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Tests of hadronic probes of GT strength

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I. MOTIVATION

The question of the distribution and absolute value of Gamow-Teller strength in nuclei has received renewed attention for three reasons.

1. It is essential for calculating neutrino absorption cross-sections, which are the basic ingredient in measurements of ν properties using astronomical sources (*i.e.* solar neutrino problem and neutrino oscillations).
2. It provides a stringent test of shell-model nuclear wave functions. Because the GT operator does not connect single-particle states of different orbital or principal quantum numbers, corrections to a complete-shell calculation of GT matrix elements due to mixing with levels from other major shells enter only in second order.
3. It provides the only rigorous probe of any renormalization of g_A in the nuclear medium.

However direct measurements of GT strength are possible only in a limited region of excitation energy as β-decays can populate only those states allowed by energy conservation. In typical favorable cases, this permits observation of only $\approx$1/5 of the total GT strength.

An alternative approach for learning about the GT strength at higher excitation energies uses hadronic probes. The (p,n) cross-section near zero degrees at $E_p \approx 100$-200 MeV seems to successfully reproduce the GT strength profile measured in β-decay[1]. However, a recent ISOLDE ^{37}Ca$\rightarrow ^{37}$K$+\beta^+ + \nu$ experiment[2] measured a GT strength distribution that appears to be at variance with that inferred from a study of ^{37}Cl$(p,n)^{37}$Ar, although these are expected to be equal assuming the charge-symmetry of nuclear forces (see ref. [3]). The discrepancies are twofold:

1. differences in the strengths of individual transitions (see Fig.1).
2. differences in the integrated strength summed up to the maximum energy observed in the β^+-decay experiment (see Fig.2). This discrepancy amounted to about $\approx$50% (*i.e.* $\sum B(GT)(\beta\text{-decay}) \approx 1.5 \sum B(GT)(p,n)$).

These findings have had a strong impact[5-7], and motivated a new measurement of the ^{37}Cl(p,n) cross-section with improved energy resolution and the ability to resolve Fermi and GT contributions *via* the spin-transfer coefficient[8]. These new results brought the GT strength in the vicinity of the analog state into agreement with our ^{37}Ca work. However, they confirmed the earlier (p,n) work regarding the discrepancies at $E_x = 1.4$ and $E_x = 3.2$ MeV. A resolution of these discrepances may be at hand. Recent work in Seattle[9] has shown that the 3.24 MeV level of ^{37}K (which is fed in ^{37}Ca decay) preferentially decays by γ emission. If this level has $\Gamma_\gamma / \Gamma_p \approx 40$, the discrepancies at $E_x = 1.4$ and $E_x = 3.2$ MeV would disappear (the yield to the bound 1.4 MeV level was inferred by requiring the sum of the beta-decay branching ratios to be unity). Although many of the discrepancies for final states with $E_x \leq 5$ MeV may be resolved, important differences remain to be understood at higher excitation energies. Fig. 3 shows a comparison between the recent (p, n) measurement and the ISOLDE β-decay result. Note that the discrepancy between the (p, n) and β-decay measurements grows with increasing excitation energy. It is therefore of considerable importance to extend the sensitivity of the ^{37}Ca decay results to higher energies in order to see a larger fraction of the predicted GT strength.

Our previous ^{37}Ca β^+-decay measurement at ISOLDE did not have enough statistics to detect the GT strength with $E_x \geq 8$ MeV as we had a flux of only 6 ions/s. The shell-model predicts that the excitation region from 8.0 to 10.6 MeV (10.6 MeV is the β-decay energy release) contains an additional 50% of GT strength, but due to phase-space restrictions the intensity of these transitions will be very low. Furthermore the (p, n) work shows a peak of GT strength at $E_x \approx 9.65$ MeV. It would be most interesting to have β decay results that extended to higher E_x in order to see if the discrepancies between β-decay and (p, n) $B(GT)$'s continue to grow at higher E_x, or if (perhaps because of isospin-violating differences in the E_x of mirror ^{37}Ar and ^{37}K final states) they diminish.

II. PROPOSAL

We propose to study ^{37}Ca decay with improved sensitivity to obtain the GT strength at excitation energies ≥ 8 MeV. The case of ^{37}Ca is particularly interesting because:

1. The exceptionally large Q-value (10.6 MeV) opens an unusually large fraction of the predicted GT strength (50% of the total GT strength is predicted to lie within the Q-value window).
2. The $A = 37$ nuclei are the *only system* with $A \leq 40$ nuclei (where high-quality shell-model calculations are available) where one can compare β decay results

for $B(GT)$ to estimates based on (p,n) measurements.

The nucleus ^{37}Ca decays to levels in ^{37}K, most of which are unbound to proton decay, so that the GT strength can be measured by measuring the proton spectrum. However, it has been shown[2] that an important fraction of the GT strength can only be detected if, in addition to the protons, one measures the γ-rays from decays that leave the recoiling nucleus (^{36}Ar) in an excited state.

We plan to use an apparatus similar to, but more efficient than, the one used in our previous ^{37}Ca experiment. The former apparatus is shown in Fig. 4. The radioactive beam will be implanted in the window of a gas ΔE detector and the β-delayed protons will be measured in a silicon surface-barrier E detector. The new apparatus will be upgraded in two ways.

1. We will replace the two 5"×6" NaI detectors which had a total efficiency of 17% for 1332 keV γ's, by an annular NaI detector that is divided into 8 independent segments. This detector has a total efficiency of 75% for 1332 keV γ's, and will improve by about a factor of 5 our ability to tag proton decays that feed excited states of ^{36}Ar.

2. We will use a thicker E counter to give us sensitivity to higher energy protons. Our former telescope used a 300 μm thick Si counter which nominally stopped protons only up to 6 MeV. Based on tests at the Seattle tandem accelerator, we will also implement better collimation to reduce further the tails on the proton peaks.

Based on our previous run (where we obtained 70 hours of data with a flux of $\approx$6 ^{37}Ca's per sec) we estimate that we could measure the GT strength in the 8-9.5 MeV region with 4 days of running given a beam of about 30 ^{37}Ca's per sec at our counting station.

As can be seen in Fig. 5, this increased number of observed decays will allow us to see an additional 30 % of GT strength, and to test the correspondence between (p, n) yields and GT strength in a region where the (p, n) and β-decay data seem to increasingly diverge. We request 14 shifts of data-taking on Ca decay and 3 shifts for tuning up the apparatus.

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FIGURES

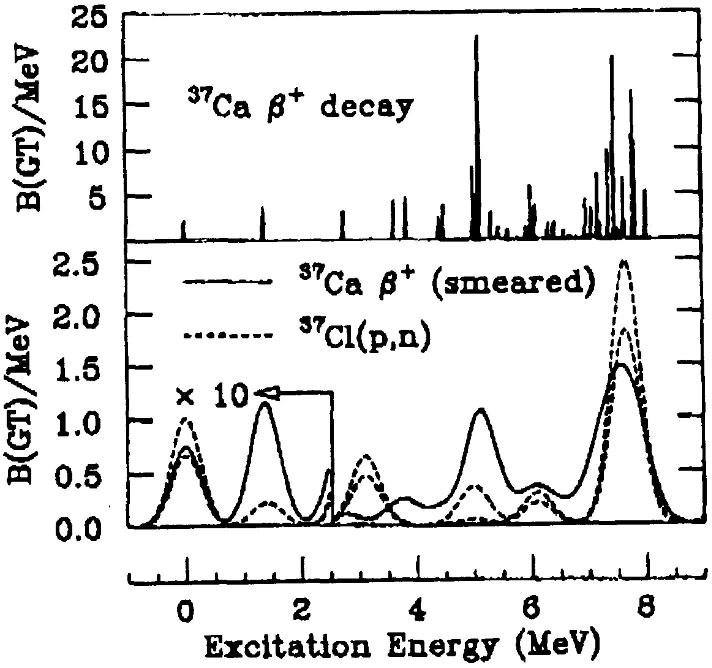

FIG. 1. Comparison of the differential $B(GT)$ distributions from the ^{37}Cl(p,n) data of ref. [4] and our ^{37}Ca β-decay results. Upper panel: ^{37}Ca β-decay results. Lower panel: ^{37}Ca β and ^{37}Cl(p,n) GT transitions represented by Gaussians whose area is $B(GT)$. The width of the (p,n) Gaussians reflects the 600 keV resolution of that experiment; the high-resolution ^{37}Ca results are plotted with widths of 600 keV to facilitate the comparison. Note the vertical scale change-the data at low E_x have been multiplied by a factor of 10.

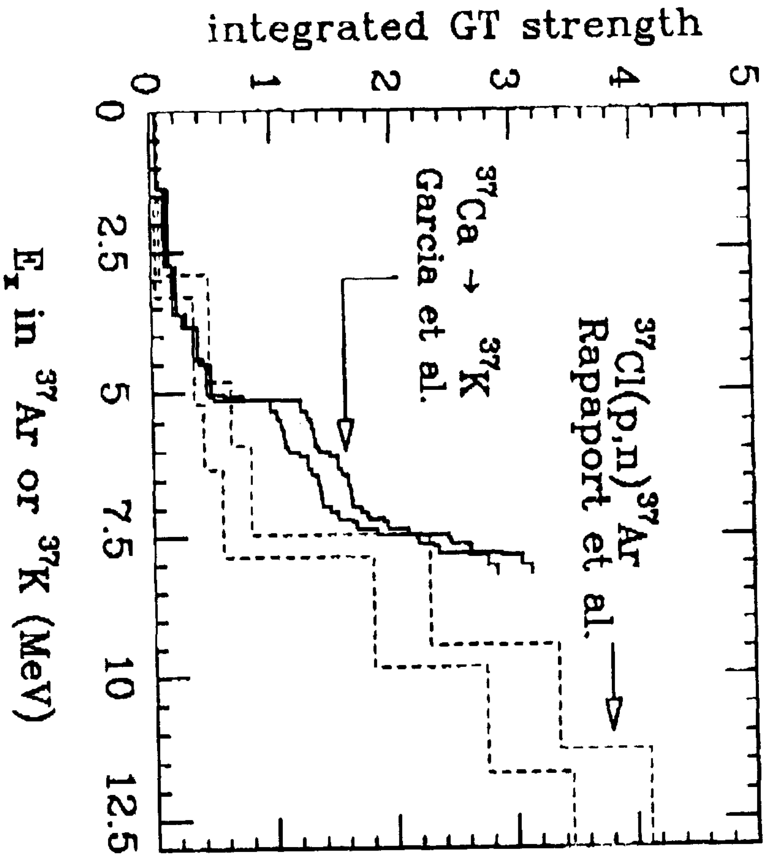

FIG. 2. Comparison of the integrated GT strength observed in the ISOLDE ^{37}Ca β-decay experiment to that inferred from the ^{37}Cl(p,n) work of ref. [4]. Up to 8 MeV we found ≈50% more GT strength than seen in (p,n).

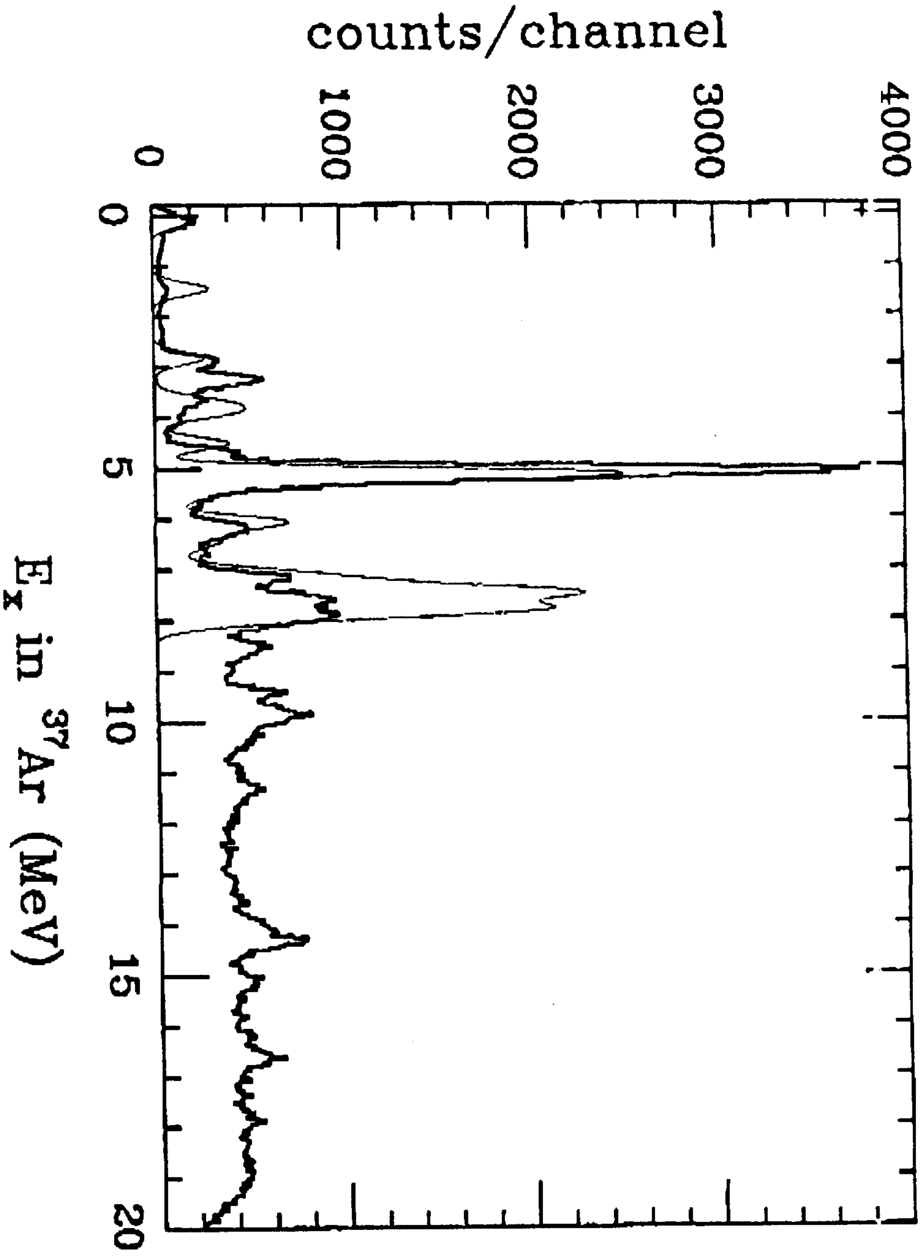

FIG. 3. Comparison of the recent ^{37}Cl(p,n) measurement and the ISOLDE β-decay work. The heavy line shows the raw 0° (p,n) spectrum, the light line shows the ^{37}Ca $B(GT)$'s obtained in ref. [2] smeared out over the 230 keV resolution of the (p,n) work. The (p,n) yield to the analog transition (which appears at $E_n \approx 91$ MeV) contains significant Fermi strength. Measurements of D_{NN} show that the GT component of this transition is consistent with the β-decay value. The discrepancies at $E_x \approx 1.4$ MeV and $E_x \approx 3.2$ MeV appear to have been resolved (see text). The remaining differences are not understood. Our proposed experiment will check whether the discrepancies observed at $E_x \approx 7$ MeV persist at higher excitation energies.

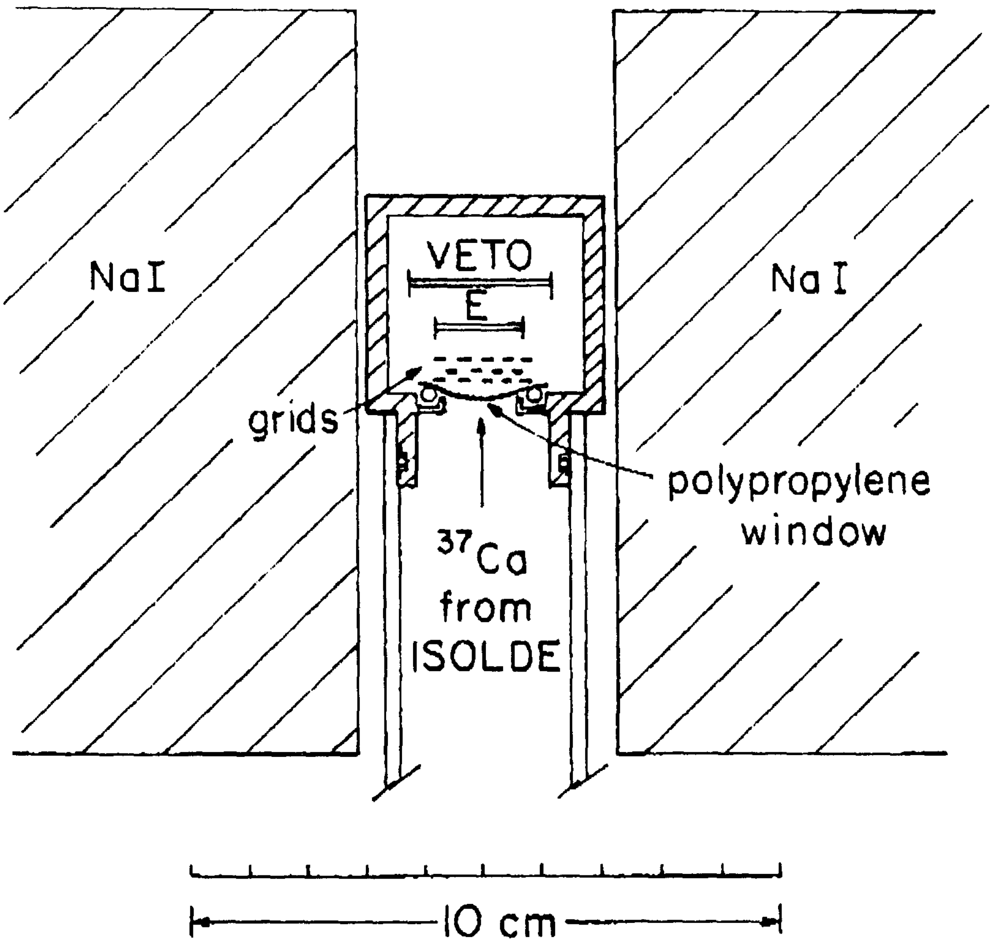

FIG. 4. Scheme of detection set-up at Isolde. The radioactive beam will be implanted in the window of the gas ΔE detector and the β-delayed proton spectrum will be measured in the silicon surface barrier E detector. The NaI detectors identify events in which the recoil nucleus is left in an excited state. For the proposed experiment the the two 5" by 6" NaI detectors will be replaced by a high-efficiency annular detector.

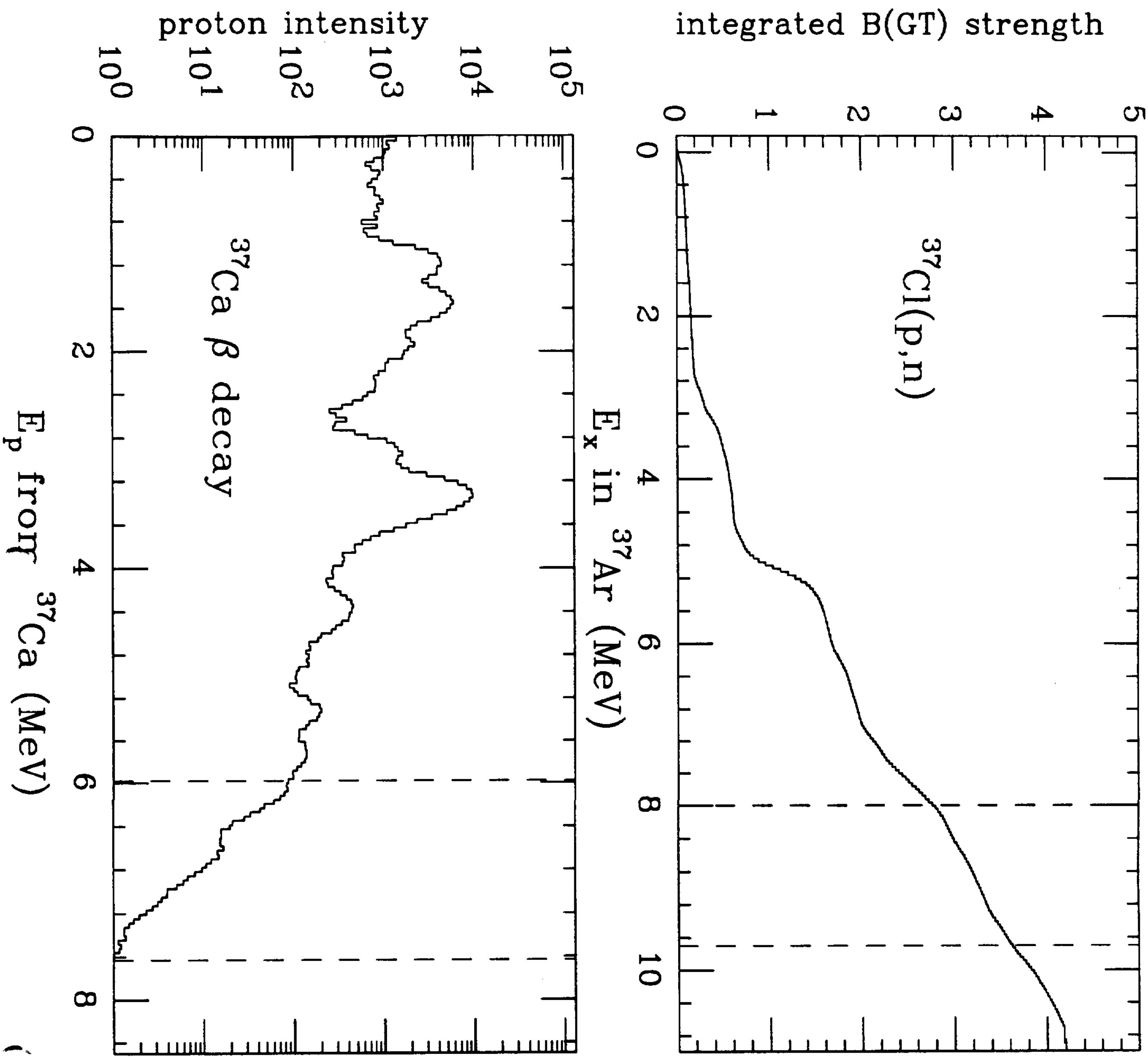

FIG. 5. Top panel: Integrated GT strength seen in the new ^{37}Cl(p,n) experiment. This was calculated under the following assumptions. 1) The 0° (p,n) yield is proportional to $B(GT)$ with the proportionality constant chosen to give the electron-capture value for the ground-state transition. 2) The GT strength lying under the Fermi peak was taken from our earlier ^{37}Ca work (this is consistent with the spin-transfer coefficient measured in the (p,n) experiment). Bottom panel: Expected ^{37}Ca delayed proton spectrum corresponding to the recent (p,n) results. This spectrum was calculated by assuming that all proton decays feed the ^{36}Ar ground state. In reality the delayed proton spectrum will show sharp peaks rather than the 230 keV wide structures inferred from the (p,n) work.