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Partonic mean-field effects on matter and antimatter elliptic flows

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Abstract

Using a partonic transport model based on the Nambu–Jona-Lasinio model, we study the effect of scalar and vector mean fields on the elliptic flows of quarks and antiquarks in relativistic heavy ion collisions that lead to the production of a baryon-rich quark matter. Although the scalar mean field, which is attractive for both quarks and antiquarks, reduces both their elliptic flows, the vector mean field, which is repulsive for quarks and attractive for antiquarks, leads to a splitting of their elliptic flows, and this effect increases with the strength of the vector coupling in the baryon-rich quark matter. Converting quarks and antiquarks to hadrons via the quark coalescence model, we further study the dependence of the transverse momentum integrated relative elliptic flow differences between protons and antiprotons, lambdas and anti-lambdas, and positively and negatively charged kaons on the strength of the quark vector coupling. These results are then compared with the experimental data measured by the STAR Collaboration in the Beam Energy Scan program at the Relativistic Heavy Ion Collider.

Keywords: Mean-field effects; Relativistic heavy ion collisions; Transport model; Elliptic flow

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1. Introduction

It was more than 15 years after one of the authors (Che Ming Ko) finished his Ph.D. at Stony Brook with Gerry when their research interests overlapped again. Both of them were interested in the question on how particle masses would change in dense nuclear medium produced in high energy heavy ion collisions. While Gerry was working with Mannque Rho on developing a general theory for hadron mass changes in medium, he was using a phenomenological model to study the in-medium properties of rho meson through the change of pion properties in nuclear medium, which he learnt as a graduate student at Stony Brook when many seminal works were done by Gerry, Dan-Olof Riska, and Wolfram Weise. Also, he had developed at that time a relativistic transport model for heavy ion collisions based on Walecka's scalar and vector meson model for nuclear matter, and realized that this model provided a self consistent framework for treating the change of nucleon mass in nuclear collisions. While the nucleon mass is small during the compression stage of a collision when the scalar field energy is large, it regains its value in free space when the strength of the scalar field decreases as the dense matter expands. On a visit to Texas A&M University around 1990, Gerry suggested to him to study if medium modification of hadron properties would play any role in particle production in high energy heavy ion collisions. Together with his postdocs and students as well as Volker Koch, who was Gerry's postdoc at that time, they found that decreased hadron masses would enhance kaon production in heavy ion collisions at AGS/BNL [1,2]. They also found that the scalar and vector mean fields would affect particle spectra in heavy-ion collisions. For example, the slope parameters of antiprotons and antikaons are changed considerably, leading to lower apparent temperatures than those of protons and kaons as observed in experiments at AGS/BNL [3,4], and the kaon azimuthal distributions in the target (and projectile) rapidity region are sensitive to the kaon potential in heavy ion collisions at SIS/GSI [5]. They further found that medium effects were needed to understand the enhanced low-mass dileptons observed in heavy ion collisions at SPS/CERN [6–10]. He still vividly remembers the numerous discussions Gerry and he had over the phone during those days. Gerry was so happy with the results of their collaboration and decided to hire his student Li Xiong and postdoc Guo-Qiang Li as postdocs at Stony Brook. Knowing that Gerry would have been very glad to know that partonic mean fields may also play an important role in the baryon-rich partonic matter produced in relativistic heavy ion collisions, as discussed in the following, he would like to dedicate this paper to the memory of Gerry.

Since the medium effects are mainly due to the high baryon density reached in high energy heavy ion collisions, they have thus not played much a role in heavy ion collisions at RHIC and LHC where the produced matter is essentially baryon free. This has, however, changed with the Beam Energy Scan Program (BES) at RHIC to study the properties of QGP at finite baryon chemical potential at much lower collision energies of $\sqrt{s_{NN}} = 7.7$, 11.5, and 39 GeV [11]. Although the hadron–quark phase transition is a smooth crossover at small baryon chemical potential [12–14], studies based on various theoretical models have indicated that this phase transition is expected to change to a first-order one when the baryon chemical potential becomes large [15–18]. To determine if the critical point, at which the crossover phase transition changes to a first-order one, exists and where it is located in the QCD phase diagram is important for understanding the phase structure of QCD and thus the nature of the strong interaction. Despite the lack of definitive signals for a first-order phase transition and the critical end point in BES experiments, a number of interesting results have been observed [19]. One of them is the increasing difference between the elliptic flows of particles and antiparticles, thus a breaking of the constituent quark number scaling of elliptic flows, as the collision energy decreases. Such a