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Quantum critical magnetocaloric effect in holography

Jun-Kun Zhao (赵俊坤)

Collaborator with Prof. Li Li (李理)

Institute of Theoretical Physics, Chinese Academy of Sciences

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- **Introduction**

  Magnetocaloric effect

  Quantum critical Magnetocaloric effect

- **Holographic setup**

  Ground states and quantum phase transition

  Thermodynamics

  Magnetocaloric effect

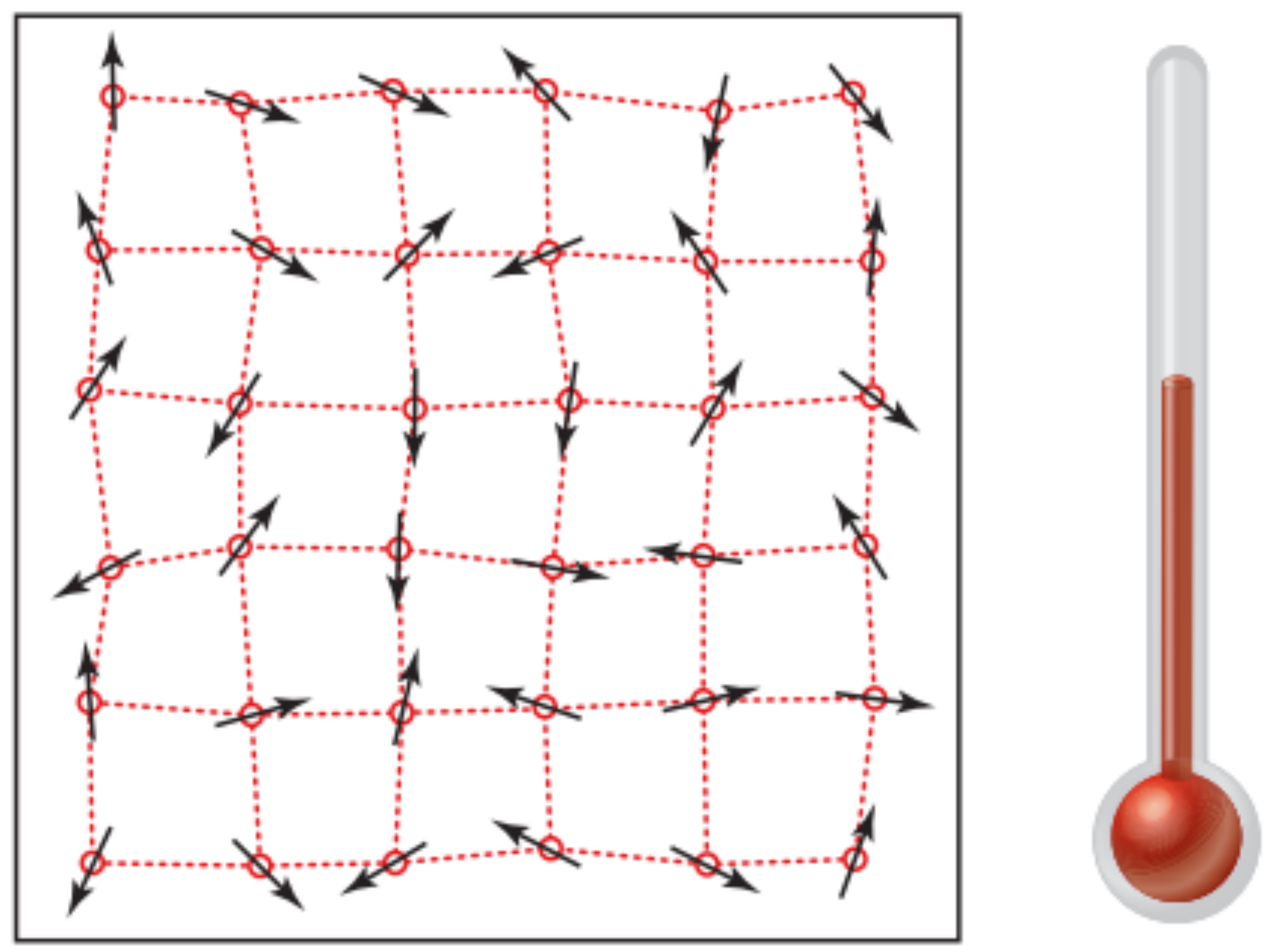
- **Summary and discussion**

Magnetocaloric effect

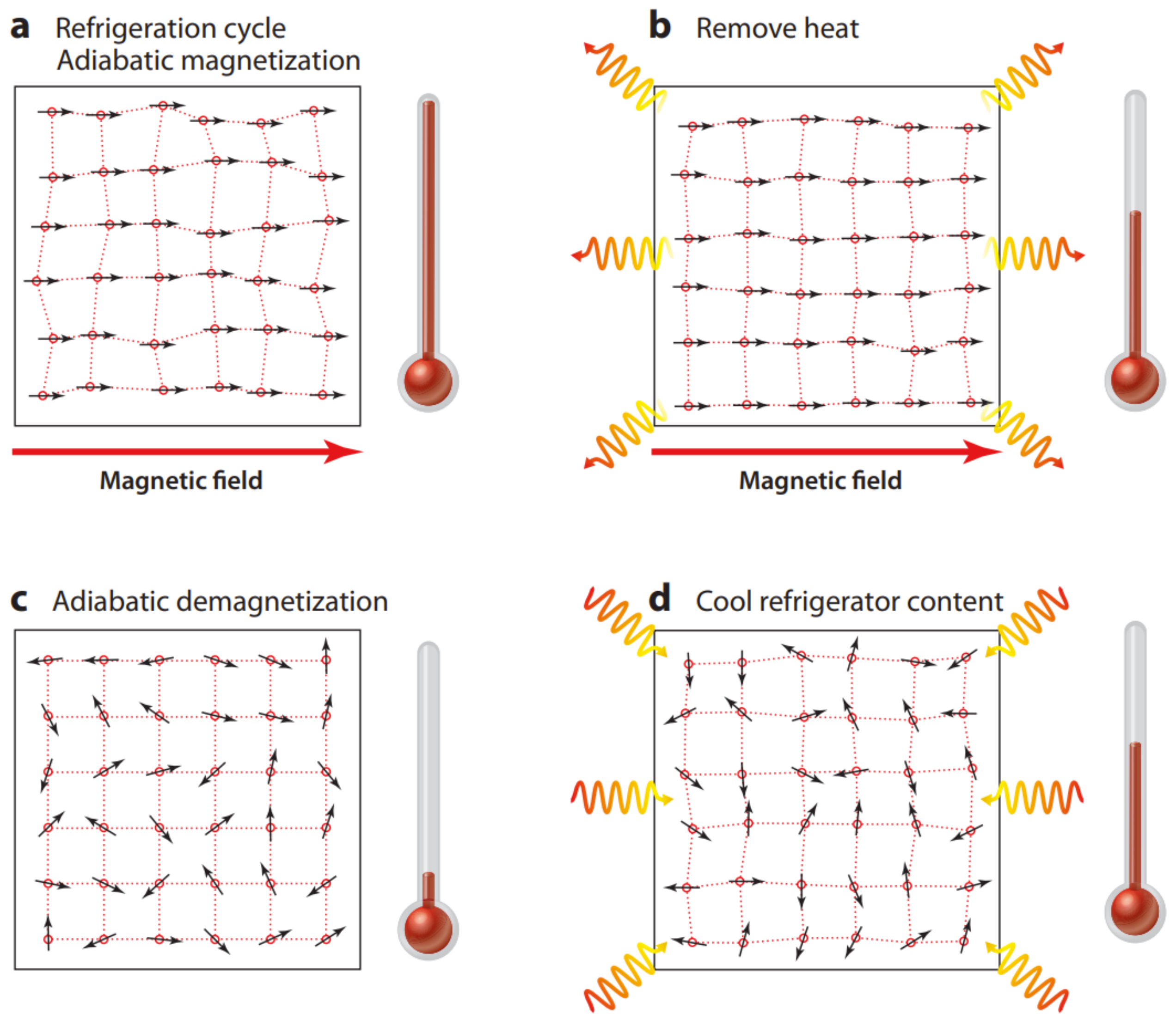
MCE has a 2-fold definition [Wolf et al, 1601.05092] :

First: Temperature change of material when magnetized or demagnetized in a reversible process;

Second: Entropy change of material when a magnetic field is applied in an isothermal process;



magnetic and lattice subsystems



four stages of the cooling cycle

Gruneisen parameter

- In a reversible adiabatic process, this effect can be characterized by the Gruneisen parameter

$$\Gamma_B \equiv \frac{1}{T}\left(\frac{\partial T}{\partial B}\right)_S,$$

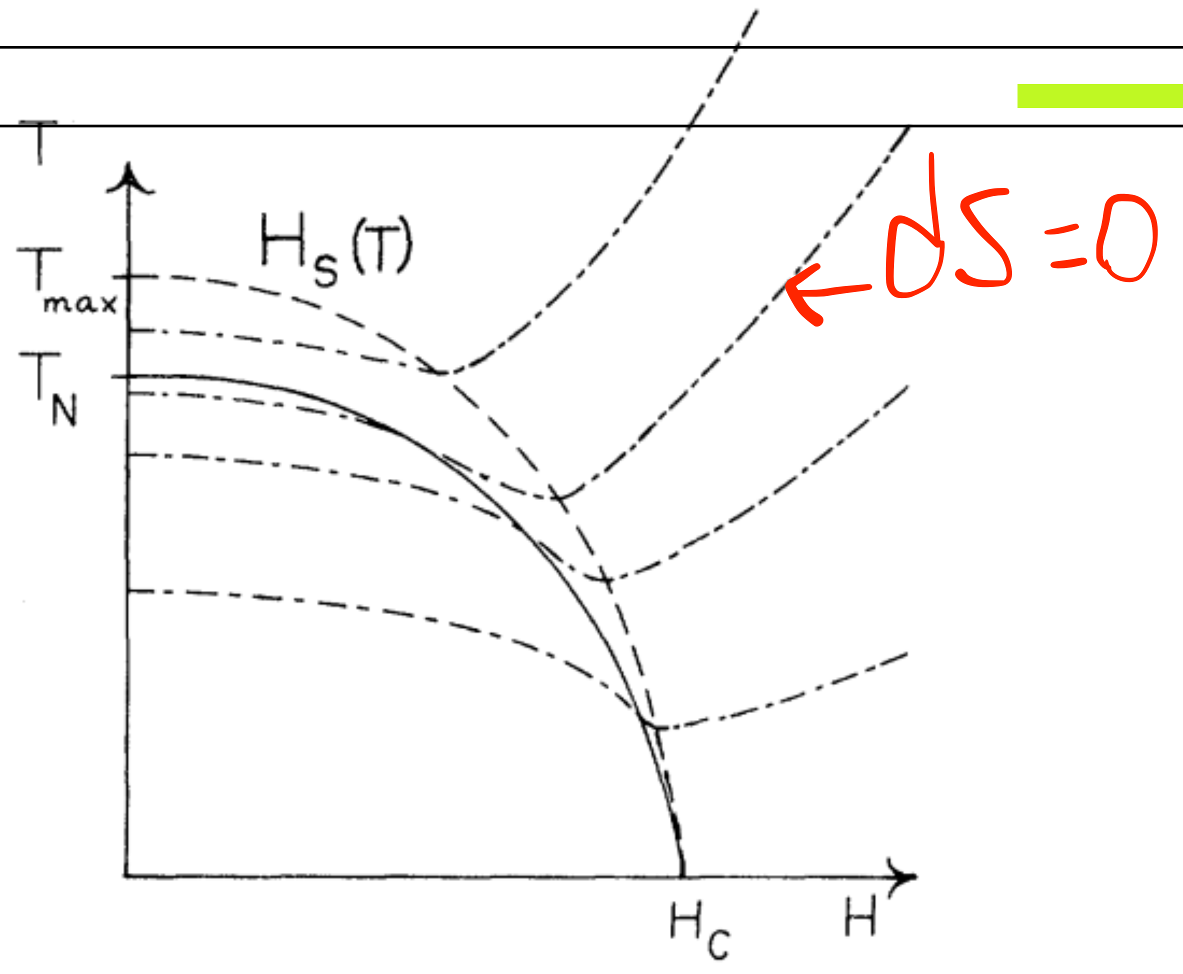
- Using thermodynamic relation and the adiabatic condition (i.e. dS = 0):

$$\Gamma_B = -\frac{1}{C}\left(\frac{\partial S}{\partial B}\right)_T = -\frac{(\partial S/\partial B)_T}{T(\partial S/\partial T)_B},$$

- It is generally expected and observed that the Gruneisen ratio is finite. For example, if a system is dominated by a single energy scale E^* (i.e. Fermi or Debye energy)

$$\Gamma = \frac{1}{E^*}\frac{\partial E^*}{\partial B}$$

Quantum critical MCE



- Early Studies in Spin 1/2 Heisenberg chain [PRA 5, 2293(1972)]

  a). The lack of a phase transition is not important;

  b). The locus of maximum cooling (dashed line) lies outside the T-H phase boundary;

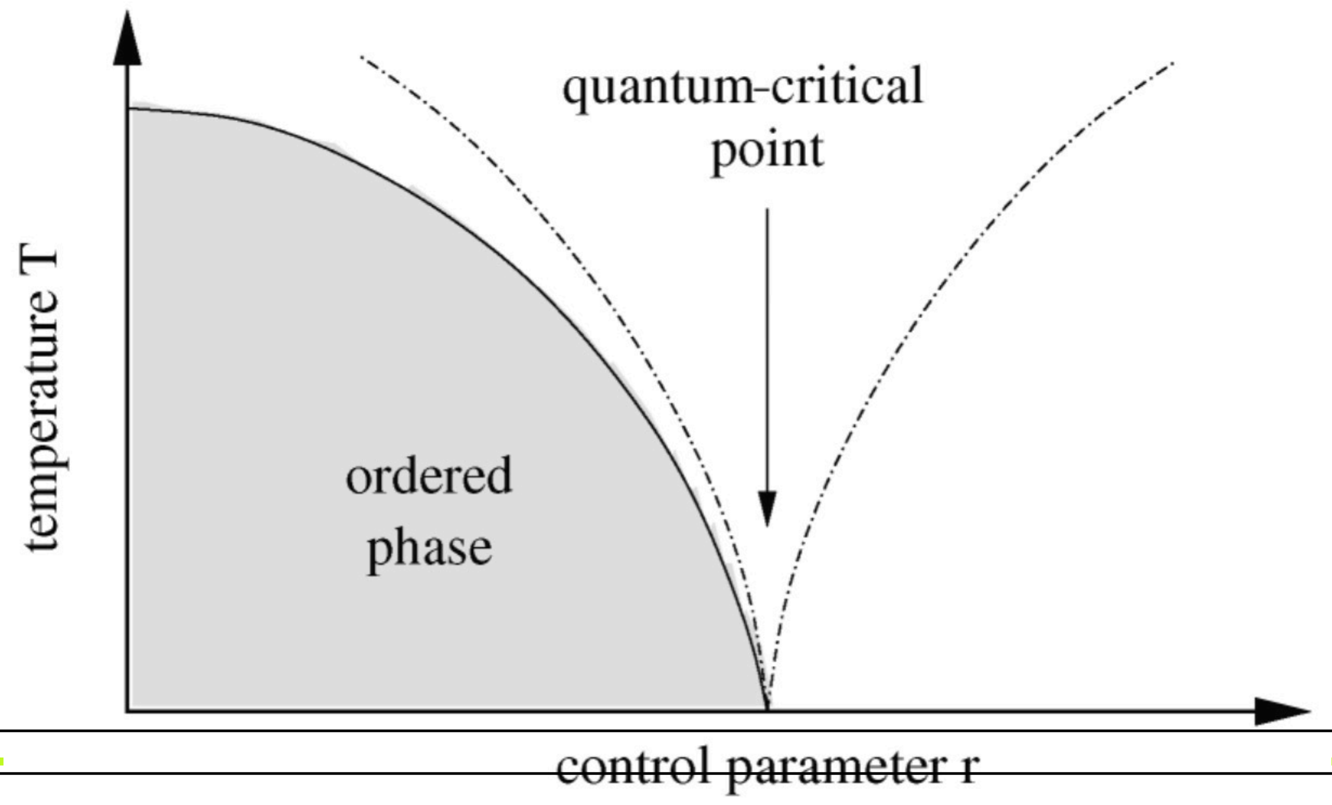
- Universally diverging Γ_B close to a QCP [PRL 91, 066404(2003)]

  Assuming the critical behavior is governed by ξ and ξ_τ at a (second order) QCP:

$$\frac{F_{cr}}{N} = -\rho_0 \left(\frac{T}{T_0}\right)^{\frac{d+z}{z}} f\left(\frac{r}{(T/T_0)^{\frac{1}{\nu z}}}\right) \Rightarrow \begin{cases} \Gamma_B \propto T^{-1/(\nu z)}, & \text{at QCR} \\ \Gamma_B = -\dfrac{G_r}{B - B_c}, & \text{in two phases} \end{cases}$$

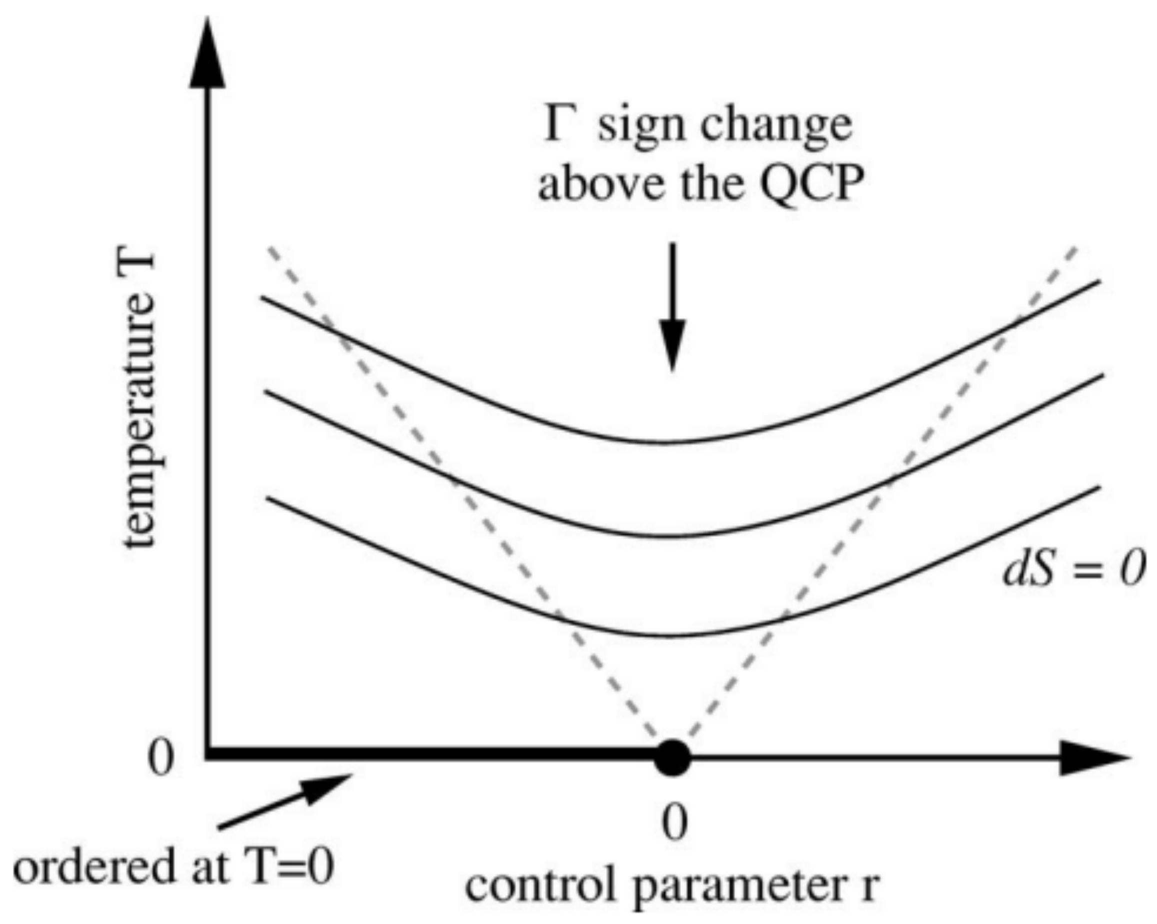
  a). Divergent MCE at any QCP

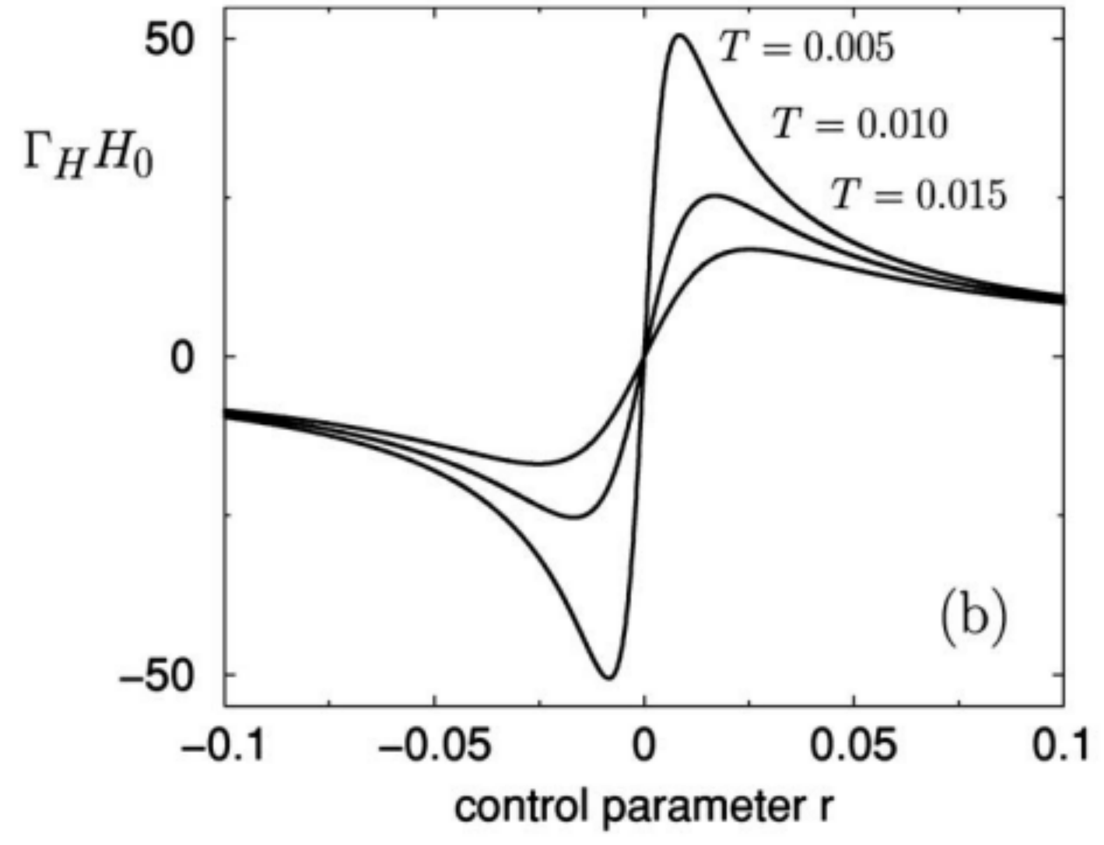
  b). Used to detect the existence of QCP and measure νz

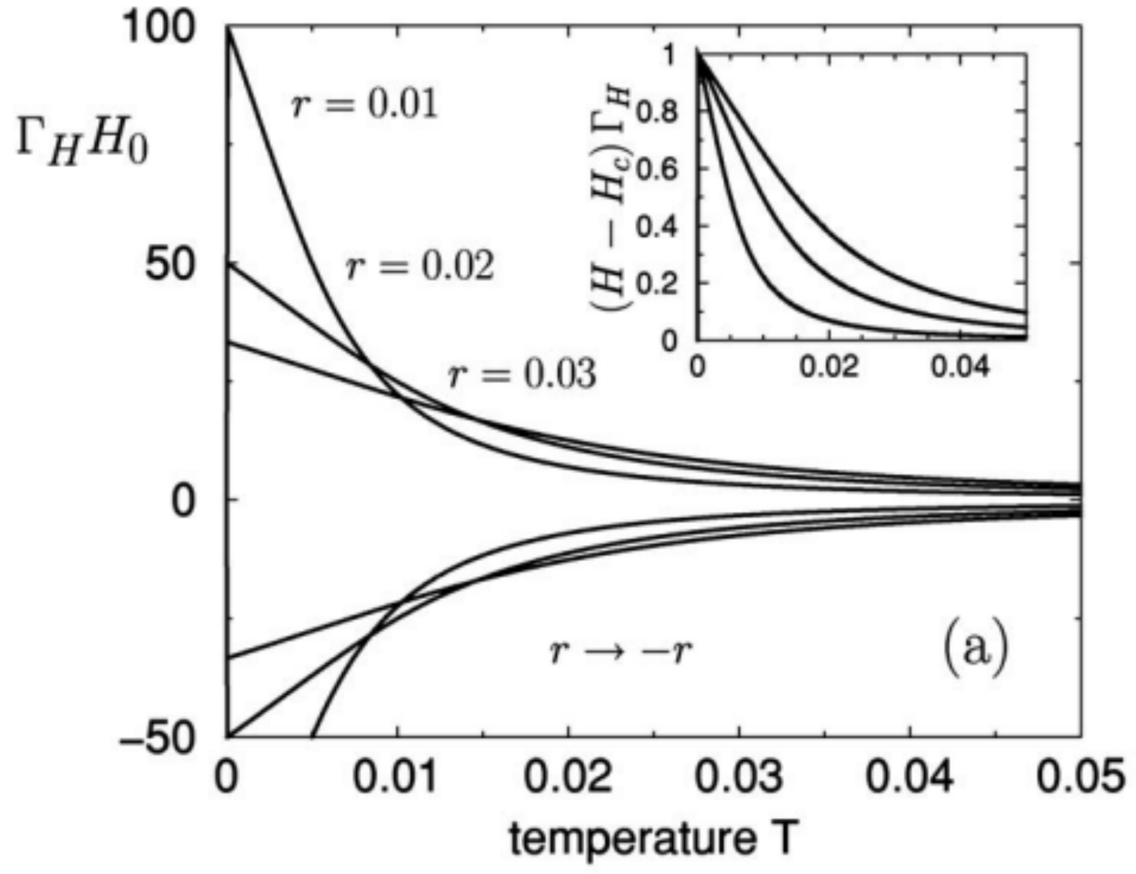


Quantum critical MCE: examples

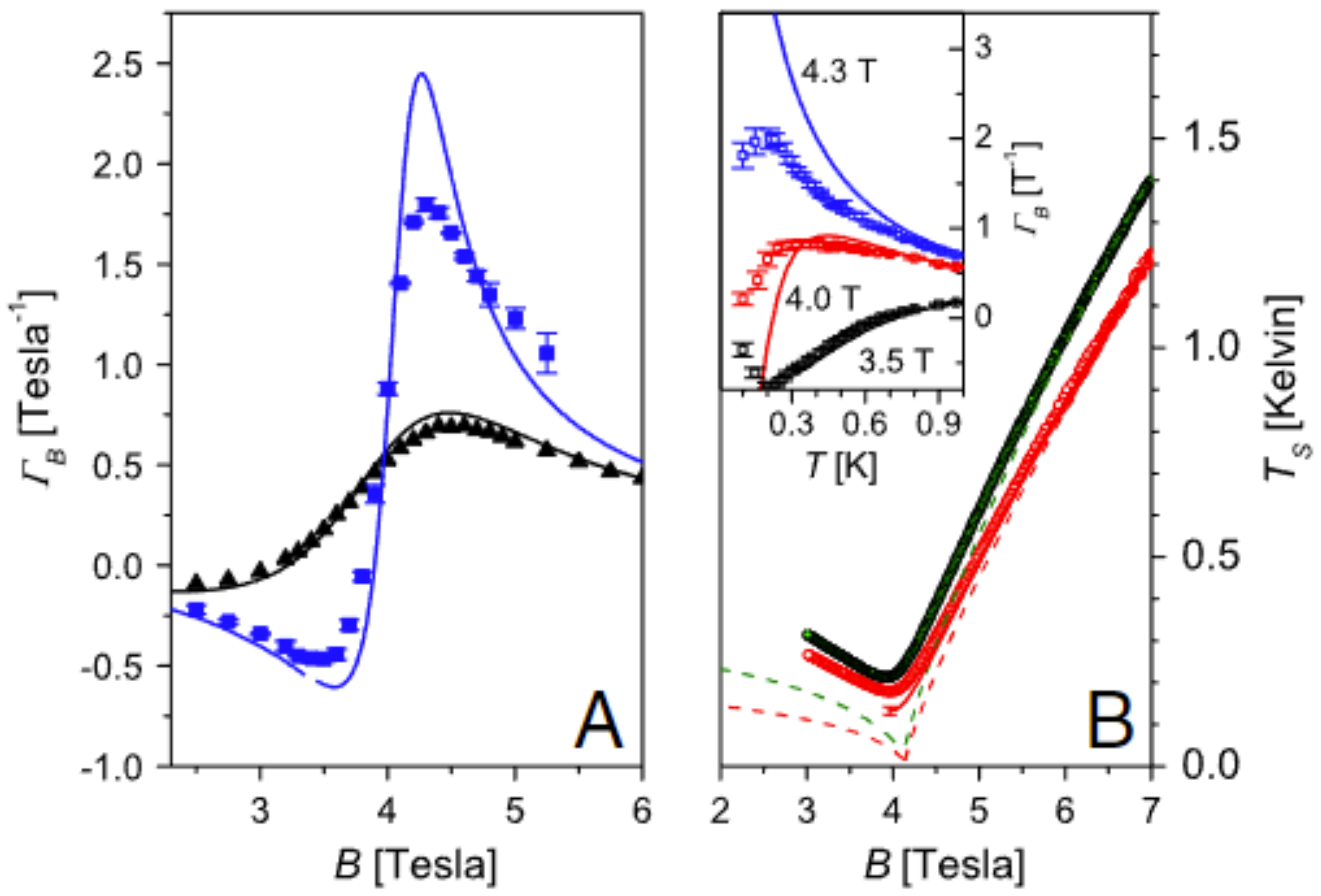
- qcMCE in Ising chain [PRB 72, 205129(2005)]







- Experiments: [PNAS 108,6862 (2011)]



Why holographic QCMCE?

- 1. Using conventional methods, it is difficult to tackle strongly coupled quantum many-body systems at finite T and finite density. In contrast, holography offers a novel approach

- 2. QCMCE is a new phenomenon that has not explored yet in holography

- 3. In holography, we have several models of magnetic PT, eg: a) magnetic QPT with probe branes [Jensen, et al, 1002.2447] b) magnetic QPT in Einstein-Maxwell-Chern-Simons system[Hoker, Kraus, 1208.1925].

- However, some of these QPTs are not fully understood. The MCE may be used to provide more information about the QPT.

Holographic setup

- 5D Einstein-Maxwell-Chern-Simons theory [D'Hoker, Kraus, 1208.1925]

$$S = \frac{1}{16\pi G}\int d^5x\sqrt{-g}\left(R + \frac{12}{L^2} - \frac{1}{4}F_{ab}F^{ab} + \frac{k}{24}\epsilon^{abcde}A_aF_{bc}F_{de}\right),$$

  a) $\kappa = 2/\sqrt{3}$, bosonic part of minimal supergravity.

  b) Anomaly of the chiral current $\partial_\mu J^\mu \propto \kappa \mathbf{E}\cdot\mathbf{B}$

  c) Instability towards a helical order if $k > k_c \approx 1.158$

- Ansatz (charged magnetic brane)

$$ds^2 = \frac{1}{u^2}\left[-\left(f - h^2p^2\right)dt^2 + 2ph^2dtdz + g\left(dx^2 + dy^2\right) + h^2dz^2 + \frac{du^2}{f}\right],$$

$$A = A_tdt - \frac{B}{2}ydx + \frac{B}{2}xdy - A_zdz\,,$$

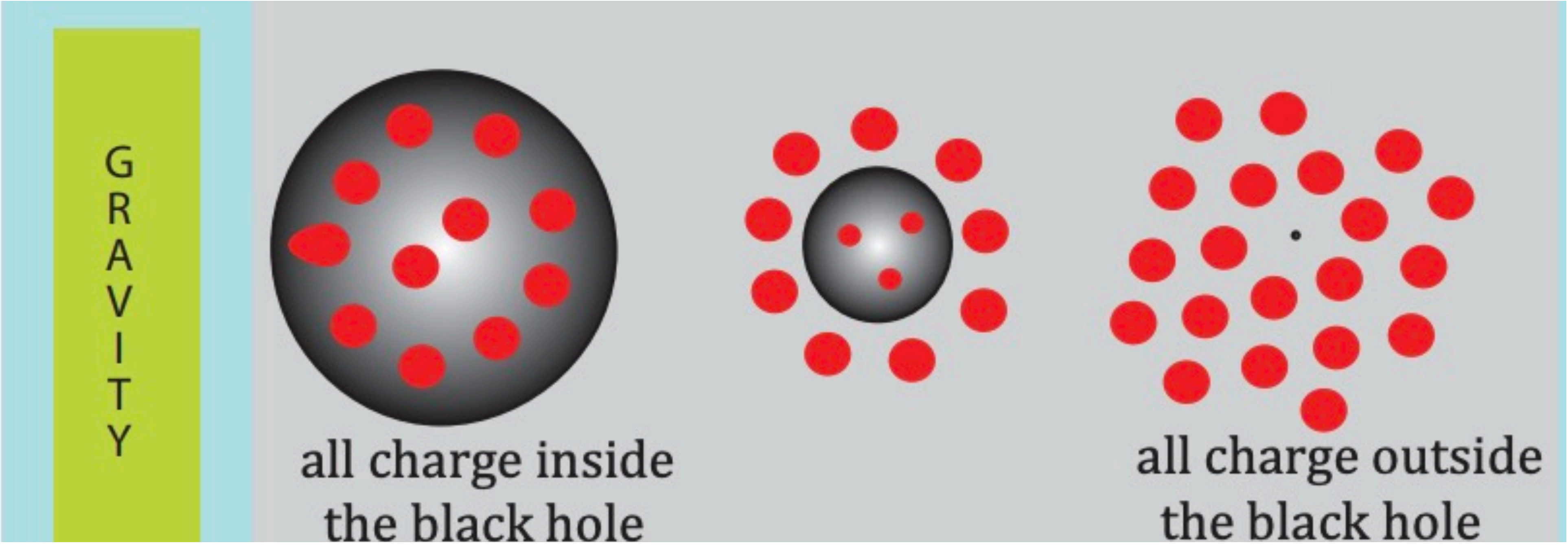
Holographic picture of the phase transition

➡$A_t \neq 0$ and $B = 0$:

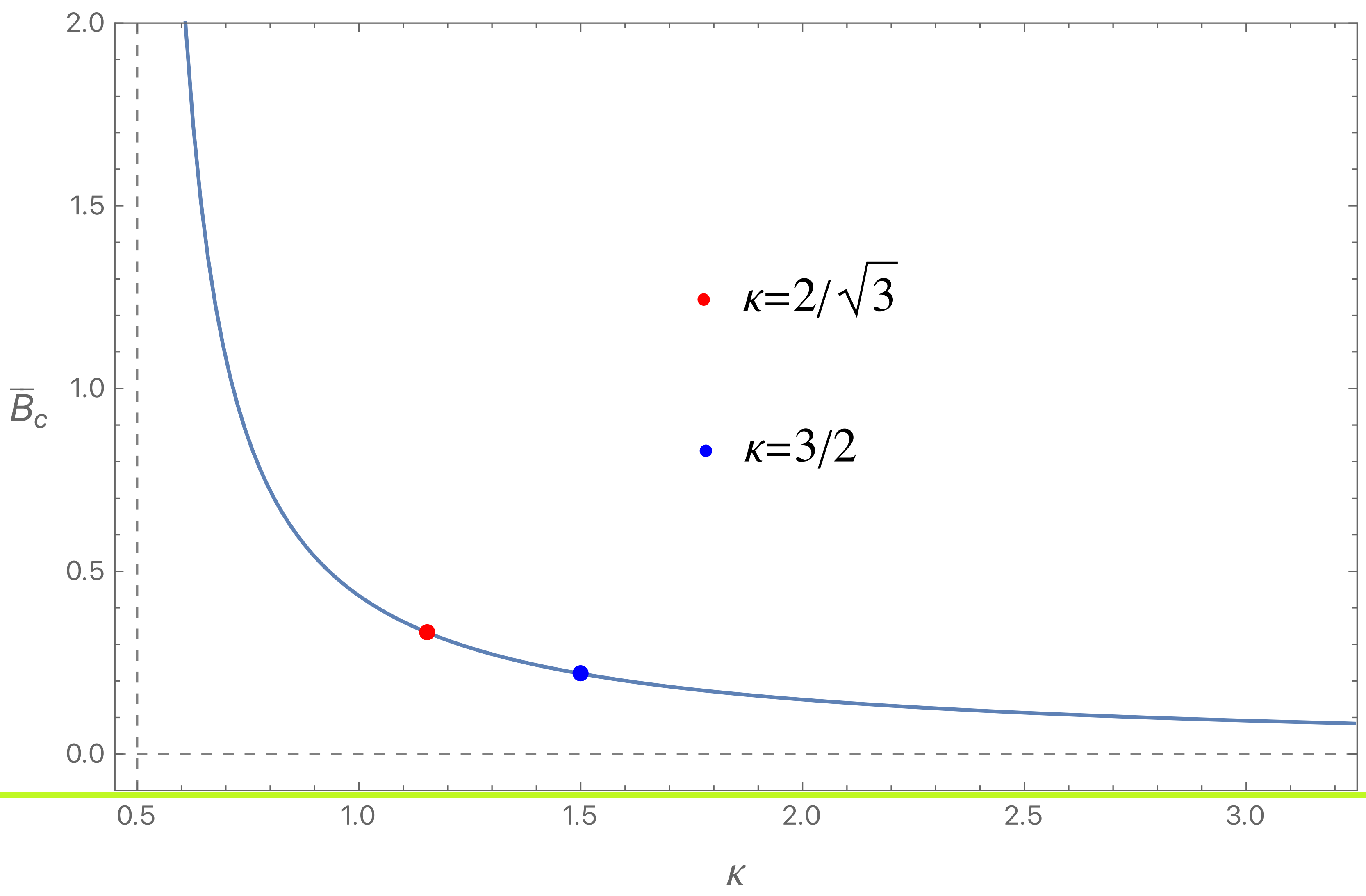
- RN-AdS with $AdS_2 \times R^3$

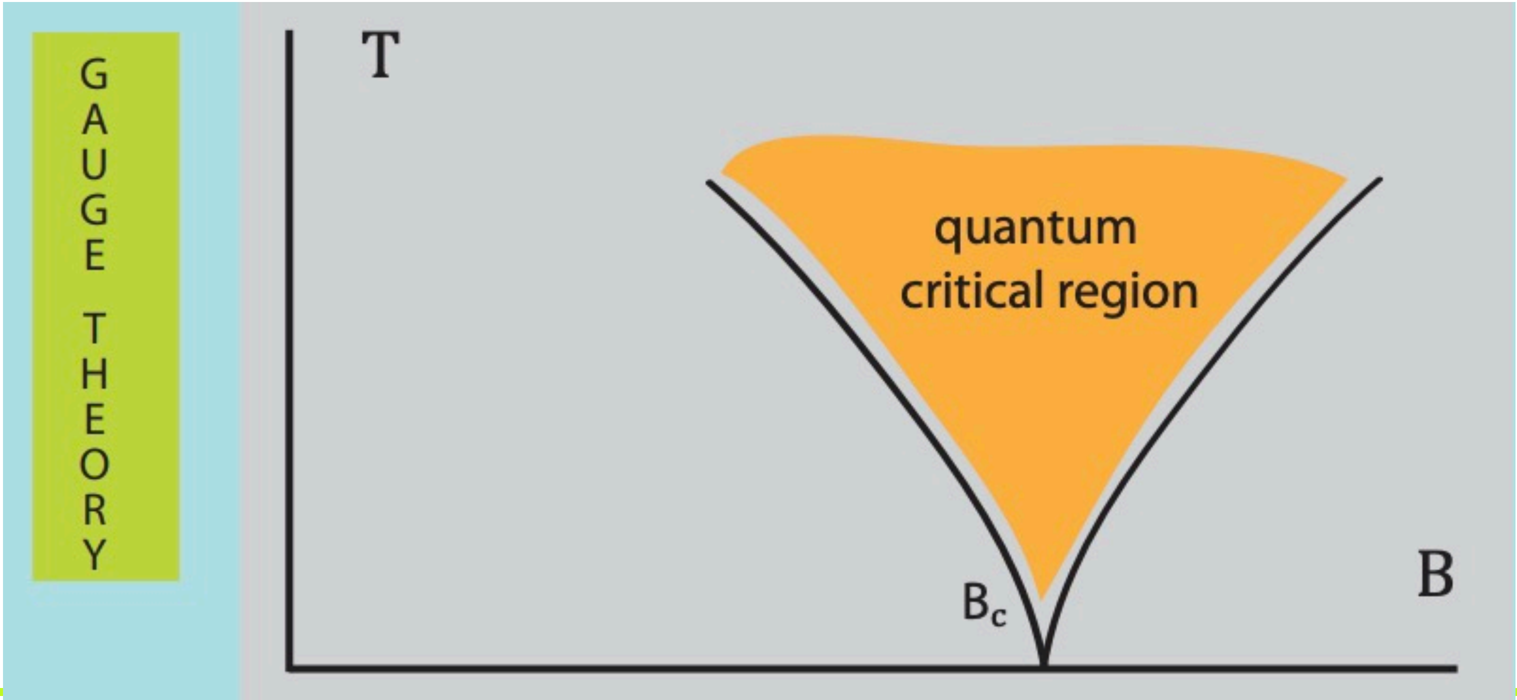
➡$A_t = 0$ and $B \neq 0$:

- Magnetic brane with $AdS_3 \times R^2$



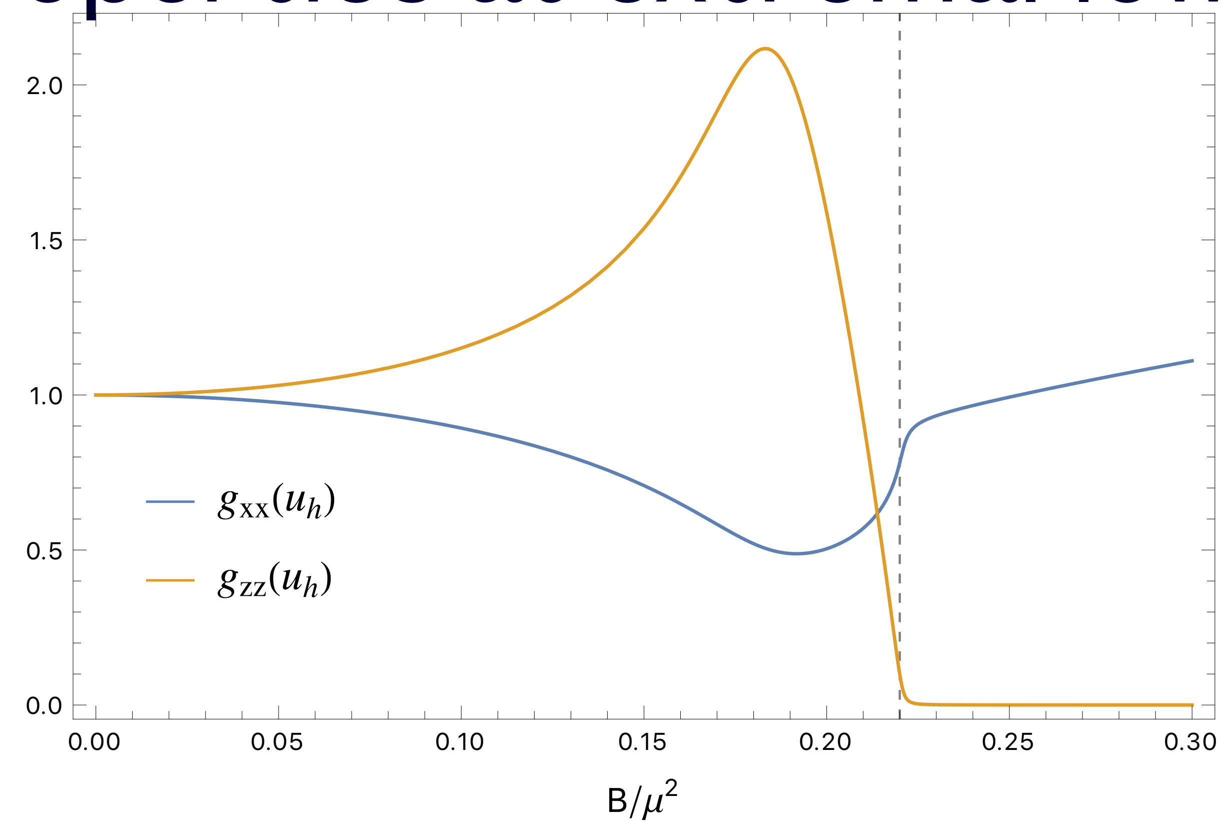
- Expulsion of electric charge from the BH [D'Hoker, Kraus]

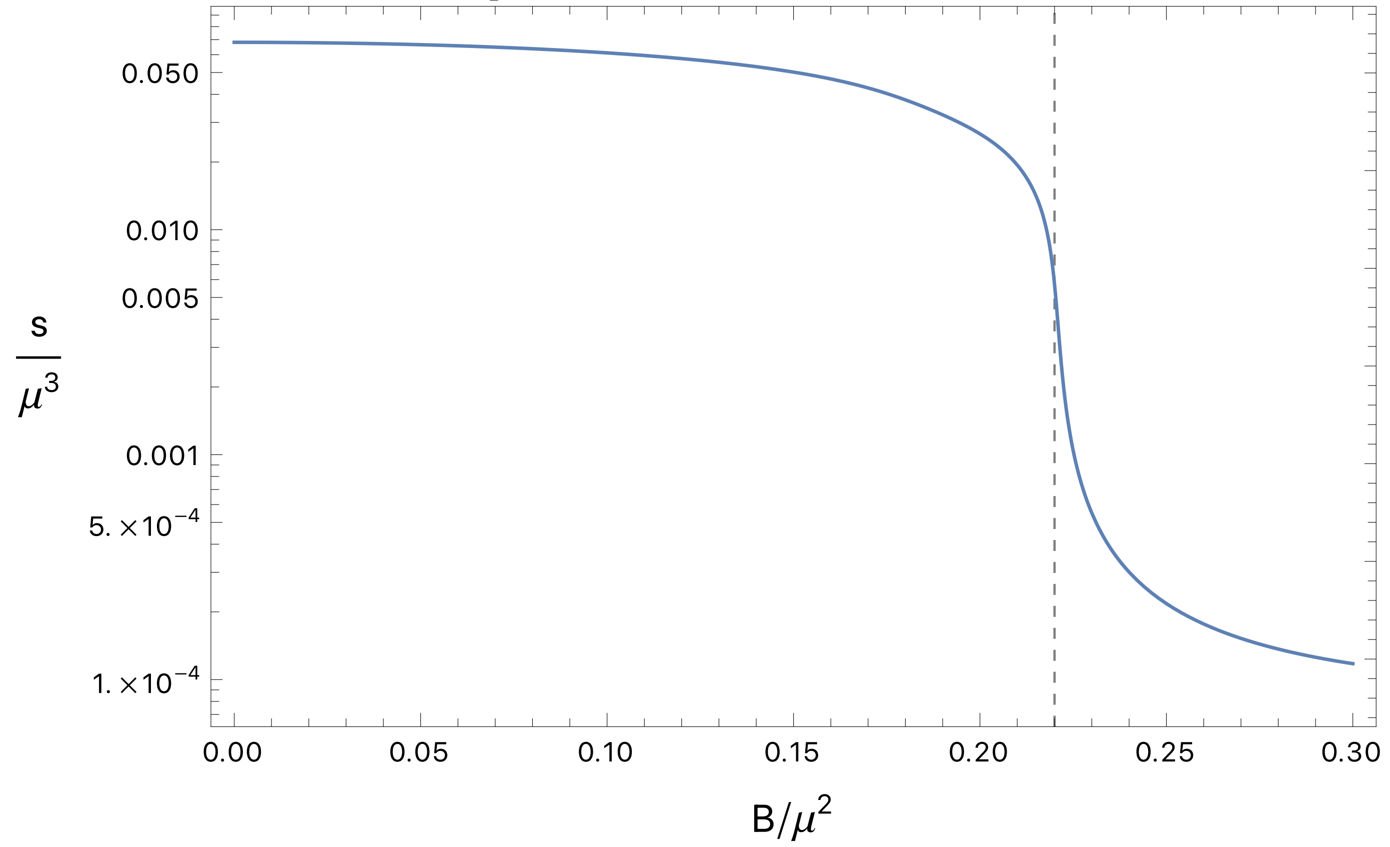




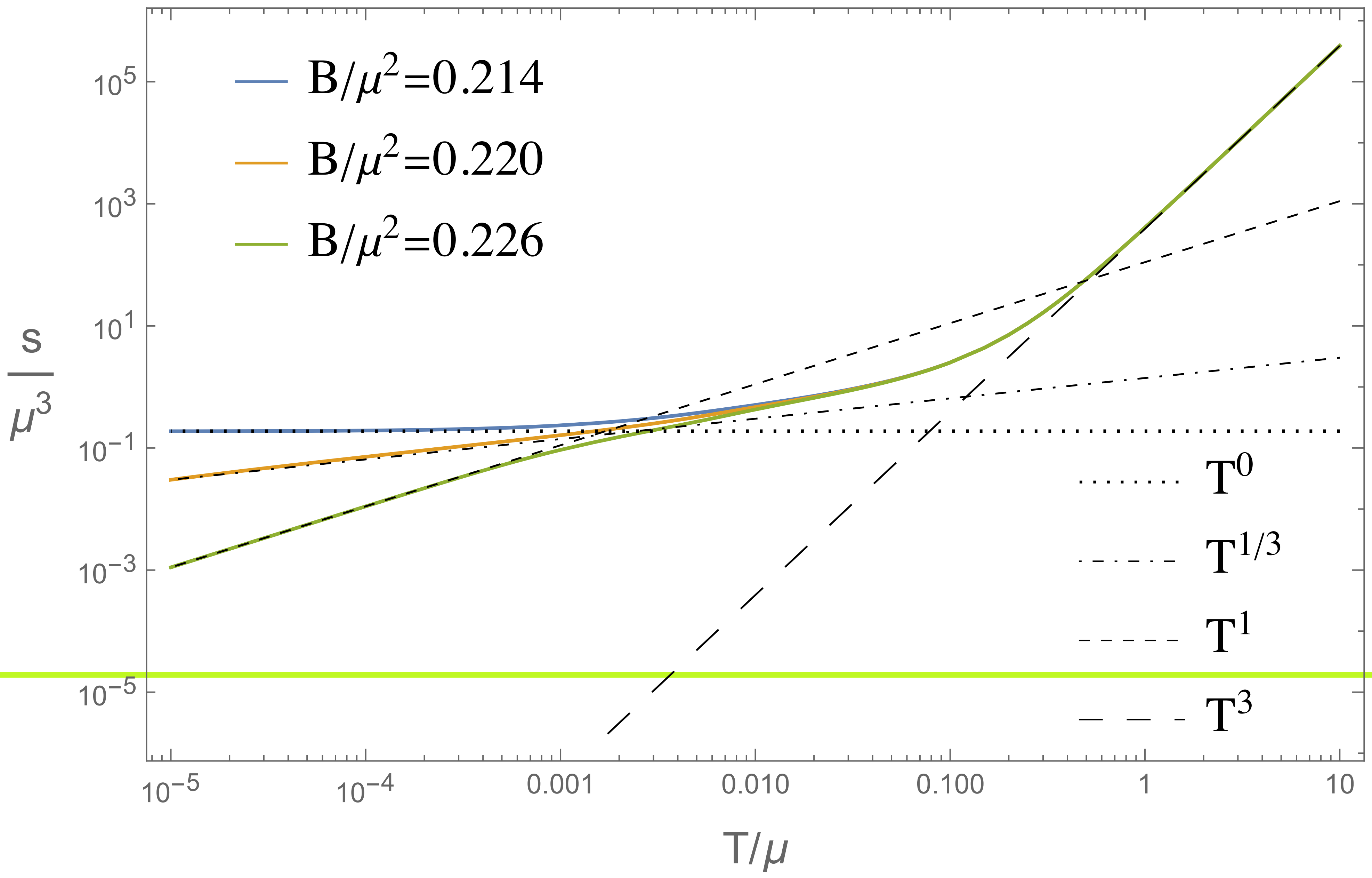
Thermodynamics

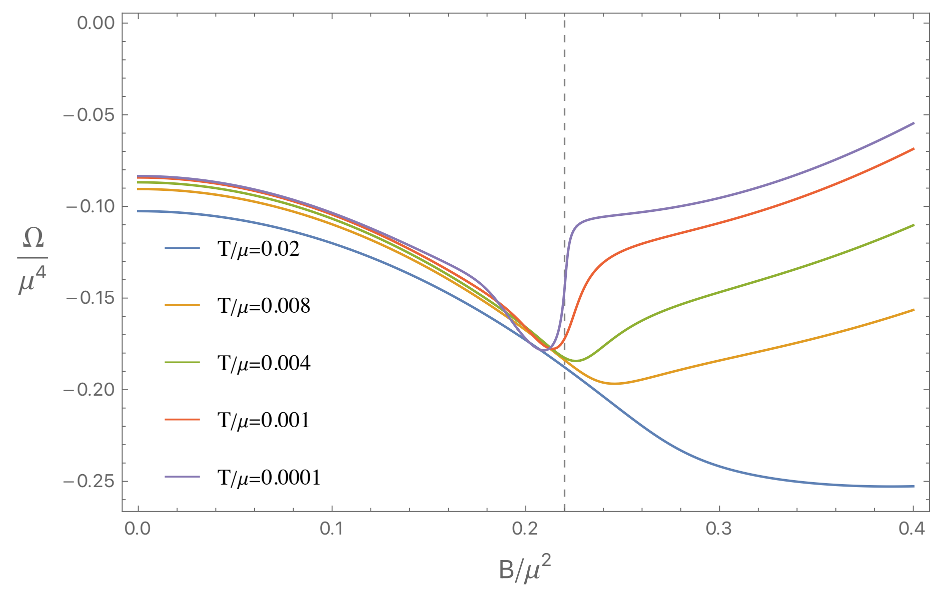
Near horizon properties at extremal low temperature $T/\mu = 10^{-4}$





The scaling of entropy

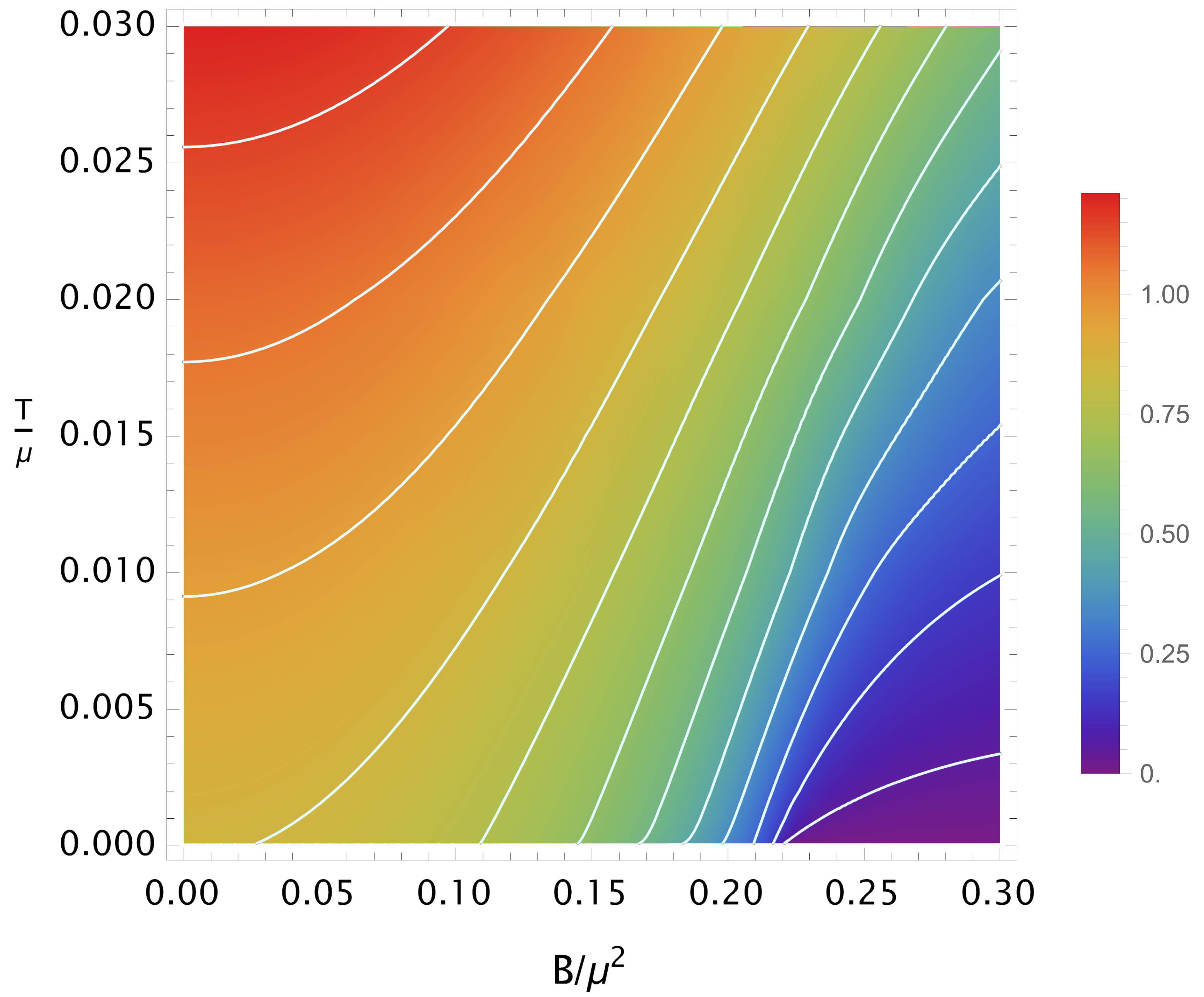


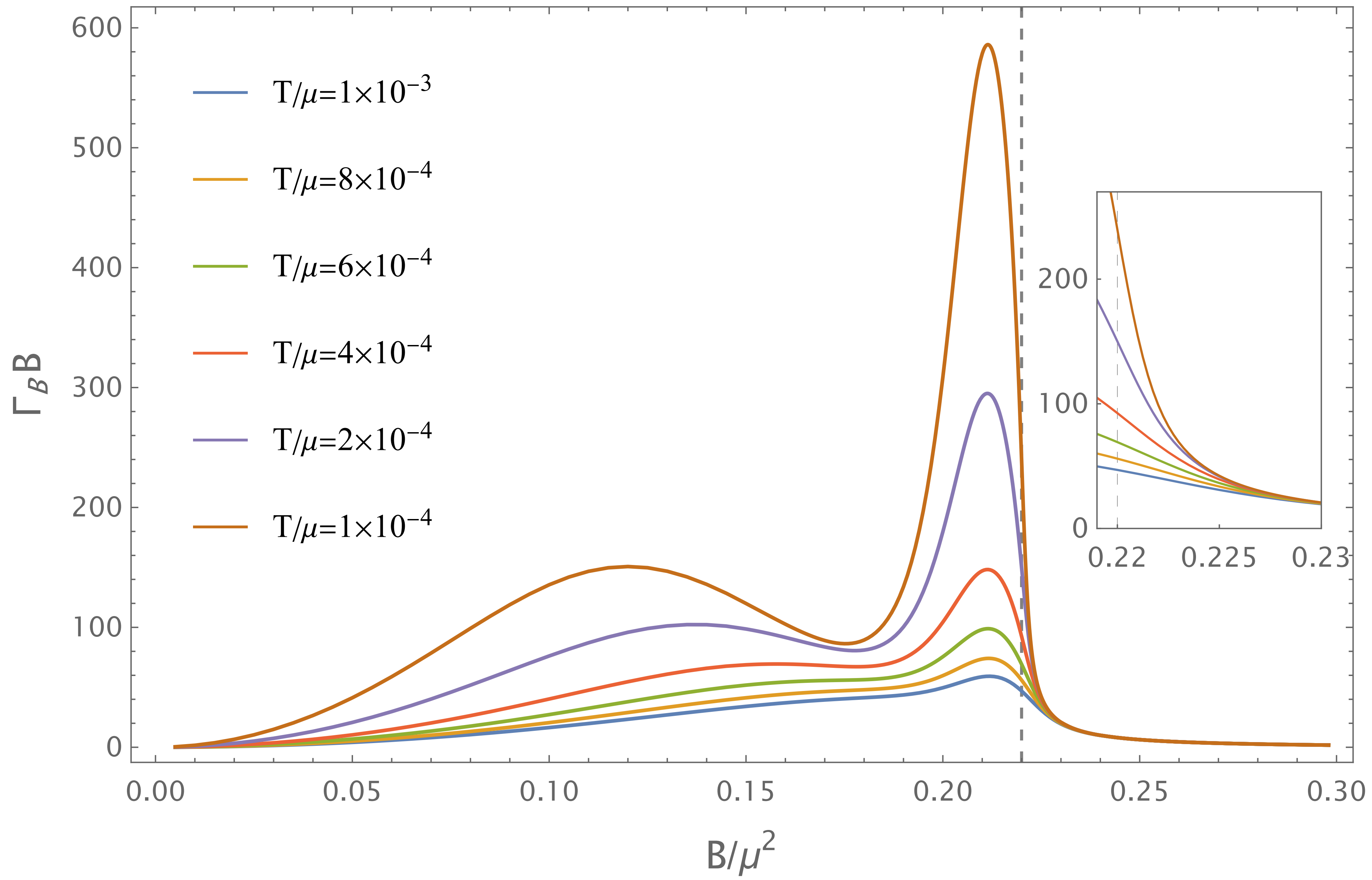


free energy density

Isentropes in T-B plane and MCE

- Entropy density s/μ^3 and (magnetic) Gruneisen parameter Γ_B





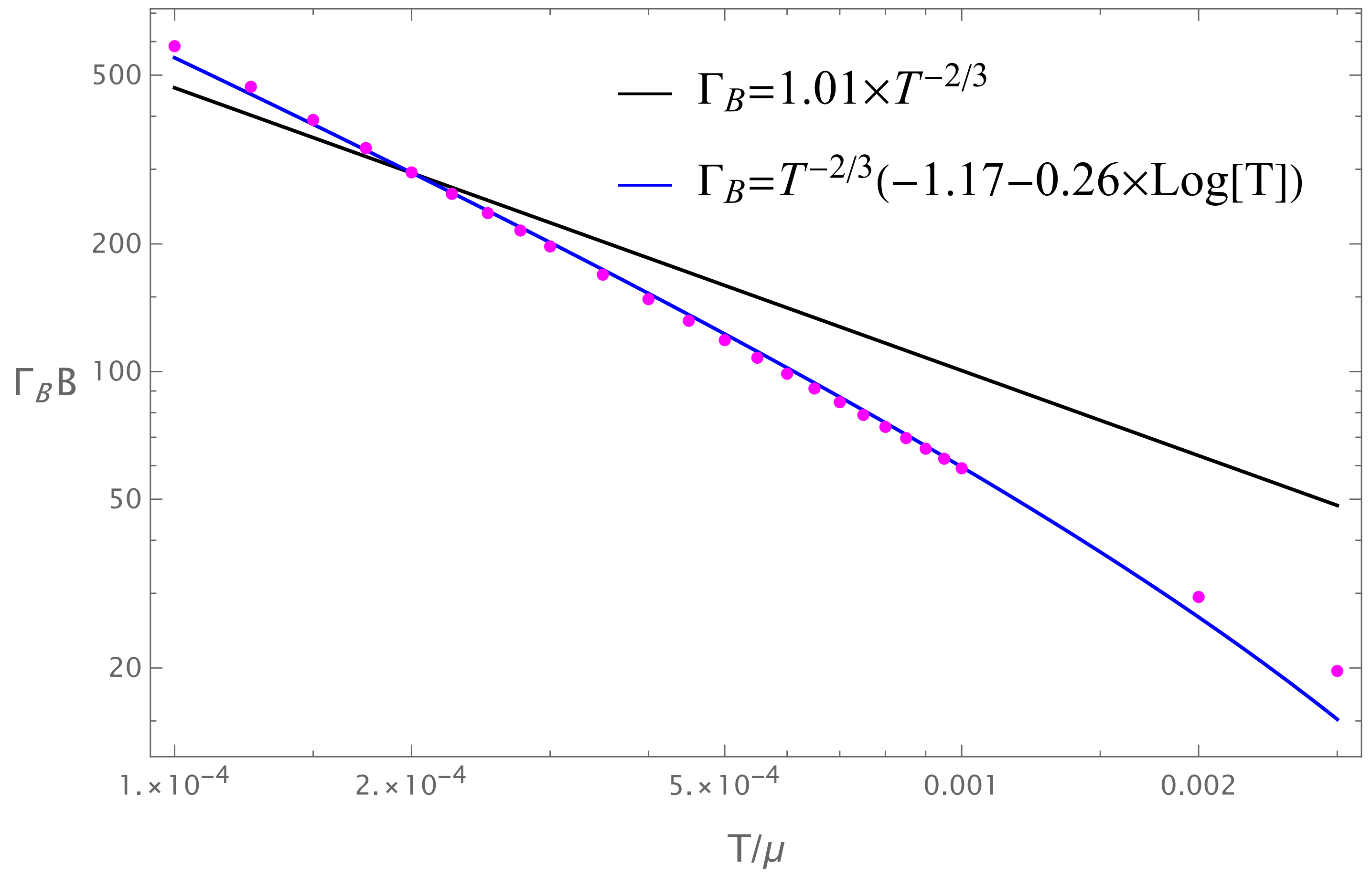
- Absence of the sign change of Γ_B

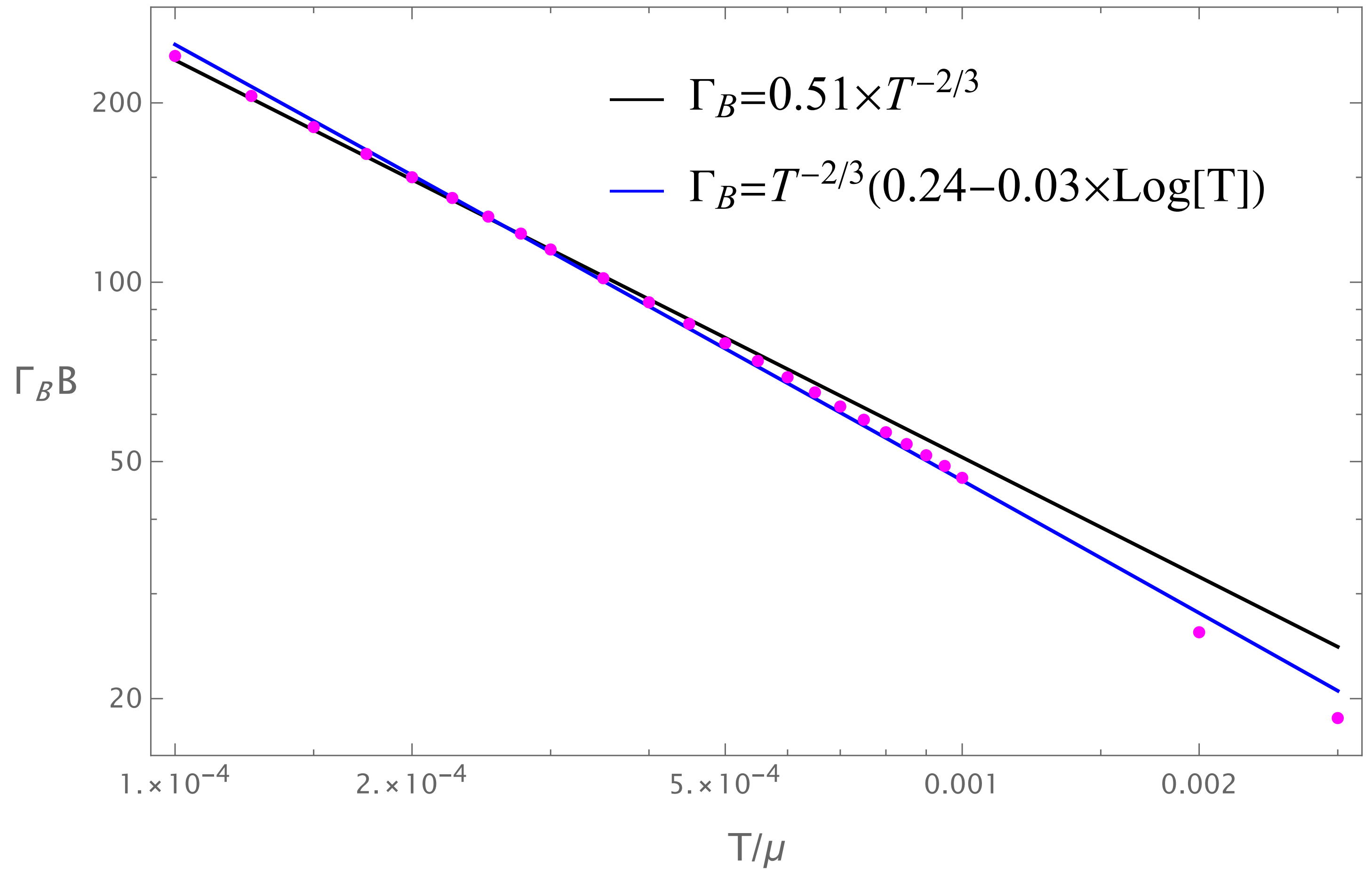
  finite ground states entropy, AdS_2 factor at $B < B_c$...

Scaling of Gruneisen parameter

➡ Near the QCP [Hoker, Kraus]. $\hat{s} = \hat{T}^{1/3} f\left(\frac{\hat{B}-\hat{B}_c}{\hat{T}^{2/3}}\right)$ Thus $z=3$ and $\nu = 1/2$, $\Gamma_B \begin{cases} \propto T^{-2/3}, & \text{at QCR} \\ = -\frac{G_r}{B-B_c}, & \text{in two phases} \end{cases}$

➡ Violation of the predicted scaling of Γ_B

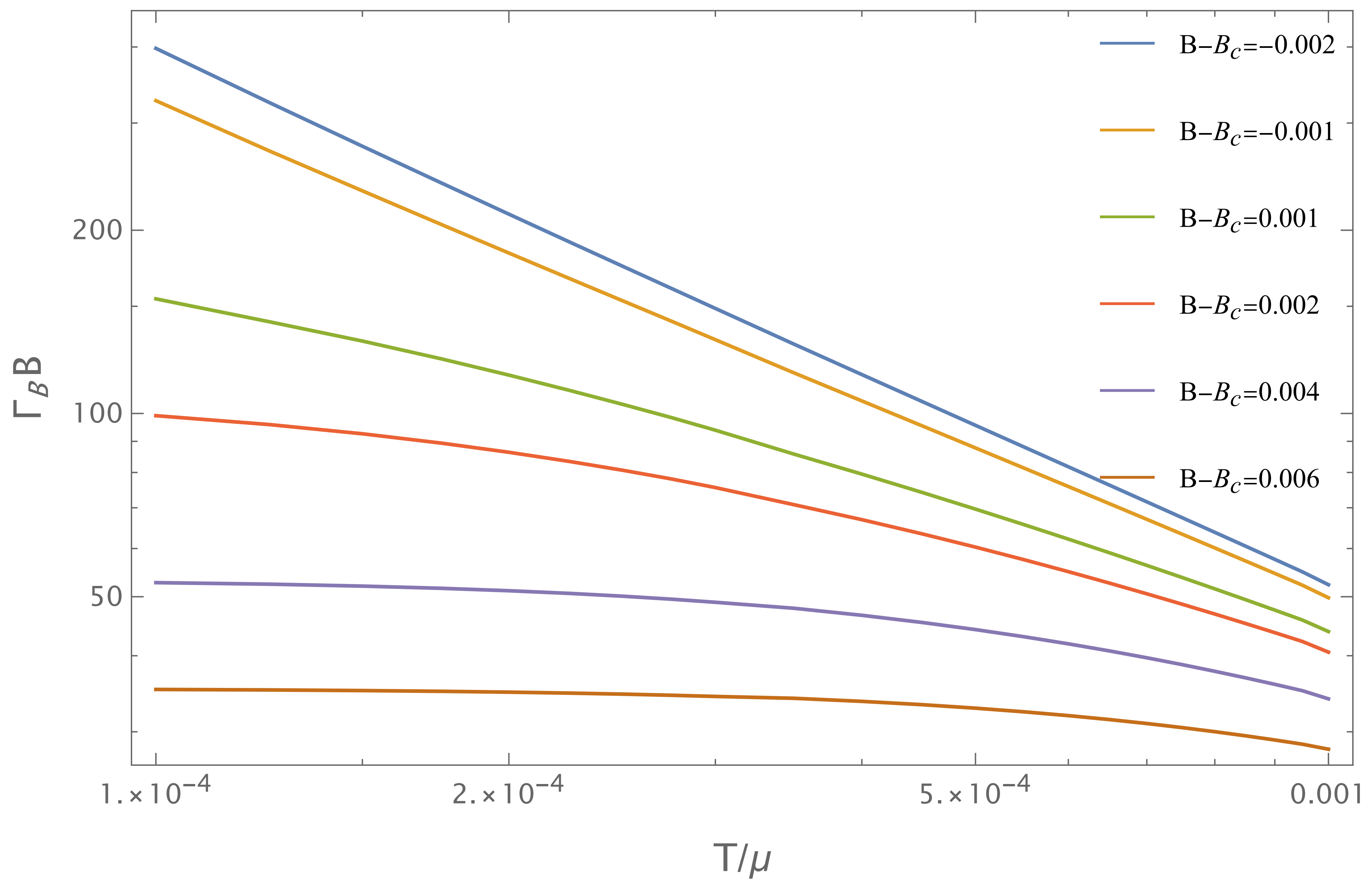


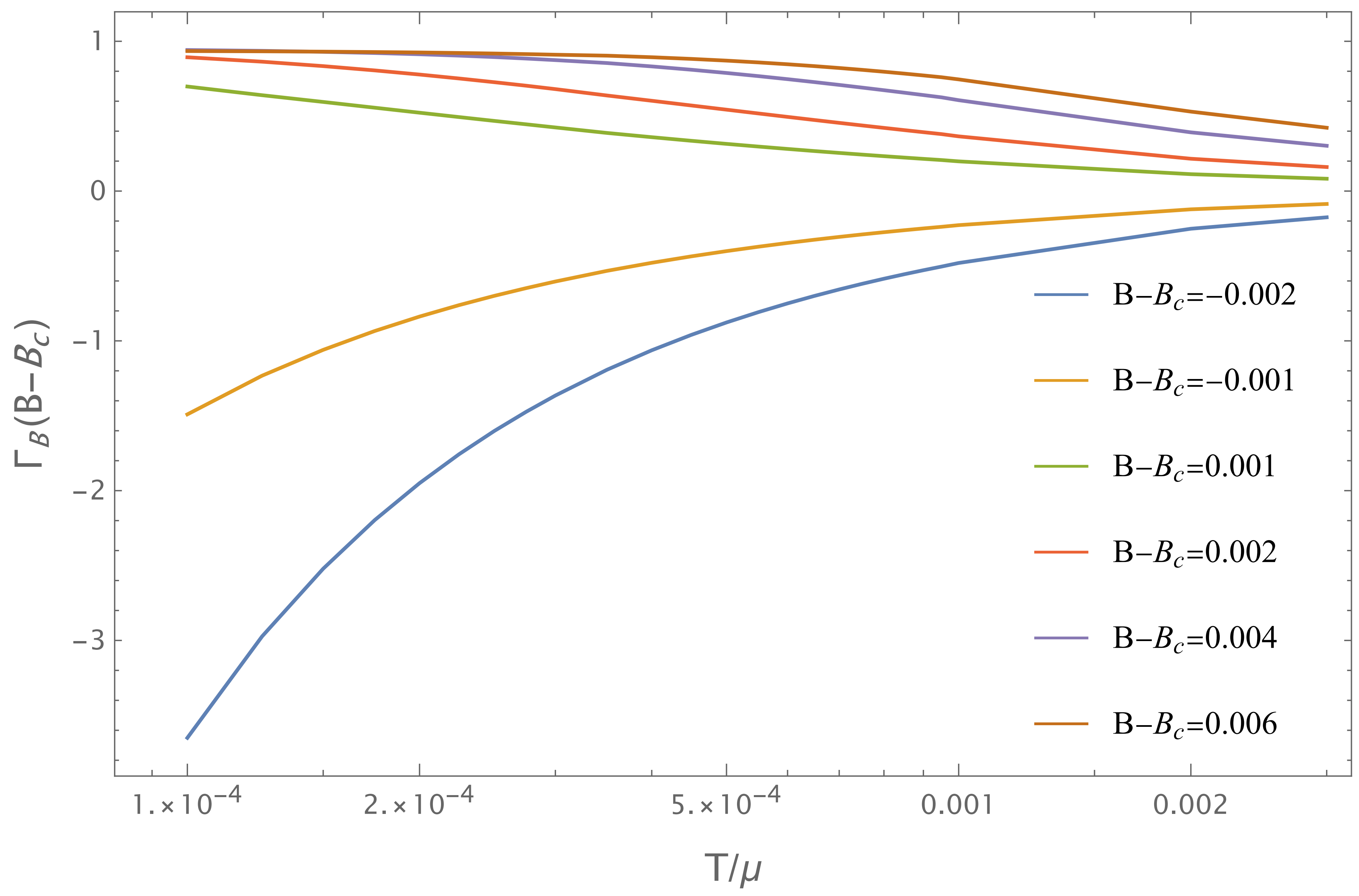


- Upper critical dimension: $d+z=4$;
- Contribution from the dangerously irrelevant coupling

Scaling of Gruneisen parameter

- Behavior of $\Gamma_B(B - B_c)$ in two phases:





- As $T \to 0$, $\Gamma_B(B - B_c)$ does not approach a universal value G_r

Summary and discussion

- We have studied the quantum critical MCE in EMCS theory.

- We find several new and interesting features in this model:

  a) Absence of sign change of the Γ_B

  b) Universal scaling of the Γ_B near the QCP is violated by irrelevant coupling

- Further questions:

  a) Can we provide a proper quantity to capture the QPT, eg. entanglement entropy?

  b) The behavior of η/s, KSS bound violation?

THANK YOU

For Your Attention