Precision Measurement of Parity Violation in Polarized Cold Neutron Capture on the Proton: the NPDγ Experiment


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Abstract. The NPDγ experiment1 at the Los Alamos Neutron Science Center (LANSCE) is dedicated to measure with high precision the parity violating asymmetry in the γ emission after capture of spin polarized cold neutrons in para-hydrogen. The measurement will determine unambiguously the weak pion-nucleon-nucleon (πNN) coupling constant fπ.

The high precision testing of the Standard Model in leptonic weak interactions is in striking contrast to measurements in hadronic systems. There, weak effects are typically 7 orders of magnitude smaller than the dominant strong interaction, and observables

1http://p23.lanl.gov/len/npdg/
are accessible through parity violating (pv) phenomena. Precise experiments that allow a clean analysis in terms of fundamental physics parameters are missing. Even the “cleanest” results are inconsistent (Fig.1b, [1]) and either complicated by nuclear model dependence or experimental difficulties. Given the precise understanding of electroweak physics at higher momentum, measurements of parity violation (PV) in nucleon-nucleon (NN) interactions provide a tool for testing the nucleon structure, quark-quark interactions and chiral symmetry breaking in the non-perturbative regime.

FIGURE 1. a) Sketch of the polarized neutron capture process on the proton. b) Present knowledge of the weak pion-nucleon coupling $f_1^\pi$. A previous n+p→d+γ measurement gives only an upper limit. Values extracted from the anapole moment measurement in $^{133}$Cs and the circular photon polarization in $^{18}$F are contradictory although nuclear effects are thought to be well understood in these systems [1]. Precision goals for this experiment are also indicated. Specific model calculations using effective field theory approaches yield results within the reasonable range of the DDH approach [2].

Desplanques, Donoghue and Holstein (DDH) developed two decades ago the ever since standard description of low-energy pv effects in NN systems by parameterization in terms of seven independent meson exchange couplings. Meson exchange currents are assumed to be the appropriate description for the low-energy NN interactions, as the typical interaction length of 1.5 fm is much larger than the range of the heavy Z and W weak exchange bosons between pointlike leptons. However, uncertainties in the strong interactions permit DDH to calculate only a broad “reasonable range” for the coupling constants. Most important, $f_1^\pi$ describes the long-range part of the NN potential with a unique sensitivity to neutral currents. Most experimentally observable processes determine a combination of different couplings, but the measurement of the pv (up-down) γ-asymmetry $A_{np}^{\gamma}$ in polarized neutron capture on the proton (Fig.1) is unique, as it allows a clean determination of $f_1^\pi$ on the few percent level without nuclear model dependence. Only recently work has started on a systematic description of hadronic PV within the framework of a low-energy effective field theory, which would finally connect the meson-exchange picture to the basic principles of QCD [3].

The NPDγ experiment sets out to measure for the first time a value of $A_{np}^{\gamma}$ with a final precision goal of $\sim 20\%$ of the DDH “best estimate” value [2]. This requires a perfect interplay of many components of the experimental apparatus (Fig.2):

- a pulsed intense cold neutron beam delivered at LANSCE (and in the future at the SNS FNPB beamline), which defines a neutron time-of-flight, and a frame definition chopper installed in flight path 12 (FP12);
The NPDγ setup in FP12 at LANSCE: a) Neutron guide, $^3$He polarizer (POL), spin flipper (SF) and CsI detector array surrounded by the guide coils in FP12. b) The liquid hydrogen target cryostat with the barrel-shaped target section. c) Result for the pv asymmetry measurement in chlorine used as calibration, as $A_C^{\gamma}$ is 4 orders of magnitude larger than $A^\gamma_{np}$.

- a $^3$He optically-polarized neutron spin filter which selects neutrons based on the strong spin dependence of the cross section for the absorption of neutrons by $^3$He;
- a resonant RF spin-flipper to reverse the neutron spin within a broad range of neutron energies. Using a specific 8-step neutron spin sequence – $\uparrow\downarrow\uparrow\uparrow\downarrow\uparrow\uparrow\uparrow$ – in our measurements minimizes certain systematic effects;
- a 16 liter liquid para-hydrogen cryo-target. In the energy range up to 15 meV the neutron scattering cross-section in para-hydrogen is of the order of the neutron capture cross-section, in ortho-hydrogen it is 2 orders of magnitude larger. Hence, at the time of neutron capture all spin information is lost. A para-hydrogen target is therefore indispensable.
- an efficient CsI $\gamma$-detector array with 48 individual counters using magnetic field insensitive vacuum photo-diodes, operating in current mode at counting statistics, and read out by low-noise amplifiers;
- a spin-polarized $^3$He neutron spin analyzer after the hydrogen target;
- a homogeneous 10 Gauss guide field with field gradient $\leq$ 1 mGauss/cm surrounding the setup to prevent Stern-Gerlach steering of neutrons;
- neutron beam monitors to measure the beam flux and polarization;
- a well-shielded experimental cave to reduce environmental noise and stray fields.

The NPDγ experiment has proven its capabilities by observation of small pv asymmetries in setup materials for systematic studies and by demonstrating negligible detector noise levels. We have also performed physics studies of PV in medium heavy nuclei (e.g. Fig 2c). NPDγ will be ready to take hydrogen production data in early 2006.

REFERENCES