Update of Experiment 01-104 to PAC 26

Helicity Structure of Pion Photoproduction

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ABSTRACT

The physics case for an experimental measurement of the helicity asymmetry in the two single-pion photoproduction processes $\gamma p \to \pi^0 p$ and $\gamma p \to \pi^+ n$ at energies up to 2.3 GeV is just as valid today as it was when Proposal 91-015 was originally submitted and when it was re-approved as E01-104 by PAC-20. Although an extensive set of measurements on these reactions has been completed at Mainz at energies up to 800 MeV, no helicity-separated exclusive data exist above 800 MeV, and none are anticipated at other laboratories before 2006 at the earliest (when the Mainz energy increases to 1.5 GeV). The data are an important input to the partial-wave analyses of pion photoproduction, and the helicity-separated angular distributions for single- and double-pion production will be helpful in understanding the individual contributions to the integrand of GDH sum rule measured by the total cross section method at Bonn. The frozen-spin target required for this project is now in the process of construction at JLab. We request that the approved status of the experiment be reaffirmed for the next 3 years, during which time we expect that the target will be ready and the experiment can be run.

As stated in the PAC-26 Call for Proposals, the rules for submission of an update under the jeopardy rule are:

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'1. indicate clearly your desire for the experiment to remain approved;
2.  update as appropriate, the scientific case for your experiment;
3.  review the status of (and update, as appropriate) the membership
    of the collaboration;
4.  indicate the technical readiness of the experiment; and
5.  provide ... an up-to-date set of all of the documents that are now
    a standard part of new proposal submissions, ...'
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We address these points in the following sections.

1 Desire for the experiment to remain approved

The proposers of this experiment hereby express their unqualified desire for this experiment to remain approved. It is a crucial part of an approved program of double-polarization measurements in pion photoproduction (E-03-105) [1], and interacts closely with other experiments which also require a frozen-spin target (E-02-112 [2] and others in preparation). The target is now under construction at JLab. The list of collaborators on the present experiment has been augmented by several additional groups of physicists who are involved in the other polarized-target proposals.

2 Updated scientific case for the experiment

2.1 Summary

Proposal 91-015 was originally submitted (in 1991) with the following scientific goals:

1. to test the hitherto untested predictions of the helicity asymmetry by partial wave analyses.
2. to evaluate accurately the single-pion photoproduction contribution to the Gerasimov-Drell-Hearn (GDH) sum rule.
3. to use the helicity asymmetry as a new diagnostic tool in searching for evidence of poorly determined baryon resonances.

4. to perform a preliminary evaluation of the contributions of other significant processes (particularly $\gamma p \to \pi^+\pi^- p$) to the GDH sum rule.

In the energy region below 800 MeV, these goals have been substantially achieved by the experiments of the GDH Collaboration at Mainz [3, 4, 5, 6]. At photon energies above 800 MeV, however, there are no measurements of the helicity asymmetry in exclusive photoproduction processes. The GDH program at Bonn [7] has produced measurements of the helicity dependence of the total γp cross section at energies up to 3 GeV, but with no identification of exclusive processes. Thus the original goals of this experiment are still highly relevant at energies above 800 MeV.

In 2003, PAC-24 approved experiment E03-105 [1], which proposed a measurement of other single- and double-polarization observables in $\gamma p \to \pi^+ n$ and $\gamma p \to \pi^0 p$ at energies between 0.4 and 2.0 GeV. Table 1 shows the proposed settings for E03-105. The single polarization observables Σ and T and the double-polarization observables P, F, G, and H are defined by the expression [8]

$$\begin{aligned} \frac{d\sigma}{d\Omega} / \left(\frac{d\sigma}{d\Omega}\right)_{unpol} = \; & 1 - P_T \Sigma \cos(2\varphi) + \\ & P_X[-P_T H \sin(2\varphi) + P_C F] - \\ & P_Y[P_T P \cos(2\varphi) - T] - \\ & P_Z[-P_T G \sin(2\varphi) + P_C E] \end{aligned} \quad (1)$$

where P_C and P_T are the circular and linear polarization of the photon beam, φ is the angle of beam polarization relative to the reaction plane, and P_X, P_Y and P_Z are the target polarization in the X, Y and Z directions (Z = incident photon axis, Y = normal to reaction plane).

Table 1: Proposed beam and target settings for E03-105 (S. Strauch *et al.*). The polarization observables are as defined by Barker *et al.* [8]

Setting	Polarization		E_γ (GeV)	E_0 (GeV)	Observables
	Beam	Target			
A	linear	transverse	0.6–2.0	several	H, P, T
B	circular	transverse	0.4–1.5 1.45–2.0	1.6 2.2	F, T
C	linear	longitudinal	0.6–2.0	several	G

A fourth setting, with circularly polarized photons and a longitudinally polarized target yielding a measurement of the observable $E = (d\sigma_{1/2} - d\sigma_{3/2})/(2d\sigma)$, was not included in the beam request for E03-105 because this configuration was already approved in the present experiment (E01-104). It is this fourth configuration which we are now re-defending here.

2.2 Scientific background for the proposal

The important points motivating this proposal in its original form are as follows: (references can be found in the original proposal for Experiment 91-015.)

1. The Gerasimov-Drell-Hearn (GDH) sum rule for the proton is the relation

$$\int_{\mathrm{thr}}^{\infty} \frac{\sigma_{1/2} - \sigma_{3/2}}{k} dk = -\frac{2\pi^2 \alpha \kappa_p^2}{m_p^2} = -204.8\mu b \ , \tag{2}$$

   where $\sigma_{1/2}$ and $\sigma_{3/2}$ are the total cross sections for hadron photoproduction on the proton in the helicity-1/2 and helicity-3/2 states, k is the laboratory photon energy, α is the fine-structure constant, κ_p the proton's anomalous magnetic moment, and m_p the proton mass. The sum rule follows from very general principles (Lorentz and gauge invariance, crossing symmetry, causality, and unitarity) applied to the forward Compton scattering amplitude, and from the earliest days there has been at least as much interest in **how** the sum rule is satisfied (i.e. rate of convergence, signs of contributions of indivdual processes, etc.) as in **whether** it is satisfied.

2. Measurements of $\sigma_{1/2}$ or $\sigma_{3/2}$ require the use of circularly polarized photons incident on longitudinally polarized protons. At the time of the original proposal, there were **no** direct measurements of $\sigma_{1/2}$ or $\sigma_{3/2}$ (or their equivalent representations), in either differential or total cross section form, for any photoproduction reaction. In the intervening years, however, detailed measurements of the helicity decomposition of both the total cross section and several exclusive channels ($\pi N, \pi\pi N, \eta p$) have been made at energies up to 800 MeV by the GDH collaboration at Mainz [3, 4, 5, 6] and an inclusive measurement of $\sigma_{3/2}-\sigma_{1/2}$ has been made at energies between 0.7 and 3.0 GeV at Bonn [7]. The most recent published value for the experimental GDH sum in the refereed literature [7] gives 255±5±12 μb for the sum from 0.20 to 1.82 GeV. The unitary isobar model MAID2002 gives a contribution of -27.5±3 μb for the region below 0.20 GeV [9]. For photon enegies above 1.82 GeV, Q^2 extrapolations of phenomenogical analyses of polarized electroproduction data by Bianchi and Thomas [10] and Simula [11] give -22 μb

and -13 μb respectively, yielding at total integral value of 205 or 214 μb, both consistent with the GDH sum within experimental uncertainties. A more recent conference contribution including Bonn data up to 2.9 GeV gives 213±5±12 μb for the full corrected sum [12].

3. Polarized deep inelastic muon and electron scattering experiments measure the spin structure function $g_1(x, Q^2)$, which is the analog of the quantity $d\sigma_{1/2} - d\sigma_{3/2}$ in photoproduction. The integral $I_1(Q^2) = \frac{2m_p^2}{Q^2}\int_0^1 g_1(x, Q^2)dx$, which is a generalization of the GDH integral for $Q^2 \neq 0$, must change extremely rapidly in magnitude and sign in order to evolve smoothly toward the GDH sum rule value at Q^2=0. Recently an experiment has been approved in Hall B to explore the low-Q^2 crossover region of the generalized GDH integral in detail as a test of chiral perturbation theory [E-03-006, M. Battaglieri, R. De Vita and M. Ripani, spokespersons].

The angular coverage of the CLAS detector is not sufficiently complete to make it a good device for measuring total cross sections in photoproduction experiments, and hence for a direct measurement of the GDH sum rule. At the time of the original proposal in 1991, prior to the start of the Mainz and Bonn programs, it was hoped that we could make a valuable contribution to testing the GDH sum rule effort by measuring the helicity-separated differential cross sections for the single-pion and 2-pion photoproduction processes within the CLAS acceptance and extrapolating to the full angular distributions. With the advent of the Mainz and Bonn data, we no longer view this experiment as a direct contribution to testing the GDH sum rule.

2.3 Update of the scientific justification

The status of other ongoing and proposed experiments to measure helicity-separated photoproduction is summarized in Appendix A. **The essential fact is that none of these programs will measure the helicity asymmetry in exclusive pion photoproduction processes at energies above 800 MeV**, at least on the time scale of this experiment. The GDH measurements at Bonn have been made using a dedicated total-cross-section detector with very high efficiency for capturing charged and neutral particles but with no way of distinguishing individual exclusive processes. The only clear competition will be from Mainz, where the upgrade to MAMI-C, with a maximum energy of 1.5 GeV, is expected to be ready for experiments by 2006. In the energy region above 1.5 GeV, this experiment has no competition.

The proposal for E-03-105 [1] expresses clearly the importance of measuring all the accessible polarization observables in pion photoproduction. As mentioned in Section 2.1 above, this experiment will provide measurements of the double polarization variable $E = (d\sigma_{1/2} - d\sigma_{3/2})/(2d\sigma)$ to complement the double polarization observables H and F and the single polarization observables T, P which will be measured by E-03-105 between 0.6 and 2.0 GeV. At energies below 800 MeV, the Mainz GDH program has already shown the power of polarization observables. It was found (see Fig. 1) that the helicity difference $\Delta_{31} = d\sigma_{3/2} - d\sigma_{1/2}$ for $\gamma p \to \pi^0 p$ differs substantially from the predictions of both the MAID [13] and SAID [14] analyses near 700 MeV, and that this discrepancy can be used to determine better values for the helicity amplitudes for the $D_{13}(1520)$ resonance [5]. There are no data above E_γ=780 MeV. Above this energy, there are substantial differences between the MAID and SAID predictions, which new data can help to resolve (see Fig. 2).

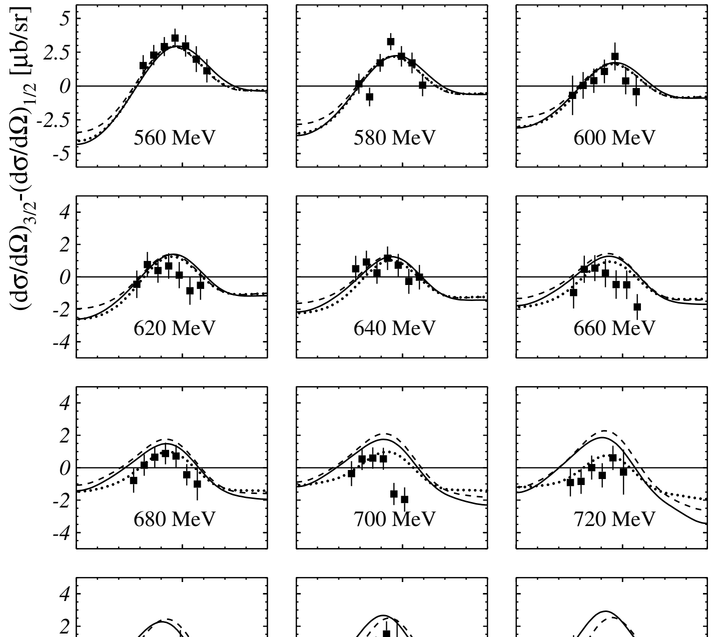

Figure 1: Helicity-dependent cross section difference $\Delta_{31} = d\sigma_{3/2} - d\sigma_{1/2}$ measured at Mainz [5]. Solid curve: SAID [14] prediction; dashed curve: MAID [13] prediction; dotted curve: MAID solution with modified helicity amplitudes for $D_{13}(1520)$.

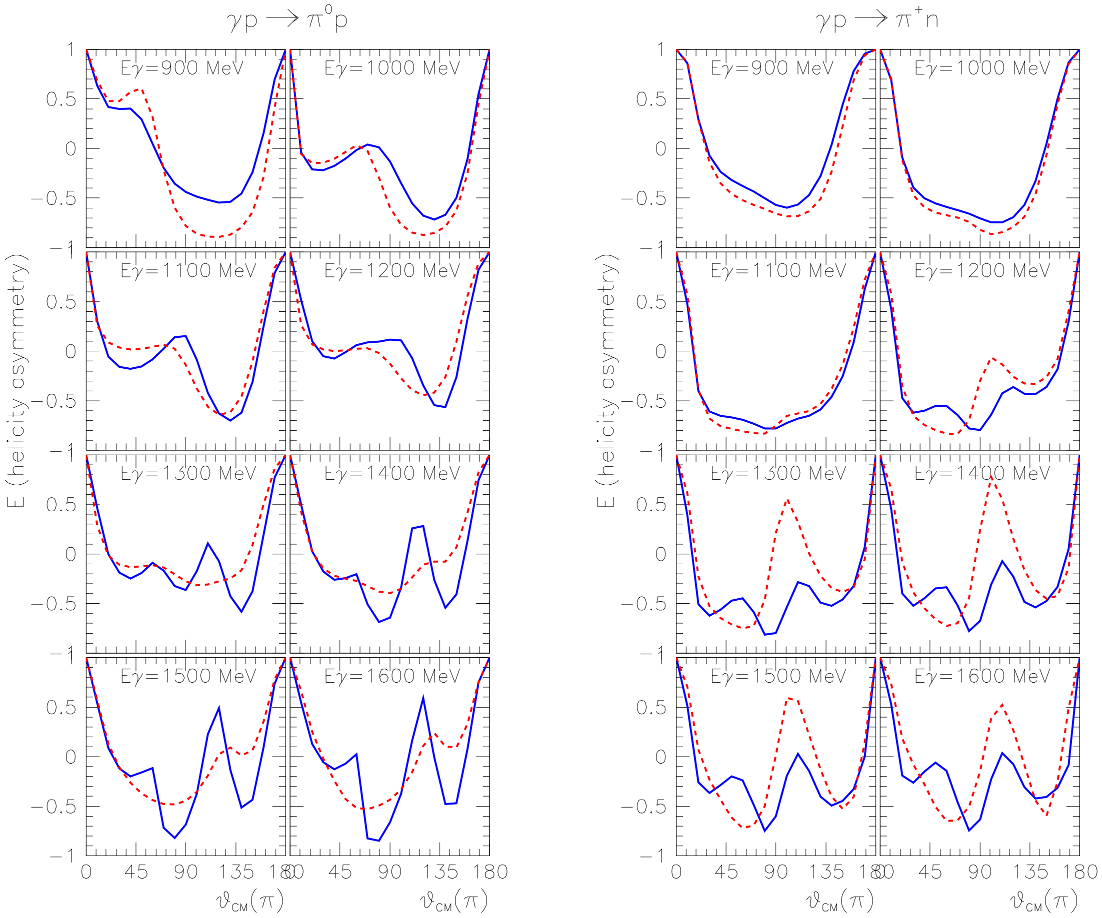

Figure 2: Comparison between predictions for the helicity asymmetry E by SAID2003 (solid curves) and MAID2003 (dashed curves).

We note in passing that the helicity decomposition of the differential cross section can be expressed in three equivalent ways:

1. the individual helicity-separated differential cross sections $d\sigma_{1/2}$ and $d\sigma_{3/2}$,
2. the unpolarized differential cross section

   $$d\sigma = \frac{d\sigma_{1/2} + d\sigma_{3/2}}{2}$$

   and cross section difference

   $$\Delta_{31} = d\sigma_{3/2} - d\sigma_{1/2} \ , \qquad \text{or}$$

3. the unpolarized differential cross section $d\sigma$ and the helicity asymmetry

$$E = \frac{d\sigma_{1/2} - d\sigma_{3/2}}{2d\sigma} \; .$$

Experimentally it is always advantageous to extract either Δ_{31} or E from the polarized-target data, and use measurements on an unpolarized target for $d\sigma$.

This experiment will also measure $\gamma p \to \pi^+\pi^- p$. (The other 2-pion final states require the detection of two neutral particles in the final state, their analysis, while possible, is not an immediate priority.) While the theoretical interpretation of the 2-pion processes is less straightforward than for single-pion production, they contain a wealth of information about resonances which couple relatively weakly to the πN system. The GDH collaboration at Mainz has analyzed all three charge states in $\gamma p \to \pi\pi N$. In a publication on the helicity dependence of $\gamma p \to \pi^+\pi^0 n$ [6], they find that the cross section near 700 MeV is predominantly helicity-3/2, and is dominated by the $D_{13}(1520)$ resonance, as predicted by theoretical models [15], but also contains a significant $\sigma_{1/2}$ contribution which implies a mechanism other than D_{13} dominance.

At the jeopardy review in 2001, PAC-20 approved this experiment for 22 days, conditional on the availability of the frozen-spin target, with the following distribution of run time: 6 days at $E_0 = 1.6$ GeV, 8 days at 2.4 GeV, and 4 days at 4.0 GeV, with 4 days added for the overhead of repolarizing the target. The 1.6 and 2.4 GeV runs were to be used for precise measurements of the helicity dependence of the 1- and 2-pion cross sections over the photon energy range 0.4–2.3 GeV. The 4.0 GeV run was intended mainly as a coarse survey of the helicity-dependence of the cross section in energy region above the Bonn GDH experiment.

Many of the goals of the proposed 4 GeV run were already achieved during a short "GDH test run" performed during the `eg1b` electron run period in January 2001 in Hall B. A highly collimated circularly polarized photon beam with energies between 2.5 and 5.3 GeV was incident on a dynamically-polarized ammonia target, and a loose trigger detected all outgoing charged particles within the combined acceptance of the CLAS detector and the target Helmholtz coils, effectively giving an angular acceptance from about 8° to 50°. For these events, which correspond to roughly 50% of the total cross section in this energy region, the helicity asymmetry was measured. Because of the short run time and the low trigger rate necessitated by the absence of a Start Counter, the statistics of the measurement were very poor, but the experiment showed a helicity asymmetry roughly consistent with the parameterization of Bianchi and Thomas [10] in the energy region above 4 GeV. Because there was no way to extrapolate this measurement to a full angular acceptance, the results were not deemed suitable for publication but were presented publicly at conferences [16].

Because the energy region above 2.4 GeV (corresponding to $W > 2.3$ GeV) is above the "resonance region" and not the subject of much current theoretical interest in 1- or 2-pion photoproduction, we have decided that there is little point in extending our measurements above 2.4 GeV. The more interesting question of the high-energy evolution of the GDH integrand above the maximum Bonn energy of 3 GeV must be explored by an experiment with more complete angular coverage than is provided by CLAS in its default configuration. Studies are under way to prepare a proposal for such a high-energy GDH measurement for a future PAC.

We thus request running time at two endpoint energies of 1.6 and 2.6 GeV. The extraction of cross sections from the polarized-target data is described in Section 4.4 below.

3 Membership of the collaboration

This proposal is approved and supported by the CLAS collaboration. Since the submission to PAC-20 in 2001, the team has been joined by several additional groups who are associated with the other experiments using the Hall B frozen-spin target. A current list of explicitly named collaborators who will be involved in run preparation, run coordination, and data analysis appears on the title page of this note.

4 Technical readiness of the experiment

4.1 Frozen-spin target status

This experiment, together with the other approved photon experiments E-02-112 and E-03-105, requires a longitudinally polarized proton target with minimal obstruction of outgoing charged particles within the entire CLAS acceptance. The previously existing Hall B polarized target [18], which has been used in electron-beam running, is a dynamically polarized target requiring a set of massive Helmholtz coils which severely restrict the angular acceptance of the experiments. For electron beams, where beam-induced radiation damage and heating requires constant dynamic polarization of the target material, such a target is the only practical choice, but for photon-induced experiments a frozen-spin target is a much more attractive choice.

The concept of the frozen-spin target is that a target sample can be dynamically polarized at high magnetic field, and then transferred to a much lower holding field at very low temperature while losing little or none of its polarization. In the absence of beam-induced radiation damage, this target can hold its polarization with relaxation times of the order of several days before repolarization is required. The holding field can be provided by a magnet of very low mass, thus allowing outgoing particles to be detected over the full CLAS acceptance. Previous PACs have endorsed the construction of such a frozen-spin target for Hall B, and the project is now well under way within the JLab target group, with the help of user groups. A detailed status report is given in Appendix B.

4.2 Circularly polarized photon beam

Circularly polarized photons are produced by the bremsstrahlung of longitudinally polarized electrons from an amorphous radiator. The circular polarization of the photon beam is equal to the longitudinal polarization of the electron beam multiplied by a numerical factor [17] which increases roughly linearly from 0 to 1 as the photon energy increases from 0 to the bremsstrahlung endpoint. In order to have high photon polarization, the photon energy should preferably be above about 0.5 E_0. Thus two electron beam energies, 1.6 and 2.6 GeV, are proposed to cover the photon energy region from 0.45 to 2.4 GeV. The circular polarization of the bremsstrahlung photons can be calculated precisely from the longitudinal polarization of the electron beam, so no beam polarimetry beyond the standard electron-beam Møller polarimeter is required. The 1.5 cm diameter of the polarized target requires that the photon beam be collimated to approximately 1 cm on the target. The 2.6 mm collimator which accomplishes this exists and has already been used in experiments. This collimation has a very small (and calculable) effect on the average circular polarization.

4.3 Other experimental equipment

Because of the large flight times from the target to the CLAS time-of-flight counters, photon beam running requires a "start counter" close to the target to suppress accidental coincidences in the trigger. Thus the target cryostat and holding magnet must be designed to be compatible with either the existing CLAS start counter or with the new start counter which is under construction. There are no fundamental incompatibilities between the start counter and the target cryostat described in Appendix B. The only detail to be worked out is the shielding of the start counter photomultipliers from the fringe field of the holding magnet. No other modifications of the standard Hall B equipment are required for this experiment.

4.4 Data analysis

We will attempt to extract the helicity dependence of the cross section from the data in the form of both Δ_{31} and E as defined in Section 2.3. Δ_{31} is determined by subtracting the normalized yields in the two polarization states; since the bound nucleons are unpolarized, the dilution factor (the ratio of total nucleons to free protons in the target) is not used in the calculation of the result, but only affects the statistics of the subtraction. This method is being used in the analysis of the Mainz GDH experiment [3, 5, 6]. For each method, the systematic uncertainty contains contributions from beam and target polarization, which should each be under control at the level of 3%, and from the method used to separate single-pion from multi-pion processes. The systematic uncertainty in Δ_{31} also contains the uncertainty in the photon flux ($\approx$ 3%) and in the areal density of free protons ($\approx$ 5%). The determination of the asymmetry E is independent of target thickness and beam flux, but requires knowledge of the effective dilution factor. Since we will identify events produced on the free protons by kinematic cuts, the effective dilution factor can be made much smaller than its nominal value (7.4 for butanol), but at the expense of requiring precise knowledge of this effective factor.

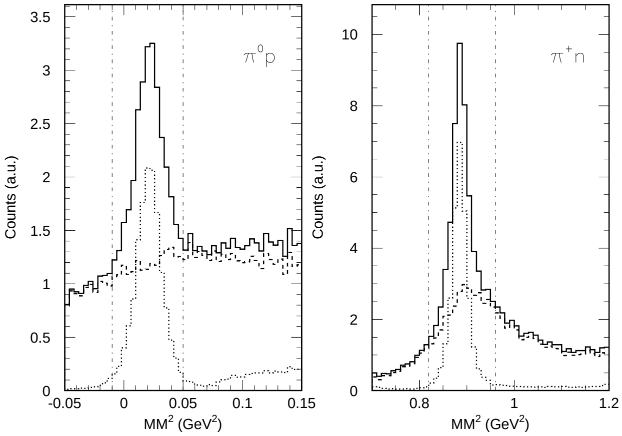

Figure 3: Normalized missing-mass-square distributions from hydrogen (dotted histogram) and ^{4}He (dashed histogram), obtained from CLAS `g1c` and `g3a` data, respectively, with E_γ between 0.6 and 1.4 GeV. The solid histogram is the sum, which approximate the experimental distribution from a butanol polarized target (from Ref. [1]).

The original proposal contained kinematic simulations which predict that the signal-to-noise ratio between free-proton and bound-nucleon events after missing-mass cuts should be of order 1:1 for $n\pi^+$ (and 1:2.5 for $p\pi^0$) for energies up to 2 GeV. In the proposal for E-03-105 [1], a comparison of CLAS data from hydrogen and helium targets gives comparable results (Fig. 3), and the analysis there gives a conservative estimate of 1:2.5 for the ratio of free-proton to bound-proton events inside reasonable cuts.

Analysis of single-pion electroproduction from a polarized target (NH_3) in the `eg1` run period confirms that there is no difficulty in selecting single-pion events from a polarized target in CLAS.

At energies above about 2 GeV, selection of free-proton events by missing mass alone may not be fully effective, but for the single-pion processes, coplanarity and other kinematic constraints can easily be imposed by detecting the neutral particle in coincidence with the charged particle. The CLAS calorimeter, which subtends angles up to 45° in all sectors (and up to 70° in two sectors), has approximately 60% detection efficiency for neutrons above about 2 GeV/c, and the time-of-flight counters have neutron efficiencies of 6–10% near 200 MeV/c [19]. The calorimeter also has a reasonably high efficiency and acceptance for $\pi^0 \rightarrow \gamma\gamma$ above 1 GeV.

4.5 Revised run plan

At PAC-20, this experiment (E01-104) requested and was awarded 22 days of running time at endpoint energies of 1.6, 2.4, and 4.0 GeV. As mentioned above, we have dropped the 4 GeV run from this update request, and plan instead to submit a proposal for a high-energy GDH run to a future PAC. We propose endpoint energies of 1.6 and 2.6 GeV for compatibility with experiment E02-112 [2], which can take data under the same conditions as this experiment.

Table 2 shows proposed run conditions for the two endpoint energies, with the statistical goals of the measurement and the time required for each energy. We assume the following conditions:

Target thickness	5 cm (3.0 g/cm^2) of butanol (C_4H_9OH)
Beam spot collimation	1.0 cm diameter at target
Average target polarization	80%
Electron beam polarization	70%
Maximum CLAS trigger rate	3500 triggers/sec

The beam time requested should be sufficient to determine the helicity asymmetry E (see Section 2.2) for $\gamma p \rightarrow \pi^+ n$ and $\gamma p \rightarrow \pi^0 p$ to a statistical uncertainty $\delta E = \pm 0.05$ in each bin of differential cross section except the most backward angle bins. The systematic uncertainty in E is estimated at $\delta E/E \approx 5\%$ due primarily to the knowledge of beam and target polarization. The tagging range for the 1.6 GeV run extends down to 450 MeV, to give substantial overlap with the Mainz measurements in the resonance region. Figure 4 shows simulated data based on SAID predictions, the acceptance of the CLAS detector for $\gamma p \to \pi^0 p$ and $\gamma p \to \pi^+ n$, and the planned statistics of this measurement (cf. Table 2).

As with the other approved frozen-spin target experiments (E02-112 and E03-105), we plan to place a carbon target downstream of the cryostat in order to make measurements of the shape of the bound-nucleon background contribution. The dilution factor (total nucleons/free nucleons) is about 8.9 when accounting for the proportion of free protons in butanol (74/10) and the ^{3}He/^{4}He bath surrounding the beads and the target cell (increasing the nominal dilution factor by $\approx 20\%$). However, we assume that kinematic cuts are used to reduce the effective dilution factor to values as low as ≈ 2 (for $\gamma p \to \pi^+ n$ in the 1.6 GeV run), improving the statistical uncertainties of the subtractions. Table 2 includes 4 days for target polarization, assuming that repolarization of the frozen-spin target will be required approximately every 3 days of running, and that, with a new system being commissioned, beam loss will be a full day for each repolarization.

Table 2: Requested run time for the two beam energies. The criterion is the statistical uncertainty desired in the helicity asymmetry E for for $\gamma p \to \pi^0 p$ and $\gamma p \to \pi^+ n$.

beam energy (GeV)	tagged photon energy (GeV)	tagging rate	angle bin	energy bin (MeV)	hours beam on target	δE for $p\pi^0$	δE for $n\pi^+$	days
1.6	0.45–1.52	22 MHz	10°	25	200	.034	.049	8
2.6	1.40–2.47	12 MHz	10°	50	180	.049	.051	7
							target polarization time	4
							total run time	19

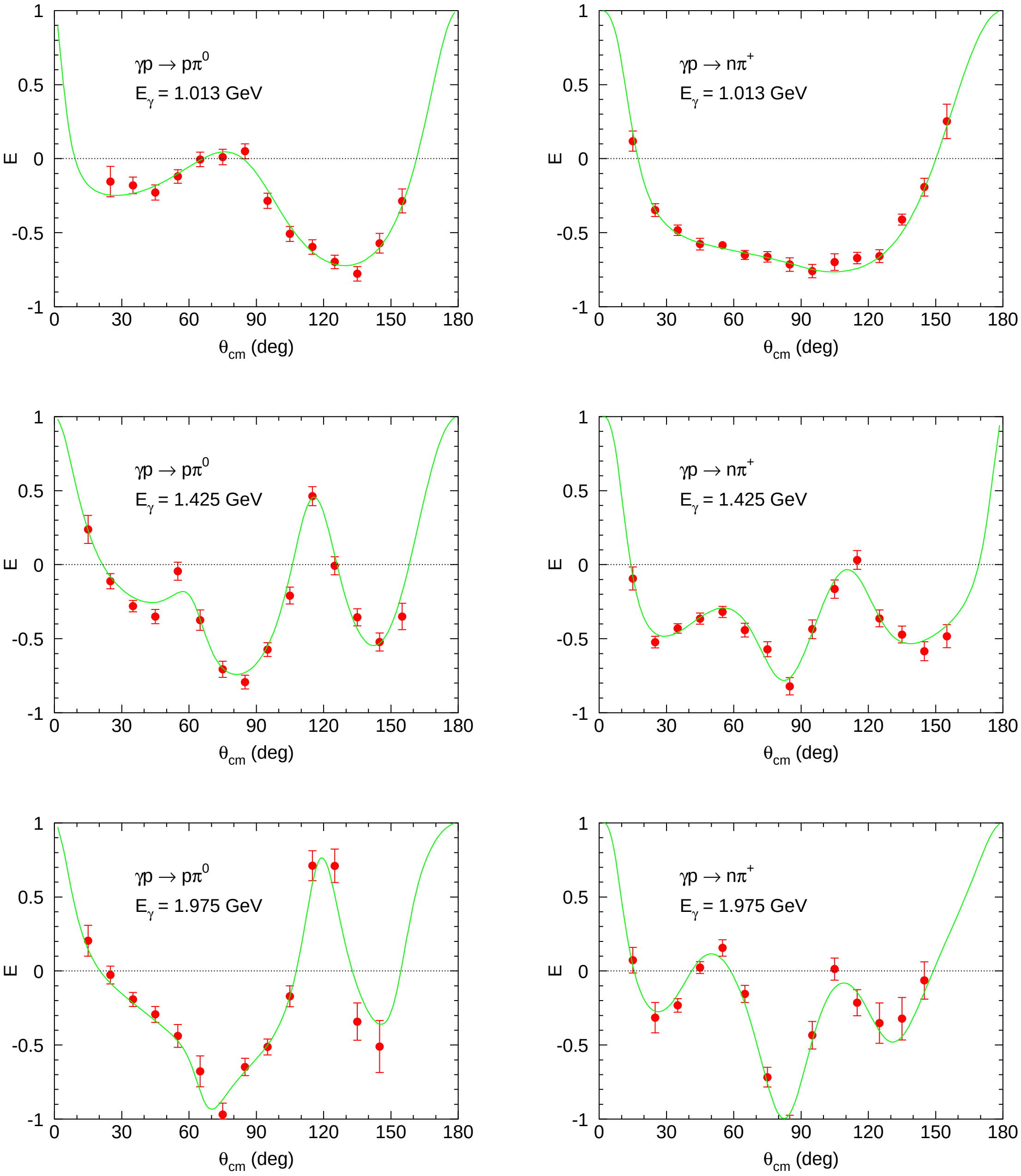

Figure 4: Simulated data for E for both reactions, $\gamma p \to \pi^0 p$ and $\gamma p \to \pi^+ n$. The SAID predictions (*curves*) are used as input, the data points and error bars represent the expected results from this measurement

Appendix A: Ongoing and proposed experiments to measure contributions to the GDH sum rule on the proton

Mainz See Section 2.3.

Bonn As part of the same experimental program as in Mainz, and using the same polarized target, a measurement of $\Delta\sigma$ (total cross section difference) at energies from 680 to 3100 MeV has been performed at Bonn using a total-cross-section detection device with only limited ability to distinguish individual final states [7].

LEGS The LEGS facility at Brookhaven National Laboratory is planning measurements of all γp and γn differential cross sections up to 470 MeV, using a new frozen-spin HD target known as "SPHICE". A polarized target sample was first placed in the beam in 2001, and preliminary physics results were presented at GDH2002 [20]. A new target is ready for installation in the beam, with the first physics program scheduled to begin during the summer of 2004.

GRAAL The GRAAL laser-backscattering facility at Grenoble also plans to use a SPHICE type HD target (called "HYDILE") to measure the GDH contributions and some exclusive cross sections up to 1.5 GeV. A Polarized HD Target Factory has been constructed at IPN Orsay, and a HD target has been delivered to the GRAAL experimental site.

LEPS The LEPS facility at SPring-8 plans to develop a frozen-spin HD polarized target, similar to the one at GRAAL, to measure $\Delta\sigma$ (total cross section difference) at photon energies from 1.5 GeV to 2.4 GeV. The schedule is for the first GDH sum rule experiment to begin in 2007.

SLAC An experiment (SLAC-E159, P.E. Bosted and D. Crabb, spokespersons (2000)) was approved to measure $\Delta\sigma$ from 5 GeV to 40 GeV using a total cross section detector, a polarized target, and a collimated coherent bremsstrahlung beam. Funding for this experiment has not yet been obtained, and the experiment is on hold.

JLab Experiment 91-023 (V. Burkert, D. Crabb, R. Minehart) has measured the Q^2 evolution of the GDH sum rule in $ep \rightarrow e'X$ in Hall B. Experiment 93-036 (H. Weller, R. Minehart) has measured the exclusive final states $ep \rightarrow e'\pi^0 p$ and $ep \rightarrow e'\pi^+ n$ in the same run.

Experiment 03-006 (M. Battaglieri, R. De Vita, M. Ripani) will measure the GDH sum rule on the proton using nearly real photon at low momentum transfer ($Q^2 = 0.01$–0.5 GeV^2).

There are also three other GDH-related electron scattering experiments (E93-009, E94-010 and E97-110) that have been measured using neutron (deuteron or ^{3}He) targets.

Appendix B: Properties of the Hall-B Frozen-Spin Polarized Target

The Hall-B frozen-spin target system will make use of an "external" polarizing magnet, located outside CLAS, and an "internal" holding magnet located inside the target cryostat. The target material will be polarized outside the CLAS detector at $B = 5$ Tesla and $T = 0.5$ K using the method of Dynamic Nuclear Polarization. After maximal polarization is achieved, the cryostat is switched to the "holding" mode at $B = 0.5$ Tesla and $T = 50$ mK and moved inside the CLAS detector. Since the target will be used only for photoproduction experiments, we expect negligible radiation damage to the polarization. This permits a wider selection of polarizable target materials (e.g. ammonia, butanol, propandiol) that can provide both high proton polarizations and long spin-relaxation times [21, 22]. At the present time we foresee the use of butanol, which has a dilution factor of 7.4, and a maximum polarization in excess of 90%. At temperatures $T = 50 - 60$ mK and holding field $B = 0.5$ Tesla, the expected relaxation time is about 10 days (200-300 hours) [21].

Some equipment and instrumentation from the previous Hall-B polarized target will be used; however, this project requires a new dilution refrigerator, holding and polarizing magnets, and infrastructure for precisely positioning the target cryostat inside the polarizing magnet and later inside the CLAS detector.

Polarizing Magnet A horizontal, 5.0 Tesla superconducting polarizing magnet with a 130 mm warm bore has been purchased from Cryomagnetics, Inc [23]. A precise NMR field map of the magnet has been recently performed at JLab and confirms:

- the magnet operates in a highly reliable manner;
- the homogeneity over a cylindrical target area, 20×50 mm^2, is better than 40 ppm, *i.e.* considerably better than the 100 ppm at which many systems operate;
- the homogeneity is good enough to allow the use of a large variety of target materials including ones with recently discovered paramagnetic centers having very narrow (less than 100 gauss) EPR lines [24];

- relative to the polarizing magnet center, we can afford about 3 mm tolerance in positioning the target cell (cryostat tail).

Holding Magnet The preliminary design of the dilution cryostat has the holding magnet wound on an inner radiation shield with a diameter $D = 40.0$ mm. Since the proposed project requires a longitudinal target polarization, we have modeled solenoidal holding magnets [25]. The holding magnet should be as transparent (i.e. minimal energy loss and multiple scattering) to outgoing particles as possible. This places a severe constraint upon the number and thickness of coil windings. On the other hand, the target's polarization relaxation time is a strong function of magnetic field and requires high fields to maintain polarization. The optimum design of the holding magnet has been investigated using both the Poisson/Superfish-2D [26] and Opera-3D [27] software packages. These calculations show that a 20 cm long solenoid with three layers of 0.1 mm diameter NbTi superconducting wire can provide a 0.5 Tesla holding field with a homogeneity better than 1% over the target volume. This homogeneity will allow us to monitor the target polarization via NMR while in the frozen-spin mode. Tests of a prototype coil yielded results that confirm corresponding calculations.

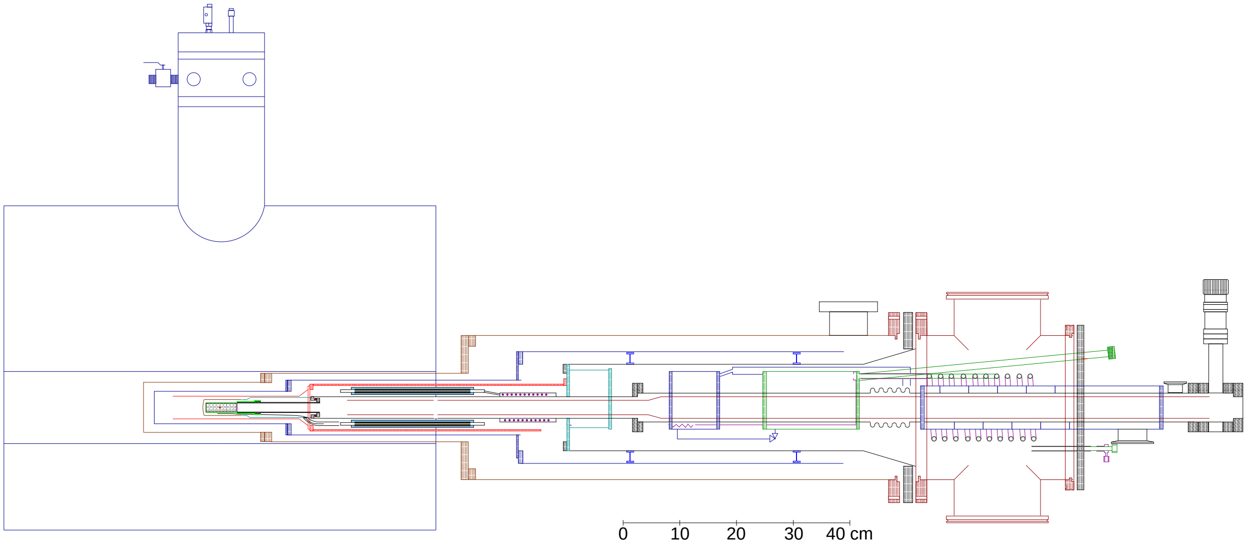

Figure 5: Sketch of the frozen-spin target for Hall B inserted into the polarizing magnet.

Dilution Refrigerator For a cylindrical target volume with 15 mm diameter and 50 mm length, approximately 20 mW of microwave power will be necessary for the polarization process at 0.5 K, with a polarization build-up time of about 30 minutes.

During experimental run conditions, the total heat load from the photon beam is about 1 μWatt. Thus in the frozen-spin mode at 0.5 Tesla and 50 mK, the target refrigerator should provide cooling power better than a few a microWatts. The only technique capable of satisfying both of these cooling requirements is ^{3}He/^{4}He dilution refrigeration. While dilution refrigerators with an acceptable base temperature and cooling power are available commercially, the geometric constraints of CLAS will require a custom-built horizontal refrigerator. This refrigerator is currently under design and construction by the JLab Target Group. A cut-through view of the target, inserted into the 5 Tesla polarizing magnet, is shown in Figure 5. A close-up of the target cell inside the refrigerator is also shown (Fig. 6).

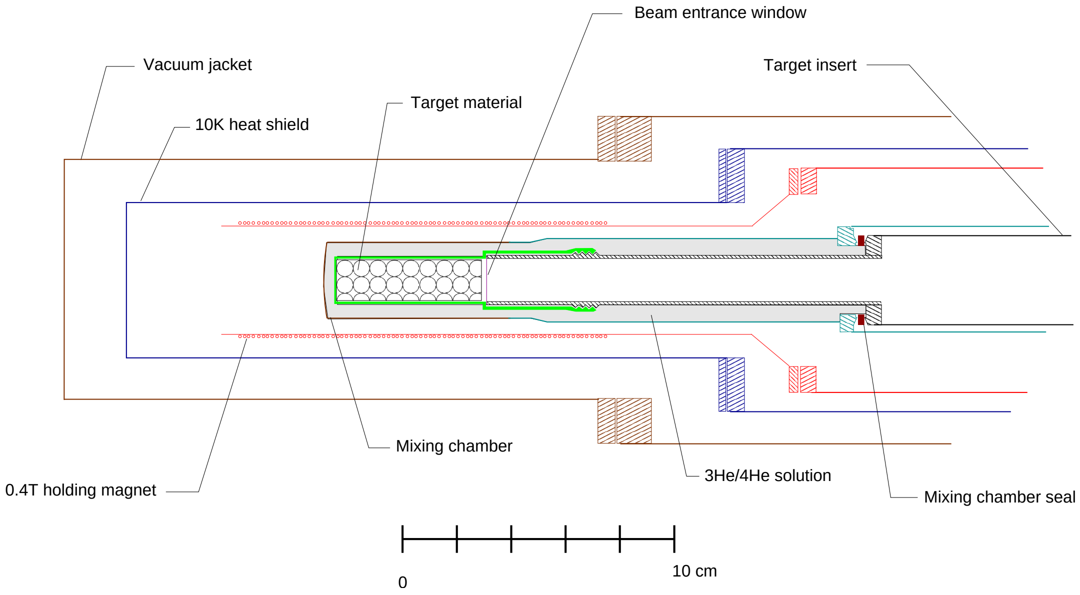

Figure 6: Cut-through view of the target cell inside the refrigerator.

The overall design is similar to refrigerators constructed and operated successfully by researchers at Bonn University [21] and at Saclay [28]. Key areas of difference include heat shielding and heat exchanger design. The JLab target will utilize one shield (in addition to the mandrel for the holding coil) rather than the customary two, thus reducing the energy loss of outgoing particles. A new heat exchanger fabricated of sintered silver powder is under design that will provide significantly more surface area for heat exchange, thus enabling greater cooling power at low temperatures. This latter point is particularly important given the geometry of the experimental layout. To be positioned at the center of the CLAS detector system, the target must be moved more than 2 meters from its polarizing position inside the 5 Tesla solenoid. While in motion, the target will be susceptible to an additional heat load resulting from both eddy currents and frictional heating of the circulating ^{3}He. In order to minimize the polarization loss during this procedure the temperature should remain below approximately 80 mK.

The target material will be placed inside the refrigerator's mixing chamber via a 2 m long insert heat-sunk at multiple locations along its length. Two NMR coils will be wrapped around the mixing chamber. The first will be used to make an absolute determination of the target polarization at 5 T. The second will be used to monitor the polarization while in the frozen-spin mode at 0.5 T. The mixing chamber walls will be a fluorinated plastic such as PCTFE in order to minimize the NMR background signal. Microwaves will be directed at the target via a waveguide located directly underneath the mixing chamber.

Construction of the target is now underway, with an estimated completion date of June 2005. This will be followed by a series of cooling and polarization tests lasting about 6 months.

Positioning Infrastructure The infrastructure for precise positioning of the cryostat inside the polarizing magnet and later inside the CLAS detector is now under design by the Hall B engineering staff and JLab Target Group. The system consists of three parts which are a cart carrying the polarized target cryostat, a second cart for a pump system, and a support structure for positioning the polarizing magnet.

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