Phase diagram in entanglement PNJL model

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Abstract

The QCD phase diagram and transitions between quark and hadron phases are in the focus of recent investigations in both theoretical and experimental fields of heavy energy physics. For a description of matter at high temperature and density effective models of Nambu-Jona-Lasinio-type have proven most useful. On the basis of NJL-type models it is possible to describe the chiral restoration transition and to describe the quark-gluon coupling and confinement transition, when the Polyakov loop is included. The Polyakov loop extended NJL (PNJL) model can reproduce results of lattice QCD at zero and imaginary chemical potential, where LQCD has no sign problem. In this poster contribution we present the dependence of the first-order phase transition line and its critical endpoint in the PNJL model phase diagram when the following aspects are taken into account:

- the parametrization of the effective potential $\mathcal{U}(\Phi,\bar\Phi;T)$;
- including of the quarks repulsion (vector interaction);
- an additional interaction between quarks and gluons.

Model description

Lagrangian of PNJL model

$$\mathcal{L}_{\rm PNJL} = \bar q\left(i\gamma_\mu D^\mu - \hat m_0 - \gamma_0\mu\right)q + G_s\left[(\bar q q)^2 + (\bar q i\gamma_5\vec\tau q)^2\right] - \mathcal{U}\left(\Phi,\bar\Phi;T\right)$$

$D^\mu = \partial^\mu - iA^\mu$ is the covariant derivative
$\mathcal{U}\left(\Phi,\bar\Phi;T\right)$ is the effective potential

Effective potential describes confinement in PNJL model and it has to

- describe Z_3-symmetry
- describe lattice thermodynamics in pure gauge sector (see block about parameters)

That's why it can have various mathematical forms.

The effective potential approximaions :
Polynomial form

$$\frac{\mathcal{U}\left(\Phi,\bar\Phi;T\right)}{T^4} = -\frac{b_2(T)}{2}\bar\Phi\Phi - \frac{b_3}{6}\left(\Phi^3+\bar\Phi^3\right) + \frac{b_4}{4}\left(\bar\Phi\Phi\right)^2,$$

where T_0 is deconfinement temperature in lattice QCD $T_0 = 0.27 GeV$ and parameter $b_2(T)$

$$b_2(T) = a_0 + a_1\left(\frac{T_0}{T}\right) + a_2\left(\frac{T_0}{T}\right)^2 + a_3\left(\frac{T_0}{T}\right)^3.$$

Parameters a_i, b_i are defined from Lattice QCD thermodynamics.

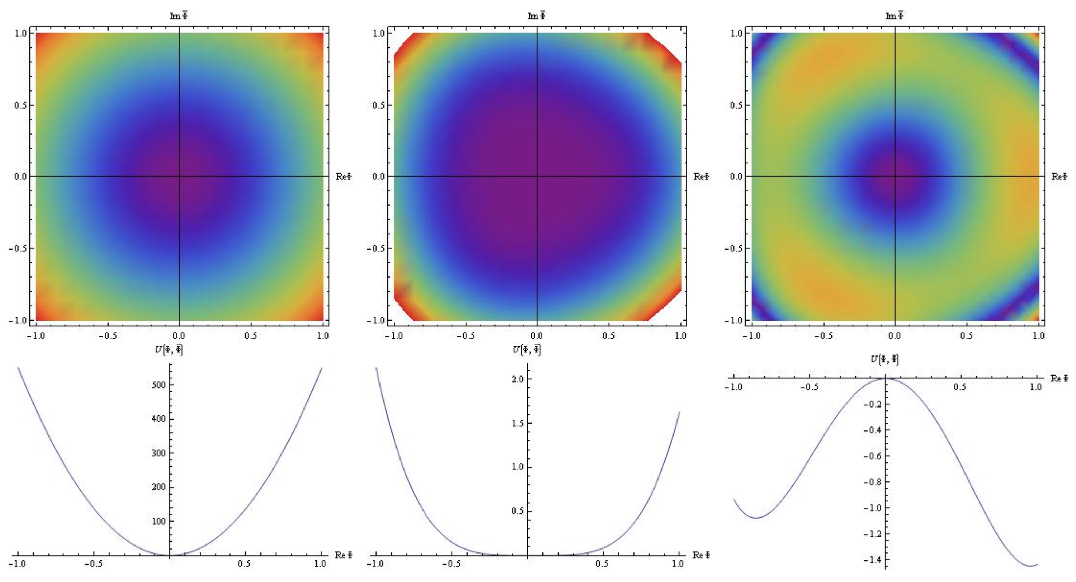

Fig. 1: Effective potential: $T < T_0$ - Z_3-symmetric phase, $T \sim T_0$ - critical conditions, $T > T_0$ - Z_3 symmetry brocken phase

Mean field approximation:

$$\Omega(\Phi,\bar\Phi,m,T,\mu) =$$
$$\mathcal{U}\left(\Phi,\bar\Phi;T\right) + G\langle\bar q q\rangle^2 - 2N_cN_f\int\frac{d^3p}{(2\pi)^3}E_p - 2N_fT\int\frac{d^3p}{(2\pi)^3}\left[\ln N_\Phi^+(E_p) + \ln N_\Phi^-(E_p)\right],$$

where functions $N_\Phi^\pm(E_p) = \left[1 + 3\left(\Phi + \bar\Phi e^{-\beta E_p^\mp}\right)e^{-\beta E_p^\mp} + e^{-3\beta E_p^\mp}\right]$
Thermal equilibrium conditions are:

$$\frac{\partial\Omega_{\rm MF}}{\partial\sigma_{\rm MF}} = 0,\quad \frac{\partial\Omega_{\rm MF}}{\partial\Phi} = 0,\quad \frac{\partial\Omega_{\rm MF}}{\partial\bar\Phi} = 0.$$

Conclusion

In the work was shown that the thermodynamics of quark-hadron matter in PNJL model

- is determined by the effective potential approximation and parameters set;
- depends on value of vector interaction constant;
- has good agreement with Lattice QCD predictions when there is an additional entanglement of couple between quark and gluon sectors;

Impact of the effective potential parameters

Effective potential parameters

	polynomial form					
	a_0	a_1	a_2	a_3	b_3	b_4
old	6.75	-1.95	2.625	-7.44	0.75	7.5
new	6.47	-4.62	7.95	-9.09	1.03	7.32

The PNJL model vs LQCD results:

- Critical point at $T = 0$ is higher than in LQCD
- Temperature of deconfinement does not coincide with temperature of chiral transition

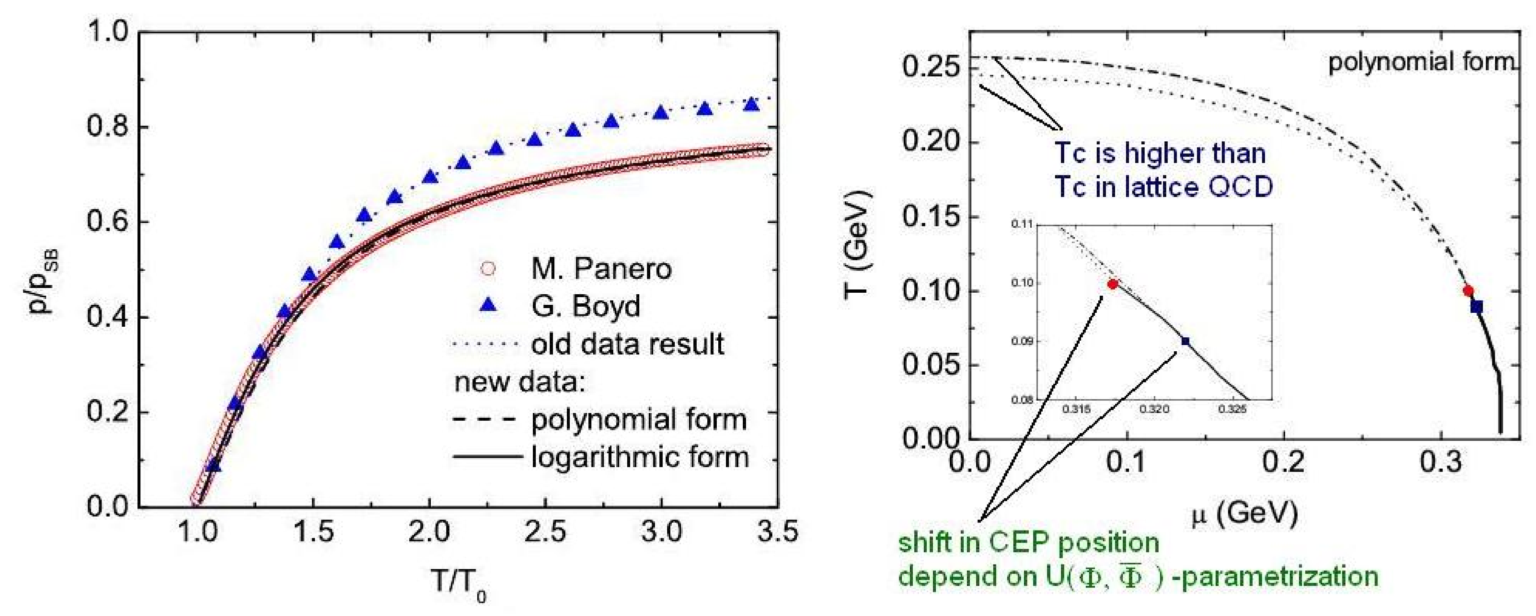

Fig. 2: Approximations of effective potential and the phase diagram for various approximations

PNJL: vector interaction

The vPNJL model vs LQCD results:

- Critical point at $T = 0$ is lower due renormalization T_0 to $T_0 = 0.19$ and is close to LQCD
- At critical value of vector couplings G_v, the first order transition disappears
- Temperature of deconfinement does not coincide with temperature of chiral transition!

Lagrangian

$$\mathcal{L}_{\rm vPNJL} = L_{PNJL} - G_v(\bar q\gamma_\nu q)^2,$$

Introduction of vector interaction leads to appearing of the normalized chemical potential

$$\tilde\mu = \mu - 4G_vN_cN_f\int_\Lambda\frac{d^3p}{(2\pi)^3}\frac{m}{E_p}\left[f_\Phi^+ + f_\Phi^-\right],$$

which is now included in the modified Fermi functions.

$$f_\Phi^\pm(E_p\mp\mu) = \left[\bar\Phi e^{-\beta(E_p\mp\tilde\mu)} + 2\Phi e^{-2\beta(E_p\mp\tilde\mu)} + e^{-3\beta(E_p\mp\tilde\mu)}\right]/N_\Phi^\pm(E_p)$$

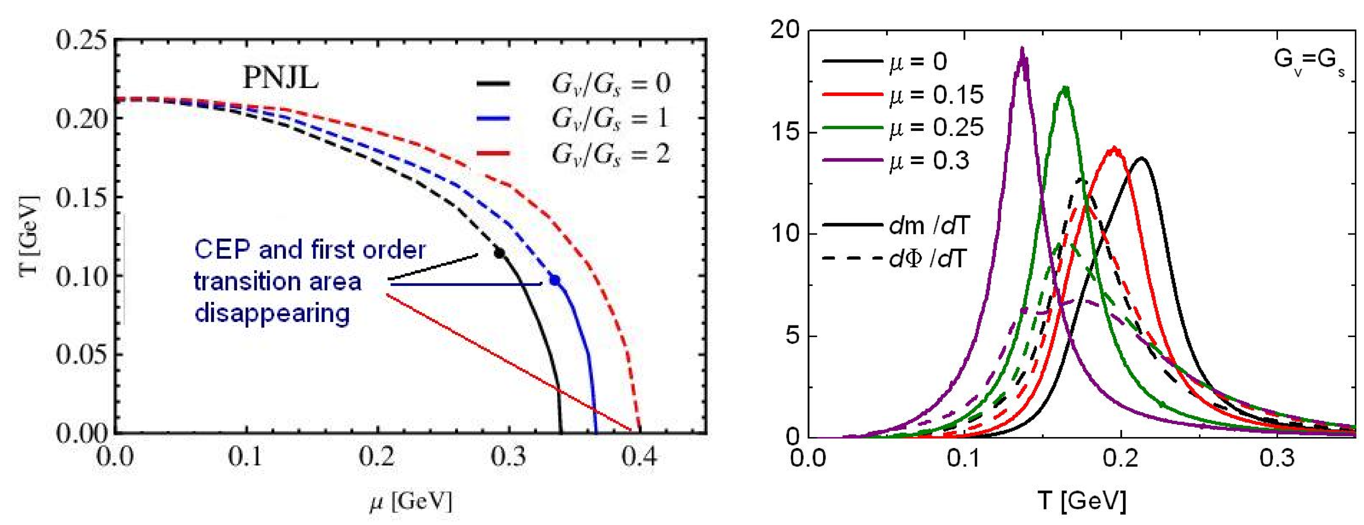

Fig. 3: Phase diagram and order parameters of PNJL model.

PNJL: entanglement

The EPNJL model vs LQCD results:

- Critical point at $T = 0$ is close to LQCD
- At critical value of vector couplings G_v, the first order transition disappears
- Temperature of deconfinement coincide with temperature of chiral transition!

The renormalized scalar and vector couplings:

$$\tilde G_s(\Phi) = G_s[1 - \alpha_1\Phi\bar\Phi - \alpha_2(\Phi^3+\bar\Phi^3)],$$
$$\tilde G_v(\Phi) = G_v[1 - \alpha_1\Phi\bar\Phi - \alpha_2(\Phi^3+\bar\Phi^3)],$$

with parameters $\alpha_1 = \alpha_2 = 0.2$ (of course, from LQCD approximation). Effect of entanglement coupling between quark and gauge sector in PNJL model:

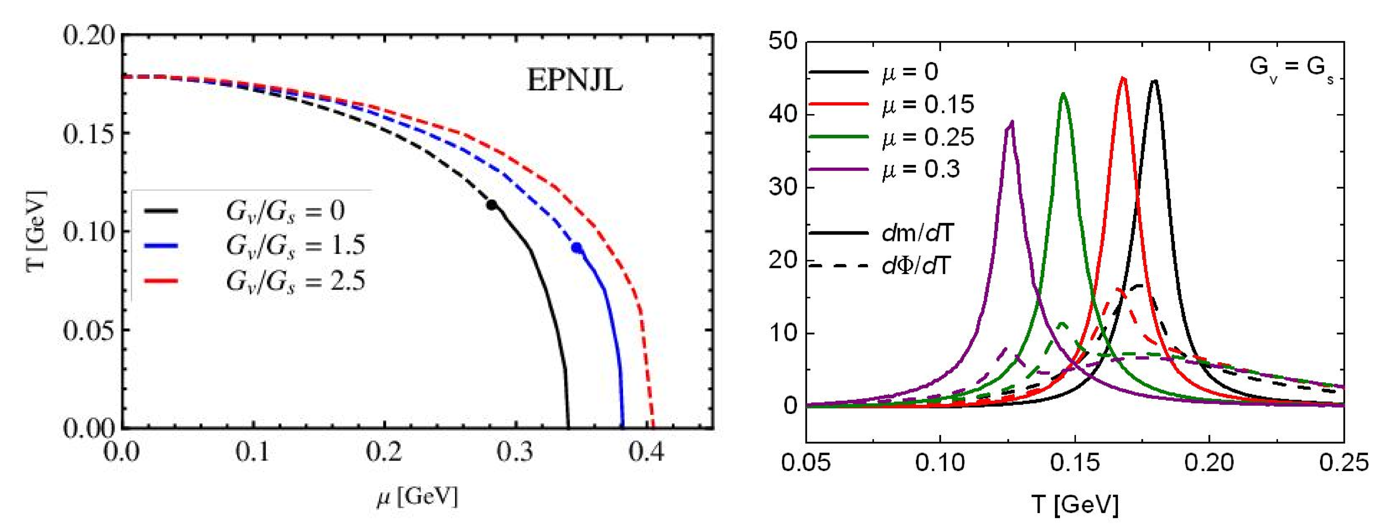

Fig. 4: Phase diagram and order parameters of EPNJL model.

References

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