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Measurements of jet quenching via hadron-jet correlations in Pb–Pb and high particle multiplicity pp collisions with ALICE

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The ALICE Collaboration presents measurements of jet quenching in the 0–10% most central Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV and high multiplicity pp collisions at $\sqrt{s} = 13$ TeV by investigating hadron-jet acoplanarity. In Pb–Pb collisions, the obtained acoplanarity distribution exhibits a marked suppression and narrowing when compared to the pp reference spectrum obtained from PYTHIA simulations. Similar measurements for pp collisions show that the acoplanarity distributions obtained in high multiplicity events are significantly suppressed and broadened relative to the analogous distributions from minimum bias events. The observed features are not caused by jet quenching, since they can be reproduced by PYTHIA 8 event generator, which does not account for jet quenching. Analysis of the PYTHIA events reveals that the suppression and broadening of the hadron-jet acoplanarity distributions are the consequence of a bias induced by the ALICE high multiplicity trigger. This trigger increases the probability to measure a high-p_{T} recoil jet in the pseudorapidity acceptance of the forward trigger detectors, and biases toward multi-jet final states.

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1. Introduction

The collisions of ultrarelativistic heavy nuclei generate unique physics conditions which lead to formation of a dense, hot, and strongly–coupled quantum chromodynamics (QCD) state of matter, known as quark–gluon plasma (QGP). Properties of this medium can be investigated utilizing high-energy partons which emerge from hard scattering processes that occur in the initial stage of the collision, prior to the QGP formation. While propagating through the colored medium, partons experience interactions with the QGP that lead to modifications of the partonic shower. This complex process leads to the observation of jet quenching effects [1]. Jet quenching measurements are crucial for characterization of the medium transport coefficient $\hat{q}$ [2], which can be obtained from broadening of the hadron-jet acoplanarity distribution in azimuth [3]. Broadening of the acoplanarity in pp collisions arises due to Sudakov radiation [3]. Interaction between the jet and the medium may further increase the hadron-jet acoplanarity. In Ref. [4] it was however proposed that radiative corrections to the in-medium modification can be negative, which would lead to the reduction of the broadening or even narrowing of the acoplanarity distribution relative to vacuum.

In these proceedings, measurements of the hadron-jet acoplanarity in the 0–10% most central Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV and high multiplicity pp collisions at $\sqrt{s} = 13$ TeV are presented. The measurements are based on the semi-inclusive Δ_{recoil} observable [5] which is defined as a difference of two trigger normalized yields of jets that recoil from high transverse momentum (p_{T}) trigger-tracks (TT), selected from two exclusive p_{T} intervals, $\mathrm{TT_{Sig}}$ and $\mathrm{TT_{Ref}}$,

$$\Delta_{\mathrm{recoil}}(p_{\mathrm{T,jet}}^{\mathrm{ch,reco}}, \Delta\varphi) = \frac{1}{N_{\mathrm{trig}}} \frac{\mathrm{d}^2 N_{\mathrm{jets}}}{\mathrm{d}p_{\mathrm{T,jet}}^{\mathrm{ch,reco}} \mathrm{d}\Delta\varphi}\Bigg|_{p_{\mathrm{T,trig}} \in \mathrm{TT_{Sig}}} - c_{\mathrm{Ref}} \frac{1}{N_{\mathrm{trig}}} \frac{\mathrm{d}^2 N_{\mathrm{jets}}}{\mathrm{d}p_{\mathrm{T,jet}}^{\mathrm{ch,reco}} \mathrm{d}\Delta\varphi}\Bigg|_{p_{\mathrm{T,trig}} \in \mathrm{TT_{Ref}}} . \quad (1)$$

The Δ_{recoil} is expressed as a function of jet transverse momentum $p_{\mathrm{T,jet}}^{\mathrm{ch,reco}}$, which is corrected for expected contribution from the underlying events [6], and the azimuthal angle $\Delta\varphi$ that is subtended by the direction of the TT and recoil jet. The c_{Ref} is a correction factor ≈ 1 [5]. The subtraction removes background jet yield uncorrelated with the TT in a purely data-driven way [5].

2. Pb–Pb collisions

The Pb–Pb collision data were recorded during the 2018 LHC run at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV. The analysis used the 0–10% most central collisions which were selected by the online centrality trigger based on a signal amplitude measured in the forward V0 scintillator detectors [7].

Jet reconstruction was performed from charged particles utilizing the anti-k_{T} algorithm with the boost-invariant p_{T}-recombination scheme and resolution parameter $R = 0.2$. Charged tracks were measured within the pseudorapidity range $|\eta| < 0.9$ in full azimuth and were required to have $p_{\mathrm{T}} > 0.15$ GeV/c. Jet candidates were accepted if they were entirely reconstructed in the fiducial volume $|\eta_{\mathrm{jet}}| < 0.9 - R$.

The trigger-normalized recoil jet distributions as a function of the jet p_{T} and $\Delta\varphi$ angle were constructed for $\mathrm{TT_{Sig}}$ and $\mathrm{TT_{Ref}}$. To ensure statistical independence, the data were split into two independent sets to search for $\mathrm{TT_{Sig}}$ with $p_{\mathrm{T}} \in (20, 50)$ GeV/c and $\mathrm{TT_{Ref}}$ with $p_{\mathrm{T}} \in (5, 7)$ GeV/c.

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The raw $\Delta_{\rm recoil}(p_{\rm T,jet}^{\rm ch,reco}, \Delta\varphi)$ distribution (Eq. 1) was corrected for underlying event fluctuations and instrumental effects by means of the Bayesian unfolding [8]. Figure 1 shows projection of the fully-corrected $\Delta_{\rm recoil}$ distribution on the $\Delta\varphi$ axis for jets with $p_{\rm T,jet}^{\rm ch} \in (30, 40)$ GeV/c.

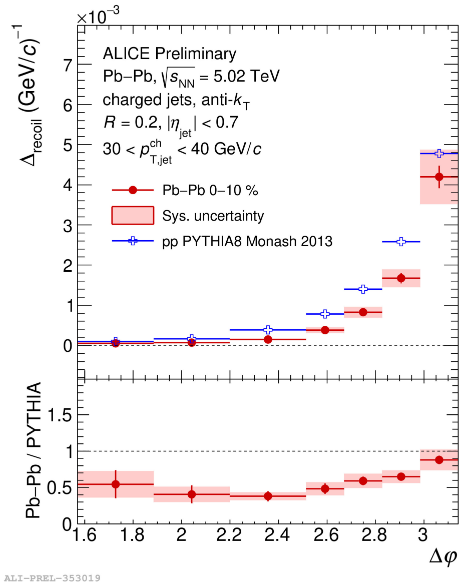

Figure 1: Fully-corrected $\Delta_{\rm recoil}(\Delta\varphi)$ distribution measured in the most central Pb–Pb collisions and the corresponding distribution from the PYTHIA pp events. Color boxes represent the systematic uncertainties.

Estimated systematic uncertainties incorporate the uncertainties due to tracking efficiency, unfolding procedure, and variation of $c_{\rm Ref}$. The measured spectrum is compared with the reference distribution obtained from PYTHIA 8 Monash tune simulations [9] of pp collisions at $\sqrt{s}$ = 5.02 TeV. The bottom panel of Fig. 1 shows that the per trigger normalized recoil jet yield measured in most-central Pb-Pb collisions is suppressed when compared to pp reference. The rising trend toward $\Delta\varphi \approx \pi$ indicates narrowing of the acoplanarity spectrum measured in the 0–10% most central Pb–Pb collisions.

3. Proton–proton collisions

The analysis was carried out utilizing the minimum bias (MB) and high multiplicity (HM) pp events at $\sqrt{s}$ = 13 TeV, which were recorded by the corresponding online triggers. The MB trigger required a time coincidence of signals from the V0 detectors. The HM events were triggered when the V0 signal amplitude, denoted as V0M, reached the threshold value of $5 \times \langle$V0M$\rangle$, where $\langle$V0M$\rangle$ is an average signal amplitude from MB collisions. Event activity was expressed in terms of scaled multiplicity V0M/$\langle$V0M$\rangle$. The analysis imposed an upper limit V0M/$\langle$V0M$\rangle$ < 9 in order to suppress residual pile-up events.

The MB and HM data were divided into two independent sets corresponding to the $\rm TT_{Sig}$ with $p_{\rm T} \in (20, 30)$ GeV/c and $\rm TT_{Ref}$ with $p_{\rm T} \in (6, 7)$ GeV/c. Reconstruction of charged-particle jets was performed using the anti-$k_{\rm T}$ algorithm with $R = 0.4$. Further details on the jet reconstruction can be found in Section 2.

The left panels of Fig. 2 show comparison of the uncorrected $\Delta_{\rm recoil}(\Delta\varphi)$ distributions obtained

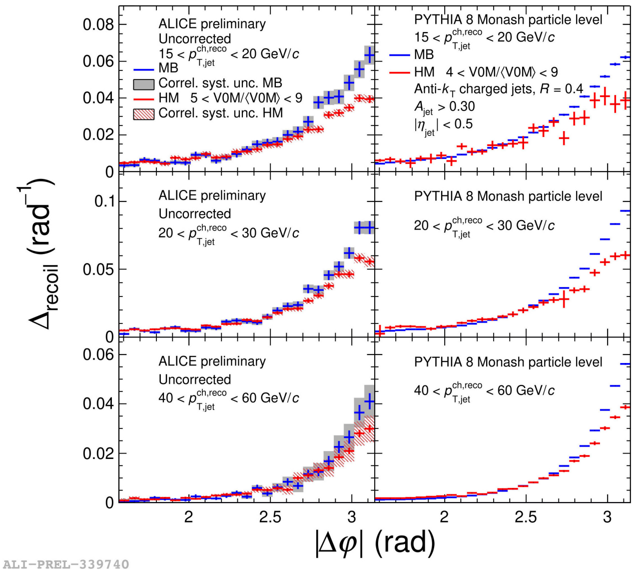

Figure 2: $\Delta_{\text{recoil}}(\Delta\varphi)$ acoplanarity distributions for different jet $p_{\text{T,Jet}}^{\text{ch,reco}}$ intervals in the MB and HM events. Left and right panels show corresponding uncorrected data and PYTHIA 8 Monash distributions.

in the MB and HM events. One can see that the HM acoplanarity distributions are considerably suppressed at $\Delta\varphi \approx \pi$ and broader for $p_{\text{T,jet}}^{\text{ch,reco}} \lesssim 40$ GeV$/c$ when compared to the MB distributions. The observed modifications of the acoplanarity distributions in HM collisions resemble the effects seen in Pb–Pb collisions that attribute to jet quenching. However the same features can be seen in the acoplanarity distributions obtained from PYTHIA 8 Monash simulations [9], see the right panels of Fig. 2. Thereby, jet quenching is not the source of the observed modifications. To investigate the causes of these phenomena, the PYTHIA events were further analyzed. The left panel of Fig. 3 shows a pseudorapidity distribution of high-p_{T} recoil jets, reconstructed within $|\eta_{\text{jet}}| < 5.6$, for three event activity intervals. One can see that the probability to measure a high-p_{T} recoil jet within the acceptance of the V0 detectors increases with the event activity. The right panel of Fig. 3 shows a frequency of the MB and HM events which have a given number of high-p_{T} jets recoiling from the TT_{Sig} within $|\eta_{\text{jet}}| < 0.5$. The bottom panel presents their ratio. It can be seen that the HM data have a lower relative frequency of events with a single high-p_{T} recoil jet when compared to the MB data. The missing high-p_{T} recoil jet may induce the HM trigger and does not balance the TT in the ALICE central barrel. Moreover, the HM data exhibits higher relative abundance of events with multi-jet topology which has on average greater acoplanarity.

4. Conclusion

The measurements of the hadron-jet acoplanarity have been performed in the 0–10% most central Pb–Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV, and MB and HM pp collisions at $\sqrt{s} = 13$ TeV. In the Pb–Pb analysis, the acoplanarity distribution is suppressed and narrowed when compared to the PYTHIA pp reference. Nonetheless, one cannot conclusively interpret these results without making a comparison to a real pp reference. In case of the pp analysis, the acoplanarity distributions, measured in HM events, exhibit marked suppression and broadening when compared to

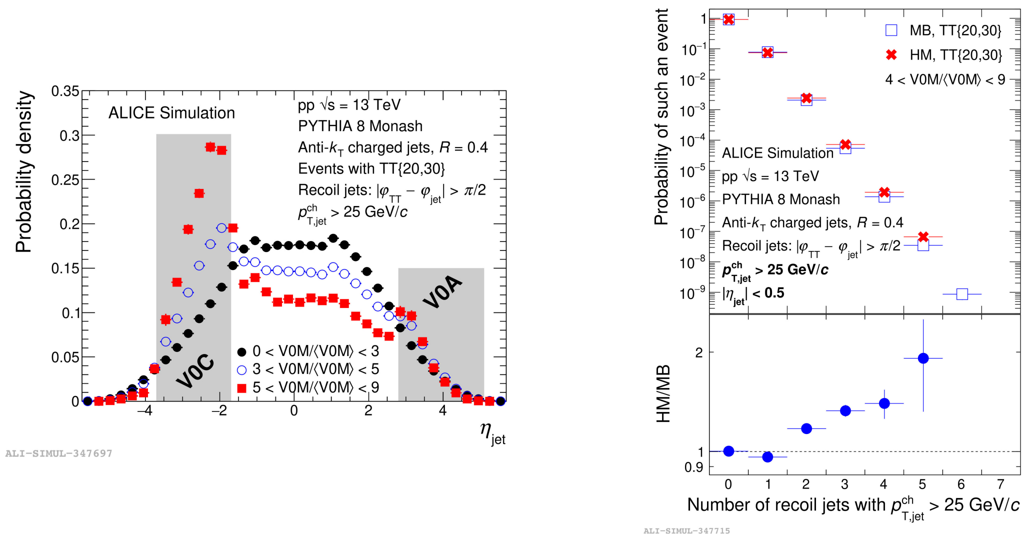

Figure 3: Left: Pseudorapidity distribution of recoil jets with $p_{\mathrm{T,jet}}^{\mathrm{ch}} > 25$ GeV$/c$ in events with the $\mathrm{TT_{Sig}}$ for different event activity V0M/⟨V0M⟩ bias. The gray boxes represent the V0A and V0C acceptances. Right: Probability density distribution of the number of recoil jets with $p_{\mathrm{T,jet}}^{\mathrm{ch}} > 25$ GeV$/c$ in the MB and HM events with the $\mathrm{TT_{Sig}}$. Bottom panel shows ratio of above distributions.

the corresponding MB distributions. At the same time, the observed modifications are reproduced by PYTHIA. The PYTHIA simulations indicate that the requirement of the HM trigger enhances the probability to measure a high-p_{T} recoil jet within the coverage of the V0 detectors. Moreover, the HM trigger biases toward events with multiple recoil jets, which lead to a broadening of the acoplanarity. These phenomena obscure possible jet quenching signals.

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