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Measurement of jet p_T spectra and R_{AA} in pp and Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV with the ALICE detector

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Abstract

Hard-scattered partons provide an ideal probe for the study of the Quark–Gluon Plasma because they are produced prior to the formation of the QCD medium in heavy-ion collisions. Jet production is therefore susceptible to modifications induced by the presence of the medium ("jet quenching"). Both RHIC and LHC experiments have provided compelling evidence of jet quenching. Jets are reconstructed in ALICE utilizing the central tracking system for the charged constituents and the Electromagnetic Calorimeter for the neutral constituents. Jet spectra are reported for central (0–10%) and semi-central (10–30%) Pb–Pb events at $\sqrt{s_{NN}} = 2.76$ TeV. The nuclear modification factor, determined using a pp baseline measured at the same collisional energy, shows a strong suppression of jet production in central Pb–Pb collisions with the expected centrality ordering. Observations are in qualitative agreement with medium-induced energy loss models. Furthermore, indication of a path-length dependence of jet suppression is inferred from measurements of the yields relative to the orientation of the event plane.

Keywords: QGP; Jets; Heavy-ion

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[1] A list of members of the ALICE Collaboration and acknowledgments can be found at the end of this issue.

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1. Introduction

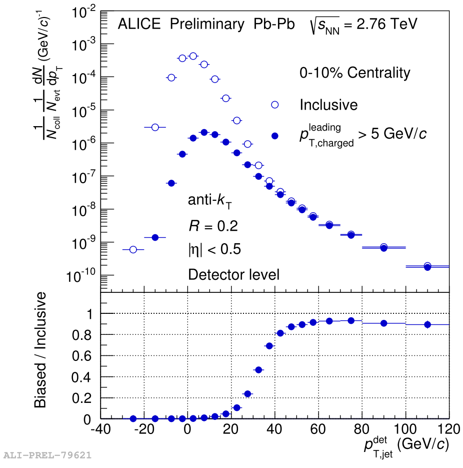
The study of jets in ultra-relativistic heavy-ion collisions is intimately connected to the investigation of the properties of the Quark–Gluon Plasma (QGP). The QGP is a deconfined state of matter, in which the relevant degrees of freedom are those of strongly-interacting quarks and gluons. Simple quantum-mechanical considerations, based on the Heisenberg principle of indetermination, imply that hard-scattering processes, with a large momentum transfer, happen at a much smaller time scale as compared to that of the QGP formation, which is driven by many low momentum scatterings. The subsequent transport of the hard scattered parton through the medium and its fragmentation are expected to be considerably modified through elastic collisions and medium-induced radiation [1]. These phenomena are usually referred to as "jet quenching". Measurements at both RHIC [2,3] and the LHC [4–6] have confirmed these predictions using a variety of observables. Jet reconstruction can take advantage of the more accurate estimate of the energy of the parton compared to high transverse momentum (p_{T}) single hadron measurements, which are often used as proxies for jets.

In these proceedings we report measurements of the jet nuclear modification factor and charged jet v_2 performed by the ALICE experiment for Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV. These results are based on data collected by ALICE in 2011 and extend previous measurements reported in Refs. [7,8].

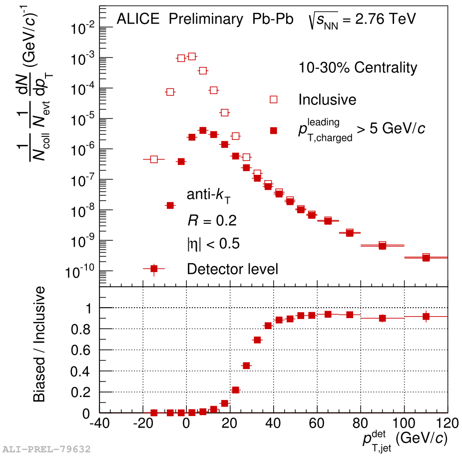
2. Experimental setup and analysis techniques

For a complete description of the ALICE detector and its performance see Refs. [10] and [11], respectively. The main sub-detectors used in the present measurement are the VZERO, the central tracking system and the Electromagnetic Calorimeter (EMCal). The VZERO detector consists of segmented scintillators covering the full azimuth at forward rapidity. It is used to measure the centrality of the Pb–Pb events and also provides the set of minimum bias and centrality triggers used to collect the presented data. The ALICE tracking system consists of the Inner Tracking System (ITS), a six-layer silicon detector, and a large Time Projection Chamber (TPC). The ITS provides a precise measurement of the first points of the tracks and a precise determination of the primary vertex. The tracking system allows reconstruction of charged tracks ranging from very low momentum ($p_{\mathrm{T}} \approx 0.15$ GeV/c) to high momentum ($p_{\mathrm{T}} \approx 100$ GeV/c), with good momentum resolution and tracking efficiency. Tracks are reconstructed at mid-rapidity ($|\eta| < 0.9$) and in full azimuth. The EMCal is a Pb-scintillator sampling calorimeter, which covers mid-rapidity ($|\eta| < 0.7$) and partial azimuth ($\Delta\phi = 100°$). In this analysis it is used to measure the decay photons of the neutral mesons, that are not detected by the tracking system. Energy deposition from charged particles, measured by the tracking system, is subtracted to avoid double counting their energy in the jet reconstruction. The details of this correction are outlined in Ref. [11].

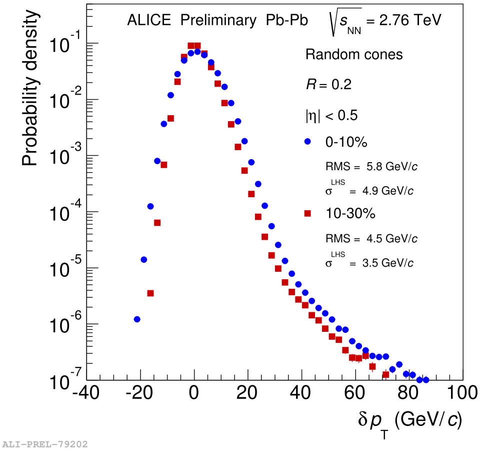
The methods utilized in this analysis follow closely those used for the charged jet suppression measurement reported in Ref. [5] and for the pp jet cross section reported in Ref. [14]. The anti-k_{T} jet finding algorithm [15] with a resolution parameter $R = 0.2$ has been employed in its FastJet [16] implementation. Jets are required to be fully contained within the EMCal acceptance. Following the proposal in Ref. [17], the average background, ρ, is calculated, event-by-event, as the median of the p_{T} density (jet p_{T} over jet area) of the jets reconstructed by the k_{T} algorithm. The average background is subtracted jet-by-jet: $p_{\mathrm{T,jet}}^{\mathrm{reco}} = p_{\mathrm{T,jet}}^{\mathrm{raw}} - \rho \times A_{\mathrm{jet}}$, where $p_{\mathrm{T,jet}}^{\mathrm{raw}}$ and A_{jet} are respectively the transverse momentum and the area of the anti-k_{T} jet candidate. Figs. 1(a) and 1(b) show the jet p_{T} spectra at detector level, after the subtraction of the average background.



(a) Jet p_T spectra (0-10% centrality class).



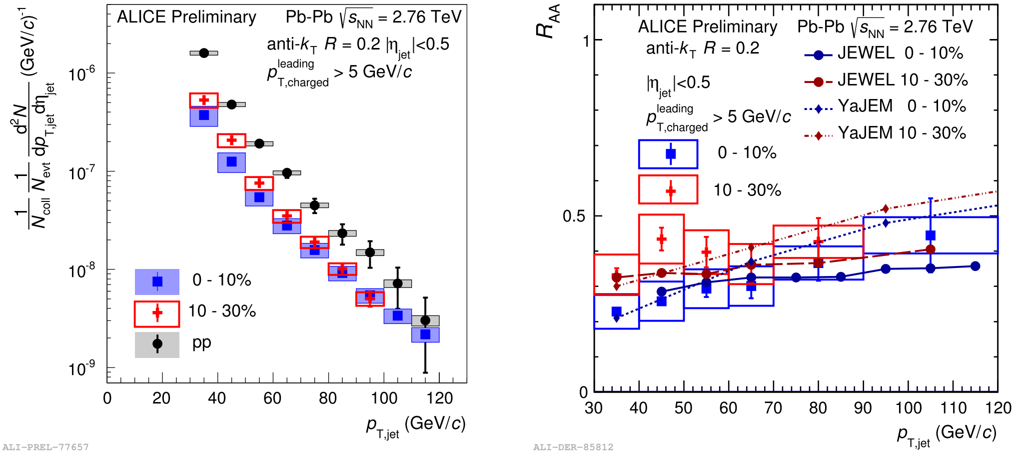
(b) Jet p_T spectra (10-30% centrality class).



(c) δp_T distributions.

Fig. 1. Jet p_T spectra at detector level and δp_T distributions in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV at mid-rapidity. Jets are reconstructed using the anti-k_T algorithm with a resolution parameter $R = 0.2$ in two centrality ranges: 0–10% (top left) and 10–30% (top right). Spectra are normalized by the number of events and the number of binary collisions obtained in a Glauber MC calculation [9]. Both the inclusive spectra and the spectra biased by requiring a leading hadron with $p_T > 5$ GeV/c are shown. The bottom panels show the ratios of the biased over the inclusive spectra. The δp_T distributions (bottom) are obtained using the random cone technique.

Both the inclusive spectra and the spectra biased by requiring a leading hadron $p_T > 5$ GeV/c are shown. The bias is applied in order to suppress the combinatorial background. Background fluctuations are estimated using the random cone technique [18]. The root-mean-square widths of the δp_T distributions, shown in Fig. 1(c), are 5.8 GeV/c for the 0–10% centrality class and 4.5 GeV/c for the 10–30%. The response of the detector to jets has been quantified through a simulation which makes use of the PYTHIA6 event generator [19] and the GEANT3 transport code [20]. The results reported in Section 3 are obtained after correcting for both detector response and background fluctuations using standard regularized unfolding methods [21,22].



(a) Jet p_T spectra.

(b) Nuclear modification factor.

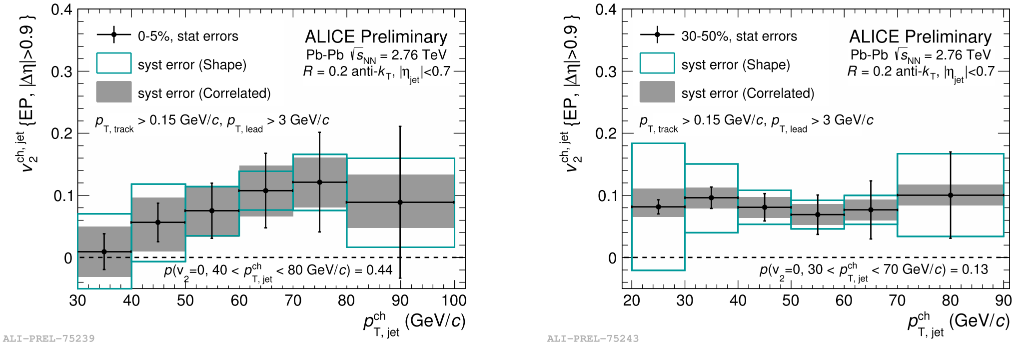
Fig. 2. Jet p_T spectra (left) and nuclear modification factor (right) at mid-rapidity for 0–10% and 10–30% centrality class Pb–Pb events at $\sqrt{s_{NN}} = 2.76$ TeV (color online). The measured R_{AA} is compared with two model predictions, YaJEM [12] and JEWEL [13], see text for details.

3. Results

Fig. 2(a) shows the anti-k_T $R = 0.2$ jet p_T spectra at mid-rapidity for the 0–10% and the 10–30% centrality classes. In order to compare with the same measurement performed in pp collisions at the same $\sqrt{s_{NN}}$ [14], the jet yield in Pb–Pb has been divided by the number of binary collisions calculated in a Monte Carlo Glauber model [9] that assumes independent binary nucleon–nucleon collisions. The systematic uncertainty is dominated by the tracking efficiency uncertainty and the unfolding regularization and is p_T dependent, with a value of about 18% at $p_{T,jet} = 60$ GeV/c for the central events and only slightly smaller for the semi-central events.

The nuclear modification factor R_{AA} is defined as the ratio of the Pb–Pb per-event yield over the pp cross section [14] multiplied by $T_{AA} = N_{coll}/\sigma_{pp}^{inel}$, obtained in the same Glauber calculation mentioned above. The measured R_{AA} is shown in Fig. 2(b). A strong suppression, with the expected centrality ordering, is observed and is in qualitative agreement with two energy loss model predictions, superimposed on the data. Both models use a combination of Glauber MC, perturbative QCD (pQCD) Leading Order (LO) calculations and PYTHIA, to describe the initial state, the hard scattering and the hadronization into final-state colorless particles. They both implement a hydrodynamic description of the medium. They differ in the specific way in which the interaction between the shower parton and the medium is modeled. In YaJEM [12] the energy loss mechanism is implemented through a pair of transport coefficients, one representing the increase of the parton's virtuality in the medium (radiative energy loss), and the other accounting for the collisional energy loss; in JEWEL [13] an average over a microscopic description of the single parton–parton scatterings is implemented, using a MC model for the LPM interference.

The path-length dependence of the jet energy loss has been investigated by studying the charged jet yield with respect to the event plane orientation. The QGP formed in semi-central collisions is expected to take an ellipsoidal shape elongated in the direction perpendicular to the reaction plane, which has been confirmed by the measurement of the azimuthal anisotropy of low-momentum particle production [23]. High Q^2 partons produced out-of-plane are expected



(a) 0-5% centrality class.

(b) 30-50% centrality class.

Fig. 3. Charged jet v_2 in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV at mid-rapidity. Jets are required to have a leading hadron with $p_T > 3$ GeV$/c$.

to be more heavily modified because they travel a longer path in the medium. The jet v_2 is defined as the second coefficient of the Fourier expansion of the jet yield with respect to the azimuthal angle between the jet axis and the event plane. For this measurement, the average background and the background fluctuations have been measured and subtracted differentially with respect to the angle with the event plane. The observed v_2 has been corrected for the finite event plane resolution by using a three sub-event technique [24]. Fig. 3 shows the charged jet v_2 for central (0–5%) and semi-central (30–50%) Pb–Pb events. In estimating the systematic uncertainties, the correlations between the in-plane and out-of-plane measurements have been taken into account. While we do not observe a significant indication for a non-zero jet v_2 in central events, the semi-central events show a hint of a difference between the in- and out-of-plane nuclear modification factor, although the result is also still compatible with $v_2 = 0$ for jets.

4. Conclusions

In these proceedings we have reported new measurements of jet suppression performed by the ALICE experiment. The measured suppression for both central and semi-central events is in qualitative agreement with both the YaJEM and JEWEL models. In order to obtain a tighter constraint on the models the path-length dependence of the parton energy loss has been explored by measuring the charged jet v_2, which shows hints of such an effect for semi-central events. ALICE has also measured jet yields in p–Pb collisions [25,26], which show that cold nuclear matter effects in the initial state cannot account for the observed suppression in Pb–Pb collisions. These observations support the interpretation of the observed suppression as a medium-induced modification of the final state parton shower.

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