WEAK INTERACTIONS

A STUDY OF SINGLE–PARTICLE PARITY–NONCONSERVING NUCLEAR MATRIX ELEMENTS

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An IUCF-LANL collaboration has been formed to measure the weak mixing between single-particle states in ^{207}Pb. The experiment is motivated by recent measurements at the Los Alamos Neutron Scattering Center by the TRIPLE collaboration. The TRIPLE collaboration has measured the helicity dependence of low-energy (1–400 eV) neutron-nucleus scattering from ^{238}U, ^{232}Th, and other isotopes.[1,2] An observed helicity dependence of the transmission cross section constitutes a parity non-conserving (PNC) effect. One surprising result from these measurements is that the signs of the asymmetries are predominantly positive, in contrast to expectations (based on compound nuclear models) that they be evenly distributed about zero. Several recent theoretical calculations[3–8] require single-particle PNC matrix elements of 50–100 eV or more to explain the experimental observables. One can conclude from these results that either the PNC strength is 10–100 times larger than that predicted by meson exchange models, or that the nucleon-nucleus reaction mechanism underlying the theoretical calculations is not well understood.

In order to help resolve the dilemma presented by the polarized neutron data, we have recently begun a measurement of parity–nonconserving matrix elements for single-particle transitions in ^{207}Pb. The experiment consists of measuring the circular polarization of the 1.063-MeV gamma rays emitted from the decay of ^{207}Bi down through states of ^{207}Pb. The circular polarization of the gamma rays, which is proportional to the single-particle PNC matrix element, is a consequence of transitions between parity-mixed states of ^{207}Pb.

The experimental setup consists of two magnetized iron-cobalt polarimeters whose polarity can be changed by reversing the direction of the applied current (see Fig. 1). Gamma rays transmitted through the polarimeters are detected with intrinsic CsI crystals read out with photomultiplier tubes. The central components of the data acquisition electronics are a 30-MHz transient digitizer and a 10-MHz CAMAC histogramming memory unit. A communications module (called the routing box), designed and built at IUCF, will transfer data between the two units. We expect that the electronics system will be capable of a data acquisition rate of 1 MHz with less than 15% overall deadtime.

The interpretation of the IUCF experimental data will be relatively simple. First, since it is a study of radioactive decay, there is no scattering phenomenology applied to the observables to extract the quantities of interest. As a result, we are free from nucleon-nucleus interaction uncertainties, which are inherent in scattering experiments. Second,

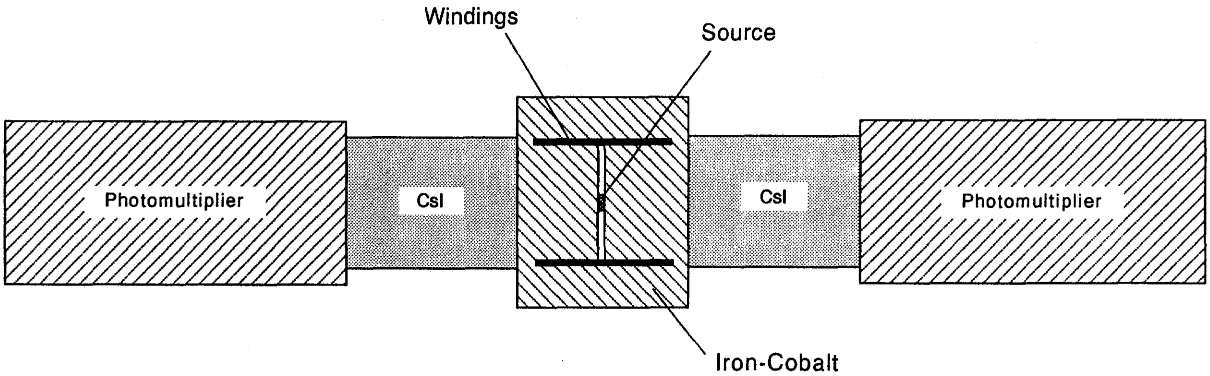

Figure 1. Layout of the apparatus for the first-phase ^{207}Pb parity experiment. The drawing is not to scale.

the single-particle transition matrix elements for ^{207}Pb can be reliably calculated using modern shell-model codes, thereby greatly reducing the nuclear structure uncertainties which have plagued PNC measurements in the past.

The polarimeter has been built and we have measured the external field of the polarimeter and the temperature rise due to resistive heating in the polarimeter. A leak has developed in one of the water-cooling jackets, so the polarimeter will be rewound. It was also discovered that the polarimeter inductance is too large to quickly switch the field. Thus, the coil will be rewound with fewer turns of larger-diameter wire and will be run at higher currents.

A 4.2-mCi ^{207}Bi source is on order. The source will be contained within an aluminum ring, which fits precisely inside the polarimeter. The relation of the source activity to the statistical sensitivity will be discussed below.

We have received two 4″× 4″× 12″ intrinsic CsI crystals from the NMS collaboration at LAMPF. Fig. 2 shows a ^{137}Cs spectrum taken with Hamamatsu R4017 phototubes on each end of an intrinsic CsI crystal. The R4017 has a good spectral sensitivity for the 310-nm radiation emitted from intrinsic CsI.

The main components of the data acquisition system are shown in Fig. 3. The purpose of the analog filter (which may be a passive or active filter) is to integrate and hold the analog pulse. The transient digitizer (DSP model 2030S) converts the output of the analog filter and stores the data. After a predetermined number of events has been converted, the routing box reads out the transient digitizer into the histogramming memory (Ortec model HM413). The HM413 can handle an instantaneous rate of 10 MHz and an average rate of at least 3 MHz (we believe this may be more like 6 MHz, but have yet to properly measure this quantity). The system is under development. The routing box has been debugged and tests are continuing to develop the software and analog front end electronics. We have been using a Lecroy FERA ADC with the HM413 at rates up to 80 kHz (albeit with 50% deadtime, which is dominated by the 8 μs conversion time in the FERA). The deadtime

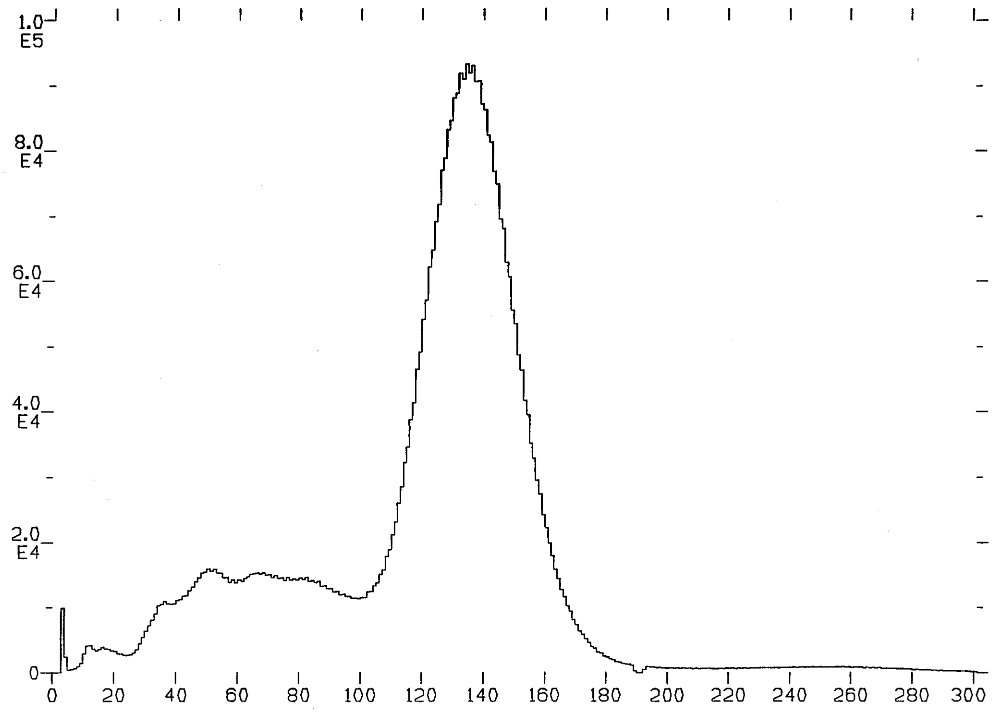

Figure 2. Energy spectrum taken with a ^{137}Cs source on an intrinsic CsI crystal.

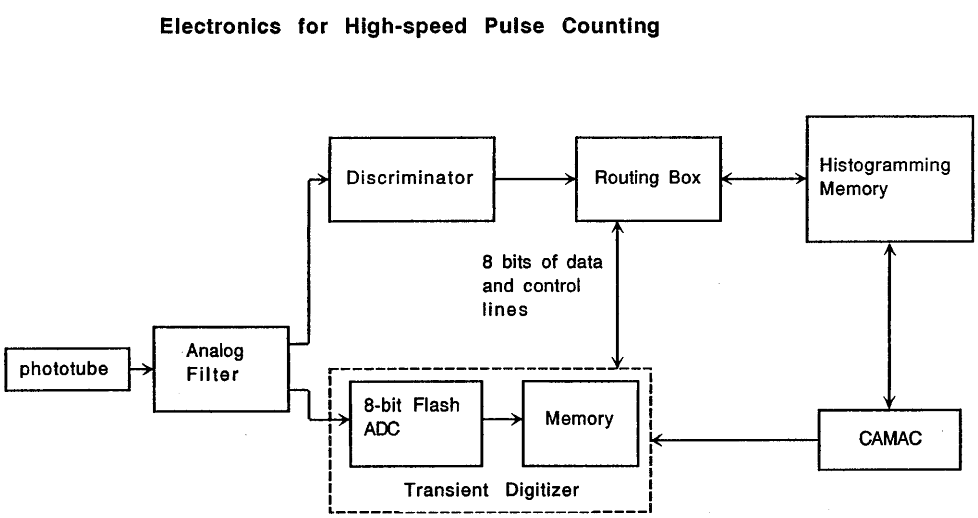

Figure 3. The data acquisition system.

will be greatly reduced when we start using the transient digitizer in place of the FERA ADC.

We plan to run the experiment for about 30 days. With the 4.2-mCi source and the polarimeter as designed, we should count at 160 kHz/detector or 320 kHz total in the 1.06-MeV line. This result includes the product of solid angle and efficiency for the polarimeter-detector combination, the 84% branching ratio for the 1.06-MeV line, and absorption by the polarimeter. The circular polarization expected for a 100-eV mixing is 3.4×10^{-4}, and the analyzing power of the polarimeter is 1.3%. Background under the 1.06-MeV line degrades the PNC effect by a factor of 0.45. The statistical sensitivity is 1.0×10^{-6} or 50 eV. If we run for 120-days, the sensitivity would be 25 eV. In either case, we can eliminate a 100-eV (or larger) single-particle weak mixing matrix element with high confidence.

Note that we have not yet proven that we can count at the necessary rates. Should pile-up in the CsI be a problem, we will subdivide the CsI crystals and count with more channels. If the data acquisition proves to be a bottleneck, we will need to use multiple transient digitizers and/or histogramming memories. Also, should we find systematic effects induced by the polarimeter field, we will rebuild the polarimeter.

The systematic effects in this experiment include: bremsstrahlung of the 10^{-4} β^+ branch for ^{207}Bi, magnetic field effects on the phototubes, multiple photon scatterings in the polarimeter, and geometric effects. We have calculated the inner bremsstrahlung probability, and found it to occur at the level of less than 10^{-7}. Field effects have been reduced by magnetic shielding and moving the phototubes away from the polarimeter. Multiple photon scatterings give false asymmetries only for non-cylindrically symmetric polarimeters and detectors. They have been found in the past to occur at less than 10^{-7} in systems with good symmetry, such as ours. Geometric effects can also give false asymmetries due to source and/or detectors moving systematically with the polarimeter (magnetic field) state. These effects have been minimized by mounting the source and detectors separately from the active part of the polarimeter, which will move and change size when the magnetic field reverses direction.

Once this initial stage of the experiment is complete, we will either have measured a large single-particle weak mixing matrix element in ^{207}Pb or have seen no effect. If we see no effect, our plans are to push the sensitivity of the ^{207}Pb measurement, if possible, down to the 1-eV level. The goal of pushing the sensitivity is to make a measurement of the isoscalar nucleon-nucleon weak amplitude within nuclei, complementary to earlier measurements for light nuclei.

The weak interaction of two nucleons in a nucleus is described by two dominant amplitudes, isoscalar and isovector, which correspond roughly to rho-exchange and pion-exchange terms. The experimental limits on these amplitudes are shown in Fig. 4 (see Ref. 9). A strong limit on the isovector amplitude is given by the measurements of the polarization of the 1081-keV gamma line in ^{18}F. Other measurements are sensitive to different linear combinations of the isoscalar and isovector amplitudes. The extraction of the isoscalar amplitude necessarily involves a nuclear structure calculation, which will be different for ^{207}Pb than in other cases. The fact that ^{207}Pb is one nucleon removed from a doubly-magic nucleus leads us to believe that modern shell model calculations will be able

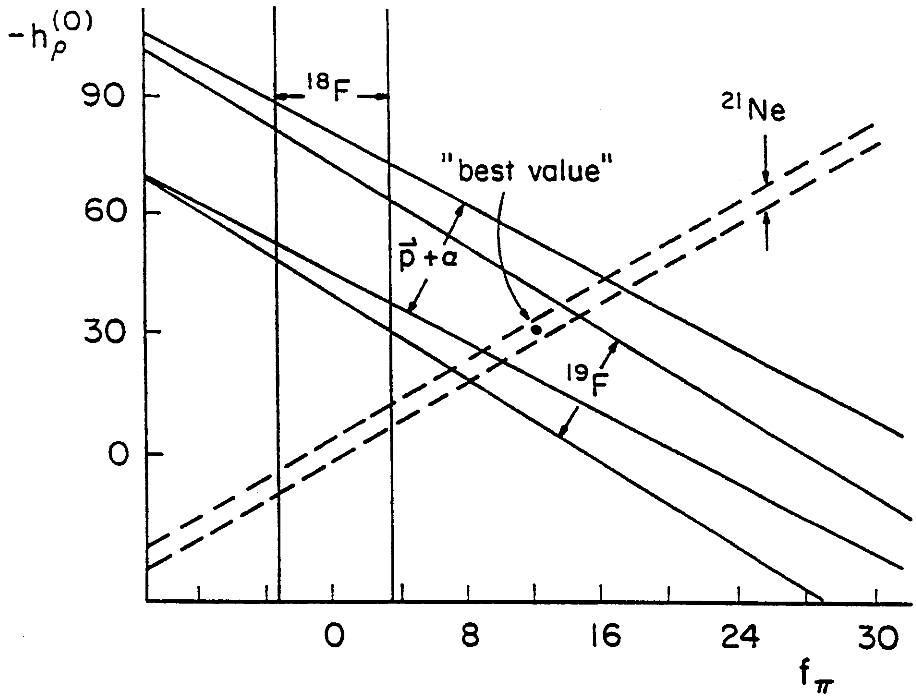

Figure 4. Plotted are the ranges in h_ρ^0 (isoscalar) – f_π (isovector) space allowed by various nuclear parity violation experiments (see Ref. 9).

to reliably predict the relevant nuclear structure. In many previous measurements of the isoscalar amplitude, nuclear structure uncertainties dominated the error in the extraction of the amplitude.

To push the sensitivity of the ^{207}Pb experiment, we have begun discussions with the Princeton group[10] on a technique for measuring the single-particle mixing in ^{207}Pb. The idea is to measure the asymmetry of gamma emissions with respect to the polarization direction of a sample of ^{207}Bi. The ^{207}Bi nuclei, once implanted within an iron (or nickel) crystal and cooled to ~10 m°K, will be essentially 100% polarized. The experimental observable is a forward-backward asymmetry in the gamma flux with respect to the polarization direction. This experiment is ideally suited to the higher sensitivity levels needed in a second phase ^{207}Pb parity experiment. There are difficult technical questions to be answered, as well as a new set of systematic effects that must be addressed, but the technique looks very promising. We are in the process of evaluating and designing this second-phase experiment.

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