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Review

Fluctuations of conserved charges in relativistic heavy ion collisions: An introduction

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ABSTRACT

Bulk fluctuations of conserved charges measured by event-by-event analysis in relativistic heavy ion collisions are observables which are believed to carry significant amount of information on the hot medium created by the collisions. Active studies have been done recently experimentally, theoretically, and on the lattice. In particular, non-Gaussianity of the fluctuations has acquired much attention recently. In this review, we give a pedagogical introduction to these issues, and survey recent developments in this field of research. Starting from the definition of cumulants, basic concepts in fluctuation physics, such as thermal fluctuations in statistical mechanics and time evolution of fluctuations in diffusive systems, are described. Phenomena which are expected to occur in finite temperature and/or density QCD matter and their measurement by event-by-event analyses are also elucidated.

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1. Introduction

1.1. Background

The medium described by quantum chromodynamics (QCD) is expected to have various phase transitions with variations of external thermodynamic parameters such as temperature T. Although the basic degrees of freedom of QCD, quarks and gluons, are confined into hadrons in the vacuum, they are expected to be liberated at extremely high temperature and form a new state of the matter called the quark–gluon plasma (QGP). It is also known that the chiral symmetry, which is spontaneously broken in vacuum, is restored at extremely hot and/or dense environment. These phase transitions at vanishing baryon chemical potential (μ_B) are investigated with lattice QCD Monte Carlo simulations. The numerical analyses show that the phase transition is a smooth crossover [1,2]. On the other hand, various models predict that there exists a discontinuous first order phase transition at nonzero μ_B. The existence of the endpoint of the first order transition, the QCD critical point [3], and possibly multiple critical points [4], are anticipated in the phase diagram of QCD on T-μ_B plane [5–7].

After the advent of the relativistic heavy ion collisions, the quark–gluon plasma has come to be created and investigated on the Earth. At the Relativistic Heavy Ion Collider (RHIC) [8] and the Large Hadron Collider (LHC) [9], active experimental studies on the QGP have been being performed. The discovery of the strongly-coupled property of the QGP near the crossover region [8,9] is one of the highlights of these experiments. With the top RHIC energy $\sqrt{s_{NN}} = 200$ GeV and LHC energy $\sqrt{s_{NN}} = 2.76$ TeV, hot medium with almost vanishing μ_B is created [10,11]. On the other hand, the chemical freezeout picture for particle abundances [12] suggests that the net-baryon number density and μ_B of the hot medium increase as $\sqrt{s_{NN}}$ is lowered down to $\sqrt{s_{NN}} \simeq 5$–10 GeV [11,13]. The relativistic heavy ion collisions, therefore, can investigate various regions of the QCD phase diagram on T-μ_B plane by changing the collision energy $\sqrt{s_{NN}}$. Such an experimental program is now ongoing at RHIC, which is called the beam-energy scan (BES) program [14]. The upgraded stage of the BES called the BES-II is planned to start in 2019 [15]. The future experiments prepared at FAIR [16], NICA [17] and J-PARC will also

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