The Cryogenic AntiCoincidence detector for ATHENA X-IFU: characterization of the last generation single pixel prototype (AC-S8)

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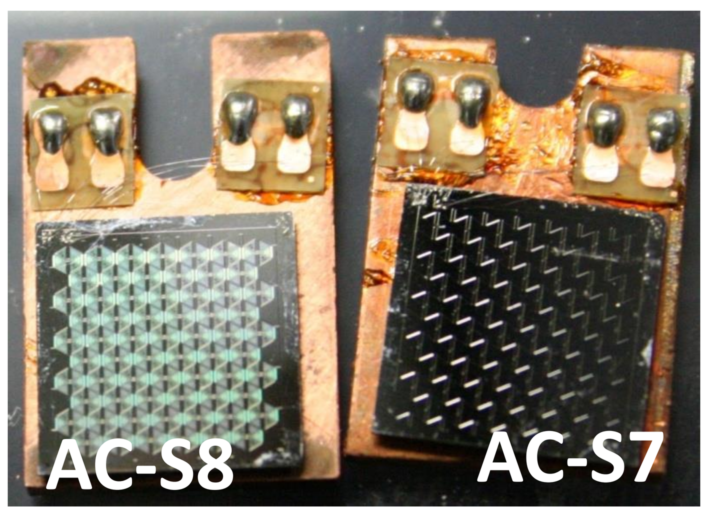
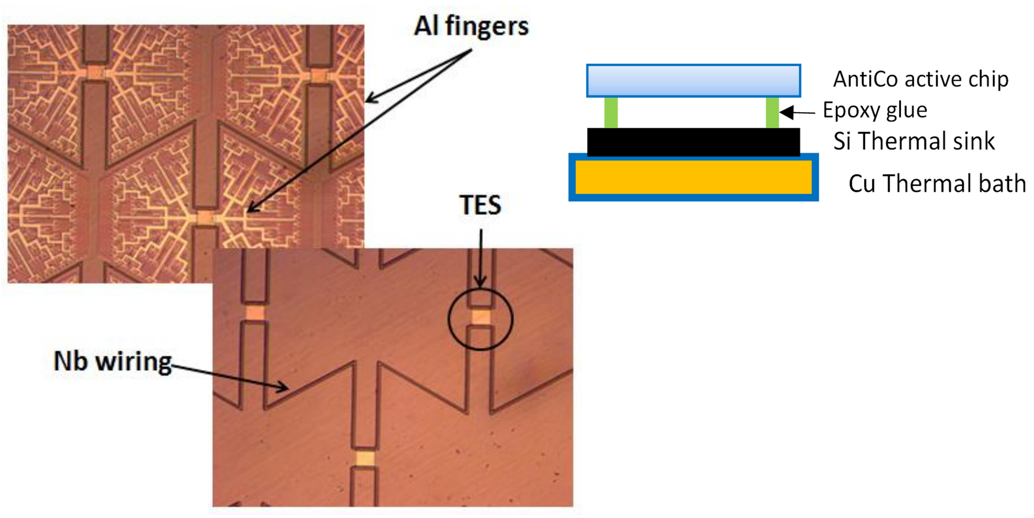
ATHENA is a large-class ESA mission, to be launched in 2028 towards an L2 orbit. One of the two on-board instruments is the X-ray Integral Field Unit (X-IFU), a cryogenic spectrometer based on a large array of TES microcalorimeters. To decrease the particle background X-IFU incorporates a TES-based Cryogenic Anticoincidence detector (CryoAC), placed <1 mm below the main array absorbers. **Here we will report the characterization measurements performed on the last generation CryoAC single pixel prototype, namely AC-S8**. This sample, 1 cm^2 Silicon absorber, incorporates 65 Ir TESes and an additional network of Aluminum fingers to improve the athermal phonons collection. **This prototype is in the path to develop the CryoAC Demonstration Model (DM) which is the detector necessary to demonstrate critical technological aspects in the CryoAC development (see M. Biasotti poster: PE-47)**.

The last-generation prototypes: AC-S7 and AC-S8

AC-S8 is one of the two prototypes developed to reach the final design for the CryoAC DM. These samples are based on **wide Silicon absorbers sensed by a network of 65 Ir TESes** in parallel connected. This design permits to have an uniform absorber coverage (**→ efficient athermal signal detection**) reducing the detector heat capacity.

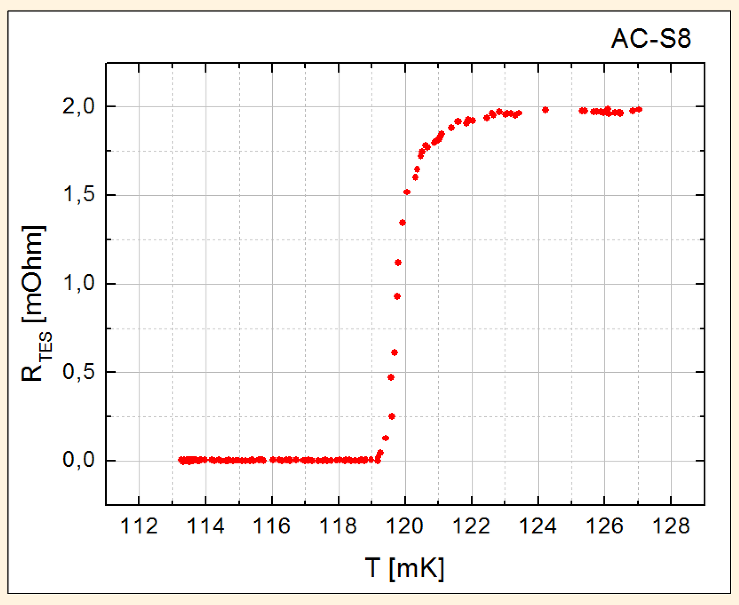


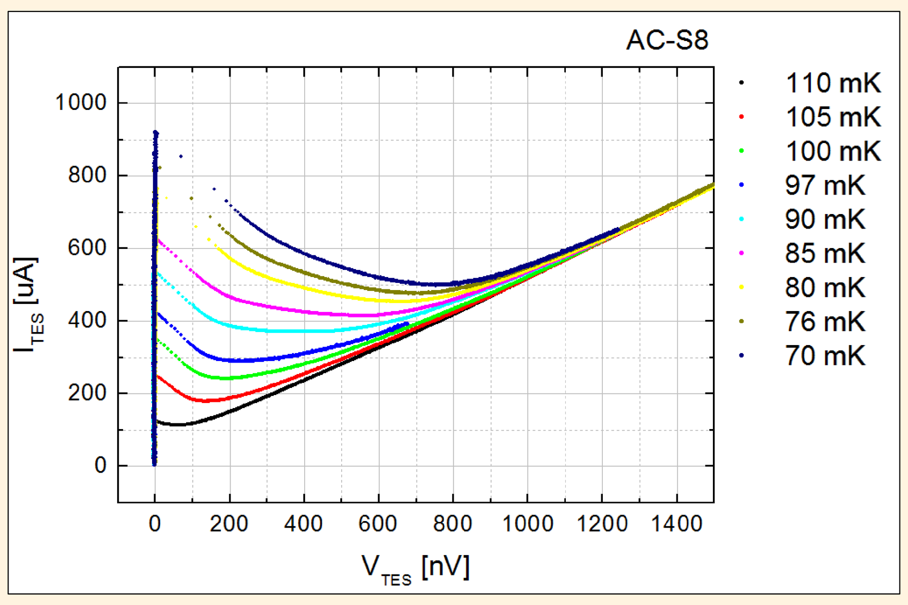


AC-S8 has in addition **a network of Al-fingers** directly connected to the TESes to investigate the feasibility of further improve the Athermal collecting efficiency.

Absorber Silicon size:	10x10 mm^2, 380 μm thick
TES (x 65) Iridium size:	100x100 μm^2, ~ 200 nm thick
Silicon wafer	5-10 Ω·cm

Electrothermal characterization of AC-S8



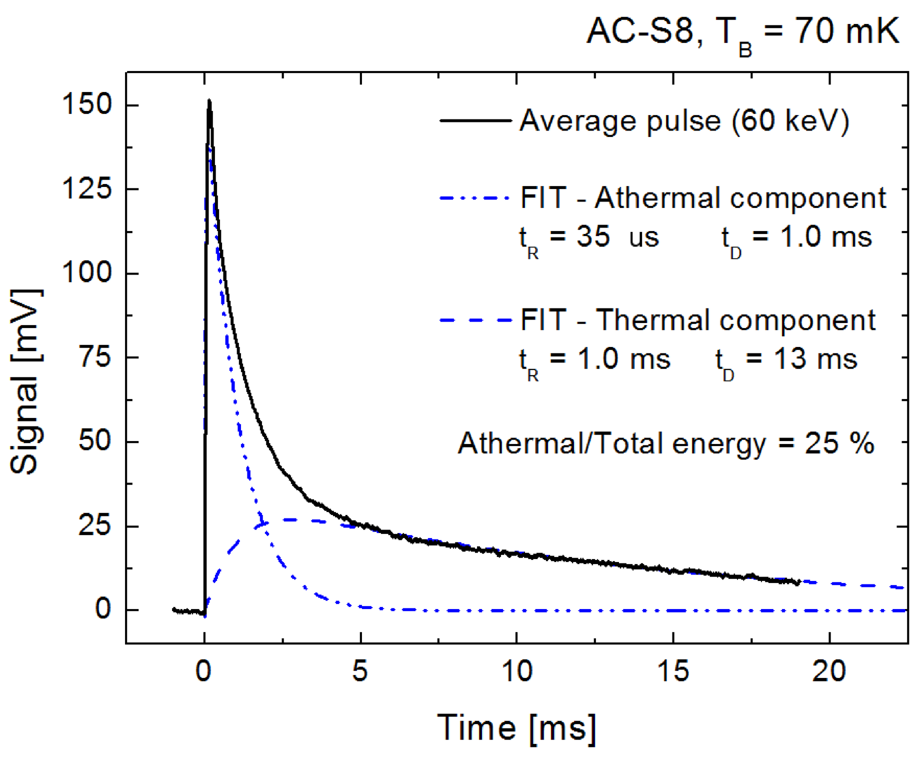


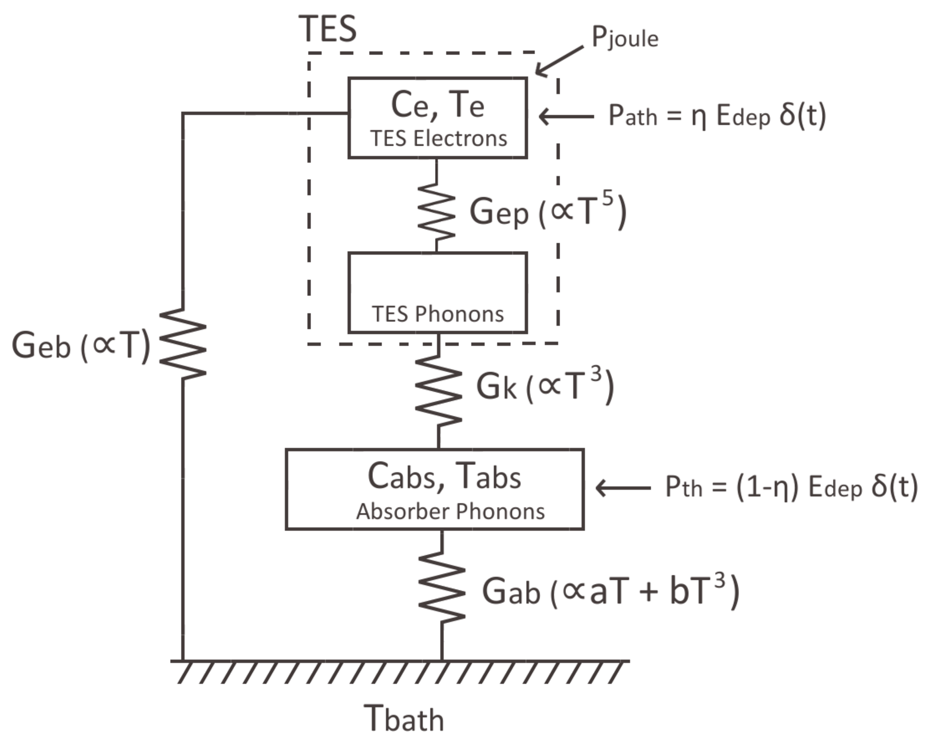
→ The critical temperature (**Tc ~ 120 mK**) and the narrow transition (**$\Delta T_{10\text{-}90\%}$ ~ 2 mK**) demonstrate the **uniformity of the TES network**.

→ The I-V curves have been acquired in a wide temperature range, demonstrating that **the detector can operate with the thermal bath quite far from the transition** (until ~ 50 mK below), as requested for the DM. However, an high bias current (I_{TES} ~ 600 μA) is needed to work in these conditions.

The pulse dynamic and the preliminary detector thermal model

The AC-S8 detector has been illuminated with a shielded **^{241}Am source (60 keV line)** and readout by a Magnicon SQuID. During 400 s of acquisition, 1244 pulses have been triggered. The average pulse clearly show **two different signal contributions**, with the **initial fast athermal component** followed by the **slower thermal** one.





This dynamic could be explained with the thermal model illustrated in the picture, **where a fraction η of the energy deposited by a particle is injected directly on the TES** through the athermal phonon population.

Assuming a **strong decoupling between phonons and electrons in the TES** (Gep << Gk, Gab, Geb) we get:

$$\tau_{ATH} = \frac{C_e}{(Geb+Gj)} \qquad \tau_{TH} = \frac{C_{abs}}{G_{ab}} \qquad Gj = \frac{\alpha_0 P_0}{T_0}\frac{(R_0 - Rsh - Rp)}{(R_0 + Rsh + Rp)}$$

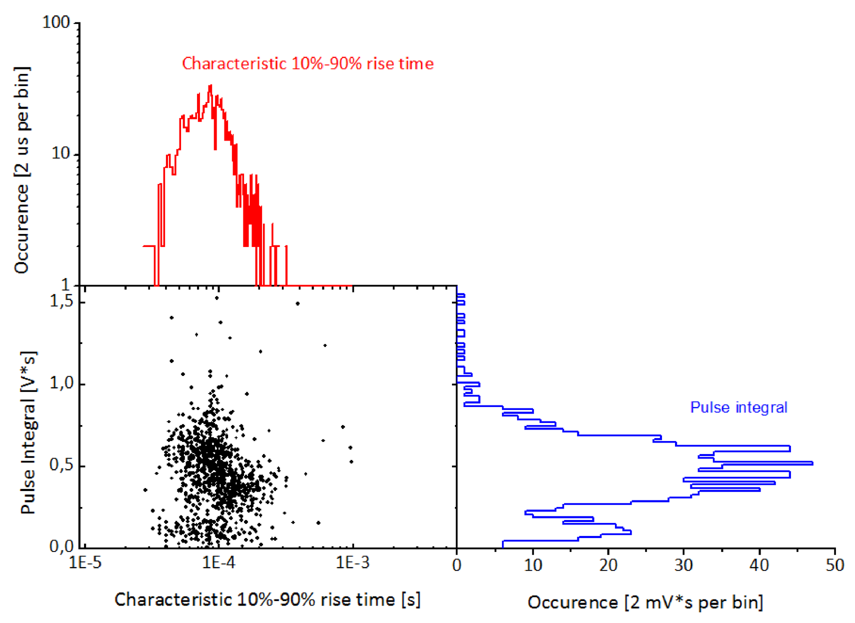
$$\Delta T_e = \frac{\eta E_{dep}}{C_e} e^{-t/\tau_{ATH}} + \frac{(1-\eta)E_{dep}}{C_{abs}(1-\tau_{ATH}/\tau_{TH})}\frac{Gep}{(Geb+Gj)}\left(e^{-t/\tau_{TH}} - e^{-t/\tau_{ATH}}\right)$$

Athermal component — Thermal component

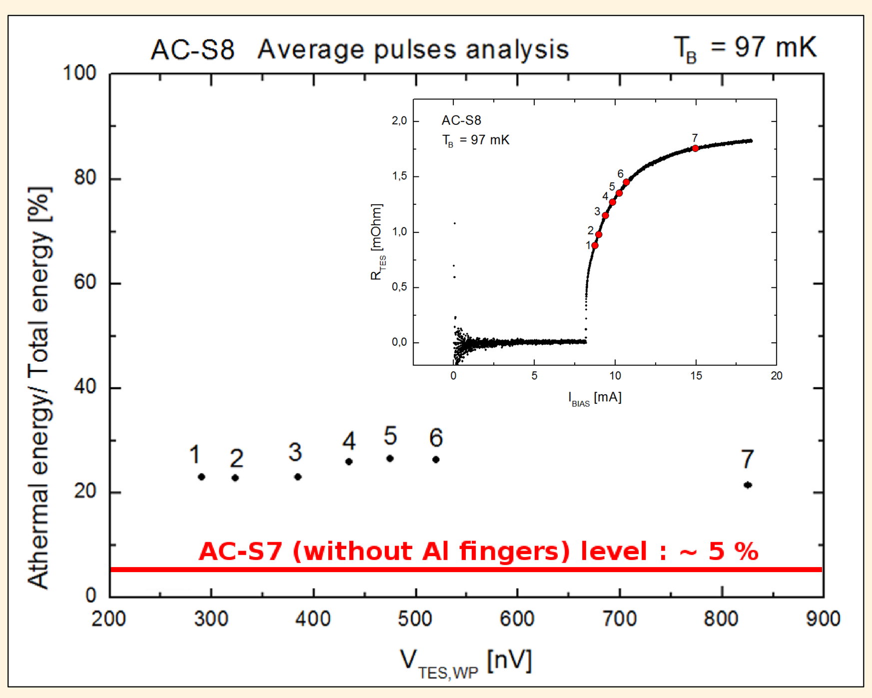
We have performed a raw analysis to investigate the pulses timing and spectrum:

→ The pulses show a **fast characteristic rise time** ($\tau_{R,\,10\%\text{-}90\%}$ ~ 100 μs), proving that the present configuration of Al fingers does not slow down the athermal rising front.

→ The spectrum shows the principal 60 keV line and a bump at lower energy compatible with the Compton Edge of 60 keV photons (11.3 keV). **The poor spectral resolution is due to the high parasitic resistance** (about 0.8 mΩ) in the TES circuit (→ bad loop gain)



AC-S7 vs AC-S8: the improvement in the athermals collection



From the average pulse we have found that for AC-S8 the ratio between the athermal and the total (athermal + thermal) energy associated to the pulses is ~ 25 %, about a factor 4 above the AC-S7 one (see D'Andrea et al. 2017, DOI: 10.1117/12.2231412). This is an evidence of the **increase of the athermals collection efficiency due to the Al finger network**.

We have consolidate this result repeating the average pulse analysis in different working point of the detector. The efficiency increasing is clearly confirmed. Furthermore, note that **the athermal/total energy ratio is independent from the working point.** This is also a validation check of our thermal model, that predicts:

$$\frac{E_{ATH}}{E_{TOT}} = \frac{1}{1 + \frac{(1-\eta)}{\eta}\frac{Gep}{Gab}}$$

Conclusions :

→ **We have shown that - with high bias current - AC-S8 could operate ~ 50 mK far from the transition temperature.**

→ **We are developing a thermal model of the detector, which is able to preliminary reproduce the pulse dynamic.**

→ **We have obtained an evidence of the improvement in athermal collection efficiency due to the use of Al fingers.**

Contacts :