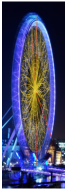
Jets from Jets

Re-clustering as a tool for large radius jet reconstruction and grooming at the LHC



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based on arXiv:1407.2922

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Introduction

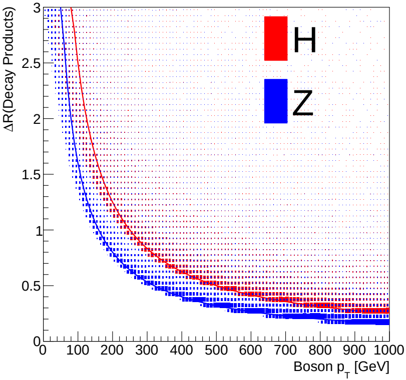
Angular separation of decay products for a massive $\mathcal{P}$, scales as $2m_{\mathcal{P}}/p_T^{\mathcal{P}}$.

$\rightarrow$ jet radius parameter R should be process dependent and scale with p_T.

In practice, the LHC collaborations use a small number of R values.

There is a distinction between *large* radius jets and *small* radius jets.

From *large* radius jets, we have seen many studies probing the **top down** substructure of jets, at fine radial scales.



Why do we **not** optimize R **per process** and **per energy scale**?

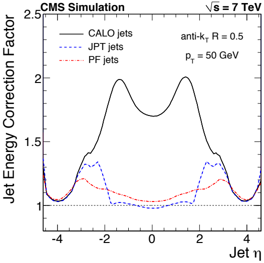
A Minor Setback: Jet Calibrations

Algorithms are not optimized per analysis due to non-trivial calibrations:

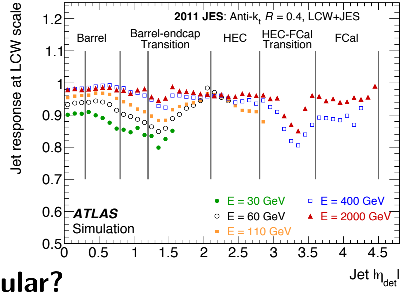
Calibration: The corrections to a jet 4-vector so that $\langle E^{\text{reco}}/E^{\text{truth}}\rangle = 1$ and is independent of η.

[Particle flow/Calorimeter cluster]
inputs to jets are calibrated,
but need to correct for e.g.

particles that were missed, merged, or below noise thresholds, energy loss in un-instrumented regions, and correlations between particles.



arXiv:1107.4277

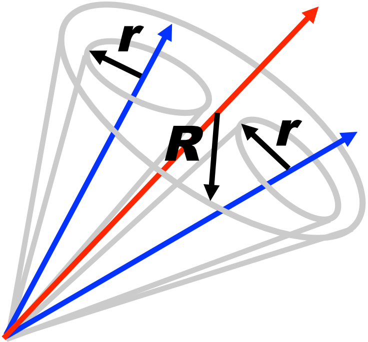


arXiv:1406.0076

Can we make jet clustering more modular?

Jets from Jets: a modular way to cluster & calibrate

Introduce a new angular scale **r** $<$ **R**;
Cluster radius **r** jets into radius **R** jets.



If chosen appropriately, the corrections and calibrations (and uncertainties!) from **r** propagate to the large radius jets.

All that must be specified ahead of time is the small radius jet algorithm.

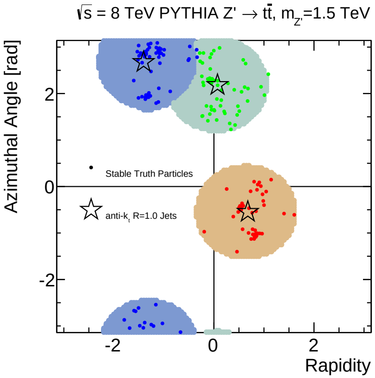
$\therefore$ Every **kinematic region** of **every analysis** for **every data-taking** condition can optimize the large radius parameter in order to maximize the sensitivity to particular physics scenarios.

N.B. The set of jets above a threshold p_T is IRC safe and so re-clustered jets inherit IRC safety.

Re-clustered Jets

Small radius jets can only be reliably calibrated to a certain p_T threshold. This threshold scales with r, but is $\sim$ 20 GeV for $r \sim 0.4$.

$\rightarrow$ Even without further considerations, re-clustering *grooms* the jets.

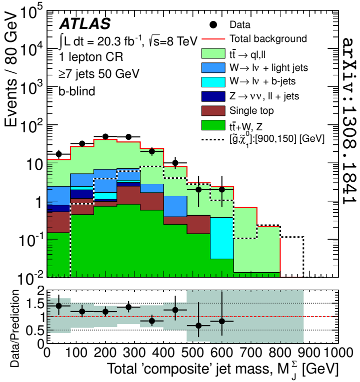


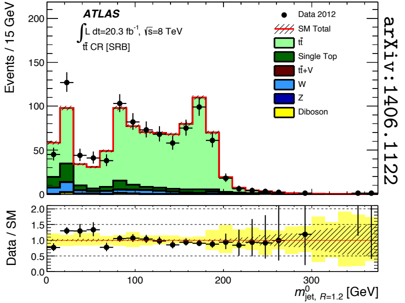
Also, the *effective area* (pileup sensitivity) of re-clustered jets is smaller.

A Brief History in ... Re-clustering

Grouping small radius jets to form composite systems of objects has been used for quite some time - for instance in forming $m_{j_1 \ldots j_n}$ for jets j_i.

Re-clustering was pioneered in recent ATLAS SUSY searches:





0 Lepton Direct Stop Search: W/Top tag with re-clustered jet (mass)

Inclusive multijets: $M_J^{\Sigma} = \sum_i$ re-clustered jet i mass

Something New: Re-clustered Grooming

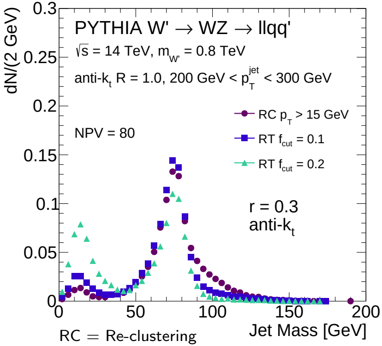
Example: re-clustered trimming (RT):

Drop all small radius r jets i re-clustered into the radius R jet J if

$$p_{T,i} < f_{\text{cut}} \times p_{T,J} = \sum_j p_{T,j}$$

Which adds a new parameter, f_{cut} – analogous to large radius jet trimming.

Small differences: f_{cut} is applied to a jet which has a small level of grooming already applied and which has been pileup corrected (not standard for the LHC experiments).



RC = Re-clustering

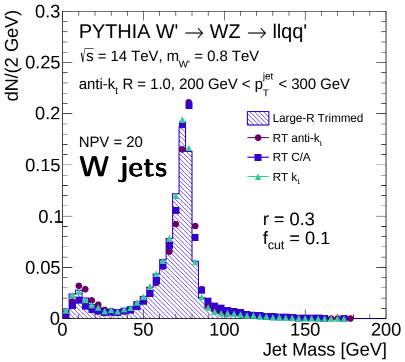
p_T cut = 15 GeV

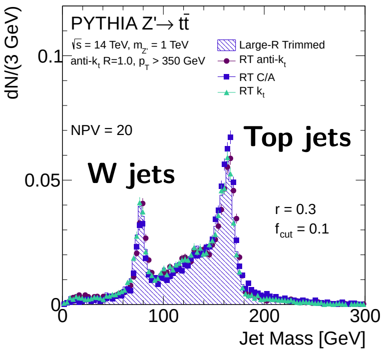
Recall: f_{cut} can be optimized per analysis and so can be p_T (and pileup) dependent.

Re-clustered Trimmed Jets in Action

With low levels of pileup, there is not a large dependance on the radius r jet algorithm.

As expected, RT jets with k_t $r = 0.3$ jets and anti-k_t $R = 1.0$ jets is nearly identical to the large R trimmed analogue with the same parameters.





Pileup Corrections

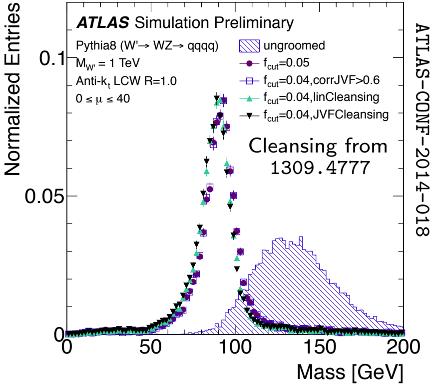
The modular structure of re-clustering easily allows for

- Pileup calibrations via $\rho \times A^{\mu}$ for each radius r jet,

  and any residual μ and NPV corrections that are needed

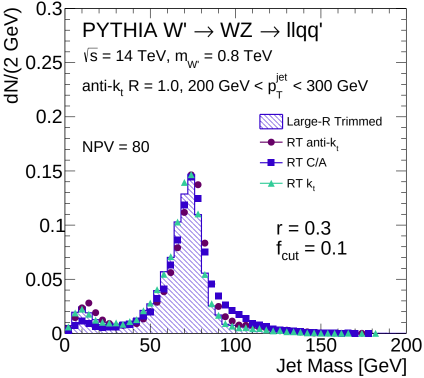
- Pileup jet removal via any one of many techniques.

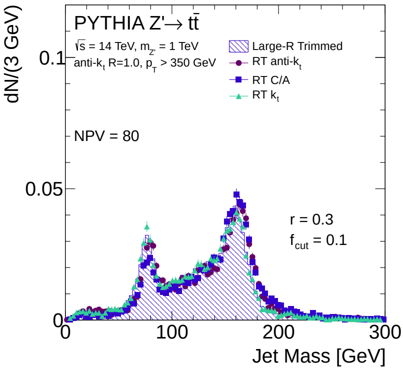
  e.g. JVF/JVT, pileup ID, cleansing, etc.



RT Jets with High Pileup

The distribution of pileup corrected (via $\rho \times A^{\mu}$) Large R trimmed jets changes shape similarly to pileup corrected radius r jets, RT.



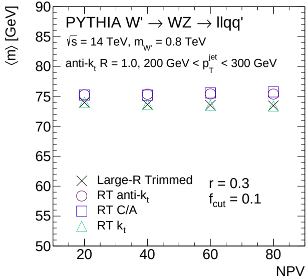


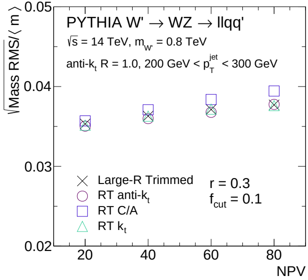
C/A jets seem to perform the worst, but this may also be an f_{cut} dependent statement as the jet area varies by algorithm.

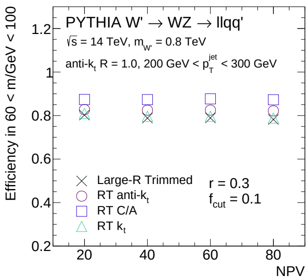
Quantitative comparison - radius r jet algorithm

For $r = 0.3$ and $f_{\mathrm{cut}} = 0.1$,

- The average mass is NPV stable
- Window efficiency is NPV stable
- C/A has the highest window efficiency, but worst resolution







Determining the size of r

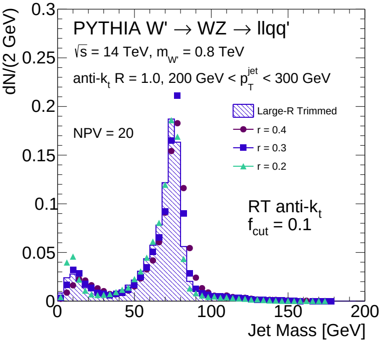
Aside from the algorithm type, the only parameter that must be decided ahead of time is r.

Pros for smaller r

Less sensitive to pileup (scales with r^2)
Resolve finer structure

Cons for smaller r

Larger residual calibration (as $r \to 0$, back to topo-clusters and PF objects)
Detector granularity ($r \lesssim 0.1$)
Phenomenological modeling ($r \lesssim 0.1$)

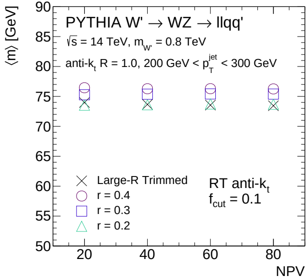


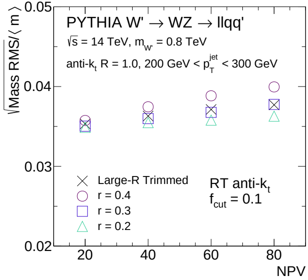
N.B. RT provides for a natural transition between 'Large' and 'small' radius jets, based on the number of re-clustered (radius r) jets.

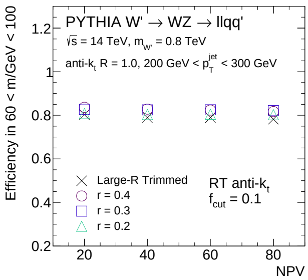
Quantitative comparison - small radius r

For anti-k_t and $f_{\mathrm{cut}} = 0.1$,

- The average mass is NPV stable
- Window efficiency is NPV stable
- Smaller r is better in terms of the resolution performance



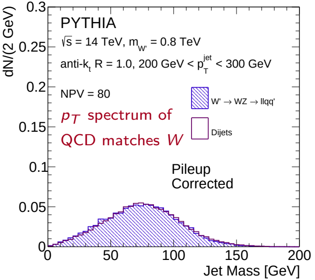


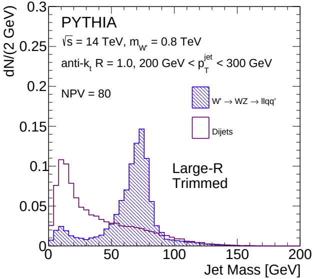


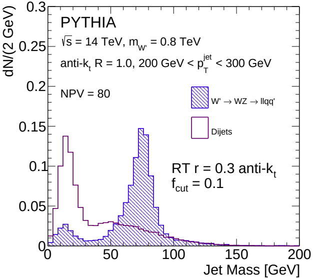
Background

So far, focused only on RT when there is hard structure - what about for the QCD background?

- Similar behavior for RT and large R trimmed.
- Subtle differences that depend on f_{cut} and the algorithm.







Re-clustering and Jet Substructure

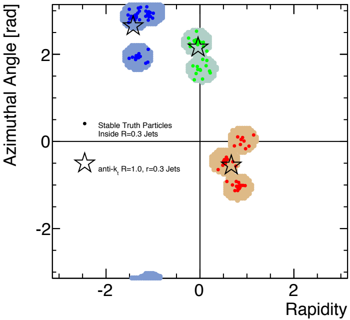
Instead of the **top-down** approach to substructure, in the re-clustering paradigm, there is **bottom-up** substructure.

Some variables come fully calibrated as a result of the re-clustering process:

1. (Jet Mass)
2. Number of subjets
3. Number of *b*-tagged subjets
4. $\sqrt{d_{ij}}$

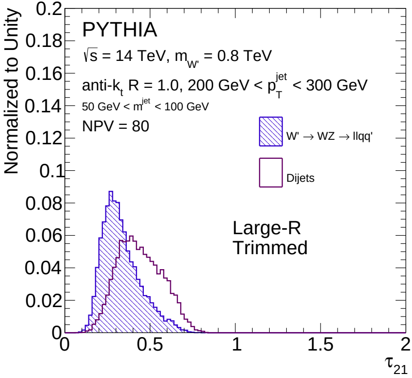
For other variables, constituents are inherited from the radius *r* jets.

1. *N*-subjettiness ratios τ_{ij}
2. Width, energy correlations, pull, etc.



RT Jet Substructure in Action

Qualitatively, similar structure when using the trimmed jet constituents and the inherited radius r constituents in RT.

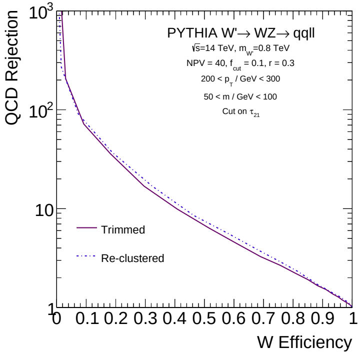


RT Jet Substructure: Quantitative Performance

For a fixed signal efficiency, the QCD rejection is very comparable between RT and large R trimming.

Some information is 'lost' in the removed (sub)jets, which impacts both methods.

Alternative: assign constituents by ΔR (drawback: increases pileup sensitivity)



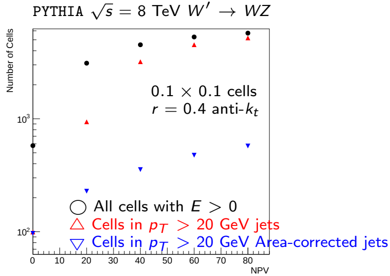
It is expected that for similar parameters, RT and standard trimming will perform similarly - however in practice RT could outperform standard grooming techniques because it can be optimized per p_T bin.

Data Storage and Speed

Though not the main motivation, there are further benefits in re-clustering from a computational perspective†.

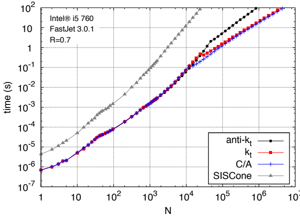
Storage

After computing ρ, there is no longer a need to store calorimeter objects not contained inside jets above the p_T threshold.



Speed

Fastjet is very fast! But if you have m algorithms, then $N\log(N)$ becomes $MN\log(N)$, whereas for re-clustering, the additional step takes $\sim$ no time.



arXiv:1111.6097

† Thanks to T. Farooque, M. Casolino, and A. Juste for pointing us to this side benefit!

The Next Steps: Validating Calibrations

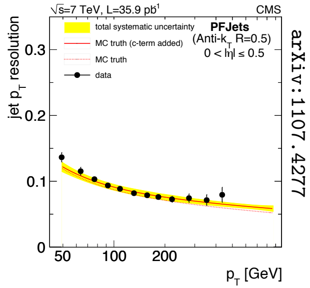
There are two effects which could lead to mis-calibrated re-clustered jets:

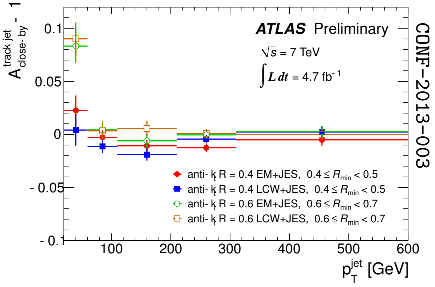
Thresholds Even though $\langle p_{T,r}^{\text{reco}} / p_{T,r}^{\text{true}} \rangle = 1$, a non-zero resolution and a falling p_T spectrum can induce $\langle p_{T,R}^{\text{reco}} / p_{T,R}^{\text{truth}} \rangle \neq 1$.

Nearby-jets Inclusively, $\langle p_{T,r}^{\text{reco}} / p_{T,r}^{\text{true}} \rangle = 1$, but when jets are very nearby, the response may differ from one on average.

These also impact large R groomed jets, but can be calibrated away.

→ Requires further study by the experimental collaborations.

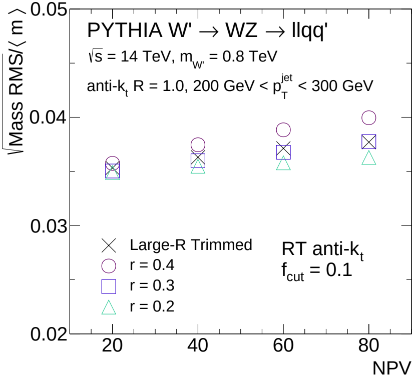




Conclusions and Future Outlook

Re-clustering is a very modular paradigm for clustering jets

- The flexibility allows for jet algorithm optimization per analysis
- There is a natural scheme for corrections, calibrations, and uncertainties
- Re-clustering can accommodate jet grooming
- Jet substructure is inherited from the radius *r* jets



Its now up to the experimental collaborations to study re-clustering as an alternative/complement for Run II and beyond!

BACKUP