TES development update

M. Rajteri

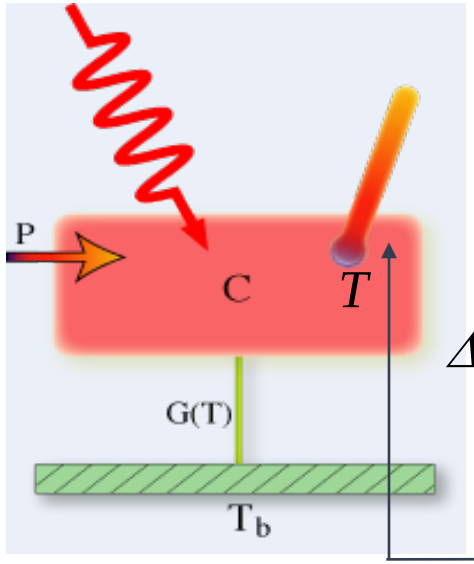
C.Pepe, H. Garrone, E. Monticone

INRiM
ISTITUTO NAZIONALE
DI RICERCA METROLOGICA

Torino-Italy

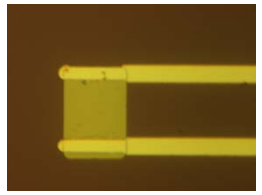
TES recap

TES: a microcalorimeter made by a superconducting film operated in the temperature region between normal and superconducting state

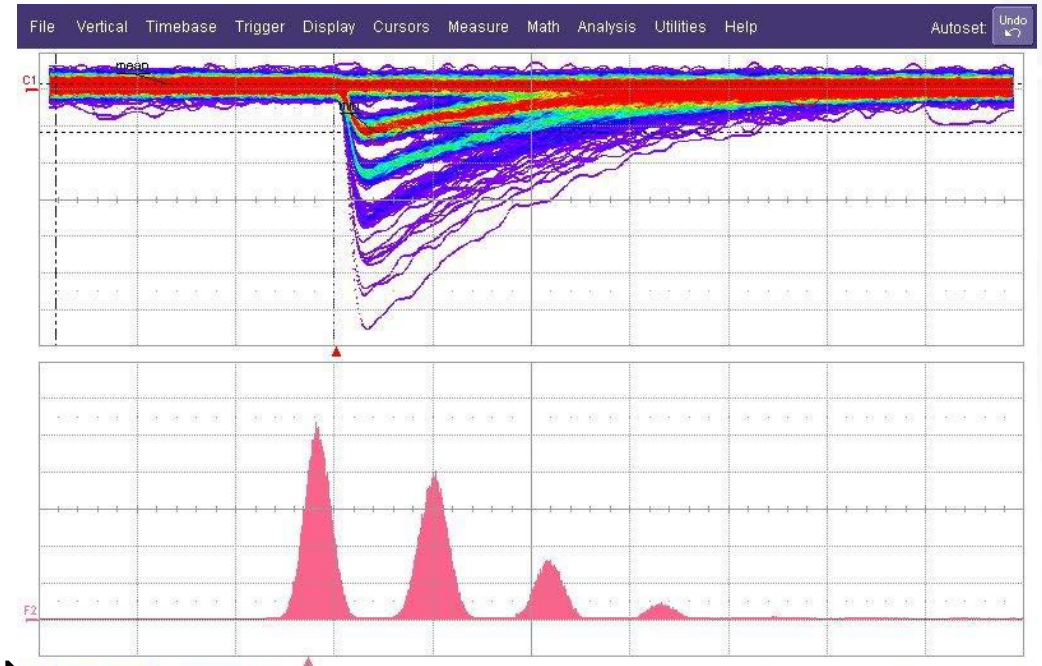


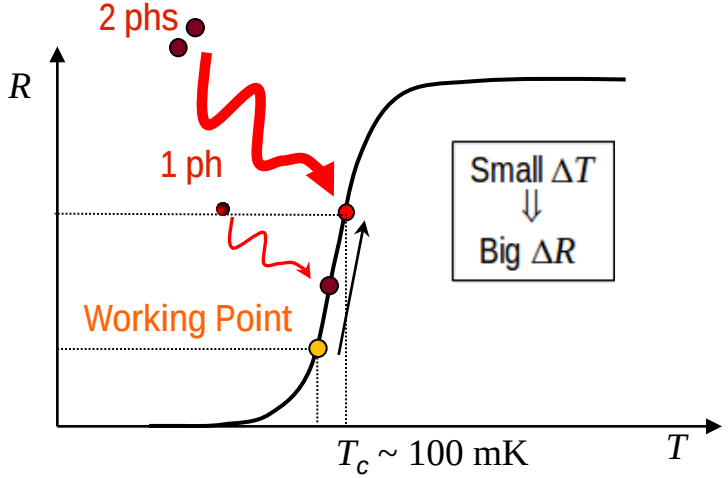
$\Delta T = E/C$

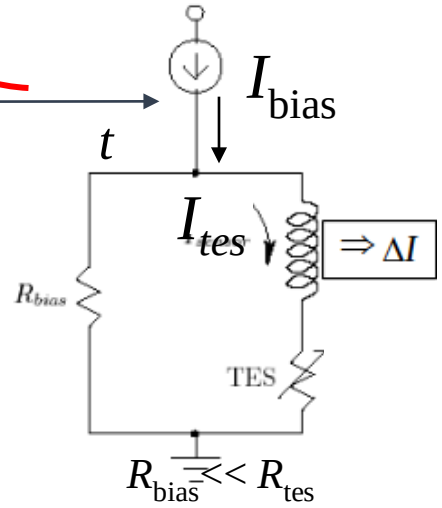
$\tau = C/G$



20 μm X 20 μm







$\Delta T \Rightarrow \Delta R$ @ **Voltage bias** $\Rightarrow$ ΔI

Photon Number Resolving (PNR) Capability

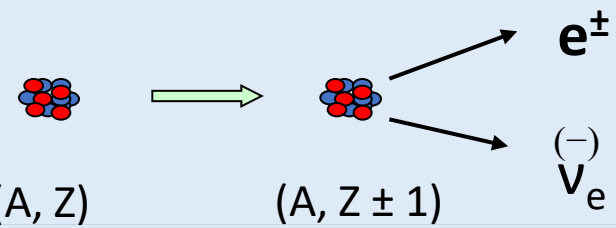
TES for PTOLEMY

Detection idea:

Massive neutrinos and neutrino capture on beta decaying nuclei

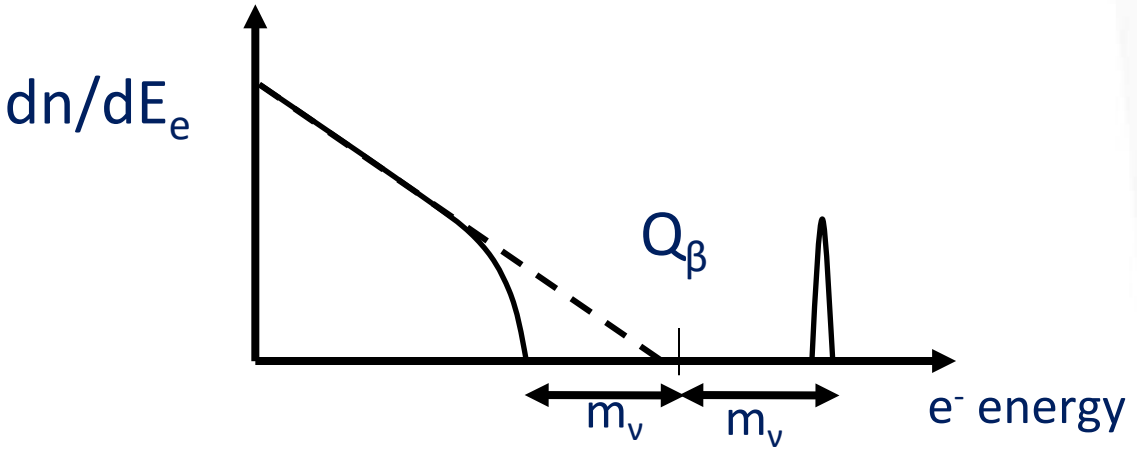
A.G.Cocco, G.Mangano and M.Messina JCAP 06(2007) 015

β decay



Neutrino Capture on a Beta Decaying Nucleus (NCB)

This process has no energy threshold !



$0.05\ eV < m_\nu < 0.2\ eV$

From neutrino oscillations

from Cosmology

INRiM ISTITUTO NAZIONALE DI RICERCA METROLOGICA

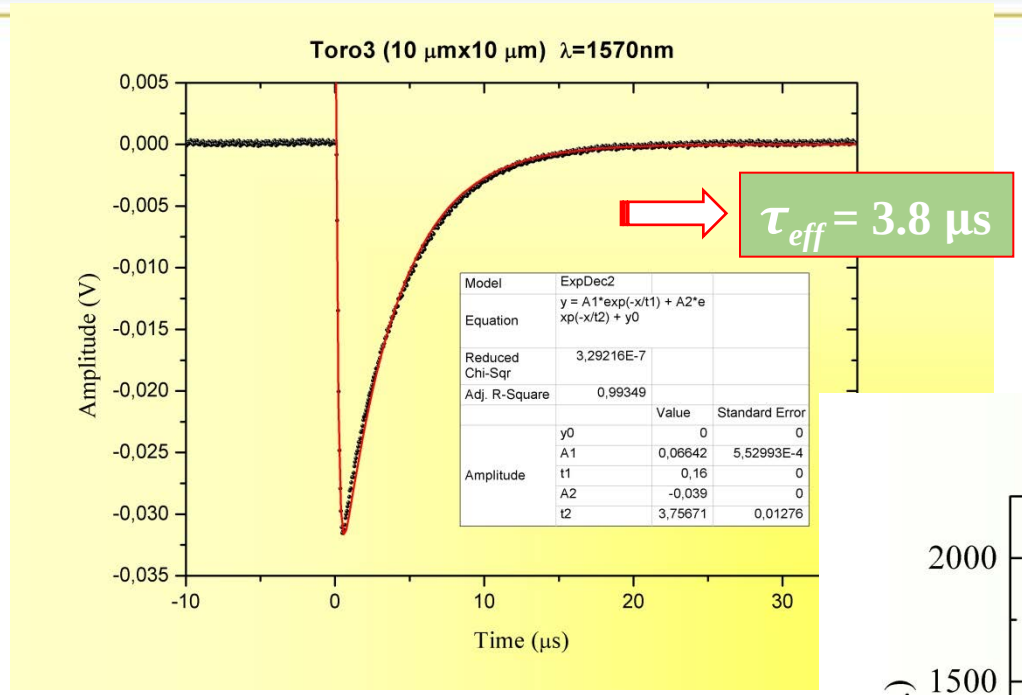
TES for PTOLEMY

- Goal for electron resolution ⇨ ΔE_e = 0.05 eV @10 eV
- TESs for UV/NIR good candidate to detect also electrons
- First charaterization will be done with optical photons

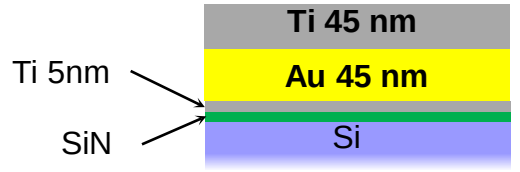
  10 eV @1550 nm ~ 13 photons

INRiM ISTITUTO NAZIONALE DI RICERCA METROLOGICA

TES starting point @ INRIM

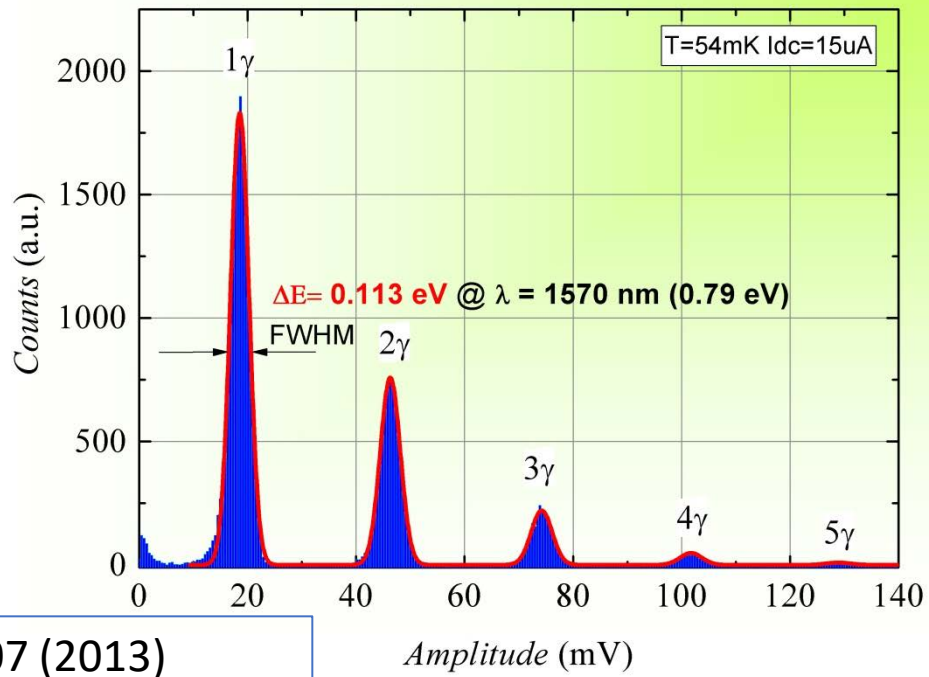


$\tau_{eff} = 3.8\ \mu s$



TiAuTi

With Wiener filter



$\Delta E = (0.113 \pm 0.001)$ eV

$$\Delta E = 2\sqrt{2\ln 2}\,\frac{\sigma_1 E_\gamma}{x_{2\gamma} - x_{1\gamma}}$$

L. Lolli et al., Appl. Phys. Lett. 103, 041107 (2013)

TES: Performances

$$\Delta E_{FWHM} \simeq 2.36 \sqrt{4kT_c^2 \frac{C_e}{\alpha} \sqrt{n/2}} \propto T_c^{3/2}$$

Energy resolution

To reduce ΔE we can work on:

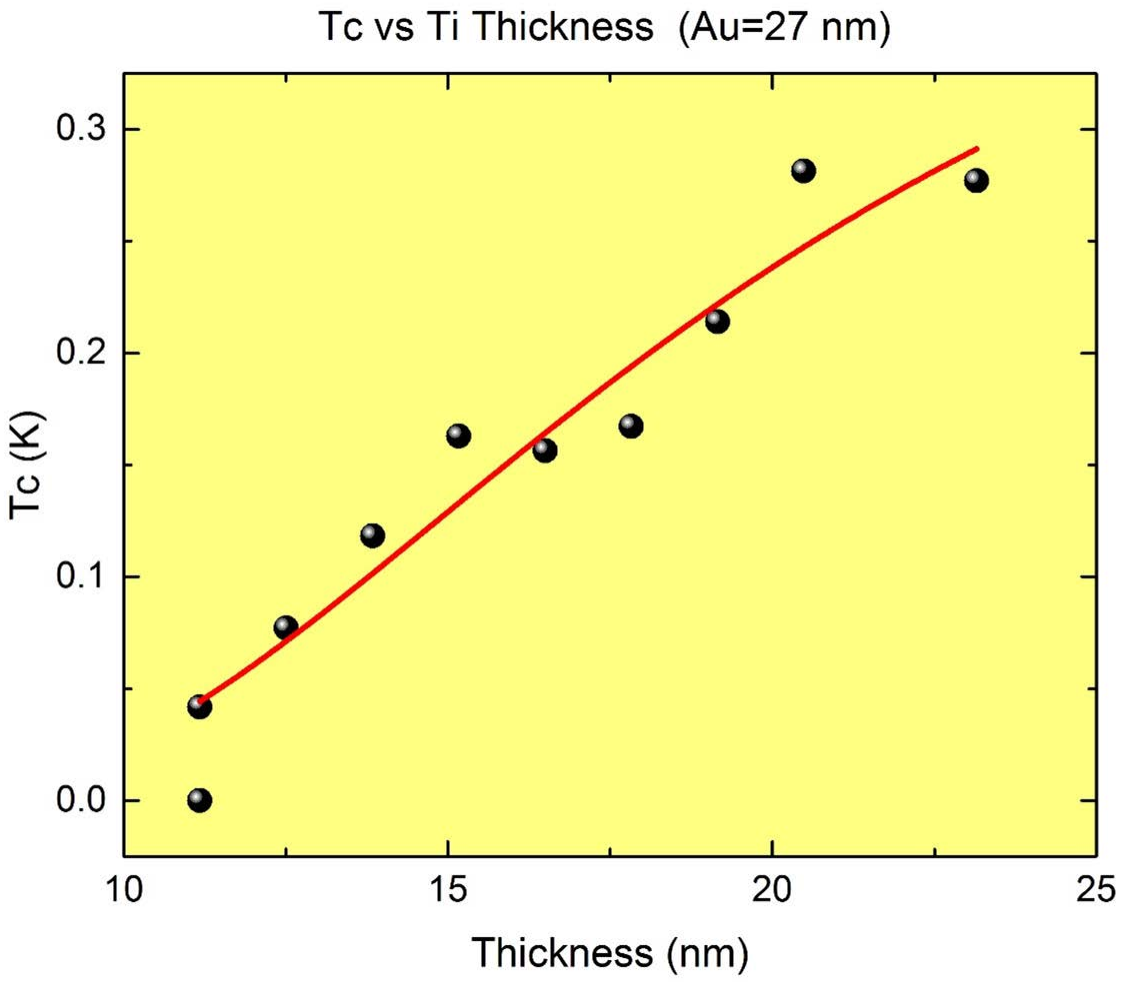
T_c ⇨material, bilayer (proximity effect), annealing

C ⇨material, volume (area & thickness), T_c

α ⇨ deposition, edges, wiring material

Film thickness reduction

Au Film thickness constant vs Ti

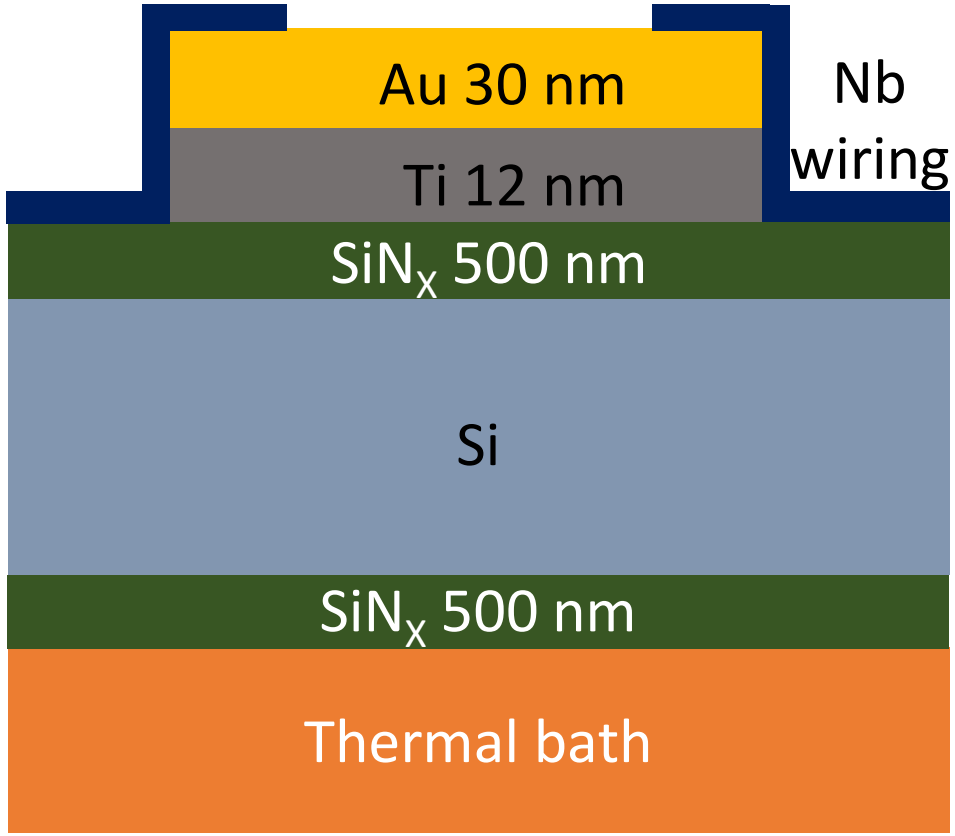


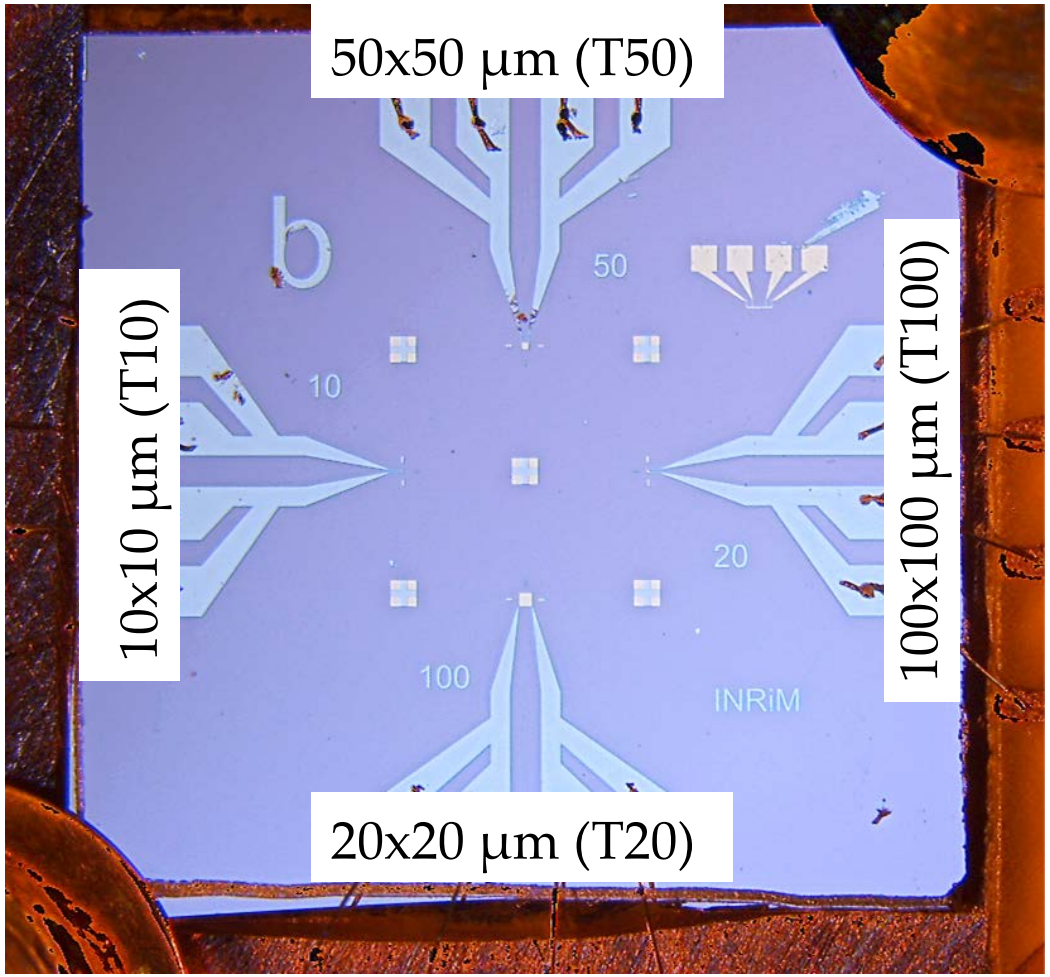
- T_c of TiAu vs Ti thickness for a constant Au layer of 27 nm.
- T_c=42 mK with:
  Ti=11 nm and Au=27 nm

  Lower limit
- The red curve is calculated by Usadel equation.

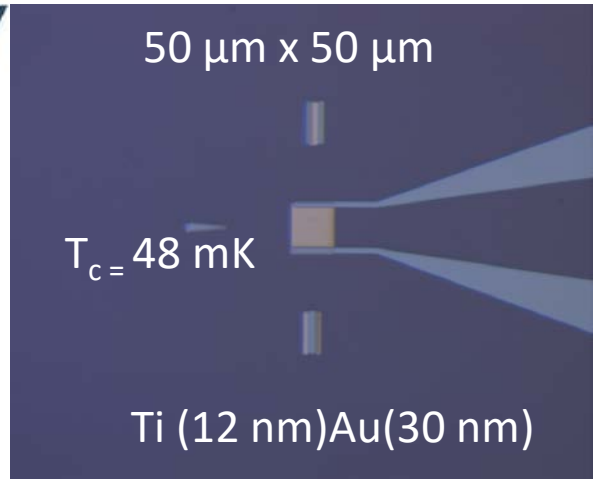
INRiM ISTITUTO NAZIONALE DI RICERCA METROLOGICA

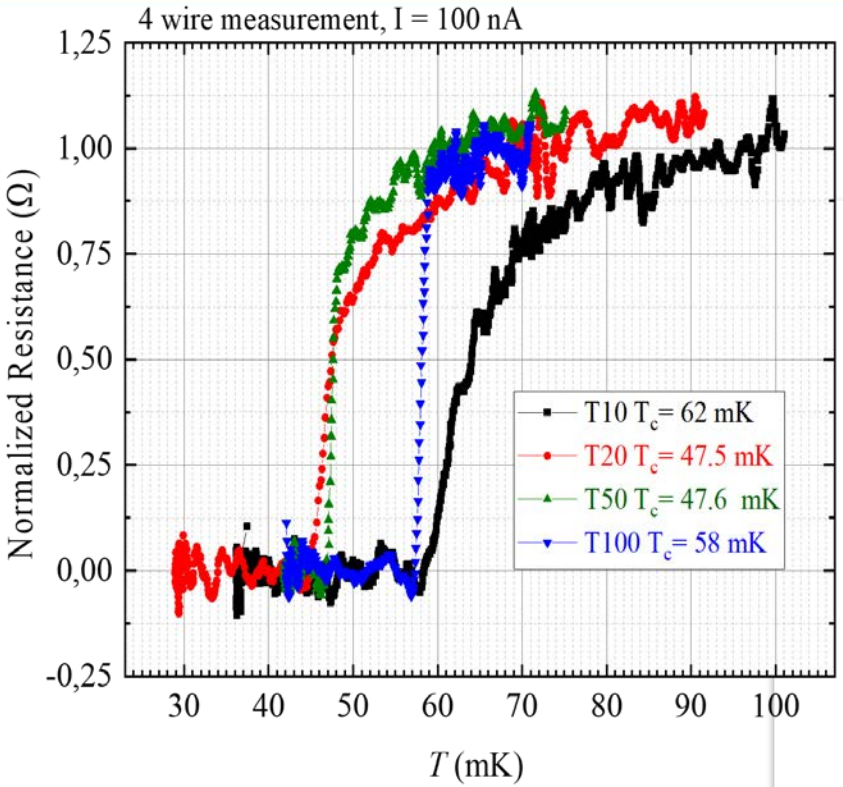
Film thickness reduction

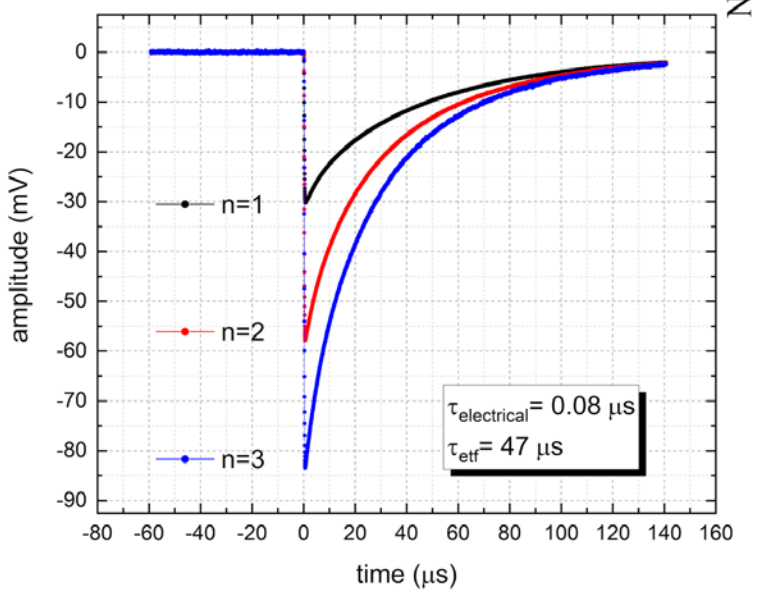


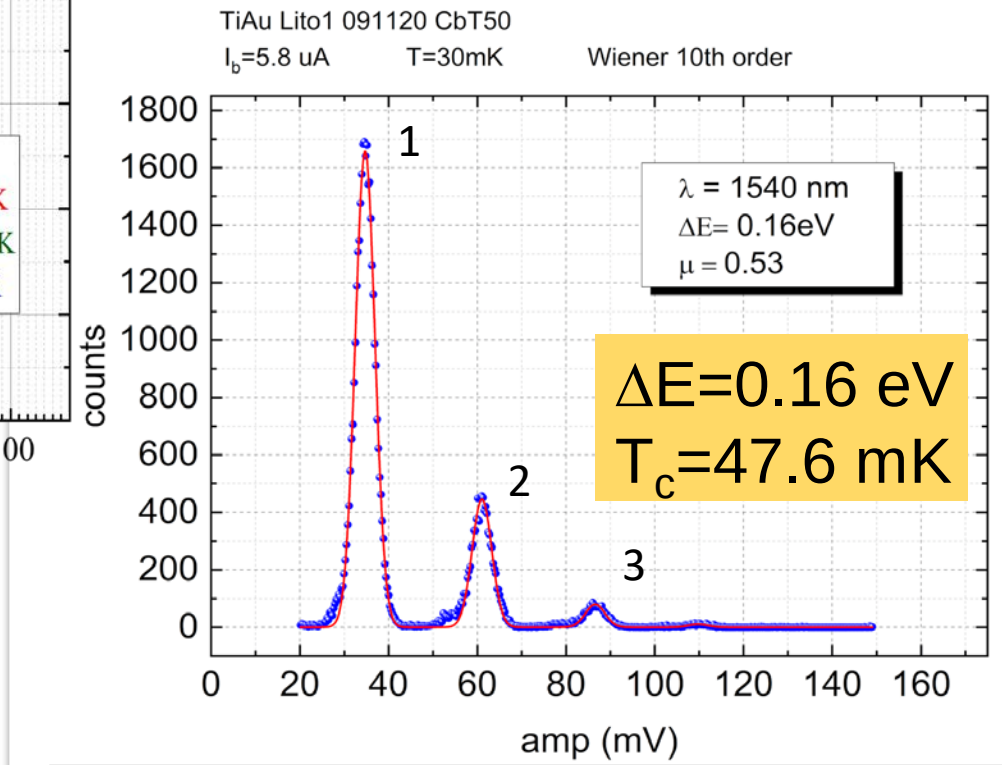


TiAu Lito1

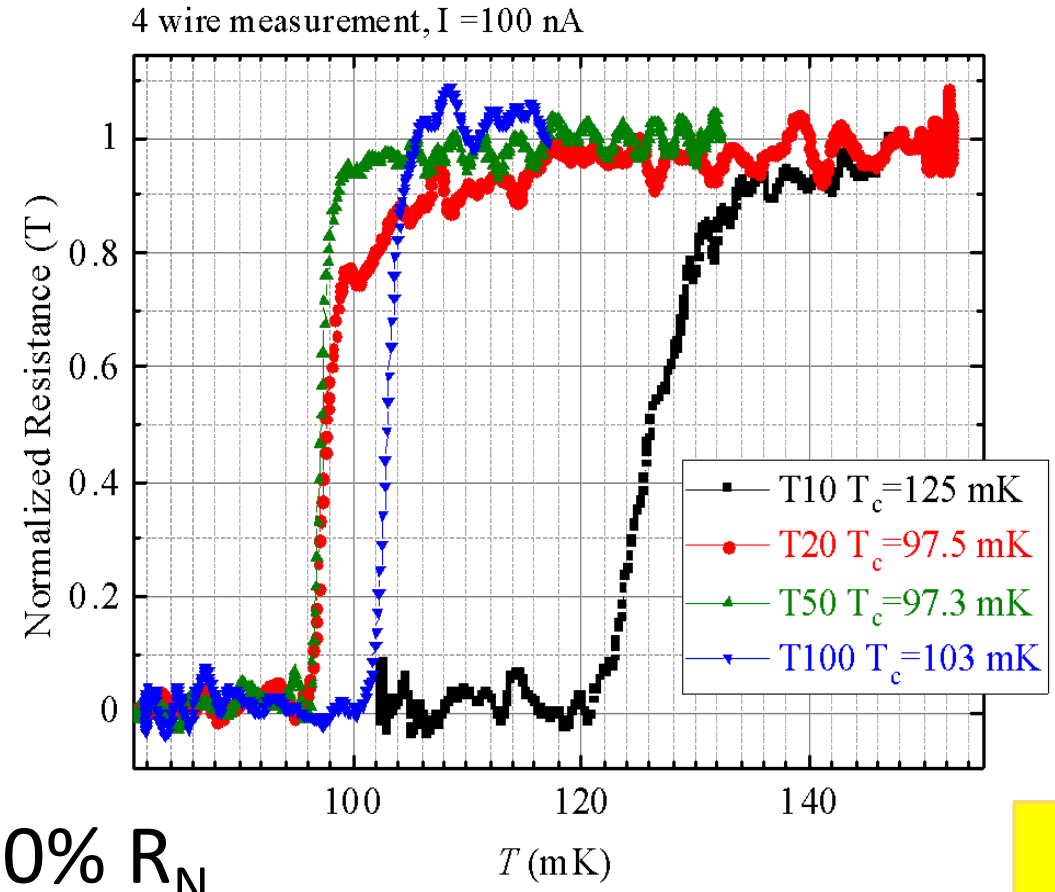

50 µm x 50 µm
T_c = 48 mK
Ti (12 nm)Au(30 nm)

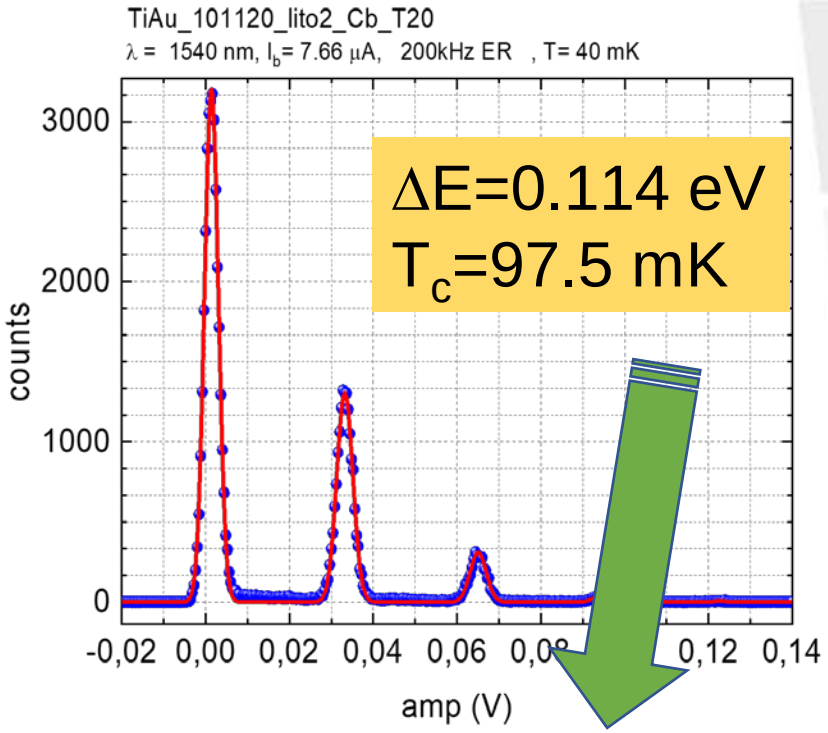

4 wire measurement, I = 100 nA
Normalized Resistance (Ω)
T (mK)
T10 T_c= 62 mK
T20 T_c= 47.5 mK
T50 T_c= 47.6 mK
T100 T_c= 58 mK


amplitude (mV)
time (µs)
n=1
n=2
n=3
$\tau_{electrical}$= 0.08 µs
τ_{etf}= 47 µs


TiAu Lito1 091120 CbT50
I_b=5.8 uA
T=30mK
Wiener 10th order
counts
amp (mV)
λ = 1540 nm
ΔE= 0.16eV
μ = 0.53
1
2
3
ΔE=0.16 eV
T_c=47.6 mK

Lito2 T20 Best energy resolution





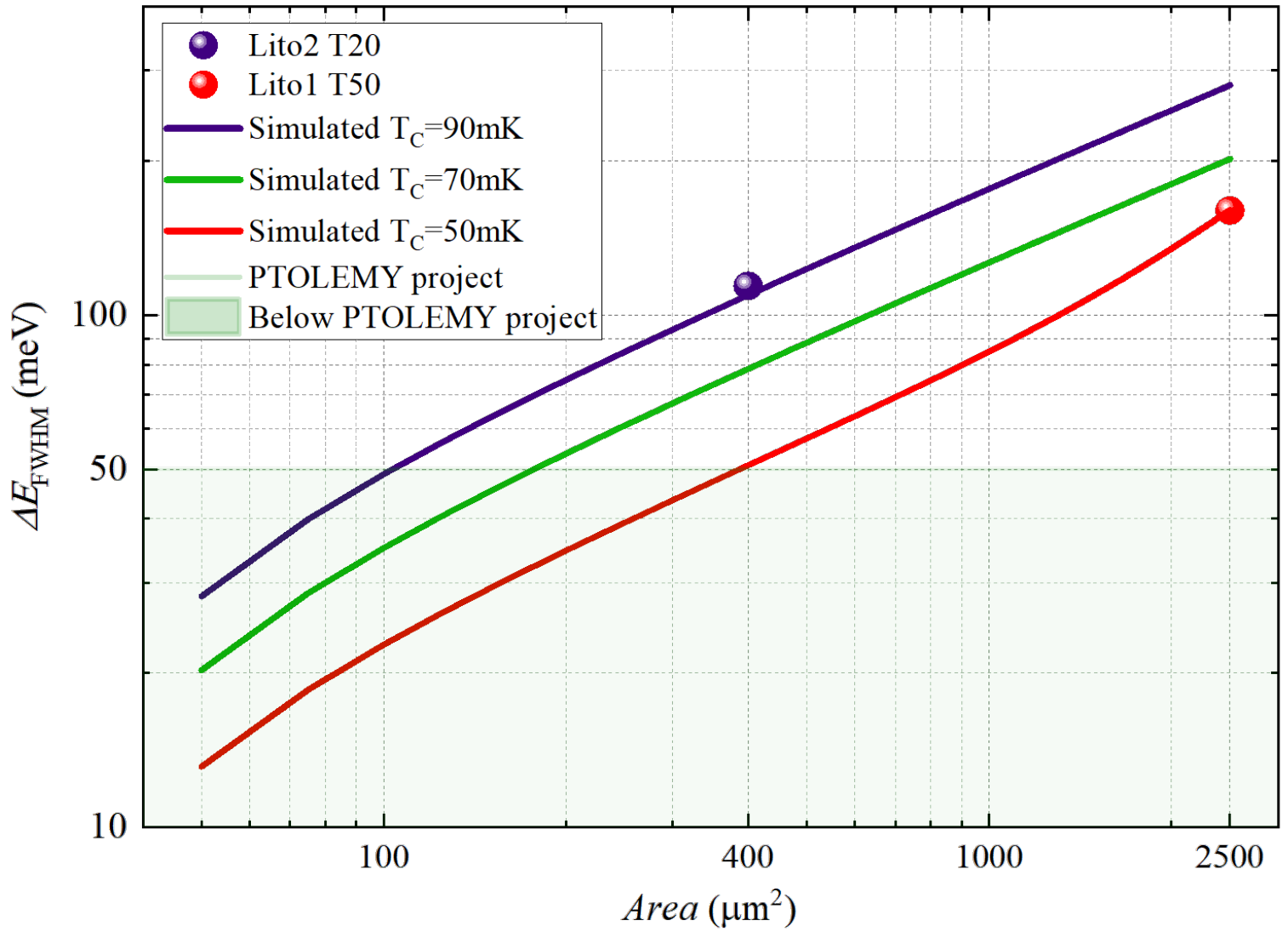
R_{TES}= 20% R_N

T_{bath}= 40 mK

λ = 1540 nm (0.8 eV)

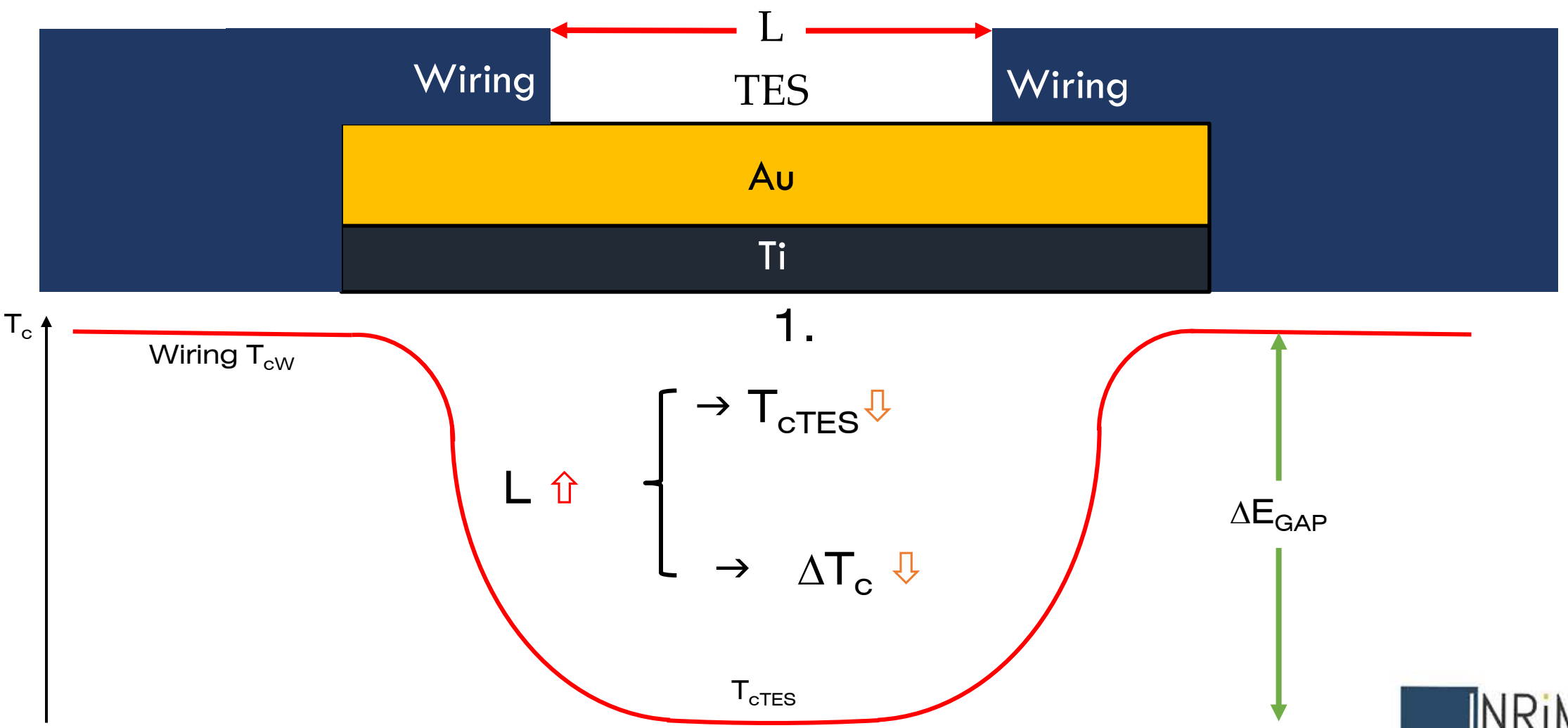
same result our APL13
but with an area
4 times greater

Simulation results



INRiM ISTITUTO NAZIONALE DI RICERCA METROLOGICA

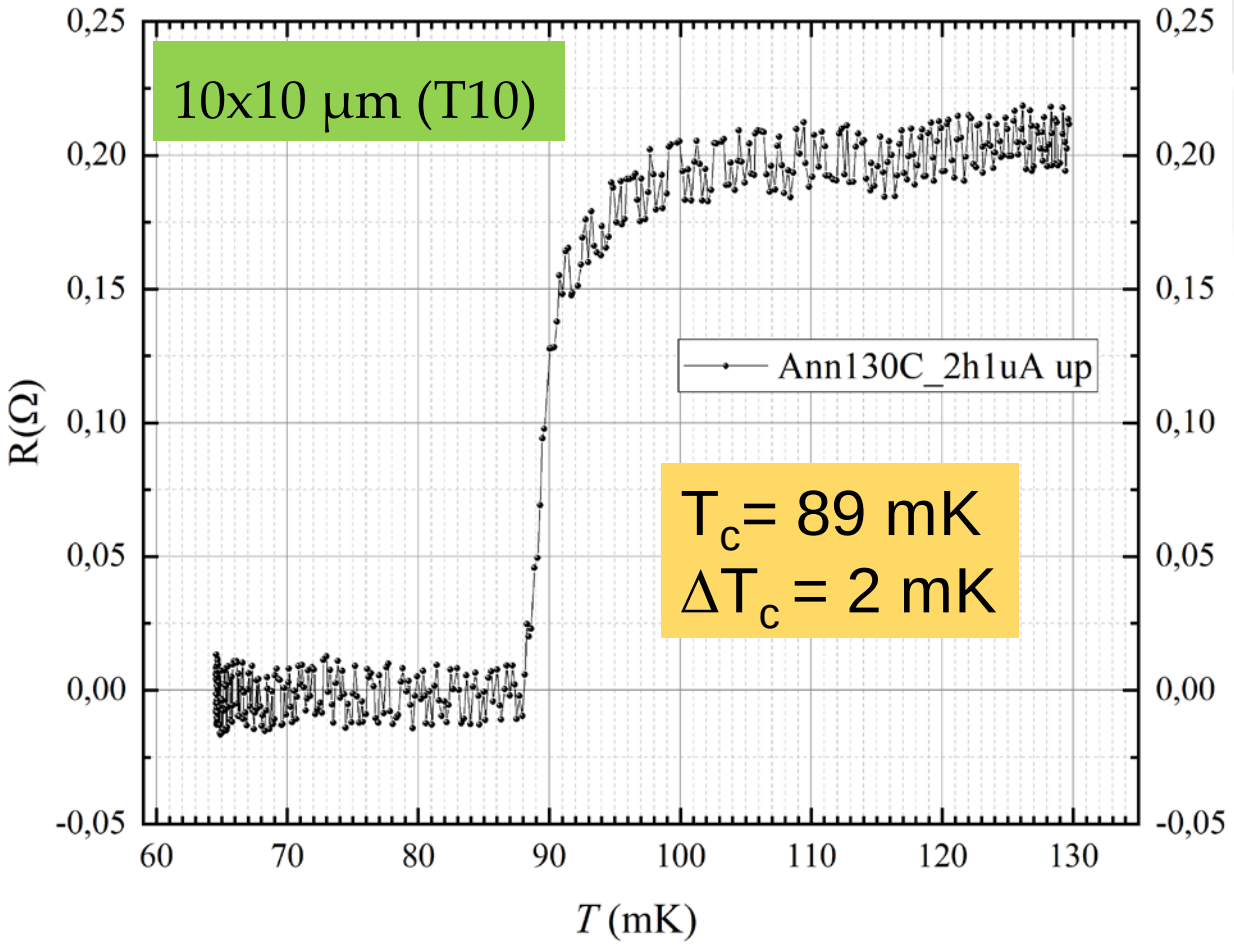
Proximity effect: wiring & TES size



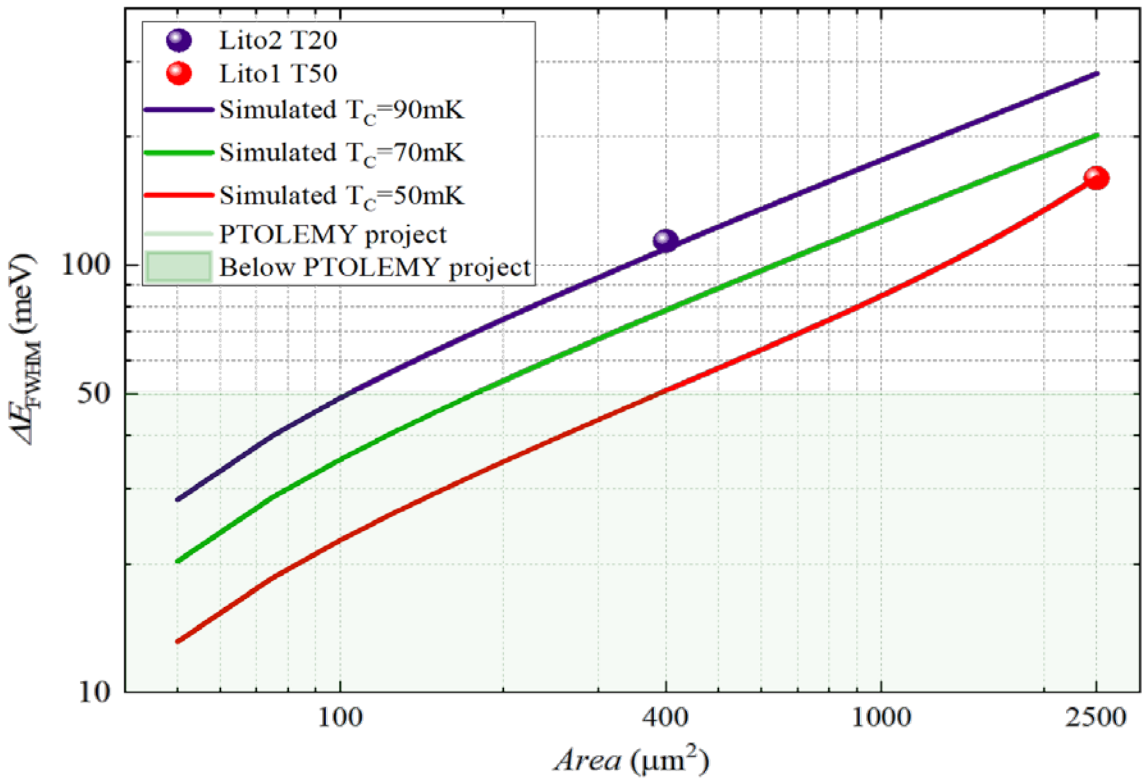
Ridder, M. L., et al. JLTP 199 (2020): 962-967.

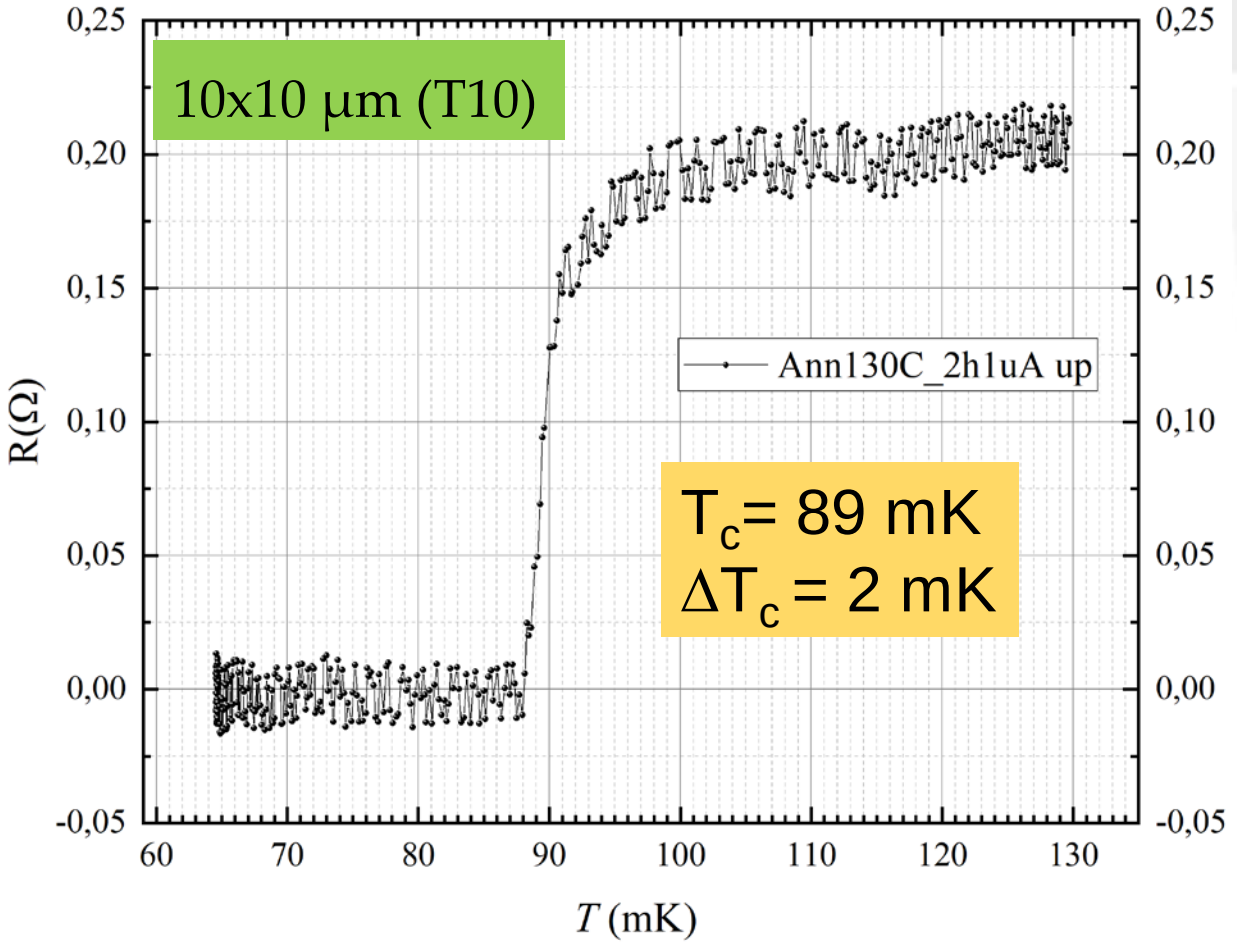
Sample annealed & Ti wiring

Sample name
PTL1 Ti: 15 nm Au: 20 nm Wiring: Ti After annealing process @ 130°C for 2 hours

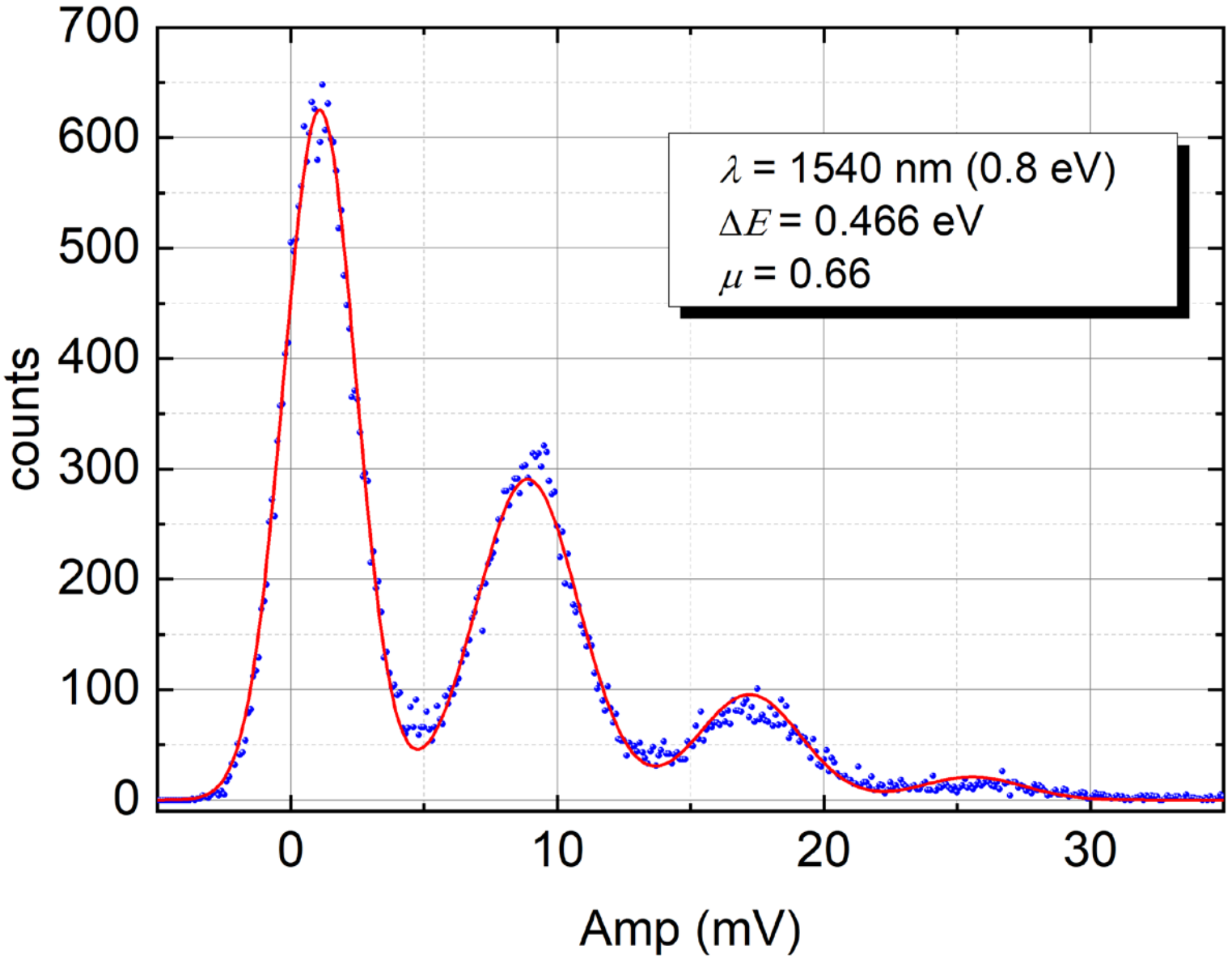


Sample annealed & Ti wiring





Sample annealed & Ti wiring



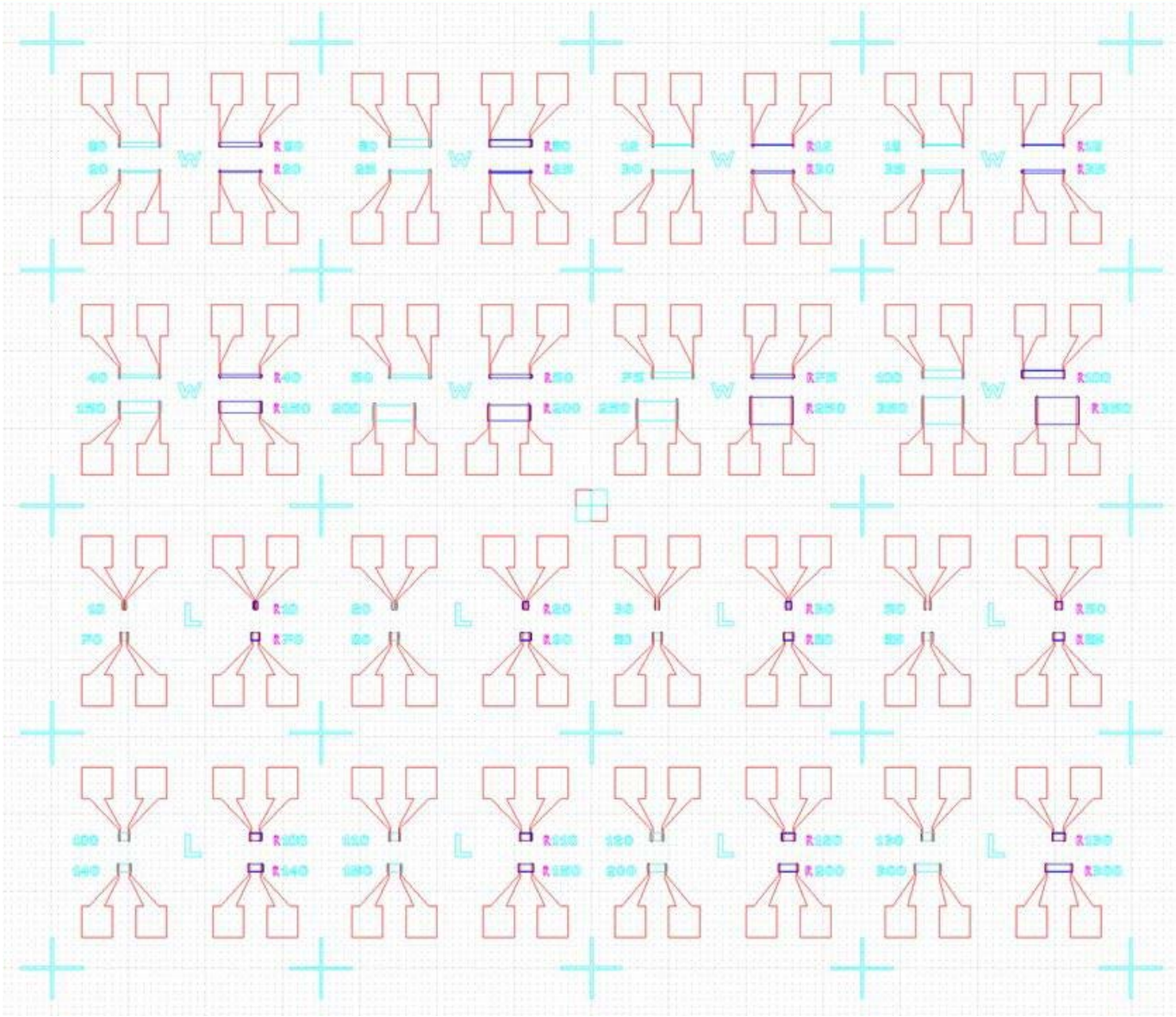
How to improve ?

⬇

Study on the effects of W, L, Wiring

INRiM ISTITUTO NAZIONALE DI RICERCA METROLOGICA

TES: W, L, ring, wiring effects



TESs: Ti(15 nm)Au(30 nm)

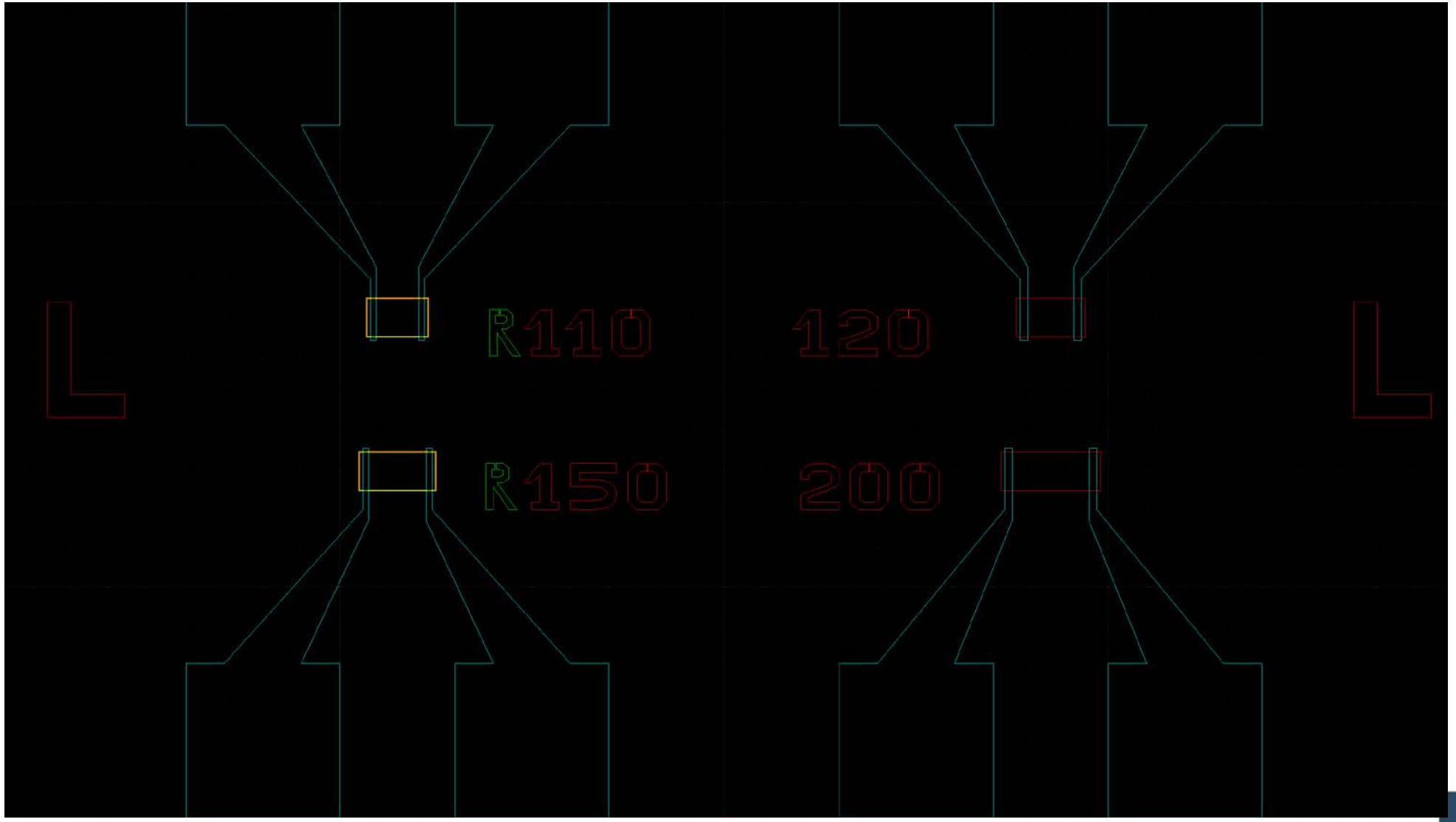
32 TES with const. W= 100 μm
(w/wo Au ring)

32 TES with const. L= 500 μm
(w/wo Au ring)

3 wiring materials:

Nb(9.2 K)
V (5 K)
Al (1.2 K)
Ti(0.4 K)

TES: W, L, ring, wiring effects



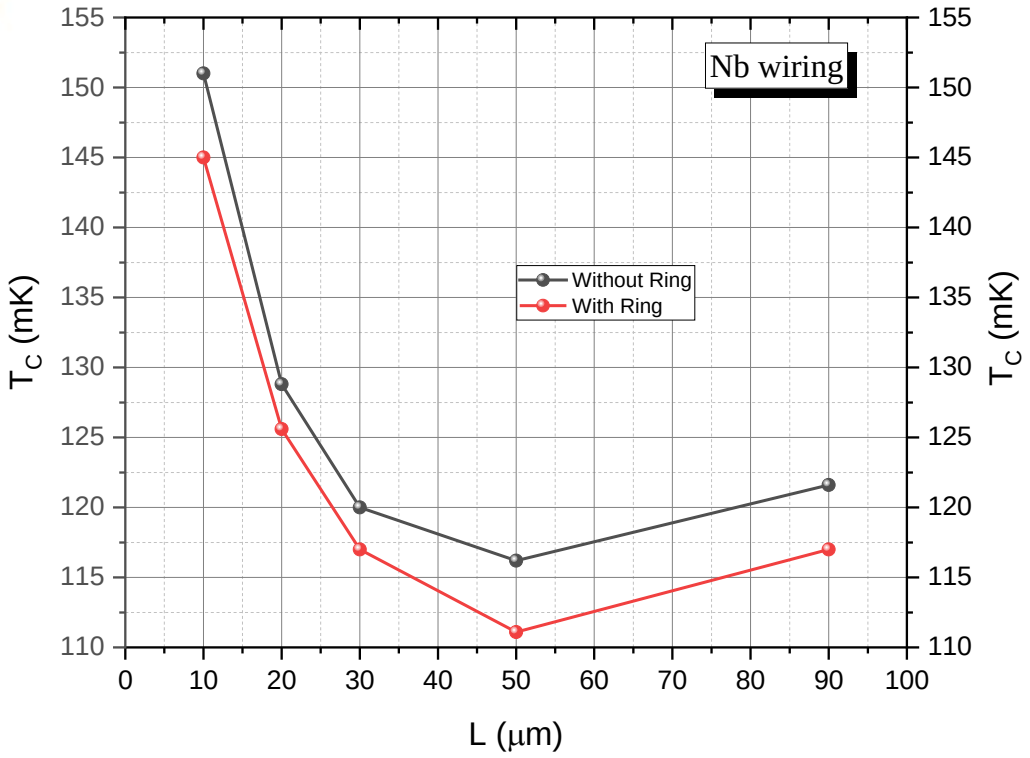
TES: W, L, ring, wiring effects

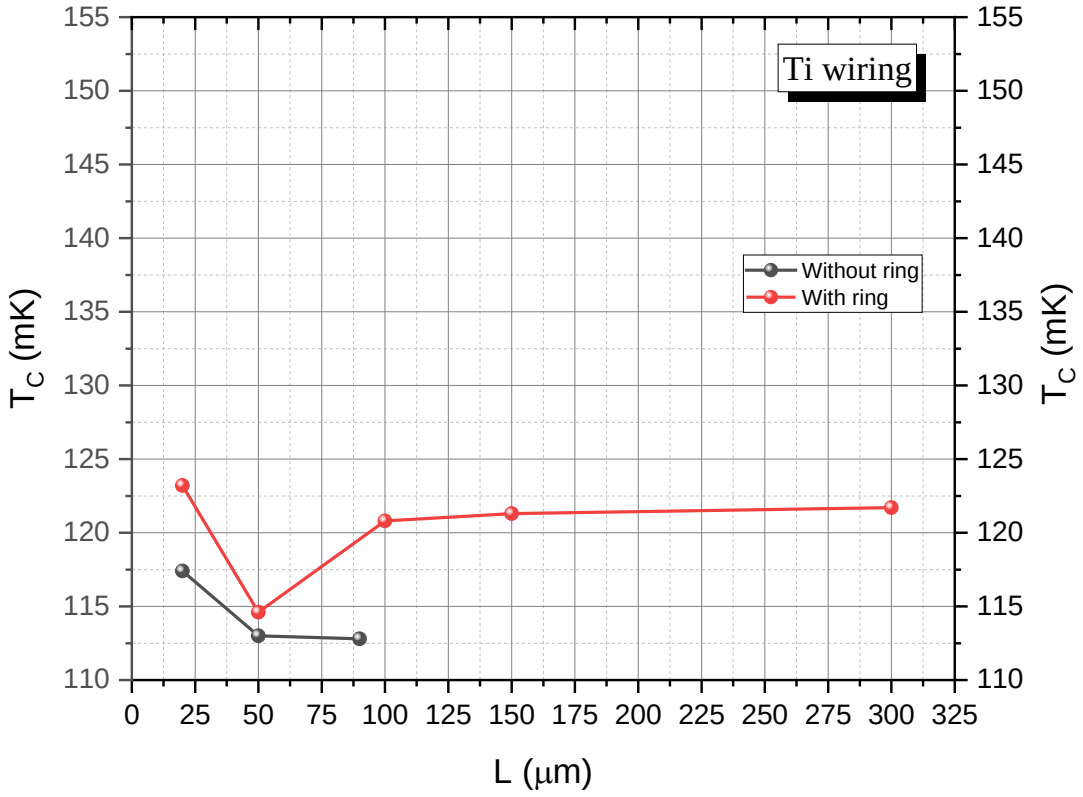
INRiM ISTITUTO NAZIONALE DI RICERCA METROLOGICA

TES: W, L, ring, wiring effects

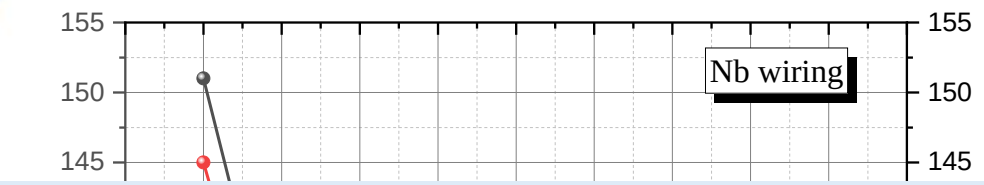
INRiM ISTITUTO NAZIONALE DI RICERCA METROLOGICA

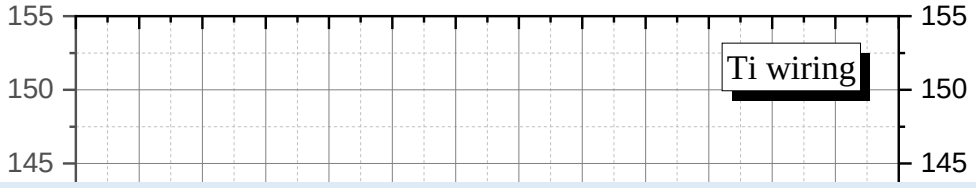
TES: L, ring, wiring effects

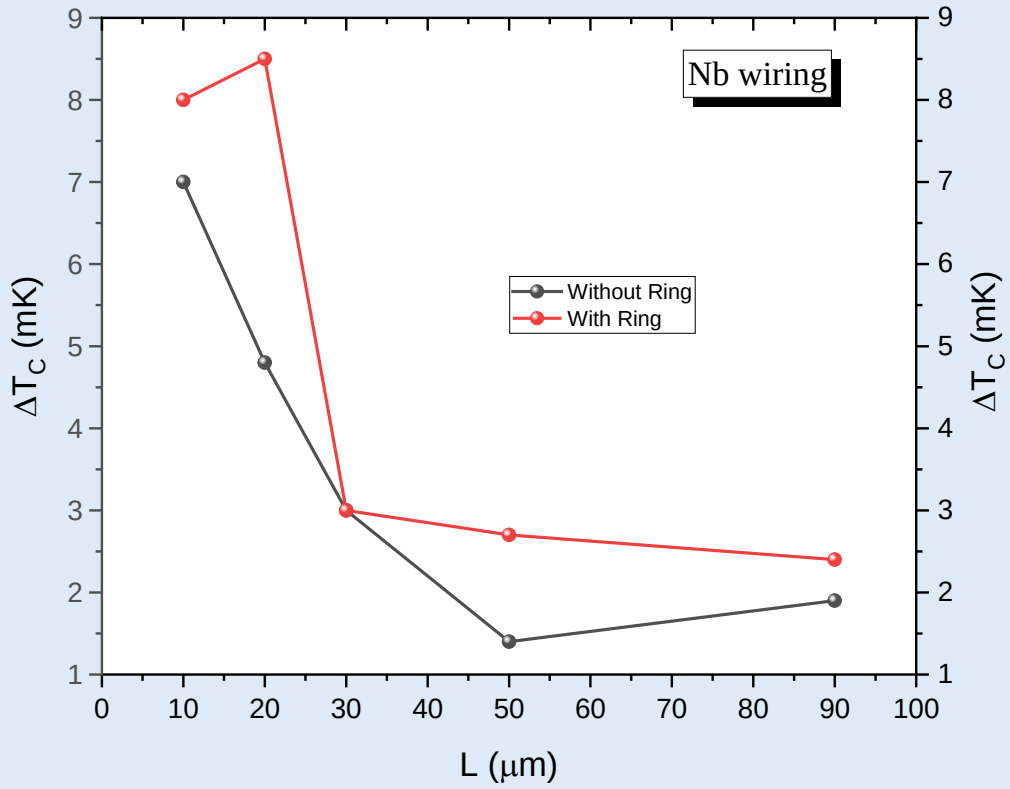


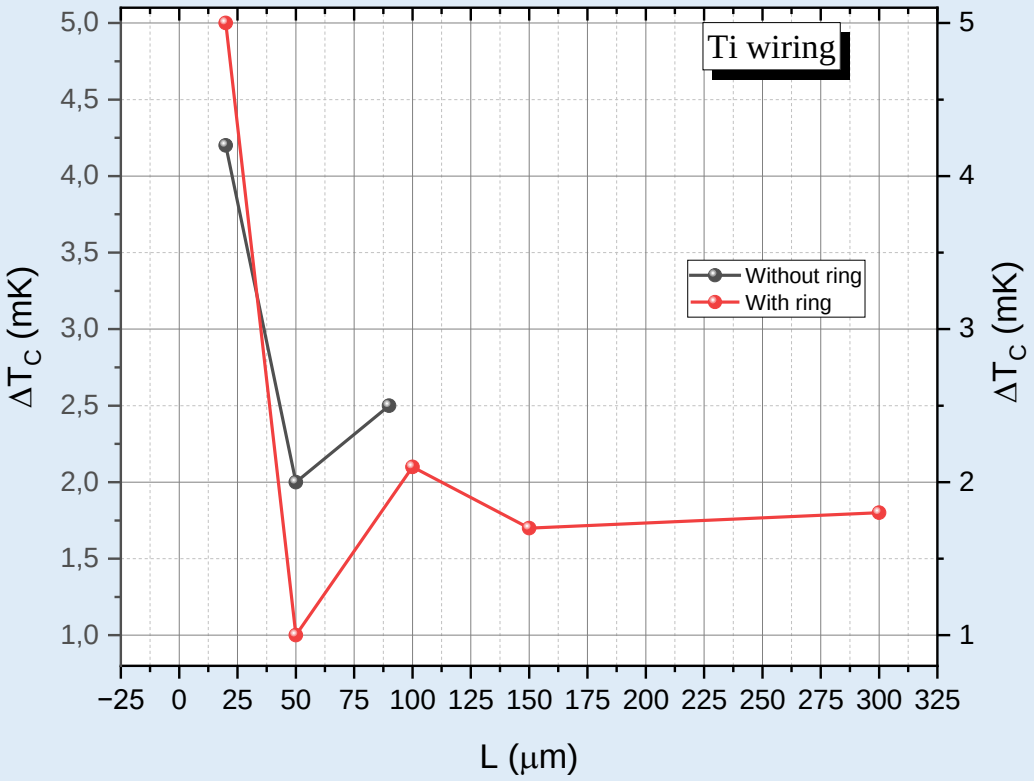


TES: L, ring, wiring effects

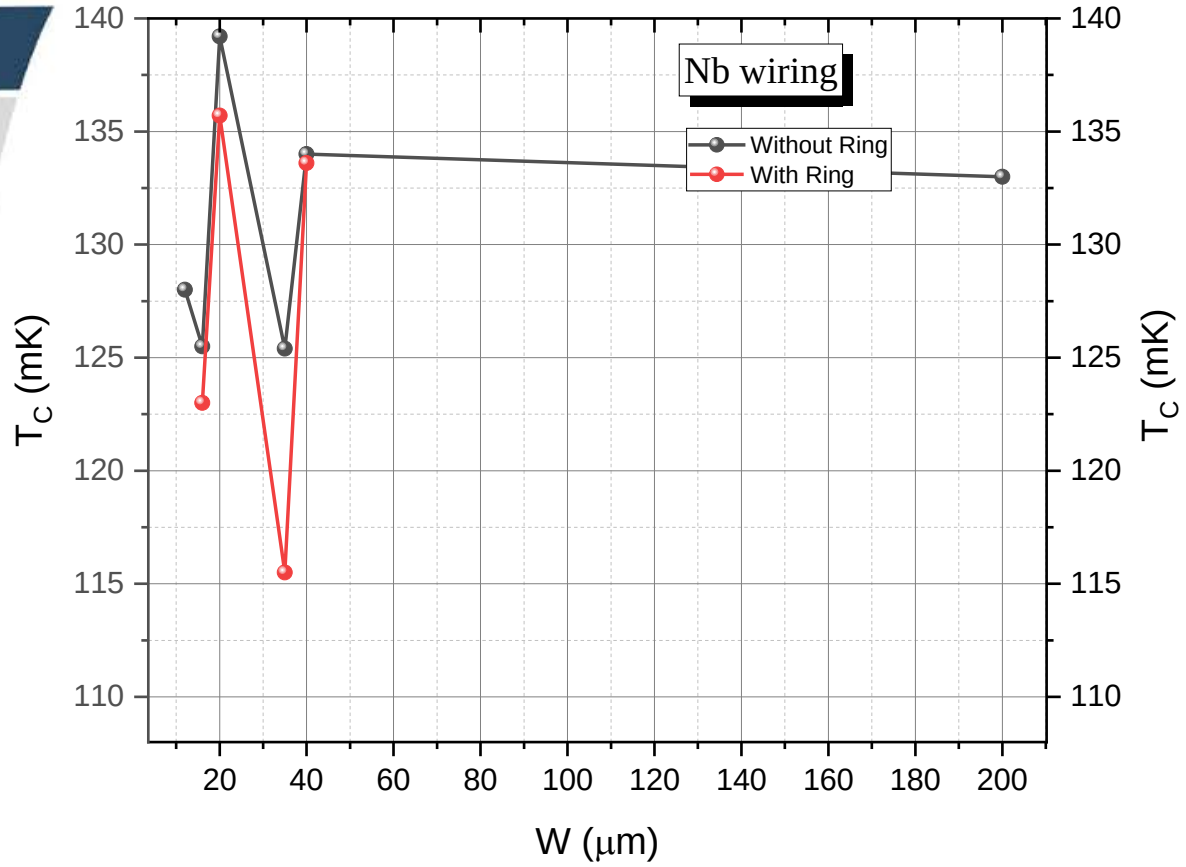


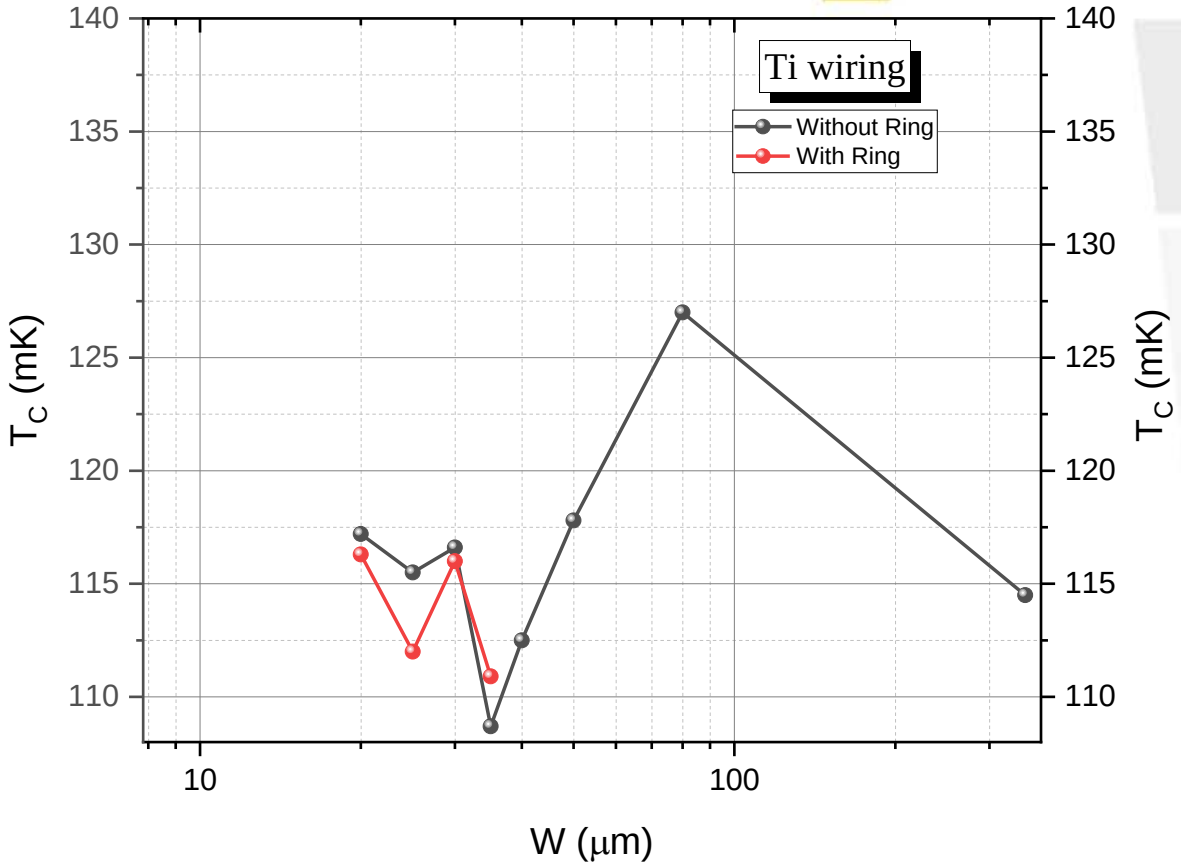




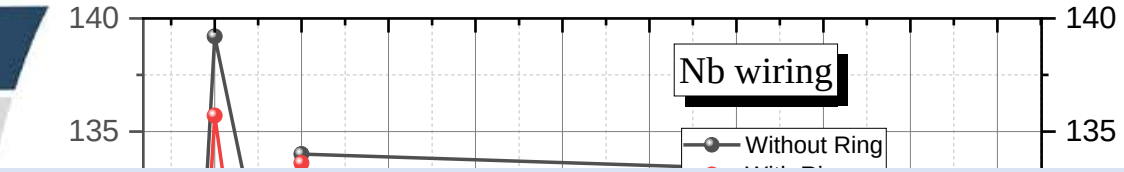


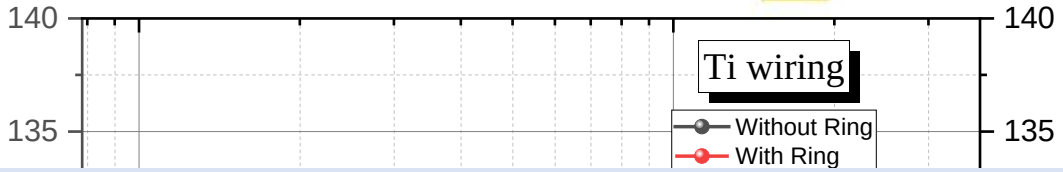
TES: W, ring, wiring effects

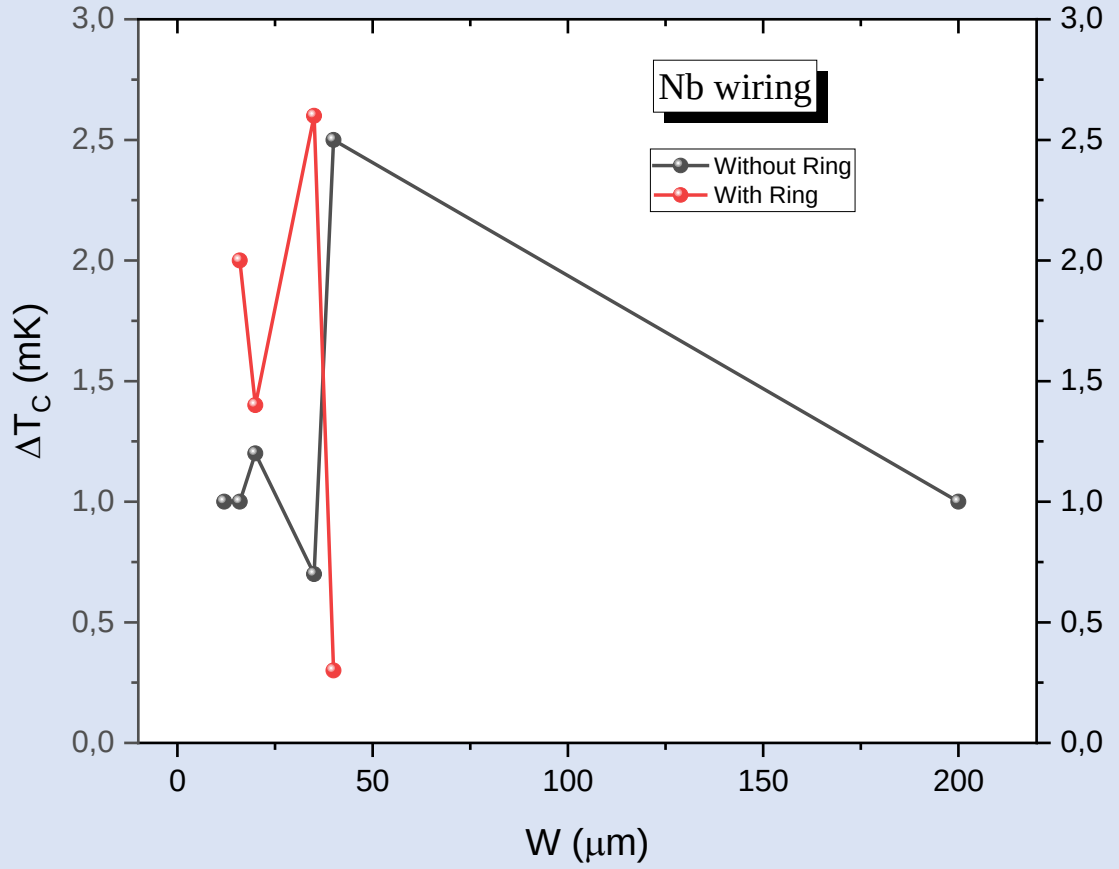


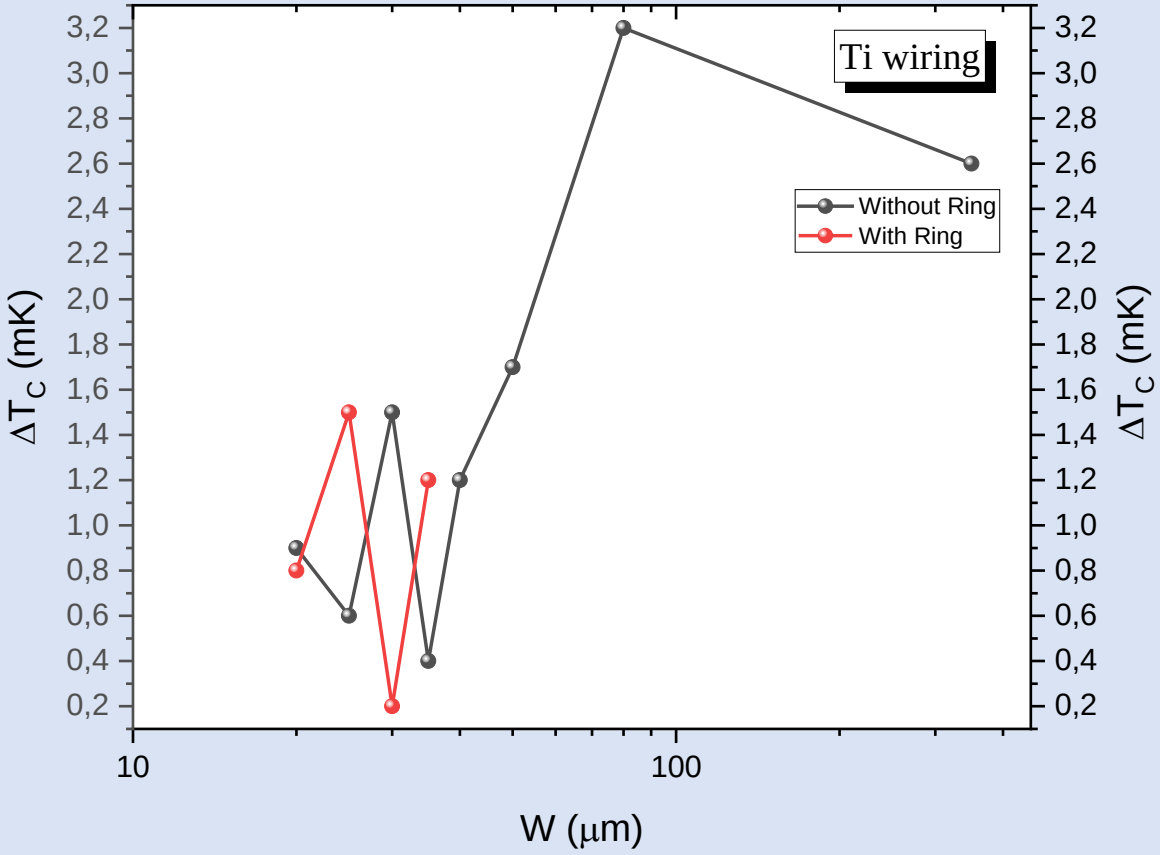


TES: W, ring, wiring effects









Conclusion

✓ PTOLEMY requirements for electron detection are very demanding

ΔE = 0.05 eV @10 eV (FWHM or σ ?)

Way to reduce the energy resolution:

✓ **Thickness reductions**: Best results up to now 👍

ΔE_e = 114 meV(σ =48 meV) (@ Tc~ 90 mK T20

✓ **Annealing**: Reduction of Tc and sharp transition 👍

✓ **Wiring material**: Nb and Ti tested, **Ti** 👎 not suitable to obtain excellent energy resolution

✓ **L, W and ring**: L strong effect, W and rings small effects, analysis to be completed

INRiM ISTITUTO NAZIONALE DI RICERCA METROLOGICA

Next steps

- ✓ **Wiring material**: test with Al and V
- ✓ **L, W and ring**: to be completed
- ✓ Design and fabricate **100 μm x 100 μm TES** with a **ground plane** around it

Next steps

- ✓ **Wiring material**: test with Al and V
- ✓ **L, W and ring**: to be completed
- ✓ Design and fabricate **100 μm x 100 μm TES** with a **ground plane** around it
- ✓ Mount the **TES inside a " mozzarella in carrozza"** CNT e-gun….

INRiM ISTITUTO NAZIONALE DI RICERCA METROLOGICA

Next steps

- ✓ **Wiring material**: test with Al and V
- ✓ **L, W and ring**: to be completed
- ✓ Design and fabricate **100 μm x 100 μm TES** with a **ground plane** around it
- ✓ Mount the **TES inside a " mozzarella in carrozza"** CNT e-gun….and taste it!!

INRiM ISTITUTO NAZIONALE DI RICERCA METROLOGICA