PROCEEDINGS OF SCIENCE

Constraints on jet quenching from a multi-stage energy-loss approach

Chanwook Park* **for the JETSCAPE collaboration**

Department of physics, McGill University,
3600 University Street, Montréal, QC, H3A 2T8, Canada

E-mail: chanwook@physics.mcgill.ca

We present a multi-stage model for jet evolution through a quark-gluon plasma within the JETSCAPE framework. The multi-stage approach in JETSCAPE provides a unified description of distinct phases in jet shower contingent on the virtuality. We demonstrate a simultaneous description of leading hadron and integrated jet observables as well as jet v_n using tuned parameters. Medium response to the jet quenching is implemented based on a weakly-coupled recoil prescription. We also explore the cone-size dependence of jet energy loss inside the plasma.

HardProbes2020
1-6 June 2020
Austin, Texas

*Speaker

PoS(HardProbes2020)150

1. Introduction

Jet evolution through the QGP is characterized by several distinct phases depending on jet virtualities, and different energy loss mechanisms are essential to describe each stage. A multi-stage approach within the JETSCAPE framework provides a unified description of the jet shower, including a high-virtuality gluon-splitting phase and a low-virtuality scattering-dominated phase. In these proceedings, we report a comprehensive study of multi-stage jet evolution by performing a model-to-data comparison to constrain the jet quenching parameter in heavy-ion collisions.

2. Unified approach in JETSCAPE

Throughout this study, a dynamically evolving QGP created in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV is simulated using (2 + 1)-D VISHNU [1] with fluctuating TRENTo [2] initial conditions, followed by free-streaming and dissipative fluid dynamics. Hard partons produced by PYTHIA [3] with initial state radiation (ISR) and multi-parton interaction (MPI) are initialized in the transverse plane by TRENTo profiles for initial binary collisions. These partons then evolve through the hydrodynamic medium. The multi-stage energy loss formalism consists of MATTER [4, 5] for the high-virtuality stage and LBT [6, 7] for the low-virtuality stage. The phase spaces for the two energy loss models are separated by a switching virtuality Q_0. The simulation of p+p collisions is performed by MATTER vacuum showers using the JETSCAPE PP19 tune [8].

MATTER is a Monte-Carlo event generator for partons with virtuality $Q > Q_0$. Parton splittings are described by a generalized Sudakov form factor, which includes vacuum and medium-modified parton splitting functions. The in-medium contribution, which induces transverse momentum broadening of jets, $\hat{q}$, in a QGP, is estimated based on the Higher-Twist energy loss model [9–11]. We have used a hard thermal loop technique [12] to formulate $\hat{q}$.

The time-ordered in-medium shower in LBT for low virtuality partons relies on solving a linearized Boltzmann equation with in-medium kernels. The model contains leading order $2 \to 2$ elastic and $2 \to 2+n$ inelastic scatterings, where n indicates multiple gluon radiation. The Higher-Twist formalism evaluates the average number of emitted gluons from a hard parton, which follows the Poisson distribution.

The switching virtuality Q_0 is set to 1, 2, and 3 GeV, and a value of $\alpha_s = 0.25$ is used for the strong coupling to determine the quenching parameter $\hat{q}$. Our previous analysis of the single hadron and jet nuclear modification factor R_{AA} constrained these model parameters [13]. Both the MATTER and the LBT in-medium showers implemented recoil partons based on a weakly-coupled picture to reproduce the medium response to jet quenching. The energies and momenta originating from incoming thermal partons during jet-medium scattering (holes) are subtracted from the jet signals in the final state.

3. Results

The left panel of Fig. 1 shows the jet cross section in p+p collisions at $\sqrt{s_{NN}} = 5.02$ TeV with two rapidity cuts, normalized by the PYTHIA predictions. The p_T dependence of the jet cross-section is consistent with data for jet $p_T > 200$ GeV at mid-rapidity. The ratio of the jet

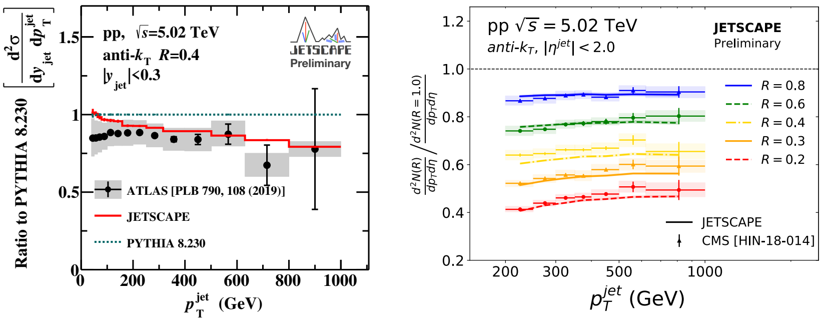

Figure 1: Comparison between the results obtained from the JETSCAPE PP19 tune at $\sqrt{s_{NN}}$ = 5 TeV and measurements. (Left) Inclusive jet cross-section with $|y_{jet}| < 0.3$ [14], normalized by the PYTHIA predictions. (Right) Ratio of the jet spectra for $R = 0.2$ to 0.8 with respect to $R = 1.0$ [15].

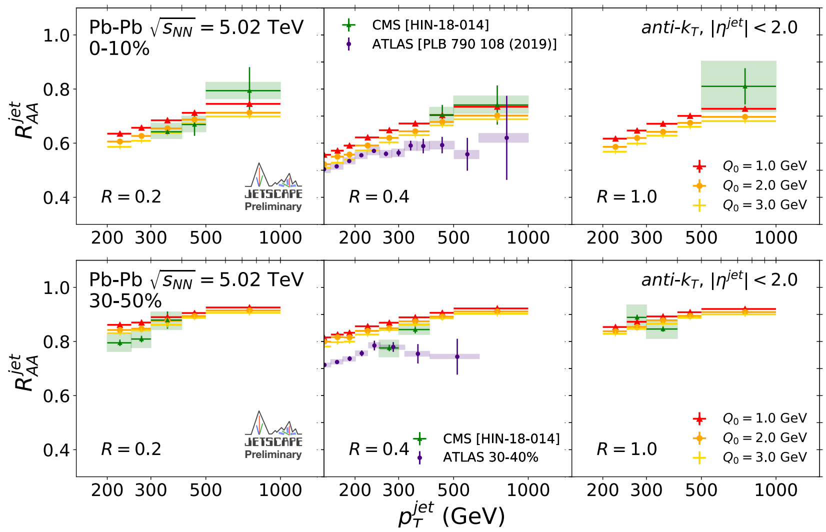

Figure 2: Inclusive jet R_{AA} in central (top panel) and peripheral (bottom panel) Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV with various R and Q_0 values [15].

cross-section with various R with respect to $R = 1.0$ is displayed in the right panel in Fig. 1. The angular dependence of the jet R_{AA} is well reproduced by the MATTER vacuum shower in JETSCAPE with the PP19 tune.

We present the jet R_{AA} with various R and switching virtualities Q_0 in central and peripheral Pb+Pb collisions in Fig. 2. We consistently observe stronger jet quenching with larger values of Q_0. The parton shower in the high-virtuality phase (MATTER) is dominated by virtuality splitting, but the low-virtuality phase (LBT) is largely affected by scatterings, which induce jet p_T broadening. This accounts for the jet R_{AA} being more suppressed when the LBT phase starts at higher virtuality Q_0. The jet R_{AA} independent to R leads to the R_{AA} ratio with respect to $R = 1.0$ consistent with unity unity as shown in Fig. 3. This monotonic behavior is independent of centrality and jet p_T, implying that the jet energy contained within $R < 0.2$ generally dominates the jet R_{AA} value. The steeply falling jet shape function shown in the left panel of Fig. 4 supports this interpretation.

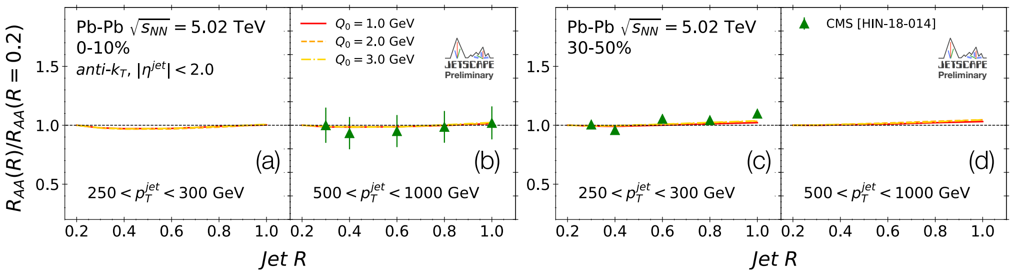

Figure 3: Ratio of jet R_{AA} as a function of R with respect to $R = 0.2$ in central (a-b) and peripheral (c-d) Pb-Pb collisions with two jet p_T intervals. The data is calculated from the jet R_{AA} results shown in Fig. 7 in [15].

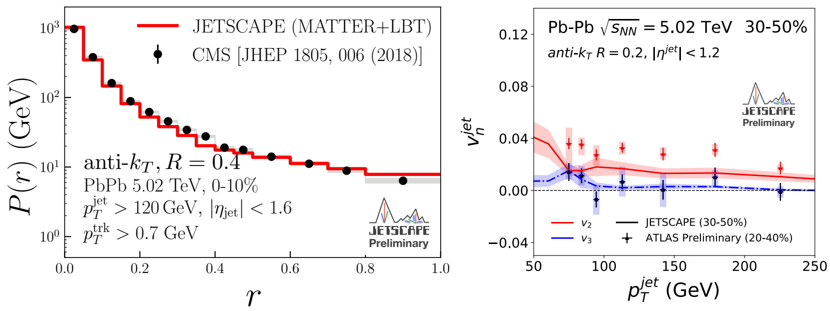

Figure 4: (Left) Jet shape function for $R = 0.4$ jets in central Pb-Pb collisions [16]. (Right) Anisotropic flow coefficients v_2 and v_3 for jets at peripheral Pb-Pb collisions [17].

However, a rigorous investigation of recoils would be necessary as their influence on jet shape is expected to be significant at larger R.

The right panel in Fig. 4 shows the jet v_2 and v_3 in peripheral Pb-Pb collisions. The observed non-zero v_2 for high-energy jets originates from the path-length dependent jet quenching in an almond-shaped QGP. The vanishing jet v_3 within the statistical uncertainties is consistent with the data.

4. Conclusion

We have studied jet modification using a unified approach within the JETSCAPE framework. The results for the jet cross-section in pp collisions using the JETSCAPE PP19 tune show good agreement with data. The multi-stage model with a combination of MATTER and LBT provides a simultaneous description of the integrated and differential jet observables. Our future work will investigate recoils for the detailed jet quenching mechanism at large R.

References

[1] Chun Shen, Zhi Qiu, Huichao Song, Jonah Bernhard, Steffen Bass, and Ulrich Heinz. The iEBE-VISHNU code package for relativistic heavy-ion collisions. *Comput. Phys. Commun.*, 199:61–85, 2016.

[2] J. Scott Moreland, Jonah E. Bernhard, and Steffen A. Bass. Alternative ansatz to wounded nucleon and binary collision scaling in high-energy nuclear collisions. *Phys. Rev. C*, 92(1):011901, 2015.

[3] Torbjörn Sjöstrand, Stefan Ask, Jesper R. Christiansen, Richard Corke, Nishita Desai, Philip Ilten, Stephen Mrenna, Stefan Prestel, Christine O. Rasmussen, and Peter Z. Skands. An introduction to PYTHIA 8.2. *Comput. Phys. Commun.*, 191:159–177, 2015.

[4] Abhijit Majumder. Incorporating Space-Time Within Medium-Modified Jet Event Generators. *Phys. Rev. C*, 88:014909, 2013.

[5] Raktim Abir and Abhijit Majumder. Drag-induced radiative energy loss from semihard heavy quarks. *Phys. Rev. C*, 94(5):054902, 2016.

[6] Xin-Nian Wang and Yan Zhu. Medium Modification of γ-jets in High-energy Heavy-ion Collisions. *Phys. Rev. Lett.*, 111(6):062301, 2013.

[7] Yayun He, Tan Luo, Xin-Nian Wang, and Yan Zhu. Linear Boltzmann Transport for Jet Propagation in the Quark-Gluon Plasma: Elastic Processes and Medium Recoil. *Phys. Rev. C*, 91:054908, 2015. [Erratum: Phys.Rev.C 97, 019902 (2018)].

[8] A. Kumar et al. The JETSCAPE framework: p+p results. 10 2019.

[9] Xin-Nian Wang and Xiao-feng Guo. Multiple parton scattering in nuclei: Parton energy loss. *Nucl. Phys. A*, 696:788–832, 2001.

[10] Abhijit Majumder. Hard collinear gluon radiation and multiple scattering in a medium. *Phys. Rev. D*, 85:014023, 2012.

[11] Guang-You Qin and Abhijit Majumder. A pQCD-based description of heavy and light flavor jet quenching. *Phys. Rev. Lett.*, 105:262301, 2010.

[12] Simon Caron-Huot and Charles Gale. Finite-size effects on the radiative energy loss of a fast parton in hot and dense strongly interacting matter. *Phys. Rev. C*, 82:064902, 2010.

[13] A. Kumar et al. Jet quenching in a multi-stage Monte Carlo approach. In *28th International Conference on Ultrarelativistic Nucleus-Nucleus Collisions*, 2 2020.

[14] Morad Aaboud et al. Measurement of the nuclear modification factor for inclusive jets in Pb+Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV with the ATLAS detector. *Phys. Lett. B*, 790:108–128, 2019.

[15] Measurement of Jet Nuclear Modification Factor in PbPb Collisions at $\sqrt{s_{NN}} = 5.02$ TeV with CMS. 11 2019.

[16] Albert M Sirunyan et al. Jet properties in PbPb and pp collisions at $\sqrt{s_{\mathrm{N\,N}}} = 5.02$ TeV. *JHEP*, 05:006, 2018.

[17] Measurements of Jet Azimuthal Anisotropies in Pb+Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. Technical Report ATLAS-CONF-2020-019, CERN, Geneva, Jun 2020.