Helium II second sound detection, heat source localisation (and more…) with transition edge sensors

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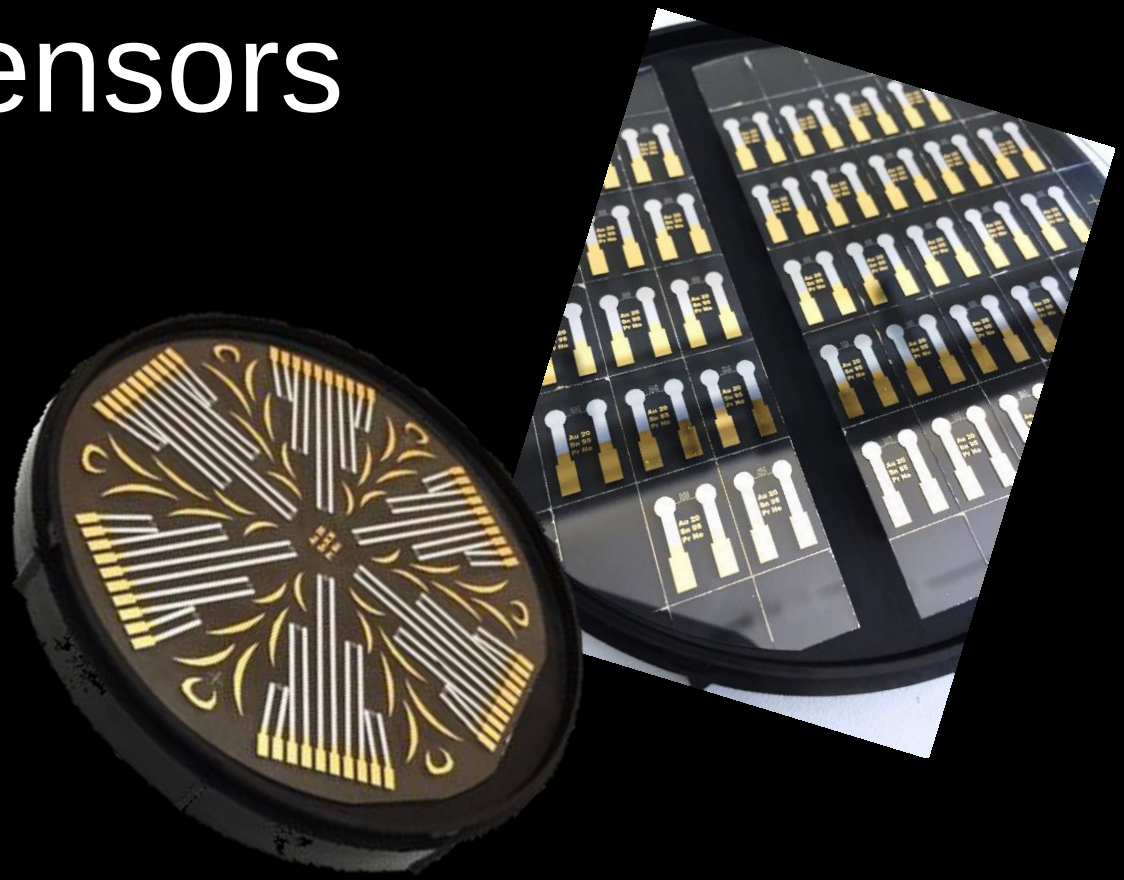
Tobias Stegmaier, Torsten Koettig, Giovanna Vandoni

ICEC 2018 – Oxford, UK – September 2018
E-08: 162

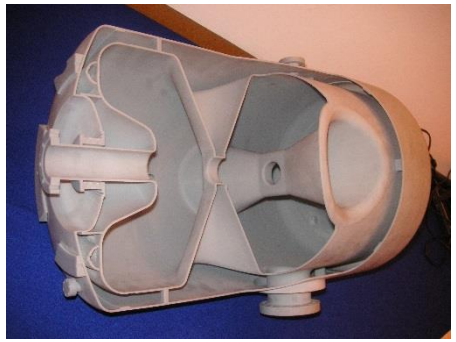


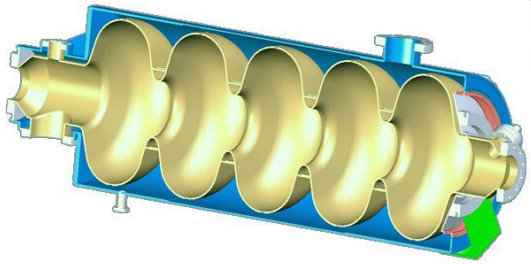
Context

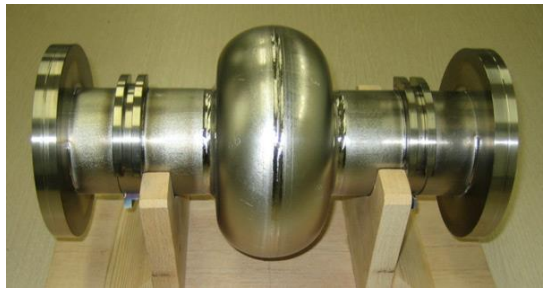
SRF cavities non-contact thermal mapping

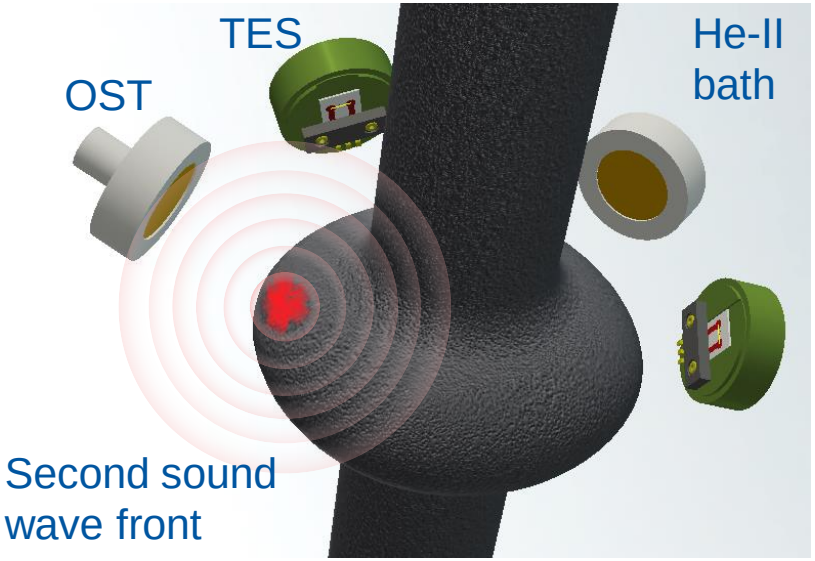
Transition edge sensors

Non contact SRF hotspots localization



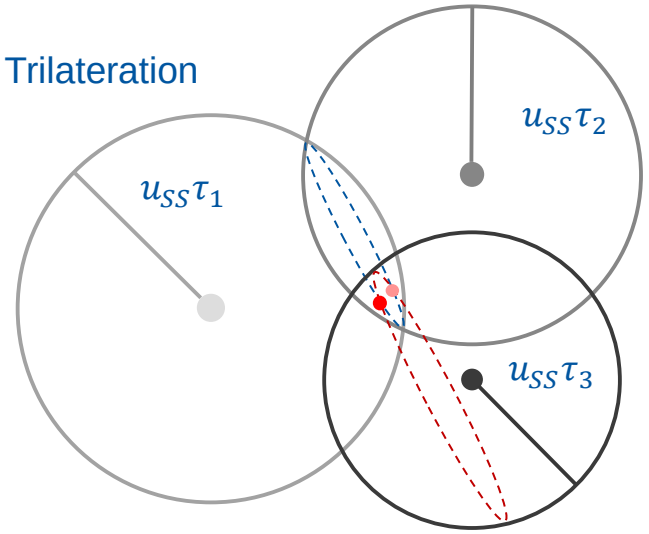


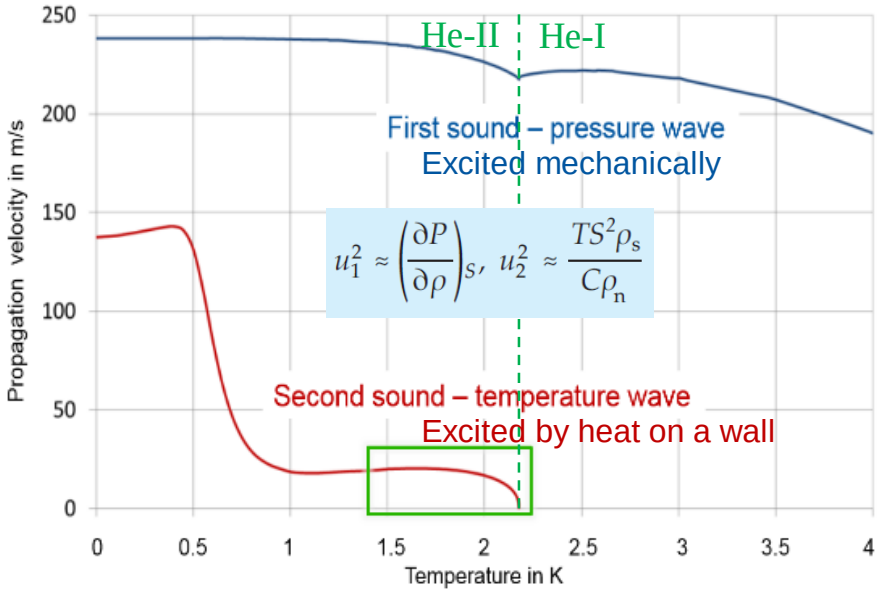




Second sound source:

$$\Delta T_{SS} \propto \frac{1}{\rho C u_{SS}} \frac{\partial q''}{\partial t}$$



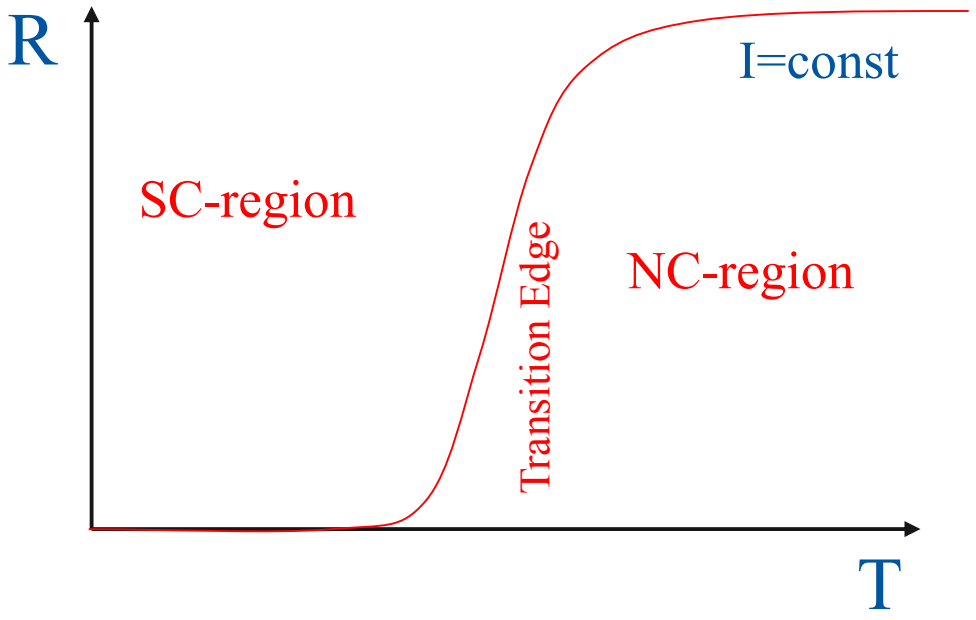


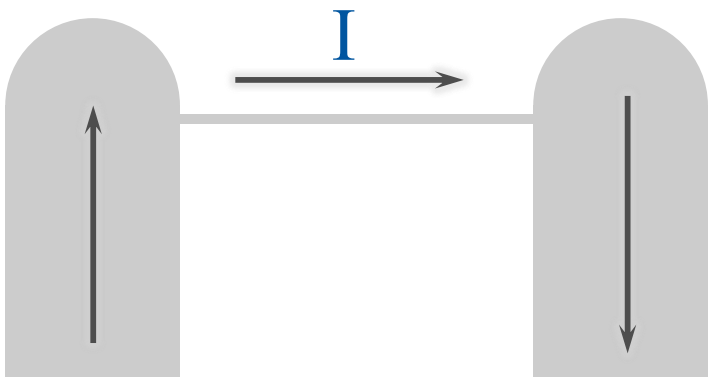
Transition Edge Sensors

Bolometers: tiny and fast temperature variations (≈1 mK, sub-ms range)

Gradual SC to NC transition of thin film alloy

Only sensitive in the transition range





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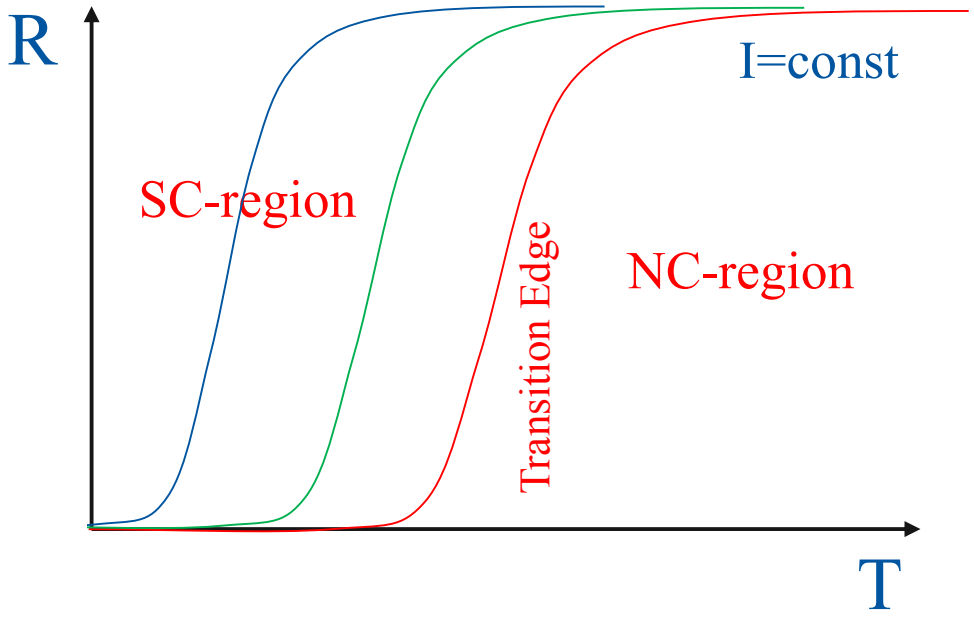
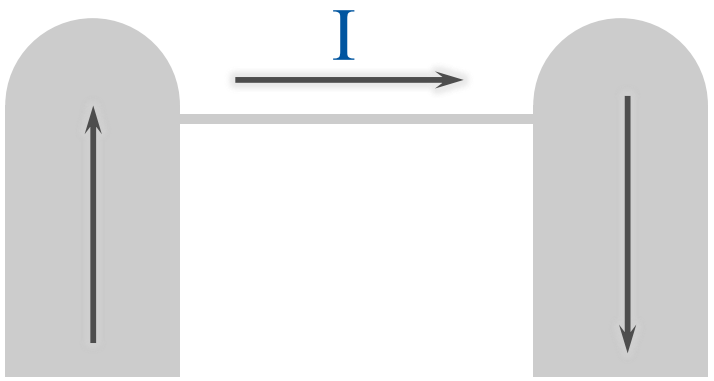
Transition range ‘tuned’ with a bias current





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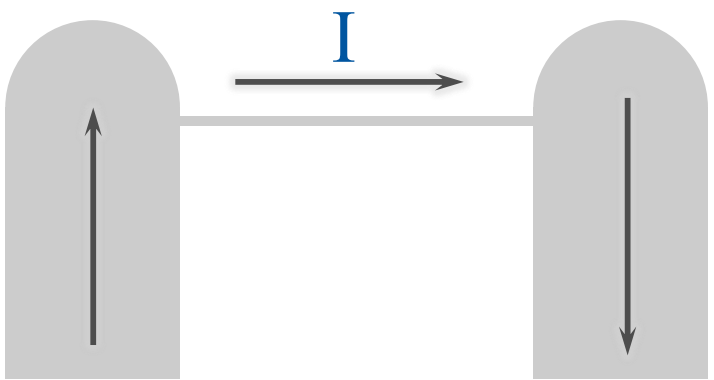
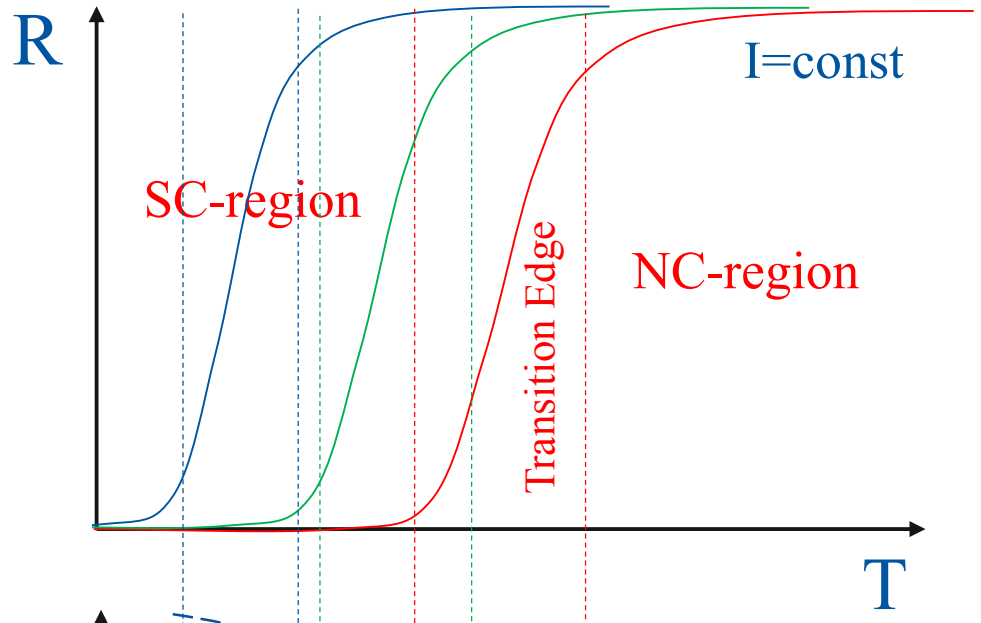
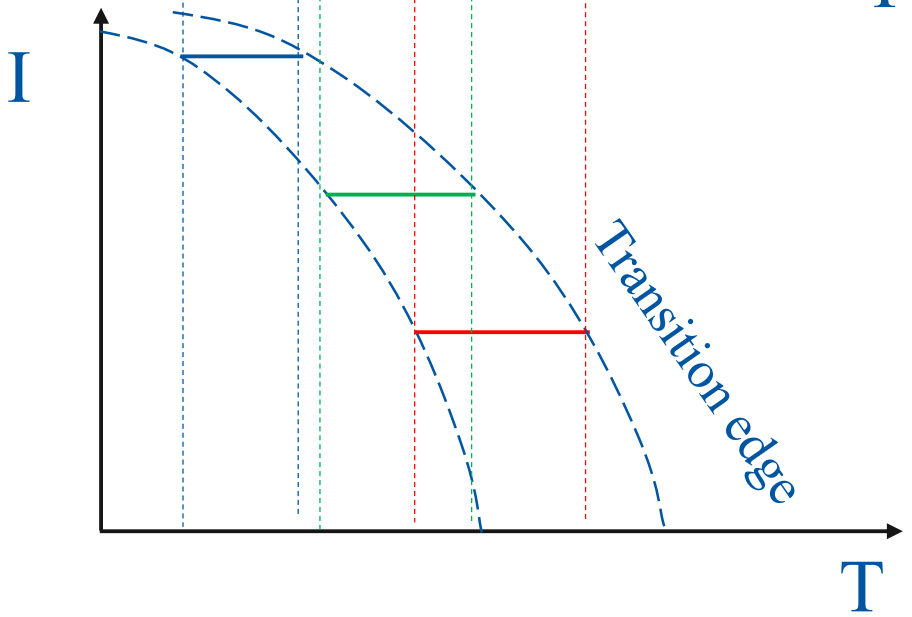






TES development at CERN

Fabrication, designs, characteristics

TES fabrication process developed at CERN

2 Lift-off-based processes with different deposition method

Process description	Cross-section
Coating positive resist	
LASER Writing Direct	
Developing	
Metal Deposition	
Evaporation / *Sputtering*	
Lift-off with solvents	

The lift-off step takes around two days.

Etching-based process

Process description	Cross-section
Metal deposition *Sputtering*	
Coating positive resist	
LASER Writing Inverted	
Developing	
Ion Beam Etching	
Resist stripping	

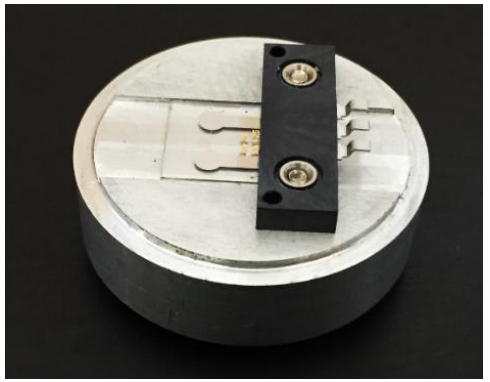
This process can be achieved in 4 hours.

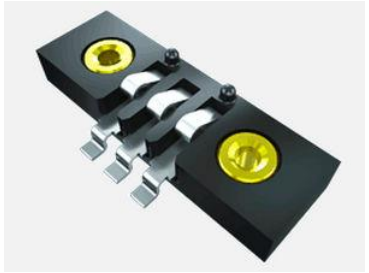
Both processes have been fully specified and mastered to obtain good sensors.

TES designs

Camera-like device

Individual chips





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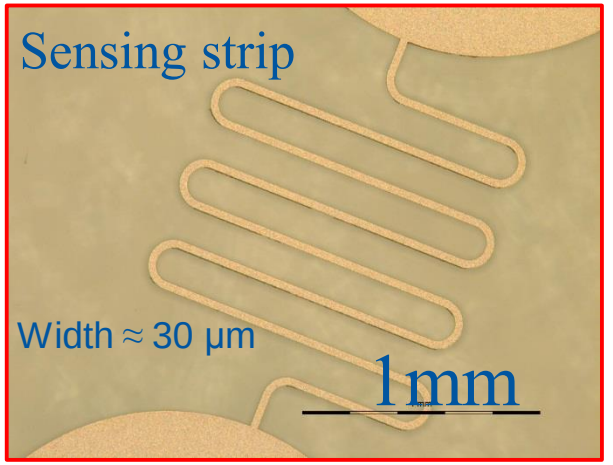
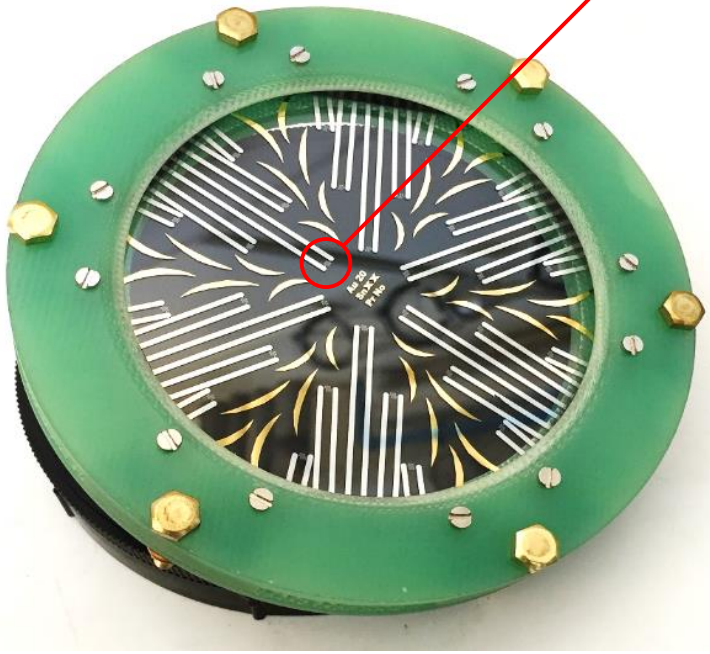


Camera-like device



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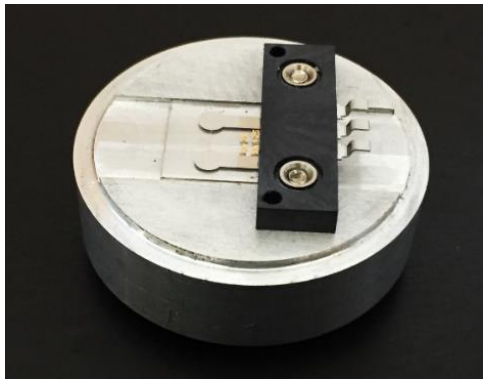
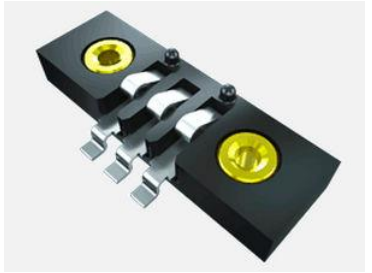
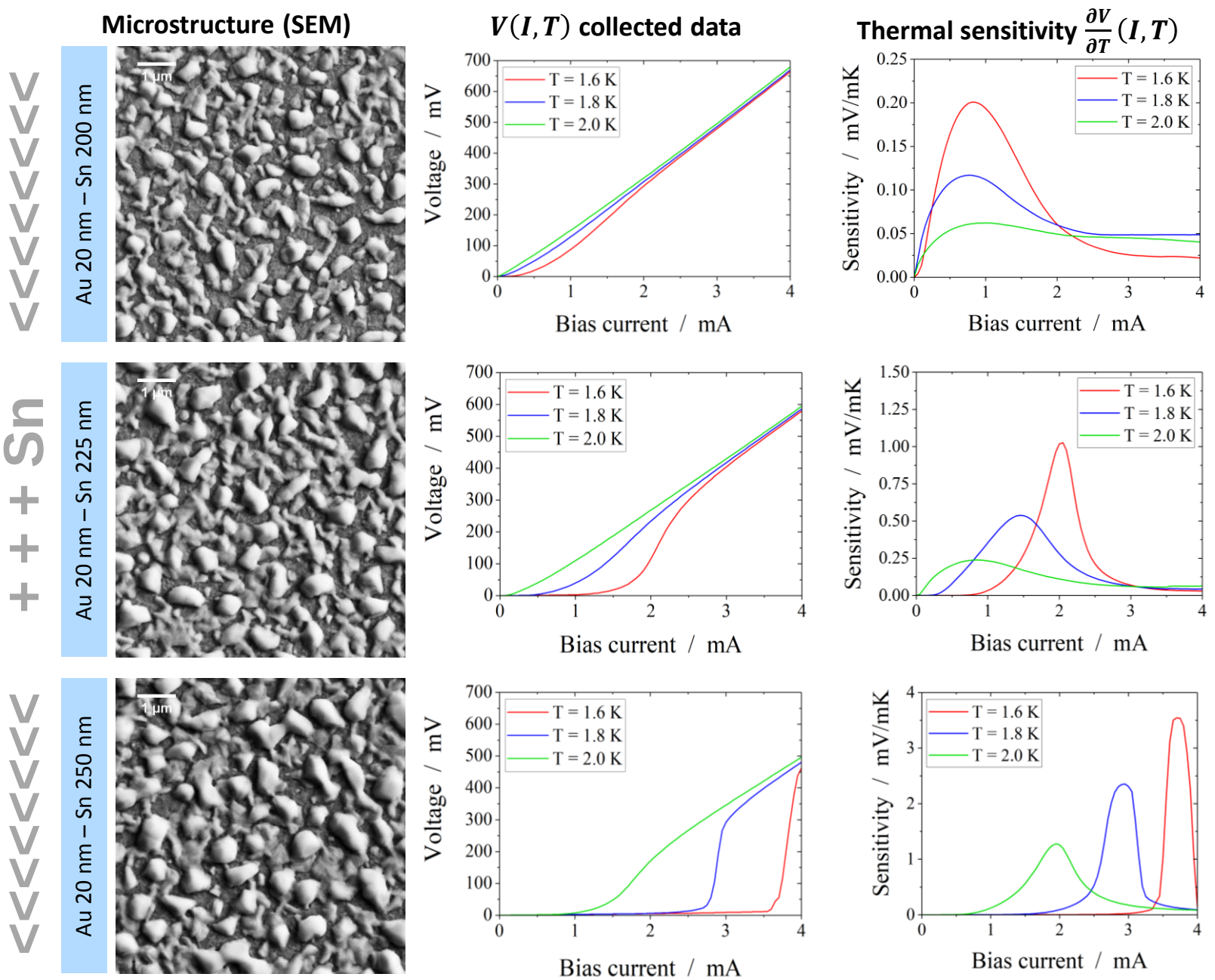




TES properties

- Au-Sn TES thin films are inhomogeneous
- Sn-rich features lay on a Sn-poorer matrix
- Transition behaviour extremely sensitive to Sn content
- SC behaviour ruled by inter-feature distance?
- The thermal history of the thin film is crucial

For more info, come and see POSTER M-09: 164



Second sound experiments with TES

Second sound speed

Localisation of small heat sources

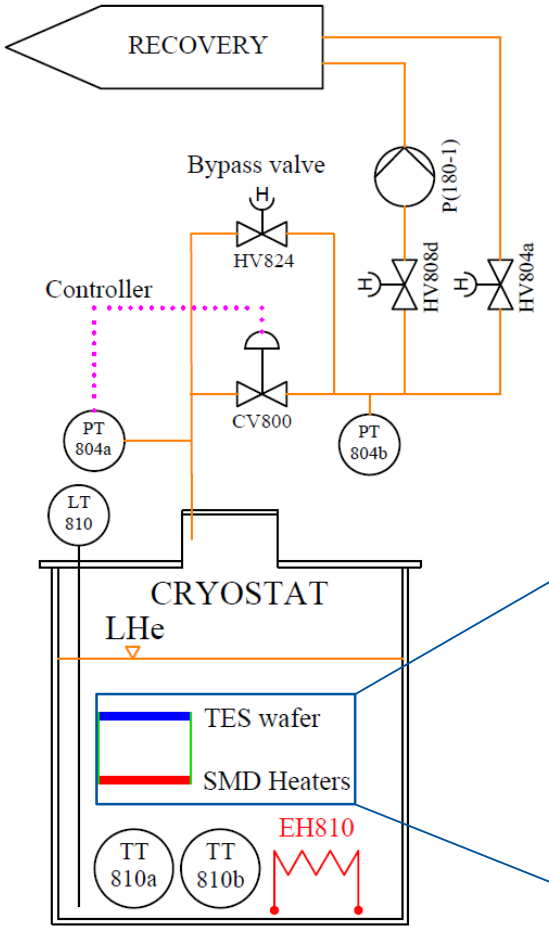
Second sound intensity distribution

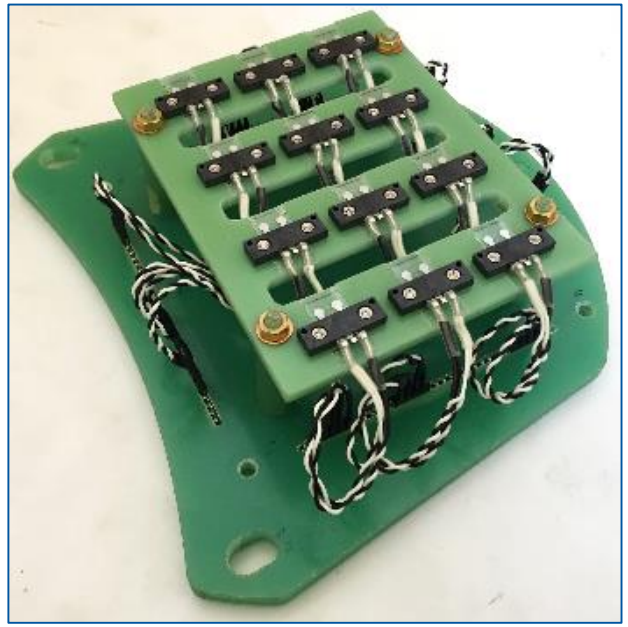
Extended heat sources

Second sound tests setup at the Cryolab

- Saturated superfluid helium ($T = 1.6 - 2.1$ K)
- TES are biased with a variable current regulated source
- SMD heaters imitate quench spot
- DAQ and heater control

  NI, up to 100 kHz, 24 bits in 3 V range





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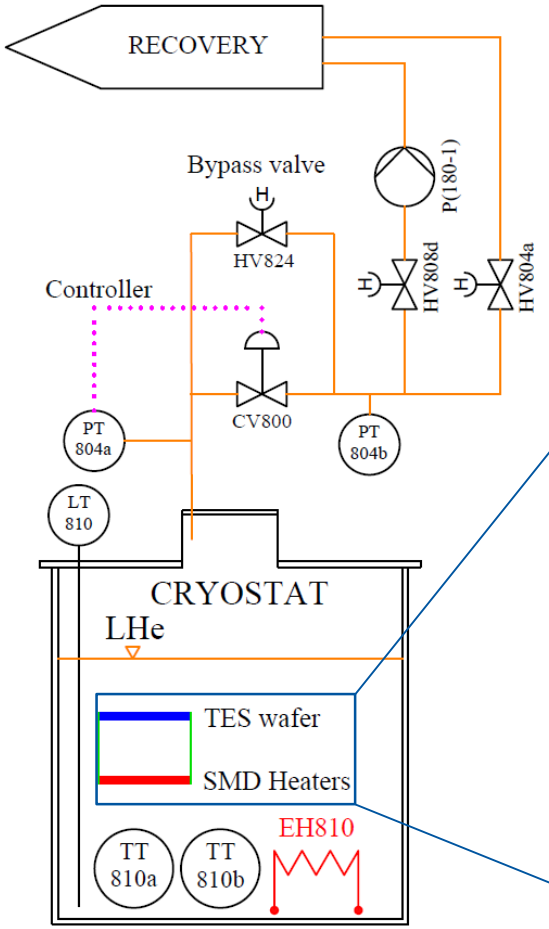
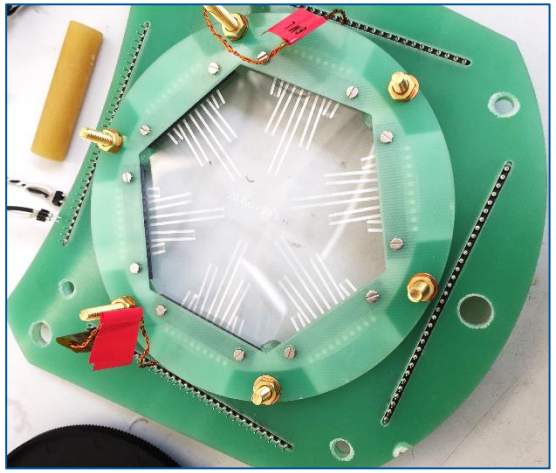
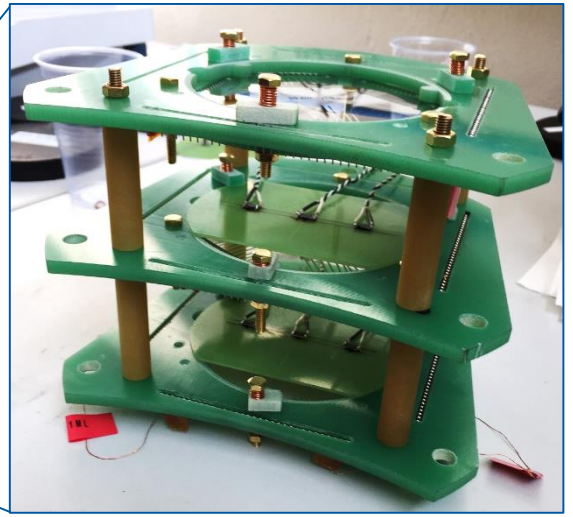
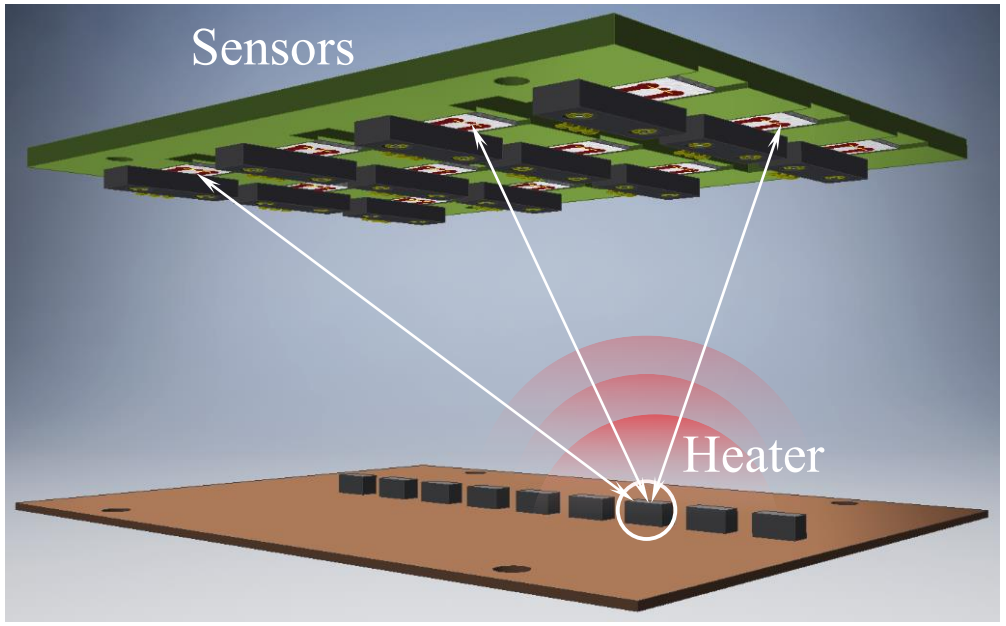


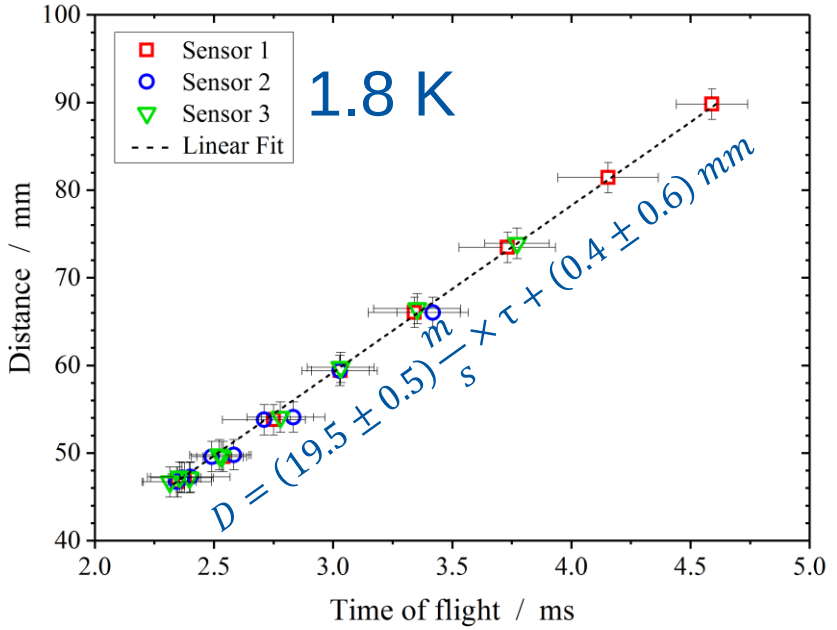


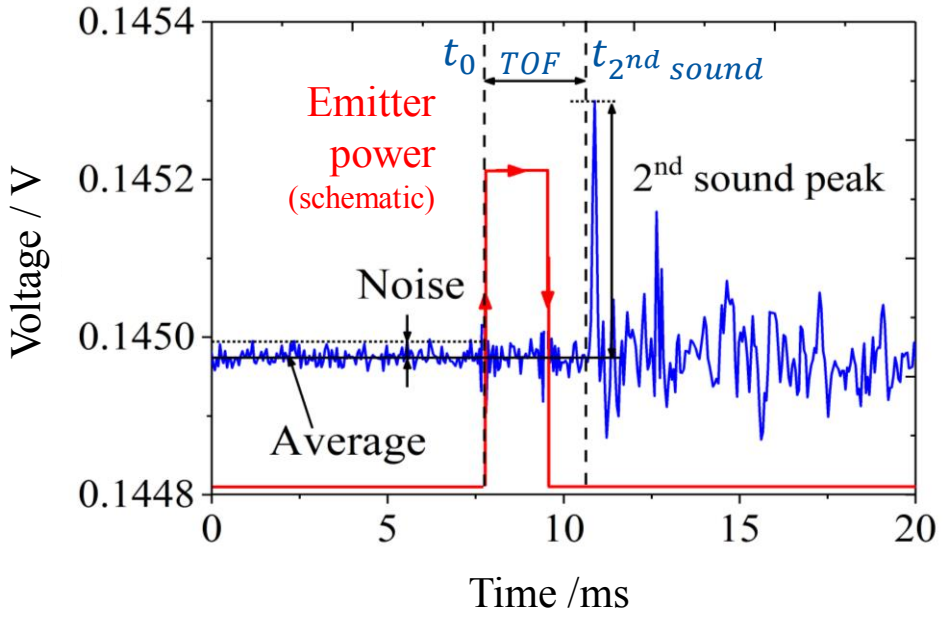


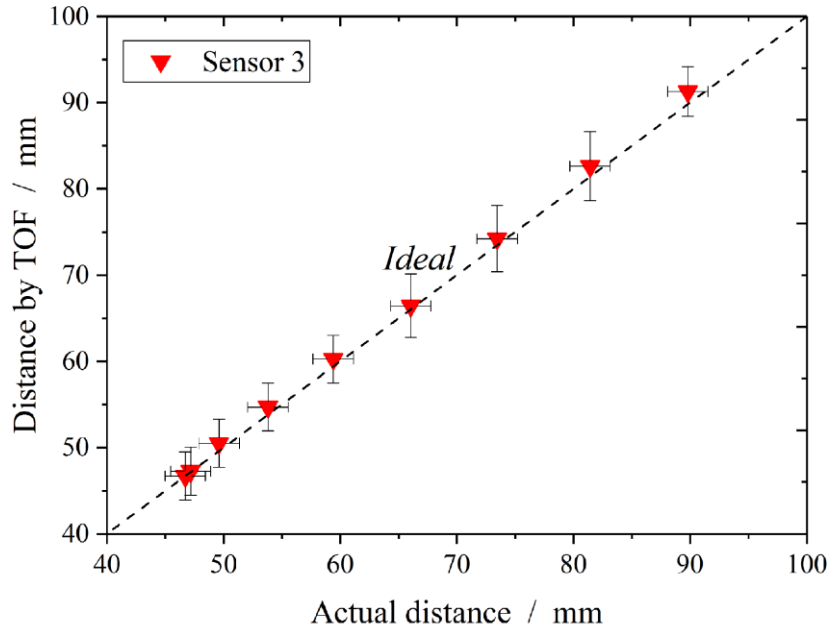
Second sound speed

- Relative position of heat sources and sensors are known
- TOF of second sound is determined from measurement
- Second sound velocity was measured to 2% agreement with values of 19.9 m/s in literature (Donnelly, J. Phys. Chem. Ref. Data, Vol. 27, No. 6, 1998).



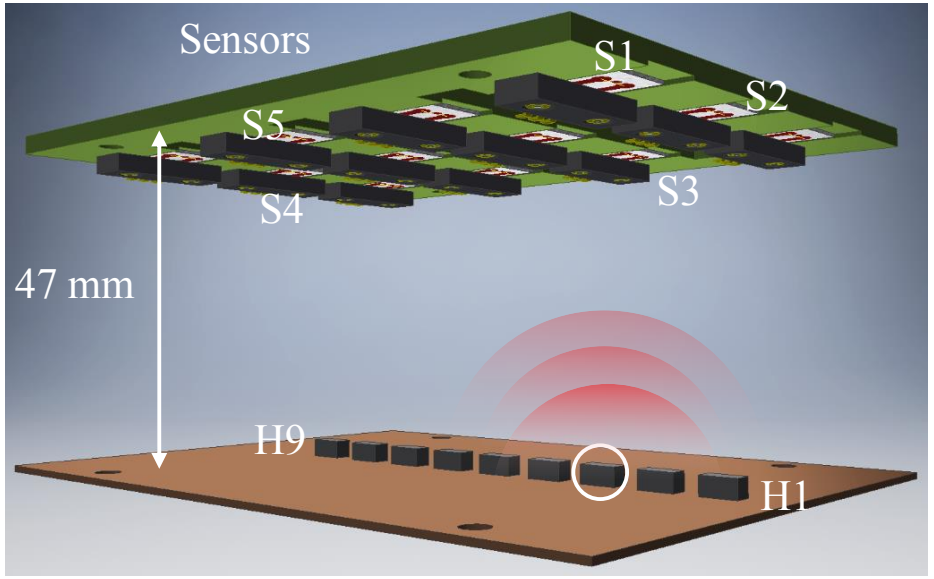






Localisation of small heat sources

Test at 2 K, with 5 sensors and 9 heaters (3 x 6 mm^2)
Second sound speed taken from literature, TOF measured
Application of trilateration algorithm (direct line of sight)



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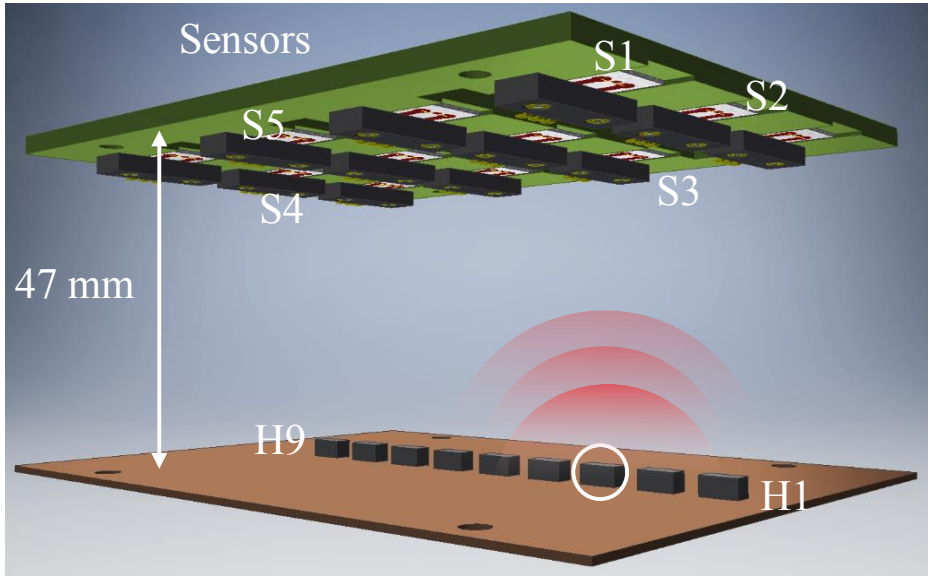

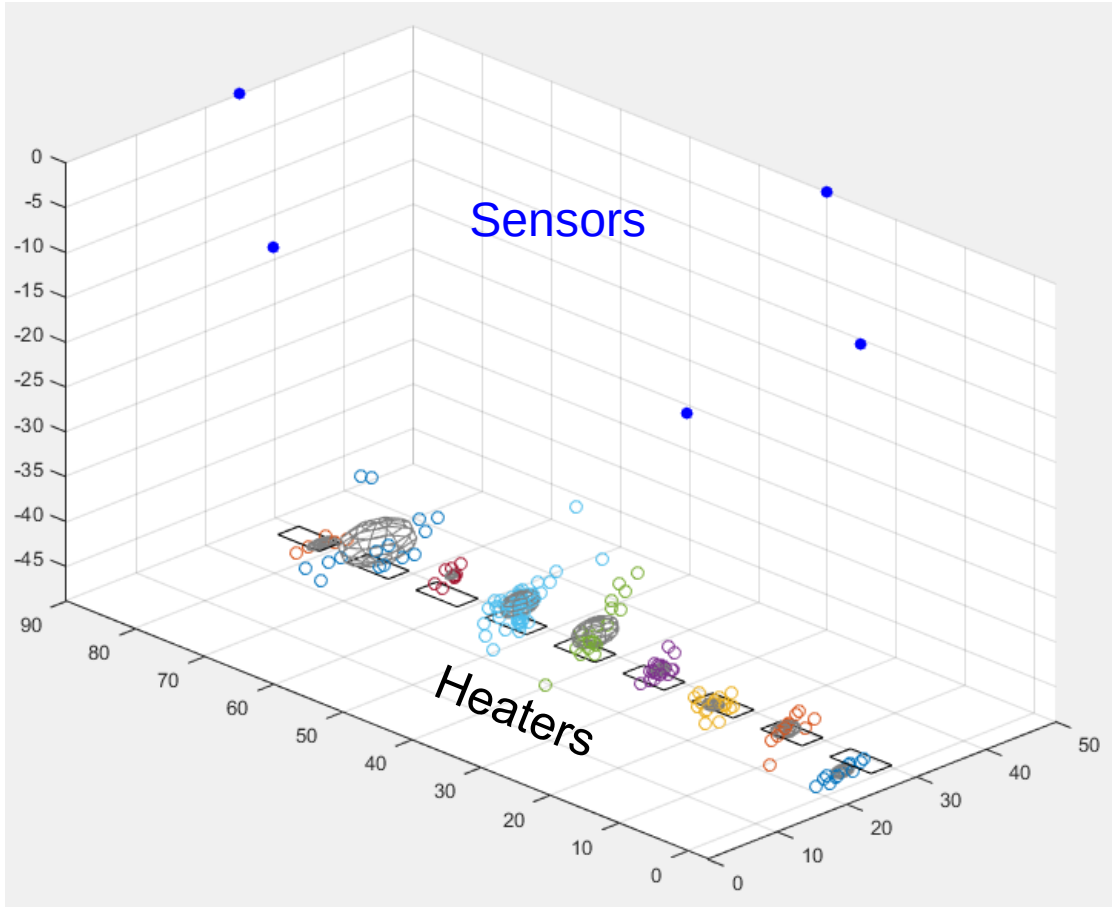

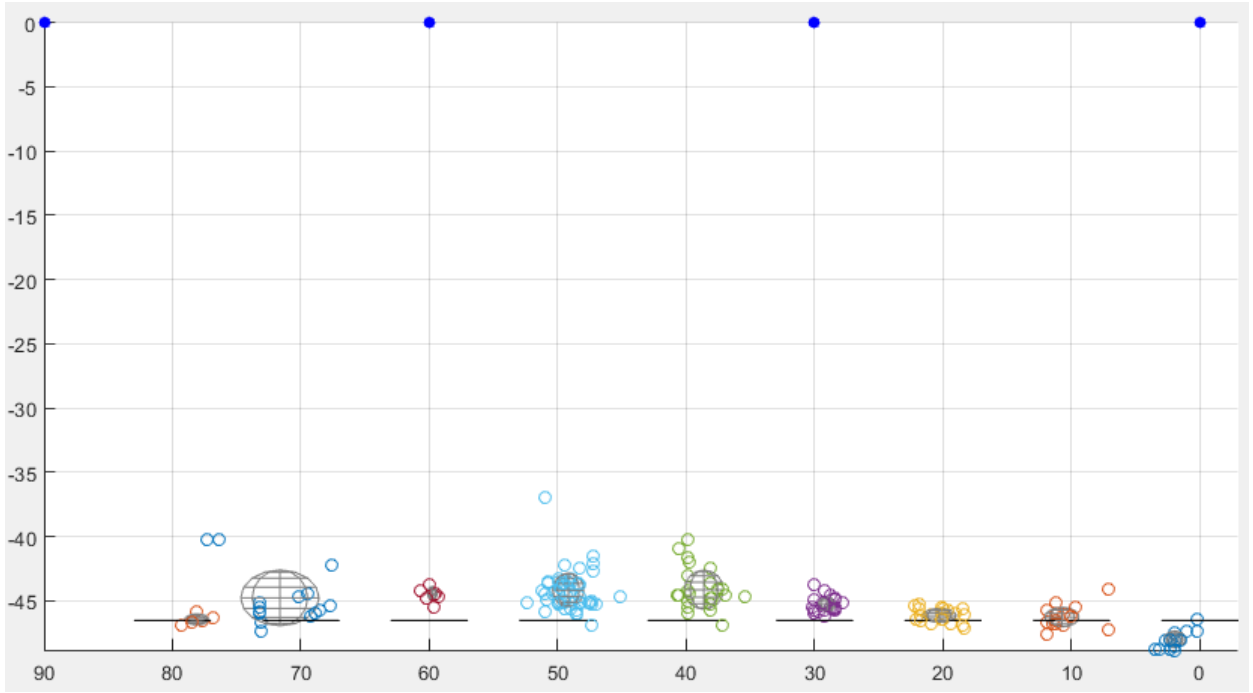

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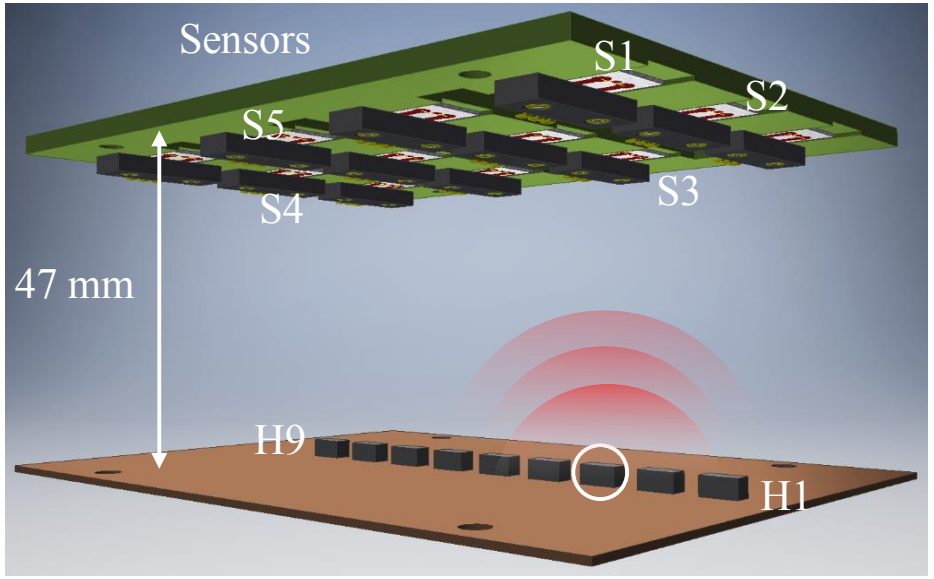
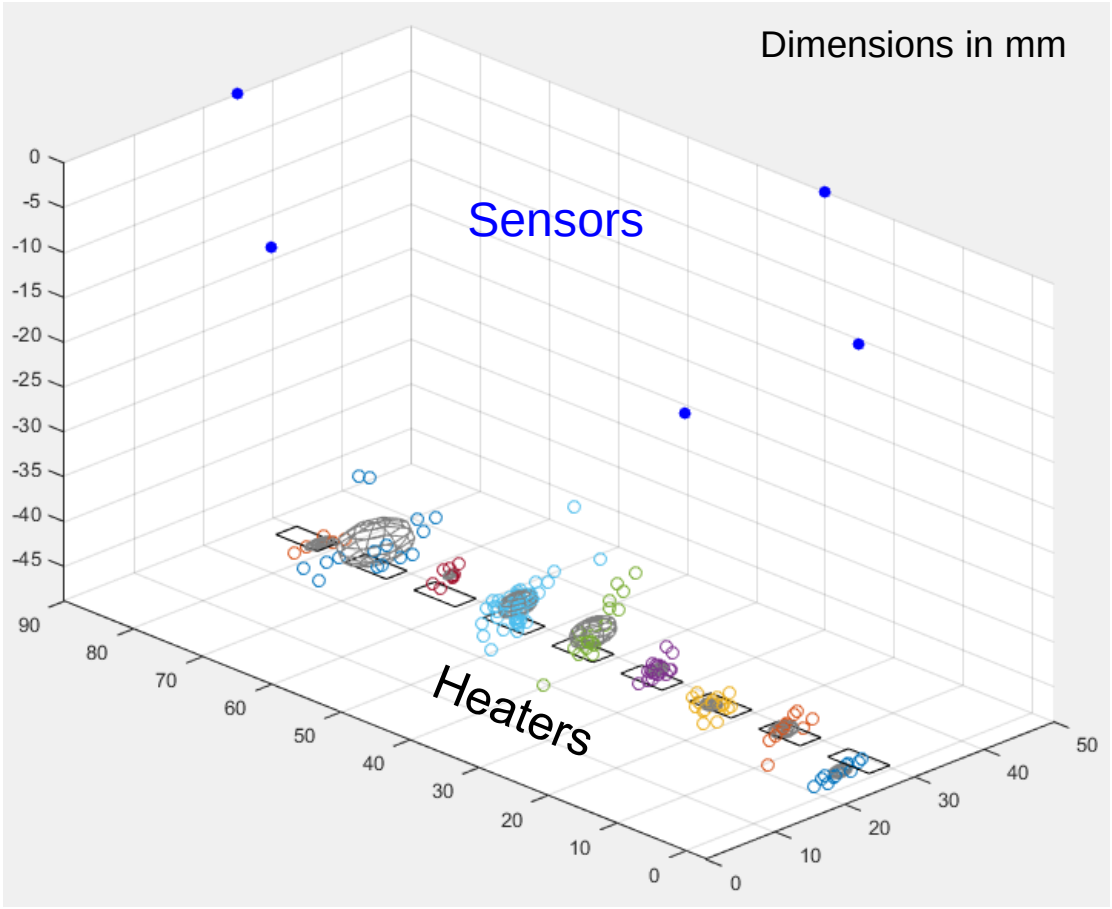
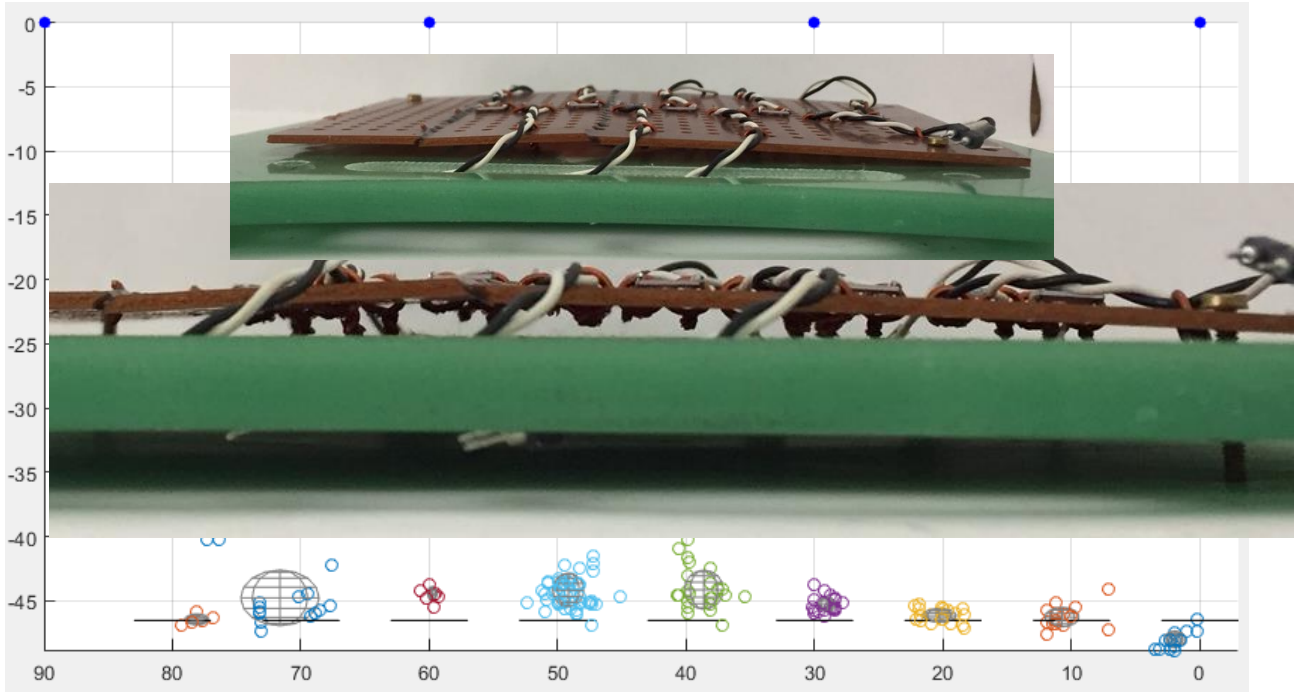
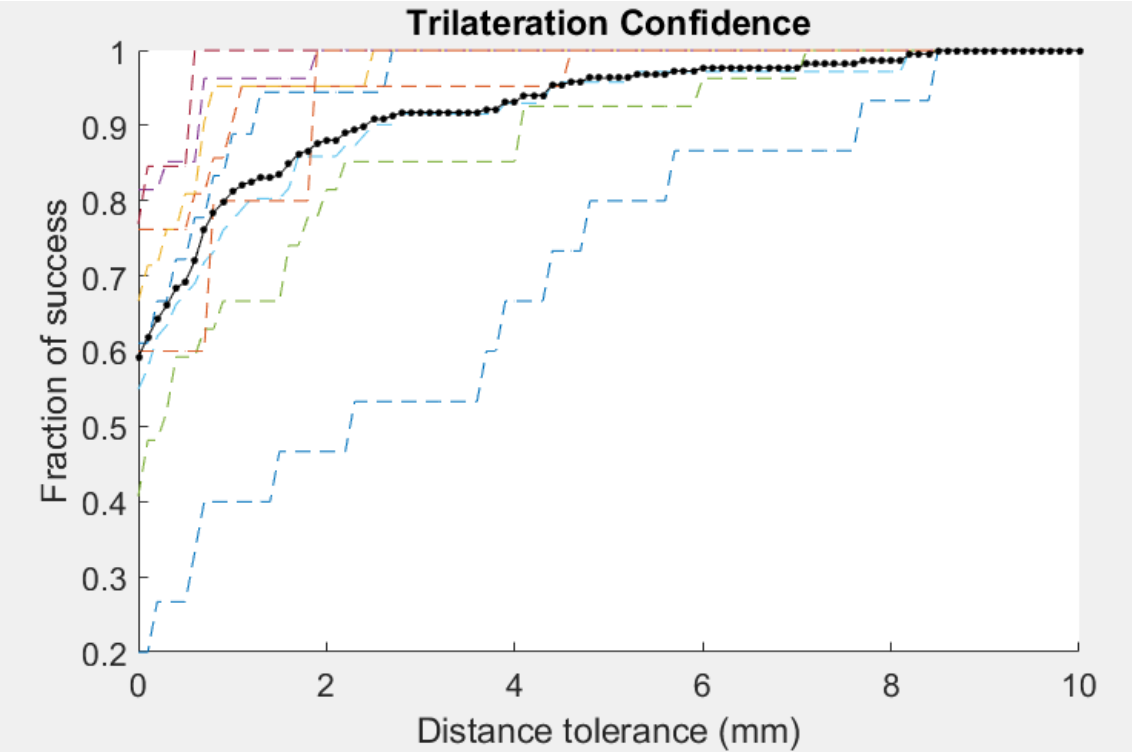


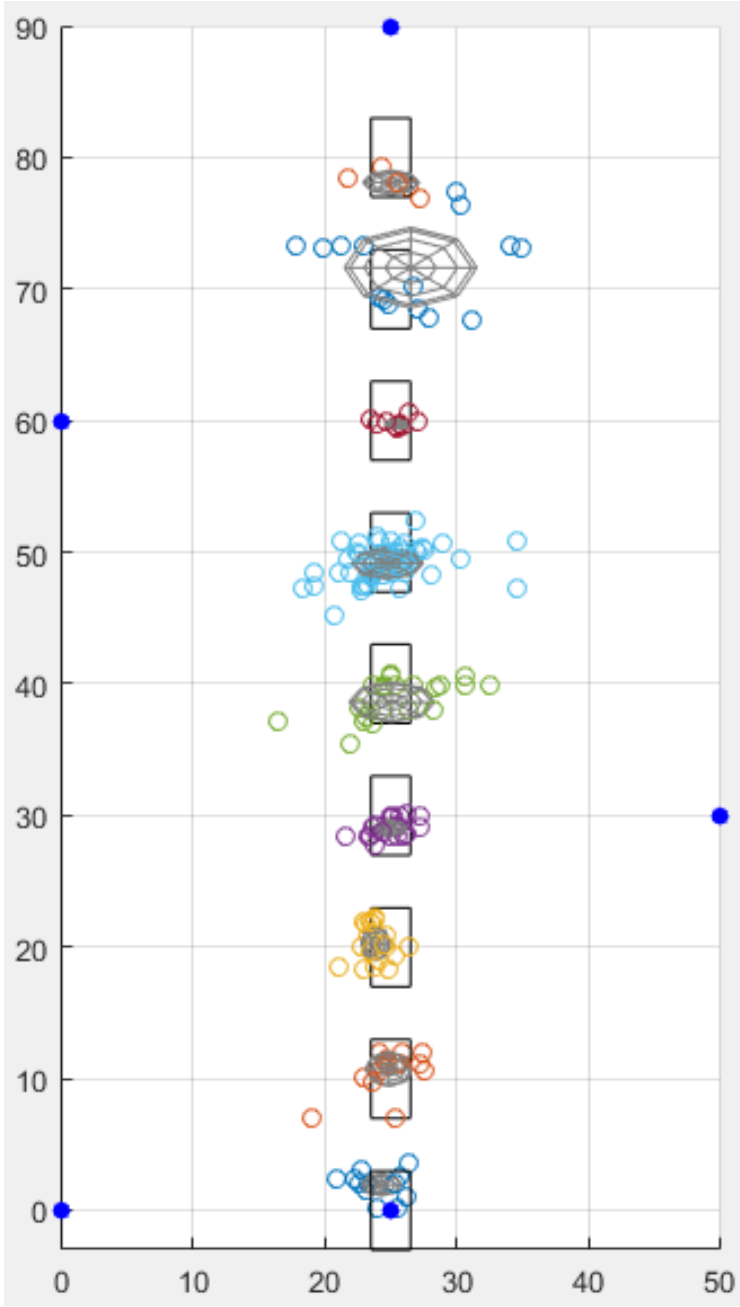




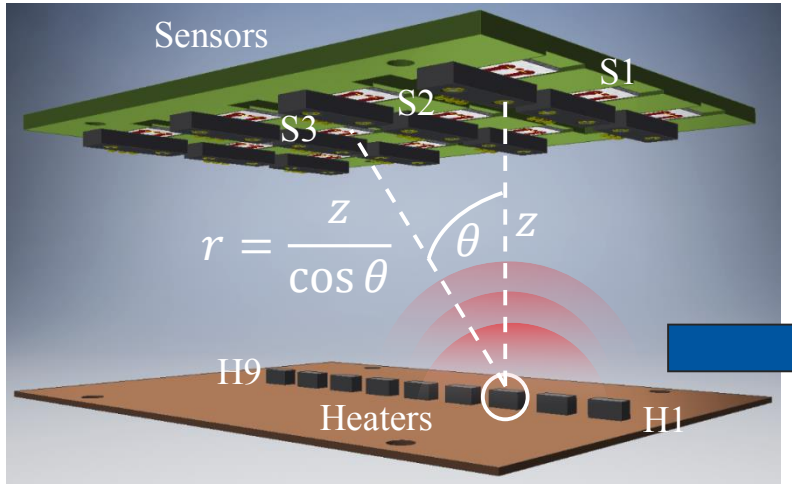
Localisation of small heat sources

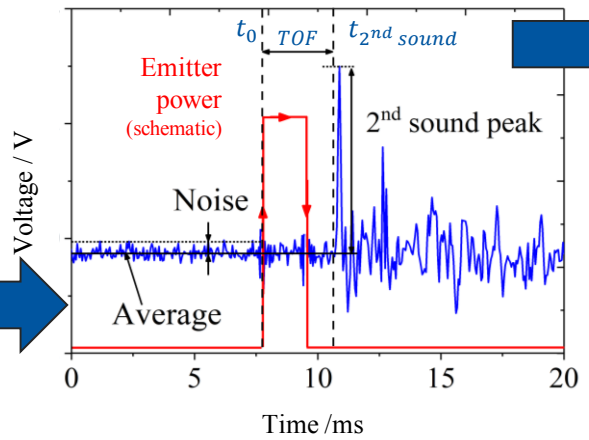
Test at 2 K, with 5 sensors and 9 heaters (3 x 6 mm^2)
Second sound speed taken from literature, TOF measured
Application of trilateration algorithm (direct line of sight)
In more than 88 % of the cases, within 2 mm precision!
Uncertainty dominated by positioning and algorithm limitations
(but not by the sensor)

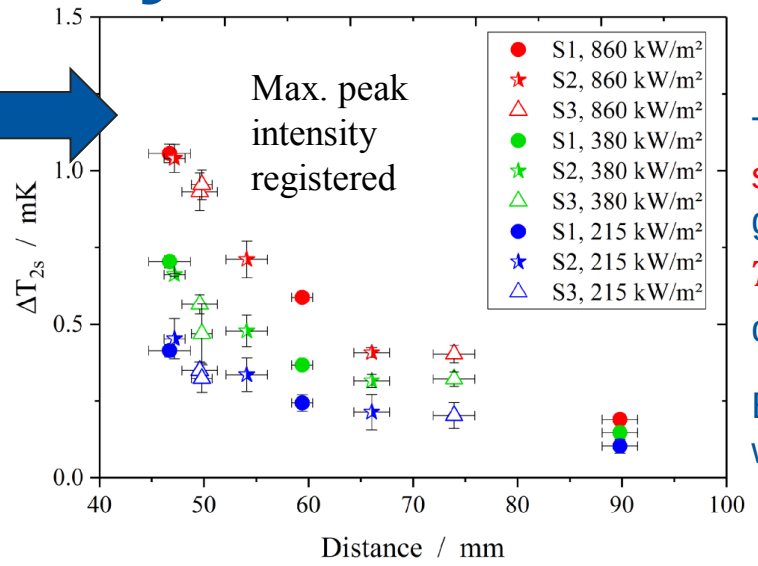




Second sound intensity distribution



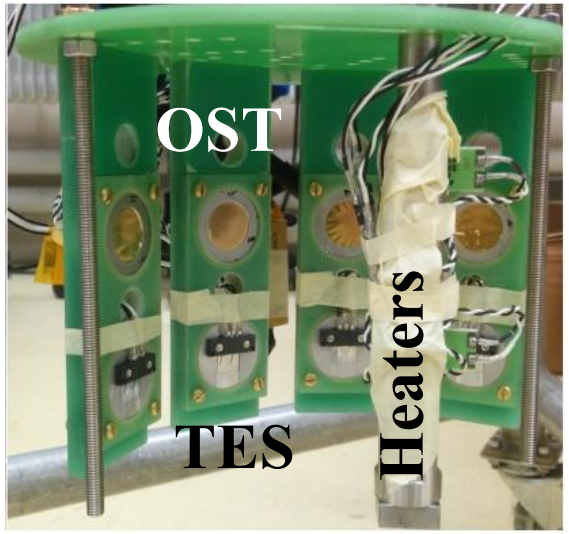


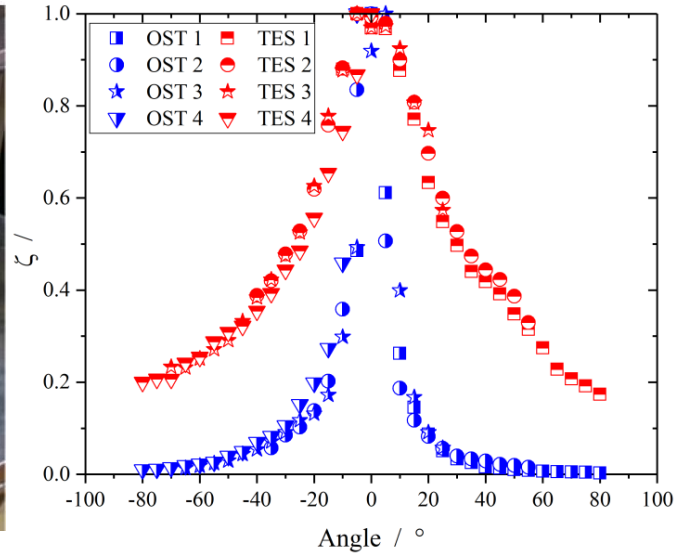


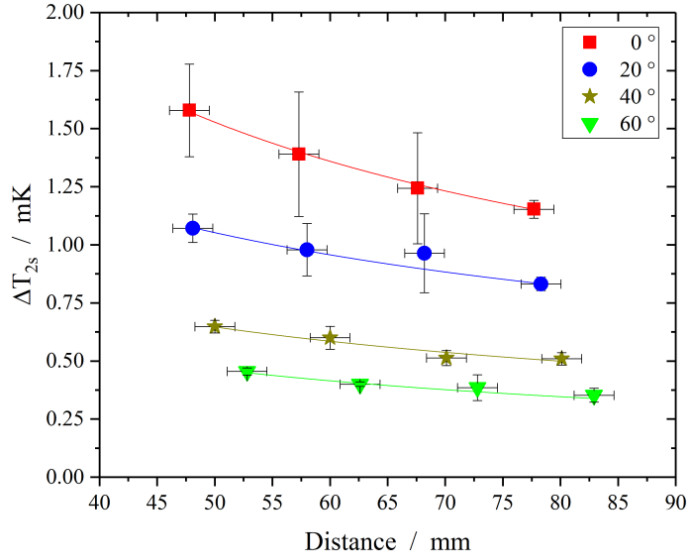
$$\frac{\partial^2 T}{\partial t^2} - c^2 \nabla^2 T = 0$$

The wave equation with spherical symmetry gives solutions of type $T = \frac{1}{r} f(r - ct)$ with f depending on B.C.

Experiment → $T = Kr^{-n}$ with $n \approx 2.5 \pm 0.2$

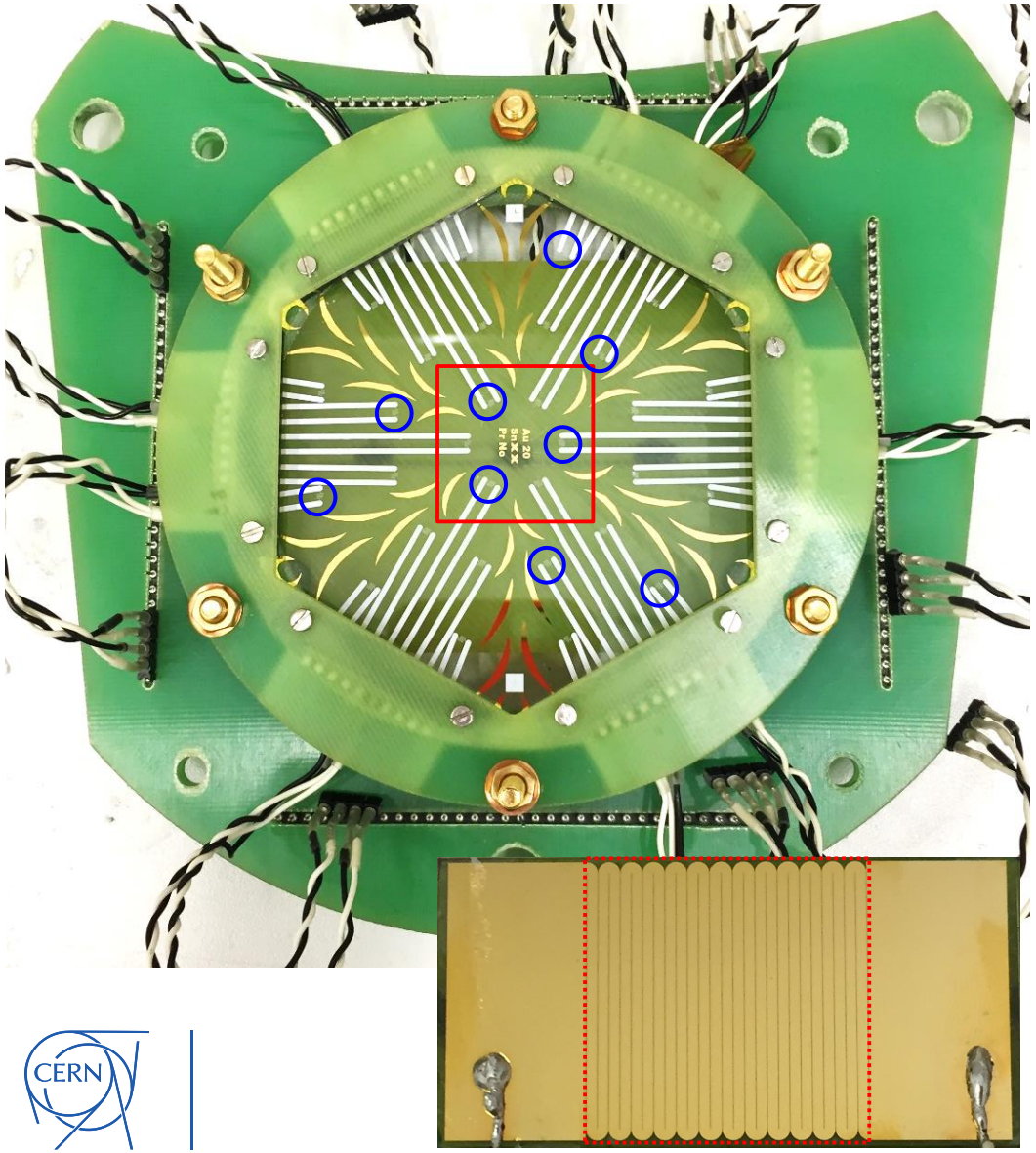


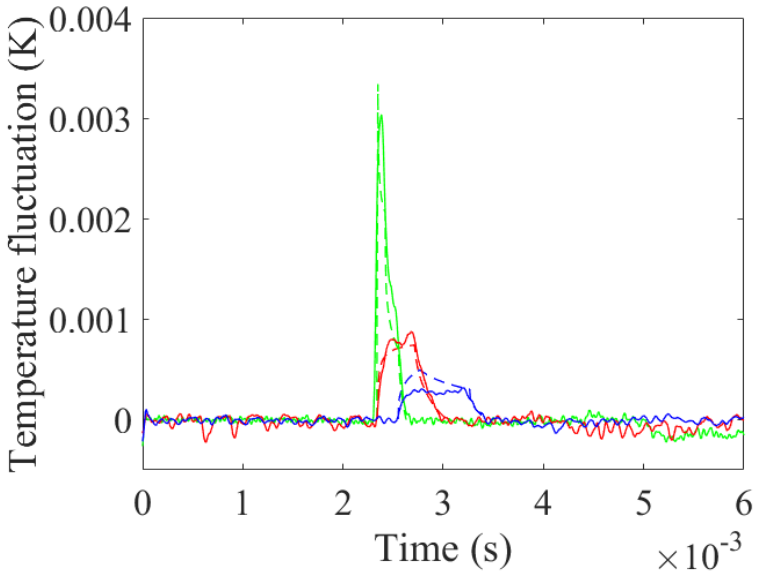


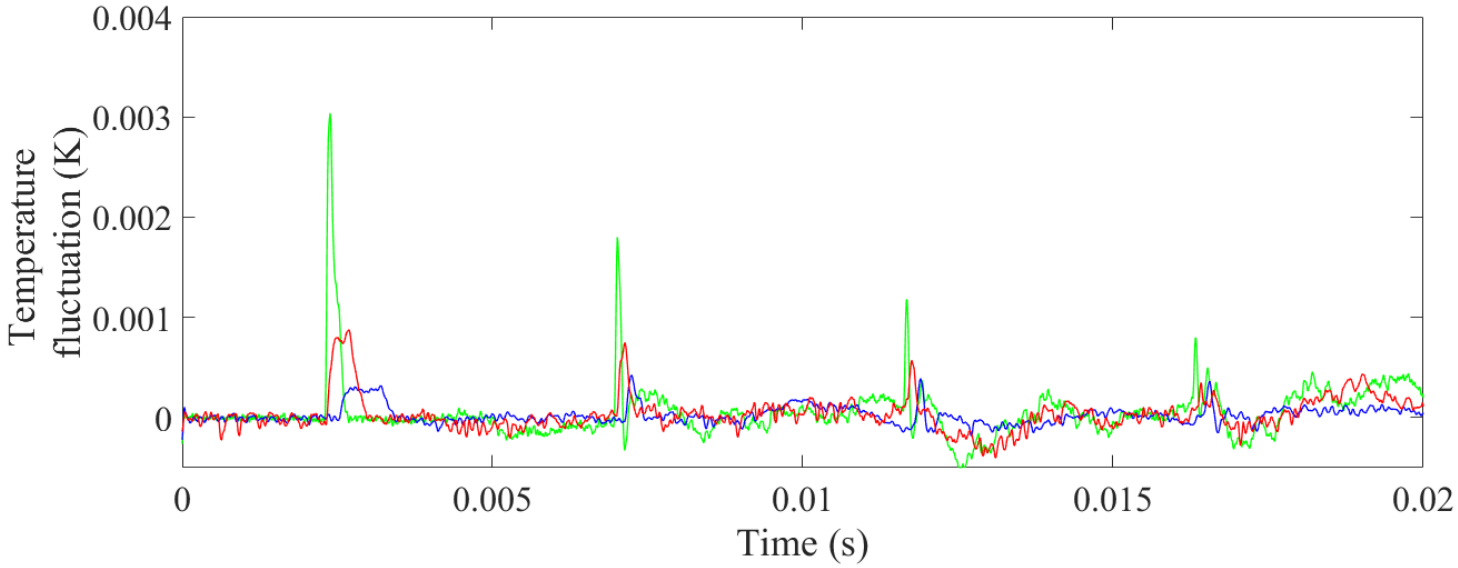


For more, come and see POSTERS E-06: 165 and 166

Experiments with extended heat sources







Different pulse shape and amplitude depending on relative position to heater. Predicted by modelling. For more, come to see posters E-06: 165 and 166

To summarize…

He-II Second sound detectors based on TES thermometry have been designed, prototyped and optimised.

- On-single-wafer Camera-like
- Individual chips

Alternative fabrication processes have been elaborated, tested and tuned.

- Evaporation Lift-off
- Sputtering Lift-off
- Sputtering IBE

TES were validated as a hotspot localisation tool through small scale experiments at the lab.

They also proved their capability as a tool for more fundamental studies.

- Second sound physics

Further development is ongoing

- Improvement of thermal response.
- Characterisation and optimization of the fabrication process.
- Production.

Giovanna Vandoni

- BE-RF
- Senior Scientist
- SRF activities coordinator

Torsten Koettig

- TE-CRG-CI
- Senior Cryogenics Scientist
- Cryolab R&D Coordinator

Hernán Furci

- BE-RF-SRF
- Senior Fellow
- Cryogenics Scientist
- R&D project responsible

Mentors

Tobias Stegmaier

- Masters thesis on Cryogenic experimental techniques for SRF

Zsolt Kovàcs

- Bachelor in Material Science with thesis in TES thin films

Ece Özelci

- Master in Mechanical Engineering developing ultra-fast response TES through microfabrication

Undergraduate students

Project started in March 2016

Acknowledgments

Cryolab	Technicians Collaboration	Infrastructure Helium
G. Rosaz, A. Mapelli, CMi of EPFL	Microfabrication techniques	Thin films expertise
A. Lunt, J. Busom Descarrega, F. Leaux	Microscopic analysis	SEM, SESI, ESB, EDX, FIB, etc.
A. Rijllart, E. Michel, P. Fernandez Lopez	DAQ advice	LabVIEW support

Do not miss the sequel! Oral E-14:163

Superconducting cavities quench localisation by He-II second sound detection with transition edge sensors

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S. Barriere, A. Castilla, N. Shipman, K. Turaj,
M. Wartak, A. Zwozniak

ICEC 2018 – Oxford, UK – September 2018

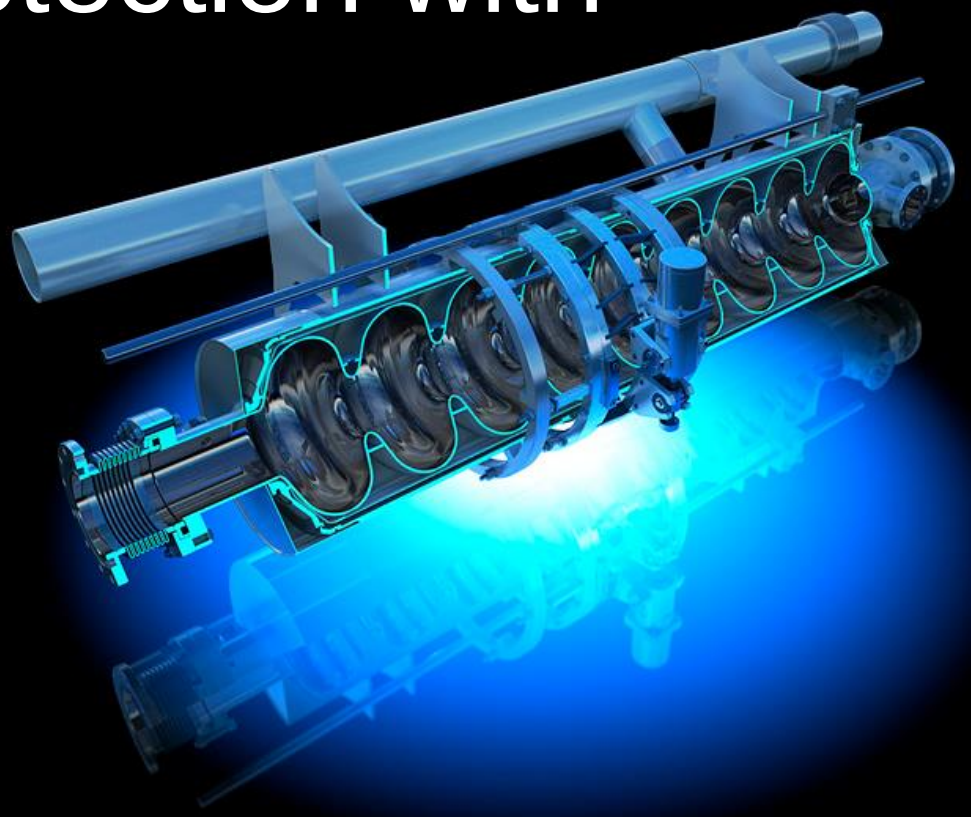

Image source: http://www.yk.rim.or.jp/~reyhori/pages/galacc4_e.html


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