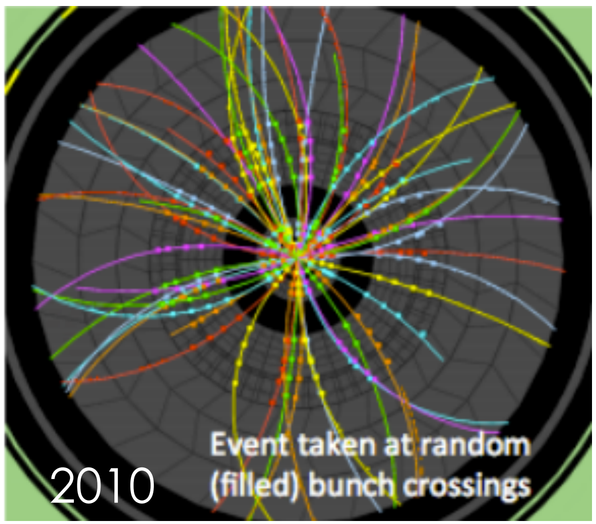
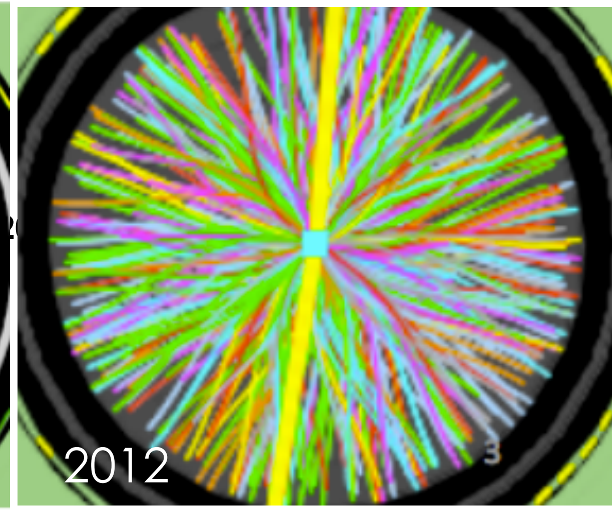
ATLAS Jet and Missing ET Performance Under HL-LHC Conditions





Ariel Schwartzman
SLAC

Snowmass Meeting
03-Aug-2013

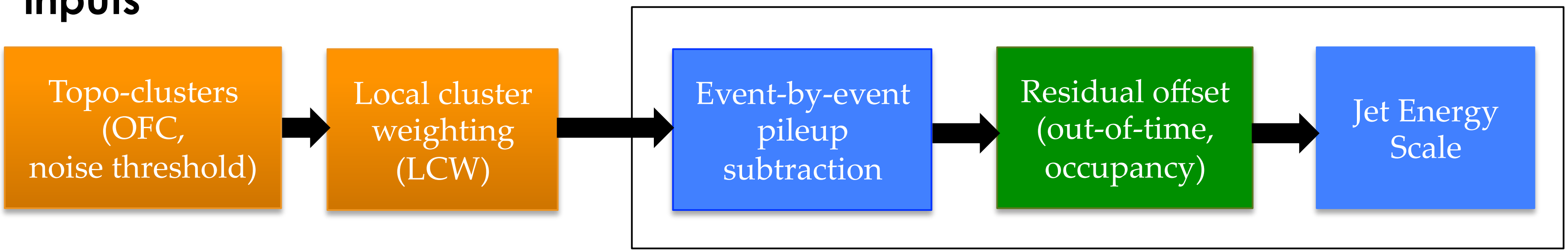
Outline

- **Overview of jet reconstruction and calibration at ATLAS**
  - Signal formation and pileup noise
- **Pileup subtraction**
  - Effect of pileup noise
- **Jet energy scale and resolution**
  - Noise term
- **Pileup jets**
- **Jet substructure**
- **Missing ET**

Jet calibration

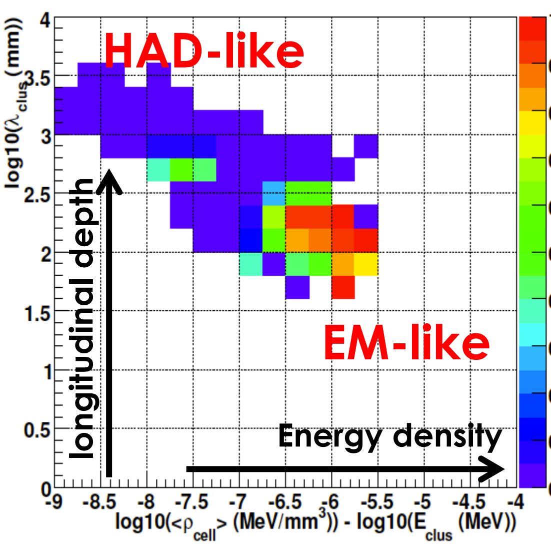
inputs

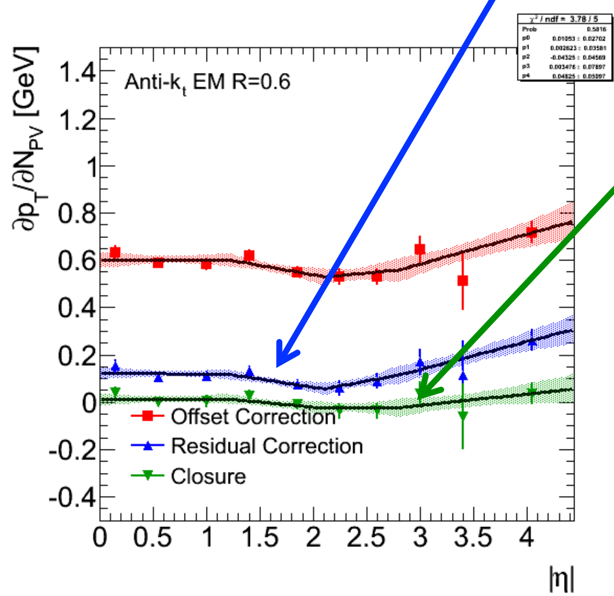
Jet energy scale

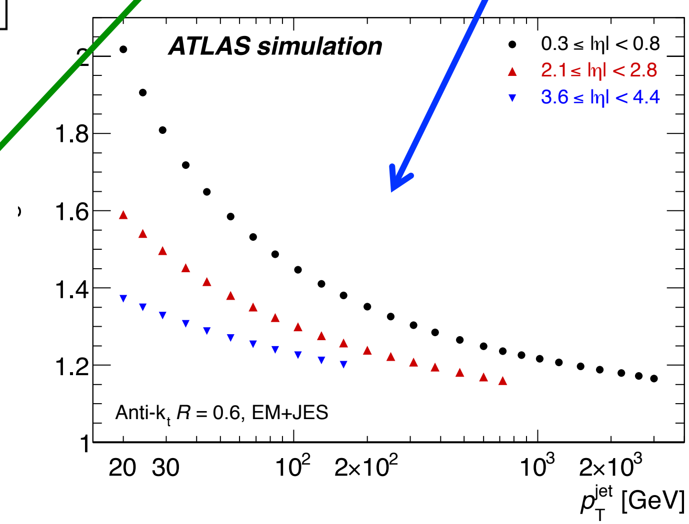


Noise
Cluster splitting/merging
EM/HAD classification
Negative energy treatment

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



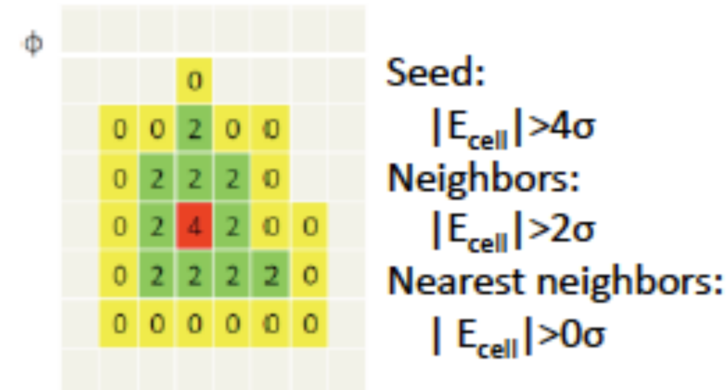


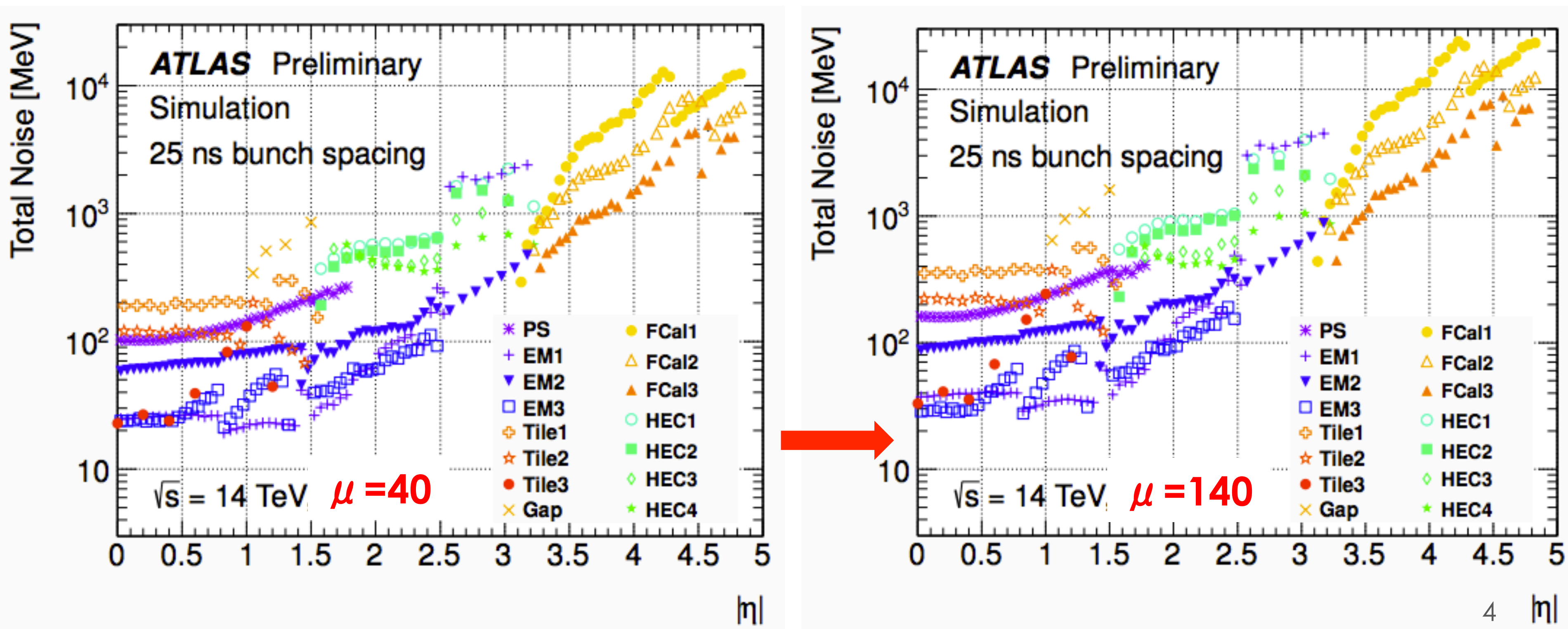


<u>**Jet performance studies require a complete calibration chain:**</u>
noise thresholds, LCW, pileup subtraction, and energy scale

Topological clusters

- Follow shower development
- Electronic + **pileup noise suppression**
- **EM/HAD local calibration** to correct for calorimeter non-compensation, energy losses in dead material, and out-of-cluster energy
  - **Derived from single pion simulation**





High luminosity scan

50ns

MU\σ	30	40	60	80	100	140	200
0	X	x	x	x	x	x	x
40		X					
60			X				
80	x	x	x	X	x	x	
140						X	
200							X

25ns

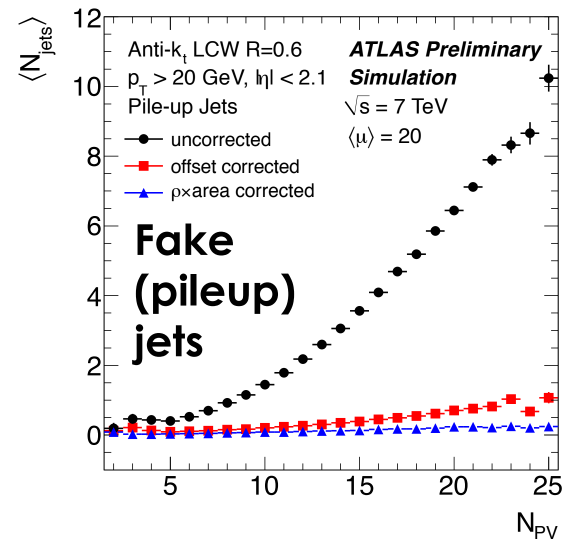
MU\σ	30	40	60	80	100	140	200
0	X	x	x	x	x	x	x
40	x	X	x	x			
60	x	x	X	x	x		
80			x	X	x		
140					x	X	x
200						x	X

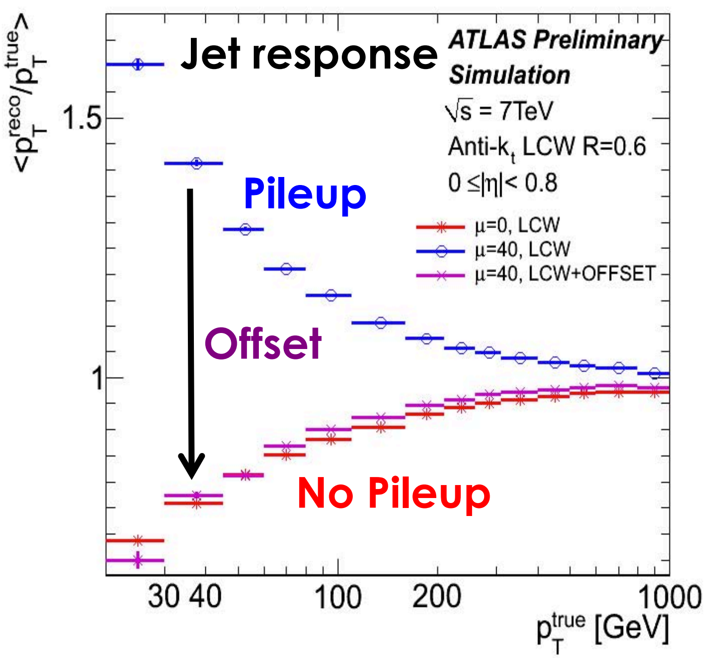
- **Production of dedicated datasets at several mu and pileup noise values (sigma)**
  - Optimized calorimeter signal reconstruction
    - From single pion Monte Carlo at each sigma value
  - Jet energy scale for all configurations
- **Calorimeter-only simulation:**
  - **No tracks available in this analysis**
  - Focus on optimization of calorimeter level reconstruction
  - **Room for improvements utilizing tracks**

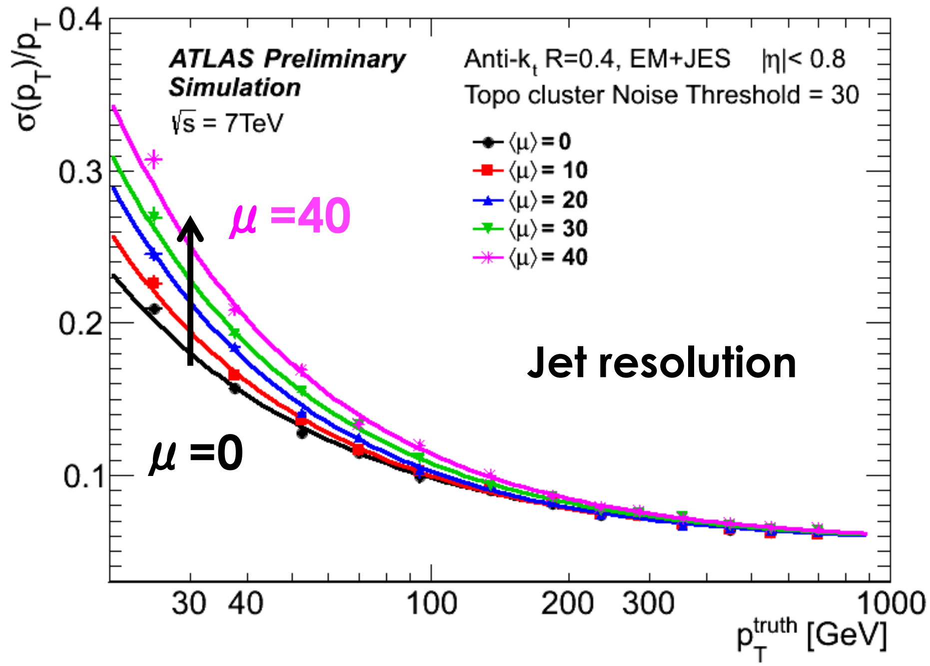
Challenges of pileup

Pileup is one of the main challenges for jets and missing ET at the LHC:

- **Additional energy (offset)**
- **Pileup fluctuations:**
  - increase the noise term of the jet **energy resolution** (event-by-event fluctuations)
  - additional **fake jets** (local fluctuations)

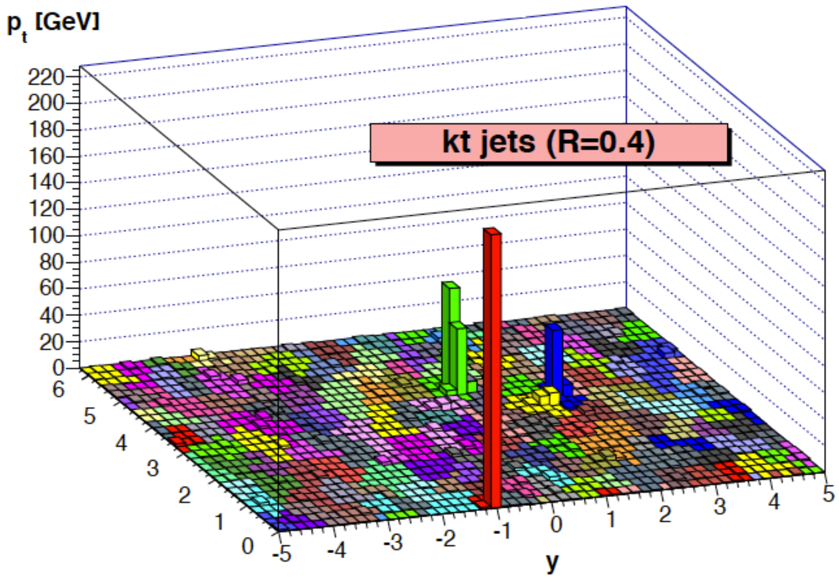




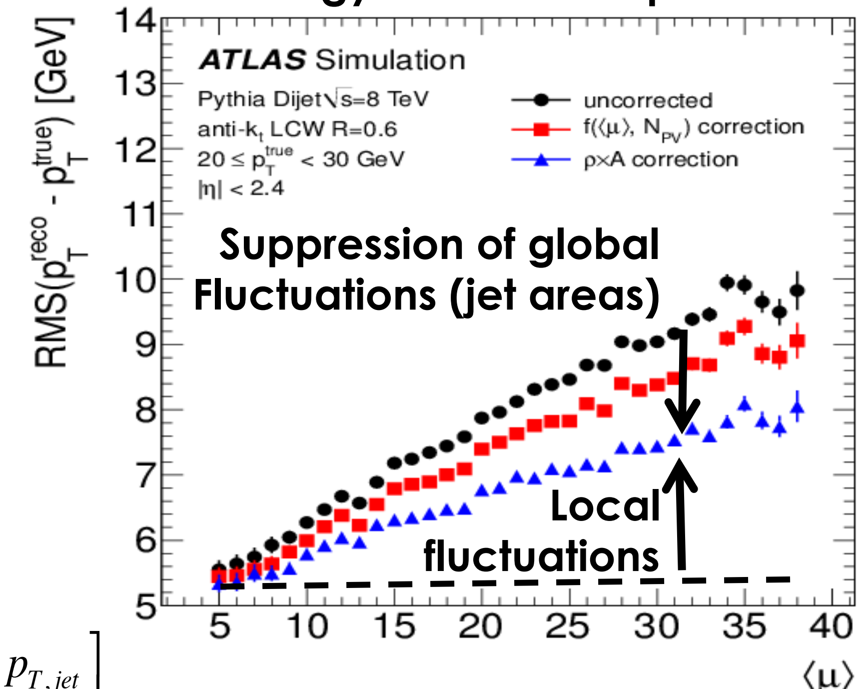


Pileup subtraction (2012)

arXiv:0707.1378 [hep-ph]



Jet energy resolution improvement



$$p_T^{jet,corr} = p_T^{jet} - \rho \times A_T^{jet}$$

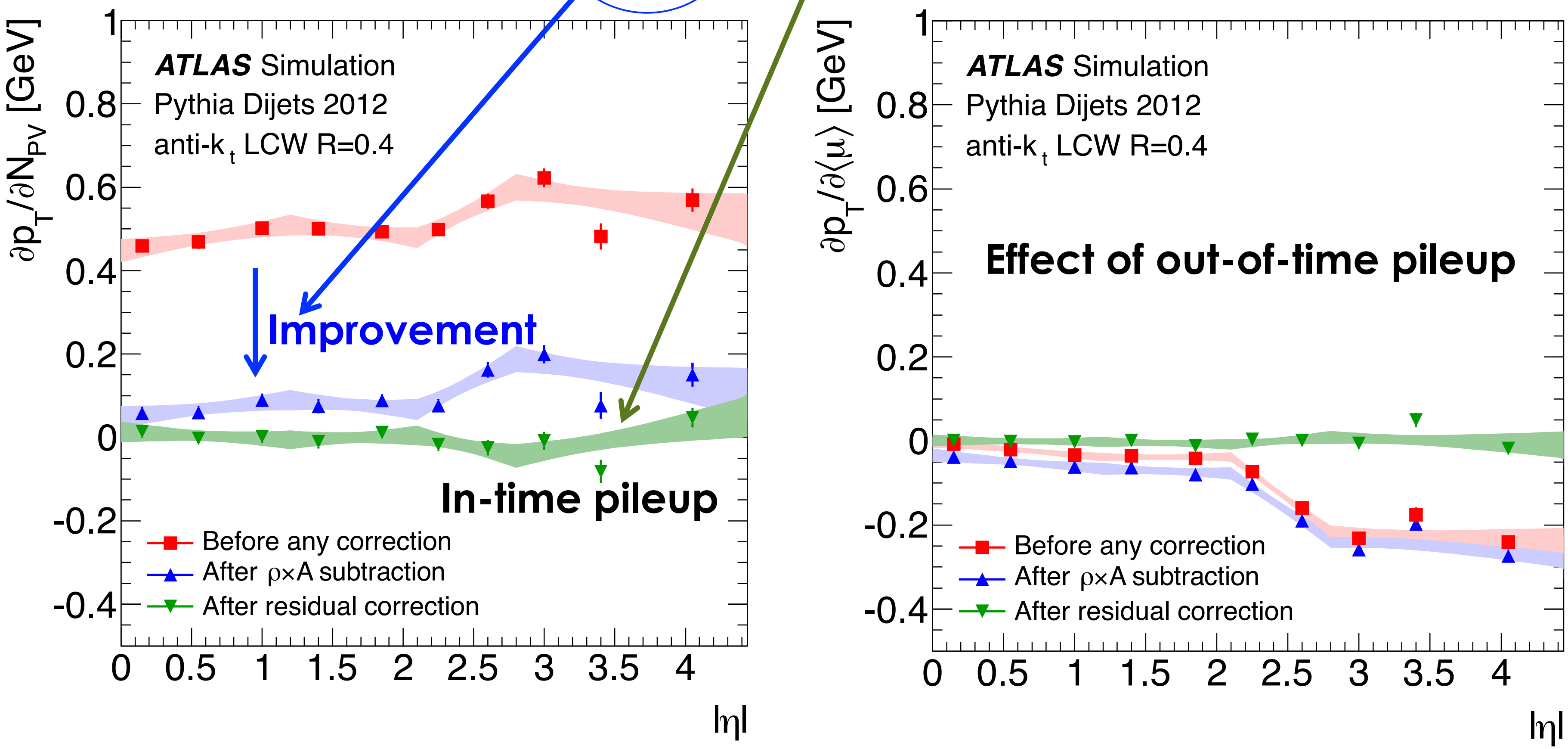
$$\rho = median\left[\frac{p_{T,jet}}{A_{jet}}\right]$$

- **Estimate, event-by-event, the pileup p_T density**
  - Based on energy depositions ***outside*** hard jets
- **Subtract pileup contribution based on jet area**
  - Accounts for *global* pileup fluctuations from one event to another
  - Global pileup estimate, not sensitive to *local* fluctuations
  - **Residual correction to account for higher occupancy inside jets and out-of-time pileup effects**

Pileup subtraction (2012)

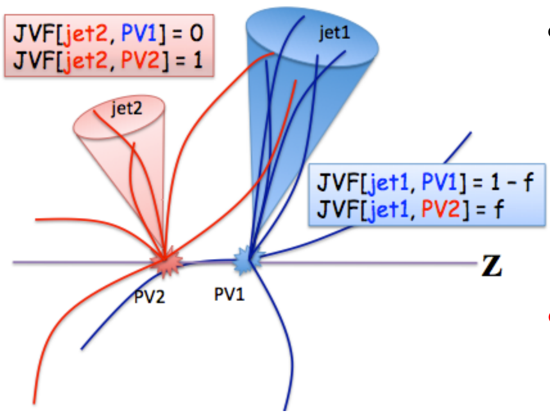
Residual correction

$$p_{\mathrm{T}}^{\mathrm{corr}} = p_{\mathrm{T}} - \rho A_{\mathrm{T}} - \boxed{\alpha(N_{\mathrm{PV}} - 1) - \beta\langle\mu\rangle}$$



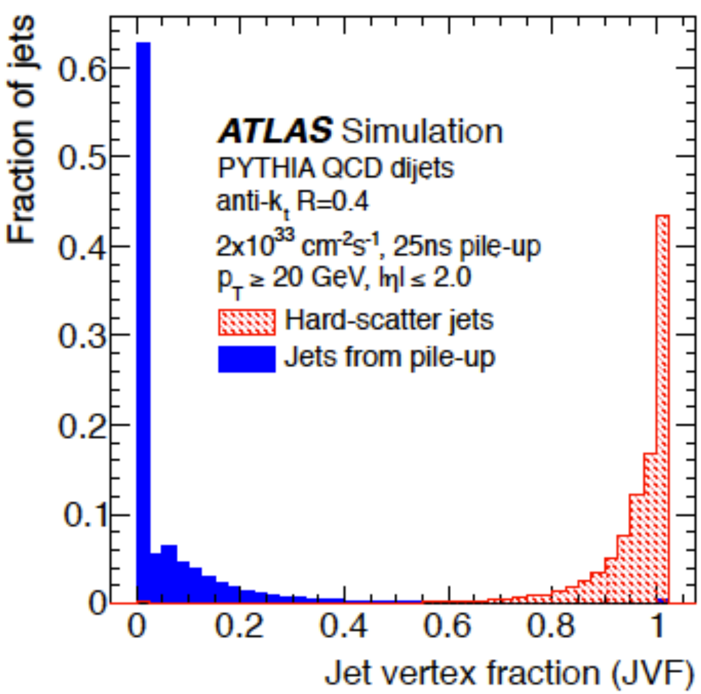
- <mu> is the average luminosity per luminosity block
  - sensitive to out-of-time pileup for fixed N_{PV}

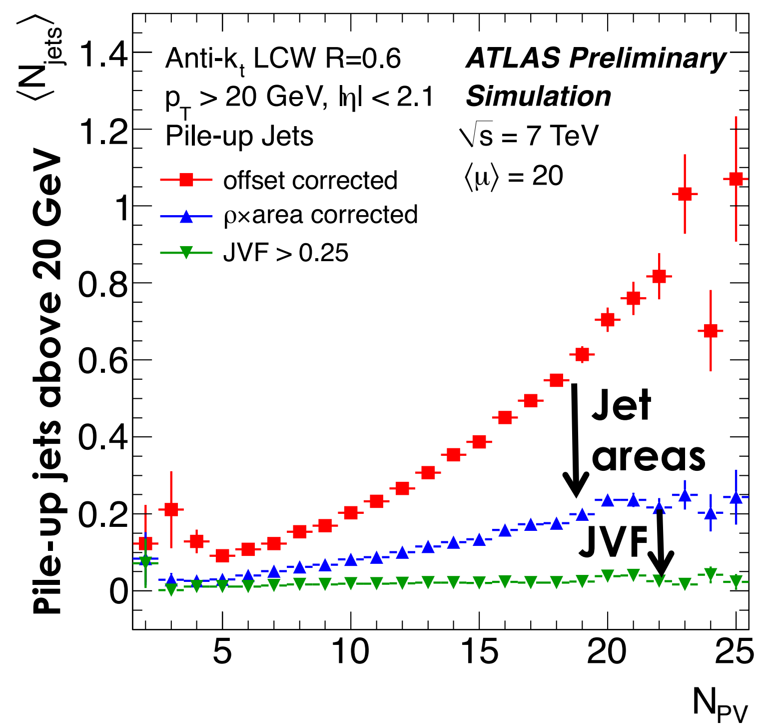
Pileup suppression (2012)



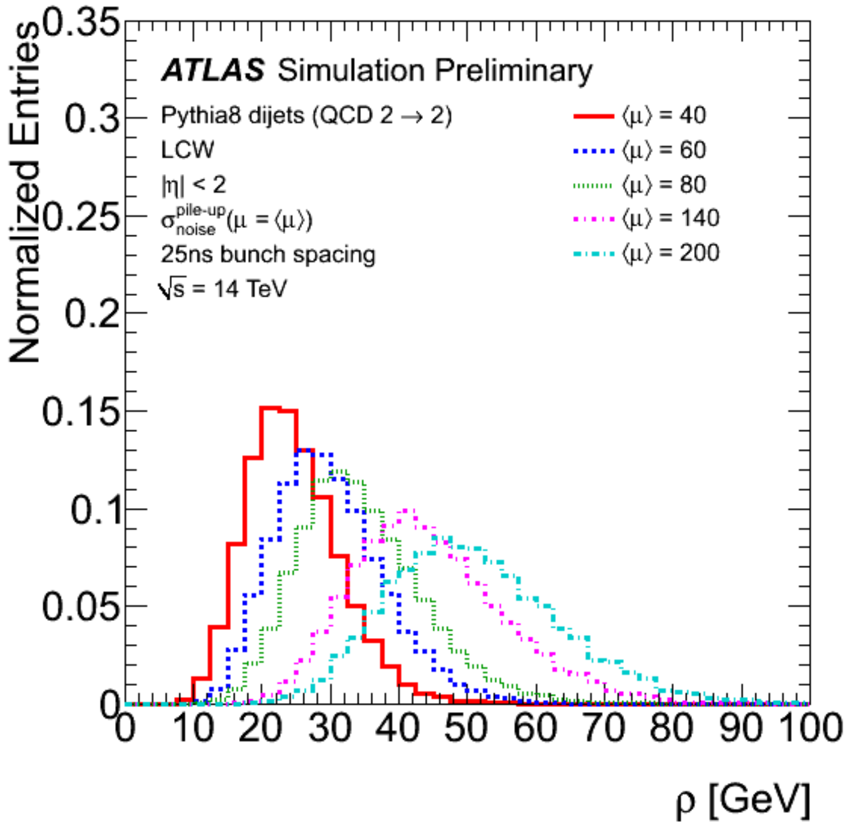
- **Pileup local fluctuations within a same event can lead to (fake) pileup jets:**
  - Mix of QCD jets from additional interactions and random combination of particles from pileup interactions
- **Jet vertex fraction algorithm**
  - Reject fake pile-up jets using tracking and vertexing information

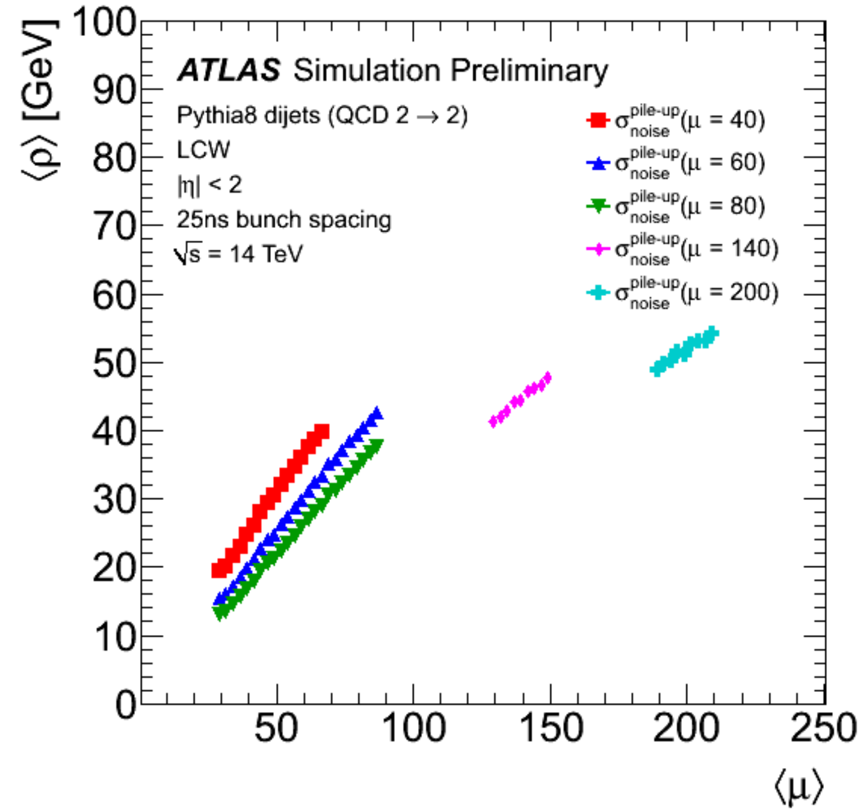
Jet Vertex Fraction (JVF)





Pileup subtraction (HL)

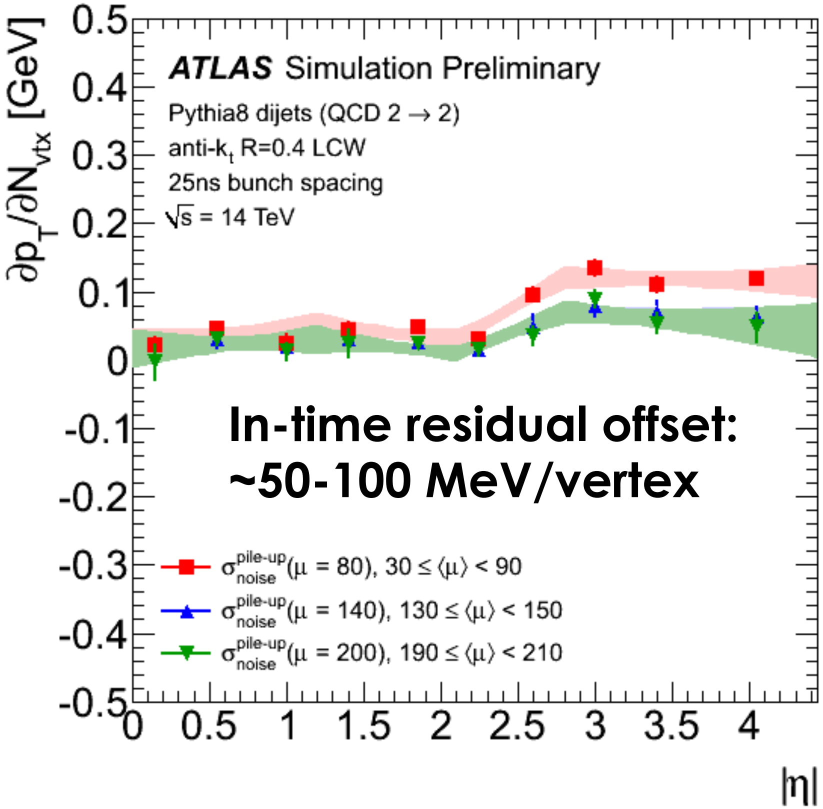


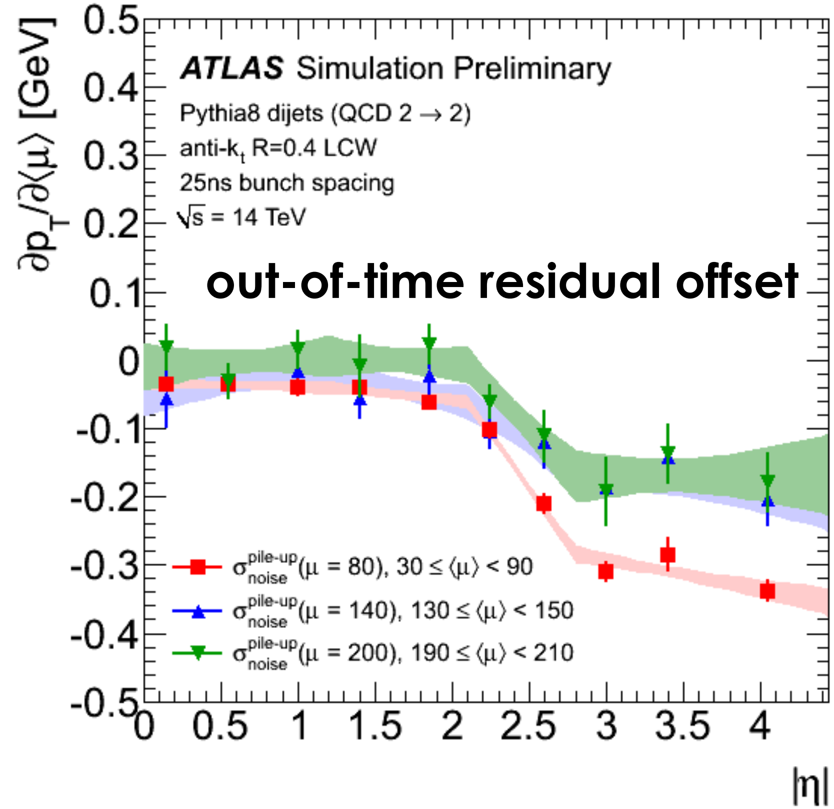


- **Significant increase on the width of the rho distribution with pileup:**
  - Larger pile-up fluctuations
- **Linear behavior of rho up to high mu for fixed pileup noise values**
- **Higher pileup noise values lead to partial suppression of pile-up:**
  - Larger suppression of pileup activity by pileup noise (sigma)

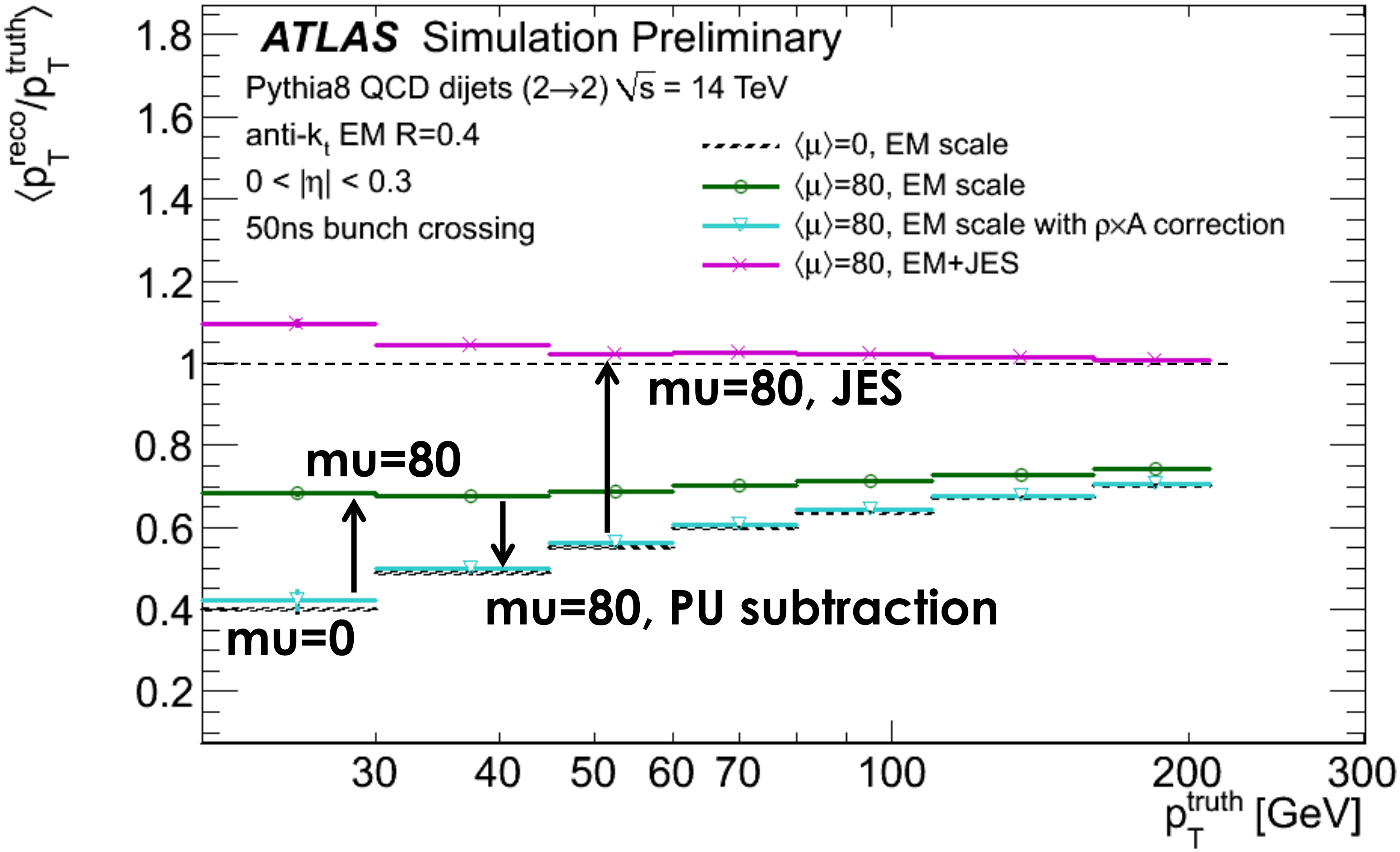
Pileup subtraction (HL)

- Residual offset after subtraction is mostly pileup independent
- **Jet areas subtraction, topo-clustering, and local cluster weighting work well at high luminosity**



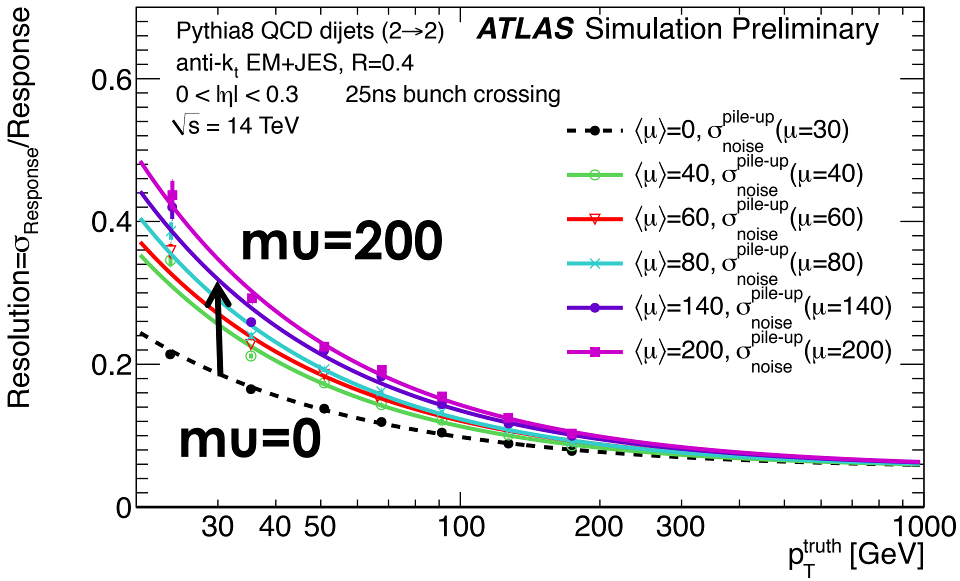


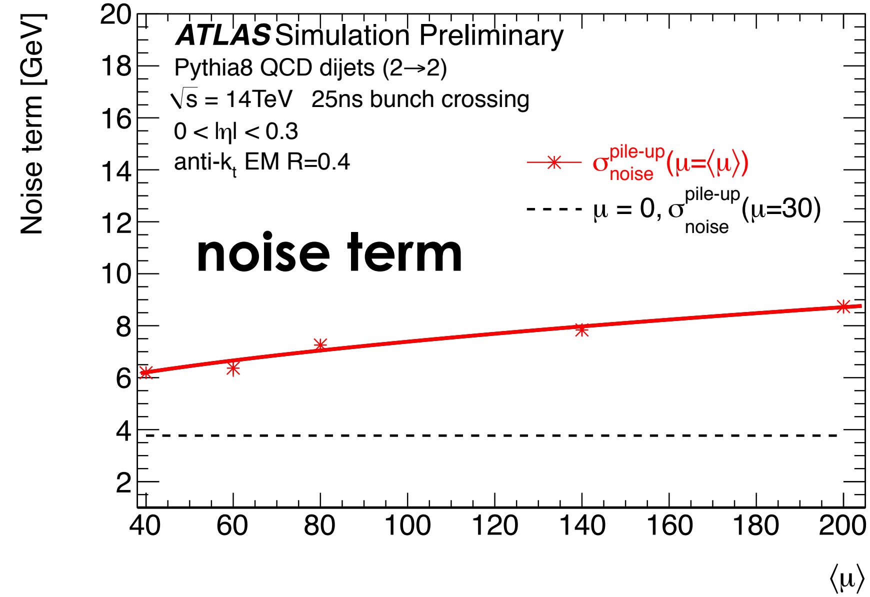
Jet energy scale



- Pile-up subtraction restores the jet response to that of the jets with mu=0
- Jet energy scale restores the response to unity
- **Jet calibration scheme works well up to very high luminosity**

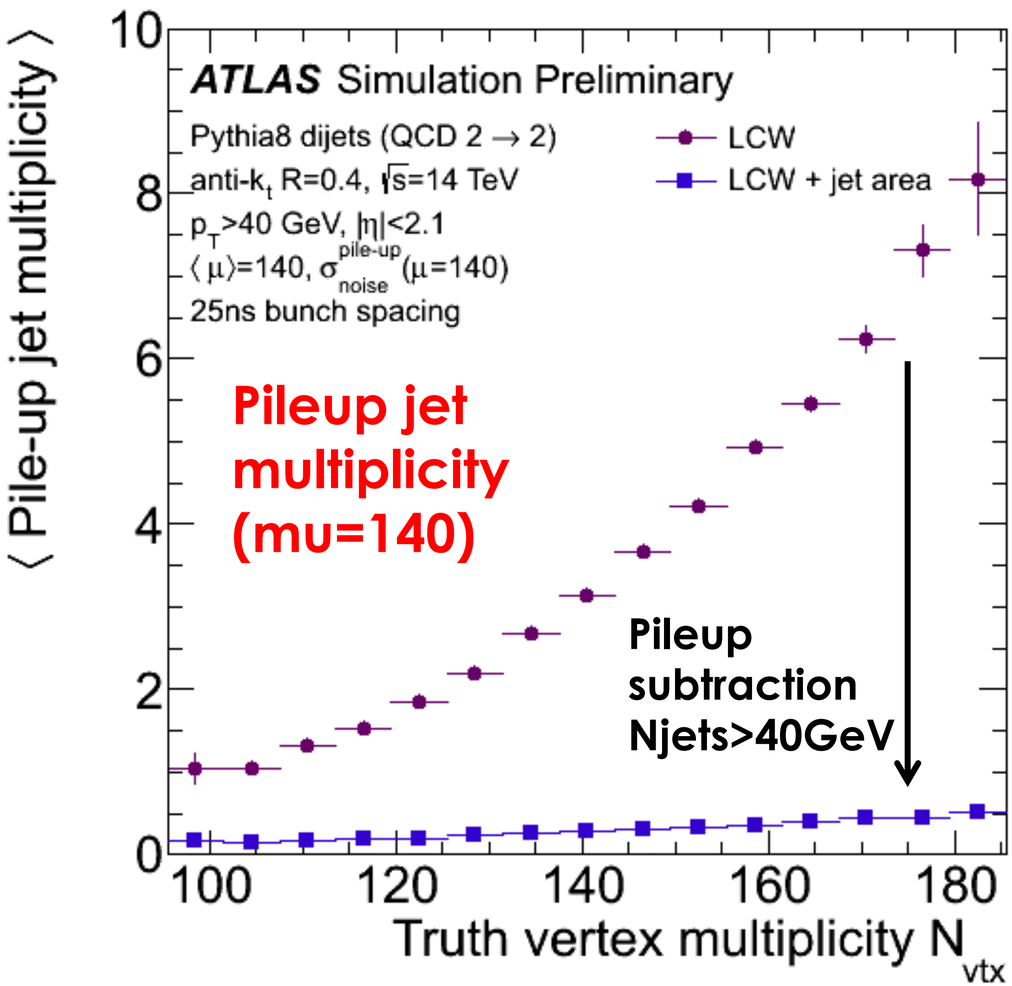
Jet energy resolution





- **Fractional jet energy resolution degrades at low p_T due to increased (pileup) noise term:**
  - Local pileup fluctuations within events, not captured by the global event-by-event median p_T density (rho) used in the calibration
- **Noise term increases as sqrt(mu)**
  - <u>**Linear behavior of topo-clustering, pileup subtraction, and jet calibration up to very high luminosity**</u>
- **Expect improvements using tracks**
  - Reduce local pileup fluctuations

Pileup jets

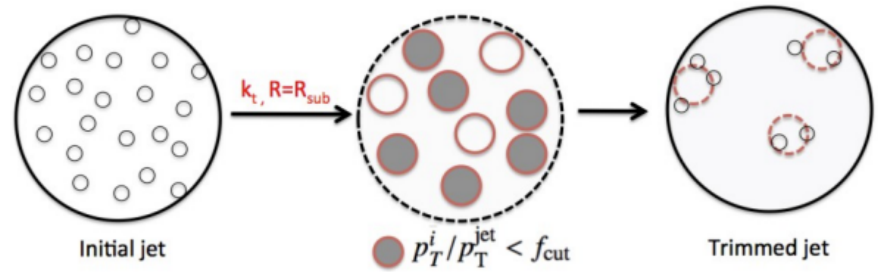


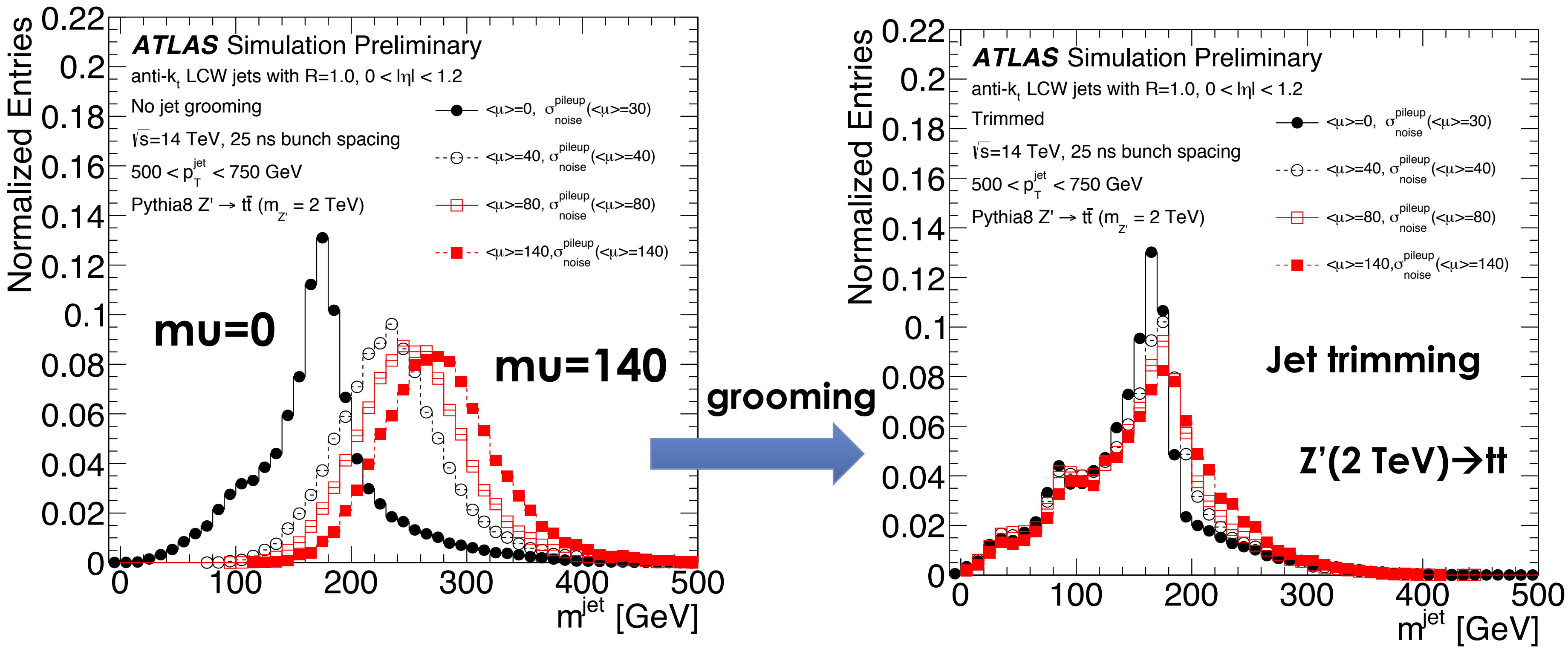
- **Pileup subtraction significantly reduces the mean number of pileup jets per event**
  - About 3 (0.5) pileup jets with p_T>20 (40) GeV per event at N_{PV} = 140
- **Further improvements expected using tracking and vertexing information**

Jet substructure

- Key technique for reconstruction of boosted objects
- Grooming algorithms significantly reduce sensitivity to pileup (reduced jet area)

Jet trimming

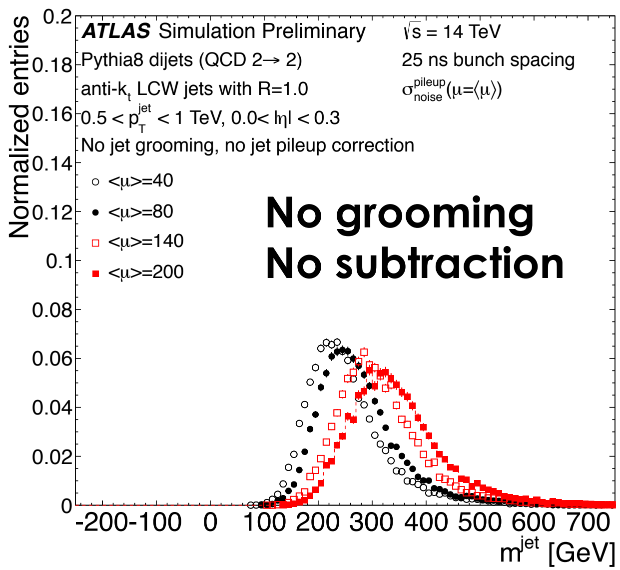




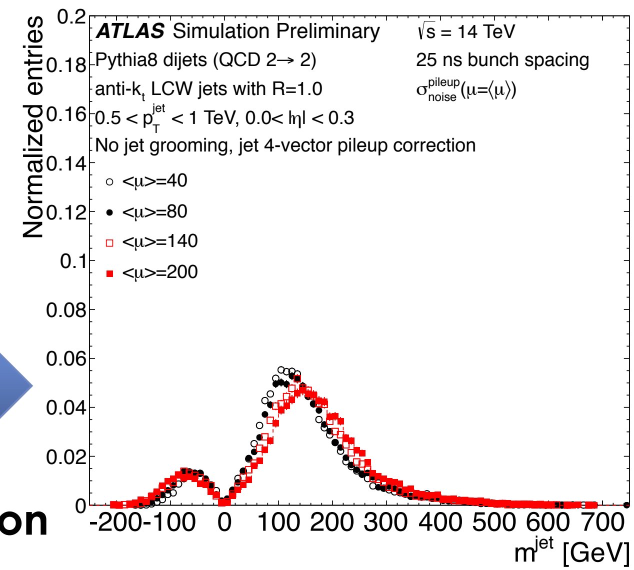
- **Trimming with 2012 parameter optimization works at mu=140**
  - **Degradation in resolution, but lots of room for improvements**

Jet grooming performance

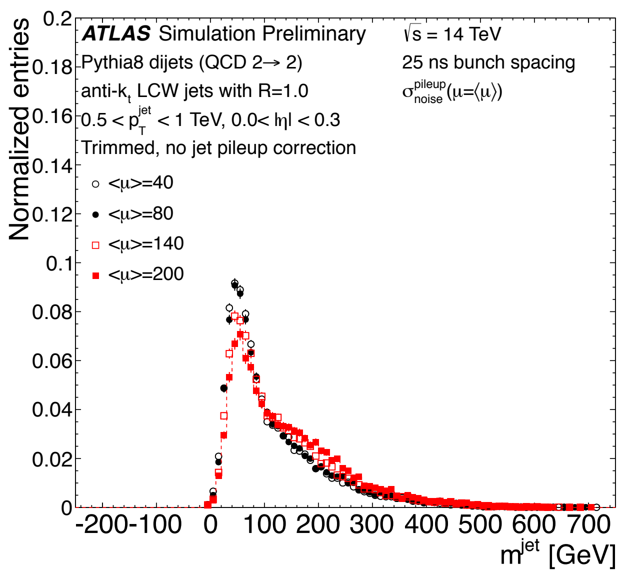
Dijet events

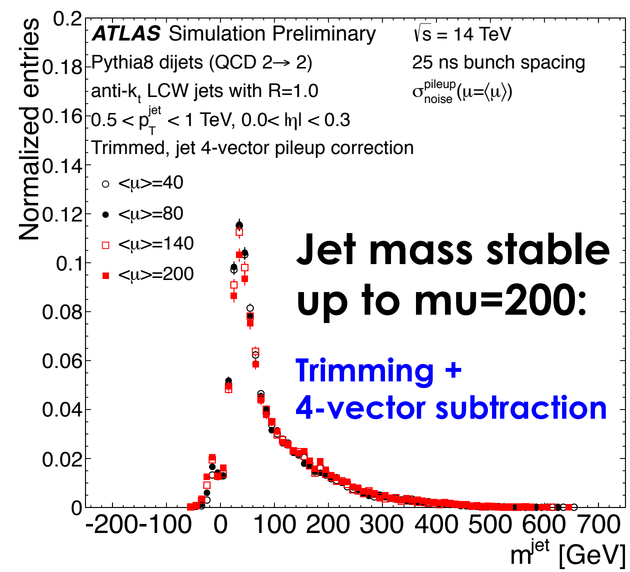


4-vector subtraction



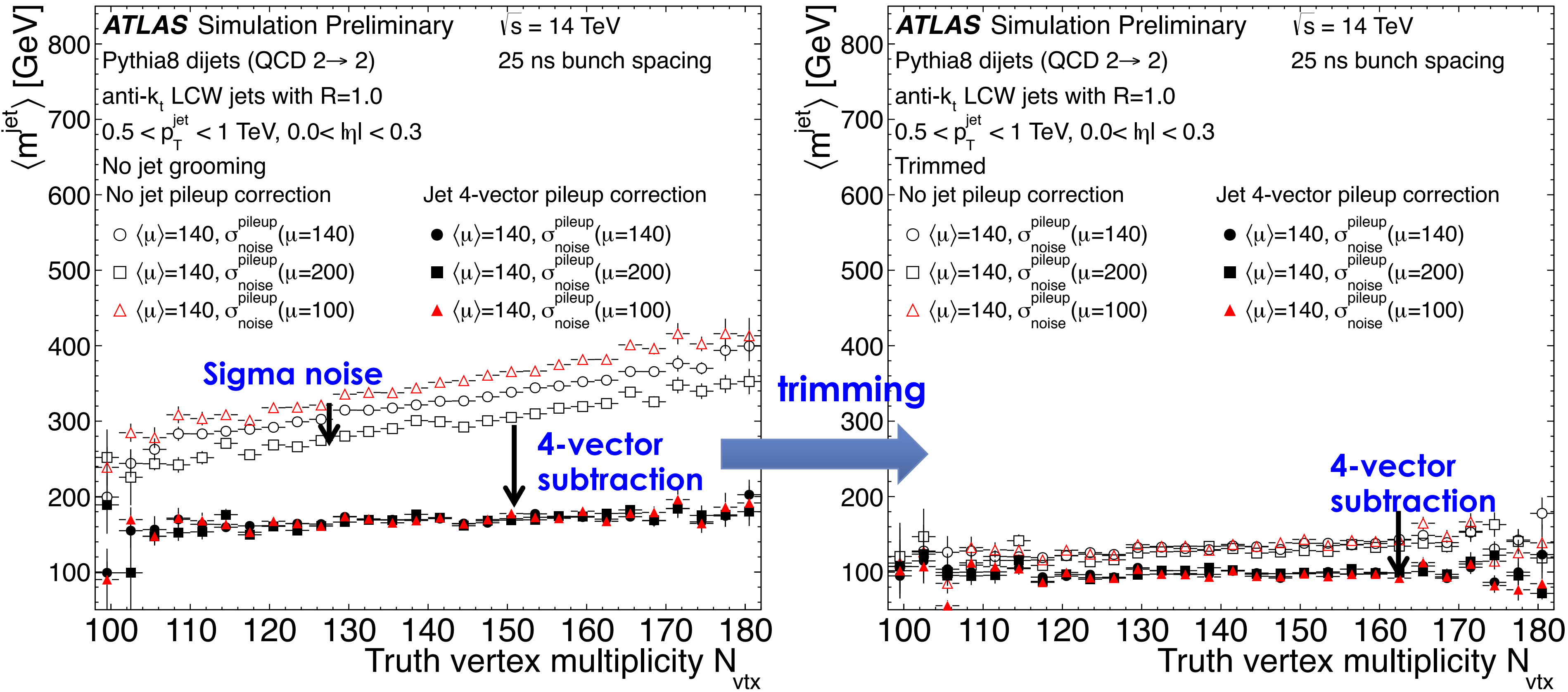
trimming





Jet grooming performance

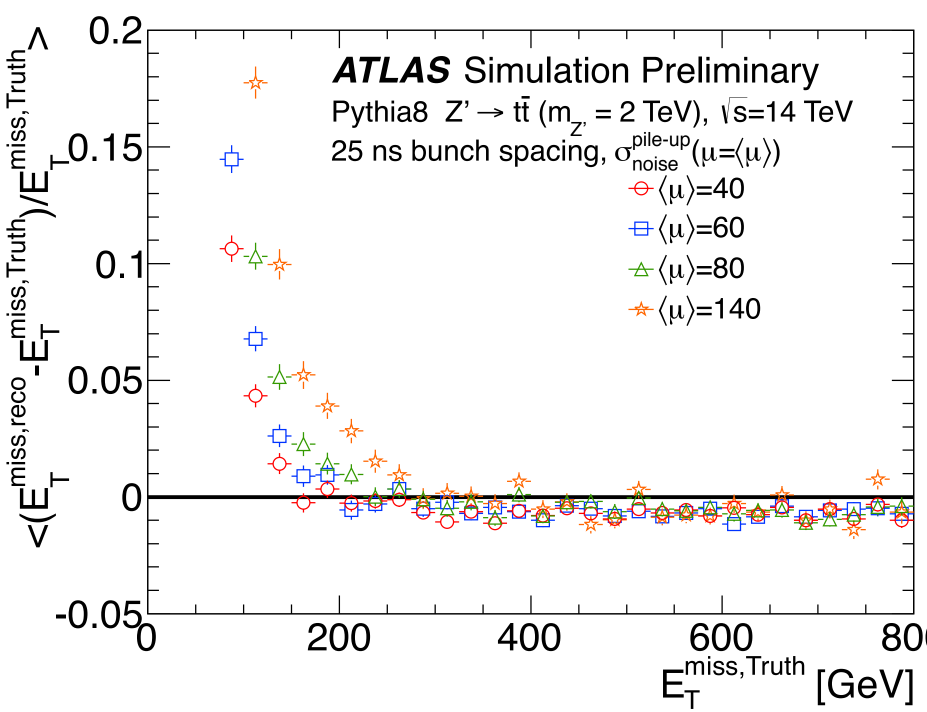
Dijet events

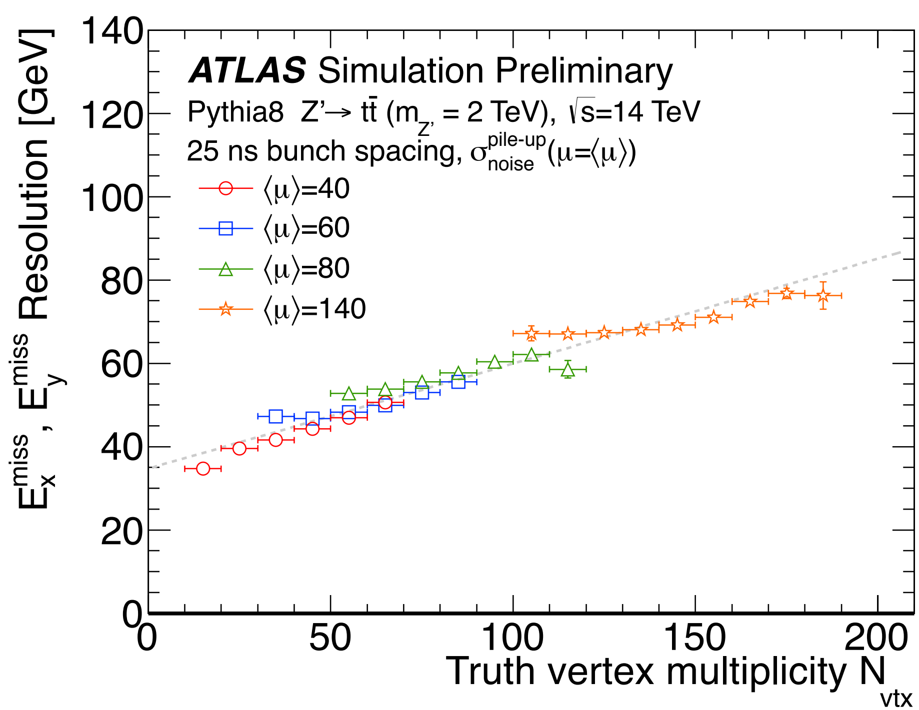


- Raising pileup noise values reduces the mean mass, but does not affect the dependence on pileup
- 4-vector subtraction successfully suppresses pileup, even without grooming
- **Trimming with subtraction further reduces pileup contributions to the jet mass**

Missing ET

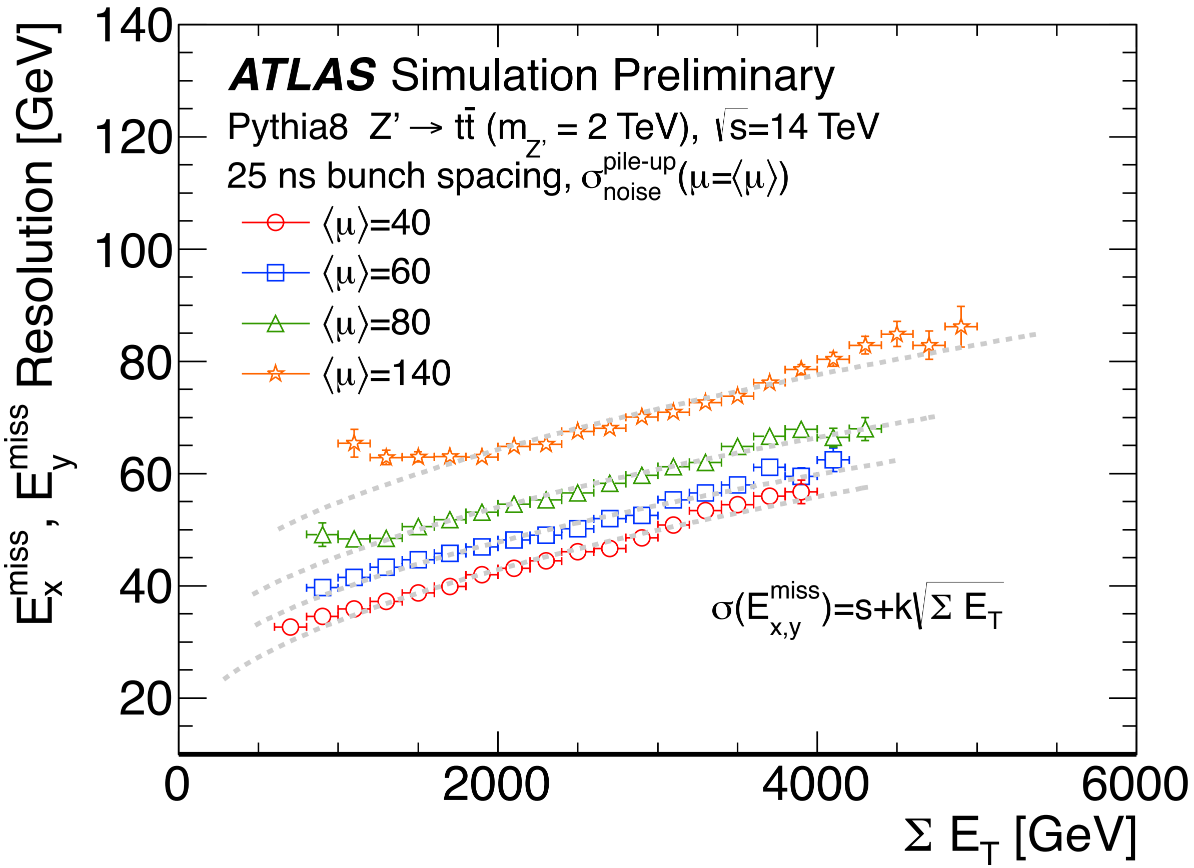
- Missing ET is computed only using topological clusters and calibrated jets
- **Linearity of the response is within 1% up to mu=140**
  - Achieve a correct missing ET scale
  - Positive bias at low missing ET is due to the finite resolution of the missing ET, and is highly dependent on the event topology
- **Missing ET resolution scaling with the number of vertices is independently of <mu>, when the optimal pileup noise values are used**





Missing ET

- **Missing ET resolution shifts upwards with pileup, but it does not change the slope with mu**
  - Pileup affects the s-term of the resolution, but the k-term remains approximately constant
  - **Large room for improvements using tracks to suppress pileup**



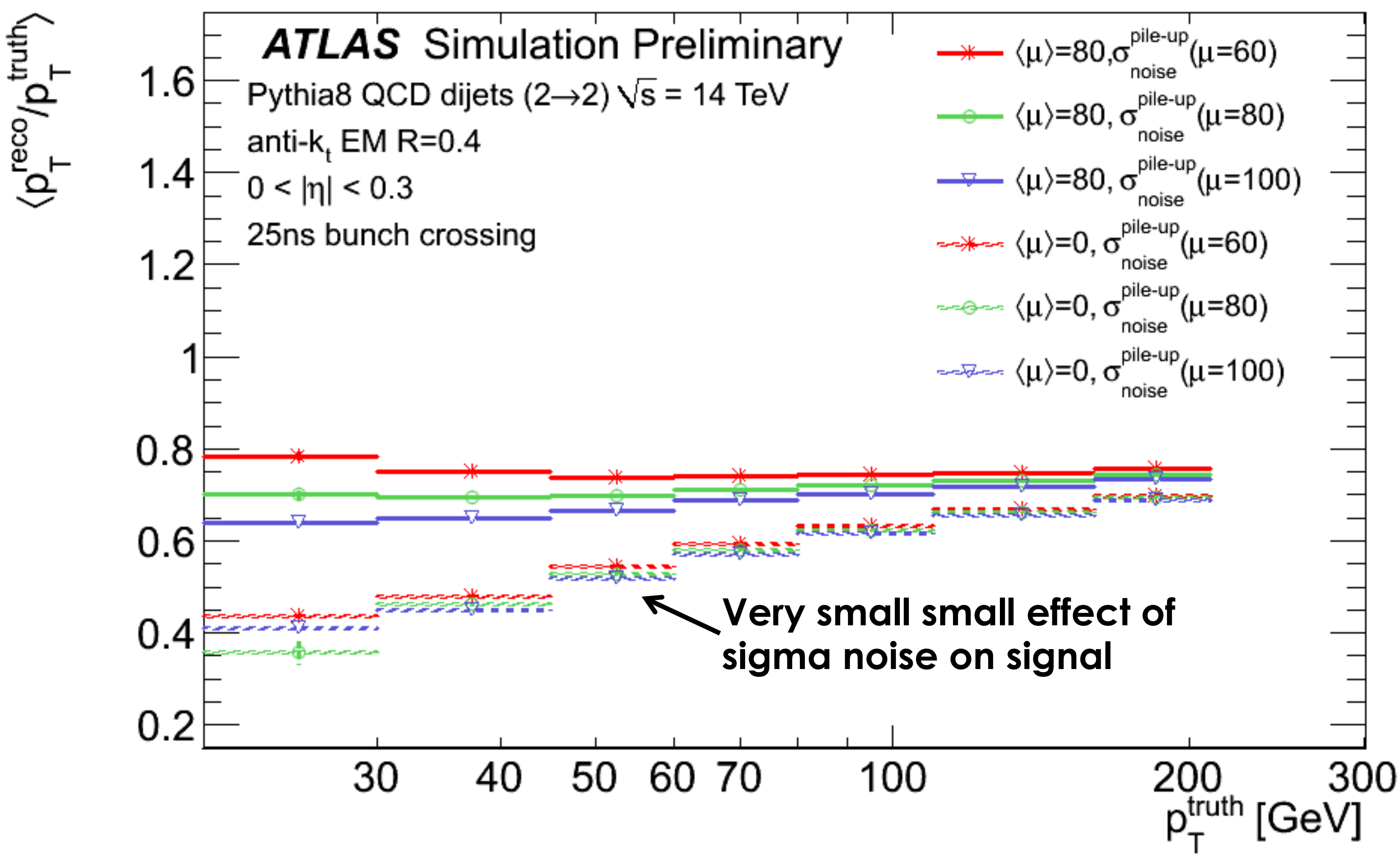
Conclusions

- **ATLAS techniques for jet, jet substructure and missing ET reconstruction and calibration work well up to very high luminosities**
  - Topological clustering and local hadron calibration
  - Pileup suppression
  - Grooming
  - Optimization of topological clustering pileup noise significantly reduces the impact of pileup at high luminosity, and event-by-event subtraction allows to maintain the same pileup offset than in Run 1 conditions

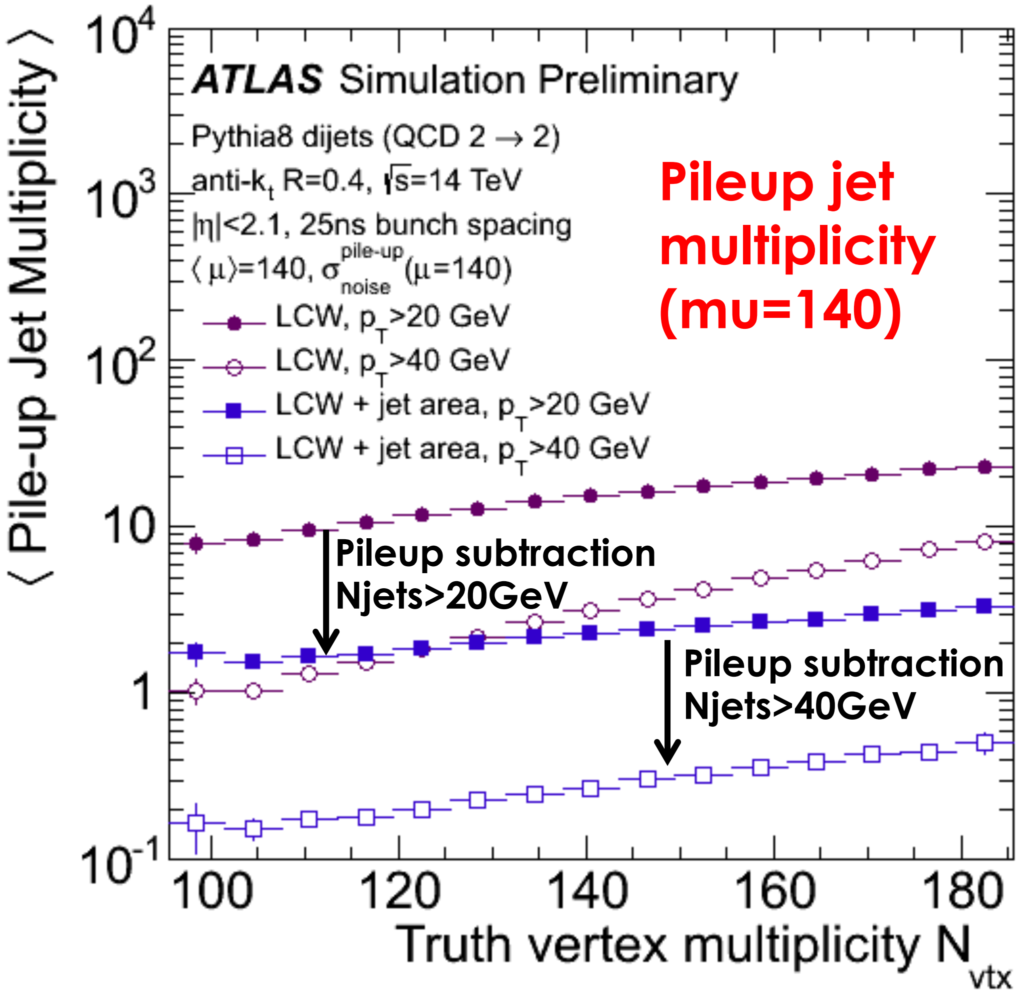
- **Resolution is degraded in some cases, but there is significant room for improvements:**
  - **<u>Use of tracks and vertices</u>**
    - Reduce local pileup fluctuations and further suppress pileup jets
      - Track-cluster matching, charged hadron subtraction, improved JVF, forward tracking, topo-clustering, …)
  - Advanced subtraction techniques using more local information
  - Optimization of grooming parameters at high luminosity

Backup slides

Jet response



Pileup jets



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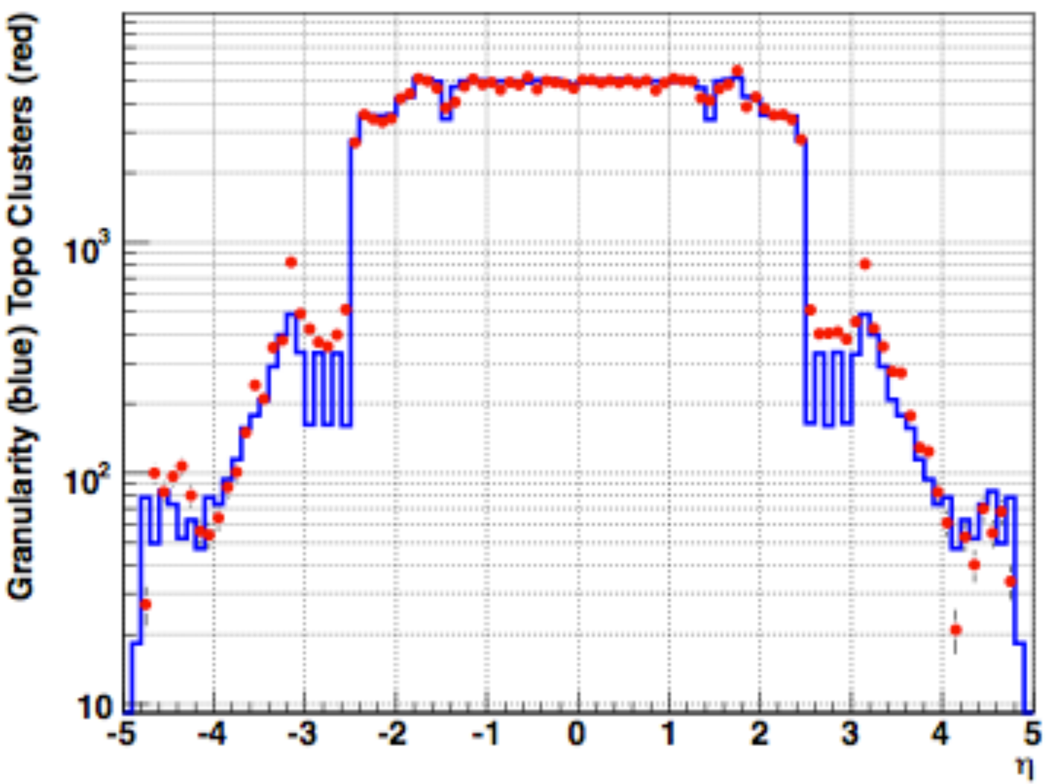
- **Further improvements expected using tracking and vertexing information**

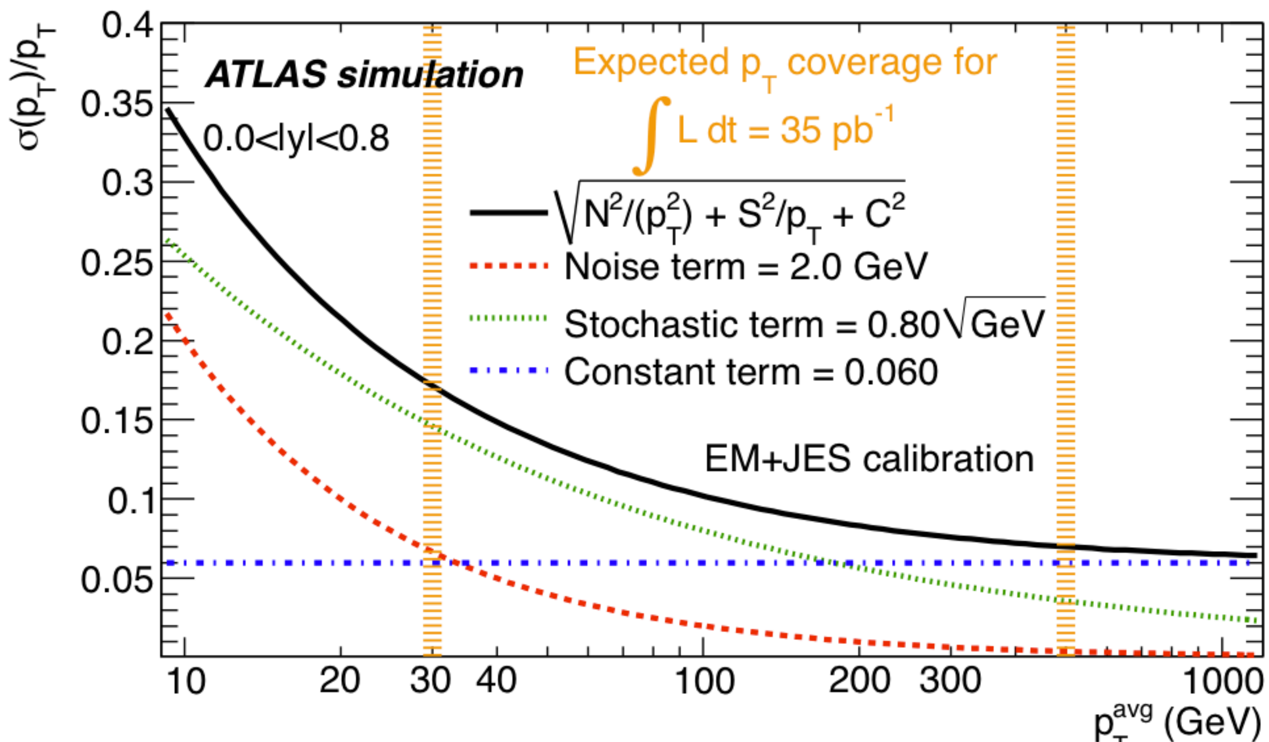
Experimental issues



- **Noise thresholds** (topoclusters) **have a different effect inside and outside the core of jets** (pileup particles outside jets are more suppressed than inside jets, where signals are more likely to be above threshold)
- **Coarser calorimeter granularity above |eta|>2:**
  - Few clusters from pileup (noise) only above threshold
  - Need to restrict the calculation of rho to the central eta region
  - Leads to a reduction in the power of the jet areas technique to correct for pile-up effects in the forward region

Jet energy resolution

- Jet resolution is described by three parameters: noise (N), stochastic (S) and constant (C) terms.
- **Pile-up determines the noise term:** $1/p_T$ dependence in the fractional resolution means a constant (p_T-independent) smearing of the absolute p_T from pile-up (noise) fluctuations
  - Constant term is not affected by pile-up
  - Noise term determines the jet resolution at low p_T
  - **The key to improve jet energy at low p_T is to reduce the pile-up fluctuations!**



Out-of-time pileup

- **ATLAS LAr calorimeter has a large integration time relative to bunch spacing:**
  - **Out-of-time** pile-up contributions
  - bi-polar shape compensates, on average, for both in-time and out-of-time pile-up, but out-of-time effects vary significantly within sub-detectors (eta-dependence)
  - ATLAS needs both in-time and out-of-time pile-up corrections
- **CMS is mostly insensitive to out-of-time pile-up:**
  - 2 time-slices (TS) for integration