Study Of Jet Production In Proton-Proton And Nucleus-Nucleus Collisions Using The ALICE Experiment

Debjani Banerjee[1,2*]
[1] *Deptartment of Physical Sciences, Bose Institute, Kolkata-700091, INDIA and*
[2] *Department of Physics, University of Illinois, Urbana, Illinois 61801, USA*

Introduction

Heavy-ion collisions at ultra-relativistic energies provide sufficient energy densities and/or temperature that allow to transform the confined hadronic matter into a deconfined state of quarks and gluons, commonly known as quark-gluon plasma (QGP). Jet quenching or partonic energy loss in the medium is one of the most important signatures in favour of the existence of QGP in heavy-ion collisions. Jets are cascades of energetic hadrons that result from the fragmentation of hard-scattered (large-Q^2) quarks and gluons in high-energy collisions. Measurements of jet production in proton-proton (pp) collisions serve as a baseline for perturbative calculations in Quantum Chromodynamics (QCD). The measurement of intra-jet properties is sensitive to details of parton shower and hadronization processes. In addition, the measurement of jet properties as a function of event multiplicity in pp collisions is important to enrich our understanding of QGP-like phenomena observed in small collision systems since no conclusive evidence of jet quenching has been found yet within the current precision achieved in experiments. This leaves the possibility of QGP formation in small collision systems as an open question that must be addressed and investigated further. This thesis presents the first measurement of the multiplicity dependence of intra-jet properties of leading charged-particle jets, the mean charged-particle multiplicity and fragmentation functions in pp collisions at $\sqrt{s}$ = 13 TeV using the ALICE detector. This thesis also reports the estimation of jet transport coefficient, $\hat{q}$, for both quark- and gluon-initiated jets in presence and absence of magnetic field using a quasi-particle model. A brief discussion of these two studies is discussed below.

*Electronic address: debjanibanerjee771@gmail.com

Multiplicity dependence of intra-jet properties in pp collisions at $\sqrt{s}$ = 13 TeV

In this work, we present the multiplicity dependence of intra-jet properties of leading charged-particle jets, the mean charged-particle multiplicity ($\langle N_{\rm ch}\rangle$) and fragmentation function ($z^{\rm ch} = p_{\rm T}^{\rm particle}/p_{\rm T}^{\rm jet,ch}$ and $\xi^{\rm ch} = ln(1/z^{\rm ch})$) in pp collisions at $\sqrt{s} = 13\,\text{TeV}$ [1]. These observables are measured for leading jets in both minimum-bias (MB) and high-multiplicity (HM) pp events. Jets are reconstructed using the anti-$k_{\rm T}$ jet finding algorithm with jet radii R = 0.2, 0.3, and 0.4. Instrumental effects are corrected using a 2-dimensional Bayesian unfolding technique implemented in the RooUnfold package. The underlying event contribution is estimated using the perpendicular cone method and subtracted on a statistical basis after unfolding. In this analysis, the main contributors to the total systematic uncertainty are the uncertainty in the tracking efficiency and the Monte Carlo event generator dependence. A monotonic increase in $\langle N_{\rm ch}\rangle$ is observed in both MB and HM events as a function of jet $p_{\rm T}$ as well as with increasing jet radius R [2]. $\langle N_{\rm ch}\rangle$ is found to be slightly larger in high-multiplicity events compared to minimum-bias ones; PYTHIA 8 also exhibits a similar pattern. A jet-$p_{\rm T}$ independent jet fragmentation is observed in both MB and HM events within certain ranges of $z^{\rm ch}$ and $\xi^{\rm ch}$ values only for wider jets (R = 0.4). The fragmentation functions in HM events are noticeably

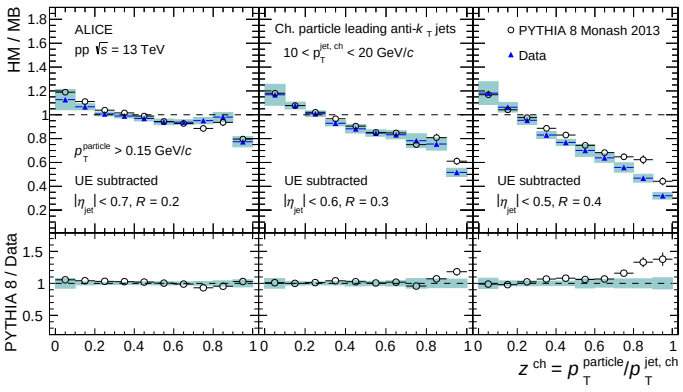

FIG. 1: The ratio between HM and MB distributions of $z^{\rm ch}$ for $p_{\rm T}^{\rm jet,ch}$ interval 10–20 GeV/c for jet R = 0.2 (left), 0.3 (middle), and 0.4 (right).

different from those in MB events. Figure 1 shows that the probability of jet fragmentation into particles with low $z^{\rm ch}$ gets enhanced, followed by a suppression of high-$z^{\rm ch}$ particles in HM events compared to that in MB. The observed jet modification is more prominent for low-$p_{\rm T}$ jets (10–20 GeV/c) with larger jet radius ($R = 0.4$) and is reduced with increasing jet $p_{\rm T}$ at a given radius. These trends are qualitatively reproduced by PYTHIA 8. An investigation using PYTHIA 8 with a less biased HM event selection also shows a similar amount of modification. A detailed study using PYTHIA 8 shows that the major sources of the modification in jet fragmentation are multiparton interactions with color reconnection and the enhanced number of gluon-initiated jets in HM events. As a result, the jet modification observed in small systems with increasing multiplicity shifts the question towards how one can attribute the observed modification to different causes, e.g., multiparton interactions, jet bias from HM event selection or jet quenching in mini-QGP. This work provides new constraints to mechanisms underlying jet modification in small systems.

Effect of magnetic field on $\hat{q}$

In this work, the estimation of $\hat{q}$ is reported using a simple quasi-particle model where a temperature-dependent degeneracy factor $g(T)$ of partons is considered [2]. The parameters of $g(T)$ are obtained by fitting the entropy density obtained from lattice QCD. The effect of finite magnetic field is introduced in the model by replacing the temperature-dependent degeneracy factor $g(T)$ with temperature and magnetic field-dependent degeneracy factor $g(T, B)$ whose parameters are obtained by fitting the magneto-thermodynamical data of lattice QCD. The $\hat{q}(T, B)$ is calculated for both quark- and gluon-initiated jets. The value of $\hat{q}$ is found to be enhanced for quark-initiated jets compared to gluon-initiated jets. The $\hat{q}$ for gluon-initiated jets and both the parallel and perpendicular components for quark-initiated jets show a significant enhancement at low temperatures, which gradually decreases towards high temperature.

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References

[1] ALICE Collaboration, Acharya, Shreyasi and others, `arXiv:2311.13322[hep-ex]`.

[2] Debjani Banerjee, Ph.D. thesis, University of Calcutta, Kolkata, `CERN-THESIS-2024-133(2024)`.