EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Status Report to the ISOLDE and Neutron Time-of-Flight Committee

IS527: Precision measurement of the half-life and branching ratio of the T=1/2 mirror β decay of ^{37}K:

January 14, 2014

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Abstract

We propose to study the T=1/2 mirror β decay of ^{37}K. Nuclear mirror β decay is a competitive mean to test the electroweak model by means of the high-precision measurement of V_{ud} element of the CKM quark mixing matrix. One key ingredient to obtain V_{ud} is the strength of the transition, Ft, which has to be determined with a relative precision better than 10^{-3}. This quantity is related to the half-life $T_{1/2}$ of the decaying nucleus, the branching ratio BR for the mirror decay and the mass difference between the mother and daughter nuclei (Q value). Another important feature is the mixing ratio ρ between Fermi and Gamow-Teller character of the transition. In most cases, ρ is the major contributor to the uncertainty on Ft. Available data concerning $T_{1/2}$ and BR of ^{37}K suffer from a lack of precision that will be easily reduced by a dedicated experiment.

Remaining shifts: 16 shifts

1. Motivation, experimental setup/technique

The nuclear β decay is an ideal laboratory to study the underlying fundamental symmetries of the standard model (SM) at low energies. According to SM, in the nuclear β^+ decay an up quark disappears and a down quark and a virtual W^+ boson are produced. The W^+ boson then decays to produce a e^+ and a ν_e. The β^+ decay is inherently sensitive to the physics of the weak interaction, and small deviations of experimental results from SM predictions translate directly into new physics beyond SM. In the case of the three quark families, the quark mixing is expressed by means of the Cabibbo-Kobayashi-Maskawa (CKM) [1] matrix. The CKM-matrix relates the quark weak interaction eigenstates to the quark mass eigenstates and, as such, the normalization of the states requires the CKM-matrix to be unitary. Up to now only the matrix elements V_{ud} and V_{us} have been determined with a precision of a 10^{-3} level and thus the most precise test of the unitarity to date is obtained from the first row of the CKM-matrix, i.e. $V_{ud}^2+V_{us}^2+V_{ub}^2=1$. The dominant input is the up-down element (V_{ud}) that has been most precisely determined from super-allowed pure Fermi transitions [2]. However nuclear mirror transitions between T=1/2 isospin doublets, offer an additional source to determine V_{ud} and thus to test the unitarity of the CKM matrix in an independent way. Such a source is then complementary to pure Fermi ($0^+ \rightarrow 0^+$) transitions, neutron decay and pion decay.

The SM incorporates the conserved-vector-current (CVC) hypothesis, which assumes that the vector part of the weak interaction is not influenced by the strong interaction. Thus, the vector coupling constant g_V is not renormalized in the nuclear medium. If CVC is verified, a universal comparative half-life Ft value, which depends only on the isospin of the decaying nucleus, gives access to g_V . Ft is determined from the experimental mixing Fermi and Gamow-Teller ratio ρ and ft values (where ”f” is the statistical rate function which depends on Q^5, and ”t” the partial half-life, this latter obtained from the half-life $T_{1/2}$ and the branching ratio BR), after applying the theoretical corrections due to isospin impurities of the nuclear states, nuclear structure differences impacting on radiative corrections as well as nucleus dependent and nucleus independent radiative corrections. As pointed out by Naviliat-Cuncic and Severijns in Ref. [3], among the available data used to calculate Ft mirror values, ^{37}K suffers from a lack of precision concerning $T_{1/2}$ and BR and thus it becomes our priority target.

Experimental techique: ^{37}K will be produced by bombarding a 40 g/cm^2 Ti target with 0.6 GeV protons from the PS Booster [4]. The potassium atoms will be ionized on a hot tungsten surface, accelerated to 60 keV, mass separated and transported to the detection setup placed at the end of LA1 beam line. The detection setup will consist of a tape transport station and a β-detection setup surrounded by two γ detectors. The electronics will work with a fixed dead-time per event which is much longer than any possible delay from the electronics or the data acquisition. Three independent data acquisition systems with different dead-times (2, 8 and 200μs) will be used. The measuring cycle will be as follows: first the ^{37}K activity will be accumulated on a tape during 1 s. As the only expected contaminant will be ^{37}Ca ($T_{1/2}$=181.1 (10) ms [5]), if we let decay the activity for about 2 half-lives of ^{37}K ($T_{1/2}$=1.226(7)s [5], so during 2.5 s, corresponding to about 14 half-lives of ^{37}Ca) almost all the ^{37}Ca will be already gone and thus no contaminants are expected during the decay-measuring time. Then the activity will be transported to the β-detection setup. The β decays will be measured for 20 half-lives by a 4π high-efficiency β gas detector. After this measuring time, the tape is moved to discard the rest of radioactivity and a new cycle starts. These cycles will be repeated until the desired statistics is achieved. Cycles with different experimental conditions like trigger thresholds, or detector high voltages will form different runs. The strongest γ ray in the decay of ^{37}K (2796 keV) has a branching ratio of 1.8%. Absolute branching ratios will be obtained by normalising the γ rays with the number of β decays observed with β gas counter. In fact to remove the uncertainty due to the β detection efficiency, decay events will be triggered only by the β detection system.

2. Status Report:

To date, the Q value of ^{37}K is known to ±0.004% [6] and the branching ratio is known to ±0.14% [7]. However, the half-life is currently known to ±0.6% [6] and is the one which currently limits the precision of the *ft*-value of this decay, together with the mixing ratio ρ.

Our priority target is to measure the half-life and the branching ratio of ^{37}K.

Concerning the experimental setup, the Geiger counter for beta detection and the tape station are ready to be used. A high-purity co-axial germanium detector has been calibrated in efficiency to a precision of a few per mill over a wide energy range [8] and will be used during the experiment for the branching ratio measurement.

Data acquisition systems, both, the fast single-channel system which will store each measurement cycle-by-cycle with two different fixed dead-times 2µs and 8µs, and the event-by-event listmode data acquisition with a fixed dead-time of 200 µs, are ready to be used.

Both half-life and branching ratio have been recently measured at TRIUMF by D. Melconian et al. However, no data have been published yet. A draft corresponding to the half-life will be eventually sent for publication early 2014 where a precision under 1ms is claimed [9]. For the branching ratio the data analysis just started [9].

Accepted isotopes: ^{37}K

Performed studies:

3. Planned experiment

The aim of our proposal CERN-INTC-2011-047, INTC-P-311, is to achieve a high-precision measurement of the half-life and the branching ratio with an error below 0.1%. To make sure that the statistical errors are below this level, we aim for the detection of 10^7 ^{37}K decays.

For the half-life measurements, with beam-on beam-off cycles, and in order to control the dead-time, we consider an effective rate of about 1000 ^{37}K decays detected during the decay-measuring time. We consider 20 h of effective measuring time per day, and hence $2.6\text{x}10^6$ ^{37}K decays will be accumulated per day ((1000 counts/cycle)*(1 cycle/28 s)*(72000 s/day). Within 3 days (9 shifts) a total of about $7.7\text{x}10^6$ ^{37}K decays will be accumulated. To make sure that the result obtained is not biased by any experimental parameter (e.g. trigger threshold, decay-measuring time, detector high-voltage, etc), one has to change these parameters during the experiment. 2 days (6 shifts) will be required for such tests. During the 15 shifts a total of $1.3\text{x}10^7$ ^{37}K decays will be accumulated, yielding a relative uncertainty (√N/N) of 0.03%.

For the branching ratio measurements, as the photo-peak efficiency is about 0.1% at 15cm for the 2796 keV transition, during the half-life measurements an average of 1 counts/cycle will be accumulated. During 5 days of measurements a total of $1.3\text{x}10^4$ counts will be accumulated, ((1 counts/cycle)*(1 cycle/28 s)*(72000 s/day)*5 days) yielding a relative uncertainty (√N/N) of $8.8\text{x}10^{-3}$. For a branching ratio of 1.8%, this yields an uncertainty of $8.8\text{x}10^{-3}$ * 1.8% = 0.016% for the mirror transition. A similar calculation can be made for the transition at 3602 keV. Therefore, with the proposed measurements, the super-allowed mirror branching ratio will be determined with a precision well below 0.1%.

Summary of required shifts: 1 shift to optimize the production rate, the ISOLDE setting and the purity of the ^{37}K beam. 15 shifts to measure the half-life and the branching ratio of ^{37}K.

So, no additional shifts are requested now.

Planned measurement with <u>available</u> shifts:

(i) Envisaged measurements and requested isotopes: Half-life and branching ratio of ^{37}K.

(ii) Have these studies been performed in the meantime by another group? Yes, but nothing published.

(iii) Number of shifts (based on newest yields) required for each isotope: 16

isotope	yield (/uC)	target – ion source	Shifts (8h)
^{37}K	7.1E+06	Ti (Ti Metal foil) 40g/cm^2 WSI(W surface)	16

Total shifts: 16

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