Gapless 2-flavor Color Superconductivity

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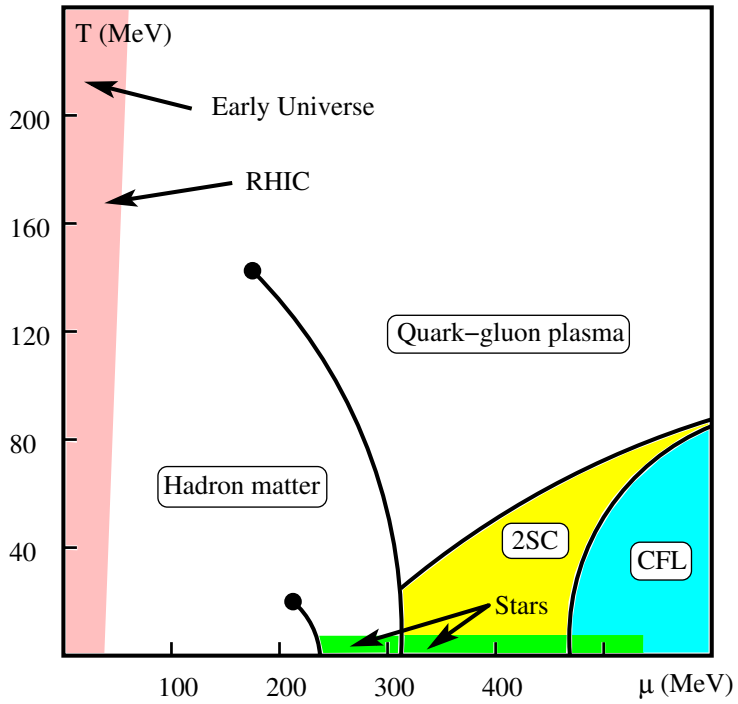
References

- I. Shovkovy and M. Huang, Phys. Lett. B **564** (2003) 205, `hep-ph/0302142`
- M. Huang and I. Shovkovy, hep-ph/0307273

Phase diagram of QCD

Dense quark matter is a color superconductor!

[Barrois,78], [Bailin & Love,84], [Alford et al.,98], [Rapp et al.,98],...



CSC in Compact Stars:

- $\beta-$equilibrium;
- Neutral with respect to electric and color charges;

  1. Global neutrality → mixed phase (Phys.Rev.D67:103004,2003)
  2. Local neutrality → homogeneous phase

Charge Neutral 2-flavor Dense Quark Matter

- Neutral 2-flavor quark matter:

$$\mathbf{n_d \approx 2n_u, n_e \approx \frac{1}{4^3}\frac{n_u}{3} \ll n_u}$$

- Cooper pairing with a mismatch between Fermi surfaces of pairing quarks:

$$\mu_{\mathbf{d}} - \mu_{\mathbf{u}} = \mu_{\mathbf{e}} = \mathbf{2}\delta\mu$$

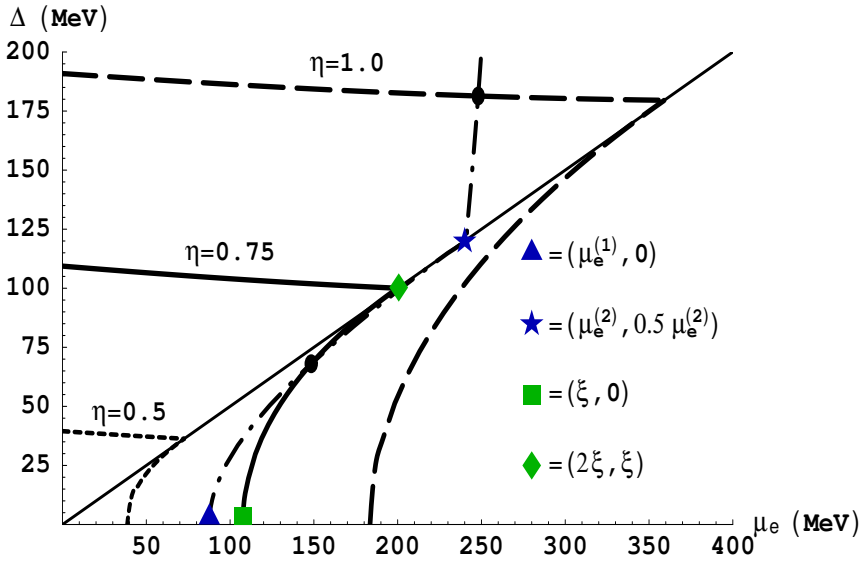
Ground State of Neutral Dense 2-flavor QM

- Diquark coupling strength η

(i) "strong":
$\eta > \eta_2^{\rm cr} \longrightarrow$ 2SC

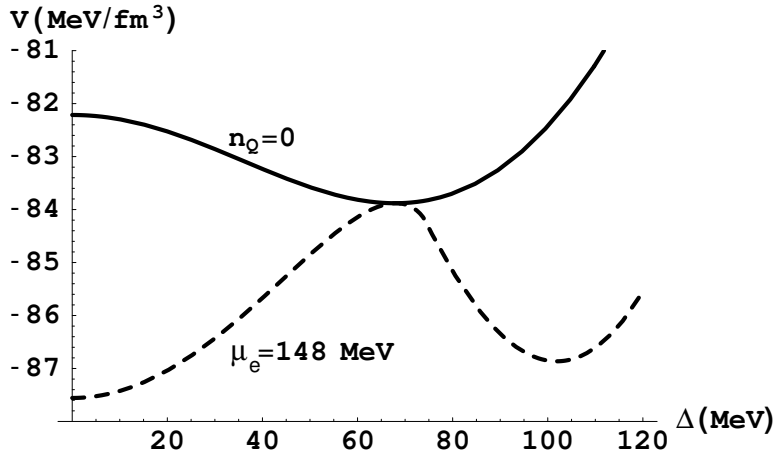
(ii) "weak":
$\eta < \eta_1^{\rm cr} \longrightarrow$ normal

(iii) "intermediate":
$\eta_1^{\rm cr} < \eta < \eta_2^{\rm cr} \rightarrow$ "g2SC"

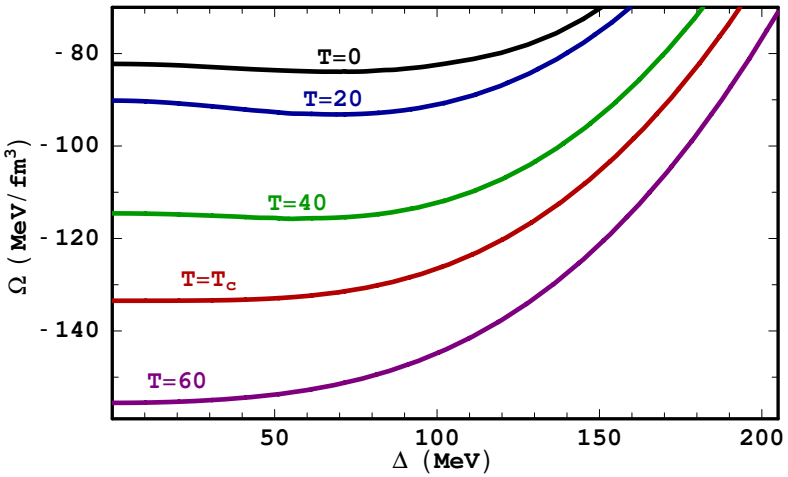


Is "g2SC" Stable?

Eff. potential at $T = 0$



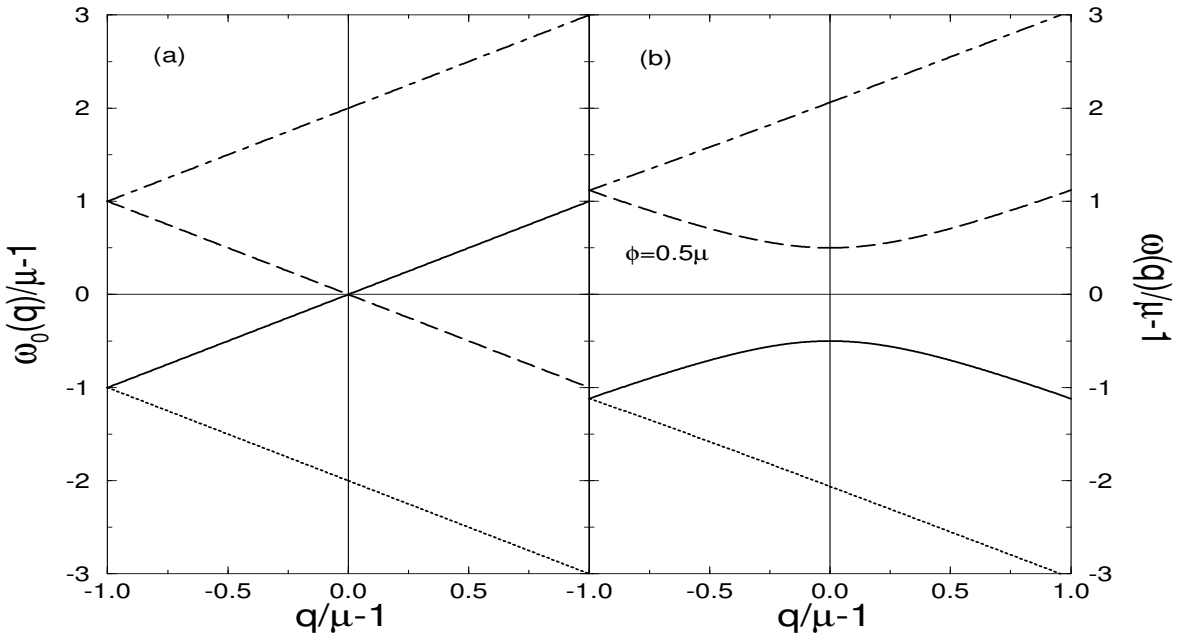
Eff. potential at $T \neq 0$



"g2SC" is stable provided $n_Q = 0$ is enforced *locally*!!

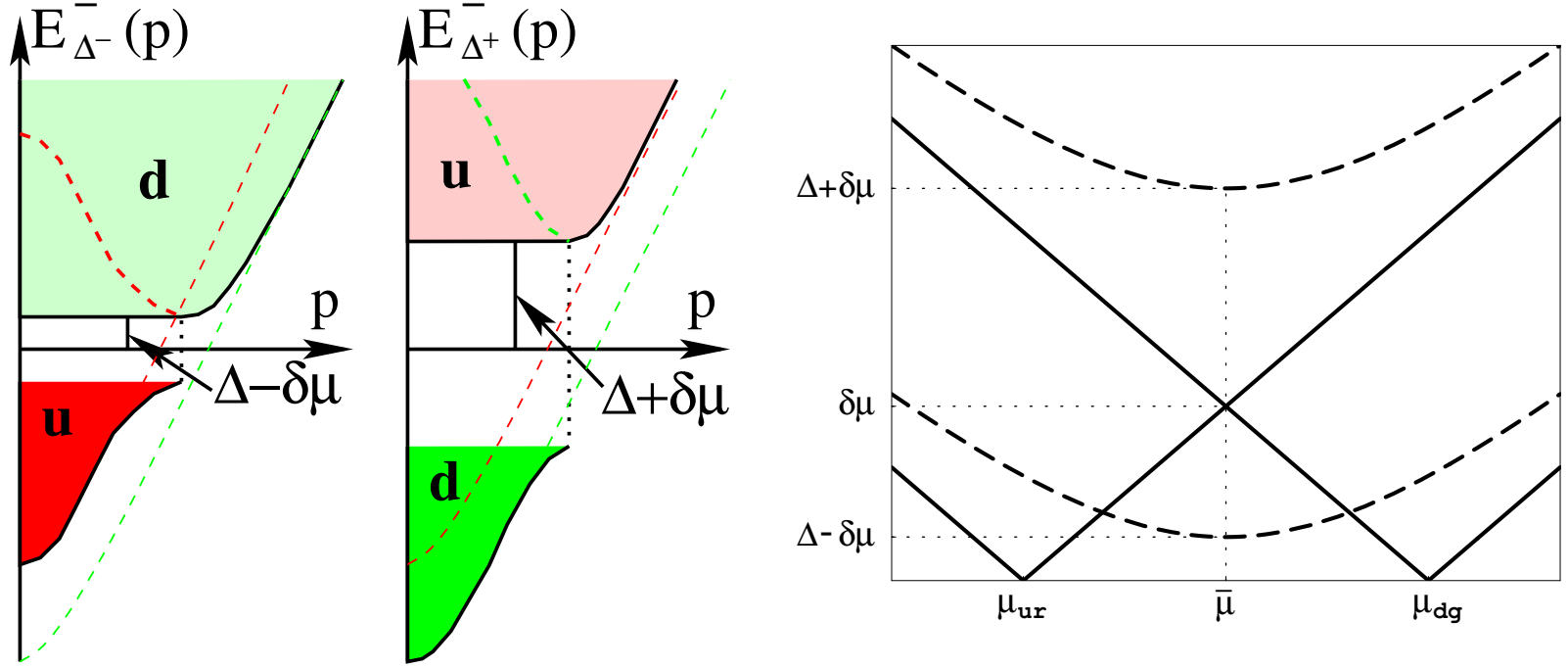
Why it is called "g2SC"?

1. 2SC Quasiparticle Spectrum if $\delta\mu = 0$



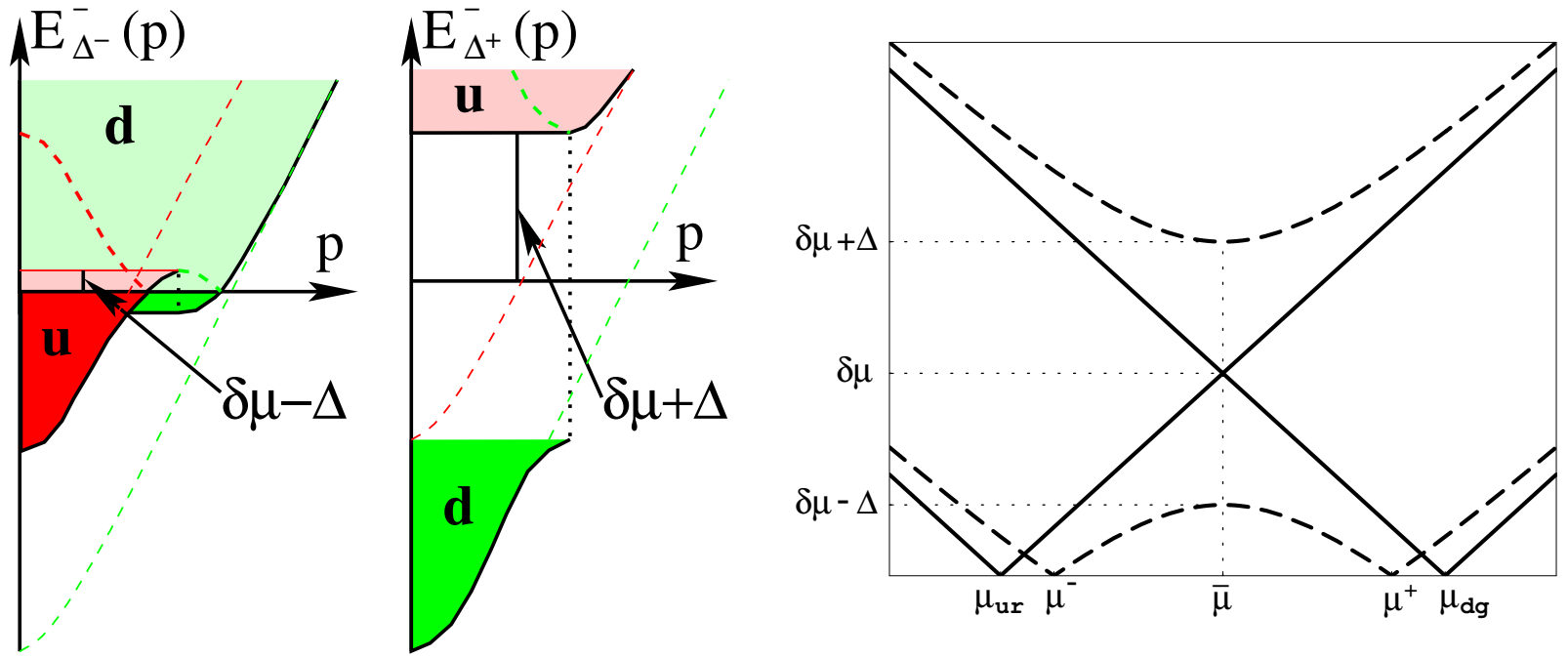
R.D. Pisarski, D.H. Rischke, Phys.Rev.D60:094013,1999

2. 2SC Quasiparticle Spectrum if $\delta\mu < \Delta$



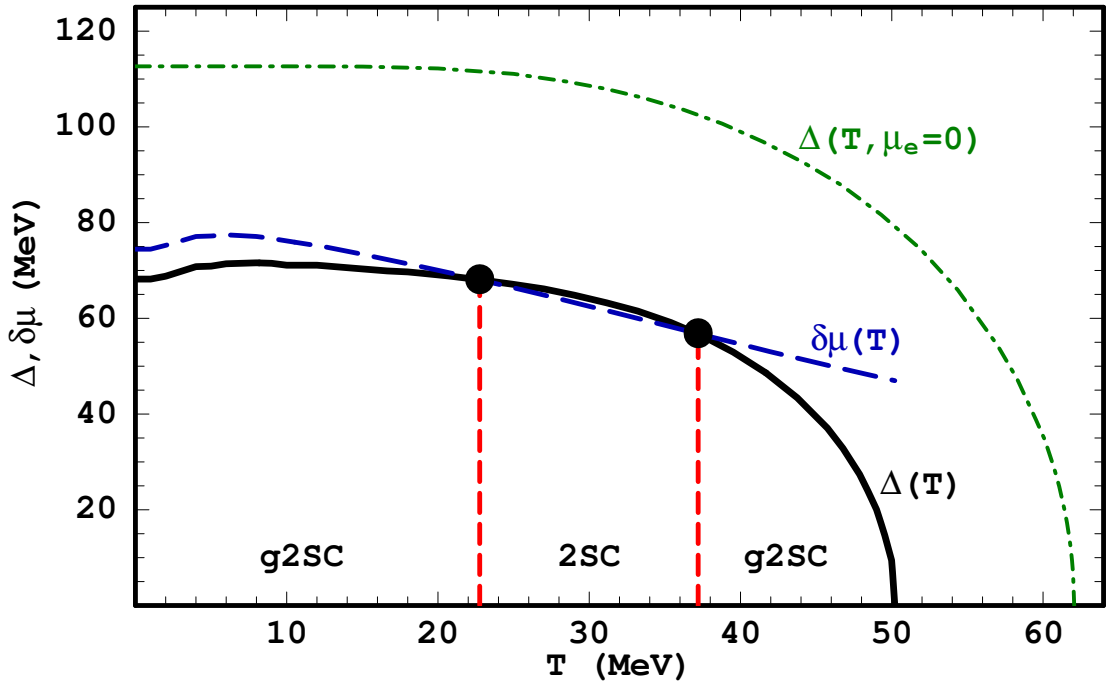
$\delta\mu$ induces two branches of excitations!

3. 2SC Quasiparticle Spectrum if $\delta\mu > \Delta$



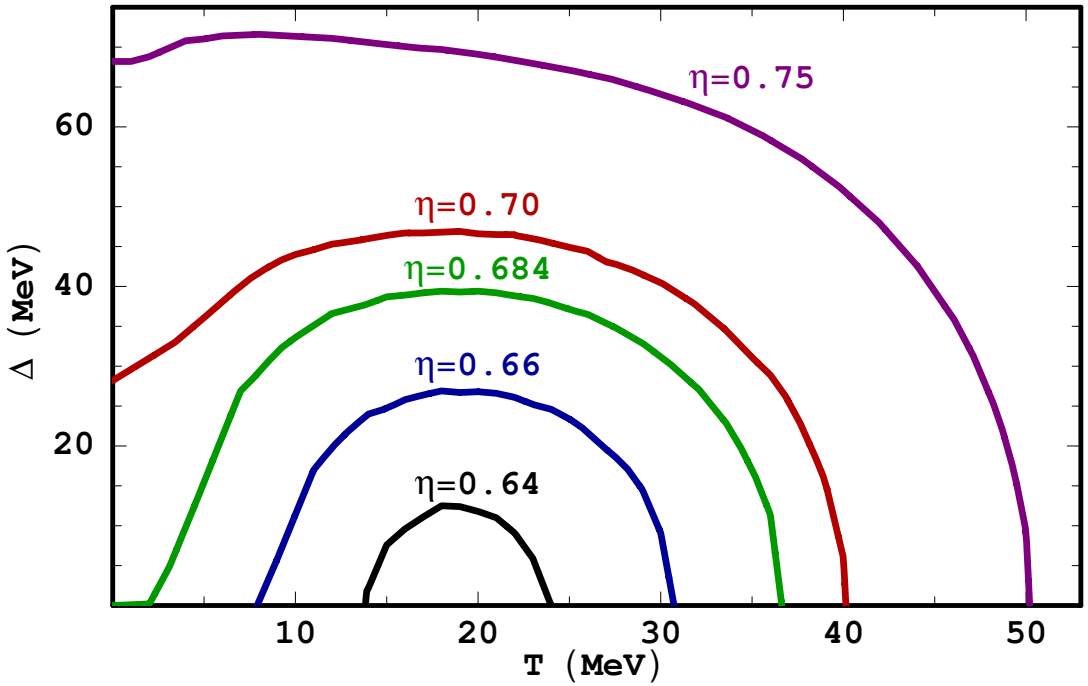
Appearance of Gapless Mode $\longrightarrow$ g2SC !!!

Temperature dependence of the gap. I.



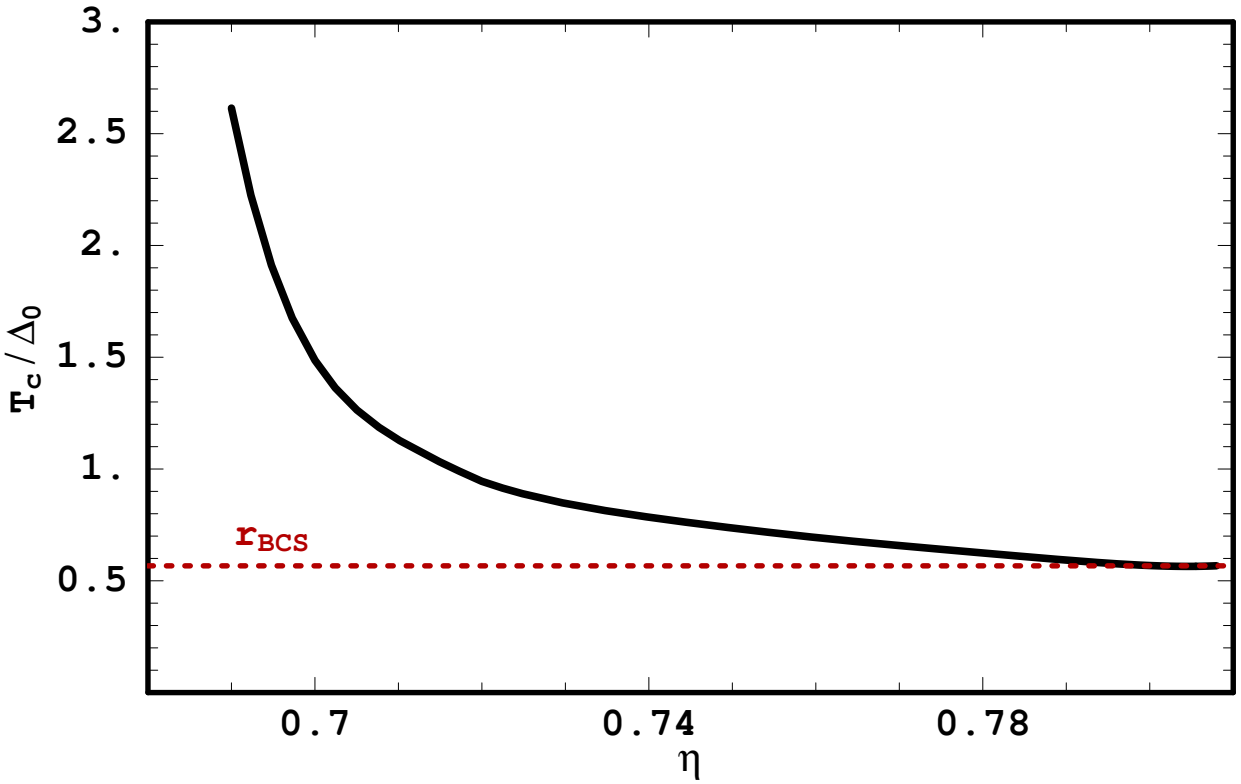
- *Nonmonotonic* temperature dependence
- Transitional behavior: g2SC → 2SC → g2SC → normal phase

Temperature dependence of the gap. II.



- Extreme *nonmonotonic* temperature dependence
- Transitional behavior: **normal phase !** → g2SC → normal phase

Nonuniversal ratio T_c/Δ_0



• The ratio is *not universal* (unlike in BCS), T_c/Δ_0 can be *arbitrarily* large for small η, and approaches r_{BCS} at large η!

Stable Gapless Mode in Other Systems:

- Superconductor with Magnetic Impurities

  D.Saint-James, G.Sarma and E.J.Thomas, *Type II Superconductivity*, Pergamon Press, 1969

- Asymetric Nuclear Matter

  A.Sedrakian and U.Lombardo, Phys.Rev.Lett84:602,2000

- Cold Atomic Gas

  W.Liu and F.Wilczek, Phys.Rev.Lett90:047002,2003

- u, s or d, s Dense Quark Matter

  E.Gubankova, W.Liu and F.Wilczek, Phys.Rev.Lett91:032001,2003

Summary

- Charge neutrality and β-equilibrium play very important role in studies of 2-flavor quark matter phases
- Gapless 2SC is a stable ground state of dense 2-flavor quark matter in a range of coupling strengths
- Temperature dependence of the gap is nonmonotonic
- Ratio T_c/Δ_0 is nonuniversal, and can be arbitrarily large
- What's in progress? Meissner Effect, Transport Properties ...