Microwave rf-SQUID multiplexing read-out for the HOLMES experiment

A. Giachero[1], D. Becker[3], D. A. Bennett[3], C. Capelli[2], M. Faverzani[1,2], E. Ferri[1], J. W. Fowler[3], J. D. Gard[3], J. P. Hays-Wehle[3], G. C. Hilton[3], M. Maino[1,2], G. Mangiagalli[2], J. A. B. Mates[3], A. Nucciotti[1,2], G. Pessina[1], A. Puiu[1,2], C.D. Reintsema[3], D. R. Schmidt[3], D. S. Swetz[3], J. N. Ullom[3], L. R. Vale[3]

[1]INFN of Milano-Bicocca, Milan, Italy
[2]University of Milano-Bicocca, Department of Physics, Milan, Italy
[3]National Institute of Standards and Technology, Boulder, CO, USA

ERC-AdG-2013 no. 340321

HOLMES

ECT* Determination of the absolute electron (anti-)neutrino mass
Trento, April 4 - 8, 2016

Overview

In recent years, the progress on low temperature detector technologies has allowed design of large scale experiments aiming at pushing down the sensitivity on the neutrino mass below 1 eV. Even with outstanding performances in both energy (~eV on keV) and time resolution (~1 μs) on the single channel, a large number of detectors working in parallel is required to reach a sub-eV sensitivity. **HOLMES** is a new experiment to directly measure the neutrino mass with a sensitivity below 2 eV. HOLMES will perform a calorimetric measurement of the energy released in the electron capture (EC) decay of ^{163}Ho. In its final configuration, HOLMES will deploy 1000 detectors of low temperature microcalorimeters with implanted ^{163}Ho nuclei. The baseline sensors for HOLMES are Mo/Cu TESs (Transition Edge Sensors) on SiN_x membrane with gold absorbers. The readout is based on the use of rf-SQUIDs as input devices with flux ramp modulation for linearisation purposes; the rf-SQUID is then coupled to a superconducting lambda/4-wave resonator in the GHz range, and the modulated signal is finally read out using the homodyne technique. The TES detectors have been designed with the aim of achieving an energy resolution of about few eV at the spectrum endpoint and a time resolution of few micro-seconds, in order to minimize pile-up artifacts.

B. Alpert et al. Eur. Phys. J. C75 (2015) 112

TESs with rf-SQUID readout

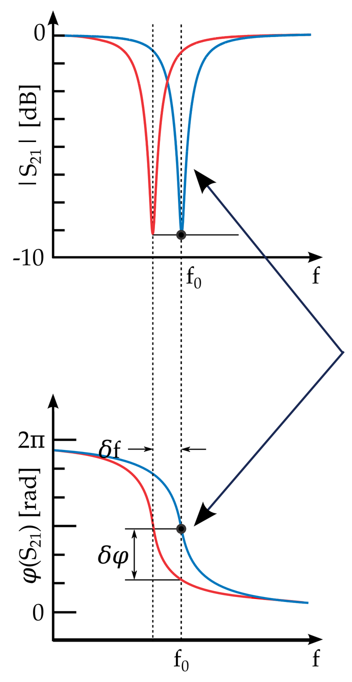
- **TES**: cryogenic particle detector that exploits the strongly temperature-dependent resistance of the superconducting phase transition;
- Multiplexed readout is an essential requirement for kilo-pixel arrays;
- To date, many techniques have been developed to multiplex TES arrays with SQUID readout: Time Division (TDM), Frequency Division (FDM), Code Division (CDM);
- The scalability of these readout approaches is limited by the finite measurement bandwidth (10 MHz) achievable in a flux-locked loop ⇒ **to achieve a time resolution around 1 μs a larger bandwidth is needed**;
- Microwave rf-SQUID multiplexing (μMux) is a novel readout technique that combines the proven sensitivity of TESs and a high-bandwidth scalable multiplexing (BW ≈ 350 - 500 kHz);

J.A.B. Mates et al., Appl. Phys. Lett. 92, (2008) 023514

- Microwave rf-SQUID read-out with flux ramp demodulation (common flux line inductively coupled to all SQUIDs);

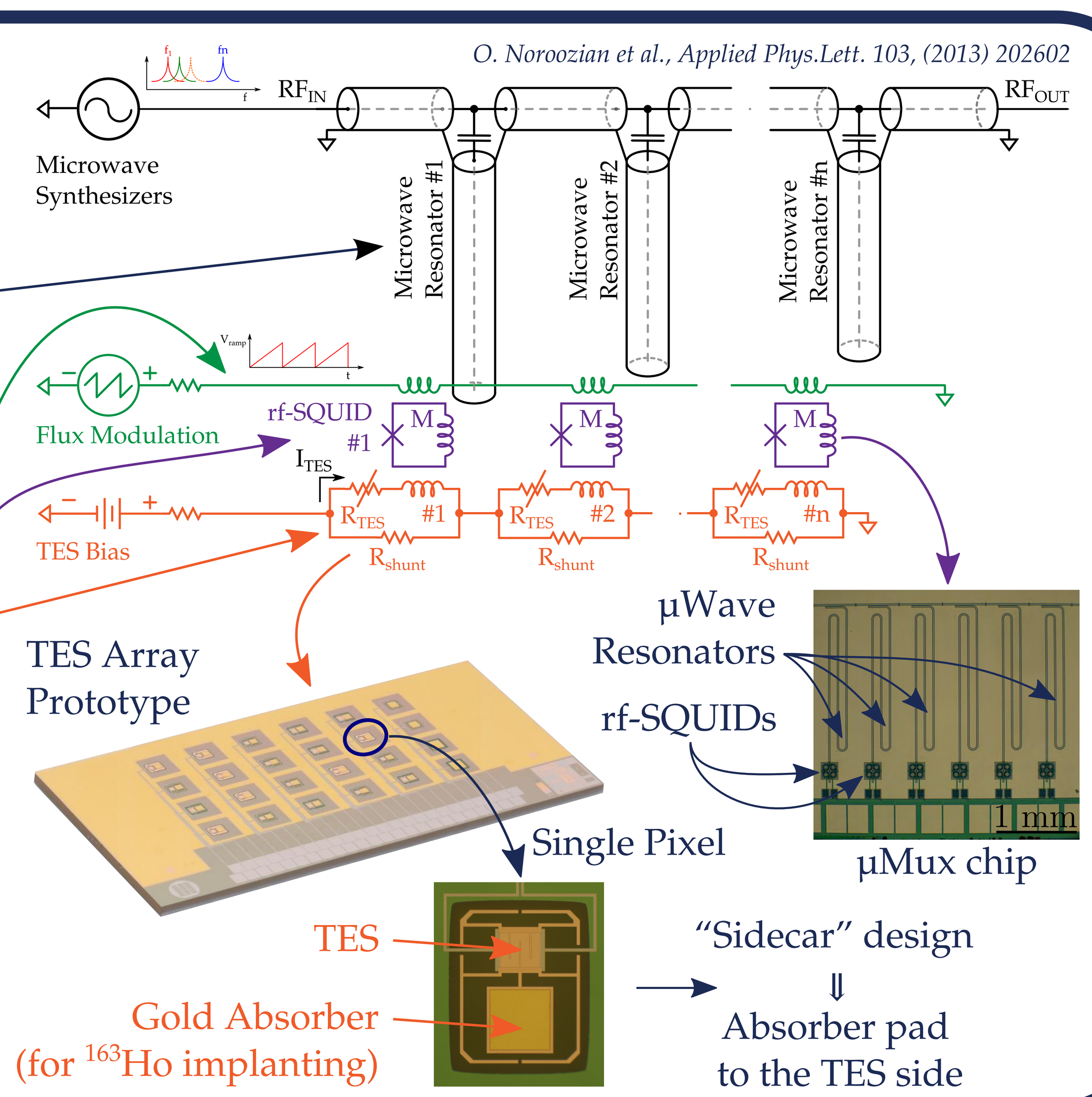
J.A.B. Mates et al., J. Low. Temp. Phys. 167 (2012) 707

- DC biased TES and rf-SQUID coupled with TES and a lambda/4-wave resonator circuit in the GHz range;



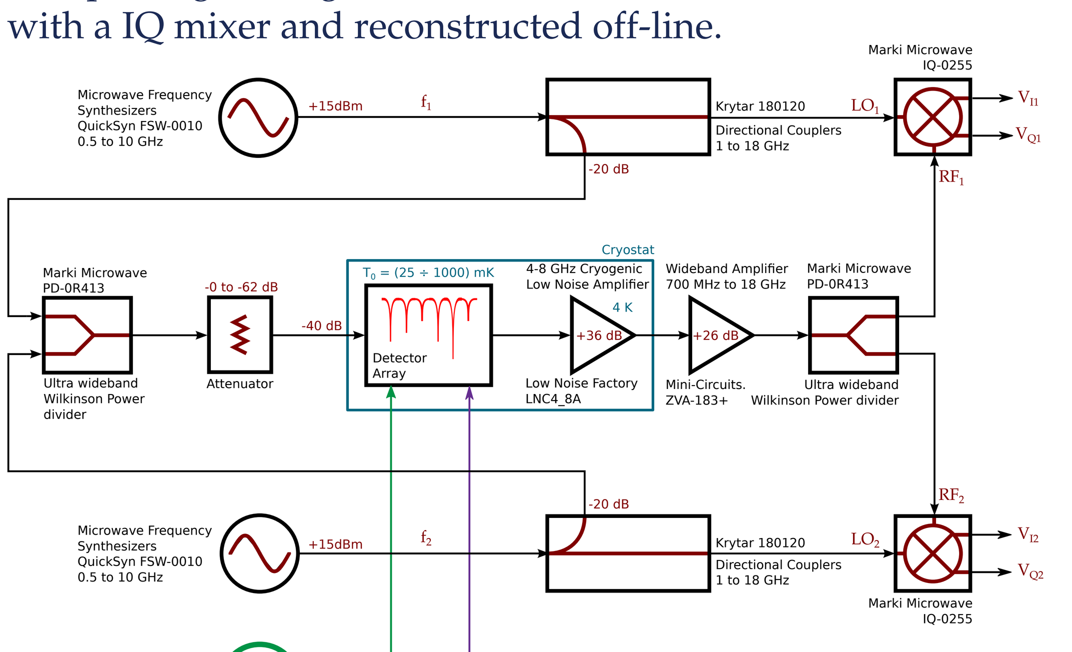
- An event in the absorber increases the temperature and therefore the resistance of the TES;
- Change in TES current ⇒ change in the input flux to the SQUID;
- The rf-SQUID transduces a change in input flux into a change of resonance frequency and phase;
- The ramp induces a controlled flux variation in the rf-SQUID, which is crucial for linearizing the response.

O. Noroozian et al., Applied Phys.Lett. 103, (2013) 202602



Experimental setup

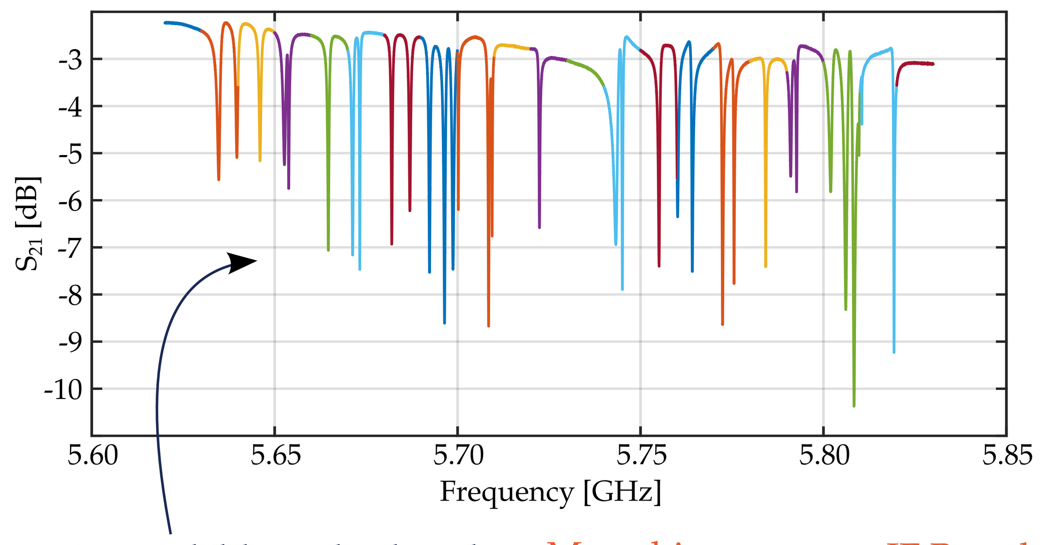
RF-homodyne setup in Milano-Bicocca for a 2-channel multplexing ⇒ signal from each detector is down-converted with a IQ mixer and reconstructed off-line.



Flux Ramp Demodulation

$\varphi(t)$: science data;
$V_Q(t)$: acquired component;
f_r : flux ramp frequency;

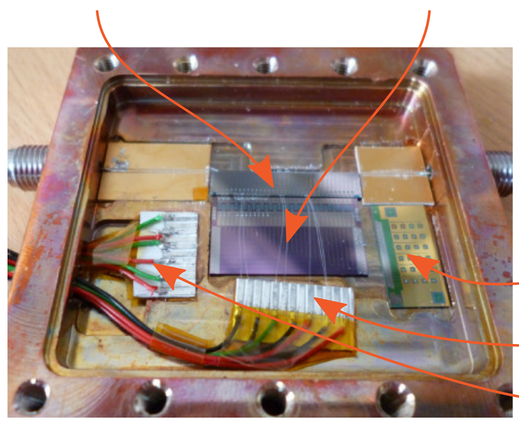
$$\varphi(t) = \arctan\left(\frac{-\sum_n V_Q(t)\sin(2\pi n f_r t)}{\sum_n V_Q(t)\cos(2\pi n f_r t)}\right)$$

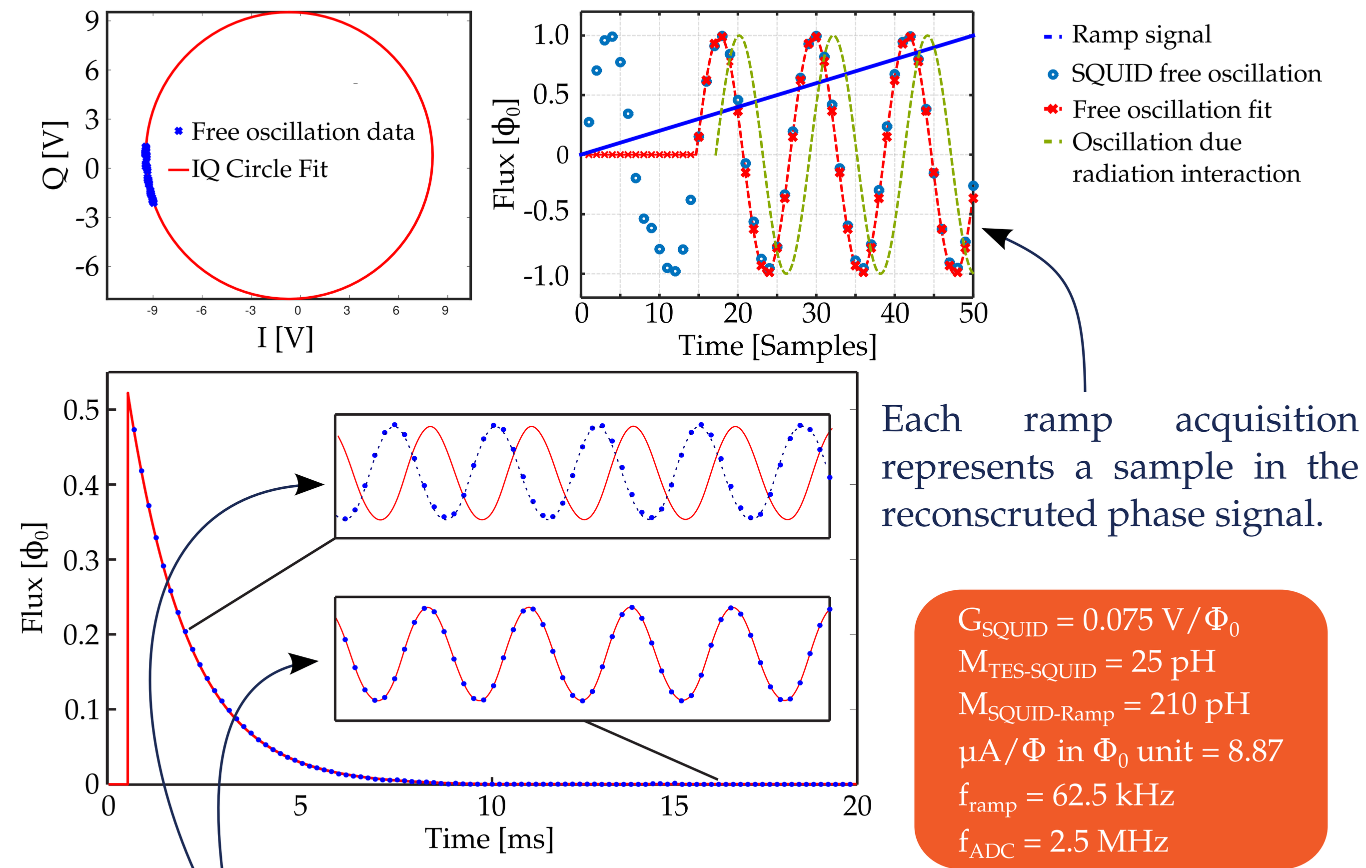


33 available multiplexed channels;

4 channels connected to TES chips illuminated with ^{55}Fe source;

3 channels with the rf-SQUID input coil connected to external lines (external stimulus).





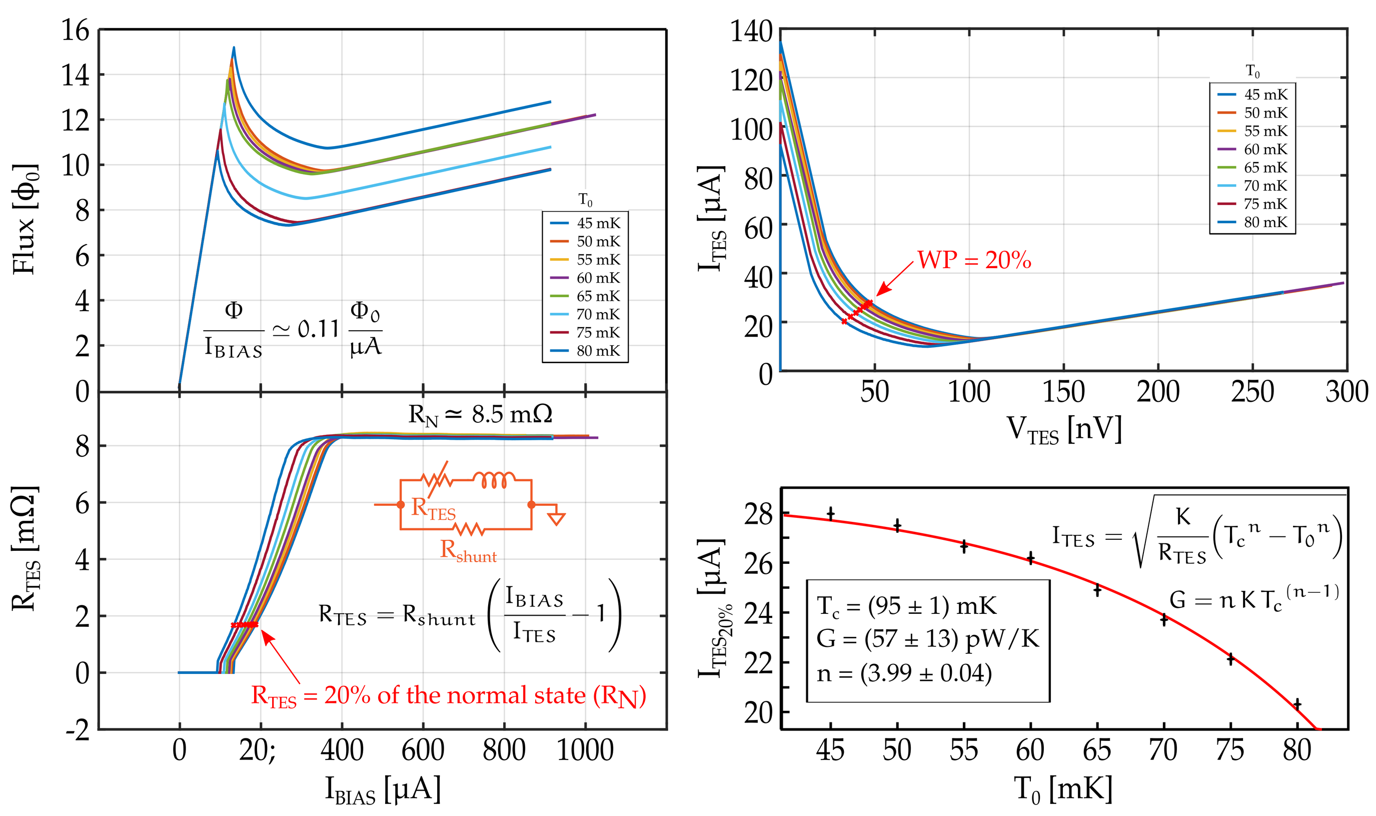
Each ramp acquisition represents a sample in the reconscruted phase signal.

G_{SQUID} = 0.075 V/Φ_0
$M_{TES-SQUID}$ = 25 pH
$M_{SQUID-Ramp}$ = 210 pH
μA/Φ in Φ_0 unit = 8.87
f_{ramp} = 62.5 kHz
f_{ADC} = 2.5 MHz

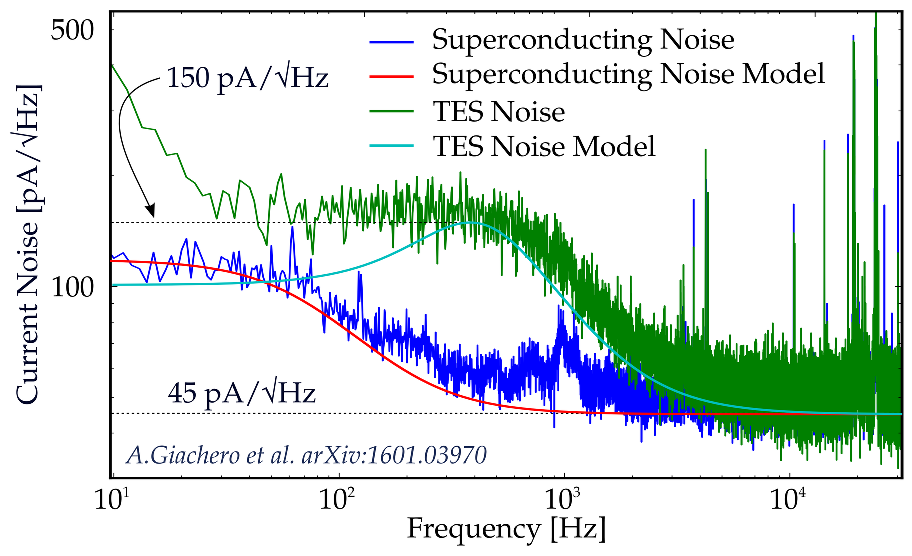
The signal is reconstructed by comparing the phase shift caused by the interaction of the radiation in the TES, with the free oscillation of the SQUID, when the TES is not biased.

First Tests and Results

- First tests and measurements performed with a TES array **with Bismuth absorber not specifically designed for HOLMES**;
- Measuring the IV curves as a function of the base temperature (T_0) is possible to extrapolate the TESs fundamental parameters.

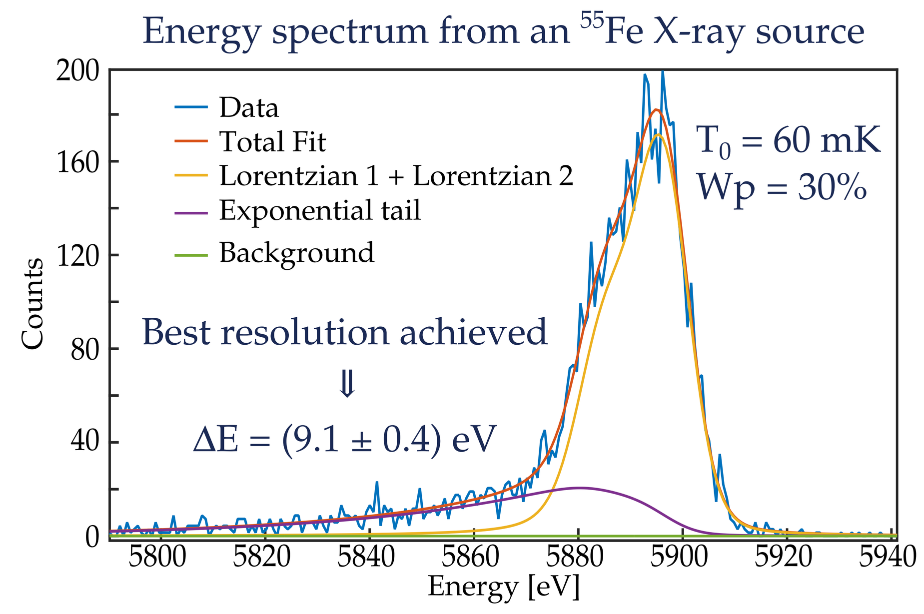


Noise spectral density obtained by the developed microwave readout system



- Measured spectra compared with the theoretical model computed by using the Irwin-Hilton theory;
- The obtained spectra agree with the model except for **high frequency peaks due to pick up** and a **low frequency 1/f component** due to **slow thermal drifts of the mixing chamber stage**;
- **The μMux readout does not introduce noise**;

Energy spectrum from an ^{55}Fe X-ray source



- Expected resolution at 6 keV around **(2 – 5) eV**;
- Resolution degradation due to thermal fluctuations ⇒ **thermal stabilization in development**;
- Slow read-out (f_{ADC} = 2.5 MS/s), only slow TESs acquirable ⇒ **new read-out system based on a faster ADC board (f_{ADC} = 250 MS/s) in development;**

Current Status

- We developed a 2-channel multiplexed readout based on the use of rf-SQUIDs;
- We are able to extrapolate all the TESs fundamental parameters ⇒ possibility to characterize the next detectors production **specifically designed for HOLMES**

Future Plans

- An improved setup to match the HOLMES requirements, based on a fast ADC card, have been developed. Tests and measurements are in progress;
- A multi-channel multiplexed readout based on a FPGA is in development.