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Excessive double strange baryon production due to strangeness oscillation in p+A, A+A collisions

P.Filip*
Institute of Physics, Slovak Academy of Sciences, Bratislava 845 11, Slovakia

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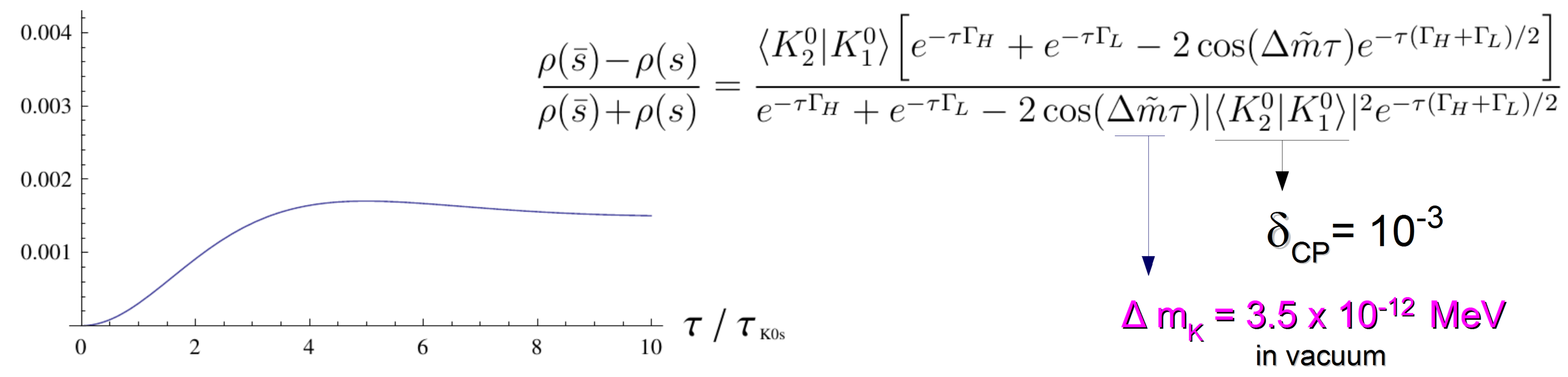
Mixing of Quantum States in B.

Abstract: ***Production of double-strange Ξ^- baryons at sub-threshold energies has been observed (HADES exp.) to be significantly enhanced compared to theoretical expectations. We suggest, that oscillation of neutral K^{0*} mesons can be affected due to high baryonic density in a specific way, which may result in the oscillation length 5-10 fm. This allows for the strangeness violation process $K^{0*} \to \bar{K}^{0*}$ to occur within the volume of dense baryonic medium in p+A and A+A interactions. Additional double strange baryons may thus be created in strangeness exchange ($\Sigma, \Lambda + \bar{K} \to \Xi + \pi$) interactions, during hadronic rescattering process. If global strangeness conservation in proton-nucleus and nucleus-nucleus interactions is assumed, the influence of strangeness exchange reactions on Ξ^- production may be underestimated.***

Is net strangeness conserved? (Not completely)

Let's assume pair of neutral kaons ($K^0\bar{K}^0$) is produced at time t=0 in strong interaction process. Net strangeness is zero $\rho(\bar{s}) - \rho(s) = 0$, when pair $\bar{s}, s$ is created. During subsequent time evolution, net strangeness increases due to CP violation effects in weak decays of K_S and K_L eigenstates [1].

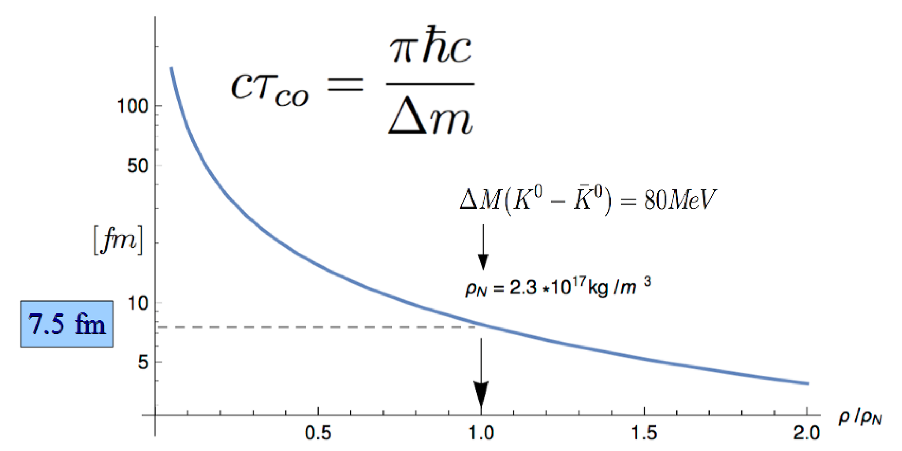
$$\frac{\rho(\bar{s})-\rho(s)}{\rho(\bar{s})+\rho(s)} = \frac{\langle K_2^0|K_1^0\rangle\left[e^{-\tau\Gamma_H}+e^{-\tau\Gamma_L}-2\cos(\Delta\tilde{m}\tau)e^{-\tau(\Gamma_H+\Gamma_L)/2}\right]}{e^{-\tau\Gamma_H}+e^{-\tau\Gamma_L}-2\cos(\Delta\tilde{m}\tau)|\langle K_2^0|K_1^0\rangle|^2 e^{-\tau(\Gamma_H+\Gamma_L)/2}}$$

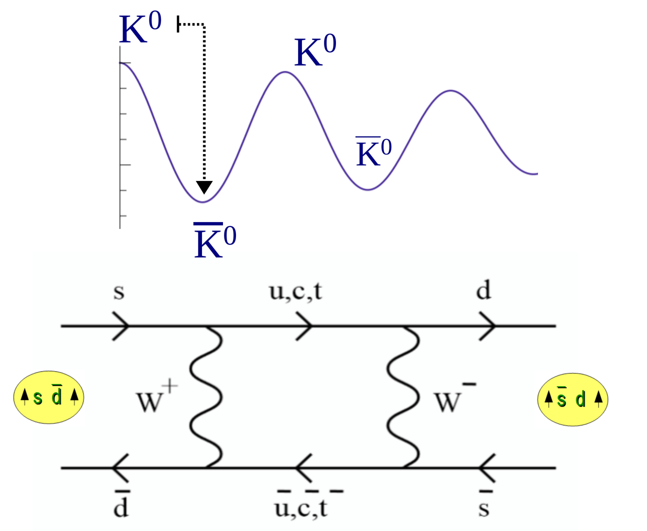


Non-conservation of net strangeness is related to the excess of $\bar{s}$ quarks in K_L eigenstate. Time evolution depends on K_L, K_S mass difference Δm.

Can strangeness oscillate within 10 fm/c time?

Oscillation period for $K^0(\bar{s}d) \to \bar{K}^0(\bar{d}s)$ depends on the mass difference of weak eigenstates $K_2 - K_1 = \Delta m$. In dense baryonic matter, masses of K, $\bar{K}$ mesons are shifted due to in-medium potentials $\Delta V \approx$ 60 - 100 MeV [4] and oscillation period $\tau_{osc} = h/\Delta m$ can become very short: $\tau_{osc} \approx$ 7-10 fm/c.





Dependence of $\bar{s} \to s$ conversion time τ_{con} = ½ τ_{osc} on baryonic medium density ρ, in units of normal density of nucleus ρ_N. We assume box diagram responsible for $K^0 \to \bar{K}^0$ scalar meson oscillations does apply also to vector meson $K^{0*}(892) \to \bar{K}^{0*}(892)$ oscillation.

We estimate $d\bar{s} \leftrightarrow s\bar{d}$ oscillation probability in medium:

For $K^0(497)$ meson, $\bar{s} \to s$ probability in baryonic matter is negligible [2,3]

$$\mathbb{M}_{K^0} = \begin{bmatrix} 497.7 + V_{K^0}(\rho_B) & e^{i\xi_M}1.74\cdot10^{-12} \\ e^{-i\xi_M}1.74\cdot10^{-12} & 497.7 - \bar{V}_{\bar{K}^0}(\rho_B) \end{bmatrix} \qquad \mathbb{H}' = \begin{bmatrix} \tilde{M}_{11} & M_{12} \\ M_{21} & \tilde{M}_{22} \end{bmatrix} - \frac{i}{2}\begin{pmatrix} \tilde{\Gamma}_{11} & \Gamma_{12} \\ \Gamma_{21} & \tilde{\Gamma}_{22} \end{pmatrix}$$

+ 20 MeV; 60 - 80 MeV; 10^{-12}

$$\mathbb{G}_{K^0} = \begin{pmatrix} 3.7\cdot10^{-12} + \gamma_{K^0}(\rho_B) & e^{i\xi_G}3.48\cdot10^{-12} \\ e^{-i\xi_G}3.48\cdot10^{-12} & 3.7\cdot10^{-12} + \bar{\gamma}_{\bar{K}^0}(\rho_B) \end{pmatrix}$$

$$[K^0 \rightsquigarrow \bar{K}^0]_{(\tau)} = \left|\frac{q_H}{p_H}\right|^2 |g_-(\tau)|^2 |(1-\theta)|^2 \approx \frac{4|M_{21} - i\Gamma_{21}/2|^2}{\Delta V^2}|g_-(\tau)|^2 \approx 10^{-26}$$

10^{-12}; ΔV^2 at nuclear density = (80 MeV)^2

For $K^{0*}(892)$ mesons, $\bar{s} \to s$ probability in baryonic medium is **P ≈ 1%** [3]

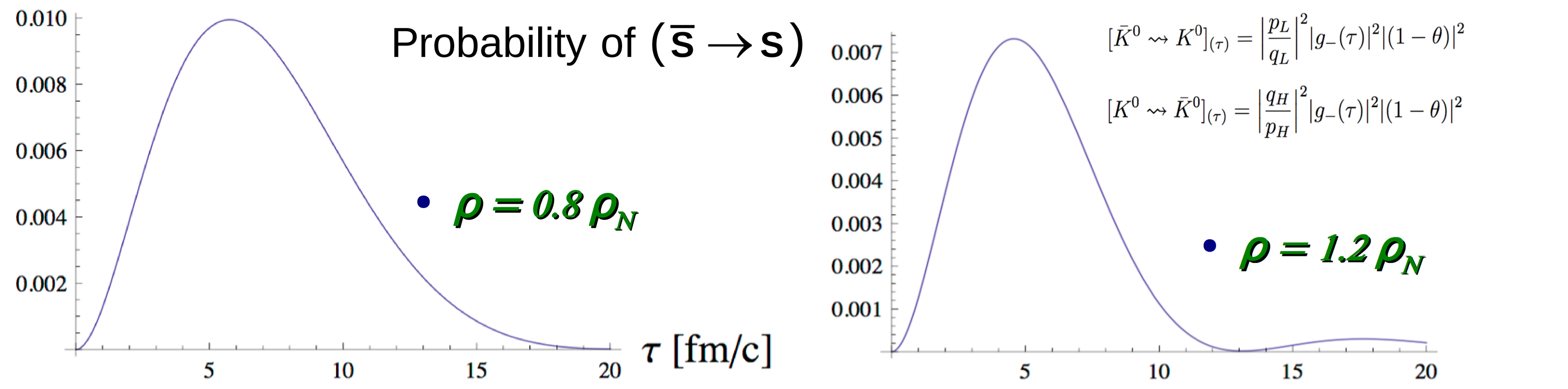
$$\Gamma_{21} = \Gamma_{21}^* = \pi\sum_F \rho_f \langle \bar{K}^{0*}|H_{wk}|F\rangle\langle F|H_{wk}|K^{0*}\rangle \qquad \mathbb{G}_{K^{0*}} = \begin{pmatrix} 48 + \gamma_{K^{0*}}(\rho_B) & 16\,e^{i\xi_{G^*}} \\ 16\,e^{-i\xi_{G^*}} & 48 + \bar{\gamma}_{\bar{K}^{0*}}(\rho_B) \end{pmatrix}$$

$|\Gamma_{21}|$ = 16 MeV; 33 %; 33 %; $\pi^0 K^0_{L,S}$; $\Gamma_{11} = \Gamma_{22}$ = 48 MeV

If N(K) / N($\bar{K}$) ≥ 100, enhanced $\bar{K}^0$ production occurs due to $\bar{s} \to s$ oscillation.

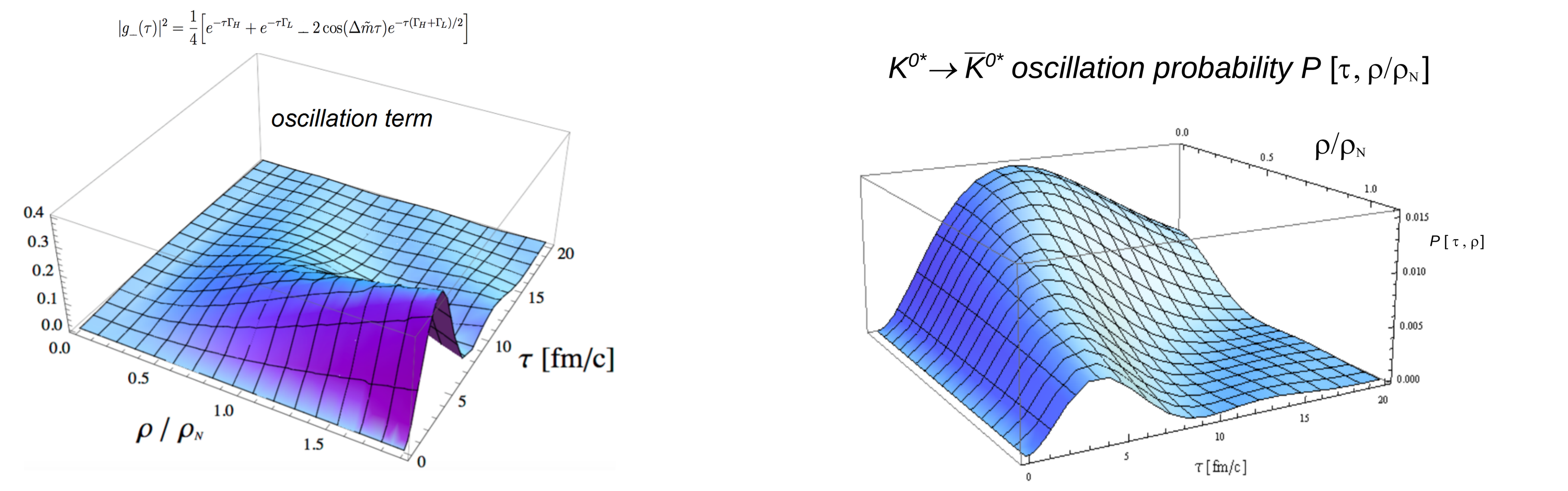
Can $\bar{s} \to s$ (1%) process be significant?

In p+A and A+A interactions at beam energy E ≈ 1.2AGeV, production of anti-Kaons occurs with ratio $\bar{K}/K \approx 5.10^{-3}$ due to binding of s-quarks into hyperons [4]. If oscillation processes ($\bar{s}d$) → ($\bar{d}s$) and ($\bar{d}s$) → ($\bar{s}d$) have the same probability, and e.g. P = 0.01 = 1%, such asymmetrical initial conditions can result in the increased $\bar{K}^0(\bar{d}s)$ yield by factor 2x - 3x above the expectations.

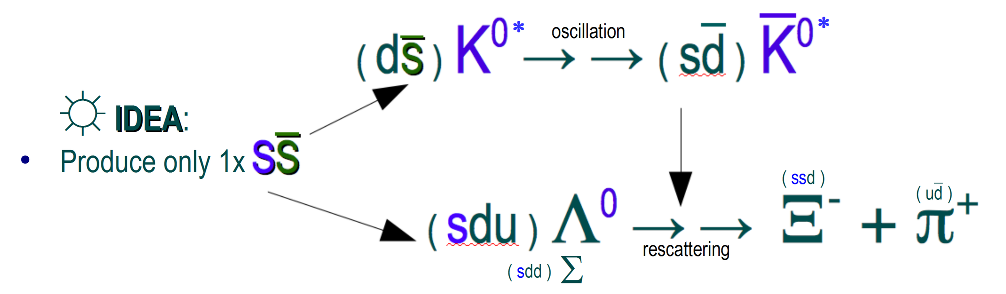


Probability of $K^{0*} \to \bar{K}^{0*}$ oscillation for $K^{0*}(892)$ neutral meson state in dense baryonic medium, at densities similar to nuclear density $\rho_N = 2x10^{17}$ kg/m³, using Γ_{11} = 48+12 MeV, Γ_{22} = 48+5 MeV, $|\Gamma_{12}|$ = 16 MeV, and assuming in-medium K^{0*} – anti-K^{0*} potential difference: $\Delta V = (\rho/\rho_N)$ 80 MeV.

Flavour oscillation $\bar{s} \leftrightarrow s$ in the medium is suppressed by baryonic density – dependent factor $(1-\theta)|q_H/p_H| = (1-\theta)|p_L/q_L|$ with CP violating differences being negligibe if $|\frac{p_L}{q_L}| = |\frac{q_H}{p_H}|$.



Could Ξ^-(ssd) yield be enhanced due to $\bar{s} \to s$?



Strangeness-exchange interactions during the rescattering process in A+A, p+A collisions can produce additional double strange Ξ(ssd) baryons, although only one ($s\bar{s}$) pair has been created in a dense baryonic medium. Production of two ($s\bar{s}s\bar{s}$) pairs remains strongly suppressed due to energy reasons.

Conclusions:

Ξ^- sub-threshold production can be enhanced

due to $K^{0*} \leftrightarrow \bar{K}^{0*}$ strangeness oscillation in the baryonic medium

excessive production of Ξ^- hyperons has been observed by HADES exp.[5]

References:

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[3] P. Filip, talk at SQM 2016 conference, July 28th at Berkeley.
[4] W. Cassing et al. Int. Jour. Mod. Phys. E17 (2008) 1367.
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*e-mail: Peter.Filip@savba.sk