M. Borghesi, B. Alpert, M. Balata, D. Becker, D. Bennett, M. Biasotti, G. Ceruti, M. De Gerone, R. Dressler, M. Faverzani, M. Fedkevych, C. Ferrari, E. Ferri, J. Fowler, G. Gallucci, J. Gard, F. Gatti, A. Giachero, G. Hilton, U. Koester, M. Lusignoli, J. Mates, E. Maugeri, S. Nisi, A. Nucciotti, G. Pessina, A. Puiu, S. Ragazzi, C. Reintsema, M. Ribeiro-Gomes, D. Schmidt, D. Schumann, D. Swetz, J. Ullom, L. Vale

Updates on the HOLMES experiment

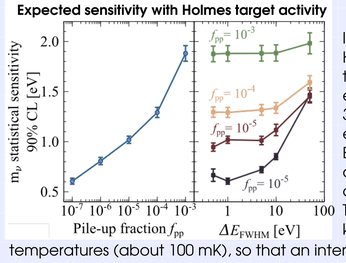
NEUTRINO 2020
XXIX International Conference on Neutrino Physics

The HOLMES experiment

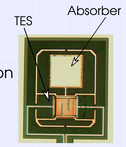
HOLMES is an ERC project started in 2014, which is currently being set up in the cryogenic laboratory of the University of Milano Bicocca.
It will perform a direct measurement of the neutrino mass with a sensitivity of the order of 1 eV. In addition, it will prove the scalability of this technique to a next generation experiment that might go beyond the spectrometers sensitivity.
The neutrino mass will be studied through the calorimetric measurement of the decay products of the decay of ^{163}Ho .

ERC-AdG-2013 no. 340321

Expected sensitivity with Holmes target activity



In order to reach the goal sensitivity, HOLMES will use 1024 low temperature microcalorimeters, each implanted with an activity of 300 Hz, that will record about 10^{13} events in three years.
Each single detector is composed of a ^{163}Ho ion-implanted gold absorber thermally coupled to a Transition Edge Sensor (TES). This kind of detector works at very low temperatures (about 100 mK), so that an interaction in the absorber produces a detectable temperature rise proportional to the energy deposited.

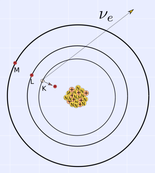


The detectors for HOLMES are kept cold by a ^{3}He/^{4}He dilution refrigerator and they need to meet rather strict requirements in terms of performance: from Monte Carlo simulations a time resolution of < 3 μs and an energy resolution below 10 eV are required to achieve a statistical sensitivity on m_ν below 2 eV.

Although ~110 MBq of purified ^{163}Ho is avaliable, we haven't yet implanted the Ho in the TES absorbers. We are currently testing the detector fabrication step and their performance, while setting up the custom ion implanter and the analysis program.
This contribution is an overview of the progress we made so far.

Calorimetric measurement of 163 Ho EC

In a calorimetric measurement of the electron capture (EC) decay of 163 Ho, all the energy is measured except for the fraction carried away by the neutrino. The energy measured, indicated as de-excitation energy E_C^H , is mostly emitted as Auger electrons from the relaxation of the 163 Dy atom.

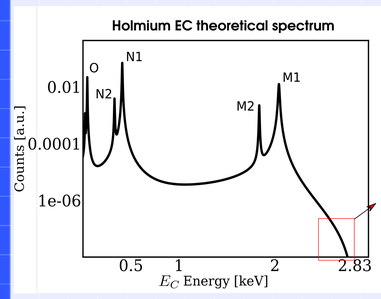


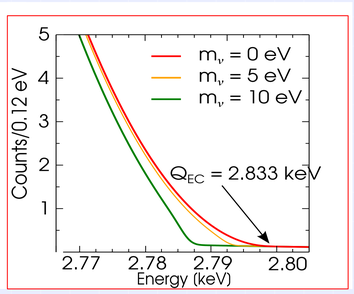
$$^{163}\mathrm{Ho} + e^- \rightarrow {}^{163}\mathrm{Dy}^H + \nu_e \; ; \; {}^{163}\mathrm{Dy}^H \rightarrow {}^{163}Dy + E_C^H$$

$$p + e^- \rightarrow n + \nu_e$$

The calorimetric spectrum of the ^{163}Ho is composed of several lorentzian-shaped peaks with energy equal to the binding energy of the electron captured from the H-shell. Although the neutrino is not detected, the value of its mass affects the shape of the de-excitation spectrum, reducing also the end-point of the spectrum by $m_{\nu e}$. The spectrum distortion is statistically significant only in a region close to the end-point, where the count rate is lowest and background can easly hinder the signal.

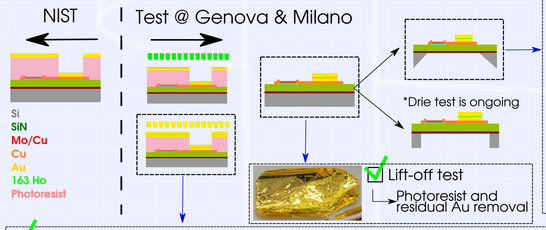
Holmium EC theoretical spectrum



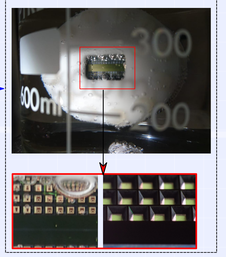


Detectors fabrication

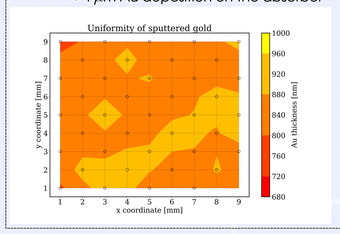
- Detectors for HOLMES: TES Mo/Cu Bilayer with Au absorbers (Sidecar geometry)
- Proper HOLMES detector finalized @ Genova & @ Milano



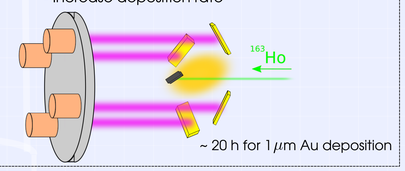
KOH silicon etching test → Membrane release



Gold sputtering test → 1 μm Au deposition on the absorber

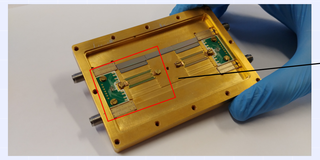


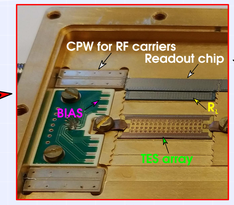
- 4 COMIC microwave sources
  - 4 argon beams
  - 4 Au targets
- Increase deposition uniformity
- Increase deposition rate



Readout and detectors performance

- TES readout with μ-wave rf-SQUID multiplexing (f_{ramp} = f_{samp} = 500 kHz)
- In HOLMES the multiplexing factor is 32 pixel per ADC board → 32 ADC boards are needed in order to cover the total 1024 pixel
- ROACH-2 board for tones generation/acquisition and for digital processing (f_{ADC} = 512 Mhz)
- Custom intermediate frequency IF circuitry for up/down conversion
  - Commercial design but customized to match the HOLMES requirements
  - Working in C-Band (4 to 8 Ghz). Fully compatible with the HEMT bandwidth
- New detector holder
  - Designed to host 2 TES array (64x2 detectors)

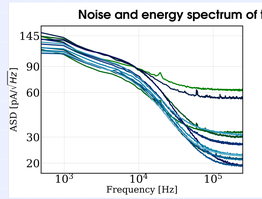


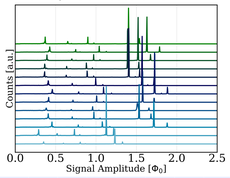


μmux17a
Designed and developed by NIST

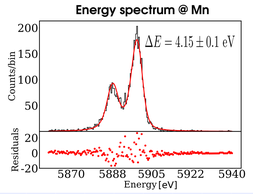
- Detector performance processed @ Milano tested with external X -ray sources → Mn; Ca; Cl; Al

Noise and energy spectrum of the first 16 pixels measurement





Energy spectrum @ Mn



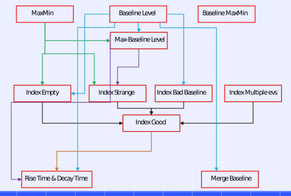
Data analysis programs

SciPy

Project Watson

- Program for signal processing and data analysis
- Only python code → - numpy & scipy; - Still very fast and flexible!; - Multiprocessing or perish
- The data are saved in HDF5 format
- It does: parameters extraction, events tag, optimum and wiener filter, cut managment, spectra fit, parameters linearization, arrival time correction, "fast" events correction...

Scheme of the raw parameters extraction

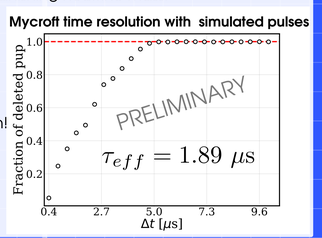


Project Mycroft

- Tool to discriminate event classes in data analysis
- Based on Singular Value Decomposition and PCA
- Used for pile-up recognition
- In HOLMES, random coincidence events are the main sources of background which impairs the ability to identify the effect of a non-vanishing neutrino mass.

With Mycroft, we are able to reach sub-sample time resolution!

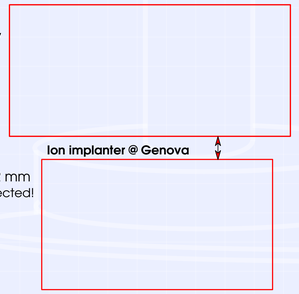
Mycroft time resolution with simulated pulses



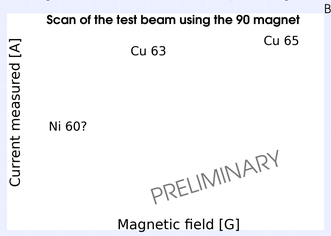
Ion implanter

- The custom ion implanter is designed to implant the Ho atoms in the microcalorimeters arrays and to select only 163 a.m.u. mass
- It has been developed in Genova and it is now in comissioning phase
- First test with a dummy copper target
  - Rough estimation of the beam spot using Cu 65 → FWHM ~ 2 mm Better than expected!

Ion implanter @ Genova



Scan of the test beam using the 90 magnet

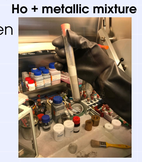


- Next step is a test with natural holmium
- Then... radioactive holmium!

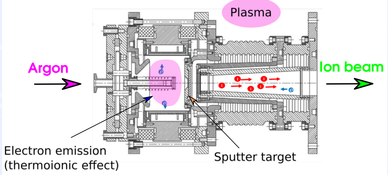
Sputter target production

- The custom ion source needs a metallic cathode containing the ^{163}Ho for its operation.
- The metallic Ho powder, obatined in a custom evaporation chamber, has been included in a metallic mixture and included in a copper support
- First target with natural holmium si ready

Ho + metallic mixture



Custom ion source schematic



Extraction potential 20-50 kV
~10 nm of implantation depth