Charm and beauty production in AA collisions in a Fokker-Planck approach

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1. Heavy-quark interactions in the sQGP
   - Heavy quarks in heavy-ion collisions
   - Heavy-quark diffusion: The Langevin Equation

2. Non-perturbative HQ interactions
   - Resonance model for HQ-q Scattering
   - T-matrix approach with lQCD potentials

3. Comparison with data
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   - D mesons at LHC
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   - Dileptons from correlated D $\bar{D}$ decays

4. Summary and Outlook
Motivation

- Fast equilibration of hot and dense matter in heavy-ion collisions: collective flow (nearly ideal hydrodynamics) ⇒ sQGP
- Heavy quarks as calibrated probe of QGP properties
  - produced in early hard collisions: well-defined initial conditions
  - not fully equilibrated due to large masses
  - heavy-quark diffusion ⇒ probes for QGP-transport properties
- Langevin simulation within UrQMD-hydro hybrid model
- sensitivity to medium evolution
- drag and diffusion coefficients
  - $T$-matrix approach with static lattice-QCD heavy-quark potentials
  - resonance formation close to $T_c$
  - mechanism for non-perturbative strong interactions
Heavy Quarks in Heavy-Ion collisions

Hard production of HQs described by PDF’s + pQCD (PYTHIA)

Hadronization to $D, B$ mesons via quark coalescence + fragmentation

HQ rescattering in QGP: Langevin simulation drag and diffusion coefficients from microscopic model for HQ interactions in the sQGP

Semileptonic decay $\Rightarrow$ “non-photonic” electron observables $R_{AA}^{e^+e^-}(p_T), \nu_{e}^{e^+e^-}(p_T)$
Relativistic Langevin process

- **Langevin process**: friction force + Gaussian random force
- in the (local) rest frame of the heat bath

\[
d\vec{x} = \frac{\vec{p}}{E_p} \, dt,
\]

\[
d\vec{p} = -A \vec{p} \, dt + \sqrt{2dt}[\sqrt{B_0 P_\perp} + \sqrt{B_1 P_\parallel}] \vec{w}
\]

- \(\vec{w}\): normal-distributed random variable
- \(A\): friction (drag) coefficient
- \(B_{0,1}\): diffusion coefficients
- Einstein dissipation-fluctuation relation \(B_1 = E_p TA\).
- flow via Lorentz boosts between “heat-bath frame” and “lab frame”
- \(A\) and \(B_0\) from microscopic models for \(qQ, gQ\) scattering
- background medium: UrQMD → hydro → UrQMD

Non-perturbative interactions: Resonance Scattering

- General idea: Survival of $D$- and $B$-meson like resonances above $T_c$
- model based on chiral symmetry (light quarks) HQ-effective theory
- elastic heavy-light-(anti-)quark scattering

- $D$- and $B$-meson like resonances in sQGP

- parameters
  - $m_D = 2 \text{ GeV}, \Gamma_D = 0.4 \ldots 0.75 \text{ GeV}$
  - $m_B = 5 \text{ GeV}, \Gamma_B = 0.4 \ldots 0.75 \text{ GeV}$

T-matrix

- Brueckner many-body approach for elastic $Qq, Q\bar{q}$ scattering

\[
T = V + T
\]

\[
\Sigma = \Sigma_{\text{glu}} + T
\]

- $V$: static $q\bar{q}$ potential from lattice QCD ($F$ and $U$)
- reduction scheme: 4D Bethe-Salpeter $\rightarrow$ 3D Lipmann-Schwinger
- $S$- and $P$ waves
- Relation to invariant matrix elements

\[
\sum |M(s)|^2 \propto \sum q d_a \left( |T_{a,l=0}(s)|^2 + 3 |T_{a,l=1}(s)|^2 \cos \theta_{\text{cm}} \right)
\]

[HvH, M. Mannarelli, V. Greco, R. Rapp, Phys. Rev. Lett. 100, 192301 (2008)]
T-matrix results

- Resonance formation at lower temperatures $T \approx T_c$
- Melting of resonances at higher $T$
- Model-independent assessment of elastic $Qq, Q\bar{q}$ scattering!
Nonphotonic electrons at RHIC

- form D and B mesons via quark-antiquark coalescence
- use PYTHIA for semi-leptonic decays
- comparison to single-electron data from PHENIX (200 AGeV Au-Au collisions)

D mesons at LHC

- form D via quark-antiquark coalescence
- comparison to D-meson data from ALICE (2.76 ATeV Pb-Pb collisions)

[Graph showing data from ALICE and UrQMD simulations]

D mesons at FAIR

- form D via quark-antiquark coalescence
- large sensitivity to initial HQ distributions
  (use estimates from HSD and PYTHIA)

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D mesons at FAIR

- form D via quark-antiquark coalescence
- large sensitivity to initial HQ distributions (use estimates from HSD and PYTHIA)
- large $\mu_B$ in resonance model: $\bar{c}$ more dragged than $c$

Dileptons from correlated $D \bar{D}$ decays

- for $m_\phi \lesssim M_{\ell^+\ell^-} \lesssim m_J/\psi$:
  - dilepton emission from thermal QGP and from correlated $D \bar{D}$ decays
- medium modifications of $D$ and $\bar{D}$ destroy correlations

Summary and Outlook

- Heavy quarks in the sQGP
- Non-perturbative interactions
  - Mechanism for strong coupling: resonance formation at $T \gtrsim T_c$
  - Lattice-QCD potentials parameter free
  - Also provides "natural" mechanism for quark coalescence


- Comparison to data and predictions for FAIR
  - $R_{AA}$ and $v_2$ of non-photonic electrons at RHIC
  - $R_{AA}$ and $v_2$ for D mesons at LHC
  - $R_{AA}$ and $v_2$ for D mesons at FAIR (pp baseline mandatory!)
  - Impact of medium modifications on correlated $D\bar{D}$ decays to dileptons

- Outlook
  - Implementation of hadronic cross sections for D/B-meson diffusion
  - Include inelastic heavy-quark processes (gluo-radiative processes)
  - Implement resonance-recombination model for hadronization
  - Charmonium/bottomonium suppression/regeneration