Chromomagnetic Instability and Gluonic Phase at Nonzero Temperature

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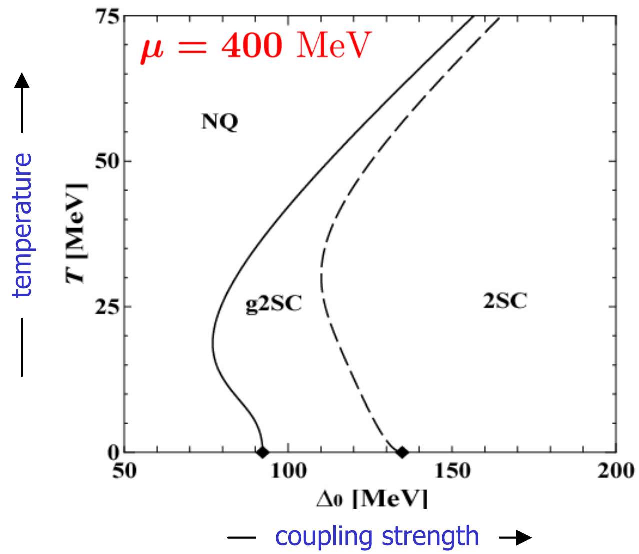
Introduction

phase diagram of neutral 2-flavor quark matter



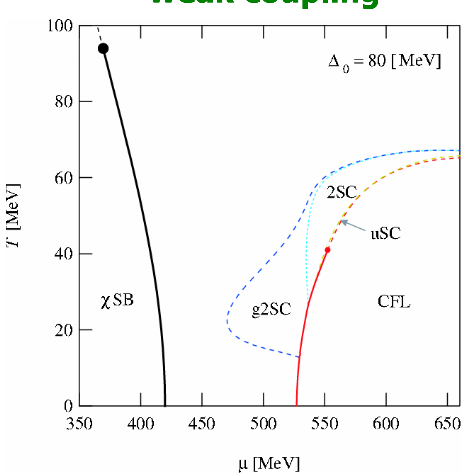
✓ qualitatively consistent with the known phase diagrams

✓ there exists **tachyonic modes** in some regions

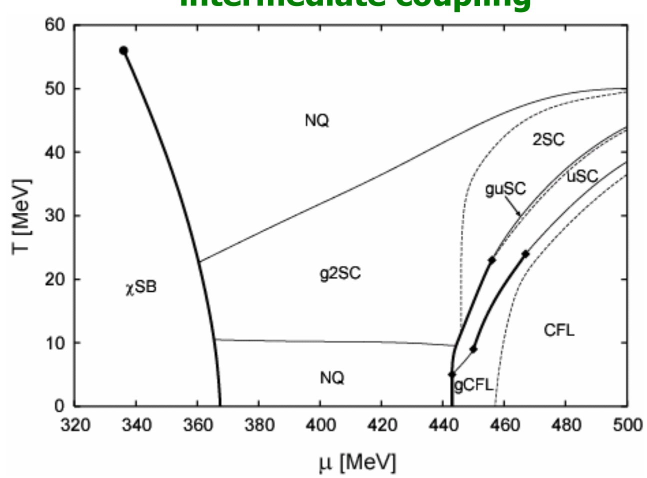
⇩

New Ground State

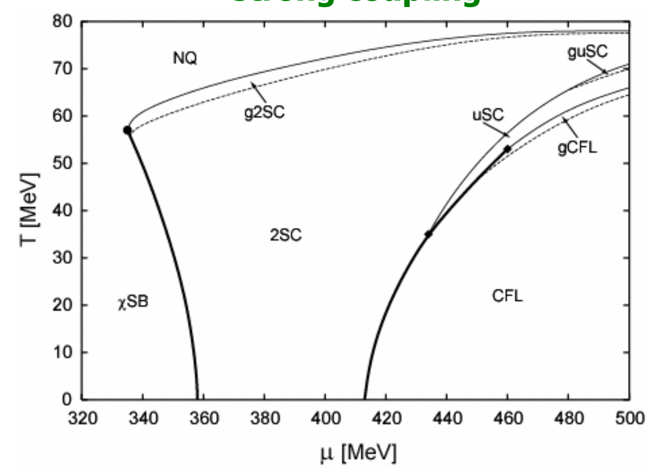
weak coupling



intermediate coupling



strong coupling

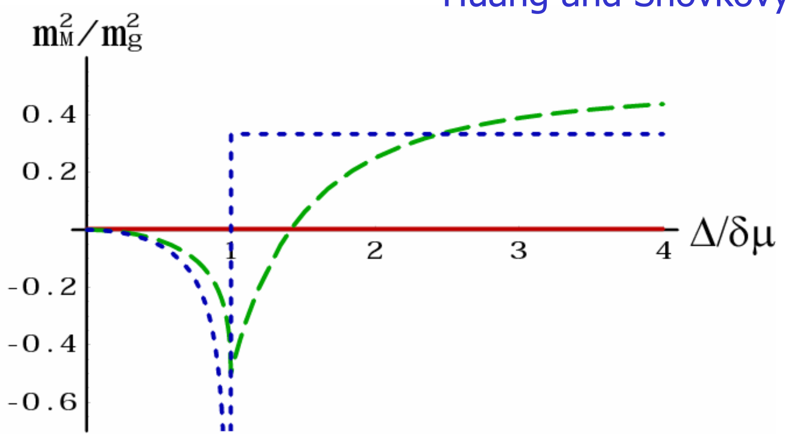


Abuki and Kunihiro, Nucl. Phys. A **768**, 118 (2006)   Ruester et al., Phys. Rev. D 72, 034004 (2005)

Chromomagnetic instability

Meissner masses squared in 2SC/g2SC

Huang and Shovkovy, Phys. Rev. D **70**, 094030 (2004)

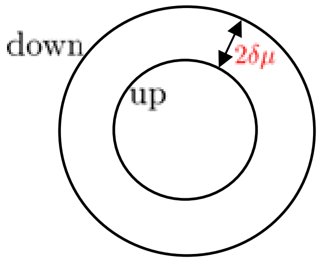


$$m^2_{M,(4,\cdots,7)} < 0 \qquad (\Delta/\delta\mu < \sqrt{2})$$

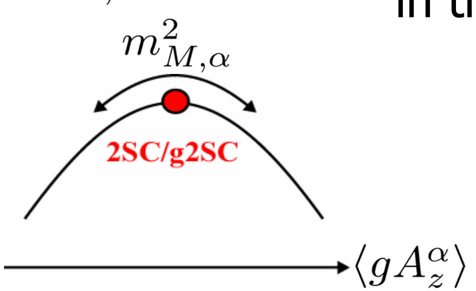
$$m^2_{M,8} < 0 \qquad (\Delta/\delta\mu < 1)$$

Δ : diquark gap

$\delta\mu$: chemical potential mismatch



$m^2_{M,\alpha} < 0 \Longrightarrow$ tachyonic mode in the direction of $\begin{cases} A_z^6 & (\alpha = 4, \cdots, 7) \\ A_z^8 & (\alpha = 8) \end{cases}$



Dynamics with gluonic vector condensates

vector condensates in gluonic cylindrical phase II

Gorbar, Hashimoto, and Miransky, Phys. Rev. D **75**, 085012 (2007)

$\mu_8 \sim \langle A_0^3 \rangle$ color neutrality

$B \sim \langle A_z^6 \rangle$ chromomagnetic instability

$B \neq 0$ dose not exclude

$\mu_3 \sim \langle A_0^3 \rangle$ color neutrality at $B \neq 0$

Model : gauged Nambu-Jona-Lasinio model (2 flavors)

$$\mathcal{L} = \bar{q}(i\gamma^\mu D_\mu + \hat{\mu}\gamma^0)q + G_D(\bar{q}i\gamma_5\tau^2\lambda^2 C\bar{q}^T)(qCi\gamma_5\tau^2\lambda^2 q) - \frac{1}{4}F^a_{\mu\nu}F^{a\mu\nu}$$

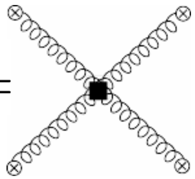
$J^P = 0^+$ diquark interaction

nondynamical gluons

Thermodynamic potential

$$\Omega = \Omega_e + \Omega_q^{(\mathrm{MFA})} + \Omega_g^{(\mathrm{tree})}$$
$$= -\frac{1}{12\pi^2}\left(\mu_e^4 + 2\pi^2 T^2 \mu_e^2 + \frac{7\pi^4}{15} T^2\right)$$
$$+\frac{\Delta^2}{4G_D} - \frac{1}{2}\sum_a^{48}\int \frac{d^3p}{(2\pi)^3}\left[|\epsilon_a| + 2T\ln(1+e^{-|\epsilon_a|/T})\right]$$
$$-\frac{1}{2g^2}\mu_8^2 B^2 + \frac{1}{2g^2}\mu_3\mu_8 B^2 - \frac{1}{8g^2}\mu_3^2 B^2$$

$$\Omega_g^{(\mathrm{tree})} =$$



$\Delta = 2G_D\langle \bar{q} i\gamma_5 \tau^2 \lambda^2 C \bar{q}^T\rangle$, $B = \langle g A_z^6 \rangle$, $\mu_{3,8}$: color chemical potentials ,
ϵ_a : quasiparticle dispersion relations

In what follows, we neglect (negligibly small) μ_3 and μ_8

vacuum subtraction

$$\Omega_R = \Omega(\Delta, \delta\mu, B; \mu, T) - \Omega(0, 0, B; \mu, T)$$

Gluonic phase at zero temperature (1)

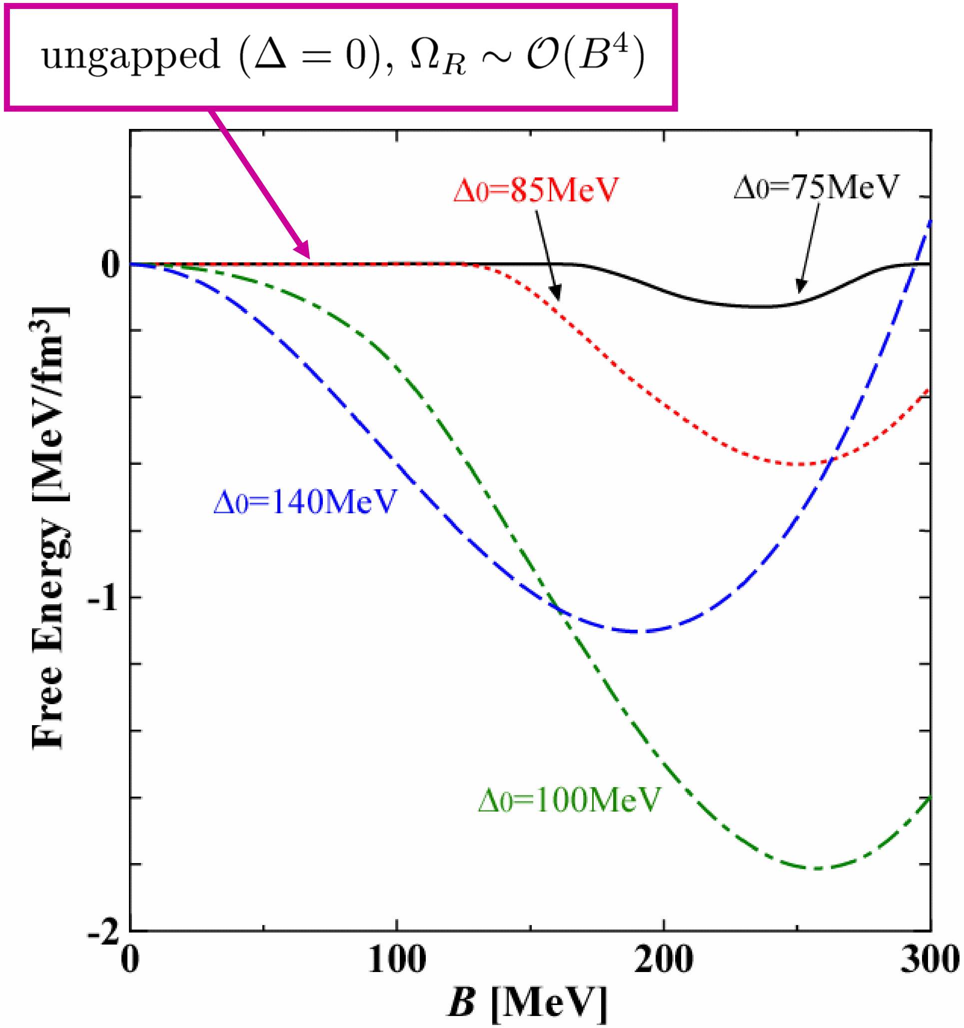
$$\frac{\partial \Omega_R}{\partial \Delta} = \frac{\partial \Omega_R}{\partial \mu_e} = 0 \text{ as a function of } B \implies \Omega_R(B)$$

Free Energy measured with respect to the NQ/2SC/g2SC phases at $B = 0$

$\mu = 400$ MeV

Δ_0 : 2SC gap at $\delta\mu = 0$

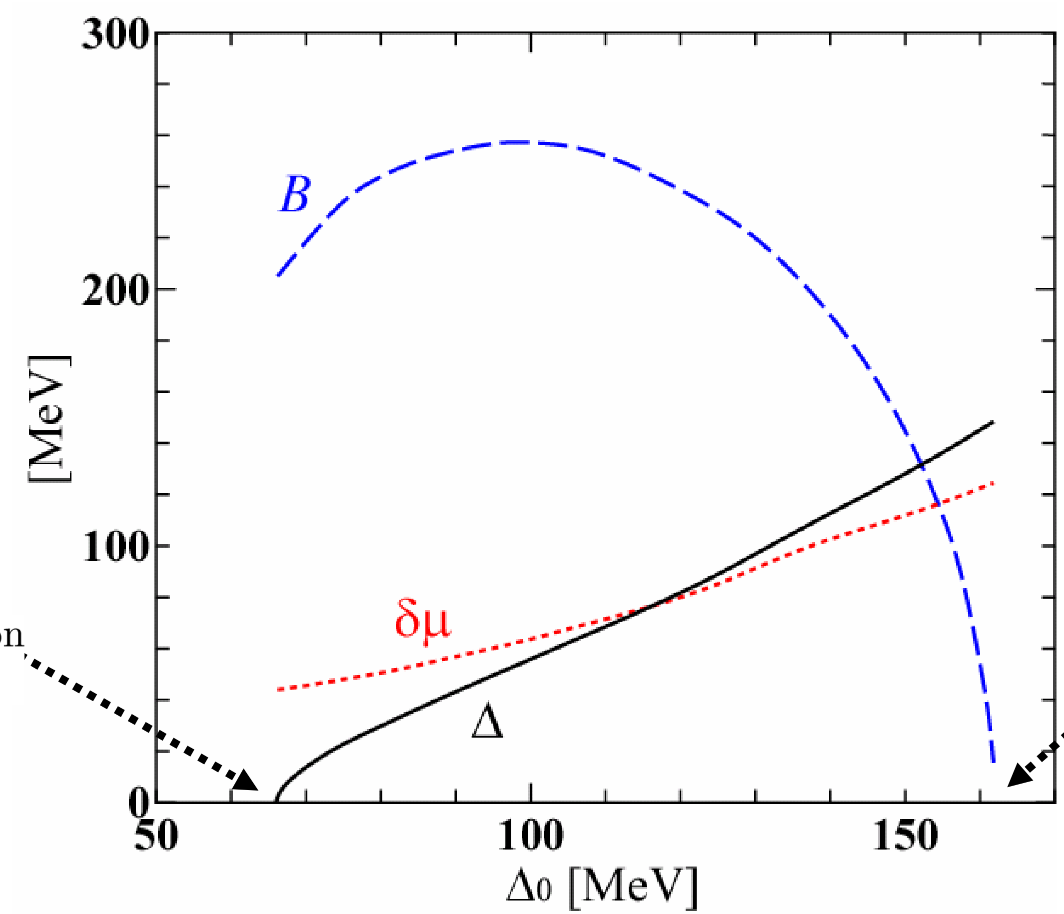
(i.e., diquark coupling strength)



Gluonic phase at zero temperature (2)

self-consistent solutions

1st order transition
at $\Delta_0 \sim 66$ MeV



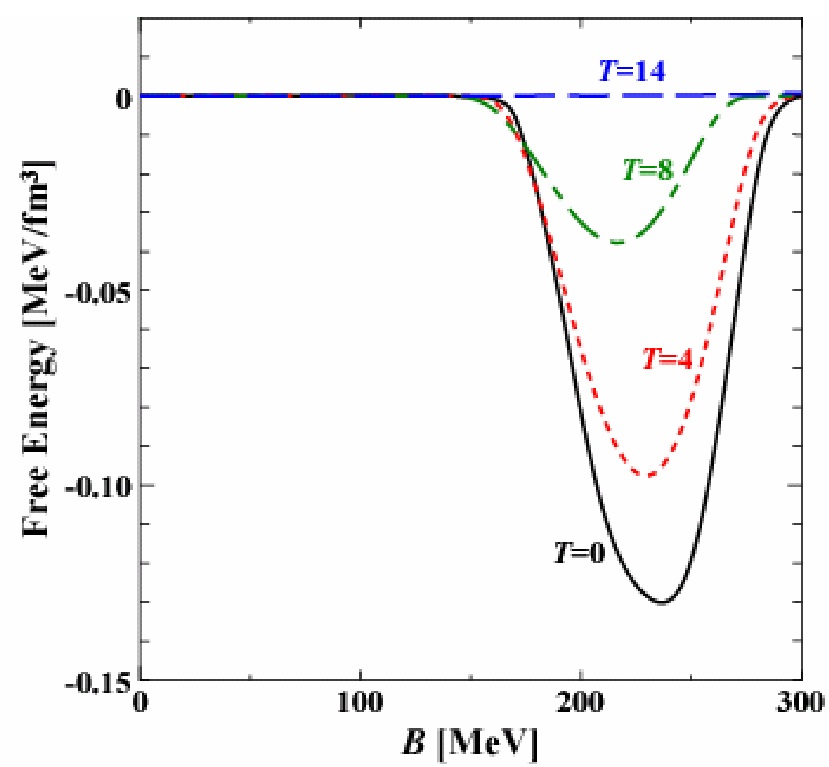
weak 1st order
at $\Delta_0 \sim 162$ MeV

c.f. Hashimoto and Miransky, arXiv:0705.2399 [hep-ph]

Gluonic phase at nonzero temperature

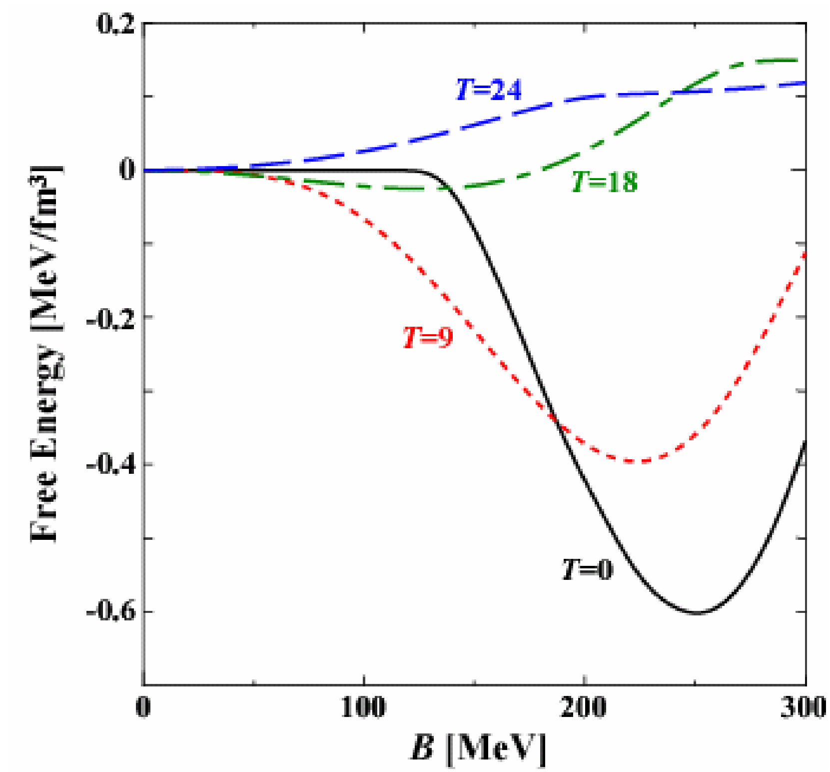
Temperature dependence of free energy

$\Delta_0 = 75$ MeV



strong 1st order transition

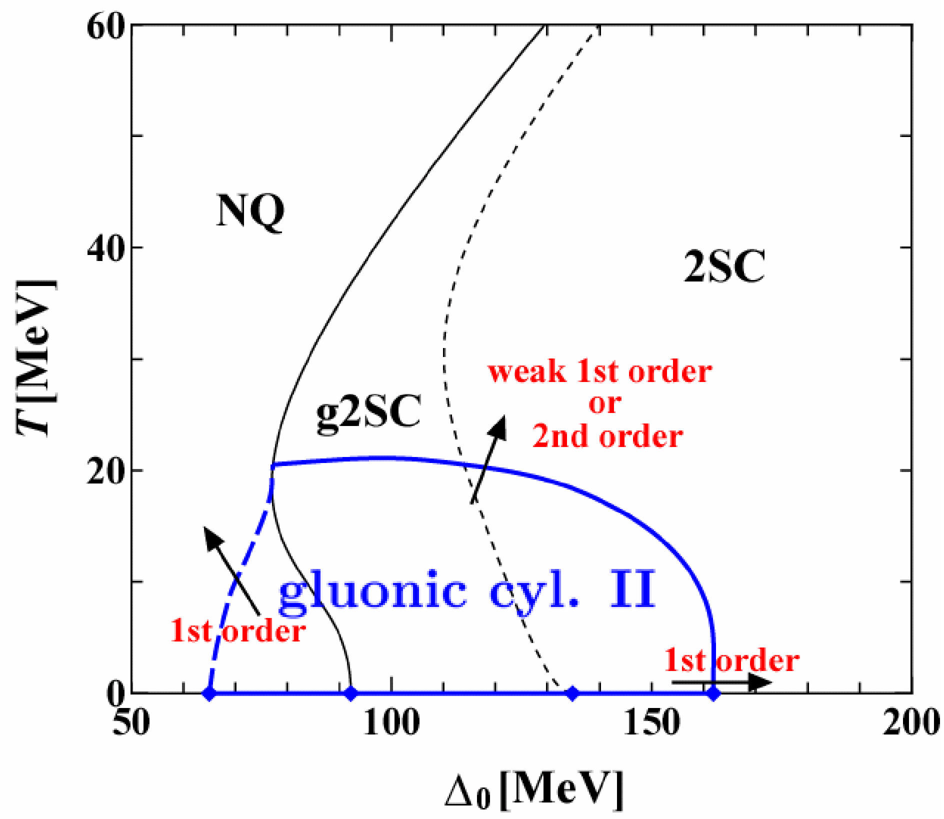
$\Delta_0 = 85$ MeV



weak 1st order or 2nd order

Conclusion

Schematic phase diagram



Gluonic phase dominates low-temperature region
of phase diagram for wide range of coupling strength