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Measurement of PV asymmetry in $\vec{\mathrm{n}}+\mathrm{p} \to \mathrm{d}+\gamma$ and $\vec{\gamma}+\mathrm{d} \to \mathrm{n}+\mathrm{p}$*

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Abstract The measurement of parity-violating (PV) observables in few-nucleon system can shed light on our current understanding of the weak interaction between nucleons. Theoretical models describe the nucleon-nucleon weak interaction at low energies use a series of undetermined parameters. Two parity violating measurements have been considered: the capture of polarized slow neutrons on hydrogen ($\vec{\mathrm{n}}+\mathrm{p} \to \mathrm{d}+\gamma$) at Los Alamos National Laboratory for first phase and Oka Ridge National Laboratory for second phase and the helicity dependence of the deuteron photodisintegration cross section using circularly polarized photons ($\vec{\gamma}+\mathrm{d} \to \mathrm{n}+\mathrm{p}$) at Shanghai Institute of Applied Physics. The goal of both experiments is to constraint the weak meson-nucleon couplings to a precision of 1×10^{-8}. The introduction of both experiments is presented.

Key words parity violation, NPDGamma, GammaDNP, neutron-proton capture, deuteron photodisintegration, weak meson couplings

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1 Introduction

Despite over 40 years of study, the details of the weak interaction between nucleons are not understood. It is worthwhile understanding the character of weak interactions between nucleons for a number of reasons [1]. 1) NN weak interactions are in principle a new probe of strong QCD; 2) The NN weak interaction is also the only practical way to study quark-quark neutral currents at low energy; 3) Knowledge of weak NN couplings can allow for a quantitative interpretation of many PV phenomena in measurements at nuclear and atomic scales, including PV observable in shell model nuclei and the the contribution to PV in the ^{133}Cs atom arising from the nuclear anapole moment; 4) Theoretical advances in the description of PV in the NN and few nucleon systems promise to make better contact with QCD in the near future.

At present the reliable theoretical description of PV about the weak NN interaction are the work of Desplanques, Donoghue, and Holstein (DDH) [2] and the approach using effective field theory (EFT) [3]. There are series of parameters in both of these theoretical descriptions (h_π^1, $h_\rho^{0,1,2}$, $h_\omega^{0,1}$, and $h_\rho^{1'}$ in DDH, $m_\mathrm{N}\lambda_\mathrm{s}^{\mathrm{pp,np,nn}}$, $m_\mathrm{N}\lambda_\mathrm{t}$, $m_\mathrm{N}\rho_\mathrm{t}$ and C_6 in EFT) which need to determined by experimental results. In the experimental side, despite a great deal of effort on the weak NN interaction, the weak meson couplings in DDH or the parameters in EFT are still undetermined. Fig. 1 shows the current situation of the constraints on linear combinations of isoscalar and isovector nucleon-nucleon weak couplings [4]. There is not an agreement between these experimental results.

In this article we report two measurements: 1) a measurement of the parity-violating asymmetry A_γ in the reaction $\vec{\mathrm{n}}+\mathrm{p} \to \mathrm{d}+\gamma$ (NPDGAmma); 2) a

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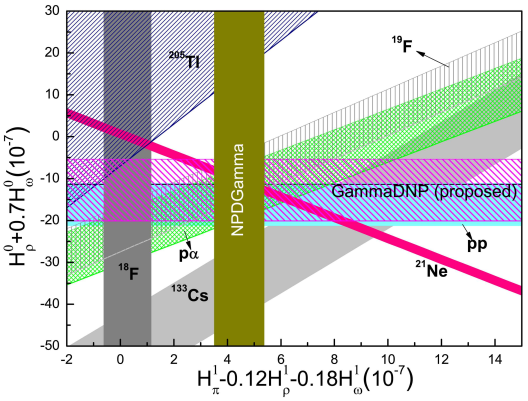

Fig. 1. constraints on linear combinations of isoscalar and isovector NN weak meson couplings. The “NPDGamma” and “GammaDNP” is the theoretical prediction for $\vec{n}+p\rightarrow d+\gamma$ and $\vec{\gamma}+d\rightarrow n+p$.

measurement of the parity-violating asymmetry $A_{\gamma d\rightarrow np}$ in the reaction $\vec{\gamma}+d\rightarrow n+p$ (GammaDNP). The NPDGamma has completed its first phase and being prepared while the GammaDNP just starts its design. The goal of both of these experiments is to reach sufficient precision to constrain NN weak couplings.

2 NPDGamma

The NPDGamma experiment proposes to measure A_γ in the capture of polarized neutrons on protons, which is performed at the Los Alamos Neutron Science Center (LANSCE) for the first phase and at the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory (ORNL) for the second. Fig. 2 shows a schematic of the flight path and experimental setup. More detailed description is shown in reference [5–11].

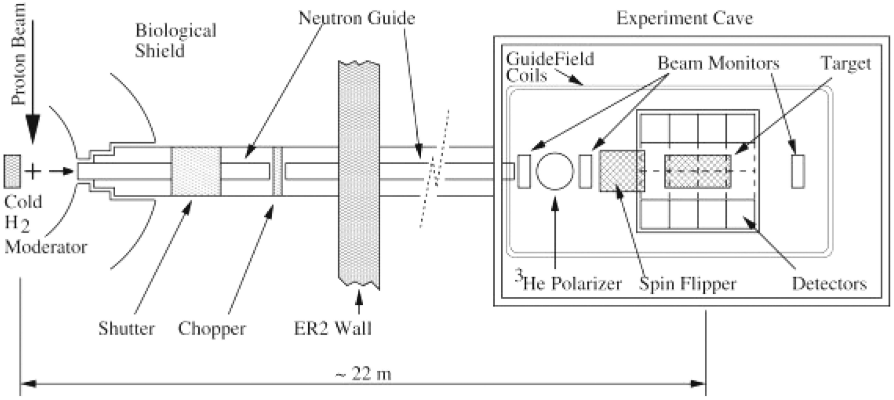

Fig. 2. Schematic of the $\vec{n}+p\rightarrow d+\gamma$ experimental setup.

The parity-violating asymmetry with respect to the neutron spin direction of γ-rays emitted in the reaction $\vec{n}+p\rightarrow d+\gamma$ is measured. The relation between the measured asymmetry and the DDH weak meson couplings is [12, 13]

$$A_\gamma=-0.1069h^1_\pi-0.0014h^1_\rho+0.0044h^1_\omega. \quad (1)$$

The first phase of the measurement was completed at the LANSCE. The preliminary results are [5]

$$\begin{aligned} A_{\gamma,\mathrm{UD}} &= (-1.2\pm2.1(\mathrm{stat.})\pm0.1(\mathrm{sys.}))\times10^{-7} \\ A_{\gamma,\mathrm{LR}} &= (-1.8\pm1.9(\mathrm{stat.})\pm0.1(\mathrm{sys.}))\times10^{-7}\ . \end{aligned}$$

The NPDGamma experiment is currently being installed on the fundamental neutron beam line (FNPB) at the SNS at Oak Ridge National Laboratory. The experiment is scheduled to resume data taking in 2010. It is expected to be able to obtain an accuracy of 1×10^{-8} in about 1 year of running.

3 GammaDNP

The GammaDNP experiment proposes to measure the asymmetry of the helicity dependence of the deuteron photodisintegration cross section using circularly polarized photons in $\vec{\gamma}+d\rightarrow n+p$. The apparatus, shown schematically in Fig. 3, consists Shanghai Laser Electron Gamma Source (SLEGS), followed by a collimator, and a liquid heavy water (D_2O) target, surrounded by graphite, ^{3}He/^{4}He gas ion chamber and gamma detector respectively, and with a ^{6}Li neutron target followed by a gamma detector. The SLEGS which is a high intensity γ-ray beamline based on Laser Compton Scattering (LCS) between relativistic electron bunches and a laser, has been proposed at the SSRF and will be constructed in the near future [14, 15]. The SLEGS is expected to generate a polarized γ-ray beam of up to 22 MeV and 10^{9-10} photons/s if using a 500 W CO_2 polarized laser and 3.5 GeV, 200–300 mA relativistic electrons in the storage ring of the SSRF. The polarization of γ-ray depends on the polarization of laser, so the switch of the polarization of γ-ray can be accomplished by changing the polarization of laser.

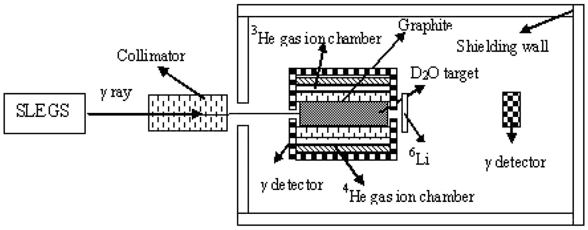

Fig. 3. Schematic of the $\vec{\gamma}+d\rightarrow n+p$ experimental setup.

After passing though the collimator, the γ-ray enters into a cylinder liquid heavy water target placed in the center of the detector array. The neutrons from the deuteron photodisintegration reaction will come out with an energy which is high enough that it may be difficult to detect. It is much easier to detect low energy neutrons. So graphite is employed as neutron moderator. The neutron detector needs to be very insensitive to γ-ray. A ^{3}He/^{4}He gas ion chamber operated in current mode is used. The gamma cross section on ^{3}He and ^{4}He is almost exactly the same, but ^{4}He does not absorb neutrons whereas ^{3}He is very large absorption. The γ detectors are used to detector the γ-ray scattered by D_2O target and the γ-ray passing though the target without reaction. The ^{6}Li target is used to absorb the neutrons from the target.

At energies just above threshold $\vec{\gamma}+d\rightarrow n+p$ is the time-reversed version of the circular polarization in unpolarized neutron capture on protons. At this γ energy, the interesting feature of this observable is that it is dominated by the isotensor term h_ρ^2 in the DDH picture, which is coming from the $\Delta=2$ component of the weak NN interaction, or the term $m_N\lambda_t$ in the EFT approach. No other two-nucleon observable is as sensitive to this component of the weak NN interaction. Therefore the parity-odd deuteron photodisintegration cross section asymmetry near threshold can give unique information on the weak NN interaction that is not provided by other 2-body experiments. The relation between the measured asymmetry and the DDH weak meson couplings at the energy of ∼2.2 MeV is [16]

$$A_{\gamma d\rightarrow np} = -(4.82g_\rho h_\rho^0 - 7.43g_\rho h_\rho^2 + 0.99g_\omega h_\omega^0)\times 10^{-3}. \qquad (2)$$

The $A_{\gamma d\rightarrow np}$ has a predicted size of 3.45×10^{-8} according to the reference [16]. The goal of $\vec{\gamma}+d\rightarrow n+p$ is to measure the asymmetry of reaction cross section to a precision of 1×10^{-8}. There is a strong possibility that a non-zero result will be seen and that the $\Delta I=0,2$ weak couplings will be constrained in a small region.

The challenge in GammaDNP experiment is to distinguish small PV asymmetry from the asymmetry signals. A source of systematic effects produces a signal in the detector that is coherent with the state of the gamma polarization. Systematic effects can be further classified according to whether they are instrumental in origin or arise from an interaction of the γ-ray other than the reaction cross section asymmetry in the $\vec{\gamma}+d\rightarrow n+p$ reaction. Finally, it is important to isolate, amplify, and study experimentally potential sources of systematic effects.

The most important experimental tool we have to isolate parity-violating signals in this experiment is the controller of laser polarization. It is therefore absolutely essential that the process of flipping the laser polarization have a negligible effect on all other properties of the apparatus. The systematic effects come from the detection system is also very essential. We need to diagnose the false asymmetry from electronic noise and detectors. We also preliminarily consider systematic effects arising from interactions of the circular polarized γ-ray (See Table 1.). In the next, we will calculate these systematic effects to make sure they are small enough compared to the statistical error.

Table 1. List of possible "false" asymmetry.varibles: gamma spin $\vec{S}_\gamma$, and the P refer to the momenta of the neutron, gamma and electron from the target.

Reaction	Invariant
$\vec{\gamma}+n\rightarrow\vec{\gamma}+n$	$\vec{S}_\gamma\cdot\vec{P}_n$ & $\vec{S}_\gamma\cdot\vec{P}'_\gamma$
$\vec{\gamma}+A\rightarrow(A-1)+n+\gamma$	$\vec{S}_\gamma\cdot\vec{P}_n$
$\vec{\gamma}+d\rightarrow\vec{\gamma}+d$	$\vec{S}_\gamma\cdot\vec{P}'_\gamma$
$\vec{\gamma}+O\rightarrow\vec{\gamma}+O$	$\vec{S}_\gamma\cdot\vec{P}'_\gamma$
$\vec{\gamma}+p\rightarrow\vec{\gamma}+p$	$\vec{S}_\gamma\cdot\vec{P}'_\gamma$
$\vec{\gamma}+e\rightarrow\vec{\gamma}+e$	$\vec{S}_\gamma\cdot\vec{P}'_\gamma$ & $\vec{S}_\gamma\cdot\vec{P}'_e$
$\vec{\gamma}\rightarrow e^++e^-$	$\vec{S}_\gamma\cdot\vec{P}'_e$

4 Conclusion

The NPDGamma experiment has completed its first phase at LANSCE and will start its second data taking in early 2010 at ORNL, by which the weak meson coupling h_{π}^{1} will be confirmed to a high precision. The GammaDNP experiment which is essential to determine the constant of h_{ρ}^{2} has been proposed at SINAP using the SLEGS that will be constructed at the SSRF in the near future.

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