TITLE: A HIGH-RATE DETECTION SYSTEM TO STUDY PARITY VIOLATION WITH POLARIZED EPITHERMAL NEUTRONS AT LANSCE

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A high-rate detection system to study parity violation with polarized epithermal neutrons at LANSCE

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We describe an apparatus for studies of parity violation in neutron-nucleus scattering. This experiment requires longitudinally polarized neutrons from the Los Alamos Neutron Scattering Center over the energy range from 1 to 1000 eV, the ability to reverse the neutron spin without otherwise affecting the apparatus, the ability to detect neutrons at rates up to 500 MHz, and an appropriate data acquisition system. We will discuss the neutron polarizer, fast neutron spin reverser, detector for transmitted neutrons, and high rate data acquisition system.

INTRODUCTION

The study of fundamental symmetries, parity and time-reversal violation, has found a very productive and instructive laboratory with polarized epithermal neutrons in the compound nuclear (CN) system. In work being performed at the Los Alamos Neutron Scattering Center (LANSCE), the TRIPLE collaboration has been using 1 – 1000 eV neutrons to conduct studies of parity violation in compound nuclear states.¹ We have been searching for parity non-conserving (PNC) longitudinal asymmetries in the scattering of polarized neutrons from nuclei (^{238}U , ^{232}Th , ^{115}In , $^{107+109}\text{Ag}$, ^{113}Cd , ^{139}La). Mixing of highly excited states in the CN results in large enhancements in PNC effects which are of the order 10^{-3} – 10^{-1} . In this presentation we will discuss the experimental setup, including the neutron polarizer, neutron spin reversal system, neutron detector, and the data acquisition system. The resulting system has the capability of counting at a rate of 500 MHz with high neutron detection efficiency.

NEUTRON POLARIZATION

The neutron beam is longitudinally polarized with a cryogenic neutron spin filter, employing cryogenic solid ammonia (NH_3), located about 6 m from the source of the moderated neutrons. The paramagnetic polarizing centers in the filter material were introduced by irradiation in an electron beam. The proton polarization of about 85% in the NH_3 is achieved with the microwave dynamic nuclear polarization process. The NH_3 filter is cooled to 1 K in a pumped ^4He bath. The filter (80 mm diameter by 13 mm thick) sits in the gap of a split-coil superconducting solenoid, which provides the spin-aligning magnetic field of 5 T. The field is homogenous to 1×10^{-4} over the filter volume. Radio-frequency power at 140 GHz provides the dynamic excitation. The proton polarization direction was changed every few days to reduce systematic errors; this is a slow method of reversing the neutron spin.

A necessary requirement of the studies of parity violating effects in compound nuclei is to be able to quickly change the direction of the neutron spins produced in the polarizer discussed above. The two desired states are parallel and antiparallel to the neutron momentum. We accomplish the fast reversal of the neutron spin by passing the neutron beam through a spatially varying system of magnetic fields in a "spin flipper,"² located immediately downstream of the neutron polarizer. This device consists of two longitudinal solenoidal coils and a pair of transverse Helmholtz coils. The solenoids are designed to produce a longitudinal field that reverses sign at the midpoint. The Helmholtz coils produce a transverse magnetic field which may be turned on or off with reversible field direction. When the transverse field coils are off, the total field is produced by the longitudinal coils; a neutron entering the spin flipper with its spin parallel to the field direction will experience no torque and exit the spin flipper with its spin direction unchanged in space but reversed relative to the longitudinal field. When the transverse coils are on, the neutron spin adiabatically follows the magnetic field, which rotates by 180 degrees as the neutron passes through the spin flipper. The neutron reverses its spin direction in space, but its direction relative to the field is unchanged. The spin flipper is used to reduce statistical and systematic errors. The neutron bursts from the pulsed source come at a frequency of 20 Hz. The spin flipper state is changed between reversing (R) and non-reversing (N) every 200 pulses in the eight-step sequence R,N,N,R,N,R,R,N. This sequence eliminates the effects of drift up to third order in time. By changing the direction of the current in the transverse coils the sequence becomes 0,+,-,0,+,0,0,-. On average, the current in the transverse coils in the two states is zero, which eliminates the effects on the detectors of stray magnetic fields from these coils. Neutron beam polarization is calculated by measuring the well-known PNC effects of the 0.734-eV p-wave resonance in ^{139}La .³ The typical neutron polarization was 70%.

NEUTRON DETECTION

The neutron detector,⁴ shown schematically in Figure 1, consists of an aluminum cylinder about 48 cm in diameter and about 12 cm in depth that encloses a 43 cm diameter by 5 cm deep cell which contains a hydrocarbon-based liquid scintillator (mineral oil) which contains 8% of ^{10}B by weight.⁵ The scintillator volume is partitioned into a hexagonal-close-packed pattern by an aluminum insert. This arrangement allows for 55 Amperex XP2262B photomultiplier tubes to view the individual cells through a glass window.

Neutrons are captured by the reaction $n + ^{10}\text{B} \rightarrow ^7\text{Li} + ^4\text{He} + 2.79 \text{ MeV}$. The $n-^{10}\text{B}$ capture cross section is inversely proportional to the neutron velocity, thus for high-energy neutrons the hydrogen in the mineral oil also plays an important role. The neutrons are first slowed down by elastic scattering off of the hydrogen; as the neutron energy decreases, the probability of a neutron-boron capture increases. In our case, the $n-p$ scattering mean-free-path is about 1 cm and is constant for neutron energies between about 1 eV and 50 keV. After two or three $n-p$ collisions, the neutrons lose their initial direction and begin to "random-walk" in the scintillator at a depth of about twice the mean-free-path. The neutron continues to lose energy in this scattering process, and is eventually captured by boron. We have measured this process to be at least 90% efficient for the neutron energies of interest by comparing this detector to a ^6Li -glass scintillation detector of known efficiency. The multiple scatterings that typically occur before the neutron slows down take time, however, leading to a "thermalization" time that also can be compared with other neutron detectors.

DATA ACQUISITION

The typical counting rate in each of the photomultiplier tubes is 10 MHz, giving a total rate for the whole detector in excess of 500 MHz. The data acquisition system that processes the signals from the detector is a hybrid system operating in a digital-analog

mode,⁶ as is shown schematically in Figure 2. The signals from each photomultiplier are standardized by a discriminator set above the single photo-electron noise and sent to the main electronics setup located about 150 m away. There the signals are reshaped in discriminators and combined in an analog summing module to yield the total "current." This analog signal is processed by a transient digitizer which samples the data with a selectable dwell time and accumulates the data in an 8192-channel memory. The full width of the shaped signals is the same as the dwell time; each neutron event is registered in one and only one time channel. The memory module is read out after each 10-second spin reversal interval and accumulated by our data acquisition computer for storage and later analysis. The transient digitizer features a subtract as well as an add mode; we exploit this by retriggering it in the subtract mode a multiple of $1/60$ s after the main trigger to eliminate noise generated by 60-Hz pickup originating in the AC power grid. This data acquisition system has the advantages of: insensitivity to pickup, as information is transmitted in the form of digital signals; low cost, as the linear summation of the 55 signals results in the need for only one digitizer and memory; and low dead time, which is that of a single detector counting at 10 MHz.

CONCLUSIONS

The scattering of epithermal neutrons from compound nuclei can result in very high instantaneous counting rates when pulsed spallation neutron sources are used. We have developed a system consisting of a neutron polarizer, a fast neutron spin reverser, a highly-segmented neutron detector, and a hybrid digital-current mode data acquisition system that together are capable of acquiring data at rates up to 500 MHz. We have found this system to be extremely useful in the study of parity nonconservation in compound nuclei, with the ability to detect many parity non-conserving resonances in a single target.

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FIGURE CAPTIONS

Figure 1. The neutron detector, showing the partitioning of the volume containing the ^{10}B -loaded liquid scintillator. Each cell of the partitioned volume is viewed by an Amperex XP2262B photomultiplier tube.

Figure 2. A schematic drawing of the signal processing system. The discriminated signals from each photomultiplier tube are summed in the analog summing module. The summed result is processed by a transient digitizer when triggered by a neutron pulse.

Figure 1.

Figure 2.