PROCEEDINGS OF SCIENCE

Jet measurements with ALICE: substructure, dead cone, charm jets

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A selection of recent jet measurements are presented from the ALICE experiment at the CERN LHC in proton-proton collisions at $\sqrt{s}$ = 13 TeV, focusing on substructure results for inclusive and charmed jets. The groomed jet momentum fractions (z_g) of inclusive full jets are shown for various jet resolution parameters, and z_g, the groomed splitting radius (θ_g) as well as the number of soft drops ($n_{\rm SD}$) of inclusive and charmed charged-particle jets are compared. The first direct measurement of the dead cone in heavy-flavor jets is also presented. Furthermore, the parallel momentum fractions of charmed $\rm D^0$ mesons and Λ_c^+ baryons are shown. Besides serving as a reference for jet structure modification measurements in heavy-ion collisions, these results provide new insight to QCD parton shower properties and flavor-dependent fragmentation processes.

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1. Introduction

Measurement of jets in small collision systems serve as fundamental tests of pQCD and hadronization models [1]. Furthermore, these measurements provide a baseline for modification of jet production rates and structures in heavy-ion collisions by their interactions with the medium that is present in such collisions [2]. Identification of jets with heavy flavor allows for the investigation of flavor-dependent production stemming from mass and color-charge effects, and the understanding of mass-dependent fragmentation. In this contribution, recent groomed substructure measurements of inclusive and heavy-flavor jets are presented, as well as the first direct measurement of the dead cone, and the parallel momentum fraction of charmed D^0 mesons and Λ_c^+ baryons. Approximately 59 pb^{-1} integrated luminosity is used from pp collisions at $\sqrt{s}$ = 13 TeV. Charged-particle jets are reconstructed in the ALICE [3] central barrel in the central pseudorapidity region $|\eta| < 0.9$ from tracks identified in the Time Projection Chamber and the Inner Tracking System (ITS). Full jets are reconstructed in a more limited acceptance within the pseudorapidity and azimuthal angle range $|\eta| < 0.7$ and $1.4 < \varphi < \pi$, also using information from the Electromagnetic Calorimeter. Heavy-flavor hadrons are fully reconstructed from their decays (in the $D^0/\overline{D^0} \to K^\pm\pi^\mp$ and $\Lambda_c^+ \to pK_S^0$ channels), aided by ITS based on statistical selection of tracks originating from a secondary vertex.

2. Groomed substructure of inclusive jets

Measurements of groomed jet substructures allow for access to the hard parton structure of a jet, while mitigating the effects of the underlying event and hadronization [4]. Ideally, it provides a direct interface with QCD calculations. Soft-drop grooming is a novel technique that is able to remove wide-angle soft radiation (such as initial-state radiation) as well as that of the underlying event [5]. In this method, the jets that had previously been reconstructed with the anti-k_T algorithm [6] are first declustered and then reclustered using the Cambridge-Aachen algorithm [7] to form a clustering tree that follows angular ordering. Then the soft branches are iteratively removed if not fulfilling the so-called soft-drop condition,

$$z > z_{cut}\theta^\beta, \quad \text{where} \quad z = \frac{p_{T,2}}{p_{T,1} + p_{T,2}} \text{ and } \theta = \frac{\Delta R_{1,2}}{R} \tag{1}$$

are the momentum fraction taken by the second prong ($p_{T,1}$ and $p_{T,2}$ being the momenta of the two prongs), and the splitting radius (defined as the ratio of the $\Delta R_{1,2}$ splitting angle between the two prongs and the resolution parameter of the anti-k_T clustering). The soft threshold is set to $z_{cut} = 0.1$. The angular exponent β is responsible for rejecting soft radiation. The jet groomed momentum fraction z_g and the groomed radius θ_g, defined as the values of z and θ corresponding to the first hard splitting fulfilling the soft-drop condition. Fig. 1 shows z_g (left panel) and θ_g (right panel) for charged-particle based jets for different choices of β. For smaller β values, more soft splittings are groomed away, leading to more collimated jets. This is clearly visible in the case of θ_g where the weight of the distribution shifts toward smaller angles with decreasing β.

Figure 2 shows the full-jet groomed momentum fraction z_g in the $30 < p_T^{jet} < 40$ GeV/c transverse for different R values. The difference suggests that jets with small radii tend to split more symmetrically, while in case of larger radii there is a higher sensitivity to non-perturbative effects. Trends observed both in the R and the β-dependent groomed jet substructure results are reproduced rather well by Monte-Carlo event generators [8, 9].

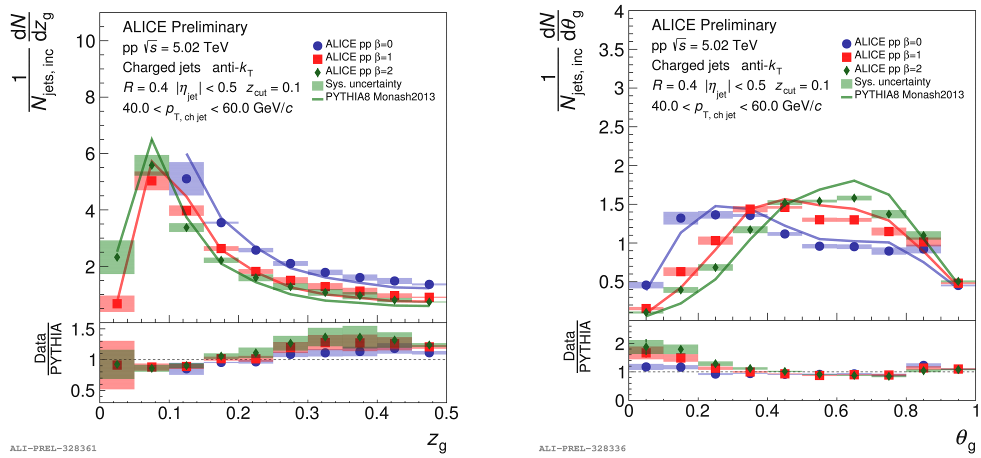

Figure 1: Charged-particle jet z_g (left) and θ_g (right) in pp collisions at $\sqrt{s} = 13$ TeV for different β values, compared to PYTHIA 8 simulations.

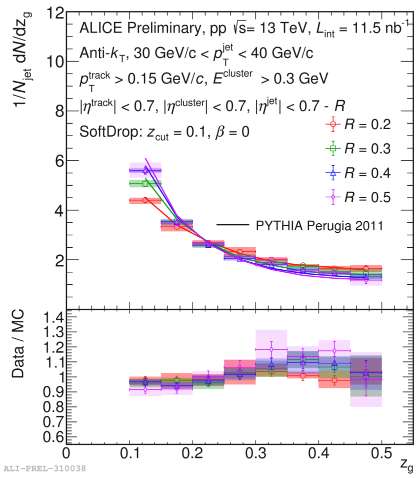

Figure 2: Full jet z_g for different jet resolution parameter values compared to PYTHIA simulations, in pp collisions at $\sqrt{s} = 13$ TeV.

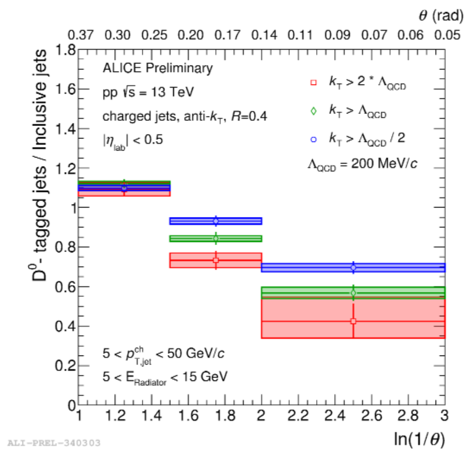

Figure 3: Ratio of the angular distribution of splittings with different k_T cuts for D^0-tagged jets over inclusive jets, shown for $5 < E_{\rm rad} < 15$ GeV.

3. Structure and fragmentation of heavy-flavor jets

In gauge theories, charged particles with a mass $m > 0$ and energy E emit radiation that is suppressed below angles $\theta \approx m/E$ with respect to the axis of the radiator. This so-called dead-cone effect is expected to be present in jets containing heavy flavor [10, 11]. The ALICE collaboration presented the first direct measurement of the dead cone in heavy-flavor jets, following the iterative declustering method proposed in Ref. [12]. A cut on the relative transverse momentum fraction of the splitting, $k_{\rm T}$, is applied to remove non-perturbative effects. Fig. 3 shows the ratio of the angular distribution of splittings for D^0-tagged jets over inclusive jets for radiator energy of $5 < E_{\rm rad} < 15$ GeV. The D^0-tagged jets show a significant suppression toward smaller splitting angles. This suppression becomes stronger if the $k_{\rm T}$ cut is set to higher values, corresponding to a

PoS(LHCP2020)143

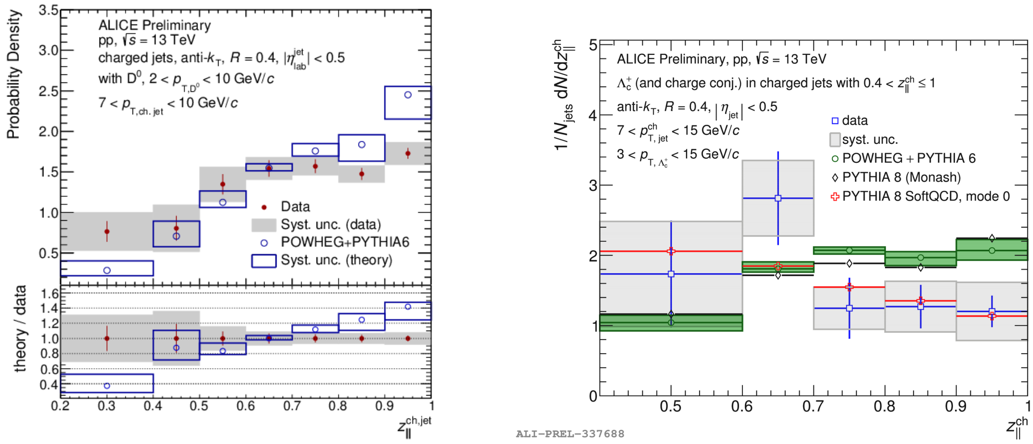

Figure 4: Parallel momentum fraction $z_{\parallel}$ of charged-particle jets tagged with D^0 mesons (left) and Λ_c^+ baryons (right).

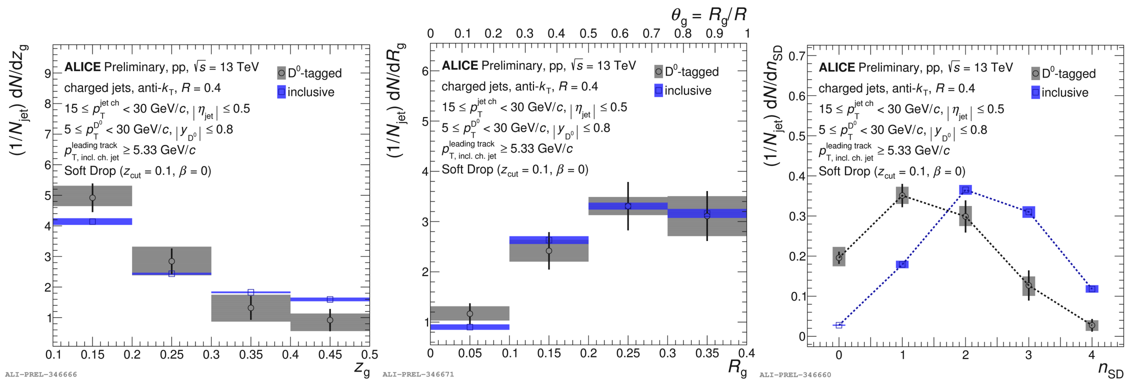

Figure 5: Substructure variables z_g (left), θ_g (center) and n_{SD} (right) of D^0-tagged charged-particle jets compared to inclusive charged-particle jets, in pp collisions at $\sqrt{s} = 13$ TeV.

cleaner dead-cone signature with less contamination by non-perturbative effects.

The reconstruction of heavy-flavor hadrons within a jet allows for direct access to the fragmentation properties, and also allows for a comparison of meson and baryon fragmentation. The parallel momentum fraction $z_{\parallel}$ of D^0 mesons and Λ_c^+ baryons, shown in Fig. 4 left and right panels respectively, exhibit similar trends in the chosen momentum range. It is to be noted however, that a quantitative description of the observations still poses a challenge to some of the most popular model calculations [9, 13, 14].

The groomed jet substructure of D^0-tagged jets has been measured for the first time, and compared to that of inclusive jets. Trends in z_g (Fig. 5 left) and θ_g (Fig. 5 center) are slightly different for charmed and inclusive jets, giving a hint about flavor-dependent jet substructure. A more obvious difference is present in the distribution of the number of splittings fulfilling the soft-drop condition, n_{SD} (Fig. 5 right). The fact that charm jets typically have less hard splittings than inclusive jets is consistent with harder heavy-flavor fragmentation caused by mass and color charge effects.

4. Summary

In this contribution, recent jet-related results were presented from the ALICE experiment in pp collisions at $\sqrt{s}$ = 13 TeV. Soft-drop groomed substructure measurements of full and charged jets provide an excellent opportunity to test perturbative QCD and hadronization models, besides serving as a baseline for heavy-ion collisions. We also presented the first direct measurement of the dead cone in heavy-flavor jets. Parallel momentum fractions of charmed D^0 mesons and Λ_c^+ baryons provide great discrimination power among models on heavy-flavor fragmentation. Charmed jets have been found to typically have less hard splittings than inclusive jets, suggesting a harder fragmentation of heavy than light flavor. The upcoming Run–3 phase of LHC with higher luminosity will allow for high-precision measurements of jets, charmed baryons as well as beauty-jets, further facilitating model developments and moving toward a deeper understanding of the strong interaction [15].

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