Importance of the thermodynamic fluctuations in the Gaździcki Gorenstein model

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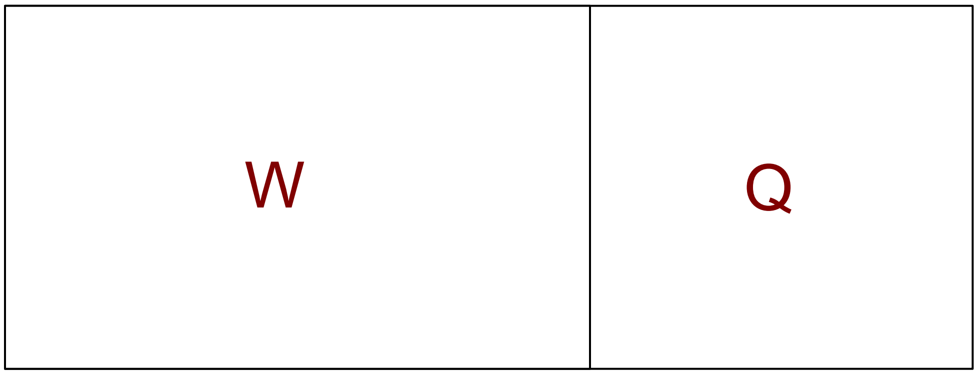
K. Zalewski, Acta Phys. Pol. B48, 1267 (2017).

M. Gaździcki and M. Gorenstein, Acta Phys. Pol. B30(1999)2705.

The W-phase and the Q-phase



$(1 - \lambda)V$ λV

$g_{Ws}/g_{Wns} = 1;$

$g_{Qs}/g_{Qns} = 0.3$

$0 \leq \lambda \leq 1.$

W-phase: each SU_3 octet gives $g_{Ws} = 4$; $g_{Wns} = 4$

Q-phase: $g_{Qs} = 2 \times 2 \times 3 = 12$; $g_{Qns} = 2 \times 12 + 2 \times 8 = 40$

The horn

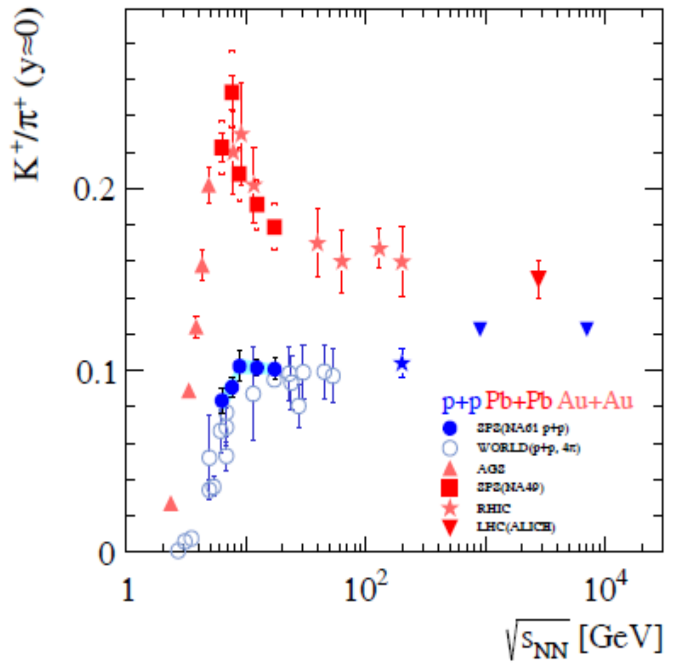


Figure 1: The *horn* structure in the energy dependence of the K^+/π^+ ratio is interpreted as evidence for the onset of deconfinement located at low CERN SPS energies. The structure was first discovered by NA49 in central Pb+Pb collisions. Surprisingly its shadow is visible in inelastic p+p interactions as indicated by the new NA61/SHINE data.

The Gaździcki Gorenstein model (simplified)

m = 0; Boltzmann statistics

$$\Omega(V, T, \mu, \lambda) = -g(\lambda)Tze^{-\beta\mu} + \lambda BV.$$

$$g(\lambda) = g_W + \lambda(g_Q - g_W); \qquad g_Q > g_W.$$

$$z = \frac{V}{2\pi^2}\int dp\, p^2 e^{-\beta p} = \frac{VT^3}{\pi^2}.$$

Evaluation of the parameter λ

$$S(\lambda) = 4g(\lambda)z.$$

$0 \leq \lambda \leq 1.$

$$\overline{\epsilon} = \frac{3T^4}{\pi^2 B} g(\lambda) + \lambda; \qquad \overline{\epsilon} = \frac{E}{BV}.$$

$$\left(\frac{\partial S(\lambda)}{\partial \lambda}\right)_{V,\overline{\epsilon}} = 0. \qquad \lambda = \frac{1}{4}(\overline{\epsilon} - 3\overline{g}); \qquad \overline{g} = \frac{g_W}{g_Q - g_W}.$$

$$g(\lambda) = \frac{1}{4}(g_Q - g_W)(\overline{\epsilon} + \overline{g}); \qquad \overline{\epsilon} - \lambda = \frac{3}{4}(\overline{\epsilon} + \overline{g}).$$

Implications for 0 ≤ λ ≤ 1

$$T = \left(\frac{\pi^2 B}{g_Q - g_w}\right)^{\frac{1}{4}}.$$

T = 200MeV implies B = 607MeV fm^{-3}.

$$p = \overline{g}B = 534 MeV fm^{-3}.$$

Further assumptions needed to relate the dimensionless Energy density with the collision Energy.

Dependence on the collision energy

$$E = A_p \eta (\sqrt{s_{NN}} - 2m); \qquad \eta = 0.67.$$

$$V = \frac{A_p}{\rho_0} \frac{2m}{\sqrt{s_{NN}}}; \qquad \rho_0 = 0.16 fm^{-3}.$$

$$6.33 GeV \leq \sqrt{s_{NN}} \leq 9.40 GeV.$$

$$\Delta \sqrt{s_{NN}} = 3.07 \text{GeV}.$$

Beyond the thermodynamic limit

a) Thermodynamic fluctuations

b) Exact strangeness conservation

R.V. Poberezhnyuk, M. Gaździcki and M.I. Gorenstein,
Acta Phys. Pol. B46(2015)1991.

Thermodynamic fluctuations

$$P(\lambda) \;=\; e^{S(\lambda)}.$$

with $$S(\lambda) \;=\; 4g(\lambda)z$$

instead of $$P(\lambda) \;=\; \delta\left(\lambda - \frac{1}{4}(\overline{\epsilon} + \overline{g})\right).$$

$S(\lambda) \;\sim\; A_p$ implies $\sqrt{\sigma^2(\lambda)} \;\sim\; A_p^{-\frac{1}{2}}.$

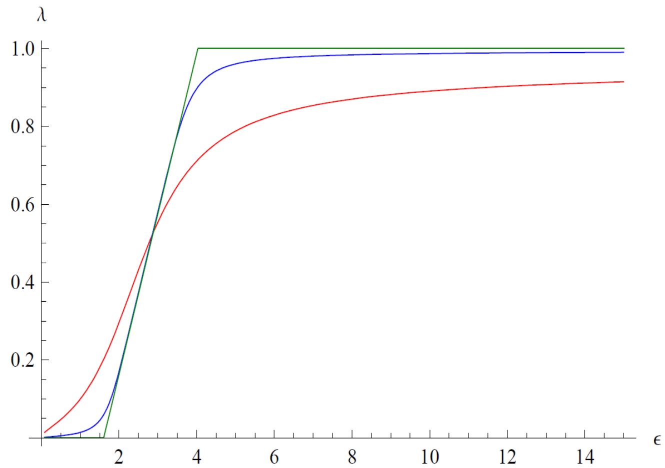


Figure 1: Dependence of the average volume fraction λ on the energy density $\epsilon = \frac{E}{V}$. For the meaning of the lines see text.

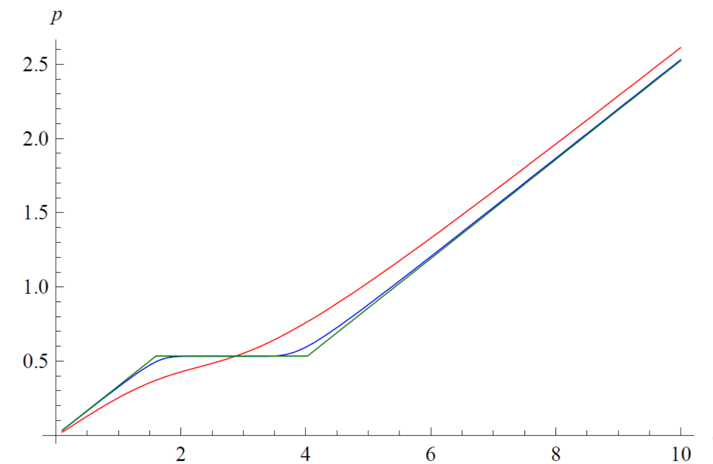


Figure 2: Dependence of the average pressure p on the energy density $\epsilon = \frac{E}{V}$. The meaning of the lines as in Fig. 1.

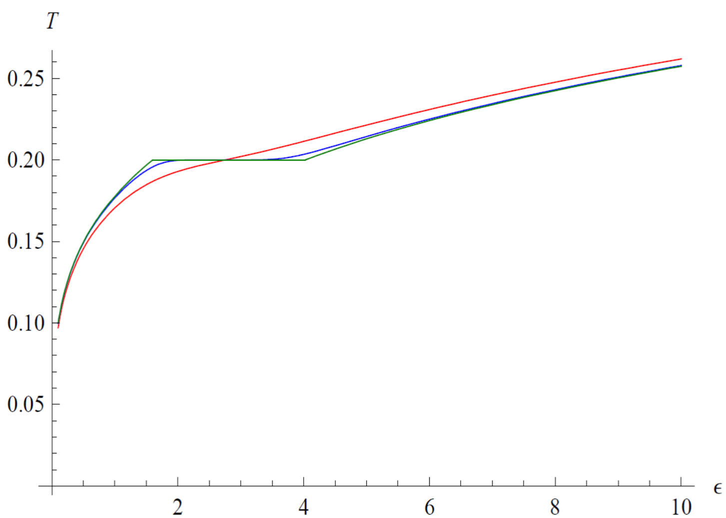


Figure 3: Dependence of the average temperature T on the energy density $\epsilon = \frac{E}{V}$. The meaning of the lines as in Fig. 1.

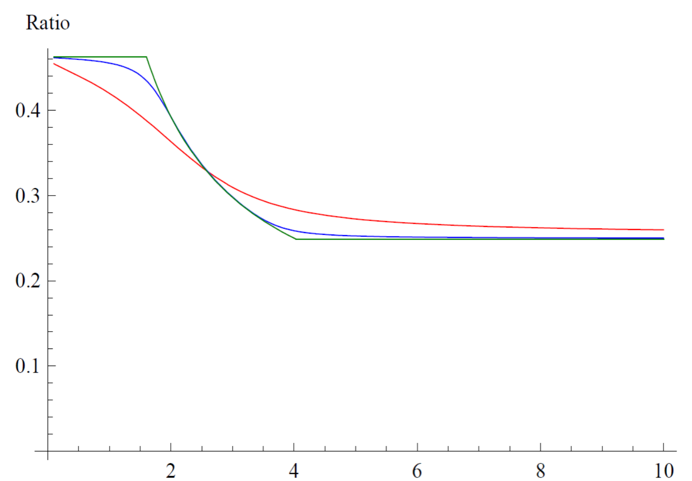


Figure 4: Dependence of the average ratio of the number of strange particles to the number of nonstrange particles on the energy density $\epsilon = \frac{E}{V}$. The meaning of the lines as in Fig. 1.

Exact strangeness conservation

R.V. Poberezhnyuk, M.Gaździcki and M. Gorenstein,
Acta Physica Polonica B46(2015)1991.

$$\Omega(V,T,\mu,\lambda) = -T g_{ns}(\lambda) z - T \log I_o(g_s(\lambda) z) + \lambda B V.$$

$$\lambda = \frac{1}{4}(\overline{\epsilon} - 3\overline{g}) - \frac{C}{A_p} \frac{\sqrt{s_{NN}}}{\overline{\epsilon} - 3\overline{g} - 4\overline{g}_s} + o(A_p^{-1}).$$

Δλ= [-.0.046, -0.051]; $\Delta\sqrt{s_{NN}}$ = [0.18GeV, 0.13GeV].

ΔT = [4MeV, 2MeV]; Δp = [37MeVfm^{-3}, 41MeVfm^{-3}].

Conclusions

At $A_p = 1$ the thermal fluctuations of λ introduce very significant corrections to the thermodynamic approximation.

These corrections decrease with increasing A_p and are very small already at $A_p = 10$.

Exact strangeness conservation gives corrections which are small down to $A_p = 1$, but introduces new features: small changes of the temperature pressure during the transition.