KEK 素核宇・物性　連携研究会　2021 3月29日

Current-driven Tricritical Point in Large-Nc Gauge Theory

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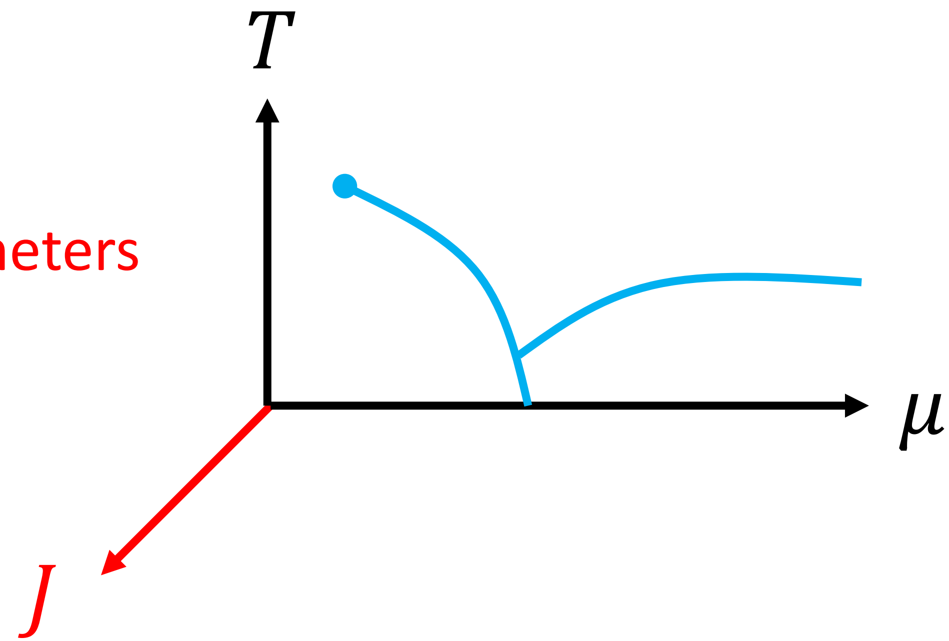
Ref. [T. Imaizumi, M. Matsumoto and S.N., PRL124 (2020) 19, 191603]

Motivation

Phase diagram: summary of macroscopic states of systems

One direction to explore
new physics:
introduction of new parameters
into the phase diagram.



J : electric current
as a new parameter
of the phase diagram.

My question:
Any new phenomena in the presence of current?

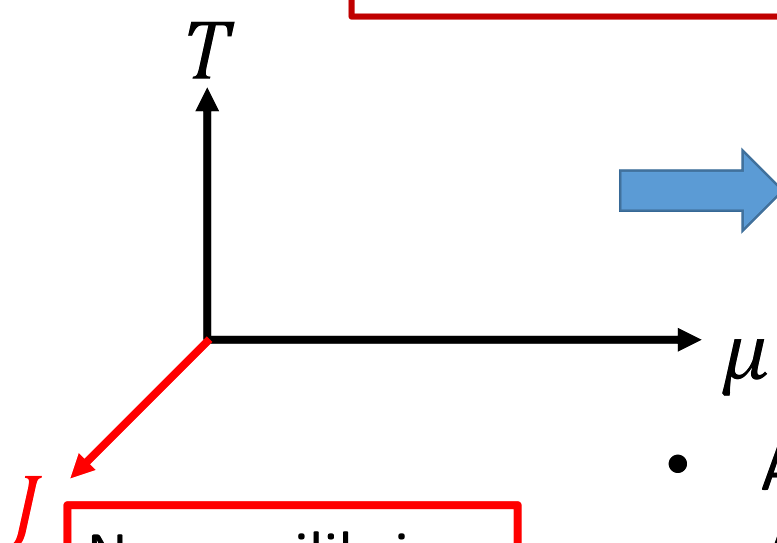
Why current?

J is rather new:

Nature of materials in the presence of J is not yet understood well.

Because, $J \cdot E$ produces heat and entropy. → **out of equilibrium**

When J and E are constant, the system is in a Non-equilibrium Steady State (NESS).

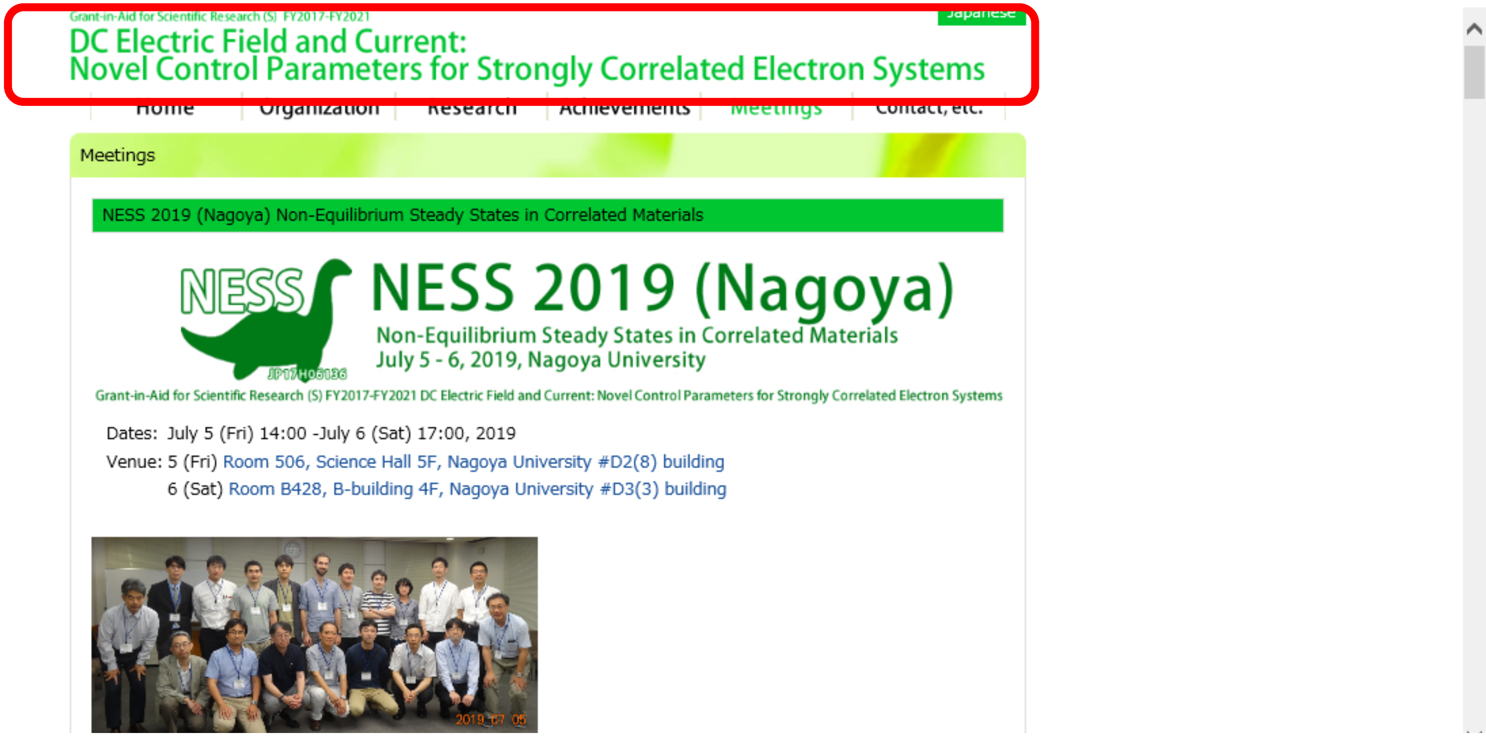


Nonequilibrium

→ **Extension of phase diagram into NESS.**

- Any new phase structure in NESS?
- Any new phenomena in NESS?

Any new phenomena in the presence of current?



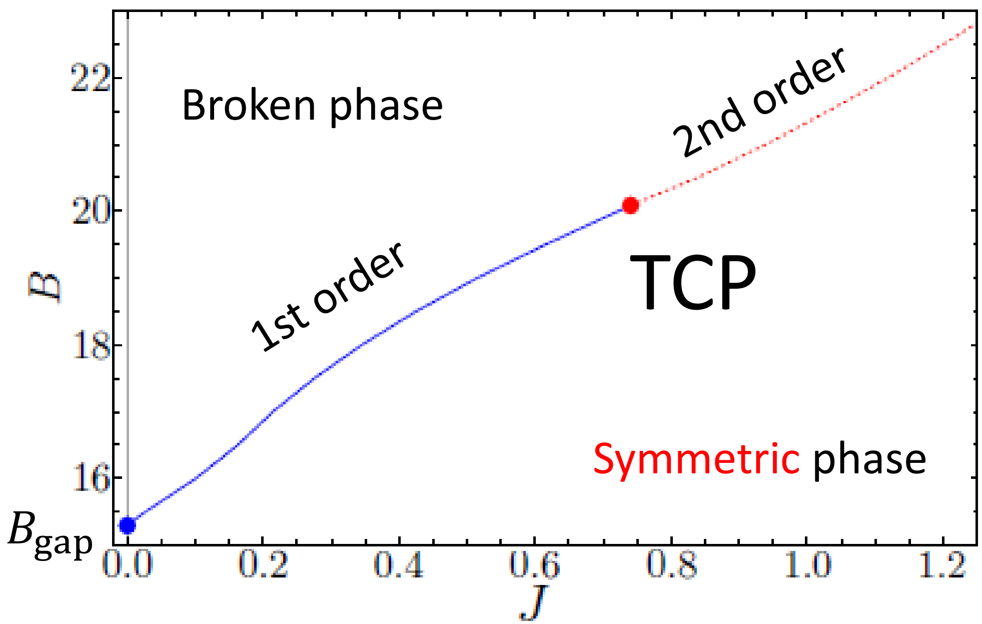
This question is shared with researchers including experimental physicists.

http://www.ss.scphys.kyoto-u.ac.jp/kibanS_h29-33/en/event.html

In this talk,

We find a novel TCP (tricritical point) that is realized only in the presence of J.

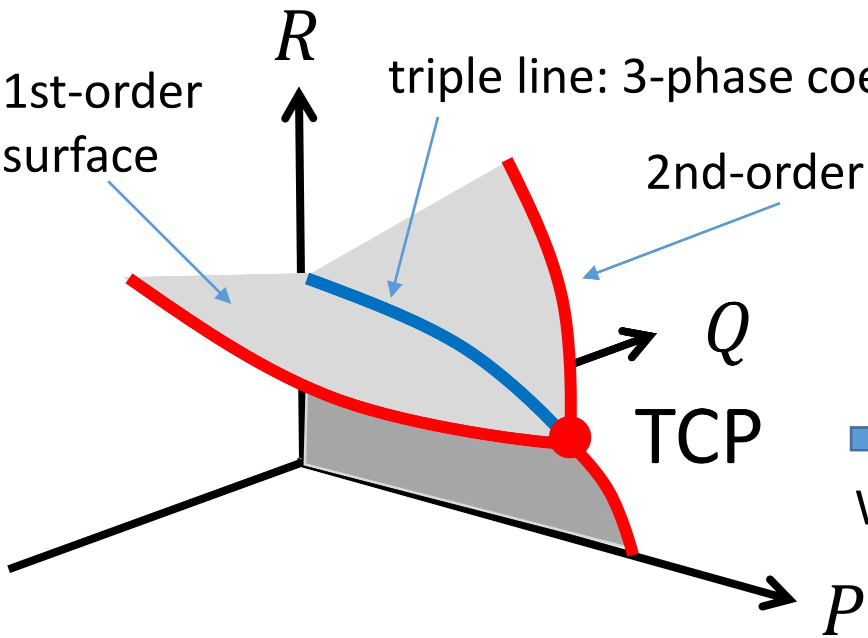
[T. Imaizumi, M. Matsumoto and S.N., PRL124 (2020) 19, 191603]



(I will explain the details of this figure later.)

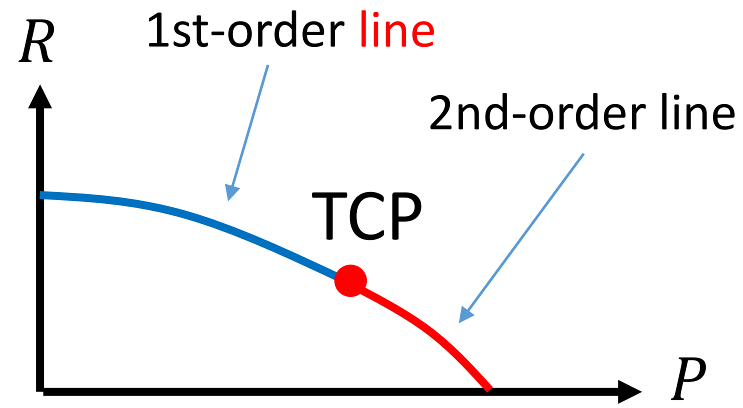
What is TCP?

A point at which three-phase coexistence terminates.

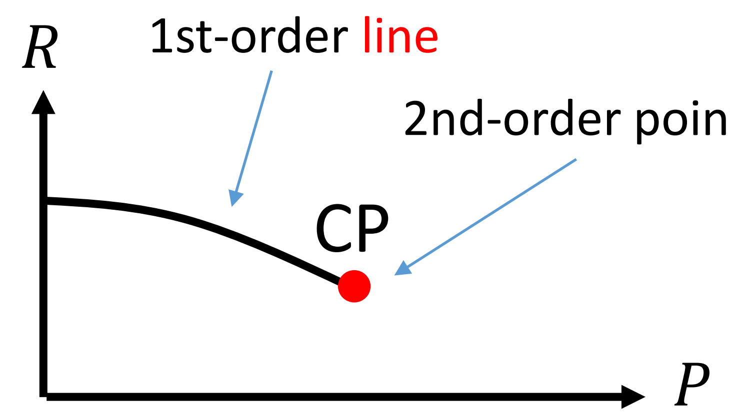


3d phase diagram with parameters P, Q and R.

When $Q = 0$



When $Q \neq 0$

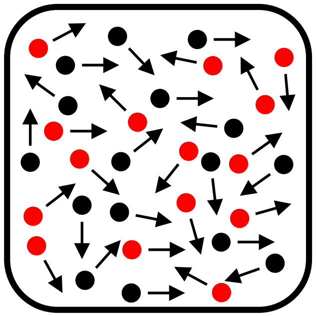


Our case: $P \rightarrow J$

We employ holography

Because we can attack non-equilibrium physics.

Microscopic theory



Coarse graining

Connection between UV and IR.

Macroscopic quantity

Expectation value of physical quantity

An advantage of holography

It has already been "encoded" in the geometry.

In holography, the expectation values are obtained (by GKP-W) once we have the dual geometry.

Our system

The D3-D7 system

[Karch and Katz, 2002]

$SU(N_c)$ $\mathcal{N}=4$ SYM + $\mathcal{N}=2$ hypermultiplet of mass m at $N_c \gg 1$ with $\lambda = g_{\mathrm{YM}}^2 N_c \gg 1$ at finite temperature T.

Our system: $m \neq 0$ with E_x (J_x), B_z at T .

Because of the conformal symmetry → Our parameters $\frac{m}{T}$, $\frac{J}{T^3}$, $\frac{B}{T^2}$.

q

φ_1 φ_2

q

“Chiral symmetry” at $m = 0$:

If m=0, we have a global U(1) symmetry under $q \to q e^{i\alpha}$, when $\langle \bar{q} q \rangle = 0$.

[Babington, Erdmenger, Evans, Guralnik and Kirsch, 2008]

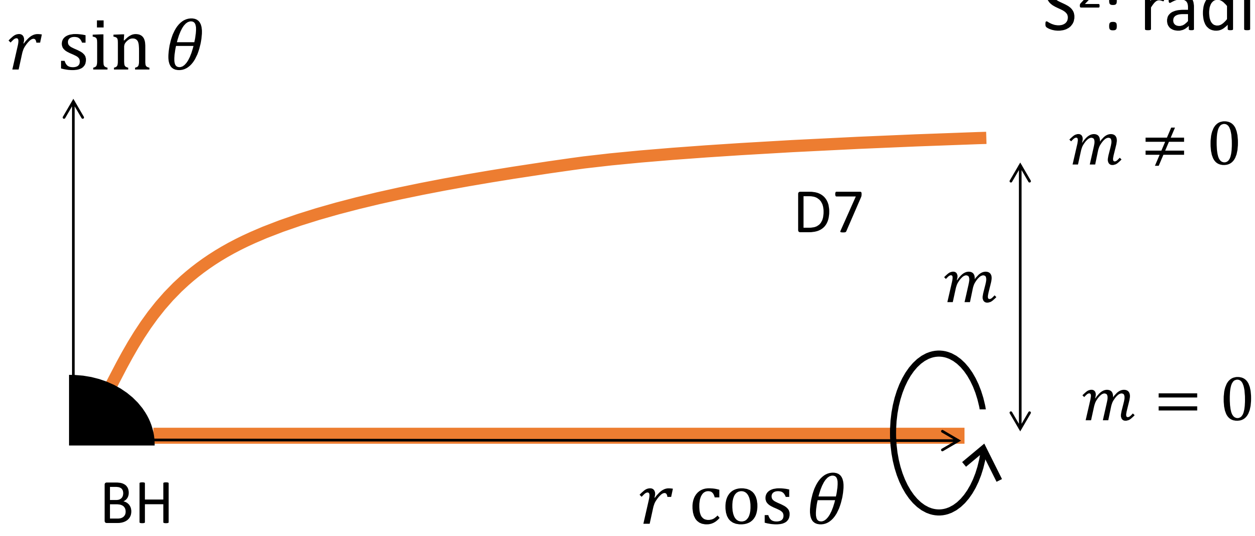
D-brane configurations

AdS$_5$ (AdS-BH at $T > 0$) S^5

	0	1	2	3	4	5	6	7	8	9
D3	○	○	○	○						
D7	○	○	○	○	○	○	○	○		

r

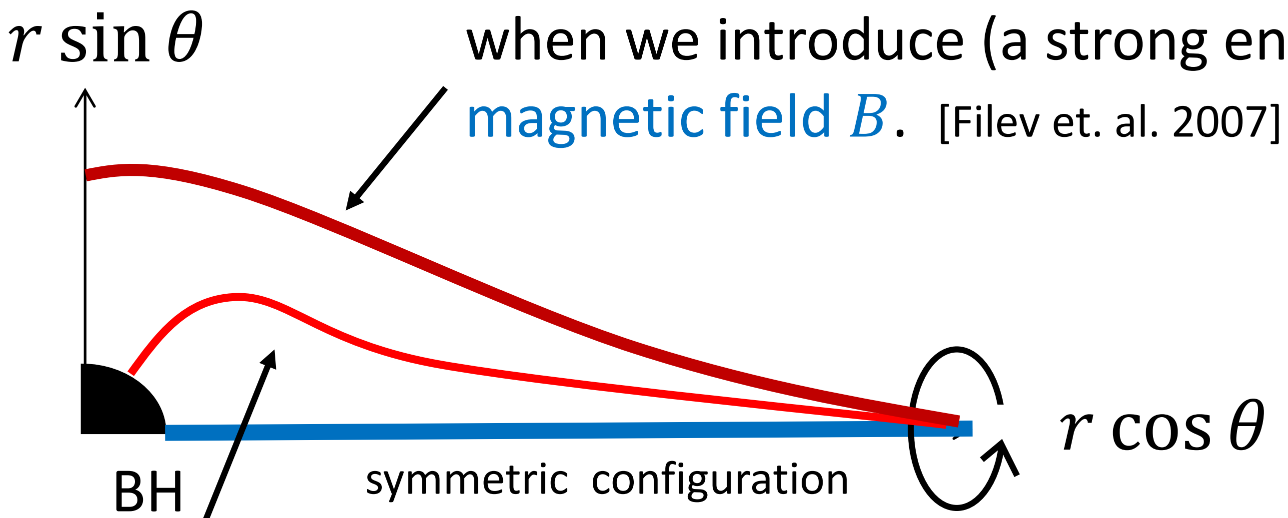
S^2: radius $\sin\theta$



symmetric under a U(1) chiral symmetry.

U(1) symmetry breaking by magnetic field B

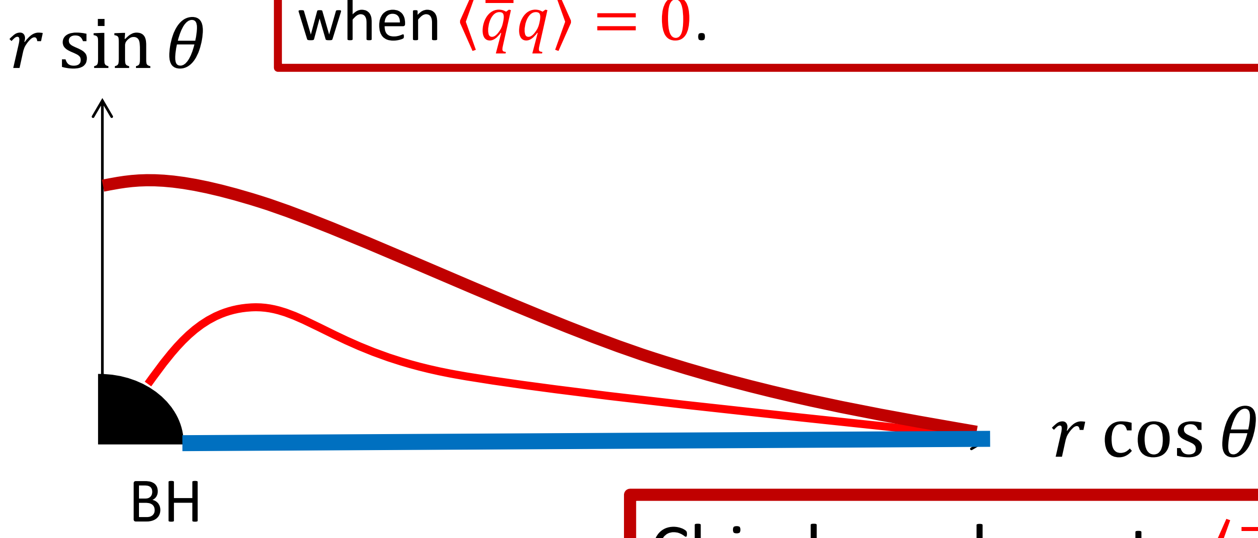
The U(1) symmetry can be broken when we introduce (a strong enough) magnetic field B. [Filev et. al. 2007]



If we apply the electric field E, this "symmetry-broken conductor phase" can also be possible.

The order parameter

The global U(1) symmetry under $q \to qe^{i\alpha}$, when $\langle \bar{q}q \rangle = 0$.



Chiral condensate $\langle \bar{q}q \rangle$ is the order parameter.

The shape of the D7 is described by the function θ(r).

$$\theta(r) = m\, r^{-1} + \text{const.}\; r^{-3} + \ldots\ldots$$

$$r \sin\theta(r)\big|_{r\to\infty} = m$$

When $m = 0$, the chiral condensate $\langle \bar{q}q \rangle$ is given by this coefficient.

Conductivity

[Karch and O'Bannon, 2007]

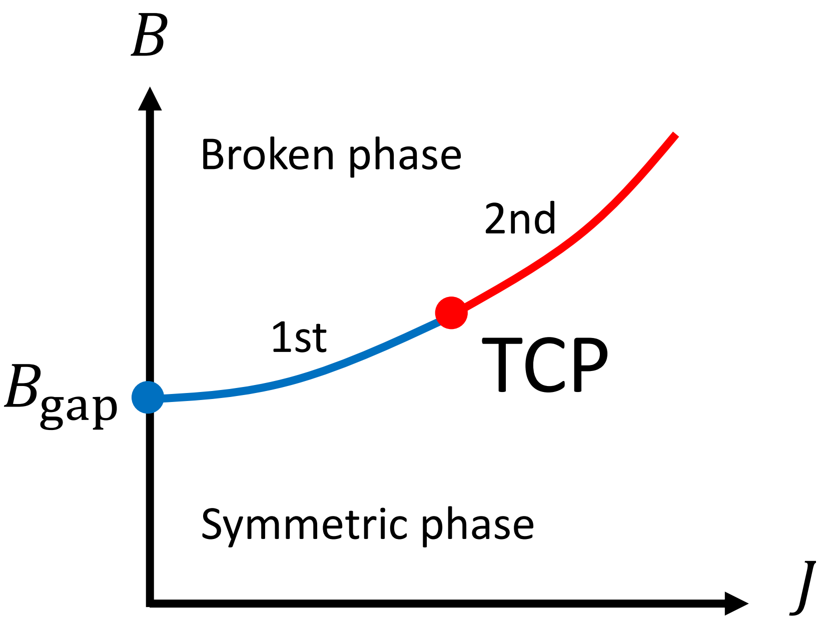
The nonlinear conductivity of the D3-D7 system can be computed by using the GKP-W prescription.

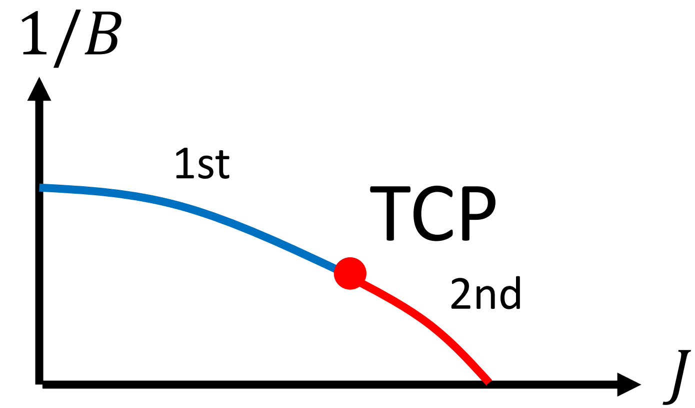
$$J = \sigma(E)\, E$$

The conductivity is computed even in the presence of external magnetic field B.

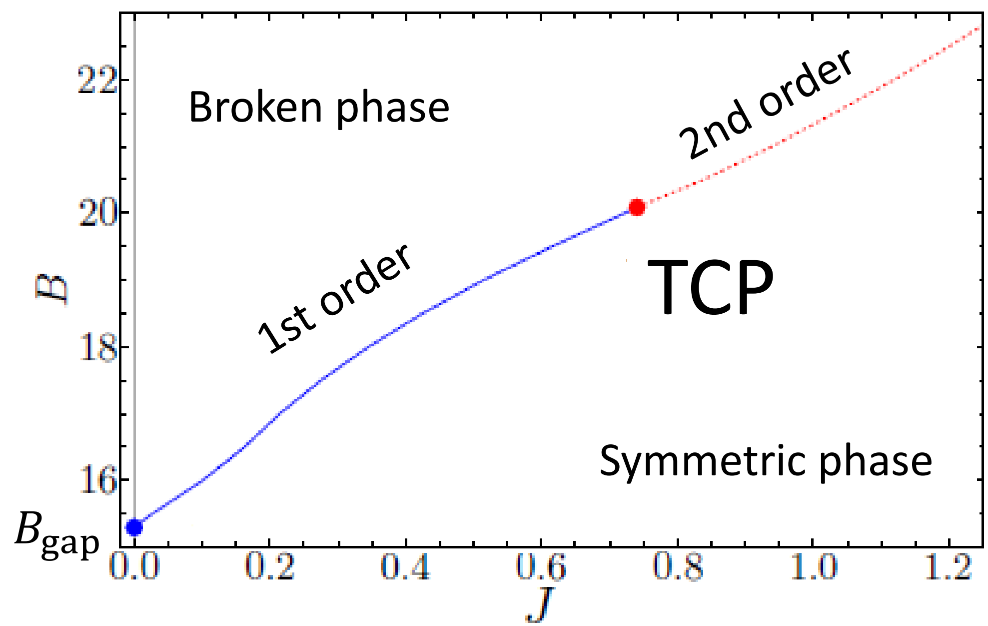
[Ammon, Ngo and O'Bannon, 2009]

What we have observed for $m = 0$





T: fixed



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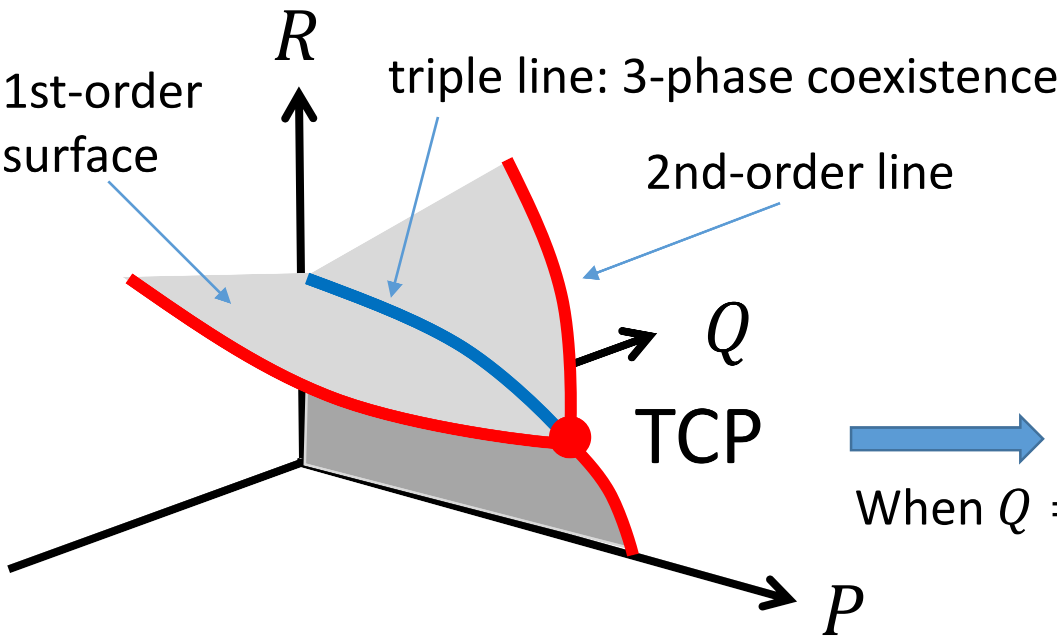
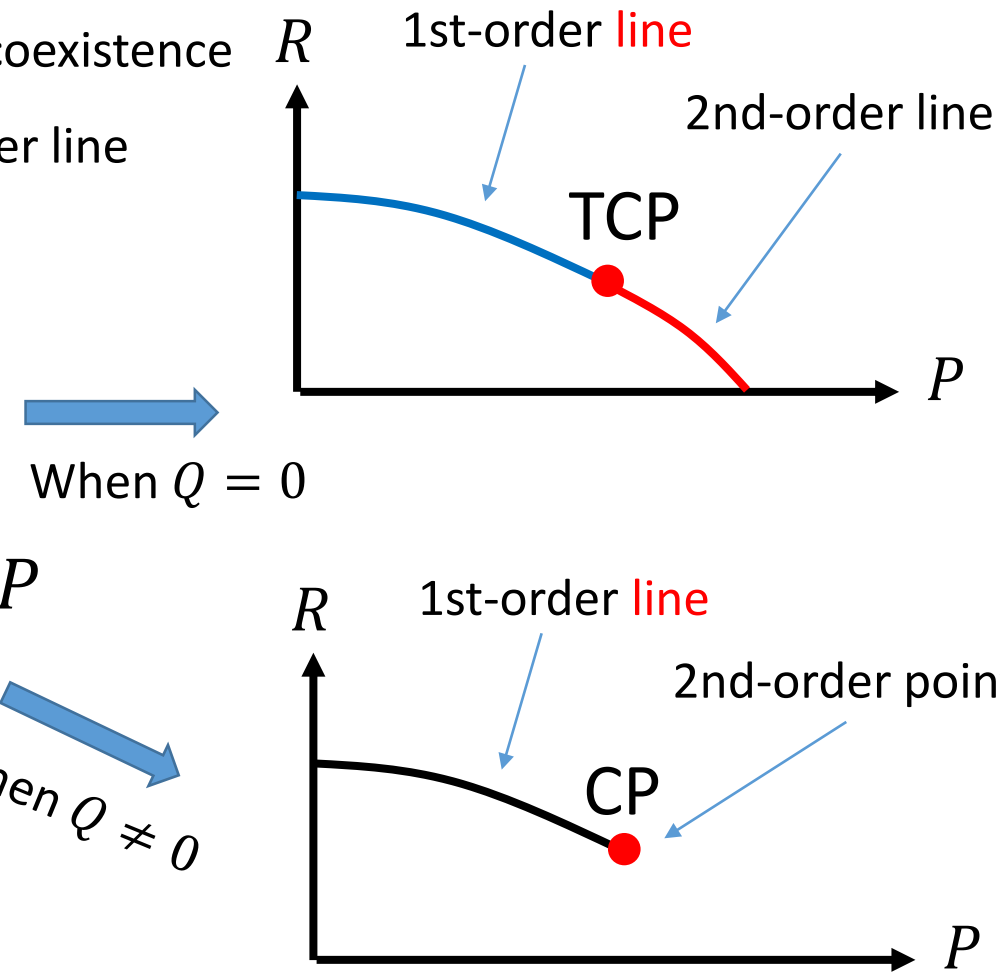
A point at which three-phase coexistence terminates.



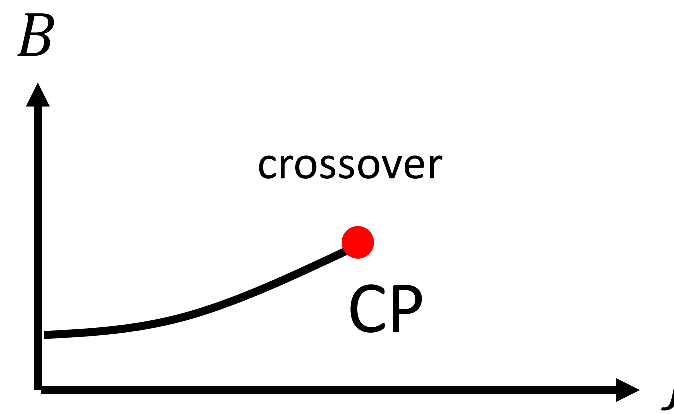
3d phase diagram with parameters P, Q and R.

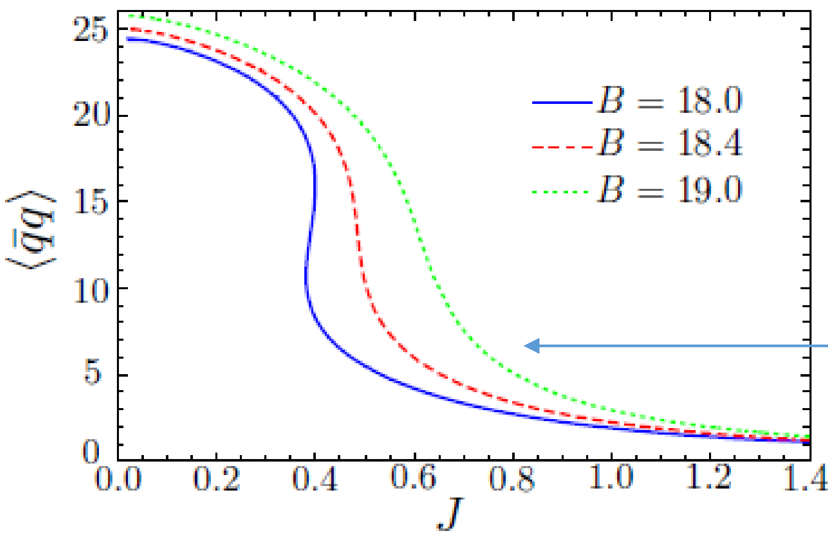


We choose $P \rightarrow J$

The 3rd parameter: m

If m corresponds to the 3rd parameter,
crossover should be observed at $m \neq 0$.



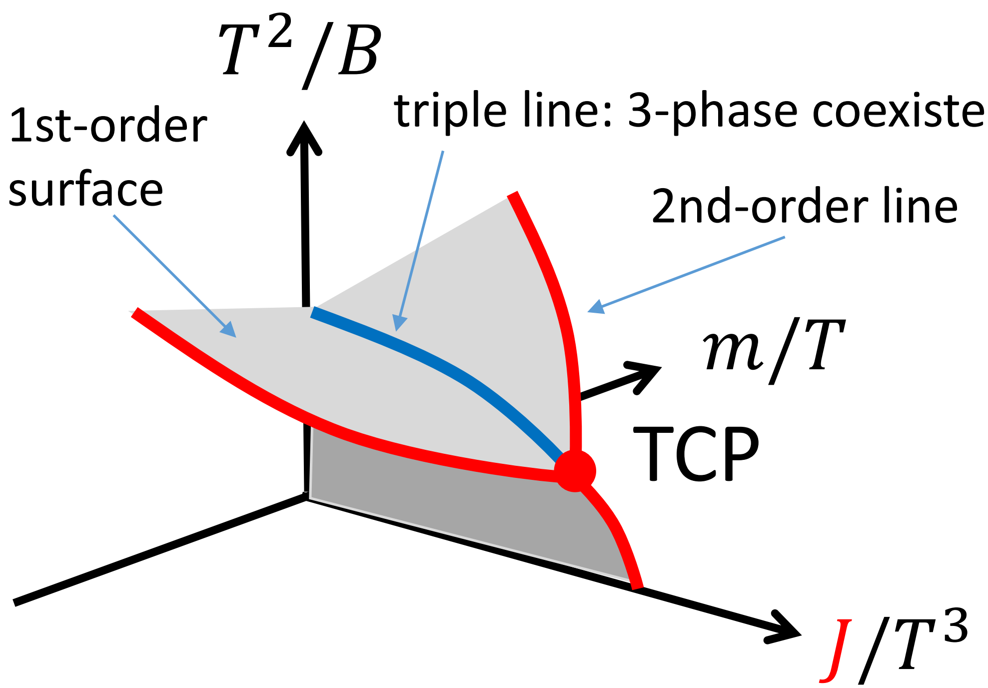


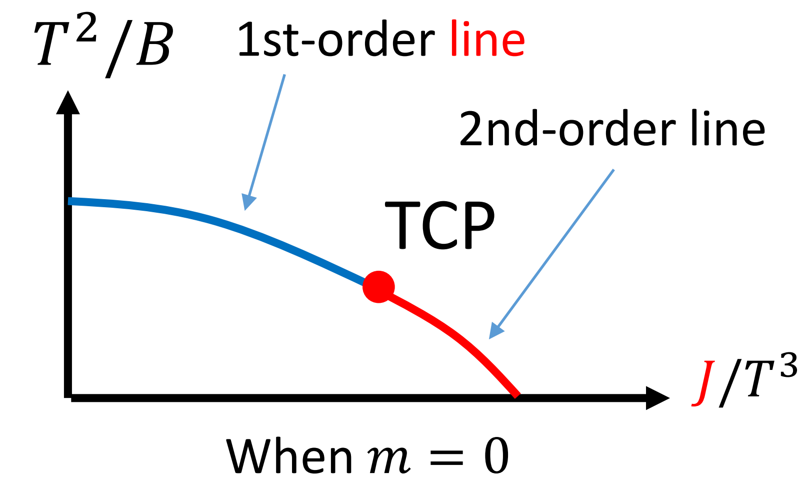
Crossover

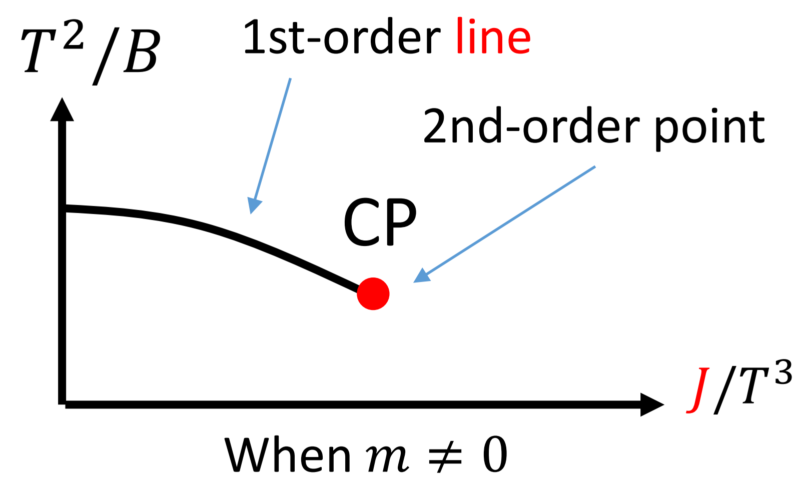
$m = 0.01$

We observed crossover.

Our phase diagram







This TCP is observed only at

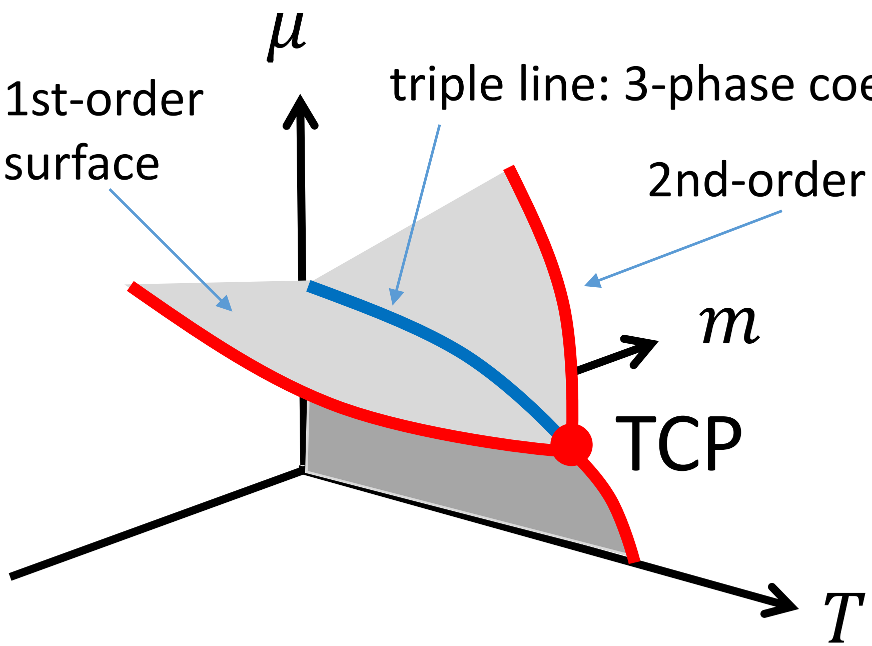
$$J \neq 0$$

where the system is a NESS.

Current-driven nonequilibrium TCP

Critical exponents: equilibrium case

Order parameter $\propto (T_c - T)^{\beta}$



Example of equilibrium phase diagram of 2-flavor QCD.

[Halaz, Jackson, Shrock, Stephanov and Verbaarschot, 1998]

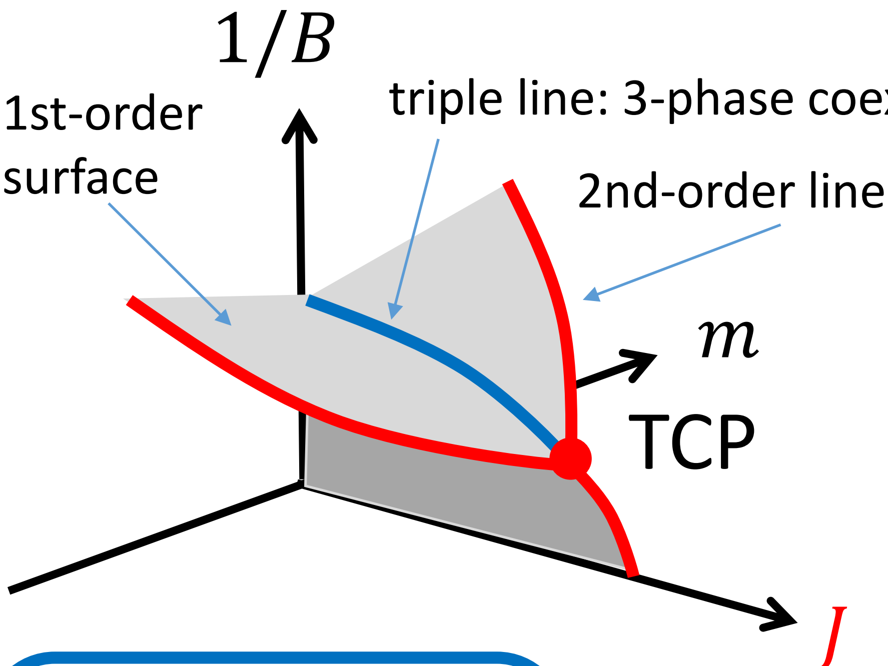
Landau theory for equilibrium systems

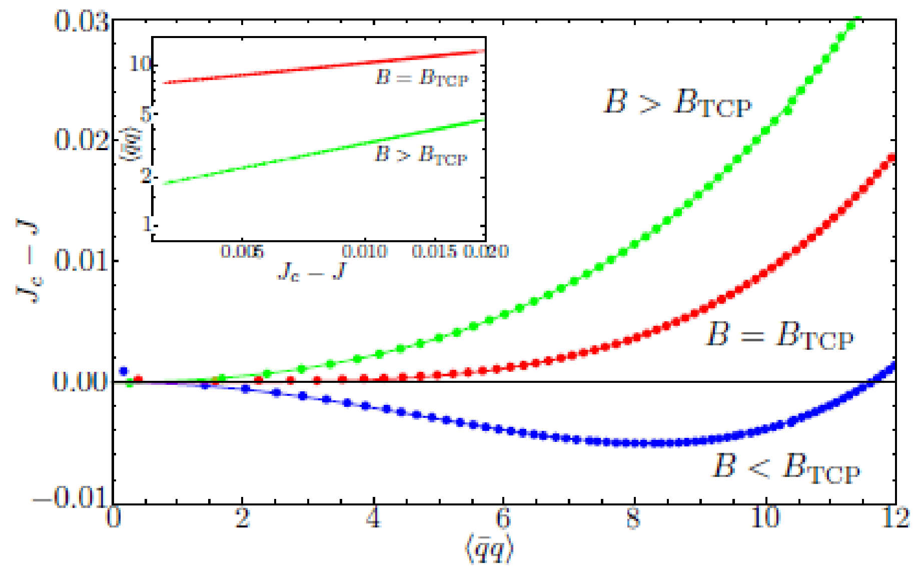
$\beta = 1/2$ at CP

$\beta = 1/4$ at TCP

Our case

Let us use J: $\langle \bar{q}q \rangle \propto (J_c - J)^{\beta}$





Landau theory
for equilibrium systems

$\beta = 1/2$ at CP

$\beta = 1/4$ at TCP

$\beta = 0.4993 \approx 1/2$ at CP

$\beta = 0.2503 \approx 1/4$ at TCP

Summary

[T. Imaizumi, M. Matsumoto and S.N., PRL124 (2020) 19,191603]

- We discovered a novel tricritical point (TCP) and associated phase transitions that appear only in NESS at $J \neq 0$.

- The obtained critical exponent β agreed with that of the Landau theory if we replace T of the Landau theory with J.

Further directions

- Other critical exponents? (work in progress)
- Possible observation in experiments?