High Intensity Gamma-Ray Source-II – Abstract for a Nuclear Physics Experiment

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**Proposal Title:**
A pilot-study for the $d(\gamma,n)p$ PV experiment

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A pilot-study for the $d(\tilde{\gamma},n)p$ PV experiment

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1. Summary

The range of weak interaction between hadrons is as short as $10^{-3}$ fm, which is far smaller than the size of nucleon. In this short distance, the hadronic weak interaction (HWI) is first-order sensitive to quark-quark correlations in nucleon and is therefore helpful to understand the mechanism of non-perturbative QCD dynamics phenomena such as color confinement and chiral symmetry breaking. The HWI can be described by DDH and EFT theory models in which a set of undetermined constants are employed respectively.

The high precision PV experiment on photodisintegration of deuteron by circularly polarized gamma photon $d(\tilde{\gamma},n)p$ is not only helpful to determine the DDH theory model’s weak coupling constant $H_1^{\alpha}(\text{DDH})$ which has become a hot spot but also the unique practical way to constrain the weak coupling constant $H_2^p(\text{DDH})$ or $m_N\lambda_t(\text{EFT})$.

As the very small size of the expected parity-odd asymmetry (~$10^{-8}$) in this reaction makes the experiment very demanding, it requires high flux and high circularly polarized gamma beam with high reversal frequencies in the energy range of 2.2-3 MeV. We propose to perform the $d(\tilde{\gamma},n)p$ PV experiment in HIGS2 in the near future. In this work, we try to do the pilot-study for the $d(\tilde{\gamma},n)p$ PV experiment systematically. We will present a report on the acquisition of the asymmetry observable $A$ of the $d(\tilde{\gamma},n)p$ PV experiment, and on the study of its systematic errors and false asymmetries, based on our simulation. The requirement and optimized conditions of carrying out the $d(\tilde{\gamma},n)p$ PV experiment based on LCS light source according to our simulation will also be talked. According to our results, in order to achieve the anticipate accuracy ($1\times10^{-8}$), some measurements are proposed before performing the $d(\tilde{\gamma},n)p$ PV experiment. And a brief introduction of our laser electron gamma source SLEGS proposed in Shanghai will be given as an additional content at last.
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2. Introduction

The hadronic weak interaction (HWI) is the weak interaction between two hadrons (including baryons and mesons) induced by the quark-quark weak interaction in the Standard Model. HWI can provide some special information on quark-quark correlations in hadrons at short distances because of the short range of HWI compared to the size of nucleon. The main reasons for the study of HWI are presented in [1-4], e.g. 1) along with the new phenomenon of double parton scattering recently observed at the LHC, HWI amplitudes are one of the few observables that are first-order sensitive to quark-quark correlations in the nucleon. It offers us a way to study the quark-quark correlations quantitatively and may eventually help us understand the mechanism of non-perturbative QCD dynamics phenomena such as color confinement and chiral symmetry breaking; 2) HWI is also the only practical way to study quark-quark neutral currents at low energy; 3) HWI amplitudes provide us a practical way to study the specific features of the nuclear many-body wave functions.

The photodisintegration reaction $d(\gamma, n) p$ with circularly polarized photons is one of a series of possible parity-violating (PV) experiments which can be used to study HWI[3]. The PV asymmetry in $d(\gamma, n) p$ can be directly related to the weak coupling constants in DDH[5] theory or the low energy constants (LEC) in EFT theory [6] and is one of the few remaining practical experiments in a two-nucleon system. It is dominated by either the isotensor term $H^2_\rho$ in the DDH[7,8], which comes from the $\Delta I=2$ component of the HWI, or the term $m_N\lambda_t$ in the EFT[9]. Thus the measurement on PV asymmetry of $d(\gamma, n) p$ is also a practical way to constrain $H^2_\rho$ or $m_N\lambda_t$. To our knowledge it is the only observable in a two-nucleon system which is both highly sensitive to the $\Delta I=2$ component of the HWI and also can be the subject of a practical experiment.

In 1988, the $d(\gamma, n) p$ PV experiment was performed at Chalk River Nuclear laboratories in Canada[10]. The achieved sensitivity of 1ppm is believed to be about two orders of magnitude away from the expected theoretical value of the asymmetry[7-9]. In this experiment, the circularly polarized gamma rays were generated by the bremsstrahlung of polarized electrons. Although the flux of polarized gammas from a source of this type can be very intense, the energy spectrum is rather broad and the rest of the phase space of the photon beam is also rather large, which is not ideal from the experimental point of view.

A Laser Compton Scattering (LCS) gamma source generates gamma rays by the Compton scattering of laser photons with a relativistic electron bunch. The features of LCS gamma ray beams include high
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intensity, quasi-monochromaticity, stability and energy tunability. Therefore, the LCS gamma source is one of the most promising candidate light sources that could be applied to perform the $d(\gamma, n)p$ PV measurement. Since the proposed upgraded HIGS2 will probably be the most high intensity gamma source, we proposed to carry on the experiment using the HIGS2 in the future.

As the very small size of the expected parity-odd asymmetry in this reaction makes the experiment very demanding, it is essential to study the PV experiment before the measurement. In our work, we have simulated the high precision PV experiment of $d(\gamma, n)p$ based on the LCS gamma source conduct a pilot study. We have given the best optimization of the $d(\gamma, n)p$ PV experiment. According to this work, we find the requirement of the gamma beam flux is at least $10^{10}$/s in the energy of 2.2~3MeV. In order to eliminate the time-dependent systematic effects, the helicity of the photons must be reversible at high frequencies (1-100Hz). The requirements of LCS gamma source used for the $d(\gamma, n)p$ PV experiment can be expressed as an equation:

$$Q_e \cdot N_{eb} \cdot f \cdot P \cdot T \cdot \varepsilon^2 \approx 1.05 \times 10^8$$  \hspace{1cm} (1)

where $Q_e$ is the charge quantity of electron bunch in unit of nC, $N_{eb}$ is the number of electron bunch, $f$ is the laser and electron collision repetition rate in unit of MHz, $P$ is the laser power in unit of W and $T$ is the data acquire time length in units of years. Under current conditions, we give a set of practical values for those parameters: $Q_e=1\text{nC}$, $N_{eb}=750$, $f=2.8\text{MHz}$, $P=10^5\text{W}$, $T=2\text{ years}$, $\varepsilon=50\%$.

Since the asymmetry observable $A$ in $d(\gamma, n)p$ PV experiment is tiny ($\sim 10^{-8}$), it is very necessary to consider all kinds of systematic errors and false asymmetry that may be mixed into the true signals in the measurement. We have also analyzed the systematic errors and false asymmetries in this experiment. We find some of them need to be considered carefully. Therefore we propose some extra measurements before the $d(\gamma, n)p$ PV experiment.

At first, we should measure the cross section of deuteron photodisintegration at the optimized energy range to estimate the running time.

Secondly, the differential cross section of deuteron photodisintegration is very sensitive to the linear polarization of gamma. If the efficiency of detectors in $d(\gamma, n)p$ PV experiment is non-uniform, then false asymmetry will produce. We must make sure the linear polarization is
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very small and unchanged when the helicity of gamma is reversed. The efficiency of detectors should also be tested.

Thirdly, the stability of gamma Flux, energy is also need to test when the helicity of gamma is reversed.

3. Experiment Description

Fig. 1 shows the conceptual layout of the proposed experiment. The detailed function of each device is introduced in table 1.

![Diagram of the experimental setup](image)

Table 1. The functions of devices in Fig. 1.

<table>
<thead>
<tr>
<th>Device</th>
<th>Functions</th>
</tr>
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<tbody>
<tr>
<td>LCS</td>
<td>to supply the required circularly polarized photon beam.</td>
</tr>
<tr>
<td>Collimator (lead)</td>
<td>to quasi-monochromatize the photon beam.</td>
</tr>
<tr>
<td>D2O target</td>
<td>deuteron target material.</td>
</tr>
<tr>
<td>Graphite</td>
<td>to moderate neutrons so for detection.</td>
</tr>
<tr>
<td>³He/⁴He ion chamber</td>
<td>to serve as neutron detectors, using the great difference between the neutron absorption cross sections of ³He and ⁴He which the gamma absorption cross sections of ³He and ⁴He are almost identical.</td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th>$\gamma$ detector (CsI)</th>
<th>to detect the photons which are not absorbed in the target.</th>
</tr>
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<tbody>
<tr>
<td>$^6$Li plate</td>
<td>to absorb the neutrons that escape from the D$_2$O target and protect the gamma detector downstream.</td>
</tr>
</tbody>
</table>

The anticipated measurement precision of $A$ is at least higher than $1 \times 10^{-8}$ and therefore a huge number of gamma ray events ($\sim 10^{16}$) is required. About $5 \times 10^{17}$ photons are needed on target to achieve this statistical accuracy assuming a cross section of 1 mbarn at $E_\gamma=2.5-2.6$ MeV and a D$_2$O target of length $L=50$cm (number density of deuterons $n_D=6.4 \times 10^{22}$/cm$^3$) and a $4\pi$ solid angle detector with efficiency of 0.5. Therefore, with a total flux of $5 \times 10^{10}$ $\gamma$/s and the flux of $2.5 \times 10^8$ on target, about 64 years of running are required to achieve the statistical accuracy. In order to perform this experiment practically, the flux on target is at least higher than $1 \times 10^{10}$ $\gamma$/s which means about 580 days running are required.

References