

Triangle singularity in the $K^-d \rightarrow p\Sigma^-$ reaction and its relevance to find the $\bar{K}N$ amplitude below threshold

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Abstract. We study for the first time the $p\Sigma^- \rightarrow K^-d$ and its time reversal reaction close to threshold and show that they are driven by a triangle mechanism, with the $\Lambda(1405)$, a proton and a neutron as intermediate states, which develops a triangle singularity close to the $\bar{K}d$ threshold. As the main result, we find that the cross section, well within measurable range, is very sensitive to different models that, while reproducing $\bar{K}N$ observables above threshold, provide different extrapolations of the $\bar{K}N$ amplitudes below threshold. The observables of this reaction will provide new constraints on the theoretical models, leading to more reliable extrapolations of the $\bar{K}N$ amplitudes below threshold and to more accurate predictions of the $\Lambda(1405)$ state of lower mass.

1 Introduction

The interaction of kaons with nucleons and nuclei has attracted much attention in the last decades and continues to draw attention. While the advent of chiral unitary theory brought much light into the issue [1–3], the present situation is such that different models agree above the $\bar{K}N$ threshold but give rise to very different $\bar{K}N$ amplitudes below threshold [4]. In this talk we present results from [5] where we suggest the use of the $p\Sigma^- \rightarrow K^-d$ ($K^-d \rightarrow p\Sigma^-$) reaction to pin down information from the $\bar{K}N$ amplitude below threshold. This reaction proceeds via the mechanism shown in figure 1.

In complete analogy with the $pp \rightarrow \pi^+d$ reaction studied in [6–10], we study the triangle mechanism shown in figure 1, where a $\Lambda(1405)$ resonance substitutes a $\Delta(1232)$ in the loop. The interesting thing observed in Ref. [10] is that the triangle mechanism for the $pp \rightarrow \pi^+d$ reaction was driven by a triangle singularity (TS), which made its strength very large and was responsible for some peculiar characteristics which were in agreement with experiment [11]. The diagrams shown in figure 1 also develop a triangle singularity which makes it stand over other possible mechanisms. TS were studied by Landau [12] and it was shown that a triangle mechanism of the type of figure 1 develops a singularity in the amplitude (in the limit of zero

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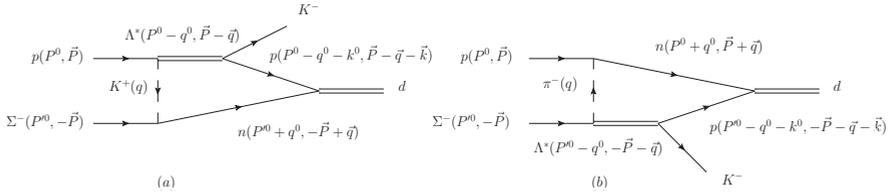


Figure 1. Feynman diagrams for the $p\Sigma^- \rightarrow K^-d$ reaction. The momenta of the lines are shown in brackets. Here, Λ^* stands for $\Lambda(1405)$.

width of the resonance) if the $\Lambda(1405)$ and the two nucleons are placed simultaneously on shell and the $\Lambda(1405)$ goes in the same direction as the K^- , together with the condition that the nucleon produced from the $\Lambda(1405)$ decay goes faster than the other nucleon and can catch up to fuse into the deuteron. The possibility that this process occurs at the classical level to give the singularity is the content of Coleman-Norton theorem [13].

2 Discussion and results

In the present case this reaction offers information on the $\bar{K}N$ amplitude below threshold, as we show below. Details on the calculations are shown in [5] and here we just present results. In figure 2 we show the contributions of the different spin transitions to the total cross section of the $K^-d \rightarrow p\Sigma^-$ reaction (σ). We see that the most important is $\uparrow\uparrow \rightarrow \uparrow\uparrow$, or $\downarrow\downarrow \rightarrow \downarrow\downarrow$ which has the same strength, where the arrows indicate the spin of the nucleons in the deuteron for the initial K^-d state, or the p or Σ in the final state.

In figure 3 we show the contribution of the higher pole of the $\Lambda(1405)$ to the $K^-d \rightarrow p\Sigma^-$ total cross section, around 1420 MeV, and the lower pole, around 1380 MeV, [14] for both diagrams of figure 1. We observe two features, the higher pole always gives the largest contribution, and the diagram (b) of figure 1 is the dominant one, because it relies upon pion exchange, contrary to diagram (a) that relies on kaon exchange. We also observe that there is a destructive interference between the two Λ^* states.

Finally, in order to show the sensitivity of the reaction cross section to different models that have the same $\bar{K}N$ amplitude above threshold, but different below threshold, we show the results with four models, namely

Oset-Ramos [1]: This first model uses a Weinberg-Tomozawa (WT) contribution as driving term in the interaction kernel. The authors took into account, for the first time, the full $S = -1$ meson-baryon basis for the regularization of the loop integral in coupled channels.

Roca-Oset [15]: This model takes as building block the previous one, yet reducing the basis to $\pi\Lambda, \pi\Sigma, \bar{K}N$ channels. It has special interest for the present study because, apart from the ordinary $K^-p \rightarrow \pi\Lambda, \pi\Sigma, \bar{K}N$ total cross sections and threshold observables, the authors incorporated the CLAS data for the $\Lambda(1405)$ photoproduction [16] in the fits to constrain the model parameters.

Cieplý-Smejkal: The third one is the model called NLO30 in Ref. [17]. This is a model based on a chirally motivated potential, written in a separable form, whose central piece is derived from the Lagrangian up to next-to-leading order (NLO). The authors took into

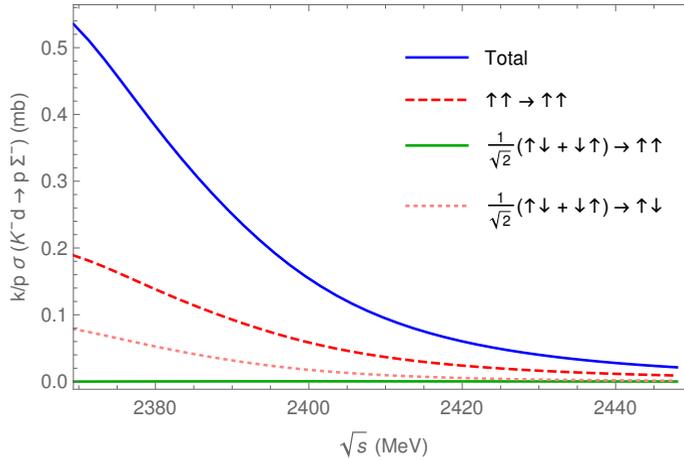


Figure 2. Contribution from several spin transitions in $\frac{k}{p}\sigma$. Here, \sqrt{s} and p are the total CM energy and the momentum modulus, respectively, of the incoming $p\Sigma^-$ system, while k represents the momentum modulus of the outgoing K^- .

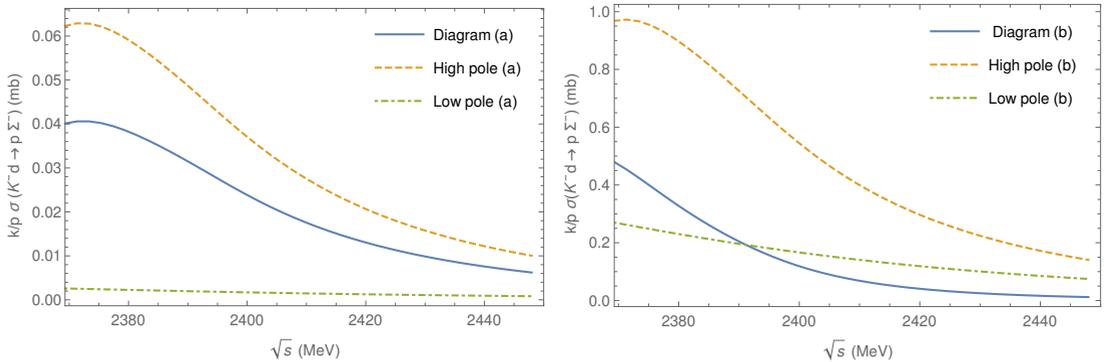


Figure 3. Contributions of the high and low mass poles to the diagrams (a) and (b) in $\frac{k}{p}\sigma$.

account in the fitting procedure the very precise measurements of the shift and width of the 1S state in kaonic hydrogen carried out by SIDDHARTA Collaboration [18].

Feijoo-Magas-Ramos [19] This model corresponds to the fit called WT+Born+NLO carried out in [19]. It was constructed by adding the interaction kernels derived from the Lagrangian up to NLO, and including additional experimental data at higher energies in the fits. This model is the natural extension of Oset-Ramos.

The results obtained with the four different models are shown in figure 4. As we can see, the cross sections can differ by a factor of two sometimes and this is due to the different amplitudes below threshold since all these amplitudes have about the same amplitude above threshold. This clearly tells us that we can use this reaction to discriminate among different models, or what is the same to pin down the $\bar{K}N$ amplitude below threshold, which is the object of present discussion and is essential to make good predictions of \bar{K} bound states in nuclei, another subject of much interest in the field [20–22].

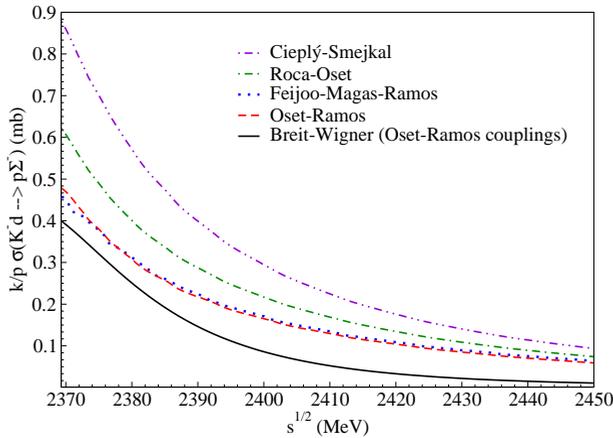


Figure 4. $K^- d \rightarrow p\Sigma^-$ cross sections ($\frac{k}{p}\sigma$) for the considered models. More details in the text.

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