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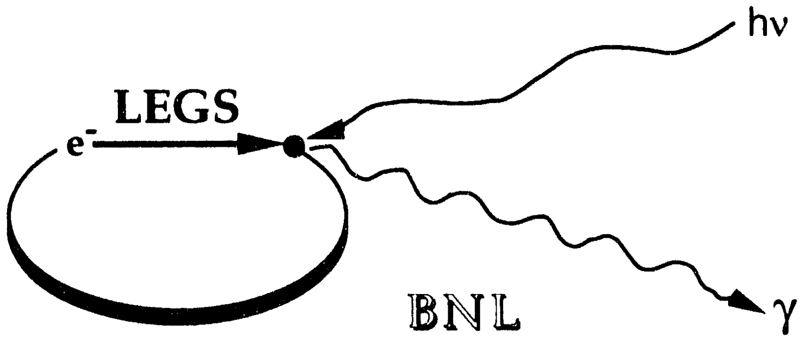

Laser Electron Gamma Source†

Brookhaven National Laboratory

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(A.M. Sandorfi, *editor*)

LEGS Facility Operations

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The LEGS facility provides intense, polarized, monochromatic γ-ray beams by Compton backscattering laser light from relativistic electrons circulating in the X-Ray storage ring of the National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory. With the start of ring operations at 2.8 GeV, LEGS γ-ray energies now extend to 370 MeV. Considerable progress has been made in the development of a new laser system that will increase the beam energies to 470 MeV, and this system is expected to come into operation before the next biennial report. The γ-ray spectra corresponding to different laser and storage-ring energies are shown in the top panel of figure 1. The total flux, the area under any one of the curves, is administratively held at $6 \times 10^6\ s^{-1}$. The γ-ray energy is determined, with a resolution of 5.5 MeV, by detecting the scattering electrons in a magnetic spectrometer. This spectrometer can 'tag' all γ-rays with energies from 185 MeV up to the Compton edge. The beam spot size at the target position is 8 mm (V) x 18 mm (H), FWHM. For a single laser wavelength, the linear polarization of the beam is 98% at the Compton edge and decreases to 50% at about 1/2 the energy of the edge. By choosing the laser wavelengths appropriately (ie. by following the solid curve in the lower panel of figure 1), the polarization can be maintained above 85% throughout the tagging range.

During the last two years, experimental running at LEGS occupied an average of 3000 hours annually. Highlights of some of the programs are discussed below.

† Supported by the US Department of Energy under contract # DE-AC02-76CH00016.

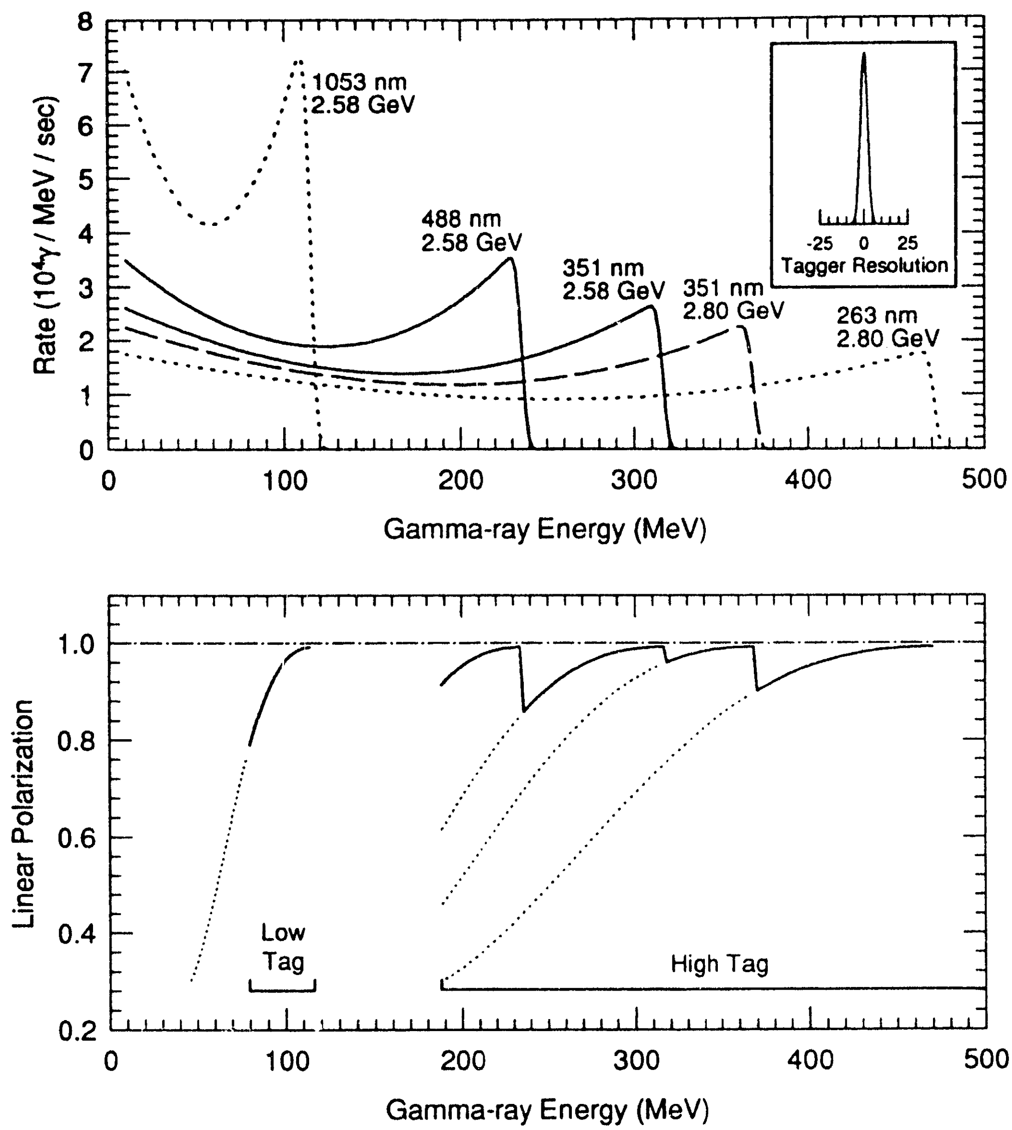

Figure 1. Spectra of γ-ray energies produced at LEGS for different combinations of laser and storage-ring energies (top). The tagged photon resolution (inset) is 5.5 MeV FWHM, nearly independent of energy. The degree of linear polarization is shown in the bottom panel.

Deuteron PhotoDisintegration through the Δ (Exps. L1-3)

The LEGS collaboration

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Several measurements of the $d(\vec{\gamma},p)n$ reaction have been completed. The experiments include five independent measurements with three different detector systems, different photon end-points from different laser wavelengths, different polarizations and two different liquid deuterium targets. These measurements overlap in various kinematic regions between 113 and 325 MeV, and the agreement in the regions of overlap is excellent. By taking weighted means of overlapping measurements, a 'net' data base has been constructed, and is available upon request[1]. Selections of these results are shown in figure 2.

As demonstrated in the first phase of these experiments[2], polarization observables in this reaction are particularly sensitive to the short range character of the nuclear tensor force. Calculations by Arenhoevel and collaborators from Mainz were quite successful in

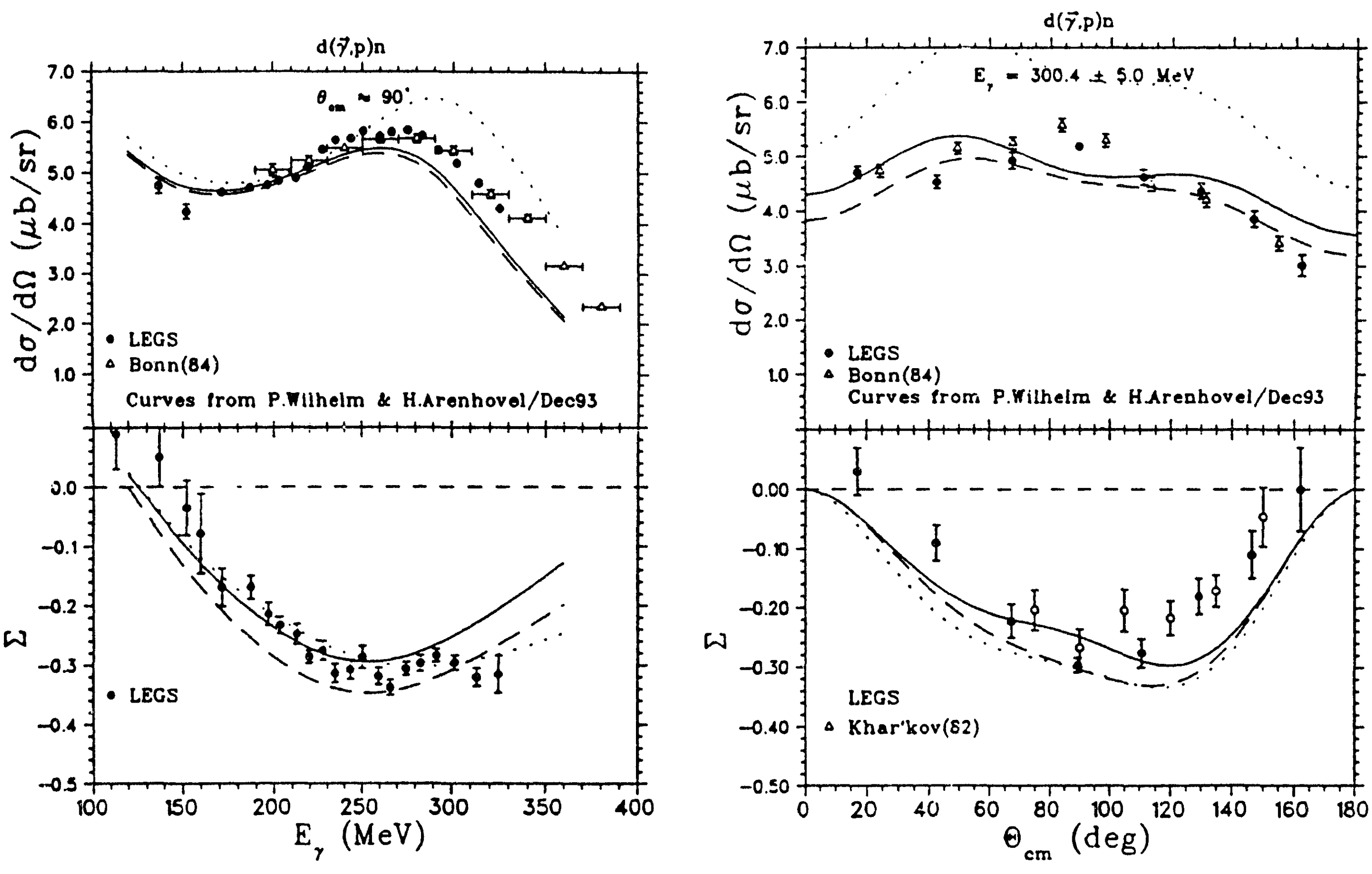

Figure 2. Deuteron PhotoDisintegration results from Release #L1-3.0. The energy dependence of the 90° cross section and linear polarization asymmetry are shown to the left. The angular distribution of these observables at 300 MeV is shown to the right. Bonn[3] and Khar'kov[4] data are also shown. The curves are coupled-channel calculations by Wihelm and Arenhoevel (see text).

describing the results around 200 MeV but showed a systematic departure from the data at the higher energies. This could be due to inadaquacies of the phenomenological parametrization used for the short range part of the tensor interaction, but the problem could also lie in an approximation that treated the N-N and N-Δ interactions as indistinguishable. The Δ peaks at about 265 MeV in d(γ,p)n and a better approach at these energies is to treat these interactions separately, solving coupled Schroedinger equations. Such calculations have been carried out by Wilhelm and Arenhoevel‡. The results have been somewhat surprising, and are shown together with a sample of the data in figure 2. The coupled-channel effects are very large. Including only the first order term involving the the $V_{N\Delta}$ interaction (dotted curves) significantly overestimates the cross sections in the energy region of the Δ, although the agreement with the polarization asymmetry, Σ, seems quite reasonable. In a more complete treatment, with the γNΔ coupling fixed by the $M_{1+}^{3/2}$ multipole for π-photoproduction, the resulting angular distributions (solid curves of figure 2) predict a depression of the cross sections near 90° throughout the region of the Δ. This depression is not present in the data. Modifying the γNΔ coupling (dashed curves in figure 2), a proceedure that includes non-resonant Born terms in an effective way, improves the overall agreement in the angular dependence of the cross section but gives a poorer representation of the polarization asymmetry, Σ. This is a difficult problem since very little is known about the NΔ interaction. Work is now in progress to include non-local and relativistic corrections. The combined data from both cross sections and polarization observables imposes stringent constraints upon such calculations.

[1] LEGS Data Release **#L1-3.0**, March/94.

[2] LEGS Collaboration, G.S. Blanpied et al., Phys. Rev. Lett. **67**, 1206 (1991).

[3] J. Arends *et al.*, Nucl. Phys. **A412**, 509 (1984).

[4] V.G. Gorbenko *et al.*, Nucl. Phys. **A381**, 330 (1982).

‡ P. Wilhelm and H. Arenhoevel, Priv. communication.

Multi-Nucleon Correlations in $\vec{\gamma}+{}^3He$ Reactions (Exp. L4)

G.S. Adams (RPI), *spokesman*

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Both inclusive ${}^3He(\vec{\gamma},p)X$, and the exclusive $(\vec{\gamma},pn)$ and $(\vec{\gamma},pp)$ channels, have been studied in Exp. L4 at LEGS[5,6]. The mass-3 system is the simplest in which 3-body correlation effects might be present, and for which exact calculations can be performed. Measurements from other laboratories (all unpolarized), for both inclusive and exclusive photodisintegration, have suggested that a substantial fraction of the cross section proceeds through the three-Nucleon absorption channel. Calculations of the inclusive (γ,p) channel, which appear to reproduce the unpolarized cross section, do not provide consistent agreement with the beam polarization asymmetry[5].

On the other hand, there is less freedom in modeling the exclusive channels, and the (γ,pp) reaction provides a unique testing ground. The momentum distributions for protons detected at 100°, integrated over the full acceptance (24° to 144°) for an accompaning p or n, are shown in figure 3 below for an average beam energy of 270 MeV[6]. The (γ,pn) cross sections (open circles) are dominated by a large quasi-deuteron component and peak at 460 MeV/c, the expected momentum from deuterium dissociation with the extra proton acting as a spectator. The solid and dotted curves are recent calculations, performed J.-.M. Laget of Saclay, and include contributions from 2N and 2N+3N photon-absorption amplitudes, respectively. The 2N dominates in (γ,pn) and

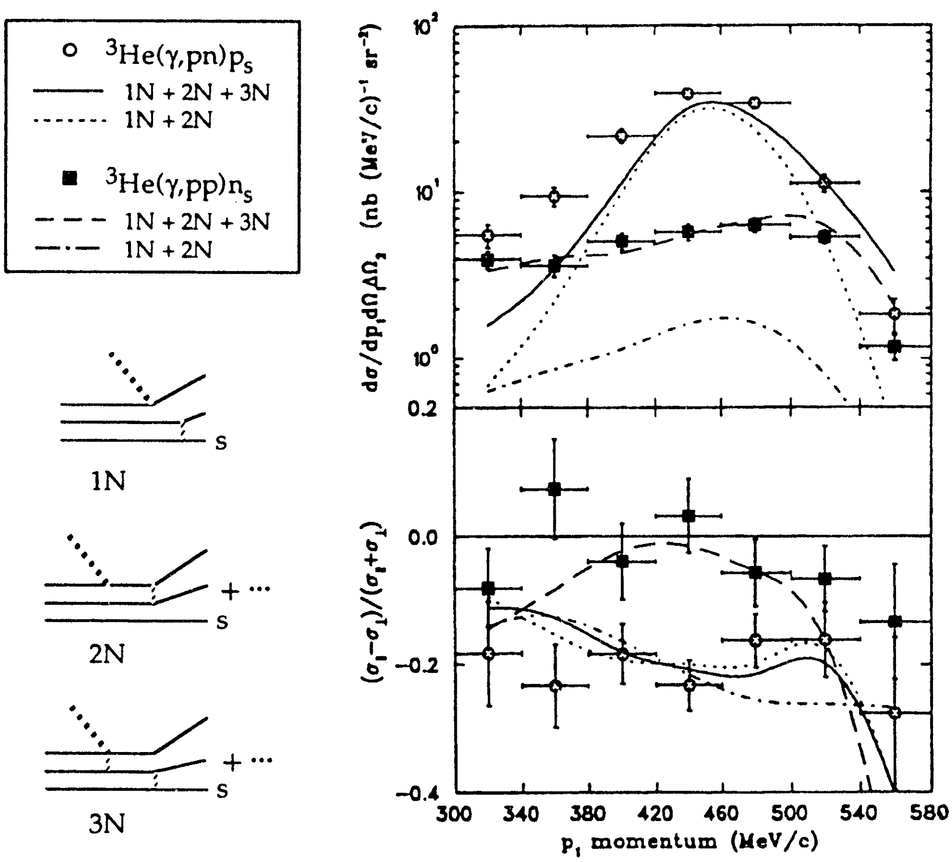

Figure 3. The momentum distributions of protons detected at $\theta_{p_1} = 100^\circ$, integrated over the full acceptance (24° to 144°) for the accompanying n or p, at a γ-beam energy of 270 MeV. Cross sections are shown in the top panel (and asymmetries in the bottom panel) for ${}^3He(\vec{\gamma},pn)$, open circles, and ${}^3He(\vec{\gamma},pp)$, solid squares, together with calculations from ref. [6].

the addition of the 3N component adds very little. However, the analogous 2N mechanism for the pp-channel is suppressed since the diproton has no dipole moment and charged meson-exchange currents cannot contribute. The (γ,pp) cross sections (solid squares in the upper panel) are much lower than those of the (γ,pn) channel, and theoretical predictions that exclude 3N amplitudes (dashed-dot curve) are a factor of 5 lower still, although they exhibit a similar momentum dependence. The addition of 3N absorption to the theory (dashed curve) produces results that are in very good agreement with the data.

Qualitatively similar results have been observed in unpolarized reactions with ^{3}He at other laboratories. However, a recurring objection can be made that, since the shapes of the predictions with (dashed curves) and without (dash-dot curves) the 3N absorption mechanism are so similar, uncertainties in the N-N potential might allow for some adjustment in the overall normalization of the 2N contribution. Exp. L4 has provided the first polarization information on these reaction channels, and the beam polarization asymmetry (lower panel of figure 3) completely rules out this scenario. The predicted (γ,pp) asymmetry from 2N amplitudes (dash-dot curve) is large and negative. It is, in fact, quite similar to that observed in deuteron photodisintegration (Exp. L1,3: figure 2 above) and to that of the $(\vec{\gamma},pn)$ channel. Increasing the 2N amplitude would only make the asymmetry more negative. In contrast, the data (solid squares), as well as the predictions including 3N absorption (dashed curve), are nearly zero. There can be no preferred direction when all three nucleons are involved.

[5] C. Ruth *et al.*, Phys. Rev. Lett. **71**, 617 (1994);
[6] D. Tedeschi *et al.*, Phys. Rev. Lett. (in press).

New Measurements of $p(\vec{\gamma},\pi)$ and the E2 Excitation of the Δ (Exp. L7)

The LEGS collaboration

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In constituent quark models, a tensor interaction, mixing quark spins with their relative motion, is introduced to reproduce the observed baryon spectrum. This necessarily results in a D-wave component to the nucleon wave function, which breaks spherical symmetry and leads to a static deformation for the proton's first excited state, the Δ resonance. The Δ is photo-excited mainly by M1 radiation. However, the D-state component results in a small E2 transition strength. The magnitude and sign of the E2/M1 mixing ratio are quite sensitive to the internal structure of the proton.

The isospin I=3/2 Δ decays with a 99.4% branch to πN final states, and with an 0.6% γN branch back to the initial state (Compton scattering). There have been many determinations of the I=3/2 photo-pion multipoles. For the most part, these agree on the dominant M1 amplitude but differ on smaller components such as E2 excitation. Isolating the component associated with the Δ requires a further decomposition of these I=3/2 multipoles into resonant and background components. This decomposition requires a model, and model dependences enter the analysis of π-production and Compton scattering in different ways. These two branches have different E2 sensitivities and both are under study at LEGS.

The $p(\vec{\gamma},\pi^\circ)$ and $p(\vec{\gamma},\gamma)$ reactions were separated by detecting photons in a high resolution NaI(Tl) spectrometer, together with the recoil protons whose trajectories were tracked through wire (drift) chambers and whose energies were measured, both by energy deposition and by time of flight in an array of plastic scintillators. This arrangement is shown in figure 4. The π^o decay photons closest in energy to Compton scattering are accompanied by low energy photons travelling in nearly the opposite direction. These were detected in additional NaI crystals placed opposite the large high-energy γ-ray spectrometer to enhance the separation of the two channels.

A typical π^o/Compton separation is shown in figure 5 where the γ-ray energy is plotted against time of flight (TOF). Here, the energy and TOF for Compton scattering, as calculated from the tagged beam energy and the proton recoil angles measured in the drift chambers, have been subtracted. Compton scattering produces a clearly resolved peak, whose width is determined by variations in the energy loss and multiple scattering of the protons recoiling in the liquid hydrogen target.

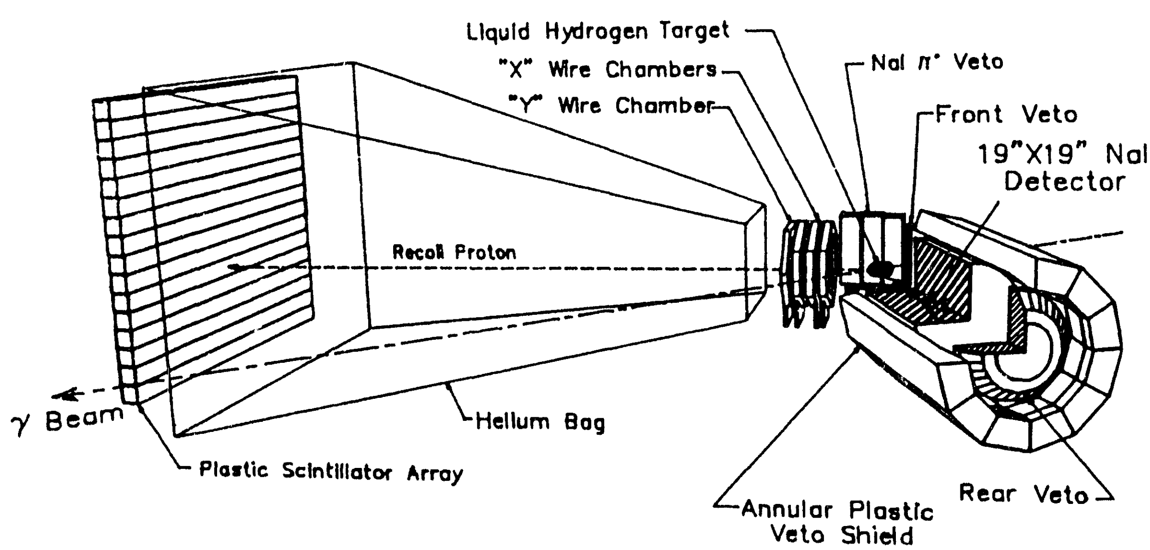

Figure 4. The arrangement of detectors used in Exps. L7 and L8. Photons, from either π^o-decay or from Compton scattering, were detected in a high-resolution 19"x19" crystal of NaI. Recoil protons were tracked through drift chambers and stopped in an array of plastic scintillators.

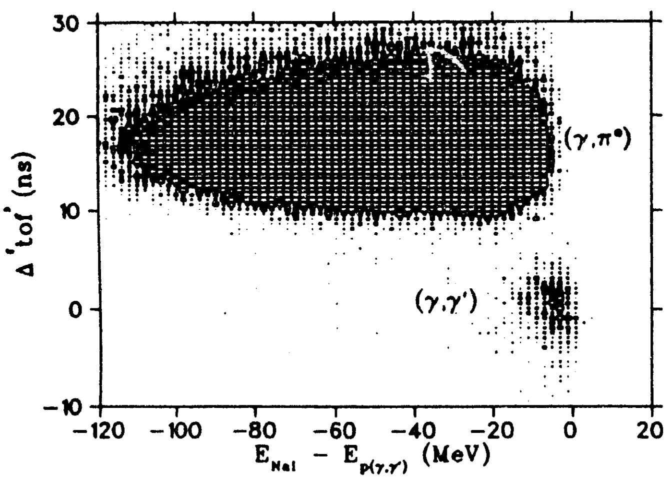

Figure 5. A typical π^0/Compton separation with the detectors of figure 4 (see text).

For π-production, in addition to the unpolarized cross section, there are 3 single- and 12 double-polarization observables. Of all of these, the observable most sensitive to an E2 component is the cross section, $\sigma_{\parallel}$, for π^0 production by linearly polarized photons whose electric vector is oriented parallel to the reaction plane. The corresponding cross section for the perpendicular orientation, $\sigma_{\perp}$, is completely insensitive to E2 excitation at all but extreme angles. Thus, the ratio $\sigma_{\parallel}/\sigma_{\perp}$ maximizes E2 sensitivity, while dividing out systematic uncertainties. The first results from LEGS (Exp. L2) provided high-statistics data on this ratio at a single angle [7], and comparisons with model calculations suggested an E2/M1 mixing ratio between -3% and -5%[8,9].

The parameters of models that are used to extract the resonant part of the E2 transition strength are obtained by fitting predictions of the models to π-production data. The agreement with the full data base (mostly unpolarized measurements) has been far from perfect, and this is at least partly due to the large number of experiments contributing to the data base, each with different systematic uncertainties. This problem is best addressed by a new experiment in which a large number of different observables are measured simultaneously, thus locking them together with a common systematic error. In Exp. L7, polarized cross sections were measured to a high accuracy for both the $p(\vec{\gamma},\pi^o p)$ and $p(\vec{\gamma},\pi^+)$ channels over a wide range of angles and energies.

A sample of the new $p(\vec{\gamma},\pi^o p)$ results[10] is plotted as the solid circles in figure 6, together with previously published data (open symbols) where available[11,12]. There are a large variety of calculations available in the literature to which one may compare such data. In figure 6 we plot curves generated with the code of Davidson, Mukhopadhyay and Wittman (DMW)[13], since this model seems to be able to give the most accurate reproduction of $(\vec{\gamma},\pi)$ data. In the DMW model, π-photoproduction is evaluated in terms of effective Lagrangians. Amplitudes are calculated at the tree level and π-loops are effectively included through a unitarization procedure. The model contains five free parameters, G_E and G_M, the electric and magnetic coupling constants at the $\gamma N\Delta$ vertex, and three constants parameterizing the off-shell behavior. With these 5 parameters adjusted to reproduce π-photoproduction, the resonant part of the E2/M1 mixing ratio is given by $-G_E/G_M$.

The long-dashed curves in figure 6 are obtained by *turning off all of the E2 strength.* The differences between these curves and the new $\sigma_{\parallel}/\sigma_{\perp}$ data are very large. However, most of this *E2-signal* results from interferences with E2 components of the Born amplitudes, and is quite uninteresting. The dashed-dot curves are obtained by including the full Born contribution while setting the resonant part of the E2 strength to zero ($G_E = 0$). It is the differences between these dashed-dot curves and the data that represents the E2 *signal* of interest, and the sensitivity is maximal at 90° CM. Modeling the $N \rightarrow \Delta$ transition requires a decomposition of each of the amplitudes into resonant+background terms, and

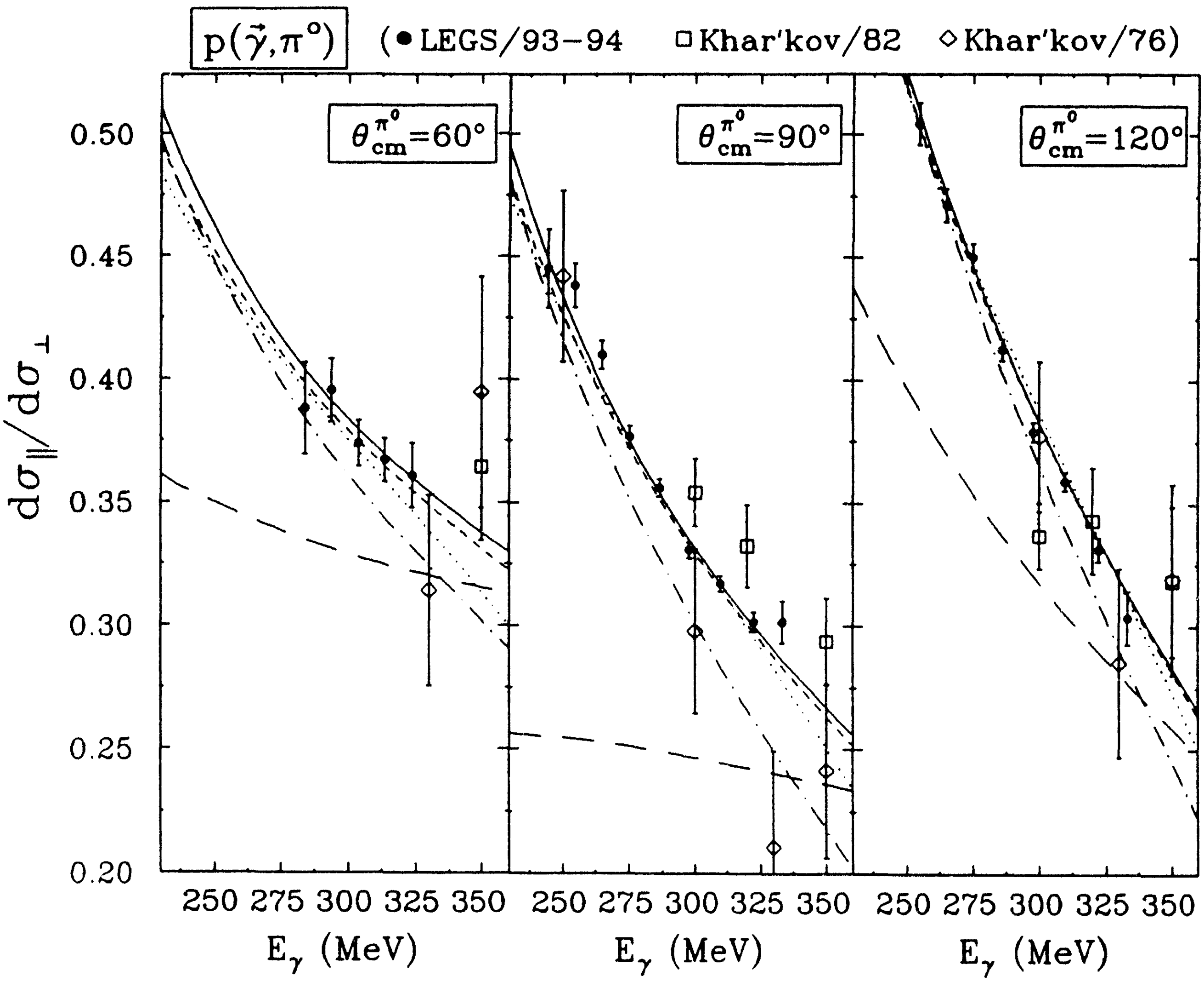

Figure 6. The E2-sensitive observable $\sigma_{\parallel}/\sigma_{\perp}$ for the $p(\vec{\gamma},\pi^o p)$ reaction. New results from Exp. L7 are plotted as the solid circles[10] and compared with previous measurements from Khar'kov[11,12]. The curves are calculations using the model of DMW[13]. The long-dashed curves are produced by setting the total E2 to 0, while the dashed-dot curves correspond to E2($N \rightarrow \Delta$) = 0. The solid, short-dashed and dotted curves are the full calculations using the *Olsson*, *K-matrix* and *Noelle* decompositions of the amplitudes into resonant+background components (see text and table 1).

this decomposition is not unique. Three choises for this decomposition have been discussed by DMW[13]: *Olsson's* method, in which the background part of the T-matrix is made separately unitary; a *K-matrix* method, in which the decomposition is made in terms of K-matrix elements; and *Noelle's* method, in which the decomposition is made in the πN phase shifts and carried through to photoproduction via unitarity. We have refitted the parameters of the DMW model to our new polarization data. Since all of the analysis is not yet complete, we have included previously measured unpolarized data from other laboratories. The results are shown in figure 6 as the solid (*Olsson*), short-dashed (*K-matrix*) and dotted (*Noelle*) curves, respectively. All three are equally good representations of the $\sigma_{\parallel}/\sigma_{\perp}$ π^o data. Compared to other observables, the *Olsson* and *K-matrix* results are essentially equivalent, while the *Noelle* predictions are somewhat worse for the π^+ asymmetry. The *resonant E2/M1* extracted from these fits are summarized in table 1. The dependence upon the method for the resonant+background decomposition is rather minimal and, from this analysis, we would conclude E2/M1($N \rightarrow \Delta$) = -2.7±0.1%. This procedure will be repeated when the analysis of the full data set has been completed. The use of a single data set in the determination of the model parameters will minimize the effects of propagating systematic errors.

Table 1. The resonant part of the E2/M1 mixing ratio, as extracted from comparisons between the new LEGS data and calculations using the DMW code of ref. [13], with three different prescriptions for decomposing the amplitudes into resonance+background components.

$N \rightarrow \Delta$ Decomposition Method	E2/M1($N \rightarrow \Delta$)
Olsson	-2.60 %
K-matrix	-2.71 %
Noelle	-2.82 %

The unitarization procedures of the DMW model inherently include the effects of the pion field. As a result, the E2/M1($N \rightarrow \Delta$) values of table 1 represent a ratio of *dressed* $\gamma N\Delta$ couplings - dressed by the proton's pion cloud. This is roughly consistent with the Skyrme model of the Nucleon but somewhat larger than Chiral-bag Model predictions. Comparison with the constituent quark model requires a further separation of E2 excitation of the bare Δ from the effects of the pion cloud. In principal, the model of Nozawa, Blankleider and Lee[14] should be able to accomplish this separation, although as yet their calculations are not able to reproduce the E2-sensitive observables. There are speculations as to why this is the case[8], and these are currently under investigation[15].

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[8] R. Davidson and N. Mukhopadhyay, Phys. Rev. Lett. **70**, 3834 (1993).
[9] A.M. Sandorfi and M. Khandaker, Phys. Rev. Lett. **70**, 3835(1993).
[10] Some preliminary results have been reported in
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[11] V.B. Ganenko *et al.*, Sov. J. Nucl. Phys. **23**, 162 (1976).
[12] A.A. Belyaev *et al.*, Sov. J. Nucl. Phys. **35**, 401 (1982).
[13] R. Davidson, N. Mukhopadhyay and R. Wittman, Phys. Rev. **D43**, 71 (1991).
[14] S. Nozawa, B. Blankleider and T.-S.H. Lee, Nucl. Phys. **A513**, 459 (1990).
[15] T.-S.H. Lee, private communication.

The $N \rightarrow \Delta$ Transition from Polarized Compton Scattering (Exp. L8)

The LEGS collaboration
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In Exp. L7, the $\Delta \rightarrow \pi N$ decay branch was studied and polarization was used to enhance E2 signals relative to the backgrounds. Compton scattering of polarized photons offers a potentially interesting alternative in which polarization differences can be used to directly cancel many background components[16]. Such measurements are technically demanding, because of the large background of photons from π^0-decay. In addition, there have been long standing speculations, based on the limited published data, that the real part of the scattering amplitude is negligible in the vicinity of the Δ resonance and a large variety of models have been proposed to accommodate this peculiar situation[17-19].

During Exp. L8, the cross sections and beam polarization asymmetries for the $p(\gamma,\gamma p)$ reaction were measured at angles from 55° to 130° CM and over energies spanning 220 to 330 MeV. Data were collected simultaneously with the π-production measurements of Exp. L7 and, as seen in figure 5, Compton scattered photons were clearly resolved from π^0

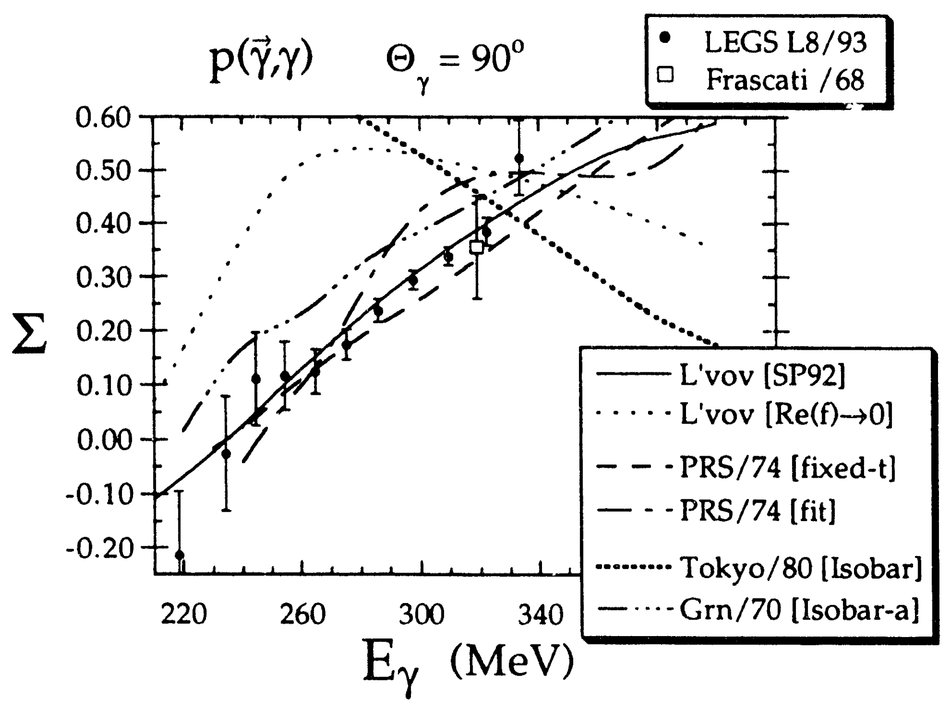

Figure 7. The polarization asymmetry of Compton scattering from the proton[10,20], together with the only published datum (from Frascati)[21]. For the curves labeled as *L'vov*, the real parts of the scattering amplitudes have been calculated with the code described in ref. [22], while the *PRS/74* predictions use the multipoles of ref. [17]. The *Isobar* predictions of *Tokyo/80* and *Grn/70* are from refs. [18] and [23], respectively.

production. Results for the 90° linearly-polarized-beam asymmetry, $\Sigma = (\sigma_{||} - \sigma_{\perp})/(\sigma_{||} + \sigma_{\perp})$, are shown in figure 7 (solid points)[10,20], along with the only published datum for this observable (open diamond)[21]. The excitation of the Δ resonance is dominated by magnetic dipole transitions. However, if only M1 scattering contributed, the asymmetry would simply reduce to the value of 3/7, independent of energy. This is clearly not the case, which implies significant contributions from other multipoles.

The predictions of a number of models are shown in the figure. By design, all cross near the one published Frascati/68 point. The corresponding predictions for the unpolarized cross section are relatively close to one another, but their separation in the asymmetry is quite dramatic. The imaginary parts of the Compton scattering amplitude are derivable from π-production via Unitarity, assuming that the π-production multipoles are known with sufficient accuracy. Dispersion relations can be used to calculate the real parts, although there is a fair amount of freedom which comes in through the choice of the subtraction functions that can accompany the dispersion integrals. The result of using (γ,π) multipoles and Unitarity to calculate the imaginary part of the Compton amplitudes, while leaving the real parts set to zero, is shown as the light-dotted curve in the figure. The real parts are clearly important. The curves labeled *L'vov[SP92]* and *PRS/74[fixed-t]* have been calculated using Compton amplitudes derived from π-production multipoles - in the case of *L'vov*[22], from the SP92 solution by Arndt & Workman[24], and in the case of *PRS/74*,[17] from the Bonn multipole analysis of Pfeil and Schwella[25]. The *L'vov[SP92]* predictions are closest to the data. There has only been one analysis which included published Compton scattering measurements into a (γ,γ) multipole decomposition, using scattering to fix the real parts of the amplitudes, while their imaginary parts were constrained by π-production. The result (*PRS/74[fit]* curve in figure 7) is quite far from these new data. Alteratively, the *Tokyo/80* and *Grn/70* calculations attempt to incorporate the structure of N* resonances into a fit of unpolarized Compton scattering data. These are completely ruled out by the new Exp. L8 data.

The sensitivity to E2 transitions in the Compton Scattering of polarized photons from the proton has been examined in a new partial-wave expansion of the scattering amplitude[16,26], which includes the 43 largest interference terms and intermediate-state spins up to 5/2. The inclusion of E2 components makes only small changes in the unpolarized cross sections, due to large cancelations among the various terms. Similar cancelations occur in the beam-polarization asymmetry, to varying degrees depending upon the multipole solutions used. However, a new polarization observable can be constructed which enhances the E2 components. The combination of cross sections measured at (scattering angle θ, polarization angle ϕ),

$$Z(E_\gamma) = \frac{d\sigma}{d\Omega}(35°,90°) - 2\frac{d\sigma}{d\Omega}(90°,35°) + \frac{d\sigma}{d\Omega}(145°,90°) \quad ,$$

cancels out the largest of the non-E2 terms, including the dominant M1 excitation of the Δ, with the result that Z is nearly vanishing in the absense of E2 strength. The behavior of Z as a function of energy depends upon the multipole solution but generally exhibits a peak near the Δ resonance.

The measurements needed to form the observable Z will begin in the fall of 1994. When combined with the cross section and asymmetry measurements of Exp. L8, these data will be used to perform a new multipole analysis of Compton scattering. The use of this combination of measurements will minimize the error in the E2/M1 interference amplitudes.

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Experiments in Early Stages of Analyses

Polarized Photon scattering from ^{4}He and the Δ-hole Interaction (Exp. L16)

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The Δ-hole model has been relatively successful in accounting for a large body of π-N scattering data. The expectations for describing photo-reaction data were quite high, since the coupling of the photon to the nucleon is known to a potentially much higher accuracy. However, Δ-hole model calculations have failed to reproduce recent measurements of scattering with unpolarized photons[27], particularly at energies below the peak of the Δ, where non-resonant contributions are expected to be large. In contrast, calculations of quasi-free scattering have succeeded in reproducing the main features of the unpolarized data. The cross section for nuclear Compton scattering is generally written in terms of two structure functions, W_T and W_{TT}. The first can be determined with unpolarized photons, but the second requires a polarized beam. It is expected that the simultaneous determination of both will significantly constrain the reaction mechanisms that are involved, and ^{4}He is a particularly interesting target since rather complete microscopic calculations can be carried out for the mass-4 system. In Exp. L16, Compton scattered photons were detected in the 19" x 19" NaI spectrometer of figure 4. Isolation of the Compton events was enhance by another NaI array surrounding the target which was used to veto π^0-decays. Analysis of $^4He(\vec{\gamma},\gamma)$ data from this experiment is underway.

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Polarized Photon scattering from ^{16}O and the Δ-hole Interaction (Exp. L14)

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Although the Δ-hole description may have difficulty modeling the scattering from ^4He, this type of particle-hole description may be better suited to nuclei with a more completely developed mean field. For this, ^{16}O provides an excellent testing ground since accurate wavefunctions are available. Detailed predictions for Compton scattering of polarized photons from ^{16}O have been published by Vesper, Drechsel and Ohtsuka (VDO)[28]. Medium effects were found to be important, and the polarized structure function, W_{TT}, was found to be particularly sensitive to model parameters. Measurements of $^{16}O(\vec{\gamma},\gamma)$ have been made using the same arrangement of detectors as in Exp. L16. A preliminary analysis of the new asymmetry data is largely consistent with the VDO calculations near the peak of the Δ, but deviates significantly at lower energies. This analysis is continuing.

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The E1/E2 Puzzle in $^4He(\vec{\gamma},dd)$ Breakup (Exp. L15)

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Polarization observables in the $^2H(d,\gamma)^4He$ reaction, and its inverse $^4He(\gamma,d)d$, provided the first evidence that the ground state of ^4He contains a D-state component. These reactions are particularly interesting because symmetry requires the d-d state to obey Bose-Einstein statistics. Assuming central forces, this forbids isovector E1 radiative transitions. Both the capture and the photodisintegration reactions have been measured several times and in the 200 MeV region the reported cross sections vary by more than a factor of 100. Even more disturbing is the fact that the two most recent published works reported angular distributions that peaked at 90° CM[29,30], which is consistent with E1 radiation, and a variety of complicated two-step meson-exchange processes have been suggested to account for this.

In Exp. L15, the $^4He(\vec{\gamma},dd)$ reaction was unambiguously identified by detecting both decay deuterons in coincidence. The polarization asymmetry is particularly important in separating the various contributing multipole transitions. Preliminary analyses show a deep minimum in the cross section near 90°, consistent with E2 radiation.

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Experiments in Preparation

The Spin-Structure of the Nucleon (Exps. L18,19)

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Recent experiments on the deep-inelastic scattering of polarized leptons from polarized protons and neutrons have raised interesting questions on the spin-structure of the nucleon, and considerable attention is now being paid to the Q^2 evolution of the spin observables. The $Q^2 = 0$ limit is determined by the total spin-dependent photo-absorption cross sections measured with photon and nucleon spins parallel, $\sigma_{3/2}$, and anti-parallel, $\sigma_{1/2}$. A variety of sum rules have been derived for the integrals of these photo-reaction cross sections. Two that are most sensitive to the spin structure are the Spin-dependent Polarizability (γ)[31], and the Drell-Hearn-Gerasimov (DHG) integrals[32]. Both are derived from considerations of the forward Compton scattering amplitude. γ can be calculated with chiral perturbation theory (χPT) and obeys a sum rule, weighted by the third power of photon energy, running from π-threshold (ω_0) to infinity,

$$\gamma = \frac{1}{4\pi^2} \int_{\omega_0}^{\infty} \frac{\sigma_{1/2} - \sigma_{3/2}}{\omega^3}\, d\omega \quad .$$

With assumptions about the pole structure of the helicity amplitudes, the DHG sum rule relates the same difference of spin-dependent cross sections, but now weighted by a single power of the energy, to the anomalous magnetic moment (κ) of the target,

$$DHG = \int_{\omega_0}^{\infty} \frac{\sigma_{1/2} - \sigma_{3/2}}{\omega}\, d\omega = -\frac{2\pi^2\alpha}{m^2}\kappa^2 \quad .$$

As yet there are no direct measurements of $\sigma_{3/2}$ or $\sigma_{1/2}$. Nonetheless, it is possible to estimate their difference using photo-production amplitudes constructed from measurements of the different charge channels in pion production. Recent results for the proton-neutron difference[33], using the FA93 multipoles from VPI, are given in table 2.

Table 2. Estimates of the γ and DHG integrals, for the proton-neutron difference, using the FA93 multipoles[33], compared with χPT predictions[31] and with magnetic moments of the DHG sum rule.

	χPT	FA93	$-\frac{1}{2}(\kappa_p^2 - \kappa_n^2)\frac{2\pi^2\alpha}{m^2}$
$\gamma_{VS} = \frac{1}{2}(\gamma_p - \gamma_n)$	-52×10^{-6} fm^4	-48×10^{-6} fm^4	
$DHG_{VS} = \frac{1}{2}(DHG_p - DHG_n)$		-65×10^{-4} fm^2	$+15 \times 10^{-4}$ fm^2

Although the multipole estimates for the proton+neutron sum, $\frac{1}{2}(DHG_p + DHG_n)$, are in quite good agreement with the magnetic moment prediction of the DHG sum rule, the estimates shown in table 2 for the difference, DHG_{VS}, are of the opposite sign and of a significantly larger magnitude. This is in sharp contrast to the FA93 prediction for γ_{VS} which is within 8% of the relativistic 1-loop χPT value. (Uncertainties in the χPT calculation are minimized in the proton-neutron difference.)

Although the γ_{VS} and DHG_{VS} integrals are weighted by different powers of energy, it is quite difficult to conjecture enough of a proton-neutron spin-difference at high energies to reconcile the conflict of table 2[33]. There are then only two other possibilities. Either (a) *both* the 2-loop corrections to the Spin-Polarizability are large *and* the existing multipoles are wrong, *or* (b) modifications to the Drell-Hearn-Gerasimov sum rule are required to fully describe the isospin structure of the nucleon.

The helicity-dependent photo-reaction amplitudes, *for both the proton and the neutron,* will be measured at LEGS from pion-threshold to 470 MeV. In these double-polarization experiments, circularly polarized photons from LEGS will be used with SPHICE, a new frozen-spin target consisting of $\vec{H} \cdot \vec{D}$ in the solid phase. Reaction channels will be identified in SASY, a large detector array covering about 80 % of 4π. Since the key physics issues with the least model dependence are in the proton-neutron difference, each of which involve cross section differences themselves, the high degree of symmetry in both target and detector will be crucial in minimizing systematic uncertainties.

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