

Elastic HQ interactions in QGP (PHSD)

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1. QGP in PHSD

Dynamical Quasi-Particle Model (DQPM)

Quark/gluon masses and widths from HTL calculations at high T limit

- **quarks:**

mass: $M_{q(\bar{q})}^2(T, \mu_B) = \frac{N_c^2 - 1}{8N_c} g^2(T, \mu_B) \left(T^2 + \frac{\mu_q^2}{\pi^2} \right)$

width: $\gamma_{q(\bar{q})}(T, \mu_B) = \frac{1}{3} \frac{N_c^2 - 1}{2N_c} \frac{g^2(T, \mu_B) T}{8\pi} \ln \left[\frac{2c}{g^2(T, \mu_B)} + 1 \right],$

- **gluons:**

mass: $M_g^2(T, \mu_B) = \frac{g^2(T, \mu_B)}{6} \left[\left(N_c + \frac{1}{2} N_f \right) T^2 + \frac{N_c}{2} \sum_q \frac{\mu_q^2}{\pi^2} \right]$

width: $\gamma_g(T, \mu_B) = \frac{1}{3} N_c \frac{g^2(T, \mu_B) T}{8\pi} \ln \left[\frac{2c}{g^2(T, \mu_B)} + 1 \right],$

Dynamical Quasi-Particle Model (DQPM)

T-dependent running coupling

$$g^2(s/s_{SB}) = d((s/s_{SB})^e - 1)^f$$

s: entropy density

$s_{SB} = 19/9\pi^2 T^3$: Stefan-Boltzmann entropy density

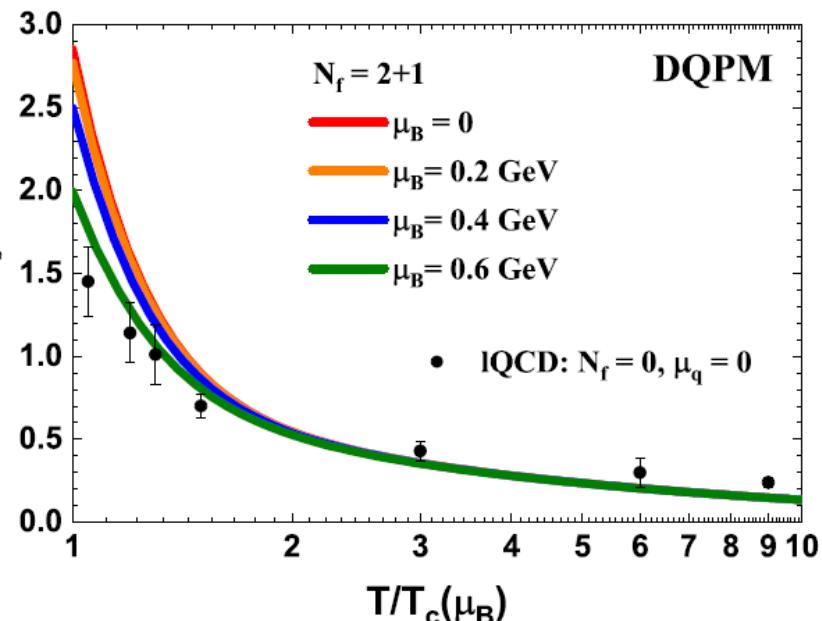
d=169.934, e=-0.178434, f=1.14631

(T, μ)-dependent running coupling

$$g^2(T/T_c, \mu_B) = g^2(T^*/T_c(\mu_B), \mu_B = 0)$$

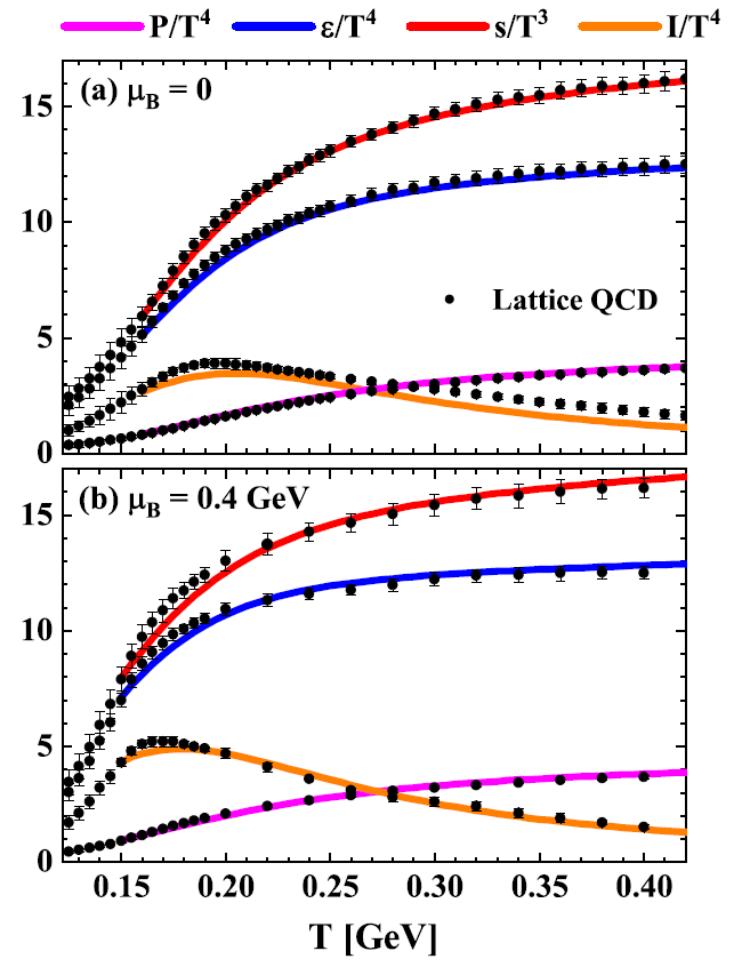
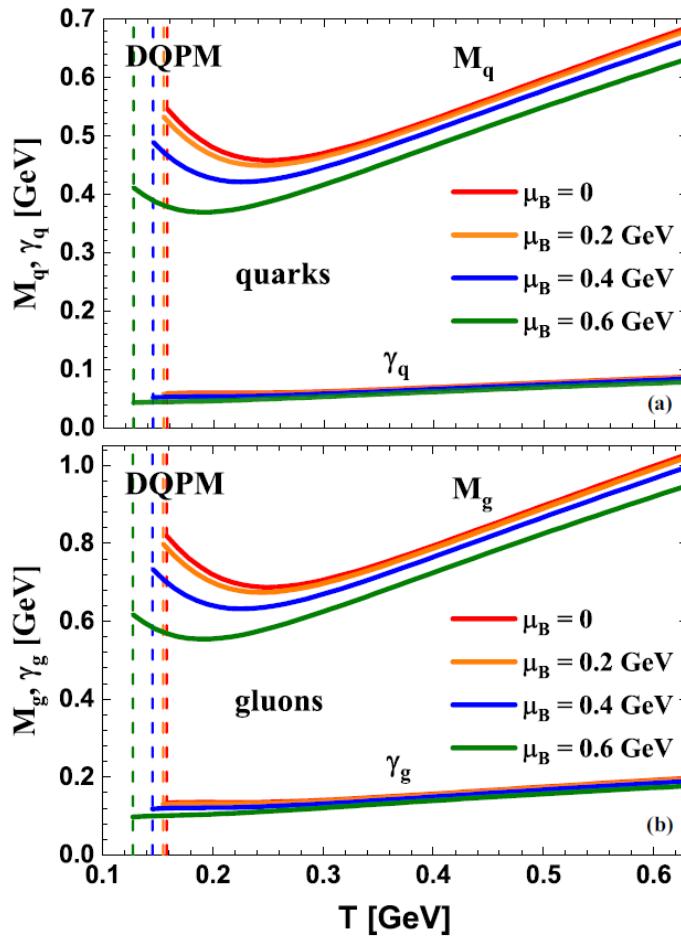
$$T^* = \sqrt{T^2 + \mu_q^2/\pi^2}, \quad T_c(\mu_B) = T_c \sqrt{1 - \alpha \mu_B^2}$$

$$\alpha = 0.974 \text{ GeV}^{-2}$$

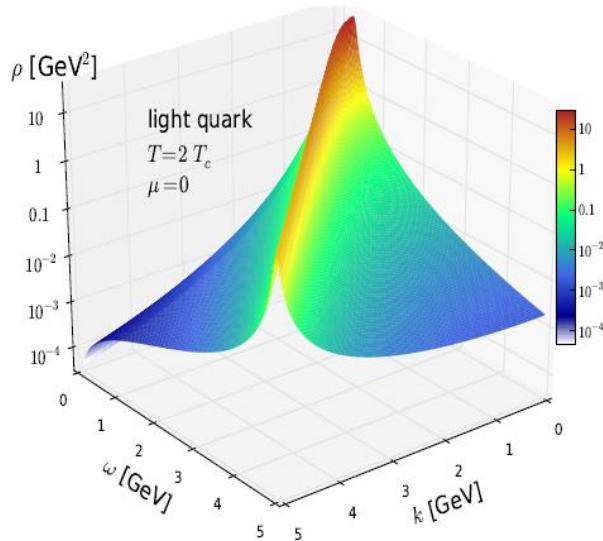


Dynamical Quasi-Particle Model (DQPM)

Lattice EOS is well reproduced both at $\mu_B = 0$ and $\mu_B \neq 0$

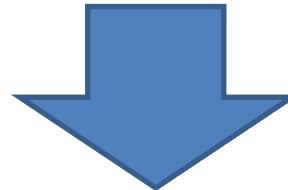


Parton spectral function

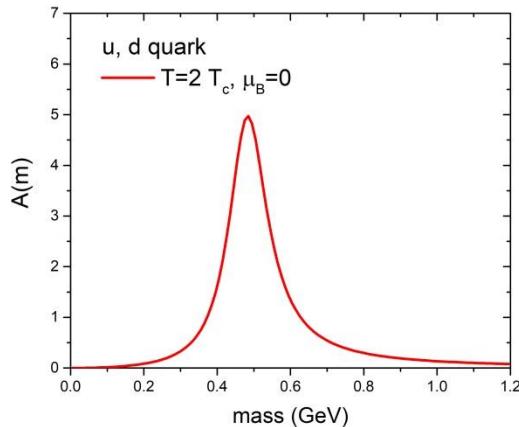


$$\rho_j(\omega, \mathbf{p}) = \frac{\gamma_j}{\tilde{E}_j} \left(\frac{1}{(\omega - \tilde{E}_j)^2 + \gamma_j^2} - \frac{1}{(\omega + \tilde{E}_j)^2 + \gamma_j^2} \right)$$

$$\equiv \frac{4\omega\gamma_j}{(\omega^2 - \mathbf{p}^2 - M_j^2)^2 + 4\gamma_j^2\omega^2}$$



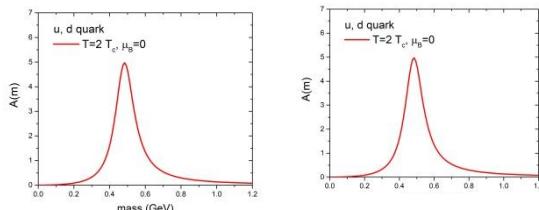
$$\rho_i^{\text{BW}}(m) = \frac{2}{\pi} \frac{2m^2\gamma_i}{(m^2 - M_i^2)^2 + (2m\gamma_i)^2}.$$



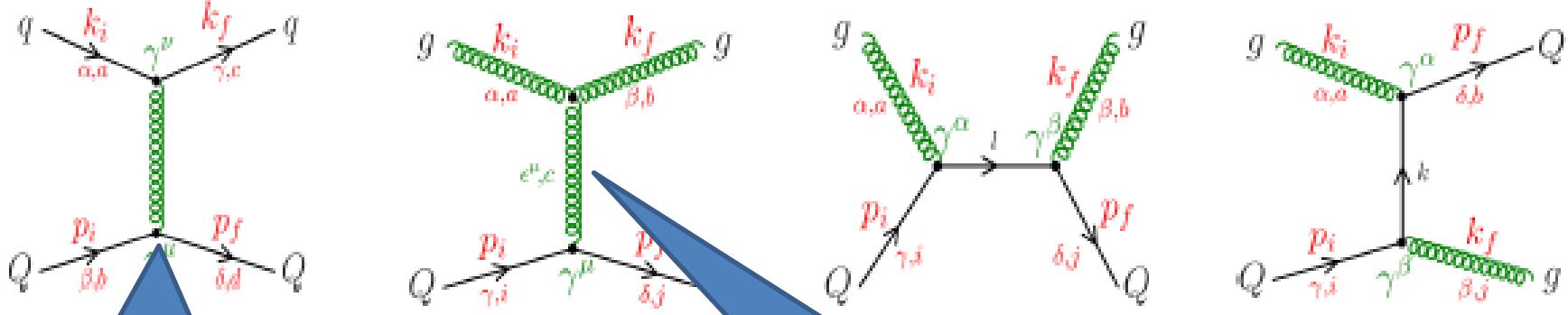
For simplicity, spectral function is approximated into Breit-Wigner form (Lorentzian form)

2. HQ interactions in QGP

Heavy quark scattering in the QGP (DQPM)



HQ interacts with off-shell massive quark/gluon



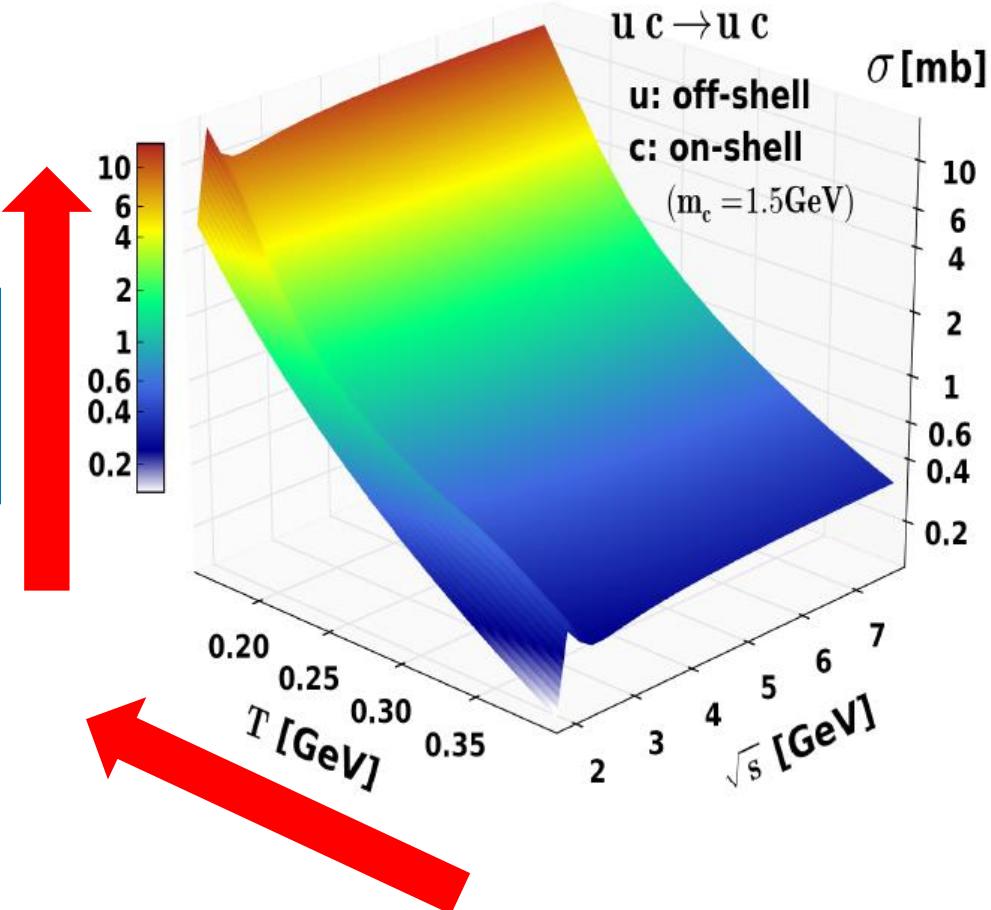
Temperature-dependent strong coupling

Off-shell massive gluon
is exchanged:
divergence-free without
introducing a screening
mass

H. Berrehrah et al, PRC 89 (2014) 054901;
PRC 90 (2014) 051901; PRC90 (2014) 064906

Elastic cross section $uc \rightarrow uc$

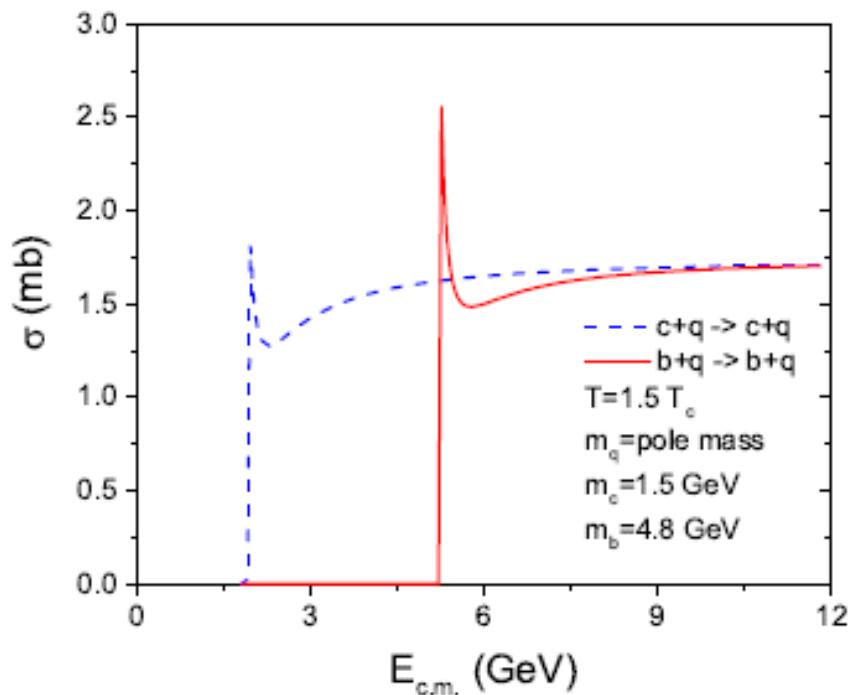
cross section rapidly increases near T_c due to $g(T)$



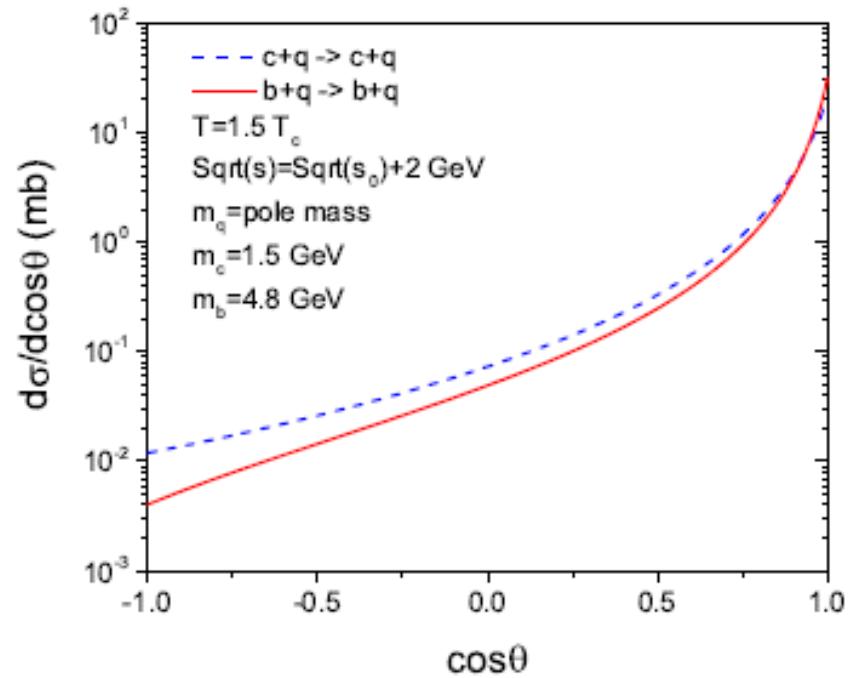
H. Berrehrah et al, PRC 89 (2014) 054901;
PRC 90 (2014) 051901; PRC90 (2014) 064906

Charm & bottom quark interaction in QGP

Total cross sections



differential cross sections



Total cross sections are similar, but bottom cross section is more highly forward peaked, because it is heavier.

3. Transport coefficients

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

Fokker-Planck Eq.

$$A(p) = -\frac{\vec{A}(p) \cdot \vec{p}}{|\vec{p}|} = -\frac{d\langle \Delta p \rangle}{dt} = \langle \langle (p - p')_x \rangle \rangle,$$

$$\begin{aligned} B_L(p) &= \frac{1}{2} \frac{p_i p_j}{|\vec{p}|^2} B_{ij}(p) \\ &= \frac{1}{2} \frac{d\langle (\Delta p_L)^2 \rangle}{dt} = \left(\frac{1}{2} \langle \langle (p - p')_x^2 \rangle \rangle \right), \end{aligned}$$

$$\begin{aligned} B_T(p) &= \frac{1}{4} \left(\delta_{ij} - \frac{p_i p_j}{|\vec{p}|^2} \right) B_{ij}(p) \\ &= \frac{1}{4} \frac{d\langle (\Delta p_T)^2 \rangle}{dt} = \left(\frac{1}{4} \langle \langle p_y'^2 + p_z'^2 \rangle \rangle \right), \\ \hat{q}(p) &= \frac{d\langle (\Delta p_T)^2 \rangle}{dx} = \frac{4E}{p_L} B_T(p), \end{aligned}$$

where

$$\begin{aligned} \langle \langle O^* \rangle \rangle &\equiv \frac{1}{2E_p} \sum_{i=q,\bar{q},g} \int \frac{d^3 k}{(2\pi)^3 2E} f_i(k) \int \frac{d^3 k'}{(2\pi)^3 2E'} \\ &\quad \times \int \frac{d^3 p'}{(2\pi)^3 2E'_p} O^* (2\pi)^4 \delta^{(4)}(p+k-p'-k') \frac{|M_{ic}|^2}{\gamma_c}, \end{aligned}$$

Transport coefficients for the interactions with off-shell particles

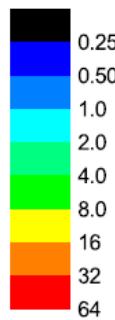
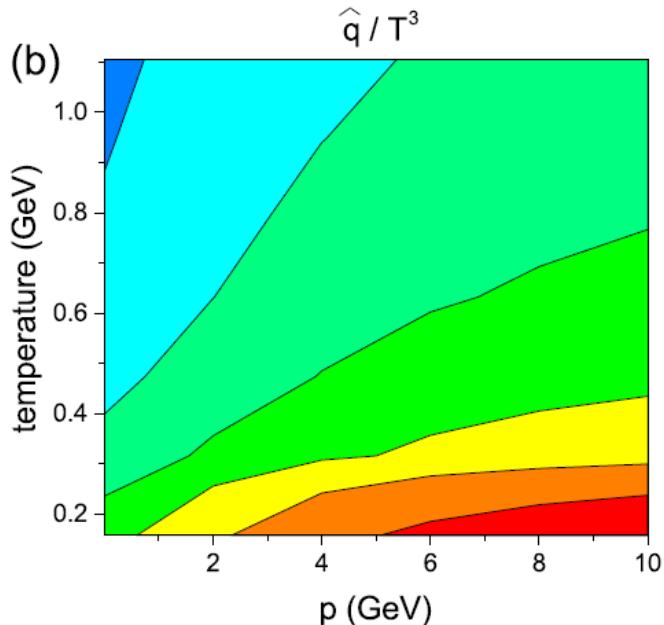
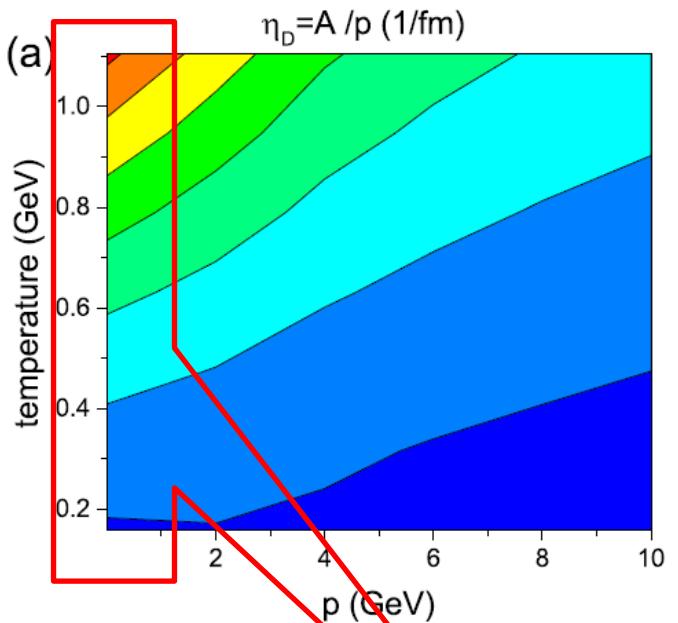
$$\rho_i(m) = \frac{2}{\pi} \frac{2m^2\gamma_i}{(m^2 - M_i^2)^2 + (2m\gamma_i)^2}.$$

Heavy quark has
a constant mass

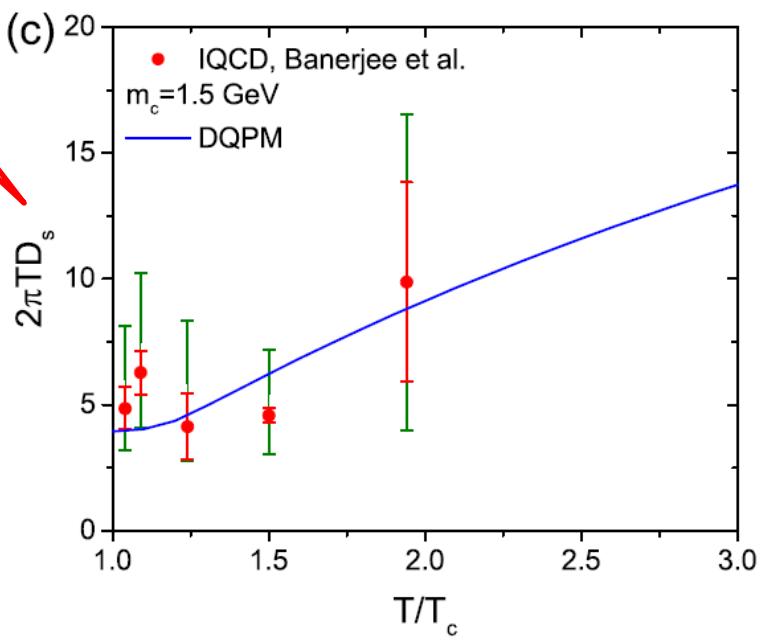
$$\begin{aligned} \langle\langle O^* \rangle\rangle &\equiv \frac{1}{2E_p} \sum_{i=q,\bar{q},e} \boxed{\int dm \rho_i(m) \int dm' \rho_i(m')} \\ &\times \int \frac{d^3 k}{(2\pi)^3 2E} f_i(k, m_i) \int \frac{d^3 k'}{(2\pi)^3 2E'} \int \frac{d^3 p'}{(2\pi)^3 2E'_p} \\ &\times O^* (2\pi)^4 \delta^{(4)}(p + q - p' - q') \frac{|M_{ic}|^2}{\gamma_c}, \quad (15) \end{aligned}$$

Integration over
initial & final
mass of scattering
parton

Compared with only pole mass (without width), spectral function decreases the transport coefficients A and B



$$D_s = \lim_{p \rightarrow 0} \frac{T}{m_c \eta},$$



Thank you for your attention!