Performance of large radius jets reconstruction at ATLAS

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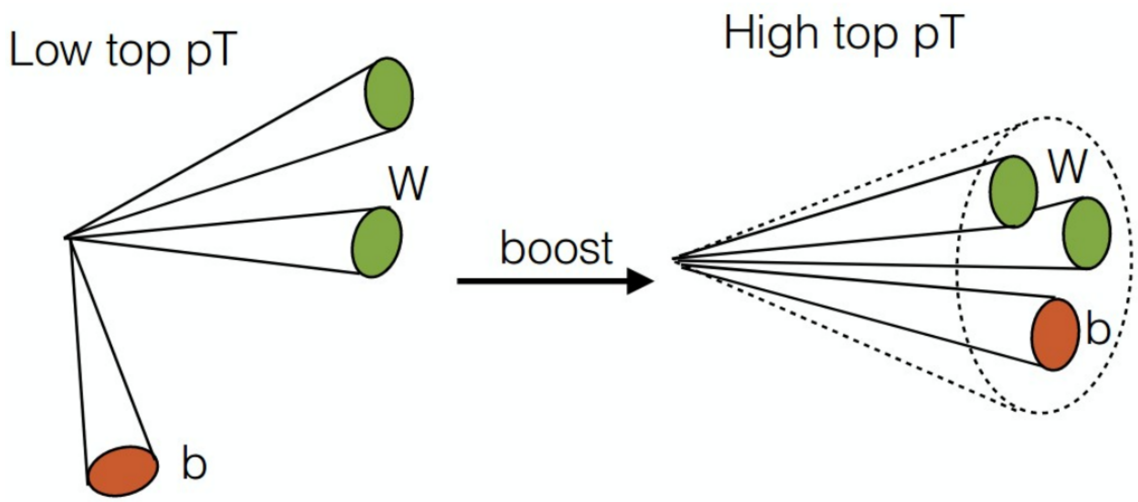
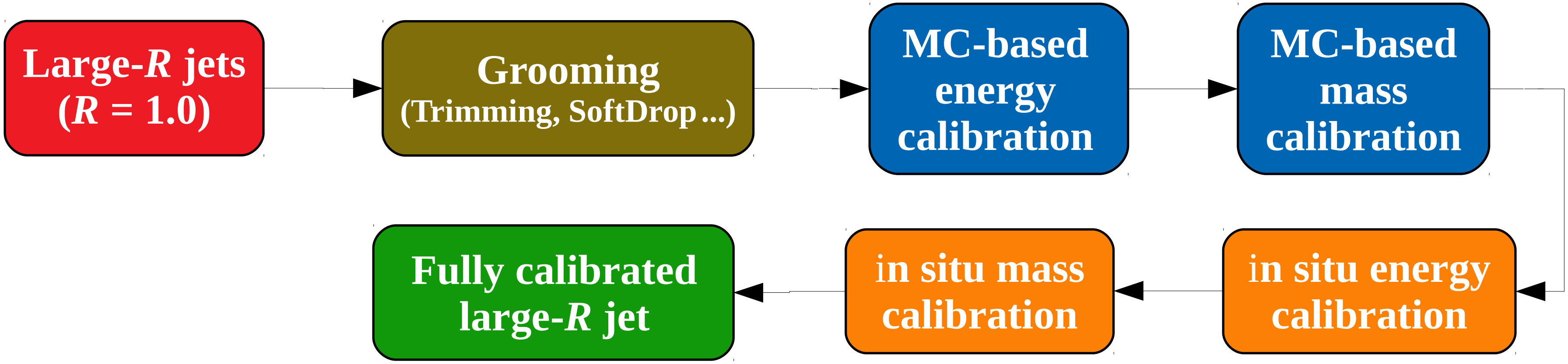
Introduction

- High-energy particle collisions such as those produced in the Large Hadron Collider (LHC) can result in the production of massive particles.
- These High p_T , massive particles such as Higgs bosons, top quarks, and W or Z bosons often decay hadronically.
- The multiple jets from the decay of particles with large p_T may be reconstructed as a jet with large radius, the so-called large-*R* jet.
- The sensitivity of physics analyses depends on an accurate knowledge of the detector response to both the jet energy and the mass.



Jet reconstruction overview

Procedure of large-*R* jet reconstruction



- Inputs: R = 1.0 jets reconstructed use anti-k_t algorithm from clusters.
- Grooming: a class of algorithms to suppress pile-up.
- MC calibration: calibrate reconstructed jet energy to MC truth scale, because a fraction of the energy in a hadronic shower is invisible to the detector.
- In situ calibration: calibrate the data-MC difference.

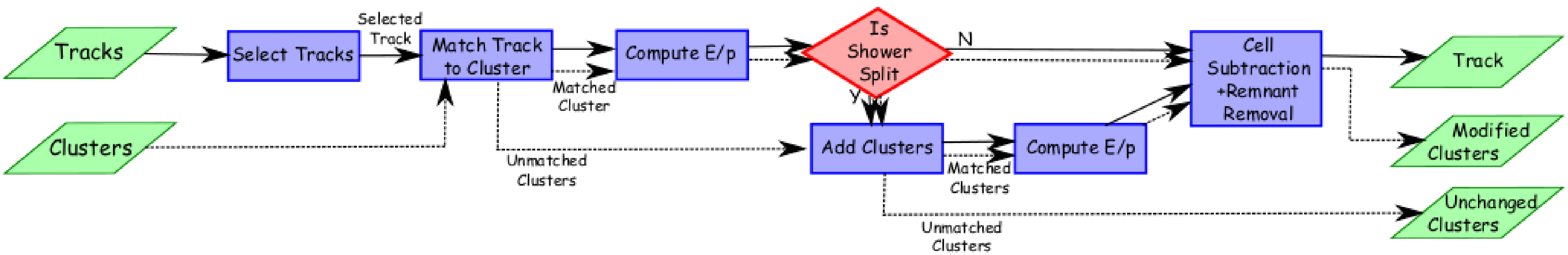
Jet inputs

Unified Flow Objects (UFO): a combination of particle flow objects (PFO) and Track Calo Clusters (TCC).

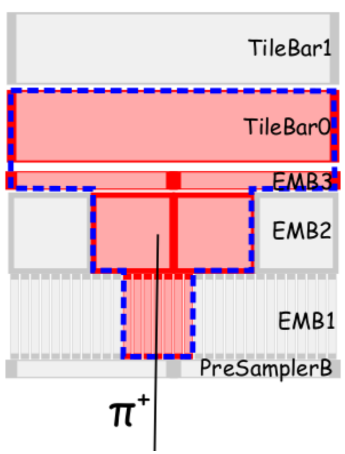
PFO

Subtract calorimeter energy deposits that match an extrapolated track, final set of constituents is a combination of tracks and remaining clusters.

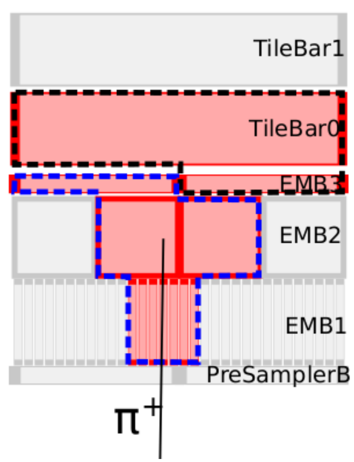
link



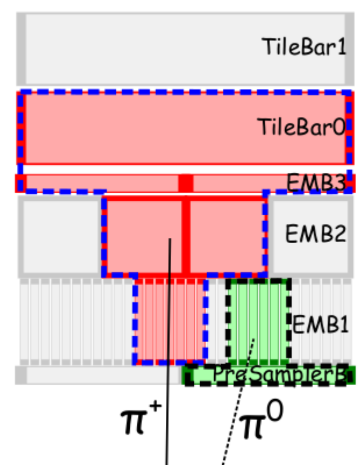
1 particle, 1 topo-cluster



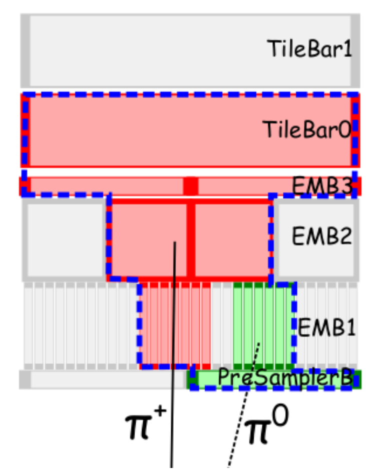
1 particle, 2 topo-cluster



2 particle, 2 topo-cluster



2 particle, 1 topo-cluster

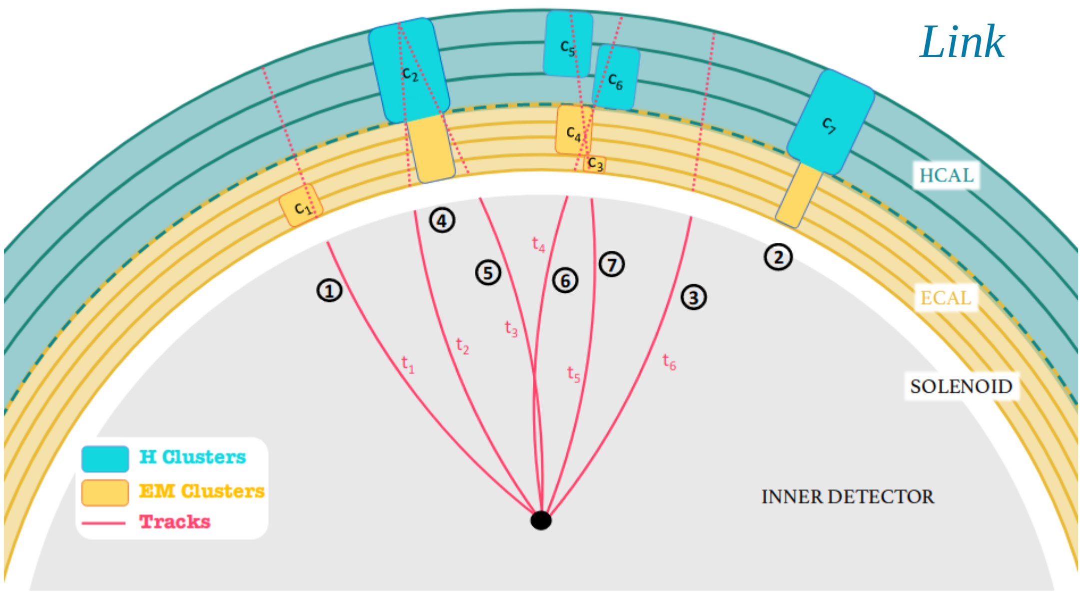


Jet inputs

TCC

A combination of track spatial coordinates and topocluster energy components, the matching procedure matches quality tracks to topoclusters.

- Attempt match if $\sigma_{\text{track}} < \sigma_{\text{cluster}}$
- Match the track to topo-cluster if $\Delta R < \sqrt{\sigma^2_{\text{cluster}} + \sigma^2_{\text{track}}}$
- Build the actual TCC 4-vectors.



$$\text{TCC}_{①} = (p_{\text{T}}^{c_1}, \eta^{t_1}, \phi^{t_1}, m^{c_1} = 0)$$

$$\text{TCC}_{②} = (p_{\text{T}}^{c_7}, \eta^{c_7}, \phi^{c_7}, m^{c_7} = 0)$$

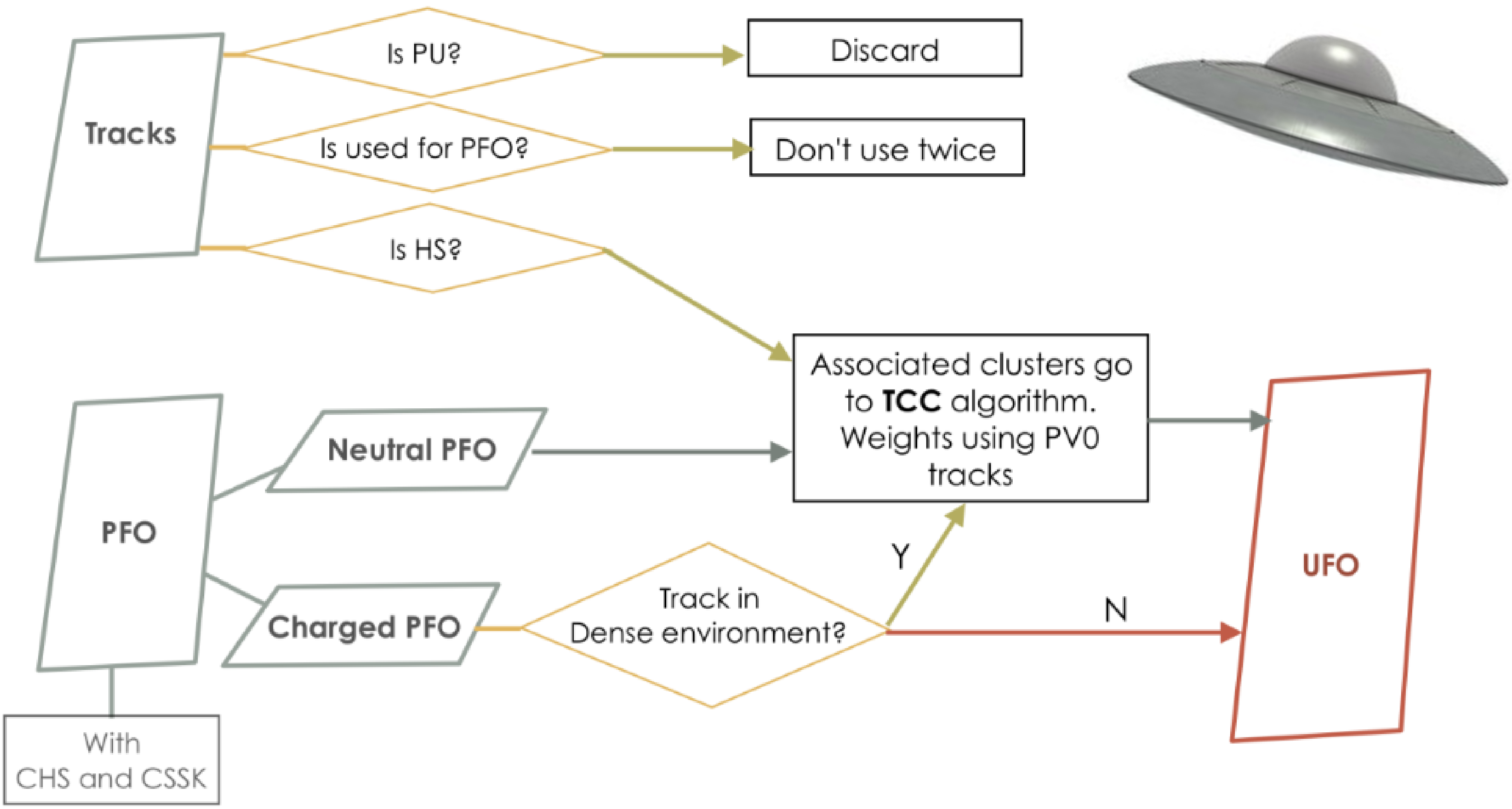
$$\text{TCC}_{③} = (p_{\text{T}}^{t_6}, \eta^{t_6}, \phi^{t_6}, m^{t_6} = 0)$$

$$\text{TCC}_{④} = \left(p_{\text{T}}^{c_2} \frac{p_{\text{T}}^{t_2}}{p_{\text{T}}\,[\mathbf{p}^{t_2} + \mathbf{p}^{t_3}]}, \eta^{t_2}, \phi^{t_2}, m^{c_2} \frac{p_{\text{T}}^{t_2}}{p_{\text{T}}\,[\mathbf{p}^{t_2} + \mathbf{p}^{t_3}]} = 0\right)$$

$$\text{TCC}_{⑤} = \left(p_{\text{T}}^{c_2} \frac{p_{\text{T}}^{t_3}}{p_{\text{T}}\,[\mathbf{p}^{t_2} + \mathbf{p}^{t_3}]}, \eta^{t_3}, \phi^{t_3}, m^{c_2} \frac{p_{\text{T}}^{t_3}}{p_{\text{T}}\,[\mathbf{p}^{t_2} + \mathbf{p}^{t_3}]} = 0\right)$$

Jet inputs

UFO merges PFO and TCC inputs, aiming to obtain a better and more stable performance in a wide p_T range.



Pile-up mitigation

Constituent level

- Constituent Subtraction + Soft Killer
  - CS subtracts low-p_{T} area in the cluster.
  - SK makes a hard p_{T} cut to remove constituents.

Jet level – Grooming

- Trimming
- Soft Drop

  recluster the jet with the C/A algorithm, if

$$\frac{min(p_{T1}, p_{T2})}{p_{T1}+p_{T2}} > z_{cut}\left(\frac{\Delta R_{12}}{R_0}\right)^{\beta}$$

  p_{T} fraction must be sufficiently large   constituents must be close enough

  the process terminates and the remaining constituents form the jet, otherwise remove the lower p_{T} branch the process is repeated. ($\beta = 1.0$, $z_{\mathrm{cut}} = 0.1$)

- Recursive Soft Drop
- Bottom-up Soft Drop

MC calibration

The aim of MC calibration is to obtain a calibration scale factor,

$$E^{\mathrm{calib}} = E^{\mathrm{reco}} \cdot \boldsymbol{C}_{\mathbf{JES}}$$

$$m^{\mathrm{calib}} = m^{\mathrm{reco}} \cdot \boldsymbol{C}_{\mathbf{JES}}\,\boldsymbol{C}_{\mathbf{JMS}}$$

where E^{calib} and m^{calib} is supposed to be calibrated to MC truth scale.

To derive these scale factors, the energy and mass response are defined as

$$R_{\mathrm{E}} = \langle E^{\mathrm{reco}} / E^{\mathrm{true}} \rangle$$

$$R_{\mathrm{m}} = \langle m^{\mathrm{reco}} / m^{\mathrm{true}} \rangle$$

For JES calibration, the responses are derived in bins of (E^{true}, η). Then calculate

$$E^{\mathrm{reco\ (NI)}} = E^{\mathrm{true}} \cdot R_{\mathrm{E}}$$

Derive the response again, but in bins of ($E^{\mathrm{reco\ (NI)}}$, η) to make the final response only correlates to E^{reco}.

$$\boldsymbol{C}_{\mathbf{JES}} = 1 / R_{\mathrm{E}}$$

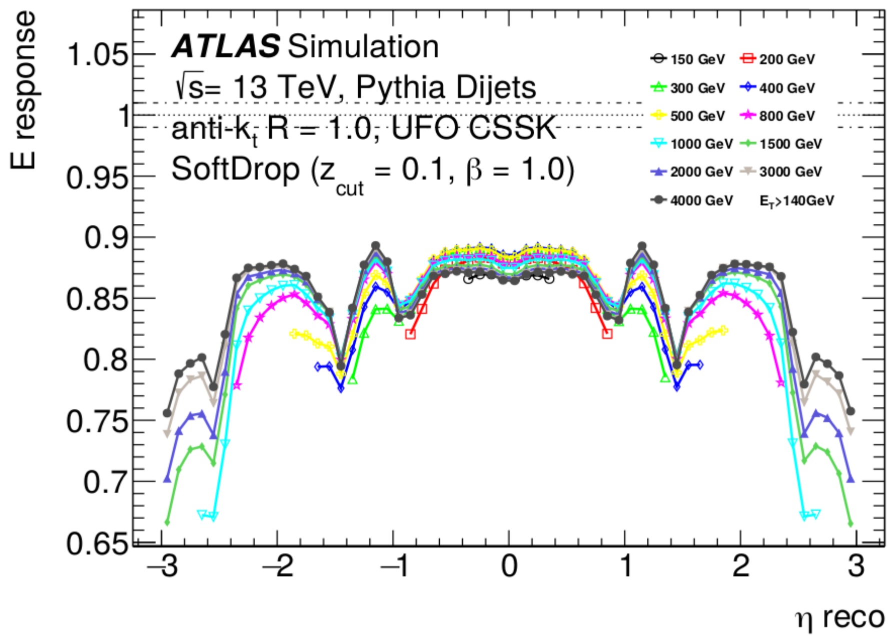
For JMS calibration, the responses are derived in bins of (E, $\ln(m/E)$, η), following similar procedure as the JES calibration.

$$\boldsymbol{C}_{\mathbf{JMS}} = 1 / R_{\mathrm{m}}$$

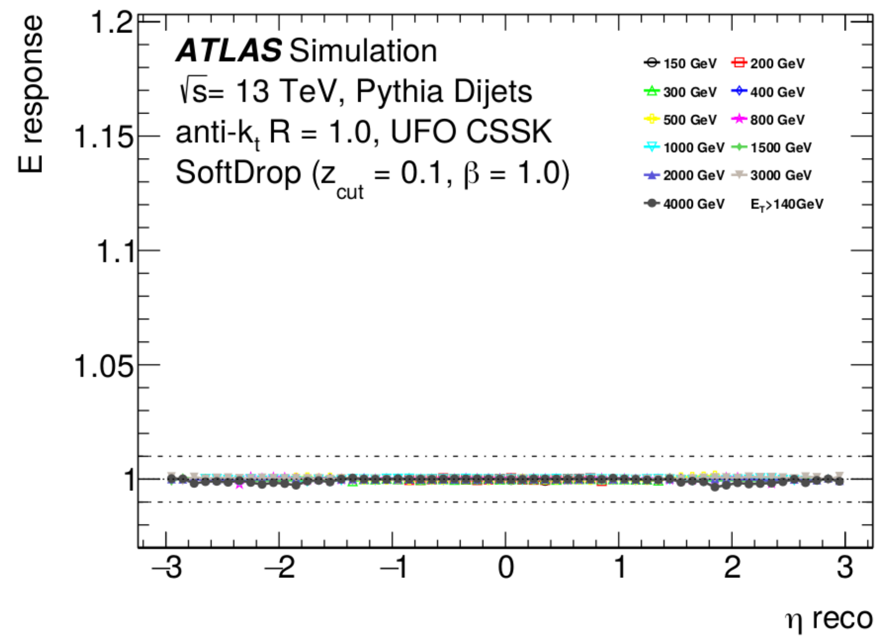
MC calibration

Uncalibrated and calibrated energy response at several E^{true} slices.

- Calibrated $R_E = \langle E^{\mathrm{calib}} / E^{\mathrm{true}} \rangle$, it is very close to unity, which means the calibrated energy is very close to truth scale.
- The non-closure in JES calibration is smaller than 0.5%.
- JMS non-closure mostly appears in p_T < 500 GeV regions, it is smaller than 4%.



Uncalibrated

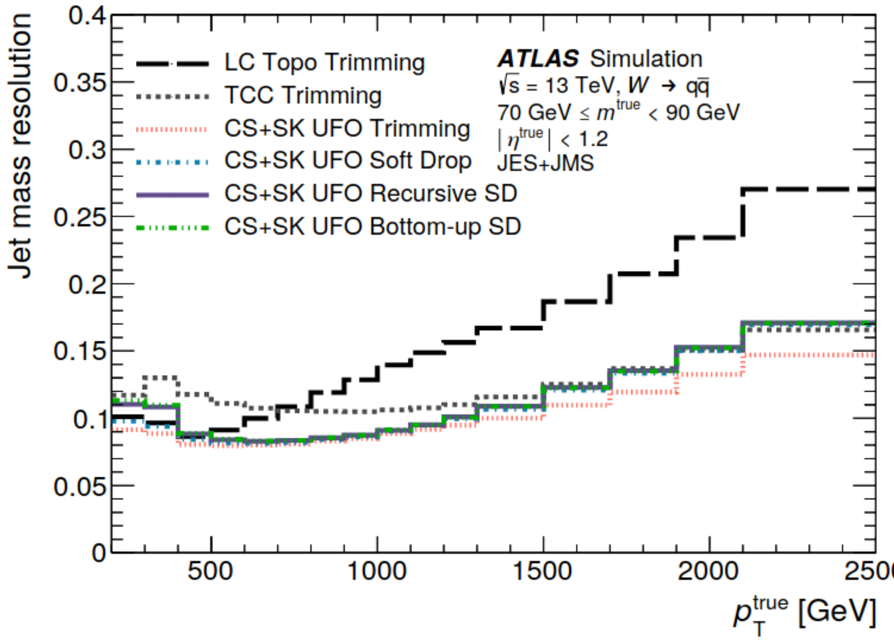


Calibrated

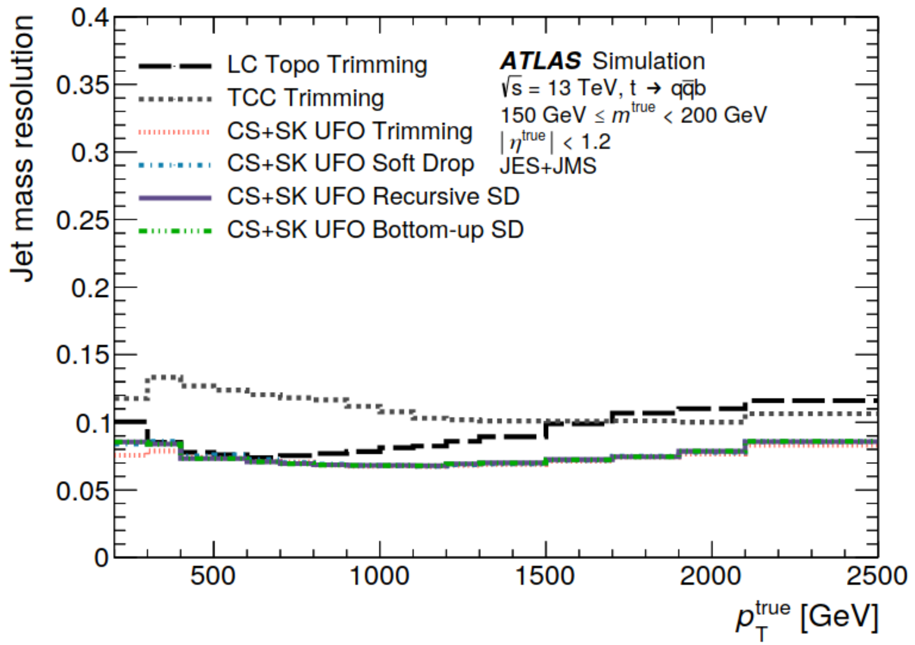
Comparison of jet definition performance

Jet mass resolution comparison between LCTopo Trimmed jet and UFO jets.

- The large-R jet mass resolution is defined as 68% interquartile range divided by twice the median of the distribution.
- The resolution for all UFO jet collections is better than LCTopo Trimmed jet.



Jet mass resolution for W jets

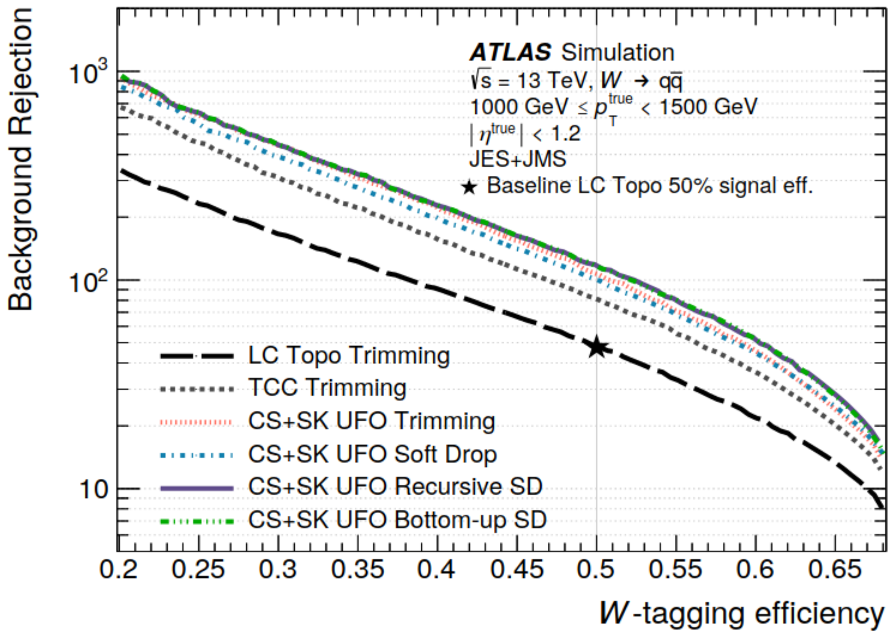


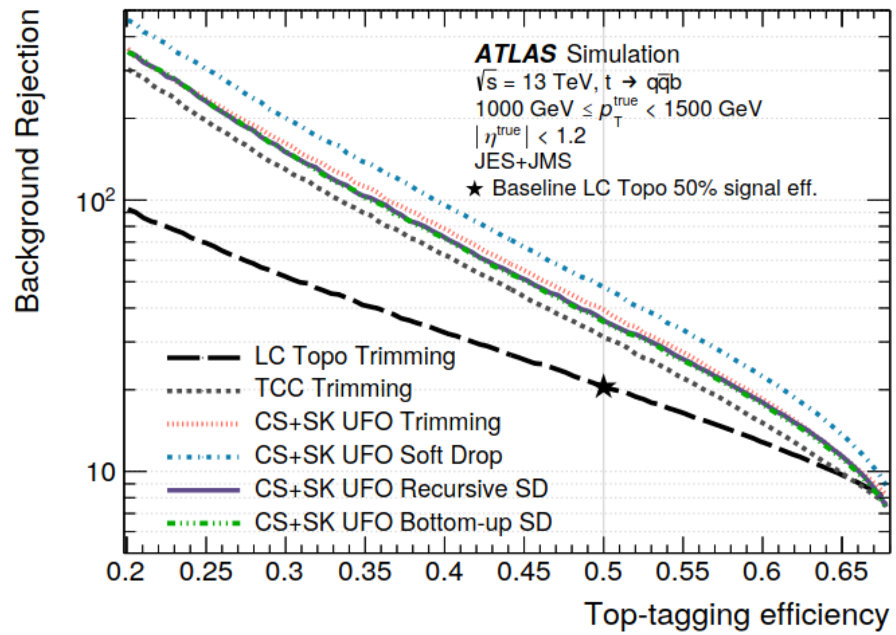
Jet mass resolution for top jets

Comparison of jet definition performance

Background rejection as a function of signal efficiency for a tagger using mass window cut and substructure variable cut.

- CS+SK UFO jets outperform LCTopo Trimmed jets and TCC Trimmed jets.
- The improvement on background rejection in high p_T region is significant.



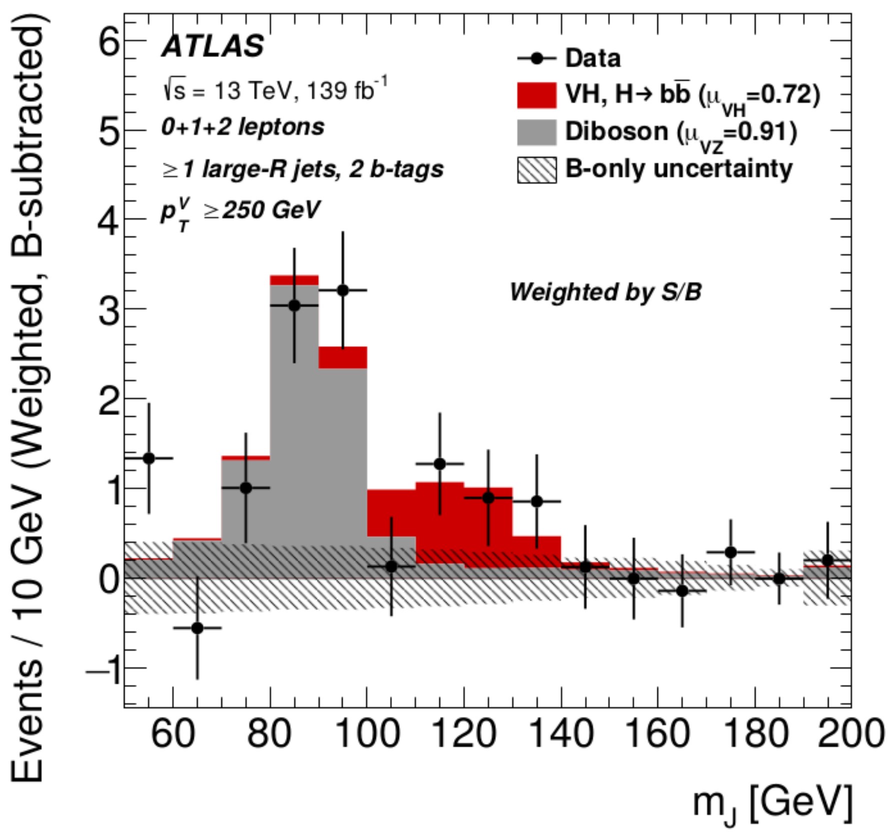


Background rejection as a function of signal efficiency for a tagger using the jet mass and D_2 (τ_{32}) for W (top) jets

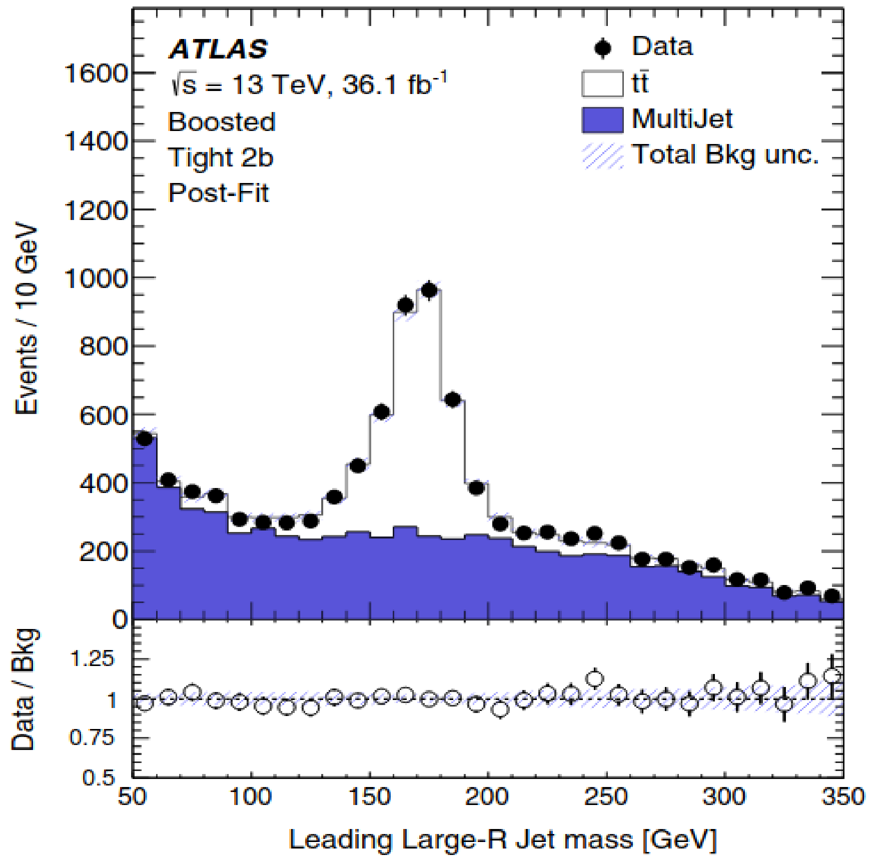
Calibrated large-*R* jet mass

Mass distributions of LCTopo Trimmed jets in physics analysis.

- Peaks of the calibrated jet mass distributions are at the correct place.



Boosted H → bb jet mass distribution



Large-*R* top jet mass distribution

Summary

- Performance of several kinds of large-*R* jet definitions has been compared.
- A new type of jet input, the Unified Flow Object, can improve the jet mass resolution and significantly increase jet tagger performance.
- Pile-up mitigation technique like CS+SK and Soft Drop can make UFO jets more stable to pile-up.
- The MC calibration of the large-*R* jet collections is able to calibrate the energy and mass of the jets to truth scale.
- CS+SK UFO Soft Drop jet definition was selected as the new ATLAS baseline.
- The full study can be found in https://arxiv.org/pdf/2009.04986.pdf

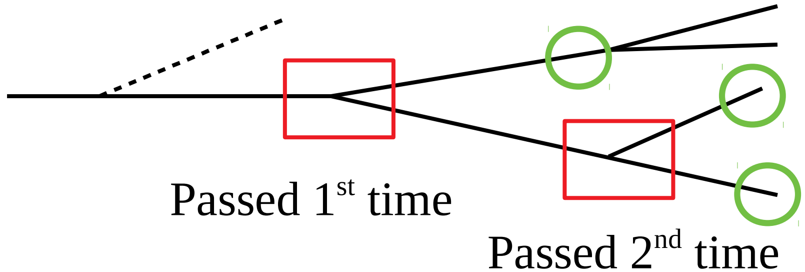
Backup

Pile-up mitigation

Jet level – Grooming

- **Recursive Soft Drop**

  apply Soft Drop to the C/A reclustered jet until the SD condition is satisfied N times. In the case of UFO jets, N is set to 2. (β = 1.0, z_{cut} = 0.05)

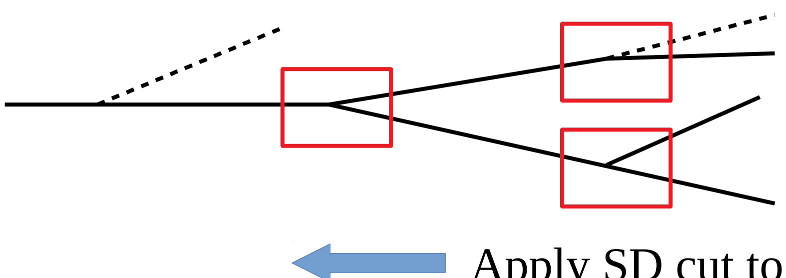


The final jet has N+1 sub-jets

Apply SD first to the branch with the widest ΔR between its two sub-jets

- **Bottom-up Soft Drop**

  Backwards Soft Drop, the SD condition is applied as a cut starting from the clustering tree of a jet. (β = 1.0, z_{cut} = 0.05)



Apply SD cut to every pairs