ROLE OF THE BARYON RESONANCES IN THE $\eta$ AND $K^+$ PHOTOPRODUCTION PROCESSES ON THE PROTON

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Very recent $\eta$ and $K^+$ photoproduction data on the proton from threshold up to $E_{\gamma} \approx 2.6$ GeV are interpreted within a chiral constituent quark formalism, which embodies all known nucleon and hyperon resonances. Possible contributions from an additional $S_{11}$ resonance are presented.

1. Introduction

Recent experimental and theoretical investigations on the photoproduction of mesons\(^1\) are providing us with new insights into the baryon spectroscopy. The present manuscript is devoted to the interpretation of the processes

$$\gamma p \rightarrow \eta p, K^+\Lambda. \quad (1)$$

Those reactions have been widely studied via Effective Lagrangian Approaches (ELA) for both $\eta$-meson\(^2,3,4,5\) and kaon\(^6,7,8,9,10\) channels. Such studies, often based on the Feynman diagrammatic technique and embodying $s$-, $u$-, and $t$-channel exchanges, have produced various models differing mainly in their content of baryon resonances. The number of exchanged particles dealt with in those isobaric models is limited\(^11\) by the number of related free parameters, which increases rapidly from 1 to 5 per resonance\(^12\), in including resonances with spin $\geq 3/2$. Given the large number of known resonances (see Table 1), such a shortcoming renders those phenomenological approaches inappropriate\(^14\) in the search for new baryon resonances predicted by various QCD-inspired formalisms\(^15\). The latter topic is of special interest in the present work.

The content of our chiral constituent quark approach, based on the broken $SU(6) \otimes O(3)$ symmetry, is outlined in the next Section. Comparisons between our models and data are reported in Section 3 and concluding remarks are given in Section 4.
Table 1. Baryon resonances from PDG [13], with mass $M_{N^*} \leq 2.5$ GeV. Notations are $L_{2J} J(J mass)$ and $L_{I2} I(J mass)$ for $N^*$ and $Y^*$, respectively.

| Baryon | Three & four star resonances | One & two star resonances |
|--------|------------------------------|--------------------------|
| $N^*$  | $S_{11}(1535)$, $S_{11}(1650)$, $P_{11}(1440)$, $P_{11}(1710)$, $P_{13}(1720)$, $D_{13}(1520)$, $D_{13}(1700)$, $D_{15}(1675)$, $F_{15}(1680)$, $G_{17}(2190)$, $G_{19}(2250)$, $H_{19}(2220)$ | $S_{11}(2090)$, $P_{11}(2100)$, $P_{13}(1900)$, $D_{13}(2080)$, $D_{15}(2200)$, $F_{15}(2000)$, $F_{17}(1990)$ |
| $\Lambda^*$ | $S_{01}(1405)$, $S_{01}(1670)$, $S_{03}(1800)$, $P_{01}(1600)$, $P_{01}(1810)$, $P_{03}(1890)$, $D_{03}(1520)$, $D_{03}(1690)$, $D_{05}(1830)$, $F_{05}(1820)$, $F_{05}(2110)$, $G_{07}(2100)$, $H_{09}(2350)$ | $D_{03}(2325)$, $F_{07}(2020)$ |
| $\Sigma^*$ | $S_{11}(1750)$, $P_{11}(1660)$, $P_{11}(1880)$, $P_{13}(1385)$, $D_{13}(1670)$, $D_{13}(1940)$, $D_{15}(1775)$, $F_{15}(1915)$, $F_{17}(2030)$ | $S_{11}(1620)$, $S_{11}(2000)$, $P_{11}(1770)$, $P_{13}(1880)$, $P_{13}(1840)$, $P_{13}(1808)$, $D_{13}(1580)$, $F_{15}(2070)$, $G_{17}(2100)$ |

2. Theoretical Frame

The starting point of the meson photoproduction in the chiral quark model is the low energy QCD Lagrangian\textsuperscript{16}

$$\mathcal{L} = \bar{\psi} \left[ \gamma_{\mu} \left( i \partial^{\mu} + V^{\mu} + \gamma_5 A^{\mu} \right) - m \right] \psi + \ldots \quad (2)$$

where $\psi$ is the quark field in the $SU(3)$ symmetry, $V^{\mu} = (\xi^i \partial_{\mu} \xi + \xi \partial_{\mu} \xi^i)/2$ and $A^{\mu} = i(\xi^i \partial_{\mu} \xi - \xi \partial_{\mu} \xi^i)/2$ are the vector and axial currents, respectively, with $\xi = e^{i\Pi f}$. $f$ is a decay constant and the field $\Pi$ is a $3 \otimes 3$ matrix,

$$\Pi = \begin{pmatrix}
\frac{1}{\sqrt{2}} \pi^0 + \frac{1}{\sqrt{6}} \eta & \pi^+ & K^+ \\
\pi^- & -\frac{1}{\sqrt{2}} \pi^0 + \frac{1}{\sqrt{6}} \eta & K^0 \\
K^- & K^0 & -\sqrt{\frac{2}{3}} \eta
\end{pmatrix}, \quad (3)$$

in which the pseudoscalar mesons, $\pi$, $K$, and $\eta$, are treated as Goldstone bosons so that the Lagrangian in Eq. (2) is invariant under the chiral transformation. Therefore, there are four components for the photoproduction
of pseudoscalar mesons based on the QCD Lagrangian,

\[ \mathcal{M}_{fi} = \langle N_f | H_{m,e} | N_i \rangle + \sum_j \left\{ \frac{\langle N_f | H_m | N_j \rangle \langle N_j | H_e | N_i \rangle}{E_i + \omega - E_j} \right\} + \mathcal{M}_T, \]

where \( N_i (N_f) \) is the initial (final) state of the nucleon, and \( \omega (\omega_m) \) represents the energy of incoming (outgoing) photons (mesons).

The pseudovector and electromagnetic couplings at the tree level are given respectively by the following standard expressions:

\[ H_m = \sum_j \bar{\psi}_j \gamma_\mu \gamma_5 \phi_j \gamma_\mu \phi_m; \]
\[ H_e = -\sum_j e_j \gamma_\mu A_\mu(k, r). \]

The first term in Eq. (4) is a seagull term. The second and third terms correspond to the s- and u-channels, respectively. The last term is the t-channel contribution and is excluded here due to the duality hypothesis\(^ {17} \).

The contributions from the s-channel resonances to the transition matrix elements can be written as

\[ \mathcal{M}_{iN^*} = \frac{2M_{N^*}}{s - M_{N^*} - i\Gamma(q)} e^{-\frac{k^2 + q^2}{6\alpha_h^2}} \mathcal{A}_{N^*}, \]

with \( k = |k| \) and \( q = |q| \) the momenta of the incoming photon and the outgoing meson respectively, \( \sqrt{s} \equiv W \) the total energy of the system, \( e^{-\frac{k^2 + q^2}{6\alpha_h^2}} \) a form factor in the harmonic oscillator basis with the parameter \( \alpha_h \) related to the harmonic oscillator strength in the wave-function, and \( M_{N^*} \) and \( \Gamma(q) \) the mass and the total width of the resonance, respectively. The amplitudes \( \mathcal{A}_{N^*} \) are divided into two parts\(^ {18} \): 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.

The contributions from each resonance is determined by introducing\(^ {19} \) a new set of parameters \( C_{N^*} \), and the substitution rule \( \mathcal{A}_{N^*} \rightarrow C_{N^*}\mathcal{A}_{N^*} \), so that \( \mathcal{M}_{iN^*}^{exp} = C_{N^*}^2 \mathcal{M}_{iN^*}^{exp} \); with \( \mathcal{M}_{iN^*}^{exp} \) the experimental value of the observable, and \( \mathcal{M}_{iN^*}^{exp} \) calculated in the quark model\(^ {18} \). The \( SU(6) \otimes O(3) \) symmetry predicts \( C_{N^*} = 0.0 \) for \( S_{11}(1650) \), \( D_{13}(1700) \), and \( D_{15}(1675) \) resonances, and \( C_{N^*} = 1.0 \) for other resonances in Table 2. Thus, the coefficients \( C_{N^*} \) measure the discrepancies between the theoretical results and the experimental data and show the extent to which the \( SU(6) \otimes O(3) \)
Table 2. Nucleon resonances with $M \leq 2$ GeV and their assignments in $SU(6) \otimes O(3)$ configurations, masses, and widths.

| States      | $SU(6) \otimes O(3)$ | Mass (GeV) | Width (GeV) |
|-------------|----------------------|------------|-------------|
| $S_{11}(1535)$ | $N(^4P_M)_{\frac{1}{2}^-}$ | $1.520$    | $0.130$     |
| $S_{11}(1650)$ | $N(^4P_M)_{\frac{1}{2}^-}$ | $1.440$    | $0.150$     |
| $D_{13}(1520)$ | $N(^2P_M)_{\frac{3}{2}^-}$ | $1.700$    | $0.150$     |
| $D_{13}(1700)$ | $N(^4P_M)_{\frac{1}{2}^-}$ | $1.675$    | $0.150$     |
| $D_{15}(1675)$ | $N(^4P_M)_{\frac{1}{2}^-}$ | $1.675$    | $0.150$     |
| $F_{15}(1720)$ | $N(^2D_M)_{\frac{3}{2}^+}$ | $1.720$    | $0.150$     |
| $F_{15}(1860)$ | $N(^2D_S)_{\frac{1}{2}^-}$ | $1.680$    | $0.130$     |
| $P_{11}(1440)$ | $N(^2S_M)_{\frac{3}{2}^-}$ | $1.440$    | $0.150$     |
| $P_{11}(1710)$ | $N(^2S_M)_{\frac{3}{2}^-}$ | $1.710$    | $0.100$     |
| $P_{13}(1790)$ | $N(^4D_M)_{\frac{5}{2}^+}$ | $1.900$    | $0.500$     |
| $P_{15}(2000)$ | $N(^2D_M)_{\frac{3}{2}^+}$ | $2.000$    | $0.490$     |

Symmetry is broken in the process investigated here. One of the main reasons that the $SU(6) \otimes O(3)$ symmetry is broken is due to the configuration mixings caused by the one-gluon exchange. Here, the most relevant configuration mixings are those of the two $S_{11}$ and the two $D_{13}$ states around 1.5 to 1.7 GeV. The configuration mixings can be expressed in terms of the mixing angle between the two $SU(6) \otimes O(3)$ states $|N(^2P_M)\rangle$ and $|N(^4P_M)\rangle$, with the total quark spin 1/2 and 3/2. To show how the coefficients $C_{N*}$ are related to the mixing angles, we express the amplitudes $A_{N*}$ in terms of the product of the photon and meson transition amplitudes

$$A_{N*} \propto <N|H_m|N>| <N^*|H_e|N>, \quad (7)$$

where $H_m$ and $H_e$ are the meson and photon transition operators, respectively. For example, for the resonance $S_{11}(1535)$ Eq. (7) leads to

$$A_{S_{11}} \propto <N|H_m|N^*|N^*|H_e|N> \propto <N|H_m|N|N^*|H_e|N> \propto <N|H_m|N|N^*|N^*> - \sin \theta_S|N|N^*|H_e|N>$$

$$= (\cos \theta_S <N|H_m|N^*|N^*|N^*|H_e|N> - \sin \theta_S|N|N^*|H_e|N>.$$ (8)

Then, the configuration mixing coefficients can be related to the configuration mixing angles

$$C_{S_{11}(1535)} = \cos \theta_S (\cos \theta_S - \sin \theta_S), \quad (9)$$
$$C_{S_{11}(1650)} = -\sin \theta_S (\cos \theta_S + \sin \theta_S), \quad (10)$$
$$C_{D_{13}(1520)} = \cos \theta_D (\cos \theta_D - \sqrt{1/10} \sin \theta_D), \quad (11)$$
$$C_{D_{13}(1700)} = \sin \theta_D (\sqrt{1/10} \cos \theta_D + \sin \theta_D). \quad (12)$$
3. Results and Discussion

3.1. $\eta$-photoproduction channel

we have fitted all $\approx 650$ data points from recent measurements for both differential cross-sections $^{21,22,23}$ and single polarization asymmetries $^{24}$. The adjustable parameters of our models are the $\eta NN$ coupling constants and one $SU(6) \otimes O(3)$ symmetry breaking strength coefficient $(C_{N^*})$ per resonance, except for the resonances $S_{11}(1535)$ and $S_{11}(1650)$ on the one hand, and $D_{13}(1520)$ $D_{13}(1700)$ on the other hand, for which we introduce the configuration mixing angles $\theta_S$ and $\theta_D$. The first model includes explicitly
GeV for a given parity, assumed to be degenerate and hence written in a compact form. In Fig. 1, we compare this model (dashed curves) to the data at nine incident photon energies. As shown in our earlier works, such a model reproduces correctly the data at low energies ($E_{\text{lab}}^\gamma \leq 1$ GeV). Above, the model misses the data. A possible reason for these theory/data discrepancies could be that some yet unknown resonances contribute to the reaction mechanism. We have investigated possible rôle played by extra $S_{11}$, $P_{11}$, and $P_{13}$ resonances, with three free parameters (namely the resonance mass, width, and strength) in each case.

By far, the most significant improvement was obtained by a third $S_{11}$ resonance, with the extracted values $M=1.780$ GeV and $\Gamma=280$ MeV. The configuration mixing angles came out to be $\theta_S=12^\circ$ and $\theta_D=-35^\circ$, in agreement with the Isgur-Karl model and more recent predictions.

The outcome of this latter model is depicted in Fig. 1 (full curve) and shows very reasonable agreement with the data, improving the reduced $\chi^2$ on the complete data-base, by more than a factor of 2.

3.2. Associated strangeness photoproduction channel

The above formalism has also been used to investigate all 1640 recent data points on the differential cross sections for the $\gamma p \rightarrow K^+\Lambda$ reaction. The adjustable parameters here are the $KYN$ coupling constant and one $SU(6) \otimes O(3)$ symmetry breaking strength coefficient ($C_{N^*}$) per nucleon resonance, as in the case of the $\eta$-channel (Table 2). Other nucleon resonances and all hyperon resonances in Table 1 are included in a compact form and bear no free parameters.

Figures 2 and 3 show our preliminary results for three excitation functions at $\theta_{CM}^K=31.79^\circ$, $56.63^\circ$, and $123.37^\circ$ as a function of total center-of-mass energy ($W$). The choice of the angles is due to the published data by the JLab group.

Given the significant discrepancies between the two data sets, the minimization procedure was performed as follows:

(i) Both data sets were fitted simultaneously, leading to curve (a) in figures 2 and 3.
(ii) Data sets from JLab and SAPHIR were fitted separately. The curve (b) in Fig. 2 is obtained by fitting only the JLab data, while the curve (d), Fig. 3, comes out from a fit only on the SAPHIR data.
(iii) The curves (a), (b), and (d) correspond to models embodying all known resonances. At this stage, a third $S_{11}$ resonance was intro-
Figure 2. Differential cross section for the process $\gamma p \rightarrow K^+ \Lambda$ as a function of total center-of-mass energy ($W$) in GeV. All the curves embody all known resonances. The dashed curve (a) is from a fit to data from both JLab [25] and SAPHIR [26]. The dotted curve (b) is obtained by fitting only JLab data. The full curve (c) corresponds to this latter data set with an additional $S_{11}$ resonance.

Reduced, in line with the $\eta$ case. With this additional resonance, the data from JLab and SAPHIR were fitted separately and the outcomes are the curves (c) and (e) in Figs. 2 and 3, respectively.

The model (a) gives a reduced $\chi^2$ of 3.7 (Table 3). Adding a third $S_{11}$
Figure 3. Same as Fig. 2, except for curves (d) and (e). The dotted curve (d) is obtained by fitting only SAPHIR data. The full curve (e) corresponds to this latter data set with an additional $S_{11}$ resonance.

resonance, improves it slightly ($\chi^2=3.5$). However, fitting separately each set of data, shows a significant sensitivity to the introduction of a third $S_{11}$ resonance. Due to this latter new resonance, for the JLab data the $\chi^2$ goes from 3.0 to 1.6, and for the SAPHIR data it gets reduced from 2.1 to 1.4. We notice that in both cases, the SAPHIR data are better reproduced within our approach.
Table 3. Summary of models (a) to (e).

| Model | Data       | # of data points | Reduced χ² | 3° S_{11}                   |
|-------|------------|------------------|------------|-----------------------------|
| a     | JLab & SAPHIR | 1640             | 3.7        |                             |
| b     | JLab       | 920              | 3.0        |                             |
| c     | JLab       | 920              | 1.6        | M=1.852 GeV ; Γ=187 MeV     |
| d     | SAPHIR     | 720              | 2.1        |                             |
| e     | SAPHIR     | 720              | 1.4        | M=1.835 GeV ; Γ=246 MeV     |

3.3. New S_{11} resonance

Several authors\textsuperscript{17,28,29,30,31,32,33} have reported on a third S_{11} resonance with a mass around 1.8 GeV (see Table 4). Our chiral constituent quark approach applied to the γp → ηp, K^{+}Λ reactions puts the mass in the range of 1.780 to 1.852 GeV and the width between 187 and 280 MeV. This dispersion is, at least partly, due to the discrepancies among data reported by different collaborations. The extracted values for the mass and width from the γp → ηp process are consistent with those predicted by the authors of Ref.\textsuperscript{29} (M=1.712 GeV and Γ=184 MeV), and our previous findings\textsuperscript{17}. Moreover, for the one star S_{11}(2090) resonance\textsuperscript{13}, the Zagreb group πN and ηN coupled channel analysis\textsuperscript{30} produces the following values \( M = 1.792 \pm 0.023 \) GeV and \( Γ = 360 \pm 49 \) MeV. The BES Collaboration reported\textsuperscript{31} on the measurements of the \( J/ψ \to p\bar{p}η \) decay channel. In the latter work, a partial wave analysis leads to the extraction of the mass and width of the S_{11}(1535) and S_{11}(1650) resonances, and the authors find indications for an extra resonance with \( M = 1.800 \pm 0.040 \) GeV, and \( Γ = 165^{+165}^{-85} \) MeV. A more recent work\textsuperscript{32} based on the hypercentral constituent quark model, predicts a missing S_{11} resonance with M=1.861 GeV. Finally, a self-consistent analysis of pion scattering and photoproduction within a coupled channel formalism, concludes\textsuperscript{33} on the existence of a third S_{11} resonance with \( M = 1.803 \pm 0.007 \) GeV.

Table 4. Summary of studies on a 3° S_{11} resonance.

| Mass (GeV) | Width (MeV) | Comment | Ref. |
|------------|-------------|---------|------|
| 1.780      | 280         | CQM applied to γp → ηp | 28; Sec. 3.1 |
| 1.835      | 246         | CQM, applied to γp → K^{+}Λ data from SAPHIR | Sec. 3.2 |
| 1.852      | 187         | CQM, applied to γp → K^{+}Λ data from JLab | Sec. 3.2 |
| 1.730      | 180         | KY molecule | 29 |
| 1.792      | 360         | πN and ηN coupled-channel analysis | 30 |
| 1.800      | 165         | J/ψ decay | 31 |
| 1.861      |             | Hypercentral CQM | 32 |
| 1.846      |             | Pion photoproduction coupled-channel analysis | 33 |
4. Summary and Concluding remarks

In this contribution, the results of a chiral constituent quark model have been compared with the most recent published data on the $\gamma p \rightarrow \eta p, K^+\Lambda$ processes, with emphasize on a third $S_{11}$ resonance. Our results are consistent with findings by other authors\cite{29,30,31,32,33}, showing evidence for such a new resonance, with $M \approx 1.8$ GeV and $\Gamma \approx 250$ MeV.

In the case of the $\eta$ photoproduction channel, we need to extend our analysis to the very recent data from ELSA\cite{35}.

The associated strangeness production channel suffers at the present time from discrepancies between the two copious data set from JLab and SAPHIR. New data from GRAAL will hopefully provide us with a better vision of the experimental situation. Within our approach, a more comprehensive interpretation of the $K^+\Lambda$ channel is underway with respect to the polarization observables\cite{36}, as well as to the observables\cite{26,27} of the $\gamma p \rightarrow K^+\Sigma^o$.

To go further, the coupled channel effects\cite{37,38,39,40,41} have to be considered. The effect of the multi-step process $\gamma p \rightarrow \pi N \rightarrow K^+\Lambda$ has been reported\cite{40} to be significant at the level of inducing 20% changes on the total cross section of the direct channel ($\gamma p \rightarrow K^+\Lambda$). The dynamics of the intermediate states $\pi N \rightarrow KY$, as well as final states interactions $KY \rightarrow KY$, with $Y \equiv \Lambda, \Sigma$ have been recently studied\cite{41} within a dynamical coupled-channel model of meson-baryon interactions. Those efforts deserve to be extended to the multi-step processes

$\gamma p \rightarrow \pi N \rightarrow \eta p, K^+\Lambda, K^+\Sigma^o, K^0\Sigma^+$,

and also embody the final state interactions.

It is a pleasure for me to thank K.H. Glander and R. Schumacher for having provided me with the complete set of SAPHIR and JLab data, respectively, prior to publication. I am indebted to my collaborators W.T. Chiang, C. Fayard, T.-S. H. Lee, Z. Li, T. Mizutani, and F. Tabakin.
References

1. See e.g. W.J. Briscoe, R.A. Arndt, I.I. Strakovski, R.L. Workman, nucl-ex/0310003.
2. N.C. Mukhopadhyay, J. F. Zhang, and M. Benmerrouche, Phys. Lett. B3, 1 (1995); M. Benmerrouche, N.C. Mukhopadhyay, J. F. Zhang, Phys. Rev. D51, 3237 (1995); N.C. Mukhopadhyay, N. Mathur, Phys. Lett. B444, 7 (1998); R.M. Davidson, N. Mathur, N.C. Mukhopadhyay, Phys. Rev. C62, 058201 (2000).
3. W.-T. Chiang, S.N. Yang, L. Tiator, D. Drechsel, Nucl. Phys. A700, 429 (2002); W.-T. Chiang et al., Phys. Rev. C68, 045202 (2003).
4. V.A. Tryasuchev, Phys. Atom. Nucl. 65, 1673 (2002).
5. I.G. Aznauryan, Phys. Rev. C68, 065204 (2003).
6. S.S. Hsiao, S.R. Cotanch, Phys. Rev. C28, 1668 (1983); R.A. Williams, C.R. Ji, S.R. Cotanch, Phys. Rev. C46, 1617 (1992).
7. R.A. Adelseck, C. Bennhold, L.E. Wright, Phys. Rev. C32, 1681 (1985); T. Mart, C. Bennhold, Phys. Rev. C61, 012201 (2000).
8. R.A. Adelseck, B. Saghai, Phys. Rev. C42, 108 (1990); J.C. David, C. Fayard, G.H. Lamot, B. Saghai, Phys. Rev. C53, 2613 (1996).
9. B.S. Han, M.K. Cheoun, K.S. Kim, I.-T. Cheon, Nucl. Phys. A691, 713 (2001).
10. S. Janssen, D.G. Ireland, J. Ryckebusch, Phys. Lett. B562, 51 (2003); S. Janssen, J. Ryckebusch, T. Van Cauteren, Phys. Rev. C67, 052201 (2003); D.G. Ireland, S. Janssen, J. Ryckebusch, nucl-th/0312103.
11. B. Saghai, nucl-th/0310025.
12. M. Benmerrouche, R.M. Davidson, N.C. Mukhopadhyay, Phys. Rev. C39, 2339 (1989); T. Mizutani, C. Fayard, G.H. Lamot, B. Saghai, Phys. Rev. C58, 75 (1998).
13. K. Hagiwara et al., Particle Data Group, Phys. Rev. D66, 010001 (2002).
14. B. Saghai, nucl-th/0105001.
15. See e.g. S. Capstick, W. Roberts, Prog. Part. Nucl. Phys. 45, 5241 (2000); and references therein; S. Capstick, these proceedings.
16. A. Manohar, H. Georgi, Nucl. Phys. B234, 189 (1984).
17. B. Saghai, Z. Li, Eur. Phys. J. A11, 217 (2001).
18. Z. Li, H. Ye, M. Lu, Phys. Rev. C56, 1099 (1997).
19. Z. Li, B. Saghai, Nucl. Phys. A644, 345 (1998).
20. N. Isgur, G. Karl, Phys. Lett. B72, 109 (1977); N. Isgur, G. Karl, R. Koniuk, Phys. Rev. Lett. 41, 1269 (1978).
21. B. Krusche et al., Phys. Rev. Lett. 74, 3736 (1995).
22. F. Renard et al. (The GRAAL Collaboration), Phys. Lett. B528, 215 (2002).
23. M. Dugger et al. (The CLAS Collaboration), Phys. Rev. Lett. 89, 222002 (2002).
24. A. Bock et al., Phys. Rev. Lett. 81, 534 (1998); J. Ajaka et al., ibid 81, 1797 (1998).
25. He Jun, Dong Yu-bing, Phys. Rev. D68 017502 (2003); J. Chizma, G. Karl, ibid D68 054007 (2003).
26. J.W.C. McNabb et al. (The CLAS Collaboration), Phys. Rev. C69, 042201.
(2004).
27. K.H. Glander et al. (The SAPHIR Collaboration), *Eur. Phys. J.* A19, 251 (2004); K.H. Glander, these proceedings.
28. B. Saghai, Z. Li, *nucl-th/0305004*.
29. Z. Li, R. Workman, *Phys. Rev.* C53, R549 (1996).
30. A. Švarc, S. Ceci, *nucl-th/0009024*; A. Švarc, these proceedings.
31. J.-Z. Bai et al., *Phys. Lett.* B510, 75 (2001).
32. M.M. Giannini, E. Santopinto, A. Vassallo, *nucl-th/0302019*.
33. G.-Y Chen, S. Kamalov, S.N. Yang, D. Drechsel, L. Tiator *Nucl. Phys.* A723, 447 (2003); S. Kamalov, these proceedings.
34. V.A. Tryasuchev, *Phys. Atom. Nucl.* 67, 427 (2004).
35. V. Credé et al., (CB-ELSA Collaboration), *hep-ex/0311045*.
36. R.T.G. Zegers et al. (The LEPS Collaboration), *Phys. Rev. Lett.* 91, 092001 (2003).
37. J. Caro Ramon, N. Kaiser, S. Wetzel, W. Weise, *Nucl. Phys.* A672, 249 (2000).
38. J.A. Oller, E. Oset, A. Ramos, *Prog. Part. Nucl. Phys.* 45, 157 (2000).
39. G. Penner, U. Mosel, *Phys. Rev.* C66, 055212 (2002).
40. W.-T Chiang, F. Tabakin, T.-S. H. Lee, B. Saghai, *Phys. Lett.* B517, 101 (2001).
41. W.-T Chiang, B. Saghai, F. Tabakin, T.-S. H. Lee, *nucl-th/0404062*, to appear in *Phys. Rev.* C.
42. T.-S. H. Lee, these proceedings.