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SEARCH FOR RARE PROCESSES AT GRAN SASSO

P. Belli[1], R. Bernabei[1], R. S. Boiko[2], F. Cappella[3], R. Cerulli[4], C. J. Dai[5], F. A. Danevich[6], A. d'Angelo[3], S. d'Angelo[1], B. V. Grinyov[7], A. Incicchitti[3], V. V. Kobychev[6], B. N. Kropivyansky[6], M. Laubenstein[4], P. G. Nagornyi[6], S. S. Nagorny[6], S. Nisi[4], F. Nozzoli[1], D. V. Poda[6], D. Prosperi[3], A. V. Tolmachev[8], V. I. Tretyak[6], I. M. Vyshnevskyi[6], R. P. Yavetskiy[8], S. S. Yurchenko[6]

[1] *Dip. Fisica, Univ. Roma Tor Vergata and INFN Tor Vergata, I-00133 Rome, Italy*
[2] *Chemical department, Kyiv National Taras Shevchenko University, Kiev, Ukraine*
[3] *Dip. Fisica, Univ. Roma La Sapienza and INFN Roma, I-00185 Rome, Italy*
[4] *INFN, Laboratori Nazionali del Gran Sasso, 67010 Assergi (AQ), Italy*
[5] *IHEP, Chinese Academy, P.O. Box 918/3, Beijing 100039, China*
[6] *Institute for Nuclear Research, MSP 03680 Kiev, Ukraine*
[7] *Institute for Scintillation Materials, 61001 Kharkov, Ukraine*
[8] *Institute for Single Crystals, 61001 Kharkov, Ukraine*

Abstract. New results achieved by the DAMA collaboration on the search for rare processes in the underground Gran Sasso National Laboratories (LNGS) of the INFN are presented. In particular, the following searches have been summarized: i) search for the α activity of ^{151}Eu; ii) measurement of $2\beta2\nu$ decay of ^{100}Mo to the first excited 0_1^+ level of ^{100}Ru; iii) search for double beta processes in ^{64}Zn.

1 Search for α decay of natural Europium [1, 2]

Both natural Europium isotopes, ^{151}Eu (natural abundance δ = 47.81(6)%) and ^{153}Eu (δ = 52.19(6)%) have a positive energy release respectively to α decay and, thus, they are potentially α radioactive. Corresponding Q_α values are: Q_α = 1.964(1) MeV for ^{151}Eu and Q_α = 0.273(4) MeV for ^{153}Eu.

The first experimental limits (90% C.L.) on the half lives of the rare alpha decays of ^{151}Eu into the first excited level of ^{147}Pm ($T_{1/2} > 2.4 \times 10^{16}$ y) and of ^{153}Eu into ^{149}Pm ($T_{1/2} > 1.1 \times 10^{16}$ y) was achieved in a preliminary measurement using a $Li_6Eu(BO_3)_3$ crystal (mass $\simeq$ 2.72 g) at LNGS [1].

In a second measurement, a low background CaF_2(Eu) crystal scintillator 3"⌀ × 1" (mass of 370 g), doped by Europium, was used to search for the α activity of ^{151}Eu [2]. The concentration of Eu in the crystal was determined with the help of the ICP Mass Spectrometry analysis: (0.4 ± 0.1)%. The detector was installed in the DAMA/R&D set-up operative at LNGS at a depth of 3600 m.w.e. The energy scale and resolution of the CaF_2(Eu) detector for γ quanta were measured with standard γ sources and the response of the detector to α particles was studied with a collimated ^{241}Am α source – by using different sets of absorbers – from 1 MeV up to 5.25 MeV (see Fig. 1a). To discriminate events from α decays inside the crystal from the $\gamma(\beta)$ background, the optimal filter method was applied and the energy dependence of the shape indicators (SI) was measured. The low energy part of the background spectrum measured with the CaF_2(Eu) crystal scintillator during 7426 h is shown in Fig.1b. There is a peculiarity in the spectrum at the energy near 250 keV –

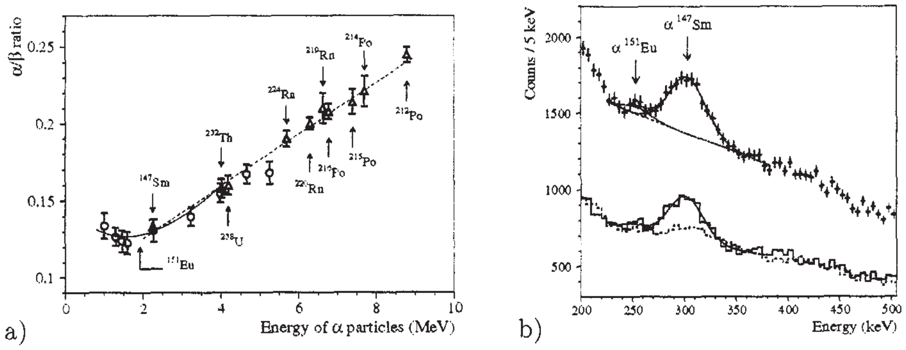

Figure 1: *Left* Energy dependence of the α/β ratio for the $CaF_2(Eu)$ scintillation detector. Measurements with ^{241}Am source using different sets of absorbers (mylar or few mm of air in some cases) are shown by circles; points shown by triangles have been obtained from the identified α activity in the background data. *Right*: Low energy part of the background spectrum measured during 7426 h in the low background set-up with the $CaF_2(Eu)$ scintillator (crosses). The peculiarity on the left of the ^{147}Sm peak can be attributed to the α decay of ^{151}Eu with the half-life $T_{1/2} = 5 \times 10^{18}$ y. The α nature of the two peaks is further supported by the pulse shape discrimination analysis; see discussion on the bottom lines given in ref. [2].

in agreement with the expected energy of the ^{151}Eu alpha decay – which gives an indication on the existence of this process. Therefore, the half-life of ^{151}Eu relatively to the α decay to the ground state of ^{147}Pm has been evaluated to be: $T^{\alpha}_{1/2}(g.s. \rightarrow g.s.) = 5^{+11}_{-3} \times 10^{18}$ y, or, in a more conservative approach: $T^{\alpha}_{1/2}(g.s. \rightarrow g.s.) \geq 1.7 \times 10^{18}$ y at 68% C.L. [2].

In addition, for the decay of ^{151}Eu to the first excited ($5/2^+$,E_{exc}=91 keV) level of ^{147}Pm a limit has also been obtained: $T^{\alpha}_{1/2}(g.s. \rightarrow 5/2^+) \geq 6 \times 10^{17}$y at 68%C.L. Theoretical half-lifes for ^{151}Eu α decay calculated in different model frameworks are in the range of $(0.3–3.6) \times 10^{18}$ y; in particular, the measured value of half-life of ^{151}Eu is well in agreement with the calculations of [3].

2 Measurement of $2\beta2\nu$ decay of ^{100}Mo to the 0^+_1 level of ^{100}Ru [4]

The me*A*su*Re**M*ent of tw*O*-*N*eutr*I*no 2β dec*A*y of ^{100}Mo to the first excited 0^+_1 level of ^{100}Ru (*ARMONIA*) consists of a Mo sample of $\simeq$ 1 kg enriched in ^{100}Mo at 99.5% in form of metallic powder installed in the four low-background HP Ge detectors (about 225 cm^3 each, all mounted in one cryostat) facility located at LNGS. The aim of this high sensitivity experiment is to measure the $2\beta2\nu$ decay of ^{100}Mo to the first excited 0^+_1 level of ^{100}Ru [$E(0^+_1)$ = 1130.5 keV] either to confirm positive results reported in [5] (with $T_{1/2}$ in the range around $6 - 9 \times 10^{20}$ y) or to confirm previous higher limit value of ref. [6] ($T_{1/2} > 1.2 \times 10^{21}$ y at 90% C.L.).

Preliminary data have been collected deep underground at LNGS during 1927 h (see Fig. 2). Two γ of 590.8 keV and 539.6 keV respectively are expected in the 0^+_1 level de-excitation of the ^{100}Ru. The measured energy distribution in the range of 500-600 keV is reported in Fig. 2 and compared

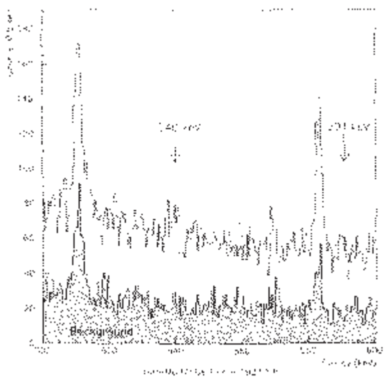

Figure 2: Spectrum of ^{100}Mo sample (mass of 1009 g) measured with 4 HP Ge detectors set-up at LNGS during 192? h in the range of 600-600 **keV.** Shaded **area** is background spectrum (without ^{100}Mo sample) normalised to the same **time of measurements.** Peaks at 583 keV and 511 keV are related with ^{2}0®Tl decay and the **positron** annihilation process, respectively.

with the background spectrum measured without the ^{100}Mo sample (shaded area). Note **that** peaks at 583 **keV** and 511 **keV** are related with $^{2O8}T1$ decay and the positron annihilation process, respectively.

A modest peak structure seems to be present - but at very low C.L. - around 540 **keV,** where one 7 searched for is expected. If **this** would be ascribed to the decay searched for, one gets: *T1/2* = 3×10^{20} y. However, no significant statistical evidence for the peak **at** the energy of 591 keV is found **at** present and a **limit** on the half-life can be derived: *T1/2* > 6×10^{20} y at 90% C.L.. These measurements have shown that ***AR.M0NIA*** is entering in the sensitivity region of interest. New data taking **with** further purified sample and larger exposure is in progress,

3 Search for 2/3 processes in ^{64}Zn with **a** ZNWO4 **scintillator** [7].

^{64}Zn is one of the few exceptions among *20*$^{+}$ nuclei having **big** natural isotopic abundance (48.268%); the mass difference between ^{64}Zn and ^{64}Ni nuclei is 1095.7(0.7) **keV** and, therefore, double electron capture *(2s),* and electron capture with emission of positron *(s[3*$^{+}$*)* are energetically allowed.

A low background ZnWO4 crystal scintillator (mass of 117 g) has been installed deep underground in the low background DAMA/R&D set-up at the LNGS for the investigation of double beta processes in ^{64}Zn with higher sensitivity. The energy scale and resolution of the Z11WO4 detector for 7 quanta were measured with ^{22}Na, ^{133}Ba, ^{137}Os, ^{228}Th and ^{241}Am sources.

The energy spectrum measured during 1902 h is presented in Fig. 3.

Comparing the simulated response **functions** for different 2/3 processes **in** ^{64}**Zn with the** experimental energy distribution accumulated with the **ZnWO4** crystal we did not find the peculiarities expected in the spectra. Therefore, lower half-life limits can be set for the *2/3* processes in decay ^{64}Zn — ^{64}Ni at 90% C.L. (see table 1) improving the previous results; moreover, the positive

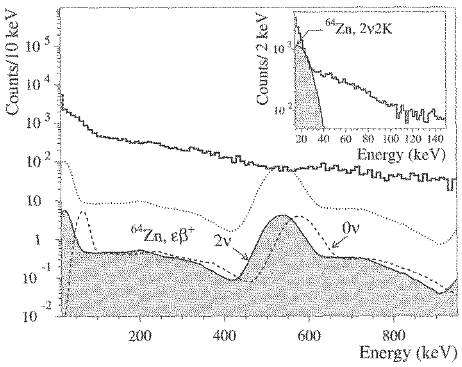

Figure 3: The measured energy spectrum of $ZnWO_4$ scintillation crystal (mass of 117 g, 1902 h of measurements) together with the excluded at 90% C.L. distributions for $\varepsilon\beta^+$ processes in ^{64}Zn. Energy spectrum of $2\nu\varepsilon\beta^+$ decay with $T_{1/2} = 1.1 \times 10^{19}$ y (central value of positive indication in Ref. [8]) is also shown by dotted line. *In the Inset:* Low energy part of the spectrum together with the $2\nu 2K$ peak of ^{64}Zn with $T_{1/2} = 6.2 \times 10^{18}$y excluded at 90%C.L.

indication for the $2\nu\varepsilon\beta^+$ decay channel ($T_{1/2} = 1.1 \times 10^{19}$ y) [8] is excluded with high confidence by the experimental data. New measurements with a larger $ZnWO_4$ crystal (mass of 0.7 kg) and with higher light output are in progress.

Table 1: Half-life limits on 2β processes in decay $^{64}\text{Zn} \to {}^{64}\text{Ni}$ at 90% C.L.

Decay channel	$T_{1/2}$ (y) Present work	$T_{1/2}$ (y) Previous results
$0\nu\varepsilon\beta^+$	$> 2.2 \times 10^{20}$	$> 1.3 \times 10^{20}$ [9]
$2\nu\varepsilon\beta^+$	$> 2.1 \times 10^{20}$	$= (1.1 \pm 0.9) \times 10^{19}$ [8]
		$> 1.3 \times 10^{20}$ [9]
$0\nu 2K$	$> 4.0 \times 10^{18}$	$> 1.2 \times 10^{17}$ [10]
$2\nu 2K$	$> 6.2 \times 10^{18}$	$> 6.0 \times 10^{16}$ [11]
$0\nu 2\varepsilon$	$> 3.4 \times 10^{18}$	$> 7.0 \times 10^{17}$ [12]

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