LEGIBILITY NOTICE

A major purpose of the Technical Information Center is to provide the broadest dissemination possible of information contained in DOE's Research and Development Reports to business, industry, the academic community, and federal, state and local governments.

Although a small portion of this report is not reproducible, it is being made available to expedite the availability of information on the research discussed herein.

1

LA-UR -88-1787

. . . 4 1988

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36

LA-UR--88-1787

DE88 014470

TITLE RATIO OF GAMOW-TELLER TO FERMI STRENGTH OBSERVED IN CARBON 13, 14 (proton, neutron) AT 492 and 590 MeV

AUTHOR(S) J. L. Ullmann, J. Rapaport, P. Lisowski, R. C. Byrd, T Carey, T. N. Taddeucci, J. McClelland, L. Rybarcyk, R. C. Haight, N. S. King, G. L. Morgan, D. A. Ling, R. Smythe, C. D. Zafiratos, D. Prout, E. Sugarbaker, W. P. Alford, W. G. Love

SUBMITTED TO Spin Observables of Nuclear Probes, Telluride Meeting, March 14, 1988

Los Alamos Los Alamos National Laboratory Los Alamos, New Mexico 87545

RATIO OF GAMOW-TELLER TO FERMI STRENGTH OBSERVED IN $^{13,14}C(p,n)$ AT 492 AND 590 MeV.

J.L. Ullmann, J. Rapaport, P.W. Lisowski, R.C. Byrd, T. Carey, T.N. Taddeucci, J. McClelland, L. Rybarcyk, R.C. Haight, N.S.P. King, and G.L. Morgan

Los Alamos National Laboratory
Los Alamos, NM 87545

D.A. Lind, R. Smythe, C.D. Zafiratos, D. Prout

University of Colorado
Boulder, CO 80309

E. Sugarbaker

The Ohio State University
Colombus, OH 43212

W.P. Alford

TRIUMF
Vancouver, B.C., Canada V6T 2A3

W.G. Love

University of Georgia
Athens, GA 55455

INTRODUCTION

It has been recognized for a number of years that certain spin-isospin components of the nucleon-nucleus effective interaction can be inferred from (p,n) reactions to states of known nuclear structure. For L = 0, S = 0 and L = 0, S = 1 transitions, the 0-degree (p,n) cross section can be related respectively to Fermi and Gamow-Teller beta decay matrix elements[1]. If these transitions occur in the same nucleus, the ratio of isovector spin-flip to non-spin-flip effective interactions can be measured without regard for absolute normalization. The best reaction to measure this is $^{14}C(p,n)$ which goes by a pure Gamow-Teller transition to the 1^+ state at 3.95 MeV in ^{14}N, and Fermi transition to the 2.31 MeV 0^+ state. This work extends the ratio measurements made at lower energies (ref. 1, 2, 3) to 492 and 590 MeV.

We also report on the $^{13}C(p,n)$ reaction which goes by a pure GT transition to the 3.51 MeV $3/2^-$ state in ^{13}N, but by a mixed Fermi plus Gamow-Teller transition to the $1/2^-$ ground state.

EXPERIMENTAL METHOD

The measurements were made on the 240 m zero-degree flight path of the WNR Target-Two facility at LAMPF. Neutrons were detected in a 25 cm × 50 cm × 7.5 cm thick plastic scintillator coupled at both ends to a RCA C31024 phototube, as was used in previous measurements. (ref. 4). The intrinsic time resolution of this system is about 300 ps FWHM. For beam energies less than 800 MeV, the last sections of the LAMPF linac are turned off and normally act as a passive drift section. Over this drift space, the normal beam energy spread ($\Delta E/E \approx 0.1\%$) slews into a time spread that is much larger than the intrinsic resolution of the detector. This width seriously limited previous measurements at energies below 800 MeV. The present measurements were made by tuning one of the unused linac cavities to adjust the phase space of the beam to produce a time focus at the detector position. (See ref. 5.) With this technique, beam pulse widths of 300 ps were observed at the target position. The effect of this bunching scheme is shown in Figure 1.

The ^{14}C target was made from amorphous carbon enriched to 89% in ^{14}C and encased in a 0.005 cm thick nickel cell. The ^{14}C thickness was 170 mg/cm^2. This is the same target as was used in the TRIUMF measurements. (ref. 3) Figure 2 shows the time spectrum for $^{14}C(p,n)$ at 492 MeV. A spectrum at 590 MeV was not obtained because of experimental difficulties. The dominant feature of the spectrum is the 1^+ Gamow-Teller state at 3.95 MeV excitation. The IAS at 2.31 MeV appears as a small shoulder on the larger GT peak. Neutron yields were obtained by fitting an asymmetric Gaussian line shape to the data. The peak-shape parameters were obtained from isolated states in ^{13}C. Special care was taken to insure that the yields obtained for the IAS were not sensitive to reasonable small changes in the fitting parameters or procedure.

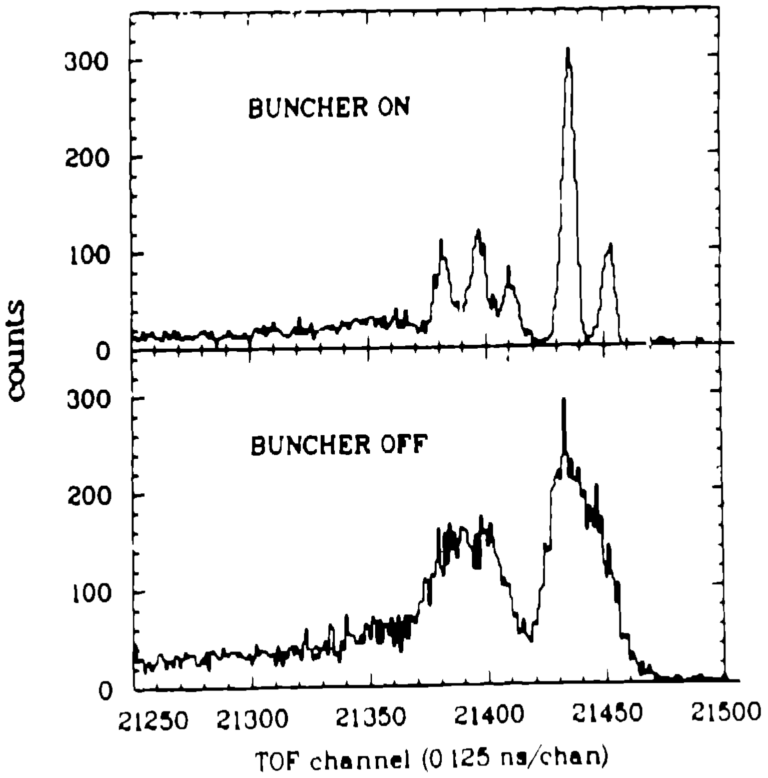

Fig. 1. Buncher on vs. buncher off for $^{13}C(p,n)$ at 492 MeV.

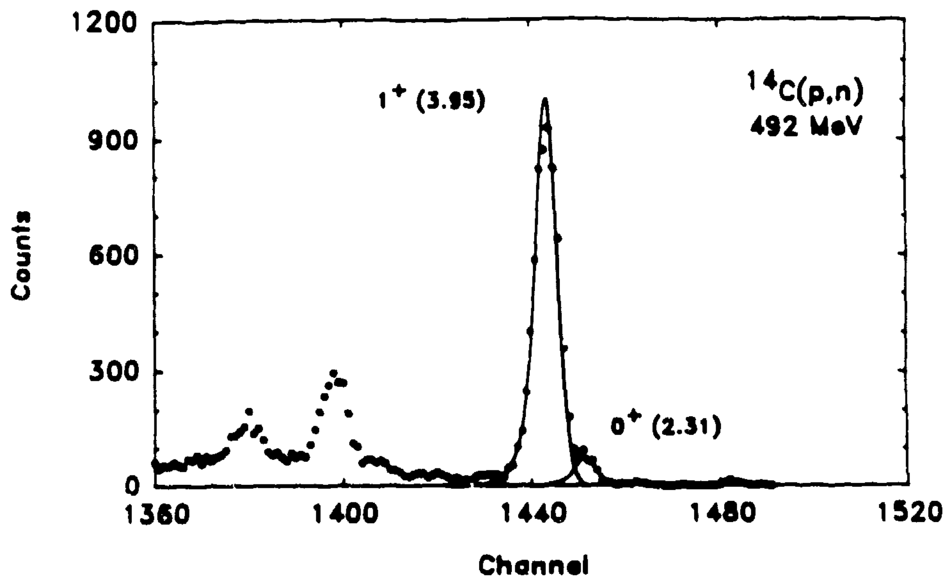

Fig. 2. Zero-degree time spectrum of $^{14}C(p,n)$ at 492 MeV (125 ps/chan). The curve fitted to the 1^+ GT state and the 0^+ IAS is shown.

The ^{13}C target was a 209 mg/cm^2 self-supporting foil consisting of ^{13}C enriched to 99% mixed with 15% binder enriched to 90%. Figure 3 shows the spectra obtained at both energies. The $1/2^-$ gs and $3/2^-$ state at 3.51 MeV are well resolved. Neutron yields were determined by simply summing counts.

RESULTS

Taddeucci (ref. 1) has given an expression for the cross section of a given type α (α = GT or F):

$$\sigma(q,\omega) = \hat{\sigma}(E,A)\ F_{\alpha}(q,\omega)\ B(\alpha) \qquad (1)$$

where $\hat{\sigma}$ is the "unit cross section" and depends on mass and bombarding energy, B is the beta-decay transition strength that contains the nuclear structure information, and F_{α} is a factor that describes the shape of the angular distribution $[F_{\alpha}(q = 0, \omega = 0) = 1]$.

The unit cross section is the factor of primary interest, and may be written approximately as

$$\hat{\sigma}_{GT} = K(E_p,0)N^D_{\sigma\tau}\ |J_{\sigma\tau}|^2$$

$$\hat{\sigma}_F = K(E_p,0)N^D_{\tau}|J_{\tau}|^2 \qquad (2)$$

where K is a kinematic factor, N^D is the distortion factor, and $J_{\sigma\tau}$ and J_{τ} are the volume integrals of the spin-flip ($V_{\sigma\tau}$) or non-spin-flip (V_{τ}) isovector central interaction. We note that

$$\hat{\sigma}_{GT} = \sigma_{GT}(q = 0, \omega = 0)/B(GT) \quad \text{and} \quad \hat{\sigma}_F = \sigma_F(q = 0, \omega = 0)/B(F) \qquad (3)$$

Table 1. B's used in determining $\hat{\sigma}$ (from ref. 1)

			B(GT)	B(F)
$^{14}C(p,n)^{13}N$	2.31 MeV	(0+)	-	2.0
	3.95	(1+)	2.76	-
$^{13}C(p,n)^{13}N$	gs	(1/2-)	0.20	1.0
	3.51	(3/2-)	0.83	-

Table 2. Measured Values of R^2

^{14}C	492 MeV	9.4 ± 0.7
^{13}C	492 MeV	13.8 ± 2.3
	590 MeV	11.4 ± 0.7

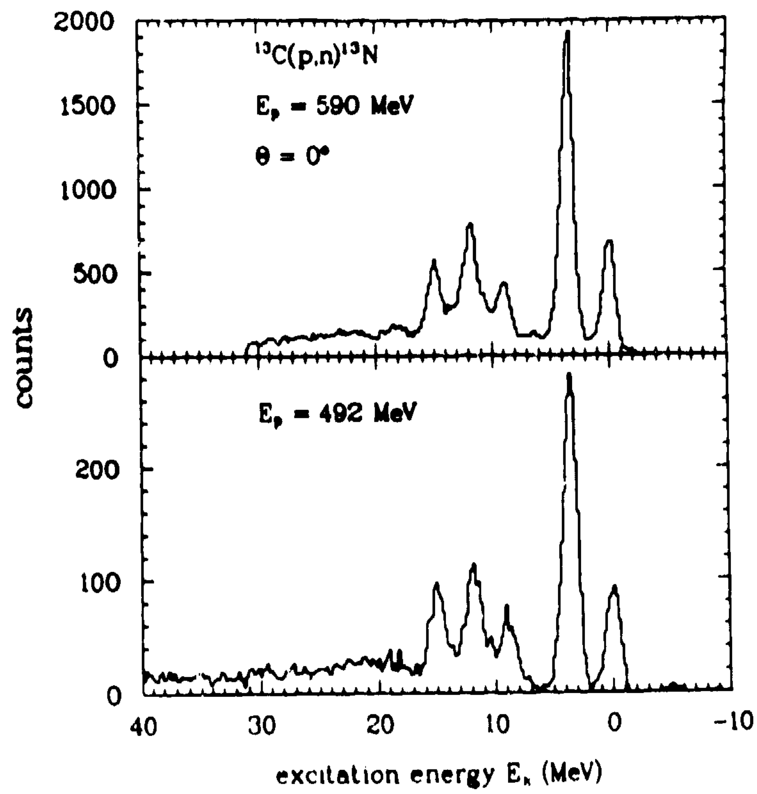

Figure 3. Zero-degree energy spectra for $^{13}C(p,n)$ at 590 and 492 MeV.

The ratio of these unit cross sections is defined as R^2,

$$R^2 = \hat{\sigma}_{GT}/\hat{\sigma}_F \tag{4}$$

which, in the factorized approximation, may be written as

$$R^2 = \frac{|J_{\sigma\tau}|^2}{|J_\tau|^2} \frac{N^D_{\sigma\tau}}{N^D_\tau} \quad . \tag{5}$$

We elect to compare values of R^2 to calculated values. R^2 can be determined directly from the data, while eq. (5) involves an approximation. We prefer to lump the uncertainty in calculating the distortion factors and other reaction details into the theoretical calculations and report numbers more closely related to experiment.

For the pure transitions in $^{14}C(p,n)$, R^2 can be obtained directly from eq. 3. However, for the mixed transitions in ^{13}C, we need to use the incoherent sum of the cross sections, and obtain

$$R^2 = \frac{B_1(F)}{(\sigma_1/\sigma_2)B_2(GT) - B_1(GT)} \tag{6}$$

The values of the beta decay transition strengths we used are those suggested by Taddeucci (ref. 1), and are obtained from β decay for all transitions except $^{13}C(p,n)^{13}N(3.51)$. The value of the latter was determined by a comparison of (p,n) data to the ground state or 15.1 MeV transitions. The values of the B's are shown in Table 1. Table 2 shows the values of R^2 that we extracted from the data.

The measured values of R^2 are compared to calculations for $^{14}C(p,n)$ in figure 4. The data points at 200 MeV and below are from ref. 1 and 2, and those between 200 and 450 from ref. 3. The calculations are described in detail in a recent paper (ref. 7). Briefly, the calculations are non-relativistic DWIA and include direct and exchange terms explicitly with central, spin-orbit, and tensor parts for each interaction. Results using two nucleon-nucleon interactions are shown. The first used a free t-matrix interaction based on Arndt's SP84 phase shifts[8]. The second is an unpublished[9] density-dependent G-matrix interaction (HM86) based on the Bonn potential[10]. The G-matrix calculation was extended to 500 MeV using the 425 MeV g-matrix. This is not, of course, well justified, but used for comparison.

The density-dependent G-matrix interaction was used to include the relatively strong medium effects on the short range processes that contribute to V_τ. The results reproduce the data well up to 300 MeV, but the trend of the data above that seems to follow more the trend of the t-matrix calculations. We note, however, that the Bonn potential used in the G-matrix calculation was only fit to the N-N data up to 300 MeV, and that above 300 MeV even the zero-density G-matrix calculations differ significantly from the t-matrix calculations[8]. A similar good reproduction of the lower energy ratios was obtained by Horowitz[11] in a relativistic calculation for the ratio $|J_{\sigma\tau}/J_\tau|^2$ that included only Pauli blocking as a medium effect. Cross section calculations were not presented, however, so a direct comparison to our data cannot be made.

Also shown in Figure 4 are our R^2 values for ^{13}C. We observe that the ratio is somewhat different in value from that measured for ^{14}C, but follows a similar trend with energy.

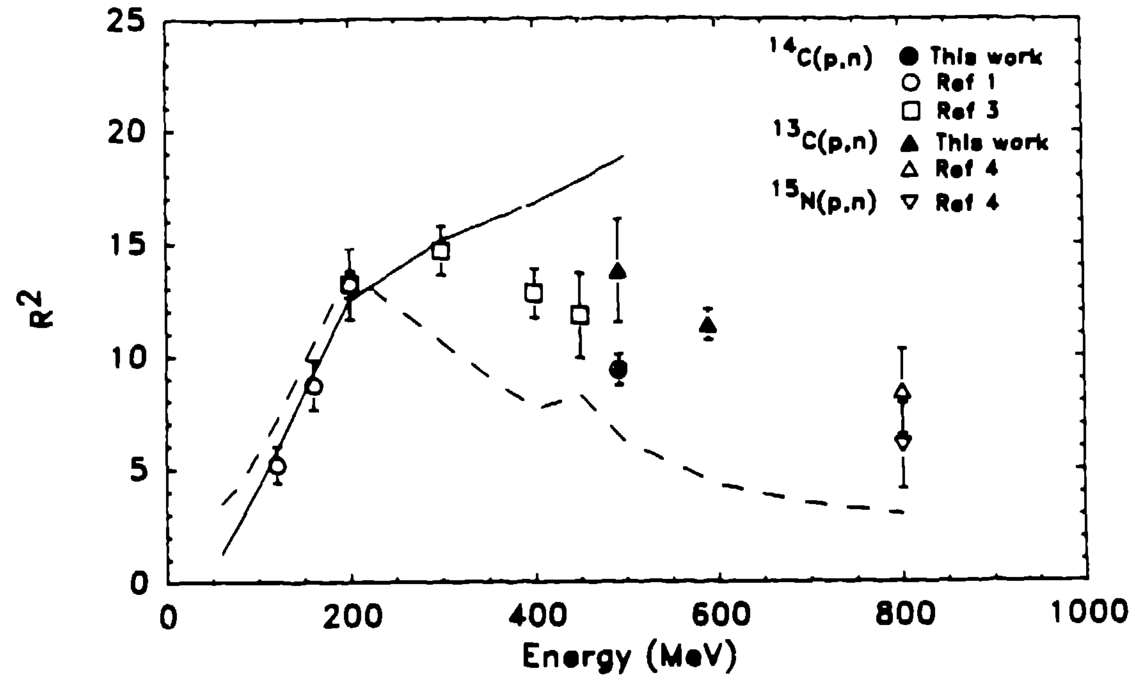

Fig. 4. Values for the ratio $R^2 = \hat{\sigma}_{\sigma\tau}/\hat{\sigma}_{\tau}$ measured in the $^{14}C(p,n)$ reaction from 100 to 600 MeV. Data from $^{13}C(p,n)$ at 492 and 590 MeV, and $^{13}C(p,n)$ and $^{15}N(p,n)$ at 800 MeV are also shown. The solid line is the result of a G-matrix calculation using the Bonn potential, and the dashed line is a calculation using a t-matrix interaction.

REFERENCES

1. T.N. Taddeucci, et al., Nucl. Phys. A469, 125 (1987).
2. J. Rapaport, et al. Phys. Rev. C 24, 335 (1981).
3. W.P. Alford, et al., Phys. Lett. B179, 20, 1986.
4. N.S.P. King, et al., Phys. Lett. B175, 279 (1986), R.G. Jeppesen, "Observation of Gamow-Teller and Fermi Strength in light nuclei using the 800 MeV (p,n) reaction." PhD Dissertation, University of Colorado, 1986 (unpublished).
5. R. Smythe, et al., to be published.
6. W.G. Love, K. Nakayama, and M.A. Franey, Phys. Rev. Lett. 59, 1401 (1987).
7. M.A. Franey and W.G. Love, Phys. Rev. C 31, 488 (1985).
8. R.A. Arndt, et al., Phys. Rev. D 28, 97, (1983).
9. K. Nakayama and W.G. Love, unpublished.
10. R. Machleidt, K. Holinde, and C. Elster, Phys. Rep. 149, 1 (1987).
11. C. J. Horowitz, to be published.