

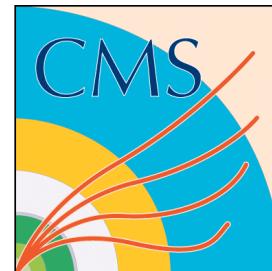
Top Tagging Algorithms: Current and Future Prospects

Top Algorithms & Detectors Subgroup

Snowmass EF Seattle

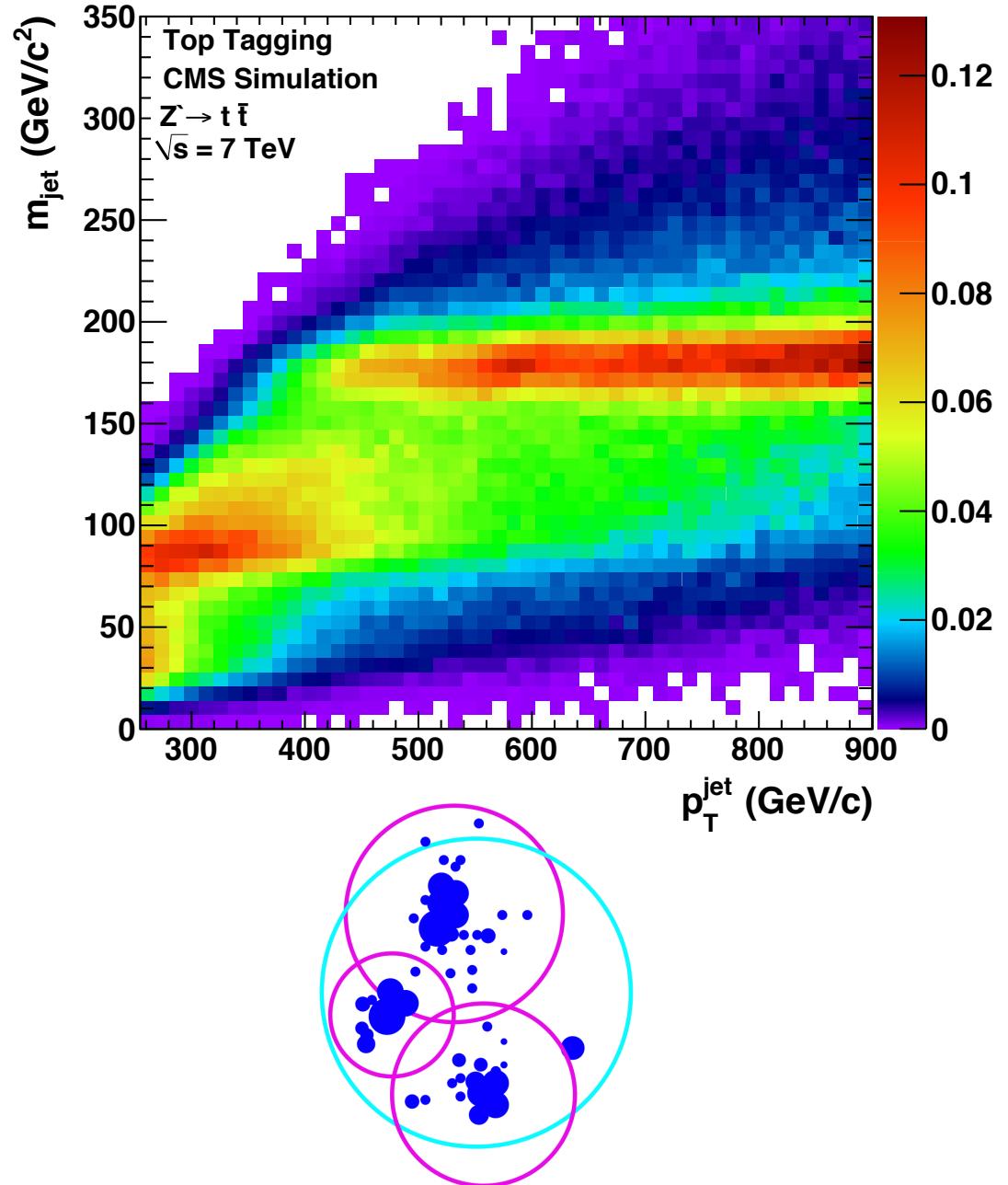
2 July 2013

Sergei Chekanov, Jim Dolen, Justin Pilot,
Roman Poeschl, Brock Tweedie



Introduction

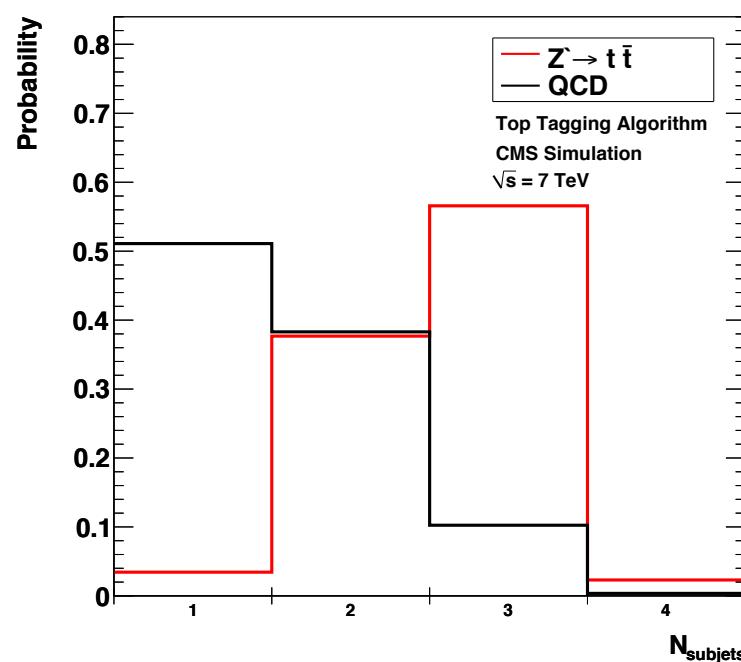
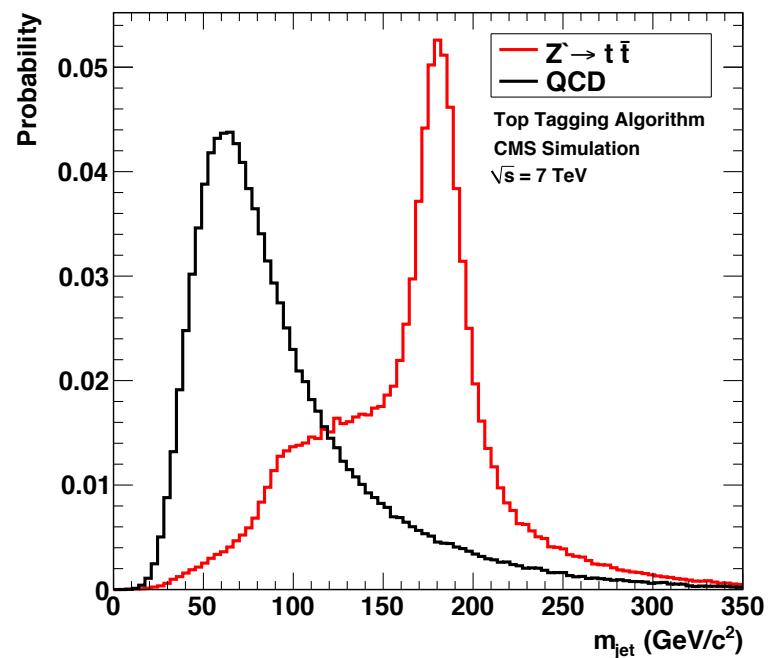
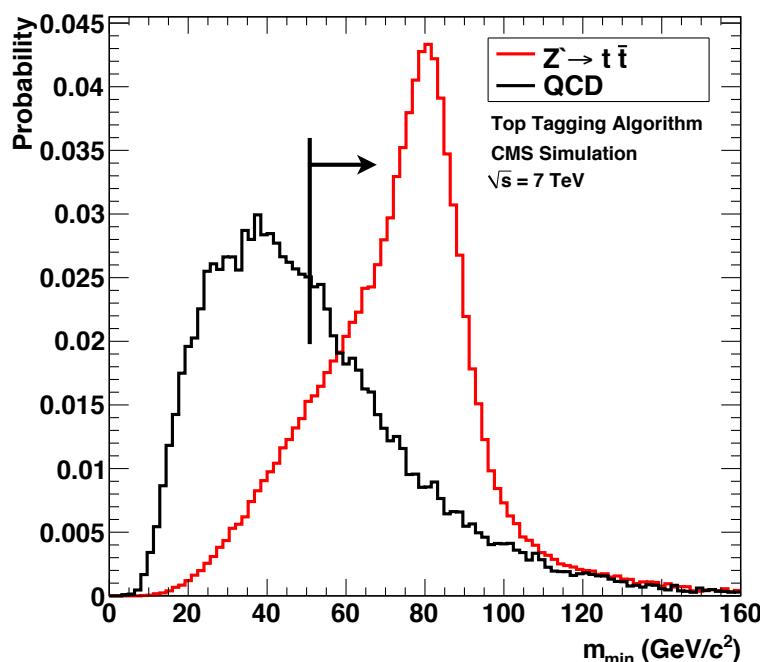
- ▶ In the high-pT regime, top quarks are highly boosted
 - ▶ Decay products collimated
 - ▶ Reconstructed as single jets
- ▶ Several algorithms exist to identify these signatures
 - ▶ Top-tagging algorithms
- ▶ As we study future experimental scenarios, we need to understand how these techniques will evolve
 - ▶ Increased boost
 - ▶ High pileup environment
- ▶ Additionally, what detector effects become important for the reconstruction



Top Tagging Algorithms

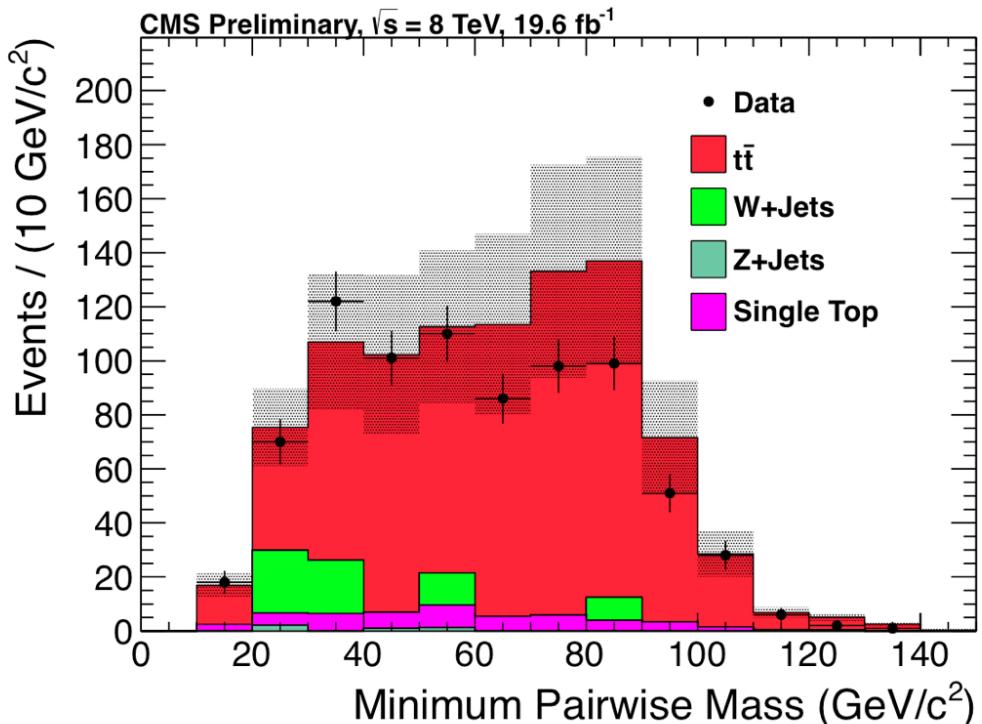
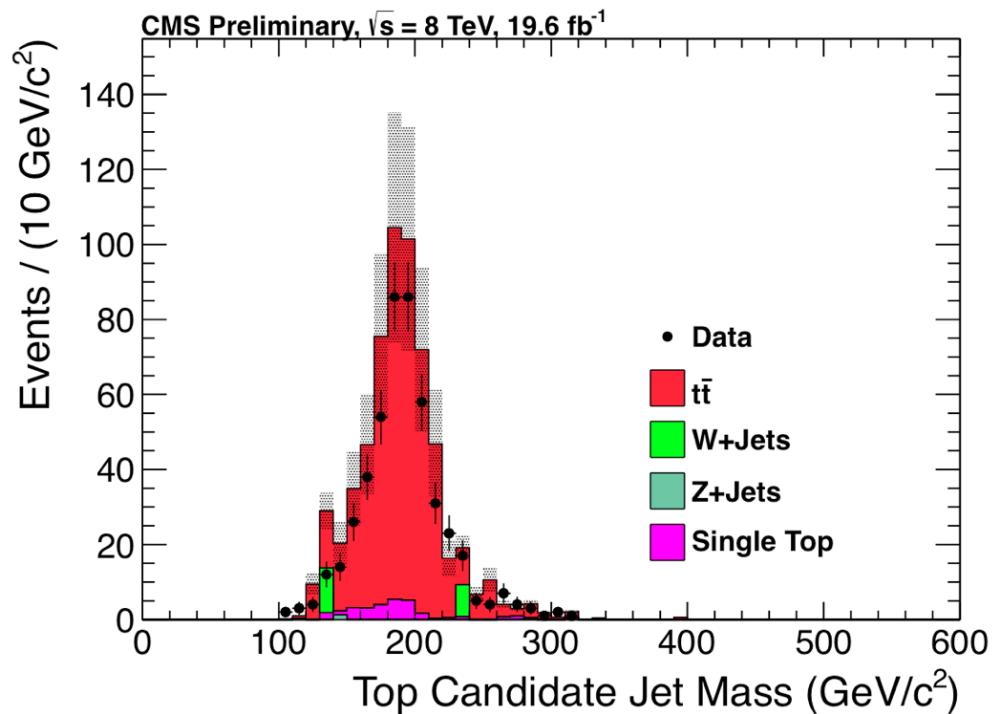
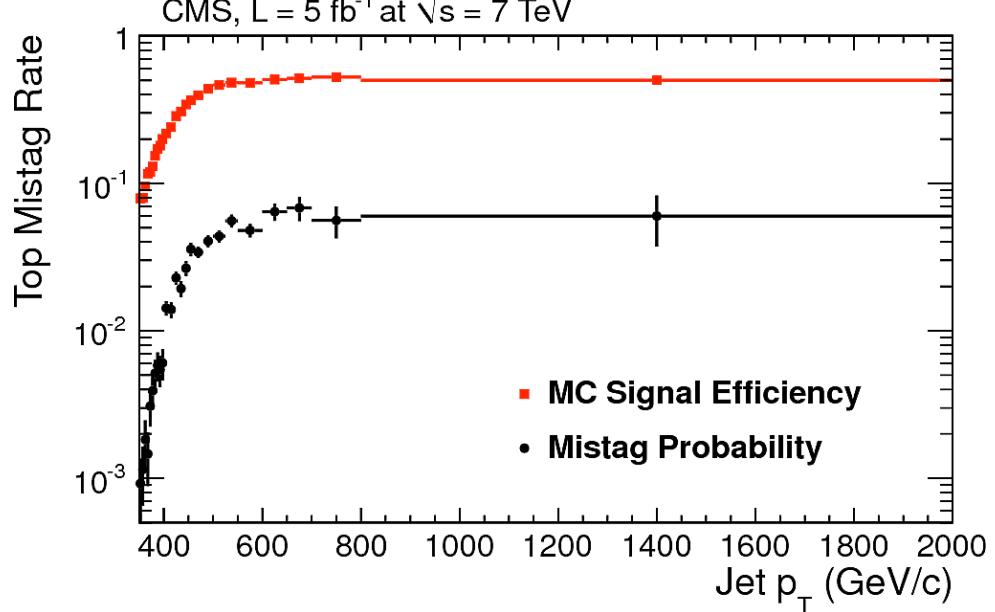
CMS PAS JME-10-013

- ▶ CMS Top Tagger based on JHU tagger
 - ▶ Declusters jets (Cambridge-Aachen $R = 0.8$) to find substructure
 - ▶ Requirements on substructure quantities:
 - ▶ ≥ 3 subjets
 - ▶ Jet mass consistent with top mass [140, 250] GeV
 - ▶ Identification of a W boson candidate using minimum pairwise subjet mass



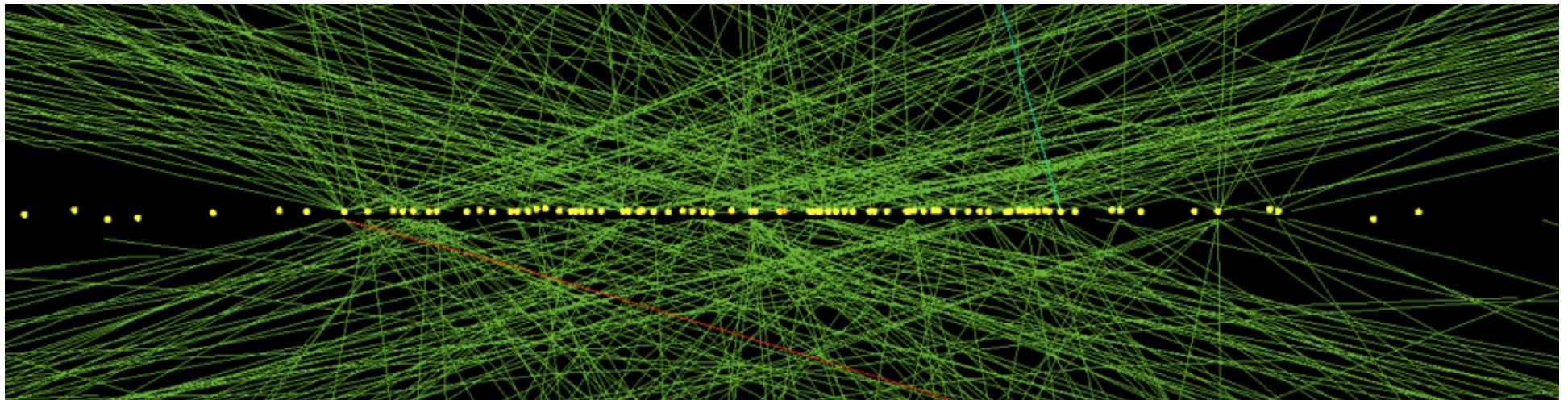
Data Validation

- ▶ Good understanding of the algorithm
- ▶ Validated in a sample of boosted top quarks in data
- ▶ Efficiency of ~50% for boosted top identification
- ▶ Pileup not playing a big role **yet** in the ability of the algorithm



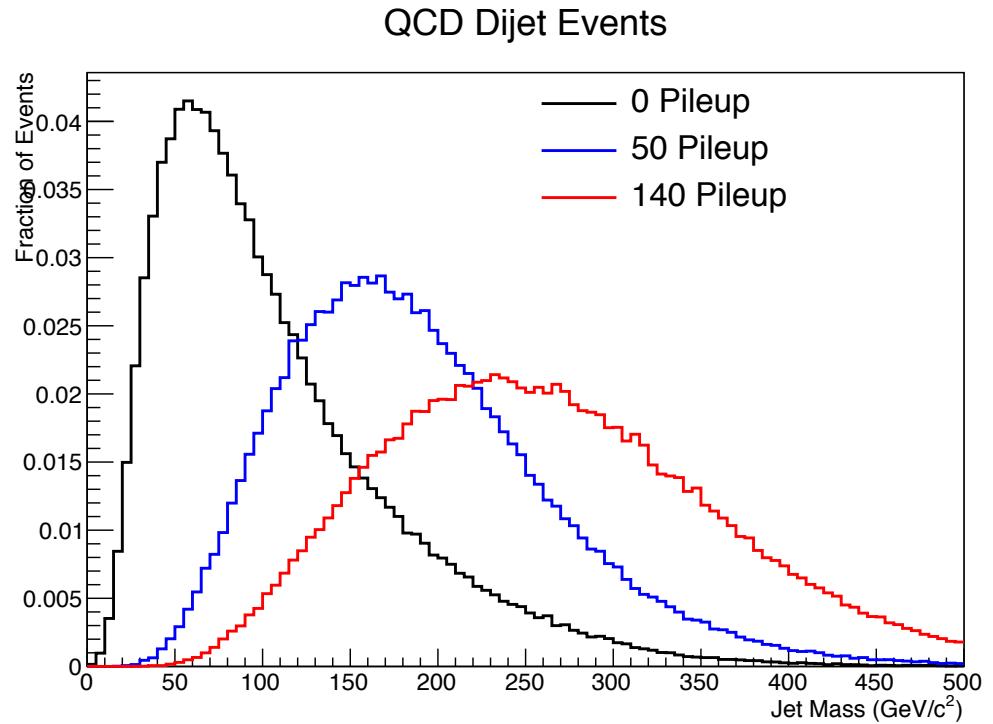
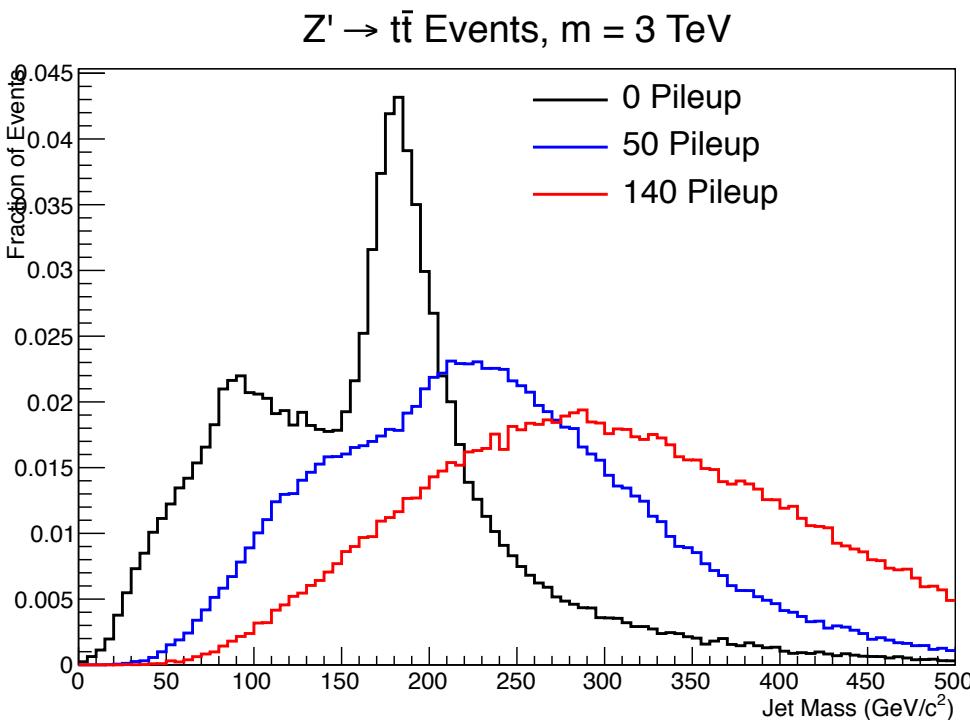
Pileup Scenarios

- ▶ Studied the JHU top tagging algorithm
 - ▶ CMS tagger based on this
- ▶ 14 TeV LHC studied
 - ▶ 3 TeV $Z' \rightarrow t\bar{t}$ events
 - ▶ QCD dijet events
- ▶ 3 pileup scenarios
 - ▶ $\langle \mu \rangle = 0, 50, 140$
- ▶ Study reconstruction of quantities used in the algorithm
 - ▶ Jet mass
- ▶ Also change in efficiency and mistag rate with the different pileup scenarios



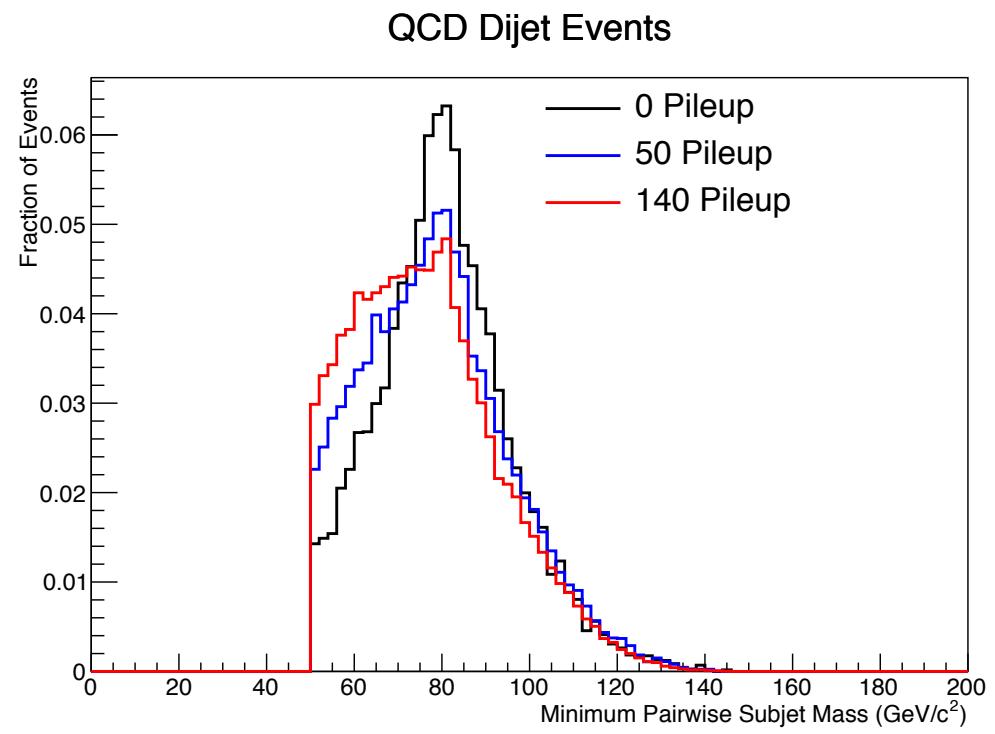
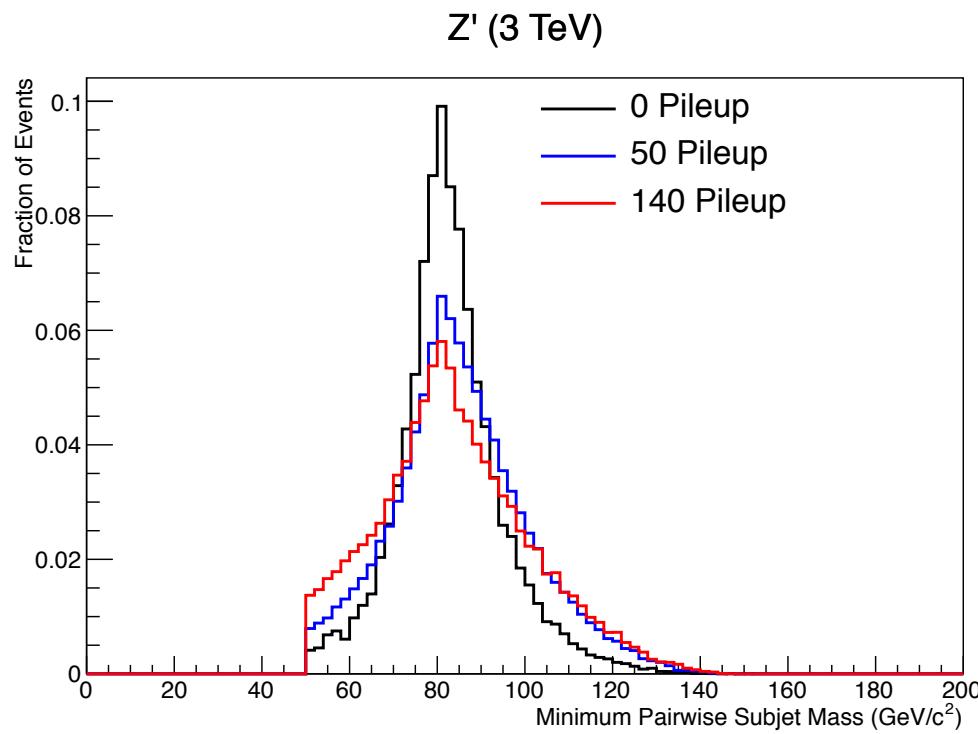
Jet (Top) Mass

- ▶ Includes charged hadron subtraction, no area correction
- ▶ QCD events push into top tag mass window



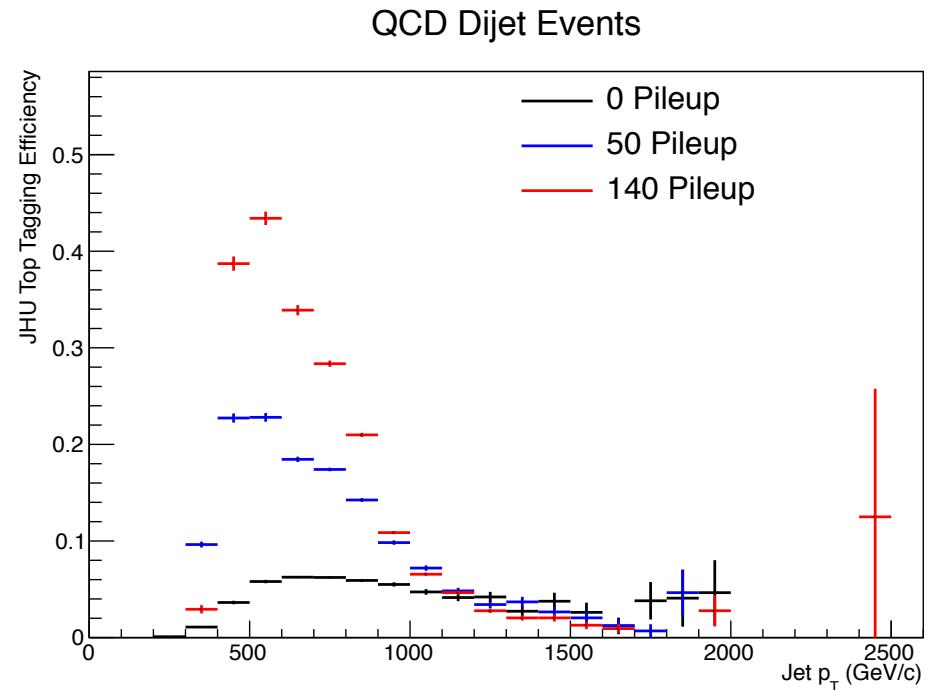
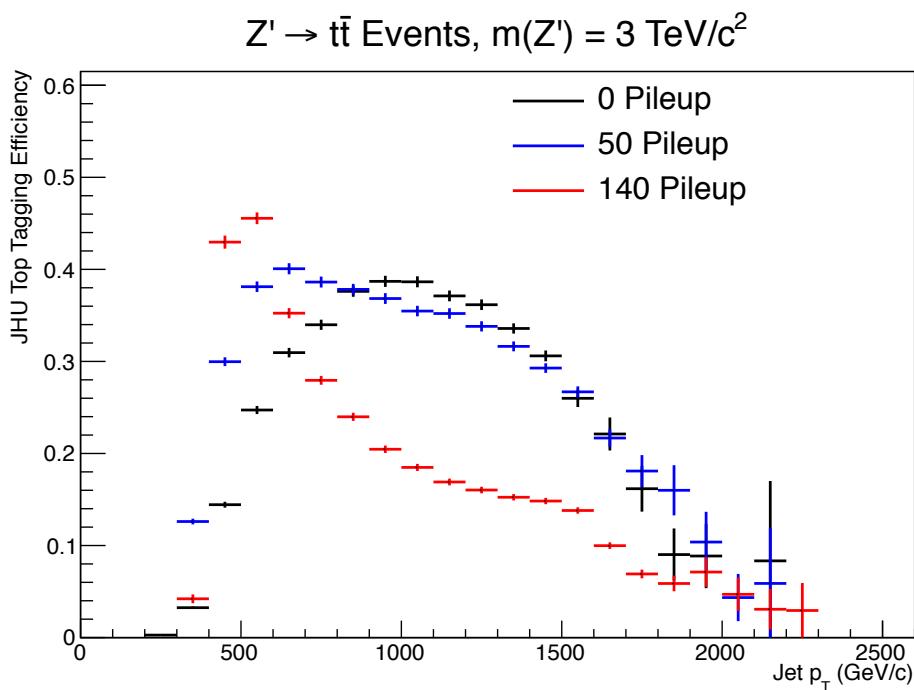
W Mass

- ▶ Includes charged hadron subtraction, no area correction
- ▶ Mass of pair of subjets closest to W mass



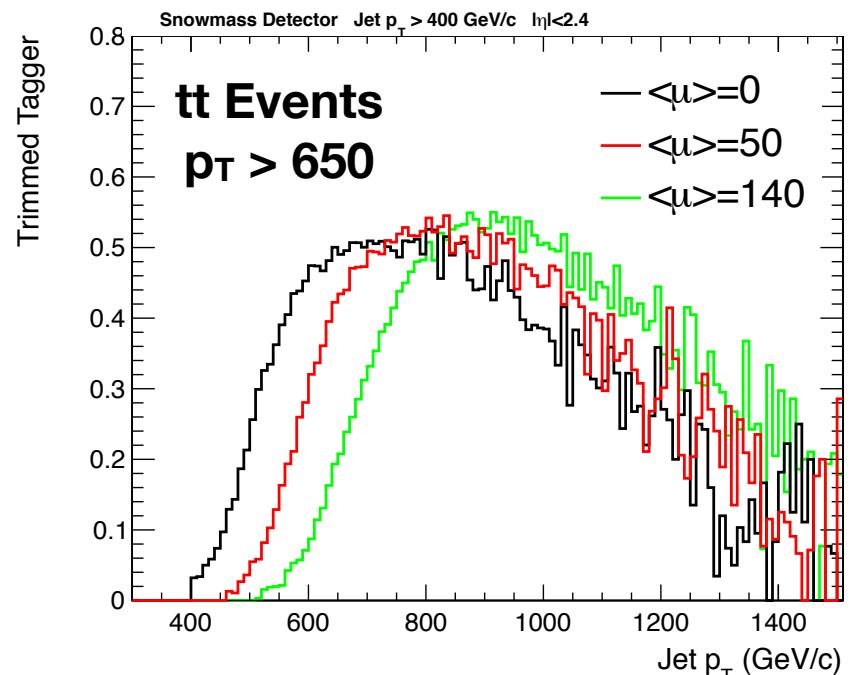
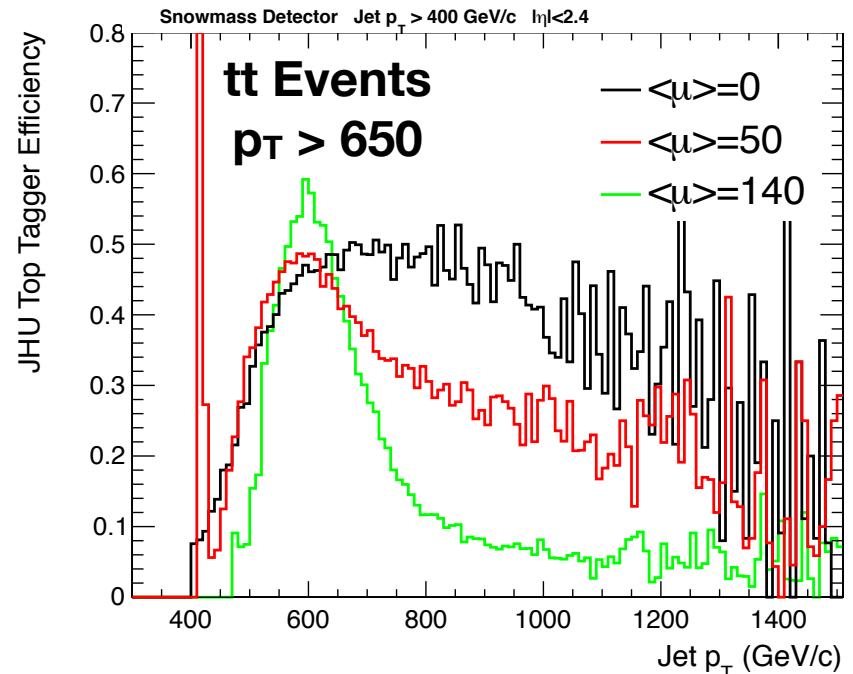
Tagging Efficiency

- ▶ Efficiency degrades with extreme boost
 - ▶ Pileup worsens things further
- ▶ Mistag rate from QCD jets explodes with high pileup



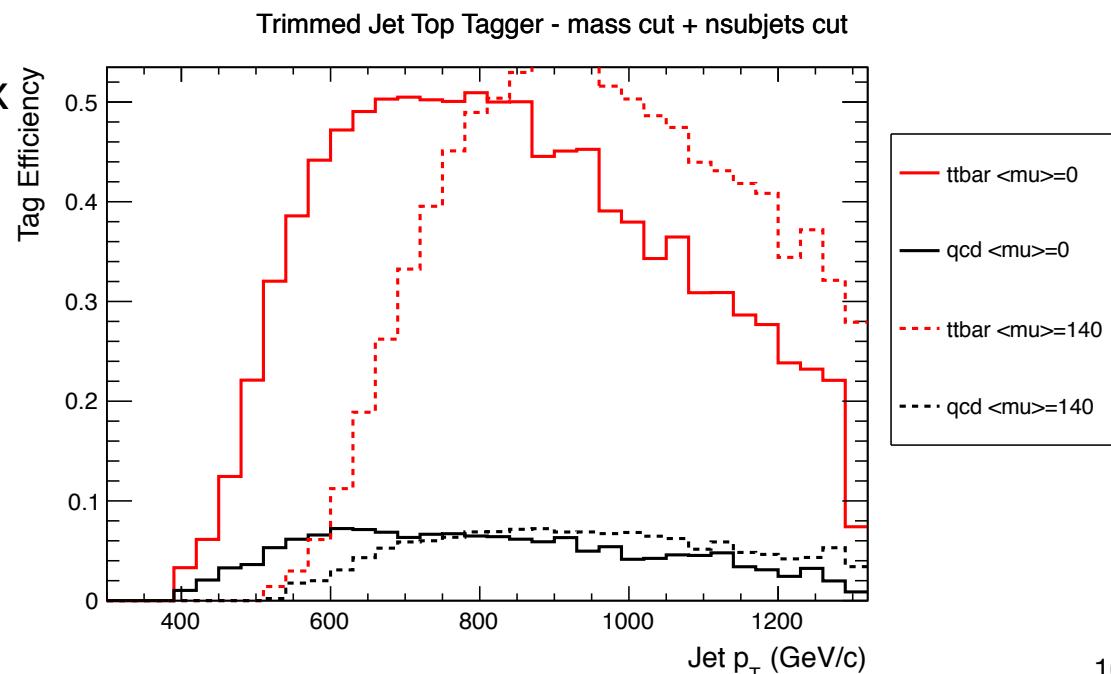
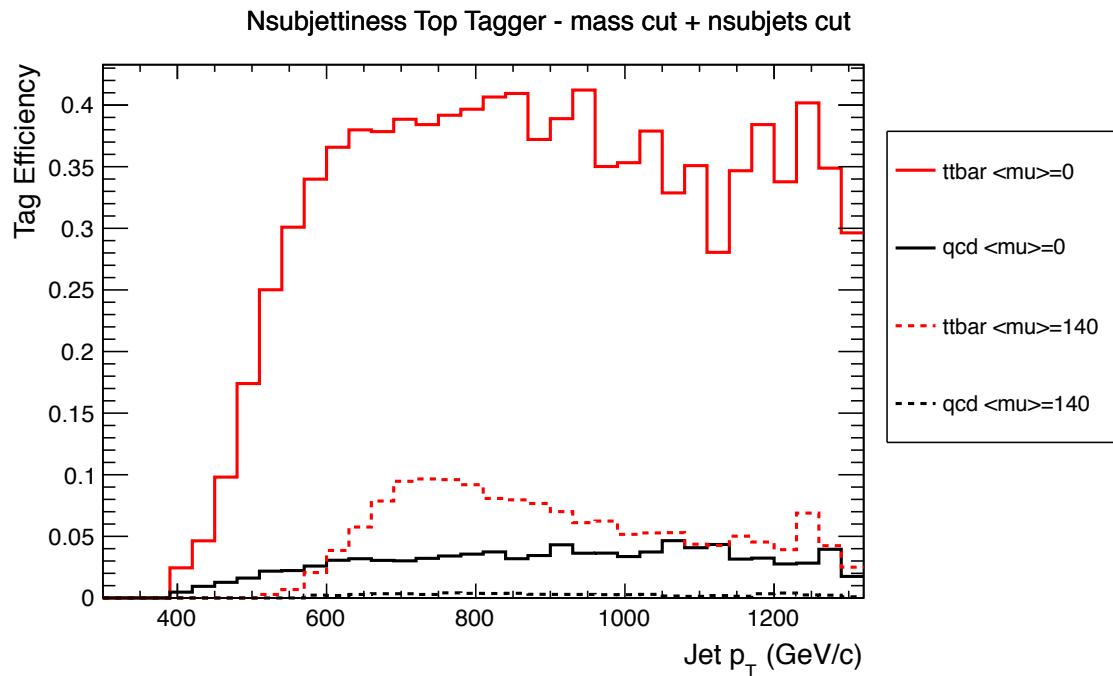
Additional Taggers

- ▶ Many of the taggers currently in use degrade with the high pileup environment
- ▶ Goal is to design an algorithm that remains robust at high pileup
- ▶ One example:
 - ▶ Use jet trimming
 - ▶ Cut on jet mass [150,230] GeV
 - ▶ Cut on number of subjets ≥ 3
- ▶ Efficiency still degrades, but much higher compared to out-of-the box top tagger



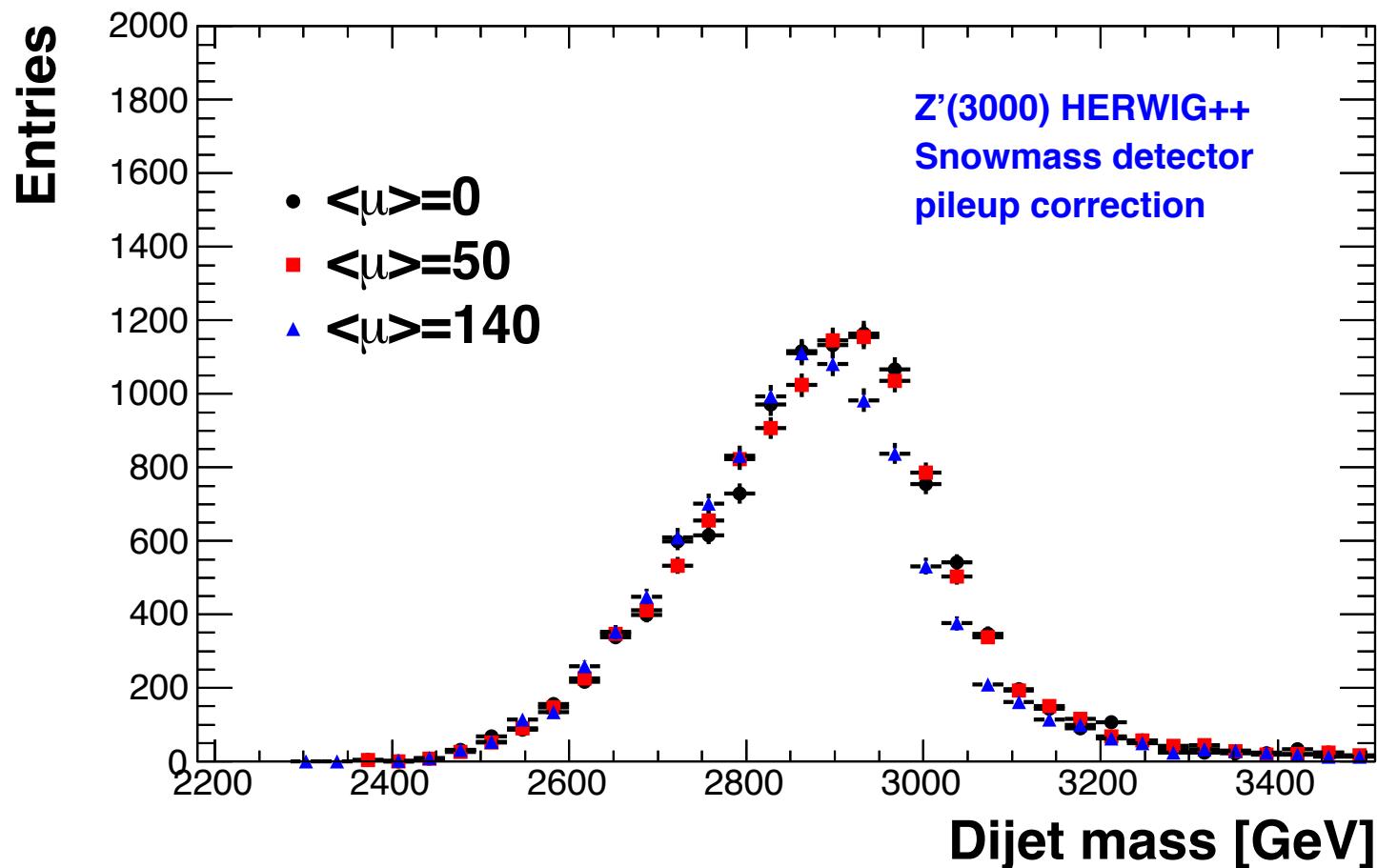
Additional Taggers

- ▶ Many of the taggers currently in use degrade with the high pileup environment
- ▶ Goal is to design an algorithm that remains robust at high pileup
- ▶ One example:
 - ▶ Use jet trimming
 - ▶ Cut on jet mass [150,230] GeV
 - ▶ Cut on number of subjets ≥ 3
- ▶ Efficiency still degrades, but much higher compared to out-of-the box top tagger
- ▶ Mistag rate remains low with the high pileup events



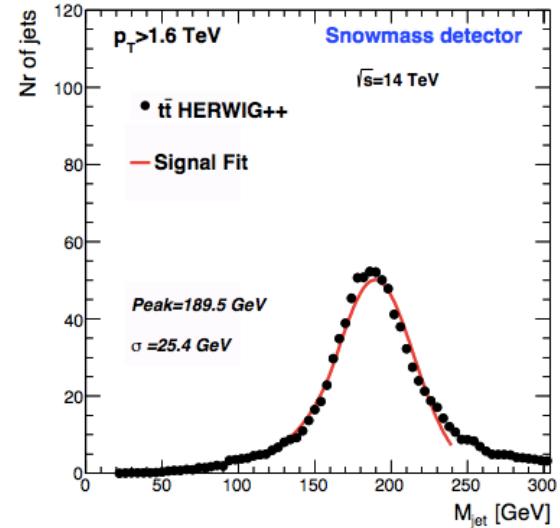
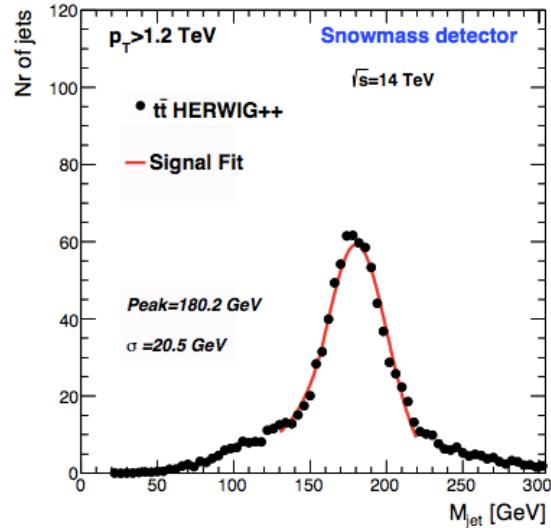
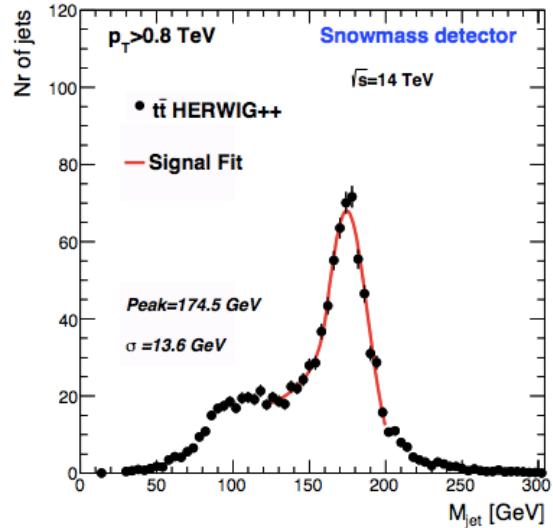
Tagging Efficiency

- ▶ Efficiency degrades with extreme boost
 - ▶ Pileup worsens things further
- ▶ Mistag rate from QCD jets explodes with high pileup
- ▶ Maybe not as bad as it seems here
 - ▶ No area-based correction implemented
 - ▶ Still can reconstruct Z' peak after correction

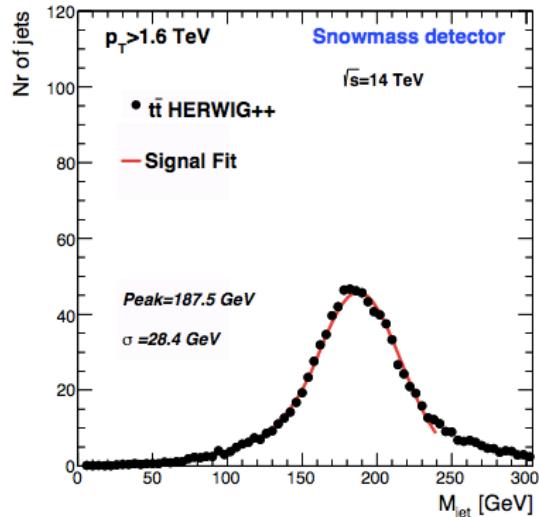
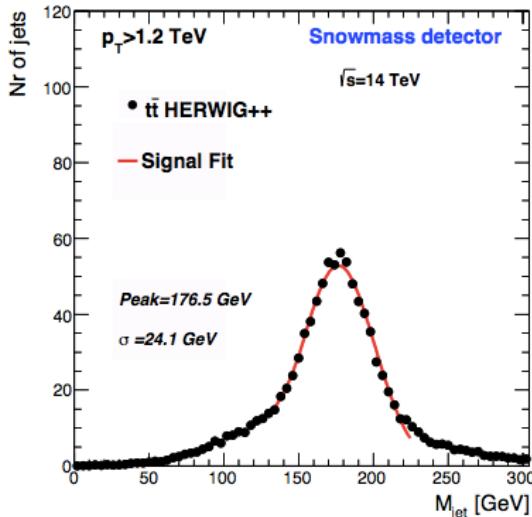
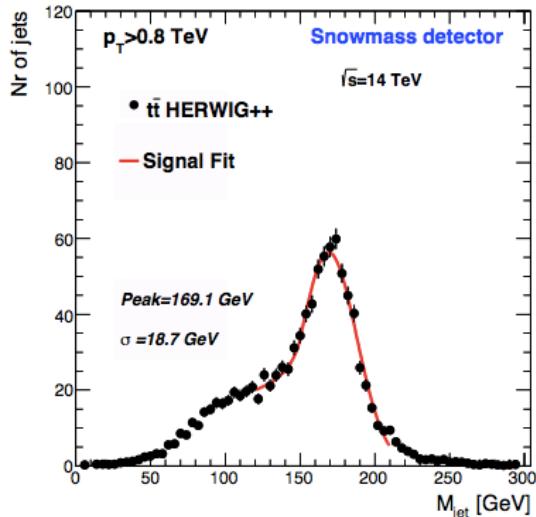


Going to Extreme pT

- Resolution of jets degrades



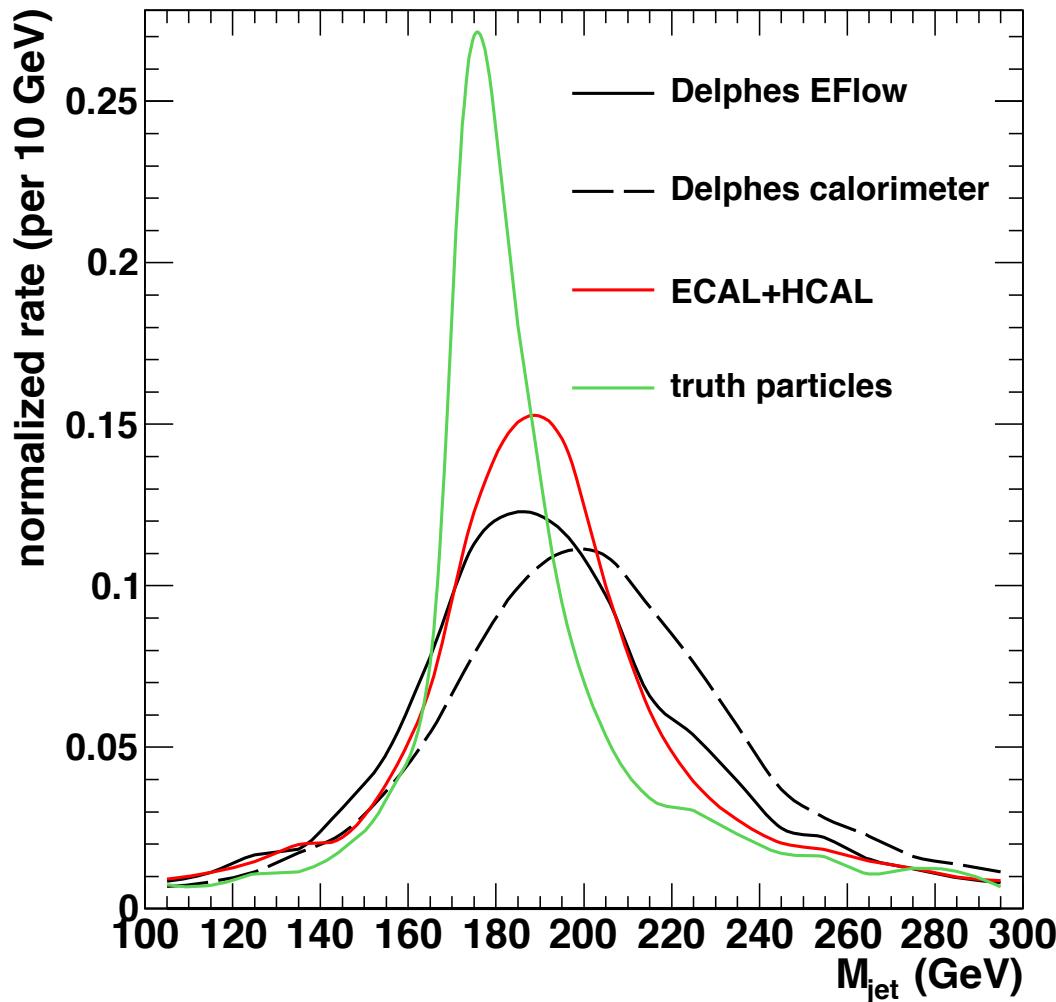
(a) $\langle \mu \rangle = 0$ scenario



(c) $\langle \mu \rangle = 140$ scenario

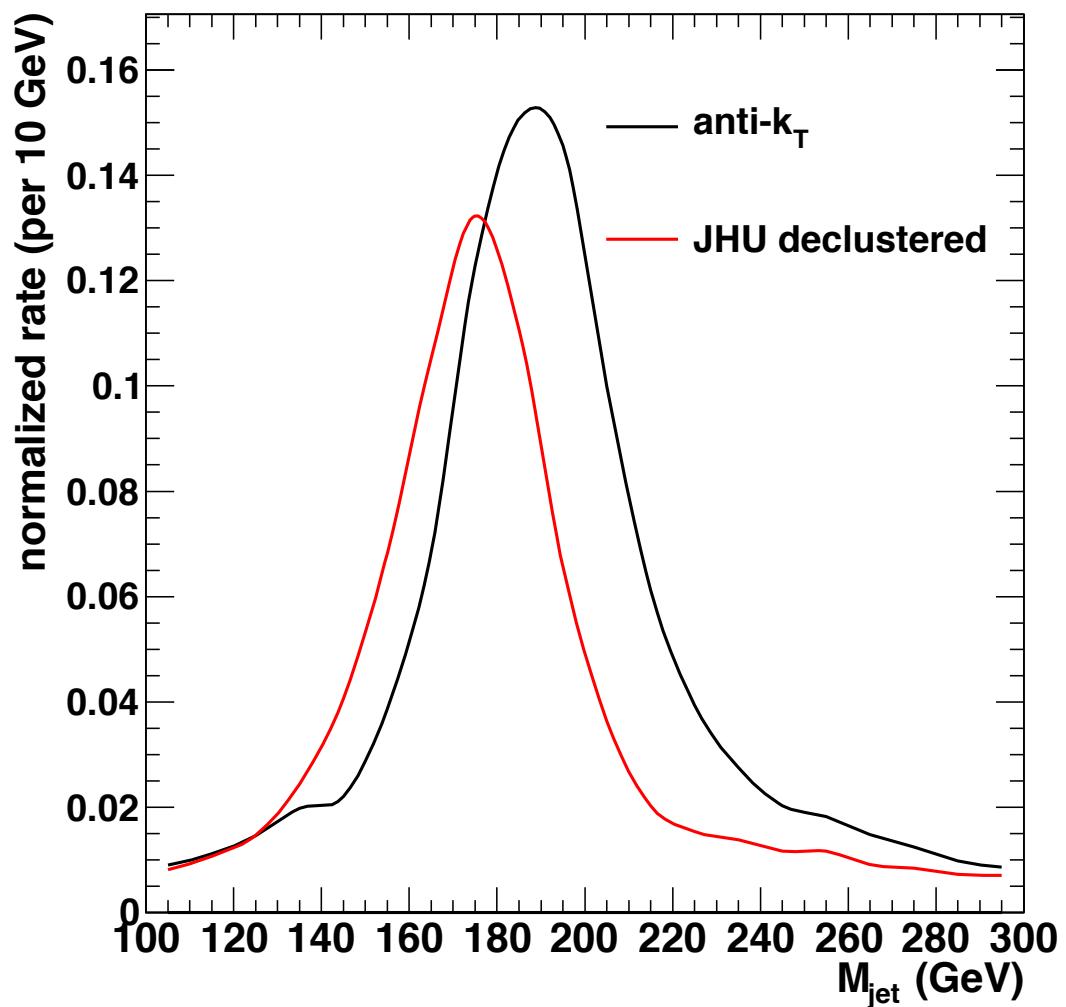
Detector Effects

- ▶ Several effects contribute to the poor reconstruction at very large top pT
 - ▶ Radiation from top quark
 - ▶ Detector (calorimeter) granularity
 - ▶ Failure of tracking in dense environment of highly-collimated decay products
- ▶ Studied effects of different calorimeter treatments
 - ▶ Delphes detector has $\eta\text{-}\phi$ segmentation of $\sim 0.087 \times 0.087$
 - ▶ In ATLAS/CMS, ECAL has finer granularity
 - ▶ Use additional Delphes simulations with 2x increased granularity
 - ▶ Use finer cells for ECAL, resum to retain original HCAL
 - ▶ No tracking information used!



Detector Effects

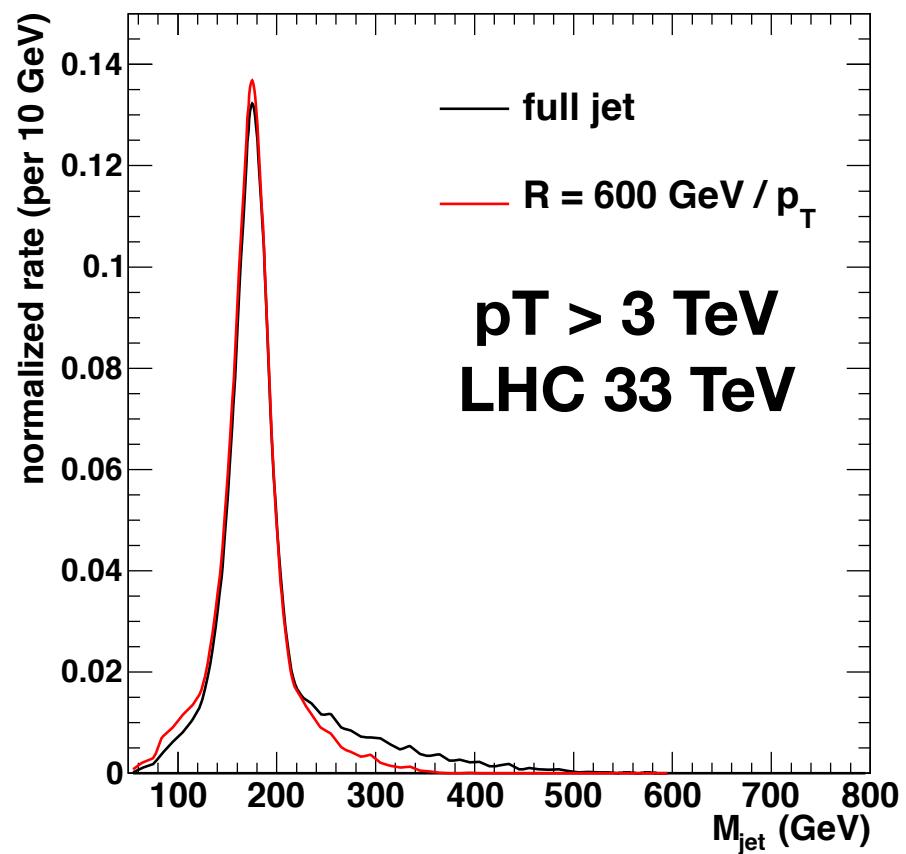
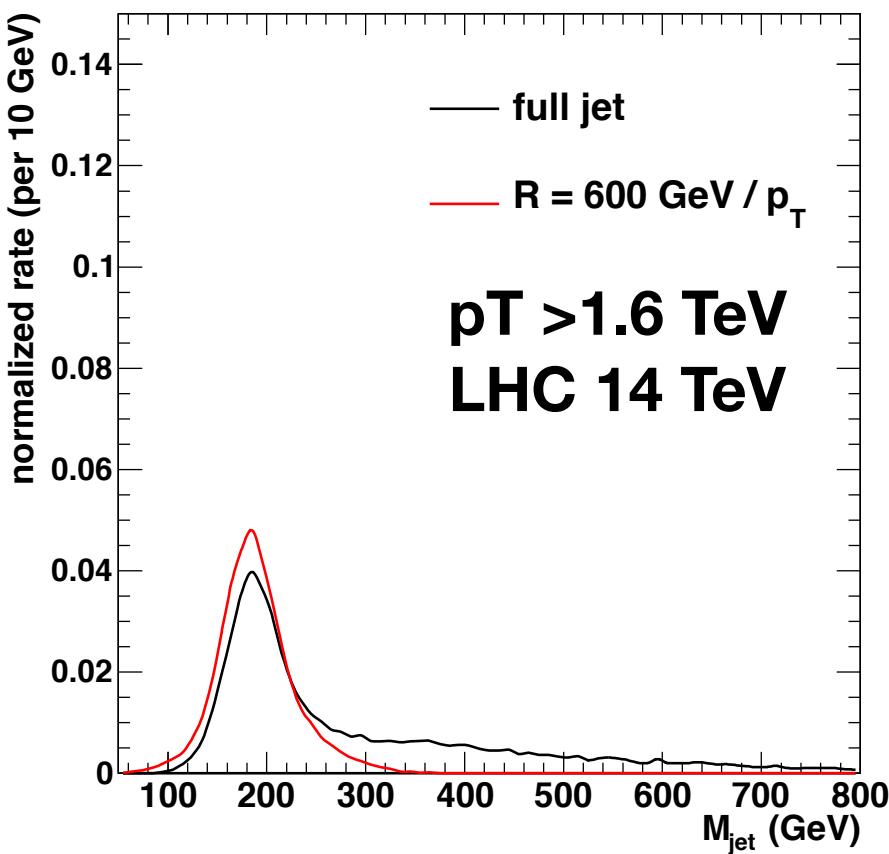
- ▶ Recluster anti- k_T jets with C/A algorithm
 - ▶ Find 3 subjets using only the declustering algorithm in the JHU tagger
- ▶ Can correct the top mass peak position to the correct value
 - ▶ Also improves resolution
- ▶ 20% loss of efficiency due to jets which fail to decluster into subjets



Detector Effects

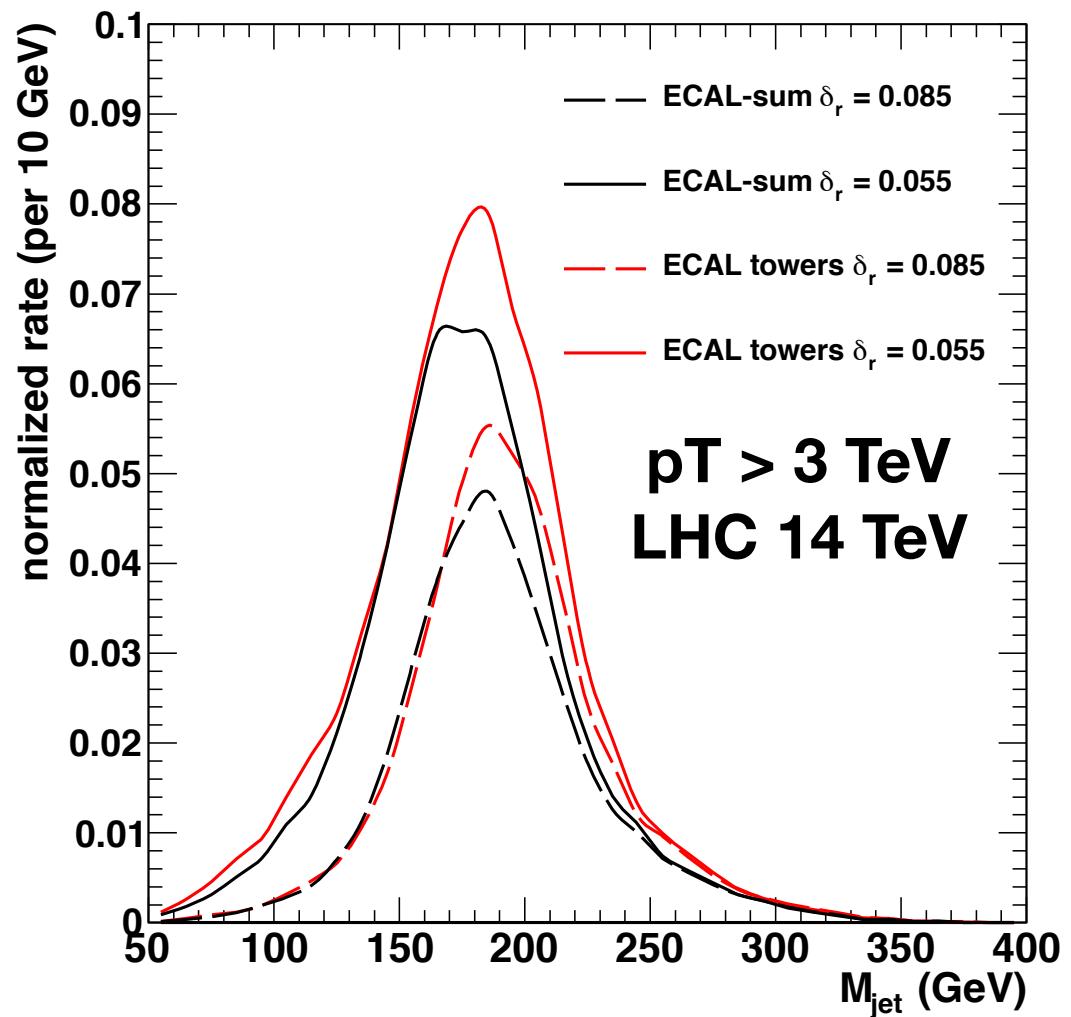
- ▶ JHU tagger cannot remove high-pT QCD emissions
 - ▶ Gives broad tail at high jet masses

- ▶ With a shrinking cone to define the jet at high pT, this tail can be mitigated
 - ▶ Use a cone size defined by $(600 \text{ GeV}) / (\text{Jet } p_T)$
- ▶ Tradeoff between removing QCD and removing top decay products



Detector Effects

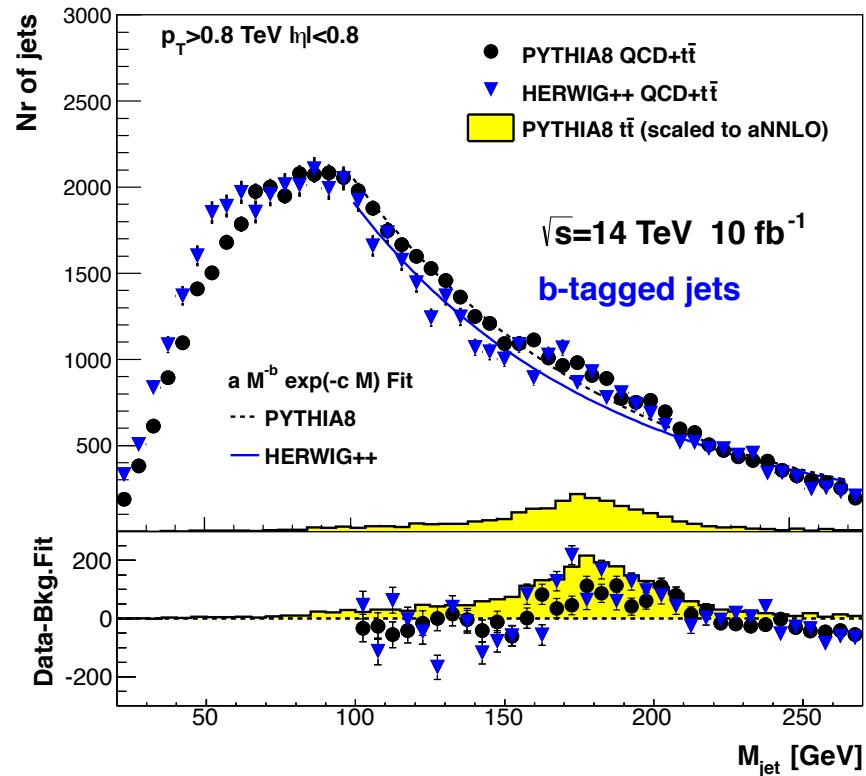
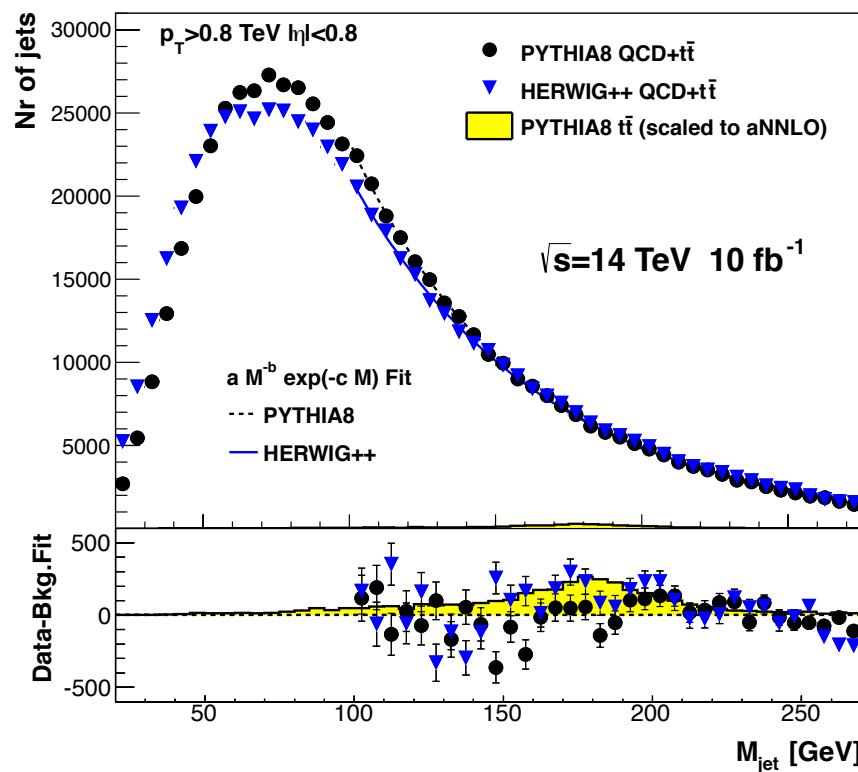
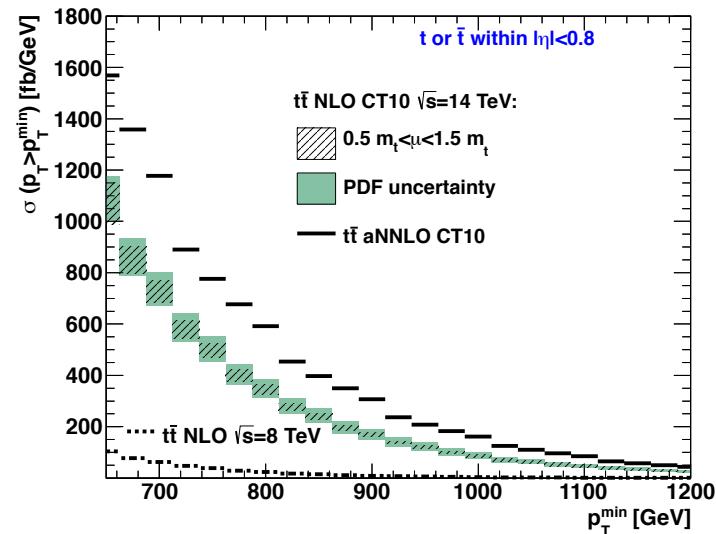
- ▶ Can also use shrinking cone size in combination with fine ECAL segmentation methods
 - ▶ Improvement in declustering efficiency
- ▶ Possible to change parameters of algorithm and detector granularity to preserve small-scale structure of jets even in the highly boosted environment



Inclusive Jet Mass

B. Auerbach, S. Chekanov, N. Kidonakis,
arXiv:1301.5810

- ▶ Possibility to probe top in the inclusive jet mass spectrum
 - ▶ Increasing cross section with NNLO corrections
- ▶ Can probe new physics models through limits on ttbar cross section alone
 - ▶ **Discrimination could be further enhanced with substructure observables!**



Conclusions

- ▶ Studied various top tagging algorithms
 - ▶ Efficiencies generally degrade with increasing pileup
 - ▶ Possible to design algorithms which are more robust against this
- ▶ Going to extreme jet p_T , resolution degrades
 - ▶ Detector effects become important
 - ▶ Some improvement can be gained through better reconstruction algorithms
- ▶ Will need to work hard to maintain physics efficiency over the next years
 - ▶ Work continues in the Snowmass effort
 - ▶ We hope to have further results for Minnesota

