The Hadron Resonance Gas at the Boundary of the Hadronic World

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The Hadron Resonance Gas and the QCD Phase Diagram

- established as a low temperature reference for lattice QCD and other theoretical approaches for bulk quantities as well as for susceptibilities
- used for the experimental determination of chemical freeze-out parameters in heavy-ion collisions [1,2]
- however: role of interactions between involved hadrons not settled

Interactions in Hadron Resonance Gases

Usual treatment: non-interacting gas of hadrons and resonances justified by phase shift analyses based on [3,4,5]

Not appropriate near the phase transition to the quark-gluon plasma [6]:
- approximation of dilute system definitely not justified (see Fig. 2)
- not all resonance states treated properly
- known short-range repulsion between baryons not accounted for

Instead: thermodynamically consistent excluded volume correction physically more appropriate (proposed in [7])

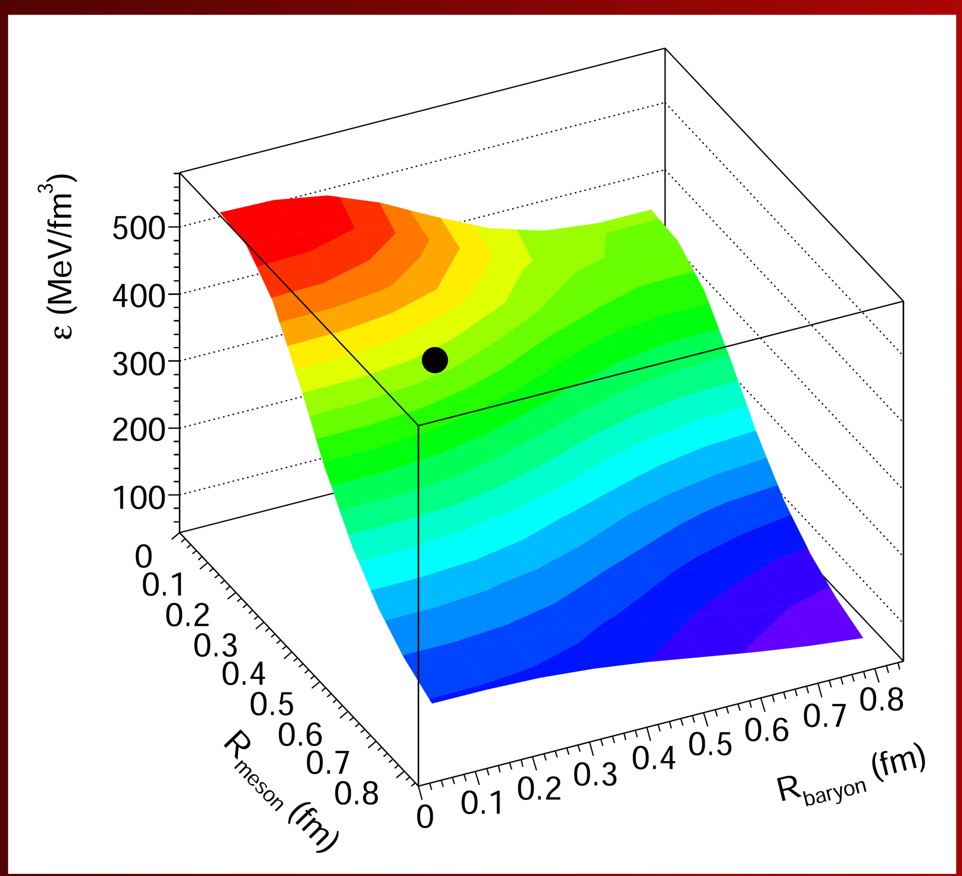

Figure 1

Fig. 1: energy density as a function of the radii used for the excluded volume of the mesons and baryons and for T=164 MeV and μ_b =0.8 MeV in our grand-canonical Hadron Resonance Gas (HRG) model [6]:
- strong dependence on the hadron volume, in particular on the meson excluded volume
- volume choice for further comparisons $R_{meson}=R_{baryon}=0.3$ fm motivated by the hard-core radius of 0.3 fm in nucleon-nucleon scattering (indicated as black point in Fig. 1)

Fig. 2: hadron density for several eigenvolume choices

Additionally shown in Figs. 2, 3 and 4: modelling of the influence of annihilations on a statistical basis by applying a correction factor on the (anti)baryon volume as a function of the baryon and antibaryon density:

$$k_{anni}=1-\frac{2\,n_{baryons}\,n_{antibaryons}}{(n_{baryons}+n_{antibaryons})^2}$$

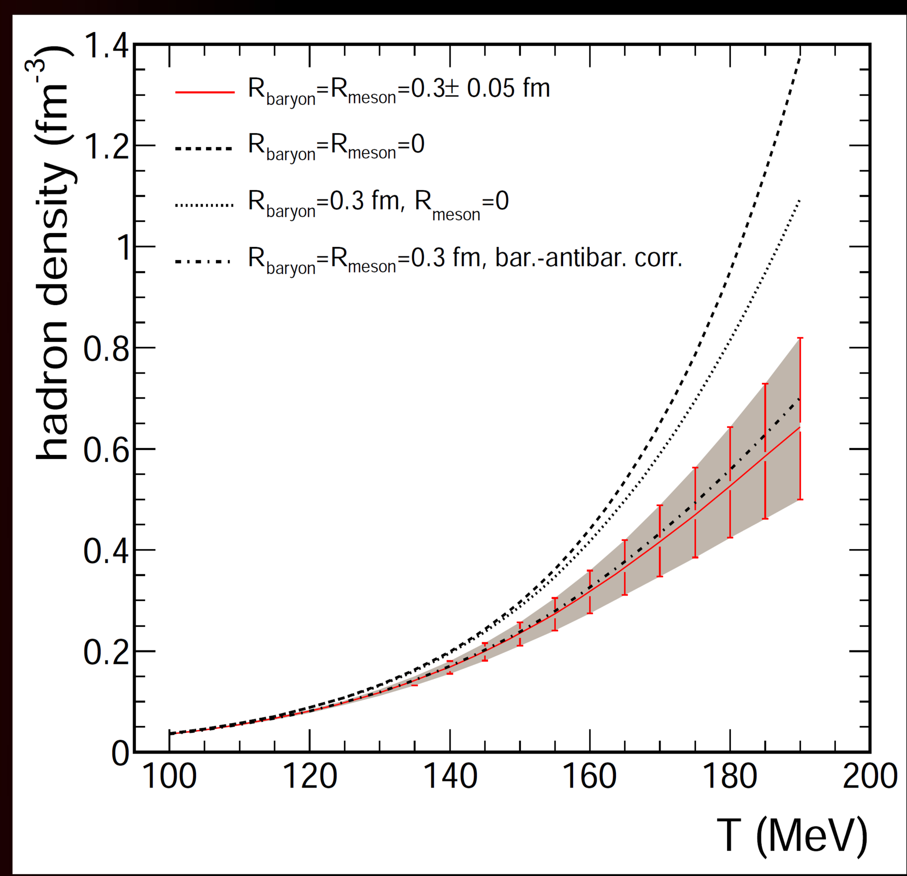

Figure 2

Comparison with Lattice QCD

Comparisons for energy density, entropy density, pressure (Fig. 3) and the trace anomaly (Fig. 4) between our HRG model and most recent LQCD data [8,9] at vanishing baryochemical potential:

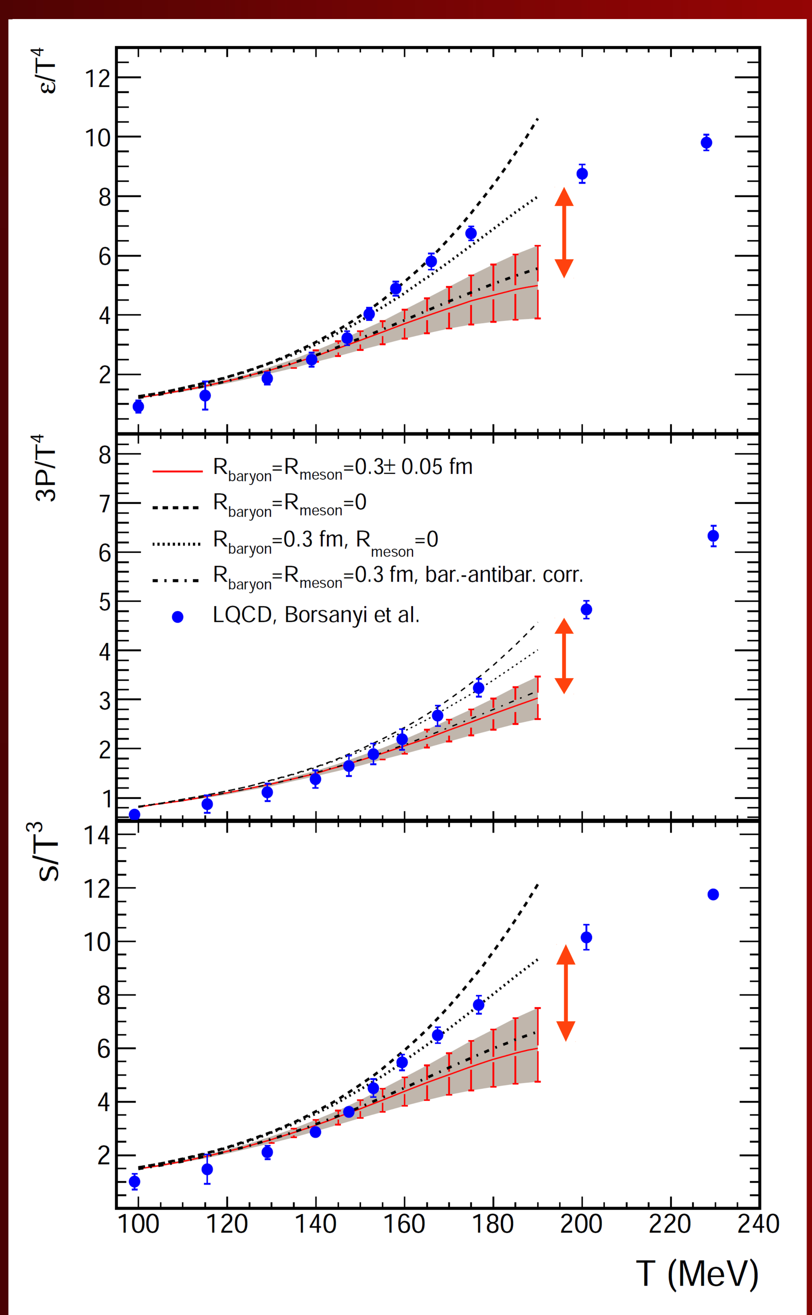

Figure 3

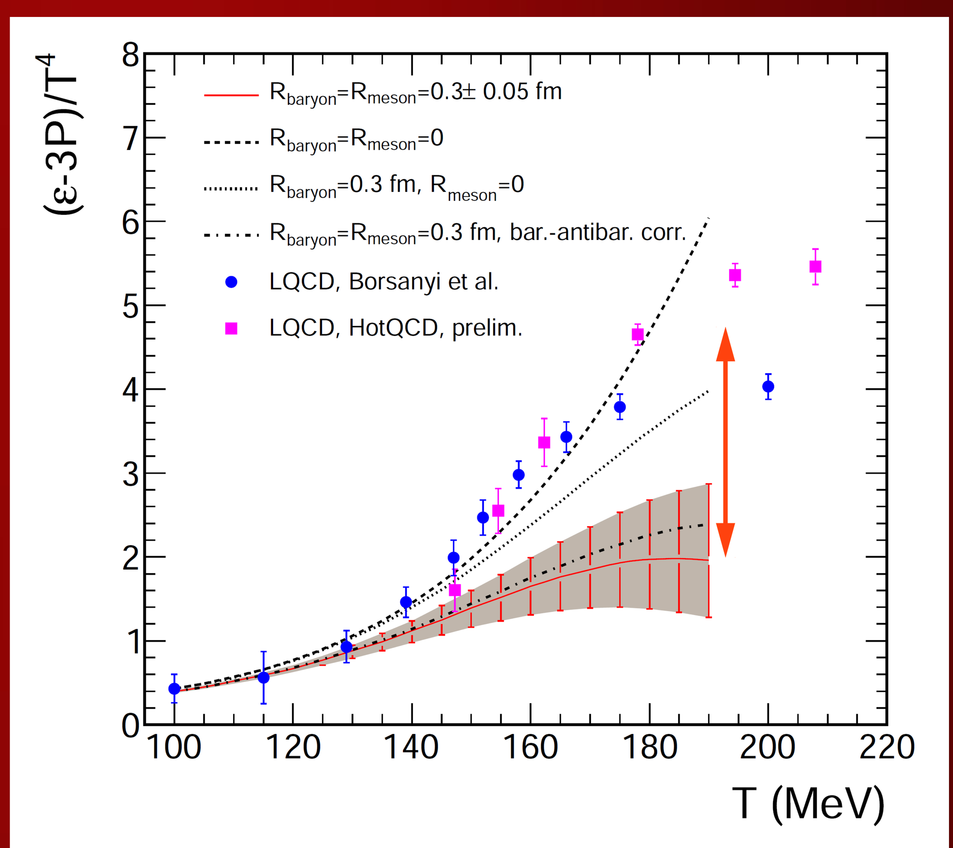

Figure 4

Strong rise of thermodynamic quantities in LQCD at cross-over:
- due to onset of deconfinement
- **should not be present** in a purely hadronic description

Conclusion

- steep increase of thermodynamic observables above T≈140 MeV in the non-interacting HRG is the residue of the Hagedorn divergence [10]
- the excluded volume model tames this behavior and provides a more realistic picture of a pure HRG without phase transition
- deviation between lattice QCD and the interacting HRG for T>150 MeV is due to the increase of the degrees of freedom associated with a quark-gluon plasma phase

References:

[1] P. Braun-Munzinger, J. Stachel, J.P. Wessels, N. Xu, Phys. Lett. B 344(1995) 43.
[2] A. Andronic, P. Braun-Munzinger, J. Stachel, Phys. Lett. B 673 (2009) 142; Erratum, Phys. Lett. B 678 (2009) 516.
[3] E. Beth, G.E. Uhlenbeck, Physica 4 (1937) 915.
[4] R. Dashen, S.-K. Ma, H.J. Bernstein, Phys. Rev. 187 (1969) 345.
[5] R. Dashen, S.-K. Ma, Phys. Rev. A 4 (1971) 700.
[6] A. Andronic, P. Braun-Munzinger, J. Stachel, M. Winn [arXiv:1201.0693].
[7] D.H. Rischke, M.I. Gorenstein, H. Stöcker, W. Greiner, Z. Phys. C 51 (1991) 485.
[8] S. Borsányi et al., JHEP 1011 (2010) 077.
[9] A. Bazavov, P. Petreczky (for the HotQCD collaboration), PoS LATTICE2010 169; W. Soldner (for the HotQCD collaboration), PoS LATTICE2010 215.
[10] R. Hagedorn, CERN-TH-4100/85 (1985).

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