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**Abstract**

Using a relativistic quark model based on the $SU(6) \otimes O(3)$ symmetry, the phenomenological parameters of which are fixed by fitting the recent data on the process $\gamma p \to \eta p$, we extract the partial $\eta N$ decay widths and/or the photo-excitation helicity amplitudes for the nucleonic resonances $S_{11}(1650)$, $P_{11}(1710)$, $P_{13}(1720)$, $D_{13}(1520)$, $D_{13}(1700)$, $D_{15}(1675)$, and $F_{15}(1680)$.

PACS: 12.39.-x; 14.20.Gk; 13.60 Le Keywords: Phenomenological quark model; $S_{11}$, $P_{11}$, $P_{13}$, $D_{13}$, $D_{15}$, $F_{15}$ resonances; $\eta$ meson

## 1 Introduction

The properties of baryon resonances decay are intimately related to the internal structure of hadrons [1–7]. The decay of the baryon resonances into the $\eta N$ channel is particularly interesting. For example, the enhancement of the resonance $S_{11}(1535)$ and the suppression of another S-wave resonance, $S_{11}(1650)$, have not yet been completely understood. To our knowledge, the most extensive theoretical results in the quark model approach have been reported in Ref. [4], where the authors, within a relativized pair-creation ($^3P_0$) model, have investigated the quasi-two-body decays of baryons and have proceeded to comparisons with the available results from partial-wave analysis [8,9]. A recent work [7], embodying the fine structure interaction between constituent quarks, has provided a qualitative description of the suppressed decay of the $S_{11}(1650) \to N\eta$ compared to the large branching ratio for the $S_{11}(1535) \to N\eta$ decay, though the electromagnetic couplings of the resonance $S_{11}(1535)$ remain to be evaluated in this approach. It has also been suggested [10] that quasi-bound $K\Lambda$ or $K\Sigma$ states might be the answer to this puzzle.

Experimental results for the cross-section [11], and single polarization asymmetries [12,13] in the process $\gamma p \to \eta p$, have been proven [14–16] to be very attractive in the extraction of the photo-excitation amplitudes of the $S_{11}(1535)$ and $D_{13}(1520)$ resonances. Perhaps more importantly, the data make it possible to improve the accuracy in the determination of the $\eta N$ branching ratios, thus providing more reliable tests of various theoretical approaches.

In a previous paper [16], starting from a quark model approach [17], we showed that the combination of the cross section data from Mainz [11] with the recent polarization data from ELSA [12] and GRAAL [13] allows us to investigate the contributions of the resonances beyond the threshold region. The polarization data play a crucial role in determining the contribution of these resonances. Our study reached the conclusion that the reaction $\gamma p \to \eta p$, for $E_\gamma^{lab} \leq 1.2$ GeV, requires significant contributions from the nucleonic resonances in the first and second regions; namely, $S_{11}(1535)$, $D_{13}(1520)$ and $F_{15}(1680)$. In addition, possible roles played by the $P_{11}(1710)$ and $P_{13}(1720)$ resonances were also investigated, and the contributions from the resonances $S_{11}(1650)$, $D_{13}(1700)$, and $D_{15}(1675)$ were consistently found [16] to be small but sensitive to the polarized target asymmetry measured recently at ELSA [12]. Qualitatively, these results are consistent with the quark model predictions.

At the present time, the available photo-couplings and partial $\eta N$ decay widths of the resonances come from [18] partial wave analysis of the "pionic" processes $\gamma N \to \pi N$ and $\pi N \to \pi N$, $\eta N$, respectively. Using these reactions for resonances considered here, leads in general to poor determination of the quantities of interest; the reasons being mainly: i) none of these resonances dominate the underlying reaction mechanisms of the "pionic" processes, ii) the branching ratios of all these resonances to the $\eta N$ final state are small ($< 10\%$), except in the case of the $S_{11}(1535)$.

Here, the $\gamma p \to \eta p$ reaction appears very attractive: while in the first two "pionic" processes both isospin 1/2 and 3/2 resonances can intervene, in the case of the $\eta$ production only the isospin 1/2 resonances can be excited. Moreover, in recent work [16] we have highlighted the sensitivity of different $\eta$ photoproduction observables to a small number of these resonances. Therefore, in investigating the properties of resonances considered here, the $\gamma p \rightarrow \eta p$ reaction is much more appropriate than the $\gamma N \rightarrow \pi N$ and $\pi N \rightarrow \pi N$ channels.

As a result, from the data and theoretical analyses of $\gamma p \rightarrow \eta p$ , the photocoupling of the resonance $S_{11}(1535)$ has been extracted [14,16] more accurately and consistently. In this paper, we attempt to extract the property of baryon resonances beyond the resonance $S_{11}(1535)$ based on the differential cross section as well as the polarization data for the reaction $\gamma p \rightarrow \eta p$.

To show how this is achieved in our quark model approach, we summarize in Section 2 the theoretical content of our work. In section 3, we present our results and compare them with other available values.

## 2 Theoretical frame

The general framework for the meson photoproduction, in particular, for the $\eta$ case, has been given in Refs. [17,19]. The contributions from the $s$-channel resonances can be written as

$$\mathcal{M}_{N^*} = \frac{2M_{N^*}}{s - M_{N^*}(M_{N^*} - i\Gamma(q))} e^{-\frac{k^2+q^2}{6\alpha^2_{ho}}} \mathcal{A}_{N^*}, \tag{1}$$

where $k = |\boldsymbol{k}|$ and $q = |\boldsymbol{q}|$ represent the momenta of the incoming photon and the outgoing meson respectively, $\sqrt{s}$ is the total energy of the system, $e^{-\frac{k^2+q^2}{6\alpha^2_{ho}}}$ is a form factor in the harmonic oscillator basis with the parameter $\alpha^2_{ho} = 0.16$ (GeV/c)$^2$ related to the harmonic oscillator strength in the wave-function, and $M_{N^*}$ and $\Gamma(q)$ are the mass and the total width of the resonance, respectively. The amplitudes $\mathcal{A}_{N^*}$ are divided into two parts [17,19]: the contribution from each resonance below 2 GeV, the transition amplitudes of which have been translated into the standard CGLN amplitudes in the harmonic oscillator basis, and the contributions from the resonances above 2 GeV treated as degenerate, since few experimental informations are available on those resonances.

The contributions from each resonance to the $\eta$ photoproduction is determined by introducing [16] a new set of parameters $C_{N^*}$, and the following substitution rule for the amplitudes $\mathcal{A}_{N^*}$:

$$\mathcal{A}_{N^*} \rightarrow C_{N^*}\mathcal{A}_{N^*}, \tag{2}$$

so that

$$\mathcal{O}_{N^*}^{exp} = C_{N^*}^2 \mathcal{O}_{N^*}^{qm}, \tag{3}$$

where $\mathcal{O}_{N^*}^{exp}$ is the experimental value of the observable, and $\mathcal{O}_{N^*}^{qm}$ has been explicitly calculated [17] in the quark model. Thus, the coefficients $C_{N^*}$ measure the discrepancies between the theoretical results and the experimental data and show the extent to which the $SU(6) \otimes O(3)$ symmetry is broken in the process investigated here.

To be more specific, the total cross section in the $\eta$ photoproduction for a given resonance can be expressed as

$$\sigma \propto \Gamma_{\eta N}(A_{1/2}^2 + A_{3/2}^2). \tag{4}$$

In the quark model, the partial width $\Gamma_{\eta N}^{qm}$ and the helicity amplitudes $(A_{1/2})_{qm}$ and $(A_{3/2})_{qm}$ are *calculated explicitly*. Then the above configuration mixing coefficients $C_{N^*}$ are introduced and their numerical values are extracted by fitting the experimental data, so that

$$\sigma \propto \Gamma_{\eta N}^{th}(A_{1/2}^2 + A_{3/2}^2)_{qm}, \tag{5}$$

where

$$\Gamma_{\eta N}^{th} \equiv C_{N^*}^2 \Gamma_{\eta N}^{qm}. \tag{6}$$

The purpose of the procedure developed here is to extract the experimental value of the partial width $\Gamma_{\eta N}^{exp}$ in

$$\sigma \propto \Gamma_{\eta N}^{exp}(A_{1/2}^2 + A_{3/2}^2)_{exp}. \tag{7}$$

Then from Eqs. (5) to (7),

$$\Gamma_{\eta N}^{exp} = C_{N^*}^2 \Gamma_{\eta N}^{qm} \frac{(A_{1/2}^2 + A_{3/2}^2)_{qm}}{(A_{1/2}^2 + A_{3/2}^2)_{exp}}. \quad (8)$$

The resonances included in our present study[16] and the corresponding $C_{N^*}$ coefficients are shown in Table 1.

As mentioned above, the quantities $\Gamma_{\eta N}^{qm}$ and $[A_{1/2(3/2)}]_{qm}$ in Eq. 8 can be explicitly calculated in the quark model, and consistency requires that the Lagrangian used in evaluating these quantities must be the same as that in deriving the CGLN amplitudes for each resonance [17]. The resulting photon vertex from the Lagrangian used in deriving the CGLN amplitudes is slightly different from those used in the previous calculations [1,3]. As we will see later, this does not lead to significant changes in the numerical results. The derivation of the helicity amplitudes is standard, and we give them in Table 2 for the process $N^* \to \gamma p$.

We would like to underline that the present quark model approach within the $SU(6)\otimes O(3)$ symmetry limit, predicts vanishing values for the $\gamma p$ photo-decay amplitudes for the resonances $D_{13}(1700)$ and $D_{15}(1675)$. In our previous

Table 1
The resonances included in our study with their assignments in $SU(6)\otimes O(3)$ configurations. The configuration mixing coefficients [16] are given in the third column, and correspond to the extracted coupling constant $g_{\eta NN} \equiv \alpha_{\eta NN}/2 = 0.54\pm0.04$. All masses and total widths (in MeV), in the fourth and fifth column, are from Ref. [18]. The width of the $S_{11}(1535)$ is taken [16] to be $\Gamma_T$=230±10 MeV.

| States | $SU(6)\otimes O(3)$ | $C_{N^*}$ | Mass | $\Gamma_T$ |
|---|---|---|---|---|
| $S_{11}(1535)$ | $N(^2P_M)_{\frac{1}{2}^-}$ | 1.83 ± 0.07 | 1535 | |
| $S_{11}(1650)$ | $N(^4P_M)_{\frac{1}{2}^-}$ | -0.37 ± 0.06 | 1650 | 167 ± 22 |
| $P_{11}(1710)$ | $N(^2S_M)_{\frac{1}{2}^+}$ | -0.04 ± 1.29 | 1710 | 100 ± 50 |
| $P_{13}(1720)$ | $N(^2D_S)_{\frac{3}{2}^+}$ | -0.57 ± 0.21 | 1720 | 150 ± 50 |
| $D_{13}(1520)$ | $N(^2P_M)_{\frac{3}{2}^-}$ | 2.50 ± 0.03 | 1520 | 122 ± 12 |
| $D_{13}(1700)$ | $N(^4P_M)_{\frac{3}{2}^-}$ | -0.26 ± 0.13 | 1700 | 100 ± 50 |
| $D_{15}(1675)$ | $N(^4P_M)_{\frac{5}{2}^-}$ | 0.33 ± 0.08 | 1675 | 160 ± 20 |
| $F_{15}(1680)$ | $N(^2D_S)_{\frac{5}{2}^+}$ | 2.50 ± 0.06 | 1680 | 130 ± 10 |

work [16], in order to investigate possible deviations from this symmetry, we used the same expressions for the $D_{13}(1700)$ resonance as for the $D_{13}(1520)$ due to the configuration mixing effects. In the case of the resonance $D_{15}(1675)$, the configuration mixing effect is very small since there is only one $D_{15}$ con-

Table 2
Electromagnetic helicity amplitudes for the $\gamma p$ within the present quark model, with $E_\gamma$ the energy of the incoming photon, $m_q$ = 330 MeV quark mass, $\mu$ = 0.13 GeV$^{-1/2}$, $e^{-\mathcal{K}^2/6\alpha_{ho}^2}$ a form factor in the harmonic oscillator basis. Here $\mathcal{K} = (\frac{2\sqrt{s}M_N}{s+M_N^2})k$, with $M_N$ the mass of the nucleon. As explained in the text, for the $D_{15}$ the $\gamma n$ helicity amplitudes are given.

| Resonance | $A_{1/2}$ | $A_{3/2}$ |
|---|---|---|
| $S_{11}$ | $\frac{2\sqrt{2}}{3}\left(\frac{E_\gamma m_q}{\alpha_{ho}^2}+\frac{1}{2}\frac{\mathcal{K}^2}{\alpha_{ho}^2}\right)\sqrt{\frac{\pi}{E_\gamma}}\mu\alpha_{ho}e^{-\frac{\mathcal{K}^2}{6\alpha_{ho}^2}}$ | |
| $P_{11}$ | $-\frac{1}{3\sqrt{6}}\left(\frac{\mathcal{K}}{\alpha_{ho}}\right)^2\sqrt{\frac{\pi}{E_\gamma}}\mu\mathcal{K}e^{-\frac{\mathcal{K}^2}{6\alpha_{ho}^2}}$ | |
| $P_{13}$ | $\frac{2}{\sqrt{15}}\left(\frac{E_\gamma m_q}{\alpha_{ho}^2}+\frac{1}{3}\frac{\mathcal{K}^2}{\alpha_{ho}^2}\right)\sqrt{\frac{\pi}{E_\gamma}}\mu\mathcal{K}e^{-\frac{\mathcal{K}^2}{6\alpha_{ho}^2}}$ | $-\frac{2}{3\sqrt{5}}\frac{E_\gamma m_q}{\alpha_{ho}^2}\sqrt{\frac{\pi}{E_\gamma}}\mu\mathcal{K}e^{-\frac{\mathcal{K}^2}{6\alpha_{ho}^2}}$ |
| $D_{13}$ | $\frac{2}{3}\left(\frac{E_\gamma m_q}{\alpha_{ho}^2}-\frac{\mathcal{K}^2}{\alpha_{ho}^2}\right)\sqrt{\frac{\pi}{E_\gamma}}\mu\alpha_{ho}e^{-\frac{\mathcal{K}^2}{6\alpha_{ho}^2}}$ | $\frac{2}{\sqrt{3}}\frac{E_\gamma m_q}{\alpha_{ho}^2}\sqrt{\frac{\pi}{E_\gamma}}\mu\alpha_{ho}e^{-\frac{\mathcal{K}^2}{6\alpha_{ho}^2}}$ |
| $D_{15}$ | $\frac{-2}{3\sqrt{10}}\frac{\mathcal{K}^2}{\alpha_{ho}^2}\sqrt{\frac{\pi}{E_\gamma}}\mu\alpha_{ho}e^{-\frac{\mathcal{K}^2}{6\alpha_{ho}^2}}$ | $\frac{-2}{3\sqrt{5}}\frac{\mathcal{K}^2}{\alpha_{ho}^2}\sqrt{\frac{\pi}{E_\gamma}}\mu\alpha_{ho}e^{-\frac{\mathcal{K}^2}{6\alpha_{ho}^2}}$ |
| $F_{15}$ | $\frac{2\sqrt{2}}{3\sqrt{5}}\left(\frac{E_\gamma m_q}{\alpha_{ho}^2}-\frac{1}{2}\frac{\mathcal{K}^2}{\alpha_{ho}^2}\right)\sqrt{\frac{\pi}{E_\gamma}}\mu\mathcal{K}e^{-\frac{\mathcal{K}^2}{6\alpha_{ho}^2}}$ | $\frac{4}{3\sqrt{5}}\frac{E_\gamma m_q}{\alpha_{ho}^2}\sqrt{\frac{\pi}{E_\gamma}}\mu\mathcal{K}e^{-\frac{\mathcal{K}^2}{6\alpha_{ho}^2}}$ |

Table 3
Expressions for the $\eta N$ decay widths of the resonances, with $\mathcal{Q} = (\frac{M_N}{E_f})q$, and $E_f$ the energy of the final state nucleon.

| Resonance | $\Gamma_{\eta N}^{qm}$ |
|---|---|
| $S_{11}$ | $\frac{4}{9}\alpha_{\eta NN}\frac{E_f}{M_{N^*}}\frac{\mathcal{Q}}{M_N^2}\left[\frac{M_{N^*}+M_N}{E_f+M_N}\frac{\mathcal{Q}^2}{\alpha_{ho}}-\frac{3}{2}\frac{E_\eta}{m_q}\right]^2e^{-\frac{\mathcal{Q}^2}{3\alpha_{ho}^2}}$ |
| $P_{11}$ | $\frac{2}{3}\alpha_{\eta NN}\frac{E_f}{M_{N^*}}\frac{\mathcal{Q}}{M_N^2}\left[\frac{M_{N^*}+M_N}{E_f+M_N}\frac{\mathcal{Q}^3}{\alpha_{ho}^2}-\frac{E_\eta\mathcal{Q}}{m_q}\right]^2e^{-\frac{\mathcal{Q}^2}{3\alpha_{ho}^2}}$ |
| $P_{13}$ | $\frac{1}{15}\alpha_{\eta NN}\frac{E_f}{M_{N^*}}\frac{\mathcal{Q}}{M_N^2}\left[\frac{M_{N^*}+M_N}{E_f+M_N}\frac{\mathcal{Q}^3}{\alpha_{ho}^2}-\frac{5}{2}\frac{E_\eta\mathcal{Q}}{m_q}\right]^2e^{-\frac{\mathcal{Q}^2}{3\alpha_{ho}^2}}$ |
| $D_{13}$ | $\frac{4}{9}\alpha_{\eta NN}\frac{E_f}{M_{N^*}}\frac{\mathcal{Q}}{M_N^2}\left[\frac{M_{N^*}+M_N}{E_f+M_N}\frac{\mathcal{Q}^2}{\alpha_{ho}}\right]^2e^{-\frac{\mathcal{Q}^2}{3\alpha_{ho}^2}}$ |
| $D_{15}$ | $\frac{4}{15}\alpha_{\eta NN}\frac{E_f}{M_{N^*}}\frac{\mathcal{Q}}{M_N^2}\left[\frac{M_{N^*}+M_N}{E_f+M_N}\frac{\mathcal{Q}^2}{\alpha_{ho}}\right]^2e^{-\frac{\mathcal{Q}^2}{3\alpha_{ho}^2}}$ |
| $F_{15}$ | $\frac{1}{15}\alpha_{\eta NN}\frac{E_f}{M_{N^*}}\frac{\mathcal{Q}}{M_N^2}\left[\frac{M_{N^*}+M_N}{E_f+M_N}\frac{\mathcal{Q}^3}{\alpha_{ho}^2}\right]^2e^{-\frac{\mathcal{Q}^2}{3\alpha_{ho}^2}}$ |

figuration in this mass region. Thus, the helicity amplitudes presented in the Table 2 correspond to the CGLN amplitudes for the $\gamma n \to \eta n$ channel, which was discussed in more detail in our previous study [16]. In this work, we have adopted the same procedure.

Finally, the formula derived within our quark model approach for the resonance decaying into the $\eta N$ are summarized in Table 3. Here also we have consistently used the same Lagrangian as that in deriving the CGLN amplitudes in Ref. [17].

## 3 Numerical results and discussion

Using this approach, we found [16] $A^p_{1/2}$ = (94±11) $10^{-3}$ GeV$^{-1/2}$ for the $S_{11}(1535)$ resonance with the input branching ratio $BR_{S_{11}(1535)\to\eta N} = 0.45$ (Ref. [18]). This result for the helicity amplitude is in good agreement with the value (90 ± 30) $10^{-3}$ GeV$^{-1/2}$ given in the latest PDG [18] issue, but significantly higher than the value (70±12) $10^{-3}$ GeV$^{-1/2}$, given in the PDG 1996 edition [20].

For the resonances considered in this paper, the quark model results for electromagnetic helicity amplitudes $[A_{1/2(3/2)}]_{qm}$ and their latest PDG values [18] are listed in Table 4. Our results for both helicity amplitudes of the $D_{13}(1520)$ and $D_{15}(1675)$ are compatible with those found in the PDG [18]. This is also the case for the $A^p_{1/2}$ components of the $P_{11}(1710)$ and $D_{13}(1700)$, as well as for the $A^p_{3/2}$ components for the $P_{13}(1720)$, and the $F_{15}(1680)$ resonances. For the other amplitudes, our results show significant deviations from the PDG values. Such trends are also reported in the literature [4,21–23].

Table 4
Numerical results for the photo-excitation helicity amplitudes in units of $10^{-3}$ GeV$^{-1/2}$.

| Reference | $P_{11}(1710)$ | $P_{13}(1720)$ | | $D_{13}(1520)$ | | $D_{13}(1700)$ | | $F_{15}(1680)$ | | $D_{15}(1675)$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $A^p_{1/2}$ | $A^p_{1/2}$ | $A^p_{3/2}$ | $A^p_{1/2}$ | $A^p_{3/2}$ | $A^p_{1/2}$ | $A^p_{3/2}$ | $A^p_{1/2}$ | $A^p_{3/2}$ | $A^n_{1/2}$ | $A^n_{3/2}$ |
| PDG [18] | 9±22 | 18±30 | -19±20 | -24±9 | 166±5 | -18±13 | -2±24 | -15±6 | 133±12 | -43±12 | -51±10 |
| Present work | -25 | 108 | -44 | - 8 | 129 | -19 | 134 | 23 | 85 | -33 | -42 |

The extraction of the $\eta N$ decay width is straightforward: the coefficients $C_{N^*}$ for these resonances are given in Table 1 together with their masses and total decay widths. We present our numerical results for the partial widths and branching ratios of the relevant resonances in Table 5, where the second column gives the predictions of the quark model (see Eq. 5 and Table 3). The only uncertainty here comes from the coupling $\alpha_{\eta NN} \equiv 2g_{\eta NN} = 1.075 \pm 0.070$ as determined in Ref. [16]. The third column correspond to $\Gamma^{th}_{\eta N} = C^2_{N^*}.\Gamma^{qm}_{\eta N}$, where another source of uncertainty is introduced because of the coefficients $C_{N^*}$ as reported in Table 1. In the fourth column our values for the experimental width $\Gamma^{exp}_{\eta N}$, as defined in Eq. 8, are reported. For this quantity, the major origin of the uncertainties comes from those in the helicity amplitudes as given in the PDG (see third row in Table 4). In the last column of Table 5, we give the branching ratio BR $= \Gamma^{exp}_{\eta N}/\Gamma_T$, where the total widths $\Gamma_T$ are taken from the PDG (see last column in Table 1). Our results for the $D_{13}(1520)$ are compatible with the width (0.6 MeV) reported in Ref. [5], and with the two values for the branching ratio (0.08±0.01 and 0.05±0.02) given in Ref. [24]. For the $F_{15}(1680)$ resonance the only other available value comes, to our knowledge, from an algebraic approach [6] which gives $\Gamma_{\eta N} = 0.5$ MeV, smaller than our result.

The uncertainties of the helicity amplitudes $[A_{1/2(3/2)}]_{exp}$, extracted from experiments and reported in the PDG [18], are major constraints on the determination of the partial decay widths or branching ratios within the present approach. For those resonances that have large experimental helicity ampli-

Table 5
$N^* \to N\eta$ decay widths (in MeV), as defined in Section 2, and branching ratios.

| States | $\Gamma^{qm}_{\eta N}$ | $\Gamma^{th}_{\eta N}$ | $\Gamma^{exp}_{\eta N}$ | BR$^{exp}$(%) |
|---|---|---|---|---|
| $D_{13}(1520)$ | $0.3 \pm 0.1$ | $1.8 \pm 0.1$ | $1.1 \pm 0.9$ | $0.9 \pm 0.7$ |
| $F_{15}(1680)$ | $1.8 \pm 0.1$ | $11.4 \pm 0.4$ | $4.9 \pm 3.3$ | $3.8 \pm 2.5$ |
| $P_{11}(1710)$ | $156.0 \pm 10.1$ | $0.3 \pm 402.9$ | | |
| $P_{13}(1720)$ | $162.0 \pm 10.5$ | $52.0 \pm 69.4$ | | |
| $D_{13}(1700)$ | $19.2 \pm 1.2$ | $1.3 \pm 4.9$ | | |
| $D_{15}(1675)$ | $14.8 \pm 1.0$ | $1.6 \pm 2.3$ | $7.2 \pm 65.0$ | $4.5 \pm 41.0$ |
| $S_{11}(1650)$ | | | $18.0 \pm 0.4$ | $10.8 \pm 7.8$ |

tudes, such as the resonances $D_{13}(1520)$ and $F_{15}(1680)$, the uncertainties are small, so that the resulting errors in the $\eta N$ branching ratios are also small. The extracted values for these two resonances are in good agreement with those in the PDG, which shows the consistency of our approach. However, for those resonances with smaller helicity amplitudes and larger uncertainties, such as the two P-wave resonances as well as the $D_{13}(1700)$ and the $D_{15}(1675)$, the $\eta N$ decay width could not be well determined within our approach. Moreover, the rather small coefficients $C_{N^*}$ for these latter resonances obtained by fitting the photoproduction data in our previous study are due to the fact that their electromagnetic couplings are small, which is indeed consistent with the quark model predictions. However, our results here show that the corresponding $\eta N$ decay widths for these resonances *could be large*. For the sake of illustration, we give our results for the $D_{15}(1675)$ resonance (Table 5). For the reasons given above, the uncertainties in the width $\Gamma^{exp}_{\eta N}$ of the resonances $P_{11}(1710)$, $P_{13}(1720)$, and $D_{13}(1700)$ are found to be so large (a few hundred MeV) that we do not find them sufficiently meaningful to merit inclusion in Table 5.

The above considerations show clearly the need for more comprehensive measurement of the $\eta$ photoproduction for *both* proton and neutron targets. The latter is especially desirable in investigation the resonances $P_{11}(1710)$, $P_{13}(1700)$, $D_{13}(1700)$, and $D_{15}(1675)$, due to the fact that their electromagnetic couplings $\gamma n$ are larger than those for the proton target. Therefore, their contributions to the $\eta$ photoproduction could be very significant.

Finally, the last row in Table 5 contains our results for the $S_{11}(1650)$ resonance. Given that the quark model used here predicts, in the $SU(6)\otimes O(3)$ symmetry limit, no contribution from the $S_{11}(1650)$ resonance, we cannot use the same approach as above for this resonance. However, we can derive the relevant expression for the partial width of this resonance following Eqs. 21 and 22 in Ref. [16]. This leads to the following relation where the Lorentz boost factor ($\mathcal{K}$ in Table 2) has been explicitly incorporated:

$$\Gamma^{exp}_{S_{11}(1650)\to\eta N} = \pi\alpha\Big[\alpha_{\eta NN} C^2_{S_{11}(1650)}\Big]\Big[\frac{1}{(A^p_{1/2})^2}\Big]^2\Big[\frac{2}{9}\frac{q}{k}\frac{M_N^3 E_\gamma^2}{M_{N^*}^2 E_f^2}\frac{s(E_f+M_N)}{(s+M_N^2)^2}\Big]$$
$$\Big[\frac{E_\eta}{m_q} - \frac{q^2}{3\alpha^2_{ho}}\Big(\frac{E_\eta}{E_f+M_N}+1\Big)\Big]^2\Big(1+\frac{k}{2m_q}\Big)^2 e^{-\frac{k^2+q^2}{3\alpha^2_{ho}}}, \qquad (9)$$

with $E_\eta$ the total energy of the outgoing $\eta$ meson.

The numerical results given in Table 5 are obtained by using $A^p_{1/2}$ = (53±16) $10^{-3}$ $\mathrm{GeV}^{-1/2}$ (Ref. [18]). The width obtained here is in agreement with values reported in the literature [5,9].

Finally, we would like to emphasize that the partial widths extracted *via* a coupled channel T matrices analysis [25] of the reactions $\pi N \to \eta N$ and $\eta N \to \eta N$ are $\Gamma_{S_{11}(1650)\to\eta N}$ = 5±5 MeV, $\Gamma_{D_{13}(1520)\to\eta N}$ = 0.1±0.2 MeV, and $\Gamma_{F_{15}(1680)\to\eta N}$ = 1±0.4 MeV. All these widths are significantly smaller than our results (Table 5).

## 4 Conclusions

To summarize, using a quark model approach and the recent data for the reaction $\gamma p \to \eta p$, we have presented, in this note, results obtained in a consistent way for the partial decay widths to the $\eta N$ channel for the resonances $S_{11}(1650)$, $D_{13}(1520)$, $D_{15}(1675)$ and $F_{15}(1680)$. For the two P-wave resonances $P_{11}(1710)$ and $P_{13}(1720)$, as well as for the $D_{13}(1700)$, we have highlighted the main sources of uncertainties which prevent us from producing meaningful results for their partial widths. Moreover, we have reported the results for the photo-excitation helicity amplitudes given by our method for all these nucleonic resonances. Our approach shows that precise polarization measurements, feasible at JLAB/CEBAF, for both neutron and proton targets would significantly improve the accuracy of the $\eta N$ decay width for these resonances.

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## References

[1] R. Koniuk, N. Isgur, Phys. Rev. D 21 (1980) 1868.

[2] S. Capstick, N. Isgur, Phys. Rev. D 34 (1986) 2809.

[3] F.E. Close and Zhenping Li, Phys. Rev. D 42 (1990) 2194; *ibid* D 42 (1990) 2207.

[4] S. Capstick, Phys. Rev. D 46 (1992) 2864; S. Capstick, W. Roberts, *ibid* D 49 (1994) 4570.

[5] R. Bijker, F. Iachello, A. Leviatan, Ann. Phys. 236 (1994) 69; Phys. Rev. C 54 (1996) 1935.

[6] R. Bijker, F. Iachello, A. Leviatan, Phys. Rev. D 55 (1997) 2862.

[7] L.Ya. Glozman, D.O. Riska, Phys. Lett. B 366 (1996) 305.

[8] Particle Data Group, J.J. Hernández et al., Phys. Lett. B 239 (1990) 1.

[9] D.M. Manley, E.M. Saleski, Phys. Rev. D 45 (1992) 4002.

[10] Zhenping Li, R. Workman, Phys. Rev. C 53 (1996) R549.

[11] B. Krusche et al., Phys. Rev. Lett. 74 (1995) 3736.

[12] A. Bock et al., Phys. Rev. Lett. 81 (1998) 534.

[13] J. Ajaka et al., Phys. Rev. Lett. 81 (1998) 1797.

[14] B. Krusche, N.C. Mukhopadhyay, J.F. Zhang, Phys. Lett. B 397 (1997) 171.

[15] N.C. Mukhopadhyay, N. Mathur, Phys. Lett. B 444 (1998) 7.

[16] Zhenping Li, B. Saghai, Nucl. Phys. A 644 (1998) 345.

[17] Zhenping Li, Hongxing Ye, Minghui Lu, Phys. Rev. C 56 (1997) 1099.

[18] Particle Data Group, C. Caso et al., Euro. Phys. J. C 3 (1998) 1.

[19] Zhenping Li, Phys. Rev. C 52 (1995) 1648.

[20] Particle Data Group, R.M. Barnett et al., Phys. Rev. D 54 (1996) 1.

[21] R.A. Arndt, I.I. Strakovsky, R.L. Workman, M.M. Paven, Phys. Rev. C 52 (1995) 2120; R.A. Arndt, I.I. Strakovsky, R.L. Workman, *ibid* C 53 (1996) 430.

[22] T. Feuster, U. Mosel, Phys. Rev. C 59 (1999) 460.

[23] D. Drechsel, O. Hanstein, S.S. Kamalov, L. Tiator, Nucl. Phys. A 645 (1999) 145.

[24] L. Tiator, D. Drechsel, G. Knöchlein, C. Bennhold, nucl-th/9902028.

[25] M. Batinić, I. Šlaus, A. Švarc, B.M.K. Nefkens, Phys. Rev. C 51 (1995) 2310; Erratum, *ibid* C 57 (1998) 1004.