Heavy-Quark Diffusion in the Quark-Gluon Plasma

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with
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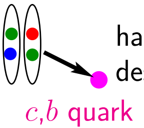
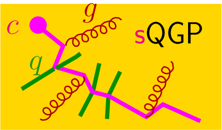
Outline

1. Heavy Quark interactions in the sQGP
2. Heavy-Quark Diffusion in the Quark-Gluon Plasma
3. Non-photonic electrons at RHIC
4. Summary and Outlook

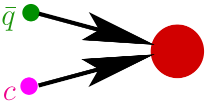
Heavy Quarks in Heavy-Ion collisions



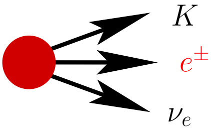
hard production of HQs
described by PDF's + pQCD (PYTHIA)



HQ rescattering in QGP: Langevin simulation
drag and diffusion coefficients from
non-perturbative many-body T matrix (sQGP)

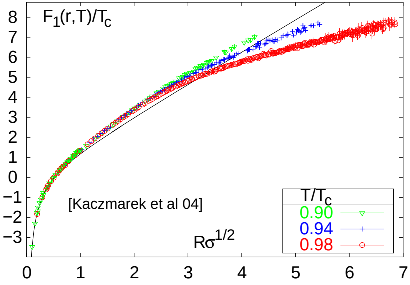


Hadronization to D,B mesons via
quark coalescence + fragmentation
V. Greco, C. M. Ko, R. Rapp, PL B **595**, 202 (2004)



semileptonic decay ⇒
"non-photonic" electron observables

Static potentials from lattice QCD



- color-singlet free energy from lattice
- use internal energy

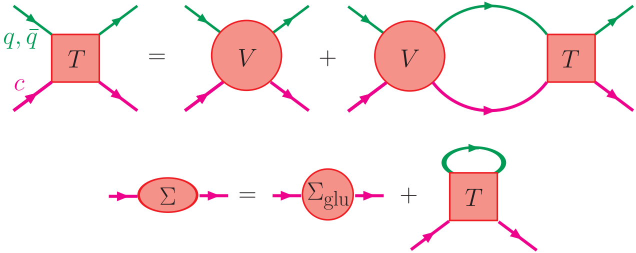
$$U_1(r,T) = F_1(r,T) - T\frac{\partial F_1(r,T)}{\partial T},$$
$$V_1(r,T) = U_1(r,T) - U_1(r \to \infty, T)$$

- Casimir scaling for other color channels [Nakamura et al 05; Döring et al 07]

$$V_{\bar{3}} = \frac{1}{2}V_1, \quad V_6 = -\frac{1}{4}V_1, \quad V_8 = -\frac{1}{8}V_1$$

T-matrix

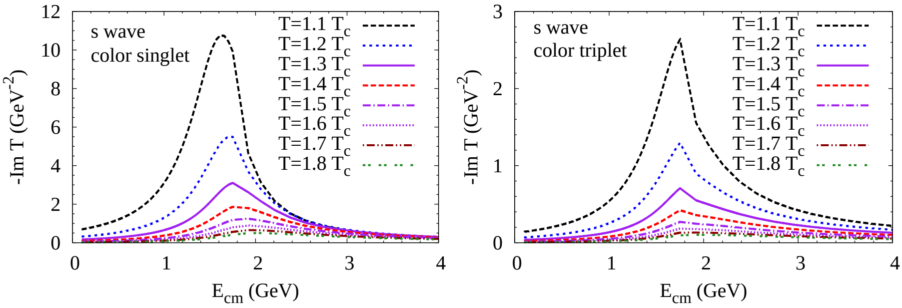
- Brueckner many-body approach for elastic Qq, $Q\bar{q}$ scattering



- reduction scheme: 4D Bethe-Salpeter → 3D Lipmann-Schwinger
- S- and P waves
- same scheme for light quarks (self consistent!)
- Relation to invariant matrix elements

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

T-matrix

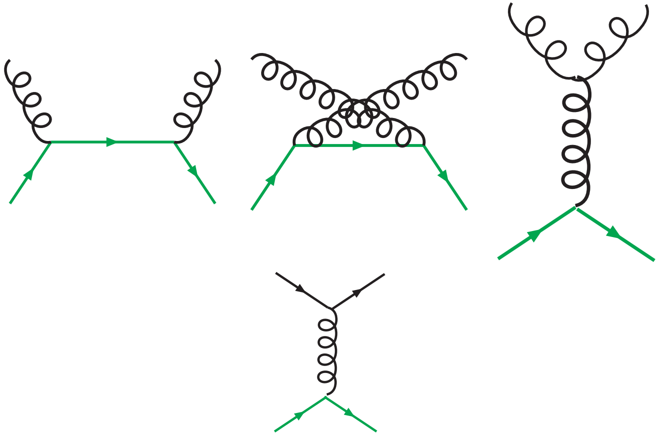


- resonance formation at lower temperatures $T \simeq T_c$
- melting of resonances at higher T! $\Rightarrow$ sQGP
- P wave smaller
- resonances near T_c: natural connection to quark coalescence

  [Ravagli, Rapp 07]
- model-independent assessment of elastic Qq, $Q\bar{q}$ scattering
- problems: uncertainties in extracting potential from lQCD in-medium potential V vs. F?

Elastic pQCD processes

- Lowest-order matrix elements [Combridge 79]



- In-medium Debye-screening mass for t-channel gluon exchange: $\mu_g = gT$, $\alpha_s = 0.4$

Heavy-Quark diffusion

- Fokker Planck Equation

$$\frac{\partial f(t,\vec{p})}{\partial t} = \frac{\partial}{\partial p_i}\left[p_i A(t,p) + \frac{\partial}{\partial p_j} B_{ij}(t,\vec{p})\right] f(t,\vec{p})$$

- drag (friction) and diffusion coefficients

$$p_i A(t,\vec{p}) = \left\langle p_i - p_i' \right\rangle$$

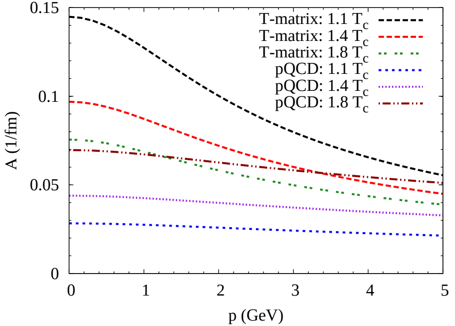
$$B_{ij}(t,\vec{p}) = \frac{1}{2}\left\langle (p_i - p_i')(p_j - p_j') \right\rangle = B_0(t,p)\left(\delta_{ij} - \frac{p_i p_j}{p^2}\right) + B_1(t,p)\frac{p_i p_j}{p^2}$$

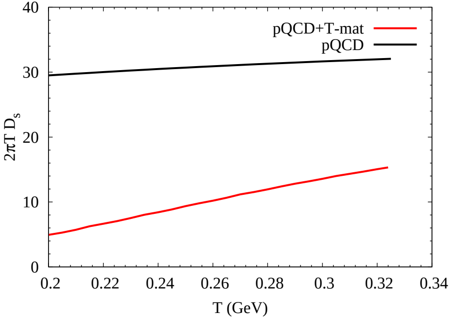
- transport coefficients defined via $\mathcal{M}$

$$\left\langle X(\vec{p}') \right\rangle = \frac{1}{\gamma_c}\frac{1}{2E_p}\int \frac{\mathrm{d}^3\vec{q}}{(2\pi)^3 2E_q}\int \frac{\mathrm{d}^3\vec{q}'}{(2\pi)^3 2E_{q'}}\int \frac{\mathrm{d}^3\vec{p}'}{(2\pi)^3 2E_{p'}} \sum |\mathcal{M}|^2 (2\pi)^4 \delta^{(4)}(p+q-p'-q')\hat{f}(\vec{q})X(\vec{p}')$$

- correct equil. lim. ⇒ Einstein relation: $B_1(t,p) = T(t) E_p A(t,p)$

Transport coefficients





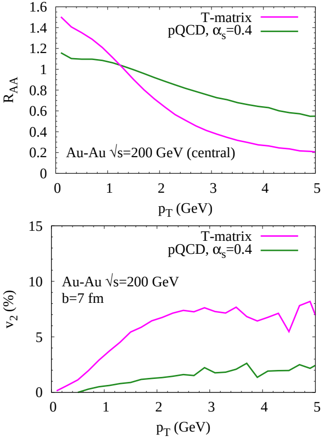
- from non-pert. interactions reach $A_{\text{non-pert}} \simeq 1/(7 \text{ fm}/c \simeq 4 A_{\text{pQCD}}$
- A decreases with higher temperature
- higher density (over)compensated by melting of resonances!
- spatial diffusion coefficient

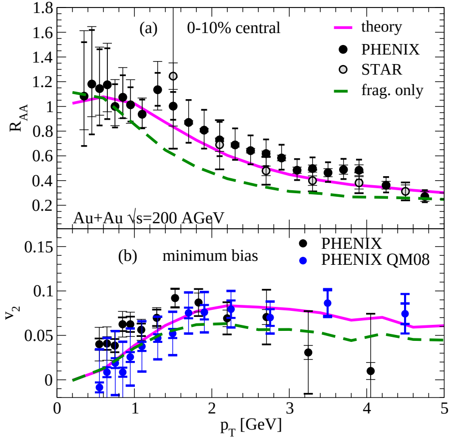
$$D_s = \frac{T}{mA}$$

increases with temperature

Non-photonic electrons at RHIC

- same model for bottom
- quark coalescence+fragmentation $\rightarrow D/B \rightarrow e + X$





- coalescence crucial for explanation of data
- increases both, R_{AA} and $v_2 \Leftrightarrow$ “momentum kick” from light quarks!
- “resonance formation” towards $T_c \Rightarrow$ coalescence natural [Ravagli, Rapp 07]

Summary and Outlook

- Summary
  - Heavy quarks in the sQGP
  - non-perturbative interactions via lQCD potentials parameter free
  - resonance formation at $T > T_c \Rightarrow$ strong coupling
  - res. melt at higher temperatures $\Leftrightarrow$ consistency betw. R_{AA} and v_2!
  - also provides "natural" mechanism for quark coalescence
  - uncertainties
    - extraction of V from lattice data
    - potential approach at finite T: F, V or combination?

- Outlook
  - include inelastic heavy-quark processes (gluon-radiation processes)
  - other heavy-quark observables like charmonium suppression/regeneration