Superallowed beta branching-ratio measurement of ^{10}C

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

^{10}C is the lightest superallowed $0^+ \rightarrow 0^+$ β emitter. Its superallowed branch is one of the 14 most precisely measured transitions that are used to derive the upper left element, V_{ud}, of the Cabibbo-Kobayashi-Maskawa (CKM) quark mixing matrix [1,2]. This element is an essential ingredient of the most demanding test available of the unitarity of the CKM matrix, a fundamental principle of the Standard Model of Particle Physics.

For each contributing superallowed transition, its comparative half-life, or $\mathcal{F}t$ value, has been determined to a precision of ~0.1%. This means that the three experimental quantities required (half-life, superallowed β-branching ratio and the decay Q_{EC}-value) and several (small) theoretical corrections must each be known to even higher precision.

What makes ^{10}C an especially interesting case is its sensitivity to the possibility of a scalar weak current, the presence of which would be a signal for physics beyond the Standard Model. Currently, the $\mathcal{F}t$ value of ^{10}C is slightly off from the world-average, hinting at interesting possibilities. To confirm whether the ^{10}C $\mathcal{F}t$ value really points towards physics beyond the Standard Model, more precise input data are needed to determine its $\mathcal{F}t$ value with greater precision. The half-life, Q_{EC} value and the theoretical corrections are all known to contribute less than 0.04 % to the $\mathcal{F}t$ value's relative uncertainty. What sticks out is the branching ratio, which is "only" known to ±0.13 %. Our goal is to equal or improve this uncertainty.

There are two major reasons that the branching-ratio measurement is such a challenge. The first is that the superallowed 0^+ state in the daughter nucleus depopulates by the emission of a 1022-keV gamma ray. This is exactly twice the energy of the 511-keV photons released by positron annihilation, which means that *piled-up* detector signals contribute unwanted counts to the 1022-keV γ-ray peak. The second reason is that the branching ratio itself is very small (1.4646(19)%). These two factors lead to opposite demands: The first calls for low count rates, while the second requires a vast amount of data to achieve statistical precision.

We have now made two one-week-long measurements to determine the branching ratio. The first measurement was carried out in November 2015 and the second in July 2016. In the first run, we used our well-established beta-gamma coincidence setup, composed of a finely calibrated HPGe detector [3] and a plastic scintillator detector [4]. The second measurement was more "experimental". Instead of using the scintillator, which has ~45% solid-angle coverage, we opted to use our 4π proportional gas counter which has nearly 100% coverage. Unfortunately, the insulation vacuum of the HPGe detector failed during the second measurement so we had to resort to our less-well-calibrated back-up HPGe detector.

In principle, the determination of the ^{10}C superallowed branching ratio is simple since the beta decay proceeds either through the T=1, 0^+ state or a lower-energy T=0, 1^+ state in the daughter ^{10}B; the branch to the ground state is second forbidden. The 0^+ state depopulates by emitting 1022-keV and 718-keV gamma rays, while the 1+ state depopulates by just emitting a 718 keV gamma ray. The superallowed branching ratio is then just the ratio of 1022-keV to 718-keV gamma rays. In practice this is not at all simple because of various systematic effects, including pile-up of annihilation radiation. The data analysis is progressing.

To arrive at the absolute number of 718-keV and 1022-keV gamma rays measured in β-γ coincidence, the efficiency of both the HPGe detector (for gammas) and the beta detector (either the scintillator or the gas detector) are needed. Both efficiencies are obtained from Monte Carlo simulations, the former being anchored by meticulous experimental calibration [3]. As a further check of the HPGe efficiencies we produced a calibration source that had vary similar γ-ray energies to the ^{10}C decay; this also allowed us to use the data from our backup detector.

The 511+511 pileup was characterized with sources and allowed us to determine the pileup "time constant" to within a few percent precision. This is enough to allow us to reach our goal of 0.1% precision, since we tuned the decay rate during the measurements so that the 1022-keV peak never contained more than a 5% contribution from pileup events.

We aim to finish the analysis during 2017.

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