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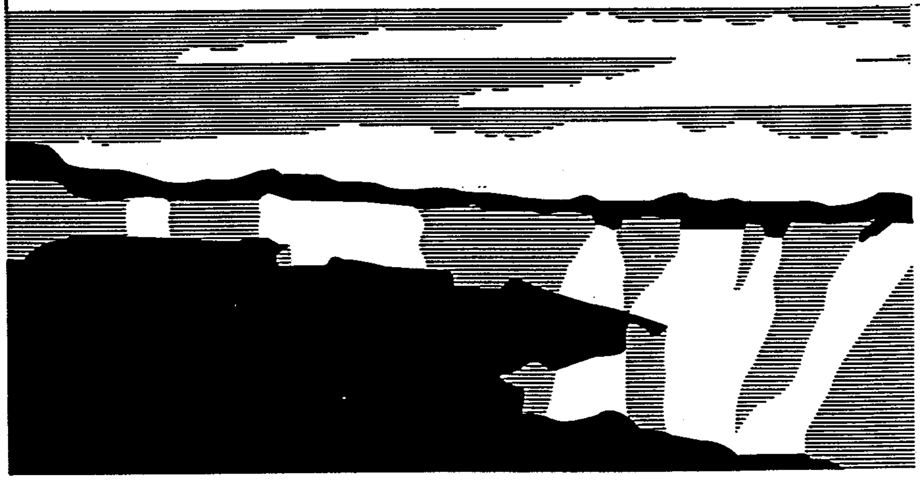

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Measurement of the Parity Violating Asymmetry A_γ in $\vec{n} + p \rightarrow d + \gamma$

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The weak pion-nucleon coupling constant H_π^1 remains poorly determined, despite many years of effort. The recent measurement of the ^{133}Cs anapole moment has been interpreted to give a value of H_π^1 almost an order of magnitude larger than the limit established in the ^{18}F parity doublet experiments. A measurement of the gamma ray directional asymmetry A_γ for the capture of polarized neutrons by hydrogen has been proposed at Los Alamos National Laboratory. This experiment will determine H_π^1 independent of nuclear structure effects. However, since the predicted asymmetry is small, $A_\gamma \approx 5 \times 10^{-8}$, systematic effects must be reduced to $< 5 \times 10^{-9}$. The design of the experiment will is presented, with an emphasis on the techniques used for controlling systematic errors.

INTRODUCTION

The hadronic weak interaction is an ideal place to study the interplay between the weak and strong nuclear forces. The weak force is well described by the standard electroweak model, and weak processes involving only leptons can be exactly calculated. Quarks, however, interact via the strong force as well, effectively modifying the manifestation of the weak force between them. Since QCD has not been solved for the non-perturbative regime characteristic of low energies, the parameters of the weak hadronic interaction must be determined from experiment.

The weak nucleon-nucleon interaction can be parameterized by a potential model of the form

$$V_{pnc} = \sum_{\mu=\pi,\rho,\omega} \sum_{\Delta I=0,1,2} H_\mu^{\Delta I} V_\mu^{\Delta I}, \qquad (1)$$

where $H_\mu^{\Delta I}$ is the weak coupling constant corresponding to the exchange of a π. ρ, or ω meson and an exchange of isospin of ΔI. Only one coupling H_π^1 is allowed for π exchange. Most theoretical calculations of this coupling, whether from symmetry considerations [1], QCD sum rules [2], or chiral perturbation theory [3, 4], give a value in the range $1 \leq H_\pi^1 \geq 10 \times 10^{-7}$. In contrast the best experimental determination, from the measurement of circular polarization in the decay of ^{18}F, gives an upper limit of $H_\pi^1 \leq 0.28 \times 10^{-7}$ [5]. In addition, the recent measurement of the anapole moment of ^{133}Cs [6] has been interpreted to give a large value of $H_\pi^1 = 2.26 \pm 0.50(\text{expt}) \pm 0.83(\text{theor}) \times 10^{-6}$ [7]. This interpretation, however, has been disputed [8].

Because of the difficulty in interpreting the results from measurements in nuclei, a measurement in the nucleon-nucleon system is necessary to definitively determine H_π^1, free from nuclear structure assumptions. While most parity-violating experimental observables are sensitive to a linear combination of several weak couplings, the directional asymmetry A_γ in the emission of gammas from *np* capture, given by

$$A_\gamma = -0.045\left(H^1_\pi - 0.02H^1_\rho + 0.02H^1_\omega + 0.04{H'}^1_\pi\right), \tag{2}$$

is (to the few-percent level) only sensitive to H^1_π. A measurement of A_γ is therefore a measurement of H^1_π. A previous measurement of A_γ has been performed [9], though not with sufficient precision to obtain a non-zero result. We are proposing an experiment to measure A_γ with a statistical precision of 10% of the predicted value, $A_\gamma \sim 5 \times 10^{-8}$, with negligible systematic error [10].

EXPERIMENTAL DESIGN

In this section, we describe the conceptual design for the proposed measurement of A_γ in $\vec{n} + p \rightarrow d + \gamma$. The apparatus, shown schematically in figure , consists of a cold neutron source, followed by a neutron polarizer, and a liquid para-hydrogen target, surrounded by an array of gamma detectors. Neutrons from the spallation source are moderated by a liquid hydrogen moderator. The source is pulsed, thus allowing measurement of neutron energy through time-of-flight techniques. The neutron guide transports the neutrons from the moderator through the biological shield with high efficiency. The neutrons are then polarized in the vertical direction by transmission through polarized ^{3}He gas. The neutron spin direction can be subsequently reversed by the radio-frequency resonance spin flipper. The use of this type of a spin flipper, which is possible at a pulsed neutron source, reduces the systematic error associated with the $\vec{\mu}_n \cdot \nabla B$ force, where $\vec{\mu}_n$ is the neutron magnetic moment. The neutrons are captured in the target, which consists of liquid para-hydrogen. This state of hydrogen is required, since neutrons depolarize quickly in ortho-hydrogen, while those with energies below 15 meV retain their polarization in para-hydrogen. Gammas emitted in the capture process are detected in the CsI(Tl) detectors surrounding the target. The parity-violating asymmetry causes an up-down asymmetry in the angular distribution of the gamma-rays for vertical neutron spin. When the neutron spin is reversed, the up-down gamma asymmetry reverses. The parity-violating asymmetry in gamma flux,

$$\frac{d\omega}{d\Omega} = \frac{1}{4\pi}\left(1 + A_\gamma \cos\theta_{s,\gamma}\right), \tag{3}$$

is a measure of H^1_π, as discussed in the introduction.

SYSTEMATIC ERRORS

We distinguish between statistical and systematic errors. The experiment is designed to measure the directional asymmetry of the emission of gamma rays with the neutron spin direction. A source of systematic error produces a signal in the detector that is coherent with the state of the neutron spin; for example, the current in a magnet used to flip the neutron spin might be picked up by the gamma detector, or a guide field might steer the neutron beam up-down as the spin is changed from up to down. A source of statistical error produces a detector signal that is not correlated with the neutron spin direction; for example fluctuations in the number of detected gamma rays due to counting statistics or drifts in amplifier offsets. The size of statistical errors is important when discussing systematic errors, because it is important to be able to diagnose systematic errors in a time that is short compared to the time it takes to measure the directional γ asymmetry. Systematic errors can be further classified according to whether they are instrumental in origin and are present whether or not neutrons are being detected or arise from an interaction of the neutron spin other than the directional γ asymmetry in the $\vec{n} + p \rightarrow d + \gamma$ reaction, for example the parity-allowed asymmetry $\vec{s}_n \cdot (\vec{k}_n \times \vec{k}_\gamma)$. Finally, it is important to isolate and study experimentally potential sources of systematic errors. For example we can search for false asymmetries from activation of components of the apparatus due to the capture of polarized neutrons by emptying the liquid hydrogen target. We can monitor in situ effects such as the parity allowed $\vec{s}_n \cdot (\vec{k}_n \times \vec{k}_\gamma)$ correlation in $\vec{n} + p \rightarrow d + \gamma$ that produces left-right asymmetries.

It is not possible to give a complete list of sources of instrumental systematic errors. Many come to mind: the influence of magnetic fields on detector gains, shifts in the mains voltage as power supplies are turned on and off, leakage of control signals into preamplifiers, etc. It is essential to be able to tell whether such effects are present in a short time, to learn where they come from, and fix them. These effects are not associated with the neutron beam. There are two types of instrumental asymmetries; additive couplings and gain shifts. Additive couplings will be diagnosed by running the experiment with the beam off and looking for a non-zero up-down asymmetry. The electronic noise is 1/100 of counting statistics. In the presence of electronic noise only, achieving an accuracy of 0.1×10^{-8} (the statistical error in A_γ will be 0.5×10^{-8} in one year of data) will require a running time $5^2/100^2$ of 1 year, $\approx$ 1 day.

In order to search for gain shifts we will illuminate the detectors with light from light emitting diodes. The level of illumination will produce a photo-cathode current 10 times larger than that due to neutron capture where we expect the number of photo-electrons per 2.2 MeV gamma from CsI(Tl) will be $\approx$ 500. The time to measure a gain shift of 0.1×10^{-8} will be $5^2/(10 \times 1000)$ of 1 year $\approx$ 1 day. We will be able to

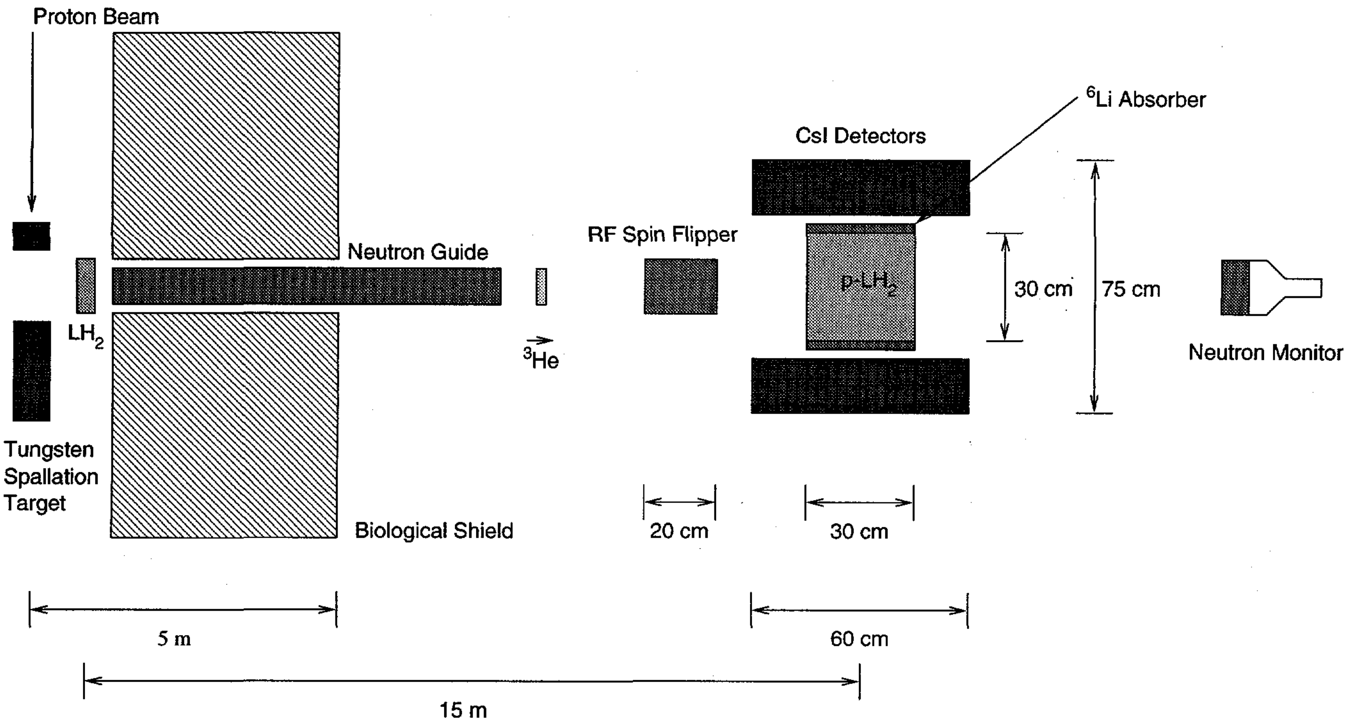

Figure 1: The conceptual design for the proposed experiment, showing the most important elements (not to scale). Approximate sizes and distances are indicated for some features.

diagnose and eliminate instrumental systematic errors before we take beam, and without a complete apparatus. We will be able to check for problems during periods when the beam is off.

The most important experimental tool we have to isolate a parity violating signal in this experiment is the neutron spin flip. It is therefore absolutely essential that the process of flipping the neutron spin have a negligible effect on all other properties of the apparatus. In this section we discuss some of the ways that this idealization may fail, and our estimates for the size of the resulting systematic effect.

In our considerations above we assumed that the spin flip process is "perfect", that is, that the only difference between the flip/no-flip states of the experiment is that the neutron polarization is reversed. In practice this condition cannot be met. We now relax these assumptions and consider the consequences. We will concentrate on two methods of neutron spin reversal: use of a RF magnetic field on the neutron beam and reversal of the polarization direction of the ^{3}He polarizer.

One method of spin reversal consists of reversing the polarization direction of the ^{3}He target. The ^{3}He spin can be reversed by an adiabatic fast passage or adiabatic reversal of the magnetic holding/guide field. The magnetic field (at the polarizer the fully polarized ^{3}He nuclei create a field of about 2 Gauss) due to the reversed magnetic moments of the polarized ^{3}He nuclei in the neutron polarizer causes a change in the static magnetic field at the location of the gamma detectors. This change is about 1×10^{-6} Gauss. Coupled with the measured change in the gamma detector efficiency 2×10^{-5} per Gauss, this gives a negligible efficiency change of 2×10^{-11}.

The other method of neutron spin reversal is effected by turning on and off the $\approx$ 30 kHz magnetic field in the spin flipper. This field, although closer to the detectors than the ^{3}He cell, can be shielded very effectively because the skin depth of the 30 kHz RF field in aluminum is 0.5 mm. In addition, the intrinsic detector efficiency should be less sensitive to an RF field than a DC field. Care must be taken to insure that there is no spurious electronic pickup induced by the RF switching. We intend to forestall this problem by switching the RF power into a dummy coil when the neutron spin is not being flipped.

We will reverse the neutron spin on a 20 Hz time scale using the RF spin flipper with a $+--+-++-$ pattern. This pattern eliminates the effects of first and second order drifts. The neutron spin will be reversed every few hours by reversing the polarization direction of the ^{3}He polarizer. Finally, we will reverse the direction of the holding/guide field every few hours. Instrumental effects arising from the state of the RF spin flipper, the ^{3}He cell, the holding/guide field, or from other parts of the apparatus will have different dependences on the different reversals. These different dependences can be used to identify the source of potential instrumental systematic errors. Any instrumental or spin-dependent systematic error that depends on the ^{3}He state, the spin flipper state, or the holding field state would be eliminated by averaging over different reversal methods.

In this section we consider systematic errors arising from interactions of the polarized neutron beam itself. This type of false effect is potentially the most difficult to eliminate. Fortunately, these effects are all small, $\ll 10^{-8}$, and do not require heroic efforts to eliminate. In order to produce a false asymmetry, an interaction must occur after the spin is reversed by the RF spin flipper, otherwise the effect of the interaction would be averaged out by the eight-step reversal sequence. The interaction must involve the inner product of the neutron spin vector and some vector made up of the vectors and scalars from the initial and final states. At least one quantity from the final state that deposits energy in the detector must be involved. We have tried to identify all possible Cartesian invariants that satisfy these conditions and evaluate the associated false asymmetries. We evaluated invariants that produced asymmetries $\approx 10^{-10}$ more carefully than asymmetries $\ll 10^{-10}$. Different potential sources of false asymmetry produce effects that depend on time of flight (neutron energy) in a characteristic fashion. The $\vec{n}+p \rightarrow d+\gamma$ directional asymmetry, A_γ, produces an up-down pattern (for neutron spin up-down) that is independent of neutron energy up to an energy of 15 meV. Above 15 meV, the neutrons depolarize in the para-hydrogen and the asymmetry vanishes.

SUMMARY

We are proposing an experiment to measure A_γ with a statistical precision of 10% of the predicted value, $A_\gamma \sim 5 \times 10^{-8}$, with negligible systematic error [10]. This measurement will determine the weak pion-nucleon coupling H_π^1 independent of nuclear structure assumptions. The experiment is designed to measure A_γ to 10% of its predicted value with negligible systematic error.

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REFERENCES

References

[1] B. Desplanques, J.F. Donoghue, and B.R. Holstein, Ann. Phys. **124**, 449 (1980).

[2] E.M. Henley, W.-Y.P. Hwang, and L.S. Kisslinger, nucl-th/9809064.

[3] D.B. Kaplan and M.J. Savage, Nucl. Phys. **A556**, 653 (1993).

[4] U.-G. Meißner and H. Weigel, nucl-th/9807038.

[5] E.G. Adelberger and W.C. Haxton, Ann. Rev. Nucl. Part. Sci. **35**, 501 (1985).

[6] C.S. Wood, S.C. Bennett, D. Cho, B.P. Masterson, J.L. Roberts, C.E. Tanner, and C.E. Wieman, Science **275**, 1759 (1997).

[7] V.V. Flambaum and D.W. Murray, Phys. Rev. C **56**, 1641 (1997).

[8] W.S. Wilburn and J.D. Bowman, Phys. Rev. C **57**, 3425 (1998).

[9] J.F. Caviagnac, B. Vignon, and R. Wilson, Phys. Lett. **B67**, 148 (1977).

[10] W.M. Snow, W.S. Wilburn, J.D. Bowman, M.B. Leuschner, S.I. Penttilä, V.R. Pomeroy, D.R. Rich, E.I Sharapov, and V. Yuan, nucl-ex/9704001.