Thermalization and Flow of Heavy Quarks in the Quark-Gluon Plasma

Hendrik van Hees

Texas A&M University

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Collaborators: V. Greco, R. Rapp
Outline

Motivation

Nonperturbative elastic heavy-quark resonance scattering

Heavy-quark rescattering in the QGP: Langevin process

Observables: $p_T$-spectra ($R_{AA}$), $v_2$

Conclusions and Outlook
Motivation

- Measured $p_T$ spectra and $v_2$ of non-photonic single electrons
- Coalescence model describes data under assumption of thermalized $c$ quarks, flowing with the bulk medium
Motivation

- Measured $p_T$ spectra and $v_2$ of non-photonic single electrons
- Coalescence model describes data under assumption of thermalized $c$ quarks, flowing with the bulk medium
- What is the underlying microscopic mechanism for thermalization?
  - pQCD elastic HQ scattering: need unrealistically large $\alpha_s$ [Moore, Teaney '04]
  - Gluon-radiative energy loss: need to enhance transport coefficient $\hat{q}$ by large factor [Armesto et al '05]
Possible non-perturbative mechanism: Survival of “D- and B-mesonic resonances” above $T_c$

suggestive from lattice QCD (Umeda et al ’02, Datta et al ’03)

provides elastic resonant rescattering of heavy quarks in the QGP

effective field-theory model based on
  
  - chiral symmetry
  - spin symmetry of heavy-quark effective theory
Elastic Resonance Scattering

- **D-meson propagators** dressed with one-loop self energies
  - Only two model parameters:
    - mass of resonances: $m_D = 2 \text{ GeV}$
    - coupling constant $\Gamma_B = 0.4 \ldots 0.75 \text{ GeV}$
  - Same model for $B$ mesons
    - $m_B = 5 \text{ GeV}, \Gamma_B = 0.4 \ldots 0.75 \text{ GeV}$
Contributions from pQCD

Lowest-order matrix elements (Combridge ’79)

In-medium Debye-screening mass for $t$-channel gluon exchange:

\[ \mu_g = gT, \quad \alpha_s = 0.4 \]
Cross sections

- pQCD and resonance cross sections: comparable in size
- BUT pQCD forward peaked ↔ resonance isotropic
- resonance scattering more effective for friction and diffusion
Drag and Diffusion coefficients

- use Fokker-Planck ansatz to calculate drag and diffusion coefficients

![Graph showing drag and diffusion coefficients](image)

- resonance contributions factor \(\sim 2 \ldots 3\) higher than pQCD
- shortens equilibration times \(\tau_{eq} = 1/\gamma\)
Drag and Diffusion coefficients

- **heavy quarks in the QGP**
  - thermal elliptic fireball parametrization for QGP
  - Fokker-Planck coefficients time dependent
  - Relativistic Langevin simulation for motion of heavy quarks
Initial conditions

- need initial $p_T$-spectra of **charm** and **bottom** quarks
  - (modified) PYTHIA to describe exp. D meson spectra, assuming $\delta$-function fragmentation
  - exp. non-photonic single-$e^\pm$ spectra: Fix bottom/charm ratio
Spectra and elliptic flow for heavy quarks
Observables: $p_T$-spectra ($R_{AA}$), $v_2$

- Hadronization: Coalescence + fragmentation
- single electrons from decay of $D$- and $B$-mesons

Data before Quark Matter ’05

Hendrik van Hees
Observables: $p_T$-spectra ($R_{AA}$), $v_2$

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Data presented at Quark Matter '05
Observables: $p_T$-spectra ($R_{AA}$), $v_2$

- Hadronization: Fragmentation only
- single electrons from decay of $D$- and $B$-mesons
Conclusions and Outlook

- Assumption: survival of resonances in the (s)QGP
- possible mechanism for nonperturbative interactions
- Equilibration of heavy quarks in QGP
- Observables via Langevin approach and coalescence
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- Assumption: survival of resonances in the (s)QGP
- possible mechanism for nonperturbative interactions
- **Equilibration** of heavy quarks in QGP
- **Observables** via Langevin approach and coalescence

- Further investigations have to be done:
  - Langevin for $D$ ($B$)-mesons in hadronic phase?
  - more realistic (softer) fragmentation
  - better control of coalescence/fragmentation ratio
  - implementation of gluon-radiation processes