Vol. 2 (2009) *Acta Physica Polonica B Proceedings Supplement* No 1

STUDY OF THE SPIN TRIPLET PROTON–LAMBDA INTERACTION WITH THE COSY-11 DETECTOR*

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(Received February 9, 2009)

Lambda hyperon production via the reaction channel $\vec{p}p \to pK^+\Lambda$ has been measured with a transverse polarised proton beam at an excitation energy of 40 MeV using the COSY-11 detection setup at the cooler synchrotron COSY in Jülich. By selecting events with kaon emission angles around $90^\circ_{\rm cm}$ the combination of differential cross-section and analysing power may allow to extract the pure spin triplet $p\Lambda$ scattering length. The preliminary analysis indicates an analysing power close to zero but the data are still under analysis. In addition to the hyperon production also η production data at 164 MeV excess energy will be extracted.

PACS numbers: 13.75.Ev, 13.75.–n, 25.40.Ve

1. Introduction

The elementary baryon–baryon interaction is a basic ingredient for the understanding of the strong interaction in the medium energy regime where mesons and baryons are the degrees of freedom. For the nucleon–nucleon interaction an extended data base exists and the scattering parameters are very well known. In the hyperon sector the data base is rather poor [1–4]. Due to the short life times of hyperons scattering experiments are impossible or at least very difficult. By far most of these scattering data have been produced in the $p\Lambda \to p\Lambda$ channel but also here the extraction of the scattering length is associated with large uncertainties. The lowest relative momentum in the scattering data is about 120 MeV/c which requires an extrapolation to zero energy from which the scattering length is determined.

In addition to hyperon–nucleon (YN) scattering multi-particle final states with a YN subsystem can be used to extract the scattering length as it was done by [5] via the $K^-d \to \pi^- p\Lambda$ channel and for the $pp \to pK^+\Lambda$

* Presented at the Symposium on Meson Physics, Kraków, Poland, October 1–4, 2008.

reaction by the COSY-11 Collaboration [6]. For the $n\Lambda$ scattering length measurements of the radiative kaon capture on deuterium $K^- d \to n \Lambda \gamma$ were proposed and a first feasibility study has been performed [7, 8]. The lowest accessible relative momentum in these multi-particle final states approaches zero, however, now the theoretical treatment has the larger error. For the description of the final state interaction effective range expansions were applied. Under the assumption that the scattering length a is larger than the effective range r_e the description simplifies to the Migdal Watson approach and the final state interaction is given as a function of a, r_e and the YN relative momentum q by: $f_{\mathrm{FSI}}(q, a, r_e) = 1/(a^2 q_{YN}^2 + (-1 + 1/2\, r_e\, a\, q_{YN}^2)^2)$. The uncertainties induced by these approximations may be large and are not well under control. A recent investigation of these effective range expansions by analysing calculations from various YN potentials showed large deviations up to about 1 fm [9].

A further complication is induced by the combination of spin triplet and spin singlet interaction in the data. In order to select spin singlet and triplet contributions experiments with polarised beam and target would be necessary but the scattering parameters extracted up to now result from unpolarised measurements. In some analyses data have been fitted with separate scattering lengths and effective range fit parameters for spin singlet and spin triplet interactions as it was recently done by [10] in a combined description of Λp scattering data and the inclusive K^+ momentum spectrum measured at SATURNE [11] but the effective range approximation applied in the analysis could induce some spin sensitivity as was pointed out by [9]. In the analysis of the $K^- d \to n \Lambda \gamma$ data [7, 8] the spectral shape differs for singlet and triplet due to the interference of S and D state of the deuteron which seems promising to separate the two components.

In order to get more precise values of the scattering lengths from large momentum transfer reactions a new method was developed by the Jülich theory group which is based on a dispersion relation technique [9, 12]. The advantage of this technique is the small and well controlled error in the relation between scattering length and experimental observable of below 0.3 fm which is comparable to the precision of 0.4 fm achieved for the nucleon scattering lengths a_{nn} and a_{pp} [13].

In the framework of this development [12, 14] also observables have been derived where spin singlet and spin triplet contributions are separated. For the $pp \to pK^+\Lambda$ reaction only spin singlet is contributing in $((1 + A_{xx} + A_{yy} + A_{zz}) \cdot \sigma_{\Theta(K)=90^\circ})$ and spin triplet in $(A_{0y} \cdot \sigma_{\Theta(K)=90^\circ})$. The measurement of a separate spin singlet contribution requires all spin correlation coefficients (A_{ii}), *i.e.* polarised beam and polarised target, but for the spin triplet component the asymmetry A_{0y} is sufficient when a special kinematic condition, kaon emission around 90°_{cm} is selected.

In Fig. 1 YN scattering data with a model description extrapolated to zero energy is shown which demonstrates the large error resulting from the data. On the right side in Fig. 1 Monte Carlo data of the invariant mass distribution of the $p\Lambda$ system as expected from the COSY-11 measurement of $\vec{p}p \to p\,K^+\Lambda$ is shown. Here the data go down to zero relative momentum which allows a precise model fit as long as the data statistics is sufficient.

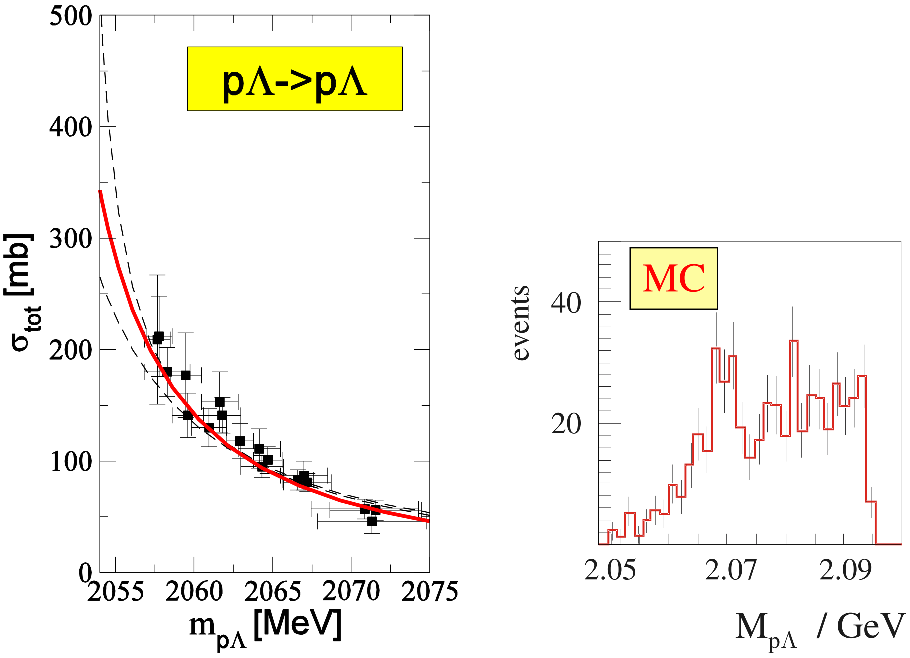

Fig. 1. Scattering data of the $p\Lambda$ system (left) showing the large uncertainties induced by the extrapolation to zero energy. Monte Carlo generated invariant mass spectrum of the $p\Lambda$ system expected from the COSY-11 measurement. Here the experimental error can be easily reduced by increased statistics and the error is mostly determined by the model description.

For a more precise determination of the YN scattering lengths a_{YN} high statistics data are needed which include polarisation observables to disentangle singlet and triplet contributions. In combination with recent developments such data will result in precisions comparable to the achievements in the NN system.

More precise a_{YN} values are important for various topics like flavour SU(3) symmetry, stability of hypernuclei, neutron stars, the understanding of production mechanism, nucleon resonances or heavy ion reactions.

2. Experiment

As a first step in this direction the Λ hyperon production via $\vec{p}p \to pK^+\Lambda$ has been measured with a transverse polarised proton beam at the internal experiment COSY-11 [15] at the cooler synchrotron COSY in Jülich [16]. The beam momentum was 2.457 GeV$/c$ which corresponds to an excess energy of 40 MeV. A sketch of the experiment is shown in Fig. 2.

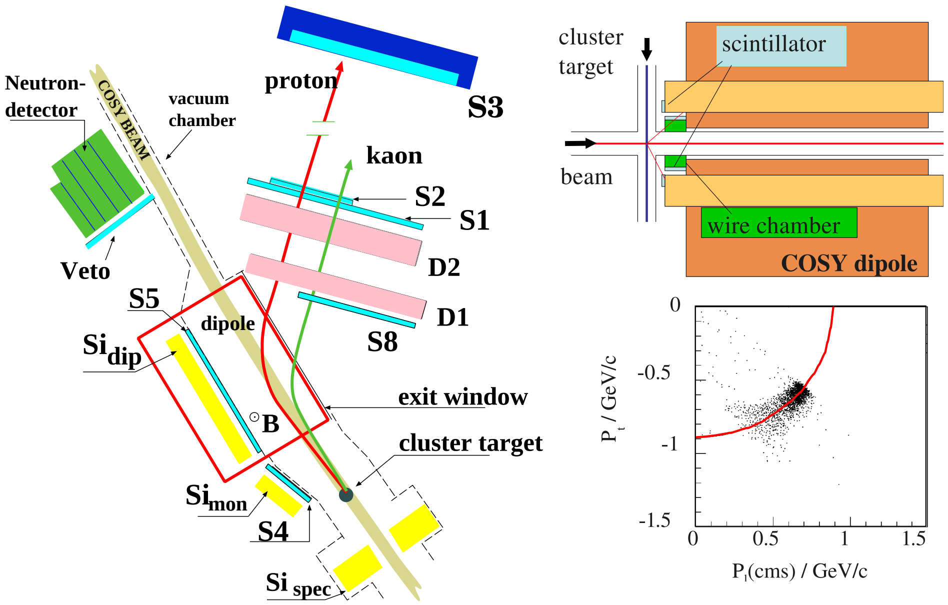

Fig. 2. Sketch of the COSY-11 detection system installed at a COSY machine dipole with drift chambers (D1,D2), scintillators (S1–S8), Si-pad (Si_x) and neutron detector (left) and the additional elements (wire chambers and scintillators) to monitor the luminosity (right, upper part). The lower part on the right side shows the well separated elastic events located around the kinematic ellipse.

It used a machine dipole as magnetic spectrometer which deflected the positively charged reaction products proton and K^+ to the inside where their trajectories were measured by drift chambers and scintillation detectors were used for a time of flight determination. By backtracking to the target point their momentum components were reconstructed and by adding the velocity information also the particle type was identified. The four momentum components of the Λ hyperon were determined via the missing mass technique.

With the asymmetric setup only one side can be measured and, therefore, the spin has to be flipped to get the analysing power. The COSY operation procedure was injection, acceleration to 2.457 GeV$/c$ and measurement with stochastic cooling for 10 minutes with a fixed polarisation direction. Every second cycle the polarisation direction was flipped. The luminosity was monitored by additional detector components, see Fig. 2, which detected elastic *pp* scattering in polarisation direction which is insensitive to the degree of the polarisation. The polarisation of the beam is determined by a comparison of the measured asymmetry of elastic *pp* scattering in the plane perpendicular to the beam polarisation direction to the known asymmetry from EDDA data [17]. The above described techniques were already successfully applied by the COSY-11 group for the measurement of the analysing power of the $pp \to pp\eta$ reaction [18, 19].

2.1. Status of the analysis

After the calibration of drift chamber and scintillator signals elastic *pp* scattering and the $pK^+\Lambda$-events have been selected.

Elastic scattering events were selected by requesting one charged particle track and an additional entry in the Si-pad detector. In the distribution of transverse *versus* longitudinal momentum the elastic pp events are located around the corresponding kinematical ellipse and can be clearly separated, see Fig. 2. The mean polarisation during the measurement was around 50%.

The $p\,K^+\Lambda$-events were separated by selecting events with one proton, one kaon, identified by the invariant masses of the two measured particles, and a Λ in the missing mass spectrum. A clear Λ peak is seen in the missing mass distribution, see Fig. 3. Details on the analysis of hyperon production with the COSY-11 experiment can be found in [6, 20–22].

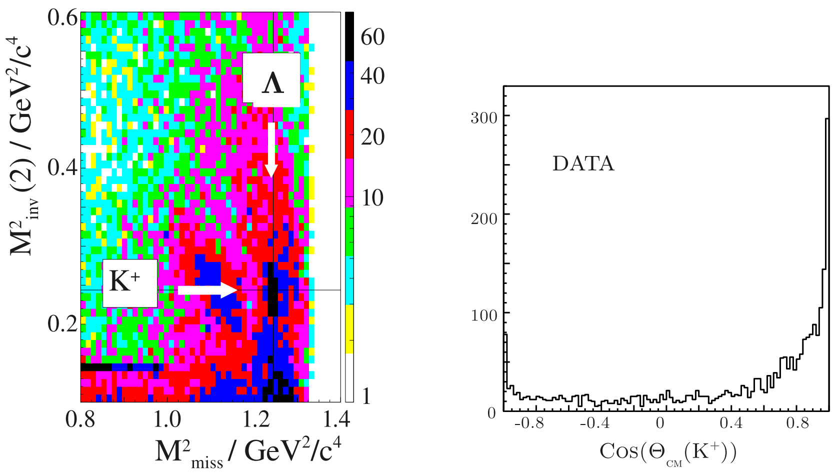

Fig. 3. Left: invariant mass of the second detected particle *versus* missing mass for events with an identified proton. Right: angular distribution of the detected K^+ mesons.

The angular distribution of the kaons resulting from $p\,K^+\Lambda$-events covers the full range including the $90^\circ_{\rm cm}$ region which is required for the extraction of the spin triplet scattering length, see Fig. 3. But unfortunately the preliminary analysis indicates a very small analysing power for kaon emission around $90^\circ_{\rm cm}$ and therefore the observable which includes only spin triplet contributions ($A_y\,\sigma$) will be also very small with large error bars. The data are checked carefully and will be analysed once more with improved calibrations before the final results will be extracted.

Besides the $pK^+\Lambda$ reaction of course also other reaction channels like $p\,p \rightarrow p\,n\,\pi^+$ and $p\,p \rightarrow p\,p\,\pi^0/\eta$ are included in the data. Fig. 4 shows the missing mass distribution with two identified protons where a clear η signal shows up. The analysis of the η production will result in cross-section and analysing power data for an excess energy of 164 MeV.

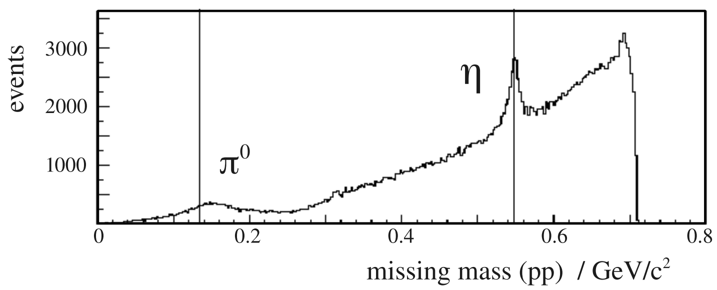

Fig. 4. Missing mass distribution for two-proton events.

3. Conclusion

The YN interaction is not very well known and even for the best studied hyperon nucleon system, the Λp, the scattering length has large uncertainties. The improvements in the theoretical treatment will allow to extract more precise results from production reactions. For a detailed analysis with a separation of spin singlet and spin triplet scattering length measurements with polarised beam and target are necessary. Still, a first attempt has been performed at the COSY-11 experiment with a polarised proton beam. By selecting a special kinematical region the contribution due to spin triplet scattering length is measurable. A preliminary analysis indicates a rather low analysing power which will introduce large uncertainties in the extracted value. For a final conclusion the results of the data analysis which is still ongoing have to be waited for. These analyses will also include the extraction of η production data at an excess energy of 164 MeV.

Further studies in this field will be continued at COSY. In the near future hyperon production studies with a polarised beam will be performed with the COSY TOF experiment [23].

The work was supported by the European Community Research Infrastructure Activity under the FP6 program (Hadron Physics, RII3-CT-2004-506078), the German Research Foundation (DFG), by the Polish Ministry of Science and Higher Education through grants Nos 3240/H03/2006/31 and 1202/DFG/2007/03, and the FFE grants from the Research Center Jülich.

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