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Using di-hadron correlations to investigate jet modifications in Pb–Pb collisions with ALICE

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The comparison of jets measured in heavy-ion collisions with jets measured in pp collisions is a rich source of information on jet-medium interactions. These medium-induced modifications can be prominent at low transverse momentum p_{T}, where traditional jet reconstruction tools are difficult to use. The measurement of di-hadron correlations provide an alternative way to study jets in this p_{T} regime. Calculating the pseudorapidity ($\Delta\eta$) and azimuthal angle ($\Delta\varphi$) differences between trigger and associated particles, one observes the manifestation of the jet fragmentation as a peak around ($\Delta\eta$,$\Delta\varphi$)=(0,0). The modification factor I_{AA} is defined as the yield of the jet-like peak in Pb–Pb divided by the corresponding yield in pp collisions at the same energy. In this contribution, we will present the latest ALICE measurements of I_{AA} with charged hadrons from collisions with a center of mass energy per nucleon-nucleon pair of 2.76 TeV. We observe that the $\Delta\eta$-dependent I_{AA} shows a narrowing in pseudorapidity in central collisions for trigger particles with a high p_{T}. We also investigate the path-length dependence of jet modification by measuring I_{AA} as a function of the relative angle between the trigger particle and the event plane. These measurements are compared to model calculations, and are expected to place strong constraints on energy loss models.

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1. Introduction

The Quark–Gluon Plasma (QGP), a strongly interacting state of matter of deconfined quarks and gluons, is produced in high energy heavy-ion collisions at the Large Hadron Collider (LHC). A strong evidence for the formation of a QGP is the so-called jet quenching caused by medium-induced quark and gluon energy loss. The di-hadron correlation technique can be a useful method to study jet properties in the low transverse momentum range ($p_{\mathrm{T,jet}} < 50$ GeV/c), where background fluctuations due to the underlying event dominate [1, 2]. First, the two-particle correlation function is constructed by obtaining the relative azimuthal angle ($\Delta\varphi = \varphi_{\mathrm{trig}} - \varphi_{\mathrm{asso}}$) and relative pseudorapidity ($\Delta\eta = \eta_{\mathrm{trig}} - \eta_{\mathrm{asso}}$) between "trigger" and "associated" particles

$$C(\Delta\varphi,\Delta\eta) = \frac{1}{N_{\mathrm{trig}}}\frac{\mathrm{d}^2N}{\mathrm{d}\Delta\varphi d\Delta\eta}. \tag{1}$$

After obtaining the pair correlation of two charged particles, the correlation function is projected onto $\Delta\eta$ over a given near-side ($|\Delta\varphi| < 0.2\pi$) range. Then, the jet peak and background component can be estimated by a fit function: a constant background plus a generalized Gaussian function to describe the peak

$$Bg + C \times \frac{\gamma_\eta}{2w_\eta\Gamma(\frac{1}{\gamma_\eta})} \times e^{-|\frac{\Delta\eta}{w_\eta}|^{\gamma_\eta}}. \tag{2}$$

After removing the background, the pair yield of the near-side jet peak can be obtained, and the in-medium modification can be studied with the observable

$$I_{\mathrm{AA}} = \frac{Y_{\mathrm{Pb\text{–}Pb}}}{Y_{\mathrm{pp}}} \tag{3}$$

, where $Y_{\mathrm{Pb\text{–}Pb}}$ is the per-trigger yield in Pb–Pb collisions, and Y_{pp} is the per-trigger yield in pp collisions.

ALICE [3, 4] has measured the I_{AA} in Pb–Pb collisions at a center of mass energy per nucleon-nucleon pair $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV [1]. The measured I_{AA} shows a significant suppression on the away-side ($|\Delta\varphi - \pi| < 0.7$) in central collisions and a moderate enhancement on the near-side ($|\Delta\varphi| < 0.7$). In this contribution, the medium modification of the longitudinal shape of the near-side peak is compared to the AMPT [5] model. Also, the di-hadron I_{AA} measurement is shown to a search for a possible path-length dependence of the modification of the near-side peak.

2. Longitudinal shape of the near-side peak

Longitudinal jet shapes from heavy-ion and pp collisions can be compared by measuring the $\Delta\eta$ dependent I_{AA} [6]. The $|\Delta\eta|$ dependent per-trigger normalized pair yield distribution is constructed by summing positive and negative $\Delta\eta$ bins to each corresponding $|\Delta\eta|$ bin. The constant background component under the jet peak is estimated by fitting and removed by subtraction. Calculating the ratio of $\mathrm{d}N/\mathrm{d}|\Delta\eta|$ between Pb–Pb and pp data results in $I_{\mathrm{AA}}(|\Delta\eta|)$.

Figure 1 shows the observed trend of $I_{\mathrm{AA}}(|\Delta\eta|)$ as a function of $|\Delta\eta|$, for different $p_{\mathrm{T,trig}}$, $p_{\mathrm{T,asso}}$, and centrality bins. In order to compare the experimental data with models, the I_{AA} was calculated by taking the ratio of the peak yields in AMPT to the peak yields in pp data and in

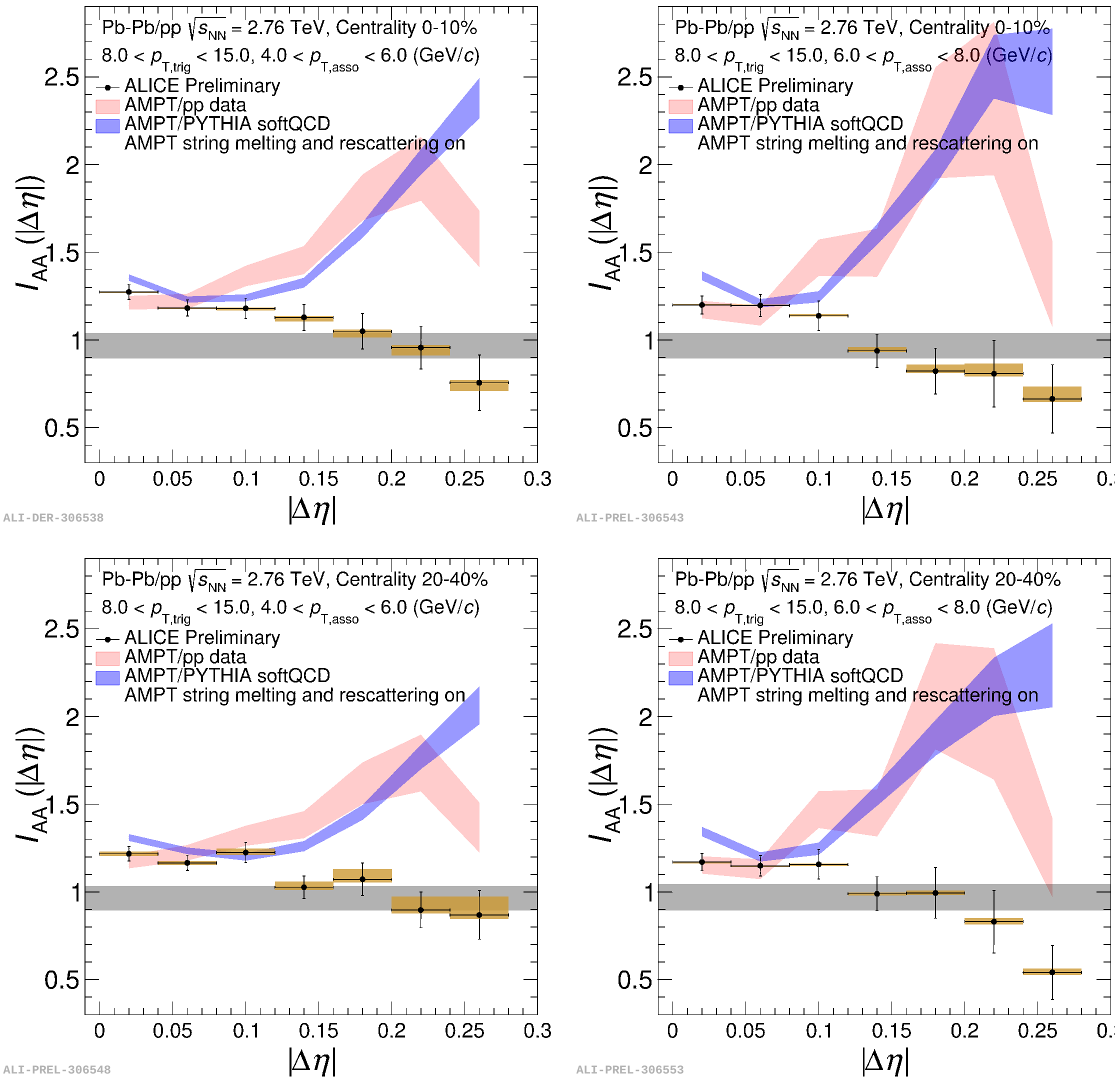

Figure 1: The I_{AA} of the near-side peak as a function of $|\Delta\eta|$. Top two figures show the results in 0–10% central events, and bottom figures show the results in 20–40% central events. Left two figures represent $8.0 < p_{T,trig} < 15.0$ with $4.0 < p_{T,asso} < 6.0$ GeV/c, and right two figure represent $8.0 < p_{T,trig} < 15.0$ with $6.0 < p_{T,asso} < 8.0$ GeV/c. Gray bands around unity show point-to-point independent scaling uncertainty. Brown boxes around the data points represent point-to-point variable systematic uncertainty. Red bands are AMPT simulation results using pp data as a reference. Blue bands are AMPT simulation results using PYTHIA softQCD as a reference.

PYTHIA [7]. A falling trend of I_{AA} is observed in all shown p_T and centrality ranges, which indicates a possibility of a narrowing in $\Delta\eta$ of the near-side jet peak in Pb–Pb collisions with respect to pp collisions. Furthermore, AMPT and PYTHIA simulations do not describe the narrowing behavior, in any of the centrality and associated p_T bins.

3. Event-plane dependence of the near-side peak

The details of the jet quenching process inside the medium, particularly in the low transverse momentum range, are not yet well understood. To quantify the amount of jet-medium interaction inside the QGP matter, measuring differential measurements of jets in di-hadron correlations with respect to the second-order event plane (Ψ_2) can provide additional information [8, 9]. These differential correlations can probe the path-length dependence of the energy loss with more sensitivity than an inclusive analysis. Using di-hadron correlations the studied kinematic range can be extended to lower transverse momenta than in the analysis of reconstructed jets.

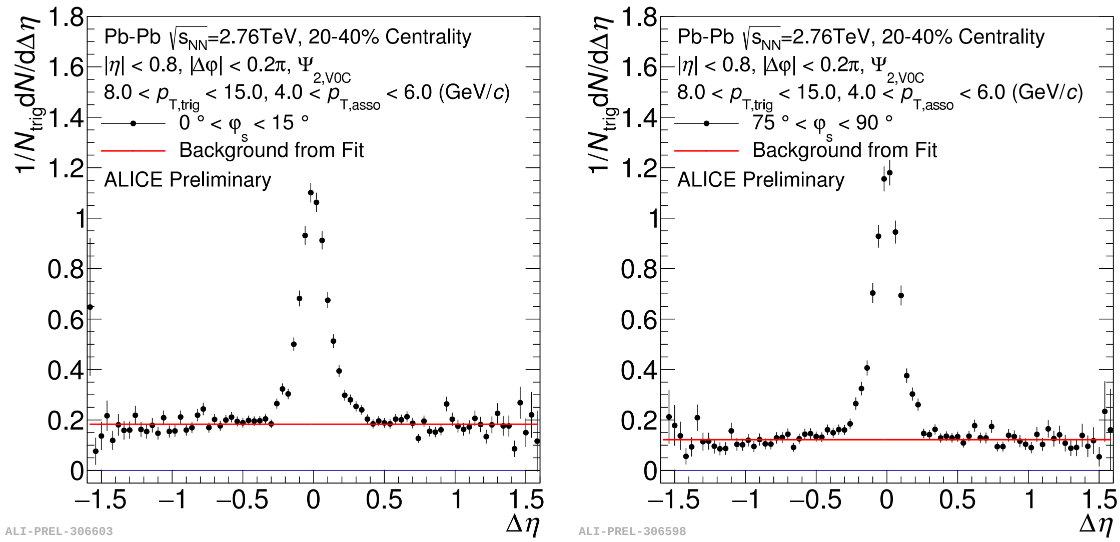

Figure 2: The event-plane dependent correlation function projected to $\Delta\eta$ axis with 20–40% central events. Left panel shows $8.0 < p_{T,trig} < 15.0$ with $4.0 < p_{T,asso} < 6.0$ GeV/c, and the right panel shows $8.0 < p_{T,trig} < 15.0$ with $6.0 < p_{T,asso} < 8.0$ GeV/c. The constant background estimated from the fit function in Eq. 2 is shown by a red line.

The differential analysis is done by using event-plane dependent two-particle correlations. The second-order event-plane is determined using the V0C [10] detector. The relative angle of the trigger particle with repect to Ψ_2 is calculated by $\varphi_s = \varphi_{trig} - \Psi_2$. As in the inclusive two-particle analysis, event-plane dependent correlation functions are obtained for each φ_s bin using the same background extraction procedure as in Eq. 2. In Fig. 2 the projections on the $\Delta\eta$ axis for given p_T and centrality bin of each pair correlations are shown. Both transverse momentum regions show a clear peak with a similar shape around $\Delta\eta = 0$ and with a constant background, for both in-plane ($0 < |\varphi_{trig} - \Psi_2| < \pi/12$) and out-of-plane ($5\pi/12 < |\varphi_{trig} - \Psi_2| < \pi/2$) trigger particles.

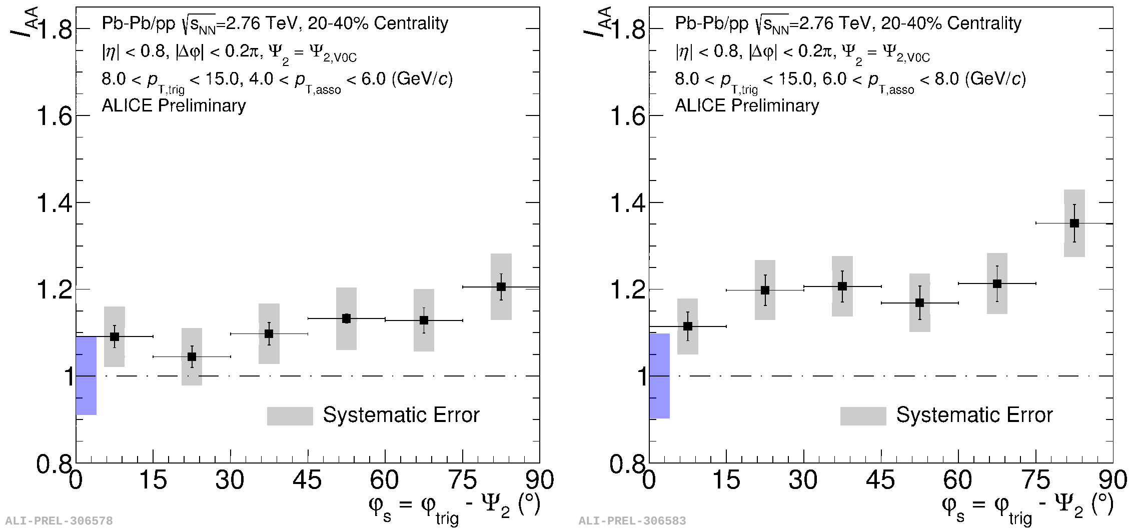

Figure 3: The I_{AA} as a function of φ_s for 20–40% central events. The left figure shows $8.0 < p_{T,trig} < 15.0$ GeV/c with $4.0 < p_{T,asso} < 6.0$ GeV/c, and the right figure shows $8.0 < p_{T,trig} < 15.0$ GeV/c with $6.0 < p_{T,asso} < 8.0$ GeV/c. The blue band around unity shows scaling uncertainties, and the gray boxes around the data points represent point-to-point systematic uncertainties.

The per-trigger yield is obtained by summing the bin contents of the event plane dependent $\Delta\eta$ correlations. Figure 3 shows I_{AA} as a function of φ_s for $8 < p_{T,trig} < 15$ GeV/c. Within the systematic and statistical uncertainties, the observed I_{AA} shows no significant dependence on the angle of the trigger particle with respect to the event-plane.

4. Conclusion

The evolution of the longitudinal shape of the near-side peak at low p_T shows narrowing in Pb–Pb collisions, compared to pp collisions. AMPT simulations were compared to the results, but do not reproduce the jet shape results in Pb–Pb collisions. The event-plane dependence of the near-side jet yield was studied, and within systematic and statistical uncertainties, no significant φ_s dependence was observed. Nevertheless, the results can be used to gain insight into jet-medium interactions and provide constraints on model parameters.

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