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A Test of Time Reversal Invariance in p-p Elastic Scattering at 200 MeV

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We have performed an experiment to test time reversal invariance (TRI) in the strong interaction by comparing a measurement of the polarization (P) with that of the analyzing power (A) in p - p elastic scattering. Previous tests of TRI in elastic scattering were performed in kinematic regions where sensitivity to time reversal violating (TRV) amplitudes was poor[1]. In polarization comparisons in elastic scattering it is possible to set model-independent limits to sensitivity based on the spin structure of the scattering. For example, the spin-flip probability, S, serves to set the limit $|P-A| < 2S$ in the elastic scattering of spin 1/2 particles. In this experiment we have measured P-A in p-p elastic scattering in a region where $2S \approx 0.8$.

The experiment utilized a technique established by Gross et al.[2], which eliminates the need to determine the absolute value of the beam polarization in the analysing power measurement and the need to know the analyzing power of a polarimeter analyzer in the polarization measurement. In adapting their procedure to p - p scattering we used CH_2 as the target and made all p - p measurements relative to p - ^{12}C. Parity conservation assures that P = A for the spin zero carbon elastic scattering so that it is used to link the observed asymmetries for the p - p process. Thus the experiment involved: (a) the simultaneous measurement of A for p↑ - p and p↑ - ^{12}C elastic scattering, and (b) the measurement of the outgoing proton polarizations in p - p and p - ^{12}C in double scattering experiments. The primary proton beam was 200 MeV and scattering was observed at 16.5° in the laboratory. Protons scattered by carbon at this angle had an energy of 198.36 MeV, while those scattered from hydrogen were at 182.30 MeV.

In detail, denoting polarizations of scattered protons by P and polarimeter analyzing power at energy E by A_E, the scattering asymmetries, for a beam of energy of 200 MeV (the subscript h refers to p - p and c to p - ^{12}C) are

$$\epsilon_h = P_h A_{182}, \qquad \epsilon_c = P_c A_{199}. \tag{1}$$

By inserting a copper degrader in front of the polarimeter, so as to reduce the energy of 199 MeV protons to 182 MeV, we measure as well

$$\epsilon_{c'} = P_c A_{182}. \tag{2}$$

Forming the ratio yields

$$P_h/P_c = (\epsilon_h/A_{182})(A_{182}/\epsilon_{c'}) = \epsilon_h/\epsilon_{c'}. \tag{3}$$

The measurement of the analyzing power was done with polarized beam incident on the same CH_2 target. Detectors at ± 16.5° with respect to the beam measured scattering asymmetries for spin up (u) and spin down (d) yielding

$$\epsilon_c^u = P_u A_c \qquad \epsilon_h^u = P_u A_h$$
$$\epsilon_c^d = P_d A_c \qquad \epsilon_h^d = P_d A_h, \tag{4}$$

so that

$$A_h/A_c = (\epsilon_h^u - \epsilon_h^d)/(\epsilon_c^u - \epsilon_c^d) \tag{5}$$

with no reference to the magnitude of beam polarizations. Results for any difference between P and A are extracted from

$$\frac{(P-A)_h}{P_c} = \frac{\varepsilon_h}{\varepsilon_{c'}} - \frac{\varepsilon_h^u - \varepsilon_h^d}{\varepsilon_c^u - \varepsilon_c^d} \tag{6}$$

with $P_c = A_c = 0.993 \pm 0.007$ for the spin zero carbon ground state[3]).

The detection setups for the P and A measurements are shown in the figure. All but the recoil and C counters were aligned and mounted on rotatable frameworks. p - p events were selected off-line by requiring a recoil proton in coincidence; p - ^{12}C events were those with no recoil. Inelastic events were distinguished with the NaI total energy detectors. To analyze both p - p and p - ^{12}C at the same energy, in the P measurement a 5.67 mm thick copper degrader was inserted in front of the S counter at numerous occasions. The p - C scattering in the T counters served as the polarization analyzer.

In the analysis, corrections were made for gain changes, count rate effects, random and prompt backgrounds, nuclear reactions in the NaI counters, and misidentified events. In the double scattering P measurement effects of finite geometry and kinematics degraded the energy resolution sufficiently so that a fitting procedure was needed to extract precise and consistent second scattering asymmetries. A complete Monte Carlo simulation of the experiment was performed to determine contributions to P - A from: (a) variations in scattering cross section and analyzing power slopes, shapes and energy dependences; (b) incident beam shape, position and direction; (c) finite geometry including primary target size; (d) p - p, p - C energy difference at second scattering; and (e) cyclotron stray fields.

The results of the measurement are:

$$P\text{-}A = 0.005 \pm 0.003\ (\text{statistical}) \pm 0.002\ (\text{systematic})$$

This puts the most stringent limit on TRV in the interaction between nucleons. A detailed paper is in preparation.

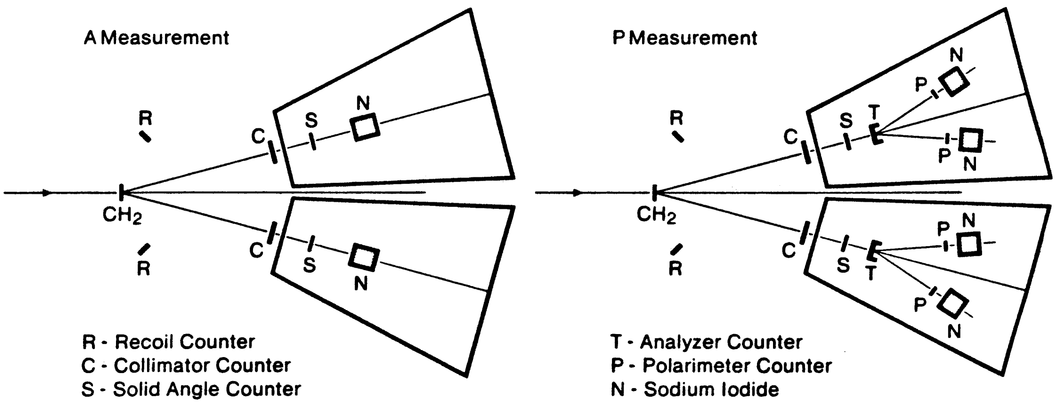

Fig. 1 Schematic layouts of apparatus for A and P measurements (not to scale)

References

1) H. Conzett, Polarization Phenomena in Nucl. Phys.-1980, AIP Ser. No. 69 (AIP, New York, 1981) p.1422.
2) E.E. Gross et al., Phys. Rev. Lett. 21 (1968) 1476.
3) H.O. Meyer, IUCF, private communication.