Update on the superallowed branching ratio in the $^{34}$Ar

V.E. Iacob, J.C. Hardy, M. Bencomo, H.I. Park, L. Chen, V. Horvat, N. Nica, B.T. Roeder, and A. Saastamoinen

Last year we reported a measurement of the branching ratios in the decay of $^{34}$Ar [1]. This experiment, along with a more precise half-life value [2] is expected to yield an $f_t$ value for the superallowed transition from $^{34}$Ar whose accuracy matches that of the well-known superallowed decays used in generating the corrected $\mathcal{F}$ values that are instrumental in extracting $V_{ud}$ and testing the unitarity of the CKM matrix [3].

The experiment described in Ref. [1] measured $\beta$-$\gamma$ coincidences and $\beta$ singles from cyclotron-produced $^{34}$Ar sources placed between a 1-mm-thick plastic scintillator (located 2.5 mm from the source) and our efficiency-calibrated HPGe detector [4] (151 mm from the source). Since then, we have analyzed the data to obtain the precise photopeak areas for all the $\gamma$ rays observed (at 461, 666, 2580, and 3129 keV). The statistical uncertainties range from 0.8% to 2.5%, the higher ones being associated with the $\gamma$ rays generated by the weaker $\beta$-decay branches (~1% or less).

These areas have to be corrected for losses. All observed $\gamma$ rays de-excite an excited state directly to the $^{34}$Cl ground state. Any $\gamma$-cascades, if they occur at all, are too weak to be detected. Thus, true $\gamma$-ray coincidences in the HPGe detector cannot occur. However, the $\gamma$ rays and the decay positrons are coincident on the timescale of our electronics and there are two mechanisms by which those positrons can generate coincident photons: (a) bremsstrahlung and (b) annihilation, either in flight or at rest. If these photons appear in the HPGe detector in coincidence with a $\gamma$ ray, then the total energy recorded in the detector is increased, thus resulting in some of the $\gamma$-ray photopeak events being lost. The combined correction associated with photon losses due to true coincidences with bremsstrahlung and positron annihilation is 2.4%.

The branching ratio for the $\beta$-decay branch $k$, which leads to emission of a $\gamma_k$ photon, can be expressed as the ratio between the $\beta_k$-$\gamma_k$ coincidences and the total number of decays (or $\beta$’s). Highly simplified, this can be expressed as:

$$BR_k = \frac{N_{\beta_k \gamma_k}}{\epsilon_{\beta_k} \epsilon_{\gamma_k}} \frac{N_{\beta_{tot}}}{\langle \epsilon_{\beta} \rangle}$$

Here $N_{\beta_k \gamma_k}$ is the number of observed $\beta_k$-$\gamma_k$ coincidence events (the $\gamma_k$ photopeak area), $N_{\beta_{tot}}$ is the total number of observed $\beta$’s associated with the $^{34}$Ar decay, $\epsilon_{\gamma_k}$ is the absolute photopeak efficiency for $\gamma_k$, $\epsilon_{\beta_k}$ is the absolute detection efficiency for a branch-$k$ positron in the plastic scintillator, and $\langle \epsilon_{\beta} \rangle$ is the average detection efficiency for all decay positrons in the plastic scintillator.

The parent $^{34}$Ar ($t_{1/2}=0.84$ s) decays to $^{34}$Cl, which itself is $\beta^+$-unstable ($t_{1/2}=1.53$ s). Obviously, it is only the $\beta$’s associated with the $^{34}$Ar decay alone that must be used in Eq. (1). Taking the known half-lives of the two nuclei, the measured time-profile of the $^{34}$Ar beam implantation, and the collect-move-
detect time-values, we determined that 47% of the total β singles recorded are associated with the parent decay. In addition, small corrections have to be applied to take account of beam impurities (~0.08%).

The plastic-scintillator efficiency for detecting β’s has a small dependence on the β-spectrum energy and, as a result, small corrections related to the ratio $\left(\varepsilon_\beta\right)/\varepsilon_\beta$ also must be applied. These corrections were derived from Monte Carlo calculations and range from -3% to +1%; the negative values correspond to weak β branches that populate high-energy excited states. Overall this leads to an average contribution of 0.4% to the final superallowed branching ratio since the whole decay is dominated by the ground-state branch.

Naturally, corrections are required to correct for all forms of dead time: in the singles channels and in the β-γ coincidences. Their combined contribution is 0.4%.

Last, small corrections must be applied to the results to incorporate the very small contribution from electron capture, which affects the decay branching but does not lead to β-coincident γ rays in our measured spectrum. For the branches in $^{34}$Ar decay these corrections range from 0.07% to 1.2%.

The data analysis continues.