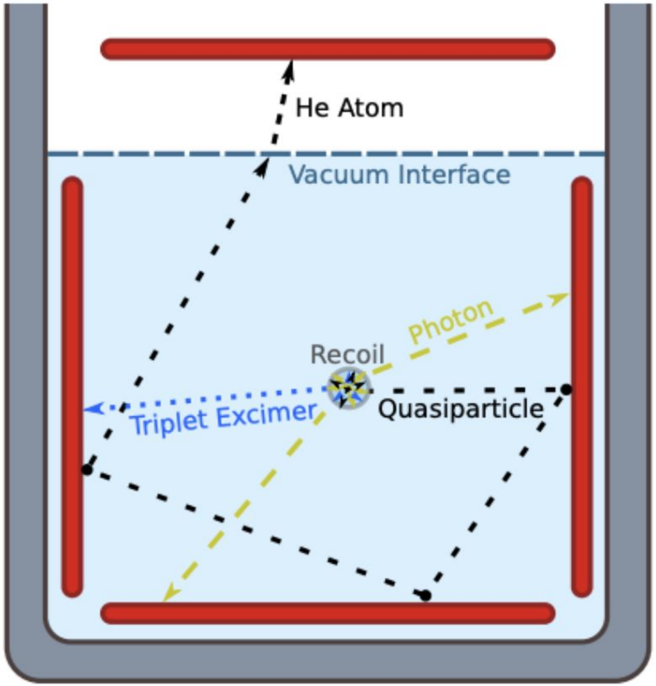
Measuring Quasiparticle Diffusion in Superconducting Al Films with a TES and Microscopic Laser-Scanning Technique

David Osterman - 12/1/2022

HeRALD: Helium Roton Apparatus for Light Dark matter



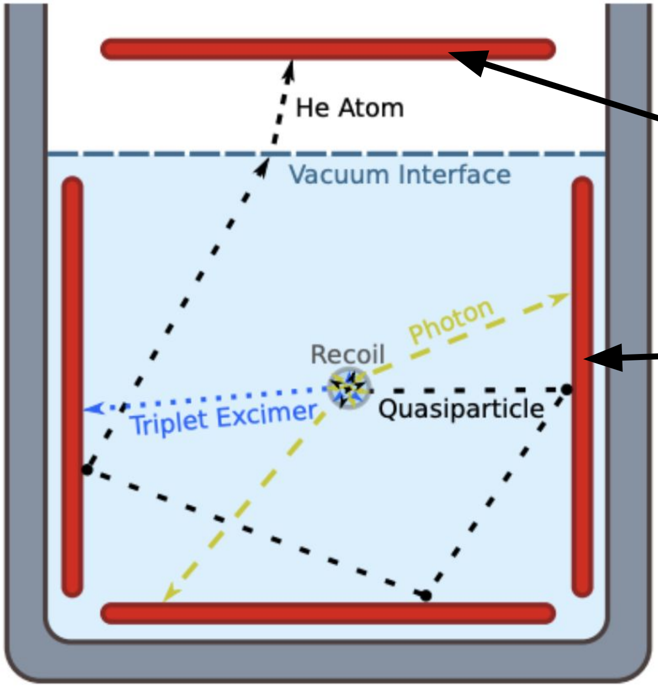
Searching for sub-GeV dark matter using a superfluid He target

Three signal channels

1. Photons - from He singlet excimers decaying with 10ns half-life
2. Triplet excimers - 13s half-life, propagate ballistically, quench on walls
3. Quasiparticles - ~1meV energy, can evaporate He atom from surface for 10x gain

[1] Hertel, S. A., et al. "A Path to the Direct Detection of sub-GeV Dark Matter Using Calorimetric Readout of a Superfluid $^ 4$ He Target." *arXiv preprint arXiv:1810.06283* (2018).

Loose goal:



Calibrate these

[1] Hertel, S. A., et al. "A Path to the Direct Detection of sub-GeV Dark Matter Using Calorimetric Readout of a Superfluid $^ 4$ He Target." *arXiv preprint arXiv:1810.06283* (2018).

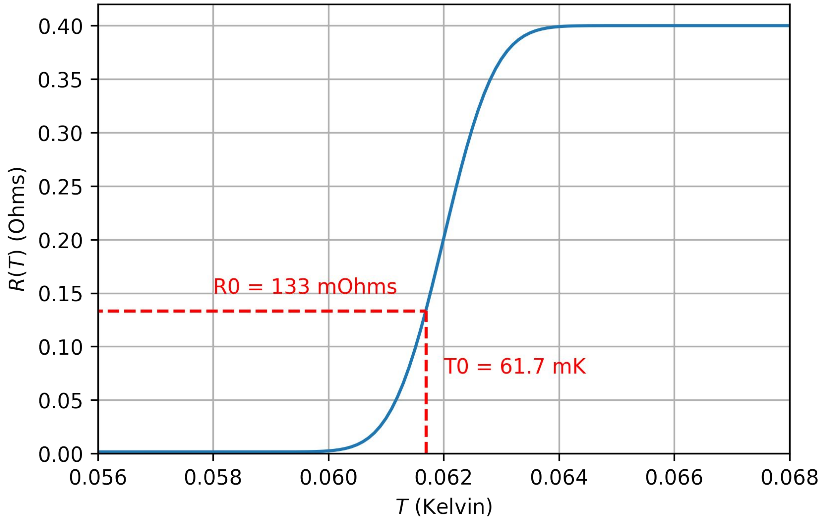
Transition edge sensors (TES)

Biased at T_0 slightly less than the transition temperature s.t. $R_0 = R_N/3$

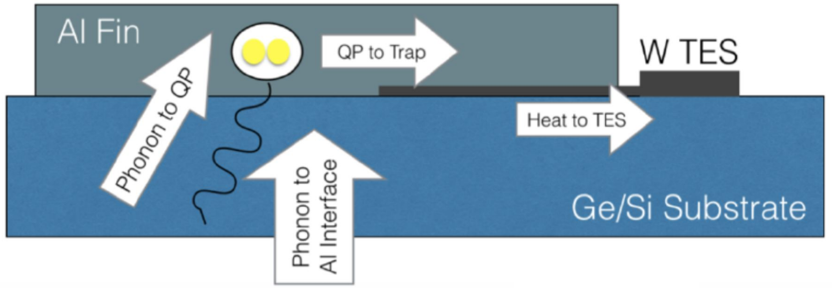
Small E deposit causes small T increase which causes sharp R increase

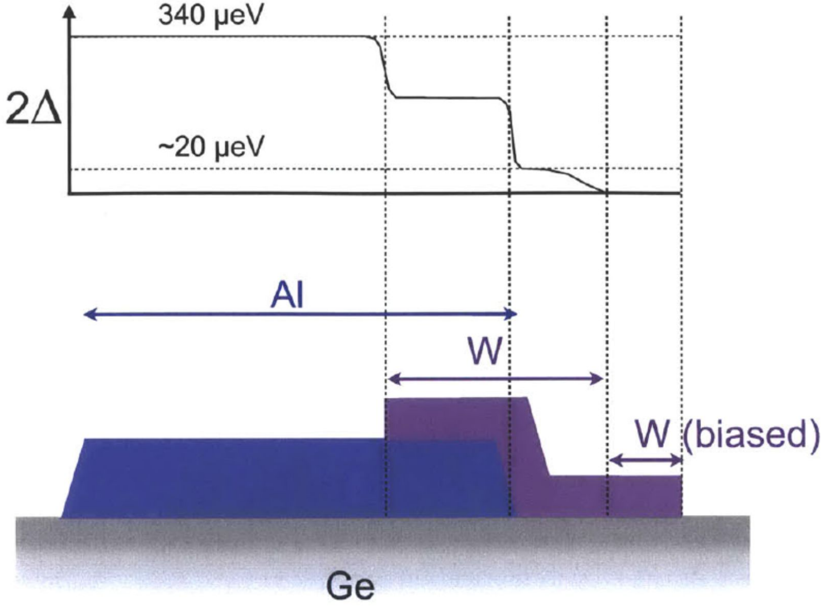
Electrothermal feedback makes the temperature stable

V-bias → Joule heating = V^2/R



Detecting energy deposits with QETs

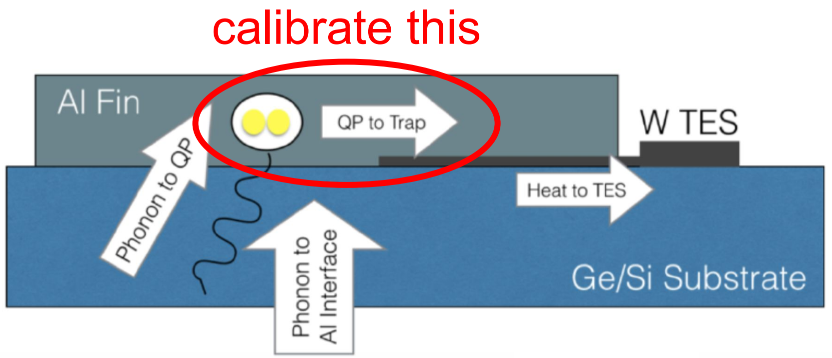




[2] Kurinsky, Noah. *The low-mass limit: Dark matter detectors with eV-scale energy resolution*. Stanford University, 2018.

[3] Hertel, Scott A. "Advancing the search for dark matter: from CDMS II to SuperCDMS." *Ph. D. Thesis* (2012).

Focused goal:



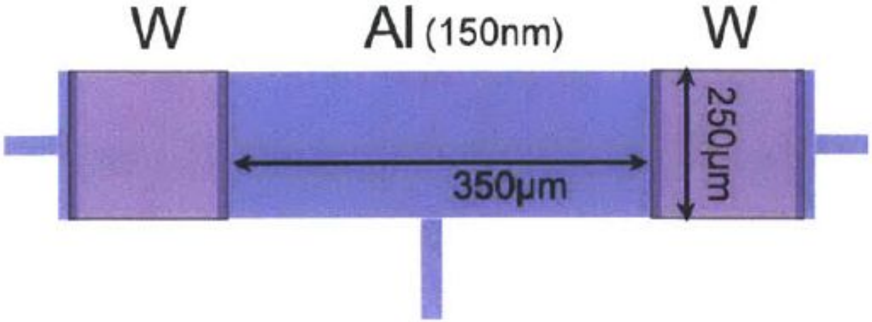
There is a tradeoff when optimizing the Al fin length

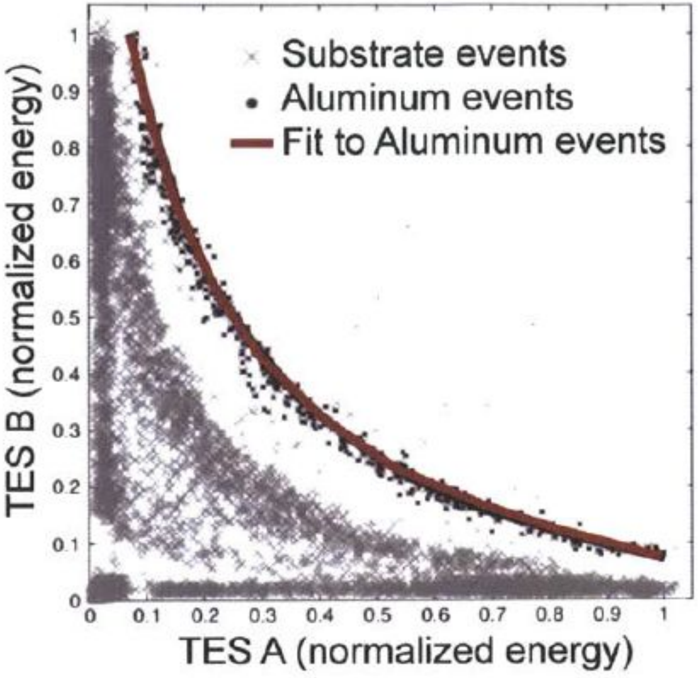
Long fins - Higher Al surface coverage will increase the efficiency of capturing athermal phonons from the substrate

Short fins - The longer the QPs need to diffuse the more QPs will be trapped by impurities in the Al, decreasing the overall energy efficiency

[2] Kurinsky, Noah. *The low-mass limit: Dark matter detectors with eV-scale energy resolution*. Stanford University, 2018.

Past study of QP diffusion: CDMS “banana” experiment





[3] Hertel, Scott A. "Advancing the search for dark matter: from CDMS II to SuperCDMS." *Ph. D. Thesis* (2012).

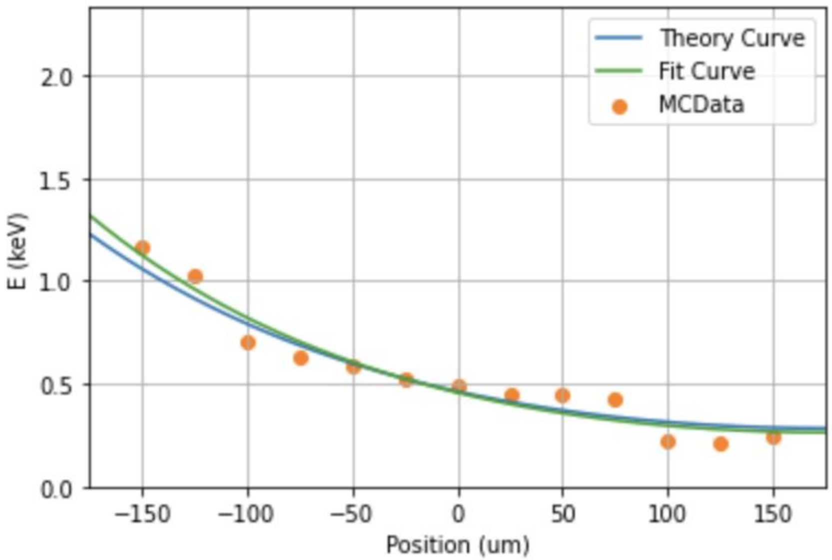
More focused goal: measure QP trapping length l_{trap}

Measure **single TES** response as a function of event position to fit for l_{trap}

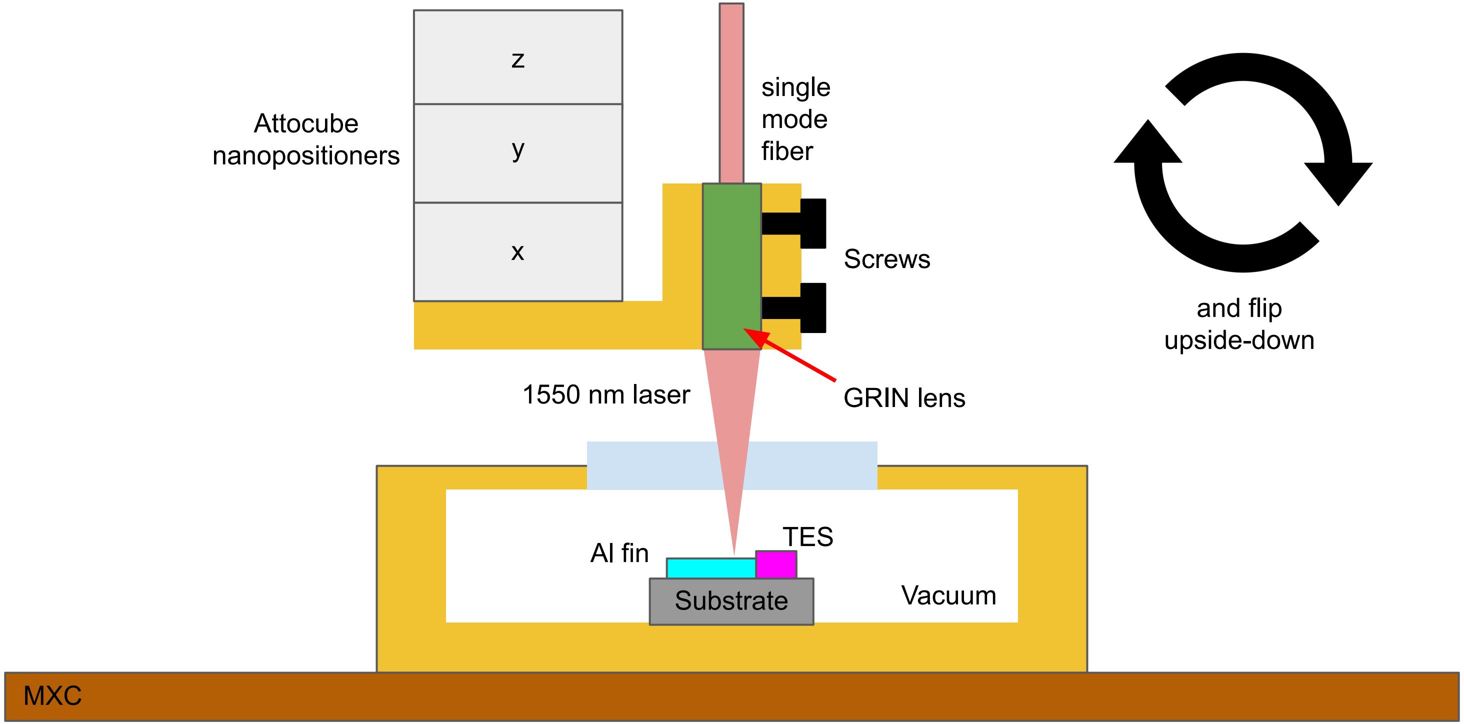
Two fitting parameters: A and l_{trap}

$$E_L\left(x\right) = A\cosh\left[\frac{1}{l_{trap}}\left(\frac{L}{2} - x\right)\right]$$

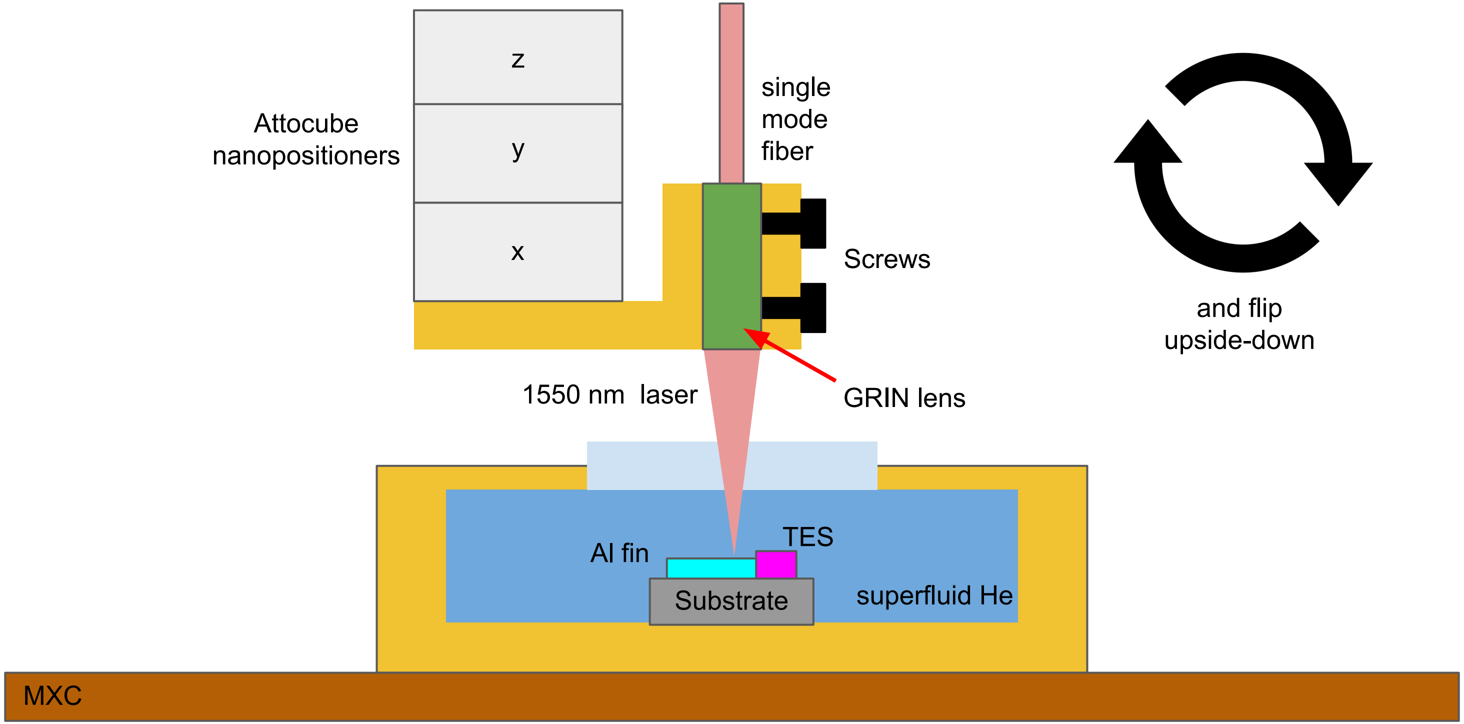
Choose position for each energy deposit



Experiment schematic



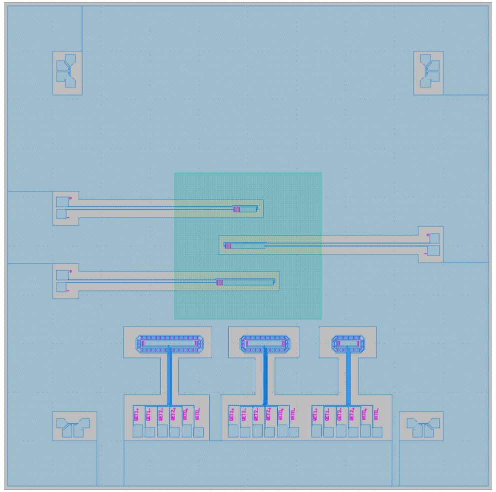
Fill with He to measure QP energy lost to superfluid

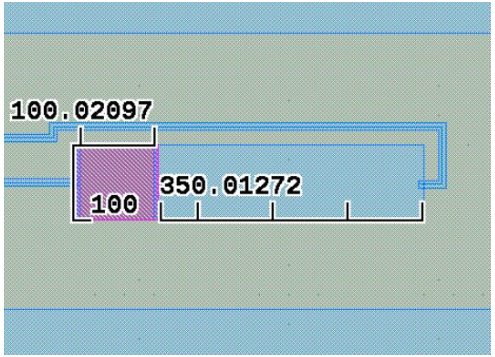


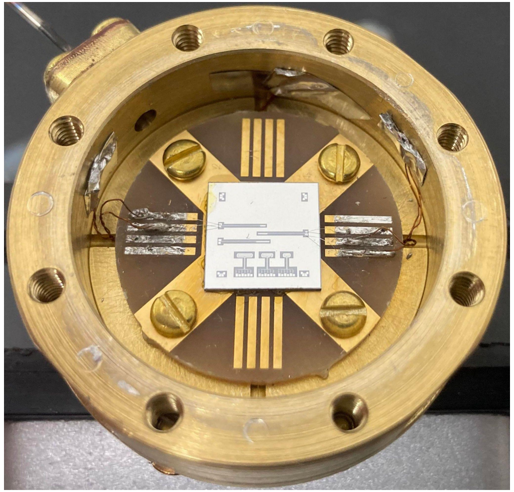
The TES-Al device

TES: Ir30nm:Pt10nm bilayer (Clarence Chang); 100um x 100um; Rn = 4.4Ω; Tc ~ 70-80mK

Al: 300nm thick; 100um x 350um



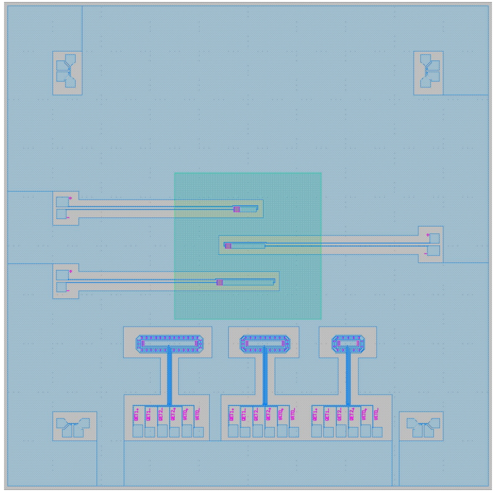


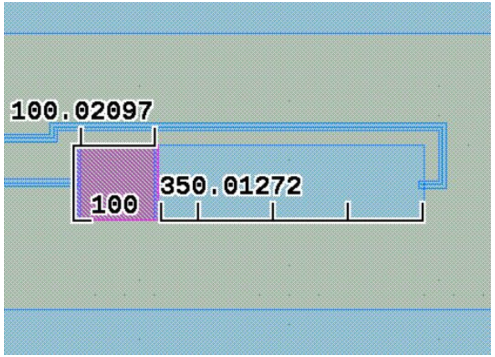


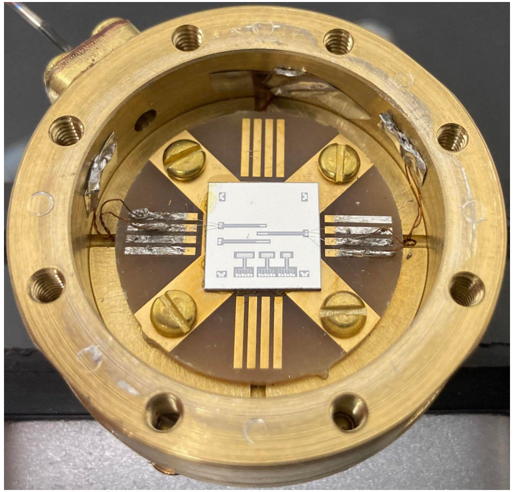
Two quick notes

First time attempting to measure energy deposit with an Argonne bilayer TES

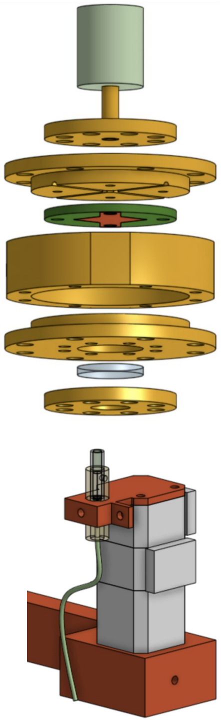
First time testing qp diffusion in Argonne Al

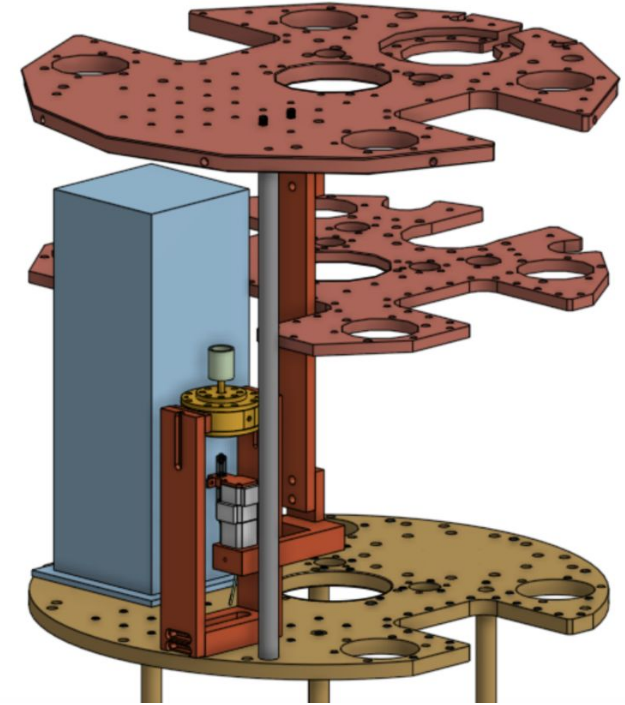


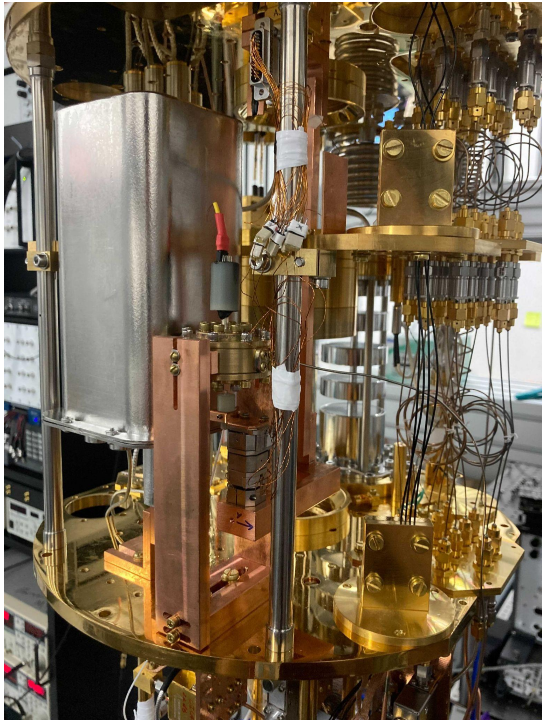




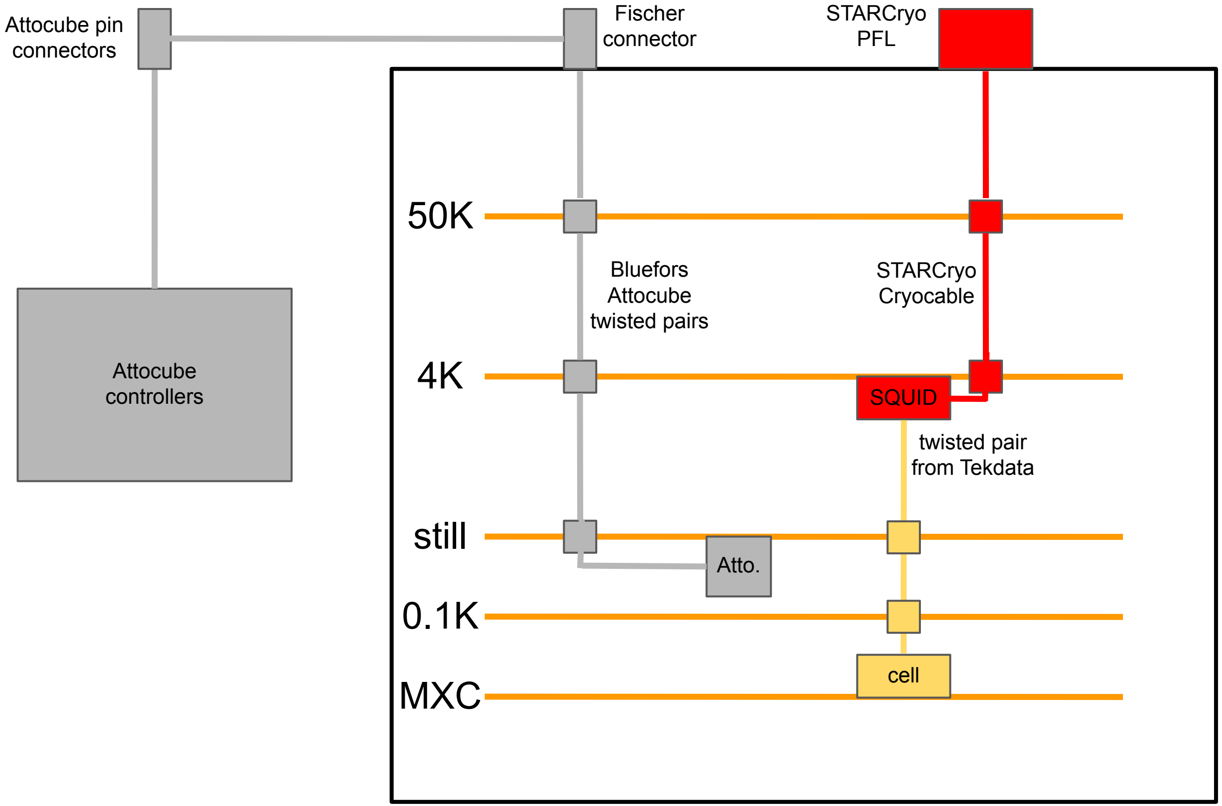
Superfluid cell and Attocube nanopositioner setup







Fridge wiring schematic



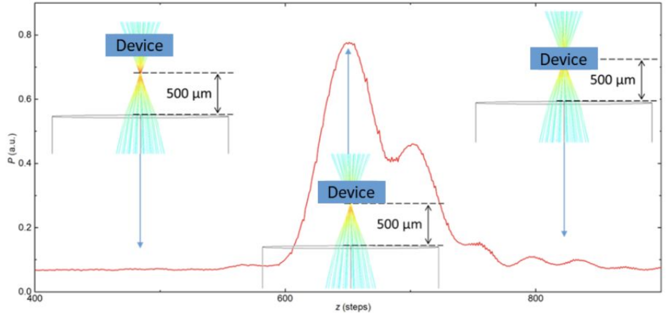
Laser scanning microscopy for positional information

Want to image the chip to locate the target device

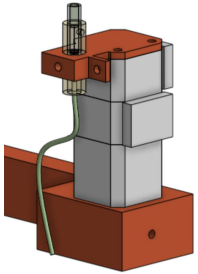
Measure the laser power reflected back into the fiber

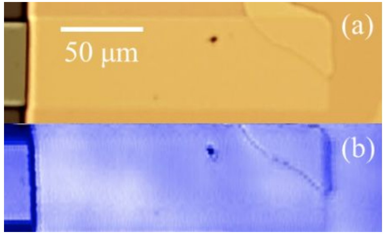
- Max reflected power indicates focused laser
- Device features show up as different reflected laser powers → image!

Focusing minimizes the spot size for the energy deposits



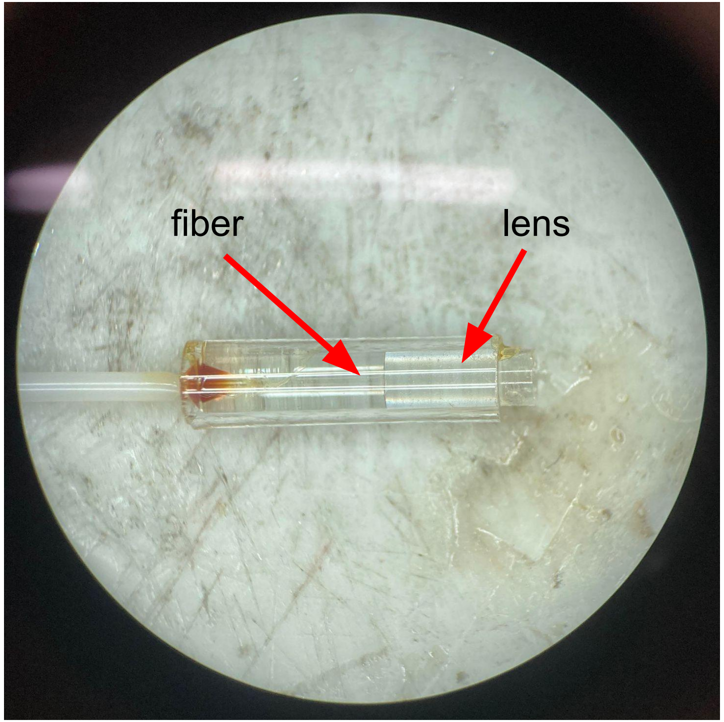
Laser focused when reflected power is at a max
(courtesy of Dr. Xianjing Zhou)

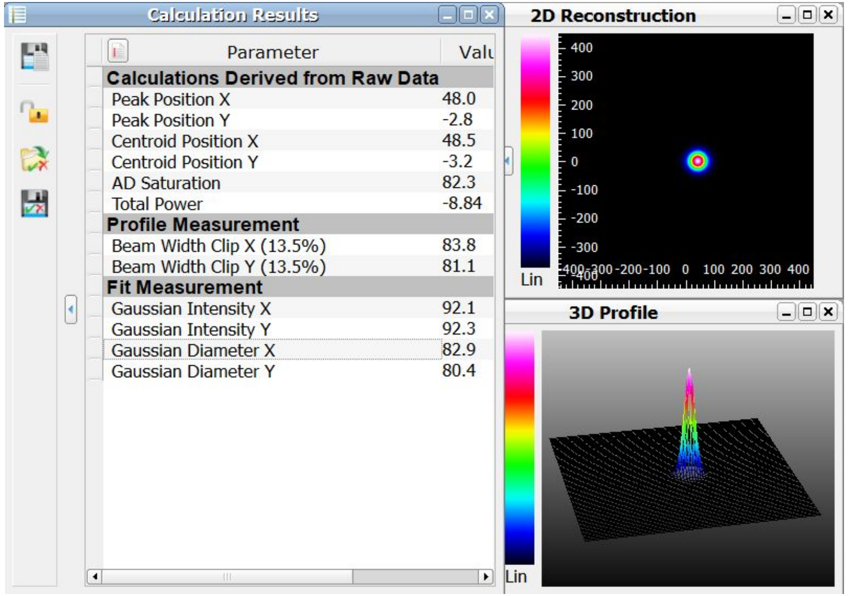




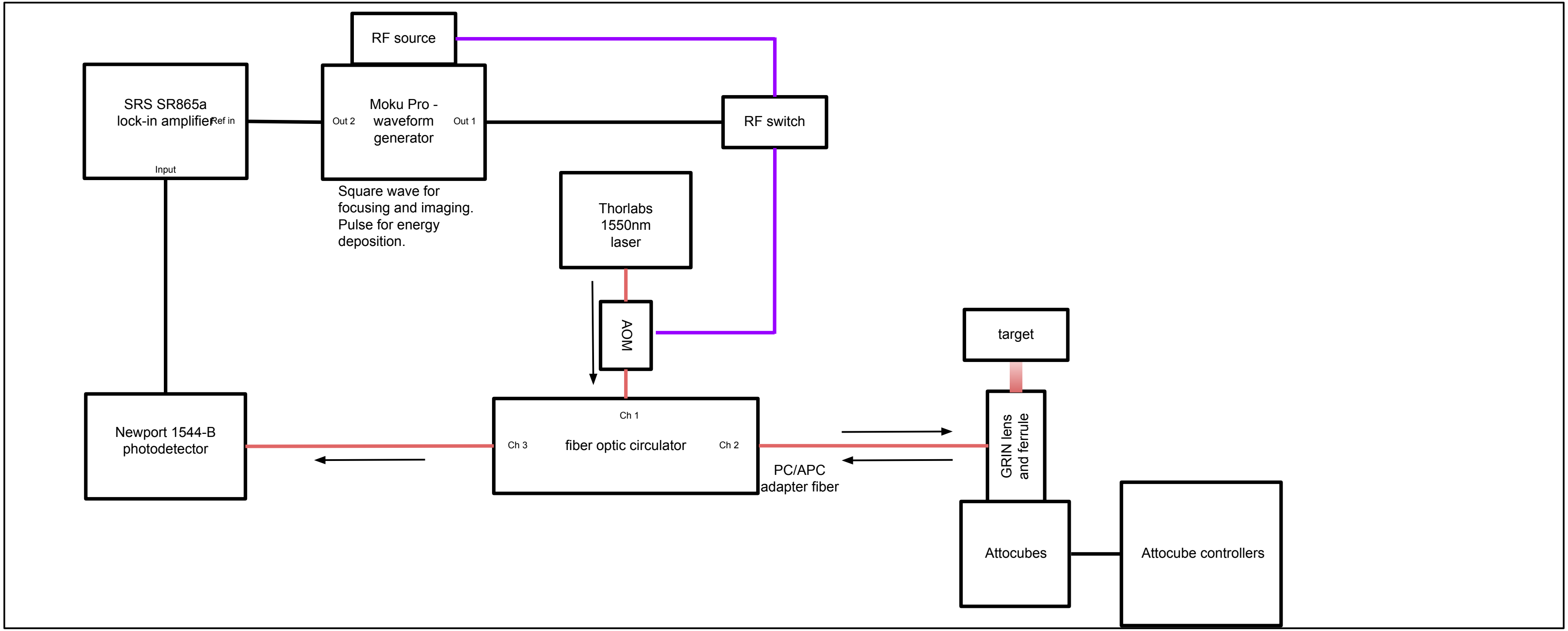
(a) SEM, (b) laser image
(courtesy of Dr. Xianjing Zhou)

Beam profiler measured focused spot to be 83um for 0mm lens-fiber separation

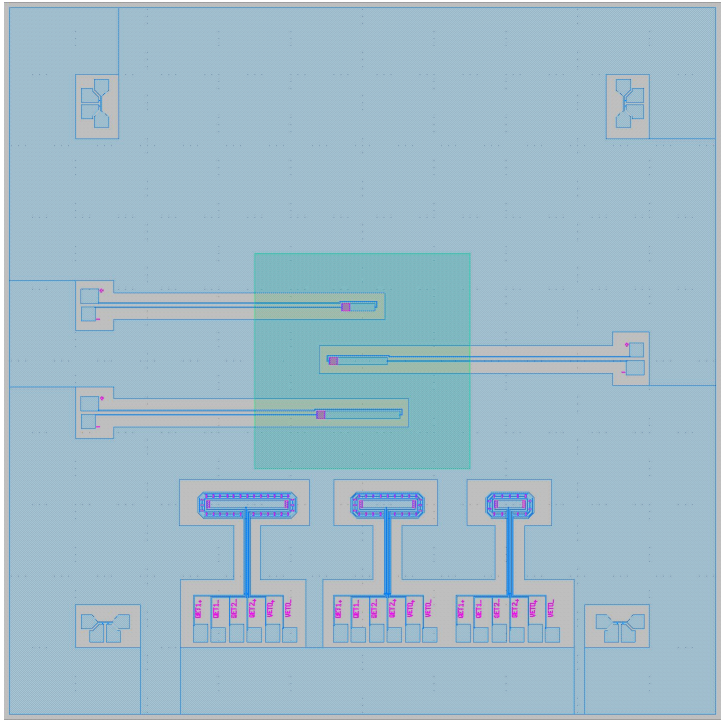


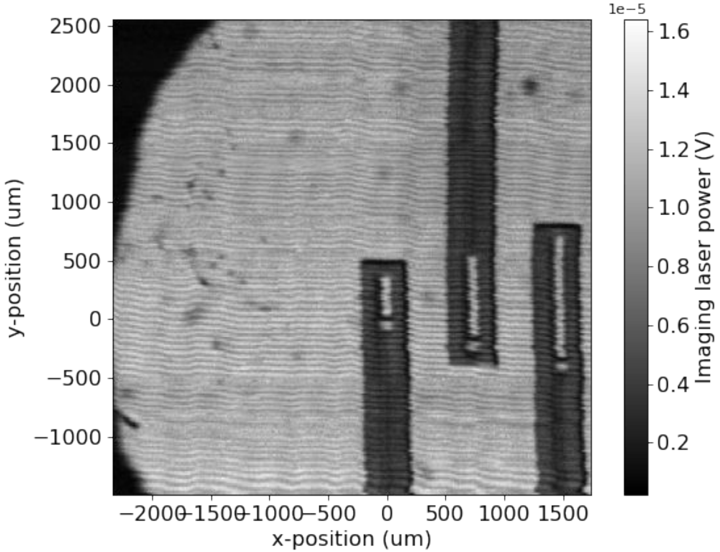


Laser imaging setup



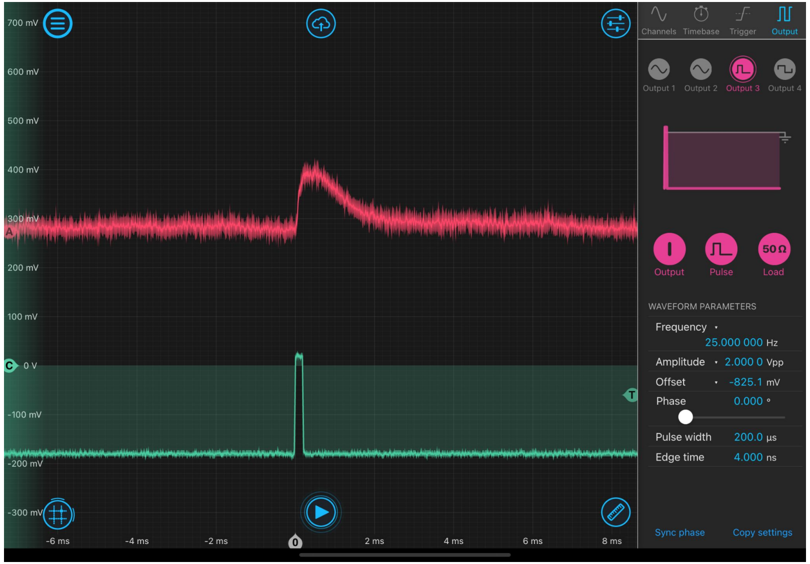
Laser imaging results



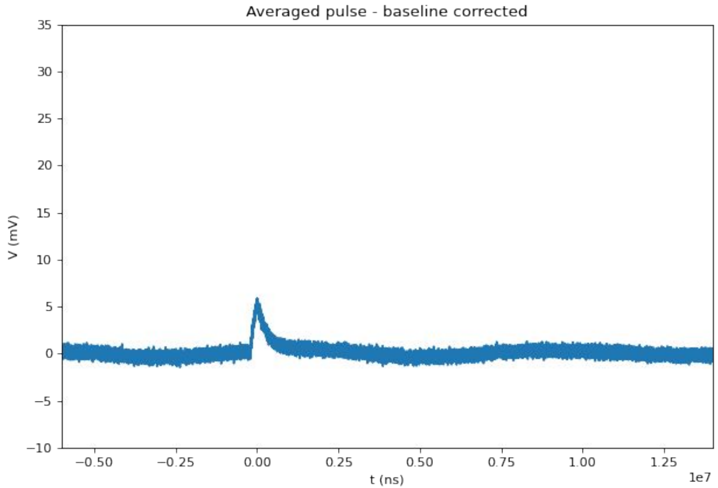


Laser pulses

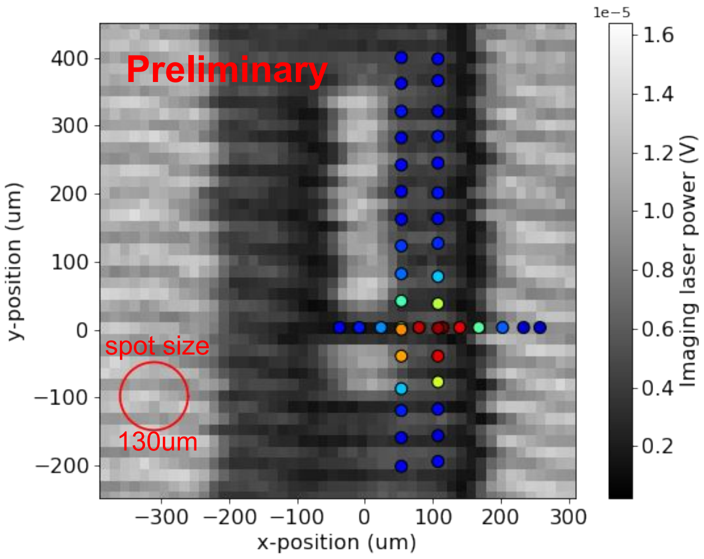
Si pulse - triggering on modulating waveform

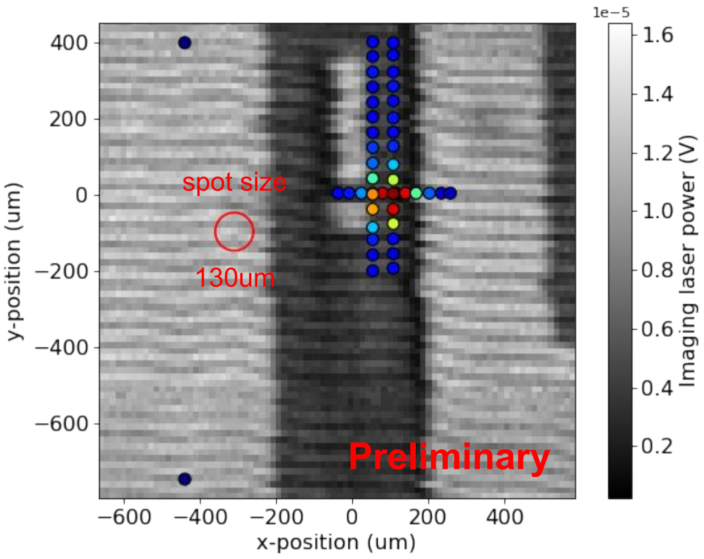


100 averaged Si pulses

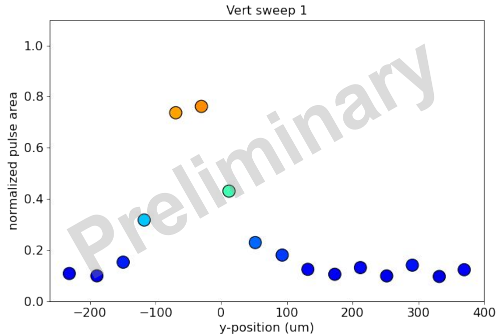


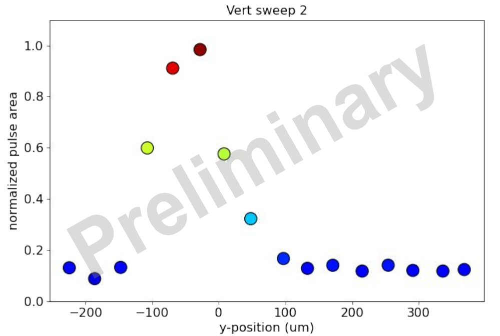
Dry device - pulse area data - points at Attocube locations

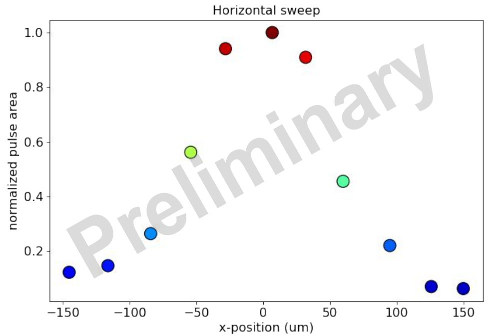




Individual sweeps





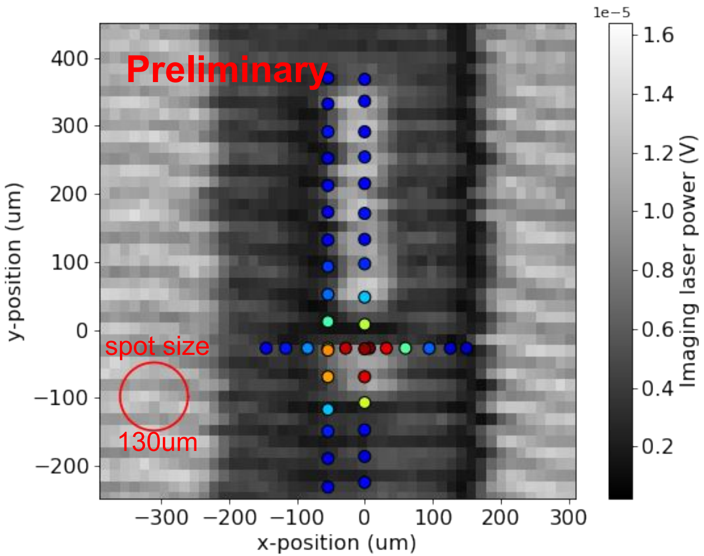


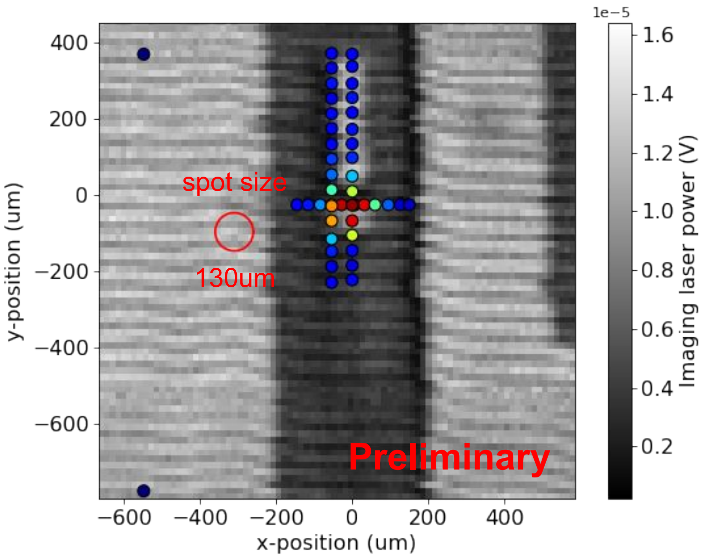
It is likely the peaks are from the gaussian profile of the large laser spot hitting the TES directly and dominating over the qp signal from the Al fin because:

1. The gaussian spot diameter is ~130um - **need to make this smaller**
2. The reflectivity at 1550nm of Ir and Pt are 85% and 75% respectively while the reflectivity of Al is 98%. The TES could be absorbing up to 10x more energy than the Al
3. More energy from the aluminum is lost because of low Al/TES interface crossing efficiency

Difficult to see signal from Al - **want to test laser technique with Al we know works**

All pulse area data - adjusted event locations





Conclusions

Results

- Located TES-Al device with focused laser-imaging technique
- Detected energy deposits from a focused laser with an IrPt bilayer TES
- Can see Si pulses - useful for calibrating phonons in Si, not just QPs in Al

Improvements for next run

- Decrease laser spot diameter from 130um to ~50um - we have a lens that can do this
- Test technique with TES-Al devices with Al we know works - we have this device

Thank you

Argonne

Prof. Dafei Jin

Dr. Xianjing Zhou

Dr. Xinhao Li

Dr. Xu Han

Dr. Yizhong Huang

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