## Mass splitting of vector meson and spontaneous spin polarization under rotation

Minghua Wei,
Mei Huang,
Yin Jiang

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tetradmetric and spin comnection The 3D phase structure

Minghua Wei, Mei Huang, Yin Jiang Institute of High Energy Physics, CAS

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Non-central Collisions

(a) Yin Jiang,Phys.Rev.C94(2016)

(C) Nucl.Phys.A 803 (2008)

## NJL model in co-rotating frame

Rotating frame: tetrad and spin connection

$$
\begin{equation*}
e_{\mu}^{a}=\delta_{\mu}^{a}+\delta_{i}^{a} \delta_{\mu}^{0} v_{i} \quad e_{a}^{\mu}=\delta_{a}^{\mu}-\delta_{a}^{0} \delta_{i}^{\mu} v_{i} \tag{1}
\end{equation*}
$$

Relation between metric and tetrad $g_{\mu \nu}=\eta_{a b} e^{a}{ }_{\mu} e^{b}{ }_{\nu}$

$$
\begin{equation*}
\Gamma_{\mu}=\frac{1}{4} \times \frac{1}{2}\left[\gamma^{a}, \gamma^{b}\right] \Gamma_{a b \mu} \quad \Gamma_{a b \mu}=\eta_{a c}\left(e_{\sigma}^{c} G_{\mu \nu}^{\sigma} e_{b}^{\nu}-e_{b}^{\nu} \partial_{\mu} e_{\nu}^{c}\right) \tag{2}
\end{equation*}
$$

$G^{\sigma}{ }_{\mu \nu}$ is the usual Christoffel connection determined by $g_{\mu \nu}$ The Lagrangian of the two-flavor NJL model in the co-rotating frame is given by

$$
\begin{align*}
\mathcal{L}= & \bar{\psi}\left[i \bar{\gamma}^{\mu}\left(\partial_{\mu}+\Gamma_{\mu}\right)-m\right] \psi \\
& +G_{S}\left[(\bar{\psi} \psi)^{2}+\left(\bar{\psi} i \gamma_{5} \vec{\tau} \psi\right)^{2}\right]-G_{V}\left[\left(\bar{\psi} \gamma_{\mu} \psi\right)^{2}+\left(\bar{\psi} \gamma_{\mu} \gamma_{5} \psi\right)^{2}\right] \tag{3}
\end{align*}
$$

## The 3D phase structure

$$
\begin{align*}
\Omega(T, \mu ; M, \tilde{\mu}, \omega)= & \int d^{3} \mathbf{r}\left\{\frac{(M-m)^{2}}{4 G_{S}}\right. \\
& -\frac{(\mu-\tilde{\mu})^{2}}{4 G_{V}}-\frac{N_{c} N_{f}}{16 \pi^{2}} T \sum_{n} \int d k_{t}^{2} \int d k_{z}\left[J_{n}\left(k_{t} r\right)^{2}+J_{n+1}\left(k_{t} r\right)^{2}\right]  \tag{4}\\
& \times\left[\ln \left(1+e^{\left(E_{k}-\left(n+\frac{1}{2}\right) \omega-\tilde{\mu}\right) / T}\right)+\ln \left(1+e^{-\left(E_{k}-\left(n+\frac{1}{2}\right) \omega-\tilde{\mu}\right) / T}\right)\right. \\
& \left.\left.+\ln \left(1+e^{-\left(E_{k}+\left(n+\frac{1}{2}\right) \omega+\tilde{\mu}\right) / T}\right)+\ln \left(1+e^{\left(E_{k}+\left(n+\frac{1}{2}\right) \omega+\tilde{\mu}\right) / T}\right)\right]\right\}
\end{align*}
$$

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## Meson mass



Figure 1: The 3D phase structure for chiral transition on $(\overline{\bar{T}}, \mu, \bar{\omega}) \begin{gathered}\text { hac } \\ 5 / 11\end{gathered}$

## Random phase approximation (RPA)

Quark propagator and onloop polarization function under rotation

$$
\begin{align*}
& S\left(\tilde{r} ; \tilde{r^{\prime}}\right)=\frac{1}{(2 \pi)^{2}} \sum_{n} \int \frac{d k_{0}}{2 \pi} \int k_{t} d k_{t} \int d k_{z} \frac{e^{i n\left(\phi-\phi^{\prime}\right)} e^{-i k_{0}\left(t-t^{\prime}\right)+i k_{z}\left(z-z^{\prime}\right)}}{\left[k_{0}+\left(n+\frac{1}{2}\right) \omega\right]^{2}-k_{t}^{2}-k_{z}^{2}-M^{2}+i \epsilon} \\
& \times\left\{[ [ k _ { 0 } + ( n + \frac { 1 } { 2 } ) \omega ] \gamma ^ { 0 } - k _ { z } \gamma ^ { 3 } + M ] \left[J_{n}\left(k_{t} r\right) J_{n}\left(k_{t} r^{\prime}\right) \mathcal{P}_{+}\right.\right.  \tag{5}\\
&\left.+e^{i(\phi-\phi)^{\prime}} J_{n+1}\left(k_{t} r\right) J_{n+1}\left(k_{t} r^{\prime}\right) \mathcal{P}_{-}\right] \\
&\left.-i \gamma^{1} k_{t} e^{i \phi} J_{n+1}\left(k_{t} r\right) J_{n}\left(k_{t} r^{\prime}\right) \mathcal{P}_{+}-\gamma^{2} k_{t} e^{-i \phi^{\prime}} J_{n}\left(k_{t} r\right) J_{n+1}\left(k_{t} r^{\prime}\right) \mathcal{P}_{-}\right\}, \\
& \Pi_{s}(q)=-i \int d^{4} \tilde{r} T r_{s f c}[i S(0 ; \tilde{r}) i S(\tilde{r} ; 0)] e^{i q \cdot \tilde{r}}, \tag{6}
\end{align*}
$$

where $\mathcal{P}_{ \pm}=\frac{1}{2}\left(1 \pm i \gamma^{1} \gamma^{2}\right)$ are projection operators Random phase approximation


Full propagator and gap equation

$$
\begin{equation*}
D_{\sigma}\left(q^{2}\right)=\frac{2 G_{S}}{1-2 G_{S} \Pi_{s}\left(q^{2}\right)}, \quad 1-2 G_{S} \Pi_{s}(0, \tilde{\nu})=\underline{0}, \tag{7}
\end{equation*}
$$

## Scalar Mesons

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Figure 2: scalar meson mass as a function of angular velocity at different chemical potentials and temperatures.

## Vector Mesons

The polarization functions of charged and neutral $\rho$ mesons are supposed to be the same under rotation

$$
\begin{equation*}
\Pi^{\mu \nu, a b}(q)=-i \int d^{4} \tilde{r} T r_{s f c}\left[i \gamma^{\mu} \tau^{a} S(0 ; \tilde{r}) i \gamma^{\nu} \tau^{b} S(\tilde{r} ; 0)\right] e^{i q \cdot \tilde{r}} \tag{8}
\end{equation*}
$$

The analysis of the Lorentz structure suggests the tensor can be decomposed according to its polarization directions

$$
\begin{equation*}
\Pi_{\rho}^{\mu \nu}=A_{1}^{2} P_{1}^{\mu \nu}+A_{2}^{2} P_{2}^{\mu \nu}+A_{3}^{2} L^{\mu \nu}+A_{4}^{2} u^{\mu} u^{\nu} \tag{9}
\end{equation*}
$$

where

$$
\begin{gather*}
P_{1}^{\mu \nu}=-\epsilon_{1}^{\mu} \epsilon_{1}^{\nu},\left(s_{z}=-1 \text { for } \rho \text { meson }\right), \\
P_{2}^{\mu \nu}=-\epsilon_{2}^{\mu} \epsilon_{2}^{\nu},\left(s_{z}=+1 \text { for } \rho \text { meson }\right),  \tag{10}\\
L^{\mu \nu}=-b^{\mu} b^{\nu},\left(s_{z}=0 \text { for } \rho \text { meson }\right) . \\
D_{\rho}^{\mu \nu}\left(q^{2}\right)=D_{1}\left(q^{2}\right) P_{1}^{\mu \nu}+D_{2}\left(q^{2}\right) P_{2}^{\mu \nu}+D_{3}\left(q^{2}\right) L^{\mu \nu}+D_{4}\left(q^{2}\right) u^{\mu} u^{\nu}, \tag{11}
\end{gather*}
$$

where coefficients $D_{i}$ have the RPA summation forms as:

$$
D_{i}\left(q^{2}\right)=\frac{2 G_{V}}{1+2 G_{V} A_{i}^{2}} \quad 1+2 G_{V} A_{i}^{2}=0
$$

## Vector Mesons



Figure 3: $\rho$ meson masses as a function of angular velocity at temperature $T=10 \mathrm{MeV}$.
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## Conclusion

Minghua Wei,

1. We have calculated the scalar, pseudoscalar and vector mesons' masses at finite temperature, chemical potential and angular velocity.
2. For the scalar and pseudoscalar cases the mass spectra are controlled by the chiral condensate which is the main mechanism generating the hadron mass in NJL model. 3. At large enough angular velocity the vector condensate vacuum would be preferred and the corresponding effective mass should be zero.

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## Thanks for Your Attention!

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