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Status of HOLMES, an experiment for measuring the ν mass

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One of the major challenges in nowadays particle physics and astrophysics is the determination of the absolute neutrino mass scale. The HOLMES experiment aims at exploiting the calorimetric approach to directly measure the neutrino mass through the kinematic measurement of the decay products of ^{163}Ho electron capture (EC). The high energy portion of the calorimetric spectrum of this decay is affected by the non-vanishing neutrino mass value. Given the small fraction of events falling the region of interest, to achieve a high experimental sensitivity on the neutrino mass it is important to have a high activity combined with a very small undetected pile-up contribution. To achieve these targets, the final configuration of HOLMES foresees the deployment of a large number of ^{163}Ho ion-implanted TESs characterized by an ambitiously high activity of 300 Hz each. This contribution will provide an overview on the HOLMES project with its physics reach and technical challenges together with the status of the major tasks that will bring HOLMES to achieve a statistical sensitivity on the neutrino mass as low as 2 eV.

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HOLMES [2] is an ERC project aiming at directly measuring the electron neutrino mass with a sensitivity of the order few eVs. As proposed by De Rújula and Lusignoli [1], HOLMES performs a calorimetric measurement of the energy released in the ^{163}Ho EC. In order to reach its goal sensitivity, HOLMES will deploy 1000 low temperature microcalorimeters, each with an activity of 300 Bq.

1. The Holmium production and embedding

One of the main challenges in the HOLMES experiment is the production of ^{163}Ho purified sample. Since ^{163}Ho does not exist in nature, it has to be artificially produced by means of neutron activation in nuclear reactor of an enriched ^{162}Er compounds. In HOLMES, the ^{163}Ho isotope is produced at the Institut Laue-Langevin (ILL, Grenoble, France) nuclear reactor by irradiating enriched Er_2O_3 samples with a thermal neutron flux of about 10^{15} n/s/cm^2. In order to minimize the production of unwanted isotopes such as ^{170}Tm, ^{171}Tm and ^{166m}Ho due to the presence of impurities (i.e. different Er isotopes and other rare earth contaminations) in the irradiated sample, the Er_2O_3 samples are pre-purified before the irradiation. Then, the accumulated holmium is radiochemically separated by means of an ion exchange chromatography procedure. The pre-purification and post-separation processes have been developed and optimized at the Paul Scherrer Institute (PSI, Zurich, CH). The efficiency of the post-purification process was estimated to be better than 98.6% on a 20 mg Er_2O_3 irradiated sample [3]. Currently, 3 different Er_2O_3 batches were already irradiated and purified, for a total resulting ^{163}Ho activity of about 110 MBq, sufficient both for testing the isotope embedding procedure and for the production of the first 512 detectors. Since the chemical purification can only remove impurities different from Ho itself, a second step based on a different technique is mandatory. This relies on magnetic dipole mass separation and it will take place in Genoa's laboratory, where a custom ion implanter has been recently installed and commissioned [4].

The ion implanter is designed to embed ^{163}Ho inside the detectors and to perform a mass separation of the ^{163}Ho from the other contaminants. It consists of a high-efficiency sputter ion source followed by an acceleration section with maximum acceleration voltage of 50 kV, a magnetic mass analyzer, an electrostatic triplet focusing stage, an XY magnetic beam scanning and a UHV target chamber in which the detectors are hosted during the ion implantation. The target chamber is equipped with a ion beam sputtering system to perform a simultaneous ^{163}Ho implantation and gold deposition. The gold co-evaporation is important 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 ensure full containment of the energy released in the EC decay, and to prevent the oxidization of ^{163}Ho, which could cause a chemical shift of the end-point. The parameters of the target chamber were tuned to achieve the uniform gold deposition. The system has been designed and optimized to separate the ^{163}Ho from ^{166m}Ho by a factor better than 10^5. Up to now, a reduced beam line including the ion source, the dipole magnet and a simple target holder has so far assembled, commissioning and calibrated [4]. This preliminary configuration of the ion implanter is sufficient for implanting the first prototype array with a small activity, around 1 Bq/det. As soon as the prototype array will be implanted, the implanter will be upgraded by adding the electrostatic triplet, the XY steering magnet and the target chamber.

2. The HOLMES detectors and read out

The HOLMES detectors are Mo/Cu bi-layer Transition Edge Sensor (TES), suspended on Si_2N_3 membrane, thermally coupled to a gold absorber in which the ^{163}Ho will be ion implanted. The TES is placed alongside the gold absorber (200x200x2 μm^3) to avoid proximity effect [5] and the thickness of the absorber is tuned in order to provide the full containment of the energy released in the ^{163}Ho decay. The detectors are arranged in 16x4 array. The final detector design was identified after an intensive measurement campaign and it has been optimized to match the experimental specifications in terms of energy and time resolution as well as pulse duration [6]. The HOLMES detectors are read out with the microwave multiplexing system based on rf-SQUID, the only technique that matches both the requirements of a large bandwidth per channel and a high multiplexing factor. The core of the microwave multiplexing is the multiplexer chip μmux17a, developed and fabricated by NIST and characterized at MIB [7]. The microwave multiplexing fits the digital approach based on the Software Defined Radio (SDR) technique. HOLMES realizes the SDR with the Reconfigurable Open Architecture Computing Hardware (ROACH-2) board [8] with a Xilinx Virtex6 FPGA. One ROACH-2 system with ADC (550 MS/s, 12 bit, 2 channels) allows to readout 32 detectors.

A first measurement with a low dose implantation array is expected to start soon, allowing to reach a limit on neutrino mass of O(10) eV. After this measurement, it will be clear how much activity per pixel can be implanted inside the detector.

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