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pQCD energy loss calculation for small systems

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Shortly after the Big Bang, the universe was in an incredibly hot and dense state, with particles moving at nearly the speed of light. During this brief period, lasting only a few microseconds, quarks and gluons were the dominant components. Due to the extremely high temperatures, these quarks and gluons—collectively known as partons—were only loosely bound and could move freely, forming a state called the quark-gluon plasma (QGP).

The QGP can be recreated in high-energy collisions at large particle colliders such as the Large Hadron Collider (LHC) at CERN. This is achieved by accelerating heavy ions, such as lead (Pb) and gold (Au), to trillions of electron volts (eV) before colliding them, resulting in an extremely hot state where matter dissolves into a QGP. This state cools rapidly, hadronizing within approximately 10 fm/c as quarks and gluons recombine into particles such as pions, kaons, protons, and neutrons. Physicists study the QGP to gain valuable insights into the conditions of the early universe and to better understand the fundamental building blocks of matter.

Jet quenching—the energy loss of high-energy partons traversing the QGP—is well-studied in large systems such as heavy-ion (AA) collisions. However, the observation of QGP-like signatures in small systems, such as proton-nucleus (pA) collisions, poses intriguing challenges. Current jet quenching models, such as the Gyulassy-Levai-Vitev (GLV) formalism, rely on several approximations valid for large systems, including the assumption of large separation distances between scattering centers. Extending these models to small systems requires re-evaluating these approximations in the context of energy loss formalisms.

This project aims to address these challenges by systematically relaxing key assumptions in the GLV framework to develop a more precise understanding of quenching in small systems. Specifically, we investigate transverse momentum broadening in the QGP using the GLV formalism. The primary goal is to determine the momentum distribution of a parton (quark or gluon) traveling through the QGP, focusing solely on broadening effects while excluding radiation.

The GLV formalism is a perturbative expansion in the number of scatterings, allowing for the systematic calculation of any finite number of scatterings. The standard GLV approach employs the eikonal approximation and the large separation distance approximation to simplify calculations. In this work, we relax the large system size approximation by incorporating all path length corrections into the GLV formalism, accounting for energy loss across all system sizes. Additionally, we relax the eikonal approximation by calculating next-to-leading order (NLO) corrections, which involve relaxing the assumption that E^+ is the dominant energy scale in the interaction and computing the corresponding correction terms.

We proceed by computing both the single scattering matrix element ($\mathcal{M}_1$) and the double scattering matrix element ($\mathcal{M}_2$). These results are then used to evaluate the color trace, which in turn allows us to compute the full momentum broadening distribution. Finally, we run numerical simulations to compare our theoretical predictions with experimental data, providing a deeper understanding of transverse momentum broadening in different system sizes.

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