Demonstration of eV-Scale Energy Resolution with the remoTES Detector Design

Kumrie Shera

on behalf of the COSINUS collaboration

TeV Particle Astrophysics 2026, Tendo, Japan

MAX-PLANCK-INSTITUT FÜR PHYSIK

COSINUS

GSI

HELSINKI INSTITUTE OF PHYSICS

TU WIEN

SICCAS Since 1928

INFN LNGS Istituto Nazionale di Fisica Nucleare Laboratori Nazionali del Gran Sasso

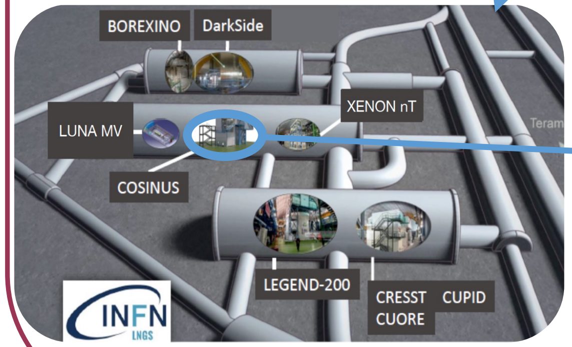
MBI Marietta-Blau-Institut für Teilchenphysik

COSINUS in a Nutshell

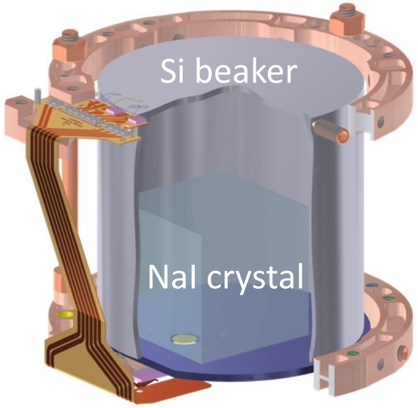
See M. Bharadwaj's talk

Goal: The **C**ryogenic **O**bservatory for **SI**gnatures seen in **N**ext-generation **U**nderground **S**earches aims to provide a model-independent cross-check of DAMA/LIBRA dark matter claim

Location: Laboratori Nazionali del Gran Sasso



Detector: NaI as cryogenic calorimeter
→ Low nuclear-recoil energy threshold



Dual channel readout:
→ Event-by-event signal/background discrimination
→ In-situ quenching factor measurement
→ Signal-only measurement

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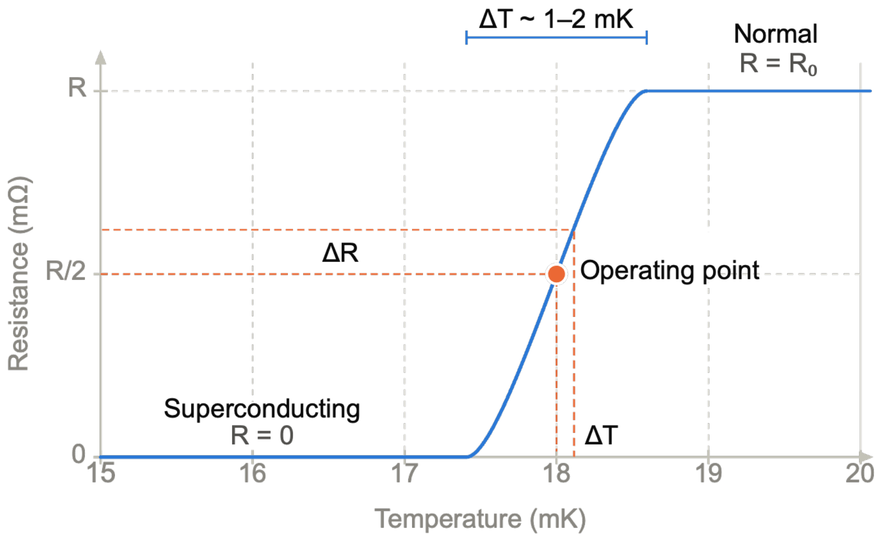
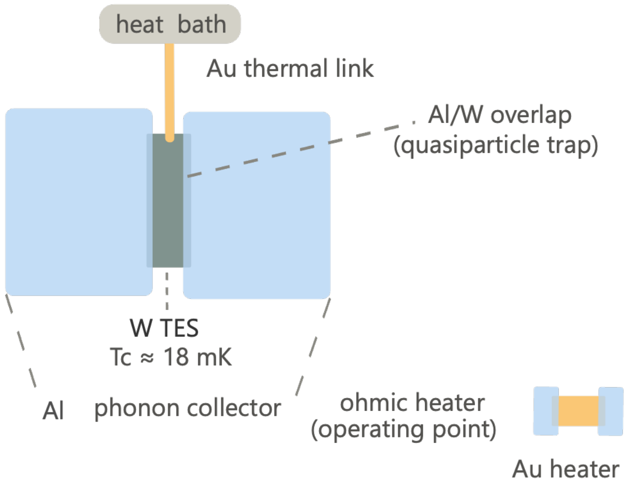
Transition Edge Sensor (TES)

- Superconducting thin film sensor operated at the superconducting transition
- Energy deposition ΔE leads to a temperature rise ΔT
- A steep transition leads to $\mathcal{O}(m\Omega)$ resistance change for $\mathcal{O}(\mu K)$ temperature change
- Resistance change measured as a current change via SQUIDs





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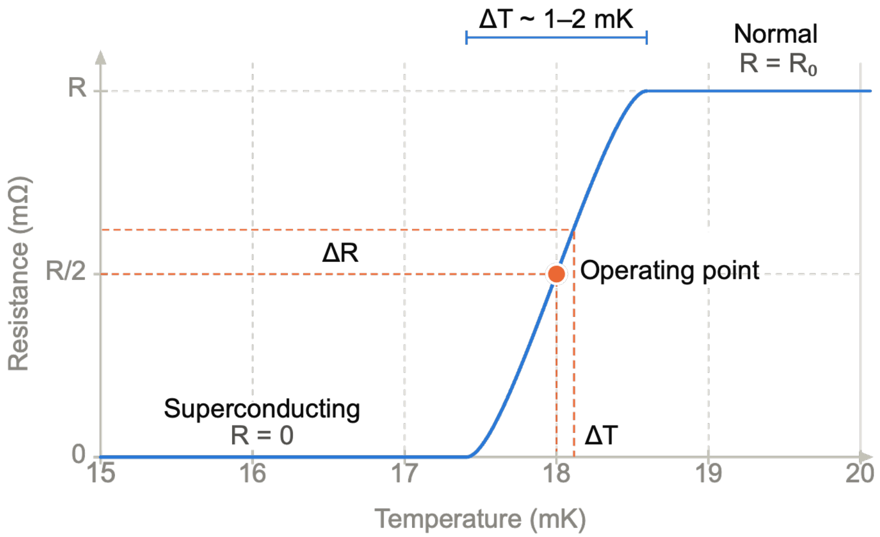
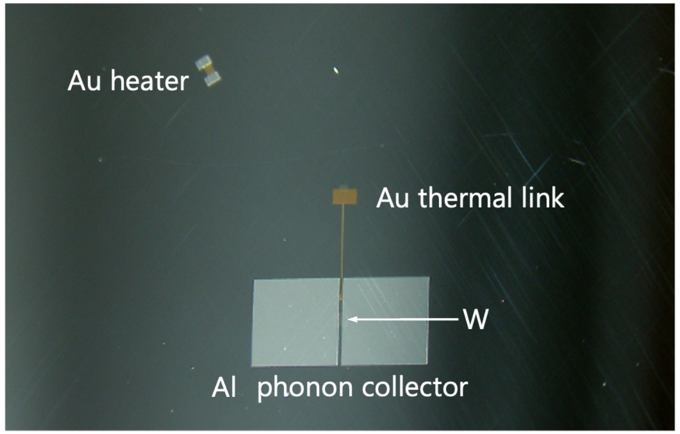
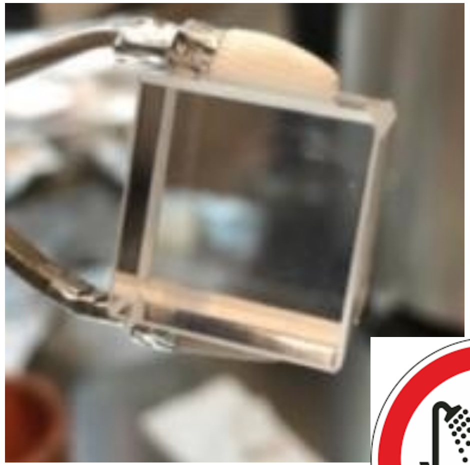
- Energy deposition ΔE leads to a temperature rise ΔT
- A steep transition leads to $\mathcal{O}$(mΩ) resistance change for $\mathcal{O}$(μK) temperature change
- Resistance change measured as a current change via SQUIDs
- Sensor directly deposited on absorber crystal for optimal thermal coupling





Sodium Iodide: The problem



Material properties

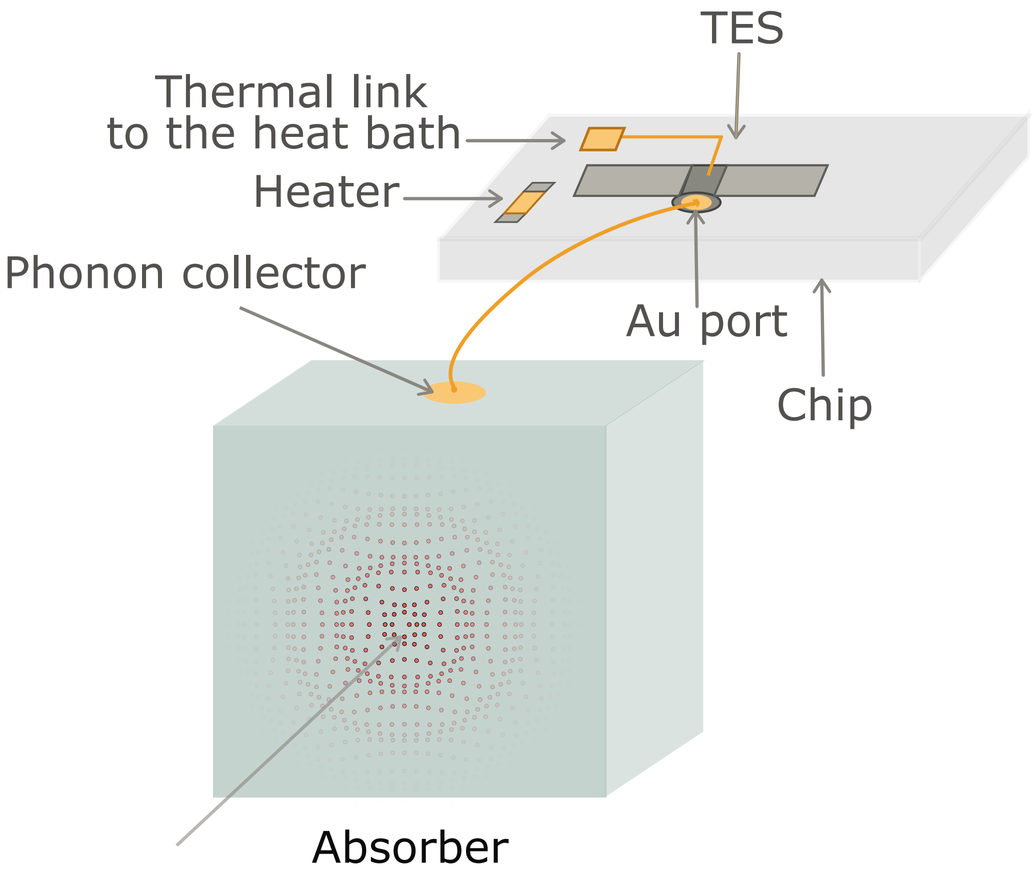
- Density: 3.67 g cm^{-3}
- Melting point: 661 ^{o}C
- Debye temperature: $\Theta_D \approx 160$ K
- Heat capacity at 20 mK: 91.3×10^{-6} μJ cm^{-3} K^{-1}

Challenges for detector fabrication

- Hygroscopic
- Mechanically soft
- Low melting point

Standard TES fabrication requires high-temperature thin-film deposition and wet chemistry → **incompatible with NaI !**

The remoTES Design: The Solution



- TES fabricated on a dedicated chip - decoupled from the absorber crystal
- Phonon collector pad deposited directly onto the target crystal surface
- Au bonding wire thermally couples the absorber to the TES

Advantages of the remoTES Design

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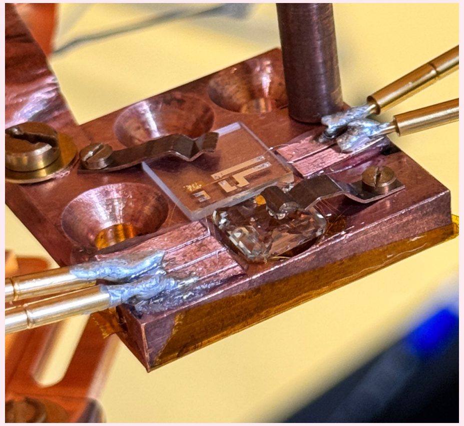
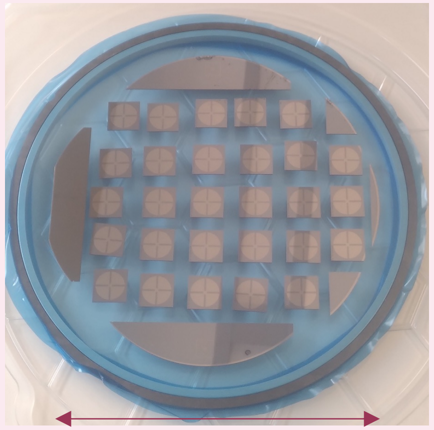
Standardized fabrication

Standardized independent of the absorber → reproducible T_c across modules, enabling mass production



remoTES

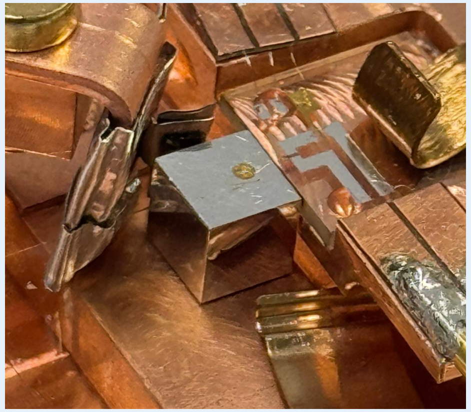


W thin film on a 6-inch wafer
HLL

Broader absorber access

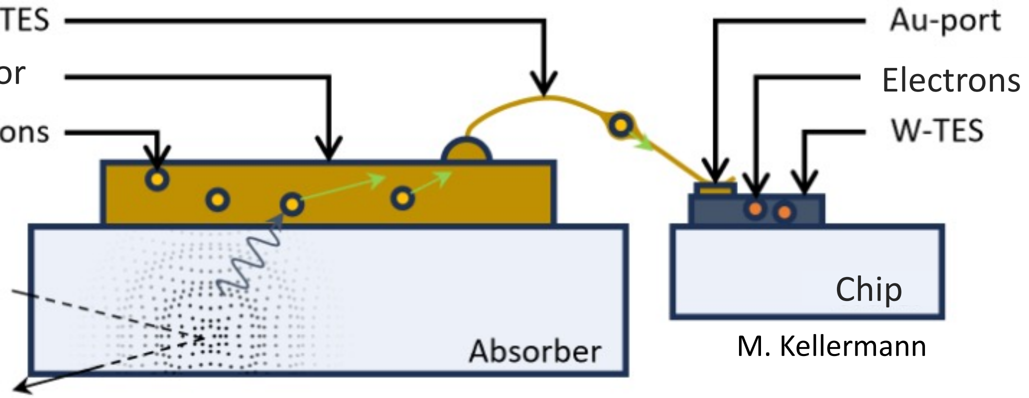
Allows using absorbers incompatible with standard TES → complementary sensitivity across rare-event searches

$Al_2SiO_4(F,OH)_2$



Al

Signal Formation Mechanism

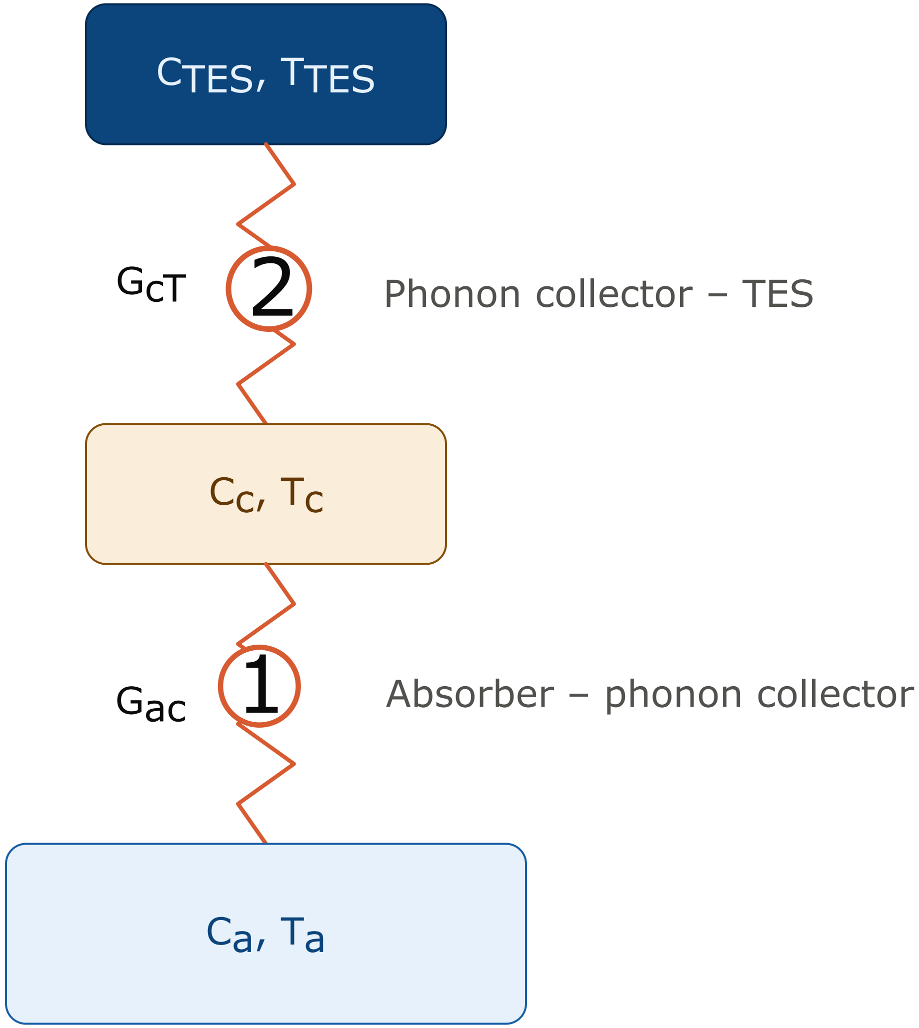


M. Kellermann

- Particle interaction → creates non-thermal phonons in the absorber crystal
- Phonon propagation:
  - Non-thermal phonons → thermalize directly in the phonon collector
  - Remaining phonons → thermalize in the absorber → reach collector via thermal conductance
- Electron–phonon coupling → phonon energy transferred to the electron system in the collector
- Hot electron diffusion → hot electrons diffuse through the Au bonding wire to the TES

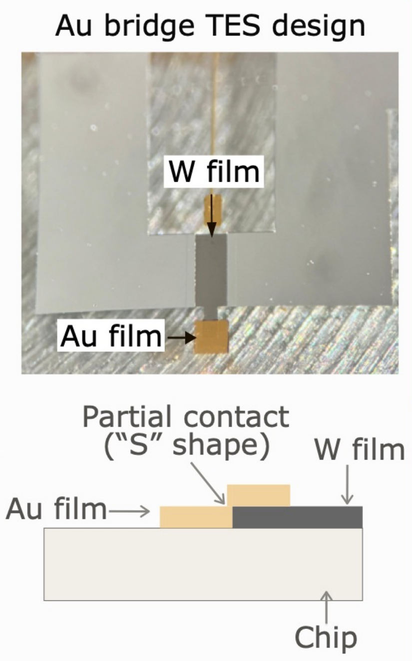
Optimizing the remoTES Design with Si Absorbers

- Goal: improve baseline resolution by optimizing the signal transmission across remoTES interfaces:
    1. Absorber - phonon collector
    2. Phonon collector - TES
- Two parameters studied: Au link on TES chip and phonon collector material
- Si chosen as benchmark absorber for direct comparison with standard TES detectors



Optimizing Signal Transmission: Phonon Collector → TES

- Au film: bonding pad + contact to underlying W film
- Au bridge design: partial W contact → small contact area → low thermal conductance



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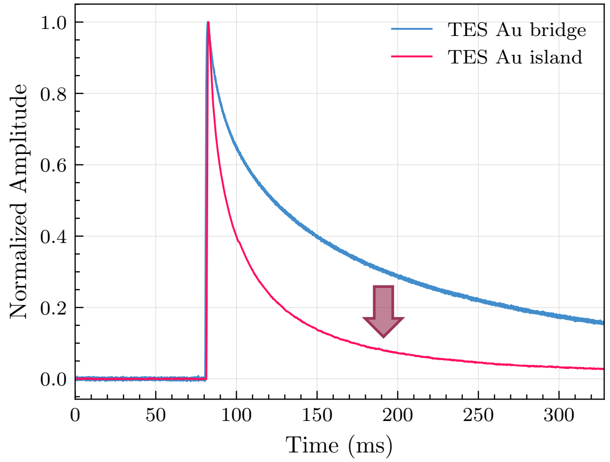
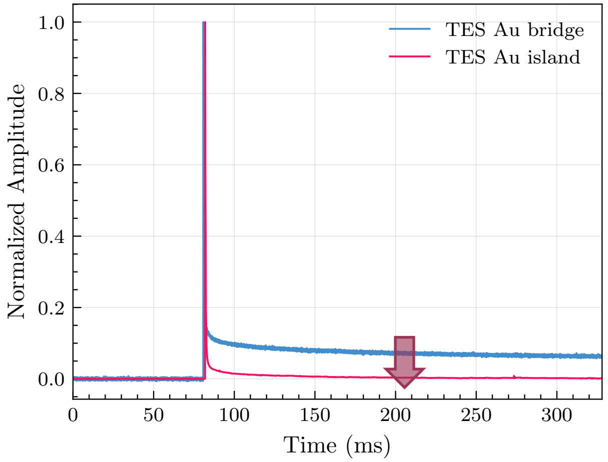
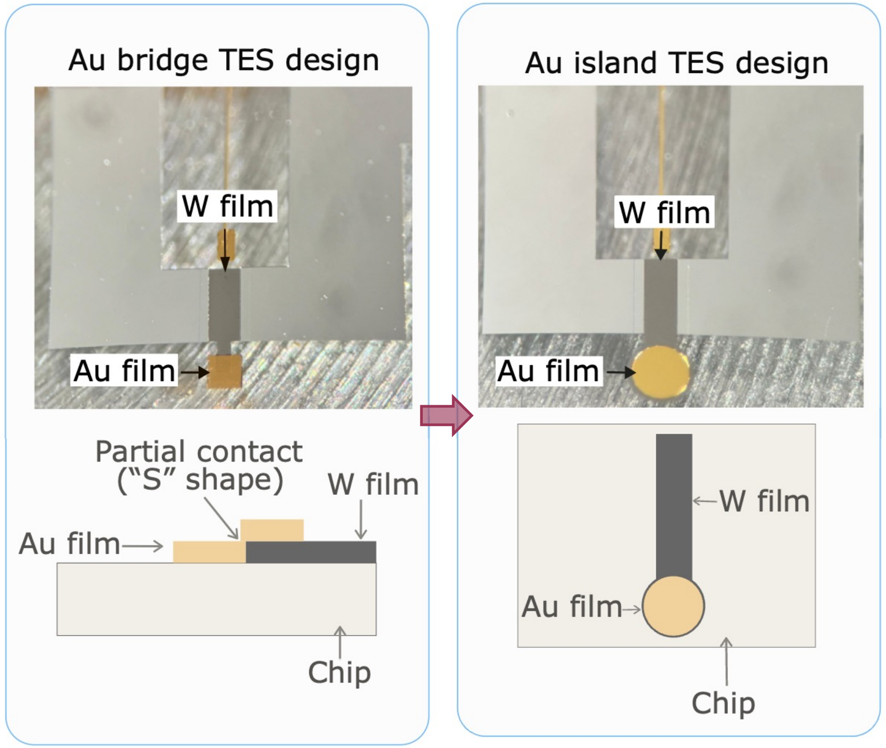
- Au island design: Au film fully on W → much larger contact area → higher thermal conductance across the interface







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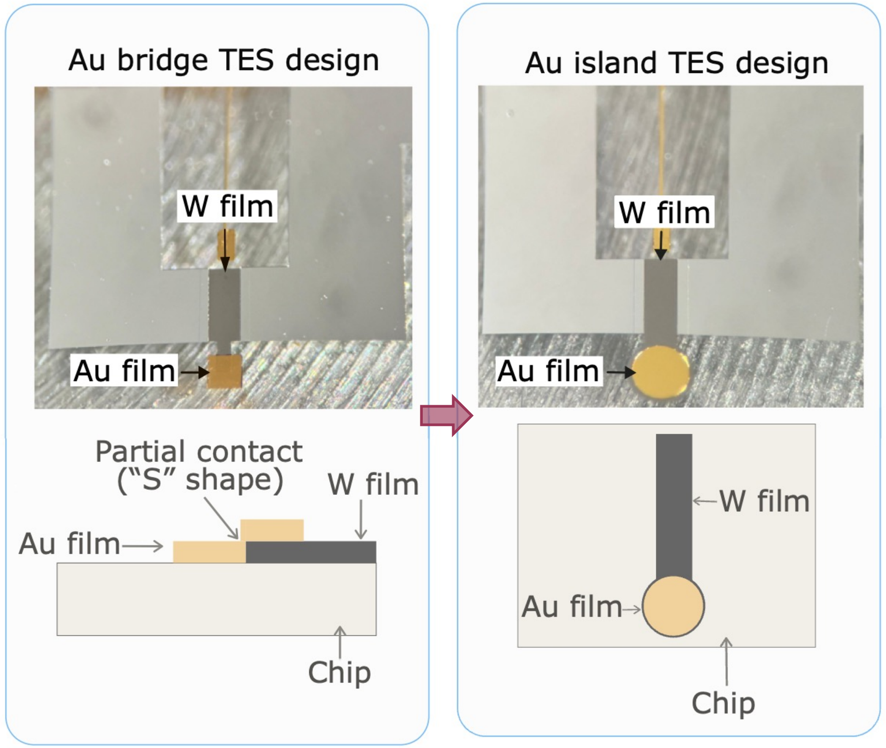
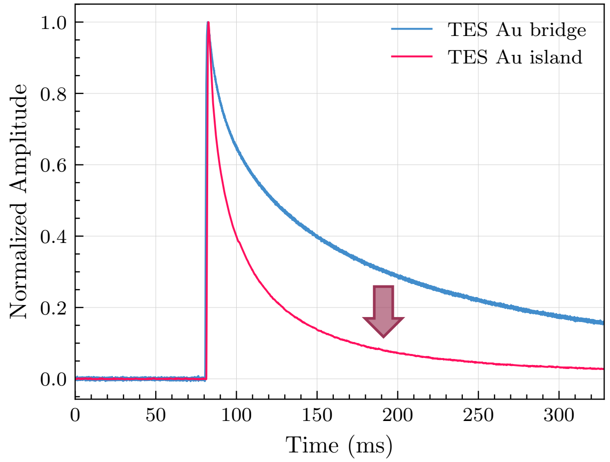
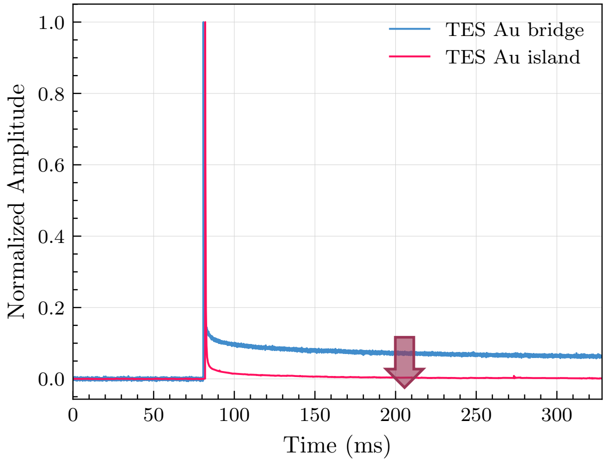






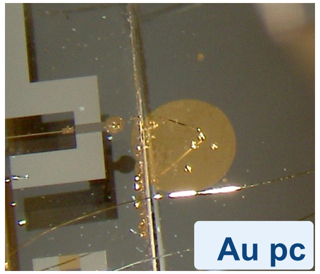
Baseline resolution

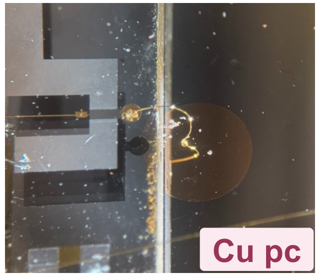
89 ± 2 eV
Si remoTES, Au phonon collector

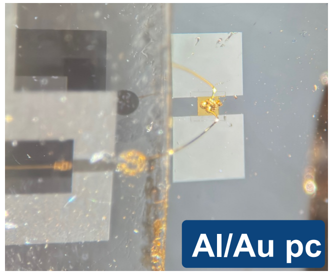
VS

1.36 ± 0.05 eV
CRESST — TES directly on Si absorber
Phys. Rev. D 107, 122003

Optimizing Signal Transmission: Absorber → Phonon Collector





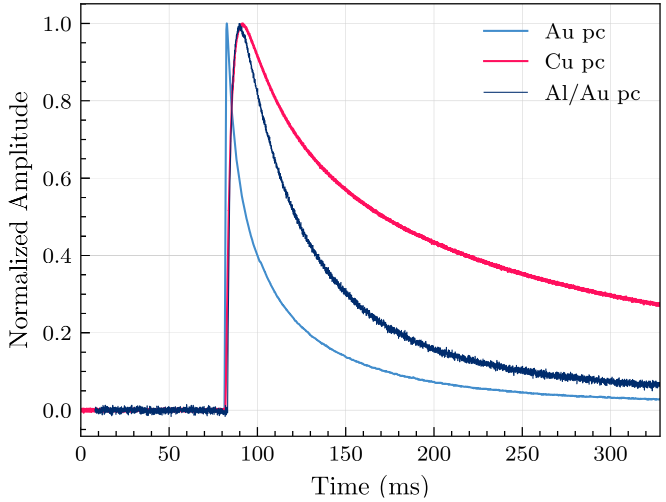


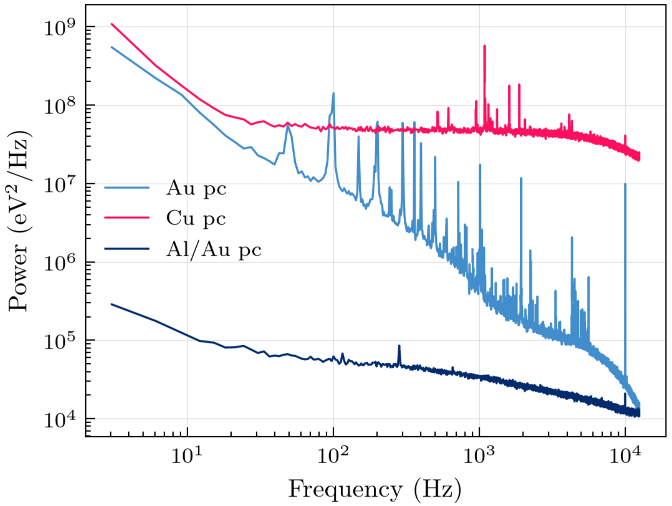
- Three Si remoTES detectors, identical except for the phonon collector material

	Au pc	Cu pc	Al/Au pc
Pad area (mm²)	3	3	2 (Al) / 0.13 (Au)
Pad thickness (µm)	0.20	0.25	1 (Al) / 0.6 (Au)
Heat capacity (µJ K⁻¹)	7.7×10^{-7}	1.5×10^{-6}	1.3×10^{-7} (Au)
	267.2 ± 2.1 eV Au pc	**94.6 ± 0.5 eV** Cu pc	**21.5 ± 0.3 eV** Al/Au pc

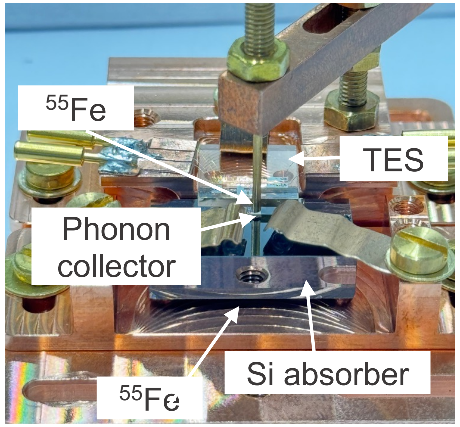
Submitted to J. Low Temp. Phys.
arXiv:2608.09544

- Phonon collector material significantly affects signal transmission and remoTES performance

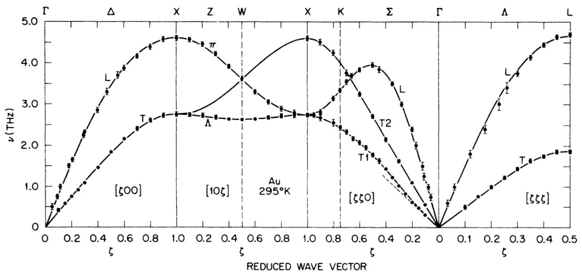




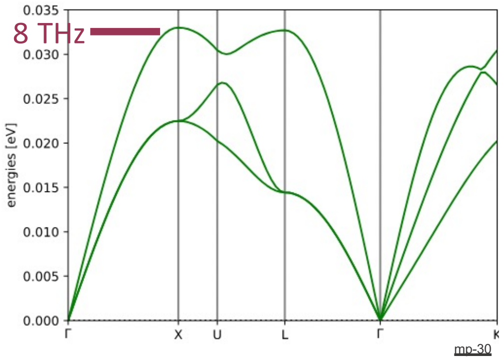
Optimizing Signal Transmission: Absorber → Phonon Collector



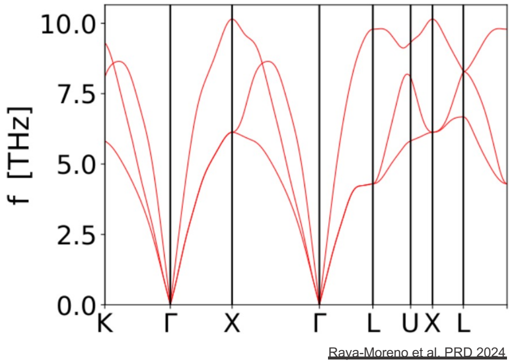
Au pc

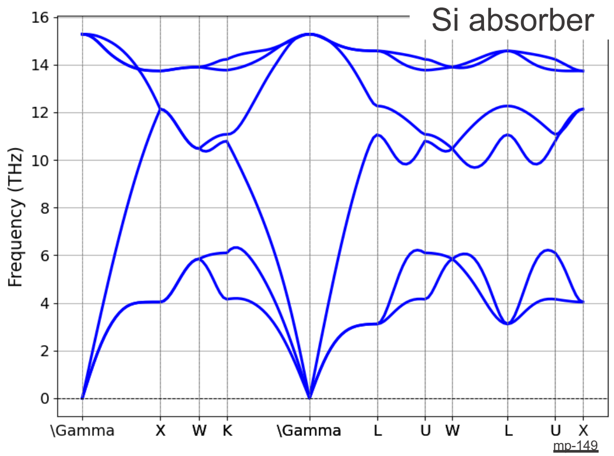


Cu pc



Al/Au pc





- Different phonon collector materials → distinct phonon dispersion curves
- Cu and Al: higher-frequency bands → accommodate higher-frequency phonons
- Two ^{55}Fe calibration sources per detector: one shining on the Si absorber, one shining on the phonon collector

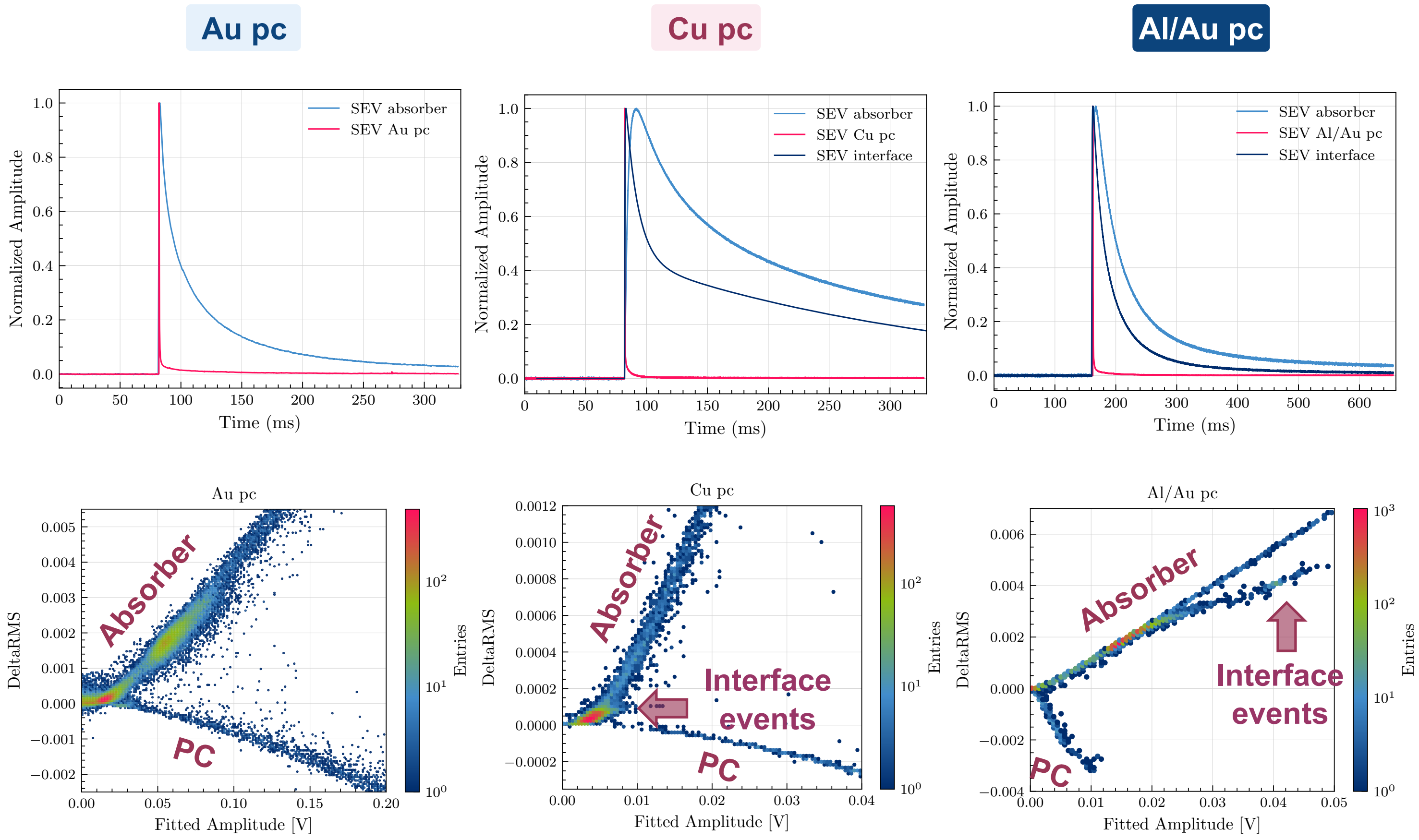
Optimizing Signal Transmission: Absorber → Phonon Collector

Bulk absorber hits
slow rise · slow decay

Phonon collector hits
fast rise · fast decay

Cu / Al-Au collectors
→ third event class

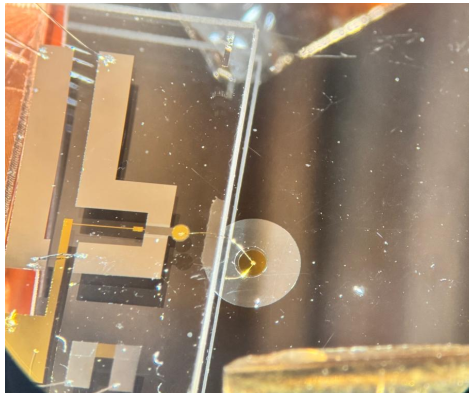
- Higher cutoff→ better spectral overlap with Si
- Better overlap → efficient collection of near-surface phonons → third interface event class



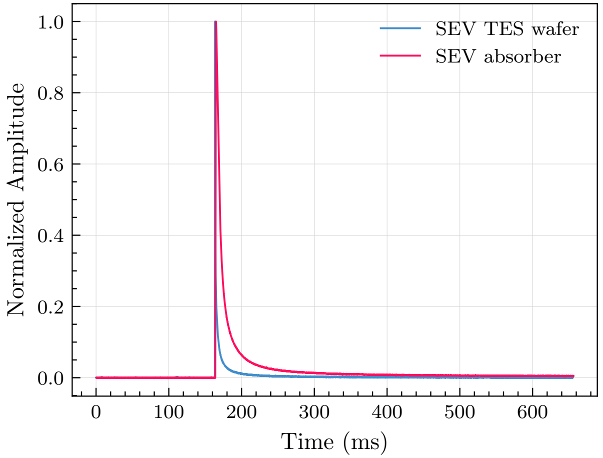
Paper in preparation

Latest Si remoTES Prototype

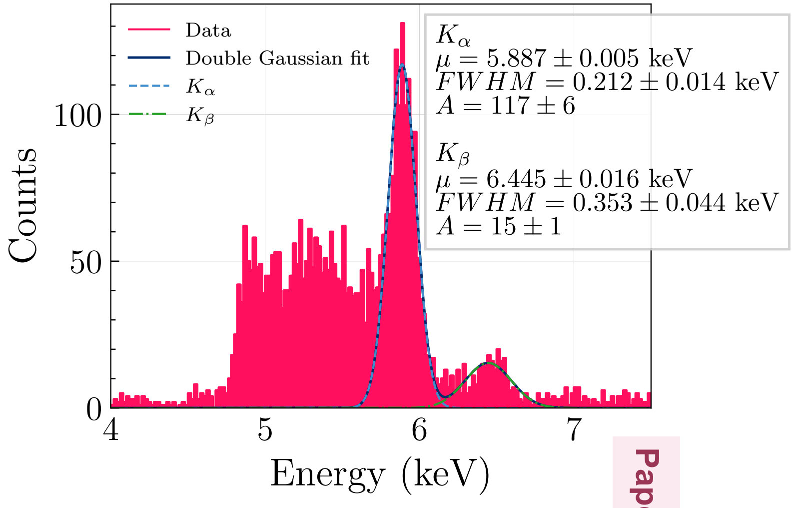
Si absorber, Al/Au phonon collector



Pulse shapes



Energy spectrum



	Dimensions
Si absorber	20 × 10 × 5 mm³, 2.33 g
Au pad	0.4 mm², 0.6 µm thick
Al collector	1.8 mm², 1 µm thick

5.7 ± 0.4 eV

baseline resolution

previous best: 21.5 eV (Al/Au remoTES)

Paper in preparation

5.7 eV closes the gap to standard TES designs (CRESST: 1.36 eV, 0.35 g)

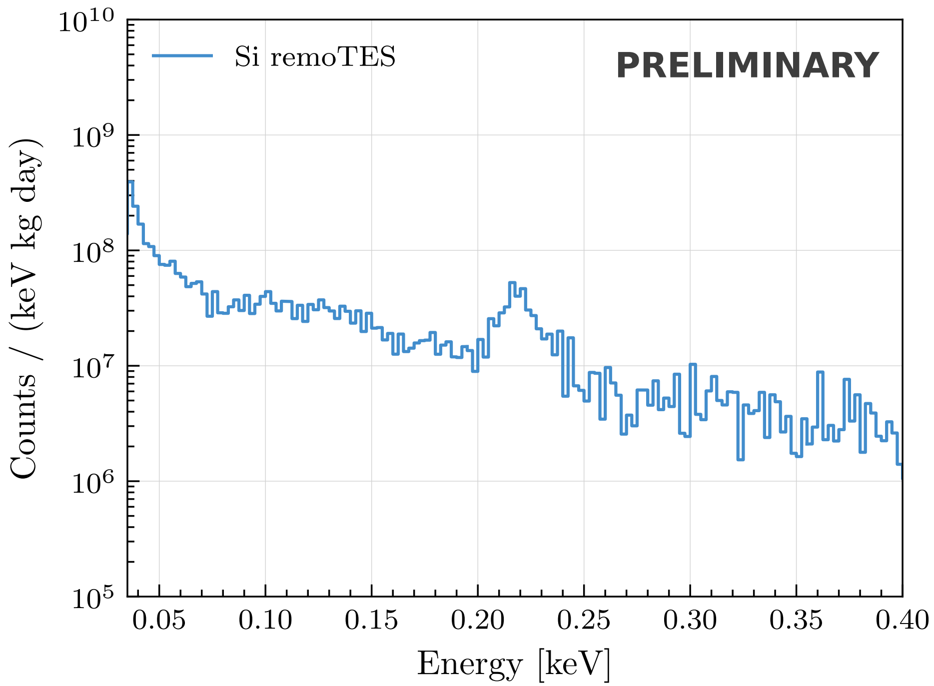
First LEE Studies with Si remoTES

The low energy excess (LEE)

- A steeply rising, unexplained population of events near the threshold observed in CRESST, NUCLEUS, SuperCDMS, TESSERACT and other experiments
- Currently the main limiting factor for sub-GeV dark matter sensitivity

Si remoTES

- 5.7 eV baseline resolution - first time in the LEE-sensitive regime
- → Enables LEE studies with a decoupled TES redout design



Future publication

Conclusions and Outlook

5.7 ± 0.4 eV
best remoTES resolution

- remoTES decouples TES fabrication from the absorber → standardized production and free choice of absorber material
- Systematic optimization of both remoTES interfaces - Au port geometry and phonon collector material - significantly improved signal transmission
- Latest Si remoTES prototype reaches 5.7 eV baseline resolution, closing the gap toward the standard TES design readout
- This resolution enables, for the first time, LEE studies with a remoTES detector
- Further systematic studies to optimize remoTES performance are ongoing

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Thank you!

Back up slides