Measurement of jet p_{T} spectra in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV with the ALICE detector at the LHC

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Abstract. Reconstruction of jets in high-energy heavy-ion collisions is challenging due to the large and fluctuating background coming from the underlying event. We report results on full jet reconstruction, obtained from data collected in 2011 by the ALICE detector at LHC for Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV. The analysis makes use of the tracking system and the electromagnetic calorimeter. Signal jets, which come from hard scattered partons, are reconstructed using the anti-k_{T} jet finder algorithm. The average background is subtracted on a jet-by-jet basis to reduce the contribution to the jet reconstructed energy coming from the underlying event. The jet spectrum is corrected to account for fluctuations in the background momentum density and detector effects through unfolding.

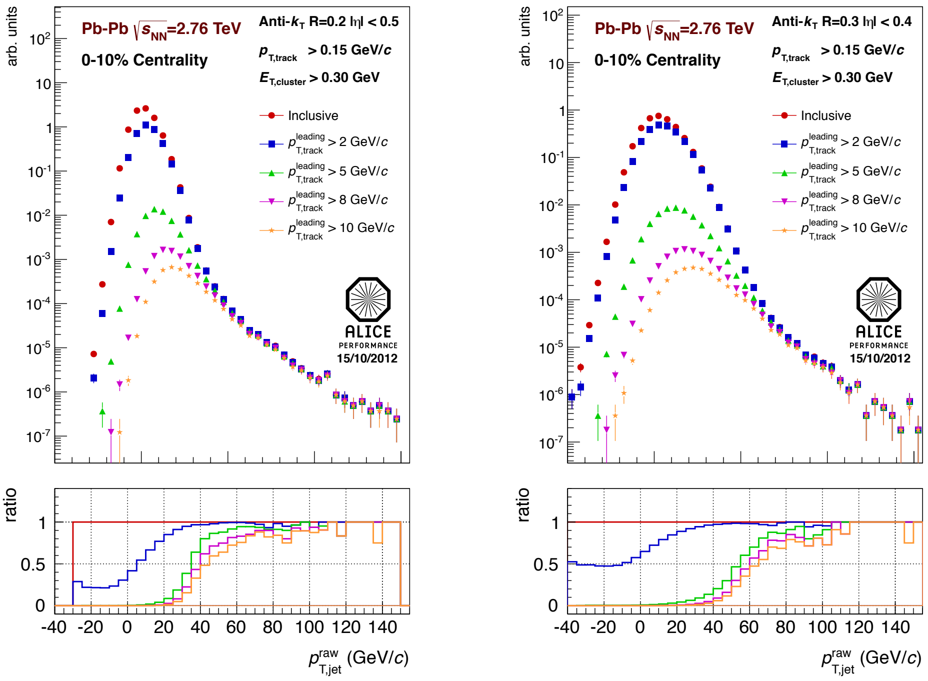
1. Introduction

QCD jets are produced in high-energy particle collisions as a result of the fragmentation of a high momentum scattered parton. Experimentally they are reconstructed using a well-defined algorithm, which acts as a working definition of a jet, to be used consistently also in phenomenological models. In heavy-ion collisions, hard scattered partons are produced in the early stages of the collision, so that they propagate through (and potentially are affected by) the hot and dense nuclear medium. The interactions suffered by the parton can result in energy loss, widening and/or complete absorption of jets. These phenomena go under the name of “jet quenching”. RHIC and LHC experiments have already collected convincing evidence of jet quenching in a number of measurements, such as the suppression of high-p_{T} particles relative to a pp baseline [1, 2, 3, 4], hadron-hadron correlations [5, 6] and jet-jet correlations at high-p_{T} [7, 8]. However, performing a full jet reconstruction in the low and intermediate p_{T} region is particularly challenging due to the overwhelming soft particle background coming from the underlying event (UE). ALICE has recently reported on a first detailed study of the background for jet reconstruction in the heavy-ion environment [9].

In these proceedings the analysis techniques utilized to fully reconstruct jets in Pb–Pb collisions with the ALICE experiment are presented. The results shown here come from data collected by ALICE in fall 2011 at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV.

2. Inputs to the jet finder

The ALICE tracking system benefits of the Inner Tracking System, a six-layer silicon detector which provides a precise measurement of the primary vertex together with the first points of the



(a) $R = 0.2$. (b) $R = 0.3$.

Figure 1: Raw jet p_T spectra in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV in the 0-10% centrality range at mid-rapidity: inclusive is shown in full circles and with increasing minimum leading hadron p_T requirement in the other symbols (color online). Jets are reconstructed using the anti-k_T algorithm with two different resolution parameters, $R = 0.2$ (left) and $R = 0.3$ (right).

tracks, and of a large Time Projection Chamber [10]. Tracks are reconstructed at mid-rapidity ($|\eta| < 0.9$) and in full azimuth. The ALICE electromagnetic calorimeter [11] is a Pb-scintillator sampling calorimeter, which covers mid-rapidity ($|\eta| < 0.7$) and partial azimuth ($\Delta\varphi = 100°$). The EMCal measures photons, e.g. from π^0 decays, which are included in the jet finder input. The shift of the jet energy scale due to unreconstructed particles, such as K_L^0 and neutrons, has been studied in pp simulations and accounted for in the final result. A full description of the ALICE experiment is available in Ref. [10].

3. Jet finding and average background

The anti-k_T [12] jet finding algorithm has been employed in its `FastJet` [13] implementation. This sequential recombination algorithm has the advantage of being "soft-resilent", namely it is little affected by the soft background [14]. Anti-k_T jets are pretty regular, cone-like shaped around some high-p_T particle. The uncorrelated energy density from soft processes is large in heavy-ion events and needs to be subtracted on an event-by-event basis. The main problem in the estimation of the average background is the separation of the UE from the hard scattering. The method used here has been proposed in Ref. [15]. 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 k_T algorithm [16] reconstructed jets. A jet-by-jet subtraction is performed: $p_{T,jet}^{raw} = p_{T,jet}^{uncorr} - \rho \times A_{jet}$, where $p_{T,jet}^{uncorr}$ and A_{jet} are respectively the transverse momentum and the area of the jet. Combinatorial jets, i.e. jets reconstructed out of the soft background, are efficiently removed by requiring a minimum leading hadron p_T. Figure 1 shows the anti-k_T raw jet p_T spectra obtained applying different

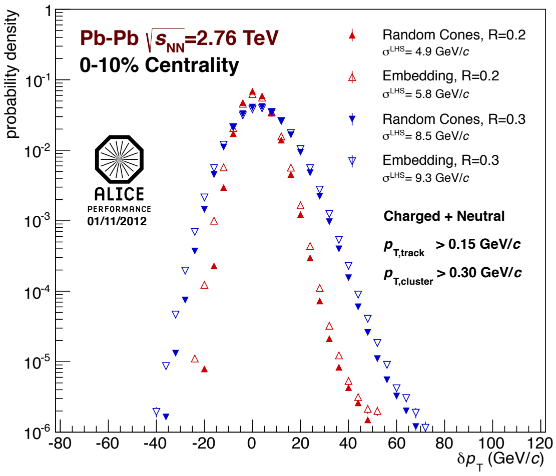


Figure 2: δp_{T} distributions for Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV in the 0-10% centrality class. Two different methods have been implemented: "random cones", shown with full symbols, and single particle embedding, shown with open symbols (see text for details); the distributions for $R = 0.2$ are narrower w.r.t. $R = 0.3$ (color online).

minimum leading hadron p_{T} requirement, from 0 (inclusive) to 10 GeV/c, for two different jet resolution parameters $R = \sqrt{\Delta\eta^2 + \Delta\varphi^2}$.

4. Unfolding

The spectra shown in Fig. 1 are not directly comparable with model predictions. In fact the measured values of the observable, the jet p_{T}, are subject to random fluctuations, due to region-to-region differences in the background momentum density and to the detector response. This means that each observation is characterized by a true (and unknown) value $p_{\mathrm{T,jet}}^{\mathrm{true}}$, and by a measured value $p_{\mathrm{T,jet}}^{\mathrm{meas}}$. The histograms for $p_{\mathrm{T,jet}}^{\mathrm{true}}$ and $p_{\mathrm{T,jet}}^{\mathrm{meas}}$ are related by a convolution through the response matrix $\mathrm{RM}_{\mathrm{tot}} = \mathrm{RM}_{\mathrm{det}} \times \mathrm{RM}_{\mathrm{bkg}}$, where $\mathrm{RM}_{\mathrm{det}}$ parametrizes the detector reponse whereas $\mathrm{RM}_{\mathrm{bkg}}$ describes background fluctuations. Unfolding is the numerical procedure that allows to get back the true distribution given the measured one and the response matrix $\mathrm{RM}_{\mathrm{tot}}$.

Background fluctuations have been estimated in two different ways [9], namely using random cones (scalar sum of the p_{T} of all particles found in a cone randomly placed in the event) and single particle embedding (with the anti-k_{T} algorithm). The residual p_{T} differences due to region-to-region fluctuations are calculated as: $\delta p_{\mathrm{T}} = p_{\mathrm{T,jet}} - p_{\mathrm{T,probe}} - \rho \times A_{\mathrm{jet}}$, where $p_{\mathrm{T,probe}}$ is the p_{T} of the embedded probe ($p_{\mathrm{T,probe}} = 0$ for random cones). The δp_{T} distributions, shown in Fig. 2, tell us how much the jet p_{T} is smeared due to background fluctuations.

The detector response to jet reconstruction has been studied with pp simulated events, using the PYTHIA6 [17] generator and the GEANT3 [18] transport code. Jets are reconstructed both at generator level and at detector level. The generator-level and detector-level jets are matched following a geometrical criterion.

5. Results

This measurement makes use of the unfolding iterative method proposed by D'Agostini [19], which contains elements of Bayesian statistics. In Bayesian unfolding the number of iterations plays the role of the regularization parameter. Based on the evolution of the covariance matrix and the converging of the solution itself, a number of four iterations has been chosen as default. Indeed after three/four iterations the procedure starts to converge. However, with more iterations a characteristic fluctuation pattern does appear along with larger variances and (anti-)correlations between far bins (indicating under-regularization). Systematic uncertainties have been estimated taking into account variations of the solution for ±1 iterations ($\sim 5\%$).

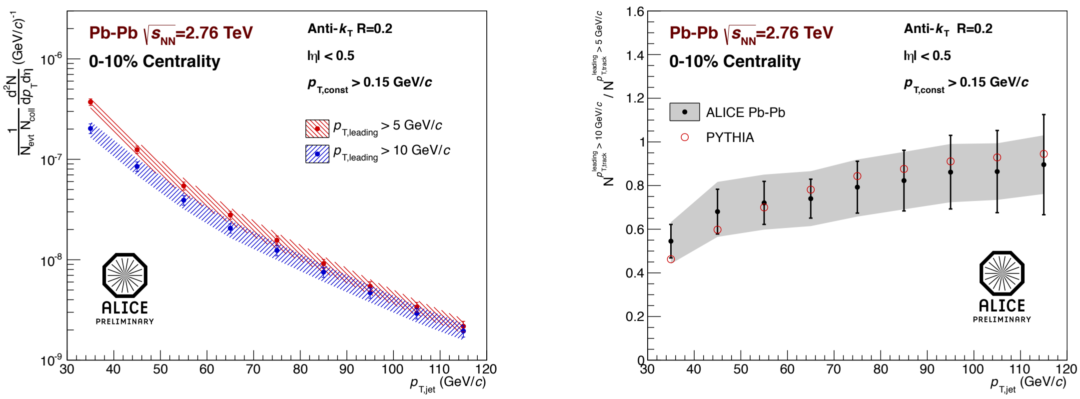


Figure 3: On the left: spectra of reconstructed jets in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV in the 0-10% centrality class with two different minimum leading hadron p_T requirements. On the right: ratio of the two spectra (solid circles) and comparison with a PYTHIA pp expectation (open circles). The bands represent the systematic uncertainty; statistical uncertainties are shown with bars, when they are larger than markers (colors online).

To better understand the effect of the leading hadron requirement in the jet p_T spectrum, the analysis was performed for $p_{T,\mathrm{leading}} > 5,\ 10$ GeV/c. Figures 3 show the two spectra with the two different leading hadron thresholds, and the ratio, compared to a PYTHIA expectation.

6. Conclusions

We have reported on the analysis techniques utilized to reconstruct jets in the 10% most central Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV recorded by ALICE in 2011. The raw jet p_T spectra are corrected for the average background and biased requiring a minimum leading hadron p_T. Corrections for background fluctuations and detector effects are applied via Bayesian unfolding.

The effect of the leading hadron requirement was studied for two different thresholds, 5 GeV/c and 10 GeV/c. The ratio between the two corrected spectra is in reasonable agreement with a PYTHIA simulation, which indicates a vacuum-like fragmentation of the jet core.

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