

Phonon Focusing in Cryogenic Detectors

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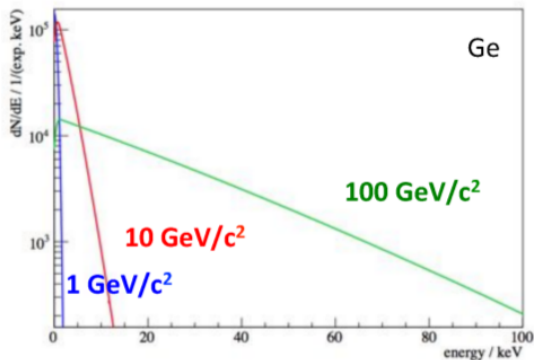
Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Outline

- 1 Motivation: Predicting Energy Thresholds
- 2 Phonon Focusing in Anisotropic Crystals
- 3 Effects in Cryogenic Detectors

Motivation: Predicting Energy Thresholds

Importance of a Low Energy Threshold

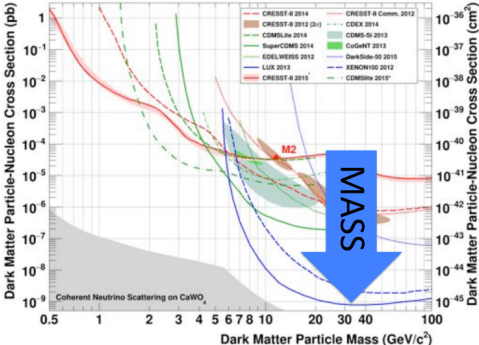


lower WIMP mass

Raimund Strauss, MPI Munich

Importance of a Low Energy Threshold

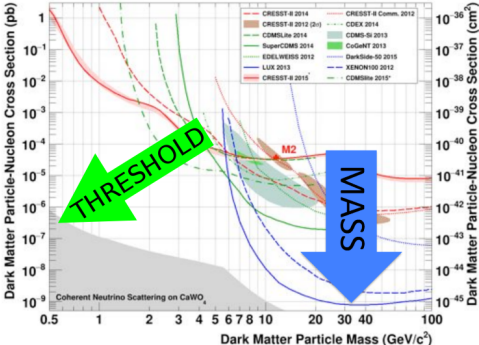
Future of Dark Matter Searches



Raimund Strauss, MPI Munich

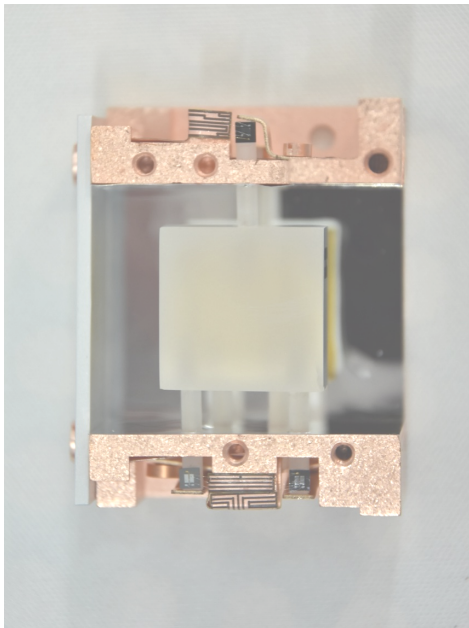
Importance of a Low Energy Threshold

Future of Dark Matter Searches



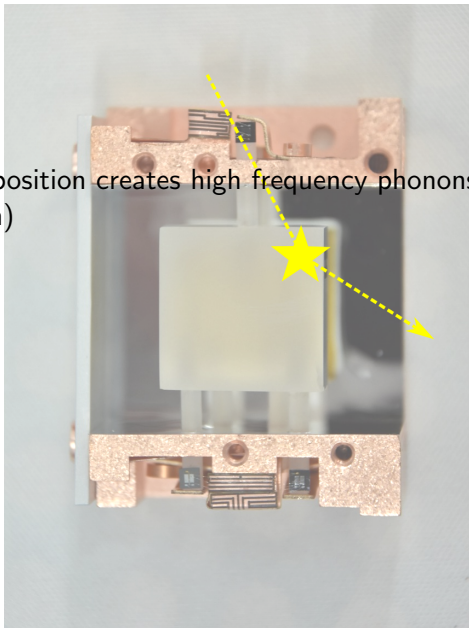
Raimund Strauss, MPI Munich

Pulse Height in Cryogenic Calorimeters



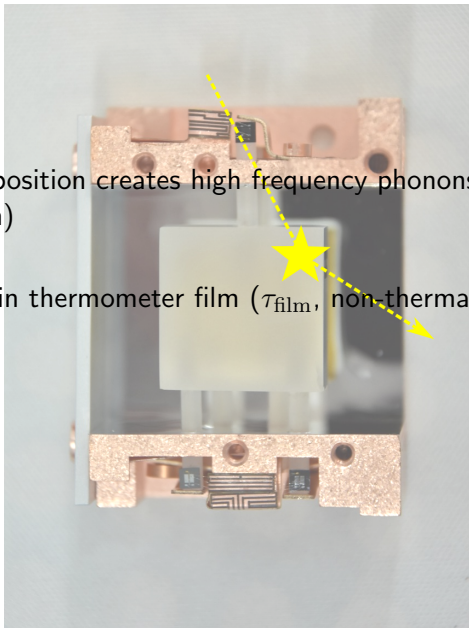
Pulse Height in Cryogenic Calorimeters

- 1 Energy deposition creates high frequency phonons (out of thermal equilibrium)



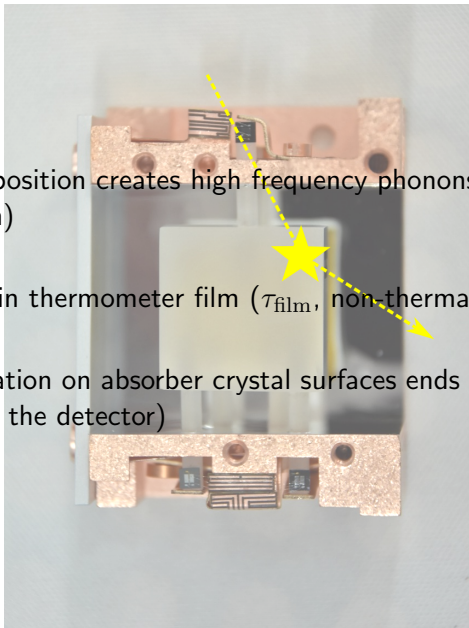
Pulse Height in Cryogenic Calorimeters

- 1 Energy deposition creates high frequency phonons (out of thermal equilibrium)
- 2 Detection in thermometer film (τ_{film} , non-thermal signal)



Pulse Height in Cryogenic Calorimeters

- 1 Energy deposition creates high frequency phonons (out of thermal equilibrium)
- 2 Detection in thermometer film (τ_{film} , non-thermal signal)
- 3 Thermalization on absorber crystal surfaces ends signal (τ_{crystal} , slight warmup of the detector)



Pulse Height in Cryogenic Calorimeters

$$\Delta T = \frac{1/\tau_{\text{film}}}{\underbrace{1/\tau_{\text{crystal}} + 1/\tau_{\text{film}}}_{\text{collection efficiency}}} \cdot \frac{\Delta E}{C_{\text{film}}}$$

Pulse Height in Cryogenic Calorimeters

$$\Delta T = \underbrace{\frac{1/\tau_{\text{film}}}{1/\tau_{\text{crystal}} + 1/\tau_{\text{film}}}}_{\text{collection efficiency}} \cdot \frac{\Delta E}{C_{\text{film}}} \approx \frac{\tau_{\text{crystal}}}{\tau_{\text{film}}} \cdot \frac{\Delta E}{C_{\text{film}}}$$

Pulse Height in Cryogenic Calorimeters

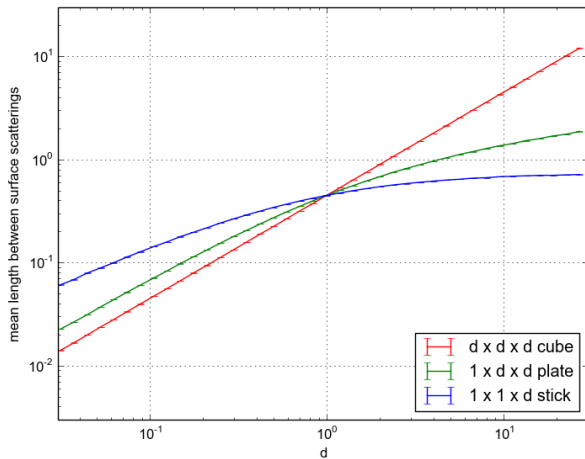
$$\Delta T = \mu \cdot \frac{l_{sc}}{V_a} \cdot \frac{A_t}{V_t} \cdot \Delta E$$

l_{sc} : mean length between surface scatterings

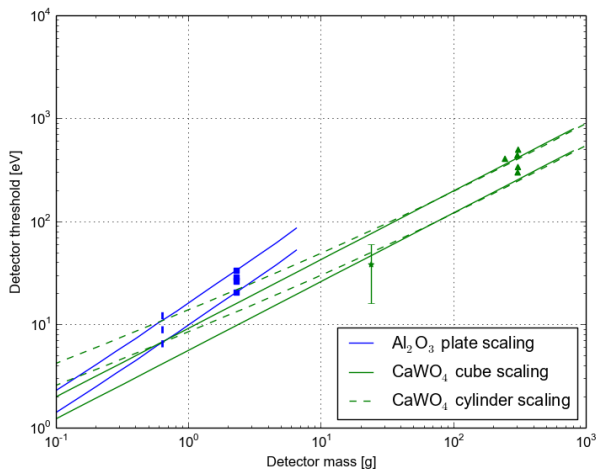
μ : material constant

- sound speed
- phonon transmission into thermometer
- thermalisation probability at crystal surface

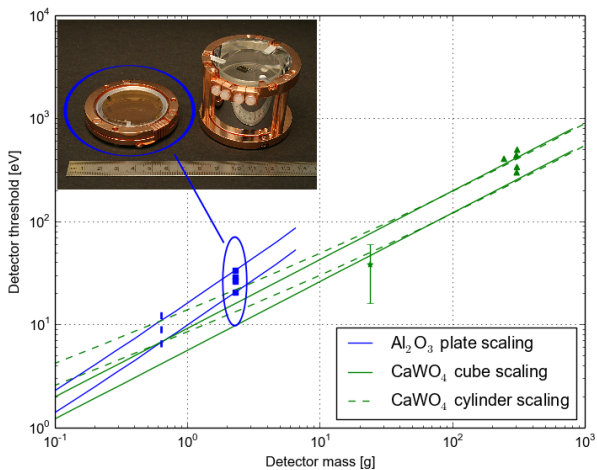
Surface Scattering Lengths for Different Geometries



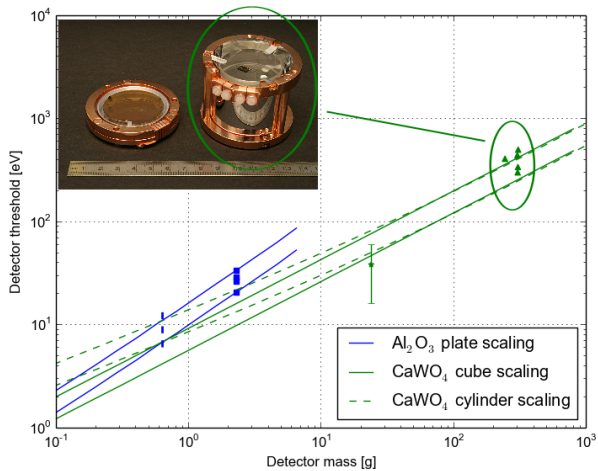
Threshold Predictions



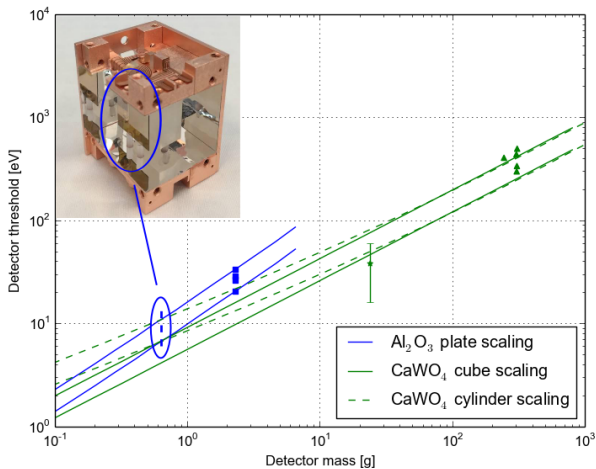
Threshold Predictions



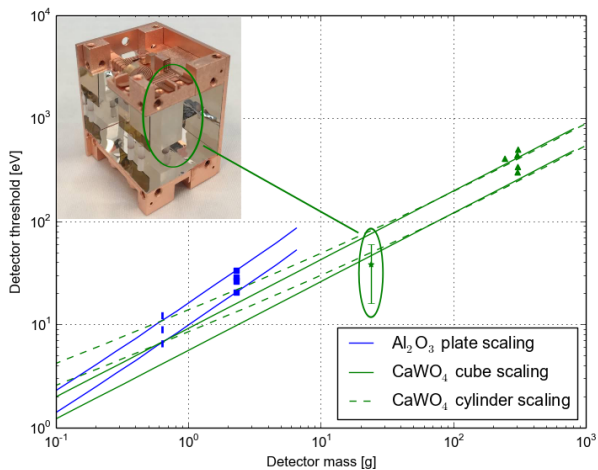
Threshold Predictions



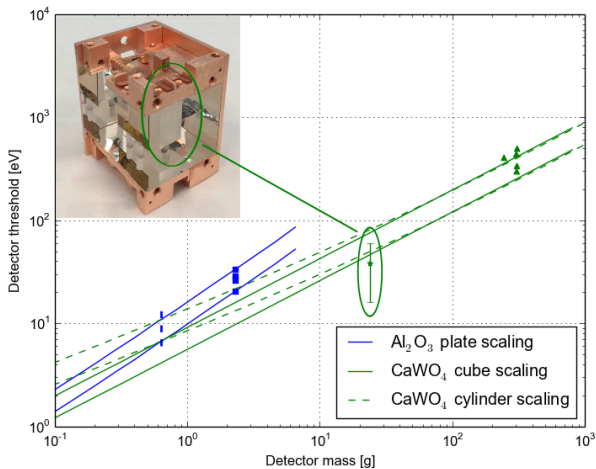
Threshold Predictions



Threshold Predictions



Threshold Predictions

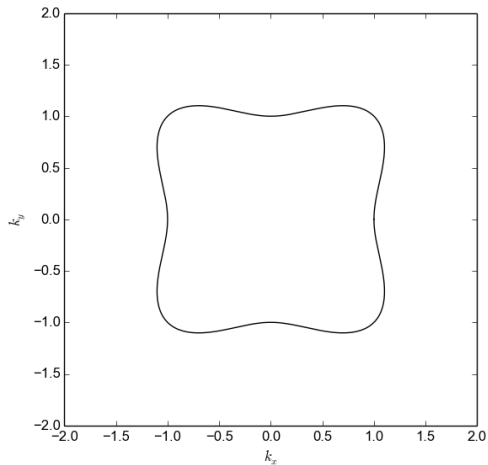


Assumption: isotropic phonon propagation!

Phonon Focusing in Anisotropic Crystals

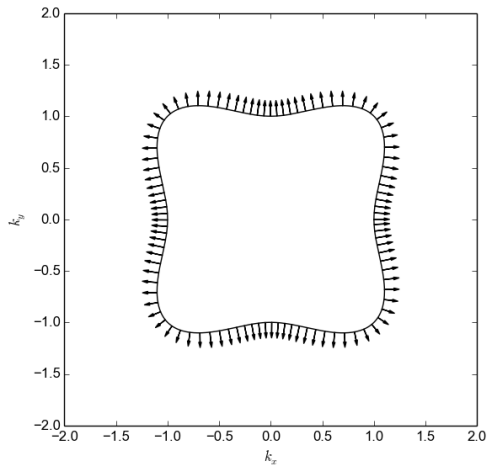
Phonon Focusing: Anisotropic Elasticity

$$\omega(k) \rightarrow \omega(\vec{k})$$



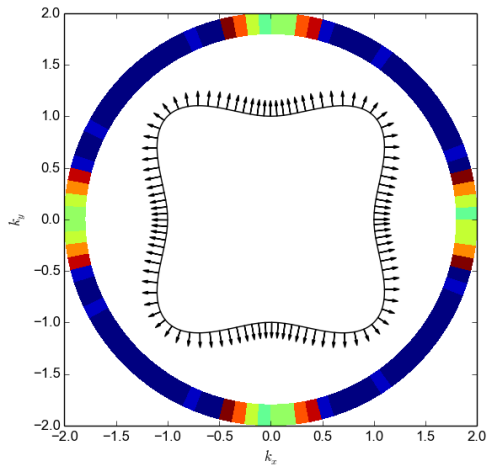
Phonon Focusing: Anisotropic Elasticity

$$\vec{v}_g = \vec{\nabla}_k \omega$$



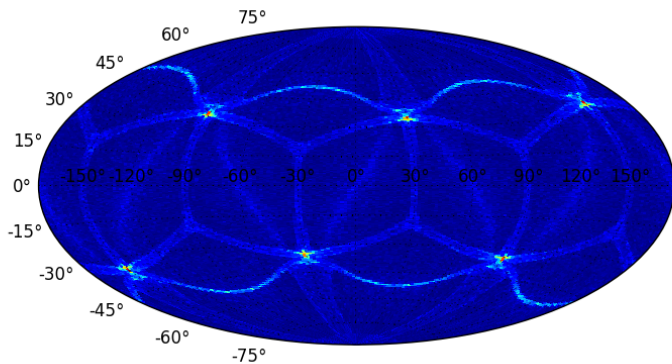
Phonon Focusing: Anisotropic Elasticity

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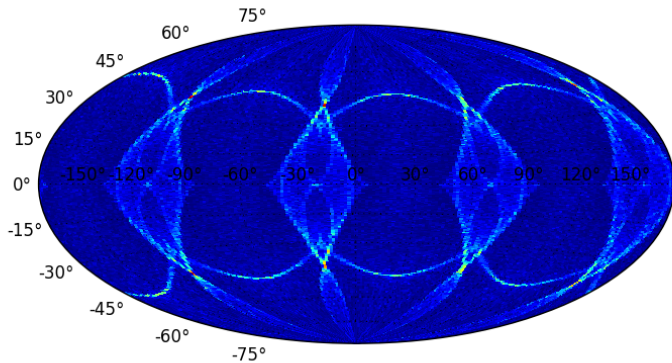
Phonon Focusing: Patterns in CRESST Materials

Sapphire



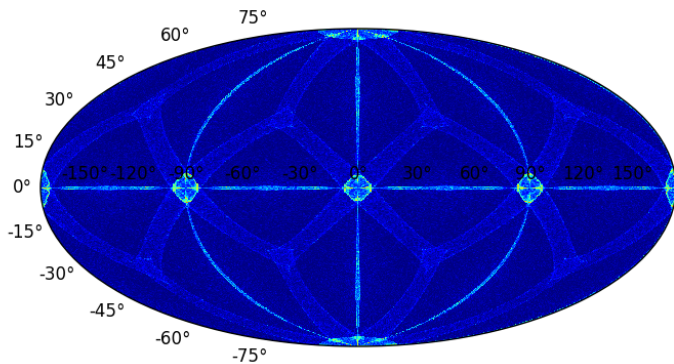
Phonon Focusing: Patterns in CRESST Materials

CaWO₄



Phonon Focusing: Patterns in CRESST Materials

Silicon

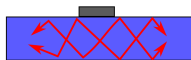


Effects in Cryogenic Detectors

Increasing Pulse Height

$$\left(\propto \tau_{\text{crystal}}/\tau_{\text{film}}\right)$$

In Planar Geometries:

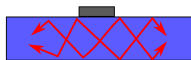


Maximize in-plane propagation!
(choosing the lattice orientation)

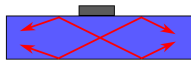
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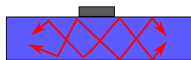


$\Rightarrow \tau_{\text{crystal}}$ grows, but τ_{film} also grows
(longer, but not higher pulses)

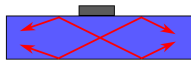
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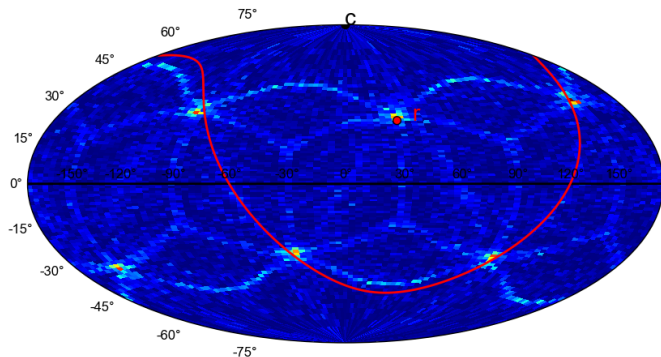
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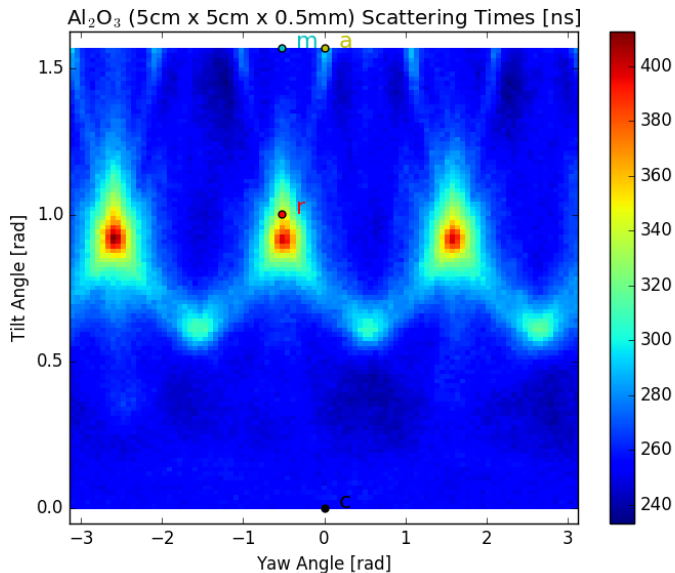
\Rightarrow lowering τ_{film} while keeping τ_{crystal} high

Quantitative Estimates

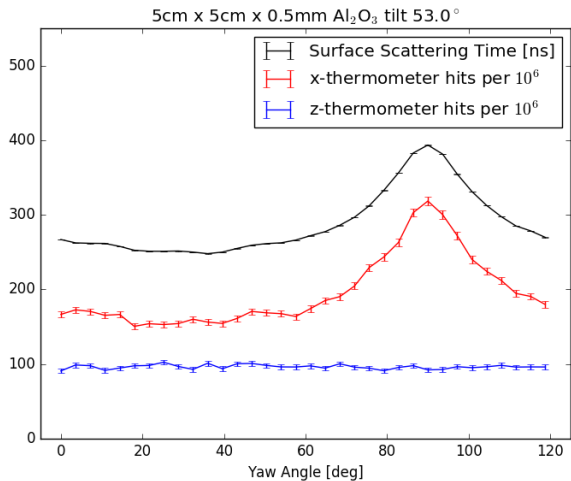
Sapphire: maximizing in-plane propagation



Quantitative Estimates

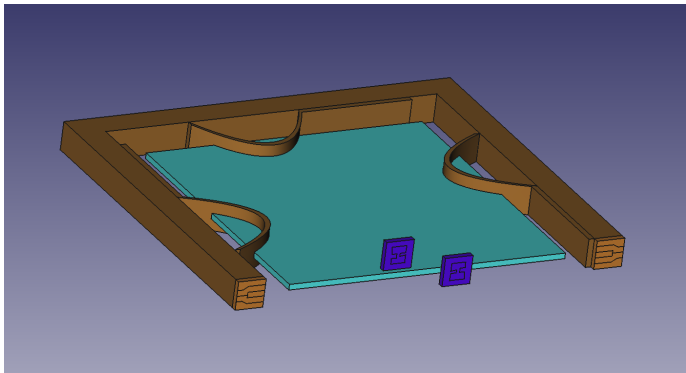


Quantitative Estimates

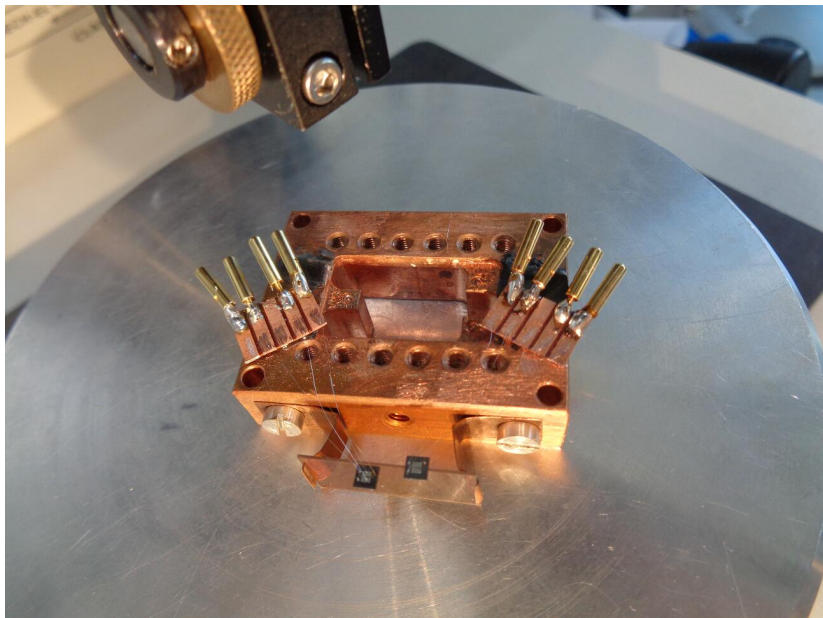


Preparing for Experimental Tests

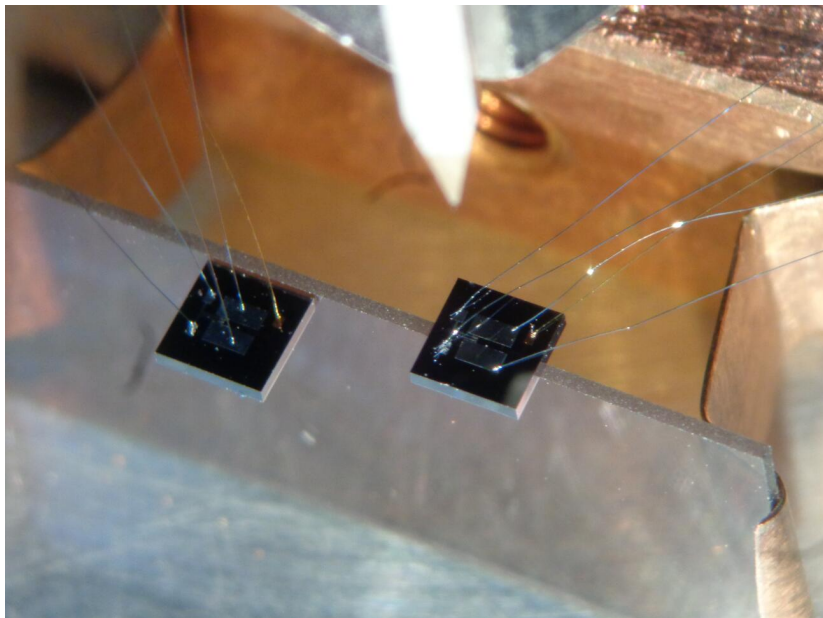
Simultaneous comparison:
“face”-thermometer vs. “edge”-thermometer



Preparing for Experimental Tests

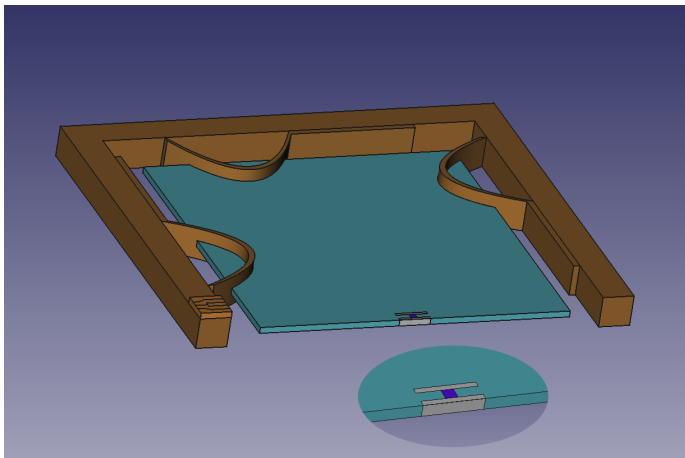


Preparing for Experimental Tests



Preparing for Experimental Tests

Phonon-focusing assisted light detector:
phonon collector on the side



Thank you!

