Polyakov—Nambu—Jona-Lasinio Model :: Revisited

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MOTIVATION

QCD-inspired non-perturbative models provide an effective approach to study strongly interacting matter at high temperature and/or high density. One such model is the The Polyakov—Nambu--Jona-Lasinio (PNJL) model where chiral and deconfinement properties are realized under a single framework. The physics reflected from the behavior of thermodynamic observables extracted from here gives an insight into QCD. Recently Lattice-QCD (LQCD) data have been obtained in the continuum limit accompanied by lowering of the transition temperature. This motivates us to modify the effective potential in the PNJL model. Alongside analysis of the basic thermodynamics, we investigate the phase diagram and sketch the fluctuations of conserved charges.

REFRAMING THE MODEL

▪ As per the latest results, for the physical case of two light and a heavier strange quark mass, LQCD simulation at zero net baryon number density indicates this cross-over temperature to be T_c ~155 MeV and 150 MeV as reported from Hot-QCD and Wuppertal-Budapest collaborations respectively.

▪ The effective potential is remoulded as

$$\frac{\mathcal{U}'(\phi[A],\bar{\phi}[A],T)}{T^4} = \frac{\mathcal{U}(\phi[A],\bar{\phi}[A],T)}{T^4} - \kappa ln[J(\phi,\bar{\phi})]$$

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

2^{nd} term is the VdM term

▪ Both b_3 and b_4 are kept T independent, however b_2(T) now takes the form:

$$b_2(T) = a_0 + a_1 exp(-a_2 \frac{T}{T_0})\frac{T_0}{T}$$

▪ The new critical temperatures from thermal susceptibilities of mean-fields for 6-quark and 8-quark type of interactions come out to be 166.5 and 162.8 MeV respectively at zero chemical potential.

▪ The thermodynamic potential having the form :

$$\Omega = \mathcal{U}'(\Phi[A],\bar{\Phi}[A],T) + 2g_S\sum_{f=u,d,s}\sigma_f^2 - \frac{g_D}{2}\sigma_u\sigma_d\sigma_s + 3\frac{g_1}{2}(\sum_f\sigma_f^2)^2 + 3g_2\sum_f\sigma_f^4 - 6\sum_f\int_\lambda^\Lambda\frac{d^3p}{(2\pi)^2}E_{p_f}\Theta(\Lambda-|\vec{p}|) -$$
$$2\sum_f T\int_\lambda^\infty\frac{d^3p}{(2\pi)^3}ln[1+3(\Phi+\bar{\Phi}exp(\frac{-(E_{p_f}-\mu_f)}{T}))exp(\frac{-(E_{p_f}-\mu_f)}{T})+exp(\frac{-3(E_{p_f}-\mu_f)}{T})] -$$
$$2\sum_f T\int_\lambda^\infty\frac{d^3p}{(2\pi)^3}ln[1+3(\Phi+\bar{\Phi}exp(\frac{-(E_{p_f}+\mu_f)}{T}))exp(\frac{-(E_{p_f}+\mu_f)}{T})+exp(\frac{-3(E_{p_f}+\mu_f)}{T})]$$

▪ All the terms having their usual significance.

▪ The parameter set used for this work is given in the adjacent table :

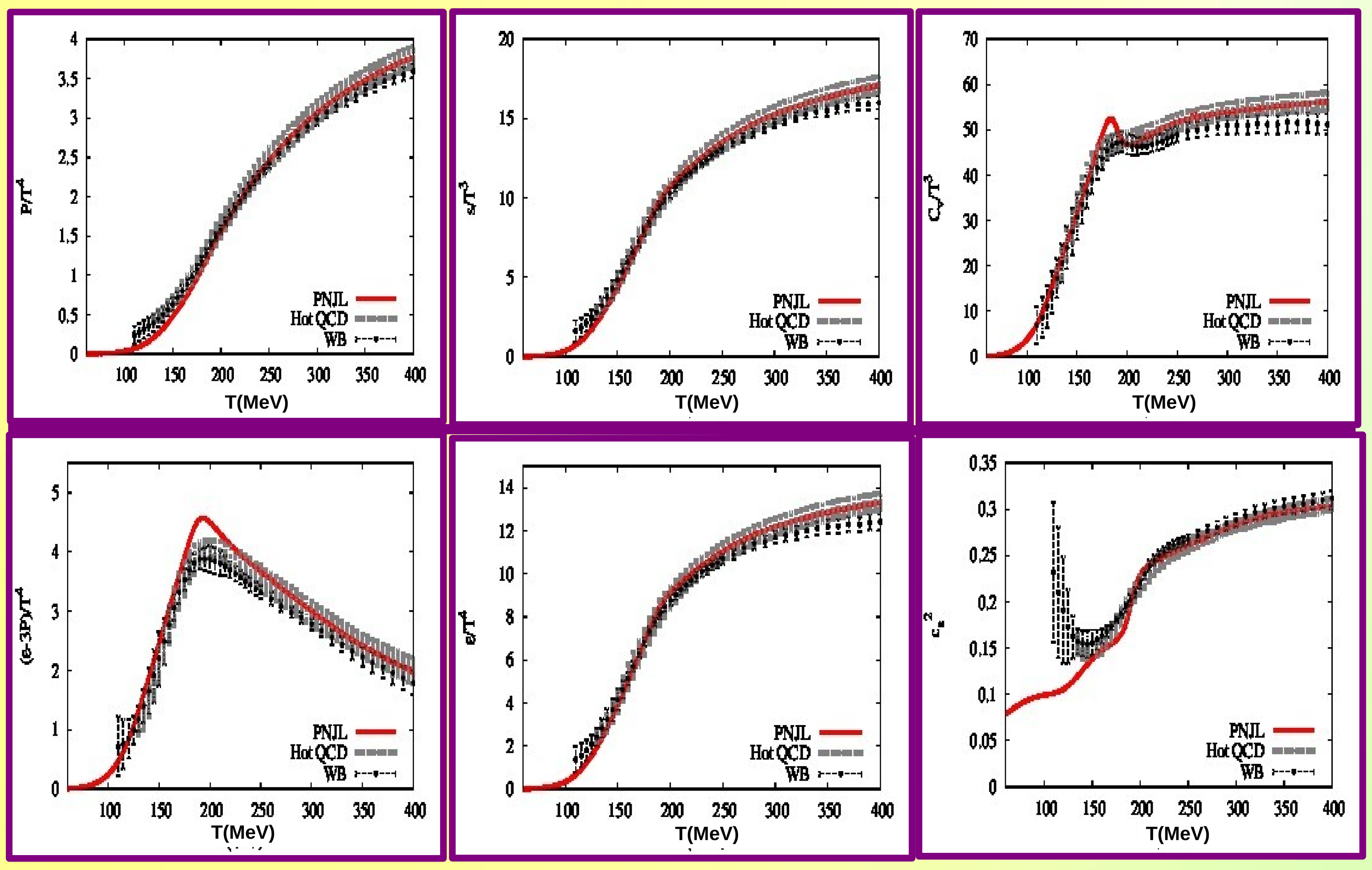
Interaction	a_0	a_1	a_2	b_3	b_4	κ
6-quark	6.75	-9.0	0.25	0.805	7.555	0.1
8-quark	6.75	-9.8	0.26	0.805	7.555	0.1

RESULTS

▪ The central motivation of this work is to contrast PNJL results using modified effective potential with recent LQCD data.

Thermodynamic Quantities

▪ Firstly, we recompute the thermodynamic observables which serve as essential candidates in order to properly understand the behavior of a system and nature of phase transitions happening during its evolution.

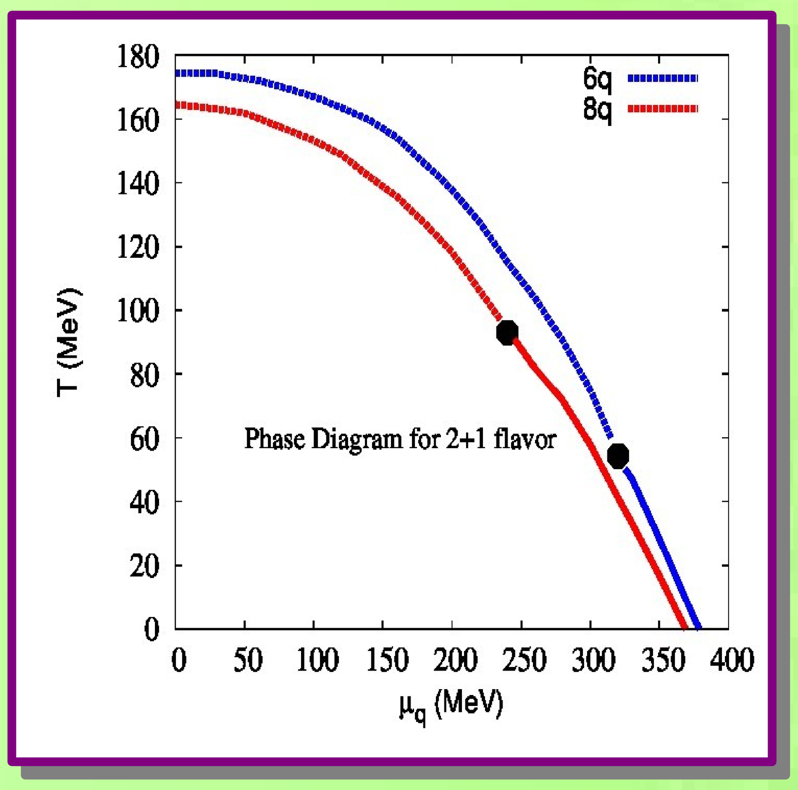


▪ With the model potential set at its modified form, we first compute the pressure in the infinite volume limit vis-a-vis Hot-QCD [1] and Wuppertal-Budapest predictions [2].

▪ From this pressure we then obtain the other thermodynamic variables of interest using the thermodynamic relations.

▪ All of the observables show a tendency of mismatch in lower temperature domain.

▪ Next we opt to draw the very important Phase Diagram shown in the right hand side figure.



▪ The cross-over temperatures at vanishing chemical potential are now subsequently decreased.

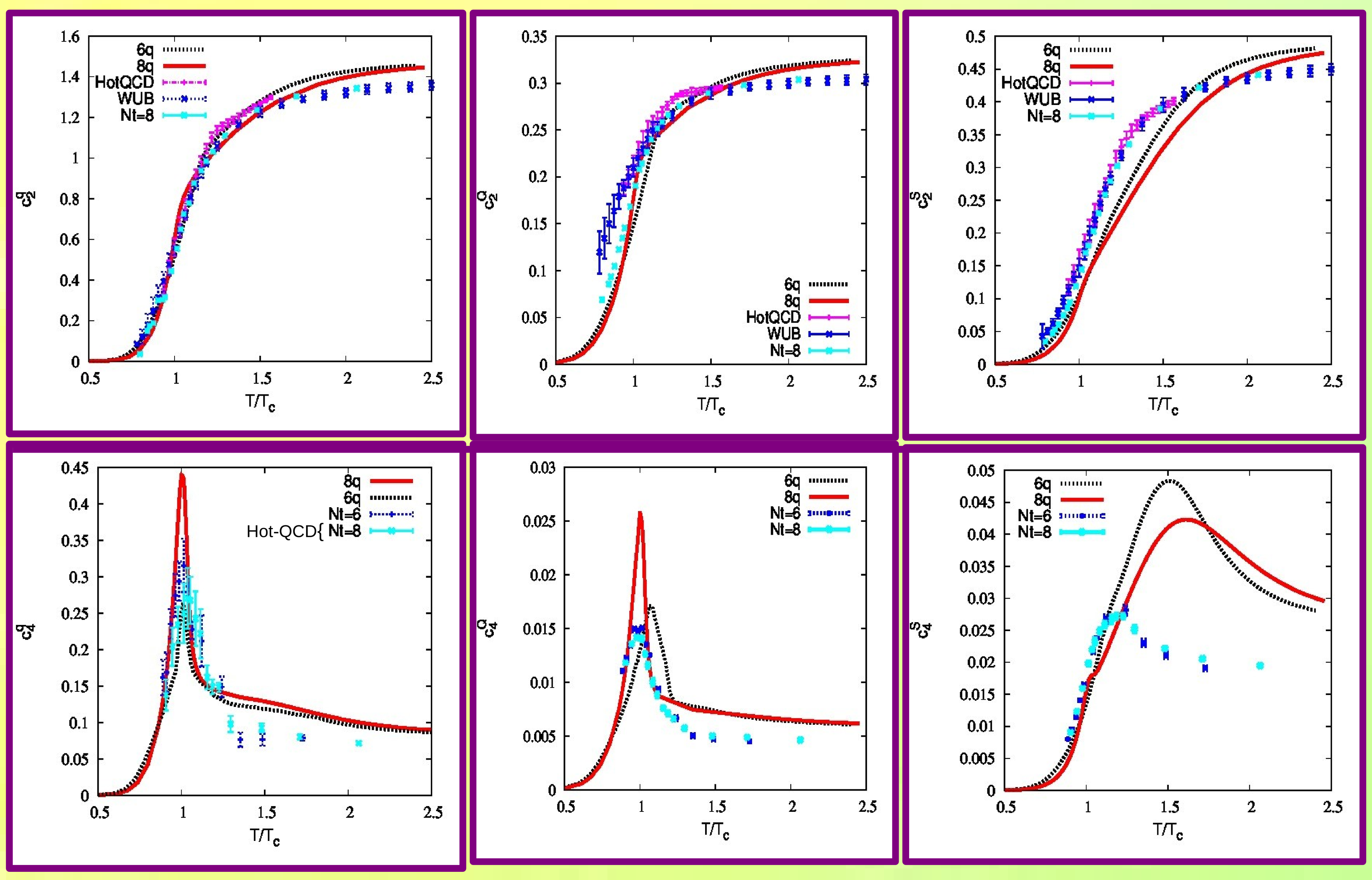
▪ Locating CEP is of crucial importance for analysis of heavy-ion physics.

▪ Modified phase diagram shows a shift in the CEP to higher μ_q and lower T which is quite encouraging for the critical point search.

Fluctuations of conserved charges

▪ Displayed are the results for 2^{nd} and 4^{th} order fluctuations for conserved charges like quark number (q), charge (Q), and strangeness (S) obtained using the relation ::

$$c_n(T) = \frac{1}{n!}\frac{\partial^n(-\Omega(T,\mu_X)/T^4)}{\partial(\frac{\mu_X}{T})^n}|_{\mu_X=0}$$



▪ These fluctuations are viable indicators for transitions from partonic state to hadronic matter.

▪ Both order fluctuations are contrasted to the available LQCD [3,4,5] results.

OBSERVATIONS

▪ We see that in the low temperature regime especially in the charge sector, there is a mismatch which indicates the lack of pionic degrees of freedom.

▪ We need to look for possible solutions which are under study.

REFERENCES

[1] A.Bazavov *et al.* PRD 90, 094503 (2014); PRD 85, 054503 (2012).
[2] S. Borsanyi *et al.* PLB 730, 99 (2014).
[3] A. Bazavov *et al.* PRD 86, 034509 (2012).
[4] S. Borsanyi *et al.* JHEP 1201 (2012) 138.
[5] A. Bazavov *et al.* PRL 111, 082301 (2013); PRL 109, 192302 (2012)

For details of the model : S. K. Ghosh *et al.* PRD 73, 114007 (2006).