MEASUREMENT OF THE WEAK PION-NUCLEON COUPLING CONSTANT, H_π^1, FROM BACKWARD PION PHOTO-PRODUCTION NEAR THRESHOLD ON THE PROTON

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The longest range weak pion-nucleon coupling constant, h_π^1, is important for nuclear parity violation. However, after considerable effort in the past two decades, its value is still poorly known largely due to many-body theoretical uncertainties. Prospects of a new measurement of h_π^1 in a theoretically clean process are presented. A measurement of the parity-violating asymmetry in pion photo-production off the proton is related to h_π^1 in a low-energy theorem for the photon polarization asymmetry at threshold in the chiral limit. At present two completed experiments - photon circular polarization for ^{18}F and the anapole moment of ^{133}Cs - have been interpreted to give very different values of h_π^1. This experiment will be the first attempt to measure h_π^1 in the single nucleon system. A reliable measurement of h_π^1 provides a crucial test of the meson-exchange picture of the weak NN interaction. Such a test of the meson-exchange picture will shed light on low energy QCD.

1 Introduction

The nucleon-nucleon (NN) weak interaction is the last sector of the weak interaction where the main aspects of the electroweak theory have not been verified. In the presence of the nuclear interaction, the weak NN interaction can be isolated via parity violation. The most comprehensive theoretical treatment to date to describe the weak NN interaction is given in a review by Desplanques, Donoghue, and Holstein (DDH) [1]. Their best guess value of the weak pion-nucleon coupling constant is $h_\pi^1 = 4.6 \times 10^{-7}$.

The determination of h_π^1 from experimental measurements in nuclei are discussed in Reference [2]. There are substantial uncertainties in interpreting most experiments in nuclei because one can not make reliable calculations of the amplitudes of the weak meson-nucleon exchange potential operators. This measurement is free from nuclear structure uncertainties and is a clean measurement of h_π^1.

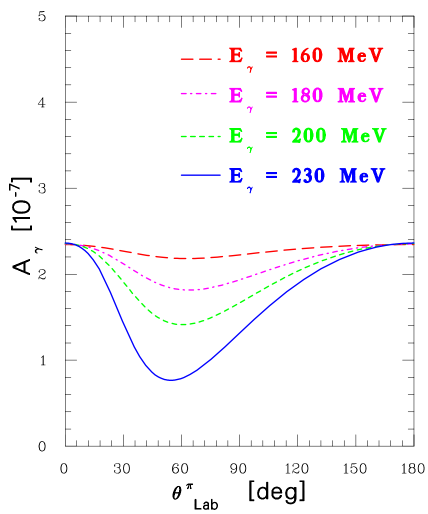

Figure 1. Asymmetry of the differential cross section for $\vec{\gamma}p \to n\pi^+$ as a function of the pion Lab angle ($h^1_\pi = 4.6 \times 10^{-7}$).

2 Pion Photoproduction at Threshold

The weak interaction induced parity-violating asymmetry in low energy pion photoproduction was calculated by Chen and Ji [3]. They found that the photon helicity asymmetry:

$$A_\gamma = \frac{d\sigma(\lambda_\gamma = +1) - d\sigma(\lambda_\gamma = -1)}{d\sigma(\lambda_\gamma = +1) + d\sigma(\lambda_\gamma = -1)} \quad (1)$$

at the first non-vanishing order (NLO) in heavy-baryon chiral perturbation theory (HBχPT) at threshold is:

$$A_\gamma(\vec{\gamma}p \to \pi^+ n)|_{\rm th} = \frac{\sqrt{2} f_\pi (\mu_p - \mu_n)}{g_A m_N} h^1_\pi \sim h^1_\pi/2 \quad (2)$$

where f_π is the pion decay constant and g_A is the neutron decay constant. There is an extended threshold region in which the effective theory description remains effective and, at the same time, the cross section is appreciable. This region is between 180 and 230 MeV in laboratory photon energy. The higher-order corrections are expected to be $\mathcal{O}(E_\gamma/M_N) \sim 20\%$.

Table 1. Experimental conditions for the proposed measurement.

Beam Energy	230 MeV
Beam Current	400 μA
Beam Polarization	80%
Radiator Thickness	3% $r.l.$ Cu (0.043 cm)
Photon Energy (E_γ)	230-180 MeV
f (N_γ/N_e)	0.006
Photon Polarization	75%
Target	80 cm LH_2
Luminosity ($\mathcal{L}$)	0.5×10^{38} cm^{-2} sec^{-1}
Average Cross Section $\frac{d\sigma}{d\Omega}(\gamma p \to n\pi^+)$	5×10^{-30} cm^2/sr
Solid Angle Acceptance	1.0 sr
Experimental Asymmetry (A)	$\mathbf{1.7 \times 10^{-7}}$

The asymmetry $A_\gamma(\theta^\pi)$ in the differential cross section for $\vec{\gamma}p \to n\pi^+$ as a function of the pion Lab angle is shown in Fig. 1. Note the strong dominance of the photon polarization asymmetry at forward and backward angles in the threshold region. Only at angles near 90° and $E_\gamma > 200$ MeV does the modification from high partial waves become significant.

3 Experimental Considerations

A polarized electron beam will be used to produce a circularly polarized photons by hitting a radiator. The electron beam will be deflected away through a chicane to a beam dump. The photon beam will be incident on a liquid hydrogen target. A toroidal magnet will bend the backward produced pions to a total absorption plastic scintillator detector. The expected counting rate is approximately 250 MHz. The detector will be out of direct view of the target and will operate in current mode.

The experimental conditions are listed in Table 1. 1000 hours of beam time are required for 20% statistical accuracy. A high quality electron beam will be used to produce the photon beam with no amplification of any of the helicity correlated differences in beam parameters (energy, angle, and position). The total systematic uncertainty is anticipated to be smaller than the statistical one.

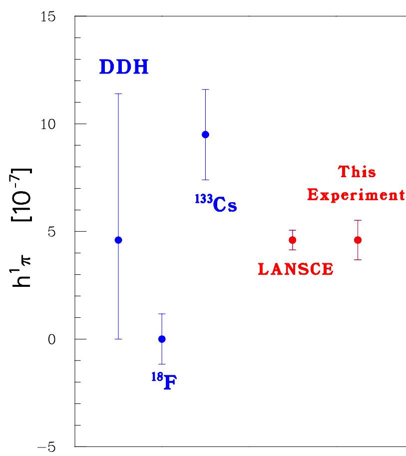

Figure 2. The projected error bar from this experiment compared to DDH theoretical estimate and other completed and planned experiments.

4 Summary

The weak pion-nucleon coupling constant will be measured in pion photoproduction to a high level of accuracy in a reasonable beam time. Fig. 2 shows values of h_π^1: (from left to right) DDH theoretical estimate, ^{18}F experiments [4], ^{133}Cs experiment [5], and expected statistical uncertainty from LANSCE experiment [6] (it will achieve this uncertainty in 9 months of data taking). The last value represents the expected statistical uncertainty from this experiment in 1.5 months of data taking.

References

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