SUPERALLOWED BETA DECAY STUDIES AT TRIUMF — NUCLEAR STRUCTURE AND FUNDAMENTAL SYMMETRIES*

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(Received January 26, 2007)

* Presented at the Zakopane Conference on Nuclear Physics, September 4–10, 2006, Zakopane, Poland.

Precision measurement of the β-decay half-life, Q-value, and branching ratio between nuclear analog states of $J^{\pi} = 0^{+}$ and $T = 1$ can provide critical and fundamental tests of the Standard Model's description of electroweak interactions. A program has been initiated at TRIUMF-ISAC to measure the ft values of these superallowed beta transitions. Two $T_z = 0$, $A > 60$ cases, ^{74}Rb and ^{62}Ga, are presented. These are particularly relevant because they can provide critical tests of the calculated nuclear structure and isospin-symmetry breaking corrections that are predicted to be larger for heavier nuclei, and because they demonstrate the advance in the experimental precision on ft at TRIUMF-ISAC from 0.26% for ^{74}Rb in 2002 to 0.05% for ^{62}Ga in 2006. The high precision *world data* on experimental ft and corrected Ft values are discussed and shown to be consistent with CVC at the 10^{-4} level, yielding an average $Ft = 3073.70(74)$ s. This Ft leads to $V_{ud} = 0.9737(4)$ for the *up-down* element of the Standard Model's CKM matrix. With this value and the Particle Data Group's 2006 values for V_{us} and V_{ub}, the unitarity condition for the CKM matrix is met. Additional measurements and calculations are needed, however, to reduce the uncertainties in that evaluation. That objective is the focus of the continuing program on superallowed-beta decay at TRIUMF-ISAC.

PACS numbers: 21.10.–k, 23.40.s, 24.80.+p, 27.50.+e

1. Introduction

Precision measurement of the ft-values for superallowed 0^{+} to 0^{+} Fermi nuclear beta decay provides one of the most demanding tests of the Standard Model's description of the electroweak interaction. These ft-values can be determined from measurement of the beta-decay half-life, Q-value, and branching ratio between nuclear analog states of $J^{\pi} = 0^{+}$ and $T = 1$. While the ft values of these superallowed transitions are nearly independent of nuclear structure, they depend uniquely on the vector part of the weak interaction. In confirmation of the conserved vector current hypothesis (CVC), the vector coupling constant G_V is demonstrated, by such measurements, to be constant to better than 3×10^{-4} [1]. Precision measurement of these quantities has constituted an intense and continuous study extending over five decades [1] and has given nuclear physicists access to unambiguous tests of some of the fundamental aspects of the weak interaction.

The CVC hypothesis stipulates that the vector coupling constant G_V is not renormalized in the nuclear medium and thus when combined with the Fermi coupling constant $G_{\rm F}$ (for pure leptonic decays), G_V (from the superallowed data) currently provides the most precise determination of $G_V/G_{\rm F} = V_{ud}$, the *up-down* element of the Cabibbo–Kobayashi–Maskawa (CKM) matrix [1]. The CKM matrix connects the weak-interaction and the mass eigenstates of the Standard Model's three-quark generations. It must satisfy the unitarity condition and if it does not, new physics will be required. The first row of the CKM matrix (V_{ud}, V_{us}, V_{ub}) is the only one that can be tested presently for unitarity with sufficient precision [1]. V_{ud} dominates the first row of the matrix, and the most precise measurement of its value comes from superallowed-beta decay [1]. At the time of the 2005 review of Hardy and Towner [1], the best values for these matrix elements were $|V_{ud}| = 0.9738(4)$, $|V_{us}| = 0.2200(26)$, and $|V_{ub}| = 0.00367(47)$ [1, 2]. With these values, $|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9966(14)$ and unitarity is not achieved. That CKM unitarity failed by more than two standard deviations was essentially the *status quo* over the past two decades or so, and during that period, new measurements on superallowed-beta decay continued to confirm CVC (*i.e.*, Ft = constant) and the value for V_{ud} [1]. However, in regard to CKM unitarity, two values for V_{us} from kaon-decay measurements appeared in 2003 [3] and 2004 [4] that disagreed significantly with the 2004 PDG adopted value [2], but were consistent with one another. Hardy and Towner [1] pointed out in their 2005 review that if these values were used, $|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9993(11)$ and unitarity would be achieved. Very recently, a new PDG evaluation [5], which also included a number of new kaon-decay measurements, proposed that $V_{us} = 0.2257(21)$. If this value is used, in conjunction with V_{ud} and V_{ub} given above, $|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9992(11)$ and CKM unitarity is achieved [5,6]. More details on CKM unitarity with up-to-date values along with a discussion of remaining questions is presented in Section 4.

Nine superallowed beta-decaying nuclei (^{10}C, ^{14}O, ^{26m}Al, ^{34}Cl, ^{38m}K, ^{42}Sc, ^{46}V, ^{50}Mn, ^{54}Co) are particularly amenable to experiment and, consequently, have received considerable attention over the past few decades [1]. With the exception of ^{10}C and ^{14}O, these are all $T_z = 0$ isotopes. In general, the $T_z = 0$ cases are more open to experimental precision because the superallowed decay is by far the largest branch (*e.g.* 99.5% in ^{74}Rb). In recent years, these nine *historical*, well-measured cases, with precision at or below the 0.15% level, have been augmented by measurements on $T_z = -1$ ^{22}Mg and ^{34}Ar [7] and $T_z = 0$ ^{74}Rb [8,9] and ^{62}Ga [11,12], discussed here. While the results for the first three provided precision only to the 0.24% to 0.39% level [1, 10], recent high precision measurements at TRIUMF-ISAC [11, 12], combined with recent high-precision mass measurements at Jyväskylä [13], have lead to an ft for ^{62}Ga with a remarkable precision of 0.05%, which now rivals the best measured *historical* cases.

While the program at TRIUMF-ISAC on the study of superallowed-beta decay includes nuclei below mass 60 (both $T_z = 0$ and $T_z = -1$ cases), we focus in this paper on two $T_z = 0$ nuclei with $A > 60$, ^{74}Rb and ^{62}Ga. In addition to being new superallowed-beta decay cases, the study of these higher Z nuclei has the added objective of evaluating the precision of the small, but critical, charge dependent isospin-symmetry breaking correction which must be calculated and applied to the final experimental ft value.

The several theoretical corrections involved, which are all on the order 1%, are applied [1] to the experimental ft value as follows: $Ft = ft(1+\delta_{\rm R})(1-\delta_{\rm C}) = K/2G_V^2(1+\Delta_{\rm R}) = \text{constant}$. Here, Ft is the transition-independent ft value, K is a constant, $\delta_{\rm R}$ and $\Delta_{\rm R}$ are the transition-dependent and transition-independent parts of the radiative corrections, respectively, and $\delta_{\rm C}$ accounts for the breaking of isospin symmetry by Coulomb and charge dependent nuclear forces. To separate out those terms that are independent of nuclear structure from those that are not, the transition-dependent radiative correction is split into two terms $\delta_{\rm R} = \delta'_{\rm R} + \delta_{\rm NS}$ where $\delta'_{\rm R}$ is a function only of the electron's energy and Z of the daughter nucleus, and $\delta_{\rm NS}$, like $\delta_{\rm C}$, depends upon nuclear structure [1]. Thus, one can write [1] $Ft = ft(1+\delta'_{\rm R})(1+\delta_{\rm NS}-\delta_{\rm C})$. Calculations [14] predict much larger (>1%) isospin-symmetry breaking effects in nuclei for $A > 60$. Thus, if one can compute these corrections reliably where they are large, one can feel assured that the corrections are even more reliable where they are small, as in the *historical* nine cases. Therefore, one of the major efforts at TRIUMF-ISAC on the study of superallowed beta decay focuses on the $T_z = 0$ isotopes above mass 60. These include ^{62}Ga, ^{66}As, ^{70}Br, ^{74}Rb, ^{78}Y, and possibly ^{82}Nb. The first study in this enterprise, the superallowed-beta decay of ^{74}Rb, commenced in 2001 at the time ISAC was being commissioned. It was a successful series of measurements on the half-life and branching ratio and although the results are now old, they are presented here in order to show the evolution of the spectroscopic systems developed since that time, culminating in the very recent measurements on ^{62}Ga which yielded an experimental ft value as good or better than the historical 9 best cases. Information on some of these instrumental developments can be found in Refs. [10, 15] and in the contribution of Garrett to this conference [16]. Thus, the ^{74}Rb [8, 9] and ^{62}Ga [11, 12] studies are singled out here from among the other on-going work at TRIUMF-ISAC on superallowed-beta decay.

2. The ^{74}Rb decay

The study of the ^{74}Rb decay represents the first detailed and precise study of this beta decay as well as the first case in the program underway at TRIUMF-ISAC to make precision ft measurements on superallowed-beta decay. It involved beta, gamma, and conversion-electron spectroscopy and was carried out prior to installation of the 8π spectrometer and its ancillary systems.

The first high-precision measurement of the ^{74}Rb half-life was done at TRIUMF-ISAC in 2001 [8] and was one of the first results from this new Radioactive Beam Facility. In that experiment, ^{74}Rb was produced by bombarding an 11.5 g/cm^2 stack of Nb foils with a 10 μA beam of 500 MeV protons. This high-precision measurement at ISAC used a fast-tape-transport system [17, 18] to collect the low-energy (30 keV) beam of radioactive ^{74}Rb coming from the ISAC isotope separator. The beam was implanted into a 25 mm wide aluminized-Mylar tape of the tape-transport system. After a collection period of about 4 half-lives, the ^{74}Rb beam was interrupted and the samples were moved out of the vacuum chamber through two stages of differential pumping and positioned in a 4π continuous-gas-flow proportional counter. After signals from the 4π counter were multiscaled for about 25 half-lives, the data were stored and the cycle repeated. In a previous measurement of the half-life of ^{74}Rb, carried out by D'Auria *et al.* in 1977, a value of 64.9(5) ms was obtained [19]. The ISAC experiment yielded a result compatible with the precision required for superallowed beta decay studies: 64.761(0.031) ms [8].

For the experiment to determine the branching ratio, the ^{74}Rb nuclei were produced in spallation reactions between the 500 MeV proton beam of 10–20 μA intensity and an electrically heated $^{\mathrm{nat}}$Nb foil stack of 22 g/cm^2 thickness. Apart from the ^{74}Rb decay products, the dominating contaminant was the 8.12 min ^{74}Ga isobar. The mass separated activity was implanted onto a movable tape in a spectrometer system located at the GP2 position on the ISAC beamline. This spectrometer system, shown in Fig. 1, was designed and constructed at Louisiana State University. The transport tape and the Si(Li) detectors are in the center, surrounded by a germanium detector and two plastic scintillators. The scintillators are coupled through light guides to photomultiplier tubes (not shown) located outside the spectrometer vacuum.

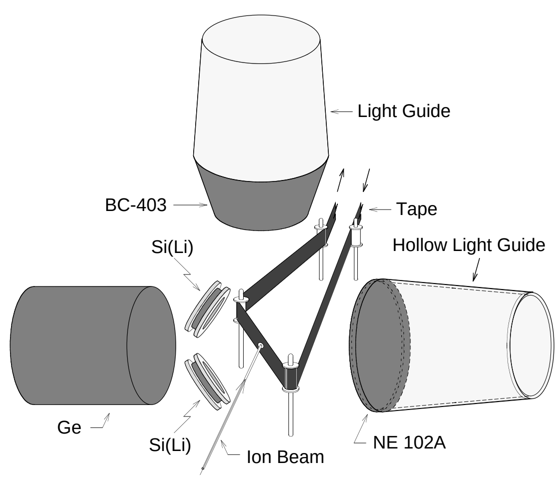

Fig. 1. Sketch of the spectrometer system constructed at LSU that was used in the ^{74}Rb branching ratio experiment.

The tape is 1/2 inch wide and 2 μm thick. It was moved periodically to prevent the buildup of long-lived contaminating activities. The light guide connected to the 2 mm scintillator was made hollow in order to reduce the 511 keV gamma background that results from the annihilation of positrons.

The implantation point on the tape was viewed by the two liquid nitrogen cooled Si(Li) diode detectors of 200 mm^2 area and 5 mm thickness for the detection of conversion electrons, and the 80% efficient HPGe detector recorded the gamma-ray spectra. Two fast NE-102A and BC-403 plastic scintillators of 2 mm and 40 mm thickness registered betas from the mass 74 decays. These beta detectors triggered the list-mode data acquisition in coincidence with the Si(Li) or HPGe detectors, and the thicker of the plastic scintillators provided energy information on the betas. During the measurements, the tape was moved every 4–6 seconds. A total of 2.1×10^8 atoms of ^{74}Rb were counted by means of the thin plastic scintillator.

A part of the conversion electron spectrum is shown in Fig. 2. The line at 495 keV corresponds to the emission of E0 K-shell conversion electrons from the 0_2^+ to 0_1^+ decay of the level at 509 keV in ^{74}Kr. The line at 507 keV corresponds to E0 L-shell conversion of the same transition, while the line at 39 keV corresponds to E2 K-shell conversion of the 52 keV 0_2^+ to 2_1^+ transition (see Fig. 4). Parts of the gamma-ray spectrum measured with the HPGe detector are shown in Fig. 3. This spectrum is dominated by the 511 keV annihilation radiation (not shown) and the ^{74}Ga decay (several lines shown). The line at 456 keV is the 2_1^+ to 0_1^+ E2 transition in ^{74}Kr that

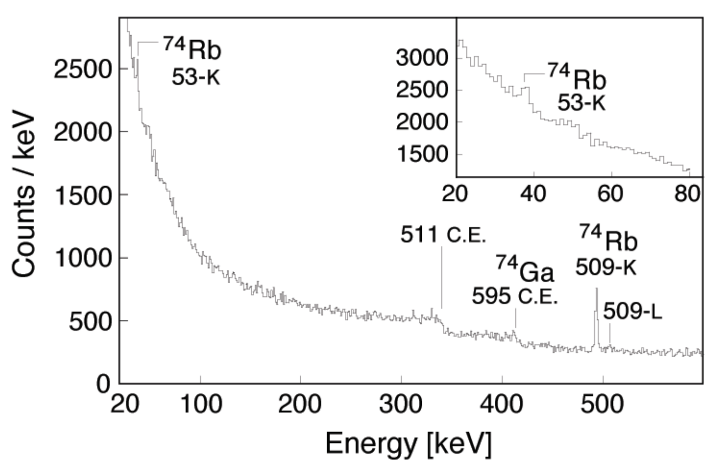

Fig. 2. Parts of the conversion electron spectrum measured with the Si(Li) diodes. Figure taken from Ref. [9].

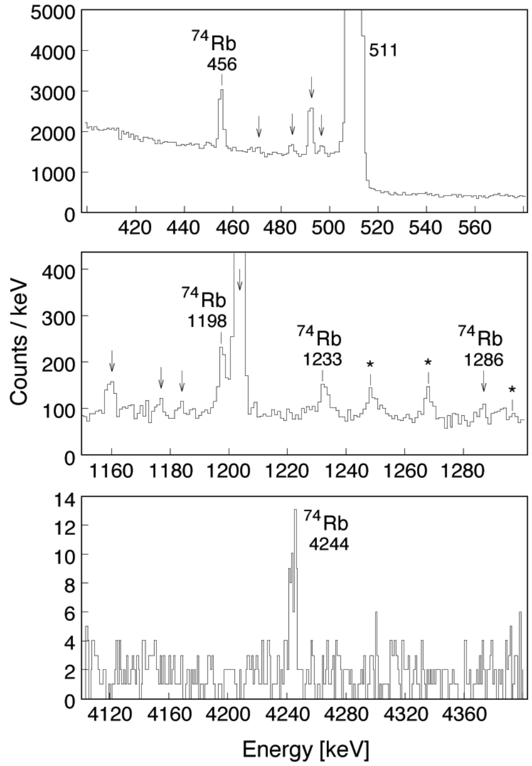

Fig. 3. Spectrum of the gamma rays from the ^{74}Rb decay. Arrows and stars indicate contamination from ^{74}Ga and ^{74}Br respectively. Figure from Ref. [9].

is well known from in-beam data and has an intensity of 0.002450 per ^{74}Rb decay [9]. Its observation clearly demonstrates that ^{74}Rb undergoes Gamow–Teller transitions to higher lying 1^+ states. As pointed out by Hardy and Towner [20], this decay branch is a critical factor in the ultimate precision of the measured superallowed ft value.

In the decay scheme presented in Fig. 4, total transition intensities are given in units of 10^{-5} per ^{74}Rb beta decay. The decay scheme shows that the low-lying levels in ^{74}Kr can act as collector states for intensity coming from unobserved, Gamow–Teller populated, 1^+ states, and that by observing their de-excitation, a large fraction of the non-analog feeding can be determined. The remaining component, which directly populates the ground state, can be deduced using a shell model calculation [14] that reproduces the relative gamma-ray intensities quite well. In this way, the superallowed ground-state branch was determined to be 99.5(1)% [9].

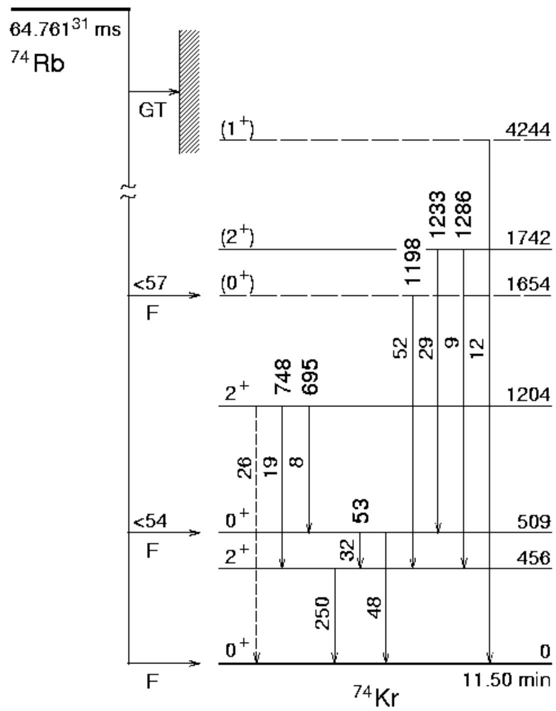

Fig. 4. The ^{74}Rb decay scheme. Intensities are given in units of 10^{-5}, thus, the branch to the 0^+ ground state is 99.5(1)%, leaving only 0.5% of ^{74}Rb decays to populate the excited states. Figure from Ref. [9].

These data on ^{74}Rb are old, but are presented here in order to demonstrate that since such excellent results were achieved with the rather rudimentary spectrometer system shown in Fig. 1, it is not unreasonable to expect nearly an order of magnitude improvement in the precision of the ^{74}Rb superallowed beta-branching ratio by using the new spectroscopy systems centered on the 8π spectrometer that were used in the high precision results obtained for ^{62}Ga [12]. Consequently, plans are underway to re-measure ^{74}Rb decay with the 8π spectrometer and its ancillary detector systems.

3. The ^{62}Ga decay

The half-life of the ^{62}Ga superallowed-beta decay was measured at TRIUMF-ISAC in 2003 by implanting a beam of approximately 200 ^{62}Ga ions/s into the aluminum tape of the same fast-tape-transport system used to measure the half-life of the ^{74}Rb decay — described in Section 2. The half-life was determined to be 116.01(0.19) ms [11]. By including this measurement with six previous measurements [11], the *world average* half-life of ^{62}Ga becomes 116.17(0.04) ms. This *world average* is dominated by the single high-precision measurement of Blank *et al.* [21].

The ^{62}Ga superallowed-beta branching ratio was recently measured at TRIUMF-ISAC [12] using a much improved ion-source system. For this experiment a 35 μA beam of 500 MeV protons induced spallation reactions in a 24 g/cm^2 ZrC target. The TRIUMF Resonant Ionization Laser Ion Source (TRILIS) [22] was used to selectively ionize Ga isotopes that were mass separated to provide a low-energy (30 keV) beam of about 2000 ^{62}Ga ions/s. This beam was implanted in a mylar tape at the mutual centers of SCEPTAR [10], an array of 20 thin (1.6 mm) plastic scintillators, and the 8π Spectrometer [23], an array of 20 Compton-suppressed HPGe detectors. In addition to Refs. [10, 12, 23] the reader is referred to the paper of Garrett in these proceedings [16] for descriptions of the experimental systems used. One-half of the 8π array is shown in Fig. 5. The black delrin sphere (approximately 7 inches in diameter) is part of the beamline. It contains SCEPTAR and the 1/2 inch mylar tape. This is shown in Fig. 6 where one of the delrin hemispheres has been removed. One-half of the SCEPTAR array sits right behind the tape. The other half is contained in the hemisphere not shown in Fig. 6 (see Fig. 5).

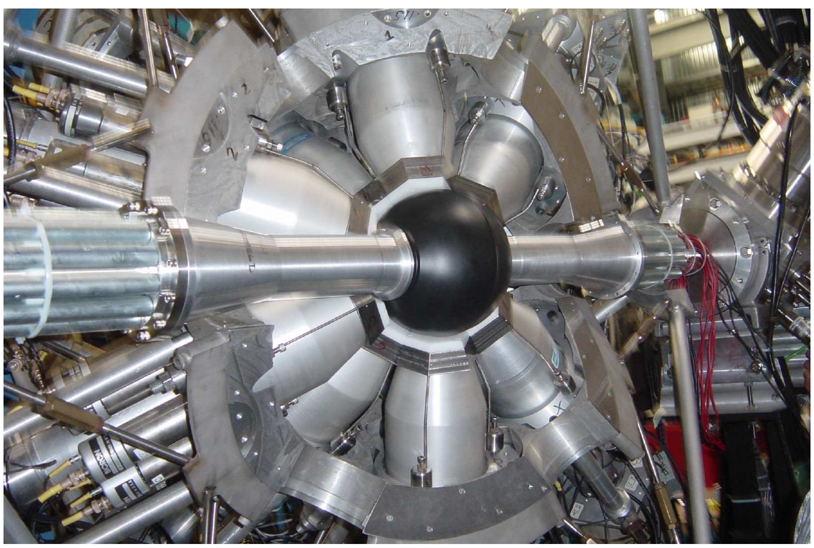

Fig. 5. A view of the 8π opened showing half of the array and the beamline with the black delrin sphere at the center. The sphere separates at the *O-ringed* equator (which lies in a vertical plane) so that the left half can be moved out of the 8π array.

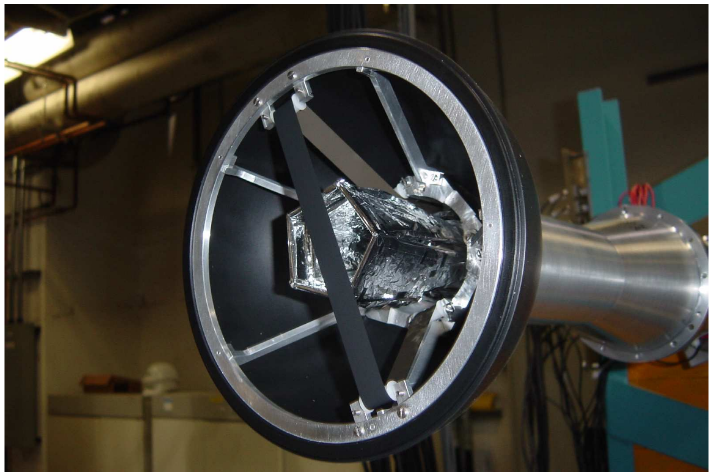

Fig. 6. A view of the 1/2 inch tape traversing the delrin hemisphere. The 10 element half of the SCEPTAR beta detector lies directly behind the tape. The tape system (MTC), not shown, was constructed at LSU.

Data were collected in cycles consisting of 2.0 s of background, a 10.0 s beam-on period during which the 116 ms ^{62}Ga activity saturated, and 2.0 s of decay counting with the beam off. The tape was then moved to limit the activity from decay products and long-lived isobaric contaminants in the beam. This cycle was repeated 19,055 times during the experiment and resulted in the detection of 2.228(17) $\times 10^8$ betas during the "beam on" period. This summed beta activity is shown in the upper left part of Fig. 7. The Compton-suppressed and bremsstrahlung-suppressed gamma-ray spectrum from the 20 HPGe detectors of the 8π array as recorded in coincidence with beta particles is shown in the remaining parts of Fig. 7. The upper panels represent gamma-rays recorded during the "beam on" period, while the lower panels show gamma rays from the "beam off" period — after the ^{62}Ga activity had decayed to a negligible level. Careful analysis of the separate coincidence spectra collected during the "beam on" and "beam off" periods enabled one to clearly distinguish gamma-rays emitted following ^{62}Ga decay from those associated with the long lived contaminants. Previous studies of ^{62}Ga decay (see Ref. [12]) reported only three gamma-ray transitions in ^{62}Zn. In the current experiment, 19 gamma-rays emitted following ^{62}Ga beta decay have been identified and placed in the decay scheme shown in Fig. 8. These data confirm the 0_2^+ state at 2342 keV and establish 5 states with $J^\pi = 1^+$ whose beta-populations, although extremely small, must be measured to obtain the requisite precision on the superallowed-beta branch, as pointed out by Hardy and Towner [20] and discussed in Section 2 for ^{74}Rb.

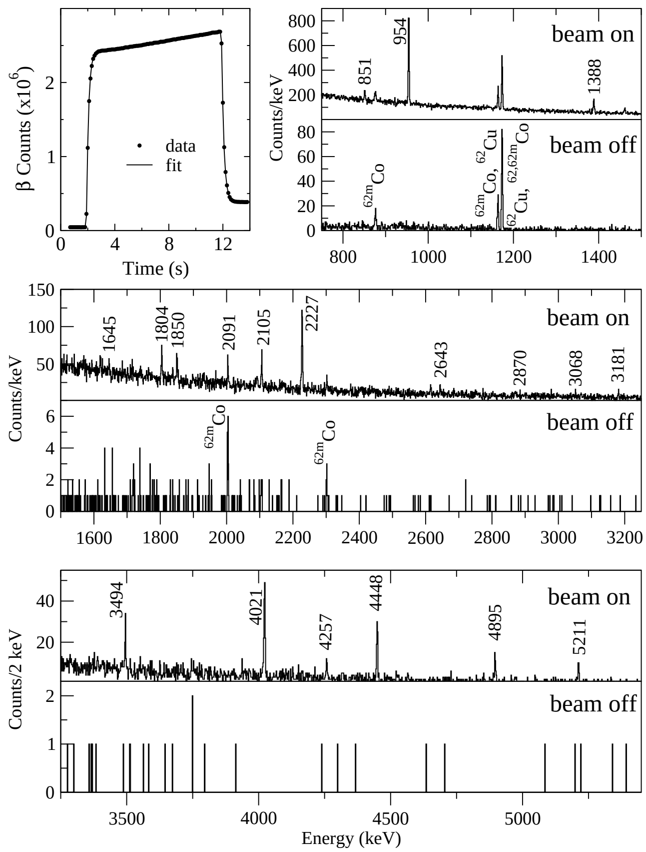

Fig. 7. The upper left panel shows the total beta activity from ^{62}Ga decay. The other panels are the beam-on (top) and beam-off (lower) parts of the gamma-ray spectra. Figure from Ref. [12].

In order to appreciate the sensitivity of this experiment, the intensity of the strongest line shown in Fig. 8, 954 keV, is only 809(33) parts per million (ppm) of ^{62}Ga beta decays, that is, one 954 keV gamma ray out of more than a thousand betas. The 3068 keV transition, for example, is only 14(7) ppm [12]. The non-superallowed-beta branching in the decay of ^{62}Ga is obtained by summing the intensities of all gamma-rays feeding the ^{62}Zn ground state and adding to that the total intensity of all unobserved ground-state transitions. To determine this latter quantity one can use the low-lying 2^+ states, for which the direct beta feeding would be second forbidden (and thus negligible), as collector states and use an updated shell-model calculation [24] with the effective Gamow–Teller strength quenched to 0.73 (as was done in the ^{74}Rb study [9]) to compute 0.010(10)% for the

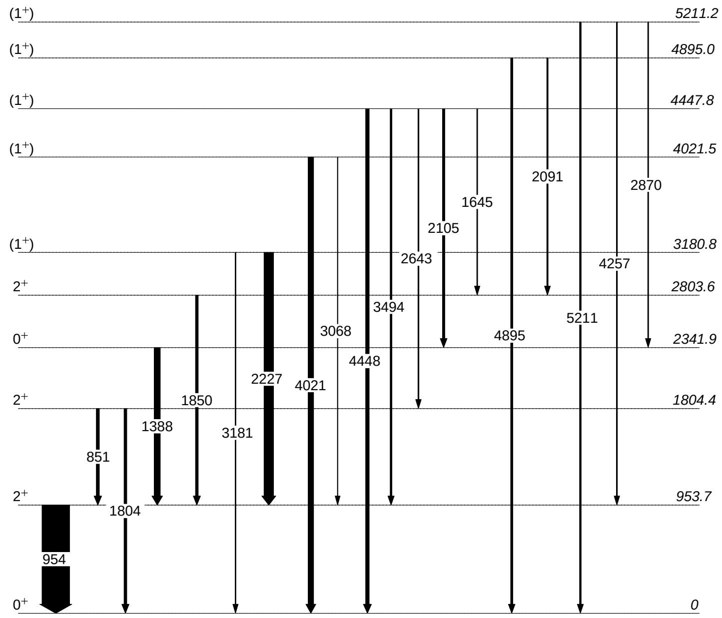

Fig. 8. The states in ^{62}Zn populated by the beta decay of ^{62}Ga. The arrow widths are scaled to transition intensities. With 99.86% of the decay going to the 0_1^+ state, only 0.14% of the decay populates the excited states. Figure from Ref. [12].

unobserved ground-state-transition intensity. Combined with the observed ground-state-transition intensity of 0.129(5)%, the non-superallowed branch becomes 0.139(11)%, leaving 99.861(11)% for the superallowed-beta branch (see Hyland *et al.* [12] for more details).

4. $\boldsymbol{Ft}$ values and CKM unitarity

As discussed in Section 1, the three quantities needed to compute ft are the superallowed-beta decay half-life, branching ratio, and $Q_{\rm EC}$ value. For ^{74}Rb we use $T_{1/2} = 64.761(0.031)$ ms [8] and branching ratio 99.5(1)% [9] from our data, along with a $Q_{\rm EC}$ value of 10416.8(4.4) keV from Kellerbauer *et al.* [25]. These quantities yield 3084.3(8.0) s for the ^{74}Rb uncorrected ft value. For ^{62}Ga, we use the world average $T_{1/2} = 116.173(38)$ ms [12] and branching ratio 99.861(11)% from our data [12], along with $Q_{\rm EC} =$ 9181.07(0.54) keV from Eronen *et al.* [13]. These quantities yield $ft =$ 3075.6(1.4) s for the ^{62}Ga uncorrected ft value. These uncorrected ft values are shown plotted in the upper panel of Fig. 9. This result for ^{62}Ga represents the first case in the $A > 60$ mass region with experimental ft uncertainty on the order of 0.05%, which rivals the best measured cases among the lighter nuclei, including the *historical* 9.

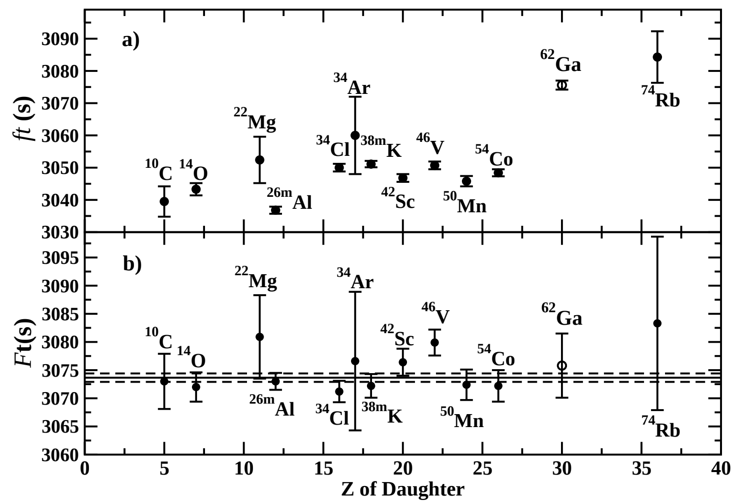

Fig. 9. The 13 precision superallowed ft (upper) and Ft (lower) values. The $Ft_{\mathrm{avg}} = 3073.70(74)$ is obtained using the current result for ^{62}Ga (open circle) and the 12 values given in Table 1 of Ref. [7] (solid circles). Figure from Ref. [12].

For ^{74}Rb the correction terms from Hardy and Towner [1] are $\delta'_{\mathrm{R}} = 1.49(12)\%$ and $\delta_{\mathrm{C}} - \delta_{\mathrm{NS}} = 1.50(41)\%$ yielding a corrected $Ft = 3084(15)$ s (see equation Section 1). For ^{62}Ga the corrections are 1.405(89)% and 1.38(16)% [12], which yield a corrected $Ft = 3075.8(5.7)$ s. These values are plotted in the lower panel of Fig. 9. The average of the 13 precision Ft values shown in Fig. 9, $Ft_{\mathrm{avg}} = 3073.70(74)$ s [12], is obtained using the 12 values given in table 1 of Savard *et al.* [7] and the value for ^{62}Ga determined in Ref. [12]. It is important to point out that the recent mass measurements of Savard *et al.* [7] using the Canadian Penning trap produced a Q_{EC} value for ^{46}V which differed by 2 keV from the 2005 survey result [1]. This Q_{EC} made the Ft value for the ^{46}V transition anomalously high with respect to the other superallowed transitions (see Fig. 9). There was considerable concern that this measurement might indicate a problem with other mass measurements, which, when corrected, would lead to a significant shift from the 2005 survey [1] result. This does not appear to be the case, however. Penning trap mass measurements at Jyväskylä [26], while confirming the Savard *et al.* Q_{EC} value for ^{46}V [7], demonstrated through Q_{EC} measurements on ^{26m}Al and ^{42}Sc decay that no significant shift in the deduced value of V_{ud} should be anticipated as a result of systematic errors in mass measurements [26]. Thus, using the value $Ft_{\mathrm{avg}} = 3073.70(74)$ s, one computes $V_{ud} = 0.9737(4)$. This is nearly identical to $V_{ud} = 0.9738(4)$ given by Hardy and Towner in their 2005 survey [1] and $V_{ud} = 0.97377(27)$ given in the 2006 PDG evaluation [5].

The PDG [5] value for $V_{ud} = 0.97377(27)$, given above, follows the recent work of Marciano and Sirlin [27] who made a major advance in controlling the theoretical hadronic uncertainties in $\Delta_{\rm R}$ and improved the precision of V_{ud} by almost a factor of two. Applied to the ft values of Ref. [7], these corrections yield $V_{ud} = 0.97377(11)(15)(19)$ [27] where the uncertainties are associated with (a) the experimental ft values combined with the transition-dependent components of the radiative corrections, (b) a discrepancy between two independent calculations [14, 28] of the isospin-symmetry breaking corrections, and (c) the remaining uncertainty in the transition-independent radiative corrections. Future lattice QCD calculations should be able to reduce this final (c) uncertainty [27]. Therefore, the precision of V_{ud} determined from the superallowed-beta decay data may ultimately become limited by the strongly nuclear-structure-dependent $\delta_{\rm C}$ corrections for isospin-symmetry breaking [12]. That is why it is important to continue to measure additional $T_z = 0$, $A > 60$ isotopes and to re-measure the ^{74}Rb decay.

In regard to CKM unitarity, Marciano and Sirlin [27] obtained $|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9992(5)(4)(8)$ where the uncertainties are associated with V_{ud}, V_{us}, and a calculated form factor, $f_+(0)$, respectively. The form factor, $f_+(0)$, involves strangeness-changing decays and is associated with V_{us}. While these results are consistent with CKM unitarity, a future violation of unitarity is still possible [27]. That possibility demands that all sources of uncertainty be reduced through new experiments and new calculations.

5. Discussion

Results of measurements on the superallowed beta decay of ^{74}Rb (old) and ^{62}Ga (recent) were presented in order to demonstrate that through the development of more sophisticated spectrographic equipment and techniques during the intervening years, TRIUMF-ISAC is in a most favorable position to measure the as yet unstudied superallowed-beta emitters, and to improve the experimental precision on a number of those presented in Fig. 9. For cases where conversion-electron spectroscopy is needed (*e.g.*, ^{74}Rb), one of the beamline sections containing a delrin hemisphere (see Figs. 5 and 6) can be replaced with a beamline section containing the PACES spectrometer (Pentagonal Array for Conversion-electron Spectroscopy). The beamline section and PACES are shown in Fig. 10. Conversion-electron spectra obtained with this system are presented by Garrett *et al.* in these proceedings [16] and in Ref. [15]. The 8π has also recently been outfitted with DANTE, an array of 10 BaF_2 crystals for fast-timing experiments [16]. This system may not seem, at first glance, to be relevant to measurements on superallowed-beta decay, but as has been demonstrated, it is essential to

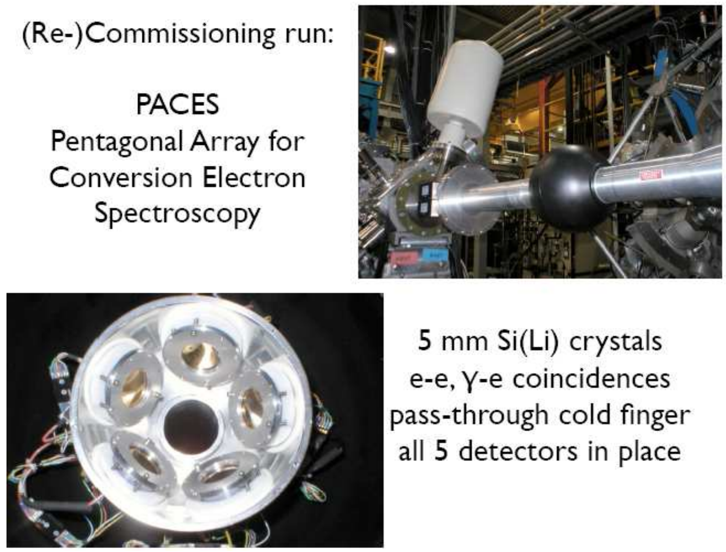

Fig. 10. The conversion electron spectrometer PACES, constructed at LSU, is shown mounted at the center point of the 8π spectrometer (upper photo — see also Fig. 5). The 5 Si(Li) detectors are shown mounted (lower photo) in the LN2 cryostat inside the delrin hemisphere. The beam travels through the hollow *cold-finger* to be deposited on the tape (not shown) at the focal point of the Si(Li) array.

ascertain as much about the structure of the daughter nucleus in order to extract precise ft values from the measurements and to make reliable theoretical corrections [9, 12]. Additionally, TRIUMF-ISAC is developing TITAN (TRIUMF's Ion Trap for Atomic and Nuclear science) to make precise mass measurements [29]. TITAN will be a unique facility for mass measurements capable of accuracies required for precise ft determinations even for very short-lived isotopes ($T_{1/2} < 50$ ms). It will employ a Penning trap coupled to an electron-beam ion trap for charge breeding. With all these systems available at ISAC, one will be able to measure all three quantities needed to extract a precision ft value, namely half-life, branching ratio, and Q_{EC}. The future looks bright for the continuation of measurements on superallowed-beta decay at TRIUMF-ISAC, and the results, especially on Isotopes of $A > 60$, will play an important role in the continued study of the electroweak interaction and on the final determination of CKM unitarity.

This work was supported by the institutions with which the authors are affiliated and by the National Research Council (Canada), the Natural Sciences and Engineering Research Council (Canada), the Department of Energy (USA), the National Science Foundation (USA), and the Engineering and Physical Sciences Research Council (UK).

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