ADVANCED OST SYSTEM FOR THE SECOND-SOUND TEST OF FULLY DRESSED CAVITIES

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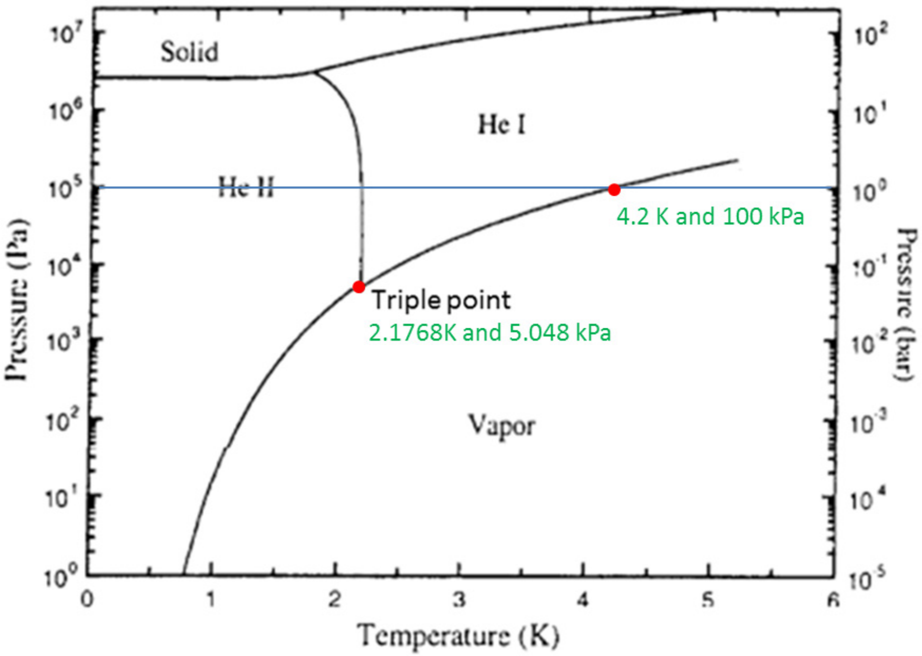
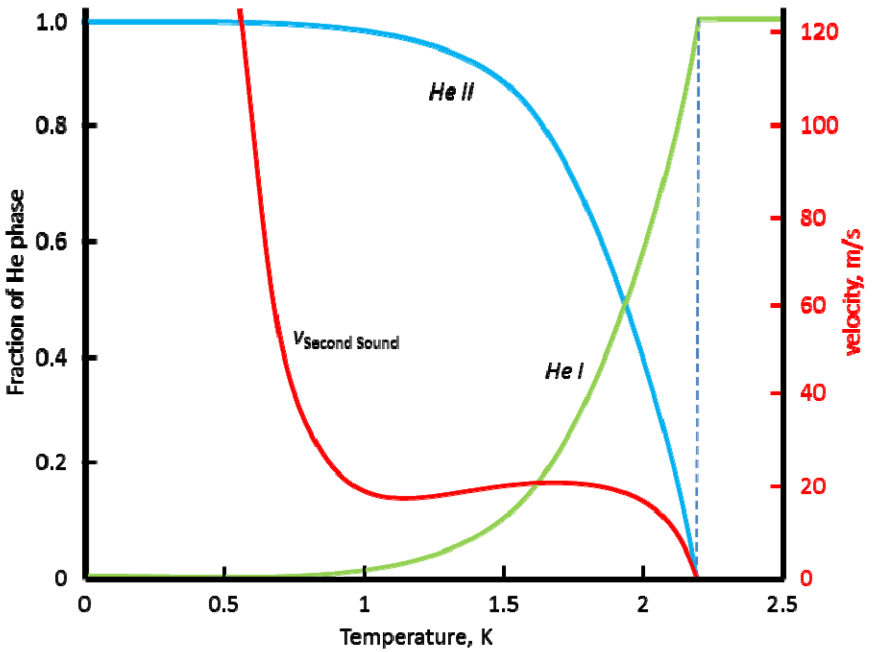
Superfluid Helium and Second Sound

Helium phase diagram



Phase fractions



$$\rho = \rho_n + \rho_s$$

$$u_1^2 \approx \frac{\partial P}{\partial \rho}$$ - first sound

$$u_2^2 \approx \frac{TS^2\rho_s}{C\rho_n}\nabla^2 T$$ - second sound

Quench

Quench in the cavity deposits heat into the helium bath

⇩

Second sound wave is induced

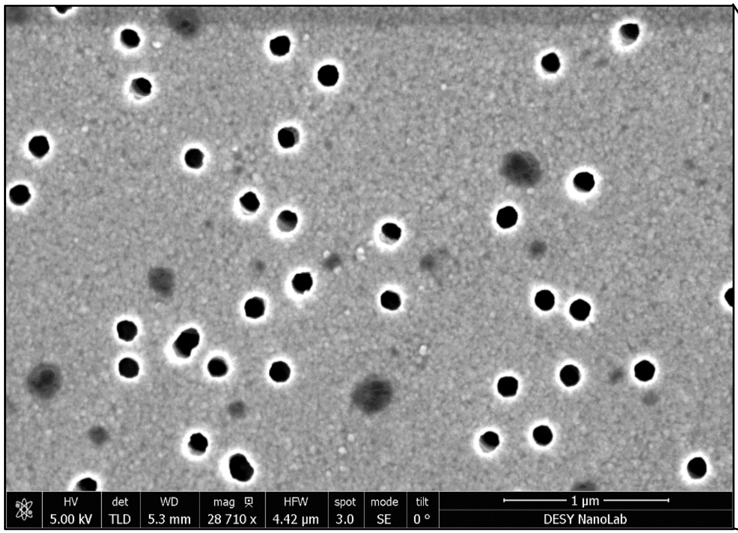
⇩

Temperature or phase oscillations can be detected

Previous talk by H. Furci

This talk

Oscillating Superleak Transducer (OST)



Cathode: porous "superleak" membrane

6 um thick polycarbonate
125 nm pores (3% of the surface area)
45 nm gold layer on one side

Only superfluid can flow through (at a given ω)

⇩

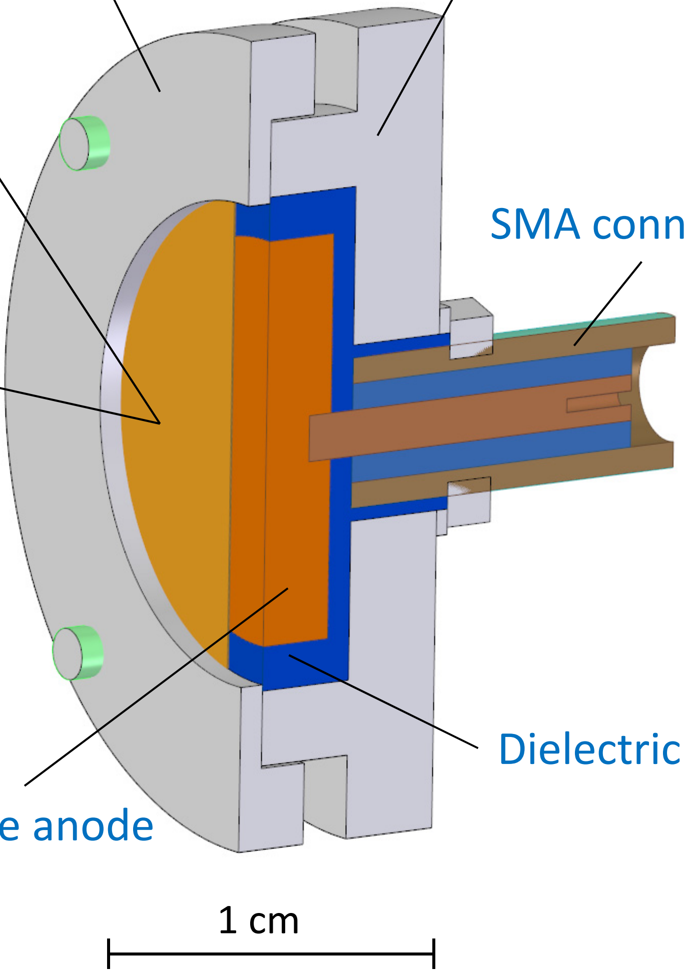
Full density $\rho = \rho_n + \rho_s$ oscillates behind the membrane

⇩

Membrane moves*

⇩

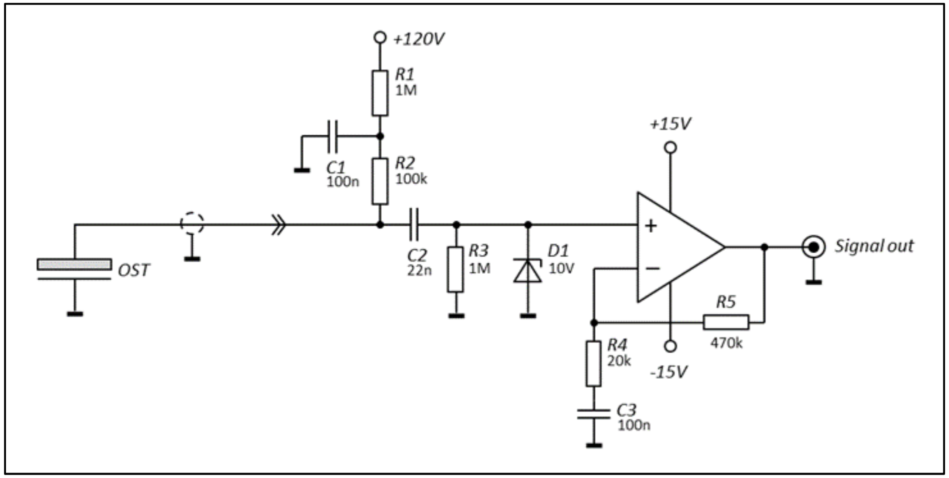
Capacitance of the OST changes



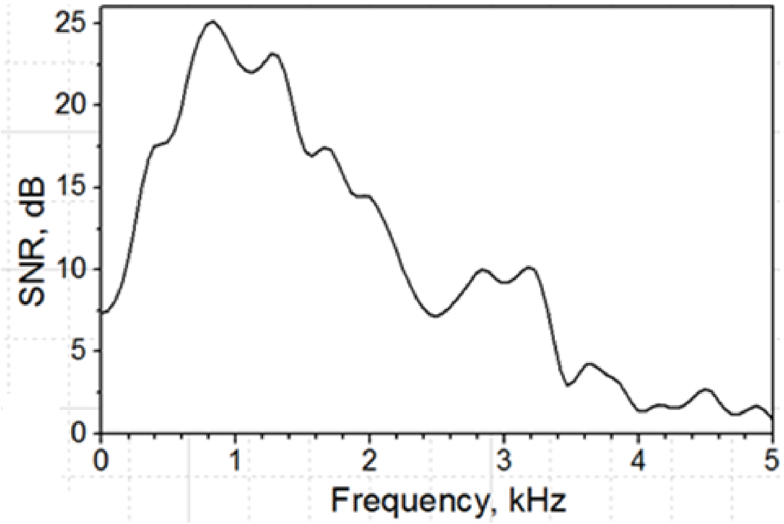
Cornell design: *Z.A. Conway, D.L. Hartill, H.S. Padamsee, E.N. Smith, "Oscillating Superleak Transducers For Quench Detection in Superconducting ILC Cavities Cooled with He-II", TESLA Technology Collaboration, Ithaca, New York, 2008.*

Signal acquisition

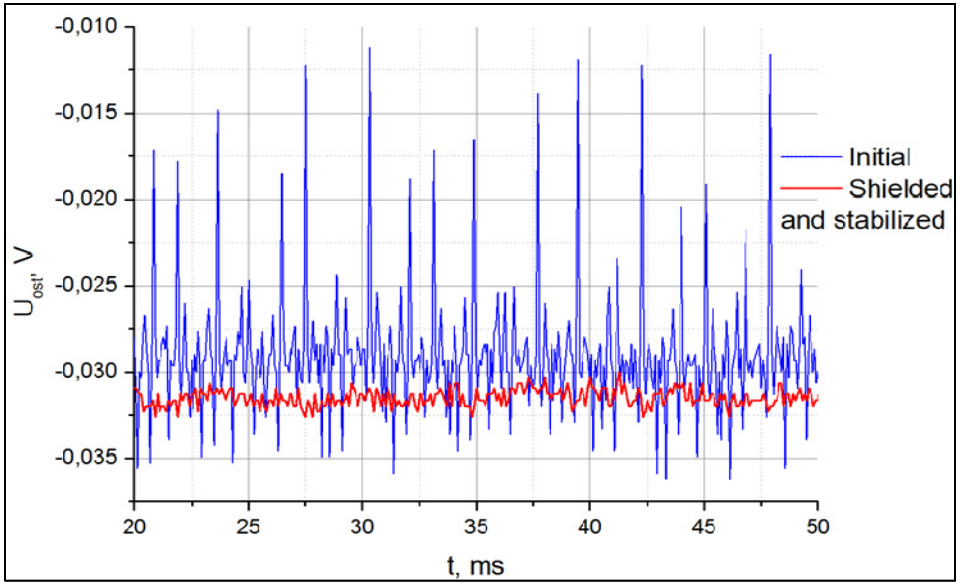
Amplification circuit



SNR spectrum of OST signal



Noise level



Signal amplifier

Power supply

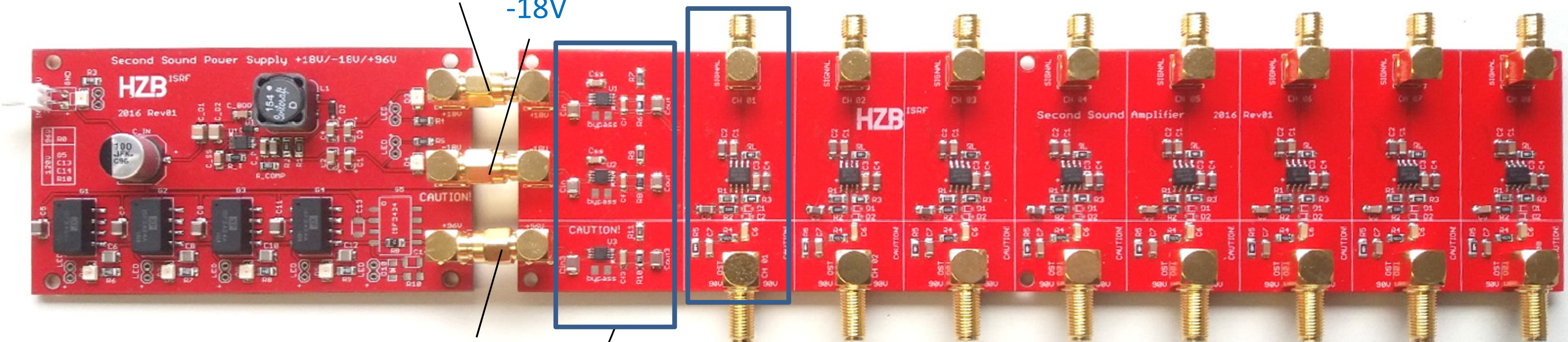
8-channel amplifier

Signal to ADC

+18V

-18V

Single-channel



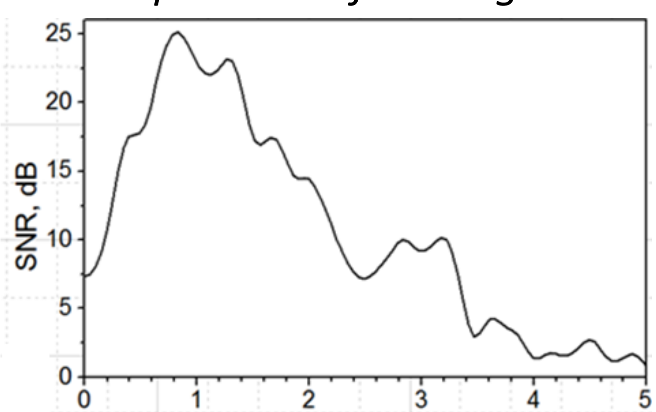
+96V

Low dropout regulators (LDO)

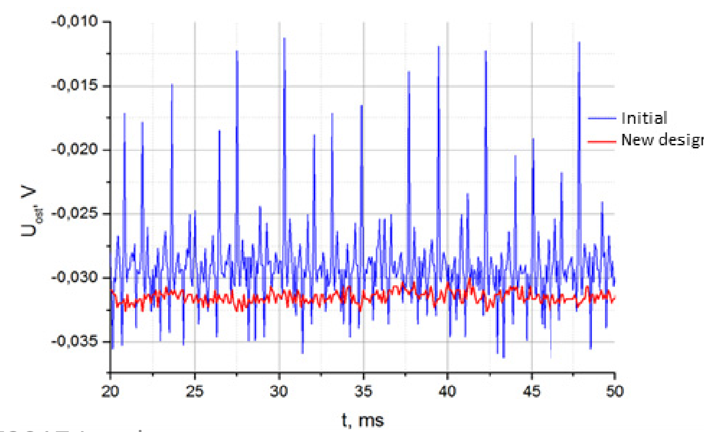
+90V to OST

Low-noise, wall-plug powered

SNR spectrum of OST signal

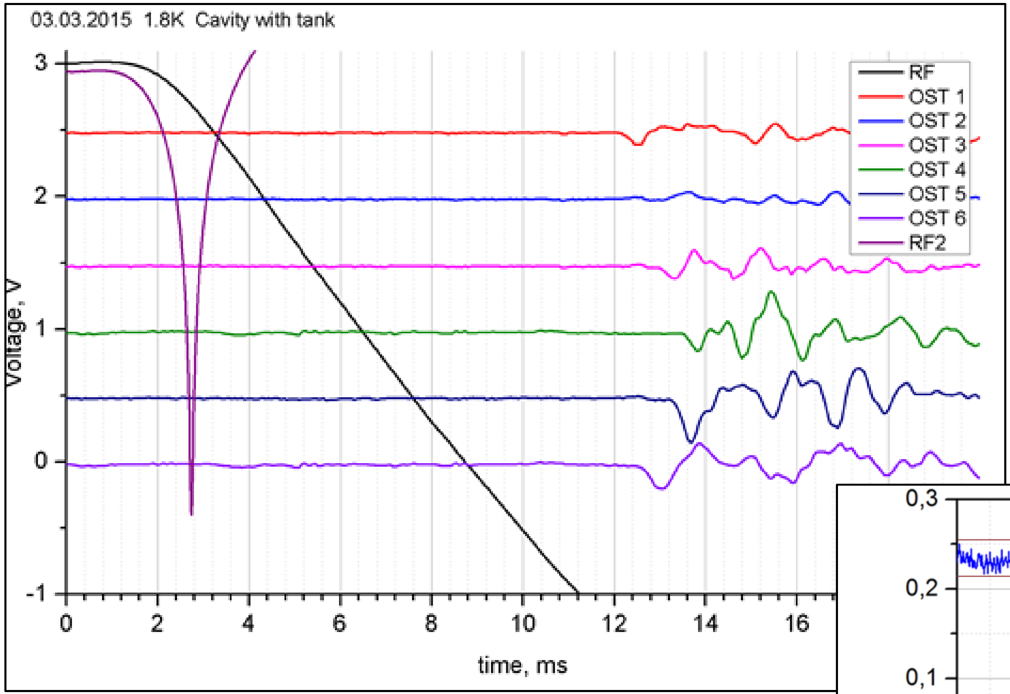


Noise level

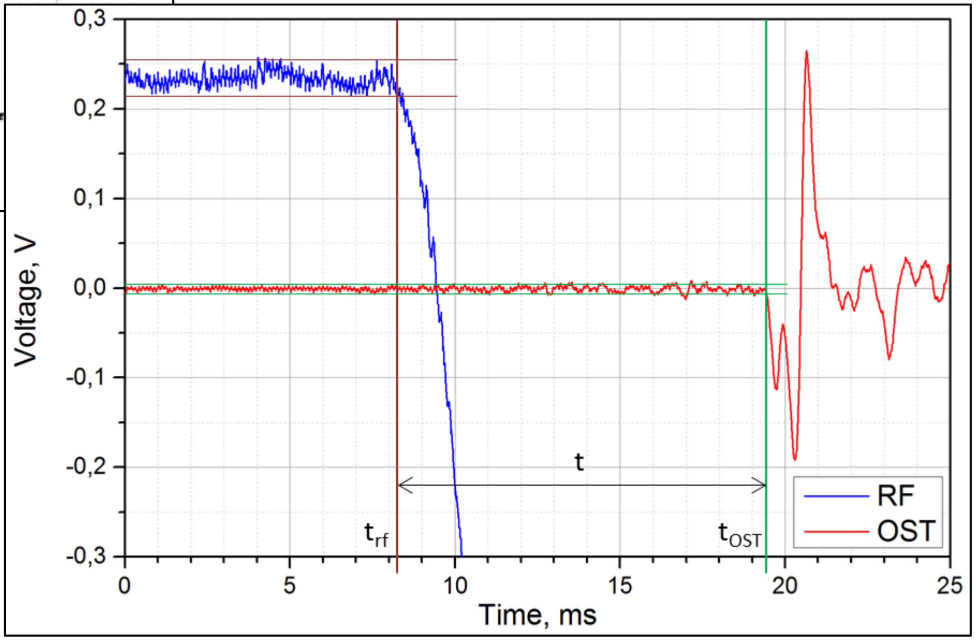


OST Signals

Up to 18 signals are acquired simultaneously



OST detection time



OST Detection time

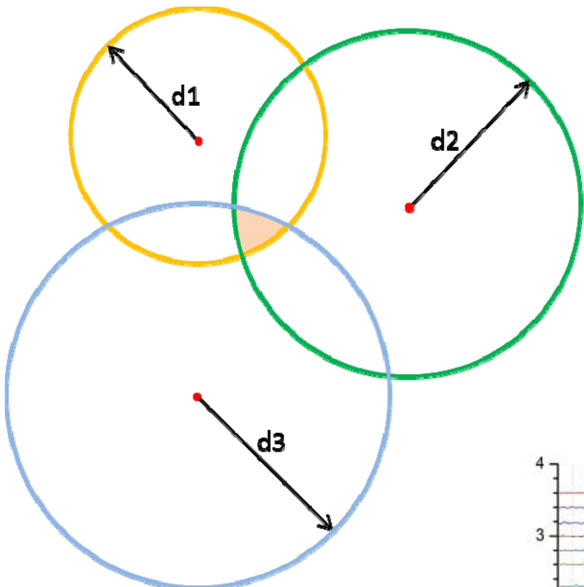
$$t = t_{OST} - t_{rf}$$

Quench distance

$$d_q = vt$$

Trilateration – not precise

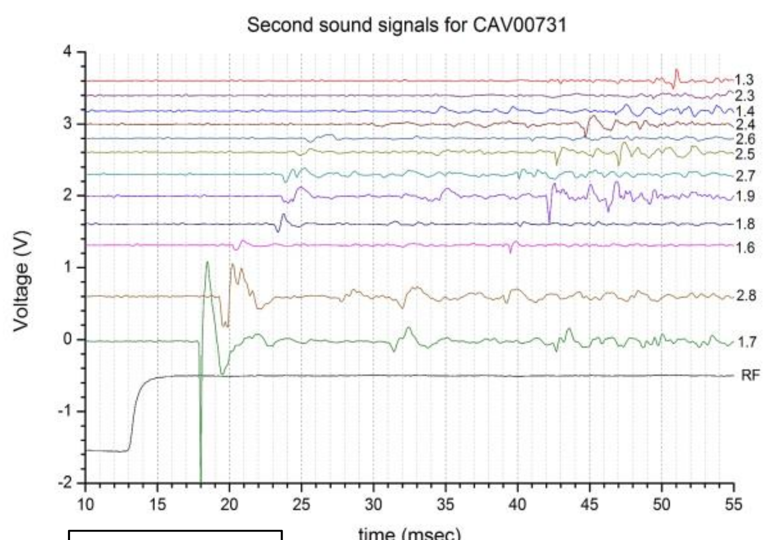
The simplest way to locate the quench is **trilateration**.



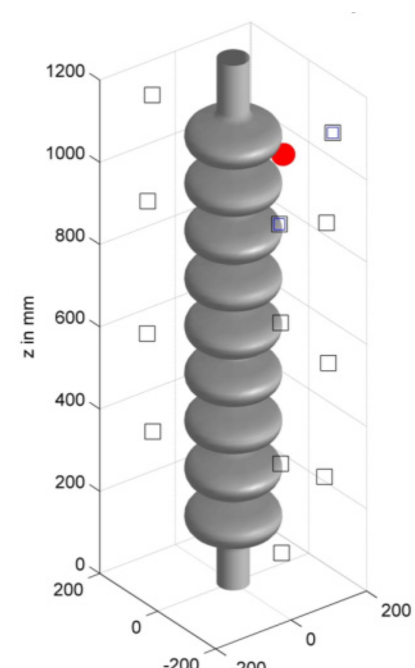
- **Low accuracy** (quench in few cm from the surface)
- **Uses only OSTs “in sight”**
- **Do not use the signals of “hidden” OSTs**

(i.e. 4-5 signals of 18 are used)

- **Requires many OSTs to cover the full surface**

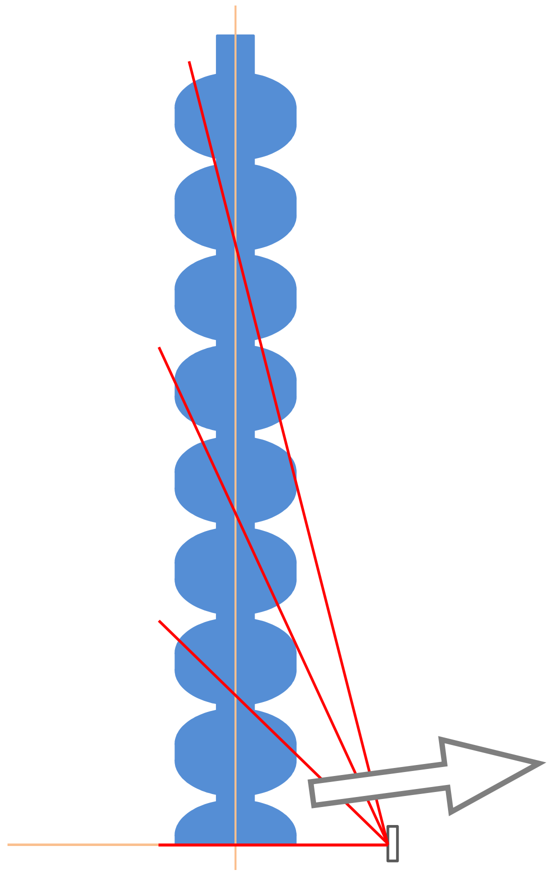


OST Signals

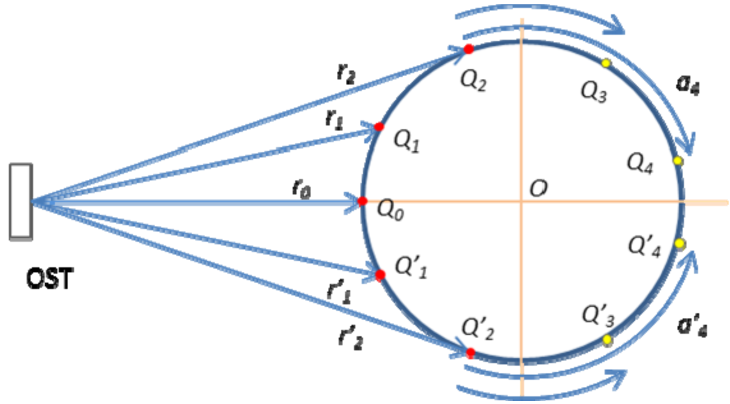


Ray tracing

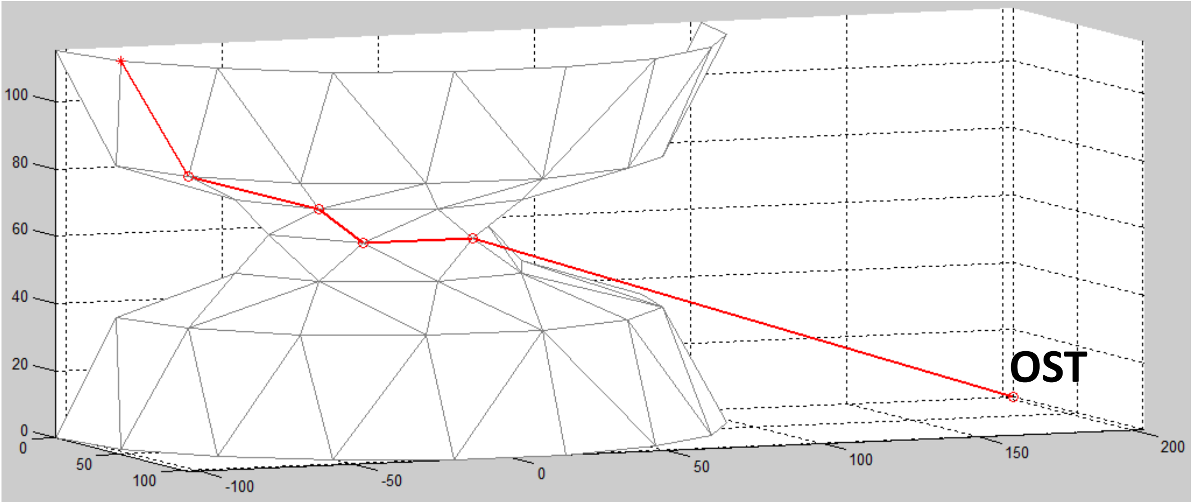
The shortest path from any point on the cavity surface to the OST can be calculated using the cavity shape



Possible paths of the wave (2D)



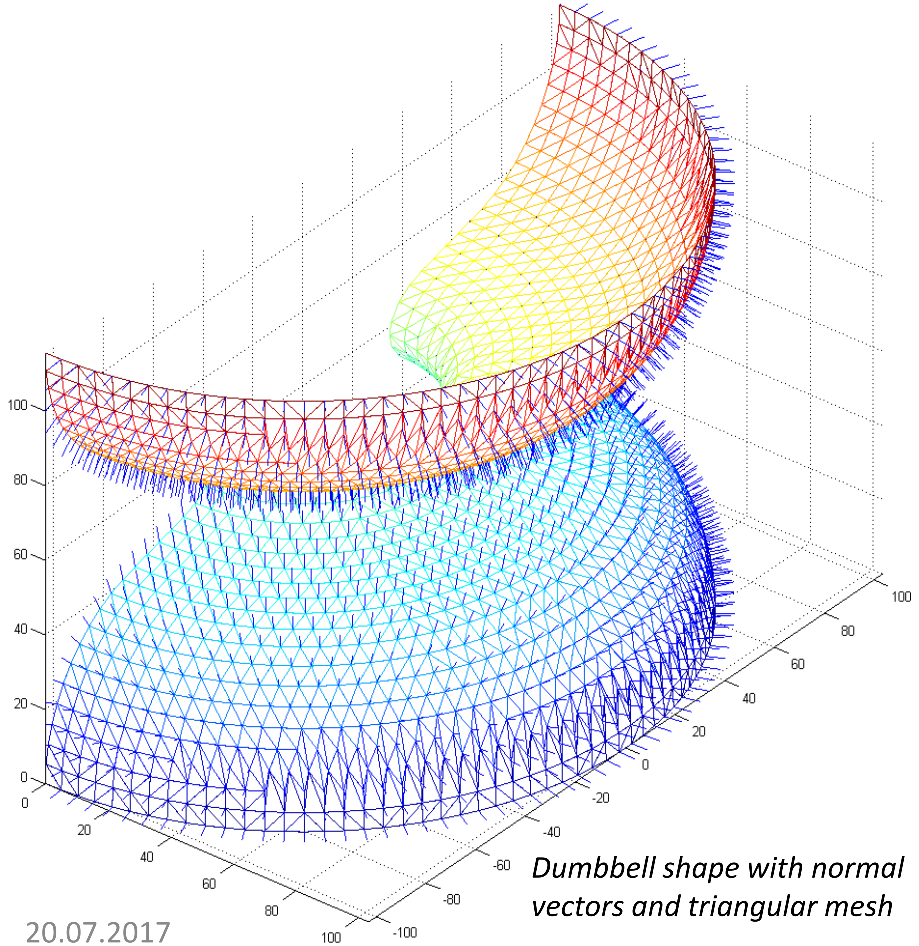
Path of the wave around the cavity (simple mesh)



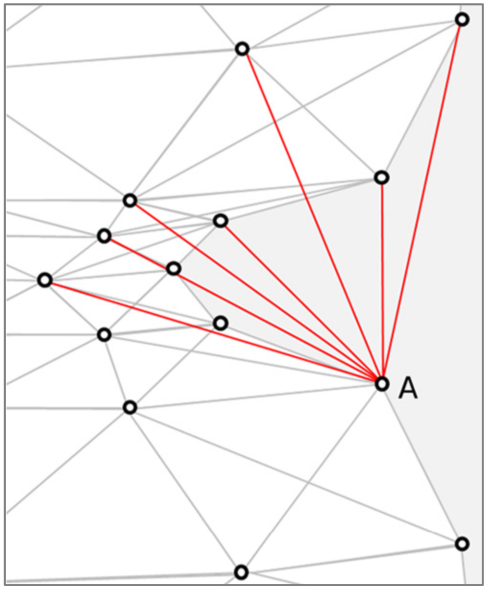
Graph of Interconnections

3D simulations are used to find the shortest paths of second sound from the quench point to each OST.

Results of 3D simulations and path calculations are stored in 2D matrices which allows using of these precalculated results during the second sound tests.



Dumbbell shape with normal vectors and triangular mesh



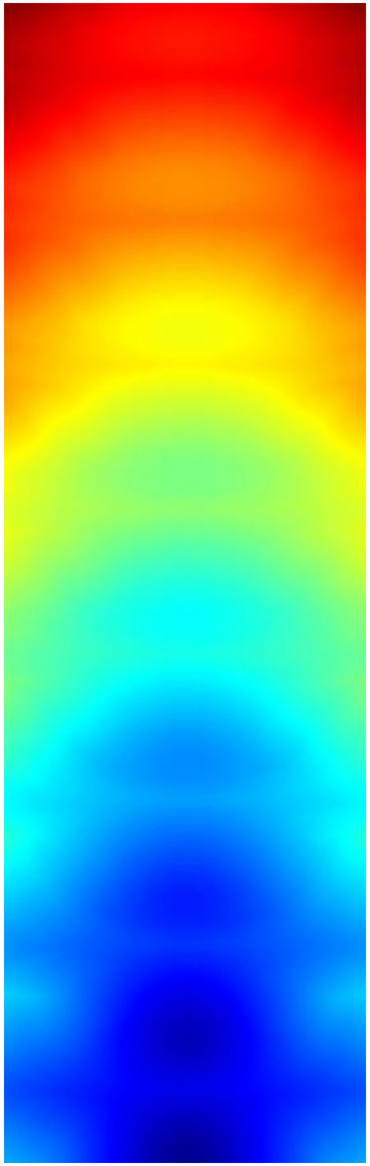
Distance map

Distance matrix

r_{35}	r_{34}	r_{33}	r_{32}	r_{31}	r_{30}	r_{29}	H
r_{28}	r_{27}	r_{26}	r_{25}	r_{24}	r_{23}	r_{22}	
r_{21}	r_{20}	r_{19}	r_{18}	r_{17}	r_{16}	r_{15}	height
r_{14}	r_{13}	r_{12}	r_{11}	r_{10}	r_{9}	r_{8}	
r_{7}	r_{6}	r_{5}	r_{4}	r_{3}	r_{2}	r_{1}	0

180° angle 0°

developed view of the cavity surface

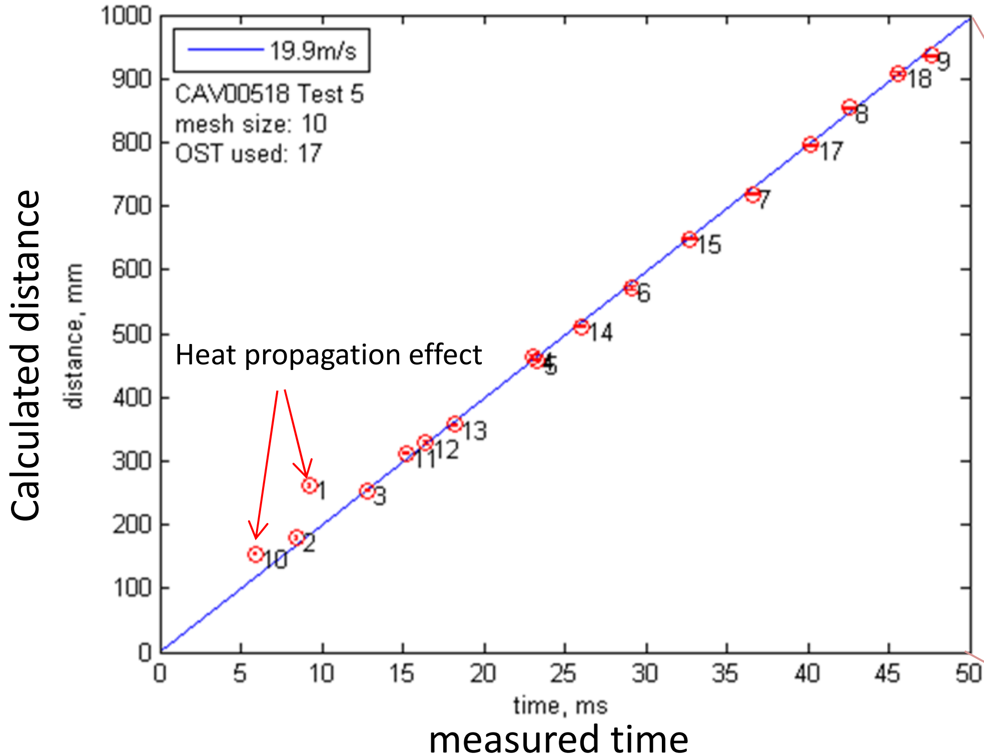


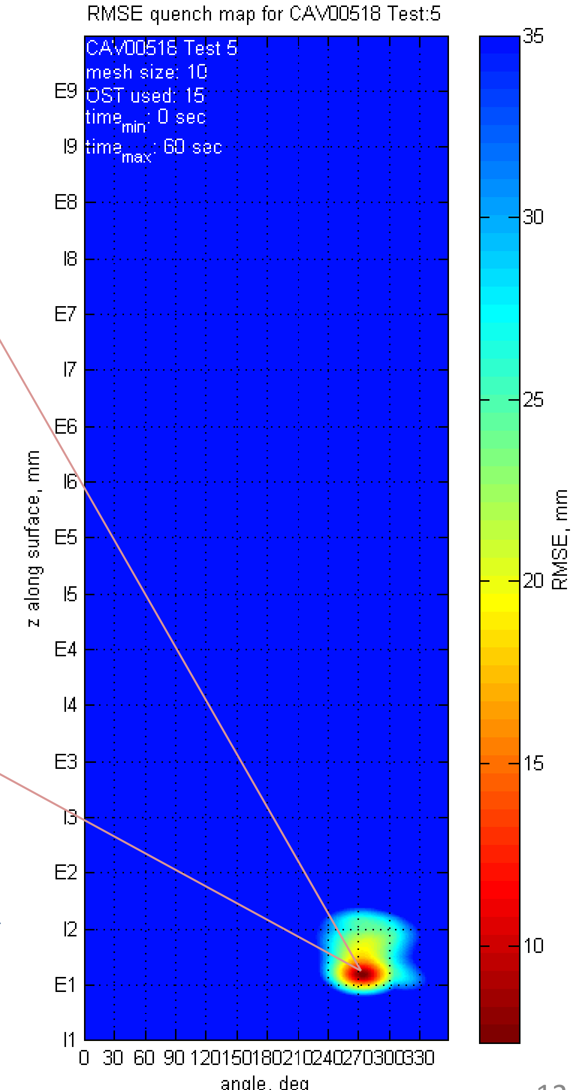
Assumptions:

- The quench origin is located on the cavity surface
- The second-sound wave reaches the OST by taking the shortest possible route
- The velocity of second sound in helium is constant for the whole volume of the cryostat

Quench Localisation

For each point of the map all OST signals are linearly fitted by the second sound velocity (19.9 m/s at 1.8 K)[4]





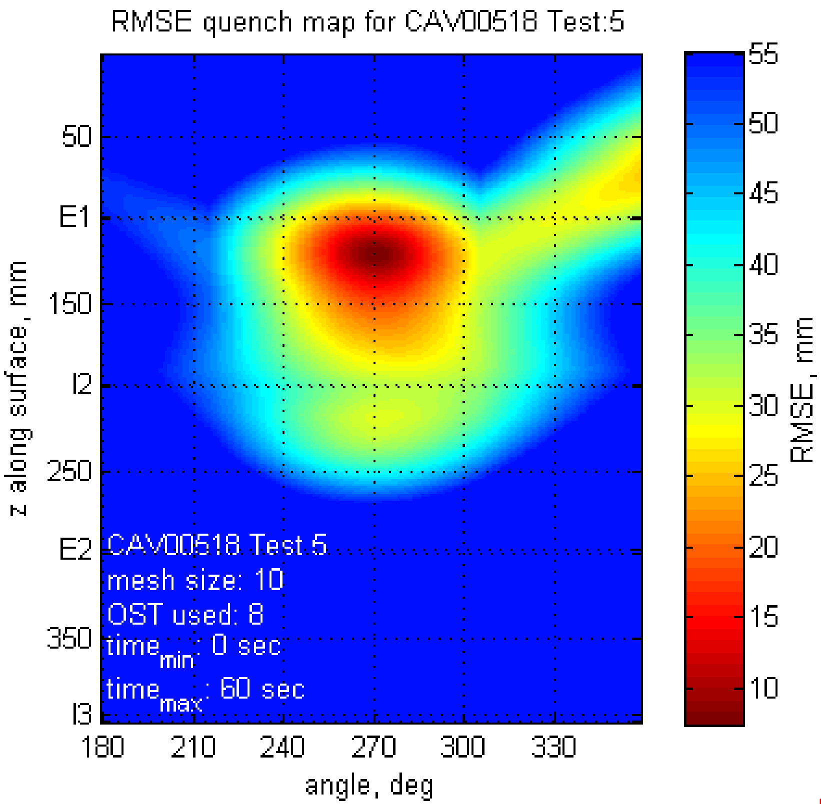
*Combination of **n** Distance maps*

$$RMSE_{z,\phi} = \sqrt{\frac{\sum_{i=1}^{n}(s_{z,\phi} - d_{q\ i})^2}{n}}$$

[4]Russell J. Donnelly - The Observed Properties of Liquid Helium at the Saturated Vapor Pressure

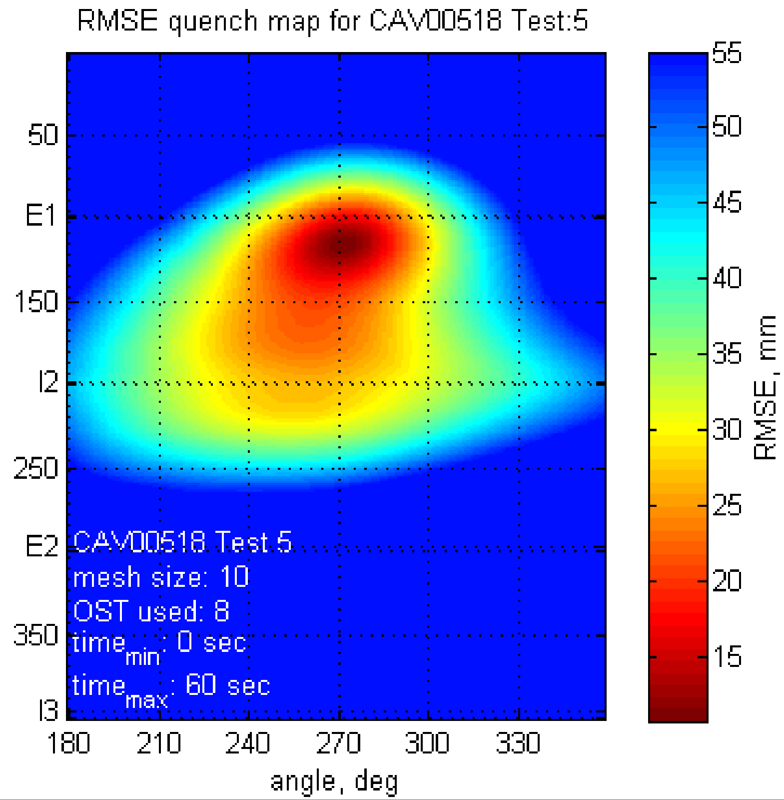
Detectors in direct view and without direct view of the quench point

OSTs in direct view



Can be also done by trilateration

OSTs without direct view

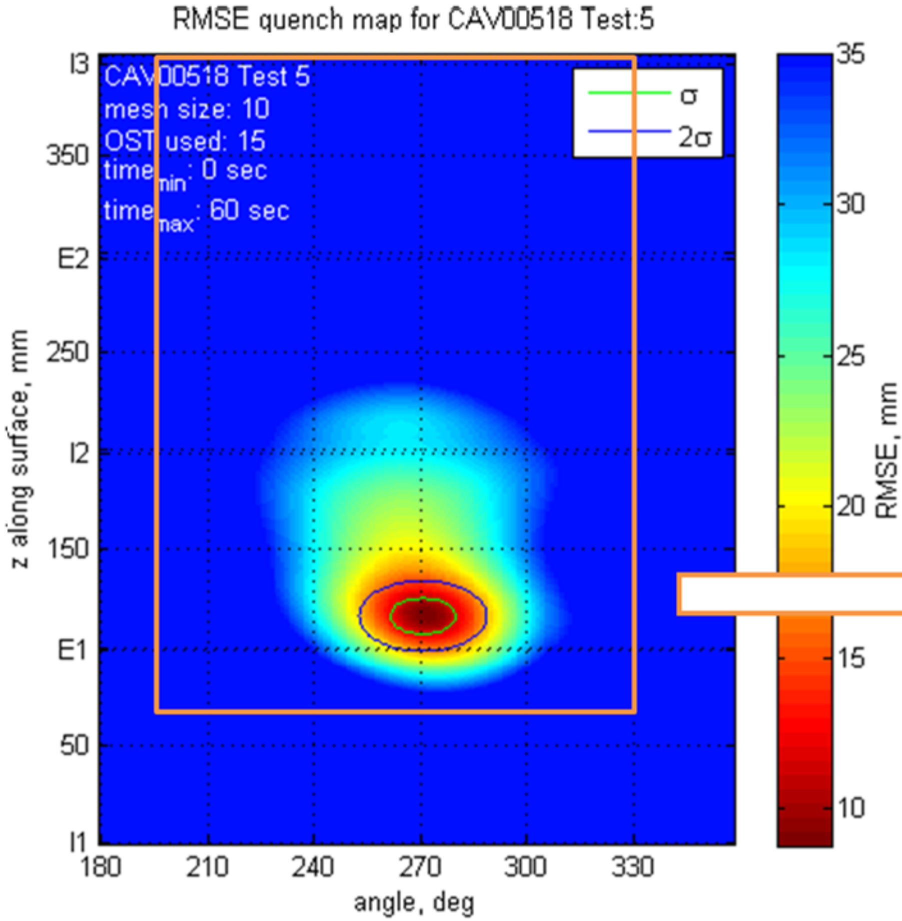


Can be done only by path calculation

The OSTs both in direct view and without direct view can be used to determine the quench position

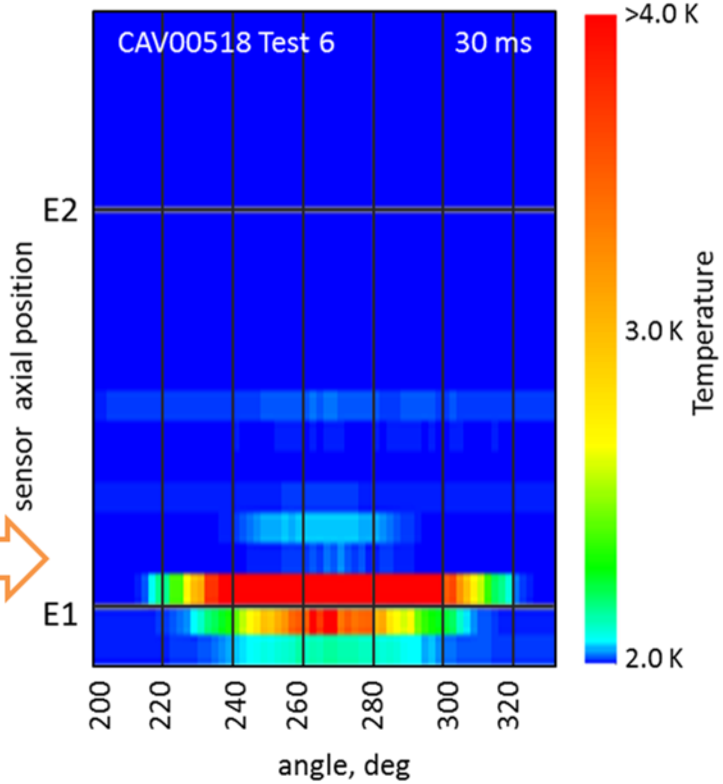
Comparing with T-mapping results (naked cavity)

Second Sound map



T-map

Temperature mapping



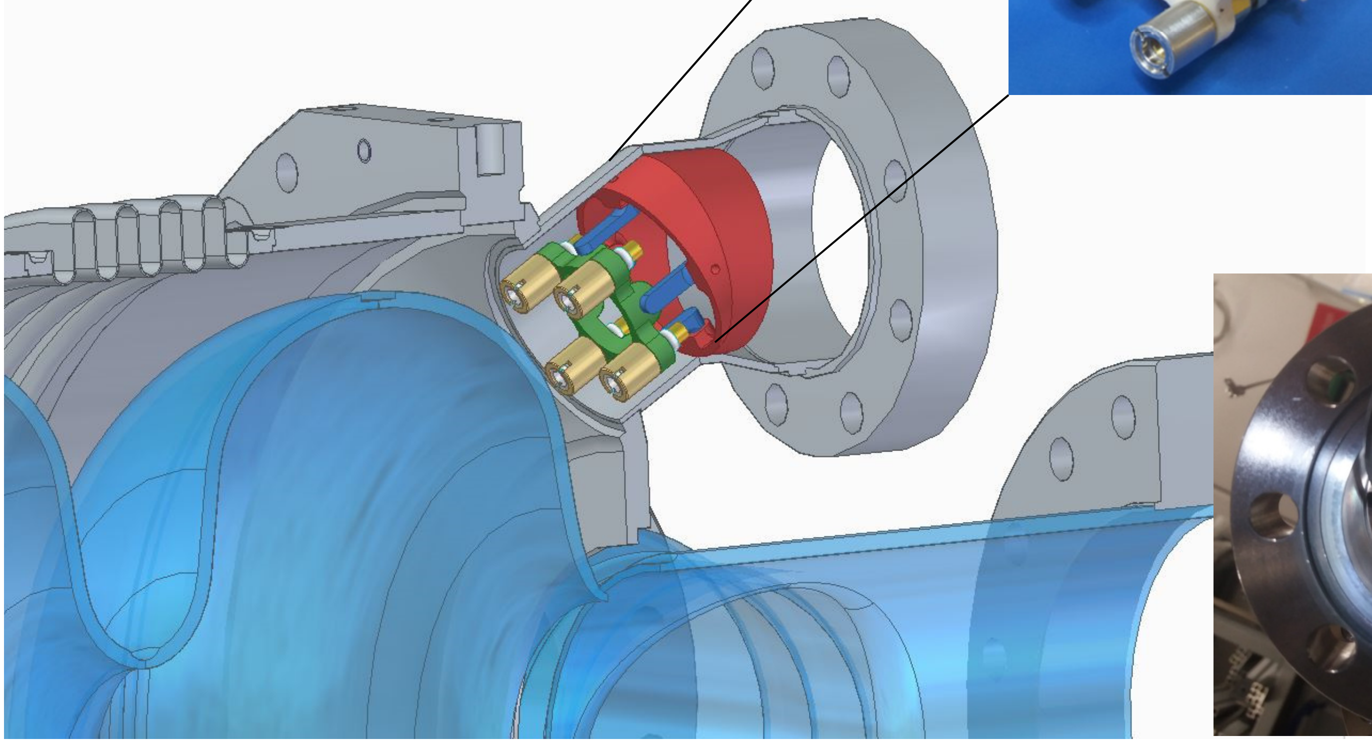
T-mapping shows the quench point close to the spot defined by the Second Sound test

Dressed Cavities

OST size is strongly limited to allow sufficient cavity cooling

4 9-mm OSTs assembled on a plastic holder

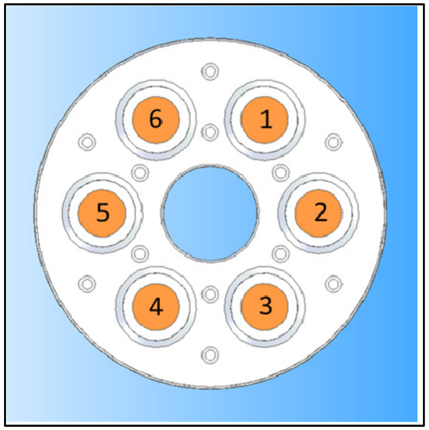
bERLinPro booster cavity
4 OST are installed in a helium pipe



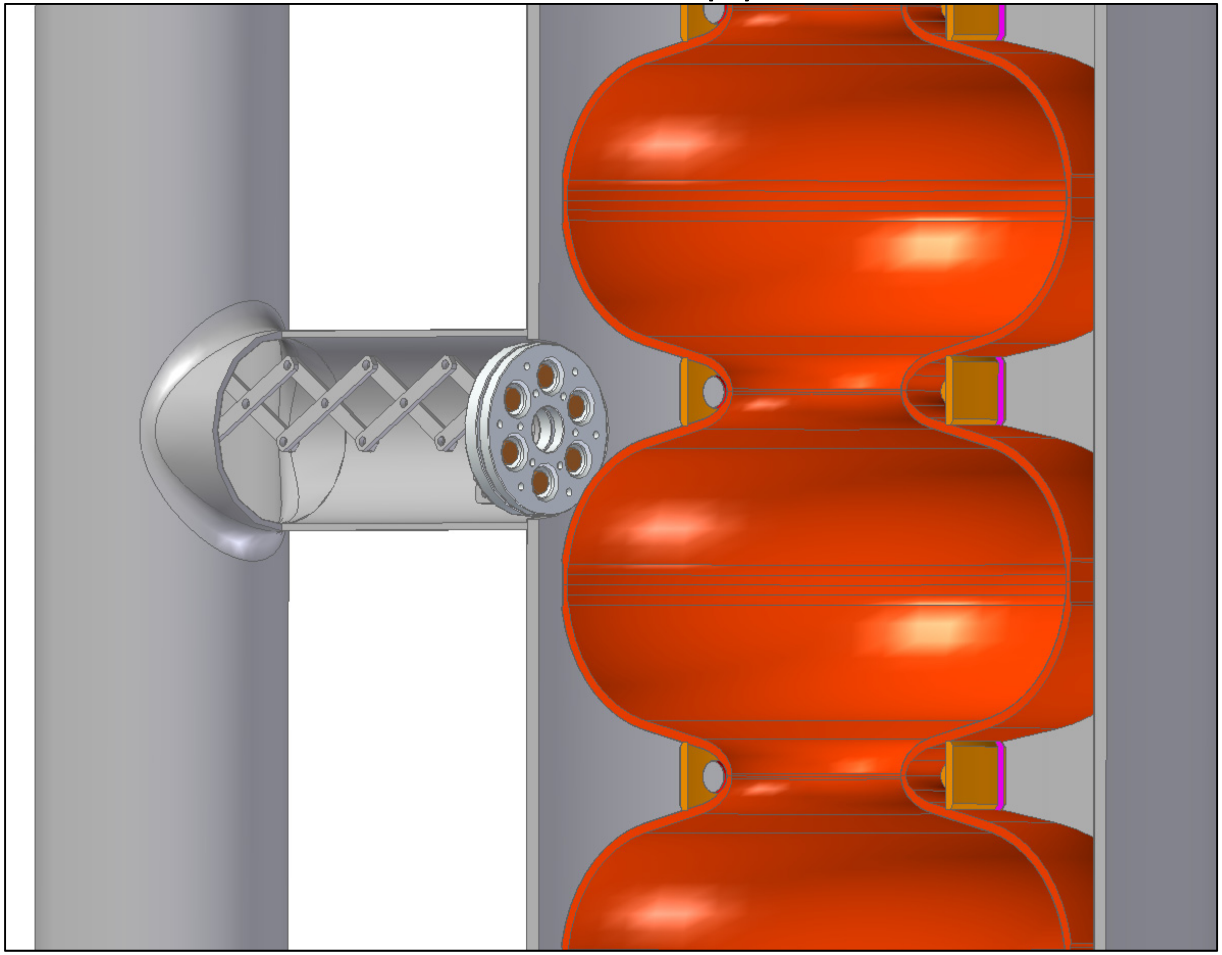
Dressed Cavities - Multi-OST

Multi-OST

6 sensors



Multi-OST installed into the helium pipe



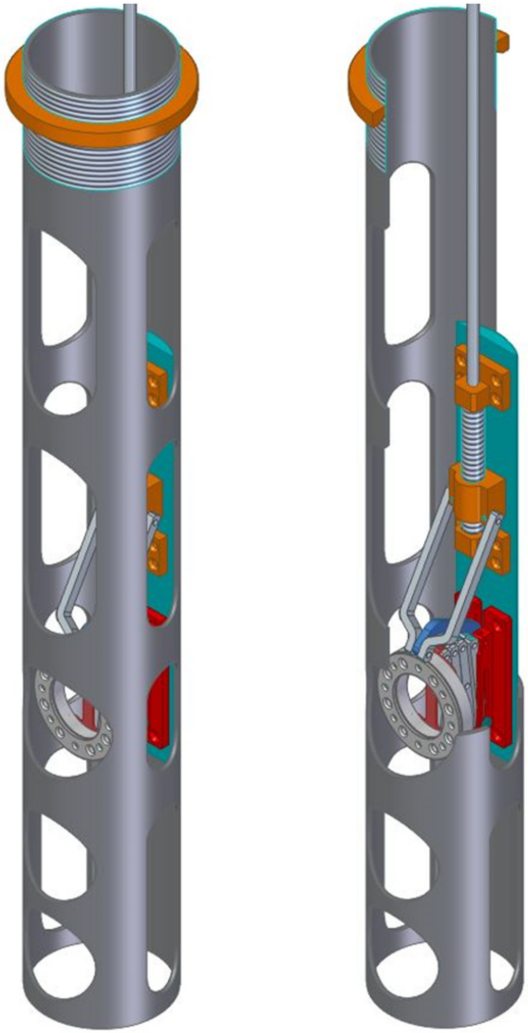
Multi-OST: various dimensions

Multi-OST of various dimensions and with different number of channels were developed.

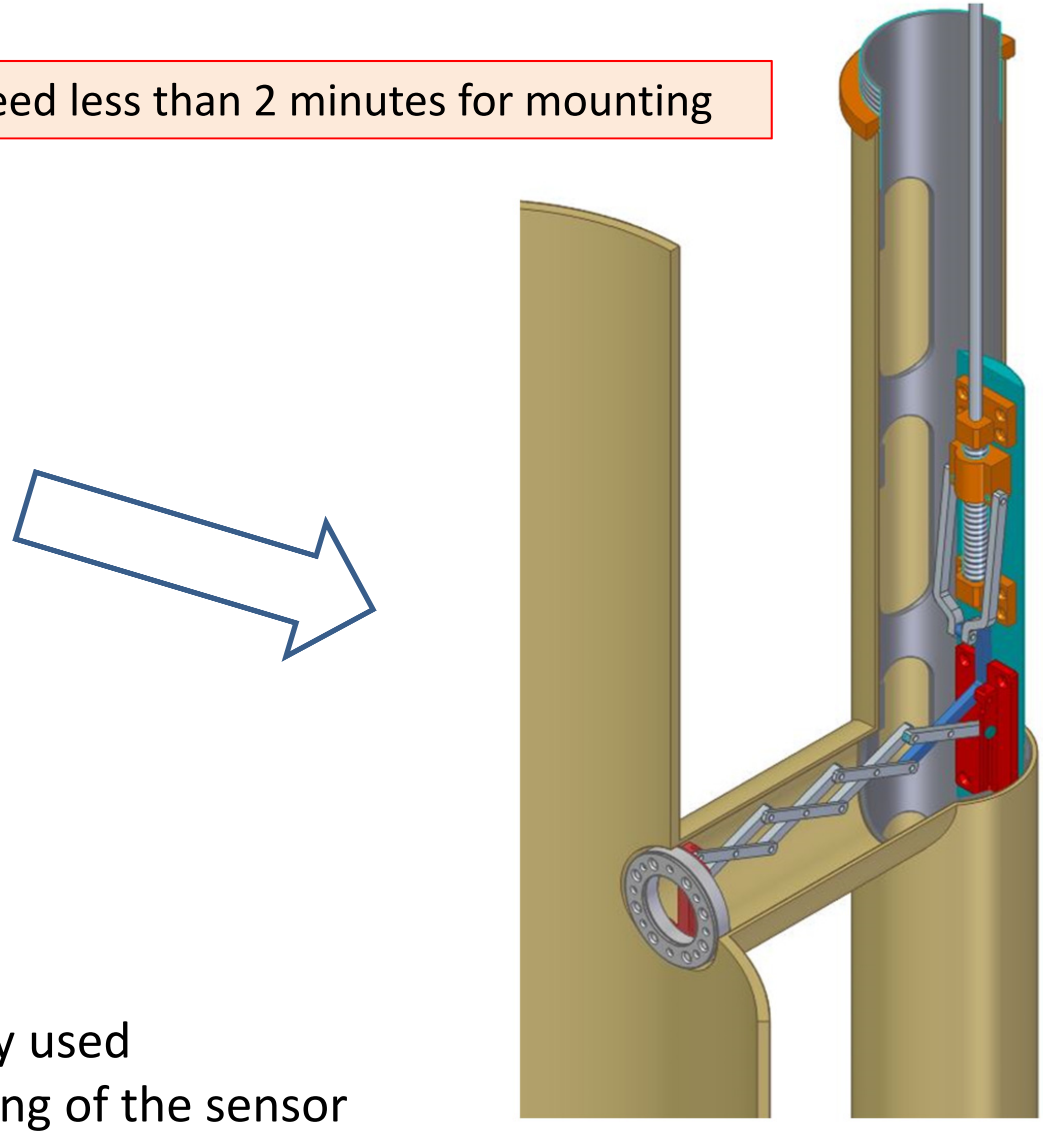
38 mm, 8-channel multi-OST

52 mm, 6-channel multi-OST in a helium tank of the cavity

Ready-to-use system for E-XFEL cavities



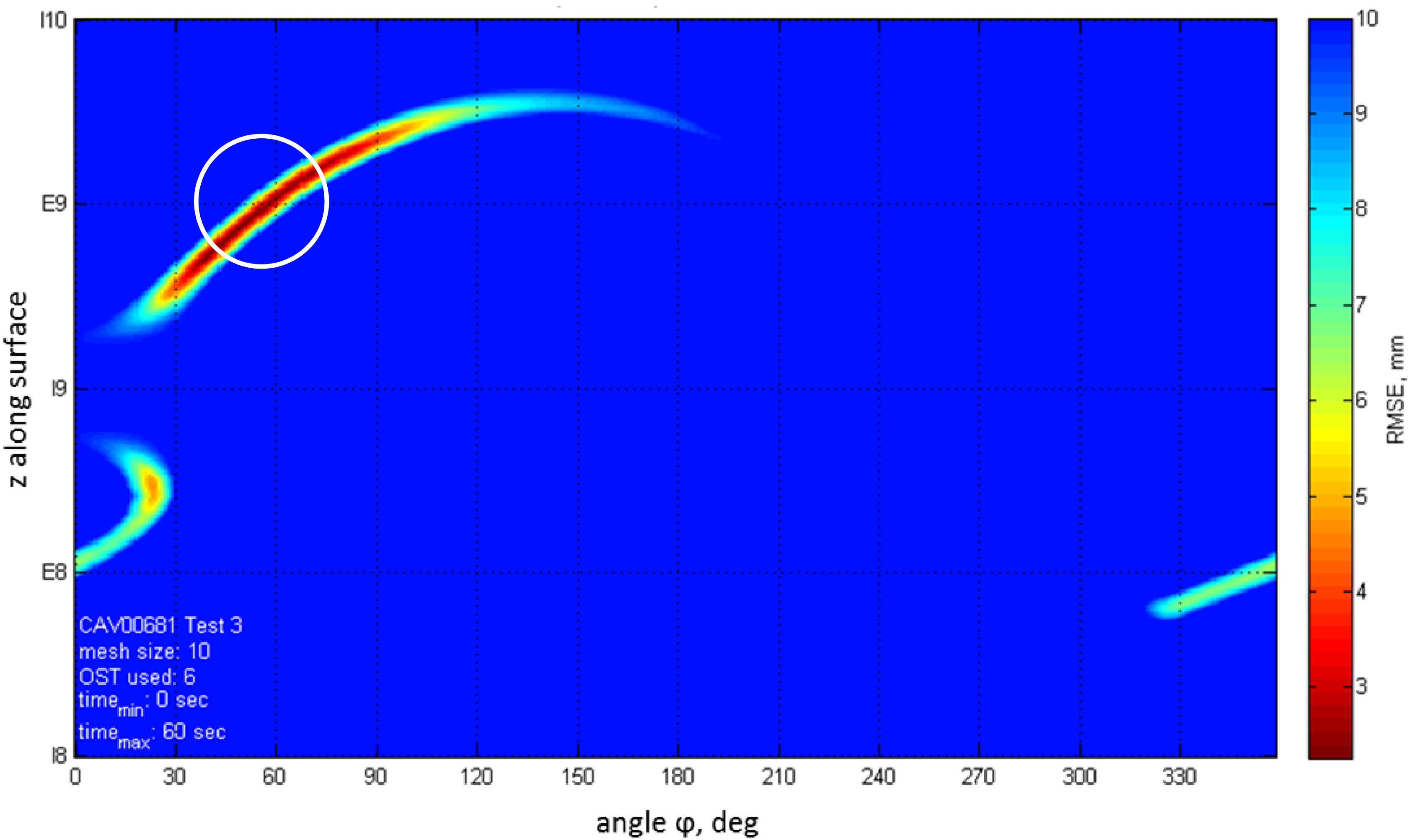
Need less than 2 minutes for mounting



- Designed to be repeatedly used
- Provides precise positioning of the sensor
- Does not require any additional cavity preparations

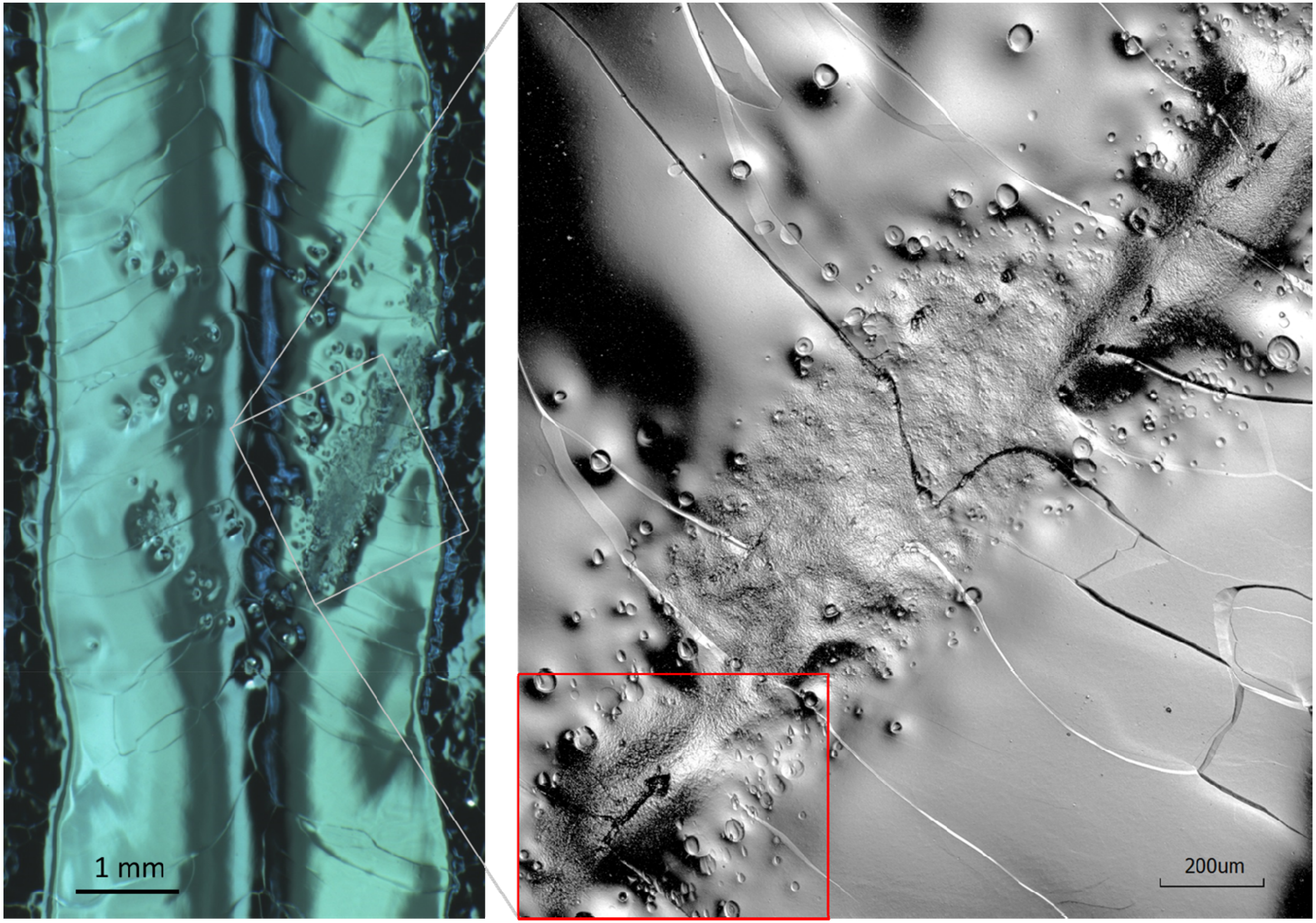
Results: Standard E-XFEL cavity with tank

A part of the quench map for the ***dressed cavity*** *CAV00683*



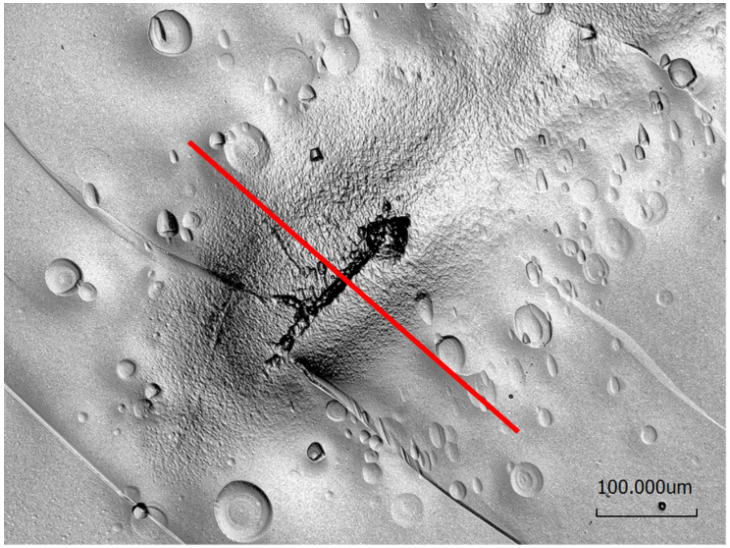
Welding seam of the Equator 9 at 50 °

Optical image (OBACHT) *Laser image of the replica*

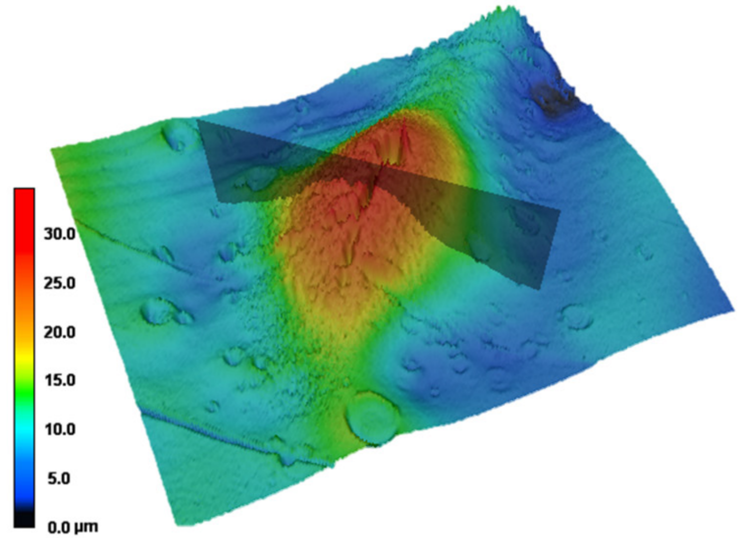


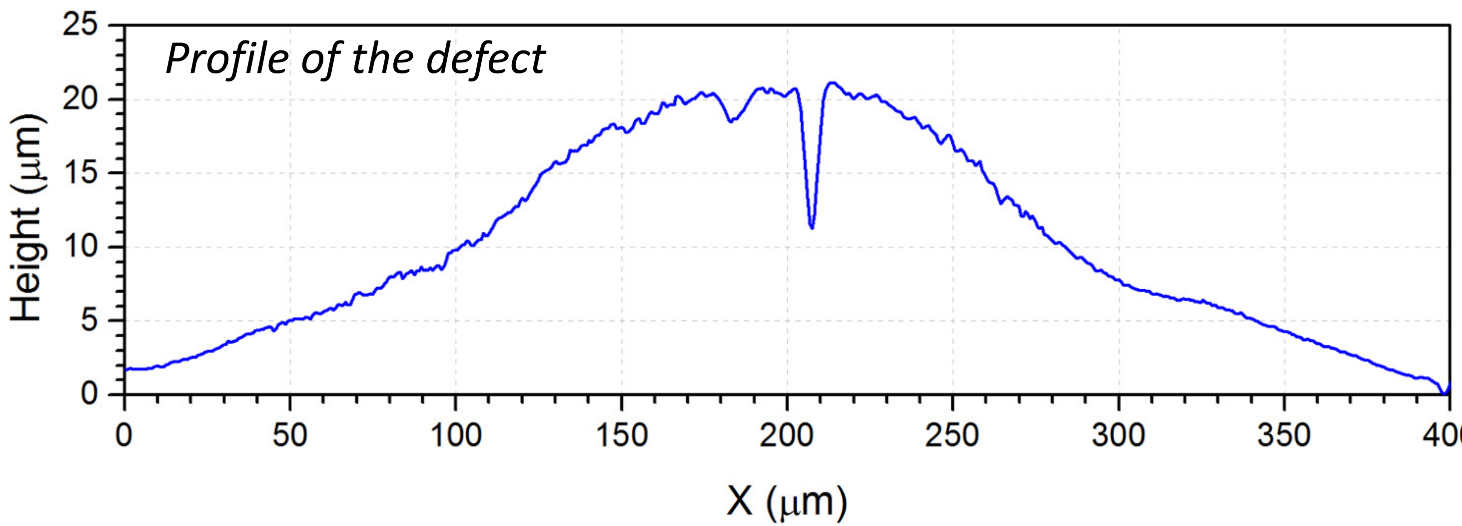
Profile of the defect

Laser image



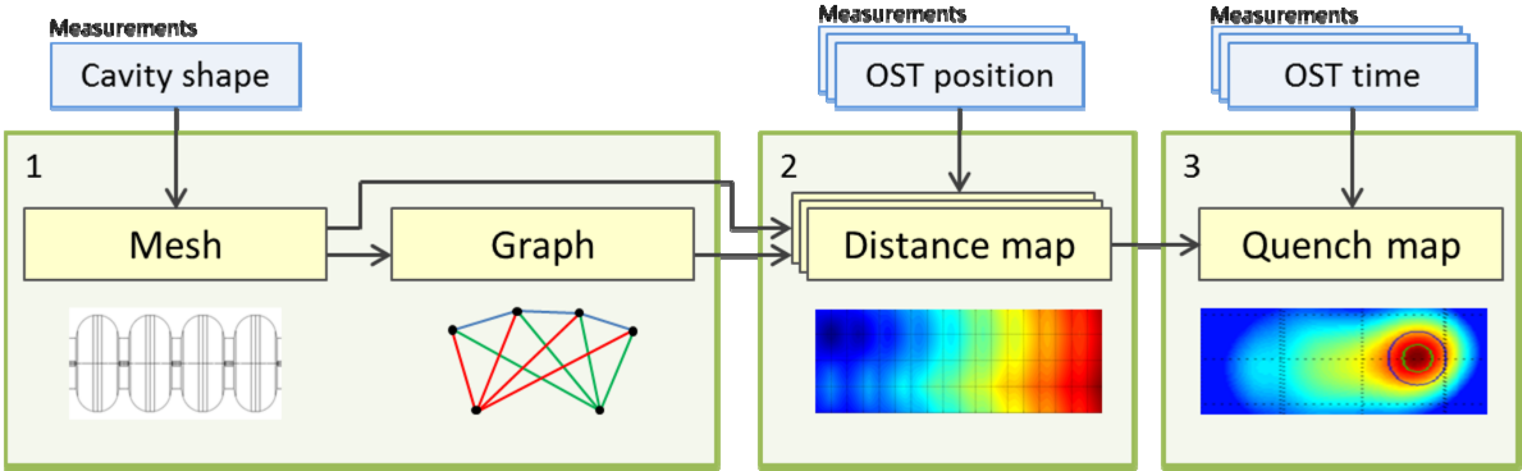
3D image





Algorithm

MatLab code is available on GitHub



The most intensive calculations

Cold Test

- The most intensive calculations (building the **graph**) are separated and done once for the cavity shape used.
- **Distance maps** should be calculated for the specific OST positions. If the same OST positions are used, the same distance maps can be used.
- Calculation of the **quench map** can be done “on-the-fly” during the cavity test

Second Sound: Results

- The hardware and algorithm for second-sound tests were developed and verified by testing 9-cell cavities.
- The precision of localisation of the quench is in a good agreement with the direct temperature measurements.
- A multi-OST for the second-sound test of a series-production XFEL cavity was developed.
- Such a system can be used with <u>different cavity shapes and sizes</u>.

A second sound test is proposed to be a part of a standard vertical test.

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