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PHOTOPRODUCTION OF η AND η' MESONS FROM THE PROTON

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Abstract

The excitation spectrum of the proton is comprised of many broad overlapping resonances, making investigations of these resonances very challenging. Two excellent tools in helping deconvolve the spectrum are η and η' meson photoproduction from the proton.

Since the beginning of this new millennium, much progress has been made in measuring η and η' meson photoproduction from the proton. These new measurements are largely in the form of differential cross sections that now cover the first and second resonance regions. In addition to differential cross section data, there have been a comparatively smaller number of beam asymmetry measurements for η photoproduction. However, these beam asymmetries cover the energy range up to only about $E_\gamma = 1.5$ GeV. In this talk, I will present preliminary Jefferson Lab CLAS data on beam asymmetry for both the η and η'. I will also discuss how the new measurements will be useful in understanding the structure and excited states of the proton.

1 Motivation

Understanding the structure of the proton is challenging due to the great complexity of this strongly interacting multi-quark system [1]. Of particular utility in investigating nucleon structure are those production mechanisms and observables that help isolate individual excited states of the nucleon and determine the importance of specific contributions. Since the electromagnetic interaction is well understood, photoproduction offers one of the more powerful methods for studying the nucleon. Because the η and η' mesons have isospin 0, ηN and $\eta' N$ final states can only originate (in one-step processes) from isospin $I = 1/2$ intermediate states. Therefore, the reactions $\gamma p \to \eta p$ and $\gamma p \to \eta' p$ isolate $I = 1/2$ resonances, providing an "isospin filter" for the spectrum of broad, overlapping nucleon resonances, a useful simplification for theoretical efforts. Moreover, since the η' meson is the only flavor singlet of the fundamental pseudoscalar meson nonet, studies of the reaction can also help yield information on the role of glue states in nucleon excitations.

2 Recent results

Six experimental facilities have been or are providing new data on meson photoproduction from the proton: GRAAL [2], SAPHIR [3], CB-ELSA [4], CLAS [5], LNS [6], and MAMI [7]. Their contributions to η and η' photoproduction from the proton will be summarized here.

2.1 The reaction $\gamma p \to p\eta$

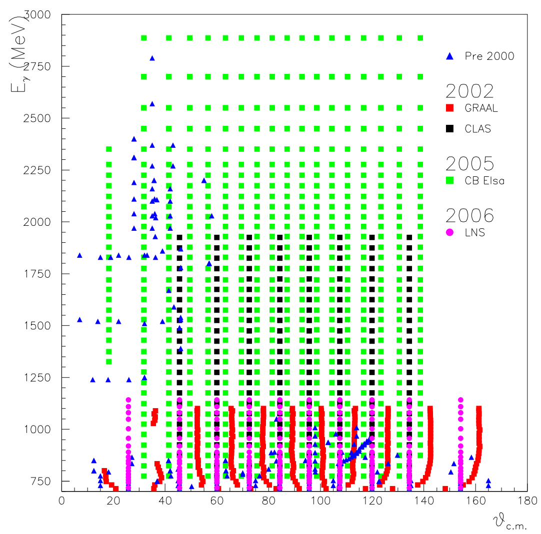

Figure 1: Coverage of differential cross section measurements for $\gamma p \to \eta p$ in terms of incident photon energy and center of mass angle. Shown are measurements before 2000 (blue triangles), GRAAL [8] (red squares), CLAS [9] (black squares), CB-ELSA [10] (green squares), and LNS [11] (pink circles).

Before 2002 the world database for $\gamma p \to p\eta$ differential cross sections was only well covered for E_γ from threshold (0.707 GeV) up to 0.8 GeV. More recently, the following groups have produced data

- In 2002, GRAAL published results on $d\sigma/d\Omega$ for E_γ up to 1.1 GeV [8], and CLAS published $d\sigma/d\Omega$ for E_γ up to 1.95 GeV [9].
- In 2005, CB-ELSA published $d\sigma/d\Omega$ results for E_γ up to 3 GeV [10].
- In 2006, LNS published $d\sigma/d\Omega$ results for E_γ up to 1.15 GeV [11].

Fig.1 shows the coverage of differential cross sections in terms of incident photon and center of mass angle. In addition to these published results, there are ongoing analyses for η differential cross sections from groups at MAMI and CLAS.

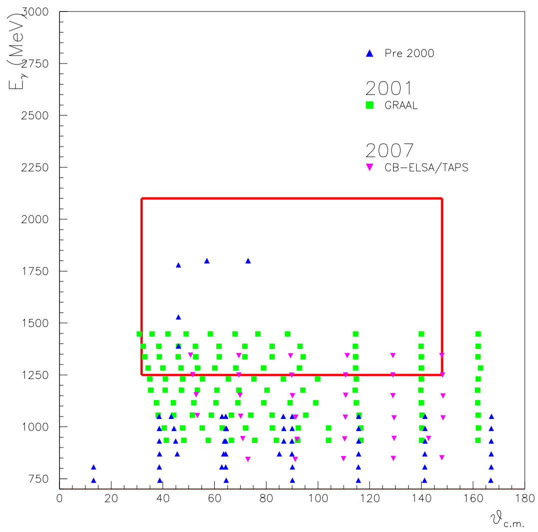

Figure 2: Coverage of beam asymmetry Σ measurements for $\gamma p \to \eta p$ in terms of incident photon energy and center of mass angle. Shown are measurements before 2000 (blue triangles), GRAAL [13] (green squares), and CB-ELSA/TAPS [14] (pink triangles). The red box represents the region that CLAS is expected to cover.

Recent beam asymmetry Σ results for $\gamma p \to p\eta$ include:

- In 1998, GRAAL published results for E_γ up to 1.050 GeV [12].
- In 2002, GRAAL published results that extended the energy range to 1.447 GeV [13].
- In 2007, CB-ELSA/TAPS produced results for energies up to 1.350 GeV [14].

During the summer of 2005, data were taken at CLAS for Σ that should allow extraction of that observable for η photoproduction from the proton for E_γ up to 2.1 GeV. Fig. 2 shows the coverage of beam asymmetry measurements in terms of incident photon energy and center of mass angle, including a rectangular box showing the region where the new CLAS measurements will provide coverage. A preview of some very preliminary CLAS results is shown in Fig. 3.

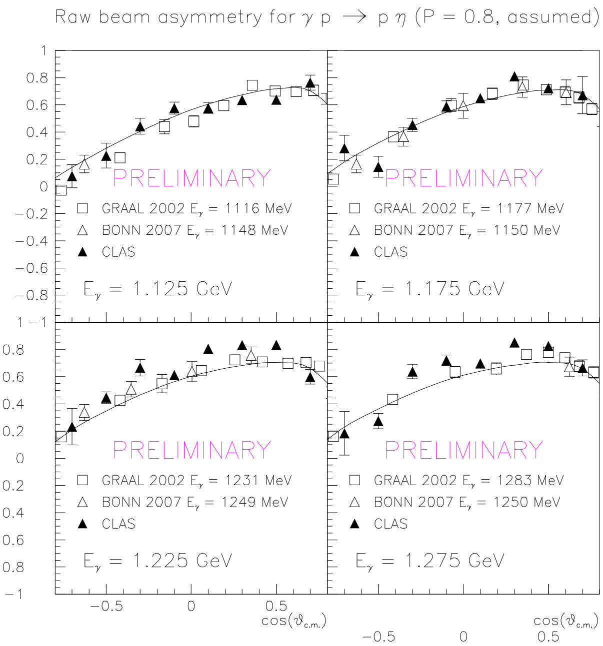

Figure 3: Beam asymmetries for $\gamma p \to p\eta$. The data points are from a preliminary CLAS analysis (filled triangles), Bonn CB-ELSA/TAPS [14] (open triangles), and GRAAL [13] (open squares). The curves are from SAID [15].

All other polarization observables are very sparsely covered in energy and angle. Future experiments are expected to enhance our knowledge of the polarization observables. In particular, an approved experiment at Jefferson Lab [16] will begin taking data later this Fall (2007) for double polarization observables (beam and target).

2.2 The reaction $\gamma p \to p\eta'$

Prior to 1998, only 18 η' photoproduction events had been measured (11 events from the ABBHHM bubble chamber experiment [17], and 7 events from the AHHM streamer chamber experiment [18]). In 1998, the SAPHIR collaboration published results [19] extracted from an additional 250 η' exclusive events. By contrast, the 2006 CLAS results [20] includes over 2×10^5 η' photoproduction events used to extract the differential cross sections shown in Fig. 4. Also shown in Fig. 4 are the results of theoretical fits to the data from K. Nakayama and H. Haberzettl (NH model [21], described in the next section) using five different sets of included resonances (see Table 1). The CLAS results span E_γ from 1.527 to 2.227 GeV.

No polarization observables have been published for this reaction. Therefore, the differential cross sections provide the only reported experimental data for the reaction $\gamma p \to p\eta'$. However, while there are currently no released data for $\gamma p \to p\eta'$ beam asymmetries, Fig. 5 shows a sample of preliminary CLAS results, along with the predictions from the NH model for each of the five resonance sets given in Table 1. It is important to note that the NH model results shown in Figs. 4 and 5 were determined by fitting only to the differential cross section data.

3 Theoretical results

As noted above, there are many new differential cross section data for the reactions discussed here. However, these alone are not sufficient to constrain theoretical models such that contributing resonances can be uniquely determined. More data on the polarization observables are desperately needed, and a coupled channel approach is required, in order to determine conclusively the contributions of various resonances.

One step in this direction comes from a model [10, 22, 23] developed by A. V. Anisovich, E. Klempt, A. Sarantsev, and U. Thoma (Bonn-Gatchina model) that couples the reactions $\gamma p \to p\pi^0$, $n\pi^+$, and $p\eta$. Bonn-Gatchina included published differential cross sections, as well as the recent GRAAL beam polarization observables. The model uses a K matrix approach for the $S_{11}(1535)$ and the $S_{11}(1650)$ resonances. The remaining resonances are described by Breit-Wigner amplitudes. The model also includes Reggeized $u-$ and $t-$channel contributions. Results from their analysis [22] find evidence for a previously unseen $D_{15}(2070)$ resonance, and indications for a new $P_{13}(2200)$ resonance.

One model that considers the η' exclusively is the NH model mentioned

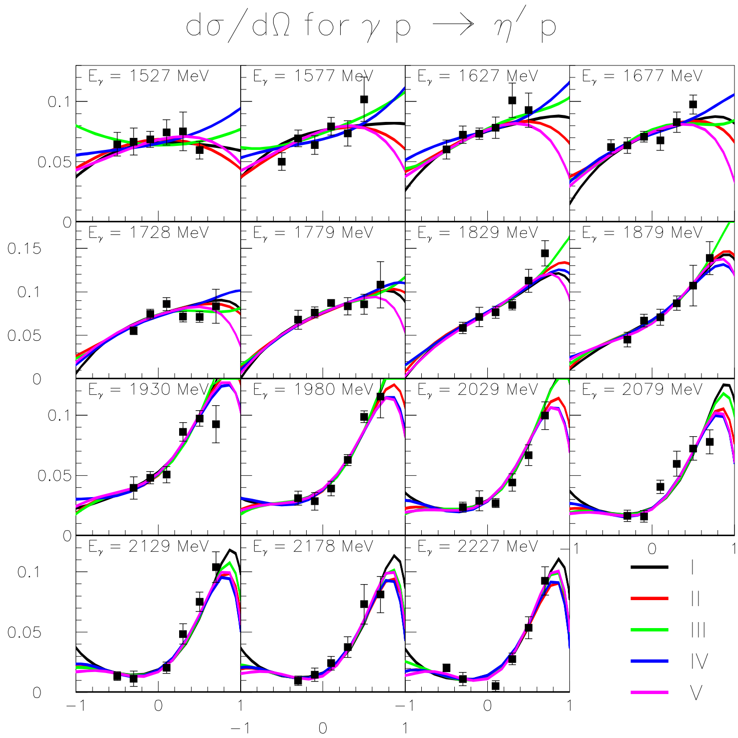

Figure 4: Differential cross sections for $\gamma p \to p\eta'$. The data points are from CLAS [20] and the curves are based on five different sets of resonances (see Table 1) using the NH model [21] described in the text.

above [21]. This model is based upon a relativistic meson-exchange model of hadronic interactions. Allowed processes include s-, t-, and u-channel contributions. The intermediate mesons for the $t-$channel exchange are the ω and ρ^0. NH tried five different sets of resonances in their fits; the masses and widths of the included resonances were allowed to vary, except for those in set V which were set to PDG values. The observed u-channel contribution allows the $g_{\eta' NN}$ coupling to be extracted (albeit in a model-dependent way). The five sets of included resonances, along with the $g_{\eta' NN}$ fit parameter, are summarized in Table 1.

Since the η' meson is the only flavor singlet of the fundamental pseudoscalar meson nonet, studies of the reaction can also help yield information on the role of glue states in excitations of the nucleon. The flavor-singlet axial charge of the nucleon ($G_A(0)$) is related to the η'-nucleon-nucleon and gluon-nucleon-nucleon coupling constants ($g_{\eta' NN}$ and $g_{GNN}(0)$, respectively)

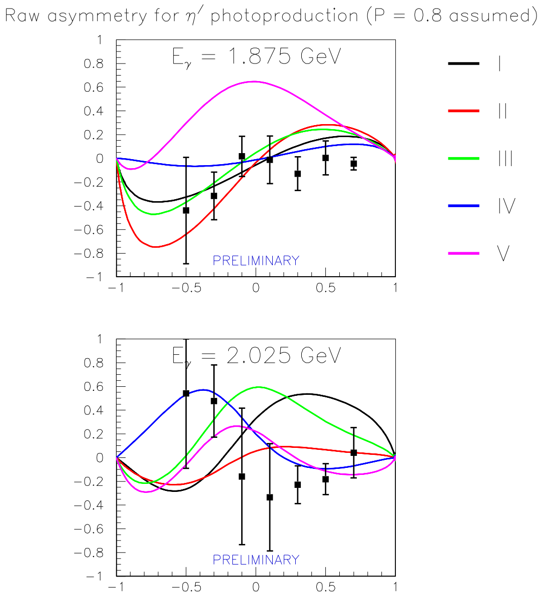

Figure 5: Beam asymmetries for $\gamma p \to p\eta'$. The data points are from a preliminary CLAS analysis, and the curves are based on five different sets of resonances (see Table 1) using the NH model [21].

through the flavor-singlet Goldberger-Treiman relation [24]:

$$2m_N G_A(0) = F g_{\eta' NN} - \frac{F^2 m_{\eta'}^2}{N_F} g_{GNN}(0), \tag{1}$$

where m_N is the mass of the nucleon, $m_{\eta'}$ is the η' mass, F is an invariant decay constant that reduces to F_π (pion decay constant) if the $U(1)_A$ anomaly is turned off [25], and N_F equals the number of flavors. When first measured [26], the singlet axial charge was found to have a value of $G_A(0) = 0.20 \pm 0.35$. (A more recent calculation [27] gives $G_A(0) = 0.213 \pm 0.138$.) At that time, the importance of the second term in Eq. 1 was unappreciated, and this low value of $G_A(0)$ was surprising: Since $g_{\eta' NN}$ is considered to be correlated with the fraction of the nucleon spin carried by its constituent quarks [28], that fraction would then be consistent with zero. Thus, neglecting the gluonic portion of Eq. 1 was one of the causes of the so-called "spin crisis." However, when the gluonic degrees of freedom are included in Eq. 1, the value of $g_{\eta' NN}$ can be large, provided that it is nearly canceled by $g_{GNN}(0)$. This equation then can be used to indirectly determine a value for $g_{\eta' NN}$.

By looking only at the differential cross sections, no particular set of resonances (from the five sets studied) appears to do much better in fitting the

Table 1: The five sets of resonances used in the NH model [21].

Set I	Set II	Set III	Set IV	Set V
		$S_{11}(1535)$	$S_{11}(1535)$	$S_{11}(1535)$
		$S_{11}(1650)$		$S_{11}(1650)$
$S_{11}(2090)$	$S_{11}(2090)$	$S_{11}(2090)$	$S_{11}(2090)$	$S_{11}(2090)$
		$P_{11}(1710)$	$P_{11}(1710)$	$P_{11}(1710)$
$P_{11}(2100)$	$P_{11}(2100)$	$P_{11}(2100)$	$P_{11}(2100)$	$P_{11}(2100)$
		$P_{11}(2400)$		
				$P_{13}(1720)$
$P_{13}(1900)$	$P_{13}(1900)$	$P_{13}(1900)$		$P_{13}(1900)$
$D_{13}(1700)$	$D_{13}(1700)$	$D_{13}(1700)$	$D_{13}(1700)$	$D_{13}(1700)$
	$D_{13}(2080)$	$D_{13}(2080)$	$D_{13}(2080)$	$D_{13}(2080)$
$g_{\eta' NN} = 0.43$	$g_{\eta' NN} = 0.25$	$g_{\eta' NN} = 1.33$	$g_{\eta' NN} = 0.002$	$g_{\eta' NN} = 1.91$

data than the others. The CLAS report on the differential cross sections [20] concentrated on resonance set III because the value of $g_{\eta' NN}$ found from that particular NH fit was 1.33. As stated in that paper

> Since differential cross sections alone do not provide sufficient constraints to this model, the $g_{\eta' NN}$ values should be taken with caution. Nonetheless, this value is consistent with the analysis of T. Feldmann [25] which gives $g_{\eta' NN} = 1.4 \pm 1.1$.

Now, with the benefit of the preliminary beam asymmetry measurements shown in Fig. 5, it would appear that resonance set IV is much more consistent with the data. Resonance set IV, however, would yield a value of $g_{\eta' NN}$ = 0.002, which is much smaller than would be expected. Since the NH fit needs to be redone to include the new beam asymmetry measurements, no definitive statements regarding the $g_{\eta' NN}$ coupling constant can be made at this time. However, it is readily apparent that beam asymmetry measurements will be vital in determining which resonances significantly contribute to the process and in delimiting the value of $g_{\eta' NN}$.

4 Summary

While there has been much progress in obtaining differential cross section data for η and η' photoproduction from the proton, and some new beam polarization (Σ) measurements have become available, more polarization observables are needed in order to provide constraints for theoretical models. Such experiments are planned for the near future. A comprehensive program for single, double and even triple polarization measurements in photoproduction is in preparation at Jefferson Lab. From the data already taken, there appears to be evidence for a new D_{15} resonance at 2.09 GeV and indications of a new P_{13} at 2.20 GeV. In the future, when the $g_{\eta' NN}$ coupling constant can be determined with a high degree of confidence, it can be used to indirectly determine the gluonic coupling to the proton through the flavor-singlet Goldberger-Treiman relation.

Acknowledgments

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