Mechanism of $K^-p \to \eta\Lambda$ reaction near threshold

Bo-Chao Liu · Ju-Jun Xie

Abstract Within an effective Lagrangian approach, we investigate the reaction mechanism of $K^-p \to \eta\Lambda$ near threshold. It is found that a new $D_{03}$ resonance, with mass $M = 1668.5 \pm 0.5$ MeV and width $\Gamma = 1.5 \pm 0.5$ MeV, is needed to interpret the experimental data reported by the Crystal Ball collaboration. To verify our results, remeasurements on the differential cross sections and $\Lambda$ polarization in this reaction will be helpful. Furthermore, we also show that the reaction $p\bar{p} \to \Lambda\bar{\Lambda}\eta$ is a good place to look for this new resonance if it exists.

Keywords effective Lagrangian · reaction mechanism · $\Lambda$ resonance

1 Introduction

The $K^- p$ reactions are important methods for studying the properties of hyperon resonances. Among of them, the reaction $K^- p \to \eta\Lambda$ is particularly interesting, because both $\eta$ and $\Lambda$ are isospin singlet, there is no contributions from the $\Sigma$ resonances, and therefore, this reaction is especially suitable for studying the properties of $\Lambda$ resonances. Even though the $\eta\Lambda$ channel is a relatively clean channel for studying $\Lambda$ resonances, current knowledge on the couplings of $\Lambda$ resonances with the $\eta\Lambda$ channel is still not satisfying. In Particle Data Group (PDG) book [1], there is only one state, $\Lambda(1670)$, which has well established decay branch to the $\eta\Lambda$ channel. The couplings of other $\Lambda$ resonances with the $\eta\Lambda$ channel are only very poorly known. This is possibly due to the weak couplings of other $\Lambda$ resonances with the $\eta\Lambda$ channel. Another possible reason is the limited early experimental data with very poor quality.
In 2001, some new experimental data with much better precision than before were reported by the Crystal Ball collaboration \cite{2}. These new data offer a better basis for investigating the reaction mechanism of $K^- p \rightarrow \eta A$ and extracting the information about $A$ resonances in this reaction.

2 Results and Discussions

Within an effective Lagrangian approach, we investigate the mechanism of $K^- p \rightarrow \eta A$ reaction near threshold \cite{3,4}. We consider $t-$channel $K^*$ exchange and $u-$channel proton exchange as background contributions (as shown in Fig. 1(a)). In $s-$channel, firstly we only include $\Lambda(1670)$ exchange, because it is the only $A^*$ state which has significant coupling to the $\eta A$ channel. We set the coupling constants appearing in the amplitudes and the mass and width of $\Lambda(1670)$ as free parameters. We also include two parameters as the relative phase factors among amplitudes. Then we fit these parameters to the data. It is found that although the total cross section data can be well described, the bowl structures shown in angular distributions cannot be reproduced at all (See Ref. \cite{3,4} for more details). This result is not unexpected as we only include one $s-$wave resonance in this fit. It seems we still need some higher partial wave contributions.

Next, we include a new $D_{03}$ resonance in the fit with setting the parameters of this resonance as free parameters. In this new fit, both total and differential cross section data can be well described. The best fitting results favor the $D_{03}$ resonance with mass $M = 1685.5 \pm 0.5$ MeV and width $\Gamma = 1.5 \pm 0.5$ MeV, which is obviously not a known $A$ resonance listed in PDG. Here it will be interesting to discuss the role of $\Lambda(1690)$ in this reaction. $\Lambda(1690)$ is a well established $D_{03}$ state and also lies near $\eta A$ threshold. In fact, in the experimental paper \cite{2} the authors also noticed the higher partial wave contributions shown in the angular distributions, and they argued that these higher partial wave contributions may come from $\Lambda(1690)$. However, the largest beam momentum of these new data is about 770 MeV, which corresponds to invariant mass $\sqrt{s} = 1.685$ GeV, the lower limit of the mass of $\Lambda(1690)$ suggested by PDG. Therefore if these higher partial wave contributions are due to $\Lambda(1690)$, one may expect that the bowl structure shown in the angular distributions should be more and more prominent with increasing energies. Such an expectation is not supported by the data, so we do not think these higher partial wave contributions are caused by $\Lambda(1690)$.

Because there are no other experimental evidences or theoretical predictions for the existence of this narrow resonance, it will be important to find some other proofs to establish the existence of this new resonance. Fortunately, there are some ways to verify our results. The first way is from the $A$ polarization data. In fact, besides the total and differential cross section data some $A$ polarization data are also reported by the Crystal Ball collaboration in the same paper [2].
Mechanism of $K^-p \rightarrow \eta\Lambda$ reaction near threshold

Fig. 2 The predictions for $\Lambda$ polarization with (black solid line) and without (red dashed line) including the narrow resonance. For details see Ref.[4].

Because the quality of the $\Lambda$ polarization data is poor and the number of these data points is small, we did not include these data in the fit. However, after fixing the free parameters by fitting to the total and differential cross section data, it will be interesting and important to check our model predictions for the $\Lambda$ polarization. The predictions of our model for the $\Lambda$ polarization are shown in Fig. 2. As can be seen from the figure, with large uncertainties of current data one cannot get any decisive conclusions. However, it is shown that with or without the narrow $D_{03}$ resonance the models give distinct predictions for the $\Lambda$ polarization at $P_{K^-} = 735\text{MeV}$. Thus if we have more accurate $\Lambda$ polarization data in the future, we will have more evidence for this narrow resonance.

Another way is the measurements on the $p\bar{p} \rightarrow \Lambda\bar{\Lambda}\eta$ reaction. With the parameters fixed in the $K^-p \rightarrow \eta\Lambda$ reaction, we can make some predictions for the observables of $p\bar{p} \rightarrow \Lambda\bar{\Lambda}\eta$ reaction based on meson exchange model (see Fig. 1(b)). In a simplified model, we ignore the initial and final state interactions and we only consider kaon exchange. The calculated results for the invariant mass spectrum of $\eta\Lambda$ system and the angular distribution of $\eta$ meson in center of mass frame are shown in Fig. 3. There are mainly two findings from these calculations. The first finding is that with or without the narrow $D_{03}$ resonance the invariant mass spectrum of $\eta\Lambda$ shows a sharp peak here. It indicates that the narrow $D$-wave resonance’s contribution is enhanced in this reaction. This enhancement is due to some simple kinematical reason. Because the threshold momentum is much larger for the $p\bar{p} \rightarrow \Lambda\bar{\Lambda}\eta$ reaction than that for the $K^-p \rightarrow \eta\Lambda$ reaction, the vertex function of $\Lambda^*KN$ vertex for $D$-wave resonance ($\sim p^2$) will be largely enhanced in the $p\bar{p} \rightarrow \Lambda\bar{\Lambda}\eta$ reaction compared to the $K^-p \rightarrow \eta\Lambda$ reaction. For $S$-wave resonance, there is no such enhancement. So the signal of the narrow $D$-wave resonance is enhanced in the $p\bar{p} \rightarrow \Lambda\bar{\Lambda}\eta$ reaction, which makes this reaction a good place to look for the narrow resonance if it exists.

3 Summary

The main conclusions of this work can be summarized as follows:
1. With including the $\Lambda(1690)$, the higher partial wave contributions shown in angular distributions cannot be explained.
2. With including a narrow $D_{03}$ resonance ($M = 1668.5 \pm 0.5\text{MeV}$, $\Gamma = 1.5 \pm 0.5\text{MeV}$), we can describe the data well.
3. Remeasurements on the differential cross section and $\Lambda$ polarization data and measurements on the reaction $p\bar{p} \to \Lambda \bar{\Lambda} \eta$ may help.
4. The $\Lambda(1670)$ plays a dominant role near threshold, while the background contributions are also important.

We suggest experimentalists to perform the new measurements and find further experimental evidences to establish the (non-)existence of this narrow resonance.

Acknowledgements We acknowledge the support of the National Natural Science Foundation of China under grant no 10905046 and 11105126. B. C. Liu is also supported by the Fundamental Research Funds for the Central Universities.

References
1. J. Beringer et al.: The Review of Particle Physics. Phys. Rev. D86, 010001 (2012).
2. Starostin, A., et al.: Measurement of $K^- p \to \eta \Lambda$ near threshold. Phys. Rev. C64, 055205 (2001).
3. Liu, B. C., Xie, J. J.: $K^- p \to \eta \Lambda$ reaction in an effective Lagrangian model. Phys. Rev. C85, 038201 (2012).
4. Liu, B. C., Xie, J. J.: Evidence for a narrow $D_{03}$ state in $K^- p \to \eta \Lambda$ near threshold. Phys. Rev. C86, 055202 (2012).