Heavy Quarkonia Decay widths in Magnetized Matter – effects of Magnetic Catalysis and PV mixing

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Introduction

The study of in-medium properties of the heavy quarkonium states (charmonium and bottomonium) in magnetized matter has relevance for ultra-relativistic peripheral heavy ion collision experiments. The heavy flavour (charm and bottom) mesons are produced at the early stage when the magnetic field resulting from the high energy nuclear collisions can still be large [1] and hence their mass modifications due to the magnetic field can modify the yields of the hidden and open heavy flavour mesons. We study the effects of the magnetic field on the partial decay widths of the charmonium state $\psi(3770)$ to $D\bar{D}$ and the bottomonium state $\Upsilon(4S)$ to $B\bar{B}$ in magnetized nuclear matter, the decaying heavy quarkonium states being the lowest states which decay to open charm (bottom) meson pairs in vacuum. The medium modifications of the decay widths are calculated from the in-medium masses of the mesons in the initial and final sates. The effects from the Dirac sea are taken into account [2] to calculate the masses of the decaying heavy quarkonium states [3] and outgoing open heavy flavour mesons [4] in a chiral effective model. These contributions are observed to lead to enhancement of the light quark condensates (proportional to the scalar fields in the effective hadronic model), an effect, called the magnetic catalysis. Further, the effects of mixing of the (spin 0) pseudoscalar and (spin 1) vector mesons (PV mixing) on the masses of these mesons are taken into consideration, in addition to the contributions (for the charged mesons) from the lowest Landau levels (LLL) in the presence of a magnetic field.

Decay widths of $\Psi(3770) \rightarrow D\bar{D}$ and $\Upsilon(4S) \rightarrow B\bar{B}$ in magnetized matter

We study the masses of the heavy flvour mesons in magnetized nuclear matter using a chiral effective model. The heavy quarkonia masses are calculated from medium modification of a scalar dilaton field, which incorporates the broken scale invariance of QCD and mimics the gluon condensates of QCD. The masses of the open charm (and bottom) mesons arise due to interaction with the nucleons and the scalar mesons. The effects of the Dirac sea are taken into account in addition to the Fermi sea contributions, through summation of the baryonic tadpole diagrams. These are observed to lead to enhancement of the light quark condensates, given through the scalar fields, $\sigma \sim (\langle \bar{u}u + \bar{d}d \rangle, \zeta \sim \langle \bar{s}s \rangle)$ within the chiral effective model. This effect of the increase of light quark condensates due to the Dirac sea contributions is called the magentic catalysis (MC) effect. The effects of the isospin asymmetry, as well as, the anomalous magnetic moments (AMMs) of the nucleons are taken into account. The contributions of the magnetic catalysis on the masses of the heavy flvour mesons (hence on the heavy quakonia decay widths) are observed to be quite significant at large values of the magnetic field. These magnetic field effects are considered in addition to the mass modifications due to the mixing of the pseudoscalar and vector mesons (PV mixing), as well as, the Landau level contributions (for the charged mesons).

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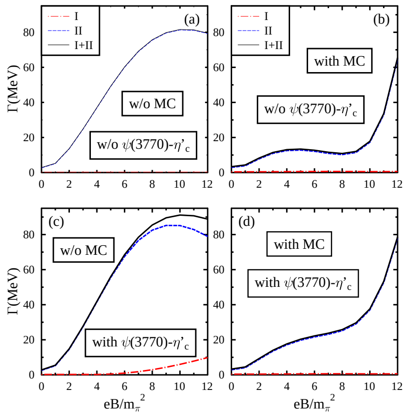

FIG. 1: The partial decay widths of $\psi(3770)$ to $D\bar{D}$, indicating the contributions for the subchannels (I) $\psi(3770) \to D^+D^-$ and (II) $\psi(3770) \to D^0\bar{D}^0$, are plotted for $\rho_B = \rho_0$ in magnetized symmetric nuclear matter, accounting for the AMMs of the nucleons. These are plotted accounting for the mass modifications of the open charm mesons due to the PV ($D - D^*$ and $\bar{D} - \bar{D}^*$) mixing effects, along with contributions due to the lowest Landau levels for the charged $D^\pm$ mesons. The subplots (a) and (c) show the decay widths without and with the $\psi(3770) - \eta_c'$, but without the contributions from Dirac sea (leading to magnetic catalysis) taken into account. In (b) and (d), the MC contributions are also considered.

bottomonium) state to $D\bar{D}$ (and $B\bar{B}$) are calculated using a field theoretic model of composite hadrons with quark (and antiquark) constituents. Using explicit constructions for the decaying and the produced particles, the matrix element is evaluated using the free Dirac Lagrangian, which acts as the light quark pair creation term. Thus, the heavy quark (antiquark) of the heavy quarkonium decaying state ($Q\bar{Q}$, where Q refers to heavy quark) combines with the light antiquark (quark) to produce the open heavy flavor mesons $Q\bar{q}$ and $q\bar{Q}$ in the final state. In figure 1, the decay widths of $\Psi(3770) \to D\bar{D}$ are shown along with the decay widths to the sub-channels (I) $\psi(3770) \to D^+D^-$ and (II) $\psi(3770) \to D^0\bar{D}^0$. The mass modifications for the open charm mesons are calculated including the Dirac sea contributions (leading to MC effect), along with the PV ($D - D^*$ and $\bar{D} - \bar{D}^*$) mixing effects [5] and Landau level contributions for the charged mesons. The decay widths of $\psi(3770)$ to the neutral $D\bar{D}$ pair are observed to be much larger compared to the D^+D^-, due to the positive contributions to the masses of the charged mesons from Landau level contributions. The MC effect leads to increase in the masses of the D and $\bar{D}$ mesons, which is observed as appreciable drop in the partial decay widths of $\psi(3770)$ to $D\bar{D}$, as can be seen from subplot (b) ((d)), as compared to (a) ((c)), when the $\psi(3770) - \eta_c'$ mixing is ignored (taken into account). The magnetic catalysis (MC) and PV effects are observed to be the dominant as compared to the effects due to the isospin asymmetry of the medium and AMMs of the nucleons.

The effects of magnetic catalysis and PV mixing are observed to be quite significant on the masses and hence on the partial decay widths of heavy quarkonium states to open heavy flavour meson pairs, at high values of the magnetic field. These should show in the observables, viz, their yields in the peripheral ultra-relativistic heavy ion collision experiments, e.g., at LHC and RHIC, where the estimated magnetic field produced is huge.

References

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