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Recent experimental results from MAMI (Mainz), ELSA (Bonn), and JLab*

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Abstract. In the past year a large set of new data on photo- and electro-production of mesons on nucleons and light nuclei has emerged, both near threshold and throughout the nucleon resonance region. Some of the most recent results from the three leading experimental facilities, MAMI (Mainz, Germany), ELSA (Bonn, Germany), and Jefferson Lab (Newport News, USA) relevant to this workshop are presented.

1 π and η photo-production on protons

In conjunction with the development of polarized target techniques and polarimetry capabilities, production of single mesons by real photon beams has recently become the richest source of information on nucleon dynamics from the meson production threshold and throughout the nucleon resonance region. The basic quantities that can be measured when polarization is exploited, are:

$$\sigma\,,\,T\,,$$

when the photon beam and the target are both unpolarized, and when the beam is unpolarized and the target is polarized along the y-direction, respectively;

$$\Sigma\,,\,H\,,\,P\,,\,G\,,$$

with linearly polarized beam and no target polarization, and with target polarized along x-, y- and z-directions, respectively;

$$F\,,\,E\,,$$

when the beam is circularly polarized and the target polarization is along the x- and z-directions, respectively. (The z-axis points along the beam; the z- and x-axes span the meson production plane; the y-axis is perpendicular to it.) In addition to resolving the spin (helicity) structures, so-called complete experiments can be performed for which measurements of the same observables have to be performed in different reaction channels, so that isospin decomposition can be done as well. Such measurements are also underway.

* Talk delivered by S. Širca

With the Crystal Ball and TAPS detectors at ELSA, preliminary results for Σ (beam-helicity asymmetry) in the $\vec{\gamma}p \to p\pi^0$ and $\vec{\gamma}p \to p\eta$ processes have been obtained at $E_\gamma = 1050\,\mathrm{MeV}$ as a function of the pion emission angle θ [1,2]. Almost the complete angular range has been covered at this energy. Apart from a few modest unresolved deviations between the ELSA and older GRAAL data sets [3] at extreme backward angles, all data are in excellent agreement with the MAID and SAID analyses, as well as the Bonn-Gatchina Partial-Wave Analysis (PWA). Moreover, there is a new precise unpolarized data set for η photo-production from MAMI [4] which provides precise cross sections up to 400 MeV above threshold. Very sturdy results have been obtained on the angular expansion coefficients A_1, A_2, and A_3, which will be of great help in improving various PWA.

On the other hand, measurements of Σ in single-pion photo-production have also been performed at Jefferson Lab within the CLAS Collaboration in the g8b group of experiments, and here the agreement with respect to the theory (in particular MAID) is not as good. Largest deviations are observed at forward angles where Σ is typically underestimated by theory. Because both final channels on the proton target ($p\pi^0$ and $n\pi^+$) have been measured, different sensitivities to $N^\star$ and Δ resonances could be probed. This is a very comprehensive and large data set encompassing all angles and photon energies from 1000 to 2000 MeV.

At ELSA, Σ has also been determined at $\theta = 110^\circ$ as a function of E_γ ranging from about 700 to 1200 MeV, indicating that the $P_{11}(1440)$, $D_{13}(1520)$ and $F_{15}(1680)$ resonances are all needed (at least within the MAID model) to reproduce the energy dependence of Σ.

Most recently, similar-quality results have been obtained at ELSA for the double-polarization asymmetry G in $\vec{\gamma}\vec{p} \to p\eta$ (energy dependence at $\theta = 110^\circ$), as well as for G in the $\vec{\gamma}\vec{p} \to p\eta$ process. In the $p\eta$ channel, at $E_\gamma = 950$ and 1050 MeV, the preliminary data on G appears to be in rough agreement with the Bonn-Gatchina PWA and MAID, but is underestimated by SAID at 1050 MeV.

2 Electro-excitation of nucleon resonances

The focus of investigations of nucleon resonance excitations has recently shifted away from the Delta region to the first and second resonance regions. The bulk of the new data comes from the CLAS Collaboration and EBAC (Excited Baryons Analysis Center) at Jefferson Lab.

The most spectacular advances have been made regarding the Roper resonance $N^*(1440)$. The transverse and scalar helicity couplings extracted from a wealth of previous single-pion production data [5, 6] and the most recent two-pion data set [7] are in excellent mutual agreement. In the framework of the EBAC analysis, this allows for a model-independent determination of the N^* electromagnetic couplings for Q^2 up to $\approx 4\,\mathrm{GeV}^2$. It is now clear that the transverse helicity amplitude $A_{1/2}$ crosses zero in the vicinity of $Q^2 \approx 0.5\,\mathrm{GeV}^2$ and that the structure of the Roper can evidently be explained in terms of a quark core as a first radial excitation of three dressed quarks, plus external meson-baryon dressing. (The CLAS12 project will test these findings to much higher $Q^2 \approx 12\,\mathrm{GeV}^2$.)

There are also new data on helicity amplitudes for the electro-excitation of the $N^*(1535)$ resonance on the proton, extracted from both the $n\pi^+$ and the $p\eta$ channel, both of which, again, are in good agreement between each other in the transverse case (while there are no $p\eta$ data in the scalar case). Note that this is the first extraction ever of $S_{1/2}(Q^2)$ up to $Q^2 \approx 4\,\text{GeV}^2$.

With the present data on $A_{1/2}$ extending to relatively high values of Q^2, it is now possible to investigate (or rather, speculate) whether transitions to the regime of perturbative QCD occur. The main motivation behind these scaling studies is to observe the transition to photon interactions with the dressed quarks. The Q^2 dependence of the product $Q^3 A_{1/2}(Q^2)$ has been studied as function of Q^2 in the P11 channel (Roper), the S11 channel ($N^*(1535)$) and the D13 channel ($N^*(1520)$). Apparently $Q^3 A_{1/2}(Q^2)$ flattens out at Q^2 as low as $\approx 3\,\text{GeV}^2$, persisting to $Q^2 \approx 4\,\text{GeV}^2$ where the data ceases. But although this plateau is appealing, extensions to higher Q^2 are needed to confirm it.

3 π, ππ, and η photo-production on deuterons

Most interesting experiments have been performed on the deuteron, in particular single-π^0 and single-η photo-production. The reaction mechanisms for π^0 photo-production are

$$\gamma + d \longrightarrow \begin{cases} \pi^0 + p(n)\ ; & \text{quasi} - \text{free on p}\ , \\ \pi^0 + n(p)\ ; & \text{quasi} - \text{free on n}\ , \\ \pi^0 + d \quad ; & \text{coherent}\ . \end{cases}$$

For $E_\gamma > 500\,\text{MeV}$, the coherent contribution is negligible. Practically all measurements focus on that region, where the sum of the exclusive processes on the proton and the neutron should almost exactly add up to the quasi-free inclusive result. This process has been previously measured at MAMI/A2 [8] and LNS Sendai [9], but has now been superseded by a much lovelier data set [10].

Single-meson production on deuterons has important ramifications regarding the inclusion of D13, F15, and D15 resonances in unitary-isobar models and partial-wave analyses, as the proton and neutron channels exhibit distinct sensitivities to these ingredients. Two-pion production on the proton and the deuteron (allowing for the extraction of the corresponding neutron channel contribution) is relevant in the very same sense [11]. New preliminary data on $\gamma p \to p\pi^0\pi^0$ and $\gamma n \to n\pi^0\pi^0$ from the CB/TAPS @ MAMI Collaboration has become available, indicating that the electro-magnetic excitation of the F15 is relatively stronger on the proton, while the excitation of the D15 is stronger on the neutron. Helicity asymmetries for these two processes have also been measured.

But of the recent data sets, one of the most exciting and puzzling is that on quasi-free η photo-production on the deuteron,

$$\gamma + d \to \eta + n(p)\ ,$$

acquired by the CB/TAPS Collaboration at ELSA. The differential cross-section for this process exhibits a narrow structure at $W \approx 1.65\,\text{GeV}$, regardless of the emission angle (specifically, it has been most often shown at $-0.9 < \cos\theta < -0.5$, $-0.3 < \cos\theta < 0.1$, and $0.1 < \cos\theta < 0.5$). The structure has been observed previously at LNS Sendai, by the GRAAL Collaboration [12], but now high precision data by the CBELSA/TAPS Collaboration has become available [13], clearly identifying the structure at

$$W = 1660\,\text{MeV}\,, \qquad \Gamma = (25 \pm 12)\,\text{MeV}\,.$$

Because the excess cross-section appears in the rescaled neutron cross-section as compared to the free-proton and quasi-free proton cases, this structure has become known as the "neutron anomaly". The reasons for the anomaly remain unknown, although several explanations have been offered. It may be an interference effect of the S11(1650) and P11(1710) resonances; it may be caused by a non-strange penta-quark; but it could also be generated by a $K\Sigma$ threshold enhancement of the neutron cross-section as a consequence of the pion loops. Note that while the ηp cross-section is $\approx 80\,\%$ S-wave, the nature of the ηn is not so well known.

At ELSA, quasi-free η photo-production has also been measured on ^{3}He nuclei. The idea behind replacing the deuteron by ^{3}He is that these nuclei have different nucleon momentum distributions (in the deuteron case, it peaks at $\approx 40\,\text{MeV}$, while it is maximal at $\approx 70\,\text{MeV}$ in ^{3}He). This should generate different proton/neutron cross-section contributions in the processes

$$\gamma +^3 \text{He} \longrightarrow \eta + p(pn)\,,$$
$$\gamma +^3 \text{He} \longrightarrow \eta + n(pp)\,.$$

Apparently the broad structure at $W \approx 1.65\,\text{GeV}$ persists, with $\Gamma = (45 \pm 11)\,\text{MeV}$, which is comparable to the experimental resolution.

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