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Parity-violating excitation of the Δ and π^- photoproduction: New results from G^0

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Summary. — We present the first measurement of A_{inel}, the parity-violating asymmetry in electron scattering from the proton to the Δ resonance, as well as the first measurement of the parity-violating asymmetry in π^- photoproduction from the deuteron. A_{inel} depends on the axial transition form factor $G^A_{N\Delta}$, which has never been measured in a neutral current process. The asymmetry in pion photoproduction is sensitive to d_Δ, a hypothesized parity-violating electric dipole matrix element, which arises from axial-vector radiative corrections. The result for A_{inel} is in agreement with theoretical expectation, but is not precise enough to extract information on $G^A_{N\Delta}$. The pion photoproduction measurement yields a result for d_Δ consistent with zero, and which does not favor very large enhancements over the "natural" scale for this matrix element.

PACS 25.30.Dh – Inelastic electron scattering to specific states.
PACS 13.60.Rj – Baryon production.
PACS 14.20.Gk – Baryon resonances ($S = C = B = 0$).

1. – Introduction

The main physics focus of the G^0 experiment, conducted in Hall C at Jefferson Lab, was the determination of the strange vector form factors of the nucleon [1, 2]. The experiment also allowed us to measure the effective axial form factor of the nucleon, and beam-normal single spin asymmetries for the proton and the neutron [3, 4]. These results have already been published. In addition, however, two other physics quantities could be extracted from our data: we made the first measurement of parity-violation in the neutral-current excitation of the $\Delta(1232)$ resonance, and a measurement of the parity-violating asymmetry in inclusive real and quasi-real π^- photoproduction from the deuteron. We report on final results from these two measurements in this contribution.

The parity-violating asymmetry in inelastic scattering from the nucleon, in the region of the $\Delta(1232)$ resonance, gives access to the axial-vector transition form factor $G^A_{N\Delta}$, which can also be expressed in terms of the Adler form factors C^i_A [5]. This isovector spin-flip response "filters away" the isoscalar (*e.g.* $s\bar{s}$) terms, and provides different

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hadron structure information. The axial-vector response in the $N \to \Delta$ transition has been studied theoretically using lattice gauge theory [6], chiral perturbation theory [7], and constituent quark models [8]. The only data available are charged-current neutrino results, most of which are old bubble-chamber data [9]. In fact, a better understanding of neutrino-induced pion production at low Q^2, where $G^A_{N\Delta}$ plays a significant role, is of importance for understanding backgrounds in neutrino oscillation experiments [10].

2. – Asymmetry for $N \to \Delta$

In the backward-angle phase of the G^0 experiment, we were able to measure the parity-violating asymmetry for inelastically scattered electrons from both hydrogen and deuterium targets. The scattered electrons, which were magnetically analyzed using a toroidal-field spectrometer, were detected in two arrays of plastic scintillators, the so-called "CED" and "FPD" detectors. Pions were rejected using aerogel Cerenkov detectors. By selecting different combinations of CED and FPD we obtained a crude kinematic separation, which enabled us to largely isolate either elastic or inelastic electron scatterings (the G^0 experiment is described in detail elsewhere [11]). The experiment was optimized for detection of the elastic channel, and the inelastic events were simply an unavoidable background. However, one woman's background is another's signal, and so we were also able to analyze the inelastic events, which accessed Δ kinematics: invariant mass $1.07 < W < 1.26\,\text{GeV}$, with the average value 1.18 GeV, and 4-momentum transfer $0.25 < Q^2 < 0.5\,(\text{GeV}/c)^2$, with an average value of $0.34\,(\text{GeV}/c)^2$ (only the higher of the two G^0 beam energies, 687 MeV, yielded any Δ production in the acceptance).

The biggest challenge in the analysis of these data was dealing with the large backgrounds. These included the radiative tail from the elastically scattered electrons, scattering from the aluminum windows of the cryogenic target, electrons from showers induced by $\pi^0 \to \gamma\gamma$ decays, and (in the case of the deuterium target) π^- events that fooled the Cerenkov requirement. The fractional contributions from each of these background sources was determined either using ancillary measurements (eg. empty target data for the aluminum), or in a fitting procedure. In the fitting procedure, we used GEANT simulations to predict the distribution of each process in the CED · FPD coincidence space, and allowed the normalizations to "float" in a fit to the observed rate distributions in this coincidence space. Of course, one must also determine, not just the fractional contribution to the event rates, but also the parity-violating asymmetries for each background process, in order to correct the observed asymmetries. For elastic scattering, we used our measured elastic asymmetries [2], after using simulation to account for the change in the asymmetry due to radiation. For aluminum, we simply assumed that aluminum and deuterium have approximately the same asymmetry (ignoring nuclear effects), and used our measured asymmetry from deuterium as a proxy for that of aluminum. For the asymmetries from real pions we used data obtained using an alternate signal path in the electronics, in which the Cerneknov detectors were used as vetoes rather than as coincidences. Table I summarizes the background corrections for both targets.

Other corrections included rate-dependent effects, beam polarization, and false asymmetries due to helicity-correlated beam properties, all of which were under good control. After all corrections, the resulting asymmetries were

$$A_{\text{inel}} = (-33.4 \pm 5.3_{\text{stat}} \pm 5.1_{\text{syst}})\ \text{ppm}$$

TABLE I. – *Background corrections to inelastic asymmetry data, where f_{bg} is the percent contribution in rate from each process, and A_{bg} is the asymmetry (in ppm) of that background. For the deuterium target, the aluminum asymmetry is not measured, but is assumed to be the same as that of deuterium.*

	Hydrogen	
Process	f_{bg}	A_{bg}
Elastic	$25.7 \pm 0.4\%$	-14.5 ± 0.8
Aluminum	$15.6 \pm 0.8\%$	-44 ± 16
π^0 Decay	$13.6 \pm 3.6\%$	0 ± 3
	Deuterium	
Process	f_{bg}	A_{bg}
Elastic	$31.0 \pm 0.3\%$	-30.7 ± 2.1
Aluminum	$9.0 \pm 0.5\%$	–
π^0 Decay	$11.3 \pm 3.2\%$	0 ± 3
π^-	$11.1 \pm 3.3\%$	0 ± 3

for hydrogen and

$$A_{\text{inel}} = (-43.6 \pm 14.6_{\text{stat}} \pm 6.2_{\text{syst}})\ \text{ppm}$$

for deuterium.

As outlined, for example, by Musolf *et al.* [12], the theoretical expression for the asymmetry for the proton can be written as the sum of three terms. The first two arise from the axial electron current interacting with the vector hadron current. The first, $A_1 = -\frac{2Q^2}{e^2}\frac{G_F}{\sqrt{2}}(1 - 2\sin^2\theta_W)$, dominates, and is hadron-structure independent (as an historical aside, the dependence of this term on the weak mixing angle prompted Cahn and Gilman [13] in 1978 to propose this measurement as a test of the electroweak Standard Model). The second is a non-resonant piece, A_2, which in the present kinematics is calculated to be small (confirmed both in a phenomenogical approach using multipoles from MAID (Mainz Unitary Isobar Model) [14], and also from the dynamical pion electroproduction model of Matsui, Sato and Lee [15]). The third, A_3, comes from the vector electron current coupling to the axial hadronic current, and depends directly on $G^A_{N\Delta}$.

Figure 1 shows our result, along with the expected asymmetry contributions for each of these terms, and the total theoretical asymmetry. Within the limited precision of the present experiment, the agreement is excellent. However, it is clearly seen that an order of magnitude higher precision on the experiment would be required in order to provide useful information on A_3 and thereby on $G^A_{N\Delta}$. For completeness, we quote the result we extracted from our asymmetry of $G^A_{N\Delta}(Q^2 = 0.34) = -0.05 \pm 0.35_{\text{stat}} \pm 0.34_{\text{syst}} \pm 0.06_{\text{th}}$, where the final uncertainty is from model dependence, mainly in the treatment of the non-resonant term.

3. – Pion photoproduction asymmetry

Generically, parity-violating asymmetries in electron scattering are expected to tend to zero in the limit of very low Q^2, since at $Q^2 = 0$ one cannot have virtual Z^0

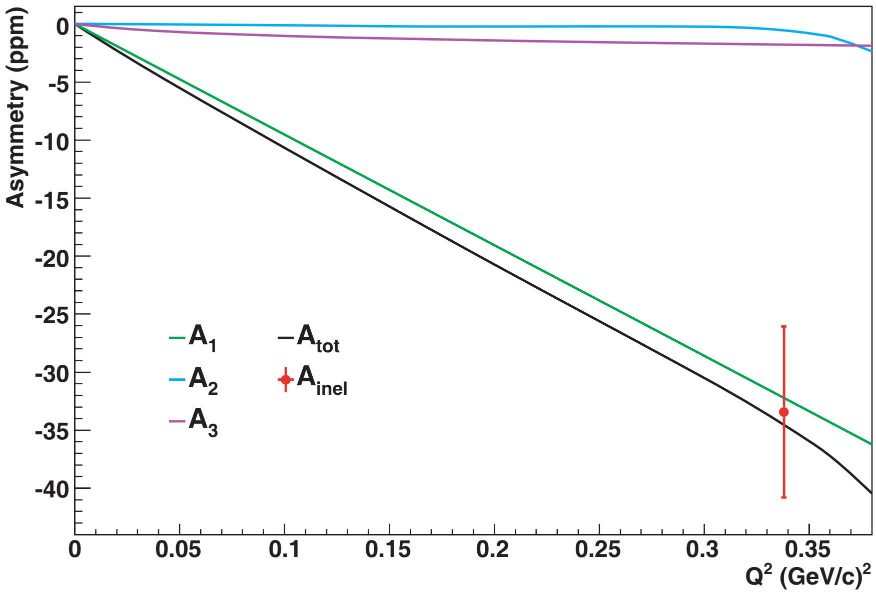

Fig. 1. – Result for $A_{\rm inel}$, the measured asymmetry for Δ excitation on the proton (circle), along with the expected asymmetry $A_{\rm tot}$, which is also broken down into the three components (see text), where $A_{\rm tot} = A_1 + A_2 + A_3$; the term A_3 encodes the axial $N \to \Delta$ response.

exchange. However in scattering from hadrons, one can also have weak interactions occuring amongst the quarks, and so non-zero asymmetries can survive in the photoproduction limit. These electroweak radiative corrections have been studied theoretically by Zhu *et al.* [16]. In particular, the asymmetry for π^- photoproduction on the deuteron was found to depend on a new low-energy constant of the effective weak Lagrangian, d_Δ, which sets the scale for the parity-violating $\gamma N \Delta$ coupling. Zhu *et al.* argued that the natural scale for such a coupling is $\sim g_\pi = 3.8 \times 10^{-8}$. However, they also investigated possible resonance-mixing enhancements which could lead to values perhaps 100× larger. Such enhancements could help to resolve the puzzle of the large parity-violating hyperon radiative decays [16].

We accessed the photoproduction asymmetry using the low beam energy (362 MeV) backward-angle data taken on the deuterium target. Here, the incident photons were real photons from bremsstrahlung in the target, along with low-Q^2 virtual photons from scattered beam electrons. The average Q^2 for accepted events was 0.0032 $(\text{GeV}/c)^2$, and the average photon energy was 320 MeV. Real π^- were detected by selecting the appropriate region of the FPD · CED detector coincidence space, with the Cerenkov detectors used to veto electrons; the resulting electron contamination in the pion signal was 2.6%.

After correcting for backgrounds, rate-dependences, helicity-correlated beam properties, beam polarization etc., and extrapolating the virtual-photon asymmetry contribution to $Q^2 = 0$ (using the A_1 dominance of the inelastic asymmetry for guidance, as confirmed in our $N \to \Delta$ measurement), we extracted the value $A_\gamma^{\pi^-} = -0.36 \pm 1.06_{\rm stat} \pm 0.37_{\rm sys} \pm 0.05$ ppm, where the last uncertainty is model dependence in the extrapolation of the virtual photon contribution to $Q^2 = 0$. We can then extract the value

$d_\Delta = (8.1 \pm 23.7 \pm 8.3 \pm 0.7) g_\pi$ for the low energy constant, which is consistent with zero. This somewhat restricts the possible range of enhancements that Zhu *et al.* considered, however still leaves considerable room for a significant parity-violating $\gamma N \Delta$ vertex term. More details on this analysis are available elsewhere [17]. Improvements on the precision of d_Δ will come from the QWeak experiment, which is now underway.

4. – Conclusions

The results of the two measurements reported here both were in good agreement with theoretical expectations. The small value which we observed for the parity-violating asymmetry for π^- electroproduction at very low Q^2 disfavors large enhancements of the parity-violating $\gamma N \Delta$ coupling. However there is still room, given the limited precision of the data, for substantial enhancements of this vertex. The asymmetry for neutral current electro-excitation of the Δ resonance, measured here for the first time, is in excellent agreement with theoretical predictions, which have the asymmetry being dominated by a "structure-independent" term. A non-zero contribution from the intriguing axial-vector form factor $G^A_{N\Delta}$ for the $N \to \Delta$ transition cannot be extracted from the present results, again, given the modest experimental precision.

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