

Detector Development for an Experiment to Measure the Parity Violating Proton Asymmetry in the Capture of Polarized Cold Neutrons on ^3He .

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Executive Summary

We request 28 days of beamtime on FP12 for prototype development of a target-detector wire chamber designed to measure the parity violating (PV) asymmetry A_p in the reaction $\bar{n} + {}^3\text{He} \rightarrow \text{p} + {}^3\text{T} + 765 \text{ keV}$. The asymmetry A_p is directly related to the weak nucleon-nucleon interaction and will be used to quantify effective degrees of freedom used to model this interaction. Aside from the prototype chamber being constructed at the University of Kentucky, the equipment for this development is the same as for the neutron precision polarimetry experiment on FP12, especially the data acquisition system, which imposes a necessity of using this flight path. The main goal is characterize the signal, noise, background sensitivity, and operating parameters of the wire chamber, to determine the final statistical sensitivity of the detector. This can be done with polarized or unpolarized neutrons. Finally, we will measure the an asymmetry to the level required to verify that certain systematical uncertainties are under control, if polarized neutrons are available.

1 Introduction

The hadronic weak interaction (HWI) lies at the intersection of the fundamental electroweak interaction and complex hadronic structure. Although the weak interaction is well understood in the standard model, the HWI is obscured by the QCD structure of the nucleon. This makes the HWI a natural probe of hadronic structure and a good test of lattice QCD calculations as they become available. Although it is $\sim 10^{-7}$ times smaller than its strong counterpart, the HWI can be detected through parity violation (PV), a unique signature of the weak interaction. In the absence of direct QCD calculations, the HWI has been modeled by the isospin-dependent couplings of the DDH meson exchange model [1] ($h_\pi^1, h_\rho^{0,1,2}, h_\omega^{0,1}$), which must be determined by experiment. The HWI can also be characterized by more general low energy effective field theoretic couplings [2]: the Danilov parameters [3] ($\lambda_t, \lambda_s^{0,1,2}, \rho_t$) describing the parity odd mixing of partial waves, plus a long-range parameter $\tilde{C}_6^\pi$ corresponding to h_π^1 in the DDH model. Thus a series of at least 6 independent observables is needed to extract the couplings in either model, and further measurements can be used to test the validity of these models. Based on the DDH model, Adelberger and Haxton [4] outline several possible experiments, some of which are in progress while others are being proposed. It is preferable to characterize the HWI in few body systems, uncomplicated by nuclear structure effects.

This proposal is for detector development of a new experiment to measure the PV proton asymmetry A_p in the reaction $\bar{n} + {}^3\text{He} \rightarrow \text{p} + {}^3\text{T} + 765 \text{ keV}$. This reaction is sensitive to the EFT coupling $\lambda_s^{I=0}$, or the $\Delta I=0$ couplings h_ρ^0 and ω_ρ^0 within the DDH framework. A_p is the parity-odd correlation between the neutron spin σ_n and momentum of the proton k_p . It is measured by observing a change in the ionization track of the protons as the neutron

spin is reversed. The experiment is relatively simple, straight forward to implement, and effective. With the exception of a combined target-detector ion chamber, it will use the standard equipment used by the NPDGamma experiment, which took data at FP12 in 2006.

This experiment has been approved to run at the SNS FnPB [5]. However, further development is needed before the full experiment can run. A prototype ^3He target-detector wire chamber must be characterised in terms of the signal, noise, background sensitivity, and operating parameters of the chamber. Systematic uncertainties must be shown to be under control. The rest of this proposal will focus on details pertinent to the test run proposed at the LANSCE FP12. We propose to do this detector development at LANSCE because of the intense neutron flux which makes a full characterization of the chamber possible in a reasonable amount of time, and also because of the time-of-flight beam structure, which allows characterization of the detector as a function of neutron energy.

2 Experimental Setup

The three components of the n- ^3He experiment are a polarized neutron beam with fast spin flipping, an unpolarized ^3He target, and a wire chamber. The first component requires the same setup being used by precision polarimetry program, also proposed for this run cycle. It consists of an optically pumped ^3He spin filter, ^3He ionization chambers to measure the neutron polarization, a spin flipper, and a holding field coil. We propose to run after the precision polarimetry experiment, and use the same setup.

The remaining two components can be efficiently combined into a single target-detector wire chamber. The operating principle of this target-detector is identical to that of the parallel plate ion chambers used in the NPDGamma experiment [6]. The neutron reacts ^3He nuclei in the chamber producing a proton and triton, which then ionize other ^3He atoms, producing an ionization current.

A prototype chamber is being designed and machined at the University of Kentucky. The 20 cm $\times$ 20 cm $\times$ 20 cm chamber will be vacuum-tight for evacuation before filling with ^3He gas. The dimensions were chosen based on the mean free path of protons in ^3He at STP, about 5 cm, from Fig. 1. The chamber extends 5 cm to each side of the neutron beam. It will have a grid of 6 $\times$ 7 sense wires at ground potential insulated from the chamber by vacuum feedthroughs. Field wires operating between 1–3 kV are interspersed as shown in Fig. 2, with a single HV feedthrough outside the chamber. The chamber and wires are aluminum with a Delrin insulator support structure. The whole wire support structure is fastened to the top plate of the chamber, which can be removed from the sides/bottom piece of the chamber for repair or modification. The chamber is filled to ambient atmospheric pressure with ^3He and a small amount of quench gas (N_2), if necessary, to prevent sparking.

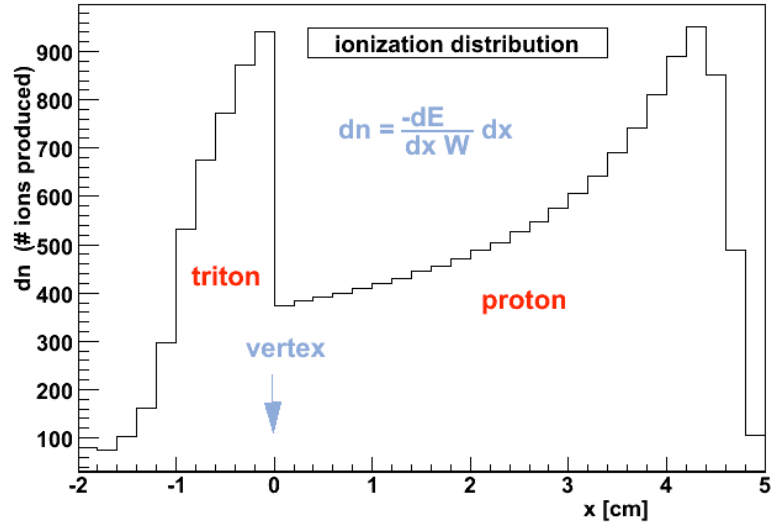


Figure 1: Ionization distribution for a back-to-back proton and triton in 1 atm ^3He .

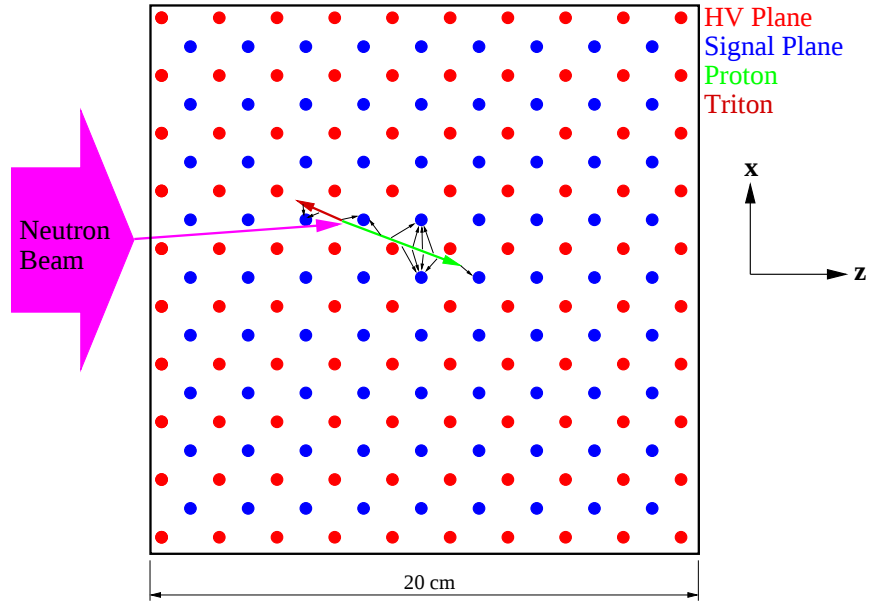


Figure 2: Schematic of the layout of HV and sense wires in the chamber. The prototype chamber will only have 42 sense wires.

Each sense wire will be fed to a preamplifier, being constructed at the University of Manitoba/TRIUMF, and to a 16 bit ADC sampling at 2.5 kHz using a similar system to the one reading out the NPDGamma CsI detectors. With separate readouts on each wire, asymmetries in two dimensions can be measured simultaneously, and the chamber can be tilted to measure the asymmetry in the third dimension.

3 Detector Tests

Two independent simulations of the detectors were performed, one using Geant4, and the second [7] a stand alone code including optimization of the neutron wavelength and the effects of correlations between wire planes. The neutron spectrum was based on a McStas simulation [8, 9]. Both codes agree in the limit of no correlation. The simulations determined:

- the ionization response in each wire plane
- the sensitivity to the asymmetry in each wire plane
- the statistical error and correlations of the signals in each wire plane
- the requirements in digitizing the output signal
- the effective statistics of the helicity asymmetry and
- the feasibility of measuring a detector asymmetry to cancel beam fluctuations

We will run various tests of the detector in beam to test our simulation model. In particular, we will investigate:

- the signal size, and signal to noise ratio
- the statistical fluctuations of each wire signal as a function of neutron flux
- potential problems with noise, sparking, cross-talk in the neutron beam
- the sensitivity to background gamma radiation
- the dependence on the high voltage
- the dependence on the gas mixture
- the dependence on the gas pressure
- the attenuation length of neutrons
- if the DAQ setup is adequate for this detector

All of these effects can be measured with an unpolarized neutron beam, and will be compared with our simulations and used to tune our model for design of the optimum target-wire chamber for the final experiment.

4 Asymmetry Estimates

The proton asymmetry $A_p \approx 3 \times 10^{-7}$ can be estimated from weak mixing of the 20.21 MeV (0^+ , $I = 0$) resonance with the closest (0^- , $I = 0$) resonance at 21.01 MeV as detailed in the full proposal [5].

The experimental asymmetry will be measured separately on each wire by alternating the neutron spin on a pulse-by-pulse basis. The difference in mean free paths of the proton and triton enables the extraction of a proton asymmetry from each wire. The sensitivity of each wire to the proton asymmetry was determined by Monte Carlo simulation.

The total statistical uncertainty the measurement of A_p is

$$\delta A_{phy} = \sqrt{\frac{\sigma_D^2 + \sigma_{coll}^2}{P_n^2 N}}, \quad (1)$$

where σ_{coll} is the sum in quadrature of noise sources such as electronics, charge collection in the chamber, and beam, and σ_D is the intrinsic detector efficiency involving the wire geometry and resolving power of proton and triton tracks.

For longitudinal neutron polarization in the configuration proposed at the FnPB, $\sigma_D \approx 6$, and the experiment will have a statistical sensitivity of $\delta A_{phy} \approx 2 \times 10^{-8}$ in a 10^7 s run. For a one week run at LANSCE, the statistical sensitivity would only be 1.1×10^{-6} , significantly greater than the expected physics asymmetry. However, the goal of the run at LANSCE is not to measure the asymmetry, but the statistical uncertainty in the asymmetry in each wire of the detector normalized by the incident neutron flux. We will also measure the correlation between the asymmetries on individual wires. This is used to test the simulations which determine the overall sensitivity σ_D of the target-detector to A_{phy} , and come up with a realistic design for the final target-detector. Again we note that the sensitivity σ_D can be inferred without polarized neutrons, by correlating signals instead of asymmetries in each wire vs. neutron current.

5 Systematic Effects

In addition to instrumental false asymmetries and background, there are a number of physical processes indistinguishable from A_p . Each is manifest as a Cartesian invariant involving the spin of the neutron. Some possible sources of false asymmetry detailed in the full proposal [5] are the parity even combinations

- $\vec{\sigma}_n \cdot (\vec{k}_n \times \vec{k}_p)$ (transverse asymmetry),
- $\vec{\sigma}_n \cdot (\vec{E} \times \vec{v}_n)$ (Mott-Schwinger scattering), and

- $\vec{\sigma}_n \cdot \vec{B}$ (Stern-Gerlach steering).

of these effects are second order for longitudinal polarized neutrons. The first two have a small contribution from misalignment of neutron spin and momentum. The Stern Gerlach effect changes the velocity of longitudinal neutrons and only depends on the difference in B-field between the spin flipper and target chamber.

For transversely polarized neutrons the first two effects are much larger and produce left-right asymmetries, which can mix with the PV up-down asymmetry. The first effect, arising from the strong capture asymmetry $\vec{n} + {}^3\text{He} \rightarrow \text{p} + \text{t}$, can be well-approximated by an expression like

$$A_y(90^\circ) = -(1.7 \pm 0.3) \times 10^{-5} \sqrt{E/\text{eV}} \approx -(1.7 \pm 0.3) \times 10^{-6} \quad (2)$$

for 10 meV neutrons [10]. For a polarization of 50%, and a detector asymmetry efficiency of 15%, this yields an experimental asymmetry of $A_{exp} \approx -1.5 \times 10^{-7}$, comparable with the statistical sensitivity from running for a week at LANSCE with a neutron flux of 10^8 n/s: $\delta A \approx 0.9 \times 10^{-7}$. The Mott-Schwinger asymmetry is an order of magnitude smaller, $A = 6 \times 10^{-8}$ [11]. The experiment would most likely not be sensitive to either LR asymmetry. But by measuring these false asymmetries to this level, we can measure an upper bound on the LR asymmetries sufficient to show that these false asymmetries will be negligible when running with longitudinally polarized neutrons. This part of the program would require polarized neutrons from the precision polarimetry setup.

6 Beamtime Request

We request 28 days of beam time in order to do the detector development tests described above, and to measure the parity allowed LR asymmetry with transversely polarized neutrons. The same data from the asymmetry measurement will be used to characterize the performance of the prototype wire chamber, optimize the final design, and determine the final sensitivity to the PV proton asymmetry at the SNS. We require two weeks to set up the detectors, electronics, and data acquisition, which can be done in parallel with the precision polarimetry or NDTGamma Compton polarimetry experiments. Most of the experiment setup will be ready from the precision polarimetry experiment, and the rest can be staged and tested outside the cave. The majority of this measurement program can be carried out even in the absence of a neutron polarizer, but if polarized neutrons are available, we can constrain LR false asymmetries to the level required for sensitivity to the parity-violating A_p .

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