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Yet stronger enhancement of Ξ production at SIS

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1. Motivation

HADES experiment: complete measurement of hadrons containing strange quarks in Ar+KCl collisions at 1.76 *A*GeV [1,2,3,4]

Observation: anomalously large ratio Ξ/Λ = (5.6±3)x10^{-3} [4]
- exceeds prediction of both statistical model [5] and transport calculation [6]

2. Our approach

1. We study relative distribution of strangeness among various hadron species. We are not interested how hadrons are produced; we know the final K^+ multiplicity.
2. Strangeness is conserved on event-by-event basis. Cascades are only produced in events with at least two strange quarks generated.
   - *this version of statistical model predicts about a factor ½ less cascades than the conventional one* [5]
3. Isospin composition is assumed to be in accord with the incoming ratio of η=(A-Z)/Z=1.14 for Ar+KCl collisions. *The experimental estimate of the number of Σ's does not agree with this. We alternate also this estimate.*
4. We take into account experimental centrality trigger. *This brings additional suppression factor ½ of cascades w.r.t. K^+'s and Λ's.*
5. We study the influence of in-medium potentials on multiplicity ratios. This brings the calculation closer to data but not completely into accord with data.

3. The minimal statistical model

- No antibaryons at SIS energies
- Strangeness is produced in pairs of S=1 and S=-1 hadrons; S=1 is carried away with K^+ and/or K^0 without thermalisation. There remains thermalised medium with net strangeness.
- We distinguish multi-kaon event classes by net strangeness of the thermalised medium. Due to correspondence to the number of kaons produced, we call them *single-kaon events, double-kaon events, triple-kaon events,* etc. Cascades cannot be produced in single-kaon events.
  Probability of n-kaon event is Poissonian

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

  The *probability of strangeness pair production* depends on freeze-out volume

$$W = \lambda V_{\rm fo}^{4/3}$$

  with λ being constant. Thus *W depends on centrality.*
- The *centrality-averaged probability of strangeness pair creation W* can be related to the experimentaly measured K^+ multiplicity

$$\langle W \rangle = (1+\eta)\mathcal{M}_{K^+}$$

  we assume that the ratio K^0/K^+ is given by η
- Then λ can be determined and we can establish the *probabilities of n-kaon events*
- Strange quarks are distributed into hadrons statistically. Probability to release strangeness in form of hadron *a* is

$$P_a = z_S^{s_a}\, V_{\rm fo}\, p_a = z_S^{s_a}\, V_{\rm fo}\, \nu_a\, e^{B_a \frac{\mu_{B,\rm fo}}{T_{\rm fo}}} f(m_a, T_{\rm fo}),$$
$$f(m,T) = \int \frac{{\rm d}^3 p}{(2\pi)^3} e^{-\frac{\sqrt{p^2+m^2}}{T}} = \frac{m^2 T}{2\pi^2} K_2\left(\frac{m}{T}\right)$$

  with baryon number B_a, degeneracy factor v_a and K_2 the Mac Donald function
- The normalization factor z_s depends on event class
- Impact-parameter-averaged multiplicity of species *a* can now be calculated

$$\mathcal{M}_a = \sum_i \mathcal{M}_a^{(i)}$$

  where we sum over multiplicities in different event classes

References

[1] G. Agakishiev *et al.*, Phys. Rev. C **80** (2009) 025290
[2] G. Agakishiev *et al.*, Phys. Rev. C **82** (2010) 044907
[3] G. Agakishiev *et al.*, Eur. Phys. J A **47** (2011) 21
[4] G. Agakishiev *et al.*, Phys. Rev. Lett. **103** (2009) 132301
[5] A. Andronic, P. Braun-Munzinger, K. Redlich, Nucl. Phys. A **765** (2006) 211
[6] L.-M. Chen, C.M. Ko, Y. Tzeng, Phys. Lett. B **584** (2004) 269

4. Selected results

Kaon ratios

$$R_{K^-/K^+} = \frac{\eta\, p_{\bar{K}}}{p_{\bar{K}} + p_\Lambda + p_\Sigma} Y_1$$

with

$$Y_1 = 1 - \frac{(1+\eta)\mathcal{M}_{K^+}\tilde{\zeta}^{(2)}\, p_\Xi}{\langle V_{\rm fo}\rangle (p_{\bar{K}} + p_\Lambda + p_\Sigma)^2} \qquad \tilde{\zeta}^{(2)} = \langle V_{\rm fo}^{\frac{4}{3}}\rangle \langle V_{\rm fo}\rangle / \langle V_{\rm fo}^{4/3}\rangle^2 \approx 1.04$$

The second term above is the correction due to correctly accounting for Ξ production only in double-kaon events. Here it is smaller than 0.02

Hyperon to kaon ratios

$$R_{\Lambda/K^+} = (1+\eta)\frac{p_\Lambda + \frac{\eta\, p_\Sigma}{\eta^2+\eta+1}}{p_{\bar{K}} + p_\Lambda + p_\Sigma} Y_1$$
$$R_{\Sigma/K^+} = \frac{(\eta^2+1)(\eta+1)}{2(\eta^2+\eta+1)} \frac{p_\Sigma}{p_{\bar{K}} + p_\Lambda + p_\Sigma} Y_1$$

Cascade production

In order to separate the effect of strangeness production, for Ξ calculate the ratio

$$R_{\Xi/\Lambda/K^+} = \eta \frac{p_\Xi/(p_{\bar{K}} + p_\Lambda + p_\Sigma)}{\langle V_{\rm fo}\rangle \left(p_\Lambda + \frac{\eta p_\Sigma}{\eta^2+\eta+1}\right)} Y_2 \qquad Y_2 = \frac{1}{2}\tilde{\zeta}^{(2)} \approx 0.52$$

the factor Y_2 is the correction due to exact strangeness conservation in each event, i.e. production of Ξ's only in multi-kaon events.

5. Comparison to data

In this table we compare data values with the results of our calculations. The calculated results also assume in-medium potentials for baryons and the kaons, which lead to changes of the yields. In the last column also the centrality trigger LVL1 is implemented via freeze-out volume averaging. In the fourth line we use the estimate of Σ production by HADES, in the fifth line we estimate Σ production from the isospin composition.

ratio	data	inclusive	triggered
$(K^-/K^+) \times 10^2$	$2.54^{+1.21}_{-0.91}$	2.55	2.55
Λ/K^+	$1.46^{+0.49}_{-0.37}$	1.50	1.50
Σ/K^+ (Hades)	$0.13^{+0.16}_{-0.12}$	0.29	0.29
Σ/K^+ (isospin)	$0.30^{+0.23}_{-0.17}$	0.29	0.29
$\Xi/\Lambda/K^+$	$0.20^{+0.16}_{-0.11}$	0.047	0.026

- Inclusion of in-medium potentials slightly improves the agreement with data, but the Ξ production is underestimated
- Inclusion of LVL1 centrality trigger effect decreases the calculated Ξ ratio by another factor of ½!!!
- We checked that earlier freeze out of cascades does not bring the calculation into agreement with data.

6. Conclusions

- In minimal statistical model the calculated Ξ multiplicity is even more suppressed w.r.t. other strange particles mainly by two effects overlooked so far:
  - exact strangeness conservation in each event which prevents Ξ's from being produced in single-kaon events
  - inclusion of centrality trigger which selects more central collisions with larger freeze-out volume
- We suggest that Ξ's most likely do not chemically equilibrate with other strange particles and leave the fireball after being produced. They must not annihilate.
  - double-hyperon processes may be effective here due to large baryon density: ΛΛ→ΞN, ΛΣ→ΞN, ΣΣ→ΞN
  - at antikaon potential U_{K^-}=-80 MeV the K^-Λ→πΞ reaction crosses the Ξ* pole and may have large cross-section

This presentation is based on
•E.E. Kolomeitsev, B. Tomášik, D.N. Voskresensky:
Strangeness Balance in HADES Experiments and the Ξ Enhancement, arXiv:1207.5738v1 [nucl-th]
•B. Tomášik, E.E. Kolomeitsev
Open and Hidden Strangeness in Hadronic Systems
Acta Phys.Pol. B Proc. Suppl. **5** (2012) 201 (arXiv:1112.1437 [nucl-th])