Thesis Preliminary Exam Writeup

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The standard model of particle physics is a quantum field theory that describes the interactions of quarks and leptons via the exchange of gauge bosons. This model lays the theoretical foundation for the electromagnetic, weak, and strong interactions. In this model, partons (quarks and gluons) are point-like constituents of stable hadrons (protons and neutrons), held together by the strong force which is mediated by the self-interacting gluon. The massive W and Z bosons mediate the weak interaction responsible for the radioactive decay of atomic nuclei, and the photon mediates the electromagnetic force responsible for the dynamics of charged particles. The theory does not describe gravity, dark matter, nor the mass of the neutrino, but 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. Rather, quarks can only exist in color-neutral states of mesons and baryons (groups of two and three quarks, respectively). This is the phenomena known as color confinement, in which the strong color force grows with confined quark separation. At great enough distances, particle-antiparticle pairs are formed out of the vacuum to create an energetically favorable state as a color-neutral composite particle. However, QCD also displays an important property known as asymptotic freedom, which means that with large interaction energies (or small distance scales), the strength of the strong force decreases. Thus, it is possible to liberate partons from their strong-force bonds by creating sufficiently hot and/or dense matter. The creation and study of such a deconfined state of matter is the primary focus of modern high-energy nuclear physics.

To achieve such such a hot and dense state, ultra-relativistic heavy-ion collisions are used. The first relativistic Pb-Pb collisions occurred at the SPS at CERN in 1984, where collective behavior and strangeness enhancement were observed, which were consistent with QGP predictions. Jet quenching observations were made at the RHIC at BNL in 2000 that suggested the creation of a hot, dense medium, also consistent with the QGP. Heavy-ion collisions at the LHC at CERN have pushed the collision energies to the largest ever. By experimentally estimating the particle yield ratios we can estimate the system’s temperature and baryon chemical potential, allowing us to prove that the system reaches states of efficient energy density for QGP formation. It has also been observed in these experiments that in peripheral collisions (where Pb-Pb ions collide with a large impact parameter), the system exhibits elliptic flow that scales with parton number. This implies that that the new medium consists of individually flowing partons, which in turn is further evidence of deconfinement.

Among the experimental tools used for QGP studies are jets: collimated sprays of hadrons resulting from the fragmentation of high-energy quarks or gluons undergoing hard scatterings. The hard-scattering cross section of a jet is a unaffected by the medium and thus comparisons to scaled pp reference are used to study medium effects. Features such as dijet asymmetry and jet quenching quantify how energy is lost in the QGP medium, and allow us to measure medium characteristics such as the QGP transport coefficient. Jet shapes are also observed to be altered in central heavy-ion collisions, which indicates that partons are interacting with the 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 measure their suppression. The suppression of bottom-quark jets (or b-jets) provide insights into the how partons of different mass interact with the the QGP. Heavy-flavor jets carry unique experimental signatures, such as long lifetimes, secondary vertices from in-flight decays, and in-con leptons. Using the advanced muon-detection system of the CMS and the jets from full particle-flow reconstruction, we implement lepton-to-jet tagging as a way to filter for jets stemming from heavy-flavor fragmentation. This study aims to look for flavor-dependent medium effects on parton propagation and test model predictions regarding heavy-flavor objects.