Strangeness production from $pp$ collisions

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The study of the strangeness production from $pp$ collisions plays important roles in two aspects: exploring the properties of baryon resonances involved and understanding the strangeness production from heavy ion collisions to explore the properties of high energy and high density nuclear matter. Here we review our recent studies on several most important channels for the strangeness production from $pp$ collisions. The previously ignored contributions from $\Delta^*(1620)$ and $N^*(1535)$ resonances are found to play dominant role for the $pp \rightarrow nK^+\Sigma^+$, $pp \rightarrow pK^+\Lambda$ and $pp \rightarrow pp\phi$ reactions near-thresholds. These contributions should be included for further studies on the strangeness production from both $pp$ collisions and heavy ion collisions.

1. Introduction

The strangeness production in heavy ion collisions has been proposed to play important roles in many aspects [1]. For an in-depth study of the heavy ion collisions, we should, firstly, have the proper understanding of the basic ingredients, i.e., $pp$ collisions. The study of the meson production from $pp$ collisions itself also plays important role for exploring the baryon spectroscopy [2].

In the intermediate energy region, the one pion production dominates the $pp$ inelastic scattering as shown in Fig. 1 while the $pp \rightarrow pK^+\Lambda$, $pp \rightarrow pK^+\Sigma^0$, and $pp \rightarrow nK^+\Sigma^+$ reactions dominate the strangeness production as shown in Fig. 2 for total cross sections [3, 4, 5, 6]. The experimental differential cross sections for these reactions are still scarce. Even for the largest channel, $pp \rightarrow pn\pi^+$, whether the $N^*(1440)$ plays important role or not is still not settled [7].

Recently, the data for the strangeness production in $pp$ collisions at near-threshold energies have been appearing [8, 9, 10, 11] and revealing large discrepancy with previous theoretical predictions. Hence these reactions have been restudied theoretically [12, 13, 14, 15].

2. Strangeness production form $pp$ collisions

The $pp \rightarrow nK^+\Sigma^+$ reaction, which has a special advantage for absence of complication caused by $N^*$ contribution because of the isospin and charge conversation, is a possible new
excellent source for studying $\Delta^{++}$ resonances. The previously theoretical works [16, 17] on this reaction only reproduce the old data at higher beam energies well, but fail by order of magnitude compared with very recent COSY-11 data at energies close to threshold [5]. Recently this reaction was restudied [12]. Besides the ingredients considered in previous calculations, the sub-$K\Sigma$-threshold $\Delta^{++}(1620)$ resonance is added by taking into account both $\pi^+$ and $\rho^+$ mesons exchange. The numerical results are shown in Fig. 3 together with the data [4, 5, 6, 18] for comparison. The contributions from $\Delta^*(1620)(\pi^+)$ exchange, $\Delta^*(1620)(\rho^+)$ exchange and $\Delta^*(1920)(\pi^+)$ exchange are shown separately by dot-dashed, dashed and dotted curves, respectively. The contribution from the $\Delta^*(1620)$ production by the $\rho^+$ exchange is found to be very important for the whole energy range, in particular, for the two lowest data points close to the threshold. This gives a natural source for the serious underestimation of the near-threshold cross sections by previous calculations [16, 17], which have neglected either $\Delta^*(1620)$ resonance contribution [16] or $\rho^+$ exchange contribution [17]. The solid curve in the figure is the simple sum of the three contributions and reproduces the COSY-11 data quite well. However, a more recent measurement of the reaction near its threshold by ANKE collaboration [6] gives a much smaller cross section than those by COSY-11 [5]. Since both detectors are not $4\pi$ solid angle detectors, there is model dependence to deduce the total cross section from a fraction of $4\pi$ solid angle measurement. A good Dalitz plot measurement with a good $4\pi$ solid angle detector would be very helpful to settle down the contradiction.

It is well known that the $N^*(1535)$ resonances couples strongly to the $\eta N$ channel [4]. Recently, it was also found [13] to have strong coupling to $K\Lambda$ based on BES data on $J/\psi \rightarrow p\bar{p}\eta$ and $J/\psi \rightarrow pK^+\Lambda + c.c.$ reactions [19]. With the large $g_{N^*(1535)K\Lambda}$ coupling constant, the contribution from $N^*(1535)$ to $pp \rightarrow pK^+\Lambda$ is checked [13] in the effective Lagrangian approach. The calculated results are shown in Fig. 4. The dashed and dotted curves represent the contribution from $N^*(1535)$ and other $N^*$ resonances [20], respectively. The solid line is the sum.

Since the $N^*(1535)$ has strong couplings to $N\eta$, $K\Lambda$ and maybe also $N\eta'$ [21], there
may be a significant $s\bar{s}$ components in it. This indicates that the $N^*(1535)$ may also have a significant coupling to the $\phi N$ channel. Assuming that the production of the $\phi$ meson in $pp$ and $\pi^-p$ collisions is predominantly through the excitation and decay of the sub-$\phi N$-threshold $N^*(1535)$ resonance, the $pp \rightarrow pp\phi$ and $\pi^-p \rightarrow n\phi$ reactions were calculated \[14\]. The results compared with the experimental data were shown by solid curve in Figs. 5 & 6. In Fig. 6, the double dotted-dashed, dotted, dashed-dotted and dashed curves stand for contributions from $\pi^0$, $\eta$, $\rho^0$-meson exchanges and their simple sum, respectively. The solid line includes the $^1S_0$ $pp$ FSI.

3. Summary

In summary, the largest strangeness production channels from $pp$ collisions, $pp \rightarrow pK^+\Lambda$, $pp \rightarrow pK^+\Sigma^0$, and $pp \rightarrow nK^+\Sigma^+$ reactions, have been restudied theoretically by including contributions from previously ignored $\Delta^*(1620)$ and $N^*(1535)$ resonances \[12,13,14,15\]. These sub-threshold resonances have been found to play dominant roles
for the strangeness productions in $pp$ collisions and should be included for further studies on the strangeness production from both $pp$ collisions and heavy ion collisions.

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