International Journal of Modern Physics: Conference Series

STATUS OF MESON PHOTOPRODUCTION EXPERIMENTS WITH CLAS

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Received Day Month Year
Revised Day Month Year

A large part of the experimental program in Hall B of the Jefferson Lab is dedicated to baryon spectroscopy. Meson photoproduction experiments are essential part of this program. CEBAF Large Acceptance Spectrometer (CLAS) and availability of circularly and linearly polarized tagged photon beams in combination with longitudinally and transversely polarized frozen spin targets provide unique conditions for this type of experiments. For the first time, a complete or nearly complete measurement became possible and will allow model independent extraction of the reaction amplitude. The measurements were complete with both proton and deuteron targets. An overview of the collected experimental data will be presented.

Keywords: baryon spectroscopy; meson photoproduction

PACS numbers: 14.20.Gk, 14.40.-n, 25.20.Lj

1. Introduction

Among the most exciting and challenging topics in sub-nuclear physics today is the study of the structure of the nucleon and its different modes of excitation, the baryon resonances. Initially, most of the information on these excitations came primarily from partial wave analysis of data from πN elastic scattering. Recently, these data have been supplemented by a large amount of information from pion electro- and photoproduction experiments. Yet, in spite of extensive studies spanning decades, many of the baryon resonances are still not well established and their parameters (i.e., mass, width, and couplings to various decay modes) are poorly known. Much of this is due to the complexity of the nucleon resonance spectrum, with many broad, overlapping resonances. While traditional theoretical approaches have highlighted a semi-empirical approach to understanding the process as proceeding through a multitude of s-channel resonances, t-channel processes, and non-resonant background, more recently attention has turned to approaches based on the underlying constituent quarks. An extensive review of the quark models of baryon masses and decays can be found in Ref.[1]. Most recently lattice QCD is making significant progress in calculations of baryon spectrum[2]. While these quark approaches are more fundamental and hold great promise, all of them predict many more resonances than have been observed, leading to the so-called "missing resonance" problem. One possible reason why they were not observed because they may have small coupling to the πN. At the same time they may have strong coupling to other final states ηN, $\eta' N$, KY, $2\pi N$. The photo and electroproduction of various mesons is very attractive tool. While the significant amount of the meson photoproduction cross section measurements became available in recent years, these data alone cannot give an unambiguous answer about resonances. Since in pseudoscalar meson photoproduction there are three objects with spin involved: incident photon, target nucleon and recoil baryon. Therefore the process is descried by four spin dependent complex amplitudes. Total number of single and double polarization observables is sixteen. In order to be able to extract the amplitude of the process without any assumption one needs to measure at least eight carefully chosen single and double polarization observables at given center of mass energy and scattering angle.

A substantial part of the experimental efforts at the experimental Hall-B of Jefferson Laboratory and is dedicated to this problem. In this report a general overview of the experimental capabilities in the Experimental Hall-B will be presented followed by a summary of all measurements done with CLAS and overall status of the program.

2. Experimental Hall-B

Experimetal Hall-B at Jefferson Lab provides a unique set of instruments for these experiments. One instrument is the CLAS[3], a large acceptance spectrometer which allows detection of particles in a wide range of θ and φ. The other instrument is a broad-range photon tagging facility[4] with the recent addition of the ability to produce linearly-polarized photon beams through coherent bremsstrahlung. The remaining component essential for the double polarization experiments is a frozen-spin polarized target (FROST) .

The Hall B photon tagger[4] covers a range in photon energies from 20 to 95% of the incident electron beam energy. Unpolarized, circularly polarized and linearly polarized tagged photon beams are presently available.

With a polarized electron beam incident on the bremsstrahlung radiator, a circularly polarized photon beam can be produced. The degree of circular polarization of the photon beam depends on the ratio $k = E_\gamma/E_e$. The magnitude of $P_\odot$ ranges from 60% to 99% of the incident electron beam polarization P_e for photon energies E_γ between 50% and 95% of the incident electron energy. CEBAF accelerator routinely delivers electron beam with polarization of 85% and higher.

A linearly polarized photon beam is produced by the coherent bremsstrahlung technique, using an oriented diamond crystal as a radiator. The degree of polarization is a function of the fractional photon beam energy and collimation and can reach 80% to 90%. With linearly polarized photons, over 80% of the photon flux is confined to a 200-MeV wide energy interval.

An essential piece of the hardware for this experiment is a polarized target capable of being polarized transversely and longitudinally with a minimal amount of material in the path of outgoing charged particles. The Hall-B polarized target[5] used in electron beam experiments is a dynamically polarized target. The target is longitudinally polarized with a pair of 5 Tesla Helmholtz coils. These massive coils limit available aperture to 55 degrees in forward direction. For photon beam experiments, a frozen-spin target is a much more attractive choice[6].

In frozen-spin mode, the target material is dynamically polarized in a strong magnetic field of 5 Tesla at the temperature of about 1K outside of CLAS. After maximal polarization is reached the cryostat is turned to the “holding” mode with much lower magnetic field of 0.5 Tesla at a temperature of about 30 mK, and then moved in CLAS. A photon beam does not induce noticeable radiation damage and does not produce significant heat load on the target material. Under these conditions the target can hold its polarization with a relaxation time on the order of several days before re-polarization is required. Since the holding field is relatively low, it is possible to design a “transparent” holding magnet with a minimal amount of material for the charged particles to traverse on their way into CLAS. The target system uses an external polarizing magnet located outside of CLAS, and an internal holding magnet inside the cryostat. Butanol was chosen as target material. The target depolarization rate was about 1% a day. This allowed us to re-polarize the target once a week and maintain an average polarization of the order of 85%.

The most recent addition is HDIce frozen spin polarized target. This new type of polarazed target allows to have both H and D polarized with significantly lower background compared to conventional polarized targets.

With all these experimental tools in hands a ”complete” or nearly compete experiment became possible.

3. Single Meson Photoroduction

The cross section for a single pseudoscalar meson photoproduction can be written as:

- polarized photons and recoil polarization

$$\begin{aligned}\frac{d\sigma}{d\Omega} = \sigma_0\{\ 1 & -P_l\Sigma\cos 2\varphi \\ & +R_{x'}(-P_lO_{x'}\sin 2\varphi - P_{\odot}C_{x'}) \\ & -R_{y'}(-P + P_lT\cos 2\varphi) \\ & -R_{z'}(P_lO_{z'}\sin 2\varphi + P_{\odot}C_{z'})\}\end{aligned} \quad (1)$$

- polarized photons and polarized target

$$\begin{aligned}\frac{d\sigma}{d\Omega} = \sigma_0\{\ 1 & -P_l\Sigma\cos 2\varphi \\ & +P_x(-P_l H\sin 2\varphi - P_\odot F) \\ & -P_y(-T + P_l P\cos 2\varphi) \\ & -P_z(P_l G\sin 2\varphi + P_\odot E)\} \end{aligned} \quad (2)$$

- polarized target and recoil polarization

$$\begin{aligned}\frac{d\sigma}{d\Omega} = \sigma_0\{\ 1 & +R_{y'}P \\ & +P_x(R_{x'}T_{x'} + R_{z'}T_{z'}) \\ & +P_y(T + R_{y'}\Sigma) \\ & -P_z(R_{x'}L_{x'} - R_{z'}L_{z'})\}. \end{aligned} \quad (3)$$

In these equations σ_0 denotes unpolarized cross section, P_l denotes degree of liner photon polarization, $P_\odot$ denotes degree of circular photon polarization, $P_{x,y,z}$ and $R_{x',y',z'}$ describe target and recoil baryon polarization components. Σ, T, P are single spin asymmetries. $G, H, F, C_{x'}, C_{z'}, O_{x'}, O_{z'}, T_{x'}, T_{z'}, L_{x'}, L_{z'}$ are double spin asymmetries. The unprimed-ccordinate system is associated with the photon beam. It is defined with $\hat{z}$-axis along the photon momentum, $\hat{y}$ is normal to the scattering plane and $\hat{x} = \hat{y} \times \hat{z}$. The primed coordinate sysyem is associated with meson and is defined so that $\hat{z'}$-axis along the meson momentum, $\hat{y'}$ is normal to the scattering plane and $\hat{x'} = \hat{y'} \times \hat{z'}$

CLAS had several running periods with tagged photon beam.

- $g1$ - circularly polarized photons on unpolrized liquid hydrogen target. Photon energy range 0.5 – 2.5 GeV. This was the first run with tagged photon beam. It allowed to measure unpolarized cross sections
- $g11$ - unpolirized photons on unpolarized liquid hydrogen target.
- $g8$ - lineraly polarized photons on unpolarized liquid hydrogen target
- $g9$-FROST - linearly and circularly polarized photons on longitudinally and transvercely polarized proton (butanol) target
- $g10$ unpolarized photons on unpolarized liquid deuterium target
- $g13$ linearly and circularly polarized photons on unpolarized liquid deuterium target.
- $g14$-HDIce linearly and circularly polarized photons on longitudinally polarized HD target.

Having all these combinations of beam and target polarizations we are able to extract eight observables for all single meson final states. In case of KY final state thanks to self-analyzing weak decay of hyperons we are able to extract *all sixteen* observables. There is also worth mentioning that some of the observables are accessible in more than on beam-target configuration providing additional handle on systematic. Table 1 summarizes all data collected for different final states. Some of

Table 1. Obseravable in single pseudoscalar meson photoproduction. "✓" indicates data accumulated and being analyzed.

	σ	Σ	T	P	P	E	F	G	H	$T_{x'}$	$T_{y'}$	$L_{x'}$	$L_{z'}$	$O_{x'}$	$O_{z'}$	$C_{x'}$	$C_{z'}$
Proton target																	
$p\pi^0$	[7]	✓	✓		✓	✓	✓	✓									
$n\pi^+$	[8]	✓	✓		✓	✓	✓	✓									
$p\eta$	[9,11]	✓	✓		✓	✓	✓	✓									
$p\eta\prime$	[10,11]	✓	✓		✓	✓	✓	✓									
$p\omega$	[12]	✓	✓		✓	✓	✓	✓									
$K^+\Lambda$	[13,14,16]	✓	✓		[13,16]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	[15]	[15]
$K^+\Sigma^0$	[13,14,17]	✓	✓		[13,17]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	[15]	[15]
Neutron (deuteron) target																	
$p\pi^-$	[18]	✓	✓		✓	✓	✓	✓									
$K^-\Sigma^+$	✓	✓	✓	✓	✓	✓	✓	✓									
$K^0\Lambda$	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
$K^0\Sigma^0$	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

them are already published, the rest are being analyzed. Some of the preliminary data are presented in contributions to this conference[19,20,21,22,23,24].

4. Two Pion Photoproduction

The reaction $\gamma p \to p\pi^+\pi^-$ has a three body final state and therefore has more independent kinematical variables and observables. In case of polarized photons and polarizd target the cross section can be written as:

$$\frac{d\sigma}{dx_i} = \sigma_0 \; \{ \; (1 + \vec{\Lambda} \cdot \vec{P}) + \delta_{\odot}(I^{\odot} + \vec{\Lambda} \cdot \vec{P}^{\odot}) \\ + \delta_l [\sin 2\beta (I^s + \vec{\Lambda} \cdot \vec{P}^s) + \cos 2\beta (I^c + \vec{\Lambda} \cdot \vec{P}^c)], \} \qquad (4)$$

where:
σ_0 the unpolarized cross section;
β the angle between photon polarization and reaction plane;
x_i the kinematic variables;
$\delta_{\odot,l}$ the degree of circular or linear photon polarization;
$\vec{\Lambda}$ the target nucleon polarization $(\Lambda_x, \Lambda_y, \Lambda_z)$;
$I^{\odot,s,c}$ single spin beam asymmetries associated with polarizedphotons;
$\vec{P}$ target asymmetry (P_x, P_y, P_z);
$\vec{P}^{\odot,s,c}$ double spin asymmetries $(P_x^{\odot}, P_y^{\odot}, P_z^{\odot})$, (P_x^s, P_y^s, P_z^s),(P_x^c, P_y^c, P_z^c).

With available combinations of beam-target polarization we can extract all these observables. The analysis is ongoing. The results for $I^{\odot}$ has been published[25].

5. Summary

CLAS has accumulated data on single and double meson photoproduction with all possible combinations of beam and target polarization on the proton and deuteron targets. These data are essential for understanding of light baryon spectrum.

Acknowledgments

This work was supported in part by the Chilean Comisión Nacional de Investigación Científica y Tecnológica (CONICYT), the Istituto Nazionale di Fisica Nucleare, the French Centre National de la Recherche Scientifique, the French Commissariat à l'Energie Atomique, the U.S. Department of Energy, the U.S. National Science Foundation, the UK Science and Technology Facilities Council (STFC), the Scottish Universities Physics Alliance (SUPA), and the National Research Foundation of Korea.

Authored by Jefferson Science Associates, LLC under U.S. DOE Contract No. DE-AC05-06OR23177. The U.S. Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce this manuscript for U.S. Government purposes.

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