Charm Quark Momentum Broadening in a Non-equilibrium Glasma

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Introduction

- Initial stages of a heavy-ion collision (HIC) constitute of an out-of-equilibrium highly-occupied plasma of gauge fields.

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- Studying the dynamics of heavy quarks in presence of such highly occupied gauge fields in the pre-equilibrium stage could be an excellent probe in understanding the approach to thermalization in such systems.

Motivation

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- Dynamics of light (nearly massless) quarks under such conditions has been studied recently using classical-statistical lattice simulations while treating quarks quantum-mechanically.

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- Our goal is to study the dynamics of quarks starting from intermediate masses going up to very heavy mass in presence of such gauge fields in a similar way to hopefully gain some insights into their collective behaviour.

Quark Spectral Function : Free vs. Interacting

- Quark spectral function is defined as,

$$\rho^{\alpha\beta}(x,y) = \left\langle \left\{ \hat{\psi}^{\alpha}(x), \hat{\bar{\psi}}^{\beta}(y) \right\} \right\rangle$$

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- In general, spectral function can be decomposed into the following parts,

$$\rho = \rho_S + i\gamma_5\rho_P + \gamma_\mu p_V^\mu + \gamma_\mu\gamma_5 p_A^\mu + \frac{1}{2}\sigma_{\mu\nu}\rho_T^{\mu\nu}$$

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- Here, the vector component of the spectral function ρ_V can be extracted as,

$$\rho_V^0 = \frac{1}{4} Tr(\rho\gamma^0), \;\; \rho_V = -\frac{E_{\mathbf{p}} p^j}{4p^2} Tr(\rho\gamma^j)$$

Quark Spectral Function : Free vs. Interacting

- Quark spectral function, in the absence of gauge fields, can be calculated to be,

$$\rho^{free}(\Delta t, \mathbf{p}) = \gamma^0 cos(E_{\mathbf{p}}\Delta t) + i\left(\gamma^j \frac{\hat{p}^j}{E_{\mathbf{p}}} - \frac{m_{\mathbf{p}}}{E_{\mathbf{p}}}\right) sin(E_{\mathbf{p}}\Delta t)$$

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- But, in presence of color fields, it shows the following behaviour,

$$Re\rho_V^0(t+\Delta t, t, p) \approx e^{-\gamma(t,m,p)\Delta t} cos\{\omega(t,m,p)\Delta t\}$$

$$Im\rho_S(t+\Delta t, t, p) \approx -e^{-\gamma(t,m,p)\Delta t} sin\{\omega(t,m,p)\Delta t\}$$

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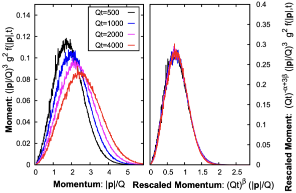
where we have taken n_0 to be 1.



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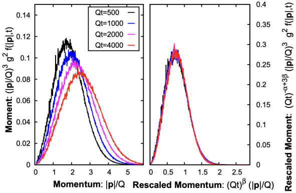

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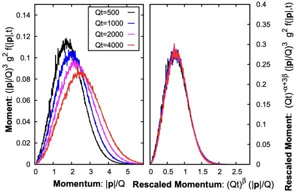

where we have taken n_0 to be 1.

- Owing to their high occupancy, gauge fields are evolved classically according to Hamilton's equations of motion.
- Such systems undergo a rapid memory loss and subsequently enter a self-similar scaling regime. [J. Berges, K. Boguslavski, S. Schlichting, and R. Venugopalan, 14]

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- Further, we have chosen the following set of quark masses, $ma_s = 0.003125, 0.08, 0.8, 1.6, 2.4, 3.2, 4.0$.

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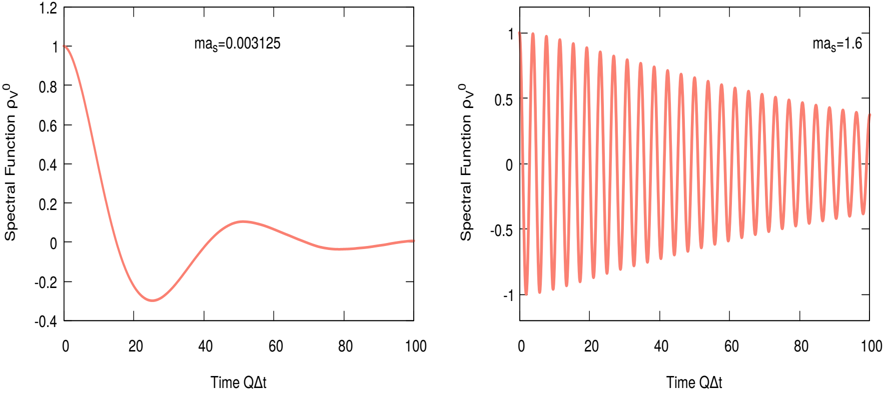
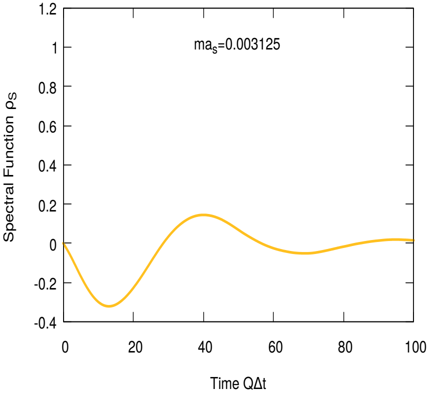
- For example, $Q \sim 1GeV \implies ma_s = 1.6$ represents a quark with mass $1.6GeV$, close to that of the charm.

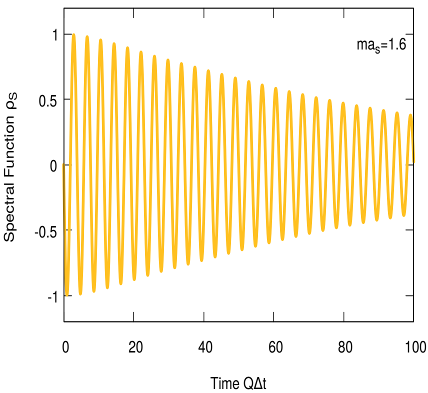
- Time evolution of ρ_V^0 component of the spectral function for almost massless fermions ($ma_s = 0.003125$) and relatively heavier fermions ($ma_s = 1.6$) comes out to be,



Results: Real-time evolution of the Spectral Function

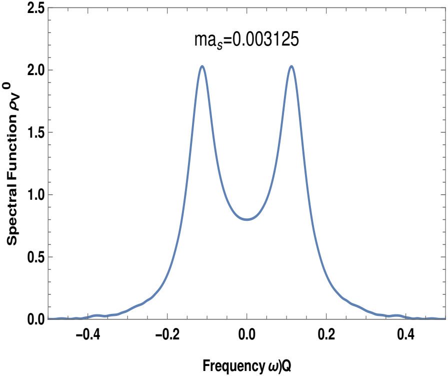
- And the time evolution of ρ_S component of the spectral function,

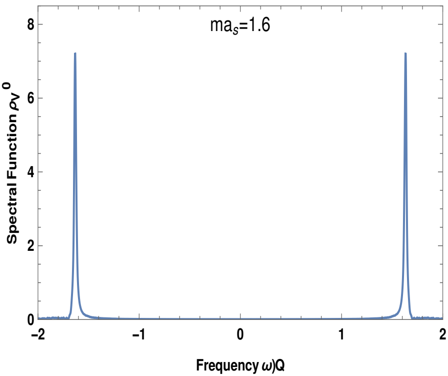




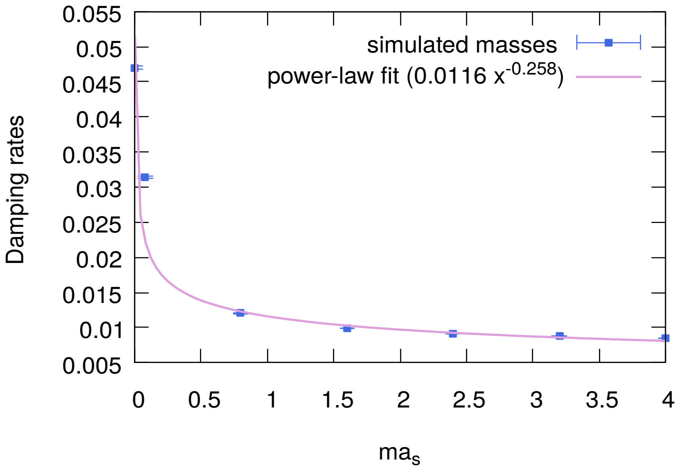
Results: Spectral Function in the frequency domain

- $\rho^{HTL+\gamma}(\omega, p) = 2\pi\beta(\omega/p, p) + \frac{2Z_+(p)\gamma_+(p)}{(\omega-\omega_+(p))^2+\gamma_+^2(p)} + \frac{2Z_-(p)\gamma_-(p)}{(\omega+\omega_-(p))^2+\gamma_-^2(p)}$





Results: Spectral Function damping rate as a function of mass



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- Heavy quarks in the presence of highly occupied gauge fields provide an excellent paradigm for studying the properties of pre-equilibrium stage of heavy-ion collisions, reheating in the early universe etc.

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- We're also studying the broadening of the momenta of a probe heavy quark traversing the glasma.

Thanks for your attention. :)

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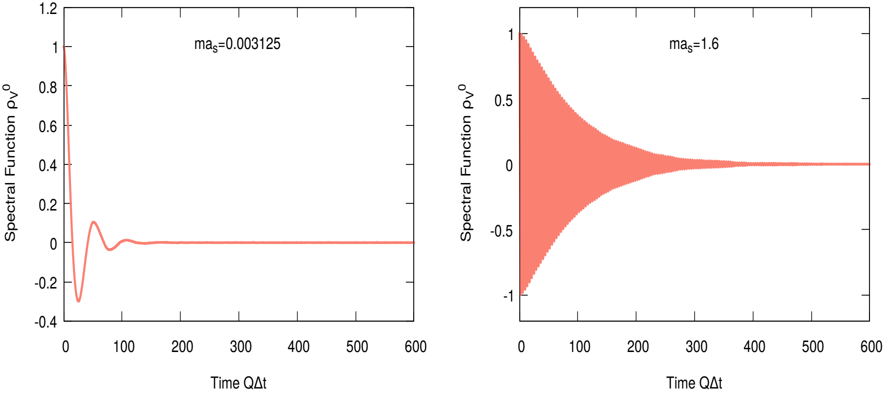

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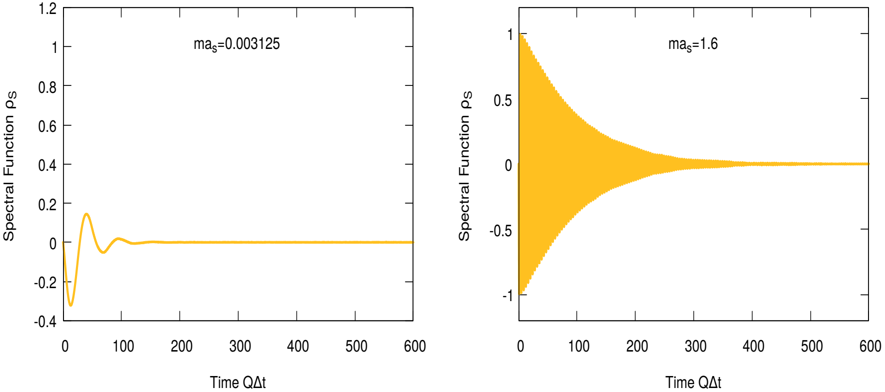

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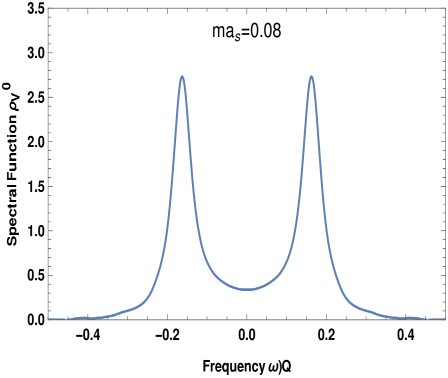

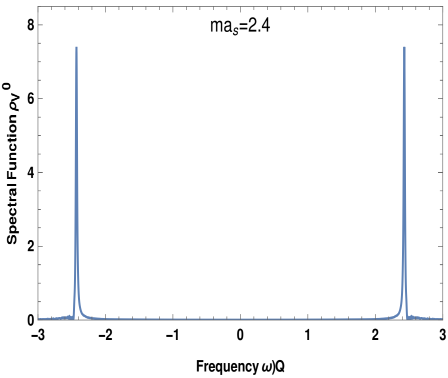

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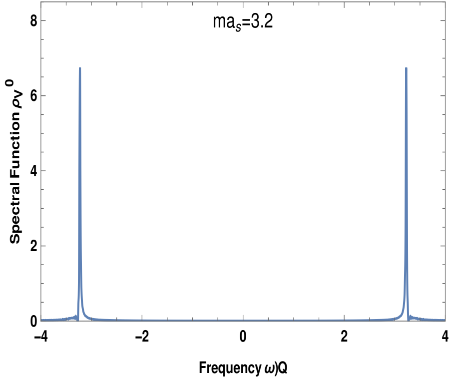

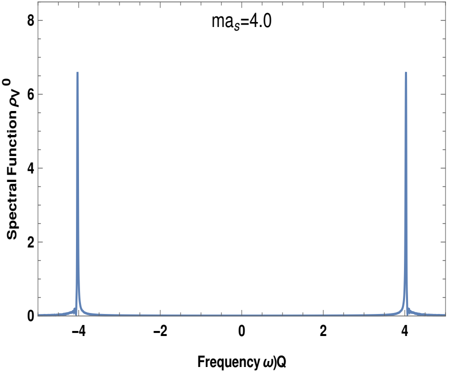

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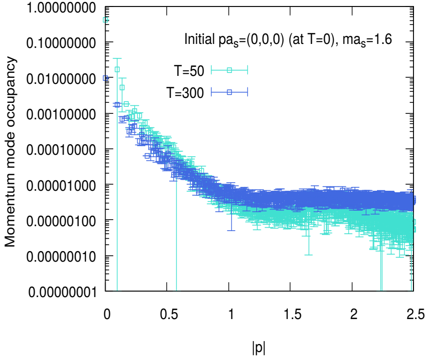

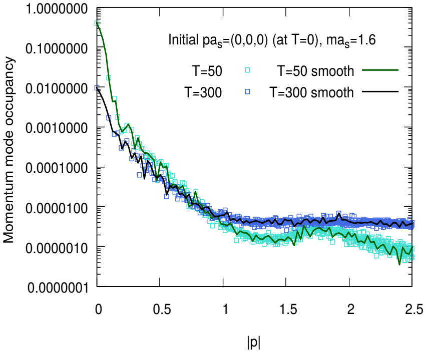

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