Lifshitz Regime and the phase diagram of QCD

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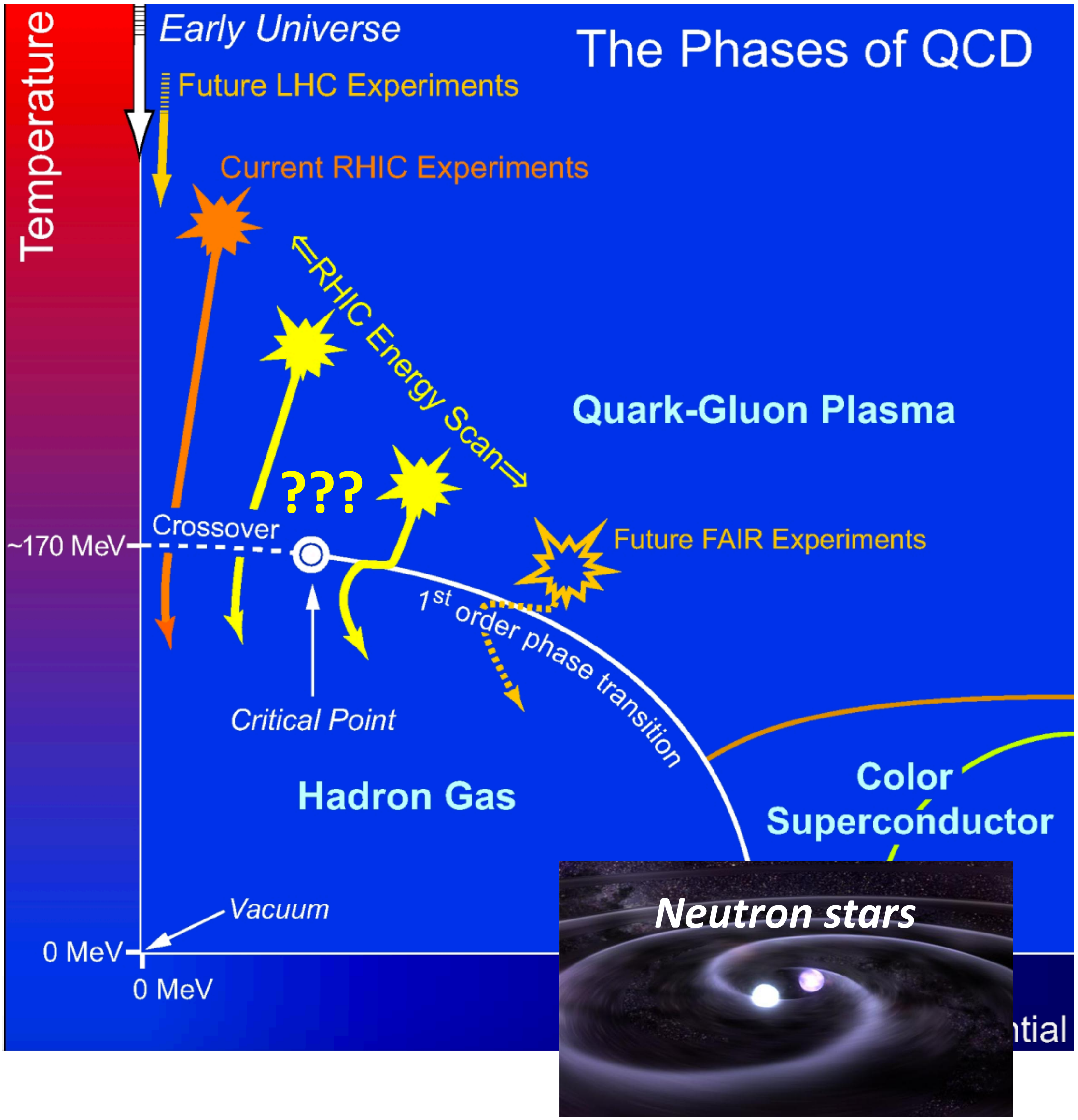
OAK, Crete, Greece

QCD at finite density



Large μ : 1st order phase transition

$\mu = 0$: crossover at T = 154 MeV

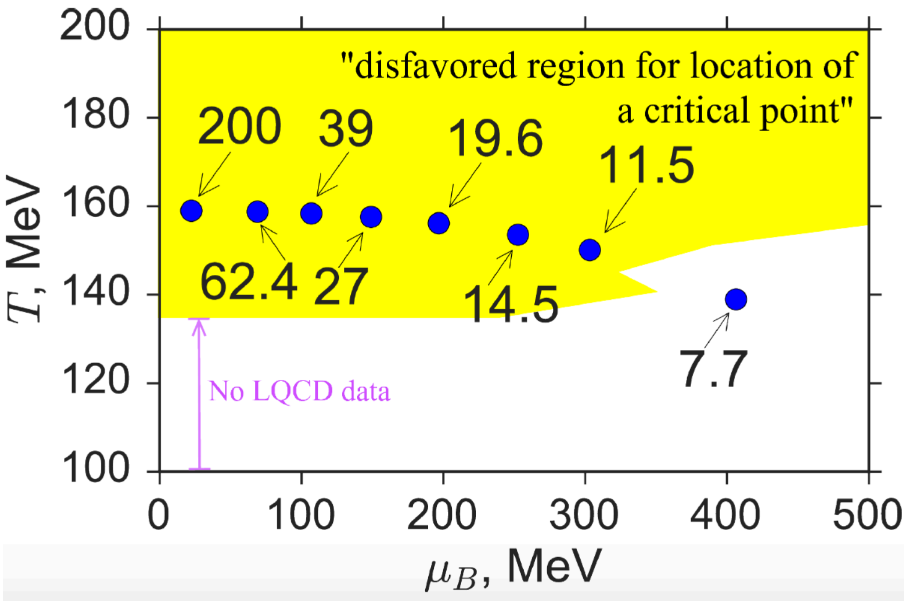
Meet at a critical end-point: 2nd order

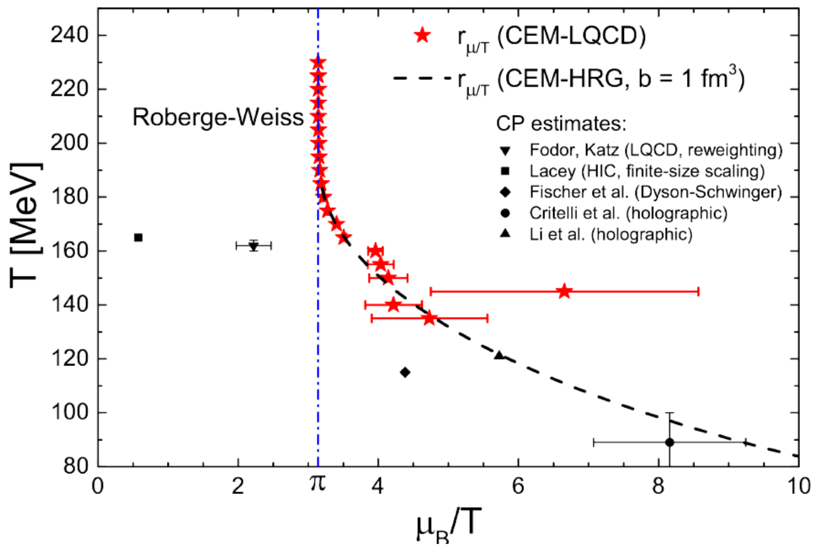
First-principle lattice: prohibitively challenging due to sign problem

Signs of CEP?

Lattice:** small mu, **Taylor expansion & estimate radius of convergence, Cluster expansion

***No signs of CEP** from lattice so far*

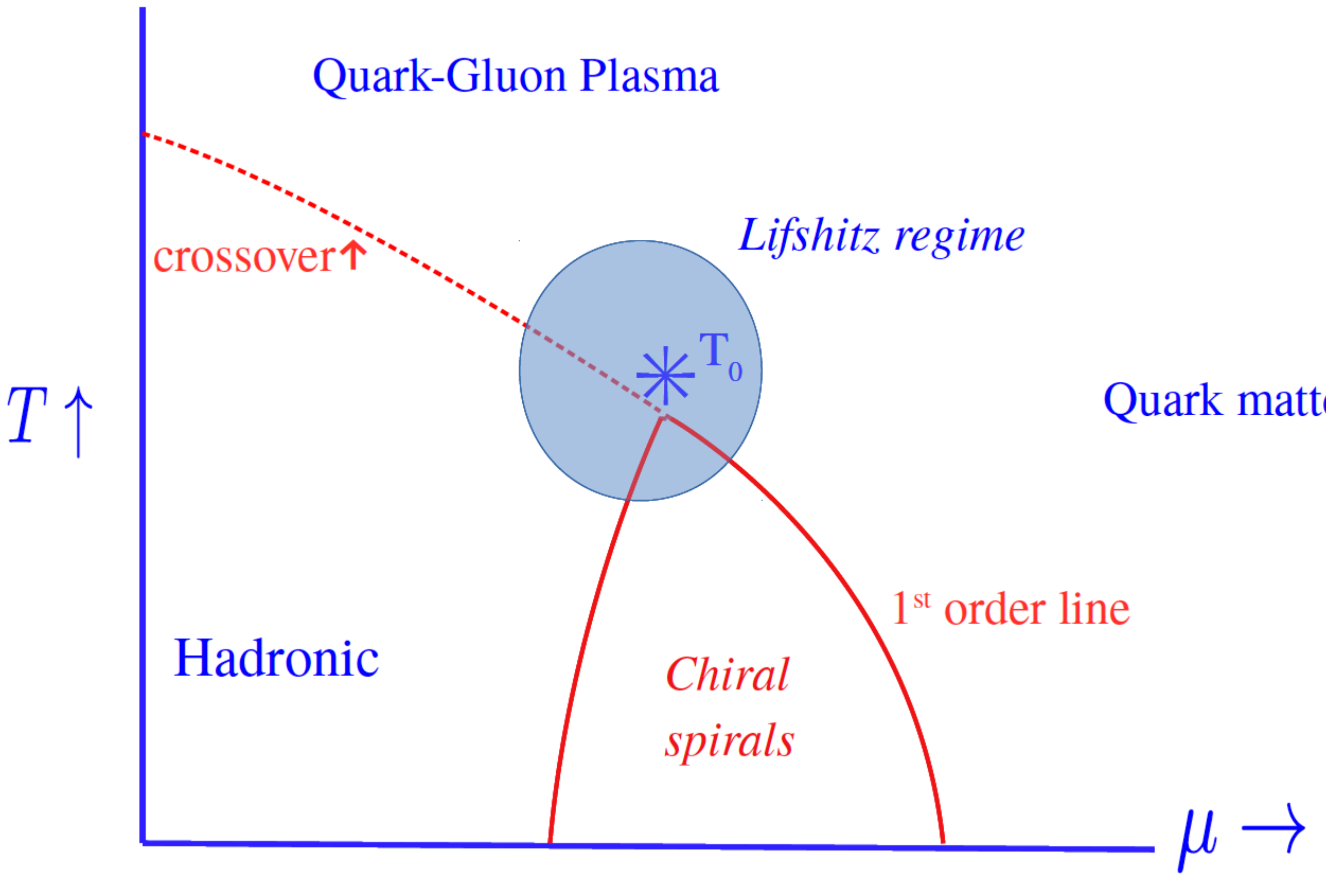




Hot QCD
Arxiv: 1701.04325

Vovchenko, Steinheimer, Philipsen, Stoecker
Arxiv:1701.04325

Lifshitz regime: alternative scenario?

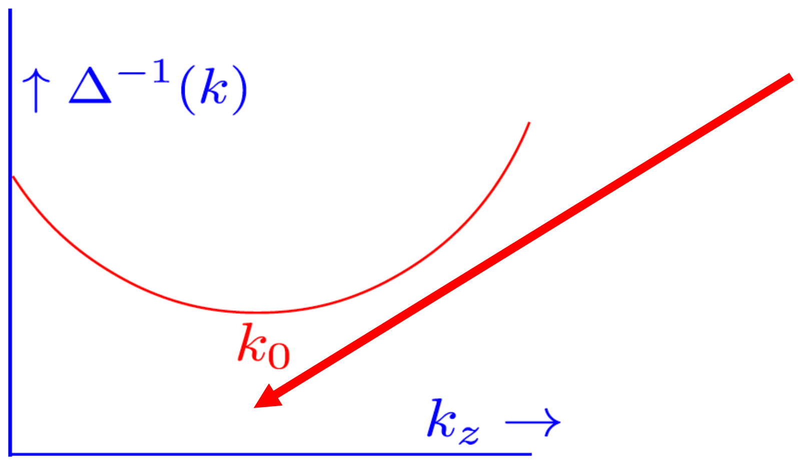


O(N) effective model

$$\mathcal{L} = \frac{1}{2}(\partial_0\phi)^2 + \frac{1}{2M^2}(\partial_i^2\phi)^2 + \frac{Z}{2}(\partial_i\phi)^2 + \frac{m^2}{2}\phi^2 + \frac{\lambda}{4}(\phi^2)^2 + \ldots$$

Implicitly assume finite density

Z is allowed to be negative:



Gap closes as Z gets sufficiently negative:

Local symmetry breaking!

$$\phi(x) = \phi_0(\cos(k_0 z), \sin(k_0 z))$$

Chiral spiral

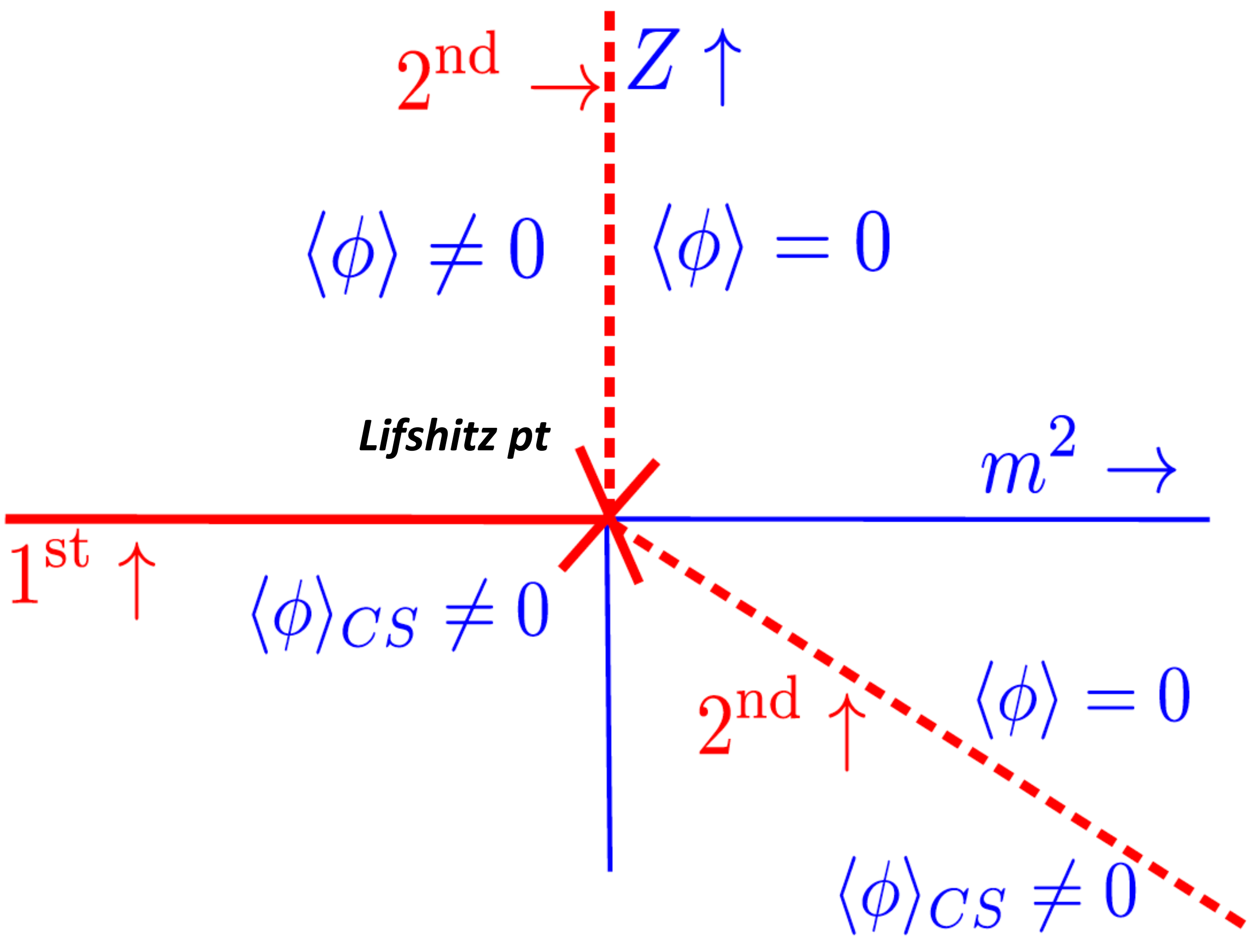
$$\Delta^{-1} = m_{eff}^2 - 2Z(k_z - k_0)^2 + \frac{1}{M^2}(4k_0 k_z \vec{k}^2 + (\vec{k}^2)^2)$$

Anisotropic fluctuations

A'la roton condensation in superfluid?

O(N) effective model

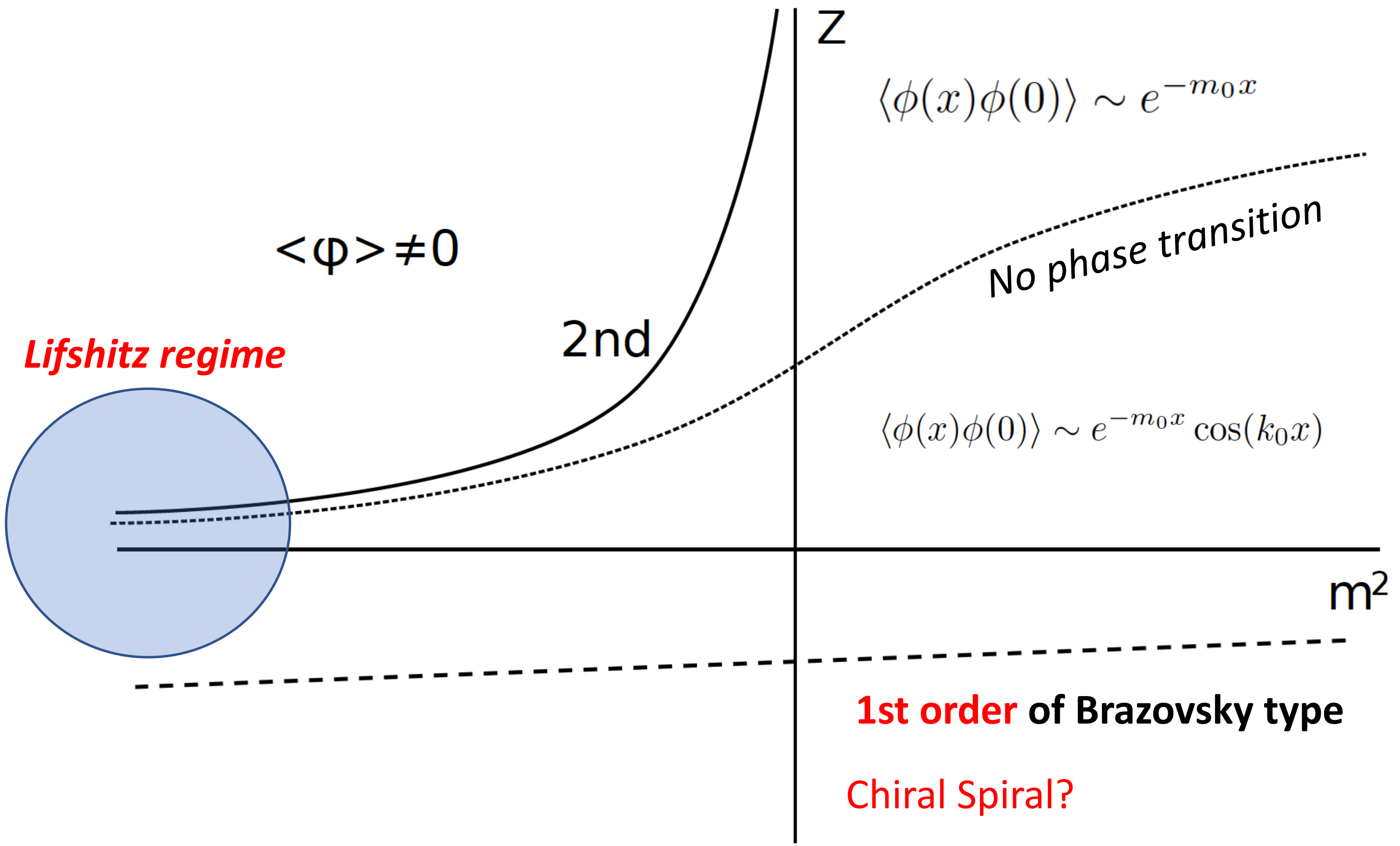
Mean-field phase diagram



Infinite N phase diagram

Effects of quantum fluctuations: dramatic change

No Lifshitz point, but Lifshitz regime

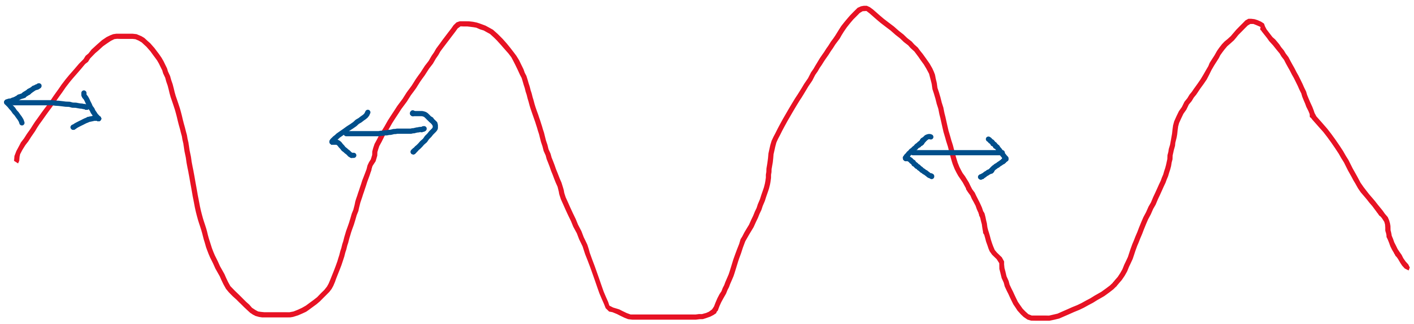


$$\Delta m^2 \sim \lambda \int d^2k_\perp dk_z \frac{1}{(k_z-k_0)^2+m_{\text{eff}}^2+\ldots} \sim \lambda \int^M d^2k_\perp \int_{m_{\text{eff}}} dk_z \frac{1}{(k_z-k_0)^2} \sim \lambda \frac{M}{m_{\text{eff}}}$$

Fate of the Chiral Spiral

***Brazovsky-type** phase transition: universal, appears due to anisotropic fluctuations*

*Effective dimensional reduction to **1-dim***



$$\phi(z)$$

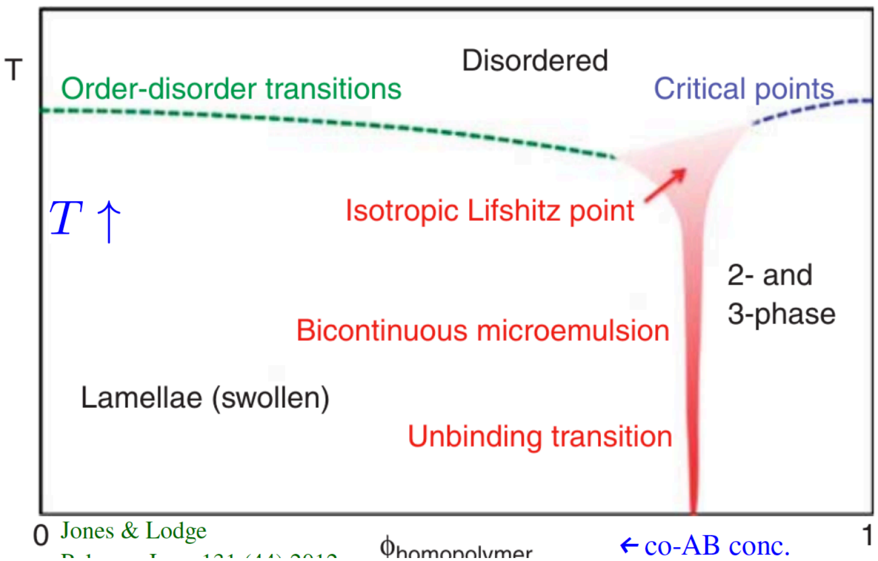
Phonon fluctuations!

↓

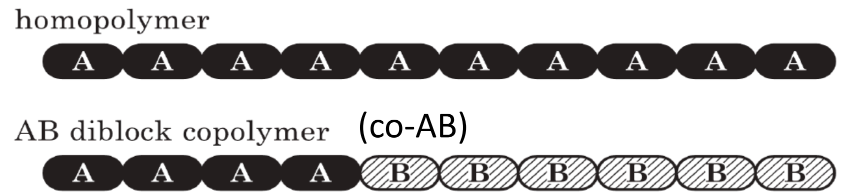
Long-range order is destroyed

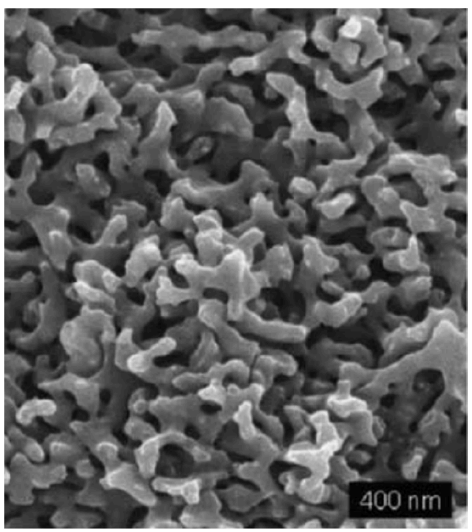
Lattice: detection of such phase is challenging

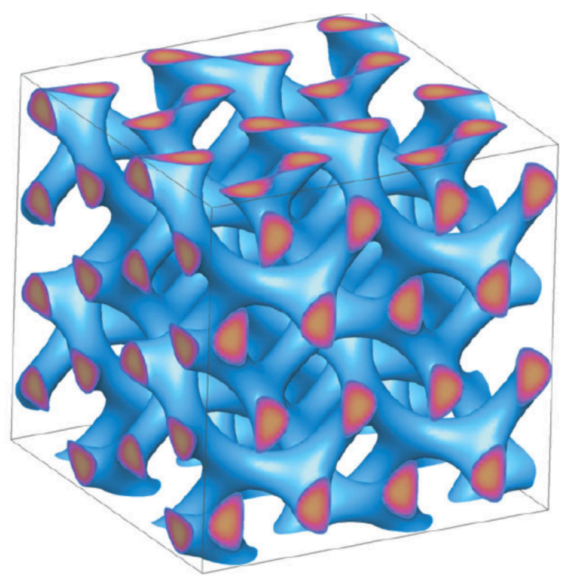
Real-world example: inhomogeneous polymers



Mixture of polymers A & B:



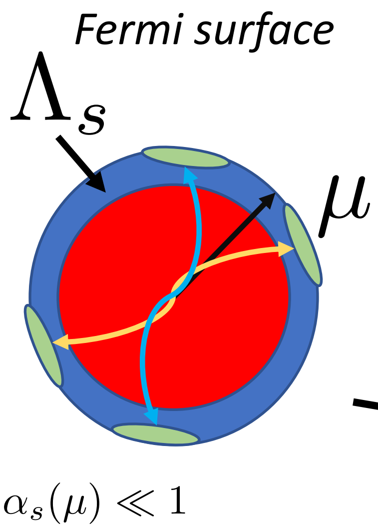


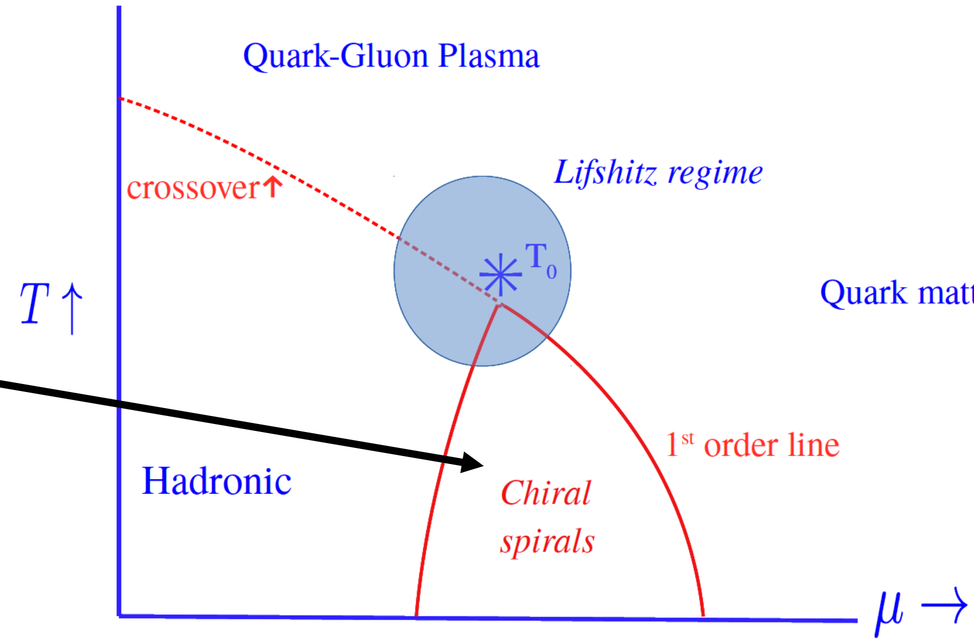


Experiment

Self-consistent field theory

Relation to QCD





Quarkionyc matter: effectively 1+1-dim patches (few are shown)

Suggestive argument in 1+1 dim: μ ***can be eliminated in the expense of Chiral Spiral:***

$$\bar{q}q = \cos(2\mu z)\bar{q}q + i\sin(2\mu z)\bar{q}\gamma_5 q$$

Quasi-long range order due to phonons:

R. Pisarski, V. Skokov, A. Tsvelik, Arxiv:1801.08156

Conclusions

1) *Lifshitz regime instead of Lifshitz point (contrary to NJL models)*

2) *Non-perturbative generation of negative Z is essential*

3) *Relation to standard CEP is unclear: both can co-exist*

4) *Lattice SU(2) “QCD” simulation?*