Lecturer L3: Prof. Michael Strickland

Relativistic dissipative hydrodynamics in heavy-ion collisions

Lecture 1 Introduction to the quark-gluon plasma

I will introduce the quark-gluon plasma (QGP) along with the basics of quantum chromodynamics (QCD). I will discuss why we expect there to be a phase transition from hadrons to QGP in the first place and how, using quantum field theory (QFT) at finite temperature/density, we can determine the QCD equation of state (EoS) directly from the QCD Lagrangian. I will demonstrate how, for an equilibrium QFT, one can use lattice QCD to provide first-principles measurements of QCD thermodynamics. These studies have shown conclusively that, at zero chemical potential, the QCD phase transition is a crossover (infinite-order phase transition). Using Taylor expansions in the chemical potential(s), lattice calculations have been extended to small chemical potential(s) allowing one to search for a possible critical point in the phase diagram. Finally, I will discuss a recent next-to-next-to-leading order (NNLO) calculation of the QGP EoS using resummed hard-thermal-loop (HTL) perturbation theory which shows that, at temperatures as low as $T \sim$ 250-300 MeV, QCD is well-described by a gas HTL-dressed quark and gluon quasiparticles.

Lecture 2 QGP observables: From theory to experimental data

I will introduce a set of the most important experimental observables, which can be used to learn something about the nature of the matter created in ultra-relativistic heavy-ion collisions (URHICs) at RHIC and LHC. Topics will include: identified hadron multiplicity/spectra, collective flow, jet quenching, and heavy quarkonium suppression. In each case, I will present theory-data comparisons and highlight the physics of the theory models used. In the process, I will demonstrate that (1) the matter generated in URHICs exhibits collective behavior, which is well-described by relativistic dissipative hydrodynamics; (2) that jet quenching is well-described by resummed perturbation theory based models which self-consistently calculate both radiative and collisional energy loss and fold this together with a realistic hydrodynamic background; and (3) measurements of charmonium and bottomonium suppression at RHIC and LHC provide a clear "smoking-gun" for the creation of the QGP in URHICs.

Lecture 3 Optimizing dissipative hydrodynamics for URHICs

I will discuss some of the challenges specific to modeling the fluid dynamics of the QGP, which include e.g. large deviations from local momentum-space isotropy. To address this challenge, I will present the anisotropic hydrodynamics (aHydro) framework, which is a non-perturbative reorganization of relativistic hydrodynamics that takes into account the large momentum-space anisotropies generated in URHICs. The aHydro framework allows one to extend the regime of applicability of hydrodynamic treatments to conditions that can be quite far from isotropic thermal equilibrium. In this lecture, I will explain the basic idea behind the approach and present evidence that it provides important improvements over existing dissipative hydrodynamics frameworks. In the end, I will present recent 3+1d aHydro results and compare them with data collected in 2.76 TeV/nucleon Pb-Pb collisions at the LHC.