

N* Physics with Meson Photoproduction

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An overview is given of the progress in the study of baryon spectroscopy from the CLAS experimental programme at Jefferson Lab. A range of photo-production measurements has been carried out, which include the extraction of several polarization observables for different reaction channels. The results so far show that these data are very useful in the search for evidence for new baryon resonances. A survey of the results is presented, together with the latest phenomenological fits.

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1. Introduction

The spectrum of baryons matters because it is a manifestation of the strong interaction at the energy scale of ordinary matter. It is also fairly evident that our knowledge of the spectrum is incomplete [1]. Most variants of the quark model predict more states than have as yet been identified. These predictions have been given strong support from the recent results from lattice QCD such as those from the Hadron Spectrum Collaboration [2], which indicate in broad terms that the spectra derived from lattice calculations share many similar features with quark models, including the number of expected states. Spectroscopy of low mass baryons was one of the major reasons driving the CLAS experimental programme.

2. Experimental Programme at CLAS

The CEBAF Large Acceptance Spectrometer (CLAS) [3] was the centrepiece of Hall B at Jefferson Lab until its last experimental run finished in June 2012. A diagram of the detector is shown in figure 1.

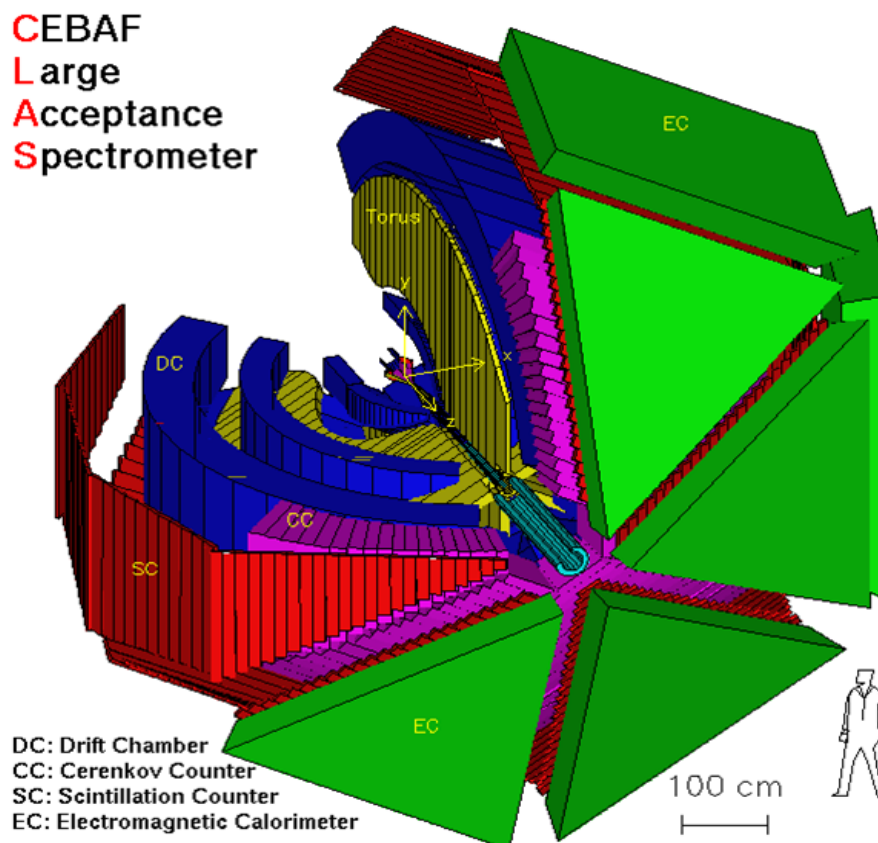


Figure 1: Diagram of the CLAS detector [3].

Reaction products are tracked by drift chambers from the target through a toroidal magnetic field. Scintillation counters measure particle time-of-flight, Čerenkov detectors allow for particle identification and electromagnetic calorimeters measure the energy of charged particles.

The programme of measurements relevant to the study of the baryon resonance spectrum is summarized in table 1. This table shows the various final states that can be measured in photoproduction with CLAS, together with the observable quantities that are possible to extract. A main feature of CLAS is the capability of measuring multiple particles in the final state, although charged particles are easier to identify cleanly than neutrals. Note that the table does not include measurements made on two pion photoproduction, which come with a different set of polarization observables.

It has to be noted that many of the results on observables listed in table 1 have yet to be published. A short summary of the findings so far now follows.

Table 1: Observables measured in the CLAS pseudoscalar meson photoproduction programme.

Observable →	σ	Σ	T	P	E	F	G	H	T_x	T_z	L_x	L_z	O_x	O_z	C_x	C_z
Final state																
Proton Targets																
$p\pi^0$	*	*	*		*	*	*	*								
$n\pi^+$	*	*	*		*	*	*	*								
$p\eta$	*	*	*		*	*	*	*								
$p\eta'$	*	*	*		*	*	*	*								
$p\omega$	*	*	*		*	*	*	*								
$p\phi$	*	*	*		*	*	*	*								
$K^+\Lambda$	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
$K^+\Sigma^0$	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
$K^0\Sigma^+$	*	*														
$K^{0*}\Sigma^+$	*	*														
$K^{+*}\Sigma^0$	*	*														
Neutron Targets																
$p\pi^-$	*	*			*	*	*									
$p\rho^-$	*	*			*	*	*									
$K^0\Lambda$	*	*	*	*	*	*	*				*	*	*	*	*	*
$K^0\Sigma^0$	*	*	*	*	*	*	*				*	*	*	*	*	*
$K^-\Sigma^+$	*	*			*	*	*									
$K^{0*}\Sigma^0$	*	*														

3. Cross Section Measurements

An example of a π^+n angular distribution of cross sections is show in figure 2. One can see that the statistical accuracy is very good, providing a tight constraint for theoretical models over the whole resonance region [4]. Progress has also been made on measurements of ω photoproduction. Figure 3 shows cross section data from [5]. Spin density matrix elements have also been extracted from those measurements.

It is not possible in the space available to show a comprehensive set of photoproduction data from CLAS. The main point to take from this is that differential cross-sections are now tied down

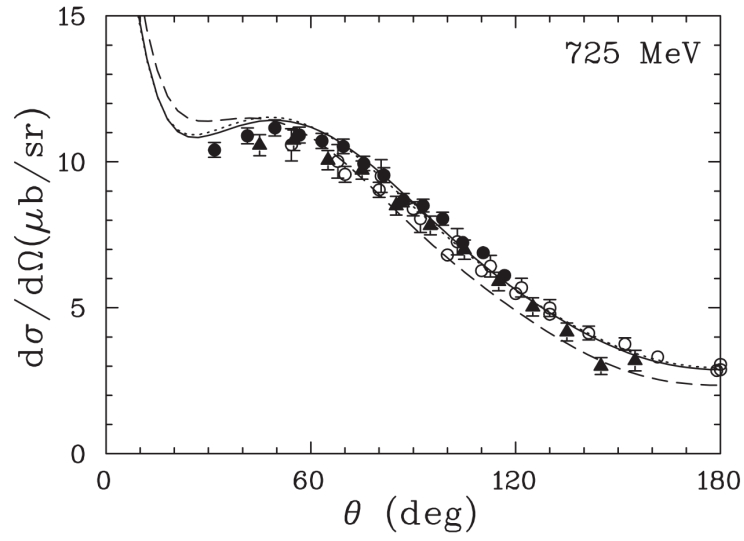


Figure 2: Example of differential cross section results for the $\gamma p \rightarrow \pi^+ n$ reaction [4].

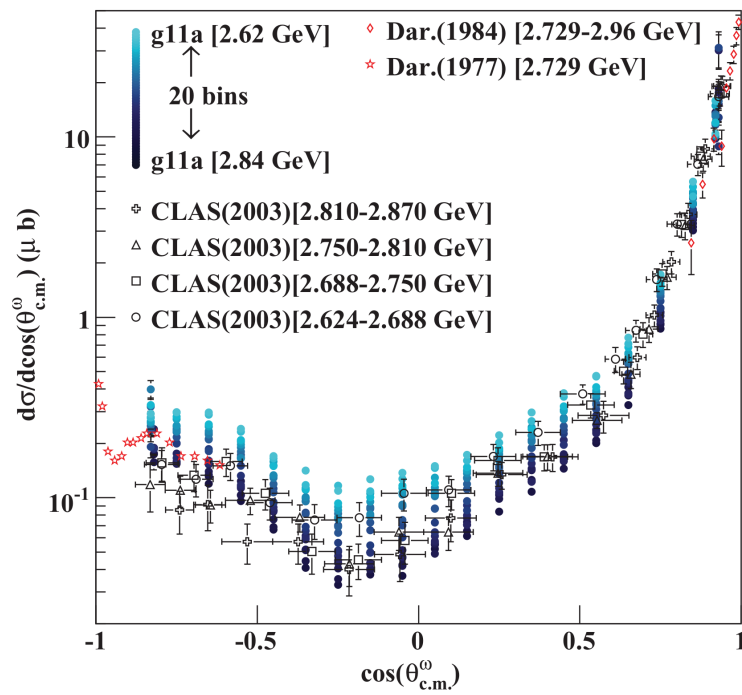


Figure 3: Example of differential cross section results for the $\gamma p \rightarrow \omega p$ reaction [5].

rather nicely, and a large fraction of the published photoproduction results are CLAS measurements.

4. Recoil Polarization

Whilst the accurate determination of cross sections is necessary, it is not sufficient for determining whether there is evidence to indicate new resonant states. Figure 4 from [6] shows that with a circularly polarized photon beam, and the ability to determine the polarization of the recoiling hyperon, the double polarization observables C_x and C_z for the $\gamma p \rightarrow K^+ \Lambda$ reaction can be extracted. These data were crucial in providing evidence for new resonances found in the analysis of [7].

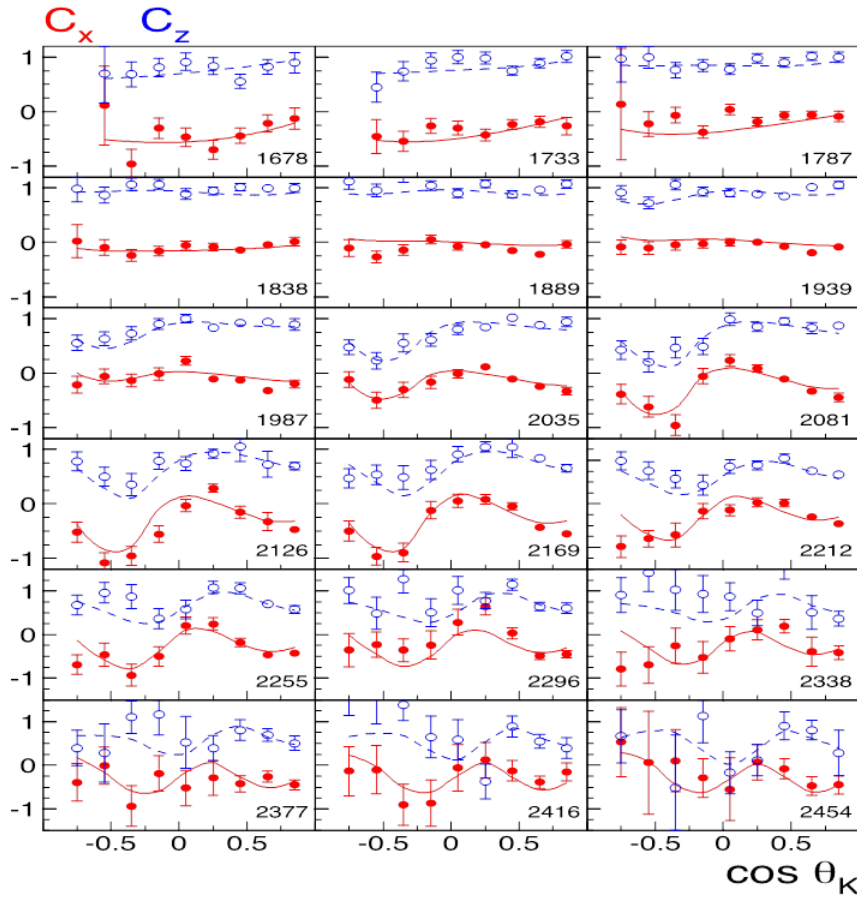


Figure 4: Double polarization observables C_x and C_z for the $\gamma p \rightarrow K^+ \Lambda$ reaction [6].

5. Linearly Polarized Photons

With the development of linearly polarized beams [8], it is now possible to measure beam asymmetry and beam-recoil double polarization observables. Examples of beam asymmetry measurements for π^0 and π^+ photoproduction are shown in figures 5 and 6 [9]. These plots clearly

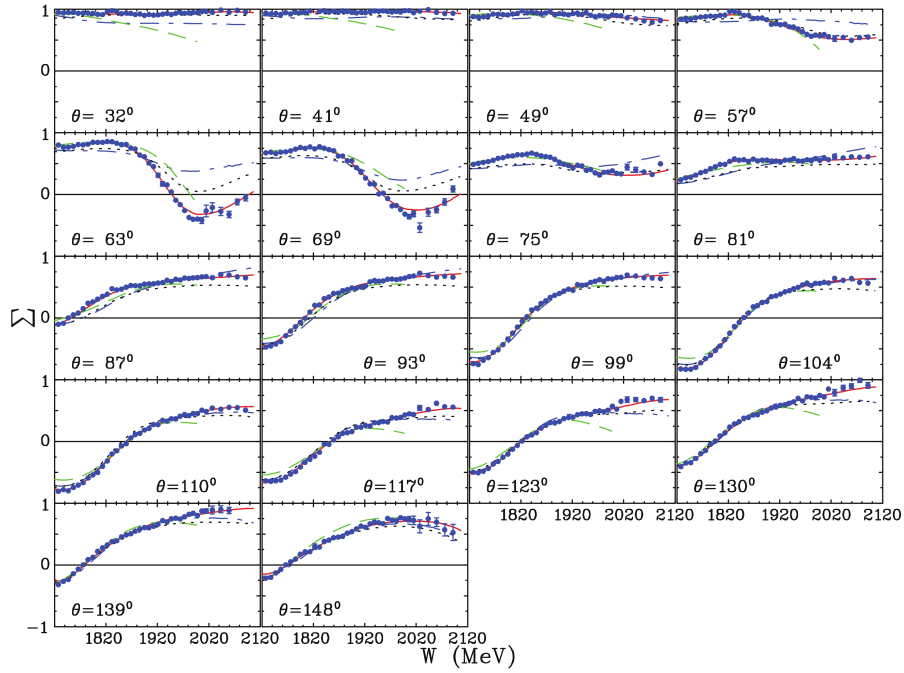


Figure 5: Beam asymmetry Σ for the $\bar{\gamma}p \rightarrow \pi^0 p$ reaction [9].

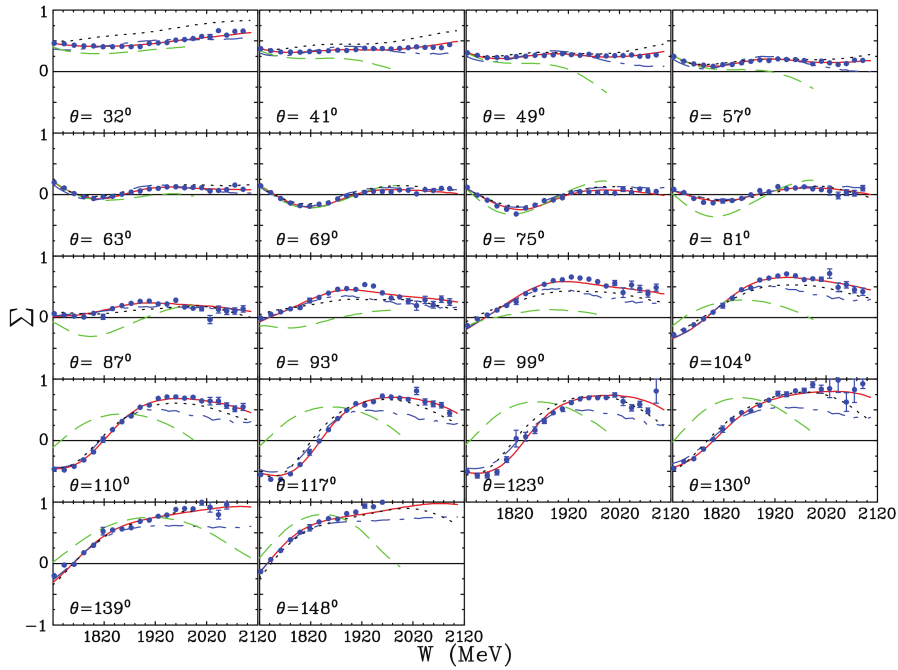


Figure 6: Beam asymmetry Σ for the $\bar{\gamma}p \rightarrow \pi^+ n$ reaction [9].

show how statistically accurate the measurements are, and also indicate how the data discriminate among various model predictions.

Measurements of the $\vec{\gamma}p \rightarrow K^+\Lambda$ reaction [10] are displayed in figure 7. The recoil polarization of the Λ can be determined, due to the self-analyzing nature of its weak decay. These data show that calculations fitted to a variety of channels and observables are still unable to predict values for observables that have been measured for the first time.

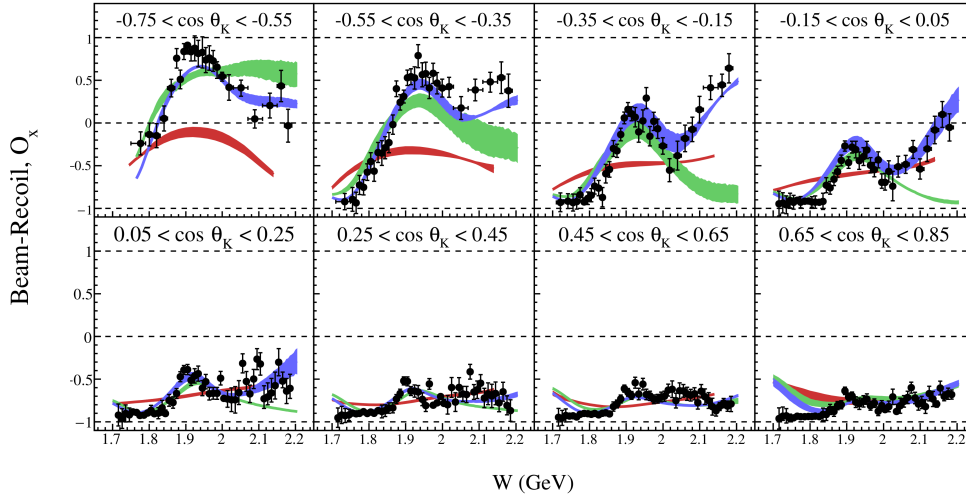


Figure 7: Beam-recoil observable O_x for the $\vec{\gamma}p \rightarrow K^+\Lambda$ reaction [10]. Calculations: red – ANL-Osaka; green – Bonn-Gatchina prediction; blue – Bonn-Gatchina refit.

6. Polarized Targets

Another advance in experimental techniques is the use of polarized targets. Data taken from experiments with the FROzen Spin Target (FROST) target have recently been published [11]. The first measurement of the polarization observable E up to $W = 2.25$ GeV has been extracted for the $\gamma p \rightarrow \pi^+n$ reaction, and a sample of the results is shown in figure 8. This is a very nice demonstration of power of new data to influence the extraction of parameters from fits. The top line shows calculations of various models that are predictions, whilst the bottom line shows the result of refitting with the new data. This analysis is providing further evidence for new resonant states.

In principle the measurement of many observables in the $K\Lambda$ and $K\Sigma$ channels that have still to be published will allow the extraction of reaction amplitudes. This is highly desirable from a phenomenological perspective, since these could lead to fitting results with the minimum amount of ambiguity in the solutions. Much effort has been brought to bear on analyses of combinations of observables that lead to a “complete” measurement. However “completeness” is only a mathematical construct that does not take into account the finite resolution of experimental results. Amplitude extraction will ultimately only be possible through the measurement of a large set of observables with sufficient accuracy.

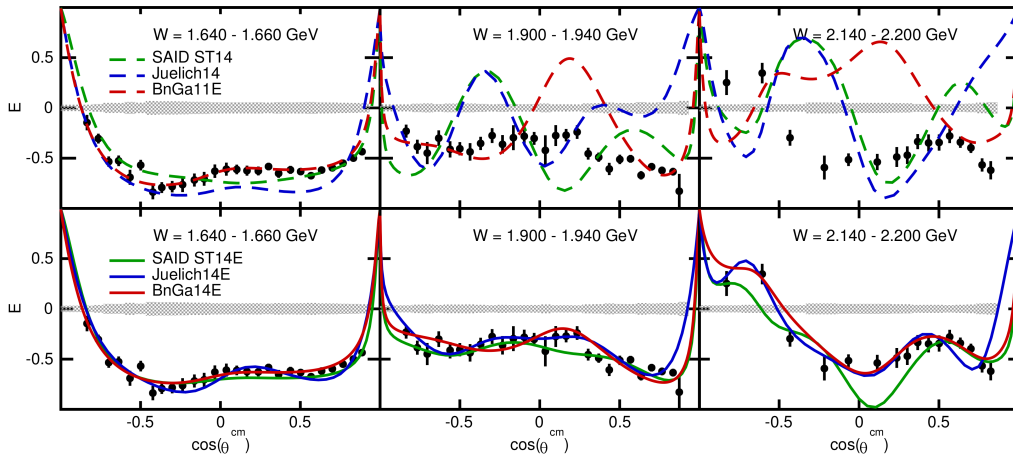


Figure 8: Beam-target double polarization asymmetry E for the $\bar{\gamma}p \rightarrow \pi^+ n$ reaction [11].

7. Summary and Outlook

The CLAS collaboration has now measured many photoproduction channels in the N^* resonance region, but the full impact of that programme will not be apparent for a few years. In terms of publications there is still a great deal more to come including: polarization observables from two-pion photoproduction; finalised results from linearly polarized photon beams, including kaon photoproduction; results from measurements with a deuterium target; more results from the frozen spin target (FROST) and the polarized proton/deuteron target HDIce.

The list above refers to experiments carried out with real photon beams. There is a wealth of other information from electroproduction measurements, both published and in the analysis phase, which has and will have significant impact on our understanding of the N^* spectrum.

As more and more observables are extracted in several reaction channels, there is a prospect that an amplitude analysis may be possible. For this to work it is essential to ensure that the data being published are self-consistent, and are also accurate enough to allow unambiguous amplitude extraction or can at least discriminate adequately among theoretical models.

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