THE 28TH INTERNATIONAL CONFERENCE ON ULTRARELATIVISTIC NUCLEUS-NUCLEUS COLLISIONS

QUARK MATTER 2019

Wuhan, China 4-9 November

Contribution ID: **122**   Type: **Poster Presentation**

Parametrized equation of state with critical point and first-order phase transition

Monday 4 November 2019 17:40 (20 minutes)

At low temperature and low density, the chiral symmetry is broken dynamically to form hadronic phase. While, at high temperature and/or high density, this symmetry is restored and consequently the quark gluon plasma (QGP) appears. In the QCD phase diagram with temperature T and baryon chemical potential μ_B, it is established from first-principle calculations that the transition from hadronic matter to the QGP is crossover at $\mu_B = 0$. On the other hand, in the finite density region ($\mu_B > 0$), the equation of state is still unknown due to the difficulty in the first-principle calculations, namely, the sign problem. Nevertheless, some effective models predict the existence of a critical point connected with a first-order phase transition line [1]. The precise position of the point is still unknown.

In this study, we construct a model of the equation of state in the entire phase space with a critical point which is connected with a first-order phase transition line by smoothly connecting several equations of state. By making use of the fact that the critical phenomena of QCD and the 3D Ising model belong to the same universality class [2], we construct an equation of state near the critical point [3]. The bag model is used in the high temperature and high density region, the lattice QCD calculation in the high temperature and low density region, the hadron resonance gas model with mean field potential in the low temperature and low density region, and the three-dimensional Ising model near the critical point. The model is designed to place the critical point at any position in the QCD phase diagram so that one can utilize it in the hydrodynamic model of nuclear collisions for critical point search. We discuss the relationship between the position of the critical point and the collision energy using the constructed equation of state.

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Session Classification: Poster Session

Track Classification: Search for the critical end point