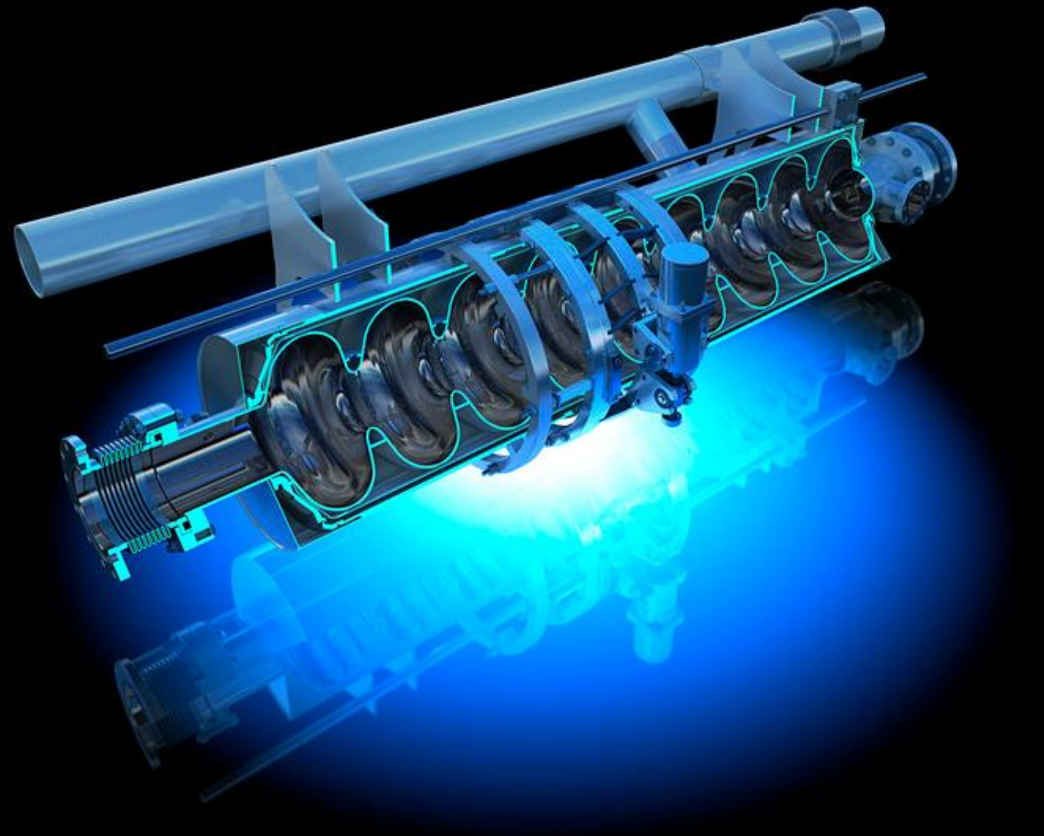
Superconducting cavities quench localisation by He-II second sound detection with transition edge sensors

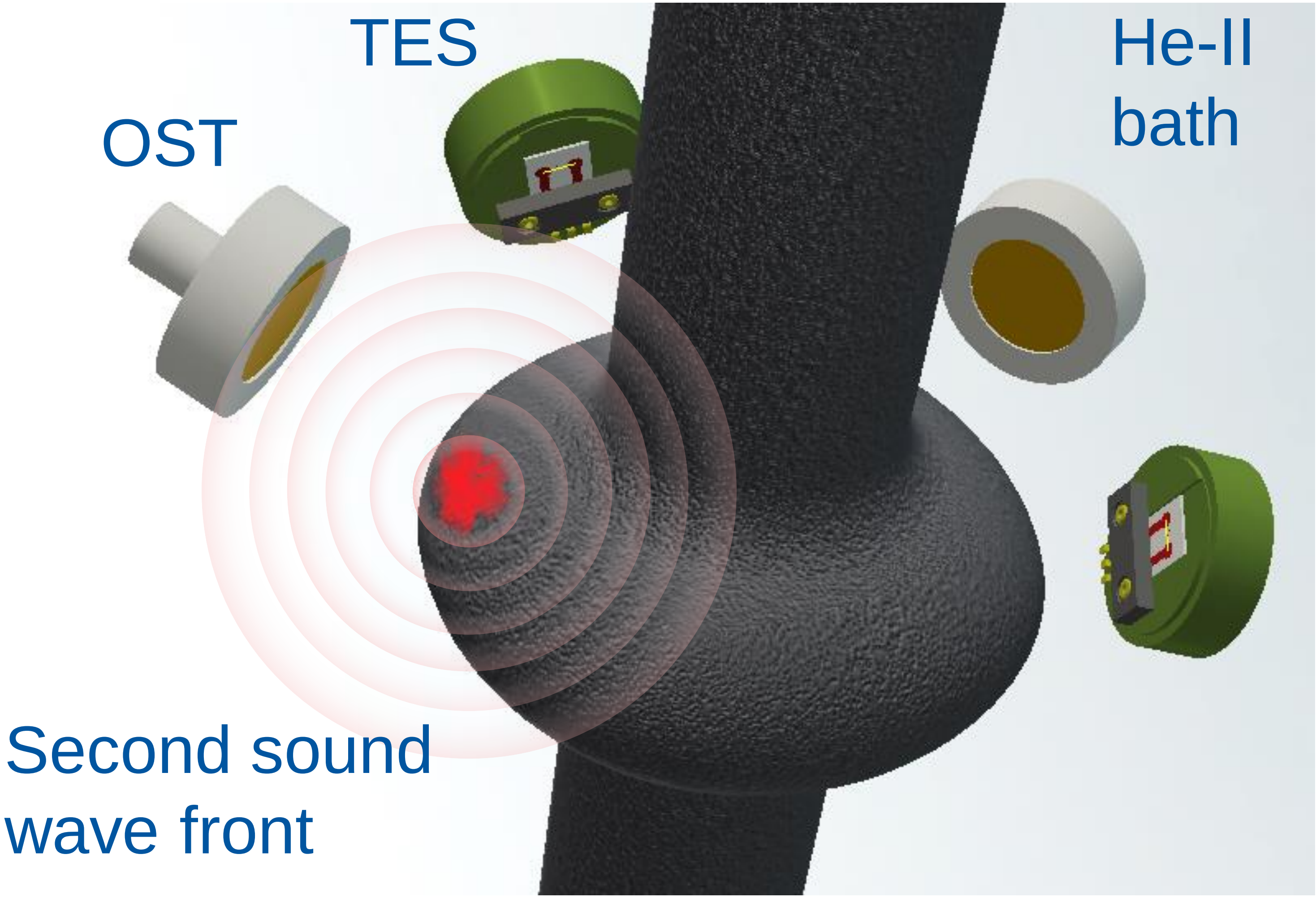
Hernán Furci hernan.furci@cern.ch
Giovanna Vandoni, Alick Macpherson
S. Barriere, A. Castilla, N. Shipman, K. Turaj,
M. Wartak, A. Zwozniak



ICEC 2018 – Oxford, UK – September 2018
E-14: 163

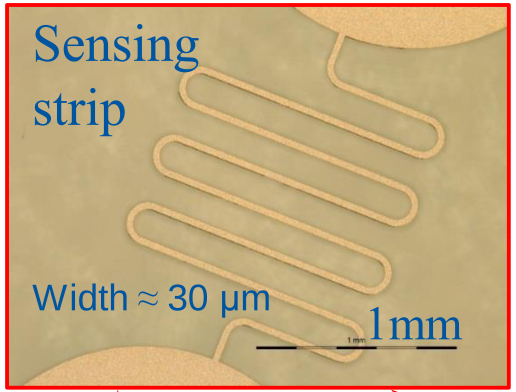
Image source: http://www.yk.rim.or.jp/~reyhori/pages/galacc4_e.html

TES at CERN for quench localisation
(E-08:162)

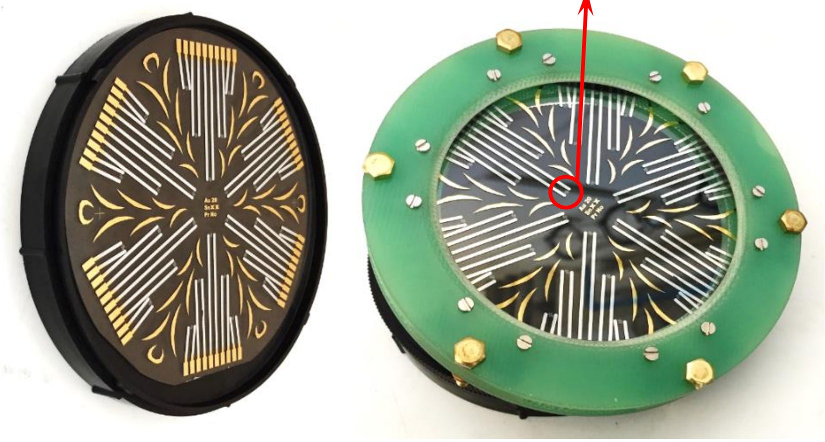


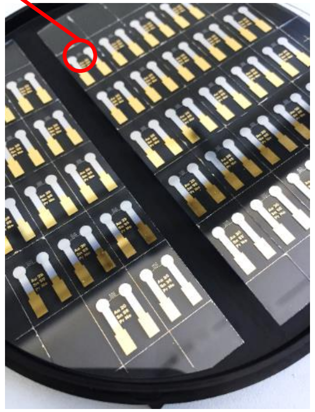
TES at CERN for quench localisation

(E-08:162)

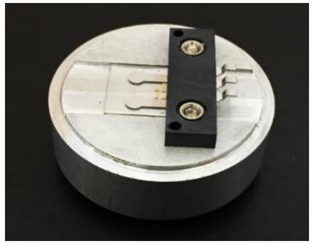


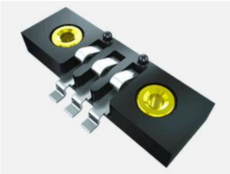
Camera-like device

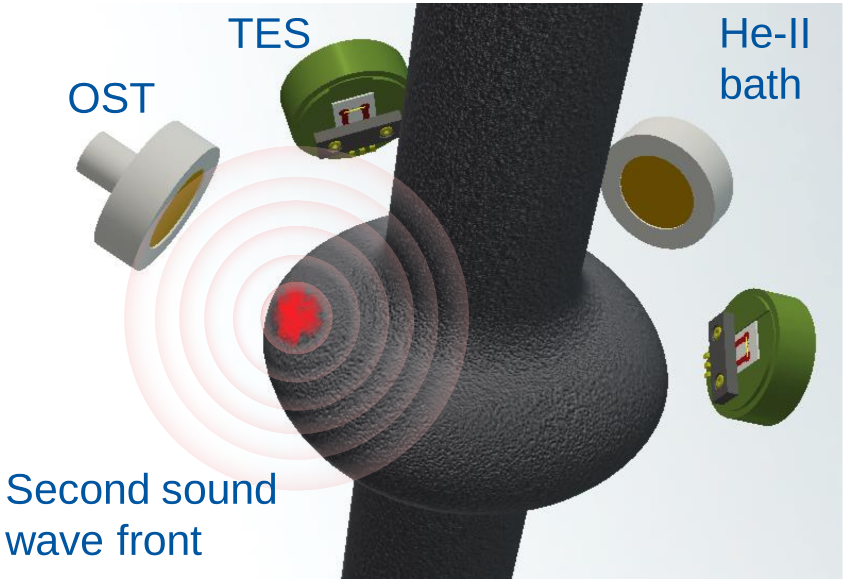




Individual chips

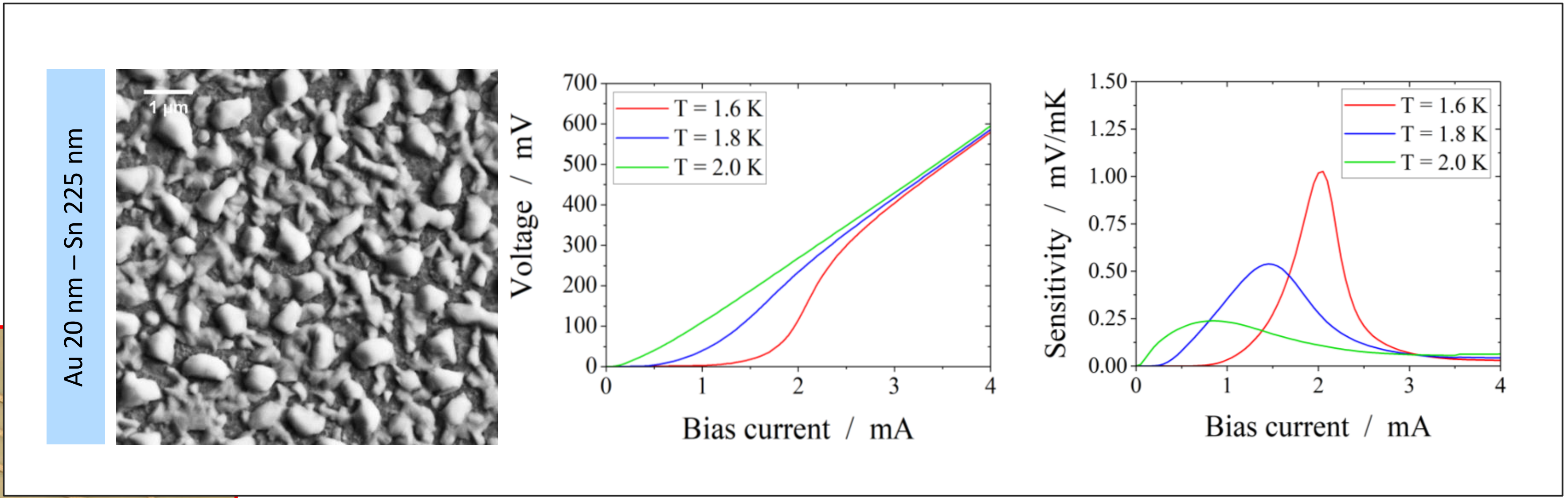


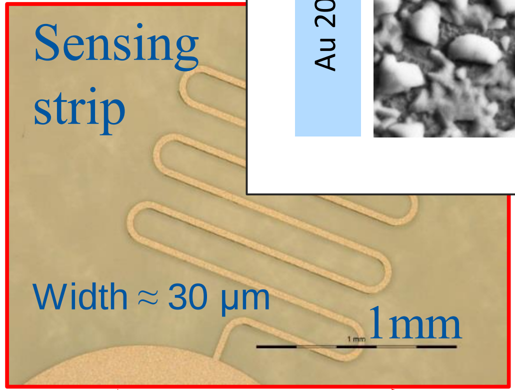




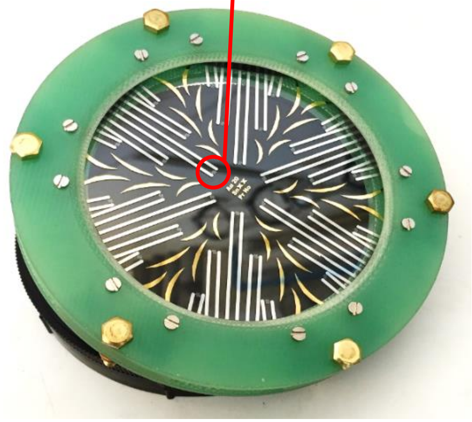
TES at CERN for quench localisation

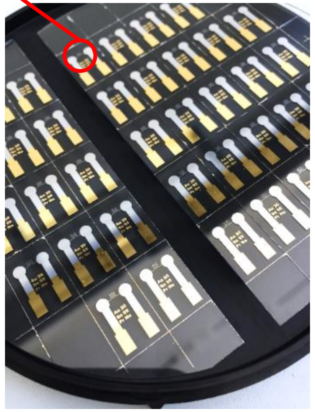
(E-08:162)



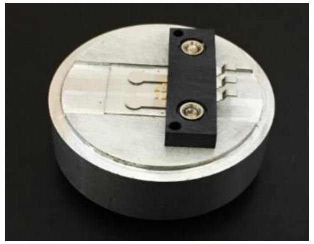


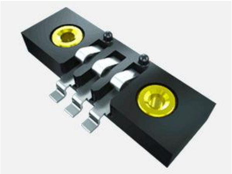
Camera-like device

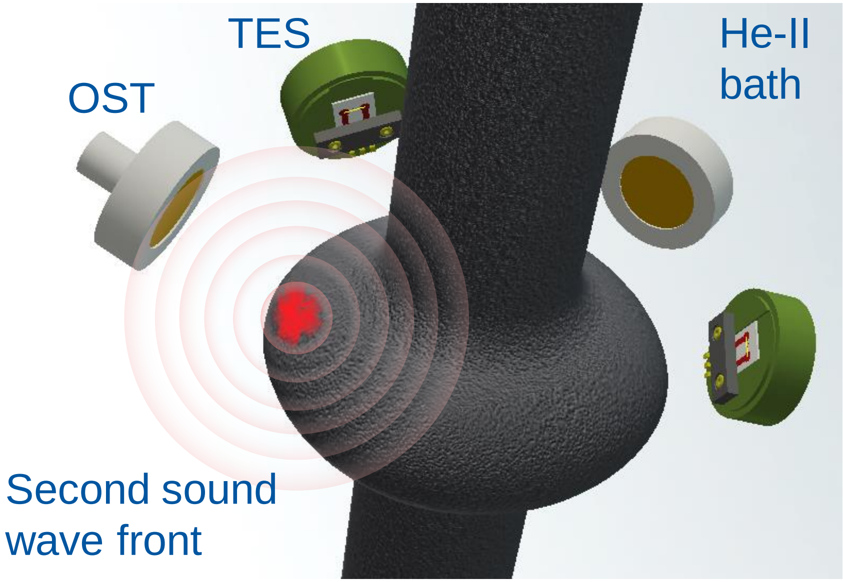




Individual chips

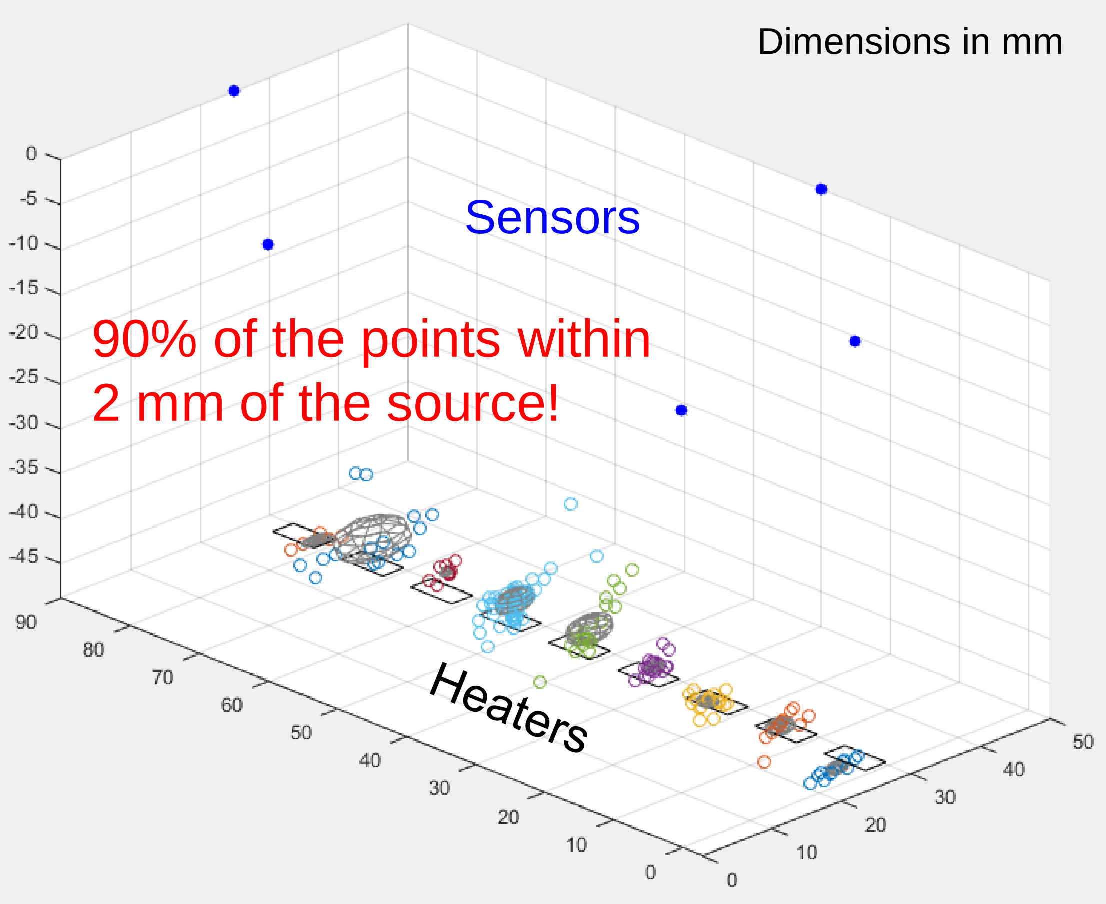


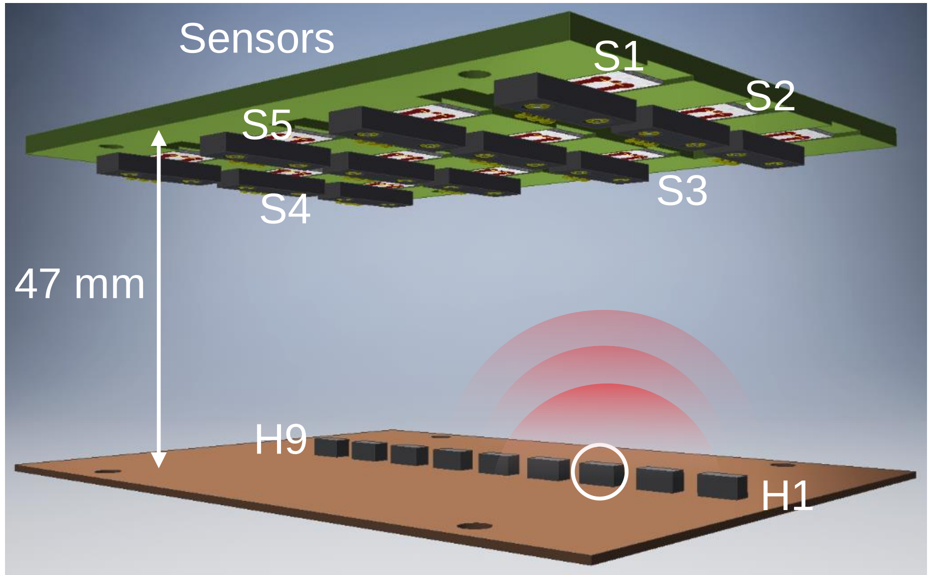


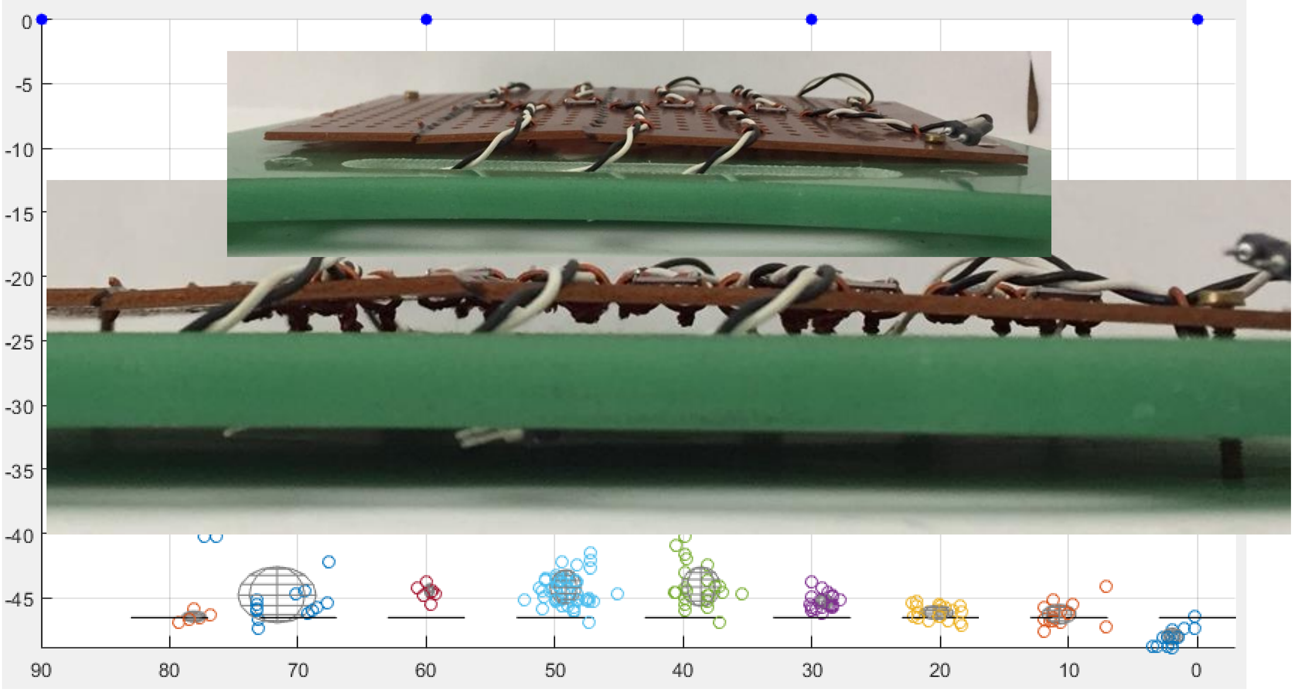


Localisation of small heat sources

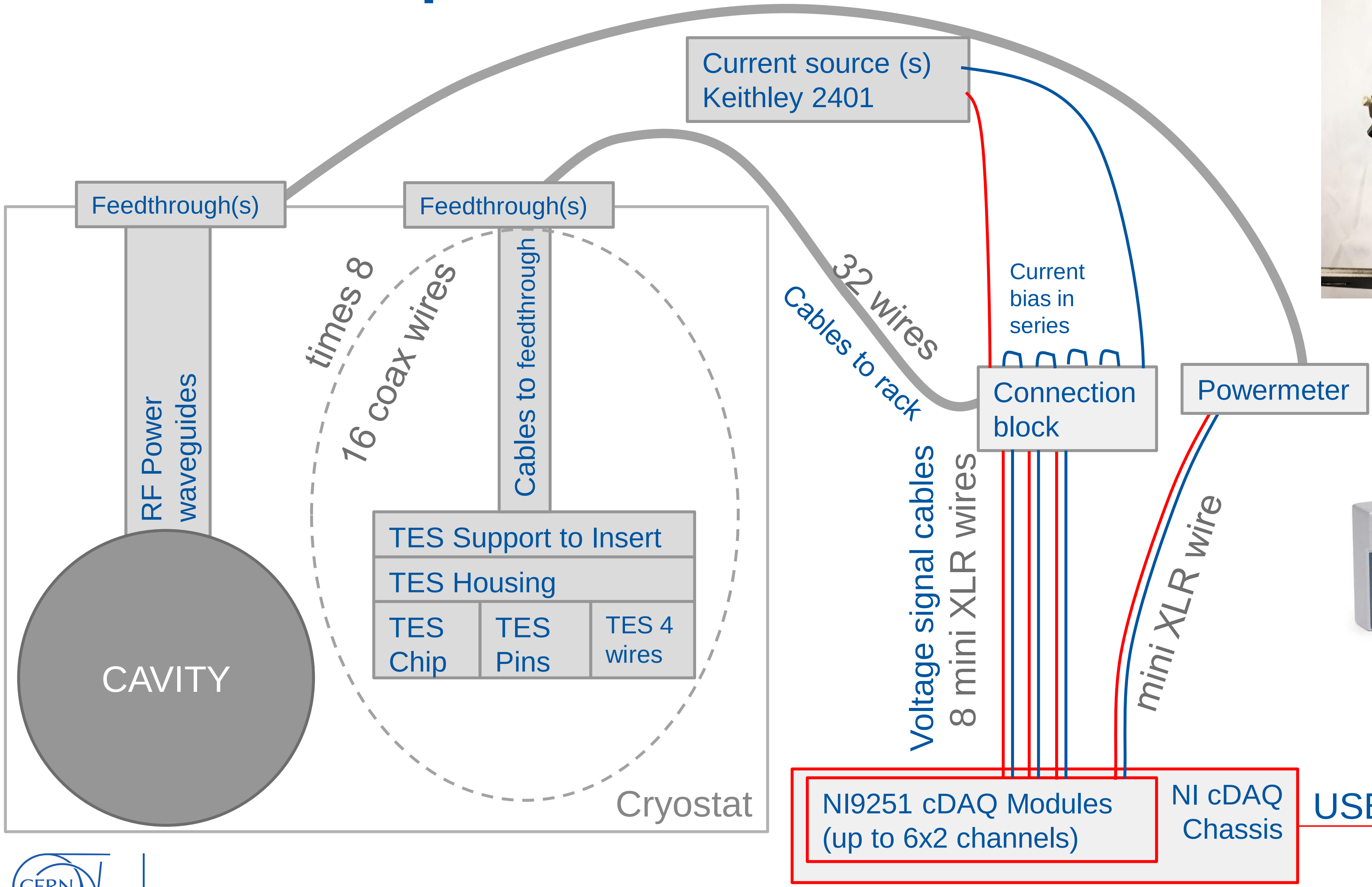
Test at 2 K, with 5 sensors and 9 heaters (3 x 6 mm^2)
Second sound speed taken from literature, TOF measured
Application of trilateration algorithm (direct line of sight)

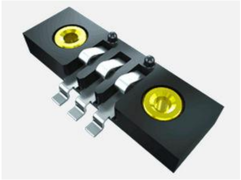


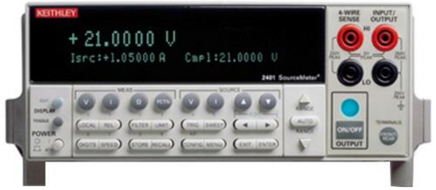




TES setup at CERN/SM18

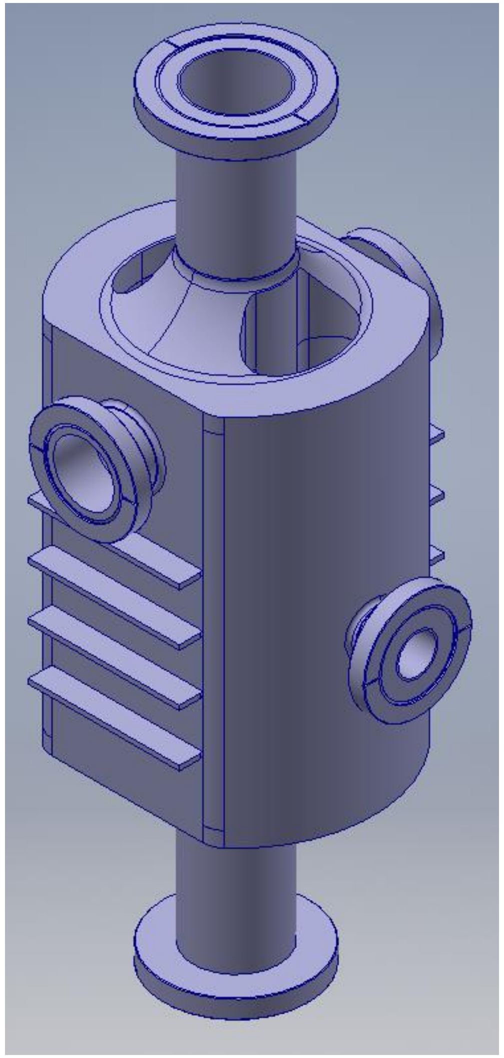






Cavities tested with TES

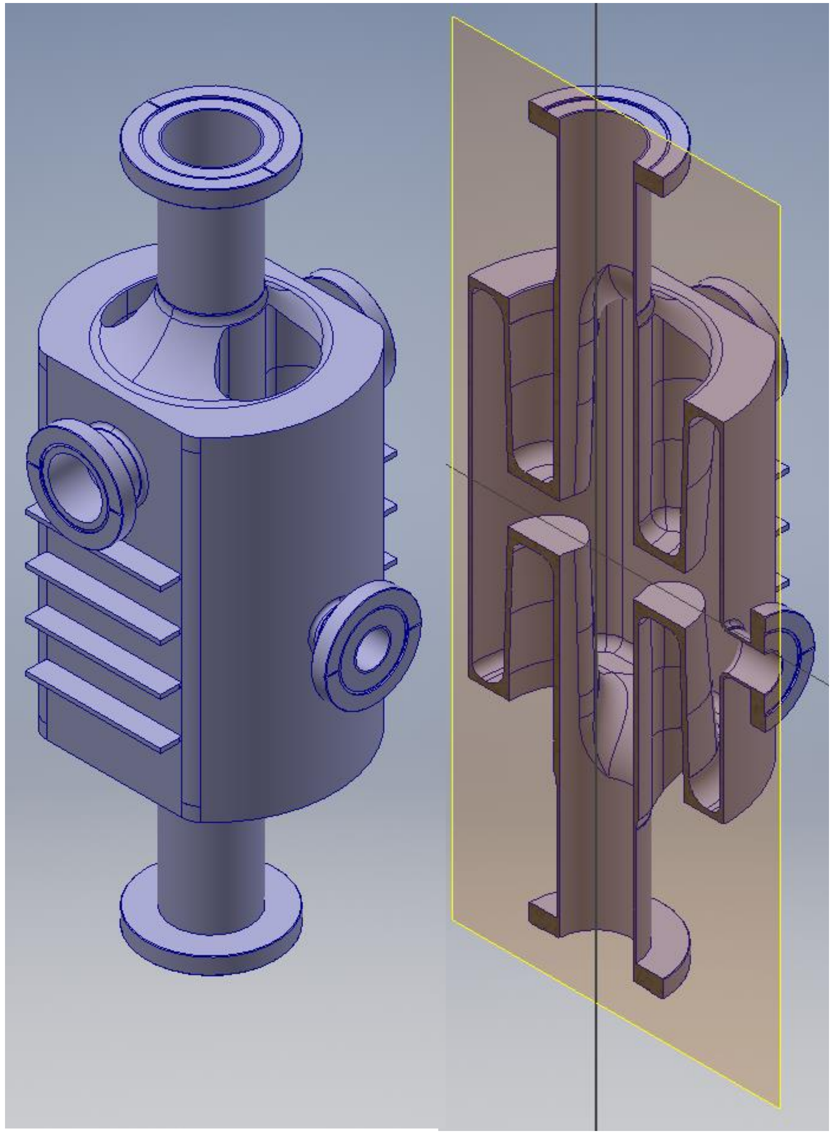
UK4Rod

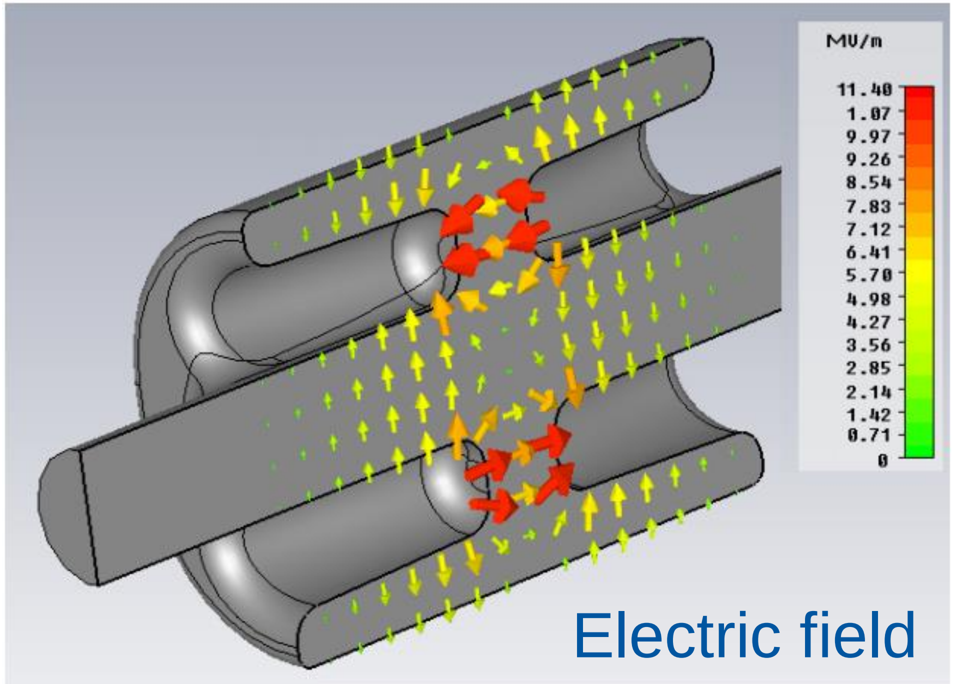


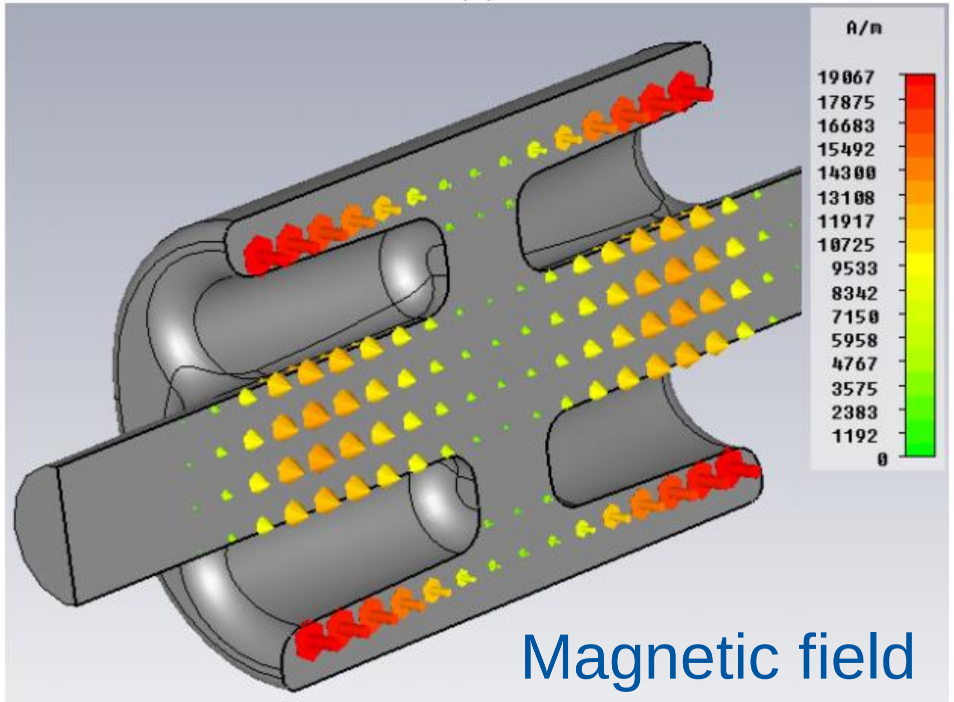
Crab PoP DQW

The UK-4Rod test

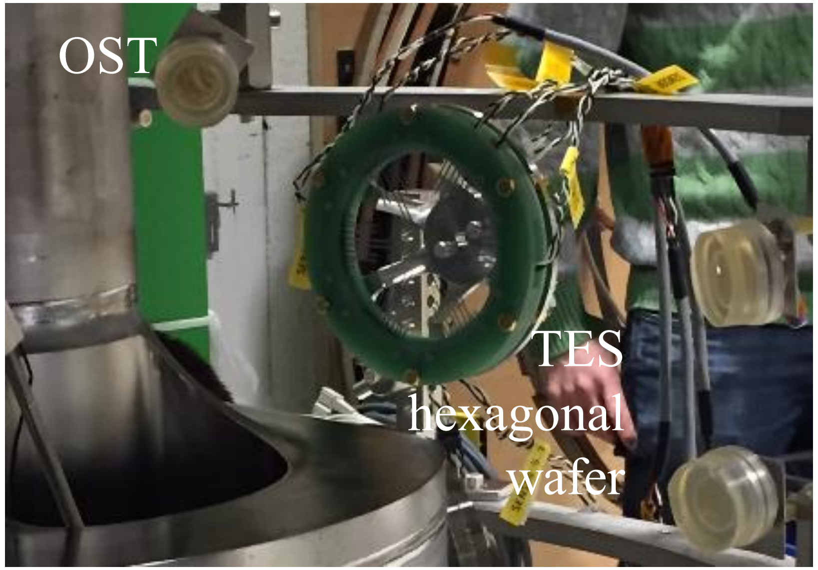
The UK-4Rod Cavity

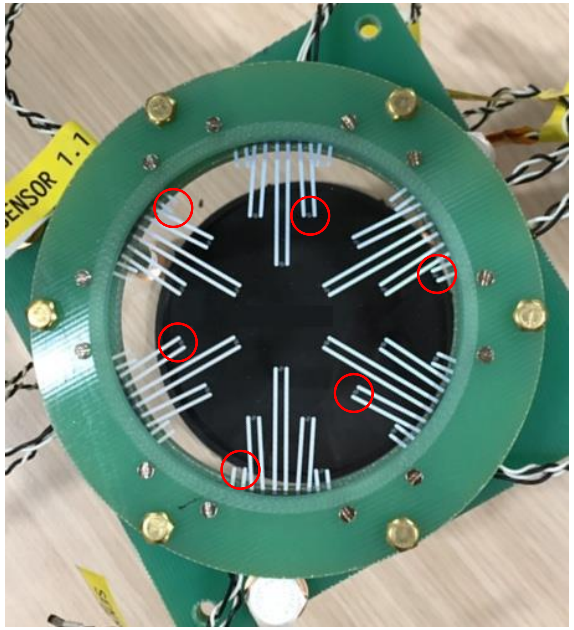


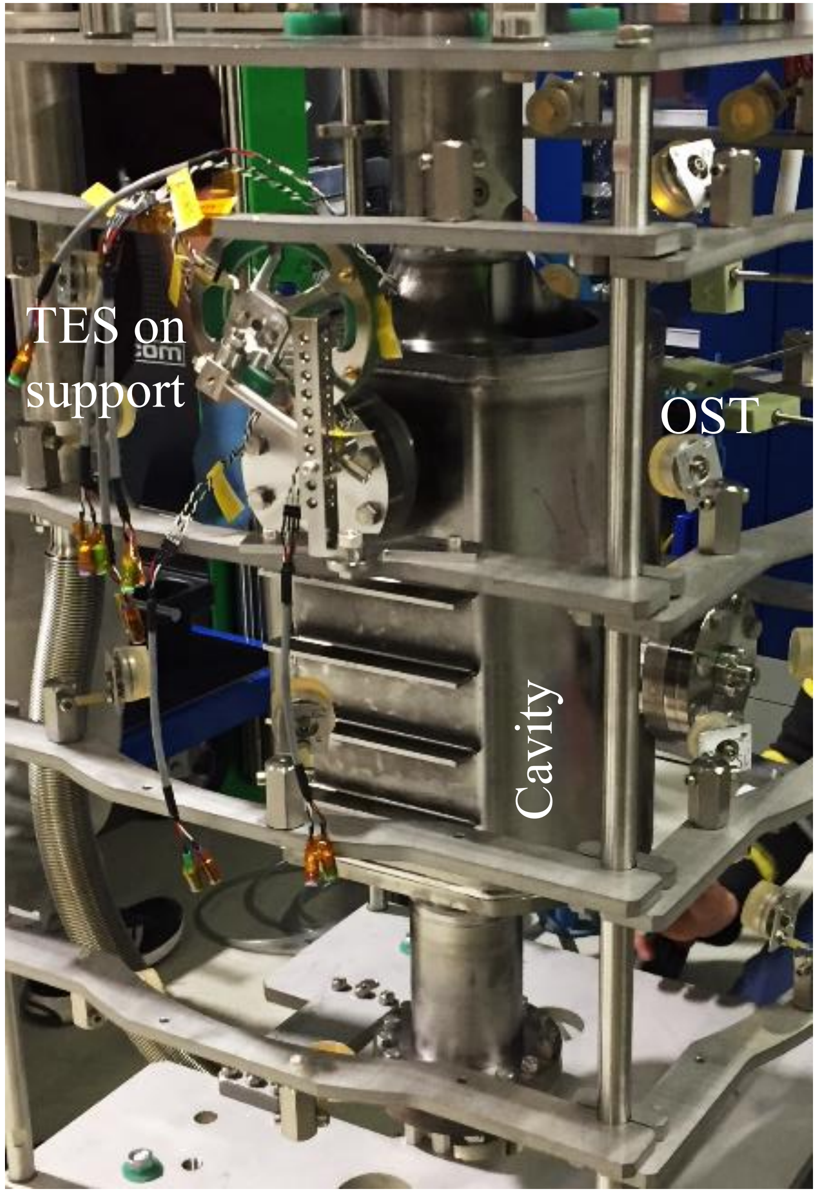


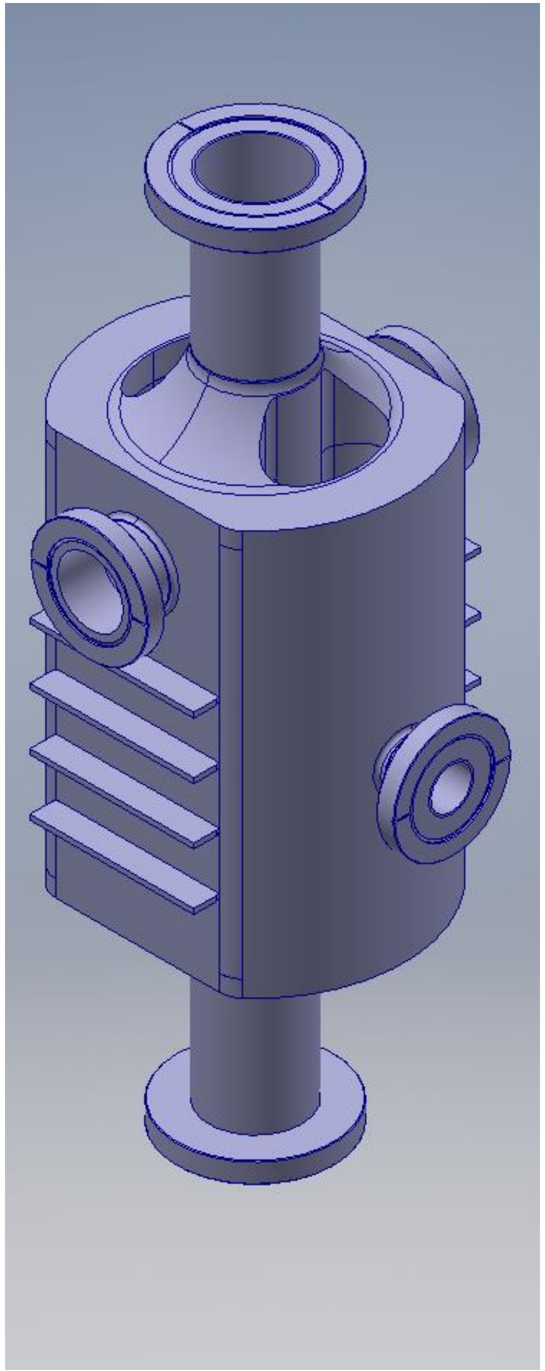


Instrumented UK-4Rod Cavity







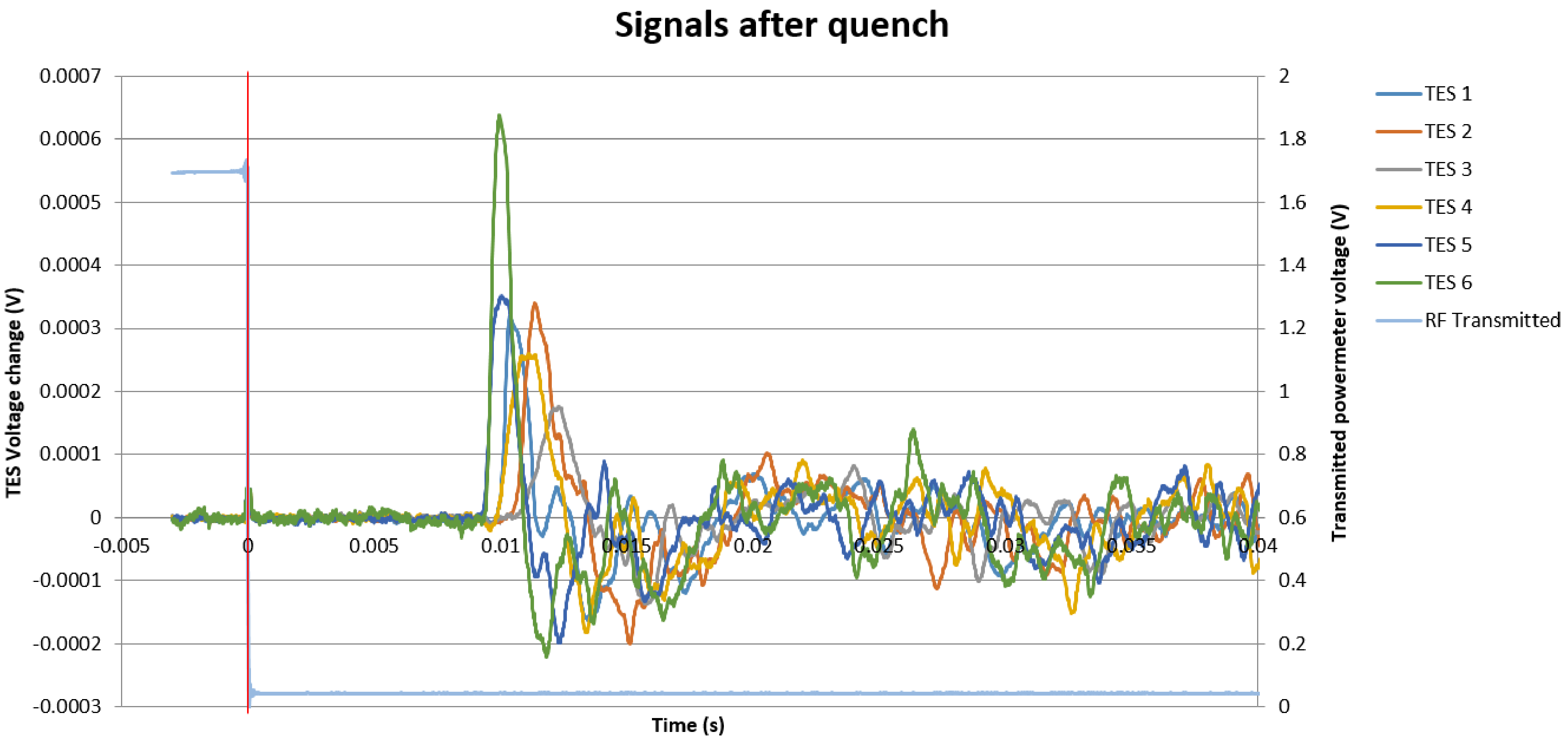


UK-4Rod measured TES signals pos-quench

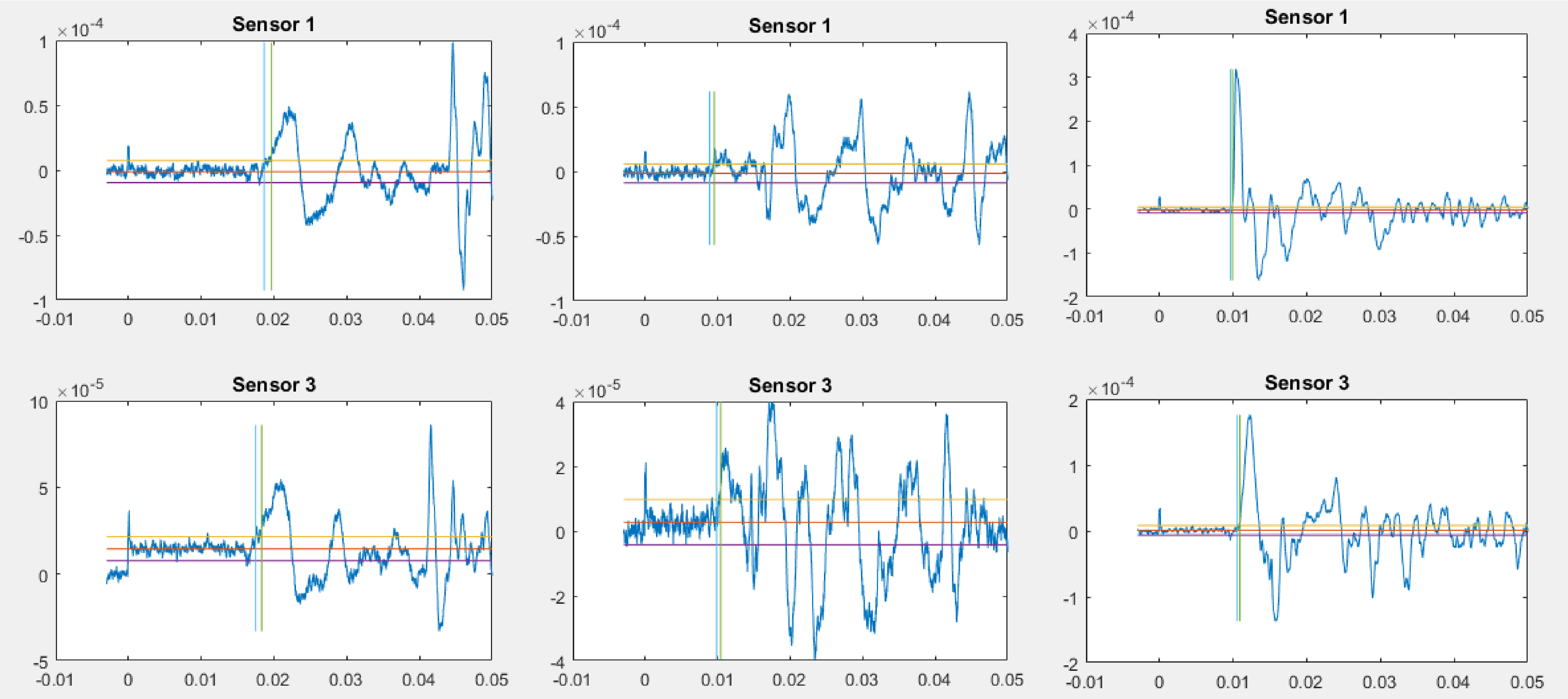
Testing conditions

2.05 – 2.1 K → strong variation of the velocity of second sound

vacuum degraded by possible leak (only observable below T lambda)



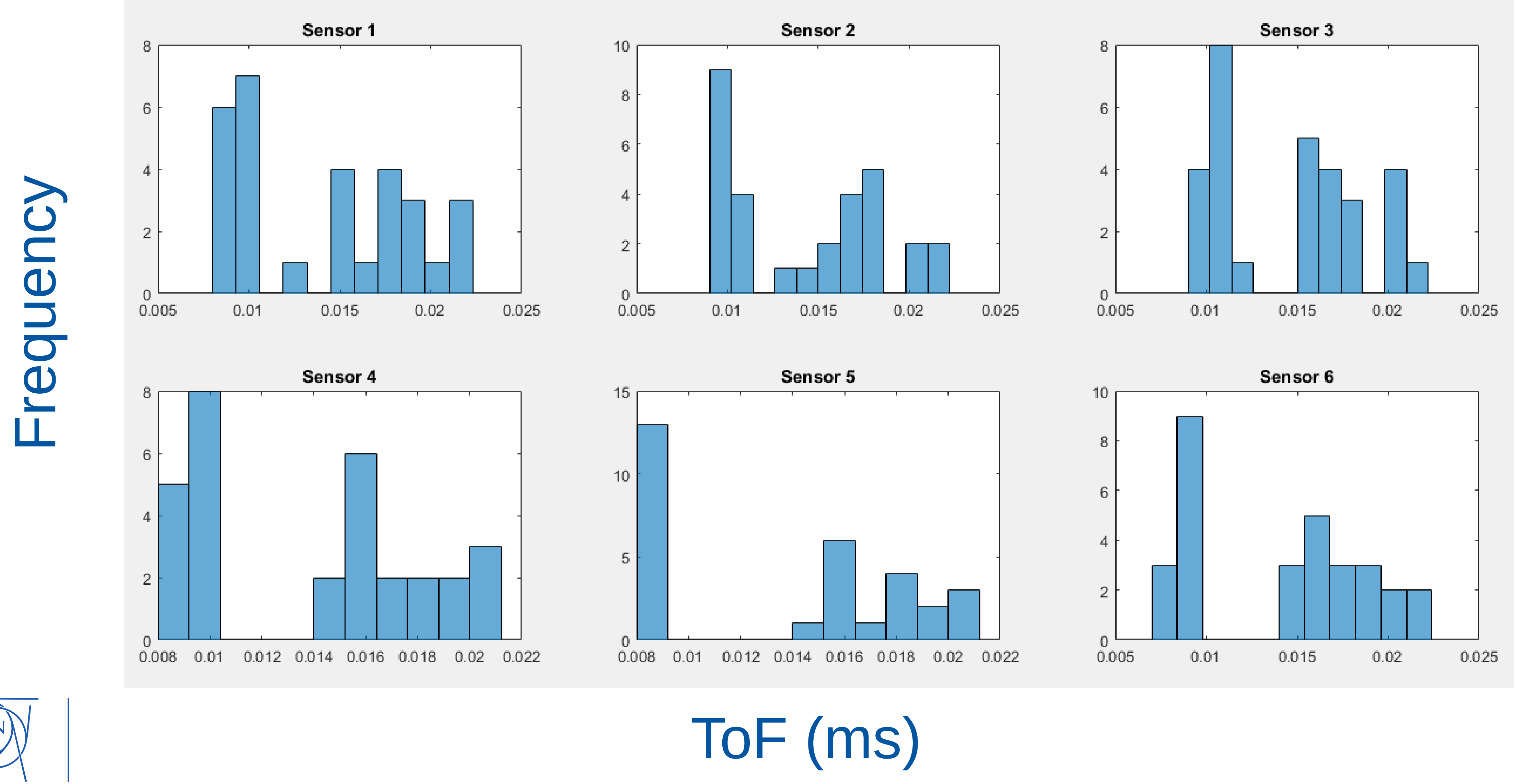
UK-4Rod measured TES signals pos-quench



Slow | Combined | Fast sharp

The repetition of the quench experiment gives different types of second sound signals, regardless of the sensors

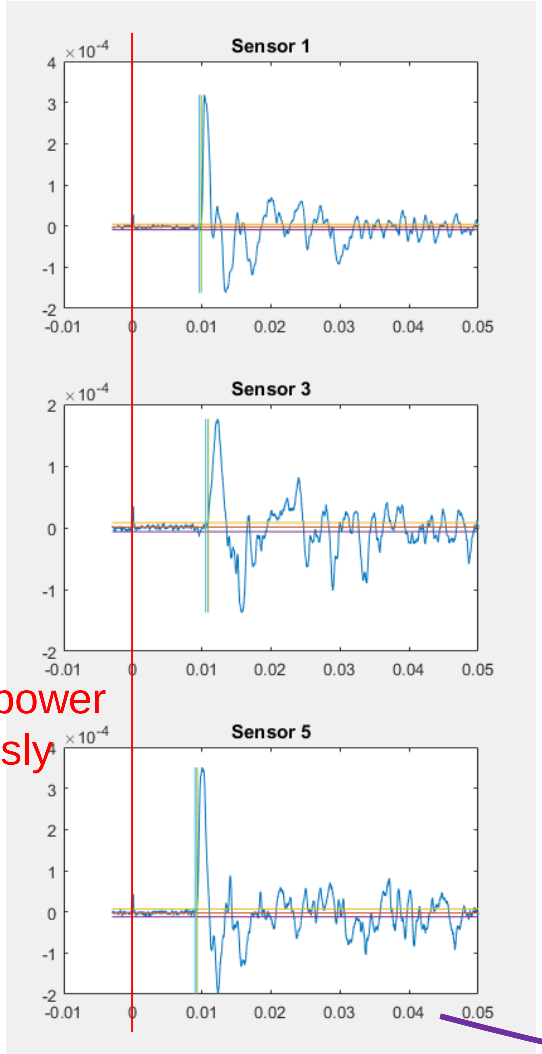
Distribution of measured time of flight



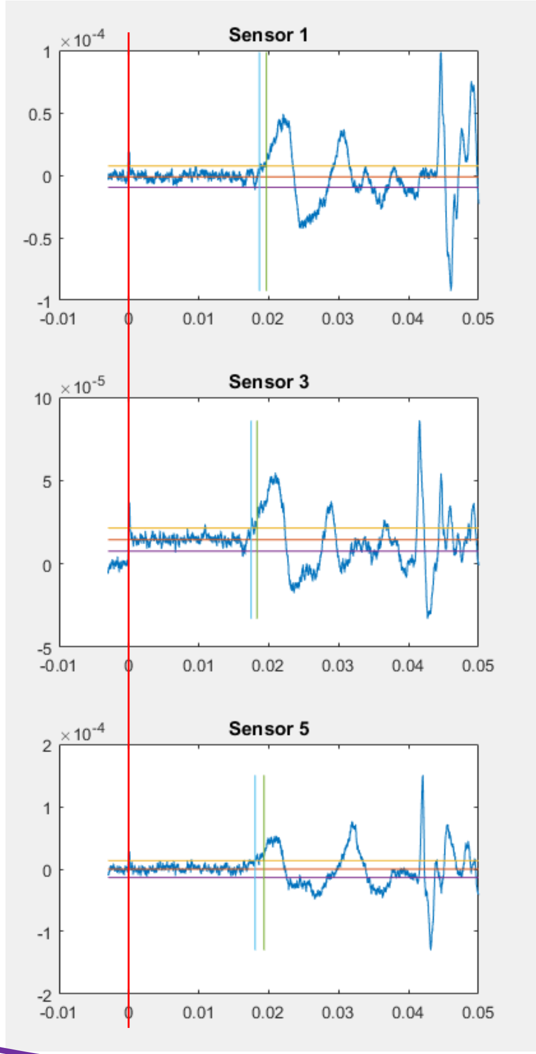
Trilateration results

Trilateration is not the right model, hotspot probably not directly seen and rays to sensors parallel with big uncertainty

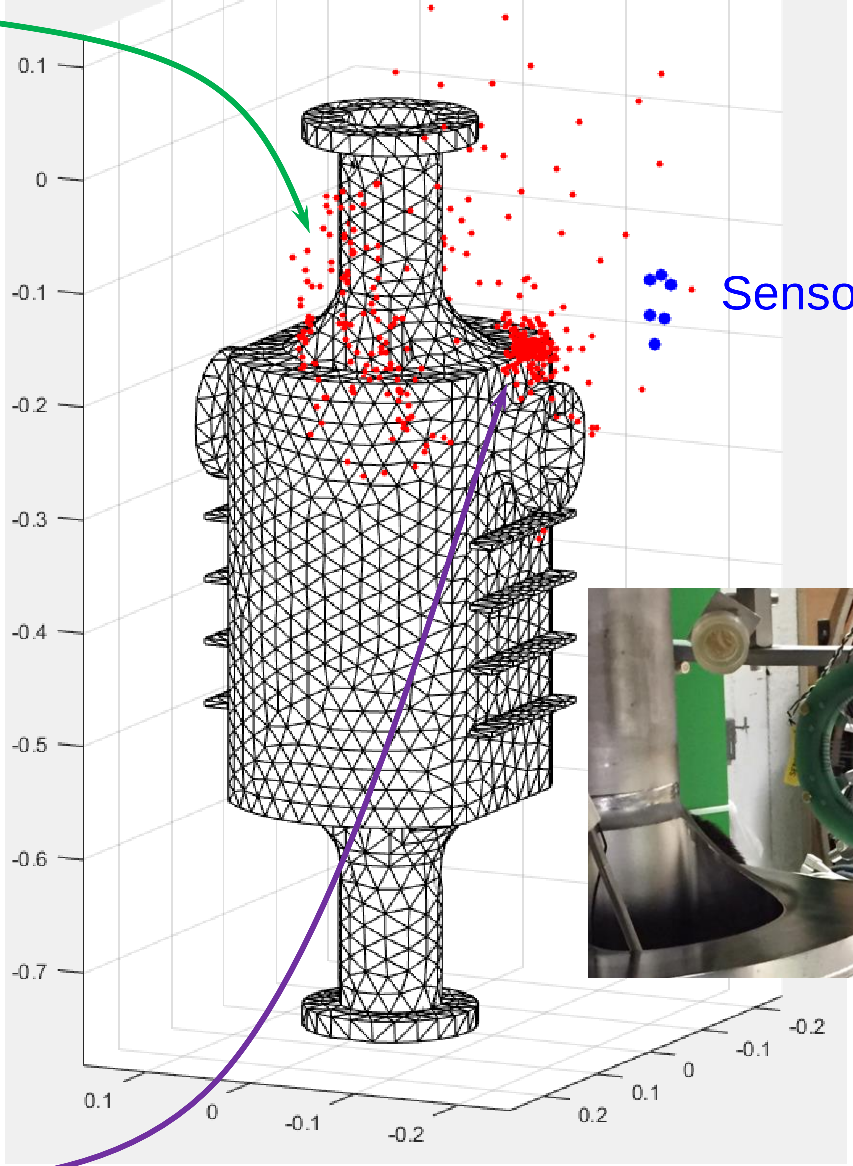
Cases with sharp second sound signal



Cases with time-spread second sound signal

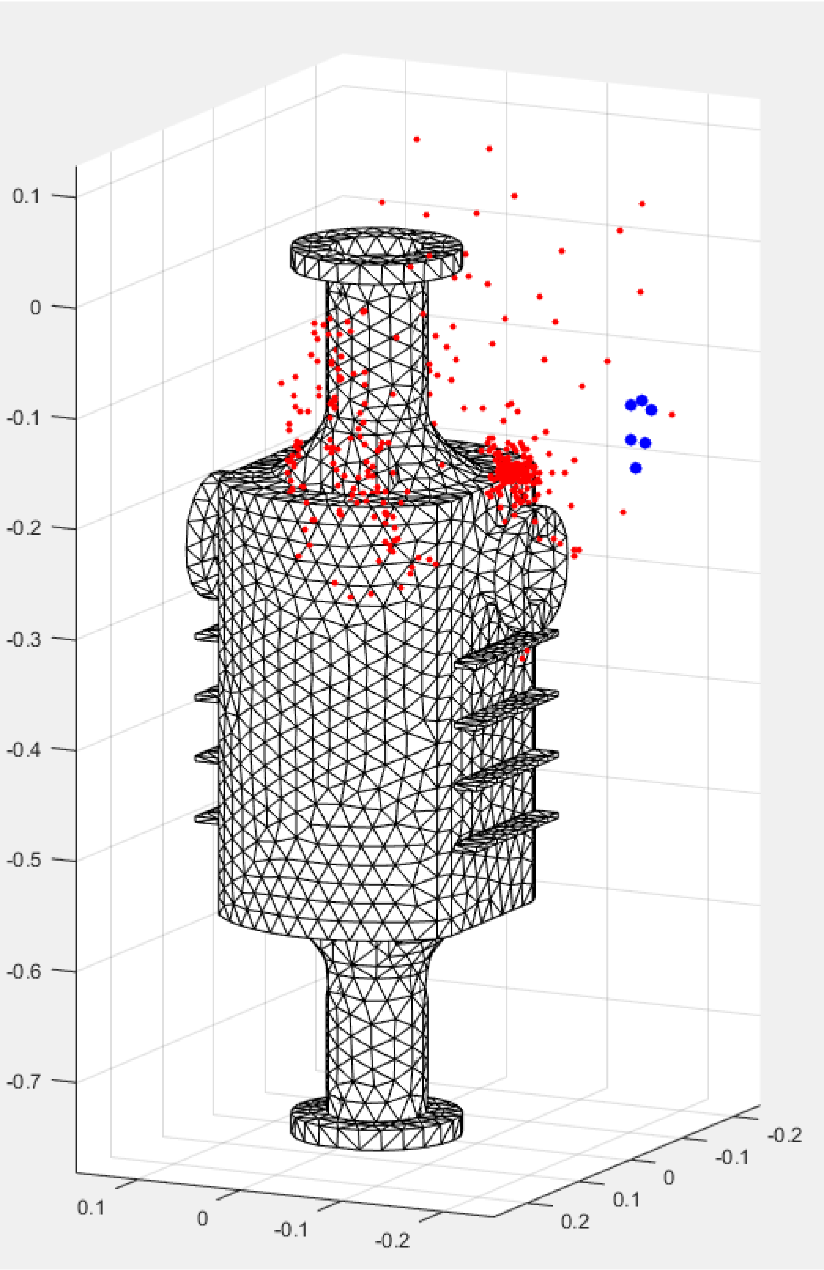


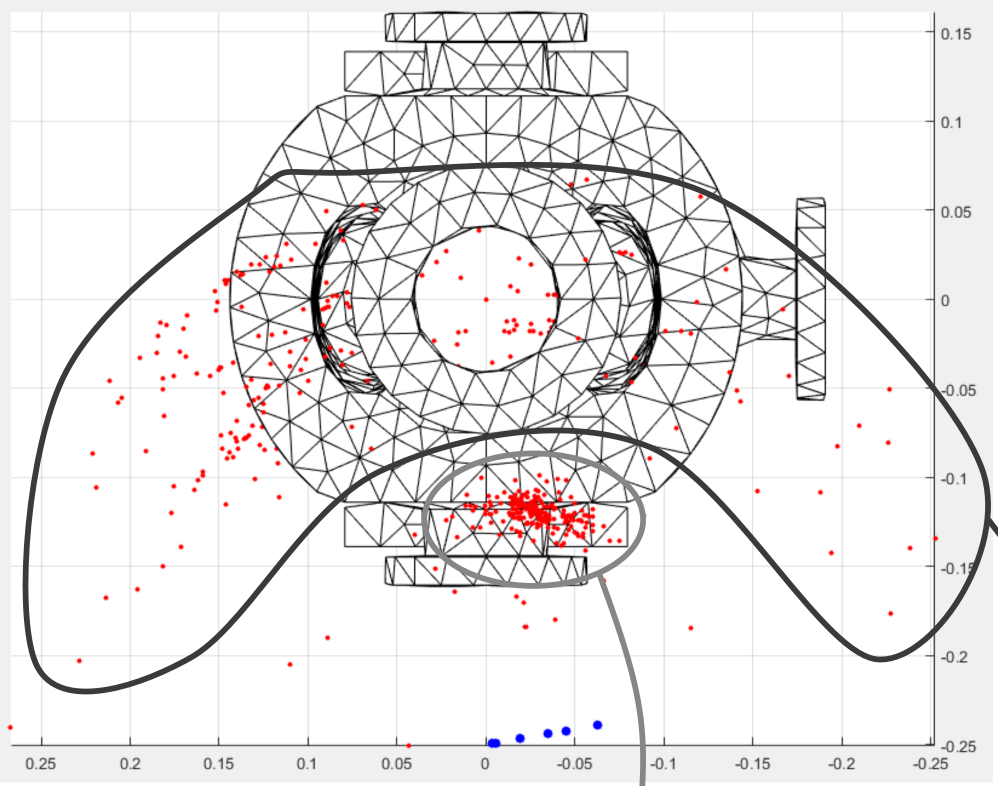
Transmitted power instantaneously drops



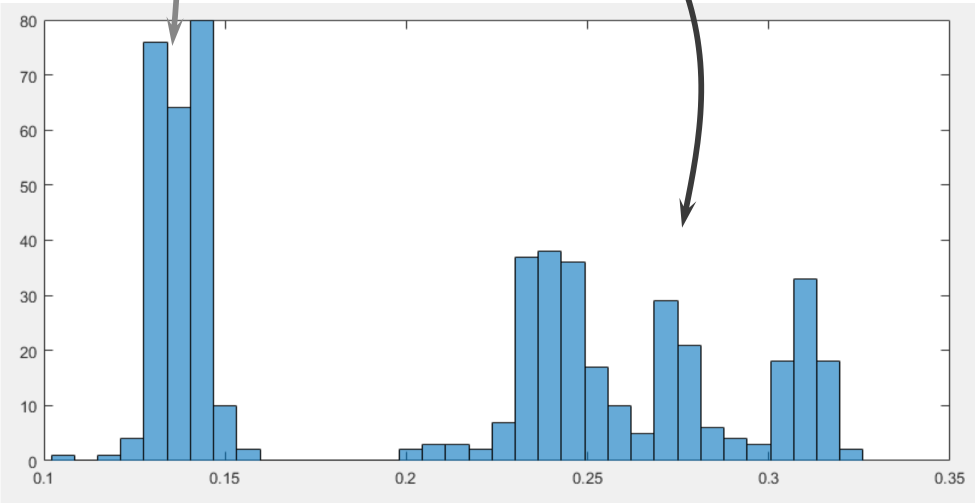
Sensors

Trilateration predicts very precise hotspot





Histogram of distance from trilaterated point to wafer centre



Open questions

Are there two quenching mechanisms that are simultaneous?

- If yes, there seem to be different signatures for each.
- High B, High E quenches?

Why the high dispersion on time of flight for the slower events?

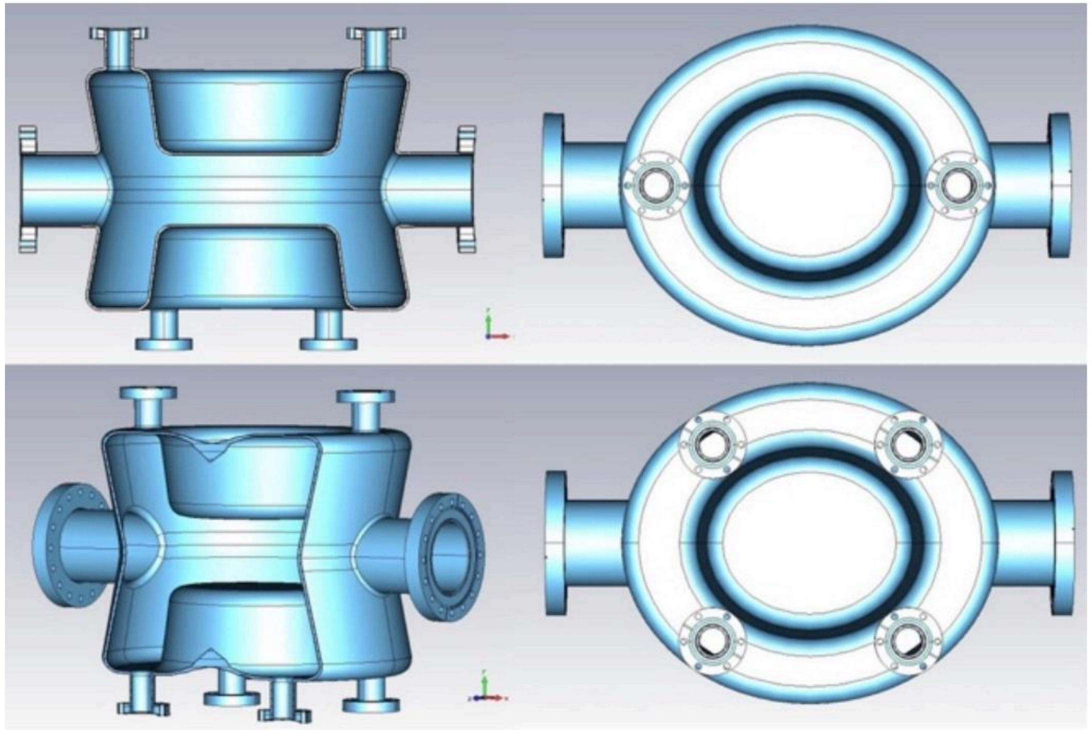
Is the quench propagating so fast in the Niobium, that it is detected from the closest spot (on the cavity) to the detectors?

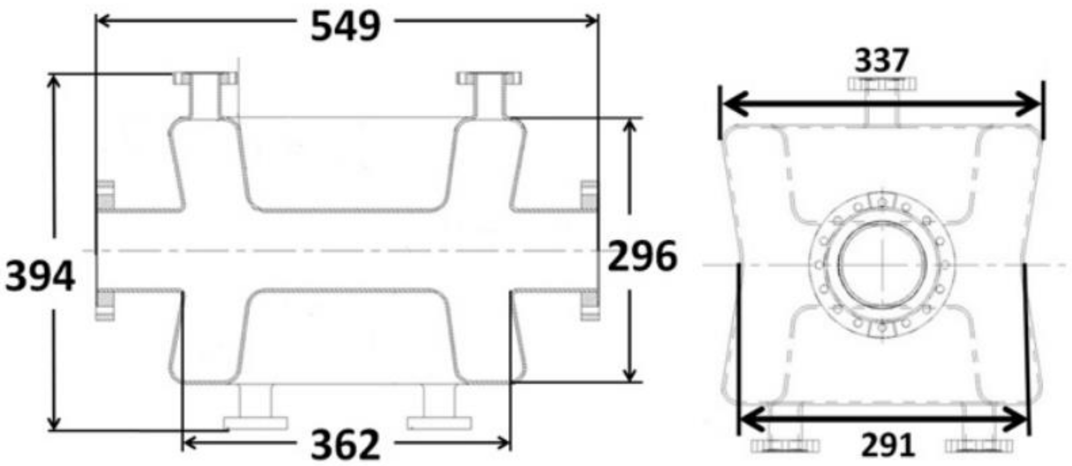
- this could be evaluated by repeating the test placing the sensors somewhere else

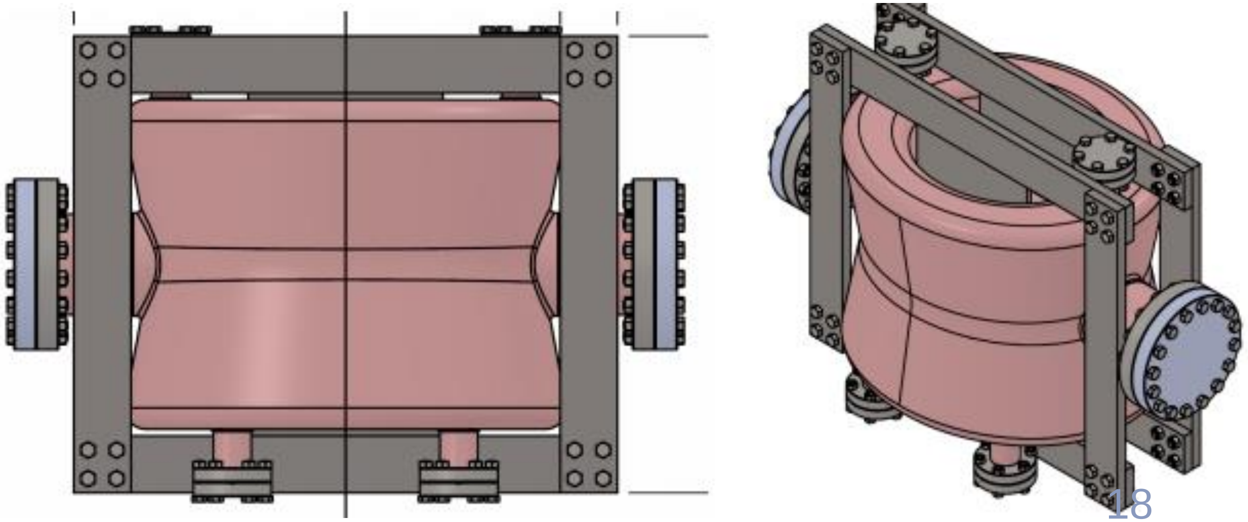
Need to apply more sophisticated algorithm to the data.

The Crab Proof of Principle Double Quarter Wave (PoP DQW) test

The PoP DQW Crab Cavity



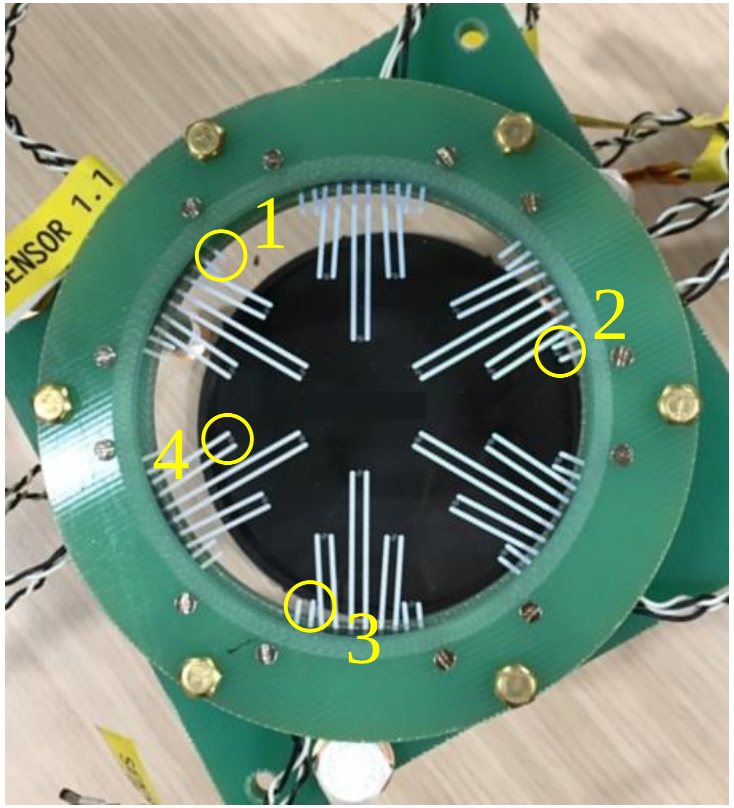


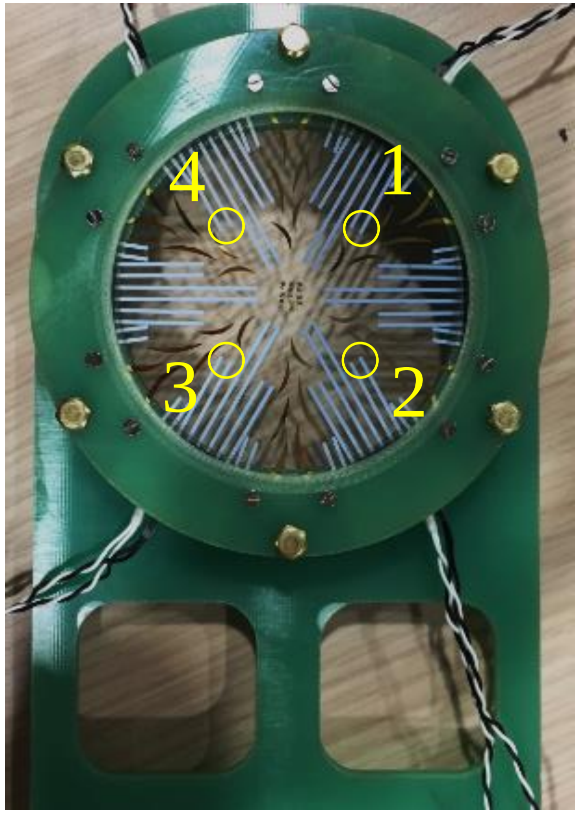


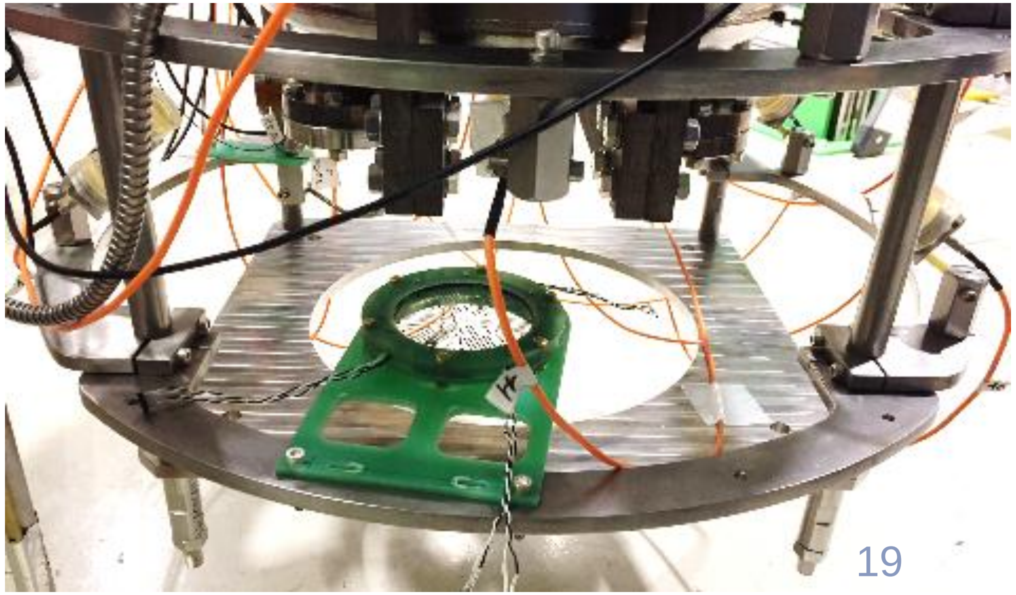
Tha cavity was tested with the stiffening frame

TES used in the test

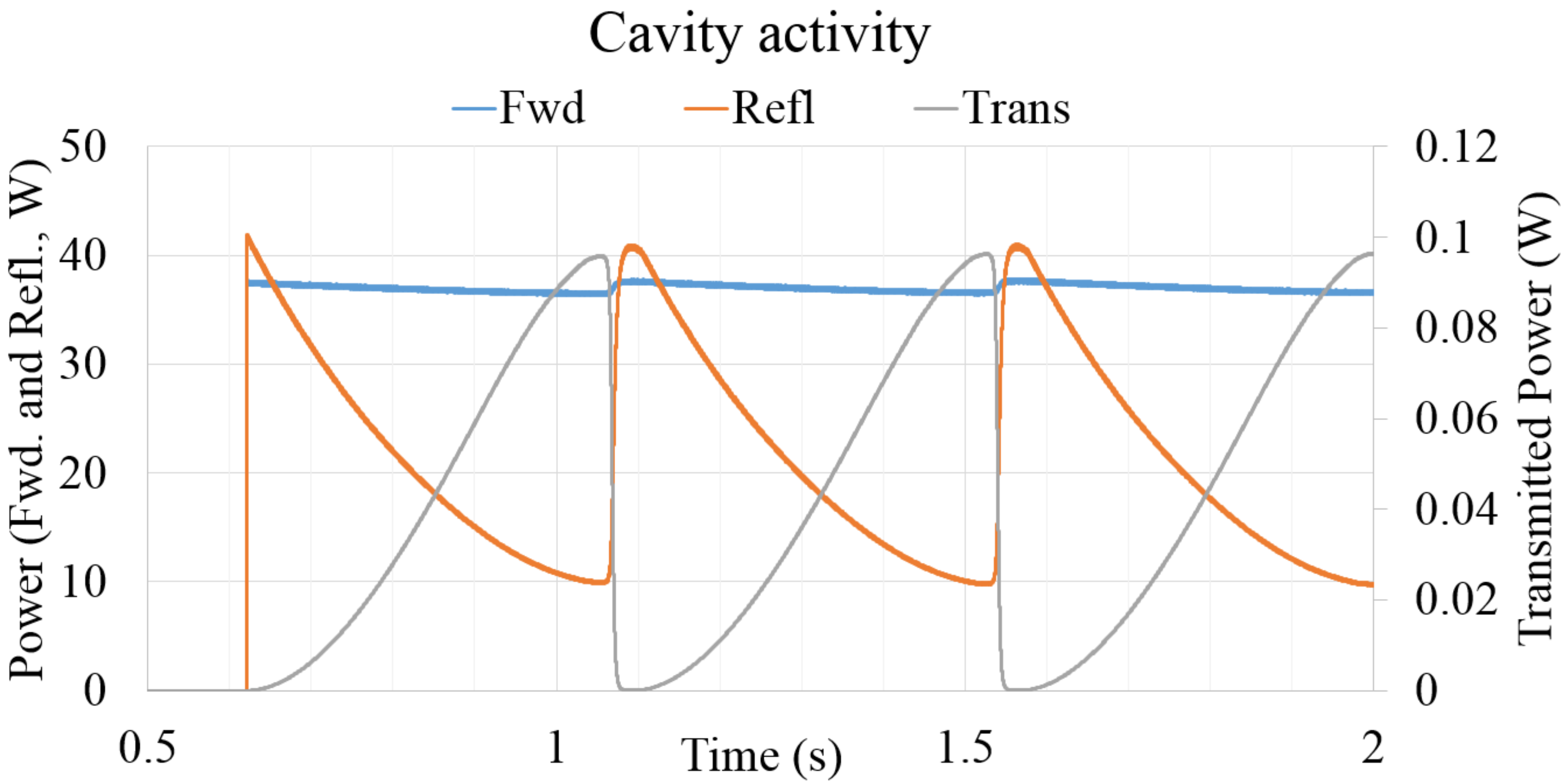
2 Hexagonal wafers, 8 sensors in total

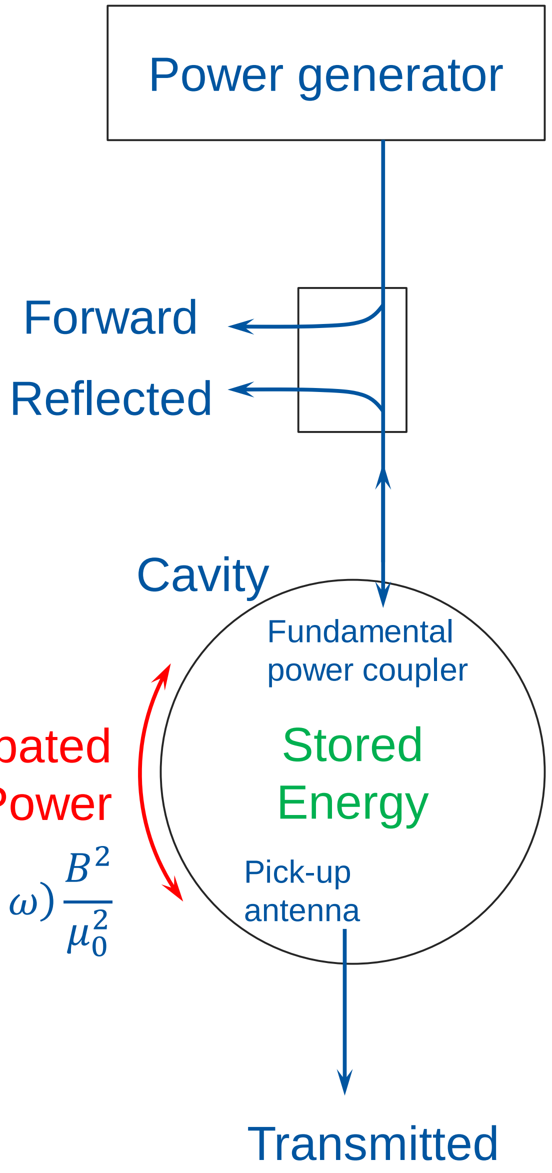






RF-thermal behaviour of the cavity



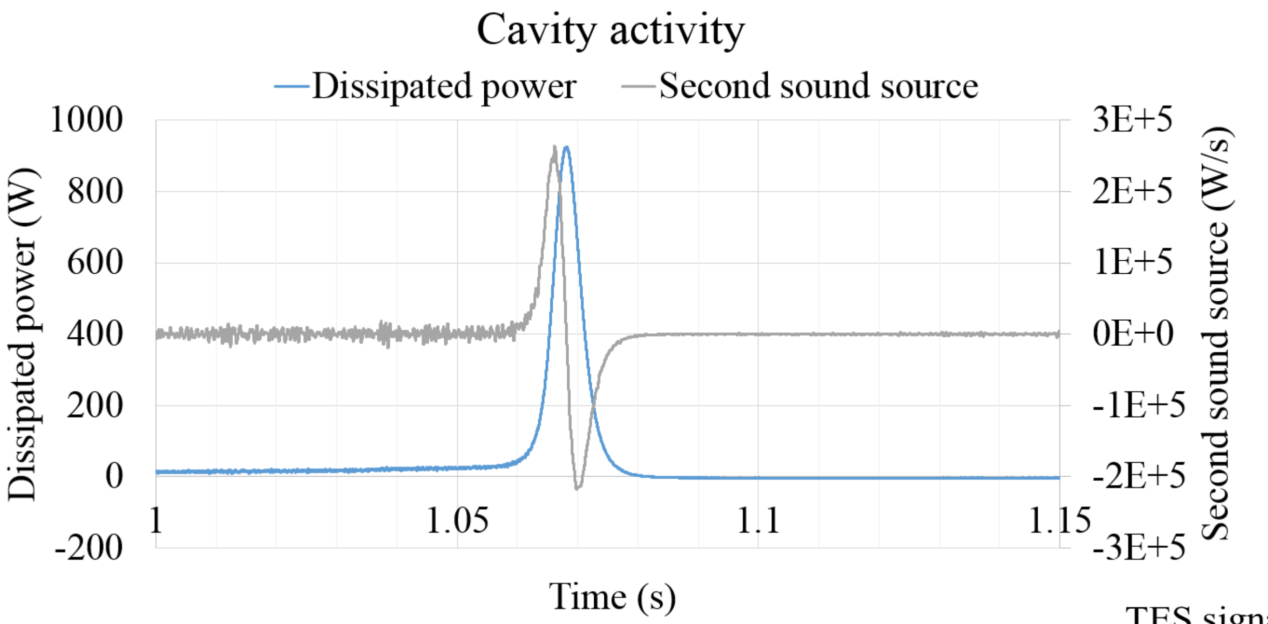


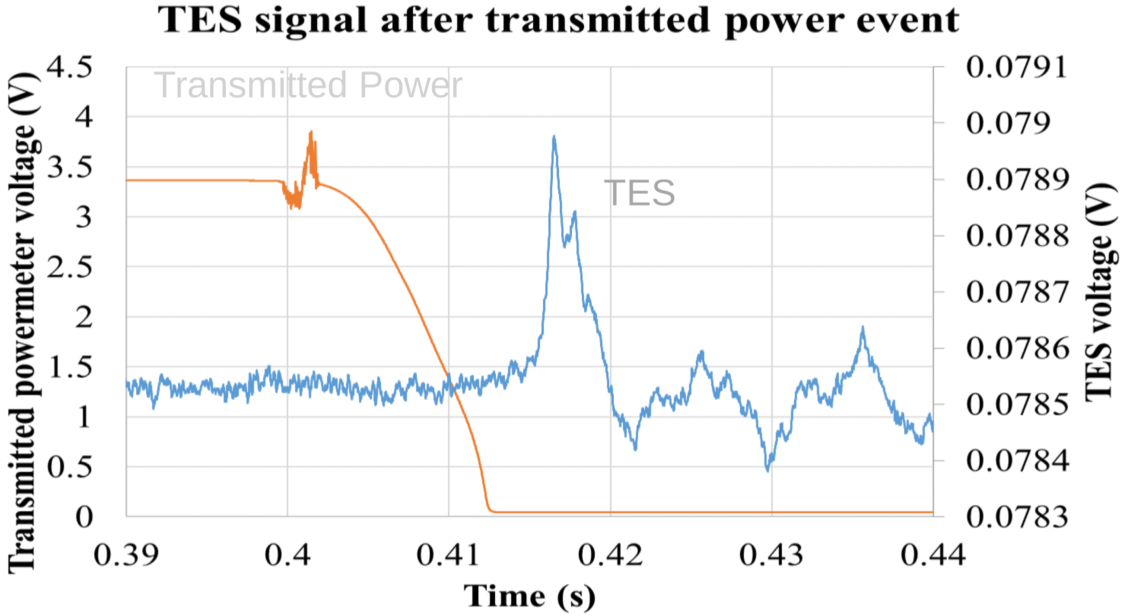
$$P_c = \frac{1}{2} R_s(T, B, \omega) \frac{B^2}{\mu_0^2}$$

The cavity has a self-pulsing hotspot! [H. Piel, 1980]
The stored energy does not decay instantaneously,
but over around 10 ms

$$P_c = P_f - P_r - P_t - \frac{dU}{dt} = P_f - P_r - P_t - \kappa \frac{dP_t}{dt}$$

RF-thermal behaviour of the cavity

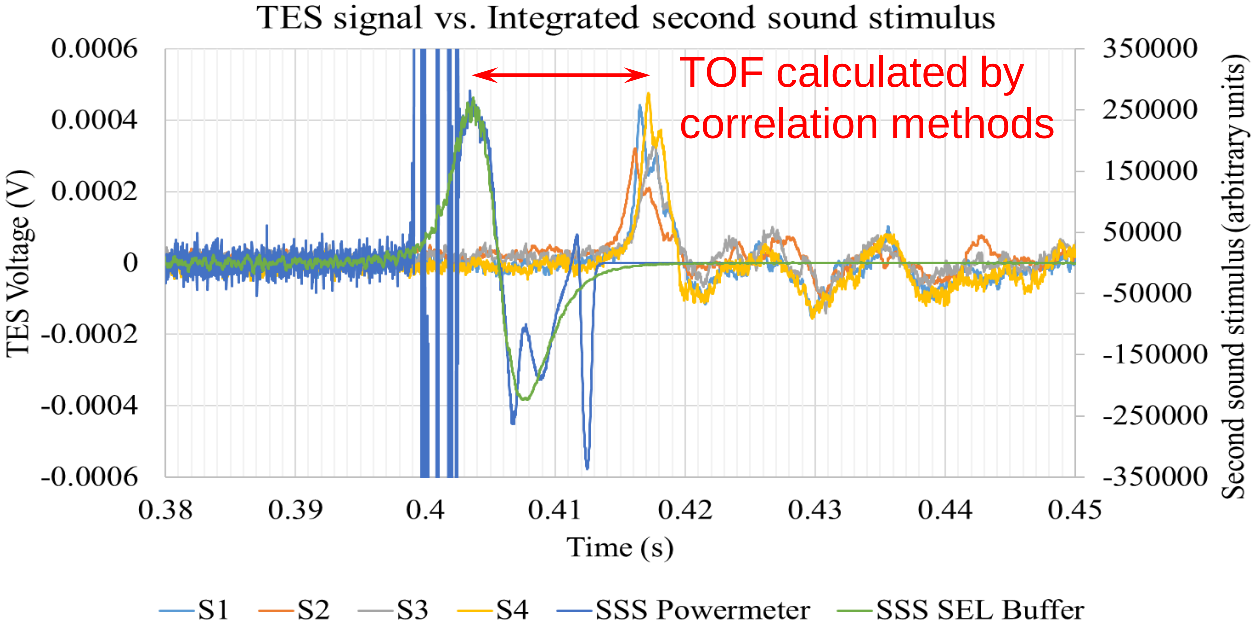




$$P_c = P_f - P_r - P_t - \kappa \frac{dP_t}{dt}$$

Second sound source term

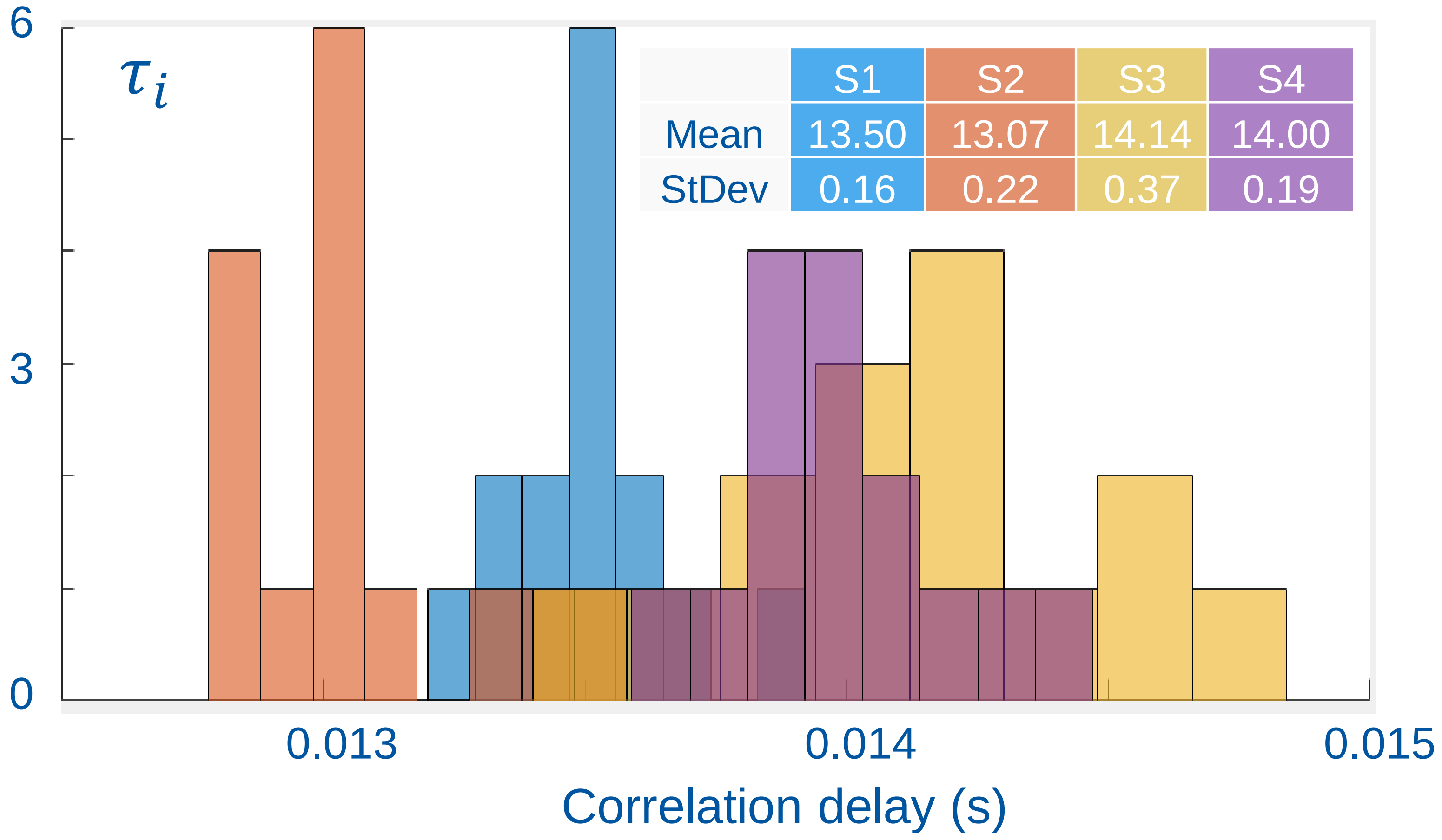
$$\frac{1}{\rho C u_{SS}} \frac{\partial q''}{\partial t} \propto \frac{dP_c}{dt} \approx -\kappa \frac{d^2 P_t}{dt^2}$$



Determination of second sound ToF for each TES

Maximize $C(\delta\tau_{ij}) = \int_{-\infty}^{+\infty} \left[S_i \frac{\partial S_i}{\partial t}\right](t) \times \left[S_j \frac{\partial S_j}{\partial t}\right](t - \delta\tau_{ij})\ dt$
to find the lag of S_i w.r.t. S_j

$$\tau_i = \bar{\theta} + \frac{\sum_j \delta\tau_{ij}}{N}$$

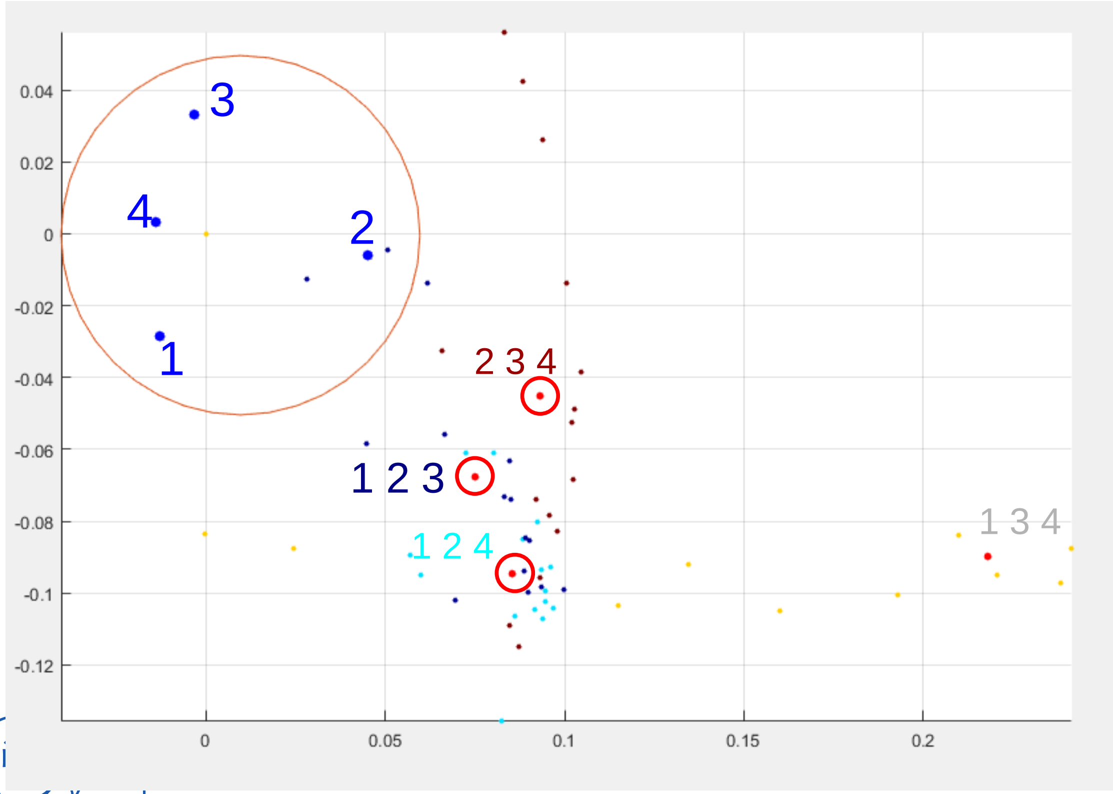


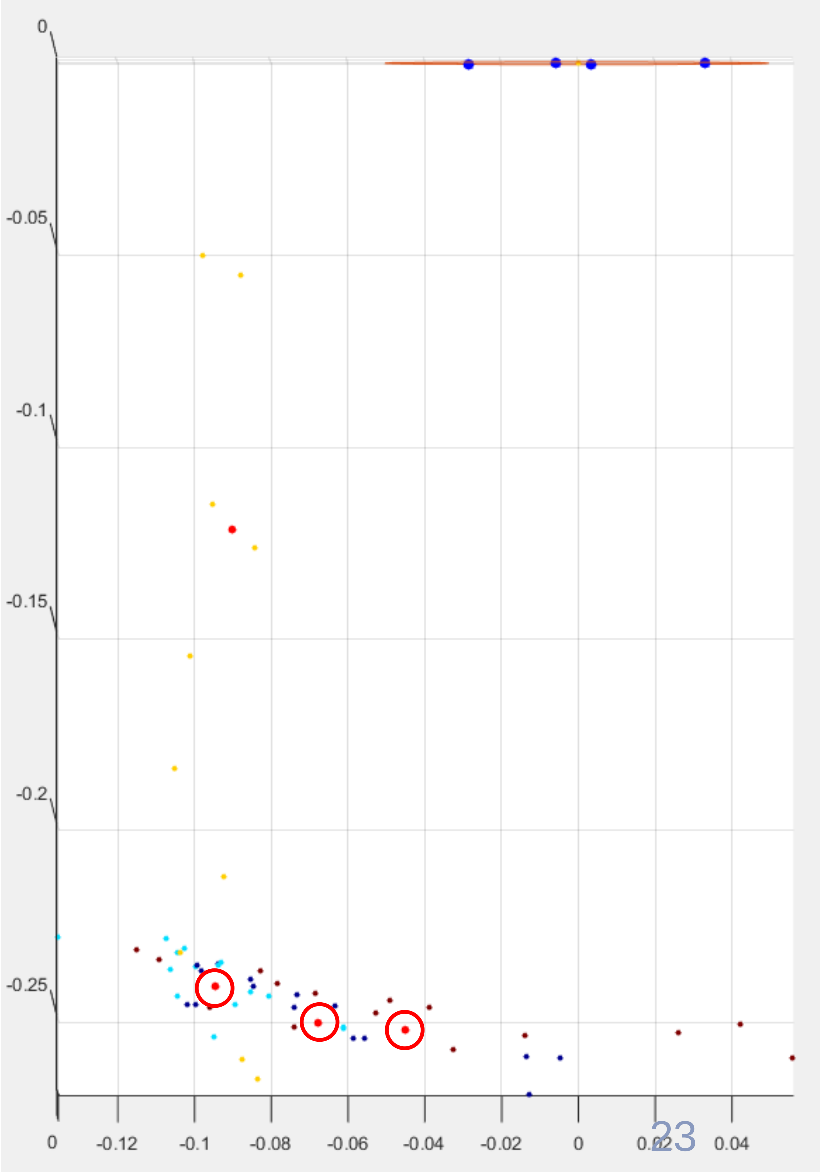
	S1	S2	S3	S4
Mean	13.50	13.07	14.14	14.00
StDev	0.16	0.22	0.37	0.19

Trilateration results

The red points are calculated with the averages of ToF for each sensor over all the cases.
Each of the other colors corresponds to a triad of sensors over the individual cases.

Triad 1 3 4 almost aligned, ToF of sensor 3 has high StDev.
Triad 2 3 4, ToF of sensor 3 has high StDev.
Triad 1 2 3 is less affected, equal-sided triangle.
Triad 1 2 4 gives the most self consistent results because sensor 3 is not present.

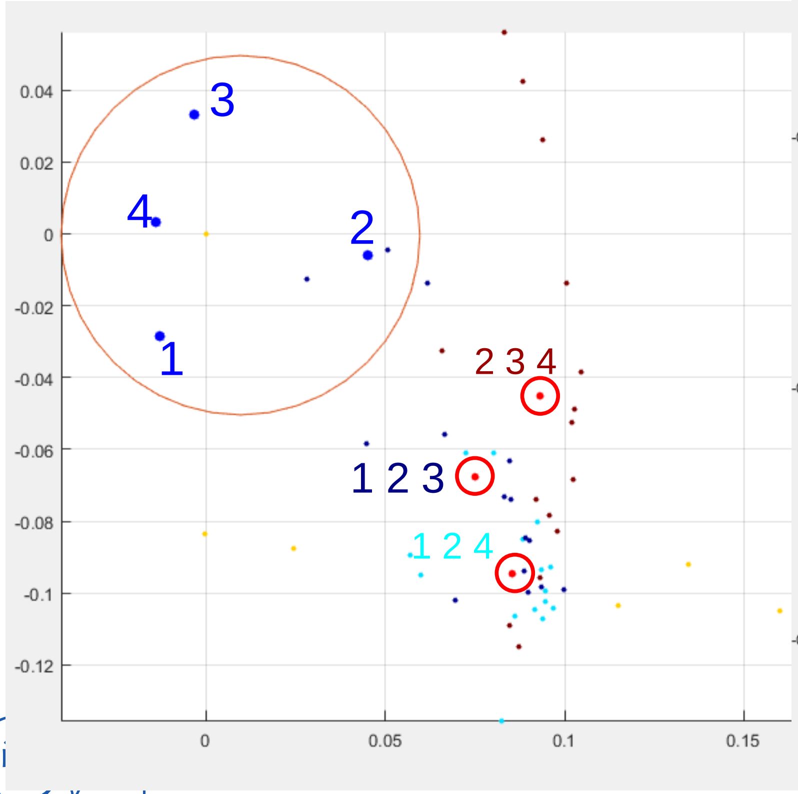


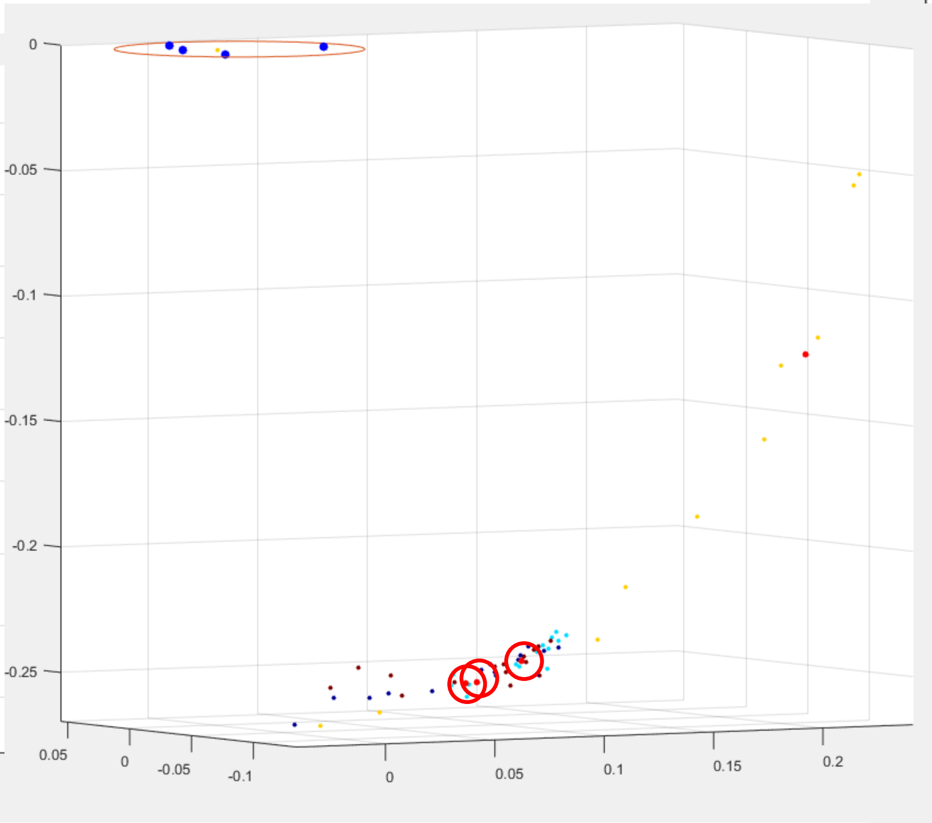


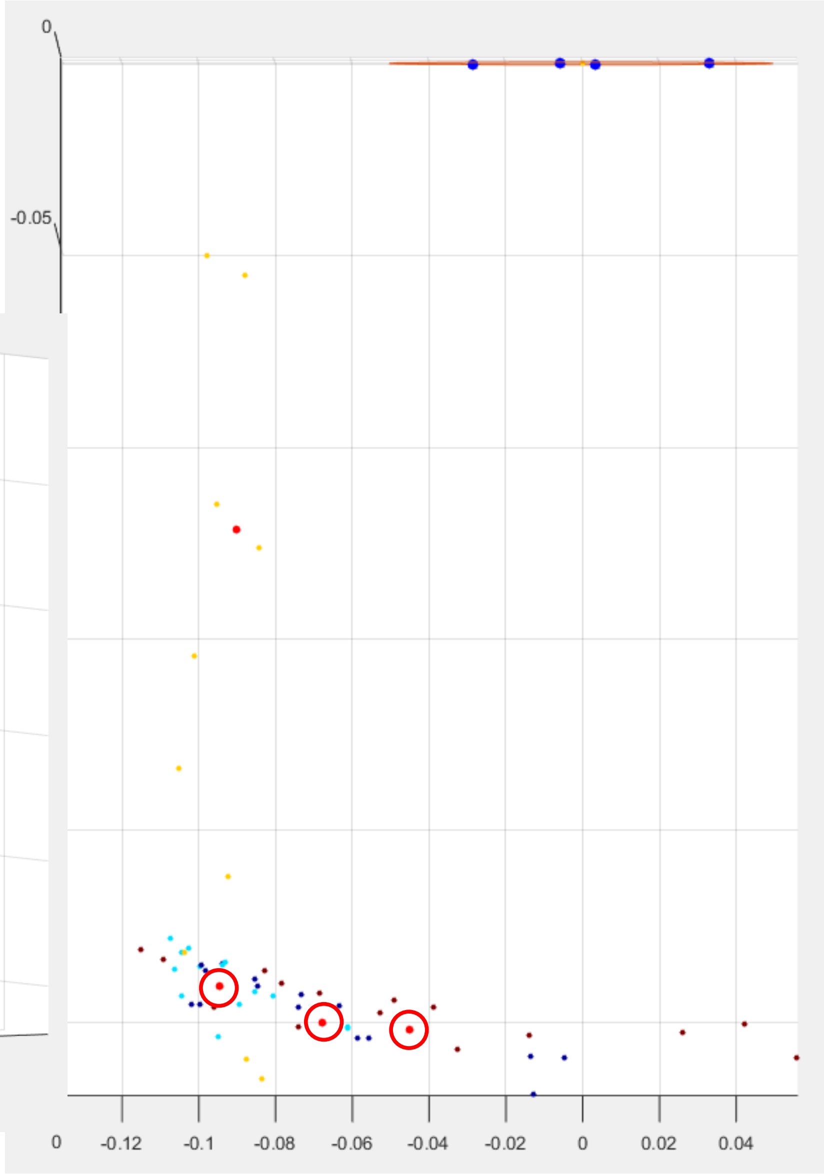
Trilateration results

The red points are calculated with the averages of ToF for each sensor over all the cases.
Each of the other colors corresponds to a triad of sensors over the individual cases.

Triad 1 3 4 almost aligned, ToF of sensor 3 has high StDev.
Triad 2 3 4, ToF of sensor 3 has high StDev.
Triad 1 2 3 is less affected, equal-sided triangle.
Triad 1 2 4 gives the most self consistent results because sensor 3 is not present.

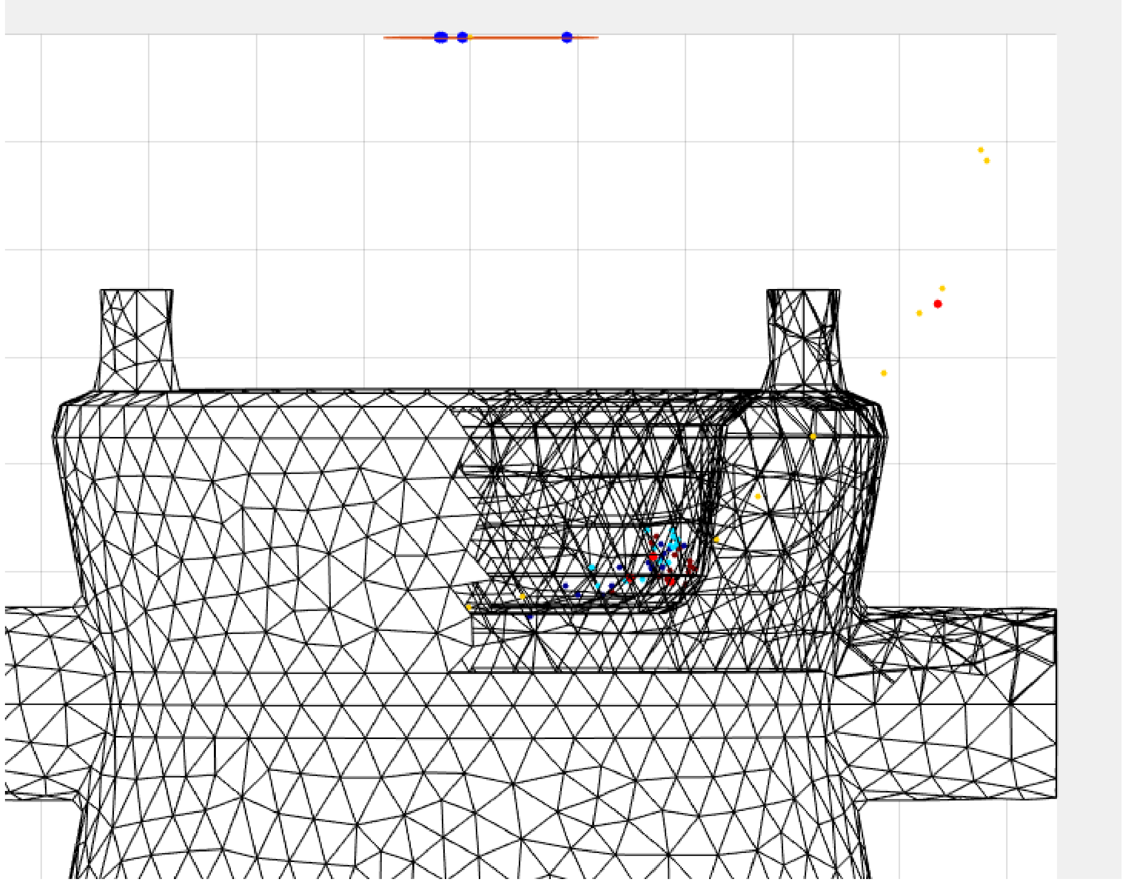


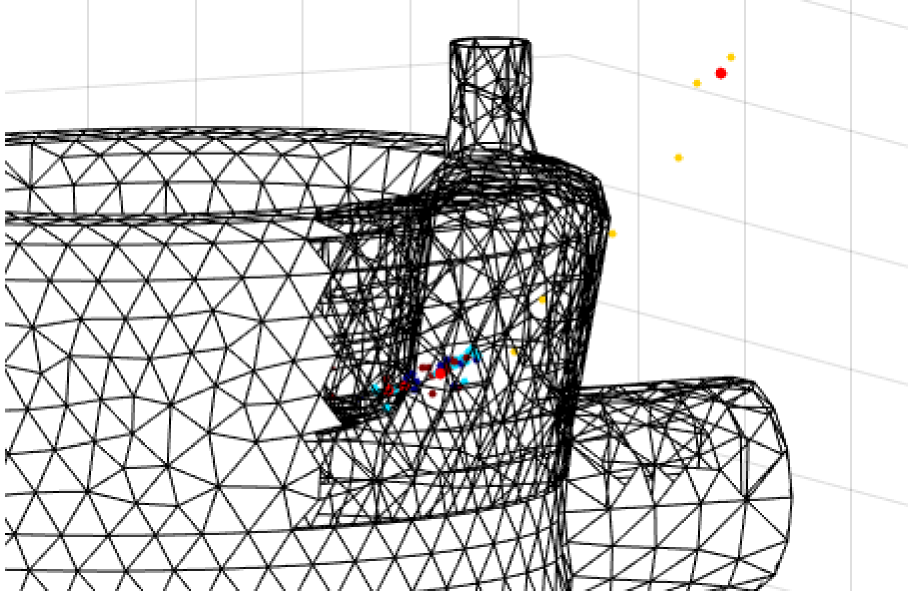


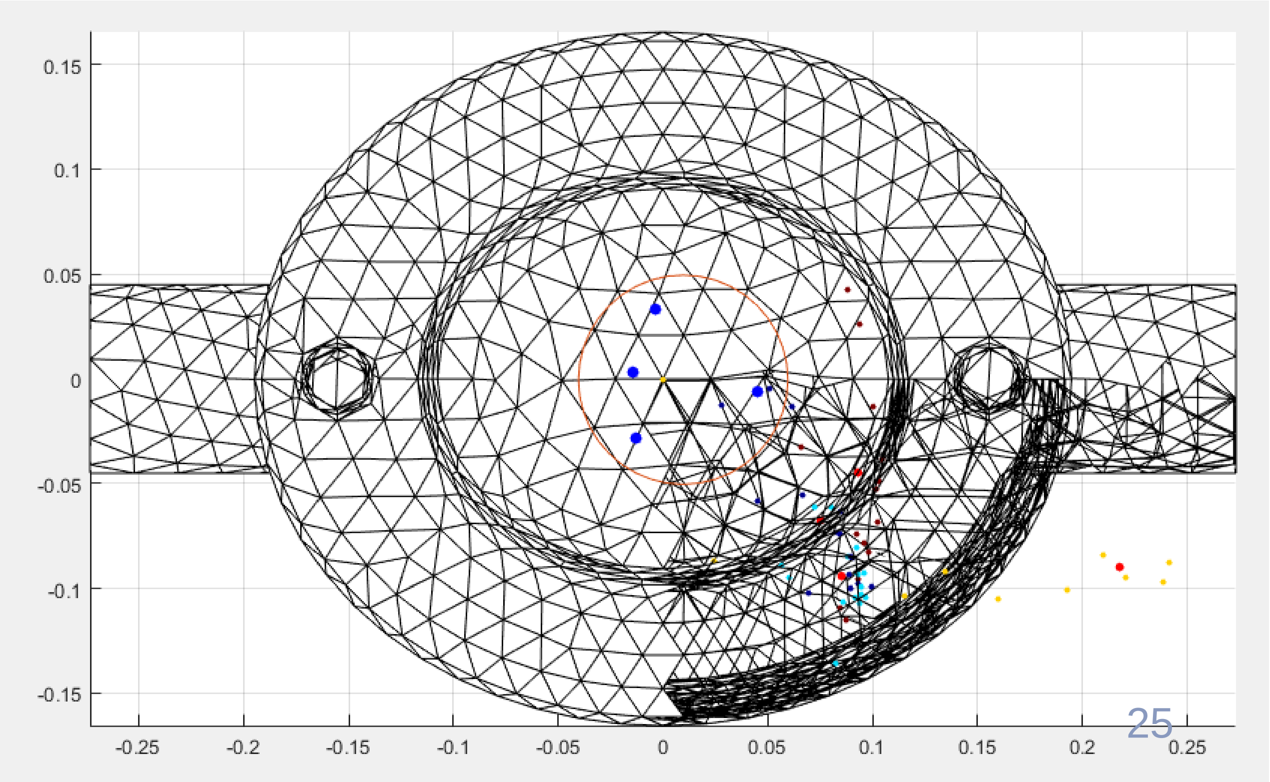


Trilateration results

The trilateration result seems to be a few cm inside the cavity.
This can be attributed to the presence of the stiffening frame.

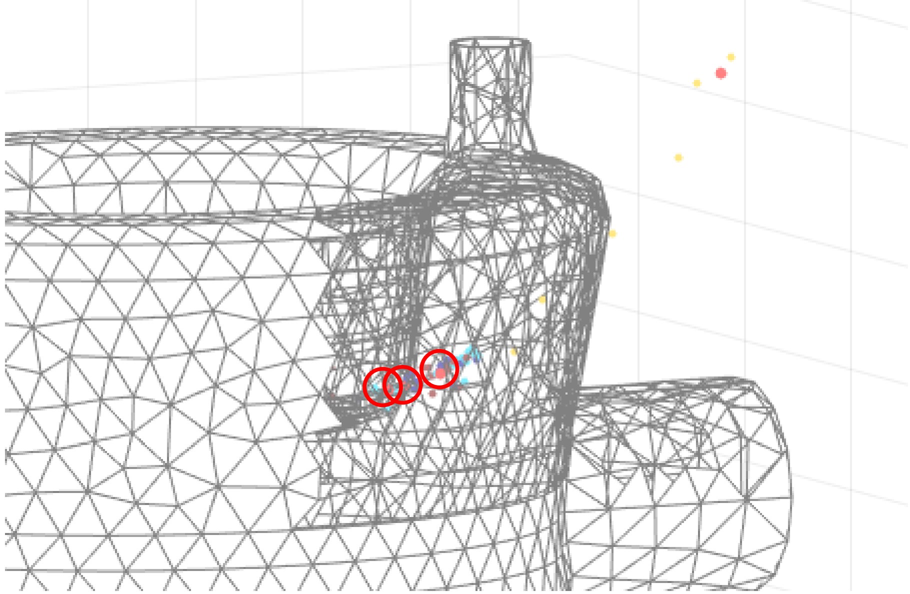


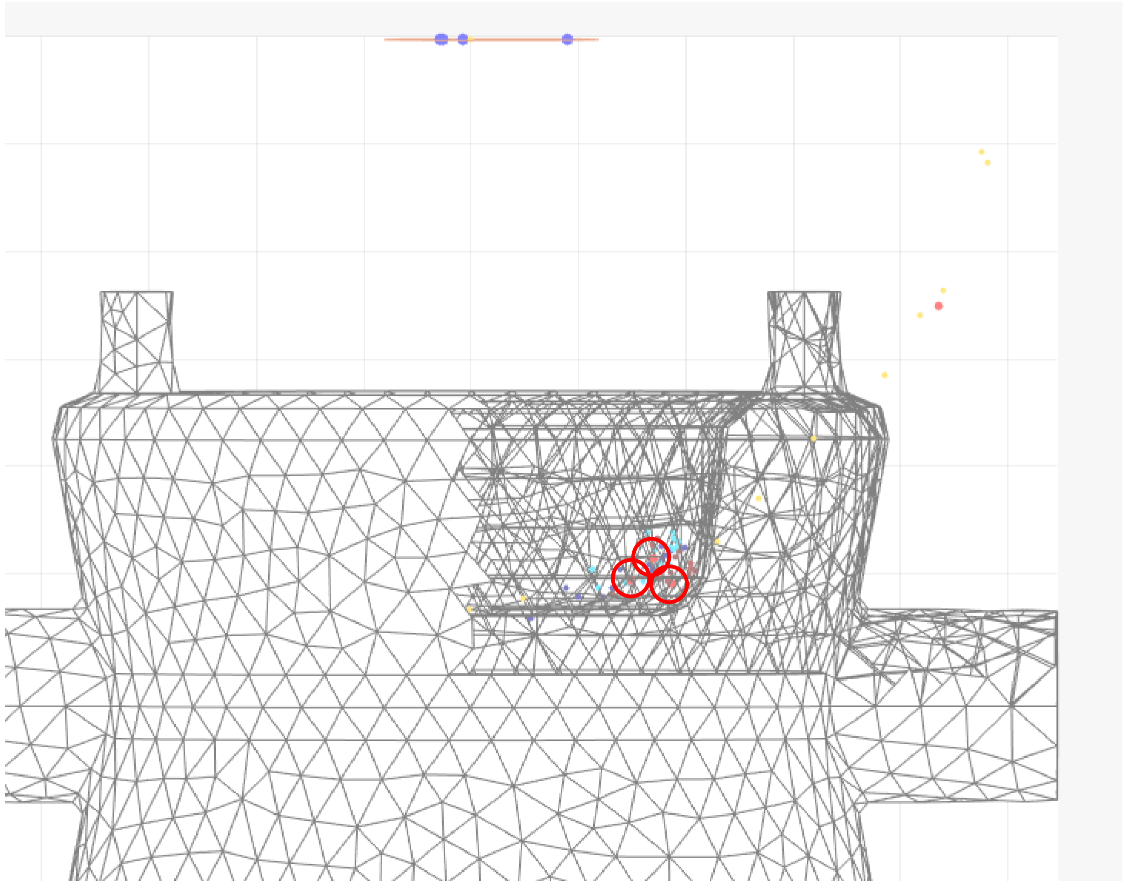


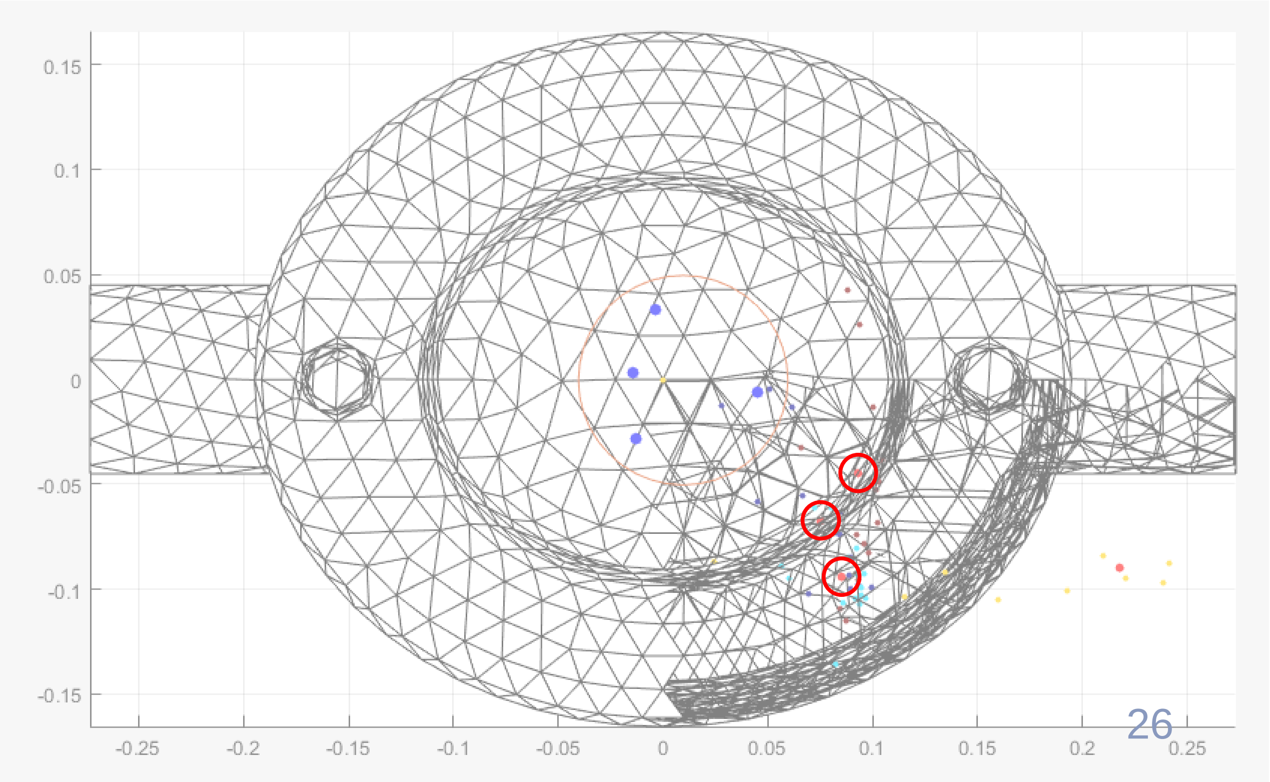


Trilateration results

The trilateration result seems to be a few cm inside the cavity.
This can be attributed to the presence of the stiffening frame.

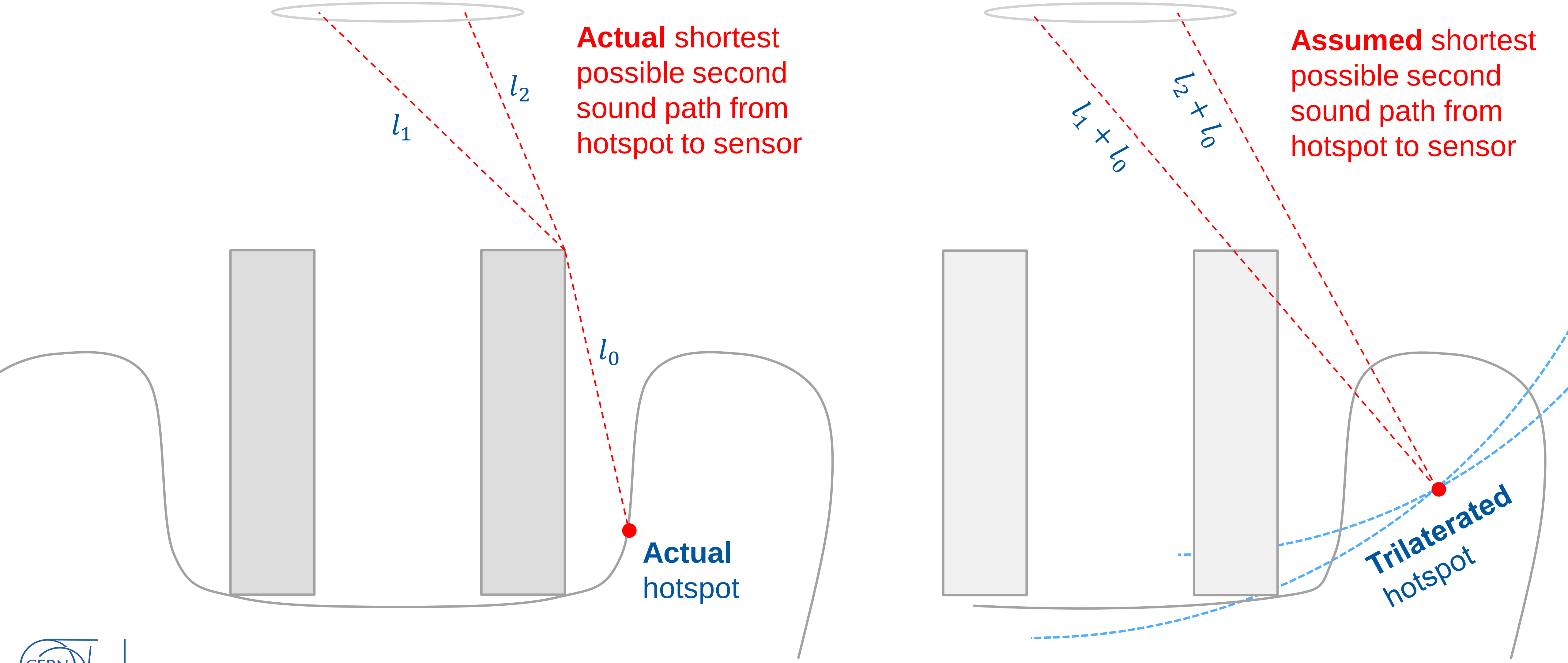






Obstacle effect

**Drawings at correct relative scale



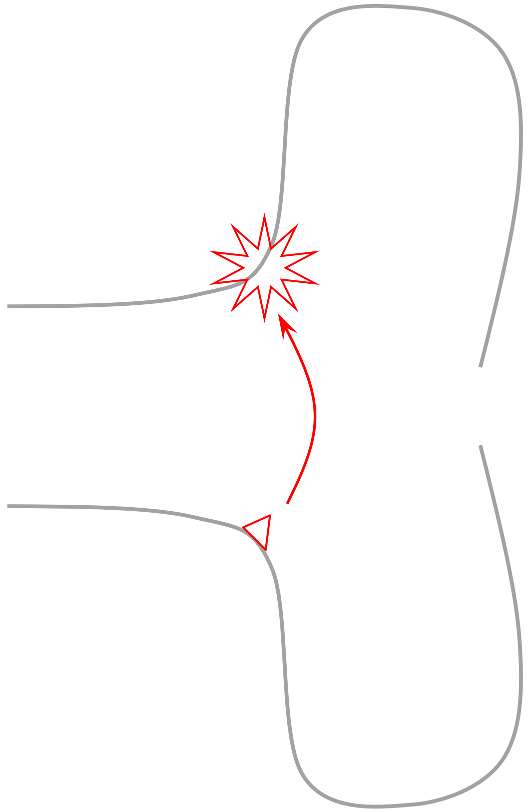
Open questions

Reason of this pulsed hotspot

- Possibly field emission with impact of electron on the hotspot
  → The hotspot is not located at the defect!

Is the obstacle enough to explain the displacement of the hotspots with respect to the surface?

Need to apply more sophisticated algorithm to the data.



Achievements and conclusions

TES as second sound detectors have been produced from Au-Sn thin films:

- Many fabrication processes proposed and evaluated
- Extensive second sound experiments at lab scale.

Camera-like and individual TES have been incorporated to SM18 test facility.

Two cavities were driven to quench and second sound was recorded with TES.

In spite of not ideal testing conditions, localisation of hot spots within a few cm was achieved.

TES non-contact thermal mapping has been validated during SRF cavity tests.

Further development is ongoing:

- Improvement of thermal response.
- Characterisation and optimization of the fabrication process.
- More cavity tests with improved conditions (cavity shape, sensor positions, temperature, etc.).

CERN