

Heavy-Quark Diffusion in the Quark-Gluon Plasma

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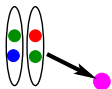
with

M. Mannarelli, V. Greco and R. Rapp



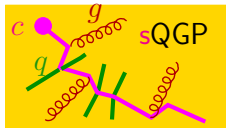
- 1 Heavy Quark interactions in the sQGP
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Heavy Quarks in Heavy-Ion collisions

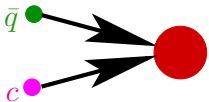


c, b quark

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

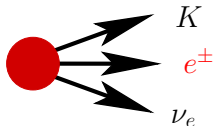


HQ rescattering in QGP: Langevin simulation
drag and diffusion coefficients from
non-perturbative many-body T matrix (sQGP)



Hadronization to D, B mesons via
quark coalescence + fragmentation

V. Greco, C. M. Ko, R. Rapp, PL B **595**, 202 (2004)



K

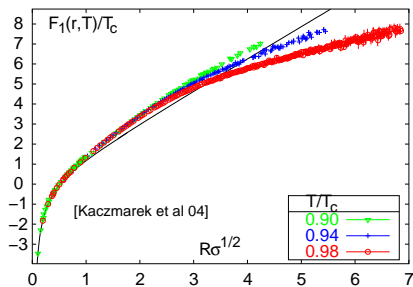
e^\pm

ν_e

semileptonic decay \Rightarrow

“non-photonic” electron observables

Static potentials from lattice QCD



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

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

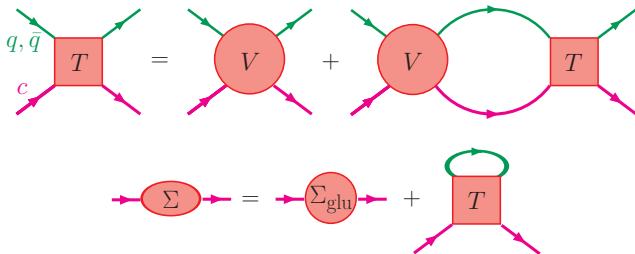
$$V_1(r, T) = U_1(r, T) - U_1(r \rightarrow \infty, T)$$

- 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

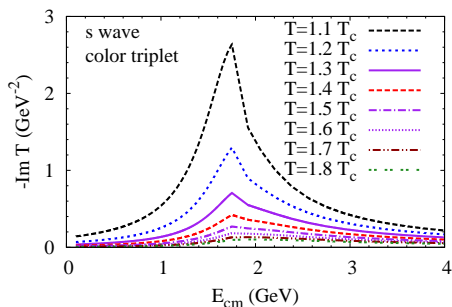
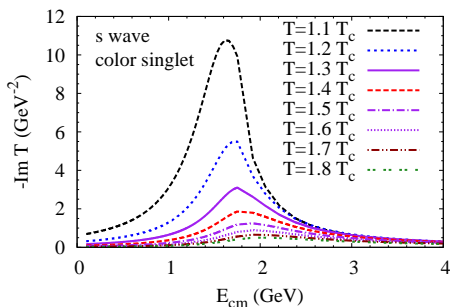
- Brueckner many-body approach for elastic $Qq, Q\bar{q}$ scattering



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

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

T-matrix



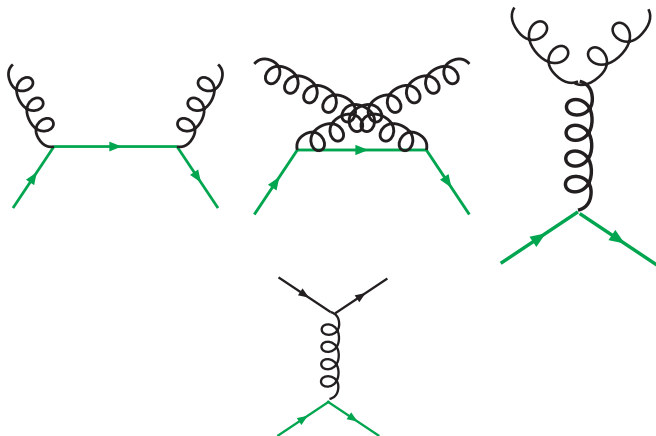
- resonance formation at lower temperatures $T \simeq T_c$
- melting of resonances at higher T ! \Rightarrow sQGP
- P wave smaller
- resonances near T_c : natural connection to quark coalescence

[Ravagli, Rapp 07]

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

Elastic pQCD processes

- Lowest-order matrix elements [Cambridge 79]



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

Heavy-Quark diffusion

- Fokker Planck Equation

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

- drag (friction) and diffusion coefficients

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

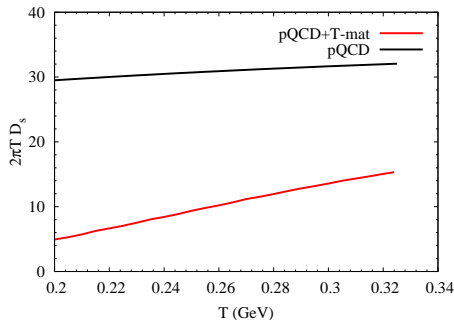
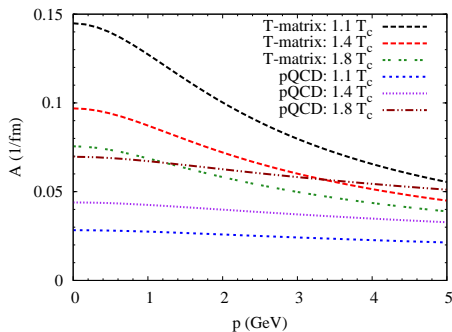
$$\begin{aligned} B_{ij}(t, \vec{p}) &= \frac{1}{2} \langle (p_i - p'_i)(p_j - p'_j) \rangle \\ &= B_0(t, p) \left(\delta_{ij} - \frac{p_i p_j}{p^2} \right) + B_1(t, p) \frac{p_i p_j}{p^2} \end{aligned}$$

- transport coefficients defined via \mathcal{M}

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

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

Transport coefficients



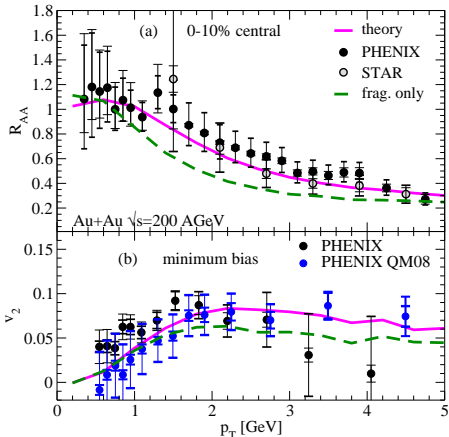
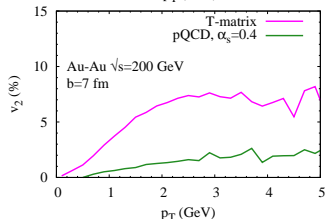
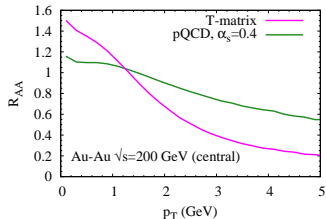
- from **non-pert.** interactions reach $A_{\text{non-pert}} \simeq 1/(7 \text{ fm}/c) \simeq 4A_{\text{pQCD}}$
- **A decreases with higher temperature**
- higher density (over)compensated by **melting of resonances!**
- spatial diffusion coefficient

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

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 IQCD 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