EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-INTC-2002-004
INTC/P 150
21 Jan 2002

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

U. C. Bergmann[1)] B. Blank[2)], M. J. G. Borge[3)], D. Cano-Ott[4)], J. Cederkäll[1)], Ph. Dessagne[5)], L. M. Fraile[1)], S. Franchoo[1)], H. Fynbo[6)], A. Gadea[4)], W. Gelletly[7)], A. Jokinen[1)8)] U. Köster[1)], K. Peräjärvi[1)8)], T. Nilsson[1)], B. Rubio[4)], O. Tengblad[3)], J. L. Tain[4)], L. Weissman[1)], J. Äysto[1)8)]

Spokespersons: J. Cederkäll and Ph. Dessagne
Contactperson: J. Cederkäll

Abstract

It is proposed to perform a precision study of the beta-decay of ^{62}Ga taking advantage of recent developments of the ISOLDE Laser Ion Source. The goal is to eventually extend the high-precision knowledge of superallowed beta-decays beyond the nine decays that presently are used for extracting the V_{ud} quark mixing matrix element of the CKM matrix. The scientific motivations are the current deviation of more than 2σ of the unitary condition of this matrix, which could be an indication of non-standard-model physics, and a test of the theoretical corrections applied to the experimental data. The experiment will utilise the Total Absorption Gamma ray (TAG) spectrometer in order to determine weak branchings to excited states in ^{62}Zn and the ISOLDE spectroscopy station to perform half-life measurements and detailed spectroscopy of this nucleus.

[1)] CERN, Geneva, Switzerland.
[2)] CENBG, Bordeaux, France
[3)] IEM, CSIC, Madrid, Spain.
[4)] IFIC, CSIC, Valencia, Spain
[5)] IRES, Strasbourg, France
[6)] Århus Univ. Århus, Denmark.
[7)] University of Surrey, Guildford, UK.
[8)] University of Jyväskylä, Jyväskylä, Finland.

1 Physics Case

Based on the Conserved Vector Current (CVC) hypothesis of the weak interaction, the world data for the V_{ud} quark-mixing element of the Cabibbo-Kobyashi-Maskawa (CKM) matrix is presently deduced from nine superallowed beta-decays in combination with muon decay data according to [1]:

$$| V_{ud} | = G'_v / G_\mu$$

where G'_v is the weak-interaction vector coupling constant from superallowed nuclear beta-decay corrected for radiative and isospin mixing effects and G_μ is the coupling deduced from muon decay. However, at present the unitary condition of the CKM matrix as given by the equation:

$$| V_{ud} |^2 + | V_{us} |^2 + | V_{ub} |^2 = 1$$

is not fullfilled within 2σ as the adopted value is 0.9968 ± 0.0014 [2, 3]. The question has been raised in recent years whether this deviation is actual or is a consequence of the small but crucial theoretical corrections that are necessary to apply to the superallowed data [3]. The corrected ft-value, denoted Ft, is according to the CVC hypothesis equal for all superallowed (J^π,T) = (0^+,1) decays and is given by the expression:

$$Ft = ft(1 + \delta_R)(1 - \delta_C)$$

V_{ud} can then be extracted using the relations; $Ft = K/G'^2_v$ with K being a known constant. As mentioned above two types of corrections are applied to the measured ft– value. They are radiative, δ_R, and Coulomb corrections, δ_C. The radiative corrections arise from quantum mechanical loop corrections to the beta-decay process. Theoretical treatments of these corrections can e.g. be found in [5]. The radiative corrections are divided into nucleus dependent and nucleus independent terms. The Coulomb corrections on the other hand are nuclear structure dependent [6]. They also consist of two parts. The first one, δ_{RO}, arises because of the mismatch in the radial wavefunction of the inital proton and the resulting neutron. The second one, δ_{IM}, is caused by isospin-symmetry breaking forces and is possible to measure experimentally by deducing the feeding to excited 0^+ states with opposite isospin. This method was first applied by Hagberg et al. [7]. One of the aims of the proposed experiment is to search for such a non-analog decay of ^{62}Ga. The measurement of decay branchings will also provide an updated value for the partial half-life of the superallowed decay. An improved measurement of the half-life is also suggested.

The physics case for the proposed experiment is very similar to the ^{74}Rb experiment carried out during the past year at ISOLDE. For further background we therefore refer to [8]. Several experiments have measured the half-life of ^{62}Ga in the past [9],[10]. As of yet the required precision has, however, not been reached in order to make it possible to include ^{62}Ga in the world data of the CKM matrix.

2 Experimental Details

^{62}Ga was recently produced in a target test using a ZrO_2 target and the Resonant Ionisation Laser Ion Source (RILIS). The target had a Zr-thickness of 8 g/cm^2 (T $\approx$ 1850°). A two step ionisation procedure was applied from the ground state into the continuum [11]. The ionisation efficiency has been measured offline to have a maximum value of 21%. During the run the selectivity of the source, defined as the number of ions produced by laser ionisation to those produced by thermal ionisation varied between 10 and 20 (see Fig.1). The target test showed that an event rate of $\approx$ 600 events/s could be obtained using the ISOLDE spectroscopy station. At the time of the test the efficiency of the beta-counters was $\approx$ 30% and the transport efficiency was rather low at $\approx$ 60%. Applying the measured release curve gives a yield of 1500 at/μC. Furthermore, taking into account that the RILIS efficiency is conservatively a factor of two higher for the GPS than the HRS [12], which was used for the test, it was concluded that the actual yield of ^{62}Ga would be $\approx$ 3000 at/μC corresponding to $\approx$ 15000 at/pulse. As a comparison the ^{74}Rb experiment carried out during the previous running period had an estimated yield, before the experiment, of 900 at/μC [8]. It should also be noticed that what makes the ISOLDE ^{62}Ga beam unique is the beam-purity caused by the high selectivity of the RILIS.

The current knowledge of the decay scheme of ^{62}Zn is naturally quite limited [13] (see Fig.2). The second, non-analog, 0^+ state at 2330(10) keV has been observed in reactions but a direct observation of a feeding to this level in a beta-decay study has not been reported so far. If the second 0^+-state is populated in the decay a γ-ray transition is expected between this state and the first 2^+ state at 954.0 keV. This transition, at 1376 keV, would thus indicate a direct feeding of the second 0^+-state. One aim of the branching ratio measurement is thus to look for this transition and the following decay to the ground state. The 954.0 keV transition from the 2^+ state to the 0^+ ground state has been seen in beta-decay experiments. Blank et al. could deduce an upper limit for the superallowed beta-decay of 99.881%, taking into account that all states populated in the beta-decay will decay via this state, using β-γ coincidence [14]. A direct measurement with TAGS should make it possible to directly identify if the 0^+ state and/or higher lying states of different spin and parity are populated in the decay.

The TAGS experiment [15] at ISOLDE provides a unique opportunity for performing high precision measurements of weak branching ratios. The radioactive nuclei are implanted onto a movable tape inside the spectrometer and γ-rays emitted following the beta-decay are detected with high efficiency, typically 90% at 5 MeV, in a massive single NaI crystal. The beta-particles can be detected in either a Si-detector or in a well-shaped scintillator. The major obstacle for measuring weak decay branches is due to brehmstrahlung created by the retarded beta-particles. It is however possible to reduce this contribution by requiring a coincidence between the beta-detector and the NaI-detector and to introduce an appropriate absorber. Simulations are ongoing in order to analyse data from previous runs. The acquired experience will be used when determining the optimal configuration for the experiment proposed here. The results so far indicate that a branching in the region of 10^{-4} can be reached using TAGS [16]. For further details of the TAG spectrometer we refer to the TAGS proposal [15].

The second part of the experiment aims at improving the value for the ^{62}Ga half-life and to attempt to perform detailed spectroscopy in the daugther nucleus, ^{62}Zn. The unique purity of the laser ionised ^{62}Ga beam and the good yield indicates that it is possible to reach a very high accuracy for the half-life. At present the best published value for the half-life is 116.12(23) ms, corresponding to an accuracy of 2×10^{-3}. The nine decays included in the world data are typically known to an accuracy of 5×10^{-4}. The purity of the beam implies that the only background in the spectrum will arise from grow-in caused by an imperfectly implanted beam. It is in principle possible to reduce this background to a very low level. We have, however, carried out simulations in order to determine the number of events needed to reach the required accuracy. Assuming that the total number of counts in the background of the decay curve is 10% of the number of counts in the decay curve itself, these simulations show that it is possible to reach the desired accuracy after 10^7 events (see Fig.3)

At this point we would like to keep the option open concerning which set-up to use for the half-life measurement. The beta-counters of the ISOLDE spectroscopy station have a low noise level since a coincidence is required between two PM-tubes connected to the same detector (see Fig.4). The long light guides used in the target test have to be exchanged for shorter ones to reduce the loss of scintillator light and thus increase the efficiency. A maximum efficiency of about 70 % is reachable considering the covered solid angle. A realistic estimate is that an efficiency of 50% can be reached. The beta-counter available for the TAG spectrometer has a higher efficiency but does not apply the low-noise approach described above.

3 Beam request

In order to measure the branching ratios to excited states in ^{62}Zn at the 10^{-4} level we estimate to reach the required statistics in 10 shifts. Similarly the required accuracy in the half-life should be obtained in 10 shifts. We thus request 20 shifts of radioactive ^{62}Ga beam. Required stable beam time is included in this estimate. We also ask for use of the ISOLDE data acquisition systems.

4 Summary

We propose to carry out a set of experiments in order to extend the spectroscopic information needed for deducing V_{ud} from the superallowed beta-decay of ^{62}Ga and to test the theoretical predictions for the Coulomb correction isospin-mixing. We request 10 shifts of beam from a ZrO_2 target using the RILIS and the GPS to search for weak branches of the decay to excited states in ^{62}Zn with the TAG Spectrometer. We furthermore ask for 10 shifts to improve on the measured half-life of ^{62}Ga. In case the search for feeding to excited states in ^{62}Zn is succesful we will request further beamtime for detailed γ-ray spectroscopy if considered feasible.

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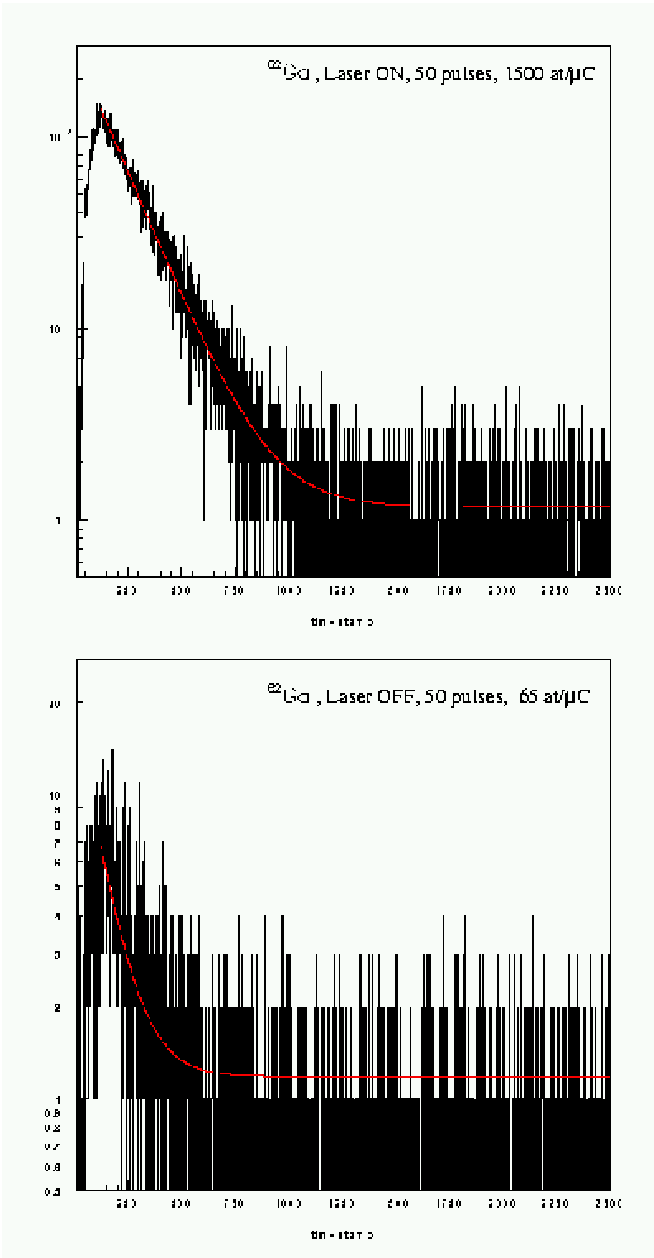

Figure 1: Yield measurement for ^{62}Ga. Note that the life-time measurement was not optimised during this test.

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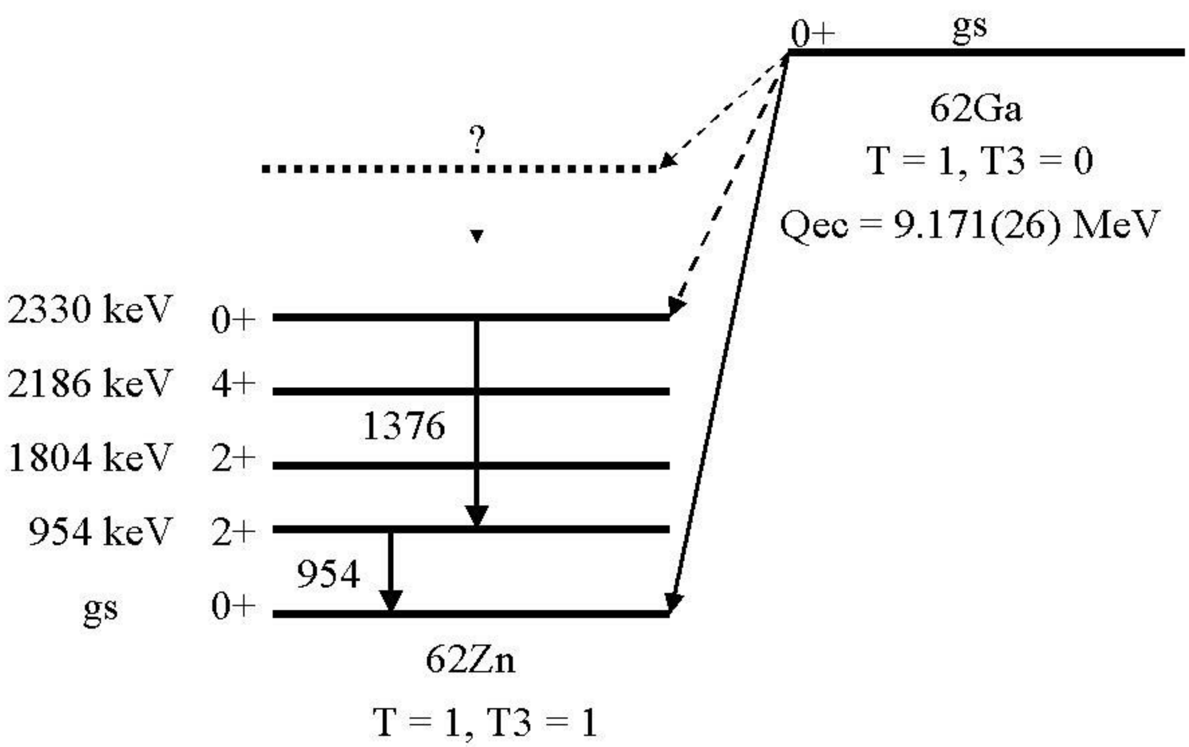

Figure 2: Low lying levels and decay properties for the ^{62}Ga decay. Measured half-life: 116.12(23) ms.

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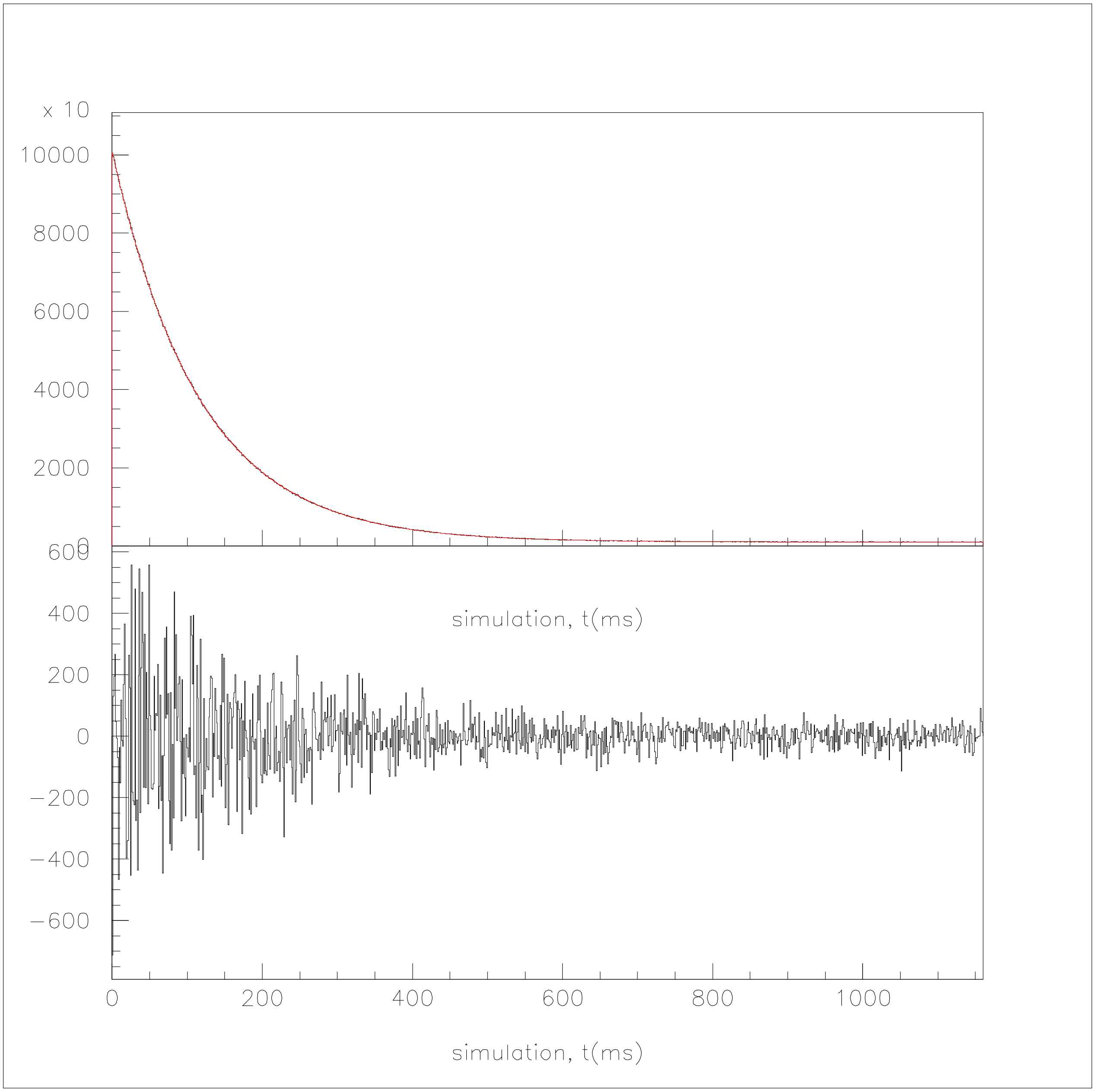

Figure 3: Simulation of the ^{62}Ga life-time as discussed in the text. 10^7 events results in a half-life of 116.01(05) ms.

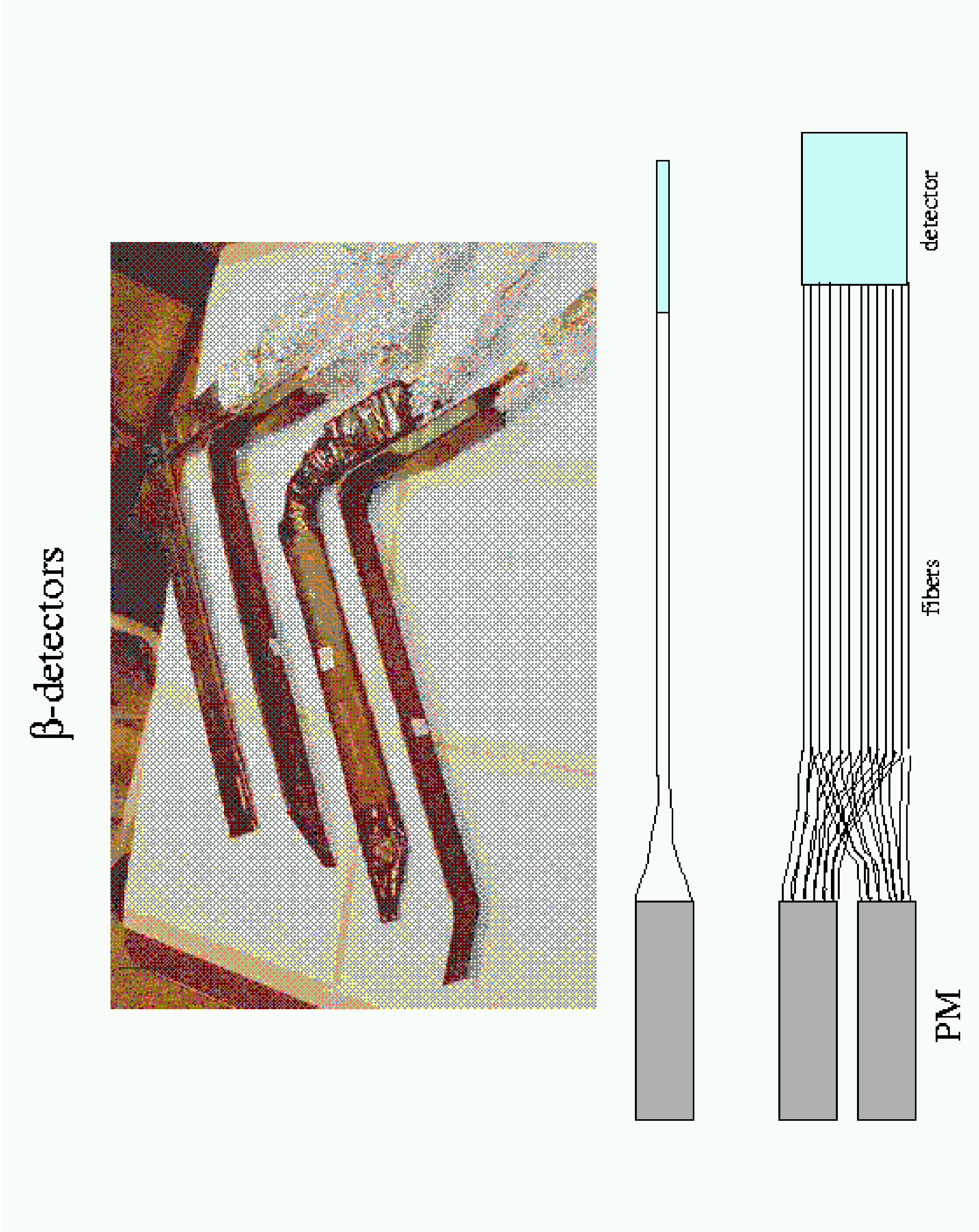

Figure 4: The low-noise beta-counters of the ISOLDE spectroscopy station.

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