# Addendum to the Proposal for the ISOLDE facility:

**CERN-INTC-2005-018 and INTC-P-196**

## Precision measurement of the half-life and the $\beta$-decay Q value of the superallowed $0^+ \rightarrow 0^+$ $\beta$ decay of $^{38}$Ca


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**Abstract**

In the above mentioned proposal, we proposed to study the $\beta$ decay of $^{38}$Ca, and in particular to measure its half-life with high precision. The INTC has raised questions concerning the feasibility of such a high precision study due to the fact that the daughter half-life is only about a factor of two longer. We have performed Monte Carlo simulations which show that for the ISOLDE situation, i.e. where an activity is accumulated for some time, transported to a measurement station and then measured, the half-life can not be determined by only measuring the $\beta$ decay. The parent and daughter half-lives are too close for a fit to describe both contributions correctly. However, with the present intensities, coincidences with the 1.57 MeV $\gamma$ ray allow to reach the high-precision goal. Details of the MC simulations and the results are described in the following.



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# 1 Experimental details

The $^{38}$Ca activity will be produced with ISOLDE as described in the proposal (fluorination of calcium) and sent to the experimental setup. The activity will be deposited on a moving tape outside a $4\pi$ "pill box" gas detector which we are setting up right now. This gas detector will be surrounded by a high-efficiency NaI setup to detect $\gamma$ rays from the decay of $^{38}$Ca. 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. Therefore, each event will generate the same dead-time, independed on e.g. the number of channels to be treated etc. This allows to precisely correct for the dead-time in the analysis. Each cycle consists of an activity collection of about 1 second, the transport of the activity into the gas detector, and a measurement period of 20 half-lives, i.e. 10 s. After each cycle, the data are written on disk and the spectra are cleared to be ready for a new cycle.

We performed Monte Carlo simulations to check whether the half-life of $^{38}$Ca can be measured in the presence of the $^{38}$K$^m$ daughter activity and, if needed, whether when requiring a $\gamma$ coincidence with the 1.57 MeV $\gamma$ ray from the $\beta$ decay of $^{38}$Ca, we can still reach sufficient statistical precision. A $\gamma$ coincidence could include part of the Compton plateau above 511 keV, as the daughter activity has no $\gamma$ line beyond the 511 keV annihilation quantum.

# 2 The Monte Carlo simulations

In the simulations, we tried to use as realistic conditions as possible. We assume an average production rate of 5000 $^{38}$Ca per second to prepare a pure sample. This is possible as $^{38}$Ca will be prepared through fluorination and none of the contaminants produce fluor molecules. However, due to the beam-on / beam-off cycles needed to determine the half-life, we will have an effective counting rate of only 500 per second. Simulations which used only the $\beta$ decay showed that a fit is not able to distinguish between the two half-life components ($^{38}$Ca and $^{38}$K$^m$) present. The two half-lives are too close to each other, even if the $^{38}$K$^m$ half-life, which is well known, is kept fix.

In order to distinguish between the decay of $^{38}$Ca and the daughter decay of $^{38}$K$^m$, we will therefore gate on the 1.57 MeV $\gamma$ ray in the decay of $^{38}$Ca. The branching ratio of this ray is about 20%. With an almost $4\pi$ geometry of NaI detectors (two detectors which sandwich the $\beta$ detector), we can reach a detection efficiency of 50% which yields a total efficiency of 10%. Therefore, we will use an effective counting rate of 500 $^{38}$Ca per 10s cycle in our simulations.

A cycle starts with the accumulation of the activity on a tape for about 1s, its transport into the detector device and the measurement of the half-life for 10 seconds, i.e. 20 half-lives by gating on the 1.57 MeV $\gamma$ ray. In addition to the 500 $^{38}$Ca counts, we added a background rate of $\beta - \gamma$ coincidences of 1 per second. The generated data are subject to a fixed dead-time (5$\mu$s). We assumed that one run will consist on average of 720 measurement cycles and that we will perform about 48 such runs. This yields a total effective measuring time of 4 days. Between the different runs, we will modify the experimental parameters such as fixed dead-time, discriminator thresholds, detector high-voltage etc. These modifications will allow us to verify that the experimental result is not biased by any experimental parameter.

# 3 Results

Figure 1 shows one measurement cycle as generated by the MC simulations. This cycle contains about 500 $^{38}$Ca decays and 10 background counts. About 2 hours of measurement will form a run. Before summing the cycles, the data are dead-time corrected channel-by-channel with the fixed dead-time to yield the dead-time corrected run data. Figure 2 shows the decay spectrum from one such simulated run. These data are then fitted with an exponential decay and constant and give a half-life value for each run. Once all the runs are treated, the error weighted average gives the final half-life.

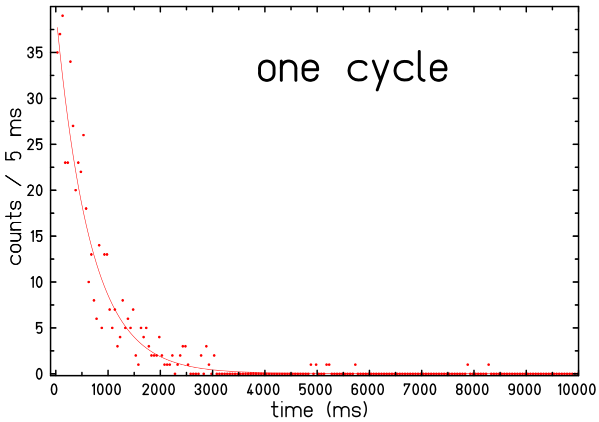


Figure 1: *Decay time spectrum for a single cycle. The spectrum contains parent and background contributions. The line is a fit to the data points.*

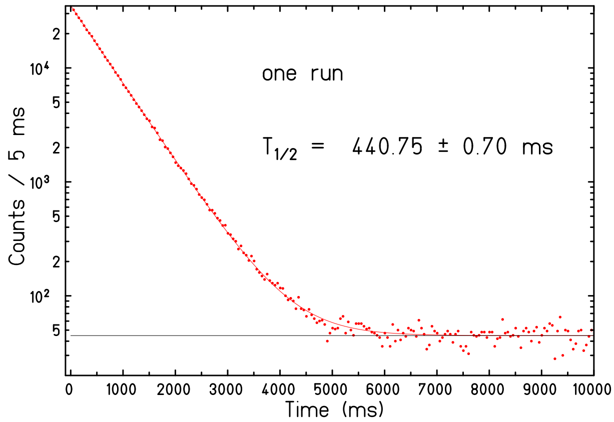


Figure 2: *Decay time spectrum for a run of about 720 cycles. The data are dead-time corrected before summation of the individual cycles. The constant shows the background contributions. The full line is the sum of background and $^{38}$Ca contribution as determined by the fit. In the figure, we give the half-life as determined for this run.*

Figure 3 gives the half-life values for the 48 runs simulated and the average half-life. It can be seen from the figure that a relative error well below $10^{-3}$ can be obtained with a measuring time of 4 days. However, experimental data usually have some additional uncertainties or inconsistancies which are not included in the simulations. For example, for the $^{62}$Ga data, the experimental errors had to be increase by a factor of almost 2 to get a reasonable $\chi^2$. Nevertheless, such a measurement will improve the half-life error for $^{38}$Ca by at least a factor of 20. With such a precision, $^{38}$Ca can be included in the compilation of the most precisely measured $0^+ \rightarrow 0^+$ $\beta$ transitions, as soon as the other quantities needed, i.e. the $Q$ value and the branching ratios, are known with an equivalent precision.

Details about the analysis procedure used here which will also be applied to the experimental data can be found in reference [1].

The $Q$ value meaurement can be performed relatively easily with ISOLTRAP and the beam time for this measurement has been accepted by the last INTC. As for the branching ratio measurement with a absolute precision of 0.1%, we have started to characterise a single-cristal germanium detector with high precision sources and simulations to reach this goal.

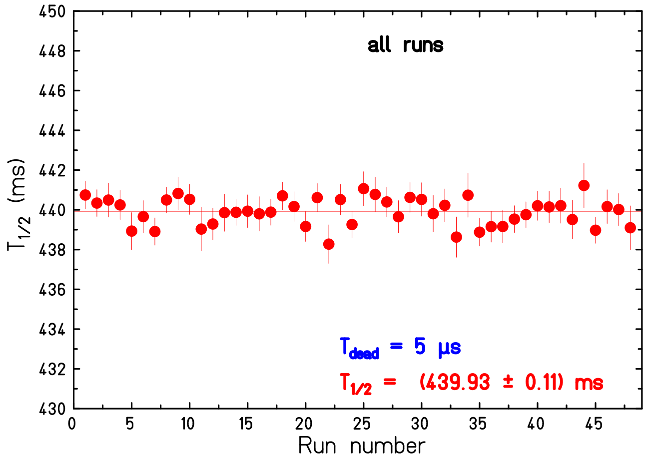


Figure 3: *Half-lives (points) as determined for the different runs. The present example is a simulation for 48 runs with an average of 720 cycles per run and a cycle duration of 10 s. The total uncertainty in the simulations amounts to 0.1 ms. The input half-life was 440 ms.*

# 4 Summary

We believe that with a total measurement time of 6 days, we can reach the goal of a half-life precision of 0.1% or less. Compared to the initial proposal, the beam-time request increased from 10 to 18 shifts. Such a measurement will allow us to make a significant contribution to our understanding of the $0^+ \rightarrow 0^+$ $\beta$ transitions and the weak interaction.

**Beam time needed for half-life measurement: 18 shifts**

# References

[1] B. Blank *et al.*, Phys. Rev. C **69**, 015502 (2004).