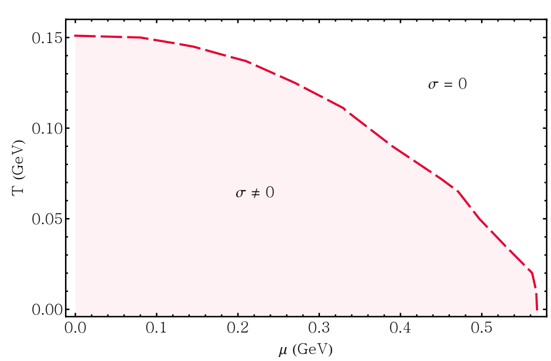
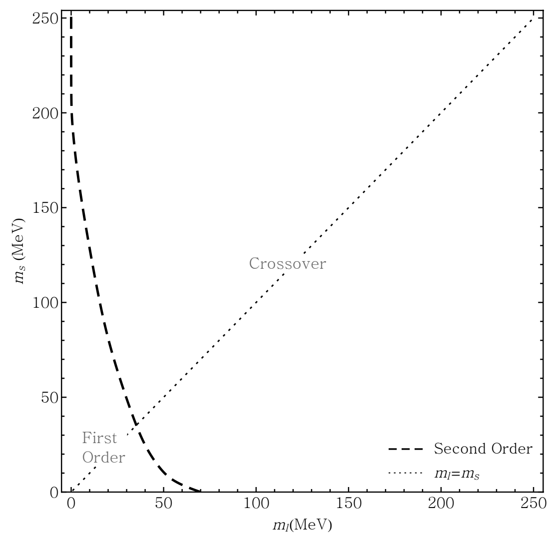
My research examines the phases of strongly-interacting nuclear matter using extra-dimensional models. One such application is in understanding the quark-gluon plasma (QGP) produced at heavy ion colliders and believed to exist shortly after the Big Bang. Understanding this phase of nuclear matter, where quarks and gluons are no longer confined to individual nuclei, is a major focus of nuclear physics research. The energy levels of bound quark-antiquark pairs is another system where strong interactions apply. Studying this regime will assist in the discovery of exotic quark combinations and glueballs, hypothesized gluon-only particles. Traditional techniques of quantum chromodynamics (QCD) cannot describe such strong interactions, so I use a string theory-inspired model, called gauge/gravity duality. This model relates the intractable calculations of strongly-coupled QCD to a weakly-coupled gravity with an extra dimension, which makes calculations possible. The mathematical equivalence of models with different numbers of dimensions gives rise to the name "holographic QCD." This theoretical approach has the added benefit of making an exciting but difficult topic accessible to undergraduate researchers.

My PhD dissertation developed a dynamical holographic model for the energy levels of quark-antiquark pairs called mesons. The gauge/gravity model that results directly from string theory does not accurately describe QCD at low temperature because it contains additional symmetries not found in nature – it is symmetric under changes in scale and changes in particle parity (chirality). Phenomenologically-motivated holographic models are produced by inserting fields to break these symmetries. In a dynamical model, these fields are derived from an action, rather than inserted as ad hoc parameterizations. The major result of my thesis is a dynamical model that correctly describes chiral symmetry breaking, a feature of QCD that manifests as a mass splitting between mesons that have the same quark constituents but different parity. I show that the mass splitting calculated by previous dynamical models is much too large. My model achieves the correct mass splitting by adding an extra field describing glueballs. The excited states for all types of light mesons calculated within this model match well with experiment. This work has been published in two papers in *Physical Review D*.

Holographic models of the quark-gluon plasma are the main focus of my ongoing research. Inserting a black hole in the gravitational dual theory is an established technique for studying the temperature and density of the QGP. In a collaboration with an undergraduate student, published in *Physical Review D*, we study restoration of chiral symmetry as a marker of the phase transition from ordinary nuclear matter to the QGP. The included figure shows the phase plot as a function of temperature and quark chemical potential $\mu$, a proxy for density. Supercomputer-based methods called lattice QCD are incapable of studying the high-density region, illustrating the usefulness of holographic techniques.






Continuing the collaboration with my undergraduate advisee, we studied how the order of the phase transition depends on the number of quark flavors and their respective masses. The plot at right shows the transition order for various mass values for strange and light quarks. We reproduce lattice results and extend to include the effects of nonzero quark chemical potential. However, we find no effect from the chemical potential, meaning no critical end point will be present in the QCD phase diagram, contrary to expectations. My next project is to modify the black hole in our model to produce this critical point. A robust prediction for the location of the QCD critical point would help guide future heavy-ion experiments and simulations. In the longer term, I plan to study the dynamics of particles moving through the plasma. Studying the dependence of in-medium momentum loss on plasma parameters is crucial in the search for the expected critical point of the QCD phase diagram.

A second thrust of my research plan is examining zero-temperature QCD with no quarks, only gluons. In an ongoing collaboration, I am developing a super-symmetry inspired approach that simplifies the process for creating a dynamical model that can also encompass finite temperature. This model predicts the energy levels of glueballs, hypothesized particles made of only gluons that may be identified at ongoing experiments at Jefferson National Lab. In addition, similar "pure glue" theories of traditional QCD are generally easier to use, so this will present another basis of comparison for holographic models.

In addition to these phenomenological explorations, my planned research also includes more formal aspects of holographic models. So far, my work at high temperature and density has relied on simple parameterizations for the black hole metric and other background fields while solving only the chiral field dynamically. I plan to take a similar approach to this regime that I did with zero-temperature holography in my dissertation research, developing a more self-consistent theory that does not depend on ad hoc parameterizations.

Although holographic models have their basis in string theory and general relativity, the necessary calculations are simple enough for undergraduate research. For instance, calculating the binding energy of a meson reduces to numerically solving a Schrödinger potential, accessible to a sophomore. Students working with me gain exposure to ongoing developments in nuclear physics while applying concepts from a variety of courses, from quantum mechanics to thermodynamics. In addition, my research advisees develop valuable computational skills, working to solve problems in environments including Mathematica and MATLAB. Students that I have advised have co-authored one paper and presented posters at the Division of Nuclear Physics fall meeting on three occasions.

Understanding the QCD phase diagram is a primary project of the nuclear physics community, with major heavy ion experiments at Brookhaven National Lab, CERN, and Darmstadt. The next experimental stage for the Relativistic Heavy Ion Collider at Brookhaven is a search for the critical point of the phase diagram, so my theoretical program searching for this endpoint will be relevant to experimental developments. The study of low-temperature bound states is also ongoing, with the search for gluonic contributions at Jefferson National Lab and the discovery of exotic states at several colliders. Gauge/gravity theories are well positioned to provide insight to these experimental efforts that cover a range of phases and conditions of strongly-interacting quark matter. I look forward to bringing my research to your department and advising undergraduate researchers in projects that will result in journal articles and conference presentations.