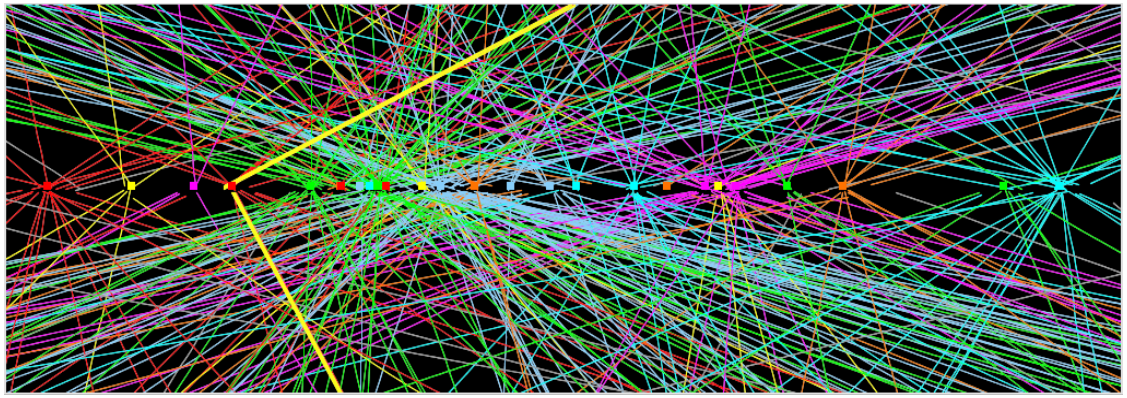
Physics event reconstruction in the presence of high pile-up: Jets and missing ET



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Joint Snowmass-EuCARD/AccNet-HiLumi LHC meeting:
Frontier Capabilities for Hadron Colliders 2013
CERN, 22-Feb-2012

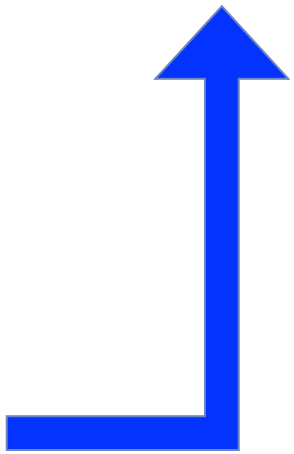
Outline

- **Jet reconstruction at ATLAS**
  - Input signals
  - Calibration techniques
- **Pile-up in 2012 data**
  - Challenges
  - Pile-up subtraction for jets
  - Pile-up suppression (fake jets)
  - Missing ET
- **Towards very high pile-up**

Jet reconstruction at ATLAS

Exploit high resolution HAD calorimeter and fine longitudinal segmentation

- **3-dimensional topological clustering**
  - Optimized to follow shower development in calorimeter / noise suppression
  - Define inputs to jet finding
  - **Ideal for jet substructure** (constituent-level calibration)
- **EM Jets** (**Electromagnetic-scale jets**)
  - Add EM/HAD energy components of clusters
  - Large p_T-Eta dependent jet energy scale correction
- **LCW Jets** (**Local cluster weighting jets**)
  - Cell/cluster weighting using local properties
  - Distinguish EM/HAD depositions
  - Small residual p_T-Eta dependent jet energy scale correction

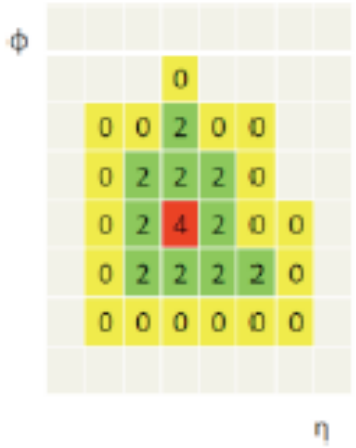


Calorimeter Jets

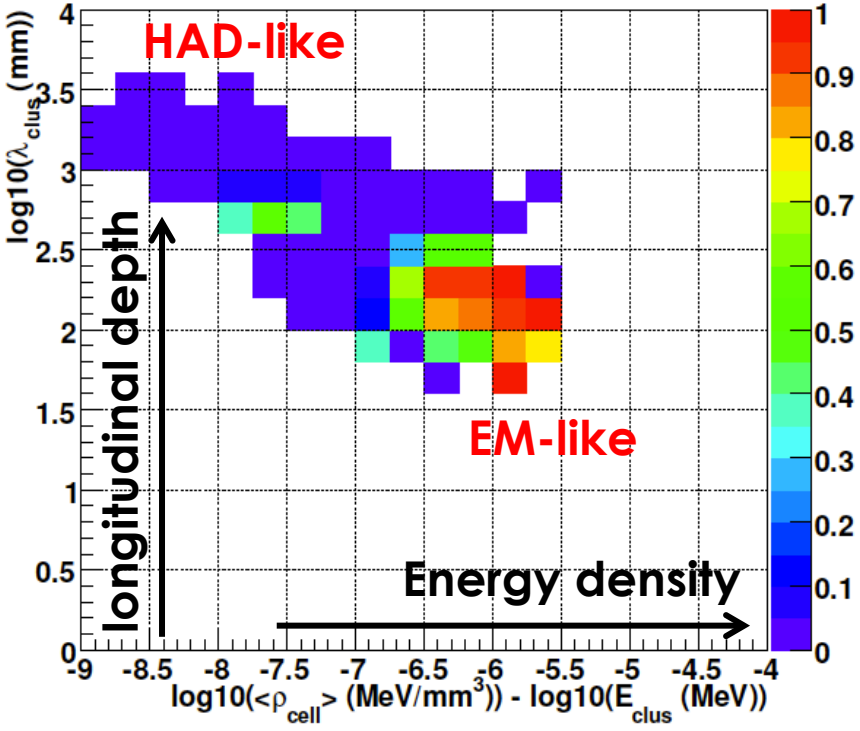
- **Tracks:**
  - **post-calibration jet-by-jet corrections:**
    - Reduce fluctuations using global information about jet fragmentation
    - Pile-up suppression
  - **Validation tool:**
    - Set the jet energy scale, insitu, from calorimeter-independent track-jets

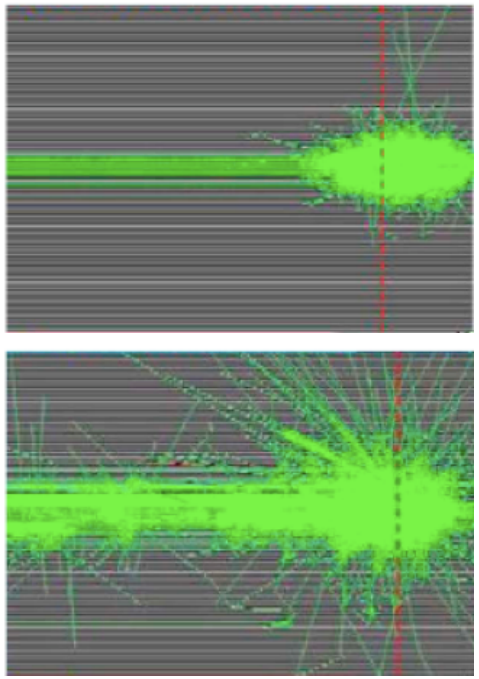
Topological clusters

- Follow shower development
- Electronic + **pile-up 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**



Seed:
$|E_{cell}|>4\sigma$
Neighbors:
$|E_{cell}|>2\sigma$
Nearest neighbors:
$|E_{cell}|>0\sigma$





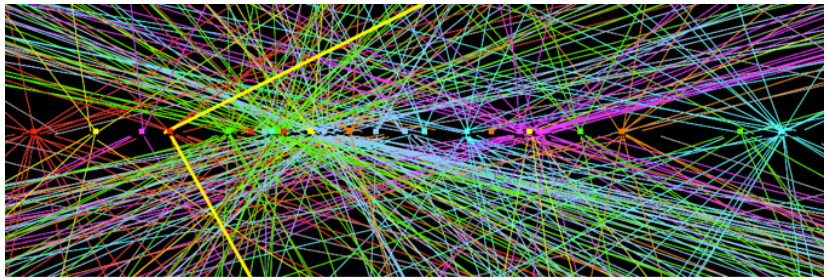
π^0

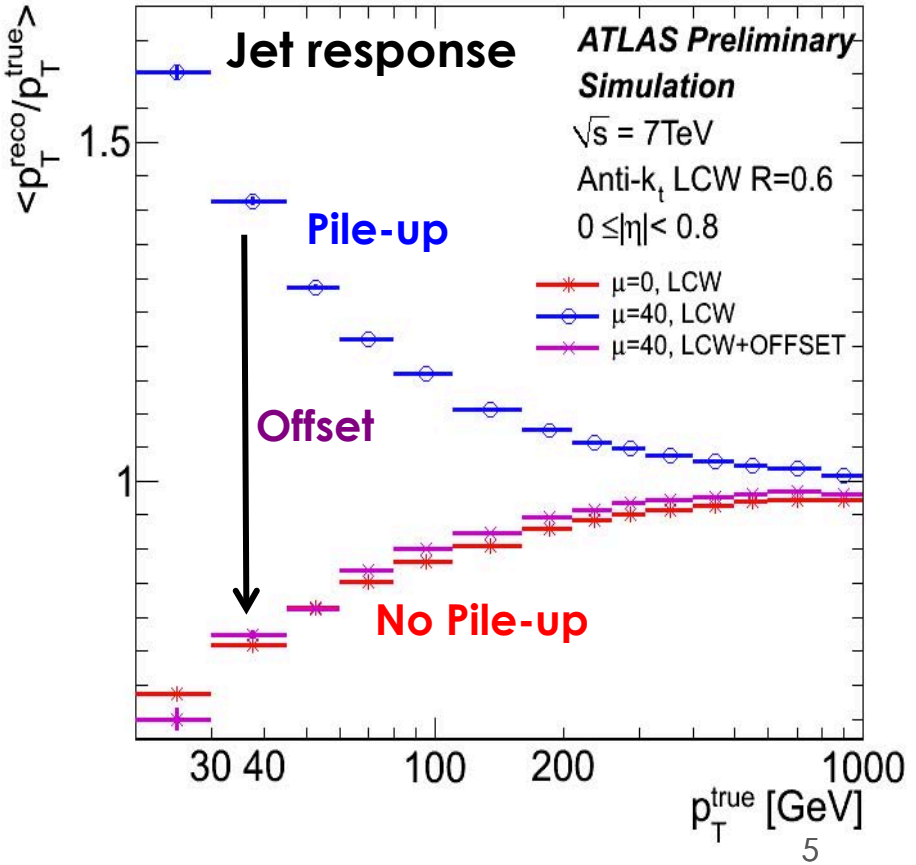
π^+

Challenges of pile-up

Pile-up is one of the main challenges for jets (and missing ET) at the LHC:

- **Additional energy** (offset)
- **Pile-up fluctuations**:
  - increase the noise term of the jet **energy resolution** (event-by-event fluctuations)
  - additional **fake jets** (local fluctuations)
- Large effect on jet mass and properties, and missing ET



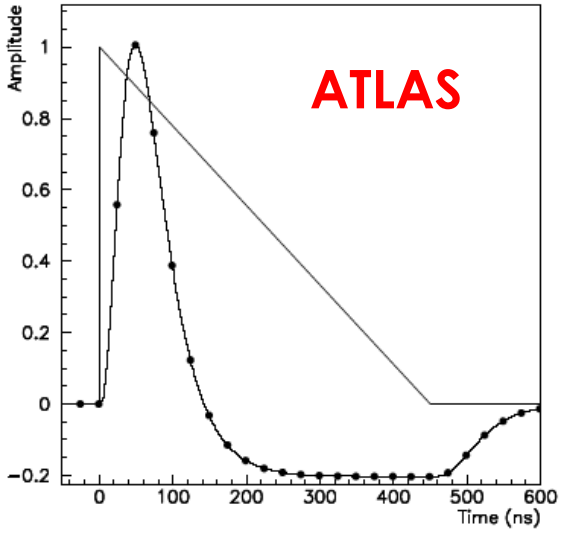


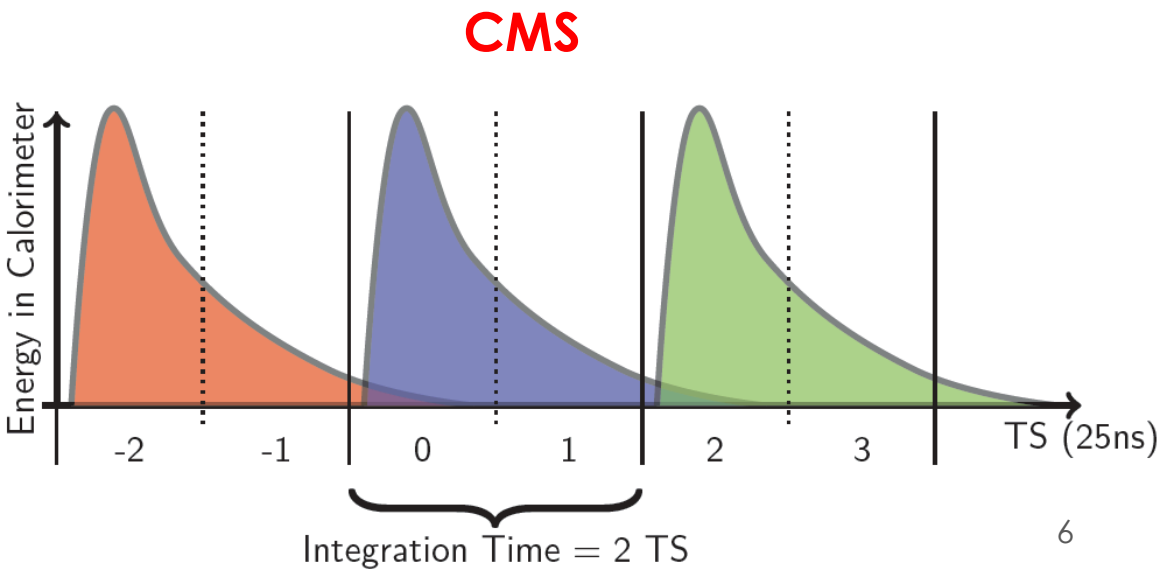
Pile-up corrections are a key component of the jet calibration strategy at the LHC:

- Restores the jet response shape to N_{PV}=1 and $\mu = 0$, and make jet performance independent of varying pile-up conditions
- Reduce (event-by-event) fluctuations
- Reject pile-up jets (pile-up suppression)

Out-of-time pile-up

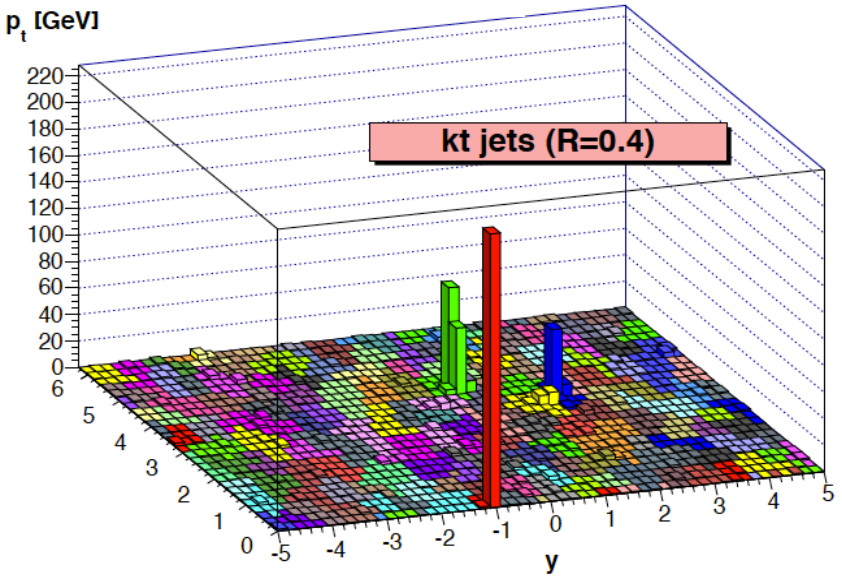
- **ATLAS LAr calorimeter has a very large integration time relative to bunch spacing:**
  - **Out-of-time** pile-up contributions
  - bi-polar shape compensates, on average, for both in-time and out-of-time pile-up, but out-of-time effects vary significantly within sub-detectors (eta-dependence)
  - ATLAS needs both in-time and out-of-time pile-up corrections
  - No direct handle on event-by-event out-of-time contributions
    - Cannot reduce out-of-time *fluctuations*
- **CMS is mostly insensitive to out-of-time pile-up:**
  - 2 time-slices (TS) for integration

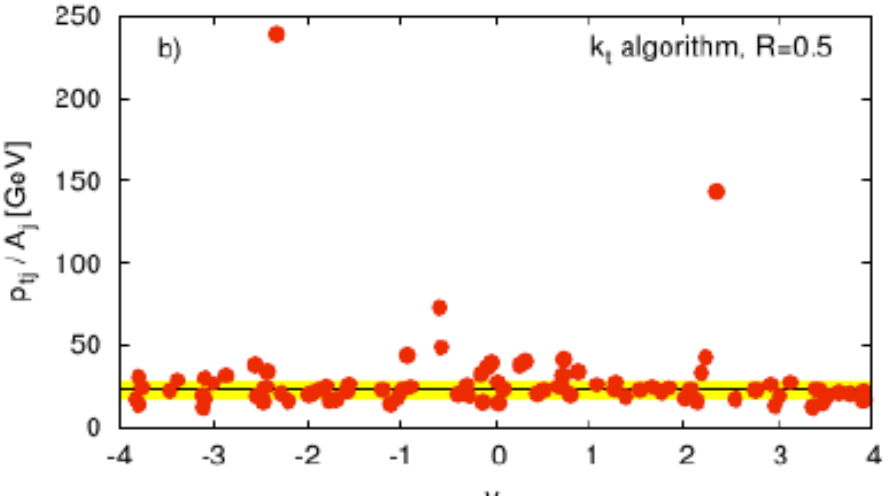




Event-by-event pile-up subtraction

arXiv:0707.1378 [hep-ph]



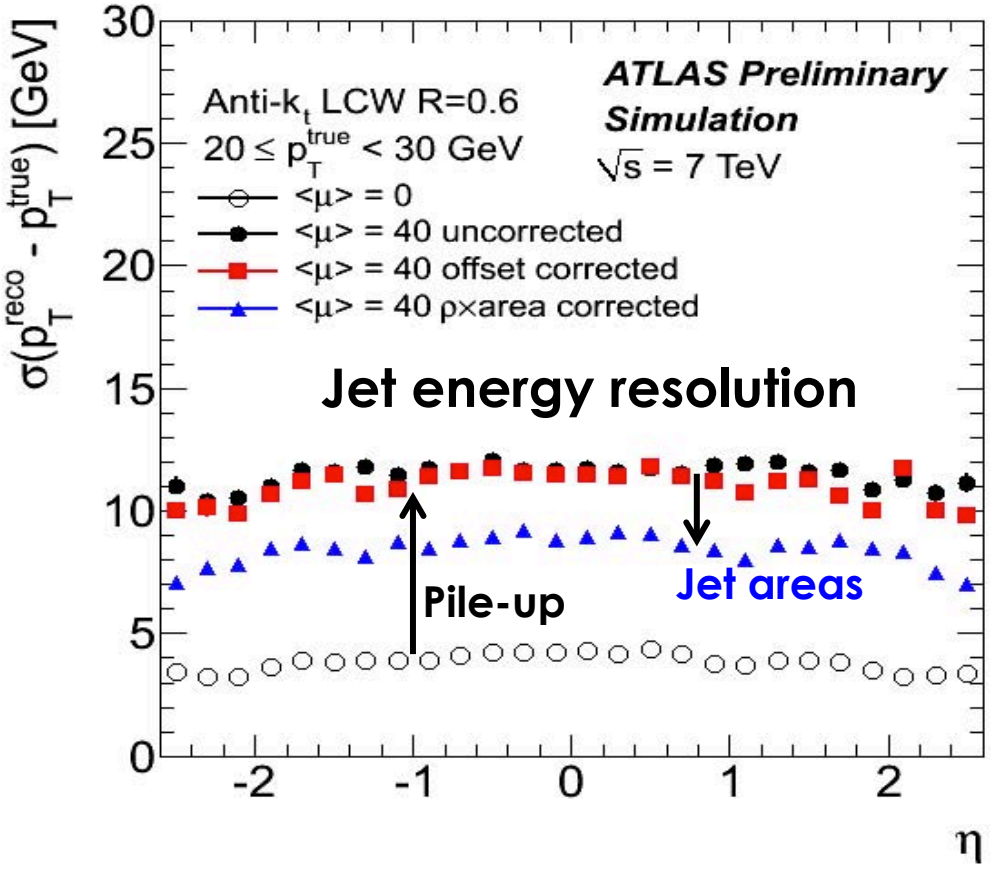


$$p_T^{jet,corr} = p_T^{jet} - \rho \times A_T^{jet}$$

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

- Estimate, **event-by-event**, the pile-up p_T density
- Subtract pile-up contribution based on **jet area**
- **Residual correction** to compensate for noise suppression, occupancy, and out-of-time pile-up

Event-by-event pile-up subtraction

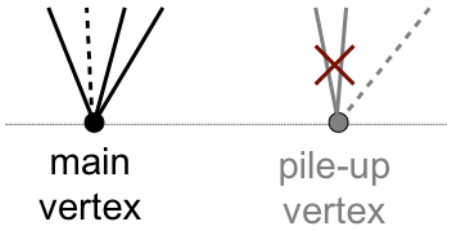


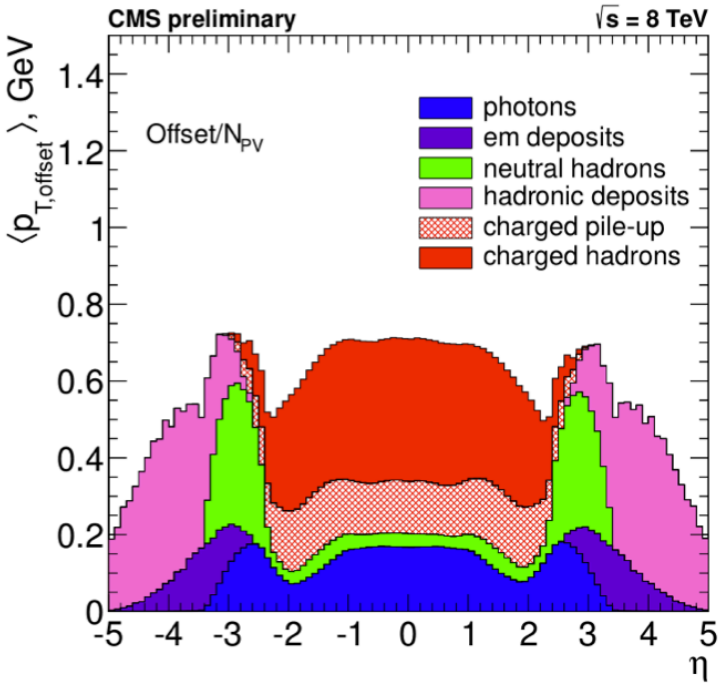
- **Reduction of event-by-event pile-up *fluctuations***
  - Key technique to reduce the noise term of the jet energy resolution
  - Applicable to jet mass and jet shapes
  - Reduced reliance on simulation to correct for pile-up (smaller systematic uncertainty)

Use of tracks

Charged Hadron Subtraction (CMS)

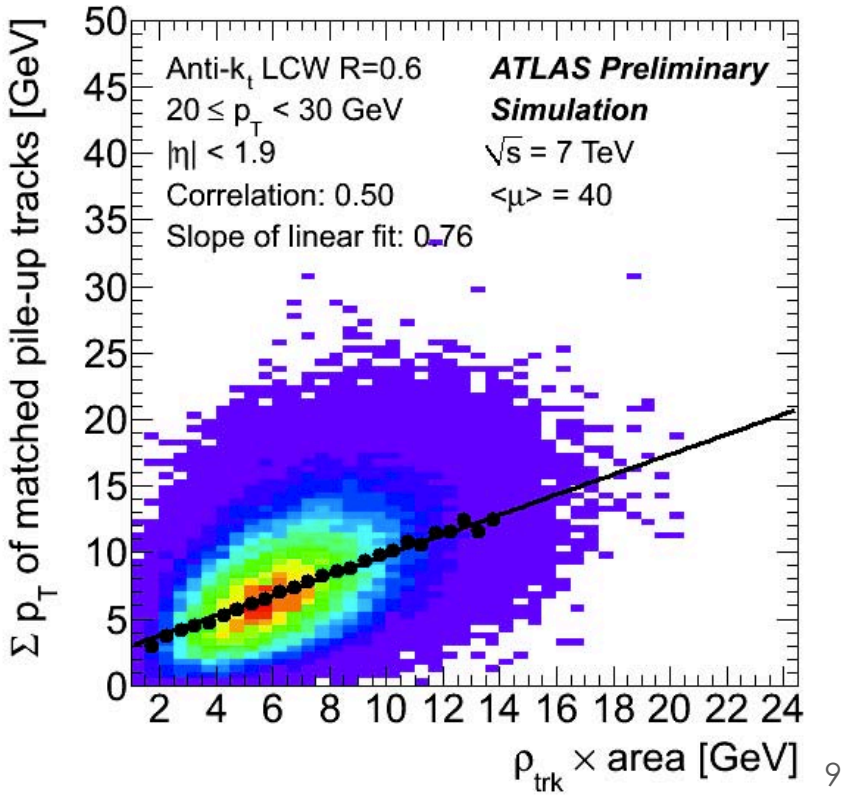
- Removes charged particles from pile-up vertices
- Used in combination with jet-areas





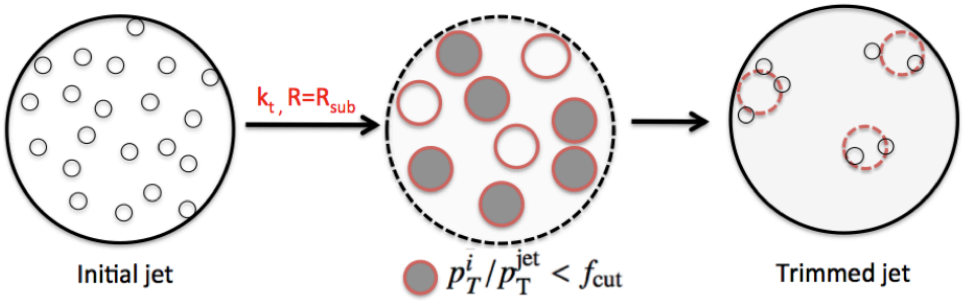
Track-based pile-up corrections (ATLAS)

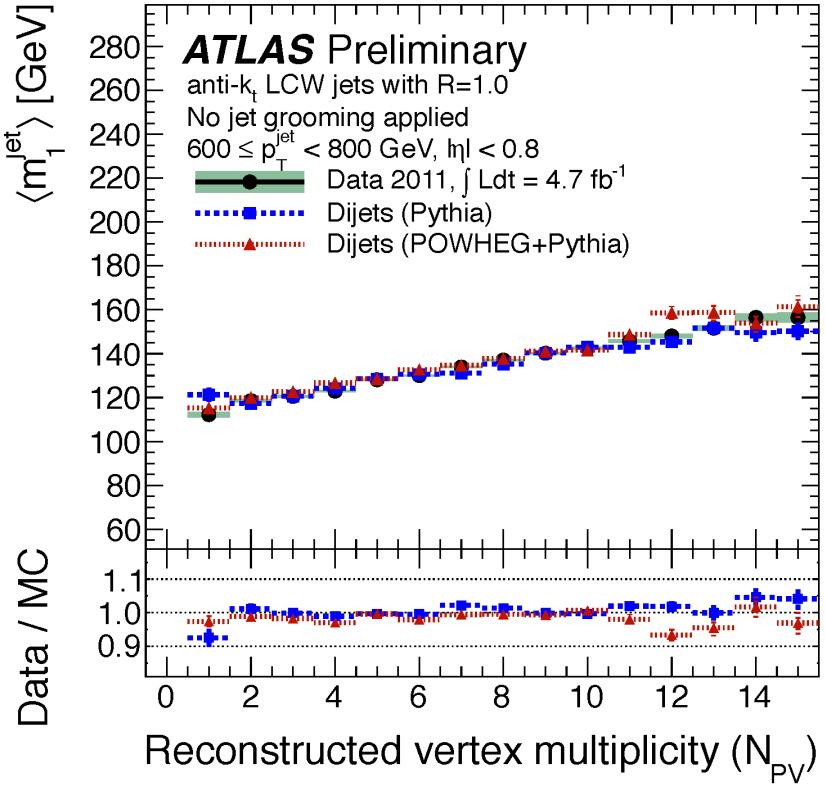
- Use track-jet p_T from pile-up vertices
- Exploit local fluctuations to improve resolution
- Not commissioned yet

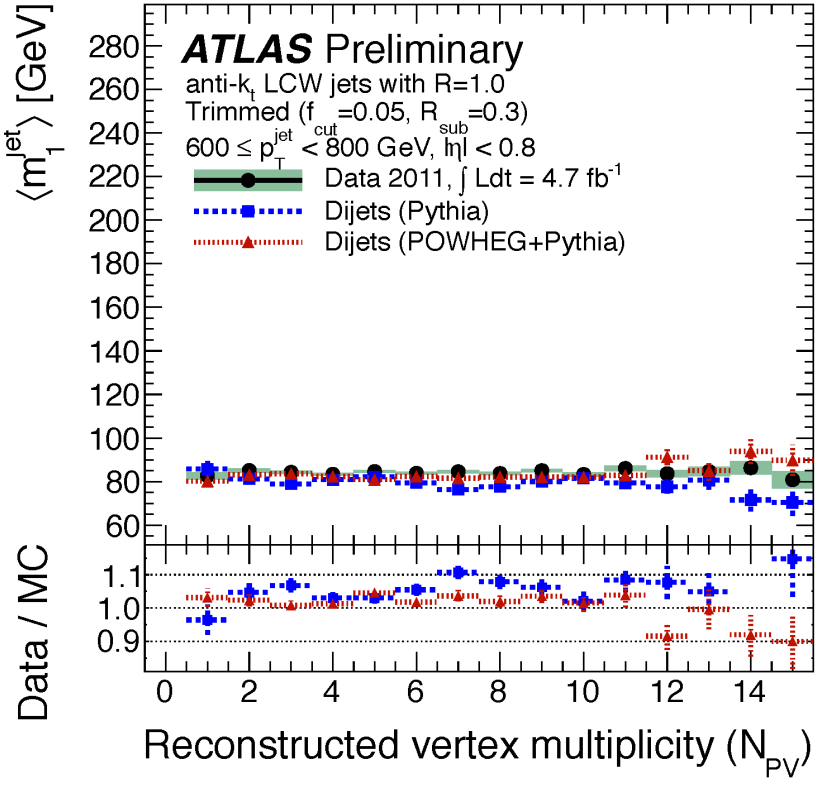


Jet grooming

- Grooming algorithms significantly reduce sensitivity to pile-up (reduced jet area)

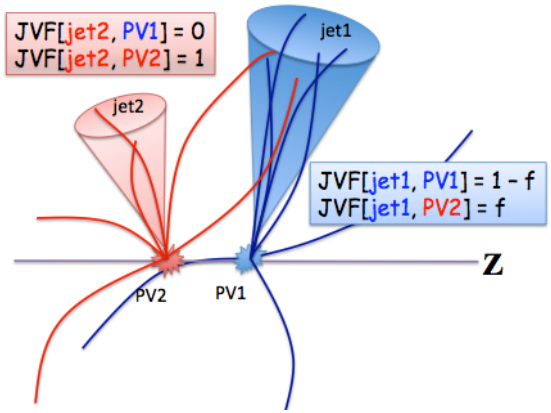






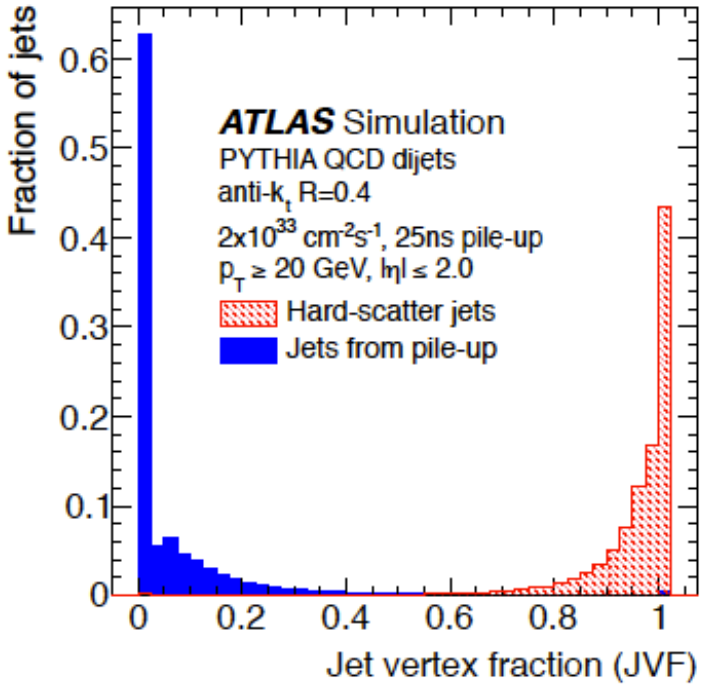
ATLAS-CONF-2012-065: https://cds.cern.ch/record/1459530

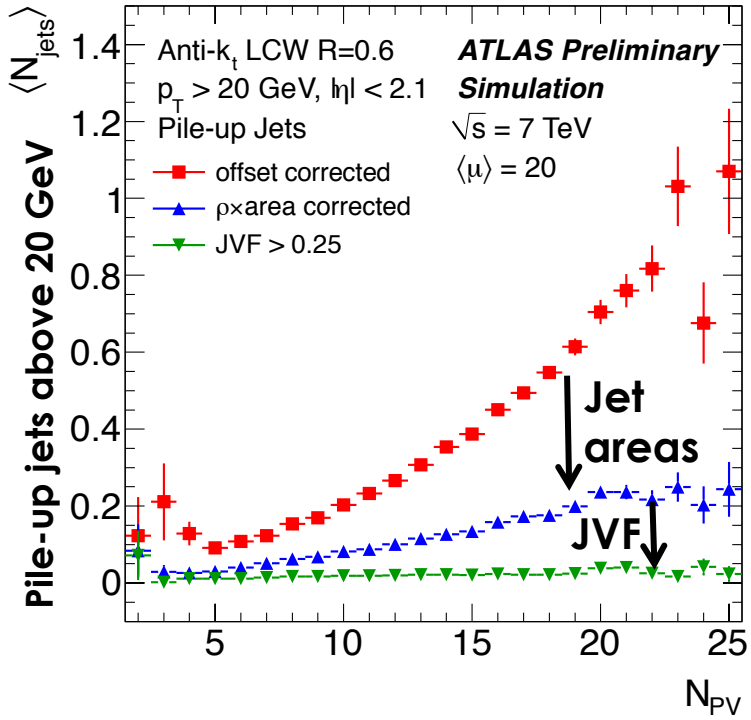
Pile-up suppression



- **Pile-up local fluctuations within a same event can lead to fake pile-up jets:**
  - Uniform distribution of particles from multiple interactions
  - Anomalous jet structure with no high p_T jet core
- **Reject fake jets from pile-up fluctuations:**
  - **Jet vertex fraction algorithm**
  - Investigating the use of **jet substructure** information

Jet Vertex Fraction (JVF)

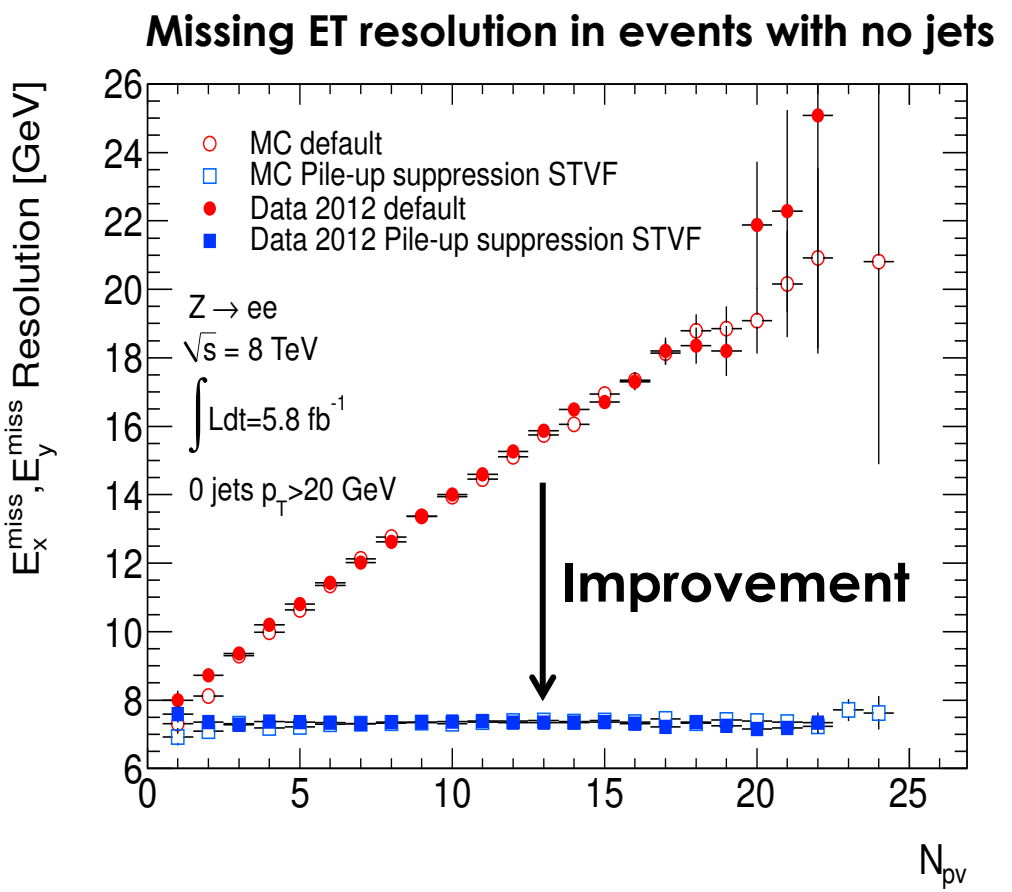




Missing ET

E_T(jets) + E_T(γ/e/μ/τ) + Soft term

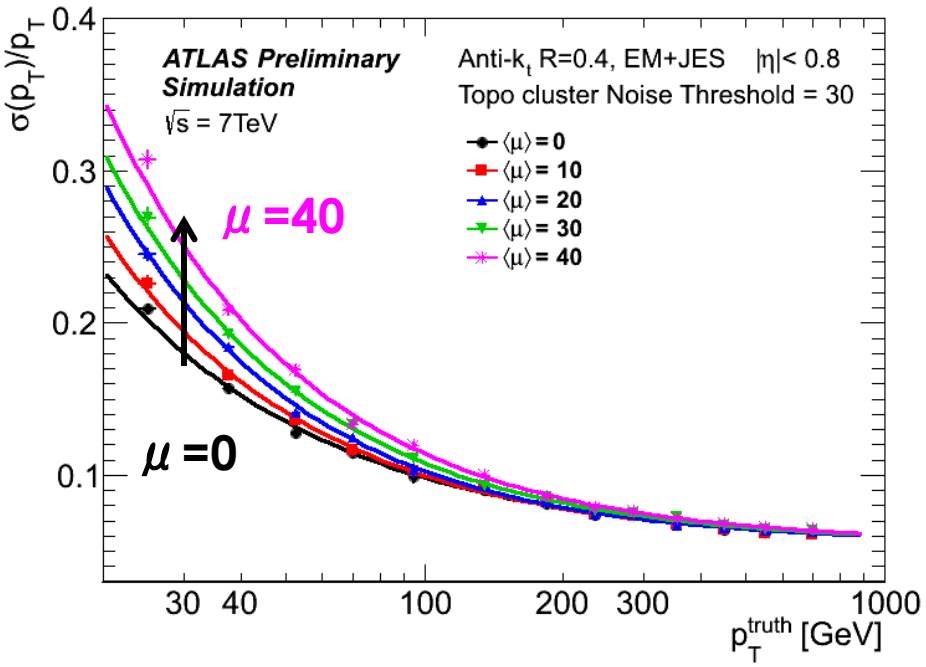
- **Pile-up is a major challenge for missing ET**
  - Very large worsening of the resolution
  - Large pile-up contributions to the soft term (CellOut)
- **Pile-up suppression using tracks: Soft Term Vertex Fraction (STVF)**
  - Extension of the JVF concept to the soft component of the missing ET

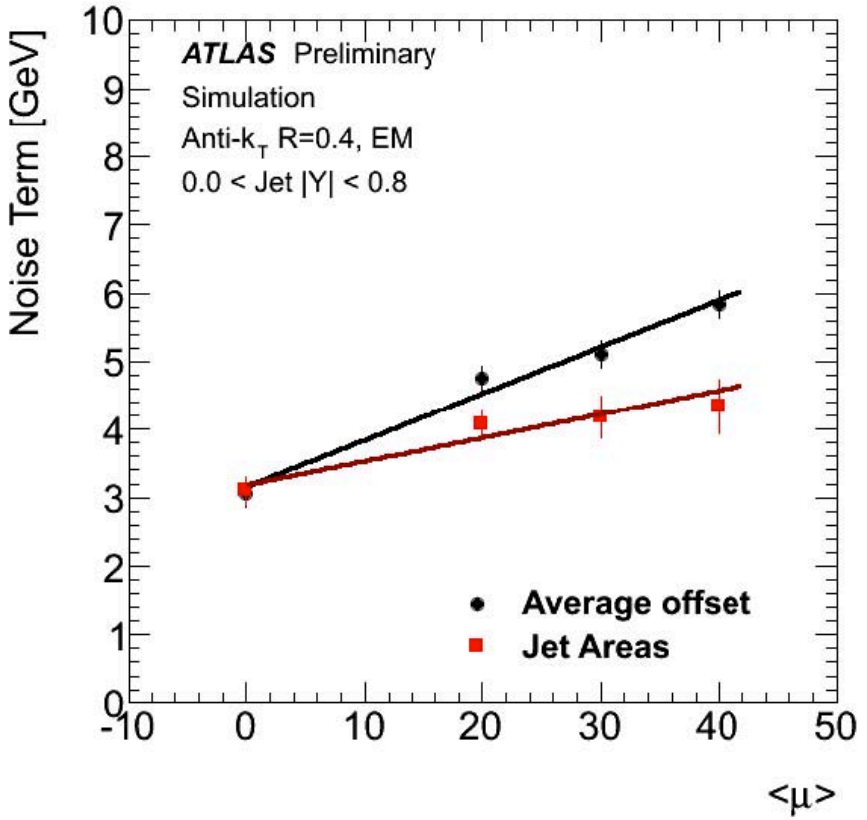


$$STVF = \left(\sum p_T^{track,PV} \Big/ \sum p_T^{track} \right)_{\substack{unmatched \\ objects}}$$

Towards very high luminosity

- **Significant increase of the noise term of the jet energy resolution**
- Non-linear effects due to topological clustering and cluster calibration degradation
  - Need to re-optimize input signals
  - Consider Heavy-Ion techniques

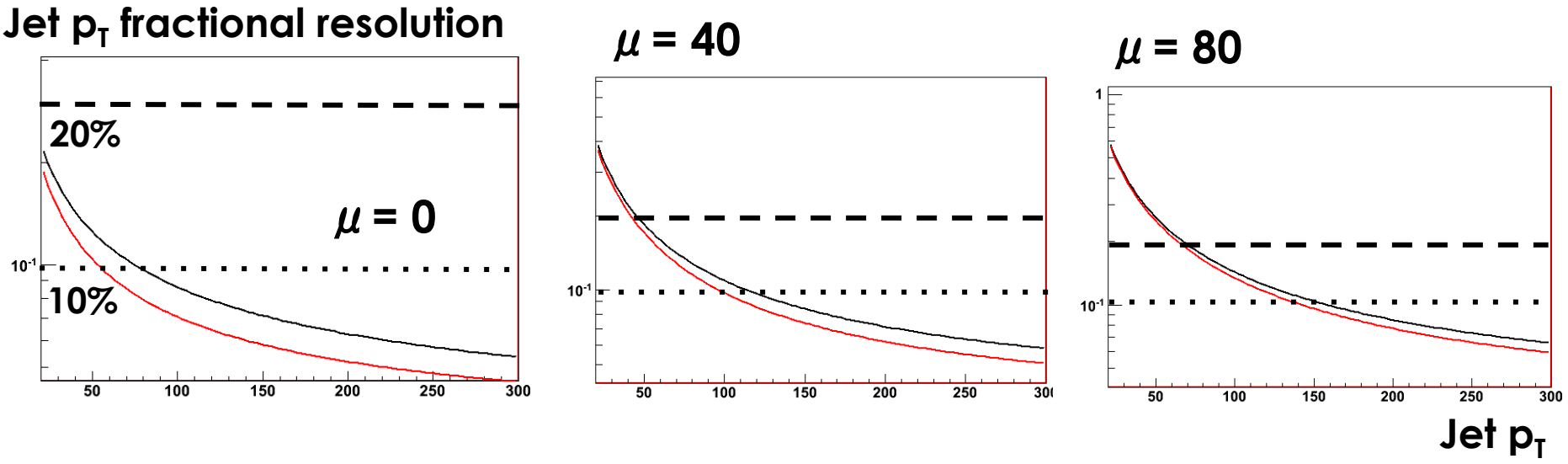




Extrapolated noise term at μ =150:
14 GeV (average offset)
8 GeV (jet-areas)

Towards very high luminosity

- Assume 25% improvement in stochastic term in different pile-up scenarios
  - **To the extent that pile-up fluctuations are reduced, improvements in stochastic term can be important**
- **At high luminosity, the key is to reduce pile-up fluctuations**



Black: jet energy resolution vs jet p_T

Red: jet energy resolution assuming 25% improvement in stochastic term

Summary

- **High pile-up introduces several challenges to jet and missing ET event reconstruction:**
  - Energy resolution
  - Fake jets
- **LHC experiments commissioned advanced pile-up subtraction and suppression techniques that mitigate the effect of pile-up in events with $<\mu>$~30:**
  - Event-by-event jet areas correction
  - Jet Vertex Fraction, Soft Term fraction, and Charged Hadron Subtraction
- **Very high luminosity will require to focus on methods to reduce pile-up fluctuations:**
  - Optimized calorimeter input signals
  - Grooming and jet-areas subtraction
  - Jet substructure to reject of fake pile-up jets
  - More use of tracking information
  - Ideas from heavy-ion jet reconstruction