Development of microwave-multiplexed superconducting detectors for the HOLMES experiment

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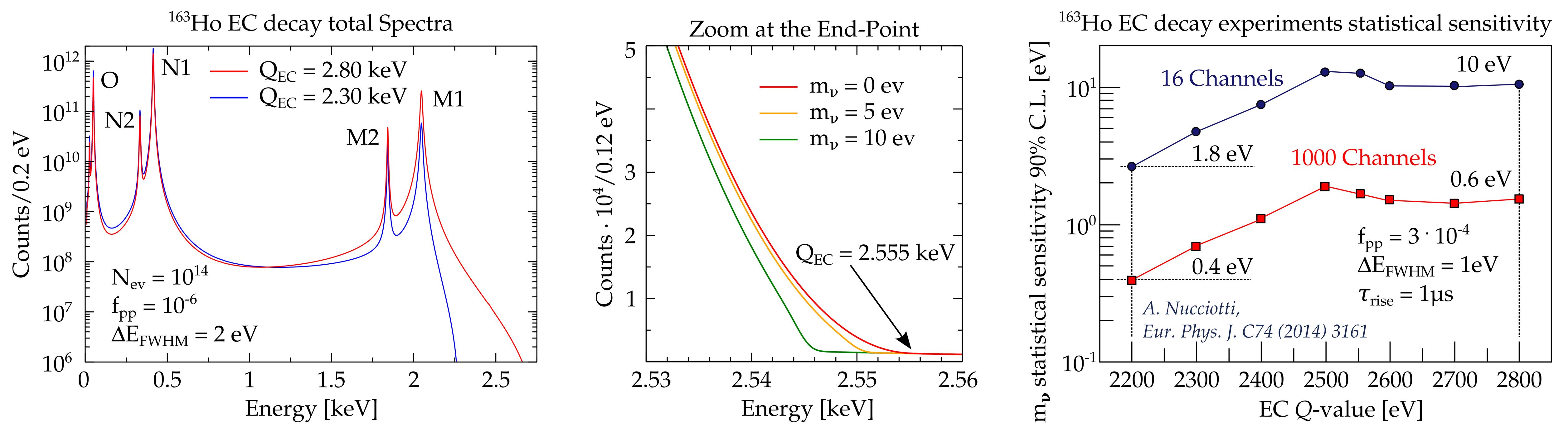
Overview

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 as low as 0.4 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 SiNx 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.

^{163}Ho EC Decay

Electron capture from shell $\geq$ M1 $\longrightarrow$ $^{163}\mathrm{Ho} + e^- \rightarrow {}^{163}\mathrm{Dy}^* + \nu_e(E_c)$

A. De Rujula and M. Lusignoli, Phys. Lett. B 118 (1982) 429.



- Calorimetric measurement of Dy atomic de-excitations (mostly non-radiative)
  $\Rightarrow$ measurement of the entire energy released except the ν energy;
- Rate at end-point and ν mass sensitivity depend on Q_{EC}
  $\Rightarrow$ Measured: $Q_{EC} = (2.3 \div 2.8)$ keV, with Penning trap: Q_{EC} = 2.833 keV;
- High specific activity $\Rightarrow \tau_{1/2}$ = 4570 years

Mid-term prototype	Full scale HOLMES
16 channels	1000 channels
t_M = 1 month	t_M = 3 years
A = 300 Bq/ch	A = 300 Bq/ch
$N_{events} = 10^{10}$	$N_{events} = 3\cdot10^{13}$

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

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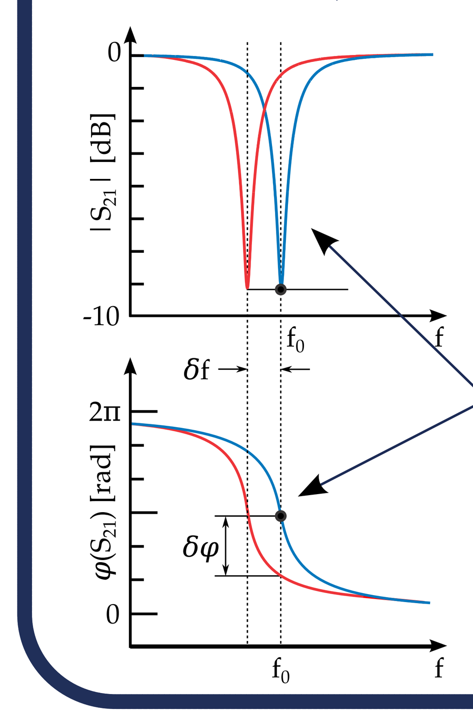
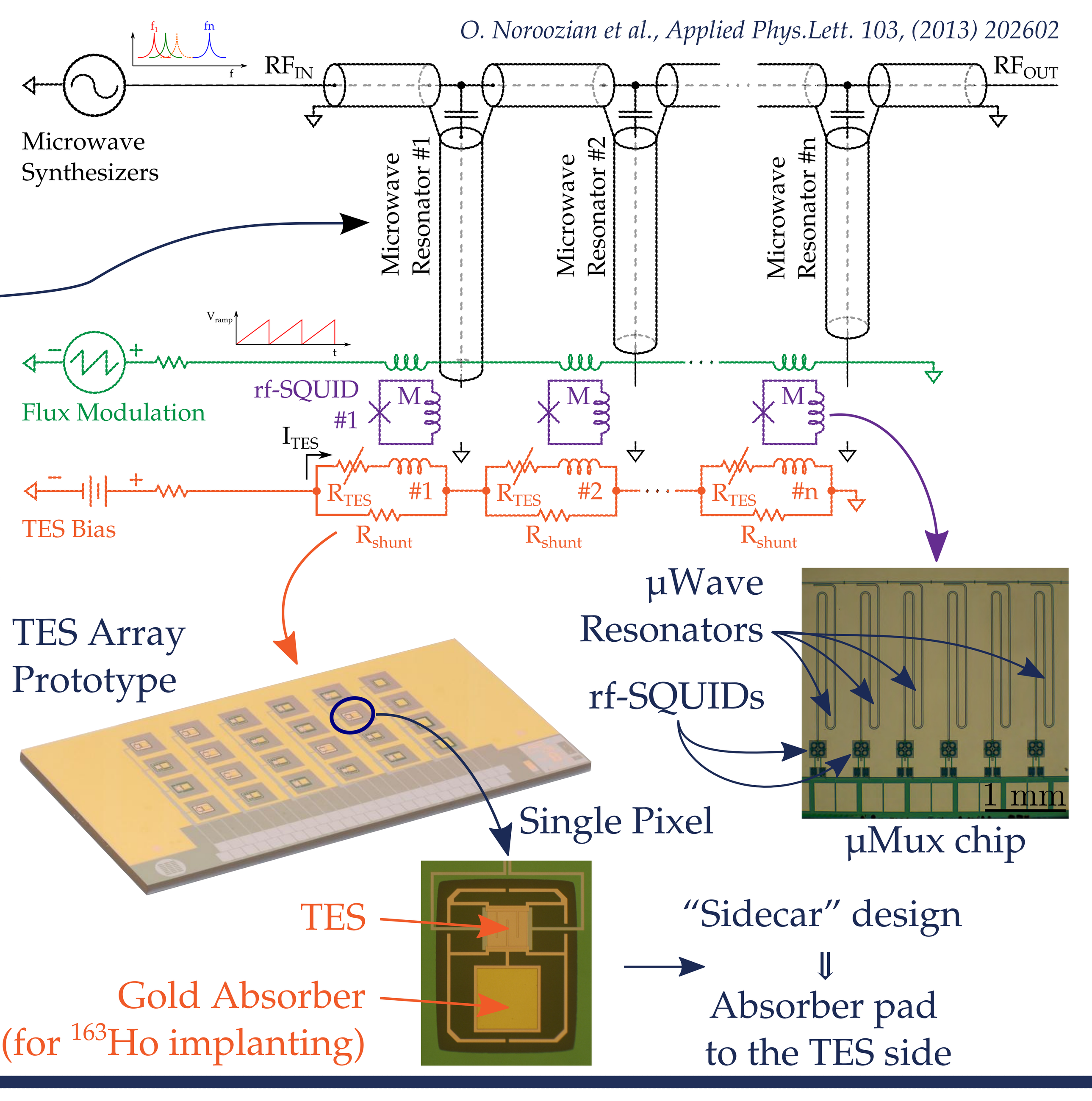
TESs with rf-SQUID readout

- **TES**: cryogenic particle detector that exploits the strongly temperature-dependent resistance of the superconducting phase transition;
- DC biased TES and SQUID coupled with TES and a LC resonator circuit in the GHz range;
- 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*



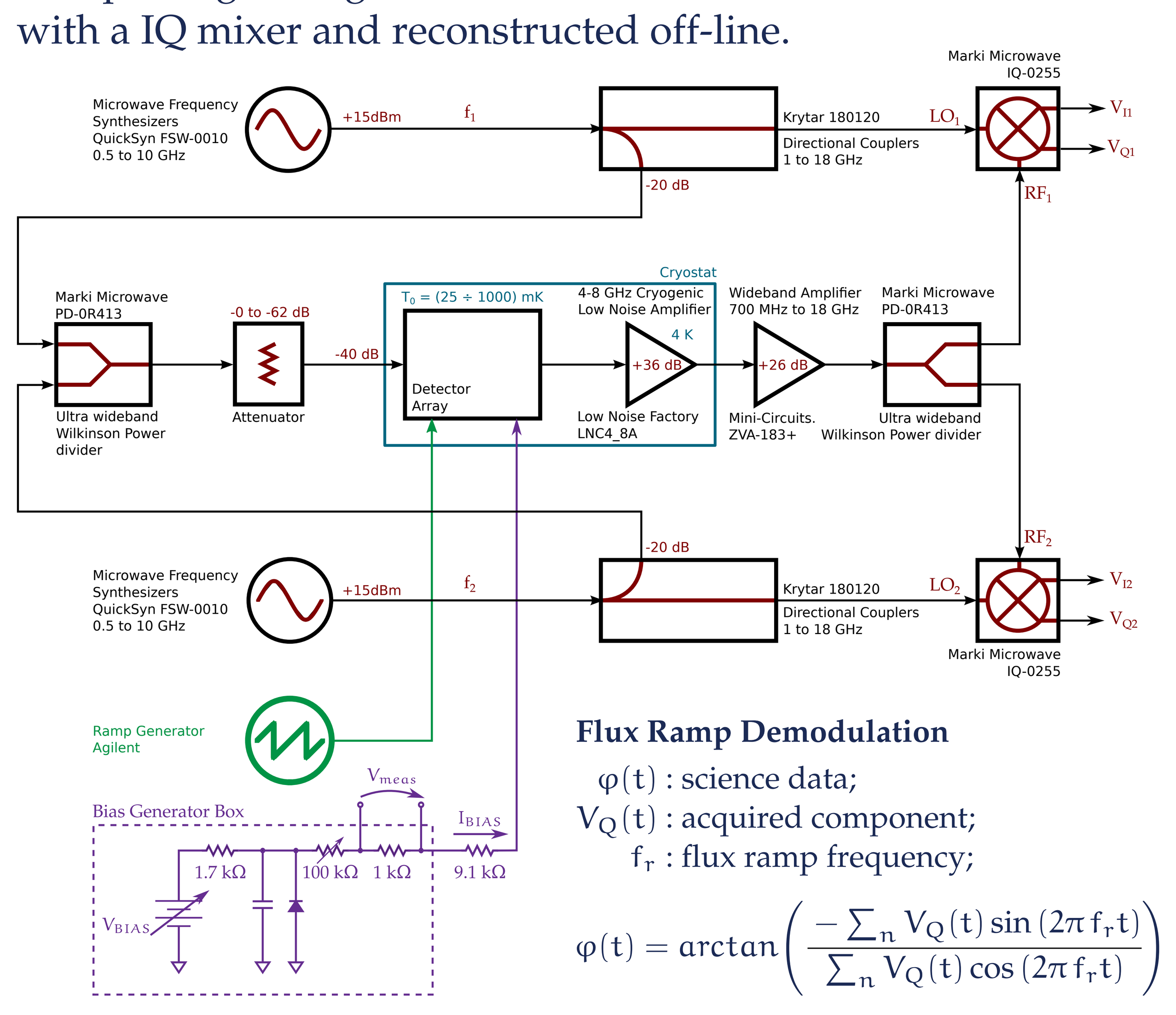
- An event in the absorber increases the temperature and therefore the resistance of the TES.
- Change in TES current $\Rightarrow$ change in the input flux to the SQUID;
- The rf SQUID transduces a change in input flux into a change of resonance frequency and phase;
- The ramp induces a controlled flux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

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

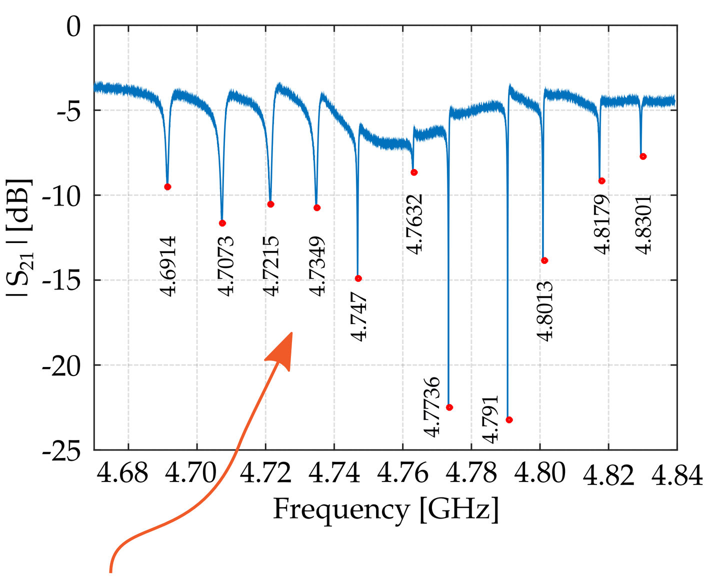


Experimental setup

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



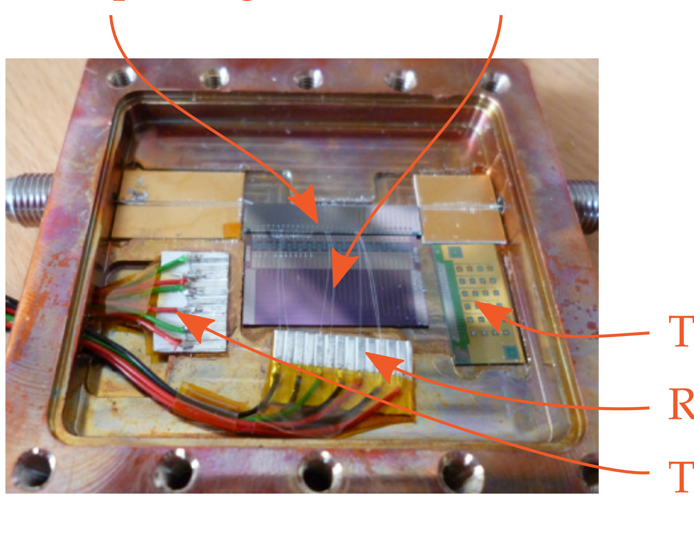
$$\varphi(t) = \arctan\left(\frac{-\sum_n V_Q(t)\sin(2\pi f_r t)}{\sum_n V_Q(t)\cos(2\pi f_r t)}\right)$$



- 11 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).

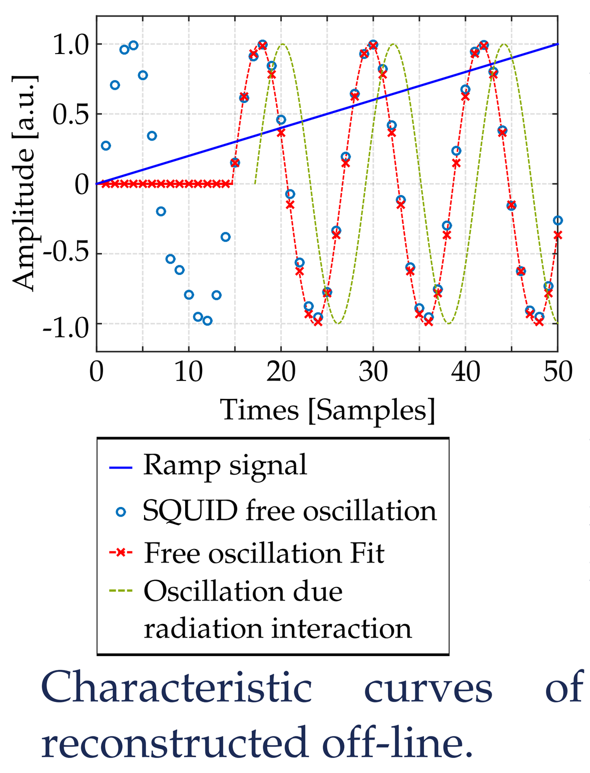
µMux chip (mutiplexing)

IF Board (R_{shunt})



$G_{SQUID} = 0.075\ V/\Phi_0$
$M_{TES\text{-}SQUID}$ = 25 pH
$M_{SQUID\text{-}Ramp}$ = 210 pH
µA/Φ in Φ_0 unit = 8.87
f_{ramp} = 62.5 kHz
f_{ADC} = 2.5 MHz

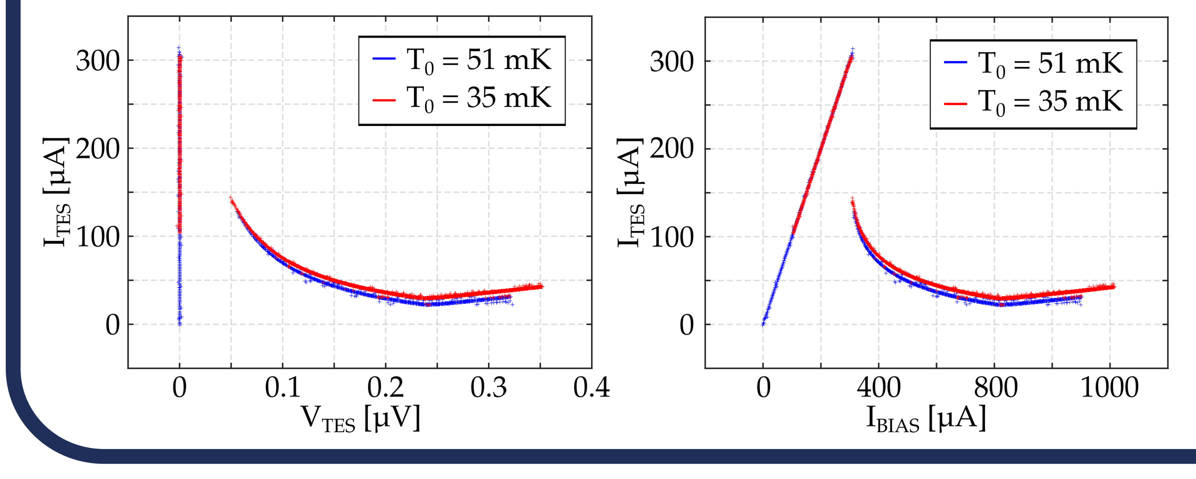
First Tests and Results



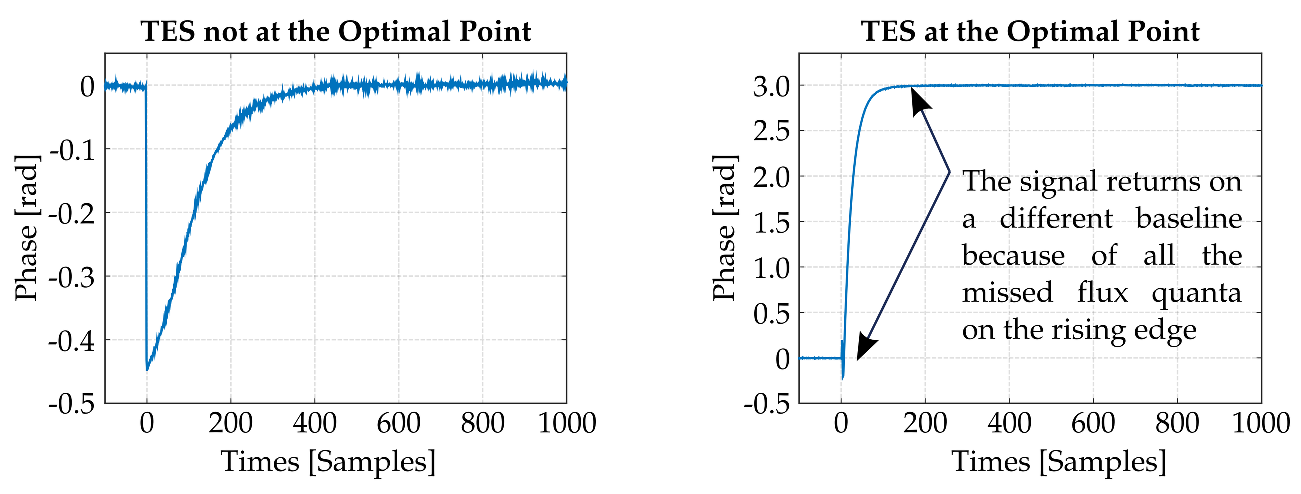
The signal is reconstructed by comparing the phase shift caused by the interaction of the radiation in the TES, with the free oscillation of the SQUID, when the TES is not biased.

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

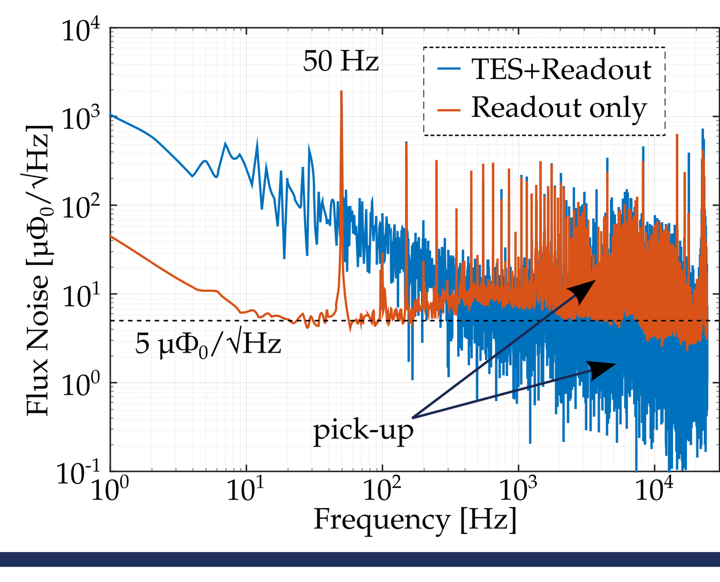
Characteristic curves of a TES acquired and reconstructed off-line.



Example of a 6 keV reconstructed pulses



Rising edge of the pulse is too fast for the system sampling rate $\Rightarrow$ the readout cannot acquire this fast part of the pulse. **A faster DAQ system is in development.**



Excess of noise due to ground loops and pick-up in the ramp and bias lines.

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Setup upgrade under study (i.e. isolating amplifier for the ramp, battery-supplied bias generator, etc)

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7 - 11 September, Torino, Italy

- We developed a multiplexed readout based on the use of rf-SQUIDs as input devices with flux ramp modulation;
- An improved setup to match the HOLMES requirements is under study;