Medium modification of jet shape observables in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV using EPOS and JEWEL event generators

Sumit Kumar Saha$^{1*}$, Debojit Sarkar$^{2}$, Subhasis Chattopadhyay$^{1}$, Ashik Ikbal Sheikh$^{1}$ and Sidharth Kumar Prasad$^{3}$

1 Experimental High Energy Physics and Applications Group, HBNI, Variable Energy Cyclotron Center, 1/AF, BidhanNagar, Kolkata-700 064, INDIA
2 Wayne State University, 666 W. Hancock, Detroit, MI 48201, USA
3 Bose Institute, 93/1, APC Road, Kolkata-700009

* sumitkumarsaha92@gmail.com

November 3, 2021

Abstract

The substructure of charged jets gets modified due to the presence of the medium in heavy-ion collisions which is an indication of redistribution of energy inside the jet cone. It helps to understand the energy loss mechanisms of jets in the medium. A model dependent study of the modification of differential jet shape ($\rho(r)$) and the angularity (g) due to medium, has been performed in the most central Pb-Pb collisions at 2.76 TeV in the jet range of 20-40 GeV/c.

1 Introduction

A partonic medium consisting of quarks and gluons is formed in the collision of heavy ions at high energies [2]. Partons suffer energy loss through radiation or collision as they travel in the medium and their fragmentation functions get modified. The internal structure of jet also undergoes modification. Thus, measurement of such observables in central heavy ion collisions with a comparison to pp collisions can help to understand the jet-medium interaction [3]. The motivation is to study jet-shape observables at lower $p_T$ without considering the recoiled partons using JEWEL [4] which helps to understand the effect of the recoiled medium partons through a comparison to the experimental data and to study the same using EPOS-3 [5–8] with a simplistic partonic energy loss mechanism and secondary hard-soft interactions.

2 Observables and analysis method

Two jet shape observables, differential jet-shape $\rho(r)$ [9] and angularity (g) or girth [10] have been studied. $\rho(r)$ describes the radial distribution of the jet $p_T$ density inside the jet cone and is
defined as,

\[ \rho(r) = \frac{1}{\delta r} \frac{1}{N_{\text{jet}}} \sum_{\text{tracks} \in [r_a, r_b]} \frac{P_{T}^{\text{track}}}{P_{T}^{\text{jet}}} \]  

(1)

The jet cone is divided into several annuli with radial width of \( \delta r \) and inner radius of \( r_a = r - \delta r/2 \) and outer radius of \( r_b = r + \delta r/2 \). \( r \) is the radial distance of the track from the jet axis and is defined as,

\[ r = \sqrt{(\phi^{\text{track}} - \phi^{\text{jet}})^2 + (\eta^{\text{track}} - \eta^{\text{jet}})^2} \leq R \]  

(2)

where \( R \) is the jet radius. The angularity is defined as,

\[ g = \sum_{i \in \text{jet}} \frac{p_{T}^i}{P_{T}^{\text{jet}}} |\Delta R^i_{\text{jet}}| \]  

(3)

where \( \Delta R \) is the distance between \( i \)-th constituent and the jet axis in \((\eta, \phi)\) space. These shape observables describe the radial distribution of the jet energy inside the jet cone. Charged jets reconstruction has been done with anti-\( k_T \) jet finding algorithm using Fastjet package \[11] with two resolution parameters \( R = 0.2 \) and \( R = 0.3 \) for \( 20 < P_{T}^{\text{jet, ch}} < 40 \) GeV/c \[1\]. Tracks with \( |\eta| < 0.9 \) and \( P_{T, \text{min}} = 0.15 \) GeV/c are used for jet reconstruction and \( |\eta^{\text{jet}}| < 0.7 \) and 0.6 for \( R = 0.2 \) and \( R = 0.3 \) are selected respectively. Background contribution is reduced by selecting jets having at least one particle with \( p_T > 5 \) GeV/c \[12,13\]. We have compared the Pb-Pb results from both the models \[1\] to the pp results obtained by JEWEL representing no medium effect.

3 Results

As shown in Fig 1 \[1\], the ratio of \( \rho(r) \) distribution of 0-10% Pb-Pb to pp collisions deviates from unity which is an indication of a modification to the jet structure due to the presence of the medium. Increasing the \( R \) to 0.3 includes the energy carried away by softer particles at larger angles from the jet axis. At higher \( r \), the ratio becomes >1 that indicates broadening of jets at

Figure 1: \( \rho(r) \) as a function of distance from the jet axis for inclusive charged jets in Pb-Pb 0-10% using the JEWEL (recoil OFF) and EPOS3 event generators compared with theminimum bias pp results along with their ratios \[1\]
the periphery in EPOS-3 which is qualitatively consistent with the experimental observations. The energy lost due to jet-medium interaction is distributed at larger distances from the jet axis and it signifies medium induced modification to the internal jet structure [9]. As shown in Fig 2 [1],

![Figure 2: Angularity (g) measured in 0-10% central Pb-Pb collisions for inclusive charged jets for $R=0.2$ and 0.3 using the EPOS-3 and JEWEL (recoil OFF) event generators [1].](image)

the jet in EPOS-3 is more collimated than JEWEL for $R=0.2$, whereas, the jets become broadened due to the medium induced modifications for $R = 0.3$.

4 Conclusion

A comparison between the results from JEWEL recoil off and EPOS-3 shows that JEWEL does not explain the distribution of lost energy at higher radii with respect to the jet-axis, whereas, EPOS-3 explains the effect quite well.

Acknowledgements

This material is based upon work supported by the U.S. Department of Energy Office of Science, Office of Nuclear Physics under Award Number DE-FG02-92ER-40713. DS would like to thank Federico Ronchetti, Alessandra Fantoni and Valeria Muccifora for their kind help and support throughout this work. Thanks to Klaus Werner for allowing us to use EPOS-3 for this work. Thanks to Dr. Subikash Chaudhury for useful discussions. Thanks to VECC grid computing team for their constant effort to keep the facility running and helping in EPOS and JEWEL data generation.

Funding information  DS would like to acknowledge the financial support from the CBM-MUCH project grant of BI-IFCC/2016/1082(A).
References

[1] S. K. Saha, D. Sarkar, S. Chattopadhyay, A. I. Sheikh and S. K. Prasad, Study of medium modified jet shape observables in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV using EPOS and JEWEL event generators, Nucl. Phys. A 1006 (2021), 122064 doi:10.1016/j.nuclphysa.2020.122064 [arXiv:2101.02685 [hep-ph]].

[2] S. A. Voloshin, A. M. Poskanzer and R. Snellings, Collective phenomena in non-central nuclear collisions, Landolt-Bornstein 23 (2010), 293-333 doi:10.1007/978-3-642-01539-7_10 [arXiv:0809.2949 [nucl-ex]].

[3] Measurement of inclusive jet charged particle fragmentation functions in Pb+Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV with the ATLAS detector, ATLAS-CONF-2012-115.

[4] R. Kunnawalkam Elayavalli and K. C. Zapp, Medium response in JEWEL and its impact on jet shape observables in heavy ion collisions, JHEP 07 (2017), 141 doi:10.1007/JHEP07(2017)141 [arXiv:1707.01539 [hep-ph]].

[5] K. Werner, B. Guiot, I. Karpenko and T. Pierog, Analysing radial flow features in p-Pb and p-p collisions at several TeV by studying identified particle production in EPOS3, Phys. Rev. C 89 (2014) no.6, 064903 doi:10.1103/PhysRevC.89.064903 [arXiv:1312.1233 [nucl-th]].

[6] K. Werner, I. Karpenko and T. Pierog, The 'Ridge' in Proton-Proton Scattering at 7 TeV, Phys. Rev. Lett. 106 (2011), 122004 doi:10.1103/PhysRevLett.106.122004 [arXiv:1011.0375 [hep-ph]].

[7] K. Werner, M. Bleicher, B. Guiot, I. Karpenko and T. Pierog, Evidence for Flow from Hydrodynamic Simulations of p-Pb Collisions at 5.02 TeV from $v_2$ Mass Splitting, Phys. Rev. Lett. 112 (2014) no.23, 232301 doi:10.1103/PhysRevLett.112.232301 [arXiv:1307.4379 [nucl-th]].

[8] H. J. Drescher, M. Hladik, S. Ostapchenko, T. Pierog and K. Werner, Parton based Gribov-Regge theory, Phys. Rept. 350 (2001), 93-289 doi:10.1016/S0370-1573(00)00122-8 [arXiv:hep-ph/0007198 [hep-ph]].

[9] S. Chatrchyan et al. [CMS], Modification of Jet Shapes in PbPb Collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Phys. Lett. B 730 (2014), 243-263 doi:10.1016/j.physletb.2014.01.042 [arXiv:1310.0878 [nucl-ex]].

[10] L. Cunqueiro [ALICE], Jet shapes in pp and Pb–Pb collisions at ALICE, Nucl. Phys. A 956 (2016), 593-596 doi:10.1016/j.nuclphysa.2016.02.060 [arXiv:1512.07882 [nucl-ex]].

[11] M. Cacciari, G. P. Salam and G. Soyez, FastJet User Manual, Eur. Phys. J. C 72 (2012), 1896 doi:10.1140/epjc/s10052-012-1896-2 [arXiv:1111.6097 [hep-ph]].

[12] F. Krizek [ALICE], Correlations and flavors in jets in ALICE, J. Phys. Conf. Ser. 668 (2016) no.1, 012018 doi:10.1088/1742-6596/668/1/012018 [arXiv:1509.02024 [hep-ex]].

[13] C. Nattrass [ALICE], Measurements of Jets in ALICE, Acta Phys. Polon. B 47 (2016), 1543-1551 doi:10.5506/APhysPolB.47.1543