Confinement Phase Transition in a Holographic QCD Model

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JHEP 03 (2013) S. He, S.Y. Wu, YY and P.H. Yuan
JHEP 11 (2014) YY and P.H. Yuan
JHEP 12 (2015) YY and P.H. Yuan
work in progress…

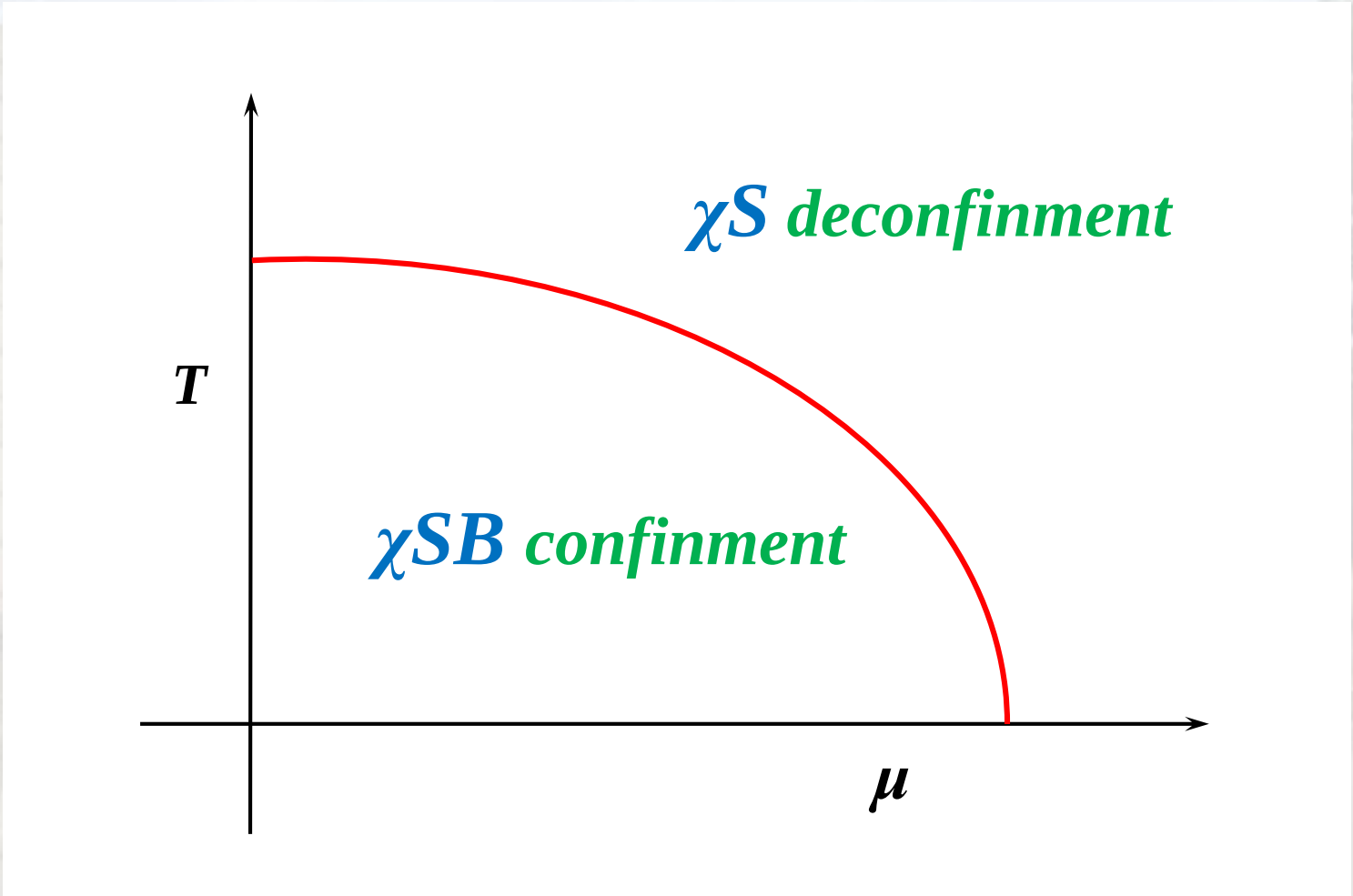
May 29, 2016

EAST ASIA JOINT WORKSHOP OF FIELDS AND STRINGS 2016 @ ICTS-USTC

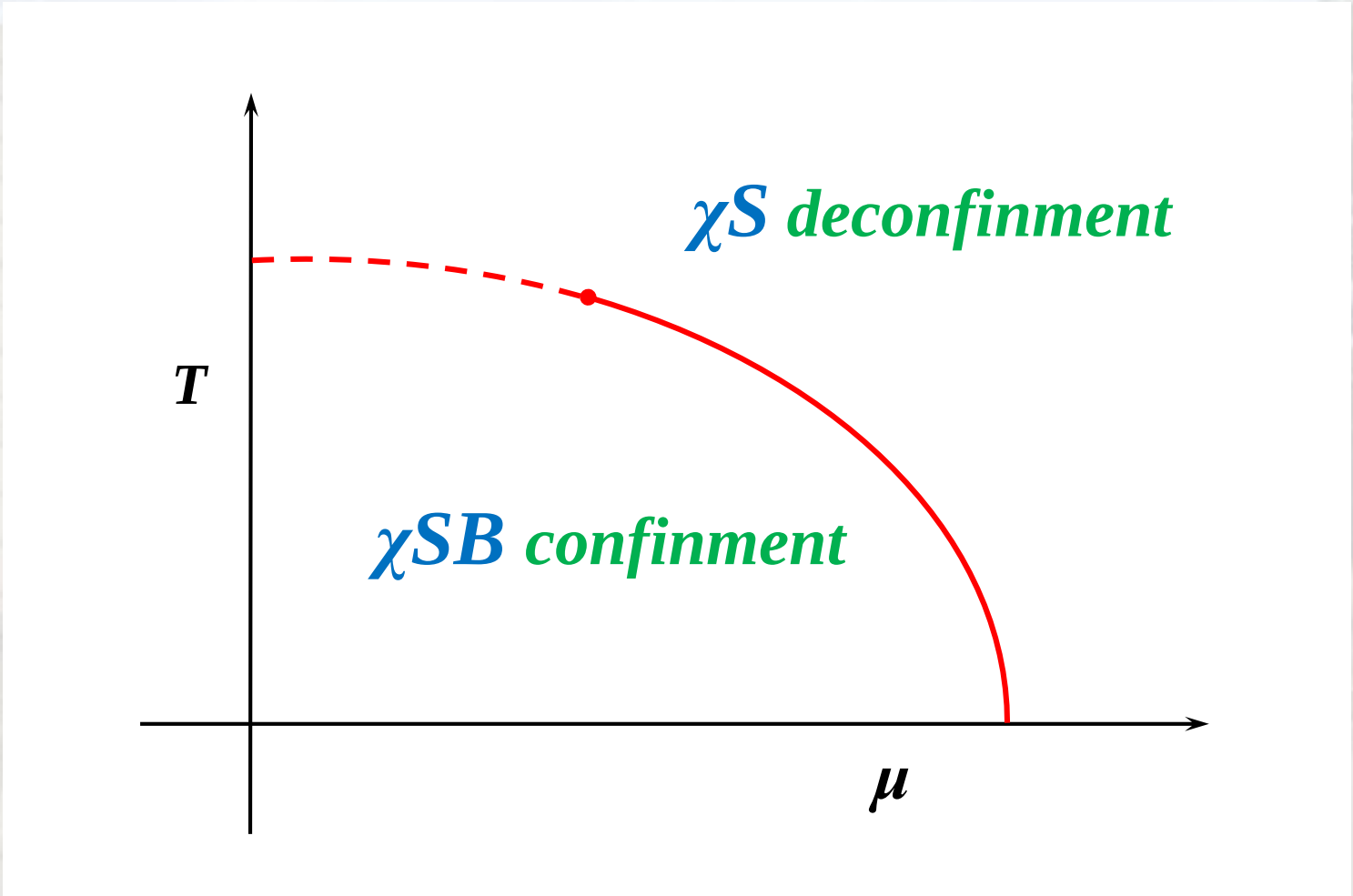
Content

- QCD Phases Diagram
- Confinement in Holographic QCD
  - Thermodynamics of background
  - Probe open strings
- Summary

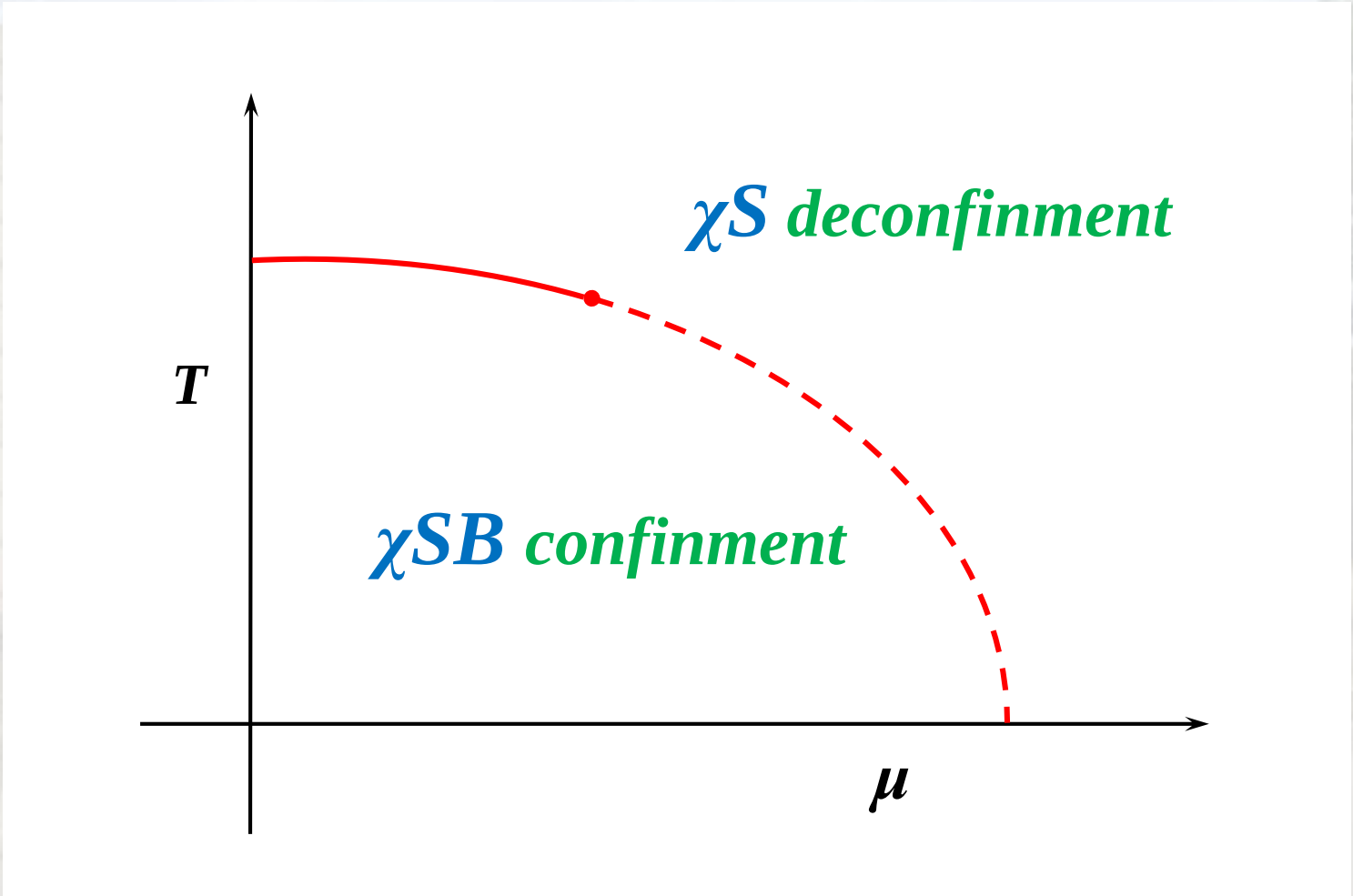
Phases in QCD for $m_q = 0$



Phases in QCD for $m_q \neq 0$



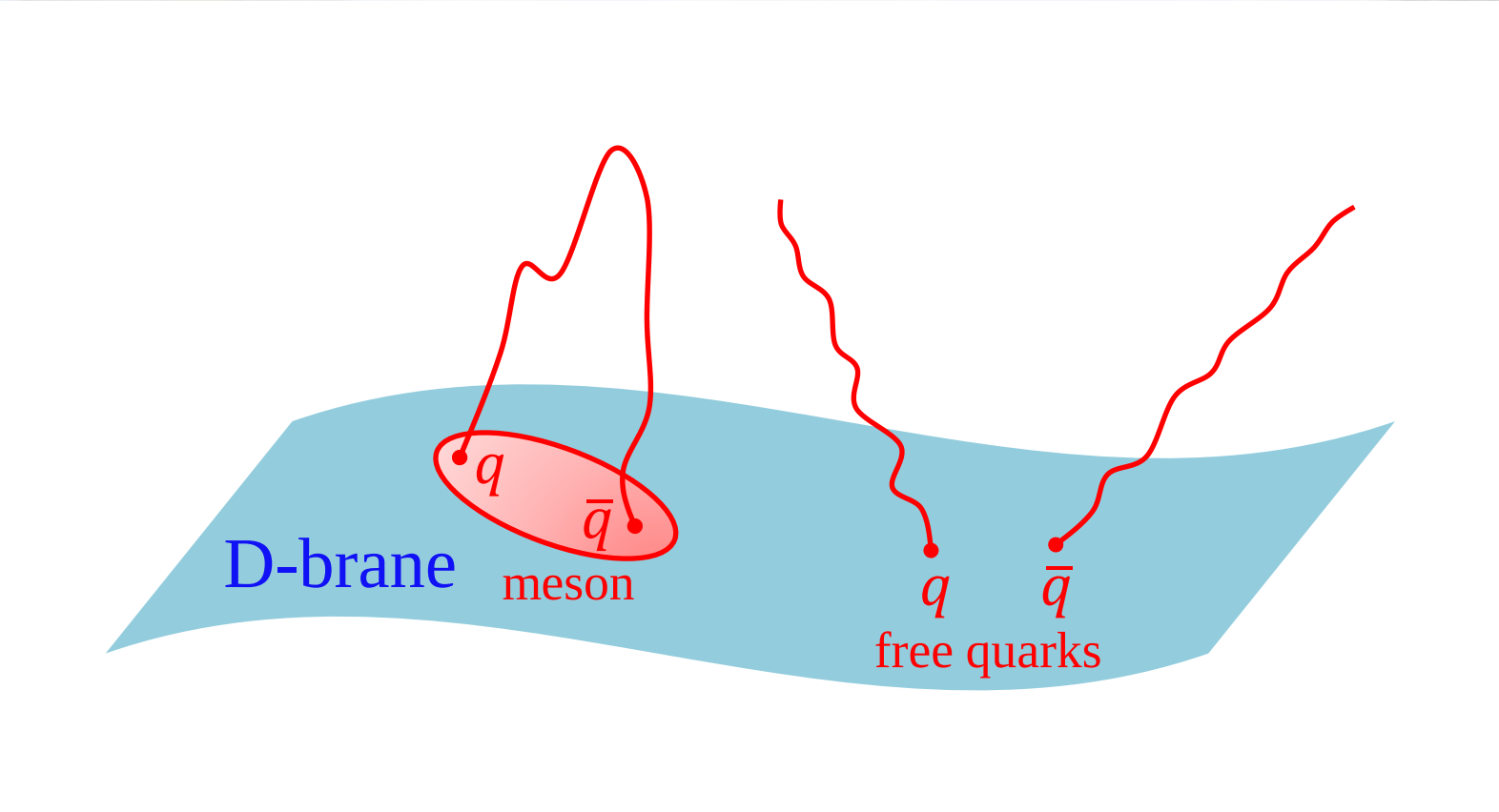
Phases in QCD for Heavy Quarks



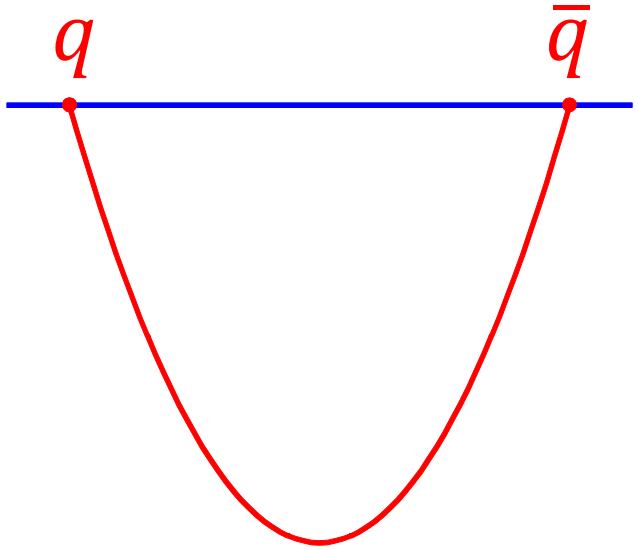
Holographic QCD

- AdS/CFT
- Top-down approach (Dp-Dq)
  - D4-D8 (Sakai-Sugimoto)
  - D3-D7
- Bottom-up approach
  - Soft-wall (linear Regge spectrum)
  - Improved soft-wall (Einstein-Maxwell-scalar)

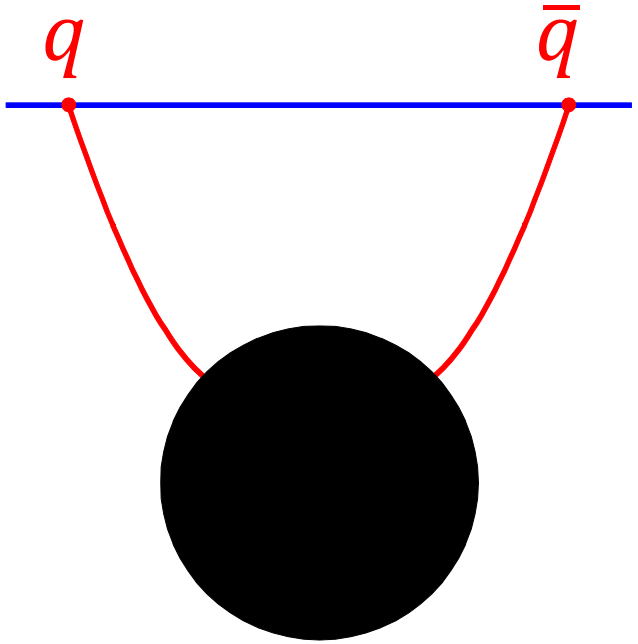
Geometric Realization



Geometric Realization of Confinement/deconfinement

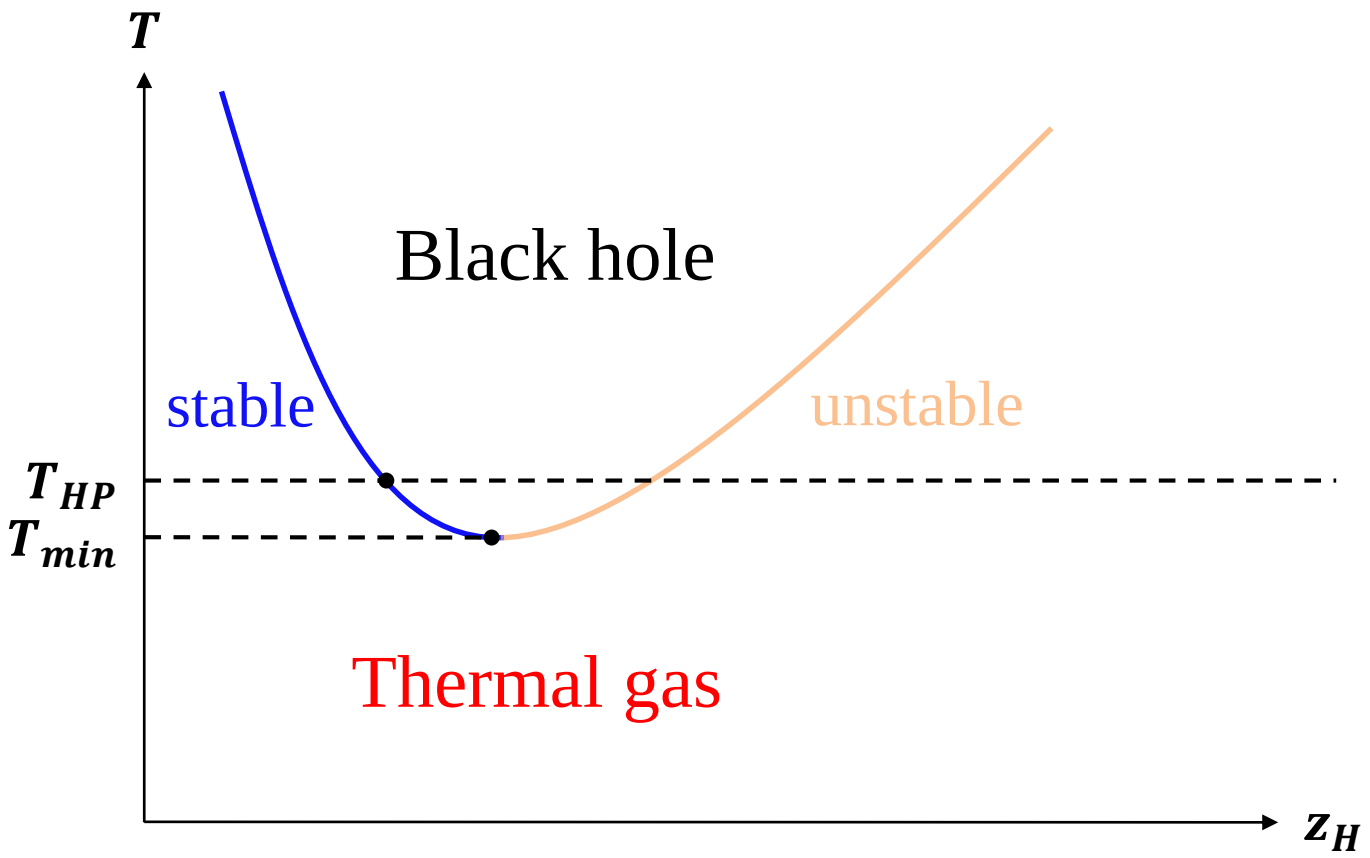


confinement

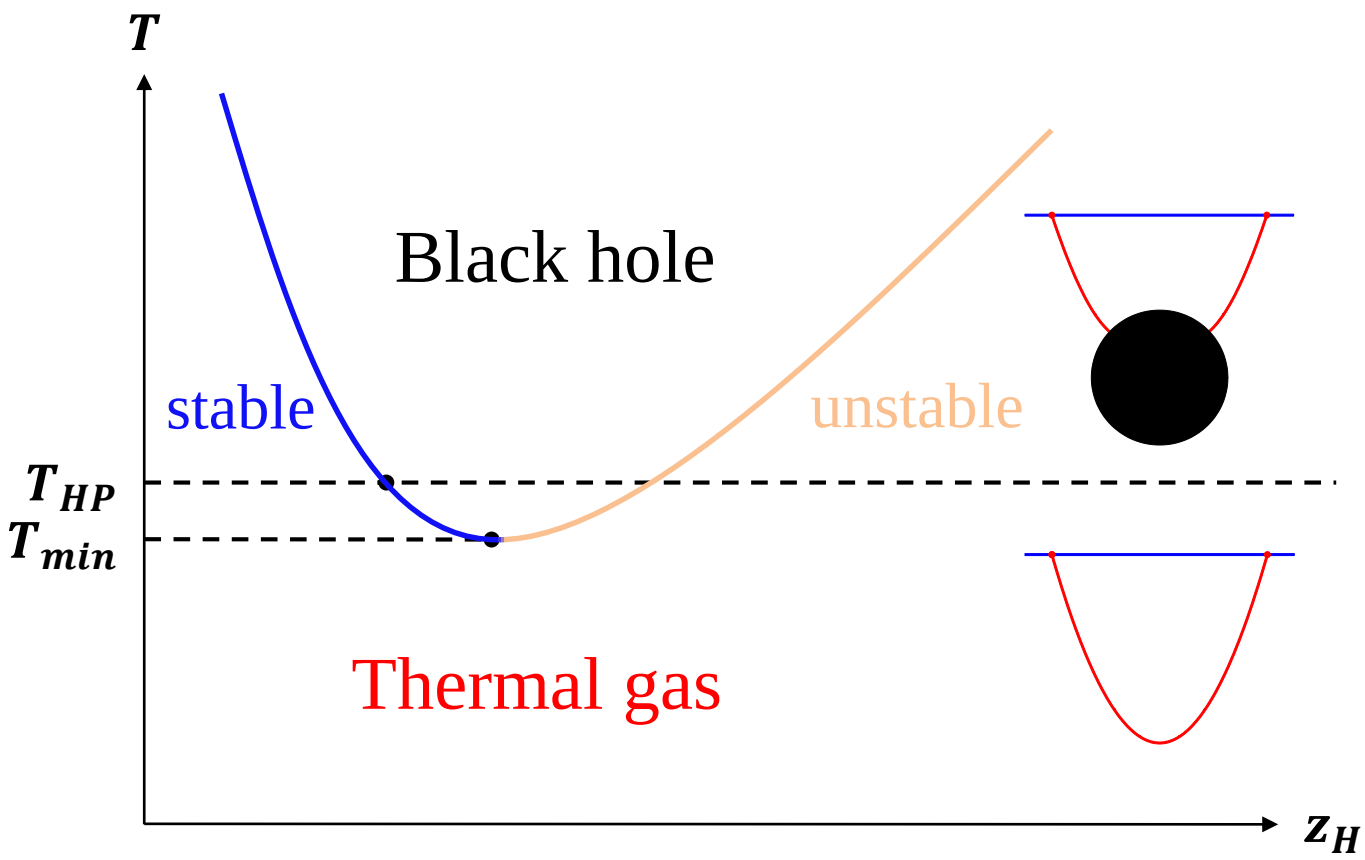


deconfinement

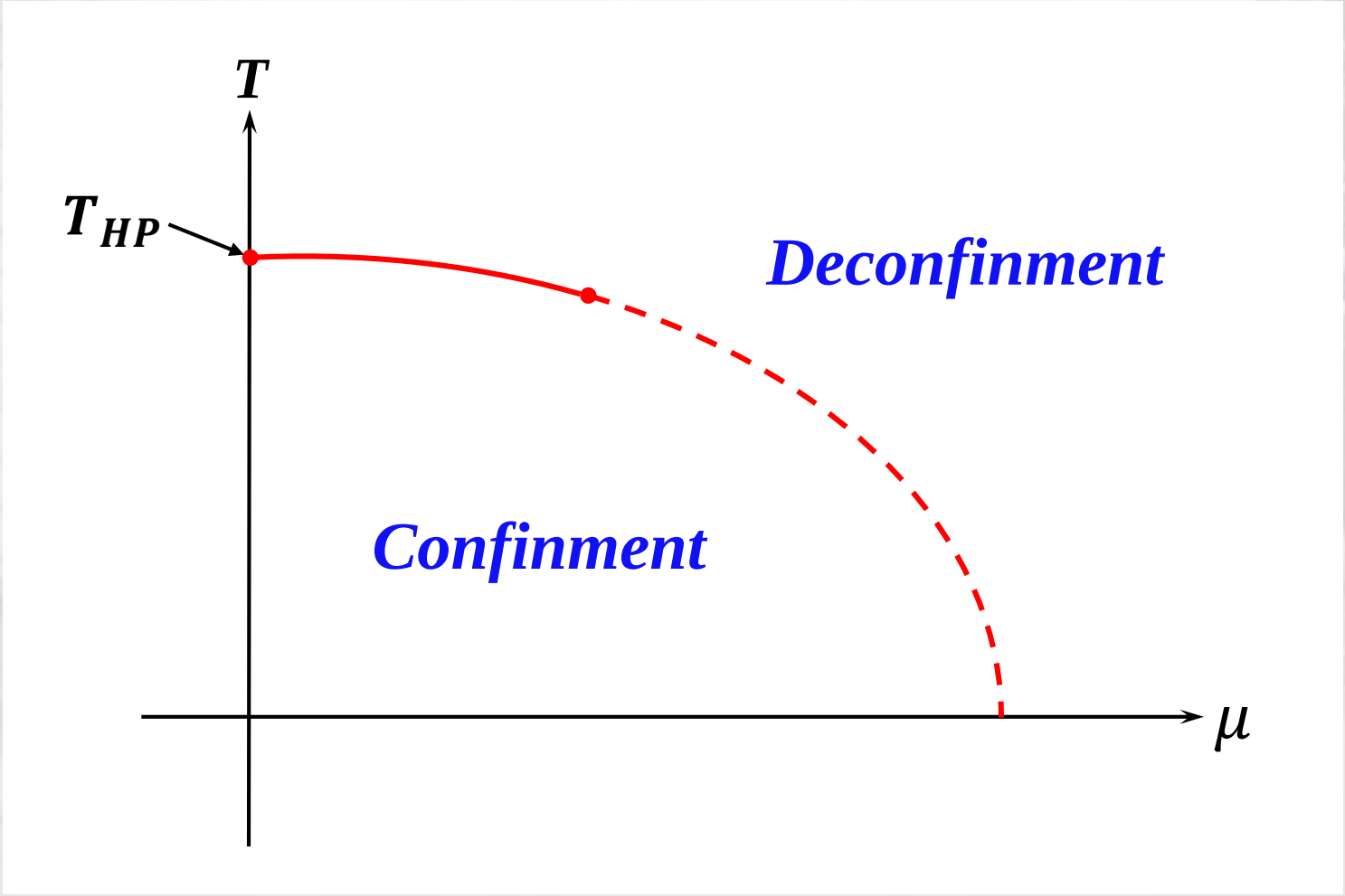
Hawking-Page Transition



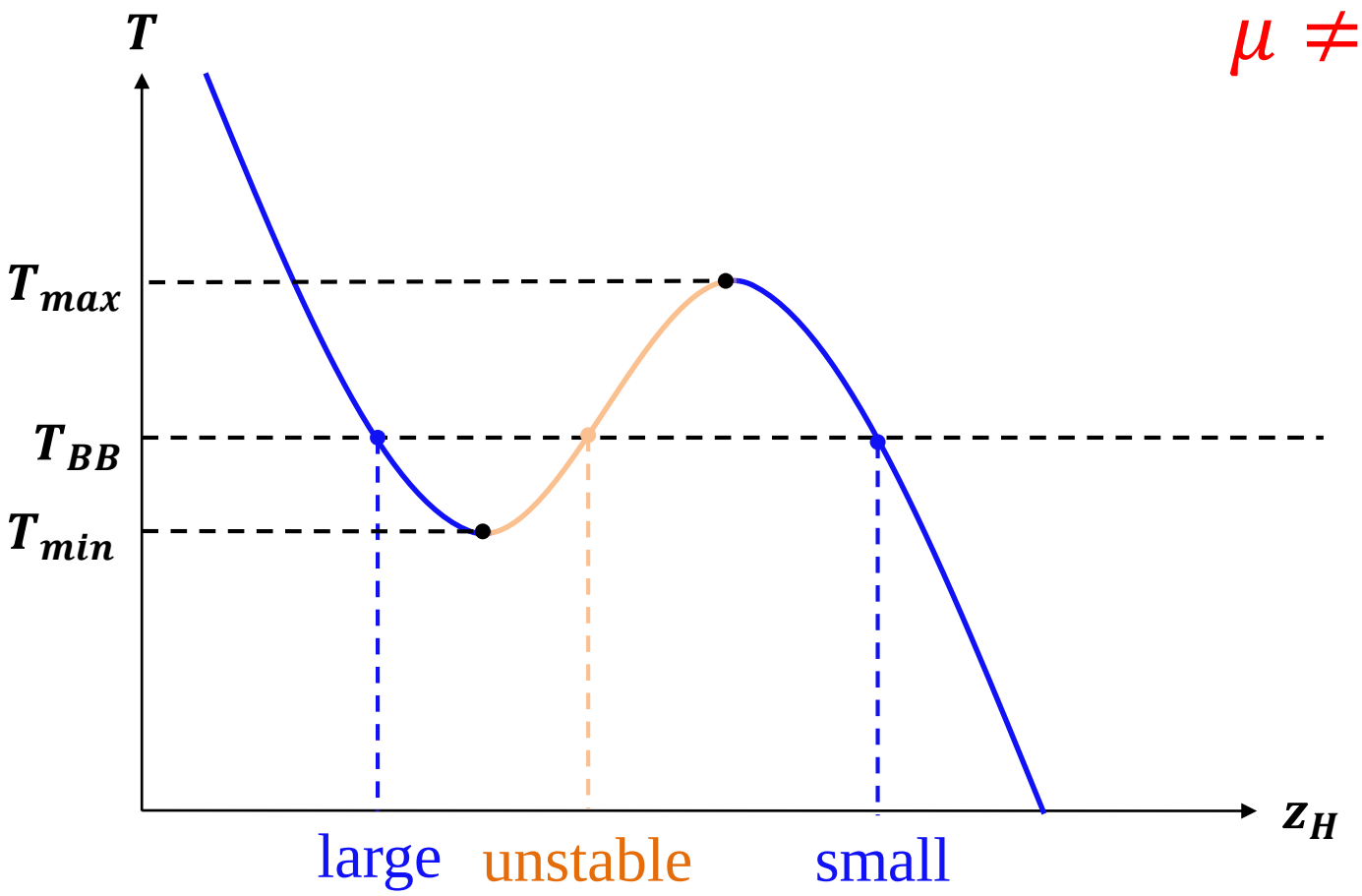
Confinment-Deconfinement



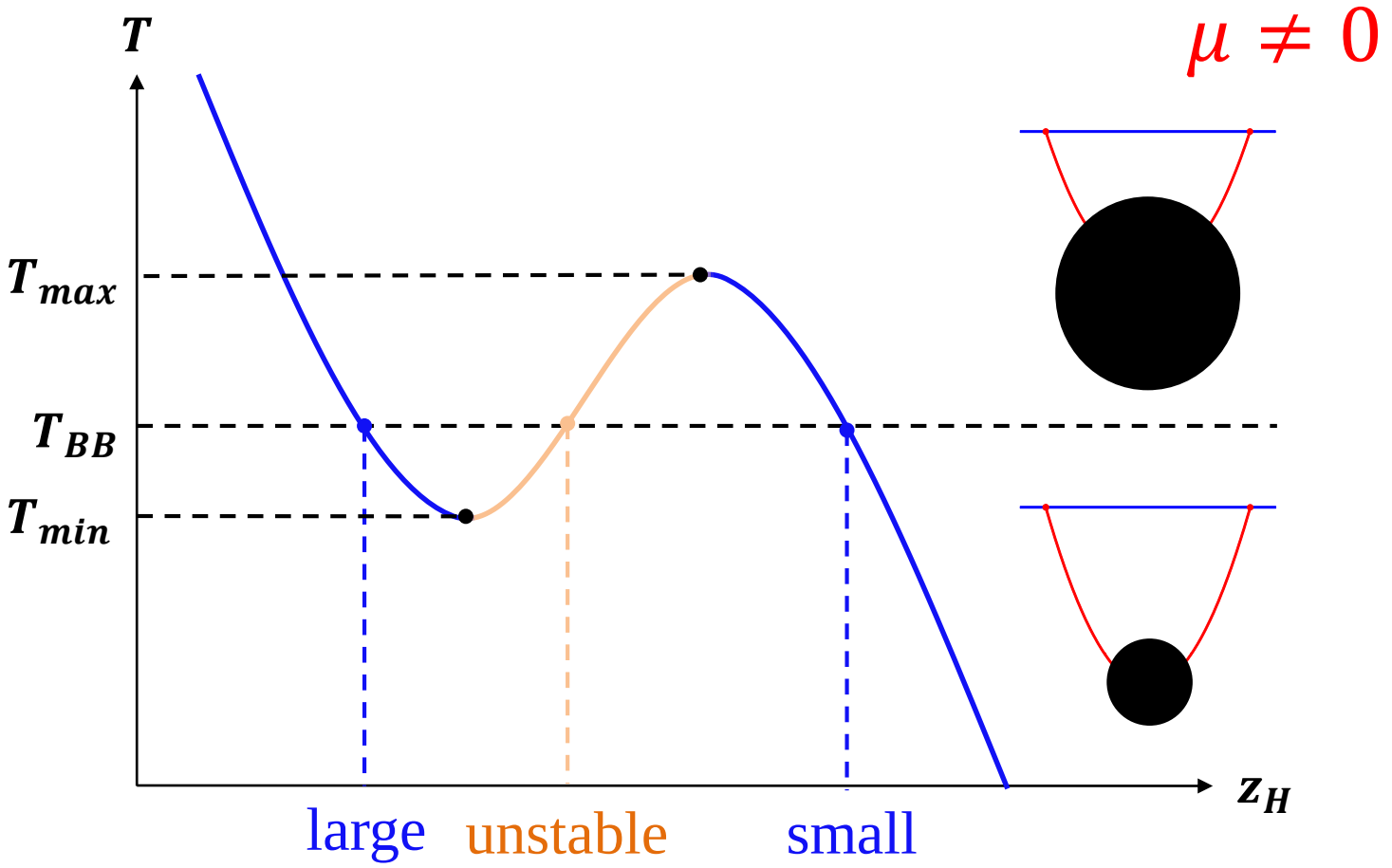
Confinement-Deconfinement Transition at $\mu = 0$



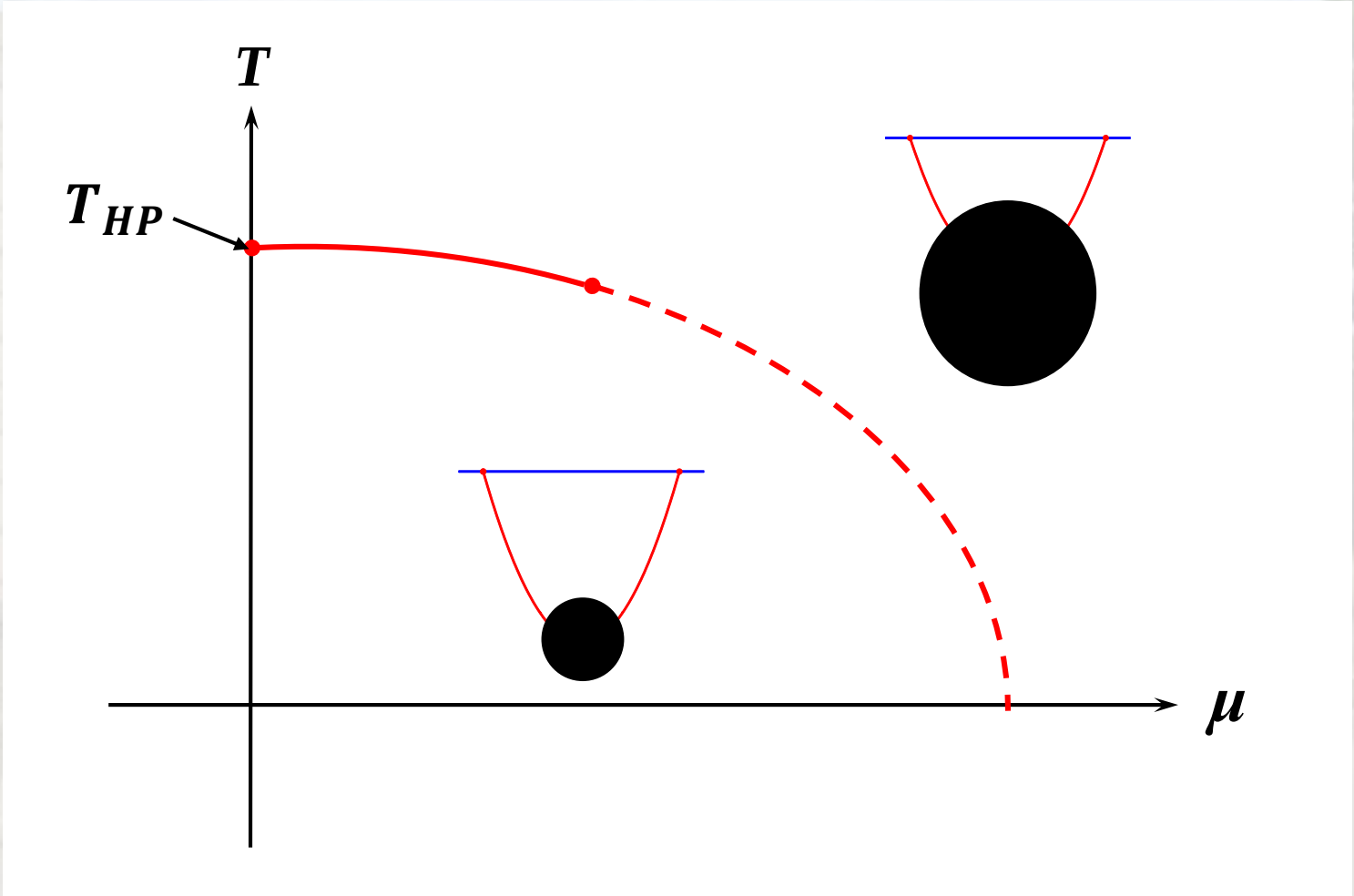
BH-BH Transition



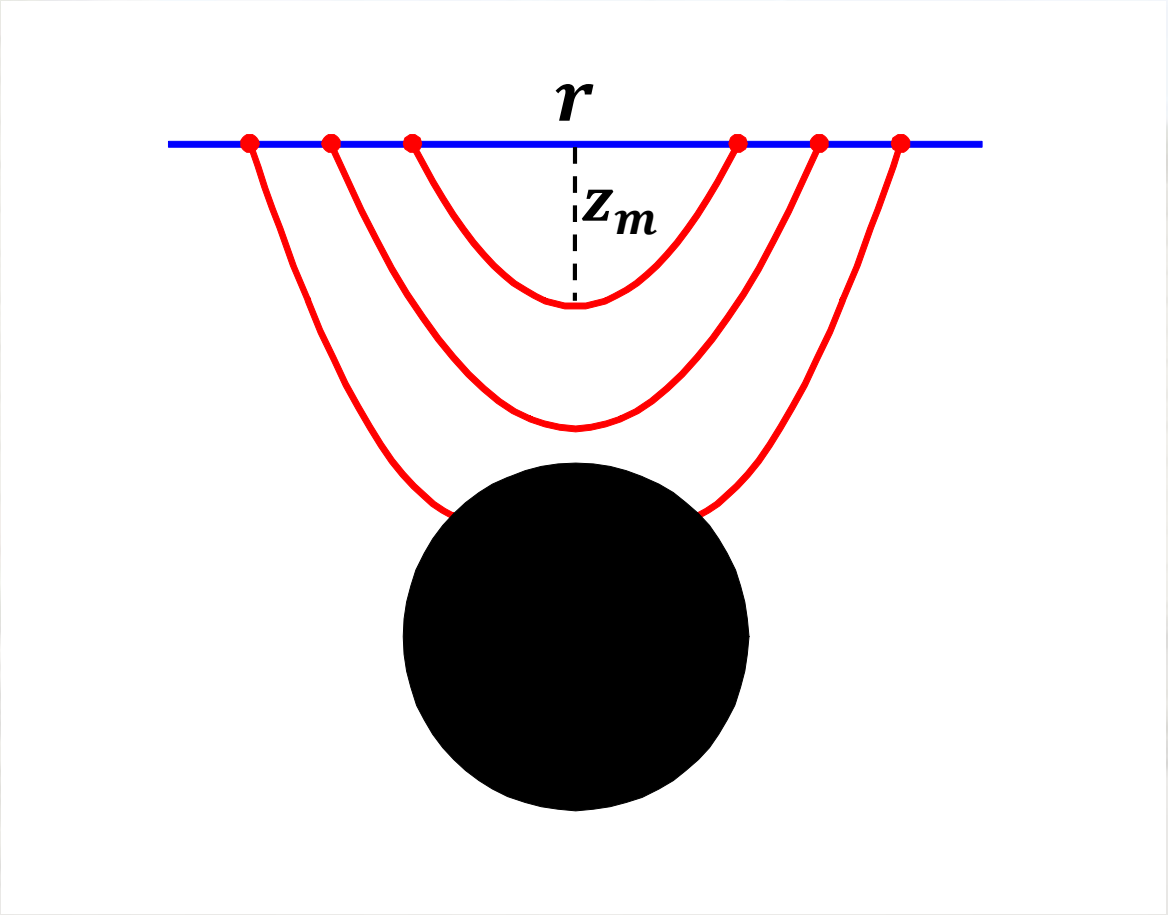
BH-BH Transition



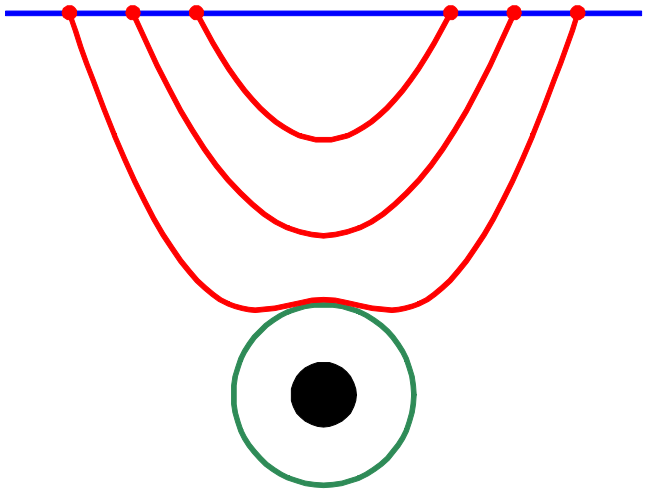
Always Deconfinement ?



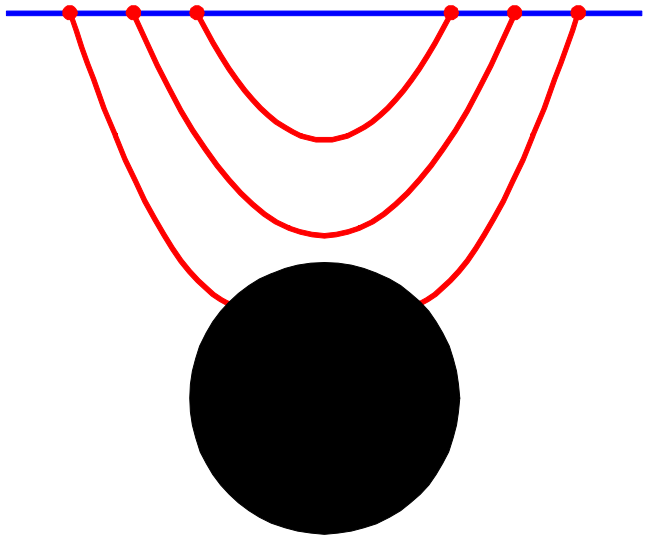
Open Strings Breaking



Dynamical Wall

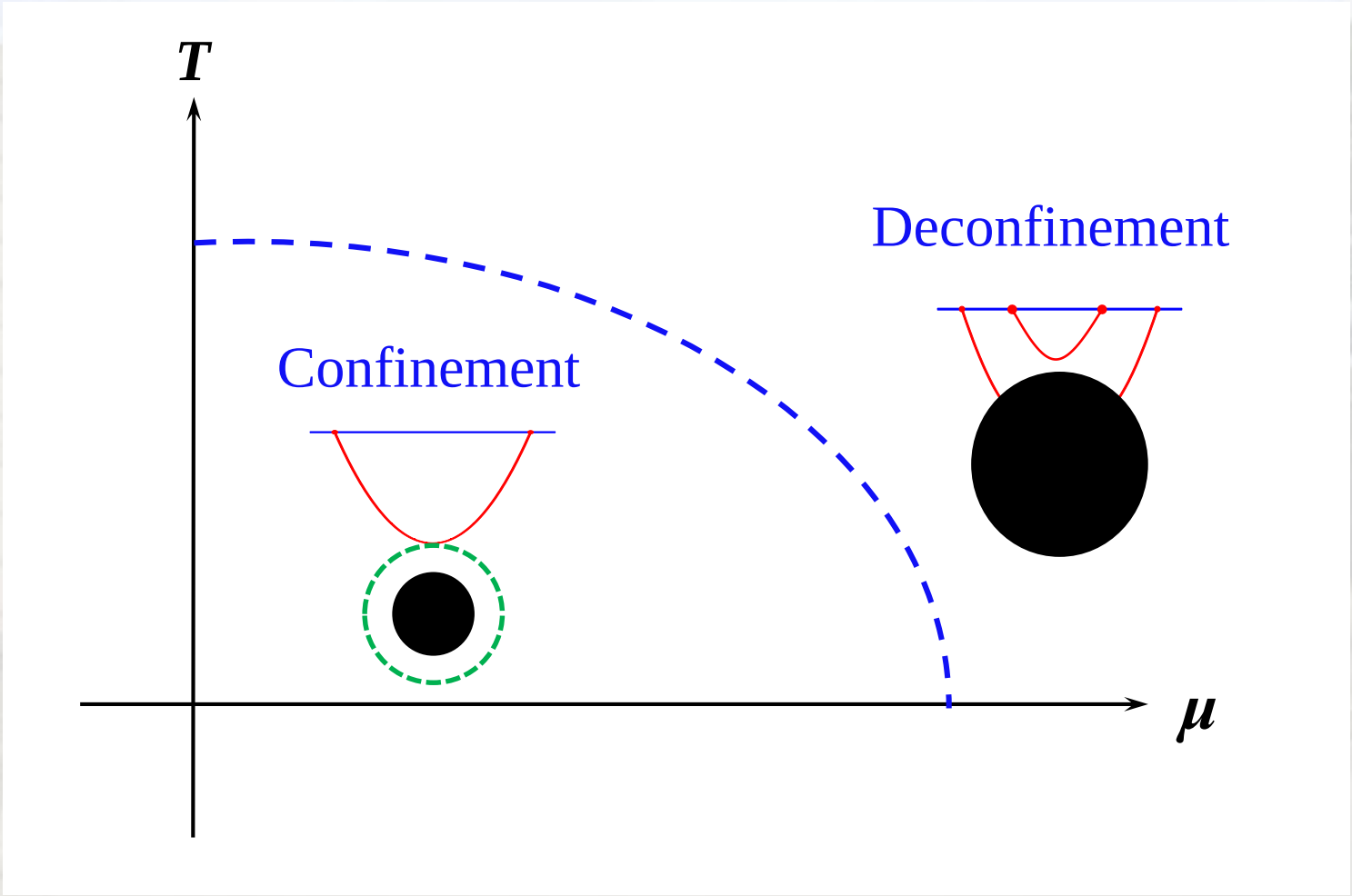


Low Temperature
Small BH
Confinement



High Temperature
Large BH
Deconfinement

Confinement-Deconfinement



A Holographic QCD Model

$$S_b = \int d^5x \sqrt{-g}\left[R - \frac{f(\phi)}{4}F^2 - \frac{1}{2}\partial\phi\partial\phi - V(\phi)\right]$$

$$S_m = -\int d^5x \sqrt{-g}\frac{f(\phi)}{4}F_m^2$$

$$g = \frac{e^{2A(z)}}{z^2}\left(-g(z)dt^2 + \frac{dz^2}{g(z)} + d\vec{x}^2\right)$$

$$A = A_t(z)dt, \qquad \phi = \phi(z)$$

Equations of motion

$$\phi'' + \left(\frac{g'}{g} + 3A' - \frac{3}{z}\right)\phi' + \left(\frac{z^2 e^{-2A} {A'_t}^2 f_\phi}{2g} - \frac{e^{2A} V_\phi}{z^2 g}\right) = 0$$

$$A_t'' + \left(\frac{f'}{f} + A' - \frac{1}{z}\right) A_t' = 0$$

$$A'' - A'^2 + \frac{z}{2} A' + \frac{\phi'^2}{6} = 0$$

$$g'' + \left(3A' - \frac{3}{z}\right) g' - z^2 e^{-2A} {A'_t}^2 f = 0$$

Boundary Conditions

- Regular at horizon: $z \sim z_H$

$$g(z_H) = A_t(z_H) = 0$$

- Asymptotic AdS at boundary: $z \sim 0$

$$A(0) = 0, g(0) = 1$$

$$A_t(z) = \mu + O(z)$$

Analytic Solutions

$$\phi'(z) = \sqrt{-6(A'' - A'^2 + 2A'/z}$$

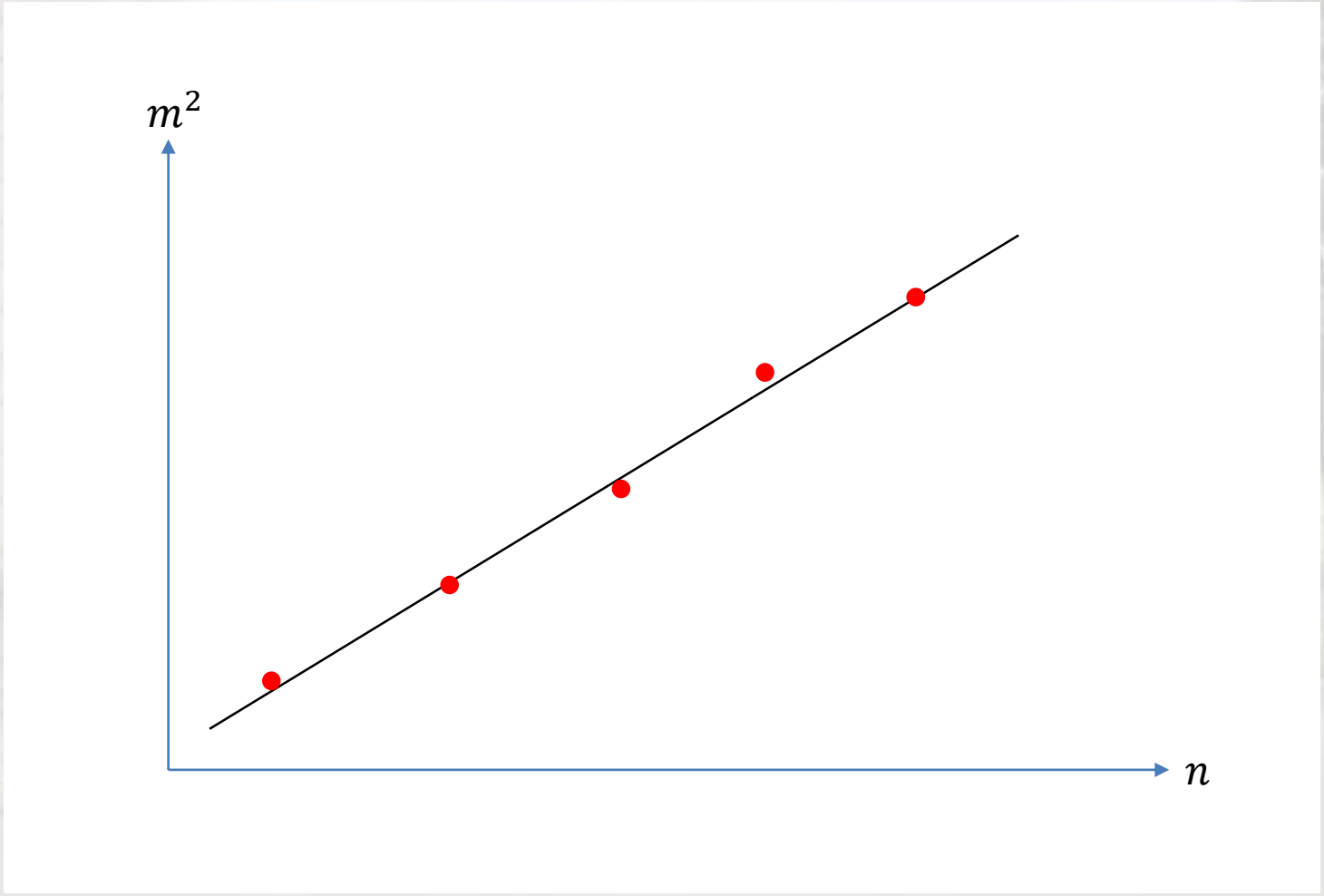
$$A_t(z) = \mu \frac{e^{cz^2} - e^{cz_H^2}}{1 - e^{cz_H^2}} = \mu + \frac{2c\mu}{1 - e^{cz_H^2}} z^2 + \cdots$$

$$g(z) = 1 + \frac{1}{I_1(0, z_H)} \left[\frac{2c\mu^2}{(1 - e^{cz_H^2})^2} \begin{vmatrix} I_1(0, z_H) & I_2(0, z_H) \\ I_1(z_H, z) & I_2(z_H, z) \end{vmatrix} - I_1(0, z) \right]$$

$$V(z) = -3z^2 g e^{-2A} \left[A'' + 3A'^2 + \left(\frac{3g'}{2g} - \frac{6}{z} \right) A' - \frac{1}{z} \left(\frac{3g'}{2g} - \frac{4}{z} \right) + \frac{g''}{6g} \right]$$

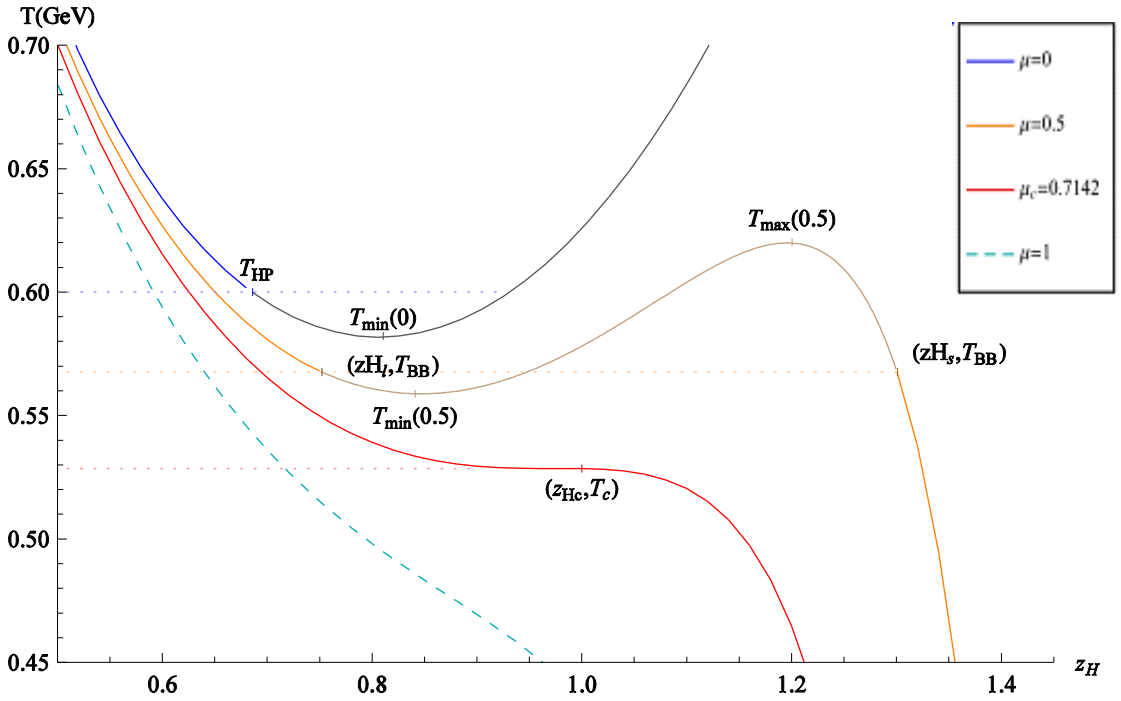
$$I_1(a,b) \equiv \int_a^b x^3 e^{-3A(x)} dx, \qquad I_2(a,b) \equiv \int_a^b x^3 e^{cx^2 - 3A(x)} dx$$

Linear Regge Meson Spectrum

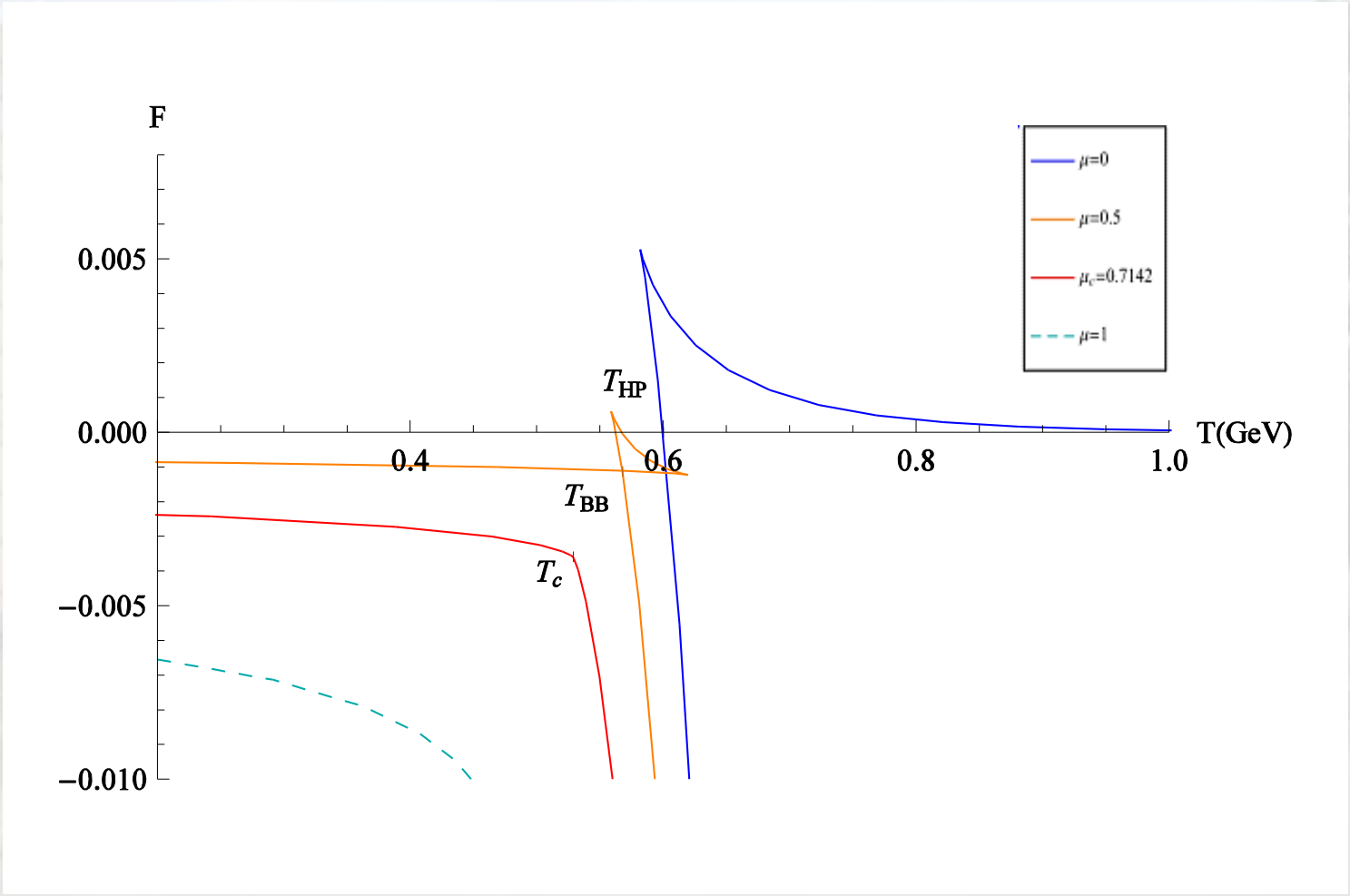


Temperature

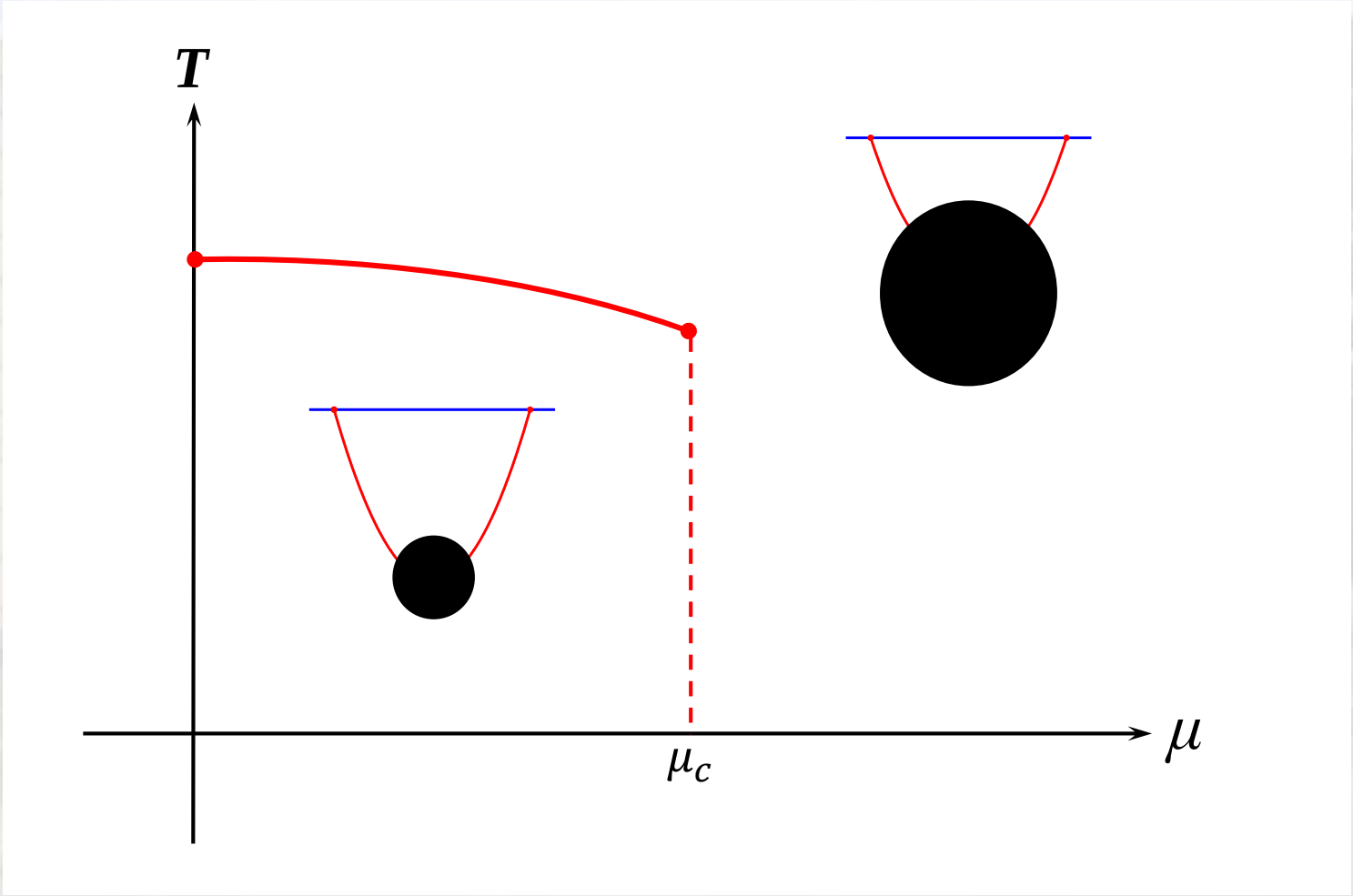
$$T = \frac{z_H^3 e^{-3A(z_H)}}{4\pi I_1(0,z_H)}\left[1 - \frac{2c\mu^2(I_1(0,z_H) - I_2(0,z_H)}{(1-e^{cz_H^2})^2}\right]$$



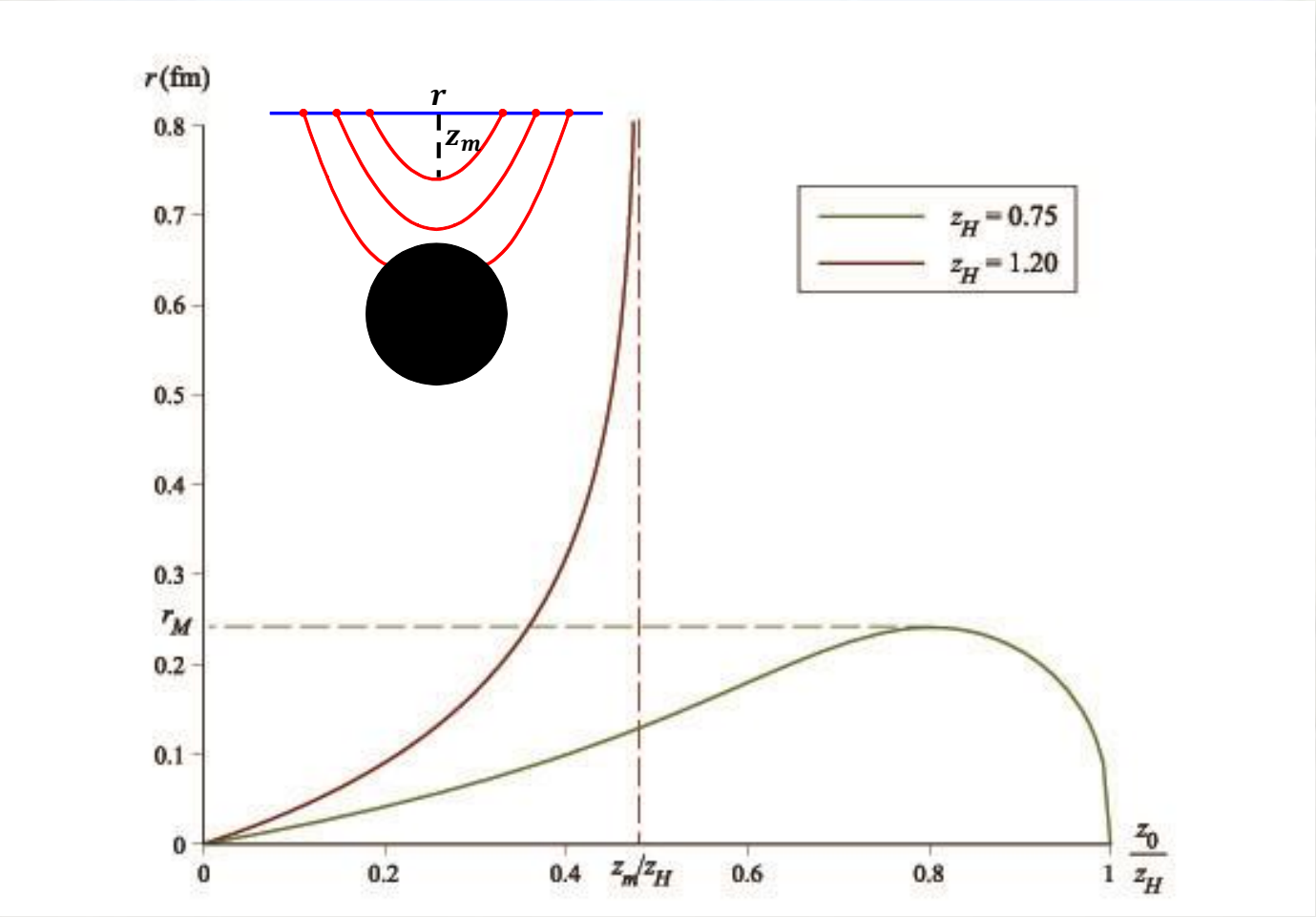
Free Energy


F
0.005
0.000
−0.005
−0.010
0.4
0.6
0.8
1.0
T(GeV)
T_{HP}
T_{BB}
T_c
μ=0
μ=0.5
μc=0.7142
μ=1

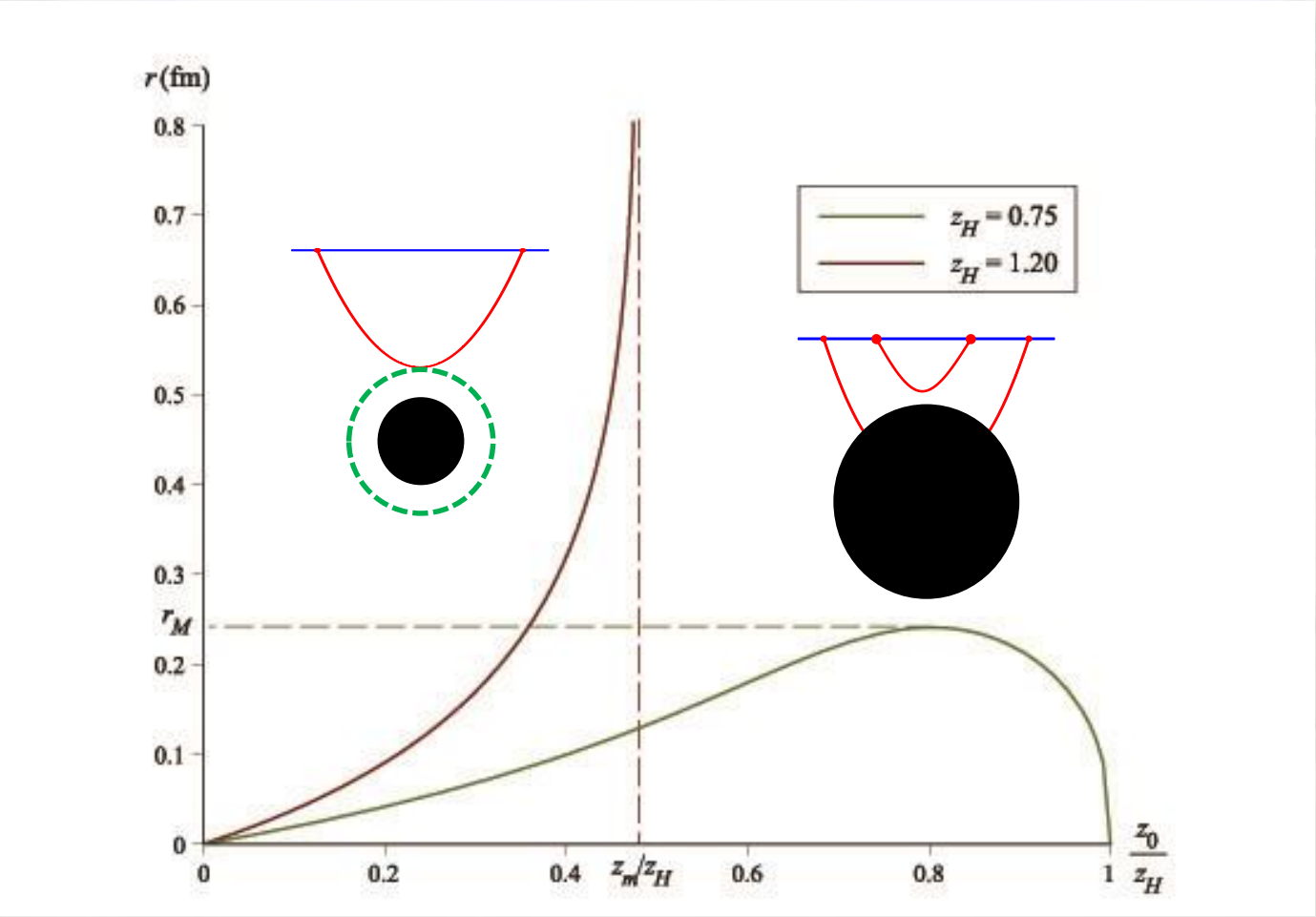
BH-BH Transition



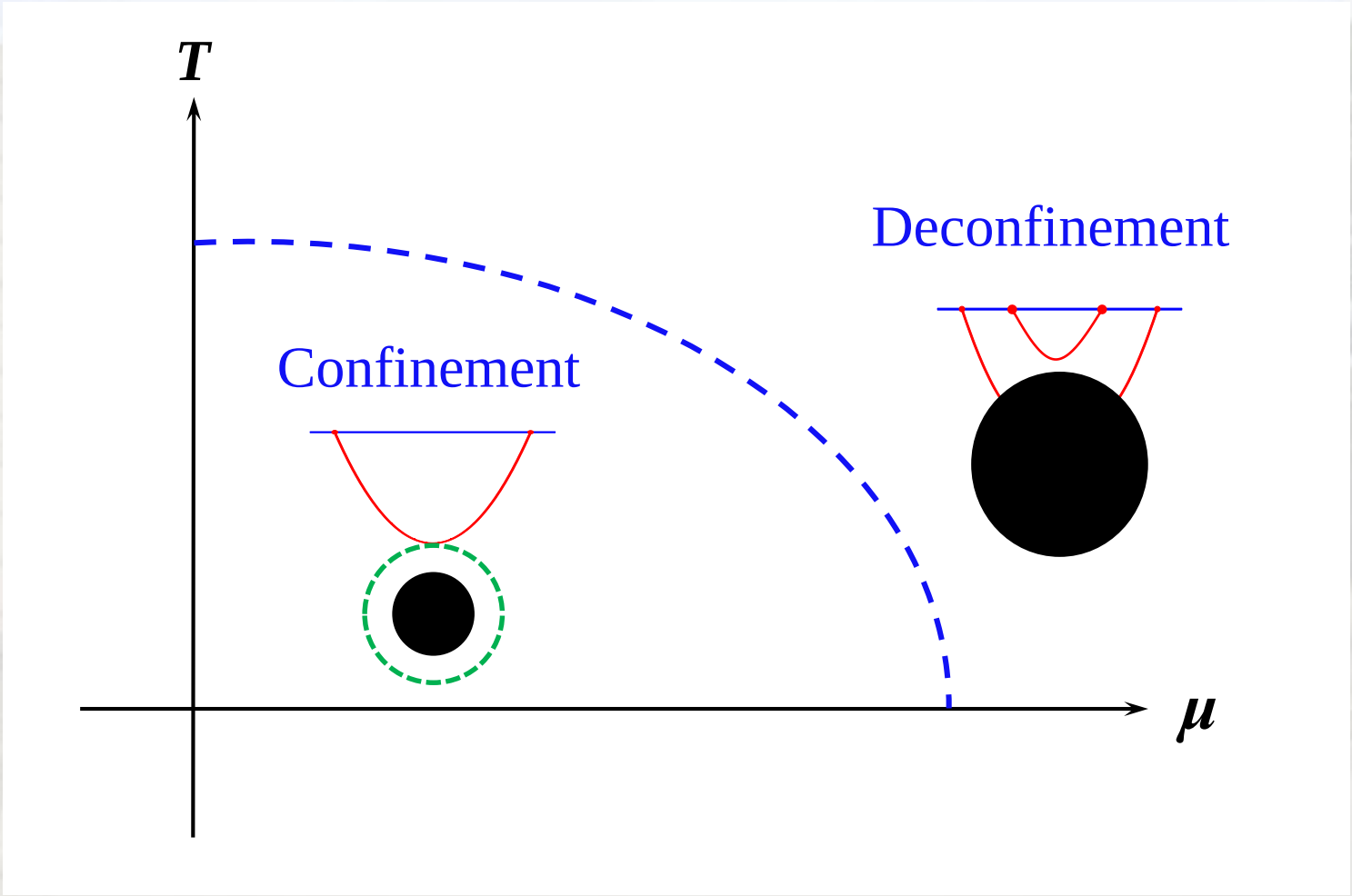
Configurations of Open Strings



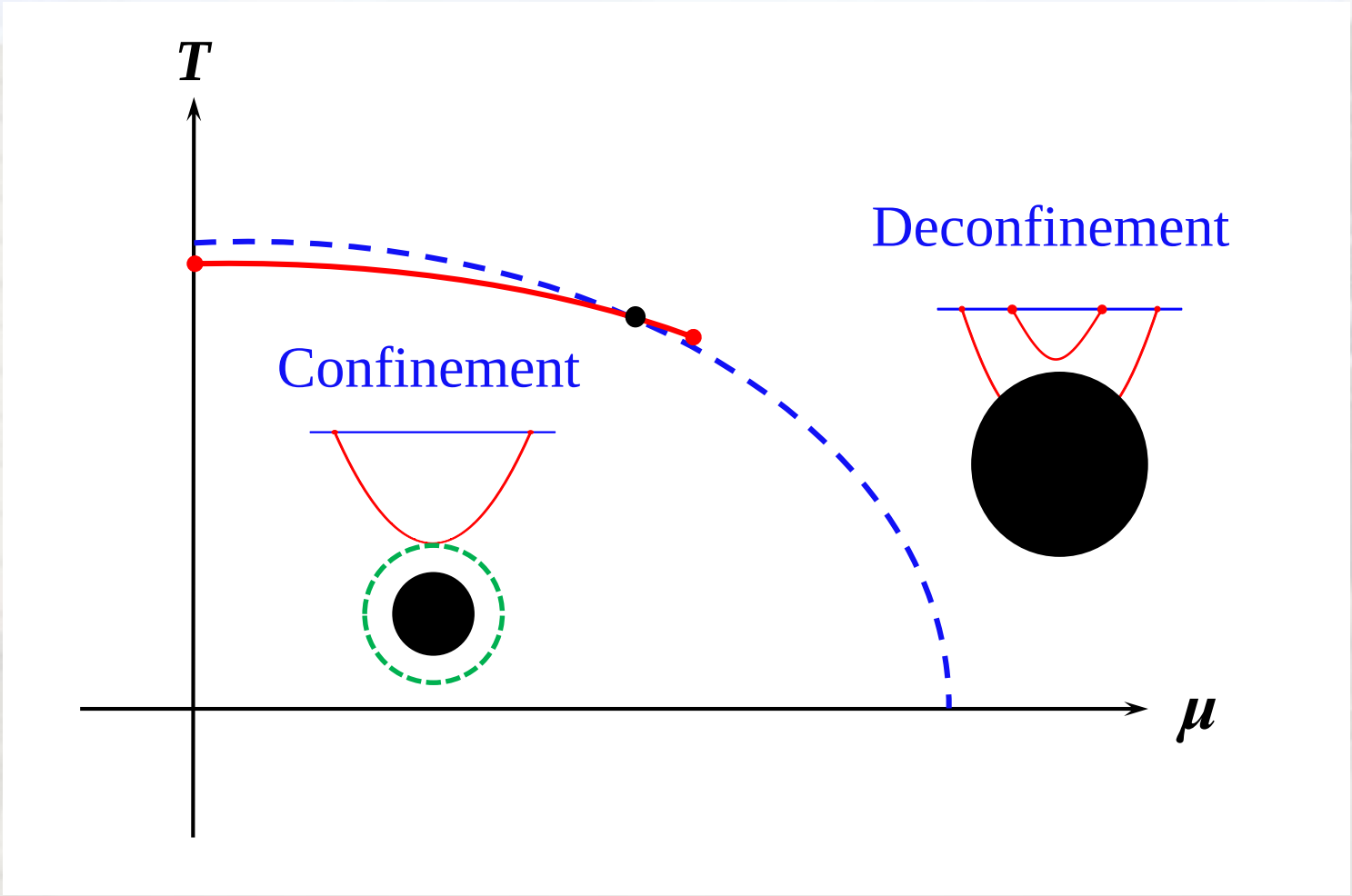
Dynamical Wall



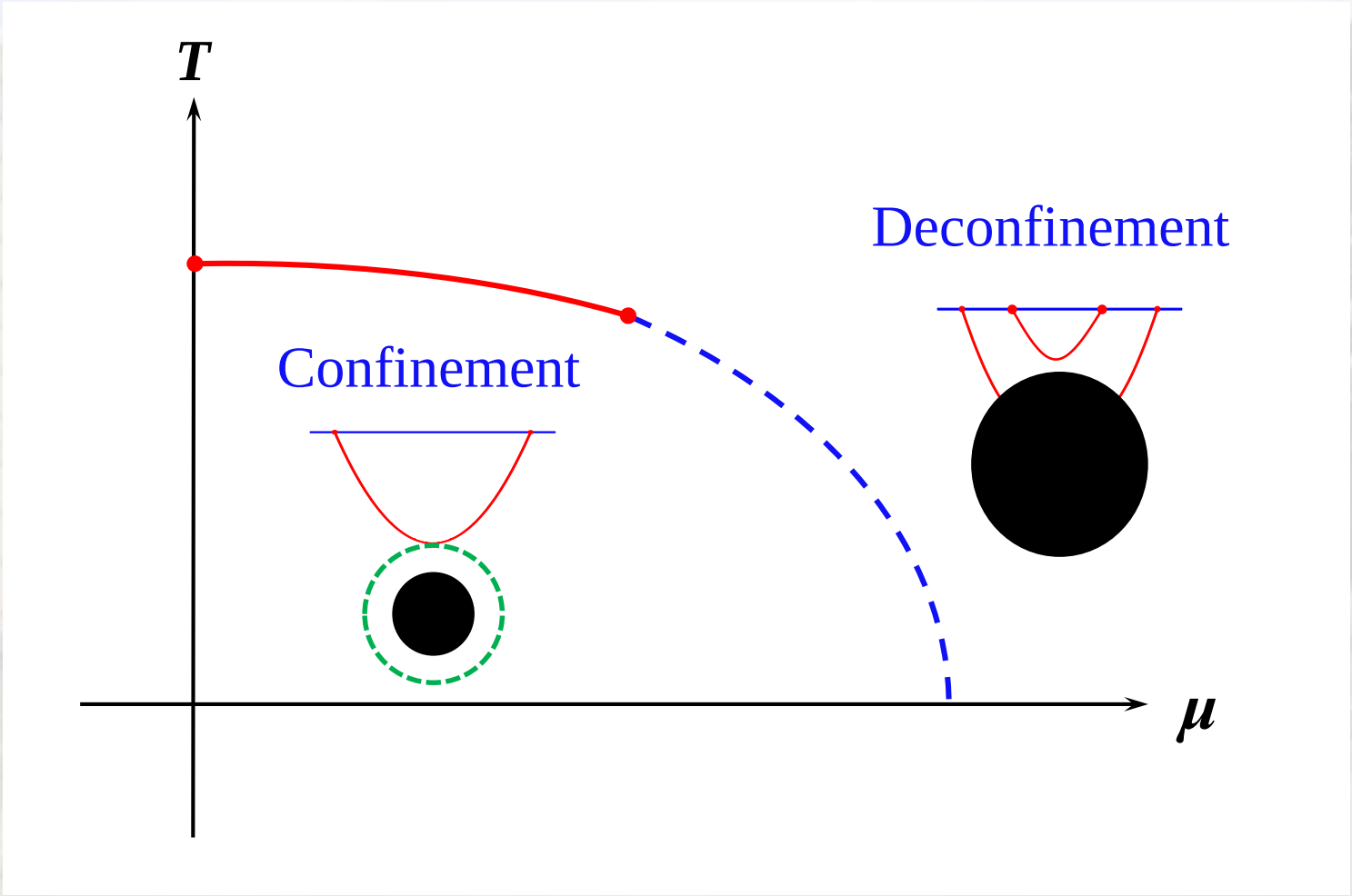
Confinement-Deconfinement



Open Strings in Background

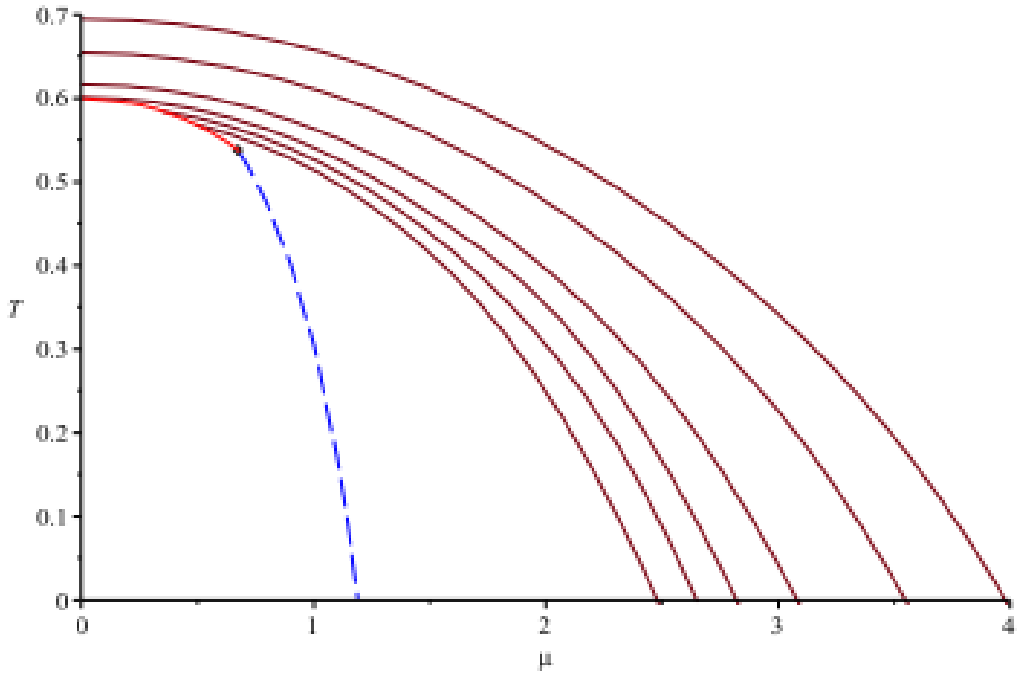


QCD Phase Diagram



Meson Melting

$$V = 2\int_0^{z_0} dz \frac{\sigma(z)}{g(z)}\left[1-\frac{\sigma^2(z_0)}{\sigma^2(z)}\right]^{-1/2} - 2\int_0^{z_H} dz \frac{e^{2A(z)}}{z^2}$$



Summary

- Gauge/gravity duality: holographic QCD
- Black hole phase transition: background
- Confinement/deconfinement: open strings
- QCD phase diagram: combine two effects
- Meson melting