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ASSOCIATED HYPERON PRODUCTION AT COSY*

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At the new COSY cooler synchrotron several experimental facilities are in operation at internal and external target stations. One main topic of the present experiments is strangeness production with emphasis to the threshold region. The combination of a high quality low emittance proton beam with high acceptance detector systems allows precise and complete experiments.

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1. Introduction

The Cooler Synchrotron COSY in Jülich started operation end of 1993. After the IUCF cooler in Bloomington and the CELSIUS ring in Uppsala it is presently the youngest of a new generation of proton accelerators with phase-space cooling. COSY provides unpolarized and polarized beams with momenta up to $> 3{,}4$ GeV/c for high precision proton-proton and proton-nucleus interaction studies. In the momentum range of COSY one can reach more than 1 GeV free energy in proton proton reactions. There are several thresholds for production of baryon excitations, of long living mesons like π, η, ω and Φ and of associated strangeness production into $K\bar{K}$ and KY.

At COSY much effort is put into the preparation of high quality beams by phase-space cooling. Extremely thin internal targets are in operation which minimize the disturbance of the reaction products and the background due to secondary interactions. They allow nevertheless for high luminosity due to the high revolution frequency of stored particles. Superslow resonance extraction with stochastic feeding produces high density external beams with an excellent duty factor. In combination with liquid hydrogen targets of only

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a few mm thickness this gives an excellent definition of the interaction region. On the detector side special efforts are made to allow for kinematically complete multiparticle measurements with full solid angle coverage and with "massless" detectors which do not absorb or disturb the reaction products. Multitrack events occur especially in associated strangeness production and after delayed decays of strange particles. High acceptance becomes therefore very important.

The geometrical separation between production and decay of strange particles *e.g.* $\Lambda \to p\pi^-$ and the directional correlations provide very useful and precise kinematical information. This in fact makes strangeness experiments with a track detector particularly simple if their sampling distance is smaller than typical decay distances.

2. Accelerator

The cooler synchrotron COSY [1] uses the old Jülich cyclotron as injector. Via stripping injection the 45 MeV cyclotron beam is transferred to the COSY-ring with a circumference of 184 m. For the phase space cooling of the beam an electron cooling system (295–645 MeV/c) and a stochastic cooling system (1.5–3.5 GeV/c) can be used, resulting in beam emittances below 1π mm mrad with momentum resolutions below 10^{-4}. A special feature of the operation is the avoidance of crossing the transition energy $\gamma_{\rm tr}$ by shifting it during the acceleration. This allows for data taking during the acceleration ramping.

For internal experiments 3–4 $\cdot 10^{10}$ protons were accelerated up to 3.45 GeV/c. The maximum extracted intensity was 1 $\cdot 10^9$ protons/s. Extraction is working over the full energy range and stochastic feeding of the resonance extraction (superslow extraction) is routinely used *e.g.* with 1 minute spill-time. Electron cooling at low energy is used for machine physics studies. Stochastic cooling is in operation and is applied for internal target experiments. In Fig. 1 the effect of stochastic cooling is shown for the internal experiment COSY-11. Without cooling the event rate during the experiment decreases due to beam losses. The radial shift of the stored beam by energy loss and the beam blow up by straggling are compensated by the cooling. As a result there is lower background and the energy loss in the target is compensated by the cooling and results in a constant event rate *i.e.* a higher mean luminosity. Available from the ion sources are unpolarized and with lower intensity polarized H^- ions. Deuteron beams will be developed in the near future.

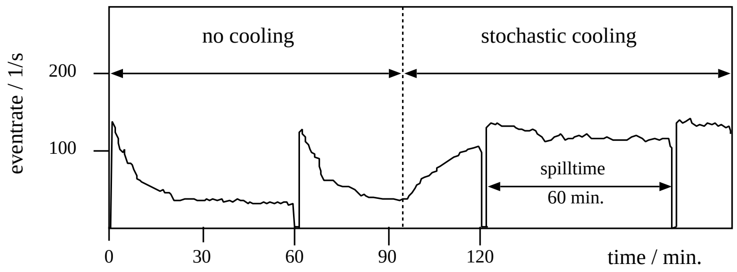

Fig. 1. Stochastic cooling at the internal experiment COSY-11. The cooling system is switched on in the middle of one spill. The event rate is increasing due to the reduction of the beam dimension which increases the beam-target overlap.

3. Physics at COSY

The main topic of the COSY physics program is the structure of mesons and baryons in the confinement regime of QCD. This field includes the analysis of decay properties and interactions of meson–meson, meson–baryon and baryon–baryon systems.

The experimental studies are characterized by keywords like threshold measurements, strangeness production, medium modification and reaction mechanisms.

- Threshold measurements are instructive for the interpretation of elementary interactions. They are limited to a few partial waves with low angular momentum. This simplifies their description. The relative velocities of the ejectiles are low which favors s-waves and final state interactions. At threshold the momentum transfer is high since the outgoing particles have small c.m. momenta. The transfer is practically the center of mass momentum of the input channel. This large momentum transfer and s-waves dominance at treshold enhance heavy meson exchanges.

- The strangeness production is an excellent tool to study hadron dynamics due to the high selectivity for the detection of delayed decays of hyperons and K_s mesons. Questions concerning the strangeness content of the nucleons and the reaction mechanisms for the dissociation can be addressed by such studies. For the $pp \to pK^+\Lambda$ reaction it is easy to measure the Λ polarization via the asymmetry of the parity violating weak decay $\Lambda \to p\pi^-$. In a simple quark model this is related to the s-quark polarization. With a polarized beam and target a detailed analysis of the spin degrees of freedom can be done.

- Modifications of the properties and interactions of hadrons within the nuclear medium are another interesting field. Questions here are for example the lifetime of hypernuclei, specific reaction mechanisms and possible medium effects especially on K-mesons which may be isolated in "subthreshold" production experiments.

To a large extent the success of COSY will depend on the ability to determine for inelastic production processes Dalitz plots with close to 100 % acceptance and fully exclusive kinematic information about all four-vectors of the participating particles. Only in this way unambiguous interpretations of the underlying physics will be possible.

4. Strangeness experiments and first results

Some of the reactions under investigation or described in proposals are summarized in Table I. Also given are the names of the experimental installations. An international community of more than 320 scientists and students is working on this physics.

TABLE I

Present program at the different experimental installations

internal	
ANKE	$p^{12}\mathrm{C} \to K^+X$, K^+dX $p^{12}\mathrm{C} \to K^+K^-X$ $\vec{p}\vec{p} \to \eta$ $\vec{p}\vec{p} \to pp\Phi$ $pp \to d\pi^+$, $pn\pi^+$, $pp\pi^0$
COSY-11	$pp \to pp\ \eta, \eta', \omega, \Phi$ $pp \to pp\pi^+\pi^-$, ppK^+K^- $pp \to pK^+\Lambda$, $pp \to pK^+\Sigma^0$ $pp \to d'\pi^+ \to pp\pi^-\pi^+$
COSY-13	$p^{238}\mathrm{U} \to K^+\ {}^{238}_{\Lambda}\mathrm{U}$ delayed fission
EDDA	$\vec{p}\vec{p} \to pp, d\pi^+$

external	
GEM	$pp \to d\pi^+$, $pp\ \pi^0$, η, η' $pd \to {}^3\mathrm{He}\eta$ $p^{40}\mathrm{Ca} \to pp({}^{39}\mathrm{Ca}\pi^-)_{1s}$ $pA \to (B\eta)^3\mathrm{He}$
MOMO	$pd \to {}^3\mathrm{He}\pi^+\pi^-$, ${}^3\mathrm{He}\ K^+K^-$
TOF	$pp \to pp$, $pp\ \gamma$, π^0, η, η' $pp \to pn\pi^+$, $d\pi^+$ $pd \to {}^3\mathrm{He}\eta$, ${}^3\mathrm{He}\eta'$ $pp \to d'\pi^+ \to pp\pi^-\pi^+$ $\vec{p}\vec{p} \to pK^+\Lambda$, $pK^+\Sigma$ $p\alpha \to N^*\alpha \to \Lambda K^+\alpha$ $pd \to {}^3_{\Lambda}\mathrm{H}K^+$, $pd \to \Lambda pp$

As experimental installations at COSY there are magnetic spectrometers which are characterized by a high momentum resolution but limited solid angle and non-magnetic systems which cover much larger laboratory solid angle but have lower resolution.

There are internal experiments like the non-magnetic EDDA [2] and COSY-13 [3] and magnetic detectors like COSY-11 [4]. A further magnetic experiment, ANKE [5], started operation in spring 98. For external experiments two stations are available, the area with the non-magnetic TOF [6] spectrometer and the non-magnetic neutron spectrometer NESSI and the area of the focussing magnetic spectrometer BIG KARL where the GEM [7] and MOMO [8] experiments are being performed.

The first data of strangeness experiments concerning elementary interactions are available from COSY-11 and TOF which will be presented in the following section. For the hyperon production in nuclei we refer to the contribution by W. Borgs *et al.*

4.1. TOF

The TOF experiments use an external large acceptance time-of-flight spectrometer [6]. It is a flexible modular system of several rotationally symmetric scintillator hodoscopes in vacuum. Finally up to 3 barrel elements can be combined with two planar front hodoscopes of 1.16 and 3 m outer diameter, providing very large solid angle coverage without holes. The central part of the endcap is the so called "quirl" detector, a three layer scintillator hodoscope with wedges and spirals in two opposite directions. Versions for operation in air have already been used elsewhere [9].

In Fig. 2 the pixel structure of such a detector is shown with elements fired by a $pK^+\Lambda$ event. The hit position is defined by the overlap of the fired detector elements. By measuring the time of flight and the direction the momentum vector can be determined for a certain mass hypothesis. Presently the Central-, Ring- and one Barrel-Hodoscope is in operation. A miniaturized liquid hydrogen target [10] with very small amount of inactive material and beam windows of only 0.9 μm Mylar is used.

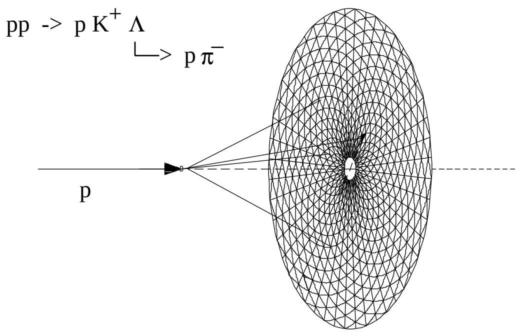

Fig. 2. Structure of the "Quirl" detector with 3 layers of wedges, left and right wound spirals. A typical $pK^+\Lambda$ event is shown.

For the measurements in the $pp \to pK^+\Lambda$ channel at proton momentum 2.5 and 2.75 GeV/c a hyperon decay spectrometer was installed close to the target which is shown in Fig. 3. The delayed decay of the Λ hyperon results in a multiplicity increase between start detector and a fibre hodoscope. This increase is used as a very selective trigger for such events. A clean, background free separation of the four fold overconstrained $pK^+\Lambda$ events is achieved. The values for the cross section $pp \to pK^+\Lambda$ are (2.7 ± 0.3) μb at 2.50 GeV/c and (12.0 ± 0.4) μb at 2.75 GeV/c [11]. Dalitz plots for the 2.75 GeV/c data are shown in Fig. 4 and in Fig. 5 the Λ polarization is given. With the same method and improved tracking near the target other channels with strangeness (Table I) will be measured at TOF like the lifetime of ${}^3_\Lambda$H or may be even the weak Λ production $pd \to pp\Lambda$ with its small branching ratio [12].

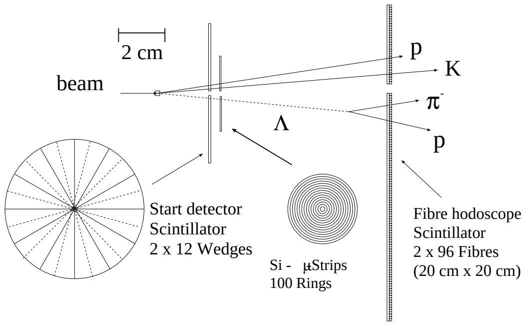

Fig. 3. Decay spectrometer for the measurement of the Λ decay in the associated strangeness production $pp \to pK^+\Lambda \to pK^+p\pi^-$.

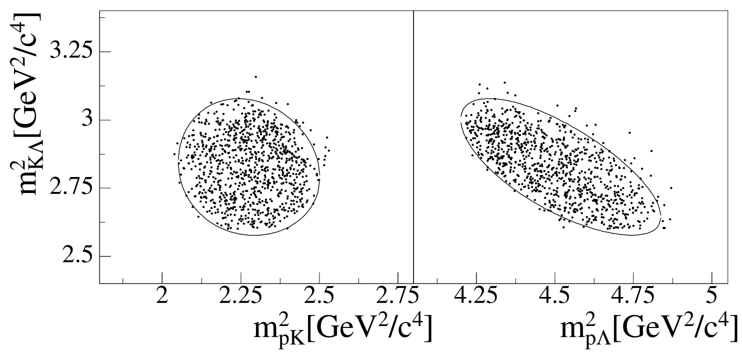

Fig. 4. Dalitz plots for the data taken at 2.75 GeV/c. At low $m^2_{p\Lambda}$ the enhancement due to the $p\Lambda$-FSI is visible.

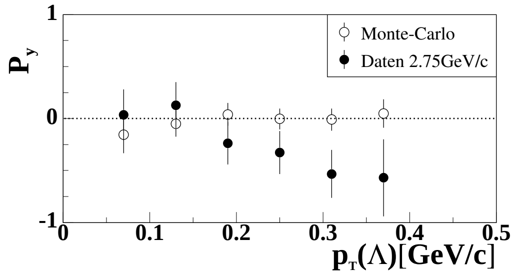

Fig. 5. Λ-polarization as a function of the transverse momentum p_T measured at 2.75 GeV$/c$ compared to unpolarized Monte Carlo events.

4.2. COSY-11

The COSY-11 installation [4] is designed for meson production studies close to threshold. It is an internal target experiment using a COSY accelerator dipole as a magnetic spectrometer. At COSY-11, first threshold measurements for the strangeness channels $pp \to pK^+\Lambda$ [13, 14], $pp \to pK^+\Sigma^0$, ppK^+K^- and η' have been done. The data for the K^+K^- and η' production are given in the contribution by P. Moskal.

Although the number of events is rather limited for the $pK^+\Lambda$ data, Dalitz plot analyses have been performed [15]. If only s-waves are involved, which is valid for these threshold measurements, the Dalitz plot is determined by the pure phase-space distribution *i.e.* a constant value in the whole kinematic region ($p\Lambda$ can then be either in singlet or triplet, the pp entrance must be in triplet). This distribution is modified by the final state interactions. The Coulomb interaction between proton and kaon leads to a depletion at low pK relative momenta which can be calculated without free parameters. The final state interaction between proton and Λ can be given in terms of scattering length a and effective range r_0, $f_{\rm FSI}(q, \bar{a}, \bar{r_0}) = 1 \,/\, \bar{a}^2 q^2 + (-1 + \frac{1}{2}\bar{r}\bar{a}q^2)^2$ with a mean a and r_0 because these data include the singlet and triplet substates. The $K^+\Lambda$ final state distortion can be neglected. By a comparison between such Monte Carlo and acceptance corrected experimental Dalitz plots the correct $\bar{a}$ and $\bar{r_0}$ values can be extracted. Figure 6 shows the result of a Dalitz plot fit. In the χ^2-distribution of a Dalitz plot fit, see Fig. 6, a valley is observed, which is consistent with existent a and r_0 parameters extracted from experimental $p\Lambda$ elastic scattering and theoretical calculations represented by the different symbols. To extract the correct $\bar{a}$, $\bar{r_0}$ pair, further information, like the elastic Λp-scattering data is needed. A fit to low energy Λp-data, described by $\sigma = 4\pi/q^2 + (-1/\bar{a} + 1/2\bar{r_0}q^2)^2$, fixing the combinations of $\bar{a}$ and $\bar{r_0}$ to the valley in Fig. 6 results in $\bar{a} = 2.0$ fm and $\bar{r_0} = 1.0$ fm, represented by the cross symbol in Fig. 6. Only mean

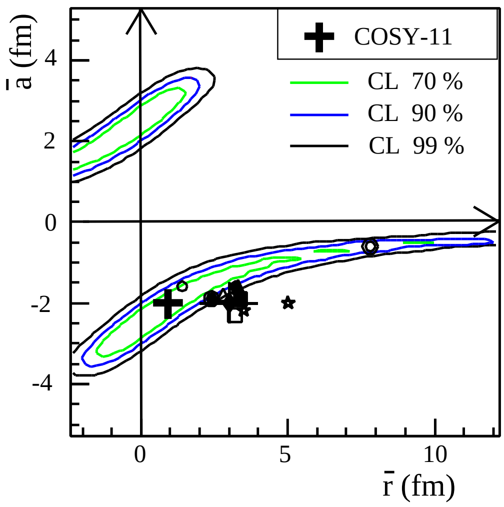

Fig. 6. Result of combined Dalitz plot fits for spin averaged scattering length a_0 and effective range r_0 for $pp \to pK^+\Lambda$ at 6 energies up to 10 MeV above threshold. The confidence levels in the χ^2-distribution are given. The cross symbol represent the COSY-11 result.

values for singlet and triplet Λp scattering parameters were extracted. The next steps in these studies should be the use of polarized beam and target which allows a separation of singlet and triplet states in the entrance and spin transfer studies to the Λ.

The preliminary cross section data for the $pp \to pK^+\Sigma^0$ reaction result in a cross section ratio $\sigma_\Lambda/\sigma_\Sigma$ at the same ε in the order of 20, which is an unexpected result [16].

5. Summary and outlook

The COSY accelerator started tuning up in 1993. Internal and external beams up to the maximum momentum of 3.4 GeV/c are now available for experiments. Presently 1/3 of the beam time is used for machine development and 2/3 is given to the experiments at the internal and external installations. Different experiments at COSY have extracted the first physics results. The COSY data for pp induced reactions are summarized in Fig. 7 which are partly preliminary. Especially in the strangeness sector new precise data are available. These studies will be continued and extended as can be seen from Table I. A central topic will be the use of polarized beams and polarized targets which allows more detailed analyses.

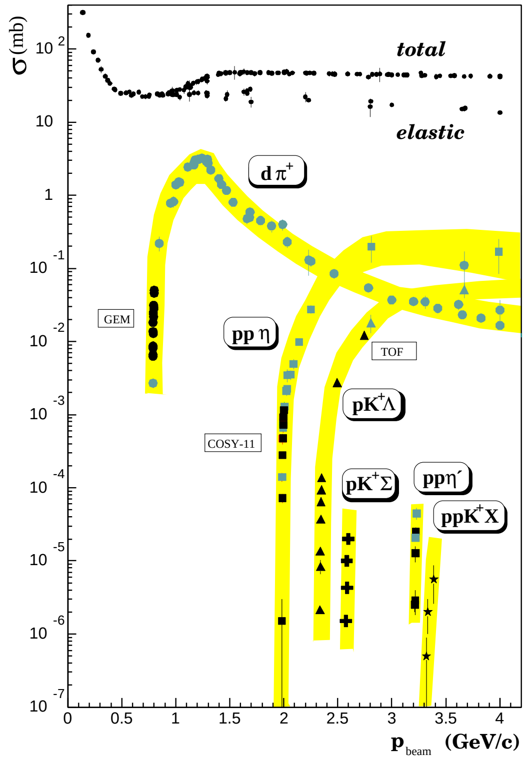

Fig. 7. Cross sections for some pp-induced reactions. The light symbols represent data from literature and the black symbols are data from COSY which are partially ($pp\eta$, $pK^+\Sigma$, ppK^+X) preliminary.

REFERENCES

[1] R. Maier, *Nucl. Instrum. Methods* **A390**, 1 (1997); K. Kilian, U.-G. Meißner, J. Speth, *Phys. Bl.* **54**, 911 (1998).

[2] D. Albers *et al.*, *Phys. Rev. Lett.* **78**, 1652 (1997); R. Maschuw, *Acta Phys. Pol.* **B29**, 3473 (1998).

[3] H. Ohm *et al.*, *Phys. Rev.* **C55**, 3062 (1997); P. Kulessa *et al.*, *Phys. Lett.* **B427**, 403 (1998); W. Borgs *et al.*, *Acta Phys. Pol.* **B29**, 3169 (1998).

[4] S. Brauksiepe *et al.*, *Nucl. Instrum. Methods* **A376**, 397 (1996); P. Moskal, *Acta Phys. Pol.* **B29**, 3091 (1998).

[5] O. Schult *et al.*, *Nucl. Phys.* **A583**, 629 (1995).

[6] R. Bilger *et al.*, *Acta Phys. Pol.* **B27**, 2953 (1996); K.-T. Brinkmann *et al.*, *Acta Phys. Pol.* **B29**, 2993 (1998).

[7] M. Drochner *et al.*, *Phys. Rev. Lett.* **77**, 454 (1996); W. Garske *et al.*, *Acta Phys. Pol.* **B29**, 3025 (1998); H. Machner, *Acta Phys. Pol.* **B29**, 3081 (1998).

[8] F. Bellemann *et al.*, *Acta Phys. Pol.* **B27**, 2945 (1996).
[9] M. Dahmen *et al.*, *Nucl. Instrum. Methods* **A348**, 97 (1994).
[10] V. Jaeckle *et al.*, *Nucl. Instrum. Methods* **A349**, 15 (1994).
[11] R. Bilger *et al.*, *Phys. Lett.* **B420**, 217 (1998).
[12] J. Haidenbauer *et al.*, *Phys. Rev.* **C52**, 3496 (1995).
[13] J. Balewski *et al.*, *Phys. Lett.* **B388**, 859 (1996).
[14] J. Balewski *et al.*, *Phys. Lett.* **B420**, 211 (1998).
[15] J. Balewski *et al.*, *Eur. Phys. J.* **A**, accepted for publication.
[16] COSY-11 collaboration, to be published.