Measurements of sub-jet fragmentation with ALICE

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Abstract

High-energy jets offer rich opportunities to study quantum chromodynamics, from investigating the limits of perturbative calculability to constraining the emergent properties of the quark-gluon plasma (QGP). In these proceedings, we present new measurements of the fragmentation properties of jets. We report distributions of the sub-jet momentum fraction z_r measured in pp and Pb–Pb collisions with ALICE at the Large Hadron Collider. These measurements serve as input to test the universality of jet fragmentation in the QGP, and offer a path to elucidate jet quenching effects in the large-z region.

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1 Introduction

Jet measurements offer opportunities to test perturbative calculations in quantum chromodynamics and to probe the properties of the QGP [1,2]. In these proceedings, we consider measurements of *sub-jets*, defined by first inclusively clustering jets with the anti-k_T algorithm [3] with radius R, and then reclustering the jet constituents with the anti-k_T algorithm with sub-jet radius $r < R$ [4]. We focus on the fraction of transverse momentum carried by the sub-jet:

$$z_r = \frac{p_{\mathrm{T,\,subjet}}}{p_{\mathrm{T,\,jet}}}.$$

In pp collisions, both the inclusive and leading sub-jet z_r distributions have been calculated perturbatively [5,6]. These calculations suggest several interesting features that can be tested by experimental data: the role of threshold resummation in the large-z_r region and, in the leading sub-jet case, nonlinear evolution of the jet fragmentation function in the perturbative calculation. In heavy-ion collisions, sub-jets have been proposed as sensitive probes of jet quenching [5–8]. The sub-jet z_r observable presents several unique opportunities:

1. *Test the universality of jet fragmentation in the QGP*. In vacuum, it is expected that the parton-to-jet fragmentation function, $J(z)$, is equal to the parton-to-subjet fragmentation function $J_r(z)$. However, it is unknown whether the universality of jet fragmentation functions holds in the QGP [9]. Measurements of z_r are directly sensitive to $J_{r,\text{med}}(z)$, and can be used to extract it. The extracted $J_{r,\text{med}}(z)$ can then be compared to an independently extracted $J_{\text{med}}(z)$ to test the universality of in-medium jet fragmentation.
2. *Probe high-z fragmentation*. Sub-jet fragmentation is complementary to the longitudinal momentum fraction of hadrons in jets [10, 11]. Sub-jet measurements offer the benefit of probing higher z than hadron measurements, and, in doing so, offer the possibility to access a quark-dominated sample of jets and expose the interplay of soft medium-induced radiation with the relative suppression of gluon vs. quark jets.
3. *Measure sub-jet energy loss at the cross-section level*. Recently, a well-defined method of measuring out-of-cone energy loss at the cross-section level was proposed, by computing moments of the leading sub-jet z_r distribution [6]. This "sub-jet energy loss", describing the fraction of jet p_{T} not carried by the leading sub-jet, can then be computed in both pp and Pb–Pb collisions, and contrasted with other measures of jet modification.

2 Results

All presented results use $R = 0.4$ jets reconstructed from charged particles with pseudorapidity $|\eta| < 0.9$, and are corrected for detector effects and (in Pb–Pb collisions) underlying-event fluctuations.

2.1 Sub-jet fragmentation in proton-proton collisions

Figure 1 shows the measured z_r distributions for inclusive (left) and leading (right) sub-jets. The z_r-differential cross sections are normalized such that their integrals are equal to the average number of sub-jets per jet. For $z_r > 0.5$ the leading and inclusive distributions are identical. As z_r becomes small, the inclusive sub-jet distribution grows due to soft radiations

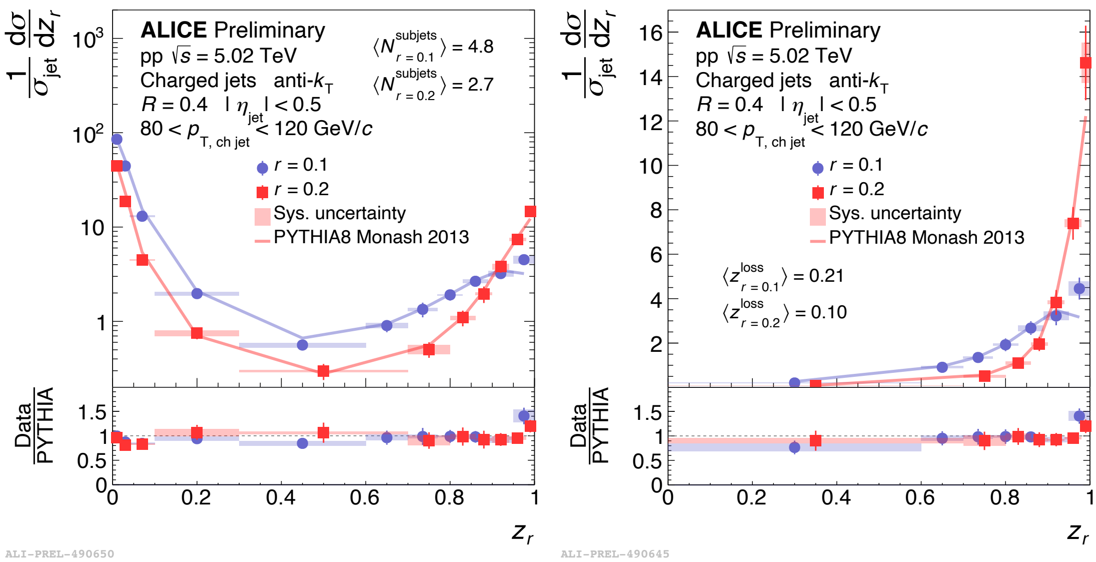

Figure 1: ALICE measurements of inclusive (left) and leading (right) sub-jet z_r distribution in pp collisions for two different sub-jet radii, compared to PYTHIA8 [12].

emitted from the leading sub-jet, whereas the leading sub-jet distribution falls to zero. The distributions are generally described well by PYTHIA8 Monash 2013 [12, 13], however there is disagreement at large z_r – this may be due to threshold resummation (which is not directly included in PYTHIA8) or to hadronization effects. Using the leading sub-jet distributions, we also compute the “sub-jet energy loss”:

$$\langle z_{\text{loss}} \rangle = 1 - \int_0^1 dz_r \, z_r \frac{1}{\sigma} \frac{d\sigma}{dz_r},$$

which describes the fraction of p_{T} inside the jet that is not contained within the leading subjet [6]. We find that $\langle z_{\text{loss}} \rangle = 0.21$ for $r = 0.1$ and decreases to $\langle z_{\text{loss}} \rangle = 0.10$ for $r = 0.2$.

2.2 Sub-jet fragmentation in Pb–Pb collisions

The fluctuating underlying event in heavy-ion collisions poses an additional challenge, since it can alter the number of reconstructed sub-jets. To simplify this problem, we focus on leading sub-jets at large z_r.[1] Figure 2 shows the z_r distributions in pp and Pb–Pb collisions for $r = 0.1$ (left) and $r = 0.2$ (right). For $r = 0.1$, the distributions are consistent with a mild hardening effect in Pb–Pb compared to pp collisions, which reverses as $z_r \to 1$. These results are compared to JETSCAPE [14–16] and SCET-based calculations [5, 9], both of which generally describe the data well. To understand the behavior of the data, note that in vacuum there are significant differences in the parton-to-subjet fragmentation functions between quarks and gluons [6]. If the QGP suppresses gluon jets more than quark jets, a hardening effect of the z_r distribution would be expected – in line with previous measurements of hadron fragmentation [19]. On the other hand, medium-induced soft radiations can shift the distribution to smaller z_r. This competition can give non-trivial modification patterns. In particular, as $z_r \to 1$, the jet sample in vacuum becomes almost entirely dominated by quark jets – exposing a region depleted by soft medium-induced emissions, which is consistent with our observations.

[1] Even with this restriction, underlying event fluctuations can cause the leading sub-jet to be misidentified, in analogy to groomed jet observables [17], although with improved robustness to mistagging effects [18].

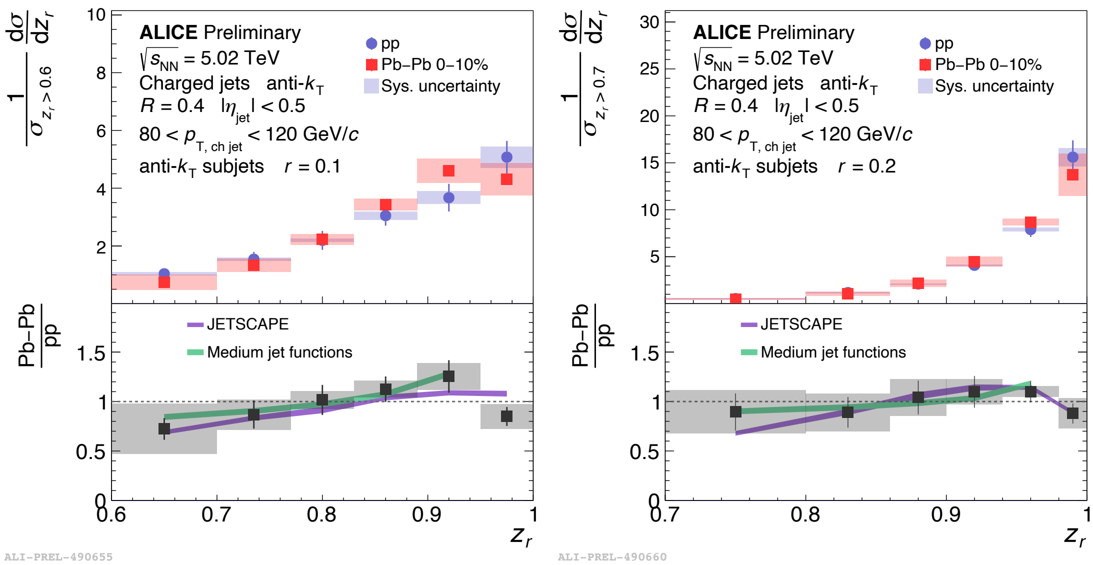

Figure 2: Measurements of sub-jet fragmentation for sub-jet radii $r = 0.1$ (left) and $r = 0.2$ (right) in pp and Pb–Pb collisions, compared to predictions [5, 9, 14–16].

3 Conclusion

We have presented new measurements of sub-jet fragmentation with ALICE. In proton-proton collisions, these measurements provide opportunities to test non-linear evolution of jet fragmentation functions and the role of threshold resummation. In heavy-ion collisions, these measurements serve as a key ingredient to test the universality of jet fragmentation in the QGP. By probing large z_r, these measurements isolate a region of quark-dominated jets that may expose a region depleted by medium-induced soft radiation. Future measurements of z_r in coincidence with other substructure observables such as the groomed jet radius [20] offer the potential to disentangle this effect from the relative suppression of gluon jets to quark jets.

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