

Jet substructure and correlations in hadronic final states from ALICE

James Mulligan for the ALICE Collaboration^{a,b,*}

^a*Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA*

^b*Physics Department, University of California, Berkeley, CA 94720, USA*

E-mail: james.mulligan@berkeley.edu

Jets of high energy collimated particles provide a rich phenomenology to study quantum chromodynamics, from first-principles tests of perturbative calculations to investigations of the emergent properties of the strongly-coupled quark-gluon plasma. In these proceedings, we highlight several recent jet measurements by the ALICE Collaboration, with a focus on jet substructure observables.

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*Speaker

1. Introduction

Jet observables in both proton-proton and heavy-ion collisions can be used to study fundamental aspects of quantum chromodynamics (QCD). In pp collisions, jet measurements test state-of-the-art perturbative calculations and explore the transition from the perturbative to the nonperturbative regimes. In Pb–Pb collisions, jets serve as probes of the quark-gluon plasma (QGP) to study the physical properties of deconfined QCD matter [1–4]. In both cases, studying the internal pattern of particles within jets, known as jet substructure, enables the design of observables to target specific regions of QCD phase space [5].

In these proceedings, we highlight a selection of recent results from the ALICE experiment [6], with an emphasis on analytically calculable jet substructure observables. All results presented utilize jets reconstructed from charged particles at midrapidity using the anti- k_T algorithm [7], and are corrected for detector effects and (in Pb–Pb collisions) underlying event fluctuations.

2. Jet measurements in proton–proton collisions

Jet angularities. The infrared and collinear safe jet angularities [8, 9] provide a flexible way to study QCD in both pp and Pb–Pb [10–12] collisions by systematically varying the weight of collinear radiation via the parameter $\alpha > 0$:

$$\lambda_\alpha = \sum_{i \in \text{jet}} \left(\frac{p_{T,i}}{p_{T,\text{jet}}} \right) \left(\frac{\Delta R_i}{R} \right)^\alpha. \quad (1)$$

ALICE recently measured the ungroomed, and, for the first time, the groomed jet angularities in pp collisions for a variety of α [13], shown in Fig. 1. The distributions are compared to SCET calculations [14, 15] using a Monte Carlo (MC) based folding procedure, and reveal a transition from generally good agreement in the perturbative regime to deviation in the nonperturbative regime.

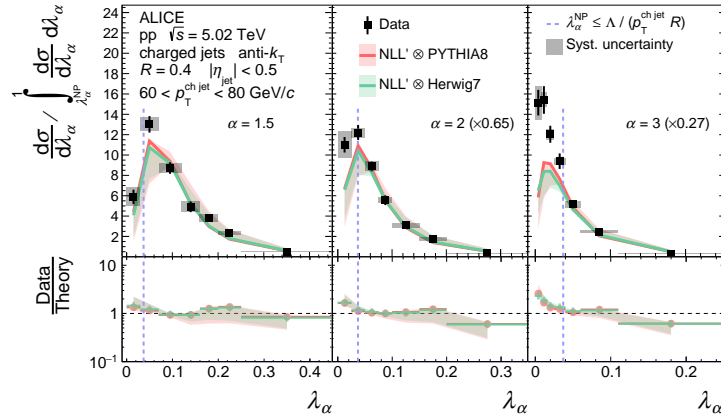


Figure 1: Comparison of measured ungroomed jet angularities λ_α in pp collisions for $\alpha = 1.5, 2, 3$ to analytical NLL' predictions [14] with MC hadronization and charged particle corrections [13].

Jet axis differences. The soft, wide-angle substructure of jets can be studied by comparing the jet-by-jet rapidity-azimuth difference between pairs of jet axes:

$$\Delta R_{\text{axis}} = \sqrt{\Delta y^2 + \Delta \varphi^2}, \quad (2)$$

where the axes can be defined by (i) the standard E -scheme recombination axis, (ii) the Soft Drop (SD) groomed axis, or the (iii) winner-take-all (WTA) recombination axis [16]. Figure 2 (left) shows the first measurement of these pairwise axis differences, where the comparison of the standard and SD axes shows small absolute differences which increase as the grooming condition becomes larger. These soft-sensitive observables can be used to study a variety of nonperturbative physics [16].

3. Jet measurements in heavy-ion collisions

Subjet fragmentation. In heavy-ion collisions, measurements of reclustered subjets have been proposed as sensitive probes of jet quenching [19, 24, 25]. We consider first inclusively clustering jets with the anti- k_T jet algorithm and jet radius R , and then reclustering the jet constituents with the anti- k_T jet algorithm and subjet radius $r < R$. We then consider the fraction of transverse momentum carried by the subjet compared to the initial jet: $z_r = p_T^{\text{ch subjet}}/p_{T, \text{jet}}$. Figure 2 (right) shows the distribution of leading subjets with $r = 0.1, R = 0.4$ in both pp and Pb–Pb collisions. The distributions are compared to theoretical predictions [19–23] which accurately reproduce a mild rising trend of the ratio with z_r , which can be attributed to jet collimation, which then falls as $z_r \rightarrow 1$, which may be due to the large quark/gluon fraction at $z_r \rightarrow 1$. These measurements offer an opportunity to probe higher z than hadron fragmentation measurements, and are an important ingredient for future tests of the universality of in-medium jet fragmentation functions.

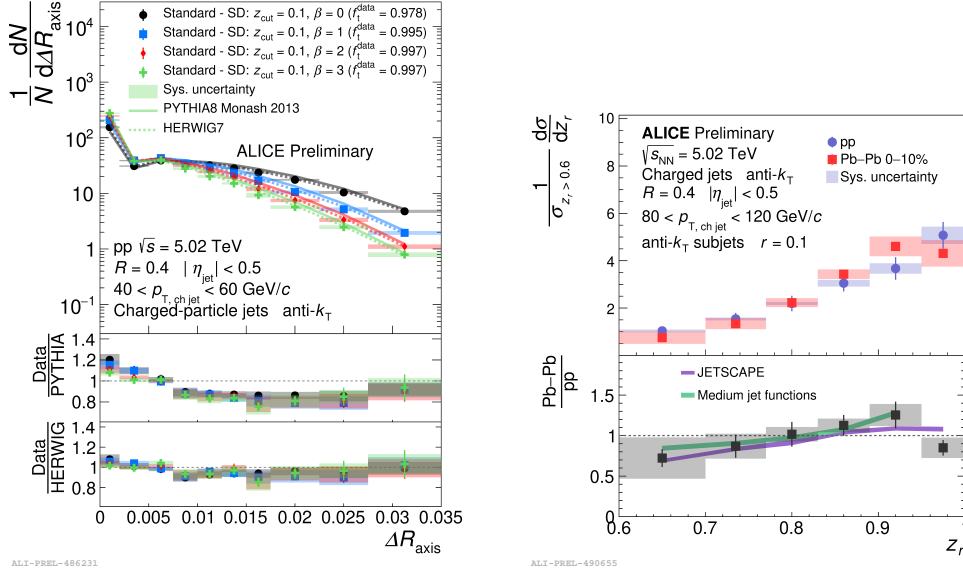


Figure 2: Left: ALICE measurements of pairwise jet axis angular differences for a variety of Soft Drop grooming conditions, compared to PYTHIA [17] and HERWIG [18]. Right: ALICE measurements of leading subjet fragmentation in pp and Pb–Pb collisions, compared to theoretical predictions [19–23].

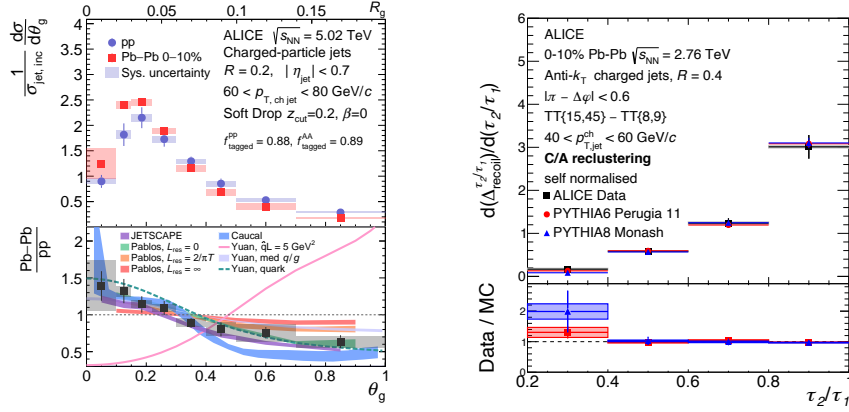


Figure 3: Left: Measurements of θ_g in Pb–Pb compared to pp collisions [43]. Right: Measurements of the τ_2/τ_1 N-subjettiness distribution in Pb–Pb collisions [47] compared to PYTHIA [17].

Groomed jet radius. Jet grooming techniques [26–28] have been applied to heavy-ion collisions to explore whether jet quenching modifies the hard substructure of jets [29–39]. By using strong grooming conditions [40], ALICE measured the groomed momentum fraction, z_g [41], and the groomed jet radius, θ_g [42], with the Soft Drop grooming algorithm. Figure 3 (left) shows a narrowing of the θ_g distributions in Pb–Pb collisions relative to pp collisions [43]. These measurements are compared to a variety of jet quenching models [21–23, 29, 31, 33–35, 44–46], most of which capture the qualitative narrowing effect observed. This behavior is consistent with models implementing an incoherent interaction of the jet shower constituents with the medium, but is also consistent with medium-modified quark/gluon fractions with fully coherent energy loss – presenting the opportunity for future measurements to disentangle them definitively.

N-subjettiness. Semi-inclusive hadron-jet correlations are well-suited to statistical background subtraction procedures in heavy-ion collisions, which allows jet measurements to low p_T and large R [48, 49]. Recently, ALICE measured the N-subjettiness [50, 51] of jets recoiling from a high- p_T hadron with this method [47]. Figure 3 (right) shows the distribution of per-trigger semi-inclusive yields of the τ_2/τ_1 ratio in Pb–Pb collisions compared to PYTHIA [17], which show no significant modification in the pronginess of jets in heavy-ion collisions. This suggests that medium-induced emissions are not sufficiently hard to produce a distinct secondary prong, in line with the lack of modification of z_g observed [43].

4. Conclusion

We have presented several new ALICE measurements of jet substructure in pp collisions, which provide new tests of our first-principles understanding of QCD by exploring the transition from perturbative to nonperturbative physics. In heavy-ion collisions, ALICE measurements are producing an emerging picture of jet quenching phenomenology: hard splittings are not strongly modified, as evidenced by z_g , τ_N , but there is a strong collimation or filtering effect of wide jets, as evidenced by θ_g . The medium-induced soft splitting responsible for this filtering may be exposed in regions dominated by quark jets, as suggested by high- z_r subjet fragmentation. Together, these observables offer future prospects to constrain physical properties of the QGP using global analyses.

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