Heavy Quarks
in Heavy-Ion Collisions

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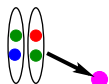
July 18, 2013

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FIAS Frankfurt Institute
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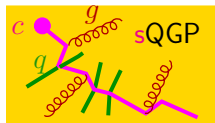
EMMI

Outline

Motivation

- Fast equilibration of hot and dense matter in heavy-ion collisions: collective flow (nearly ideal hydrodynamics) $\Rightarrow$ 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 $\Rightarrow$ probes for QGP-transport properties
- Langevin simulation within UrQMD-hydro hybrid model
- 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

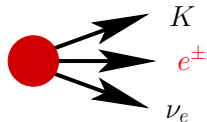hard production of HQs
described by PDF's + pQCD (PYTHIA)

c,b quark

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

Hadronization to D,B mesons via
quark coalescence + fragmentation

semileptonic decay $\Rightarrow$
"non-photonic" electron observables
$R_{AA}^{e^+e^-}(p_T)$, $v_2^{e^+e^-}(p_T)$

Relativistic Langevin process

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

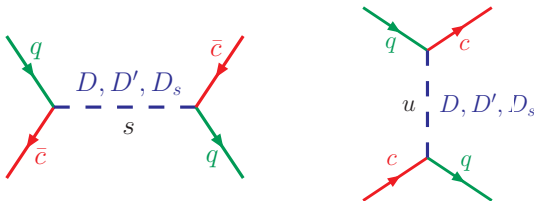$$\mathrm{d}\vec{x} = \frac{\vec{p}}{E_p}\mathrm{d}t,$$

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

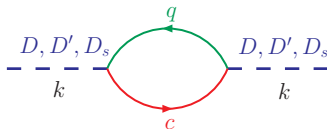- $\vec{w}$: normal-distributed random variable
- A: friction (drag) coefficient
- $B_{0,1}$: diffusion coefficients
- Einstein dissipation-fluctuation relation $B_1 = E_p T A$.
- flow via Lorentz boosts between "heat-bath frame" and "lab frame"
- A and B_0 from microscopic models for qQ, gQ scattering
- 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
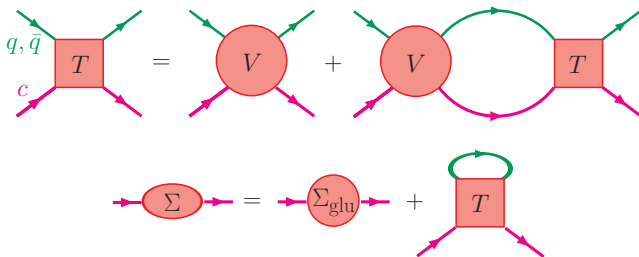- elastic heavy-light-(anti-)quark scattering

- D- and B-meson like resonances in sQGP

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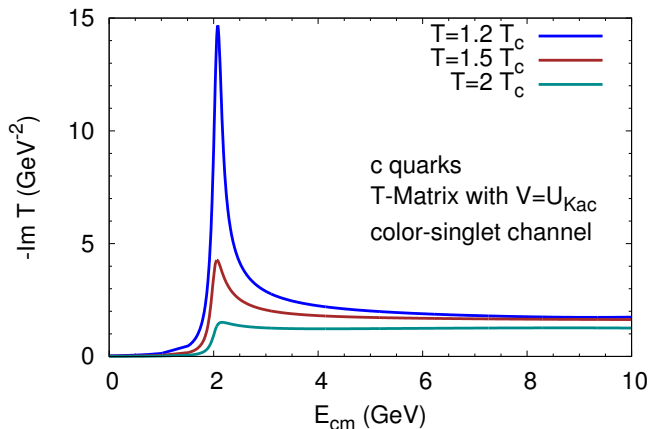 - $m_B = 5$ GeV, $\Gamma_B = 0.4 \ldots 0.75$ GeV

T-matrix

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

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

$$\sum |\mathcal{M}(s)|^2 \propto \sum_q d_a \left(|T_{a,l=0}(s)|^2 + 3|T_{a,l=1}(s)|^2 \cos\theta_{\rm cm} \right)$$
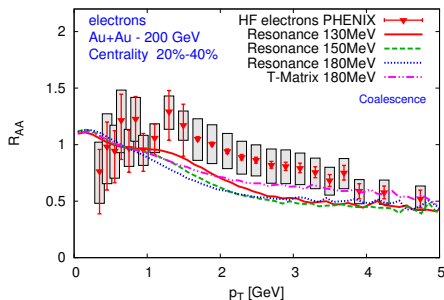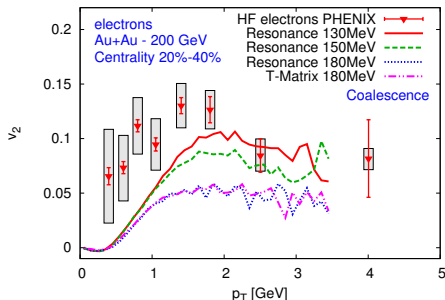
T-matrix results

- resonance formation at lower temperatures $T \simeq T_c$
- melting of resonances at higher T
- model-independent assessment of elastic Qq, $Q\bar{q}$ scattering!
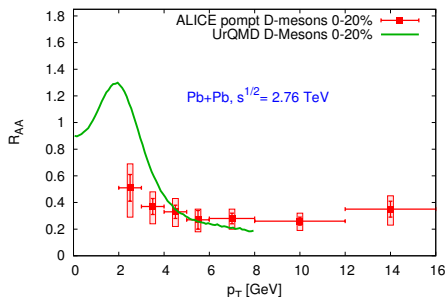
Nonphotonic electrons at RHIC

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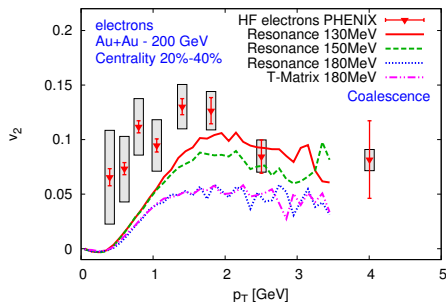- comparison to single-electron data from PHENIX
  (200 AGeV Au-Au collisions)

[T. Lang, HvH, J. Steinheimer, M. Bleicher, arXiv: 1211.6912 [hep-ph]]

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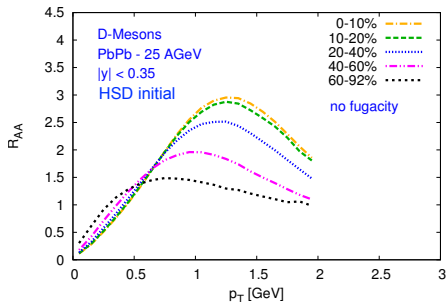- comparison to D-meson data from ALICE (2.76 ATeV Pb-Pb collisions)

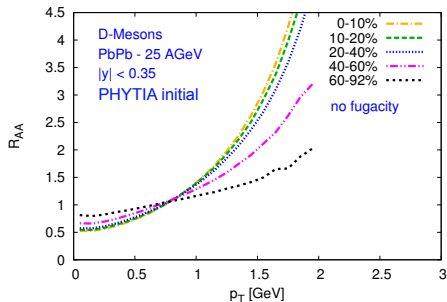[T. Lang, HvH, J. Steinheimer, M. Bleicher, arXiv: 1211.6912 [hep-ph]]

D mesons at FAIR

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

[T. Lang, HvH, J. Steinheimer, M. Bleicher, arXiv: 1305.1797 [hep-ph]]

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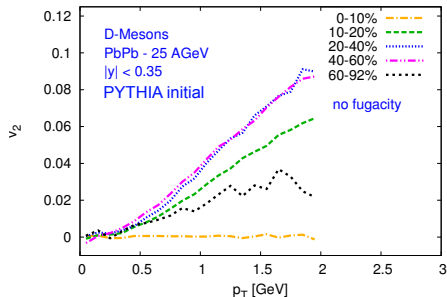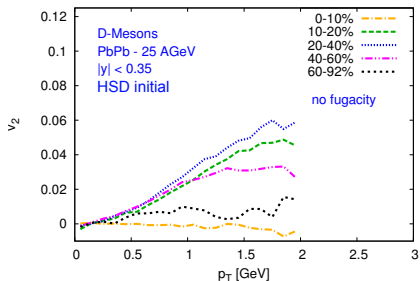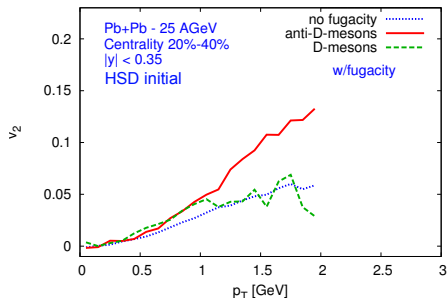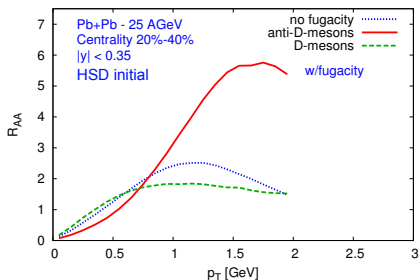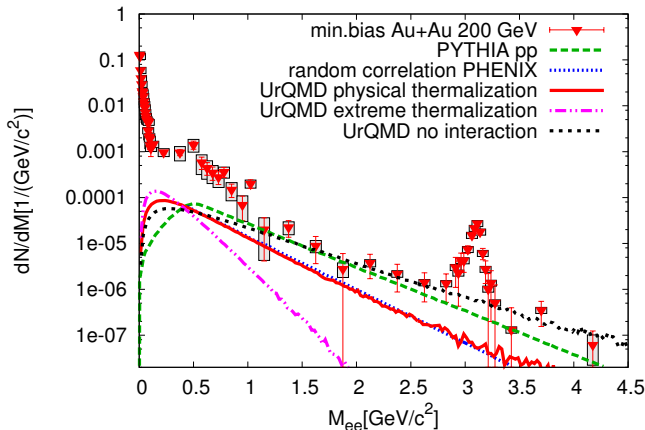 (use estimates from HSD and PYTHIA)
- large μ_B in resonance model: $\bar{c}$ more dragged than c

[T. Lang, HvH, J. Steinheimer, M. Bleicher, arXiv: 1305.1797 [hep-ph]]

Dileptons from correlated D $\overline{\text{D}}$ decays

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

[T. Lang, HvH, J. Steinheimer, M. Bleicher, arXiv: 1305.7377 [hep-ph]]

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 $\overline{\text{D}}$ 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