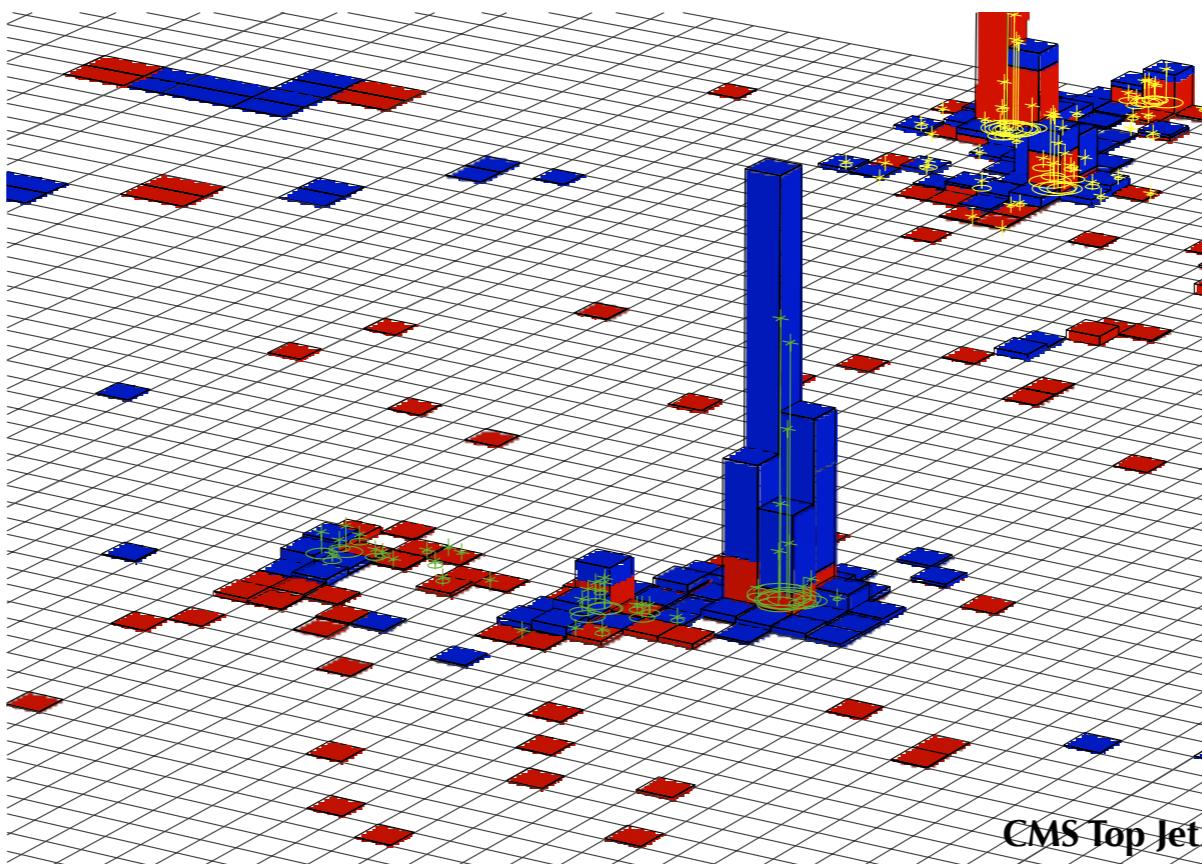


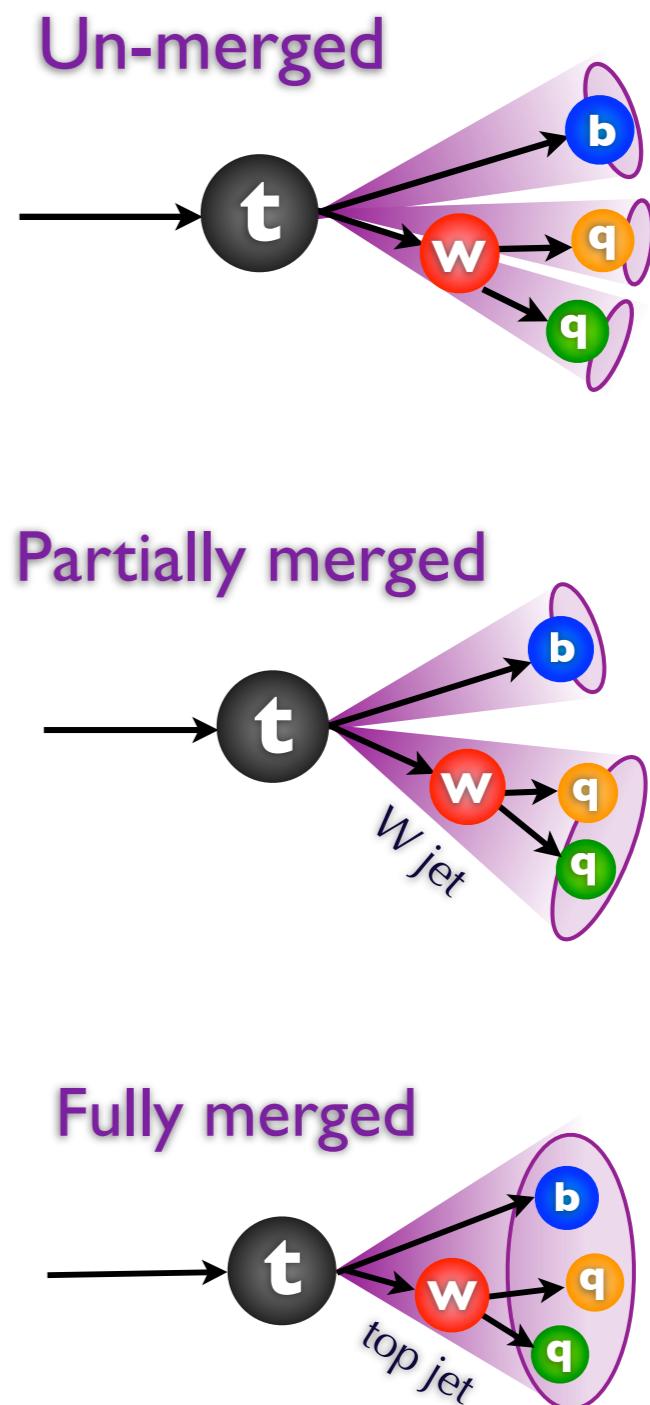
Summary of Boosted Tops



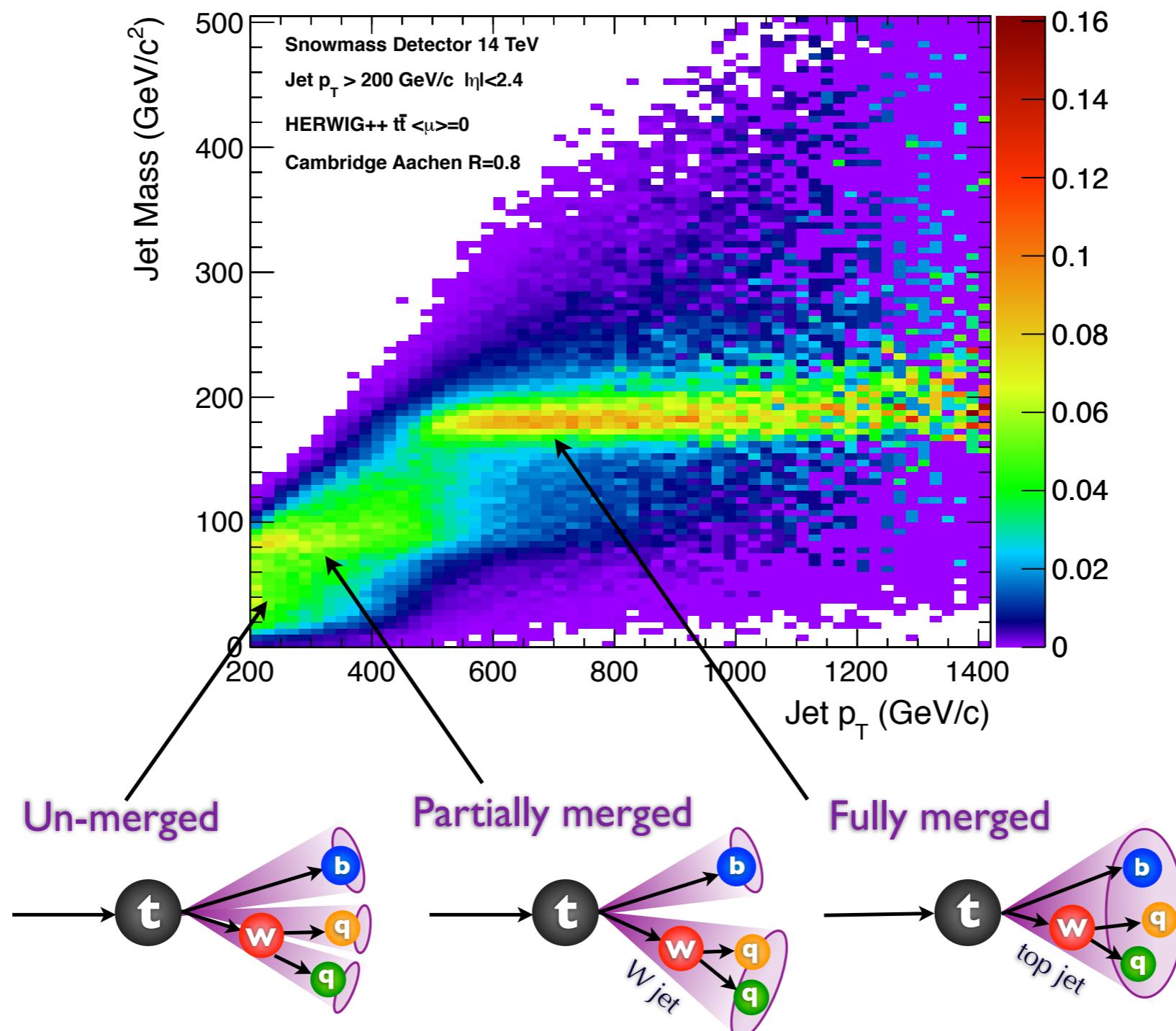
Snowmass Top Algorithms and Detectors Subgroup
Contacts: Sergei Chekanov, James Dolen, Justin Pilot, Roman
Poeschl, Brock Tweedie

Introduction

- Top quarks produced with large p_T have collimated decay products
 - Low boost
 - Decay products are individually reconstructed as jets (un-merged)
 - Hemisphere approach
 - Moderate boost
 - Top decay products merge into 2 jets, with W daughters within 1 jet (W jet)
 - Large boost
 - All top decay products merge into a single jet (top jet)

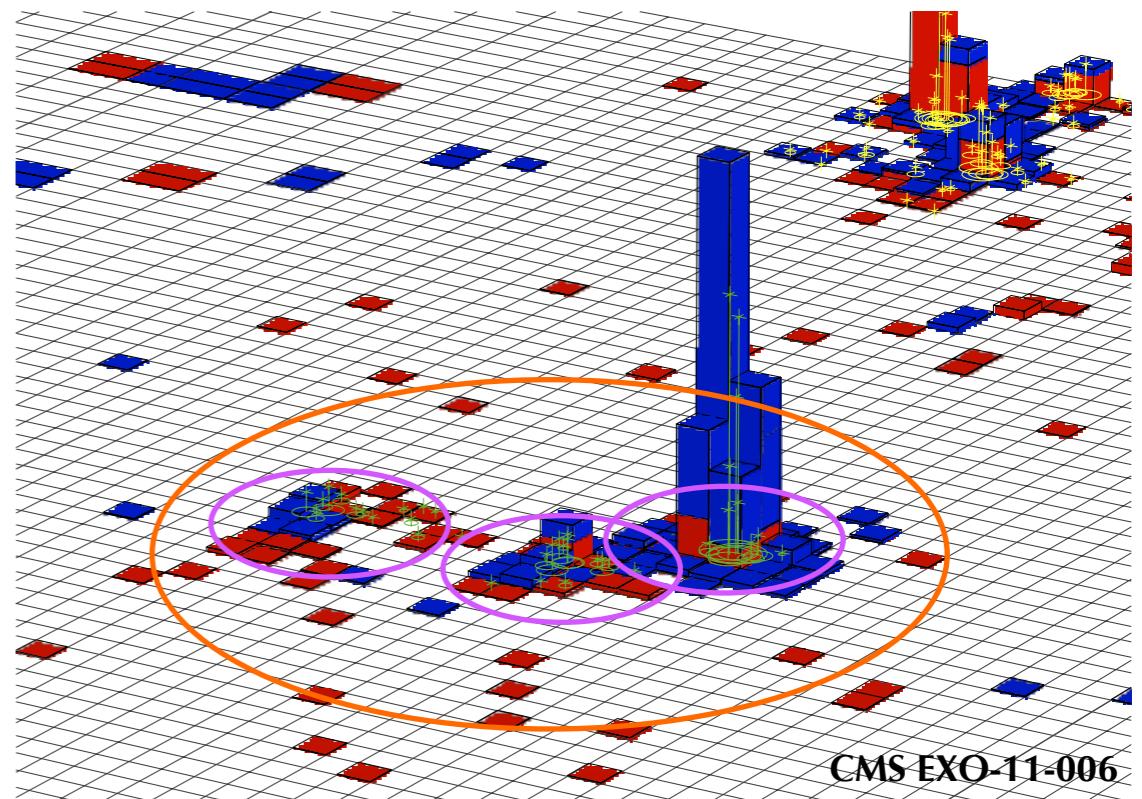


Introduction



Boosted top tagging

- Identifying features of top jets
 - Jet mass \approx top mass
 - Substructure (3 subjets)
 - Pairwise mass of two subjets \approx W mass
- How well can we reconstruct these features at very high pile-up and p_T ?

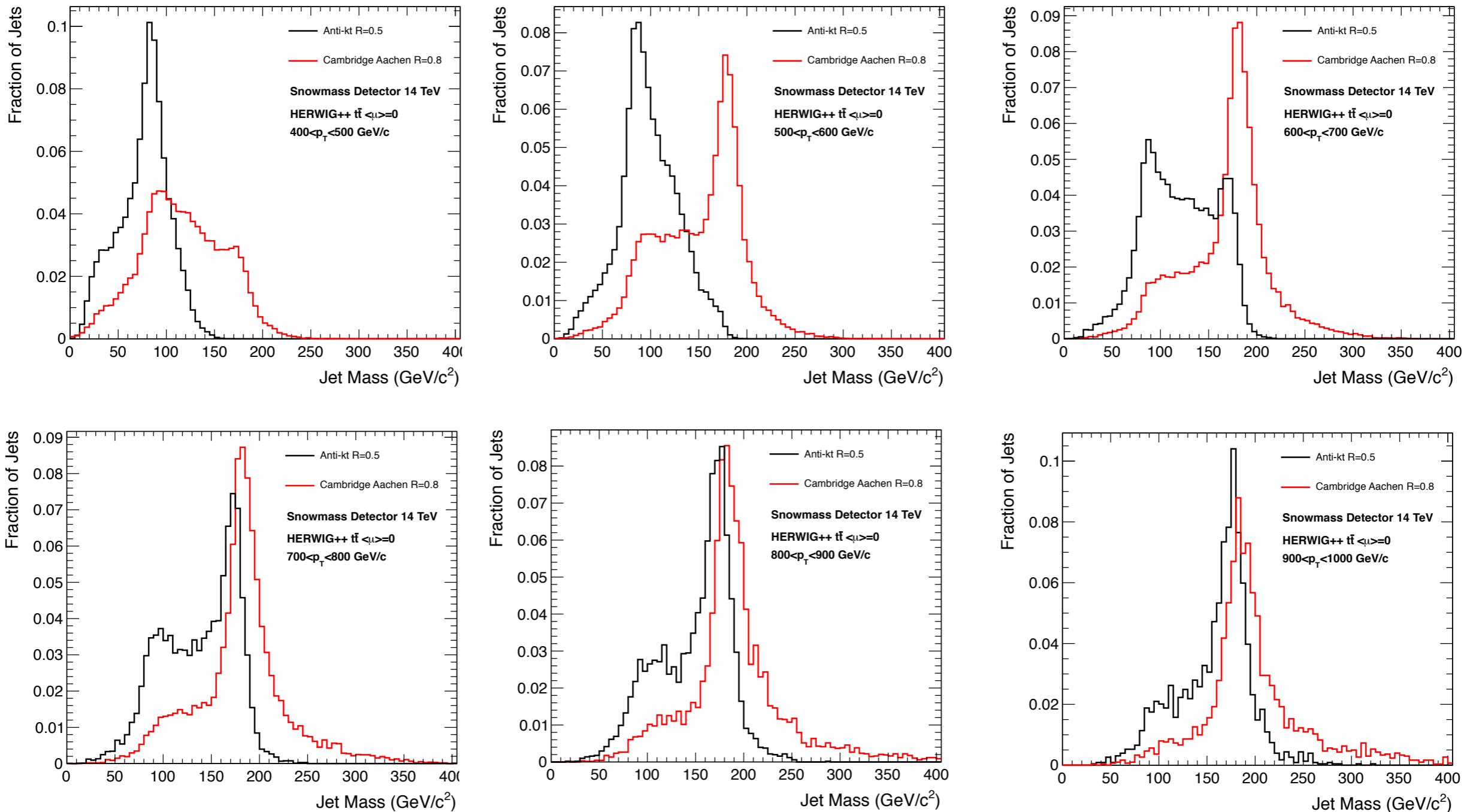


Substructure in Delphes

- Delphes Ntuples contain two types of jets
 - Anti-kt R=0.5 - used for most analyses
 - Cambridge Aachen R=0.8 - larger to catch all decay products within one jet
- Top group Ntuples
 - Jet constituents are stored for CA jets with $pT > 200$
 - Recluster jets to access jet substructure information
 - <https://atlaswww.hep.anl.gov/asc/wikidoc/doku.php?id=snowmass2013:montecarlo>
- Official Delphes Ntuples
 - No jet constituents stored
 - Some variables relevant to boosted top tagging have been added:
 - Groomed jet mass, Nsubjets, Nsubjettiness,
 - Top and W tag bools

Jet comparison

As pT increases, transition from partially to fully merged tops. This transition occurs at pT~600 GeV/c for AK R=0.5 and pT~400 GeV/c for CA R=0.8



Pile-up study

- Top and Detectors WG samples
 - Herwig++ 14 TeV
 - ttbar and QCD - $pT > 650$
 - 0, 50, 140 pileup interactions
- CA R=0.8
 - Require $pT > 400$, $|\eta| < 2.4$
 - Recluster jet for substructure
- Compare variables relevant to top tagging in high pile-up samples
 - Jet mass
 - Jet grooming
 - Nsubjets/Nsubjettiness
 - W mass

Pileup and jets

- Pileup contributes some average energy to each jet but fluctuates from jet to jet

$$\Delta p_T \approx \rho A \pm \sigma_\rho \sqrt{A}$$

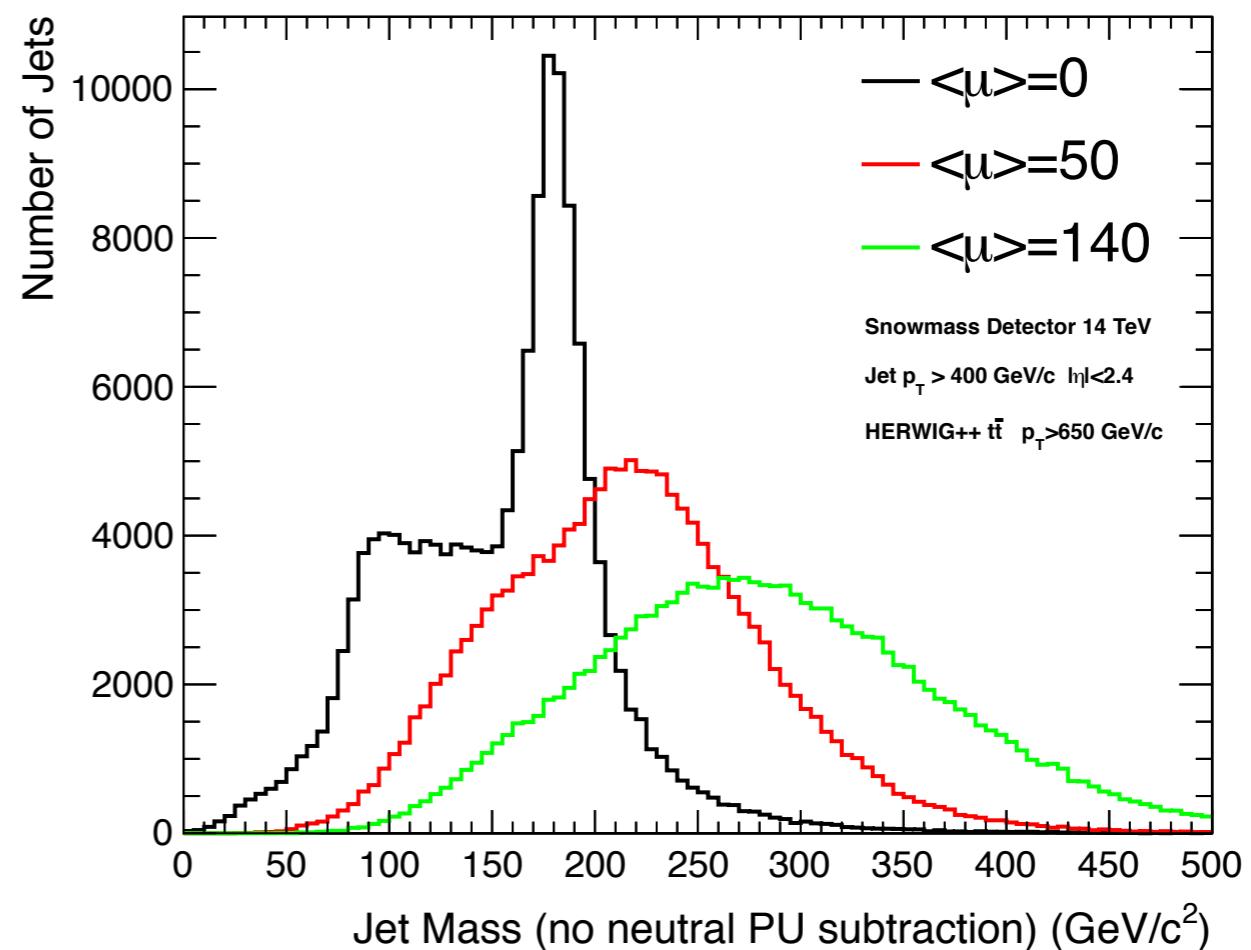
Cacciari, Salam
arXiv:0707.1378v2

ρ = mean pT per unit area from pileup

A = jet area

σ_ρ = fluctuation of ρ within the event

- Result : shifted (due to added pT) and smeared (due to fluctuations within the event) jet distributions

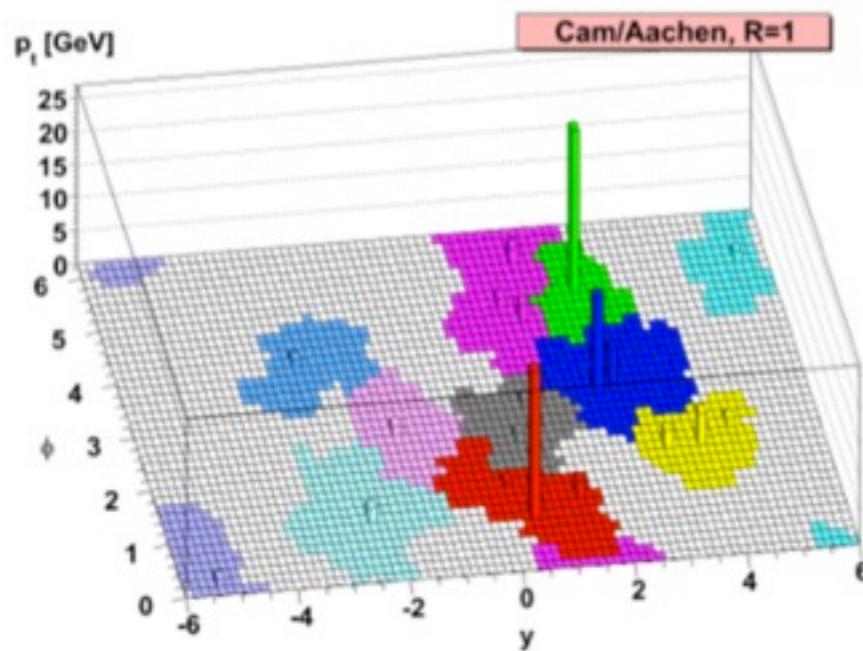


Pile-up mitigation in jets

- Pile-up subtraction
 - Average offset
 - p_T and η dependent jet energy subtraction
 - Jet area based pile-up subtraction
 - Measure the pile-up p_T density and jet area and subtract jet by jet
 - Charged hadron subtraction (CHS) - partial subtraction
 - charged particles from non-primary vertices are removed before clustering jets
- Pile-up suppression
 - Reject jets likely to be PU
- Jet grooming
 - Trimming and filtering recluster the jet with small jets and keep only the hard subjets
 - Pruning reclusters the jet and keeps only the hard small angle particles

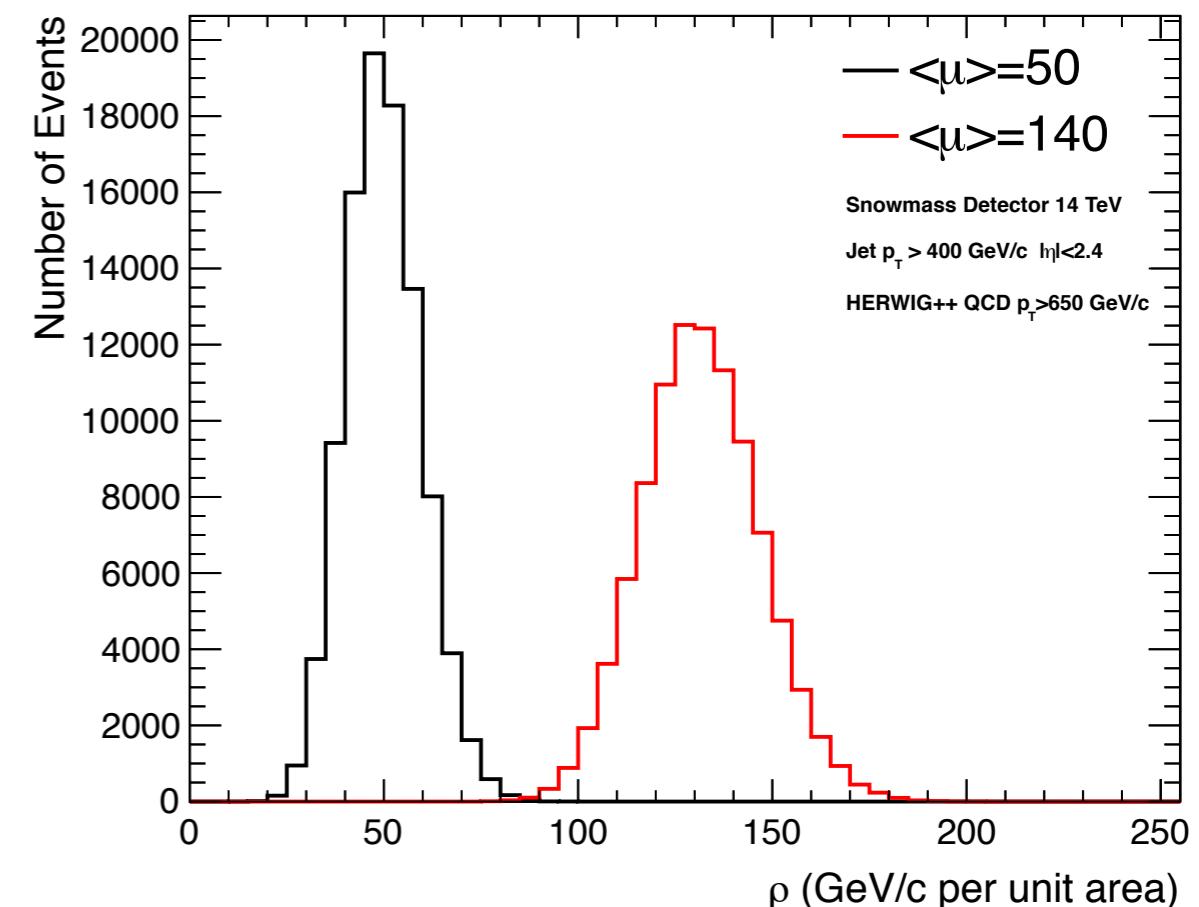
Area based pileup subtraction

- Jet pT contribution from pileup can be subtracted:
 - Measure rho in each event:
 - Measure area of each jet using active area
 - ▶ Cluster infinitely soft “ghosts” along with jet



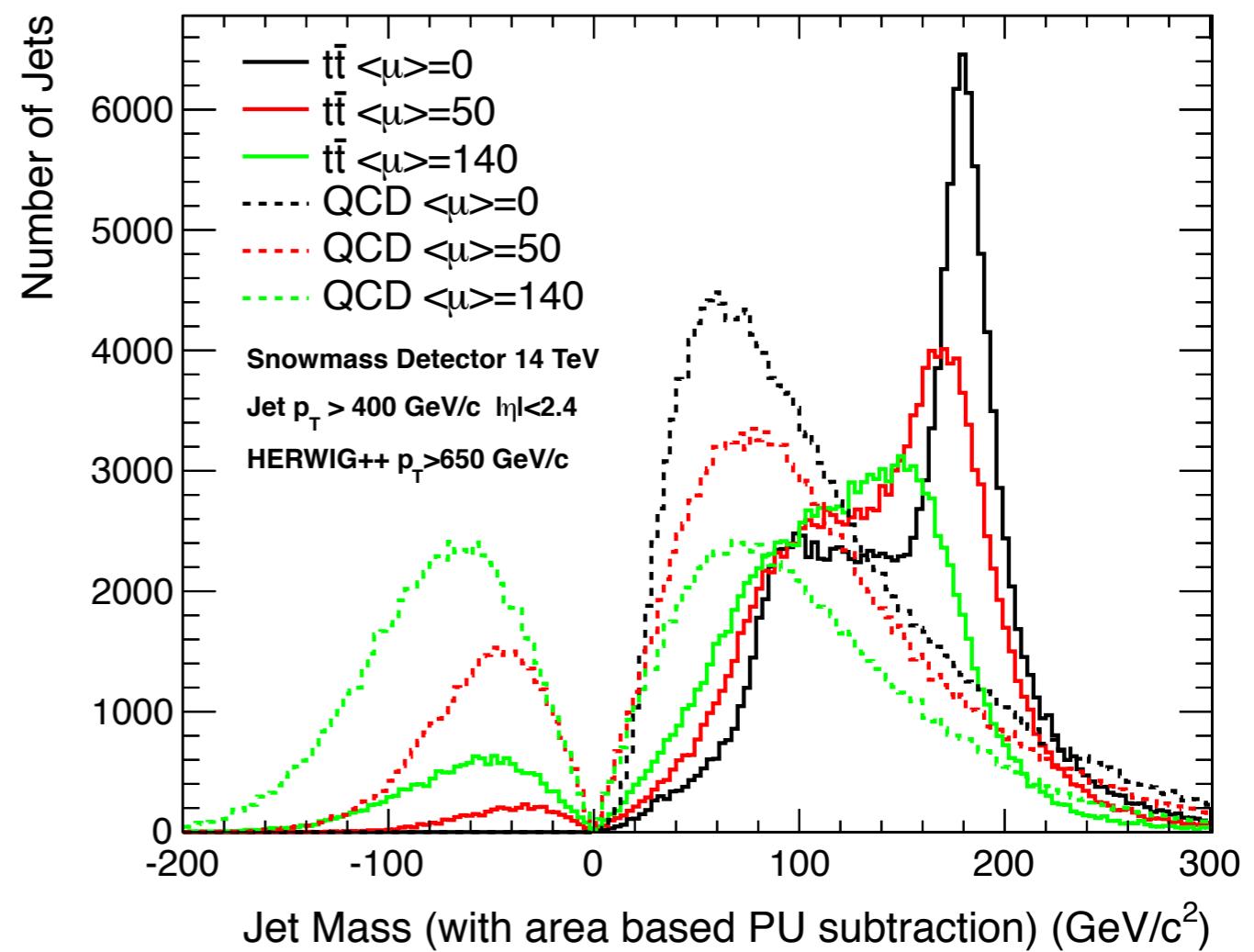
Cacciari, Salam, Soyez

$$p_T^{\text{sub}} = p_T - \rho A$$
$$\rho = \text{median}[p_{Tj}/A_j]$$



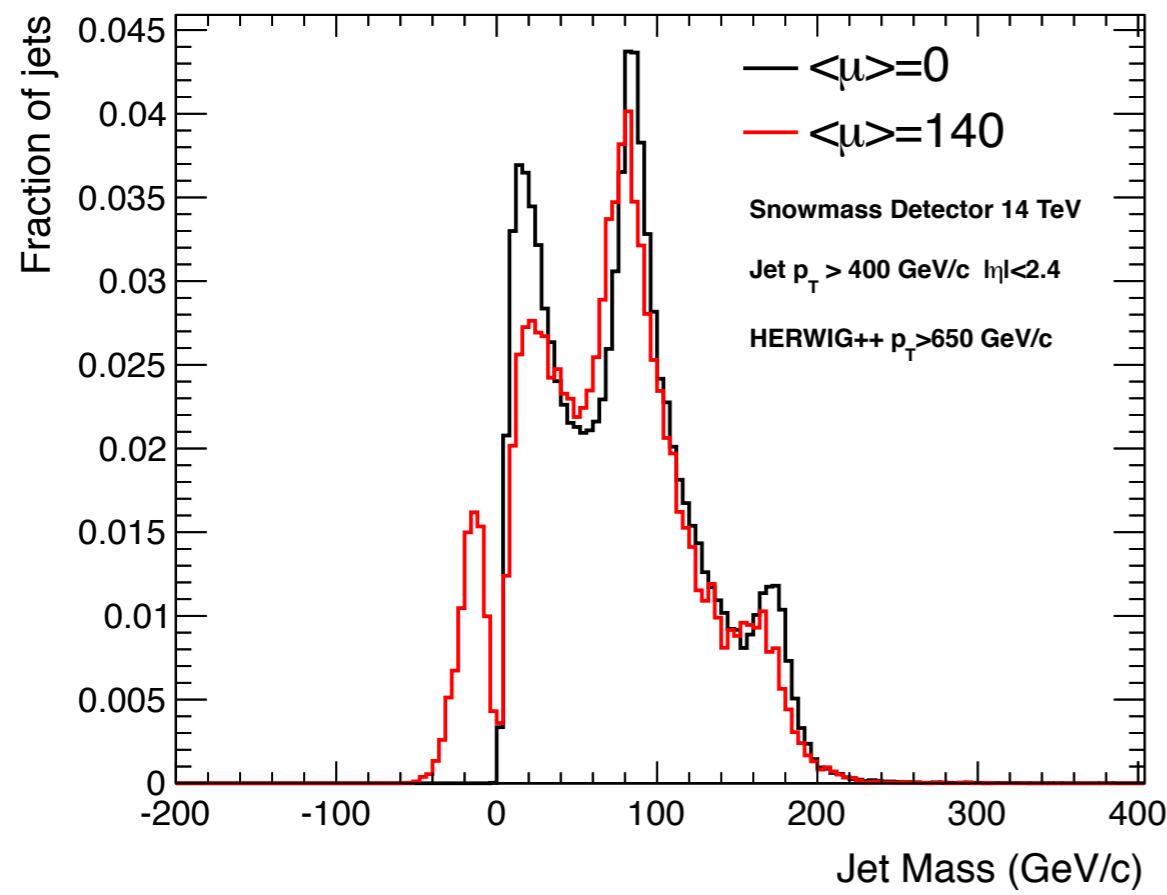
Area based pileup subtraction

- Correcting jet mass is more complicated
 - 4-vector correction: $p_\mu^{sub} = p_\mu - \rho A_\mu$
 - 4-vector area is calculated by integrating a massless 4-vector over the area of the jet (FastJet)
- Fluctuations in rho can lead to negative mass jets
- Jet mass (after area based pileup subtraction) can be used to discriminate top and QCD jets even with 140 pileup, but the top mass peak is smeared and shifted

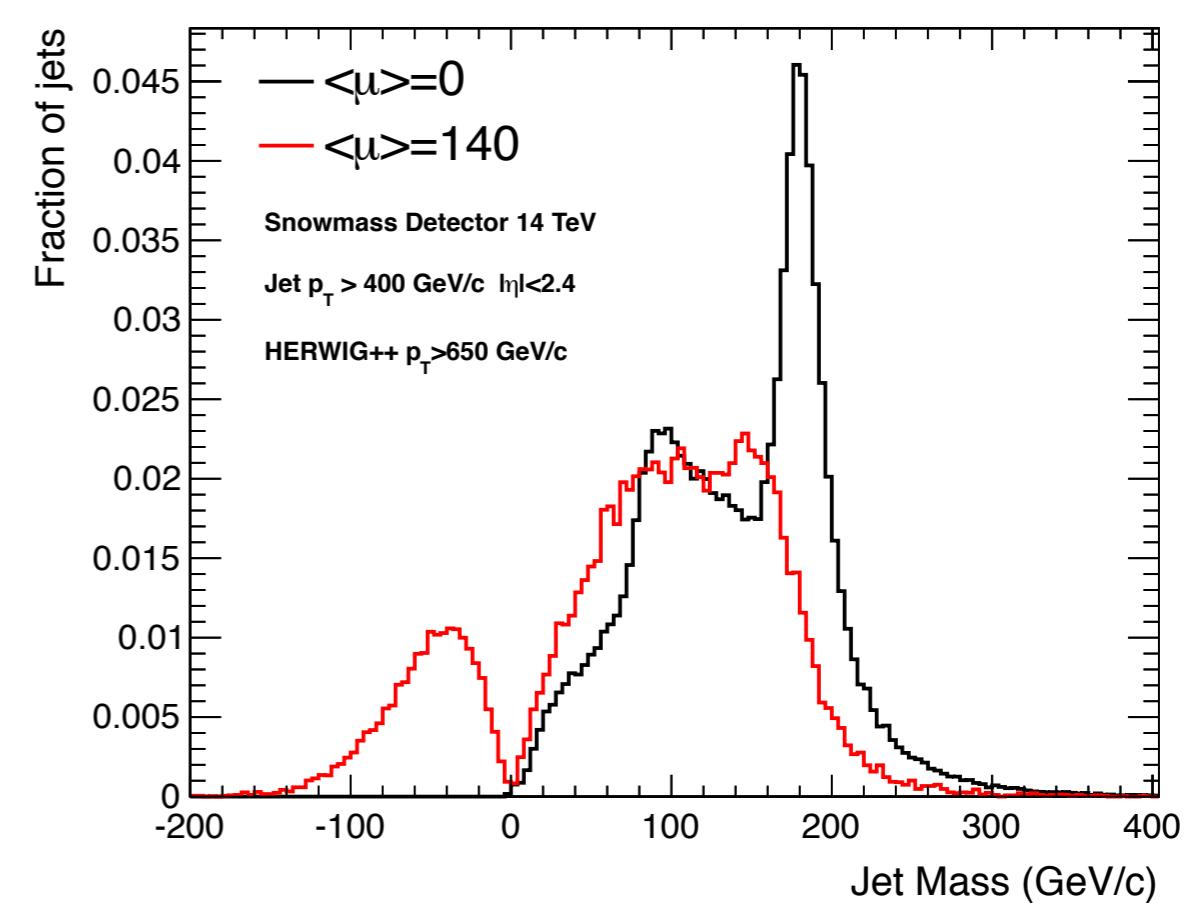


Jet mass after area PU subtraction

AK R=0.5



CA R=0.8



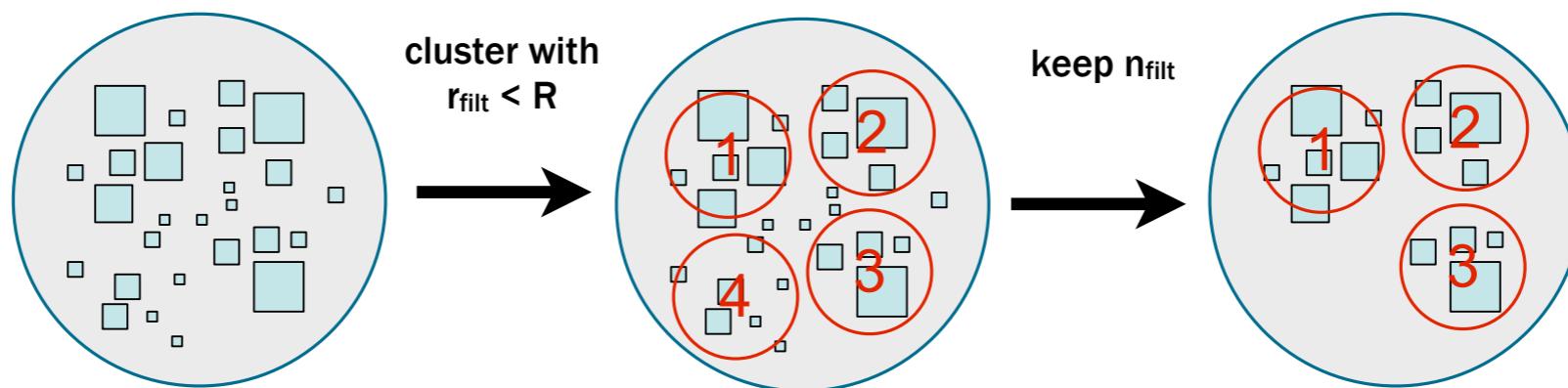
Small area jets have less smearing

Jet Grooming

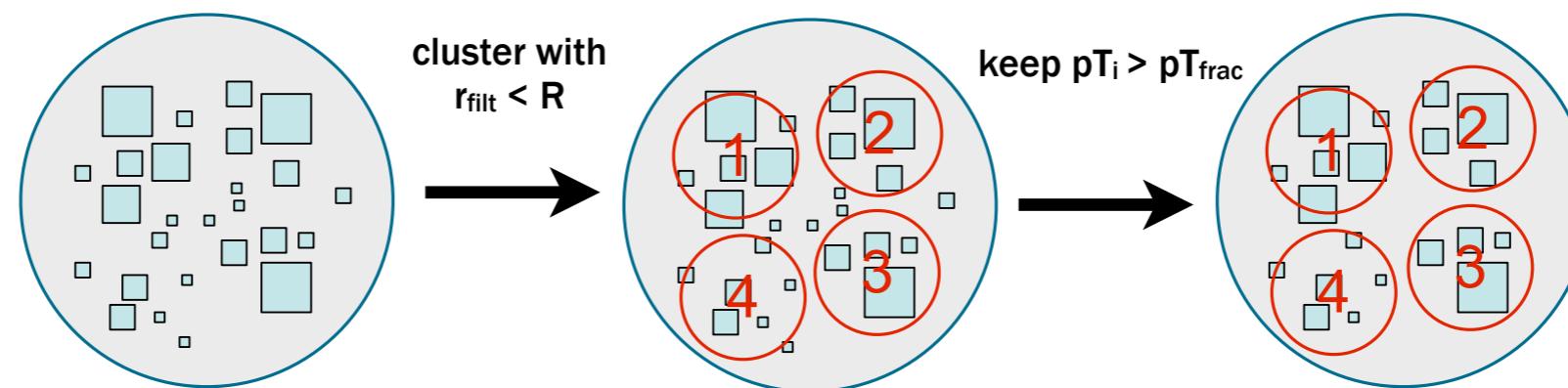
- Jet grooming is another technique to reduce jet contamination from pileup and soft QCD
 - Trimming (Krohn et al.) and filtering (Butterworth et al.) recluster the jet with small jets and keep only the hard subjets
 - Pruning (Ellis et al.) reclusters the jet and keeps only the hard small angle particles

Jet Grooming

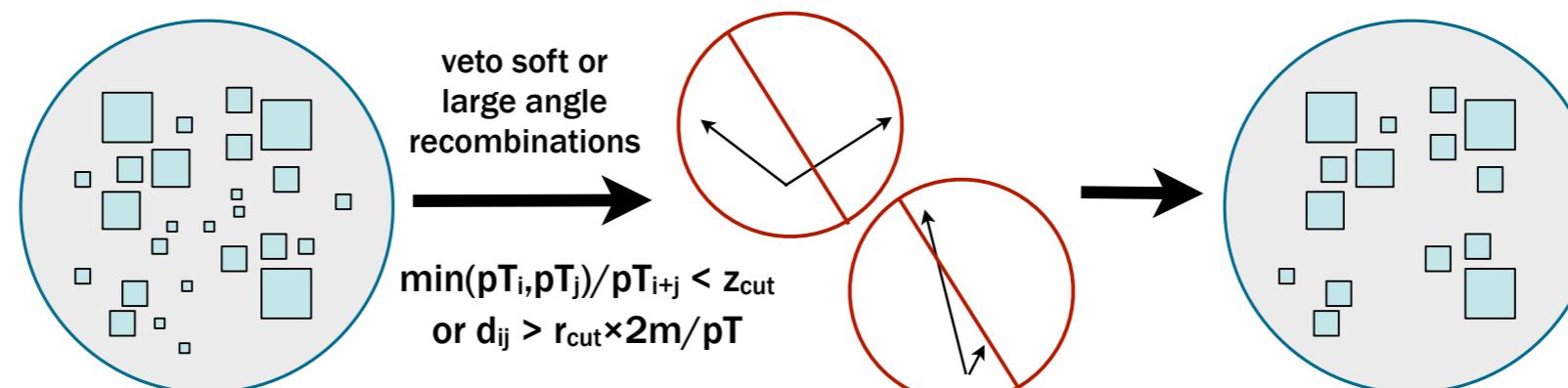
filtering



trimming

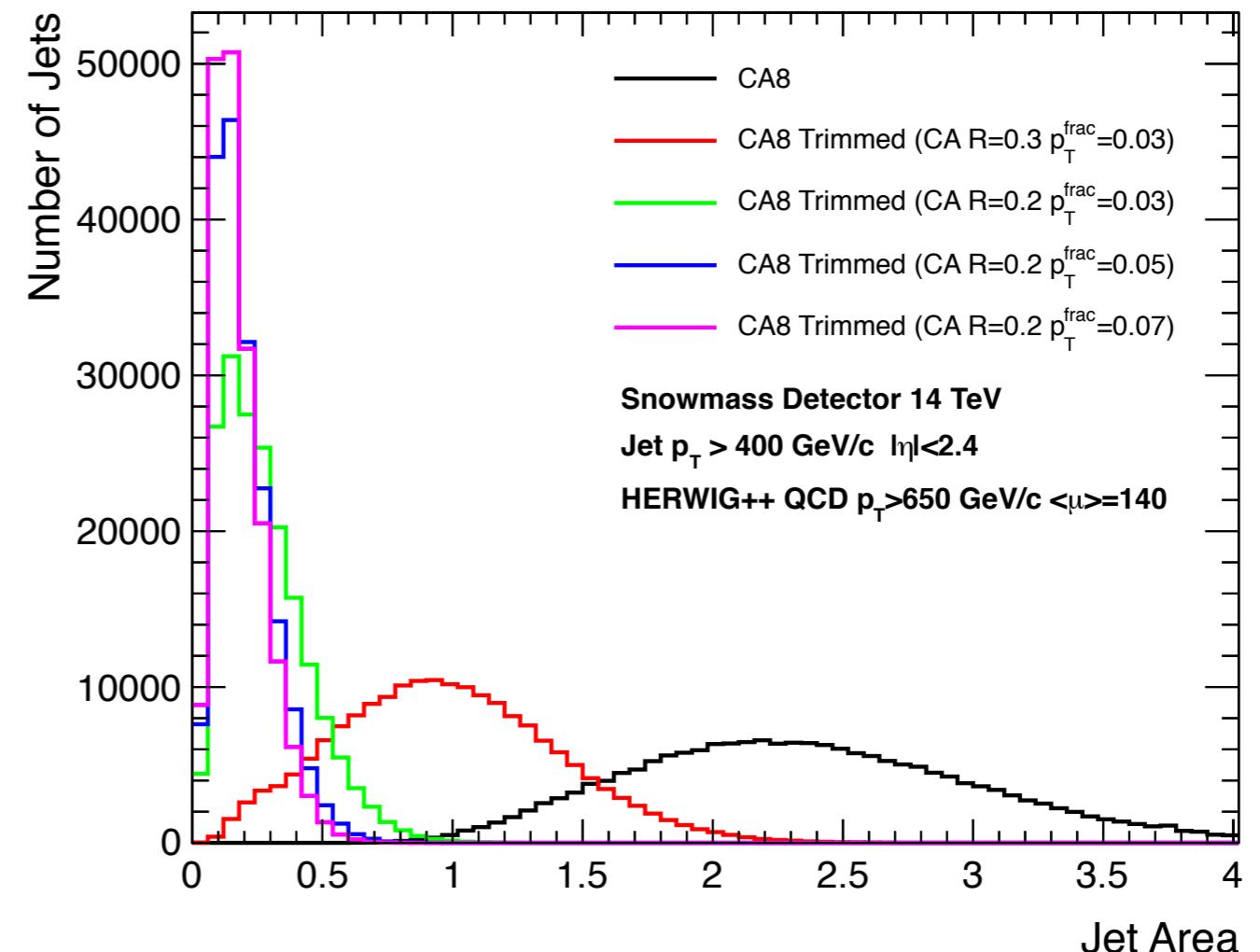


pruning



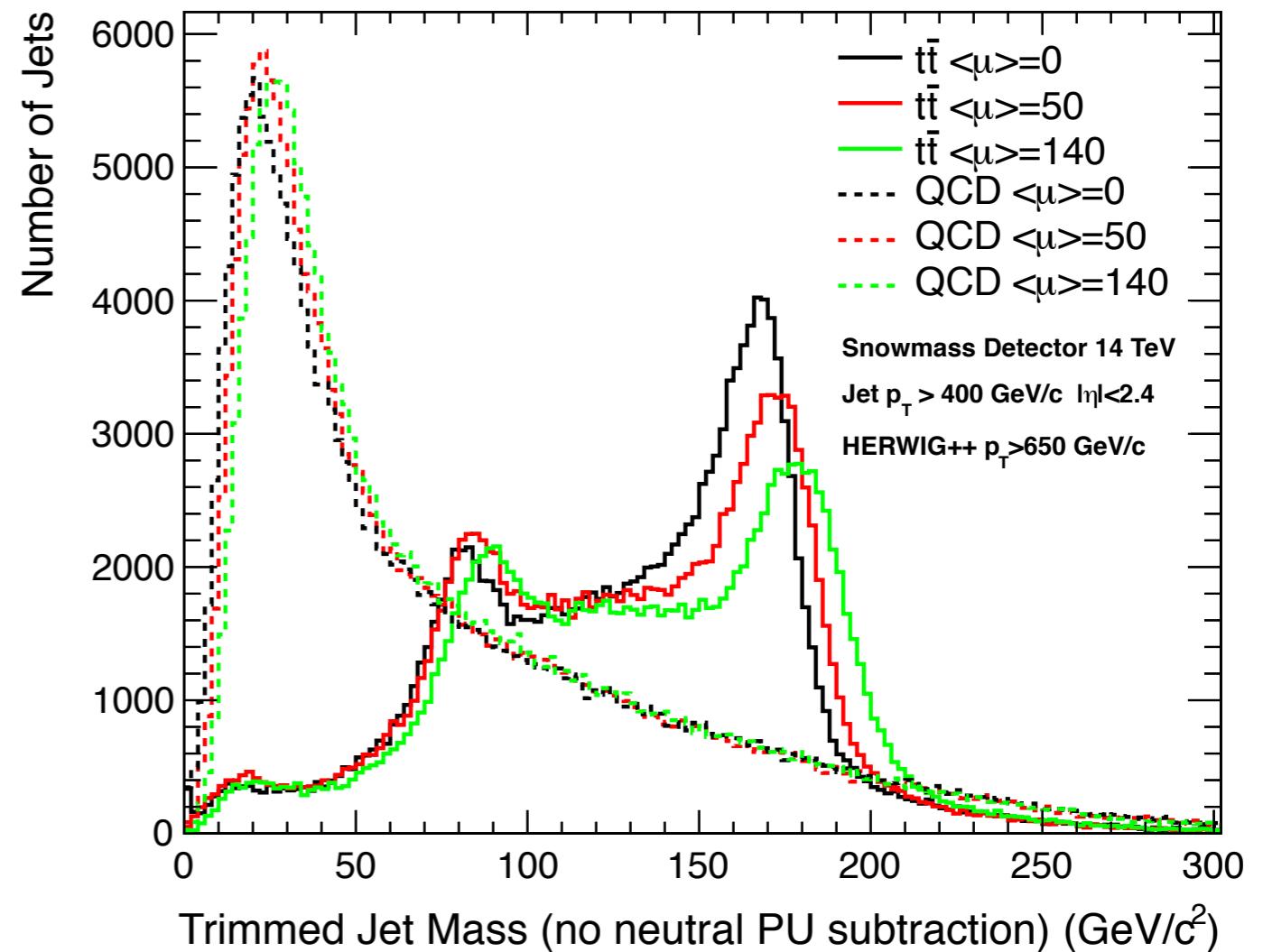
Jet Grooming

- Grooming substantially reduces jet area → reduced pileup contamination



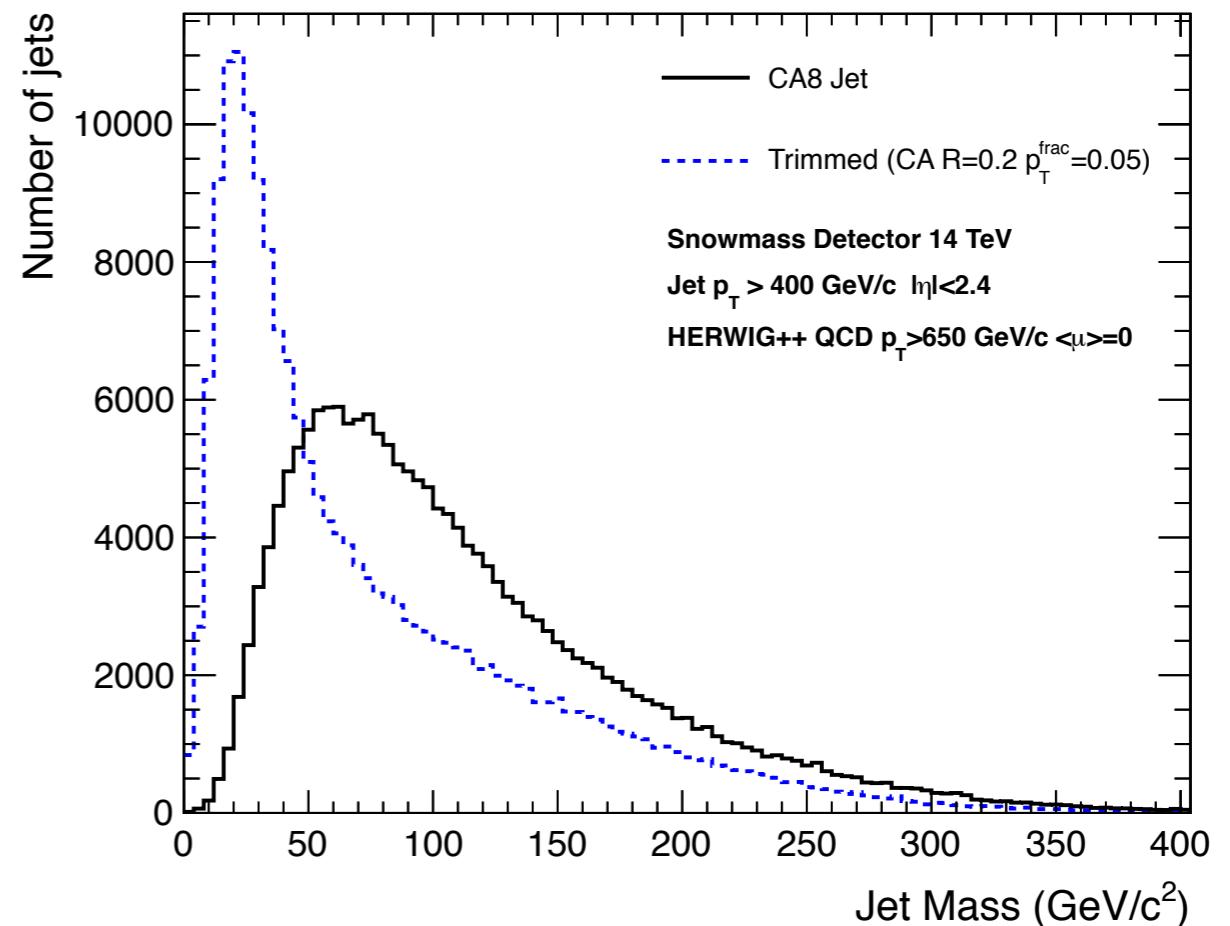
Effects of jet grooming

- Jet mass more stable with increasing pileup
- Small jet area → need much smaller PU correction (in this case none is applied)



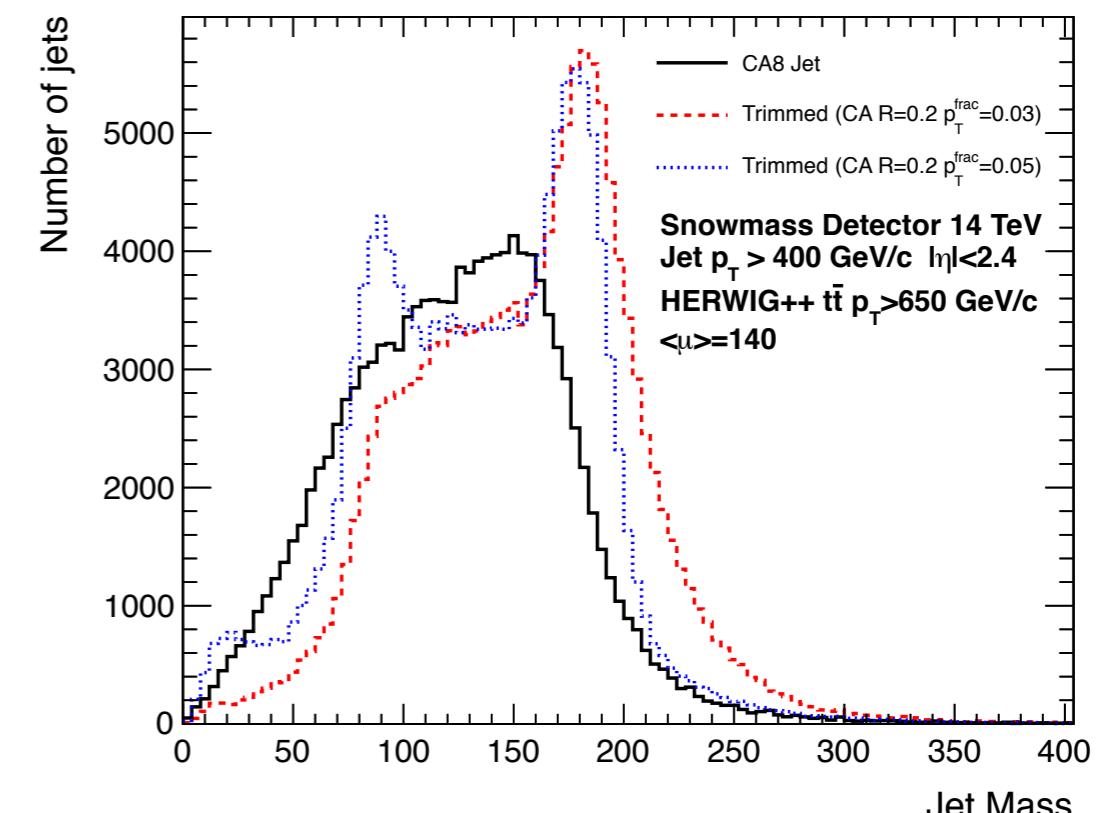
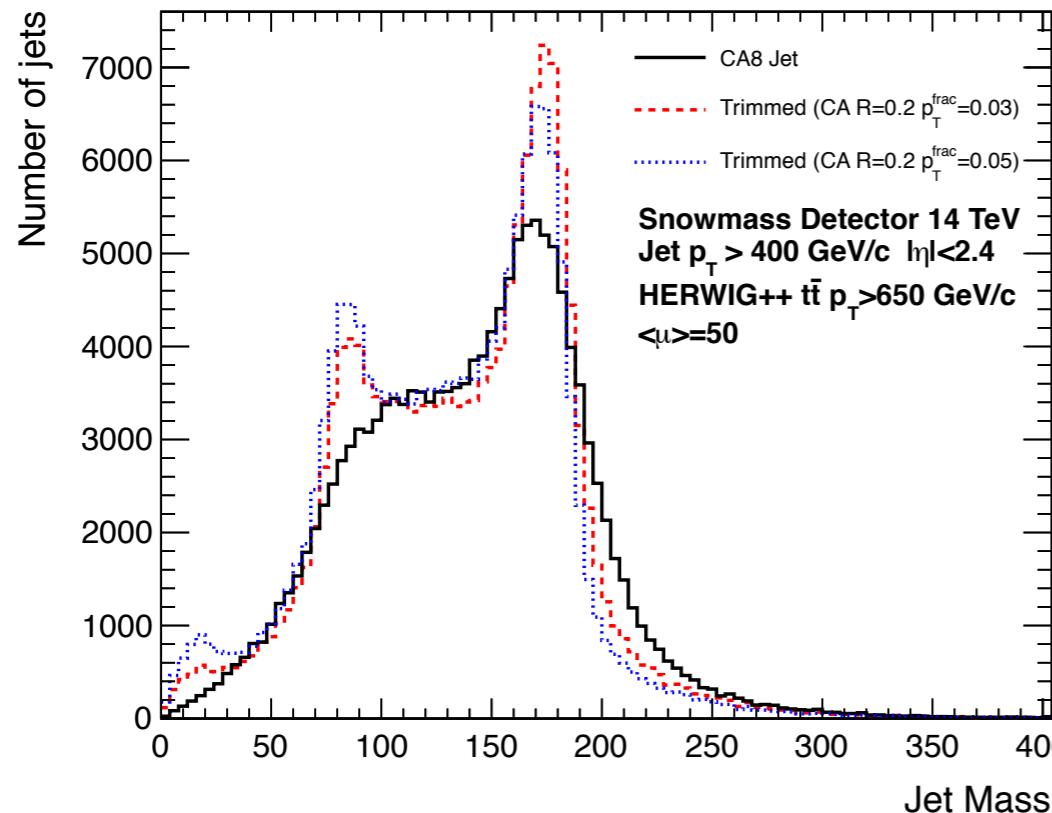
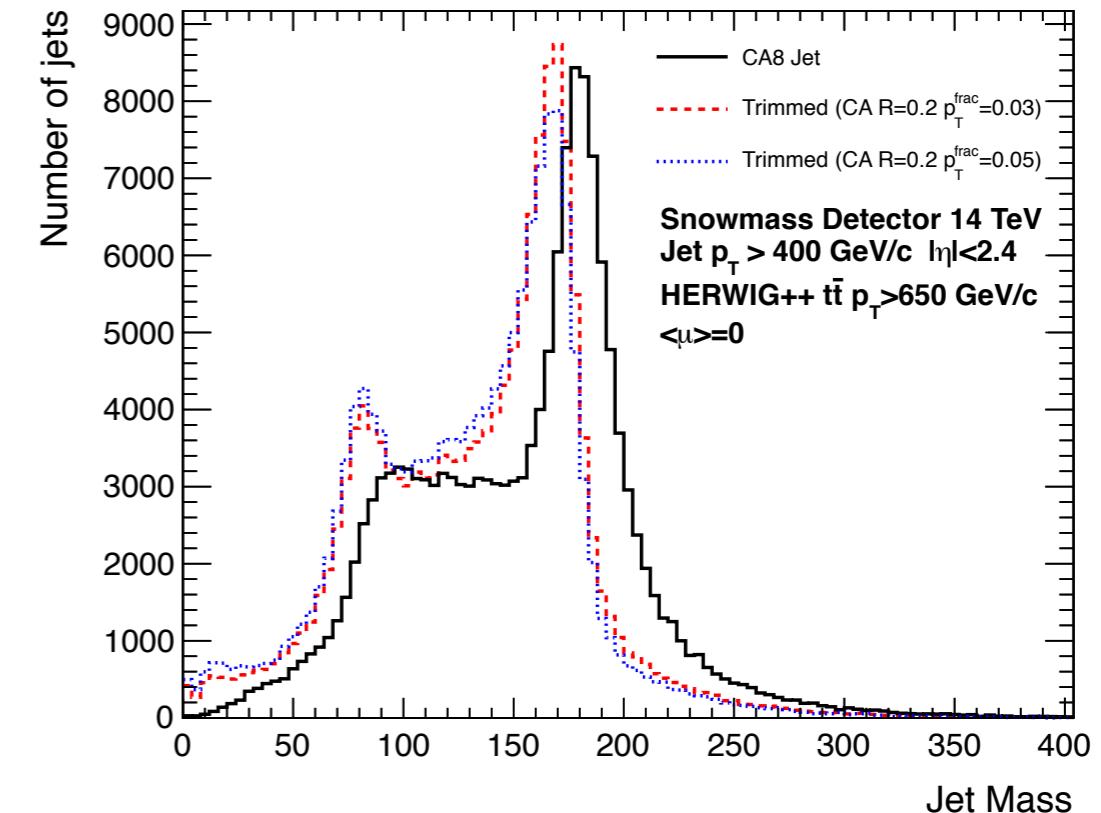
Effects of jet grooming

- Decreased mass of QCD jets
 - Decreased number of QCD jets with mass in top mass window



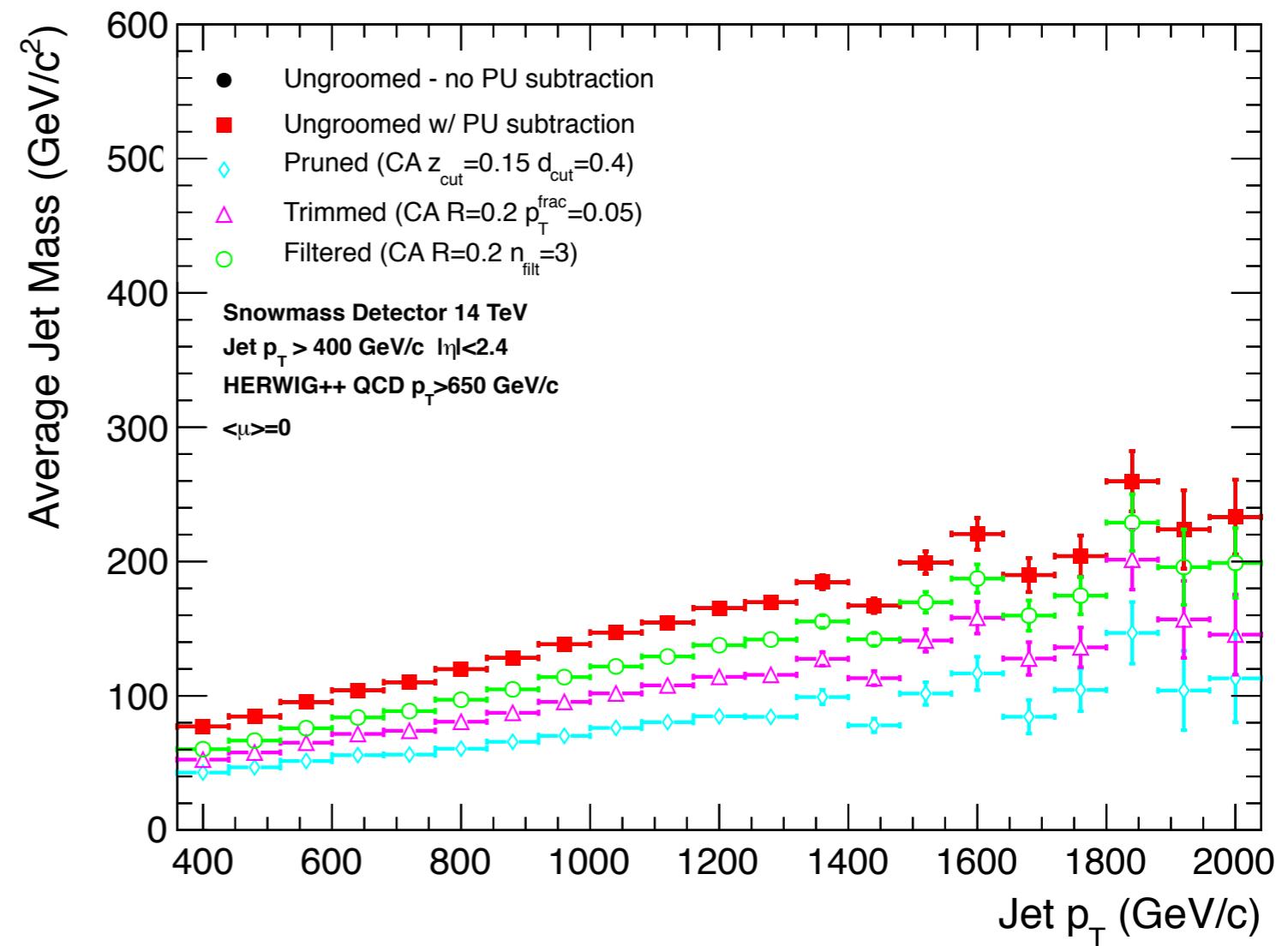
Effects of jet grooming

- Sharpens top mass peak (especially with pileup)
- With zero pileup top mass peak is shifted lower



Effects of jet grooming

- Decreases the jet mass dependence on pT

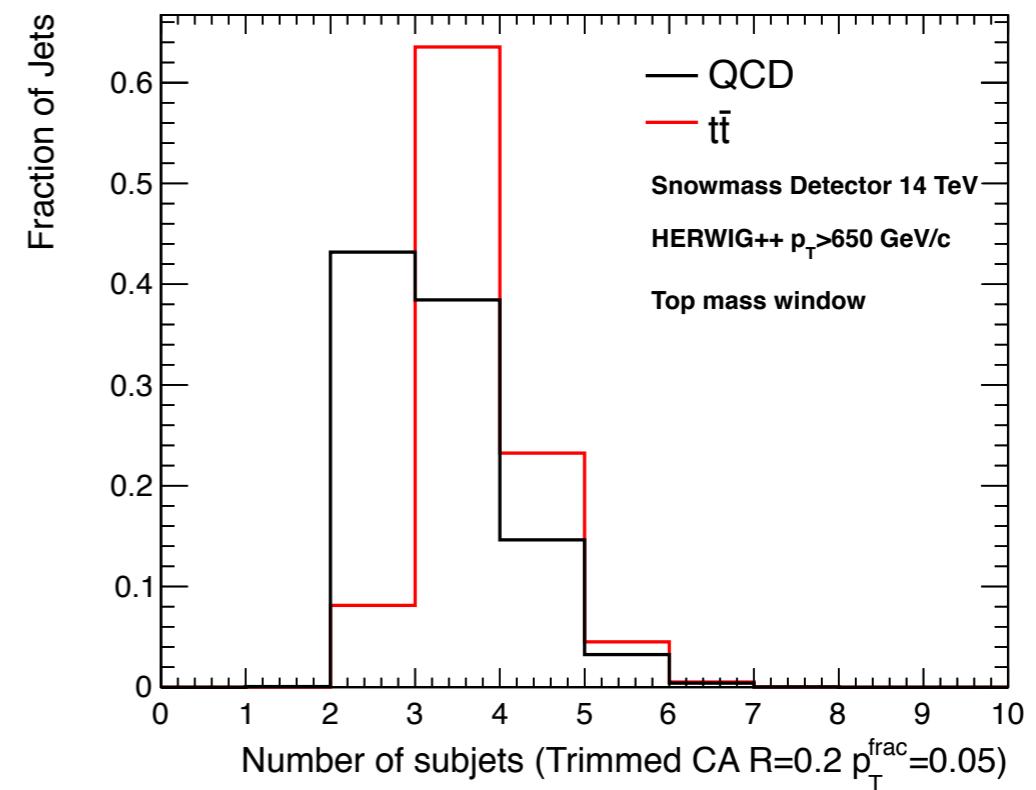
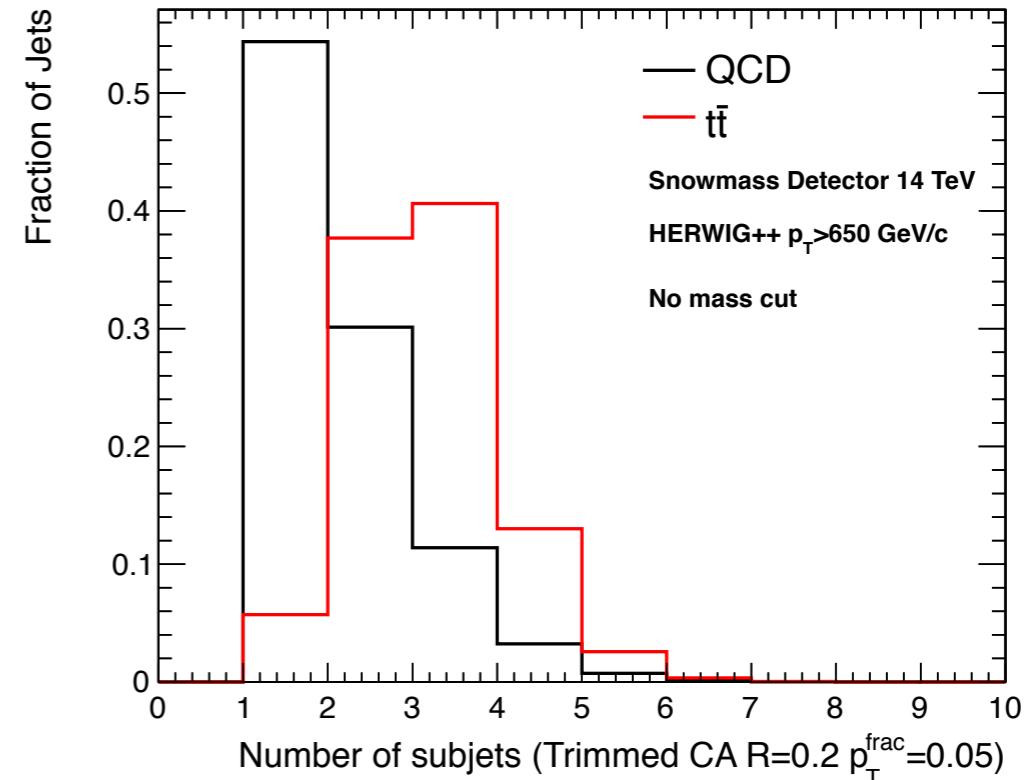


Other tagging variables

- Number of subjets
- Nsubjettiness
- W mass

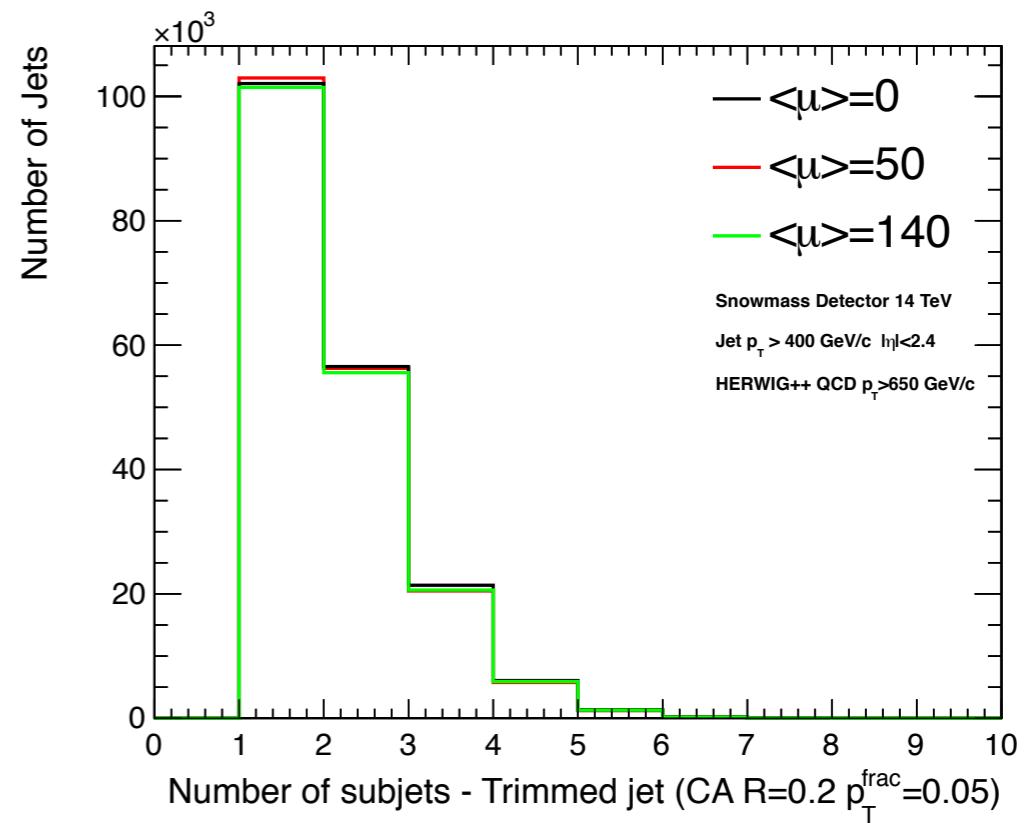
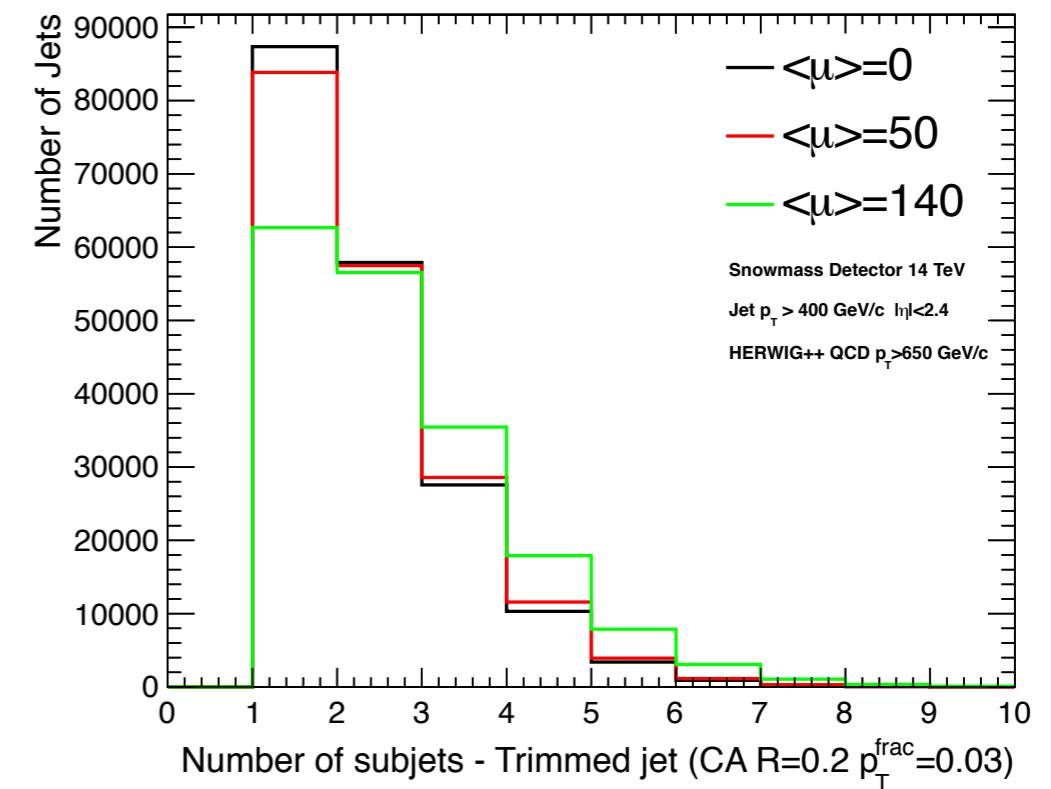
Number of Subjets

- There are many methods to find subjets
- One method: trimming
 - Trimming reclusters jet with small R jets and keeps those that pass a pT fraction requirement (p_T^{frac})
- Number of subjets is a discriminating variable
- Retains some discrimination after applying a jet mass cut



Number of Subjets

- Number of subjets is pile-up stable with the right choice of p_T^{frac}

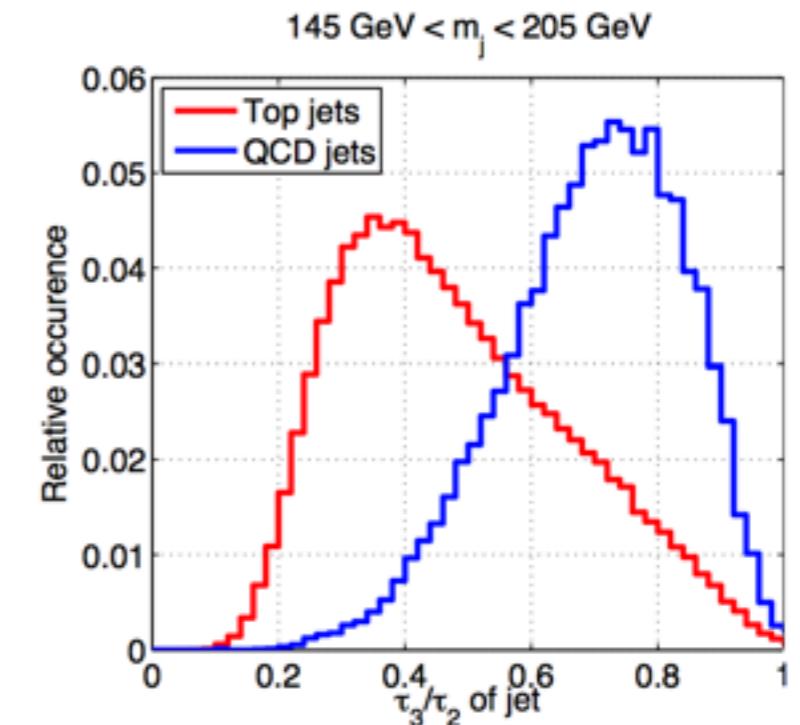
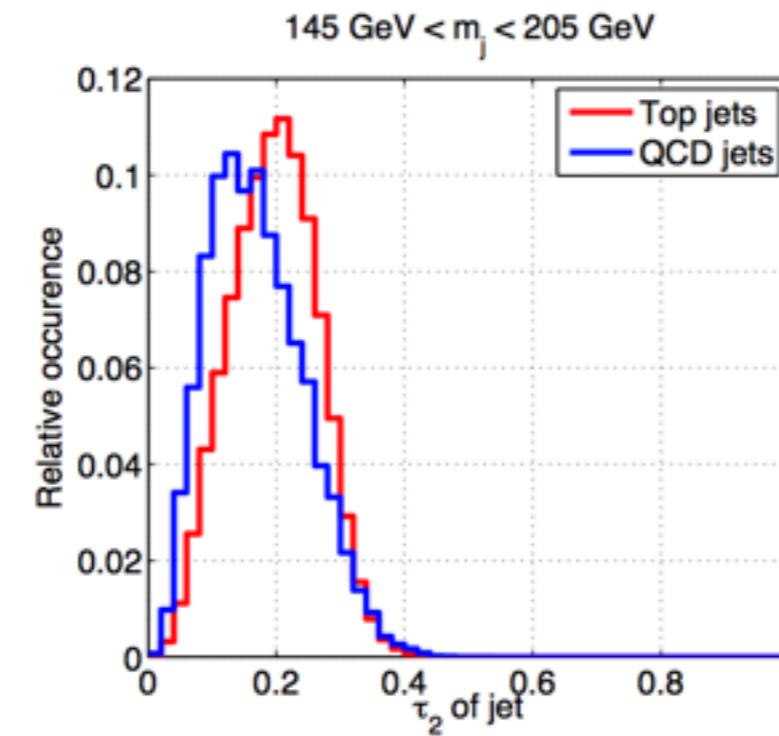
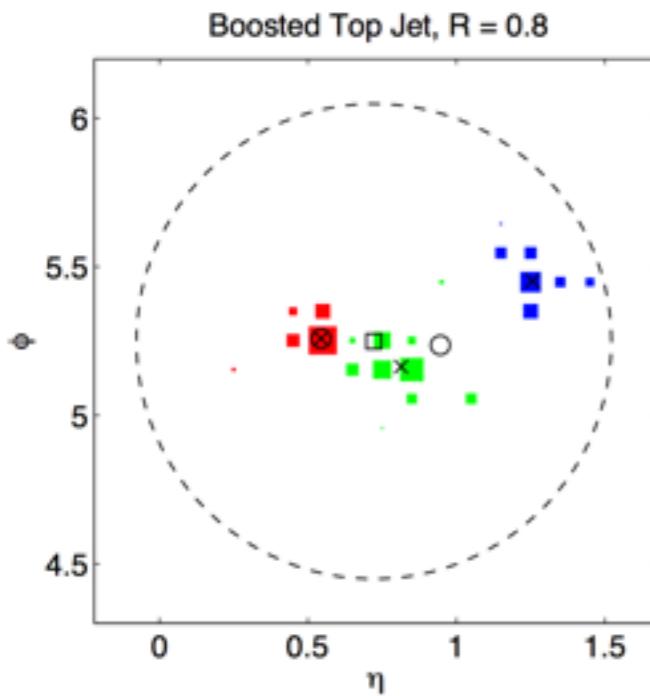


Nsubjettiness

- J. Thaler, K. Van Tilburg (arXiv:1011.2268)
- Define a variable which determines how consistent a jet is with having N subjets

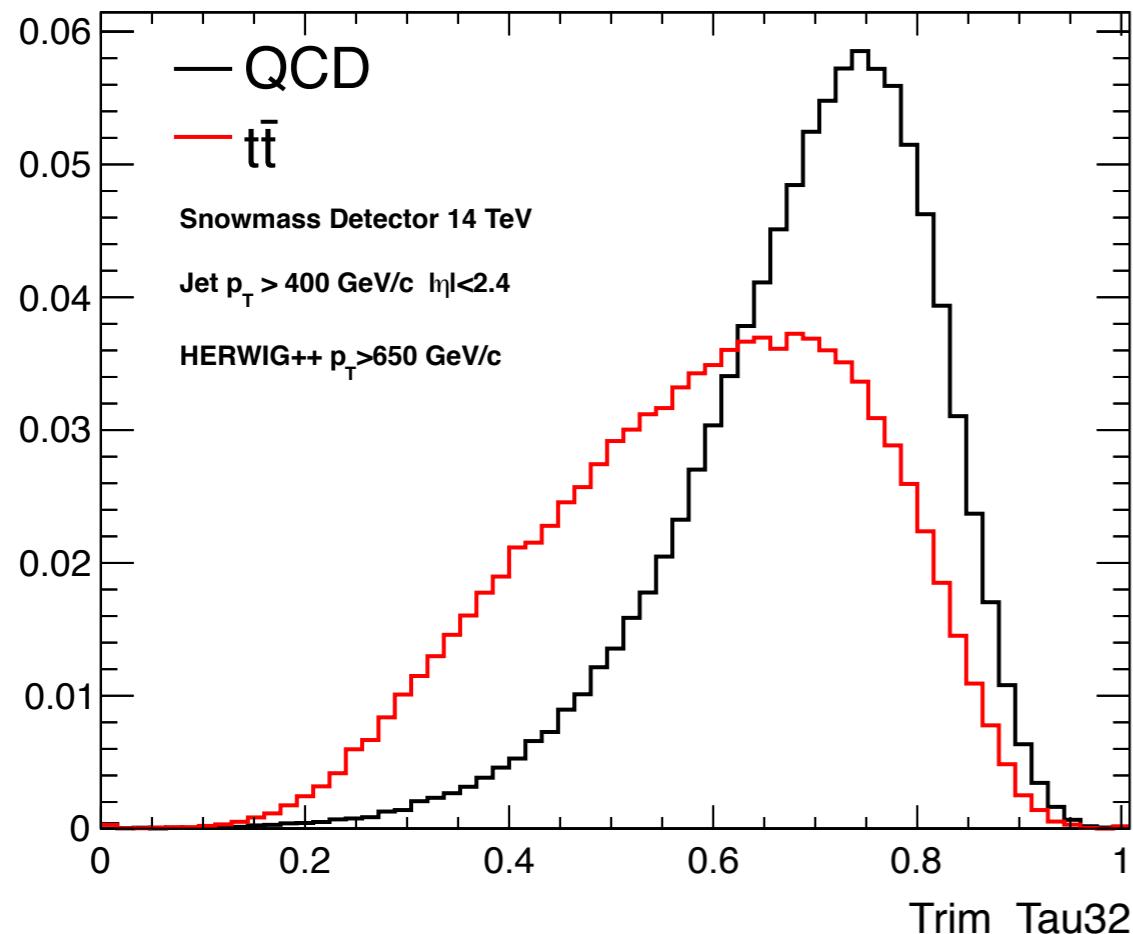
$$\tau_N = \frac{1}{d_0} \sum_k p_{T,k} \min \{ \Delta R_{1,k}, \Delta R_{2,k}, \dots, \Delta R_{N,k} \}$$

- More discrimination by using ratios
- One-pass optimization

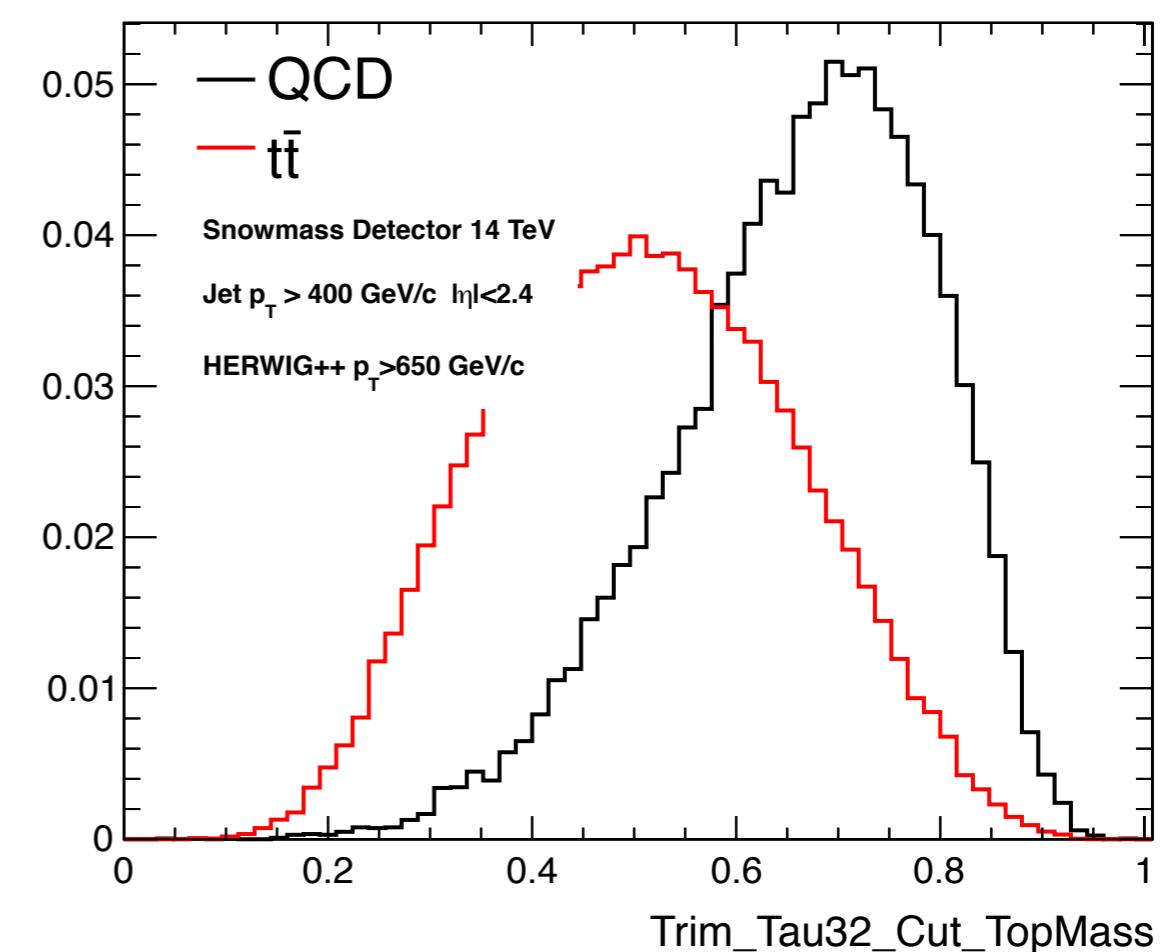


Nsubjettiness

No jet mass requirement



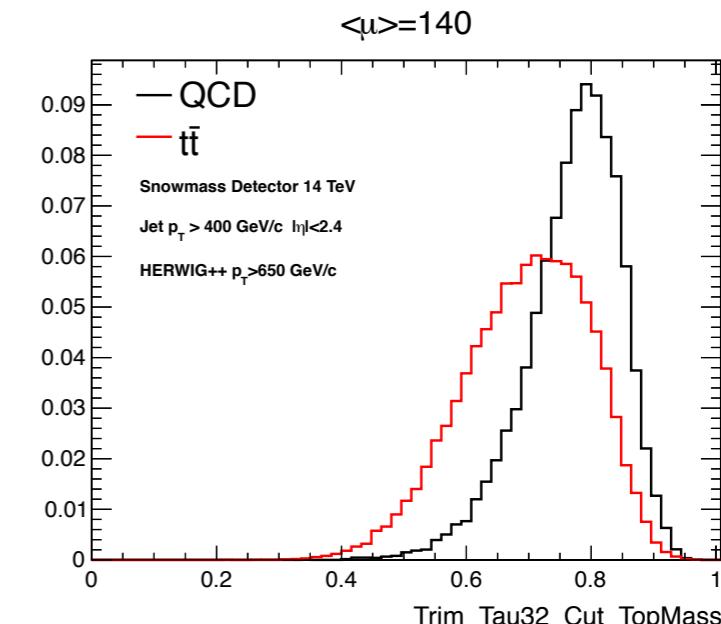
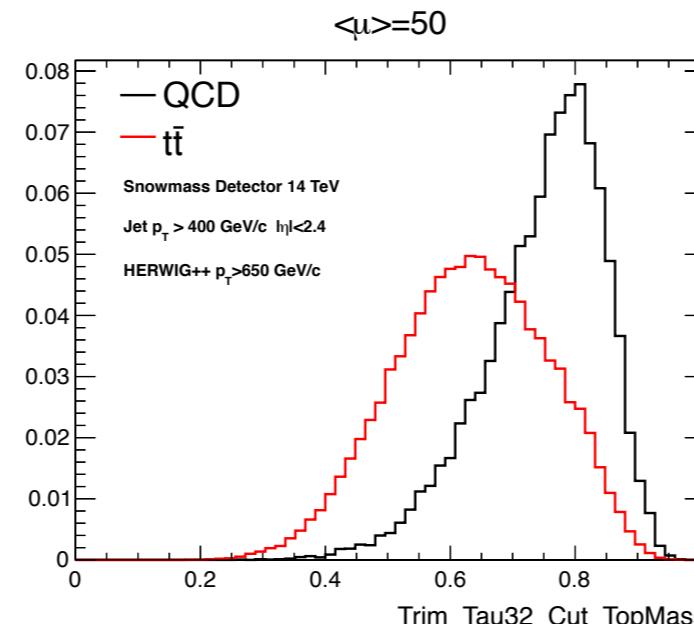
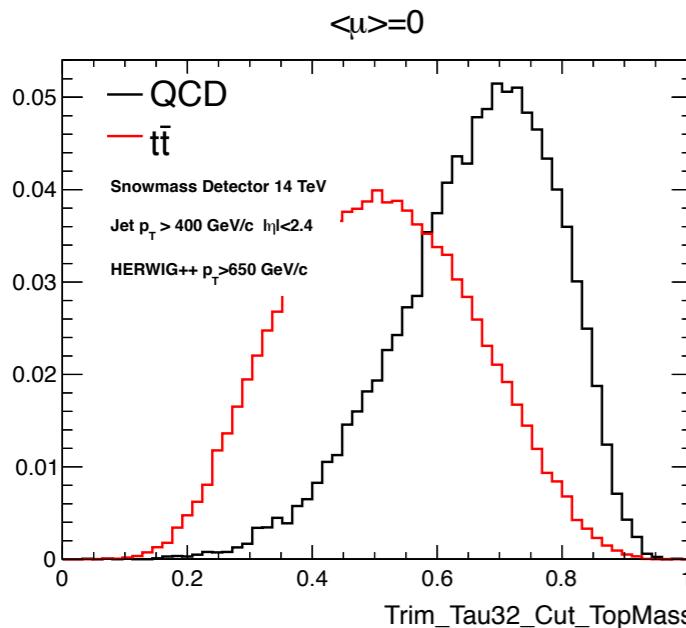
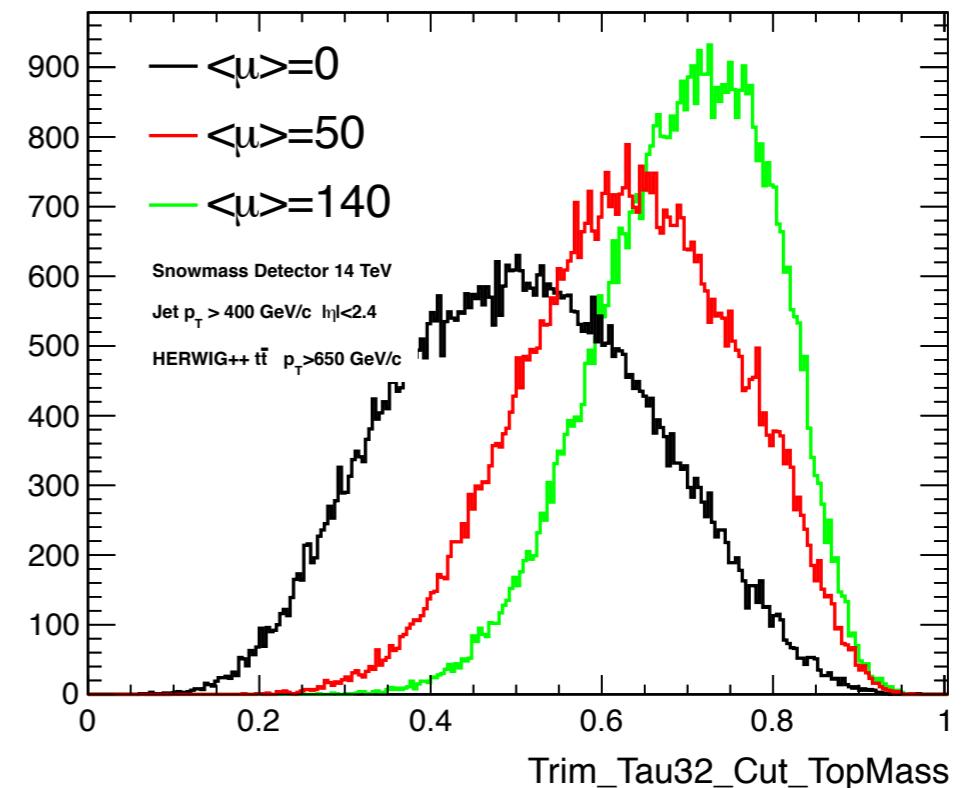
Top mass window
 $150 < m_{\text{trim}} < 230$



- Good discrimination
- Relatively uncorrelated with jet mass

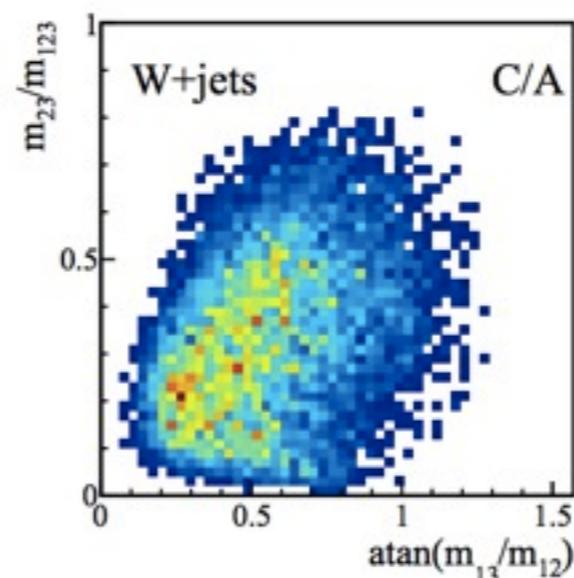
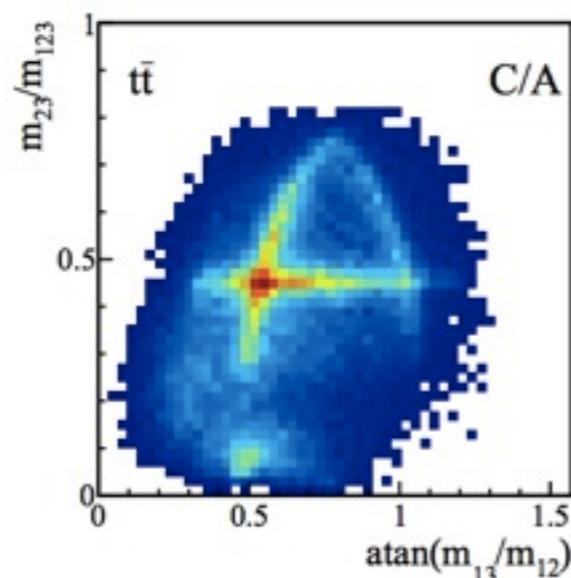
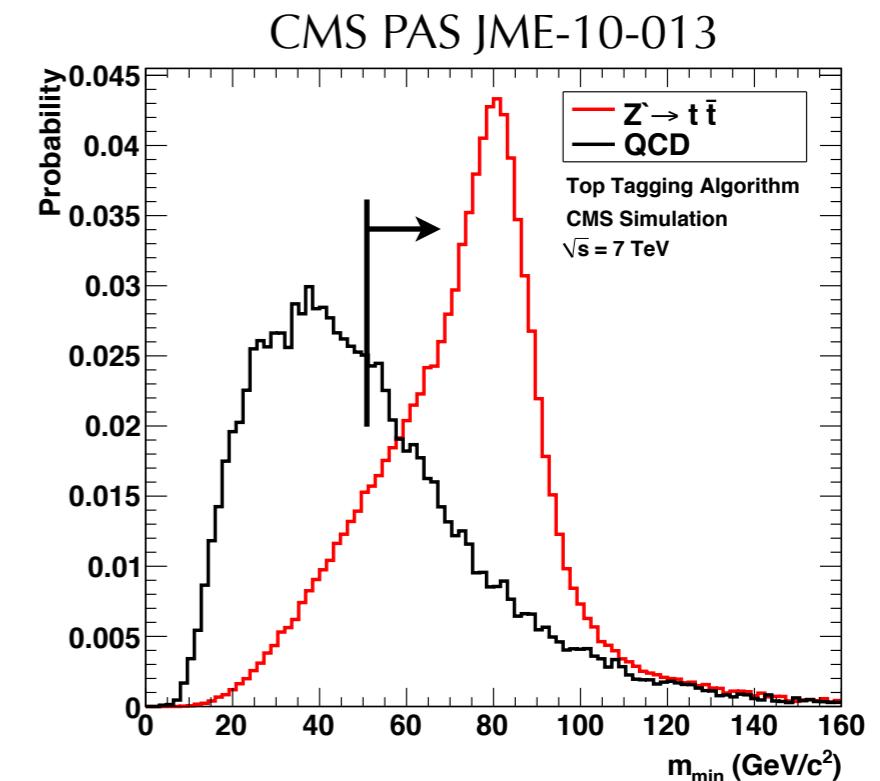
Nsubjettiness

- No pile-up subtraction
- Discrimination degrades at high pile-up
- Entire distribution shifts
 - Cut as a function of N_{vtx} ?

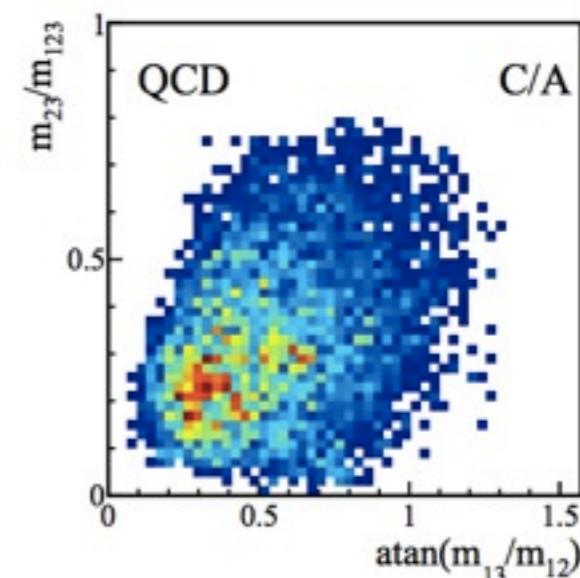


W mass within top jet

- Pairwise mass of two subjets should reconstruct the W mass
 - Additional kinematic variable
- Which pair of subjets?
 - HEP Top Tagger - ratio of pairwise masses
 - JHU/CMS Top tagger - minimum pairwise mass ($m_{\min} = \min[m_{01}, m_{12}, m_{02}]$)

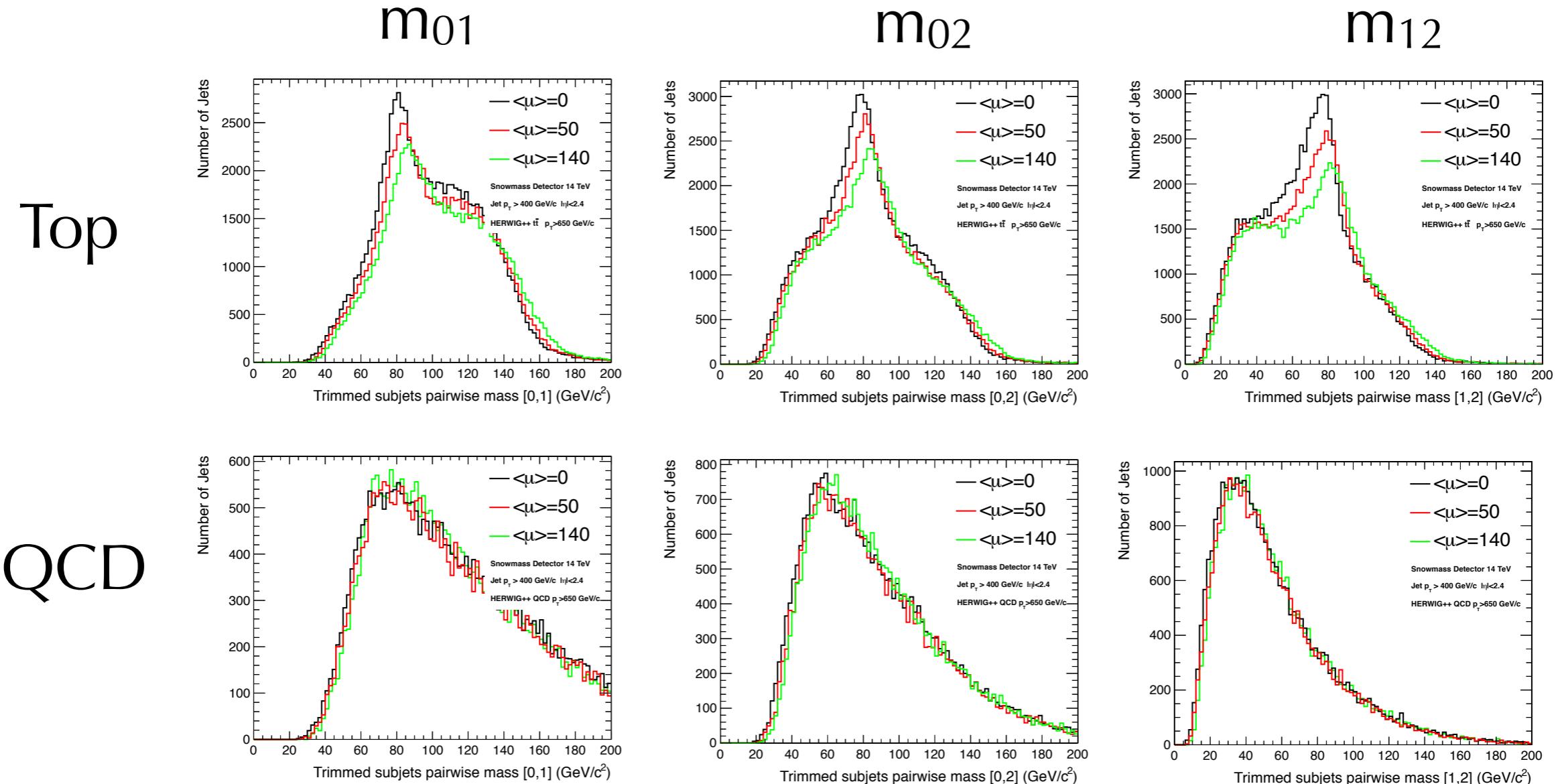


Plehn et al. (arXiv:1006.2833)



W mass within top jet

- Subjet pairwise mass for leading 3 subjets in trimmed jets
 - W peak is useful for identifying tops
- Relatively pile-up stable



Conclusion

- Top tagging is still viable at very high pile-up but with some degradation in performance
- Some variables are more susceptible
 - Grooming is necessary for large R jets if you are cutting on jet mass
- To do:
 - Take a look at 33 TeV files
 - Explore other top taggers and variables
 - CMS Top Tagger
 - HEP Top Tagger
- Justin will continue this discussion

Backup

Tagging in official Ntuples

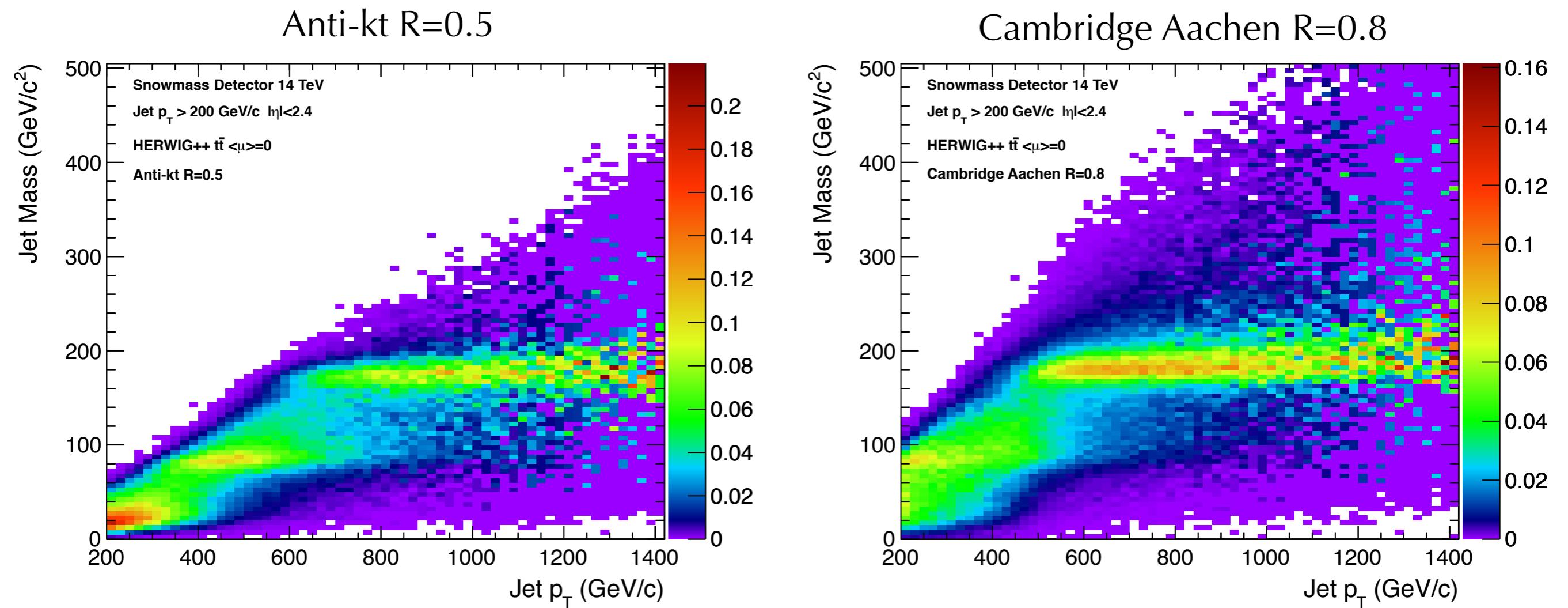
Variables

- Trimmed mass
- Tau1
- Tau2
- Tau3
- Nsubjets
- Mass Drop

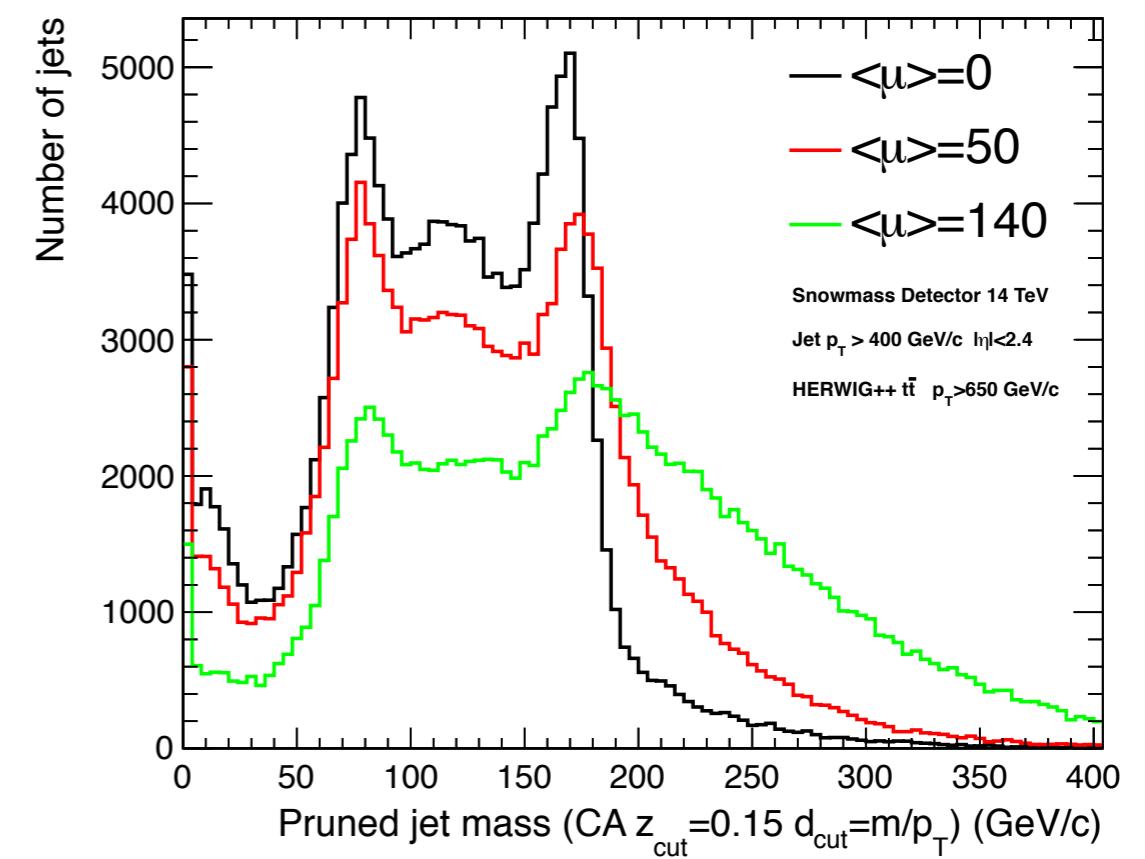
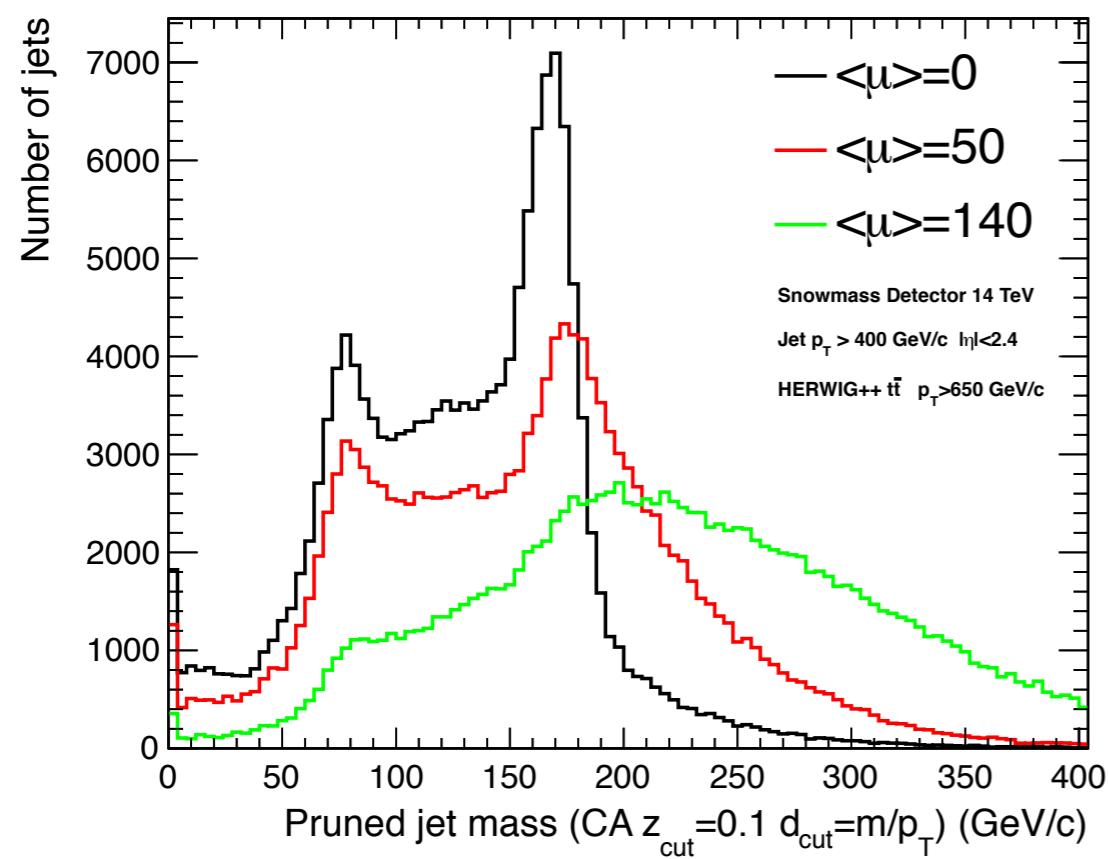
Taggers

- Top tag bool - trimmed top tagger
 - trimmed jet parameters: pTfrac = 0.5, CA R=0.2
 - trimmed jet mass [140,230]
 - trimmed Nsubjets ≥ 3
- W tag bool
 - trimmed jet parameters: pTfrac = 0.5, CA R=0.2
 - trimmed jet mass [60,120]
 - mass drop < 0.4
- H tag bool
 - trimmed jet parameters: pTfrac = 0.5, CA R=0.2
 - trimmed jet mass [100,140]
 - mass drop < 0.4

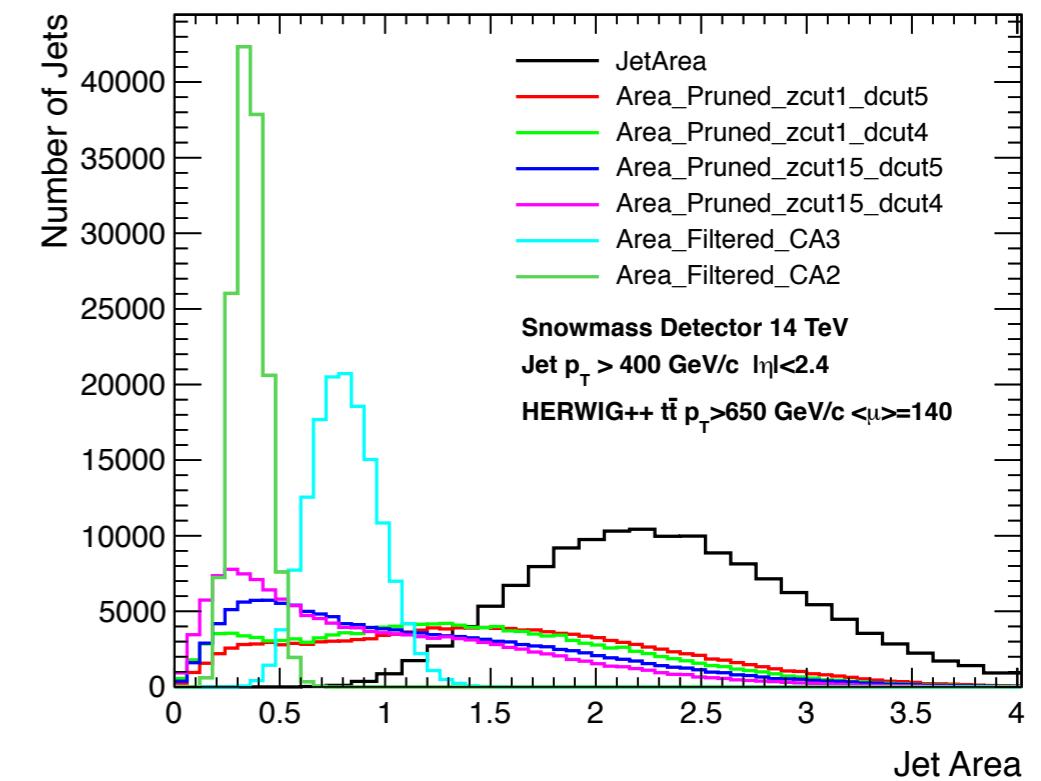
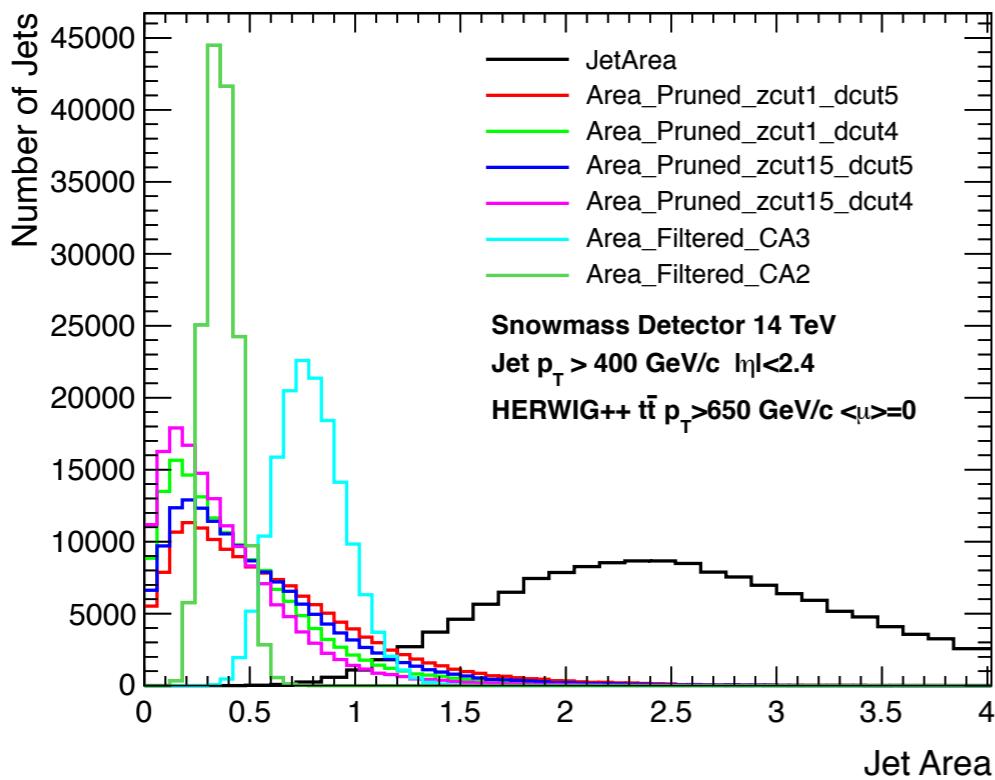
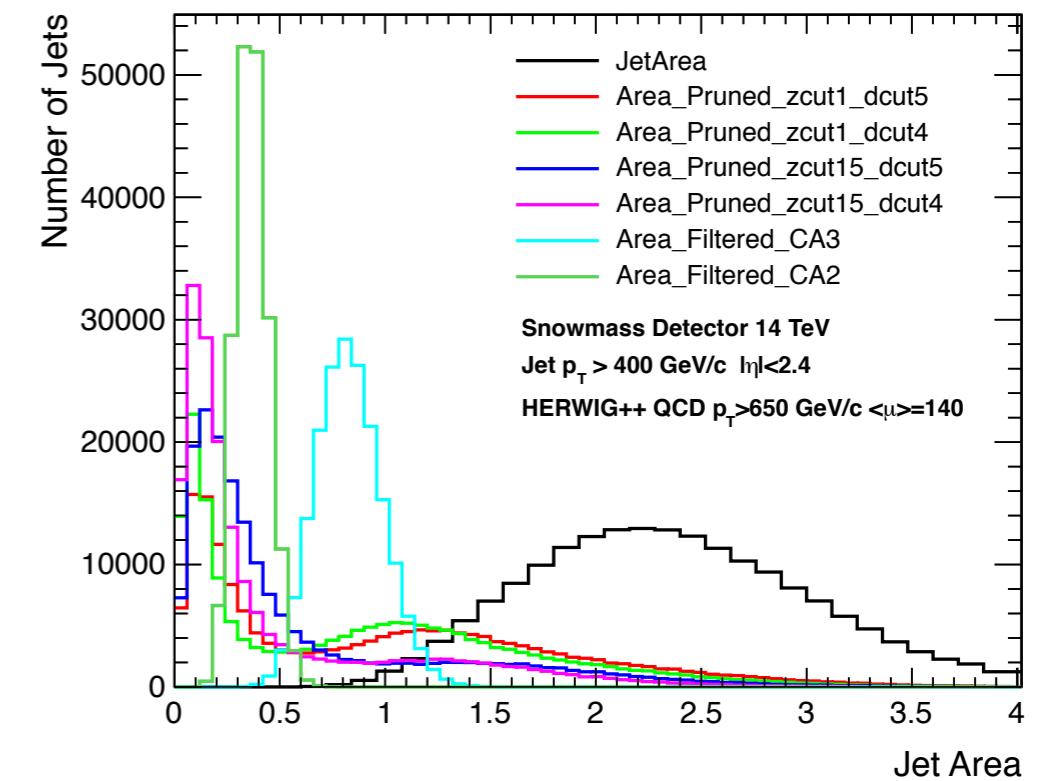
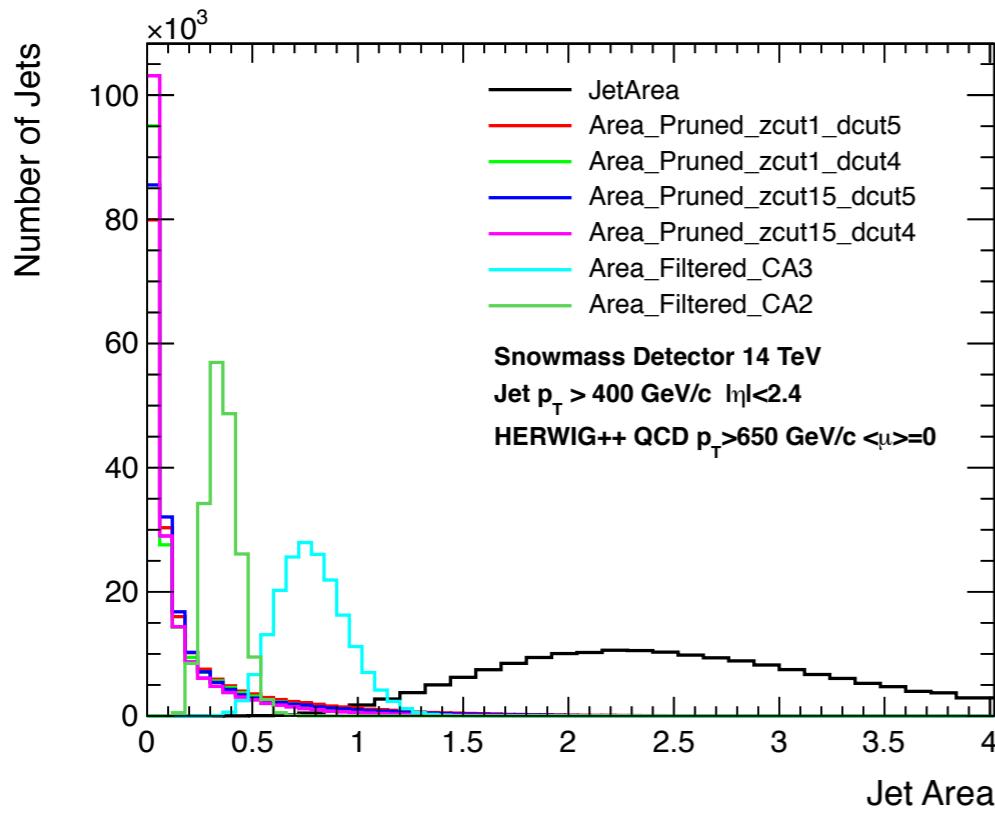
Compare distance parameter



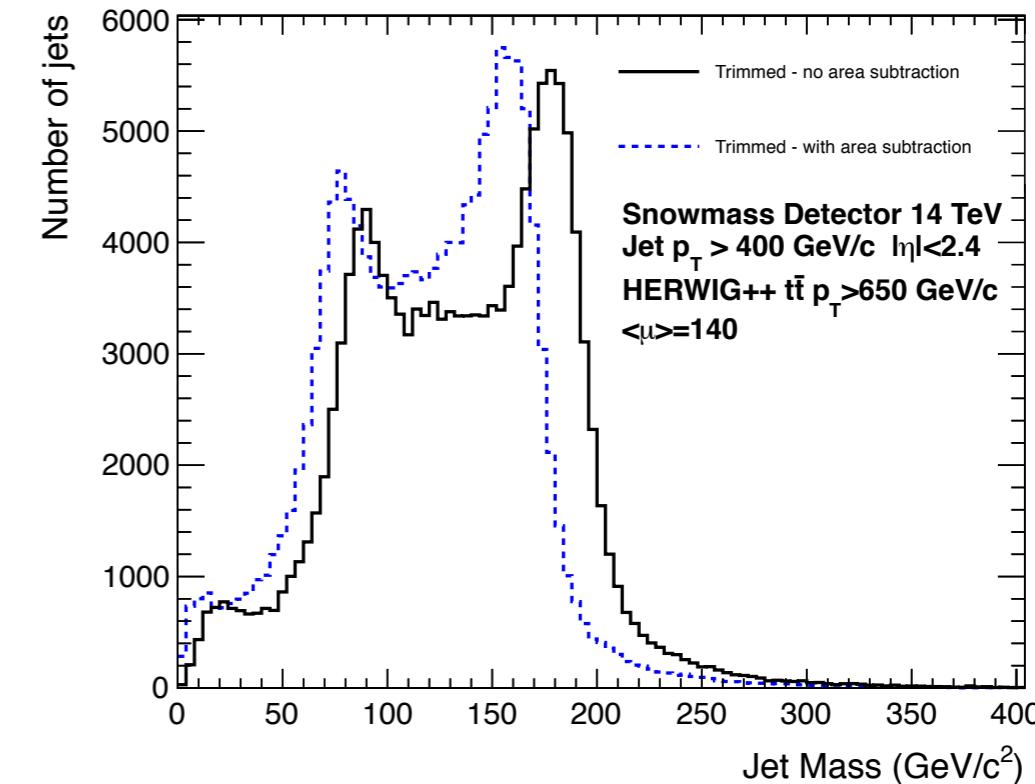
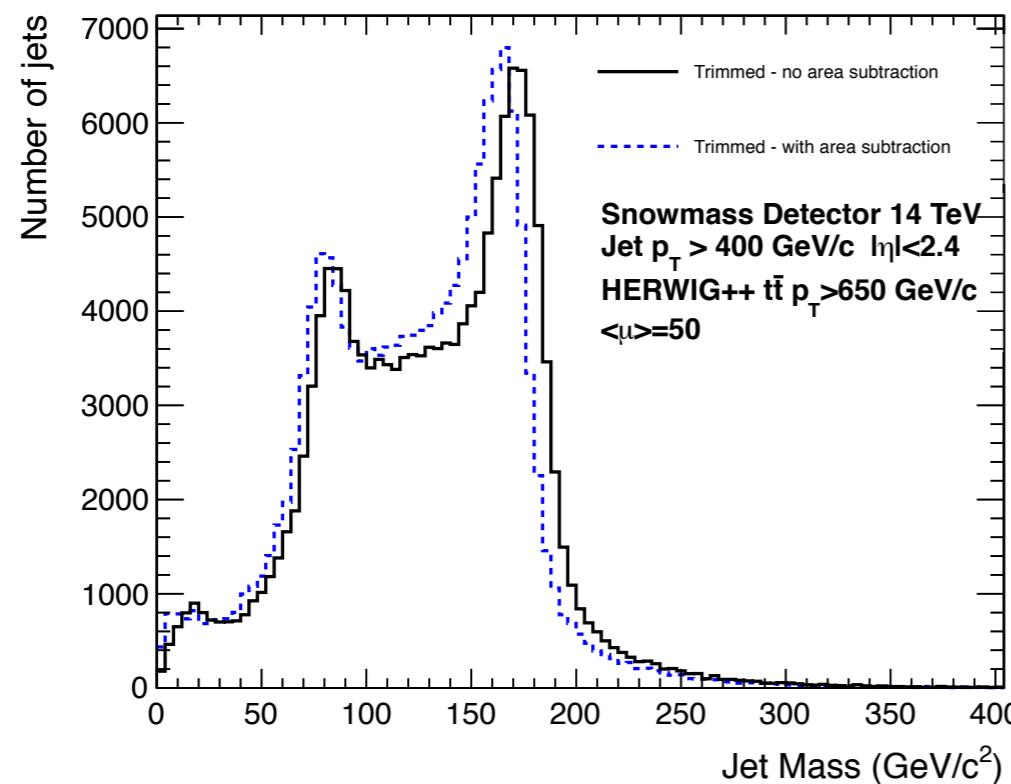
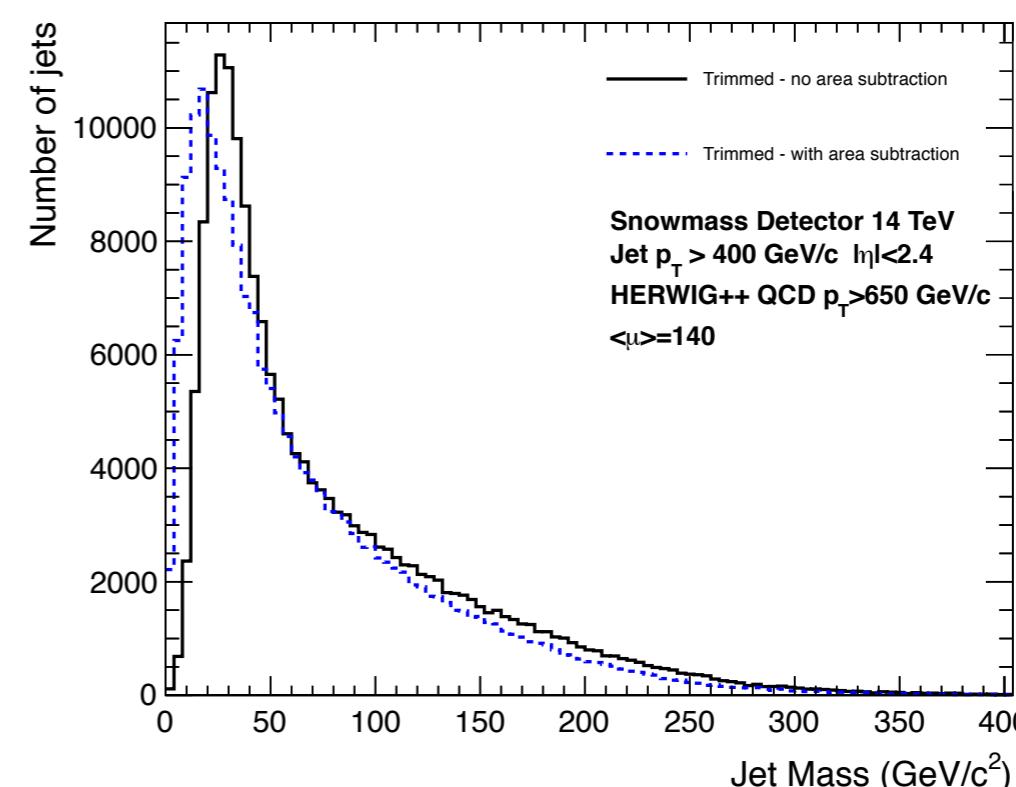
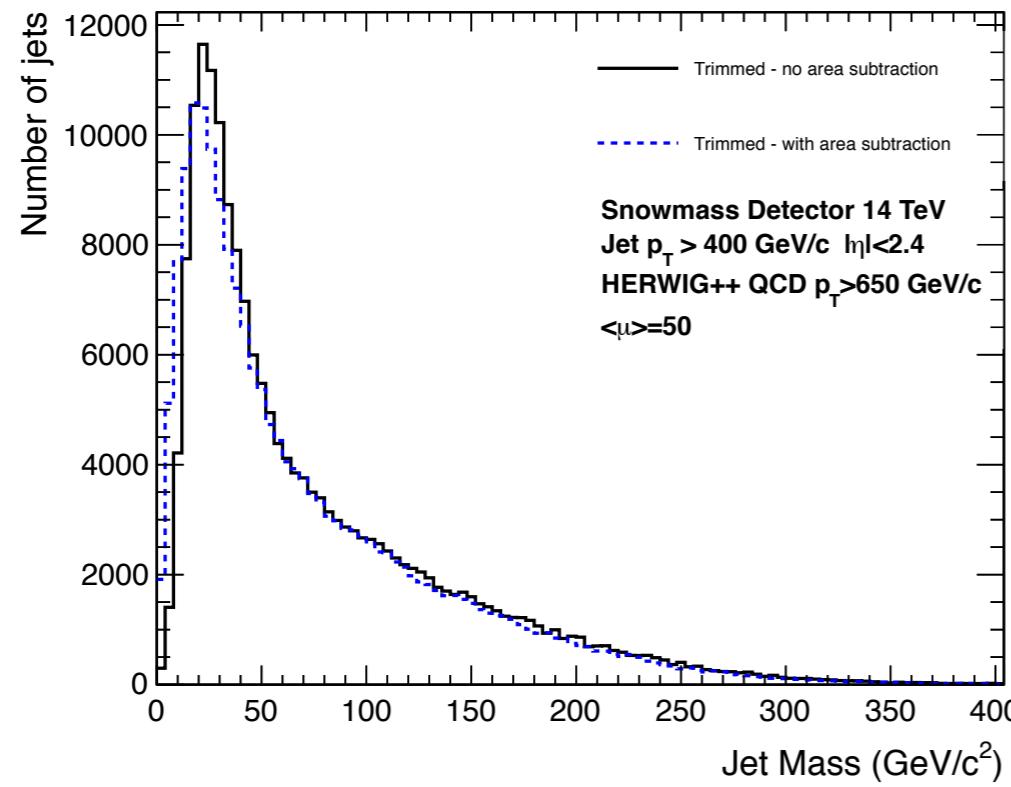
Jet Pruning



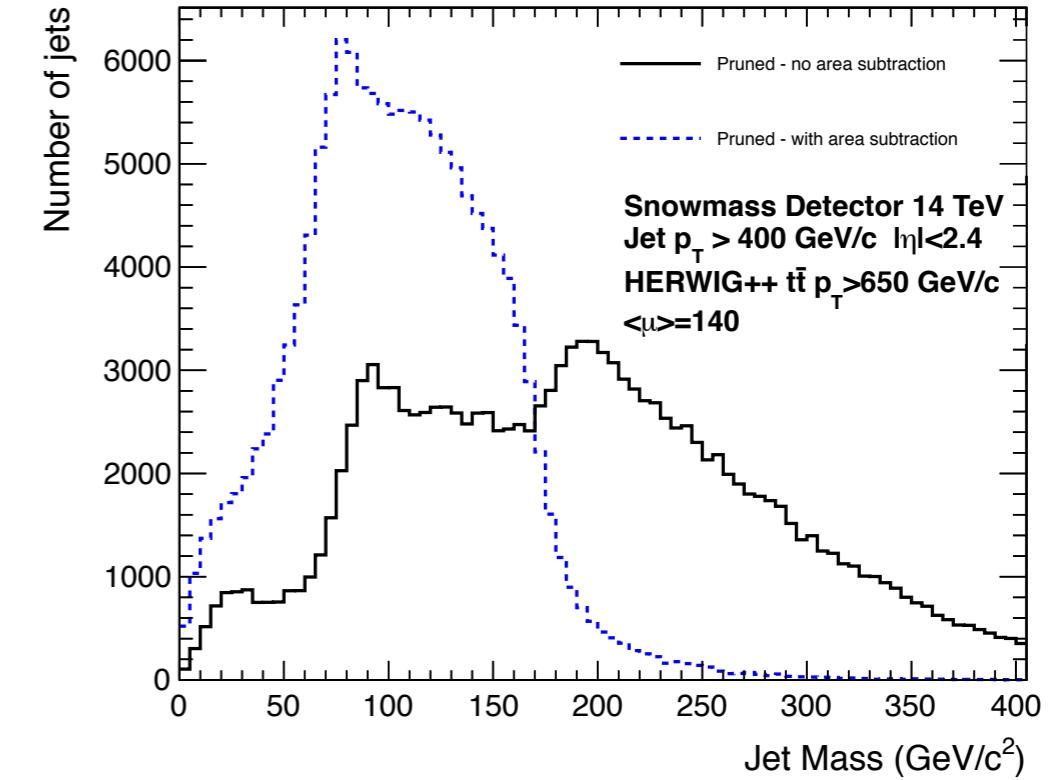
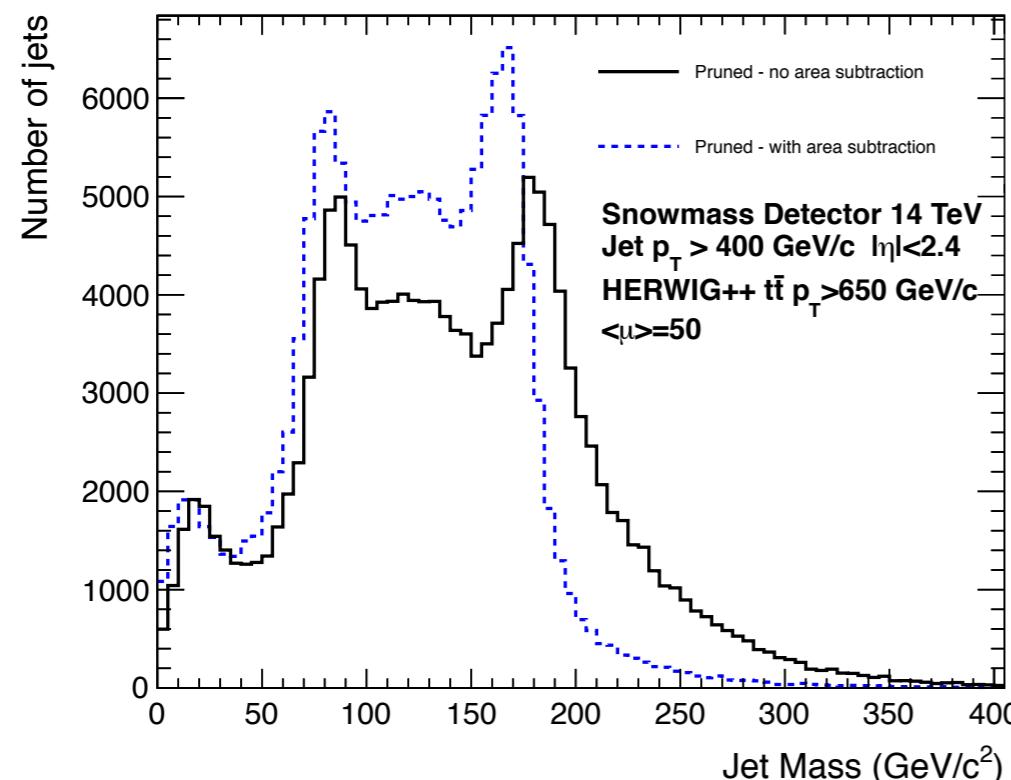
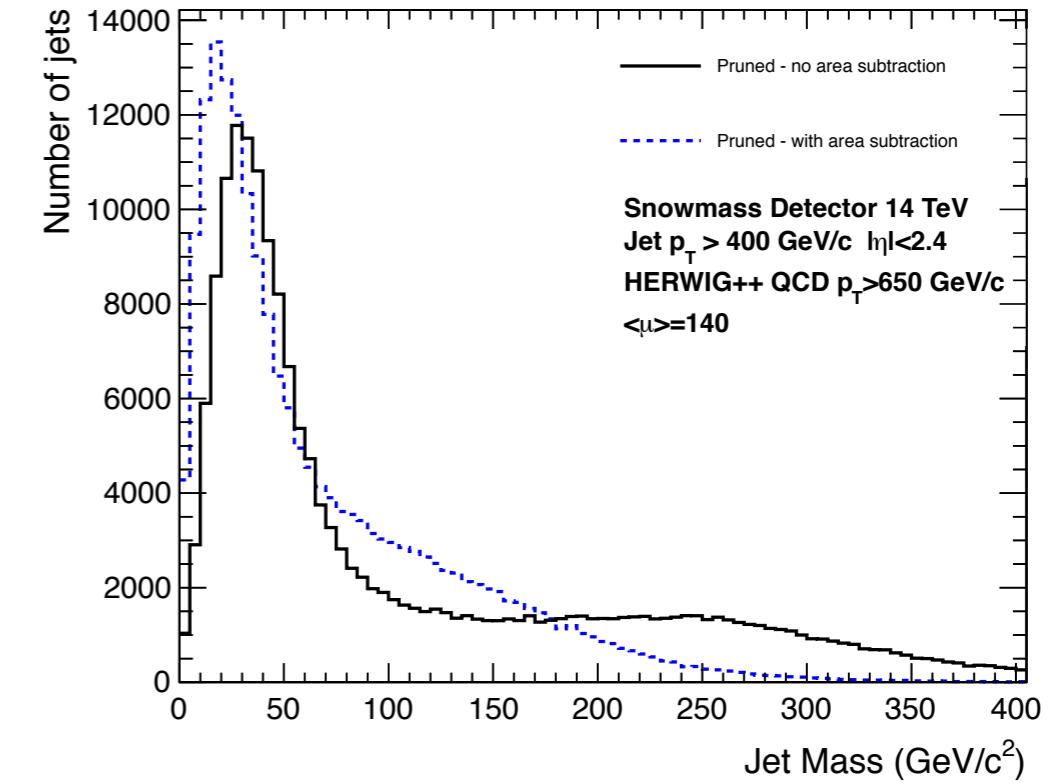
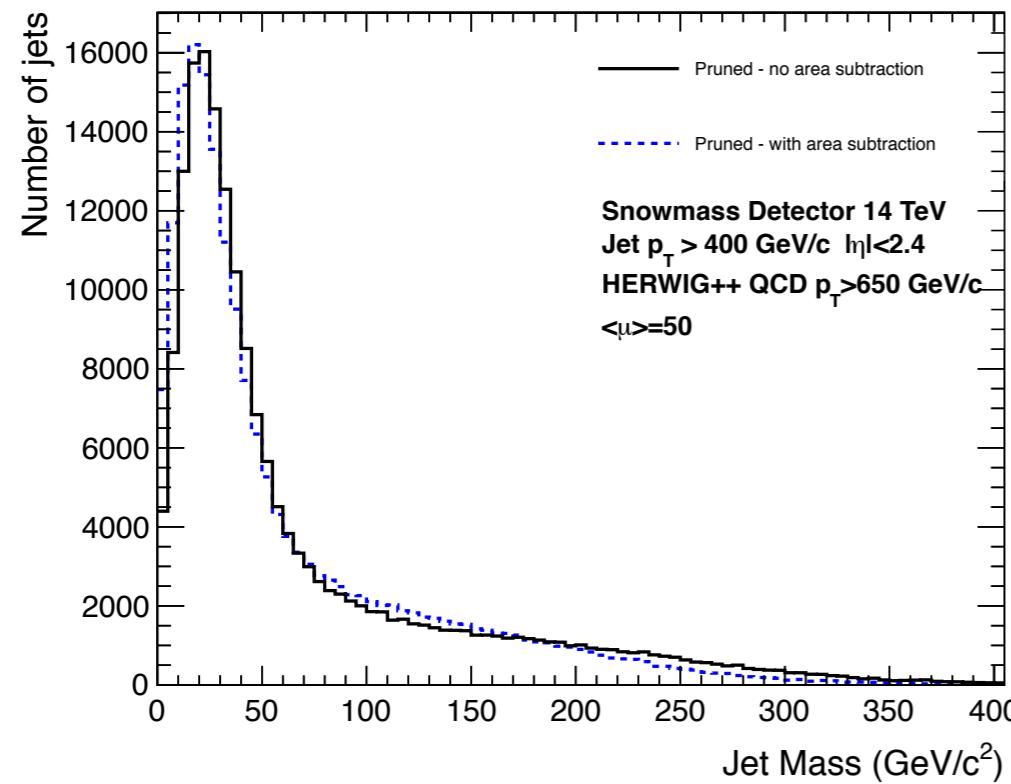
Groomed jet area



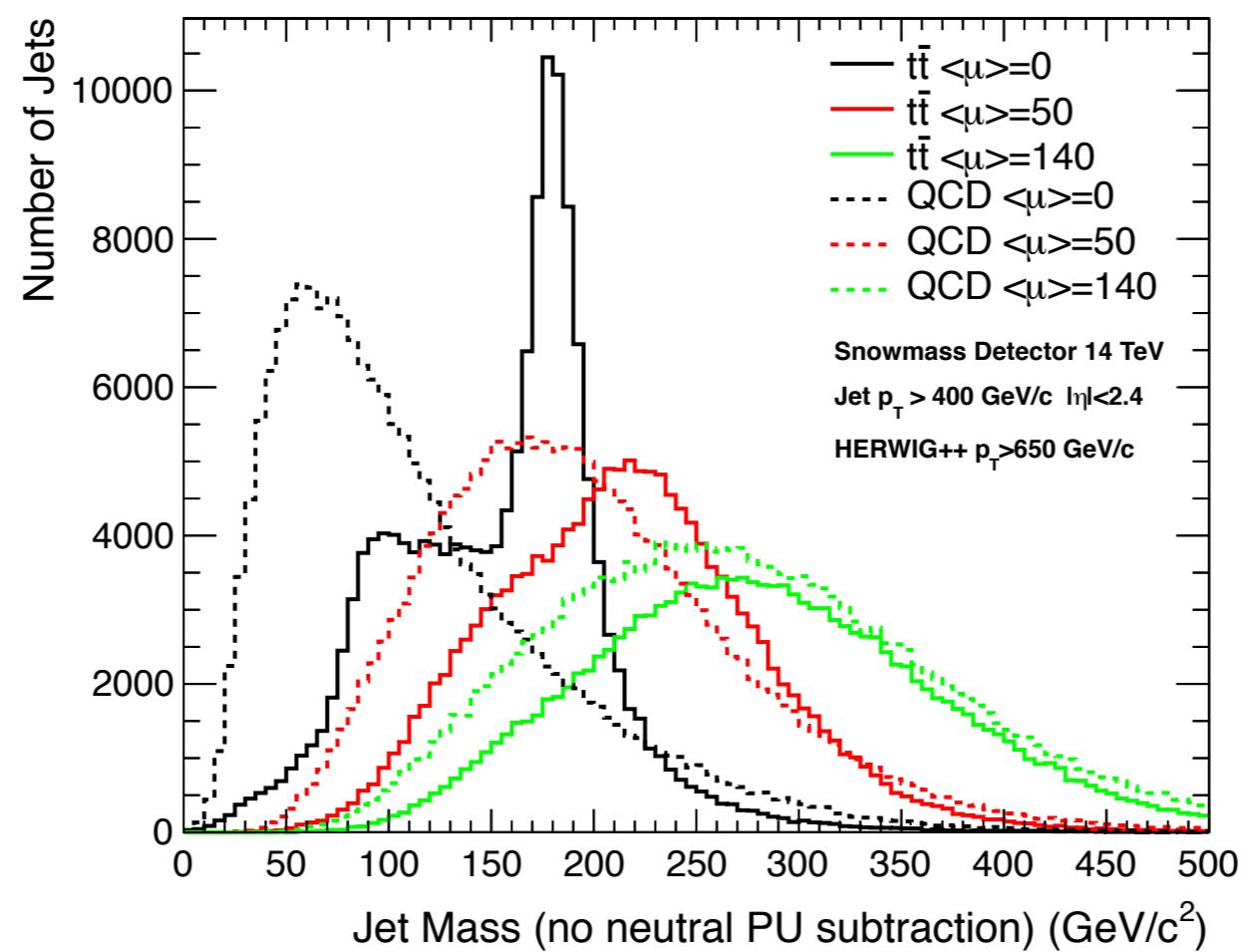
Trimmed + Area subtraction



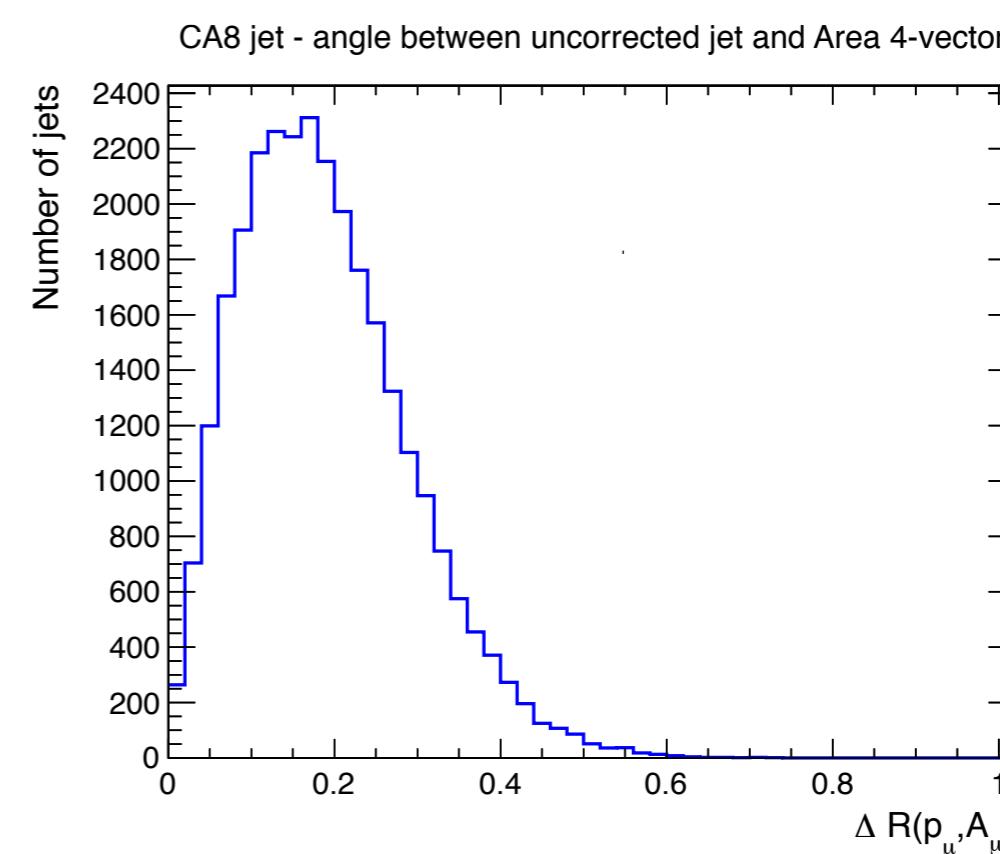
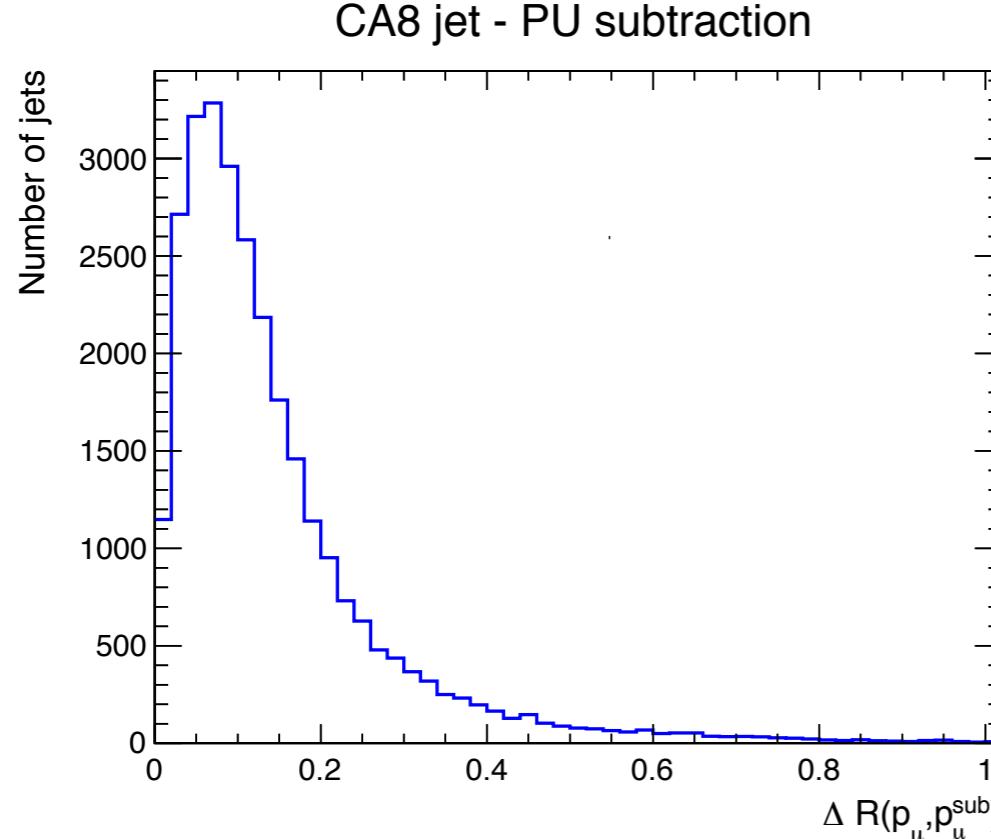
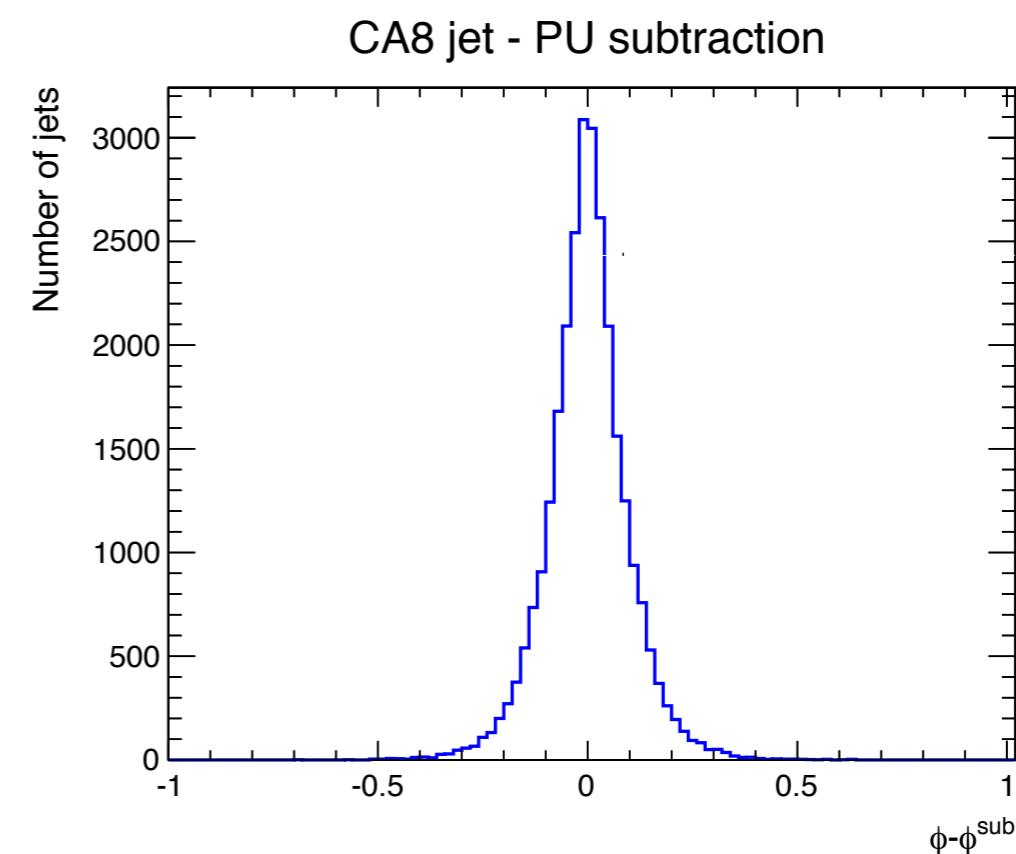
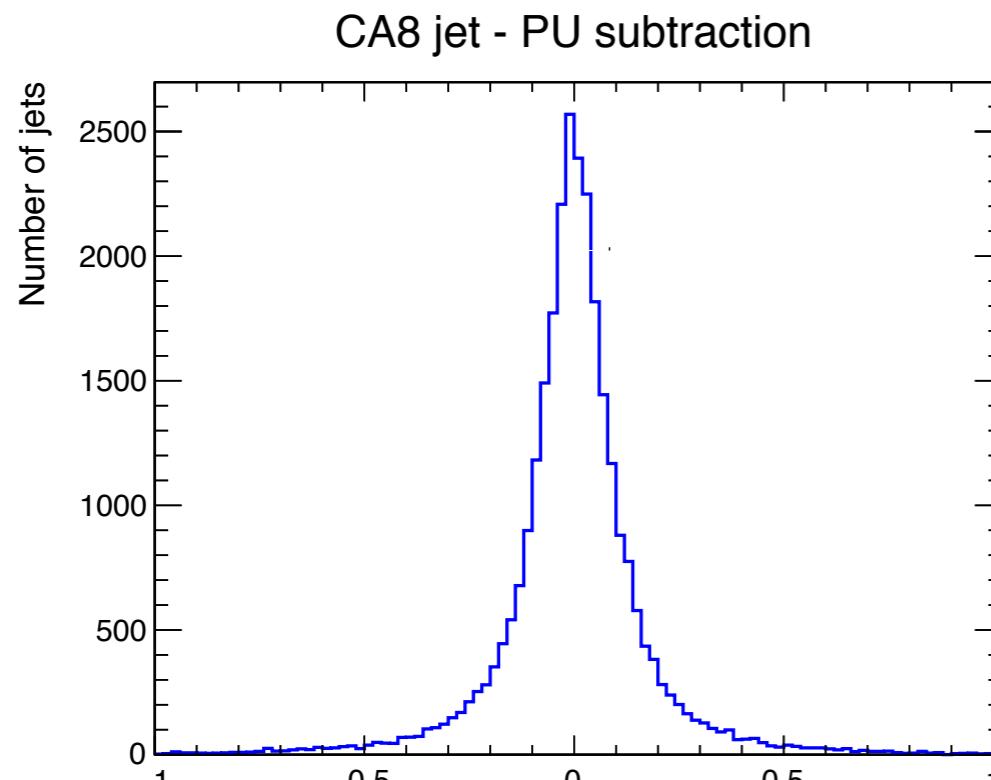
Pruned + Area subtraction



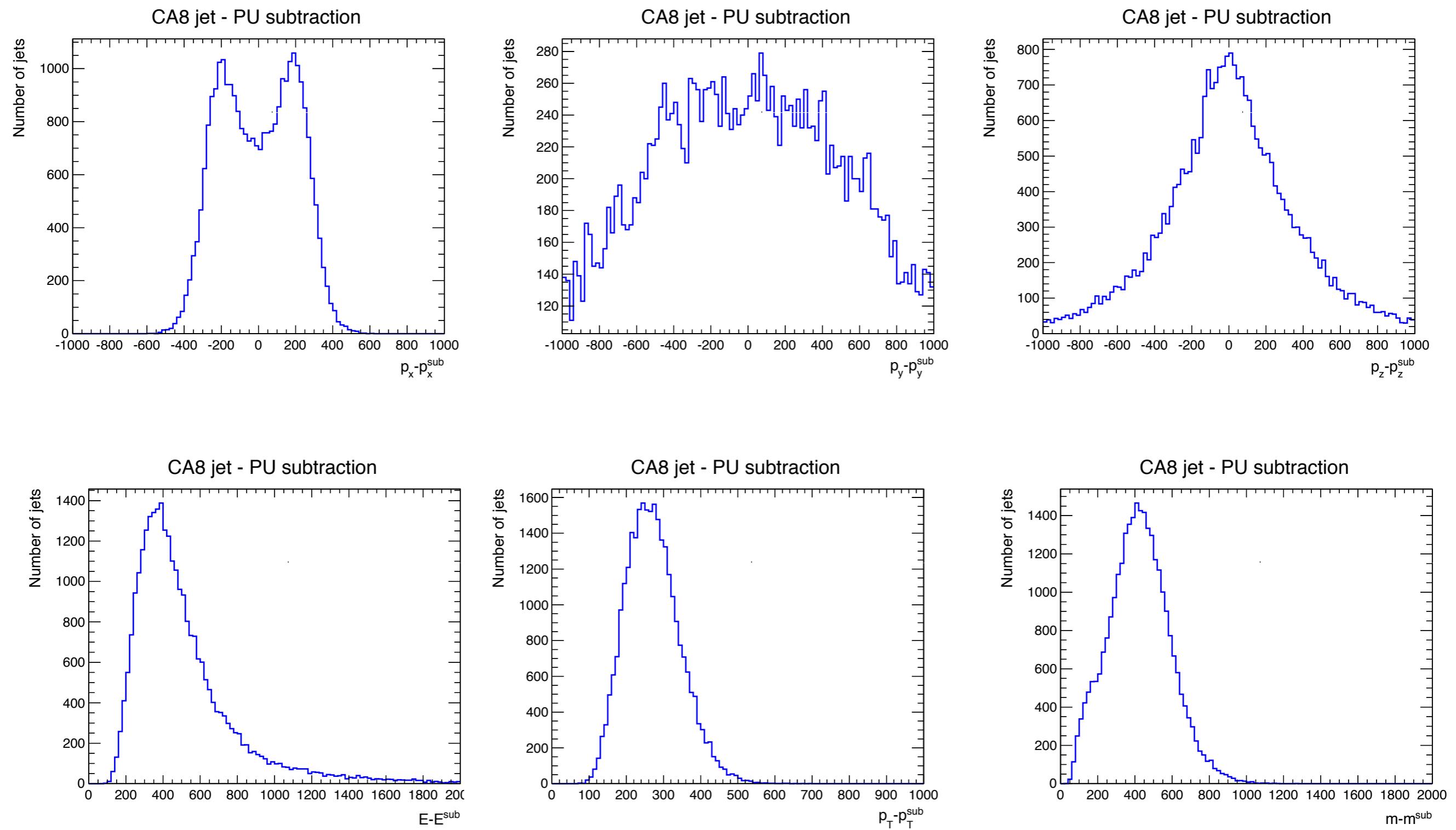
No PU subtraction



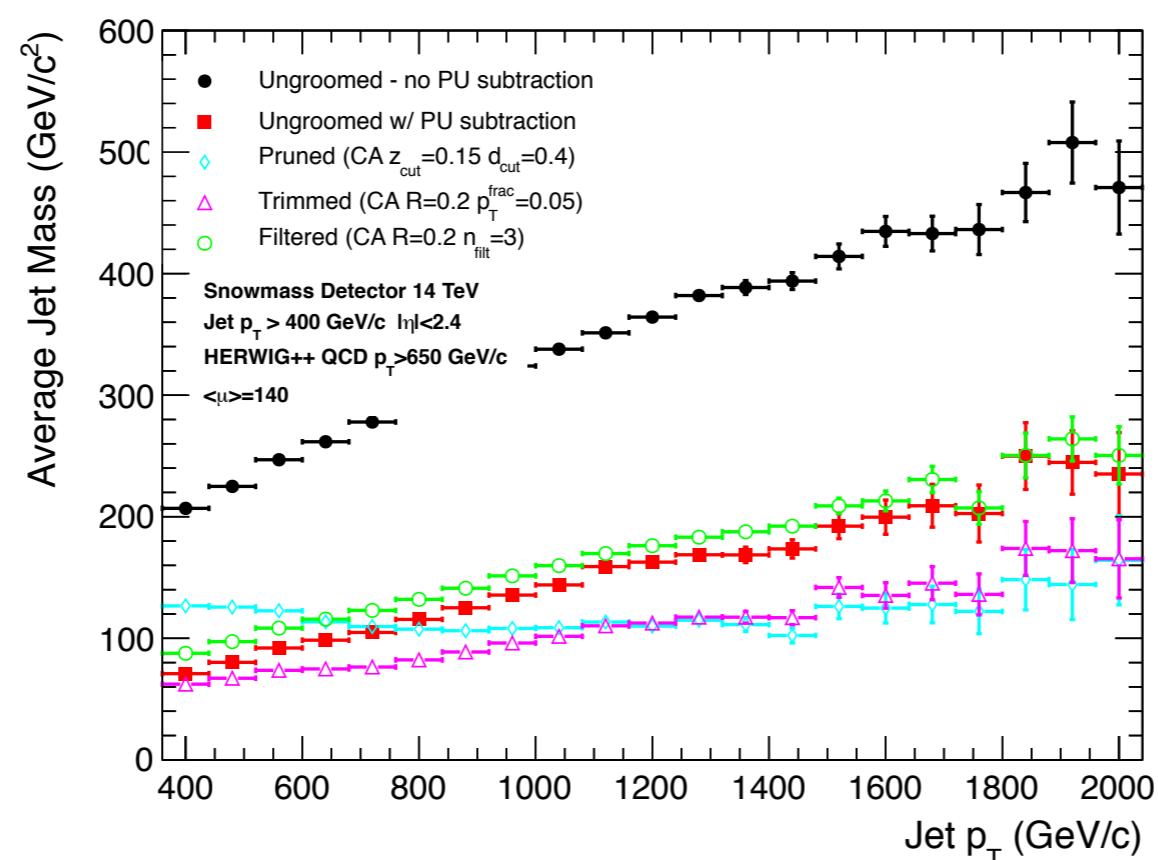
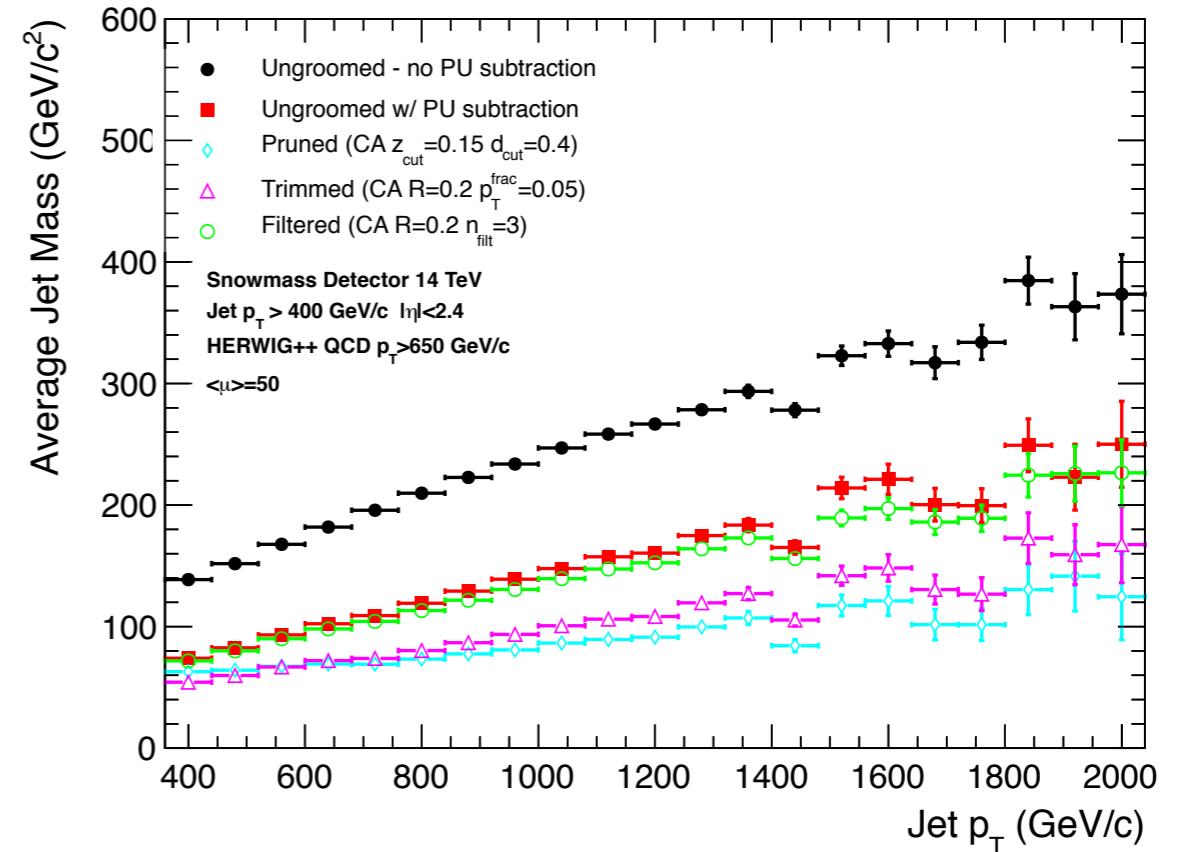
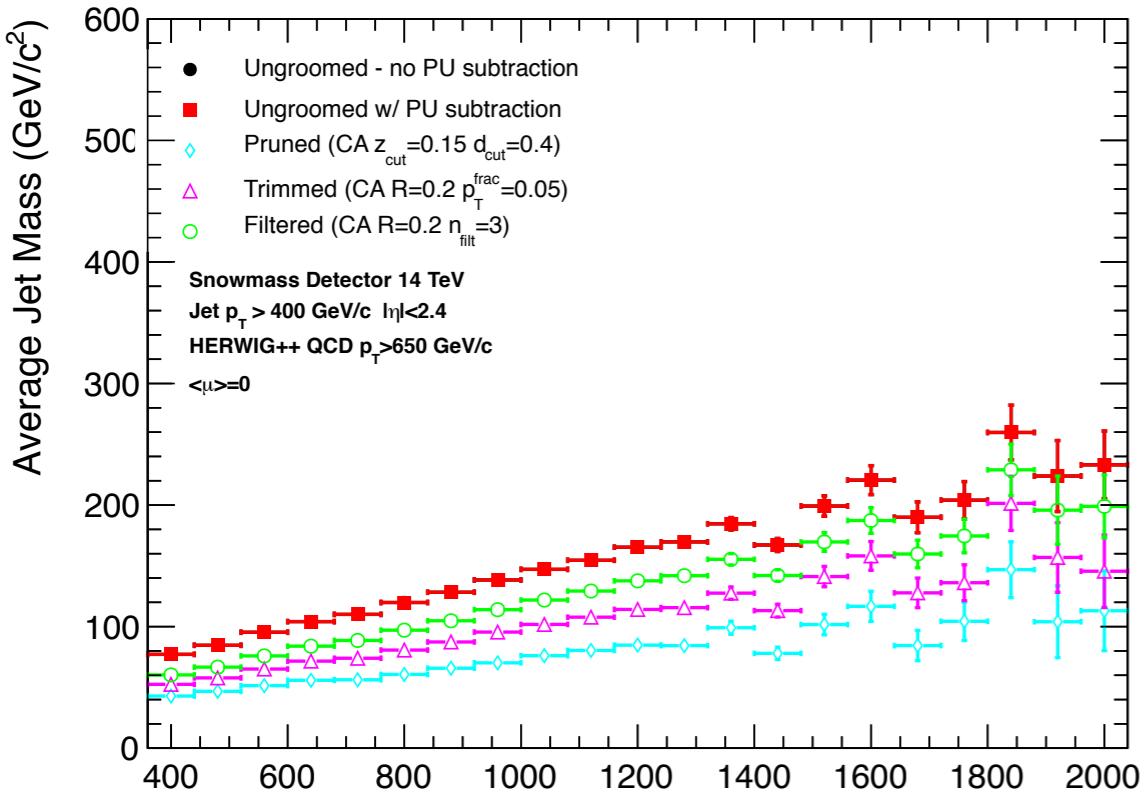
PU Subtraction



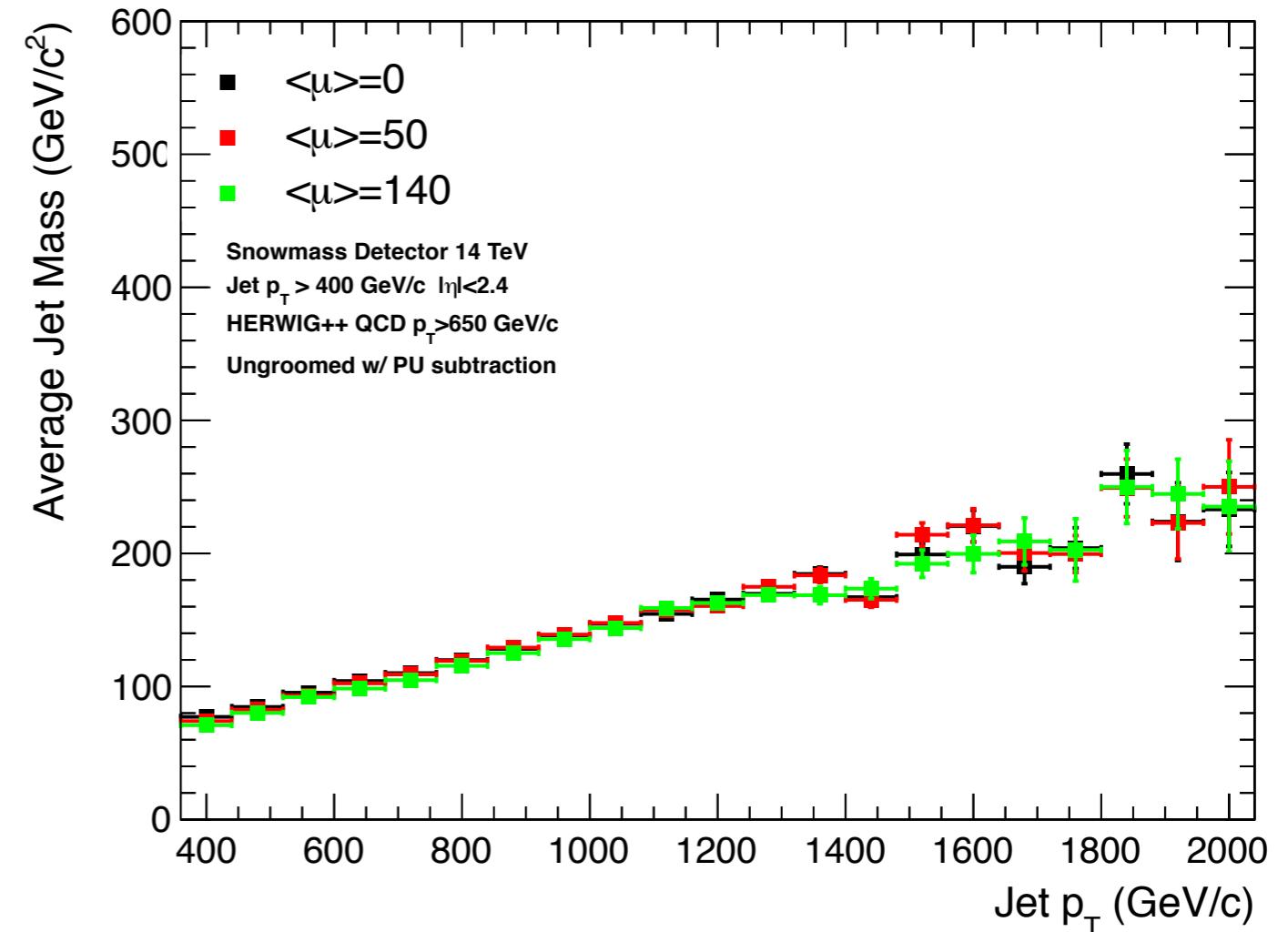
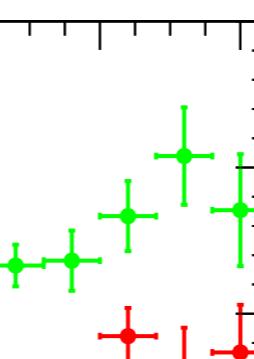
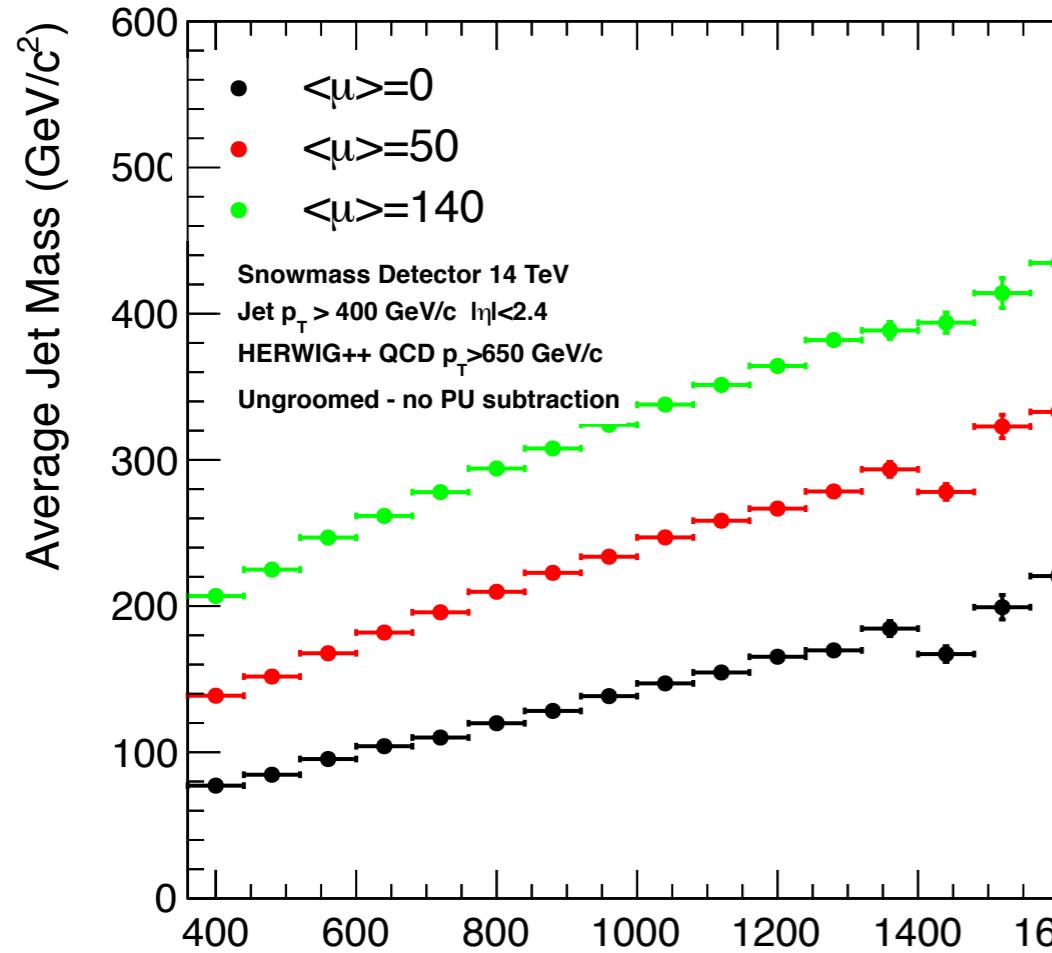
PU Subtraction



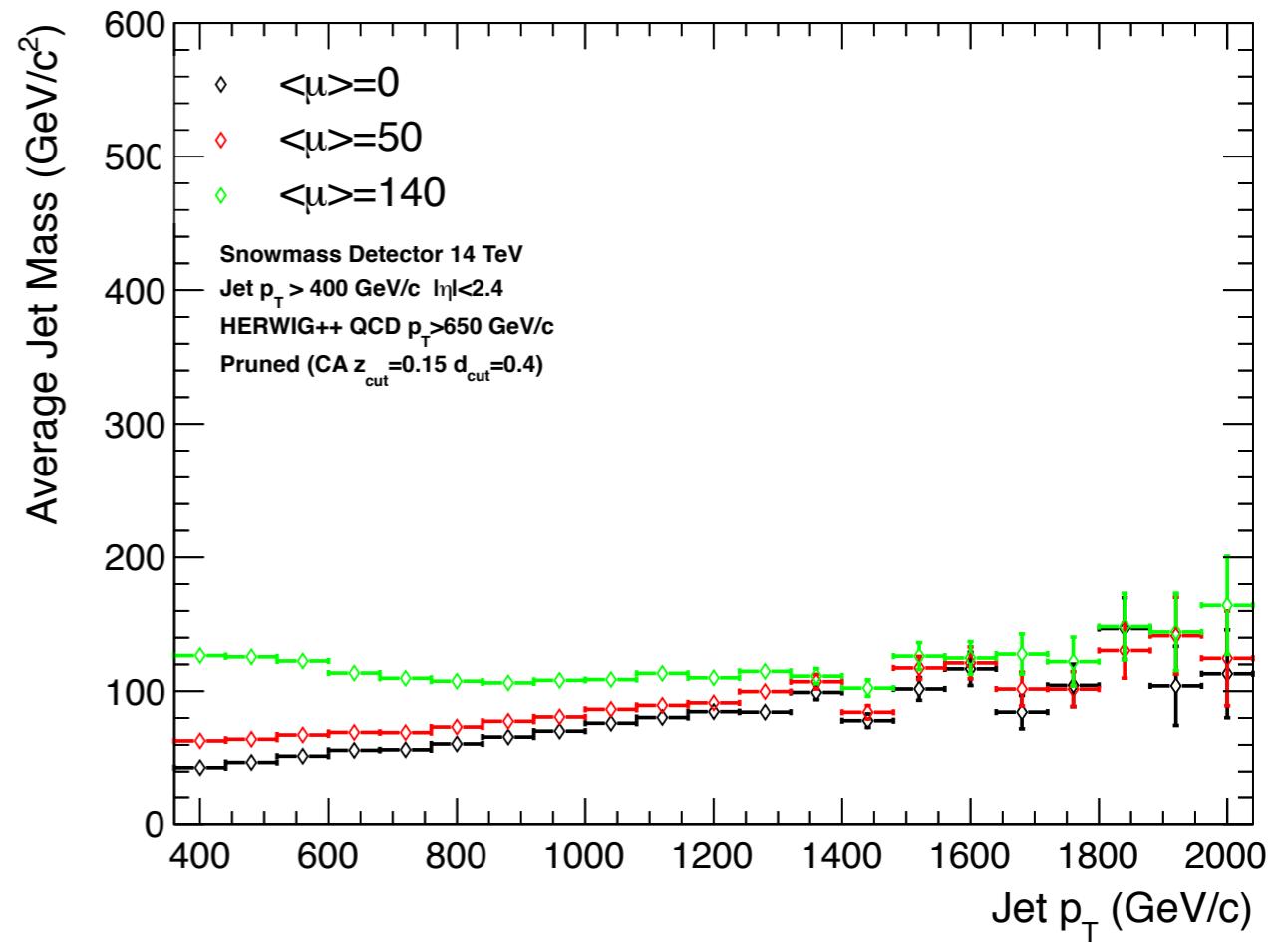
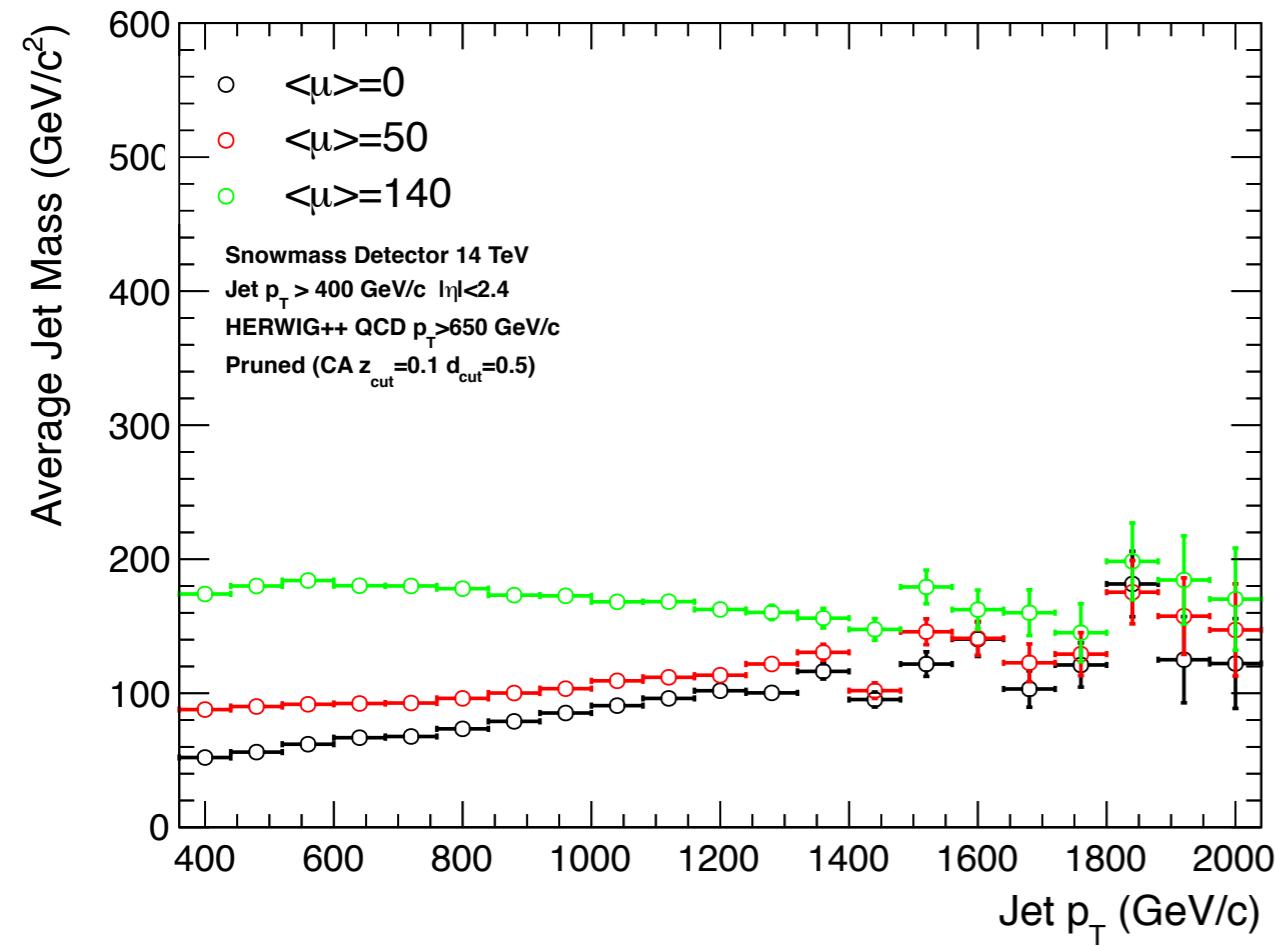
QCD Compare All



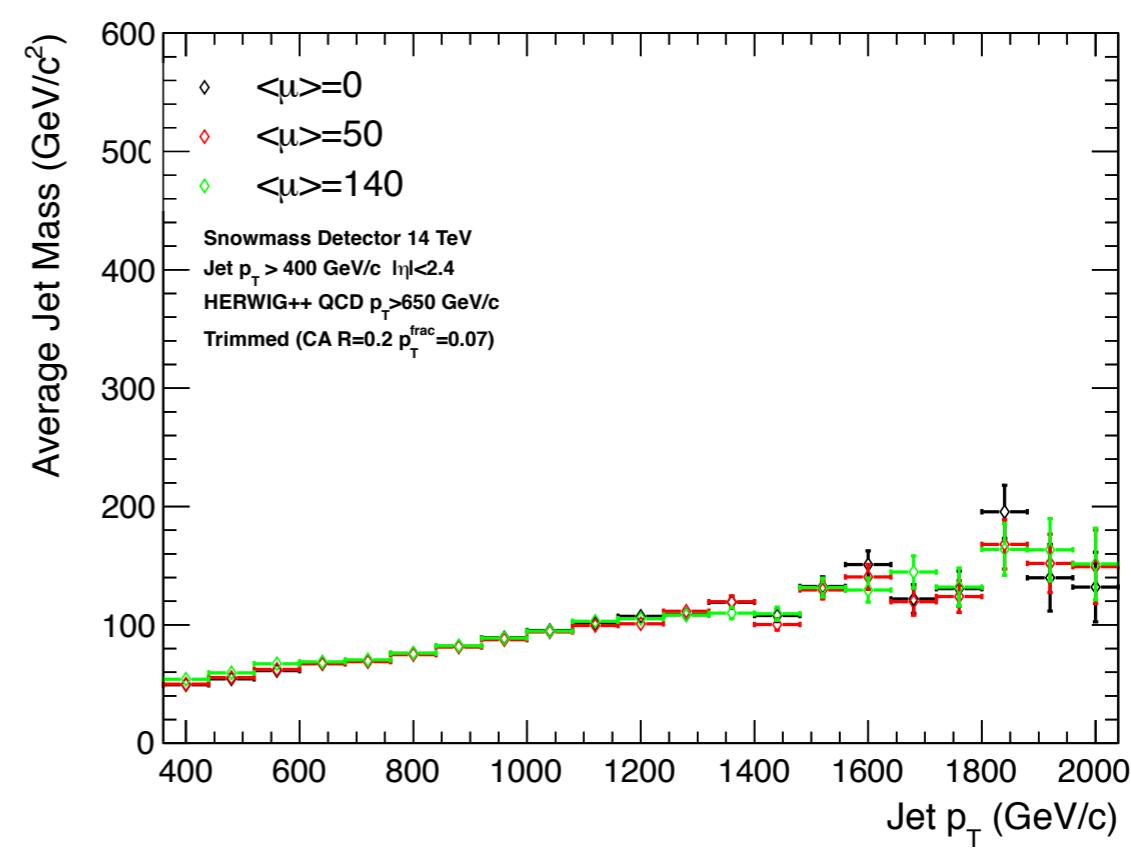
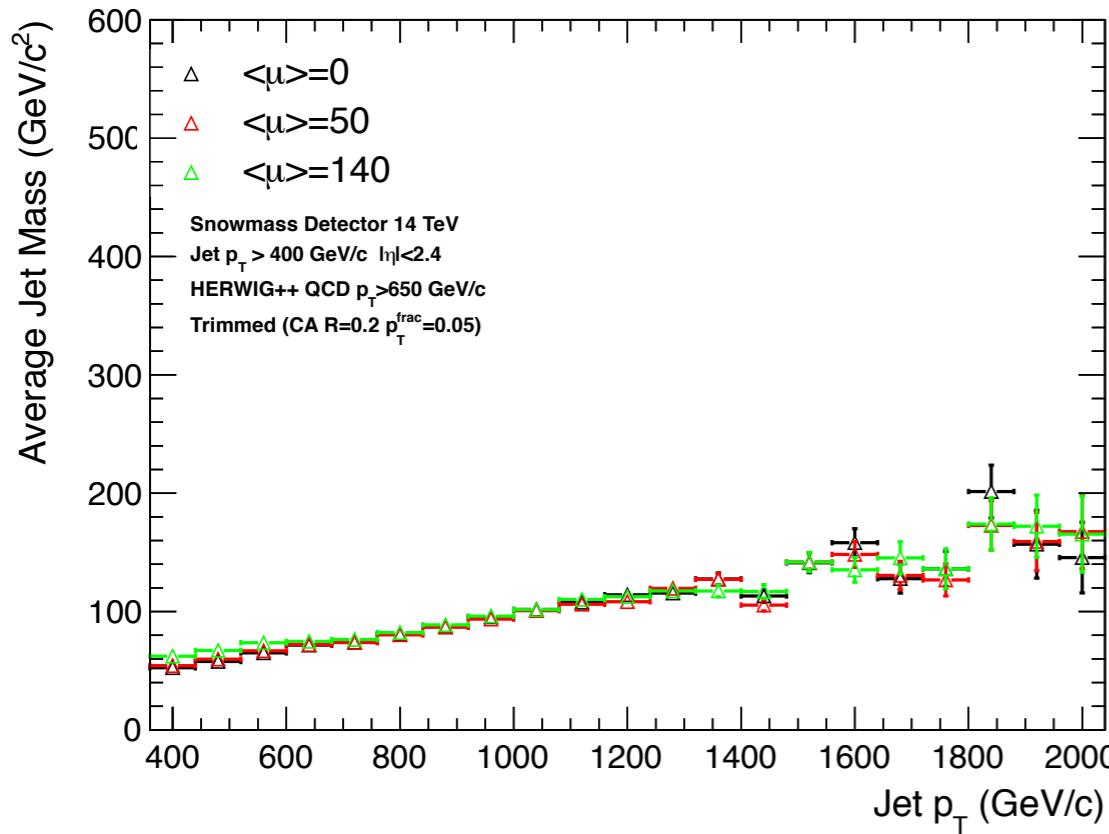
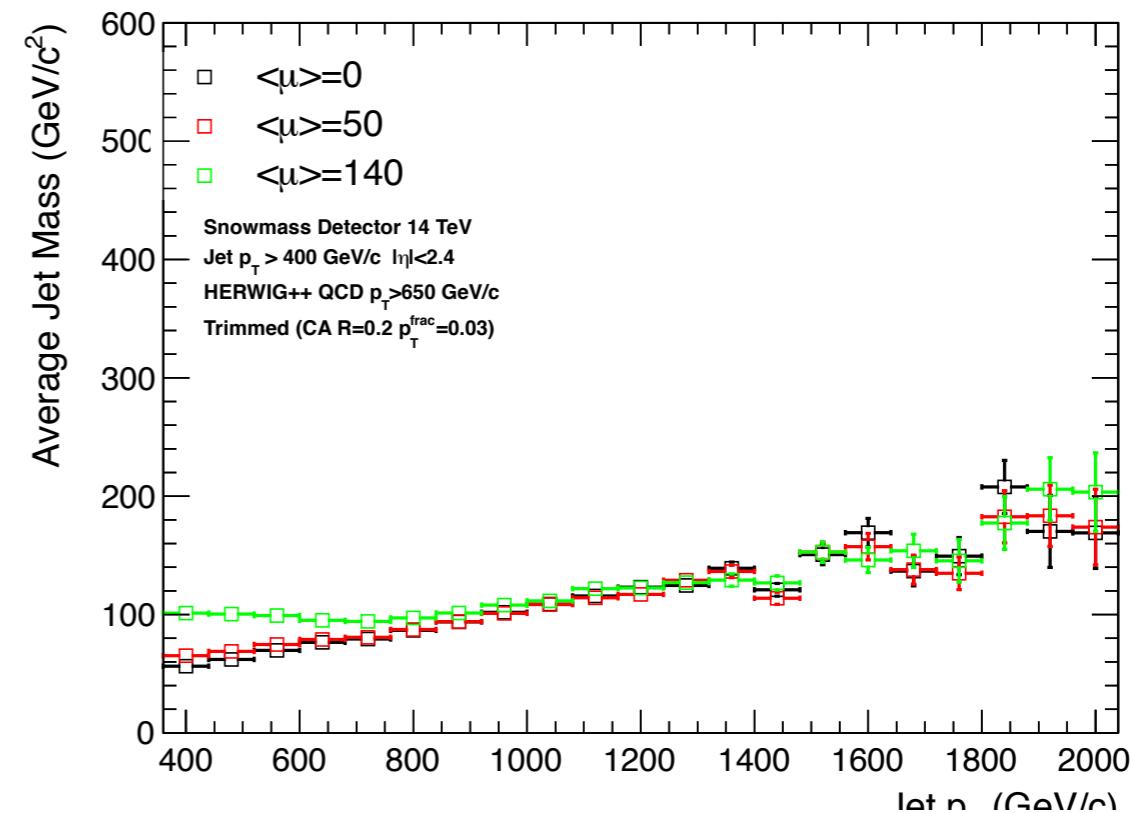
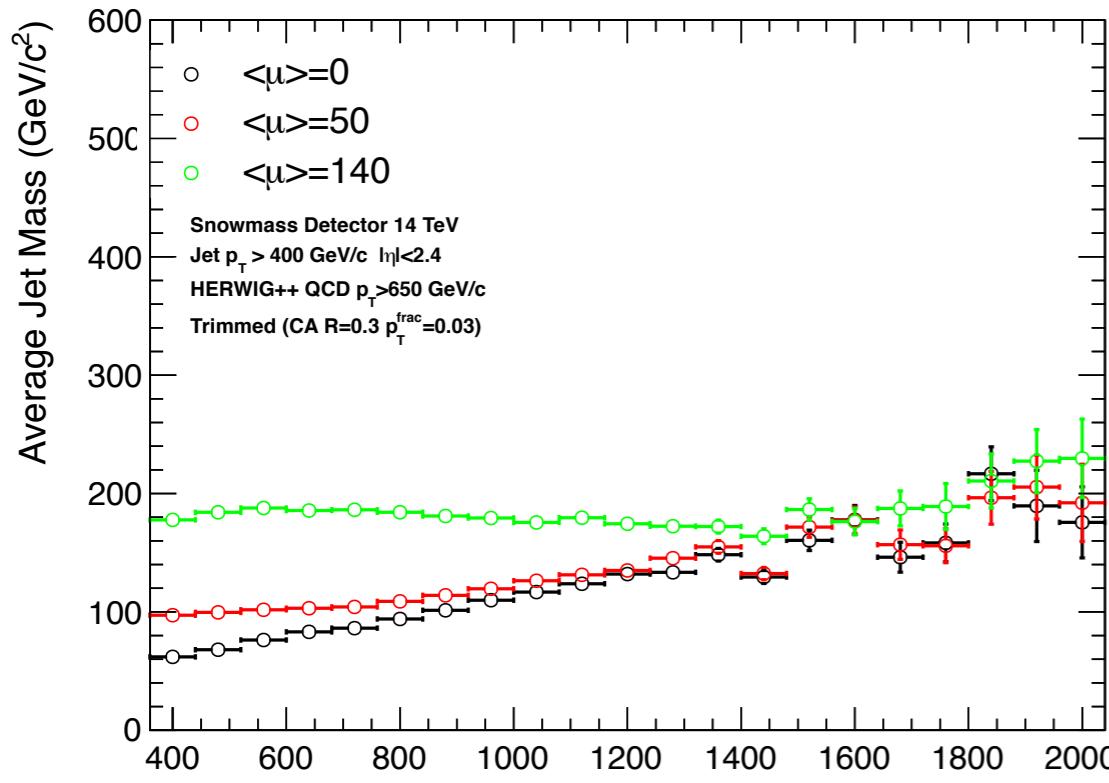
QCD Compare PU subtraction



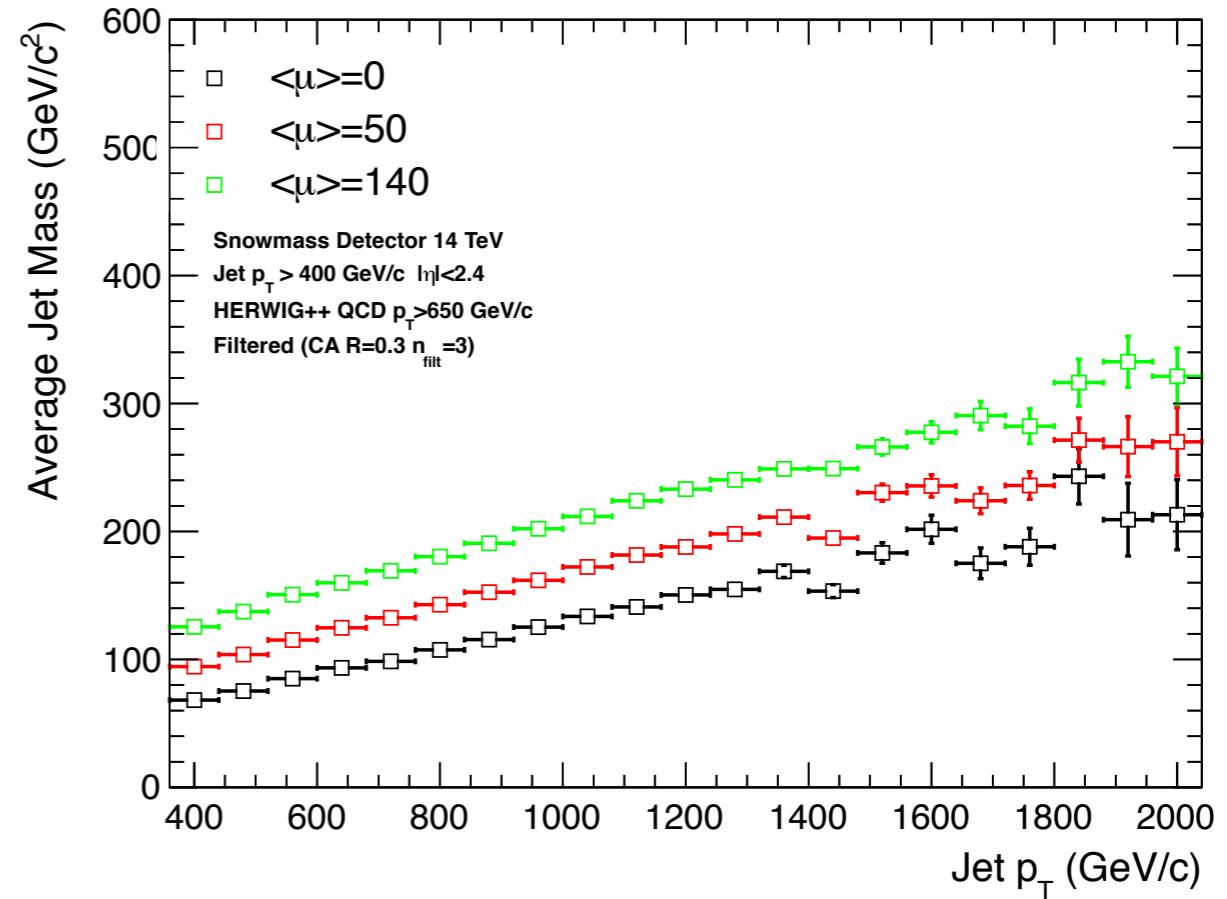
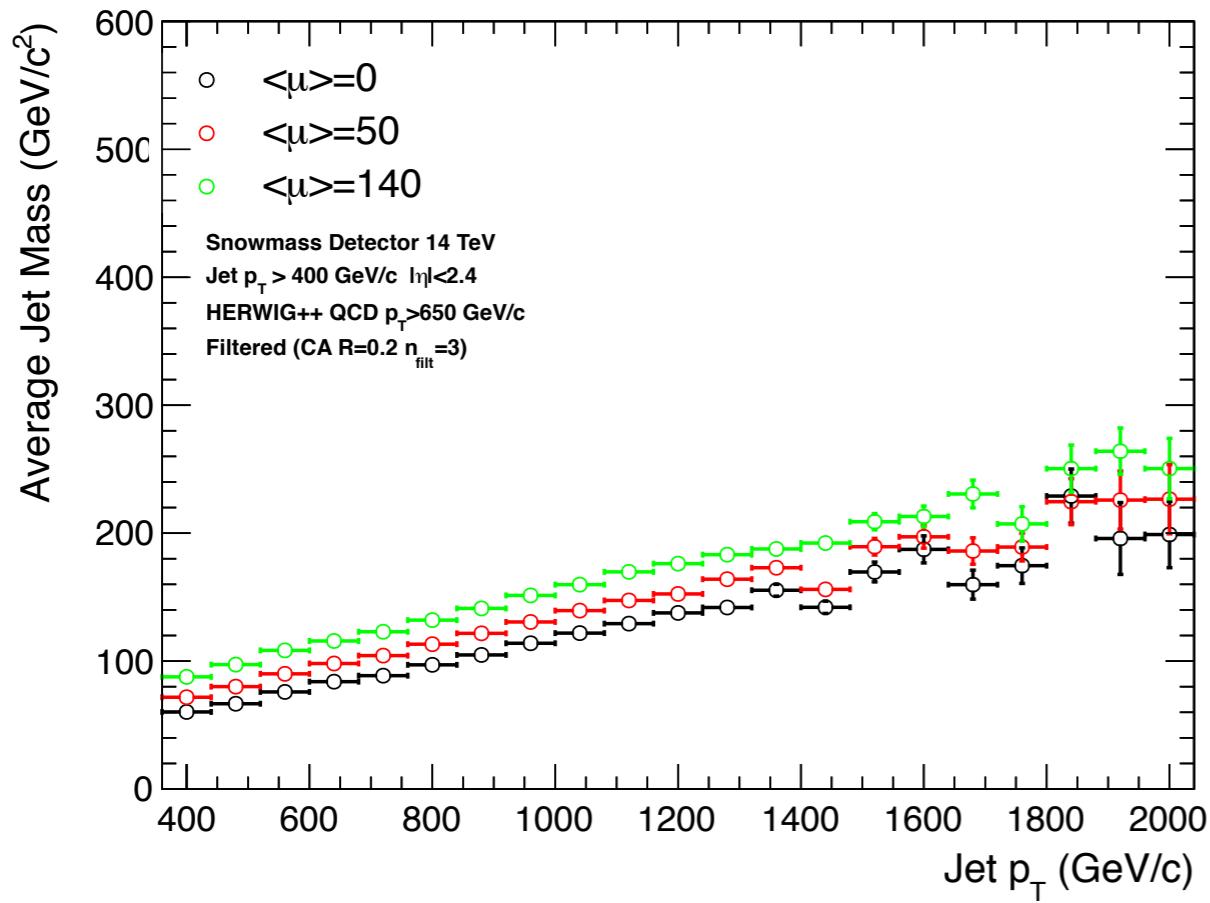
QCD pruning



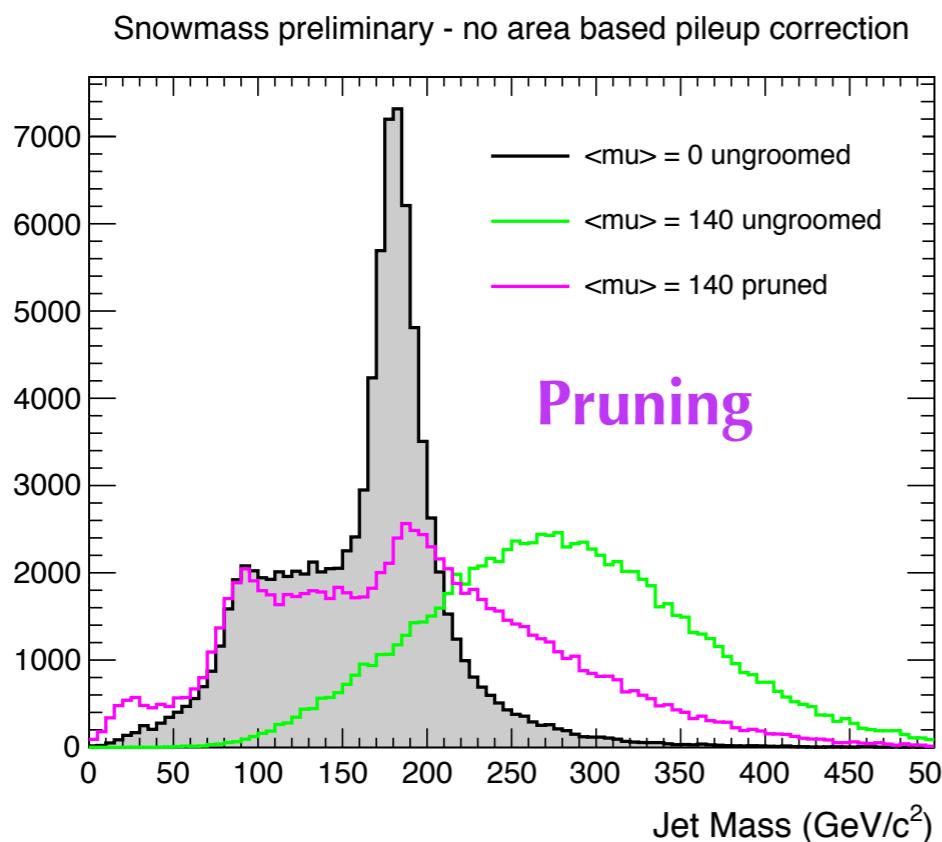
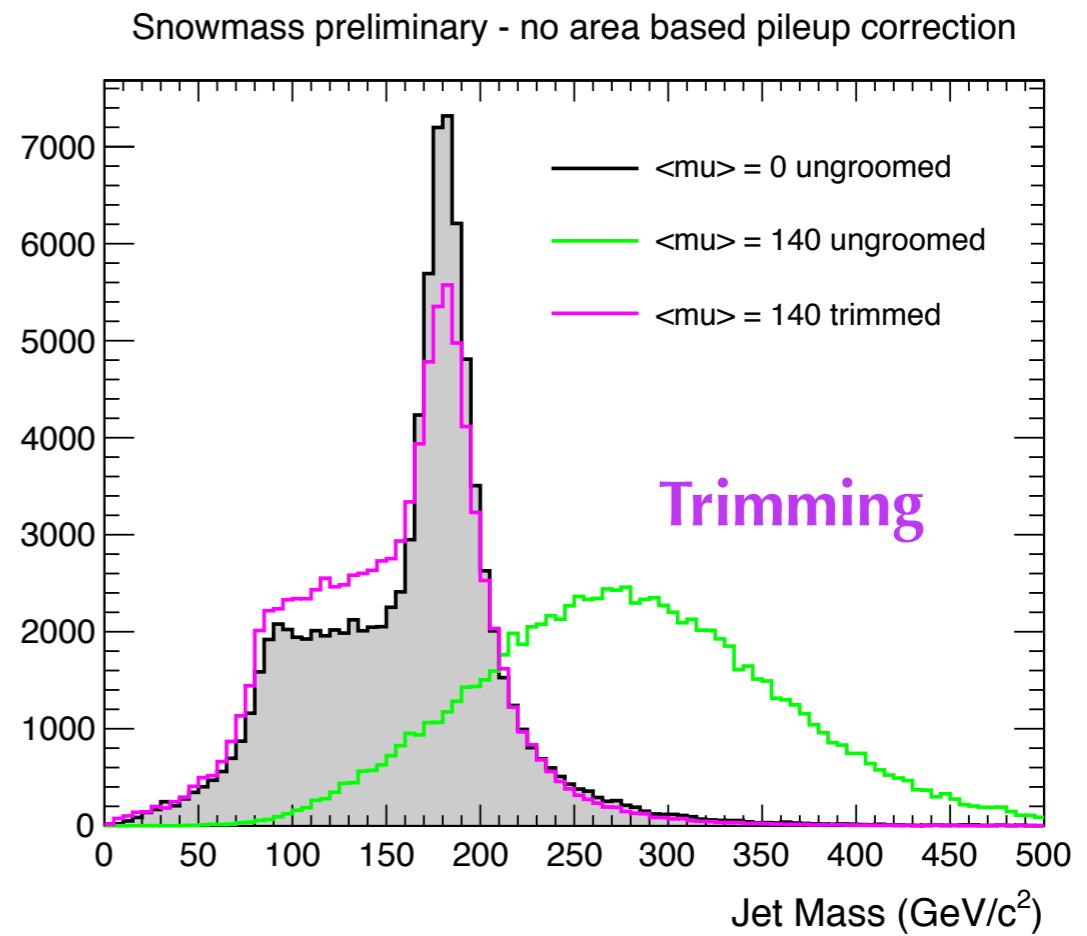
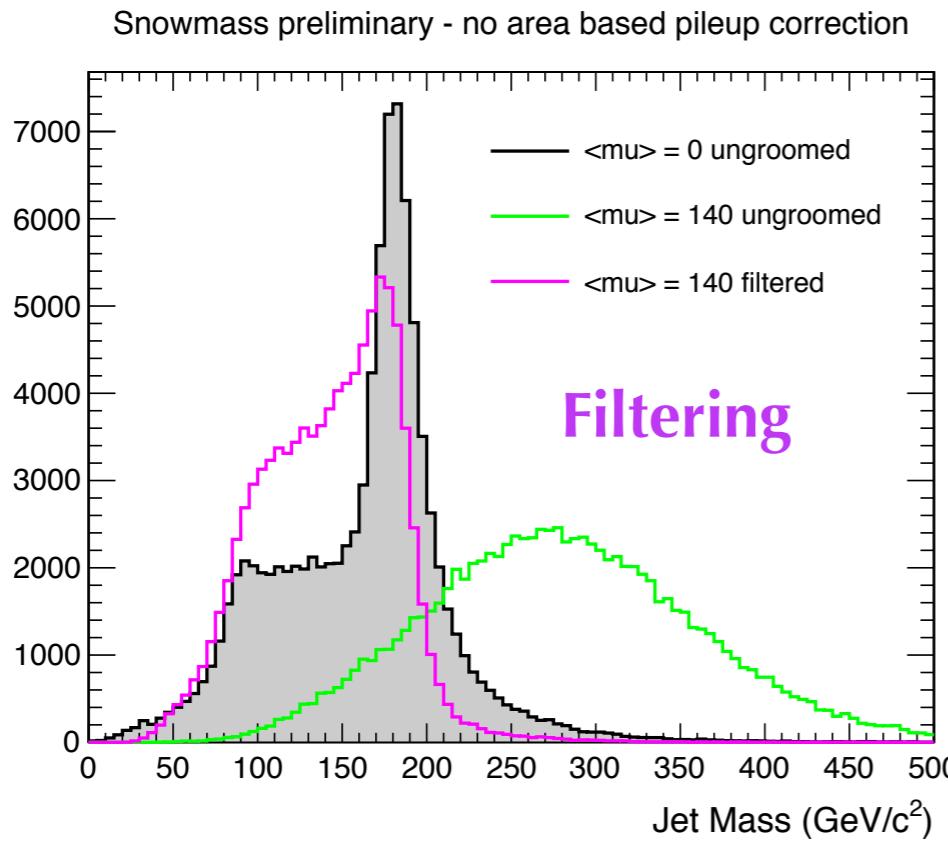
QCD trimming



QCD Filtering

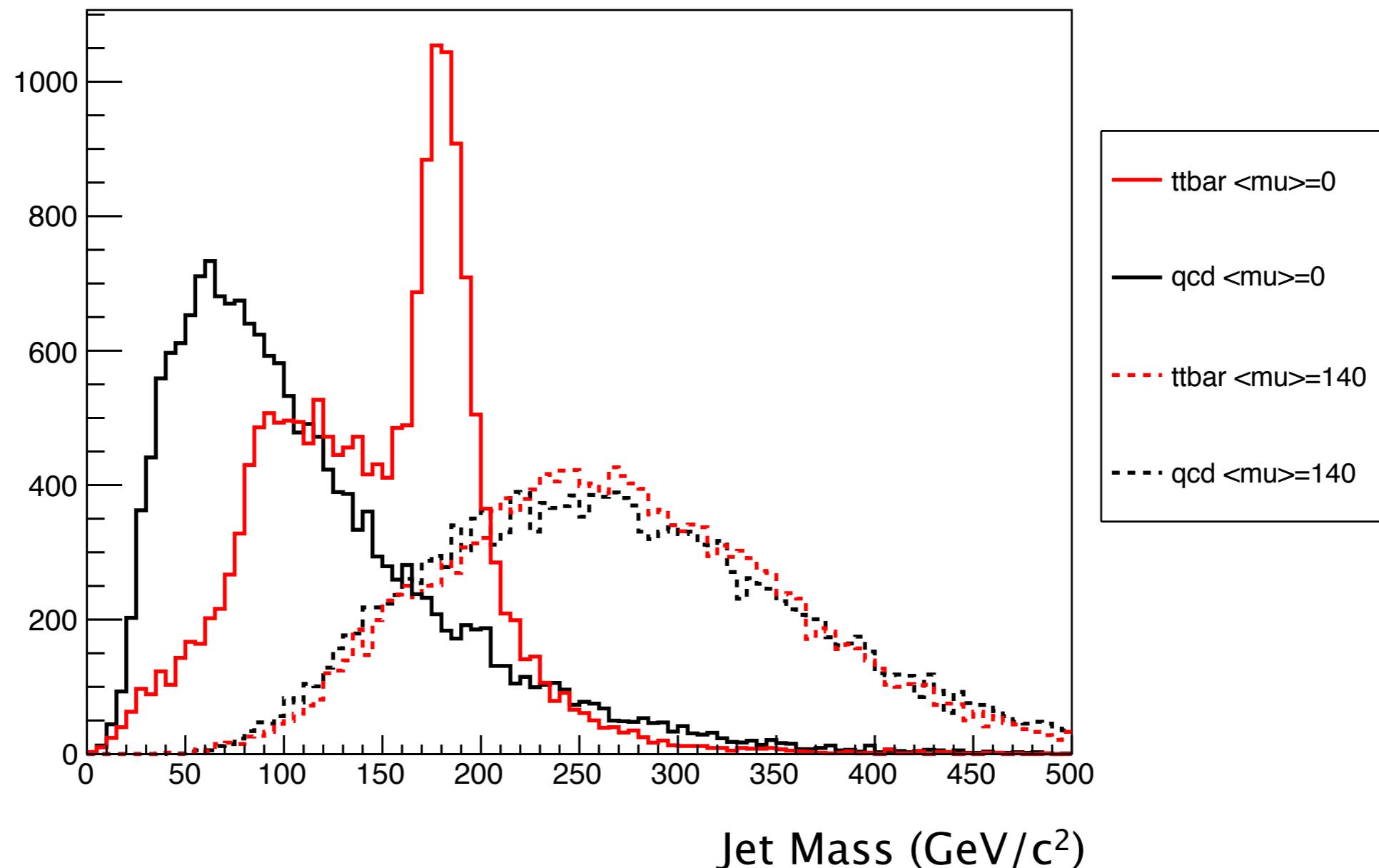


Results of Groomer Study

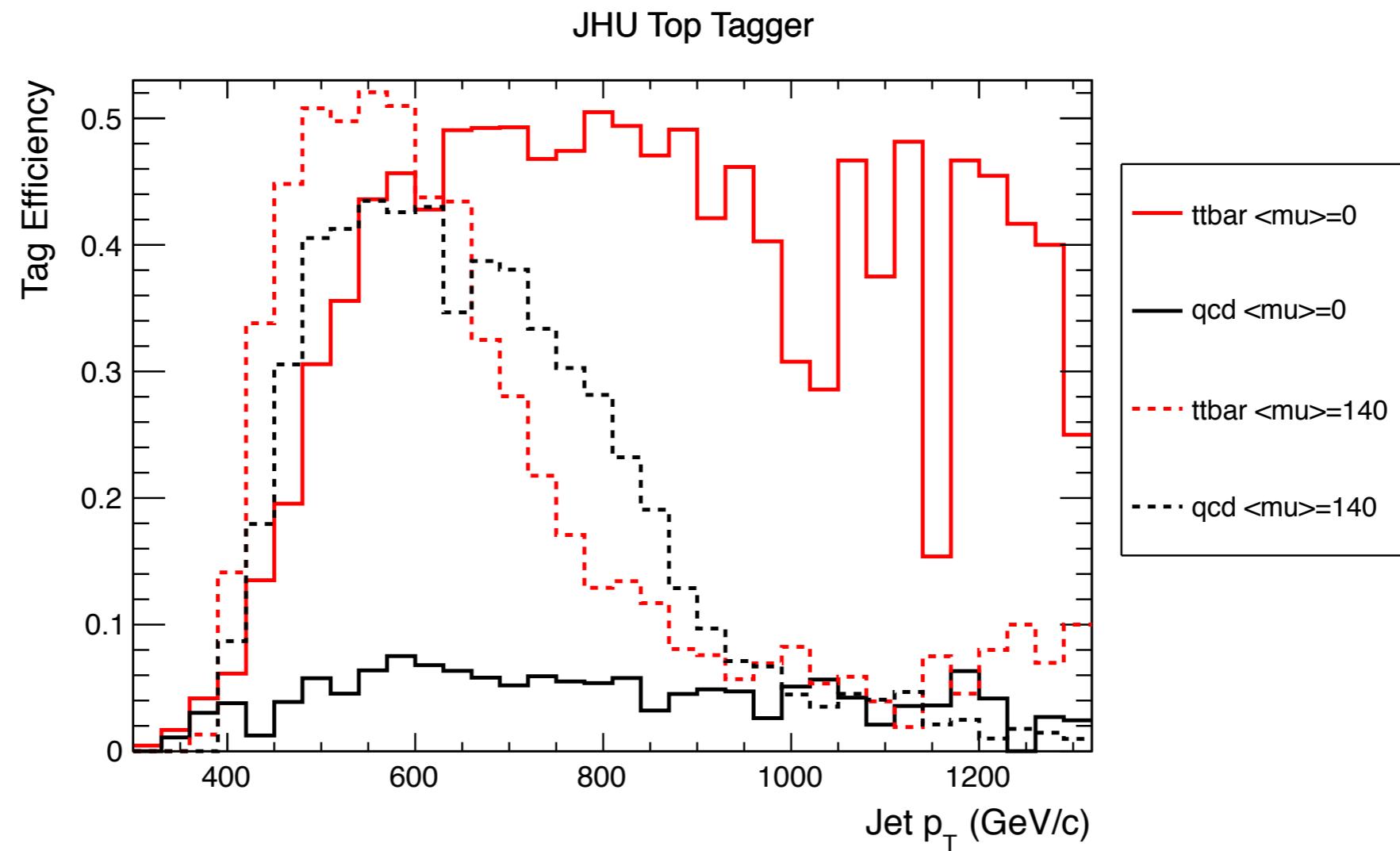


Best results:
trimming
 $r_{\text{filt}} = 0.2$
 $pT_{\text{frac}} = 0.3 \text{ or } 0.5$

Jet Mass - no PU correction

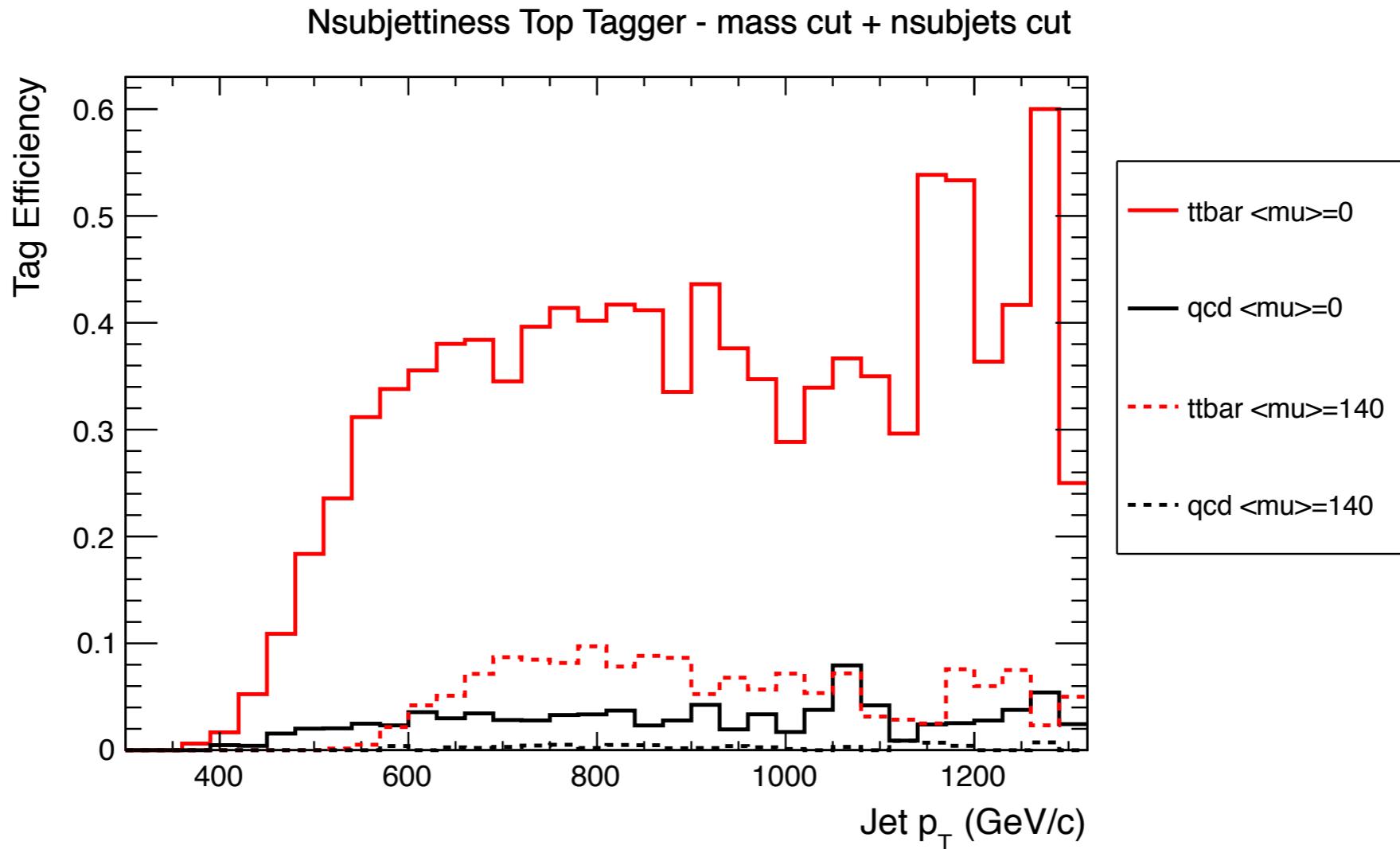


JHU Top Tagging Efficiency



- Good performance with 0 pileup
- High p_T + high pileup = jets with mass larger than the top mass window = low efficiency

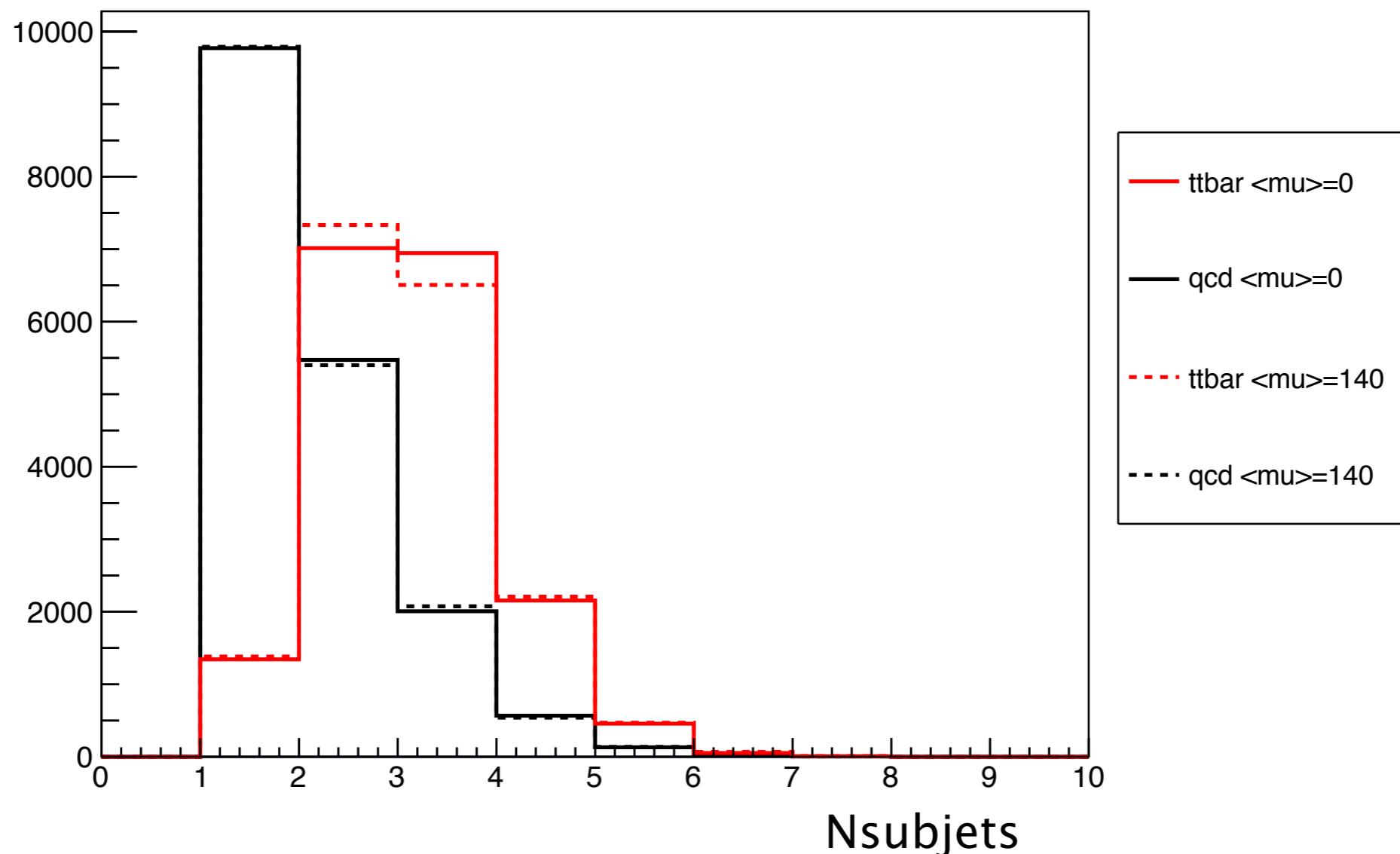
Trimmed jet + nsubjettiness



- Good performance with 0 pileup
- Low efficiency at high pT (cut is not optimal for high pileup)

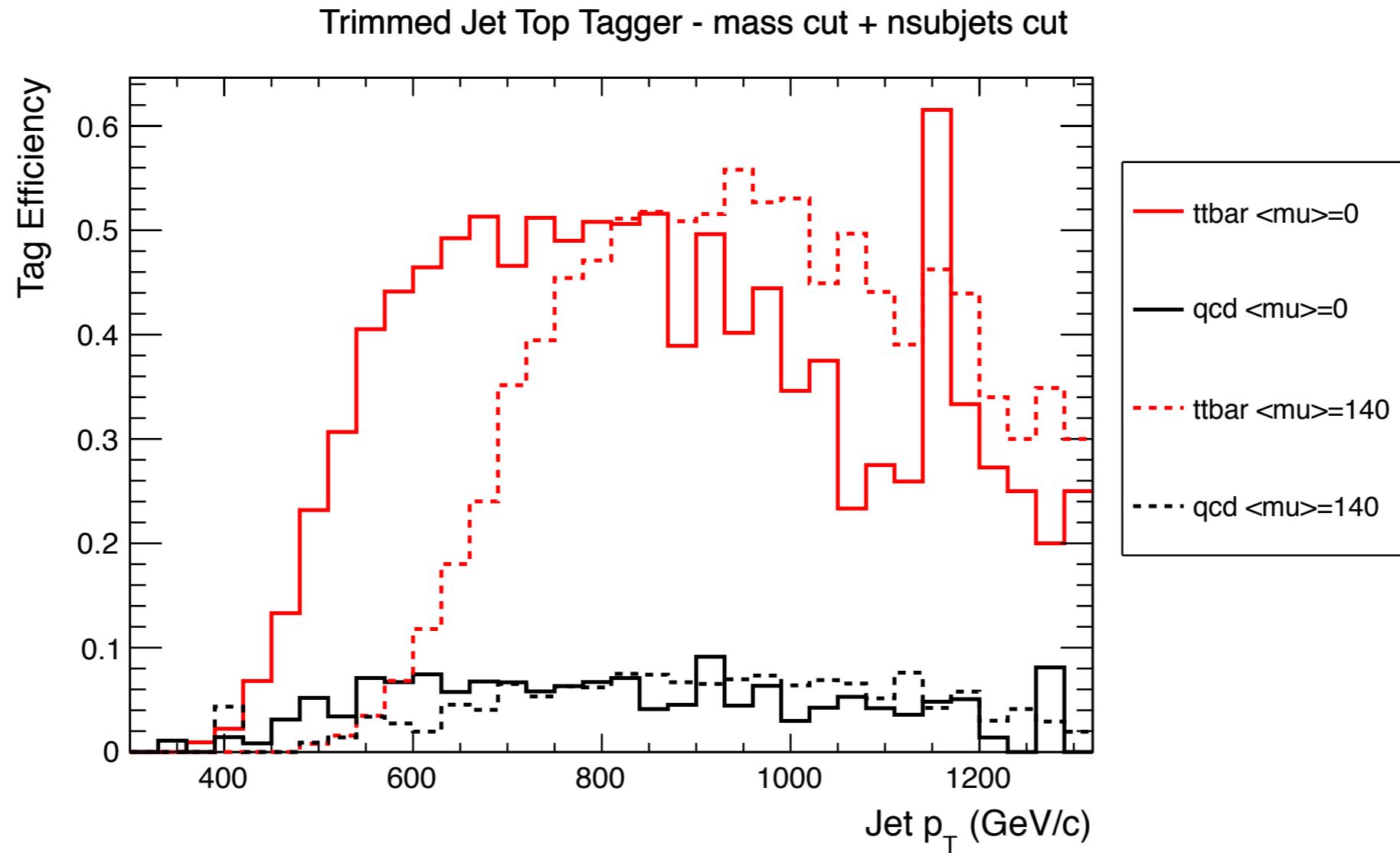
Nsubjets

Nsubjets_Trimmed_CA2_PFRAC5



- Require Nsubjets ≥ 3
- Stable with pileup

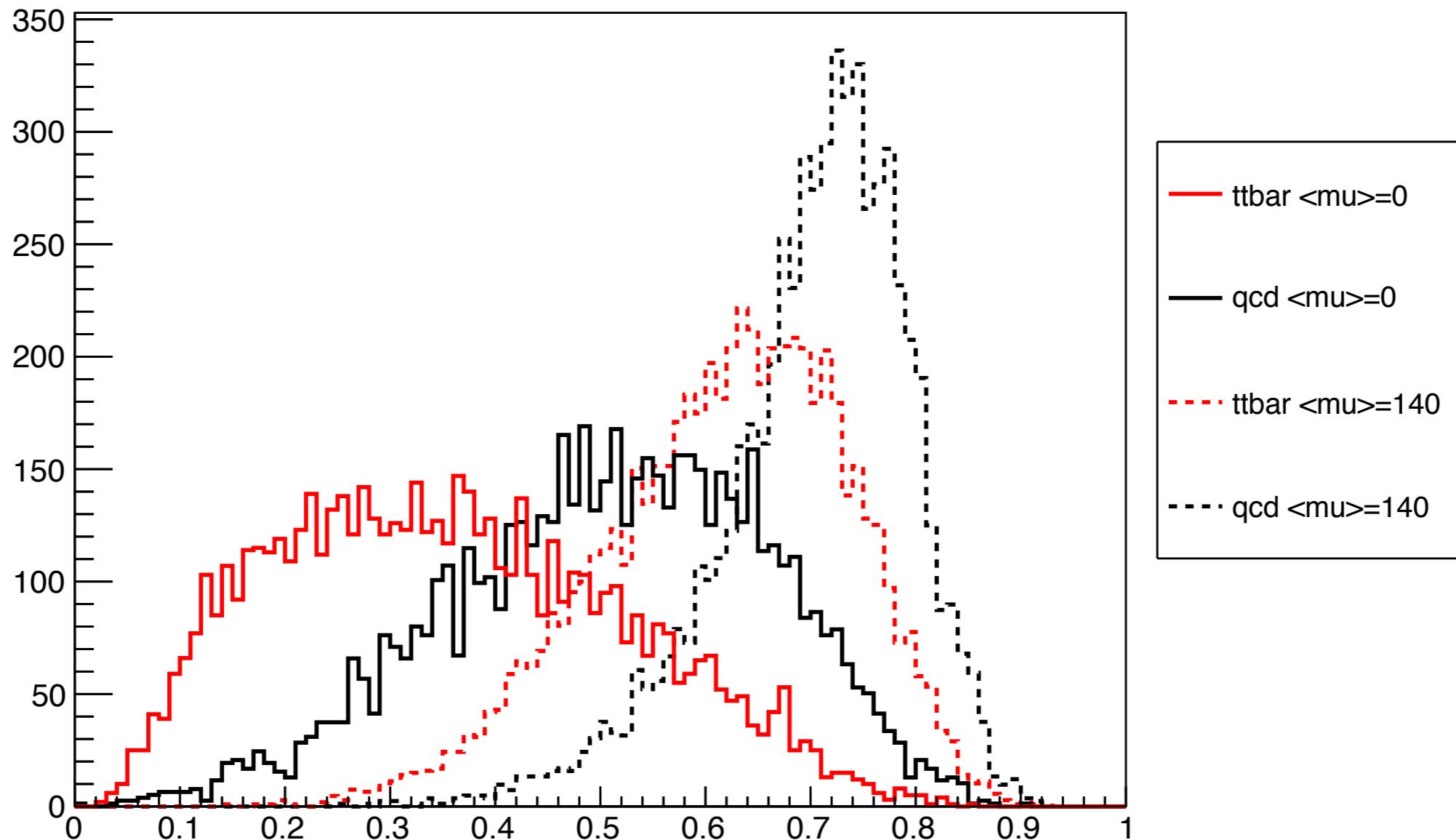
Trimmed Jet Tagger



- Simple tagger, stable with pileup
- Mistag rate slightly higher than other taggers

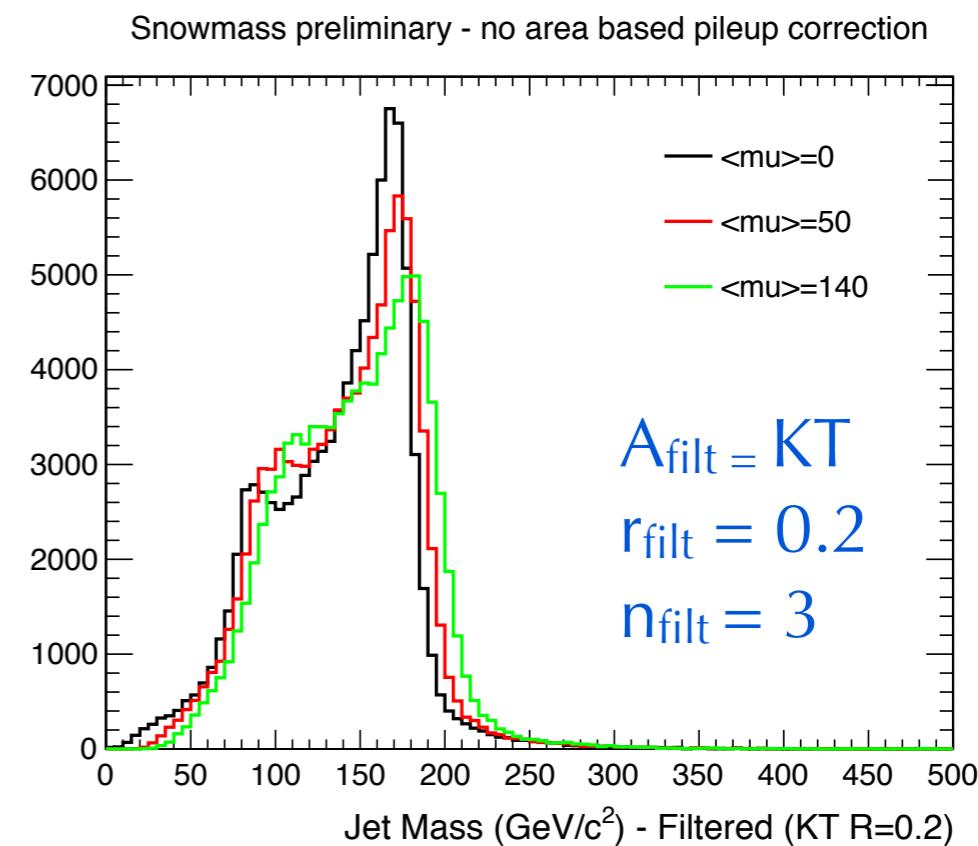
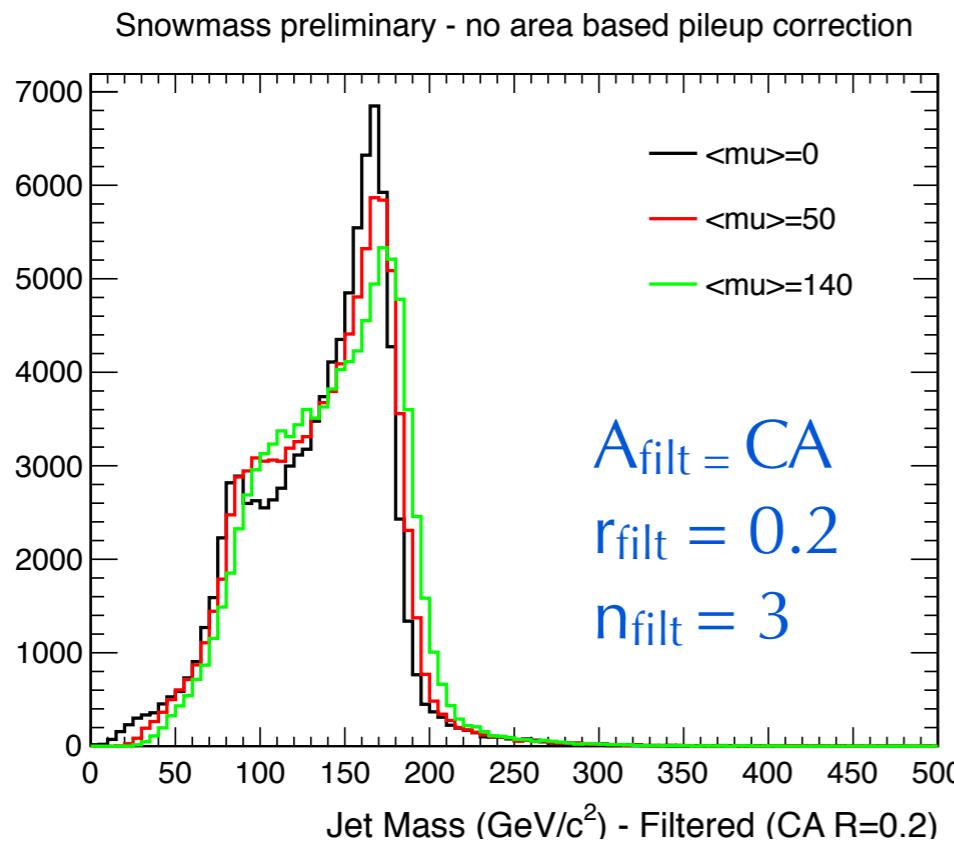
Nsubjettiness tau2/tau1

Trim_Tau21_Cut_Wmass

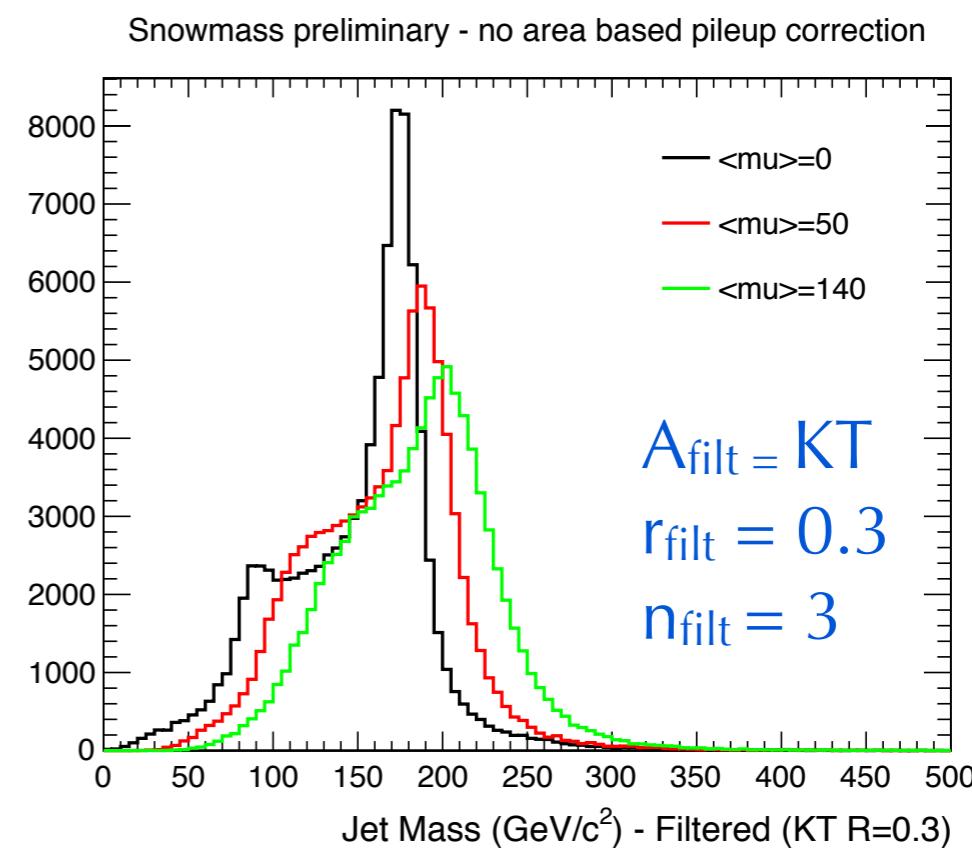
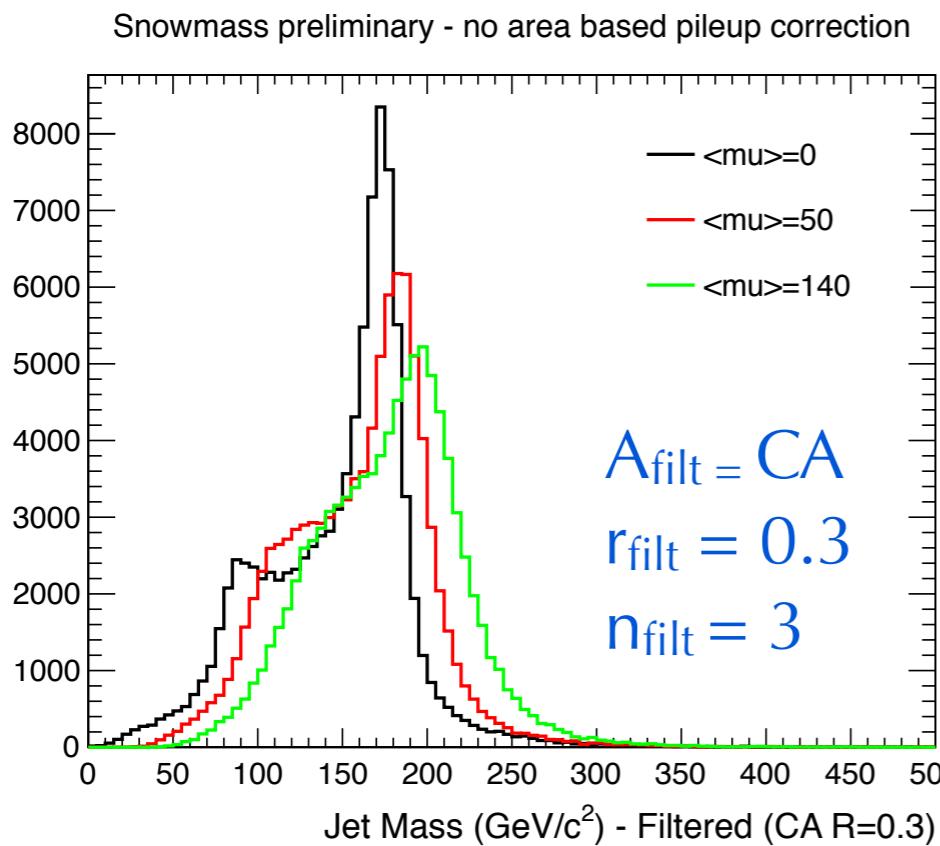


Jet Filtering - parameter study

Initial jet: CA R=0.8

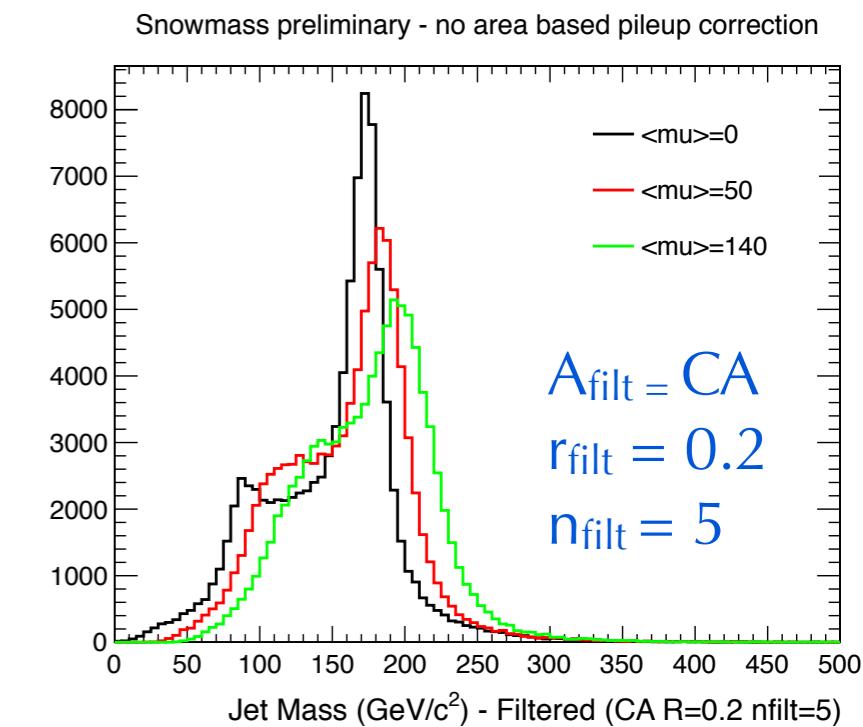
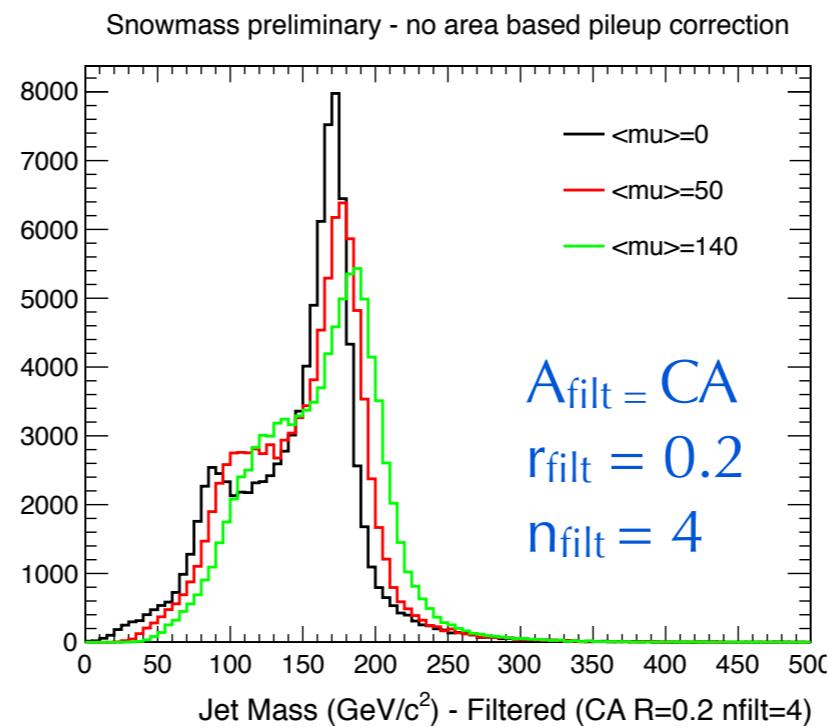
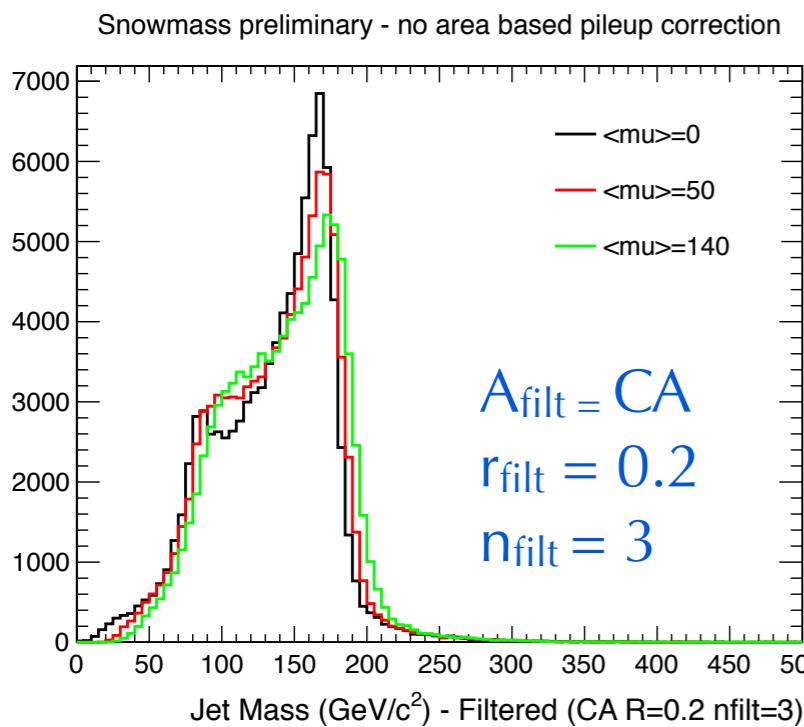


Increase
 r_{filt}



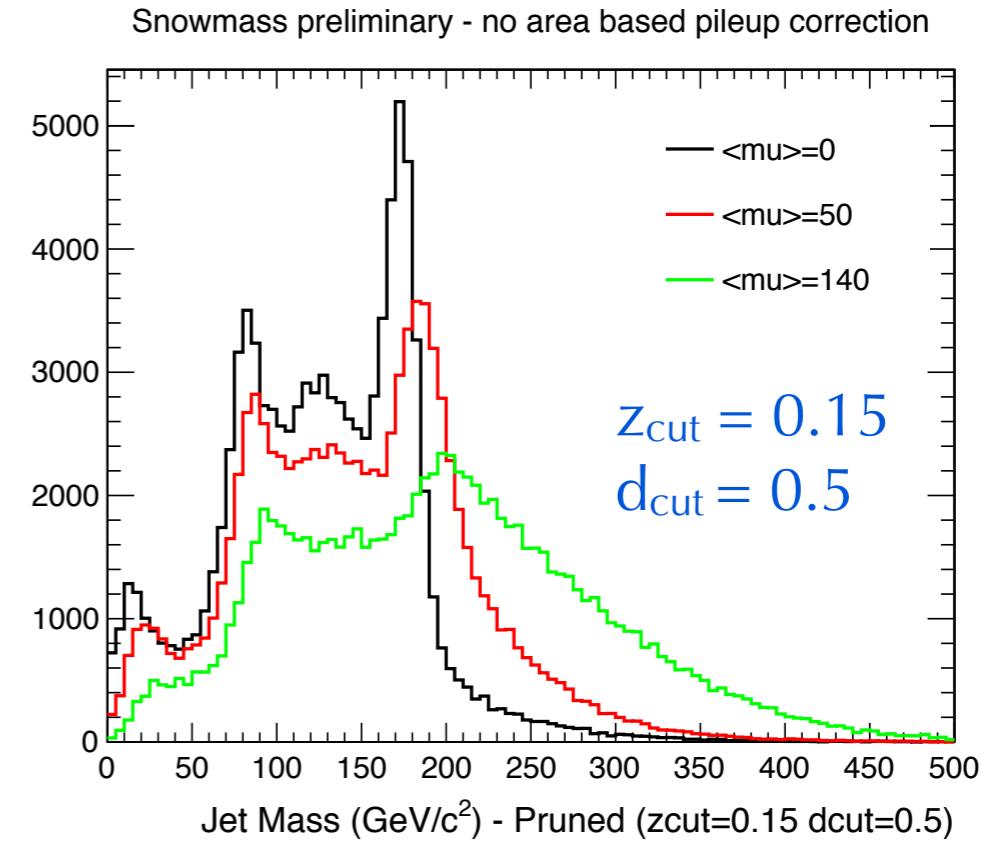
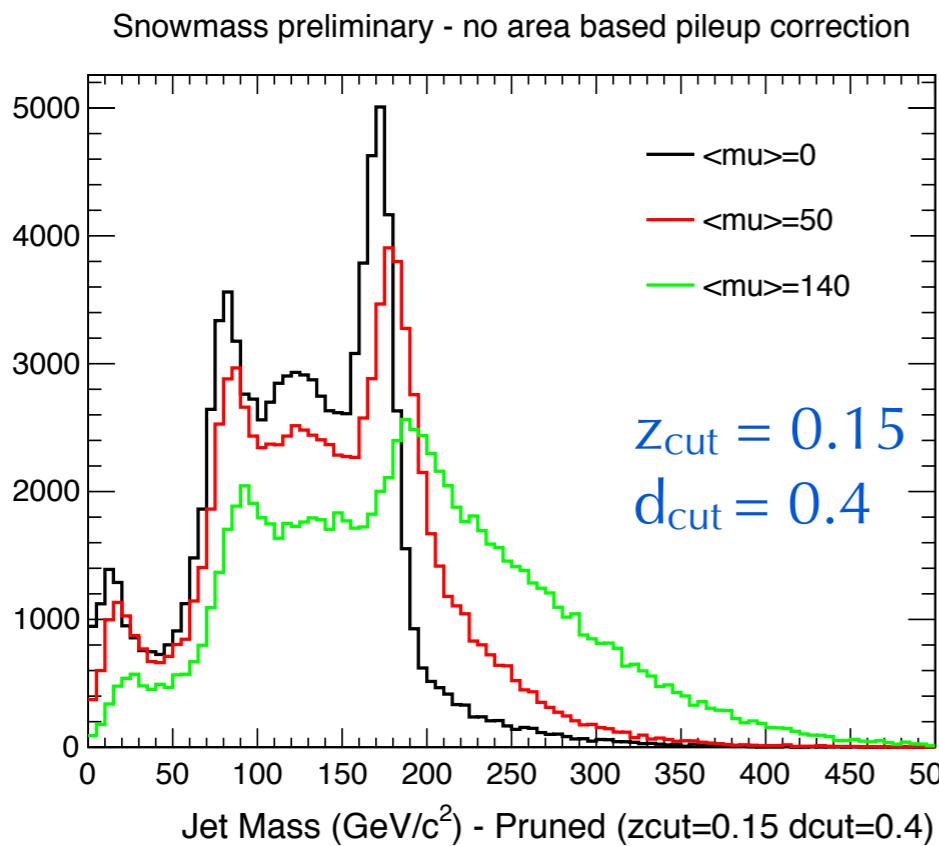
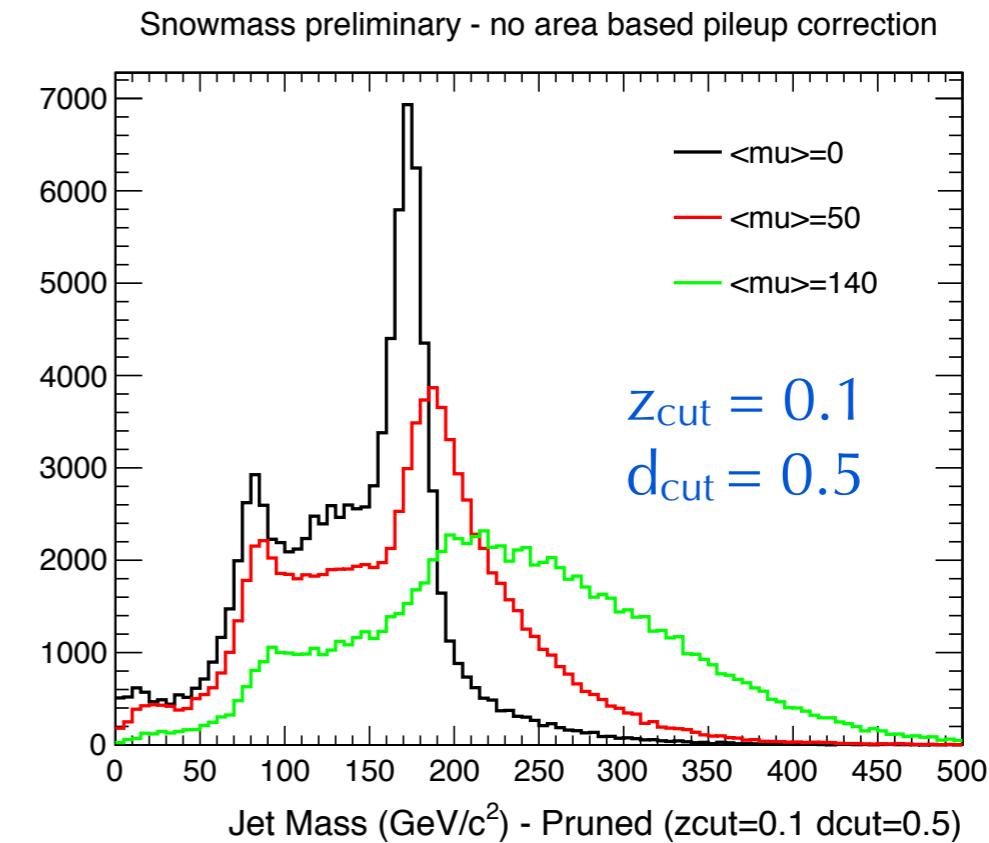
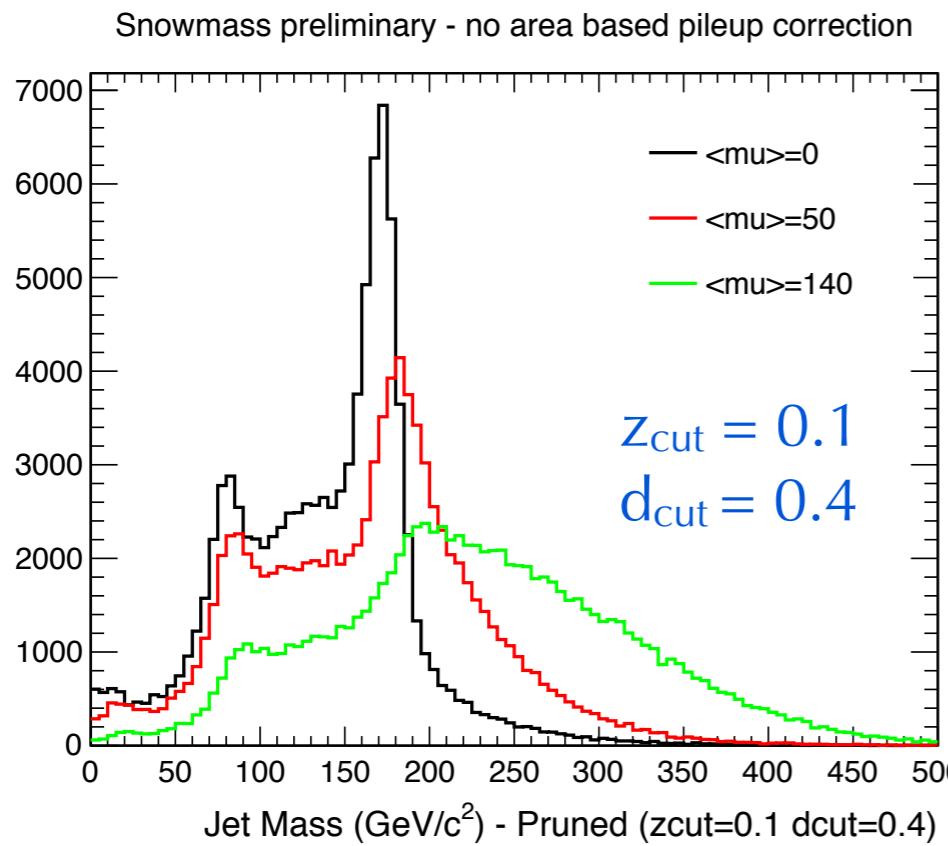
Jet Filtering - parameter study

Initial jet: CA R=0.8

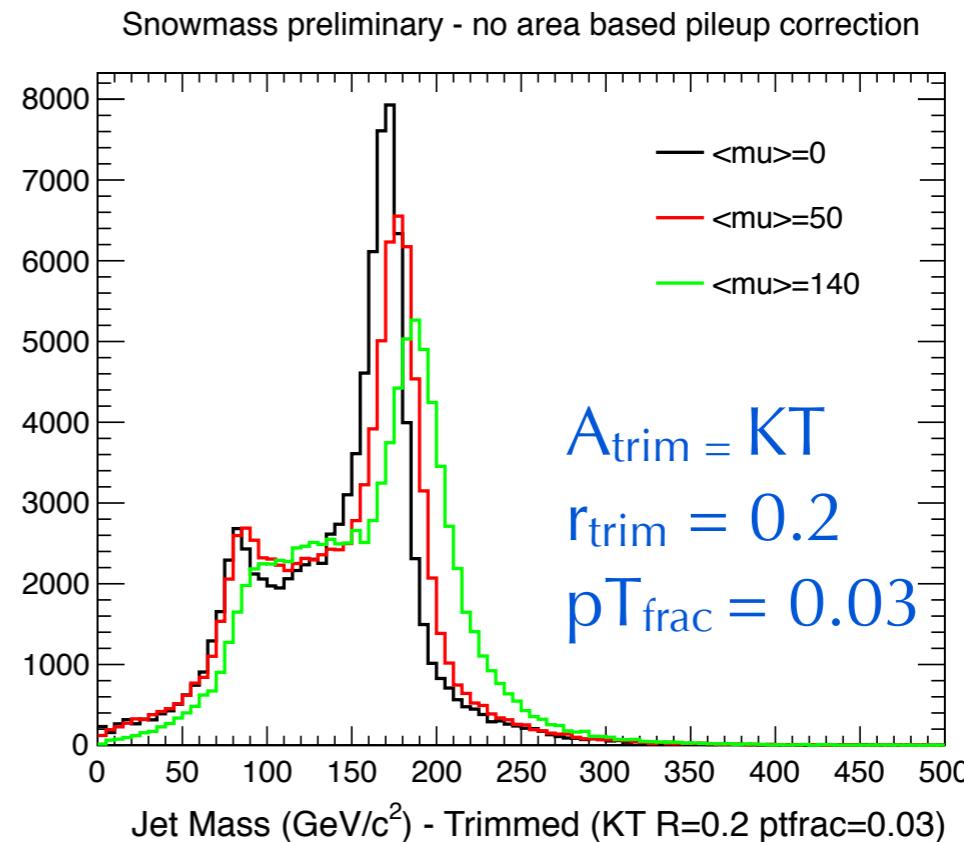
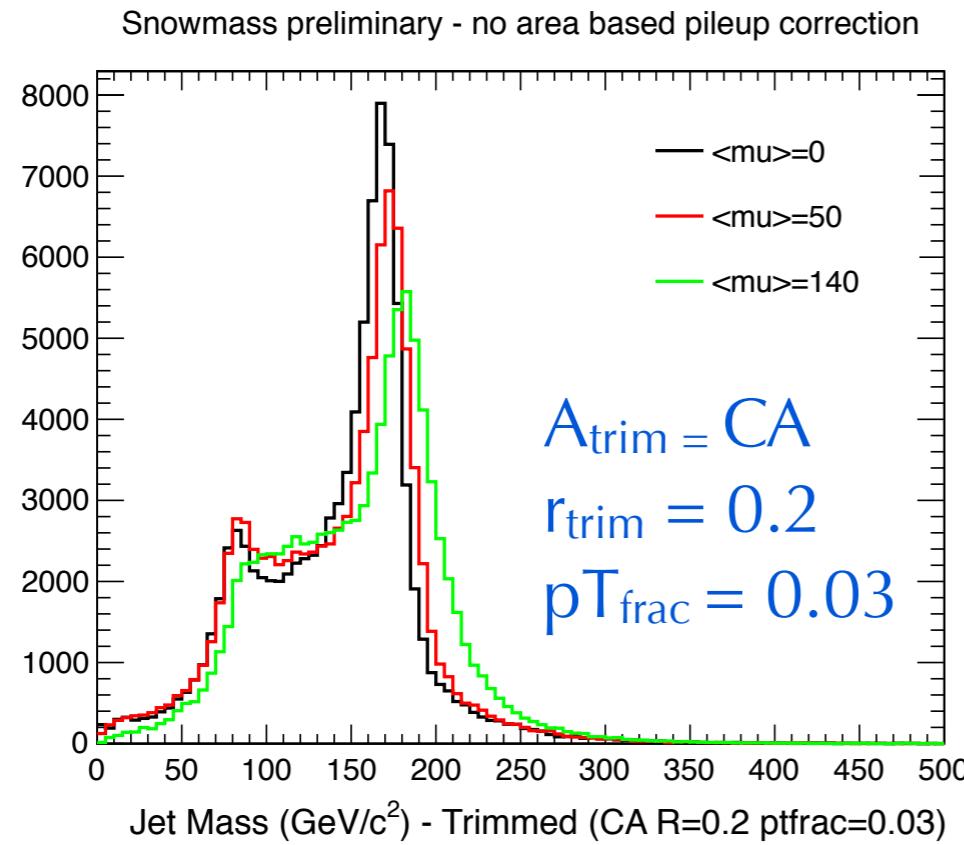


Increase
 n_{filt} →

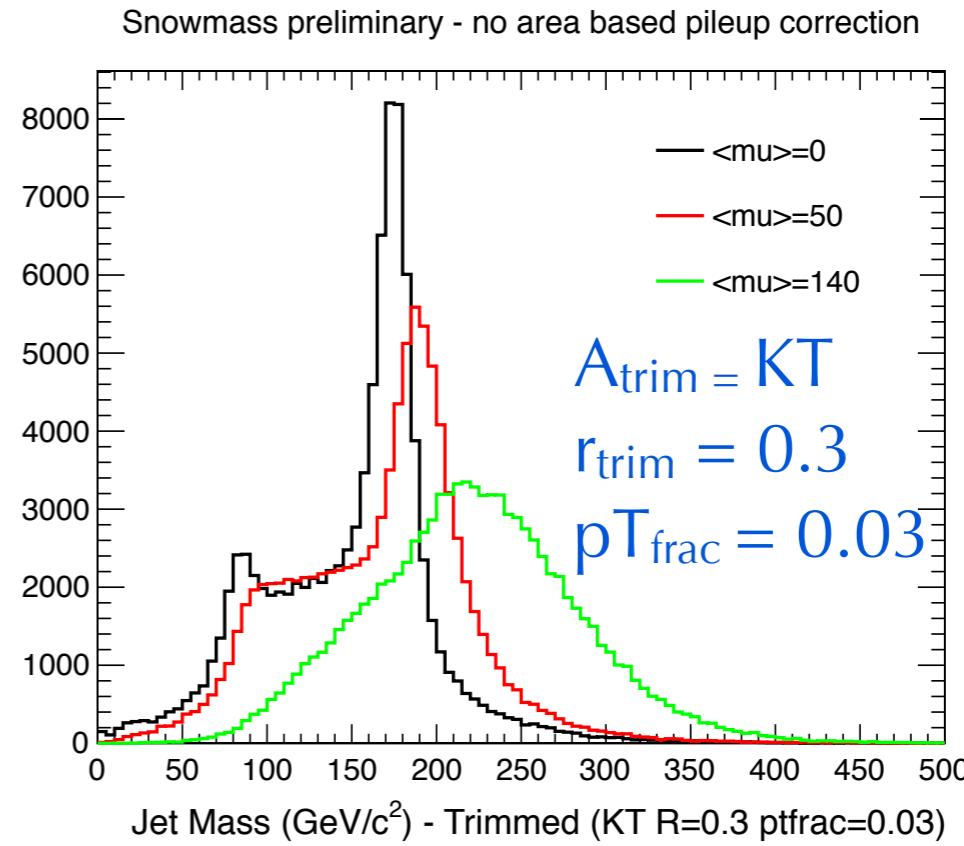
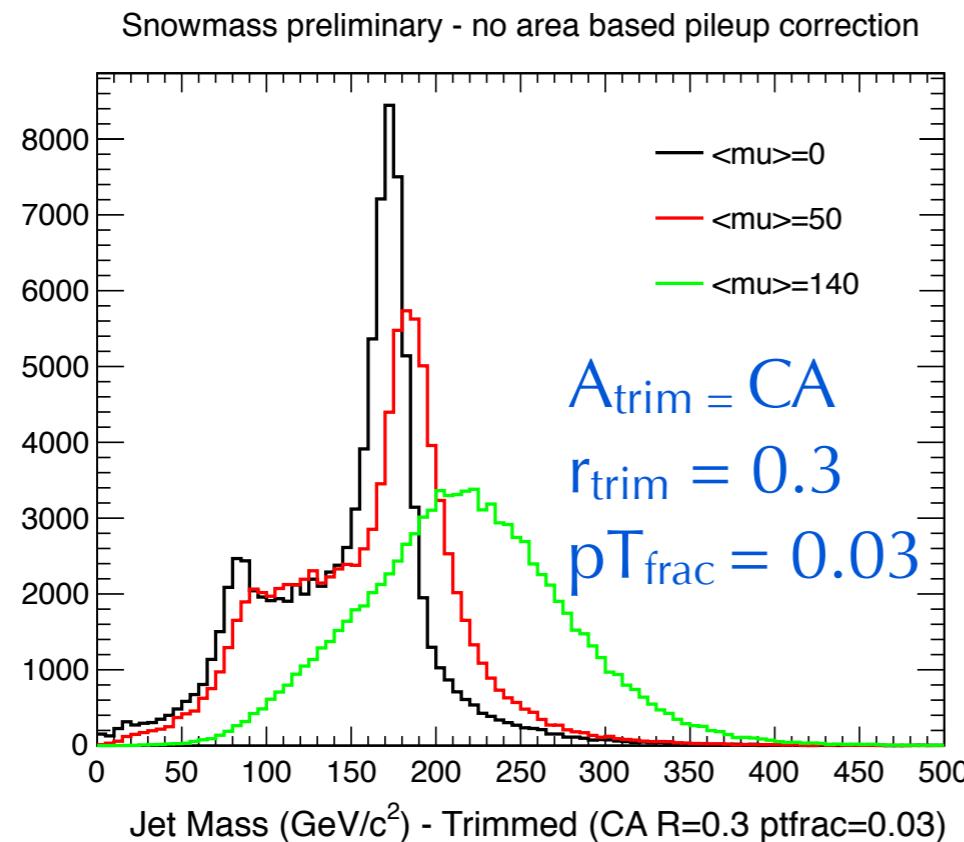
Jet Pruning - parameter study



Jet Trimming - parameter study



Increase
 r_{trim}



Jet Trimming - parameter study

