Lineshape of the $\Lambda(1405)$ Measured at CLAS

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Abstract. The $\Lambda(1405)$ has been a subject of controversy for decades, and its nature as a hyperon resonance has yet to be established firmly. Its peculiar lineshape, *i.e.*, its $\Sigma\pi$ invariant mass spectrum has lead to various theoretical studies, and some of these show that it may possess strong dynamical components which are not seen in other well-known baryons. With the CLAS detector system in Hall B at Jefferson Lab, we have measured the photoproduction reaction $\gamma + \mathrm{p} \to K^+\Lambda(1405)$ with high statistics over different $\Sigma\pi$ decay channels. The reconstructed invariant mass distribution has been measured, as well as the differential cross sections for the nearby $\Lambda(1405)$, $\Sigma(1385)$, and $\Lambda(1520)$. Our analysis method is discussed and our near-final results for the $\Lambda(1405)$ lineshape is presented.

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The exact nature of the $\Lambda(1405)$ hyperon resonance ($S = -1, J^P = 1/2^-$), has remained undetermined for decades. Early bubble chamber experiments found a distortion of the invariant mass distribution ("lineshape") from a simple Breit-Wigner form, and this lead to speculation of its nature. The closeness of the nearby $N\overline{K}$ threshold is assumed to influence the lineshape, and the coupling between this channel and the $\Sigma\pi$ channel into which the $\Lambda(1405)$ decays may lead to a dynamical description of this resonance, as in the original prediction by Dalitz [1].

Using the CLAS [2] detector system in Hall B at the Thomas Jefferson National Accelerator Facility, we have done a photoproduction measurement of the $\Lambda(1405)$ with unprecedented statistics. With the high statistics and good resolution of the CLAS system, we were able to extract the $\Lambda(1405)$ lineshapes and differential cross sections in all three of its $\Sigma\pi$ decay channels. Our measurements give a much improved quantitative description of the $\Lambda(1405)$, and may lead to further insights into its nature.

From a theory point of view, there has been a renewed interest in the $\Lambda(1405)$ in recent years, especially from the point of view of chiral dynamics [3, 4, 5], where the $\Lambda(1405)$ is dynamically generated. More recent developments show that there may be two poles for the $\Lambda(1405)$ [5, 6], which may lead to different lineshapes of the $\Lambda(1405)$ for different reactions. Figure 1 shows a theory prediction of the $\Lambda(1405)$ lineshape [7], where the lineshapes are distorted from the simple Breit-Wigner form, and are different for each decay channel due to the coupled channels mixing isospin contributions. Our analysis shows that indeed the experimentally obtained lineshapes are different for each decay channel.

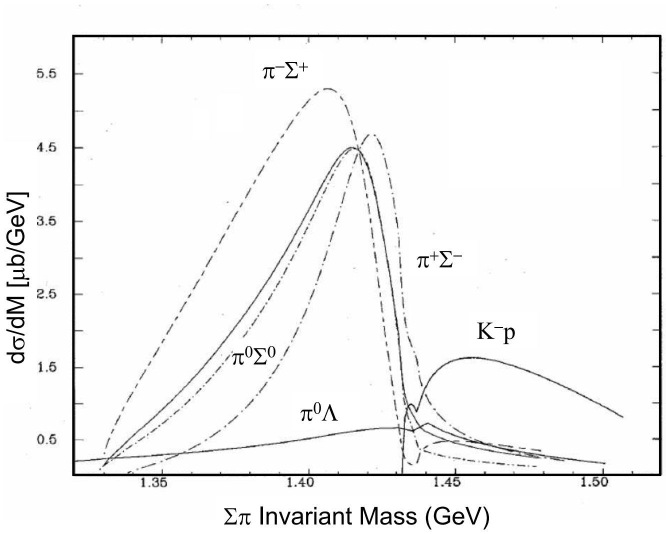

FIGURE 1: Theoretical lineshapes predicted [7] for the $\Lambda(1405)$ using one particular chiral unitary approach. Due to the interfering isospin 0 and 1 terms, the lineshapes are distorted from the simple Breit-Wigner form. In more recent years, attention has also focused on a possible two pole structure of the $\Lambda(1405)$ in the $I = 0$ channel alone. This too is expected to influence the lineshapes [5, 6].

CLAS DATA ANALYSIS AND RESULTS

The CLAS detector system at Jefferson Lab presents unique opportunities to study the excited spectrum of mesons and baryons in the several GeV regime, where many bound states of the strong force are observed. A detailed study of these states may lead to further insights on how the strong force interacts in this non-perturbative regime. Using the CLAS detector, we have obtained a large dataset containing $\Lambda(1405)$ events by tagging real photons from $K^+\Lambda(1405)$ threshold up to 2.84 GeV in center-of-mass energy. Charged particles decaying from the reaction $\gamma + \mathrm{p} \to K^+ + \Lambda(1405)$, $\Lambda(1405) \to \Sigma\pi$ were detected for the decay channels $\Sigma^+\pi^-$, $\Sigma^0\pi^0$, and $\Sigma^-\pi^+$.

The main background reactions are $\gamma + \mathrm{p} \to K^+ + \Sigma(1385)$ and $\gamma + \mathrm{p} \to K^* + \Sigma$. The $\Sigma(1385)$ is measured in its main decay mode to $\Lambda\pi$, and scaled by the known branching ratio so that its $\Sigma\pi$ yield is fixed in each bin of center-of-mass energy and center-of-mass kaon angles $\cos\theta_{K^+}^{\mathrm{c.m.}}$. The K^* was simulated with Monte Carlo templates and subtracted off, as were the $\Lambda(1520)$ and other remaining backgrounds.

Our results for the lineshape of the $\Lambda(1405)$, after acceptance-correction, are summed over all center-of-mass kaon angles for 100 MeV-wide center-of-mass energy bins. Figure 2 shows the lineshapes of the $\Lambda(1405)$ for each of the $\Sigma\pi$ decay channels that we have measured for $1.95 < W < 2.05$ GeV, where we are just below the edge of the nominal K^* threshold, and the K^* has very limited kinematic influence. The measured lineshapes are seen to be quite different from each other showing difference in peak positions and widths. This is similar to the chiral unitary prediction shown in Figure 1, but the $\Sigma^+\pi^-$ and $\Sigma^-\pi^+$ channels have opposite behavior from the prediction.

CONCLUSION

The photoproduction differential cross section of the $\Lambda(1405)$ has been measured using the CLAS detector system at Jefferson Lab's Hall B. Our lineshape results show strong

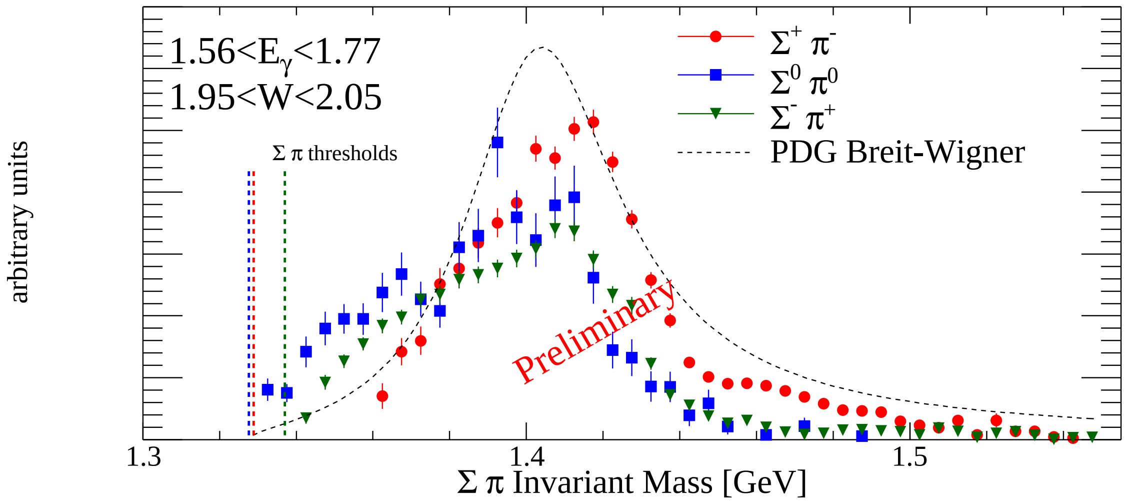

FIGURE 2. (Color online) The $\Sigma\pi$ invariant mass spectra measured for the $\Lambda(1405)$ in the energy range $1.95 < W < 2.05$ GeV. The different decay channels are shown as $\Sigma^+\pi^-$ (red circles), $\Sigma^0\pi^0$ (blue squares), and $\Sigma^-\pi^+$ (green triangles). An example of a relativistic Breit-Wigner function using the PDG [8] values for the $\Lambda(1405)$ mass and width are shown as the dashed line.

differences between $\Sigma\pi$ decay channels, which has been predicted in the chiral unitary coupled channel approach, albeit with channel characteristics being interchanged with respect to the prediction. We hope to present our final results in the near future, which will include the lineshape measurements in each $\Sigma\pi$ channel, and the differential cross sections of the $\Lambda(1405)$, $\Sigma(1385)$, and $\Lambda(1520)$. Also of interest is our spin-parity analysis of the $\Lambda(1405)$, where for the first time it can be shown directly from experiment that the spin-parity of the $\Lambda(1405)$ is indeed $J^P = 1/2^-$. Our large data on the $\Lambda(1405)$ and closeby hyperons will help shed light on the nature of the $\Lambda(1405)$and its production mechanism.

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