



第十八届全国中高能核物理大会

# Fluctuations and correlations of conserved charges in the 2 + 1 flavor low energy effective model

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Based on: R.W. , Hunag Chuang, Wei-jie Fu, Phys. Rev. D **99**, 094019  
R.W. , Wei-jie Fu, in preparation



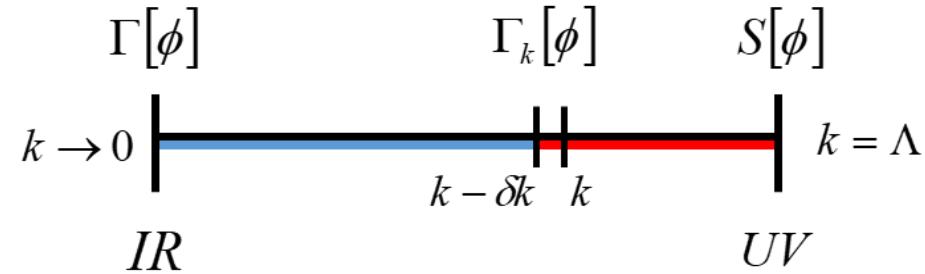
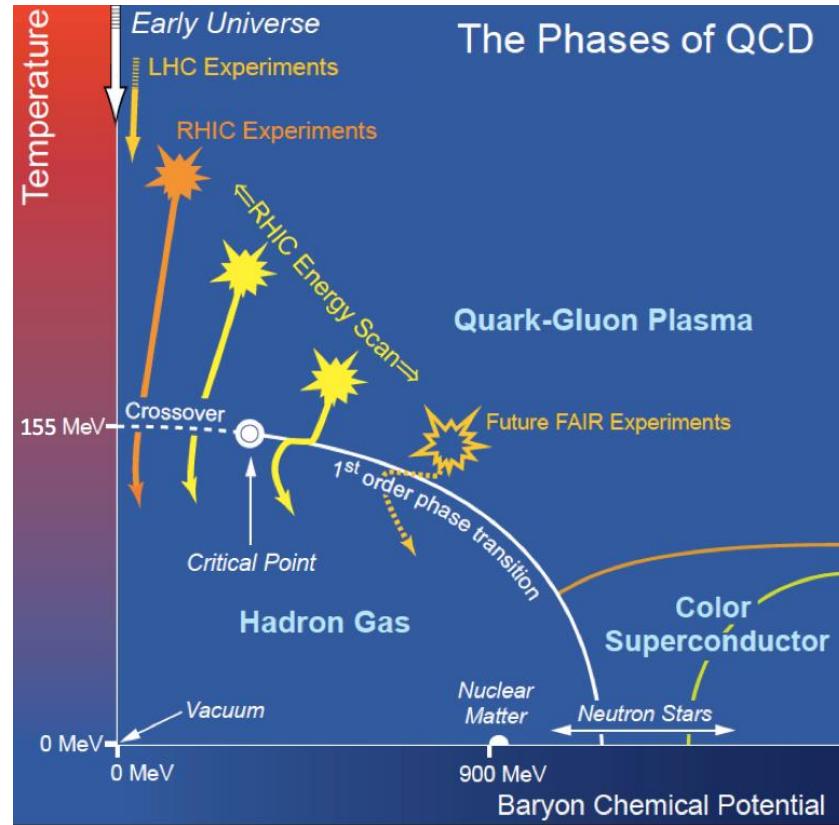
# Outline

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- Introduction
- Effective action and flow equation
- Result
- Summary and outlook



# Introduction



The Wetterich equation:  $\partial_t \Gamma_k[\phi] = \frac{1}{2} \text{Tr } G_k \partial_t R_k$

$$\partial_t \Gamma_k[\Phi] = \frac{1}{2} \quad - \quad - \quad + \frac{1}{2}$$

The Hot QCD White Paper (2015)



# The 2 + 1 flavor PQM scale-dependant effective action

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$$\Gamma_k[\Phi] = \int_x \left\{ \bar{q} [\gamma_\mu \partial_\mu - \gamma_0 (\hat{\mu} + igA_0)] q + h \bar{q} \Sigma_5 q + \text{tr}(\bar{D}_\mu \Sigma \cdot \bar{D}_\mu \Sigma^\dagger) + \tilde{U}_k(\Sigma) + V_{glue}(L, \bar{L}) \right\}$$

local potential approximation (LPA):  $\partial_t Z_{\phi/q} = 0, \partial_t h_{l/s} = 0$

The quark chemical potential:  $\hat{\mu} = \text{diag}(\mu_u, \mu_d, \mu_s)$

$$\mu_u = \mu_B/3 + 2\mu_Q/3$$

$$\mu_d = \mu_B/3 - \mu_Q/3$$

$$\mu_s = \mu_B/3 - \mu_Q/3 - \mu_S$$



## The $2 + 1$ flavor PQM scale-dependant effective action

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$\Sigma$  means the meson field:  $\Sigma = T^a (\sigma^a + i\pi^a)$        $\Sigma_5 = T^a (\sigma^a + i\gamma_5 \pi^a)$

The covariant derivative of meson fields:  $\bar{D}_\mu \Sigma = \partial_\mu + \delta_{\mu 0} [\hat{\mu}, \Sigma]$ .

The meson effective potential:

$$\tilde{U}_k(\Sigma) = U_k(\rho_1, \tilde{\rho}_2) - c_A \xi - j_L \sigma_L - j_S \sigma_S, \quad \xi = \det(\Sigma) + \det(\Sigma^\dagger),$$



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The Polyakov loops:  $L(x) = \frac{1}{N_c} \langle \text{Tr } \mathcal{P}(x) \rangle, \quad \bar{L}(x) = \frac{1}{N_c} \langle \text{Tr } \mathcal{P}^\dagger(x) \rangle,$

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

Glue potential

$$\begin{aligned} \frac{V_{glue}}{T^4} = & -\frac{1}{2} a(t) \bar{L} L + \frac{c(t)}{2} \left( L^3 + \bar{L}^3 \right) + d(t) (\bar{L} L)^2 \\ & + b(t) \ln \left( 1 - 6 \bar{L} L + 4 \left( L^3 + \bar{L}^3 \right) - 3 (\bar{L} L) \right) \end{aligned}$$



# Flow equation

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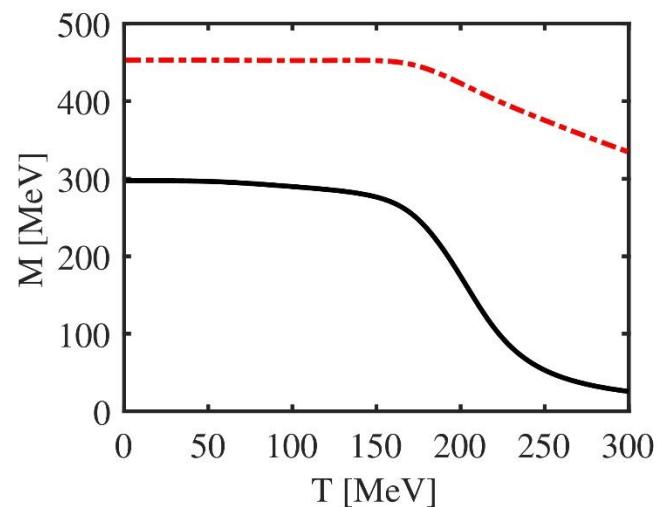
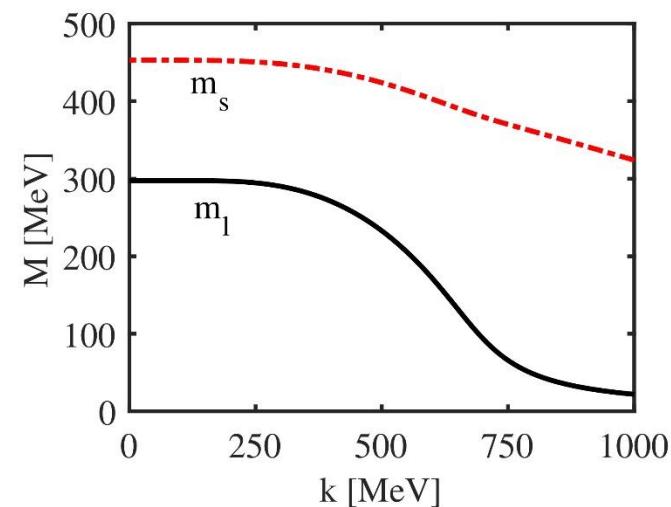
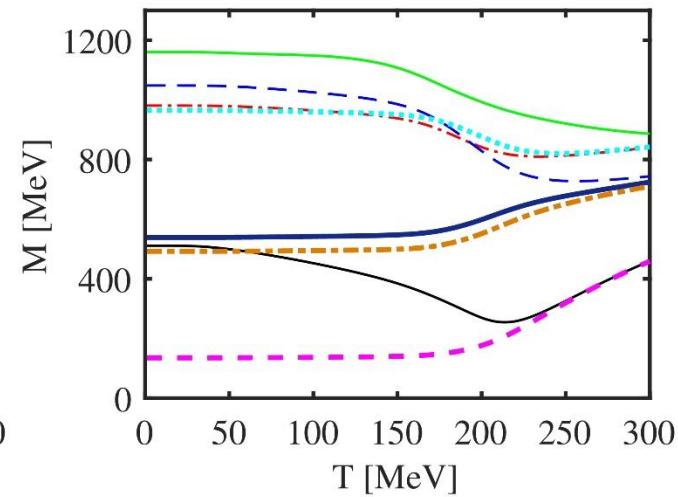
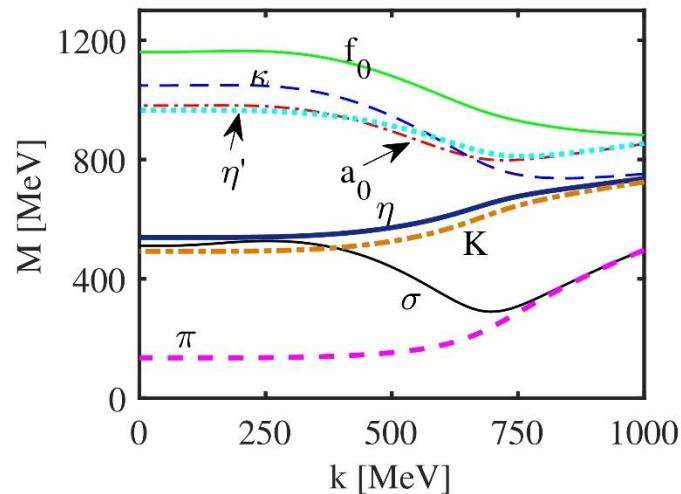
$$\begin{aligned}
 \partial_t U_k(\rho_1, \tilde{\rho}_2) = & \frac{k^4}{4\pi^2} \left\{ l_0^{(B)}(\bar{m}_{\pi,k}^2; T, 0) + 2 l_0^{(B)}(\bar{m}_{\pi,k}^2; T, \mu_u - \mu_d) \right. \\
 & + 2 l_0^{(B)}(\bar{m}_{K,k}^2; T, \mu_u - \mu_s) + 2 l_0^{(B)}(\bar{m}_{K,k}^2; T, \mu_d - \mu_s) \\
 & + l_0^{(B)}(\bar{m}_{\eta,k}^2; T, 0) + l_0^{(B)}(\bar{m}_{\eta',k}^2; T, 0) \\
 & + l_0^{(B)}(\bar{m}_{a_0,k}^2; T, 0) + 2 l_0^{(B)}(\bar{m}_{a_0,k}^2; T, \mu_u - \mu_d) \\
 & + 2 l_0^{(B)}(\bar{m}_{\kappa,k}^2; T, \mu_u - \mu_s) + 2 l_0^{(B)}(\bar{m}_{\kappa,k}^2; T, \mu_d - \mu_s) \\
 & + l_0^{(B)}(\bar{m}_{f_0,k}^2; T, 0) + l_0^{(B)}(\bar{m}_{\sigma,k}^2; T, 0) \\
 & - 4N_c \left[ l_0^{(F)}(\bar{m}_{l,k}^2; T, \mu_u) + l_0^{(F)}(\bar{m}_{l,k}^2; T, \mu_d) \right. \\
 & \left. \left. + l_0^{(F)}(\bar{m}_{s,k}^2; T, \mu_s) \right] \right\}
 \end{aligned}$$

$$l_0^{(B)}(m^2; T, \mu) = \frac{1}{3\sqrt{1+m^2}} \left( 1 + n_B(m^2; T, \mu) + n_B(m^2; T, -\mu) \right)$$

$$l_0^{(F)}(m^2; T, \mu) = \frac{1}{3\sqrt{1+m^2}} \left( 1 - n_F(m^2; T, \mu, L, \bar{L}) - n_F(m^2; T, -\mu, \bar{L}, L) \right)$$



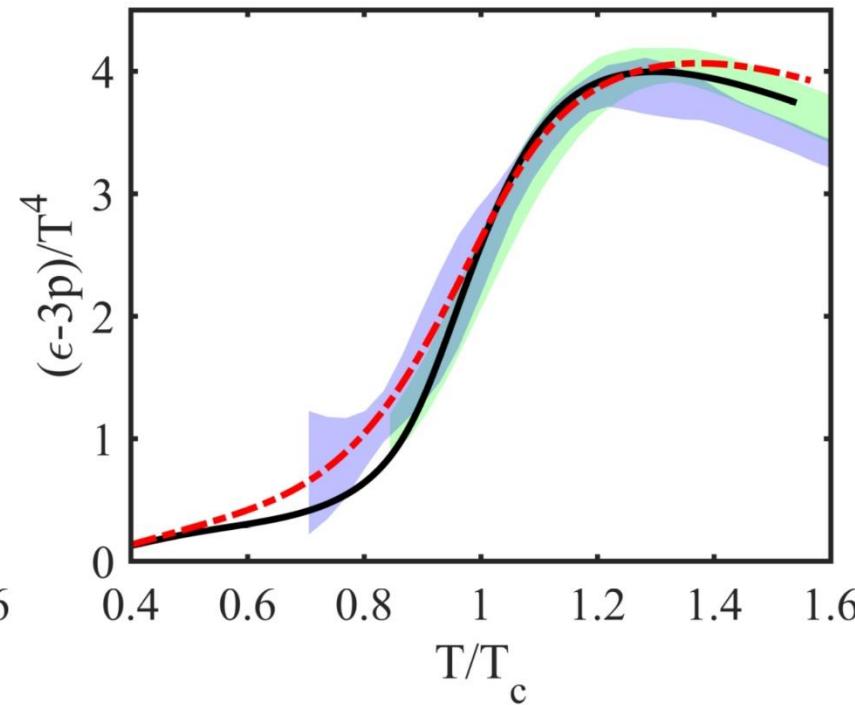
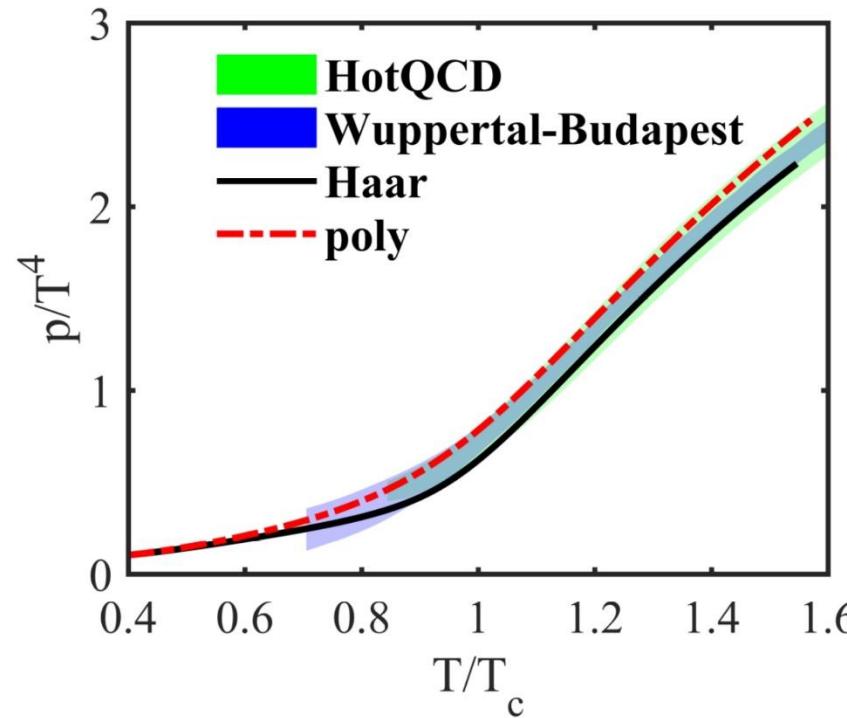
# The meson and quark masses





# The pressure and the trace anomaly

$$\Delta = \epsilon - 3p$$



$T_c=194$ [MeV]

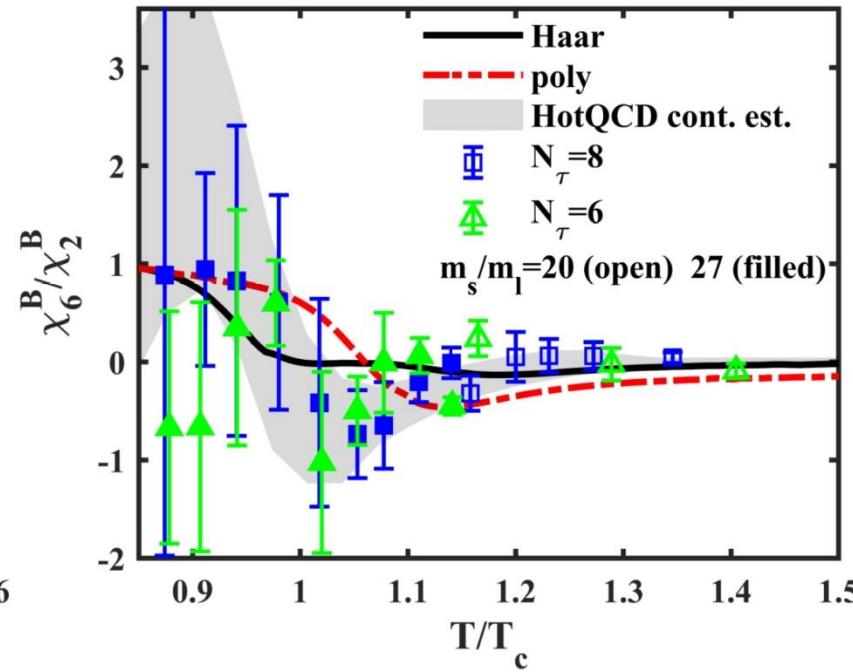
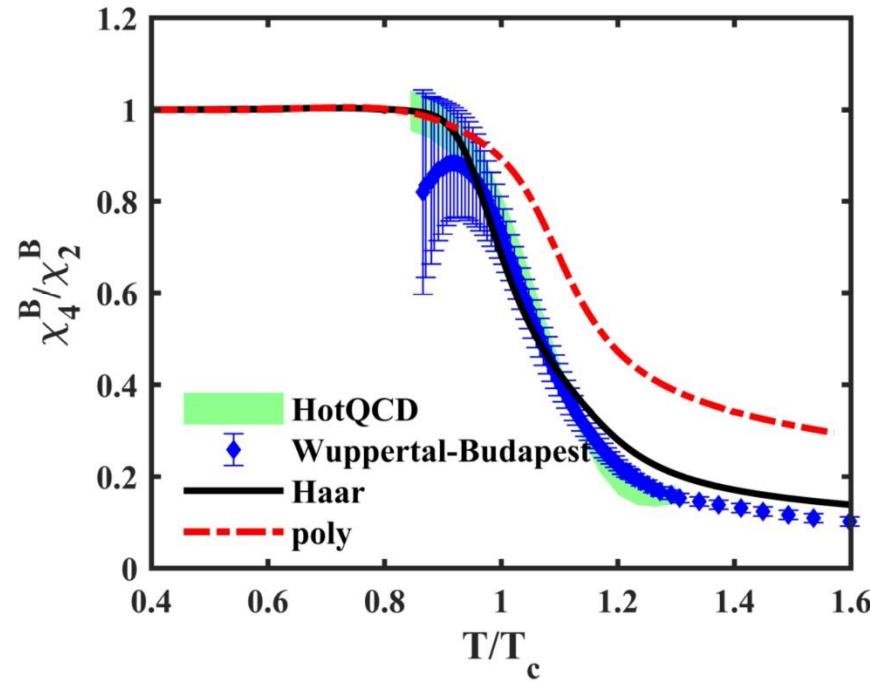
HotQCD [arXiv:1407.6387]  $T_c=154$ [MeV]

Wuppertal-Budapest [arXiv:1309.5258]  $T_c=156$ [MeV]



# Baryon number fluctuations

$$\chi_n^B = \frac{\partial^n}{\partial(\mu_B/T)^n} \frac{P}{T^4}, n \in \mathbb{Z}$$



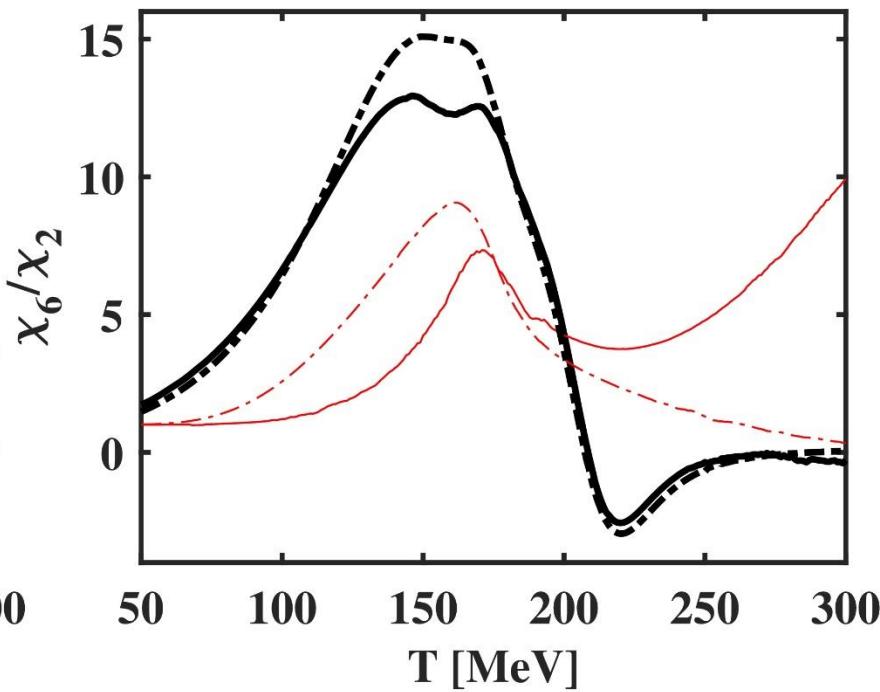
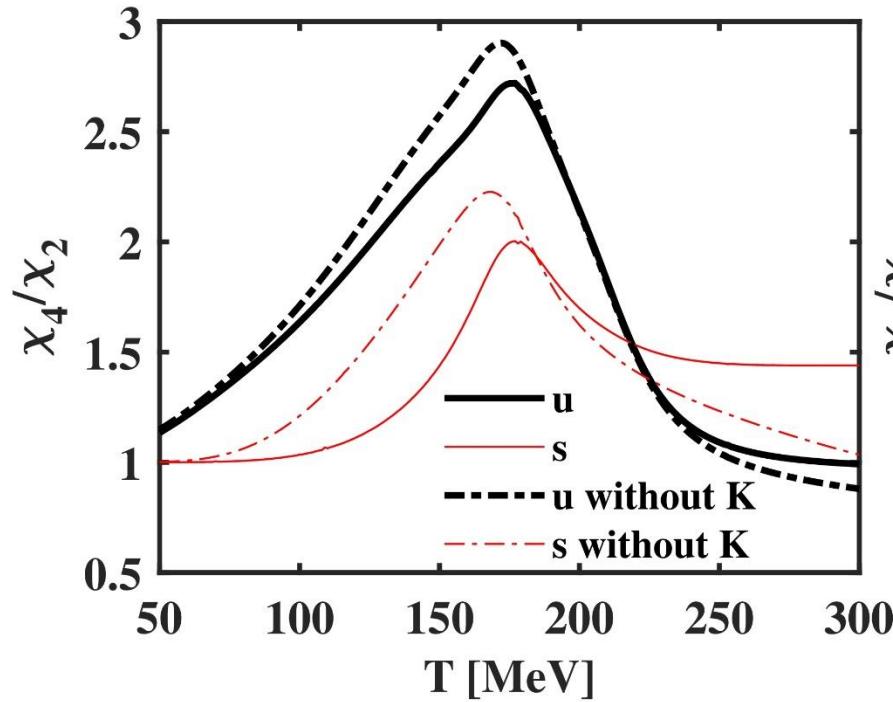
HotQCD [arXiv:1708.04897]

Wuppertal-Budapest[arXiv:1305.5161]



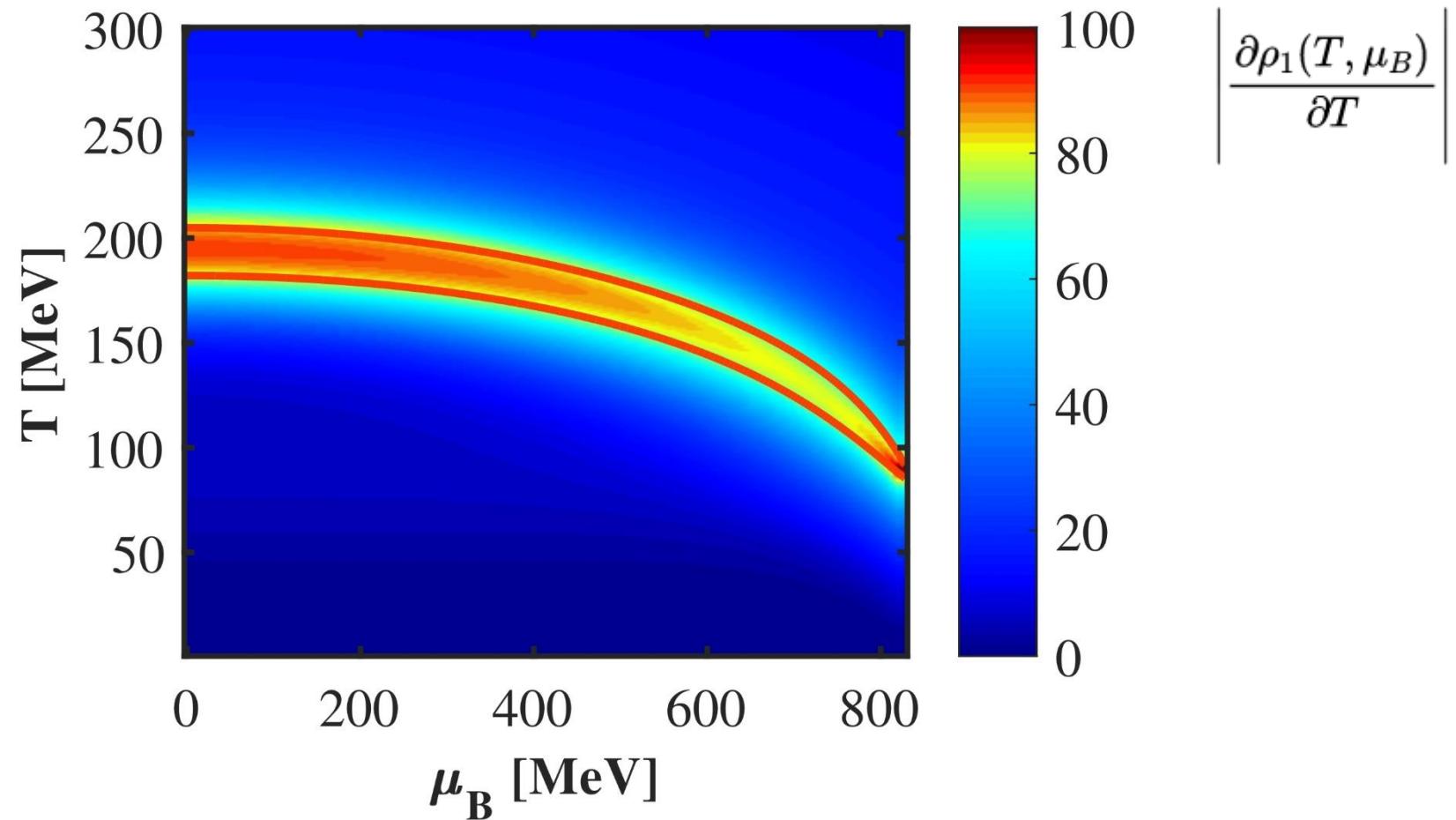
# The quarks fluctuations

$$\chi_n = \frac{\partial^n}{\partial(\mu/T)^n} \frac{P}{T^4}, n \in \mathbb{Z}$$





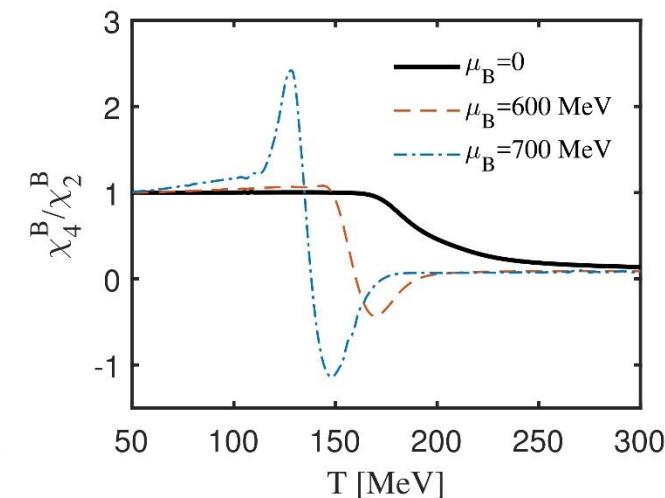
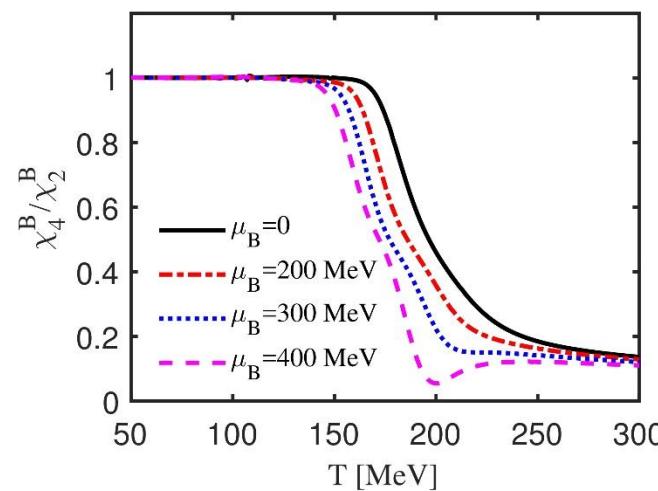
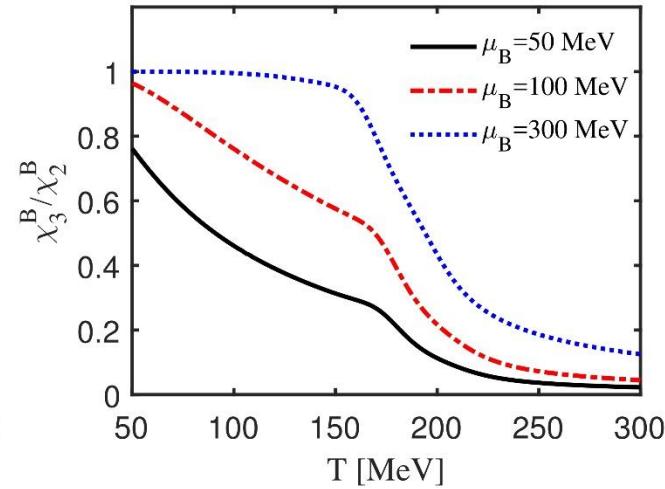
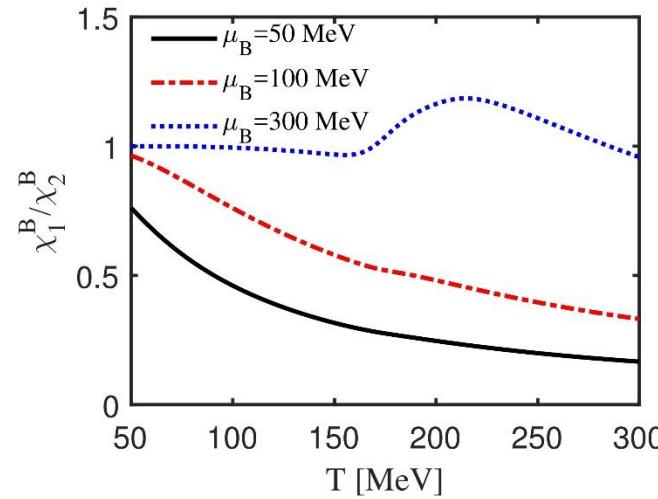
# Phase diagram



$$T_{CEP} = 84[MeV], \mu_{B_{CEP}} = 840[MeV]$$



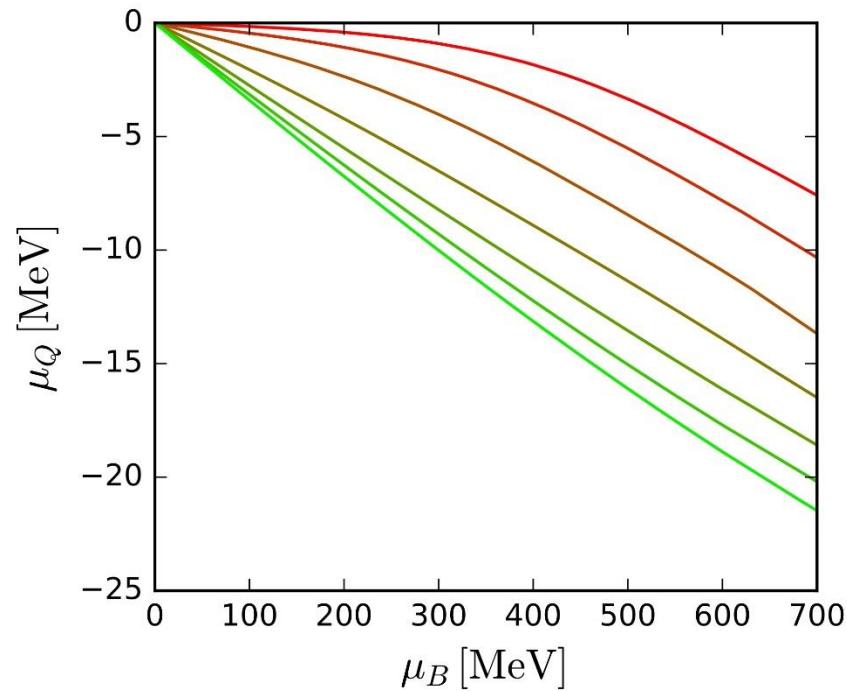
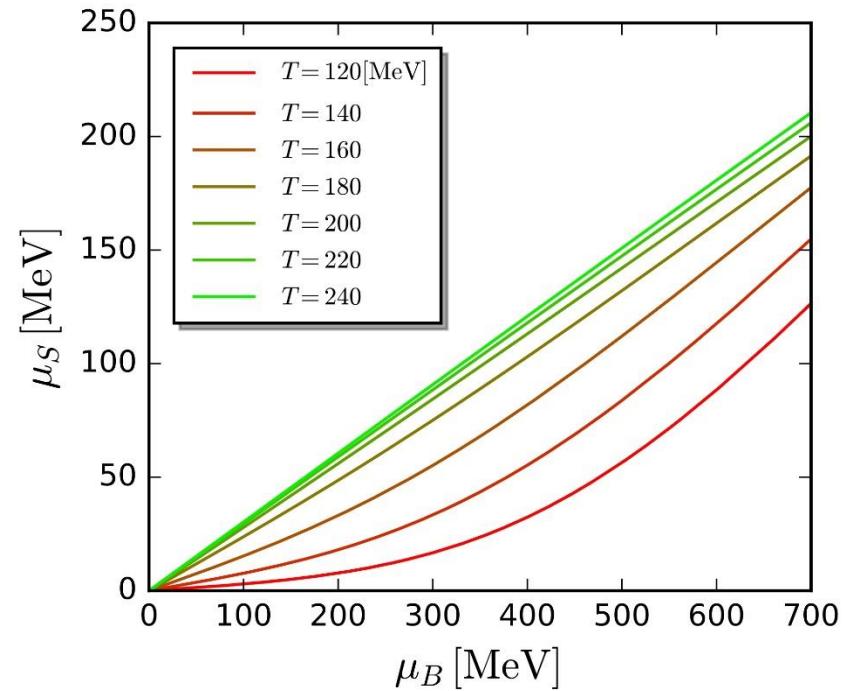
# Ratios of baryon number fluctuations





# Strange neutrality and fixed electric-baryon ratio

$$n_S = 0 \quad n_Q/n_B = 0.4$$

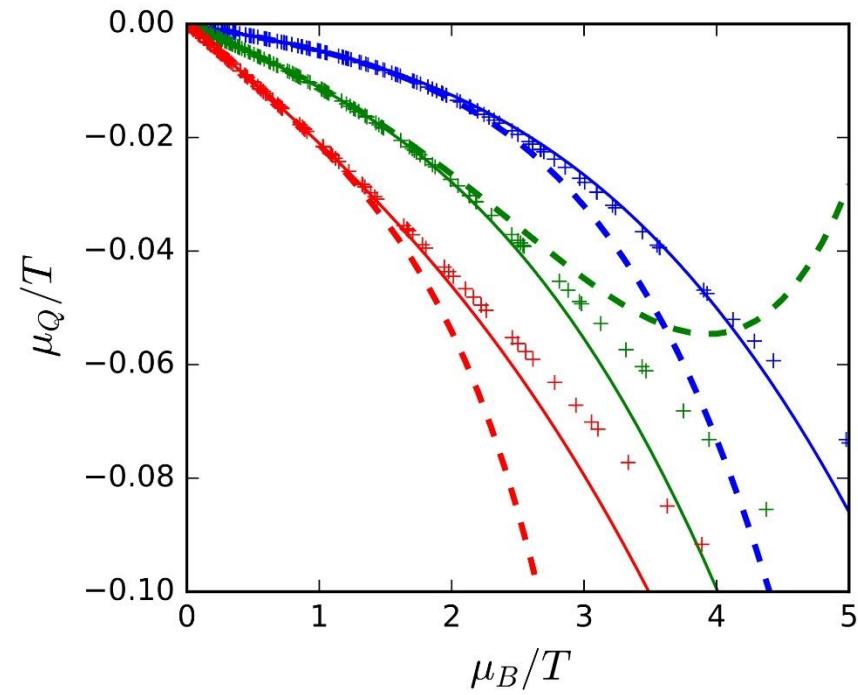
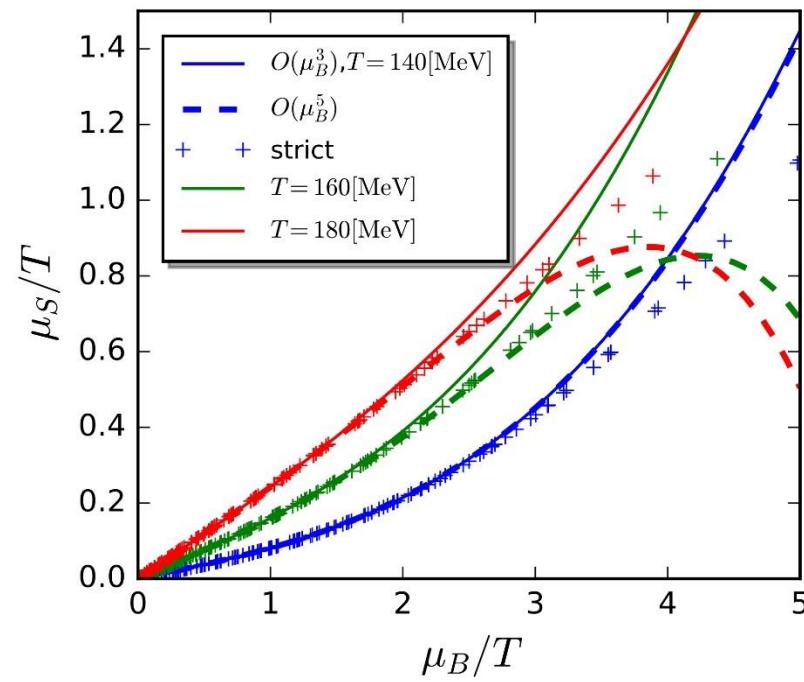




# Convergence radius

$$\hat{\mu}_Q = q_1 \hat{\mu}_B + q_3 \hat{\mu}_B^3 + q_5 \hat{\mu}_B^5 + \dots$$

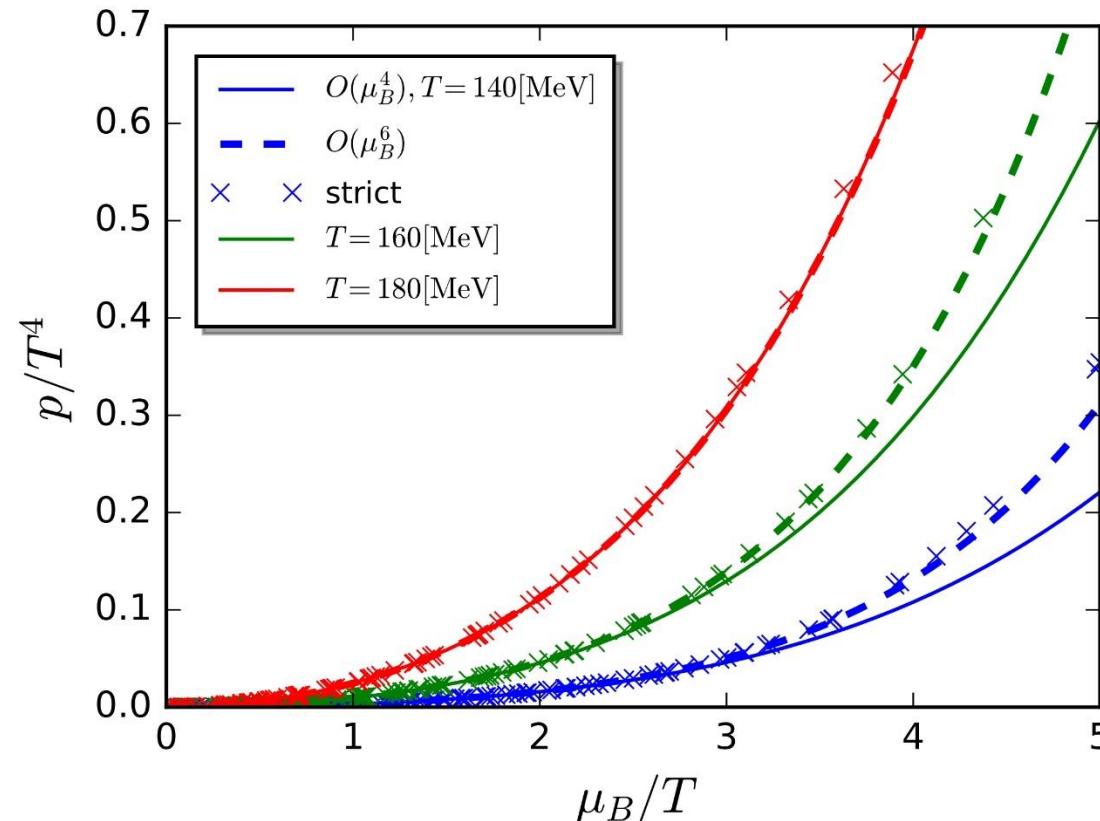
$$\hat{\mu}_S = s_1 \hat{\mu}_B + s_3 \hat{\mu}_B^3 + s_5 \hat{\mu}_B^5 + \dots$$





# Convergence radius

$$\frac{P(T, \mu_B)}{T^4} = \sum_{k=0}^{\infty} \frac{d^{2k}}{(2k)! d\hat{\mu}_B^{2k}} \left( \frac{P}{T^4} \right) \Big|_{\hat{\mu}=0} \cdot \hat{\mu}_B^{2k}$$





## Summary and Outlook

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- The equation of state and baryon number fluctuations up to 6th order agree with the lattice results.
- Strange neutrality and fixed electric-baryon ratio  $r=0.4$  conditions are considered.
  
- Going beyond the LPA truncation and extending the low energy effective theory to the 2+1 flavor rebosonized QCD

Thank you