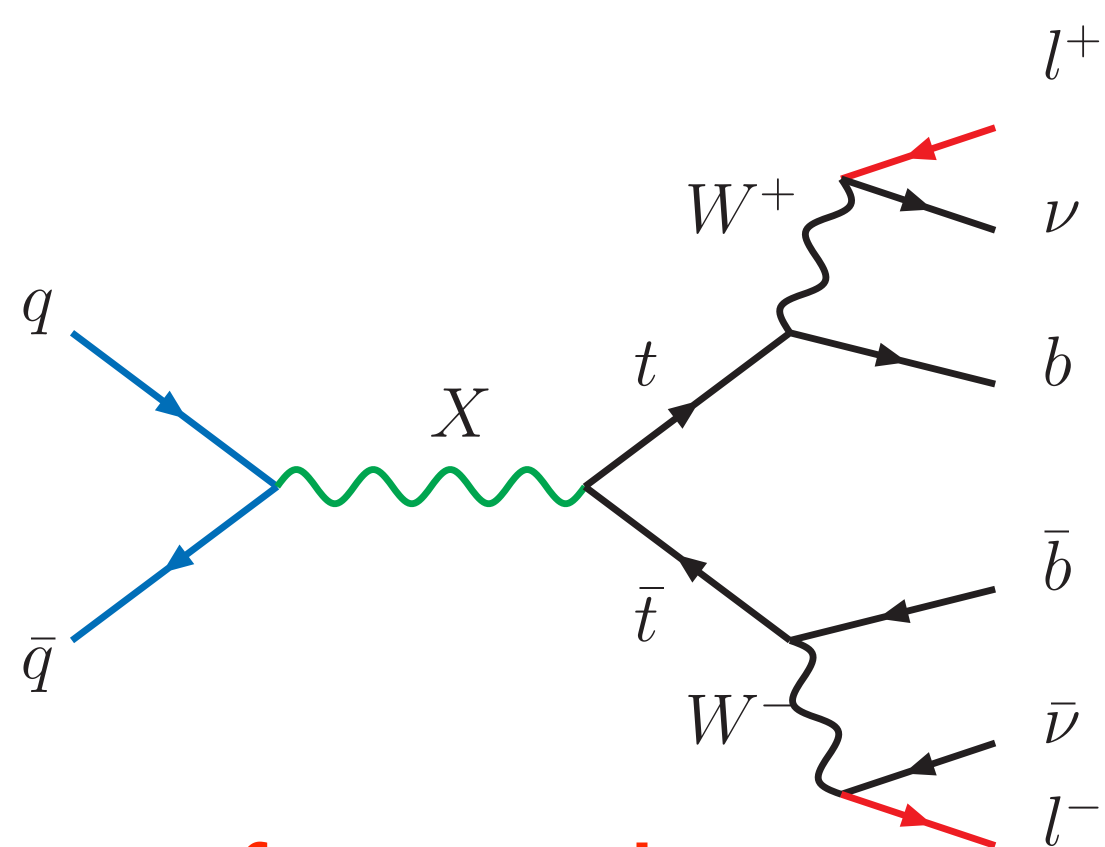






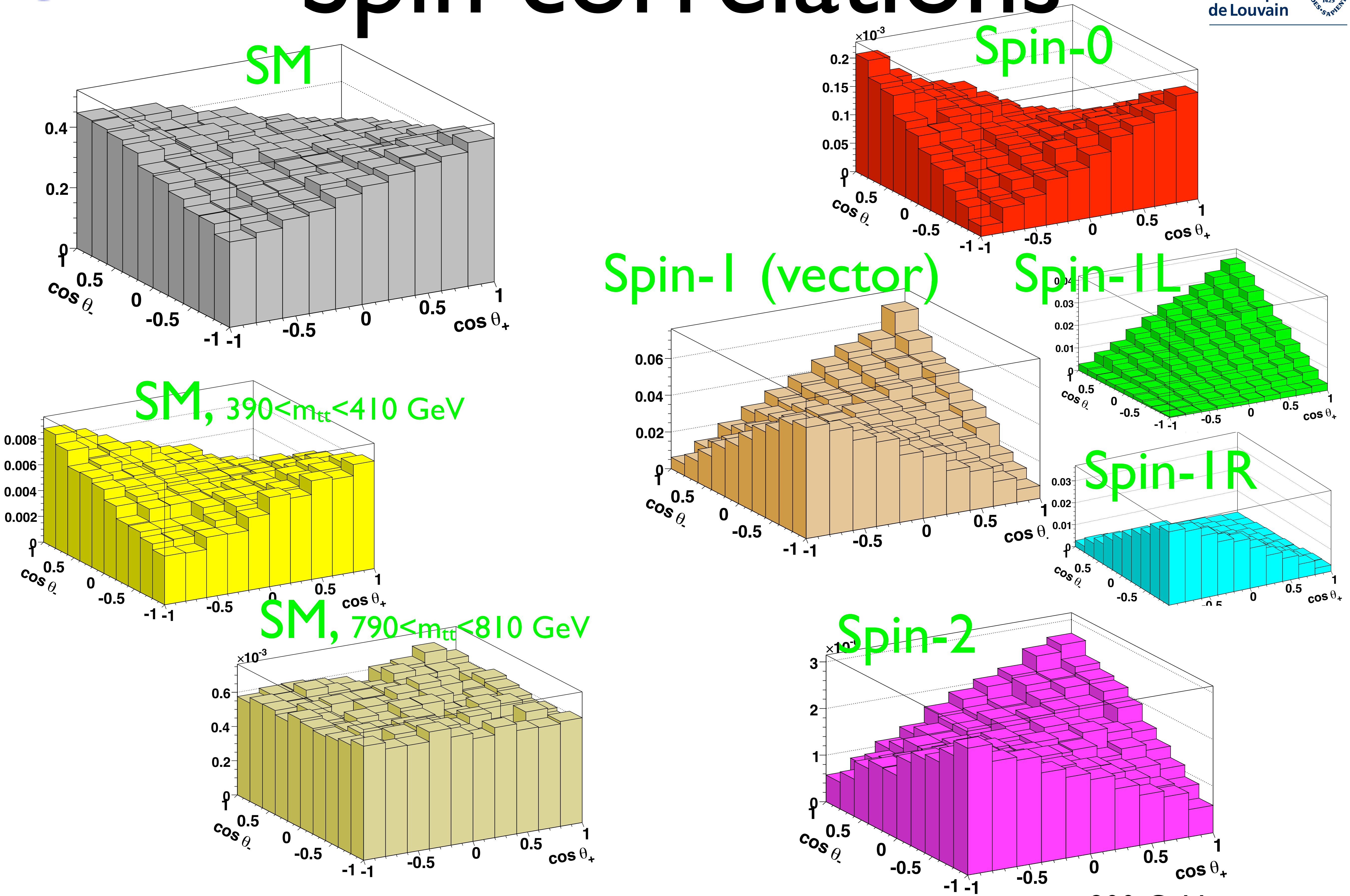
How to extract the spin information about the resonance?

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



Gives also info about parity for spin-1 resonances

Spin correlations



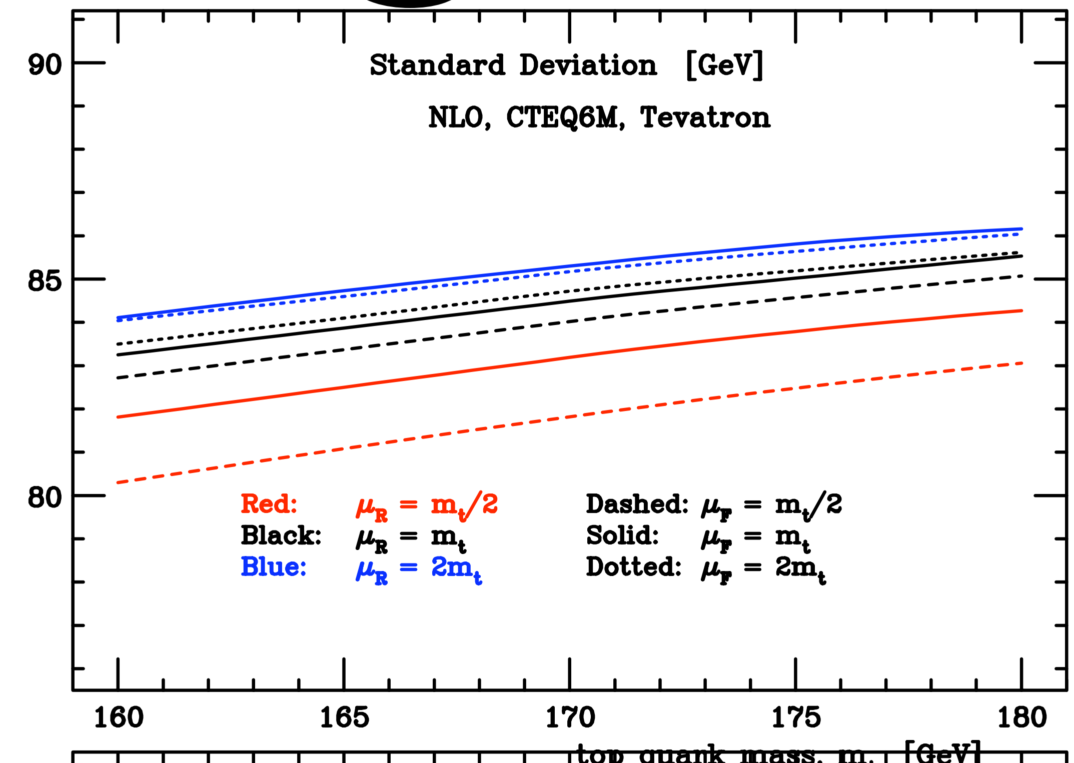
800 GeV resonances

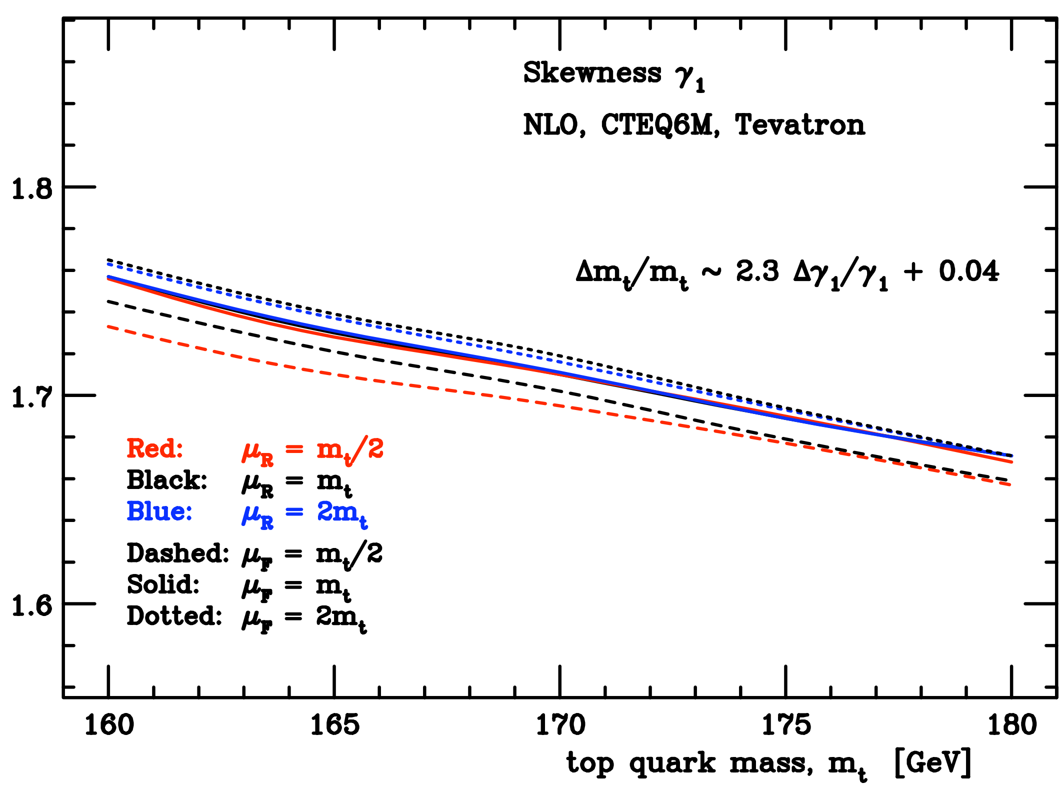
Top mass from higher moments @ Tevatron

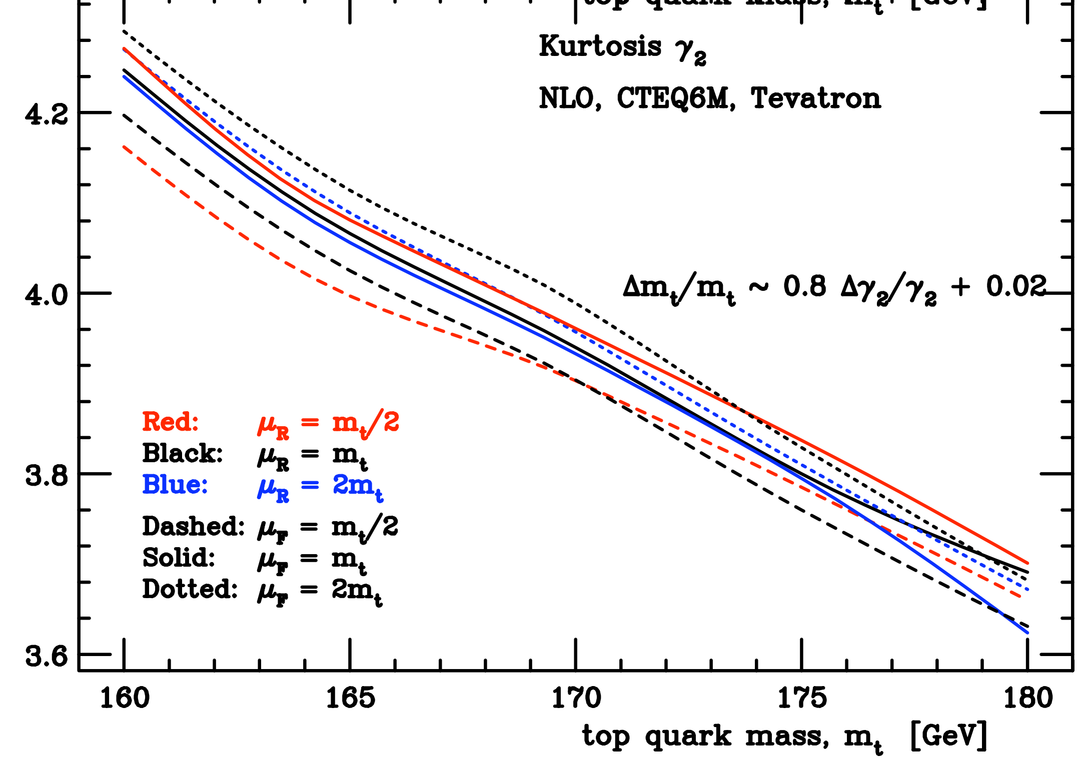
$$s = \sqrt{\mu_2}, \qquad \gamma_1 = \frac{\mu_3}{\mu_2^{3/2}}$$ and

$$\gamma_2 = \frac{\mu_4}{\mu_2^2} - 3,$$ where

$$\mu_n = \int \mathrm{d}m_{t\bar{t}} \left(m_{t\bar{t}} - \langle m_{t\bar{t}} \rangle\right)^n \frac{\partial \sigma}{\partial m_{t\bar{t}}}\Big|_{\rm norm.}$$







Top mass
from higher moments @ LHC

$$s = \sqrt{\mu_2}, \qquad \gamma_1 = \frac{\mu_3}{\mu_2^{3/2}}$$ and

$$\gamma_2 = \frac{\mu_4}{\mu_2^2} - 3,$$ where

$$\mu_n = \int \mathrm{d}m_{t\bar{t}} \left(m_{t\bar{t}} - \langle m_{t\bar{t}} \rangle\right)^n \frac{\partial\sigma}{\partial m_{t\bar{t}}}\Big|_{\text{norm.}}$$