Jet Reconstruction and Calibration at High Luminosity at ATLAS

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Boost 2012 – Jet Substructure Performance

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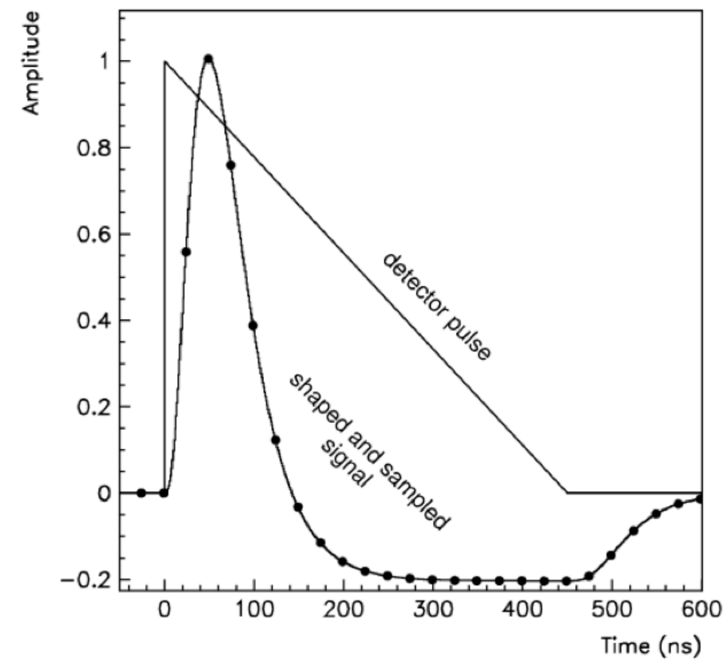
Pile-up at ATLAS

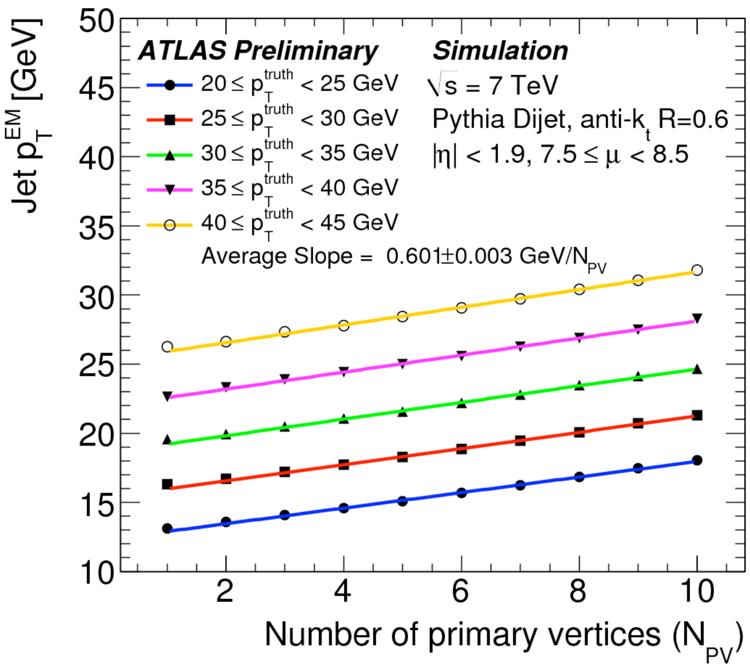
- **In-time pile-up: additional interactions in the same bunch crossing**
  - Directly related to the number of reconstructed primary vertices (N_{PV})
  - Generally adds energy by *contributing additional* topo-clusters
  - Significant global and local fluctuations not described by N_{PV}

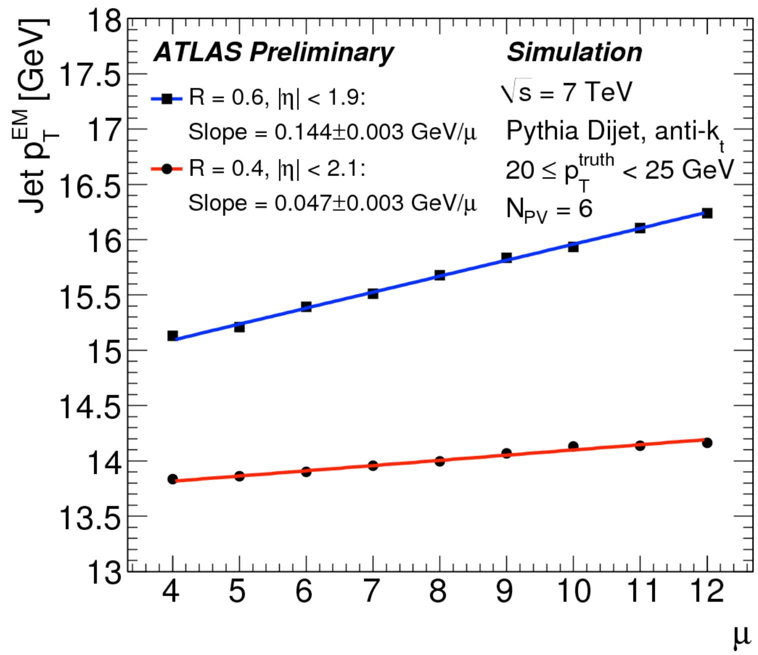
- **Out-of-time pile-up: several preceding bunch crossings contribute to the calorimeter signal**
  - LAr signal shape spans approximately 600 ns with a long negative tail
  - Generally subtracts energy from *pre-existing* topo-clusters
  - We use the instantaneous luminosity to obtain an estimate of the out-of-time activity: $\langle\mu\rangle = L_{inst} \times \sigma_{inel}/(N_{bunch} \times f_{LHC})$



An Average Offset Correction

$$\langle \Delta p_T \rangle = \alpha \times (N_{PV} - 1) + \beta \times \langle \mu \rangle$$

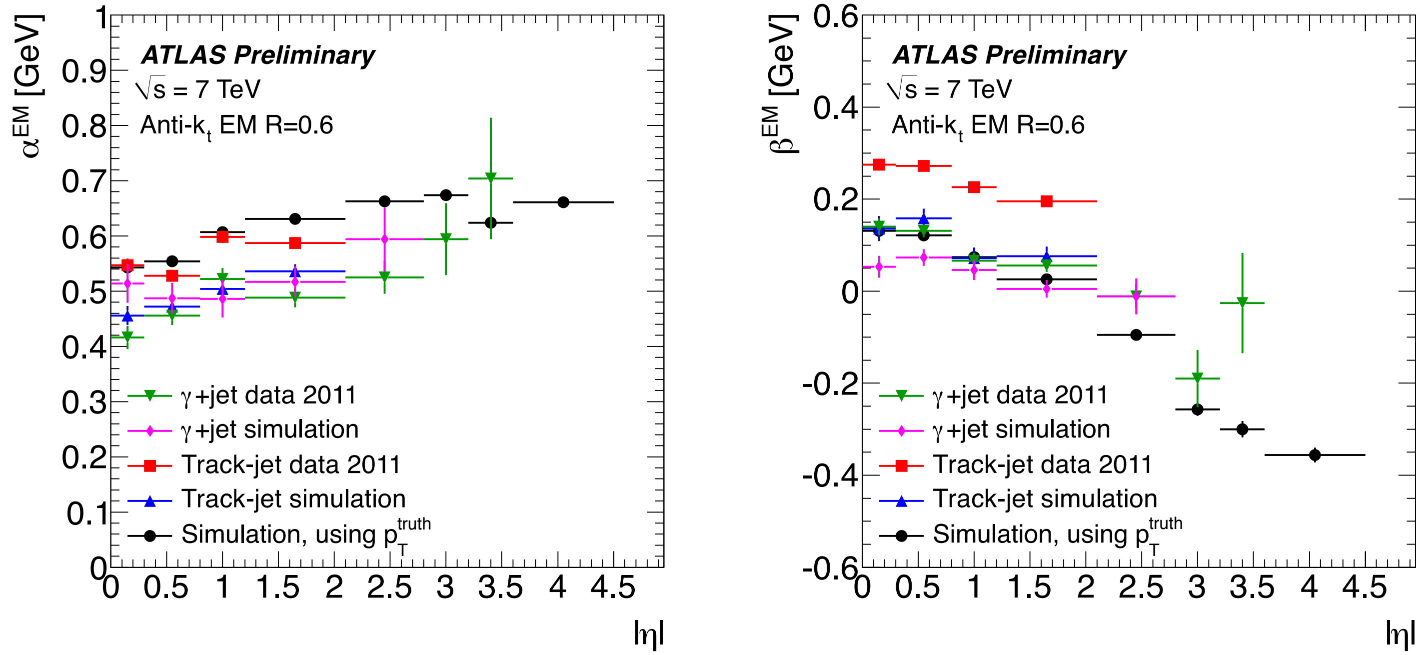




- Coefficients α and β are partial derivatives of the uncalibrated jet p_T with respect to N_{PV} and <μ>, dependent on jet type and |η|
- Correction is derived in MC and validated using track jets and γ+jet

Offset Dependence on Jet |η|

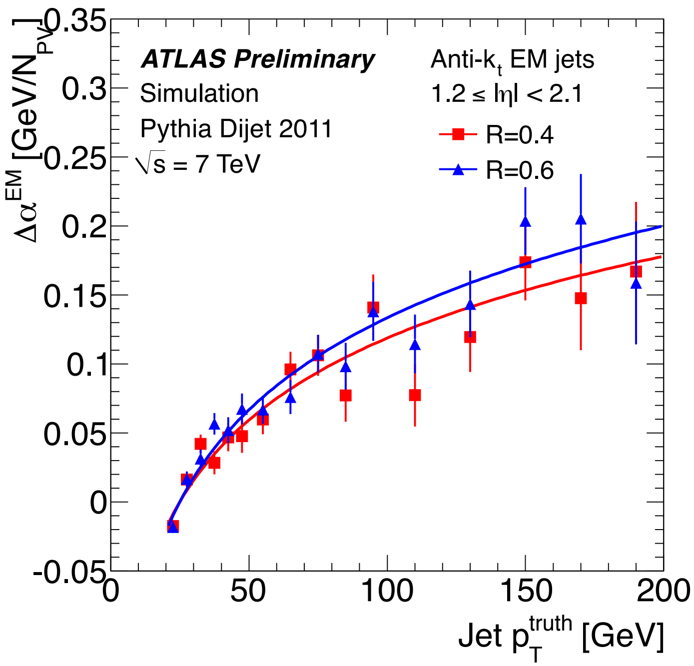
$$\langle \Delta p_T \rangle = \alpha \times (N_{PV} - 1) + \beta \times \langle \mu \rangle$$

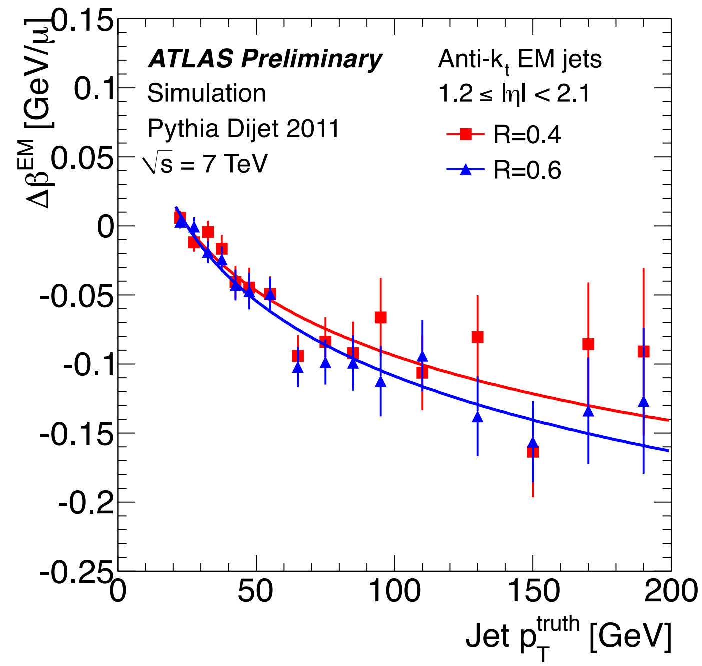


- Small but significant dependence on |η| for in-time term
- Sensitivity to out-of-time pile-up is highly |η|-dependent, due to varying granularity and signal shape, as well as occupancy and cluster size

Offset Dependence on Jet p_T

$$\langle \Delta p_T \rangle = \alpha \times (N_{PV} - 1) + \beta \times \langle \mu \rangle$$

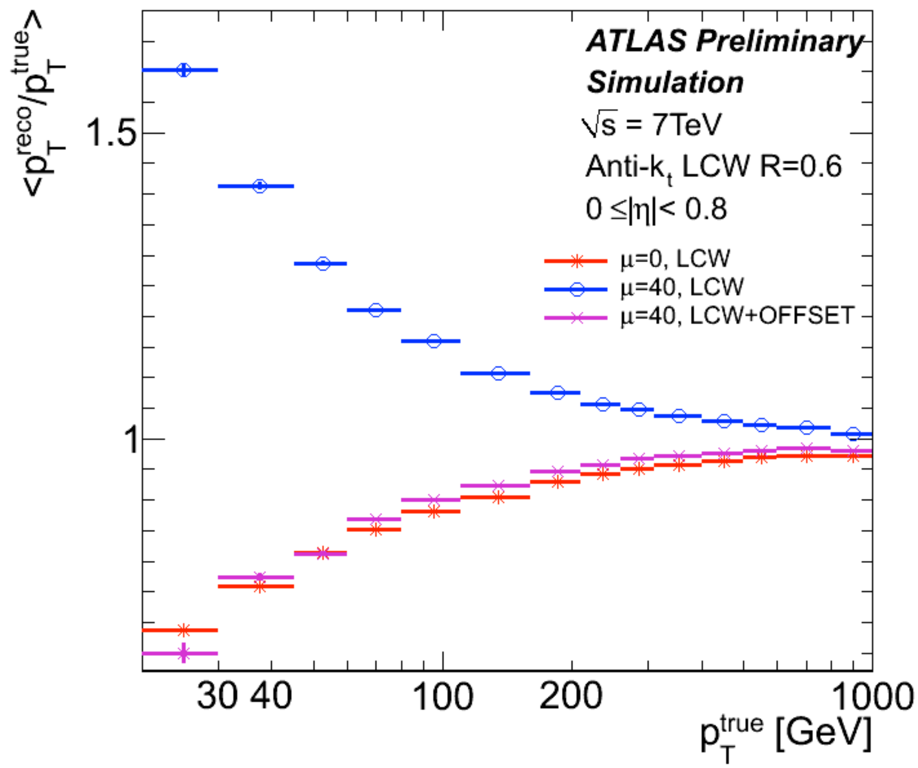




- Pile-up offset initially expected to be independent of jet p_T: contributions from pile-up are not directly related to the hard jet
- *Sensitivity* to pile-up is related to occupancy in the jet core, which depends on jet p_T (more deposits above the noise threshold)

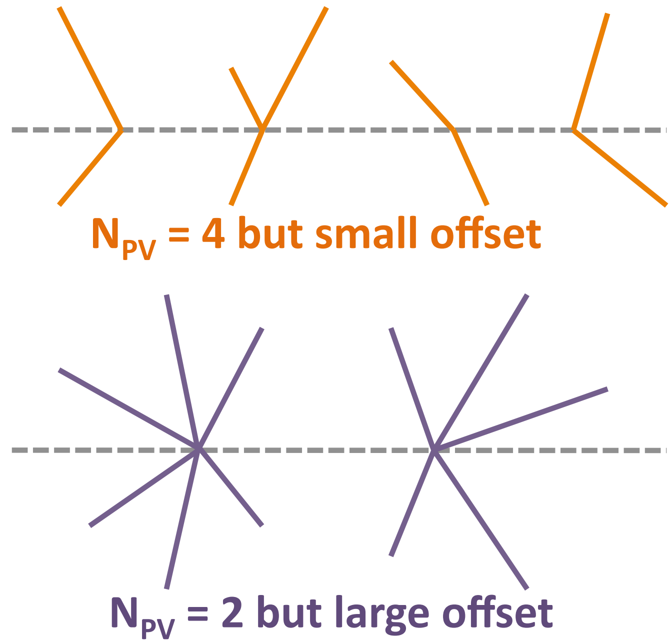
Effect of the Offset Correction

- With no pile-up correction, **average jet response is time-dependent**: pile-up conditions vary with time
- The average offset correction restores the jet response to what we expect in the absence of pile-up (μ = 0)
- Subsequent response corrections are thus allowed to be time-independent



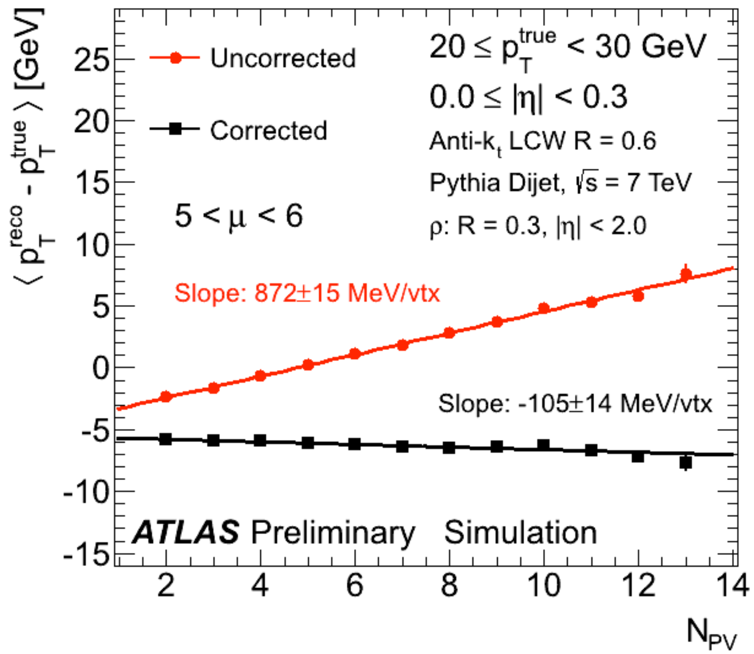
A More Sophisticated Correction

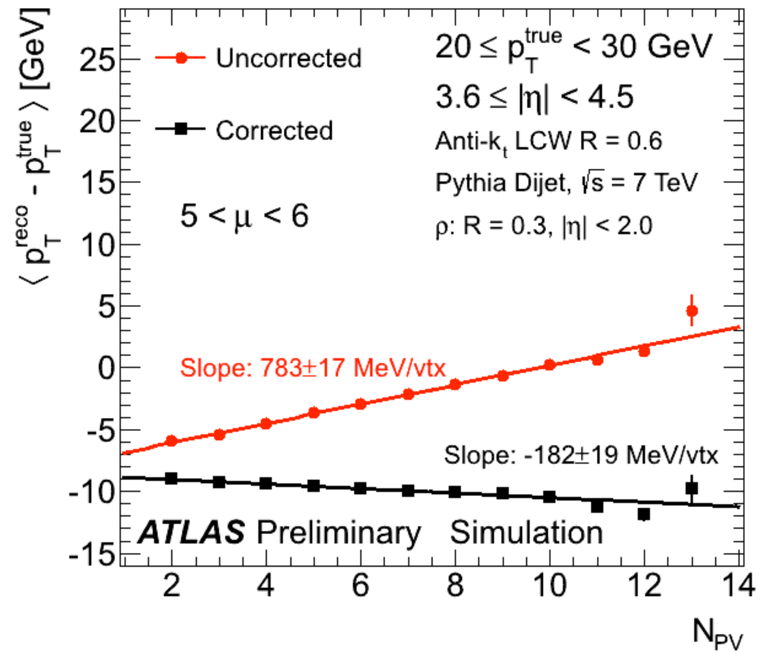
- **<μ> and N_{PV} are *at best* indirect indicators of pile-up activity**
  - ➢ <μ> is an average over *$O(10^9)$* bunch crossings, so it cannot describe fluctuations in out-of-time pile-up
  - ➢ Large fluctuations in the offset for any given number of pile-up interactions
  - ➢ N_{PV} sensitive to vertex reconstruction inefficiencies



- **The "jet areas" correction technique addresses all of these issues**
  - ➢ Obtain a direct estimate of in-time *and out-of-time* pile-up activity from low-p_T calorimeter deposits: **ρ = median(p_T/area) of R = 0.3 k_t jets, $|\eta| < 2.0$**
  - ➢ Take into account variations in jet catchment area: **$p_T^{corr} = p_T - \rho \times \text{area}$**
  - ➢ Ideally, a single correction applicable to all jet definitions, *including subjets!*

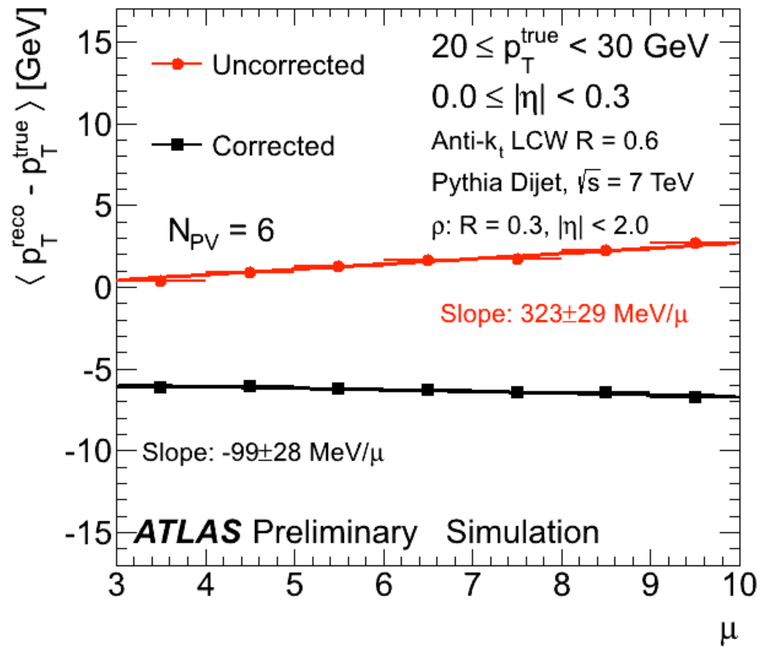
Jet Areas Correction: In-time Pile-up

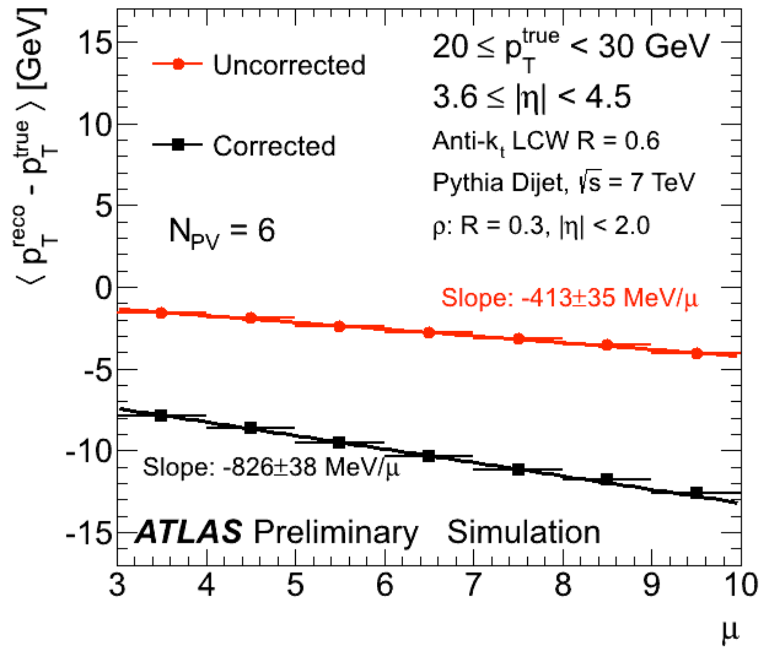




- Jet areas correction performs well in both central and forward regions: sensitivity to in-time pile-up is roughly constant in $|\eta|$
- Small overcorrection: ρ calculated from very low p_T R=0.3 k_t jets, applied to 20 GeV R=0.6 anti-k_t

Jet Areas Correction: Out-of-time Pile-up



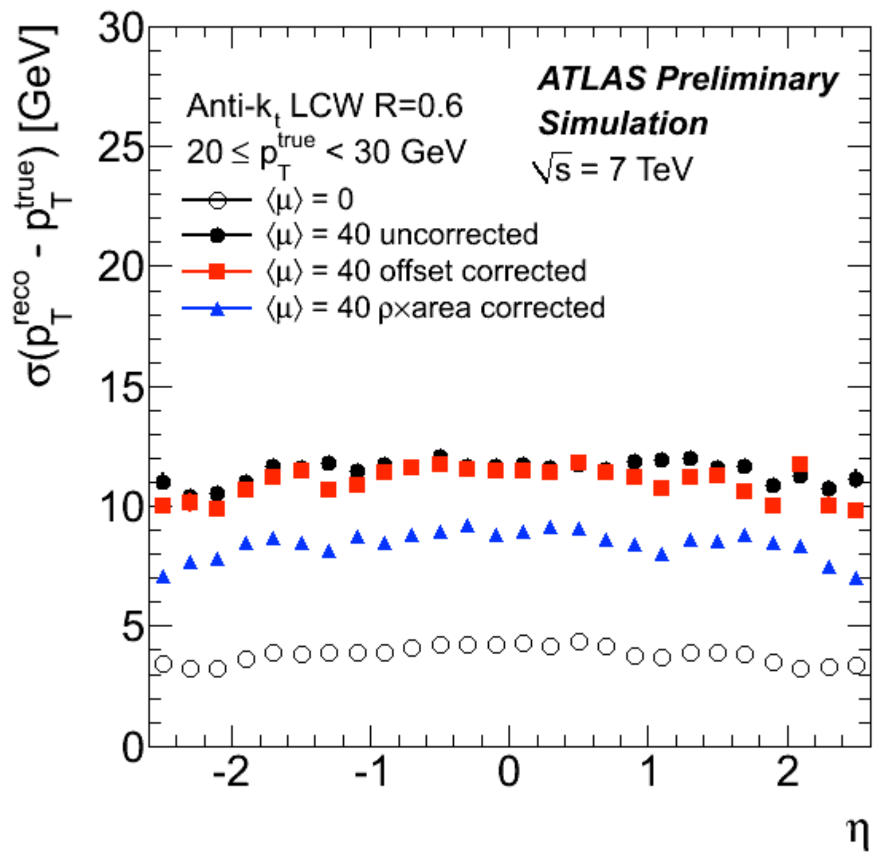


- Jet areas correction performs well against out-of-time pile-up for central jets, *but not for forward jets*
- Sensitivity to out-of-time pile-up is strongly η-dependent, but ρ is determined from clusters in |η| < 2
- A residual (η, μ)-dependent correction is under development

Pile-up Fluctuations and Jet Resolution

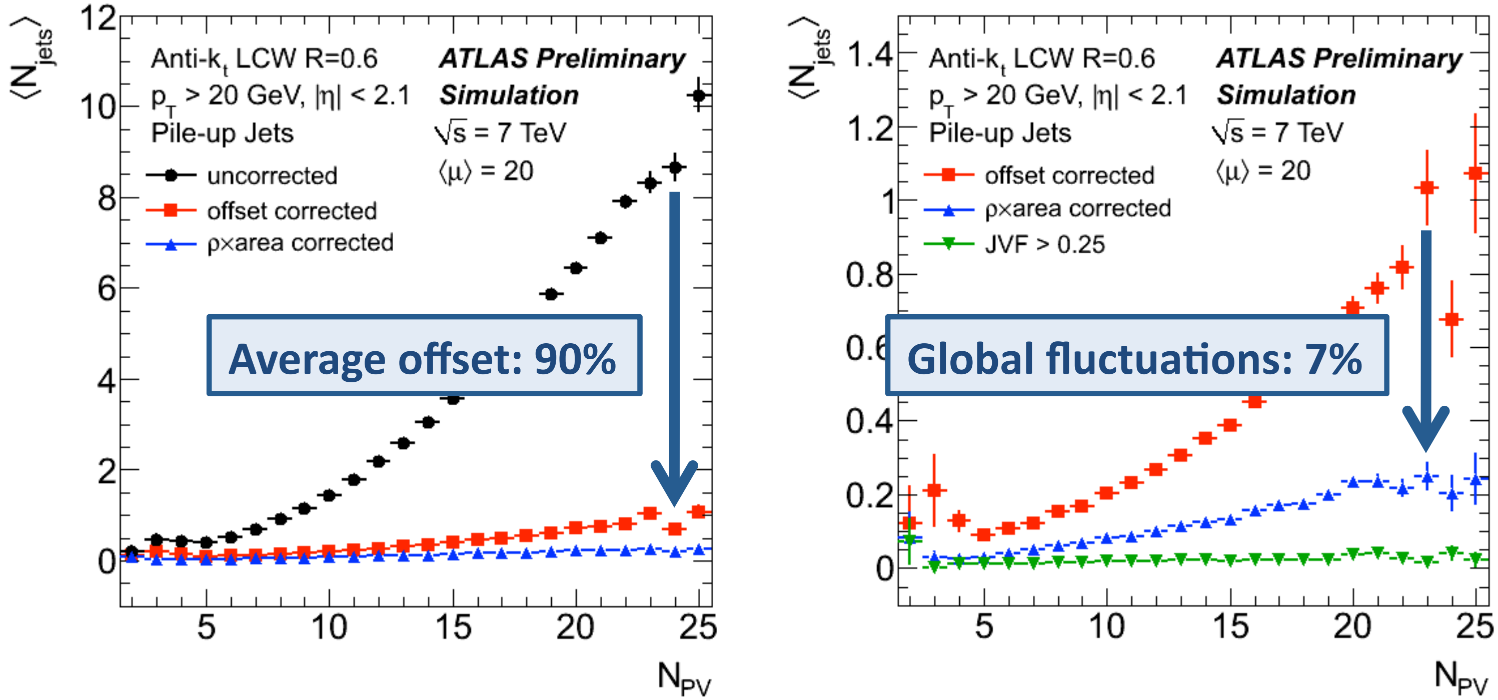
Pile-up induced offset in a random cone: $\Delta p_T = \langle \Delta p_T \rangle \pm \sigma_{global} \pm \sigma_{local}$

- Global and local pile-up fluctuations lead to a large degradation in resolution
- Average offset correction does not account for these fluctuations
- **Jet areas correction recovers 30-40% of the degradation**
- Remaining 60-70% due to localized fluctuations that may be captured with tracking information



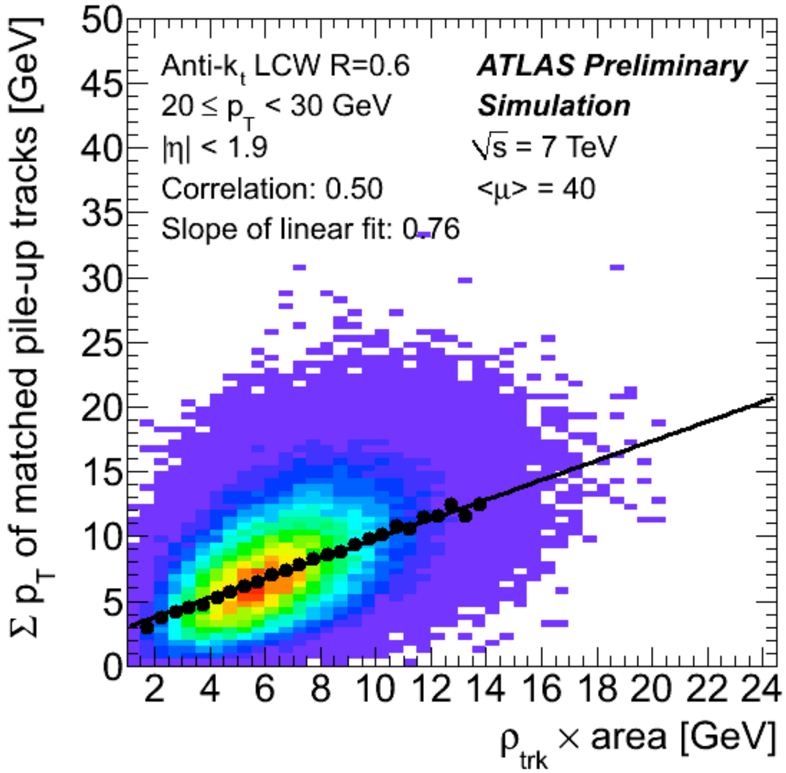
Pile-up Jets: Multiplicity

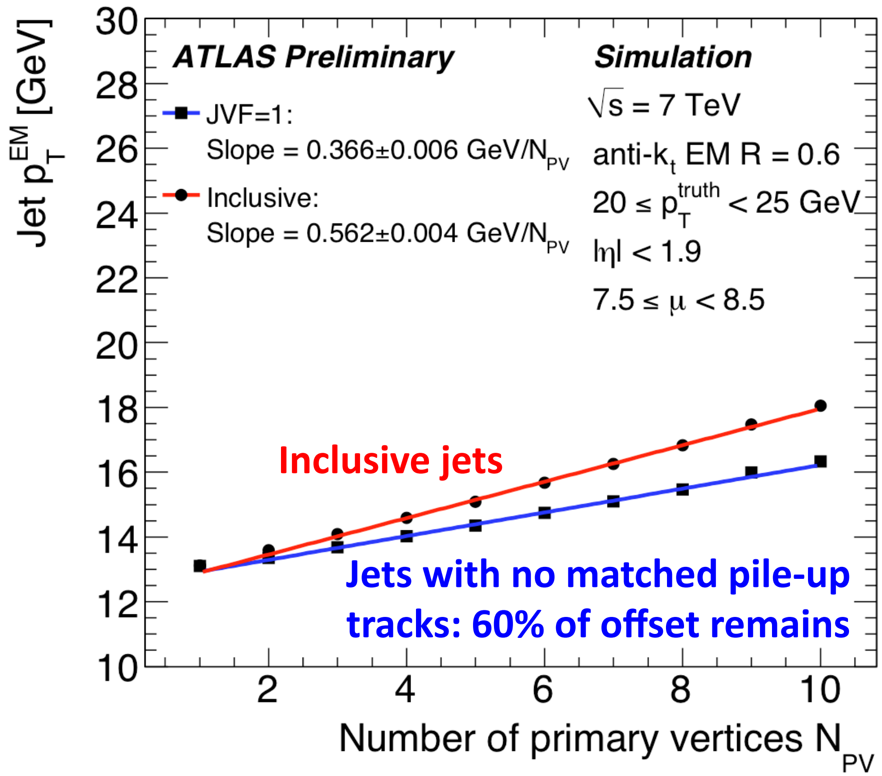
Pile-up induced offset in a random cone: $\Delta p_T = \langle \Delta p_T \rangle \pm \sigma_{global} \pm \sigma_{local}$



- Global pile-up corrections eliminate up to 97% of "pile-up jets"
- Remaining 3% due to localized fluctuations
- Reject nearly all pile-up jets with the **jet vertex fraction (JVF)**: fraction of matched track p_T compatible with the hard scatter

Local Fluctuations and Tracks





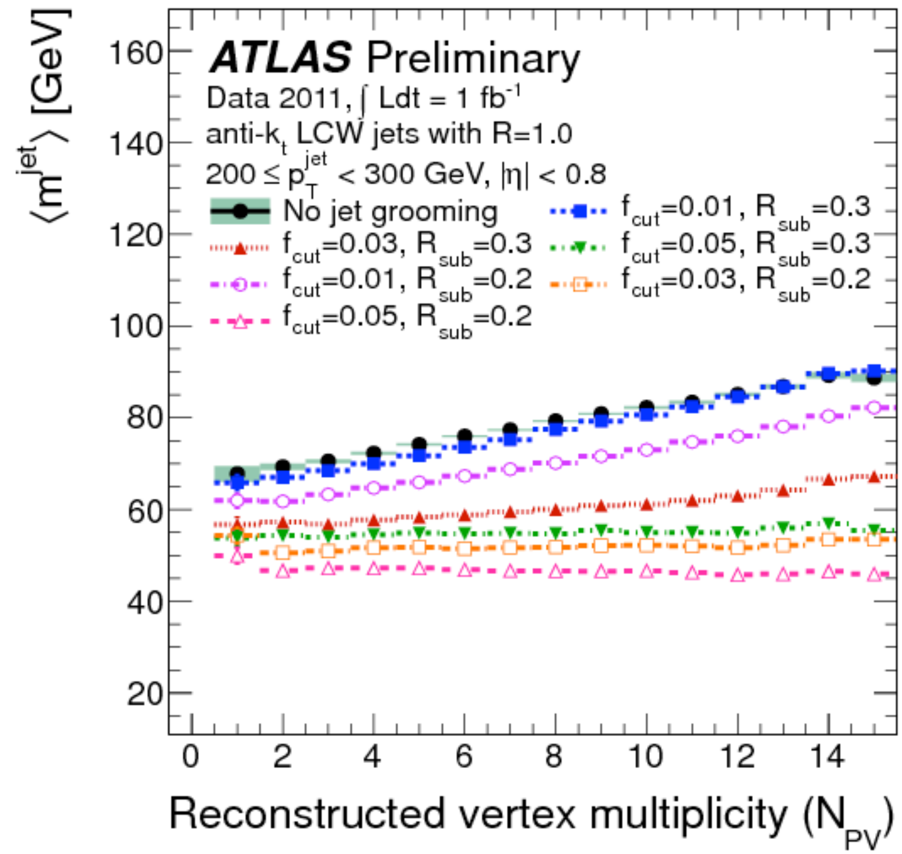
- By matching tracks to jets, we can assess the impact of pile-up on a jet-by-jet basis
- Fluctuations are similar in size to the expectation from global pile-up activity
- However, **tracks describe only 40% of the pile-up offset**
- Work is ongoing to understand the potential of tracks to address local fluctuations

Local Fluctuations Without Tracks

- Tracking information is only available for $|\eta| < 2.5$, but forward jets are important for many analyses (e.g. VBF Higgs)
- **Given a forward jet, how to classify it as hard-scatter or pile-up?**
- Pile-up jets are generally random combinations of particles from several interactions
- As compared to a hard-scatter QCD jet, **pile-up jets should be wider, with no prominent core**
- **Calorimeter-based substructure should be very useful!**
  - ➢ Width, prominence of leading subjet…
  - ➢ Response to grooming procedure (both ΔR and p_T)
  - ➢ Angular structure function (ASF)
  - ➢ Ideas from image processing…

Relevance to Boosted Object Analyses

- Trimming at 5% (R_{sub} = 0.3) is necessary for 200 GeV jets at N_{PV} = 15
- At higher levels of pile-up *(up to N_{PV} = 30 already in 2012)*, we should expect that 5% may be insufficient
- **An elegant solution: apply a pile-up correction (jet areas, track-based) to subjets *before trimming***
  - ➢ "Automatically" correct the jet shape, including mass
  - ➢ Loosen trimming parameter?



Summary and Conclusions

- **In the past year, there has been significant progress in understanding the effects of pile-up on jets in ATLAS**
  - Commissioning of an average offset correction that accounts for both in-time and out-of-time pile-up
  - Development of a "jet areas" correction technique that accounts for global fluctuations in pile-up
  - Preliminary understanding of both global and local pile-up fluctuations, as well as the interplay between pile-up and noise suppression
- **Moving forward, there's still much left to do:**
  - Commission the jet areas correction, with specific attention to issues in the forward region
  - Develop track-based corrections/classifiers for local pile-up fluctuations
  - Explore the use of substructure to reject pile-up jets
  - Test these correction techniques in the context of substructure analyses