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Reflections on Symmetries at SPIN '94

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INTRODUCTION

In my view, the parallel sessions on 'Symmetries' were amongst the most stimulating sessions of this conference. Speakers reported on experimental tests of Charge Symmetry, Parity, and Time Reversal violation and their theoretical interpretation, spanning a wide range of energy scales and experimental techniques. I hope that this brief summary will whet the reader's appetite to explore the many contributed papers which follow.

CHARGE SYMMETRY VIOLATION

Charge Symmetry is an approximate symmetry of the strong interaction, and the small extent to which this symmetry is broken has been long established, as illustrated by familiar examples such as low energy scattering length differences in nucleon-nucleon scattering and binding energy differences of mirror nuclei. However, until recently, precision tests in very simple systems offering unambiguous theoretical interpretation have been elusive. For high precision tests, the np system is particularly attractive, since the Coulomb interaction does not contribute to the individual measurements which are compared to evaluate the degree of charge symmetry violation.

W.T.H. van Oers(1) reported a new result from TRIUMF which is the third in a series of high-precision measurements of charge symmetry breaking (CSB) in np scattering at intermediate energy based on a common experimental technique. The CSB test is performed by comparing the transverse spin dependent analyzing power $A(\theta)$ for $(\vec{n}+p)$ and $(n+\vec{p})$ elastic scattering. The scattering cross section for transversely polarized beam or target is given by: $\frac{d\sigma(\theta)}{d\Omega} = \frac{d\sigma^{\circ}(\theta)}{d\Omega}(1 + PA(\theta))$, where P is the beam polarization. The very small ($\simeq 10^{-3}$) difference between the analyzing powers, $\Delta A(\theta) = (A_n(\theta) - A_p(\theta))$ is a measure of charge symmetry breaking in the np system. The experiment can only be done to sufficient precision at one angle θ_o where $A(\theta) = 0$, and the result becomes independent of beam and target polarizations. ΔA is determined by comparing restricted angular distributions of $A_n(\theta)$ and $A_p(\theta)$ near the zero-crossing angles $\theta_{on} \simeq \theta_{op}$. The TRIUMF result at 350 MeV is in good agreement with theoretical predictions accounting for direct electromagnetic effects and the up-down quark mass difference. The three new np measurements are shown in figure 1; all are in good agreement with theory.

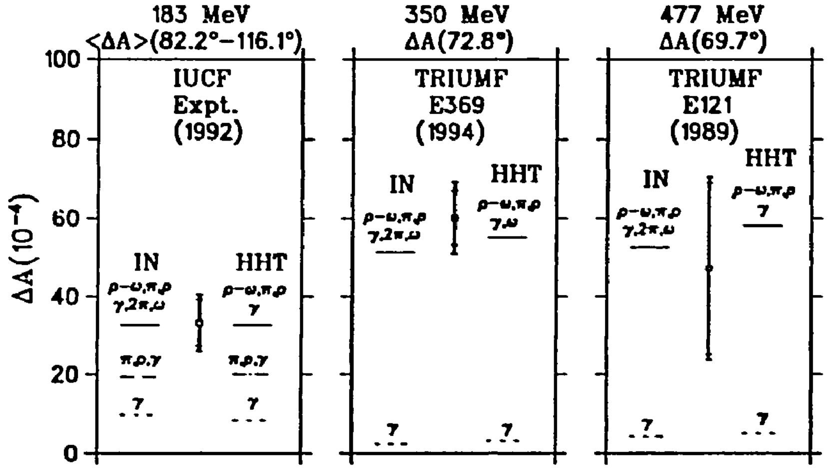

FIGURE 1: Comparison of high precision CSB tests in np scattering(1). The new TRIUMF measurement at 350 MeV is shown in the center panel. Theoretical predictions are indicated by the solid lines – see reference (1) for discussion.

G.A. Miller(2) outlined a consistent theoretical approach for calculating CSB effects in a variety of strongly interacting systems. The major contributions to CSB in the np experiments include electromagnetic effects, isospin mixed $\rho^{\circ}-\omega$ exchanges, and π exchange, calculated using the Bonn meson-exchange potential. At present, a spirited debate is ongoing regarding the magnitude of the isospin mixing $\rho^{\circ}-\omega$ contribution to a variety of CSB experimental results, via the q^2 dependence of the $\rho^{\circ}-\omega$ mixing matrix element. Unfortunately, this contribution is just one of many to the value of ΔA in np scattering; at 350 MeV, the $\rho^{\circ}-\omega$ contribution is negligible at θ_o, but it contributes significantly to the slope of the angular distribution of ΔA in that region. The TRIUMF group is currently exploring ways to extract this angular distribution, which suffers from the imprecision of beam and target polarization measurements, from their data, in hopes of shedding light on this important question.

PARITY VIOLATION

The study of the weak interaction in strongly interacting systems is perhaps equally challenging both to experiment and to theory. At low and intermediate energy, a meson exchange model of the weak nucleon-nucleon interaction has been the most successful at describing experimental data, with a minimum of 6 independent weak meson-nucleon coupling constants for π, ρ, and ω exchanges of different isospin character predicted with relatively large uncertainties using the Standard Model and QCD(3). Existing data can place constraints on the values of 4 weak meson-nucleon couplings, but not all data are consistent. The most stringent constraints are from a new generation of high precision measurements in $\vec{p}p$ scattering, which have determined the helicity dependence of the total scattering cross-section: $A_z = \frac{(\sigma^+ - \sigma^-)}{(\sigma^+ + \sigma^-)}$ to $\pm 2 \times 10^{-8}$ at low energy.

J. Birchall(4) presented a status report on an experiment underway at TRIUMF to measure A_z in $\vec{p}p$ scattering at 223 MeV with the goal of achieving a precision of $\pm 2 \times 10^{-8}$. The experiment will be performed in transmission geometry using parallel plate ionization chambers operated in current mode. In a partial wave decomposition, the dominant contribution to A_z below 100 MeV is due to the interference between S and P waves in the scattering amplitude. The TRIUMF experiment (E497) is designed to be carried out at 223 MeV, where the ${}^1S_0 - {}^3P_0$ amplitude averages to zero over the acceptance of the detectors, leaving the ${}^3P_2 - {}^1D_2$ amplitude as the sole contribution to A_z, as illustrated in figure 2. The $S - P$ term depends on weak ρ and ω exchanges with roughly equal weight, whereas the $P - D$ term depends on ρ exchange alone, enabling an independent constraint to be placed on the elusive weak meson-nucleon coupling constants from the 223 MeV experiment.

A new beamline and target have just been commissioned at TRIUMF for this challenging experiment, and many years of development work and optimization of the TRIUMF Optically Pumped Polarized Ion Source will be relied on for the very stringent requirements of systematic error control. The TRIUMF group plans to begin initial data taking in late 1994, and to follow this experiment with a second measurement at 450 MeV which would require only minor changes to the 223 MeV apparatus. (Plans are also underway at COSY to perform a parity violation measurement in $\vec{p}p$ scattering at 230 MeV, using a similar apparatus, as proposed by P.D. Eversheim et al.)

M. Shmatikov(6) presented an overview of the theoretical approaches that have been used to calculate the parity-violating asymmetry in $\vec{p}p$ scattering. A thorough, one-meson exchange model calculation performed by Driscoll and Miller(5) is illustrated in figure 2. Straightforward extensions to this model include the consideration of two-pion exchanges and Δ-isobar excitations, but both are expected to be small at low and intermediate energy. An additional mechanism involving parity-mixed $\rho - a1$ meson exchanges has been considered by Iqbal and Niskanen(7), but caution must be applied to avoid double-counting, since the form of this term is similar to a contribution to the conventional weak ρ-nucleon couplings. Shmatikov also presented the results of his own nonrelativistic quark model calculations up to 250 MeV. It is important to realize that there are no meson exchanges in this model, which contains no adjustable parameters in the prediction of A_z. Calculations based on these two contrasting approaches differ dramatically in the strength of the J=2 contribution (${}^3P_2 - {}^1D_2$) which will be measured in the TRIUMF experiment, both in the scale and in the shape of the energy dependence, as illustrated in figure 2. A lively discussion ensued, focussing on the surprising result that this treatment of direct quark-vector boson exchanges leads to an interaction of longer range than ρ and ω exchange.

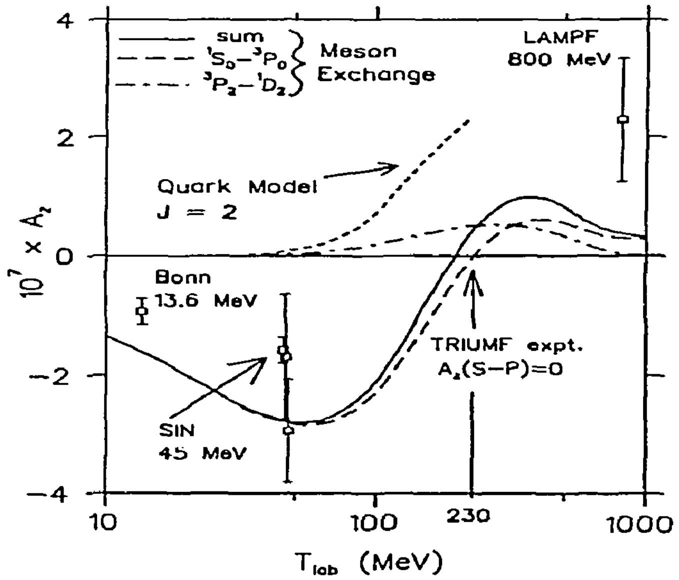

FIGURE 2: Energy dependence of A_z in $\vec{p}p$ scattering. A partial wave decomposition of A_z calculated by Driscoll and Miller(5) using the weak meson exchange model is shown. The (${}^3P_2 - {}^1D_2$) contribution calculated in a nonrelativistic quark model by Shmatikov(6) is indicated for comparison.

Several years ago, new data from measurements of helicity dependence of low energy (≤ 500 eV) neutron transmission on heavy nuclear targets indicated a number of unusually large ($\simeq 10^{-1}$) parity-violating asymmetries(8). Perhaps the most tantalizing feature of the initial data was the tendency for most of the parity-violating asymmetries observed in ^{232}Th+$\vec{n}$ and ^{238}U+$\vec{n}$ resonances to have the same (positive) sign. Calculations which were able to account for the observed sign effect via compound nuclear statistical models in most cases invoked the existence of unexpectedly large single-particle parity mixing matrix elements, of order $\simeq 100$ eV, as compared with the matrix elements of less than 1 eV which have been measured in light nuclei.

M. Leuschner(9) reported on the status of two gamma ray experiments which were designed to measure a single-particle parity mixing matrix element in the nucleus ^{207}Pb with a sensitivity at roughly the 10 eV level. The advantage of ^{207}Pb is that its level structure is relatively simple, so that interpretation of the result can be formulated as a two-level mixing problem. The gamma ray of interest is emitted in a 1063 keV transition between the third ($J^\pi = \frac{13}{2}^+$) and second ($J^\pi = \frac{5}{2}^-$) excited states in ^{207}Pb. Parity mixing of the $\frac{5}{2}^-$ ($2f_{\frac{5}{2}}$ neutron hole) state with a $\frac{5}{2}^+$ ($3d_{\frac{5}{2}}$ neutron hole) state at 6 MeV higher excitation *leads to circular polarization of the 1063 keV γ-rays (P_γ) or equivalently to a* forward-backward asymmetry (A_γ) of the 1063 keV transition when the latter is fed by the β decay of polarized ^{207}Bi. Both measurements are technically challenging: for P_γ, the circular polarimeter sensitivity is $\simeq 1\%$, while for A_γ the nuclear polarization of the source which has been achieved to date at low temperature is limited to about 10%. Results thus far from the A_γ measurement are more precise and have been used to place an upper limit of $\simeq 21$ eV on the single-particle matrix element. With the new neutron resonance data presented by Y.-F. Yen(10) in a plenary talk, which suggest that the positive asymmetry trend is unique to ^{232}Th, emphasis has shifted to attempting to achieve the best possible precision in the ^{207}Pb experiments.

C. Horowitz(11) reported on calculations of the matrix element which account for relativistic effects in nuclear matter using a Hartree Fock approach. Small renormalizations ($\leq 10\%$) of the effective weak meson-nucleon couplings were found. The value of the matrix element is reduced by cancellations between π, ρ and ω contributions which are particularly sensitive to the treatment of short-range correlations. Including correlations in an approximate manner, the matrix element was estimated to be of order 0.05 eV; nonrelativistic calculations range from 0.4 to 1.2 eV. If the ^{207}Pb measurements can reach the level of ± 1 eV accuracy or better, they might be used to help constrain predictions of the weak meson-nucleon coupling constants. Unfortunately, the large energy gap in ^{207}Pb between the $\frac{5}{2}^+$ and $\frac{5}{2}^-$ one-hole states means that such a stringent constraint on the matrix element must come from a measurement which is many orders of magnitude more difficult than the neutron resonance experiments which motivated the original study.

TIME REVERSAL VIOLATION

Perhaps the most well-known experimental test of time reversal symmetry violation is the search for an electric dipole moment of the neutron, which is currently constrained to be less than 10^{-25} e cm. In a plenary session at this conference, B. Heckel(12) reported results of an experiment on ^{199}Hg atoms, placing an even smaller upper limit of less than 10^{-27} e cm on this elusive quantity. The electric dipole moment is odd under both parity (P) and time reversal (T). In contrast, the upper limits on direct P-even T violation are not nearly as well constrained – the most familiar and stringent limit in this category being the detailed balance test: ^{24}Mg(α,p)^{27}Al. To date, no direct experimental evidence of time reversal violation has been found. Comparisons of the significance of different experiments rely on theoretical interpretations based on meson exchange models of P-odd, T-odd and P-even, T-odd interactions. The usual approach is to determine an upper limit for the ratio of (T-odd/T-even) nuclear matrix elements and attempt to relate this to an upper limit for the ratio of (T-odd/T-even) couplings in the underlying interaction.

*P. Huffman(13) reported new results of a P-even time reversal test in po*larized neutron transmission through an aligned nuclear target of ^{165}Ho. The experiment searches for a five-fold correlation that is P-even and T-odd, of the form: $(\vec{\sigma}.(\vec{I}\times\vec{k}))(\vec{I}.\vec{k})$ where $\vec{\sigma}$ is the neutron spin, $\vec{k}$ is the neutron momentum, and $\vec{I}$ is the direction of the nuclear spin alignment ($I = \frac{7}{2}$), achieved by cooling a crystalline target to low temperature. *(Recall that for an aligned target, $m_I = m_{-I}$).* The neutron beam energy of 6.57 MeV does not correspond to any resonance in the compound nucleus. The neutron beam is polarized vertically, while the axis of alignment of the Ho crystal is in the horizontal plane, which contains the beam axis. The Ho target is physically rotated so that the axis makes an angle $\theta(t)$ to the direction of $\vec{k}$. A double asymmetry formed by simultaneously flipping the spin of the neutron beam while rotating the target gives a unique $sin(2\theta)$ signature for T-violation. The result is consistent with zero, placing an upper limit of 3.8×10^{-3} on the ratio of T-odd/T-even nuclear matrix elements, which is comparable to the limit of 3.5×10^{-3} set by ^{24}Mg(α,p)^{27}Al. False effects arising from spin misalignments require two sequential parity-violating interactions, resulting in negligible corrections at this level of accuracy. The collaboration plans to continue the experiment with the aim of reducing this upper limit to $\leq 1 \times 10^{-4}$.

P.D. Eversheim(14) discussed another P-even test of T violation planned for COSY. The experiment is a null test which depends on a fivefold correlation using an aligned nuclear target – in this case, a polarized proton beam at 2 GeV will interact with a tensor polarized deuteron target in the COSY ring. The ring will act as a forward spectrometer with essentially zero acceptance for scattered beam, which is an important feature rendering the experiment insensitive to false effects associated with double scattering. The observable is denoted $A_{y,xz}$, where the cross-section for polarized beam and target is given by: $\sigma = \sigma_o(1 + P_y^p P_{xz}^d A_{y,xz})$. A time reversed state can be reached either by flipping the proton beam polarization or by rotating the deuteron tensor alignment axis by 90°, offering the possibility to invoke a double asymmetry test for systematic error suppression. The goal is to reach an accuracy of $\Delta A \leq 10^{-6}$; in contrast, P-odd, T-even asymmetries are expected to be an order of magnitude smaller. Many of the possible false T-violating systematic errors are ruled out in forward scattering at the 10^{-6} level, either by rotational or parity invariance.

Y. Masuda(15) reported on progress towards a P-odd time reversal test in the transmission of low energy polarized neutrons through a polarized ^{139}La target at KEK. (This experiment was also suggested by Y.F. Yen(10) in her plenary session talk.) The test is proposed at 0.734 eV neutron energy where a p-wave resonance shows a huge parity-violating asymmetry, $A_z = (9.55 \pm 0.35)\%$, enhanced by compound nuclear structure; this same mechanism is expected to enhance the basic T-odd interaction. The P-odd, T-odd transmission asymmetry for polarized neutrons interacting with a polarized nuclear target arises from a $\vec{\sigma}.(\vec{k} \times \vec{I})$ term in the forward scattering amplitude. The incident neutron spin is longitudinal at the entrance to a transverse, vertically polarized La nuclear target. In the target region, a combination of external and internal fields precess the neutron spin by exactly 180° so that it exits from the target with the opposite helicity. With this arrangement, both $< \vec{\sigma}.\vec{k} >$ and $< \vec{\sigma}.\vec{I} >$ are zero inside the target region. A double transmission asymmetry can be formed by combining measurements when the neutron spin is flipped upstream of the target for opposite target spin precessions, cancelling many systematic errors. The success of the experiment hinges in part on achieving high polarization of the Lanthanum nuclei over a reasonably large volume target; thus far, polarization of roughly 20% has been achieved in a moderate-sized crystal. The goal of this experiment is to achieve an upper limit of T-odd/P-odd matrix elements at the 10^{-3} level or better. To set a scale for comparison, Herczeg(16) has estimated an upper limit on the ratio of the dominant T-odd/P-odd pion coupling constants to be 4×10^{-3}.

SUMMARY AND FUTURE OUTLOOK

Results, progress and plans for many new experimental tests of Charge Symmetry, Parity and Time Reversal violation in strongly interacting systems were presented. While much has been accomplished in this active field, many interesting avenues remain to be explored. The concluding speaker, B.M.K. Nefkens(17), advocated the need for more tests of C and G-parity invariance using polarization as a probe to better determine the u-d quark mass difference, and gave examples of many possible reactions which could be used. The ambitious possibility of performing CP tests in η-meson decays, such as a measurement of the longitudinal polarization of muons in the rare decay branch $\eta \rightarrow \mu^+\mu^-$ (B.R. 6×10^{-6}) was also raised, although reaching the required level of accuracy might pose an incredible experimental challenge.

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