Beam-Target Polarization Asymmetries for $\vec{\gamma}\vec{n} \to \pi^- p$ and Excited States of the Neutron

While the proton and neutron are regarded as the building blocks of the chemical elements, each is in fact a complex system of sub-atomic quarks and gluons. A successful description of the excited levels of a composite system is a basic test of how well the underlying forces are understood. While Quantum Chromodynamics (QCD) is generally regarded as a mature theory of interacting quarks, the excited states of the neutron and proton (referred to collectively as *nucleons*, or N) pose many challenges. This partly arises because of the complexity of multiple effects (beyond the scope of current QCD calculations) that *dress* the interactions, and partly because the excited states are very short-lived, causing them to be spread out in energy and often overlapping. The latter makes the probability of their excitation (their *amplitudes*) difficult to disentangle without information from many different types of measurements.

Excited nucleons (N^*) decay by emitting mesons, such as pions (π), and their decay probabilities determine the N^* energy (*invariant Mass*, or W) and lifetime, which are the same for states excited from either neutrons or protons. However, the probabilities for exciting an N^*, the γNN^* electromagnetic couplings, reflect the mechanisms involved in excitation and these important dynamical properties are different for states excited from protons or from neutrons. Very little is known about the latter, due to an extreme paucity of neutron target data.

The E06-101 experiment at Jefferson Lab, the *g14* run with CLAS in Hall B, has reported the first beam-target double-polarization measurements of the asymmetry $E = \frac{1}{P_\gamma P_T}\frac{\sigma_A - \sigma_P}{\sigma_A + \sigma_P}$ in the reaction $\gamma n \to \pi^- p$ [1]. Reaction rates (σ) have been measured with beam (P_γ) and target polarizations (P_T) anti-parallel (A) and parallel (P) to the beam momentum, as illustrated at the top of figure 1. Reactions with polarized deuterium in crystals of solid *HD* were used to deduce the π-production rates from polarized neutrons.

Figure 1 shows the results (blue squares) for a sample of two (of 21) bins in invariant mass. The solid red and solid black curves are two independent Partial Wave Analysis (PWA) fits that have been adjusted to reproduce these new results. The other various dashed and dotted curves are earlier predictions that were made before this experiment [1]. These two panels illustrate the general trends – while earlier model predictions come close to the measured asymmetries at low energies, they become wildly disparate for W above about 1800 MeV. Higher energy N^*s tend to have higher intrinsic spin, and so it is not surprising that spin-dependent measurements are needed to properly characterize them.

The probability amplitudes for N^* excitation are complex functions that exhibit a characteristic behavior: when graphed against one another (an *Argand* plot), their real and imaginary parts trace out a counter-clockwise rotating loop as the invariant mass is stepped through an N^* resonance. The amplitude for photo-exciting a neutron into a $spin^{(parity)} = 7/2^-$ state, as deduced from two independent

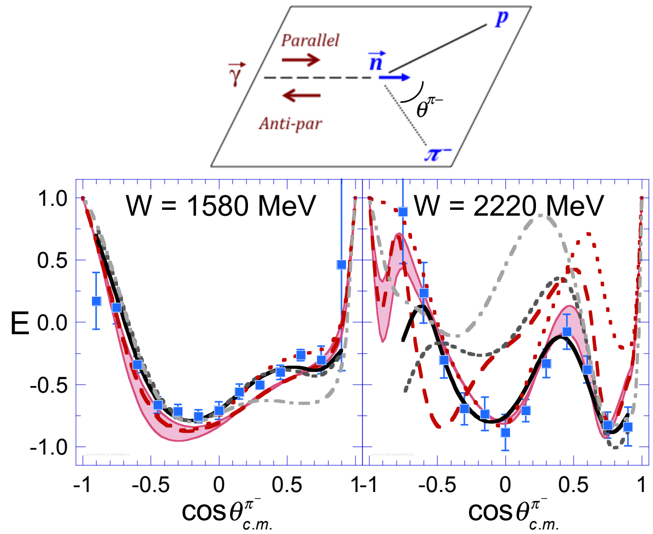

FIG. 1. Dependence of the beam-target asymmetry for $\gamma + n \to \pi^- + p$ on the angles of the emitted π^-, for two ± 20 MeV bins in W [1]. Solid curves are model fits that include these data. Other curves are earlier predictions predating this experiment [1].

PWA [1], is shown in Fig. 2. Solid arrows indicate the direction of increasing W. The loops are produced by the $N^*(W = 2190)7/2^-$ state. Dark green squares result from fits to the new CLAS $g14$ data, which differ considerably from earlier predictions (eg. light-green and red points) [1]. The new asymmetry measurements have pinned down the γNN^* couplings deduced from independent PWA, which now agree for this state. Similar revisions have occurred in the couplings of several other N^* states. These will provide important guides to models of the internal structure of the nucleon.

[1] D. Ho *et al.*, CLAS Collaboration, Phys. Rev. Lett. **118**, 242002 (2017).

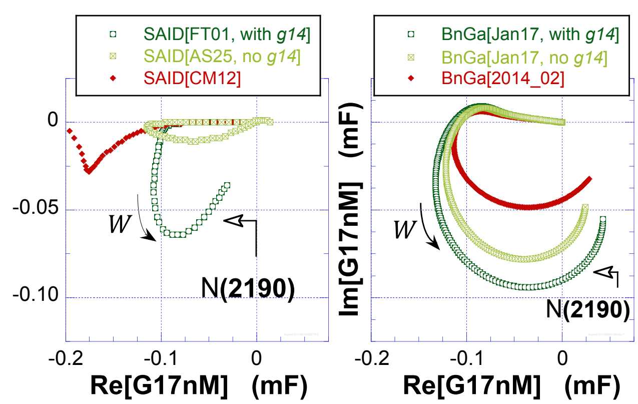

FIG. 2. The probability amplitudes for exciting a neutron into a negative-parity spin 7/2 state, from the SAID (left) and BnGa (right) PWA calculations [1]. Dark green squares result from fits to the new CLAS $g14$ data. Other points predate these results.