Letter of Intent for the ISOLDE facility:
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Precision measurement of the half-life, of non-analogue branches and of the β-decay Q value of the superallowed $0^+ \rightarrow 0^+$ β decay of ^{70}Br

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Abstract

We propose to study the β decay of ^{70}Br which is dominated by a super-allowed branch to the ground state of ^{70}Se. We intend to perform a high-precision study of the half-life of this nucleus and of its non-analogue decay branches. These measurements are essential for a better understanding of the theoretical corrections (in particular the δ_c correction factor) needed to calculate the universal Ft value from the ft value determined for individual nuclei. In order to test these theoretical corrections, the high-mass nuclei (A>54) are considered important, as for these nuclei the correction factors increase significantly and the model calculations (i.e. shell model or mean-field models) become more and more difficult and uncertain. Therefore, these nuclei are an ideal test case for the correction factor which limit today the precision on the universal Ft value and therefore on the value of the vector coupling constant and on the V_{ud} matrix element of the CKM quark-mixing matrix.

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1 Introduction

Superallowed $0^+ \rightarrow 0^+$ β decays are compelling because of their simplicity. The axial-vector decay strength is zero for such decays, so the measured ft values are directly related to the weak vector coupling constant through the following equation [1]:

$$Ft = ft(1 + \delta'_R)(1 + \delta_{NS} - \delta_c) = \frac{K}{M_F^2 G_V'^2} \qquad (1)$$

where K is a known constant, G'_V is the effective vector coupling constant and M_F is the Fermi matrix element between analogue states. Radiative corrections, δ'_R, modify the decay rate by about 1.5% and structure-dependent corrections (δ_c, δ_{NS}) modify the "pure" Fermi matrix element by about 0.5-1%.

Accurate experimental data on Q_{EC}-values, half-lives and branching ratios combined with the three correction terms permit precise tests of the Conserved Vector Current (CVC) hypothesis, via the constancy of Ft values, irrespective of the $0^+ \rightarrow 0^+$ decay studied [1]. The CVC test achieved through these nuclear physics experiments is currently far superior to any particle physics tests [1, 2]. At present, the best hopes for further improvements are also in the field of superallowed β decay.

These data also yield a value for G'_V which, in combination with the weak vector coupling constant for the purely leptonic muon decay, provides a value for V_{ud}, the up-down quark mixing element of the CKM matrix. Together with the smaller elements, V_{us} and V_{ub}, this matrix element provides a stringent test of the unitarity of the CKM matrix. At present, the unitarity condition is violated at the two standard deviation level, if one takes the values for V_{us} and V_{ub} as suggested by the Particle Data Group (PDG) [3]. We mention, however, that new measurements [4, 5] seem to indicate that the currently accepted value for V_{us} is too low. Although creating other problems, the newly measured values would restore unitarity for the first row of the CKM matrix at the level of precision achieved today. Other possible origins for the non-unitarity of the CKM matrix span from right-handed currents to additional quark generations.

V_{ud} is the most precisely known element of the CKM matrix [3] but, because of its large size, also the largest contributor of uncertainty in unitarity tests of the first row and the first column of the CKM matrix. It is therefore vital to improve the precision of this element. The existing data set of superallowed β emitters can be improved and enlarged through additional measurements on heavier superallowed Fermi emitters.

2 Physics case

A critical analysis of the sources of a possible non-unitarity of the CKM matrix is important. While the situation for V_{us} has to be clarified, we concentrate here on V_{ud} which falls in the domain of low-energy nuclear physics.

The constancy of the corrected Ft values, as seen in Figure 1, indicates that the vector current is indeed conserved, independent of the nucleus it is acting in. The constancy test simultaneously probes the accuracy of the charge-dependent corrections, in that erroneous predictions would scatter or put a slant to the line through the data points. These nuclear-structure-dependent corrections are considered by many physicists to be the weakest link in the superallowed $0^+ \rightarrow 0^+$ research [6].

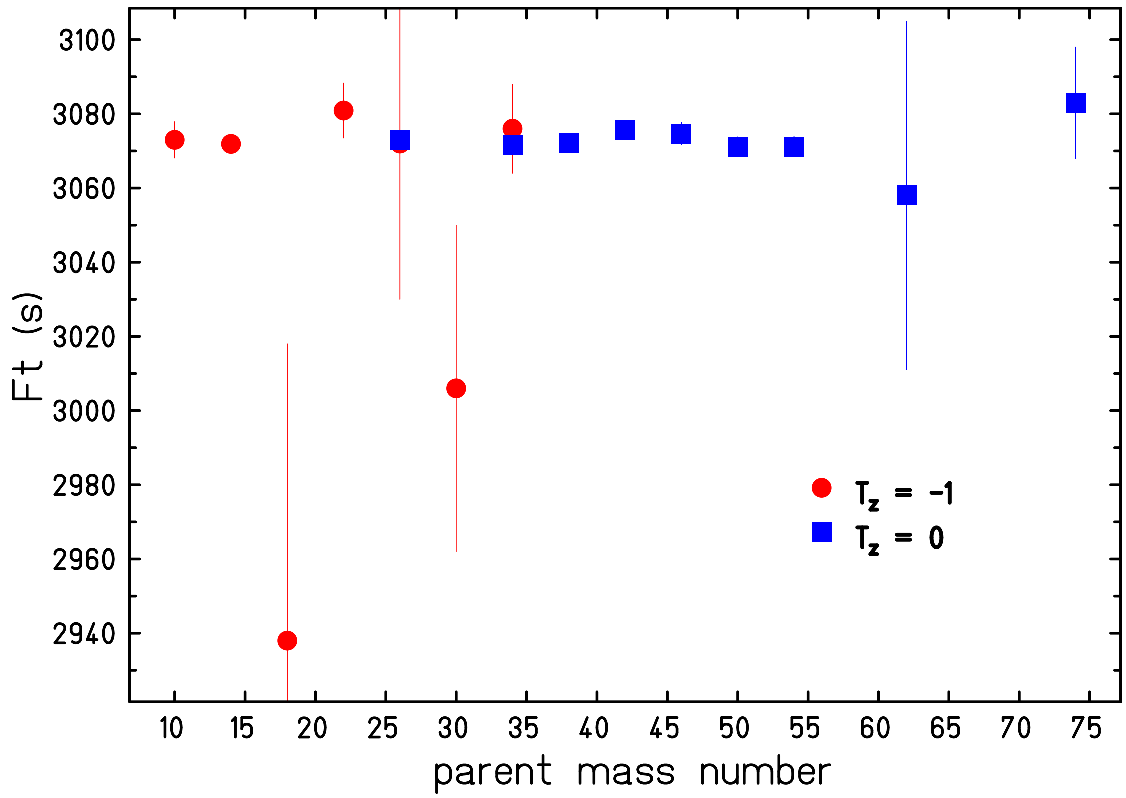

Figure 1: *Ft value as compiled by Hardy and Towner [1].*

The corrections calculated for ^{62}Ga, ^{66}As, ^{70}Br and ^{74}Rb are unusually large (see Figure 2) and the shell-model space used is different from the nine precisely measured cases. If the corrected Ft values for the new heavier cases agree with those obtained for the nine well-studied decays then the confidence in the CVC hypothesis and the charge-dependent correction calculations would receive a significant boost. This has been reached partly recently with the determination of Ft for ^{74}Rb [7], however, the error bar for the Ft value of ^{74}Rb is still rather large and will be difficult to improve as the measurements used have reached their precision limits. ^{62}Ga will certainly be the next heavy nucleus to be included in the $0^+ \rightarrow 0^+$ systematics [8, 9, 10]. However, as precision mass measurements for ^{62}Ga and ^{62}Zn are still to be performed, it is nor clear, which final precision can be reached.

The information we are aiming at in this proposal is the half-life, the non-analogue decay branches, and the β-decay Q value of ^{70}Br. The half-life of ^{70}Br has been measured twice in the past [11, 12]. However, these measurements reach a precision of only 1%, an error by far to large to contribute in any way to the subject discussed here. No measurement at all exists for the branching ratios. The β-decay Q value was measured once with a considerable error bar (Q_{EC} = (9970±170)keV) by an end-point measurement [13].

In the past, counting rates per second and micro-ampere of about 800 ^{70}Br were produced at ISOLDE with the SC beams and a niobium powder target. With the higher PSB intensity now available for ISOLDE, a counting rate of 1000-1500 ^{70}Br per second can be expected [14]. Such a rate would be sufficient to perform a high-precision measurement with the aim of a half-life error well below the 0.1% level within one week of beam

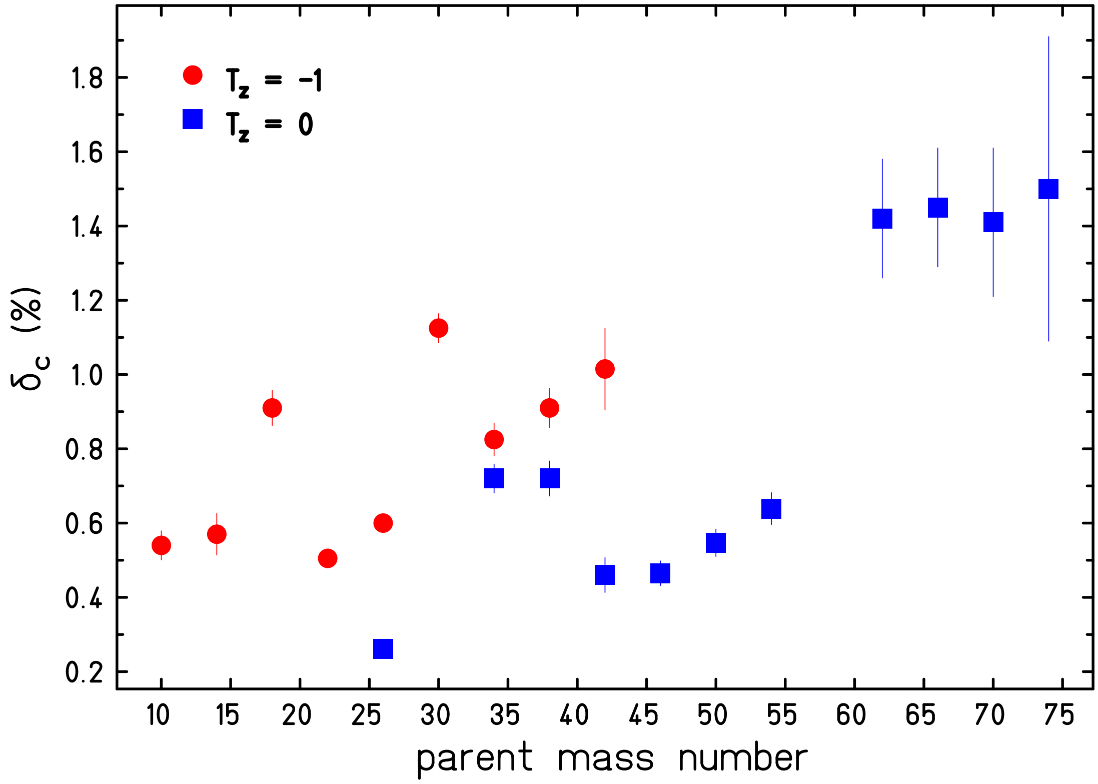

Figure 2: δ_c *correction factors as calculated by Hardy and Towner [1].*

time (see e.g. [9] were a similar production rate was used). Similarly, the non-analog branching ratios can be measured with the required precision in another week of beam time. However, these measurements depend on a negative ion source to be tested after the summer at ISOLDE. At a later stage, mass measurements with ISOLTRAP should be possible to determine the Q value for the β decay of ^{70}Br.

3 Request

To test the feasibility of such experiments with a ^{70}Br beam from ISOLDE, we suggest therefore that tests for the ^{70}Br production be included in the test with the negative ion source. This would allow to more reliably estimate the production rates for this isotope and to make sure that ^{70}Br is produced mainly in its ground state, as needed, and not in its isomeric state.

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