Contribution ID: **70** Type: **Talk**

Quarkonium production in pp and heavy-ion collisions

Tuesday, June 4, 2024 2:00 PM (20 minutes)

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 quantal 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 quantal 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 bottonium production in heavy-ion collisions, where the properties of bottonium in a QGP, the dissociation temperature and the temperature-dependant radius, are obtained by solving the Schr\"{o}dinger 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 bottonium is too much suppressed during the expansion as compared to the experimental results for Pb+Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ 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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Session Classification: Track2-HF&Q

Track Classification: Heavy-Flavours & Quarkonia