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Jet-hadron correlations relative to the event plane at the LHC with ALICE

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Abstract

In ultra relativistic heavy-ion collisions at the Large Hadron Collider (LHC), conditions are met to produce a hot, dense and strongly interacting medium known as the Quark Gluon Plasma (QGP). Quarks and gluons from incoming nuclei collide to produce partons at high momenta early in the collisions. By fragmenting into collimated sprays of hadrons, these partons form 'jets'. The outgoing partons scatter and interact with the medium, leading to a manifestation of medium modifications of jets in the final state, known as jet quenching. Within the framework of perturbative QCD, jet production is well understood in pp collisions. We use jets measured in pp interactions as a baseline reference for comparing to heavy-ion collision systems to detect and study jet quenching. The jet quenching mechanism can be studied through the angular correlations of jets with charged hadrons and is examined in transverse momentum (p_{T}) bins of the jets, p_{T} bins of the associated hadrons, and as a function of collision centrality. A robust and precise background subtraction method is used in this analysis to remove the complex, flow dominated, heavy-ion background. The analysis of angular correlations for different orientations of the jet relative to the event plane allows for the study of the path-length dependence of medium modifications to jets. The event plane dependence of azimuthal angular correlations of charged hadrons with respect to the axis of an R=0.2 reconstructed full (charged + neutral) jet in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ =2.76 TeV in ALICE is presented. Results are compared for three angular bins of the jet relative to the event plane in mid-peripheral events. The yields relative to the event plane are presented and then quantified through yield ratio calculations. The results show no significant path-length dependence on the medium modifications.

Keywords: ALICE, jets, jet-hadron correlations, energy loss, path-length dependence, background subtraction, RPF

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1. Introduction

Jets are formed from hard-scattered partons created early in the collision, prior to the formation of the QGP, making them ideal probes to study the properties of the QGP. The hard-scattered partons are modified in the presence of a medium through additional scatterings (collisional energy loss) or medium-induced gluon radiation (radiative energy loss), both of which depend on the path-length traversed through the medium. These partonic modifications are observed at both RHIC and LHC energies via the suppression of high-momentum particles [1, 2, 3, 4, 5, 6, 7] and also by the suppression of high-momentum di-hadron correlations [8, 9, 10, 11].

Jets, ideally, allow for a more complete picture of the redistributed energy from parton modifications. By fully reconstructing a jet, more direct access to the original parton energy is possible. This increases the kinematic reach of correlation measurements. Studying jet-hadron correlations relative to the event

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plane constrains the path-length tranversed by jets in the medium enabling measurements of the path-length dependence of medium modifications. The goal is to answer the question: can we experimentally distinguish between the effects of path-length dependence and the enhancement of vacuum-like fluctuations [12]?

2. Jet-hadron correlations

The data used in this analysis were collected by the ALICE Experiment during the 2011 2.76 TeV Pb–Pb collision run. Full R=0.2 jets are reconstructed using the anti-k_T jet-finding algorithm available within the FastJet package [13]. These jets are reconstructed in ALICE from clusters measured in the Electromagnetic Calorimeter (EMCal) and charged hadrons measured with the central tracking system [4]. Charged hadrons are reconstructed using information from the Time Projection Chamber (TPC) and the Inner Tracking System (ITS). A complete description of the ALICE detector can be found in [14]. Tracks are measured in the full azimuthal range and in a pseudo-rapidity interval of $|\eta_{lab}|$ <0.7 when reconstructed in a jet, and $|\eta_{lab}|$ <0.9 for the associated charged hadrons. The acceptance of the EMCal is $|\eta_{lab}|$ <0.7 and $|\Delta\phi|$=107°. This analysis requires a minimum constituent cut of 3 GeV/c for both clusters and tracks. Additionally, to reject more event background and match thresholds of the trigger conditions [15], the jets are required to contain a cluster > 6 GeV in transverse energy. The influence of the underlying event is small due to the high constituent cuts and thus not subtracted from the jets [16]. Furthermore, there are currently no corrections to the jet p_{T} for detector effects. The jets in this analysis are binned in 3 distinct angular orientations (in-, mid-, and out-of-plane) relative to the second harmonic event plane to study the path-length dependence of medium modifications. The event plane is calculated using the signal from the VZERO detector [17], which has a pseudo-rapidity acceptance of its two scintillators spanning $2.8 < \eta < 5.1$ and $-3.7 < \eta < -1.7$. The angular difference between the jet and the reconstructed event plane, $\Delta\varphi$, is binned such that in-plane corresponds to $0 < |\Delta\varphi| < \frac{\pi}{6}$, mid-plane by $\frac{\pi}{6} < |\Delta\varphi| < \frac{\pi}{3}$, and out-of-plane by $\frac{\pi}{3} < |\Delta\varphi| < \frac{\pi}{2}$.

The jet-hadron correlation function including the heavy-ion background is defined as:

$$\frac{1}{N_{trig}}\frac{d^2N_{assoc,jet}}{d\Delta\phi d\Delta\eta} = \frac{1}{\epsilon a N_{trig}}\frac{d^2N^{same}_{pairs}}{d\Delta\phi d\Delta\eta} - b_0\left(1 + \sum_{n=1}^{\infty} 2v_n^{trig}v_n^{assoc}\cos(n\Delta\phi)\right). \tag{1}$$

It is generally expressed as an azimuthal distribution given by $\Delta\phi = \phi_{jet} - \phi_{assoc}$, after projection along $\Delta\eta$. The first term of Eq. 1 denotes the same-event pairs which are corrected for the limited detector acceptance and efficiency through the use of mixed events, provided by the correction term a. The mixed events consist of hadrons and jets from different events. ϵ denotes the single track reconstruction efficiency of associated particles. N^{same}_{pairs} represents the number of same-event pairs of the correlation, while the normalization of N_{trig} denotes the number of jets. The combinatorial heavy-ion background is given by the second term where b_0 is the average background level and the v_n terms are used to express the Fourier coefficients of the jet and associated particles.

To study the jet signal in Pb–Pb collisions, it is necessary to subtract the large combinatorial background from the raw $\Delta\phi$ distributions. Use of the ALICE detector allows for a high precision measurement of low p_{T} particles, which enhances the ability to subtract uncorrelated background. When the jets are binned relative to the event plane, both the background level and the v_n are modified. The new formulation of the background will now depend on the event plane resolution. Derivations of these background equations relative to the event plane are given in [18]. The event plane resolution describes the difference between the reconstructed event plane and the underlying symmetry plane, Ψ_n, since the true reaction plane can not be experimentally measured.

Background subtraction methods were developed in [19] and applied to the azimuthal correlation functions. The reaction plane fit (RPF) uses the assumption that the signal is negligible in the large $\Delta\eta$ and small $\Delta\phi$ region. After the raw 2D correlation functions are corrected by the mixed events, they are projected for 0.8< $|\Delta\eta|$ <1.2 to define the background dominated region in bins relative to the event plane. The signal+background region is defined by the region of $|\Delta\eta|$ <0.6. The three bins relative to the event plane are simultaneously fit in the region $|\Delta\phi| < \pi/2$ up to fourth order in v_n to constrain the shape and background level. They are also required to have the same fit parameters, while having different functional forms which are due to the modification of the background level and v_n terms. Results in [16, 20] show the effectiveness of this model to data.

The jet-hadron correlation signal is extracted by removing the large combinatorial background from the correlation function by the RPF background subtraction method. Fig. 1 shows the signal for a p_{T}^{assoc} range of 1.5-2.0 GeV/c. The jets have a p_{T} ranging from 20-40 GeV/c. From left to right are in-, mid-, out-of-plane, and then all combined angles. At this low p_{T}, the uncertainties are dominated by statistical errors.

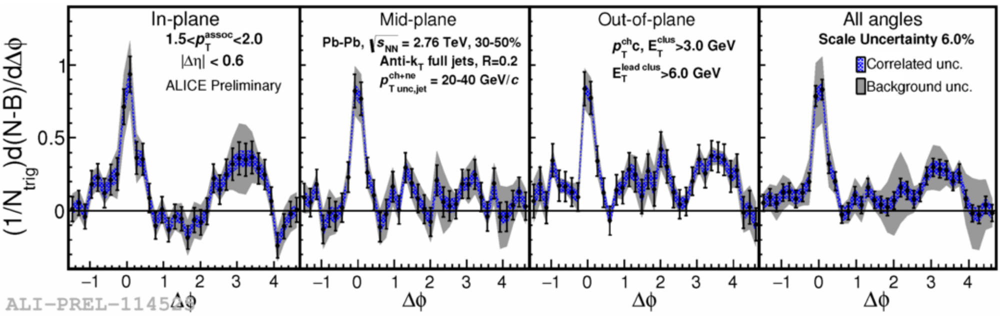

Fig. 1. Corrected $\Delta\phi$ correlation function for 1.5< p_{T} <2.0 GeV/c associated hadrons for full jets in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 2.76 TeV for the 30-50% centrality class. The blue band corresponds to the correlated uncertainty and the grey band corresponds to the background uncertainty which is correlated point-to-point [19, 20]. There is an additional 6% global scale uncertainty.

The yields are defined by:

$$Y = \frac{1}{N_{trig}} \int_c^d \int_a^b \frac{d(N_{meas} - N_{bkgd})}{d\Delta\phi} d\Delta\phi d\Delta\eta, \tag{2}$$

where $a = -\pi/3$ to $b = \pi/3$ for the near-side and $a = 2\pi/3$ to $b = 4\pi/3$ for the away-side. The integration limits in $\Delta\eta$ are $c = -0.6$ to $d = 0.6$. On the near-side of a jet-hadron correlation, little to no modification is expected. However, the away-side should be much more sensitive to path-length dependent effects. It was seen in [16] that there was little to no modification when comparing the yields, but these results had large statistical uncertainties. Competing effects like jet quenching and gluon radiation may occur at different magnitudes across different p_{T} ranges. To quantify the path-length dependence of these yield calculations, ratios of the yields for mid/in-plane and out/in-plane were calculated and are shown by Fig. 2.

By taking ratios of the yields, the uncertainties partially cancel. The away-side jets traverse larger path-lengths as their angle relative to the event plane increases, due to the initial collision geometry. This leads to the expectation of a yield ratio less than 1.0 (suppression) when comparing out-of-plane to in-plane and mid-plane to in-plane yields on the away-side at higher p_{T}. Fig. 2 shows no significant dependence of path-length to the yields on both the near-side and away-side for both out/in-plane and mid/in-plane. This is consistent with a re-analysis of STAR data done in [20].

3. Summary and Outlook

The results shown in these proceedings present a measurement carried out with the ALICE detector of jet-hadron correlations relative to the event plane. The RPF background subtraction method used in this analysis has less bias and fewer assumptions than prior methods and does not require independent measurements of the v_n, as they are extracted from the fits themselves. By quantifying the path-length dependence of the yields through ratios, this work shows no significant path-length dependence on the medium modifications. Our observations can be reproduced by JEWEL [21] studies with the same analysis cuts as this work [22]. This is an indication that path-length is a secondary effect to fluctuations of jet energy loss in the medium.

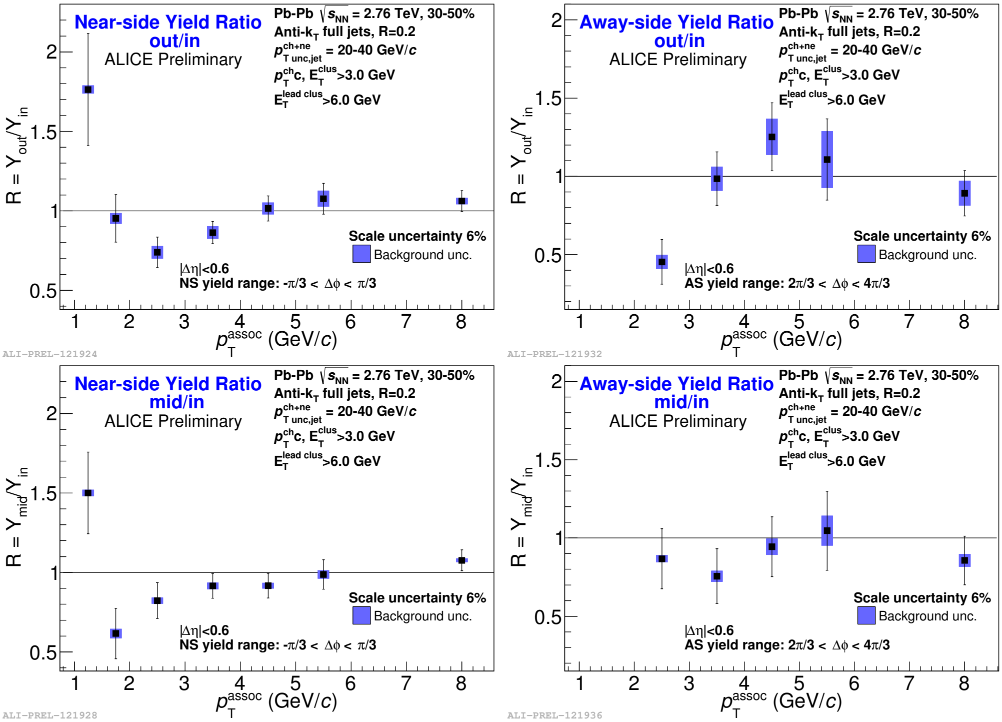

Fig. 2. The near-side (out/in, mid/in) yield ratios (top left, bottom left) and away-side (out/in, mid/in) yield ratios (top right, bottom right) for full jets in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV for the 30-50% centrality class. The colored bands correspond to the correlated uncertainties and the grey band corresponds to the background uncertainty which is correlated point-to-point [19, 20]. There is an additional 6% global scale uncertainty.

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