Young scientists' workshop and 58. Karpacz Winter School of Theoretical Physics "Heavy Ion Collision: From First to Last Scattering"

Sunday 19 June 2022 - Saturday 25 June 2022

Artus Hotel Karpacz

Lecturers and topics

Quarkyonic matter

I describe the properties of strongly interacting quark matter at high energy density. This matter at very may be thought of as a Fermi Sea of quarks surrounded by a Fermi shell of confined matter. It is therefore named Quarkyonic since it has both properties fo quarks and baryons. This matter has properties needed to describe the equation of state extracted from neutron stars. I describe recent progress in developing a theoretical framework for the description of such matter.

Thermalisation and attractors in ultrarelativistic heavy-ion collisions

Studies of quark-gluon plasma dynamics have led to a puzzle concerning the successful application of fluid dynamics to systems far from local equilibrium. I will describe a circle of ideas which has the potential to resolve this puzzle; it involves so called early-time attractors, which have been identified in a number of models of equilibration. I will also show how modern asymptotic methods have shed light on the emergence of hydrodynamic behaviour. Despite much activity in this area, there are many unanswered questions which I will try to highlight.

Lattice QCD and equation of state

We will discuss recent lattice QCD results on bulk thermo-dynamical behavior of quarks and gluons at high temperatures, including the pressure and, energy and entryopy densities that emerge in such systems. I will present the results at zero baryon number density and review various expansion schemata that can be used to obtain results at nonzero baryon number density. Expansion coefficients of the pressure w.r.t chemical potentials] are discussed for various reasons. They can be used to (i) distinguish between hadronic sectors and to identify relevant degrees of freedom in the system, to (ii) extract freeze-out parameters by a comparison to experimental results of conserved charge fluctuations, and (iii) to discuss universal critical behavior within QCD. In this lecture we will touch upon all three application. The latter is most fundamentally connected to the structure of the phase diagram and the search for the QCD critical point. Here we will discuss how lattice simulations with lighter than physical quark masses or with imaginary chemical potential might add to the analysis of the phase diagram.

Fluid dynamics and its derivation

Relativistic fluid dynamics is one of the most important tools in understanding the dynamics and properties of strongly interacting matter created in ultrarelativistic nuclear collisions.

It emerges as an approximation to the full microscopic dynamics when microscopic length and time scales are sufficiently small compared to the macroscopic scales, e.g. when the mean free path of particles is small compared to the macroscopic size of the system. In this limit the dynamics is controlled by just few few transport coefficients and equation of state, instead of full microscopic details of the interactions between the particles.

In these lectures we will go through the basic features of relativistic fluid dynamics, and derive the basic equations of second-order relativistic fluid dynamics starting from relativistic Boltzmann equation by employing the so-called method of moments.

Transport and hybrid approaches

The first part of the lecture will focus on transport approaches. Starting with an introduction to the Boltzmann equation, the necessary particle properties and cross-sections are going to be discussed. The main transport approaches employed to model the dynamics of heavy-ion reactions will be mentioned. Last, validation strategies and observables in few GeV heavy-ion collisions are discussed.

The second part of the lecture covers hybrid approaches, where transport approaches are connected to hydrodynamic calculations for the hot and dense stage of the reaction. The interfaces at the initial and final stage of the reaction deserve special attention. Observables in intermediate and high-energy heavy-ion collisions that are sensitive to hadronic rescattering are going to be shown.

Both lecture parts will come with a set of questions in the end that can be discussed first in small groups and then exchanged in the plenum. So the timeline is 1 hour for the lecture and 1/2 hour for questions/discussions for each part.

Fluid and correlations from experimental perspective

The so-called standard model of heavy ion collisions is currently very successful in describing the bulk properties. In this lecture I will discuss measurements, with a focus on the anisotropic flow, which lead to this standard model and describe how these were and currently are being done.

Bayesian analysis of heavy-ion collisions

Bayesian analysis is a method for obtaining a joint probability distribution for model parameters matching the given target data, taking into account our prior knowledge of the possible parameter values. It has recently become a popular tool for performing global model-to-data fits in the field of relativistic heavy ion collisions. In this lecture we go through the basic concepts and workflow of the analysis, including model emulation using Gaussian processes and Markov chain Monte Carlo sampling of the multidimensional probability distribution.