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Report to INTC on the Experiment IS406

Precision Study of the β-decay of ^{62}Ga

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1.0 Introduction

In 2002 the INTC approved 10 shifts for the experiment IS406. The request in the proposal [1] was for 10 shifts to measure the half-life of the β-decay of ^{62}Ga and for 10 shifts to measure the branching of the same decay into excited states in ^{62}Zn [2]. The committee recommended the experiment to focus on the branching ratio measurement using the Total Absorption Spectrometer (TAS) that had recently been used in studies of ^{74}Kr [3] and ^{76}Sr[4] at ISOLDE. This measurement is very challenging and includes a rather sophisticated and time consuming analysis step while the half-life measurement and the corresponding analysis is significantly easier to perform. The details of the two procedures are given below. The estimate was that an accuracy of 10^{-4} could be reached in the branching ratio and the half-life measurements after spending 10 shifts on each of these. One should note that accruing a maximum number of events for the branching ratio measurement of the decay of ^{62}Ga, with a half-life of 116 ms, is not completely compatible with measuring the half-life itself with high precision. This is so because a high precision measurement of the half-life requires that the decay curve reaches a stable background level over some time for the precision of the fit to reach the desired level. In the ^{62}Ga case the required time between collections is longer than the ~1 s between proton pulses at ISOLDE. Using the yields from a target test with target ZrO-209 it was estimated that 10^7 good events could be collected in 10 shifts. This time period would also be the minimum time required for the branching ratio measurement. To the best of our knowledge this experiment is the first application of TA spectrometry to superallowed beta decay. One can also note that the half-life of ^{62}Ga was subsequently re-measured by other groups [5]. The decay scheme of the low lying states in ^{62}Zn has also been addressed recently [6]. As will be discussed below, this is an advantage for the analysis of the present experiment.

2.0 Conditions during the 2002 and 2004 runs

The first run of experiment IS406 took place in September of 2002. An 8.5 g/cm^2 ZrO_2 target (target ID ZrO-216) was used together with the RILIS. The ion source included a tungsten ionizer. In total the experiment took beam for 2306 min. (38.4 h) which corresponds to 4.8 shifts.

Several challenges were encountered during the run with the primary one being instabilities in the laser ion source. The total number of events collected in the TAS energy spectrum was 8.901E+6. The rate was 945 at/s. The transmission from the primary target to the setup was 50% and the TAS efficiency was 80%. Totally 8 proton pulses were taken out of a cycle of 18 pulses. The intensity was 3E13 protons per pulse. The trigger signal was given by a disk shaped scintillator detector covering a solid angle ~20%. In general the yield was reasonable in the 2002 run. However, as mentioned one should note that in order to maximize the number of collected events for the branching ratio measurement the time between collections that could be used for measurement of the half-life was only 1.2 s due to the structure of the supercycle. It was therefore not planned to use this data set for improving the precision of the half-life.

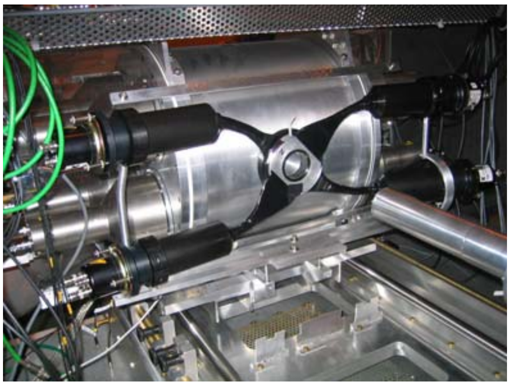
As the experiment had only used an effective beam time of 4.8 shifts the measurement was revisited again in June 2004. This time the target thickness had been reduced to 4.0 g/cm^2. The RILIS was used together with target ZrO-270 which included a Ta ionizer. Major improvements had been made in the setup for the 2004 run. In particular a new set of scintillator detectors had been constructed in order to improve the beta detection efficiency to 70%.

However, although the experiment ran for 2170 min. (36.18 h) using 6 of 16 pulses in the supercycle only 4.05E5 events were collected in the TAS spectrum in coincidence with the beta trigger. The production rate was thus considerably lower than in 2002 and the expectation to double the statistics was not met. Except for the low production rate from the target significant problems were also encountered with the proton beam and the beam transport elements for the radioactive beam. On the positive side the structure of the supercycle during this run made it possible to use a longer time between collections and consequently it was possible to use the data to estimate if the precision necessary for an improved half-life measurement could be reached.

3.0 Setups

The 2002 experiment used a standard set of detectors previously used at TAS. These consisted of:

- A plastic scintillator covering ~20% solid angle with and intrinsic efficiency of 80%, thickness 2 mm, radius 30 mm, mounted close to the collection point inside the TAS.
- A Ge telescope, consisting of 1 cm LEP and a 5 cm HP detector, both having a radius of 5 cm.
- The TAS NaI crystal with diameter of 38 cm and length of 38 cm.
- Tape collection system



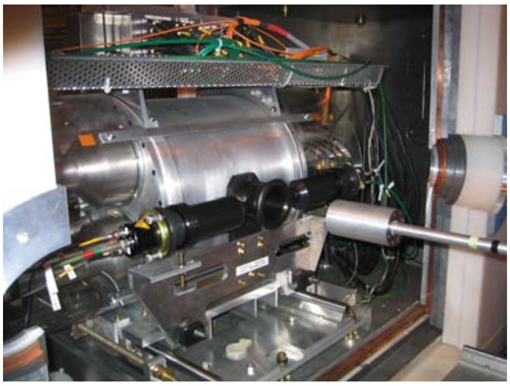


Fig. 1 The experimental setup in 2004. To the left; the TAS crystal container and the four PM tubes that read out the two cylindrical scintillator detectors. The beam pipe enters the picture from the right. To the right; the readout of the scintillator disk via its two PM tubes. The Ge telescope is also seen to the right in this picture. The scintillator disk was used also in the 2002 experiment.

As mentioned the trigger detector of the setup was improved for the 2004 experiment. In addition to the scintillator disk two thin cylindrical detectors were added. In total the solid angle covered by beta detectors increased to ~70%. The setup is shown in Fig. 1 above.

4.0 Analysis

The general approach to analyzing a TAS spectrum is to perform a deconvolution of the response function of the spectrometer using a statistical model of the decay. The analysis thus amounts to constructing the response matrix, R, for all different types of radiation that interact within the setup and give rise to energy deposition in the NaI crystal. A vital part of this analysis is consequently to simulate the response of the

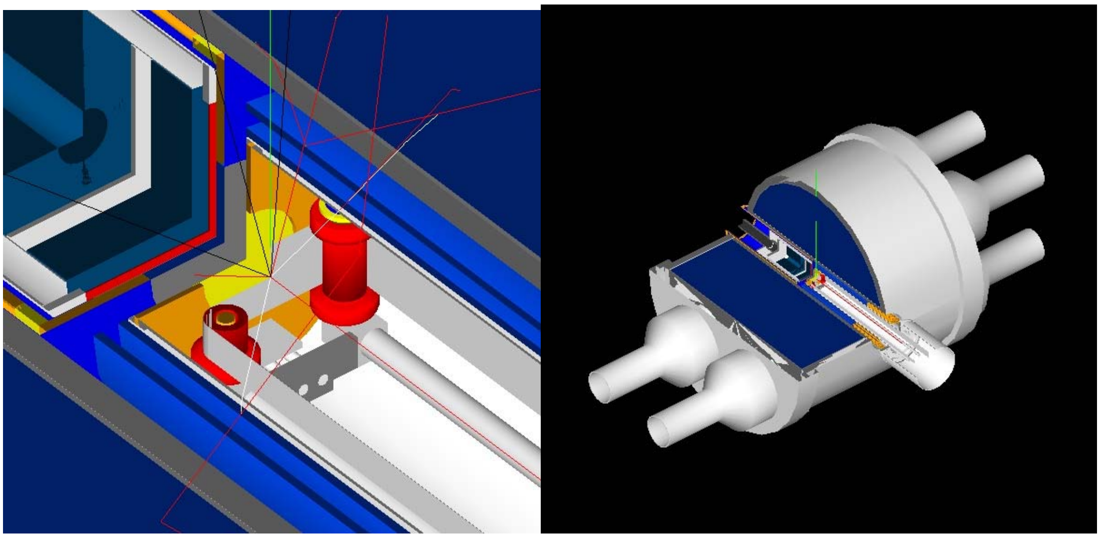


Fig. 2. The left panel shows a zoomed in view of the central part of the TAS as used in the 2004 experiment. The tape system (red and silver), the end cap with the Kapton window (yellow) the scintillator disk (blue), the two cylindrical scintillator detectors (blue) and the Ge telescope (green) can be seen. The tracks arising from the decay of one single ^{62}Ga atomic nucleus is also shown. The right panel shows an overview of the TAS in its casing (aluminium).

spectrometer with respect to various kinds of radiation. An example of how the setup looks like in one of our simulations using GEANT4 is shown in Fig. 2.

Building the geometry in GEANT 3 and/or GEANT4 to the necessary level of detail requires several months of work. Due to the rather recent implementation of low energy electromagnetic processes in GEANT4, an aspect which was not developed fully in GEANT3, we have now implemented both the 2002 and 2004 geometries in the latest version of the program. Since 2006 the direct analysis work is now carried out by the two spokespersons.

The strength of the TAS technique compared to discrete gamma-ray spectroscopy using high-resolution detectors is that the complete feeding pattern can be deduced. In discrete gamma-ray spectroscopy one usually do not get full information on the feeding pattern due to the high level density at higher excitation energy. This problem has been extensively treated in the literature as the so-called Pandemonium problem. In the following we give a few details of the method. Some more detailed information can be found in Refs. [7,8,9,10].

If the measured spectrum is denoted, **d,** and the feeding distribution is given by **f** then the TAS technique amounts to finding the inverse to the equation:

$$d_i = \sum_j R_{ij} \cdot f_j,\ j=0,j_{max} \text{ and } i=1,i_{max} \quad \text{or} \quad \mathbf{d} = \mathbf{R} \cdot \mathbf{f} \tag{1}$$

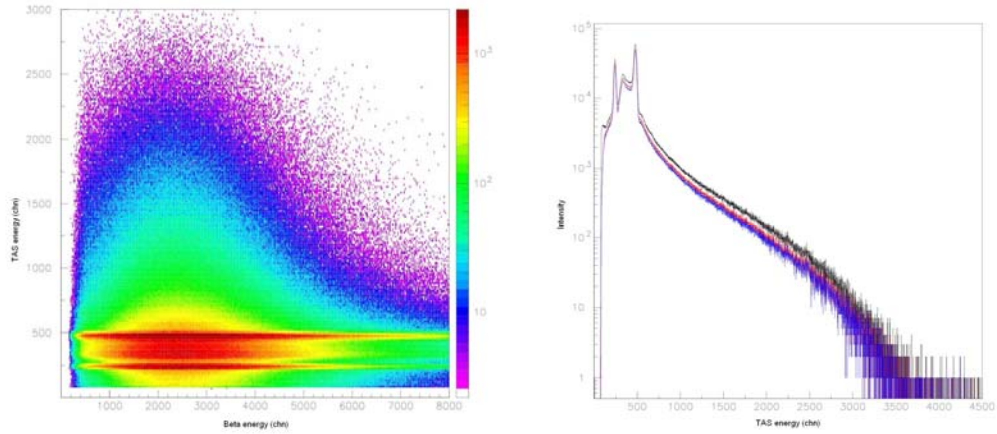


Fig 3a & b: The left panel shows the TAS energy response (y-axis) in coincidence with the energy signal from the beta detector (x-axis). On the right is the projection on the TAS energy axis from the former 2D spectrum for different conditions. The black curve includes events where the detected beta signal from the left and right PM was above channel 150, the red curve gives the same projection for events in the beta detector with the additional condition that only prompt coincidences were taken into account. Finally, the blue curve includes events that fulfill the timing condition and have a beta detector response above channel 500.

where d_i is the response in channel i of the spectrum to feeding to level j in the daughter nucleus. If **R** can be determined then **f** is given by its inverse and the known spectrum **d**:

$$\mathbf{f} = \mathbf{R}^{-1} \cdot \mathbf{d} \qquad (2)$$

One should note that the purpose is to determine the response function from normalized spectra given by the simulation. This means that the response to two coincident quanta is given by the folding of the respective individual responses. This is sometimes written as:

$$[p \otimes q]_i = \sum_{k=0}^{i} p_{i-k} q_k \qquad (3)$$

Where **p** and **q** are two separate responses. For the general case applied here the response matrix can be divided into the following components:

$\mathbf{R}_j$:total response to level j

$\mathbf{r}_j$:response to electromagnetic de-excitation of level j

$\mathbf{g}_{jk}$:response to gamma-ray transition from level j to k

e^K_{jk} :response to K,… conversion electron transition from level j to k

$b^{\pm}_j$:response to e^+ emission in beta-decay to level j

$\mathbf{x}$:response to X-Ray emission

b_{jk} :branching ratio for transition j to k

α^{tot}_{jk}, α^K_{jk} :conversion electron coefficients for transition j to k

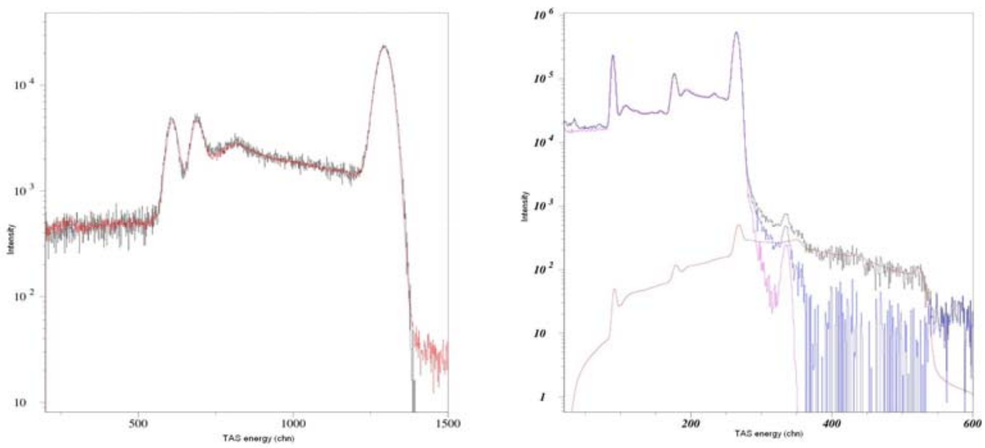


Fig. 4 a&b: The left panel shows a comparison between the simulated (red) and experimental (black) TAS spectrum for a ^{60}Co source in the configuration where the pipe, the beta detector and the Ge detector were inserted into the central part of the crystal. The right panel gives similar information for the same configuration using a ^{24}Na source. Here the black curve gives the experimental spectrum, the red curve is the deduced pile-up and the blue spectrum the difference between these two. The pink spectrum is the result of the simulation. Note in particular the small but significant deviation at approximately channels 300-350. Ongoing simulation work focuses, among other things, on eliminating this discrepancy.

Where $\mathbf{r}_j$ is obtained recursively using the ground state level response; $\mathbf{r}_0$, $r_{00}=1$, $r_{i0}=0$, $i\neq 0$ using:

$$\mathbf{r}j = \sum_{k=0}^{j-1} b_{jk} \, \mathbf{g}_{jk} \otimes \mathbf{r}_k \tag{4}$$

where the conversion electron process is taken into account via:

$$\mathbf{g}_{jk} \rightarrow \frac{1}{1+\alpha_{jk}^{tot}} \mathbf{g}_{jk} + \frac{\alpha_{jk}^{K}}{1+\alpha_{jk}^{tot}} \mathbf{e}_{jk}^{K} \otimes \mathbf{x} + \ldots \tag{5}$$

Finally the response is constructed from the convolution of the electromagnetic response with the response due to the decay process:

$$\mathbf{R}_j^{\beta+} = \mathbf{b}^{+} \otimes \mathbf{r}_k \tag{6}$$

$$\mathbf{R}_j^{EC} = \mathbf{x} \otimes \mathbf{r}_k \qquad (7)$$

It can be mentioned that the simulation of the response function also includes models that take into account the non-linear relationship between deposited energy in the NaI crystal and light output. Other important factors include pulse-pile up correction. However, before constructing the matrix, R, it is vital to test the simulation using the response of the spectrometer to different sources. This procedure involves measuring TAS spectra for different configurations inside the spectrometer in order to be able to fine tune the distances between the components of the inner structure. In order to give an impression of the current status of this process we present a number of spectra from the 2002 run in the following. In the first of these (Fig. 3a) the TAS energy is plotted against the beta-response for coincident events (beta-TAS coincidences). The dominant feature in the spectrum is as expected the two lines at 511 and 1022 keV. The total number of events in this spectrum is 8.9E6. The corresponding projection can be found in Fig. 3b where one also can notice that the shape of the projected spectrum stays fairly constant for successively higher cuts in energy on the beta counter. This is a good indication that the spectrum is not distorted by background related events from noise etc.

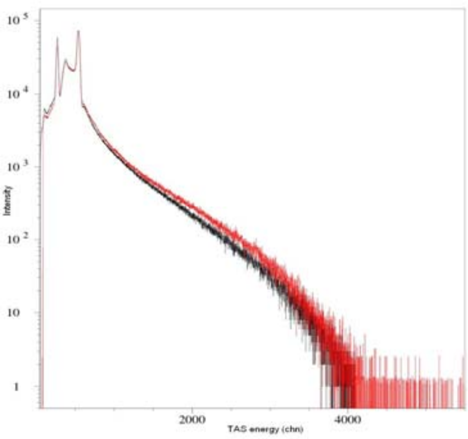


Fig.5 Experimental TAS spectrum in red compared to the simulated response. There is an indication of excess feeding above approximately channel 1000.

The next set of spectra that we find to be of interest for this report contain a comparison between the simulated response using GEANT and the experimental response. As mentioned source measurements were carried out for a number of different configurations of the inner structure. The sources used were typically ^{60}Co and ^{24}Na. Figures 4a and b give a comparison between the simulated response and the experimental spectrum for a configuration including the beam pipe, the beta counter and the Ge detector. Figure 4b also includes a decomposition of the experimentally obtained spectrum using the deduced pile-up spectrum. This spectrum can in turn be compared to the simulation. Of particular interest here is to note the difference between the two spectra around channels 300-350. Experience from previous measurements with TAS gives that this discrepancy will be improved upon by including the low energy processes mentioned above. Work towards this end started in 2007 and continues.

The simulated spectrum for the 0^+ to 0^+ decay, using the information from Ref. [6] and the level distribution given by the backshifted Fermigas model, is given in Fig. 5. It is clear in this spectrum that a certain excess in the feeding may be present above channel 1000. However, this conclusion is sensitive to the normalisation of the spectrum and it is vital that the intensity ratio between the 511 and 1022 keV peaks in the simulation and the experimental spectrum agrees with each other. From the simulation work it is clear that this intensity ratio is sensitive to the relative distance of the Ge telescope to the collection point. Further investigations of the impact of small changes in the geometry are ongoing in parallel to the simulations carried out in GEANT4 as mentioned above.

Finally, some decay spectra from 2004 are given in Fig. 6. The deduced half-life of 116.713 ± 0.342 is close to the currently accepted value. With an order of

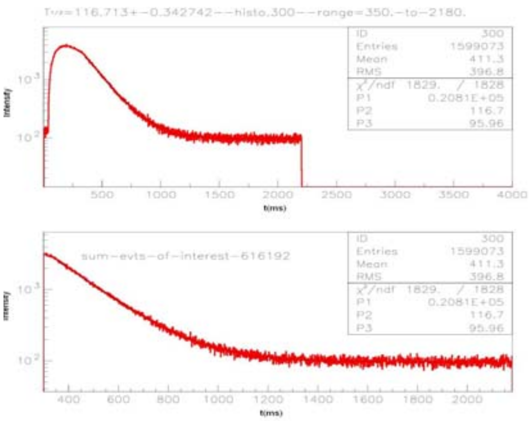


Fig. 6: Example of decay spectra from the 2004 run.

magnitude more statistics, i.e. corresponding to what was expected, it is likely that a competitive measurement of the half-life could have been made in a dedicated effort. The main advantage being the purity of the ISOLDE ^{62}Ga beam.

5.0 Conclusion

In conclusion the status of experiment IS406 can be summarized as follows:

- Two runs have been carried out, one in 2002 and one in 2004.
- Approximately half of the allotted shifts have been used under the expected conditions in 2002.
- Machine related challenges and low yield resulted in very low statistics in 2004.
- The data collected in 2002 is being analyzed with respect to the branching ratio.
- The 2004 data will not contribute significantly to the branching ratio analysis.
- Simulations in GEANT3 and GEANT4 are carried out and detailed geometries have been built for the 2002 and 2004 setups. GEANT4 simulations are vital for proper treatment of some of the low energy processes.
- It is foreseen to publish the result from the 2002 run before the experiment asks for the remaining shifts.

- If the result shows the method has potential addenda and/or new proposals are planned for the two superallowed emitters: ^{74}Rb and ^{70}Br.

[1] Proposal to INTC, CERN-INTC-2002-004

[2] J. C. Hardy & I. S. Towner, Phys. Rev. Lett. 88 (2002) 252501

[3] E. Poirier et al. Phys. Rev. C69 (2004) 034307

[4] E. Nacher et al. Phys. Lett. 92 (2004) 232501

[5] B. Blank et al. Phys. Rev. C69 (2004) 015502

[6] B. Hyland et al., Phys. Rev. Lett. 97 (2006) 102501

[7] D. Cano-Ott el al., Nuclear Instrum. and Methods A430 (1999) 333

[8] J. L. Tain and D. Cano-Ott, Nuclear Instrum and Methods A571 (2007) 719

[9] J. L. Tain and D. Cano-Ott, Nuclear Instrum and Methods A571 (2007) 728

[10] D. Cano-Ott et al., Nuclear Instrum. and Methods A430 (1999) 488