Conserved charge fluctuations at vanishing net-baryon density from Lattice QCD

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Introduction

- Cumulants of net charge fluctuations and their correlations at vanishing values of the charge chemical potentials ($\mu_{B,Q,S} = 0$) provide the basis for Taylor expansions of various thermodynamic observables at non-zero values of the chemical potentials. At $\mu_{B,Q,S} = 0$ continuum extrapolated results for these cumulants can directly be compared with charge fluctuations and correlations currently being measured by the ALICE collaboration and by the STAR collaboration at highest beam energy $\sqrt{s}$.
- Moreover looking at the behaviour of the expansion coefficients one can constrain the location of the QCD critical point.

Second order cumulants

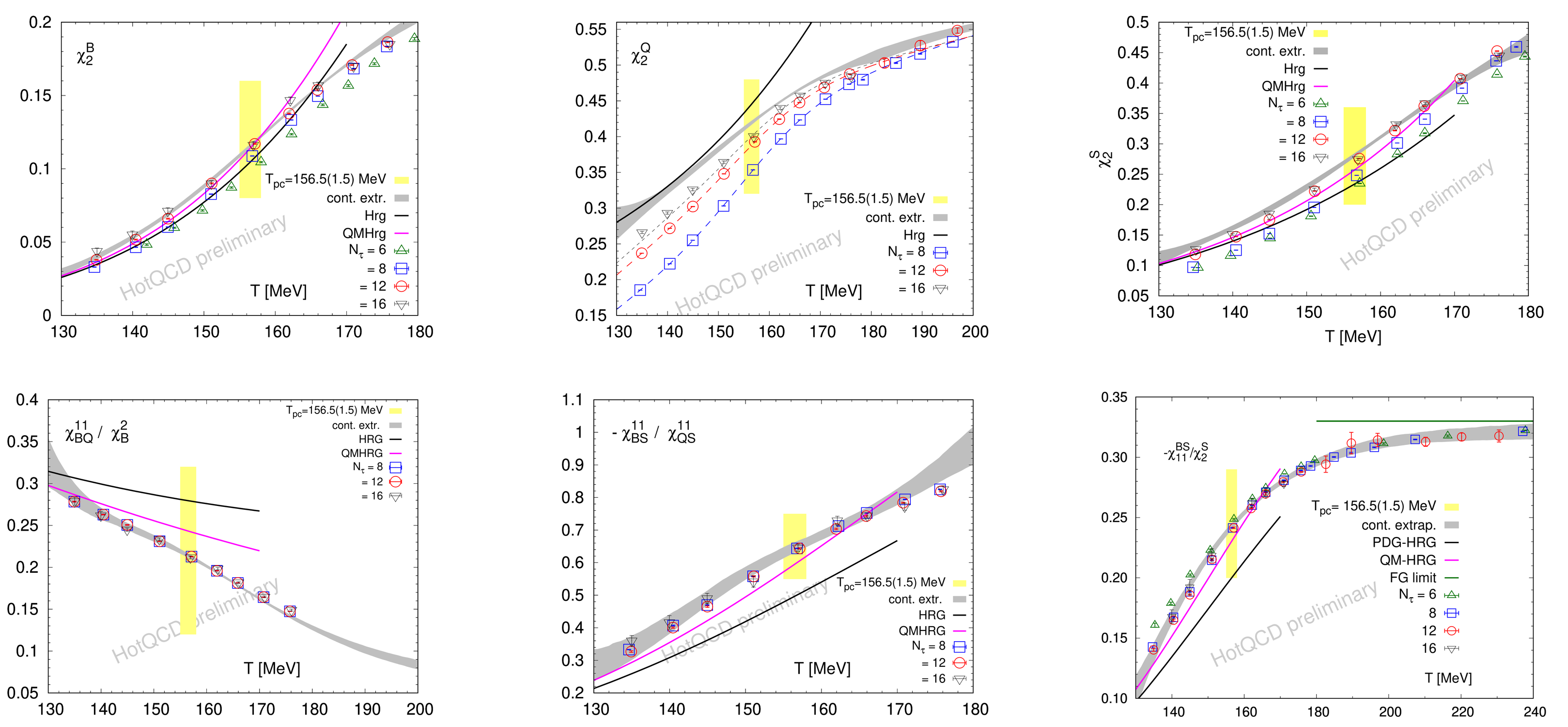


Figure 1: Continuum extrapolated results for 2^{nd} order cumulants in (2+1)-flavor QCD

Fluctuations and correlations involving strangeness deviate significantly from non-interacting HRG model results at low temperatures. Inclusion of strange hadrons predicted by Quark Model calculations give better agreement. The 2^{nd} order cumulants are related by following constraint equations,

$$\chi_2^S = 2\chi_{11}^{QS} - \chi_{11}^{BS}$$
$$\chi_2^B = 2\chi_{11}^{BQ} - \chi_{11}^{BS}$$

Ratios of cumulants eliminate volume factors and thus are comparable with experimental data,
ALICE freeze-out, T_{fo}[1] == QCD crossover, T_{pc} == $156.5(1.5)$ MeV.[2]

If, $T_{fo} = 156.5$ MeV	If, $T_{fo} = 165$ MeV,
$\chi_{11}^{BQ}/\chi_2^B = 0.214(3)$	$\chi_{11}^{BQ}/\chi_2^B = 0.182(3)$
$-\chi_{11}^{BS}/\chi_2^S = 0.239(6)$	$-\chi_{11}^{BS}/\chi_2^S = 0.27(6)$
$-\chi_{11}^{BS}/\chi_{11}^{QS} = 0.646(5)$	$-\chi_{11}^{BS}/\chi_{11}^{QS} = 0.739(5)$

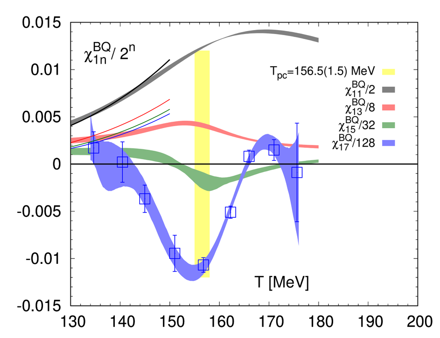
For example due to the Constraints for 2^{nd} order cumulants, HRG motivated analysis and from ALICE data at freeze-out,[3]

$$-\chi_{11}^{BS}/\chi_2^S = 1 - 2\chi_{11}^{QS}/\chi_2^S$$
$$-\chi_{11}^{BS}/\chi_2^S > 0.193 \pm 0.0127$$

Conclusions

- 2^{nd} order cumulant ratios involving strangeness show significant deviations from non-interacting HRG model calculations. This should be testable at LHC. 4^{th} order cumulants generally deviate strongly from HRG model calcualtions at the frezze-out (pseudo-critical) temperature.
- Many higher order cumulants, turn negative at T=140MeV or lower, suggesting that a critical point will only be found at lower temperatures (and thus large values of μ_B> 400MeV).

Radius of Convergence



A toy example,

$$F(T,\hat{\mu}) = c_1\hat{\mu} + c_3\hat{\mu}^3 + c_5\hat{\mu}^5 + c_7\hat{\mu}^7$$

All the expansion coefficients are only positive at $T \leq 140$ MeV.

$T \sim 150$ MeV, $c_1 = 0.042, c_3 = 0.045, c_5 = 0.0029, c_7 = -0.029$

Pade-approximant, P[5,6]=$\frac{0.042x+0.083x^3+0.046x^5}{1.+0.90x^2+0.057x^4+0.58x^6}$

$$\{-0.95-0.74i, -0.95+0.74i, -0.90i, +0.90i, 0.95-0.74i, 0.95+0.74i\}$$

Singularities in the complex plane $\Longrightarrow$ No phase transition.
However, nearest singularity gives the radius of convergence.
The CEP can be determined when all the expansion coefficient are of same sign.[Plausible scenario: $T_{pc} \simeq 130-140$ MeV, $\mu_B \geq 400$ MeV].[4]

Fourth order cumulants

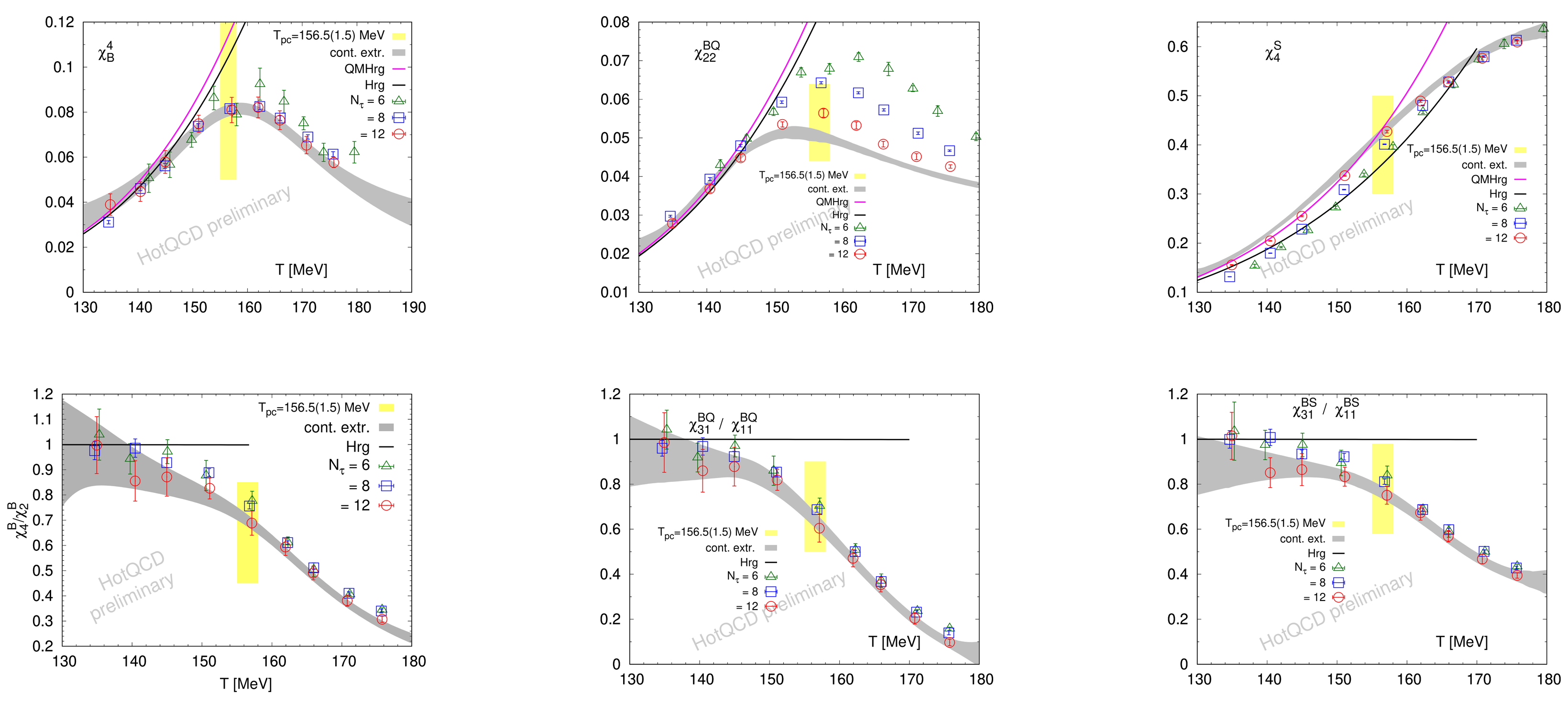


Figure 2: Continuum extrapolated results for 4^{th} order cumulants in (2+1)-flavor QCD

4^{th} order cumulants deviate significantly from HRG results at the freeze-out (pseudo-critical) temperature. Ratios of 4^{th} order cumulants at $T_{pc} = 156.5(1.5)$ MeV,

$$\chi_4^B/\chi_2^B = 0.63(6)$$
$$\chi_{31}^{BQ}/\chi_{11}^{BQ} = 0.64(6)$$
$$\chi_{31}^{BS}/\chi_{11}^{BS} = 0.76(5)$$
$$\chi_{211}^{BQS}/\chi_{121}^{BQS} = 0.45(1)$$

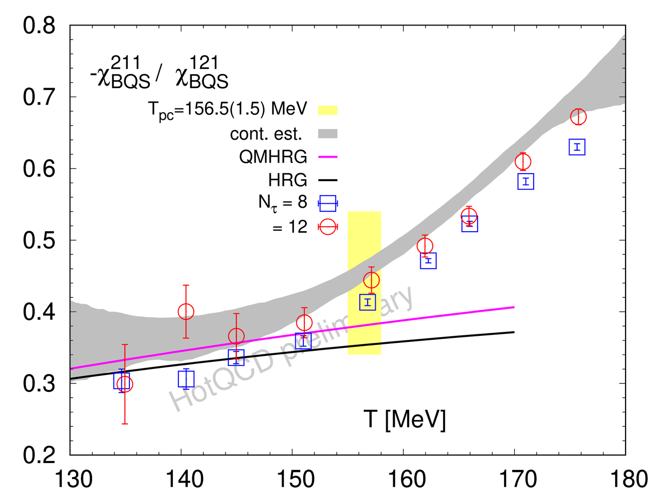


Figure 3: A 4^{th} order correlation for charged strange baryons.

References

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[4] F. Karsch, PoS CORFU **2018**, 163 (2019) [arXiv:1905.03936].

Acknowledgements

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