Study of high-p_{T} hadron-jet correlations in ALICE

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Abstract. We report the measurement of semi-inclusive p_{T} spectra of charged particle jets that recoil from a high-p_{T} hadron trigger in Pb–Pb and pp collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV and $\sqrt{s} = 7$ TeV, respectively. In this analysis, the copious yield of uncorrelated trigger hadron-jet matchings in central Pb–Pb collisions is removed by calculating the difference between two spectra corresponding to exclusive trigger hadron p_{T} ranges. This procedure does not impose any fragmentation bias on the recoil jet population, which is therefore collinear and infrared safe. The resulting distributions obtained for different values of jet resolution parameter are used to study the modification of jet structure in the medium.

1. Introduction

Collisions of ultrarelativistic heavy nuclei produce an exotic state of matter which is believed to consist of deconfined quarks and gluons. Strong pressure gradients present at the initial collision stage lead to a rapid collective expansion of the created medium during which quarks and gluons form colorless hadrons. Jets and high-p_{T} hadrons have many advantageous properties to be considered as well suited probes of this matter. First of all they originate from hard parton-parton interactions that occur during early stages of the collision. These scattered partons are known to undergo large energy losses when penetrating through the medium which has direct impact on the energies of outgoing jets and high-p_{T} hadrons. As a result of this parton-medium interaction we observe the so called jet quenching phenomenon manifested by highly p_{T} imbalanced pair of jets.

Heavy-ion collisions result usually in events where the multiplicity of final-state particles is high. Thus, hard scattering products are often embedded into a densely populated, soft, and fluctuating background. Under these conditions, jet finding algorithms frequently create also artificial jets composed of background particles only. In principle, the number of these artificial jets can be reduced by imposing an additional requirement to have a high-p_{T} leading track within the reconstructed jet. Such constraint, however, breaks down the infrared safety and biases the jet fragmentation. Consequently, this can have an obvious unwanted impact especially on the quenched jets that resemble the artificial background jets.

As suggested in [1] hadron-jet coincidence measurements offer a way to remove the contribution of artificial jets at the event-ensemble level without introducing a bias on the jet population. Following this idea we report on the analysis of p_{T} spectra of jets associated with a high-p_{T} trigger hadron in Pb–Pb collisions at a center-of-mass energy per nucleon pair $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV.

2. Data analysis

We analyzed 9 M events (10% most central events) and 3 M events (20% most central events) of Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV measured by the ALICE detector [2] in 2010 and 2011, respectively. Accepted charged tracks had pseudorapidity range $|\eta| < 0.9$ and $p_{\mathrm{T}} > 150$ MeV/c. Jet reconstruction uses the charged tracks only and is based on the anti-k$_{\mathrm{t}}$ algorithm [3]. The imposed infrared cutoff is given by the low p_{T} cut on tracks. Three values of the resolution parameter were employed, $R = 0.2$, 0.4 and 0.5. In order to have all jets fully contained within the ALICE acceptance the centroids of reconstructed jets were constrained to be within the pseudorapidity interval $|\eta_{\mathrm{jet}}| < 0.9 - R$.

The background energy density ρ is estimated with the area based method [4]. The reconstructed jet p_{T} is then event by event corrected for the underlying event activity estimated by the product of the calculated background density and jet area.

The raw p_{T} spectrum of jets has to be corrected for the momentum smearing induced by the fluctuating background and for detector response. The corresponding response matrix that relates the p_{T} of matched reconstructed jets on the particle and detector level is assumed to factorize into a product of matrices that describe both effects. The response matrix was inverted and regularized by means of the SVD [5] and Bayes' theorem [6] based algorithms implemented in the RooUnfold package [7] and was used to correct the raw spectra.

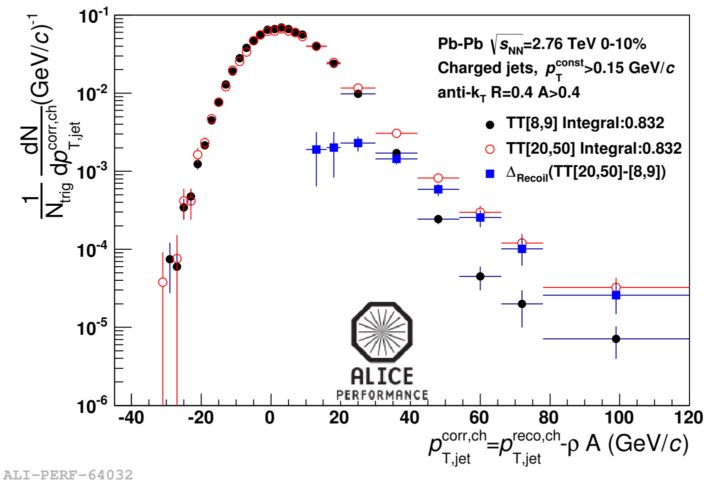

Figure 1. Raw p_{T} spectra of recoil jets associated with two exclusive trigger hadron p_{T} bins, [8,9] GeV/c and [20,50] GeV/c. The corresponding Δ_{recoil} distribution was calculated based on Eq. (1). See text for more details.

The presented analysis is based on jets that are oriented nearly back-to-back in azimuth w.r.t. a high-p_{T} trigger hadron, namely $|\varphi_{\mathrm{trig}} - \varphi_{\mathrm{jet}} - \pi| < 0.6$ rad. The benefit of this choice follows from the fact that the presence of the outgoing high-p_{T} trigger hadron biases the hard scattering to be located close to the surface and the mother parton to be directed toward the outside of the collision zone [8]. Hence, the recoiling jet will on average travel longer distance through the medium. Figure 1 shows background corrected, per trigger normalized raw p_{T} spectra of recoil jets associated with two exclusive trigger hadron p_{T} ranges, $[8, 9]$ GeV/c and $[20, 50]$ GeV/c. The trigger hadrons from the p_{T} bin $[20, 50]$ GeV/c originate on average from hard scattering processes with larger Q^2 than the trigger hadrons from $[8, 9]$ GeV/c. Therefore the associated recoil jets in the first case have also a harder p_{T} spectrum than in the latter case. The positive part of the spectrum is, however, populated also by random matchings of trigger hadron with background jets and the data do not show a clear separation between the contributions of true and accidental coincidences. In the negative part of the spectrum, accidental combinations of trigger hadron with background jets dominate and the jet yield per trigger is to a good approximation independent of the trigger p_{T}. Based on p_{T} spectra of recoil jets associated with two exclusive trigger hadron p_{T} ranges we define

$$\Delta_{\text{recoil}} = \frac{1}{N_{\text{trig}}} \frac{\mathrm{d}N_{\text{jet}}}{\mathrm{d}p_{\text{T,jet}}}\bigg|_{p_{\text{T,trig}}\in[20,50]} - \frac{1}{N_{\text{trig}}} \frac{\mathrm{d}N_{\text{jet}}}{\mathrm{d}p_{\text{T,jet}}}\bigg|_{p_{\text{T,trig}}\in[8,9]} \tag{1}$$

where N_{trig} is the number of trigger hadrons in the given transverse momentum bin, here $p_{\text{T,trig}} \in [20, 50]$ GeV/c and $[8, 9]$ GeV/c, respectively. By construction, Δ_{recoil} does not contain the yield of background jets. For both trigger hadron p_{T} bins, this contribution is the same and is removed by the subtraction. Let us also add that the Δ_{recoil} observable does not impose any bias on the jet fragmentation.

The Δ_{recoil} distribution, fully corrected for the effects related to detector response and background fluctuations, can be used to study the medium induced modification of jet fragmentation. One possibility is to compare the yield of recoil jets in Pb–Pb and pp collisions using the ratio

$$\Delta I_{AA} = \Delta^{\text{Pb-Pb}}_{\text{recoil}} / \Delta^{\text{pp}}_{\text{recoil}} \tag{2}$$

where $\Delta^{\text{Pb-Pb}}_{\text{recoil}}$ spectrum obtained in Pb–Pb system is divided by the reference $\Delta^{\text{pp}}_{\text{recoil}}$ data measured in pp collisions at the same center-of-mass energy per nucleon pair. Alternatively one can search for the modification of transverse jet structure based on the ratio of two $\Delta^{\text{Pb-Pb}}_{\text{recoil}}$ distributions corresponding to different R.

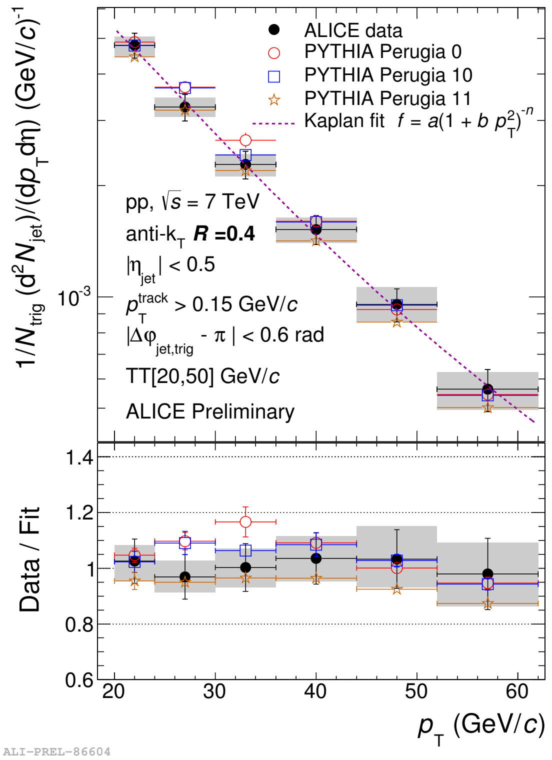

Figure 2. Top: Per trigger normalized p_{T} spectrum of anti-k$_{\text{t}}$ $R = 0.4$ recoil charged jets associated with a [20,50] GeV/c trigger hadron in pp collisions at $\sqrt{s} = 7$ TeV. Systematic uncertainties on the measured data are marked by the gray boxes. The ALICE data are compared to three PYTHIA Perugia tunes 0, 10, and 11. Bottom: Ratio of the data sets w.r.t. to the Kaplan function fit of the measured data.

Owing to the limited statistics of the pp data at $\sqrt{s} = 2.76$ TeV the reference spectrum was estimated by means of the PYTHIA event generator using Perugia 10 tune [9]. To validate this approach PYTHIA predictions were tested on the measured semi-inclusive recoil jet yield from pp at $\sqrt{s} = 7$ TeV. This data set contains 168 M minimum bias events and was taken in 2010. The analysis of recoil jet yields in pp collisions at $\sqrt{s} = 7$ TeV closely follows the Pb–Pb data analysis. Underlying event activity was estimated in a $R = 0.4$ cone rotated by 90 degrees in azimuth w.r.t. the leading jet in event. As can be seen from Fig. 2 and Figs. 3 and 4, the PYTHIA Perugia tunes reproduce the fully corrected measured jet spectrum as well as the ratios of recoil jet yields corresponding to different R. Our studies suggest that the Perugia 10 tune provides the best description of the data.

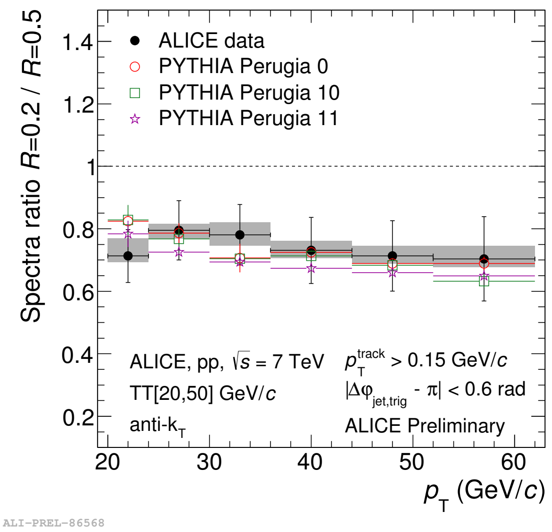

Figure 3. Ratio of per trigger normalized p_{T} spectra of charged anti-k$_{\mathrm{t}}$ $R = 0.2$ and $R = 0.5$ jets associated with a [20,50] GeV/c trigger hadron in pp collisions at $\sqrt{s} = 7$ TeV. Gray boxes mark the systematic uncertainties on the measured data. The ALICE data are compared to PYTHIA Perugia tunes.

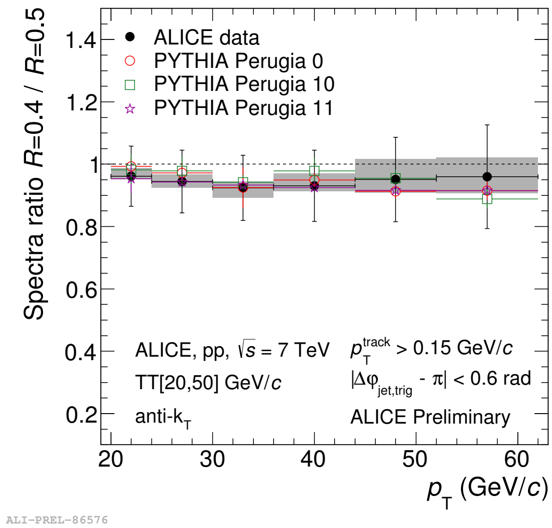

Figure 4. The same as Fig. 3 but for $R = 0.4$ and $R = 0.5$ jets.

Using a pp reference from PYTHIA Perugia 10 we evaluated the ΔI_{AA} ratio, see Fig. 5. The observed suppression of the recoil jet yield in Pb–Pb relative to pp is a consequence of the jet quenching phenomenon. Within the statistical and systematic uncertainties no p_{T} dependence of ΔI_{AA} is observed.

As noted above, the ratio of two $\Delta_{\mathrm{recoil}}^{\mathrm{Pb\text{-}Pb}}$ distributions that correspond to different R carries information about the transverse jet structure. The magnitude of the medium induced modification can be inferred from a comparison of the measured ratio with the data representing the vacuum fragmentation, see Fig. 6. The vacuum fragmentation is estimated by the PYTHIA Perugia tunes. The measured data do not exhibit any significant energy redistribution w.r.t. PYTHIA which means that there is no evidence for intra-jet broadening within $R = 0.5$.

To conclude, hadron-jet correlation observables represent a promising way to study the modification of jet fragmentation in medium. The main advantage of this approach is that it does not impose a fragmentation bias on the recoil jet and in addition it allows to study low p_{T} jets with large radii and with a minimum infrared cutoff.

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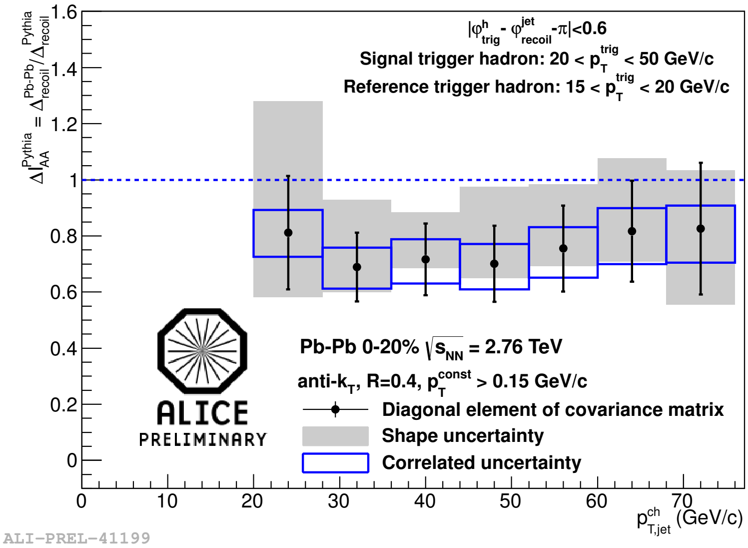

Figure 5. ΔI_{AA} corresponding to anti-k$_{\rm t}$ $R = 0.4$ jets in Pb–Pb at $\sqrt{s_{\rm NN}} = 2.76$ TeV. The pp reference was estimated by PYTHIA Perugia 10 tune.

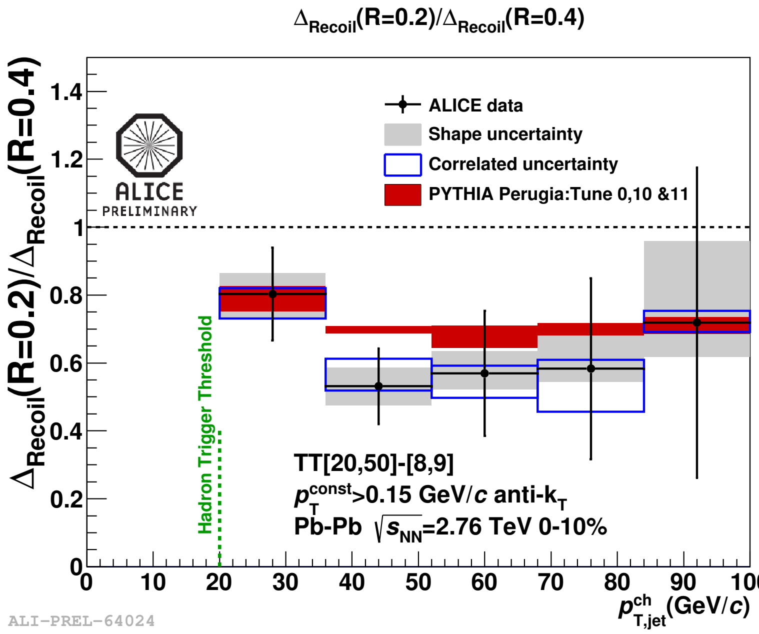

Figure 6. Ratio of two $\Delta_{\rm recoil}$ spectra corresponding to different jet R, here $R = 0.2$ and $R = 0.4$. Measured data are from 0-10% centrality bin of Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV. The red band shows the spread of predictions of this ratio by the PYTHIA Perugia tunes and represents the trend expected from vacuum fragmentation.

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