

Quarkonium production in pp and heavy-ion collisions

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Quarkonium is considered as a probe, which may expose properties of the expanding QGP, produced in ultra-relativistic heavy-ion collisions. The theoretical description of the formation and the propagation of such a bound state of $c\bar{c}$ or $b\bar{b}$ quark-antiquark pairs is a challenging task.

Here we propose a model, which realizes quarkonium production in pp and AA collisions with help of quantum density matrices. This identification is embedded in a quantum-mechanical description of heavy quark propagation and interaction.

The Quarkonium production is realized in two steps:

- 1) The heavy quark production in pp collisions is given by the PYTHIA event generator;
- 2) The formation of a quarkonium from a $c\bar{c}$ or $b\bar{b}$ pair is described by the Wigner projection in momentum space with a spatial separation based on the uncertainty principle~\cite{Song:2017phm}. With this formalism we find a good agreement with the experimental rapidity and transverse momentum distributions for the ground states as well as for the excited states of $c\bar{c}$ and $b\bar{b}$ mesons in pp collisions from RHIC to LHC energies.

In a second step we test whether the quantum Remler formalism to describe bound state production in an expanding medium can be realized in a Monte Carlo approach for a QGP. For this study we use a box of thermalized QGP and investigate the time evolution of the c and \bar{c} , which are initially not in equilibrium with the QGP, either by localizing them in a smaller box and/or by giving them initially a different temperature. Comparing numerical and analytical results we demonstrate that, if there is no potential interaction between the c and \bar{c} , the original Remler formalism has to be modified by introducing a spatial diffusion rate to compensate for the expansion of the system~[1].

As a third step we study bottomonium production in heavy-ion collisions, where the properties of bottomonium in a QGP, the dissociation temperature and the temperature-dependant radius, are obtained by solving the Schrödinger equation with the free energy from lattice QCD calculations as heavy quark potential. The elastic scattering of heavy (anti)quarks with light plasma partons is described by the dynamical quasi-particle model (DQPM). It turns out that the bottomonium is too much suppressed during the expansion as compared to the experimental results for Pb+Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV.

To take into account the small size and color neutrality of bottomonium, we introduce a suppression of its scattering rate in a QGP to 10 % of bottom and antibottom quarks.

Such a suppression of the scattering rate brings the centrality dependence of the yields as well as the rapidity and transverse momentum distributions to a good agreement with the experimental findings~[2].

Considering that the two (anti)bottom quarks interact independently with QGP partons - as in the Remler formalism - and underestimate bottomonium yield, color neutrality has to be taken into account for agreement with the experimental results~[3].

[1] T.-Song, J.-Aichelin and E.-Bratkovskaya, Phys. Rev. C 96, no.1, 014907 (2017).

[2] T.-Song, J.-Aichelin and E.-Bratkovskaya, Phys. Rev. C 107, no.5, 054906 (2023).

[3] T.-Song, J.-Aichelin, J.-Zhao, P.-B.-Gossiaux and E.-Bratkovskaya, Phys. Rev. C 108, no.5, 054908 (2023).

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