Matrix Elements, Parton Showers and Jet Merging

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Outline

- Motivation/Background
  - Importance of jet matching in MC event generation
  - Merged jets as a sensitive probe of MC modeling
- Two comparative studies on merged jet modeling in MC generators
  - boosted top quark decays
  - QCD multijet events

Motivation

- Modern colliders require increasingly sophisticated MC event generation
  - Large final state jet multiplicities expected
  - Growing importance of jet structure to identify decays of boosted particles

- To what extent can we trust MC generators in potentially tricky regions of phase space?
- Can we identify variables which discriminate between MC models?

Jet Merging

- Jet reconstruction may merge two or more 'low mass jets'
  - Either from a boosted particle decay, or from 'uncorrelated' hard partons

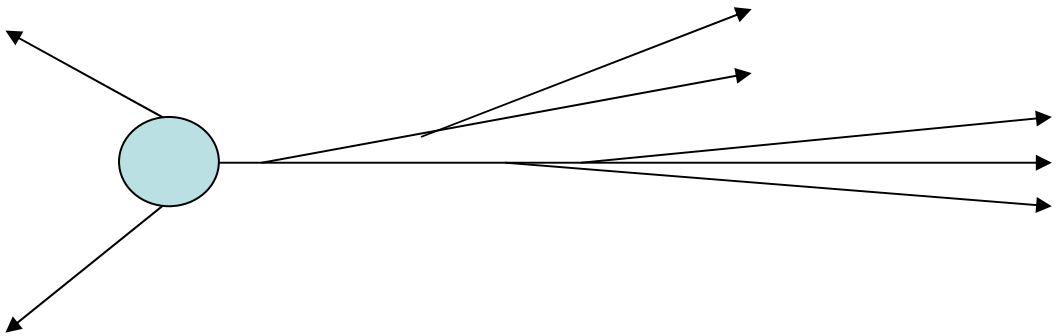
- Merged Jet mass largely determined by p_T and separation of sub-jets
  - May produce a shoulder or peak in jet mass distribution

MC Event Generation

- $2 \rightarrow 2$ Generators (e.g. Pythia, Herwig)
  - Rely on parton shower for additional jet production
  - More difficult to produce large numbers of hard jets

- $2 \rightarrow n$ Generators (e.g. Alpgen, Sherpa)
  - May improve modeling of hard jets and heavy particle decays
  - Inherent double counting problem

ME-PS Jet Matching



Should this radiation be produced in the matrix element or parton shower?

- MLM Matching (implemented in Alpgen)
  - Event generation proceeds without restriction
  - Require hard jets to match parton-level quarks and gluons from matrix element (ME)
- CKKW Matching (implemented in Sherpa)
  - Suppresses the production of hard jets in the parton shower (PS)

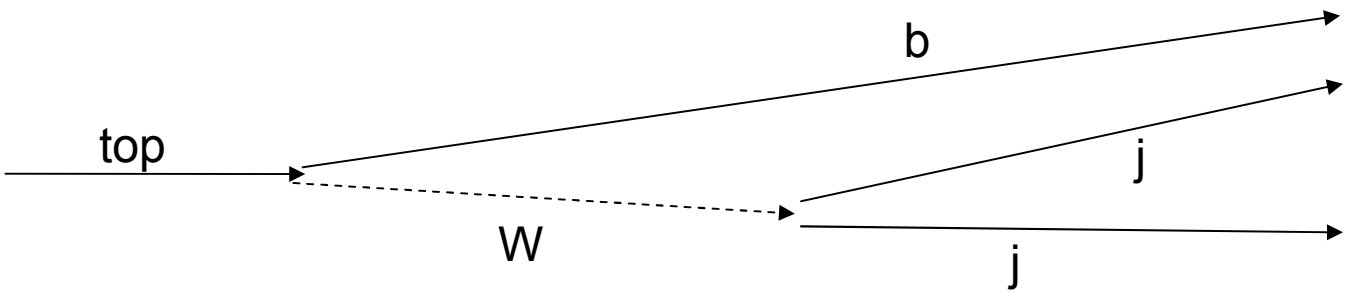
Simulations

- Two data sets have been considered
  - ttbar+jets
    - Jet mergers produced by heavy particle decay
  - QCD multijet
    - ‘uncorrelated’ jet mergers
- 14 TeV center of mass energy pp collisions
- Multiple interactions turned off
- FastJet + SpartyJet used for particle level jet reconstruction
  - D0 Run-II Cone, Anti-k_T, and Cambridge/Aachen jet algorithms

Event Generation: ttbar (+jets)

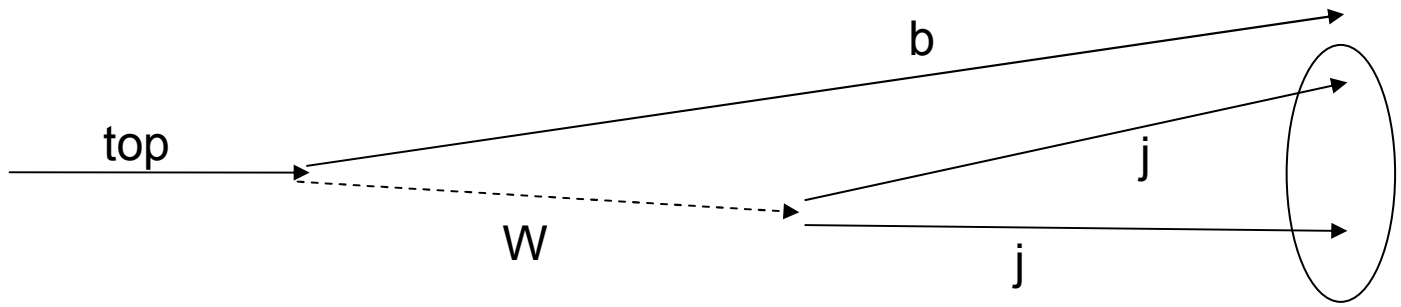
- $2 \rightarrow 2$ generators:
  - Pythia6, Pythia8, Herwig++
- Alpgen: tt + 1,2 Jets
  - MLM merging scale = 25 GeV
  - Tiny cross section for tt+0 jets
  - Parton shower performed by Pythia6
- Sherpa (Comix): tt + 0,1,2 jets
  - CKKW merging scale = 30 GeV

Top Quark Decays and Jet Mergers



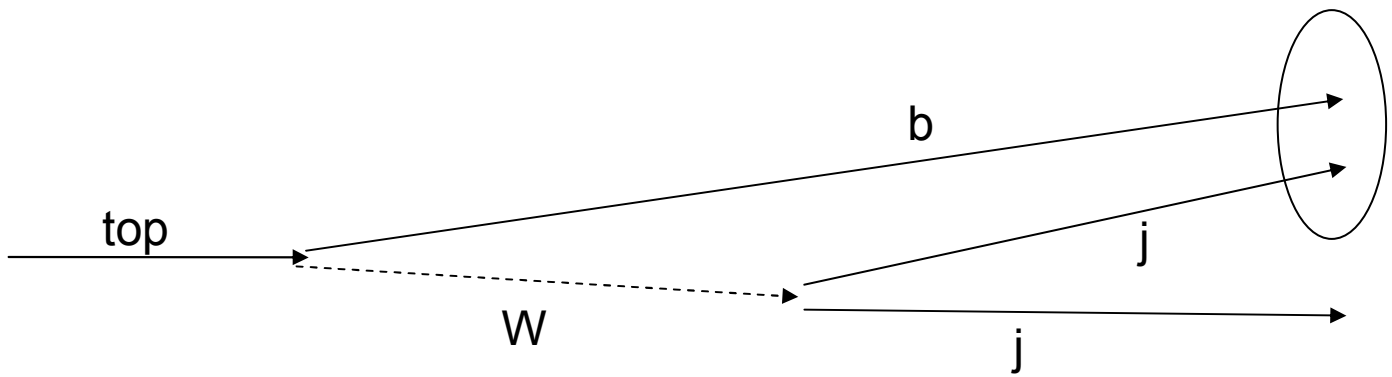
- Top quarks decay hadronically into 3 quarks, through an intermediary W boson

Top Quark Decays and Jet Mergers



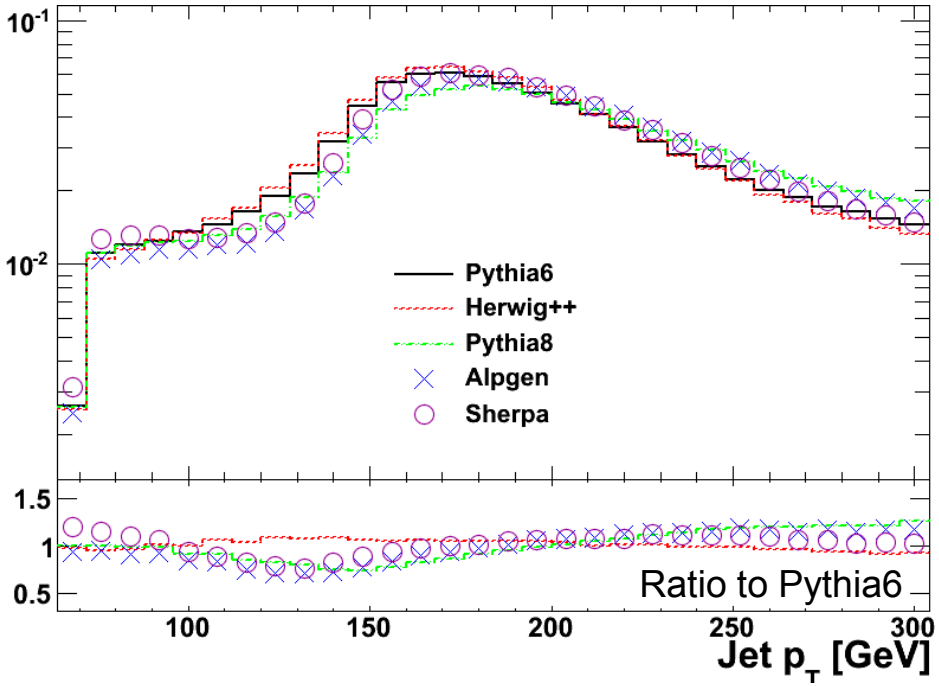
- ‘W-jet’ mergers contain both W boson decay products
  - Separation between parton and jet axis < R
  - May also contain the bottom quark
  - Strongly constrained by decay kinematics
    - Good experimental calibration signal

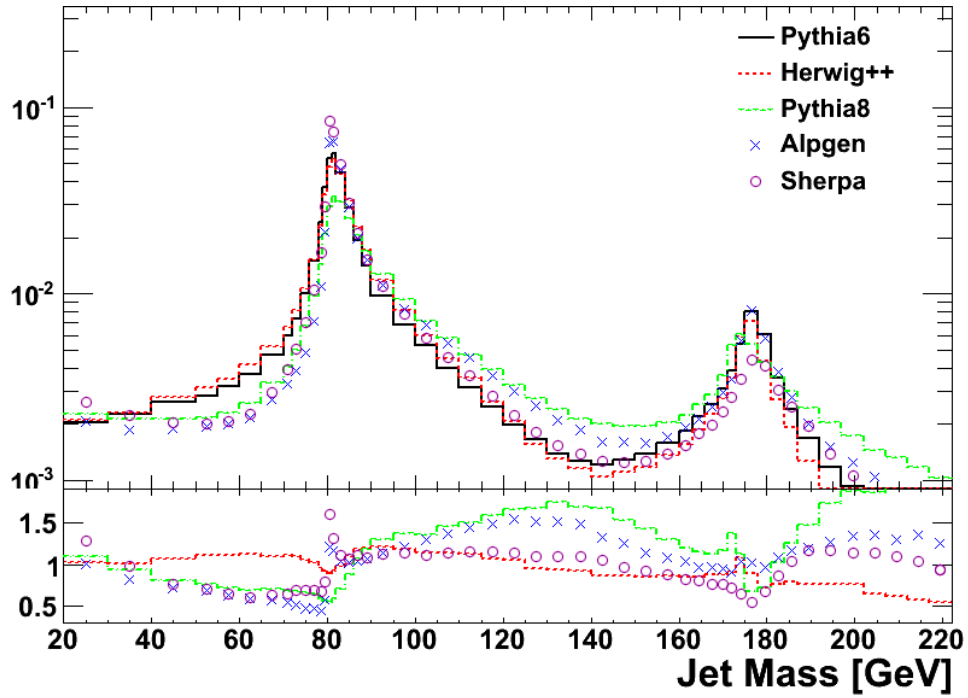
Top Quark Decays and Jet Mergers



- ‘b-jet’ mergers contain bottom quark and a single W boson decay product
  - Less strongly constrained by decay kinematics

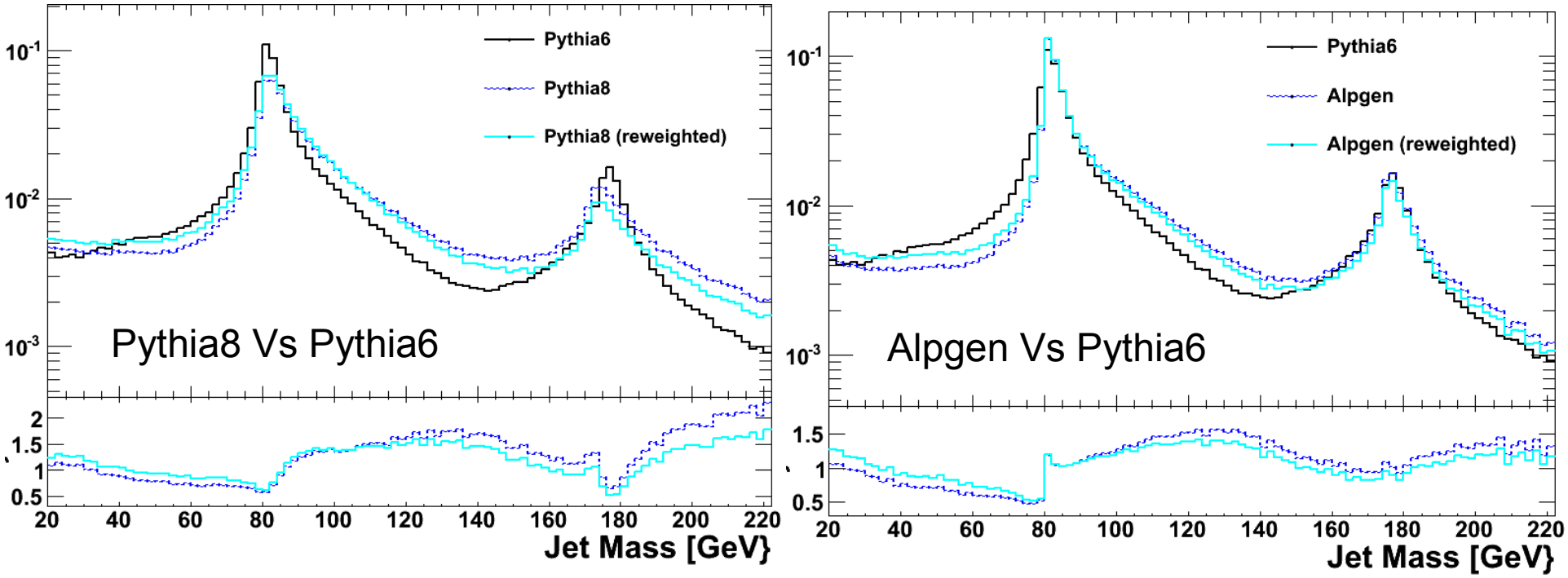
‘Merged W-jets’





- Require both W boson decay products to be contained within the same jet
- $|y|<4.5$, $p_T>70$ GeV
- Cambridge/Aachen R=1.0

P_T Reweighted 'Merged W-jets'

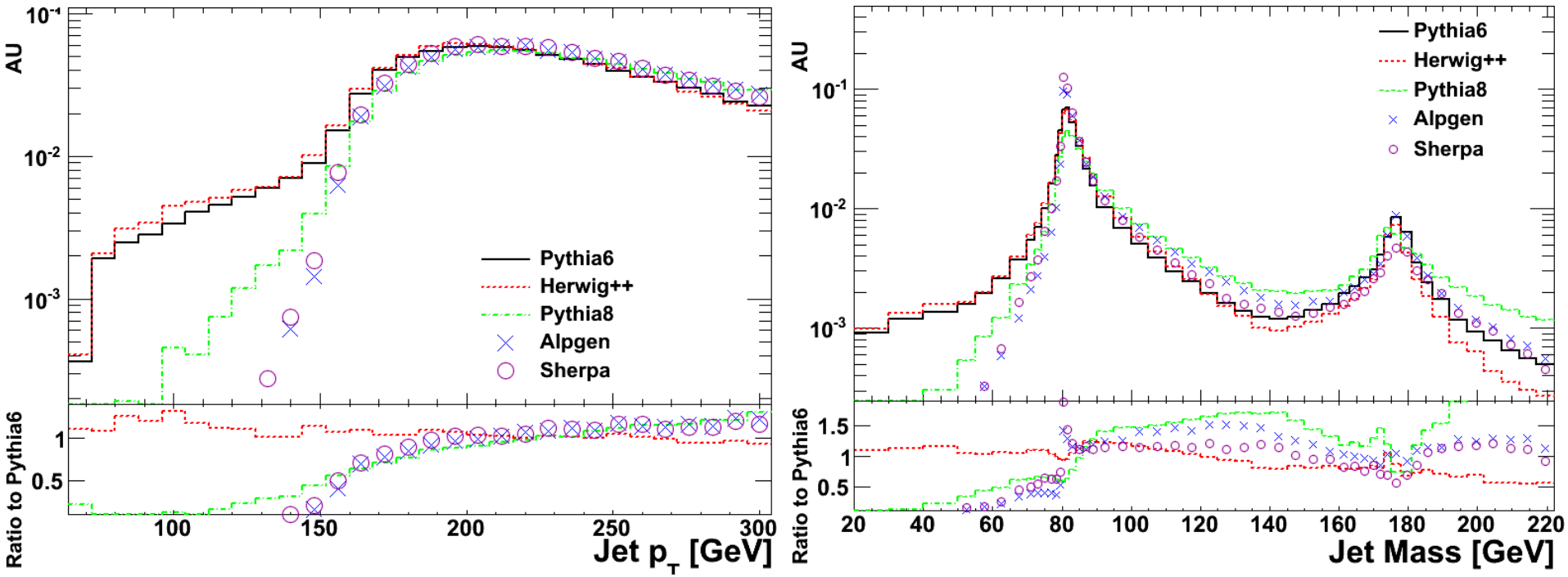


→Little effect

– Large differences remain

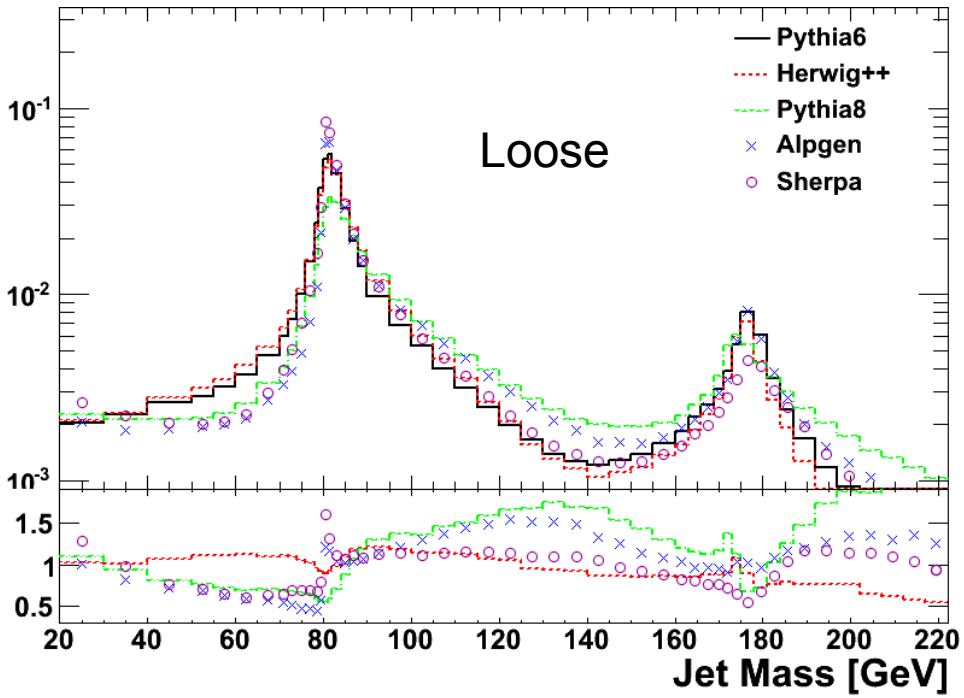
- Cambridge/Aachen R=1.0

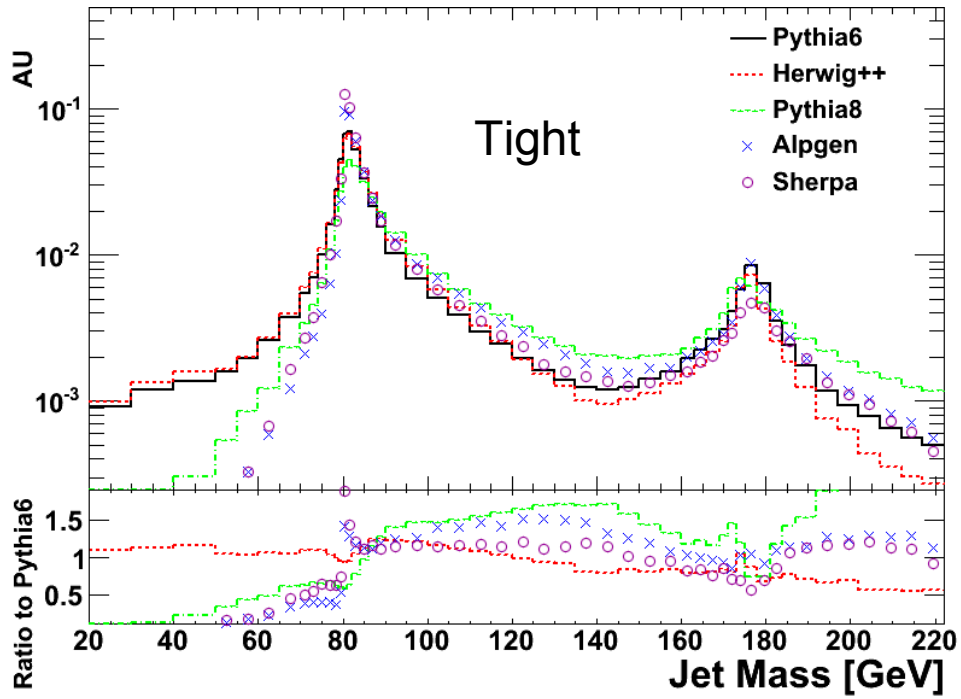
Tightly 'Merged W-jets'



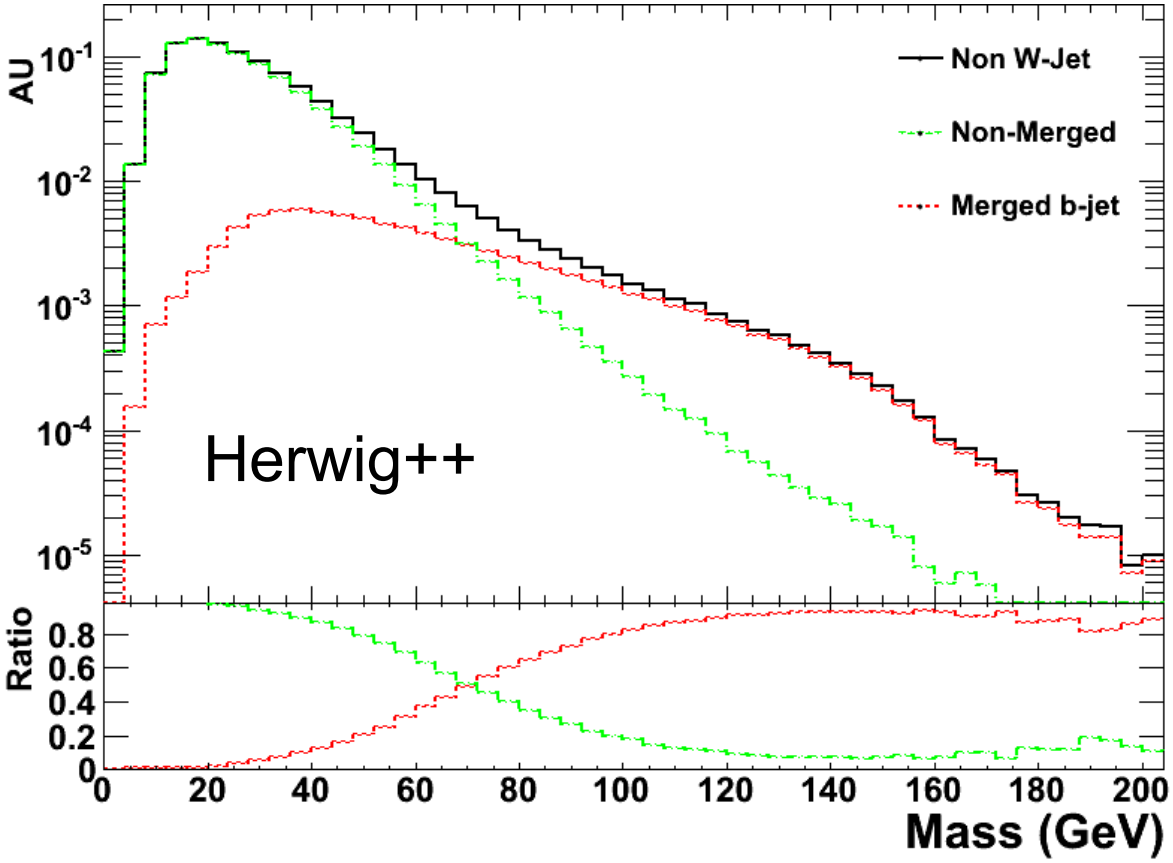
- Require both W boson decay products contained within *half* of the jet radius
- $|y|<4.5$, $p_T>70$ GeV
- Cambridge/Aachen R=1.0

Loose vs. Tight Selection





‘Merged b-Jets’



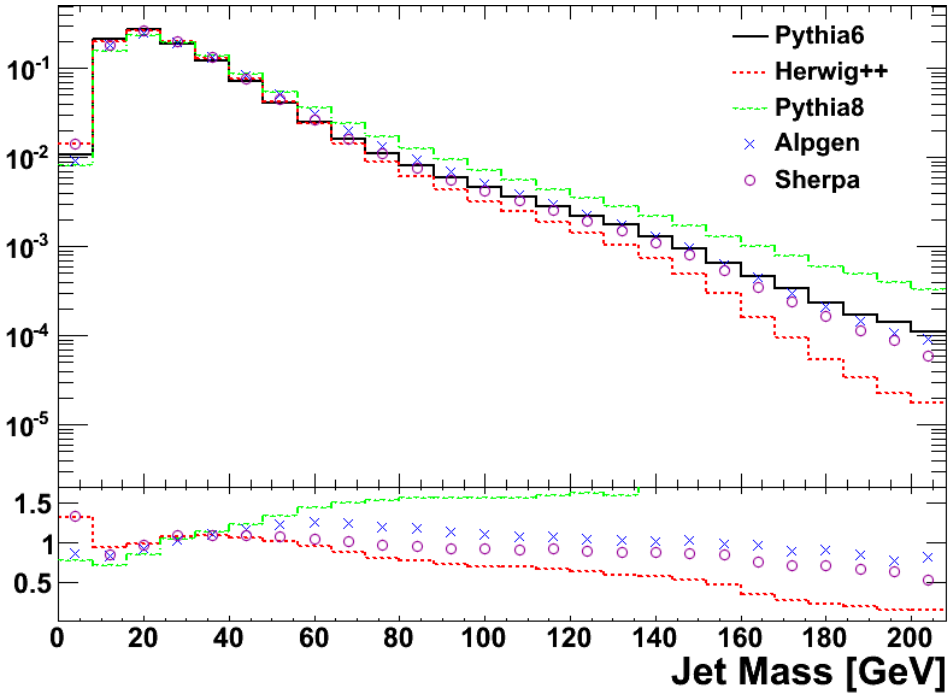
‘Merged b-jets’ contain bottom quark and one of two W boson daughters from the same top quark

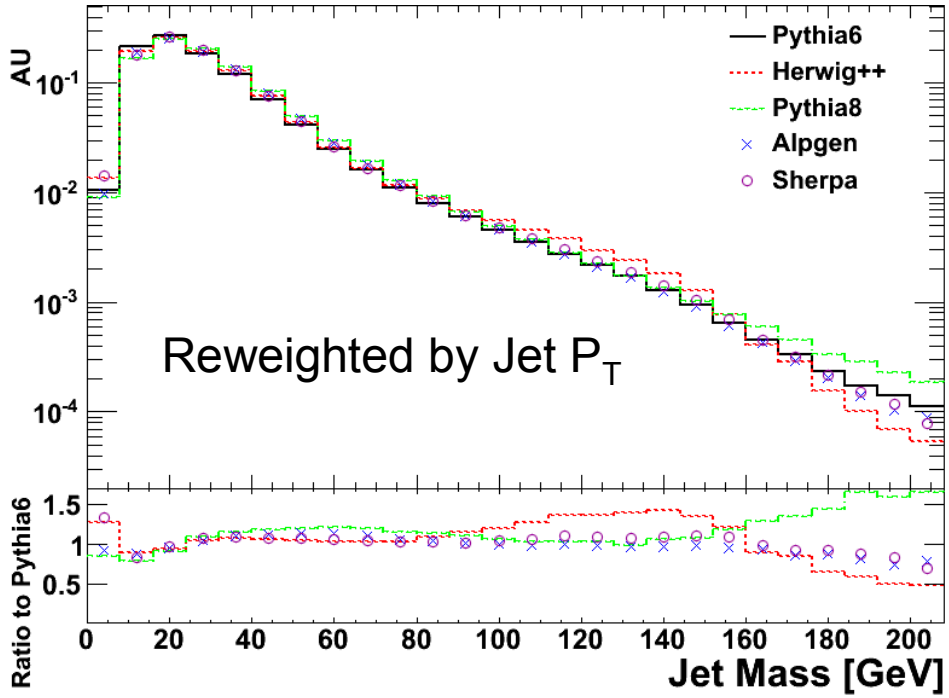
|y|<4.5, pT>70 GeV
Anti-k_T R=0.8

- Shoulder is created by ‘merged b-jets’
- Most obvious in Anti-k_T R=0.8, but present in Cambridge/Aachen as well

- |y|<4.5, pT>70 GeV

Non ‘Merged W-jets’





- $|y|<4.5$, $p_T>70$ GeV
- Anti-k_T R=0.8

QCD MultiJet Analysis Outline

- Need to select interesting events in the face of enormous QCD cross sections
  - Generator level cuts
  - 2 event selection choices
    1. Select events with many small jets
    2. Directly select jets with two smaller sub-jets
- Should be sensitive to jet matching and parton showering

Event Generation: QCD MultiJet

- Pythia6, Pythia8, Herwig++:
  - Hard Process p_T>100 GeV
- Alpgen: 2-5 jet hard process
  - MLM merging scale=48 GeV
  - $|y|<2.0$
- Sherpa(Comix): 2-5 jet hard process
  - CKKW merging scale=30 GeV
  - Parton p_T>60 GeV
  - Leading jet p_T>200 GeV (Anti-k_T R=1.3)

Event Selection 1:

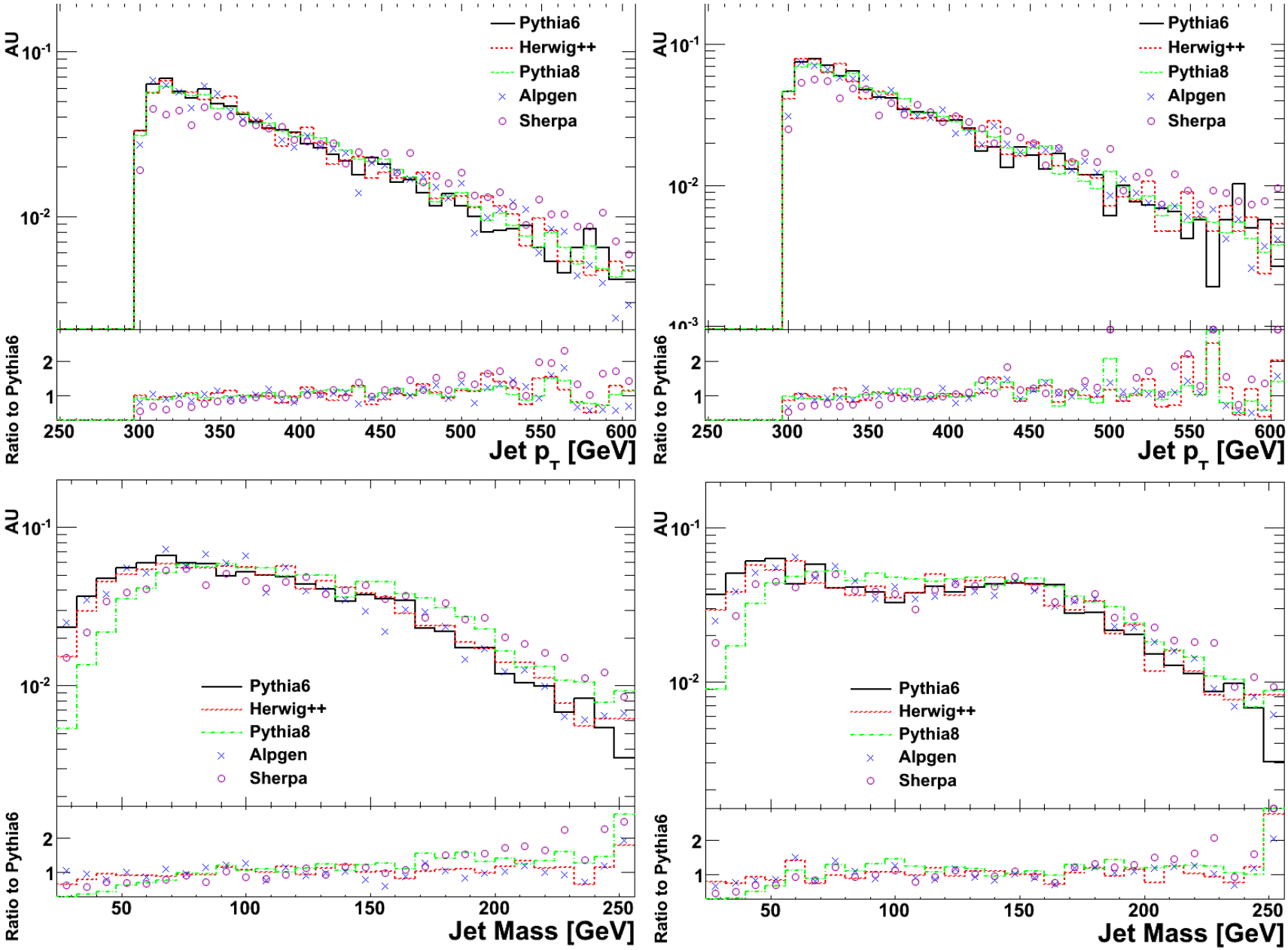
- Apply 'narrow jet' algorithm
  - (either D0 Run II Cone or Anti-k_T R=0.2)
- And a 'fat jet' algorithm
  - (Anti-k_T R=1.0)

- Require leading 'fat jet' in $|y|<1.5$ region to have $p_T>300$ GeV

- Count jets with $|y|<1.5$, require:
  - At least 1 narrow jet with $p_T>170$ GeV
  - At least 4 narrow jets with $p_T>60$ GeV

→Create highly jetty environment where mergers become likely

→Large cross section remains after cuts (~1nb)



Anti-k_T narrow jet selection

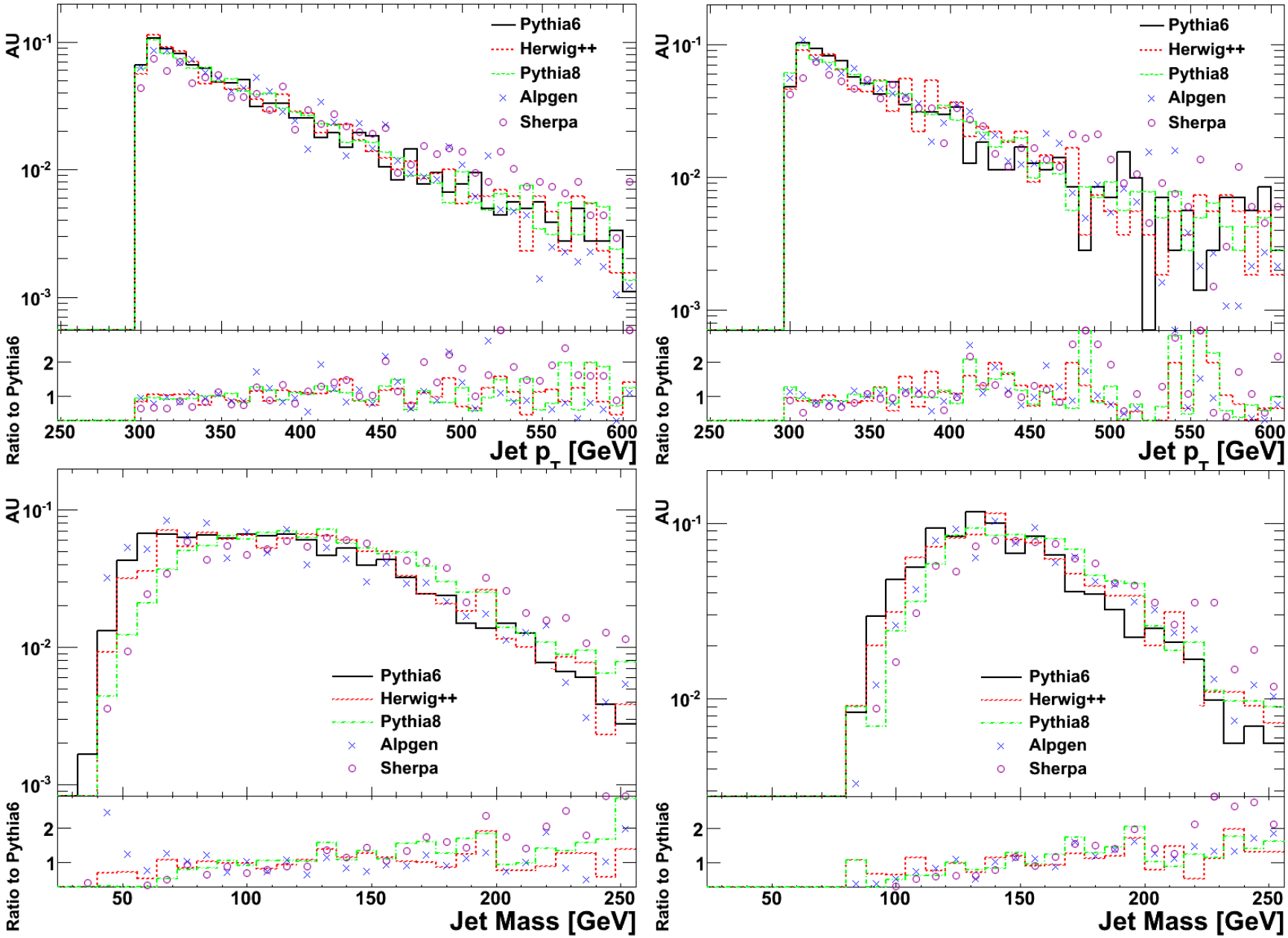
Run II Cone narrow jet selection

Event Selection 2

- Require leading 'fat jet' (Anti-k_T R=1.0) in $|y|<1.5$ region to have $p_T>300$ GeV
- Leading 'fat jet' should contain at least 2 narrow jets with $p_T>60$ GeV
  - (separation between 'narrow' and 'fat' jet axes<R=1.0)

→Direct selection of merged jets.

→Still large cross section (~2-3 times smaller than previous analysis)



Anti-k_T narrow jet selection

Run II Cone narrow jet selection

Efficiencies

	Selection 1		Selection 2	
narrow jet :	Anti-k_t	D0 Run II Cone	Anti-k_t	D0 Run II Cone
PYTHIA6	$.137 \pm .002$	$.070 \pm .001$	$.048 \pm .001$	$.019 \pm .001$
HERWIG++	$.126 \pm .002$	$.066 \pm .002$	$.051 \pm .001$	$.021 \pm .001$
ALPGEN	$.133 \pm .003$	$.071 \pm .001$	$.045 \pm .002$	$.015 \pm .001$
PYTHIA8	$.163 \pm .002$	$.128 \pm .002$	$.078 \pm .001$	$.038 \pm .001$
SHERPA	$.181 \pm .002$	$.109 \pm .002$	$.057 \pm .001$	$.028 \pm .001$

Likelihood for events with a p_T>300 GeV leading fat jet in the range |y|<1.5 to survive event selection

Conclusions

- Studied modeling of merged jets both from boosted particle decays and from QCD multijet backgrounds
- Jet mergers provide a ‘window’ towards better understand MC jet modeling.
- Decent overall agreement between generators
- Differences observed in key observables such as jet mass, with substantial variations in jet rates observed