Strangeness Balance in Heavy-ion Collisions

Evgeni E. Kolomeitsev

(University of Matej Bel, Slovakia)

work in collaboration with B.Tomasik and D.N. Voskresensky

- Why do we love strangeness
- Properties of strange particles in-medium
- HADES data on strangeness production. Ξ puzzle.
- Minimal statistical model for strangeness

Strangeness is interesting because

- ✓ It is a **tag** on a hadron, saying
  that it was not in colliding nuclei but is **produced** in the course of collision.

- ✓ **Strange quarks** like **baryons**: K,Λ,Σ,Ξ,Ω,..., **anti-strange quarks** like **mesons** K, .

  → strangeness/anti-strangeness **separation** in baryon-rich matter

- ✓ Strangeness is **conserved** in strong interaction

  → Strangeness production **threshold is high**,
  → sensitive to possible **in-medium effect**.
  QGP signal? (Rafelski-Mueller conjecture)

Strangeness is difficult because

- ✓ Strangeness **production cross sections** poorly known
  (new data from HADES on pp, COSY on pn, ANKA)

- ✓ Limited exp. information about **elementary reactions** among strange particles

- ✓ **Strong couplings** among various strange species. Complicated dynamics

Strange particles is nuclear medium

1. Hyperons $E_Y(p) = \sqrt{m_Y^2 + p^2} \longrightarrow \sqrt{(m + S_Y)^2 + p^2} + V_Y$

potential model

scalar and vector potentials

In relativistic mean-field models S and V originates from exchanges of scalar and vector mesons

Usually one relates vector potentials to the potential for nucleons $V_Y = \alpha_Y V_N$

where α_Y is deduced from some quark counting rule

Scalar potentials are fixed by the optical potential $U_Y = S_Y + V_Y$, acting on hyperons in an atomic nucleus

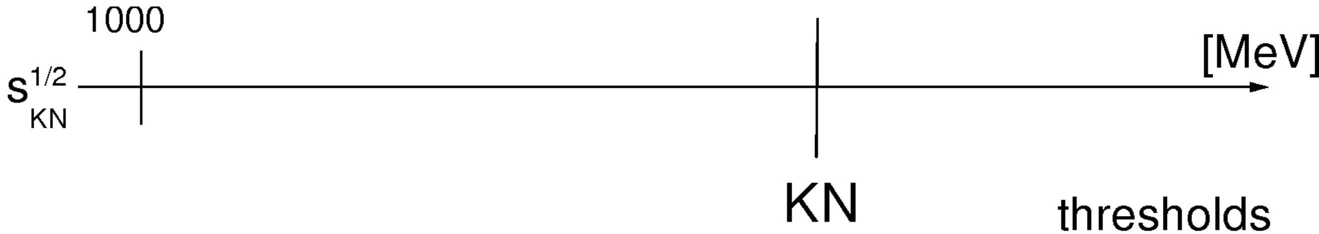
$U_\Lambda = -27\ \mathrm{MeV}$ [Hashimoto, Tamura, Prog.Part.Nucl.Phys. 57, 564 (2006)]

$U_\Sigma = +24\ \mathrm{MeV}$ [Dabrowski, Phys.Rev.C 60, 025205 (1999)]

$U_\Xi = -14\ \mathrm{MeV}$ [Khaustov et al., Phys.Rev.C 61, 054603 (2000)]

Caution: extrapolation of the attractive hyperon potentials in RMF models to higher densities may lead to problems with astrophysical constrains on the neutron star masses!!!

2. anti-strange mesons

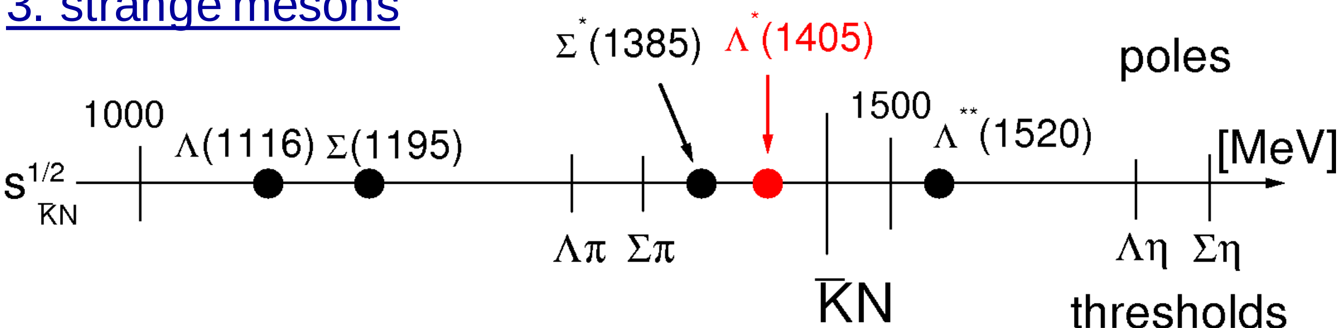


potential model

$$E(p) = \sqrt{m^2 + p^2} \longrightarrow \sqrt{(m+S)^2 + p^2} + V$$

scalar and vector potentials: common prejudice $S<0$; $V>0$

3. strange mesons



Exp. $\overline{K}N$ scattering

scattering amplitudes

bad data

good data

scattering model including s-,p-,d-partial waves

Coupled-channel scattering:
Weise, Kaiser,…
Oset, Ramos,…
Lutz, EEK,…

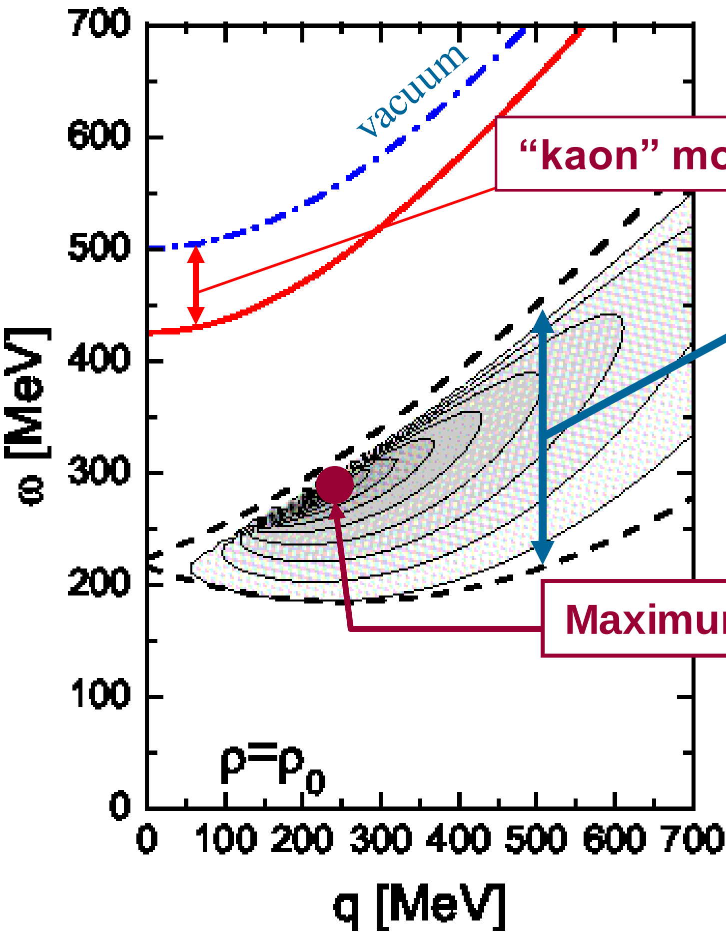
Various partial wave couple in medium

4. K⁻ in medium

schematic spectral density

EEK,Voskresensky, Kampfer NPA588(1995);
EEK, Voskresnensky, PRC60 (1999)

spectral density

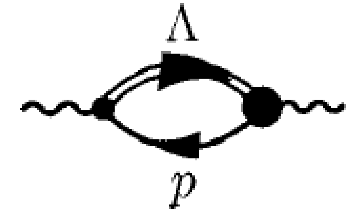


"kaon" mode with attractive potential

quasi-particle branch

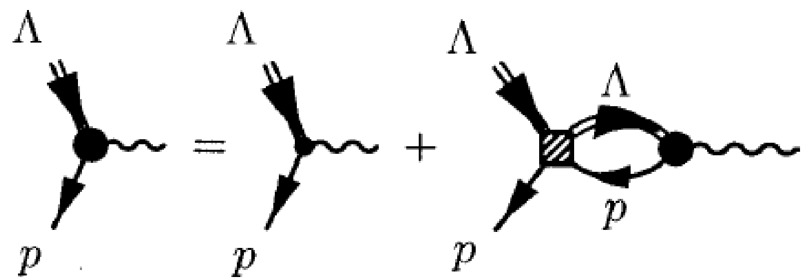
particle-hole modes

$$\omega \sim m_\Lambda - m_N$$



Maximum of the spectral function is shifted to higher energies

short-range correlations



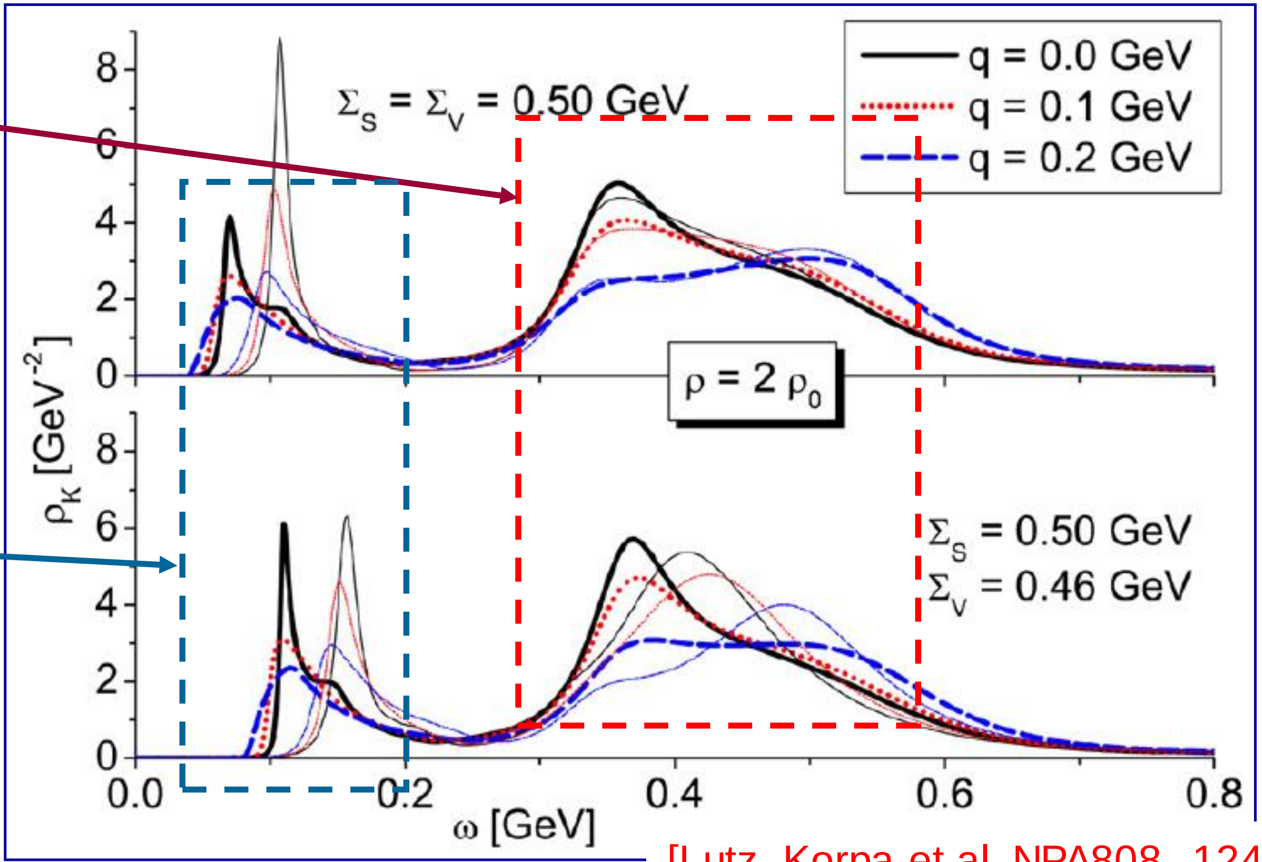
realistic spectral densities

realistic K^-N interactions + self-consistent calculations

Oset, Tolos et al; Lutz, Korpa, et al

$\Lambda(1405), \Sigma(1385)$

$\Lambda(1116), \Sigma(1190)$



[Lutz, Korpa et al, NPA808, 124]

Courageous attempts to include spectral function in transport codes by Giessen, Frankfurt , and Nantes groups [Bratkovskaya, Cassing, Aichelin et al]

How to release the in-medium kaons?

fireball break up time ~$1/m_\pi$

$$m_K \to m_K - 75\ \mathrm{MeV}\rho/\rho_0$$

HADES: complete measurement of particles containing strange quarks in Ar+KCl collisions @ 1.76 AGeV

Agakishiev (HADES) PRL 103, 132301 (2009); Eur. Phys.J. A47 21 (2011)

one experimental set-up for all particles!

We study the relative distributions of strangeness among various hadron species

We are not interested in how strangeness is produced!

We know the final K^+ multiplicity!

$$R_{K^-/K^+} = \frac{N_{K^-}}{N_{K^+}} = 2.5^{+1.2}_{-0.9} \times 10^{-2} \qquad R_{\Lambda/K^+} = \frac{N_{\Lambda+\Sigma^0}}{N_{K^+}} = 1.46^{+0.49}_{-0.37}$$

$$R^{(\mathrm{Hades})}_{\Sigma/K^+} = \frac{1}{2}\frac{N_{\Sigma^+ + \Sigma^-}}{N_{K^+}} = 0.13^{+0.16}_{-0.11} \qquad R_{\Xi/\Lambda/K^+} = \frac{N_{\Xi^-}}{N_{\Lambda+\Sigma^0}\, N_{K^+}} = 0.20^{+0.16}_{-0.11}$$

if $K^+ + K^0_s$ data are used for total strangeness

$$R^{(\mathrm{iso})}_{\Sigma/K^+} = \frac{1}{2}\frac{N_{\Sigma^+ + \Sigma^-}}{N_{K^+}} = 0.30^{+0.23}_{-0.17}$$

total strangeness is $(1+\eta)\, K^+$

This number is much bigger than the results of stat. models and transport codes

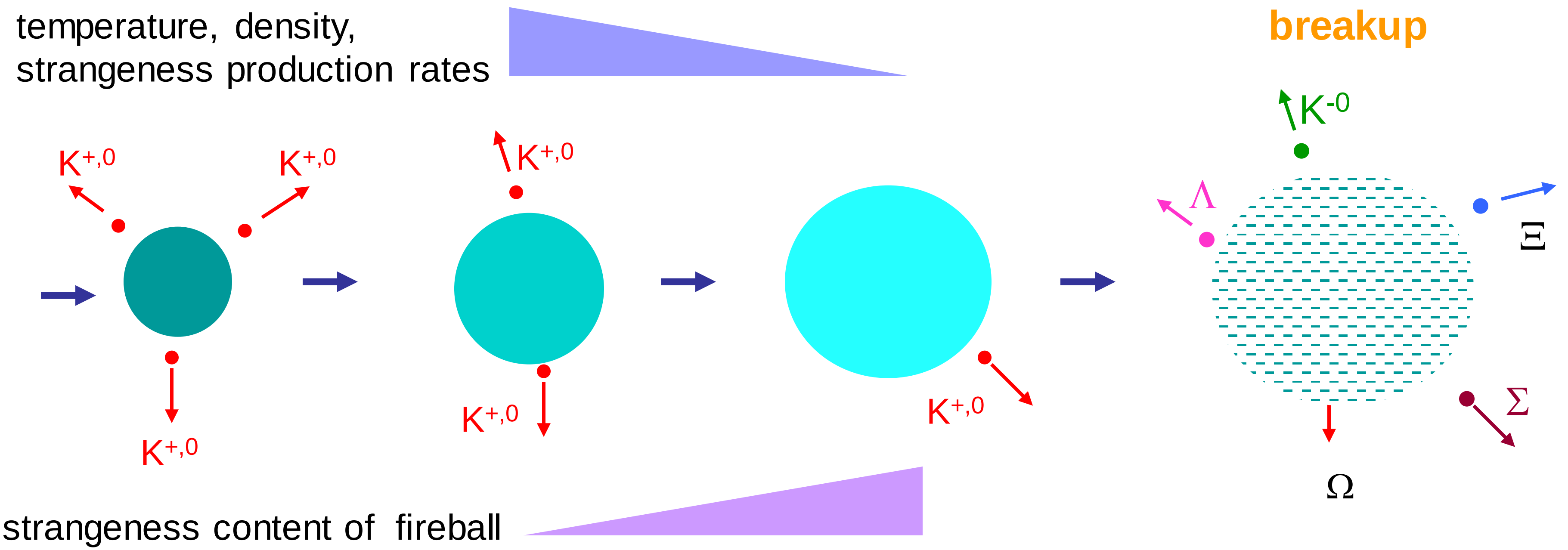
isospin asymmetry factor $\eta = \frac{A-Z}{Z}$

for ArK and ArCl collisions $\eta=1.14$

Minimal statistical model for strange particles:

At SIS energies K^+ and K^0 have long mean free paths and escape the fireball right after their creation in direct reactions.

The fireball have some negative strangeness which is statistically distributed among K^-, anti-K^0, Λ, Σ, Ξ, Ω



anti-strangeness released = *strangeness accumulated inside*= **strangeness released at breakup**

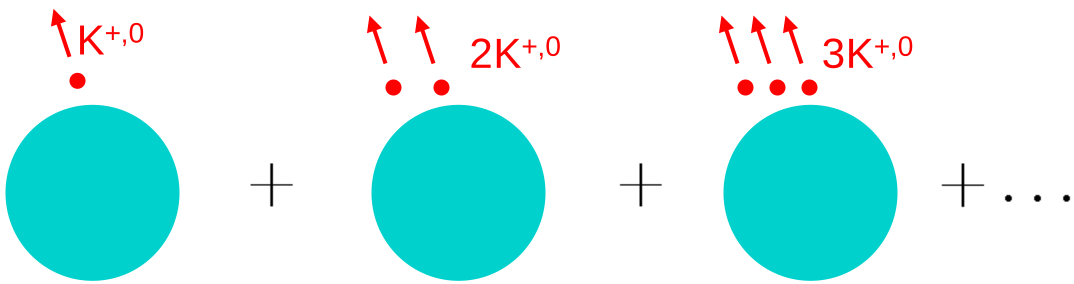
[C.-M. Ko, Phys. Lett. B 120, 294 (1983); Kolomeitsev,Voskresensky,Kämpfer, IJMP E5, 316 (1996)]

We know the average kaon multiplicity $\mathcal{M}_{K^+} = (2.8 \pm 0.4) \times 10^{-2}$

Of course kaons are produced not piecewise but as whole entities.

events with K^+ ⟶ $N_{K+} = M_{K+} \cdot N_{tot}$ ⟵ *total number of events*

Multi-kaon event classes:



isospin asymmetry factor

$$\eta = \frac{A-Z}{Z}$$

$$P_{s\bar{s}}^{(1)} N_{\text{tot}} + P_{s\bar{s}}^{(2)} N_{\text{tot}} + P_{s\bar{s}}^{(3)} N_{\text{tot}} + \cdots = N_{\text{tot}} (1+\eta) \mathcal{M}_{K^+}$$

$P_{s\bar{s}}^{(n)}$ probaility of creation of n $s\bar{s}$ pairs

at breakup

$\bar{K}, \Lambda, \Sigma$ — no Ξ, Ω!

$\bar{K}, \Lambda, \Sigma, \Xi$ — no Ω!

$\bar{K}, \Lambda, \Sigma, \Xi, \Omega$

$$P_{s\bar{s}}^{(n)} = \Lambda^n e^{-\Lambda} / n!$$

Λ -- integral probability of the pair production

Let $\mathcal{W}$ be the probability of (s bar-s) pair production in a unit of volume and a unit of time, which is a function of local temperature and density.

$$\Lambda = \int_0^{t_{\rm col}} V(t)\mathcal{W}(\rho(t),T(t))\,\mathrm{d}t$$

$$V(t) = f(t)\,V_{\rm fo}$$

$$t_{\rm col} = \tau V_{\rm fo}^{1/3}$$

$$\Lambda = \tau\,\overline{\mathcal{W}}\,V_{\rm fo}^{4/3} = \lambda\,V_{\rm fo}^{4/3}$$

$V_{\rm fo}$ freeze-out volume

The value of λ is fixed by the total K^+ multiplicity observed in an inclusive collision.

We denote the multiplicity of K^+ mesons produced in each n-kaon events as:

$$M_{K^+}^{(n)} = \frac{n}{1+\eta} P_{s\bar{s}}^{(n)}$$

$$\mathcal{M}_{K^+} = \sum_n \langle M_{K^+}^{(n)} \rangle = \frac{1}{1+\eta} \sum_n n\,\langle P_{s\bar{s}}^{(n)} \rangle = \frac{\langle \Lambda \rangle}{1+\eta}$$

$$\langle \dots \rangle = \frac{2}{b_{\max}^2} \int_0^{b_{\max}} \mathrm{d}b\,b\,(\dots)$$

-- averaging over the collision impact parameter

$r_0 = 1.124\ \mathrm{fm} \quad b_{\max} = 2\,r_0\,A^{1/3}$

$$V_{\rm f.o.}(b) = \frac{2\,A}{\rho_{B,\rm fo}}\,F(b/b_{\max})$$

overlap function

[Gosset et al, PRC 16, 629 (1977)]

$$\langle V_{\rm f.o.} \rangle \approx \frac{A}{2\,\rho_{B,\rm fo}}$$

$\rho_{B,\rm fo}$ ↑ freeze-out density

$$\langle P_{s\bar{s}}^{(1)} \rangle = (1+\eta)\,\mathcal{M}_{K^+}\left[1-(1+\eta)\zeta^{(2)}\mathcal{M}_{K^+}+\tfrac{1}{2}\zeta^{(3)}(1+\eta)^2\mathcal{M}_{K^+}^2\right]$$

$$\langle P_{s\bar{s}}^{(2)} \rangle = \tfrac{1}{2}(1+\eta)^2\mathcal{M}_{K^+}^2\left[\zeta^{(2)}-(1+\eta)\zeta^{(3)}\mathcal{M}_{K^+}\right]$$

$$\langle P_{s\bar{s}}^{(3)} \rangle = (1+\eta)^3\tfrac{1}{6}\zeta^{(3)}\mathcal{M}_{K^+}^3$$

$$\zeta^{(n)} = \frac{\left\langle V_{\mathrm{fo}}^{\frac{4}{3}n}\right\rangle}{\left\langle V_{\mathrm{fo}}^{4/3}\right\rangle^n}$$

$$\zeta^{(1)} = 1\,, \quad \zeta^{(2)} = 2.51\,, \quad \zeta^{(3)} = 8.11$$

enhancement factors!!

total strangeness multiplicity $\quad M_S^{(n)} = n\,P_{s\bar{s}}^{(n)}$

Using the experimental kaon multiplicity $\mathcal{M}_{K^+} = (2.8 \pm 0.4) \times 10^{-2}$ we estimate

$$\frac{\langle M_S^{(2)} \rangle}{(1+\eta)\mathcal{M}_{K^+}} \simeq 15\%$$ **of kaons is produced pairwise**

$$\frac{\langle M_S^{(3)} \rangle}{(1+\eta)\mathcal{M}_{K^+}} \simeq 1\%$$ **of kaons is produced triplewise**

The statistical probability that strangeness will be released at freeze-out in a hadron of type a with the mass m_a is

$$P_a = {z_S}^{s_a} V_{\rm fo}\, p_a = {z_S}^{s_a} V_{\rm fo}\, \nu_a\, e^{q_a \frac{\mu_B(t)}{T(t)}}\, f(m_a, T_{\rm fo})$$

s_a # of strange quarks in the hadron

ν_a spin-isospin degeneracy factor

q_i baryon charge of the hadron

$$f(m,T) = \frac{m^2 T}{2\pi^2} K_2\left(\frac{m}{T}\right)$$

baryon chemical potential $\mu_B(t) \simeq -T(t) \ln\left\{4\left[f(m_N,T) + 4\, f(m_\Delta,T)\right]/\rho_B(t)\right\}$

z_S is a *normalization factor* which could be related to a probability of one s-quark to find itself in a hadron a

This factor follows from the requirement that the sum of probabilities of production of different strange species and their combinations, which are allowed in the finale state, is equal to one.

This factor depends on how many strange quarks are produced.
Hence, it is different in single-, double- and triple-kaon events.

$$P_a^{(n)} = z_S^{(n)\, s_a} V_{\rm fo}\, p_a$$

single-kaon event: $n = 1$ only K̄, Λ and Σ can be in the final state

$$P_{\bar{K}}^{(1)} + P_{\Lambda}^{(1)} + P_{\Sigma}^{(1)} = 1 = z_S^{(1)} \, V_{\text{fo}} \left(p_{\bar{K}} + p_{\Lambda} + p_{\Sigma} \right)$$

multiplicity of $\bar{K}, \Lambda, \Sigma$

$$M_a^{(1)} = g_a \, P_{s\bar{s}}^{(1)} \, P_a^{(1)} = g_a \, P_{s\bar{s}}^{(1)} \, z_S^{(1)} \, V_{\text{fo}} \, p_a$$

isospin factor → g_a

double-kaon event: $n = 2$ K̄K̄, K̄Λ, K̄Σ, $\Lambda\Lambda$, $\Lambda\Sigma$, $\Sigma\Sigma$ and Ξ can be in the final state

$$\left(P_{\bar{K}}^{(2)} + P_{\Lambda}^{(2)} + P_{\Sigma}^{(2)} \right)^2 + P_{\Xi}^{(2)} = 1$$

$$z_S^{(2)2} \, V_{\text{fo}}^2 \left(p_{\bar{K}} + p_{\Lambda} + p_{\Sigma} \right)^2 + z_S^{(2)2} \, V_{\text{fo}} \, p_{\Xi} = 1$$

multiplicity of $\bar{K}, \Lambda, \Sigma$

$$M_a^{(2)} = g_a \, 2 \, P_{s\bar{s}}^{(2)} \, P_a^{(2)} \left(P_{\bar{K}}^{(2)} + P_{\Lambda}^{(2)} + P_{\Sigma}^{(2)} \right)$$

multiplicity of Ξ

$$M_{\Xi}^{(2)} = g_{\Xi} \, P_{s\bar{s}}^{(2)} \, P_{\Xi}^{(2)}$$

particle ratios:

We included leading and next-to-leading contributions

$$R_{K^-/K^+} = \eta \frac{\langle M_{\bar K}^{(1)} + M_{\bar K}^{(2)}\rangle}{(1+\eta)\,\mathcal{M}_{K^+}} = \frac{\eta\, p_{\bar K}}{p_{\bar K} + p_\Lambda + p_\Sigma} Y_1$$

$$R_{\Lambda/K^+} = \frac{1}{\mathcal{M}_{K^+}} \left\langle M_\Lambda^{(1)} + M_\Lambda^{(2)} + \eta \frac{M_\Sigma^{(1)} + M_\Sigma^{(2)}}{\eta^2+\eta+1} \right\rangle = (1+\eta)\frac{\left[p_\Lambda + \frac{\eta\, p_\Sigma}{\eta^2+\eta+1}\right]}{p_{\bar K} + p_\Lambda + p_\Sigma} Y_1$$

$$R_{\Sigma/K^+} = \frac{\eta^2+1}{2(\eta^2+\eta+1)} \frac{\langle M_\Sigma^{(1)} + M_\Sigma^{(2)}\rangle}{\mathcal{M}_{K^+}} = \frac{(\eta^2+1)(\eta+1)}{2(\eta^2+\eta+1)} \frac{p_\Sigma}{p_{\bar K} + p_\Lambda + p_\Sigma} Y_1$$

$$R_{\Xi/\Lambda/K^+} = \frac{\frac{\eta}{1+\eta}\langle\left(M_\Xi^{(2)} + M_\Xi^{(3)}\right)\rangle}{\langle M_\Lambda^{(1)} + M_\Lambda^{(2)} + \eta\frac{M_\Sigma^{(1)}+M_\Sigma^{(2)}}{\eta^2+\eta+1}\rangle \mathcal{M}_{K^+}} = \eta \frac{p_\Xi/(p_{\bar K} + p_\Lambda + p_\Sigma)}{\langle V_{\rm fo}\rangle \left(p_\Lambda + \frac{\eta p_\Sigma}{\eta^2+\eta+1}\right)} Y_2$$

in **blue** the standard results; in **red** corrections

$$Y_1 = 1 - \frac{(1+\eta)\mathcal{M}_{K^+}\, p_\Xi}{(p_{\bar K} + p_\Lambda + p_\Sigma)^2} \frac{\langle V_{\rm fo}^{5/3}\rangle}{\langle V_{\rm fo}^{4/3}\rangle^2}$$

small correction <5%

$$Y_2 = \frac{1}{2}\tilde\zeta^{(2)} = \frac{1}{2}\frac{\langle V_{\rm fo}^{5/3}\rangle}{\langle V_{\rm fo}^{4/3}\rangle^2}\langle V_{\rm fo}\rangle \simeq 0.52$$

strong suppression!

Ξ/Λ/K ratio is sensitive to the fireball freeze-out volume

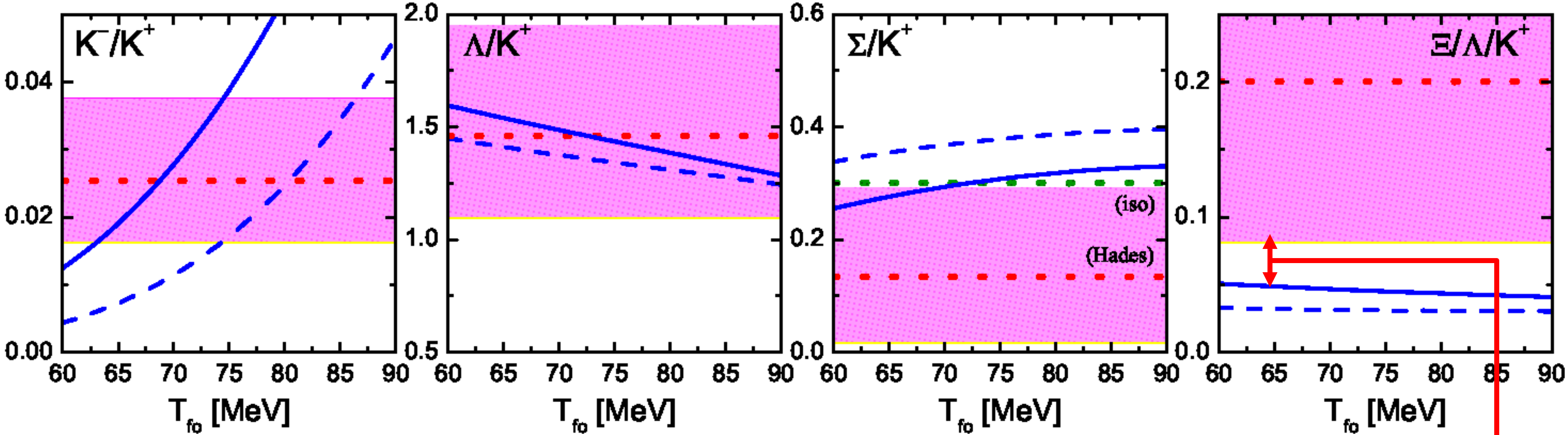
Ratios as functions of the freeze-out temperature

parameters of the model: $\rho_{B,\mathrm{fo}} = 0.6\,\rho_0$

potential models for strange particles in medium

potentials for nucleons Δs:

$$S_N \simeq S_\Delta \simeq -190\ \mathrm{MeV}\,\rho_B/\rho_0$$
$$V_N \simeq V_\Delta \simeq +130\ \mathrm{MeV}\,\rho_B/\rho_0$$



double strangeness suppression Y_2

results with in-medium potentials

results with vacuum masses

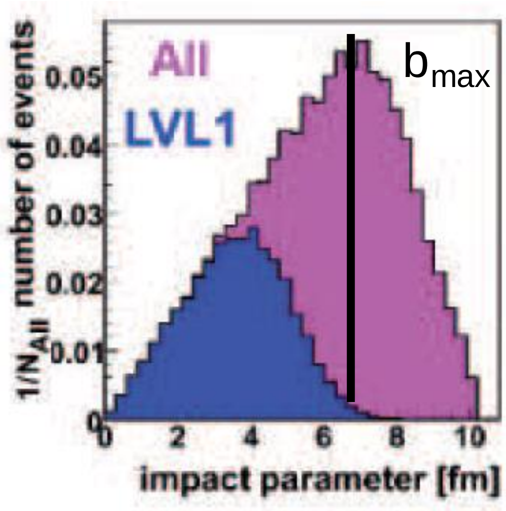
best fit for K^{-},Λ ratios: $T_{\mathrm{f.o}}$=69 MeV

Inclusion of potentials
improves the temperature match for K and Λ ratios,

improves Σ ratio (repulsive potential),
increases Ξ ratio (not strong enough)

HADES trigger effect

LVL1 trigger — HADES counts only the events with MUL>16



[Schade, PhD thesis2010]

trigger function

$$T_{\rm LVL1}(b) = \begin{cases} b\,, & b < 3.9 \text{ fm} \\ 3.6\, e^{-0.27\left(\frac{b}{1\rm fm} - 3.75\right)^2}, & b \geq 3.9 \text{ fm} \end{cases}$$

$$\langle V_{\rm f.o.}\rangle_{\rm LVL1} = \frac{2\,\pi \int_0^{b_{\rm max}} {\rm d}b\, T_{\rm LVL1}(b)\, V_{\rm f.o.}(b)}{2\,\pi \int_0^{b_{\rm max}} {\rm d}b\, T_{\rm LVL1}(b)} = 1.77\,\langle V_{\rm f.o.}\rangle$$

$$R_{\Xi/\Lambda/K^+} \propto \frac{1}{\langle V_{\rm fo}\rangle} \qquad R_{\Omega/(\Lambda K^-)/K^+} \propto \frac{1}{\langle V_{\rm fo}\rangle^2} \qquad R_{\Omega/\Xi/K^+} \propto \frac{1}{\langle V_{\rm fo}\rangle}$$

ratio	exp. value	inclusive	triggered
$\Xi/\Lambda/K^+$	$0.20^{+0.16}_{-0.11}$	0.047	0.026

Triggering can effect the ratios with multi strange particles

1. in medium potential and freeze-out density

A more attractive Ξ in-medium potential? We would need $U_{\Xi} < -120$ MeV to increase the ratio $\Xi^-/\Lambda/K^+$ up to the lowest end of the empirical error bar.

Such a strong attraction exceeding the nucleon optical potential is unrealistic. It would imply that Ξ baryon is bound in nucleus stronglier than two Λs,

$$2(m_{\Lambda}+U_{L}) - (m_{\Xi}+m_{N}+U_{\Xi}+U_{N}) \sim 100\ \mathrm{MeV} > 0.$$

This would influence the description of doubly strange hypernuclei

The leading order analyzis of hyperon and nucleon mass shifts in nuclear matter using the chiral perturbation theory [Savage, Wise, PRD 53, 349 (1996)] shows that the Ξ shift is much smaller than nucleon and Λ shifts.
Recent analyses [Polinder, Haidenbauer, Meissner, PLB 653, 29 (2007),
Gasparyan, Haidenbauer, Hanhart, arXiv:1111.0513]
support the relative smallness of ΞN scattering lengths.

We can take somewhat larger freeze-out density: $\rho_{B,\mathrm{fo}} = 0.7\,\rho_0$

$$R_{\Xi/\Lambda/K^+} = 0.026 \longrightarrow 0.028$$

2. Non-equilibrium effects

The main assumption of our model is that the strange subsystem is in thermal equilibrium with a non-strange subsystem and that strange particles are in chemical equilibrium with each other.

For L and Σ

$$\Lambda N \leftrightarrow \Lambda N \qquad \Sigma N \leftrightarrow \Sigma N \qquad \Lambda N \leftrightarrow \Sigma N$$

$$\sigma \sim 80 - 25 \text{ mb}$$

for relative moments p_T to $2p_T$

p_T~300 MeV is the thermal momentum for T=70 MeV

For $\bar{K}$

$$K^- N \leftrightarrow \pi\Lambda(\Sigma) \qquad \pi\Lambda(\Sigma) \leftrightarrow \pi\Lambda(\Sigma)$$

resonance reactions

For Ξ

ΞN interaction is expected to be smaller than ΛN and ΣN interactions

$$\sigma(\Xi^- p \to \Xi^- p) \sim 15 \text{ mb} \qquad \sigma(\Xi^- p \to \Lambda\Lambda) \lesssim 10 \text{ mb} \qquad \sigma(\Xi^0 p \to \Xi^0 p) \lesssim 15 \text{ mb}$$

[Polinder, Haidenbauer, Meissner, PLB 653, 29 (2007)]

Scattering of Ξs on pions for nearly isospin symmetrical matter is considerably weaker than the πN scattering (vey narrow Ξ*(1532) resonance, not broad Δ(1232))

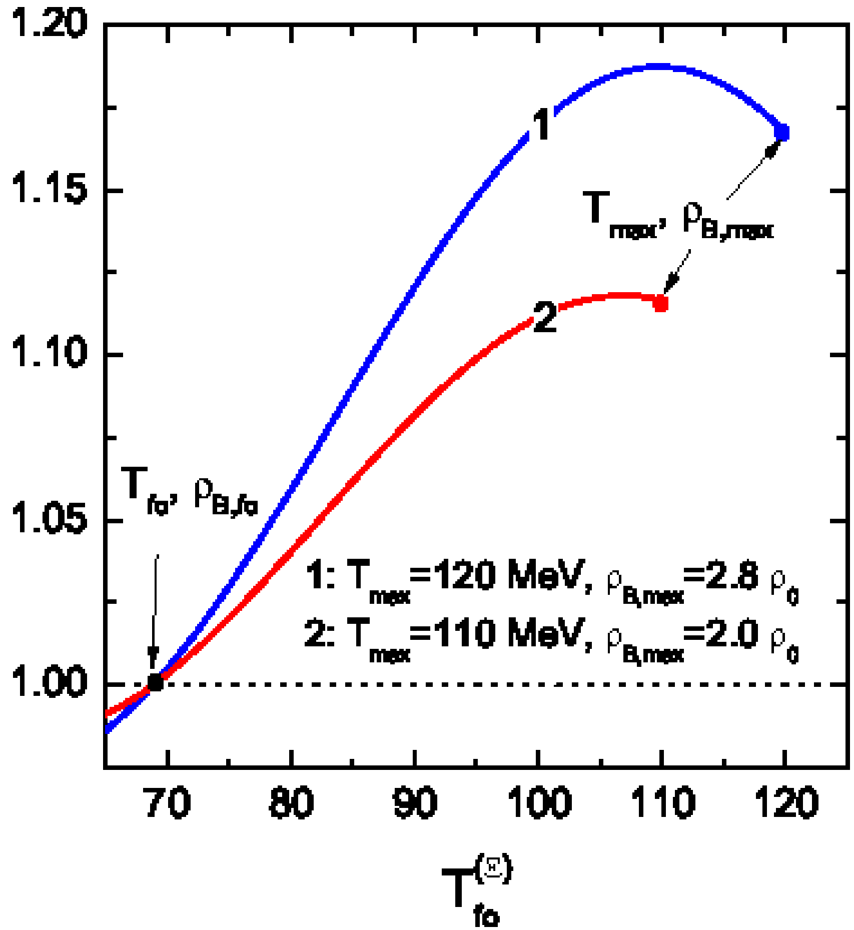
Ξ baryons are presumably weakly coupled to the non-strange system

Earlier freezeout!

$$R^{\rm non-eq.}_{\Xi/\Lambda/K^+} \sim \frac{p_\Xi[\widetilde{T}_{\rm fo}]}{(p_\Lambda + \frac{1}{3}p_\Sigma)\,(p_{\bar{K}} + p_\Lambda + p_\Sigma)[T_{\rm fo}]} Y_2 \qquad \widetilde{T}_{\rm fo} > T_{\rm fo}$$

increase of the ratio

$$h_\Xi = \frac{R^{\rm non-eq.}_{\Xi/\Lambda/K^+}}{R_{\Xi/\Lambda/K^+}}$$



The enhancement is too small! We need at least factor 5!

3. Direct reactions

To get any substantial increase in the number of Ξ's we have to assume that these baryons are not absorbed after being produced and their number is determined by the rate of direct production reactions, as, for example, for dileptons.

However, this raises a new question:
whether there are sufficiently strong sources of Ξ baryons and enough time t?

Where do Ξ baryons come from?

strangeness creation reactions: $\bar{K}N \to K\Xi - 380\ \mathrm{MeV}$ $\quad N_{K^-} \ll N_{\Lambda,\Sigma}$

$\pi\Sigma \to K\Xi - 480\ \mathrm{MeV}$ *very exothermic,*

$\pi\Lambda \to K\Xi - 560\ \mathrm{MeV}$ *very inefficient*

strangeness recombination reactions:

ss quarks are strongly bound in Ξ!

anti-kaon induced reactions

$\overline{K}\Lambda \to \Xi\pi + 154\ \mathrm{MeV}$ $\quad \sigma \sim 10\ \mathrm{mb}$

$\overline{K}\Sigma \to \Xi\pi + 232\ \mathrm{MeV}$ [Li,Ko NPA712, 110 (2002)]

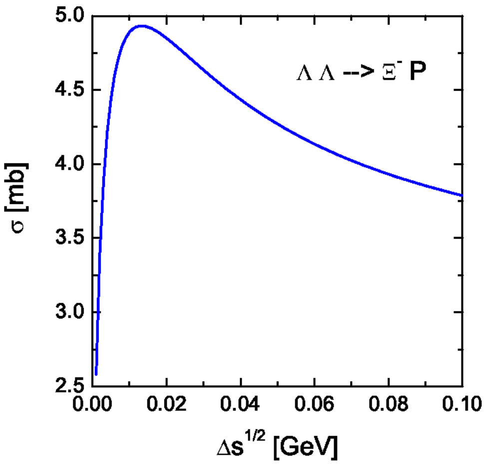
double-hyperon processes

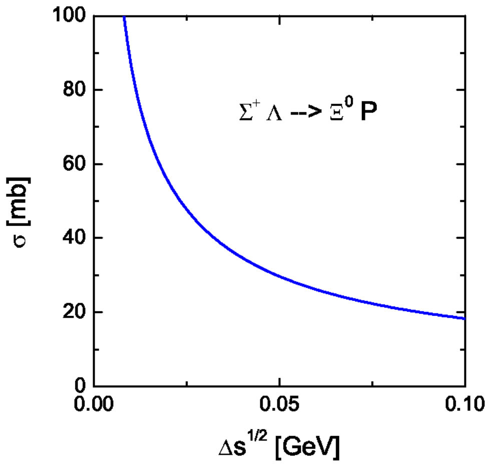
$\Lambda\Lambda \to \Xi N - 26\ \mathrm{MeV}$ can be more efficient since

$\Lambda\Sigma \to \Xi N + 52\ \mathrm{MeV}$ $\quad N_{K^-} \ll N_{\Lambda,\Sigma}$

$\Sigma\Sigma \to \Xi N + 130\ \mathrm{MeV}$ [Tomasik, E.K., arXiv:**1112.1437**]

[Polinder, Haidenbauer, Meissner, PLB 653, 29 (2007)]





[Li,Chen,Ko,Lee 1204.1327] calculated the same cross sections in Born approximation [much larger σ] and implemented in transport code.

→ increased Ξ production

Conclusions:

Strangeness is interesting and complicated!
We need "complete strangeness measurement not only kaons, hyperons but also multi-strange baryons and phi's!

- HADES data show the problems with the strangeness balance:
  too few Σ baryons and too many Ξ are observed.

- Isospin corrections could help to understand Σ yield.

- With an inclusion of in-medium potentials yield we can describe K^-/K^+, Λ/K^+, and Σ/K^+;

- $\Xi/\Lambda/K^+$ ratio cannot be described. Suppression of the ration calculated in the statistical model is due to explicit strangeness conservation in each collision and HADES event trigger!

Ξ out of chemical equilibrium! Production via direct reaction!

- The main source of Ξ's is strangeness recombination reactions.
- Double-hyperon processes can be very important.
- Anti-kaon induced reactions can be strongly enhanced if the attractive kaon potential is included