J Low Temp Phys (2012) 167:1035–1040
DOI 10.1007/s10909-011-0421-6

MARE-1 in Milan: Status and Perspectives

E. Ferri · C. Arnaboldi · G. Ceruti · M. Faverzani · F. Gatti · A. Giachero · C. Gotti · C. Kilbourne · S. Kraft-Bermuth · A. Nucciotti · G. Pessina · D. Schaeffer · M. Sisti

Received: 15 July 2011 / Accepted: 14 November 2011 / Published online: 30 November 2011

Abstract The international project MARE (Microcalorimeter Array for a Rhenium Experiment) aims at the direct and calorimetric measurement of the electron neutrino mass with sub-eV sensitivity. Although the baseline of the MARE project consists in a large array of rhenium based thermal detectors, a different option for the isotope is also being considered. The different option is ^{163}Ho. The potential of using ^{187}Re for a calorimetric neutrino mass experiment has been already demonstrated. On the contrary, no calorimetric spectrum of ^{163}Ho has been so far measured with the precision required to set a useful limit on the neutrino mass.

The first phase of the project (MARE-1) is a collection of activities with the aim of sorting out both the best isotope and the most suited detector technology to be used for the final experiment. One of the MARE-1 activities is carried out in Milan by the group of Milano–Bicocca in collaboration with NASA/GSFC and Wisconsin groups. The Milan MARE-1 arrays are based on semiconductor thermistors, provided by the NASA/GSFC group, with dielectric silver perrhenate absorbers, $AgReO_4$. The experiment, which is presently being assembled, is designed to host up to 8 arrays.

E. Ferri (✉) · C. Arnaboldi · G. Ceruti · M. Faverzani · A. Giachero · C. Gotti · A. Nucciotti · G. Pessina · M. Sisti
Università degli Studi di Milano-Bicocca and INFN Milano-Bicocca, Milano, Italy
e-mail: elena.ferri@mib.infn.it

D. Schaeffer
ABB AB, Corporate Research, Vsterås, Sweden

S. Kraft-Bermuth
Institut für Physik, Johannes-Gutenberg-Universität Mainz, Mainz, Germany

C. Kilbourne
Goddard Space FlightCenter, NASA, Greenbelt, USA

F. Gatti
Università di Genova and INFN di Genova, Genova, Italy

With 288 detectors, a sensitivity of 3 eV at 90% CL on the neutrino mass can be reached within 3 years.

This contribution gives an outlook for the MARE activities for the active isotope selection. In this contribution the status and the perspectives of the MARE-1 in Milan are also reported.

Keywords Neutrino mass · Cryogenics detector

1 Introduction

Nowadays we know that neutrinos are massive particles. The experiments, based on kinematic analysis of electrons emitted in single β-decay, are the only ones dedicated to effective electron-neutrino mass determination. The method consists in searching for a tiny deformation caused by a non-zero neutrino mass to the spectrum near its end point.

The most stringent results come from electrostatic spectrometers on tritium decay (E_0 =18.6 keV). The Troitsk experiment has set an upper limit on neutrino mass of 2.5 eV/c^2 [1], while the Mainz collaboration has reached $m_\nu \leq 2.3$ eV/c^2 [2]. KATRIN, the next generation experiment, is designed to reach a sensitivity of 0.2 eV/c^2 in five years [3, 4].

An alternative approach to spectrometry is calorimetry where the β-source is embedded in the detector so that all the energy emitted in the decay is measured, except for the one taken away by the neutrino. In this way the measurement is completely free from systematics induced by any possible energy loss in the source and due to decays into excited final states. The remaining systematics may be due to energy lost in metastable states living longer than the detector response time. In contrast to the spectrometric approach, the full beta spectrum is acquired. Therefore, the source activity has to be limited to avoid pile-up which would deform the shape of beta spectrum. As a consequence the statistics near the end-point is limited as well. This limitation may be then partially balanced by using β-emitting isotopes with an end-point energy as low as possible. Thanks to the MIBETA and MANU results, the two calorimetric experiment using Re as beta source, a new large scale experiment able to explore the sub-eV neutrino mass range with a calorimetric approach has been projected.

2 The MARE Project

MARE is a new large scale experiment to measure directly the neutrino mass with a calorimetric technique. The MARE project has a staged approach. The goal of the last phase (MARE-2) is to achieve a sub-eV sensitivity on neutrino mass. It consists of deployment of several arrays of thermal microcalorimeters. The first phase (MARE-1) is a collection of activities with the aim of sorting out both the best isotope and the most suited detector technology to be used for the final experiment. The two competing isotopes are ^{187}Re and ^{163}Ho.

Rhenium is in principle suited for fabricating thermal detectors. Metallic rhenium crystals allow to reach high sensitivity thanks to their low thermal capacity. Also dielectric compounds can be used. Up to now, only two β decay experiments have been carried out with thermal detectors: MANU [7, 8] and MIBETA [5, 6] experiments. MANU used metallic rhenium single crystal as absorber, while MIBETA used $AgReO_4$ crystals. Collecting a statistic of about 10^7 events, they achieved an upper limit on neutrino mass of about 26 eV/c^2 at 95% CL and 15 eV/c^2 at 90% CL, respectively. In these experiments, the systematic uncertainties are still small compared to the statistical errors. The main sources of systematics are the background, the theoretical shape of the ^{187}Re β spectrum and the detector response function.

The major issue remains the metallic rhenium absorber coupled to the sensor. Persisting difficulties, probably due to an incomplete energy conversion in the absorber, have prevented from realizing the target performances with rhenium absorbers so far. In order to have an alternative to the rhenium as β source, the MARE collaboration is considering the possibility to use ^{163}Ho electron capture (EC) [9].

^{163}Ho EC decay has been the subject of many experimental investigations aimed at determining the neutrino mass thanks to its low transition energy ($\sim$2.5 keV). ^{163}Ho decays to ^{163}Dy and the capture is only allowed from the M shell or higher. The EC may be only detected through the mostly non radiative atom de-excitation of the Dy atom and from the Inner Bremsstrahlung (IB) radiation. There are three proposed independent methods to estimate the neutrino mass from the ^{163}Ho EC: (a) absolute M capture rates or M/N capture ratios [10], (b) IB end-point [11] and (c) total absorption spectrum end-point [12].

There has been no experiment attempting to exploit the last method which consists in studying the end-point of the total absorption spectrum as proposed by De Rujula and Lusignoli [12]. The total spectrum is composed by peaks with Breit-Wigner shapes and it ends at $E_0 - m_\nu$, in analogy to what happens for β spectrum. Also in ^{163}Ho experiments the sensitivity on m_ν depends on the fraction of events at the end-point: this fraction increases for decreasing the end-point value and the neutrino mass sensitivity increases accordingly. The ^{163}Ho end-point is still unknown and the various E_0 determinations range from 2.2 to 2.8 keV [13].

More MARE-1 activities are devoted to the design of the single detector for the final MARE large scale experiment. This mainly consists in optimizing the coupling between rhenium crystals—or ^{163}Ho implanted absorbers—and sensitive sensors like Transition Edge Sensor (TES) [14], Metallic Magnetic Calorimeters (MMC) [15] or Microwave Kinetic Inductance Detectors (MKID) [16].

3 MARE 1 in Milan

The Milano–Bicocca group in collaboration with NASA/GSFC and Wisconsin groups is in charge of one of the MARE-1 activities.

The Milan MARE-1 arrays are based on semiconductor thermistors, provided by the NASA/GSFC group, with dielectric silver perrhenate absorbers, $AgReO_4$. These arrays consist of 6×6 implanted Si:P thermistors with a size of $300 \times 300 \times 1.5$ μm^3. The $AgReO_4$ absorber are grown by Mateck GmbH in Germany. Mateck has developed a procedure to grow large single crystal with high purity and to cut them as precisely as possible. So the crystals are cut in regular shape of $600 \times 600 \times 250$ μm^3.

A mass of a single crystal is around 500 µg, giving 0.27 dec/s. To adapt the thermistors developed by NASA to our purpose silicon spacers of $300 \times 300 \times 10\ \mu m^3$ are used. Gluing them between the thermistor and the larger absorber it is possible to achieve an energy and time resolution of 25 eV at 2.6 keV and 250 µs, respectively. With 288 detectors and such performances, a sensitivity on neutrino mass of 3 eV at 90 % CL can be achieved in 3 years [17].

The performance of such bolometers, which are characterized by high impedance at low temperature (around 4 MΩ at 85 mK), depends not only on the thermistors and the quality of the crystals but also on the read-out electronics. For that reason a cold buffer stage, based on JFETs at 120 K, is installed as close as possible to the detector to shift down the thermistor impedance. This stage is followed by an amplifier stage at room temperature. The amplifier stage subtracts the signal present at the cold buffer output from the reference ground signal. The presence of only one ground signal for all channels, which corresponds to the detector holder, cancels the ground loop interference. The output signal is filtered with an active Bessel low pass antialiasing filter, placed close to the DAQ system [18].

In the original design [19], to electrically connect the cold buffer stage (120 K) to the detector at 85 mK two different stages of microbridges were used. Microbridges were low thermal conductance wires produced by Memsrad/FBK in Trento, Italy. The first microbridge stage provided the thermal decoupling between the detectors and the JFET holder at 4 K. These microbridges were made of Titanium. The second microbridges stage were in the JFET box and the microbridges were made in Aluminium.

During the assembly there was an unexpected failure of the two microbridges stages. As a consequence, the schedule has been delayed by about two years. For that reason an R&D work has been dedicated to determine the best wires suited to replace the Ti and Al microbridges. Our studies have shown that Stainless Steel and Al/Si 1% wires are the best replacements for Ti and Al microbridges, respectively. The length of Stainless Steel wires is around 2 cm and the diameter is 12.5 µm, instead the length of Al/Si 1% wires is around 1.3 cm and the diameter is 17.5 µm. Stainless Steel and Al/Si 1% wires do not guarantee the mechanical stability. Therefore, material with low thermal conductivity are used as mechanical support, namely Kevlar and Vespel. The mechanical support of the PCB, where the Stainless Steel wires are soldered, consists of 3 Kevlar crosses (see left panel of Fig. 1). The 4 K parts are suspended by these crosses. In the right panel of Fig. 1 one can see the two thin Vespel rods, used as mechanical support for the JFET PCB.

Since the last LTD two Cu braids are added in order to increase the thermal link between 4 K parts, which was too weak. One braid is located between the preamplifier support and the copper rod screwed on the IVC plate, and the other between the preamplifier support and the 4 K parts suspended by the 3 Kevlar crosses.

The energy calibration system, located between the detector holder and the JFETs boxes, consists of fluorescence sources with ^{55}Fe, whose activity is 10mCi, as a primary source movable in and out of a Roman lead shield [19]. The ^{55}Fe source is at 4 K. The fluorescence targets, made of Al, Si, NaCl, $CaCO_3$ and Ti, are at the Mixing Chamber temperature and they allow a precise energy calibration around the end-point of ^{187}Re with the K_α and K_β X-rays.

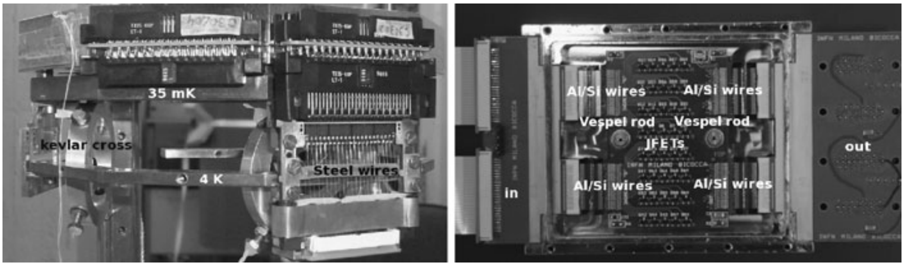

Fig. 1 *Left panel*: the first decoupling stage between detector and JFET box. Stainless Steel wires, which replace the Ti microbridges, are used to electrically connect the detectors. Instead, the mechanical stability is guaranteed by three Kevlar crosses. *Right panel*: the second decoupling stage inside the JFET box. The PCB is suspended by two thin Vespel rods and Al/Si wires replace the Al microbridges, which were broken during the first assembly

Last year a thermal shield at 35 mK was added to the entire set-up in order to shield the detectors from the thermal radiation. It has been projected to match with the cryogenic set-up of MARE-1. In particular, two holes are made on its bottom: one for the calibration system and the other one for the JFET connections. The new improvements in the MARE-1 cryogenic set-up (i.e. copper braids, thermal shield and wires) were tested over the last two years.

The cryogenic set-up of MARE-1 in Milan is mounted in a Kelvinox KX400 dilution refrigerator, located in the cryogenic laboratory of the University of Milano-Bicocca. It can host up to eight arrays but only two of them with electronics have been funded so far. Therefore, read-out electronics have been installed only for 80 channels.

A test run with two arrays and the entire MARE-1 cryogenic set-up is planned to start at the end of this year. One array is equipped with 10 $AgReO_4$ crystals and the other with two thin Sn absorbers characterized by a very low heat capacity. The Sn absorbers, whose size is $500 \times 500 \times 25\ \mu m^3$, will measure the environmental background below the Re end-point. This run has several goals. First of all it is useful to check the functionality of all channels, but it is also a final test for the thermal coupling between thermistors and silicon spacer. Therefore, two different kinds of epoxy resins are tested: five silicon spacers are attached with Araldite Normal and the other five with ST1266 epoxy. ST2850 epoxy is used to glue all the $AgReO_4$ absorbers on the silicon spacers.

After this test, the remaining $AgReO_4$ crystals will be attached to the thermistors. The first measurement of 72 channels should start in 2012. With two arrays, a sensitivity of 4.5 eV at 90% C.L. is expected in three years running time.

4 Conclusion

The first phase of MARE-1 in Milan is getting ready to start using silicon implanted thermistors array equipped with $AgReO_4$ single crystals absorbers. The experiment, which starts with 72 channels, is designed to be expanded to 288 channels to increase the sensitivity on the neutrino mass.

References

1. V.M. Lobashev, Nucl. Phys. B, Proc. Suppl. **91**, 280–286 (2001)
2. Ch. Kraus, Eur. Phys. J. C **40**, 447–468 (2005)
3. A. Osipowic et al., hep-ex/0109033 (2001)
4. J. Angrik et al., *Design Report* **7090** (2004). http://bibliothek.fzk.de/zb/berichte/FZKA7090.pdf
5. M. Sisti et al., Nucl. Instrum. Methods A **520**, 125 (2004)
6. C. Arnaboldi et al., Phys. Rev. Lett. **91** (2003). doi:10.1103/PhysRevLett.91.161802
7. F. Gatti et al., Nucl. Phys. B **91**, 293 (2001)
8. M. Galeazzi et al., Phys. Rev. C **63** (2001)
9. F. Gatti et al., J. Low Temp. Phys. **151**, 603 (2008)
10. C.L. Bennett et al., Phys. Lett. B **107**, 19 (1981)
11. A. De Rujula, Nucl. Phys. B **188**, 414 (1981)
12. A. De Rujula, M. Lusignoli, Phys. Lett. B **118**, 72 (1982).
13. C.W. Reich et al., Nucl. Data Sh. **111** (2010). doi:10.1016/j.nds.2010.04.001
14. M. Ribeiro-Gomes et al., AIP Conf. Proc. **1185** (2009). doi:10.1063/1.3292403
15. J.-P. Porst, J. Low Temp. Phys. (2011, this issue)
16. M. Faverzani, J. Low Temp. Phys. (2011, this issue)
17. A. Nucciotti, J. Low Temp. Phys. **151**, 597–602 (2008)
18. C. Gotti, J. Low Temp. Phys. (2011, this issue). doi:10.1007/s10909-011-0423-4
19. D. Schaeffer et al., J. Low Temp. Phys. **151**, 623–628 (2008)