Mesonic spectral function in effective mean field model.

Chowdhury Aminul Islam

Saha Institute of Nuclear Physics
Kolkata

09.12.14

Based on arXiv:1411.6407

Prepared for XXI DAE-BRNS, 2014

Outline:

- Introduction.
- Correlation function and its spectral representation.
- Effective QCD models: NJL & PNJL.
- Ring approximation.
- Results.
- Conclusions.

- **Introduction.**
- Correlation function and its spectral representation.
- Effective QCD models: NJL & PNJL.
- Ring approximation.
- Results.
- Conclusions.

QCD phase diagram:

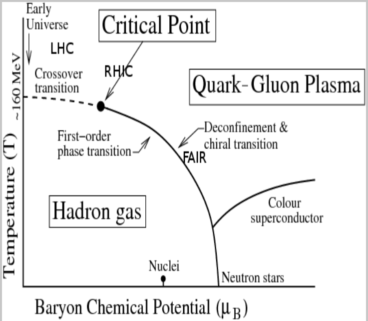


Figure : Phase Diagram of QCD

- Quantum Chromodynamics (QCD) exhibits a very rich phase structure at extreme conditions, *i.e.*, high temperature and/or high density.

Tools of studying QCD:

- Experiments like RHIC @ BNL and LHC @ CERN are exploring this noble state.
- New experiments are in the pipeline, as for example *FAIR* @ GSI, expected to run from 2018 onwards.
- Different methods: PQCD, LQCD & Effective QCD Models.
- Our work is based on Effective QCD Model, namely NJL and its Polyakov Loop extended version, PNJL.

- **Introduction.**
- Correlation function and its spectral representation.
- Effective QCD models: NJL & PNJL.
- Ring approximation.
- Results.
- Conclusions.

Generalities:

- Mesonic correlation functions are constructed from meson currents and they can be of different types.
- Many properties of deconfined, strongly interacting matter are reflected in the structure of the correlation functions and its spectral representation.
- Here we will talk only about the dilepton rate.
- Remember, the correlation functions and its spectral representation can be studied through many of the aforementioned methods to study QCD.

Euclidean current-current correlation function:

- Thermal Current-Current Correlator in Eucledean time τ:

$$\mathcal{G}_M^E(\tau,\vec{\mathbf{x}}) = \langle \mathcal{T}(J_M(\tau,\vec{\mathbf{x}})J_M^\dagger(0,\vec{\mathbf{0}}))\rangle_\beta$$
$$= T\sum_{n=-\infty}^{\infty}\int \frac{d^3p}{(2\pi)^3}\, e^{-i(\omega_n\tau+\vec{\mathbf{p}}\cdot\vec{\mathbf{x}})}\, \mathcal{G}_M^E(\omega_n,\vec{\mathbf{p}})$$

- Meson currents: $J_M = \bar{\psi}(\tau,\vec{\mathbf{x}})\Gamma_M\psi(\tau,\vec{\mathbf{x}})$, $\Gamma_M = \mathbb{I}, \gamma_5, \gamma_\mu, \gamma_\mu\gamma_5$.

- The spectral function $\sigma_H(\omega,\vec{q})$ can be obtained through analytic continution of $\mathcal{G}_H^E(\omega_n = \omega + i\epsilon)$ in full complex plane

$$\sigma_H(\omega,\vec{\mathbf{p}}) = \frac{1}{\pi}\mathrm{Im}\; \mathcal{G}_H^E(\omega+i\epsilon,\vec{\mathbf{p}})$$

- $H = (00, ii, V)$ denotes (temporal, spatial, vector).

Dilepton rate from the spectral function:

- The differential dilepton production rate in terms of spectral function:

$$\frac{dR}{d^4xd^4Q} = \frac{5\alpha^2}{54\pi^2}\frac{1}{M^2}\frac{1}{e^{\omega/T}-1}\sigma_V(\omega,\vec{q})$$

with, $\alpha = \frac{e^2}{4\pi}$; $Q \equiv (q_0 = \omega, \vec{q})$ and $q = |\vec{q}|$, invariant mass $M = \sqrt{\omega^2 - q2}$.

- **Introduction.**
- Correlation function and its spectral representation.
- Effective QCD models: NJL & PNJL.
- Ring approximation.
- Results.
- Conclusions.

NJL model with vector type interaction:

- The Lagrangian we work with is the two flavour *NJL* model with isoscalar-vector type interaction:

$$\mathcal{L}_{\rm NJL} = \bar{\psi}(i\gamma_\mu\partial^\mu - m)\psi + \frac{G_S}{2}[(\bar{\psi}\psi)^2 + (\bar{\psi}i\gamma_5\vec{\tau}\psi)^2] - \frac{G_V}{2}(\bar{\psi}\gamma_\mu\psi)^2$$

- $\bar{\psi} = (\bar{\psi}_u, \bar{\psi}_d)$; $m = diag(m_u, m_d)$ with $m_u = m_d$ and $\vec{\tau} \rightarrow$ Pauli matrices.

- G_S and G_V denote coupling constants of the scalar type four-quark and vector type four-quark interactions respectively.

PNJL model with vector type interaction:

- In PNJL model we have a couple of more mean fields in the form of the expectation value of the Polyakov Loop fields Φ and $\bar{\Phi}$.

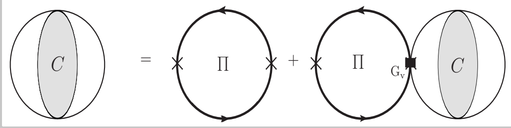
$$\begin{aligned} \mathcal{L}_{\rm PNJL} &= \bar{\psi}(i\gamma_\mu D^\mu - m)\psi + \frac{G_S}{2}[(\bar{\psi}\psi)^2 + (\bar{\psi}i\gamma_5\vec{\tau}\psi)^2] - \frac{G_V}{2}(\bar{\psi}\gamma_\mu\psi)^2 \\ &- \mathcal{U}[\Phi, \bar{\Phi}, T] \end{aligned}$$

- $D^\mu = \partial^\mu - ig\mathcal{A}_a^\mu\lambda_a/2$, $\mathcal{A}_a^\mu$ being the $SU(3)$ background fields and λ_a's are the Gell-Mann matrices.

- **Introduction.**
- Correlation function and its spectral representation.
- Effective QCD models: NJL & PNJL.
- Ring approximation.
- Results.
- Conclusions.

Ring approximation(RPA):

- We have studied the properties of the vector meson current-current correlation function with and without the isoscalar-vector interaction.
- The influence of isoscalar-vector interaction on the vector meson correlator is obtained using the ring approximation(RPA).



- The coupling constant G_V, which is considered to be a free parameter in our calculation, comes into the picture.

DSE for resummed vector correlator:

- The DSE for $C_{\mu\nu}$ within ring summation:

$$C_{\mu\nu} = \Pi_{\mu\nu} + G_V \Pi_{\mu\sigma} C^{\sigma}_{\nu},$$

where $\Pi_{\mu\nu}$ is one loop vector correlator.

- The general structure of the resummed vector correlator in medium reads (The master Eq.):

$$C_{\mu\nu} = \frac{\Pi_T}{1 - G_V \Pi_T} P^T_{\mu\nu} + \frac{\Pi_L}{1 - G_V \Pi_L} P^L_{\mu\nu},$$

$P^{L(T)}_{\mu\nu}$ are longitudinal (transverse) projecton operators.

Resummed vector correlation and spectral function:

- The resummed vector correlator:

$$C_{\mu\nu} = \frac{\Pi_T}{1 - G_V \Pi_T} A^T_{\mu\nu} + \frac{\Pi_L}{1 - G_V \Pi_L} A^L_{\mu\nu}$$

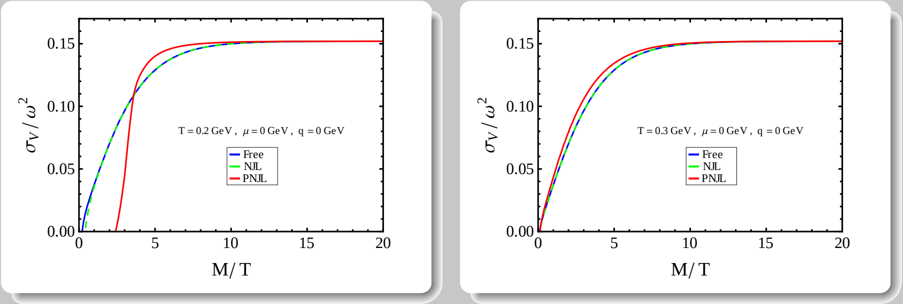
- Corresponding resummed spectral function:

$$\sigma_V^R = \frac{1}{\pi}\Big[\mathrm{Im}\, C_{00} - \mathrm{Im}\, C_{ii}\Big].$$

- The imaginary parts (temporal & spatial) of one loop vector correlator are associated with a energy conserving delta function that imposes a finite limit of the quark loop momentum: $p_\pm = \frac{\omega}{2}\sqrt{1 - \frac{4M_f^2}{M^2}} \pm \frac{q}{2}$.
- For a given G_V and T, the resummed spectral function picks up continuous contribution above the threshold, $M^2 > 4M_f^2$.

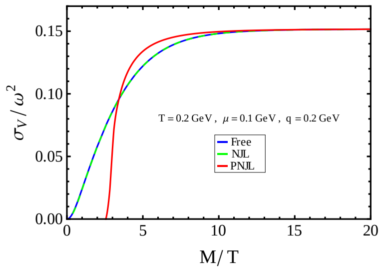
- **Introduction.**
- Correlation function and its spectral representation.
- Effective QCD models: NJL & PNJL.
- Ring approximation.
- Results.
- Conclusions.

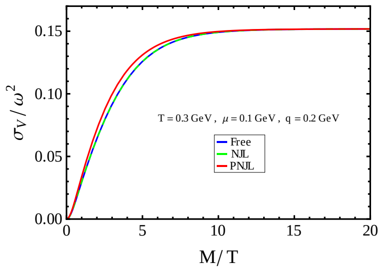
Scaled spectral function with $G_V = 0$:



- At $T = 200$ MeV the spectral function in PNJL model has larger threshold than NJL model because of the larger quark mass.
- At $\vec{q} = 0$ and $\mu_q = 0$ the spectral function is proportional to $[1 - 2f(E_p)]$, $f(E_p)$ is the fermion distribution function.
- Presece of Polyakov Loop $\rightarrow$ suppression in $f(E_p)$, hence enhancement in spectral function.

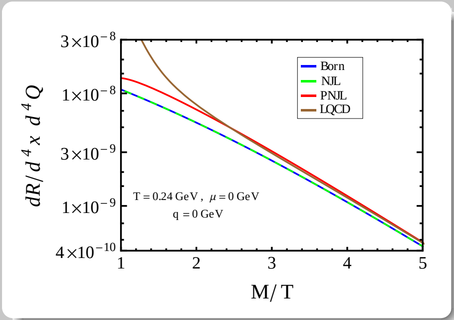
Scaled spectral function with $G_V = 0$:





- Plots of the scaled spectral function for nonzero q and μ.

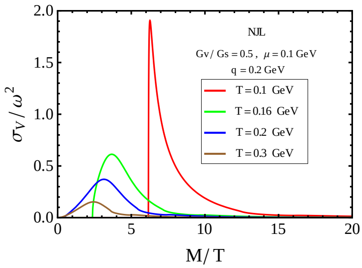
Dilepton rate with $G_V = 0$:



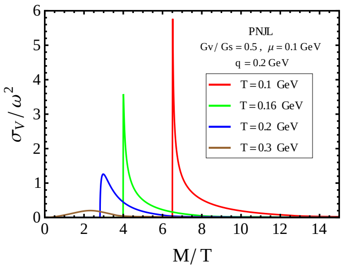
- As temperature increases, the dilepton rates for Born and NJL case become almost same.
- The result is compared with the available quenched QCD results [Ding *et. al.* PRD 83 (2011)].

Scaled spectral function for different T with $G_V \neq 0$:

NJL

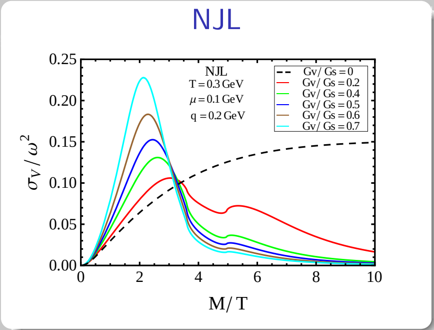


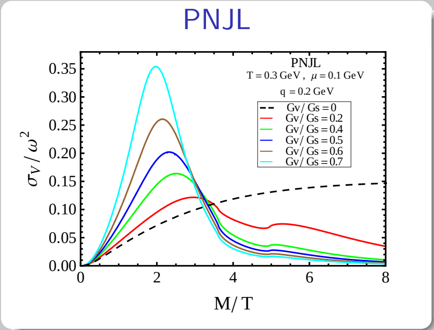
PNJL



- Bound state formation in the presence of G_V.
- The vector meson in NJL model acquires a width earlier compared to PNJL.
- Peaks get smeared as we increase the temperature.

Scaled spectral function with diffrent G_V:

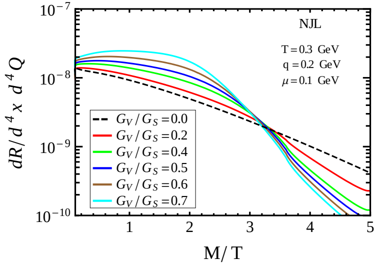




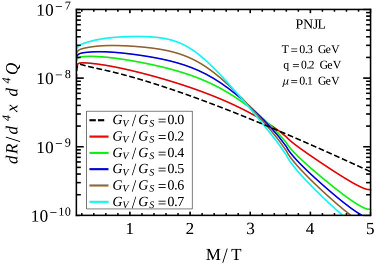
- Spectral strength increases with the increase of G_V.
- For a given G_V, spectral strength is always larger in PNJL model, due to the presence of the Polyakov Loop fields.

Dilepton rate with diffrent G_V:

NJL



PNJL



- The differential dilepton production rate increases with the increase of G_V.
- Dilepton production rate is always larger in PNJL model than NJL for a given G_v.

- **Introduction.**
- Correlation function and its spectral representation.
- Effective QCD models: NJL & PNJL.
- Ring approximation.
- Results.
- Conclusions.

Conclusions:

- Vector meson current-current correlation and spectral function are investigated in the framework of the mean field models namely, NJL & PNJL with and without isoscalar-vector interaction extension.
- The influence of the isoscalar-vector interaction is obtained using ring approximation (RPA).
- Then dilepton rate from a hot and dense matter has been studied using the resummed vector correlator.
- It has been observed that the dilepton rate gets enhanced in low invariant mass region when the vector coulping is nonzero.

Collaborators:

Sarbani Majumder, Najmul Haque and **Munshi G. Mustafa**.

Saha Institute of Nuclear Physics

Kolkata

Thank You

Backup Slide No:1

Temporal part:

$$\mathrm{Im}\Pi_{00}(\omega,\vec{q}) \;=\; \frac{N_f N_c}{4\pi}\int_{p_-}^{p_+} p\ dp\ \frac{4\omega E_p - 4E_p^2 - M^2}{2E_p q}\ \left[f(E_p-\tilde{\mu}) + f(E_p+\tilde{\mu}) - 1\right]$$

Spatial part:

$$\mathrm{Im}\Pi_{ii}(\omega,\vec{q}) \;=\; \frac{N_f N_c}{4\pi}\int_{p_-}^{p_+} p\ dp\ \frac{4\omega E_p - 4p^2 + M^2}{2E_p q}\ \left[f(E_p-\tilde{\mu}) + f(E_p+\tilde{\mu}) - 1\right]$$