Cavitation and thermal dilepton production in QGP

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Introduction

- In heavy ion collision after initial thermalisation, hydrodynamics is used to model the evolution of Quark-Gluon Plasma (QGP).
- QGP: Low shear viscosity, however recent theoretical studies indicate high values of bulk viscosity near T_C.
- We study the role of *non-ideal* effects near T_c due to bulk viscosity, EoS and viscosity induced cavitation on the thermal dilepton production.
- Thermal dileptons carry information regarding the early phase of hot fireball created in heavy ion collision and we can use these dilepton spectra to get the information about the viscosity of QGP.

Relativistic Dissipative Hydrodynamics

- Energy momentum tensor of the fluid element is $T^{\mu\nu} = \varepsilon\, u^\mu\, u^\nu \, - P\, \Delta^{\mu\nu} + \Pi^{\mu\nu}$ with viscous contribution $\Pi^{\mu\nu} = \pi^{\mu\nu} - \Delta^{\mu\nu}\,\Pi$, where $\pi^{\mu\nu}$ (traceless) gives the shear viscosity and Π gives the bulk viscosity contributions.
- We use second order causal dissipative hydrodynamics (Israel-Stewart) to model the expanding plasma in heavy ion collisions
- Bjorken's prescription to describe the 1D boost invariant expanding flow using the proper time $\tau = \sqrt{t^2 - z^2}$ and space-time rapidity η_s; $t = \tau\, \cosh \eta_s$ and $z = \tau\, \sinh \eta_s$
- In the local rest frame of the fireball $T^{\mu\nu} = \mathrm{diag.}(\varepsilon, P_\perp, P_\perp, P_z)$
- Viscosity contribution in the effective pressure in the transverse and longitudinal directions:

$$P_\perp = P + \Pi + \tfrac{1}{2}\Phi \text{ and } P_z = P + \Pi - \Phi$$

- Φ is the shear ($\pi^{ij} = \mathrm{diag}(\Phi/2, \Phi/2, -\Phi)$) and Π is the bulk viscosity contributions to the equilibrium pressure P.
- The set of equations dictating the longitudinal expansion of the medium are

$$\frac{\partial\varepsilon}{\partial\tau} = -\frac{1}{\tau}(\varepsilon + P + \Pi - \Phi)\,,$$

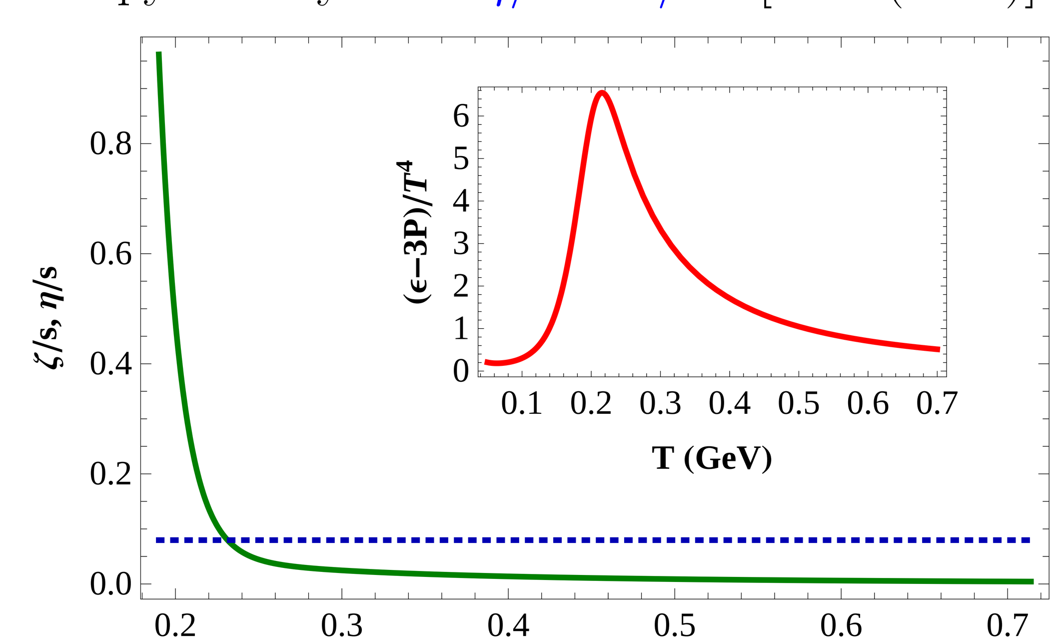
$$\frac{\partial\Phi}{\partial\tau} = -\frac{\Phi}{\tau_\pi} + \frac{2}{3\beta_2}\frac{1}{\tau} - \frac{1}{\tau_\pi}\left[\frac{4\tau_\pi}{3\tau}\Phi + \frac{\lambda_1}{2\eta^2}\Phi^2\right],$$

$$\frac{\partial\Pi}{\partial\tau} = -\frac{\Pi}{\tau_\Pi} - \frac{1}{\beta_0\tau}.$$

- $\tau_\pi(T) = \tau_\Pi(T)$ as we don't have any reliable prediction for τ_Π and $\tau_\pi = \frac{2-\ln 2}{2\pi T}$
- EoS is needed to close the system.

Non-ideal effects: EoS and Bulk viscosity

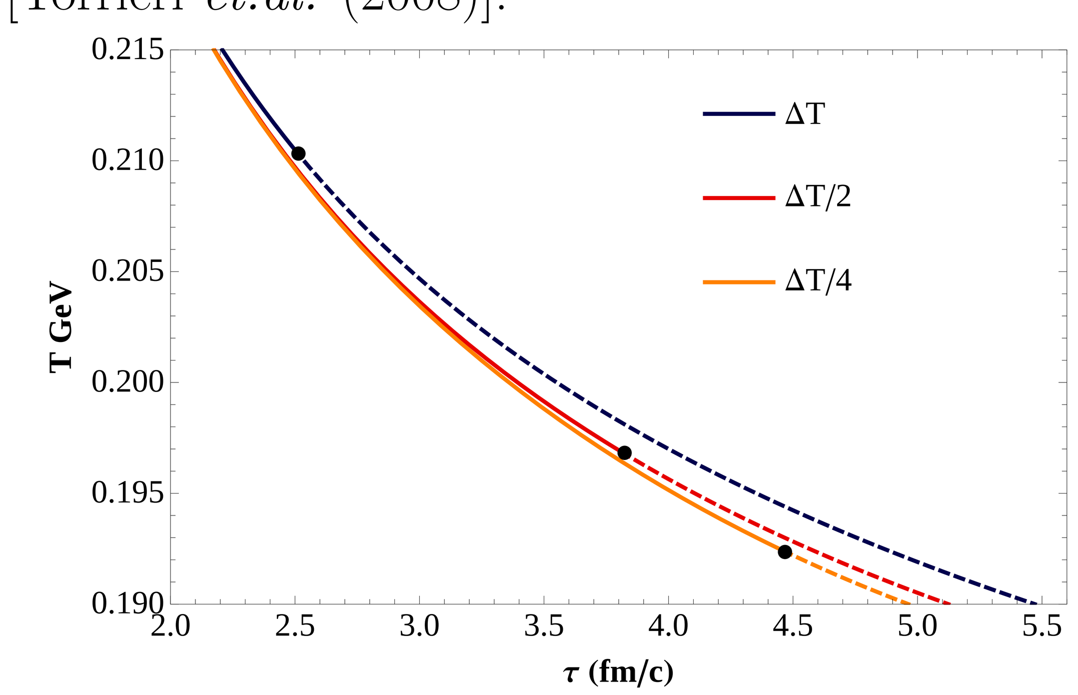
- We use lattice QCD result for *non-ideal* ($\varepsilon - 3P \neq 0$) EoS [A. Bazavov *et al.* (2009)], which is very important near T_c.
- Unlike *ideal* EoS ($\varepsilon - 3P = 0$), bulk viscosity is not negligible with non-ideal case.
- We use the result of Meyer (2008) based upon Lattice QCD calculations for ζ/s, which indicate the existence a peak of ζ/s near T_c, however the height and width of this curve are not well understood.
- We use the lower bound of the shear viscosity to entropy density ratio $\eta/s = 1/4\pi$ [KSS (2005)]



$(\varepsilon - 3P)/T^4, \zeta/s$ (and $\eta/s = 1/4\pi$) as functions of temperature T. Around critical temperature ($T_c = .190$ GeV) $\zeta \gg \eta$ and departure of equation of state from ideal case ($\varepsilon = 3P$) is large.

Hydrodynamic evolution and Cavitation

- In order to understand the temporal evolution of temperature $T(\tau)$, pressure $P(\tau)$ and viscous stresses - $\Phi(\tau)$ and $\Pi(\tau)$, we numerically solve the hydrodynamical equations describing the longitudinal expansion of the plasma
- Initial conditions: we use relevant initial condition for RHIC $\tau_0 = 0.5 fm/c, T_0 = .310 GeV$ and initial values of viscous contributions as $\Phi(\tau_0) = 0$ and $\Pi(\tau_0) = 0$.
- Since $\Pi < 0$, from the definition of longitudinal pressure $P_z = P + \Pi - \Phi$ if either Π or Φ is large enough it can drive P_z to negative values.
- $Pz = 0$ defines the condition for the *cavitation*.
- At this instant when of P_z becoming zero the expanding fluid will break apart in to fragments and *hydrodynamic treatment looses its validity* [Torrieri *et.al.* (2008)].



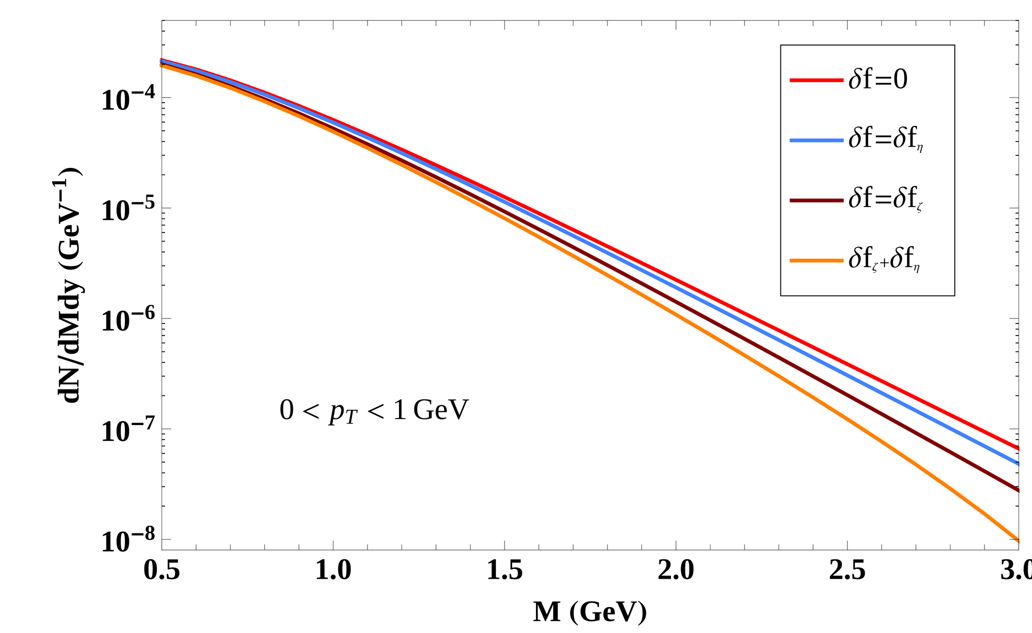
Temperature is plotted as a function of time. Solid line in the curve ends at the time of cavitation, while the dashed lines shows that how system would continue till T_c if cavitation is ignored. The parameter ΔT controls the width of the ζ/s curve

Viscous Corrections to the Thermal Dilepton rates

- In QGP the dominant mechanism for the production of thermal dileptons is $q\bar{q} \rightarrow \gamma^* \rightarrow l^+ l^-$.
- Particle distribution functions are modified by viscosity $\Longrightarrow$ modified dilepton rates
- Modified distribution function from corrections due to η and ζ (up to quadratic order of momentum) are

$$f(p) = f_0(p)\left(1 + \frac{\eta/s}{2T^3}p^\alpha p^\beta \nabla_{\langle\alpha}u_{\beta\rangle} + \frac{2\zeta/s}{52T^3}p^\alpha p^\beta \Delta_{\alpha\beta}\Theta\right)$$

- Once the evolution of temperature is known from the hydrodynamical model, the *total dilepton spectrum* is obtained by integrating the total rate over the space time history of the collision.
- In the case of cavitation, we must be integrating the rates from τ_0 to τ_c instead of $\tau_1 = \tau_f$ (with $T(\tau_f) = T_c$) to avoid over-estimation of the yields [Bhatt *et.al* (2010)]



Invariant mass distribution of mid-rapidity thermal dileptons in RHIC scenario calculated at the low p_T regime. Effect of viscous corrections to the rate are shown separately.

Summary and Conclusions

- We have studied the effect of bulk and shear viscosities on thermal dilepton spectra from QGP at RHIC.
- Bulk viscosity plays a dual role in heavy-ion collisions: On one hand it enhances the time by which the system attains the critical temperature, while on the other hand it can make the hydrodynamical treatment invalid much before it reaches T_c by inducing cavitation.
- We have shown that if the phenomenon of cavitation is ignored one can have erroneous estimates of the dilepton production.

- References:
  Jitesh R. Bhatt, H. Mishra, and Sreekanth V, [arXiv:1101.5597] (2011)
  Jitesh R. Bhatt, H. Mishra, and Sreekanth V, JHEP 11 (2010) 106. [arXiv:1011.1969]

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