# Discovery of Jet Quenching and Beyond

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In the last three years, since the physics operation of the Relativistic Heavy-ion Collider (RHIC) at Brookhaven National Laboratory (BNL), one has witnessed tremendous progress in heavy-ion experimental physics and many milestones in the search for the elusive quark gluon plasma (QGP) that is expected to be formed in high-energy heavy-ion collisions. One of the most exciting phenomena observed at RHIC is jet quenching, or suppression of leading hadrons from fragmentation of hard partons due to their strong interaction with the dense medium. Such a phenomenon was long predicted by a pQCD-based model calculation, but was not seen in high-energy heavy-ion collisions until the first measurements in central $Au + Au$ collisions at $\sqrt{s} = 130$ GeV at RHIC. The azimuthal distribution of high $p_T$ hadrons was also found to display large anisotropy with respect to the reaction planes of non-central $Au + Au$ collisions which was expected to be caused by the path-length dependence of jet quenching.

The measurements were confirmed and further extended to a larger $p_T$ range in $Au + Au$ collisions at $\sqrt{s} = 200$ GeV, and the suppression was found to have a weak $p_T$-dependence at $p_T > 6$ GeV/$c$, independent of hadron species. At the same time, the back-side high-$p_T$ two-hadron correlation in azimuthal angle, characteristic of high-$p_T$ back-to-back jets in $p+p$ collisions, was found to disappear in central $Au+Au$ collisions, confirming the predicted mono-jet phenomenon of jet quenching.

The final milestone in the experimental discovery of jet quenching was achieved during the third year of the RHIC physics program, when both the single-hadron spectra and the disappearance of away-side two-hadron correlation were found to be absent in the same central rapidity region of $d + Au$ collisions at $\sqrt{s} = 200$ GeV. These $d + Au$ results prove that the observed high-$p_T$ suppression patterns in $Au + Au$ collisions are not initial state effects encoded in the wavefunction of a beam nucleus, but are jet quenching caused by final state interaction of hard partons with the produced dense medium.

Following these three major experimental results, additional data—such as the dependence of away-side suppression on the azimuthal angle relative to the reaction plane, modification of the hadron distributions (fragmentation functions) both along and opposite the direction of the triggered high-$p_T$ hadron, and absence of suppression in the direct photon spectra in $Au+Au$ collisions—have now solidified the conclusion that the observed jet quenching is caused by parton multiple scattering and energy loss in the hot and dense medium. Furthermore, the splitting of baryon and meson spectra suppression and azimuthal anisotropy in the intermediate $p_T < 6$ GeV/$c$ region also point to non-trivial medium modification of hadronization that is indicative of dense partonic matter. Such a wealth of data affords one a quantitative phenomenological analysis of jet quenching and a tomographical picture of the hot and dense matter formed in heavy-ion collisions at RHIC.

In this report [1], we will first briefly review the recent progress in pQCD study of parton multiple scattering and induced radiative energy loss in a dense medium. Combining this with the pQCD parton model of high-$p_T$ jet and hadron production, one can analyze the observed jet quenching phenomena to extract properties of the dense matter produced. One can combine the deduced properties with other information from analyses of bulk particle spectra such as collective flow and total multiplicity and energy production to present a collection of compelling evidence for the existence of a strongly interacting quark gluon plasma in $Au + Au$ collisions at RHIC. However, we will focus in this report only on the analysis of jet quenching data and the properties of the dense matter one can extract from these data.

AS a summary, recent observation of high-$p_T$ hadron spectra suppression and mono-jet production in central $Au + Au$ collisions and their absence in $d + Au$ collisions at RHIC have confirmed the long predicted phenomenon of jet quenching in high-energy heavy-ion collisions. Detailed analyses of the experimental data also show parton energy loss as the mechanism for the discovered jet quenching. Using a pQCD parton model that incorporates medium modified parton fragmentation functions and comparing to experimental data from deeply inelastic scattering off nuclei, one can conclude that the initial gluon (energy) density of the hot matter produced in central $Au+Au$ collisions that causes jet quenching at RHIC is about 30 (100) times higher than in a cold $Au$ nucleus. Combined with data on bulk and collective properties of the hot matter, the observed jet quenching provides strong evidence for the formation of a strongly interacting quark gluon plasma in central $Au + Au$ collisions at RHIC.

[1] X.-N. Wang, Nucl. Phys. **A750**, 98 (2005), nucl-th/0405017.