DBA. Search for double beta decay of ^{100}Mo with liquid argon ionization chamber.

V.D. Ashitkov[1], A.S. Barabash[1], S.G. Belogurov[1], G. Carugno[2], S.I. Konovalov[1], F.Massera[4], G. Puglierin[2], R.R. Saakyan[1,3], V.N. Stekhanov[1], V.I. Umatov[1],

[1]Institute of Theoretical and Experimental Physics, B. Cheremushkinskaya 25, 117259 Moscow, Russia

[2]Dipartimento di Fisica e INFN, Universita di Padova, via Marzolo 8, I-35131 Padova, Italy

[3]Laboratori Nazionali del Gran Sasso dell'INFN, I-67010 Assergi (L'Aquila), Italy

[4]INFN, Sezione di Bologna, 40126, via Berti Pichat, 6/2 (Bologna), Italy

Abstract

The experiment is located in the Gran Sasso Underground Laboratory (3500 m w.e.). Full weight of ^{100}Mo under investigation is 306 g. New measurement run was done (1355 h). As a result the limits on half-lives for 0ν- and $0\nu\chi^0$-decays of ^{100}Mo were obtained as $3.4 \cdot 10^{21}$ y and $2.2 \cdot 10^{20}$ y, respectively, at 90% CL. The $2\nu\beta\beta$ decay of ^{100}Mo was firmly detected ($> 6\sigma$ of effect) and its half-life was measured, $[6.8 \pm 1.1(stat) \pm 0.7(syst)] \cdot 10^{18}$ y.

1 Introduction

At present time the neutrinoless double beta decay is one of the best probe for physics beyond the standard model of electroweak interactions providing the unique information about the lepton number non-conservation, existence and nature of neutrino mass and many other fundamental aspects of particle physics. In connection with $0\nu\beta\beta$-decay the detection of double beta decay with the emission of two neutrinos is also of great importance since it enables the experimental determination of nuclear matrix elements involved in double beta decay processes.

In order to search for double beta decay of ^{100}Mo with a novel technique a multisectional liquid argon ionization chamber was suggested [1]. The experiment was installed in Gran Sasso Underground Laboratory in 1996.

The experimental setup consists of a liquid argon ionization chamber placed in passive shielding (15cm of lead), gas system, electronics and data acquisition system. The active detection portion of the chamber is composed of alternating circular planes of anodes and cathodes with screen grids placed between them. The cathodes are made of molybdenum foil approximately 50 mg/cm^2 thick. The chamber contains 14 cathodes, 15 anodes and 28 screening grids. The grid anode distance is 5.5 mm and the grid-cathode is 14.5 mm. The sensitive volume's diameter is 30 cm and its height is 56 cm. Each anode is connected to a charge-sensitive preamplifier, followed by an amplifier and a shaper. Shaped and unshaped signals are digitized by two 8-bit flash ADC with the 50 ns sampling time. Unshaped pulse analysis gives the space information of events. The trigger for data collection requires that at least one anode signal exceeds the threshold (700 keV). Each trigger causes digitized signals from all anodes to be written to a data tape. The more detailed description of the experimental setup can be found in previous Annual Reports [2, 3, 4].

2 Collaboration activity in 1999

In the last year DBA collaboration has made a notable progress in the detector hardware upgrade as well as in data taking and analysis. The main features of the experimental activity in 1999 are listed below.

- Total mass of ^{100}Mo has been increased up to 306 grammes. The measurements have been done with this mass of enriched isotope which is more than double of the isotope mass used before.

- Heating system maintaining the temperature of liquid argon has been redone so as to get rid of the electronic noise due to this system. This made it possible to reduce significantly detector dead time.

- Remote slow control facilities for the most essential detector parameters such as pressure in the fiducial volume and liquid nitrogen level in the detector's cryostat have been included in experimental setup.

- Liquid nitrogen refilling system (LN2) has been also modified. The very low continuous flux of LN2 going through the pipe-line in the detector cryostat was used instead of batch operation mode with periodical filling. It reduces the manpower needed to maintain the detector during the measurements and improves the measurement/maintenance time ratio.

- Neutron passive shielding has been developed and is being constructed. It will consist of 25 cm of water for neutron thermalisation and 1 cm of boron acid (H_3BO_3) to capture the thermal neutrons. The resulting gamma radiation will be captured by passive shielding of lead. Preliminary calculations show that this shielding can reduce the background due to the (n,γ) reactions in the fiducial volume in two orders of magnitude.

- 1355 hours of data taking were done. The results have been analysed and they are presented below.

3 Experimental results

The chamber has been assembled with eight cathodes containing enriched ^{100}Mo and six cathodes with natural molybdenum. This configuration is optimal to provide background subtraction for two-neutrino double beta decay measurement. Experimental run have been performed with electric fields of 1.93 kV/cm for the cathode-grid gap and 3.64 kV/cm for the anode-grid gap. The chamber filled with liquid Ar has been calibrated by ^{22}Na (1275 keV) and ^{88}Y (1836 keV) radioactive sources. Extrapolation gives the energy resolution (FWHM) of 6% at the energy of ^{100}Mo double beta decay transition (3033 keV). The total measurement time was 1355 hours. The single electron spectrum used to explore ^{42}Ar content is shown in figure 1.

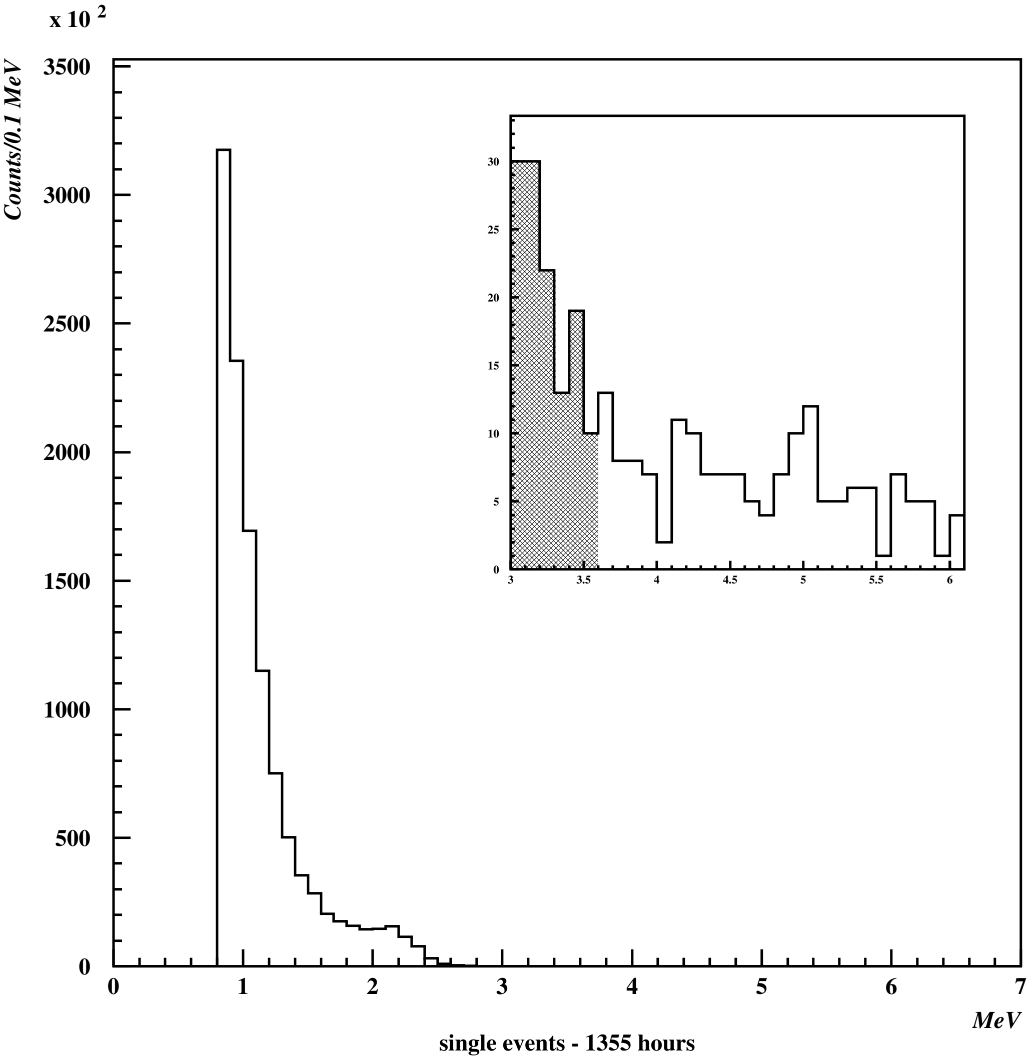

Figure 1: The single electron spectrum.

To search for double beta decay we select so called "double" events when signals appear in two neighbouring channels and when there are no signals in other 13 channels. In addition, we choose the time difference between the maxima of the pulses $< 0.6\mu$s. The detection efficiency for each decay mode was calculated in a GEANT-based MC program. In the off-line analysis we used the combined results from the last and previous (1998) experimental runs. This corresponds to the 458 kg*hours and 303 kg*hours of measurements with enriched and natural molybdenum respectively (fig. 2). Considered individually below are various types of the decay processes under study.

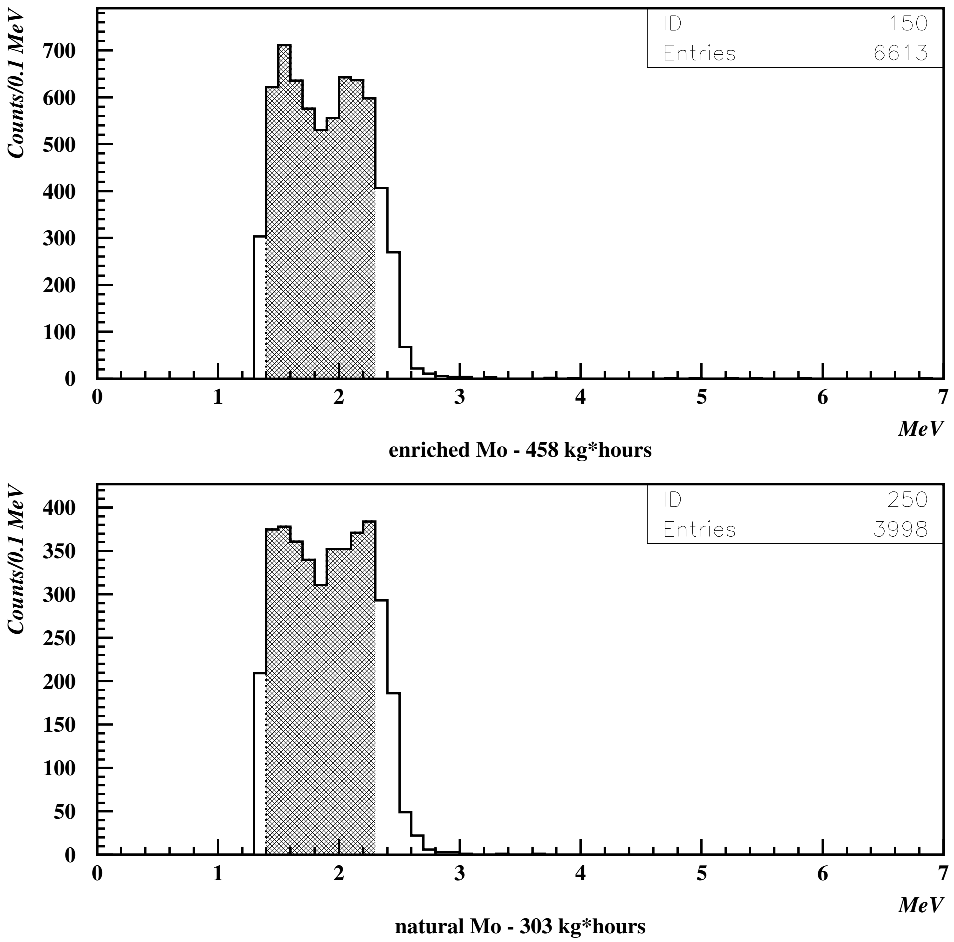

Figure 2: Spectra of double electron events

3.1 0ν-decay

A loss of the detection efficiency due to pulse shape analysis applied to the high energy events and software cuts of 1 MeV for single electrons are well compensated by the background reduction factor in the ^{100}Mo $0\nu\beta\beta$ energy region. Three events in the enriched foils and three events in the natural ones were detected in the energy interval of $2.8-3.1$ MeV. Taking into account the efficiency of 6.9% and assuming Poisson distributions for the numbers of true, observed and estimated background counts, one can obtain a limit on the 0ν decay of ^{100}Mo, $T_{1/2} > 6.4(3.4)\cdot 10^{21}$ y at 68%(90%) C.L.

3.2 $0\nu\chi^0$-decay

The energy interval of $2.3-3.0$ MeV was investigated. 783 events were recorded for enriched Mo foils. Taking into account the difference of masses natural Mo foils gave 843 events, i.e. there was no excess of double events in the enriched foils. Using the efficiency value of 5.7% we obtained the limit, $T_{1/2} > 2.8(2.2)\cdot 10^{20}$ y at 68%(90%) C.L.

3.3 2ν-decay

The best signal-to-background ratio according to MC calculations was found in the energy interval of $1.4 - 2.3$ MeV. The off-line analysis applied to this energy region (figure 2) gives more than 6.2σ of effect due to the 2ν decay of ^{100}Mo. Background subtraction leads to the final value of the effect, 636 ± 102 events. Using the calculated detection efficiency of the $2\nu\beta\beta$ decay of ^{100}Mo (2.2%) one gets the half-life:

$T_{1/2} = [0.68 \pm 0.11(stat) \pm 0.07(syst)] \cdot 10^{19}$ y.

3.4 ^{42}Ar content

The spectrum of single electrons (figure 1) was used to obtain the limit on radioactive ^{42}Ar contamination of natural argon contained in the operating volume. During 1355 hours of counting 124 events were obtained in the energy range of 3 to 3.6 MeV to be compared with 41 events collected for 440 hours in the previous measurements [5]. The values are in good agreement and lead to the same limit, ^{42}Ar/^{nat}Ar$< 6 \cdot 10^{-21}$. According to the MC simulations the main contributions in counting above 3 MeV can be due to ^{42}Ar, (n,γ) reactions from external neutron background or β-decay of ^{214}Bi in the fiducial volume of the detector. In particular, the neutron background is clearly seen now at the high energy edge of spectrum. Passive shielding of water and boron acid installed around the lead shielding will strongly reduce this type of background and will allow to reach the higher sensitivity to ^{42}Ar.

4 Discussions and prospects

Two neutrino double beta decay of ^{100}Mo has been firmly detected ($> 6\sigma$ of effect). It was demonstrated that only 3 months of data taking will allow to measure $2\nu\beta\beta$-decay of ^{100}Mo with accuracy of 10-12%.

In [6] it was proposed that the difference in the decay rate in $2\nu\beta\beta$ process at "present" (direct counter experiments) and in the "past" (geochemical experiments) can be explained by the time variation of the weak interaction constant. It was pointed out that ^{100}Mo is one of the best candidate to check this hypothesis because it has the maximum rate of decay and quite high concentration of the ^{100}Mo (9.6%) in the natural molybdenum. Besides, the ^{100}Ru arised due to the 2β-decay of ^{100}Mo will be kept in minerals. Therefore measuring the half-life of the $2\nu\beta\beta$ decay of ^{100}Mo with accuracy down to 10% or better is of great interest and importance given also that two most accurate modern results for ^{100}Mo give the different values of its half-life [7, 8].

It is expected that H_2O/H_3BO_3 passive shielding will reduce the neutron background in two orders of magnitude. If the count rates in the 0ν energy range are mainly due to neutron background, 4 months of counting with this shielding will make it possible to reach the sensitivity to 0ν decay at the level of the best present experiments with ^{100}Mo. In this case one year of measurements will increase the sensitivity to 0ν- and $0\nu\chi^0$-modes to the level of $(1-2) \cdot 10^{23}$ y and $(1-2) \cdot 10^{22}$ y respectively. However, if ^{42}Ar content in the Earth's atmosphere is more than 10^{-21} g/g it will limit the sensitivity of the experiment to 0ν decay. At the same time the ^{42}Ar content will be carefully investigated and determined. Furthermore ^{42}Ar production mechanism in the atmosphere will be understood. We plan also to develop a method for identifying the background from ^{42}Ar in the future argon-based low background detectors operating at low energy.

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6 Publications and Conferences in 1999

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