Λ-anomaly in the hadronic chemical freeze-out

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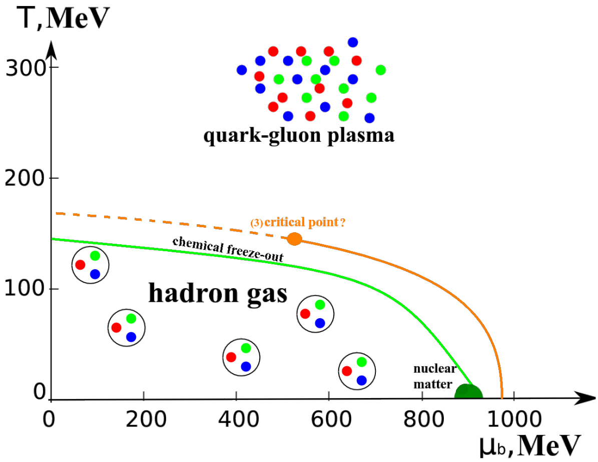
December 2, 2014

Hadron matter phase diagram



Hadron Resonance Gas Model (HRGM)

- Traditional HRGM: one hard-core radius $R = 0.25 - 0.3$ fm

  A. Andronic, P.Braun-Munzinger, J. Stachel, NPA (2006)777

- two hard-core radii: $R_\pi = 0.62$ fm, $R_{other} = 0.8$ fm

  G. D.Yen. M. Gorenstein, W. Greiner, S.N. Yang, PRC (1997)56

  or: $R_{mesons} = 0.25$ fm, $R_{baryons} = 0.3$ fm

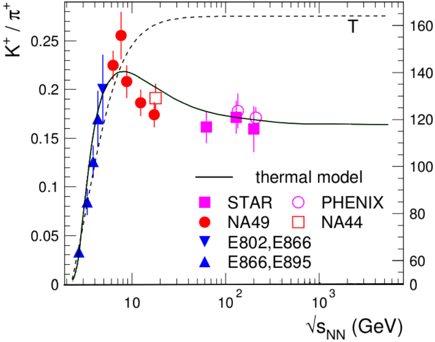
  A. Andronic, P.Braun-Munzinger, J. Stachel, NPA (2006) 777, PLB (2009) 673

These authors FORGOT about the second virial coefficient between different sorts of hadrons

There is still a problem with strange particle description!

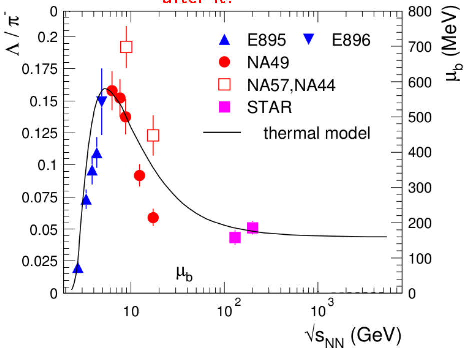
Problems with description K^+/π^+ and Λ/π^- ratios

Too slow decrease after maximum!



$$\chi^2/dof = 21/12$$

Too steep increase before maximum and too slow decrease after it!



$$\chi^2/dof = 79/12$$
$$\gamma_S \simeq 0.85 - 1.05$$

"Anti-lambda problem"

A. Andronic, P.Braun-Munzinger, J. Stachel, PLB (2009) 673

Hadron Resonance Gas Model

One component gas: $p = p^{id.gas} \cdot exp\left(-\frac{pV^{exc}}{T}\right)$

Multicomponent case: $p = \sum_{i=1}^{\infty} p_i^{id.gas}(\mu_i) \cdot exp\left(-\frac{p_i V^{exc}}{T}\right)$

All hadrons are in full chemical equilibrium

The number of particles of i-th sort:

$$N_i = \phi_i(T, m_i, g_i) e^{\frac{\mu_i}{T}} \equiv \frac{g_i V}{(2\pi)^3} \int exp\left(\frac{-\sqrt{k^2 + m_i^2} + \mu_i}{T}\right) d^3k$$

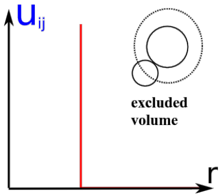
$$\mu_i = \mu_B B_i + \mu_S S_i + \mu_{I_3} I_{3_i}, \; i = 1..s$$

g_i - degeneracy factor

ϕ_i -thermal particle density

$V_{ij}^{exc} = \frac{2\pi}{3}(R_i + R_j)^3$ - excluded volume

hard-core repulsion of the Van der Waals type



Bugaev K. A., Oliinychenko D. R., Sorin A. S. and Zinovjev G. M.,Eur. Phys. J. A 49 (2013) 30–1-8.

K-th charge density of the i-th hadron sort n_i^k (K $\in$ [B, S, I_3])
$\mathcal{B}$ - symmetric matrix of the second virial coefficients with the elements $b_{ij} \equiv \frac{2\pi}{3}(R_i + R_j)^3$

$$p = T \sum_{i=1}^{N} \xi_i, \quad \xi = \begin{pmatrix} \xi_1 \\ \xi_2 \\ \dots \\ \xi_s \end{pmatrix}, \quad n_i^K = Q_i^K \xi_i \left[1 + \frac{\xi^T \mathcal{B} \xi}{\sum_{j=1}^{N} \xi_j} \right]^{-1}, \tag{1}$$

ξ_i **are the solutions of the following system:**

$$\xi_i = \phi_i(T) \exp\left(\frac{\mu_i}{T} - \sum_{j=1}^{N} 2\xi_j b_{ij} + \frac{\xi^T \mathcal{B} \xi}{\sum_{j=1}^{N} \xi_j} \right), \quad \phi_i(T) = \frac{g_i}{(2\pi)^3} \int \exp\left(-\frac{\sqrt{k^2 + m_i^2}}{T} \right) d^3 k$$

$\phi_i(T)$– thermal particle density
$\mu_i = \mu_B B_i + \mu_S S_i + \mu_{I_3} I_{3_i}$ – chemical potential of the i-th hadron sort

Q_K – charge, m_i – mass, g_i – degeneracy

Strange particles non equilibrium

$$\phi_i(T) \to \phi_i(T)\gamma_s^{s_i}$$

s_i — number of strange valence quarks and anti-quarks
J. Rafelski, Phys. Lett. B 62, 333 (1991);

Fit parameters: $T, \mu_B, \mu_{I_3}, \gamma_s$

μ_S – is found from the net zero strangeness condition.

K. A. Bugaev et al., EPJ A 49, 30–1-8 (2013);
K. A. Bugaev et al., EL 104, 22002, p.1- 6 (2013)

- Resonance decay:

$$n^{fin}(X) = \sum_{Y} BR(Y \to X) n^{th}(Y),$$

where $BR(X \to X) = 1$,
BR=BRANCHING RATIO (taken from PDG);

- Width correction:

$$\int exp\left(\frac{-\sqrt{k^2+m_i^2}}{T}\right) d^3k \to \frac{\int_{M_0}^{\infty} \frac{dx_i}{(x-m_i)^2+\Gamma^2/4} \int exp\left(\frac{-\sqrt{k^2+x^2}}{T}\right) d^3k}{\int_{M_0}^{\infty} \frac{dx_i}{(x-m_i)^2+\Gamma^2/4}},$$

Breit-Wigner distribution having a threshold M_0,
m - resonance mass,
Γ - resonance width.

Hadron Resonance Gas Model corrections

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$R_{ij} = \frac{N_i}{N_j} = \frac{\rho_i}{\rho_j}$ $\Rightarrow$ volume is excluded

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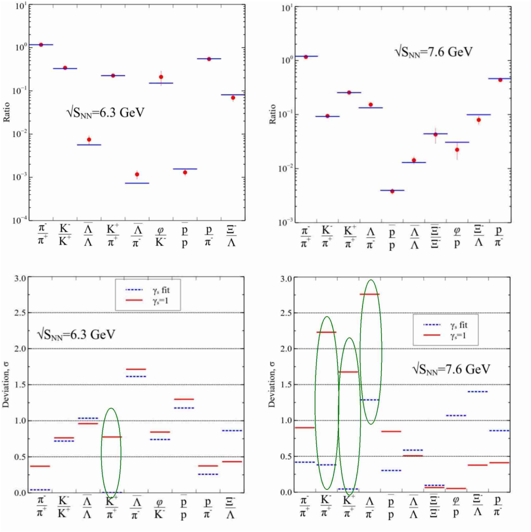


We fitted 111 hadron yield ratios measured for 14 $\sqrt{s_{NN}}$ values with overall $\chi^2/dof = 63.4/55 = 1.15$.

$R_{pions} = 0.1$ fm, $R_{kaons} = 0.38$ fm,

$R_{mesons} = 0.4$ fm, $R_{baryons} = 0.2$ fm.

$\sigma = \frac{|r^{theor} - r^{exp}|}{\sigma^{exp}}$ – relative deviation

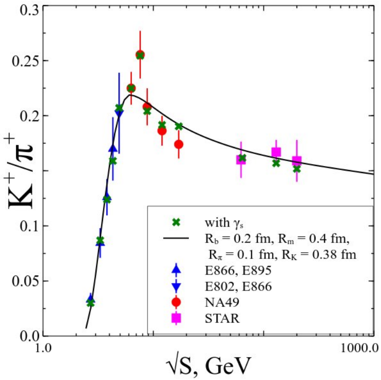
$$\chi^2 = \sum_i \frac{(r_i^{theor} - r_i^{exp})^2}{\sigma_i^2},$$

r_i^{exp} - experimental value of i-th particle ratio,
r_i^{theor} - theoretical value of i-th particle ratio
σ_i - total error of experimental value.

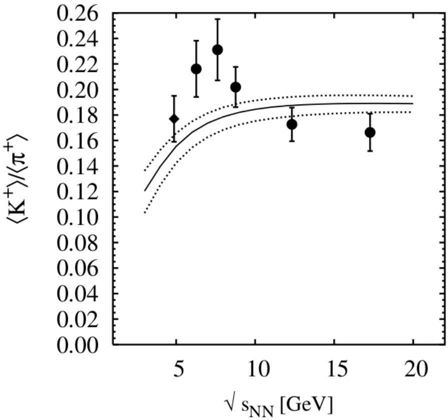
K. A. Bugaev, D. R. Oliinychenko,

J. Cleymans, A. I. Ivanytskyi,
I. N. Mishustin, E. G. Nikonov, VVS,
Europhys. Lett. 104 (2013) 22002.

Strangeness Horn description

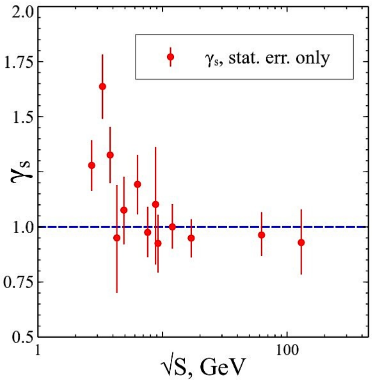


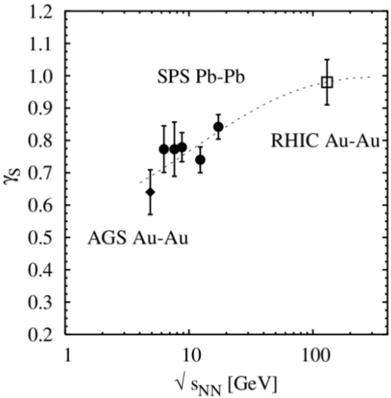
Description of K^+/π^+ ratio with $\chi^2/dof = 6.3/14$.



F. Becattini et al., PR C 73 044905 (2006)

Model parameters



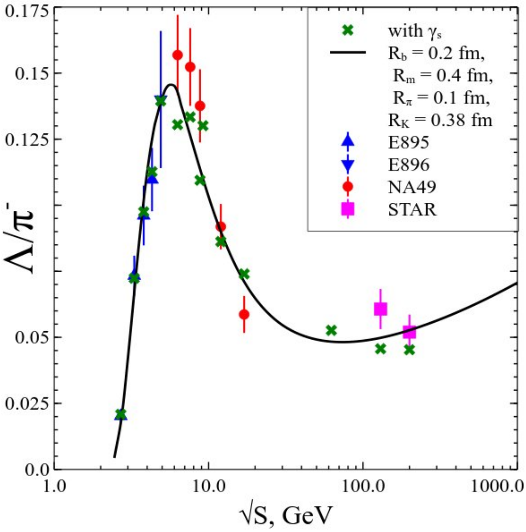


F. Becattini et al., PR C 73 044905 (2006)

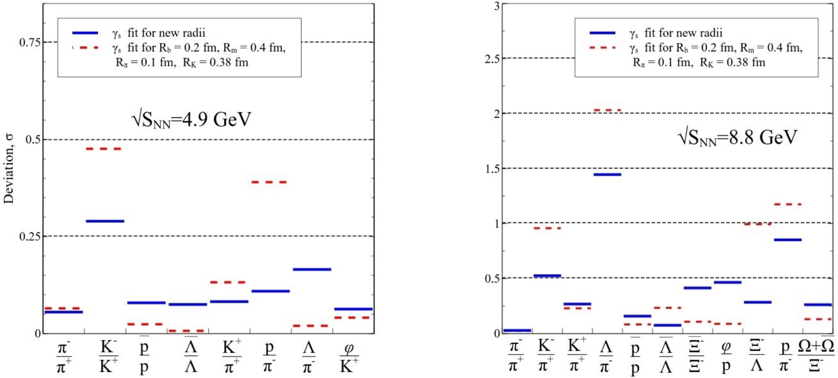
In contrast to the low quality fit by F. Becattini et al., PR C **73** 044905 (2006), we find $\gamma_s > 1$ for $\sqrt{s_{NN}} = 2.7, 3.3, 3.8, 4.9, 6.3, 9.2$ GeV

$\Longrightarrow$ Strangeness enhancement

Λ/π^- description



Description of Λ/π^- ratio with $\chi^2/dof = 14.9/12$.

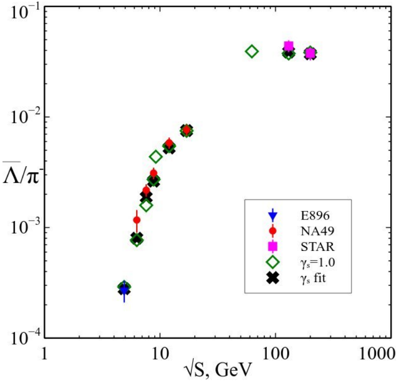


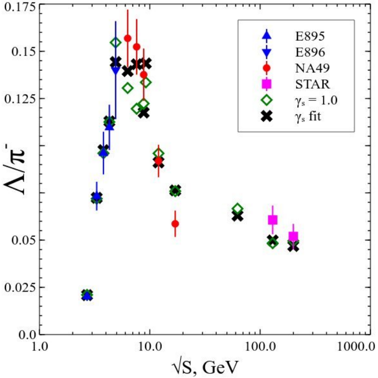
$\chi^2/dof = 52/55 \simeq 0.95$.

$R_{pions} = 0.1$ fm, $R_{kaons} = 0.38$ fm, $R_{mesons} = 0.4$ fm, $R_{baryons} = 0.355$ fm, $R_{lambda} = 0.11$ fm.

V. V. Sagun, UJP 59, 8 (2014).

$\bar{\Lambda}/\pi^-$ and Λ/π^- ratios





$\chi^2/8 = 6.49/8$

$\chi^2/12 = 10.22/12$

V. V. Sagun, UJP 59, 8 (2014).

Conclusions

- A new way to overcome the Λ hyperon selective suppression, which is known as the Λ-anomaly is suggested;
- with our HRGM the high quality fit is achieved for 111 independent hadron ratios measured at 14 values of the center of mass energy $\sqrt{s_{NN}}$ measured at the AGS, SPS and RHIC energies with the accuracy $\chi^2/dof = 52/55 \simeq 0.95$;
- in contrast to earlier results, we find that in heavy ion collisions is a sizable enhancement of strangeness with $\gamma_s \simeq 1.2 - 1.6$ at low energies;
- introduction of the additional hard-core radius for the Λ hyperon has essentially improved the description of the collision energy dependence of Λ/π^- and $\bar{\Lambda}/\pi^-$ ratios with the accuracy $\chi^2/dof = 10.22/12$ and $6.49/8$, respectively;
- the description of the Strangeness Horn shows a very good match between experimentally and theoretically determined points with $\chi^2/dof = 3.92/14$.

thank you for your attention!