Toward the first neutrino mass measurement of HOLMES

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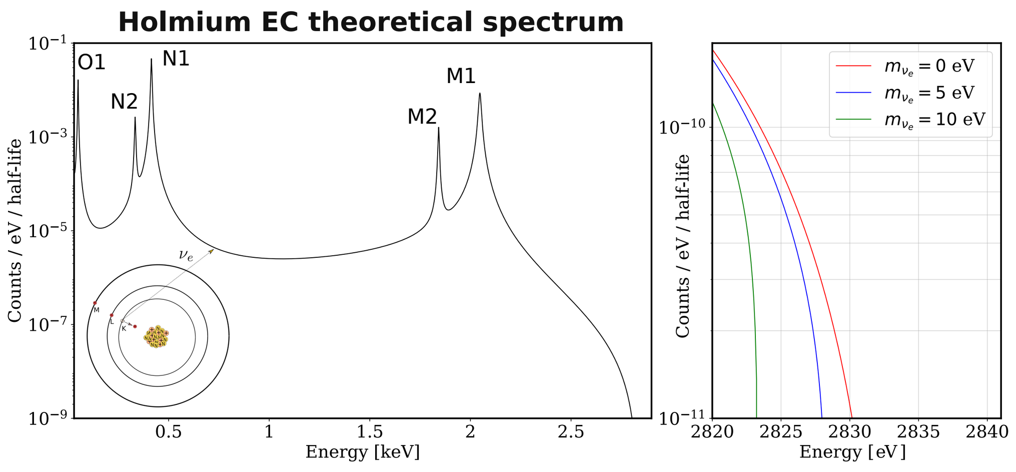
Abstract

The absolute mass of neutrinos is one of the most important riddles yet to be solved, since it has many implications in Particle Physics and Cosmology. HOLMES is an ERC project started in 2014 that will tackle this topic. It will perform a model independent calorimetric measurement of the neutrino mass with a sensitivity of the order of 1 eV using 1000 low temperature microcalorimeters detectors (TES). The goal is to employ these detectors to study the end-point region of the electron capture (EC) decay of 163 Ho.
In such a measurement, all the energy is measured except for the fraction carried away by the neutrino. Holmes has adopted a high-risk/high-gain approach: with a target single pixel activity of 300 Bq, both the detectors and the readout will be tested to their technical limits, requiring also advanced discrimination techniques to decrease the resulting number of pile-up events. This contribution presents the recent results achieved that lay the grounds for the low-activity phase of the Holmes experiment, that will lead to its first limit on the neutrino mass.

HOLMES

Holmium EC theoretical spectrum



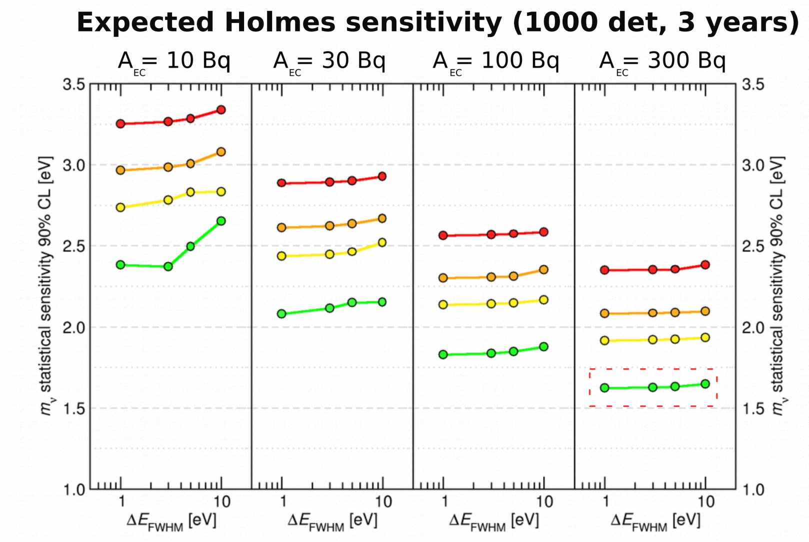
- Calorimetric measurement of EC decay of 163 Ho: isotope embedded inside the detectors.
- Neutrino is not detected, but its mass affects the shape of the de-excitation spectrum.
- The detectors of HOLMES are kept cold (~100 mK) by a 3He/4He diluition refrigerator. They need to meet rather strict requirements in terms of performance:

  Energy resolution < 10 eV
  Time resolution < 3 μs

- 163 Ho not(yet) embedded inside the detectors.
- Two steps approach to prove the technique potential and scalability:

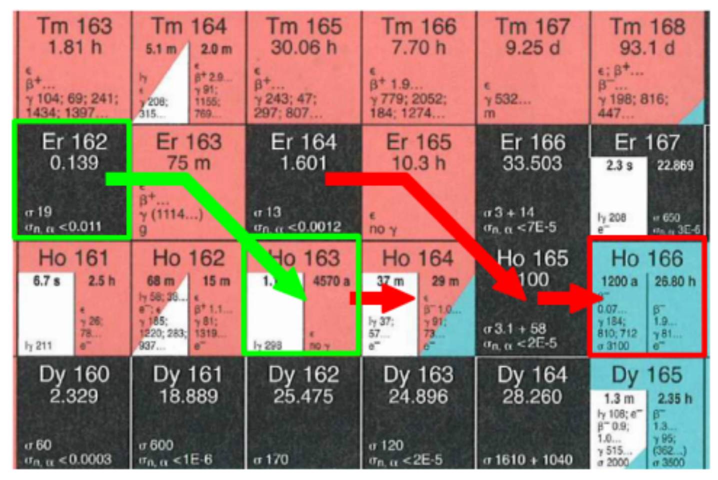
  Mid-term prototype ($A_{EC} \leq 1$ Bq)
  64 channels, 1 month, m_ν sensitivity $\mathcal{O}(10)$ eV
  Full scale ($A_{EC} = 300$ Bq)
  1000 channels, 3 years, m_ν sensitivity $\mathcal{O}(1)$ eV

Expected Holmes sensitivity (1000 det, 3 years)



Ho production and embedding

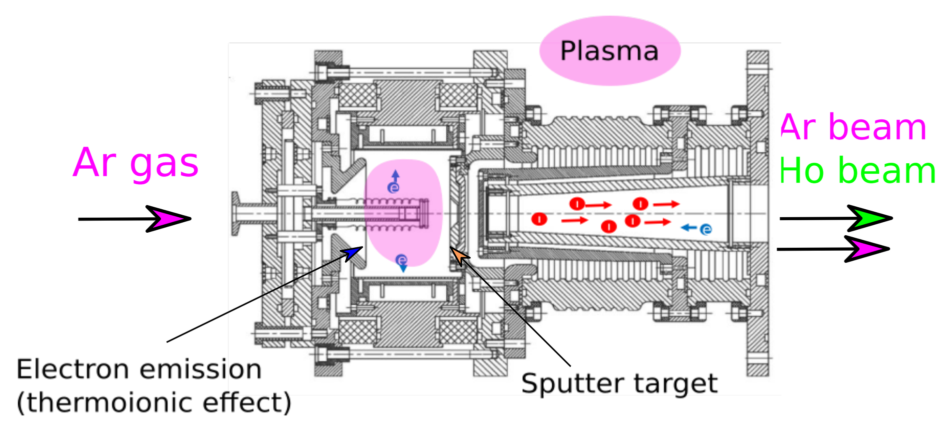
- 163 Ho produced by neutron irradiation of Er_2O_3 enriched (30%) in ^{162}Er @ILL.
- 110 MBq of purified 163Ho available



- Custom ion implanter @Genova designed to implant Ho atoms in the microcalorimeters array and to select only 163 a.m.u. mass

Ion implanter @ Genova

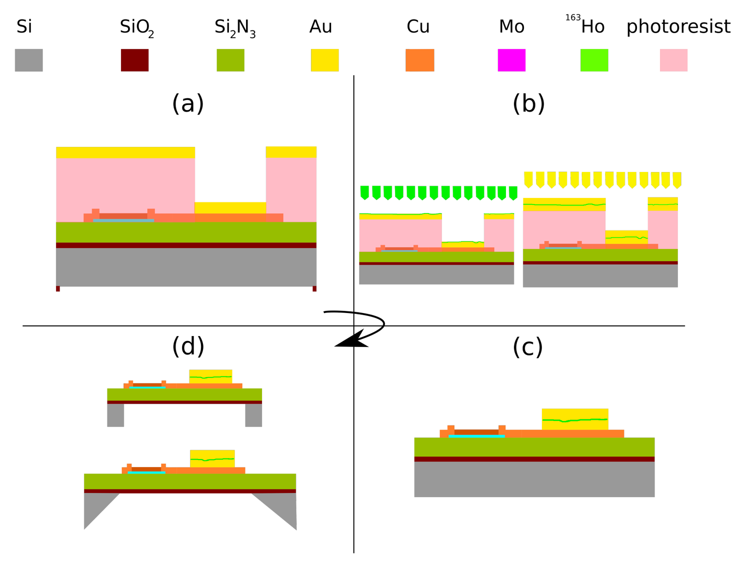
Custom ion source schematic

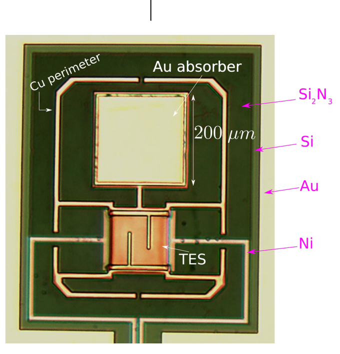


- Now in the last step of the comissioning phase! See De Gerone's poster:

Development and commissioning of the ion implanter for the HOLMES experiment

TES array fabrication





- A TES is a superconductor film operated in the narrow temperature region between the resistive and the superconducting state

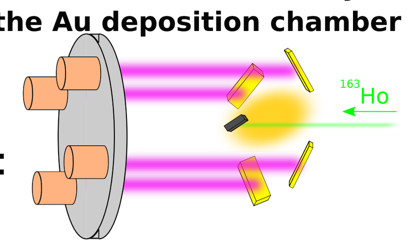
  Very sensitive thermometer!

- Detectors for HOLMES: TES Mo/Cu bilayer with Au absorbers (Sidecar geometry).
- The Holmes detectors array have to undergo different fabrication steps in order to have the 163Ho implanted inside the gold absorbers.
- Fabrication steps succesfully tested, 163 Ho implantation soon!

(b) + (c) Au sputtering and lift-off

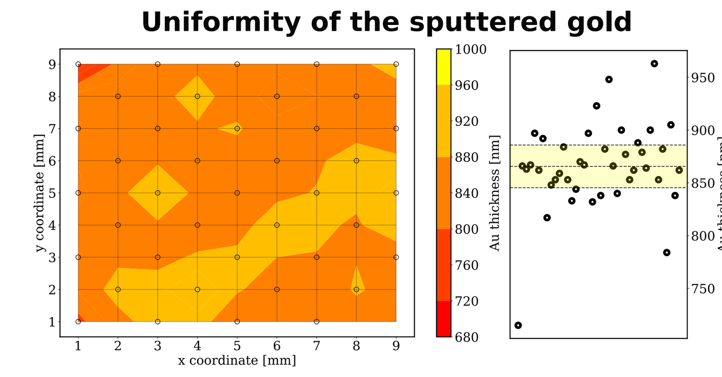
- 4 Ar beams sputter the gold from 4 Au target in a high vacuum chamber.
- Deposited gold is uniform all over the array

Schematic of the Au deposition chamber



- Deposition rate achieved: ~ 20 h for 1 μm Au

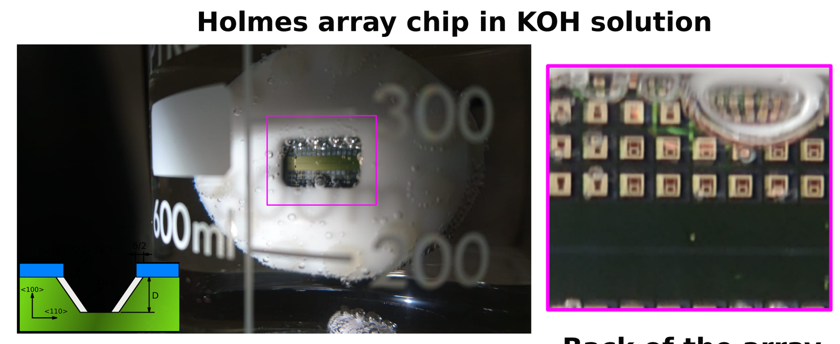
Uniformity of the sputtered gold



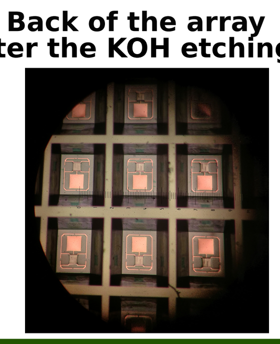
(d) Silicon KOH etching

- TES array places in 33% KOH with isopropanol solution
- Temperature between 65 and 70 deg avoid turbolent motion in the solution

Holmes array chip in KOH solution



Back of the array after the KOH etching



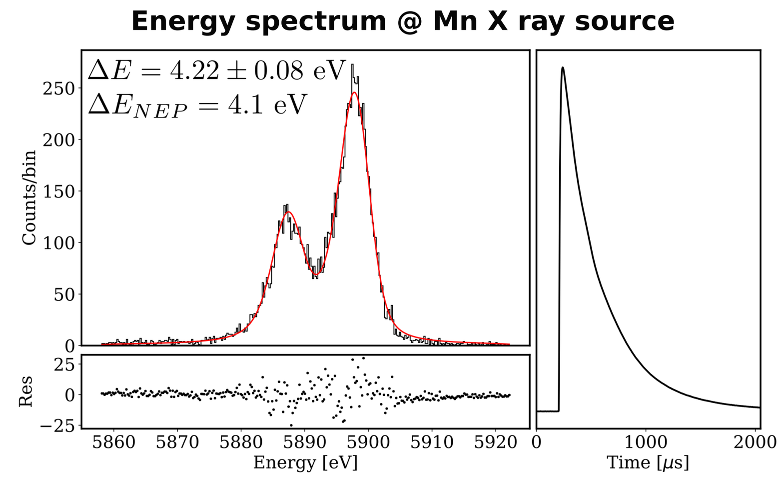
- Silicon etch rate ~ 40-45 μm/h

TES array performance

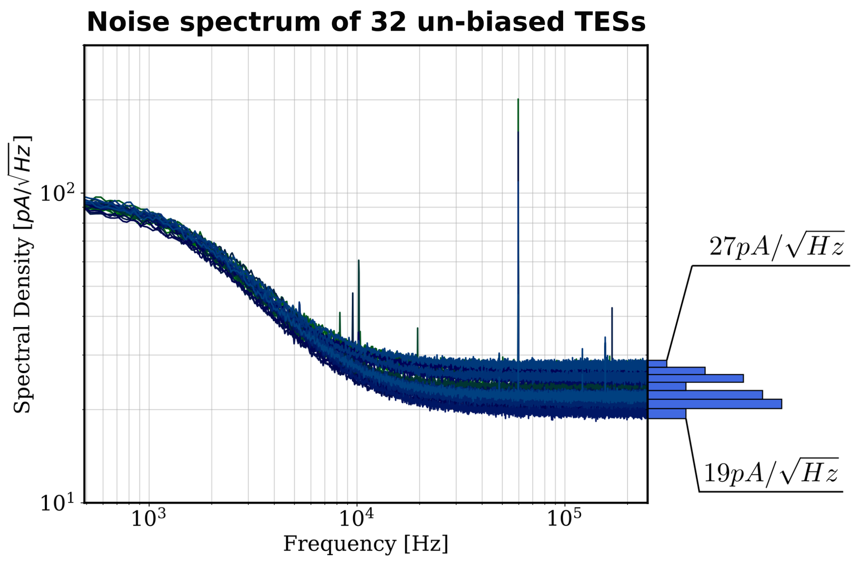
- Holmes microwave multiplexing readout is based on modules of 32 channels each. If one is able to correctly readout one single module, increasing the number of detectors is just a matter of scaling the modules.
- 2021 first time multiplexing readout of 32 channels!

  No significant IMD noise present!

Energy spectrum @ Mn X ray source



Noise spectrum of 32 un-biased TESs

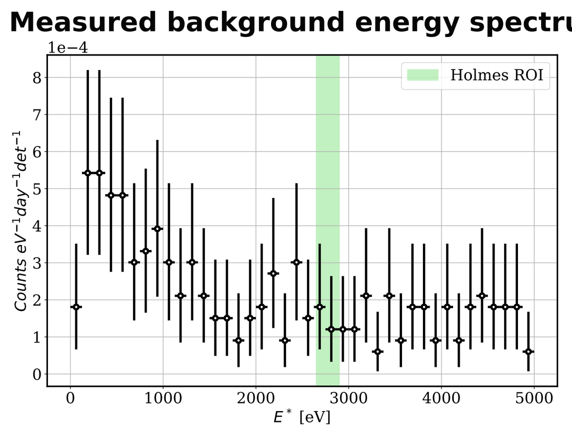


- The fabrication process did not spoil the TES performances.

Preliminary background studies

- Background rate in the ROI due to natural radioactivity and cosmic rays was estimated through dedicate measurements and MC simulations.

Measured background energy spectrum



Background rate in the ROI
1×10^{-4} counts eV^{-1} day^{-1} det^{-1}

Fraction of muon induced events:
$E[f_\mu] = 0.460 \pm 0.002$

- Reduction of the bkg rate of ~ 25% expected with a simple muon veto
- Influence of 40K on the final m_ν estimation will be negligible.

Scheme of the 40K simulations