1 Summaries of Experimental Activities

1.1 E91-011

Investigation of the $N \to \Delta$ Transition via Polarization Observables in Hall A

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We have measured recoil polarization in the $p(\vec{e}, e'\vec{p})\pi^0$ reaction at $Q^2 \approx 1$ $(\mathrm{GeV}/c)^2$ near the Δ resonance, obtaining angular distributions for a total of 16 independent response functions in a 5×2 grid of (W, Q^2). Although not statistically independent, we have also obtained response functions for a single bin, defined by $W = 1.23 \pm 0.02$ GeV and $Q^2 = 1.0 \pm 0.2$ $(\mathrm{GeV}/c)^2$, that is centered on the $\Delta(1232)$ resonance. The data analysis has been discussed in previous progress reports and is almost finished, with just a few consistency checks remaining. Drafts of a PRL and a PRC paper are in preparation.

Preliminary angular distributions for $(W, Q^2) = (1.22 \pm 0.2, 0.9 \pm 0.1)$ are shown in Fig. 1 versus $x = \cos\theta_{cm}$. The 12 response functions shown in columns 2–4 have been observed here for the first time. The response functions in the third column depend upon real parts of interference products and are dominated by resonant amplitudes while those in the second and fourth columns depend upon imaginary parts and are more sensitive to the nonresonant contributions.

The unpolarized response functions are compared with the published Hall B data of Joo *et al.* [1]. Note that the Hall B data for R_{L+T} contain two beam energies while the Hall A data for $\epsilon \sim 0.95$ lie slightly higher, as expected. In general we find good agreement between the two experiments, but the statistical precision of the present data is considerably higher than that of the published Hall B data; higher statistics from the latter will be forthcoming. The limited spectrometer acceptance in ϕ for $x \sim 0$ does not permit separation there between R_{L+T} and R_{TT}, but the cross section data (not shown) were included in the partial-wave and multipole analyses.

Two types of analyses have been performed. In Fig. 1 we compare the data with fits based upon Legendre expansion of the angular dependence of each response function independently, while in Fig. 2 multipole amplitudes for low partial waves were fit to all of the data for a given (W, Q^2) bin simultaneously with higher partial waves based upon MAID2000 [2]. Both analyses describe the data well, but the Legendre fits are sometimes better because this more phenomenological representation ignores the correlations between Legendre coefficients for different response functions expected from expansions of those coefficients in terms of products of multipole amplitudes. The multipole analysis is more fundamental and employs fewer parameters.

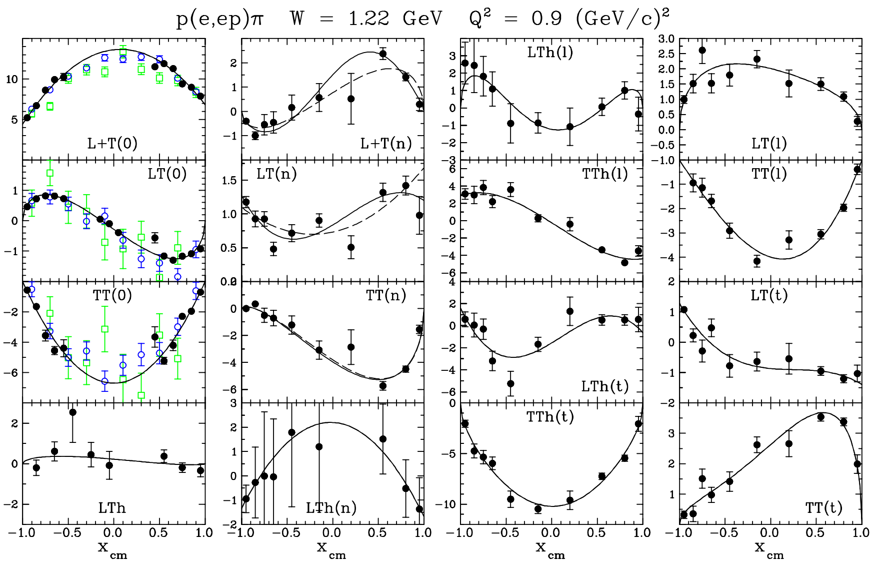

Figure 1: Data for response functions at $W = 1.22 \pm 0.02$ GeV and $Q^2 = 0.9 \pm 0.1$ $(\mathrm{GeV}/c)^2$ are compared with Legendre fits in the sp truncation (dashed) and with a few extra terms as needed (solid). Results from CLAS are shown as green squares for $k_i = 1.645$ GeV or blue open circles for $k_i = 2.445$ GeV.

Most previous analyses in the Δ region have limited the expansions to s- and p-waves and have used the assumption of M_{1+} dominance to truncate these expansions to terms involving the M_{1+} amplitude. Thus, using the coefficients fitted to the unpolarized cross sections one would deduce

$$EMR = \frac{\mathrm{Re} E_{1+}^* M_{1+}}{|M_{1+}|^2} \approx \frac{3A_2^{L+T} - 2A_0^{TT}}{12 A_0^{L+T}} \tag{1}$$

$$SMR = \frac{\mathrm{Re} S_{1+}^* M_{1+}}{|M_{1+}|^2} \approx \frac{A_1^{LT}}{3A_0^{L+T}} \tag{2}$$

where A_n^α is the coefficient of P_n in the expansion of response function α. Our nearly complete set of recoil-polarization response functions makes it possible to perform a more rigorous multipole analysis. The sensitivity of fitted multipole amplitudes to uncertainties in higher partial waves can be gauged by comparing fits using different baseline models for higher partial waves. An advantage of this type of analysis is that it minimizes the dependence upon models; however, it does not guarantee that the fitted multipole amplitudes will depend smoothly on both W and Q^2. Model-dependent analyses which adjust parameters of an effective Lagrangian should produce kinematically smooth multipole amplitudes at the expense of possible bias.

The dashed lines in Fig. 2 show a fit that varies all s- and p-wave multipole amplitudes for $(W, Q^2) = (1.22, 0.9)$ while the solid lines vary d-wave amplitudes also. MAID2000 was used as the baseline model for higher partial waves. There appears to be no systematic improvement in the fits by varying d-wave amplitudes but the fits are not as accurate as the Legendre analysis either, which may indicate a deficiency of the nonresonant contributions to the baseline model or inconsistencies in the preliminary data.

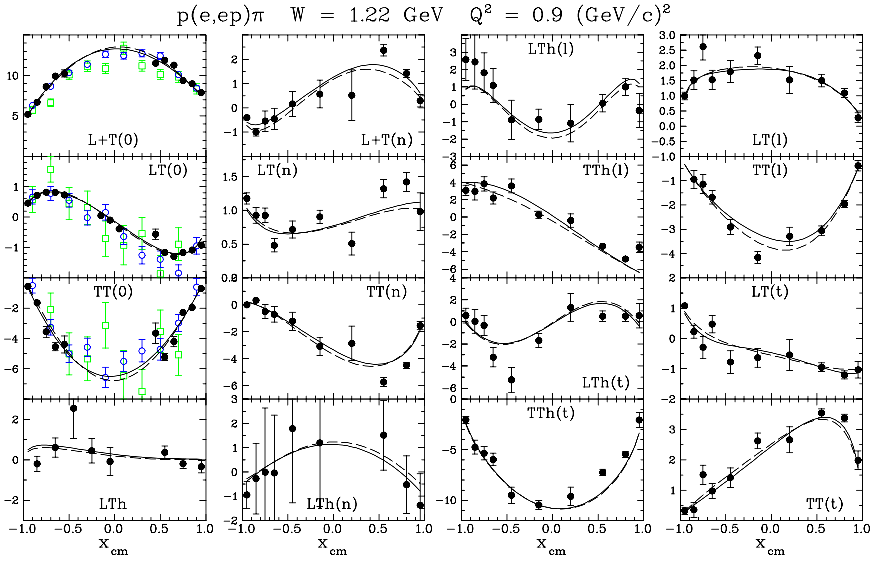

Figure 2: Data for response functions at $W = 1.22 \pm 0.02$ GeV and $Q^2 = 0.9 \pm 0.1$ $(\mathrm{GeV}/c)^2$ are compared with fits that vary *sp* (dashed) versus *spd* (solid) multipole amplitudes. Results from CLAS are shown as green squares for $k_i = 1.645$ GeV or blue open circles for $k_i = 2.445$ GeV.

The quadrupole deformation parameters can now be obtained directly from the fitted multipole amplitudes using

$$EMR = \frac{\mathrm{Re}E_{1+}^{*}M_{1+}}{|M_{1+}|^2} = \frac{\mathrm{Re}E_{1+}\mathrm{Re}M_{1+} + \mathrm{Im}E_{1+}\mathrm{Im}M_{1+}}{\mathrm{Re}M_{1+}\mathrm{Re}M_{1+} + \mathrm{Im}M_{1+}\mathrm{Im}M_{1+}} \tag{3}$$

$$SMR = \frac{\mathrm{Re}S_{1+}^{*}M_{1+}}{|M_{1+}|^2} = \frac{\mathrm{Re}S_{1+}\mathrm{Re}M_{1+} + \mathrm{Im}S_{1+}\mathrm{Im}M_{1+}}{\mathrm{Re}M_{1+}\mathrm{Re}M_{1+} + \mathrm{Im}M_{1+}\mathrm{Im}M_{1+}} \tag{4}$$

where $\mathrm{Re}M_{1+} \to 0$ at the physical mass, $W \to M_\Delta = 1.232$ GeV. The deformation of the $N \to \Delta$ transition is generally quoted at $W = 1.232$ GeV after correction for the isospin-1/2 contribution, but this correction has not yet been made.

These two methods for determination of EMR and SMR are compared in Fig. 3. The left panel uses the truncated Legendre analysis while the right panel uses the multipole analysis. We also extracted EMR and SMR for the MAID2000 [2], DMT [3], and SAID [4] models by applying the same formulas to calculations that were used for data in each panel. The difference between the two methods at $W = 1.232$ GeV is a measure of the accuracy of the truncated Legendre analysis.

The experimental results for SMR are stable and both methods give similar W dependencies over this entire range. The model calculations for SMR are also in agreement with the data near 1.232 GeV and describe the W dependencies well, although MAID2000 and DMT are in better agreement with each other than with SAID. For EMR, on the other hand, the two methods produce different W dependencies and the variation among models is greater; nevertheless, these variations remain fairly small in the immediate vicinity of M_Δ. The experimental results are more sensitive to the choice of variables and baseline model for EMR than for SMR. The red stars were obtained from the bin centered on the Δ and are consistent with interpolation among the black points. Although at this Q^2 truncated Legendre analyses appear to be sufficiently accurate for extraction of EMR and SMR, the present data for helicity-independent recoil polarization do show significant deviations from models and sensitivity to the relative phase between resonant and nonresonant amplitudes.

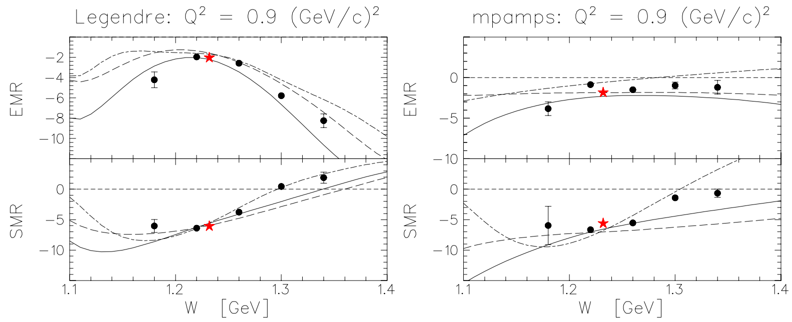

Figure 3: EMR and SMR data for $Q^2 = 0.0$ (GeV/c)^2 are compared with MAID2000 (solid), DMT (dashed), and SAID (dash-dot). In addition, the red star shows the result for $W = 1.23 \pm 0.02$, $Q^2 = 1.0 \pm 0.2$. Left: results from truncated Legendre expansion. Right: results from multipole analysis varying *sp* amplitudes wrt MAID2000. Within each panel data and curves employ the same formulas.

2 References

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