

Current-driven Tricritical Point in Large- N_c Gauge Theory

Shin Nakamura (Chuo U.)

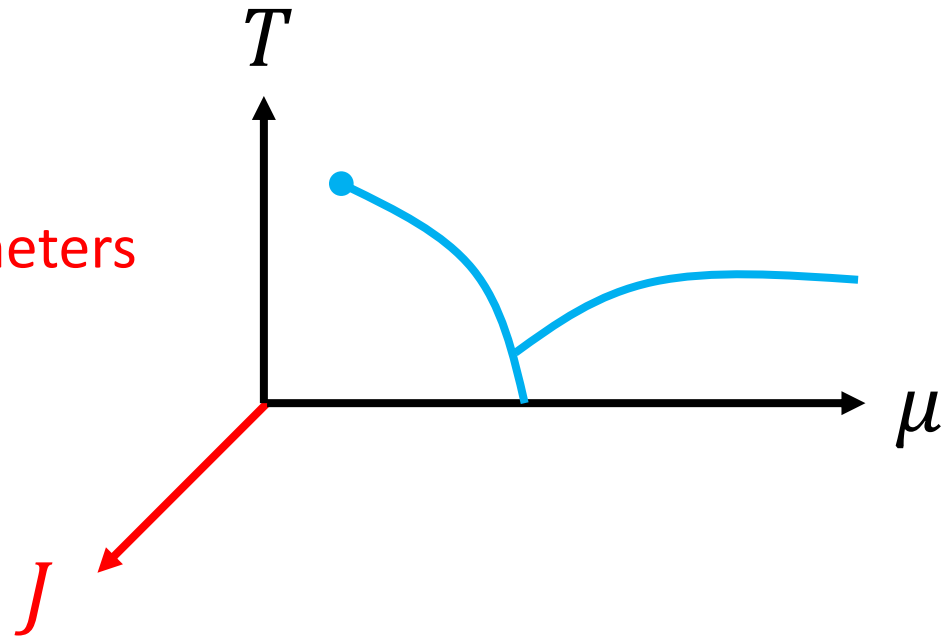
Ref. [T. Imaizumi, M. Matsumoto and S.N., [PRL124 \(2020\) 19, 191603](#)]

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?

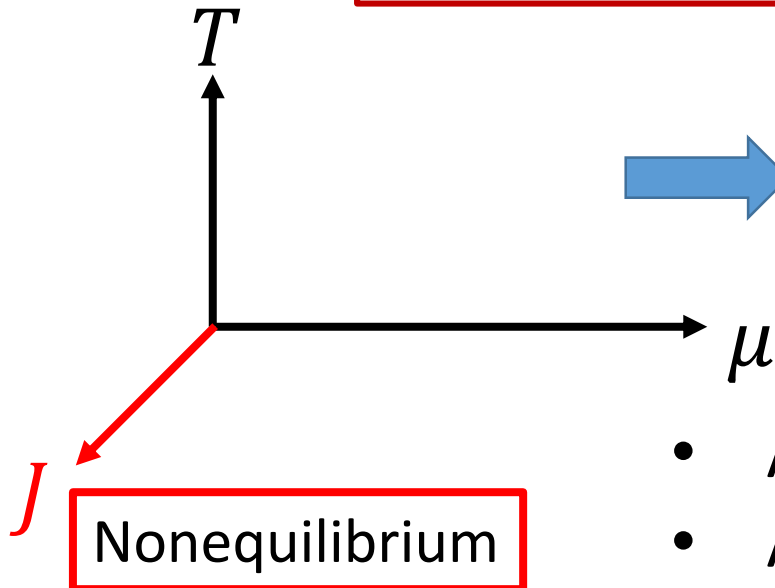
J is rather new:

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

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

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

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?**

Grant-in-Aid for Scientific Research (S) FY2017-FY2021 Japanese
**DC Electric Field and Current:
Novel Control Parameters for Strongly Correlated Electron Systems**

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Meetings

NESS 2019 (Nagoya) Non-Equilibrium Steady States in Correlated Materials

 **NESS 2019 (Nagoya)**
Non-Equilibrium Steady States in Correlated Materials
July 5 - 6, 2019, Nagoya University

Grant-in-Aid for Scientific Research (S) FY2017-FY2021 DC Electric Field and Current: Novel Control Parameters for Strongly Correlated Electron Systems

Dates: July 5 (Fri) 14:00 -July 6 (Sat) 17:00, 2019

Venue: 5 (Fri) Room 506, Science Hall 5F, Nagoya University #D2(8) building
6 (Sat) Room B428, B-building 4F, Nagoya University #D3(3) building

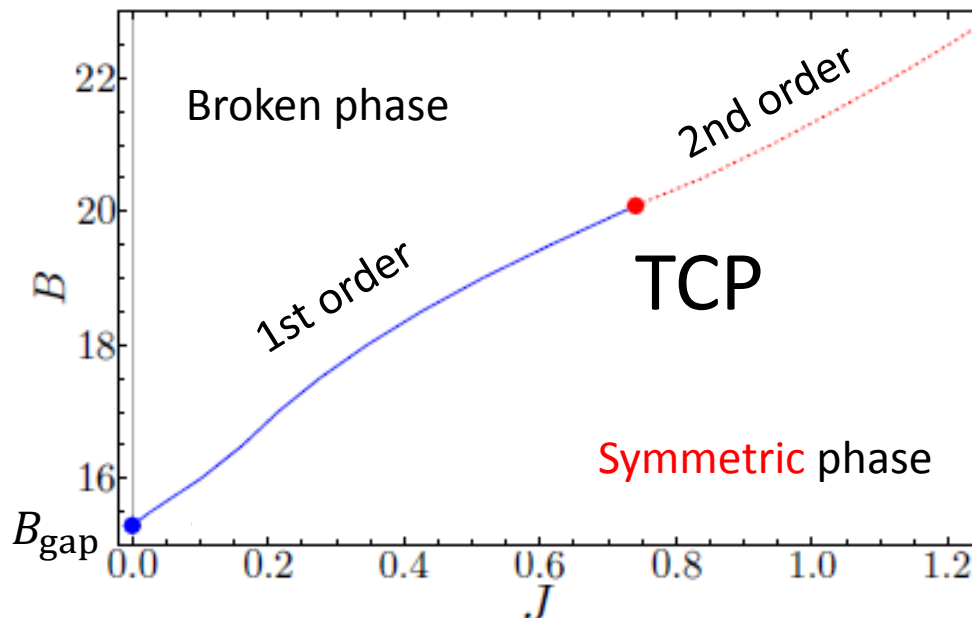


This question is **shared** with researchers including **experimental physicists**.

In this talk,

We find a novel **TCP** (trⁱcritical p^oint)
that is realized **only** in the presence of J .

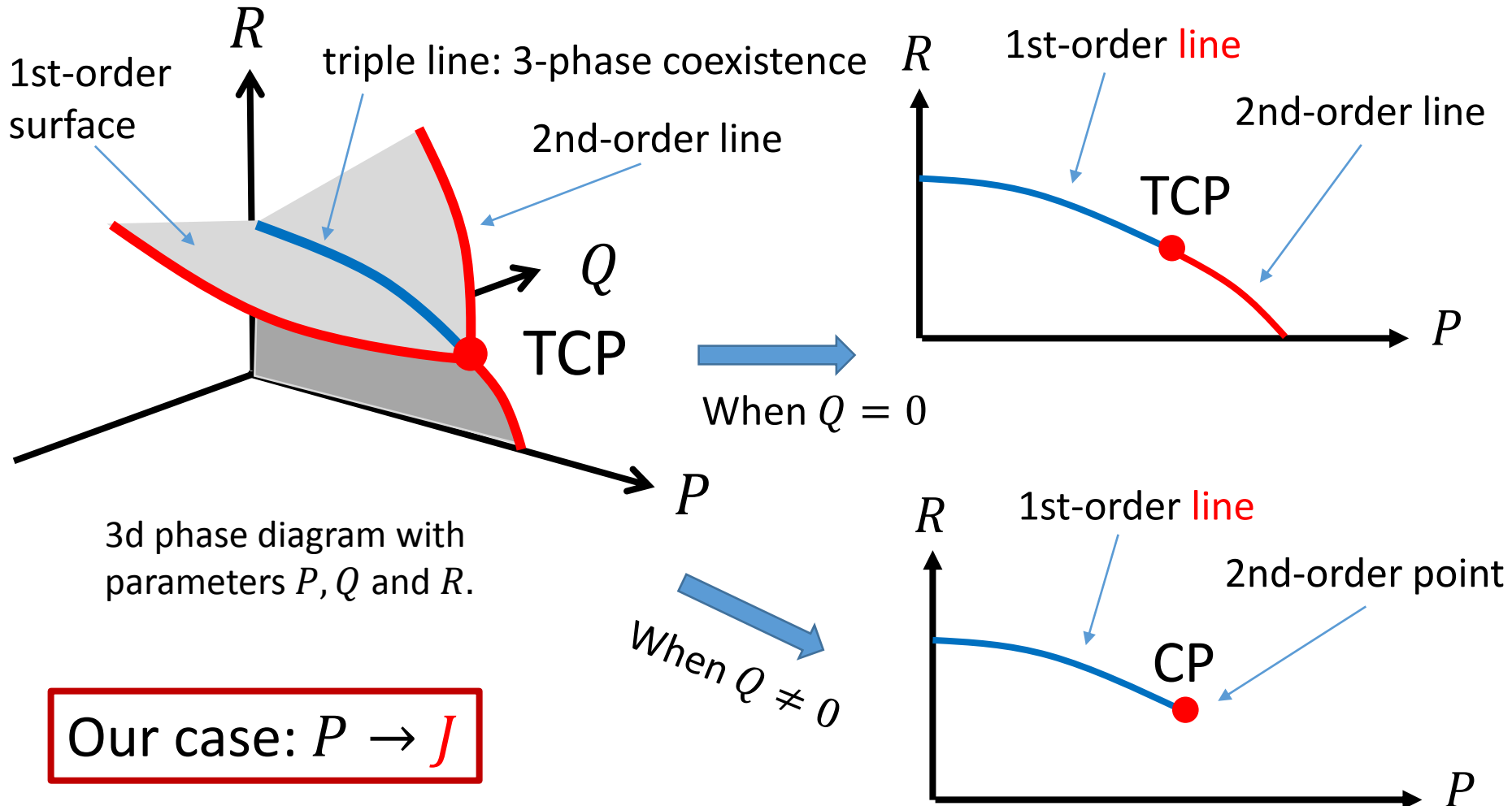
[T. Imaizumi, M. Matsumoto and S.N., **PRL**124 (2020) 19, 191603]



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

What is TCP?

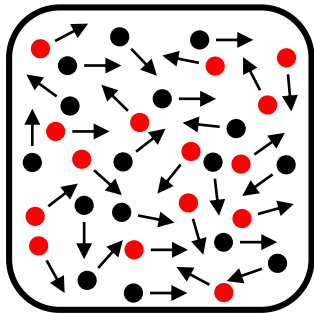
A point at which **three-phase coexistence terminates**.



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 $\lambda = g_{\text{YM}}^2 N_c \gg 1$ 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



$\frac{m}{T}$, $\frac{J}{T^3}$, $\frac{B}{T^2}$.

“Chiral symmetry” at $m = 0$:

φ_1 φ_2
 q

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

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

D-brane configurations

AdS₅ (AdS-BH at $T > 0$)

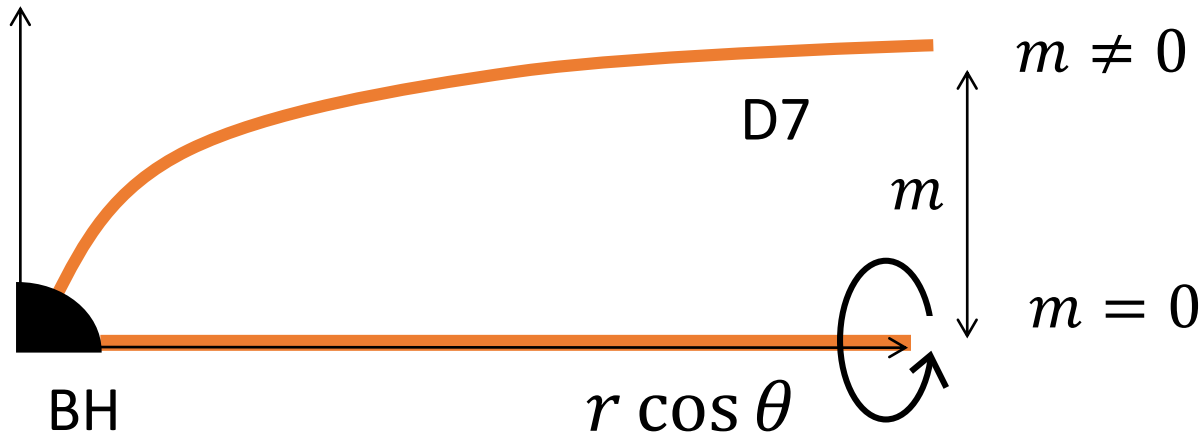
S⁵

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

r

S²: radius $\sin \theta$

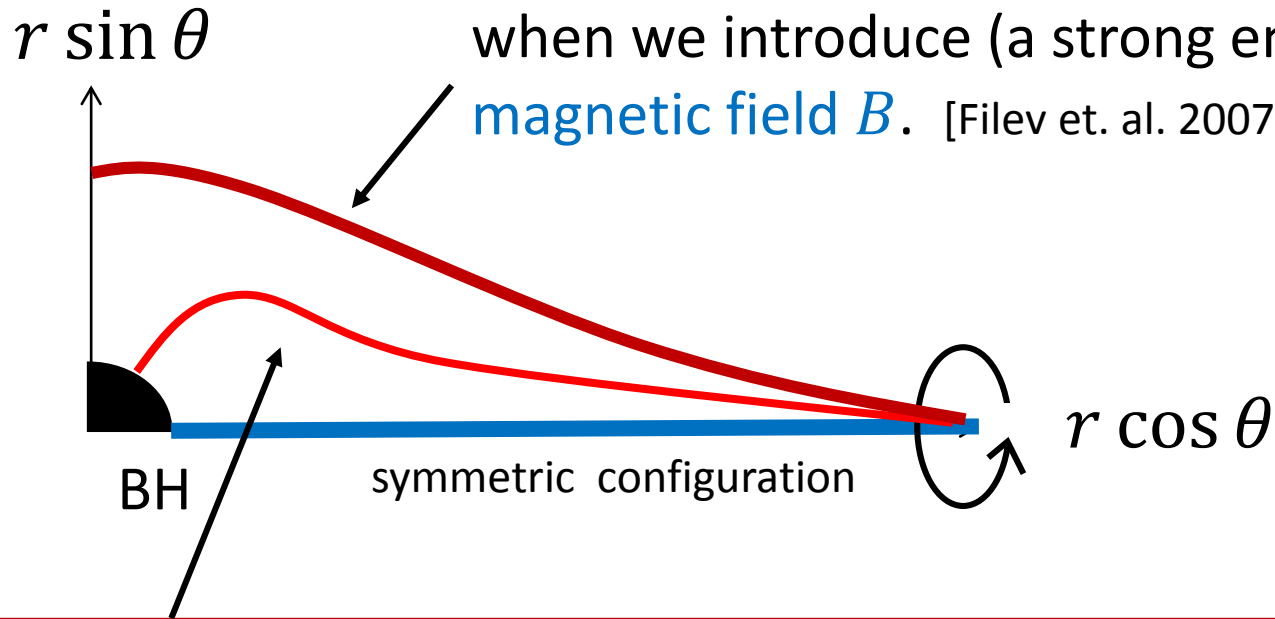
$r \sin \theta$



symmetric under a **U(1)** chiral symmetry.

U(1) symmetry breaking by magnetic field B

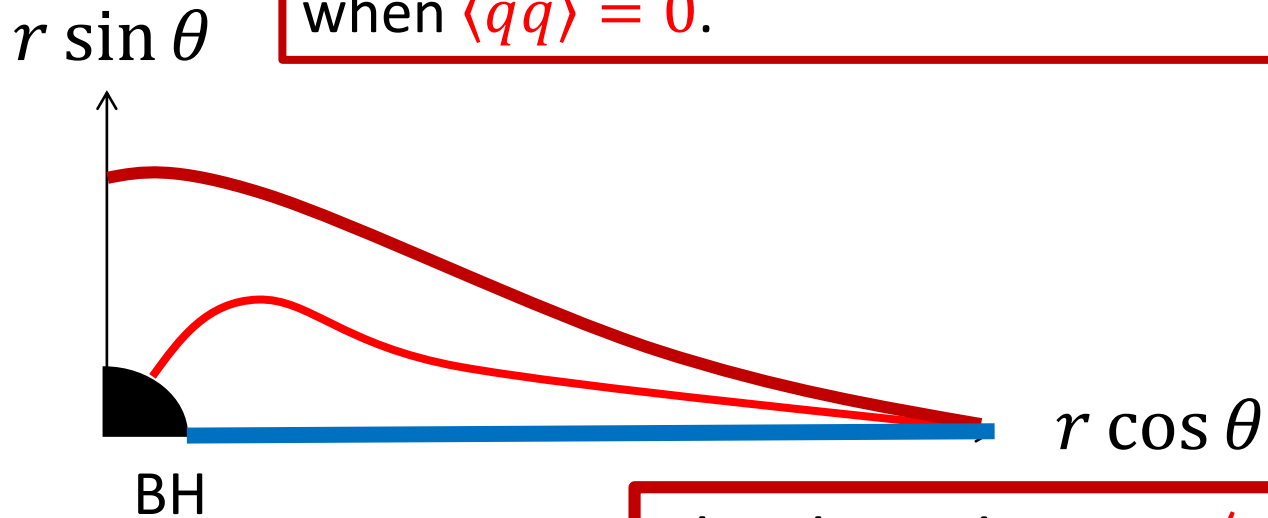
The **U(1) symmetry can be broken** when we introduce (a strong enough) **magnetic field B** . [Filev et. al. 2007]



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 $q \rightarrow qe^{i\alpha}$,
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 $\theta(r)$.

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

$$r \sin \theta(r) \Big|_{r \rightarrow \infty} = m$$

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

Conductivity

[Karch and O'Bannon, 2007]

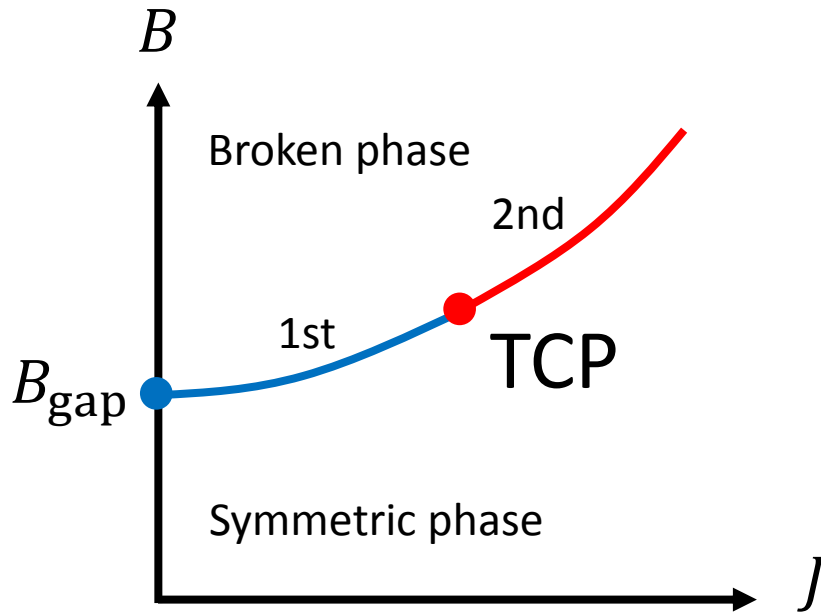
The **nonlinear conductivity** of the D3-D7 system can be computed by using the **GKP-W** prescription.

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

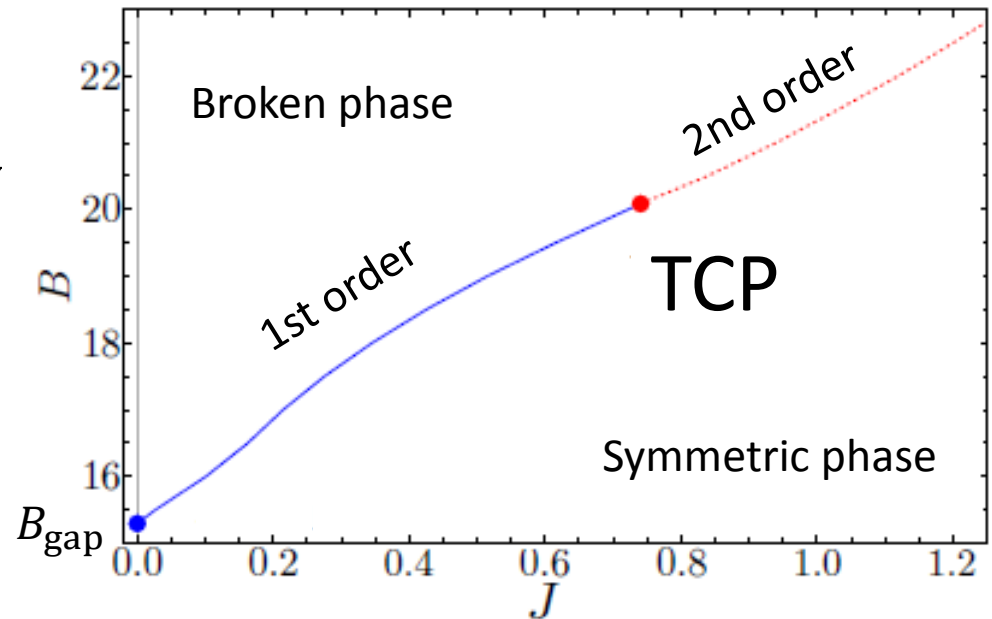
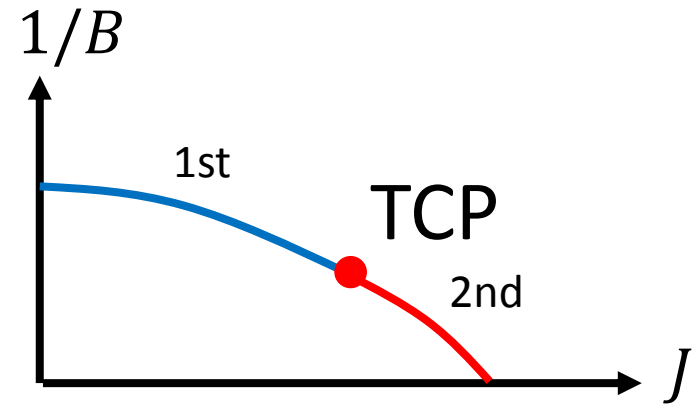
The conductivity is computed even in the presence of external magnetic field **B** .

[Ammon, Ngo and O'Bannon, 2009]

What we have observed for $m = 0$

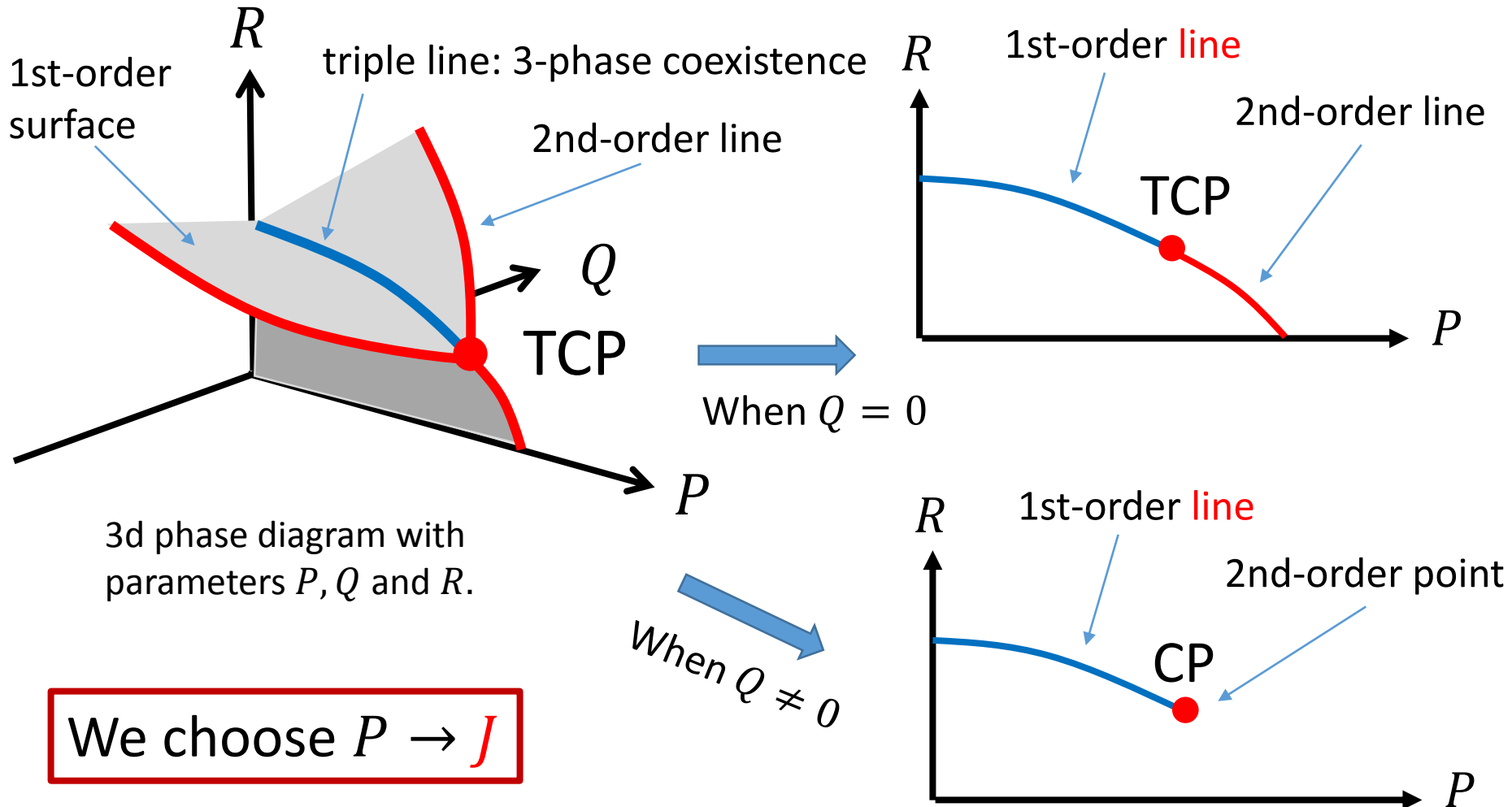


T : fixed



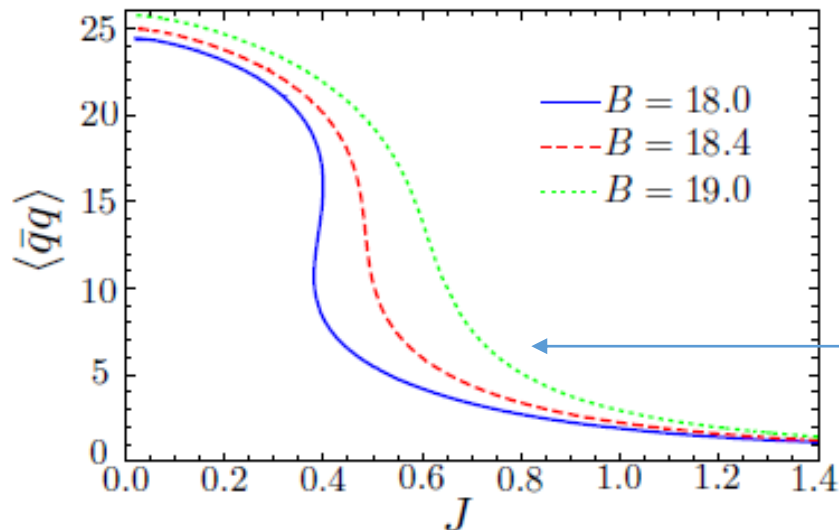
What is TCP?

A point at which **three-phase coexistence terminates**.

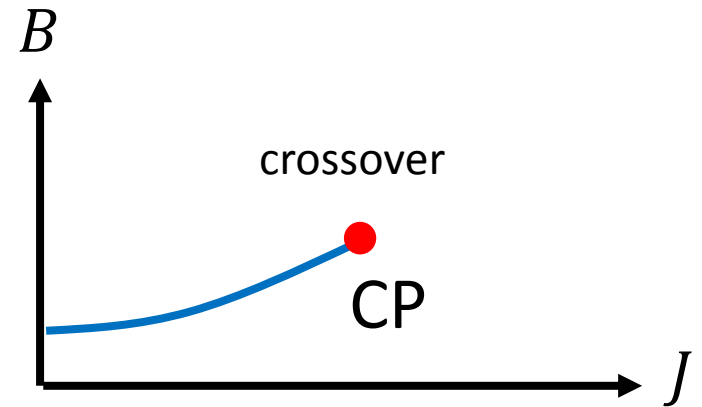


The 3rd parameter: m

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



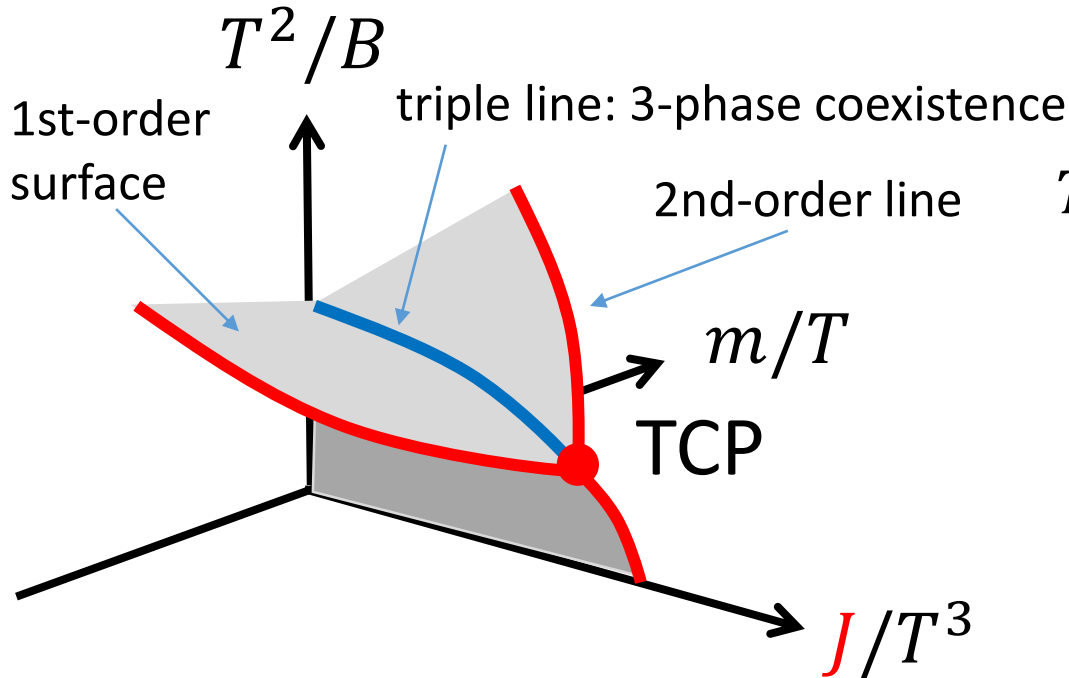
$m = 0.01$



Crossover

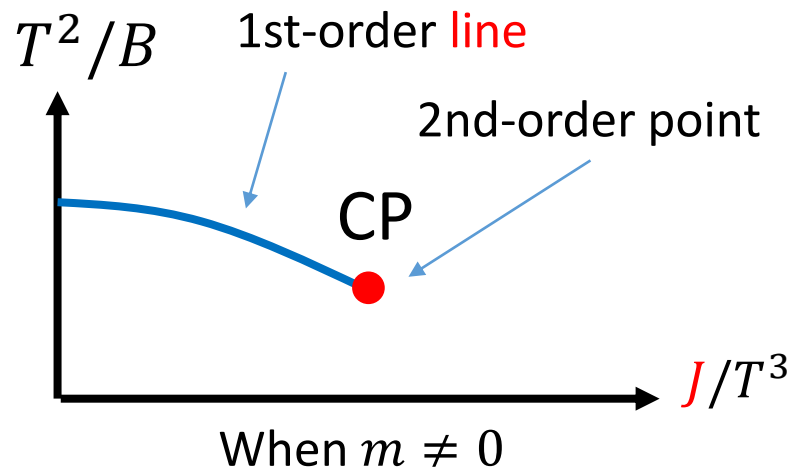
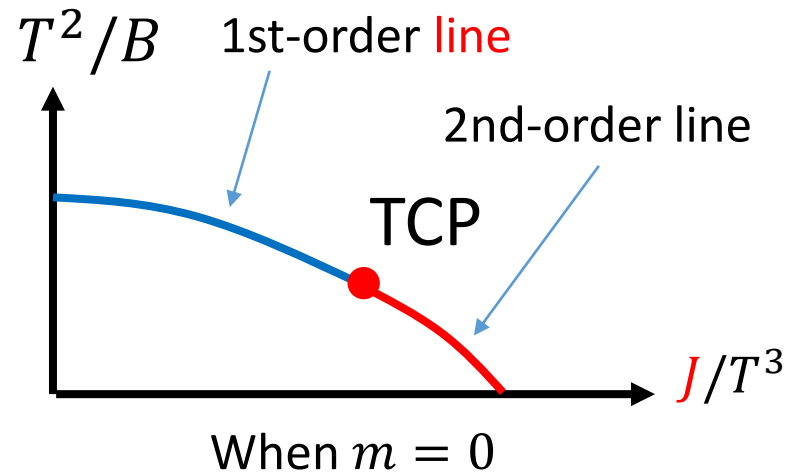
We observed **crossover**.

Our phase diagram



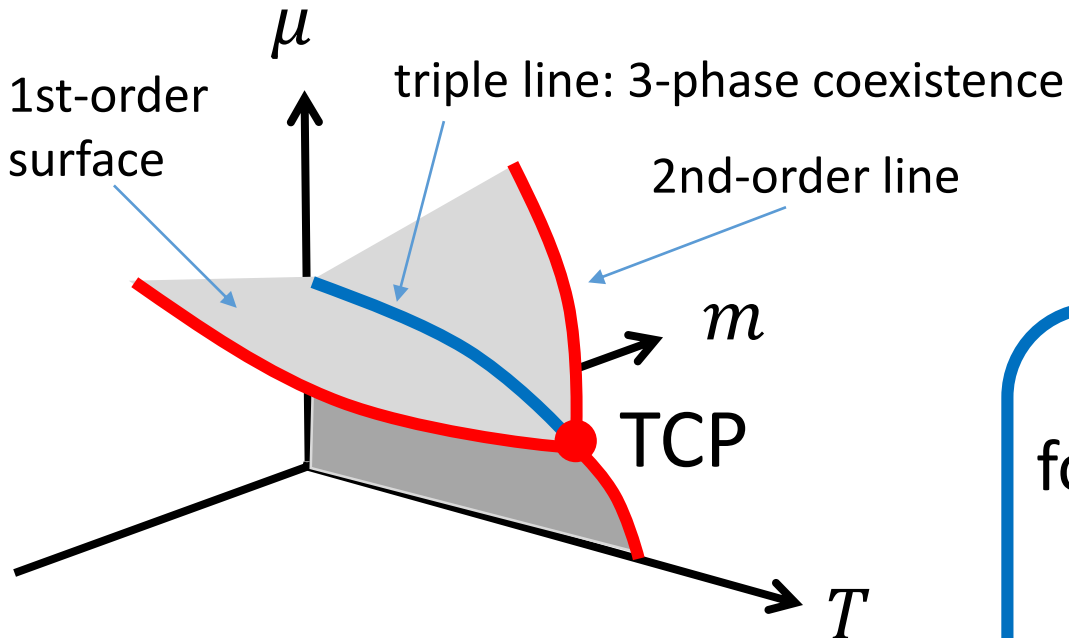
This TCP is observed **only at**
 $J \neq 0$
where the system is a **NESS**.

**Current-driven
nonequilibrium TCP**



Critical exponents: equilibrium case

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



Example of **equilibrium** phase diagram of 2-flavor QCD.

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

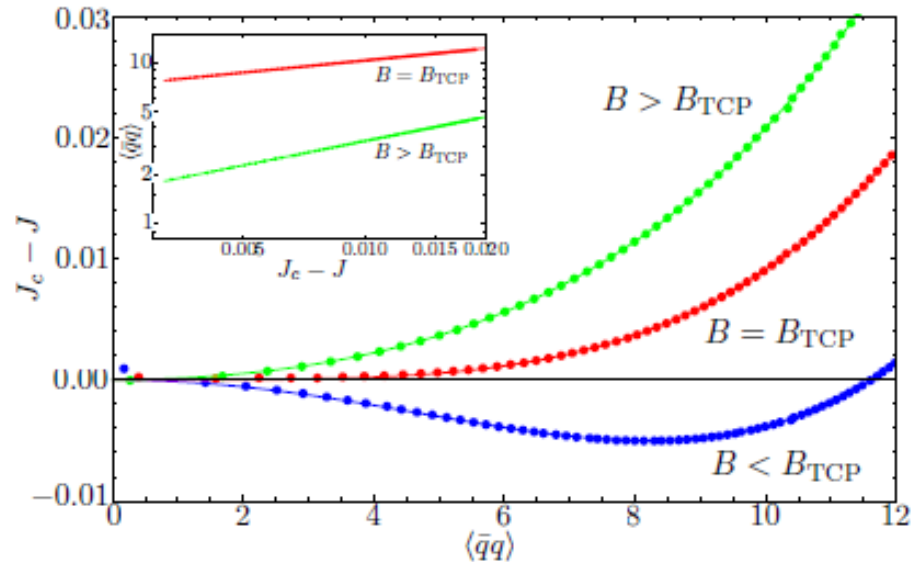
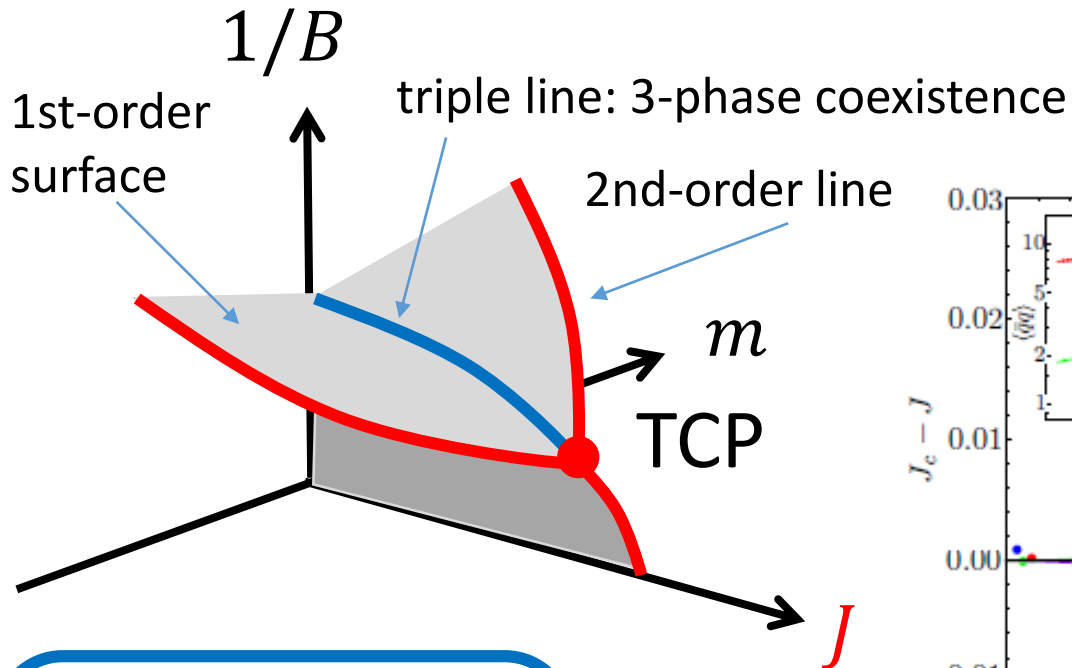
Landau theory for **equilibrium** systems

$$\beta = 1/2 \text{ at CP}$$

$$\beta = 1/4 \text{ at TCP}$$

Our case

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



Landau theory
for **equilibrium** systems

$$\beta = 1/2 \text{ at CP}$$

$$\beta = 1/4 \text{ at TCP}$$

$$\beta = 0.4993 \approx 1/2 \text{ at CP}$$

$$\beta = 0.2503 \approx 1/4 \text{ at TCP}$$

Summary

- 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?