Mesonic dynamic and QCD phase transition

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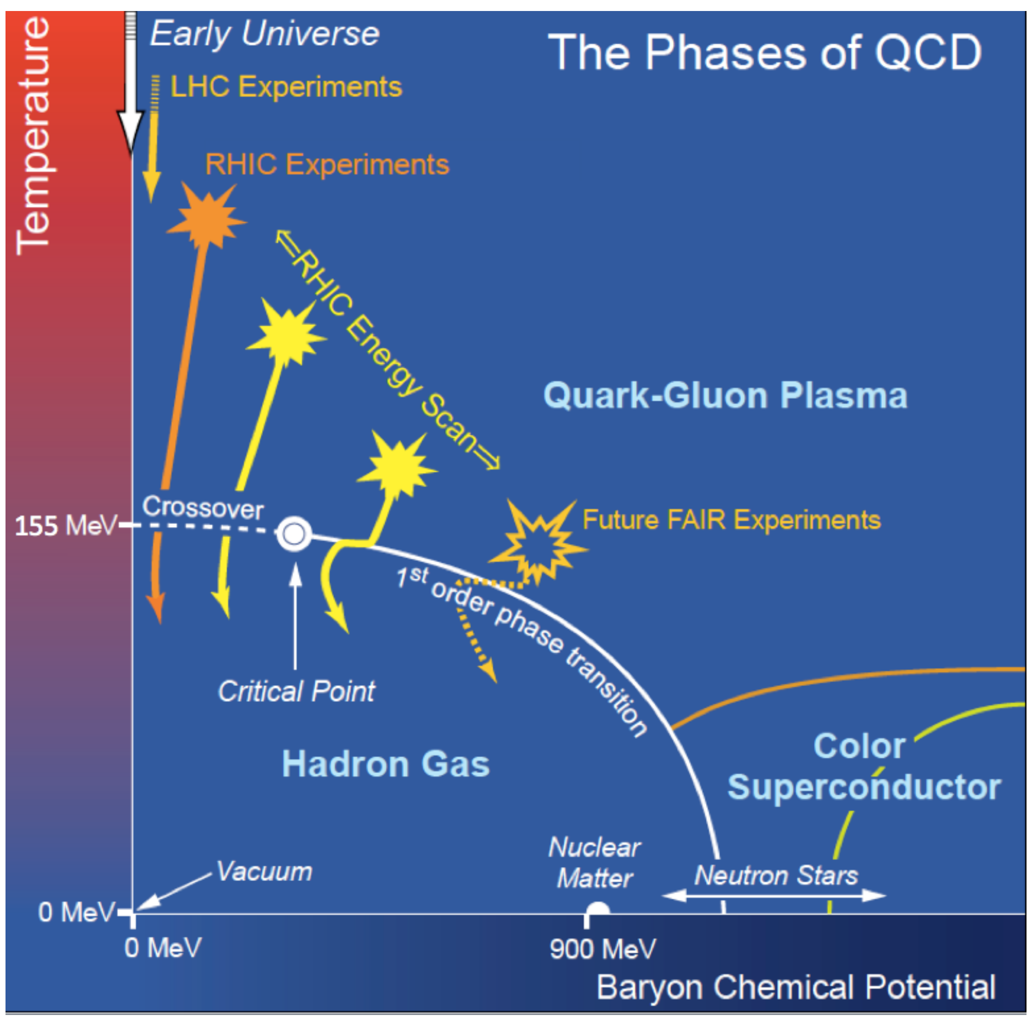
Outline

- Introduction
- Thermodynamic quantities
- Baryon number fluctuation
- Effective potential and Yukawa coupling
- Summary

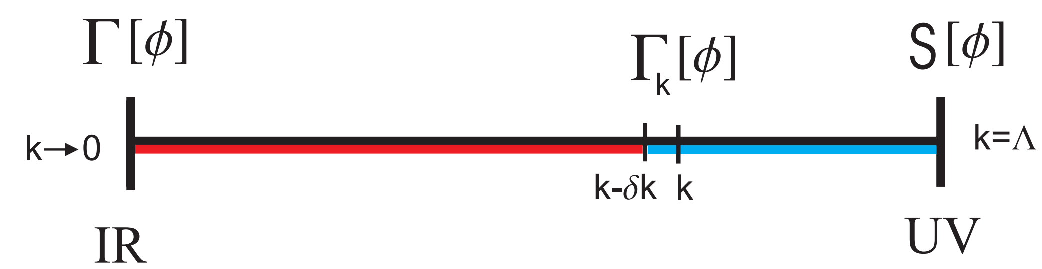
Introduction

QCD Phase diagram



The Hot QCD White Paper (2015)

Functional renormalization group

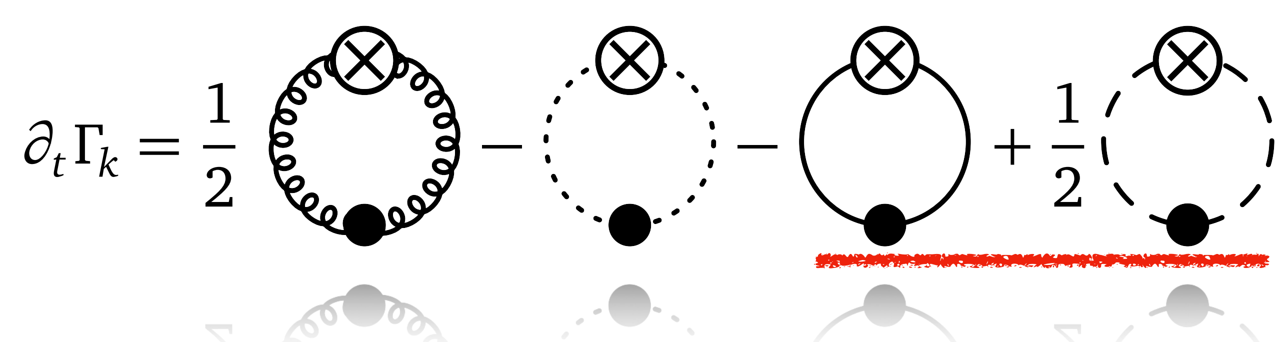


effective action of the PQM: $N_f = 2$ **2 flavor**

$$\Gamma_k = \int_x \{ Z_{q,k}\bar{q}(\gamma_\mu \partial_\mu - \gamma_0(\mu + igA_0))q + \frac{1}{2} Z_{\phi,k}(\partial_\mu \phi)^2$$

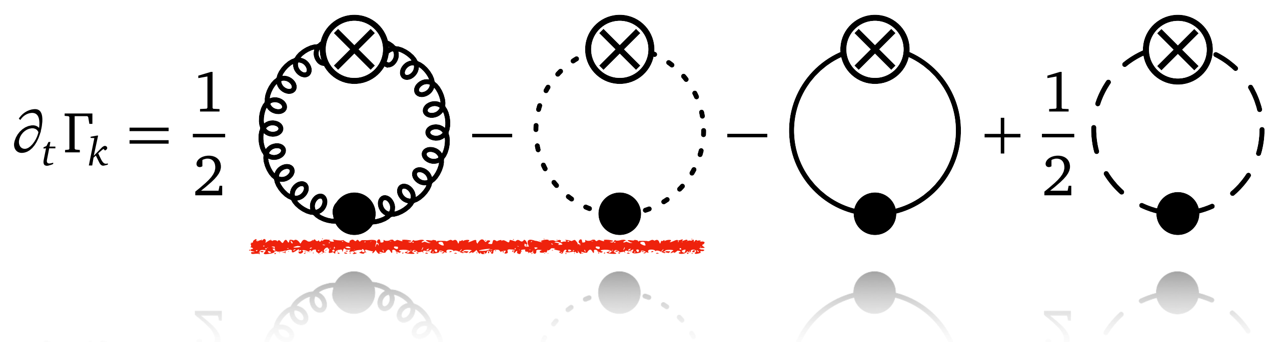
$$+ h_k \bar{q}(T^0\sigma + i\gamma_5 \vec{T}\cdot\vec{\pi})q + V_k(\rho) - c\sigma \} + \cdots$$

flow equation:



Quark-Meson model

Gluon



Glue potential:

$$V_{glue}(L,\bar{L}) = -\frac{a(T)}{2}\bar{L}L + b(T)\ln M_H(L,\bar{L})$$

$$+\frac{c(T)}{2}(L^3+\bar{L}^3) + d(T)(\bar{L}L)^2$$

$$M_H(L,\bar{L}) = 1 - 6\bar{L}L + 4(L^3+\bar{L}^3) - 3(\bar{L}L)^2$$

$$L(\vec{x}) = \frac{1}{N_c}\left\langle Tr\mathcal{P}(\vec{x})\right\rangle$$

$$\bar{L}(\vec{x}) = \frac{1}{N_c}\left\langle Tr\mathcal{P}^{\dagger}(\vec{x})\right\rangle$$

$$\mathcal{P}(\vec{x}) = \mathcal{P}\exp\left(ig\int_0^{\beta} d\tau A_0(\vec{x},\tau)\right)$$

Distribution function

$$n_F(x,T) = \frac{1}{\exp(\frac{x}{T})+1}$$

Replace

$$n_F(x,T,L,\bar{L}) = \frac{1+2\bar{L}e^{x/T}+Le^{2x/T}}{1+3\bar{L}e^{x/T}+3Le^{2x/T}+e^{3x/T}}$$

Break of the O(4) symmetry

In finite temperature field theory $O(4)$**-symmetry replaced by** $\mathcal{Z}_2 \otimes O(3)$

momentum: $p = (\omega_n, \vec{p}) = (2\pi n T, \vec{p})$

Here we investigate the influence of the meson wave function renormalization

$$\Gamma_k = \int_x \{ Z_{q,k}\bar{q}(\gamma_\mu \partial_\mu - \gamma_0(\mu + igA_0))q + \frac{1}{2} Z_{\phi,k}(\partial_\mu \phi)^2 + h_k \bar{q}(T^0\sigma + i\gamma_5 \vec{T}\cdot\vec{\pi})q + V_k(\rho) - c\sigma \} + \cdots$$

Propagator:

$$G_k^\pi = \frac{1}{\underline{Z_{\phi,k}}(q_0{}^2 + \vec{q}^{\,2}(1+r_B) + \bar{m}_\pi^2)}$$

$$\Downarrow$$

$$G_k^\pi = \frac{1}{\underline{Z^{\parallel}_{\phi,k}} q_0{}^2 + \underline{Z^{\perp}_{\phi,k}} \vec{q}^{\,2}(1+r_B) + m_\pi^2}$$

$$\Gamma_k = \int_x \{ Z_{q,k}\bar{q}(\gamma_\mu \partial_\mu - \gamma_0(\mu + igA_0))q + \frac{1}{2} Z^{\parallel}_{\phi,k}(\partial_0 \phi)^2 + \frac{1}{2} Z^{\perp}_{\phi,k}(\partial_i \phi)^2 + h_k \bar{q}(T^0\sigma + i\gamma_5 \vec{T}\cdot\vec{\pi})q + V_k(\rho) - c\sigma \} + \cdots$$

Flow equation

The flow of the wave function renormalization:

(anomalous dimension)

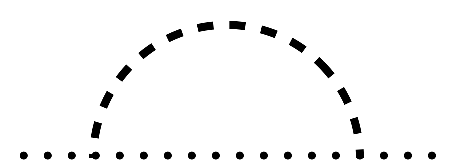
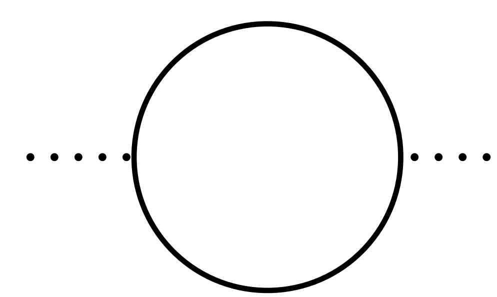
$$\boxed{\begin{aligned} {\eta_{\phi,k}}^{\perp} &= -\frac{\partial_t {Z_{\phi,k}}^{\perp}}{{Z_{\phi,k}}^{\perp}} \\ {\eta_{\phi,k}}^{\parallel} &= -\frac{\partial_t {Z_{\phi,k}}^{\parallel}}{{Z_{\phi,k}}^{\parallel}} \end{aligned}}$$

$$\partial_t = k\frac{\partial}{\partial k}$$

Wetterich equation:

$$\partial_t \Gamma_k = \frac{1}{2} STr\left\{\tilde{\partial}_t \ln\left(\Gamma_k^{(2)} + R_k\right)\right\}$$

$$\partial_t Z_{\phi,k} \sim -\frac{1}{2}\tilde{\partial}_t (G_k^{\sigma} F_k^{\sigma\pi} G_k^{\pi} F_k^{\sigma\pi}) + \frac{1}{2}\tilde{\partial}_t (G_k^{q\bar{q}} F_k^{\bar{q}q} G_k^{q\bar{q}} F_k^{\bar{q}q})$$

$-\frac{1}{2}$  $+\frac{1}{2}$ 

Thermodynamic quantities

Renormalized dimensionless meson mass and quark mass:

$$\bar{m}^2_{\pi,k} = \frac{V_k^{'}(\rho)}{k^2 Z^{\perp}_{\phi,k}}$$

$$\bar{m}^2_{\sigma,k} = \frac{V_k^{'}(\rho) + 2\rho V_k^{''}(\rho)}{k^2 Z^{\perp}_{\phi,k}}$$

$$\bar{m}^2_{q,k} = \frac{h_k^2 \rho}{2k^2 Z^2_{q,k}}$$

Fluctuation:

$$\chi_n^B = \frac{\partial^n}{\partial(\mu_B/T)^n} \frac{p}{T^4}$$

Kurtosis:

$$\kappa\sigma^2 = \frac{\chi_4^B}{\chi_2^B}$$

Trace anomaly:

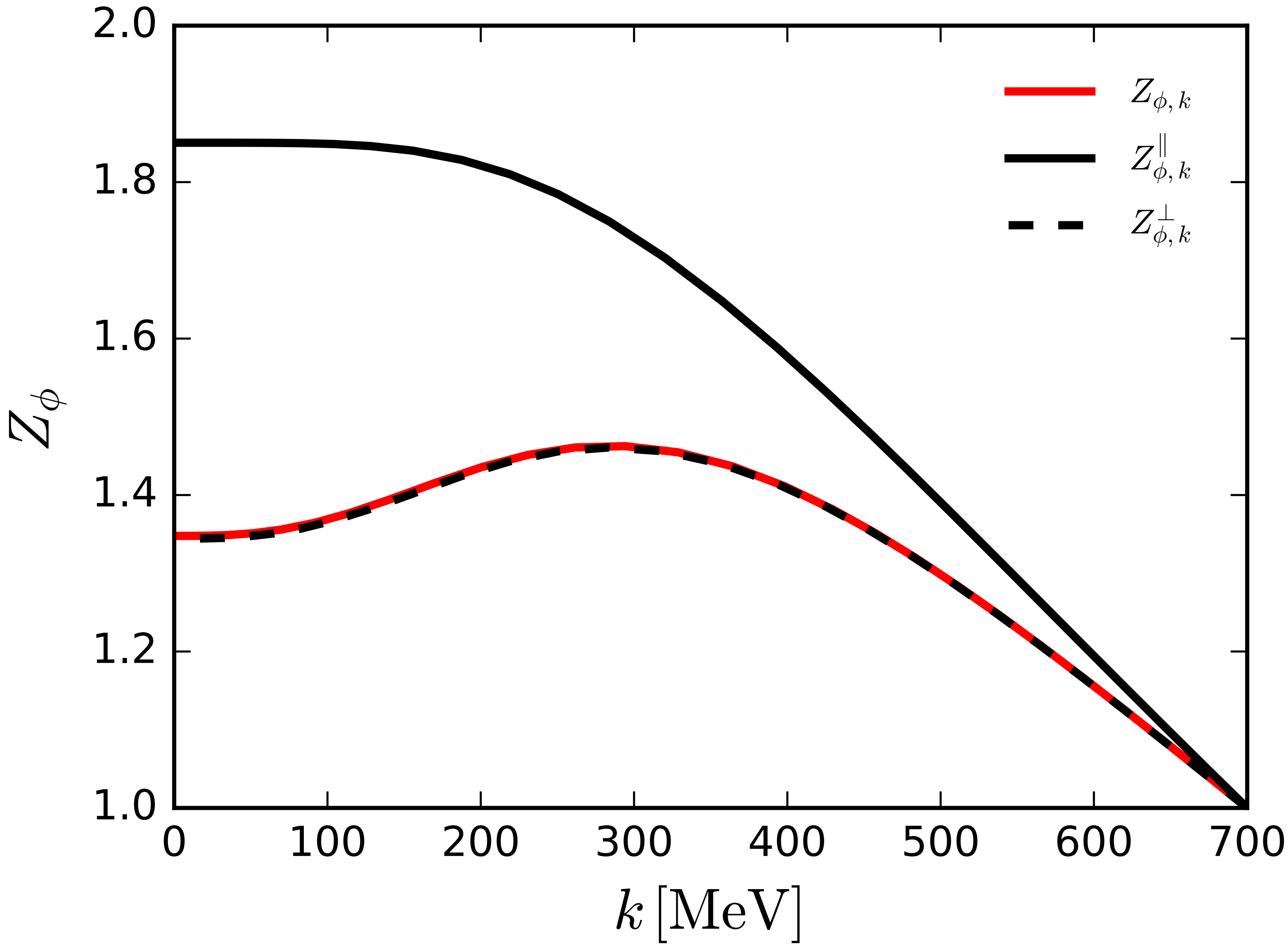
$$\frac{\varepsilon - 3p}{T^4}$$

Pion decay constant:

$$f_\pi = <\sigma>$$

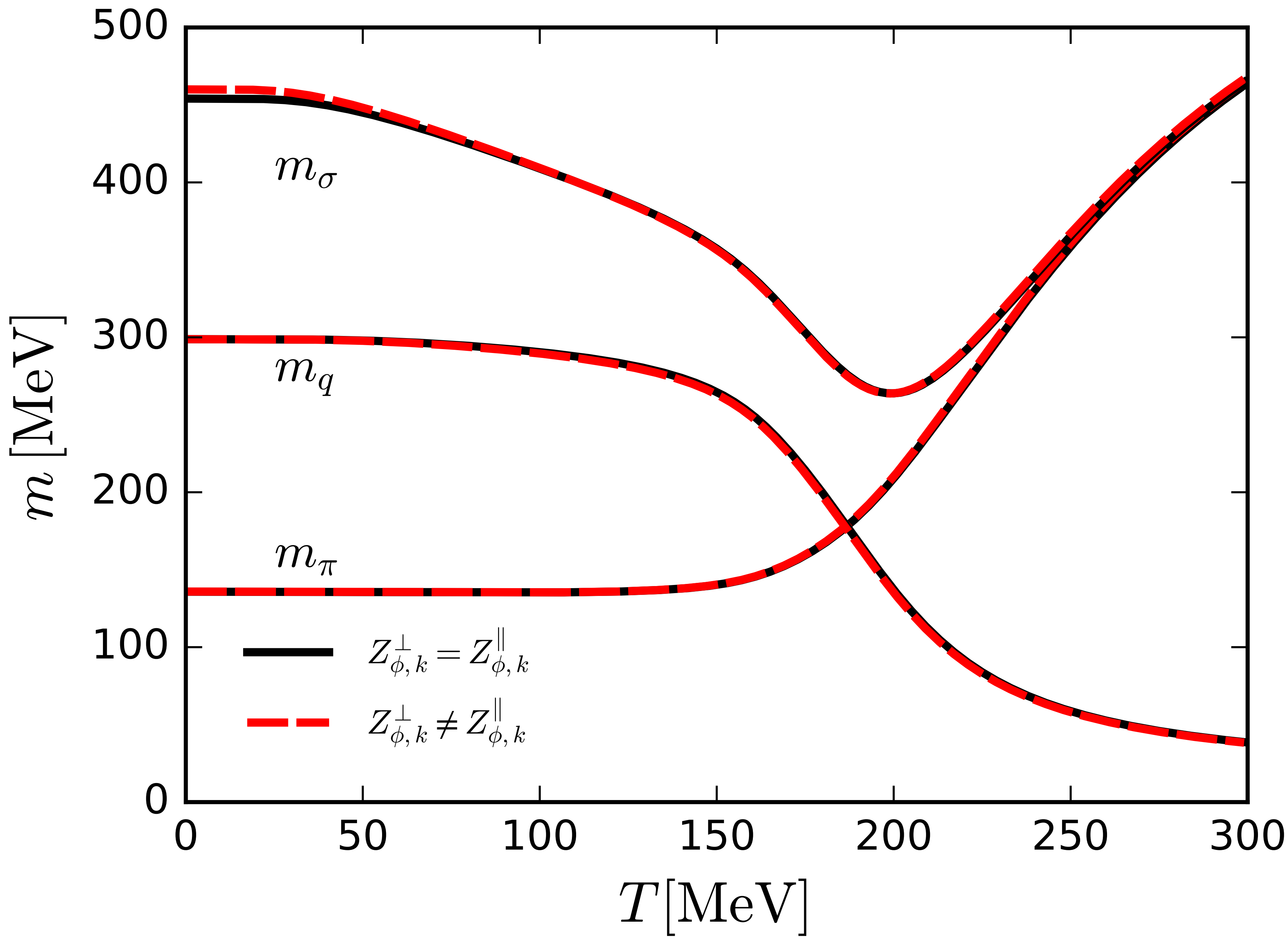
Thermodynamic quantities

The meson wave function renormalization as a function of k at T=0



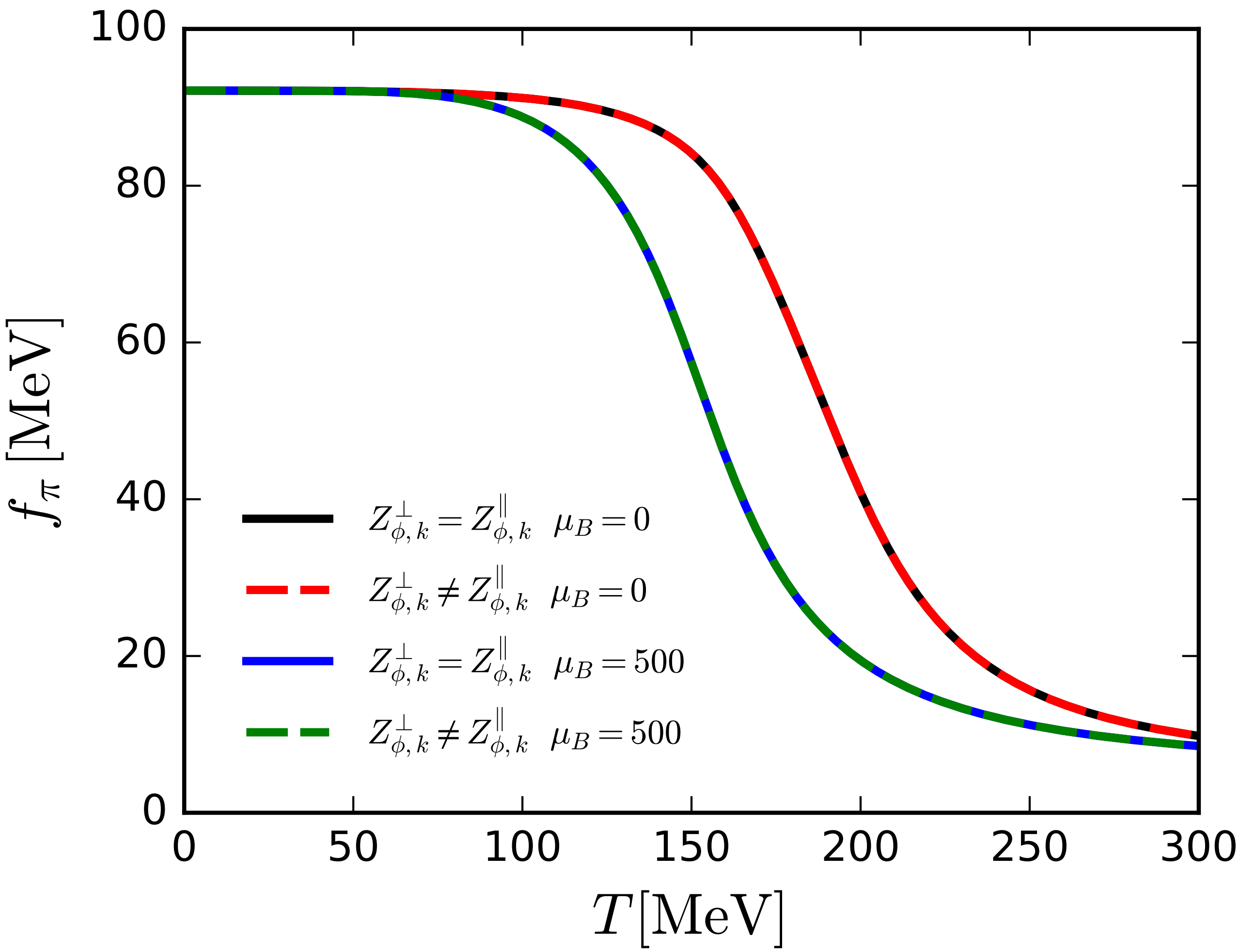
Thermodynamic quantities

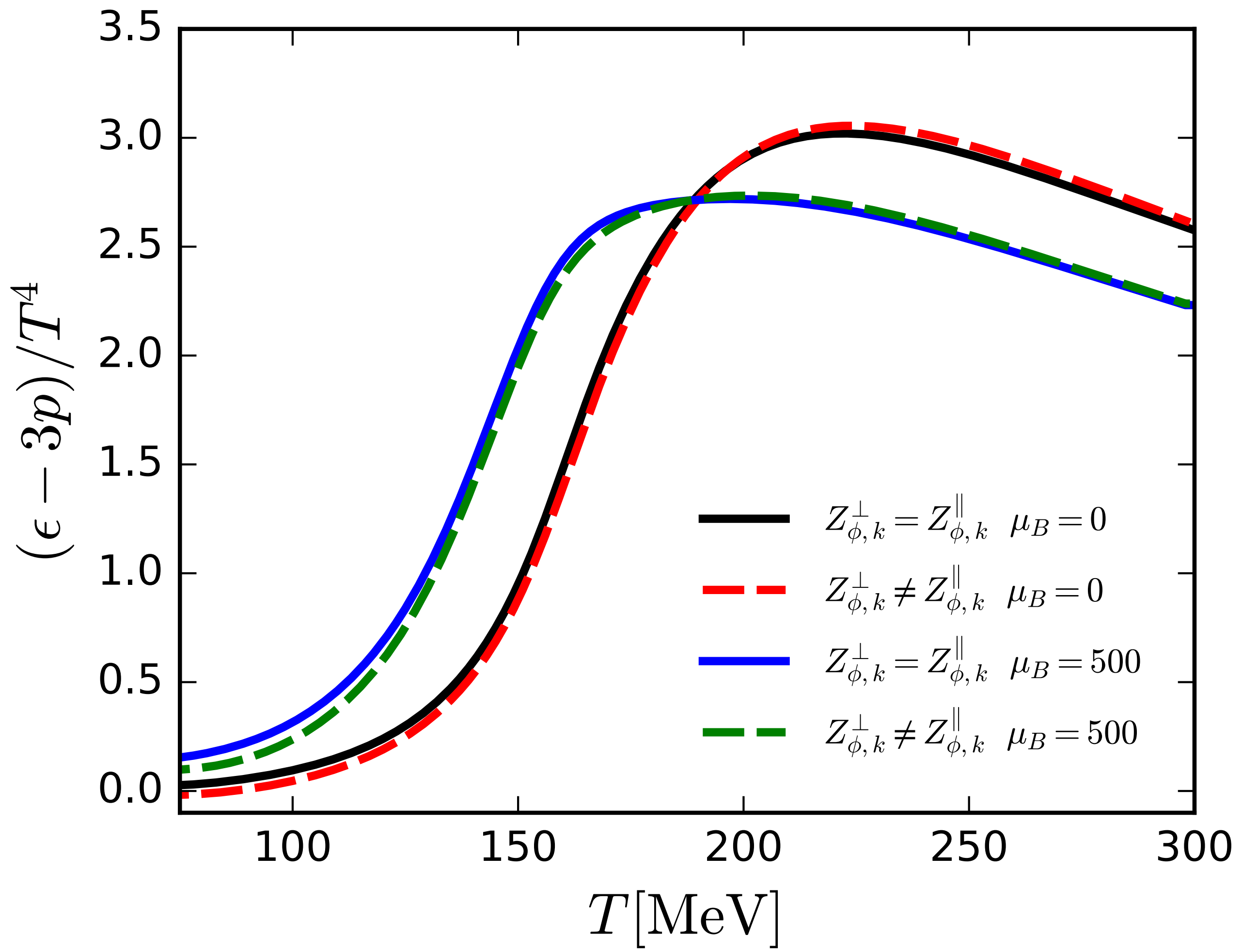
The pion mass and quark mass as a function of temperature



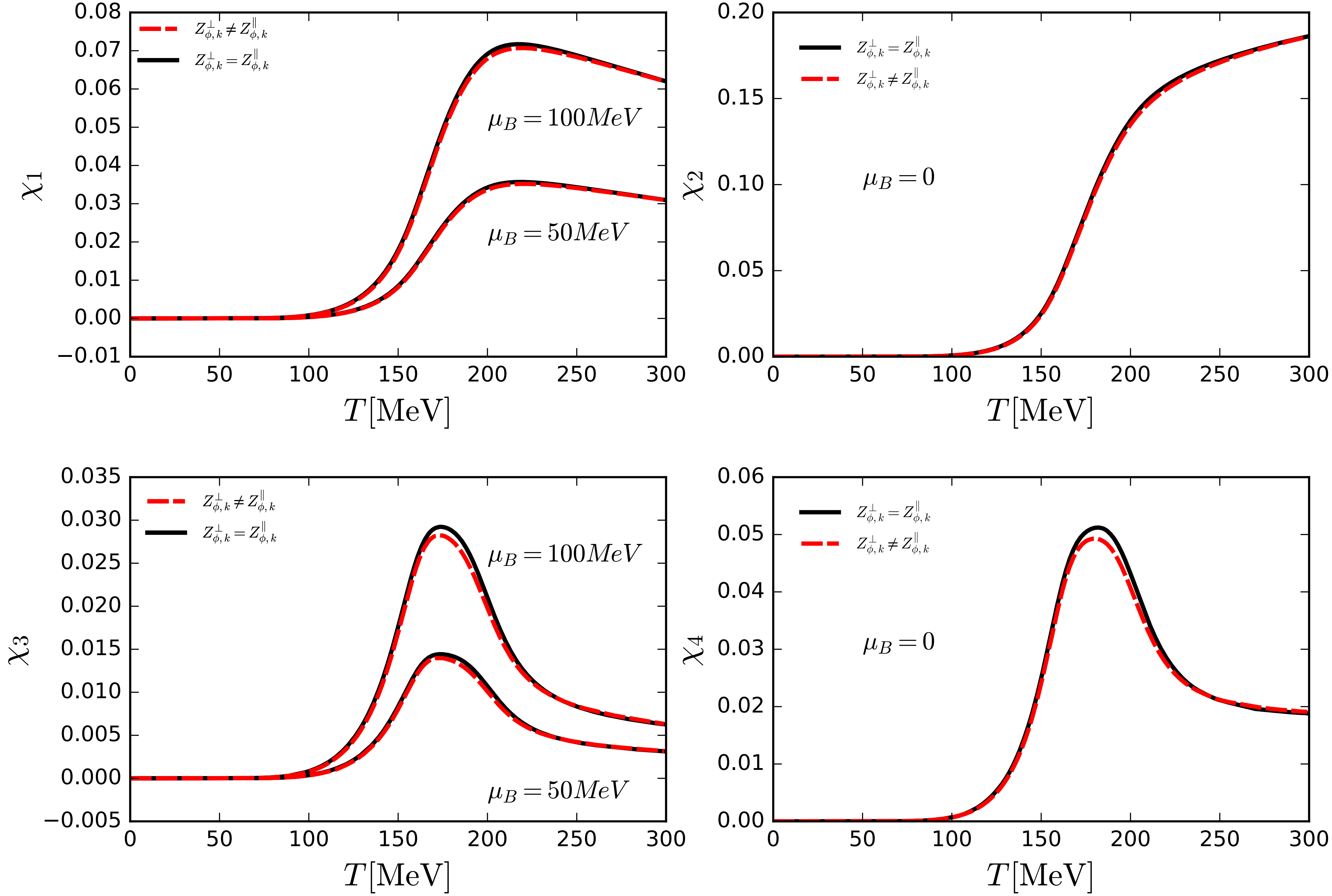
Thermodynamic quantities

Trace-anomaly and Pion decay constant as a function of temperature

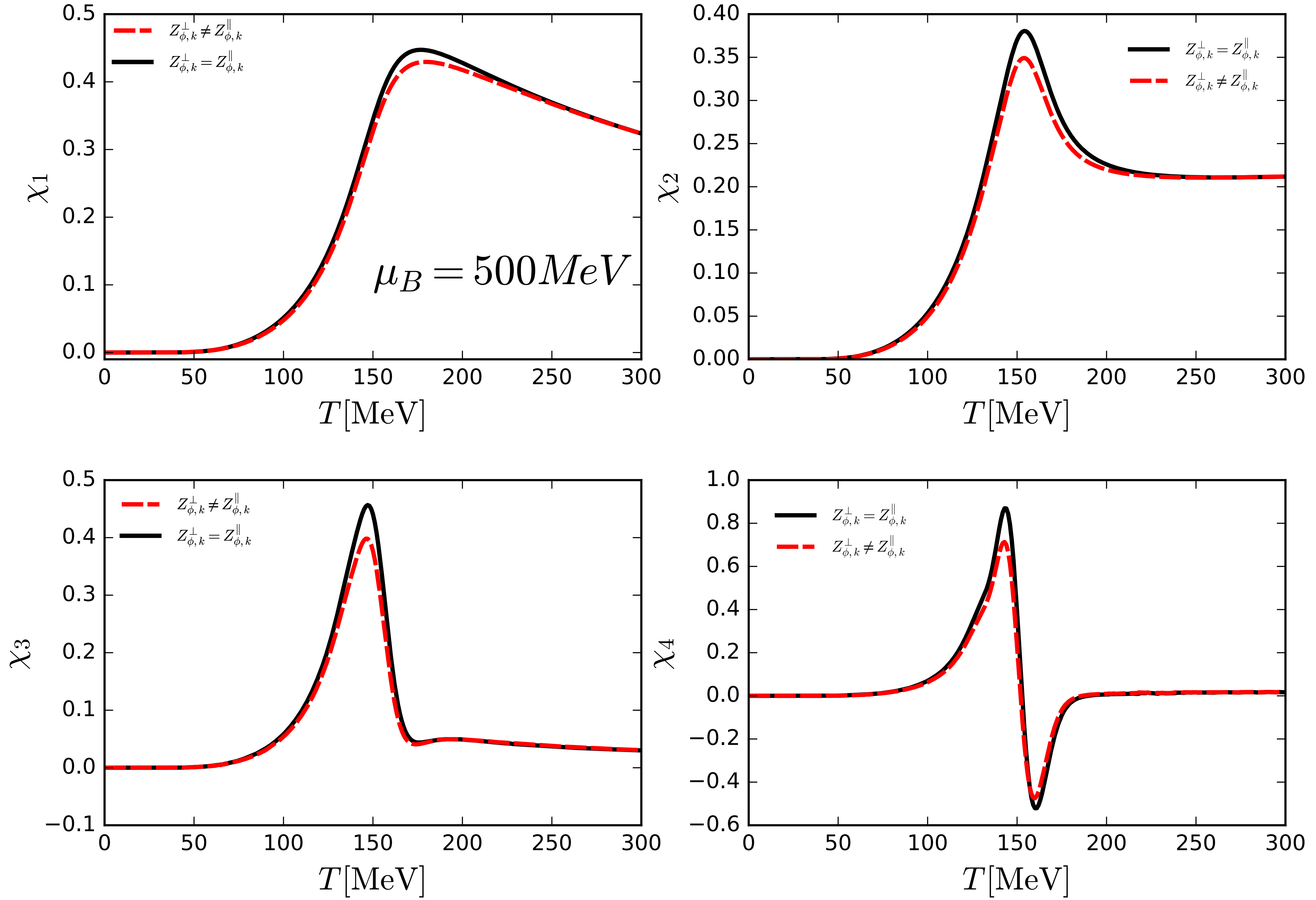




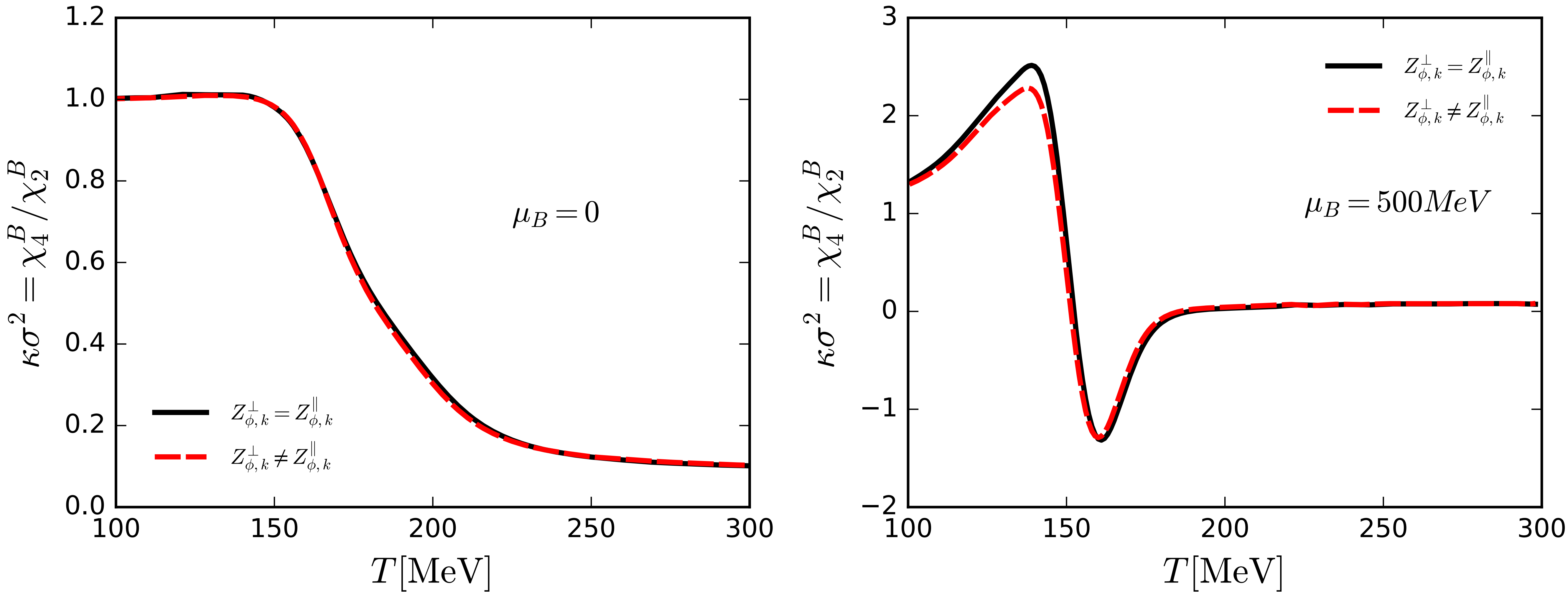
Baryon number fluctuation



Baryon number fluctuation



Baryon number fluctuation



Effective potential and Yukawa coupling

Effective potential:

$$\bar{V}_k(\bar{\rho}) = \sum_{n=0}^{N} \frac{\bar{\lambda}_{n,k}}{n!}(\bar{\rho} - \bar{\kappa}_k)^n$$

$$n_V = 5$$

Yukawa coupling:

$$\bar{h}_k(\bar{\rho}) = \sum_{n=0}^{N} \frac{\bar{h}_{n,k}}{n!}(\bar{\rho} - \bar{\kappa}_k)^n$$

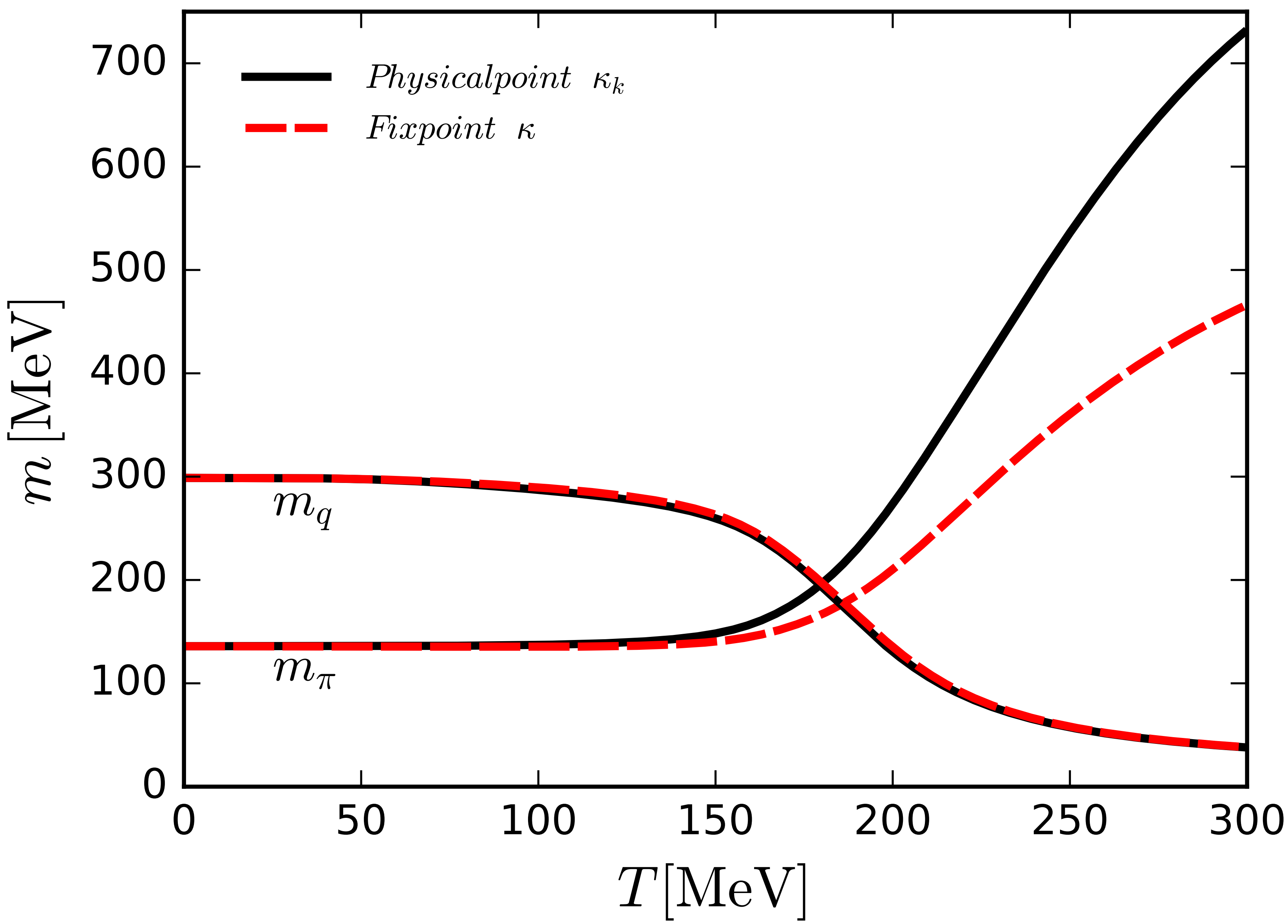
$$n_h = 5$$

Fix point: $\bar{\kappa}_k = Z_{\phi,k}^{\perp}\kappa$

Physical point: $\bar{\kappa}_k = Z_{\phi,k}^{\perp}\kappa_k$

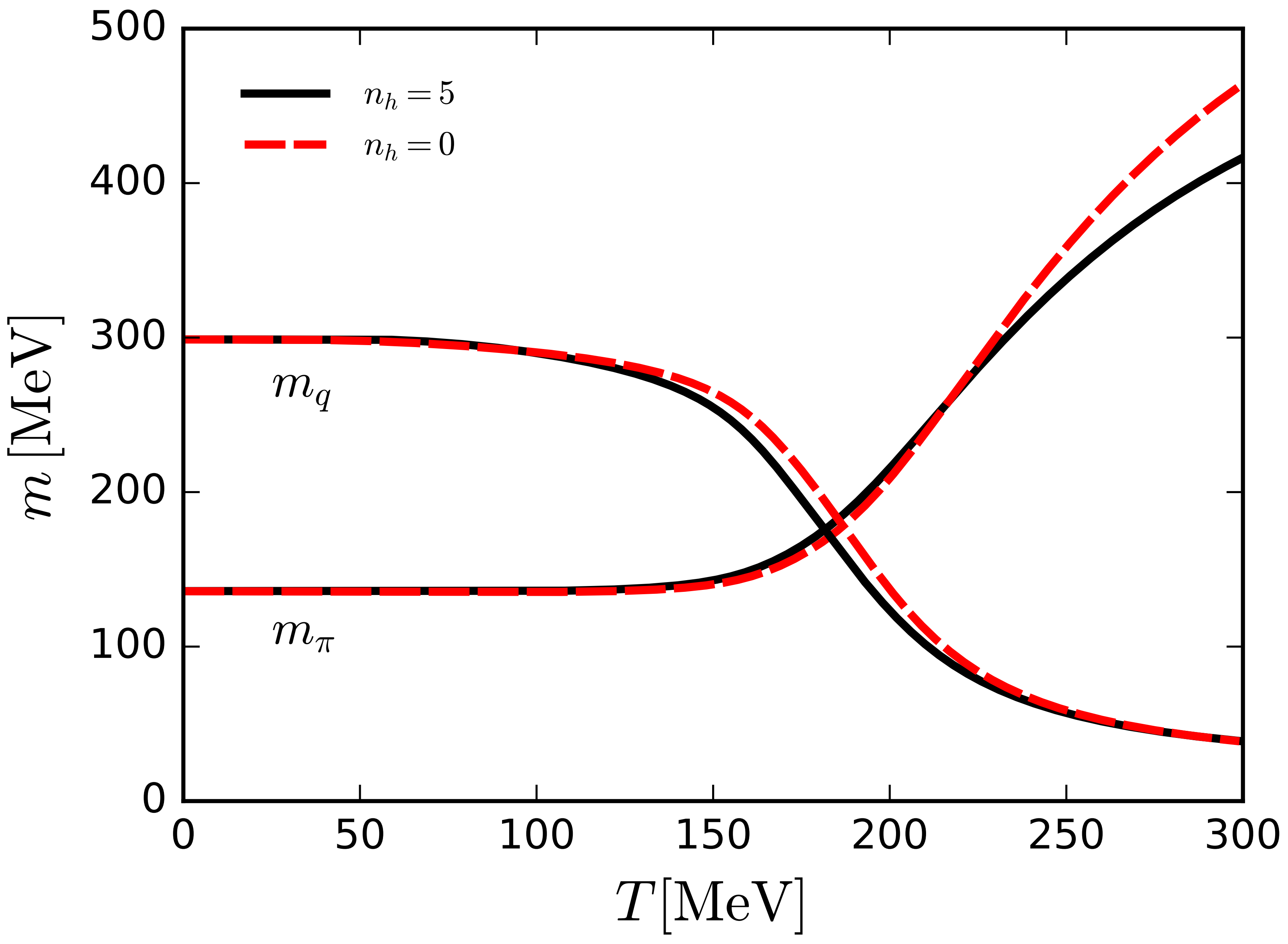
Effective potential and Yukawa coupling

The fix point and physical point for effective potential:



Effective potential and Yukawa coupling

The n=0 for Yukawa coupling and n=5 for Yukawa coupling:



Summary

★ The meson wave function renormalization has a little affect on the low order thermodynamic quantities and will little suppress the higher order fluctuations at high chemical potential.

★ The physical point expansion of the effective potential will accelerate the de-couple of the meson mass as the function of temperature. The expansion of the Yukawa coupling will slow down the de-couple of the meson mass as the function of temperature

Thanks for your attention