TES-based photon detectors for WISP searches

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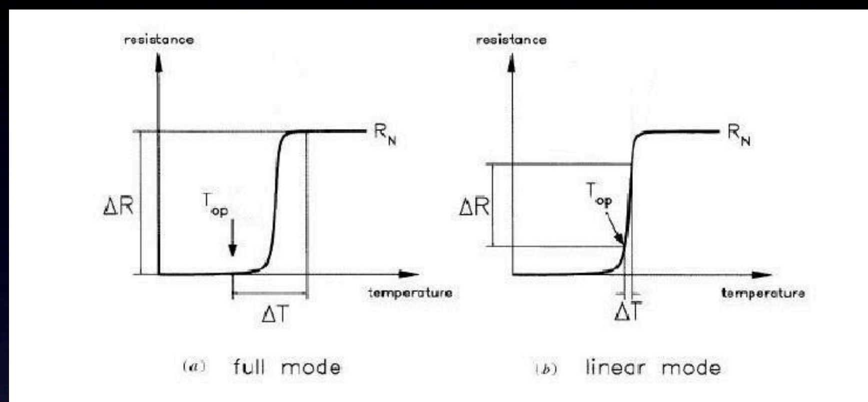
Summary

- TES-based photon sensor - VSI
- TES in WISP searches: pro’s and con’s
- Low energy TES preliminary tests
- Extending the energy range: the META concept
- Outlook

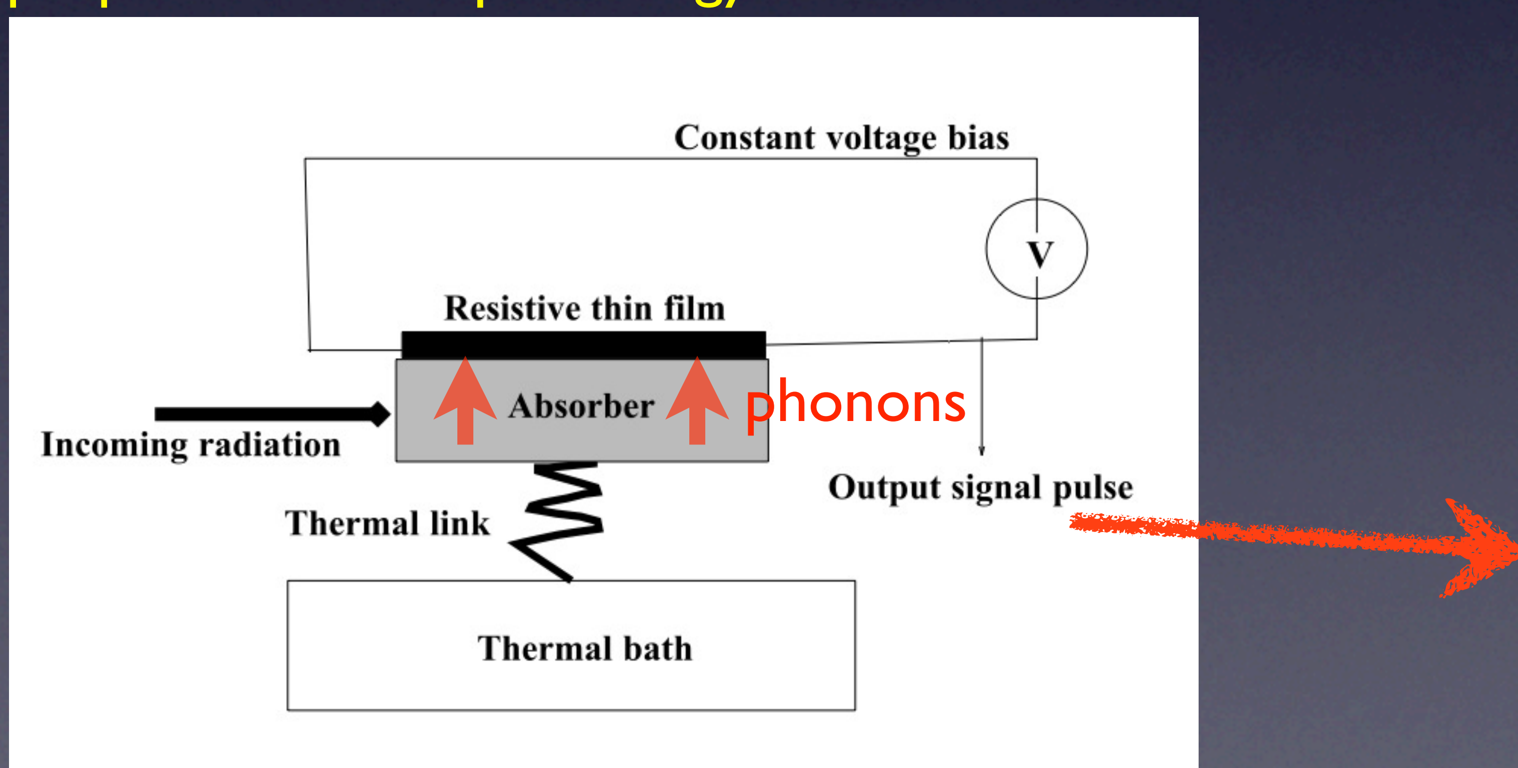
TES-based photon sensors - a Very Short Introduction

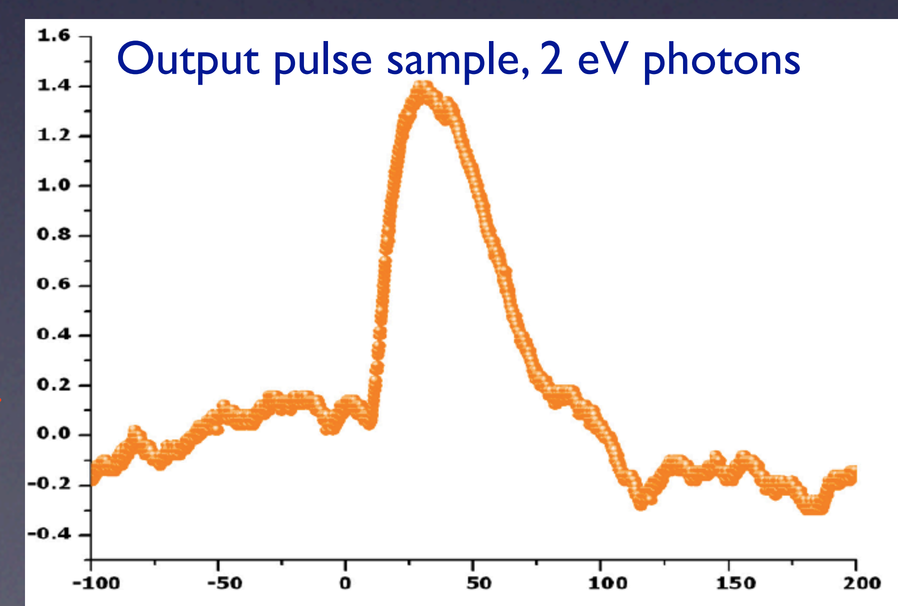
- Transition Edge Sensors (TES) are based on a resistive thin film held at its transition edge between normally and super conducting



T_{op} ranges usually from 50 to 300 mK

- An excess of incoming energy causes phonons to be absorbed by the film, which suddenly changes its electrical resistance and forms a pulse in the bias current. Pulse amplitude is proportional to input energy.



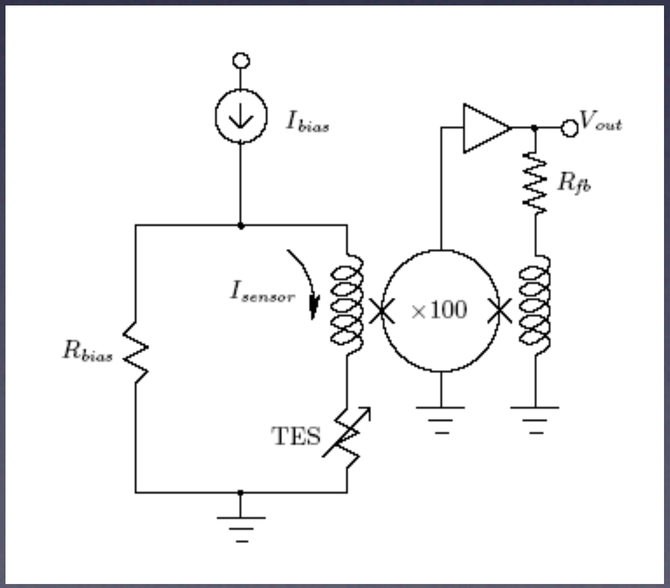


From D. Bagliani et al, J Low Temp Phys (2008) 151: 234–238

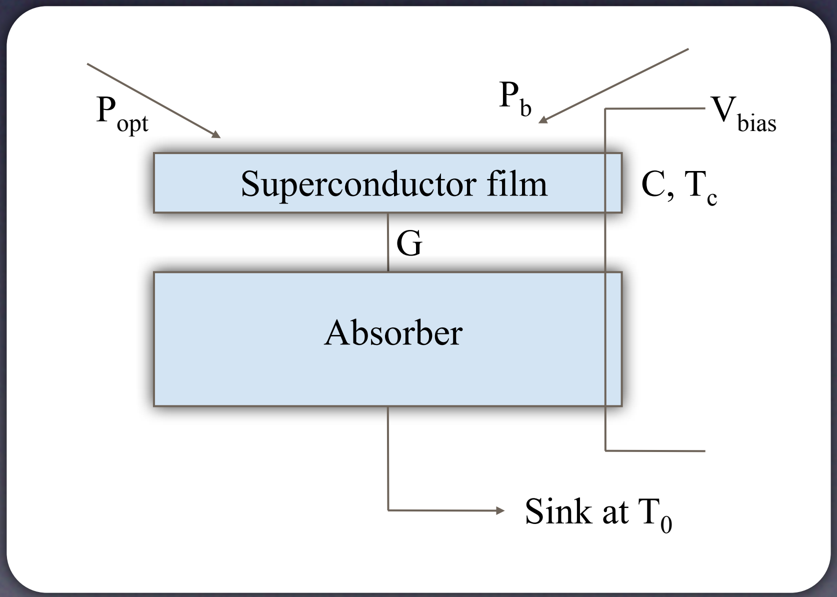
TES - VSI II

- An electro-thermal feedback loop holds the device at its transition temperature and monitors the resistance
- The power absorbed by the sensor is the sum of the incident radiation power and of the Joule heating power due to the bias, $P = P_{opt} + P_b$
- If the sensor is biased at a constant voltage V, then $P = V^2/R$, therefore
  - increase in T → increase in R → decrease in P → decrease in T → decrease in R → increase in P → increase T → .....
- This is called Negative Electro Thermal Feedback (NETF)
- In a NETF state the heat flow between film and absorber is kept constant and temperature changes can be read quickly without the need to wait for the absorber to thermalize

TES constant voltage bias



Electro-thermal feedback schematic



TES VSI III

- TES intrinsic noise is practically zero since at mK temperatures no phonons are excited
- Pulse widths are normally around 100 µs, relatively slow when compared to a "standard" particle detector, more than enough when expected rates are exceedingly small, as in WISP searches
- Incoming energy can have any form as long as phonons are tramsmitted to the film: TES where originally invented as sensitive bolometers. The type of application is essentially determined by the choice of absorber.
- When using TES as photon detectors the absorber geometry and material determine the photon energy range of maximum quantum efficiency.

TES in WISP searches

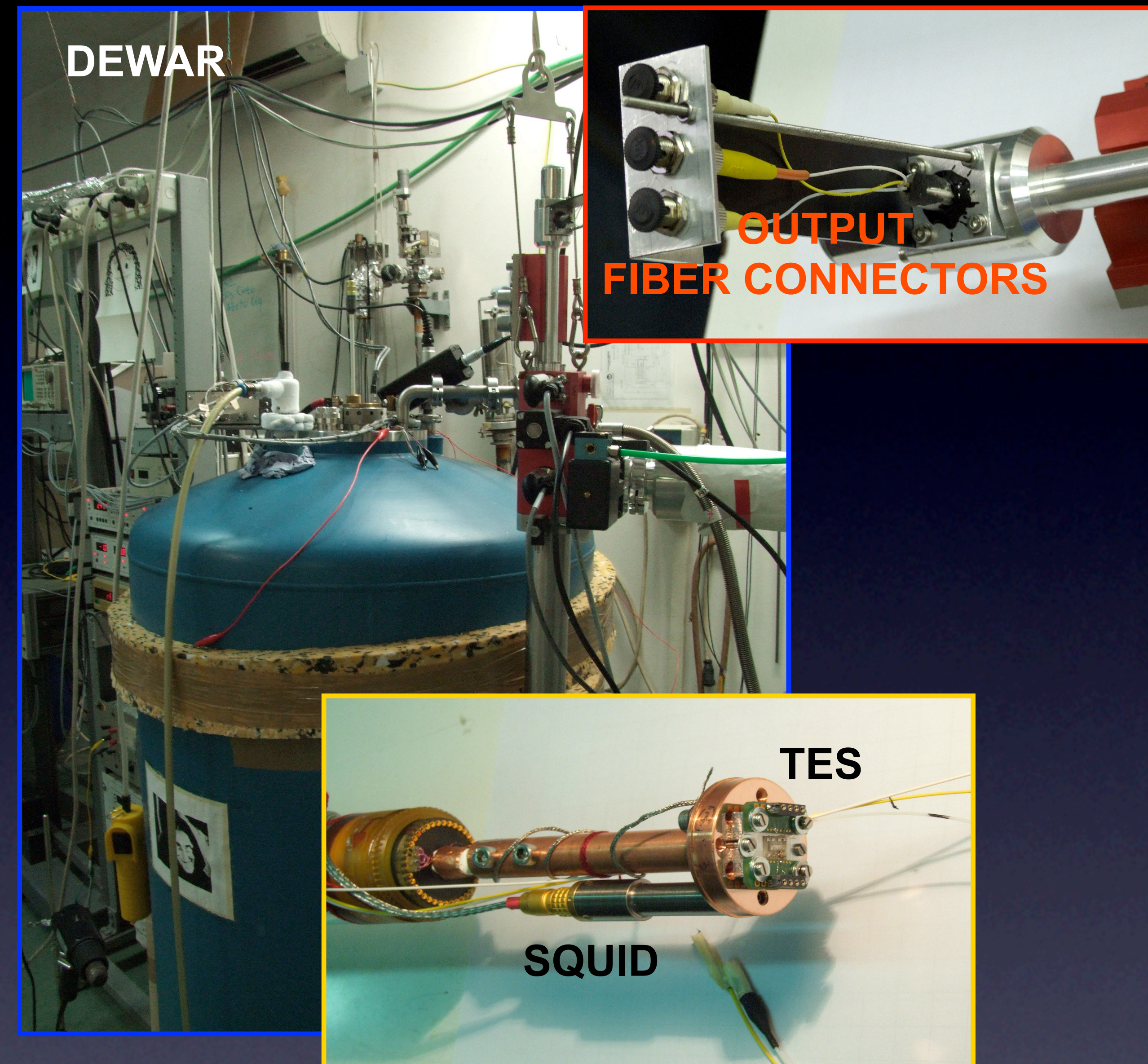
- Pro's
  - VERY LOW background (< 1 mHz over 1 hour acquisition times from preliminary tests)
  - single-photon counting capability even at low energies (1 eV or less)
  - spectroscopic capability
  - can be optimized, in the design stage, for specific wavelengths in a wide range up to tens of keVs
- Con's
  - operating at sub-K temperatures (T around 100 mK)
  - small active area (typically 100x100 μm^2 or less for a single sensor)
  - difficult to interface with the photon source (easier at visible energies)

Tests on eV range TES

- Preliminary tests on eV-optimized TES were conducted by the BaRBE_LT group starting in 2010 at the University of Camerino in Italy.
- The TES devices were manufactured by NIST (USA) and INRIM (Italy)
- BaRBE_LT group
  - G. Cantatore and M. Karuza (University and INFN Trieste - Italy)
  - G. Di Giuseppe and R. Natali (University of Camerino - Italy)
- The ALPS group participated in the early tests with Jan Dreyling from DESY Hamburg

BaRBE_LT: Camerino TES test apparatus

University of Camerino dilution refrigerator



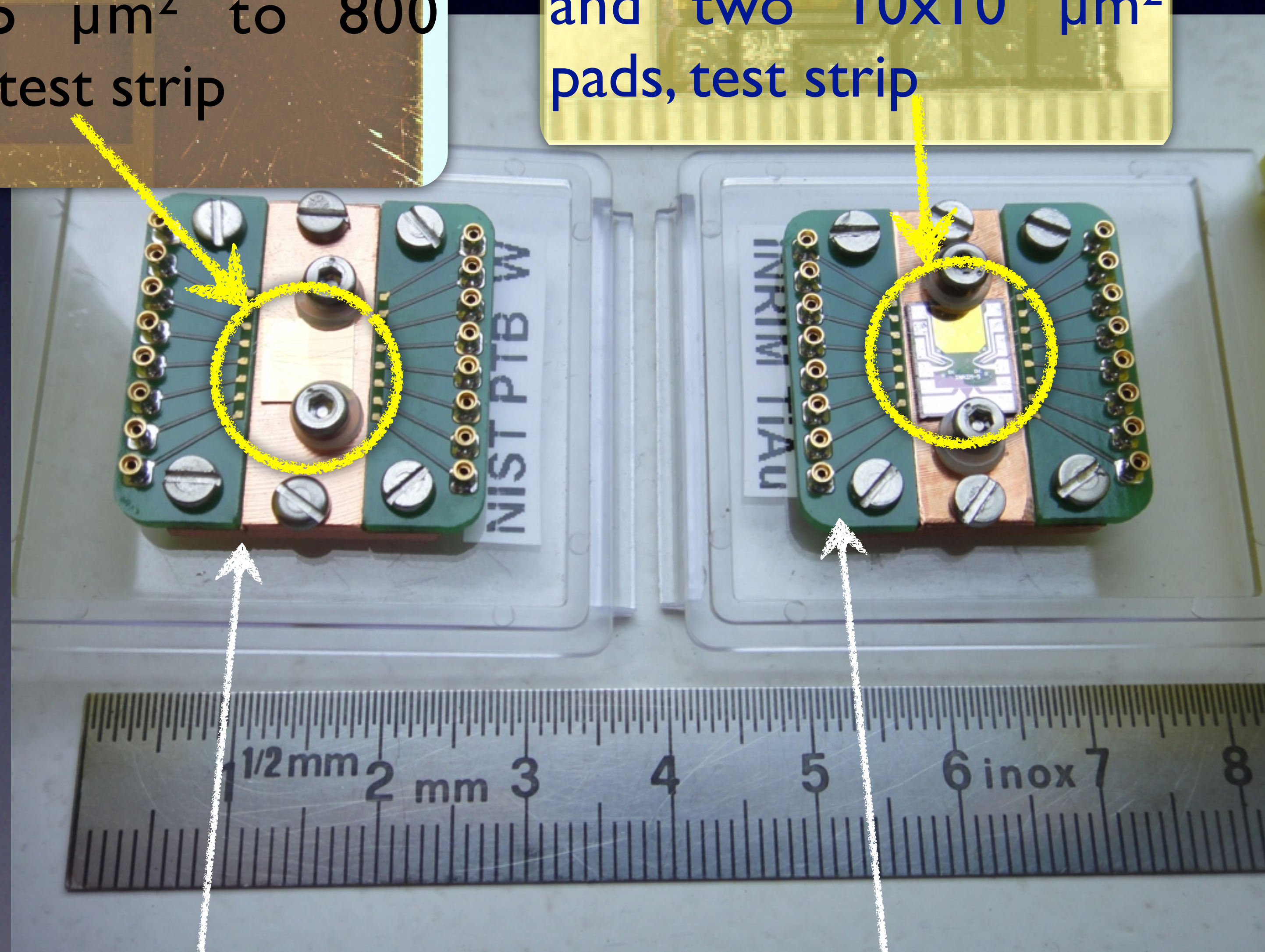
- **TES apparatus for BaRBE**
  - **dilution refrigerator (T ~ 30 mK)**
  - **TES sensors mounted on PCB-copper base and coupled by optical fiber**
  - **cryogenic readout electronics (SQUID)**
  - **data acquisition and control system**

2011-2012 Tests 1

- NIST and INRIM sensors optimized for visible photons

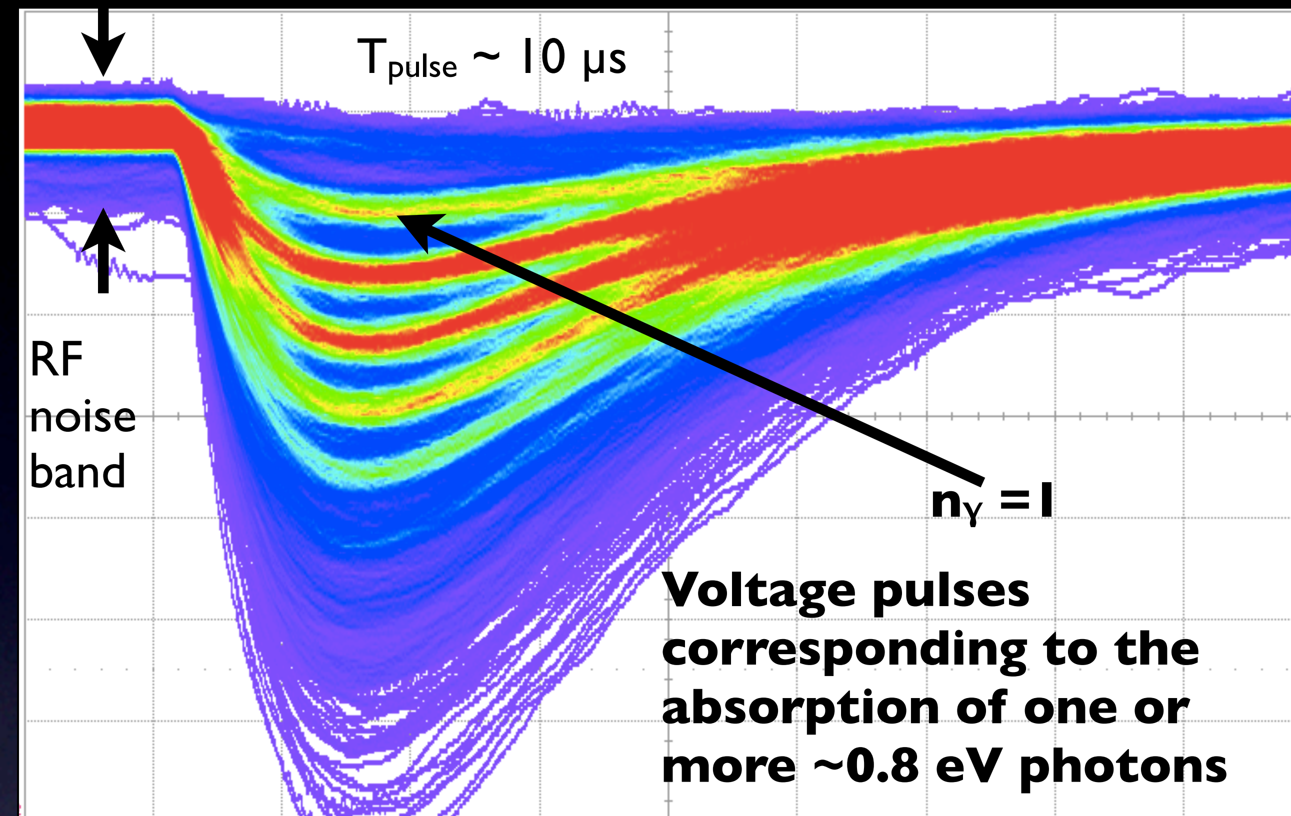
W TES chip from NIST (USA): 6 sensor pads, sizes ranging from 25x25 μm^2 to 800 μm^2, test strip

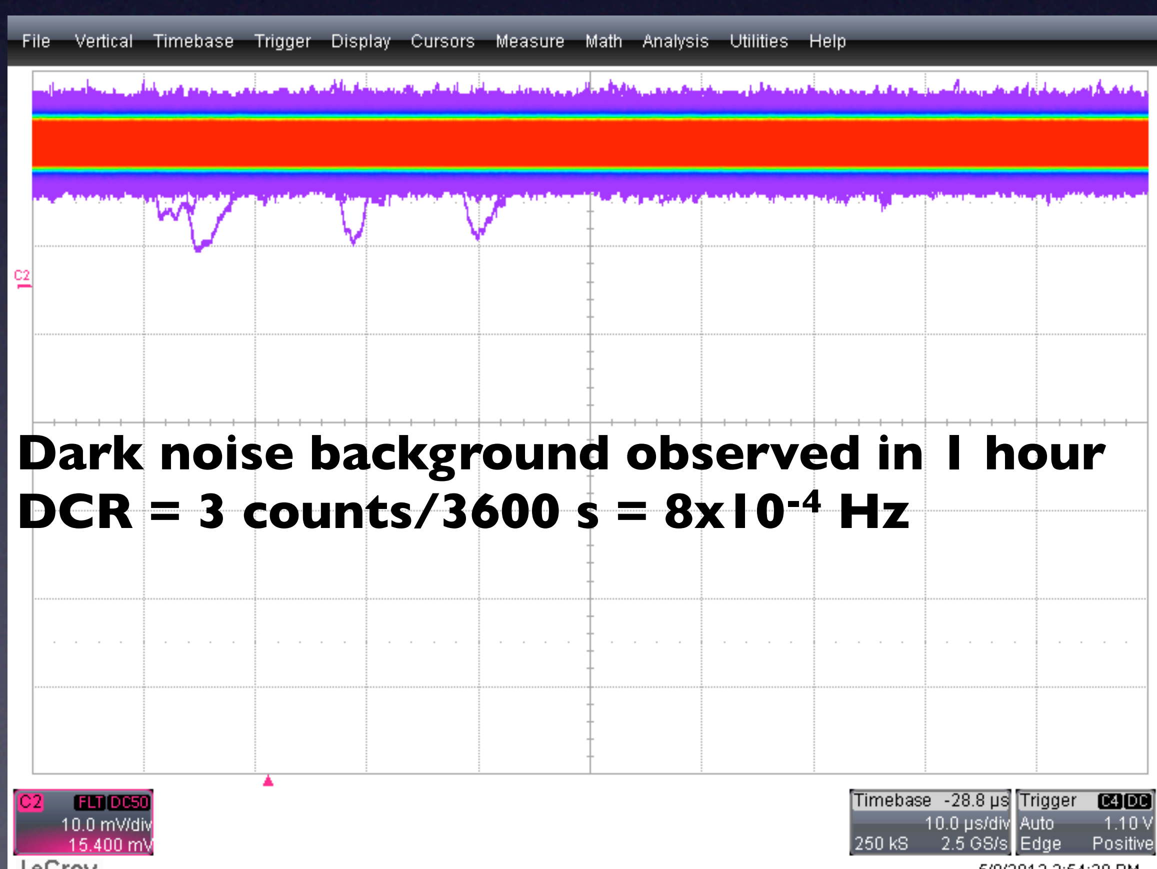
TES chip with 4 Ti-Au sensors from INRIM Torino: two 20x20 μm^2 and two 10x10 μm^2 pads, test strip

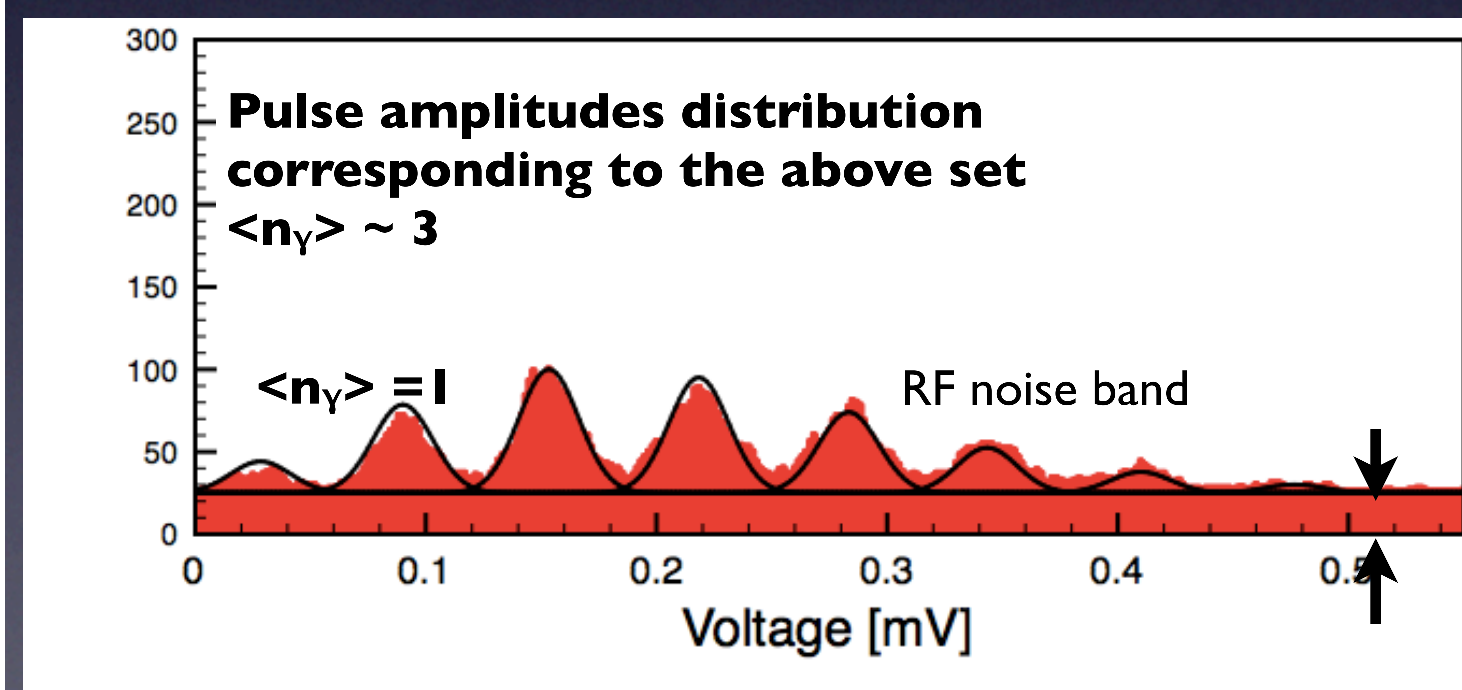


2011-2012 Tests: first results

- Measurement done in the Camerino dilution refrigerator with TES sample sensor made by NIST
- TES excited by 1550 nm photons (from pulsed laser) through an optical fiber
- Operating temp. T = 30 mK





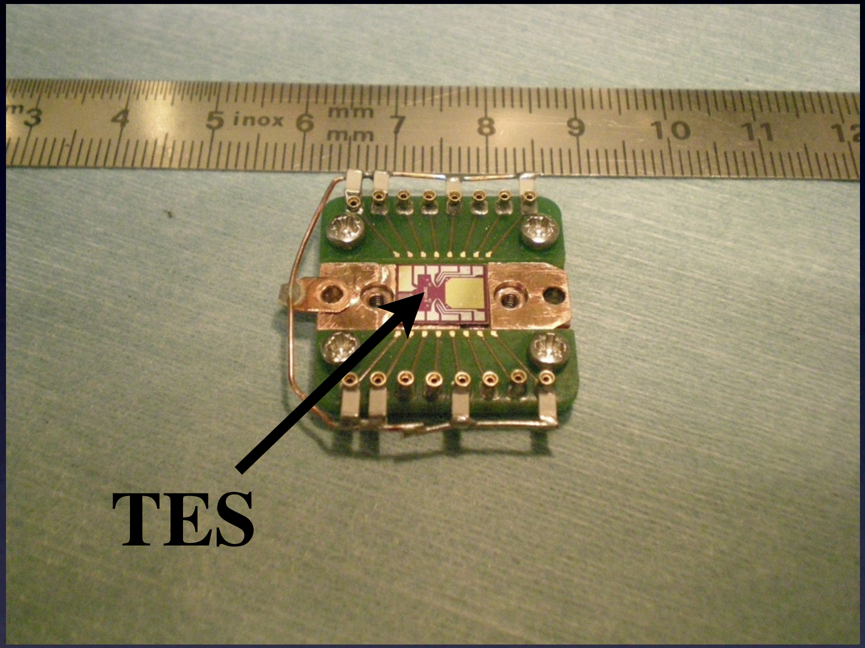


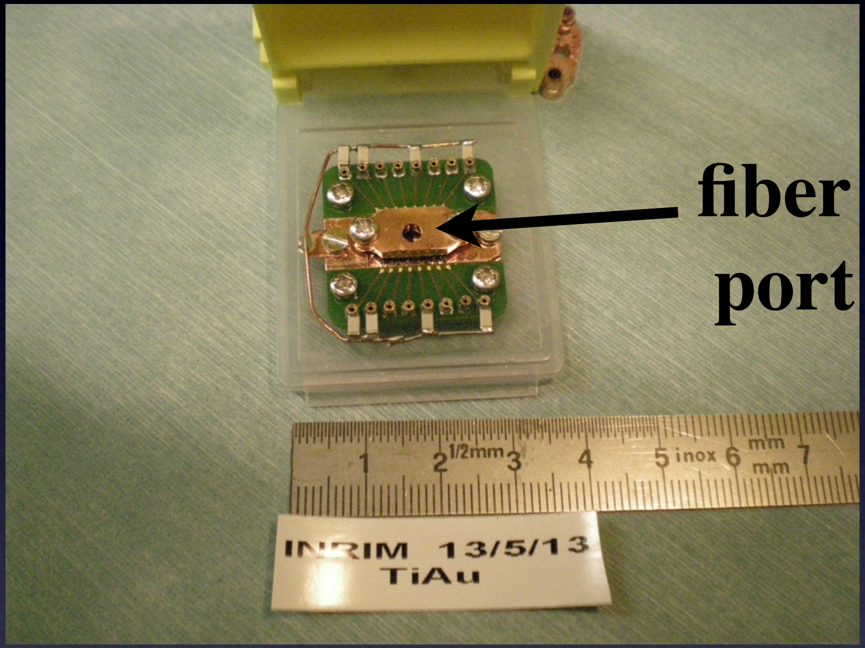
Current tests in Camerino I

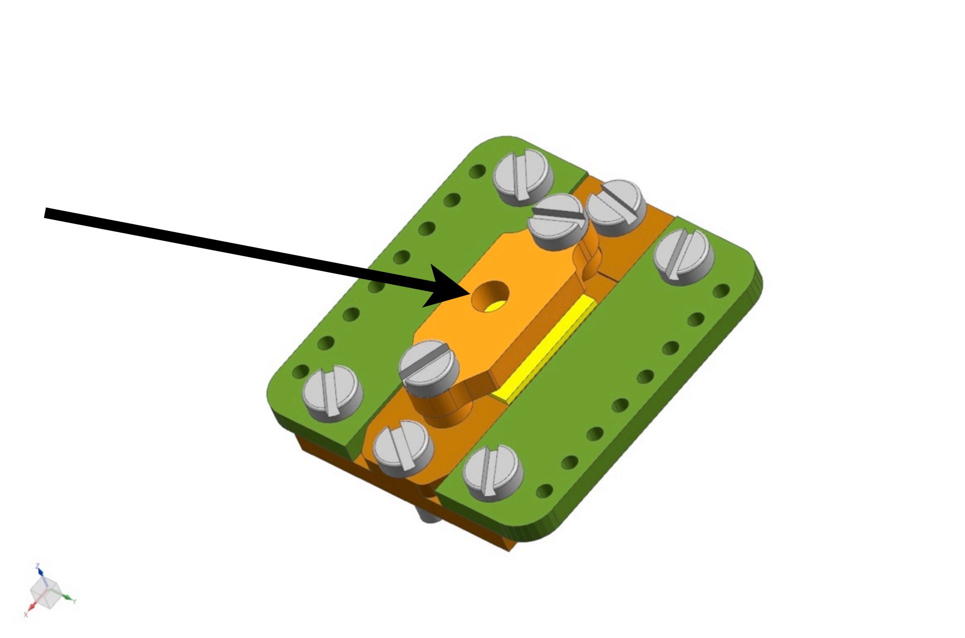
- Problems in 2012 tests
  - RF noise injection
  - bias current limited by SQUID amplifier
- Implemented solutions
  - new electrically insulating vacuum feedthroughs
  - SQUID upgrade

Current tests in Camerino II

- Ti-Au double layer INRIM TES, 20x20 μm^2 pads, transition temperature 290 mK
- mounted and bonded on copper base with fiber holder port







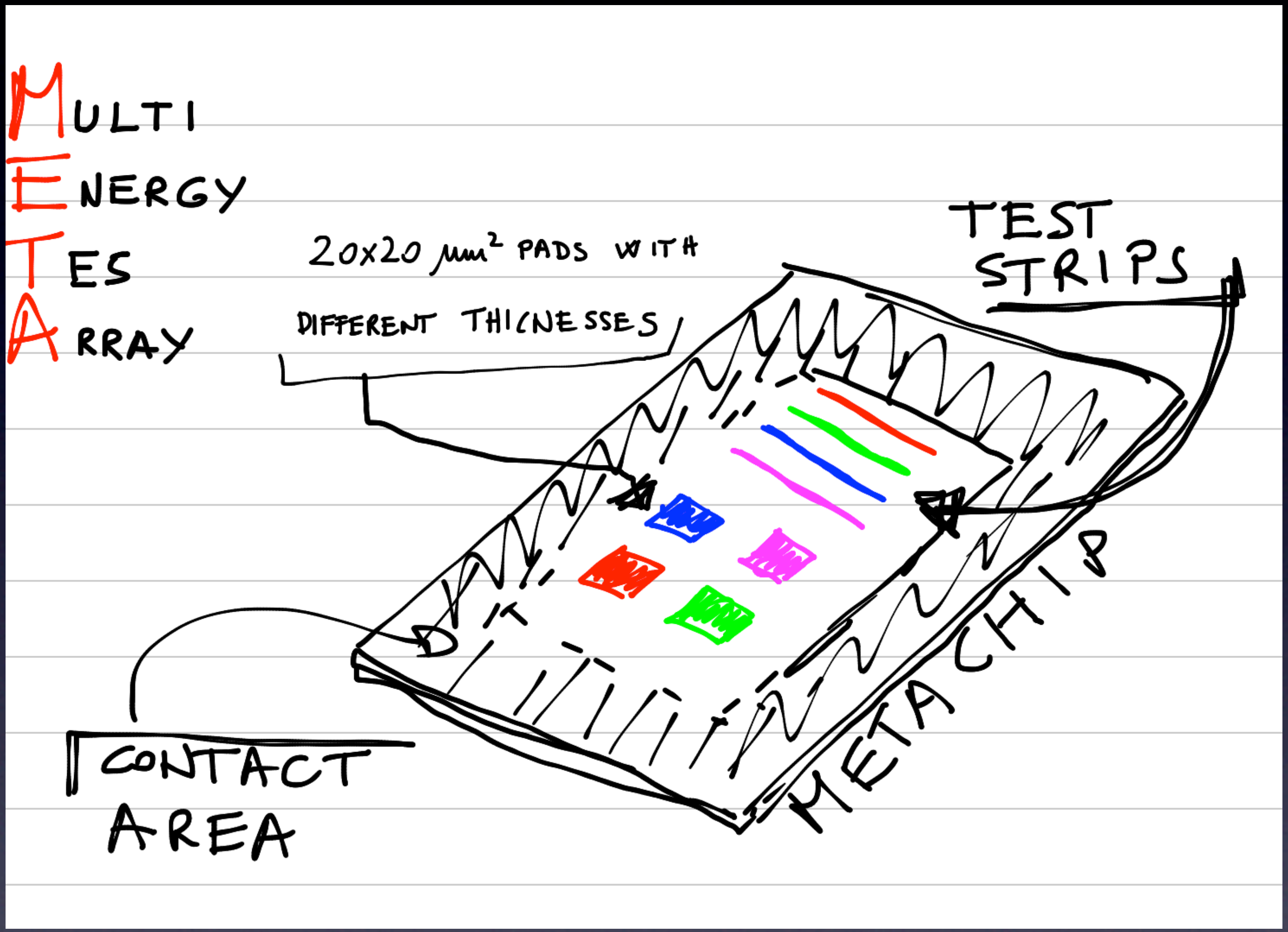
- Goals
  - check RF noise reduction
  - measure long term background
  - controlled injection of visible photons
  - measure efficiency

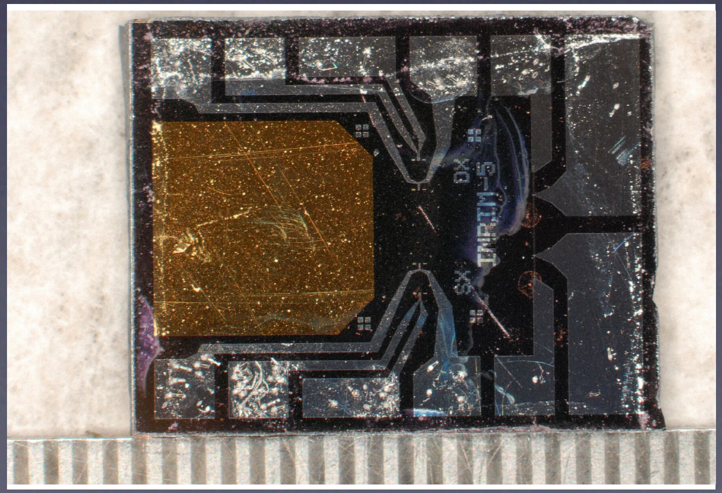
Extending the energy range

- No single device is capable of covering at the same time all the main photon energy intervals to be explored in WISP searches. For instance:
  - 2-4 keV for solar ALPS
  - < 1 keV for solar chameleons
  - 1-2 eV for optical LSW experiments
  - sub-eV for relic axion searches
  - 1-100 eV for hidden photons
- The characteristics of TES-based sensors offer a possible solution:
  - integrate on the same chip several sensor pads optimized for different photon energies
  - organize pads in an array to be read in parallel to maximize active area
  - pads could be arranged side by side (tiled) or sandwiched
    - Potential problems
      - achieving a ~1 cm^2 sensitive area
      - TES pads with different absorbers might operate at different transition temperatures
      - individual tuning of the electro-thermal feedback for difeerent pads

META (Multi Energy TES Array) prototype concept

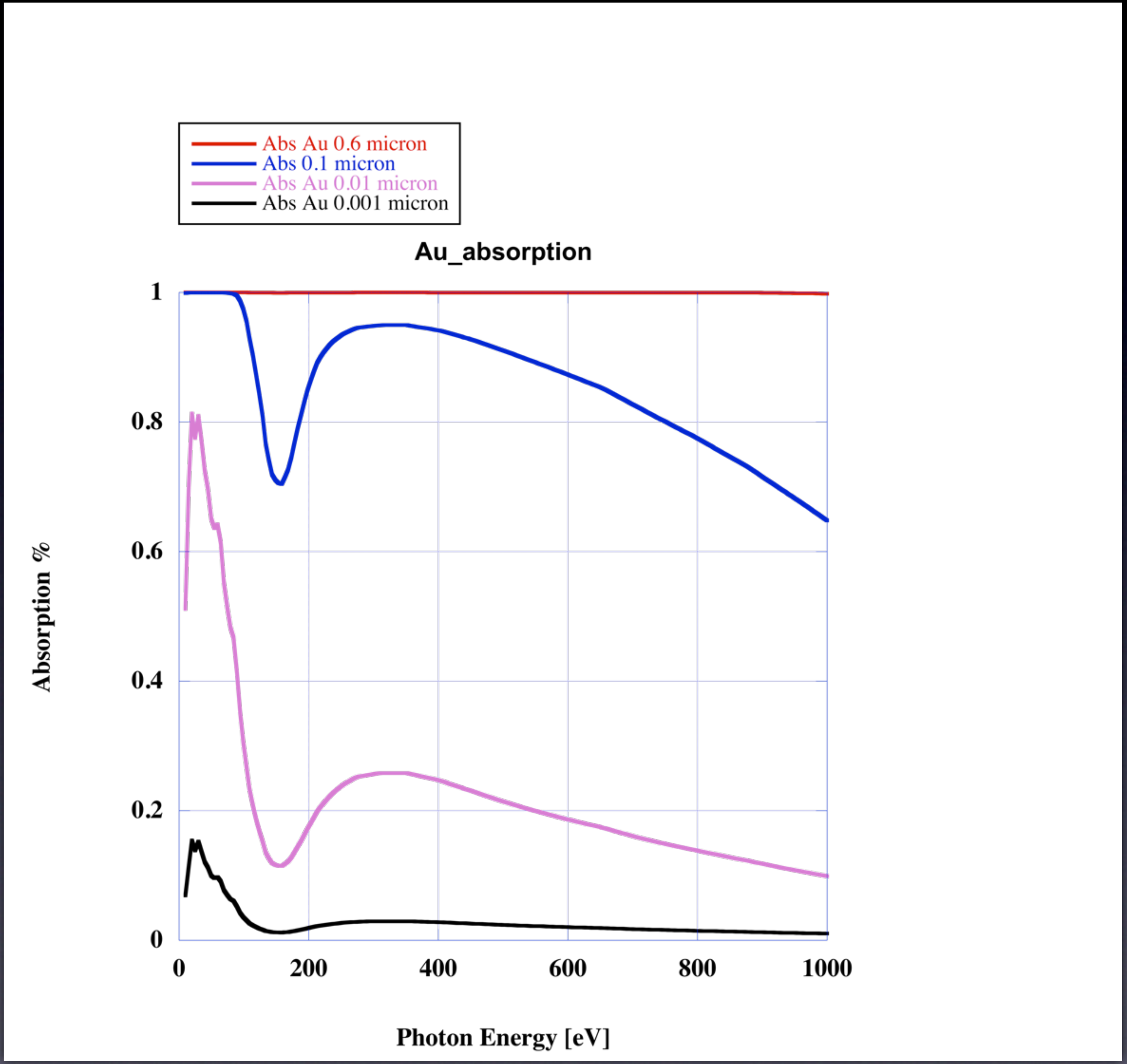
- Start with a proven technology
  - stay with INRIM Ti-Au double layer and simply change Au thickness
- Manufacture a prototype chip with few pads
  - 4 pads can cover range from 1 eV to 1 keV
- Test pads individually and as an array
  - potential problem
    - phonon cross-talk between pads when working simultaneously on a wideband beam




current INRIM chip

META photon absorption

- current technology
- four 20x20 μ^2 pads, Ti-Au double layer
- 0.001, 0.01, 0.1, 0.6 μm thicknesses of Au
- same transition temperature (290 mK)
- same electro-thermal feedback loop
- potential problems
  - phonon cross-talk
  - photon source for testing



Outlook

- Low background photon sensors are crucial for WISP search experiments
- TES-based photon counters have several desirable characteristics
- Multi-energy detection capability is an advantange, especially in helioscopes, such as CAST and the future IAXO
- The META concept offers a possible approach to a multi-energy, low background sensor suitable for helioscopes, where the expected photon spectrum is wide and the use of telescopes offsets the small sensitive area of the sensor

Boreas, Greek god of the cold ...

Detail of Boreas, the winged god of the north wind, from a painting depicting his pursuit of the Athenian princess Oreithyia. He is shown with winged shoulders and feet.