Energy dependence of the Λ/Σ^0 production cross section ratio in p–p interactions.

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Abstract. Measurements of the near threshold Λ and Σ^0 production via the $pp \to pK^+\Lambda/\Sigma^0$ reaction at COSY–11 have shown that the Λ/Σ^0 cross section ratio exceeds the value at high excess energies (Q $\geq$ 300 MeV) by an order of magnitude. For a better understanding additional data have been taken between 13 MeV and 60 MeV excess energy.

Within the first 20 MeV excess energy a strong decrease of the cross section ratio is observed, with a less steep decrease in the higher excess energy range.

A description of the data with a parametrisation including $p-Y$ final state interactions suggests a much smaller $p-\Sigma^0$ FSI compared to the $p-\Lambda$ system.

INTRODUCTION

At the COSY–11 facility [1] measurements of the Λ and Σ^0 hyperon production were performed via the $pp \to pK^+\Lambda$ and $pp \to pK^+\Sigma^0$ reactions close to threshold [2] resulting in a cross section $\sigma(\Lambda)$ for the Λ production which is more then one order of magnitude larger than the cross section $\sigma(\Sigma^0)$ for the Σ^0 production.

Since the quark contents of these two hyperons are the same, based on the isospin relations only, the ratio of the cross sections $\mathcal{R} = \sigma(\Lambda)/\sigma(\Sigma^0)$ should be equal to three. In fact at high excess energies [3] a ratio of ~ 2.5 is observed in contrast to the by more then one order of magnitude larger $\mathcal{R}$ at threshold.

In order to understand this behavior, measurements [4] in the intermediate energy range (13 MeV $\leq Q \leq$ 60 MeV), where the ratio $\mathcal{R}$ was expected to decrease from ~ 28 to ~ 2.5, have been performed.

EXPERIMENT

The measurements of the hyperon production were performed at the COSY–11 facility [1, 5] (see figure 1) at the **Co**oler **Sy**nchrotron COSY-Jülich [6].

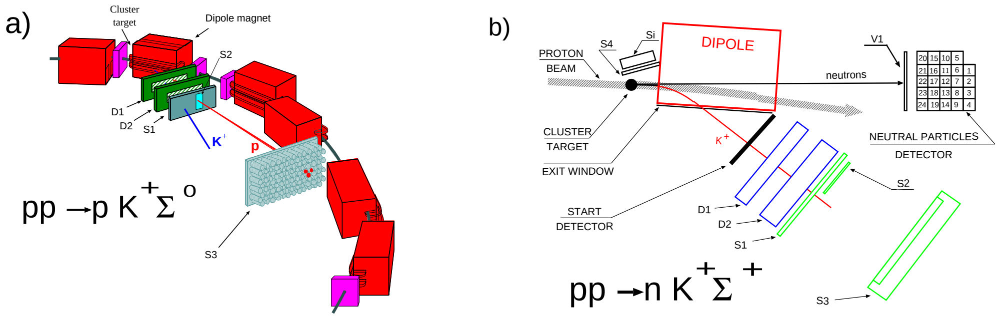

FIGURE 1. a) COSY–11 facility. b) Setup extended by the start and neutral particle detectors used in the measurements of the $pp \to nK^+\Sigma^+$ reaction.

One of the regular COSY dipole magnets serves as a magnetic spectrometer with a H_2 cluster beam target [7] installed in front of it. The interaction between a proton of the beam with a proton of the cluster target may lead to the production of neutral hyperons (Σ^0, Λ) via the reactions $pp \to pK^+\Lambda(\Sigma^0)$.

Events of the $pK^+\Lambda(\Sigma^0)$ production are selected by the detection of both positively charged particles in the exit channel (i.e. proton and K^+). The unobserved neutral particle is identified via the missing mass method.

Positively charged ejectiles are directed from the circulating beam by the magnetic field of the dipole towards the inner part of the COSY ring, where they are registered in a set of two drift chambers D1 and D2 for the track determination. Their momenta are reconstructed by tracking back the particles through the well known magnetic field to the assumed interaction point. The velocities of the ejectiles are given by a measurement of the time of flight between the S1(S2) start and the S3 stop scintillator hodoscopes from which in combination with the momentum the invariant mass of the particle is given. Therefore, the four-momentum vectors for all positively charged particles are known and the four-momentum of the unobserved neutral hyperon is uniquely determined.

To avoid systematical uncertainties as much as possible, COSY was operated in the ”supercycle mode” i.e. the beam momenta were changed between the cycles, such that for example 10 cycles with a beam momentum corresponding to the excess energy $Q = 20$ MeV above the Σ^0 threshold were followed by one cycle with the same Q above the Λ production threshold. The ratio of the number of the cycles was chosen inversely proportional to the ratio of the expected cross sections for the Λ and Σ^0 production. Thus, both cross sections were measured under the same conditions and possible changes in the detection system did not influence the data taking procedure, especially for the determination of the cross section ratio.

The extention of the detection system by an additional neutral particle detector (see figure 1b) allows for the measurements of neutrons in the exit channel. This upgrade of the detection system allows to extend the study reported in this paper into the production of charged hyperons, e.g via the $pp \to nK^+\Sigma^+$ reaction. To increase the acceptance an additional start detector for K^+ was installed in the system.

RESULTS

The hyperon production via $pp \to pK^+\Lambda(\Sigma^0)$ has been studied in the excess energy range between 13 and 60 MeV. In figure 2a) and figure 2b) the excitation functions and the energy dependence of the cross section ratio are shown, respectively. The most drastic decrease of the cross section ratio is observed between 10 MeV and 20 MeV following by a less steep decrease towards higher Q-values.

The first published close–to–threshold data [2] have triggered many theoretical discussions. The results of available calculations are shown in figure 2b) and are briefly discussed in the following section.

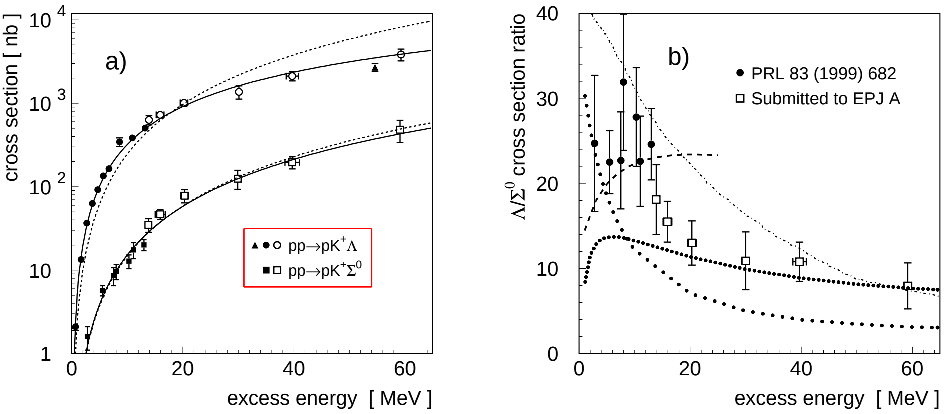

FIGURE 2. a) Total cross sections for the $pp \to pK^+\Lambda$ and $pp \to pK^+\Sigma^0$ production (full symbols [2, 8], open symbols [4] and triangle [9]). b) Cross section ratio for the $pp \to pK^+\Lambda$ and $pp \to pK^+\Sigma^0$ reactions.

Comparison with theoretical predictions

Presently different theoretical calculations with various dominant production mechanisms are available which reproduce at least the trend of the data, see figure 2b).

Calculations by Sibirtsev, Tsushima et al. [10, 11] were performed within two different models. In the first one – Boson Exchange Model – (dense dotted line) pion and Kaon exchange is considered as the most important mechanism of the hyperon production [12]. The second model (dotted line) bases on the assumption that the hyperon is produced in the decay of N^* resonances excited via the exchange of π, η and ρ mesons [11, 13].

Hyperon production via N^* resonances was also investigated by Shyam et al. [14] (dashed-dotted) where $N^*(1650)$, $N^*(1710)$, $N^*(1720)$ were assumed to be excited by the exchange of the π, ρ, ω and σ mesons. The authors state that, at least close to threshold, the dominant contribution to the hyperon production is the $N^*(1650)$ resonance.

Gasparian et al. [15] performed calculations within the Jülich Meson Exchange Model, where π and K-exchange was assumed including the interference between these two amplitudes (dashed line). It is observed by the authors, that in the case of the Λ

production K-exchange is dominant and consequently constructive or destructive interference between π and K-exchange give similar results. For the Σ^0 production, however, the strength of the contributions from π and K exchange are comparable resulting in a strong reduction of the Σ^0 production with a destructive interference by which the observed cross sections at threshold are reproduced. Within their calculations [15, 16] the energy dependence of the cross section for other isospin channels are predicted like the Σ^+ production in the reaction $pp \to nK^+\Sigma^+$. Here, the predicted behavior of the cross sections for destructive and constructive π and K-exchange is opposite to that observed in Σ^0 production. For a destructive interference the cross section for $pp \to nK^+\Sigma^+$ is expected to be a factor of three higher and for constructive interference a factor of three lower than the cross section for $pp \to pK^+\Sigma^0$.

Data in the other isospin channels will help to extract the dominant mechanisms in the threshold hyperon production.

Measurements of the $pp \to nK^+\Sigma^+$ reaction have been already performed at the COSY–11 facility. The data are presently under analysis [17].

Effective range parameters

The final state interactions of a two body subsystem in a 3-body final state like pK^+Y influence the excitation function in the threshold region and its analysis allows to extract information on the effective range parameters (for review see ref. [18]). A parametrisation of the cross section which relates the shape of the threshold behavior to the effective range parameters is e.g. given by Fäldt and Wilkin [19]:

$$\sigma = const \cdot \frac{V_{ps}}{\mathrm{F}} \cdot \frac{1}{\left(1 + \sqrt{1 + \frac{Q}{\varepsilon'}}\right)^2} = C' \cdot \frac{\mathrm{Q}^2}{\sqrt{\lambda(\mathrm{s}, \mathrm{m}_p^2, \mathrm{m}_p^2)}} \cdot \frac{1}{\left(1 + \sqrt{1 + \frac{Q}{\varepsilon'}}\right)^2}\,. \qquad (1)$$

The phase space volume V_{ps} and the flux factor F are given by [20]:

$$V_{ps} = \frac{\pi^3}{2} \frac{\sqrt{\mathrm{m}_p\,\mathrm{m}_{K^+}\,\mathrm{m}_Y}}{(\mathrm{m}_p + \mathrm{m}_{K^+} + \mathrm{m}_Y)^{\frac{3}{2}}}\,\mathrm{Q}^2, \qquad \mathrm{F} = 2\,(2\pi)^{3n-4}\,\sqrt{\lambda(\mathrm{s}, \mathrm{m}_p^2, \mathrm{m}_p^2)}\,. \qquad (2)$$

with the triangle function $\lambda(x,y,z) = x^2 + y^2 + z^2 - 2xy - 2yz - 2zx$.

The results of χ^2 fits using the Fäldt and Wilkin formula are presented in figure 2a) by the solid lines (the dotted lines correspond to pure S-wave phase space distributions). The parameter ε', which is related to the strength of the $p - Y$ final state interaction, and the normalization constant C' were extracted by the fits performed for each reaction separately resulting in:

$C'(\Lambda)$ = (98.2 ± 3.7) nb/MeV^2 $\qquad$ $\varepsilon'(\Lambda)$ = $(5.51^{+0.58}_{-0.52})$ MeV

$C'(\Sigma^0)$ = (2.97 ± 0.27) nb/MeV^2 $\qquad$ $\varepsilon'(\Sigma^0)$ = (133^{+108}_{-44}) MeV.

Assuming only S-wave production, the $p-\Lambda(\Sigma^0)$ systems can be described using the Bergman potentials [21], where scattering length $\hat{a}$ and effective range $\hat{r}$ are given by:

$$\hat{a} = \frac{\alpha+\beta}{\alpha\beta}, \qquad \hat{r} = \frac{2}{\alpha+\beta}, \tag{3}$$

with a shape parameter β, and $\varepsilon' = \alpha^2/2\mu$ where μ is the reduced mass of the $p-Y$ system [21]. The negative value of α is chosen since (at least for $p-\Lambda$) an attractive interaction is expected [22, 23].

The parameters $\hat{a}$ and $\hat{r}$ are interdependent and only correlations between them can be deduced. In figure 3 the correlations obtained for the $p-\Sigma^0$ and $p-\Lambda$ systems are presented by solid and dashed lines, respectively. The errors in ε' are reflected in the error ranges and shown in the figure by the thinner lines. The cross symbol represents the singlet and triplet averaged value of the $p-\Lambda$ scattering length and effective range parameters extracted from a FSI approach in threshold Λ production [24].

It seems that the $p-\Sigma^0$ FSI are much smaller than the FSI for $p-\Lambda$ system.

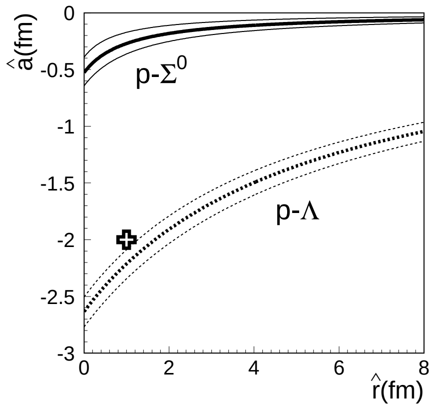

FIGURE 3. Correlation between the $p-\Sigma^0$ (solid lines) and $p-\Lambda$ (dashed lines) effective range parameters.

SUMMARY

Measurements of the energy dependence of the total cross sections for the $pp \to pK^+\Lambda$ and $pp \to pK^+\Sigma^0$ production performed at the COSY–11 facility at excess energies between 14 and 60 MeV show that the cross section ratio strongly decreases in the excess energy range between 10 and 20 MeV.

Different theoretical models are able to describe the data within a factor of two with more or less the same quality, even though they differ in the dominant contribution to the production mechanism. Data in the hyperon sector are still too limited to put exact constrains on the existing models.

The new data suggest that the final state interaction in the $p-\Sigma^0$ channel is much weaker than in the case of the $p-\Lambda$ system.

Measurements of the hyperon production in other isospin channels like e.g. the $pp \to nK^+\Sigma^+$ reaction measured recently at COSY–11 will help to disentangle the production mechanisms in the threshold region.

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