Double Resonance in Dalitz Plot of $M_{p\Lambda}$-$M_{K\Lambda}$ in DISTO Data on $p + p \rightarrow p + \Lambda + K^+$ at 2.85 GeV

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(Received Feb 23 ty, 2015, talk given at Int Conf Hyp2015, Sendai, in press in JPSJ-suppl)

The $X(2265)$ resonance was previously observed in DISTO data of $p + p \rightarrow p + \Lambda + K^+$ at 2.85 GeV on an attempt of searching for the kaonic nuclear state $K^-pp \rightarrow p + \Lambda$. In the present paper we report an additional finding, namely, a double resonance type phenomena, not only with a peak at $M(p\Lambda) = 2265$ MeV/c$^2$ but also a broad bump at $M(K^+\Lambda) \sim 1700$ MeV/c$^2$. This “double-resonance” zone is expressed as $XY(2265, 1700)$. The latter bump may result from nearby nucleon resonances, typically $N^*(1710)$, as well as by attractive $K^+ - \Lambda$ final-state interaction. We point out that this double resonance $XY(2265, 1700)$ as seen in DISTO at 2.85 GeV cannot be populated kinematically in a HADES experiment at 3.5 GeV.

KEYWORDS: kaonic nuclear state, strange dibaryon, $K^-pp$, $X(2265)$, double resonance $XY(2265, 1700)$

1. Introduction

The DISTO collaboration has reported \cite{1,2} in the $p + p \rightarrow p + K^+ + \Lambda$ at 2.85 GeV reaction an observation of a statistically significant broad resonance with baryon number 2, strangeness $-1$ with its mass centered around 2267 MeV/c$^2$ (aka $X(2265)$), 100 MeV below the threshold. The analysis was performed on an attempt of searching for a kaonic nuclear bound state, i.e. the most basic dibaryonic $KNN_{S=0,I=1/2} = K^-pp$ system \cite{3,4}. This search followed the prediction \cite{5} that it can be produced abundantly in $p + p \rightarrow K^+ + \Lambda^* + p \rightarrow K^+ + K^-pp$ reaction through the $\Lambda^* + p$ as a doorway, if the $K^-pp$ is exceptionally dense, as predicted, so as to be formed by extraordinary strong sticking of $\Lambda^*$ and $p$ produced in the short-range $p - p$ collision. Here, $\Lambda^* \equiv \Lambda(1405) \equiv I = 0 K^-p$ plays an essential role. In fact, a successive $p - p$ experimental data taken at 2.5 GeV incident energy \cite{6}, which is too low to produce $\Lambda^*$, demonstrated that the yield for the peak $X(2265)$ is diminished. @ The quest for the kaonic nuclear bound states has been pursued since the original prediction \cite{3,4} for over a decade, but except for DISTO \cite{1,2}, which owed a special favorable reaction mechanism \cite{5}, it was difficult to find some robust signature in singles spectra over quasi-free hyperon backgrounds. From ”unsuccessful” observation one tends to believe that our object, $K^-pp$, does not exist, thus being confused between its existence versus its production. Only recently a new tide of excitements with developed experimental configurations has become available.

The E27 experiment at J-PARC reported a ”$K^-pp$-like structure”, which was observed to an extremely small level of signal to background ratio ($\sim 0.01$) in the $d(\pi^+, K^+)$ reaction at 1.69 GeV/c \cite{7}. The $K^-pp$ peak was not expected to appear in singles spectra of the $d(\pi^+, K^+)$ reaction (see Fig.11 of
[5]), and thus, they configured coincidence counter arrays, which helped to reveal a significant peak with its mass and width similar to the $X(2265)$. On the other hand, the initial claim of an observation of a strange dibaryon by FINUDA in the stopped $K^-$ reaction on several light nuclear targets decaying to back-to-back $\Lambda-p$ [8] has not been reproduced, as reported by their updated data and analysis [9, 10]. Some negative results of $K^-pp$ search have also been reported, using photoproduction [11]. One may say that the production of $\Lambda(1405)$ in the same reaction plays a key leading role as a doorway for $K^-pp$ formation. No sizable appearance of $\Lambda(1405)$ is seen in such “unsuccessful” experiments.

Only one exception to this understanding might be the case of the $pp$ reaction at 3.5 GeV by HADES collaboration [12]. We will come back to this point after discussing the main subject of the present paper. Here, we discuss one new feature of the $X(2265)$ data seen in the 2.85 GeV data, $M(p\Lambda) - M(K^+\Lambda)$ double resonance, which could explain the non-observation of the $X(2265)$ in the HADES data [12] at 3.5 GeV. We also find a follow-up paper [13] by some of the authors of [12], who hold doubts and criticisms on our analyses [1,2,6]. Those our replies to this paper besides the interpretation of their 3.5 GeV data will be published elsewhere [14].

2. Dalitz plot presentation of the $pp \rightarrow p\Lambda K^+$ reaction

Figure 1 shows the Dalitz plot of the $pp \rightarrow p\Lambda K^+$ reaction at $T_p = 2.85$ GeV in $M(p\Lambda)$ vs $M(K^+\Lambda)$ presentation and their projections. Here, the mass-linear expression is taken for easier readability of the mass. As described in Ref. [1], the acceptance uncorrected data was normalized bin by bin by the Monte Carlo data of pure phase space $p\Lambda K^+$ final states analyzed in an exactly same manner as the real data. In this way we expect a flat $M^2(p\Lambda)$ and $M^2(K^+\Lambda)$ distribution if the reaction is purely for phase space and on the other hand, if the reaction contains any resonances or final state interactions, the distribution will deviate from the flat distribution. A proton angular cut ($|\cos \theta_{cm}(p)| < 0.6$) is applied to the data in order to suppress the ordinary $p\Lambda K^+$ decay process and to enhance relatively the $pp \rightarrow K^+ + X(2265)$ component [1].

The $M(p\Lambda)$ projection shows a distinct peak of $X(2265)$. In the $M(K^+\Lambda)$ distribution one sees also a non-flat, structure peaked at around 1700 MeV/$c^2$ that may be attributed to a presence of $N^*$ resonances. Though several $N^*$ resonances could contribute to it, $N^*(1710)$, which could be dominant at this energy [15], is known to have a broad width of 50 to 250 (~ 100) MeV and to decay to $K^+$ and $\Lambda$ with a 5-25% branching ratio [16].

We consider the following two-step process with a population of $\Lambda(1405)$ to form the $X(2265)$, and a final state interaction between $\Lambda$ and $K^+$.

$$p + p \rightarrow (p + \Lambda^*) + K^+ \rightarrow X(2265) + K^+ \rightarrow p + \Lambda + K^+ \quad (1)$$

The population of $N^*$ (or equivalently, attractive $\Lambda - K^+$ final state interaction) seems to favor the production of $X(2265)$ at the crossing point of two resonances. We may call this double resonance peak as $XY(2265,1700)$. Assuming Eq. 1, the sticking probability of $\Lambda(1405)$ and proton to form $X(2265)$ is found to be very high (> 0.5). Possibly the resonance is pronounced by a joint effect of two resonances. A similar double resonance phenomenon has been reported at low energy heavy-ion reactions [17]. In this case: $^{12}\text{C} + ^{12}\text{C} \rightarrow ^{12}\text{C} + \alpha + ^8\text{Be}$, the intensity is peaked at the crossing point of two resonances, namely $^8\text{Be} + \alpha \leftrightarrow ^{16}\text{O}$ and $\alpha + ^{12}\text{C} \leftrightarrow ^{12}\text{C}$.

Figure 2 depicts a possible Feynman diagram of such a reaction.

3. Non-population of $XY(2265,1700)$ at 3.5 GeV HADES collision

This leads to another interesting consequence which explains a non-observation of the $X(2265)$ resonance in the same $pp \rightarrow p\Lambda K^+$ reaction at a higher energy at 3.5 GeV by HADES [12] and even
Fig. 1. Dalitz plot presentation of the $p + p \to X(2265) + K^+$ reaction at $T_p = 2.85$ GeV collected by DISTO collaboration in $M(p\Lambda)$ vs $M(K^+\Lambda)$ [1] and its projections. The data are presented as deviation spectra from the pure phase-space scenario, which is supposed to be flat (here, however, the flatness is approximate as the mass linear expression is taken). Both projections show clear structures, $M(p\Lambda) \sim 2265 \text{ GeV/c}^2$ and $M(K^+\Lambda) \sim 1700 \text{ GeV/c}^2$.

Fig. 2. Feynman diagram of the $pp \to p\Lambda K^+$ reaction with $X(2265)$ and $N^*$ double resonance.

higher energies [18, 19]. As seen in Fig. 3, the double resonance point of $X(2265)$ and $N^*$ is outside of the kinematically allowed oval Dalitz domain of $T_p = 3.5$ GeV and higher.

We reported earlier [6] that the $T_p = 2.5$ GeV is too low for the production of $X(2265)$, since the energy is only marginally above the production threshold of $\Lambda(1405)$ that would be fused with proton to form a $X(2265)$. Together the choice of the $T_p = 2.85$ GeV turned out to be very unique.
Fig. 3. Kinematically allowed Dalitz domain of the $pp \rightarrow p\Lambda K^+$ reaction at various incident proton kinetic energies. The two resonances observed in Ref. [1] are indicated by horizontal and vertical dashed lines. The double resonance point sits outside of the Dalitz domain for the $T_p = 3.5$ GeV case where the non observation of $X(2265)$ was reported.

4. Summary

In the exclusive data of $pp \rightarrow p\Lambda K^+$ reaction at $T_p = 2.85$ GeV, two resonances are observed, namely, $M(p\Lambda) \sim 2265$ GeV/c$^2 = X(2265)$ and $M(K^+\Lambda) \sim 1700$ GeV/c$^2$. The events are pronounced at the crossing point of these two resonances, namely, at $XY(2265, 1700)$. We discussed a possibility of two resonances that lead to a high production yield of the $X(2265)$ resonance. We also found the uniqueness of the 2.85 GeV proton incident energy of this reaction for the production of the $X(2265)$.

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