ETA PHOTOPRODUCTION IN A COUPLED-CHANNELS APPROACH

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Eta photoproduction on the nucleon is studied in a coupled-channels approach based on an effective Lagrangian. We compare to new differential cross section and beam asymmetry data data from the GRAAL collaboration. At energies above the $S_{11}(1535)$ region we find no sign of p-wave nucleon resonance contributions. The forward-peaking of the beam asymmetry data at higher energy is explained in terms of vector meson t-channel contributions. These new polarization data also reveal a novel role played by the $D_{13}(1700)$ state, similar to the role of the $D_{13}(1520)$ at lower energy.

1 Introduction

Among the many possible excitation mechanisms for nucleon resonances, pion scattering and pion photoproduction have supplied most of the information on N^*s over the past fifty years. Recently, however, due to the improvement of experimental facilities, other reactions that may constitute only a small fraction of the total photoabsorption cross section, have begun playing a more important role. Among these is eta photoproduction, which has more recently established itself as a new, powerful tool to selectively probe certain resonances that may be difficult to explore with pions. It is well known that the low-energy behavior of the eta production process is governed by the $S_{11}(1535)$ resonance[1]. A well-known example of the power of the (γ,η) reaction is the extraction of the $A^p_{1/2}$ helicity amplitude of the $S_{11}(1535)$ state. Due to the combined cusp-resonance nature of this resonance, analyses based solely on pion photoproduction consistently underestimate this quantity to be around 0.060 $GeV^{-1/2}$ while extractions from eta photoproduction place the value closer to 0.10 $GeV^{-1/2}$. Recent coupled-channel analyses[2,3] that properly include the cusp dynamics as well as the resonance phenomena have confirmed a range of values consistent with eta photoproduction.

While the very precise threshold measurements of the total and differential cross sections that lead to an improved understanding of the $S_{11}(1535)$ polarization observables, can provide a new doorway[4] to access smaller, non-dominant resonances by relying on the dominant E_{0+} multipole to interfere with a smaller amplitude. Using polarized photon asymmetry data measured at GRAAL it was shown[5] that this interference effect can reveal less well known properties of the $D_{13}(1520)$, such as an ηN

branching ratio of less than 0.1% and the helicity amplitude $A^p_{1/2}$.

In order to provide a consistent and complete picture of an individual nucleon resonance, the various possible production and decay channels must be treated in a multichannel framework that preserves unitarity and permits separating resonance from background contributions. Here, we focus our ongoing investigation of N^* properties[6] on the role of selected resonances in the eta photoproduction process. Based originally on the work by Feuster and Mosel[3], we use an expanded version of their model with the asymptotic channels $\gamma N, \pi N, \pi\pi N, \eta N, K\Lambda$, $K\Sigma$, and $\eta' N$ up to the center of mass energy $\sqrt{s}$ of 2.0 GeV.

2 Low-Energy Region: $S_{11}(1535)$ and $D_{13}(1520)$

The threshold region has been discussed in great detail and its dominant features are well understood. The pioneering work of the TAPS collaboration at MAMI B which measured threshold total and differential cross sections with great precision[7] confirmed not only the s-wave dominance but also a very small background, due to a small $g_{\eta NN}$ coupling constant of around 0.1 and the small contributions of the t-channel vector mesons in the threshold region. This can be seen from the absence of p-wave contributions in the threshold differential cross section data. While the TAPS data found the p-wave amplitude to be compatible with zero, they did reveal a small but non-negligible d-wave. With the arrival of the GRAAL photon polarization data[8] and by using the above mentioned inference effect, this d-wave component could be identified as stemming from the $D_{13}(1520)$ state[5,9].

All of the above results are reproduced within our coupled-channels framework, with the results shown in Table 1 and in Figs. 1 and 2. In this second resonance region the data are now of high quality for the $\pi N \to \pi N$, $\gamma N \to \pi N$ and $\gamma N \to \eta N$ reactions. Besides the various two-pion channels the missing link is the $\pi N \to \eta N$ reaction which is still under analysis by the Crystal Ball Collaboration. Including those data should settle remaining questions about the relative size of $S_{11}(1535)$ partial and totals widths. We find an $S_{11}(1535)$ total width of around 250 MeV, towards the upper end of the values from PDG[10], $100-250$ MeV, and considerably larger than the value obtained by another recent coupled-channels analysis[2], 112 MeV, but more in line with Ref.[11], 212 MeV. Our result for the $S_{11}(1535)$ photocoupling is similar to (γ,η) single-channel extractions of this quantity[9]. Our total width for the $D_{13}(1520)$ state is 84 MeV, a bit lower than the values from PDG and the Pitt-ANL group. While our value for the $A^p_{3/2}$ amplitude of the $D_{13}(1520)$ is comparable to other analyses, our value for the $A^p_{1/2}$ is compatible with zero, outside accepted ranges. This finding is especially mysterious in view of the recent work[5] which used the (γ,η) GRAAL data and found a value of $A^p_{1/2} = -0.079$ GeV$^{-1/2}$.

Table 1. Parameters of the nucleon resonances discussed in the text. The first line shows our results while the second line is from PDG.

	$S_{11}(1535)$	$S_{11}(1650)$	$D_{13}(1520)$	$D_{13}(1700)$
	1556	1679	1506	1690
M (MeV)	1520-1555	1640-1680	1515-1530	1650-1750
	252	219	84	202
Γ_{tot} (MeV)	100-250	145-190	110-135	50-150
	72	138	50	0.71
Γ_{π} (MeV)	53-83	83-135	50-60	5-18
	157	26	0.01	1.5
Γ_{η} (MeV)	45-83	5-15	-	-
	23	53	34	199
$\Gamma_{\pi\pi}$ (MeV)	1.5-15	15-30	48-60	85-95
	111	46	2	11.2
$A^{p}_{1/2}$ $(10^{-3}GeV^{-1/2})$	90±30	53±16	-24±9	-18±13

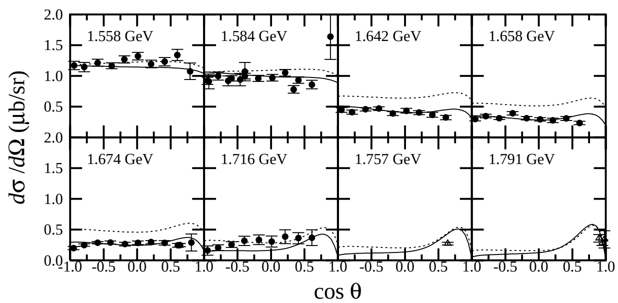

Figure 1. Differential cross section for eta photoproduction. The full curve shows the coupled-channels calculation while the dotted curve has the channel coupling turned off. The data are from MAMI B and GRAAL, except for the panels at W=1.757 and 1.791 GeV which show older data, quoted in previous references.

3 Intermediate-Energy Region: $S_{11}(1650)$ and $D_{13}(1700)$

As can be seen in Fig.1, the intermediate-energy region continues to be remarkably absent of p-wave contributions. Thus, while smaller in cross section, the dominant resonance in this region, still interfering with the $S_{11}(1535)$, appears to be the $S_{11}(1650)$. With 26 MeV we find an ηN branching ratio larger than other studies.

The flatness of the angular distribution up to a W=1675 MeV appears to rule out any major contribution of the $P_{11}(1710)$ state which had once been hypothesized to have an appreciable decay width into the ηN channel. An unconstrained multi-channel fit actually produces a small $P_{11}(1710) \to \eta N$ width, which however leads to a predicted cross section ruled out by the data. Another feature of interest is the contribution from channel coupling: it is negligible in the threshold region, becomes very significant around $W = 1650 MeV$ and then recedes again at higher energies. The nucleon resonance that plays an important role in Σ polarization observable at higher energies is the second D_{13} state 1700 MeV. This is a very inelastic resonance which decouples almost completely from the πN channel. Figure 2 illustrates that the data can not be reproduced if the $D_{13}(1700)$ is excluded. However, the angular distribution of Σ reveals that the situation is more involved compared to the threshold region. The new GRAAL data at higher energies[12] display a forward peaking that varies weakly with W and in our model is naturally explained by vector-meson t-channel contributions. In the differential cross section, the vector mesons show up more prominently above $W = 1700$ MeV where our calculations predict a forward peaking for the cross sections as well. The GRAAL data can neither confirm nor rule out this feature at the present moment, older data at higher energies are sparse with large uncertainties. Final confirmation of the size of the vector meson terms will have to be left to the JLAB data.

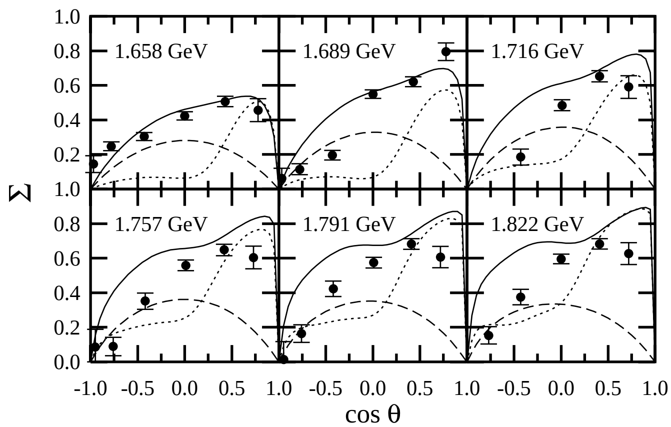

Figure 2. Polarized photon asymmetry for eta photoproduction. The full curve shows our coupled-channels result, while the dashed (dotted) line shows the results without vector mesons ($D_{13}(1700)$). The data are from GRAAL.

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References

1. C. Bennhold and H. Tanabe, *Nucl. Phys.* A **530**, 625 (1991); M. Benmerrouche, N.C. Mukhopadhyay and J.-F. Zhang, *Phys. Rev.* D **51**, 3237 (1995).
2. T.P. Vrana, S.A. Dytman, and T.-S. H. Lee *Phys. Rept.* **328**, 181 (2000).
3. T. Feuster and U. Mosel, *Phys. Rev.* C **59**, 460 (1999).
4. L. Tiator, C. Bennhold, and S.S. Kamalov, *Nucl. Phys.* A **580**, 455 (1994).
5. L. Tiator *et al.*, *Phys. Rev.* C **60**, 035210 (1999).
6. C. Bennhold *et al.*, nucl-th/9901066, nucl-th/0008024, and *these proceedings*; A. Waluyo *et al.*, nucl-th/0008023.
7. B. Krusche *et al.*, *Phys. Rev. Lett.* **74**, 3736 (1995).
8. J. Ajaka *et al.*, *Phys. Rev. Lett.* **81**, 1797 (1998).
9. N.C. Mukhopadhyay and N. Mathur, *Phys. Lett.* B **444**, 7 (1998).
10. Particle Data Group, *Eur. Phys. J.* C **15**, 1 (2000).
11. B. Krusche *et al.*, *Phys. Lett.* B **397**, 171 (1997).
12. F. Renard, *et al.*, hep-ex/0011098 and A. D'Angelo, *these proceedings*.