

# Future prospects in jet substructure performance with ATLAS

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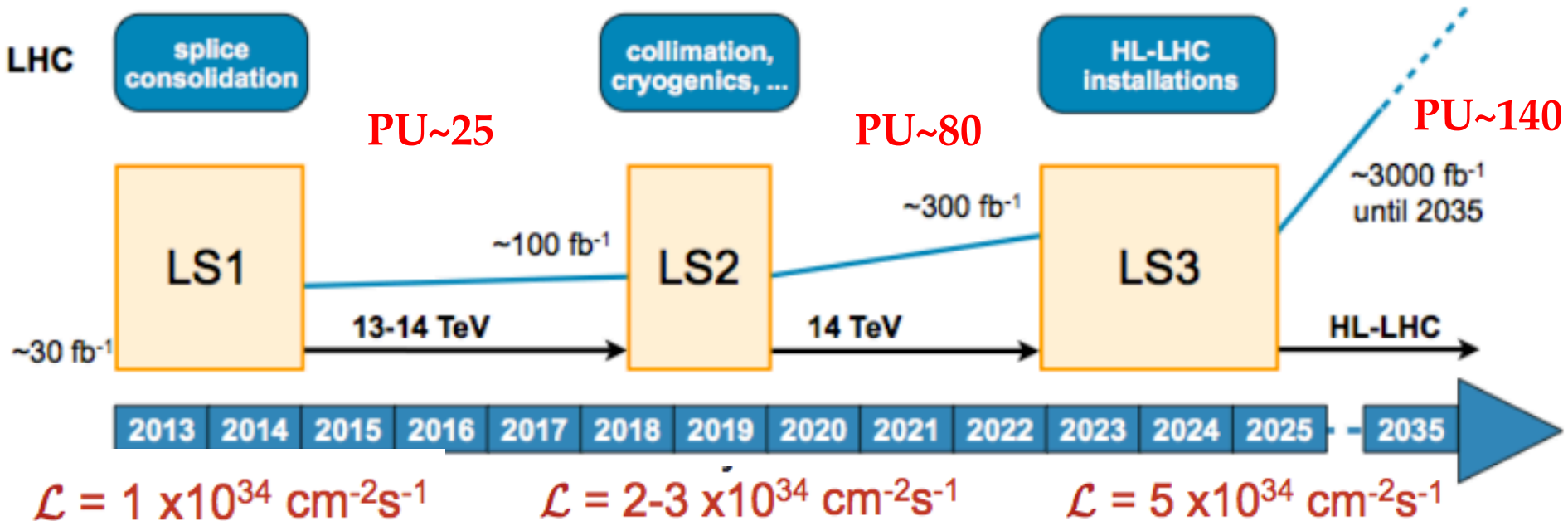
**Ariel Schwartzman (SLAC)**

On behalf of the ATLAS Collaboration

BOOST 2014

UCL, 20 Aug 2014

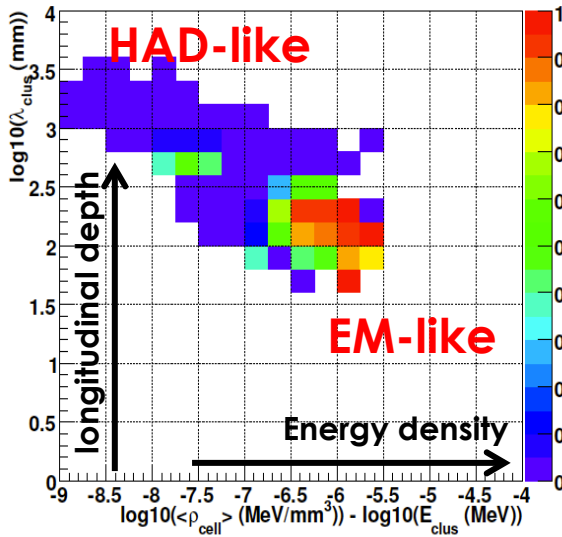
# The pileup frontier



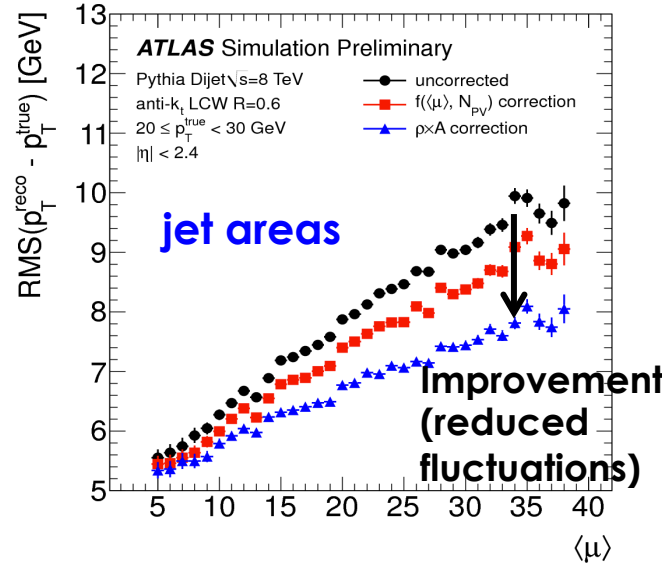
- **Need to maintain (or improve) reconstruction performance at much higher luminosity environment, with up to  $\sim 140$  additional interactions per bunch crossing**
  - Major tracking and trigger upgrades
  - Advanced pileup mitigation techniques and boosted jet and b-tagging reconstruction at high luminosity

# State of the art

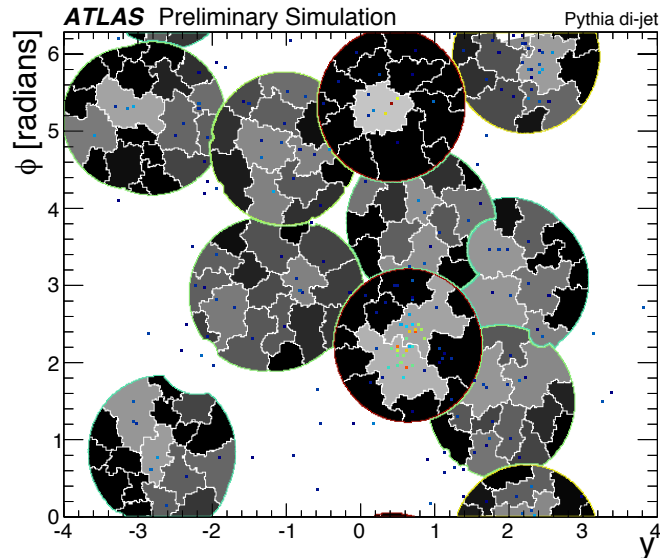
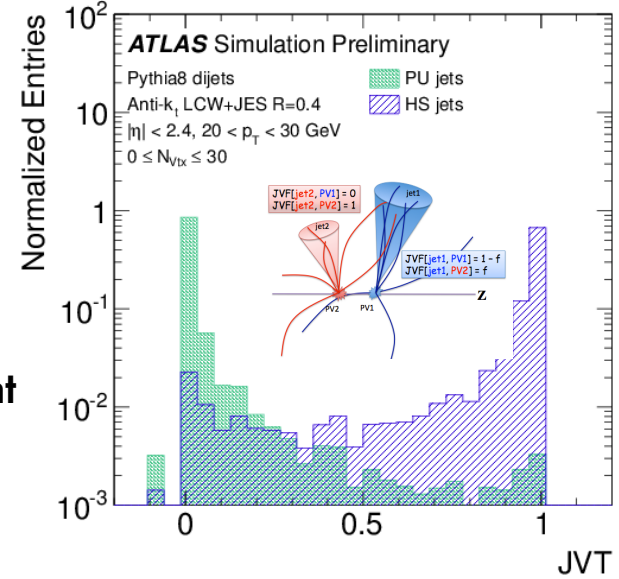
## topoclustering



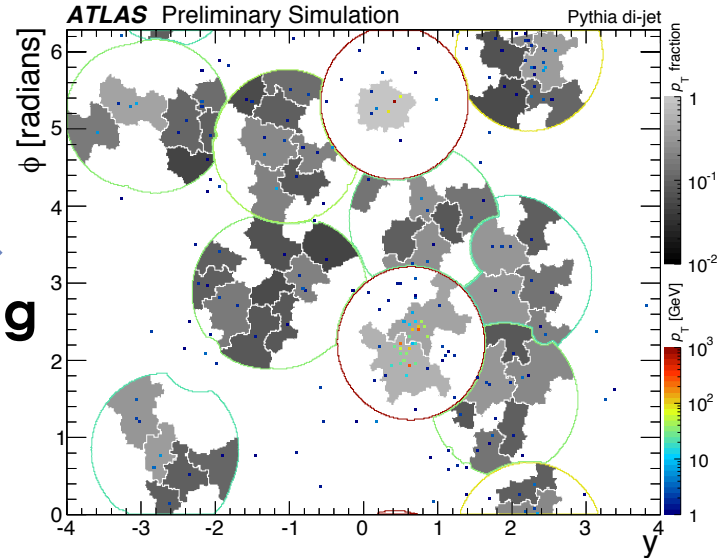
## pileup subtraction



## pileup jet suppression



→  
**grooming**



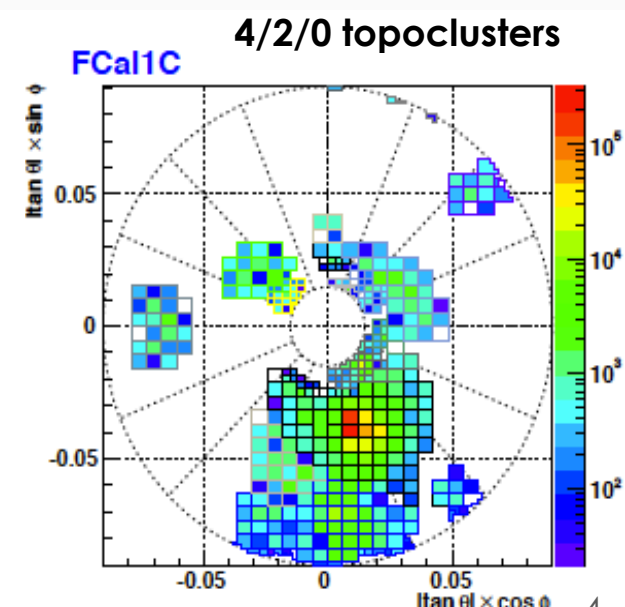
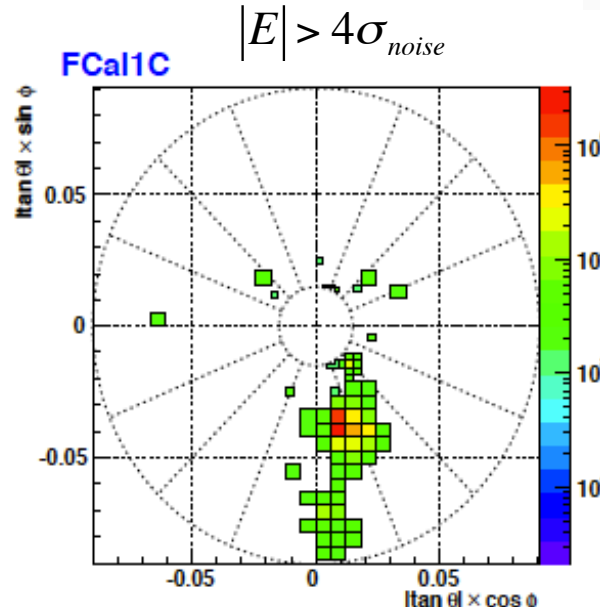
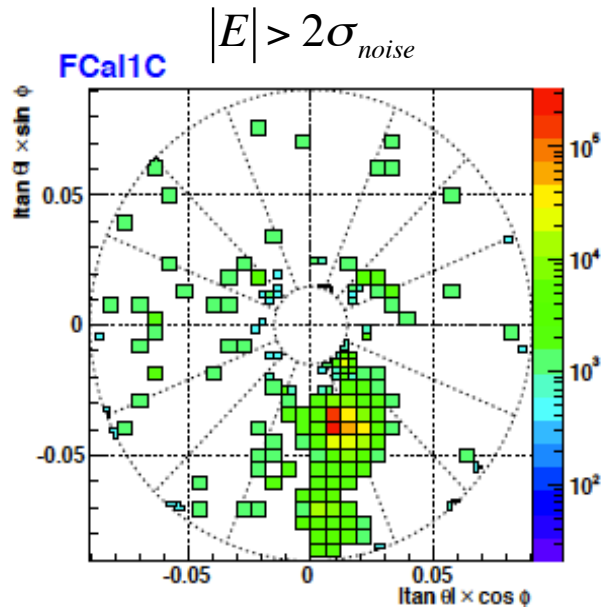
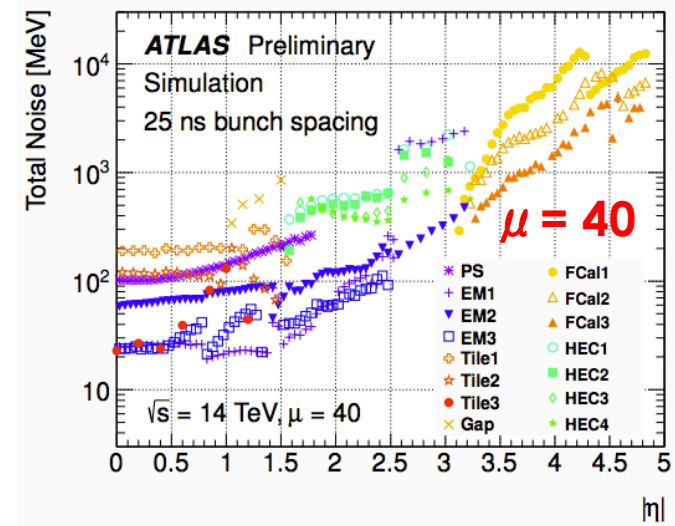
# Topoclustering

- **Topological clusters:**

- 3D nearest-neighbor algorithm that clusters calorimeter cells with energy significance ( $|E_{\text{cell}}| / \sigma$ )  $> 4$  for the seed,  $> 2$  for neighbors, and  $> 0$  at the boundary

- **Sigma noise:** electronic + pileup noise

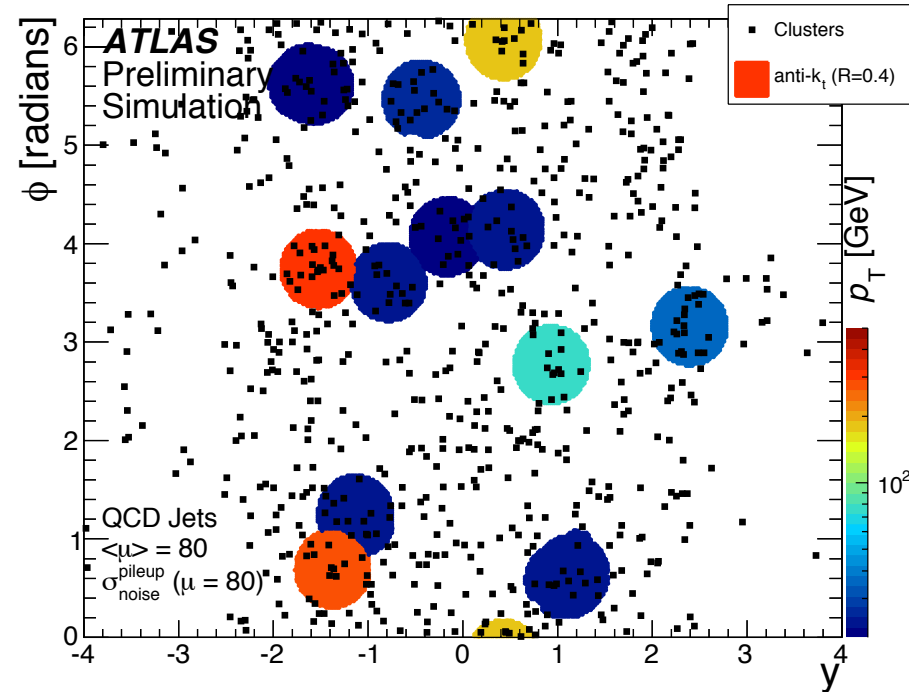
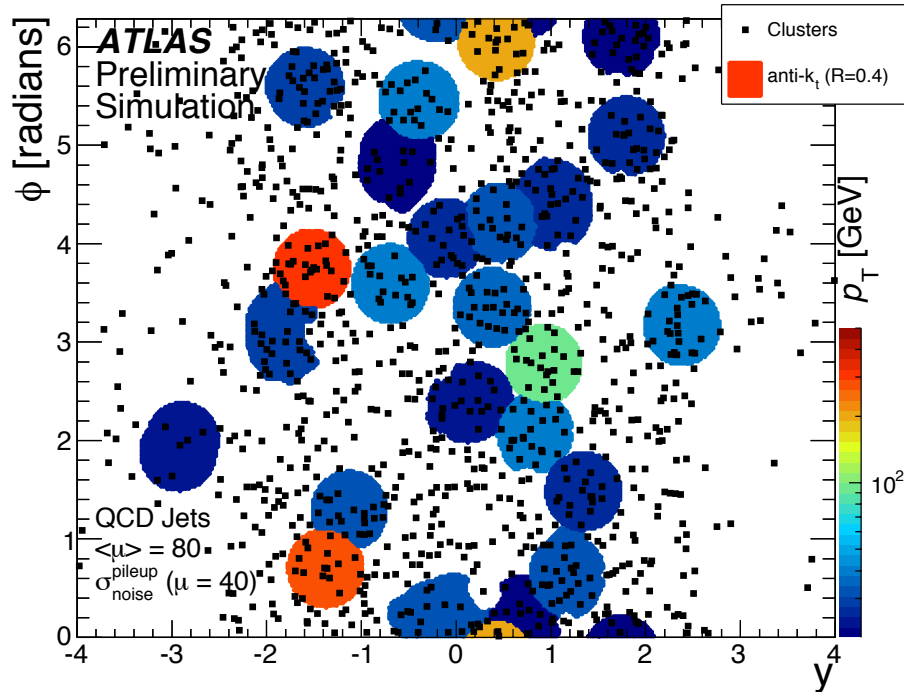
- Adjusted with  $\mu$  for **pileup noise suppression**
  - $\sigma = \sigma(\mu=8)$  in 2011,  $\sigma = \sigma(\mu=30)$  in 2012



# Topoclustering pileup suppression

$\mu=80$

$\mu=80$



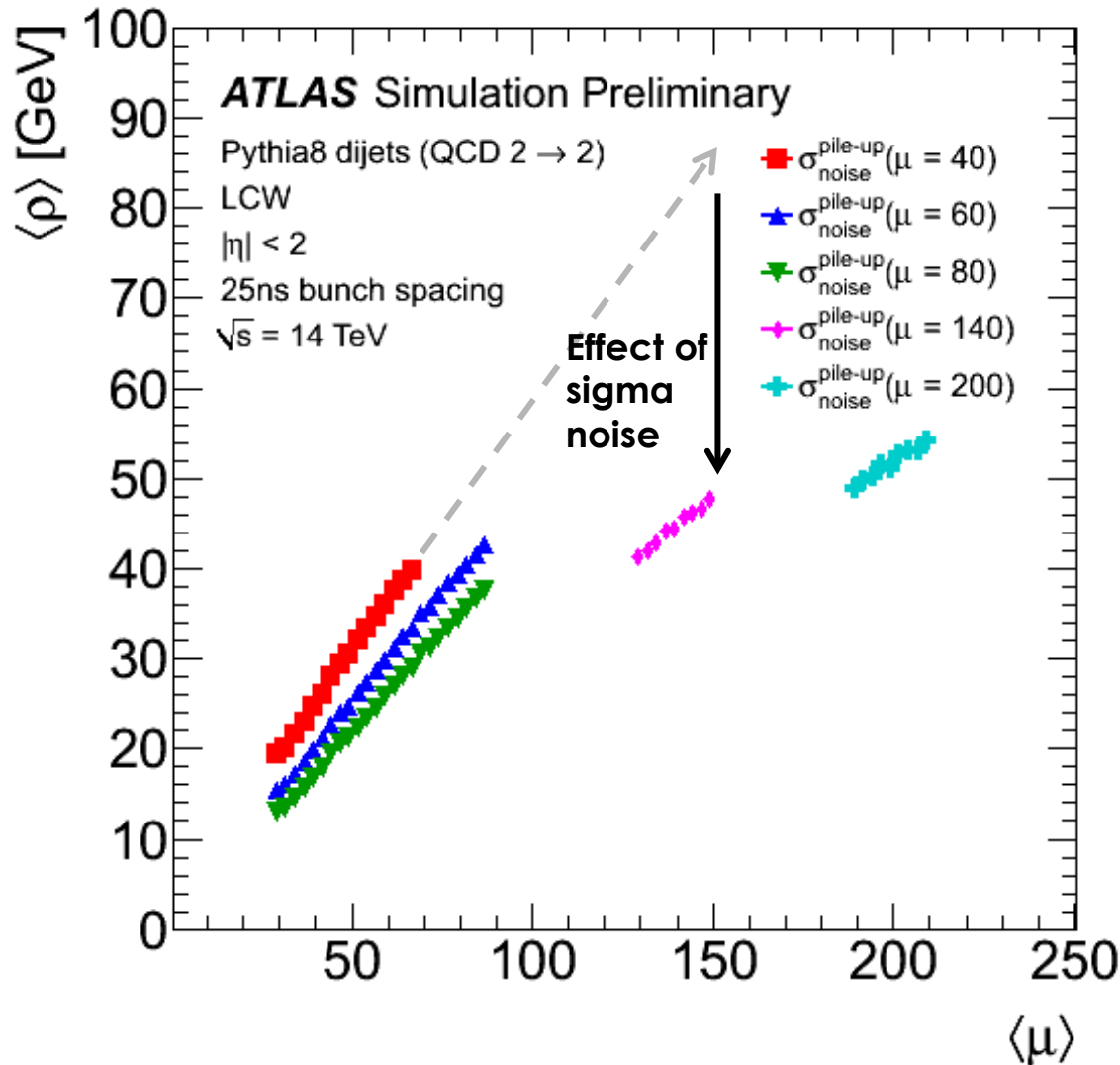
$\sigma_{noise}^{pileup}(\mu = 40)$



$\sigma_{noise}^{pileup}(\mu = 80)$

**Sigma noise provides particle (cluster) level pileup suppression**

# Pileup subtraction (I)

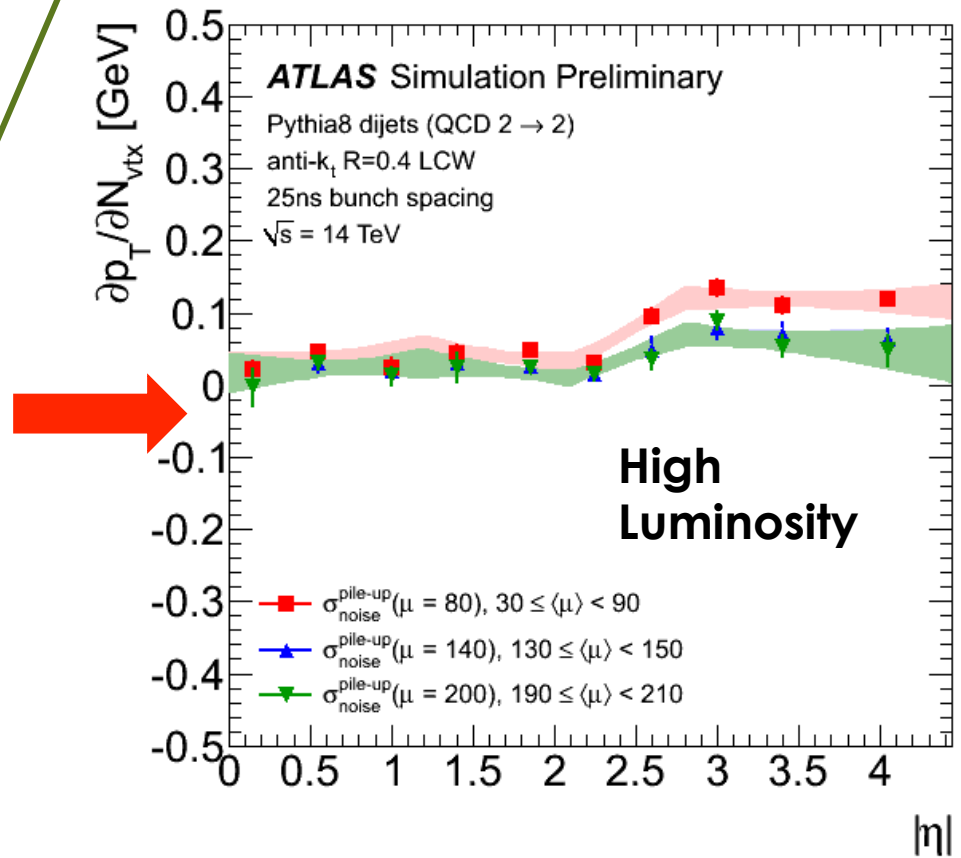
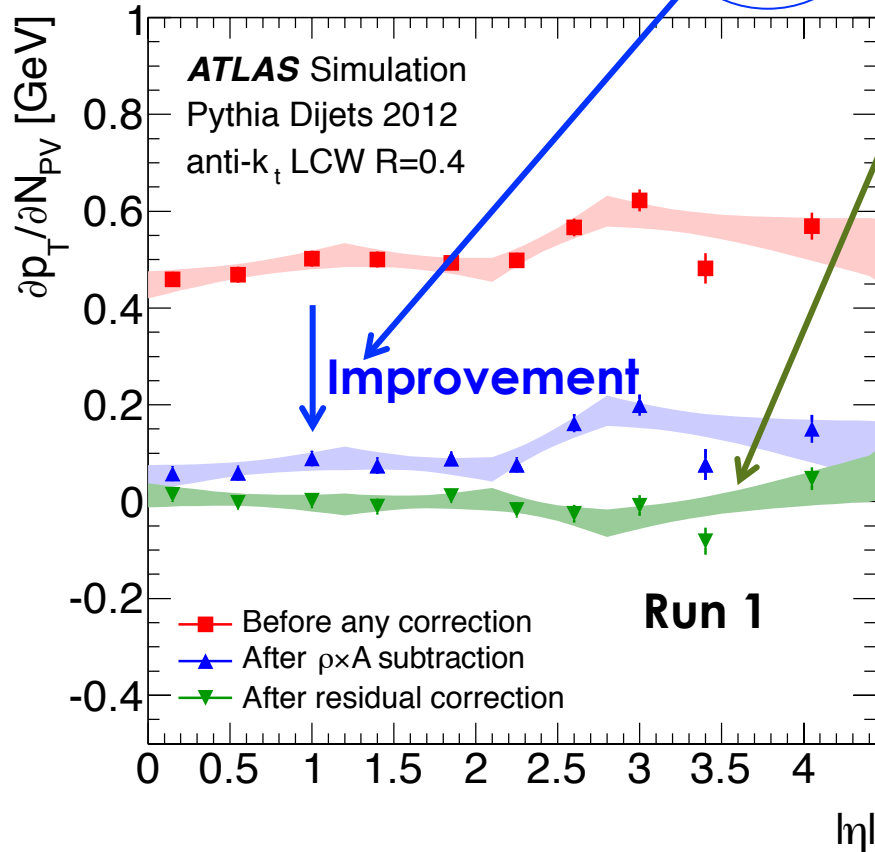


- Linear behavior of rho up to high mu for fixed sigma noise values
- Higher pileup noise values lead to partial suppression of pileup
- **Optimization of topoclustering sigma noise is key to reconstruct jets at high luminosity**

# Pileup subtraction (II)

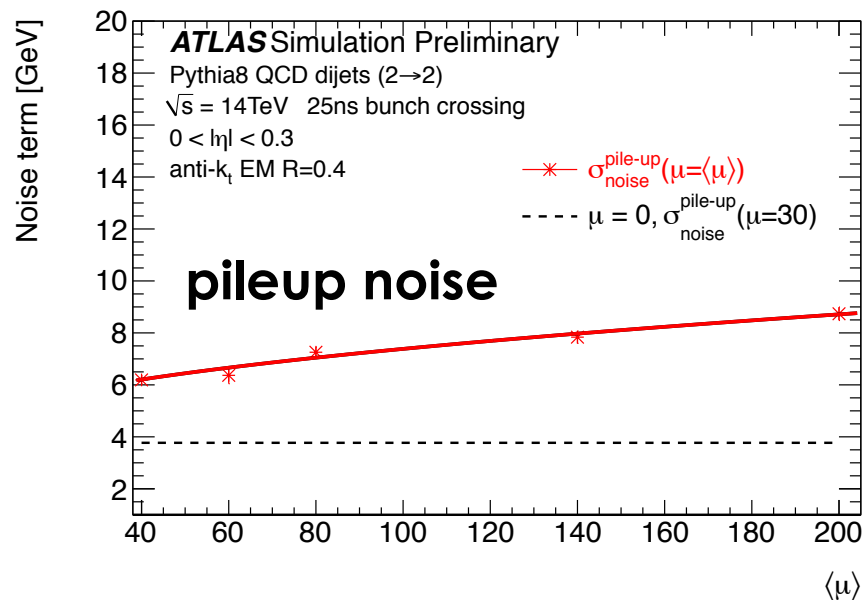
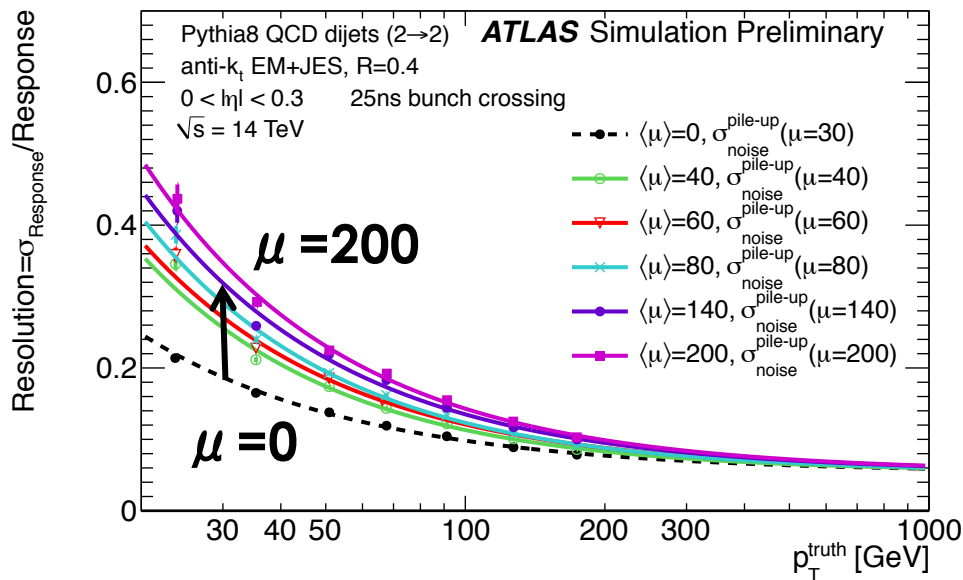
Residual correction

$$p_T^{\text{corr}} = p_T - \rho A_T - \alpha(N_{\text{PV}} - 1) - \beta\langle\mu\rangle$$



- Residual offset is mostly pileup independent, after adjusting sigma noise
- Topoclustering, jet areas subtraction, and local cluster weighting work well up to very high luminosity**

# Jet energy resolution

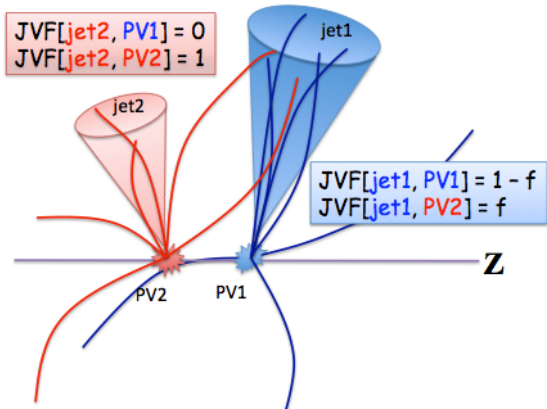


- Fractional jet energy resolution degrades at low  $p_T$  due to local pileup fluctuations within events
- Expect improvements using tracks and particle-level pileup removal techniques



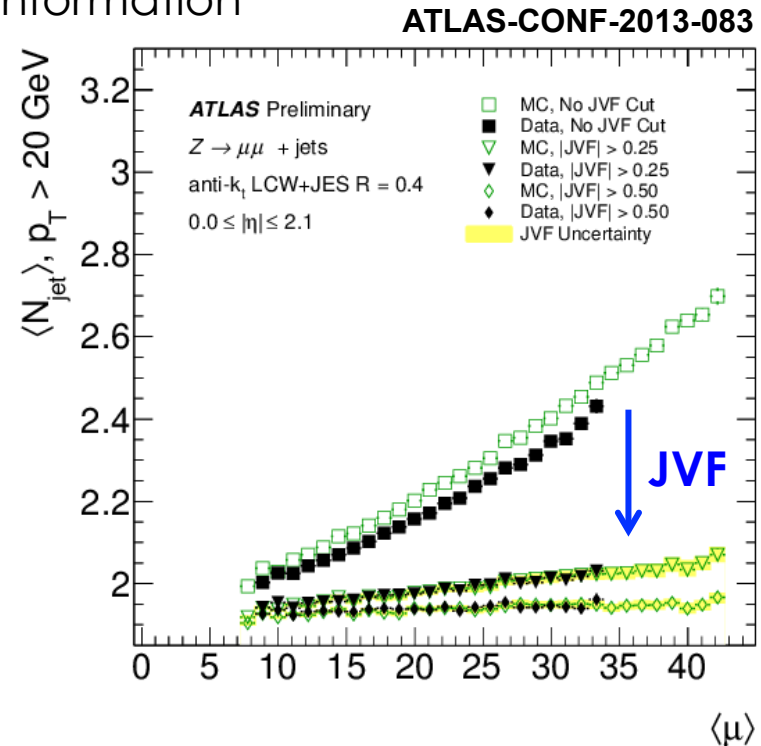
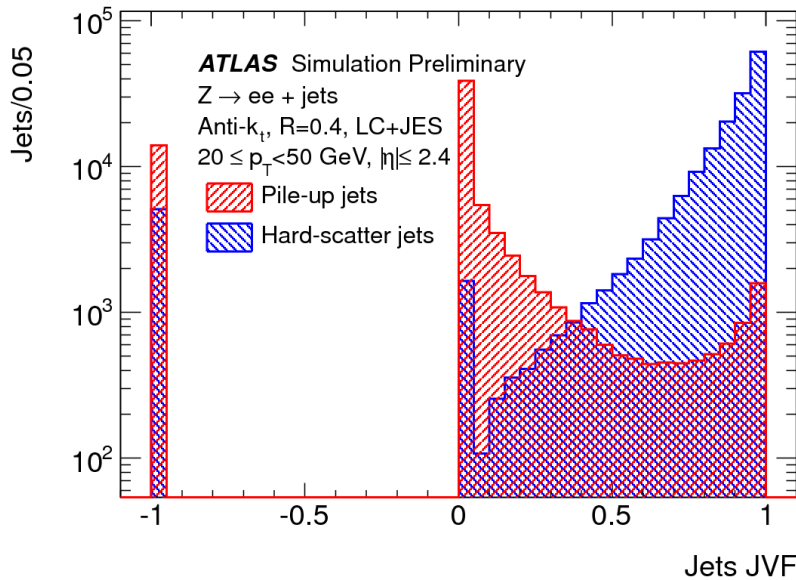
# Pileup jet suppression

- Pileup local fluctuations within a same event can lead to **pileup jets**:
  - QCD jets originating from pileup vertices and random combination of particles from multiple pileup interactions (“stochastic pileup jets”)
- **Jet vertex fraction algorithm**
  - Tag and reject pileup jets using tracking and vertexing information

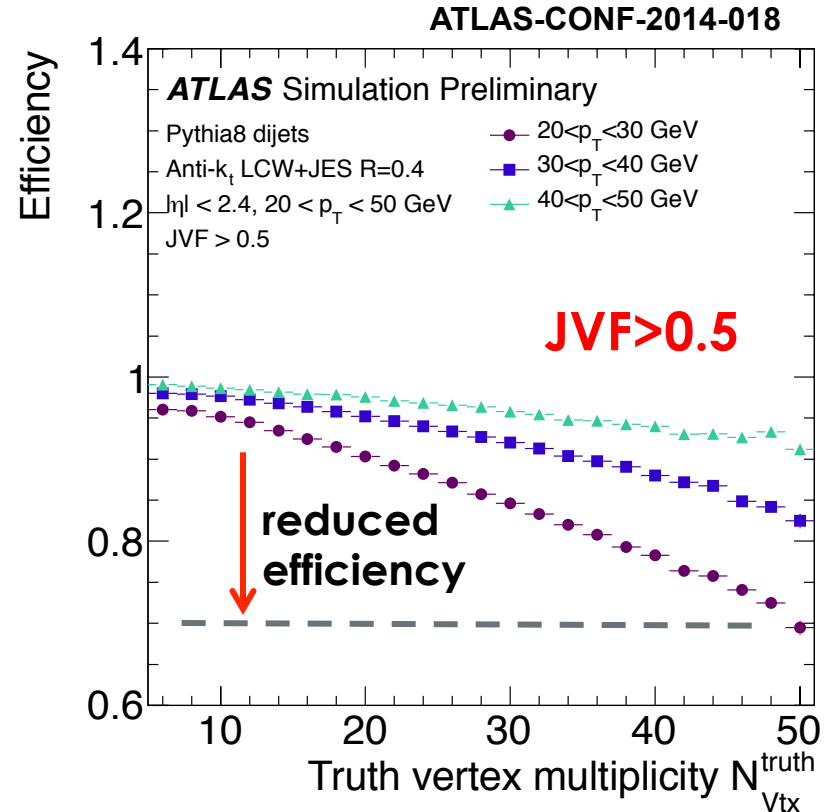
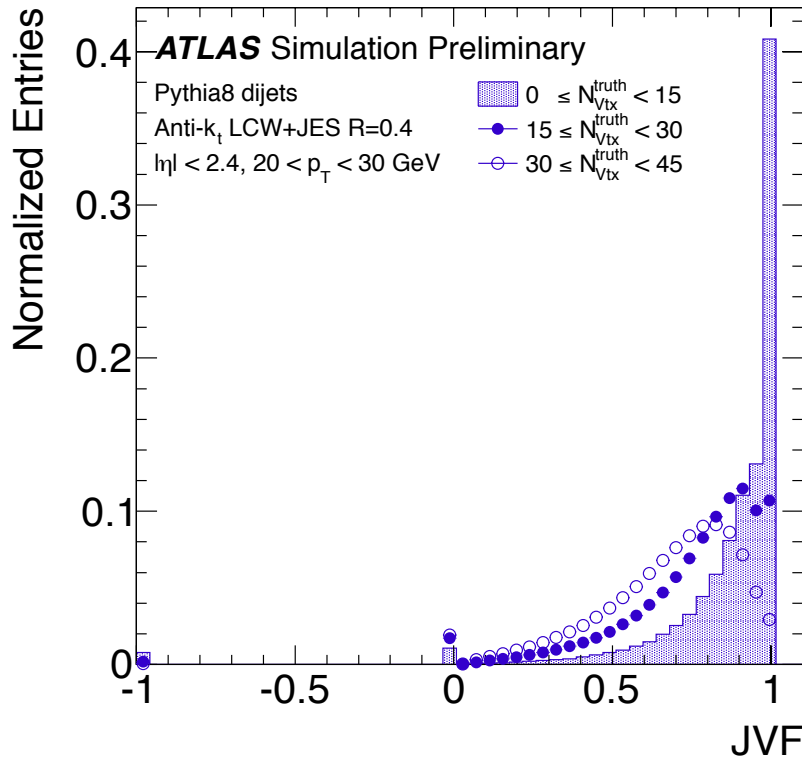


## Jet Vertex Fraction (JVF)

$$JVF = \frac{\sum_k p_T^{\text{trk}_k}(\text{PV}_0)}{\sum_l p_T^{\text{trk}_l}(\text{PV}_0) + \sum_{n \geq 1} \sum_l p_T^{\text{trk}_l}(\text{PV}_n)}$$



# JVF at high luminosity



- JVF measures the fraction of track  $p_T$  from the hard-scatter primary vertex:
  - JVF decreases with increasing luminosity:
  - **Pileup-dependent jet selection efficiency for fixed JVF cuts**

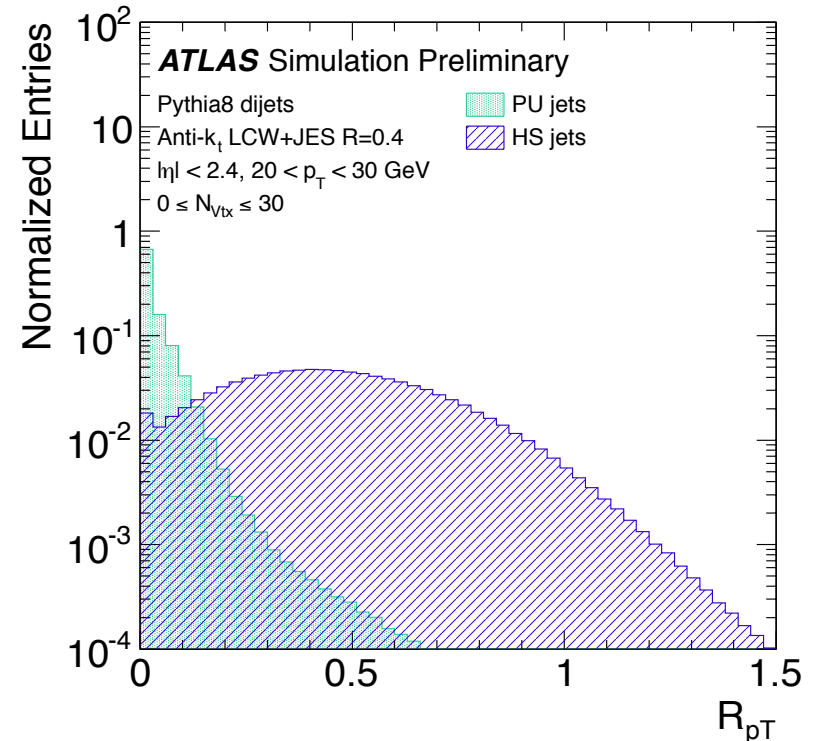
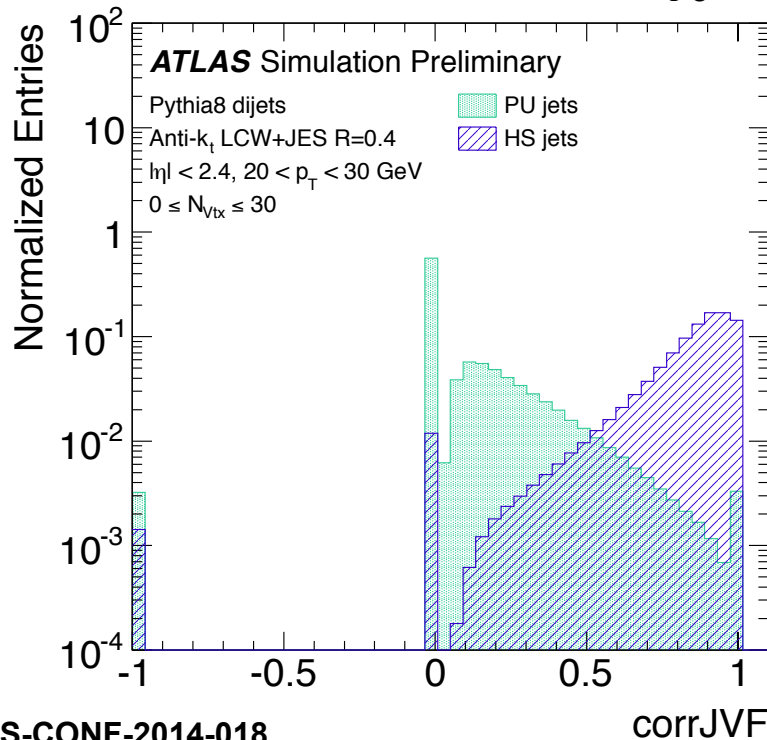
# New jet-vertex tagging variables

- Correct JVF for its pileup dependence:

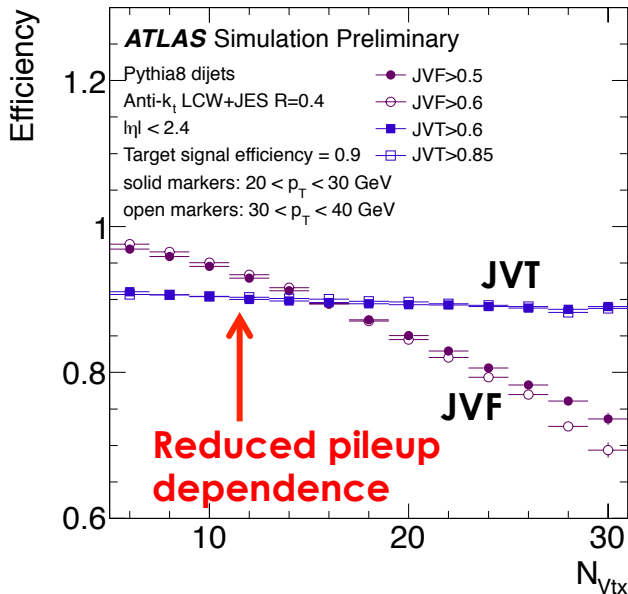
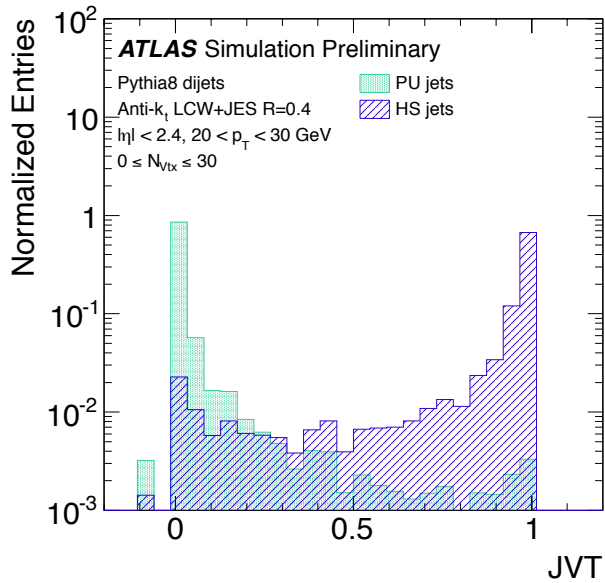
$$CorrJVF = \frac{\Sigma p_T^{trk}(PV_0)}{\Sigma p_T^{trk}(PV_0) + \frac{\Sigma p_T^{trk}(PU_n)}{k n_{PU}^{trk}}}$$

- Use pileup-corrected observables:

$$R_{pT} = \frac{\Sigma p_T^{trk}(PV_0)}{p_T^{jet}}$$

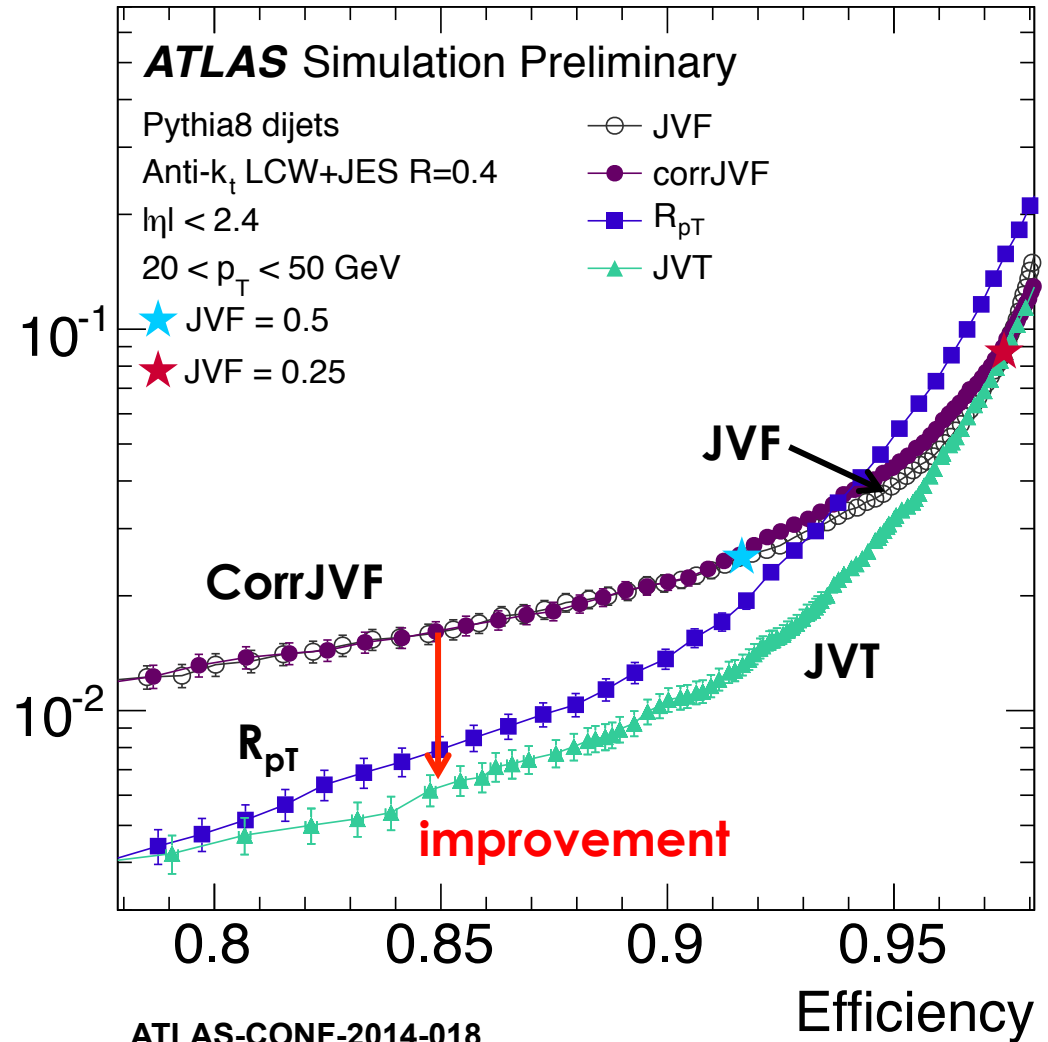


# Jet Vertex Tagger (JVT)

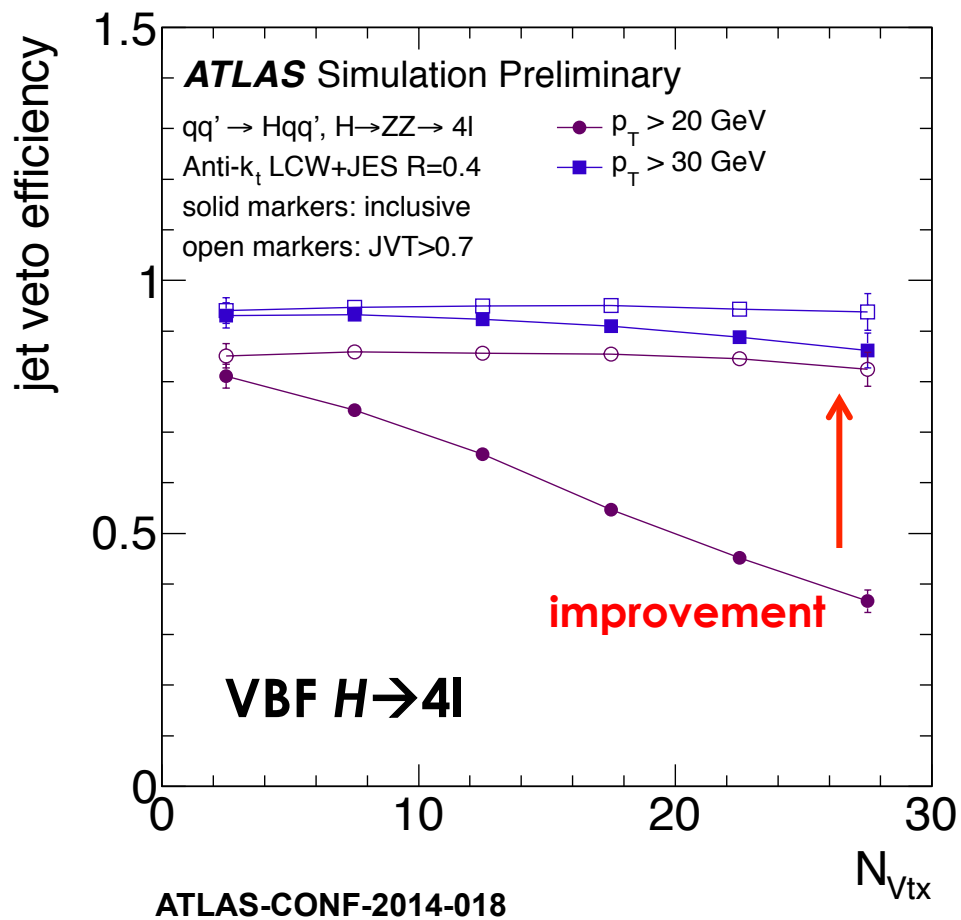
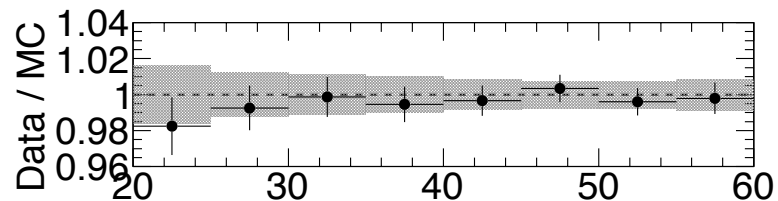
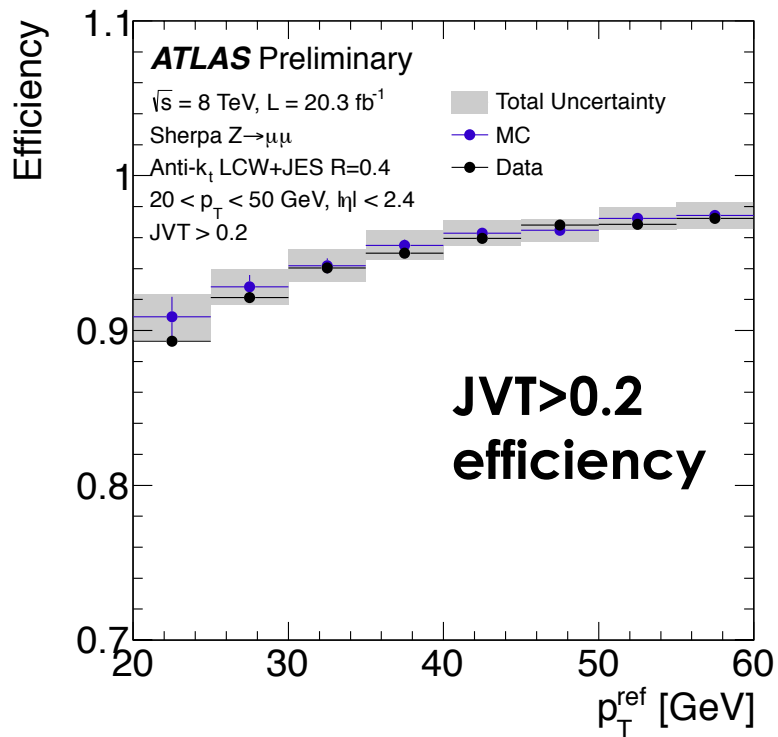


2D likelihood combining CorrJVF and RpT

Fake Rate

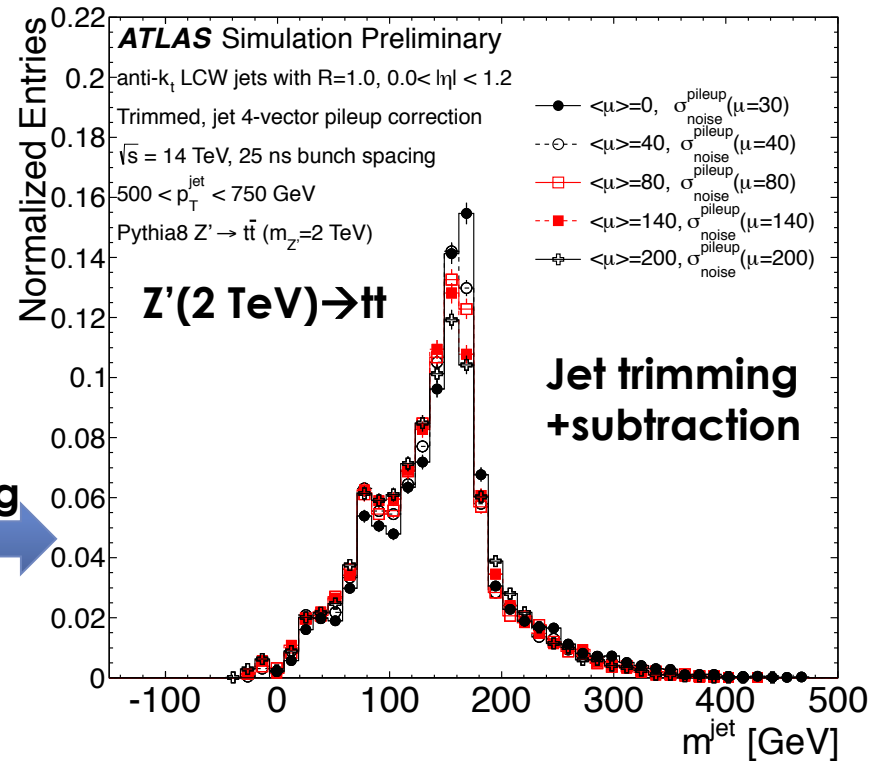
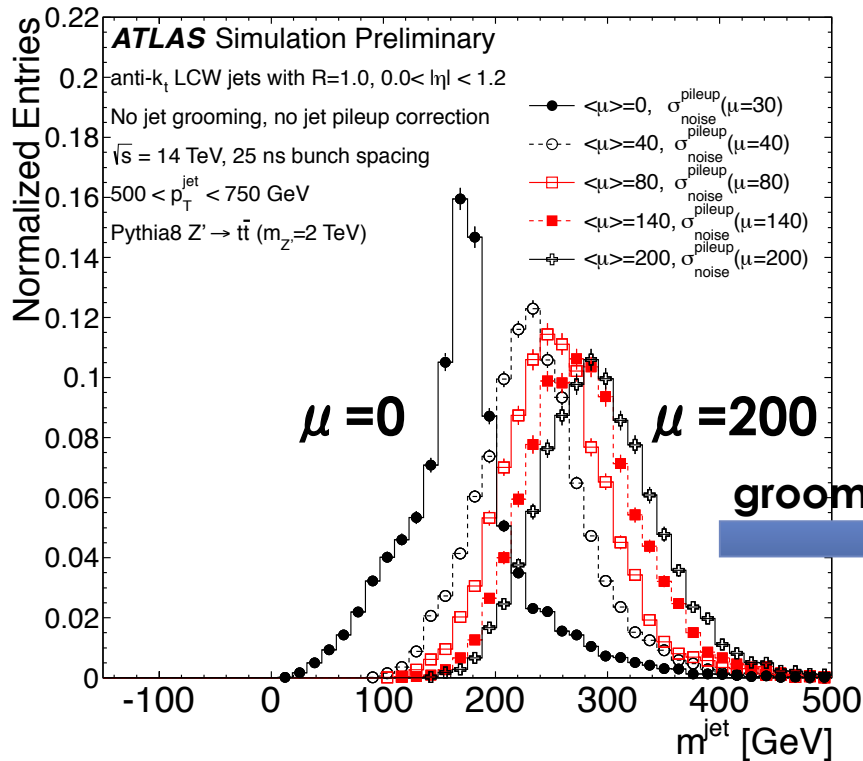
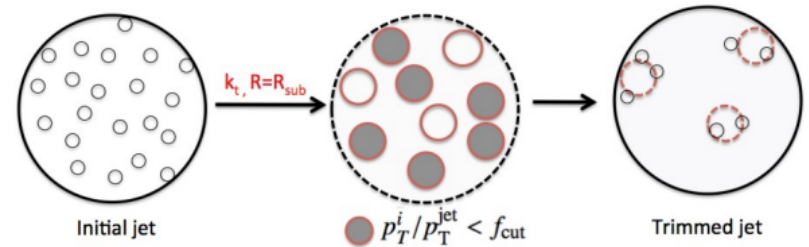


# Jet Vertex Tagging performance



# Jet substructure (I)

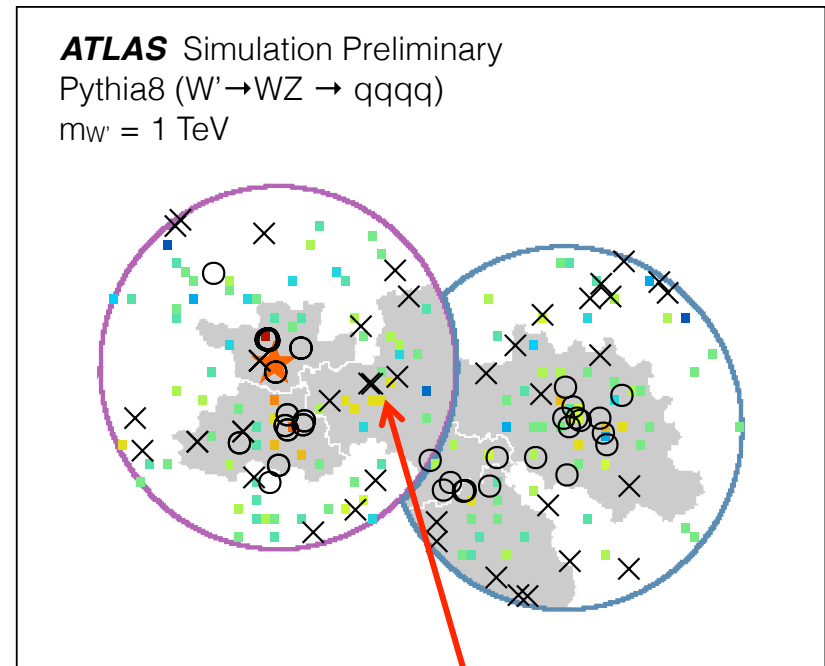
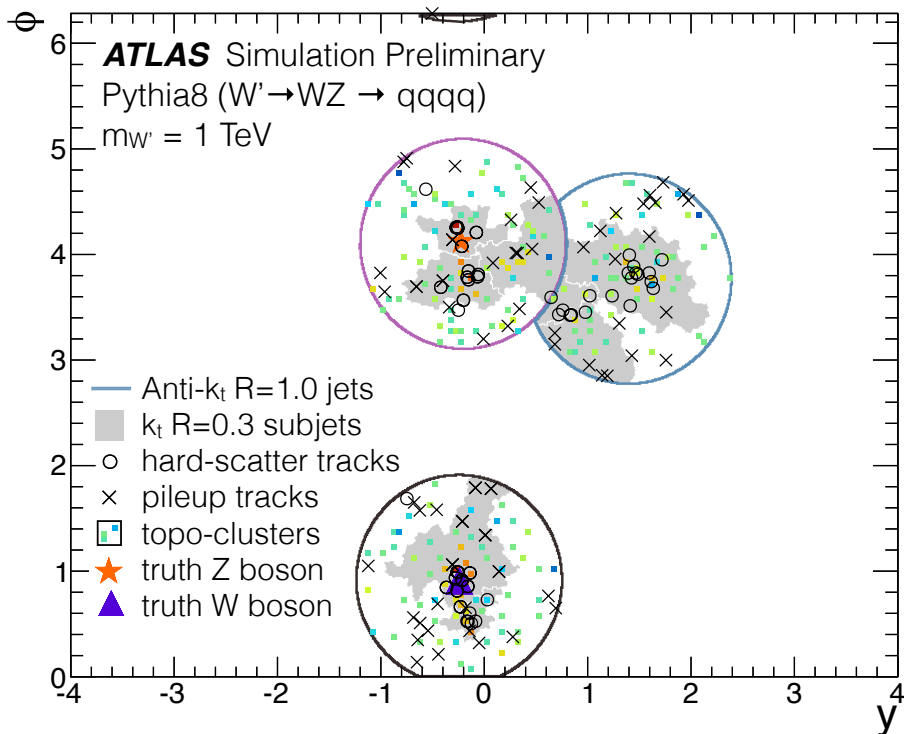
- **Jet trimming:**
  - anti- $k_T$   $R=1.0$
  - $R_{k_T}=0.3$ ,  $f=5\%$



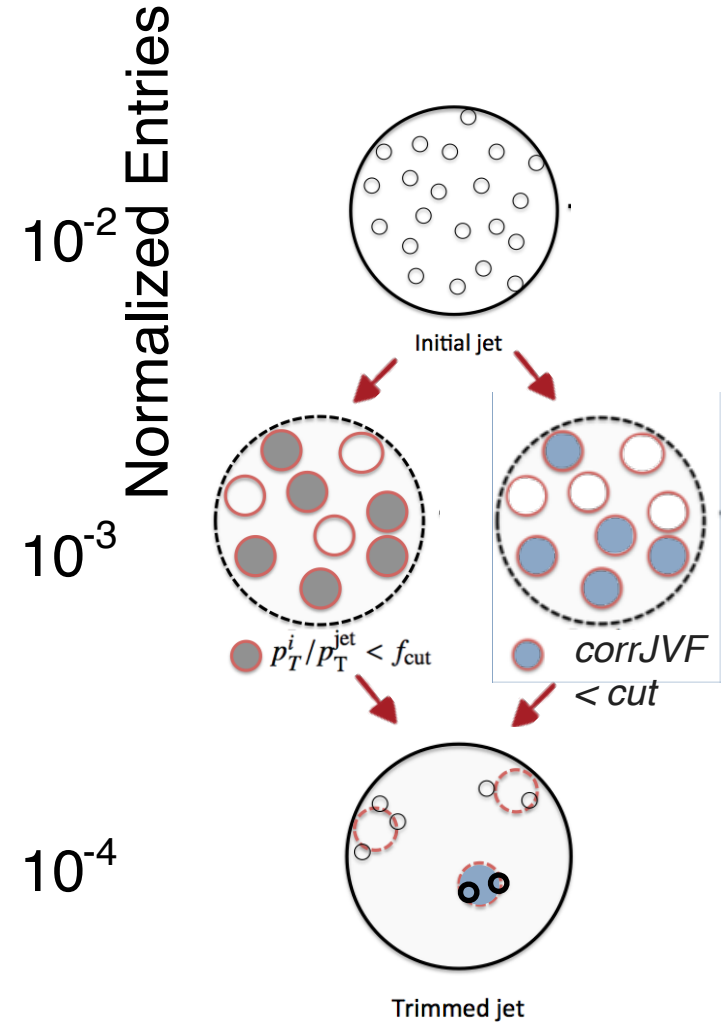
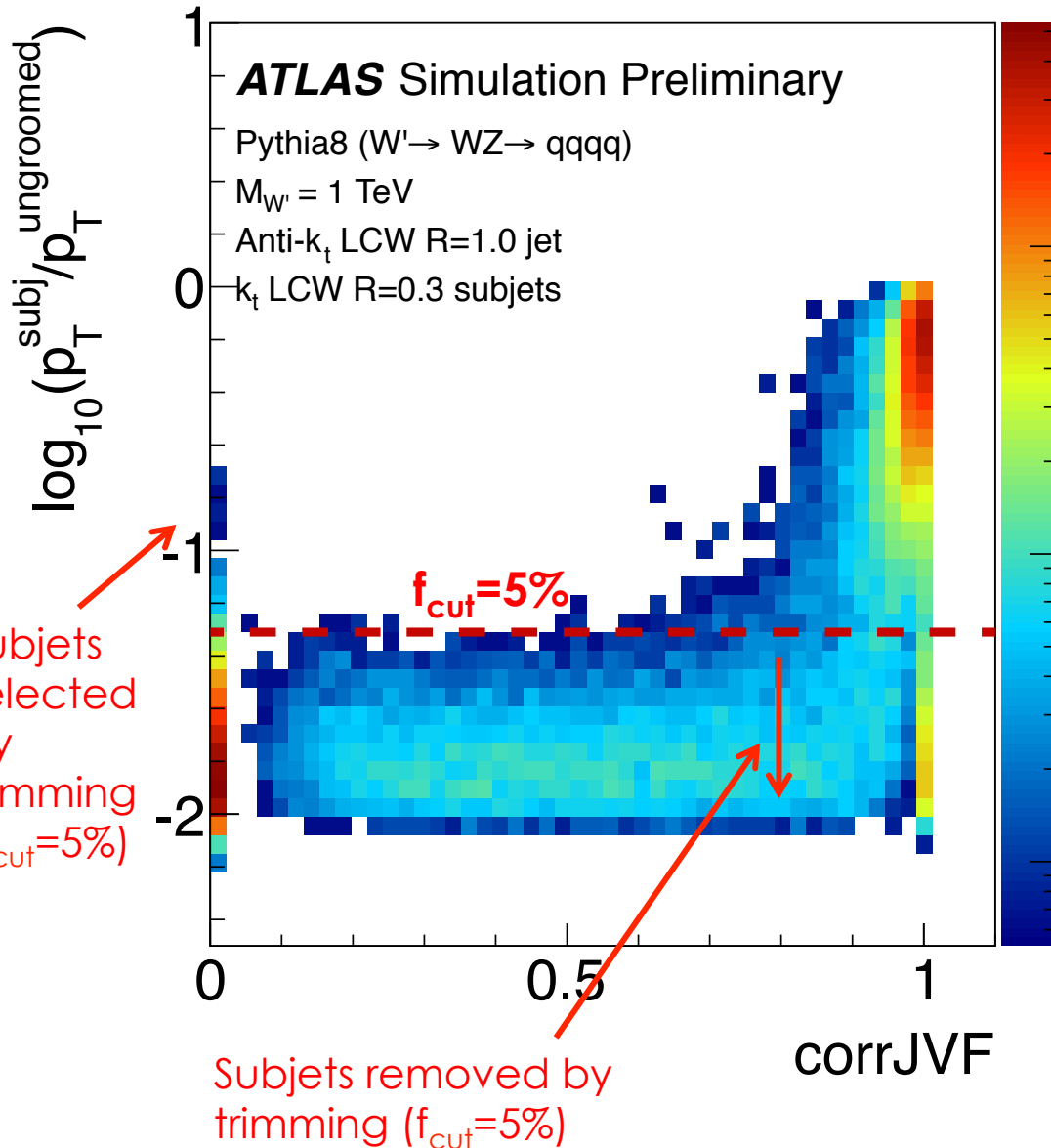
- **Trimming continues to work up to  $\mu = 200$** 
  - Jet mass distribution stable with  $\mu$  up to very high luminosity

# Track-based grooming

- Improve grooming techniques by extending JVT concept to large-R jets
  - Remove subjects based on track-vertex information



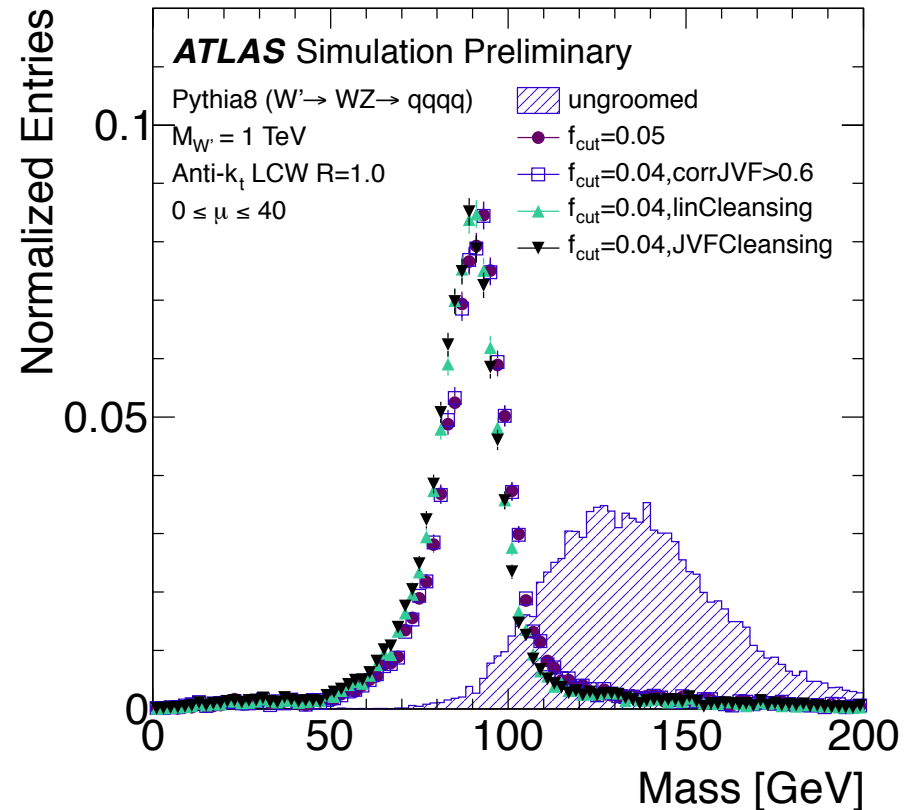
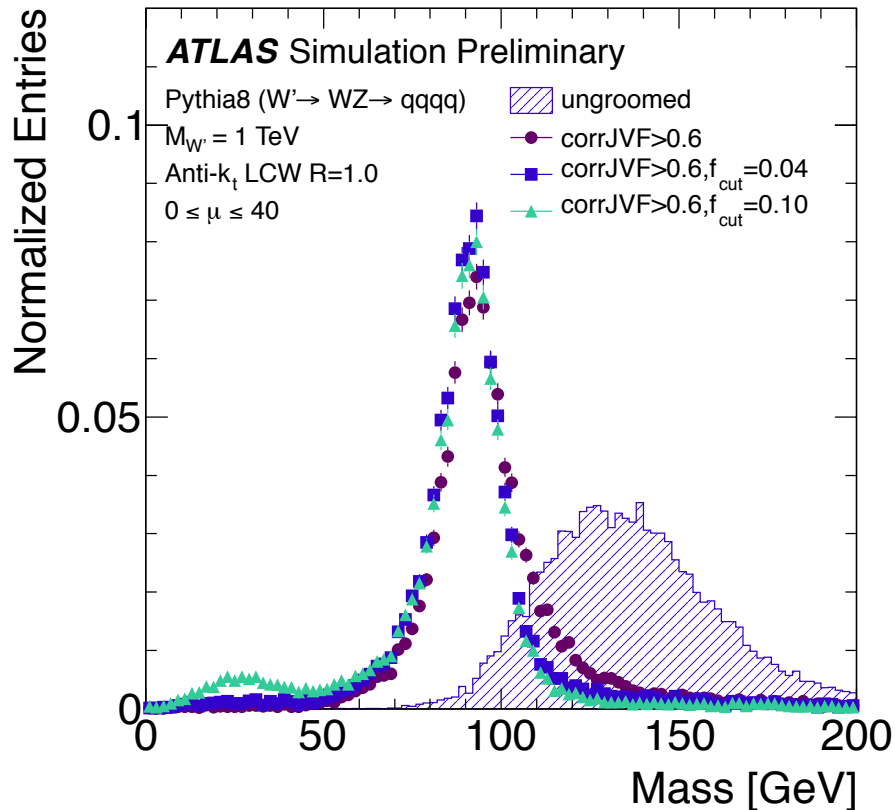
# CorrJVF Trimming





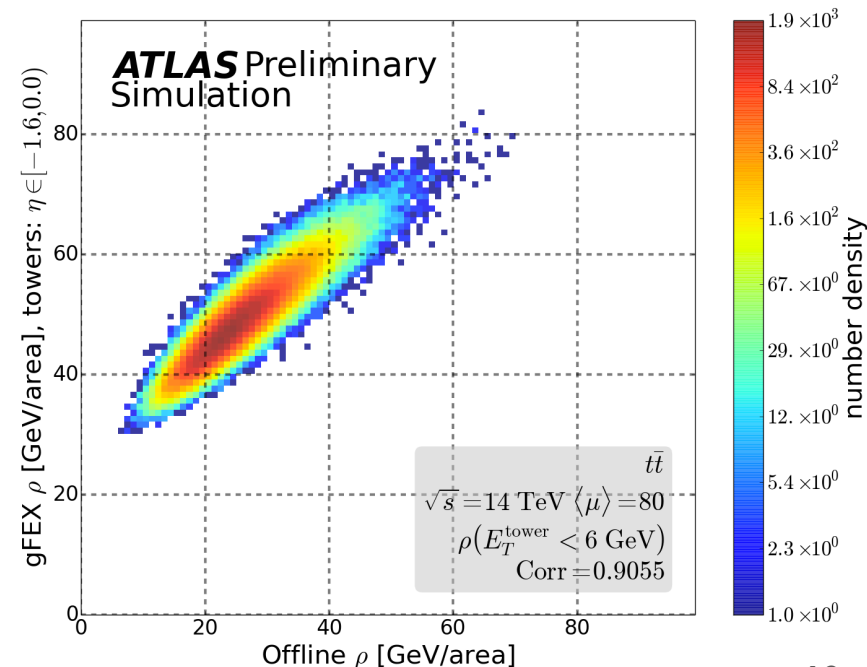
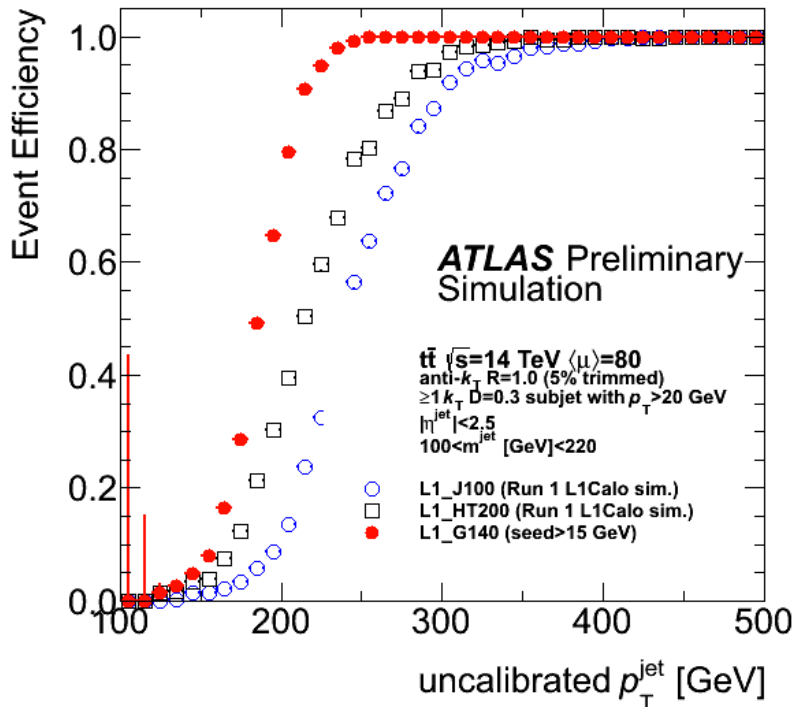
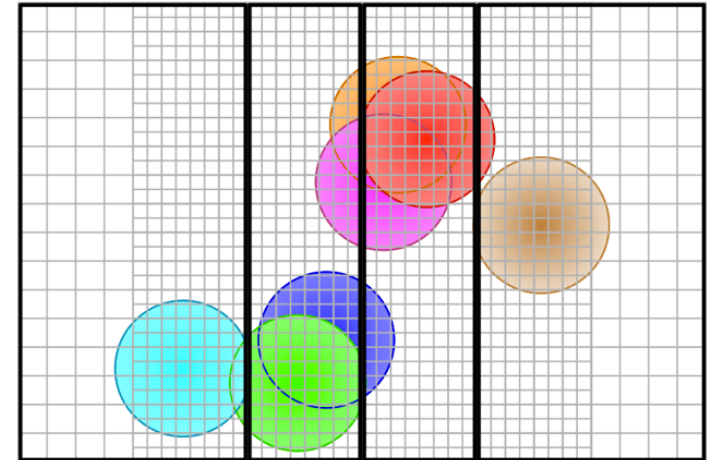
# Track grooming performance

- Best performance for  $\text{CorrJVf} > 0.6$  and  $f_{\text{cut}} = 4\%$ 
  - Similar performance than calorimeter-only trimming ( $f_{\text{cut}} = 5\%$ ) and linear cleansing (arXiv:1309.4777)



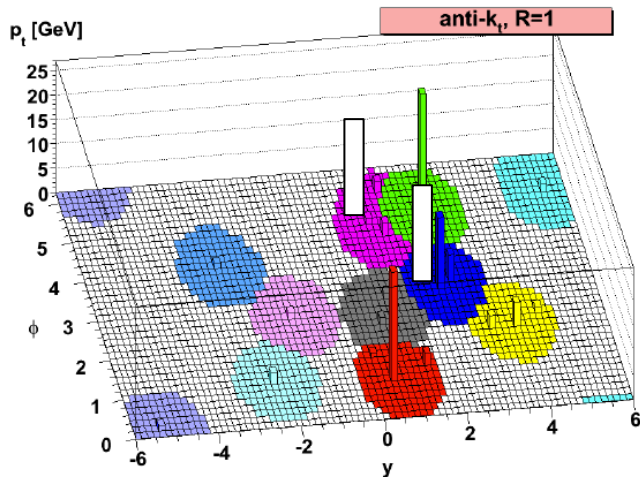
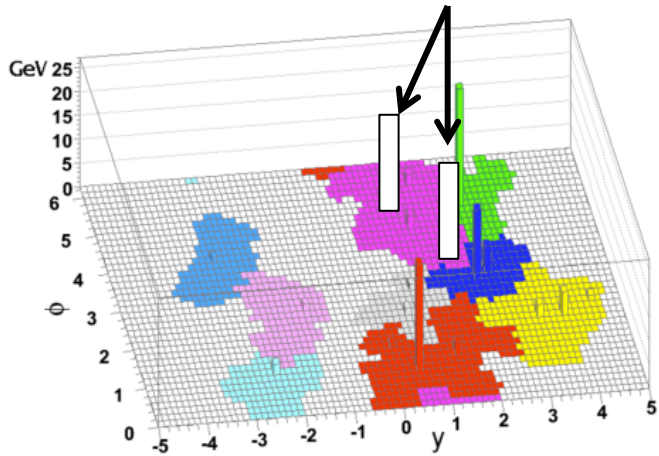
# Fat-Jet trigger L1 upgrade

- New large-R jet trigger at L1 for phase 1 upgrade based on global event information
  - Improved efficiency for jet substructure
  - Event-by-event pileup subtraction



# b-tagging

b-Hadrons

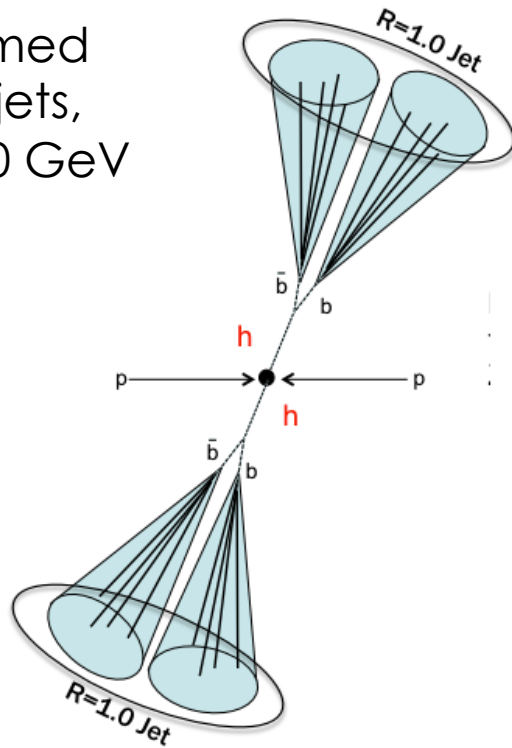


- Run 1 b-tagging algorithms are not optimal for jet algorithms and subsets of irregular shape
- **Developing more flexible b-tagging algorithms that can be more broadly applicable to different jet and subset algorithms, and boosted topologies:**
  - Improve the ability to resolve and b-tag heavy flavor jets from the decay of boosted heavy particles
  - **Track-jet b-tagging for b-Hadron tagging, independent of jet algorithms**

# Track-jet b-tagging

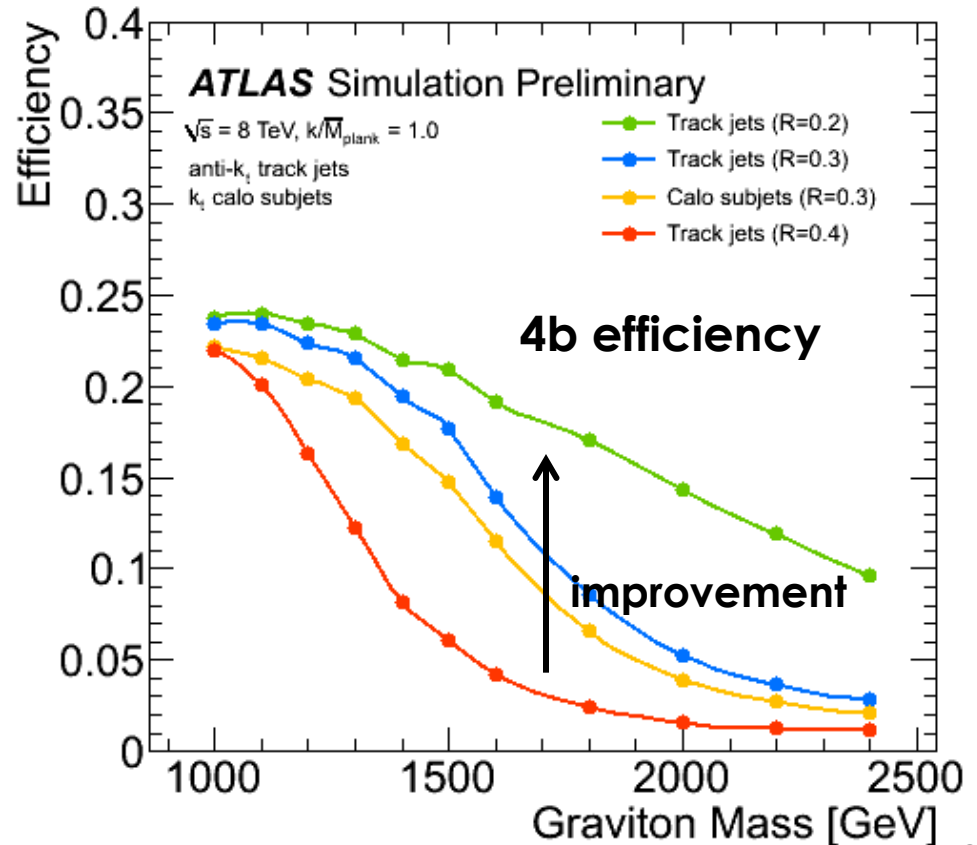
RSG  $\rightarrow hh \rightarrow bb bb$

2 trimmed  
R=1.0 jets,  
 $p_T > 200$  GeV



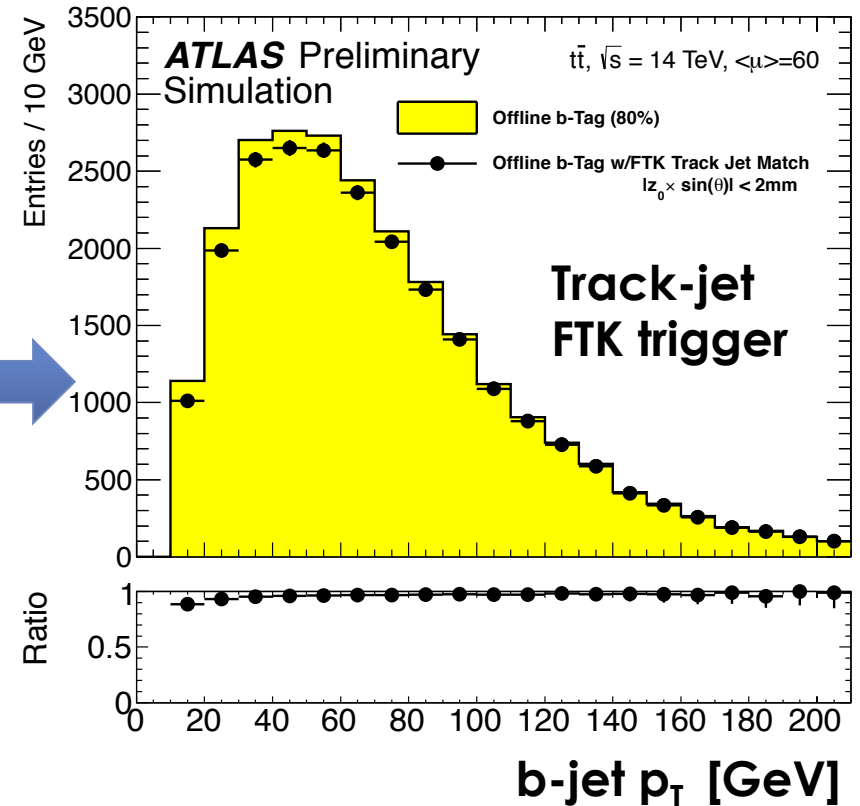
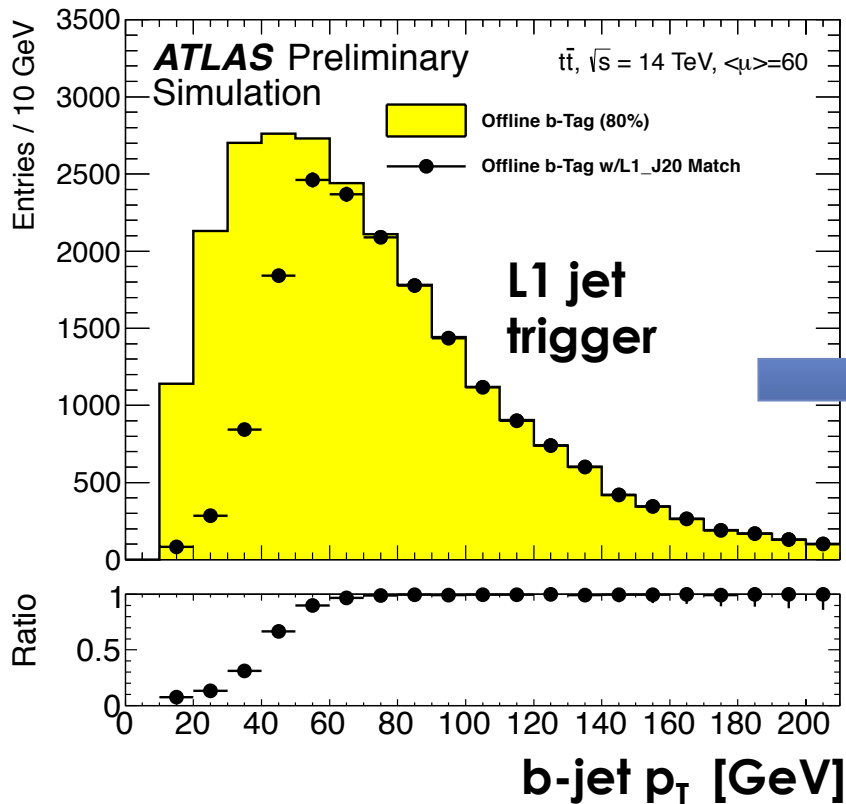
Technique independent of  
large-R jet and subjet  
reconstruction

- **R=0.2 track-jet b-tagging:**
  - Increased ability to tag close-by b-Hadrons
  - Increased efficiency to tag low  $p_T$  b-Hadrons (removed by trimming  $f_{cut}$ )



# Track-jet b-tag trigger upgrade

- FTK track-jet trigger increases the b-jet trigger efficiency at low jet  $p_T$

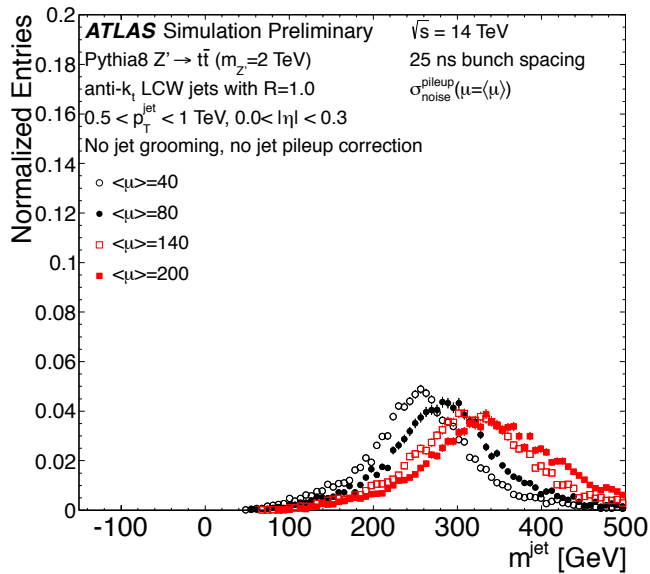


# Summary

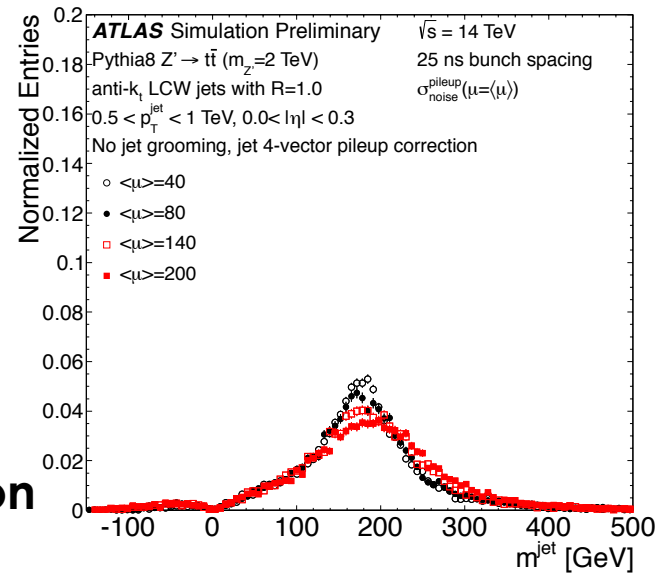
- **ATLAS Run 1 techniques for jet reconstruction and jet substructure continue to work well up to very high luminosity**
  - Topoclustering
  - Event-by-event pileup subtraction
  - Pileup jet suppression using jet-vertex tagging
  - Grooming
- **Performance limited by local fluctuations of pileup**
  - Several promising new ideas recently proposed can bring further improvements and are under investigation in ATLAS
- **Detector upgrades and further exploration of new ideas will lead to an improved jet substructure toolkit for Run 2 and beyond**
  - Pileup mitigation
  - b-tagging in boosted topologies
  - Trigger upgrades for boosted topologies and b-tagging

# Backup

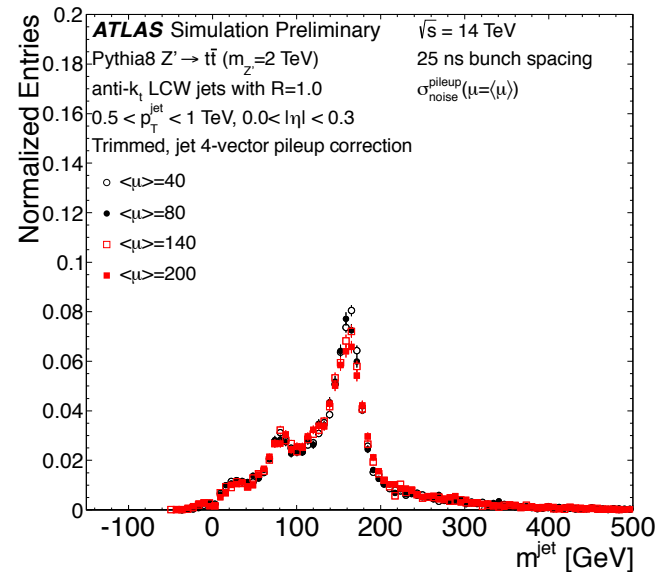
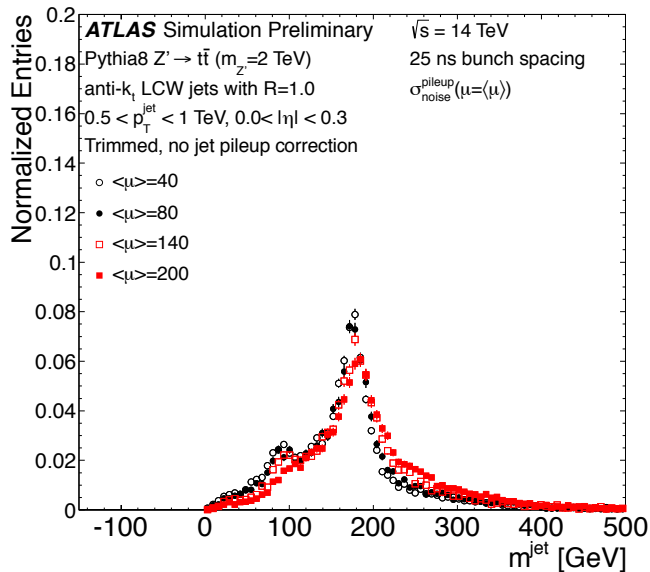
# Jet substructure (II)



**Pileup subtraction**



**grooming**



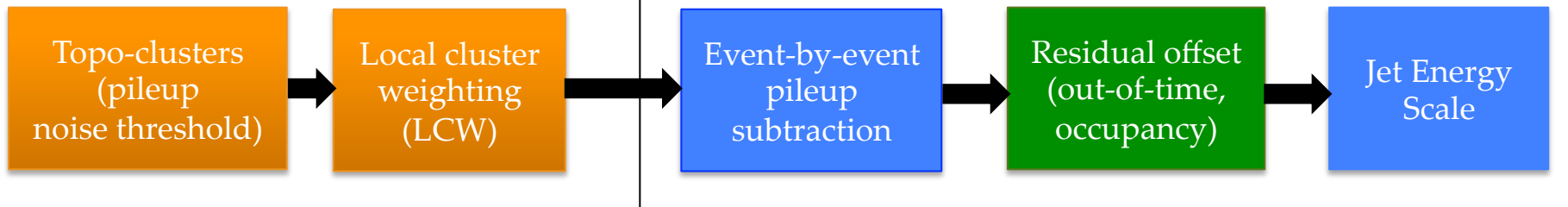
Trimming  
 $R_{kt}=0.3$   
 $f=5\%$



# Jet calibration

Jet energy scale

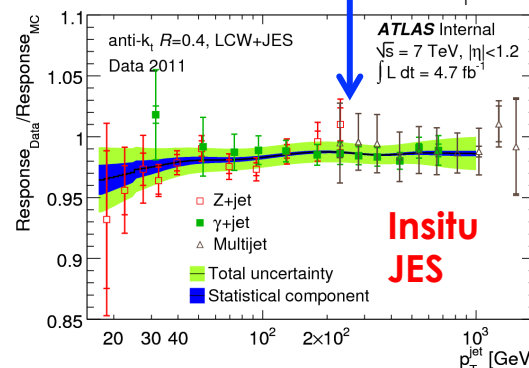
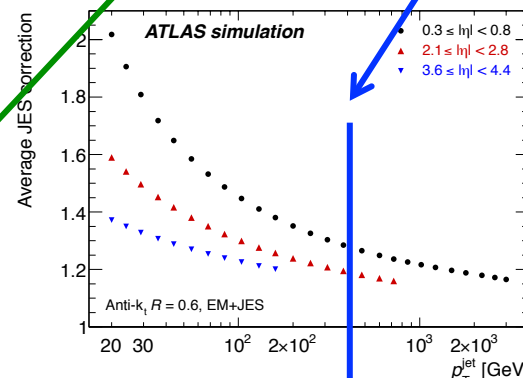
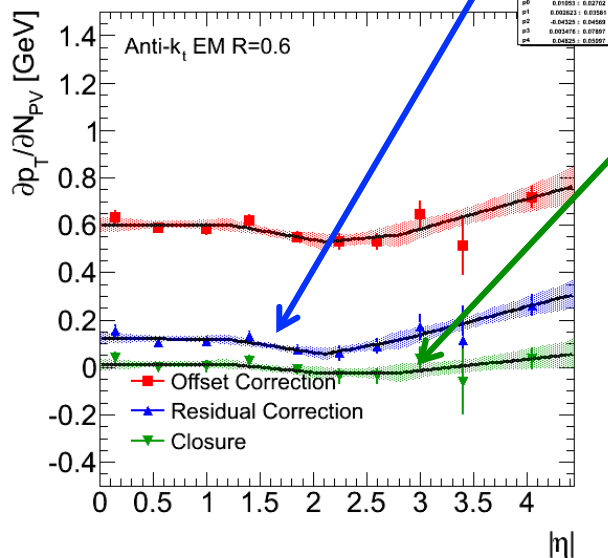
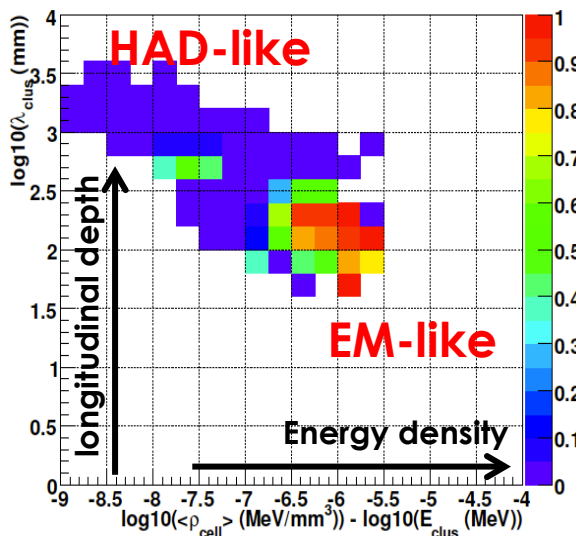
inputs



Pileup noise:  
 $\sigma(\mu)$

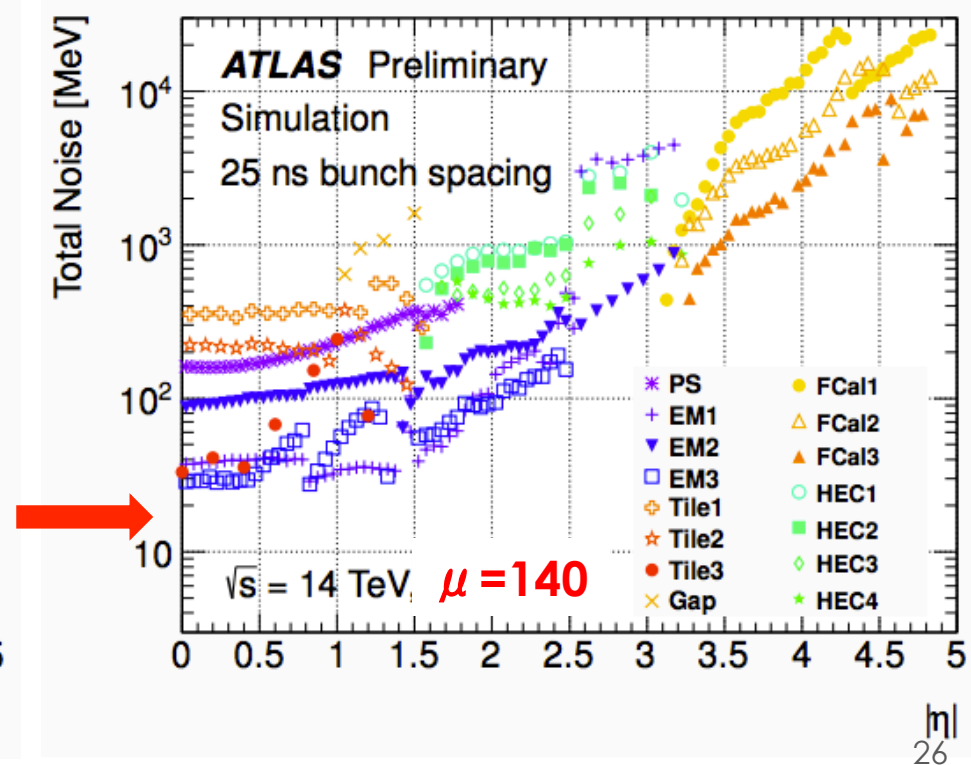
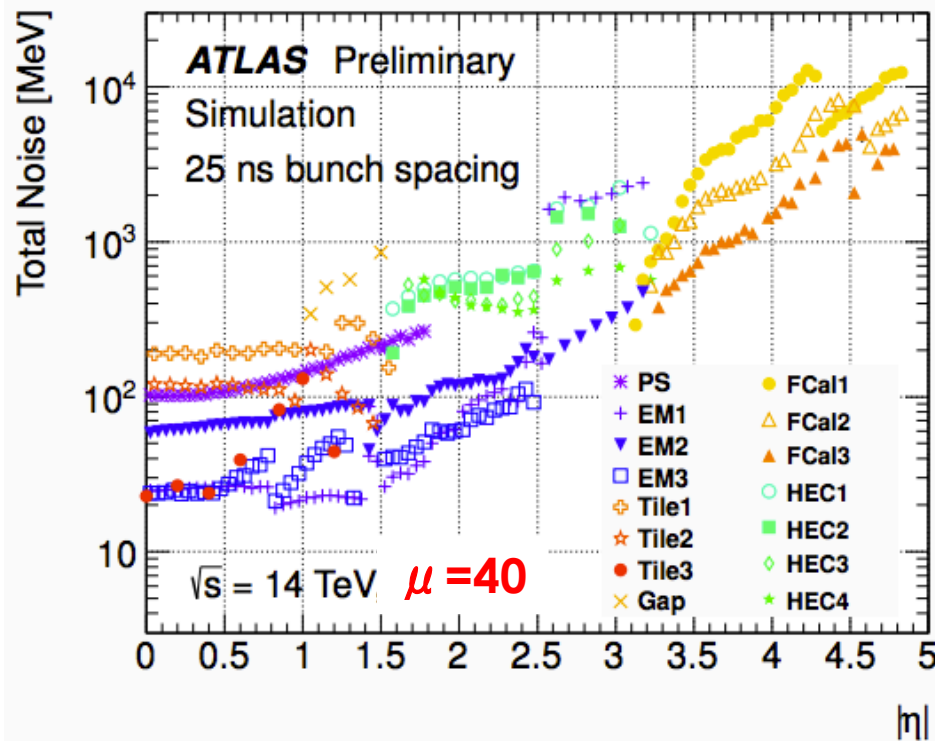
EM/HAD  
classification

$$p_T^{calib} = \left( p_T - \rho A - \alpha(N_{PV} - 1) - \beta \langle \mu \rangle \right) \times JES$$

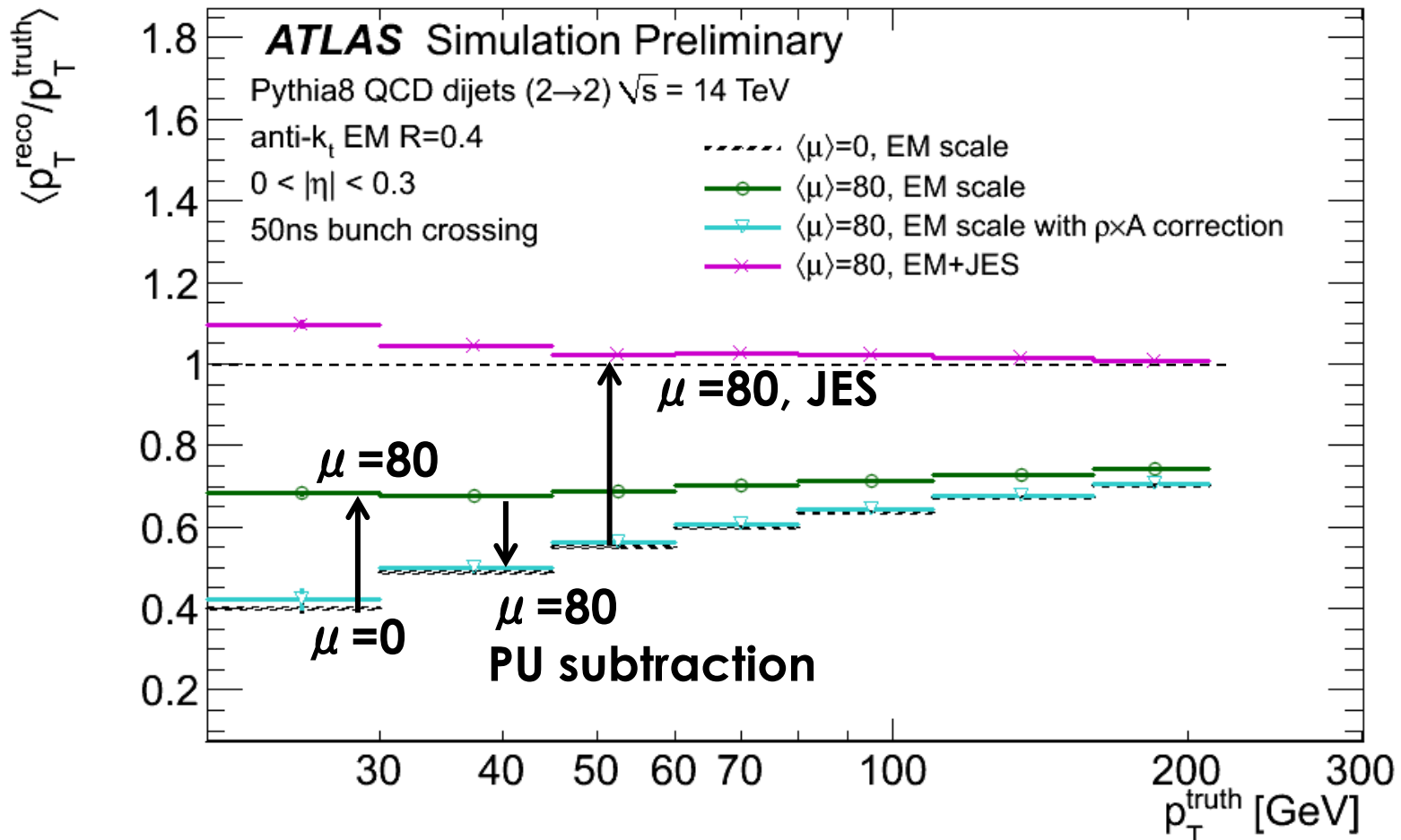


# Topo-clustering at high luminosity

- Adjust  $\sigma$  pileup noise for each  $\mu$  configuration
- Optimization of local calibration for EM/HAD cluster classification for each pileup noise value
  - Derived from single pion simulation with  $\mu = 0$  and  $\sigma (\mu > 0)$



# Jet energy scale

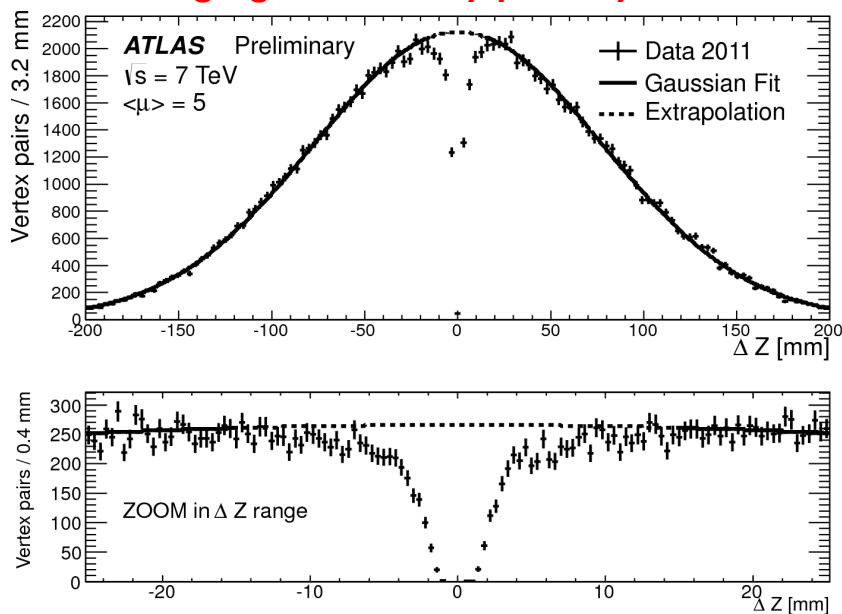


- Pileup subtraction restores the jet response to that of the jets with  $\mu=0$
- Jet energy scale restores the response to unity
- **Jet calibration scheme continues to work at high luminosity**

# Experimental challenges

- **Vertex shadowing at high luminosity can limit the ability to separate pileup particles close to the hard-scatter vertex:**
  - Limited by detector resolution, vertex reconstruction algorithm, and density of interactions (beam spot longitudinal profile)

**Merging of close-by primary vertices**



**Vertex masking at high luminosity**

