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:

September 25, 2019

T. Kurtukian-Nieto[1], B. Blank[1], P. Ascher[1], G. Benzoni[2], A. De Roubin[3], X. Fléchard[4], M. Gerbaux[1], J. Giovinazzo[1], S. Grévy[1], G. Grinyer[5], E. Liénard[4], J. Liendo[6], G. Quemener[4], J.C.Thomas[7], M. Versteegen[1]

[1] CENBG, IN2P3/CNRS/Université de Bordeaux, CS10120 F-33175 Gradignan, France
[2] INFN, Sezione di Milano, via Celoria 16, I-20133 Milano, Italy
[3] Department of Physics, University of Jyväskylä, Jyväskylä, Finland
[4] LPC CAEN-ENSICAEN, 6 Boulevard du Marechal Juin, 14050 Caen Cedex, France
[5] Department of Physics, University of Regina, Regina, SK S4S 0A2, Canada
[6] Universidad Simon Bolivar, Baruta. AP 89000, Caracas,Venezuela.
[7] GANIL, CEA/DSM-CNRS/IN2P3, Bvd Henri Becquerel, 14076 Caen, France

Spokesperson(s): Teresa KURTUKIAN NIETO (kurtukia@cenbg.in2p3.fr)
Bertram BLANK (blank@cenbg.in2p3.fr)
Local contact: Karl JOHNSTON (karl.johnston@cern.ch)

Abstract

We propose to study the T=1/2 mirror ß decay of ^{37}K. Nuclear mirror ß decay is a competitive means to test the electroweak standard model by means of a high-precision measurement of the Vud element of the CKM quark mixing matrix. One key ingredient to obtain Vud 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 the 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.

Requested shifts: 12 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 an 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 Fermi and Gamow-Teller mixing 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. The half-life of ^{37}K has been recently measured to be 1.23651(94) s [4], however the precision in the ground-state branching ratio BR = 97.99(14)% is still an important limiting factor on the ft value. ρ has been recently determined to be ρ = 0.576(6) from an A_β beta asymmetry measurement [5]. Improving the precision on $T_{1/2}$ and BR will allows one to obtain ft with the required precision.

2. Performed studies:

In 2014 we used 11 shifts to study ^{37}K. During this experiment we measured both the half-life and the branching ratio. Our half-life value of ^{37}K, $T_{1/2}$ = (1236.35 ± 0.88) ms, even though in agreement with the previous measurement of Ref. [4], and has the required precision, was dominated by a systematic error induced by high counting rates obtained during the first 1 s of the decay curve. We believe that this effect is due to the nonlinearity/saturation of the photomultipliers at high rates. We would like to measure again this half-life with a better control on the rates.

In the case of the branching ratio, our result is (2.19 ± 0.17)%, which is in agreement with previous measurements, but did not achieve the required precision. The problem in this measurement was again related to the high counting rates, since we had strong problems of pile-up.

We would like to measure again both $T_{1/2}$ and BR for ^{37}K once the aforementioned problems were identified, and that can be solved in the next beam time by limiting the beam intensity and including also a new data acquisition, FASTER [6].

3. Planned experiment

The ^{37}K isotopes will be produced by spallation reactions in a CaO target, induced by the PS Booster proton beam at 1.4 GeV. Mass A=37 nuclei will be selected by the GPS and sent to the measurement point, the LA1 beam line of ISOLDE. At LA1, the beam will be intercepted by a 1.25 mm wide aluminized mylar tape. After the accumulation, the tape will transport the activity for about 5 cm between a $46 \times 17 \times 3$ mm^3 plastic scintillator and a HPGe detector calibrated in efficiency to a high precision [7].

Two different cycles will be used, for $T_{1/2}$ we will use long cycles of ~36 s, and for BR short cycles of ~11s, following the structure : accumulation, transport, decay, transport, background.

In order to test systematic effects linked to the data acquisition system (DAQ), three independent systems will be used, each one of them running with different parameters and data recording.

The plastic scintillator will be placed at a distance of 0.2 mm from the tape and read out by two photomultiplier tubes (PMT) connected on either side to the scintillator. The PMT signals will be injected in a fast amplifier and a constant fraction discriminator. The coincident signal from both PMTs will trigger the data acquisition.

The germanium detector will be installed at 150 mm from the activity on the tape. The full-energy γ-ray detection efficiency at the energy of the most intense ray from the ^{37}K decay at 2796 keV will be 0.1%.

The aim of our proposal 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 2000 ^{37}K decays detected during the decay-measuring time. We consider 20 h of effective measuring time per day, and hence $4\text{x}10^6$ ^{37}K decays will be accumulated per day ((2000 counts/cycle) * (1 cycle/36 s) * (72000 s/day). Within 7 shifts a total of about $9.3\ \text{x}10^6$ ^{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. 1 shift will be required for such tests. During the 8 shifts a total of 1.1×10^7 ^{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 2 counts/cycle will be accumulated. We will use short cycles to optimise the counting rate. During the previous long cycle shifts a total of 1.1×10^4 counts will be accumulated, ((2 counts/cycle)*(1 cycle/36 s)*(72000 s/day)*1 days/ 3 shits * 8 shifts). During 3 extra shifts of short cycles, a total of o 1.3×10^4 counts will be accumulated ((2 counts/cycle)*(1 cycle/11 s)*(72000 s/day)*1 day/ 3 shifts * 3 shifts). All in all a total of 2.4×10^4 counts will be acquired, yielding a relative uncertainty (√N/N) of 6.4×10^{-3}. For a branching ratio of 1.8%, this yields an uncertainty of 6.4×10^{-3} * 1.8% = 0.012% 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 of 0.1%.

Summary of requested shifts:

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

Total shifts: 12

References:

[1] N. Cabibbo, Phys. Rev. Lett. 10 (1963) 531. Kobayashi, M and Maskawa K., Prog. Thor. Phys. 49 (1972) 282.
[2] J.C. Hardy and I.S. Towner, Phys. Rev. C 79 (2009) 055502.
[3] O. Naviliat-Cuncic and N. Severijns, Phys. Rev. Lett. 102 (2009) 142302.
[4] P. D. Shidling et al., Phys. Rev. C 90, (2014) 032501(R).
[5] B. Fenker et al., Phys. Rev. Lett. 120, (2018) 062502.
[6] FASTER (Fast Acquisition SysTem for nuclEar Research), http://faster.in2p3.fr/.
[7] B. Blank et al., Nucl. Instrum. Meth. A 776, 34 (2014).

Appendix

DESCRIPTION OF THE PROPOSED EXPERIMENT

The experimental setup comprises: *(name the fixed-ISOLDE installations, as well as flexible elements of the experiment)*

Part of the Choose an item.	Availability	Design and manufacturing
[if relevant, name fixed ISOLDE installation: COLLAPS, CRIS, ISOLTRAP, MINIBALL + only CD, MINIBALL + T-REX, NICOLE, SSP-GLM chamber, SSP-GHM chamber, or WITCH]	☐ Existing	☐ To be used without any modification
GPS / LA1	☒ Existing	☒ To be used without any modification ☐ To be modified
	☐ New	☐ Standard equipment supplied by a manufacturer ☐ CERN/collaboration responsible for the design and/or manufacturing

HAZARDS GENERATED BY THE EXPERIMENT

(if using fixed installation) Hazards named in the document relevant for the fixed [COLLAPS, CRIS, ISOLTRAP, MINIBALL + only CD, MINIBALL + T-REX, NICOLE, SSP-GLM chamber, SSP-GHM chamber, or WITCH] installation.

Additional hazards:

Hazards			
	[Part 1 of the experiment/equipment]	*[Part 2 of the experiment/equipment]*	*[Part 3 of the experiment/equipment]*
Thermodynamic and fluidic			
Pressure	[pressure][Bar], [volume][l]		
Vacuum			
Temperature	[temperature] [K]		
Heat transfer			
Thermal properties of materials			
Cryogenic fluid	[fluid], [pressure][Bar], [volume][l]		
Electrical and electromagnetic			
Electricity	[voltage] [V], [current][A]		
Static electricity			
Magnetic field	[magnetic field] [T]		
Batteries	☐		
Capacitors	☐		
Ionizing radiation			
Target material	[material]		
Beam particle type (e, p, ions, etc)			
Beam intensity			

Beam energy			
Cooling liquids	[liquid]		
Gases	[gas]		
Calibration sources:	☐		
- Open source	☐		
- Sealed source	☐ [ISO standard]		
- Isotope			
- Activity			
Use of activated material:			
- Description	☐		
- Dose rate on contact and in 10 cm distance	[dose][mSV]		
- Isotope			
- Activity			
Non-ionizing radiation			
Laser			
UV light			
Microwaves (300MHz-30 GHz)			
Radiofrequency (1-300MHz)			
Chemical			
Toxic	[chemical agent], [quantity]		
Harmful	[chemical agent], [quantity]		
CMR (carcinogens, mutagens and substances toxic to reproduction)	[chemical agent], [quantity]		
Corrosive	[chemical agent], [quantity]		
Irritant	[chemical agent], [quantity]		
Flammable	[chemical agent], [quantity]		
Oxidizing	[chemical agent], [quantity]		
Explosiveness	[chemical agent], [quantity]		
Asphyxiant	[chemical agent], [quantity]		
Dangerous for the environment	[chemical agent], [quantity]		
Mechanical			
Physical impact or mechanical energy (moving parts)	[location]		
Mechanical properties (Sharp, rough, slippery)	[location]		
Vibration	[location]		
Vehicles and Means of Transport	[location]		
Noise			
Frequency	[frequency],[Hz]		
Intensity			
Physical			
Confined spaces	[location]		
High workplaces	[location]		
Access to high workplaces	[location]		
Obstructions in passageways	[location]		
Manual handling	[location]		
Poor ergonomics	[location]		

3.1 Hazard identification

Liquid nitrogen for cooling Ge detector

HV for PM and Ge detectors

3.2 Average electrical power requirements (excluding fixed ISOLDE-installation mentioned above): *(make a rough estimate of the total power consumption of the additional equipment used in the experiment)*

Standard connections/demands