Preliminary measurement of the superallowed β-branching ratio of ^{10}C

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^{10}C is one of the superallowed $0^+ \rightarrow 0^+$ β emitters that can be used to test the Standard Model of Particle Physics [1]. It is the V_{ud} matrix element of the Cabibbo-Kobayashi-Maskawa (CKM) quark mixing matrix that can be derived from the superallowed β emitters, and V_{ud} is a key component used in testing the unitarity of the matrix.

There are three experimental quantities that are required with high precisionin order for a superallowed β decay to contribute to these studies. These are the half-life ($t_{1/2}$), branching ratio (BR) and the total decay energy (Q_{EC}). In addition, a few theoretical corrections of order 1% are needed to correct for radiative and isospin-symmetry-breaking effects. Combined, a comparative half-life value, denoted $\mathcal{F}t$, is obtained for each transition. The average of $\mathcal{F}t$ values for the 14 transition currently known with high precision yields the world-average $\mathcal{F}t$ value that is used for testing the Standard Model.

For ^{10}C, all the three experimental quantities have already been measured with quite high precision, but the branching ratio has a fractional uncertainty three times that of the half-life and the Q_{EC}-value of the transition, as can be seen from Fig. 1. Thus, any improvement in the precision of the branching ratio alone would directly translate into an improvement in the $\mathcal{F}t$ value for ^{10}C. The current branching ratio value of 1.4646(19)% derives primarily from two twenty-year-old measurements [2, 3].

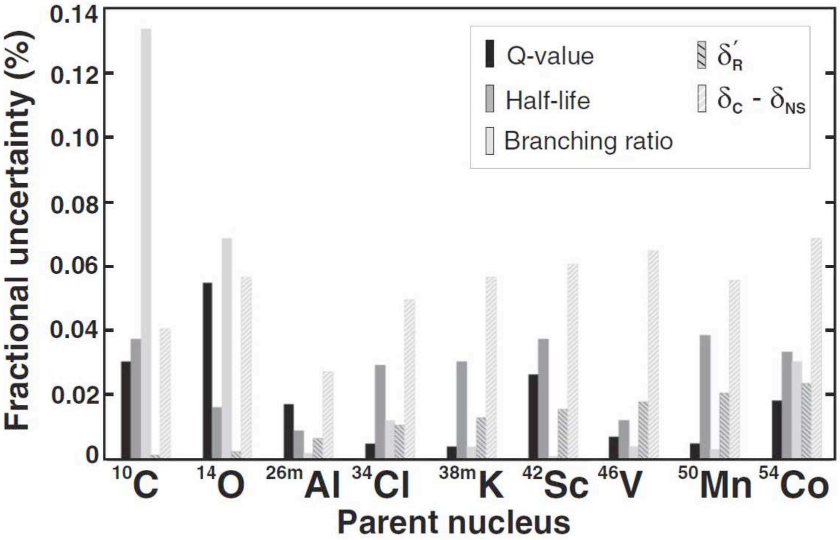

FIG. 1. Fractional uncertainties of experimental and theoretical quantities for some of the superallowed β transitions used to test the unitarity of the CKM matrix. Clearly the branching ratio of ^{10}C needs to be improved if it is to be equivalent to the rest of the quantities. This figure is from Ref. [1].

More interesting than just the precision of the $\mathcal{F}t$ value itself is its relationship to the world average of $\mathcal{F}t$ values for transitions in heavier nuclei, since the ^{10}C transition is the most sensitive to the possible presence of a scalar current. Currently the $\mathcal{F}t$ value for ^{10}C is slightly higher than the world average $\mathcal{F}t$ value, with an error bar that just about touches the world average value's error bar. If a more precise $\mathcal{F}t$ value of ^{10}C were found to deviate with greater statistical significance, it would be a signal for the existence of a scalar current.

A project to improve the superallowed β branching ratio of ^{10}C was initiated at the Cyclotron Institute of Texas A&M University in the Fall of 2015. One week of beam time was used in November 2015 to produce ^{10}C via the ^{1}H(^{10}B,n)^{10}C reaction. In this preliminary investigation, we measured the branching ratio using the $\beta - \gamma$ coincidence setup that has been specifically developed here for extremely high-precision branching-ratio measurements. It includes a germanium detector that has been calibrated to 0.15% relative absolute efficiency [4] and a thin scintillator for detecting positrons. The angular coverage of the germanium detector is about 1% and the scintillator about 40%. The setup has already been used several times for other branching ratio measurements, (e.g. see Ref. [5]).

The decay scheme of ^{10}C is relatively simple, as seen in Fig. 2. In principle the superallowed branching ratio can be obtained directly from a ratio of the observed rate for the 1022-keV γ ray relative to the rate for the 718-keV γ ray, but in practice there are several important systematics effects that need to be carefully taken into account.

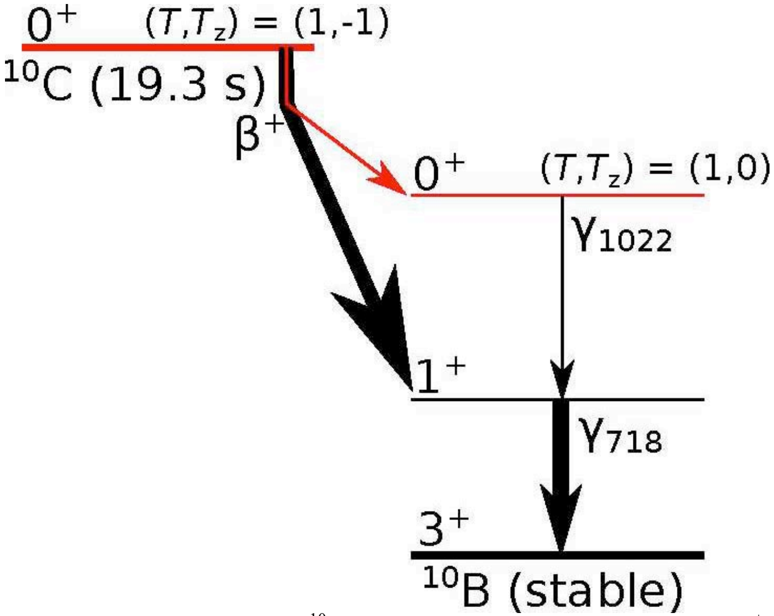

FIG. 2. Decay scheme of ^{10}C. Most of the decays populate the 1^+ state directly, with only a small fraction of about 1.5% proceeding through the superallowed transition to the 0^+ state. The two decay paths merge at the 718 keV level, so there is a 718 keV γ emitted in every decay. The superallowed transition is marked in red.

Pileup of detector signals

To get enough statistics for the weak superallowed branch (the 1022 keV γ-ray line), a sufficient decay rate is needed in a limited beam-time period. High rate, however, increases the chance of detector signals piling up. This is especially troublesome for the 1022-keV γ-ray peak since 511-keV photons originating from positron annihilation can pile up at that energy, causing interference with the relatively weak γ-ray peak. With the decay rates during our first measurement the fraction of pileup counts of the whole peak was determined to be 5-10%. Separate studies to characterize the 511+511 keV pileup are ongoing.

Positron detection efficiency

The endpoint energy of the emitted positrons in the $0^+ \rightarrow 0^+$ branch is rather low, about 1 MeV, whereas the endpoint energy for the $0^+ \rightarrow 1^+$ branch is about 2 MeV. These energies are so significantly different that the scintillator's detection efficiencies for the two transitions differ by more than 10%. The energy dependence of the scintillator's efficiency is now being characterized with sources and Monte Carlo simulations.

Gamma detection efficiency

The germanium detector has been extensively efficiency-calibrated with both Monte Carlo simulations and sources [4]. To confirm these results for our specific energies – 718 and 1022 keV – we are using sources with similar energies.

Analysis of the data collected in the November 2015 run is ongoing. Another run is needed to obtain sufficient statistics in the 1022 keV peak. In November, we maximized the production rate by using all the available beam intensity. Unfortunately isotopically enriched ^{10}B was not available for use in the ion source at that time, leaving a potential boost of ×5 for the future. The rate should be not too high, though, to swamp the 1022 keV peak with pileups rather than the 1022-keV γ rays we seek to measure.

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