Role of the low-lying nucleon resonances in the $p\bar{p} \to \psi\eta$ reaction

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Within the effective Lagrangian approach, we study the $p\bar{p} \to \psi\eta$ ($\psi \equiv \psi(3686)$, $J/\psi$) reaction at the low energy where the contributions from nucleon pole and low-lying nucleon resonances, $N(1520)$, $N(1535)$ and $N(1650)$ are considered. All the model parameters are determined with the help of current experimental data on the decay of $\psi \to p\bar{p}\eta$. Within the model parameters, the total and differential cross sections of the $p\bar{p} \to \psi\eta$ reaction are predicted. We show that the relative phases between different amplitudes of different nucleon resonance will change significantly the angular distributions of the $p\bar{p} \to \psi\eta$ reaction. Therefore, we conclude that these reactions are suitable to study experimentally the properties of the low lying nucleon resonance and the reaction mechanisms. We hope that these theoretical calculations could be tested by the future experiments.

I. INTRODUCTION

The charmonium, $H_c$, production in the $p\bar{p} \to H_cX$ (the $X$ is a light meson) reaction is an interesting tool to gain a deeper understanding of the strong interaction and also of the nature of the hadrons [1]. There is a forthcoming experimental effort, the Anti-Proton Annihilations at Darmstadt (PANDA), dedicated to this reaction [2]. On the theoretical side, there exist several previous studies of this reaction. In Ref. [3], Gallard and Maiani firstly estimated differential cross sections for the process of $p\bar{p} \to \psi\eta p$ in the soft pion limit. While in Refs. [4–6], it was pointed out that, with these $N^*N\psi$ couplings extracted form the corresponding $\psi \to p\bar{p}N$ decays, the contributions of intermediated $N^*$ resonances and nucleon pole to the process of $p\bar{p} \to \psi X$ can be investigated. Then, Lin, Xu and Liu [7] considered the contributions of the intermediate nucleon pole and the effect of form factors (FFs) to the charmonium production in the low energy $p\bar{p}$ interaction at PANDA. It was shown that the effect of the FFs is significant.

Since the experimental data on the $\psi \to p\bar{p}X$ decays become rich, we can consider the contributions from nucleon resonances in the $p\bar{p} \to \psi X$ reaction where parameters can be fixed through the process of $\psi \to p\bar{p}X$. Indeed, in Refs. [8–10], the authors have calculated the cross sections of the processes $p\bar{p} \to J/\psi\pi^0$, $p\bar{p} \to \psi(3770)\pi^0$ and $p\bar{p} \to Y(4220)\pi^0$, respectively, where the contributions from the intermediate nucleon resonances were considered. And it was found that the contributions from these nucleon resonances are non-negligible. Their contributions will significantly change the angular distributions of the $p\bar{p} \to \psi X$ reaction.

The experimental results of both CLEO and BESIII Collaboration [11, 12] show that the nucleon resonance $N(1535)$ have significant contribution in the decay of $\psi(3686) \to p\bar{p}\eta$. This may be because the large coupling of the $N(1535)$ to the $\eta N$ channel. As a matter of course, we will consider that the $N(1535)$ may have significant contribution in $p\bar{p} \to \psi\eta$ reaction. Along the above line, in this work, we will calculate the production cross sections of the process $p\bar{p} \to \psi\eta$ within the effective Lagrangian approach and also give the angular distributions, where the contributions from nucleon pole and three $N^*$ states are considered. We consider the contributions from nucleon resonances $N(1520)$ ($\equiv D_{11}$) with $J^P = \frac{1}{2}^-$, $N(1535)$ ($\equiv S_{11}$) and $N(1650)$ ($\equiv S_{11}$) with $J^P = \frac{1}{2}^-$, which have appreciable branching ratios for the decay into the $\eta N$ channel. On the other hand, there are unknown model parameters, which will be determined through fitting the experimental data of $\psi \to p\bar{p}\eta$ and $\psi \to p\bar{p}\eta$ decays.

This article is organized as follows. First, the formalism and ingredients of $p\bar{p} \to \psi\eta$ within the effective Lagrangian approach are presented in Sec. II. In Sec. II B, we fit the experimental data on the $\psi \to p\bar{p}\eta$ and $\psi \to p\bar{p}\eta$ decays to determine these unknown parameters. In Sec. III, we show the numerical results and make a detailed discussion. Finally, a short summery will be given in Sec. IV.

II. FORMALISM AND INGREDIENTS

In this section, we introduce the theoretical formalism and ingredients for investigating the $p\bar{p} \to \psi\eta$ reaction within the effective Lagrangian method, by including the contributions from the nucleon pole and the low lying nucleon excited states that have strong couplings to the $\eta N$ channel.

A. The $p\bar{p} \to \psi\eta$ reaction

The production of charmonium ($\psi \equiv \psi(3686)$ and $J/\psi$) plus a light meson $\eta$ in the low energy $p\bar{p}$ interaction can be achieved by exchanging intermediate nucleon and nucleon excited states. There are two type of Feynman diagrams to depict the $p\bar{p} \to \psi\eta$ reaction on the tree-level as shown in Fig. 1.
In this calculation, we use the effective interaction Lagrangian densities for each vertex in Fig. 1. For the $\eta N\bar{N}$ and $\eta\bar{N}N$ vertexes, we use the effective Lagrangians as

$$\mathcal{L}_{\eta NN} = -i g_{\eta NN} \bar{N} \gamma_{\mu} N \phi^\mu,$$  \hspace{1cm} (2.1)

where $\phi$ denotes the field of $N^*$. Then, we can write the scattering amplitudes of process $p\bar{p} \rightarrow \eta N$ as,

$$\mathcal{M}_N = ig_{\eta NN} \bar{N} \gamma_{\mu} (p_3) \left[ \gamma_{\mu} G_{\eta NN}^1 (p_3) \gamma_5 F(u) + \gamma_5 G_{\eta NN}^1 (p_3) \gamma_{\mu} F(t) \right] u(p_1),$$ \hspace{1cm} (2.7)

$$\mathcal{M}_\pi = g_{\eta NN} \bar{N} \gamma_{\mu} (p_3) \left[ \gamma_{\mu} G_{\eta NN}^1 (p_3) \gamma_5 F(u) + \gamma_5 G_{\eta NN}^1 (p_3) \gamma_{\mu} F(t) \right] u(p_1),$$ \hspace{1cm} (2.8)

$$\mathcal{M}_D_{13} = g_{\eta NN} \bar{N} \gamma_{\mu} (p_3) \left[ G_{\mu}^1 (p_3) (i \gamma_5 \bar{p}_3) (i p_3^3) F(u) + (i \gamma_5 \bar{p}_3) (i p_3^3) G_{\mu}^1 (p_3) F(t) \right] u(p_1),$$ \hspace{1cm} (2.9)

where $u = p_3^2 = (p_1 - p_4)^2 = (p_3 - p_2)^2, t = p_1^2 = (p_1 - p_3)^2 = (p_4 - p_2)^2$. The $F(u)$ and $F(t)$ stand for the form factor of $u$- and $t$-channel, respectively. Besides, we adopt the expression as used in Refs. [20–23]

$$F(u/t) = \frac{\Lambda_{N}^4}{\Lambda_{N}^4 + (u/t - m_{N}^2)},$$ \hspace{1cm} (2.10)

where the cutoff parameter $\Lambda_{N}$ can be parameterized as

$$\Lambda_{N} = m_{N} + \beta \Lambda_{QCD},$$ \hspace{1cm} (2.11)

with $\Lambda_{QCD} = 220$ MeV, and the $\beta$ will be determined by fitting the experimental data on the $(3686) \rightarrow p\bar{p} \eta$ decay.

The Breit-Wigner form of the propagator $G^J(p)$ for the $J = \frac{1}{2}$ and $J = \frac{3}{2}$ can be written as [24]

$$G^J(p) = \frac{i}{p^2 - m_N^2 + i m_{N} \Gamma_N},$$ \hspace{1cm} (2.12)

Note that we take the energy-dependent form for the decay width $\Gamma_{N}$ of $N(1535)$ resonance, we take the energy-dependent form, which is given by [25]

$$\Gamma_{N}(q^2) = \Gamma_{N\rightarrow \eta N}(q^2) + \Gamma_{N\rightarrow \eta N}(q^2) + \Gamma_0,$$ \hspace{1cm} (2.13)

where $\beta$ is the decay constant with $\lambda(x,y,z) = (x - y - z)^2 - 4yz$. We take the $g_{\eta N N} = 0.62$ and $g_{\eta NN} = 1.85$, which are determined from the partial widths of $N(1535)$ decay to $N\pi$ and $N\eta$. With these values we can get $\Gamma_{N\rightarrow \eta N} = 54.9$ MeV and $\Gamma_{N\rightarrow \eta N} = 55.1$ MeV if we take $\sqrt{q^2} = 1524$ MeV. To agree with experimental result, we choose $\Gamma_0 = 19$ MeV for $\Gamma_{N}(q^2) = 130$ MeV. Here, the mass and width of $N(1535)$ are adopted in Ref.[12].

The other coupling constants in the above Lagrangian densities can be also determined from their partial decay widths. The obtained numerical results for these relevant coupling constants are listed in Tables II and I. The coupling constants $g_{\phi NN}$ are obtained from the decay process of $\eta \rightarrow NN^* = NN^* \rightarrow p\bar{p} N^*$, while the coupling constant $g_{\phi \bar{p} p}$ is 1.63 is extracted from the $J/\psi \rightarrow \bar{p} p$. In addition, for the coupling constants $g_{\eta NN}$ and $g_{\gamma(3686)NN}$ we will discuss them below.
TABLE I: The coupling parameters $g_{J^P}^{N^*}$ are estimated from the branching fraction (B.F.) of each intermediate nucleon resonance of $J/\psi \rightarrow NN^* + N^*N$ + $ppn^0$ (second column), the width of $J/\psi$ is 92.9 KeV. The last column is the parameter of $g_{J^P}^{\psi^*}$, which are estimated by formula $g_{J^P}^{\psi^*} = g_{J^P}^{N^*} e^{\chi_{J^P}}$.

| $N^*$s   | B.F.(1385→pp0)(10^{-5}) | $g_{J^P}^{N^*}$ (10^{-5}) | $g_{J^P}^{\psi^*}$ (10^{-5}) |
|----------|-------------------------|-----------------------------|-------------------------------|
| N(940)   | -                       | 21.87                       | 14.56                         |
| N(1520)  | 7.96                    | 4.36                        | 2.55                          |
| N(1535)  | 7.58                    | 8.5                        | 4.87                          |
| N(1650)  | 9.06                    | 0.99                        | 1.42                          |

Finally, in the center of mass (cm) frame, the differential cross section of $p\bar{p} \rightarrow \psi \eta$ process can be written as

$$d\sigma \over dcos\theta = \frac{1}{32\pi s} \frac{|\vec{p}_1|^2}{|\vec{p}_1^cm|} |M_{tot}|^2,$$  

(2.18)

where $\theta$ is the scattering angle of outgoing $\eta$ relative to direction of antiproton beam in the center of mass frame, while the $\vec{p}_1^cm$ and $\vec{p}_3^cm$ are the three-momentum of proton and $\psi$ in the center of mass frame, respectively. The $M_{tot}$ is the total invariant scattering amplitude of the $p\bar{p} \rightarrow \psi \eta$ reaction, which can be written as

$$M_{tot}(p\bar{p} \rightarrow \psi \eta) = M_N + \sum_{N^*} M_{N^*} e^{-i\phi_{N^*}},$$  

(2.19)

where $M_N$ and $M_{N^*}$ are the contributions from the nucleon pole and the nucleon resonances, respectively. Besides, we introduce relative phase $\phi_{N^*}$ between $M_{N^*}$ and $M_N$.

B. Determine the model parameters from the analysis of the $\psi(3686) \rightarrow p\bar{p}\eta$ decay

On the tree level, the process $\psi \rightarrow p\bar{p}\eta$ is described by the Feynman diagrams as shown in Fig. 2.

![Feynman Diagrams](image)

FIG. 2: The Feynman diagram of $\psi \rightarrow p\bar{p}\eta$ through the nucleon pole and the nucleon excited states. The (a) is $u$-channel exchange, the (b) is $t$-channel exchange.

With the effective interaction Lagrangian densities given above, we can easily obtain the decay width of $\psi \rightarrow p\bar{p}\eta$, which can be written as

$$d\Gamma = \frac{1}{(2\pi)^2} \frac{1}{16M^2} |M_{tot}(p\bar{p} \rightarrow \psi \eta)|^2 d\Omega d\Omega_2 dm_{\eta},$$  

(2.20)

where $\vec{p}_2^c$ ($\Omega_2^c$) stands for the three momentum (solid angle) of the proton in the rest frame of the $p$ and $\eta$ system. $\vec{p}_1^c$ ($\Omega_1^c$) is the three momentum (solid angle) of the antiproton in the rest frame of $\psi$, and $m_{\eta}$ is the invariant mass of $p$ and $\eta$ system.

On the other hand, the amplitude $M_{tot}(p\bar{p} \rightarrow \psi \eta)$ is easily obtained just by applying the substitution to $M_{tot}(p\bar{p} \rightarrow \psi \eta)$: $p_1 \rightarrow -p_3, p_2 \rightarrow -p_2, \eta(0_p) \rightarrow \eta(-p_3), v(p_1) \rightarrow v(-p_3), v(p_2) \rightarrow u(-p_2)$.

The $\psi(3686) \rightarrow p\bar{p}\eta$ decay are experimentally studied by the CLEO and BESIII Collaborations [11, 12], and they found that the most contributions are from nucleon excited state $N(1535)$, which has large coupling to the $N\eta$ channel. However, since the $N(1520)$ and $N(1650)$ have significant couplings to the $N\eta$ channel, in this work, we will also take the contributions from them into account. Then, we perform five-parameter ($g_N^{\psi(3686)} \equiv g_n^{\psi(3686)NN} \times g_{NN^*} \times g_{N(1535)} \times g_{N(1520)}$ and $g_{N(1650)}$ and $\beta$) $^1 \chi^2$ fits to the experimental data [12] on the $\psi \eta$ invariant mass distributions for the $\psi(3686) \rightarrow N\eta^0 + N^*\eta \rightarrow p\bar{p}\eta$ decay.

The fitted parameters are: $\phi_{N(1520)} = 0.14 \pm 0.08, \phi_{N(1535)} = 1.76 \pm 0.06, \phi_{N(1650)} = 4.63 \pm 0.05, \beta = 3.70 \pm 0.82$, and $g_N^{\psi(3686)} = (8.45 \pm 1.10) \times 10^{-3}$. The resultant $\chi^2/DOF$ is 0.39. The best fitted results are shown in Fig. 3, compared with the experimental data. One can see that we can describe the experimental data quite well. The $N(1535)$ gives the dominant contribution below $m_{\eta} = 1.6$ GeV, and the contribution from $N(1650)$ is also significant, while the other contributions are quite small. Furthermore, there are strong interferences between $N(1535)$ and $N(1650)$, which make the peak of $N(1650)$ disappear in the total results.

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1 Note that we take the same parameter $\beta$ for all the nucleon resonances that we considered, and all the other parameters are shown in Table II.
TABLE II: The coupling parameters of $g_{N'N}$ (seventh column) and $g_{\psi N'N}$ (eighth column) are estimated from the branching ratio of $N' \rightarrow N\pi$ and $N' \rightarrow N\eta$ respectively. The ninth column are the parameters $g'_{N}$ which estimated from the branching ratio of $\psi(3686) \rightarrow NN'$ + $N'\bar{N} \rightarrow \bar{p}p\eta$, the last column are $g'_{N'\bar{N}}$ which calculated from the relationship what exist in $g_{N'N}, g_{\psi NN'}, g'_{N}$ and $g'_{N'\bar{N}}$. In this table, relevant experimental data adopted from PDG [34], but the mass and total width of $N(1535)$ we adopt the values given in Ref. [12].

| $N$'s | Mass (GeV) | $\Gamma$ (GeV) | $B$.F.($N'\rightarrow N\pi$) | $B$.F.($N'\rightarrow N\eta$) | $B$.F.($\psi(3686)\rightarrow \bar{p}p\eta$) | $g_{N'N}$ | $g_{\psi NN'}$ | $g'_{NN'}$ | $g'_{N'\bar{N}}$ |
|-------|------------|---------------|-------------------------------|-----------------------------|---------------------------------|---------|----------------|------------|----------------|
| $N(1520)$ | 1.515 | 0.110 | 0.6 | $8.0 \times 10^{-4}$ | 0.64 | 4.09 | 4.55 | 1.09 | 1.22 |
| $N(1535)$ | 1.524 | 0.130 | 0.42 | 0.425 | 2.47 | 0.62 | 1.85 | 0.51 | 1.53 |
| $N(1650)$ | 1.650 | 0.125 | 0.6 | 0.25 | 3.76 | 0.68 | 0.98 | 0.62 | 0.89 |

Although the contribution of $N(1535)$ is very predominant in the decay process $\psi(3686) \rightarrow \bar{p}p\eta$, but its contribution for the $p\bar{p} \rightarrow \psi(3686)\eta$ is not so important. The contributions of the $N'$ resonances are suppressed due to the highly off-shell effect of their propagators in the $t$- and $u$-channel.

III. THE TOTAL CROSS SECTIONS AND ANGULAR DISTRIBUTIONS OF $p\bar{p} \rightarrow \psi\eta$

In this section, we show theoretical results on the total cross sections and angle distributions of the $p\bar{p} \rightarrow \psi\eta$ reaction near reaction threshold.

A. The total cross sections and angular distributions of $p\bar{p} \rightarrow \psi(3686)\eta$

In Fig. 4, we show the numerical cross sections of $p\bar{p} \rightarrow \psi(3686)\eta$ as a function of the energy of center of mass $E_{cm}$ = $\sqrt{s}$. It is shown that the nucleon pole contribution is predominant in the whole energy region, but the contributions of the $N'$ resonances gradually become significant when the $E_{cm}$ is increasing, especially for the contribution from $N(1520)$. The contributions from $N(1535)$ and $N(1650)$ are mainly reflected in forepart and begin to decreasing around the $E_{cm}$ = 4.4 GeV.

We also calculate the angular distribution of the $p\bar{p} \rightarrow \psi(3686)\eta$ reaction at $E_{cm}$ = 4.3, 4.4, 4.5, 4.7, 4.9, 5.1, 5.3 and 5.5 GeV. The numerical results of $d\sigma/d\cos \theta$ as a function of $\theta$ are shown in Fig. 5, where the red solid line stands for the total contribution, and the blue dashed line is result of only considering the contribution of nucleon pole. The every gray concentric circle means same value of $d\sigma/d\cos \theta$, and these concentric circles are evenly spaced from inside to outside, whose difference value is labeled in the bottom left corner. From Fig. 5 one sees that the blue dashed lines are symmetry with respect to $\theta = 90^\circ$ or $\theta = 270^\circ$, which is because the contributions from $u$-channel and $t$-channel have the same weights for all of $E_{cm}$ if the only contribution from nucleon pole is considered. However, the shape of red solid lines are not symmetry with respect to $\theta = 90^\circ$. The symmetry behavior of angular distribution is helpful to identify the role of excited nucleon resonances in the $p\bar{p} \rightarrow \psi(3686)\eta$ reaction in future PANDA experiment.
The total cross sections and angular distributions of $p\bar{p} \rightarrow J/\psi \eta$

1. The $J/\psi \rightarrow p\bar{p}\eta$ decay

For the case of $J/\psi \rightarrow p\bar{p}\eta$ decay, we do not have available experimental data to determine the unknown $\beta$ and relative phase $\phi$ parameters. Firstly, we calculate the invariant mass distribution of $J/\psi \rightarrow \bar{p}p\eta$ without considering the interference between different $N^*$ resonance. The numerical results obtained with $\beta = 1.42$ are shown in Fig. 6, where one can see that the $N(1535)$ and $N(1650)$ have significant contributions. Secondly, we consider only the contributions from $N(1535)$ and $N(1650)$, and we choose four typical values of $0$, $\pi/2$, $\pi$ and $3\pi/2$ for the relative phase between them. In Fig. 7, we can see that phase interference will greatly change the line shape of the $p\eta$ invariant mass distribution. These different line shape behaviors can provide valuable information for future experimental analyses on the process $J/\psi \rightarrow \bar{p}p\eta$. 

Next, we pay attention on the $p\bar{p} \rightarrow J/\psi \eta$ reaction. Although the present existing experimental data are not enough to determine the relative phases between different scattering amplitudes, we can still accurately estimate the absolute magnitude of cross sections from different nucleon resonance.
In Fig. 8, we show the numerical results of the total cross sections of \( \bar{p}p \rightarrow J/\psi \eta \) reaction as a function of \( E_{cm} \), where the relative phases between different nucleon states are not taken into account. The results indicate that the total cross section have maximum of about 80.5 pb at \( E_{cm} = 5.5 \) GeV. From Fig. 8, one can also clearly see that contributions from excited nucleon resonances are significant, and the contribution from \( N(1520) \) even exceeds the contribution of nucleon pole when \( E_{cm} > 5.0 \) GeV.

In addition, we also calculate the angular distributions of the process \( \bar{p}p \rightarrow J/\psi \eta \), which are presented in Fig. 9. Compared with the results for the process of \( \bar{p}p \rightarrow \psi(3686)\eta \), one can see that the angular distributions of the \( \bar{p}p \rightarrow J/\psi \eta \) reaction are always symmetry with respect to \( \theta = 90^\circ \) or \( \theta = 270^\circ \) for all the energies that we take. This is because that we did not consider the possible interference contributions among different scattering amplitudes of nucleons. Combining with the angular distributions of \( \bar{p}p \rightarrow \psi(3686)\eta \) and \( \bar{p}p \rightarrow J/\psi \eta \) reactions, we can conclude that the weight difference between \( u \)-channel and \( t \)-channel is also due to the interference amplitudes from relative phases between different nucleon states.

### C. Comparison with other work

The \( \bar{p}p \rightarrow \psi \eta \) reactions are also studied in Refs. [1, 7]. In Table III, we make a comparison between our results and other theoretical results of Refs. [1, 7]. For the reaction of \( \bar{p}p \rightarrow \psi(3686)\eta \) and \( \bar{p}p \rightarrow J/\psi \eta \), our results are smaller than those of Ref. [1], but larger than the ones of Ref. [7].

| Reaction                  | This work (pb) | Ref. [1] (pb) | Ref. [7] (pb) | \( E_{cm} \) |
|---------------------------|----------------|---------------|---------------|--------------|
| \( \bar{p}p \rightarrow \psi(3686)\eta \) | 23             | 33 ± 8        | 9             | 5.38         |
| \( \bar{p}p \rightarrow J/\psi \eta \)     | 56             | 1520 ± 140    | 36            | 4.57         |

In Ref. [1], the authors estimated the total cross sections of \( \bar{p}p \rightarrow \psi \eta \) assuming a constant amplitude for the \( \psi \rightarrow \bar{p}pX \) decay. Under this approximation, it implies that the contributions of these intermediate resonances in the decay and production process are same. Hence, this approximation may lead to overestimation of the cross sections of \( \bar{p}p \rightarrow \psi \eta \). In this work, one can clearly see that the contributions from different intermediate resonances are very different in decay and production processes, especially for \( N(1535) \). The \( N(1535) \) have extremely significant contribution in the decay process of \( \psi \rightarrow \bar{p}p\eta \), but it is not important for the production process of \( \bar{p}p \rightarrow \psi \eta \). However, the constant amplitude approximation provides a good idea that the information of \( \bar{p}p \rightarrow \psi \eta \) can be extracted from the decay process \( \psi \rightarrow \bar{p}p\eta \).

In Ref. [7], the authors first introduced the form factor in predicting the cross sections of \( \bar{p}p \rightarrow \psi \eta \), where the only nucleon pole contribution is included. Their results are shown in fourth column of Table III, which are smaller than our results because the contributions from nucleon resonances are considered in our numerical results.

Finally, it needs to emphasize that we take the same form factors for both the \( \bar{p}p \rightarrow \psi \eta \) reaction and the decay process \( \psi \rightarrow \bar{p}p\eta \), although they should be different in these two different processes. However, since the hadron structure is still an open question, the hadronic form factors are generally adopted phenomenologically. Of course, the reliability of the treatment here can be left to future experiment to test.
IV. SUMMARY

The forthcoming PANDA will an ideal platform to carry out the study of hadron physics. Among these running facilities of particle physics, BESIII can provide abundant experimental data to the physics of charm tau physics. In fact, these studies on PANDA and BESIII can be borrowed with each other, which was indicated in Refs. [9, 10].

In this work, based on the studies of the process $\psi \to p\bar{p}\eta\psi$, we have calculated the total cross sections and angular distributions of the $p\bar{p} \to \psi\eta$ reaction within an effective Lagrangian approach. These contributions from nucleon resonances $N(1520), N(1535)$ and $N(1650)$ in $p\bar{p} \to \psi\eta$ reaction are considered for the first time. Our results show that these contributions from excited nucleon resonances are very important for estimating the cross section of $p\bar{p} \to \psi\eta$, and the relative phases between different amplitudes will influence the total cross section and change the shape of the angular distributions. Hence, the $\psi \to p\bar{p}\eta\psi$ reactions are suitable for investigating the properties of the low lying nucleon resonance.

We hope that these theoretical calculations presented in this work may stimulate experimentalist’s interest in exploring the $p\bar{p} \to \psi\eta$ reaction through the PANDA experiment. Meanwhile, we also suggest our colleague to pay more attentions to the theoretical issue around the charmonium production via the $p\bar{p}$ scattering processes since the present work is only a start point.

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