$t\bar{t}$ production studies with various MC's

K.Cranmer, Yaquan Fang, B.Mellado, S.Paganis,
W.Quayle, Sau Lan Wu

University of Wisconsin

MC Tools for the LHC, CERN, July 2003

Outline

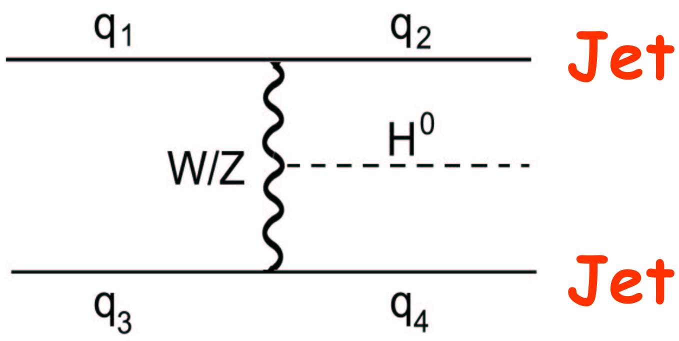
- Motivation

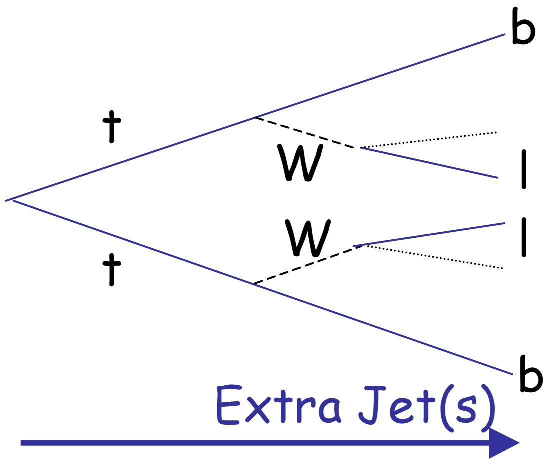
- Matrix Element (ME) and Parton Shower (PS) matching for pp->X+everything:

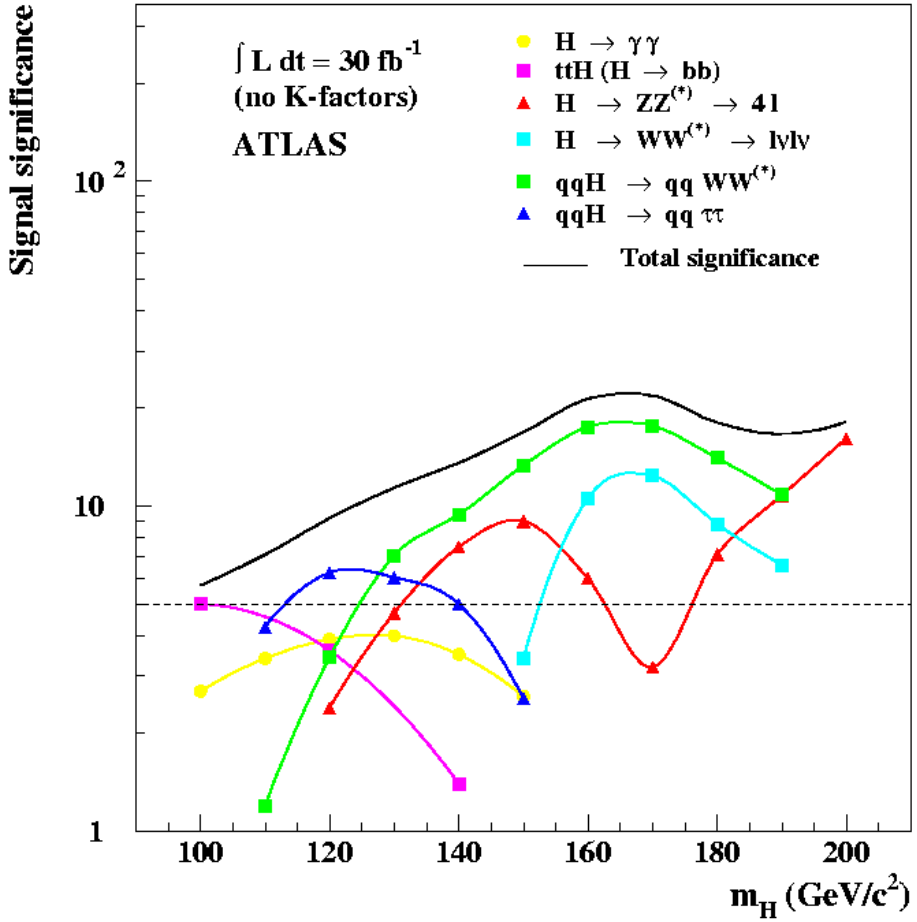
  1. Wisconsin-Rainwater: use a cutoff p_t to match X+nJets+PS to X+(n+1)Jets+PS (n=0,1)
  2. MC@NLO: use exact NLO ME calculation for certain final states X, interfaced with a PS Monte Carlo which produces the full final state

- Apply for X=tt, compare with other MC's

tt major background to the Higgs search (example: VBF->Higgs)







tt major background to the Higgs search

pp->tt+X comprises ~2/3 of the VBF H->WW background!
Parton level estimates of H -> WW tt background give (D. Rainwater):

2% tt, 80% tt+1jet, 18% tt+2jets

- Must understand extra jet emission in tt events
- PS programs are expected to do well for the soft/collinear emissions but not for the hard emissions
- QCD Hard Process in pp is currently treated by exact LO Matrix Element calculations $\rightarrow$ hard gluon radiation present at NLO could be missed
- Use higher (than LO) order for the calculation of the hard process ME

Monte Carlo studies

- Match LO QCD Matrix Elements for pp -> X+nJets with a Parton Shower MC using a low p_t cutoff and merge the pt spectrum smoothly (July/02 Atlas Higgs WG).
  - Apply for X=tt and compare to PYTHIA

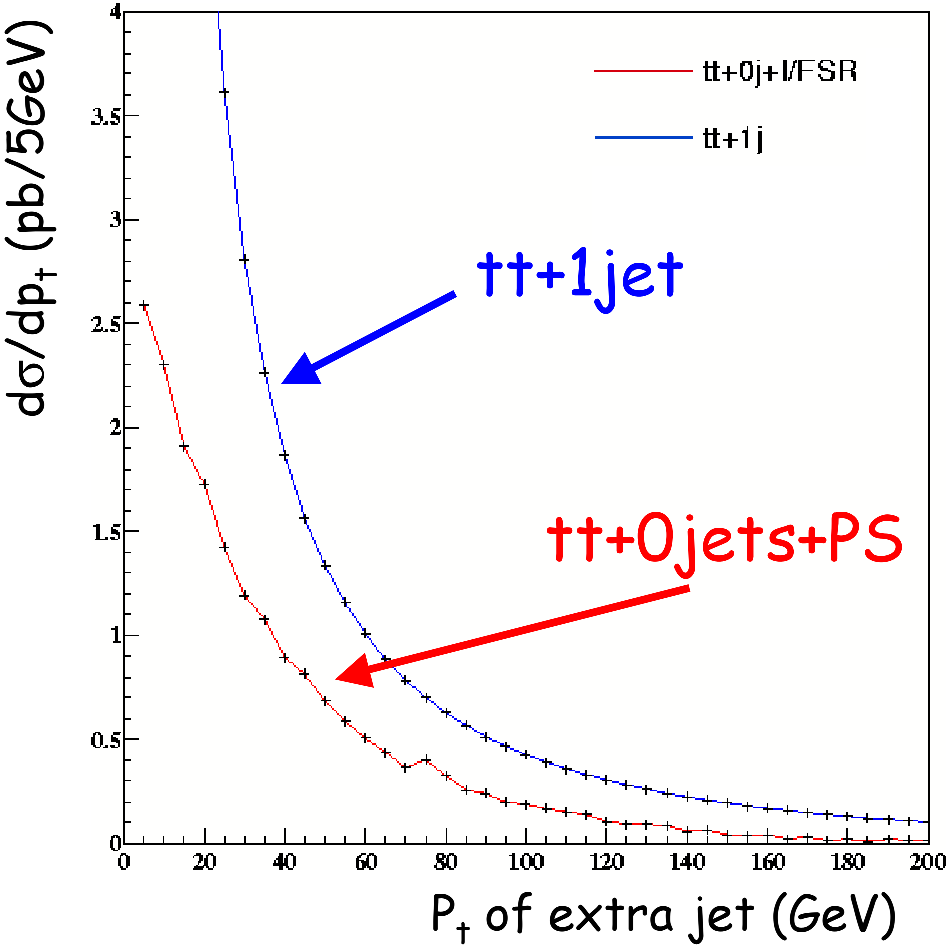
- Use MC@NLO to study tt production and compare it to HERWIG and PYTHIA MC's:
  - Compare recoil tt system p_t
  - Compare $\Delta\phi$ between t and tbar
  - Compare the leading jet p_t reconstructed by ATLAS

ME-PS matching: tt+0,1,2 jets

- Generate events with a MC generator (calculating the LO ME of pp->tt+nJets and then using PYTHIA) as follows:
  - tt + 0jet + Parton Shower
  - tt + 1jet + Parton Shower
  - tt + 2jets + Parton Shower

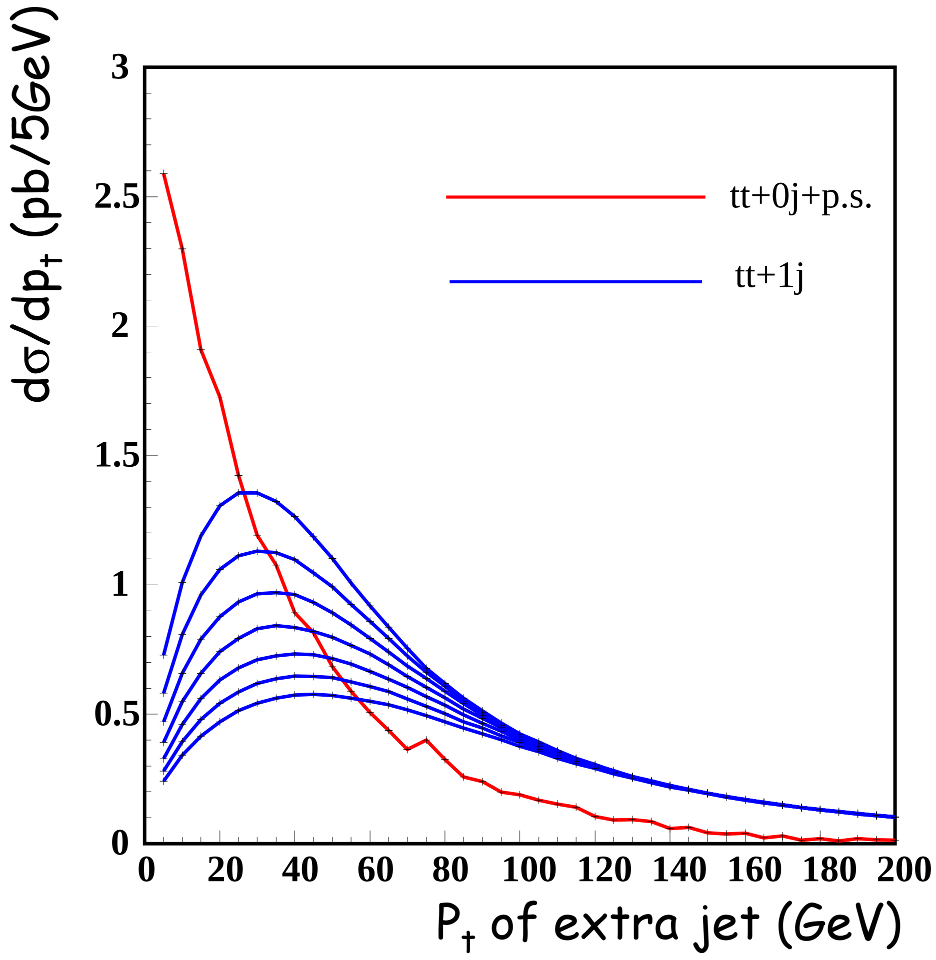
- Choose a (low) value of p_t (p_{Trans}) and generate events:
  - When $p_t < p_{Trans}$ for all jets, use tt+0jet+PS
  - When $p_t < p_{Trans}$ for all but leading jet, use tt+1jet+PS
  - When $p_t > p_{Trans}$ for both jets, use tt+2jets+PS

How to determine the matching p_{Trans}



- Use tt+1j from MC (no shower)
- The divergence at low p_t for tt+1j prevents crossing of the two distributions. The selection of a p_{Trans} here will lead to a discontinuity.
- One solution is to use a suppression factor for the tt+1j distribution that regulates the low p_t behaviour.
- The dependence on the choice of the p_{Trans} has to be understood

Suppression factor and p_{Trans}

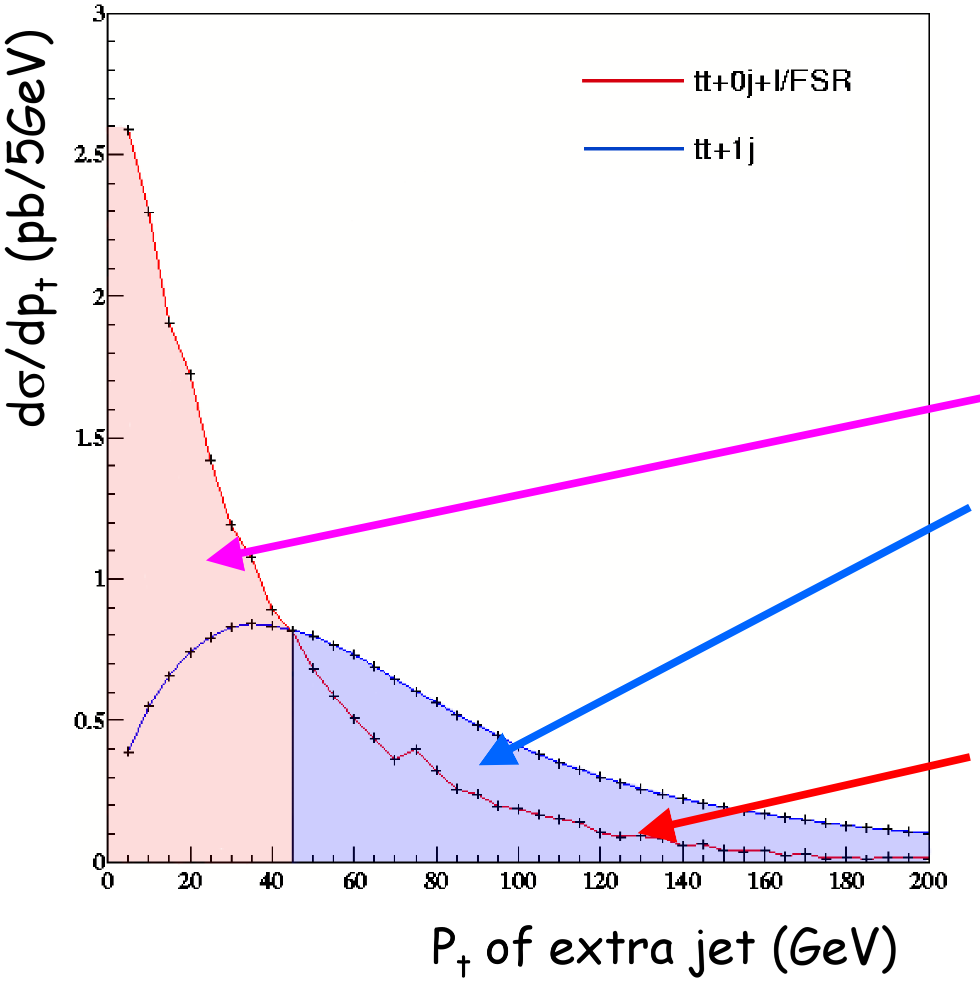


- Apply suppression factor for tt+1j case:

$$M_{t\bar{t}+1j} \rightarrow M_{t\bar{t}+1j} \cdot \left(1 - e^{-p_{t,jet}^2 / P_{T0}^2}\right)$$

- p_{T0} is chosen to minimize the kink in $d\sigma/dp_t$
- p_{T0}=55 GeV was chosen
- Variation of p_{T0} leaves the high p_t region unaffected

tt+0jet and tt+1jet matching (demo)



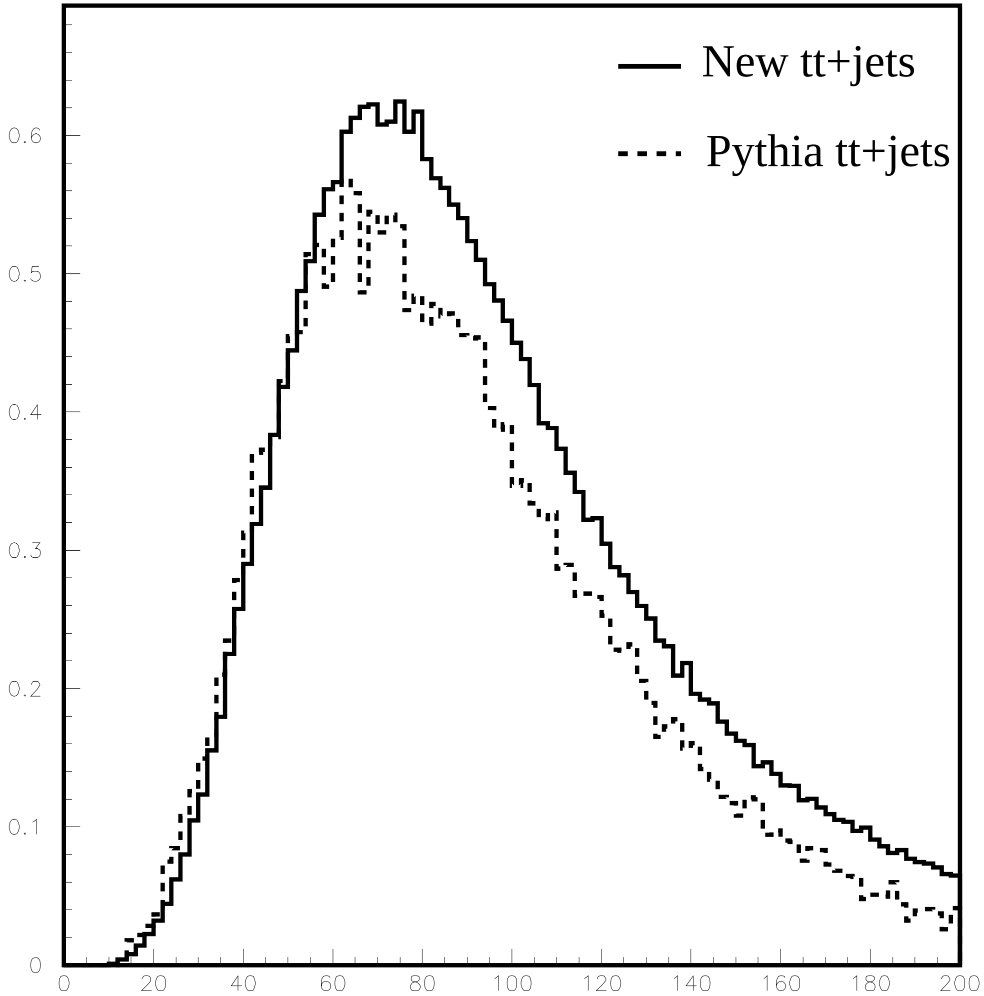
- For the chosen suppression factor the curves now cross at p_t=45 GeV

Cross-sections

- tt+0jet (matched): 14.51 pb
- tt+1jet (matched): 12.39 pb
- Total (matched): 26.90 pb
- tt+0jet (unmatched): 20.8 pb

Consistent with K-factor of 15%

Comparison with Pythia



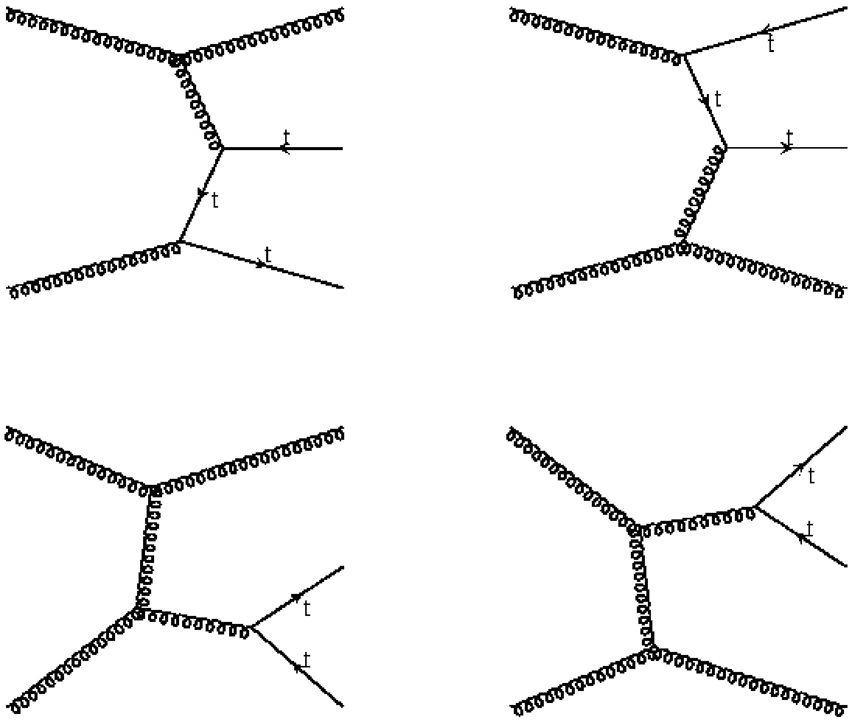
Leading Jet P_t (GeV)

- Pythia tt+jets vs Matched tt+jets: curves normalized to their respective cross-sections.
- 'Leading Jet' is any jet, including b-jets from top decays
- Matched tt+jets produces harder leading jet spectra as expected

hep-ph/0305252

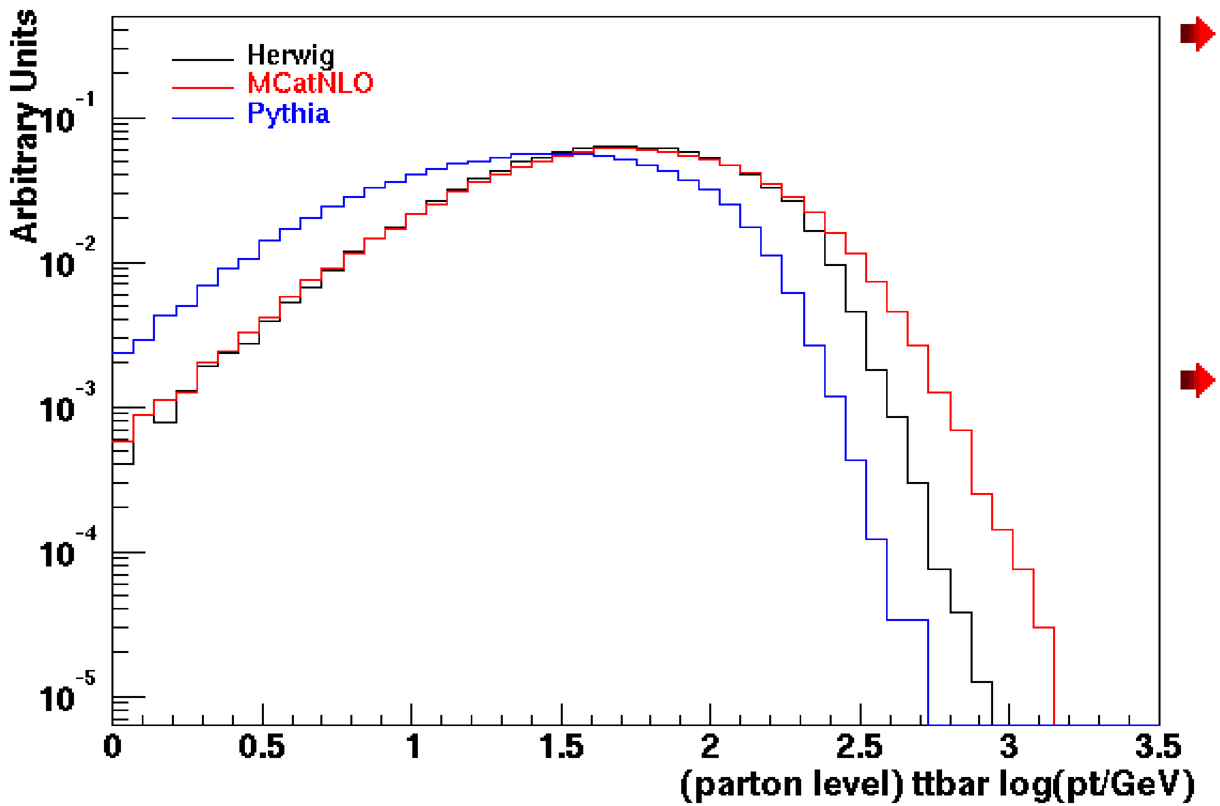
MC@NLO (S.Frixione, P.Nason, B.Webber)

Matches the NLO calculation of a given QCD process with a parton shower MC (in this case HERWIG-6.5)

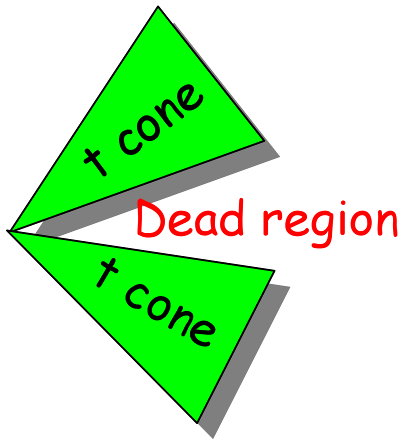


1. Generates fully exclusive events with total rates accurate to NLO
2. Hadronization is performed according to the MC model
3. Hard emissions are treated as in NLO calculations while soft/collinear emissions are handled by the MC simulation with the MC log accuracy
4. Matching between hard and soft/collinear emission regions is smooth

tt system (recoil) p_t distribution

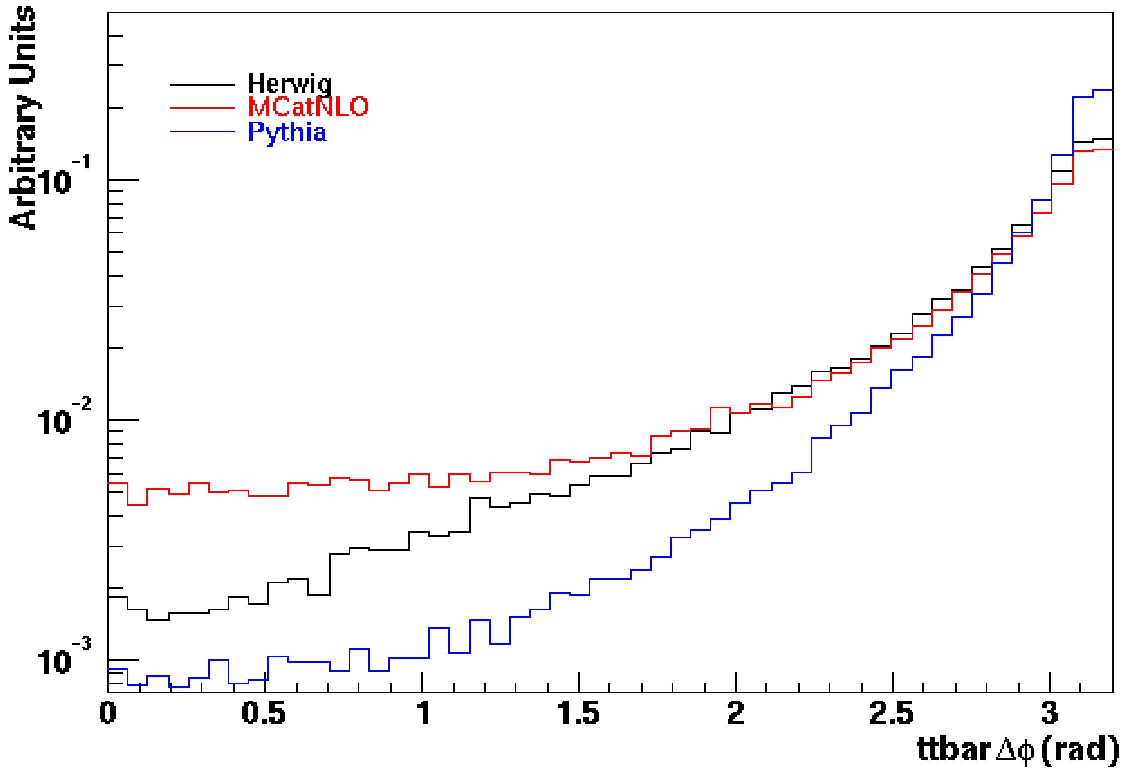


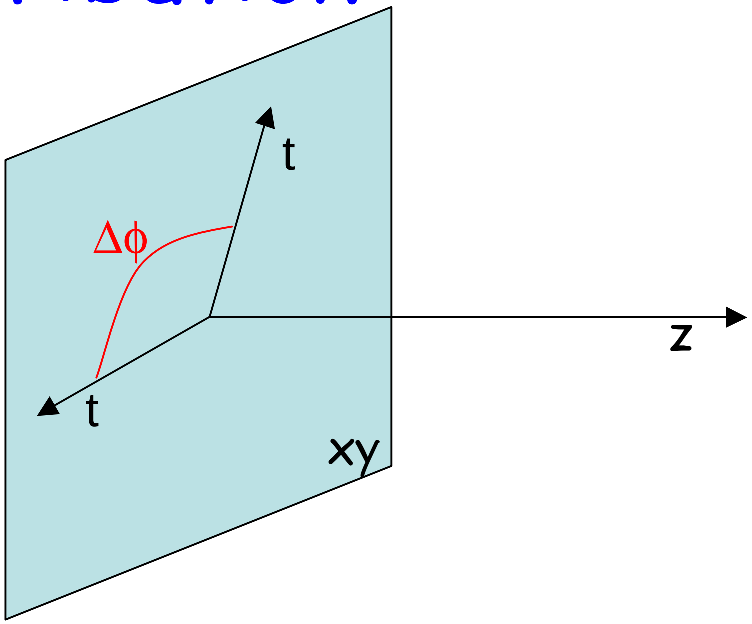
- MC@NLO cross-section much larger than MC (Herwig) at large recoil pt: hard emissions are correctly treated in NLO
- Pythia completely disagrees with Herwig



Why Herwig PS fails at high pt: gluon radiation is confined within angular regions specified by the color flow.
Hard non-collinear emissions are missed.

tt system Δφ distribution

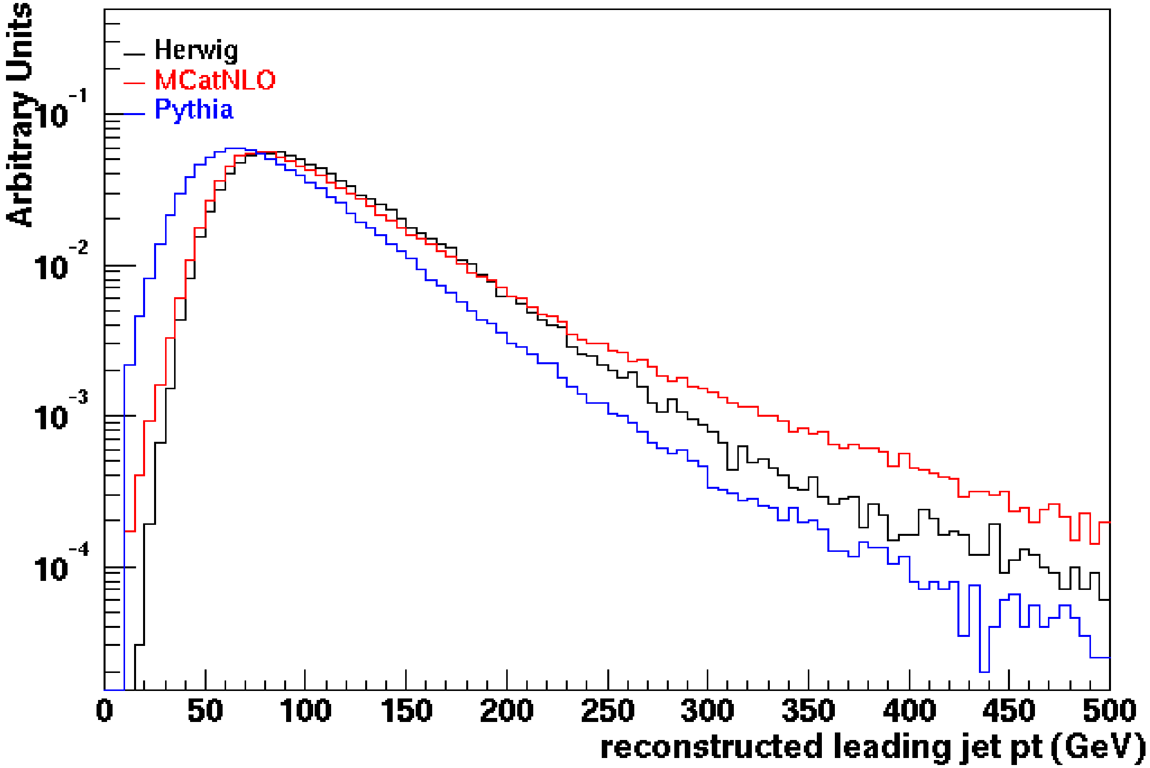




- MC@NLO: small azim. angle region is more populated due to the increase in the hard single parton emission at NLO.
- Pythia predicts an almost back-to-back tt system

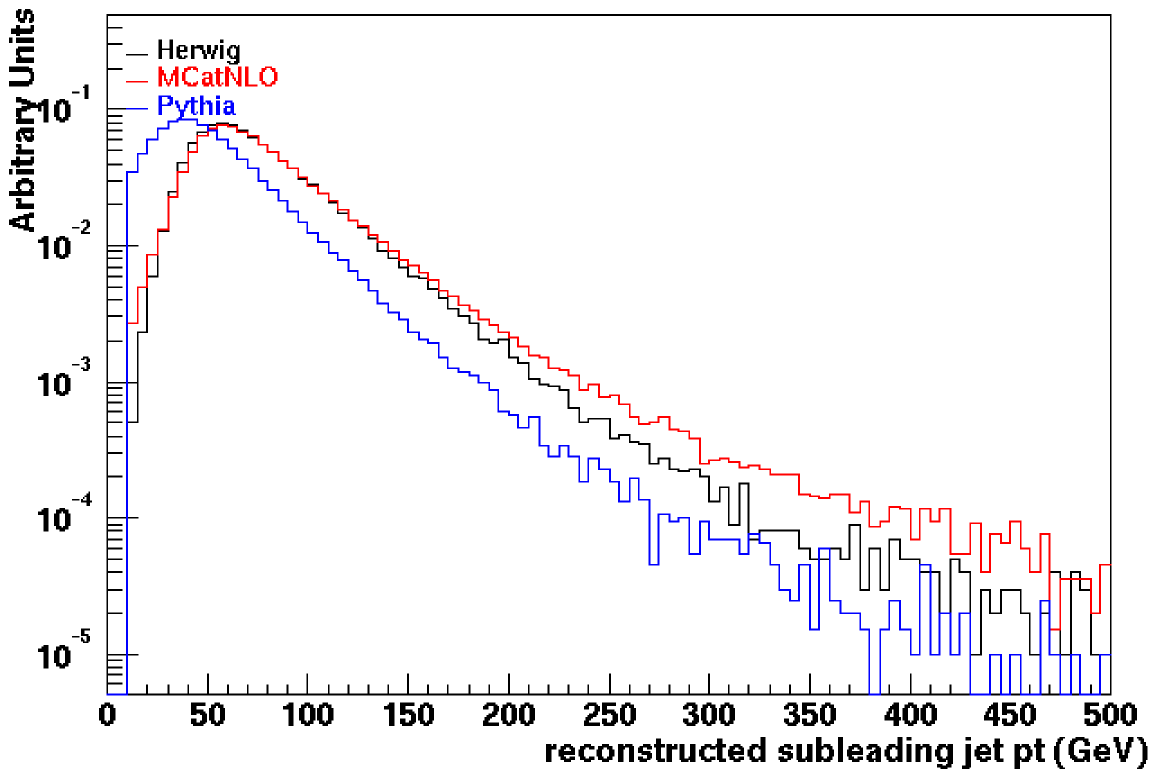
Leading Jet p_t in ATLAS

(AtlFast, no b Jet veto)



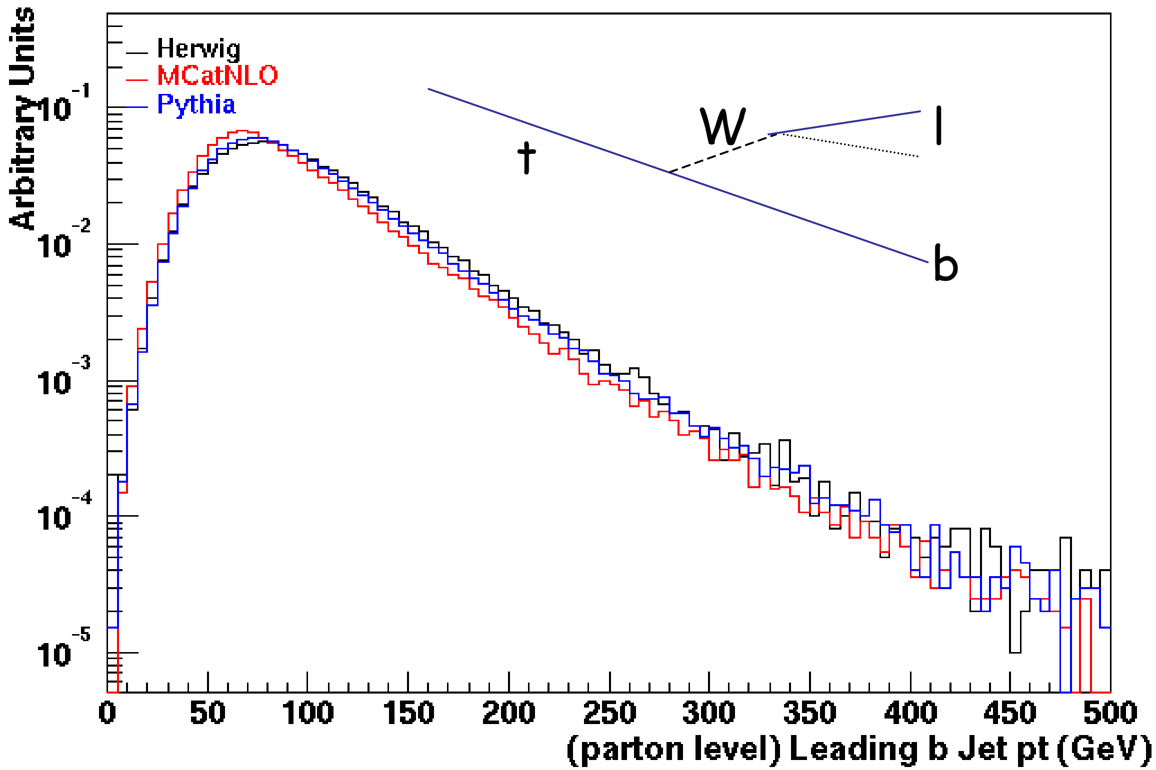
- MC@NLO: produces more hard jets than HERWIG for pt>250 GeV
- Pythia high p_t tail is also significantly lower than the MC@NLO

Subleading Jet p_t in ATLAS

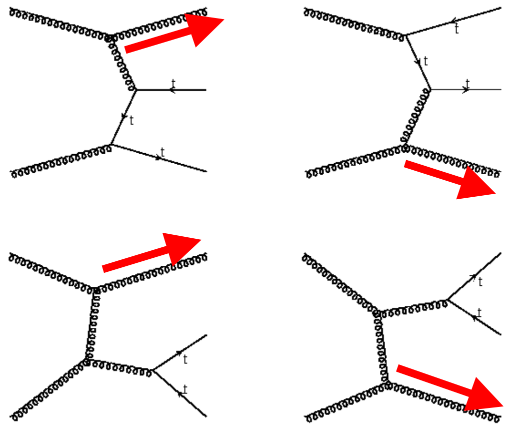


- MC@NLO: still produces harder subleading jets but now the difference with HERWIG is smaller.

Where do these extra jets come from?



- Herwig and Pythia agree on the p_t distributions of the b quark coming from the top decays. MC@NLO b p_t is somewhat softer.
- Extra hard jets come from radiation from the hard process treated by the NLO part of MC@NLO



Summary

- Herwig and Pythia (LO ME) vs MC@NLO and matched tt+nJet:
  - for tt+nJet, where the jet is not coming from the tt system itself, the cross-section at high jet transverse momenta could be underpredicted by Pythia and Herwig: poor understanding of the background for LHC searches.
- MC@NLO:
  - calculates pp->tt+X at NLO and uses Herwig for PS and hadronization
  - produces more hard jets than Herwig at p_t>250GeV the majority of which come from gluon radiation at NLO.
- Pythia vs Herwig:
  - Agreement in the b quark (from top decay) p_t distributions
  - Large discrepancy between the two MC's at the LHC energies. Pythia predicts softer leading jet spectra than Herwig.