Superallowed beta decay

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Superallowed $0^+ \rightarrow 0^+$ beta decay between T=1 analogue states has been a subject of continuous and often intense study for five decades. The *ft* values of such transitions are nearly independent of nuclear-structure ambiguities and depend uniquely on the vector part of the weak interaction. Their measurement gives us access to clean tests of some of the fundamental precepts of weak-interaction theory, and, over the years, this strong motivation has led to very high precision being achieved in both the experiments and the theory used to interpret them. We have a major program at the Cyclotron Institute to study superallowed beta decay.

To obtain the *ft* value for any transition, three quantities must be measured: the half life of the parent, the Q_{EC} value for the transition of interest and the branching ratio for that transition. This year we produced a complete new survey [1] of existing data on these superallowed decays to replace our previous one [2], which was already out of date. Although the latter was published as recently as 2005, there has been an avalanche of new measurements – some from our group and some from a variety of other groups worldwide – that have been published in the intervening time.

As in all our surveys, the new one provides a critical evaluation of all the experimental data for each superallowed transition and obtains final *ft* values from the averaged results. To these *ft* values are applied improved radiative and isospin-symmetry-breaking corrections [3] in order to derive a final set of "corrected ft values", denoted $\mathcal{F}t$. Two new features were added this time: The calculated statistical rate function, *f*, now accounts for possible excitation in the daughter atom [4], a small effect but one which merits inclusion at the present level of experimental precision; and we have re-examined the systematic uncertainty associated with the isospin symmetry-breaking corrections by evaluating the radial-overlap correction using Hartree-Fock radial wave functions [5] and comparing the results with our earlier calculations, which used Saxon-Woods wave functions.

With the updated world data and improved corrections the $\mathcal{F}t$ values are completely consistent with one another as shown in the right panel of Figure 1. Since these corrected $\mathcal{F}t$ values are inversely proportional to the square of the vector coupling constant, G_V, the constancy of G_V is demonstrated to 1.3 parts in 10^4. Not only is this an important confirmation of the Conserved Vector Current (CVC) hypothesis but it sets the stage for using the average value of G_V to test a fundamental principle of the electroweak standard model: the unitarity of the Cabibbo-Kobayashi-Maskawa (CKM) matrix. The up-down quark mixing element of that matrix, V_{ud}, is given by $V_{ud} = G_V / G_F$, where G_F is the weak interaction constant for the purely leptonic muon decay. The value of V_{ud} is a key component of the most demanding test available for the unitarity of the CKM matrix, the sum of squares of its top-row elements [1]. Superallowed nuclear beta decays provide by far the most precise and reliable value for V_{ud} and, in fact, that element is also the most precisely known one in the CKM matrix – by an order of magnitude! Its value, as obtained from our new survey and analysis is 0.97425(22), a result that is consistent with, but a factor of two more precise than, our previous value [2].

For several decades, the top-row unitarity sum differed from unity by several standard deviations but, over the past several years, new results from kaon decay have demonstrated conclusively that the value of another element of the top row, V_{us}, was not correct. The now accepted value for V_{us}, when combined with the nuclear value for V_{ud}, yields a unitarity sum of 0.99995(61). This stunning confirmation of CKM unitarity is not only a significant verification of the standard model but the uncertainty quoted on the sum provides a tight limit on any possible new physics beyond the standard model.

In short, superallowed $0^+ \rightarrow 0^+$ beta decay provides a high-profile application of nuclear-physics measurements to the study of fundamental symmetries, a subject of vital interest to both nuclear and particle physicists. Although much has already been achieved in this field by nuclear physicists, improvements are still possible. Reducing the uncertainty on the unitarity sum – and, with it, the scope for new physics – remains the primary goal of our research program.

The left panel of Fig. 1 shows the experimental *ft* values while the right panel shows the corrected $\mathcal{F}t$ values. The principal difference between the two panels is the inclusion of the nuclear-structure-dependent corrections, δ_{NS} and δ_C, in the derivation of the $\mathcal{F}t$ values. Since these corrections were determined [3] completely independently of the superallowed decay data, the consistency of the $\mathcal{F}t$ values is also a powerful validation of these calculated corrections: obviously they act very well to remove the considerable "scatter" that is apparent in the left panel and is effectively absent in the right one.

The 2009 survey [1], which considered a body of world data comprised of more than 145

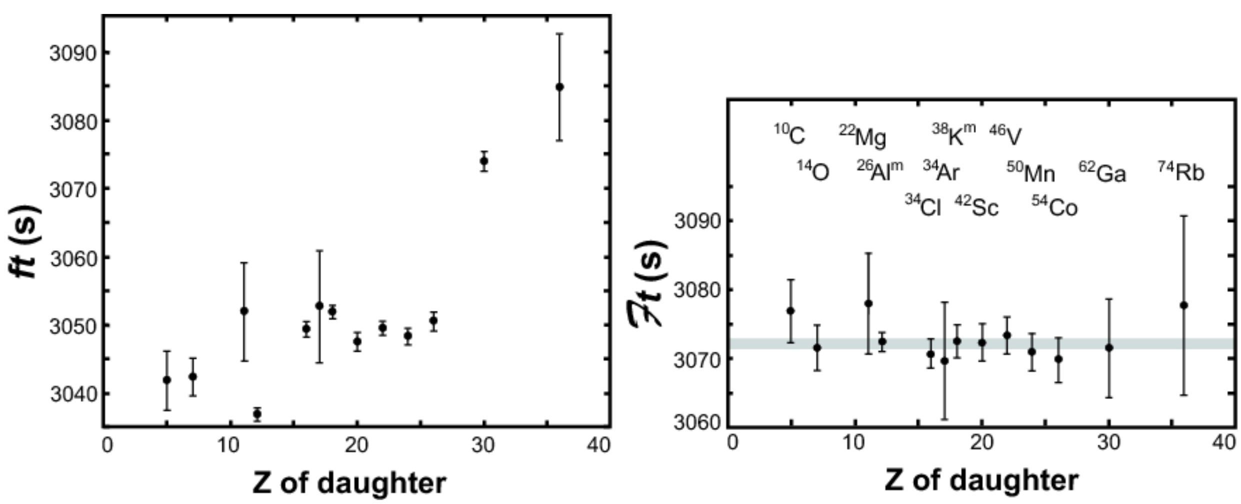

FIG. 1. Results from the 2009 survey [1]. The uncorrected *ft* values for the thirteen best known superallowed decays (left) are compared with the same results after corrections have been applied (right). The grey band in the right-hand panel is the average $\mathcal{F}t$ value, including its uncertainty.

individual measurements, presents a remarkably consistent picture for the nuclear results. Even so, it is still possible for well selected experiments to make real improvements. For example, the validation of the nuclear-structure-dependent correction terms can be improved by the addition of new transitions selected from amongst those with large calculated corrections. If the *ft* values measured for cases with large calculated corrections also turn into corrected $\mathcal{F}t$ values that are consistent with the others, then this must verify the calculations' reliability for the existing cases, which have smaller corrections. At TAMU we are focusing on T_z = -1 parent nuclei, which consistently have higher predicted structure-dependent correction terms than the well known T_z = 0 cases. In that context, during this past year we have been working on half-life measurements for the decays of ^{26}Si [6] and ^{38}Ca [7].

There are also compelling reasons to confirm and improve the *ft* values for the T_z = 0 cases as well. After all, these are the transitions that principally determine the value of V_{ud}. Since ^{46}V was a key transition that led to important improvements in the structure-dependent corrections when its Q_{EC} value was found to have been incorrectly measured by reaction studies in the past, we have been re-measuring its half-life [8] to be sure that no errors are lurking there. In addition we have extended Penning-trap measurements of Q_{EC} values to ^{34}Cl and ^{38}K^m [9], both to improve the precision on these two values and to test more completely for systematic differences between reaction-based and Penning-trap-based Q_{EC} value measurements.

We also continue to focus on improving and securing our analysis procedures for precise branching-ratio measurements. We are working to improve the temperature-stability of our new laser-based system intended to determine the source-to-HPGe-detector distance for each sample delivered by our tape-transport system; and we have continued our source measurements and Monte Carlo calculations to thoroughly characterize our beta detector [10].

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