PROCEEDINGS OF SCIENCE

The HOLMES experiment: status and perspective

B.Alpert,[a] M.Balata,[b] D.Becker,[a] D.Bennett,[a] M.Biasotti,[c] V.Ceriale,[c] M.De Gerone,[c] R.Dressler,[d] M.Faverzani,[e] E.Ferri∗,[e] J.Fowler,[a] G.Gallucci,[c] J.Gard,[a] F.Gatti,[c] A.Giachero,[e] J.Hays-Wehle,[f] S.Heinitz,[d] G.Hilton,[a] U.Köster,[g] M.Lusignoli,[h] J.Mates,[a] S.Nisi,[b] A.Nucciotti,[e] A.Orlando, [i] G.Pessina,[e] A.Puiu,[e] S.Ragazzi,[e] C.Reintsema,[a] M.Ribeiro-Gomes, [l] D.Schmidt,[a] D.Schumann,[d] D.Swetz,[a] J.Ullom,[a] L.Vale.[a]

[a]*National Institute of Standards and Technology, Boulder, CO, USA.*
[b]*Laboratori Nazionali del Gran Sasso, INFN, Assergi, AQ, Italy.*
[c]*Unversità di Genova and INFN Sez. di Genova, Genova, Italy.*
[d] *Paul Scherrer Institut, Villigen, Switzerland.*
[e]*Università degli Studi di Milano-Biccocca and INFN Sez. di Milano-Bicocca, Milan, Italy.*
[f] *NASA, Goddard Space Flight Center, Greenbelt, USA*
[g] *Institut Laue-Langeving, Grenoble, France.*
[h] *INFN Sez. di Roma 1, Roma, Italy.*
[i] *Cardiff University, Cardiff, UK*
[l] *Multidisciplinary Centre for Astrophysics (CENTRA-IST), University of Lisbon, Lisbon, Portugal.*

One of the most crucial challenges in today particle physics and cosmology is the determination of the neutrino absolute mass scale. Currently, the only model independent method to set a limit neutrino mass is the study of the nuclear beta spectrum end-point. Performing a calorimetric measurement of the end point of the Electron Capture decay spectrum of ^{163}Ho, the HOLMES experiment aims at pushing down the sensitivity on the smallest neutrino mass at the order of $\sim$ eV. In its final configuration HOLMES will deploy an array of 1000 microcalorimeters based on Transition Edge Sensors with gold absorbers in which the ^{163}Ho will be ion implanted with a target activity of 300 Hz/det. In order to achieve a statistical sensitivity on the neutrino mass in the eV range, there are stringent requirements on the detector performances: fast time resolution ($\sim$ 1 μs) to solve pile-up events and an energy resolution of few eV at the Q-value (2.8 keV). Furthermore, the detectors must be multiplexable. The best technique to easily readout such a number of detector with a common readout line is the microwave frequency domain readout. We outline the HOLMES project with its physics reach and technical challenges together with its status and perspectives. In detail, we report the status of HOLMES activities concerning the ^{163}Ho isotope production, the TES and multiplexed array read-out and the isotope embedding process.

Neutrino Oscillation Workshop (NOW2018)
9 - 16 September, 2018
Rosa Marina (Ostuni, Brindisi, Italy)

∗Speaker.

PoS(NOW2018)073

1. The HOLMES experiment

The HOLMES experiment aims at directly measuring the electron neutrino mass with a sensitivity around 2 eV studying the electron capture decay of ^{163}Ho. As proposed by De Rújula and Lusignoli [1], HOLMES performs a calorimetric measurement of the energy released in the decay process. In this way, all the atomic de-excitation energy is measured, except for the fraction carried away by the neutrino. For reaching its target, HOLMES will deploy an array of 1000 microcalorimeters characterized by an energy and time resolution of few eV at the end point and of $\sim$ 1 μs, respectively. A good time resolution is an important element since the sensitivity is strongly dependent on the unresolved pile-up fraction in the region of interest. Applying pile-up resolving algorithms to pulses with 10 μs rise time sampled at 500 kHz [2, 3] it is possible to obtain a time resolution better than 3 μs.

1.1 ^{163}Ho Production and Embedding

The ^{163}Ho isotope is produced at the Institut Laue-Langevin (ILL, Grenoble, France) nuclear reactor by irradiating Er_2O_3 samples enriched in ^{162}Er with a thermal neutron flux of about 10^{15} n/s/cm^2. If other Er isotopes are present in the enriched target, the neutron irradiation of the sample could create long-living isotopes such as ^{170}Tm and ^{171}Tm with very high activities. For this reason, the Er_2O_3 samples are pre-purified before the irradiation. After the neutron irradiation the accumulated holmium is radiochemically separated in hot-cells with an efficiency better than 79 %. The pre-purification and post-separation processes have been developed and optimized at the Paul Scherrer Institute (PSI, Zurich, CH). Three $^{162}Er_2O_3$ samples have been already irradiated at ILL and processed at the PSI [4]. With these samples we estimate a production of about 100 MBq of ^{163}Ho which is enough both for testing the isotope embedding and for the production of the first 512 detectors. The ^{163}Ho is embedded in the gold absorber by a custom ion implanter which consists of a high-efficiency sputter ion source, a mass analyzing magnet, an electrostatic triplet focusing stage and an XY magnetic beam scanning [5]. The system has been designed and optimized to separate the ^{163}Ho from contaminants not removed by chemical methods, such as ^{166m}Ho. The system is integrated with a UHV Target Chamber in which the detectors are hosted during the ion implantation. The Target Chamber [6] is equipped with an ion beam sputtering system to control the ^{163}Ho concentration in the detectors, to compensate the absorber atom sputtering caused by ion implantation and to deposit the final layer of gold both to prevent the the oxidization of ^{163}Ho, which could cause a chemical shift of the end-point, and to contain the entire energy released in the EC decay. The whole embedding system is expected to be ready for detector implantation testing early in 2019.

1.2 HOLMES detectors, Microwave Multiplexed Readout, and DAQ

The HOLMES detectors are Mo/Cu bi-layer TES suspended on Si_2N_3 membrane equipped with 2 μm-thick gold absorbers in which the ^{163}Ho will be ion implanted. The pixel design has been optimized to match the experimental specifications in terms of energy and time resolution, pulse duration and full containment of ^{163}Ho decay products [7, 8, 9]. The HOLMES detectors are read out with the microwave multiplexing system (μmux) [10], which is based on the use of the rf-SQUIDs. Therefore, the TESs are coupled to multiplexed rf-SQUIDs operated in flux ramp modulation for linearization purposes. The rf-SQUIDs are then coupled to superconducting quarter wavelength resonators in the GHz range, from which the modulating signal is finally recovered using Software Defined Radio techniques (SDR). The SDR is implemented in the firmware developed at NIST of a ROACH-2 boards The SDR ADC sampling frequency (f_{ADC}) is 550 MHz. Up to now, two μmux chips (MUX16a and MUX17a) have been characterized [11]. The chips have 33 2-MHz-wide resonances in 500 MHz frequency interval with an average separation of 14 MHz. The multiplexing factor achievable with one ROACH-2 board is $n_{TES} \sim 0.005 f_{ADC} \tau_{rise}$ for a signal sampling frequency of about 500 kHz. With a τ_{rise} of 10 μs, the number of TES detectors which can be multiplexed is 36. The HOLMES DAQ is ready for the experiment.

2. Future plans

The first HOLMES detectors are currently being fabricated at NIST and the embedding system will be fully operational early in 2019. HOLMES will soon start to optimize the isotope implantation process. As soon as the first implanted arrays will be available, the first high statistics calorimetric measurements will provide a new competitive limit on electron neutrino mass.

Acknowledgments

The HOLMES experiment is funded by the European Research Council under the European Union Seventh Framework Programme (FP7/2007-2013)/ERC Grant Agreement No. 340321. We also acknowledge support from INFN for the MARE project, from the NIST Innovations in Measurement Science program for the TES detector development, and from Fundação para a Ciência e a Tecnologia (PTDC/FIS/116719/2010) for providing the enriched Er_2O_3 used in preliminary ^{163}Ho production by means of neutron irradiation.

References

[1] A De Rújula and M Lusignoli, *Nucl. Phys.* B **219** 277 (1983)

[2] Ferri E et al, *J. Low Temp. Phys.* **184** 405 (2016)

[3] Alpert B et al, *J. Low Temp. Phys.* **184** 263 (2016)

[4] S. Heinitz et al, *PLOS ONE* (2018)

[5] G. Gallucci et al, *J. Low Temp. Phys.* (2018)

[6] A. Orlando et al, *J. Low Temp. Phys.* **193** 771 (2018)

[7] J.P. Hays-Wehle et al., *J. Low Temp. Phys.* **184** 492 (2016).

[8] M. Faverzani et al., *J. Low Temp. Phys.* **184** 922 (2016).

[9] M. Faverzani et al., submitted to *EPJC* (2018).

[10] J A B Mates et al *Appl. Phys. Lett.* **92** 023514 (2008)

[11] A. Puiu et al., *J. Low Temp. Phys.* **193** 1167 (2018)