Associated Strangeness Production in the Threshold Region

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Associated strangeness production close to threshold is a particularly clean example of how energy is converted into hadronic matter. Final results from the completed experiments of the PS185 collaboration at LEAR/CERN, using the antiproton-proton interaction to produce antihyperon-hyperon pairs, demonstrate that such studies form a powerful tool. First results from the ongoing investigations of the COSY-11 collaboration at COSY-Jülich, measuring the strangeness dissociation into both hyperon-kaon and kaon-kaon pairs from proton-proton scattering, are presented and plans for further investigations are discussed. Finally, an interesting possibility for future studies of the strangeness production mechanism in the antiproton-proton interactions with antiproton beams of momenta $\geq 5$ GeV/c is suggested.

1. INTRODUCTION

The focus of the experiments discussed in this contribution is to explore the physics of strange-antistrange quark production and the role of these quarks in the configuration of the emerging hyperons and/or mesons. In view of the attempts to understand the nature of the quark-flavour composition, its structure, and its creation process, the associated strangeness production is of fundamental interest. It is essential that different complementary tools are used for the understanding of the complex hadronic systems. The first results on electromagnetic probes have been reported during the present conference. However, we concentrate on the hadronic entrance channel interaction.

In a systematic study, the PS185 collaboration at the Low-Energy Antiproton Ring at CERN (LEAR/CERN) investigated antihyperon-hyperon ($\bar{Y}Y$) production and the decay via the reaction $\bar{p}p \rightarrow \bar{Y}Y \rightarrow \bar{p}\pi^{+} p\pi^{-}$ in the threshold region. Cross sections, polarization, spin correlations and singlet fractions have been extracted. At the COler SYnchrotron COSY-Jülich the COSY-11 collaboration investigated the associated strangeness production via two channels. In the $pp \rightarrow pKA$ reac-

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tion \[2,3\] the strangeness is dissociated into a hyperon and a meson and in the reaction \[4,5\] the antistrange-strange quark pair is divided between two mesons. Total cross sections have been determined and lead to the first physics interpretations.

Theoretical models in nuclear physics, in particular heavy-ion physics, depend critically on input from elementary particle interactions. Meson-nucleon and meson-meson interactions dominate the nucleus-nucleus scattering mechanisms. Therefore, knowledge of the kaon production cross section in the elementary NN interaction is important for studies of the production of hypernuclei in nucleon scattering on nuclei, and for investigations of the strangeness production mechanism in heavy-ion collisions, which may provide information about hot, dense nuclear matter and eventually the existence of a quark-gluon plasma. More details and applications are given in the contribution by G. Brown in these proceedings.

Both experimental investigations - PS185 and COSY-11 - have been carried out in the production threshold region offering the advantage that
1) experimentally the reaction products are confined in a forward cone, whereas background reactions populate the phase-space more homogeneously and
ii) the momentum transfers are relatively large with only the lowest partial waves contributing, which should simplify the theoretical framework.

Finally, a natural continuation of the associated strangeness production would be a study and a comparison of the two systems $\bar{\Omega}\Omega$ and $\phi\phi\phi$ \[6–8\], which both contain three $s$ quarks and three $\bar{s}$ quarks in different configurations at rather similar masses as 3.344 GeV/$c^2$ and 3.058 GeV/$c^2$, respectively.

1.1. The two Accelerators LEAR and COSY

The LEAR cooler and accelerator \[9\] might well be regarded as the father of a whole generation of further similar machines as the cooler at Indiana \[10\], the CELSIUS ring in Uppsala \[11\], and the COSY facility at Jülich \[12\]. Whereas LEAR, with an antiproton beam of momenta $\leq 2 \text{ GeV}/c$, was shut down at the end of 1996 after 15 years of very successful operation, COSY is just at the beginning of an extensive program using proton beams with momenta $\leq 3.4 \text{ GeV}/c$. Polarized proton beams are presently under development. Both machines have electron as well as stochastic cooling facilities, resulting in a high phase-space density with momentum resolution of $\Delta p/p \approx 10^{-4}$. At both accelerators, internal and external target stations were/are used.

For the $\bar{p}p$ interaction at LEAR a total energy of $\sqrt{s} = 2.43 \text{ GeV}$ was available at the maximum beam momentum and, due to the baryon number $B = 0$, this energy could entirely be converted into newly created hadronic matter. At COSY the $pp$ interaction results in a maximum total energy of $\sqrt{s} = 2.86 \text{ GeV}$ but, due to conservation of the baryon number $B = 2$, the energy which may be converted into hadronic matter is about 1 GeV.

In order to demonstrate the complementarity of the two accelerators and their
experiments, a brief summary of results from one experiment at LEAR will be given next, before turning to the first results from COSY.

2. $\bar{Y} - Y$ PRODUCTION in PS185

The PS185 collaboration [1] has collected high-precision data on the $\bar{p}p \rightarrow \bar{Y}Y$ reactions at LEAR, with the following conclusions. The excitation functions of the $\bar{\Lambda}\Lambda$ and $\bar{\Lambda}\Sigma^0 + cc$ productions follow a similar pattern, as can be seen in Fig. 1. The measured cross sections for the charged $\Sigma$ hyperons do not agree with predictions based on quark-line diagrams but rather seem to favour a meson-exchange picture [13]. An early onset of p-wave contributions to the cross section is found near threshold.

![Figure 1. Total cross sections for: $ar{p}p \rightarrow \bar{\Lambda}\Lambda$ (crosses), $ar{p}p \rightarrow \bar{\Lambda}\Sigma^0 + cc$ (filled circles), $ar{p}p \rightarrow \bar{\Sigma}^+\Sigma^+$ (open circles), and $ar{p}p \rightarrow \bar{\Sigma}^-\Sigma^-$ (open square).](image)

![Figure 2. Data for the parameter $A$ as collected by the PS185 collaboration.](image)

An universal behaviour of the $\bar{Y}Y$ differential cross sections, showing a strong forward rise followed by a flat distribution, is observed except for the $\bar{\Sigma}^-\Sigma^-$ channel. The shapes of the $\bar{\Lambda}\Lambda$ differential cross sections and the spin correlations appear to be essentially energy independent which is not the case for the $\Lambda(\bar{\Lambda})$ polarisation. The $\bar{\Lambda}\Lambda$ pairs are produced in parallel-spin configurations with a weighted mean singlet fraction of $<S_F> = 0.007 \pm 0.009$, whereas the spins of the $\bar{\Lambda}\Sigma^0 + cc$ channel show a more statistical distribution. Finally, the normalized asymmetry value $A = (\alpha + \bar{\alpha})/(\alpha - \bar{\alpha})$ (where $\alpha(\bar{\alpha})$ is the asymmetry parameter for $\Lambda(\bar{\Lambda})$) has a
value of 0.006 ± 0.014 (see Fig. 2], which is, at least on this level, consistent with zero, as expected if CP is conserved.

3. Associated Strangeness Production in the pp Scattering

The first results of elementary reactions have been obtained with COSY: i) at the installation COSY-11, measurements for the processes: \( pp \rightarrow pp\eta, pp \rightarrow pp\eta', \) \( pp \rightarrow ppK^+K^-, pp \rightarrow pK^+\Lambda, \) and \( pp \rightarrow pK^+\Sigma^0 \) ii) at the facility TOF, measurements for the \( pp \rightarrow pK^+\Lambda \) reaction at higher excess energies.

The COSY-11 installation \[14\] is an internal setup in a bending section of the COSY ring. Figure 3 shows a sketch of the experiment. In front of a machine dipole, a hydrogen cluster target \[15\] is installed. Positively charged reaction products - which have a reduced momentum compared to the primary proton beam - are bent to the inner region of the ring and are detected with a system of drift chambers and scintillators. Negatively charged ejectiles are detected by a silicon pad detector arrangement which follows a long scintillation detector in the dipole gap; these counters are not seen in the figure.

3.1. Strangeness Production into \( pK^+\Lambda \)

In Fig. 4, the world set of data for the \( pp \rightarrow pK^+\Lambda \) reaction up to an excess energy of 200 MeV is shown. Before the startup of COSY, the lowest-energy data point for

\[ \text{Figure 3. The COSY-11 installation in a bending section of the COSY ring. The ejectile momenta are reconstructed using the track information from: the drift chambers D1, D2 and time of flight from the scintillator hodoscopes S1, S2 and S3. The plotted tracks result from MC calculations of some } pp \rightarrow ppK^+K^- \text{ events at an excess energy of 2 MeV.} \]
the total production cross section was at \(\approx 160\) MeV excess energy [16]. (Inclusive \(K^+\) production for a limited angular range was performed at SATURNE for lower excess energies [17].) In the threshold region, several data points have been added by experiments at COSY, where the result at the highest momentum is consistent with the lowest bubble chamber data [16]. The lines represent different model calculations. The parametrisations of Randrup and Ko [18] and of Schürmann and Zwermann [19] (solid lines), and new calculations of Fällt and Wilkin [20] (range between dotted lines) and Sibirtsev [21] (dashed line), are shown.

A crucial requirement for measuring cross sections in the threshold region is an exact knowledge of the beam momentum, which is the dominant error for the excitation curve. The COSY-11 data were used by themselves for the calibration of the beam momentum. The absolute momentum setting for a fixed COSY optics is limited to the order of \(10^{-3}\) due to an insufficient knowledge of the orbit length of the COSY beam. The relative error for a momentum change at the same optics, however, is negligible. Therefore a data set taken in one run with a fixed optics can be used for the calibration. The data are fitted by a phase-space distribution including \(p\Lambda\) final-state interaction and the Coulomb correction for the \(pK^+\) system, from which the correct excess energy could be extracted. The deviation from the nominal excess energy given by COSY was as little as 0.2 MeV [3].

### 3.2. Strangeness Production into \(pp K^+K^-\)

The production of a \(K^+K^-\) meson pair is very interesting in view of the existence of \(K\bar{K}\) molecules and especially for the structure of the objects \(f_0(980)\) and \(a_0(980)\). The structure of these two resonances has provoked a long standing discussion in the literature describing them as normal \(q\bar{q}\) states, exotic hybrids, hadronic \(K^+K^-\)
molecules and even glueball candidates. Again, they have been at the center of attention during the recent HADRON’97 conference where the controversial discussion could best be summarized by three presentations given

i) by Lafferty [22] from the OPAL collaboration, which observed the decay $Z^0 \rightarrow f_0(980), f_2(1270),$ and $\phi(1020),$ and conclude that all features of the $f_0(980)$ are consistent with a pure $q\bar{q}$ scalar-meson description,

ii) by Lebrun [22] from the FERMILAB E-687 collaboration, which found a strong $f_0(980)$ resonance in the invariant mass of two oppositely-charged pions in the $D_s \rightarrow \pi^+\pi^-\pi^+$ decay, but observed no such resonance in the $D^+ \rightarrow \pi^+\pi^-\pi^+$ channel, an indication of a significant strangeness component in the $f_0(980)$ resonance. However, for final conclusions additional data would be required,

iii) by Kirk [22] from the OMEGA collaboration, which measured central proton-proton collisions and found that “the $f_0(980)$ acts in an opposit fashion from all known $q\bar{q}$ states”. This observation is based on a small momentum transfer to the produced resonance state, as typically expected for gluon-rich mechanisms.

For a general review of the present stage of speculations about the scalar mesons and glueballs from the theoretical and experimental point of view see ref. [23,24].

![Figure 5](image1.png)

**Figure 5.** Squared invariant mass of the third charged ejectile versus the squared missing mass in the pp system for data at 3.321 GeV/c beam momentum.

![Figure 6](image2.png)

**Figure 6.** Squared invariant mass of the third particle vs. the missing mass in the ppK$^+$ system. Two events remain consistent with a $pp \rightarrow ppK^+K^-$ hypothesis.

The first results of the COSY-11 collaboration on $K^+K^-$ meson pair production in the $pp \rightarrow ppK^+K^-$ reaction are given in Figs. [6] and [4], which show missing
masses vs. the invariant mass of the third positively-charged particle. The gray region indicates the invariant mass range which is accepted for the kaons in the further analysis. The data result from a run at 3.321 GeV/c, which corresponds to an excess energy of 6.1 MeV. Two events could be selected with a clear signature for the $K^+K^-$ production. The resulting cross section is $\approx 500pb$. In the measurement below threshold, made with comparable luminosity, no events were observed. At COSY-11, further data on $K^+K^-$ production have been taken at different excess energies, with an expected yield of some ten events for each momentum setting. The data are under evaluation and will give an excitation curve in the threshold region which might serve for a first comparison to theoretical expectations. Preliminary results seem to indicate that the relative cross section increase with increasing excess energy ($6 \rightarrow 27$ MeV) is much smaller than would be expected by a four-body phase-space distribution for the reaction $pp \rightarrow pp K^+K^-$. On an absolute scale, no theoretical cross section predictions to which the present data could be compared are available.

4. Triple Associated Strangeness Production

A systematic study of $\bar{Y}Y$ pairs with increasing strangeness content is certainly interesting due to the change of quark dynamics in the different flavour composition of hadronic matter. As more and more up and down quarks are replaced by strange quarks to produce the higher-mass baryons, the importance of boson-exchange contributions may diminish. At the same time, the gluonic degrees of freedom may become of increasing significance. The possibility of observing three $\bar{s}$ and three $s$ quarks in different hadronic environments should be stressed, i.e. the production into the final channels of an $\bar{\Omega}\Omega$ baryon pair compared to three $\Phi$ mesons ($\Phi\Phi\Phi$). Certainly, a study of such production mechanisms will contribute to the knowledge of dynamics in the quark-gluon sector. Angular distributions of the production of $\bar{\Omega}\Omega$ baryon pairs could provide further insight. Whereas $\Phi\Phi$ meson production will always result in symmetric angular distributions since they are indistinguishable, the $\bar{\Omega}$ (or $\Omega$) would be symmetric around 90° only if the intermediate state is a compound like gluonic system. If, however, a meson-exchange process is dominant, such symmetry would most likely be broken.

A distinct feature of the $\bar{\Omega}\Omega$ production is the creation of two spin 3/2 objects. Results from the $\bar{\Lambda}\Lambda$ PS185 experiment provide proof of a clear dominance of the triplet $\bar{s}s$ quark production in the threshold region. Since in $\bar{\Omega}$ ($\Omega$) the three $s$ quarks (three $\bar{s}$ quarks) are orientated parallel, the three $\bar{s}s$ pairs produced out of the gluonic intermediate state must have spin-parity quantum numbers $3^-$, whereas in the case of triple $\Phi\Phi\Phi$ production such a correlation is not required. Figure 7 shows a symbolic representation of a quark-line diagram. It would certainly be very interesting to observe which type of configuration is preferred by nature.

To end by quoting Dover from his conclusions at the Workshop on Physics at SuperLEAR in October 1991: "Neither of these pictures - meson exchange or quark mechanisms - offers reliable predictive power, although estimates for $\bar{p}p \rightarrow \Omega\Omega$ were
Figure 7. Intuitive quark-flow diagram for reaction products following the \( \bar{p}p \) interaction into the channels: \( \Omega \Omega \), and \( \Phi \Phi \).

presented”. Based on the similar mass values of the two systems, he speculated further that near the \( \Omega \Omega \) threshold, bound states which decay via \( \Omega \Omega \rightarrow 3\Phi \) in a natural way may be found.

In this contribution, the mutual complementarity of different experiments has been demonstrated. Using different tools at different accelerators, a unique understanding of complicated hadronic matter should arise.

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