Cold nuclear matter effects on jet suppression in heavy-ion collisions

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Abstract. These proceedings discuss the sensitivity of the nuclear modification factor R_{AA} of fully reconstructed jets to cold nuclear matter effects. To test the parton energy loss interpretation of the observed R_{AA} of $\sim$0.3, obtained from reconstructed jets in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$=2.76 TeV, we measured the inclusive jet production in minimum bias p–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$=5.02 TeV for resolution parameters R=0.2 and 0.4. The reconstructed jets incorporate the neutral and charged energy component and cover a momentum range $p_{\mathrm{T}}^{\mathrm{jet}}$=20-90 GeV. The comparison of the jet yield to PYTHIA simulations shows no significant depletion in the measured jet cross section attributed to cold nuclear matter effects present in p–Pb collisions.

1. Introduction

The depletion of the reconstructed jet yield in heavy-ion collisions, quantified by R_{AA} and R_{CP}, was demonstrated by several measurements at the LHC. The results of ALICE, ATLAS, and CMS showed that the suppression increases with centrality and decreases slightly with $p_{\mathrm{T}}^{\mathrm{jet}}$ [1, 2, 3, 4, 5]. To pin down the extent of suppression that can be attributed to the hot and dense phase in heavy-ion collisions, other possibilities for jet suppression must be studied as well. Cold nuclear matter effects have been suggested to possibly contribute to the measured suppression of jets in heavy-ion collisions. Cold nuclear matter effects incorporate several mechanisms by which the jet cross section in a nucleus-nucleus collision can be modified with respect to a pp reference, aside from energy loss due to a deconfined phase of the collision [6]. One of these mechanisms is that by taking pp collisions as a reference one does not preclude the fact that measurements in heavy-ion collisions may already deviate from the former due to a modified parton distribution function (PDF) of a nucleon as part of a nucleus with respect to a free proton [7]. The extent to which the nuclear modification factor R_{AA} is sensitive to a modified PDF can be tested by comparing the data with calculations including different PDFs. This is shown later in this proceeding. One way to test the influence of cold nuclear matter effects on R_{AA} is to study this observable in p–Pb collisions. These collisions should exhibit cold nuclear matter effects while inhibiting the creation of a hot and dense phase present in heavy-ion collisions.

R_{pPb} and R_{dAu} of reconstructed jets have been measured at LHC and RHIC [8, 9, 10, 11, 12]. Results by ATLAS indicate that R_{pPb} of jets deviates from unity for larger $p_{\mathrm{T}}^{\mathrm{jet}}$ (>100 GeV) and for forward-going rapidities (p-going side). Results from PHENIX further show that R_{dAu} exhibits a centrality dependence with R_{dAu} >1 for peripheral collisions and <1 for central collisions. These two effects combined produce an R_{dAu} ≈1 for a minimum bias event selection.

These effects challenge present understanding and may come from various mechanisms [8, 11]. The results reported by ALICE, on the other hand, demonstrated an R_{pPb} of unity for charged jets, independent of the selected centrality percentile. It was however noted that the type of centrality selection can introduce dynamical biases on this observable [10].

Comparing to full jets including the neutral component for the same reconstructed $p_{\mathrm{T}}^{\mathrm{jet}}$, charged jets on average stem from higher p_{T} partons. Thus, every effect in R_{pPb} that is dependent on the parton energy scale might result in differences in the p_{T} dependent R_{pPb} measurement for the two jet types. Furthermore, the majority of published results on reconstructed jet R_{AA} include the neutral energy component into their jet reconstruction analysis. These two considerations motivate a cross check of the results obtained by ALICE for charged jets [9] (including only charged tracks in the jet reconstruction) by an independent measurement of jets that include additionally the neutral energy component. This is discussed below.

2. Experimental setup and jet reconstruction in p–Pb collisions

The ALICE detector is a versatile spectrometer dedicated to study heavy-ion collisions [13]. Of primary importance for the present analysis is its inner tracking system (ITS) and the time projection chamber (TPC) for charged track reconstruction, as well as the electromagnetic calorimeter (EMCal) for determining the neutral energy component of reconstructed jets.

2.1. Event selection and jet reconstruction

This analysis used ∼90 million p–Pb minimum bias events at $\sqrt{s_{\mathrm{NN}}}$=5.02 TeV, which were selected based on their primary vertex quality and position. Since this analysis focuses on jets including the neutral energy component, the η and φ acceptance of the EMCal ($|\eta|$ <0.7 and φ=80°-180°) is a limiting factor for the jet reconstruction.

For the jet reconstruction an anti-k_{T} algorithm [14] was run over charged particle tracks with p_{T}>0.15 GeV/c and EMCal clusters with p_{T}>0.3 GeV/c. Jets were analyzed for a resolution parameter of R=0.2 and 0.4. Jets were rejected from the analysis, if they were not fully contained in the EMCal acceptance and if their reconstructed area did not fulfill A> $0.6\pi R^2$.

2.2. Underlying event subtraction

The underlying event, produced in the p–Pb collision, shifts the reconstructed jet p_{T} to slightly higher values. This additional energy was estimated and subtracted from the jets on an event-by-event basis. In order to estimate the underlying event magnitude, a k_{T} jet finder was applied to charged tracks only. To avoid a contribution of signal jets to the background determination, the two k_{T}-background jets with the highest p_{T} were excluded. The remaining background jets were used to calculate the median jet momentum area density

$$\rho_{chrg.}^{BKG} = \mathrm{median}\left\{\rho_j^{jet}\right\} = \mathrm{median}\left\{\frac{p_T^{jet,j}}{A^{jet,j}}\right\}. \quad (1)$$

To exclude pure ghost jets, $\rho_{chrg.}^{BKG}$ is calculated only for background jets that contain at least one charged track. The momentum density of the underlying event in p–Pb collisions is about two orders of magnitude lower than in Pb–Pb collisions, which causes the background to be scarcely populated in some areas. This "emptiness" of the event was accounted for by correcting $\rho_{chrg.}^{BKG}$ by an event occupancy factor C [15]. For each event C was defined as the the sum of background jet areas $A^{jet,j}$ normalized by the area of the TPC (which defines the acceptance of charged background jets). This factor C corrects the fact that $\rho_{chrg.}^{BKG}$ only determines the momentum density within reconstructed k_{T} jets. The anti-k_{T} signal jet however can lie anywhere in the acceptance, also in areas scarcely populated by tracks. The above procedure is performed only with charged tracks due to the larger acceptance of the TPC in comparison with the EMCal, resulting in a better control over local background fluctuations. The charged+neutral background density is scaled up from the charged background density with a scaling factor

$$SF = \frac{\sum E^{cl.-EMC} + p_T^{track-EMC}}{\sum p_T^{track-TPC}} \cdot \frac{A^{TPC}}{A^{EMC}}, \tag{2}$$

which builds the ratio of summed charged momenta and neutral energy in the EMCal acceptance to the sum of charged momenta in the TPC acceptance, corrected by the ratio of the two acceptances. Figure 1 combines the final corrected background momentum area density $\rho_{full}^{BKG,corr.}$ into a probability density for the event. The mean momentum background density is ∼3 GeV/c for central and ∼1 GeV/c for peripheral events.

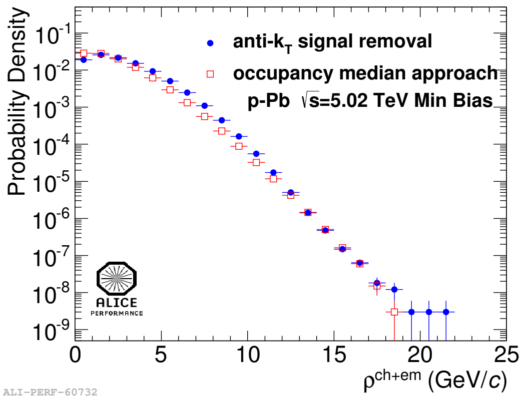

Figure 1. The probability density for extracting a certain momentum area density $\rho_{full}^{BKG,corr.}$ (labeled as ρ^{ch+em}), which describes the background of charged and neutral signals to the measured jet p_{T} in the event. The method described in the text is labeled "occupancy median approach". Another approach, not further discussed here, is the exclusion of overlap between a anti-k_{T} signal jet and a k_{T} background jet (blue dots).

2.3. Corrected jet spectra

The measured raw jet spectra for R=0.2 and 0.4 were corrected for their underlying event contribution by subtracting the obtained momentum area density of the event via:

$$p_T^{full\,jet} = p_T^{full\,jet+BKG} - A_{jet} \cdot \rho_{full}^{BKG,corr.}. \tag{3}$$

The background subtracted jet spectra were then corrected for detector and resolution effects by an unfolding procedure. For this, jets generated with PYTHIA6 were reconstructed at the particle and detector level and geometrically matched to each other. This way, a response matrix was generated that links the measured to the true jet momenta and thus encodes effects such as momentum resolution, and track and cluster reconstruction efficiency on the reconstructed jet momentum. The additional effect of local background fluctuations was also determined and included into the response matrix, as described in Ref. [16]. The unfolding procedure is based on the Singular Value Decomposition approach and uses the above-described response matrix to recover the true jet p_{T} spectrum. The unfolded jet spectra for resolution parameters R=0.2 and 0.4 are presented in Fig. 2. Since the EMCal acceptance does not cover the full azimuth, the measured yield was scaled up to $\varphi = 2\pi$ and is shown per unit η.

3. Results and conclusions

The fully-corrected jet p_{T} spectra were normalized to the number of events and the mean number of binary collisions in minimum bias p–Pb events (N_{coll}=6.87±0.56) [9] in order to compare the results to simulations and to other collision systems like pp and Pb–Pb. The absence of a pp reference spectrum of full jets at $\sqrt{s_{\mathrm{NN}}}$=5.02 TeV prevents the direct comparison to measured

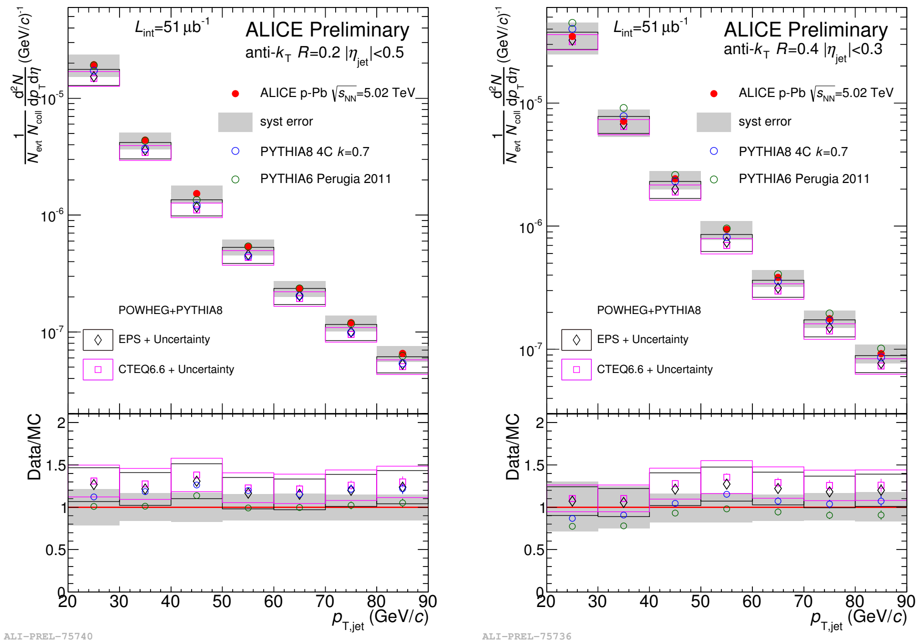

Figure 2. Fully corrected jet p_T spectra for R=0.2 (left) and R=0.4 (right). Lower panel show the ratio of data to different simulations.

data at the same energy. Therefore, PYTHIA simulations (Version 6, Perugia 2011 tune) at $\sqrt{s_{NN}}$=5.02 TeV were used as a reference. The data were divided by the PYTHIA simulation, which was scaled by the number of simulated events, to obtain a better visualization of the agreement between p–Pb data and the pp simulations. The ratio is shown in the lower panels of Fig. 2. The ratio is consistent with unity for both resolution parameters. Additionally, the measurements are compared to POWHEG calculations with either proton PDFs (CTEQ6.6) or nuclear PDFs (EPS09) included. Hadronization was in both cases modeled with PYTHIA8. The comparison of proton and nuclear PDFs shows that the influence of different PDFs on this observable is insignificant. Overall, the ratio illustrates that the low R_{AA} of ∼0.3 measured in Pb–Pb collisions [2] cannot be explained by cold nuclear matter effects. The suppression can thus be attributed to a hot and dense phase, only believed present in heavy-ion collisions.

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