

Inclusive Jet Spectra in p-Pb Collisions at ALICE

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Abstract

Jet suppression has been observed in central heavy ion collisions. This suppression is attributed to partonic energy loss in the Quark Gluon Plasma (QGP) formed in such collisions. However, this measurement is influenced by all stages of the collision. It is expected that in p-Pb collisions similar initial conditions occur as in Pb-Pb collisions without creating a QGP, allowing modification to the jet spectra due to cold nuclear matter effects to be quantified. Inclusive jet spectra in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV measured by ALICE are presented. Jets are reconstructed via the anti- k_T algorithm with different resolution parameters by combining charged tracks measured in the ALICE tracking system with the neutral energy deposited in the electromagnetic calorimeter. The jet spectra can be used to determine a nuclear modification factor R_{pPb} while the jet profile in p-Pb is studied by dividing spectra measured with different resolution parameters and comparing to the same ratio measured in pp collisions.

1. Introduction

Jets, the collimated sprays of particles resulting from hard scattering processes, are an excellent probe for heavy ion collisions. Since the hard scattering happens early in the collision, the partons probe all stages of the collision while traversing the produced medium. Suppression of jet production is quantified by comparing the fully corrected jet spectrum measured in central Pb-Pb collisions to that measured in pp scaled by the average number of binary collisions, N_{coll} [1, 2]. This suppression is attributed to partonic energy loss in the Quark Gluon Plasma (QGP) created in heavy ion collisions. However, cold nuclear matter (CNM) effects due to the initial state could also influence this measurement. Measurements of the jet cross section in p-Pb collisions, which experience CNM effects without the creation of the final state QGP are critical for disentangling initial and final state effects on the observed Pb-Pb jet spectra.

2. Analysis Details

The present analysis uses minimum bias 5.02 TeV p-Pb events collected by the ALICE experiment during the 2013 LHC run with an integrated luminosity of $51 \mu b^{-1}$. Input to the jet reconstruction algorithm are clusters, measured in the electromagnetic calorimeter (EMCal) with $E_T > 300$ MeV/c and charged tracks with $p_T > 150$ MeV/c measured in the ALICE central tracking system, which consists of a time projection chamber (TPC) and a silicon inner tracking system (ITS). To correct the EMCal clusters for energy deposited by charged tracks, 100% of the momentum of any tracks geometrically matching that cluster is subtracted from the cluster [3]. Jets are reconstructed with the anti- k_T jet finding algorithm with resolution parameters, $R = 0.2$ and $R = 0.4$ using the FastJet package [4]. To remove “fake” jets, clustered constituents that did not originate from a hard scattering, the area of the jet, A_{jet} , is required to fulfill $A_{jet} > 0.6\pi R^2$. To ensure the jet is fully within the detector acceptance, the jet axis must be at least R away from the edge of the detector. The detector boundaries are defined by the EMCal acceptance, $|\eta| < 0.7$ and $1.4 < \phi < \pi$.

Energy from the underlying event is also clustered into the jets by the algorithm and must be subtracted from the total raw jet energy. An average energy density, ρ , is determined on an event-by-event basis and then subtracted from each jet in the event according to $p_{T,jet}^{reco} = p_{T,jet}^{raw} - \rho_{scaled} \times A_{jet}$. To reduce the effect of the limited EMCal acceptance, we base the background density on the charged track p_T density, ρ , which is measured in full azimuth and scale it up to ρ_{scaled} , using a scale factor that is determined from measured data to include electromagnetic contributions, as done in the Pb-Pb jet spectra analysis [2]. While for Pb-Pb the median method was used to calculate the charged track

background density, a median occupancy method, which is a slightly modified implementation of that presented in [5], is used here. The median occupancy method, defined by

$$\rho = \text{median} \left\{ \frac{p_T^i}{A_i} \right\} \times C, \quad (1)$$

is determined by running the k_T algorithm over all tracks plus “ghost particles” (unphysical particles with negligible momentum added artificially by FastJet for the jet area calculation) in the event [4]. Before determining the median of the physical jets, any k_T jets overlapping with signal jets are excluded. Signal jets are defined as anti- k_T jets with $p_T > 5$ GeV/c. The median is then scaled by an occupancy correction factor, $C = A_{\text{physical jets}}/A_{\text{all jet}}$, where $A_{\text{physical jet}}$ is the total area of all physical jets and $A_{\text{all jet}}$ is the area of all jets, including jets that only contain ghost particles. This factor, C , accounts for the emptiness of the p-Pb event.

2.1. Unfolding

The measured spectra must be corrected for detector effects and the influence of fluctuations on the underlying event. The effect of the detector on the spectra is determined by passing PYTHIA events at $\sqrt{s} = 5.02$ TeV through a GEANT simulation of the ALICE detector. Jets are reconstructed at the detector level using the same cuts as applied on the data. Jets are also reconstructed at the particle level without cuts to give the true jet p_T . All detector level jets are geometrically matched to the nearest particle level jet. A 2-dimensional histogram or response matrix (RM) maps detector level jet p_T to particle level jet p_T and is used in the unfolding procedure. Figure 1 shows an example of the detector RM for $R = 0.4$. A correction is also applied to account for the jet reconstruction efficiency. This correction is determined by dividing the true PYTHIA jet spectrum by a projection of the RM onto the particle level jet p_T axis.

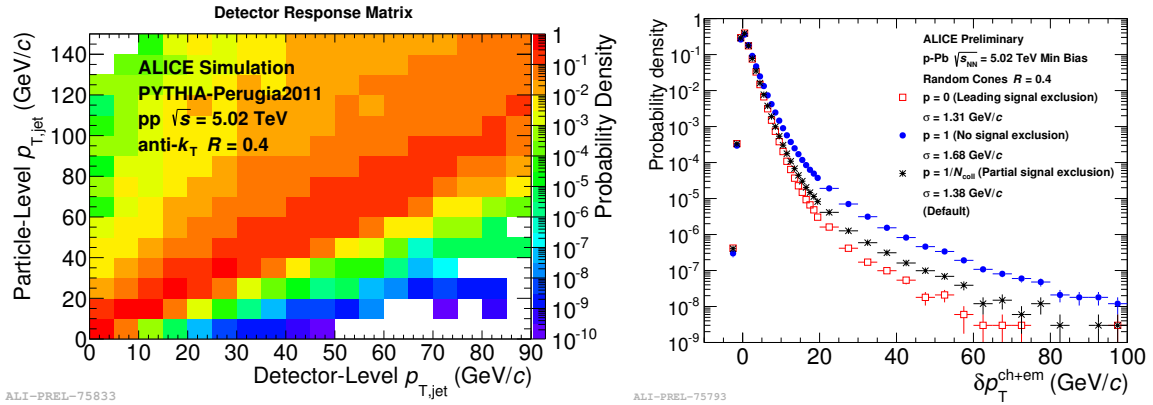


Figure 1: (Left) Detector response matrix mapping the reconstructed detector level jet p_T to particle level jet p_T . (Right) The δp_T^{ch+em} determined using Random Cones. The leading jet from each event were removed with a probability of $1/N_{\text{coll}}$ (black asterics) for the analysis. To estimate the systematic uncertainty, all (red open squares) and no leading jets are removed (blue circles). Both plots are for anti- k_T jets with $R = 0.4$.

The underlying event energy density is determined on an event-by-event basis, however, even within a single event there are fluctuations within the background energy density. The momentum of the jet may be over- or underestimated if it was positioned on an upward or downward fluctuation. These fluctuations can be quantified by measuring the δp_T^{ch+em} distribution using the method of Random Cones (RC) according to

$$\delta p_T^{ch+em} = p_T^{RC} - \pi R_{RC}^2 \times \rho, \quad (2)$$

where the ρ of the event is compared to the total momentum, p_T^{RC} , within a cone of radius, R_{RC} , placed randomly in the event. The right panel of Figure 1 shows the δp_T^{ch+em} distribution for $R_{RC} = 0.4$. The long tail on the right hand side of the distribution represents the probability of having two overlapping jets. Since the random cone can be thought of as introducing an additional jet to the event, this probability is artificially enhanced. We account for this effect by excluding the leading jet from the event at a rate of $1/N_{\text{coll}}$ (black points). To estimate the systematic uncertainty on

this procedure, this exclusion probability can be varied between zero, where no jets are removed, and one, where all leading jets are removed. The δp_T^{ch+em} distribution with no jets removed and all leading jets removed from each event are shown as blue circles and red squares respectively in Figure 1 and result in a 3% uncertainty on the final spectra.

The final RM, the multiplication of the detector RM and the δp_T^{ch+em} distribution, is input to the unfolding algorithm. The singular value decomposition (SVD) algorithm was chosen as the default for unfolding the spectrum [6]. Unfolding with the Bayesian method was also performed and the difference used in the estimation of the systematic uncertainties [7]. A bin-by-bin correction procedure was found to be in good agreement with the other methods.

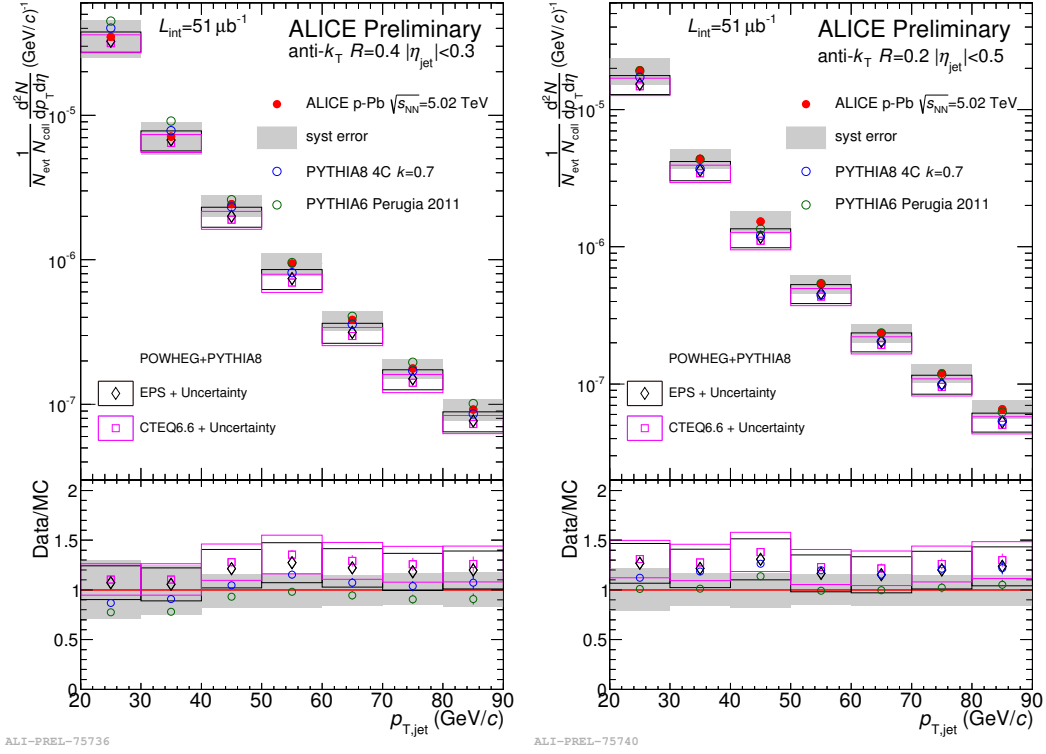


Figure 2: Fully corrected p-Pb jet spectrum for $R = 0.4$ and $R = 0.2$ scaled by N_{coll} compared to PYTHIA and POWHEG simulations at 5.02 TeV.

3. Results

The resulting spectra after unfolding for $R = 0.4$ and $R = 0.2$ are shown in Figure 2. The spectra were normalized per average number of binary collisions, N_{coll} , to make a direct comparison to the pp references. Due to the lack of a measured pp reference at $\sqrt{s} = 5.02$ TeV, we compare the p-Pb data to simulations. The plot includes PYTHIA8, PYTHIA6 and POWHEG with 2 different parton distribution functions (PDF). The POWHEG calculations include uncertainties on the factorization and renormalization scales (13%) and the uncertainty in the PDF (6% for CTEQ and 9% for EPS). The ratios between the data and the different models are all consistent with one, indicating there are no cold nuclear matter effects to the jet spectrum. However, the spread and uncertainty from these different references is significant and highlights the need for a data reference to better quantify this statement. Despite this uncertainty, the p-Pb results clearly demonstrate that the strong suppression observed in the Pb-Pb is not purely due to initial state effects, but is rather a result of energy loss in the produced medium.

One may question whether the fragmentation could be modified in p-Pb collisions while the total jet cross section is not. A first indication of the fragmentation behavior of these jets can be obtained by taking the ratio of the spectra measured with different R . Figure 3 shows the ratio of the $R = 0.2$ spectrum to the $R = 0.4$ spectrum for 5.02 TeV p-Pb (red circles) and for 2.76 TeV pp (black squares) collisions. The agreement between the two collision systems

suggests that the fragmentation behavior for jets in p-Pb is very similar to that in pp collisions. Of course, more differential studies will provide more detailed insight into the fragmentation properties.

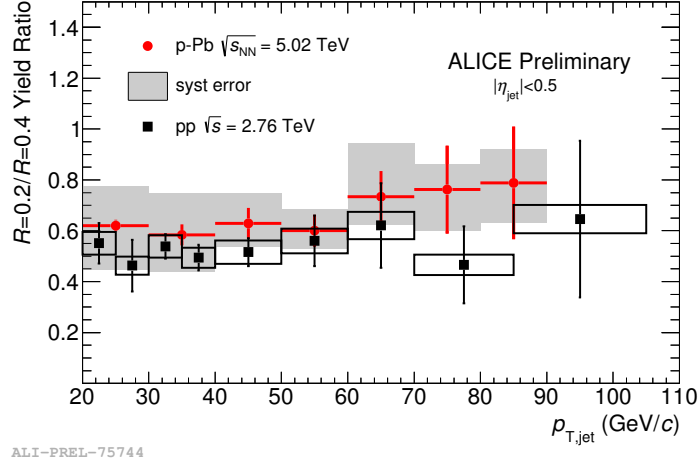


Figure 3: Cross-section ratio between $R = 0.2$ jet spectrum and $R = 0.4$ jet spectrum for fully reconstructed jets in 5.02 TeV p-Pb collisions (red) and 2.76 TeV pp collisions (black).

4. Conclusions

The fully reconstructed jet spectra for $R = 0.2$ and $R = 0.4$ have been measured by ALICE in 5.02 TeV p-Pb collisions in the p_T range 20-90 GeV/c. Comparisons to model predictions of the 5.02 TeV pp jet spectra indicate that the strong suppression observed in Pb-Pb collisions is an effect of the medium and not an initial state effect. To better quantify the CNM effects, if any, on the jet spectrum, systematic uncertainties on this measurement must be reduced. In particular, the uncertainty on the reference can be reduced by measuring pp collisions at 5 TeV at the LHC. The ratio between spectra reconstructed with different R is consistent with the same ratio in pp collisions. This also indicates no modification to the substructure of the jet. Inclusion of EMCAL triggered events will extend the kinematic reach of this measurement and allow for multiplicity dependent studies.

References

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