Meson Photoproduction (CLAS)

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This is a brief and selective discussion of meson photoproduction measurements with the CEBAF Large Acceptance Spectrometer (CLAS) at Jefferson Lab. Meson photoproduction is being used as a tool for various investigations, including the spectroscopy of baryons and mesons and the search for vector-meson medium modifications.

The following is a discussion of some of the more recent results of meson photoproduction experiments by the CLAS Collaboration [1]. The program includes the spectroscopy of baryons and mesons and the search for vector-meson medium modifications; for a complete list of publications see Ref. [2]. The experimental equipment in Hall B at Jefferson Lab is well suited for the pursuit of these investigations. The CLAS detector [3] provides efficient detection of neutral and charged particles over a good fraction of the full solid angle. The tagging facility [4] provides unpolarized, circularly polarized, and linearly polarized tagged-photon beams. A new frozen spin polarized target (FROST) was constructed by the JLab polarized target group with butanol as target material. The target provides configurations for longitudinal and transverse proton polarization.

The study of the baryon spectrum presents an avenue to a deeper understanding of the strong interaction, since the properties of the excited states of baryons reflect the dynamics and relevant degrees of freedom within them. A large part of the experimental program of the CLAS Collaboration is dedicated to baryon spectroscopy. Most recently, the CLAS Collaboration has published differential cross sections for the reaction $\gamma p \to n\pi^+$ and photon beam energies from 0.725 to 2.875 GeV [5]. Where available, the new data compare well with previously published results for the reaction. Agreement with the SAID and MAID analyses is only found below 1 GeV. After including these new data, an updated SAID analysis is much more satisfactory at higher energies. While resonance couplings have not changed significantly, significant changes have occurred in the high-energy behavior of the SAID cross-section predictions and amplitudes. Further improvement will be possible with measurements of spin observables. These are crucial to constrain otherwise largely unconstrained models and especially partial-wave analyses. Ultimately, a complete set of certain polarization observables is necessary to unambiguously determine the amplitudes of the reaction. The CLAS Collaboration has completed measurements of the induced Λ recoil polarization and the polarization-transfer observables C_x and C_z for the reactions $\gamma p \to K^+\Lambda$ and $\gamma p \to K^+\Sigma^0$ [6, 7, 8]. The hyperon polarizations are accessible through the decay angular distributions of the hyperons' decay products. For the Λ, the polarization transfer coefficient along the photon momentum axis, C_z, was found to be near unity for a wide range of energy and kaon production angles. The associated transverse polarization coefficient C_x is smaller than C_z by a roughly constant difference of unity. Most significantly, the total Λ polarization vector, including the induced polarization P, has magnitude consistent with unity at all measured energies and production angles when the beam is fully polarized. For the Σ^0 this simple phenomenology does not hold. All existing hadrodynamic models

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are in poor agreement with these results. These CLAS double-polarization data have been instrumental in a recent analysis of photo- and pion-induced reactions by Nikonov *et al.* [9], which found further evidence for a nucleon excited state, $N(1900)P_{13}$. That state is a 2-star resonance and is predicted by symmetric three-quark models but is not expected to exist in diquark-quark models. Beam-helicity asymmetries for the two-pion-photoproduction reaction $\vec{\gamma}p \to p\pi^+\pi^-$ have been studied for the first time between $W = 1.35$ and 2.30 GeV [10]. The experiment was performed with circularly polarized tagged photons incident on an unpolarized hydrogen target. The large values for this single polarization observable $I^{\odot}$ [11] exhibit strong sensitivity to the kinematics and dynamics of the reaction. The data, compared with the results of various phenomenological model calculations, show that these models currently do not provide an adequate description for the behavior of this new observable. The CLAS frozen-spin target program combines a series of meson photoproduction experiments [12, 13, 14, 15, 16] to measure single- and double-polarization observables with polarized photons on a longitudinally or transversely polarized proton target. The first round of experiments with FROST was completed early 2008 on a longitudinally polarized target [17]. The data will greatly constrain partial-wave analyses and reduce model-dependent uncertainties in the extraction of nucleon resonance properties, providing a new benchmark for comparisons with QCD-inspired models. The analyses of these data will be supported by the newly established Excited Baryon Analysis Center (EBAC) at Jefferson Lab [18].

Two recent CLAS meson photoproduction experiments were motivated by the study of low-lying scalar mesons and the search for exotic mesons. The former study is the first measurement of exclusive $f_0(980)$ meson photoproduction on protons for $E_\gamma = 3.0-3.8$ GeV and $-t = 0.4-1.0$ GeV^2 [19]. The resonance was detected via its decay in the $\pi^+\pi^-$ channel by performing a partial wave analysis of the reaction $\gamma p \to p\pi^+\pi^-$. Clear evidence of the $f_0(980)$ meson was found in the interference between P and S waves at $M_{\pi^+\pi^-} \sim 1$ GeV. The S-wave differential cross section integrated in the mass range of the $f_0(980)$ was found to be a factor of about 50 smaller than the cross section for the ρ meson. These data can be used in phenomenological analyses that will provide information about the resonance structure and production mechanisms. The other CLAS experiment performed a search for exotic mesons in the $\pi^+\pi^+\pi^-$ system photoproduced by the charge exchange reaction $\gamma p \to \pi^+\pi^+\pi^-(n)$ with photon energies in the 4.8 to 5.4 GeV range [20]. The main objective of this study was to look for the photoproduction of an exotic $J^{PC} = 1^{-+}$ resonant state in the 1 to 2 GeV mass range. A partial wave analysis was performed on a sample of 83 000 events, the highest such statistics to date in this reaction at these energies. This analysis shows production of the $a_2(1320)$ and the $\pi_2(1670)$ mesons, but no evidence for the $a_1(1260)$, nor the $\pi_1(1600)$ exotic state at the expected levels. An upper limit of 13.5 nb is determined for the exotic $\pi_1(1600)$ cross section, less than 2% of the $a_2(1320)$ production.

The generation of hadronic masses is connected to spontaneous breaking of chiral symmetry and in-medium hadron properties, such as their masses and widths, are expected to change with chiral symmetry restoration. Medium modifications of mesons in a controlled environment, at zero temperature and normal nuclear matter density, are experimentally accessible in photonuclear or elementary hadronic reactions on heavy nuclei. The best approach, free of final-state interactions, is the study of the leptonic decay channel of these mesons. The CLAS Collaboration studied the photoproduction of light vector mesons (ρ, ω, and ϕ) on deuterium and the heavier targets of carbon, titanium, and iron and their subsequent rare leptonic decay in the e^+e^- channel [21, 22]. The experimental e^+e^- invariant mass distribution includes the spectral distribution from the decay of the vector mesons

ρ, ω, and ϕ. It also contains background from events where the electron and the positron originate in correlated or uncorrelated processes. The background from uncorrelated e^+e^- pairs, the combinatorial background, is unambiguously determined by an event-mixing technique and subtracted. Background contributions from other physical processes leading to correlated e^+e^- pairs have been studied in detailed simulations based on a semi-classical Boltzmann-Uehling-Uhlenbeck (BUU) transport model [23]. The simulations show that from those background processes only the Dalitz decay of the ω mesons contributes appreciably in the e^+e^- mass region of interest. The BUU model calculations describe the data well. The narrow distributions of the ϕ and ω meson, including its Dalitz decay, are readily normalized to the data. The subtraction of these distributions results in the experimental spectra of the ρ mass. The extracted experimental ρ mass spectrum is well described by the ρ functional form obtained from the exact calculations given in Refs. [24, 25, 26] with no modification beyond standard nuclear many-body effects. The in-medium widths of the ρ for the nuclear targets are slightly larger than the free value, but are well understood as collisional broadening [27] as modeled in the BUU calculations. They are not compatible with the doubling of the ρ width reported by NA60 [28]. The observed in-medium ρ masses are consistent with the free value. The relative ρ-mass shift for the Fe-Ti target and ρ momenta ranging from 0.8 to 3.0 GeV is $\alpha = 0.02 \pm 0.02$. This is consistent with the predictions of no significant mass shift by the calculations of Ref. [29, 30] and those of Ref. [23, 31] at ρ vector meson momenta > 1 GeV. It does not favor the prediction of Refs. [32] and [33] for a 20% mass shift and $\alpha = 0.16 \pm 0.06$ respectively, and is significantly different from other similar experiments [34, 35, 36], where $\alpha = 0.092 \pm 0.002$, with no broadening in the width of the ρ meson.

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