Prospects of Dynamic Radius Jet Clustering Algorithm at the LHC

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Based on JHEP 04 (2023) 019 [2301.13074]

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Motivation

- High-energy colliders are crucial in advancing particle physics.
- Jets appearing from quark/gluons, are a common phenomenon in these colliders.
- High-energy machines can also produce fat jets from the boosted heavy particles.
- In-depth study of these varied objects are crucial for exploring both SM and BSM scenarios.
- However, the current fixed radius jet algorithms (kt, anti-kt, C/A) are inadequate to capture these features in a single go.
- Variable radius jet clustering algorithm would thus be an important asset in our toolbox.

Jets at Collider: QCD jets

Single colored particle gives rise to a bunch of collimated hadrons.

G. Sterman and S. Weinberg, Phys. Rev. Lett. 39 (1977) 1436.

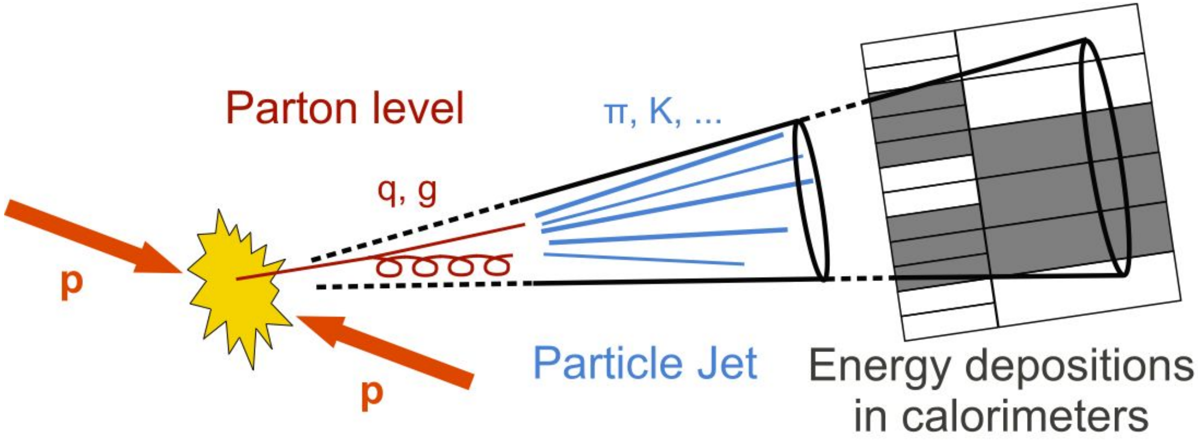


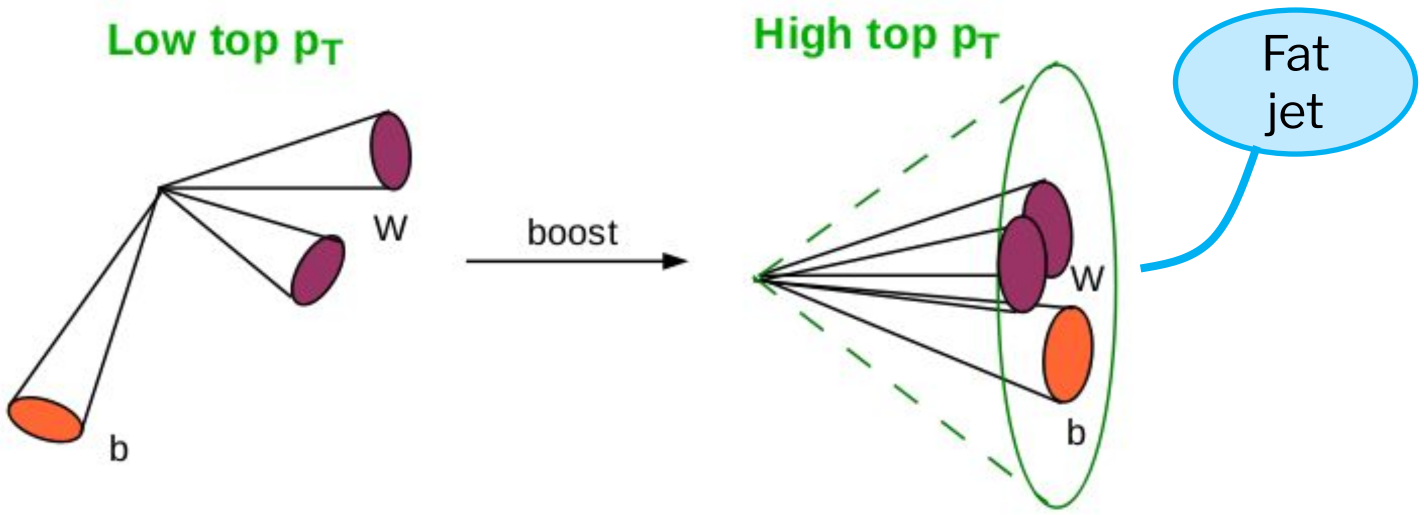
Image: CMS, CERN

Jets at Collider: Fat jets

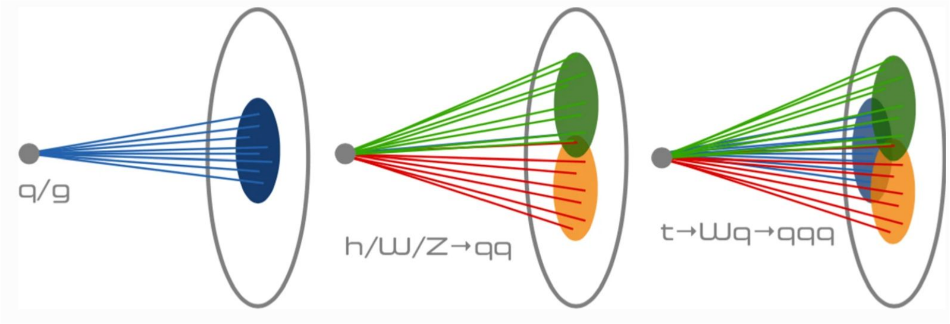
If a heavy particle (W, Z, top, etc.), are boosted enough, their decay products also come within a small solid angle.

These jets, called fat jets, are wider than traditional QCD jets.

Fig.: quantumdiaries.org



Jet Clustering Algorithm



Be it a narrow QCD jet or a boosted fat jet, one needs an algorithm to find it by clustering the collimated sprays of hadrons.

Fig: Eur. Phys. J. C **80**, 58 (2020)

Jet Clustering Algorithm

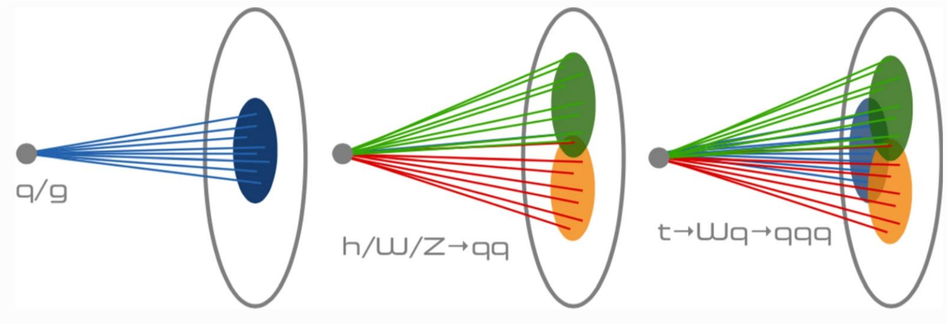


Fig: Eur. Phys. J. C **80**, 58 (2020)

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Jet Clustering Algorithm

Sequential Recombination Algorithm

Take all the four-momenta in a list, calculate all possible d_{ij} and d_{iB}

$$d_{ij} = \min\left(p_{T_i}^{2p}, p_{T_j}^{2p}\right) \Delta R_{ij}^2, \qquad \Delta R_{ij} = \left(y_i - y_j\right)^2 + \left(\phi_i - \phi_j\right)^2$$

$$d_{iB} = p_{T_i}^{2p} R_0^2$$

p	0	1	-1
Name	CA	KT	AK

1. Find the minimum of the d_{ij} and d_{iB}.
2. Minimum is a d_{ij}: combine i, j and add to the list, remove i and j, return to step 1
3. Minimum is a d_{iB}: declare i to be a jet (final), remove it from the list, return to step 1.
4. Stop when list gets empty.

Review: *Eur. Phys. J. C 67 (2010) 637*.

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Fixed radius R_0

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Dynamic Radius Jet Algorithm

$$d_{ij} = \min\left(p_{T_i}^{2p}, p_{T_j}^{2p}\right) \Delta R_{ij}^2, \qquad \Delta R_{ij} = \left(y_i - y_j\right)^2 + \left(\phi_i - \phi_j\right)^2$$

$$d_{iB} = p_{T_i}^{2p} \boxed{(R_0 + \sigma_i)^2} \rightarrow R_d^2$$

Radius modifier

$$\sigma_i^2 = \frac{\sum_{a<b} p_{T_a} p_{T_b} \Delta R_{ab}^2}{\sum_{a<b} p_{T_a} p_{T_b}} - \left(\frac{\sum_{a<b} p_{T_a} p_{T_b} \Delta R_{ab}}{\sum_{a<b} p_{T_a} p_{T_b}}\right)^2 ; \; a, b \in i$$

$\langle \Delta R^2 \rangle$ $\qquad$ $\langle \Delta R \rangle^2$

p	0	1	-1
Algorithm	DR-CA	DR-KT	DR-AK

AK: video.
DR-AK: video.

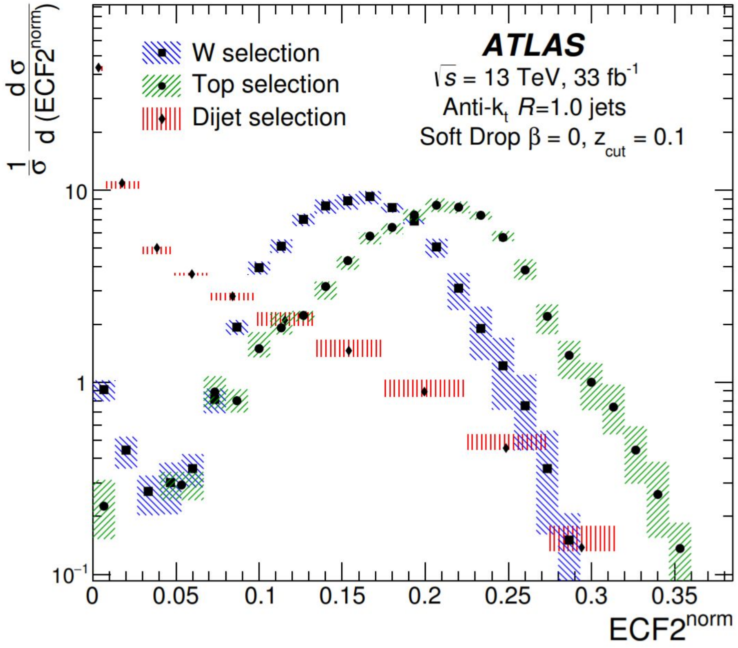
Why σ_i ?

- $\sigma_i^2 = \langle \Delta R^2 \rangle - \langle \Delta R \rangle^2$ (standard deviation) measures fuzziness of a jet.

- Fat jets are expected to be fuzzier than QCD jets

- Energy Correlation Function:

$$\mathrm{ECF2}_\beta = \sum_{a<b} p_{T_a} p_{T_b} \Delta R_{ab}^\beta$$



ECF: *JHEP* 06 (2013) 108.

Fig: *JHEP* 08 (2019) 033.

Implementation and tools

Implemented within the framework of **FastJet3** as a plugin.

GitHub: https://github.com/tousiksamui/DynamicRJetAlgorithm

$$pp \to tj$$
$$pp \to b'b' \to tW^-\bar{t}W^+$$

- Model: SARAH + SPheno
- Event generation: MadGraph5 + Pythia8

13 TeV LHC

Illustration (SM): $pp \to tj$

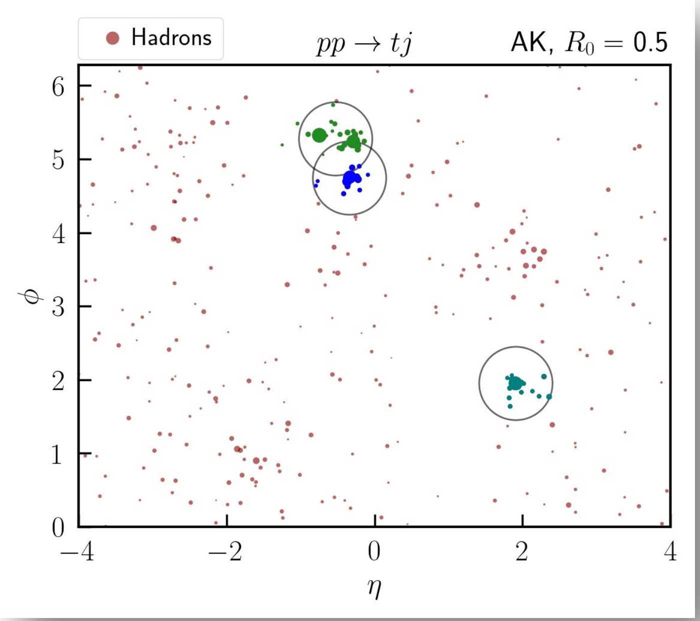
$$pp \to t\ j$$

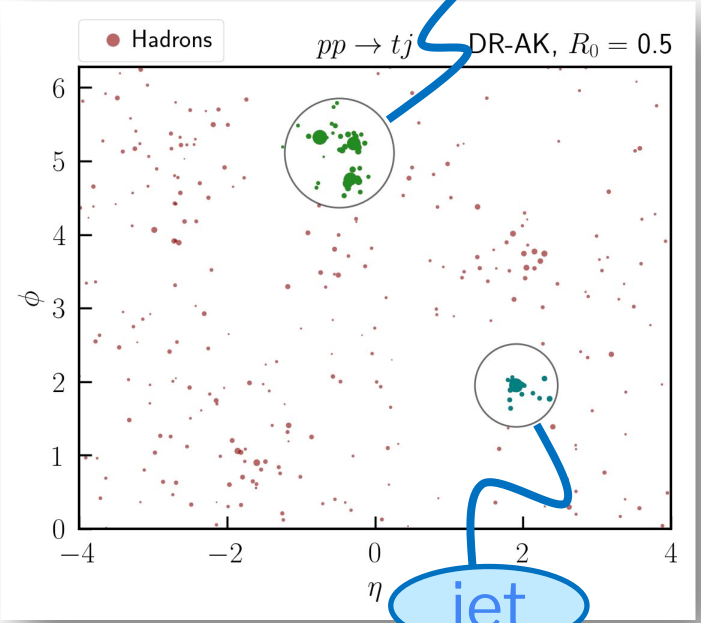
13 TeV LHC

Fat jet

QCD jet

top

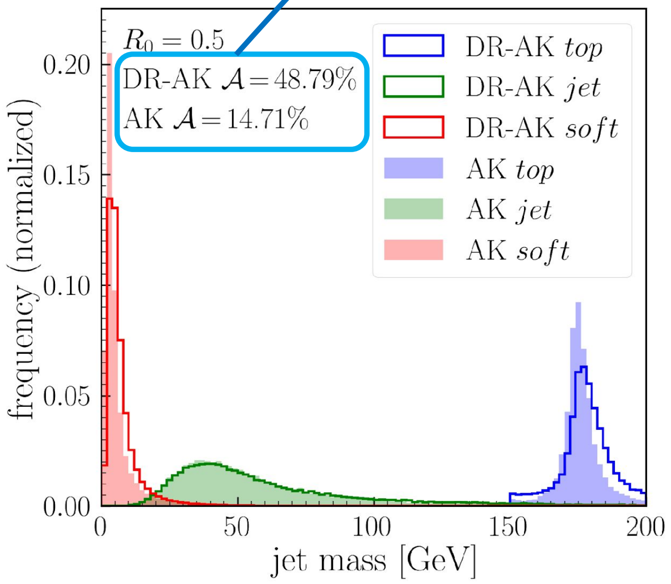


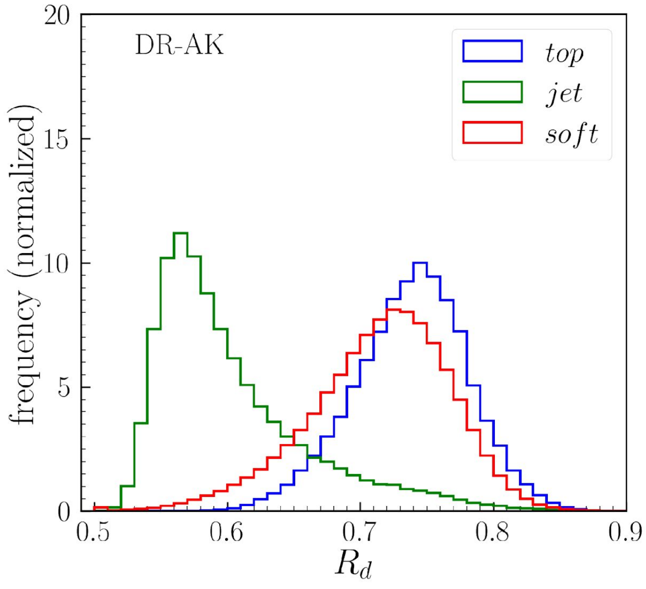


jet

Illustration (SM): $pp \to tj$

$$\text{Acceptance efficiency } \mathcal{A} = \frac{\text{No. top recontructed events}}{\text{No. of total events}}$$





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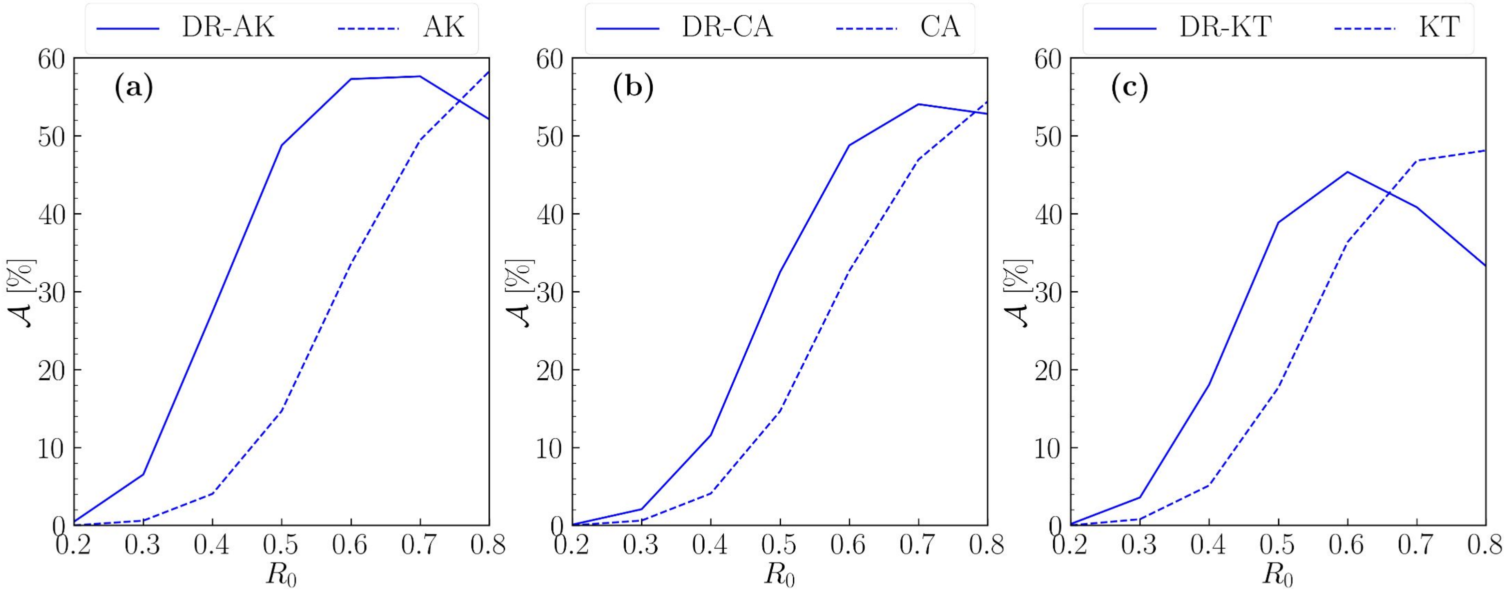


Acceptance efficiency ($\mathcal{A}$) vs. initial radius (R_0)

Illustration (BSM): $pp \to b'\bar{b}' \to tWtW$

$$pp \to b'\overline{b'} \to tWtW$$

13 TeV LHC

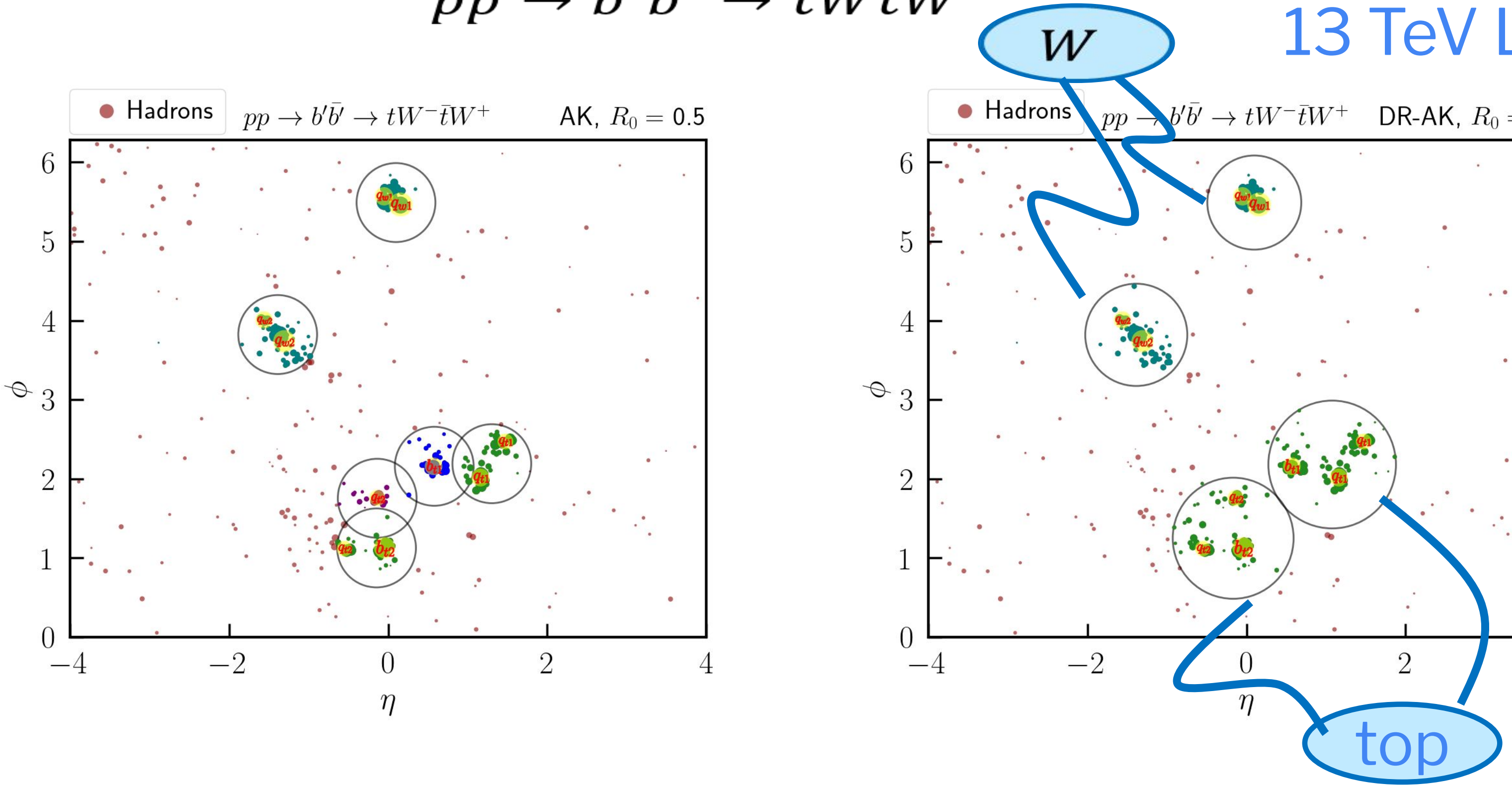
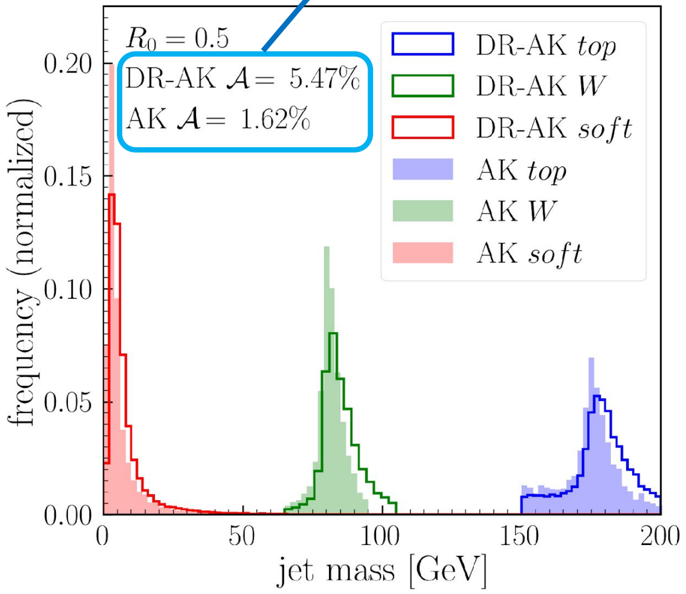
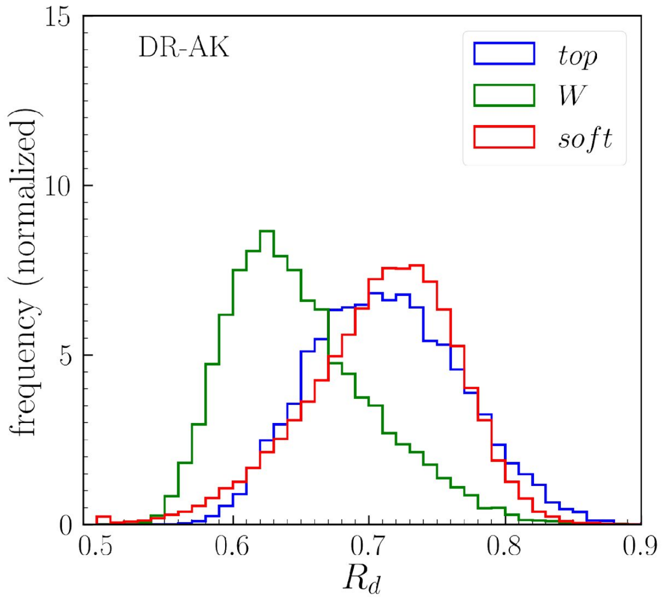


Illustration (BSM): $pp \to b'\bar{b}' \to tWtW$

$$\text{Acceptance efficiency } \mathcal{A} = \frac{\text{No. top and } W \text{ recontructed events}}{\text{No. of total events}}$$





Summary

- There is a need for variable radius jet algorithm. Current fixed-radius algorithms are inadequate for this purpose.
- We have proposed a jet algorithm with dynamic radius.
- Discussed the idea, implementation this algorithm and utility
- Applicable in scenarios with differently sized jets.
- The usefulness of the DR jet algorithm has presented in two process at 13 TeV LHC.
- It has implications in the study of heavy objects (top/W/Z/H).
- Other studies related to this algorithm are ongoing.

Outlook

- Phenomenological implications especially in the BSM context has also been proposed to be studied.
- Prospects in object based studies: q/g discrimination, dark jets, W/Z/top jets.
- Prospects in theoretical, phenomenological, developmental aspects of this algorithm.
- Studies with **Open Data**:
  - A detailed study of pileup and jet energy resolution calibration (JERC) with open data has been proposed.
  - Assessing performance of the algorithm in handling boosted objects or heavy flavour jet.
  - Study of boosted objects with this new algorithm would be useful.

Thank You