The $pp \to p\Lambda K^+$ and $pp \to p\Sigma^0 K^+$ Reactions in the Chiral Unitary Approach

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We study the $pp \to p\Lambda K^+$ and $pp \to p\Sigma^0 K^+$ reactions near threshold by using a chiral unitary approach. We consider the single-pion and single-kaon exchange as well as the final state interactions of nucleon-hyperon, K-hyperon and K-nucleon systems. Our results on the total cross section of the $pp \to p\Lambda K^+$ reaction is consistent with the experimental data, and the experimental observed strong suppression of Σ^0 production compared to Λ production at the same excess energy can also be explained in our model.

1 Introduction

By using the chiral unitary approach, we study the $pp \to p\Lambda K^+$ and $pp \to p\Sigma^0 K^+$ reactions near threshold considering pion and kaon exchanges [1], where the $p\Lambda$ final state interaction (FSI) is very important [2,3]. The $\pi N \to K\Lambda$ amplitude also appears in this scheme, and the unitarization of this amplitude produces naturally the $N^*(1535)$ resonance [4], such that we can make a quantitative statement on its relevance in the $pp \to p\Lambda K^+$ reaction. We find that the $p\Lambda$ interaction close to threshold is very strong [5], and the FSI due to this source is unavoidable in an accurate calculation and we also take it into account.

We use a dynamical model similar to the one in Ref. [3] but we allow all pairs in the final state to undergo FSI, as a consequence of which we obtain a contribution from the $N^*(1535)$ using chiral unitary amplitudes. Our approach also differs from the other approaches on how the FSI is implemented, and for this we follow the steps of Ref. [6]. Furthermore, the experimental total cross section for the $pp \to p\Sigma^0 K^+$ reaction is strongly suppressed compared to that of the $pp \to p\Lambda K^+$ reaction at the same excess energy. This was explained by a destructive interference between π and K exchange in the reaction $pp \to p\Sigma^0 K^+$ [3].

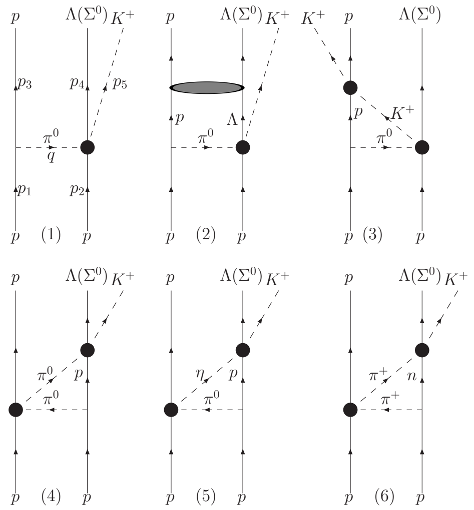

Figure 1: The π exchange mechanism of the $pp \to p\Lambda(\Sigma^0)K^+$ reactions including the final state interactions.

2 Formalism and ingredients

At the reaction threshold, the processes involving the exchange of π and K mesons are the dominant contributions, as in Ref. [3] and other works of the Juelich group. Accordingly we show the dominant diagrams exchanging π mesons in Fig. 1, where the definitions of the kinematics (p_1, p_2, p_3, p_4, p_5, and q) are shown in the first diagram. Those exchanging K mesons can be similarly obtained. First we write out the amplitudes for elementary production processes. For the first diagram of Fig. 1, we have

$$\mathcal{A}^1_\pi = -F_{\pi NN}(q^2) f_{\pi^0 pp} \sigma_z(1) q_z \frac{i}{q^2 - m^2_\pi} T_{\pi^0 p \to K^+ \Lambda}, \tag{1}$$

where $F_{\pi NN}(q^2)$ is the form factor containing a cutoff parameter Λ_π:

$$F_{\pi NN}(q^2) = \frac{\Lambda^2_\pi - m^2_\pi}{\Lambda^2_\pi - q^2}, \tag{2}$$

We can similarly obtain the "elementary production amplitudes" for the other diagrams, and the total production amplitude $\mathcal{M}$ can be written into two parts:

$$\mathcal{M} = \mathcal{M}_\pi + \mathcal{M}_K, \tag{3}$$

where $\mathcal{M}_\pi$ is for those diagrams involving π exchange ($\mathcal{M}_K$ for K exchange):

$$\mathcal{M}_\pi = \mathcal{A}^1_\pi + \sum_{i=2}^{6} \mathcal{A}^i_\pi G^i_\pi T^i_\pi, \tag{4}$$

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where $\mathcal{A}^i_{\pi/K}$ are the elementary production processes which can be obtained similarly to Eq. (1) and G^i_π the loop functions of one meson and a baryon propagators, or two baryon propagators. Together with the final state interactions for meson-baryon cases (such as $T^3_\pi = T_{K^+p\to K^+p}$, etc.) and for baryon-baryon cases ($T^2_\pi = T_{\Lambda p\to\Lambda p}$, etc.), we can obtain the full total production amplitude $\mathcal{M}$.

The meson-baryon G-functions and T-matrices have been calculated in Refs. [7], and we only need to calculate the baryon-baryon ones which are done using the experimental data [8]. We also consider the transition between $pp \to p\Lambda K^+$ and $pp \to p\Sigma^0 K^+$, which is discussed in Ref. [1] in detail.

3 Numerical results and Discussion

The total cross section versus the excess energy (ε) for the $pp \to p\Lambda K^+$ and $pp \to p\Sigma^0 K^+$ reactions are calculated by using a Monte Carlo multi-particle phase space integration program. The results for ε from 0 MeV to 14 MeV is shown in Fig. 2 for the $pp \to p\Lambda K^+$ reaction with the cutoff $\Lambda_\pi = 1300$ MeV, together with the experimental data [8] for comparison. The solid and dashed lines show the results from our model with and without including the $p\Lambda$ FSI, respectively.

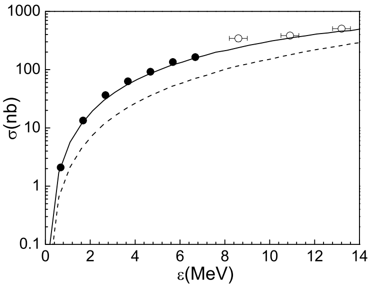

Figure 2: Total cross section vs excess energy ε for the $pp \to p\Lambda K^+$ reaction compared with experimental data from Refs. [8] (filled and open circles).

We can see that we can reproduce the experimental data quite well for the excess energy ε lower than 14 MeV. The dashed line is about two and a half times smaller than the experimental data at threshold but less than a factor of two smaller than experimental data at $\epsilon \sim 14$ MeV. This indicates that the $p\Lambda$ FSI is very important in the $pp \to p\Lambda K^+$ reaction close to threshold. This energy dependence of the FSI is what allows the determination of the ΛN interaction in other approaches which do not try to get absolute cross sections [9].

Acknowledgments

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References

[1] J. J. Xie, H. X. Chen and E. Oset, arXiv:1105.4791 [nucl-th].

[2] R. Siebert *et al.*, Nucl. Phys. A **567**, 819 (1994); A. Sibirtsev, J. Haidenbauer, H. W. Hammer and S. Krewald, Eur. Phys. J. A **27**, 269 (2006); F. Hinterberger, A. Sibirtsev, Eur. Phys. J. A **21**, 313-321 (2004); A. Gasparyan, J. Haidenbauer, C. Hanhart, J. Speth, Phys. Rev. C **69**, 034006 (2004); T. Rozek *et al.*, Phys. Lett. B **643**, 251 (2006); A. Sibirtsev, J. Haidenbauer, H. W. Hammer and U. G. Meissner, Eur. Phys. J. A **29**, 363 (2006); B. C. Liu, B. S. Zou, Phys. Rev. Lett. **96**, 042002 (2006); K. Tsushima, A. Sibirtsev, A. W. Thomas, Phys. Lett. B **390**, 29 (1997); A. Sibirtsev, J. Haidenbauer, U. -G. Meissner, Phys. Rev. Lett. **98**, 039101 (2007); S. Abdel-Samad *et al.* [COSY-TOF Collaboration], Phys. Lett. B **632**, 27 (2006); B. -S. Zou, J. -J. Xie, Int. J. Mod. Phys. E **17**, 1753-1764 (2008); H. X. Yang *et al.* [BES COllaboration], Int. J. Mod. Phys. A **20**, 1985 (2005); R. Shyam, Phys. Rev. C **73**, 035211 (2006).

[3] A. Gasparian, J. Haidenbauer, C. Hanhart, L. Kondratyuk, J. Speth, Phys. Lett. B **480**, 273 (2000).

[4] N. Kaiser, P. B. Siegel, W. Weise, Phys. Lett. B **362**, 23 (1995); N. Kaiser, T. Waas, W. Weise, Nucl. Phys. A **612**, 297 (1997); J. Nieves, E. Ruiz Arriola, Phys. Rev. D **64**, 116008 (2001).

[5] C. B. Dover, A. Gal, Prog. Part. Nucl. Phys. **12**, 171 (1985); P. M. M. Maessen, T. A. Rijken, J. J. de Swart, Phys. Rev. C **40**, 2226 (1989).

[6] J. Yamagata-Sekihara, J. Nieves, E. Oset, Phys. Rev. D **83**, 014003 (2011).

[7] E. Oset and A. Ramos, Nucl. Phys. A **635**, 99 (1998); E. Oset, A. Ramos, and C. Bennhold, Phys. Lett. B **527**, 99 (2002); T. Inoue, E. Oset, M. J. Vicente Vacas, Phys. Rev. C **65**, 035204 (2002).

[8] J. T. Balewski et al., Phys. Lett. B **4**20, 211 (1998); S. Sewerin et al., Phys. Rev. Lett. **8**3, 682 (1999).

[9] A. Budzanowski *et al.*, Phys. Lett. B **687**, 31 (2010); F. Hinterberger, S. N. Nedev and R. Siudak, Int. J. Mod. Phys. A **20** (2005) 291.