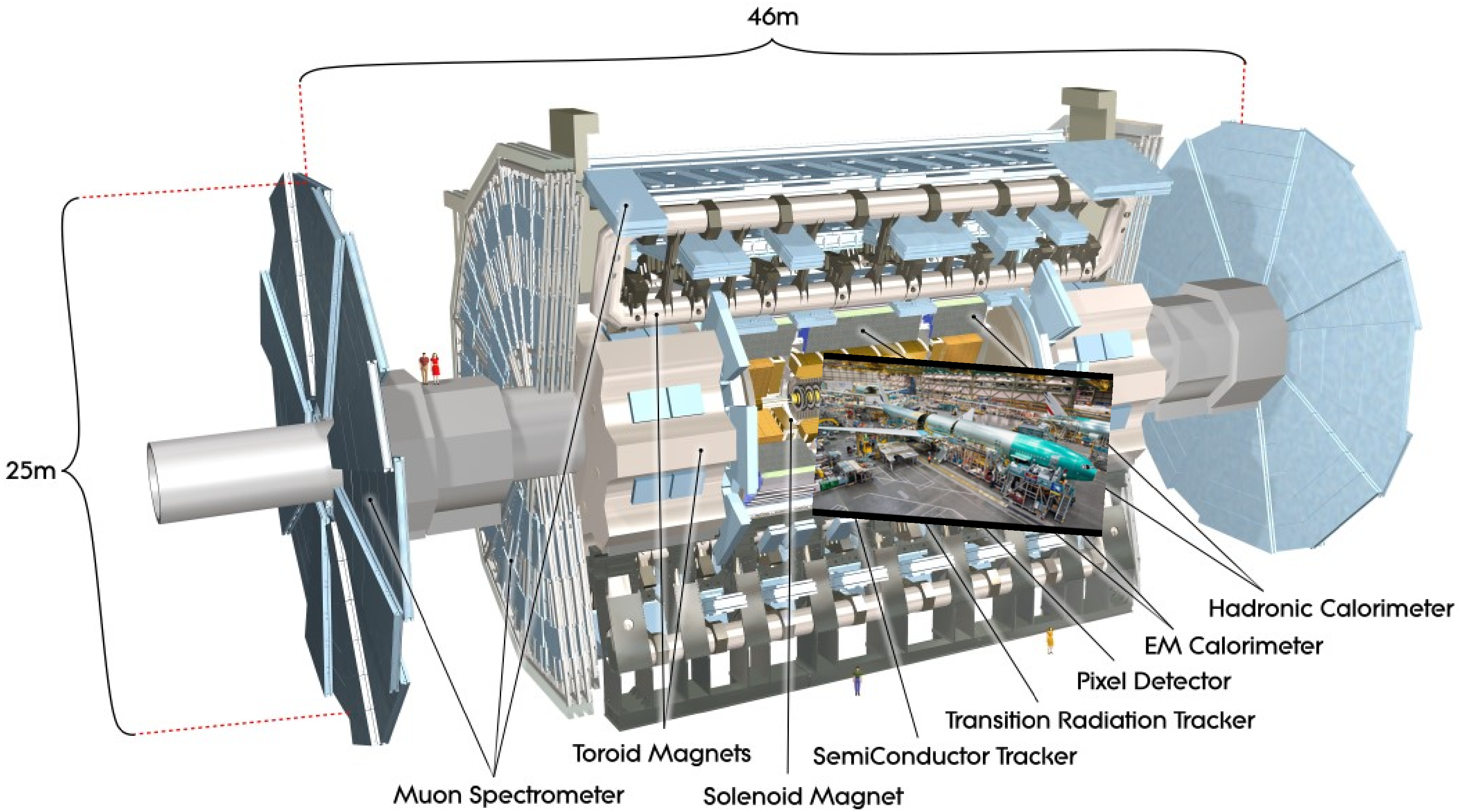
Inputs and Procedures of Jet Reconstruction in ATLAS



Chaowaroj (Max) Wanotayaroj
on behalf of the ATLAS Collaboration

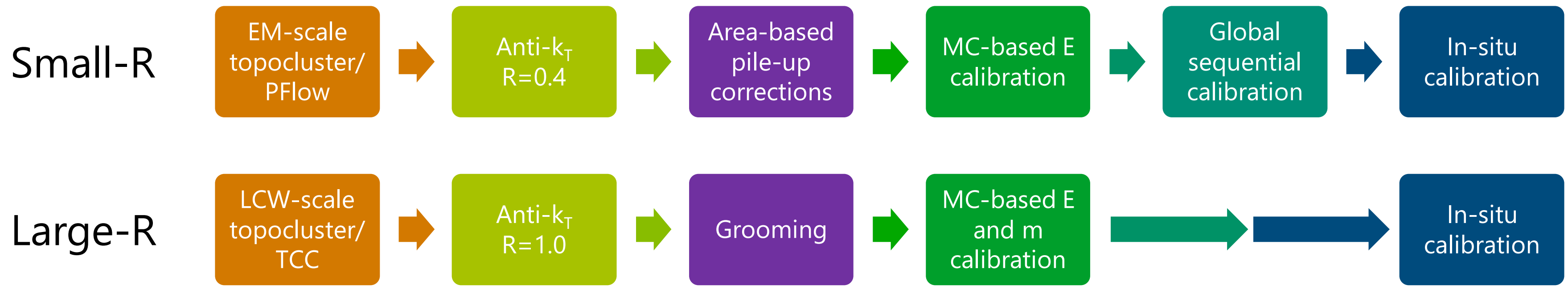
Intro

- Jets are important for almost all ATLAS analyses
- Most use anti-k_T jets with R=0.4 (small-R) or R=1.0 (large-R)
  - Some use both
  - Also looking at other sizes in some cases
- How we build and calibrate jets has wide-reaching impact
  - ➢ What is(are) the best choice(s)?
- Jet energy scale uncertainty and jet energy resolution dominate many searches and measurements
  - ➢ Work to reduce these uncertainties as much as possible

Jet Reco and Calibration Chain

1. Inputs
2. Jet reconstruction
3. Pile-up corrections
4. MC-based calibration
   - Match truth to reco jets, then calculate reco/truth “response”
   - Correct the jet 4-momentum to truth level
5. In-situ calibration for data

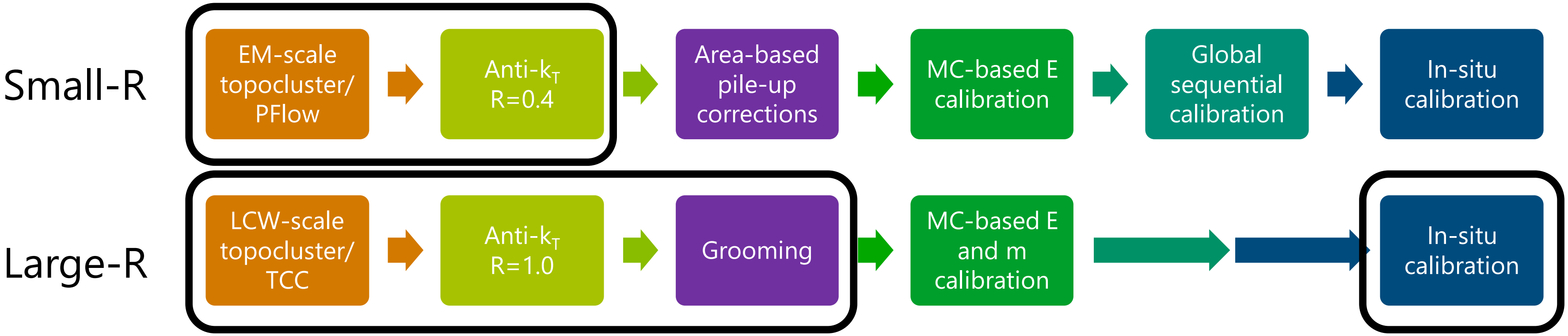
Jet Reco and Calibration Chain



1. Inputs
2. Jet reconstruction
3. Pile-up corrections
4. MC-based calibration
   - Match truth to reco jets, then calculate reco/truth "response"
   - Correct the jet 4-momentum to particle level

   4.1 (small-R) Global sequential calibration
   - Reduce flavor dependence and correct various detector effects
5. In-situ calibration for data

Outline



1. Small-R, update on jet energy scale/resolution (JES/JER)
2. Large-R, in-situ calibration with 80 fb^{-1}
3. Large-R, alternative inputs and grooming strategies

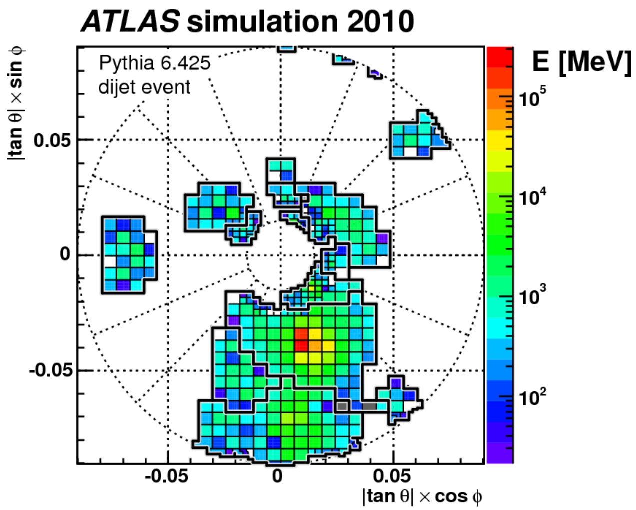
Small-R JES/JER

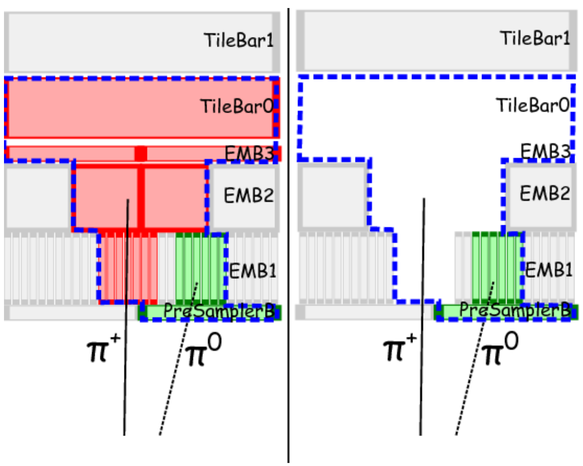
Taking advantage of particle flow jets

Jet Inputs

PERF-2014-07, PERF-2015-09

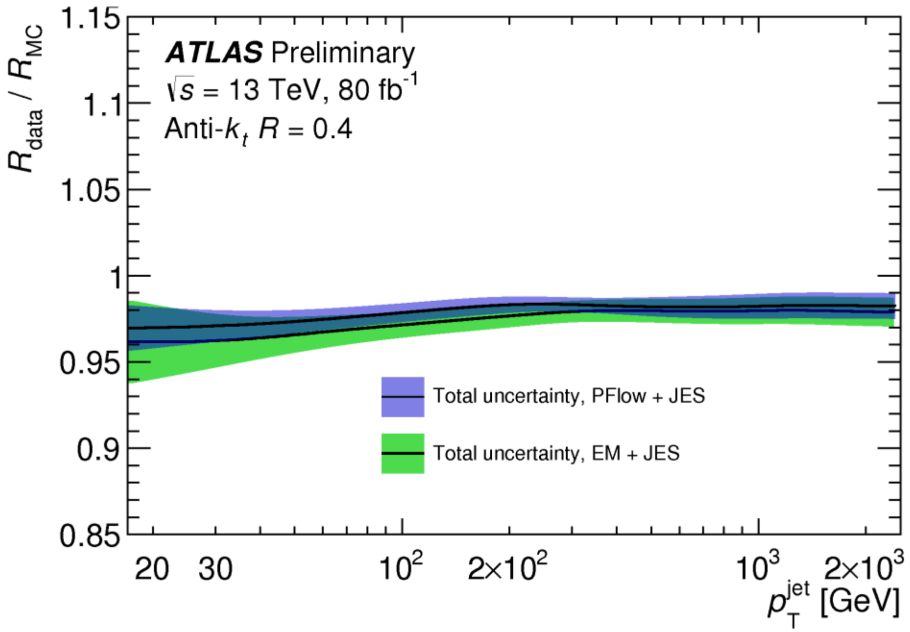
- Topocluster: calorimeters only
  - 4σ-above-noise seed cells, iteratively add all 2σ neighbors and cells surrounding them
  - These are called EM-scale topoclusters
  - Topocluster are corrected to point at the primary vertex (origin correction)
- Particle flow (PFlow): Subtract matched tracks' momentum from topoclusters
  - Remaining clusters and tracks form PFlow objects
  - Only PFlow objects matched to primary vertex tracks are used for jet building
  - Great performance for low p_T

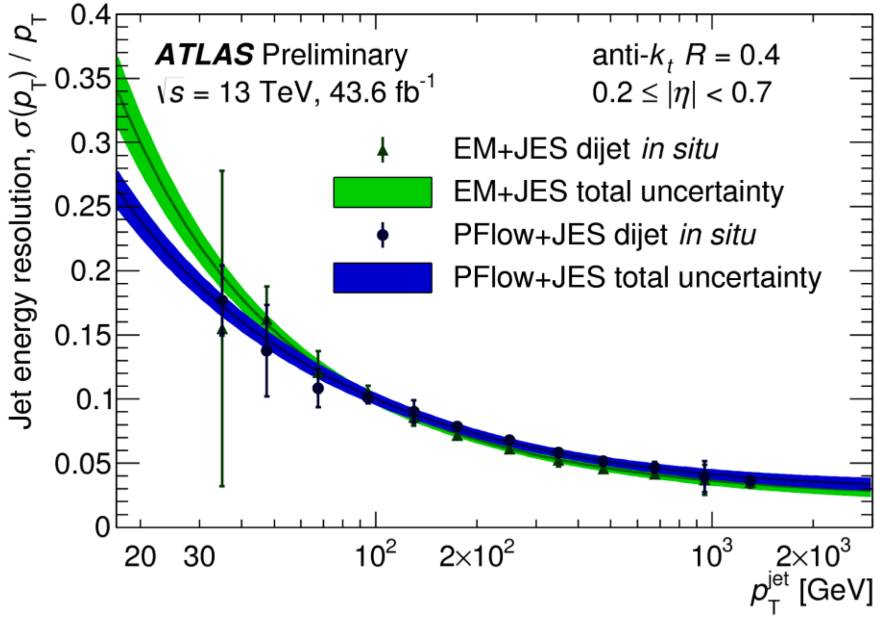




PFlow/EM-scale Jets Resolution

JETM-2018-005





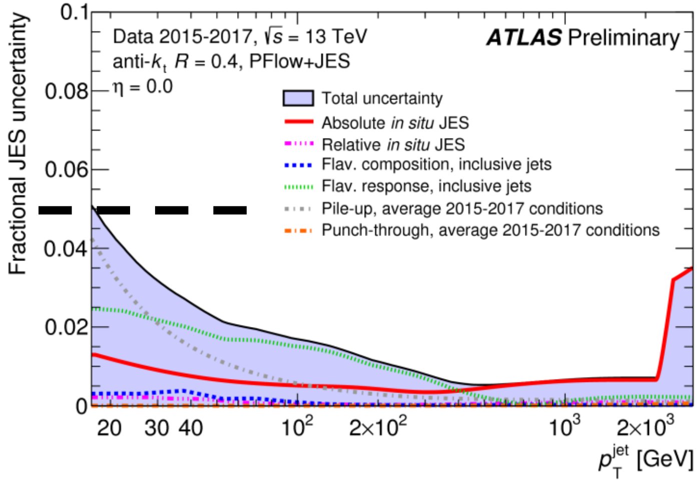
- ATLAS jet usage is moving toward PFlow
- It is now the primary option in ATLAS
  - Better response
  - Better resolution at low p_T, and comparable to EM-scale at high p_T
- EM-scale topocluster jets still used by some analyses

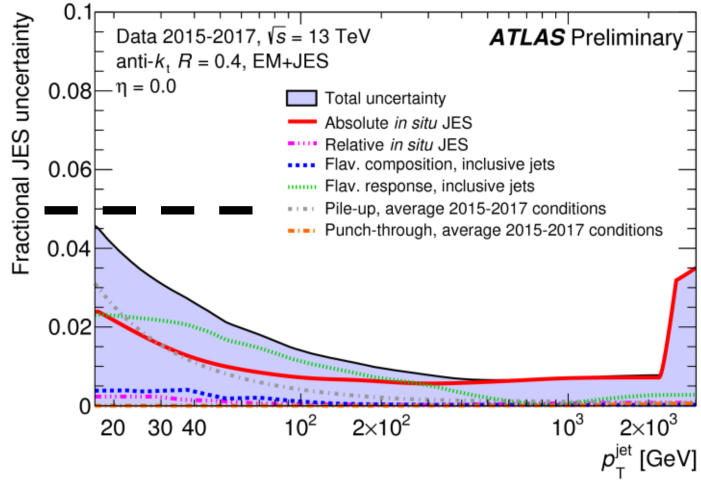
JES/JER Uncertainty

JETM-2018-005, JETM-2018-006

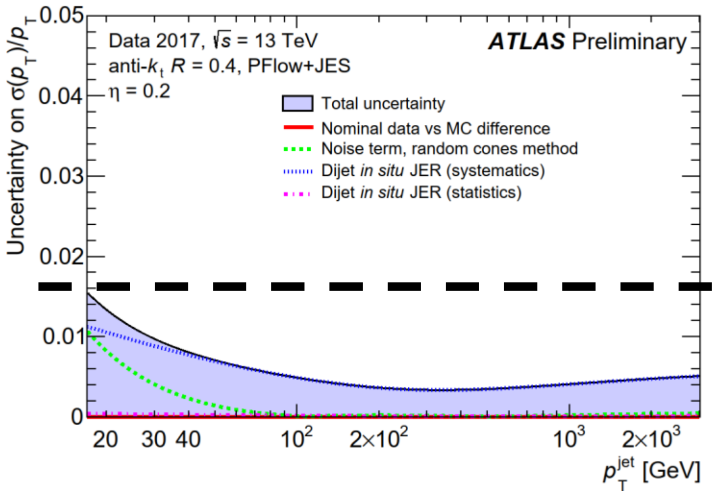
Particle flow | EM-scale Topocluster

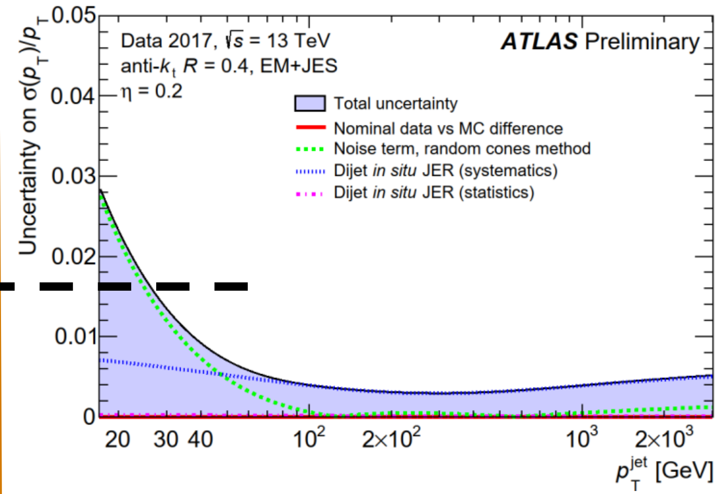
JES uncertainty





JER uncertainty





- PFlow jets have comparable JES uncertainty, and much better JER uncertainty at low p_T compared to topocluster jets

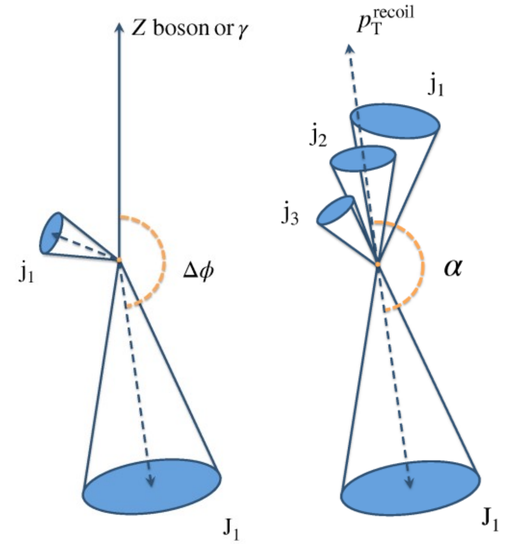
Large-R, In-situ Calibration

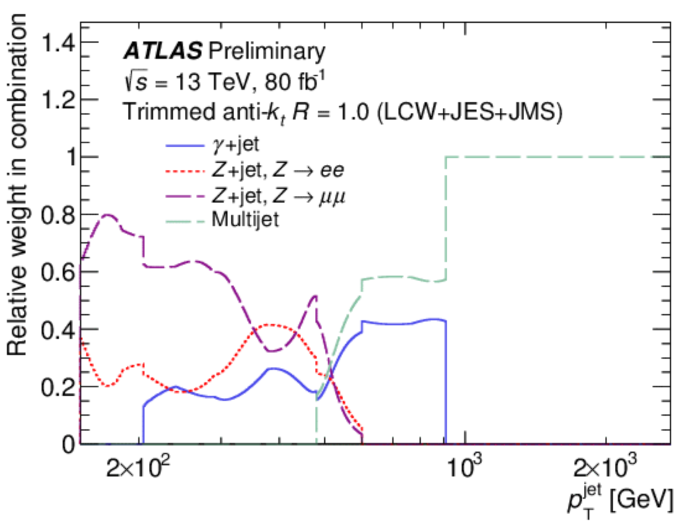
Updated with 80 fb^{-1}

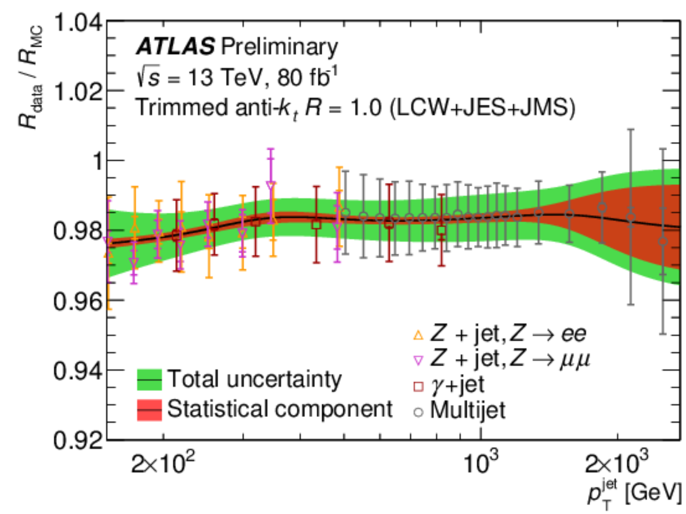
In-situ Calibration—JES

JETM-2019-05, Eur. Phys. J. C 79 (2019) 135

- Derived from a jet recoiling against a well-measured object:
  1. Z boson or γ as reference objects
  2. Several lower-p_T small-R jets for high-p_T jets
- Combining three techniques to cover the full p_T range
  - Z+jet method runs out of statistics ~450 GeV
  - γ+jet is used until ~1 TeV
  - Use multijet method above that threshold
- Combine methods in overlapping regions
  - Overall uncertainty can be reduced as overlapping regions agree and each method's uncertainties are mostly independent



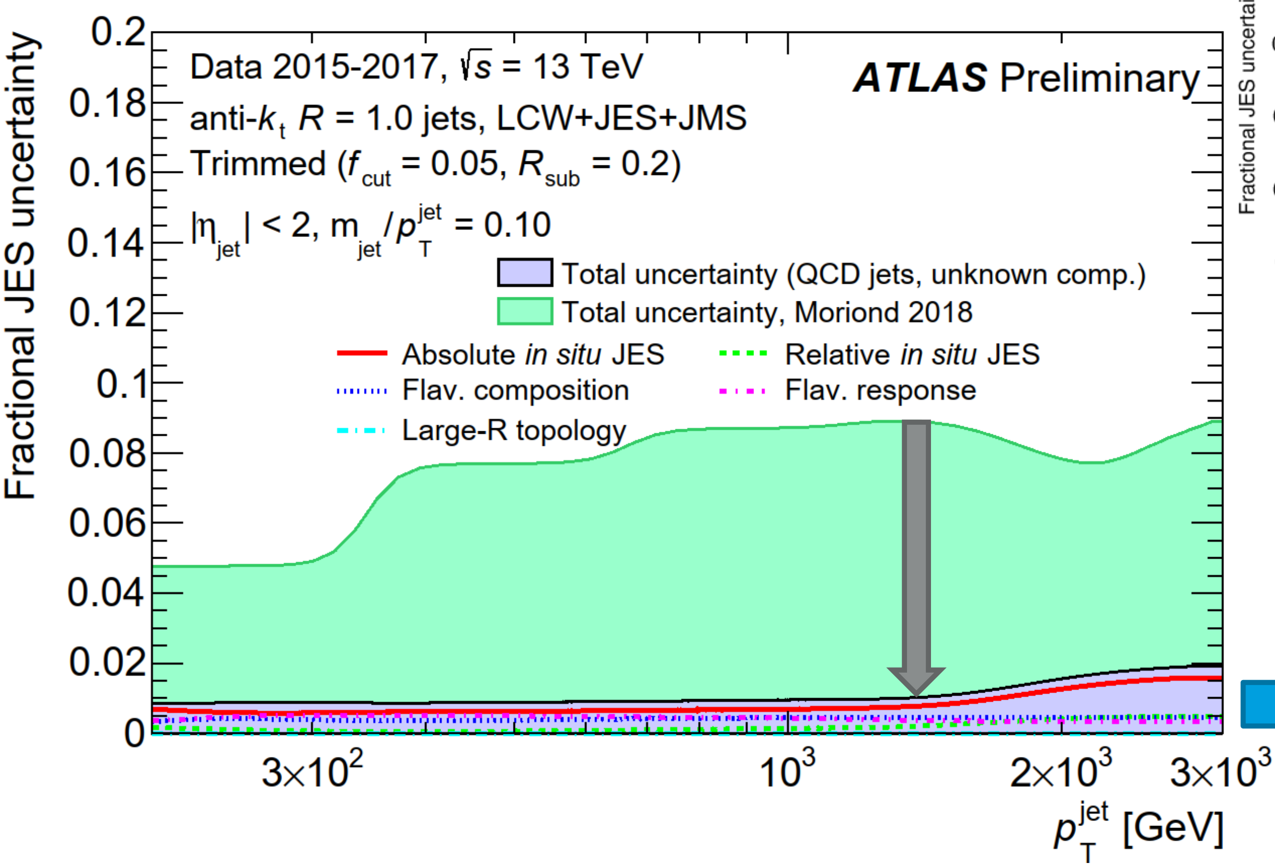


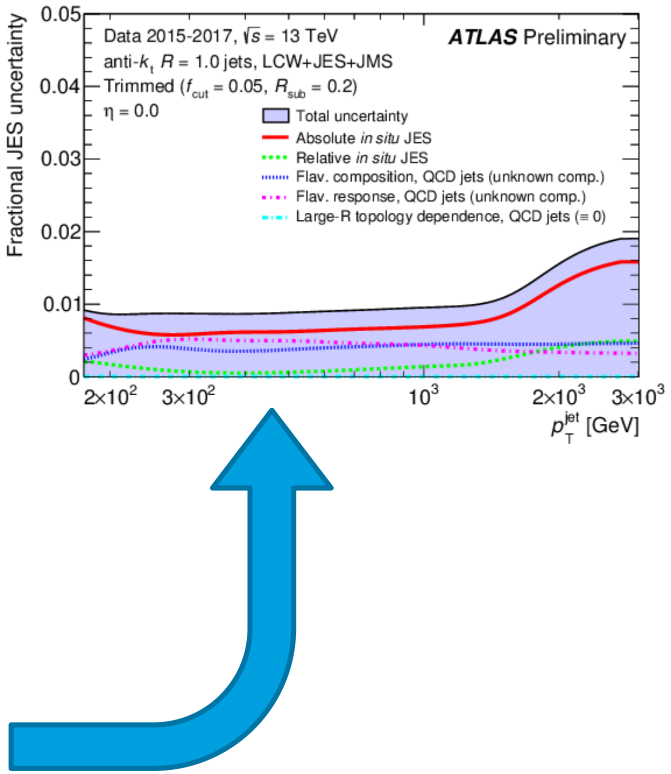


JES Uncertainty

JETM-2019-05 , Eur. Phys. J. C 79 (2019) 135

- Large reduction compared to without in-situ calibration
  - Total uncertainty depends on the assumption of the topology (W, Z, or top) and flavor (quark or gluon initiated) composition of the jets

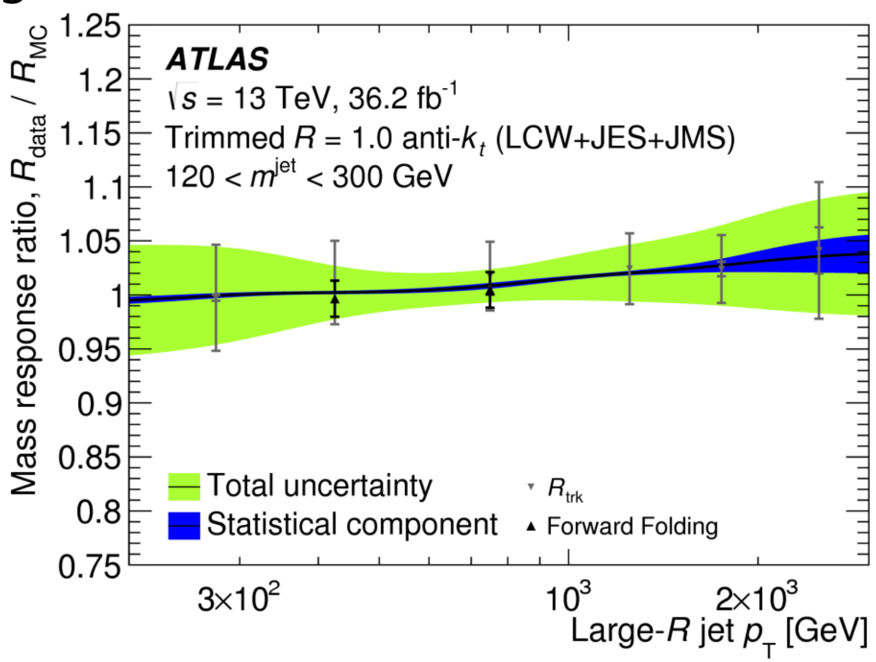




In-situ Calibration—JMS/JMR

[Eur. Phys. J. C 79 (2019) 135]

- For large-R jets, we also need in-situ calibration for the mass
- Two methods for in-situ mass calibration:
  1. Forward-folding: Use high purity top sample, shift and stretch jet mass resolution function so that the simulation matches the data
  2. $R^{m}_{track} = \frac{m_{track}}{m_{calo}}$: Tracker provides an independent (charged only) measurement of a jet, so any deviation of the double ratio, $\frac{R_{MC}}{R_{Data}}$, from 1 provides an estimate of the scale uncertainty
- Forward-folding has smaller uncertainty, but R_{track} covers a much broader p_T and mass range



Large-R, Alternative Inputs and Jet Grooming

Inputs, constituent-level pile-up suppressions, and grooming scan

Large-R Jet Inputs

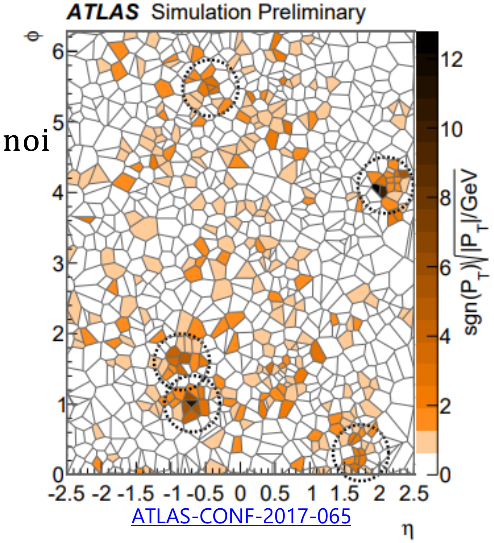
- Topocluster: calorimeters only
  - 4σ-above-noise seed cells, add all 2σ neighbors and cells surrounding them
  - Calibrate to account for EM and HAD differences, dead material and out-of-cluster deposits to get Local Cell Weighting (LCW) topoclusters
  - Topocluster are corrected to point at the primary vertex (origin correction)
- Particle flow (PFlow): Subtract matched tracks' momentum from topoclusters
  - Remaining clusters and hard-scatter tracks form PFlow objects
  - Remove PFlow object matched to non-primary vertex tracks
  - Great performance for low p_T
- Track-CaloCluster (TCC): Use energy from topoclusters and angle from tracks
  - For multiple-to-multiple matching, energy is shared among tracks to create multiple TCC objects
  - Remove TCC objects with non-primary vertex tracks
  - Great performance for high p_T

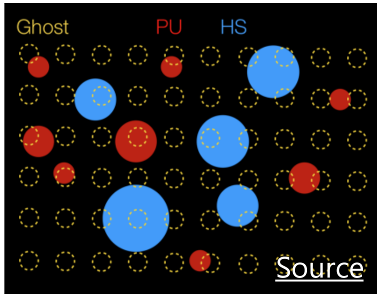
Pile-up Correction

- From inputs:
  - Topocluster: noise suppression
  - PFlow/TCC: charged objects not associated with primary vertex are rejected
- Constituents-level (topocluster) correction:
  - Voronoi Subtraction (VS): correct constituent's energy by $\rho \cdot A_{\text{Voronoi}}$
    - ρ: transverse momentum density
  - Constituent Subtraction (CS): Add ghosts with $p_T^g = \rho \cdot A_g$ then:

$$\begin{aligned} \text{If } p_{\mathrm{T,i}} \geq p^g_{\mathrm{T,k}}: \quad & p_{\mathrm{T,i}} \longrightarrow p_{\mathrm{T,i}} - p^g_{\mathrm{T,k}}, \\ & p^g_{\mathrm{T,k}} \longrightarrow 0 \text{ GeV}; \\ \text{otherwise:} \quad & p^g_{\mathrm{T,k}} \longrightarrow p^g_{\mathrm{T,k}} - p_{\mathrm{T,i}}, \\ & p_{\mathrm{T,i}} \longrightarrow 0 \text{ GeV}, \end{aligned}$$

  - SoftKiller (SK): p_T cut so half of $\eta - \phi$ grid spaces are empty
  - PUPPI: p_T cut based on information from nearby constituents





- Jet-level: Grooming

New!

Grooming Algorithm	Name	Parameters Tested
Soft Drop	SD	$(z_{\text{cut}}, \beta) \in [0.1] \times [0, 0.5, 1]$
Bottom-up Soft Drop	BUSD	$(z_{\text{cut}}, \beta) \in [0.05, 0.1] \times [0, 0.5, 1]$
Recursive Soft Drop	RSD	$(z_{\text{cut}}, \beta, N) \in [0.05, 0.1] \times [0, 0.5, 1] \times [2,3,5,\infty]$
Pruning	Pruned	$(z_{\text{cut}}, R_{\text{cut}}) \in [0.15] \times [0.25]$
Trimming	Trimmed	$(f_{\text{cut}}, R_{\text{sub}}) \in [5, 9]\% \times [0.1, 0.2]$

Based on previous study (ATL-PHYS-PUB-2017-020)

Large-R Jet Performance Study

ATL-PHYS-PUB-2019-027

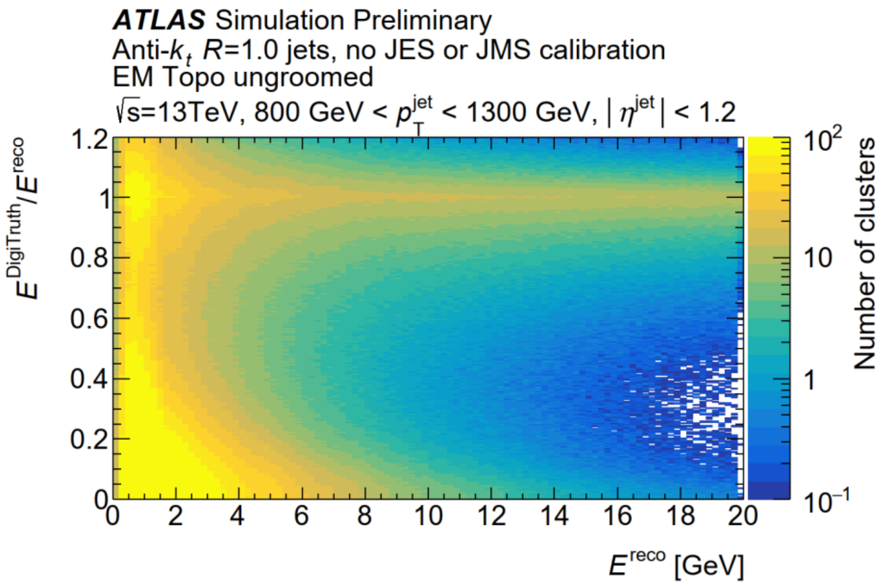
- Three inputs (Topocluster, PFlow, TCC)
- Many pile-up suppression techniques
  - Some of them can also be combined
  - Based on previous study (ATL-PHYS-PUB-2017-020), we choose:
    - Constituent Subtraction + SoftKiller (CS+SK)
    - Voronoi Subtraction + SoftKiller (VS+SK)
    - PUPPI for PFlow only

Two methods:

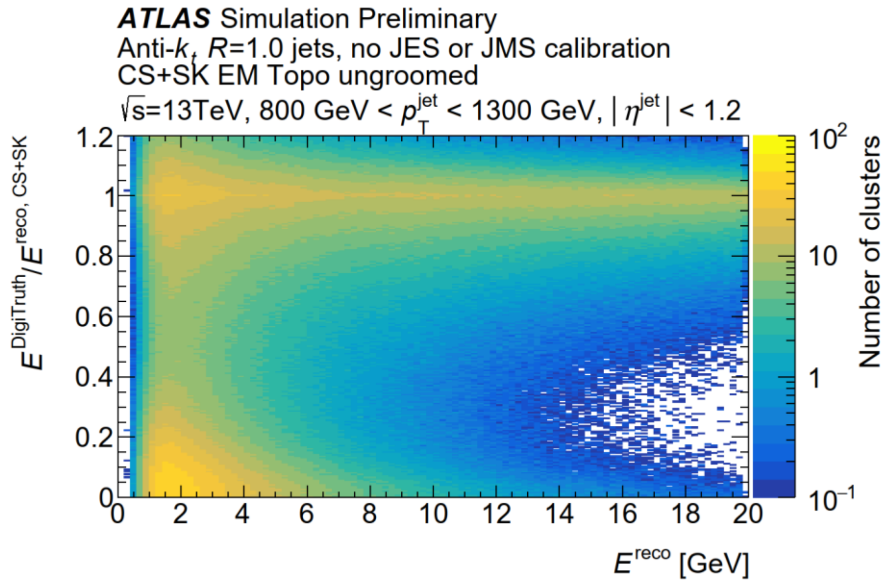
1. Compare the impact of different pile-up mitigation techniques on individual clusters with and without pile-up included in simulation (“DigiTruth”)
2. Scan over choices of input, constituent-level pile-up suppression, and grooming, and compare them with ATLAS’ standard trimmed jet
   - Compare the performance. Specifically:
     - Pile-up stability
     - Topology dependence
     - Tagging performance

DigiTruth Study

ATL-PHYS-PUB-2019-027



Ungroomed

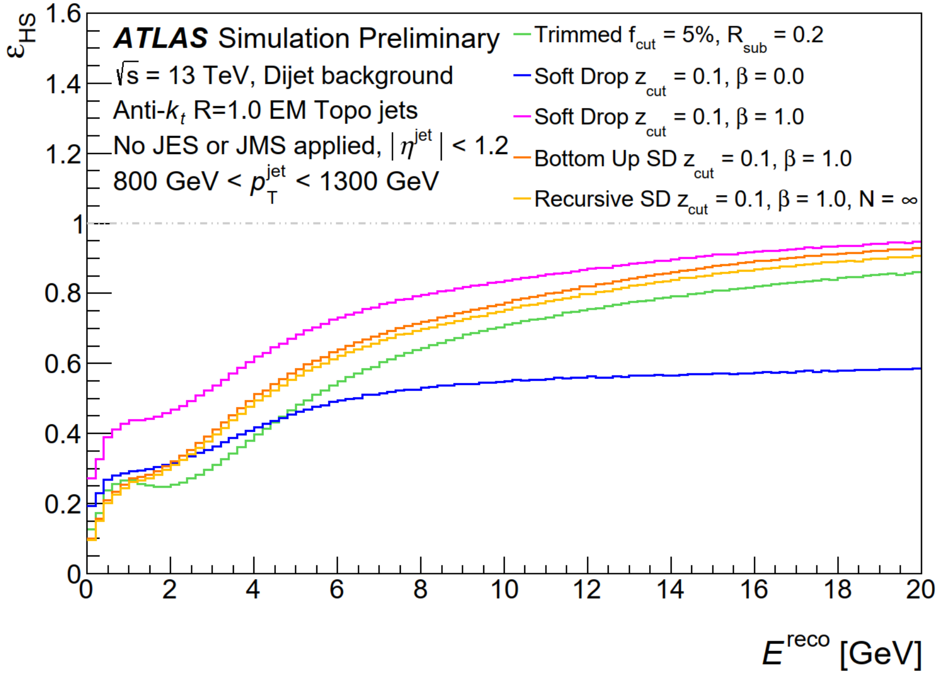


Ungroomed with CS+SK

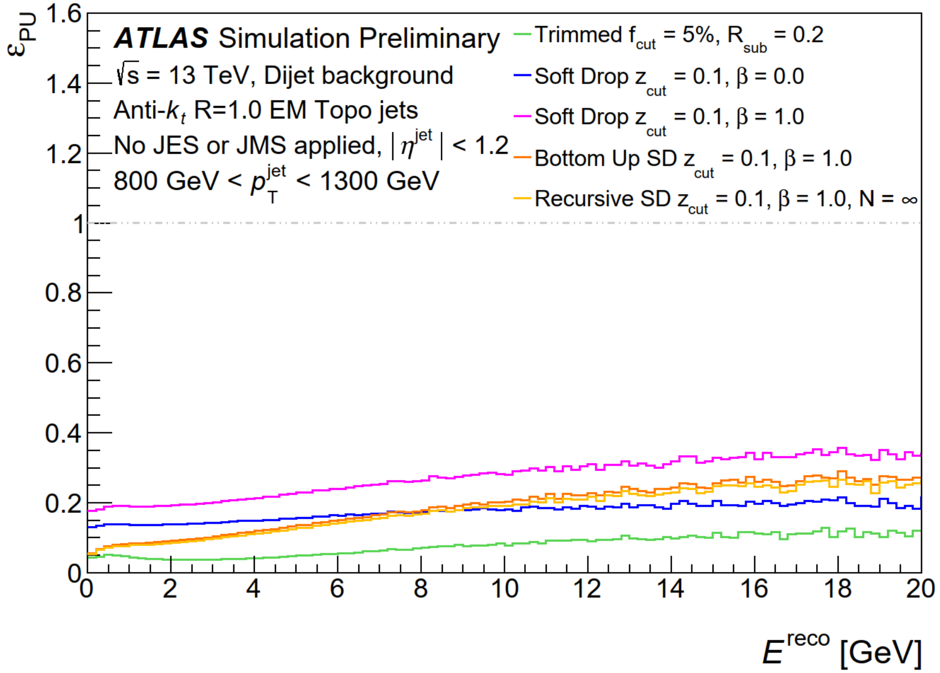
- Showing $E^{DigiTruth}$ (no pile-up) over E^{reco} (with pile-up)
  - $E^{DigiTruth}$ does include underlying event → 1 is not necessary the ideal value
- Majority of clusters tend to be dominated by hard-scatter (HS) or pile-up (PU)
  - So we will call $\frac{E^{DigiTruth}}{E^{reco}}$>0.5 a HS cluster and <0.5 a PU cluster
- CS+SK is removing pile-up; HS clusters are more pronounced

DigiTruth Study

ATL-PHYS-PUB-2019-027



Hard-scatter cluster efficiency (1 is better)

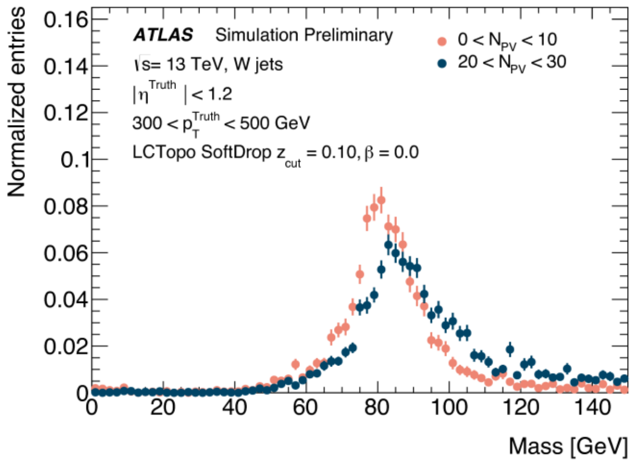


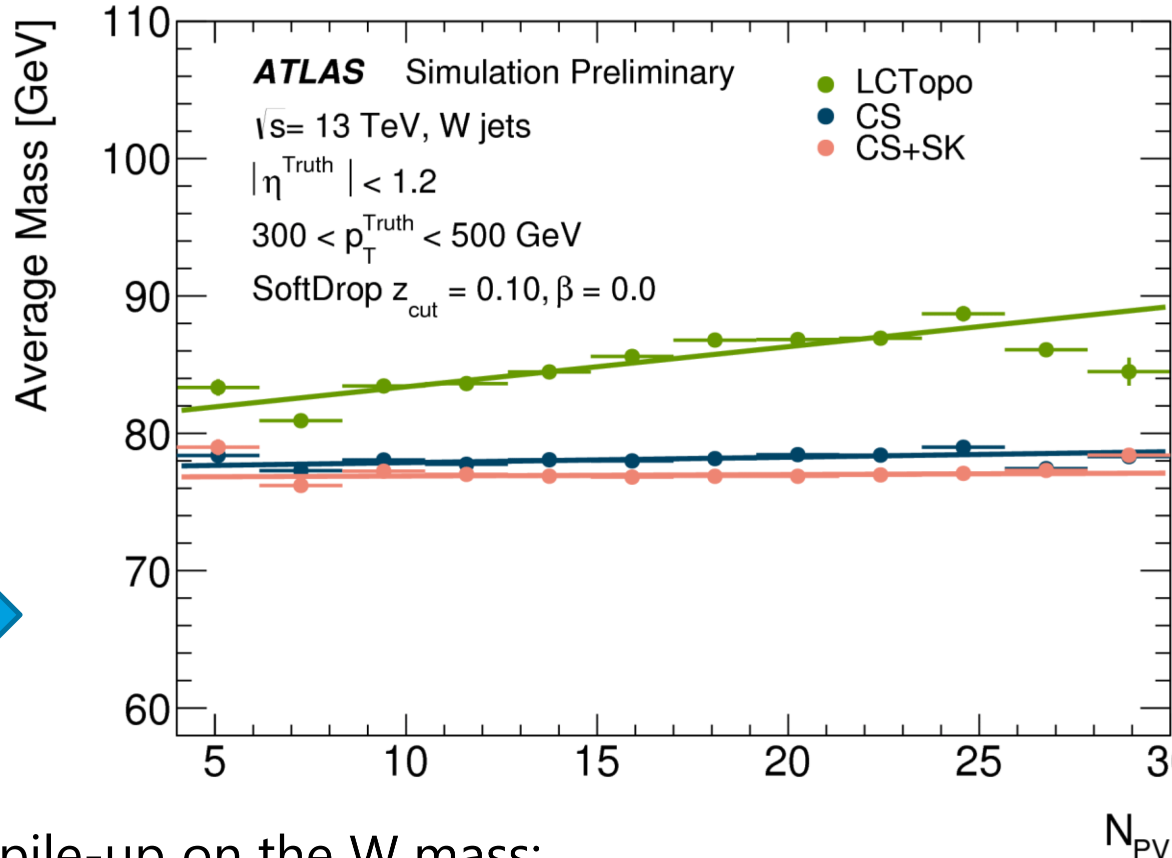
Pile-up cluster efficiency (0 is better)

- All algorithms remove more pile-up than hard-scatter clusters
- Standard ATLAS trimming is doing well

Pile-up Stability—Mass

ATL-PHYS-PUB-2017-020

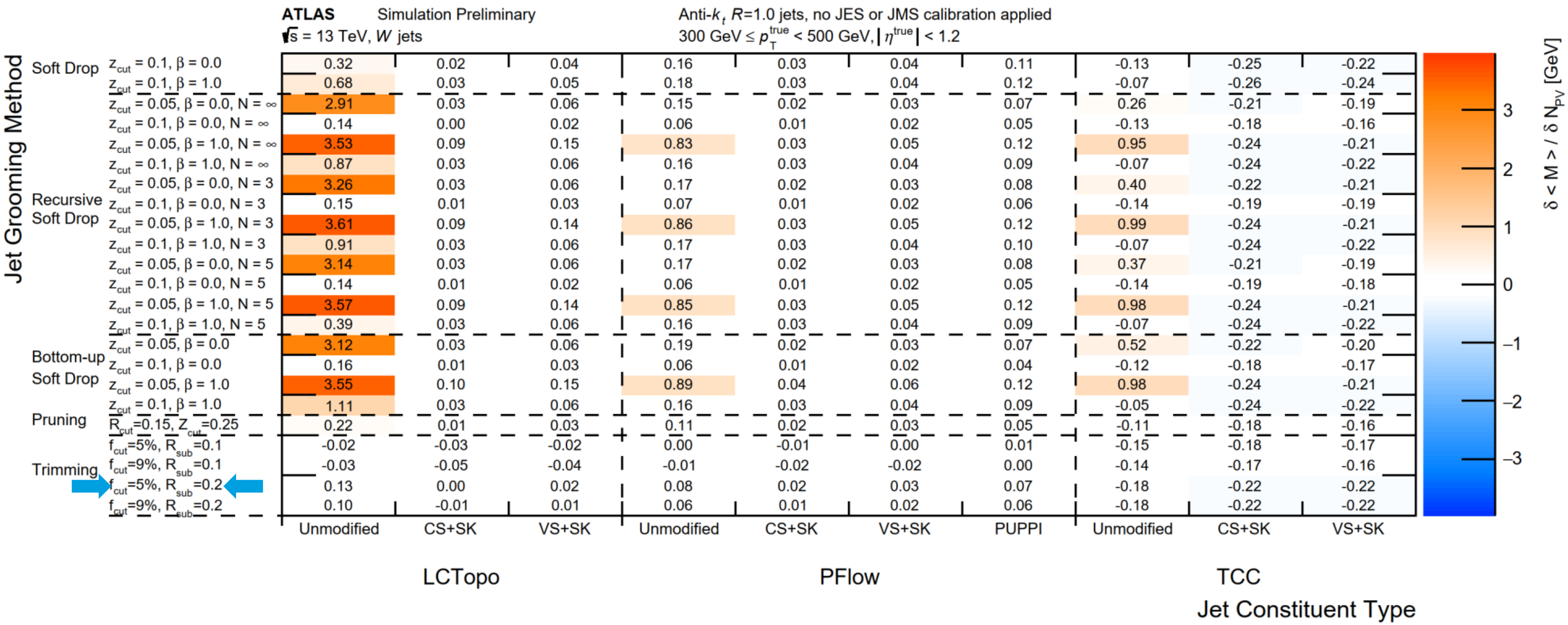




- Quantifying the effect of pile-up on the W mass:
  1. Take the mass distribution of W-jet sample in a N_{PV} bin
  2. Fit a Gaussian on the W mass peak
  3. Plot either the central value or the width as a function of N_{PV}
  4. Fit a line and measure the slope

W Mass Peak Values Slope

ATL-PHYS-PUB-2019-027

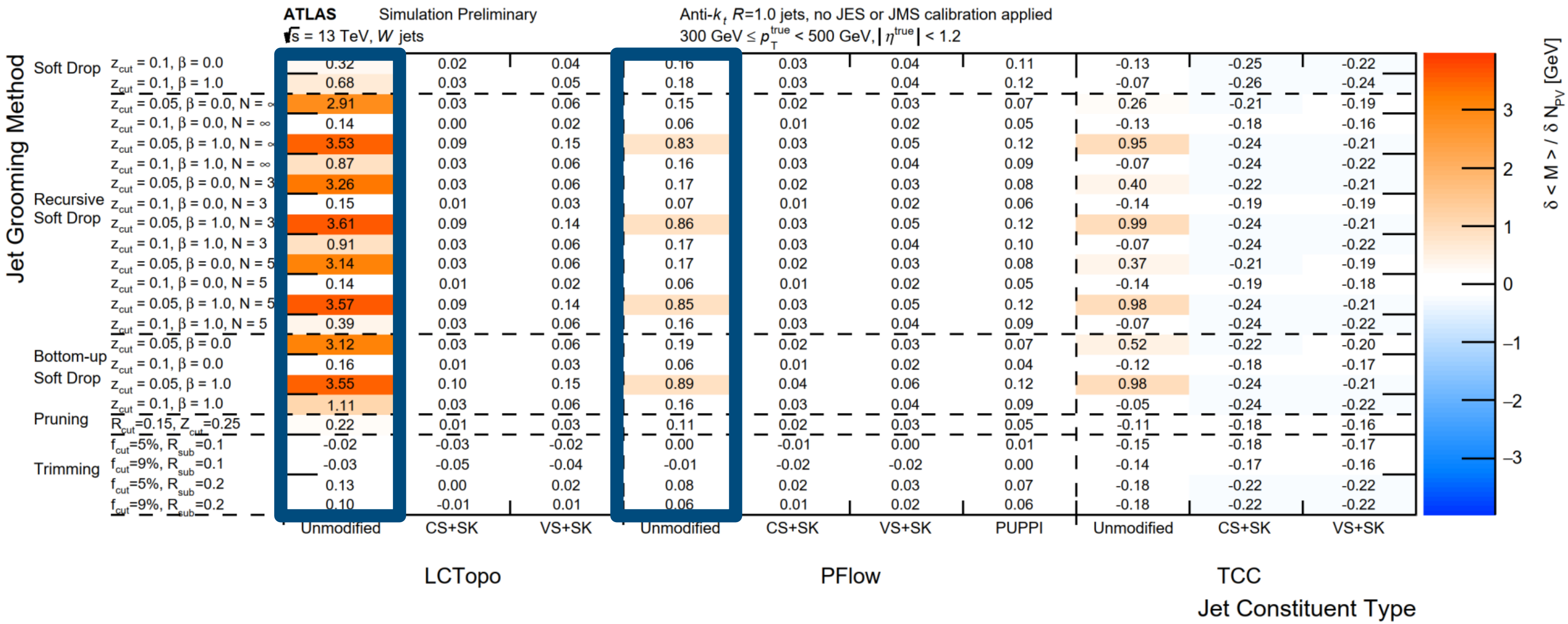


Jet Grooming Method		LCTopo Unmodified	LCTopo CS+SK	LCTopo VS+SK	PFlow Unmodified	PFlow CS+SK	PFlow VS+SK	PFlow PUPPI	TCC Unmodified	TCC CS+SK	TCC VS+SK
Soft Drop	z_{cut} = 0.1, β = 0.0	0.32	0.02	0.04	0.16	0.03	0.04	0.11	-0.13	-0.25	-0.22
	z_{cut} = 0.1, β = 1.0	0.68	0.03	0.05	0.18	0.03	0.04	0.12	-0.07	-0.26	-0.24
Recursive Soft Drop	z_{cut} = 0.05, β = 0.0, N = ∞	2.91	0.03	0.06	0.15	0.02	0.03	0.07	0.26	-0.21	-0.19
	z_{cut} = 0.1, β = 0.0, N = ∞	0.14	0.00	0.02	0.06	0.01	0.02	0.05	-0.13	-0.18	-0.16
	z_{cut} = 0.05, β = 1.0, N = ∞	3.53	0.09	0.15	0.83	0.03	0.05	0.12	0.95	-0.24	-0.21
	z_{cut} = 0.1, β = 1.0, N = ∞	0.87	0.03	0.06	0.16	0.03	0.04	0.09	-0.07	-0.24	-0.22
	z_{cut} = 0.05, β = 0.0, N = 3	3.26	0.03	0.06	0.17	0.02	0.03	0.08	0.40	-0.22	-0.21
	z_{cut} = 0.1, β = 0.0, N = 3	0.15	0.01	0.03	0.07	0.01	0.02	0.06	-0.14	-0.19	-0.19
	z_{cut} = 0.05, β = 1.0, N = 3	3.61	0.09	0.14	0.86	0.03	0.05	0.12	0.99	-0.24	-0.21
	z_{cut} = 0.1, β = 1.0, N = 3	0.91	0.03	0.06	0.17	0.03	0.04	0.10	-0.07	-0.24	-0.22
	z_{cut} = 0.05, β = 0.0, N = 5	3.14	0.03	0.06	0.17	0.02	0.03	0.08	0.37	-0.21	-0.19
	z_{cut} = 0.1, β = 0.0, N = 5	0.14	0.01	0.02	0.06	0.01	0.02	0.05	-0.14	-0.19	-0.18
	z_{cut} = 0.05, β = 1.0, N = 5	3.57	0.09	0.14	0.85	0.03	0.05	0.12	0.98	-0.24	-0.21
	z_{cut} = 0.1, β = 1.0, N = 5	0.39	0.03	0.06	0.16	0.03	0.04	0.09	-0.07	-0.24	-0.22
Bottom-up Soft Drop	z_{cut} = 0.05, β = 0.0	3.12	0.03	0.06	0.19	0.02	0.03	0.07	0.52	-0.22	-0.20
	z_{cut} = 0.1, β = 0.0	0.16	0.01	0.03	0.06	0.01	0.02	0.04	-0.12	-0.18	-0.17
	z_{cut} = 0.05, β = 1.0	3.55	0.10	0.15	0.89	0.04	0.06	0.12	0.98	-0.24	-0.21
	z_{cut} = 0.1, β = 1.0	1.11	0.03	0.06	0.16	0.03	0.04	0.09	-0.05	-0.24	-0.22
Pruning	R_{cut}=0.15, Z_{cut}=0.25	0.22	0.01	0.03	0.11	0.02	0.03	0.05	-0.11	-0.18	-0.16
Trimming	f_{cut}=5%, R_{sub}=0.1	-0.02	-0.03	-0.02	0.00	-0.01	0.00	0.01	-0.15	-0.18	-0.17
	f_{cut}=9%, R_{sub}=0.1	-0.03	-0.05	-0.04	-0.01	-0.02	-0.02	0.00	-0.14	-0.17	-0.16
	f_{cut}=5%, R_{sub}=0.2	0.13	0.00	0.02	0.08	0.02	0.03	0.07	-0.18	-0.22	-0.22
	f_{cut}=9%, R_{sub}=0.2	0.10	-0.01	0.01	0.06	0.01	0.02	0.06	-0.18	-0.22	-0.22

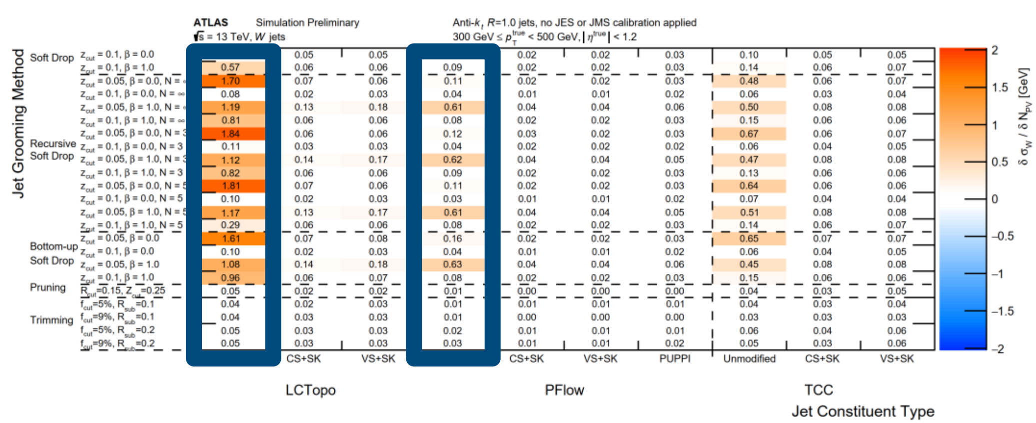
- Row: grooming algorithm (e.g. standard ATLAS trimming)
- Column: jet constituent type
- Number: Slope (also color coded)
- Prefer zero (pile-up stable)

W Mass Peak Values Slope

ATL-PHYS-PUB-2019-027

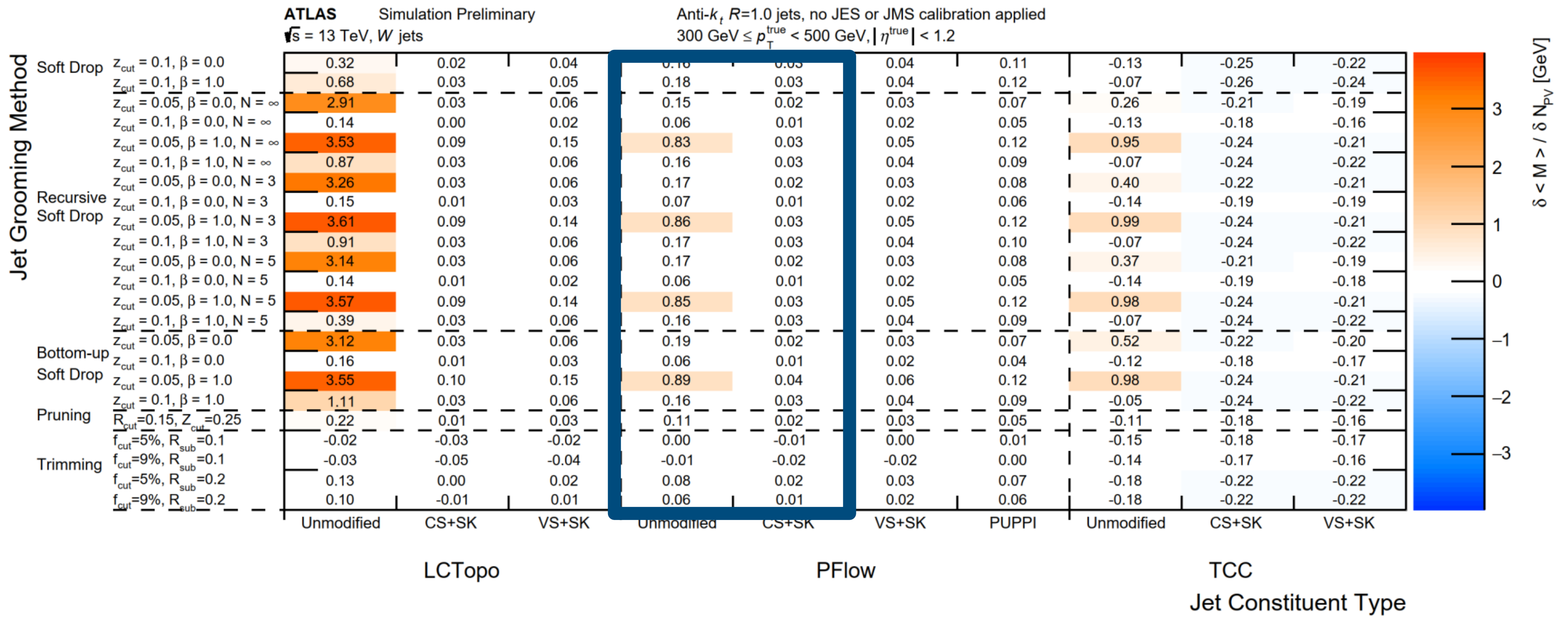


- PFlow is more stable than topocluster, even unmodified
- Also reduce the width



W Mass Peak Values Slope

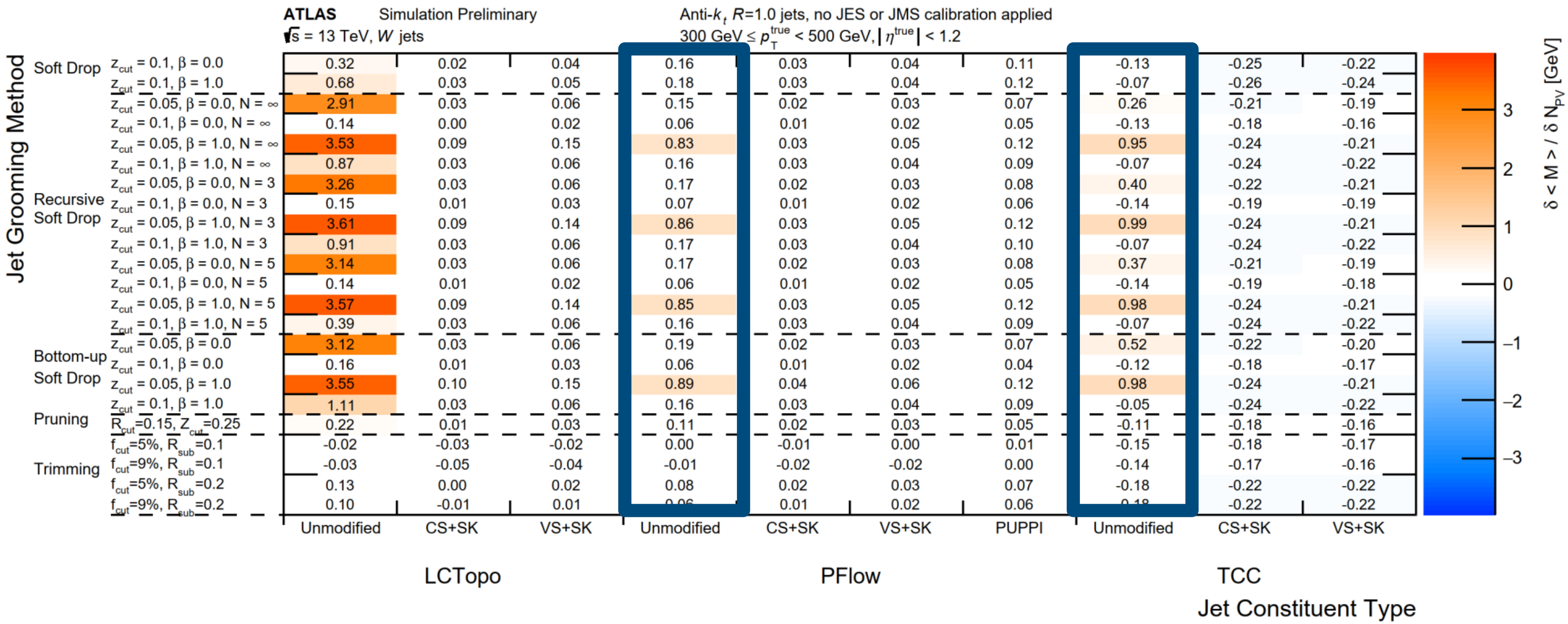
ATL-PHYS-PUB-2019-027



- But still benefit from constituent pile-up suppression

W Mass Peak Values Slope

ATL-PHYS-PUB-2019-027



- Peak values increase with pile-up in PFlow
- The opposite is true for TCC
  - TCC over-subtract the pile-up
    - TCC use all tracks for cluster splitting, so more clusters are removed by matching with pile-up tracks

W Mass Peak Values Slope

ATL-PHYS-PUB-2019-027

ATLAS Simulation Preliminary
$\sqrt{s}$ = 13 TeV, W jets
Anti-k_t, R=1.0 jets, no JES or JMS calibration applied
300 GeV ≤ p_T^{true} < 500 GeV, $|\eta^{true}|$ < 1.2

$\delta < M > / \delta N_{PV}$ [GeV]

Jet Grooming Method		LCTopo Unmodified	LCTopo CS+SK	LCTopo VS+SK	PFlow Unmodified	PFlow CS+SK	PFlow VS+SK	PFlow PUPPI	TCC Unmodified	TCC CS+SK	TCC VS+SK
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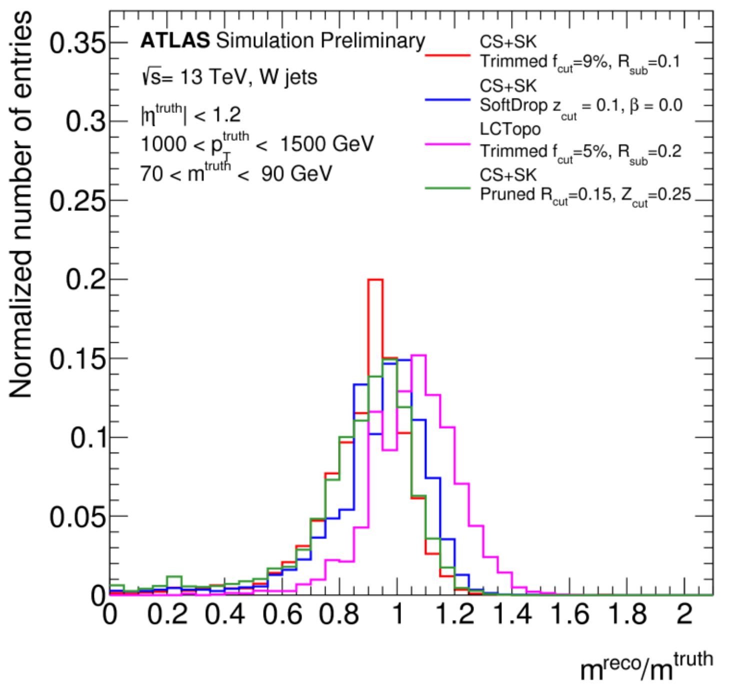
	z_{cut} = 0.1, β = 0.0, N = ∞	0.14	0.00	0.02	0.06	0.01	0.02	0.05	-0.13	-0.18	-0.16
	z_{cut} = 0.05, β = 1.0, N = ∞	3.53	0.09	0.15	0.83	0.03	0.05	0.12	0.95	-0.24	-0.21
	z_{cut} = 0.1, β = 1.0, N = ∞	0.87	0.03	0.06	0.16	0.03	0.04	0.09	-0.07	-0.24	-0.22
	z_{cut} = 0.05, β = 0.0, N = 3	3.26	0.03	0.06	0.17	0.02	0.03	0.08	0.40	-0.22	-0.21
	z_{cut} = 0.1, β = 0.0, N = 3	0.15	0.01	0.03	0.07	0.01	0.02	0.06	-0.14	-0.19	-0.19
	z_{cut} = 0.05, β = 1.0, N = 3	3.61	0.09	0.14	0.86	0.03	0.05	0.12	0.99	-0.24	-0.21
	z_{cut} = 0.1, β = 1.0, N = 3	0.91	0.03	0.06	0.17	0.03	0.04	0.10	-0.07	-0.24	-0.22
	z_{cut} = 0.05, β = 0.0, N = 5	3.14	0.03	0.06	0.17	0.02	0.03	0.08	0.37	-0.21	-0.19
	z_{cut} = 0.1, β = 0.0, N = 5	0.14	0.01	0.02	0.06	0.01	0.02	0.05	-0.14	-0.19	-0.18
	z_{cut} = 0.05, β = 1.0, N = 5	3.57	0.09	0.14	0.85	0.03	0.05	0.12	0.98	-0.24	-0.21
	z_{cut} = 0.1, β = 1.0, N = 5	0.39	0.03	0.06	0.16	0.03	0.04	0.09	-0.07	-0.24	-0.22
Bottom-up Soft Drop	z_{cut} = 0.05, β = 0.0	3.12	0.03	0.06	0.19	0.02	0.03	0.07	0.52	-0.22	-0.20
	z_{cut} = 0.1, β = 0.0	0.16	0.01	0.03	0.06	0.01	0.02	0.04	-0.12	-0.18	-0.17
	z_{cut} = 0.05, β = 1.0	3.55	0.10	0.15	0.89	0.04	0.06	0.12	0.98	-0.24	-0.21
	z_{cut} = 0.1, β = 1.0	1.11	0.03	0.06	0.16	0.03	0.04	0.09	-0.05	-0.24	-0.22
Pruning	R_{cut}=0.15, Z_{cut}=0.25	0.22	0.01	0.03	0.11	0.02	0.03	0.05	-0.11	-0.18	-0.16
Trimming	f_{cut}=5%, R_{sub}=0.1	-0.02	-0.03	-0.02	0.00	-0.01	0.00	0.01	-0.15	-0.18	-0.17
	f_{cut}=9%, R_{sub}=0.1	-0.03	-0.05	-0.04	-0.01	-0.02	-0.02	0.00	-0.14	-0.17	-0.16
	f_{cut}=5%, R_{sub}=0.2	0.13	0.00	0.02	0.08	0.02	0.03	0.07	-0.18	-0.22	-0.22
	f_{cut}=9%, R_{sub}=0.2	0.10	-0.01	0.01	0.06	0.01	0.02	0.06	-0.18	-0.22	-0.22

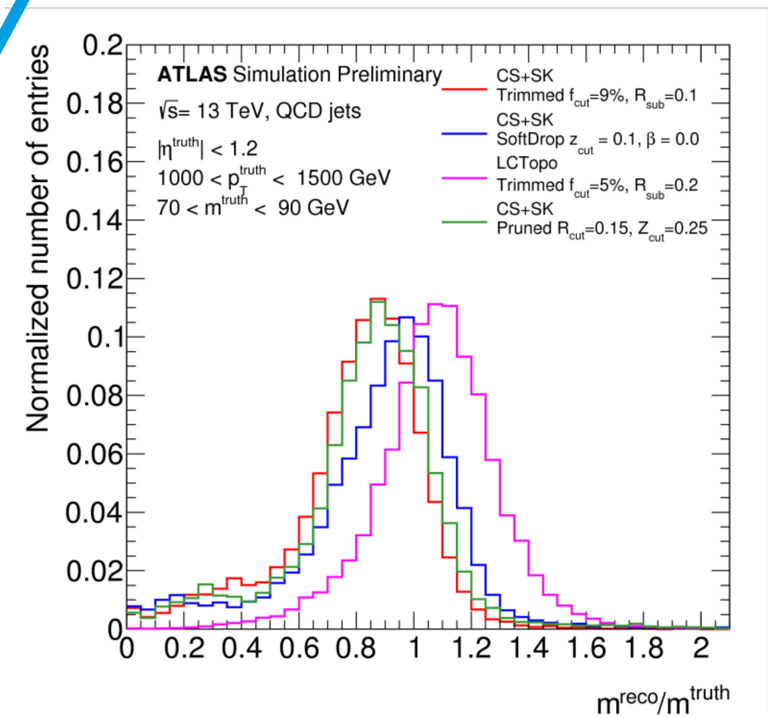
Jet Constituent Type

- Since TCC is already over-subtracting, adding constituent pile-up suppressions make it worse

Topology Dependence

ATL-PHYS-PUB-2017-020

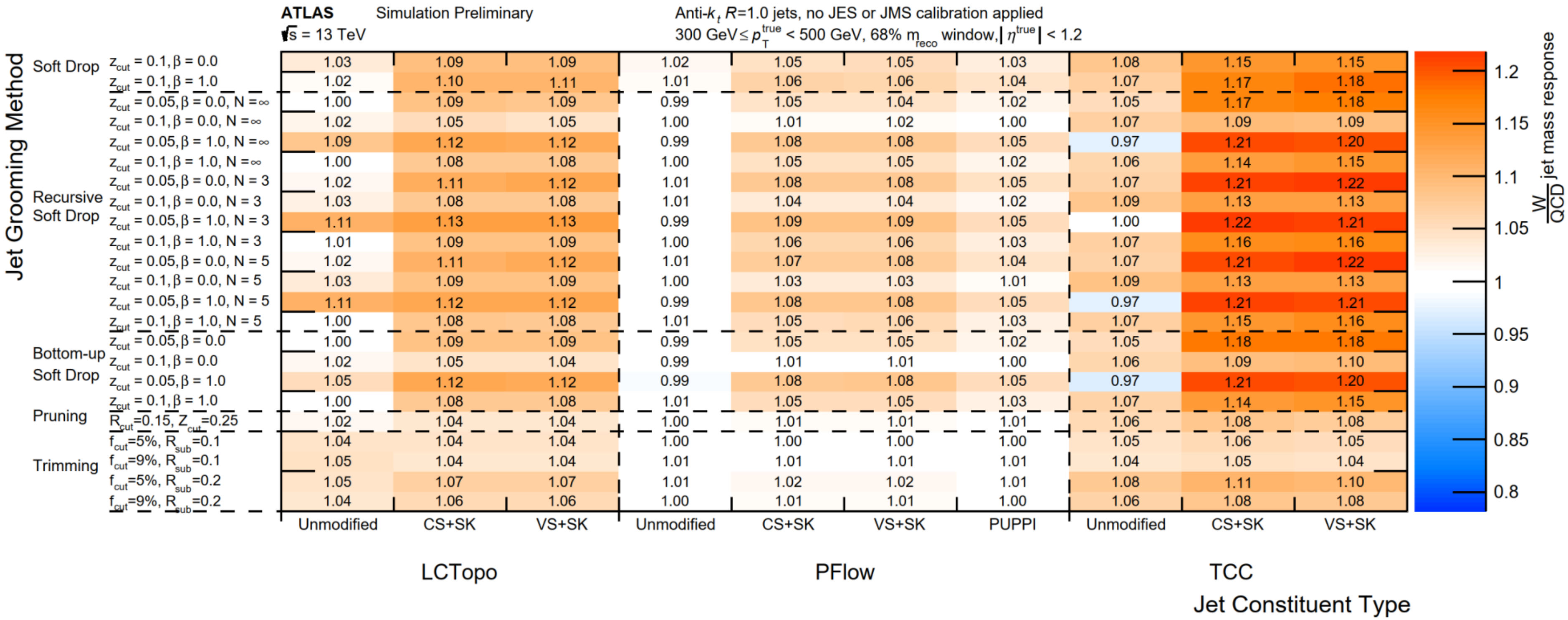




- Quantifying the mass scale calibration's dependence on jet topology
- Take the ratio of the average mass response ($\frac{m^{reco}}{m^{truth}}$) of W-jets over QCD jets

Topology Dependence

ATL-PHYS-PUB-2019-027

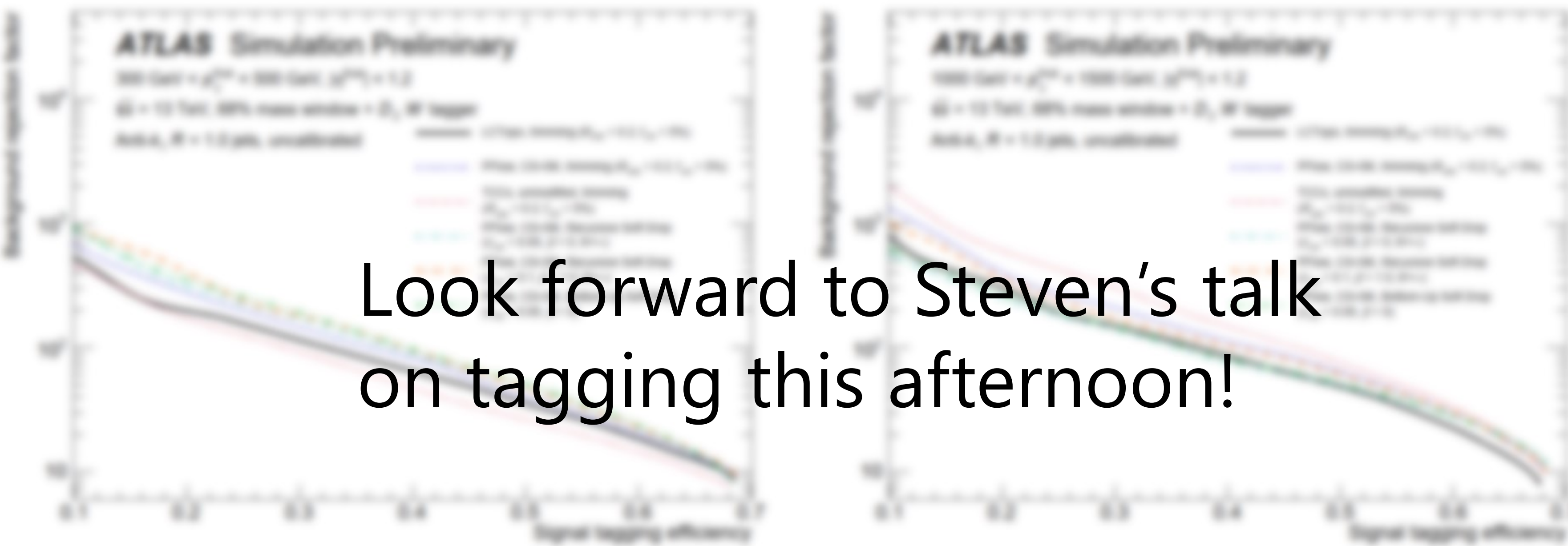


Jet Grooming Method		LCTopo Unmodified	LCTopo CS+SK	LCTopo VS+SK	PFlow Unmodified	PFlow CS+SK	PFlow VS+SK	PFlow PUPPI	TCC Unmodified	TCC CS+SK	TCC VS+SK
Soft Drop	z_{cut} = 0.1, β = 0.0	1.03	1.09	1.09	1.02	1.05	1.05	1.03	1.08	1.15	1.15
Soft Drop	z_{cut} = 0.1, β = 1.0	1.02	1.10	1.11	1.01	1.06	1.06	1.04	1.07	1.17	1.18
Recursive Soft Drop	z_{cut} = 0.05, β = 0.0, N = ∞	1.00	1.09	1.09	0.99	1.05	1.04	1.02	1.05	1.17	1.18
Recursive Soft Drop	z_{cut} = 0.1, β = 0.0, N = ∞	1.02	1.05	1.05	1.00	1.01	1.02	1.00	1.07	1.09	1.09
Recursive Soft Drop	z_{cut} = 0.05, β = 1.0, N = ∞	1.09	1.12	1.12	0.99	1.08	1.08	1.05	0.97	1.21	1.20
Recursive Soft Drop	z_{cut} = 0.1, β = 1.0, N = ∞	1.00	1.08	1.08	1.00	1.05	1.05	1.02	1.06	1.14	1.15
Recursive Soft Drop	z_{cut} = 0.05, β = 0.0, N = 3	1.02	1.11	1.12	1.01	1.08	1.08	1.05	1.07	1.21	1.22
Recursive Soft Drop	z_{cut} = 0.1, β = 0.0, N = 3	1.03	1.08	1.08	1.01	1.04	1.04	1.02	1.09	1.13	1.13
Recursive Soft Drop	z_{cut} = 0.05, β = 1.0, N = 3	1.11	1.13	1.13	0.99	1.09	1.09	1.05	1.00	1.22	1.21
Recursive Soft Drop	z_{cut} = 0.1, β = 1.0, N = 3	1.01	1.09	1.09	1.00	1.06	1.06	1.03	1.07	1.16	1.16
Recursive Soft Drop	z_{cut} = 0.05, β = 0.0, N = 5	1.02	1.11	1.12	1.01	1.07	1.08	1.04	1.07	1.21	1.22
Recursive Soft Drop	z_{cut} = 0.1, β = 0.0, N = 5	1.03	1.09	1.09	1.00	1.03	1.03	1.01	1.09	1.13	1.13
Recursive Soft Drop	z_{cut} = 0.05, β = 1.0, N = 5	1.11	1.12	1.12	0.99	1.08	1.08	1.05	0.97	1.21	1.21
Recursive Soft Drop	z_{cut} = 0.1, β = 1.0, N = 5	1.00	1.08	1.08	1.01	1.05	1.06	1.03	1.07	1.15	1.16
Bottom-up Soft Drop	z_{cut} = 0.05, β = 0.0	1.00	1.09	1.09	0.99	1.05	1.05	1.02	1.05	1.18	1.18
Bottom-up Soft Drop	z_{cut} = 0.1, β = 0.0	1.02	1.05	1.04	0.99	1.01	1.01	1.00	1.06	1.09	1.10
Bottom-up Soft Drop	z_{cut} = 0.05, β = 1.0	1.05	1.12	1.12	0.99	1.08	1.08	1.05	0.97	1.21	1.20
Bottom-up Soft Drop	z_{cut} = 0.1, β = 1.0	1.00	1.08	1.08	1.01	1.05	1.05	1.03	1.07	1.14	1.15
Pruning	R_{cut}=0.15, Z_{cut}=0.25	1.02	1.04	1.04	1.00	1.01	1.01	1.01	1.06	1.08	1.08
Trimming	f_{cut}=5%, R_{sub}=0.1	1.04	1.04	1.04	1.00	1.00	1.00	1.00	1.05	1.06	1.05
Trimming	f_{cut}=9%, R_{sub}=0.1	1.05	1.04	1.04	1.01	1.01	1.01	1.01	1.04	1.05	1.04
Trimming	f_{cut}=5%, R_{sub}=0.2	1.05	1.07	1.07	1.01	1.02	1.02	1.01	1.08	1.11	1.10
Trimming	f_{cut}=9%, R_{sub}=0.2	1.04	1.06	1.06	1.00	1.01	1.01	1.00	1.06	1.08	1.08

- Prefer one (no topology dependence)
- Constituent pile-up suppression make it worse, but there are good option available, especially for PFlow

Tagging Performance

- Perform a simple two-variable tagger:
  - 68% signal mass window cut
  - One-side cut on D_2 (W) or τ_{32} (top)
- Compare background rejection (1/background efficiency) vs. signal efficiency



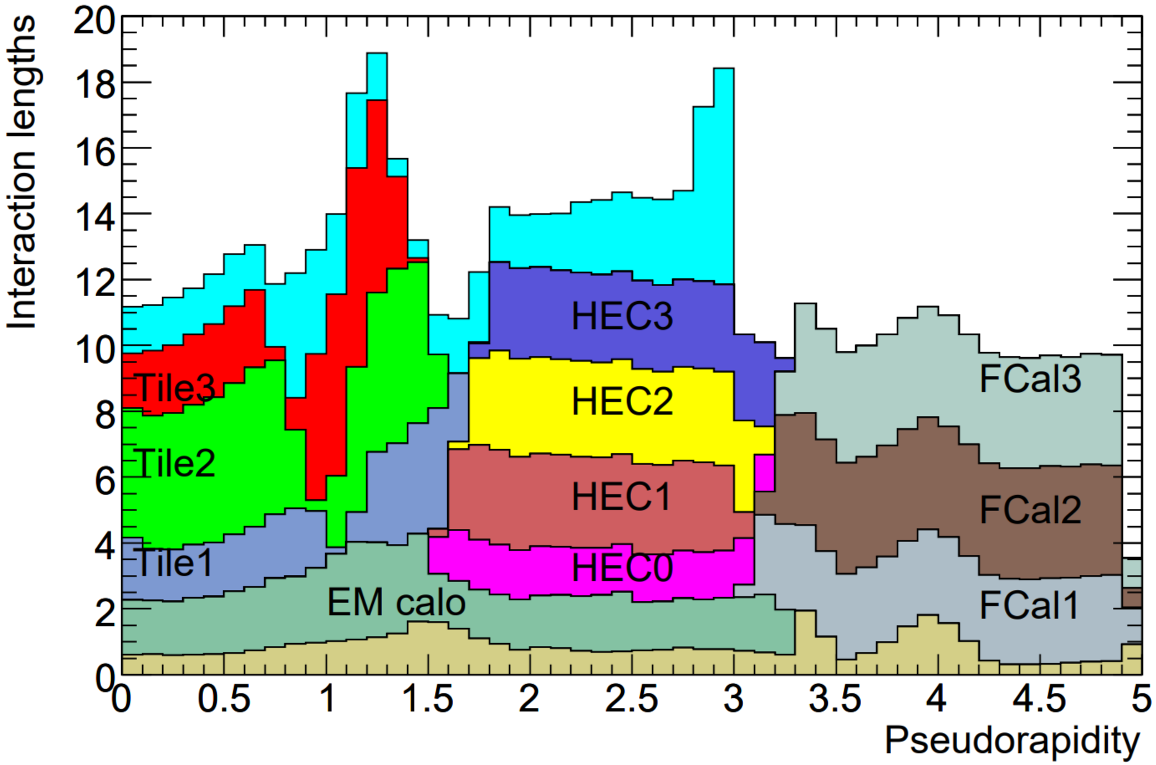
Look forward to Steven's talk on tagging this afternoon!

Summary

- ATLAS is moving towards particle flow for small-R jets
  - Better pile-up suppression, better resolution
- In-situ JES calibration for large-R jets is done with 80 fb^{-1} of data
  - Reduce the JES uncertainty significantly (from 8% to 1% !)
- Study the impact on the large-R jet performance with various choices of inputs, constituent pile-up suppression, and grooming algorithms
  - PFlow jets outperform LCW topocluster jets across the board
  - TCC can be better than PFlow for high-p_T jets, but poor performance at low-p_T
  - Both PFlow and topocluster benefit from pile-up suppression at constituent level
    - Among the choices in this study, CS+SK did best
  - Standard ATLAS trimming does well, but some SoftDrop configurations show possible improvement

Backup

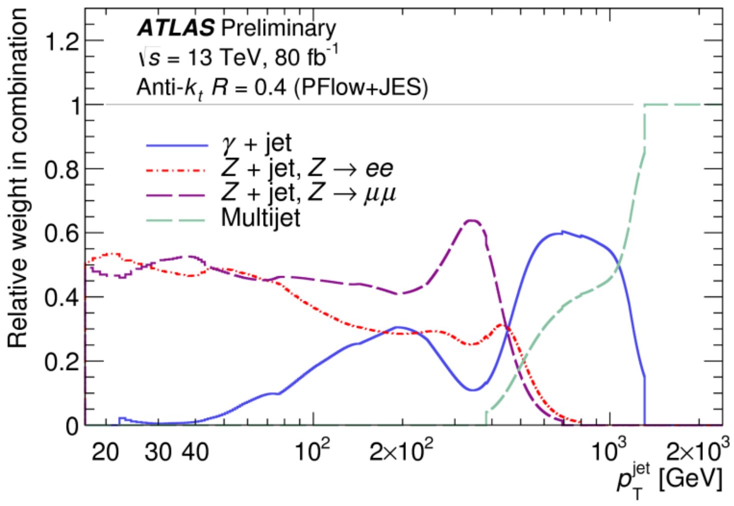
ATLAS Detector

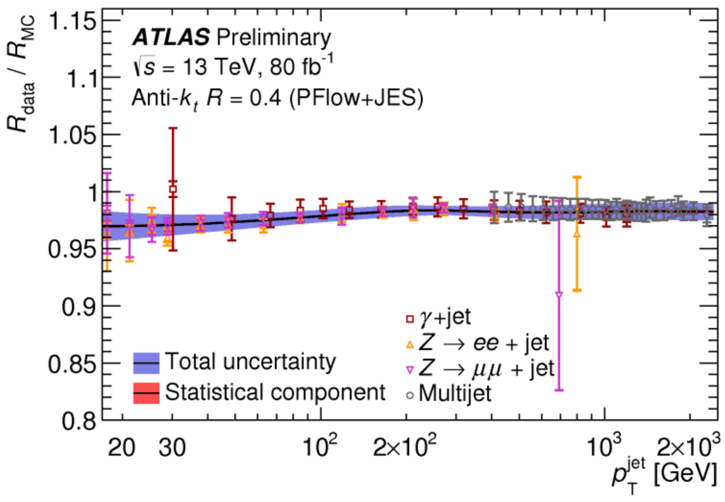


- Inner tracker
  - Inside solenoid magnet
- EM+Hadronic calorimeters
- Muon spectrometer
  - With toroid magnet

In-situ Calibration —Small-R

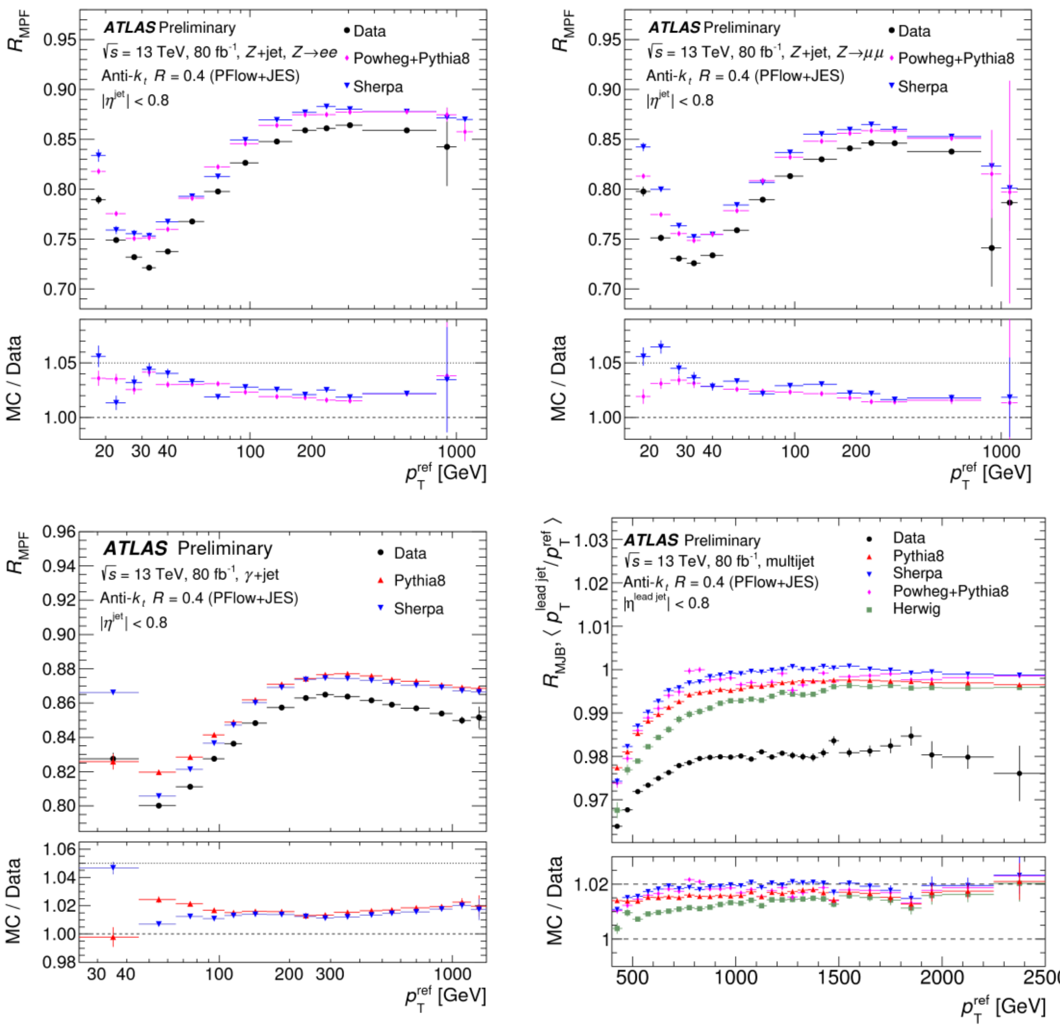
JETM-2018-006





In-situ Calibration

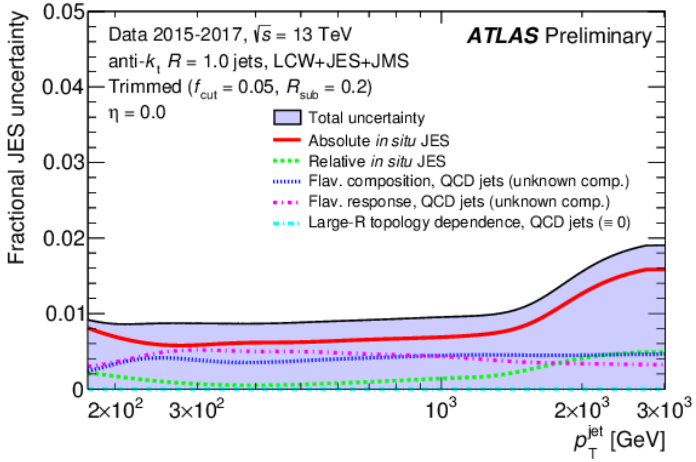
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/JETM-2019-02/

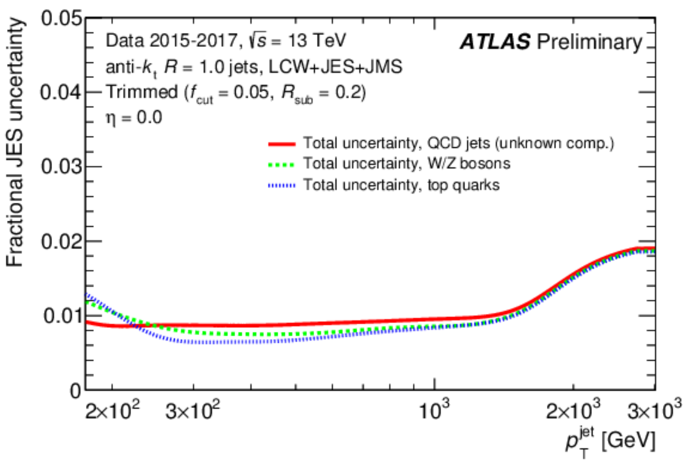


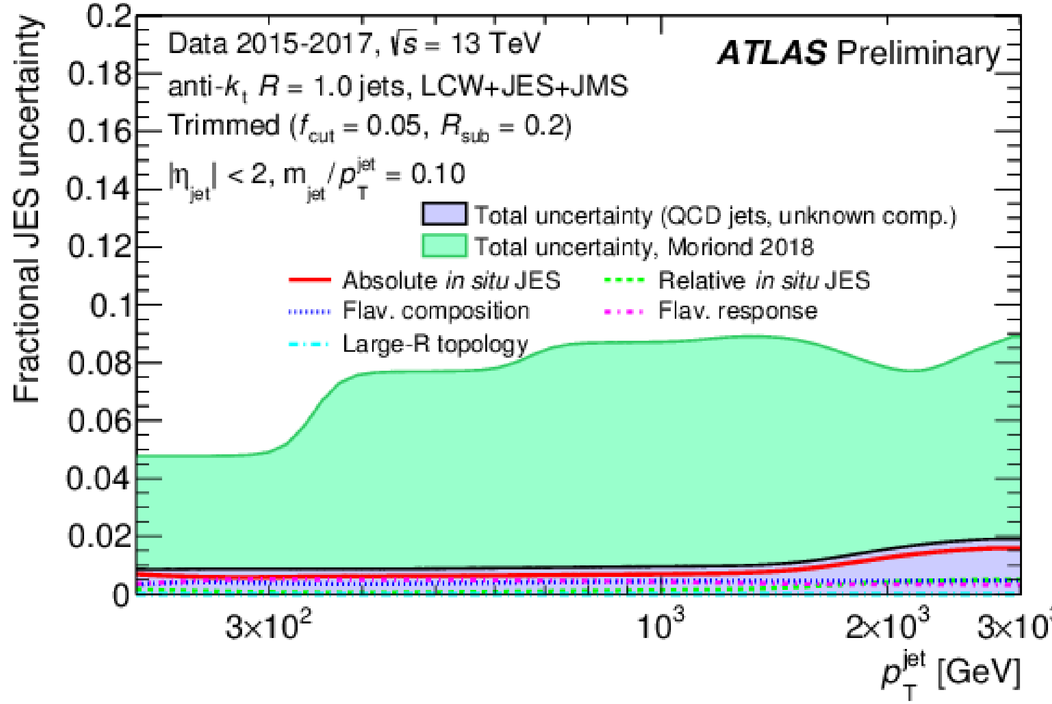
- PFlow jet p_T response derived from $Z \rightarrow ee$, $Z \rightarrow \mu\mu$, γ, and multijet using MPF technique

JES Uncertainty

JETM-2019-05 , Eur. Phys. J. C 79 (2019) 135





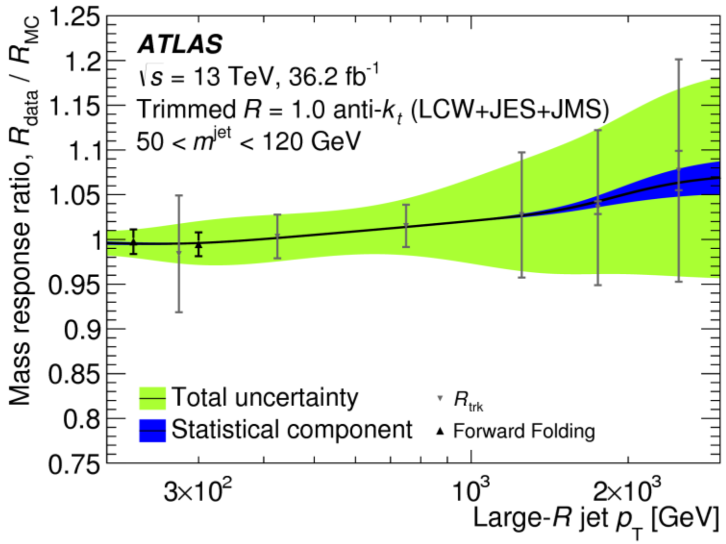


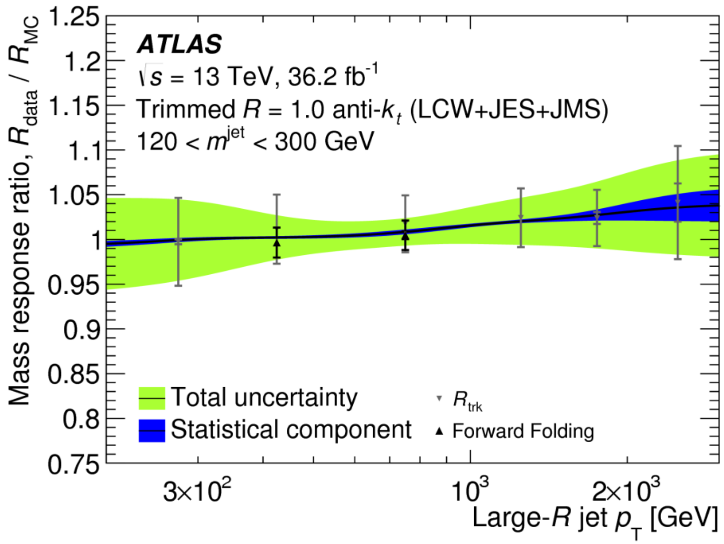
- Total uncertainty depends on the assumption of the topology (W, Z, or top) and flavor (quark or gluon initiated) composition of the jets
- Large reduction compared to without in-situ calibration

In-situ Calibration—JMS/JMR

Eur. Phys. J. C 79 (2019) 135

- For large-R jets, we also need in-situ calibration for the mass
- Two methods for in-situ mass calibration:
  1. Forward-folding: Use high purity top sample, shift and stretch jet mass resolution function so that the simulation matches the data
  2. $R^{m}_{track} = \frac{m_{track}}{m_{calo}}$: Tracker provides an independent (charged only) measurement of a jet, so any deviation of the double ratio of $R_{track,MC}/R_{track,Data}$ between data and MC from 1 provides an estimate of the scale uncertainty
- Forward-folding has smaller uncertainty, but R_{track} covers a much boarder p_T and mass range





Pile-up Stability—D_2

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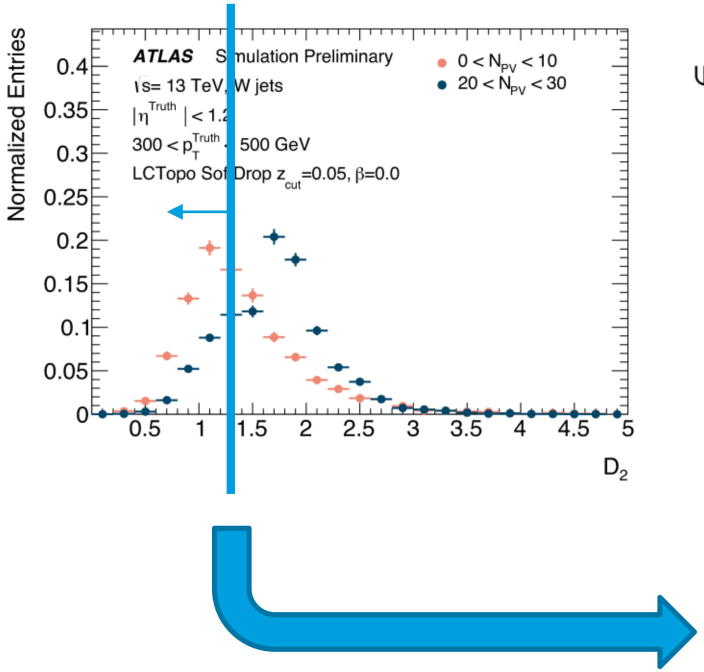

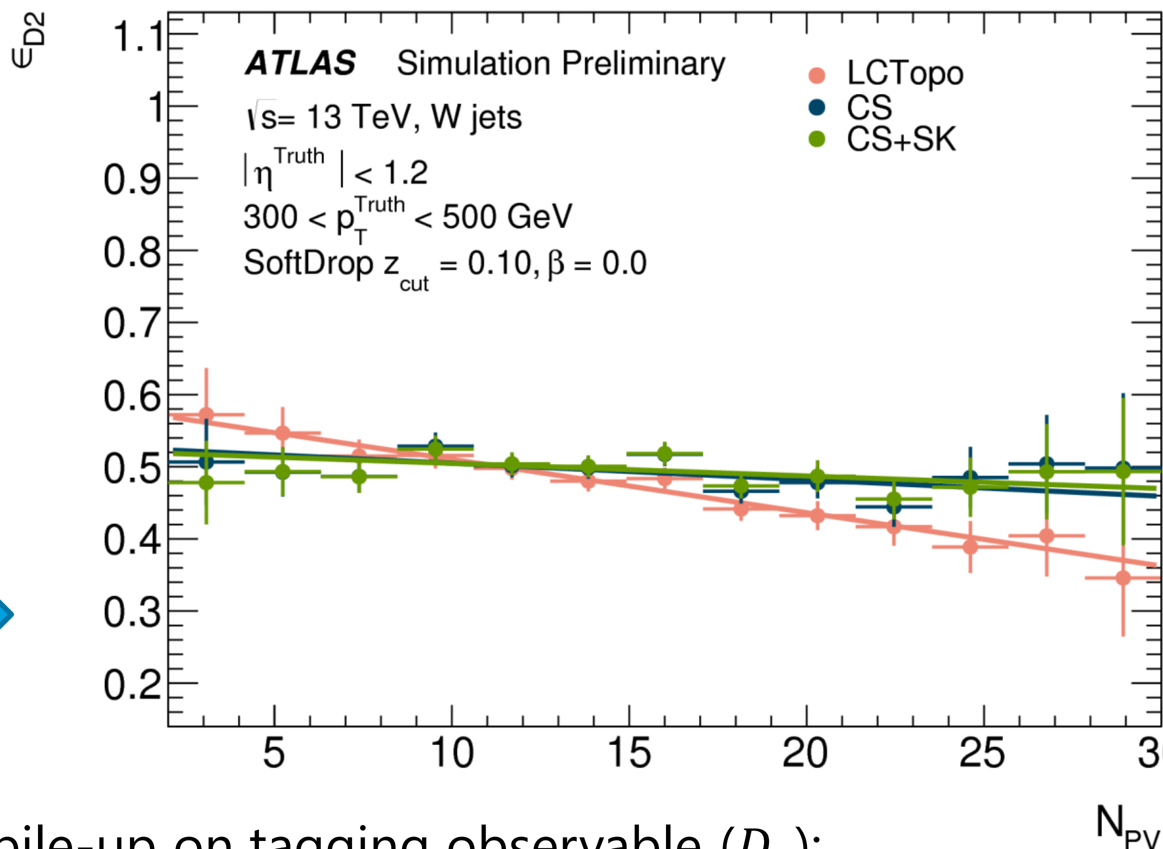

- Quantifying the effect of pile-up on tagging observable (D_2):
  1. Take the D_2 distribution of W-jet sample in the low pile-up (N_{PV} < 15) bin
  2. Find a cut with 50% efficiency
  3. Apply the cut in bins of N_{PV} and plot the efficiencies
  4. Fit a line and measure the slope

D_2 Cut Efficiency Slope

ATLAS Simulation Preliminary
$\sqrt{s}$ = 13 TeV, W jets
Anti-k_t, R=1.0 jets, no JES or JMS calibration applied
300 GeV ≤ p_T^{true} < 500 GeV, $|\eta^{true}|$ < 1.2

$\delta(\varepsilon D_2) / \delta N_{PV}$ (%)

Jet Grooming Method		LCTopo Unmodified	LCTopo CS+SK	LCTopo VS+SK	PFlow Unmodified	PFlow CS+SK	PFlow VS+SK	PFlow PUPPI	TCC Unmodified	TCC CS+SK	TCC VS+SK
Soft Drop	z_{cut} = 0.1, β = 0.0	-0.92	-0.17	-0.18	-0.53	-0.14	-0.17	-0.32	-0.20	0.12	0.13
	z_{cut} = 0.1, β = 1.0	-1.46	-0.19	-0.20	-0.56	-0.11	-0.14	-0.26	-0.38	0.12	0.11
Recursive Soft Drop	z_{cut} = 0.05, β = 0.0, N = ∞	-1.58	-0.33	-0.34	-0.69	-0.11	-0.12	-0.20	-0.66	0.06	0.05
	z_{cut} = 0.1, β = 0.0, N = ∞	-0.67	-0.15	-0.16	-0.21	-0.07	-0.07	-0.14	-0.06	0.06	0.06
	z_{cut} = 0.05, β = 1.0, N = ∞	-0.96	-0.48	-0.55	-1.31	-0.15	-0.19	-0.32	-1.14	0.05	0.02
	z_{cut} = 0.1, β = 1.0, N = ∞	-1.49	-0.23	-0.25	-0.55	-0.13	-0.15	-0.23	-0.34	0.08	0.08
	z_{cut} = 0.05, β = 0.0, N = 3	-1.56	-0.33	-0.34	-0.72	-0.11	-0.13	-0.22	-0.67	0.07	0.07
	z_{cut} = 0.1, β = 0.0, N = 3	-0.70	-0.15	-0.15	-0.21	-0.07	-0.08	-0.14	-0.07	0.08	0.08
	z_{cut} = 0.05, β = 1.0, N = 3	-0.97	-0.47	-0.54	-1.30	-0.15	-0.19	-0.32	-1.14	0.05	0.03
	z_{cut} = 0.1, β = 1.0, N = 3	-1.39	-0.22	-0.25	-0.57	-0.13	-0.15	-0.24	-0.35	0.09	0.08
	z_{cut} = 0.05, β = 0.0, N = 5	-1.57	-0.33	-0.34	-0.71	-0.12	-0.13	-0.20	-0.66	0.06	0.06
	z_{cut} = 0.1, β = 0.0, N = 5	-0.68	-0.15	-0.15	-0.21	-0.07	-0.07	-0.13	-0.06	0.07	0.07
	z_{cut} = 0.05, β = 1.0, N = 5	-0.96	-0.48	-0.55	-1.31	-0.15	-0.19	-0.33	-1.14	0.05	0.02
	z_{cut} = 0.1, β = 1.0, N = 5	-1.27	-0.23	-0.25	-0.56	-0.13	-0.15	-0.24	-0.34	0.08	0.08
Bottom-up Soft Drop	z_{cut} = 0.05, β = 0.0	-1.51	-0.34	-0.37	-0.82	-0.12	-0.15	-0.22	-0.78	0.06	0.06
	z_{cut} = 0.1, β = 0.0	-0.84	-0.16	-0.16	-0.25	-0.08	-0.09	-0.14	-0.09	0.08	0.07
	z_{cut} = 0.05, β = 1.0	-0.81	-0.48	-0.56	-1.34	-0.16	-0.19	-0.32	-1.16	0.05	0.02
	z_{cut} = 0.1, β = 1.0	-1.54	-0.23	-0.26	-0.57	-0.13	-0.15	-0.24	-0.38	0.08	0.08
Pruning	R_{cut}=0.15, Z_{cut}=0.25	-0.69	-0.17	-0.20	-0.38	-0.11	-0.13	-0.15	-0.11	0.04	0.03
Trimming	f_{cut}=5%, R_{sub}=0.1	0.03	-0.04	-0.05	0.00	-0.03	-0.03	-0.03	0.03	0.04	0.04
	f_{cut}=9%, R_{sub}=0.1	0.07	-0.01	-0.01	0.04	0.00	0.00	0.02	0.03	0.04	0.04
	f_{cut}=5%, R_{sub}=0.2	-0.27	-0.11	-0.10	-0.18	-0.07	-0.08	-0.13	0.04	0.12	0.12
	f_{cut}=9%, R_{sub}=0.2	-0.22	-0.10	-0.08	-0.17	-0.09	-0.09	-0.13	0.05	0.13	0.13

Jet Constituent Type

- Shown only W-jet with D_2, but result are consistent with top and τ_{32}
- Prefer zero (pile-up stable)
- Generally, efficiency decreases with pile-up, except TCC

Pile-up Stability—Jet Topology

ATLAS Simulation Preliminary
$\sqrt{s}$ = 13 TeV
Anti-k_t, R=1.0 jets, no JES or JMS calibration applied
1000 GeV $\leq p_T^{true}$ < 1500 GeV, 68% m_{reco} window, $|\eta^{true}|$ < 1.2

Jet Grooming Method		LCTopo Unmodified	LCTopo CS+SK	LCTopo VS+SK	PFlow Unmodified	PFlow CS+SK	PFlow VS+SK	PFlow PUPPI	TCC Unmodified	TCC CS+SK	TCC VS+SK
Soft Drop	z_{cut} = 0.1, β = 0.0	1.04	1.04	1.04	1.00	1.01	1.01	1.00	1.02	1.04	1.03
	z_{cut} = 0.1, β = 1.0	1.01	1.03	1.03	0.98	0.99	1.00	0.98	1.04	1.05	1.05
Recursive Soft Drop	z_{cut} = 0.05, β = 0.0, N = ∞	1.00	1.01	1.01	0.98	0.99	0.99	0.98	1.02	1.03	1.02
	z_{cut} = 0.1, β = 0.0, N = ∞	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.00	1.02	1.01
	z_{cut} = 0.05, β = 1.0, N = ∞	1.00	1.04	1.04	0.98	1.01	1.00	0.99	1.04	1.06	1.06
	z_{cut} = 0.1, β = 1.0, N = ∞	1.00	1.01	1.01	0.97	0.99	0.99	0.97	1.03	1.05	1.04
	z_{cut} = 0.05, β = 0.0, N = 3	1.01	1.03	1.02	0.98	0.99	0.99	0.98	1.03	1.04	1.04
	z_{cut} = 0.1, β = 0.0, N = 3	1.03	1.04	1.03	1.00	1.01	1.01	1.01	1.01	1.04	1.02
	z_{cut} = 0.05, β = 1.0, N = 3	1.01	1.04	1.04	0.99	1.01	1.01	0.99	1.05	1.06	1.07
	z_{cut} = 0.1, β = 1.0, N = 3	1.00	1.02	1.02	0.97	0.99	0.99	0.98	1.04	1.05	1.04
	z_{cut} = 0.05, β = 0.0, N = 5	1.02	1.03	1.03	0.98	0.98	0.98	0.98	1.03	1.04	1.03
	z_{cut} = 0.1, β = 0.0, N = 5	1.03	1.04	1.04	1.02	1.02	1.02	1.02	1.02	1.03	1.02
	z_{cut} = 0.05, β = 1.0, N = 5	1.00	1.04	1.04	0.98	1.01	1.01	0.99	1.05	1.06	1.06
	z_{cut} = 0.1, β = 1.0, N = 5	1.00	1.02	1.02	0.97	0.99	0.99	0.97	1.03	1.05	1.04
Bottom-up Soft Drop	z_{cut} = 0.05, β = 0.0	1.00	1.01	1.01	0.98	0.99	0.99	0.98	1.02	1.03	1.02
	z_{cut} = 0.1, β = 0.0	1.01	1.02	1.02	1.02	1.02	1.02	1.02	1.01	1.03	1.01
	z_{cut} = 0.05, β = 1.0	1.00	1.04	1.04	0.98	1.01	1.00	0.99	1.04	1.06	1.06
	z_{cut} = 0.1, β = 1.0	1.00	1.01	1.01	0.98	0.99	0.99	0.97	1.03	1.05	1.04
Pruning	R_{cut}=0.15, Z_{cut}=0.25	1.02	1.04	1.04	1.01	1.02	1.02	1.01	1.01	1.04	1.01
Trimming	f_{cut}=5%, R_{sub}=0.1	1.04	1.04	1.05	1.01	1.01	1.01	1.01	1.02	1.04	1.02
	f_{cut}=9%, R_{sub}=0.1	1.06	1.06	1.06	1.02	1.02	1.02	1.02	1.02	1.03	1.02
	f_{cut}=5%, R_{sub}=0.2	1.02	1.03	1.03	0.99	1.00	1.00	0.99	1.05	1.07	1.06
	f_{cut}=9%, R_{sub}=0.2	1.00	1.02	1.01	0.98	0.99	0.99	0.98	1.04	1.07	1.04

Jet Constituent Type

$\frac{W}{QCD}$ jet mass response: 0.94, 0.96, 0.98, 1, 1.02, 1.04, 1.06

- Prefer one
- Constituent pile-up suppression make it worse, but there are good option available, especially for PFlow