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Search for medium-induced jet quenching effects in small collision systems with ALICE

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Collisions of small systems show signatures suggestive of collective flow associated with QGP formation in heavy-ion collisions. Jet quenching is also a consequence of QGP formation, but no significant evidence of it in small systems has been found to date. Measuring or constraining the magnitude of jet quenching in small systems is essential to determine the limits of QGP formation. The ALICE Collaboration presents a broad search for jet quenching in minimum bias (MB) and high multiplicity (HM) pp and p-Pb collisions, based on several observables: the semi-inclusive acoplanarity distribution of jets recoiling from a high-p_{T} hadron (h+jet) and intra-jet measurements. Marked broadening of the h+jet acoplanarity distribution is observed in HM compared to MB events, which could arise from jet quenching. Both data and PYTHIA simulations suggest that this broadening arises from a generic bias of the HM selection towards multi-jet final states. We also report the average charged-particle multiplicity and jet fragmentation functions in HM and MB-selected populations in pp and p-Pb collisions, whose differences are qualitatively described by PYTHIA. Finally, to disentangle jet fragmentation and hadronisation effects, the transverse momentum (j_{T}) distributions of charged-particle jet constituents are measured for several longitudinal momentum fraction of jet constituents (z) ranges in pp and p-Pb collisions. No significant difference is observed within the measurement uncertainties. We discuss the implications of these results for the understanding of collective effects and jet quenching in small systems.

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1. Introduction

Jets are collimated clusters of stable particles that result from the fragmentation of high-energy quarks and gluons, typically produced during hard scattering processes. They play a pivotal role in the study and comprehension of Quantum ChromoDynamics (QCD) theory. Moreover, jets are considered one of the most crucial probes for investigating the deconfined state of strongly interacting matter known as Quark-Gluon Plasma (QGP). Over the past decades, various studies of QGP in large collision systems have provided evidence of a hot and dense medium. For example, in the jet nuclear modification factor studies in the previous ALICE measurement, there was significant suppression of the jet yields in different centrality classes [1]. Additionally, in the jet acoplanarity measurement, highly deflected recoil jets were observed in the Pb−Pb collisions [2]. A clear near-side long-range correlation has been observed in high-multiplicity pp and p-Pb collisions [3], suggesting the presence of collectivity in these small collision systems, an effect typically associated with QGP formation. However, no significant jet yield modification has been detected in the previous R_{pPb} study in ALICE [4]. Furthermore, studying cold nuclear matter effects in such collision system is also interesting. In these proceedings, we highlight recent findings concerning jet deflection and jet substructure modification, shedding light on the interactions between jets and the medium in small collision systems.

2. Experimental setup

For these analyses, data from 5.02 and 13 TeV pp collisions recorded with ALICE detector between 2016 and 2018, as well as 5 TeV p−Pb collision data from 2016, were utilized. The reconstruction of charged-particle jets was performed using the ALICE Tracking detector, which includes the Inner Tracking System (ITS) and the Time Projection Chamber (TPC). The jet reconstruction are done using the anti-k_{T} algorithm with a jet resolution parameter (R) set to 0.4. Regarding event activity selection, the V0M detector which consist of V0A and V0C was employed. Specifically, for the selection of high-multiplicity (HM) events, we have defined a scaled multiplicity as V0M/⟨V0M⟩ where events with $5 < \mathrm{V0M}/\langle\mathrm{V0M}\rangle < 9$ are categorized as HM events.

3. Results

3.1 Hadron+jet acoplanarity in high-multiplicity pp at $\sqrt{s}$ = 13 TeV

The hadron+jet acoplanarity was measured in high-multiplicity pp collisions. The h+jet acoplanarity is the angular separation between a trigger hadron and a recoil jet, expressed mathematically as follows, where TT{X, Y} denotes the p_{T} range (expressed in GeV/c) of the trigger hadron.

$$\Delta_{\mathrm{recoil}}(\Delta\phi) = \frac{1}{N_{\mathrm{trig}}}\frac{dN_{\mathrm{jet}}}{d\Delta\phi}\Big|_{\mathrm{TT}\{20,30\}\&p^{\mathrm{ch}}_{\mathrm{T,jet}}} - c_{\mathrm{ref}}\cdot\frac{1}{N_{\mathrm{trig}}}\frac{dN_{\mathrm{jet}}}{d\Delta\phi}\Big|_{\mathrm{TT}\{6,7\}\&p^{\mathrm{ch}}_{\mathrm{T,jet}}}$$

The upper panel of Figure 1 shows the Δ_{recoil} distributions for both Minimum Bias (MB) and High-Multiplicity (HM) 13 TeV pp collisions, categorized within $20 < p_{\mathrm{T,jet}} < 40$ and $40 < p_{\mathrm{T,jet}} < 60$ (GeV/c). Notably, these figures reveal a broadening of the h+jet acoplanarity distribution in the High Multiplicity (HM) sample in comparison to the MB sample. This observed broadening could

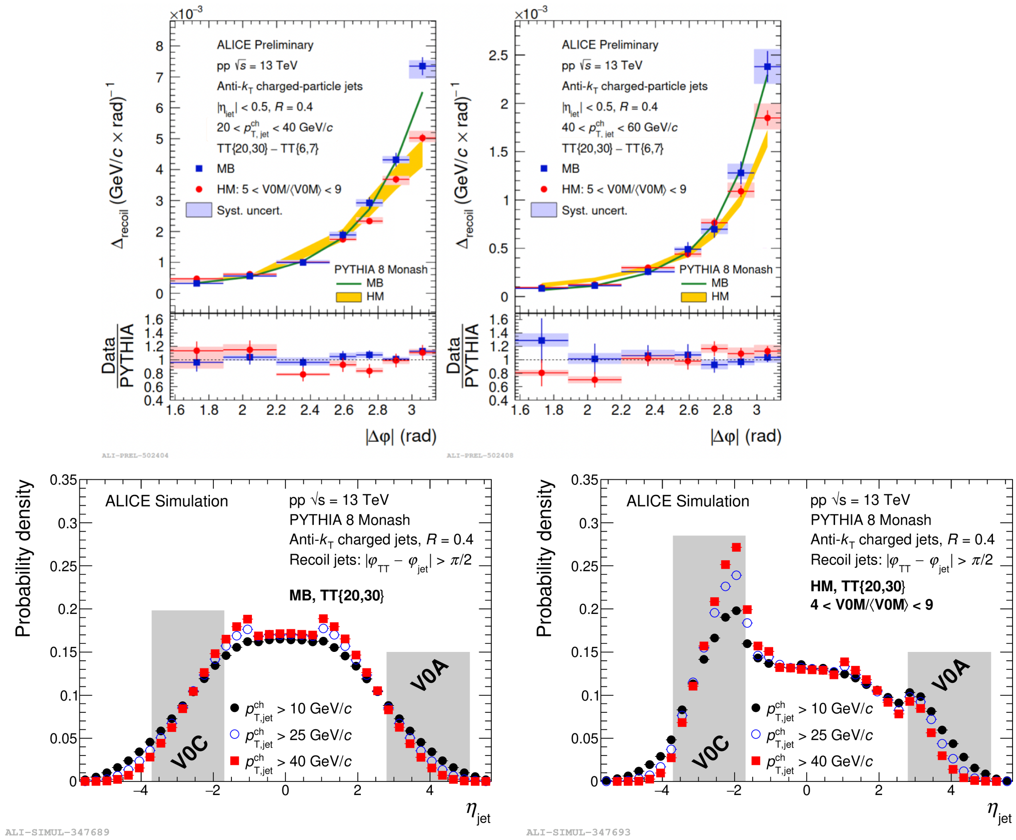

Figure 1: Δ_{recoil} distribution (upper panel) and η_{jet} distribution of recoil jets generated using PYTHIA8 Monash (bottom panels)

potentially signify the occurrence of jet quenching. However, this suppressive behavior at HM is qualitatively well described by PYTHIA8 Monash[5] which indicates that the effect is not due to the jet-medium interactions. In light of this, we have conducted a PYTHIA8 model study to investigate the origin of this observed behavior. The bottom panels of Figure 1 depict the η_{jet} distribution of recoil jets generated using PYTHIA8 Monash. The bottom left panel corresponds to the MB sample, while the bottom right panel corresponds to the HM sample. Notably, a larger enhancement in the V0C detector due to the asymmetric η acceptance of V0A and V0C in HM events is present. The right-side figure demonstrates that V0C is positioned much closer to the collision point compared to V0A. The bias becomes stronger with increasing jet p_{T}. For HM events, the inclination to select broader jets in the V0C detector could potentially conceal the signal of jet-medium interactions. This bias should be considered in further studies of jet-medium interactions in small systems.

3.2 Charged-particle leading jet properties in pp and p−Pb collisions

The next study focuses on the analysis of charged-particle leading jets in pp and p−Pb collisions. In this analysis, we have measured the multiplicity of in-jet charged particles (N_{ch}) and the jet fragmentation function (z^{ch}). In these proceedings, we will only present the results of z^{ch}

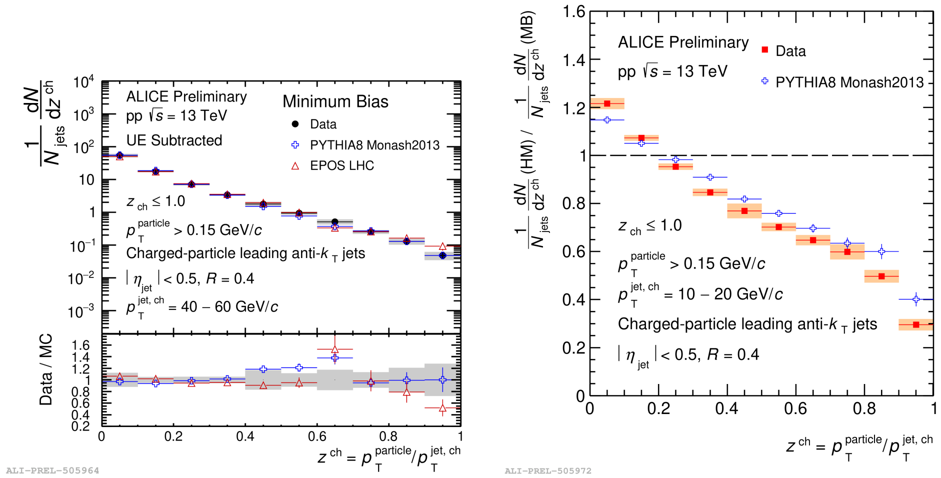

Figure 2: z^{ch} distribution (left panel) and HM to MB ratio of z^{ch} distributions (right panel)

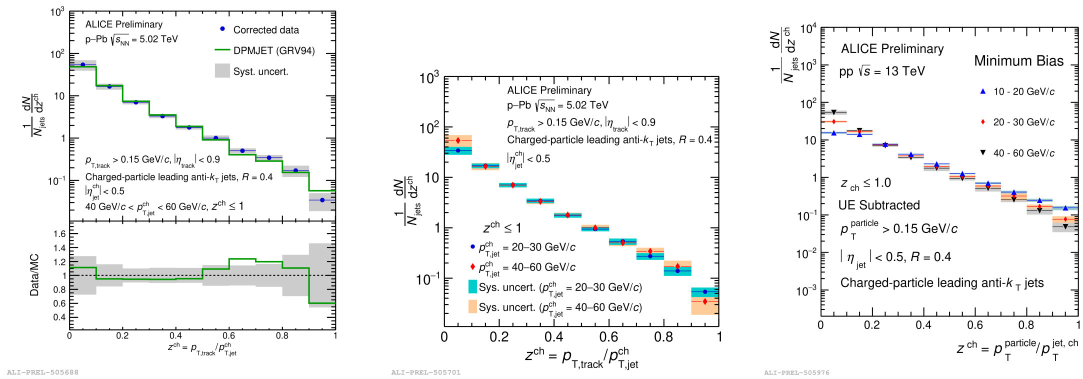

Figure 3: z^{ch} distributions in minimum bias p−Pb and model comparison with DPMJET (left panel), z^{ch} distributions for different jet p_T in minimum bias p−b (middle panel) and pp (right panel) collisions

measurements, shown in the equation below. z^{ch} is computed as shown in the equation below.

$$z^{ch} = \frac{p_T^{particle}}{p_{T,jet}^{ch}}$$

In Figure 2, for MB pp collisions, both models show a good agreement with the data. When comparing MB pp to HM events, we observed a softening of the jet fragmentation in HM for z^{ch} values greater than 0.2. This softening is qualitatively reproduced by PYTHIA8, indicating that it may not be attributed to jet-medium interactions. Instead, the behavior is likely due to MPI (Multi Parton Interactions) with CR (Color Reconnection) and the enhanced number of gluon-initiated jets in HM events. Figure 3 are z^{ch} distributions in p−Pb collisions, DPMJET[6] shows a good description within the systematic uncertainty. Furthermore, when comparing z^{ch} distributions in pp to p−Pb collisions, no significant distinction is evident between the two. More detailed quantitative comparisons and model assessments will be presented in the upcoming paper.

3.3 Transverse momentum (j_T) distributions of charged-particle jet fragments for several z ranges in pp $\sqrt{s}$ = 5.02 TeV

We have carried out a more differential jet substructure study to disintangle the processes of parton showering and hadronisation. According to QCD theory, a smaller radiation angle and lower virtuality are favored as the number of showering partons increases. In line with QCD expectations, one might intuitively anticipate a prevalence of high j_T (transverse momentum of jet constituents) and z (momentum fraction of the parton carried by the jet) components during the early stages of jet evolution. Conversely, the later stages may exhibit lower j_T and z components. As a result, by examining the z-dependent j_T in a specific kinematic region, we can potentially distinguish the jet constituent particles primarily originating from the early stage, which is linked to the parton showering process, from those associated with the late stage, characterized by non-perturbative hadronisation processes. This distinction provides an opportunity to explore potential manifestations of jet quenching in small systems. The j_T and z are expressed as follow.

$$j_T = \frac{|\vec{p}_{T,jet} \times \vec{p}_{T,track}|}{|\vec{p}_{T,jet}|}, z = \frac{\vec{p}_{T,jet} \cdot \vec{p}_{T,track}}{p^2{}_{T,jet}}$$

In the previous ALICE j_T measurements[7], the j_T distributions in inclusive z remains comparable between pp and p−Pb collisions within the uncertainties. These findings indicate an absence of substantial jet modifications in small-scale systems. But in this study, where we have measured j_T in several z ranges we have seen the j_T distributions widen with increasing z in Figure 4. In the comparisons of the differential to inclusive z distributions, the low j_T components are dominant at low z, and the high j_T components are dominant in the high z, which is consistent with QCD theory. These results are also compared to different MC generators, where the model descriptions differ in the different kinematic ranges. For example, HERWIG7[8] underestimates the high z region and overestimates the low z, high j_T region. These results are the first z dependent j_T analysis compared to models, and can provide valuable constraints to model predictions. Further research comparing these results with HM pp or p−Pb collisions in a specific kinematic region may enable us to explore the potential interaction between jets and the medium in small collision systems.

4. Summary

ALICE has undertaken an extensive investigation into the phenomenon of medium-induced jet quenching in small-scale systems, employing a range of observables. Recent measurements carried out by ALICE have revealed discernible differences between MB and HM pp collisions. However, it is essential to acknowledge that these distinctions are influenced by other possible sources than QGP formation such as a selection bias intrinsic to the event activity selection process and MPI with CR. Notably, in the comparison of jet substructure variables between pp and p−Pb collisions, thus far, no substantial differences have been observed. Excitingly, further results stemming from these recent investigations and more are forthcoming in new ALICE papers. The upcoming ALICE Run 3 data, with significantly augmented statistics, holds the promise of unveiling subtle effects associated with the modification of jets in small-scale systems.

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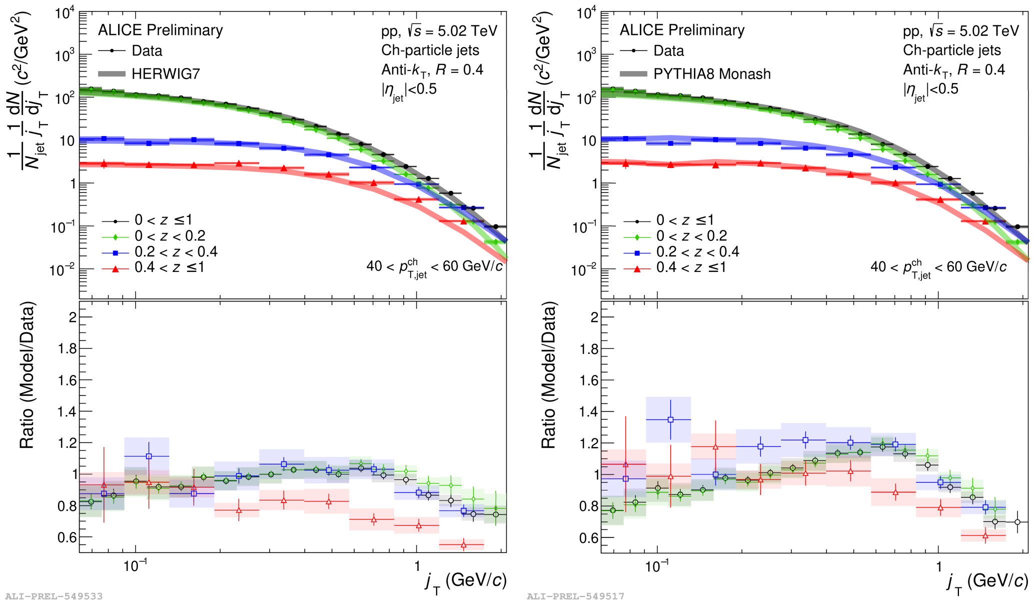

Figure 4: z^{ch} dependent j_{T} distributions and model comparison with HERWIG7 and PYTHIA8 Monash

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