NEWS - WP7

Advanced superconducting techniques for particle detectors

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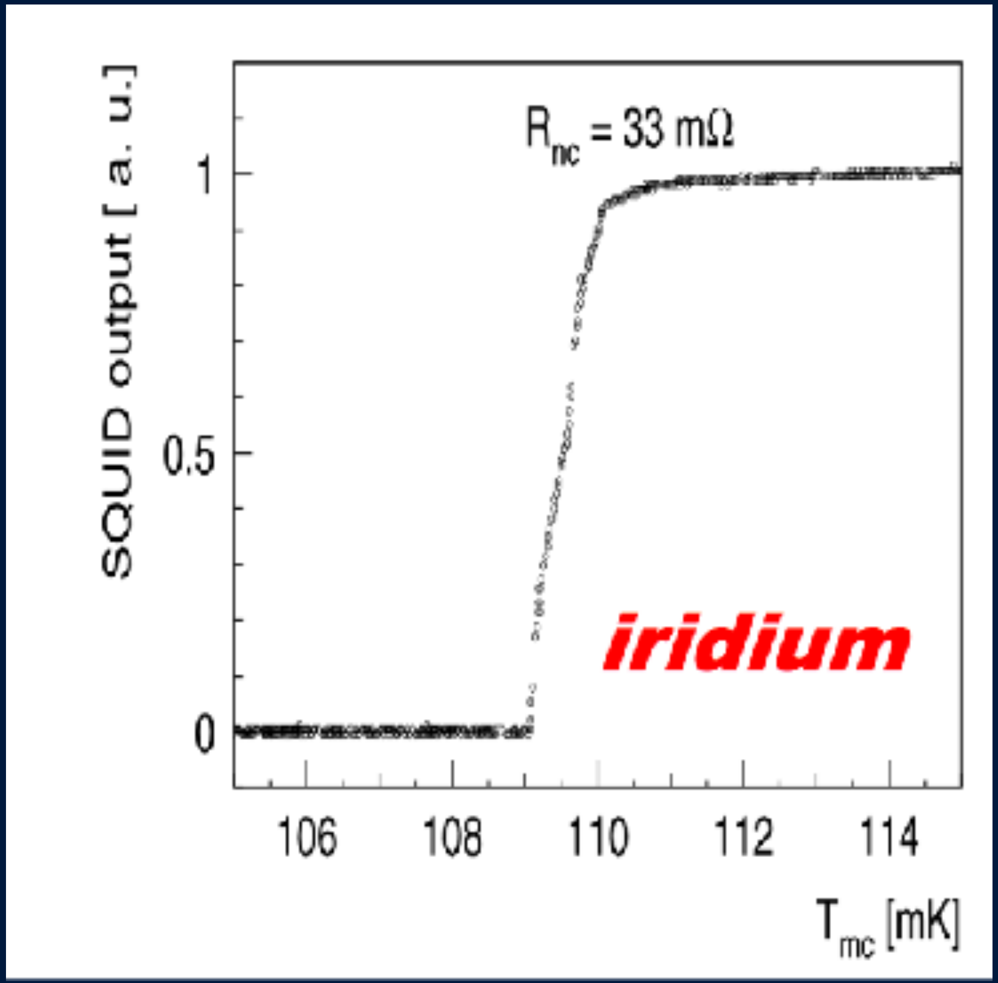
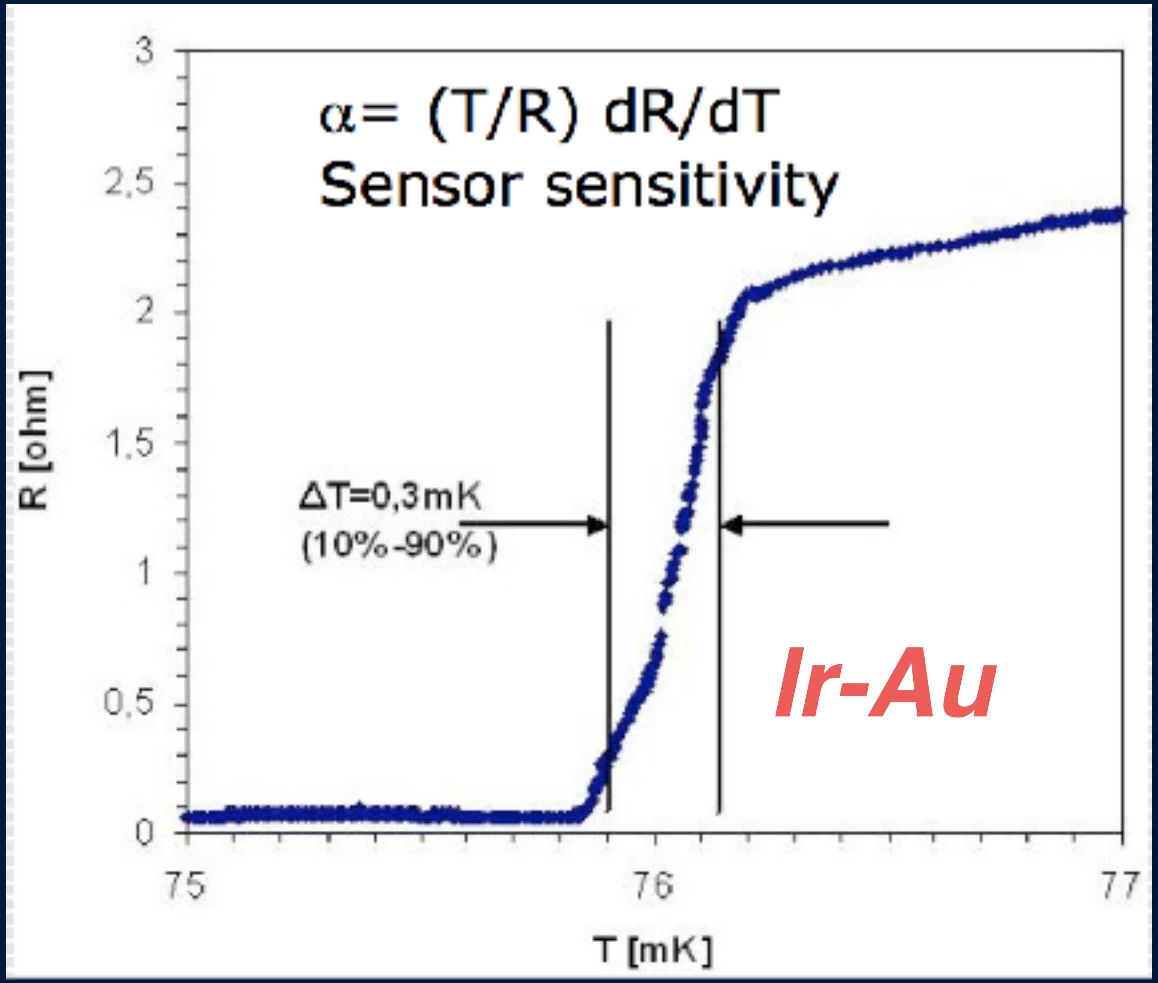
University of Genova

How single photonTES detector works

snapshot from LTD-10 conference, Genova, 2003. ltd-10.ge.infn.it

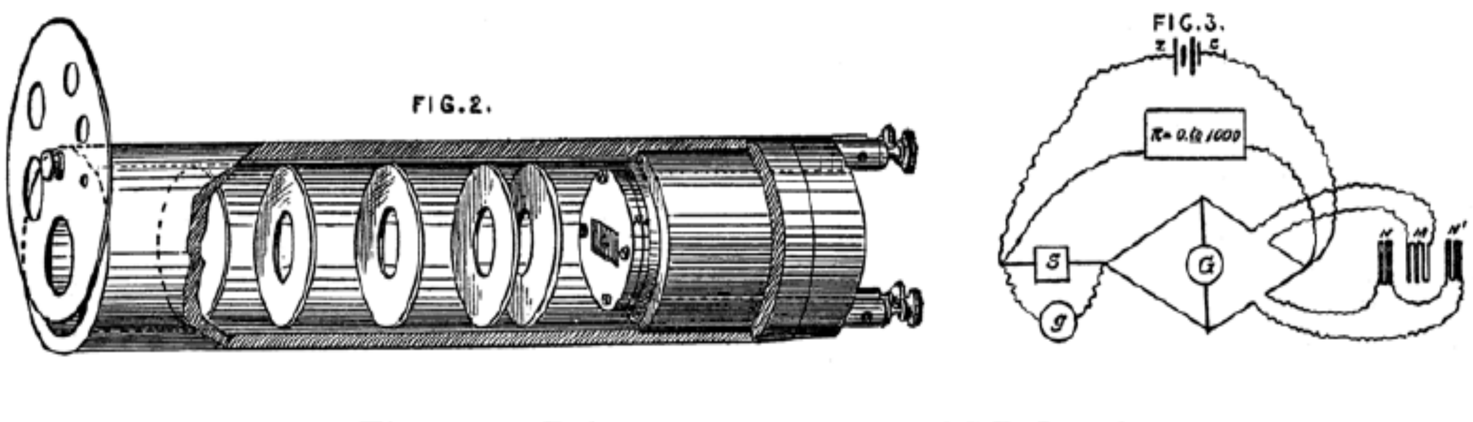
High quality film with steep superconducting to normal transition

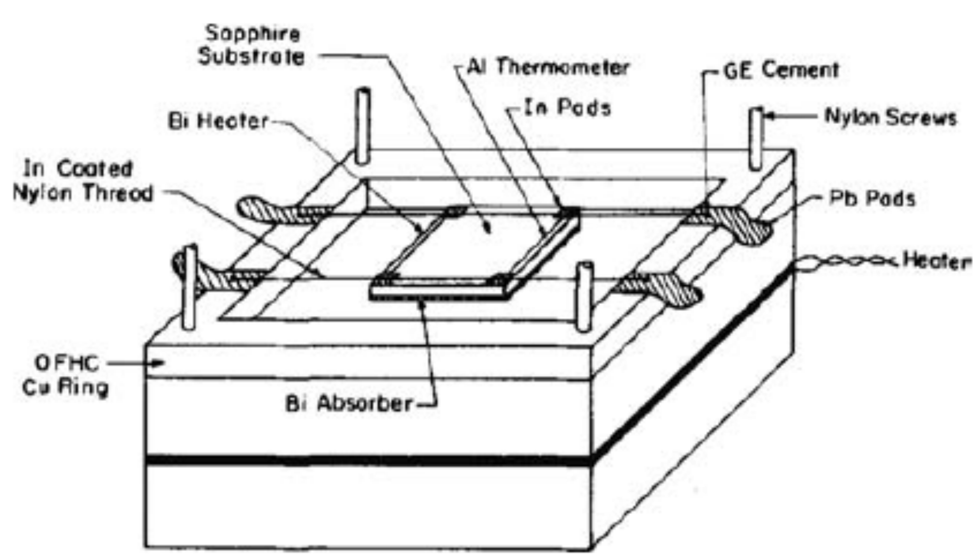




History

S. Langley, "The Bolometer," *Nature*, vol. 25, p. 14, 1881.





Clarcke et al. 1977
NEP $10^{-13} – 10^{-12}$ W/Hz

The Effect of Alpha-particles on a Superconductor*

D. H. Andrews, R. D. Fowler and M. C. Williams
Chemistry Department, The Johns Hopkins University, Baltimore, Maryland
May 9, 1949

SUPERCONDUCTING bolometers have been bombarded with alpha-particles from a polonium source, and it is found that countable electrical pulses are produced, one for each particle impact. The bolometer used in the experiment reported here was made of a strip of columbium nitride, approximately $3.5 \times 0.4 \times 0.006$ mm, mounted with bakelite lacquer on a copper base, and maintained at the operating temperature of 15.5°K in a cryostat, as previously described;[1] its time constant was about 10^{-3} sec.

To provide a mounting for the polonium source, a glass tube *ca.* 30 cm long and 3 cm diameter was sealed to the cryostat nose facing the bolometer. The source could be slid back and forth in this tube, placing it at distances from the bolometer ranging from 2 cm to 20 cm.

The source consisted of polonium on a nickel disk 1 cm diameter, attached to the face of a steel cylinder. A vacuum of better than 10^{-6} cm was maintained in the source tube and around the bolometer by a charcoal trap at liquid nitrogen temperature aided by the many contiguous surfaces at 15°K, so that the α-particles traveled from the source to the bolometer with no significant loss

In Italy ….

A Superconducting Bolometer as a High Sensitivity Detector for Molecular Beams

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Gruppo Nazionale di Struttura della Materia del C.N.R.

(Z. Naturforsch. **24 a**, 1850—1851 [1969]; received 31 July 1969)

The construction, operation and calibration of a superconducting bolometer is reported. Operated as a molecular beam detector the bolometer has, for Argon, a maximum sensitivity of $7 \cdot 10^{8}$ molecules sec^{-1} corresponding to a N.E.P. of $3 \cdot 10^{-13}$ Watt $Hz^{-\frac{1}{2}}$.

The use of a liquid He cooled Ge infrared detector as a high sensitivity bolometer detector for molecular beams has been recently reported [1] and its usefulness in molecular scattering experiments has been shown [2,3].

The present note is intended to report on the construction, operation and calibration of a superconducting bolometer which, operated as a molecular beam detector, showed an order of magnitude improvement in signal to noise ratio compared with the previously used Ge bolometer.

A superconducting bolometer has been reported, almost ten years ago, by MARTIN and BLOOR [4] which showed a noise equivalent power (N.E.P.) of about $3 \cdot 10^{-12}$ Watt $Hz^{-\frac{1}{2}}$ (reflection coefficient $\alpha = 0.1$) with a time constant of about $50 \cdot 10^{-3}$ sec. The sensitive element was an evaporated tin film maintained at a fixed temperature, to within 10^{-5} °K, in its superconducting transition (around 3.7 °K). In this condition the film has a very large temperature coefficient of resistance that can be used to transduce a chopped power imput to a voltage output which may then be integrated with standard techniques.

Up to the present time the superconducting bolometer has not been widely adopted in infrared spectroscopy for two main reasons. The first is the difficulty of thermo-regulating the sensitive element within 10^{-5} °K, and the second is the extreme delicacy of its construction.

Taking into account that the N.E.P. of Martin and Bloor's bolometer was reported to be limited by the electronics available at that time, we undertook the development of a superconducting bolometer with the aim of solving the mechanical ruggedness problem by relaxing the requirement that the film, when operating, should be homogeneous in temperature.

Indeed the possibility of a superconducting thin film acting as a non isothermal bolometer is qualitatively quite obvious and has also been quantitatively discussed theoretically in the literature by FRANZEN [5].

A superconducting bolometer of the non isothermal kind has also been reported by V. A. KONOVODCHENKO et al. at the 11th Low Temperature Conference (St. Andrews 1968). With respect to this point it should be noted, however, that it is not clear whether or not a non isothermal bolometer can be operated only in the way described by FRANZEN [5]. Indeed the transition curves obtained by us (see Fig. 1) were of the kind expected for a non isothermal element. Two types of operations are then possible: namely in the region a or in the region b. Region b corresponds to the type described by Franzen. If sufficient thermal stability is available one can operate in region a which, in our opinion, corresponds to a different non isothermal kind of opera-

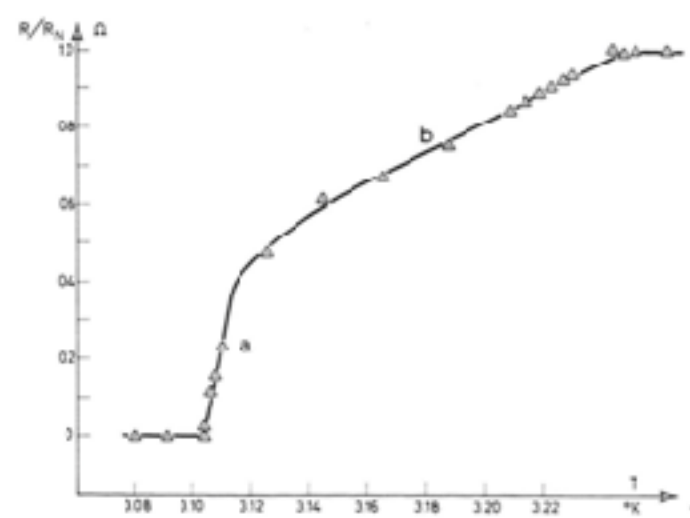


Fig. 1. Transition curve of a typical bolometer.

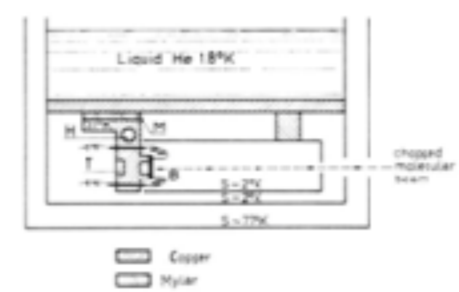
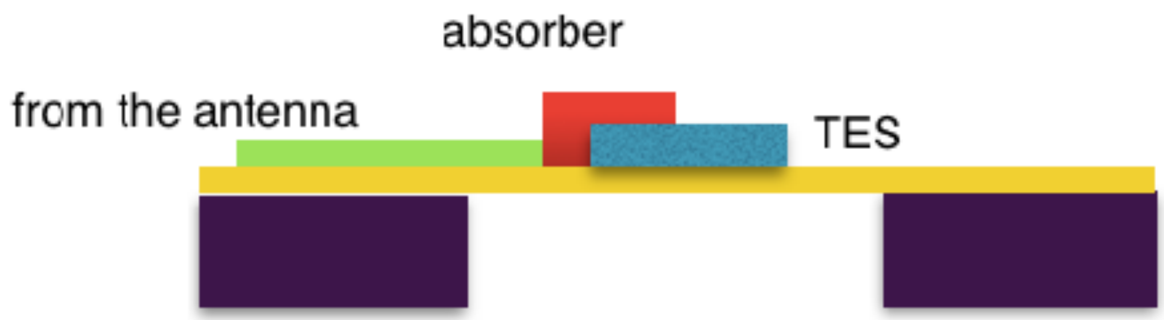


Fig. 2. Schematic experimental set-up.

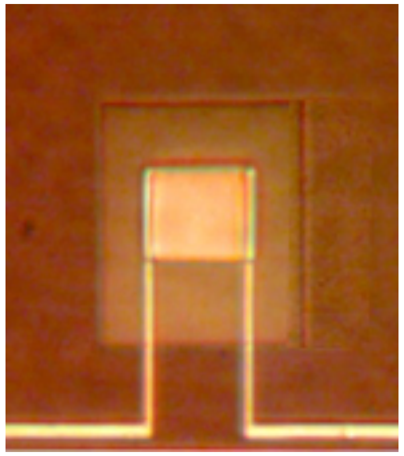
Reprint requests to Dr. G. SCOLES, Istituto di Fisica Sperimentale dell'Università di Genova, Viale Benedetto XV, 5, *I-16132 Genova*, Italy.

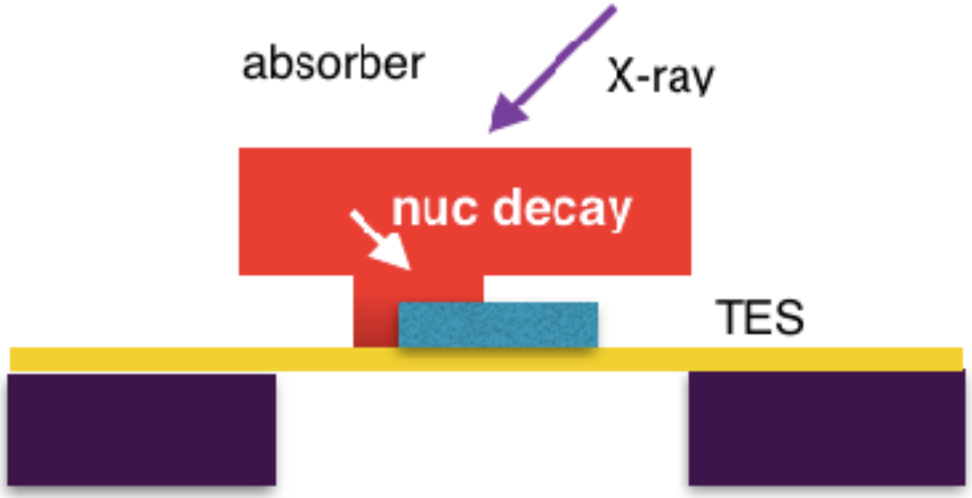
[1] M. CAVALLINI, G. GALLINARO, and G. SCOLES, Z. Naturforsch. **22 a**, 413 [1967].
[2] P. CANTINI, M. CAVALLINI, M. G. DONDI, and G. SCOLES, Phys. Letters **27 A**, 284 [1968].
[3] M. G. DONDI, G. SCOLES, F. TORELLO, and H. PAULY, J. Chem. Phys. **51**, 392 [1969].
[4] D. H. MARTIN and D. BLOOR, Cryogenics **1**, 159 [1961].
[5] W. FRANZEN, J. Opt. Soc. Am. **53**, 596 [1963].

Configurations

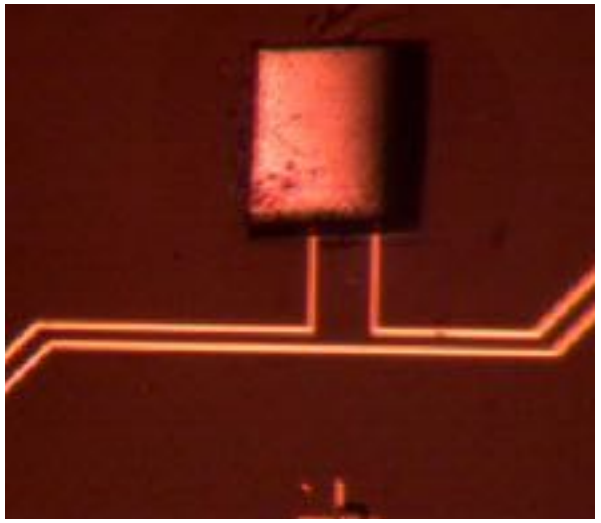


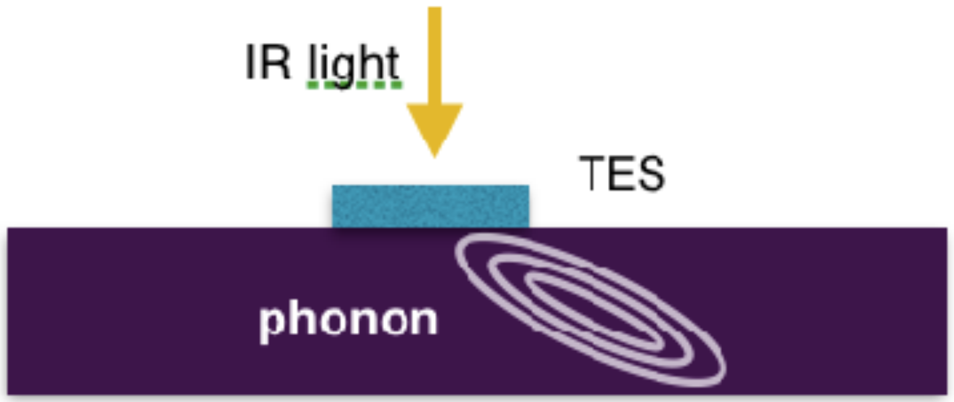
Simple Ir TES on suspended membrane



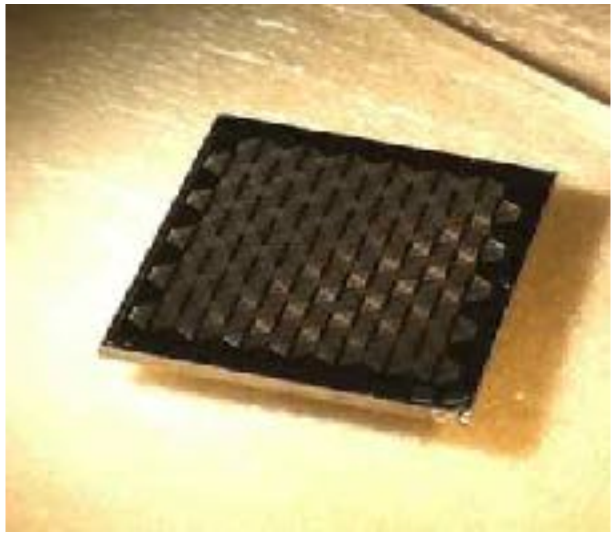


Re-Crystal TES microcalorimeter for Re-187 beta decay Presently changed to gold absorber for Ho-163 (ERC- HOLMES)



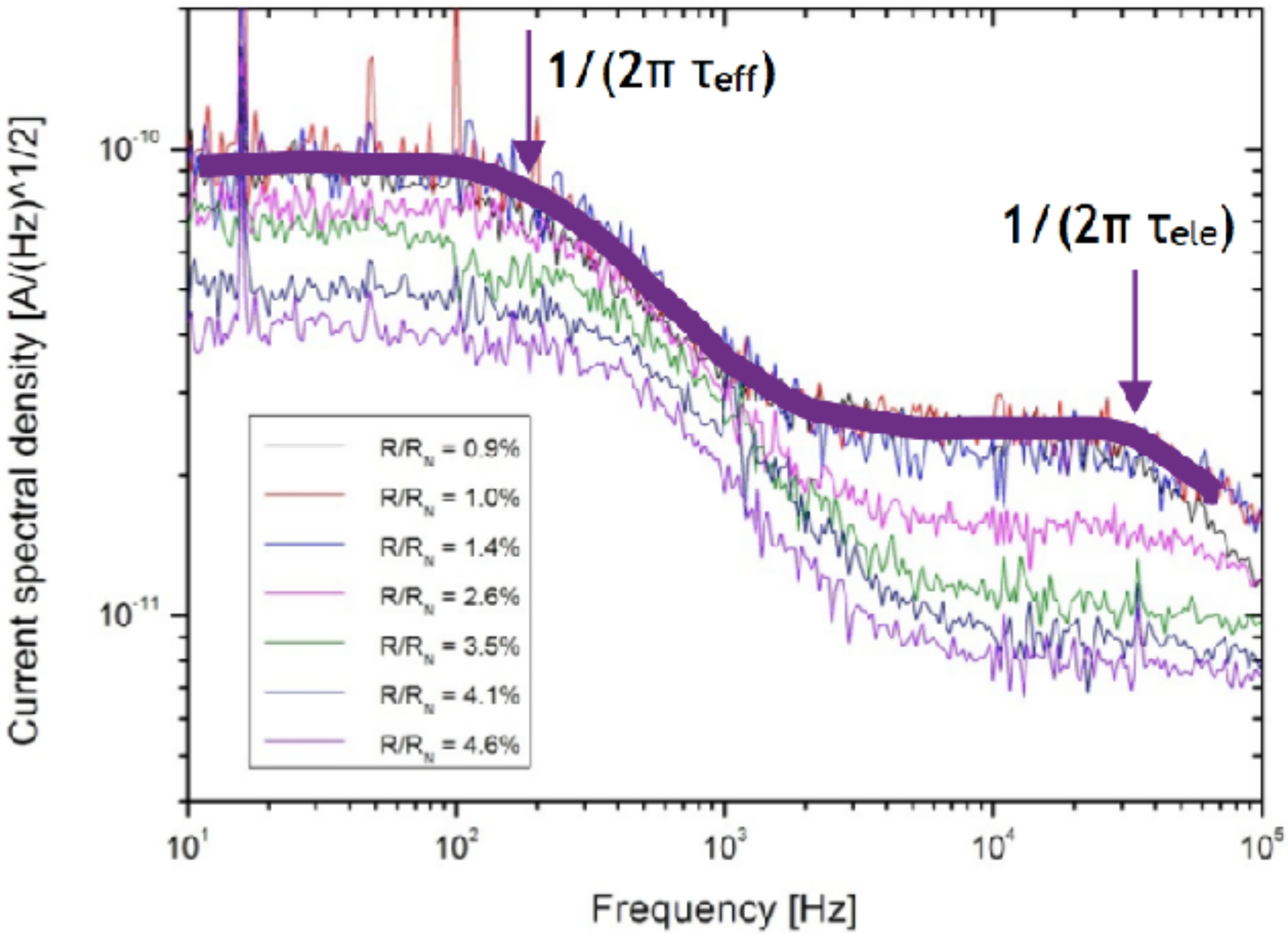


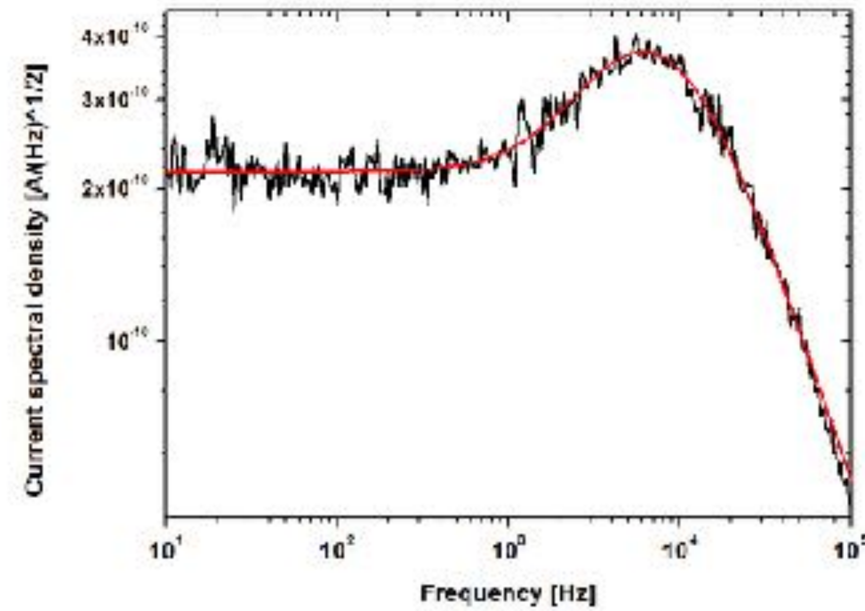
Anti coincidence Xray Space Telescope ATHENA



TES noise spectra

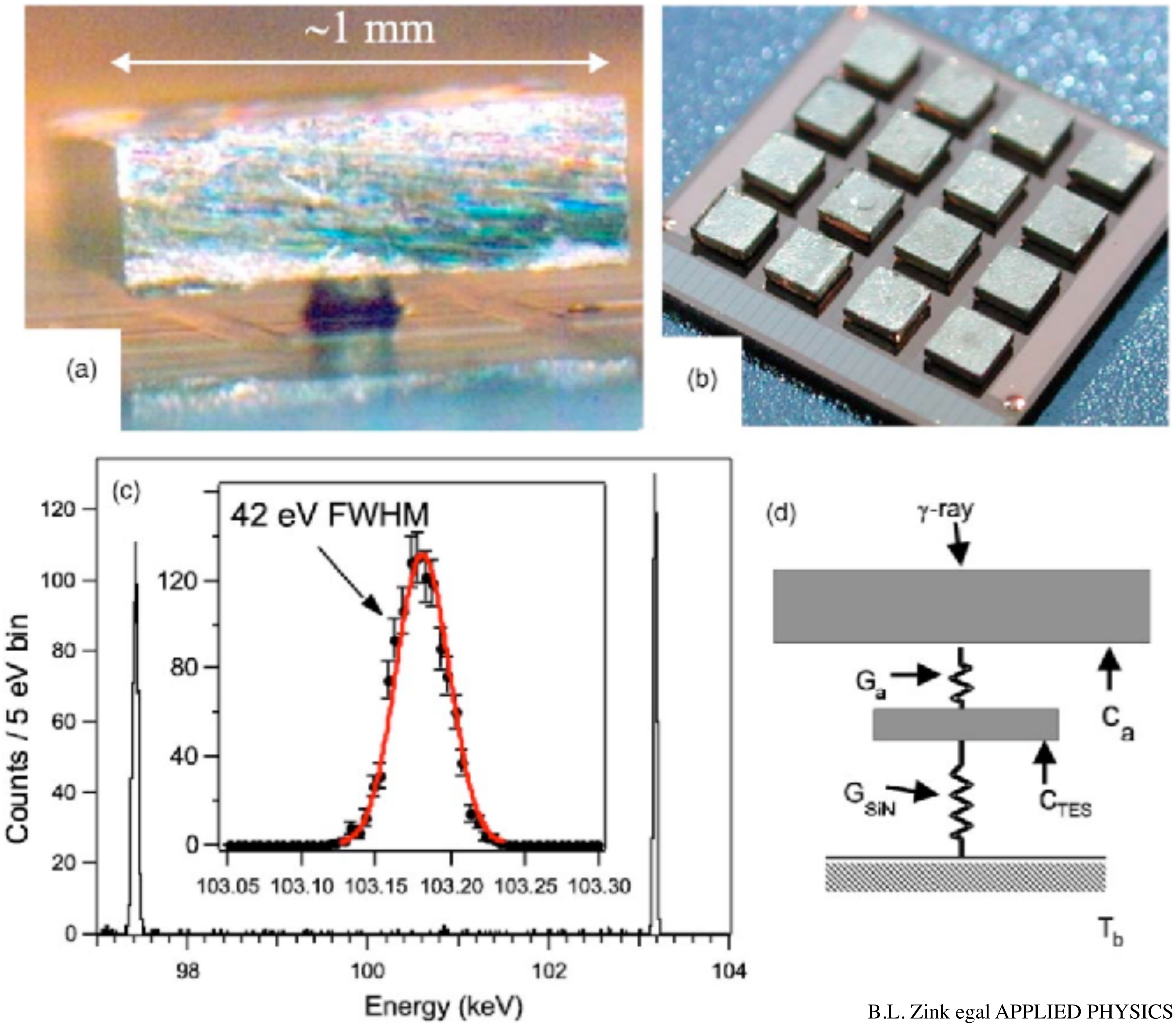
Ideal spectrum





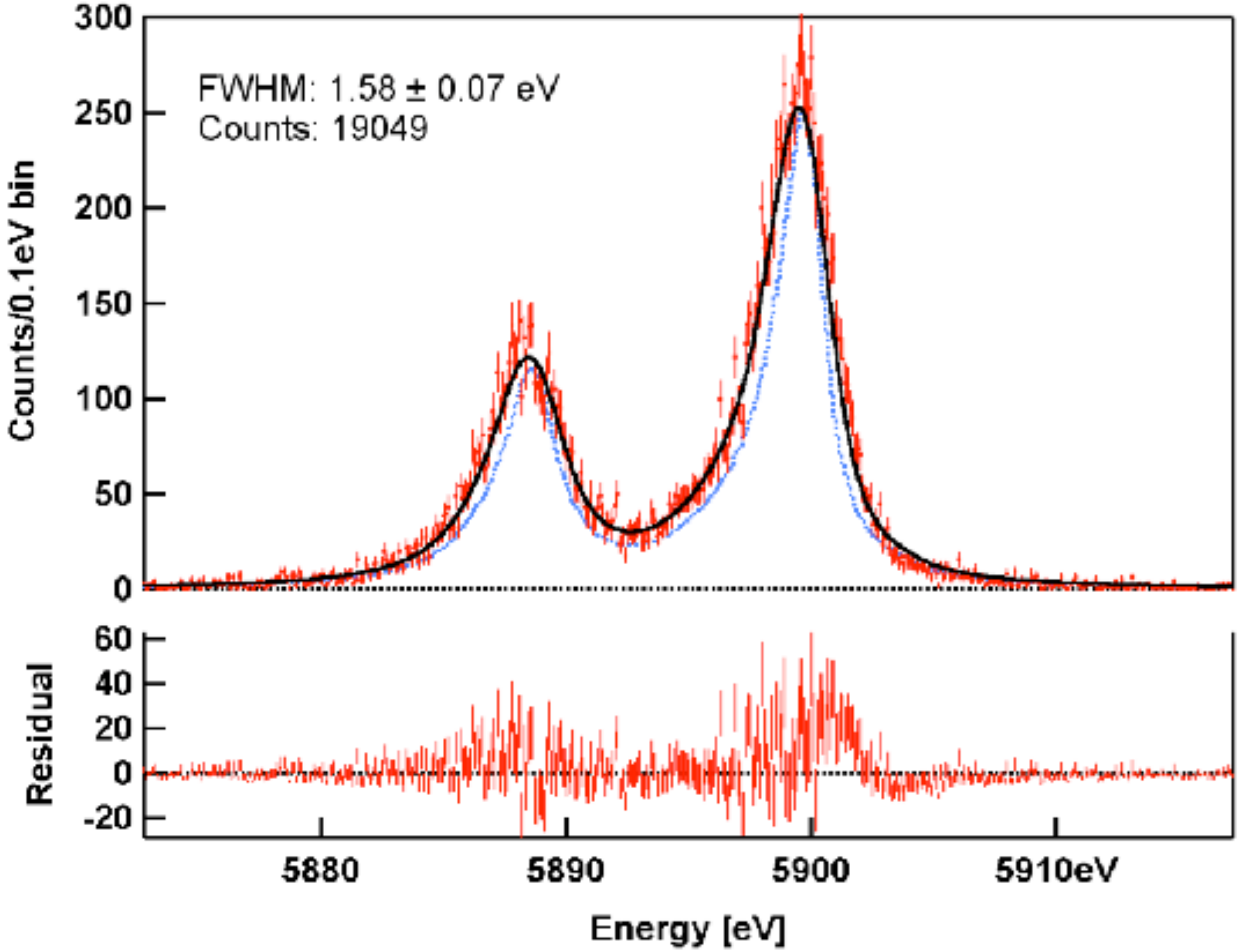
“Excess” noise spectrum

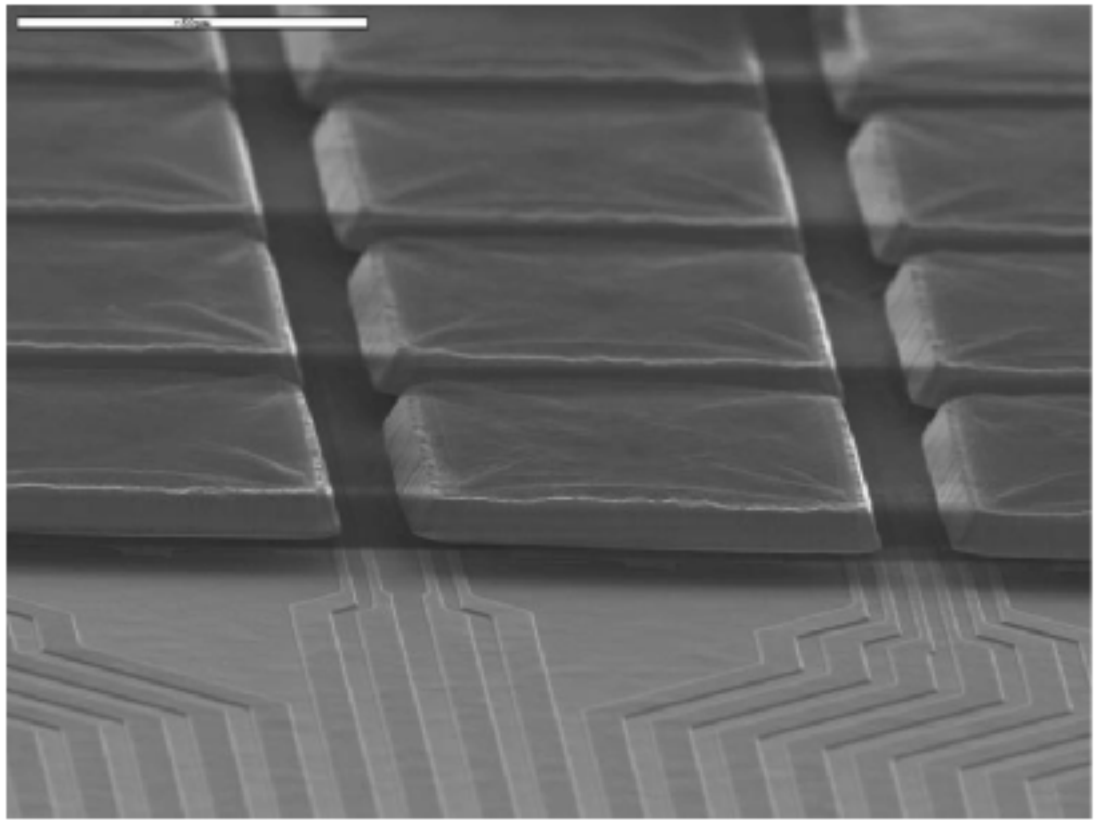
High Energy Photons



B.L. Zink egal APPLIED PHYSICS LETRS **89**, 124101 2006

Soft X-ray Photons



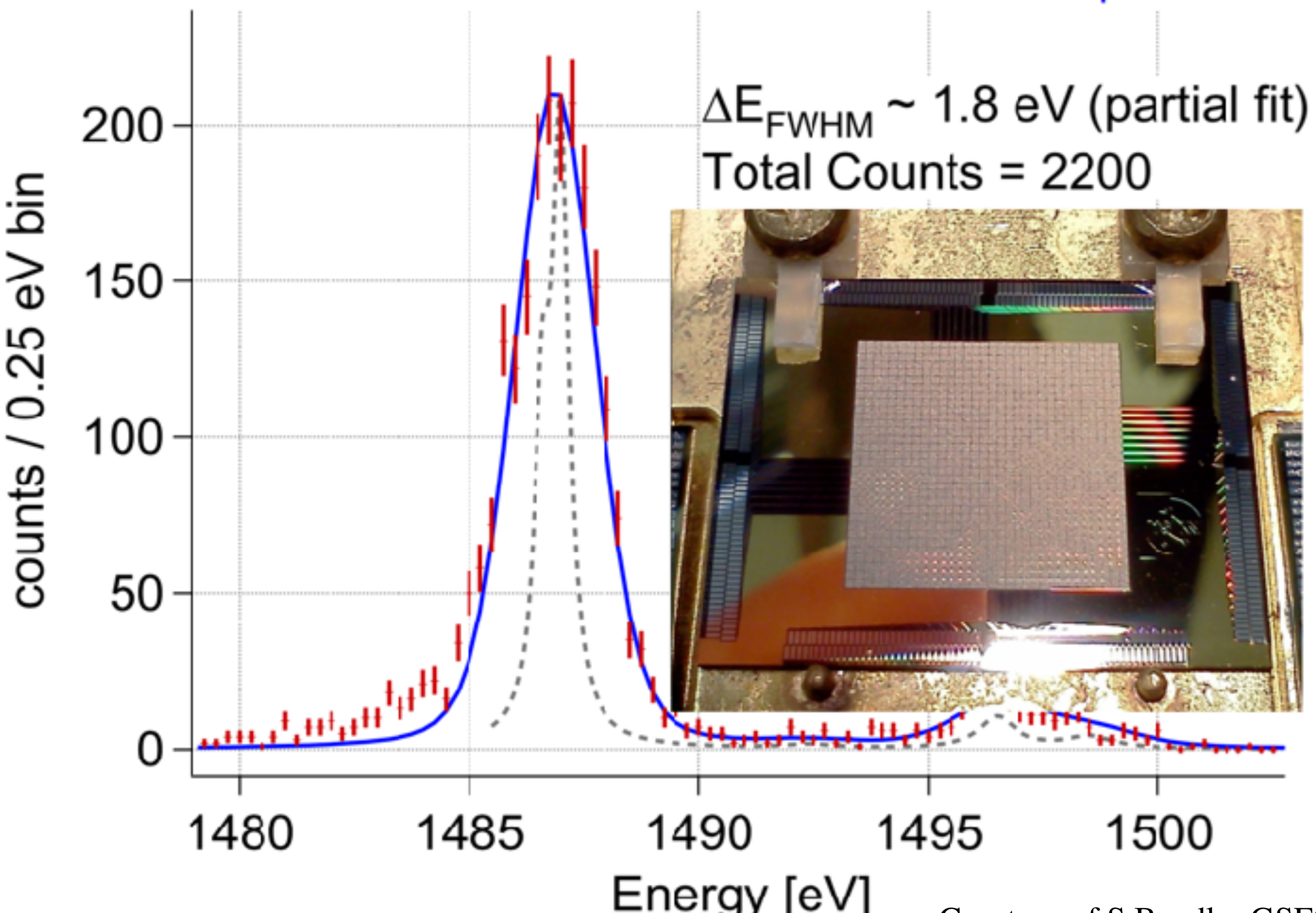


57 μm pixel with 30 μs time constant

Courtesy of S.Bandler GSFC NASA

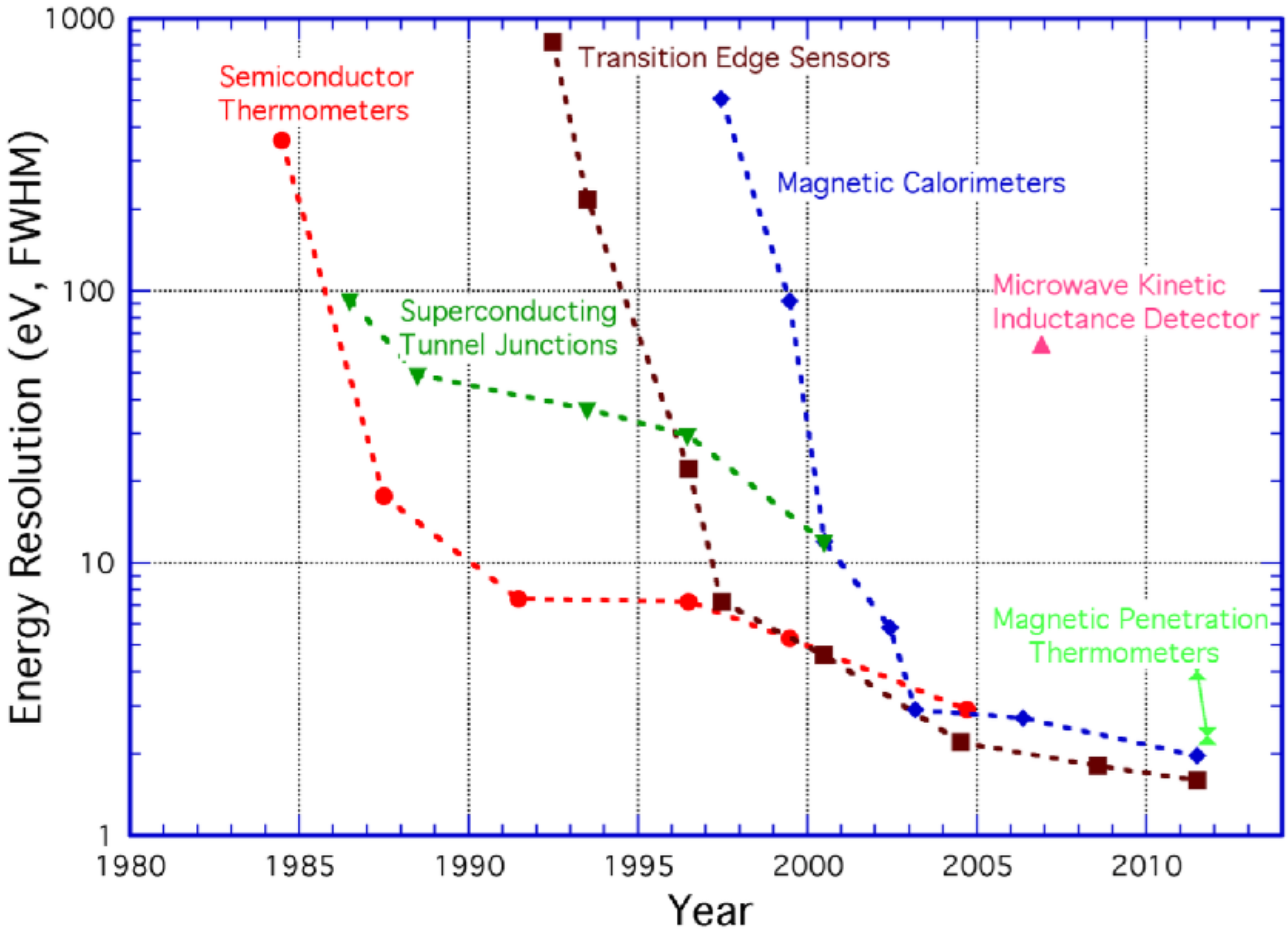
Soft X-ray Photon

32 x 32 array with
300 micron pixels

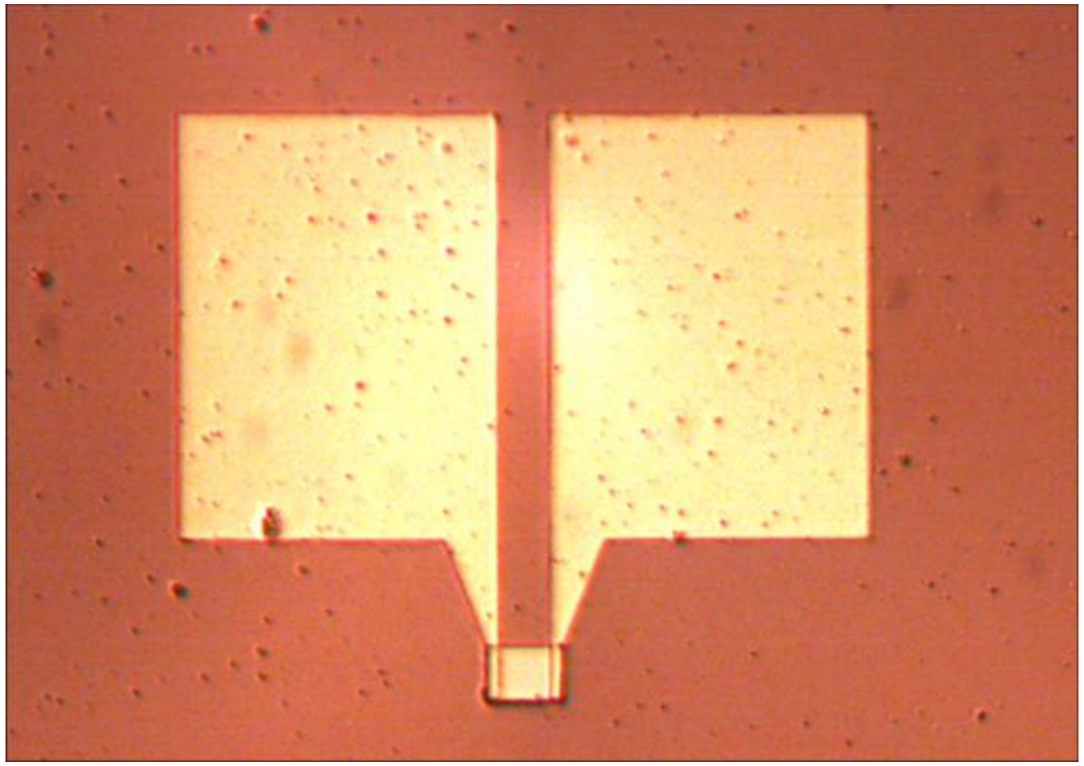


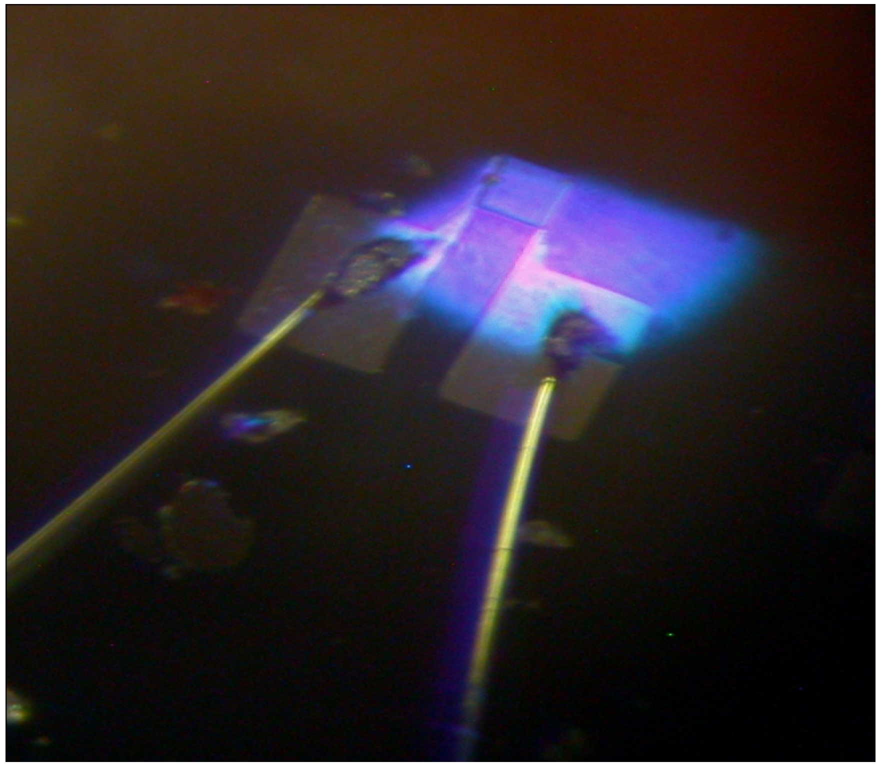
Courtesy of S.Bandler GSFC NASA

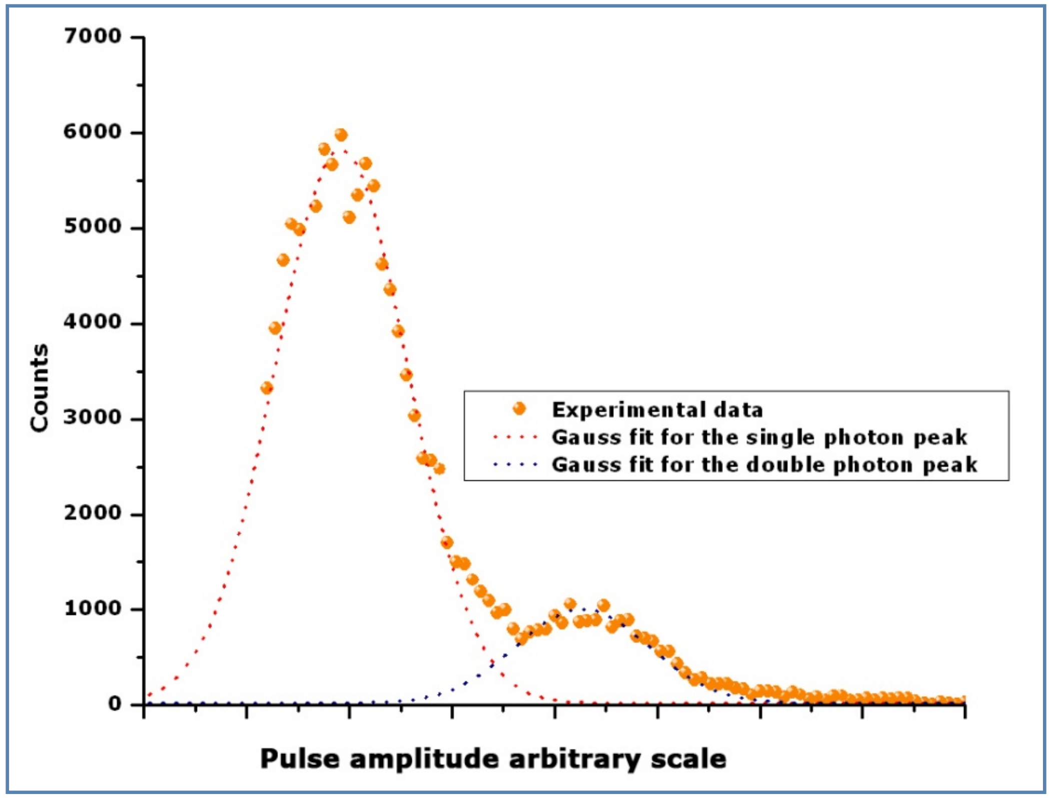
Soft x-ray Photon Resolution

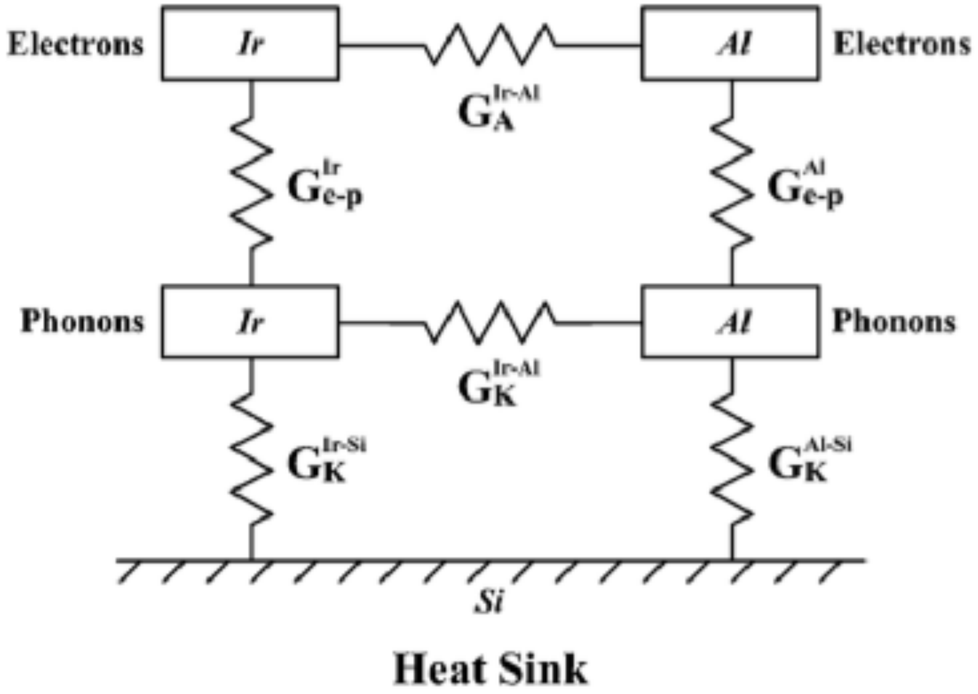


Blue Light TES SPD



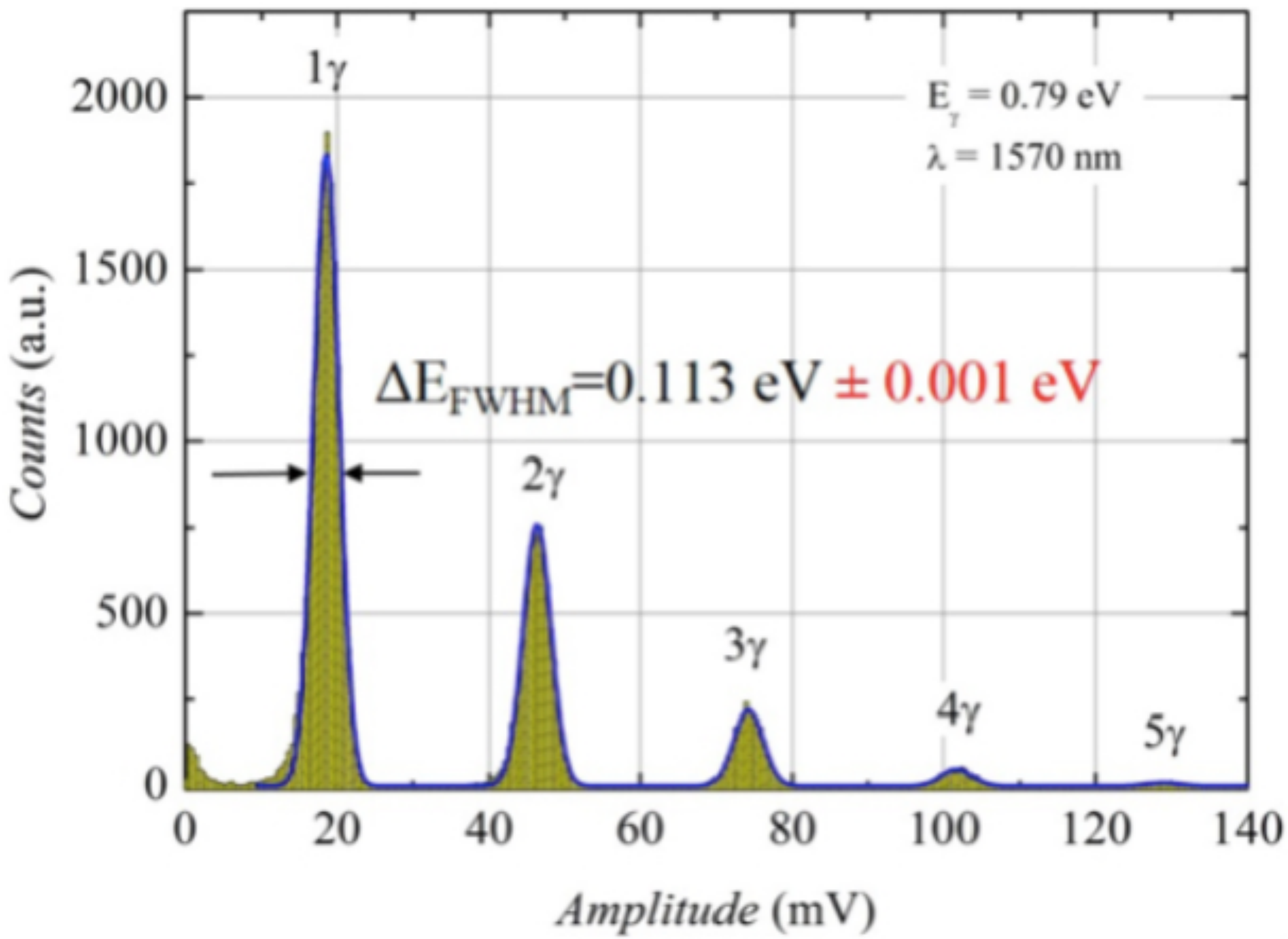




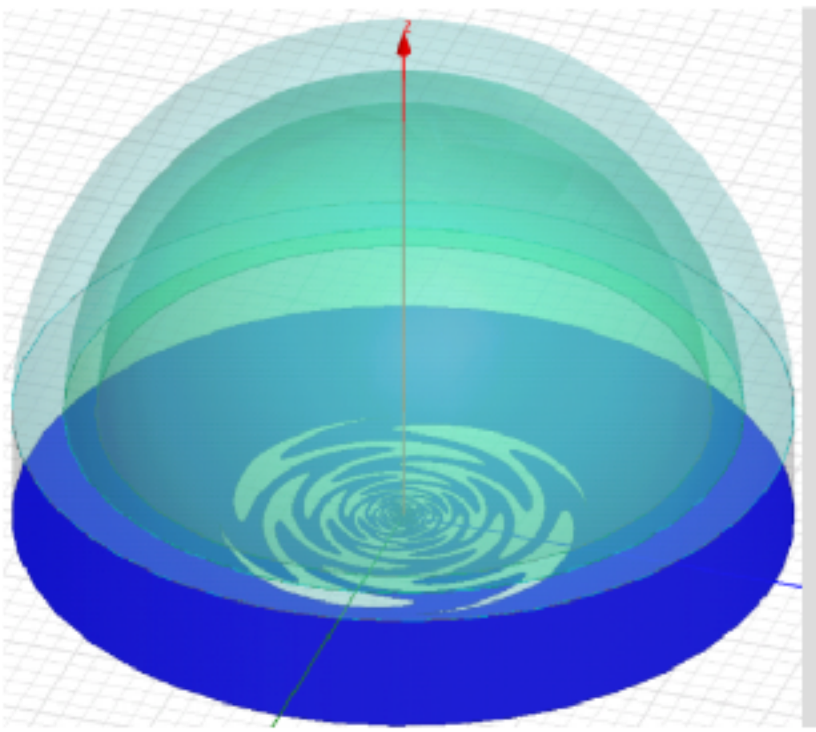


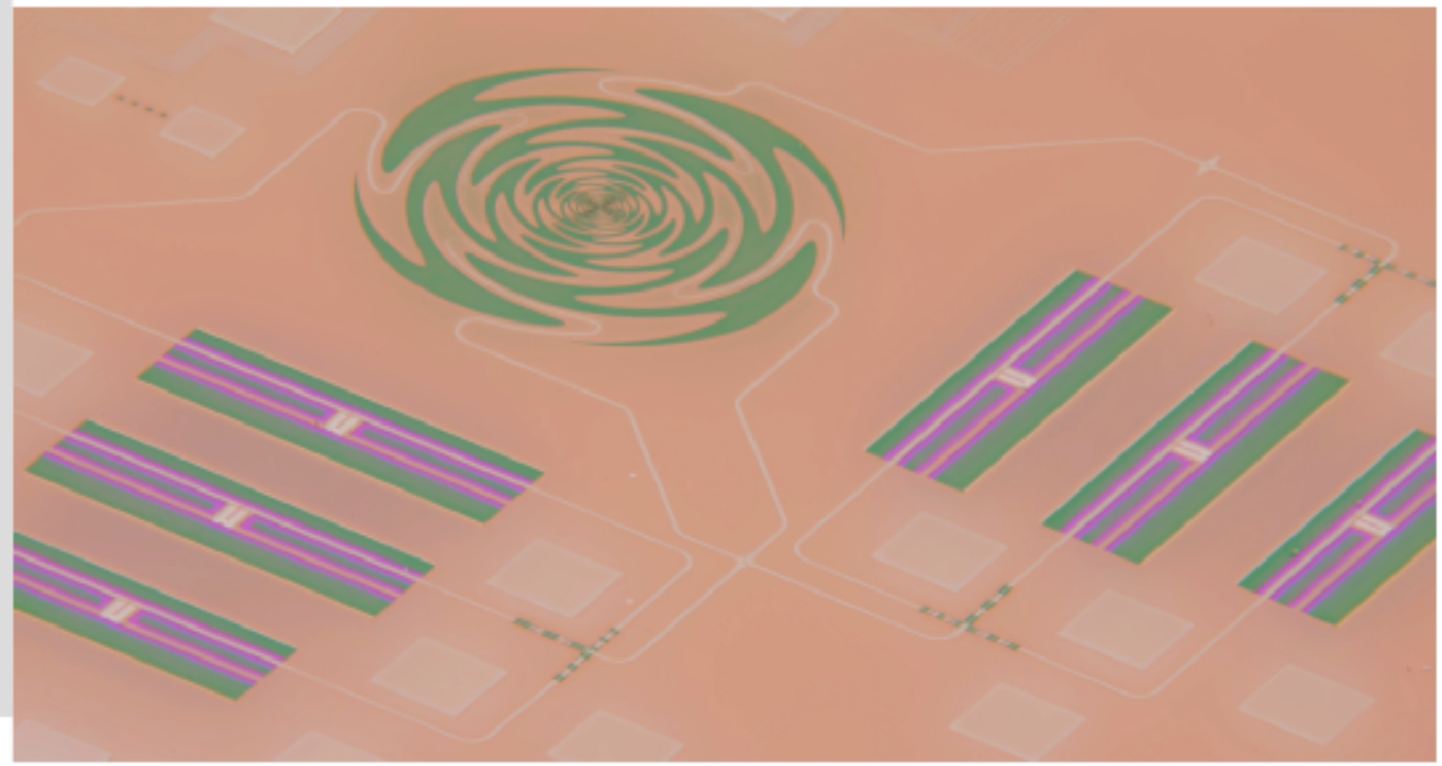
1550 nm TES SPD

M.Rajteri et , INRIM Torino



Antenna Coupled TES

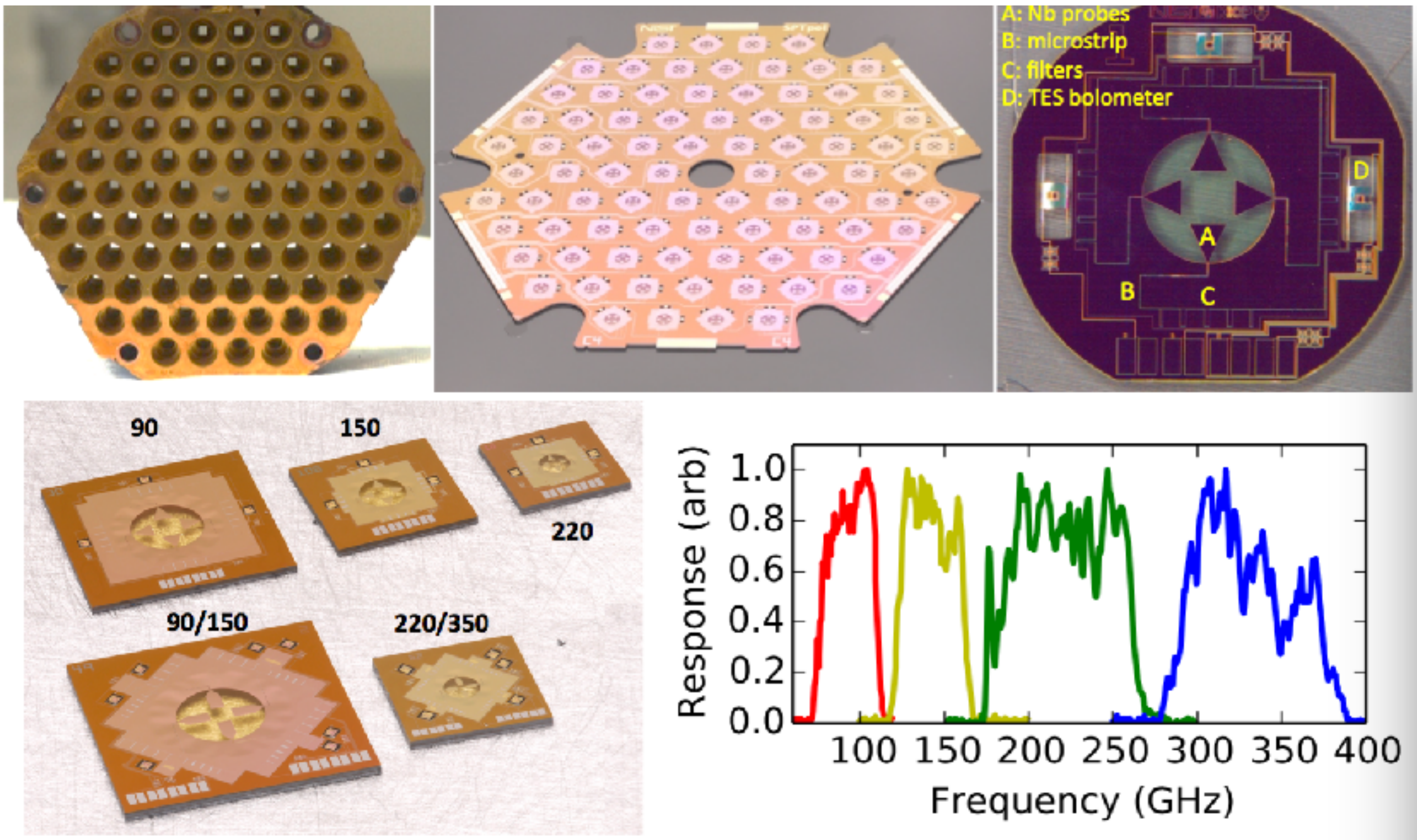




A. Lee, UCB, “Workshop CMB from Space” Tokyo 12 Dec 15

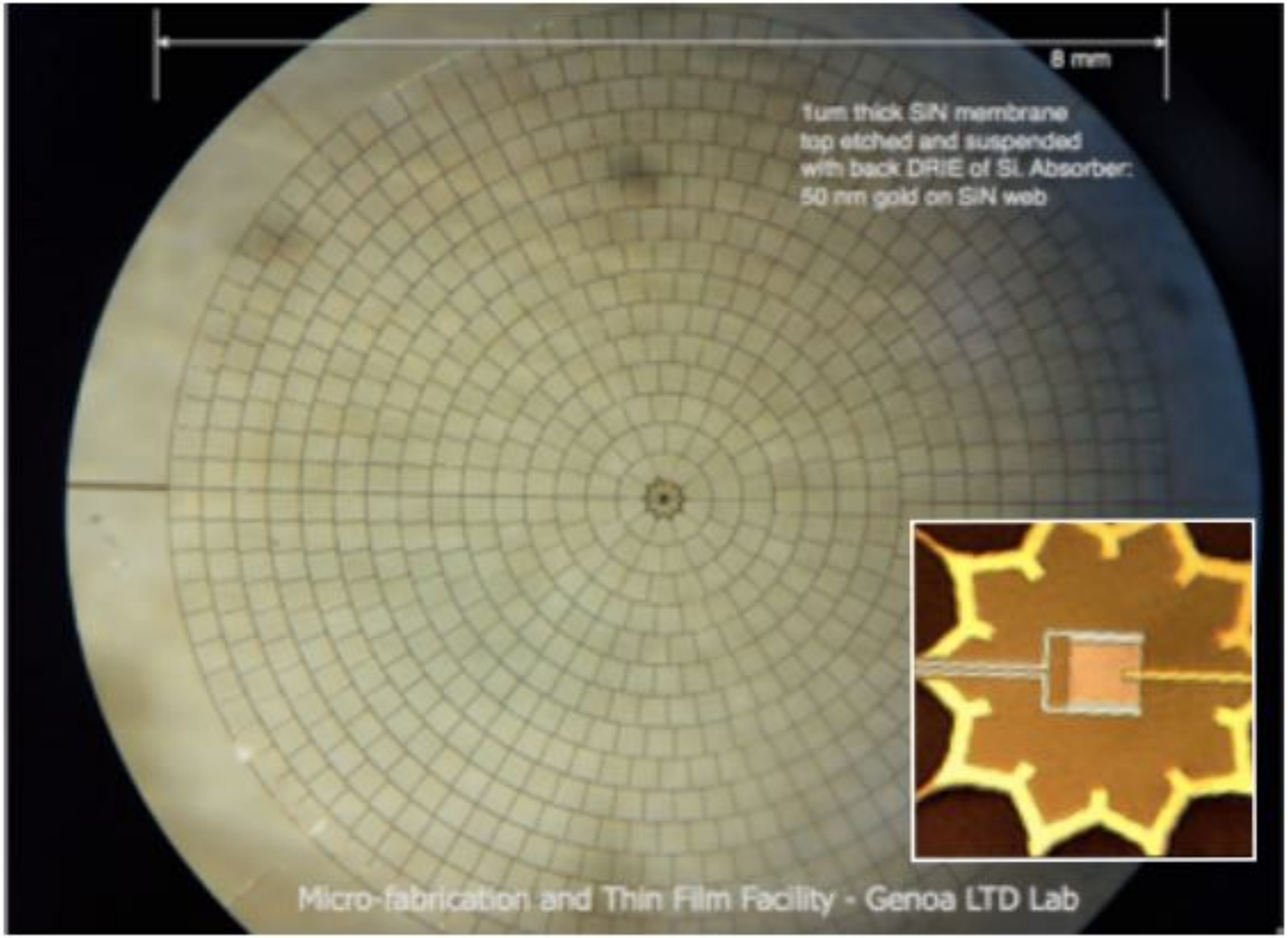
Wide Band Antenna Coupled TES Bolometer

Microwave Antenna Coupled Bolometer

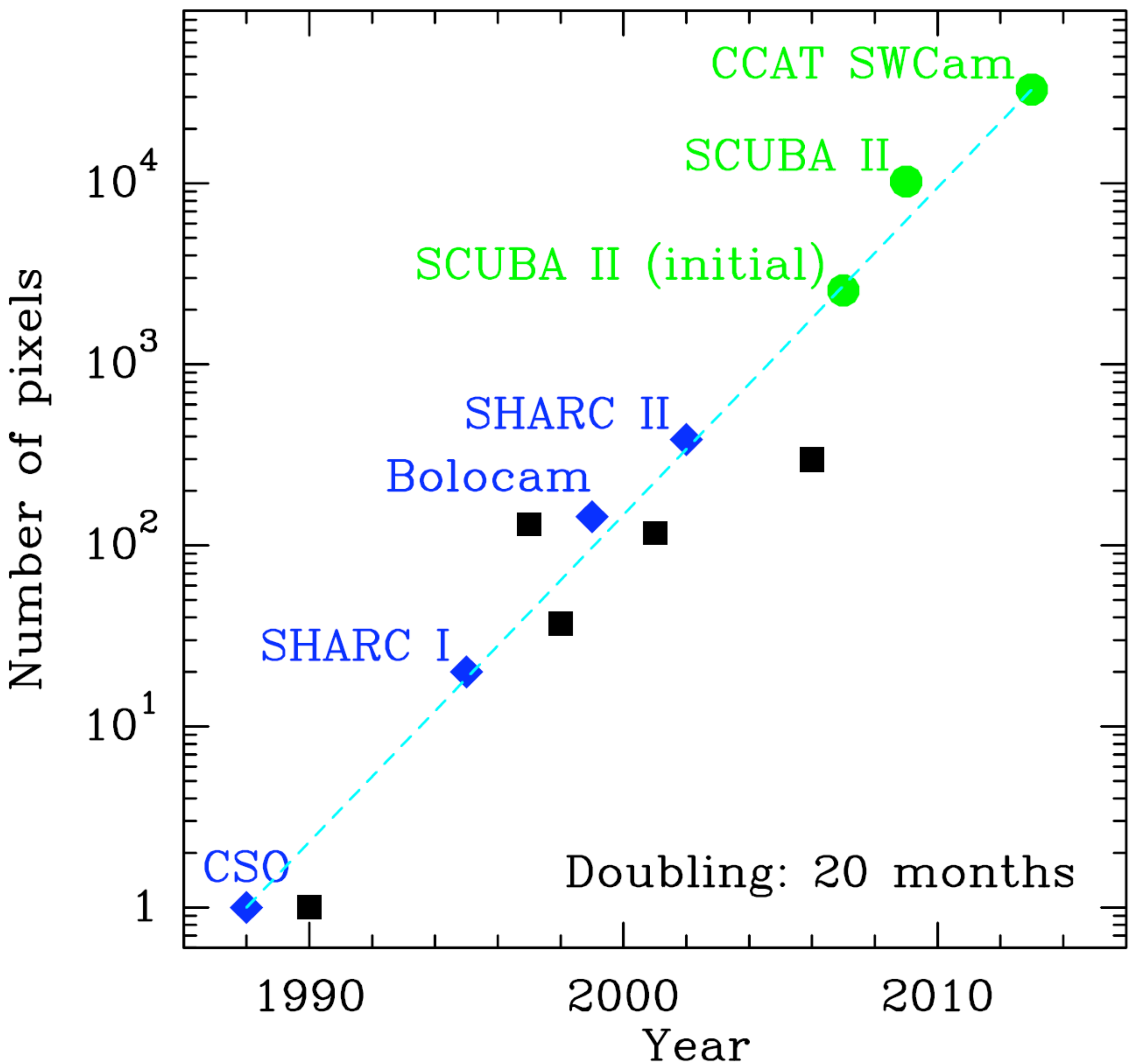


A. Lee, UCB, “Workshop CMB from Space” Tokyo 12 Dec 15

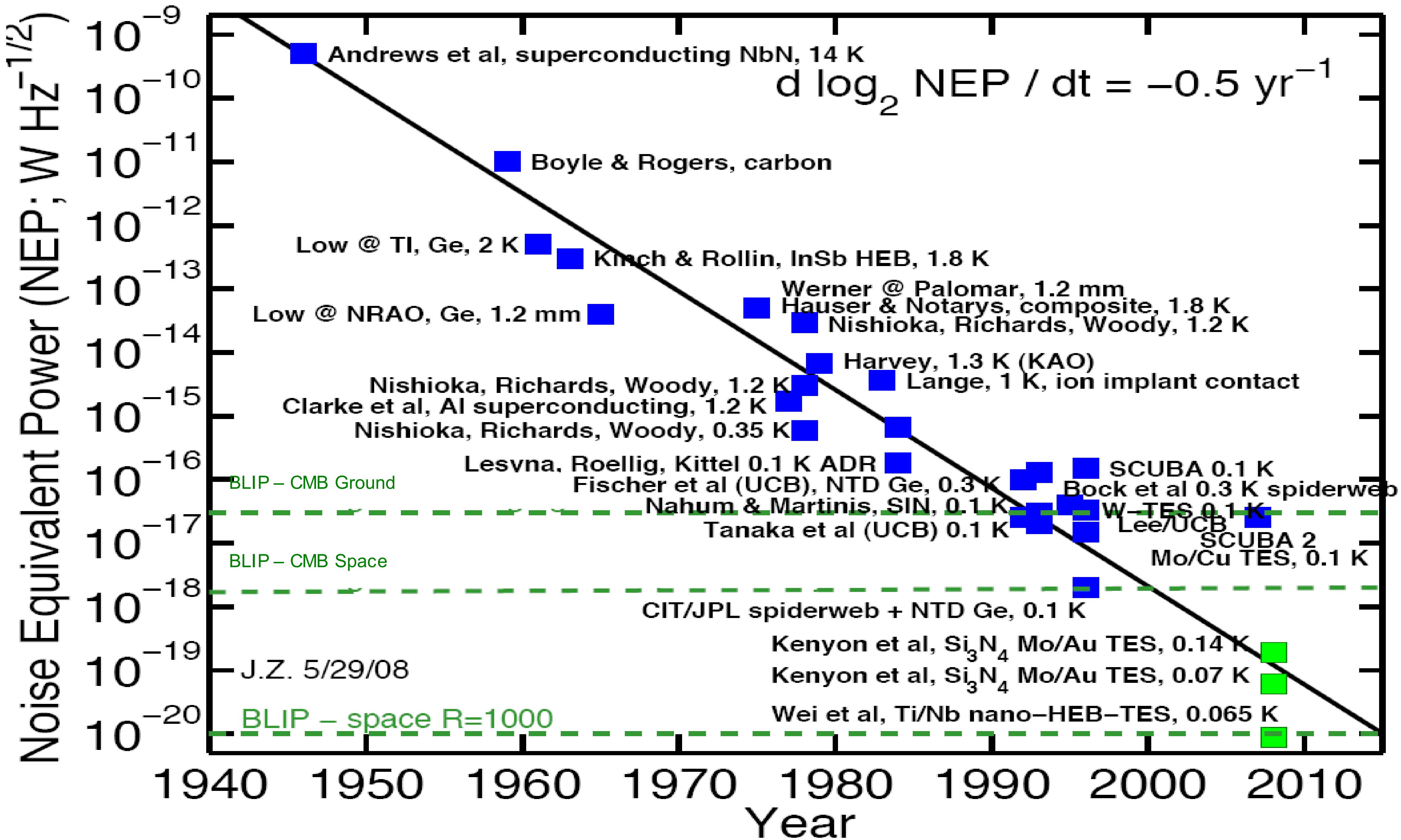
CMB in Italy - TES SW bolometer for the LSPE ballon borne CMB polarisation



Large Array

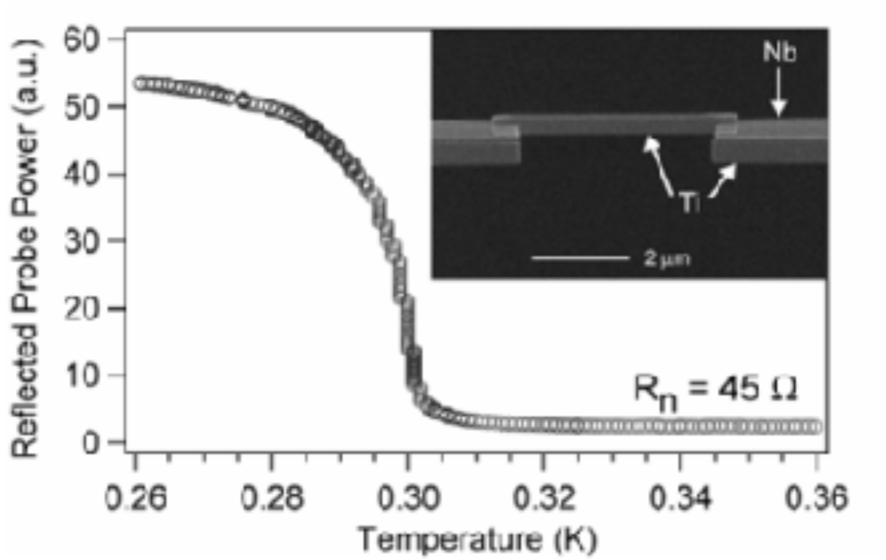

CCAT SWCam
SCUBA II
SCUBA II (initial)
SHARC II
Bolocam
SHARC I
CSO
Doubling: 20 months
Number of pixels
10^4
10^3
10^2
10^1
1
1990
2000
2010
Year

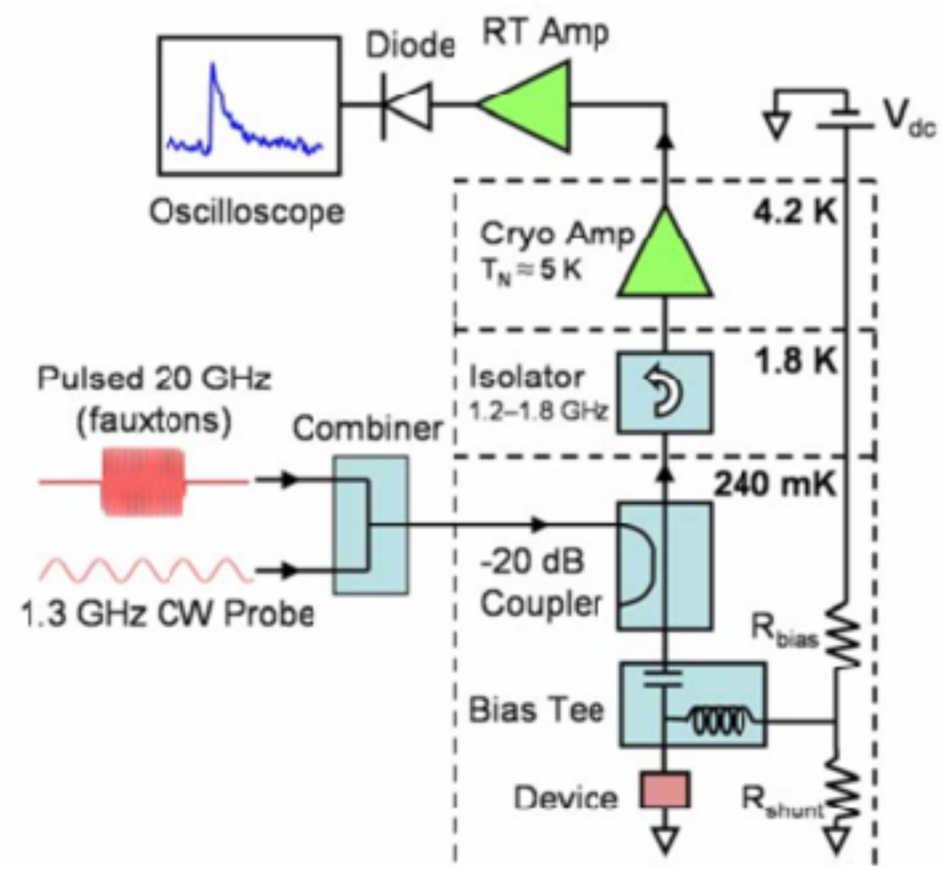
The NEP Challenge

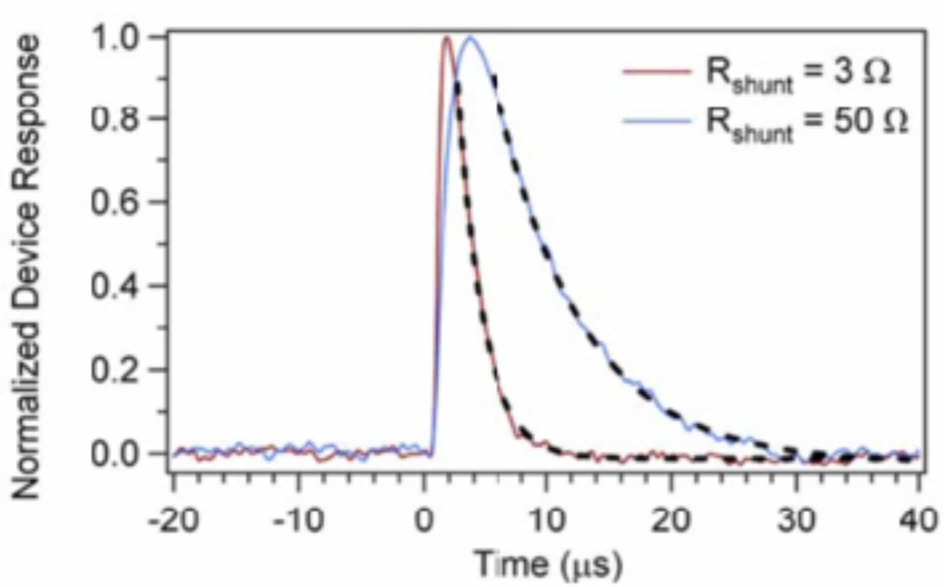


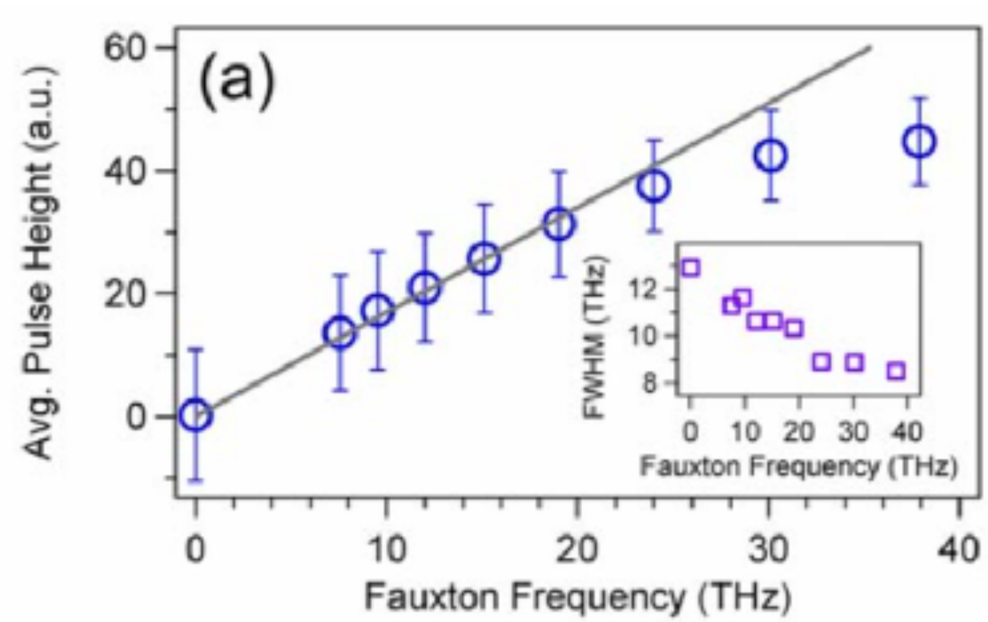
Towards Single Photon @ 100 GHz

Santavicca .. Frunzio…et al









Micro/nano structured TES matched with the antenna like this…

Work Package Number	7			1 - 48			
Work Package Title	Advanced superconducting techniques for particle detectors (Research, Training, Transfer of Knowledge)						
Lead Beneficiary	UNIGE						
Participant Short Name	UNIGE	FNAL	KIPAC	CALTECH			
Person-months per Participant:	47	0	0	0			

Objectives:

O7.1: Develop the design of antenna coupled superconducting TES bolometers sensitive to the polarization for large area focal plane of microwave telescope at 50-100 mK and very high sensitivity test in the LSPE Balloon cosmology program.
O7.2: Choose the material and characterize the thermal and transport properties of superconducting material for the detector.
O7.3: Define fabrication processes and tools and provide a TES Bolometer prototype for laboratory qualification test.
O7.4: Integration of demonstrative few channel instrument in CMB telescope and data taking and analysis.
O7.5: Investigation of materials, structures and operating mode of superconducting single photon detector in the 100 GHz band.
O7.6: Fabrication of a prototype of superconducting single photon detector in the 100 GHz band and first operation test.

Description of Work and Role of Specific Beneficiaries / Partner Organisations

T7.1: Design and modelling (UNIGE, CALTECH, ER/ESR for 9M, start M1). Design an antenna coupled bolometer for mm wave multiband with polarization sensitivity. This includes the study of the EM coupling in a planar broad band polarization sensitive antenna, a superconducting planar transmission line in the 100-800 GHz band, the filtering in sub-bands and the power dissipation in a small bolometer. The modelling will couple the EM and the Thermal sub systems as a whole.
T7.2: Materials and fabrication processes (UNIGE, CALTECH, FNAL, ER/ESR for 9M, start M1). Materials are of primary importance for the superconducting high efficiency transmission line and filtering at this frequency band. Absorber and TES must be carefully designed for best performance. After the requirement's definition, material choice or synthesis, characterizations and tests are mandatory.
T7.3: Prototype fabrication and qualification (UNIGE, CALTECH, ER/ESR for 9M, start M1). The prototype of an antenna coupled TES bolometer will be tested in dilution fridge system coupled with microwave generator.
T7.4: Data taking in ground or balloon telescope (UNIGE, CALTECH, ER/ESR for 10M, start M12). We expect to integrate a small prototype in ground telescope (at the site of QUBIC experiment) or in the LSPE Ballon telescope.
T7.5: Single photon detector in the 10-100 GHz (UNIGE, FNAL, ER/ESR for 10M, start M1). This is a highly innovative investigation that will take advantage of the expertise in developing antenna coupled bolometers, new materials, nanostructuring and very low temperature operations (10 mK or lower). A prototype to be tested with mm-wave EM field is foreseen.

Description of Deliverables

D7.1: Full EM-Thermal model of antenna coupled TES Bolometer polarization sensitive, multiband (document) - M12
D7.2: Materials study and fabrication process definition - M24
D7.3: Prototype ready and qualified at low temperature with Gun Diode - M30
D7.4: Single photon detector at 100 GHz study - M36
D7.5: Prototype ready (document and device) - M44
D7.6: Data from short campaign in CMB telescope of the antenna coupled TES Bolometer polarization sensitive, multiband (document) - M48
D7.7: Data of laboratory test of single photon detector at 100 GHz study (document) - M48

Conclusions

- TES is a well known and high level of readiness technology.
- TES detector performance driven by the science and technology case: Xray, CMB, DM, 2β decay, metrology, analysis tools…
- IR light TES (and other SSPDs) at 1550 driven by quantum optics, free space communications, quantum cryptography
- Axion Searches with Single Photon Detection in GHz Band opens a new and big challenge … “No risk, no Fun”