1 - 16 Role of Nucleon Resonances in the π N $\rightarrow \eta'$N Reaction*

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The spectrum of nucleon resonances is essential for our understanding of structure and component of nucleon, but our knowledge of them with the mass of around 2.0 GeV is still far from complete. The main reasons are that many resonances are emerging and several reaction channels are opening in this energy region. The η'N production threshold is about 1.89 GeV so it is a good place for studying the high lying resonances. For instance, we can use this reaction to search for the $P_{13}(1900)$ state close to the threshold, which is unfavored by qudrk-diquark models[1], but predicted in the conventional constitute quark models [2]. Also, the long-sought third S_{11} and P_{11} states at about 2 000 MeV, which are spin quartet of nucleon resonances, are expected to be present in this reaction. Moreover, the $s\bar{s}$ components in the wave function of η' meson is thought to be a good probe of the internal strange component of relevant nucleon resonances.

The total amplitude of the $\pi^{\pm}(\mathrm{p_i})\ \mathrm{N}(\mathrm{p_a}) \rightarrow \mathrm{R} \rightarrow \eta'(\mathrm{p_f})\mathrm{N}(\mathrm{p_b})$ reaction may be written as,

$$\mathcal{M}_{\rm tot} = \sqrt{2}\sum_R g_{\eta' {\rm N}R} g_{\pi {\rm N}R} {\rm e}^{i\phi_R} [F_R(q)\bar{u}(p_t)\Gamma^R_{\eta' {\rm N}R} G_R(q) \Gamma^R_{\pi {\rm N}R} u(p_b) + F_R(q')\bar{u}(p_t)\Gamma^R_{\pi {\rm N}R} G_R(q') \Gamma^R_{\eta' {\rm N}R} u(p_b)]$$

with isospin pre-factor $\sqrt{2}$, the Dirac spinors $u(p)(\bar{u}(p))$ and the propagators $G_R(q)$ $(G_R(q'))$ of the resonances R with intermediate four momentum $q = p_b + p_i$ and $q' = p_b - p_f$ for s and u channel, respectively. The off-shell form factors $F_R(q)$ are used to suppress the contribution of resonances with large momentum q. Here the interaction vertices $\Gamma_{\eta' {\rm NR}}$ and $\Gamma_{\pi {\rm NR}}$ with the coupling strength $g_{\eta' {\rm N}R}$ and $g_{\pi {\rm N}R}$ can be constructed directly as 1, $i\gamma_5$ and $ip^{\mu}_{f,i}/m_R$ for $R = S_{11}$, P_{11} and P_{13} resonances, respectively. The total amplitude $\mathcal{M}_{\rm tot}$ is the coherent sum of all resonances with the relative phase ϕ_R, which are free parameters to be determined by the data.

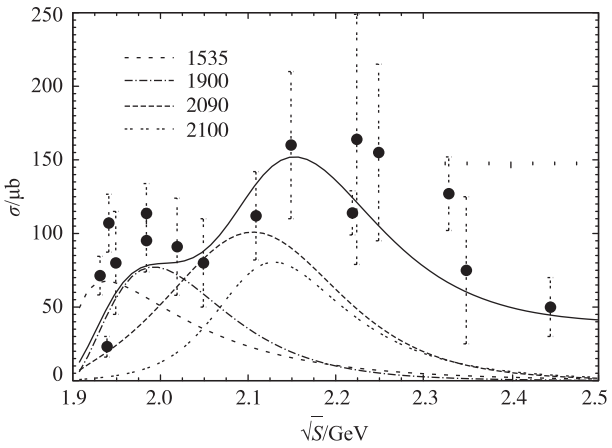

Fig. 1 Seleted diagrammatic representation for the fitted results with the combination of four resonances, see Table 1 for the corresponding parameters. The solid line is the total contributions of all considered resonances.

In Fig. 1, we show a representative result of the total cross section of πN $\rightarrow \eta'$N reaction with good fitting quality $\chi^2 = 2.5$. Four resonances, namely $S_{11}(1535)$, $P_{13}(1900)$, $S_{11}(2090)$ and $P_{11}(2100)$, are included in the model. The first two resonances contribute significantly to the first bump in the total cross section of this reaction, while the latter two resonances are important for description of the second bump. There is improvement to add $P_{11}(1710)$ into the fit but the significance is small.

These nucleon resonances play obvious role in the hadronic decay channels of heavy quarkonium, *e.g.* the J/ψ, $\psi(3686)$, $\psi(3770)$, χ_{cJ}, $\Upsilon(nS)$, and χ_{bJ} states. As the isospin filter, these decays are very useful in extracting empirical information of the nucleon resonances N* with isospin 1/2. Our extracted parameters in Table 1 are meaningful for the exploration of the decay channel N$\bar{\rm N}\eta'$ of these heavy quarkonium.

Table 1 The parameters of nucleon resonances used in the calculation. The Breit-Wigner masses, widths and branching ratios (BR) are quoted from the central values of the PDG[3]. The coupling constants $g^2_{\pi {\rm N}R}$ of nucleon resonances to π N are determined by the $BR_{\pi {\rm N}}$. The coupling constants $g_{\eta' {\rm N}R}$ of nucleon resonances to η' N and relative phases $\phi(^\circ)$ are extracted in the fit with the combination of four resonances. *: The values are set to be zero in the fit.

N^* mass/MeV	Width/MeV	$BR_{\pi {\rm N}}$/%	$g^2_{\pi {\rm N}R}$	$g_{\eta' {\rm N}R}$	$\phi/(^\circ)$
1 535	137.5	45.0	0.47	5.54 ± 2.88	0.0*
1 900	180.0	5.5	1.13	14.88 ± 1.67	0.0 ± 36.1
2 090	350.0	18.0	0.305	1.11 ± 0.49	251.2 ± 46.7
2 100	200.0	10.0	0.666	4.21 ± 2.34	78.5 ± 50.6

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