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HOLMES, an experiment for a direct measurement of neutrino mass

A. PUIU([1])([3])(*), D. BECKER([2]), D. BENNETT([2]), M. BIASOTTI([4]), M. BORGHESI([1])([3]), V. CERIALE([4]), M. DE GERONE([5]), M. FAVERZANI([1])([3]), E. FERRI([3]), J. FOWLER([2]), G. GALLUCCI([5]), J. GARD([2]), J. HAYS-WEHLE([6]), G. HILTON([2]), A. GIACHERO([1]), J. MATES([2]), A. NUCCIOTTI([1])([3]), A. ORLANDO([3]), G. PESSINA([3]), D. SCHMIDT([2]), D. SWETZ([2]), J. ULLOM([2]) and L. VALE([2])

([1]) *Università di Milano-Bicocca - Milano, Italy*
([2]) *National Institute of Standards and Technology (NIST) - Boulder, CO, USA*
([3]) *INFN, Sezione di Milano-Bicocca - Milano, Italy*
([4]) *Università di Genova - Genova, Italy*
([5]) *INFN, Sezione di Genova - Genova, Italy*
([6]) *NASA Goddard Space Flight Center - Greenbelt, MD, USA*

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Summary. — The neutrino mass is a fundamental parameter of the Standard Model and the measurement of its value is one of the most compelling issues in particle physics. HOLMES is an experiment set up at the University of Milano-Bicocca aiming at performing a direct measurement of the neutrino mass from the Electron Capture (EC) decay of ^{163}Ho. HOLMES will use low-temperature calorimeters, avoiding the typical systematics of spectrometers arising from the use of any external source, in order to precisely measure the energy of the electrons emitted in the EC decay. In this contribution we outline the steps which will lead to the HOLMES measurement of the neutrino mass.

1. – HOLMES

The use of the EC decaying isotope ^{163}Ho was originally proposed in 1982 by De Rújula and Lusignoli [1], but only in the last decade has the technological progress in detector development allowed to design a competitive experiment capable of probing the neutrino mass to values as low as $1\,\mathrm{eV}/c^2$ (90% CL) [2].

In a low-temperature calorimeter the energy release is converted into a temperature signal measured by a sensitive thermometer such as the TES [3]. The advantage of the

(*) E-mail: andrei.puiu@mib.infn.it

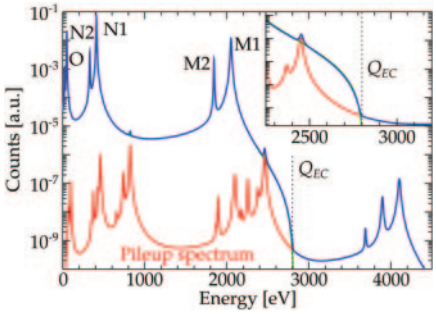

Fig. 1. – Simulated EC spectrum (green) and pile–up spectrum (red). The pile–up spectrum is simulated assuming a pile–up discrimination ability of 3×10^{-4} [5], achieved with $1\,\mu$ s time resolution and 300 Bq activity on each pixel. The spectrum in blue is the sum of the two contributions.

calorimetric approach is to eliminate all the uncertainties and systematic effects of the use of external sources employed in the spectrometric measurements, such as backscattering and decays on excited states [4]. This is achieved through embedding the decaying isotope in the absorber of the detector and all the released energy is recorded, except for the fraction carried by the neutrino. The effect of a non-vanishing neutrino mass is a deformation and a shift of the end point of the EC spectrum towards lower energies. The EC spectrum and the pile–up spectrum are shown in fig. 1. The term pile–up refers to multiple events occuring within the resolving time of the detector. Such unresolved pile–up is the main source of background close to the end point. The pile–up fraction $f_{pp} = A_{Ho} \times \tau_R$ is proportional to the source activity and the time resolution of the detector. The goal of HOLMES is to keep the pile–up fraction as low as 3×10^{-4}.

2. – Detector preparation

The calorimeters for HOLMES are produced at NIST and they have to undergo a few processing steps before being ready for measurement. In order to embed the desired amount of ^{163}Ho in the absorber, a custom ion implanter has been set up in Genova, as shown in fig. 2. The implantation system consists of a source, a mass selecting dipole magnet, a focusing stage and a so-called end station. Ho atoms are extracted from a metal alloy disc and ionised by an Ar plasma, subsequently an accelerating stage boosts the ions towards the selecting stage. The magnet is tuned to separate ^{163}Ho from any eventual contaminant, with special care for the exclusion of ^{166m}Ho, which poses a threat due to its high-enery (1856 keV) beta decay. The end station of the implanter is the chamber where the detectors are placed, together with the detector holder and handling mechanism. Inside the chamber there is a gold evaporation system which runs not only during the implantation process in order to replace the gold atoms kicked away by the incoming Ho ions, but for the deposition of the top $1\,\mu$m thick Au layer as well. The final Au layer is important in order to guarantee full containment of the 2.8 keV electrons emitted in the decay. Finally, after the absorber is loaded with ^{163}Ho and completed, a chemical KOH etching is performed in order to release the membrane on top of which the detectors are placed.

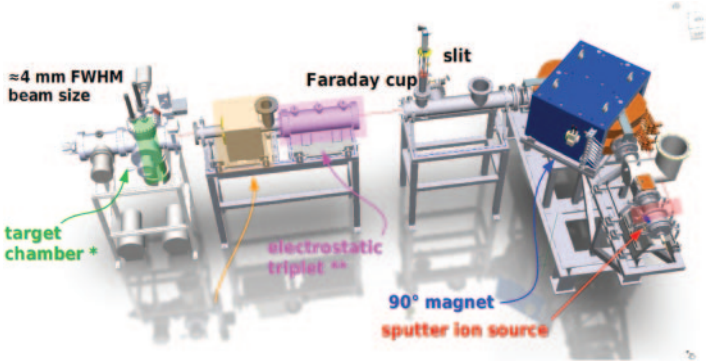

Fig. 2. – The scheme of the implanter and its components.

3. – Detector operation and readout

The thermometers coupled to the absorbers where the ^{163}Ho is embedded are TES with a critical temperature of 100 mK and are coupled to the colder (∼60 mK) mixing chamber of a dilution refrigerator, which acts as thermal bath and recovers the detector temperature after an energy deposit. After testing various detector designs we selected the detector with the best performace in terms of energy resolution and time response. The former is a crucial parameter since it is strictly correlated to the pile–up discrimination ability. The time response is determined, at first order, by the working resistance of the TES and by the inductance of the bias circuit. A stray inductance is to be added in order to tune the time response to the desired 10 μs rise time.

In order to successfully apply the pile–up resolving algorithms that allow to push the time resolution down to 1 μs [6], a 500 kHz sampling rate of each pulse is needed. This constraints, combined with the total ADC bandwidth, result in a multiplexing factor of ∼30 per each ROACH–2 acquisition board.

Finally, we tested the energy resolution of the detectors using an X–ray emitting source composed of Al (1.48 keV), Cl (2.62 keV), Ca (3.63 keV) and Mn (5.98 keV). We succedeed in pushing below 5 eV, the 8.4 eV FWHM resolution at the Mn line obatined in the previous work [7].

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