Thesis Preliminary Exam Writeup

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The standard model of particle physics, a quantum field theory describing quark and lepton interactions through gauge boson exchanges, establishes the theoretical basis for electromagnetic, weak, and strong forces. In this model, partons (quarks and gluons) are constituents of stable hadrons, bound by the strong force mediated by the self-interacting gluons. While the model successfully explains electromagnetic, weak, and strong interactions, it does not encompass gravity, dark matter, or neutrino mass, yet it is experimentally verified to great precision.

According to the standard model, quarks carry color charge, but experimentally, a quark has never been observed in isolation. Instead, quarks exist in color-neutral states of mesons and baryons (groups of two and three quarks, respectively) due to a phenomenon known as color confinement. The strong color force, confining the partons into color-neutral composite particles, grows with distance if these partons are separated beyond the scale of hadronic size. Quantum Chromodynamics (QCD) prescribes the asymptotic freedom feature on the other end of the distance scale, allowing partons to move near free of the strong-force bonds within hadrons. QCD predicts that sufficiently hot and/or dense nuclear matter can exhibit partonic deconfinement on lengthscales beyond the hadronic sizes — creating such a deconfined state of matter, termed Quark-Gluon Plasma (QGP), to explore QCD phenomena at the extremes is an essential focus of modern high-energy nuclear physics.

Ultra-relativistic heavy-ion collisions are employed to achieve such a hot and dense state. The first relativistic Pb-Pb collisions in 1984 at the SPS at CERN revealed collective behavior and strangeness enhancement, consistent with QGP predictions. These collective phenomena were more definitively seen with the start of RHIC operations in 2000; in particular, it was found that elliptic flow of identified hadrons exhibits scaling behavior with constituent quarks number, providing further evidence of deconfinement and partonic nature of created matter. Measurements of the identified particle yield ratios allowed for system temperature and baryon chemical potential estimations. The extracted temperatures confirmed the state of efficient energy density for QGP formation. Observations of jet quenching for the first time at RHIC were also in line with QGP expectations of a hot, dense, strongly interacting medium. Heavy-ion collisions at the LHC have set new energy records, allowing for detailed characterization of QGP properties and studies of their temperature dependencies.

Among the experimental tools for QGP studies are jets—collimated sprays of hadrons resulting from a high-energy quark or gluon fragmentation following a hard scattering. The hard scatterings occur in the very early stages of the collisions; thus, the scattering cross-section is unaffected by the medium, enabling comparisons of the experimental observables for hard processes to a scaled pp reference for studying medium effects. Jet quenching features such as modified dijet asymmetry quantify energy loss in the QGP medium, allowing measurement of characteristics such as the QGP transport coefficient. Altered jet shapes in central heavy-ion collisions provided further details about parton interactions in the QGP medium.

An active area of research in high-energy nuclear physics is the flavor dependence of partonic energy loss and interactions with the QGP medium. In my thesis, I plan to use data from the CMS detector to isolate jets stemming from the fragmentation of bottom quarks and characterize their in-medium suppression. The suppression of bottom-quark jets (b-jets) provides insights into how partons of different masses interact with the QGP. Heavy-flavor jets carry unique experimental signatures, and by utilizing the advanced muon-detection system of the CMS and jets from full particle-flow reconstruction, lepton-to-jet tagging is implemented to filter for jets stemming from heavy-flavor fragmentation. This study aims to investigate flavor-dependent medium effects on parton propagation and test model predictions regarding heavy-flavor objects.