Development of Transition Edge Sensors with rf-SQUID based multiplexing system for the HOLMES experiment

European Research Council

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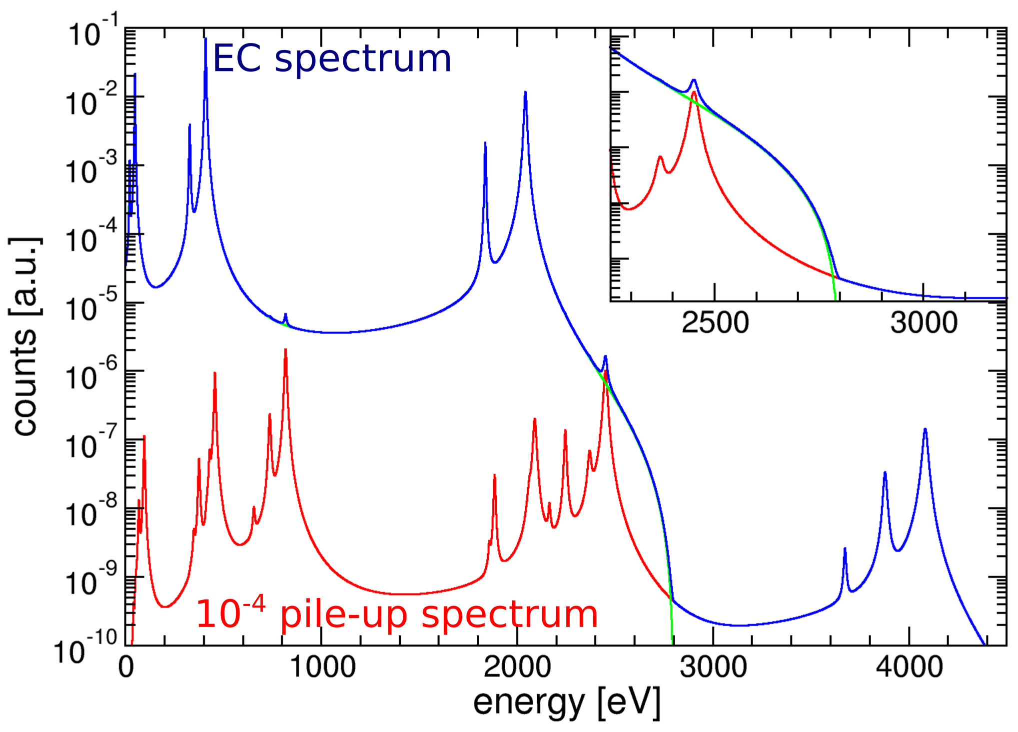
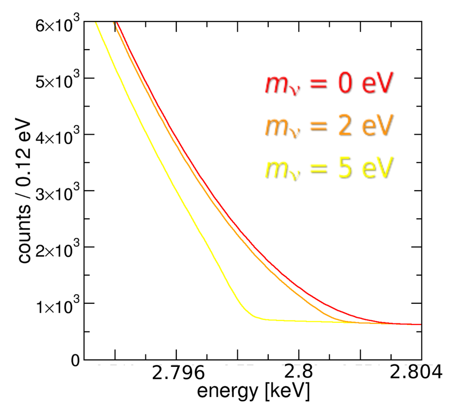
Measuring the neutrino mass is one the most compelling issues in particle physics. HOLMES is an experiment funded by the European Research Council for a direct measurement of neutrino mass. HOLMES will perform a precise measurement of the end point of the Electron Capture decay spectrum of 163Ho in order to extract information on neutrino mass with a sensitivity as low as 1 eV.

HOLMES, in its final configuration will deploy a 1000 pixel array of low temperature microcalorimeters: each calorimeter consists of an absorber, where the Ho atoms will be implanted, coupled to a Transition Edge Sensor thermometer. The detectors will be kept at the working temperature of ~70 mK using a dilution refrigerator. In order to gather the required $3*10^{13}$ events in a three year long data taking with a pile up fraction as low as 10^{-4}, detectors must fulfill rather high speed and resolution requirements, i.e. 20 µs rise time (10-90) and ~1 eV resolution.

Measuring neutrino mass from the Electron Capture spectrum of ^{163}Ho



The non vanishing neutrino mass deformes the Electron Capture spectrum of ^{163}Ho.
For reaching a sensitivity of 1 eV on the neutrino mass $3*10^{13}$ events must be gathered during the three years long measurement of HOLMES



Pile up is the limitng factor on sensitivity and has to be kept as low as possible using fast detectors and rejection algorithms

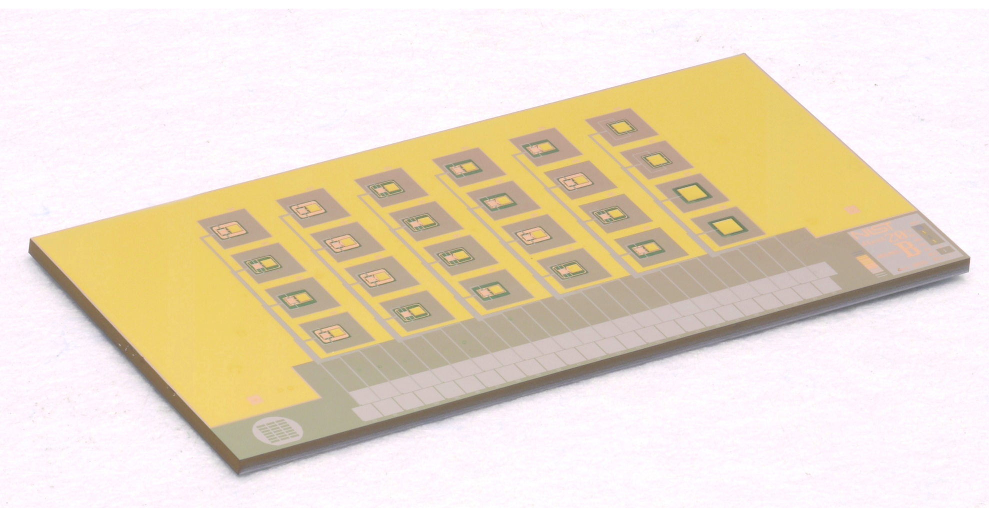
Requirements for achieveing 1 eV sensitivity on neutrino mass:

- $3*10^{13}$ events in 3 years
- ~1 eV energy resolution
- Pile-up fraction $3*10^{-4}$

Experimental requirements

- 1000 detectors
- 300 Bq/pixel
- 1 µs resolution on offline pile-up rejection: 20 µs rise time detectors sampled at 500 kHz

High performance detectors for HOLMES: Transition Edge Sensors



Mo/Cu Transition Edge Sensors coupled to Gold absorbers where ^{163}Ho will be implanted

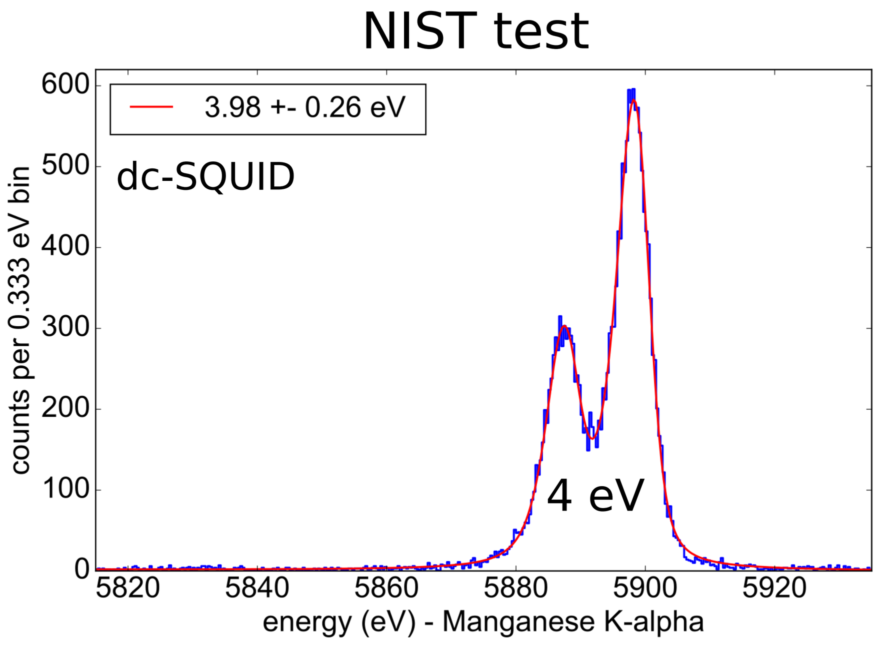
Production and R&D for detectors optimization: NIST, Boulder-Co USA

Implantation: Genova

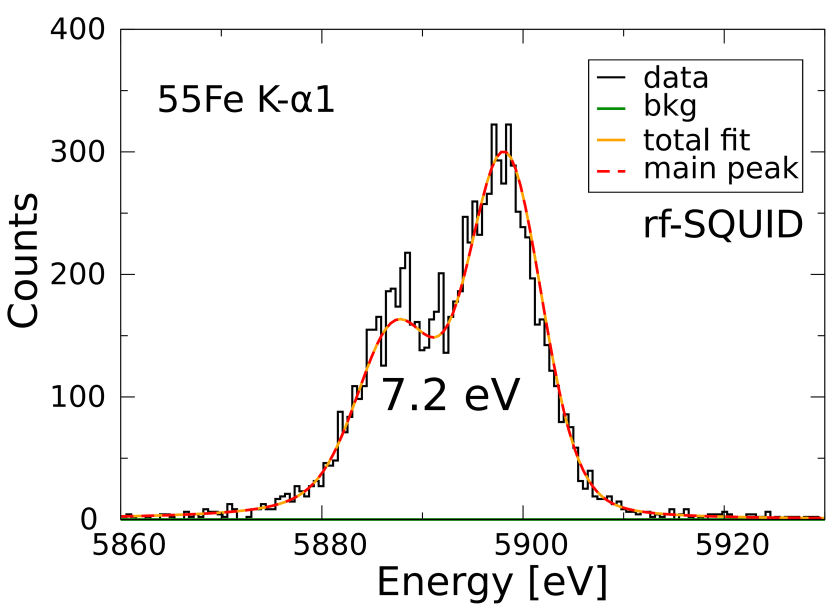
Test and measurement: Milano Bicocca

Different pixel variants have been produced and tested in order to select the heat capacity and the thermal conductivity that meet the requirements for HOLMES
- Rise and fall times are tuned with electrical inductance and thermal conductivity to match requirements
- Can be tuned again for future upgrades
- Prototype design soon to be used in implanted production arrays

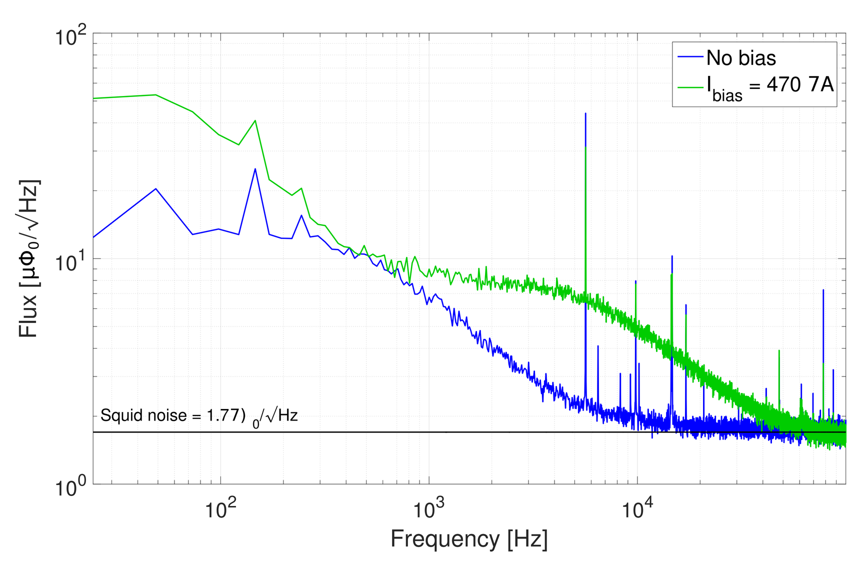
NIST test



Milano test



We have succesfully measured the prototype detectors for HOLMES to prove the energy resolution and the time response.
Low frequency excess noise limits our resolution at the moment: we are working for improving the thermal stability of the system

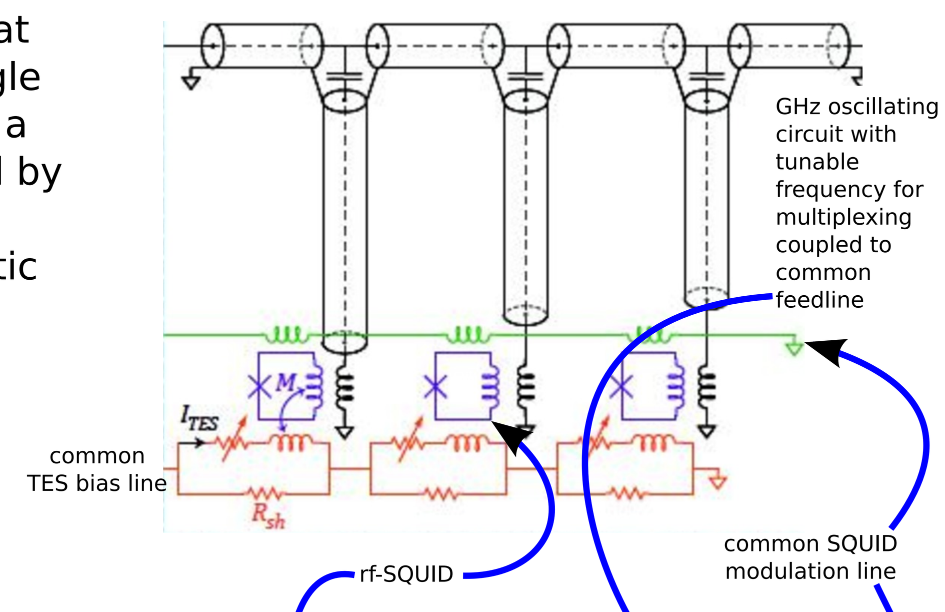


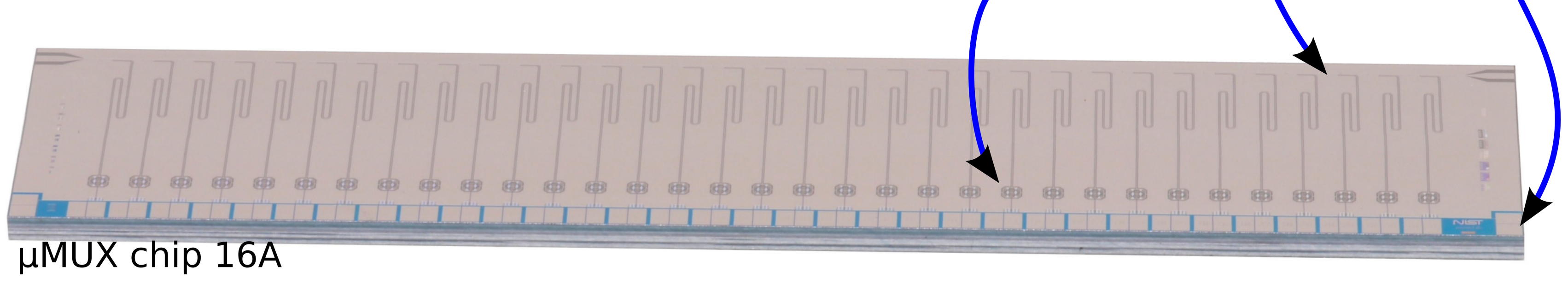
In the near future:

- Production and test of the final HOLMES array
- ROACH2 30 channel multiplexed system
- Test on first implanted detectors
- 16X4 detector array with implanted 163Ho for short calorimetric measurement of EC spectrum

Fast and multiplexed readout for HOLMES: the rf-SQUID

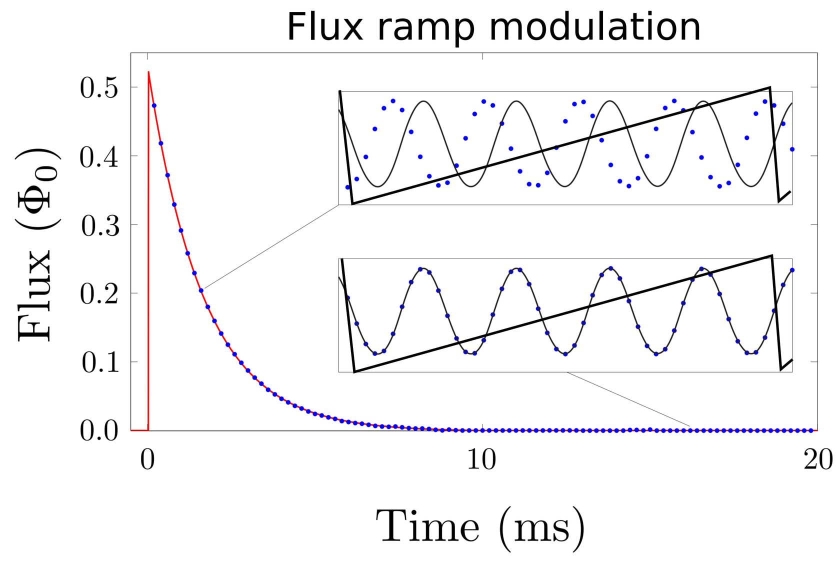
The rf-SQUID provides a perfect readout that maintains the speed and energy of the single pixel in a 1000 detectors array operated in a dilution refrigerator at ~50 mK, as required by HOLMES.
- Current variation in TES increases magnetic flux in rf-SQUID
- Flux in a rf- SQUID modulates inductance
- SQUID inductance modulates resonance frequency of its resonator
- Resonance frequency modulates transmission of fixed microwave tone





µMUX chip 16A

Flux ramp modulation



To linearize the SQUID response, a voltage ramp is constantly applied to every SQUID trough a common line.
The signal is reconstructed by comparing the output of the SQUID when the TES temperature varies (solid line), with the free oscillation of the SQUID caused only by the ramp modulation when the TES is not biased (dotted line).
The ramp frequency is the effective pulse sampling

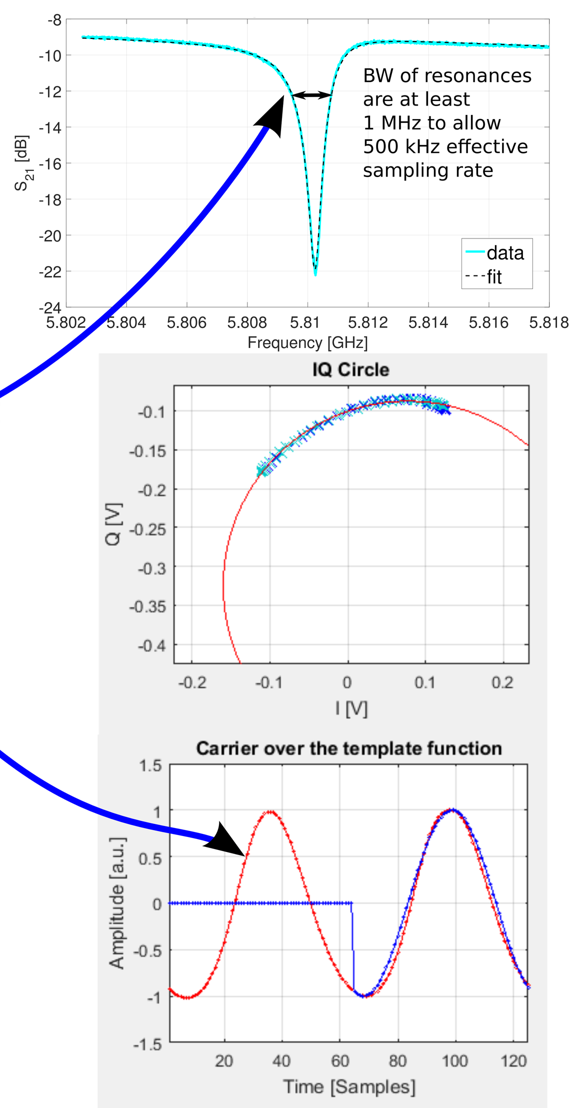
The signal acquisition: high frequency sampling of fast rising pulses for optimal pile-up rejection

In order to achieve 1 µs time resolution we will sample the 20 µs rising edge of the pulses at 500 kHz.

High sampling fixes the bandwidth of the resonators hence the overall multiplexing factor

- Effective sampling: ramp frequency f_{RAMP} =500 kHz
- double side band for each resonator: **2**
- resonance spacing NS for no crosstalk ~ 10 b/w, R&D for 7.5
- Available bandwidth with ROACH2 system: BW_{ROACH}=550 MHz
- Number of SQUID oscillations per ramp n_{Φ_0}=2

$$N_{pixels} = \frac{BW_{ROACH}}{NS \times 2 \times n_{\Phi_0} \times f_{RAMP}}$$



µMUX chip 16A produced at NIST meets the requirements for HOLMES

- 1 MHz bandwidth resonators that allow the necessary 500 kHz signal sampling ability
- Low SQUID noise (~2 µΦ_0 / √Hz)
-> Succesfully sampled 20 µs rise time pulses at 500 kHz in Milan