Entanglement between deconfinement and chiral symmetry restoration

Phys. Rev. D 82, 076003 (2010)
arXiv: 1104.2394 (2011)

Yuji Sakai

Kyushu University

Takahiro Sasaki[A], Hiroaki Kouno[B], Masanobu Yahiro[A]

Kyushu Univ.[A], Saga Univ.[B]

Strategy

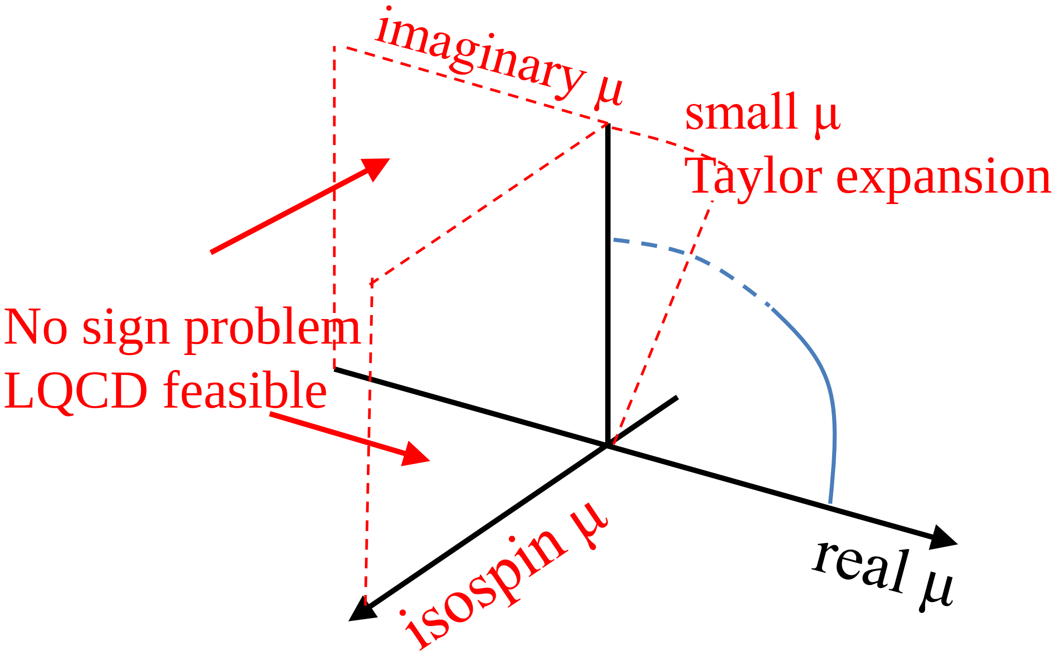
1) Sign problem at real chemical potential

2) No sign problem at imaginary μ, isospin μ.

   Lattice data is then available in these regions.

3) We construct a reliable effective model in these regions

   and then apply the model to real μ.



Polyakov loop extended NJL (PNJL) model

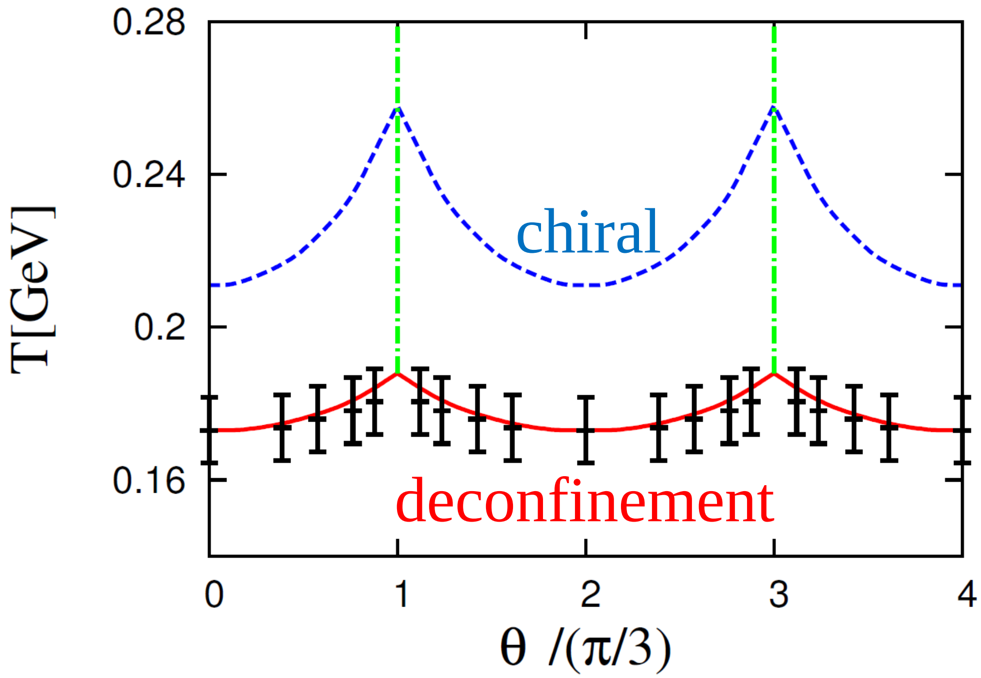
Fukushima; PLB591(04)

$$\mathcal{L} = \bar{q}(i\gamma_\nu D^\nu - m_0)q + G_s[(\bar{q}q)^2 + (\bar{q}i\gamma_5\vec{\tau}q)^2] - \mathcal{U}(\Phi[A], \Phi^*[A], T)$$

quark sector (Nambu-Jona-Lasinio type)

gluon sector
function of Polyakov loop (Φ)

LQCD/ Forcrand,Philipsen; NPB642



Roberge Weiss (RW) periodicity

$$\Omega(\theta) = \Omega(\theta + 2\pi/3)$$

$$\theta = \mathrm{Im}(\mu)/T$$

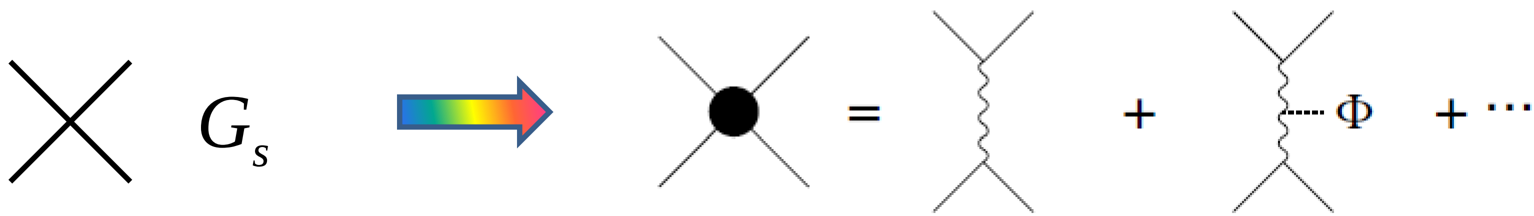
Entanglement PNJL (EPNJL)

The 4-quark vertex depends on the Polyakov loop (Φ).

$$G_{\rm s}(\Phi)[(\bar{q}q)^2 + (\bar{q}i\gamma_5\vec{\tau}q)^2]$$

PNJL

Entanglement-PNJL (EPNJL)



The function form is determined by respecting the RW periodicity.

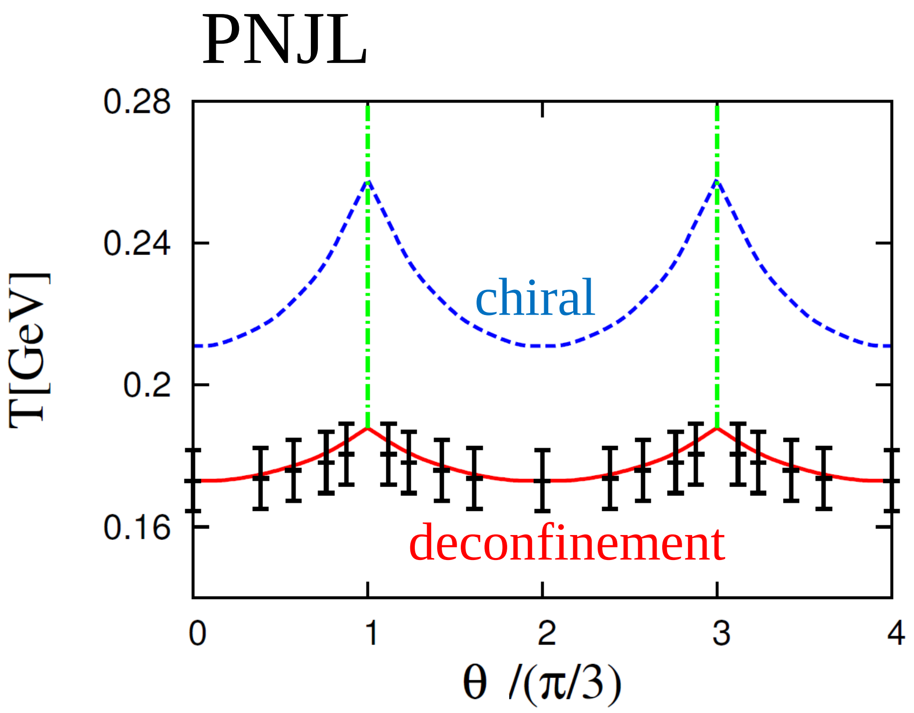
$$G_{\rm s}(\Phi) = G_{\rm s}[1 - \alpha_1\Phi\Phi^* - \alpha_2(\Phi^3 + \Phi^3)]$$

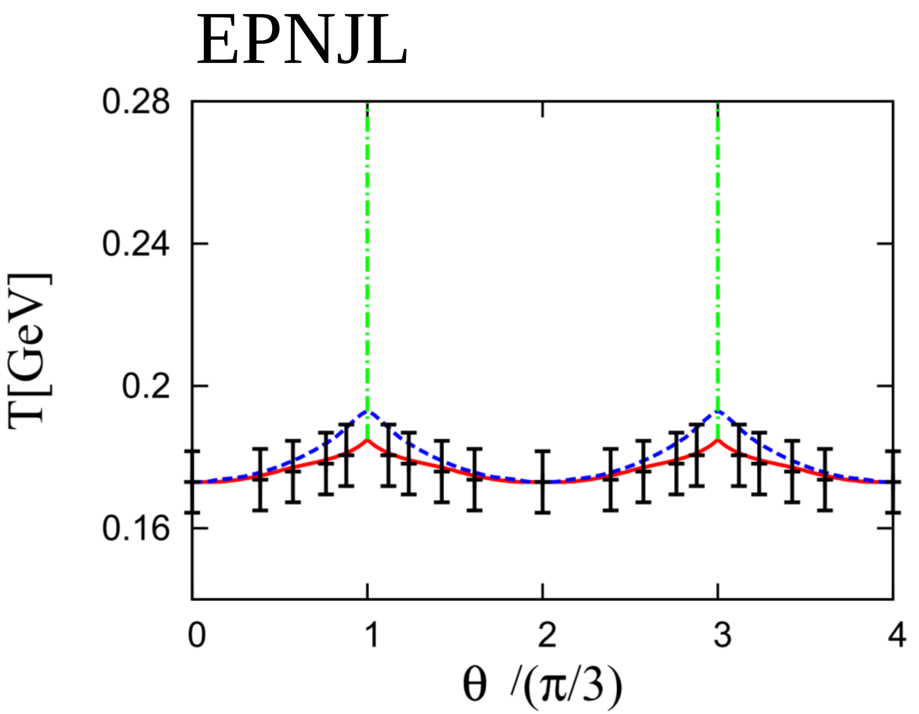
The parameters are determined to reproduce the LQCD @ imaginary μ.

$$\alpha_1 = \alpha_2 = 0.2$$

Result of the EPNJL model

The chiral and deconfinement transitions coincide with each other.
The EPNJL model gives a consistent result with the lattice data.





$$\theta = \mu/T$$

LQCD/ Forcrand,Philipsen; NPB642

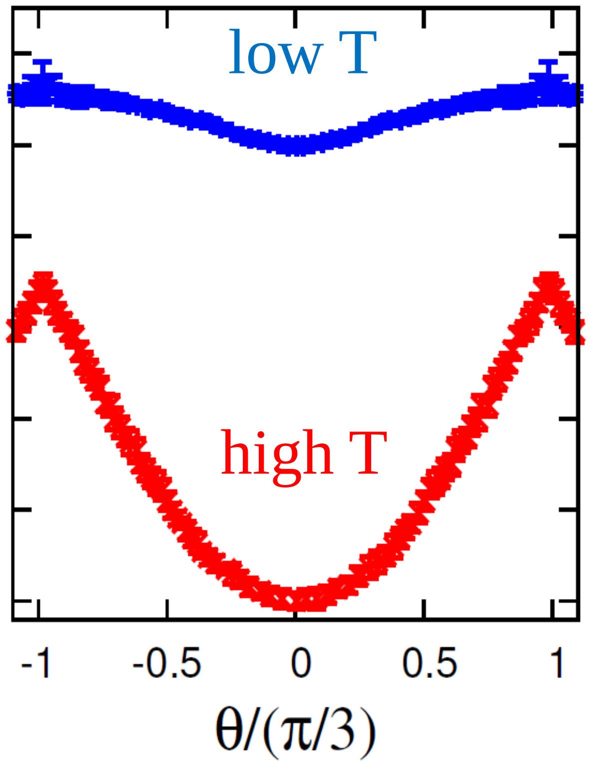
Roberge Weiss (RW) transition

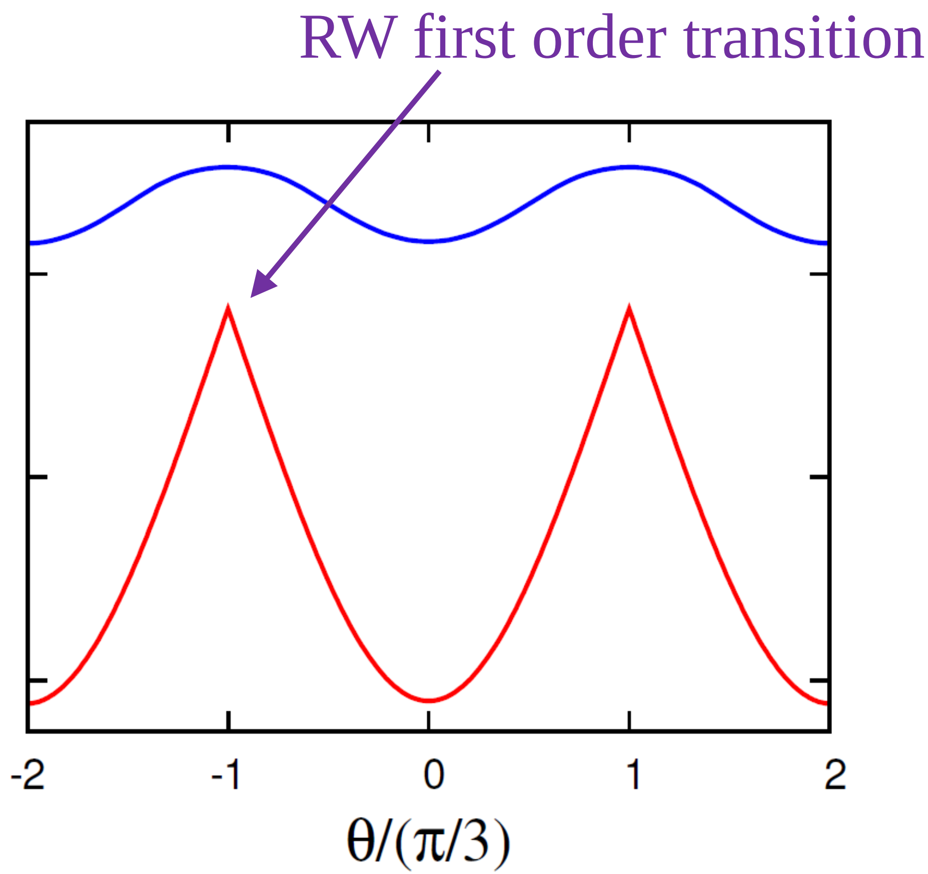
The thermodynamic potential has a cusp @ θ=π/3 and high T.

This means the first order transition occurs there.

$$\theta = \mu/T$$

LQCD/ Kratochvila, Forcrand; PRD**73**





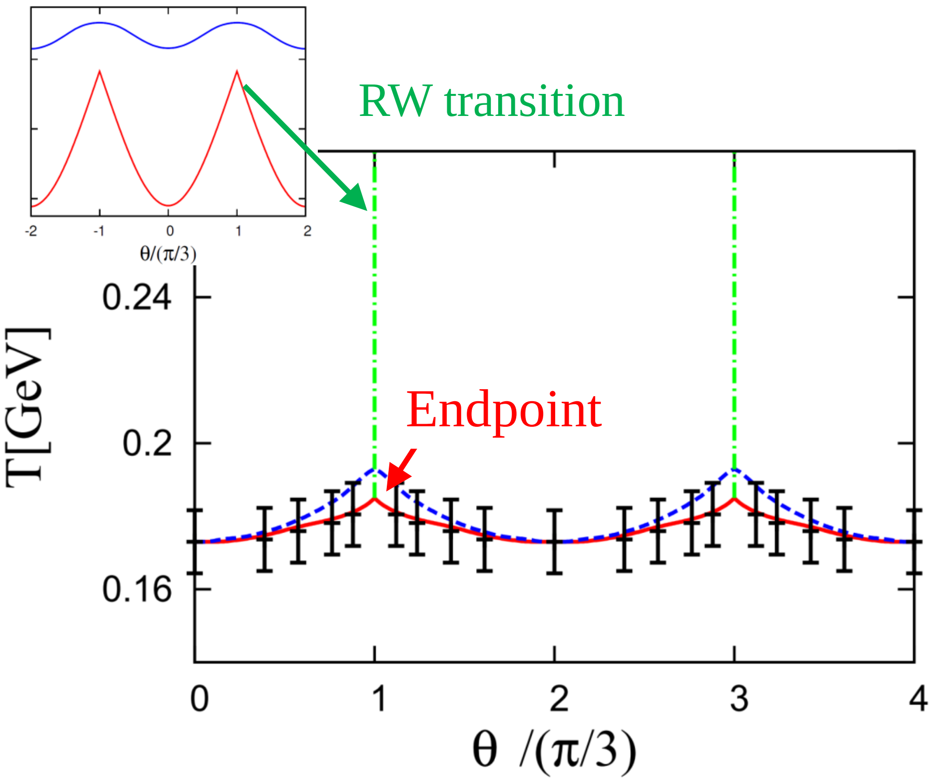
Mass dependence of the RW endpoint

LQCD : 1st (small mass) → 2nd (intermediate) → 1st (large).

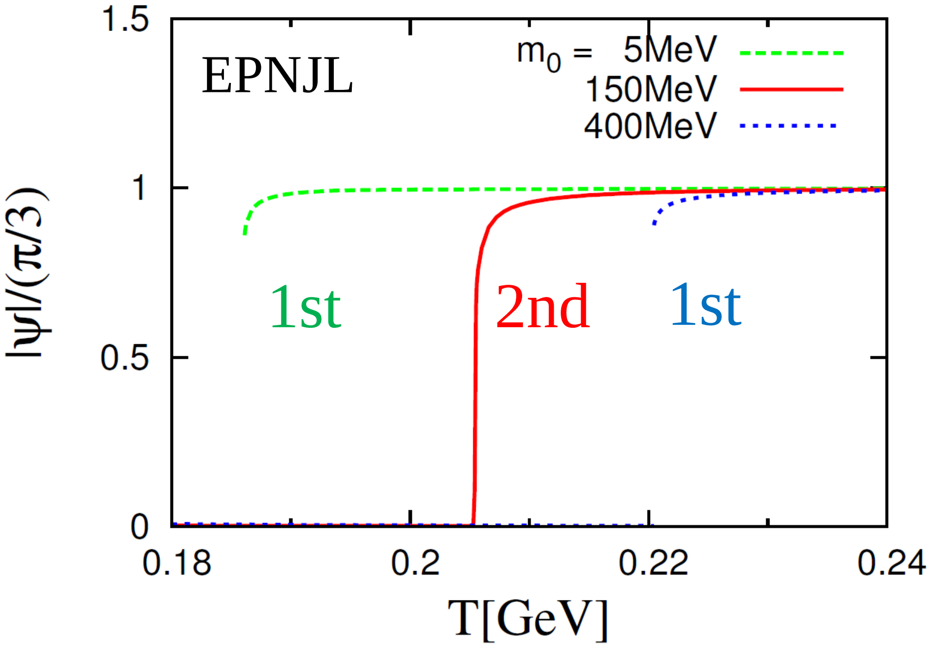
M. D'Elia, F. Sanfilippo, Phys. Rev. D 80, 11501 (2009).

PNJL : always 1st order.

EPNJL : consistent with the lattice result.



Phase of the Polyakov loop

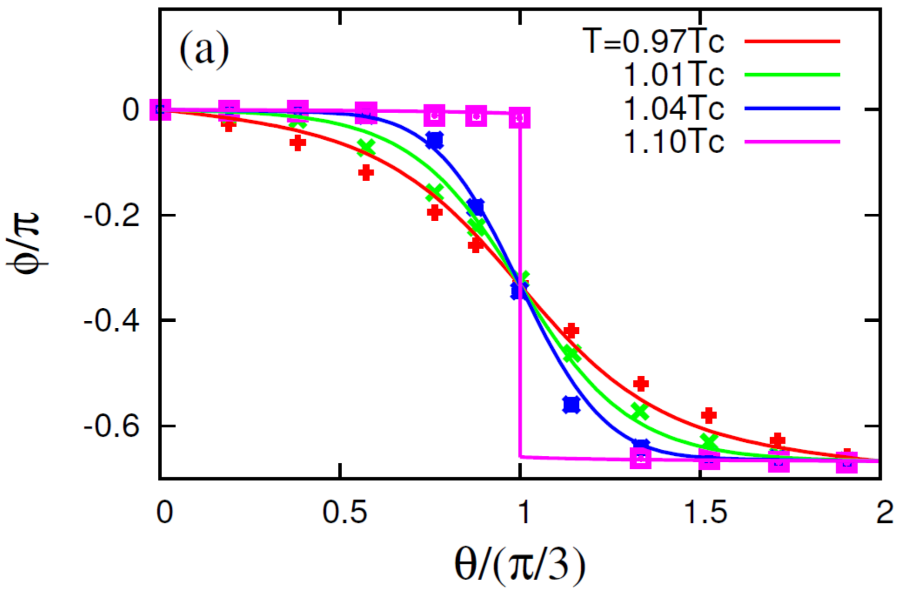


Phase of the Polyakov loop

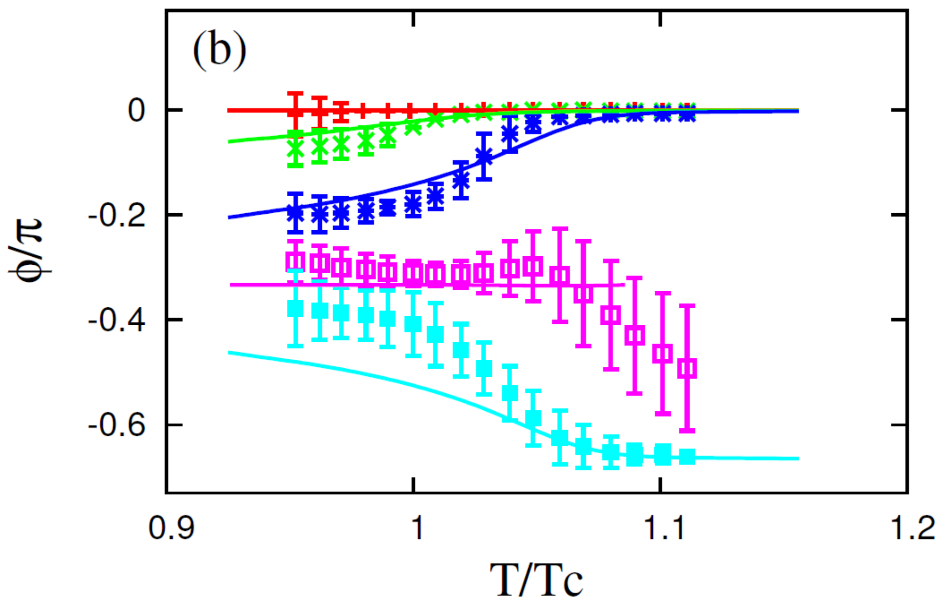
The EPNJL model gives the perfect agreement with LQCD.

LQCD/ Forcrand, Philipsen, NPB 642 (02).

θ dependence



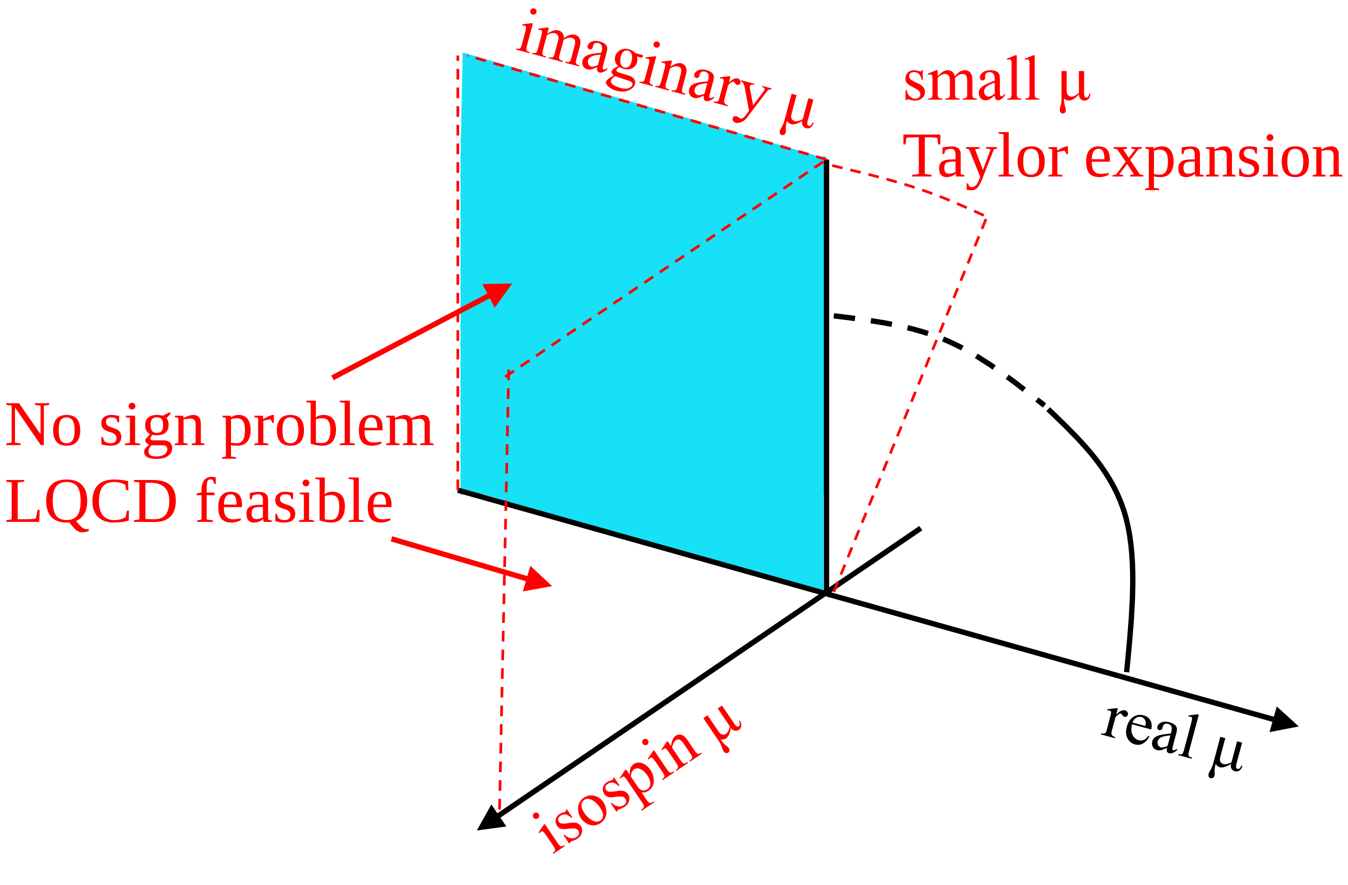
temperature dependence



Test of the EPNJL model

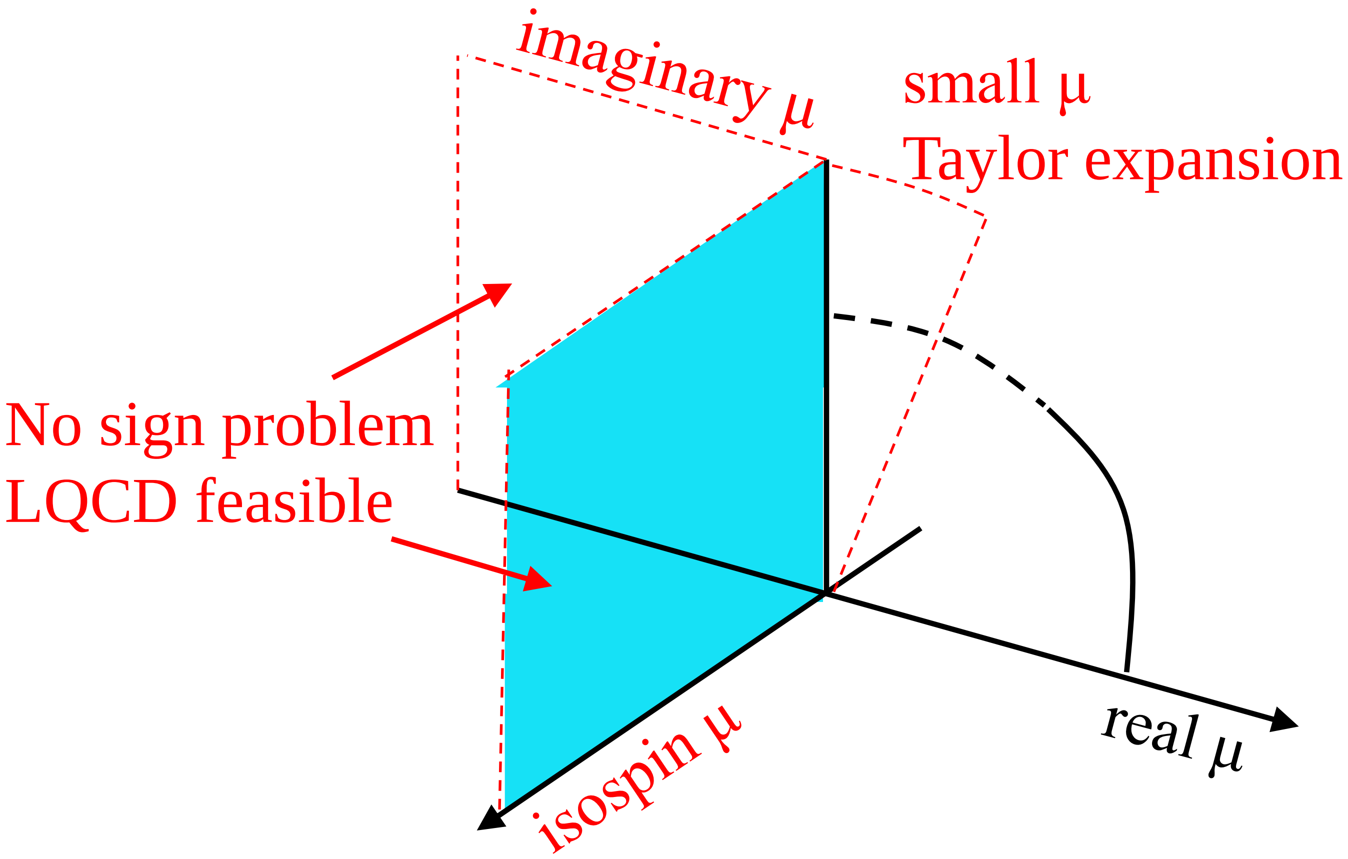
The EPNJL model reproduces the lattice data @ imaginary μ.

The reliability of the model is tested @ isospin μ and small real μ.

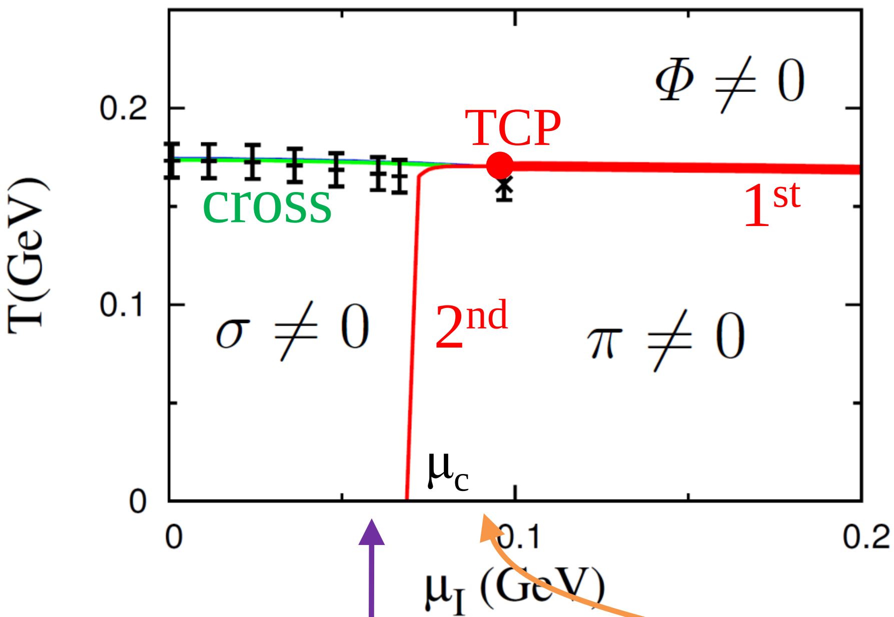


Test of the EPNJL model

We consider the isospin chemical potential region.

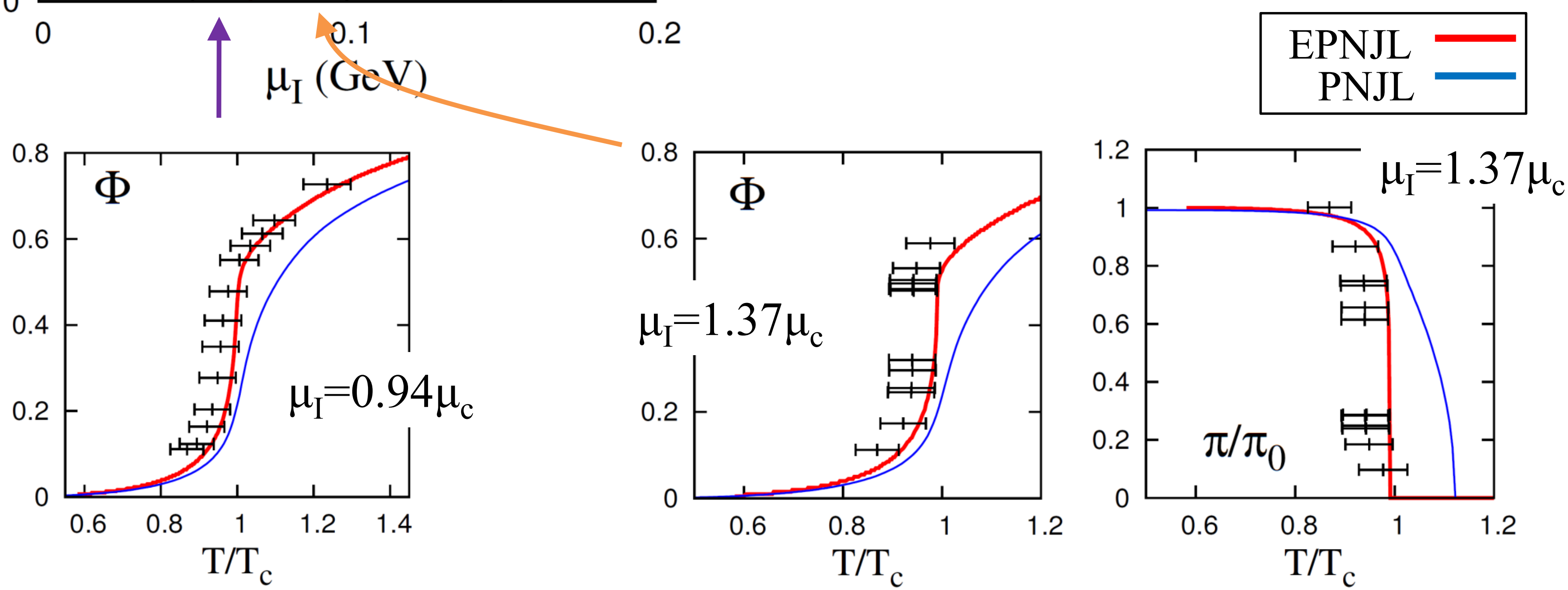


@ Isospin μ (μ_I)

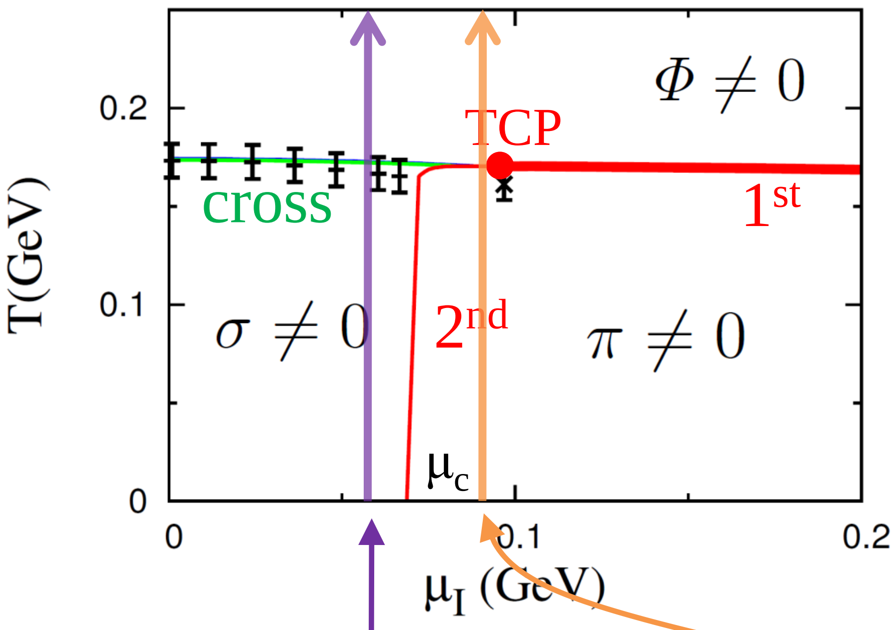


The EPNJL model is consistent with the lattice data in this region.

LQCD/ Kogut, Sinclair
Phys. Rev. D 70, 094501(04)

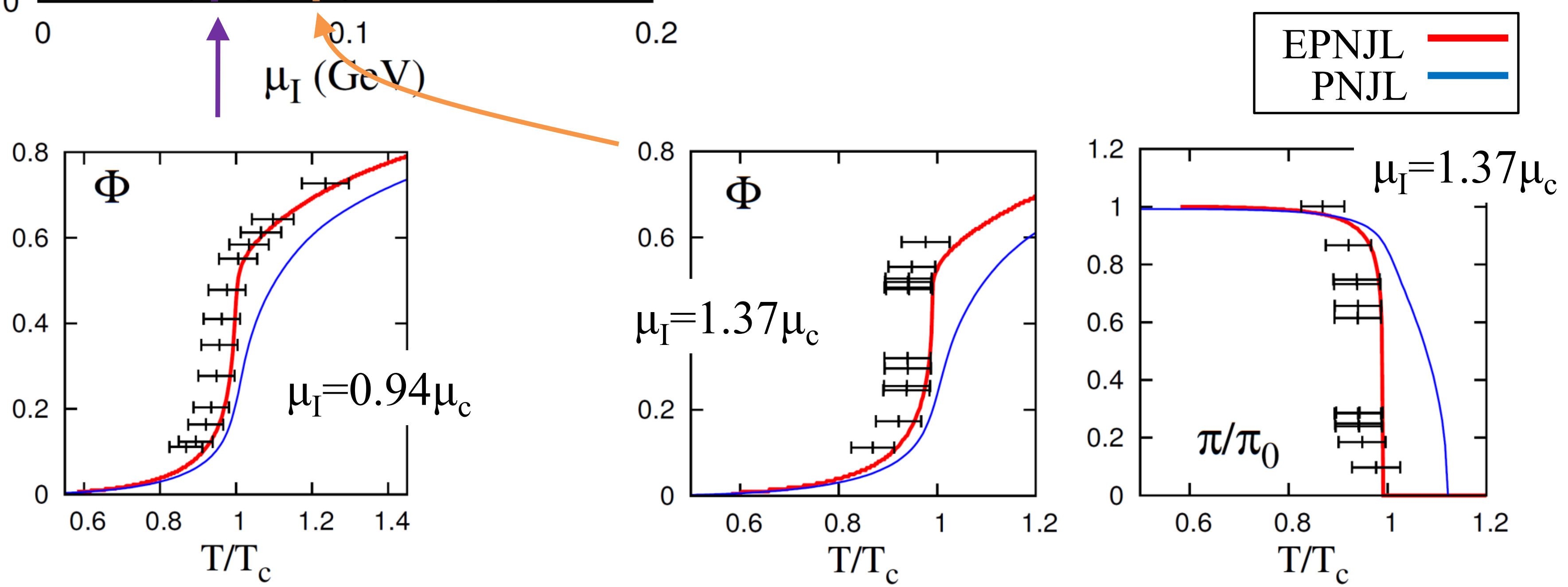


@ Isospin μ (μ_I)



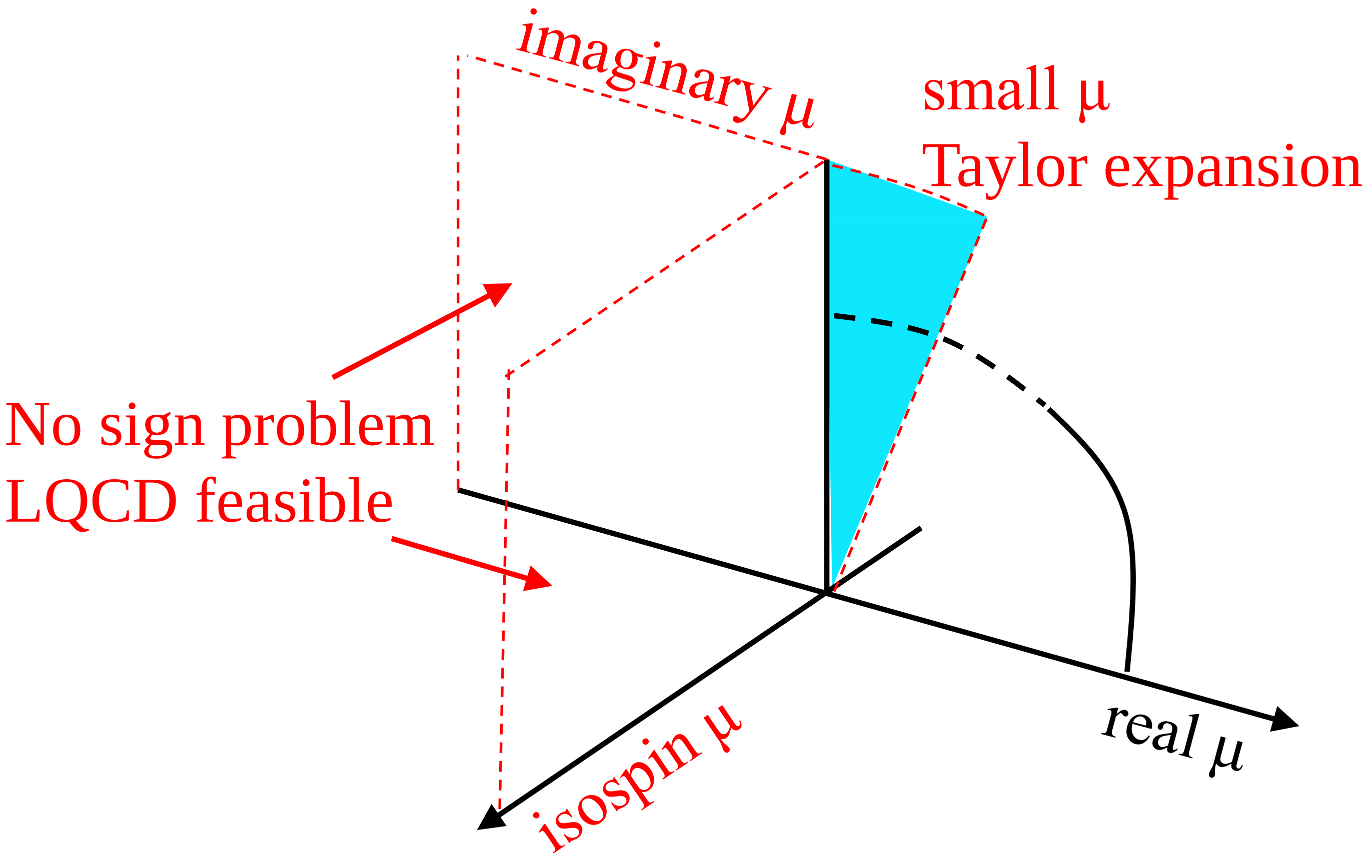
The EPNJL model is consistent with the lattice data in this region.

LQCD/ Kogut, Sinclair
Phys. Rev. D 70, 094501(04)



Test of the EPNJL model

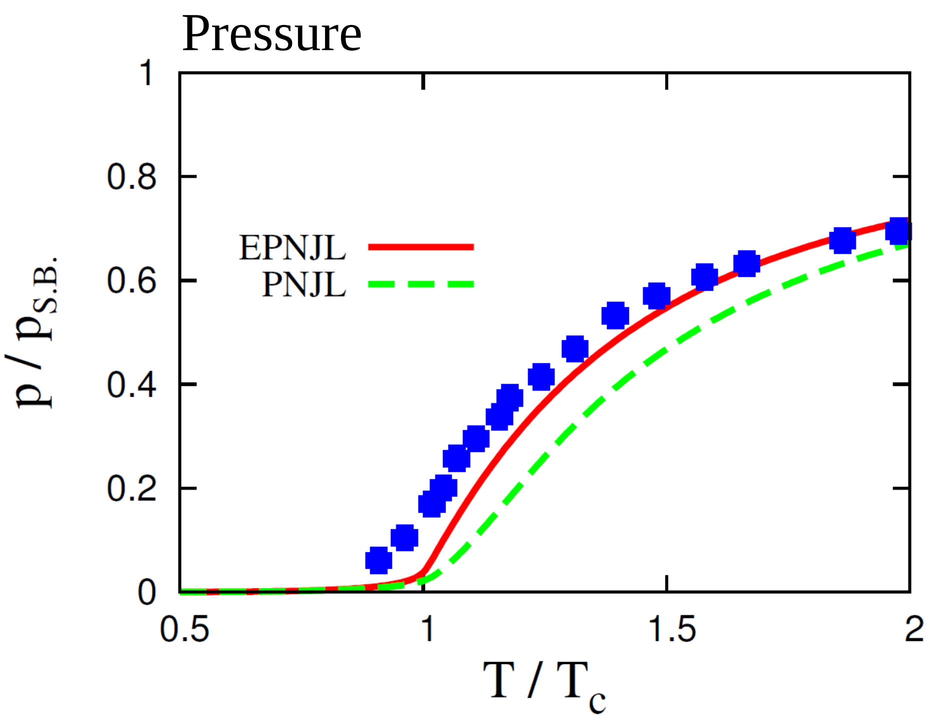
We consider zero or small real quark chemical potential region.

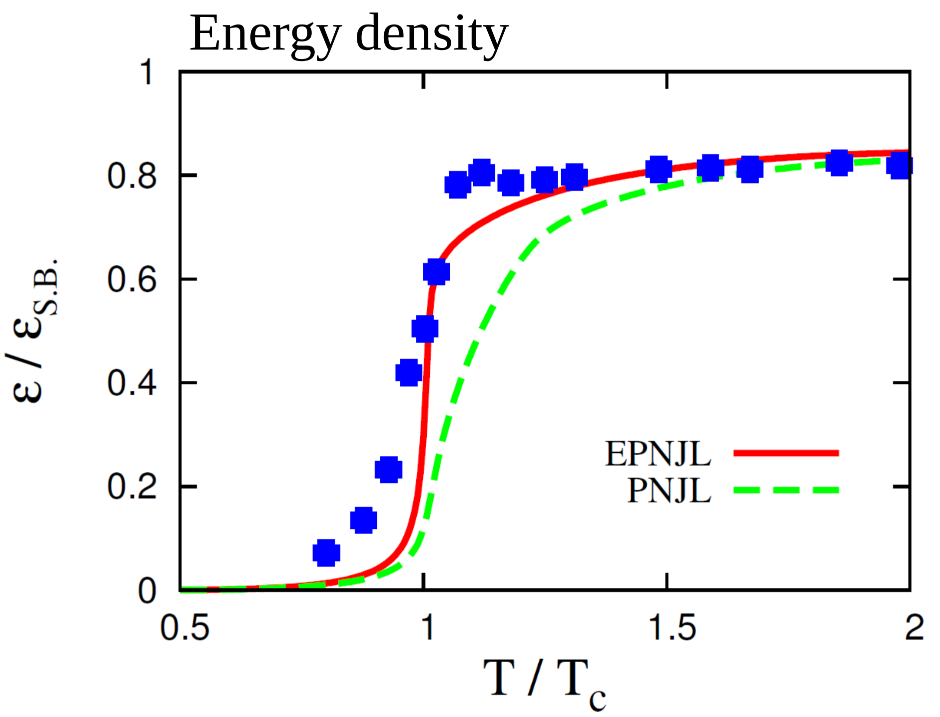


@ $\mu=0$

The EPNJL model gives better agreement with the lattice data.

LQCD/ A. Ali Khan, et., al.
Phys. Rev. D 64, 074510 (01).



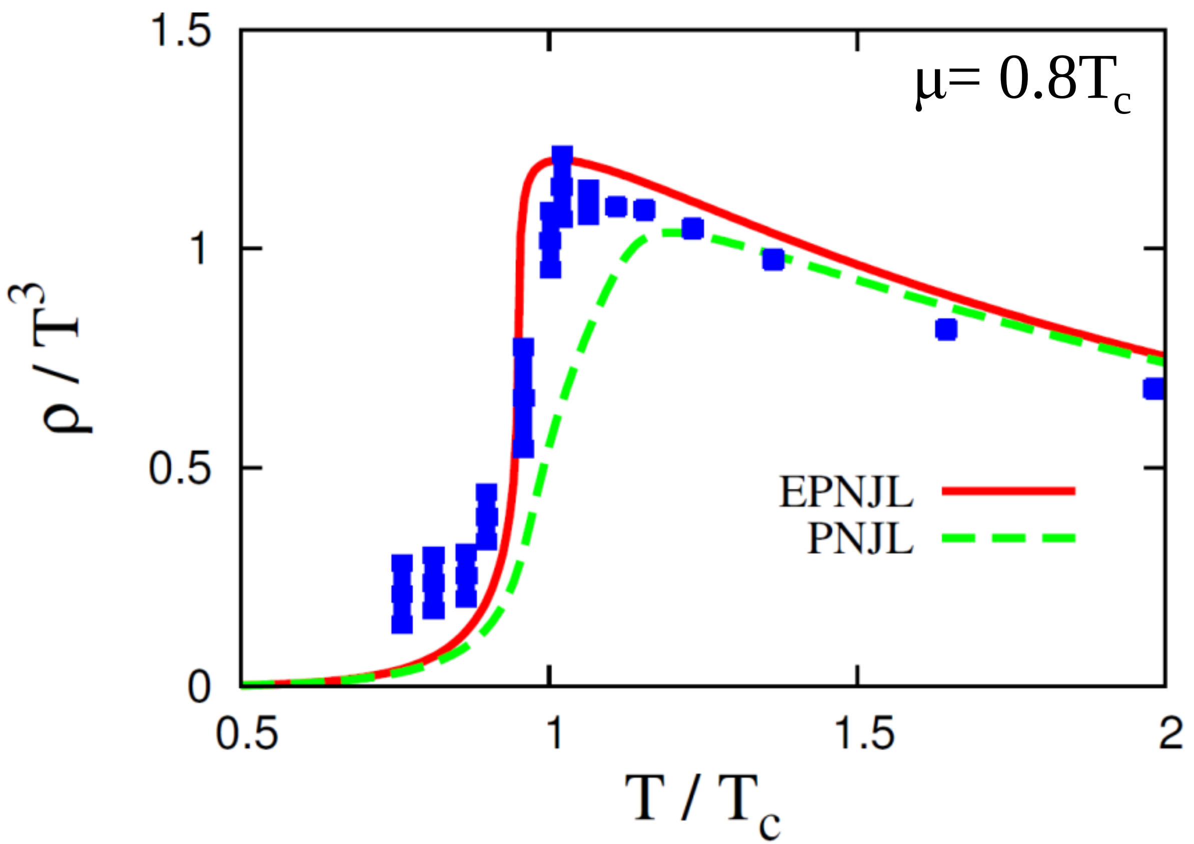


@ small real μ

The EPNJL model is consistent with the lattice data.

LQCD/ C. R. Allton, et., al.
Phys. Rev. D 68, 014507 (03). → Taylor expansion.

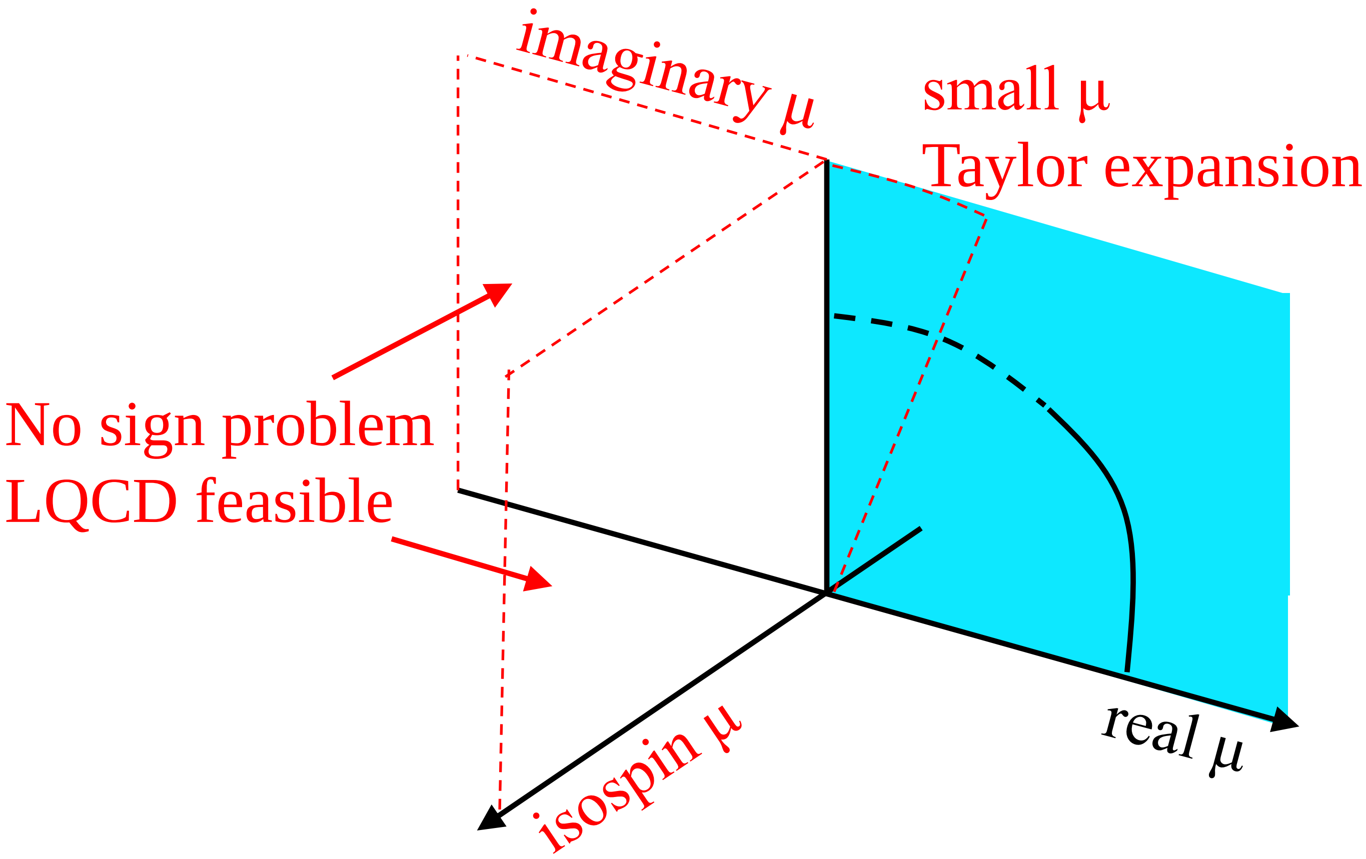
Number density



Apply to real μ

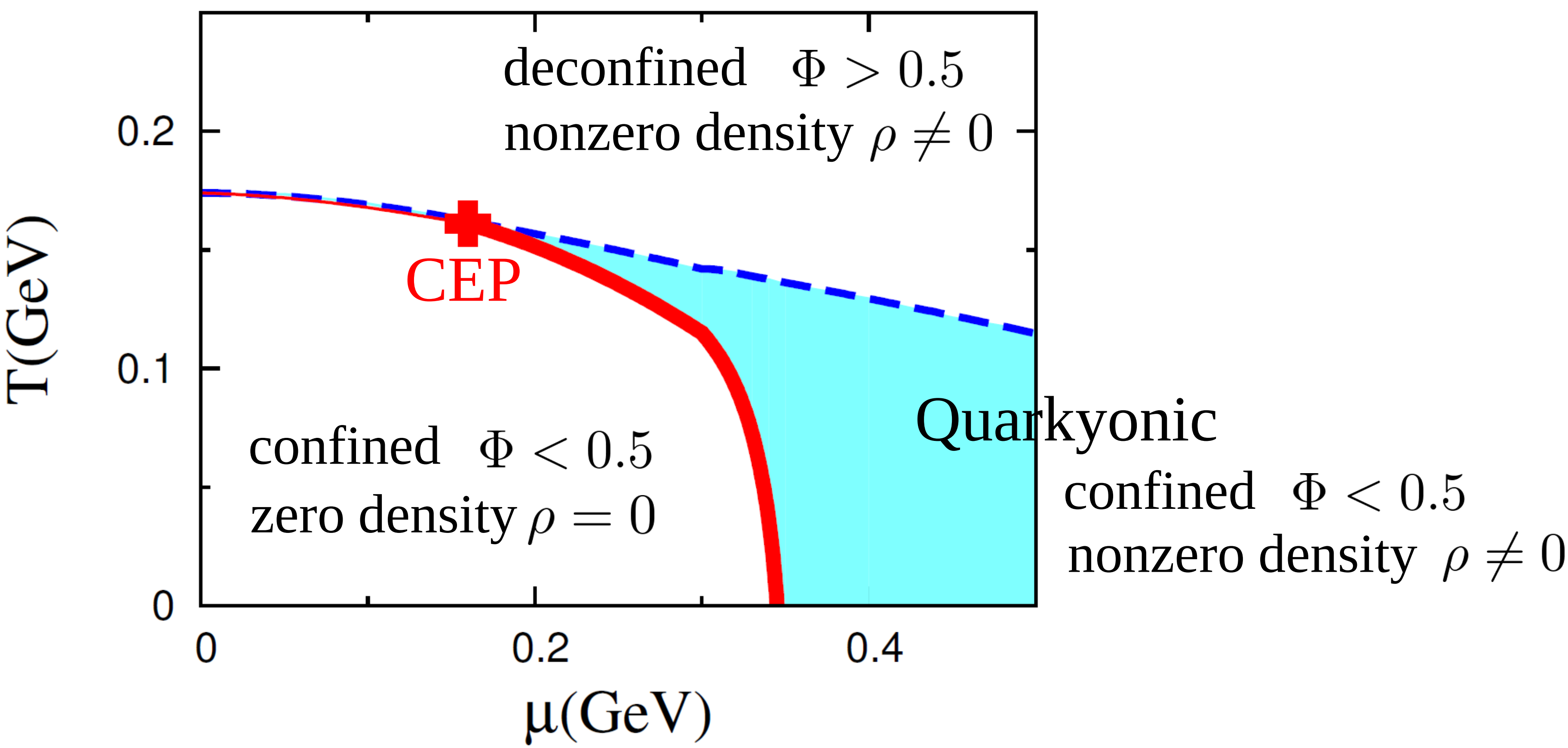
Throughout all the analyses, we can say the EPNJL model is reliable
because the model reproduces all the lattice data systematically.

We apply the model to study the QCD phase diagram @ real μ.



Phase diagram @real μ

The two transition coincide with each other at small μ
by the strong correlation between the two phase transitions.
However, the two transition diverge at this critical endpoint.



End