Radiative energy loss of heavy quarks in quark-gluon plasma within the T-matrix approach

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When a heavy quark propagates through the quark-gluon plasma (QGP) it can either collide elastically with the thermal constituents or change its trajectory due to an acceleration that triggers the radiation of gluons, similar to the radiation of photons off accelerating electric charges. The radiation is usually concentrated in the forward direction as to slow down the heavy quark. Understanding the transition from collisional to radiative process remains a key challenge in the description of the transverse-momentum spectra of heavy-flavor particles as observed in ultrarelativistic heavy-ion collisions (URHICs). In particular, the importance of non-perturbative interactions in collisional processes in the low-momentum regime has been clearly established now [1].

Here, we extend our previously developed many-body *T*-matrix formalism [2] to study this problem, thereby treating the collisional and radiative contributions within a uniform nonperturbative framework. The theoretical formalism is based on the Kadanoff-Baym equations where the heavy-quark selfenergy in the real-time formalism can be written as

$$\Sigma_Q^{>}(\omega,\mathbf{p},t) = \int d\widetilde{\Pi}\,\delta^{(4)}|M|^2 G_Q^{>}(\omega',\mathbf{p}')G_g^{>}(\nu,\mathbf{k}) = \int d\widetilde{\Pi}\,\delta^{(4)}|M|^2\rho_Q(1-f_Q)\rho_g(1+f_g).$$

The $G_{Q/g}^{>}$ are the Green functions for quarks/gluons, $G_{Q/g}^{>} = \rho_{Q/g}\big(1 \pm f_{Q/g}\big)$, where $\rho_{Q/g}$ denotes the pertinent spectral functions and $f_{Q/g}$ the Bose/Fermi distribution functions; M is the amplitude for one-to-two processes, i.e., the radiation of a gluon. This selfenergy represents the collisional rate inducing radiation in the medium. To compute the pertinent heavy-quark transport coefficients (friction coefficient or thermalization rate, *A*), an extra angular weight, $(1-\mathbf{p}\cdot\mathbf{p}'/\mathbf{p}^2)$ is required leading to

$$A(p) = \int d\widetilde{\Pi}\,\delta^{(4)}|M|^2\rho_Q\big(1-f_Q\big)\rho_g\big(1+f_g\big)\left(1-\frac{\mathbf{p}\cdot\mathbf{p}'}{\mathbf{p}^2}\right)\ .$$

The spectral functions of ρ_Q and ρ_q are taken from our previous results within the nonperturbative selfconsistent *T*-matrix formalism (for the so-called strong-binding scenario solution which leads to a strongly coupled QGP). For the "radiation" amplitude M, we adopt the perturbative QCD (pQCD) form.

The friction coefficients calculated by above formalism are shown in Fig.1 where we compare several cases with different inputs. Case (1) is a baseline calculation where we use a pQCD Coulomb potential as interaction kernel and only include second order Born diagrams for the T-matrices used to calculate the spectral functions. In case (2), we include an extra confining interaction relative to case (1). For case (3), we further include the all-order resummation of *t* channel diagrams relative to case (2). For case (4), we include additional off-shell effects relative to case (3). In a short, from case (1) to (4), we subsequently account for more nonperturbative effects. As shown in Fig. 1, the friction coefficients generically increase with temperature and momentum, reflecting the opening of the phase space for the radiated gluon. As the temperature and momentum increase, the nonperturbative effects become much less important. However, at low momentum and temperature, the nonperturbative effects largely enhance the radiative contribution to the friction coefficient. As seen from the ratios shown in the lower panels of Fig. 1, this enhancement can reach up to ~100 times when comparing the full calculations (case 4) to the baseline perturbative calculation (case 1).

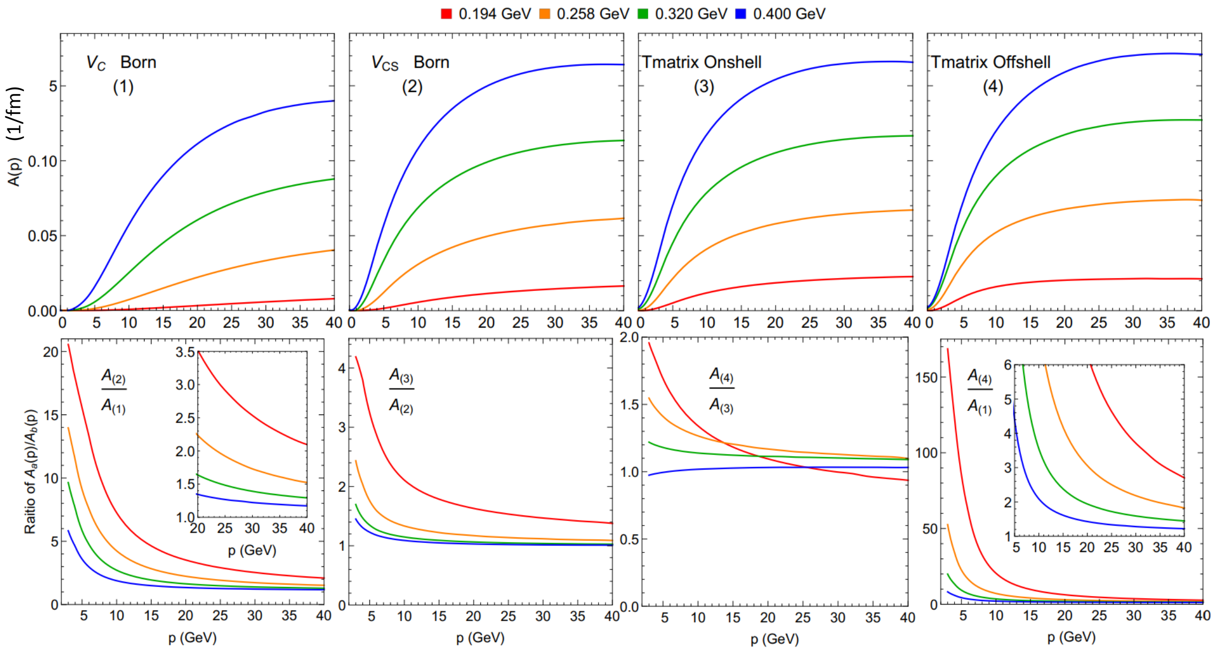

FIG. 1. Upper panels: charm-quark friction coefficients for the four different cases (1) to (4) of increasing nonperturbative effects (from left to right) as discussed in the text. The lower panels show the ratios, $\boldsymbol{A_i/A_j}$, of friction coefficients for adjacent cases (left and 2 middle panels) and for the ratio between case (4) and (1) (right panel).

The nonperturbative theoretical framework to calculate the energy loss caused by radiative processes set up in the present work complements our earlier calculations of collisional energy loss and will help us to achieve a more complete understanding of heavy-quark transport including large momentum scales, and thus arrive at a more comprehensive interpretation of heavy-flavor observables in URHICs.

[1] R. Rapp *et al.* [EMMI Rapid Reaction Task Force], Nucl. P hys. **A879**, 21 (2018).
[2] S.Y.F Liu and R. Rapp, Phys. Rev. C **97**, 034918 (2018).