Optical calibration of superconducting quantum sensors for particle detection

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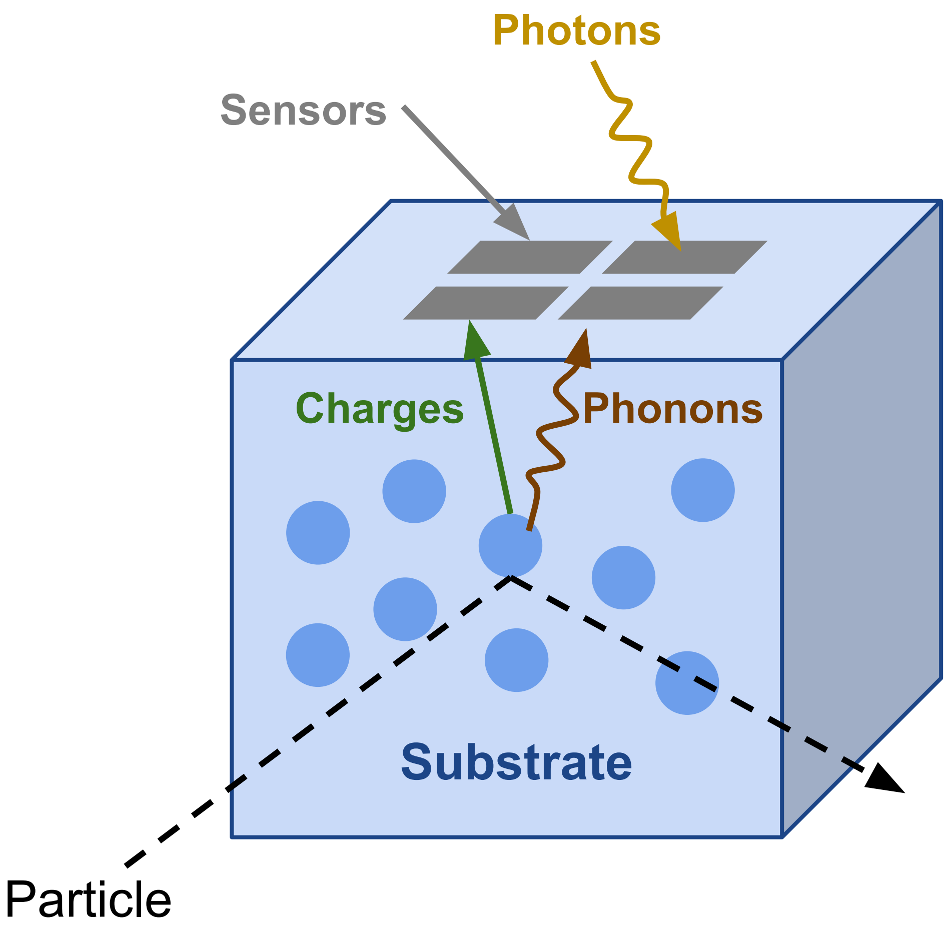
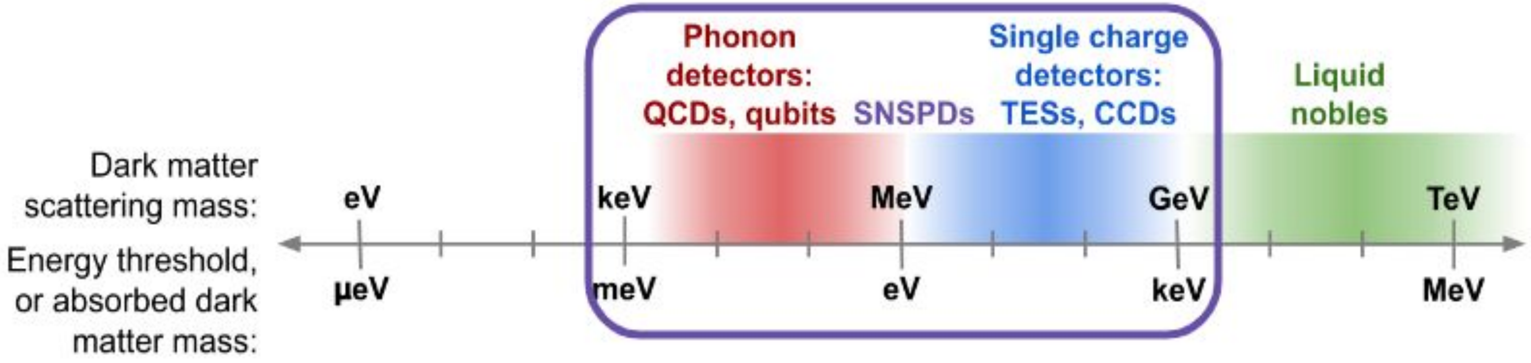
Cryogenic sensors for particle detection:

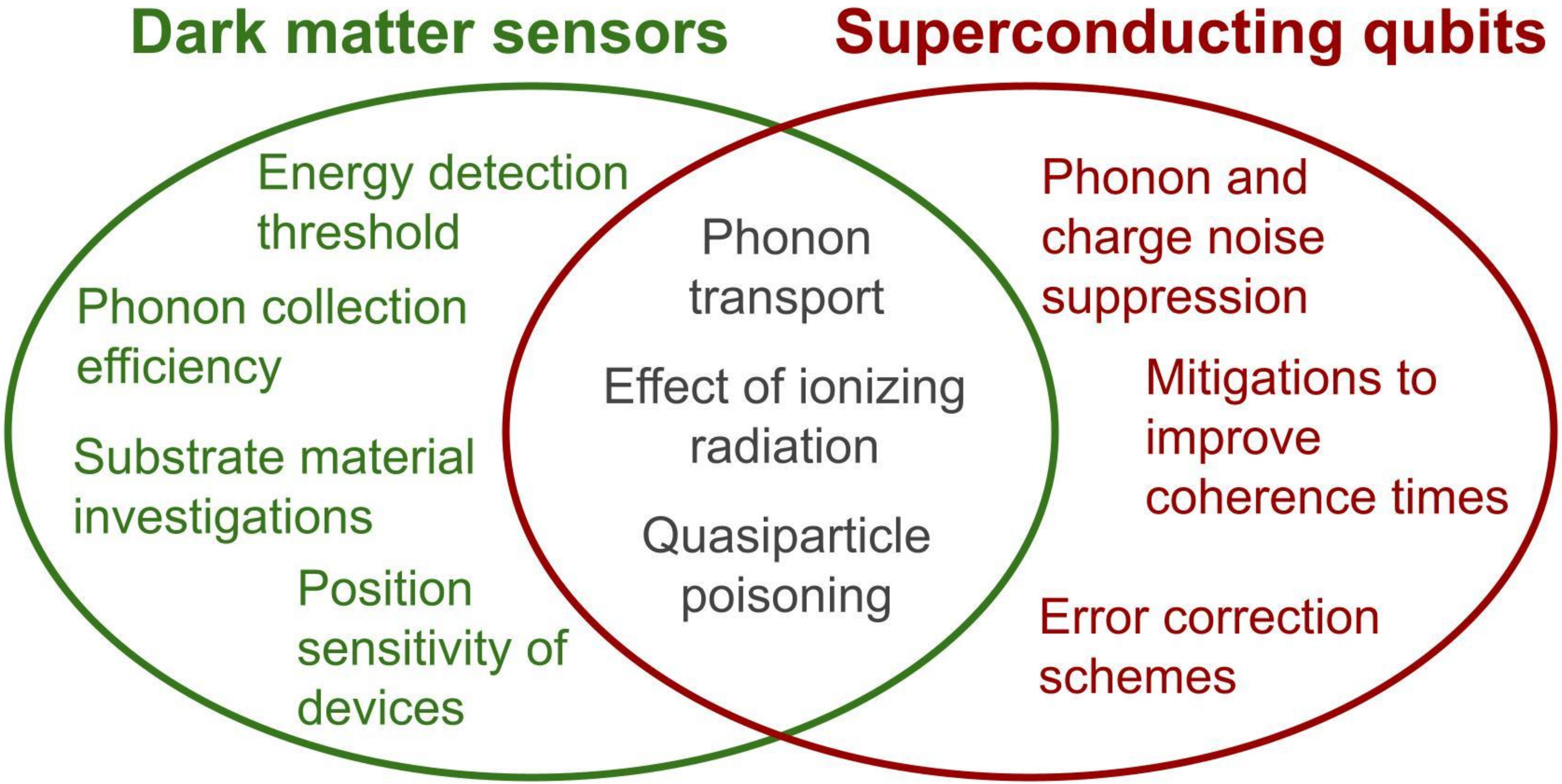




Detection of sub-GeV dark matter requires detectors sensitive to energy deposits of <1 keV

Novel calibration devices are required for the development and testing of these extremely sensitive detectors

Technical challenges shared with QIS community



Checklist for ideal calibration source:

- ❑ **Works at range of low energies:** from O(eV) down to O(meV)
- ❑ **Time-resolved:** ~μs pulsed operation for timing resolution
- ❑ **Position-dependent:** steerable over significant area of device
- ❑ **Spatially localized:** small beam spot (~50μm) to target small structures
- ❑ **Cryo-friendly:** functional at low temps (~10mK), low power dissipation
- ❑ **Device Independent**
- ❑ **Inexpensive**
- ❑ **No light leakage**

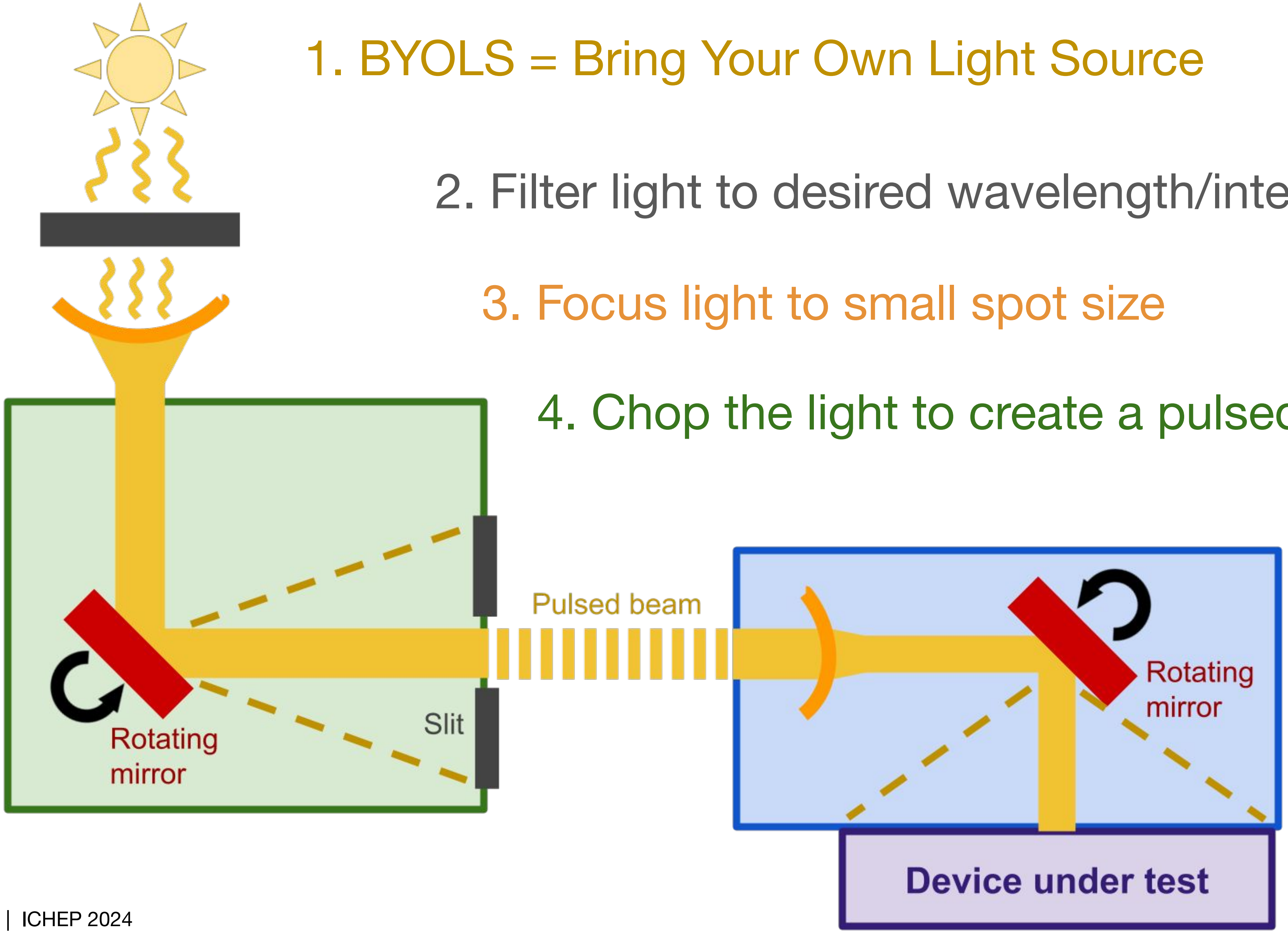
Pulsed, steerable laser system for use with cryogenic devices:

1. BYOLS = Bring Your Own Light Source

2. Filter light to desired wavelength/intensity

3. Focus light to small spot size

4. Chop the light to create a pulsed beam



5. Steer pulsed beam to desired location…

6. …to produce energy deposits in your device

Technical challenge:

Cryogenic movement

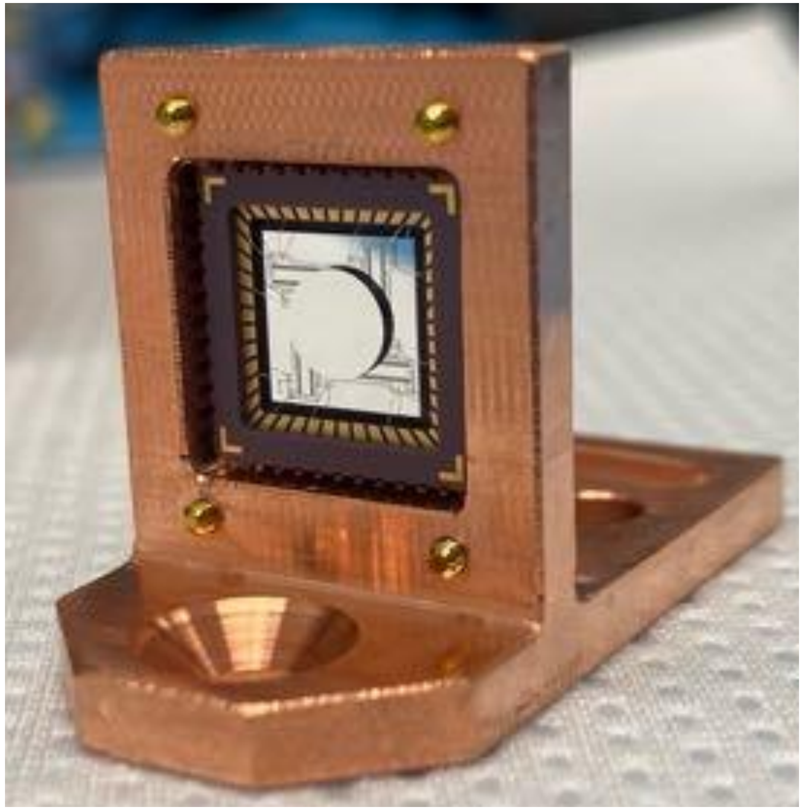
- Power dissipation
- Freeze out of movement mechanisms/control

Our solution: modified MEMS mirrors (right)

- Al deposited over doped Si control lines for mK operation

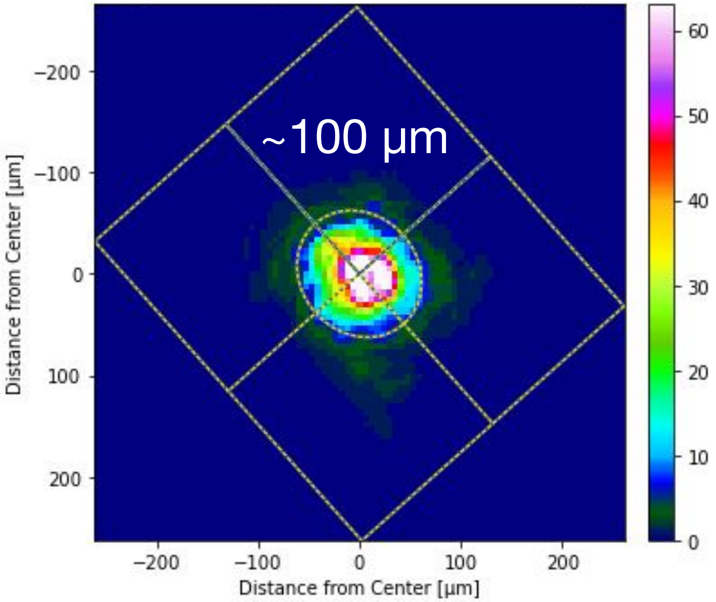
Good because:

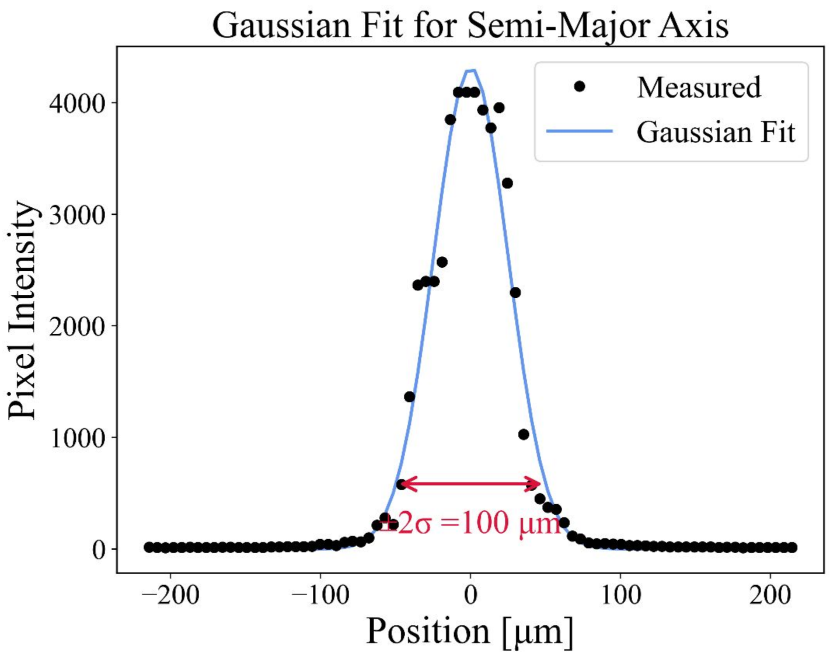
- High broadband reflectance
- Relatively large deflection angles (~5°)
- Limited power dissipation (~1 μW)

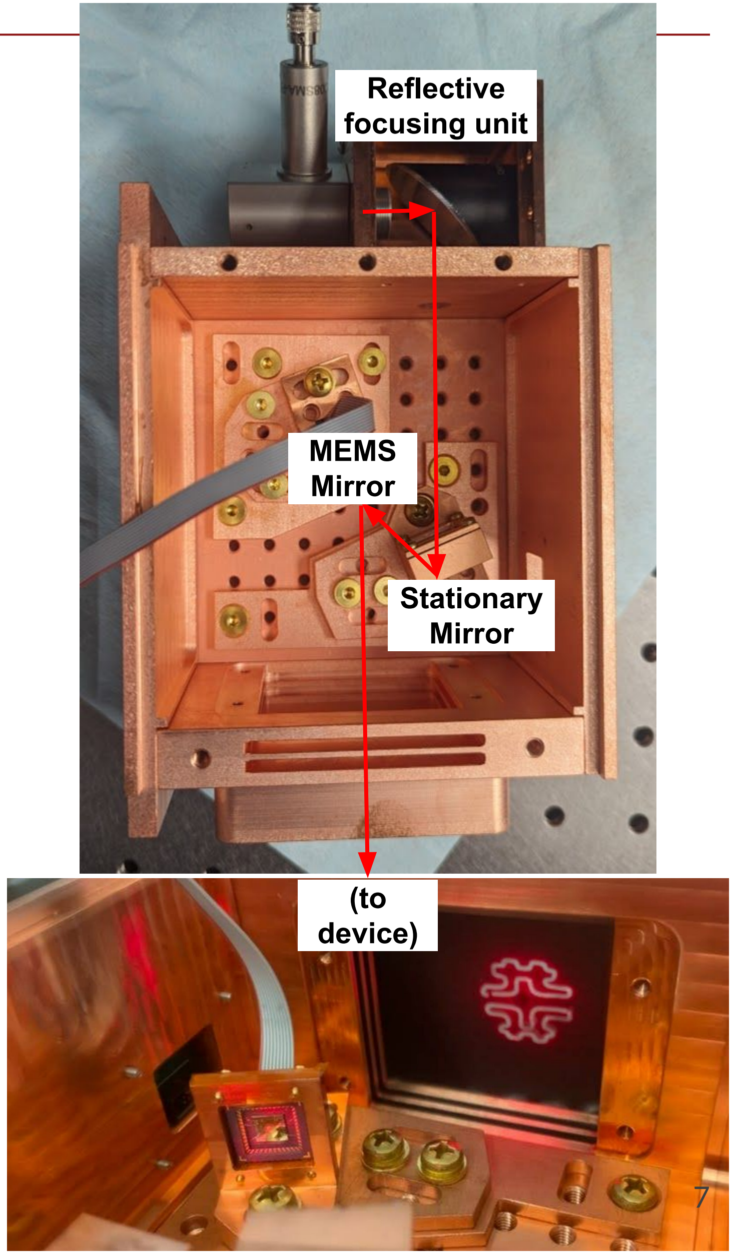


Scanning unit design using MEMS mirror:

- Custom focusing unit that works over a range of wavelengths
- Spot size of ~100 μm that can scan over a ~3 x 3 cm area

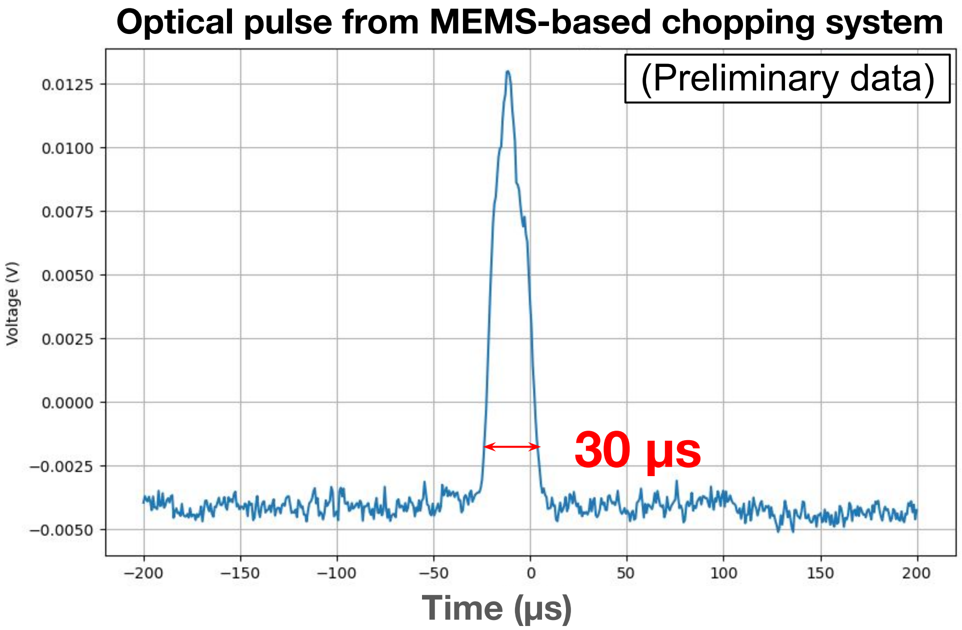


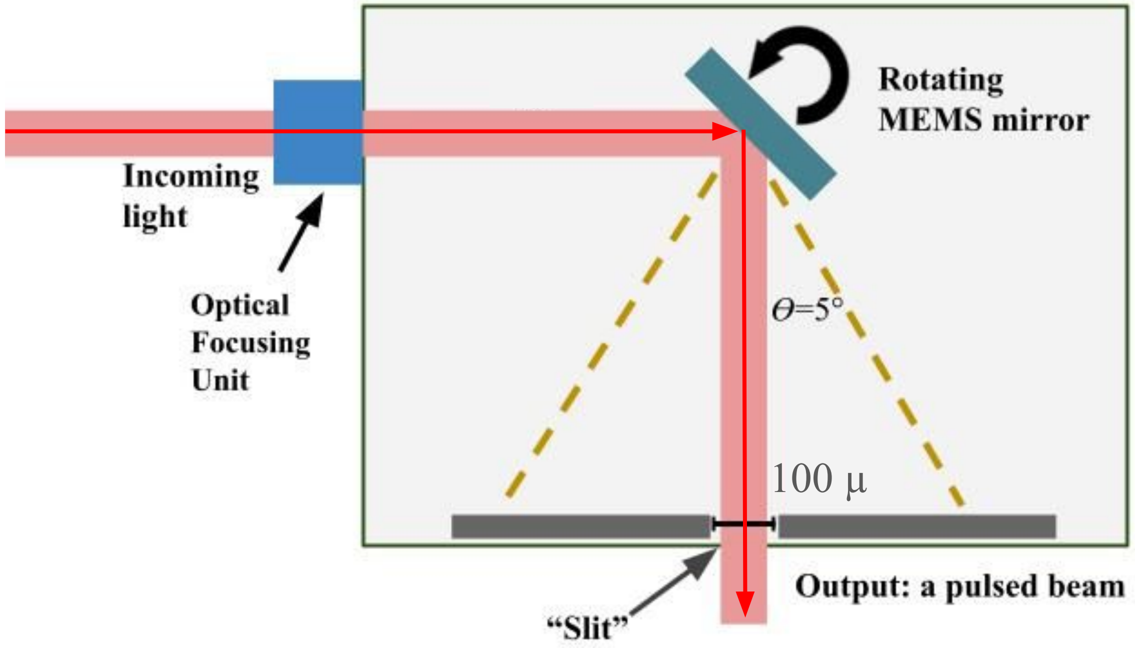


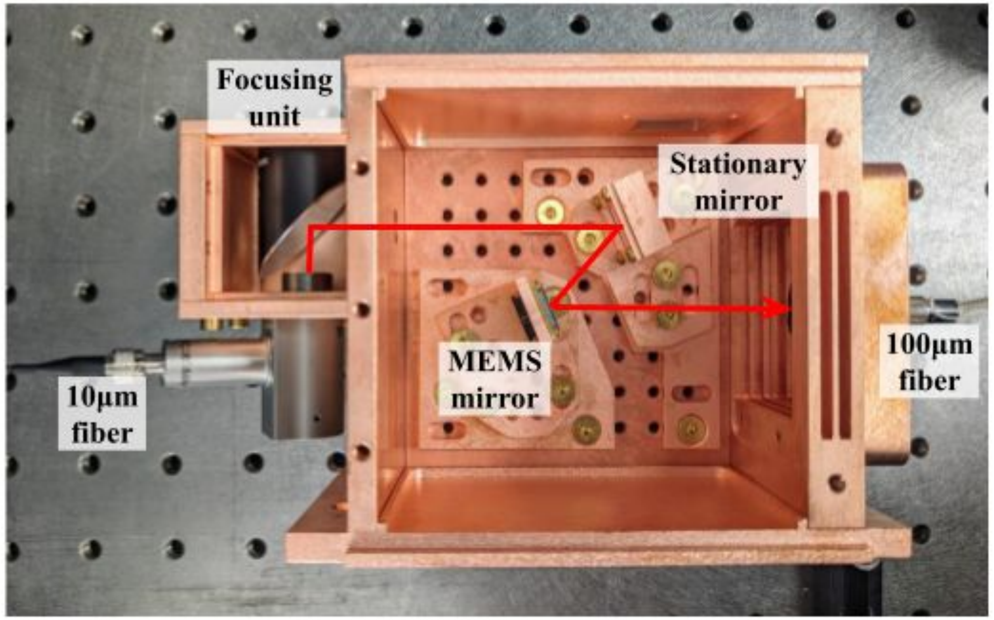


Broadband Optical Chopping

- Can generate ~10 - 30 μs pulses over the energy range of ~1.2 - 3 eV
- This will be used to distinguish calibration signals from backgrounds







[Paper in progress, Tabassum, N. et al.]

Checklist for ideal calibration source:

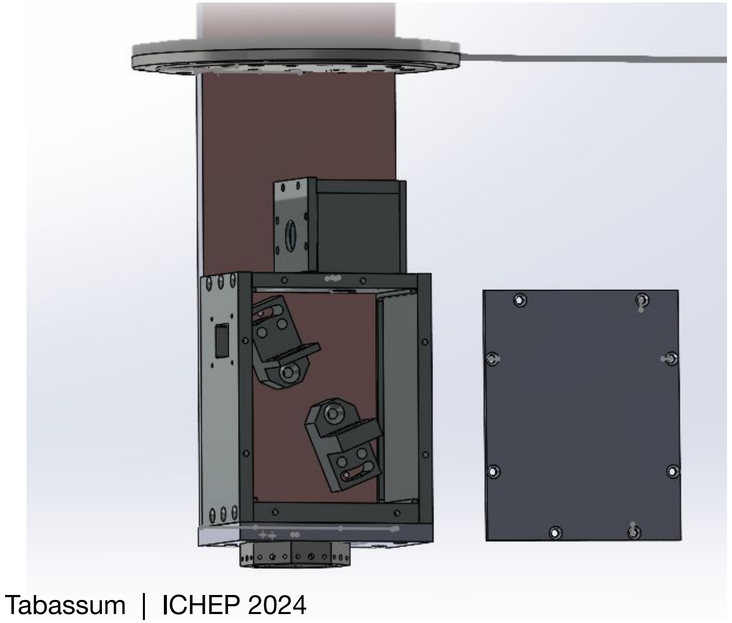
- ✅ **Works at range of low energies:** Mirrors rated to deliver 60 meV - 6 eV photons (further limited to ~1.2 - 3 eV by available optical fibers)
- ✅ **Time-resolved:** < 30 μs pulsed operation for timing resolution
- ✅ **Position-dependent:** steerable over ~3 x 3 cm
- ✅ **Spatially localized:** small beam spot (<100 μm) to target small structures
- ✅ **Cryo-friendly:** functional at low temps (~10 - 20 mK), low power dissipation (~1 μW)
- ✅ **Device-independent:** deployed with multiple device types
- ✅ **Inexpensive:** ~$10k
- ❏ **No light leakage:** will be investigated with TESs and KIDs

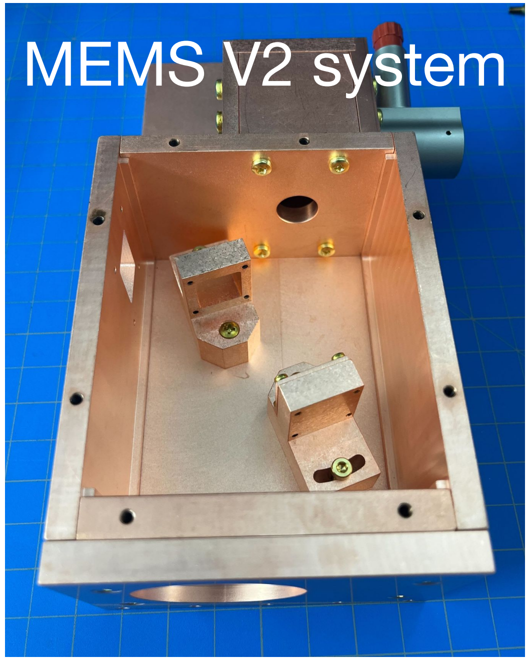
Deployment in other QIS groups

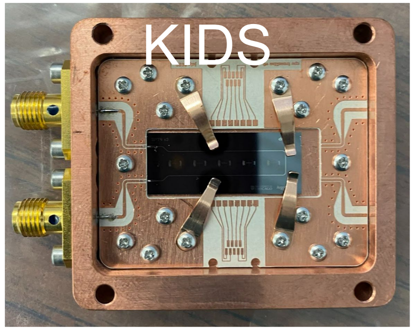
Deploying systems at:

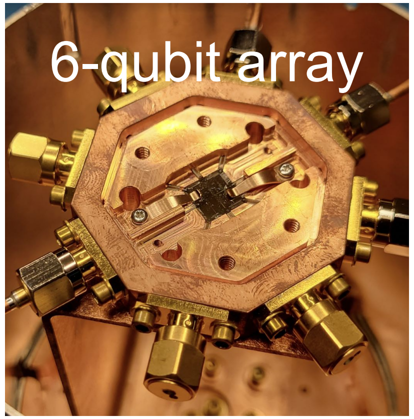
- Fermilab (KIDs, qubits on Si and sapphire)
- Syracuse (qubits, KIDs)
- UW - Madison (qubits, quantum dots)
- Livermore National Lab (KIDs, SNSPDs)

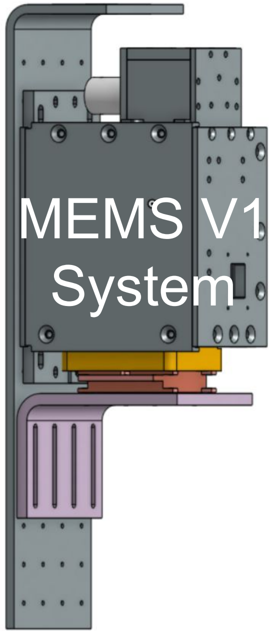
Version 2 housing allows for use of magnetic shield

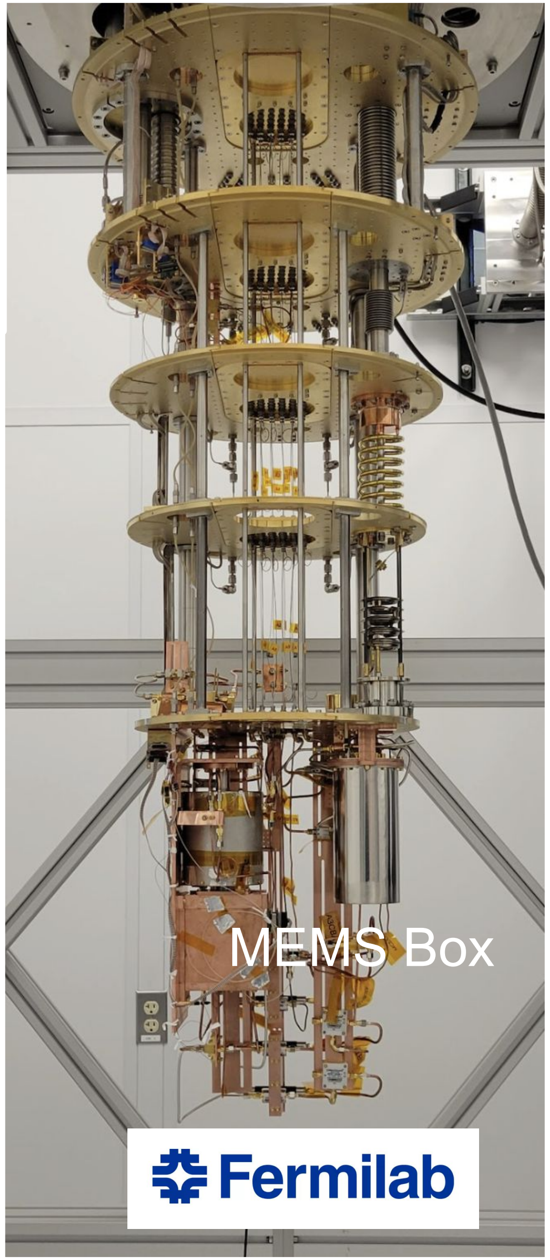






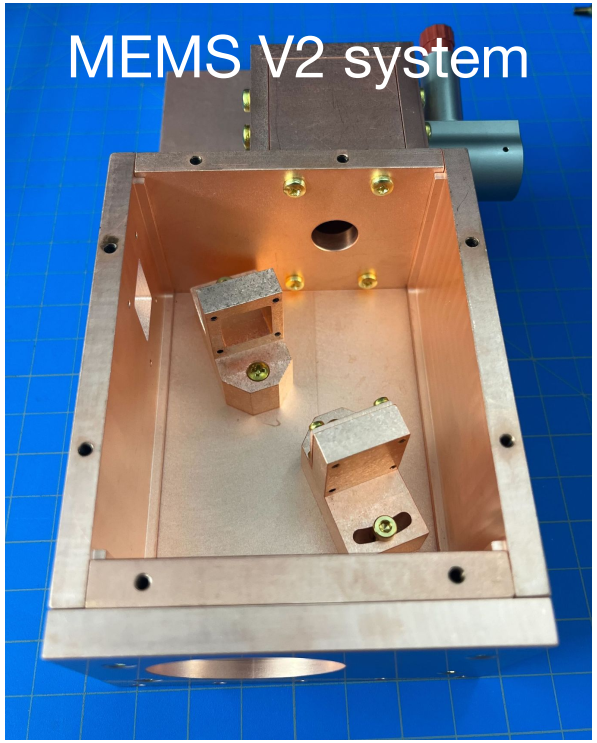






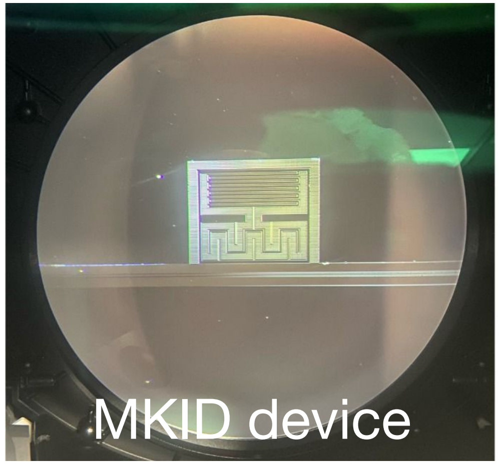
arXiv:2405.02258

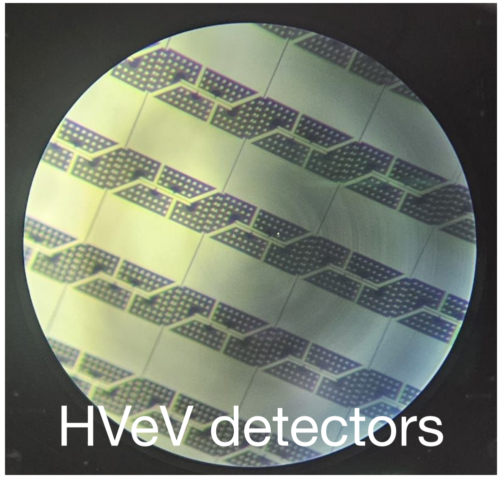
Calibration of KID and HVeV detectors at SLAC



- Deploying the V2 MEMS calibration system with KIDs and TES-based HVeV detectors in the next 1-2 months

- This system will be used to investigate phonon transport, position sensitivity, and phonon loss mechanisms in the substrate of the detector

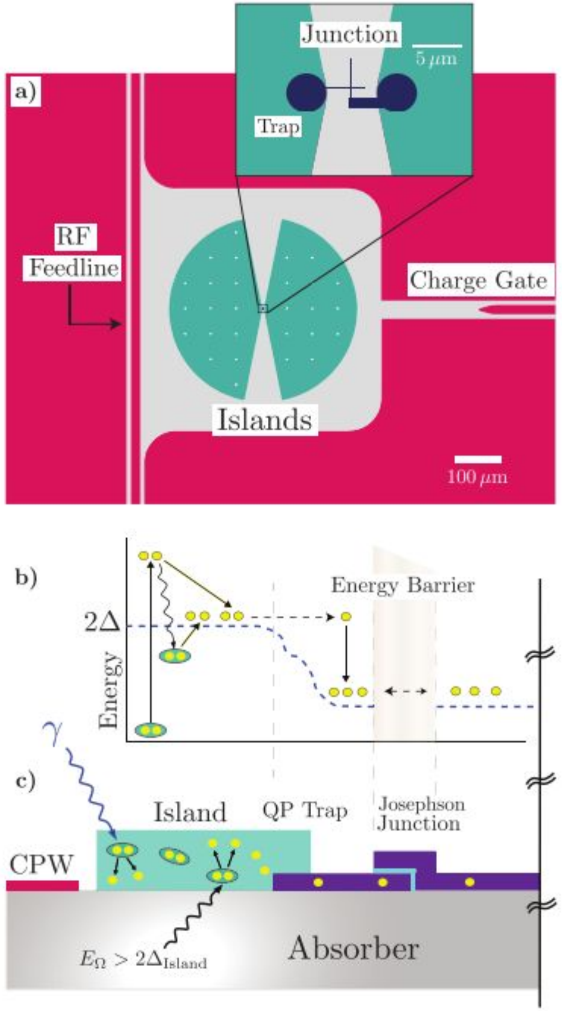


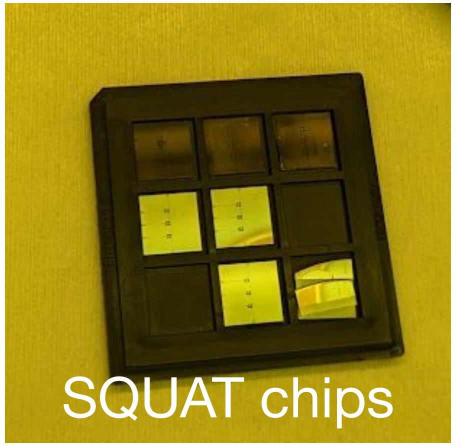


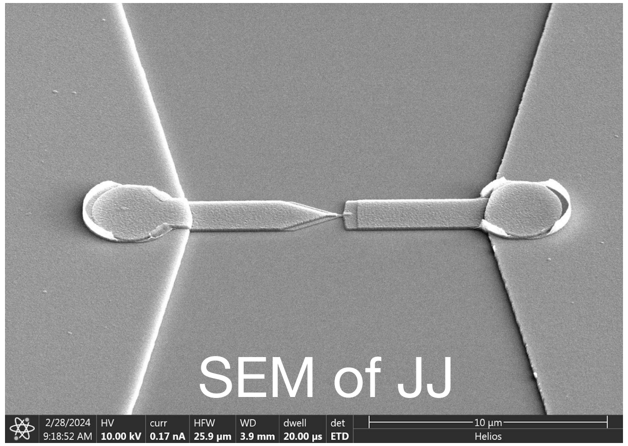
Top right: KID made of 50 nm AlMn on Si (credit: Zoe Smith)
Bottom right: HVeV detector made of 600 nm Al/40nm W on Si (credit: Aviv Simchony)

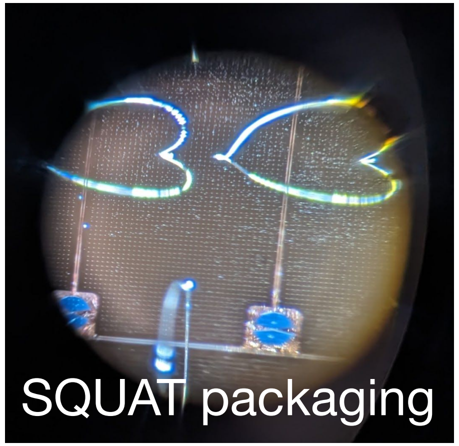
Calibration of SQUATs at SLAC

- Novel qubit-based sensors, Superconducting Quasiparticle Amplifying Transmons, designed to detect small amounts of deposited energy
- Can be used to probe dark matter with meV-scale recoils and axions in the THz photon regime
- Will be coupled to the MEMS V2 System







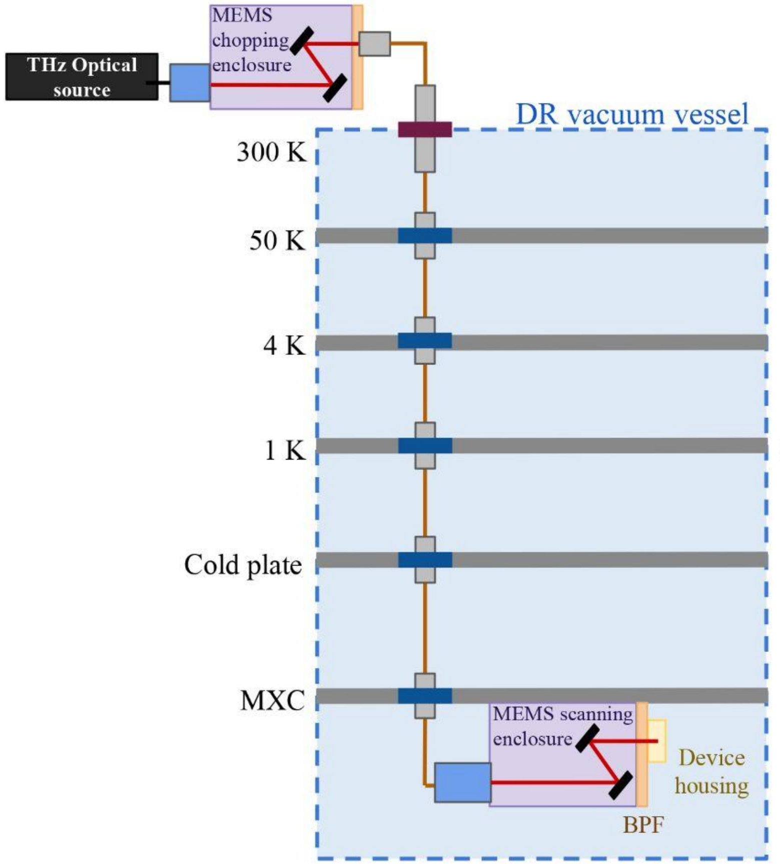


arXiv:2310.01345

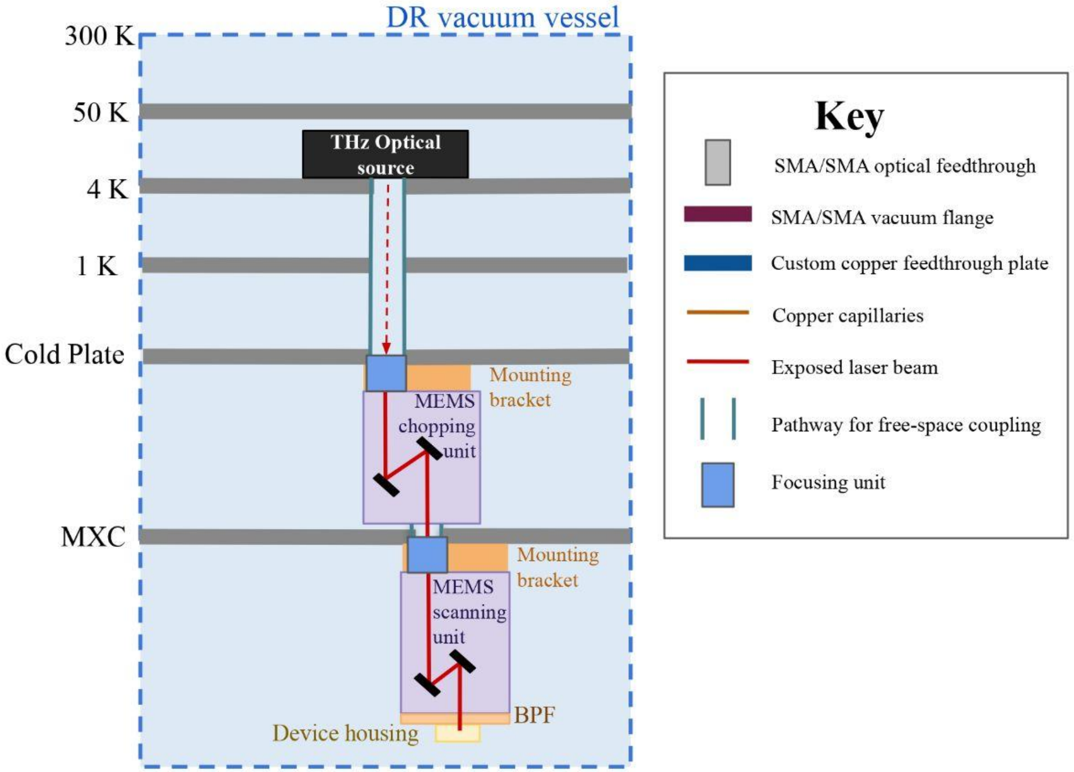
Extending MEMS for THz calibrations

Two possible use cases:

1. Room-temperature THz source

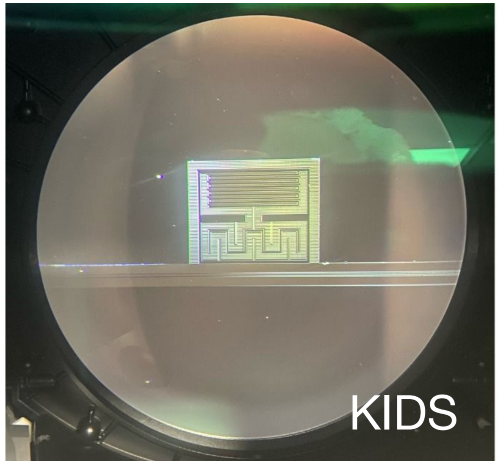


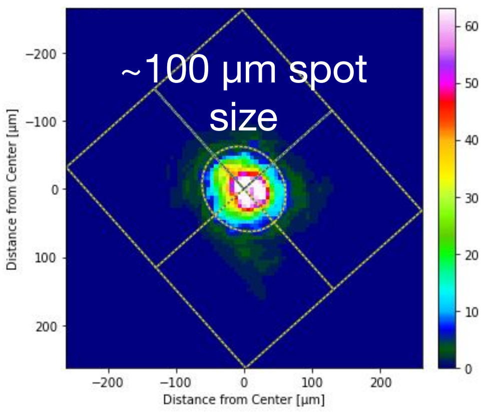
2. In-situ filtered blackbody source

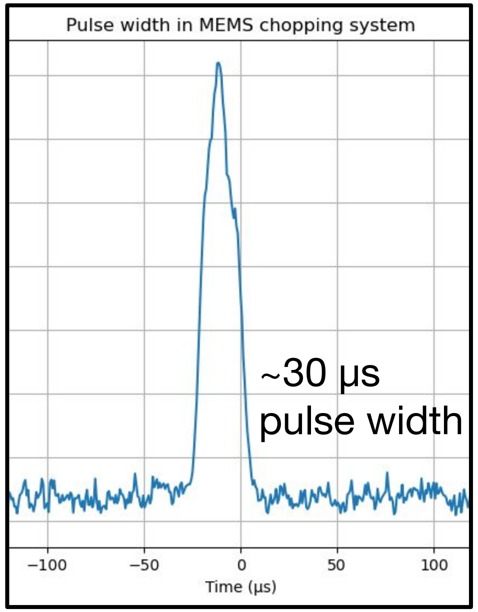


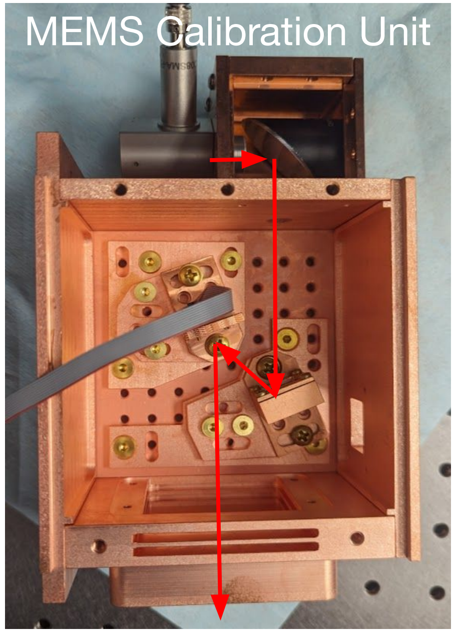
Conclusion

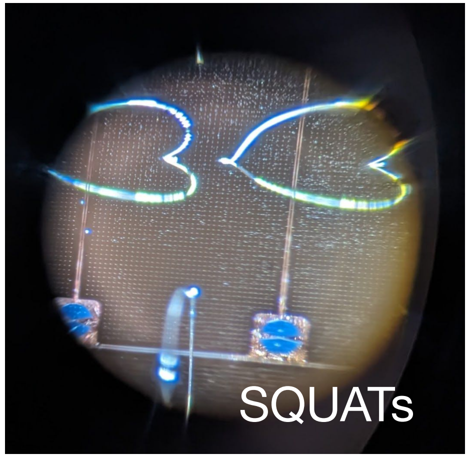
- Novel cryogenic detectors require low-energy calibrations
- Our MEMS mirror-based design can provide a pulsed, steerable beam in sub-eV regime with easily configurable intensity and pulse characteristics in a cryo-friendly way
- **Many impactful science topics to be explored**

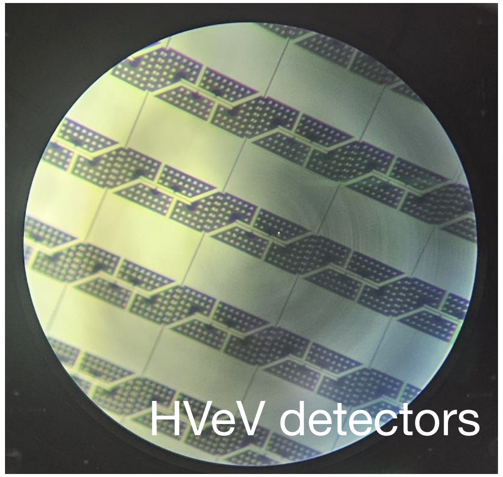












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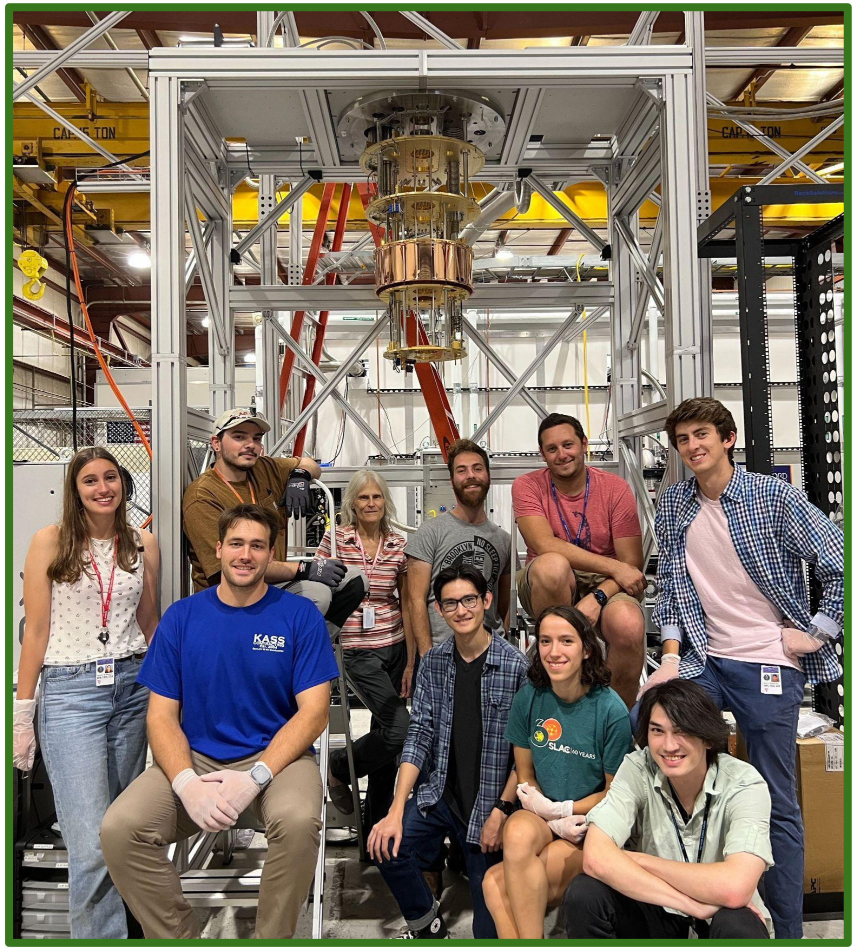
Noah Kurinsky (SLAC staff)





Previously: Anthony Nunez (Stanford ugrad), Sukie Kevane (Stanford ugrad), Haley Stueber (Stanford grad)



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