2 eV resolution @ 5.9 keV with high aspect ratio TiAu TES microcalorimeter under ac bias

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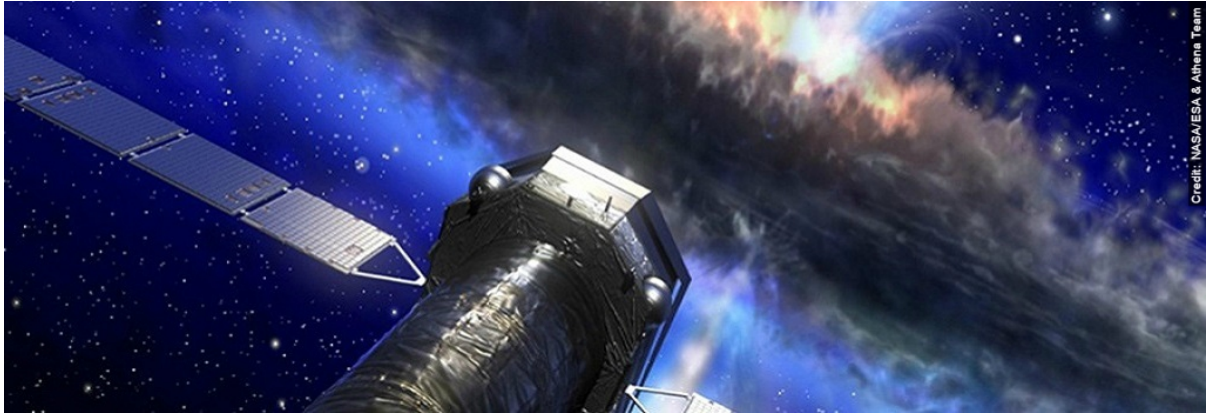
Netherlands Organisation for Scientific Research (NWO)

Introduction



Athena:

ESA's second L (large) mission of its Cosmic Vision 2015-2035 programme to address the *Hot and Energetic Universe science theme*.

Two main instruments:

1. Wide Field Imager (DEPFET Active Pixel Sensor, 40 arcmin FOV)
2. **X-ray Integral Field Unit (X-IFU)**
   - Cryogenic TES based calorimeter array (~ 3000 pixels, 5 arcmin FOV)
   - High energy resolution (2.5 eV @ 7 keV)

SRON is developing:

- Focal plane assembly
- FDM readout system as baseline technology
- X-ray TiAu TES array as backup technology

→ **Interaction between detector and readout system plays a crucial role to meet the requirement**

Kurume, Fukuoka, 2 years ago…

Two, frequency dependent, physical processes have been identified as being responsible for the degradation of the single pixel performance of MHz biased TES micro-calorimeters

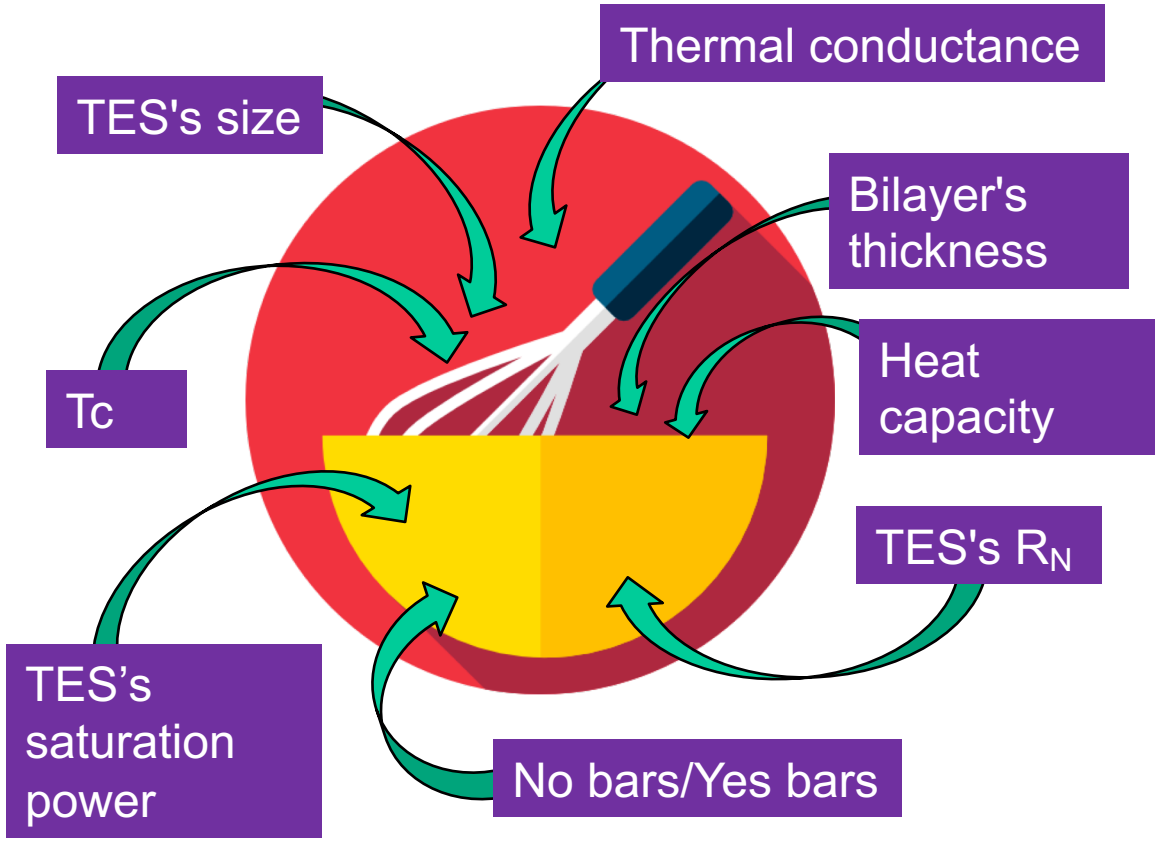
1. **Josephson effect** (*non dissipative*): Reasonably well described by the resistively-shunted-junction (RSJ) model. Weak-links effect can be minimized using TES with high normal resistance and high saturation power.

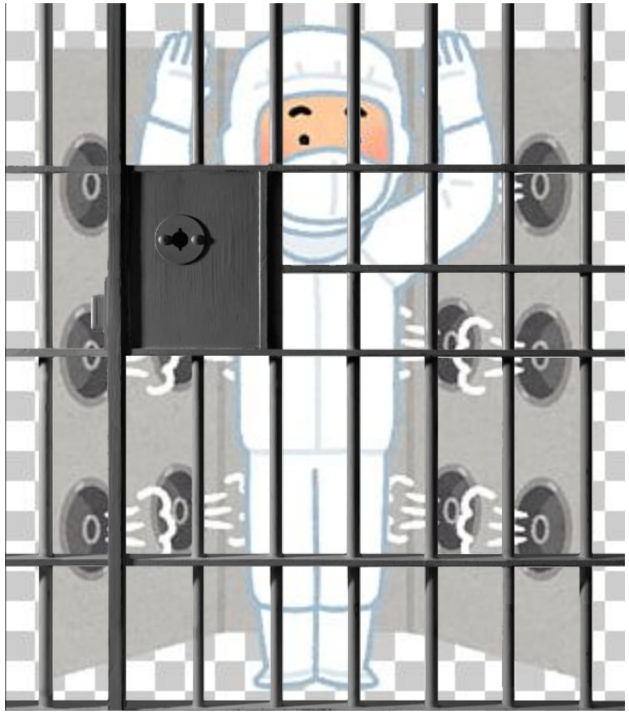
   Of course thicker TESs have less internal thermal fluctuation noise

2. **AC loss** (*dissipative*) in normal metal structure (absorber) close or connected to the TES's. Bare TESs have less weak-link than TESs with normal metal structures

SRON, Utrecht, time ago…

…so to maximize the performances of the detector under AC bias in the FDM readout system, there is of course a trade off…

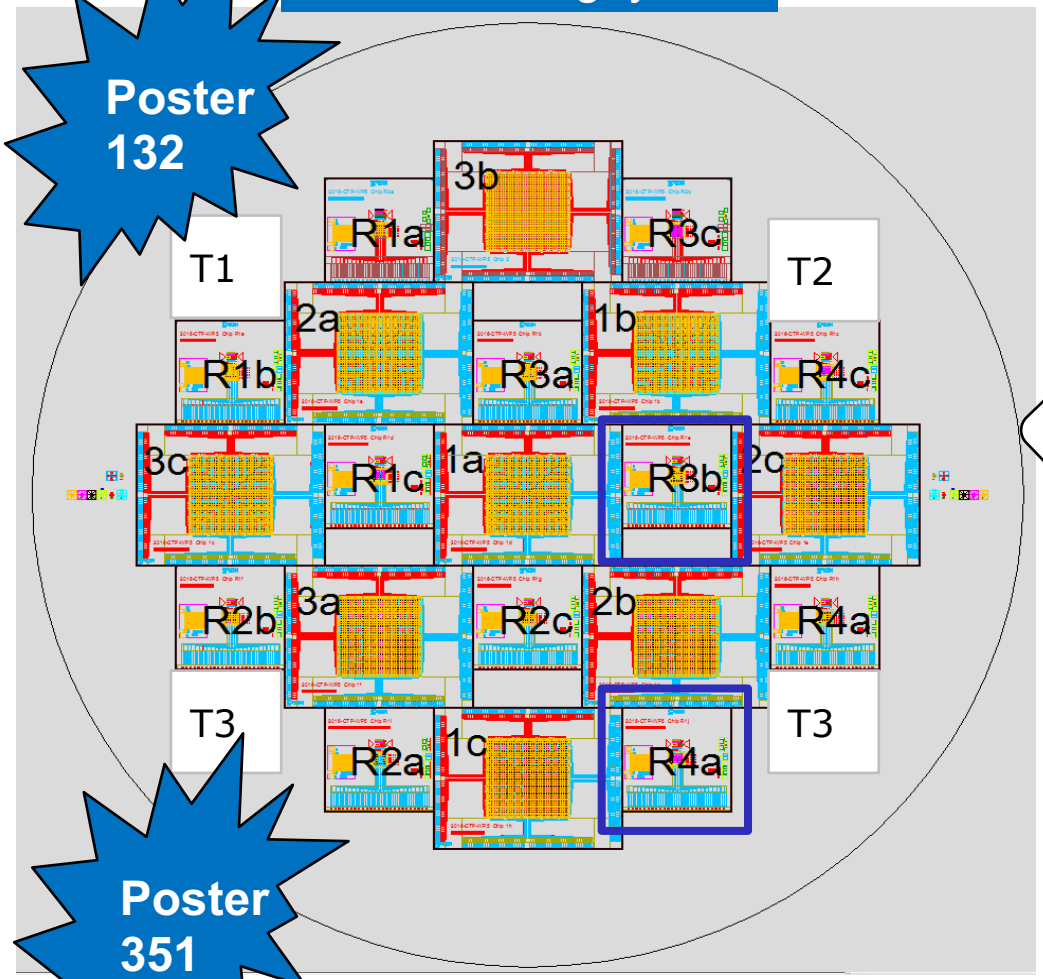




SRON, Utrecht, three weeks later…

Kenichiro Nagayoshi

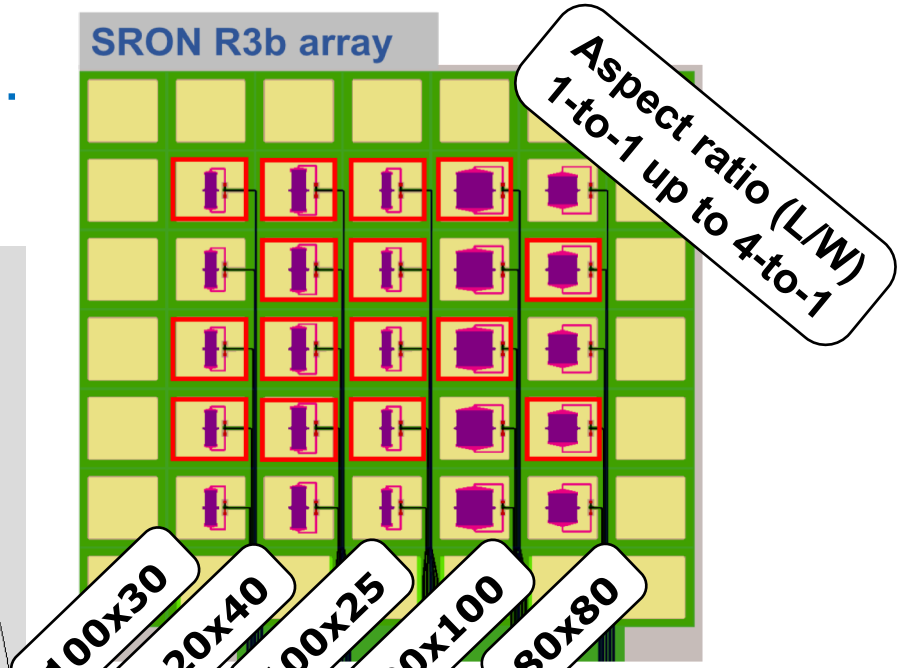
Poster 132

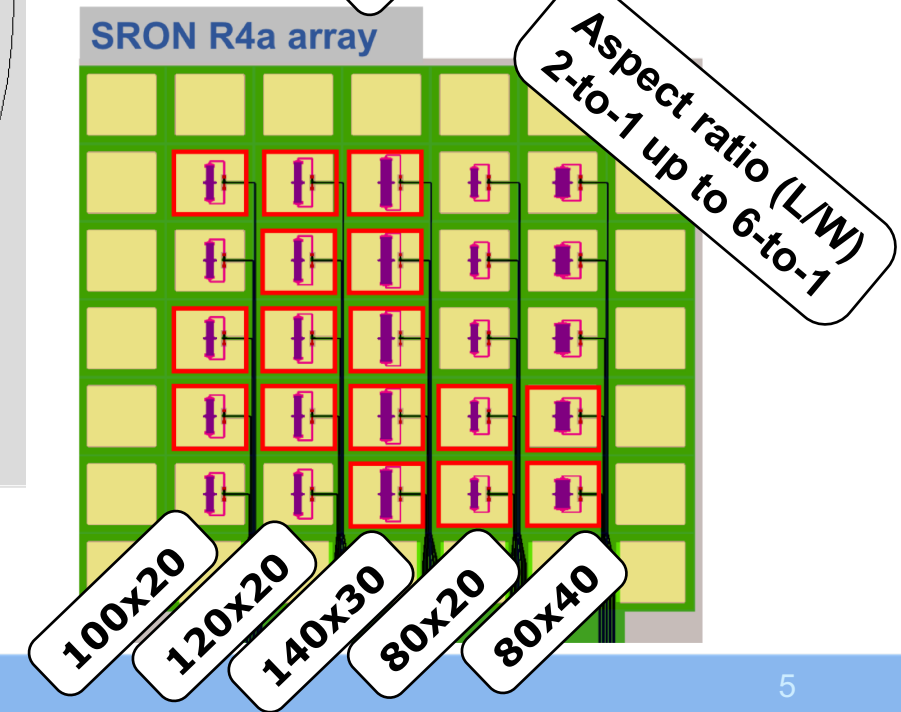


Poster 351

Marcel Ridder

SRON

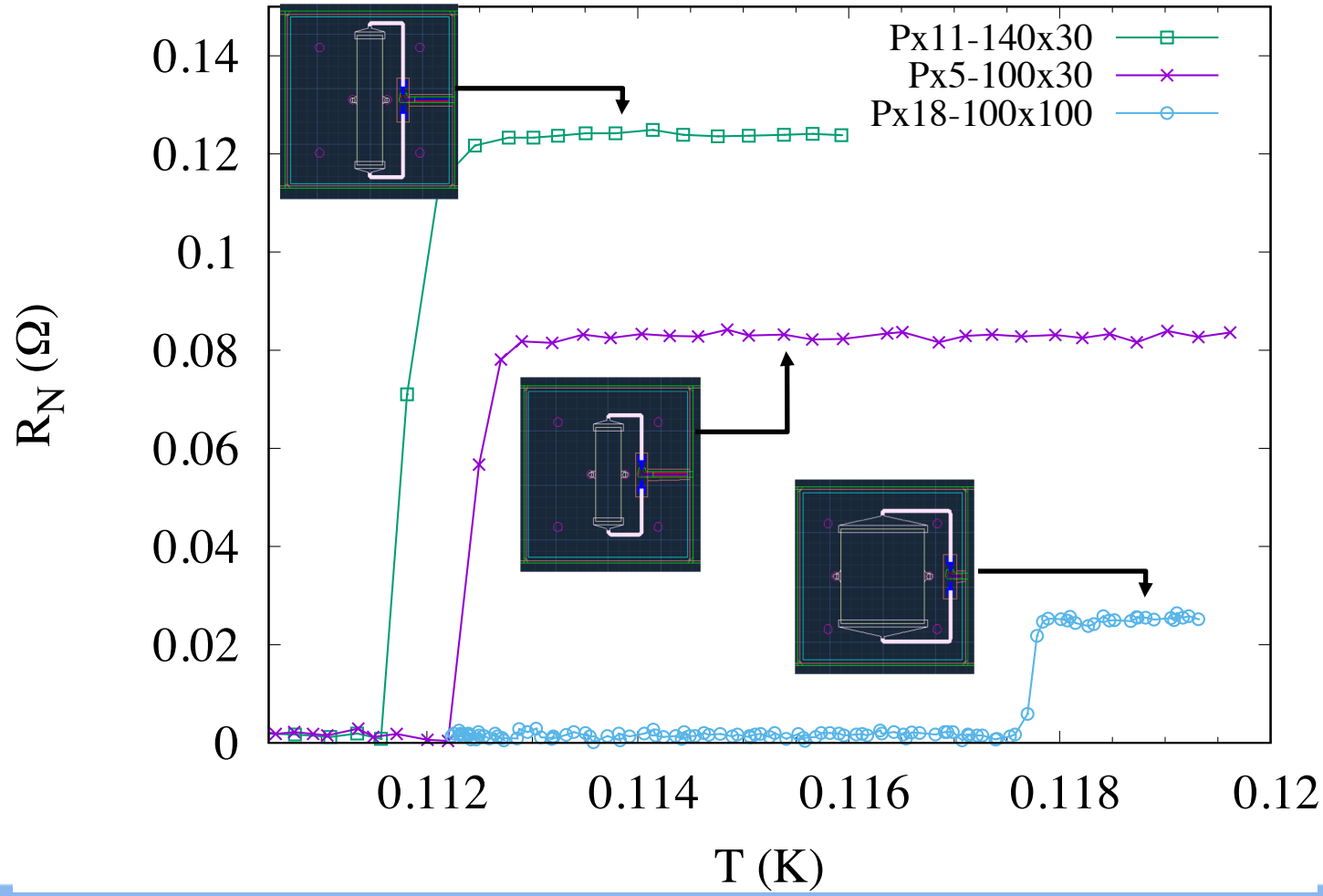




Expectation from the pixels design

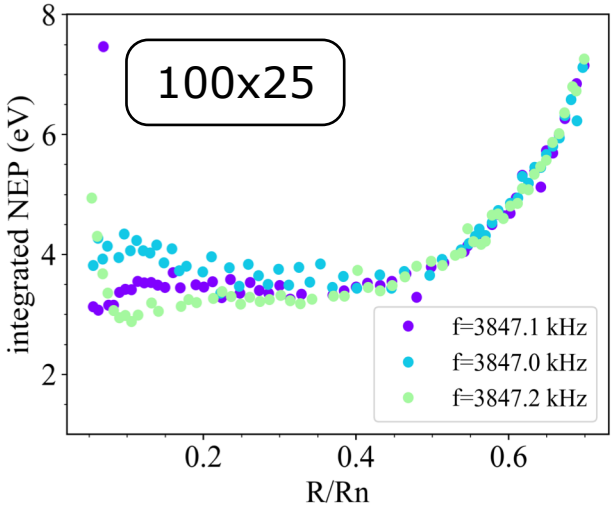
- Bare Bilayer Ti (35 nm) Au (200 nm)
- Only Au absorber, 2.3 μm thick, 240x240 μm^2
- C = 1.1 pJ/K

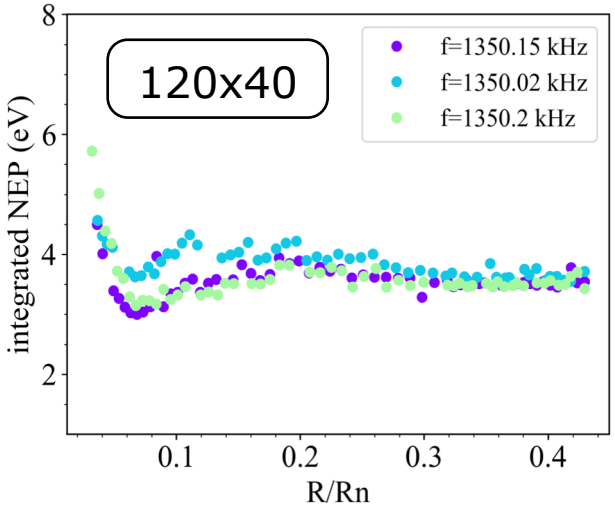
- Squared normal resistance R_{nsq} as expected
- T_c higher than 90 mK expected
- G also higher in part due to higher T_c

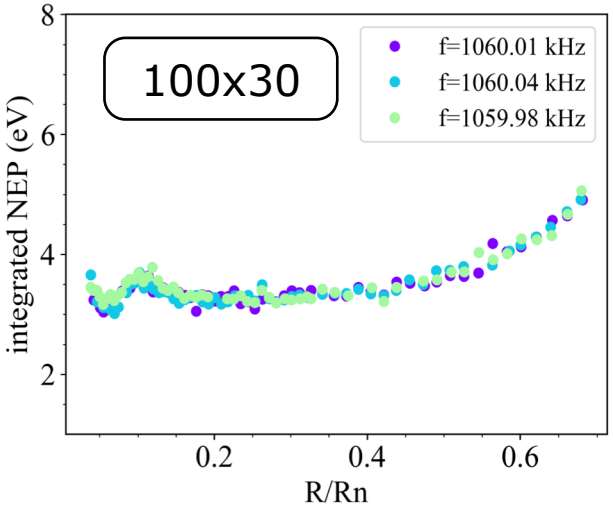


Integrated NEPs overview: “low” aspect ratio R3b array

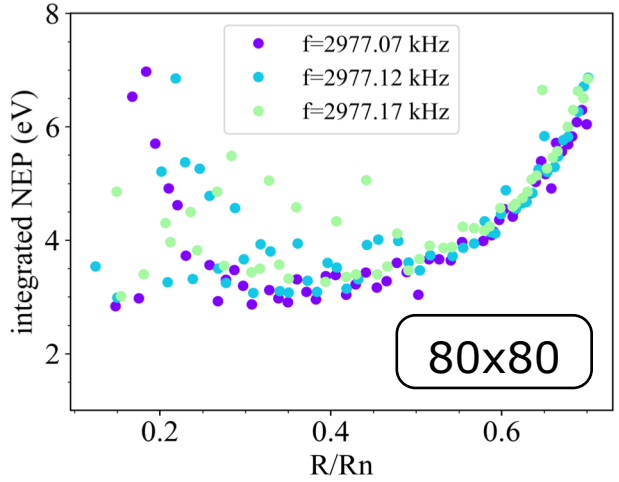
L/W from 4-to-1





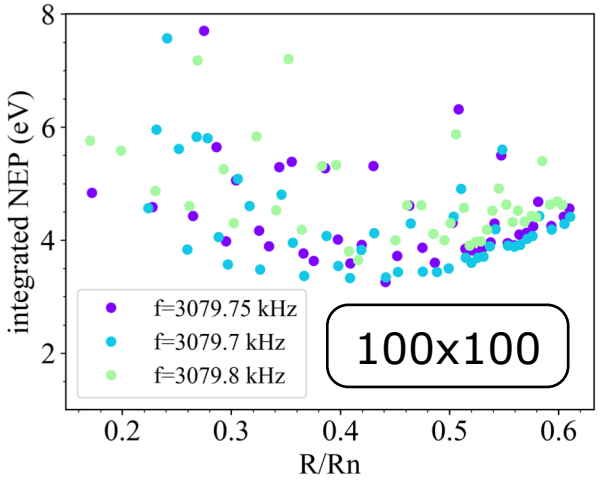


to 1-to-1



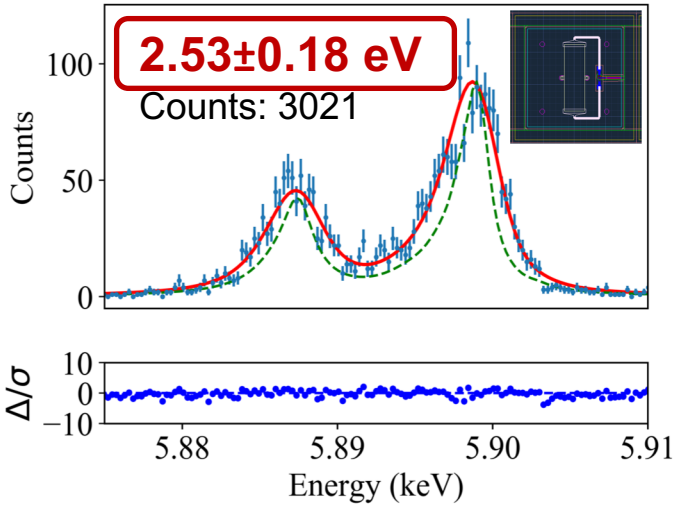
As expected weak-links effect is lower for high normal resistance device.

In general the squared TESs are less flat in the NEPs

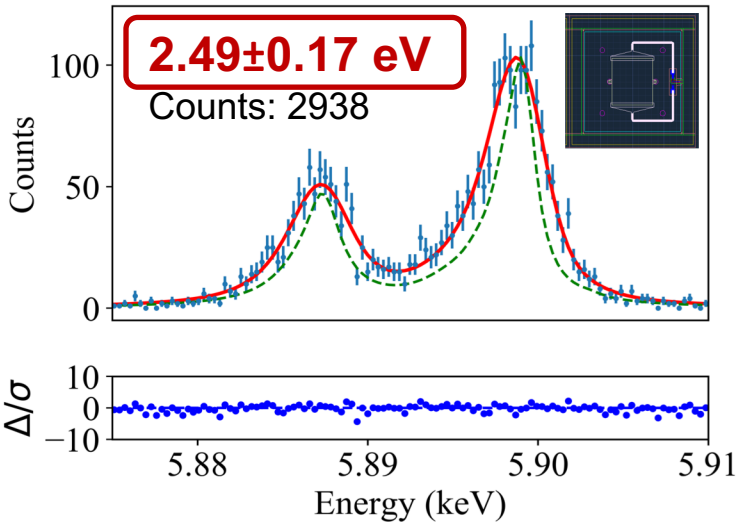


X-Ray energy resolution: “low” aspect ratio R3b array

120x40 μm² | f = 1.3 MHz

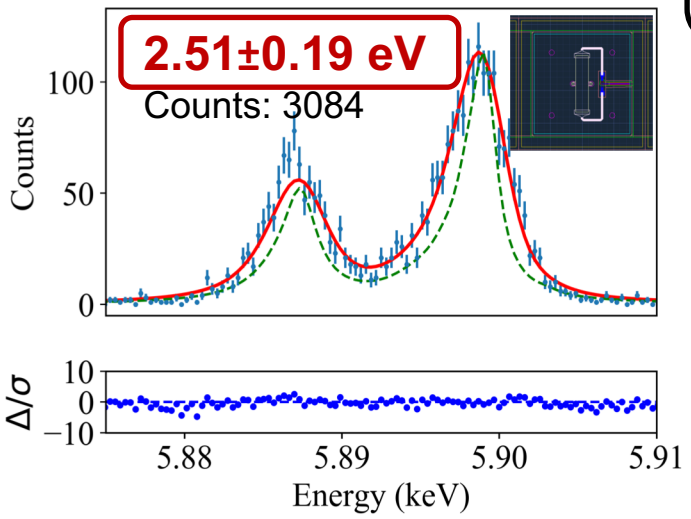


80x80 μm² | f = 2.9 MHz

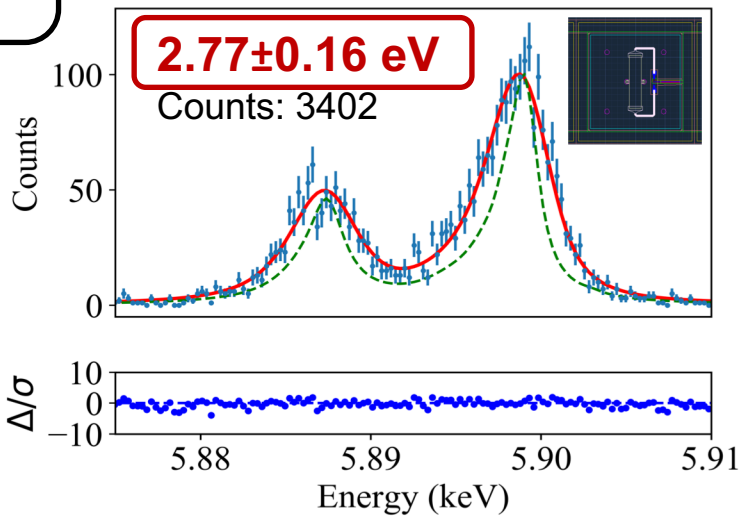


Px13 – TES 12
100x25 μm²

f = 3.8 MHz

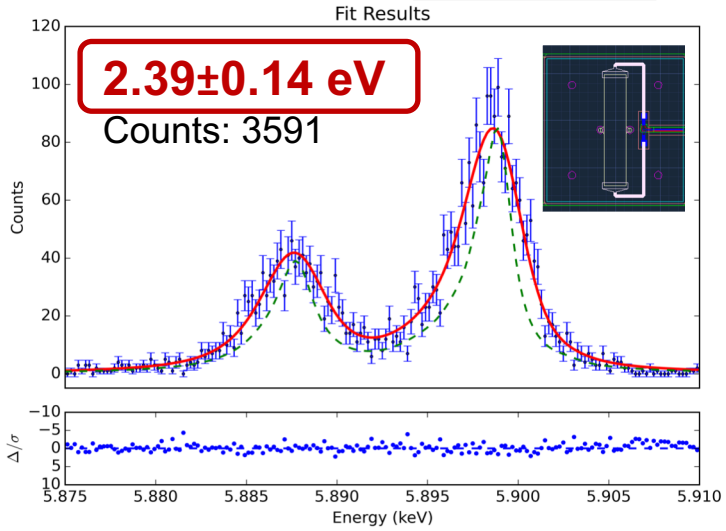


f = 4.6 MHz

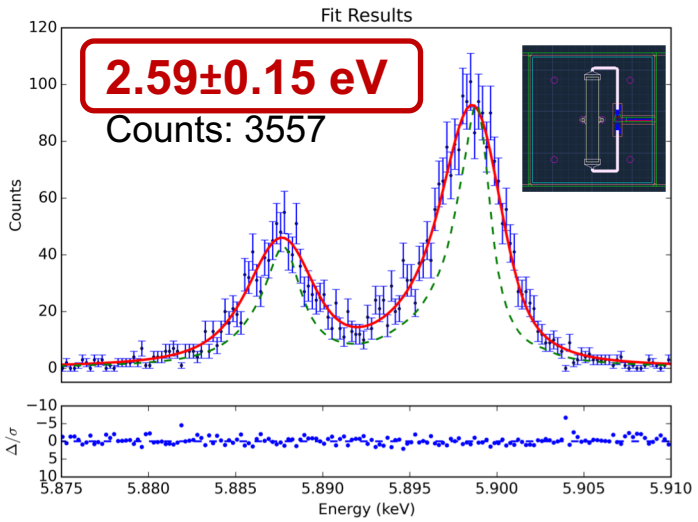


X-Ray energy resolution: “high” aspect ratio R4a array

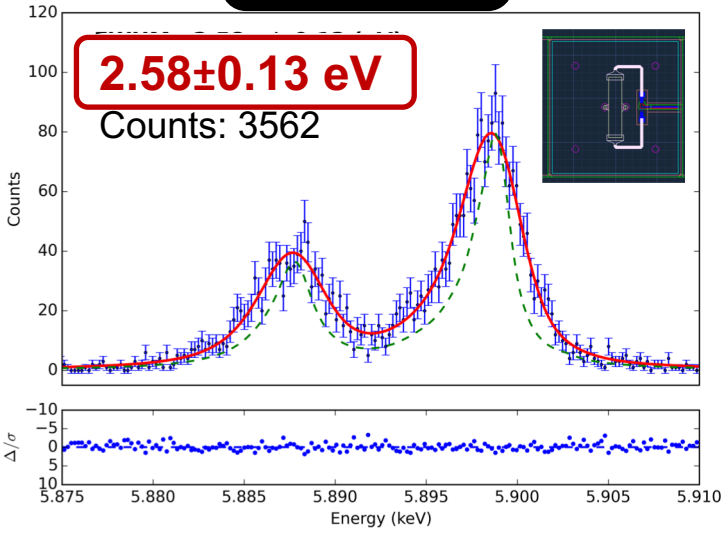
140x30 μm^2 | f = 1.6 MHz



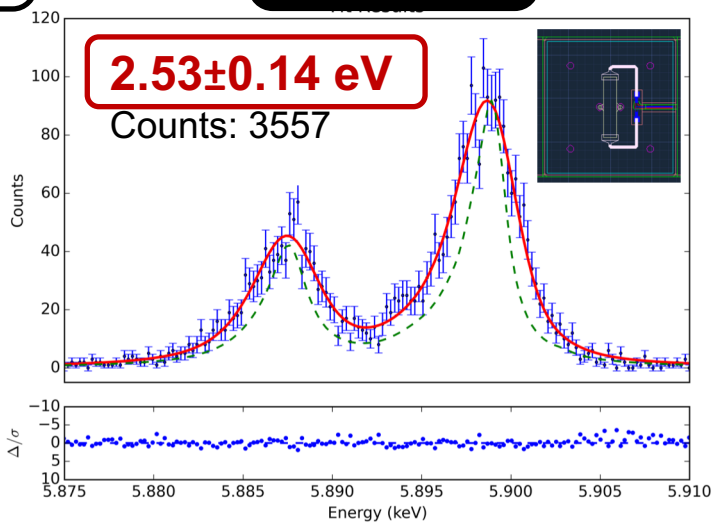
120x20 μm^2 | f = 3.9 MHz



f = 1.2 MHz

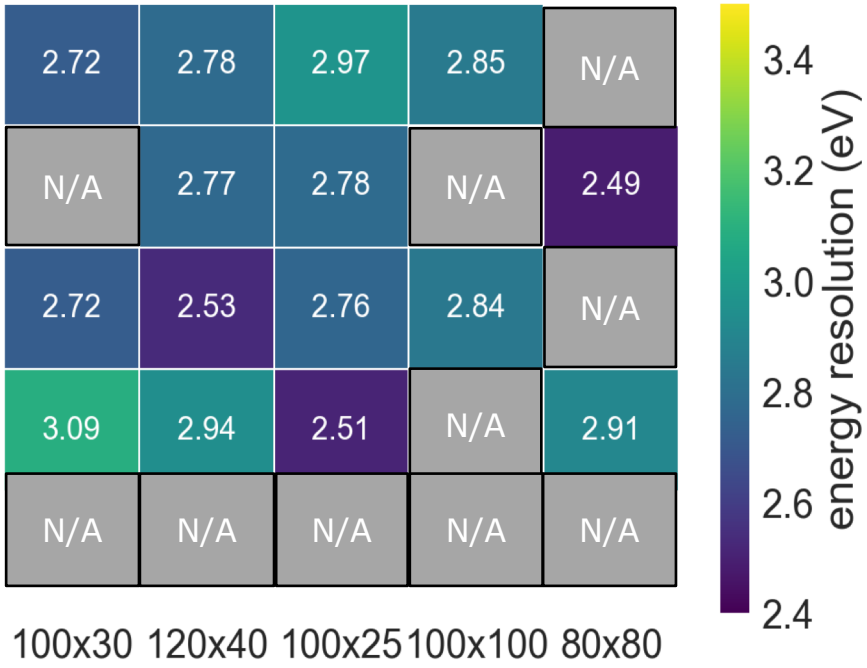


80x20 μm^2 | f = 2.6 MHz

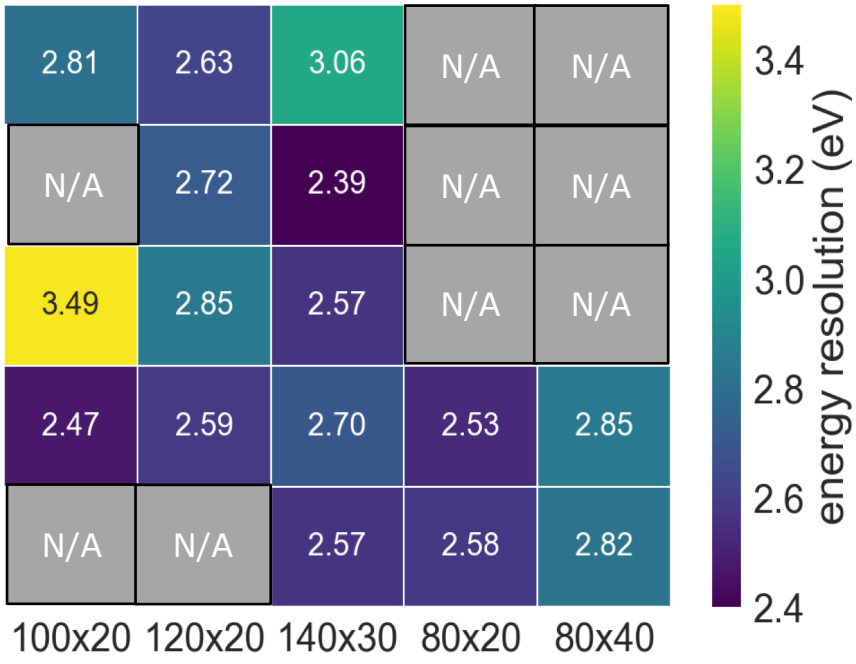


X-Ray energy resolution overview

"Low" aspect ratio array R3b



"High" aspect ratio array R4a



Setup 1
Temperature stability ±3μK @ 50 mK

Setup 2
Temperature stability ±1.9 μK @ 55 mK

Poster 99

Luciano Gottardi

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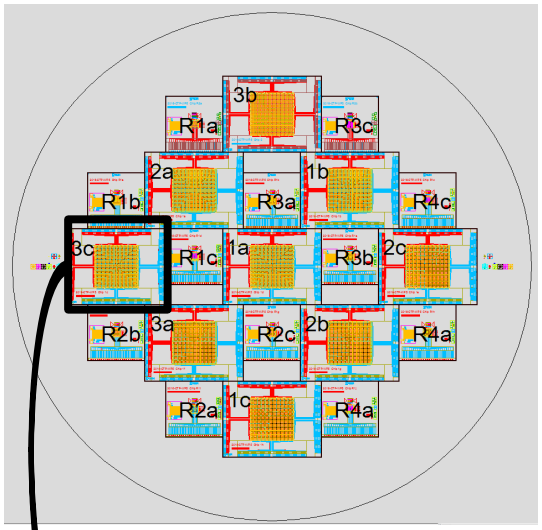
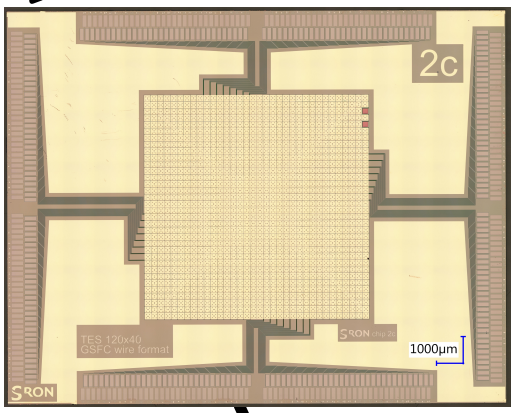
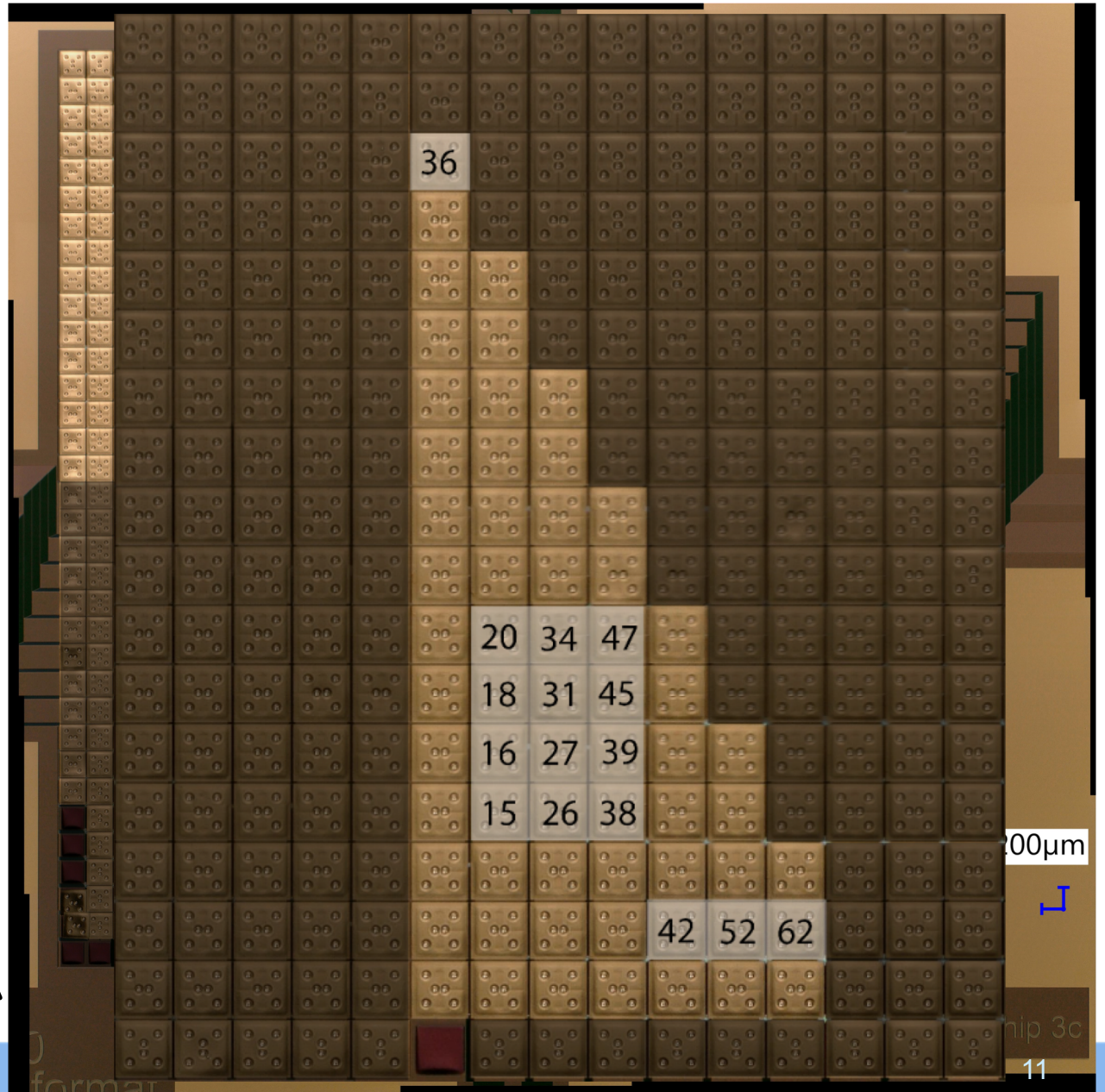
Kilo-pixels array

32x32 kilo-pixel array with 140x30 μm² (L/W 4.6-to-1) TiAu TES - Tc ~ 110 mK

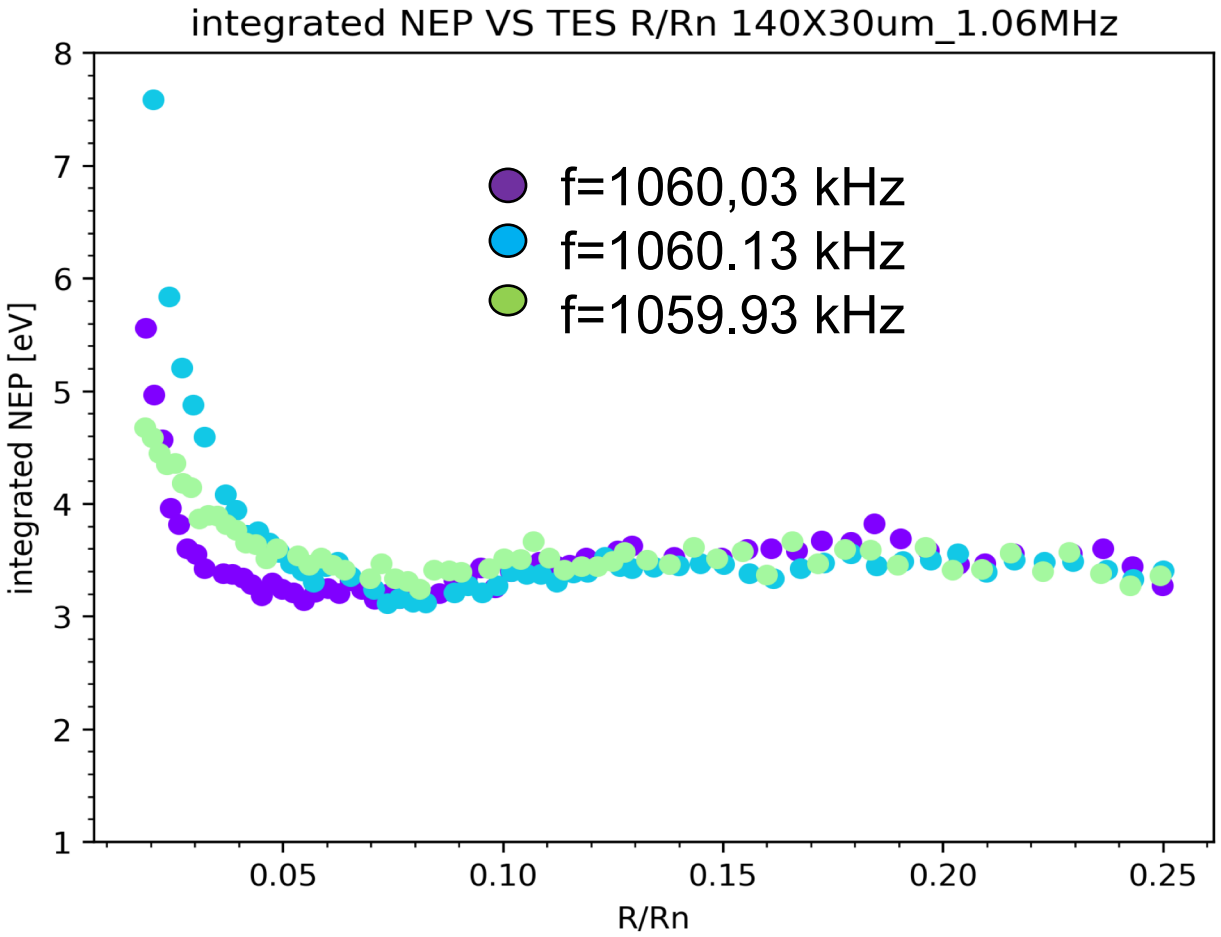


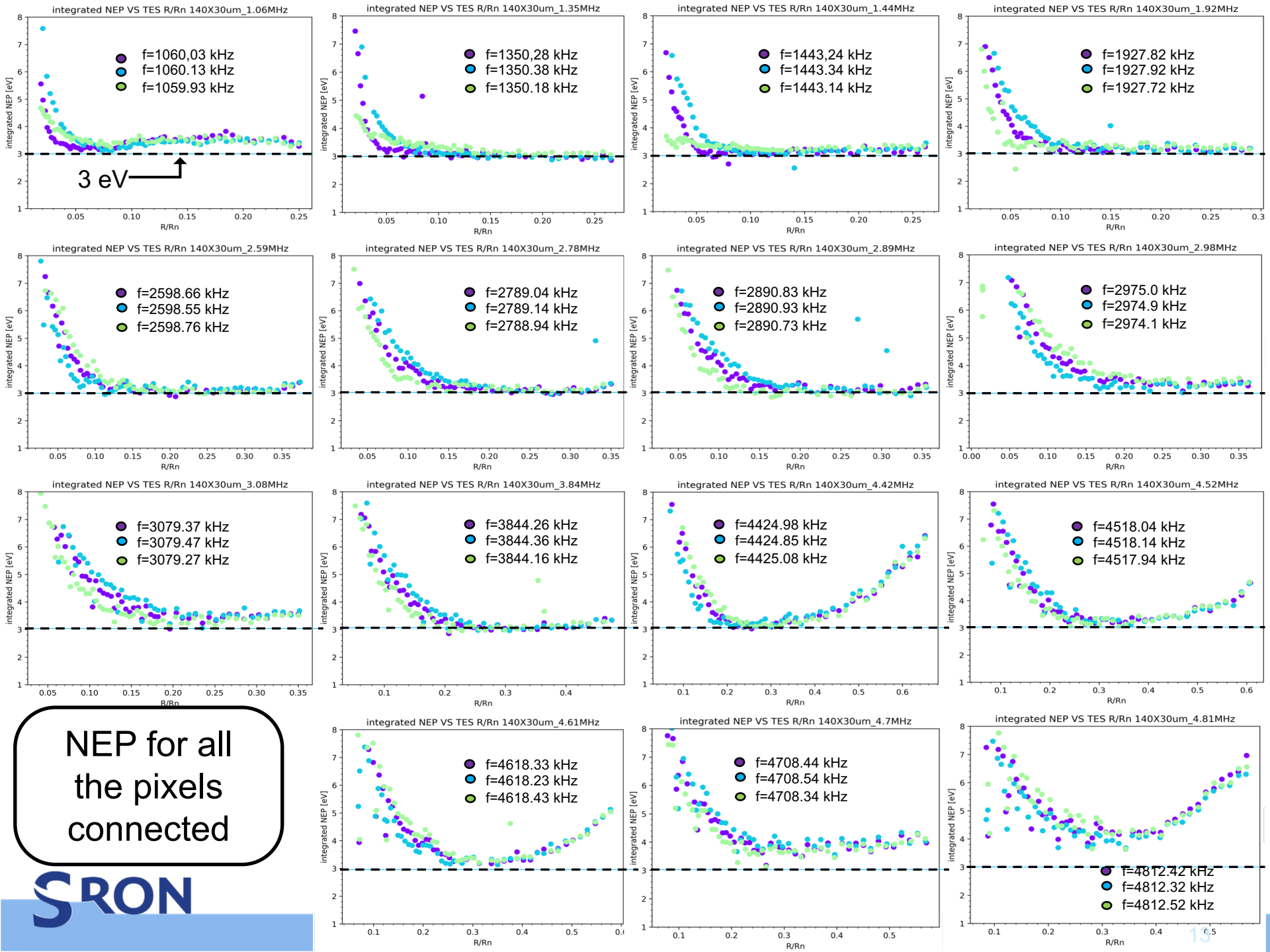




Preliminary results on Kilo-pixels array

Flat NEP from 5% up to 25% in the transition





NEP for all the pixels connected

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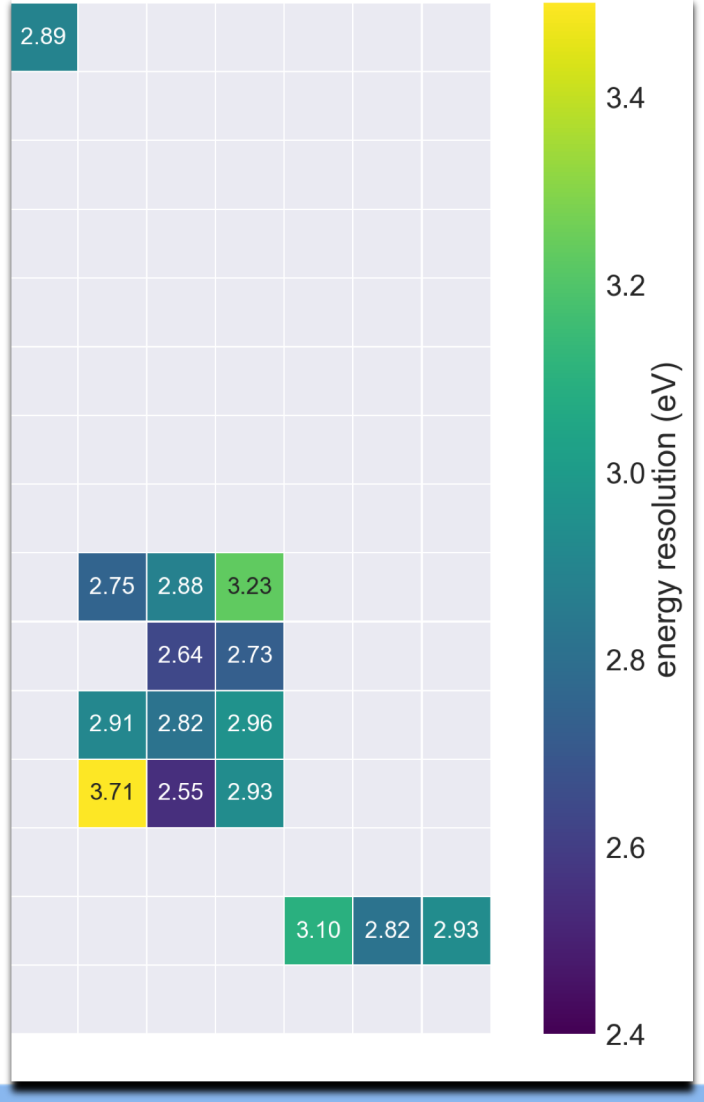
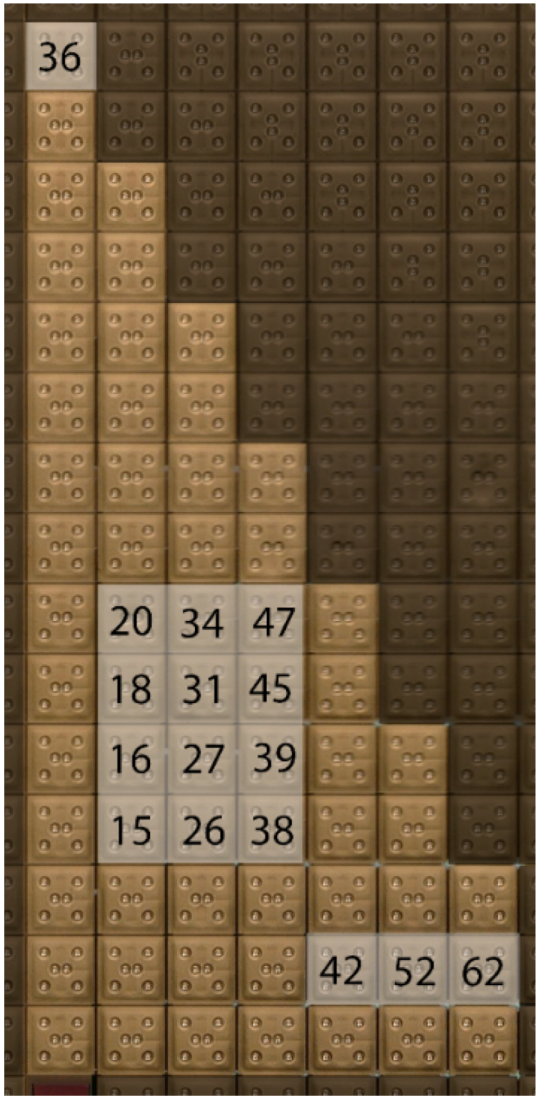
Kilo-pixel energy resolution overview (preliminary results)

XFDMLarge in high inductance limit L~0.6Lcrit: NEP is worse than X-ray resolution due to non-stationary noise effect and large signal effect.



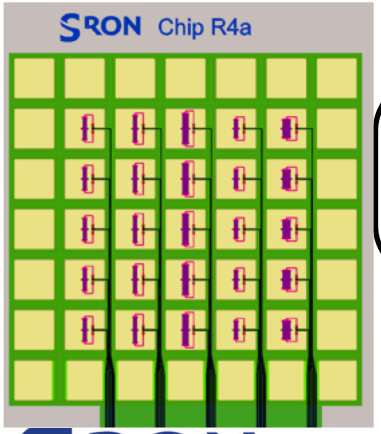


What if we reduce T_c

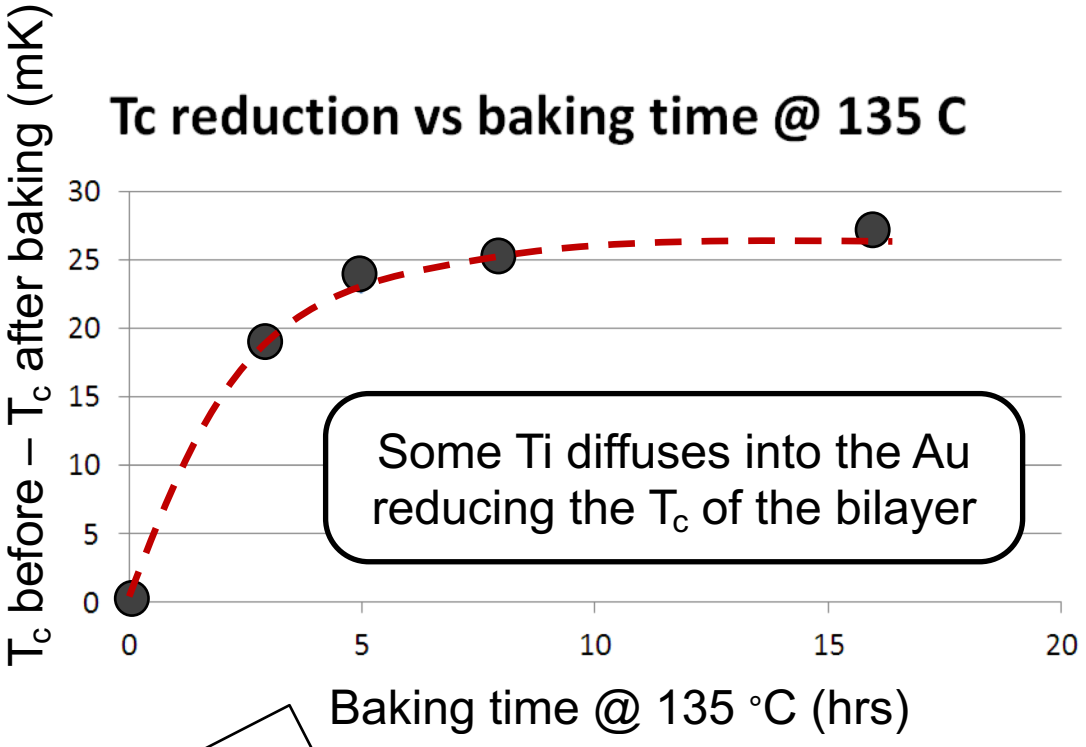
$$\Delta E \approx \sqrt{4kT_c^2 \frac{Ce}{\alpha} \sqrt{\frac{n}{2}}} \propto T_c^{3/2}$$

As already said Tc~110 mK
but we aimed to 90 mK
We used our knowledge on baking TESs…

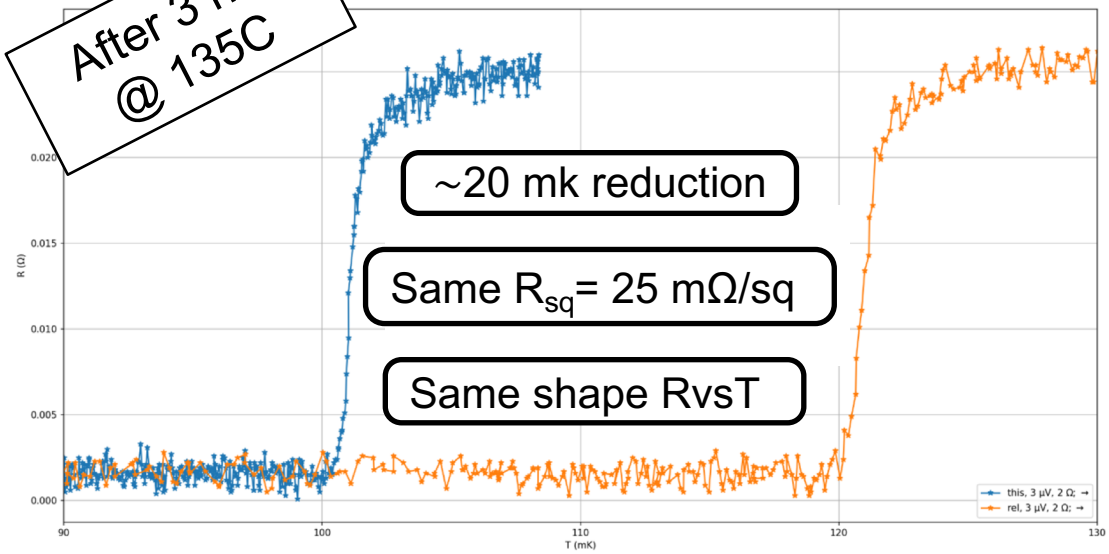
"High" aspect ratio - array R4a
Has been baked →
Tc from 115 to 90 mK



We expect
~20%
ΔE reduction



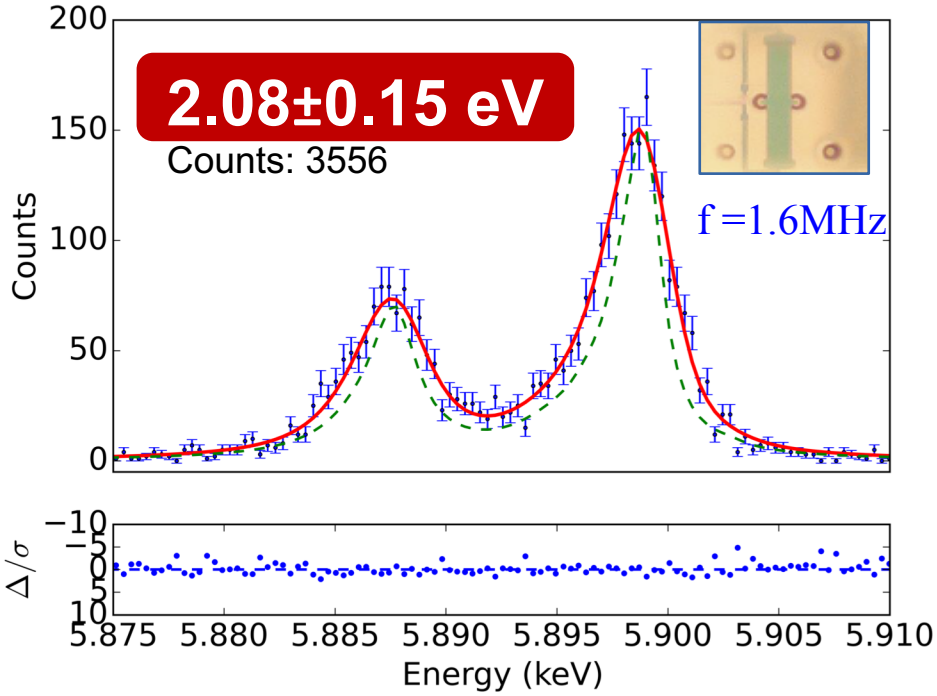
After 3 hrs @ 135C



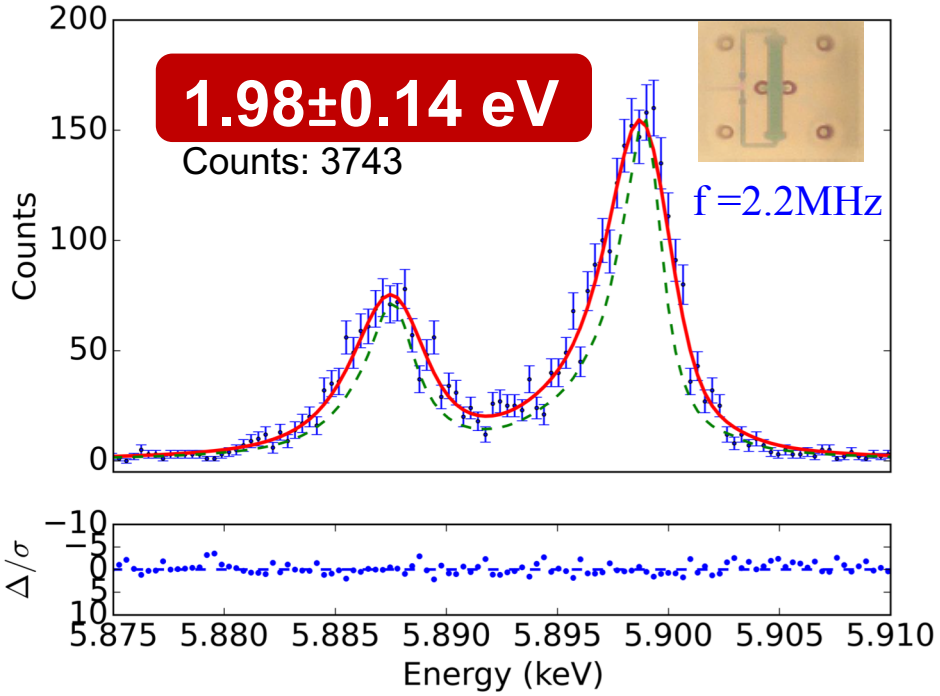
What is changed?

The title of this presentation of course, but due to this results…

AR=4.6:1 140x30um^2
Rn=117mOhm



AR=6:1 120x20um^2
Rn=150mOhm



Conclusion

- Energy resolution between 2.4 and 2.8 eV at 5.9 keV on 20 out of the 31 TiAu TESs with T_c~110 mK

- Backing the TESs getting a T_c~90 mK has improved the energy resolution up to 1.98 eV at 5.9 keV.

- TiAu TESs under ac can accomplish detector requirements of the X-IFU instrument

- Ready to test the kilo-pixels array with the FDM readout in multi pixels mode

Acknowledgement

European Space Agency (ESA) and other European efforts under ESA CTP contract ITT AO/1-7947/14/NL/BW.

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Thank you for you attention