PROCEEDINGS OF SCIENCE

Searching for jet quenching effect using high-multiplicity inclusive jet and hadron-jet semi-inclusive jet in pp collisions with ALICE

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Several unforeseen collective phenomena have been observed in high-multiplicity small collision systems that resemble the well-established signatures of the quark-gluon plasma (QGP) formation in heavy-ion collisions. However, jet quenching effects have not been observed in small collision systems. Quantification or setting limits on the magnitude of jet quenching in small systems is essential for understanding the limits of the QGP formation. This contribution to the proceedings presents the outcomes of a search for jet quenching effects performed by the ALICE collaboration in pp collisions at $\sqrt{s}$ = 13 TeV as a function of charged-particle multiplicity, measured in the forward rapidity. Two jet observables are studied: inclusive p_{T}-differential jet cross section, and the semi-inclusive yield of jets recoiling from a high-p_{T} trigger-hadron. Jets are reconstructed from charged-particle tracks using the anti-k_{T} algorithm with resolution parameter R in the range $0.2-0.6$. To search for jet quenching effects, both analyses compare jet yields measured in different multiplicity intervals. The analysis of inclusive jets reveals that the rise of event activity leads to an increase in jet production with a weak impact on the spectra slope for high-p_{T} jets. In the semi-inclusive analysis, the acoplanarity distribution of recoil jets measured in high-multiplicity events exhibits a substantial suppression and broadening when compared to the corresponding spectrum obtained from minimum-bias events. These peculiar features are also seen in pp events simulated by the PYTHIA 8 Monte Carlo event generator. Further studies of the PYTHIA 8 data suggest that the observed suppression and broadening arise from a bias posed by the ALICE high-multiplicity trigger. This bias leads to a growth of the probability to measure high-p_{T} recoil jets in the acceptance of the forward V0 detector. Furthermore, the high-multiplicity trigger biases toward final states with multi-jet topology.

41st International Conference on High Energy physics - ICHEP2022
6-13 July, 2022
Bologna, Italy

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https://pos.sissa.it/

PoS(ICHEP2022)459

1. Introduction

Jets serve as a multi-purpose tool for studying various aspects of the strong interaction at high-energy densities and temperatures achieved in heavy-ion collisions. The jet quenching phenomenon, which arises as a direct consequence of the quark-gluon plasma (QGP) formation, provides deeper insights into mechanisms of the interaction of a high-Q^2 parton with the medium constituents. In addition, the QGP properties are explored by measuring collective flow. Unexpectedly, collective phenomena have been observed in high multiplicity pp collision data. They are qualitatively similar to the well-established signatures of the QGP formation in heavy-ion collisions. As an example, one can single out the long range near-side ridge structure [1] and the elliptical flow of heavy-flavor hadrons [2]. However, the lack of reliable experimental evidence of jet quenching signals in small collision systems [3, 4] raises an important question of whether the observed flow-like effects are the result of medium formation or if other physics mechanisms come into play.

This contribution to the proceedings presents the results of a search for jet quenching signals in high multiplicity pp collisions at $\sqrt{s}$ = 13 TeV, obtained utilizing two jet observables: p_{T}-differential cross section of inclusive jets and semi-inclusive hadron-jet azimuthal correlations. A minimum bias (MB) data sample was used as the reference data in both analyses. The main goal of the inclusive jet measurements was to study the dependence of jet production on the charged-particle multiplicity in an event. The semi-inclusive analysis aimed to measure the medium-induced hadron-jet acoplanarity. The width of the acoplanarity distribution in vacuum results from a combination of intrinsic k_{T} of colliding partons and soft gluon radiation associated with the Sudakov logarithms [5]. The acoplanarity becomes greater when jets are deflected as a result of an interaction with the medium.

2. Analyzed data sample

Both analyses studied pp collisions at $\sqrt{s}$ = 13 TeV which were recorded by the ALICE detector from 2016 to 2018. An elaborate description of the ALICE detector is presented in Ref. [6]. Minimum-bias events were selected with the MB trigger which required a time coincidence of the signals provided by the V0A and V0C scintillator arrays [7] covering pseudorapidity intervals $2.8 < \eta < 5.1$ and $-3.7 < \eta < -1.7$, respectively. Figure 1 shows the distribution of event activity which is expressed in terms of the sum of the signal amplitudes from the V0A and V0C detectors, labelled as “V0M amplitude”, scaled by its average value $\langle \mathrm{V0M} \rangle$ in a MB event. The scaling eliminates the impact of the V0 scintillator aging on the distribution shape. The MB data sample was divided into several multiplicity classes. The highlighted regions in Fig. 1 correspond to the chosen percentile intervals of the $\mathrm{V0M}/\langle \mathrm{V0M} \rangle$. In addition, the semi-inclusive analysis utilized the high multiplicity (HM) pp data collected by the dedicated trigger. In this case, the selected events had a total V0M amplitude at least 5 times larger than the average $\langle \mathrm{V0M} \rangle$ signal from a MB event.

3. Multiplicity dependence of inclusive jet production

Jets were reconstructed from charged-particle tracks by employing the anti-k_{T} algorithm with R in the range 0.2 – 0.6 using the boost-invariant p_{T} recombination scheme [8]. Jet constituent tracks

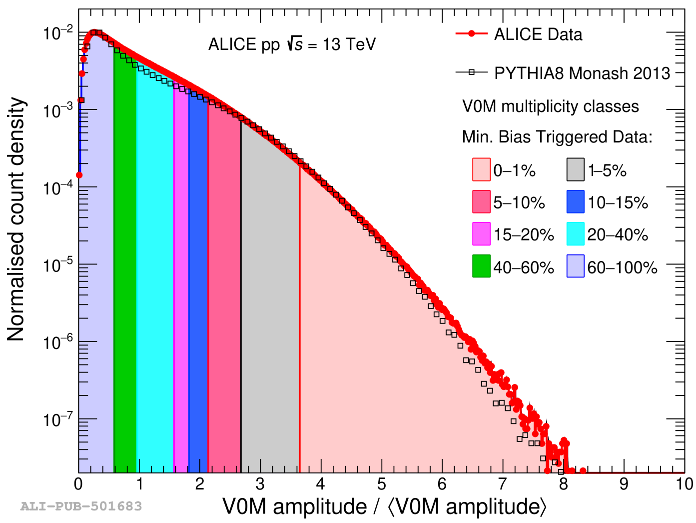

Figure 1: Distribution of V0M/⟨V0M⟩ amplitude which is used to characterize event activity in terms of charged-particle multiplicity measured in forward rapidity. The colored regions correspond to the selected multiplicity classes.

were required to have $|\eta| < 0.9$ and $p_{\mathrm{T}} > 0.15$ GeV/c. The reconstructed jets were constrained to the pseudorapidity range $|\eta_{\mathrm{jet}}| < 0.9 - R$ to ensure their full reconstruction within the ALICE fiducial volume. Jet p_{T} was corrected for the contribution from underlying events utilizing the area-based approach [9]. All presented distributions were corrected for jet energy scale smearing due to local background fluctuations and detector effects. Track reconstruction efficiency is the main source of systematic uncertainty for this analysis.

The left plot of Fig. 2 shows the normalized yield of inclusive jets with $R = 0.4$ measured in different multiplicity intervals. It can be seen that the jet yield grows with the V0M multiplicity. This is also apparent from the right plot of Fig. 2 which shows the ratio of the jet spectra from the left plot to the corresponding MB spectrum. The jet yield in the highest event activity class ($0-1\%$) is roughly 9 times larger than in MB events whilst the ratio reaches $\sim 8\%$ for events with the lowest activity ($60-100\%$). Moreover, the event activity bias poses a mild effect on the spectrum slope for jets with $p_{\mathrm{T}} > 20$ GeV/c, i.e. the slope remains similar to the one measured in MB events.

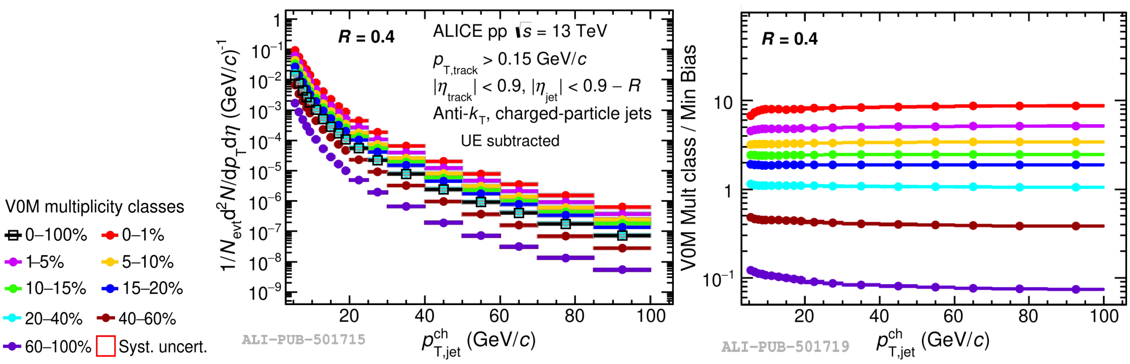

Figure 2: Left: Inclusive jet yield measured in different V0M multiplicity classes of pp collisions at $\sqrt{s} = 13$ TeV. Right: Corresponding ratios with respect to MB data.

4. Semi-inclusive measurements of hadron-jet acoplanarity

The analysis was based on a measurement of charged-particle jets that recoil from a charged trigger track (TT) with a high transverse momentum $p_{\mathrm{T,\,trig}}$ [4, 10]. The jet yield was measured for two exclusive $p_{\mathrm{T,trig}}$ intervals: $p_{\mathrm{T,\,trig}} \in (20, 30)$ GeV/c and $p_{\mathrm{T,\,trig}} \in (6, 7)$ GeV/c. These intervals are denoted as TT$\{20, 30\}$ and TT$\{6, 7\}$. Jet reconstruction was carried out using the anti-k_{T} algorithm with $R = 0.4$. Additional details of the jet reconstruction were discussed in Sect. 3.

The medium-induced hadron-jet acoplanarity was measured using the semi-inclusive Δ_{recoil} observable [10],

$$\Delta_{\mathrm{recoil}}(p_{\mathrm{T,jet}}^{\mathrm{ch,corr}}, |\Delta\varphi|) = \frac{1}{N_{\mathrm{trig}}} \frac{\mathrm{d}^2 N_{\mathrm{jets}}}{\mathrm{d}p_{\mathrm{T,jet}}^{\mathrm{ch,corr}} \mathrm{d}|\Delta\varphi|}\Bigg|_{\mathrm{TT}\{20,30\}} - \frac{1}{N_{\mathrm{trig}}} \frac{\mathrm{d}^2 N_{\mathrm{jets}}}{\mathrm{d}p_{\mathrm{T,jet}}^{\mathrm{ch,corr}} \mathrm{d}|\Delta\varphi|}\Bigg|_{\mathrm{TT}\{6,7\}}, \tag{1}$$

which is defined as a difference between two per trigger-normalized yields of recoil jets associated with TT$\{20, 30\}$ and TT$\{6, 7\}$. The subtraction removes the background jet yield uncorrelated with the high-Q^2 process which produces the TT. The recoil jet yield is expressed as a function of the jet transverse momentum $p_{\mathrm{T,jet}}^{\mathrm{ch,corr}}$ that was corrected for the expected contribution from underlying events [9], and the azimuthal angle $|\Delta\varphi|$ between the direction of the TT and recoil jet.

The Δ_{recoil} distribution from Eq. (1) was corrected for the detector effects. The dominant contribution to systematic uncertainty comes from track reconstruction efficiency. The hadron-jet acoplanarity distributions were obtained by projecting the Δ_{recoil} distribution onto the $|\Delta\varphi|$ axis for recoil jets with p_{T} constrained to some interval. Figure 3 shows a comparison of the corrected acoplanarity distributions measured in MB and HM events for recoil jets with $p_{\mathrm{T}} \in (20, 40)$ GeV/c.

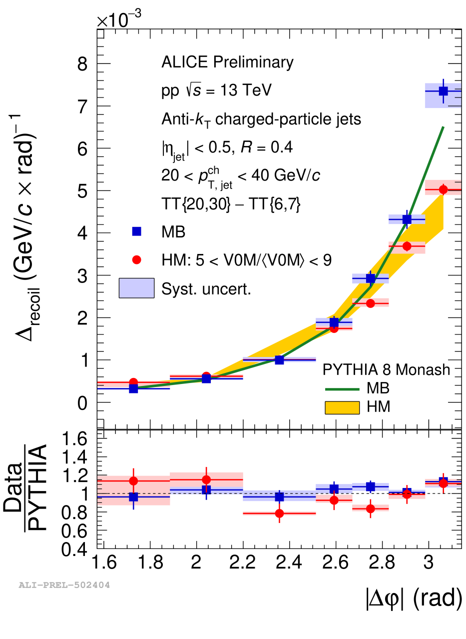

Figure 3: Comparison of the corrected Δ_{recoil} distributions measured in MB and HM pp events for recoil jets with $p_{\mathrm{T}} \in (20, 40)$ GeV/c. The color bands show the data simulated by the PYTHIA 8 generator. Systematic uncertainties are represented by the colored boxes.

The acoplanarity distribution obtained in HM events shows a substantial suppression at $|\Delta\varphi| \approx \pi$ and broadening when compared to the distribution measured in MB events. The observed features qualitatively resemble a modification of the recoil jet production that would be expected due to jet quenching. Additional insights into the observed phenomena can be inferred from a comparison with the acoplanarity distributions simulated by the PYTHIA 8 event generator with the Monash tune [11]. In Fig. 3, the PYTHIA 8 data are shown by the color bands. The width of the bands represents the statistical uncertainty. The bottom panel shows the ratio between the experimental data and the corresponding PYTHIA 8 distributions. One can see that the PYTHIA 8 simulation describes the data well. Since the PYTHIA 8 generator does not incorporate any phenomenological models of jet quenching, the observed modification is likely not caused by jet quenching.

Further studies of recoil jets from the PYTHIA 8 events reveal two key aspects which can explain the observed suppression and broadening of the HM acoplanarity distribution. The left plot of Fig. 4 shows the pseudorapidity distribution of recoil jets with $p_{\mathrm{T,jet}}^{\mathrm{ch}} > 25$ GeV/c reconstructed in a wide pseudorapidity range which covers the acceptances of the V0A and V0C detectors. The considered events contained TT{20, 30}. Each distribution corresponds to a different event multiplicity selection imposed by a cut on V0M/⟨V0M⟩. It can be seen that a gradual increase in the multiplicity bias induces a strong bias of the probability to measure high-p_{T} recoil jets in the acceptance of the V0C detector. A pronounced asymmetry of the probability is explained by the closer location of the V0C detector to the interaction point [7].

The second important observation relates to the number of recoil jets with $p_{\mathrm{T,jet}}^{\mathrm{ch,corr}} > 25$ GeV/c reconstructed in the ALICE central barrel acceptance $|\eta_{\mathrm{jet}}| < 0.5$, see the right plot of Fig. 4. The measurement was performed for MB and HM events with TT{20, 30}. Both spectra are steeply falling. By taking their ratio, one can note that the population of HM events having a single recoil jet

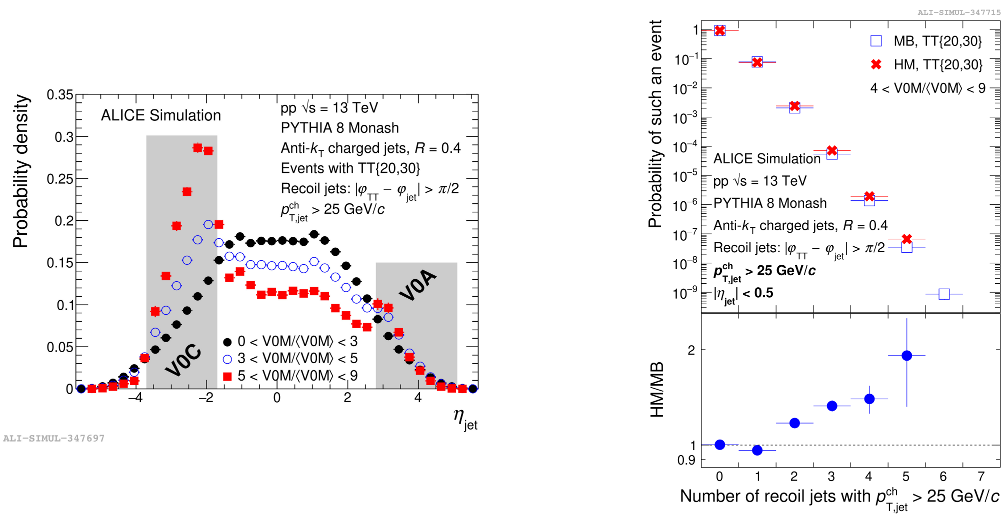

Figure 4: Left: Pseudorapidity distribution of recoil jets with $p_{\mathrm{T,jet}}^{\mathrm{ch}} > 25$ GeV/c in the PYTHIA 8 events with TT{20, 30} for different event activity classes V0M/⟨V0M⟩. The gray boxes represent the acceptances of the V0A and V0C. Right: Probability to measure a given number of recoil jets with $p_{\mathrm{T,jet}}^{\mathrm{ch}} > 25$ GeV/c in the PYTHIA 8 MB and HM events with TT{20, 30}. The bottom panel shows a ratio of the distributions.

is suppressed with respect to MB events. The suppression of the acoplanarity distribution in Fig. 3 can be attributed to dijet events where one of the jets provides a TT and the associated recoil jet hits the V0 detector inducing the HM trigger. This recoil jet is then missing in the midrapidity region where one measures the hadron–jet acoplanarity. This leads to suppression. Furthermore, HM data have a higher relative abundance of events with multiple high-p_{T} recoil jets. The broadening of the acoplanarity distribution can be explained by a multi-jet topology.

5. Conclusion

The measurements of inclusive jet production and semi-inclusive hadron-jet acoplanarity in HM pp collisions at $\sqrt{s}$ = 13 TeV have been performed. No jet quenching signals are observed in both analyses. The potential signal could be rather small, and the accuracy of the used techniques may be not sufficient for its detection. The yield of inclusive high-p_{T} jets in events with different multiplicity differs from the yield in MB events only in magnitude, with a weak dependence of the spectrum slope on jet p_{T}. In the case of the semi-inclusive analysis, the observed suppression and broadening of the HM acoplanarity distribution relative to the MB one are due to a bias caused by the HM trigger. This trigger leads to an increase of the probability to measure high-p_{T} recoil jets within the acceptances of the forward V0 detectors. Moreover, the HM trigger biases towards events with multiple recoil jets in the ALICE central barrel acceptance, therefore leading to an increase of hadron-jet acoplanarity.

Acknowledgments: This work was supported by the Ministry of Education, Youth and Sports of the Czech Republic project LTT17018.

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