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Study of Temperature Wave Propagation in He II Focusing on RF Cavity Cooling

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Content

- Introduction to superconducting RF cavities
- Quench spot localisation – quality insurance
- Oscillating Superleak Transducer => OST
- Second sound in He II – non linear effects

- Experimental set-up to investigate high heat flux sources and 3D propagation

- Measurement results, dependency on:

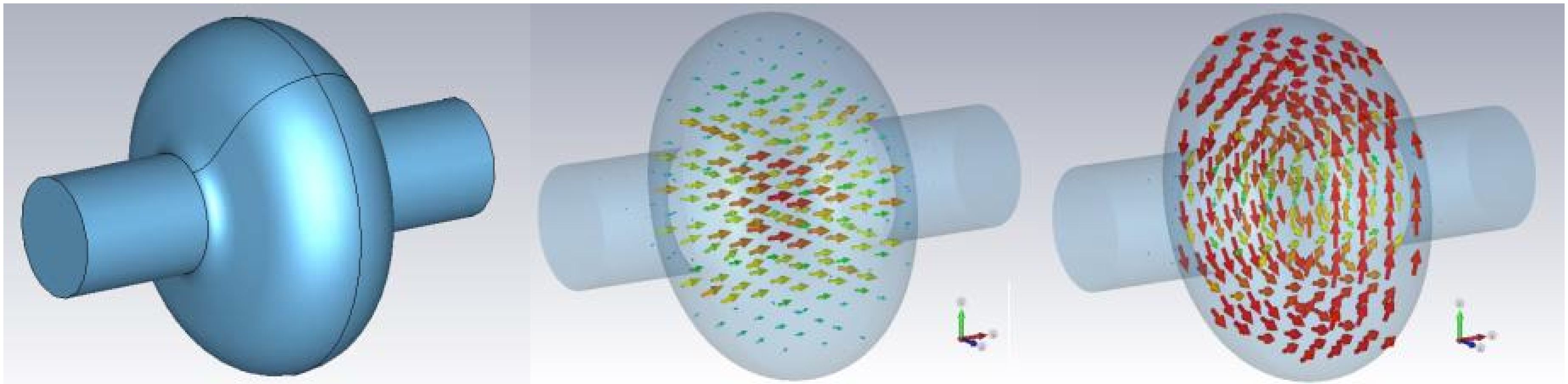
  - He II - bath temperature
  - Heat flux
  - Incident angle of the second sound wave

- Application of OST detection for CRAB cavity tests for HiLumi LHC

Superconducting radio frequency cavities

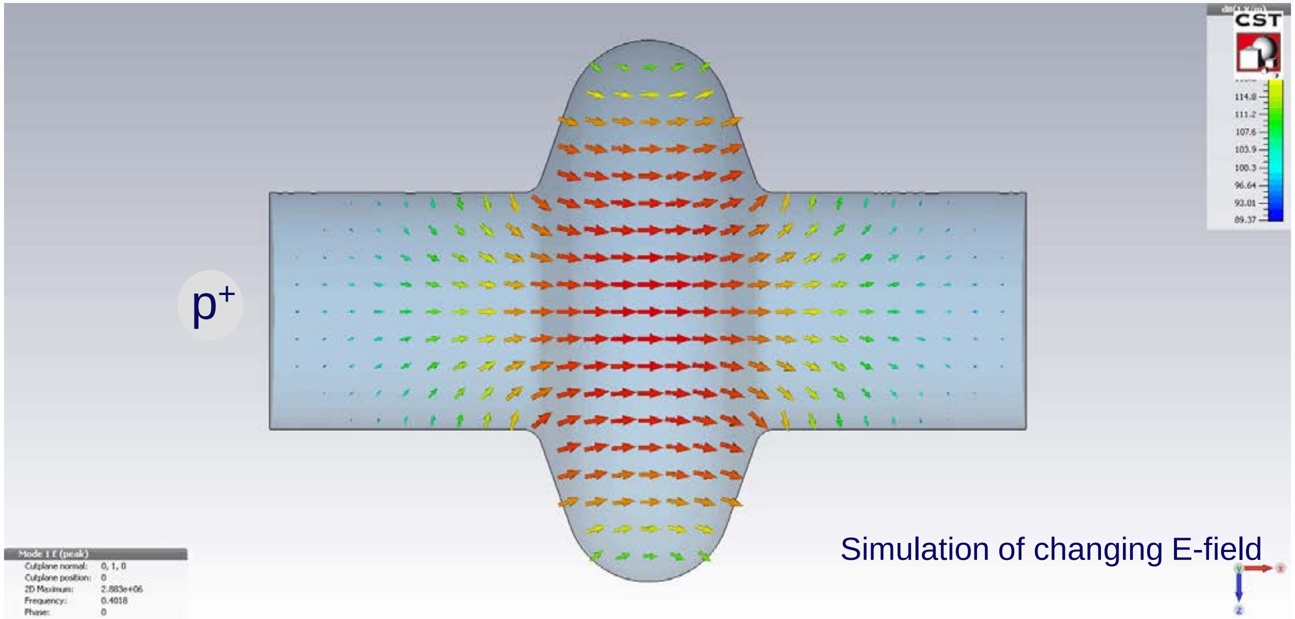
- Resonators are used to accelerate charged particles in an alternating electric field
- The ac electric field is resulting in an ac magnetic field
- The resonator houses the electro magnetic field by surface currents
- Currents lead to heating of the cavity related to the electric resistance of the resonator
- Electrical resistance is minimized by use of superconductors

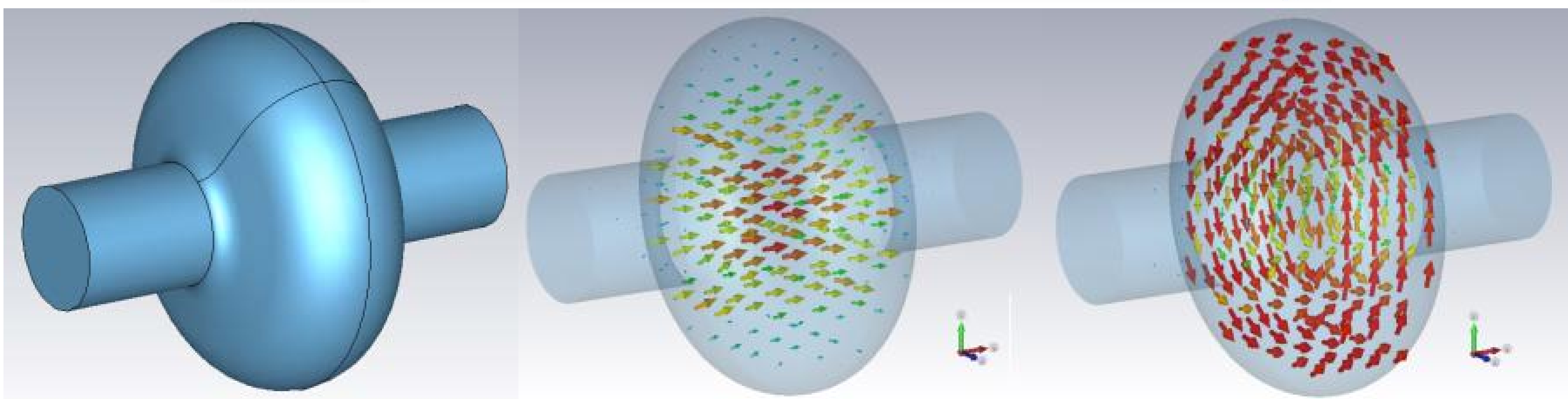
Elliptical cavity, standing wave resonator => electric field distribution magnetic field distribution



Courtesy: P. Zhang simulation tesla style cavity

Superconducting radio frequency cavities

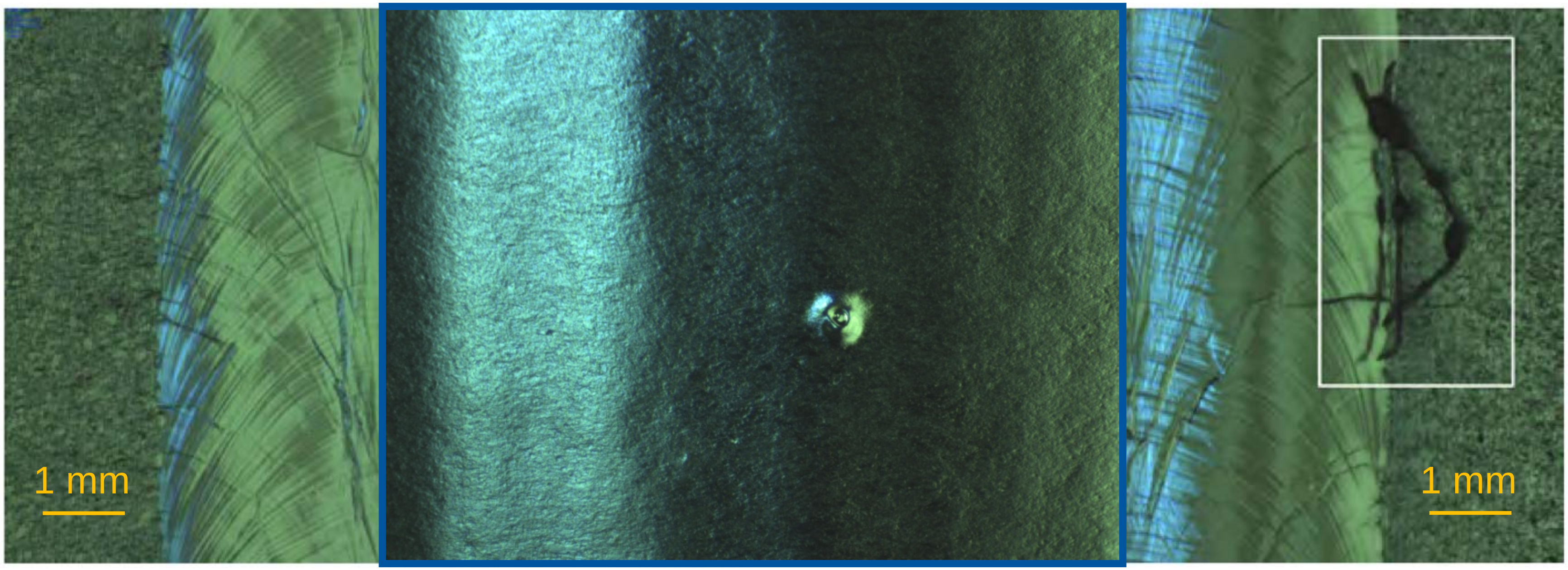




Courtesy: P. Zhang simulation tesla style cavity

Superconducting radio frequency cavities - imperfections

- Loss of superconductivity due to exceeding critical temperature or magnetic field
- AC electromagnetic field causes dissipation at the normal conducting spot (defect),
  => can lead to a propagating quench.

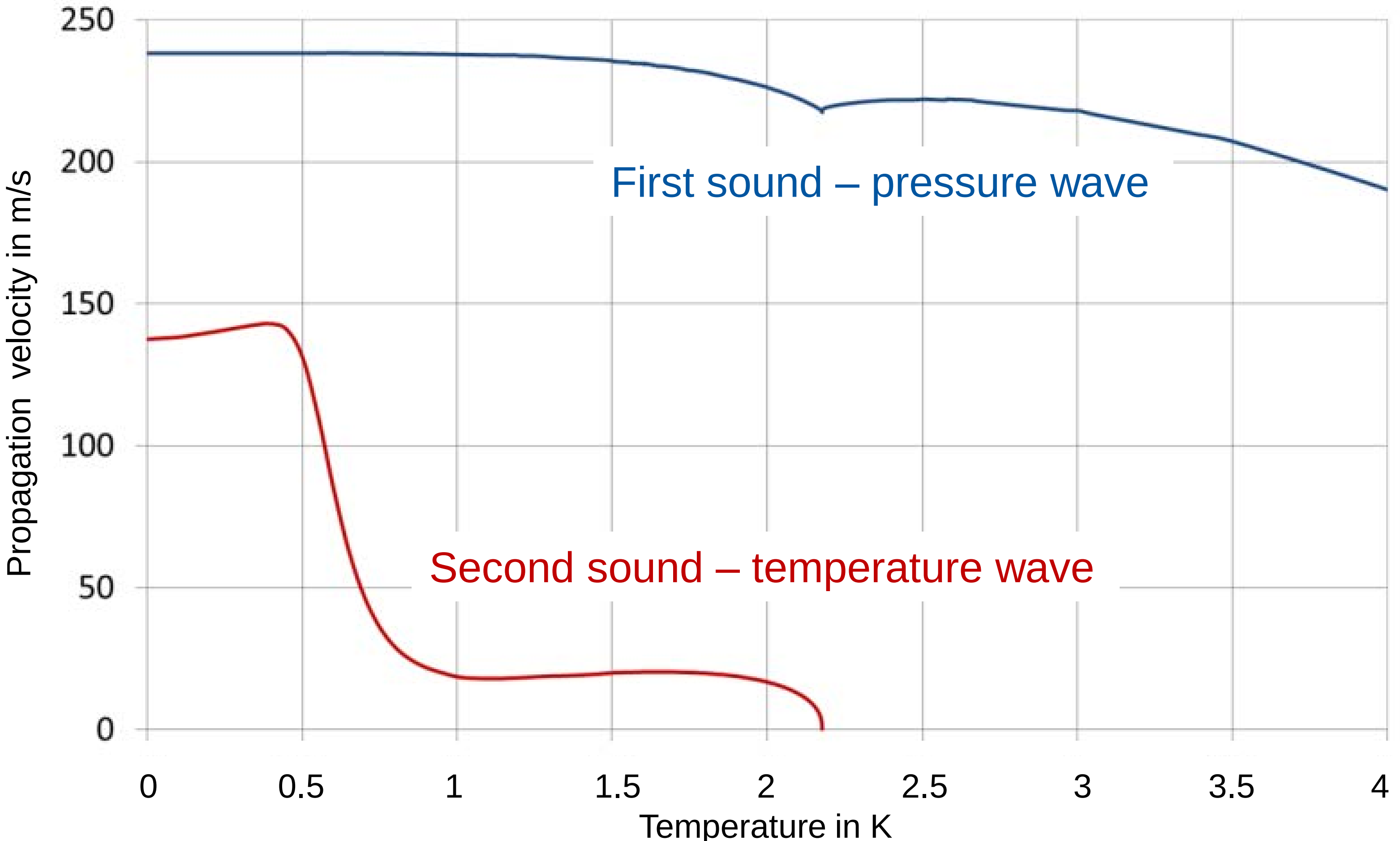


Pictures courtesy of: S. Horvath-Mikulas, CERN BE/RF-SRF

- Stored energy of an acceleration cavity is often in the range of **100 J**.
- Duration of a quench is typically in the range of **milliseconds**.
- Typical defects are usually significantly smaller than **1 mm**.

$\dot{q} > 1\ \mathrm{kW/cm^2}$

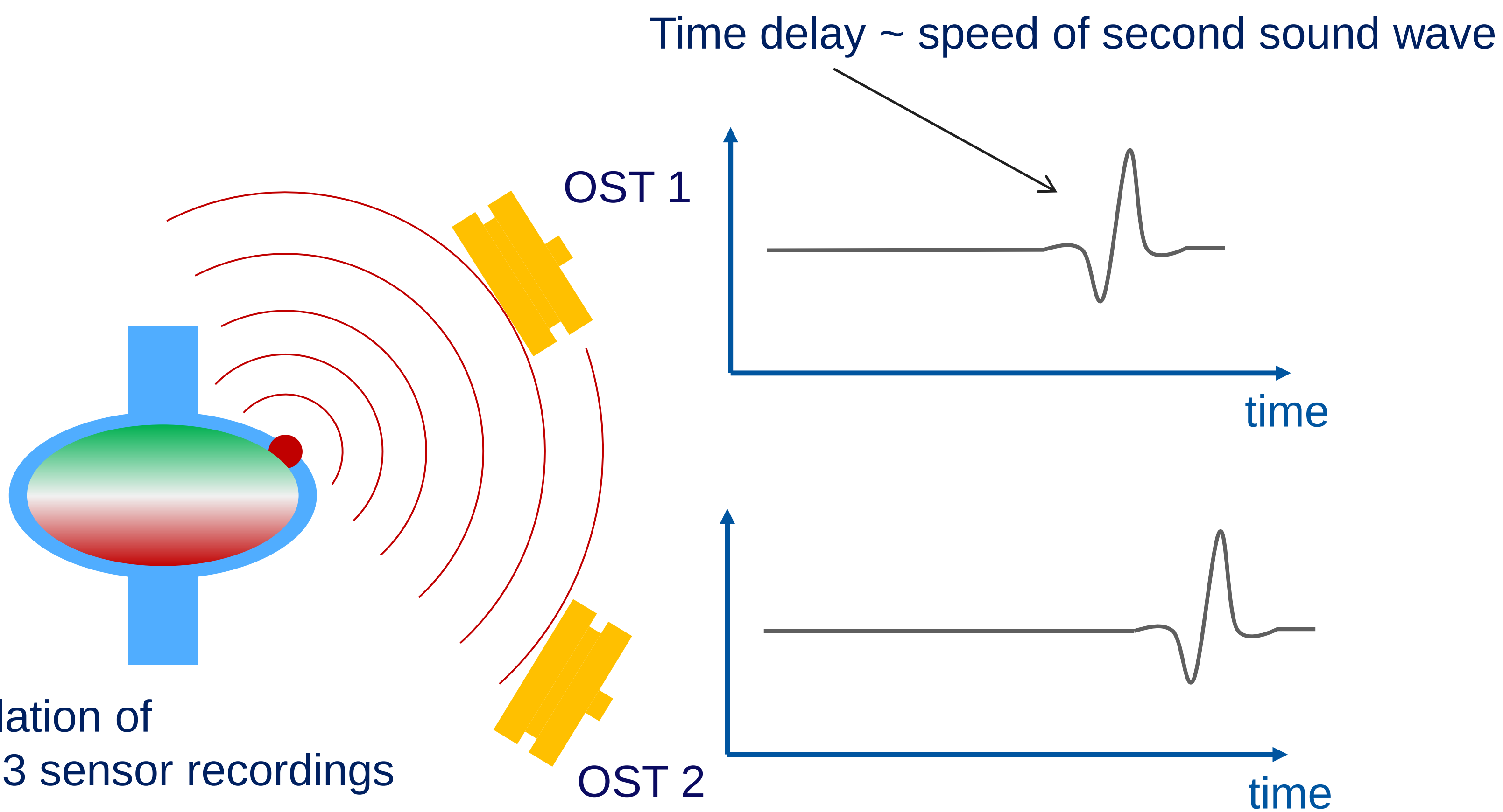
First and second sound in He II



Data from Hepak®

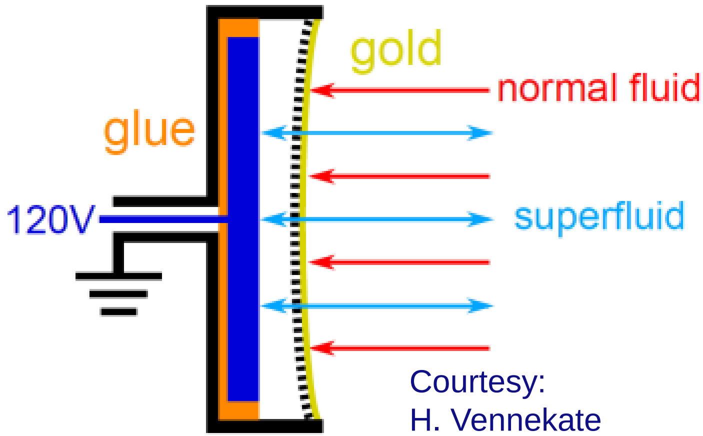
Oscillating Superleak Transducer (OST)

Detection and localisation of quenches on superconducting RF cavities by the measurement of the second sound with OSTs.

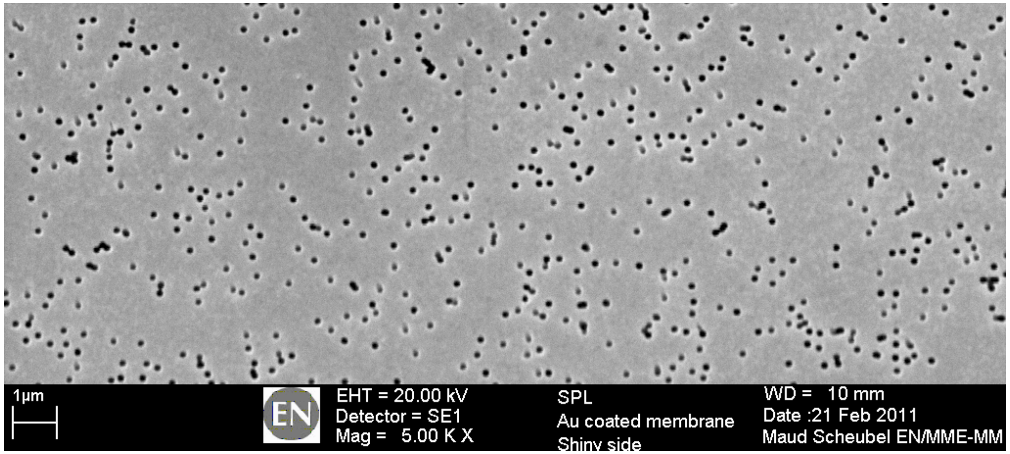


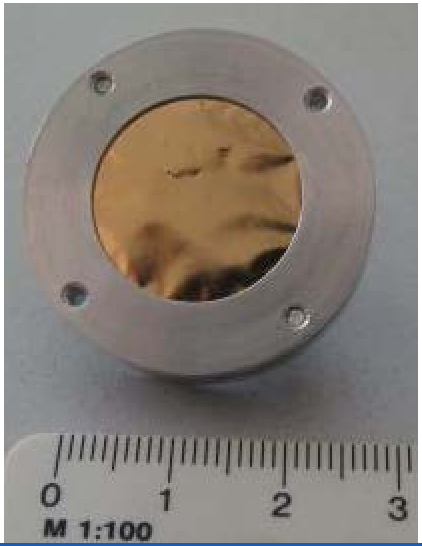
Triangulation of
at least 3 sensor recordings

Oscillating Superleak Transducer (OST)

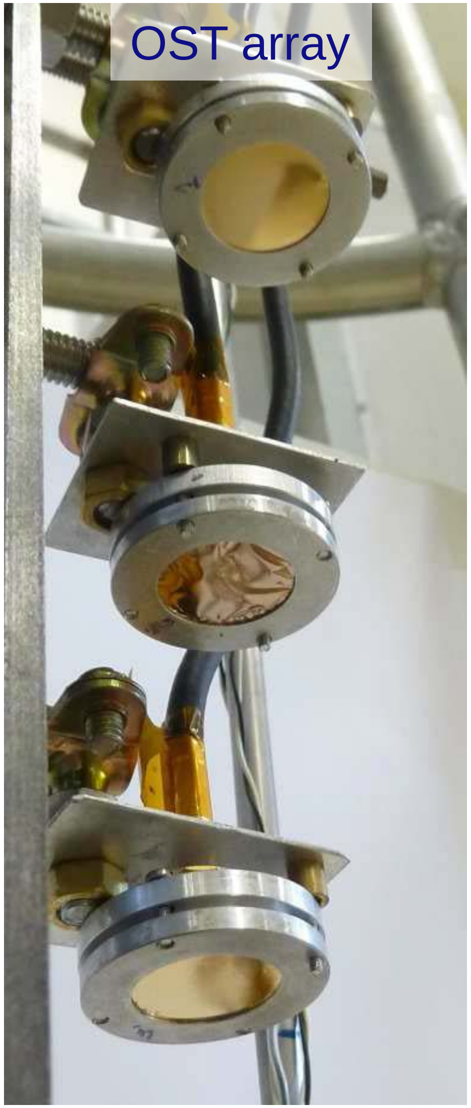


Courtesy:
H. Vennekate

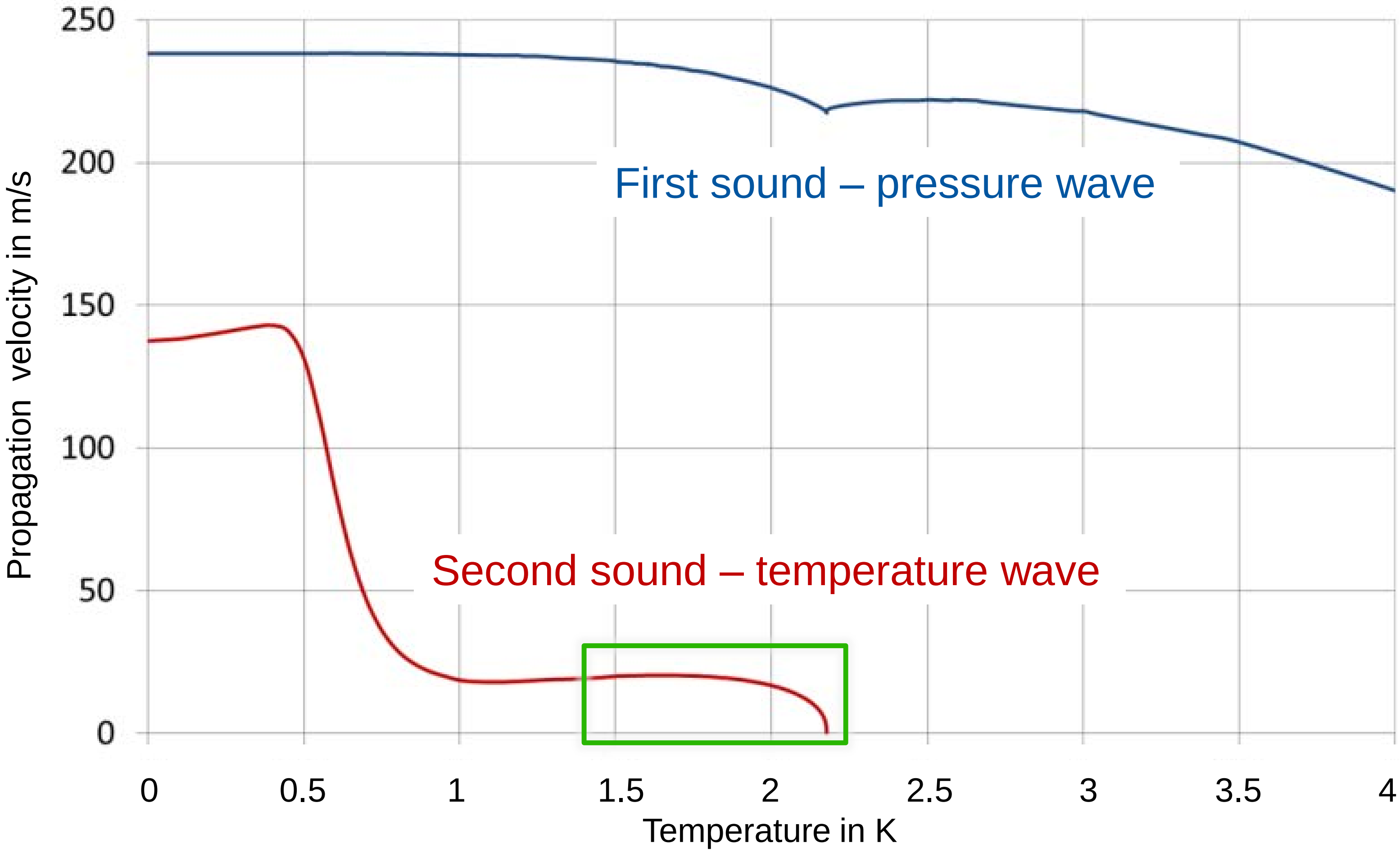




OST experimental set-up

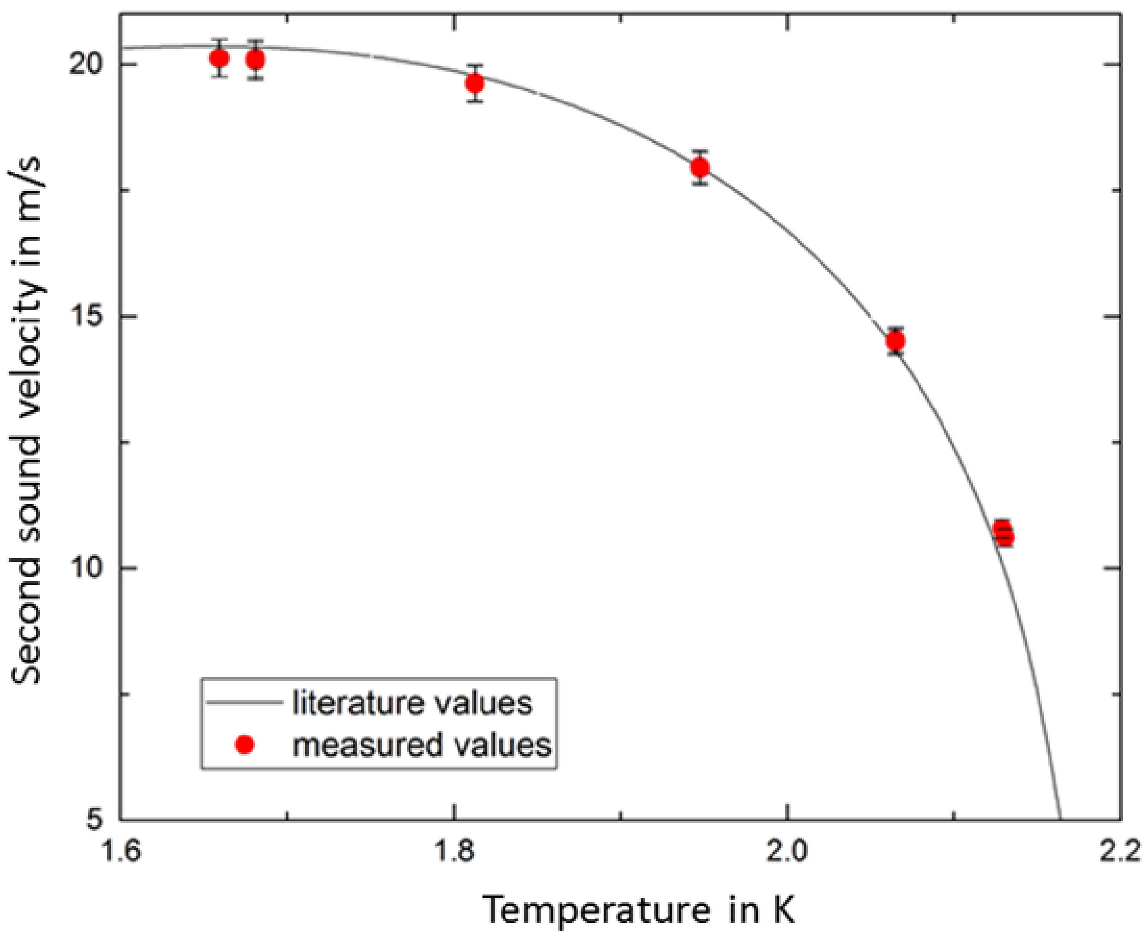


Propagation velocity of second sound in He II



Data from Hepak®

Second sound velocity - low heat flux



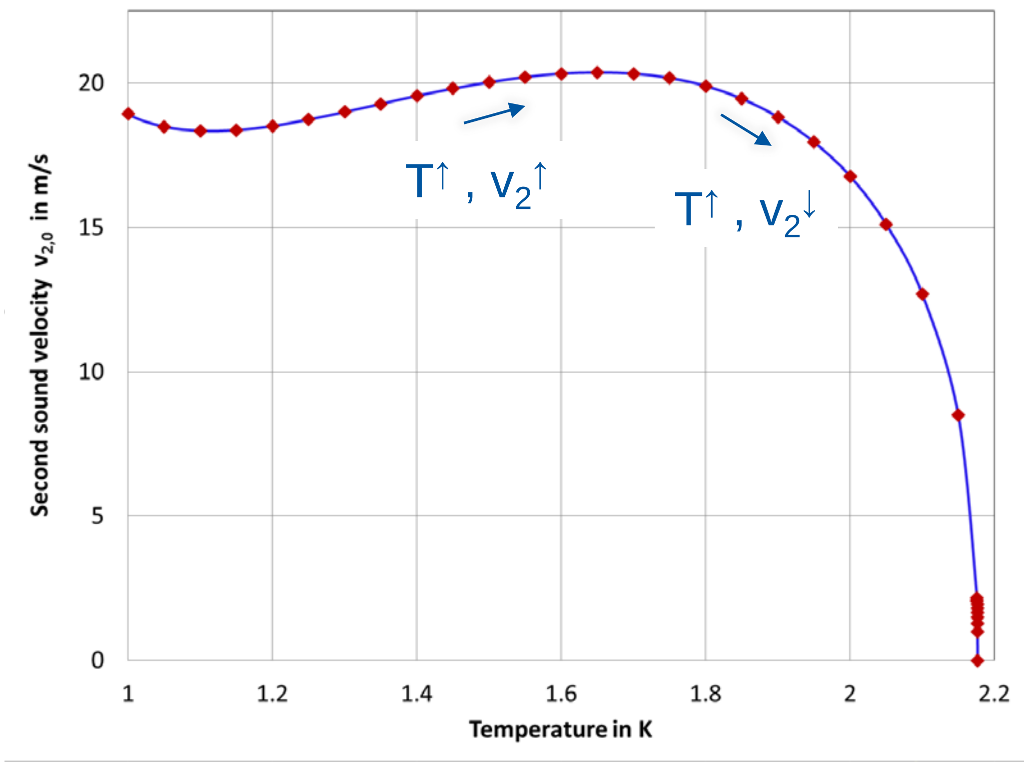
Commonly agreed literature data of 2nd sound from: Donelly, The Observed Properties of Liquid Helium at the Saturated Vapor Pressure.

Second sound velocity high heat flux - non-linear effects

- The two fluid model assumes superfluid and normal-fluid component
- Component ratio depends on temperature and vice versa
- For high heat fluxes non-linear effects can be observed, which alter the observed second sound velocity.

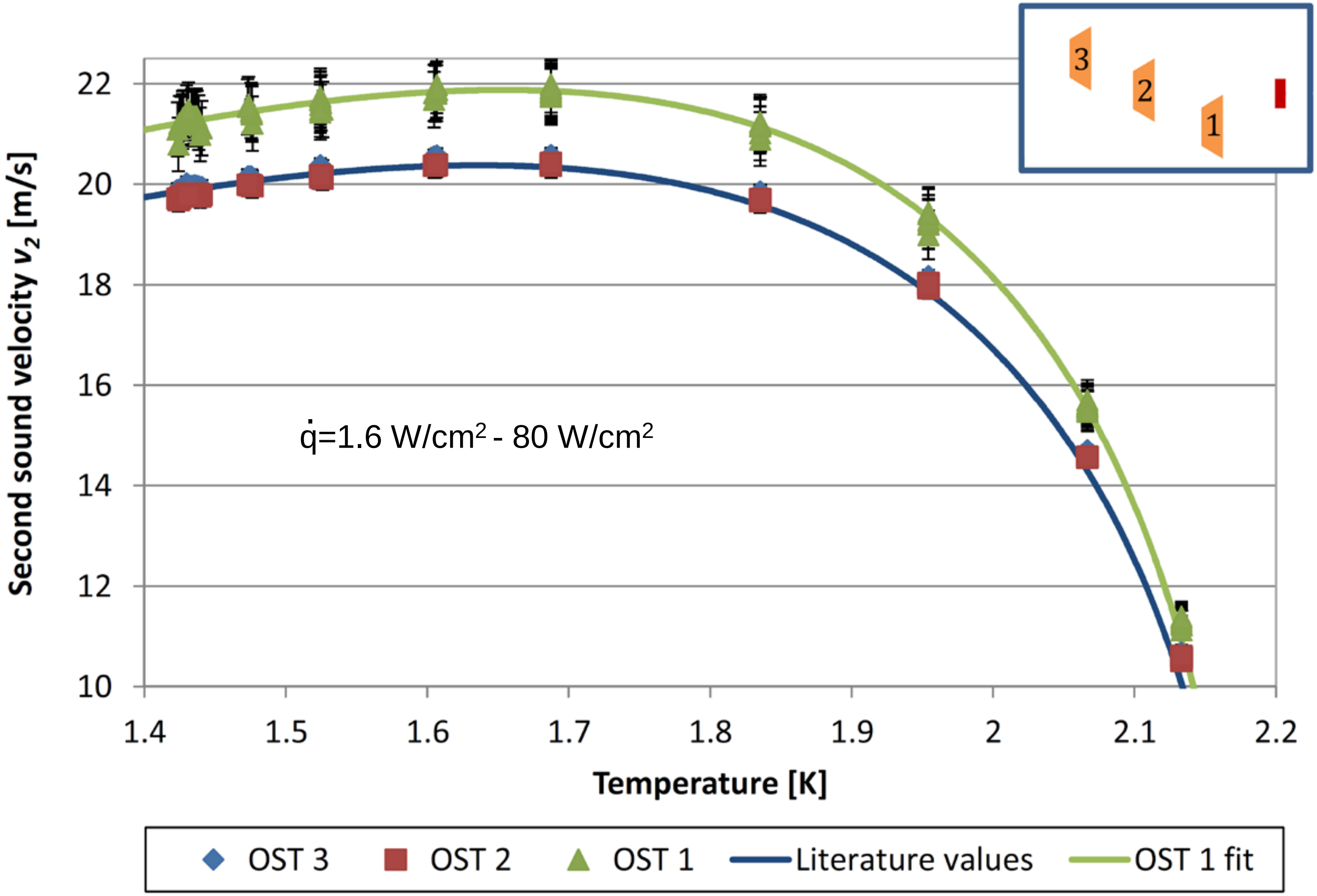
$$u_2 = u_{2,0} + \Gamma_2(T)\dot{q}$$

$$\Gamma_2(T) = \frac{u_2 - u_{2,0}}{\dot{q}}$$

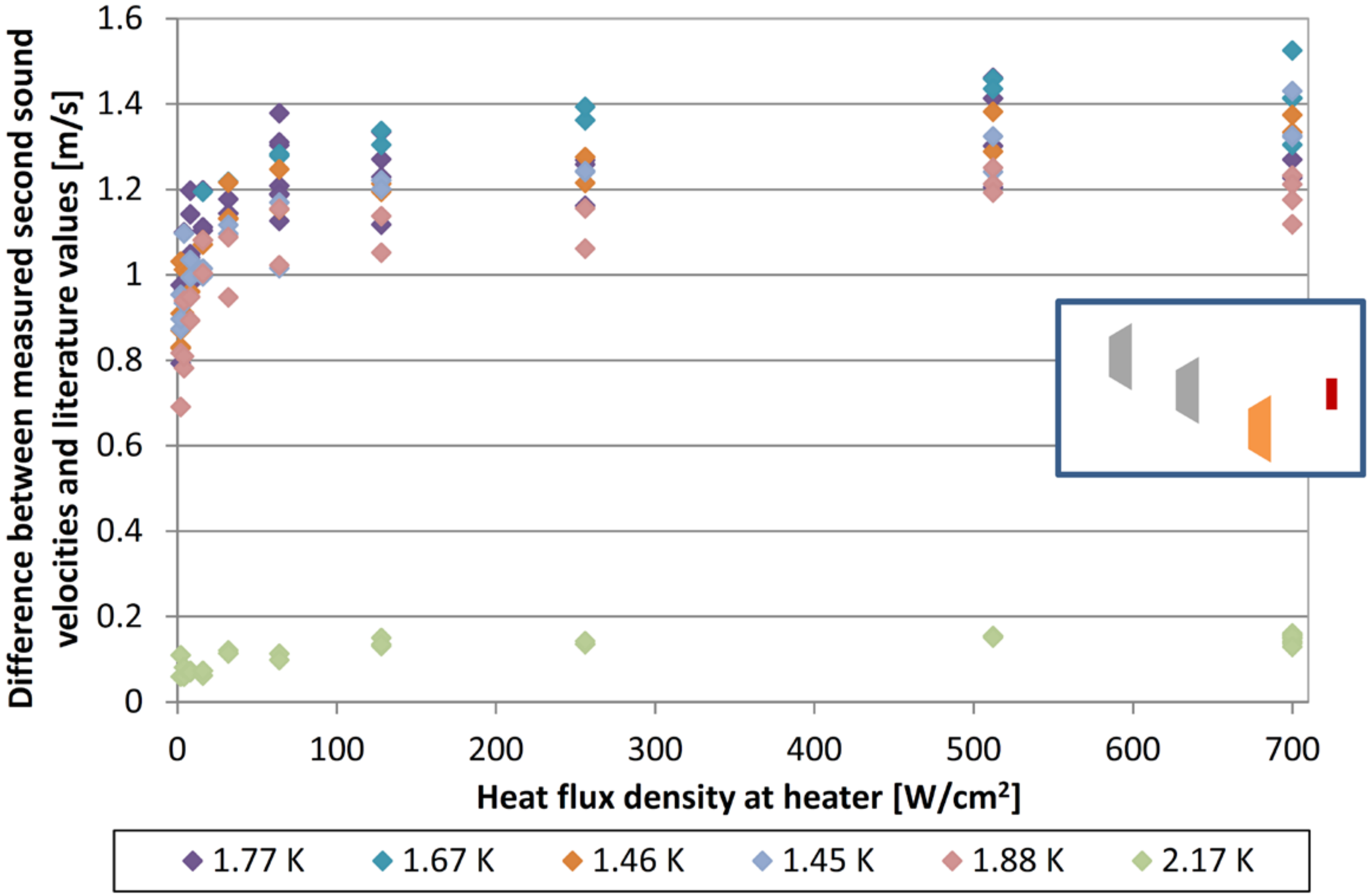


Data from: Hepak®

Second sound velocity - heat flux dependency

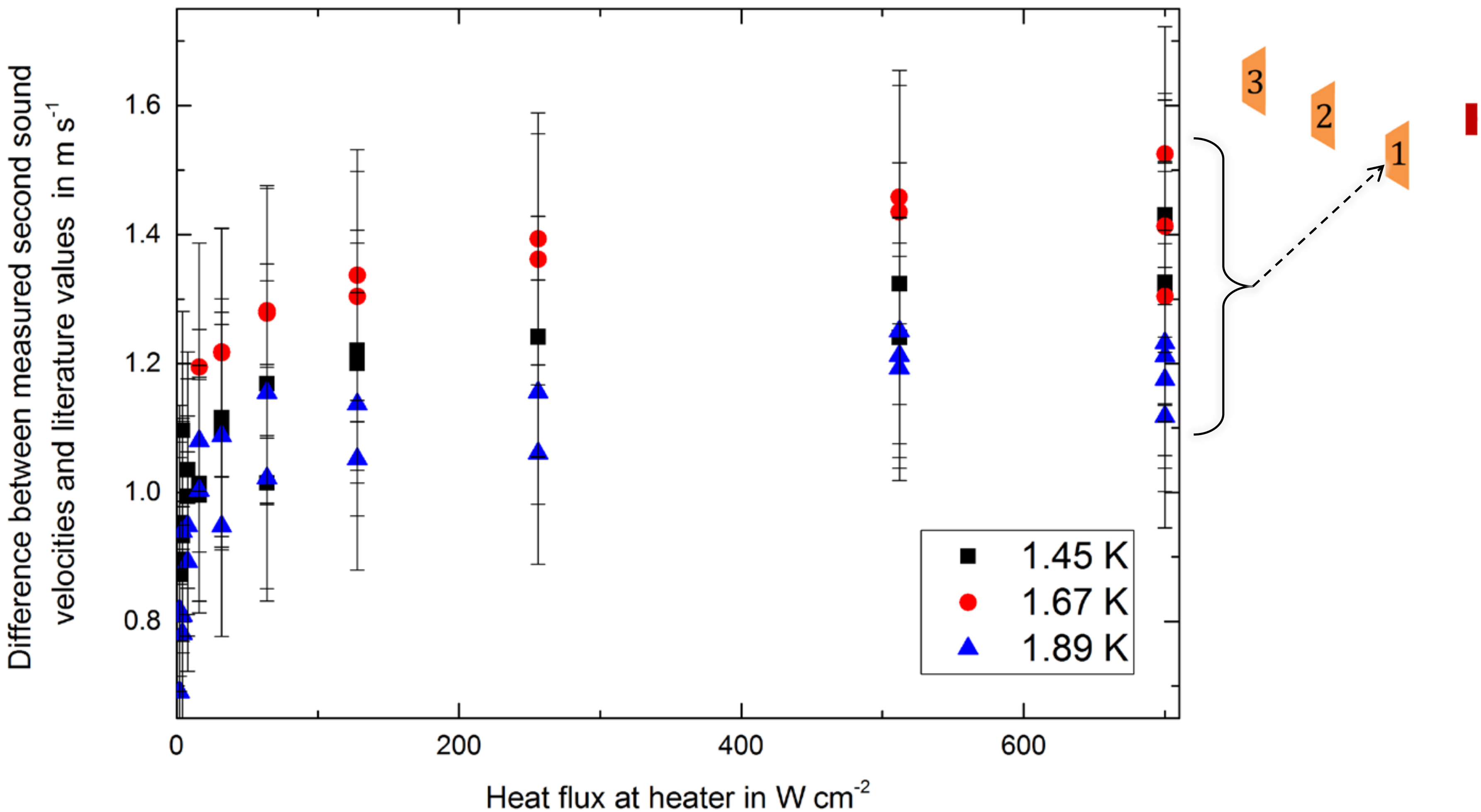


Second sound velocity - heat flux dependency



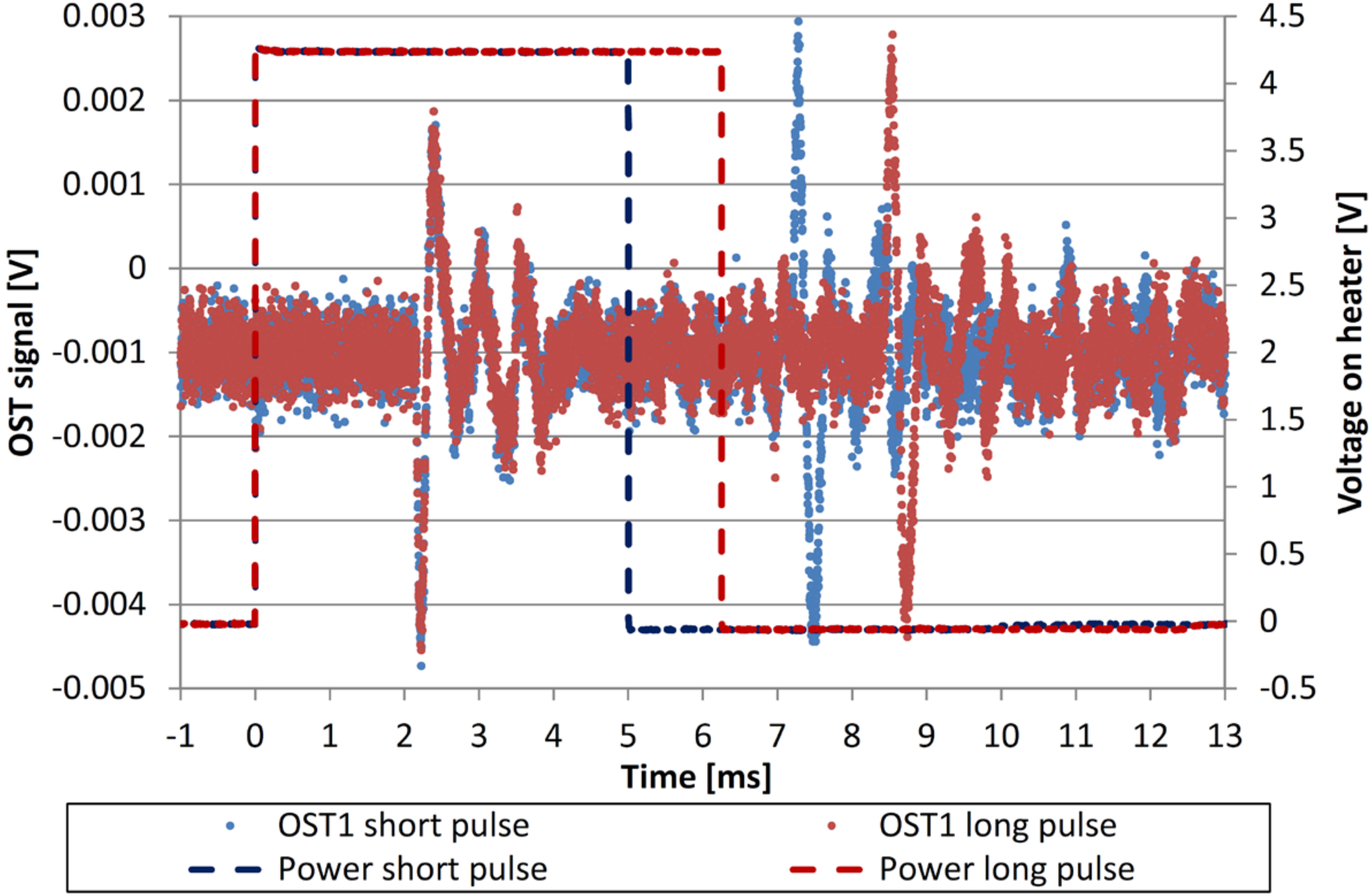
The maximum recorded difference to the literature value is depicted. Distance of the OST is 5 cm.

Second sound velocity - heat flux dependency

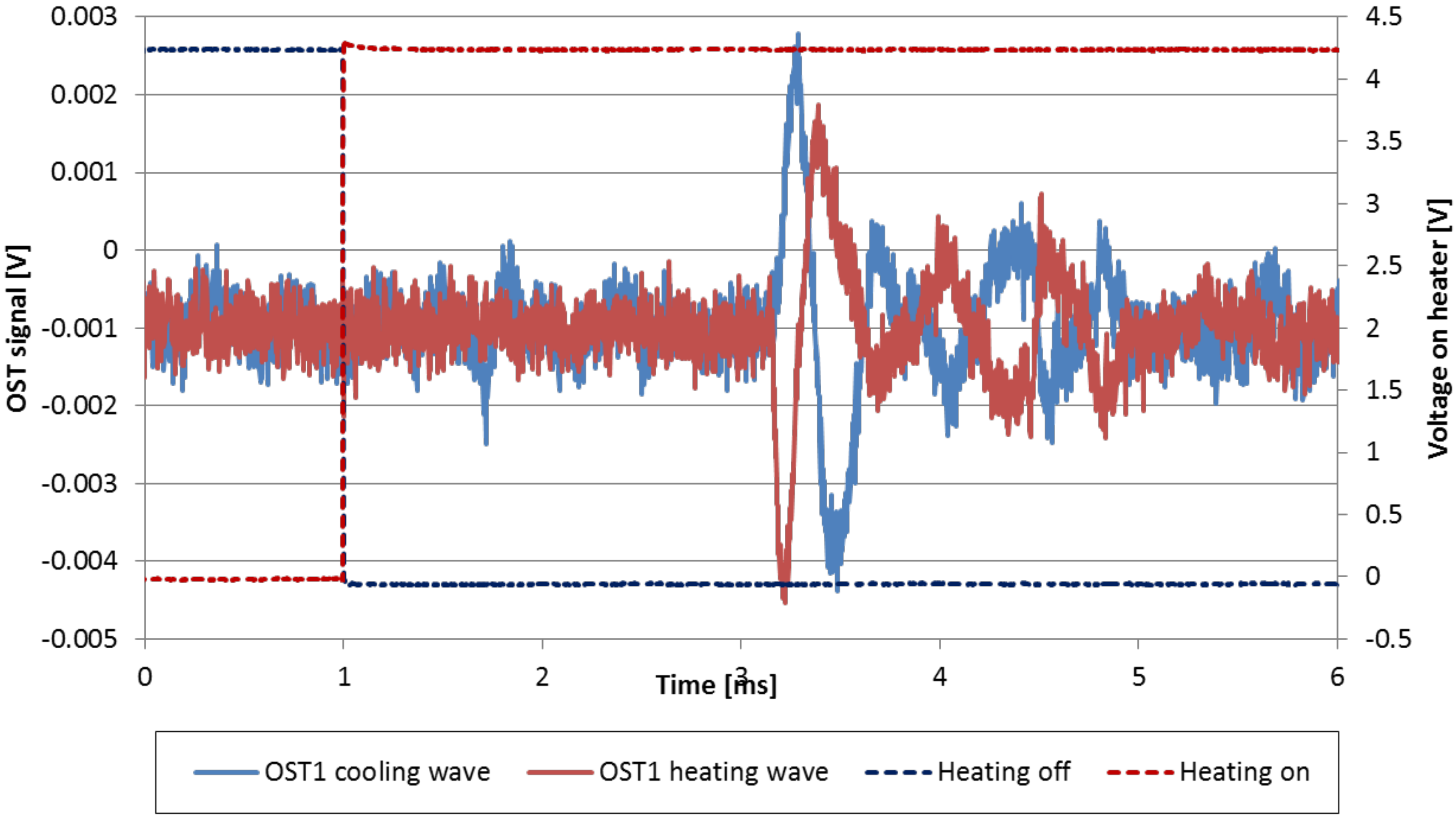


The maximum recorded difference to the literature value is depicted. Distance of the OST is 5 cm.

Second sound – 3D propagation

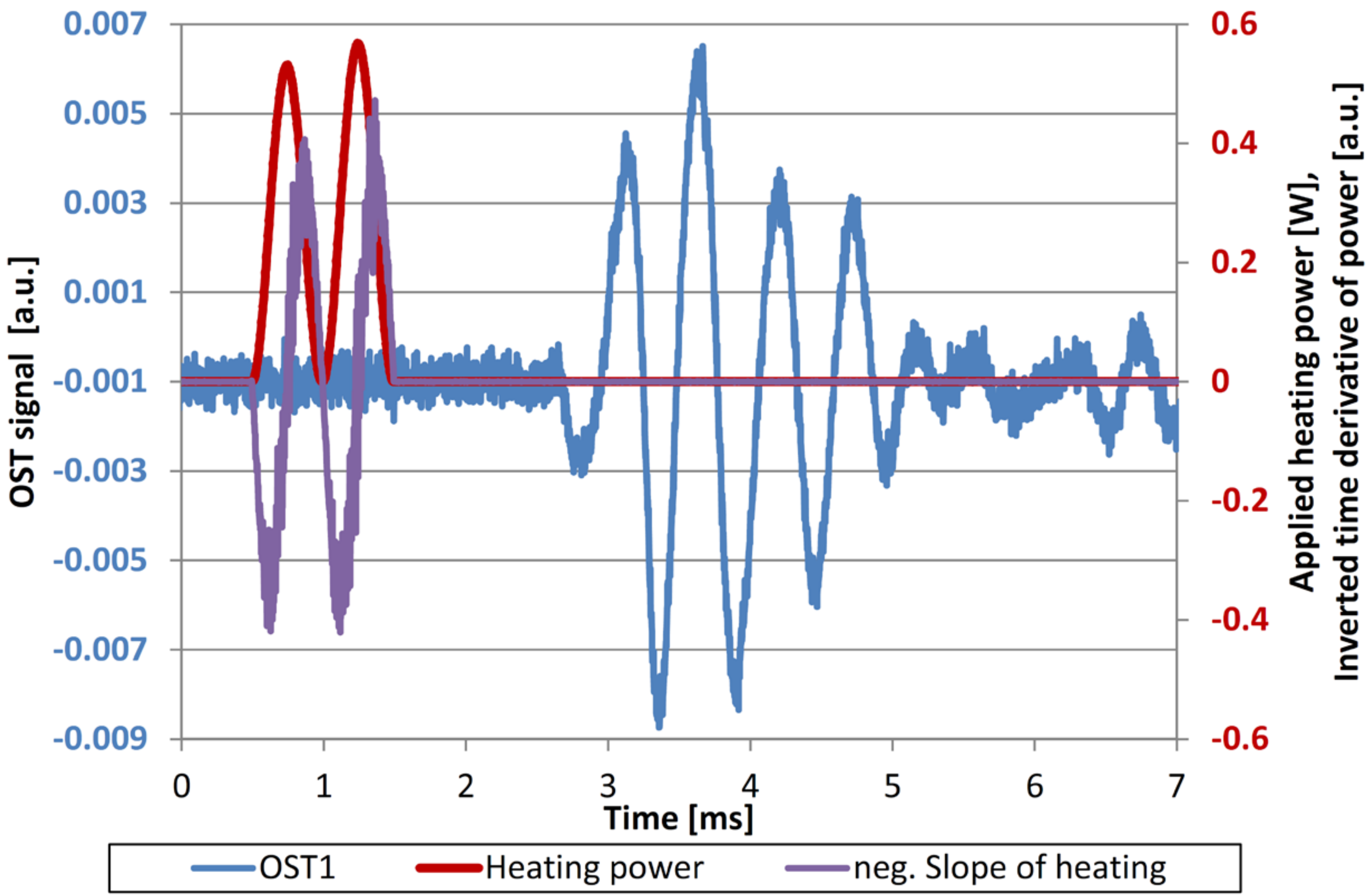


Second Sound velocity – 3d propagation



→ Switching the applied heating **on/off** results in an **inverted signal** on OST

Second Sound velocity – 3d propagation

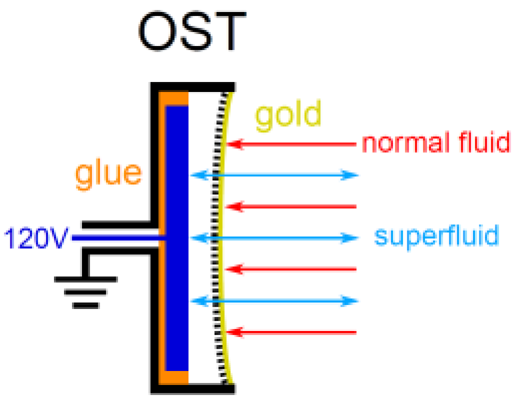


Observed boiling effect in He II

RF heater in He II => no heating

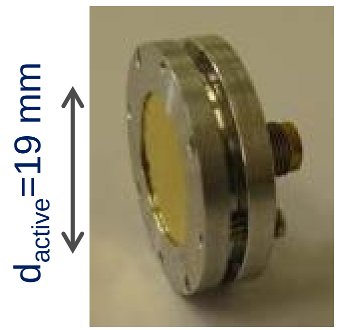
RF heater in He II => $\dot{q}$=700 W/cm^2

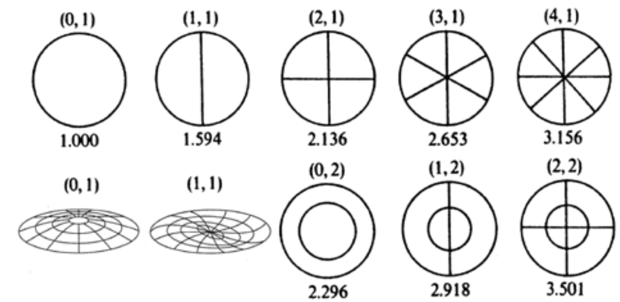
What influences the signal shape of an OST?

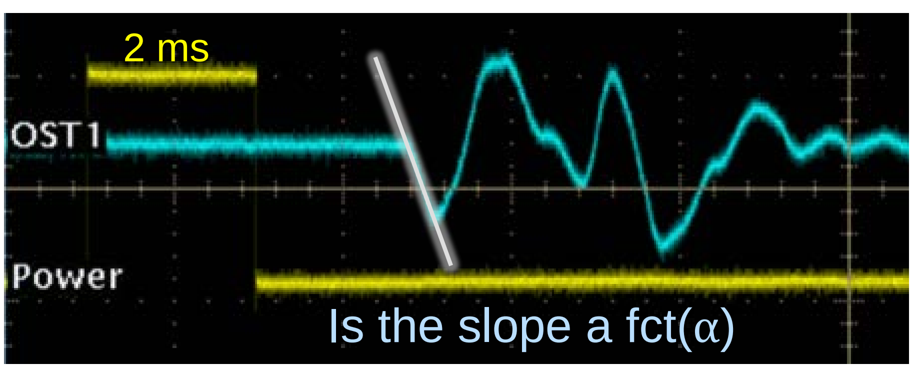


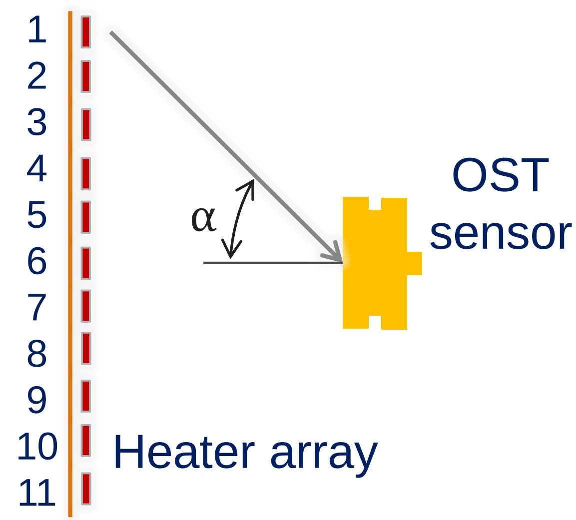
Courtesy
H. Vennekate

- Size vs. signal resolution
- Membrane oscillation mode
- How to gain more information from the signal
  => signal slope dependency of incident angle



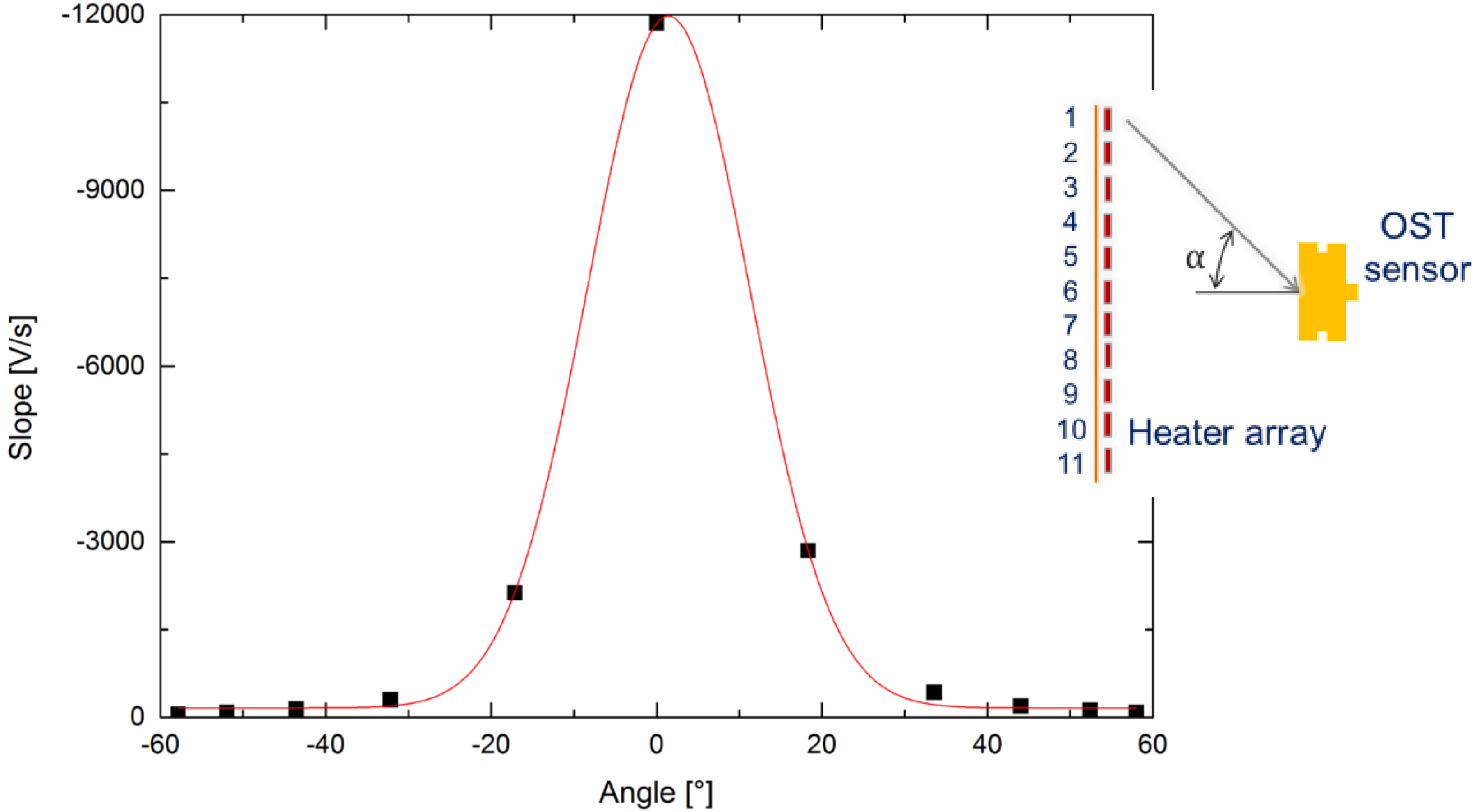






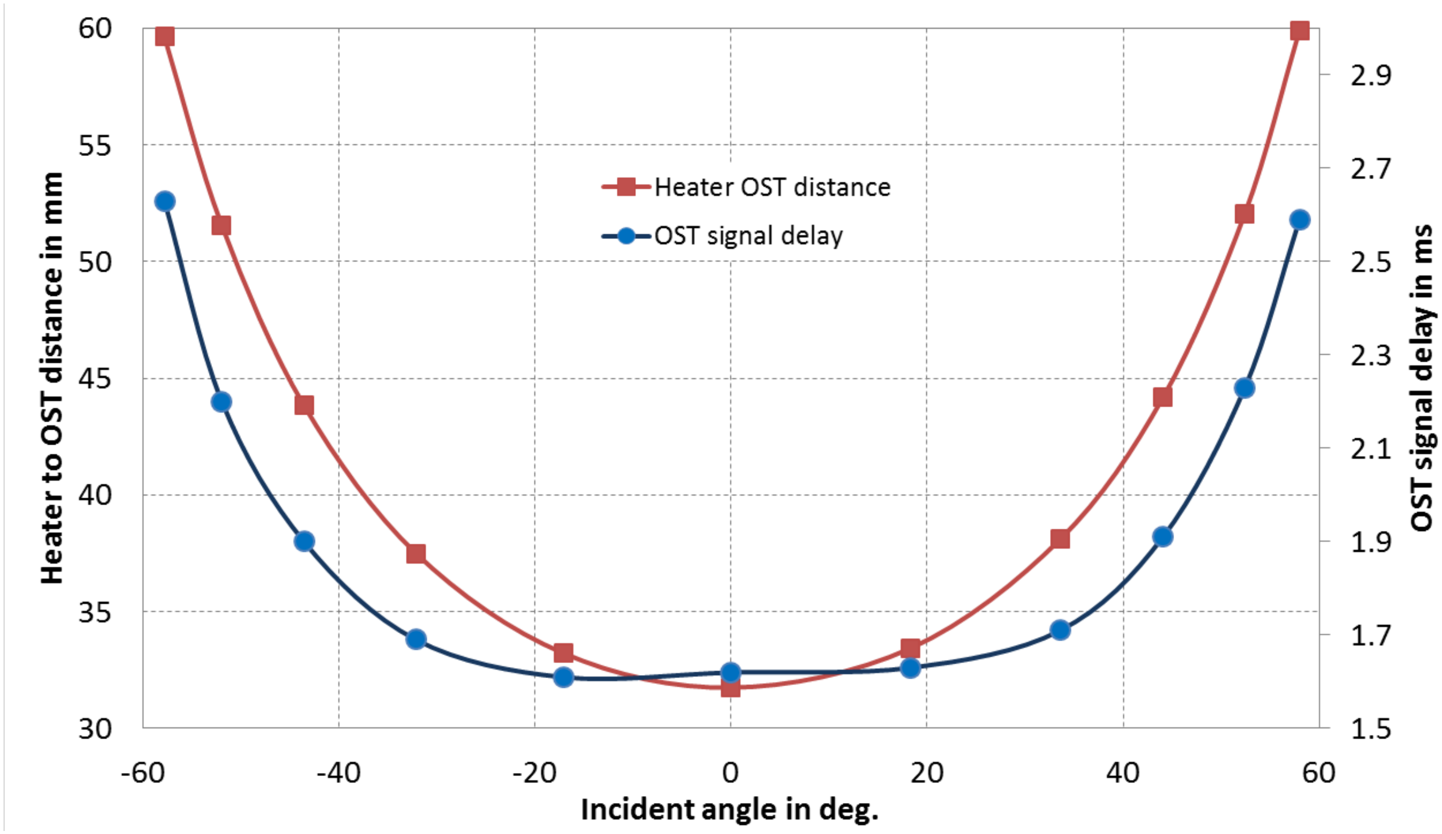
Inclination angle dependency

LHe temperature T=1.50 K. The heat flux on the heater surface is 13.6 W/cm^2



Inclination angle vs. distance dependency

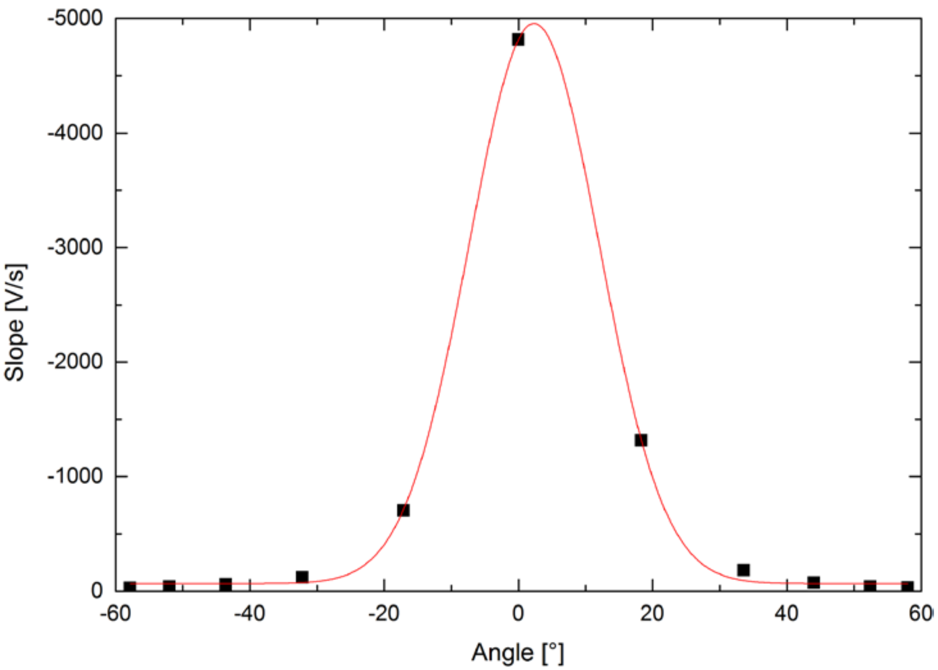
LHe temperature T=1.50 K. The heat flux on the heater surface is 8.6 W/cm^2



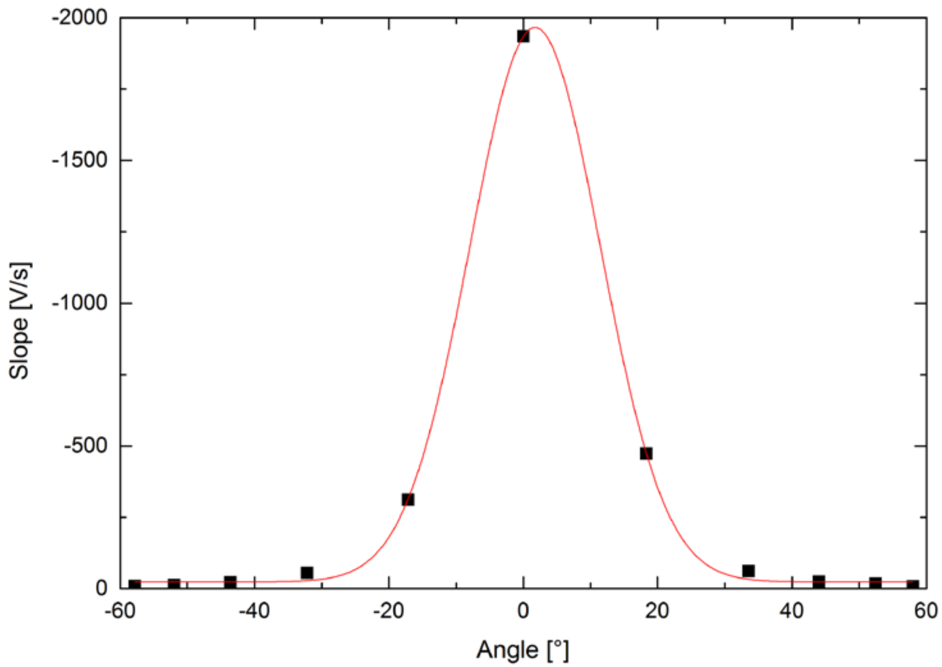
Inclination angle dependency

The heat flux on the heater surface is 13.6 W/cm^2

LHe temperature T=1.77 K

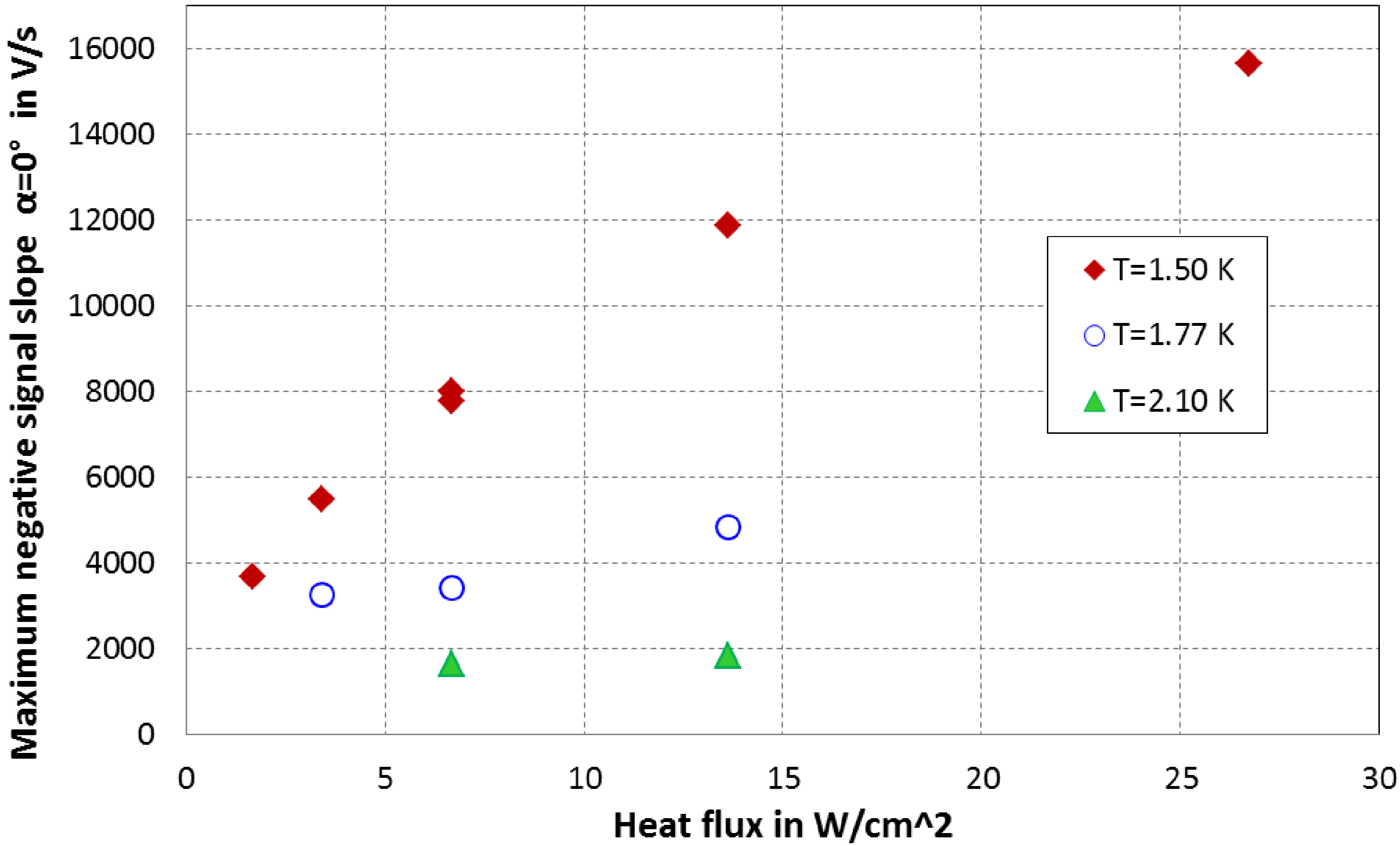


LHe temperature T=2.10 K

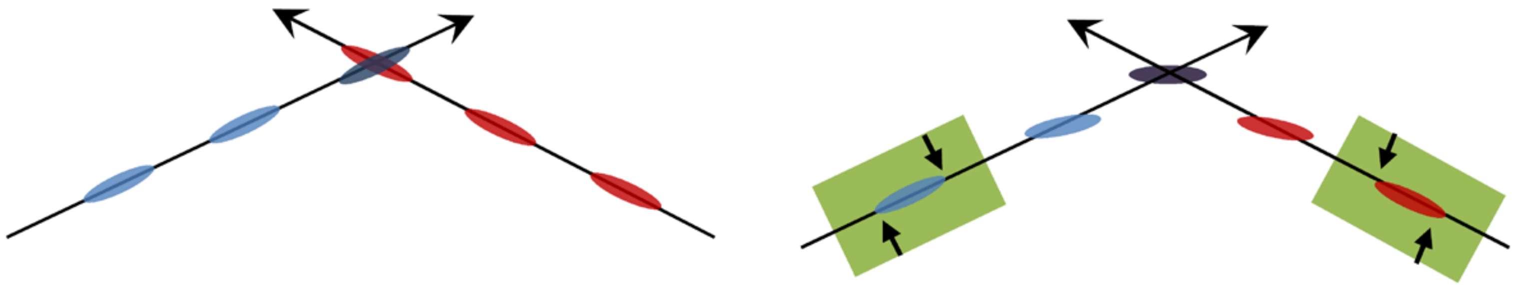


OST signal slope vs. heat flux dependency

Comparison of the peak value of the OST slope signal for different temperatures.



OST Quench localization - CRAB cavity (BE/RF-SRF)



Collision of two particle beams without crab cavities. Only a part of the particle bunches can interact.	Collision of two particle beams with crab cavities. The whole particle bunches can interact.

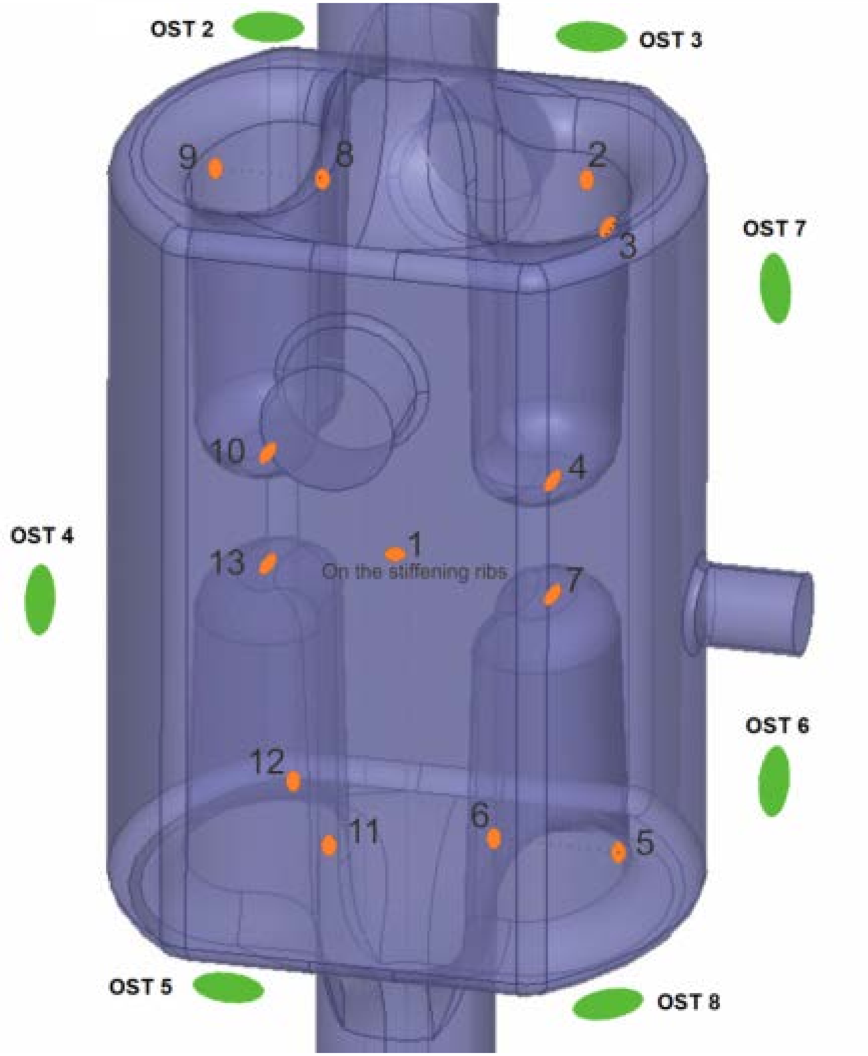
One of the possible CRAB geometries has been tested

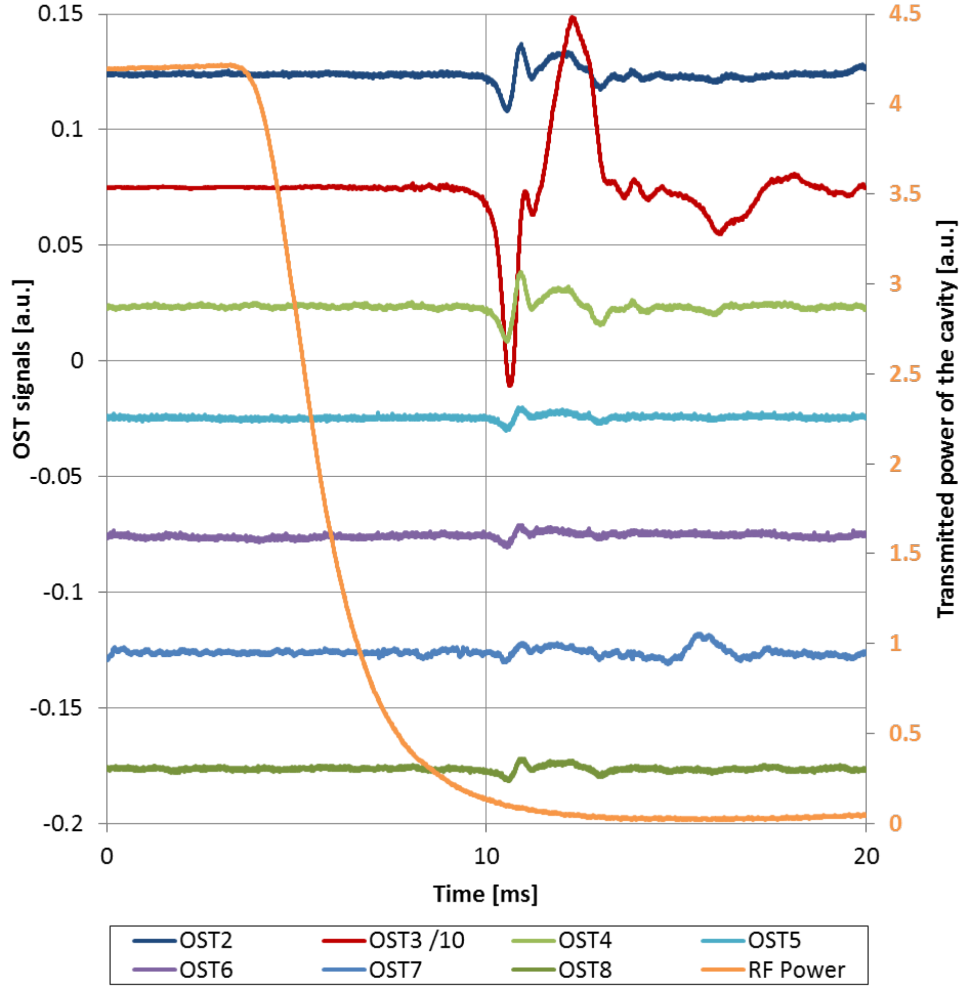
Integration in a vertical cryostat

7 OST placed around the cavity

13 temperature sensors were glued to the surface

OST Quench localization - CRAB cavity (BE/RF-SRF)





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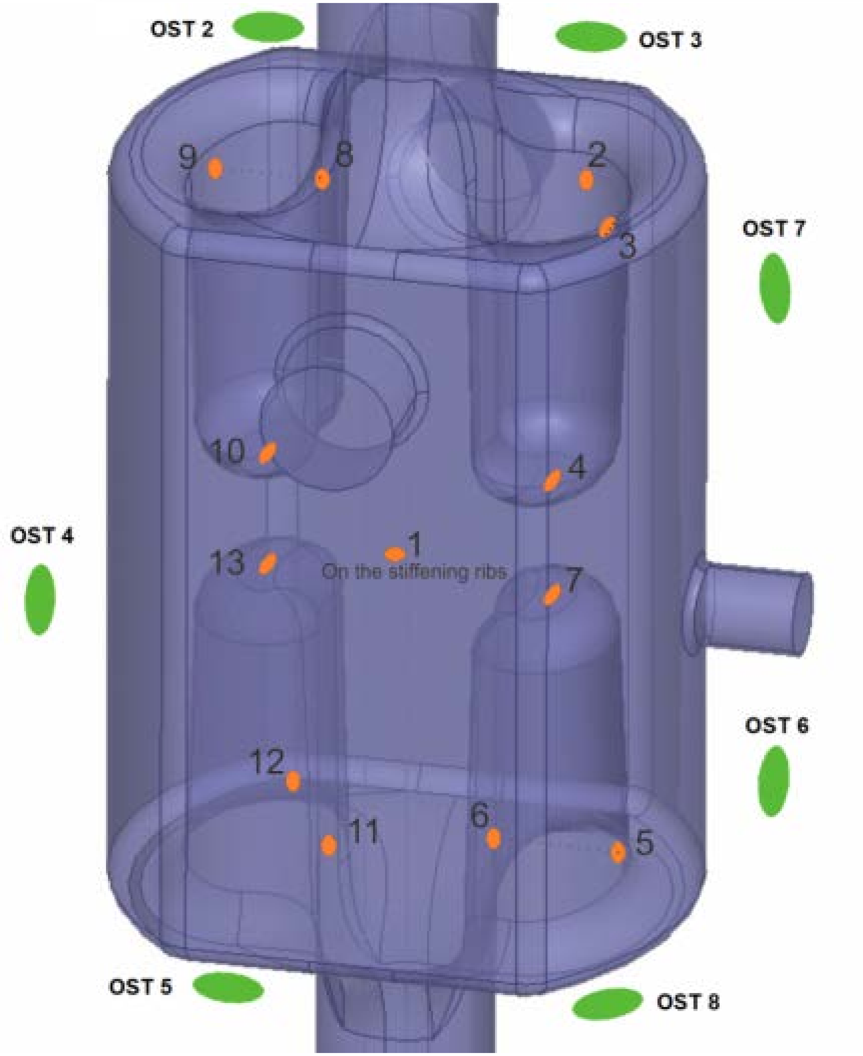

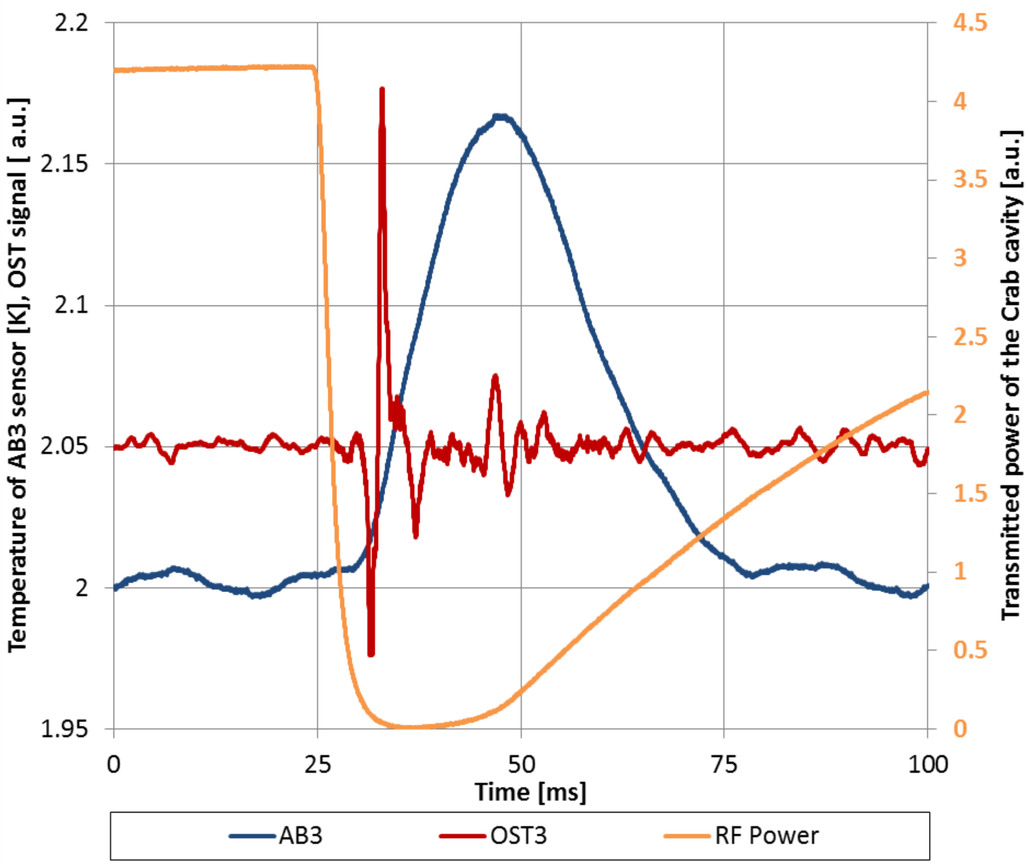

Summary

- High heat flux second sound propagation has been investigated in 3-dim using OSTs.
- The non-linear relation between $\dot{q}$ and $\boldsymbol{\Delta v_2}$ is not the main reason for the widely observed faster than second sound propagation during cavity quenching.
- Localized boiling effects in the vicinity of the heat spots could be an explanation.
- The slope of the measured OST signals (voltage vs time) is directly related to the angle between heat source and OST.
- This can serve as a valuable cross check for quench positions obtained by trilateration.
- Careful data analysis is however advised, because the slope also strongly depends on temperature and heat flux.

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