Subthreshold Ξ production in $p + A$ collisions in a BUU model

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Strangeness in Quark Matter
Utrecht, 10-15 July 2017

Introduction

HADES has measured Ξ^- production in

- $Ar + KCl$ at $\sqrt{s_{NN}} = 2.61$ GeV: [Phys.Rev.Lett. 103, 132301 (2009)]

  $\frac{P_{\Xi^-}}{P_{\Lambda+\Sigma^0}} = (5.6 \pm 1.2^{+1.8}_{-1.7}) \times 10^{-3}$

- $p + Nb$ at $\sqrt{s_{NN}} = 3.2$ GeV: [Phys.Rev.Lett. 114, 212301 (2015)]

  $(2.0 \pm 0.4 \pm 0.3) \times 10^{-4}$ Ξ^-/event

  $\frac{P_{\Xi^-}}{P_{\Lambda+\Sigma^0}} = (1.2 \pm 0.3 \pm 0.4) \times 10^{-2}$

Below the threshold of $\sqrt{s_{NN,thr}} = 3.25$ GeV

Ξ multiplicity is 25$\times$ the prediction of a statistical model

Only UrQMD can describe the data

- heavy resonances decaying to ΞKK wit BR=10%
- tuned to $p + Nb \rightarrow$ describe $Ar + KCl$

Introduction

Subthreshold strangeness production is interesting, because

- sensitive to reaction dynamics
  (collision of secondaries, Fermi motion, in-medium effects, etc.)
- strangeness is conserved $\rightarrow$ high threshold
  $\rightarrow$ still subthreshold at higher energies where large baryon densities are reached

$p + A$ reactions are important, because

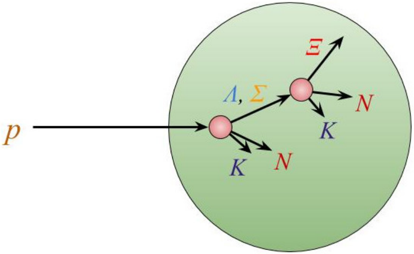
- intermediate step between $p + p$ and $A + A$
- cleaner than $A + A$
- less production channels
  (e.g. collision of two secondaries is unlikely)

Possible Ξ production channels:

$$\bar{K}Y \rightarrow \pi\Xi \quad (Y = \Lambda, \Sigma), \qquad YY \rightarrow \Xi N, \qquad \eta\Lambda \rightarrow \Xi K$$

Ξ production in $\Lambda/\Sigma + N$

New production mechanism:



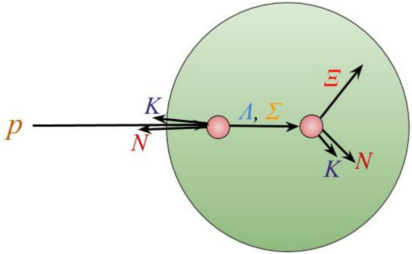
$p + N \rightarrow N + K + \Lambda/\Sigma$: $\sqrt{s_{NN}} = 3.2$ GeV c.f. $\sqrt{s_{thr}} = 2.55$ GeV for Λ

$\sqrt{s_{thr}} = 2.62$ GeV for Σ

$\Lambda/\Sigma + N \rightarrow N + \Xi + K$: $\sqrt{s_{\Lambda N}}_{max} = 3.05$ GeV c.f. $\sqrt{s_{thr}} = 2.75$ GeV

Ξ production in $\Lambda/\Sigma + N$

New production mechanism:



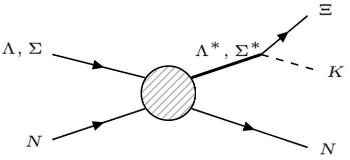
$p + N \to N + K + \Lambda/\Sigma$: $\sqrt{s_{NN}} = 3.2$ GeV c.f. $\sqrt{s_{thr}} = 2.55$ GeV for Λ
$\sqrt{s_{thr}} = 2.62$ GeV for Σ

$\Lambda/\Sigma + N \to N + \Xi + K$: $\sqrt{s_{\Lambda N}}_{max} = 3.05$ GeV c.f. $\sqrt{s_{thr}} = 2.75$ GeV

Cross section for $\Lambda/\Sigma + N \to N\Xi K$

Assume that Ξ production proceeds via an intermediate Λ^*/Σ^*

If everything else is also created via Λ^*/Σ^* resonances, then $\sigma_{YN,tot}$ = resonance production cross section



Ξ production: $\sigma_{YN\to\Xi} \approx BR_{Y^*\to\Xi K} \times \sigma_{YN,tot}$

$\sigma_{YN,tot} \approx 10$ mb (similar to $p + p$ total cross section)

$\Lambda(2100)$ $7/2^-$ $\quad I(J^P) = 0(\frac{7}{2}^-)$

Mass m = 2090 to 2110 ($\approx$ 2100) MeV
Full width Γ = 100 to 250 ($\approx$ 200) MeV

$\Lambda(2100)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\overline{K}$	25–35 %	751
$\Sigma\pi$	$\sim$ 5 %	705
$\Lambda\eta$	<3 %	617
ΞK	<3 %	491
$\Lambda\omega$	<8 %	443
$N\overline{K}^*(892)$	10–20 %	515

$BR_{Y^*\to\Xi K} \approx 3\%$

$\to \sigma_{YN\to\Xi} \approx 0.3$ mb

BUU

Version of BUU developed by Gy. Wolf

24 baryon resonances are propagated

Elementary cross sections for (non-strange) particle production are described by resonance production and decays

Resonance properties and creation cross sections are determined by a fit to πN and NN data

Successfully applied to strangeness production near and below threshold

[H.W. Barz, M.Z., Gy. Wolf, B. Kämpfer, NPA 705 ('02) 223]

[H. Schade, Gy. Wolf, B. Kämpfer, PRC 81 ('10) 034902]

Ξ^- production in BUU ($p + Nb$ at $\sqrt{s_{NN}} = 3.2$ GeV)

With the "naive" cross section, $\sigma_{YN \to \Xi} \approx 0.3$ mb:

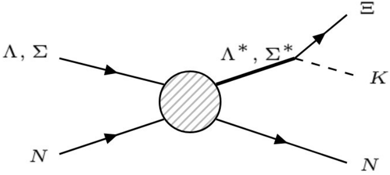
10×10^{-4} Ξ^-/event too much!

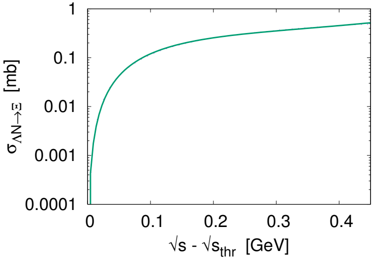
HADES experiment:

$(2.0 \pm 0.4 \pm 0.3) \times 10^{-4}$ Ξ^-/event

BUT: $\sqrt{s}$ dependence of $\sigma_{YN \to \Xi}$ was neglected

"Model" for $YN \to \Xi$ cross section





Include the (better) known Λ^*-s and Σ^*-s from PDG

Assume (universal) constant Y^* production matrix elements

Assume universal $BR_{Y^* \to \Xi K} = 3$ %

Include mass dependence of Γ_{Y^*}

Add contributions incoherently

Results for $p + Nb$ at $\sqrt{s_{NN}} = 3.2$ GeV

Using the above "model" in BUU we get:

$$1.4 \times 10^{-4} \quad \Xi^-/\text{event}$$

$$\frac{P_{\Xi^-}}{P_{\Lambda+\Sigma^0}} = 0.68 \times 10^{-2}$$

HADES experiment:

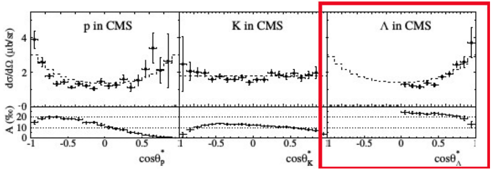
$$(2.0 \pm 0.4 \pm 0.3) \times 10^{-4} \quad \Xi^-/\text{event}$$

$$\frac{P_{\Xi^-}}{P_{\Lambda+\Sigma^0}} = (1.2 \pm 0.3 \pm 0.4) \times 10^{-2}$$

BUT: Y production is isotropic in the BUU code

If it were forward peaked, then it would enhance Ξ production!

Results for $p + Nb$ at $\sqrt{s_{NN}} = 3.2$ GeV



[COSY-TOF, EPJ A46 (2010) 27]

Angular distribution measured at three energies

Expanded in Legendre-polinomials

With anisotropic hyperon production in BUU we get:

$$2.16 \times 10^{-4} \quad \Xi^- / \text{event}$$

$$\frac{P_{\Xi^-}}{P_{\Lambda+\Sigma^0}} = 1.14 \times 10^{-2}$$

HADES experiment:

$$(2.0 \pm 0.4 \pm 0.3) \times 10^{-4} \quad \Xi^- / \text{event}$$

$$\frac{P_{\Xi^-}}{P_{\Lambda+\Sigma^0}} = (1.2 \pm 0.3 \pm 0.4) \times 10^{-2}$$

Conclusions

The high Ξ^- multiplicity found by HADES in subthreshold $p + Nb$ can be explained via the reaction

$$Y + N \to \Xi K N$$

Both the energy, and the two units of strangeness are accumulated in two steps

Reasonable assumptions on the microscopic cross sections

Clearly non-thermal production mechanism

The angular distribution of hyperon production is relevant! (+50%)

Calculation for A+A to come