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Measurements of nuclear modification factors for inclusive jet measurements in Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV with ALICE

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Jets are excellent probes for the study of the deconfined matter formed in heavy ion collisions. The interaction of jets produced in relativistic heavy-ion collisions with the quark-gluon plasma (QGP), lead to effects such as a suppression of jet yields at high p_{T} and modification of internal jet structure that are used to constrain the properties of the QGP.

This report shows the nuclear modification factor measurements of full jets in Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV recorded by the ALICE detector. In Pb-Pb collisions, accessing low p_{T} jets is important because the lower p_{T} jets are more strongly suppressed. However, it is very difficult to estimate the accurate background and reduce fluctuation in the low p_{T} region. In this study, the background is estimated with two methods: an area based method and using machine learning (ML) techniques [1]. The ML estimator enables to access lower transverse momenta and larger jet radii than that in the area based method. The potential bias introduced by the ML method is investigated and its impact is quantified.

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1. Introduction

Jet quenching in heavy ion collisions can be studied with the measurement of inclusive jet spectra in pp and Pb-Pb collisions systems and the nuclear modification factor of inclusive jets. A detailed study of jet quenching effect and comparison with physical models will help to clarify the physical properties of the quark-gluon plasma (QGP) and the details of the energy suppression mechanisms in QCD interaction. This report shows the latest results of jet quenching in Pb-Pb collisions by the ALICE experiment. Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV were collected by ALICE experiment in 2015 with an integrated luminosity of 0.4 $n\mathrm{b}^{-1}$. In this study, the jets are reconstructed using charged particles measured in central detectors (Inner Tracking system (ITS) and Time Projection Chamber (TPC)) and the electromagnetic clusters measured in the electromagnetic calorimeter (EMCal) [2]. The centrality estimation is based on the distribution of the sum of amplitudes measured in V0.

2. Analysis Methods

The jets are reconstructed by the anti-k_{T} algorithm [3] of the Fastjet package [4]. In this study, a resolution parameter of $R = 0.4$ is used.

The reconstructed jet contains background from the underlying event. In this study, the background is estimated with two methods: an area based method and using ML techniques. First, in the area-based method, the median transverse momentum density p_{T}/A of the jets reconstructed by the k_{T} algorithm, excluding the leading and sub-leading jets, is obtained as expressed in Eq. (1).

$$\rho = \mathrm{median}(p_{\mathrm{T},i}/A_i), \tag{1}$$

where A_i indicates the area of jet and i means jets numbering. This ρ value is determined event-by-event, and the transverse momentum of the jet is obtained subtracting $\rho \times A$ for p_{T} obtained by the anti-k_{T} algorithm.

On the other hand, the ML method learns the correlation between jet parameters and background transverse momentum in the jet by using physics simulation model, and then applies it to the experimental data to measure the actual jet transverse momentum. In this analysis, the jets were generated by PYTHIA8 [5], and the thermal background model was created by randomly generating charged particles so that the multiplicity distribution follows the Gaussian distribution.

The ML package obtained the correlation between the jet parameters and the background transverse momentum from mixed PYTHIA8 and thermal model simulations. In this study, neural network, random forest, and linear regression were used as ML. As inputs, the p_{T} of the jet, the number of tracks, the number of clusters, the jet shape angularity, the average p_{T} of the tracks, and the p_{T} of each track and cluster were used. To avoid overfitting, the only five parameters in these parameters are selected, the p_{T} of the jet, the average p_{T} of the tracks, the tracks with the second and third largest p_{T}, and the clusters with the largest p_{T}. For the experimental data, the background p_{T} is measured as jet-by-jet using these five parameters as input and measured actual jet p_{T}.

Next, the PYTHIA8 jets were embedded in the experimental data and the truth-level jets and detector-level jets were reconstructed with each of the two reconstruction methods to produce a response matrix. Using this response matrix as input, the jet p_{T} momentum distribution was unfolded by the RooUnfold package. Finally, R_{AA} was obtained by comparing this unfolded p_{T} distribution with the one of p-p collisions [6].

3. Results

Figure 1 shows the results of the resolutions of the jet p_{T} obtained by each method. The resolution δp_{T} is defined as

$$\delta_{p_{\mathrm{T}}} = p_{\mathrm{T,rec}} - p_{\mathrm{T,true}}, \tag{2}$$

where $p_{\mathrm{T,rec}}$ is the p_{T} of reconstructed jet from embedded into data and $p_{\mathrm{T,true}}$ shows the p_{T} of PYTHIA8 jet. The distributions of δp_{T} with the area-based method and the three ML based estimators are presented in Fig. 1. The Fig. 1 shows clearly the reduction of the width of δp_{T} for ML background estimators. This is because the ML method computes the background p_{T} on jet-by-jet, while the area-based method only computes it on an event-by-event basis. No significant difference is observed between the three different ML methods.

Figure 2 shows the R_{AA} results obtained by the two background measurement methods and the comparison of the models [7]. In both methods, the R_{AA} was smaller than unity, confirming the jet suppression effect. The fluctuation of the jet p_{T} in the ML method was smaller than that in the area-based method, so the unfolding was more stable and the R_{AA} in the lower p_{T} region could be measured. The right panel of Fig. 2 shows the comparison between data and several models. JEWEL [8] is a model to explain the energy loss mechanism with a parton shower. In this model different options allow to include the recoiling thermal medium particles in the jet energy or not. The linear Boltzmann transport (LBT) [9] is a model to describe the evolution of jet and recoiling medium particles based on a higher twist gluon radiation spectrum by elastic scattering with linear Boltzmann equations. In the soft collinear effective theory with Glauber gluons (SCETG) [10], the jet energy loss is described as interactions of partons with the hot QCD medium in an effective field theory via the exchange of Glauber gluons. The hybrid model [11] is a model which explain the parton energy loss mechanism as a gauge-gravity duality computation calculated by $N = 4$ supersymmetric Yang-Mills at infinitely strong coupling and N_c. The comparison between data and models presented here constrains the models in lower jet p_{T} region.

4. Summary

By using the 2015 Pb-Pb collision ($\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV), at the centrality 0 – 10% in ALICE, the nuclear modification factor of the full jet is measured and confirm the effect of jet suppression. Comparing two different methods of measuring the background p_{T} (area-based and ML), it was found that the ML method has less fluctuation of the jet p_{T} than that in the area-based method. Such an improvement allows the measurement of R_{AA} down to the low p_{T} region. On the other hand, the method based on ML techniques depends on the physics model, so it is necessary to measure the area-based method as well. This analysis handled only the 10% central collision data due to statistical limitation, but the R_{AA} measurement at different collisions centrality will be measured by using new data set measured in 2018. Then since the contribution of the background is smaller in peripheral collisions, area-based methods are expected to be able to measure R_{AA} down to low p_{T} regions.

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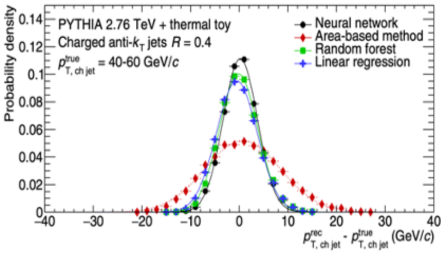

Figure 1: The resolutions of p_{T} of jets at p_{T} =40-60 GeV/c.

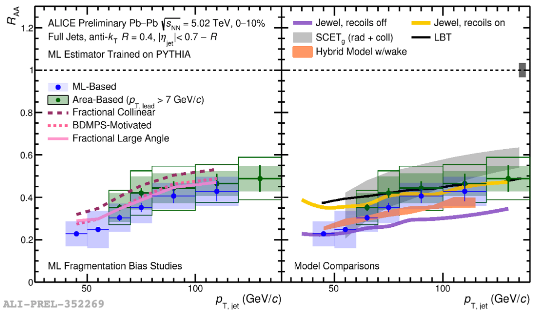

Figure 2: R_{AA} for full jets in Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV and model comparison.

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