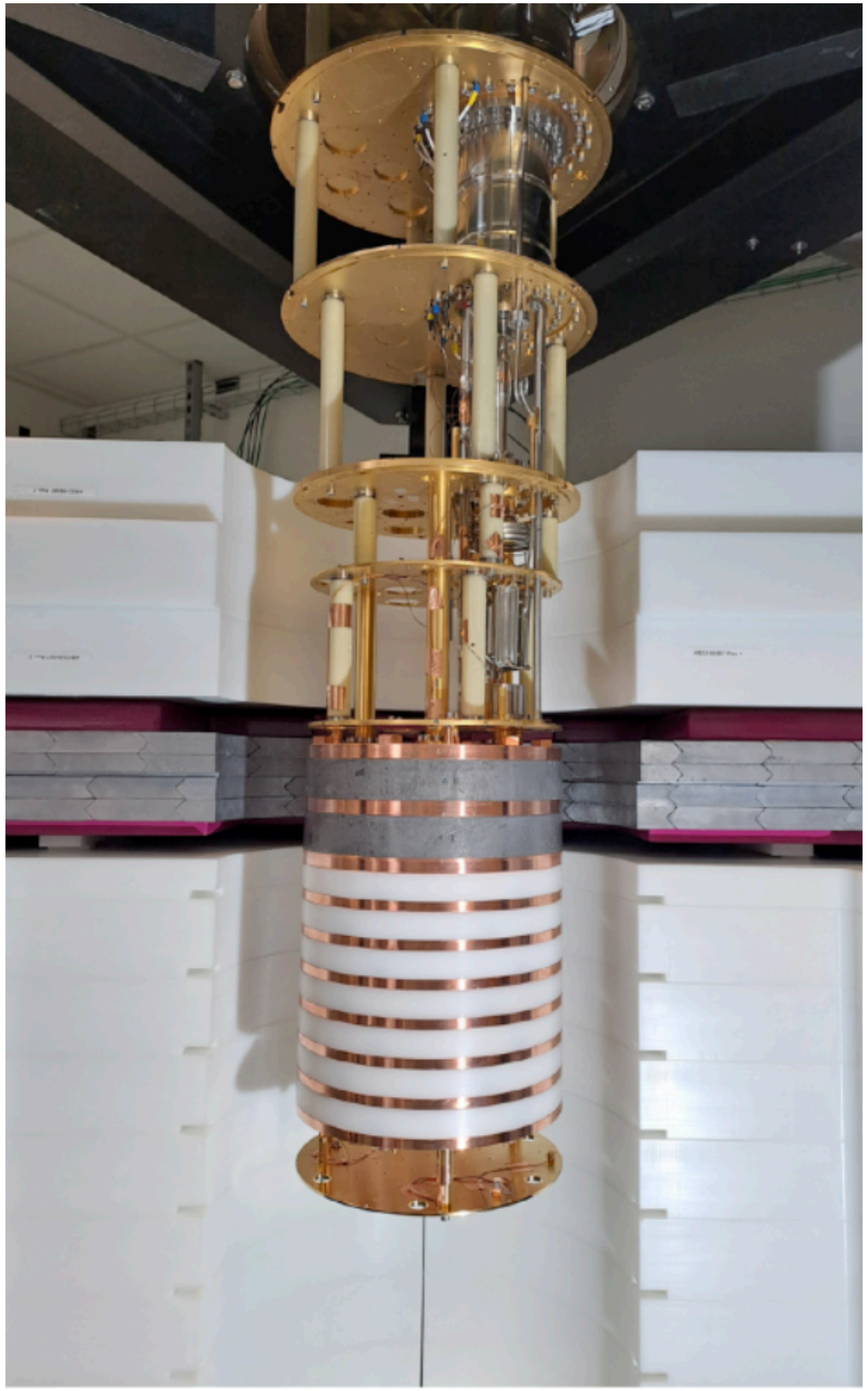


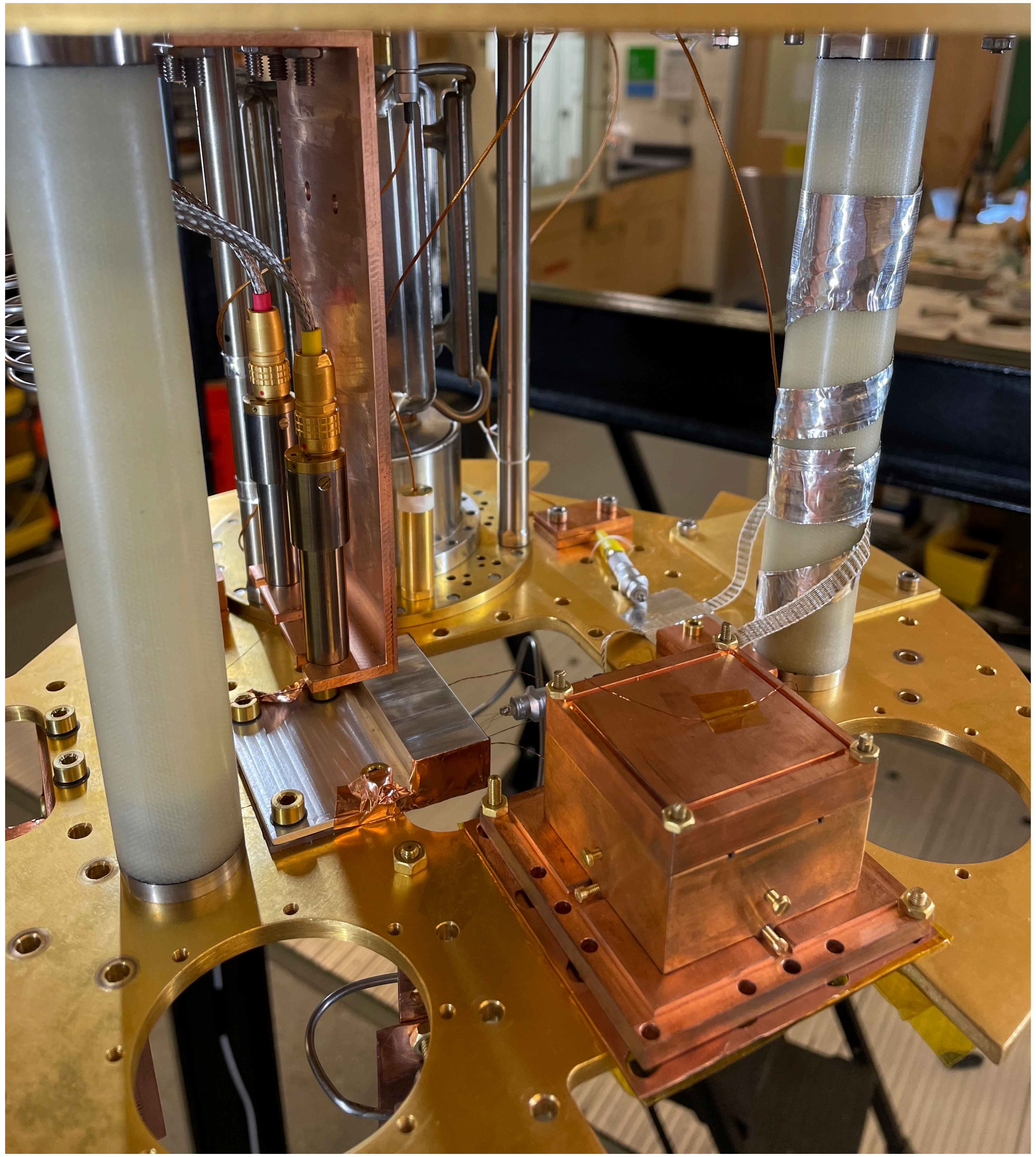
Results From a Prototype TES Detector for the Ricochet Experiment

Doug Pinckney, on behalf of the Ricochet Collaboration
23 March 2023

RICOCHET
A Coherent Neutrino Scattering Program

Overview

- The Q-Array and TES detectors
- R&D from a proof-of-concept detector at UMass Amherst
- Future plans and conclusions

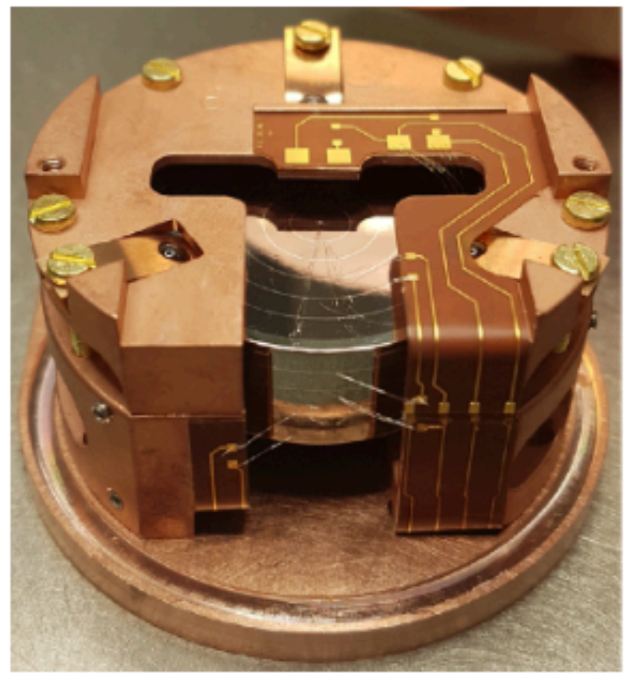


The Q-Array In Context

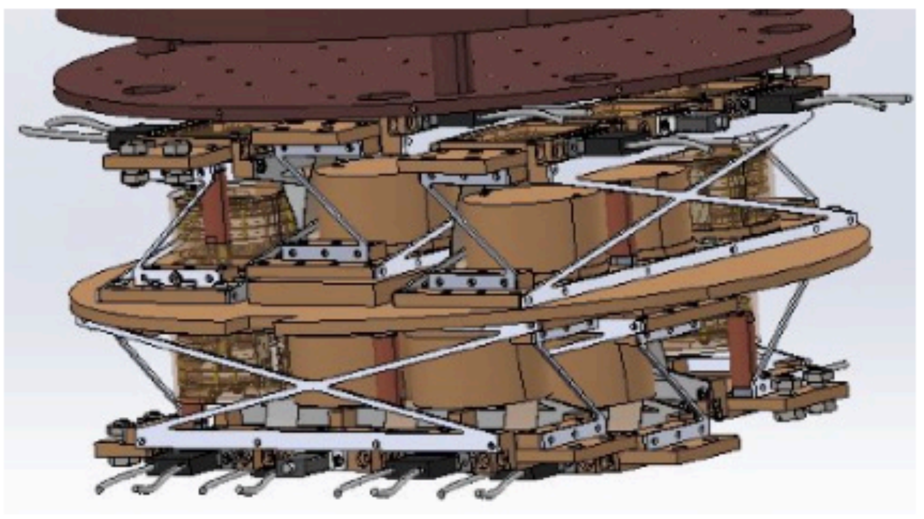
RICOCHET
A Coherent Neutrino Scattering Program

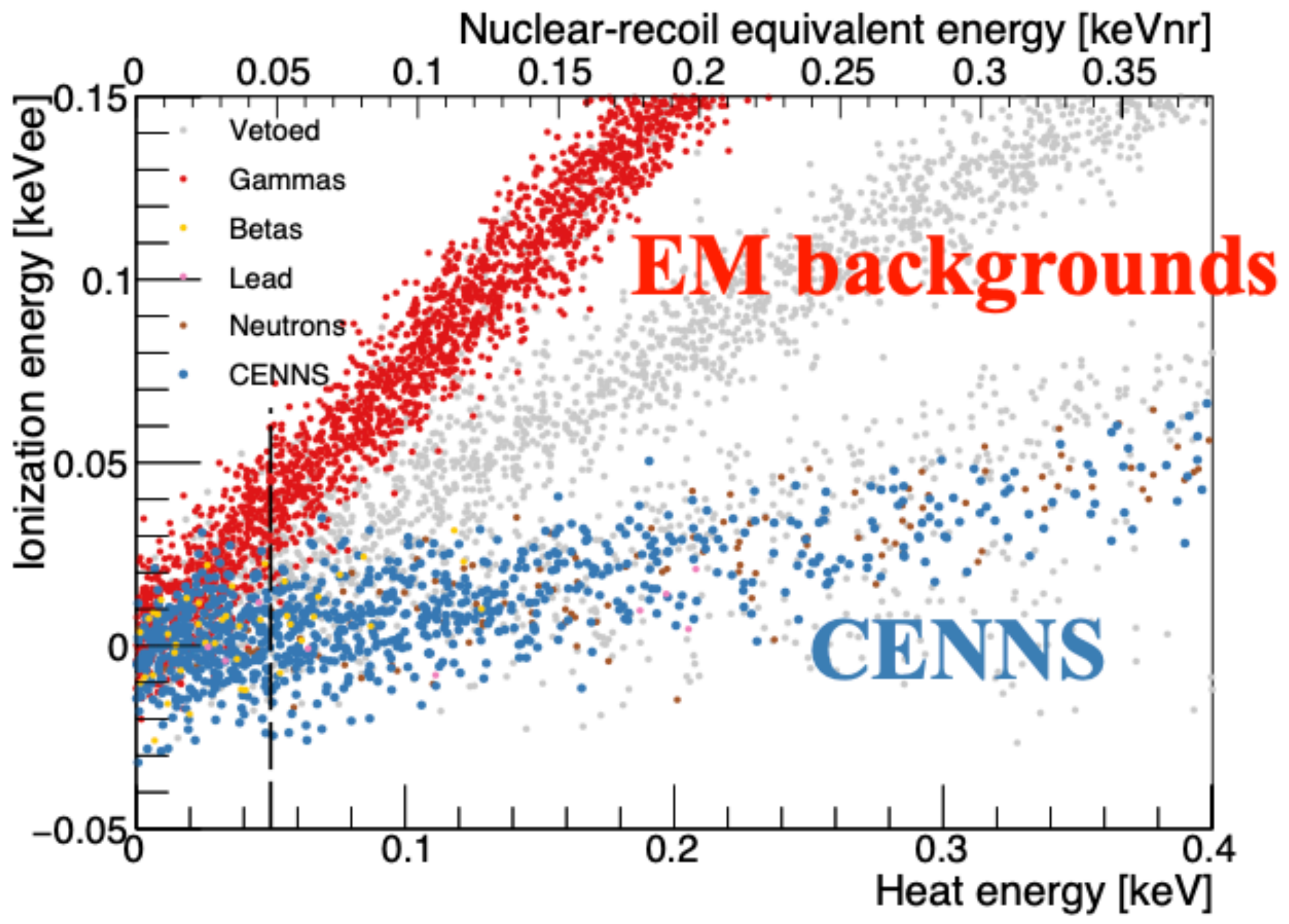
Technological key features of RICOCHET: Particle Identification down to sub-100 eV

Germanium semiconductor



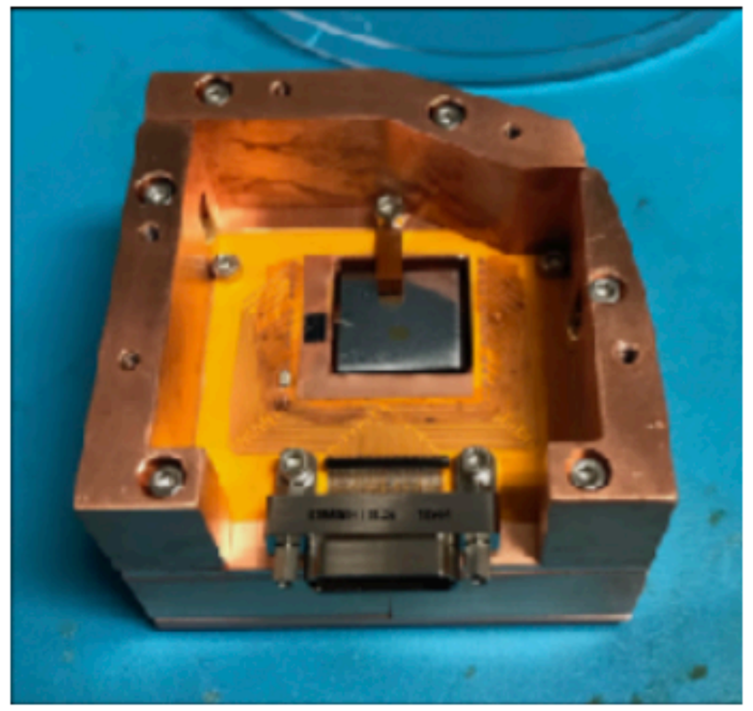
Array of 18-to-27 42-g Ge detectors



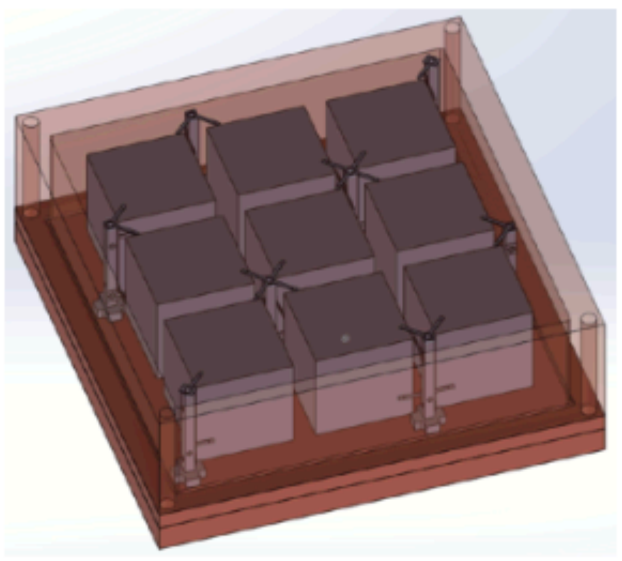


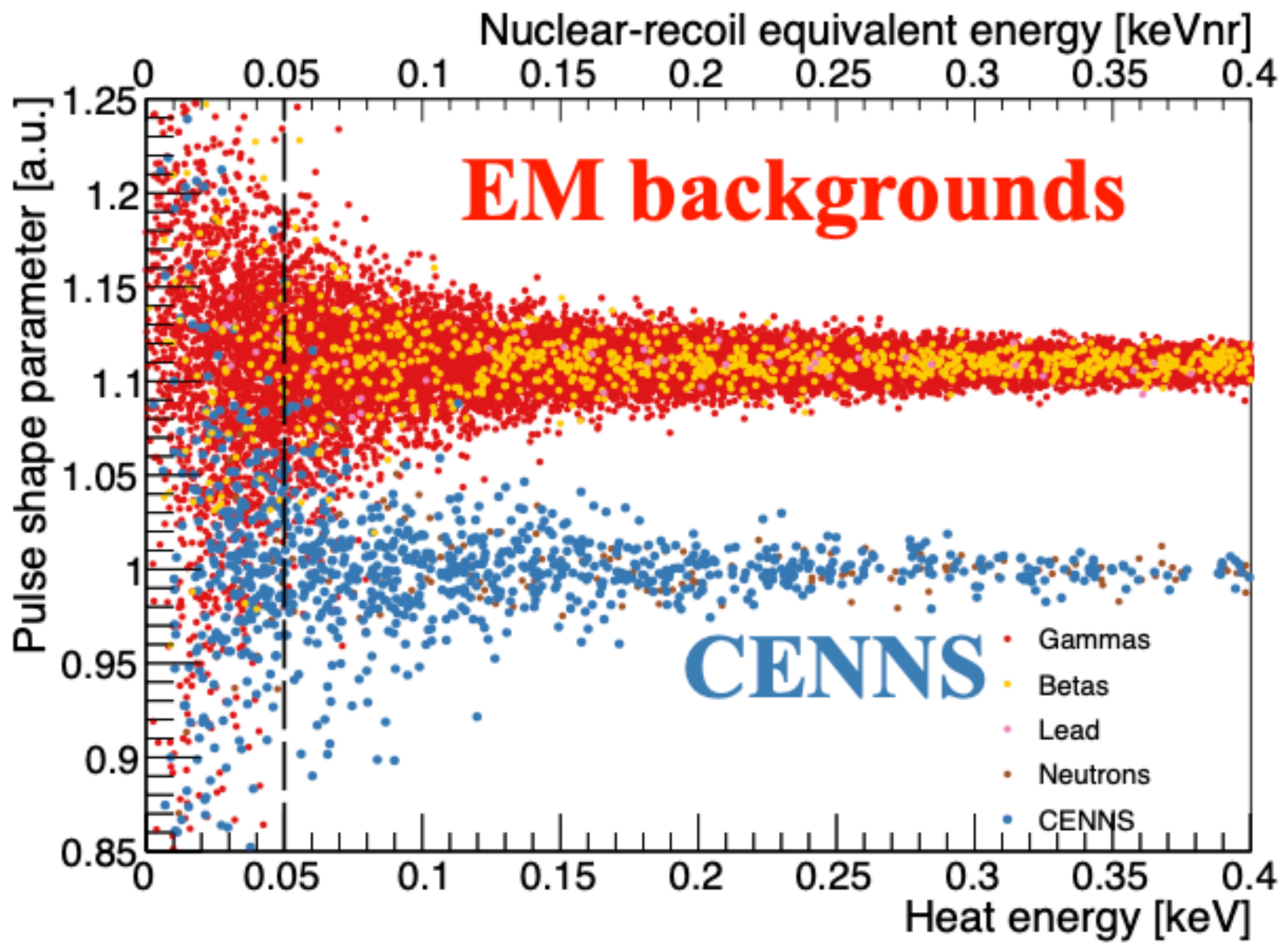
Particle ID based on **Ionization / heat** ratio

Zinc superconducting metal



Array of 9 32-g Zn detectors





Particle ID based on **Prompt / delayed** heat signals

Slide from
Julien Billard

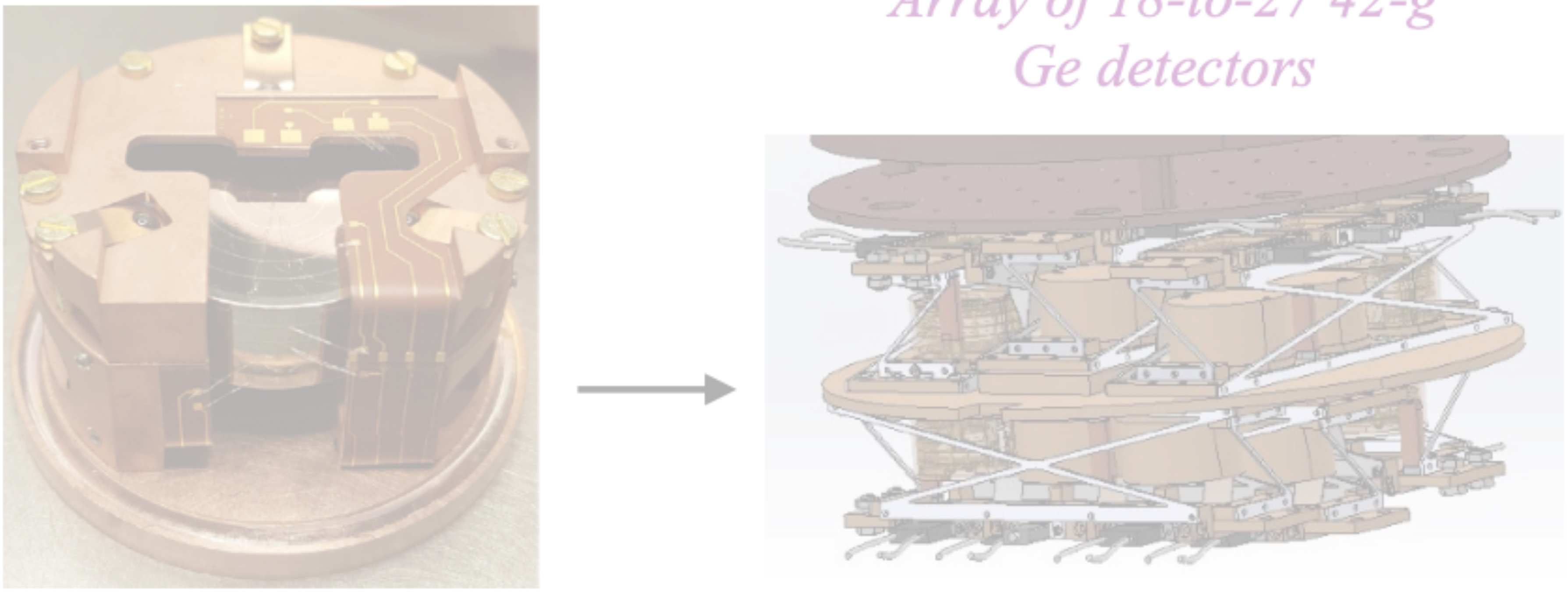
The Q-Array In Context

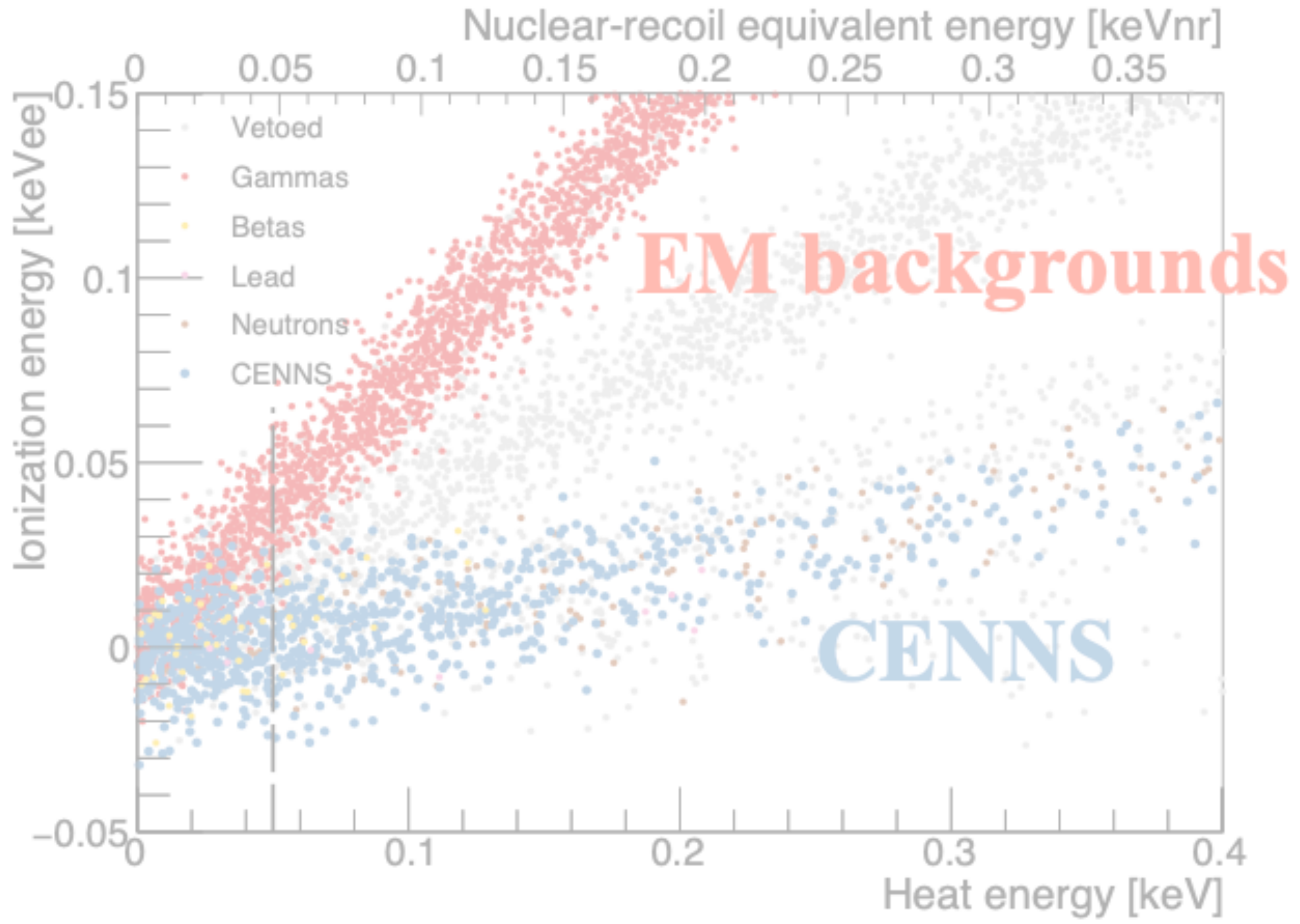
A Coherent Neutrino Scattering Program

Technological key features of RICOCHET: Particle Identification down to sub-100 eV

Germanium semiconductor

Array of 18-to-27 42-g Ge detectors

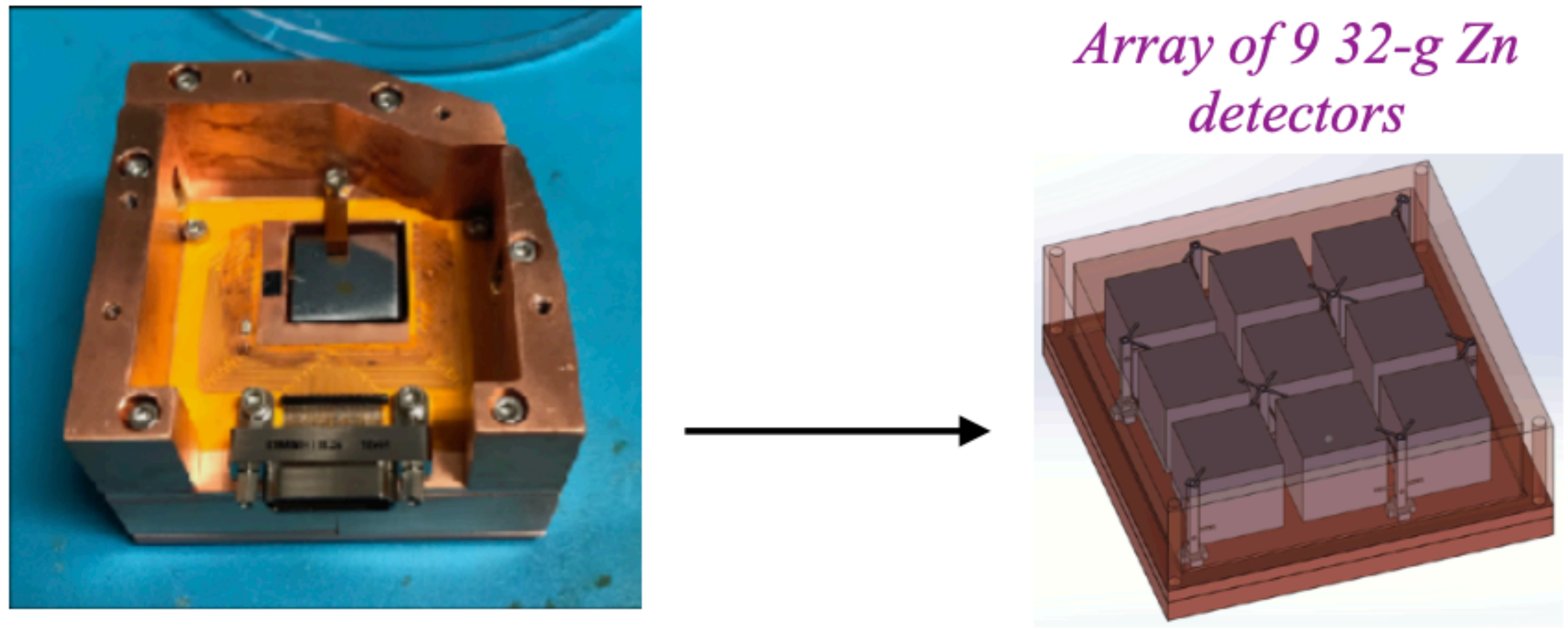


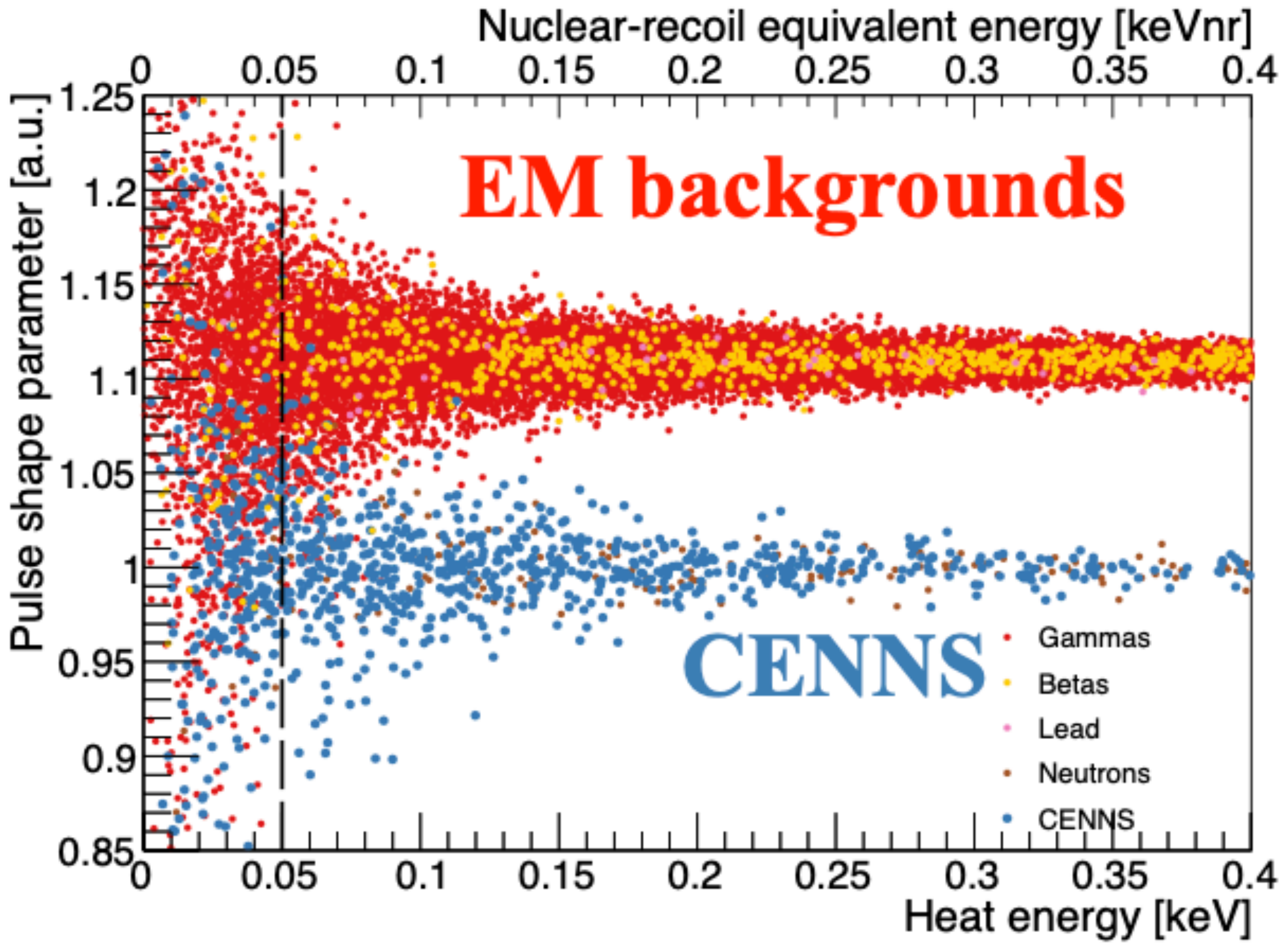


Particle ID based on **Ionization / heat** ratio

Zinc superconducting metal

Array of 9 32-g Zn detectors



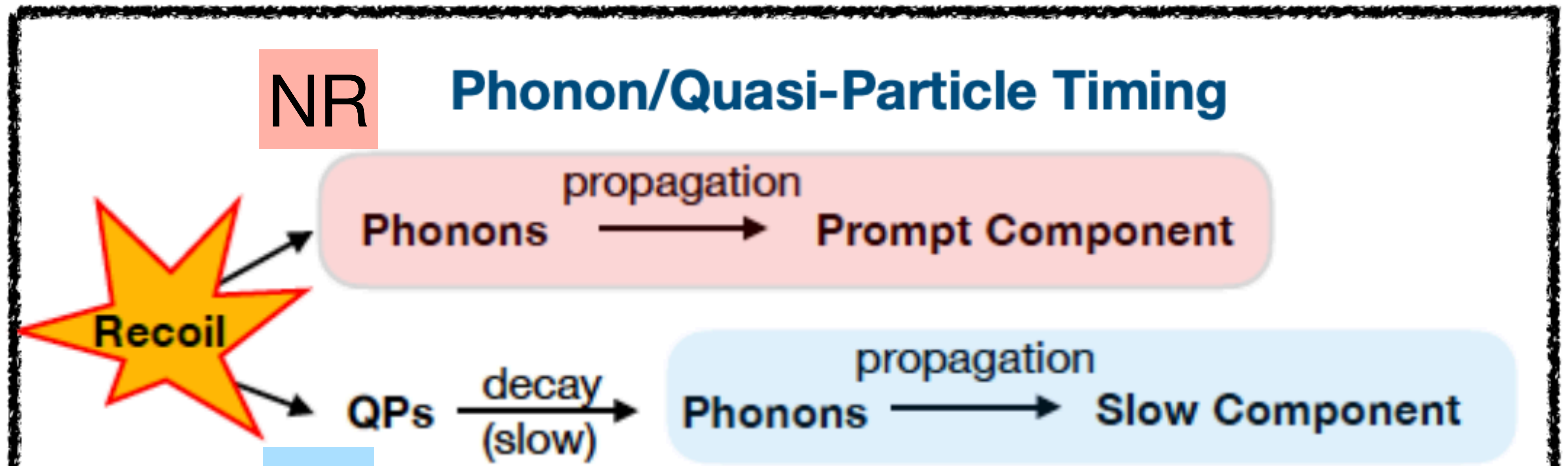


Particle ID based on **Prompt / delayed** heat signals

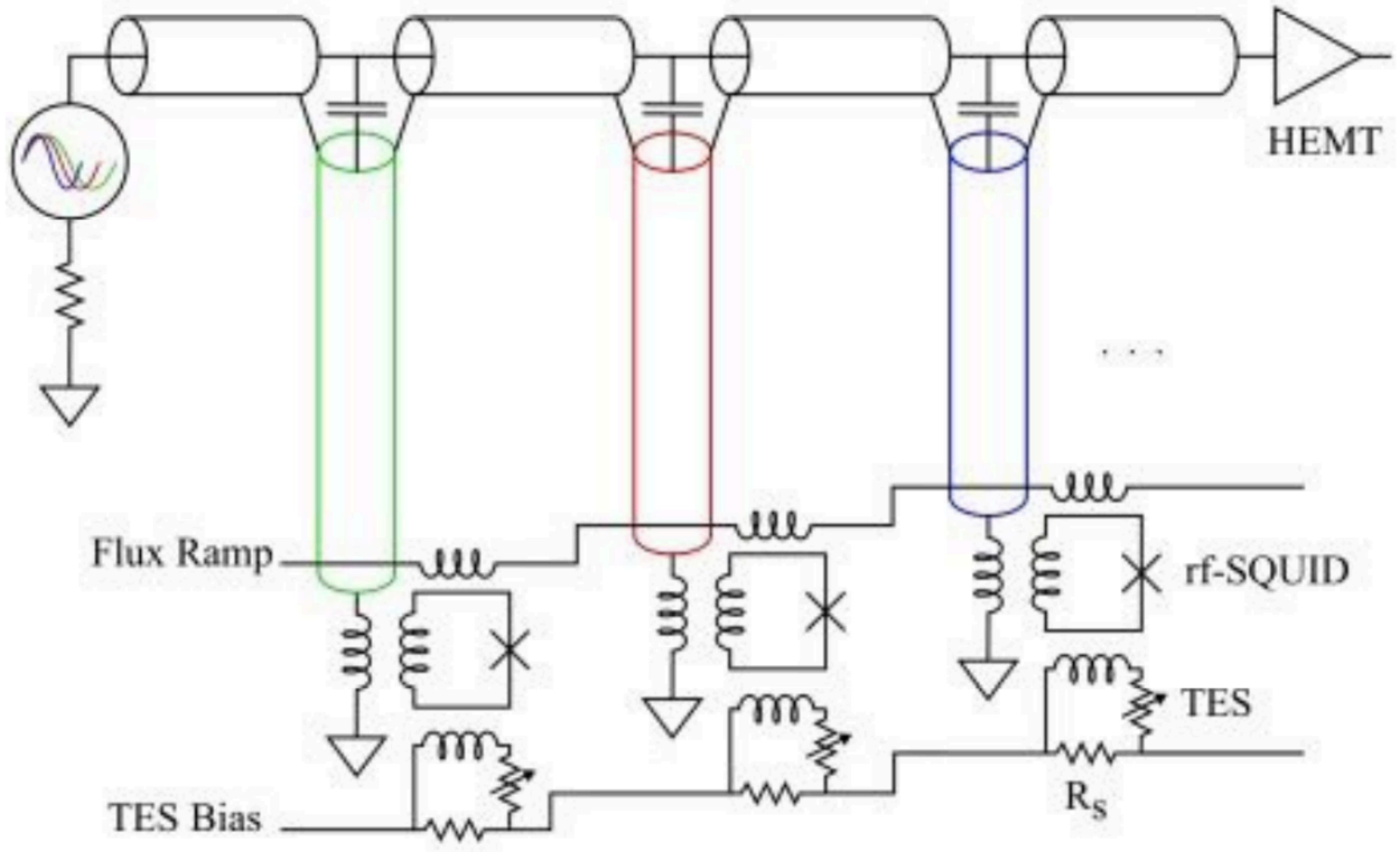
Slide from Julien Billard

The Q-Array

- TESs reading out superconducting targets (Al, Zn, Sn…)
- Particle identification through QP/phonon ratio
    - Different signal timing
- Multiplexed readout using RF SQUIDs
- TESs physically separated from the superconducting target allows for scalability



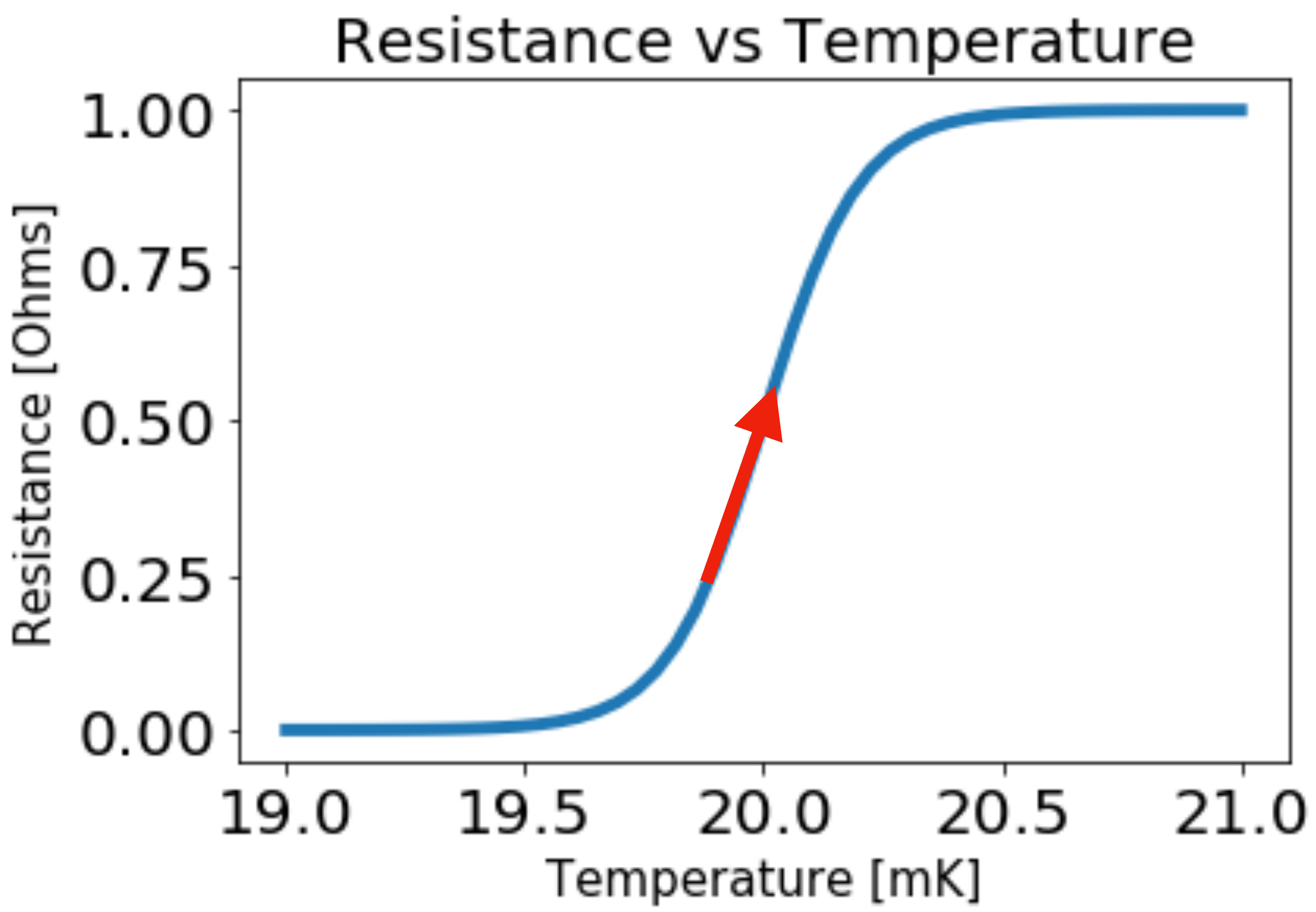
Joe Formaggio

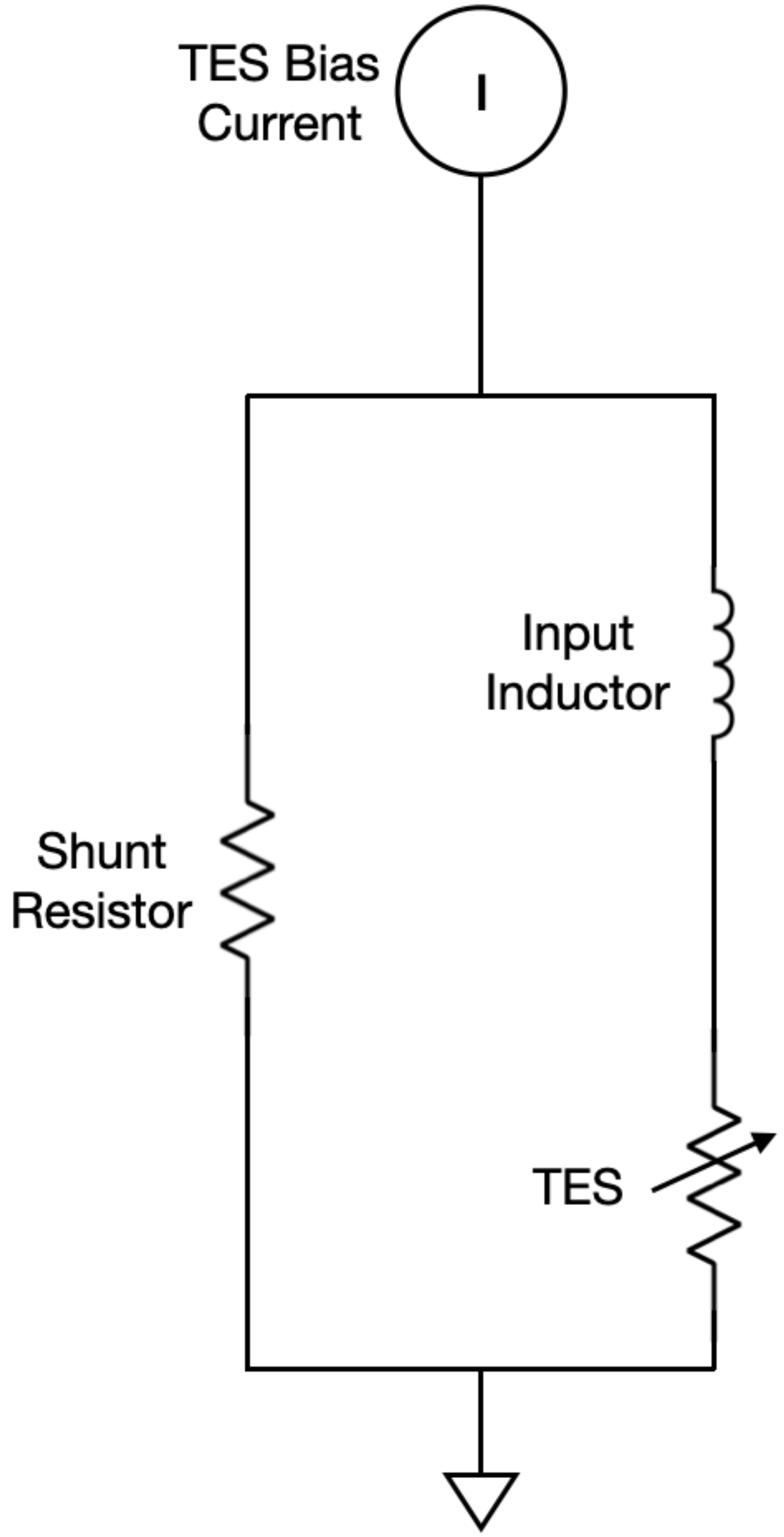


Simons Observatory

TESs and their Readout

- In our application, a transition edge sensor (TES) converts temperature to current
- In general, the colder the TES the more sensitive it is (decreasing heat capacity)

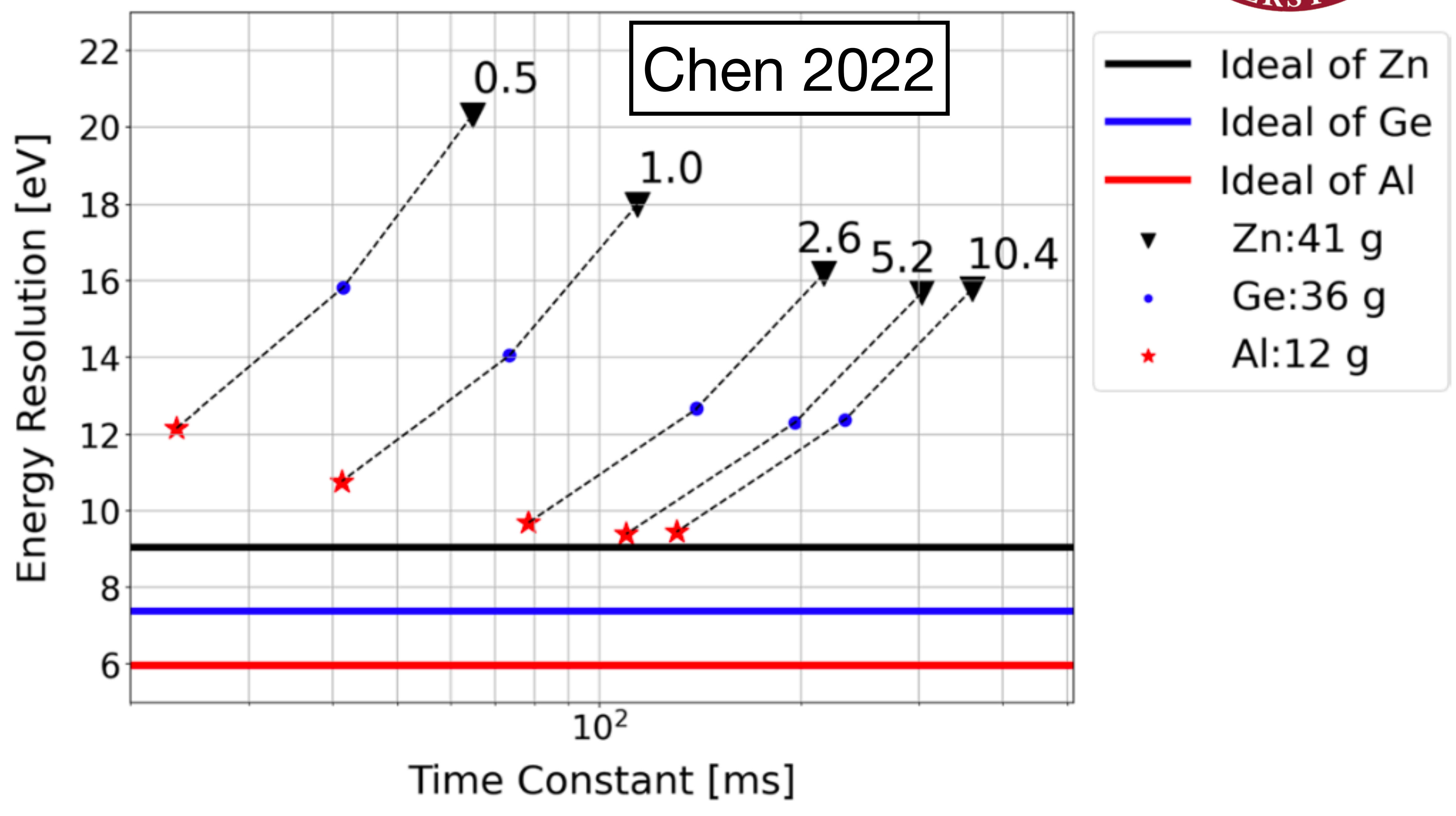


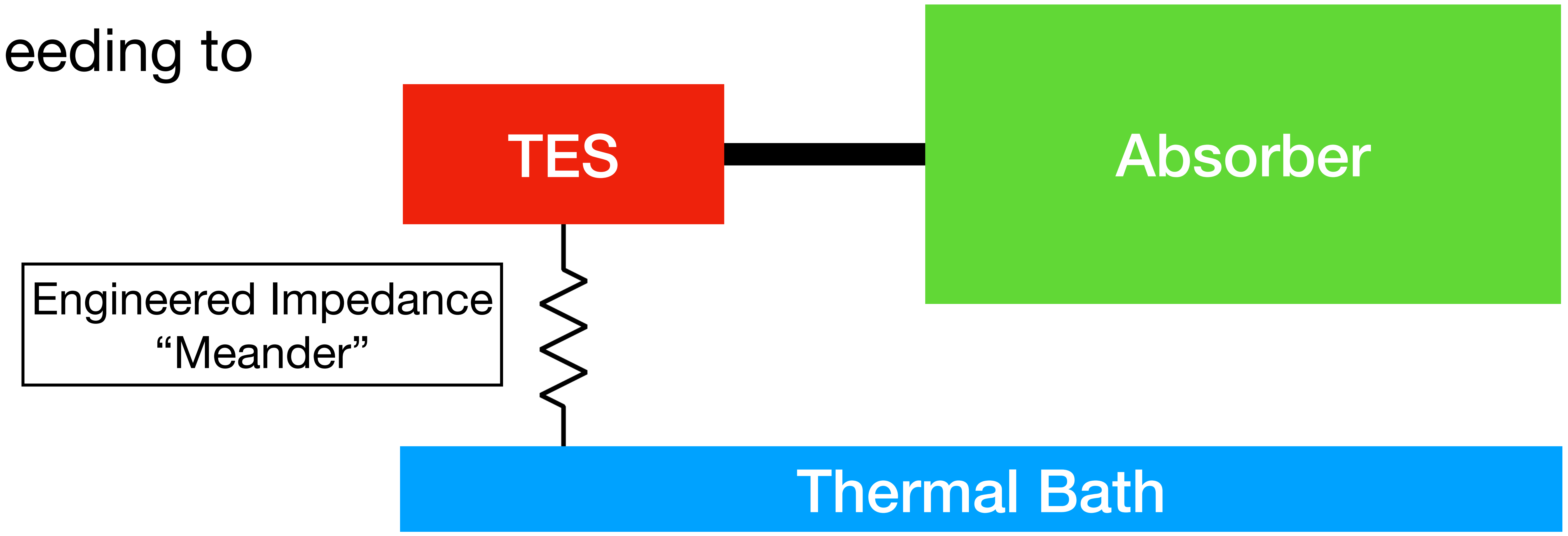


The Q-Array: TES Architecture

- Separate the TES from the target:
  - Fabricate many TESs at once
  - Allow for more target materials (superconductors, hygroscopic crystals)
- Angloher 2023, Chen 2022, Bastidon 2018
- Takes a penalty in efficiency, needing to transfer energy to the TES

Simulation





RICOCHET
A Coherent Neutrino Scattering Program

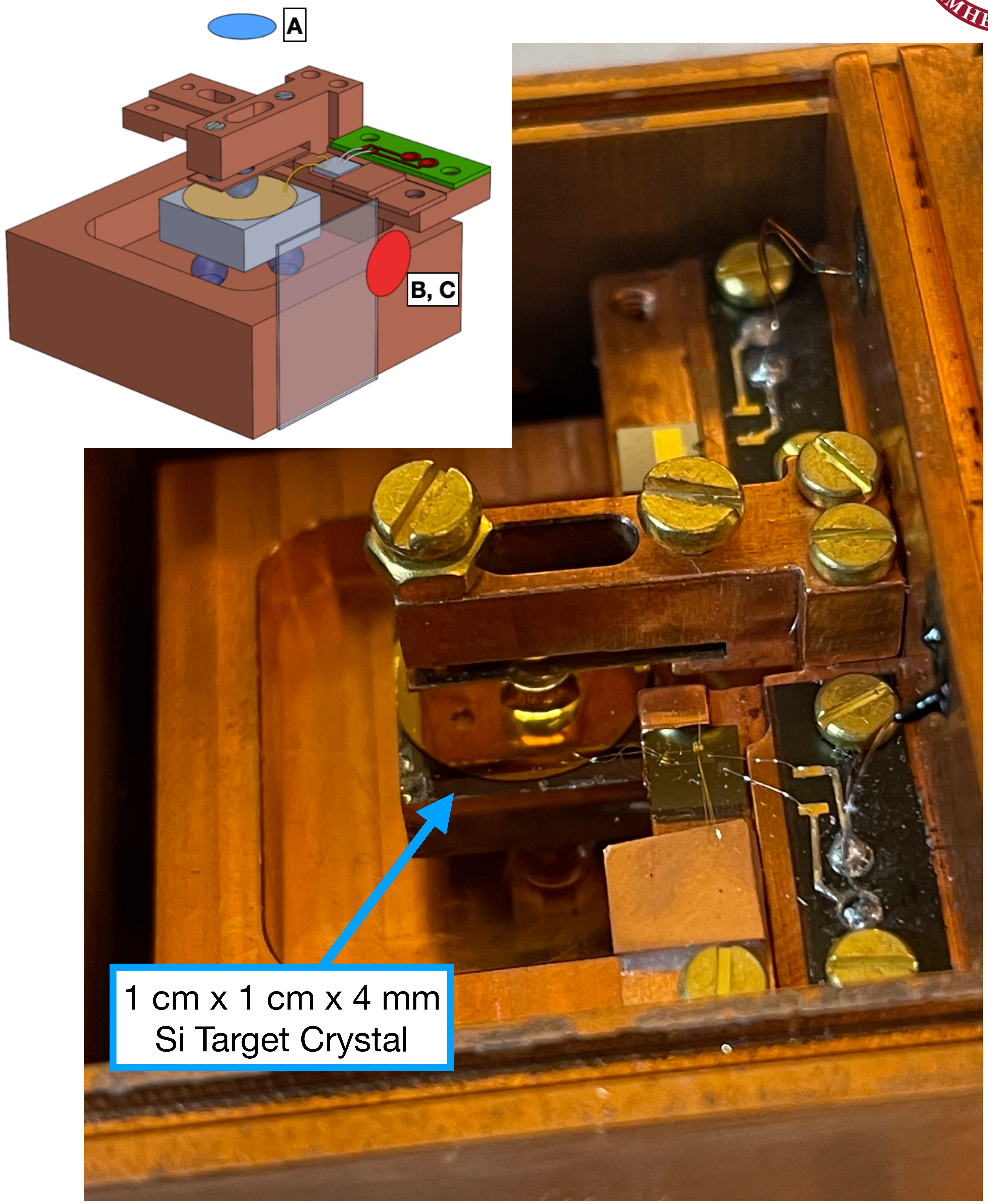
The Prototype Setup

RICOCHET
A Coherent Neutrino Scattering Program

- **<u>Goal:</u>** Focus on understanding the TES and target material interface:
    - Small (1 g), non-superconducting crystal (Si) readout with DC SQUIDs

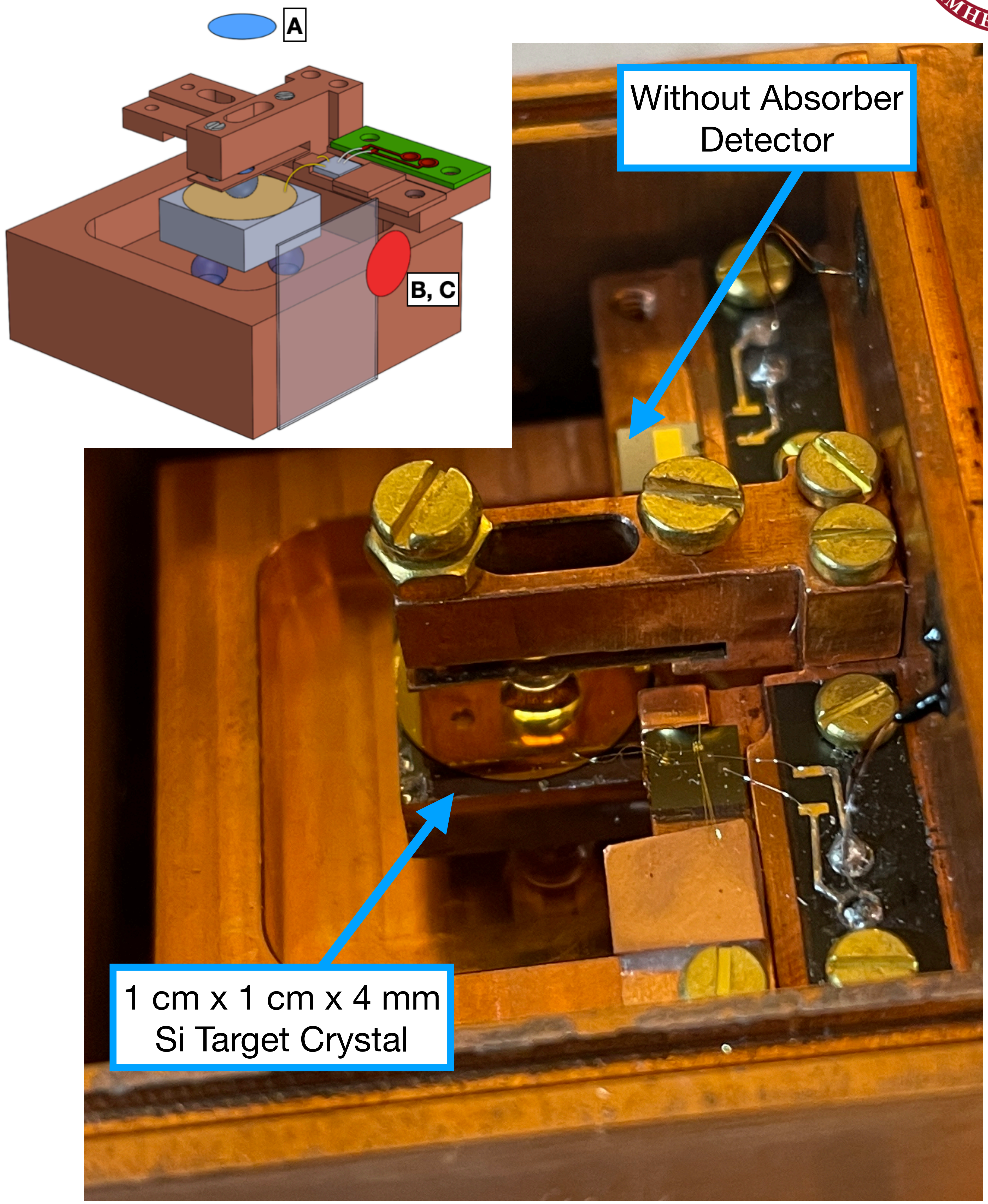
The Prototype Setup

- **Goal:** Focus on understanding the TES and target material interface:
    - Small (1 g), non-superconducting crystal (Si) readout with DC SQUIDs
- Flexible R&D holder design (accommodates a variety of targets)
- Use ^{55}Fe X-rays to calibrate. Runs with source in 3 locations: “A, B, C”



The Prototype Setup

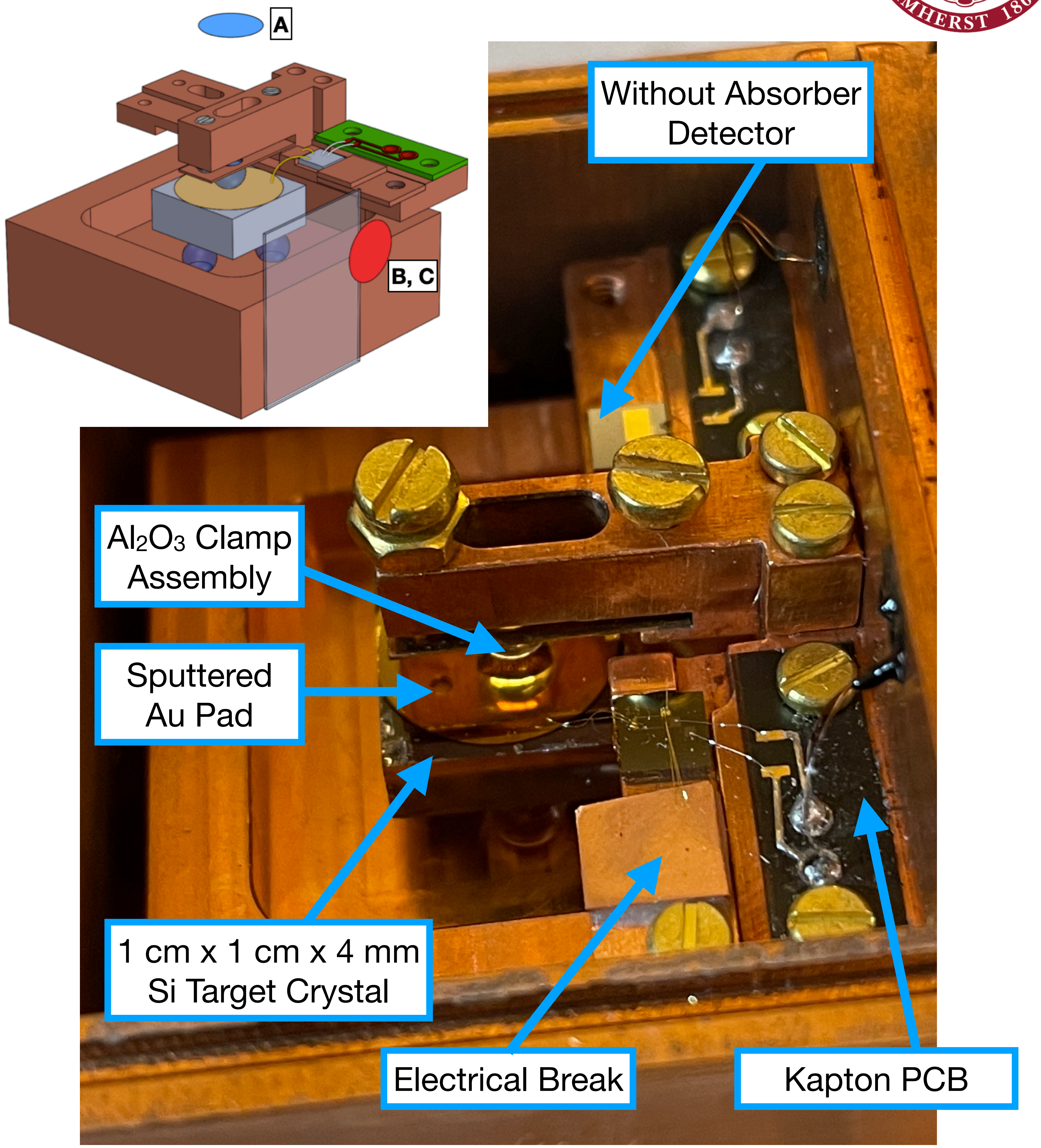
- **<u>Goal:</u>** Focus on understanding the TES and target material interface:
    - Small (1 g), non-superconducting crystal (Si) readout with DC SQUIDs
- Flexible R&D holder design (accommodates a variety of targets)
- Use ^{55}Fe X-rays to calibrate. Runs with source in 3 locations: “A, B, C”
- Two detectors: “with absorber” and “without absorber”



The Prototype Setup

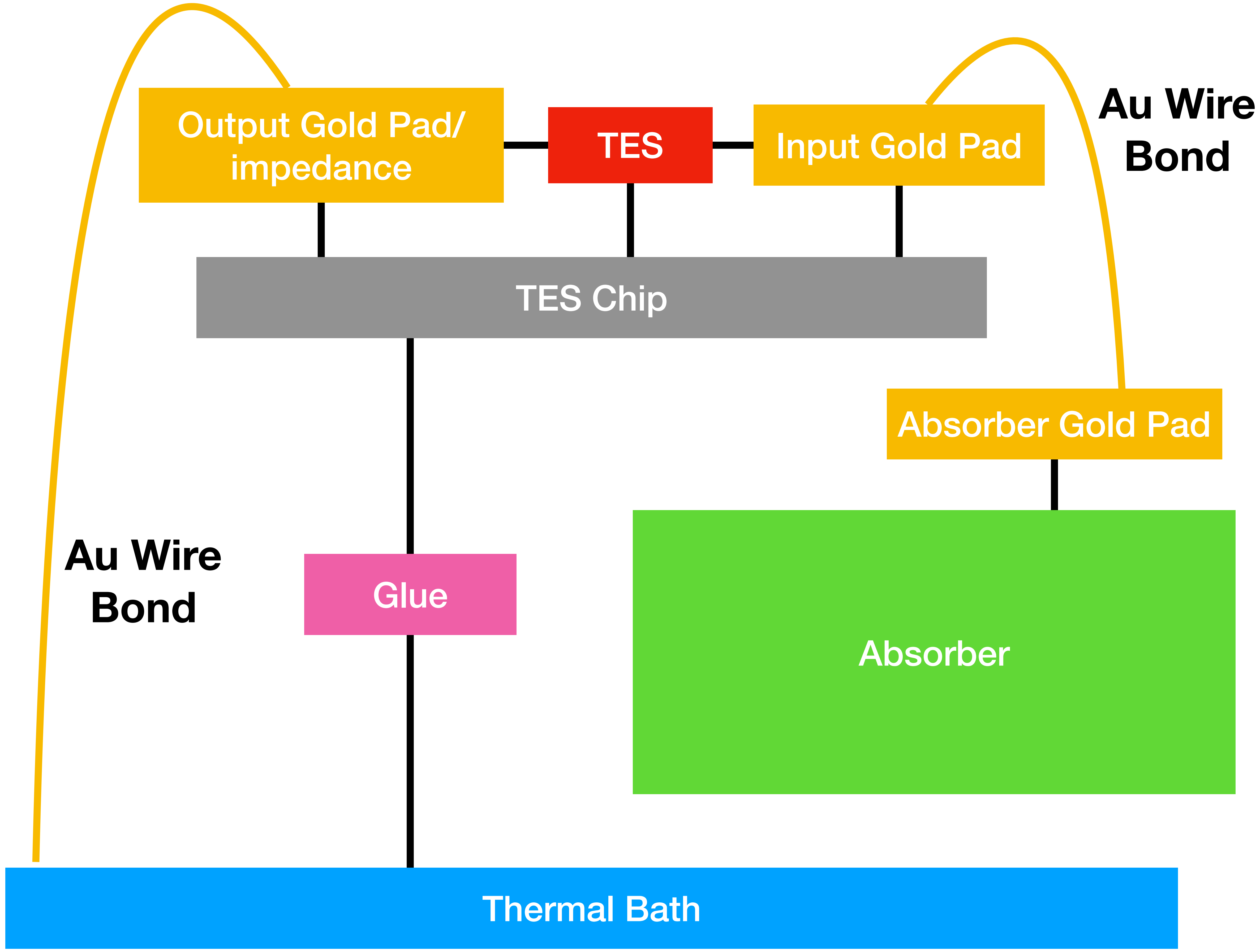
RICOCHET
A Coherent Neutrino Scattering Program

- **<u>Goal:</u>** Focus on understanding the TES and target material interface:
    - Small (1 g), non-superconducting crystal (Si) readout with DC SQUIDs
- Flexible R&D holder design (accommodates a variety of targets)
- Use ^{55}Fe X-rays to calibrate. Runs with source in 3 locations: "A, B, C"
- Two detectors: "with absorber" and "without absorber"

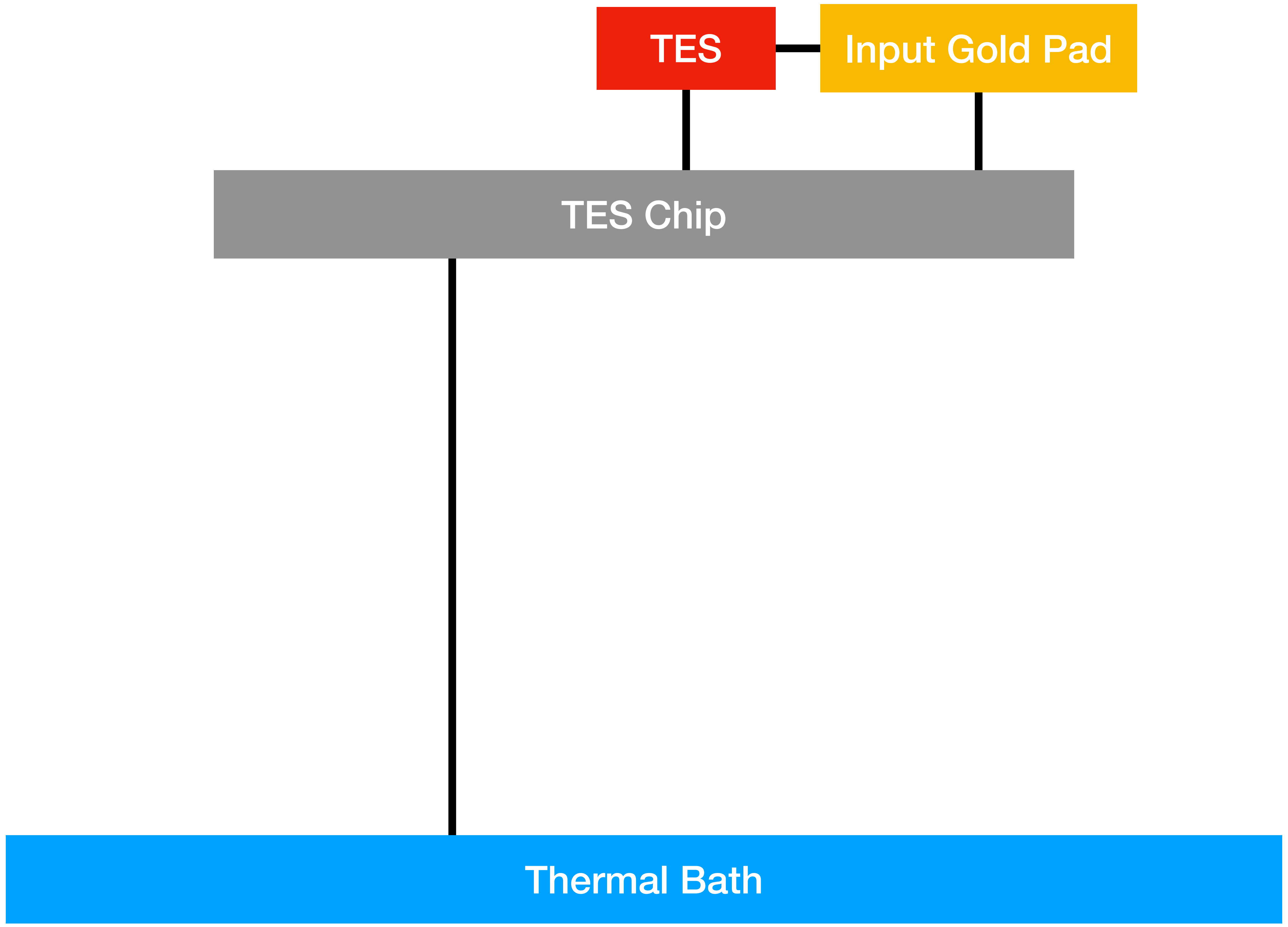


Different Architectures

RICOCHET
A Coherent Neutrino Scattering Program



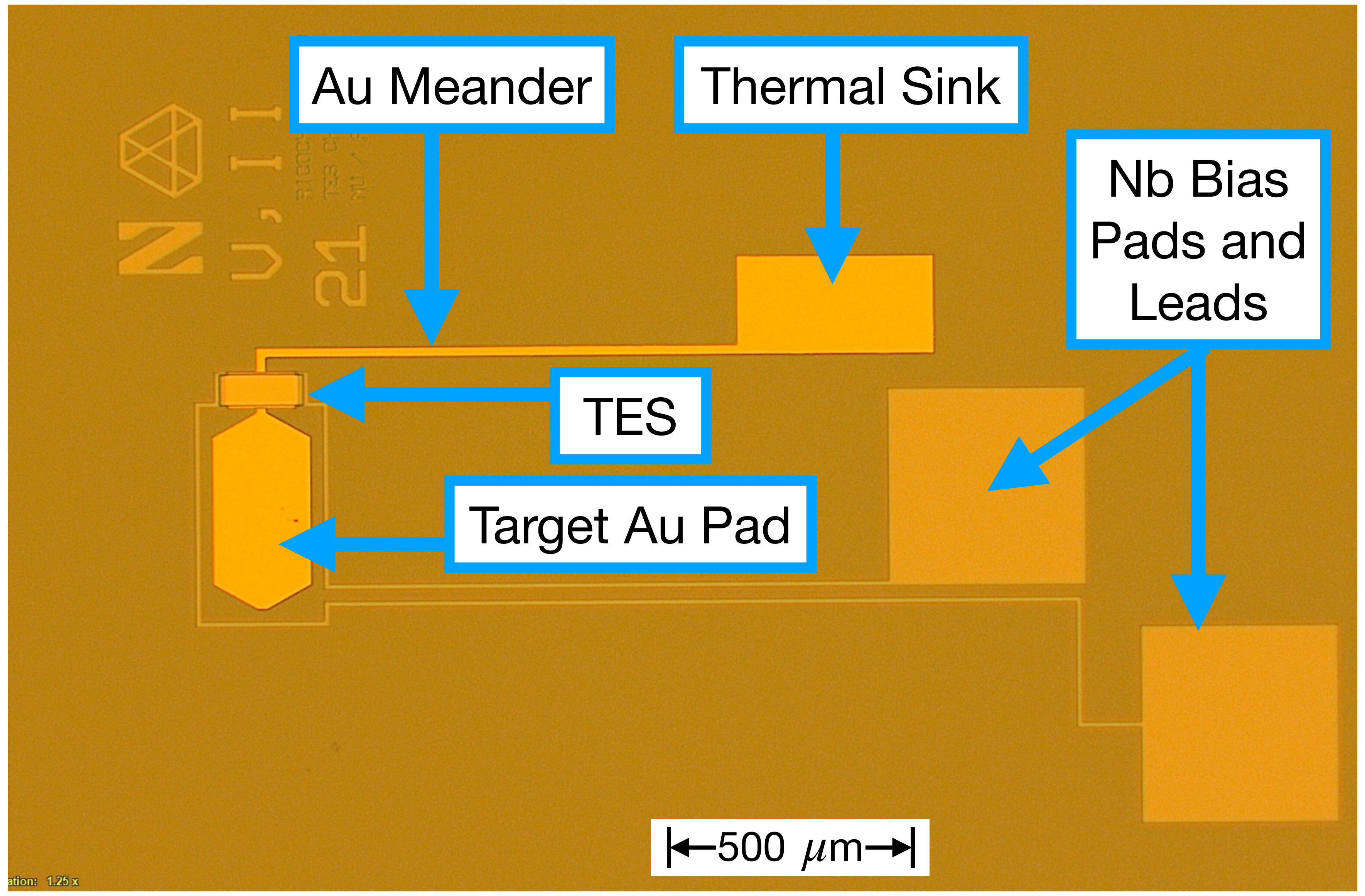
With Absorber

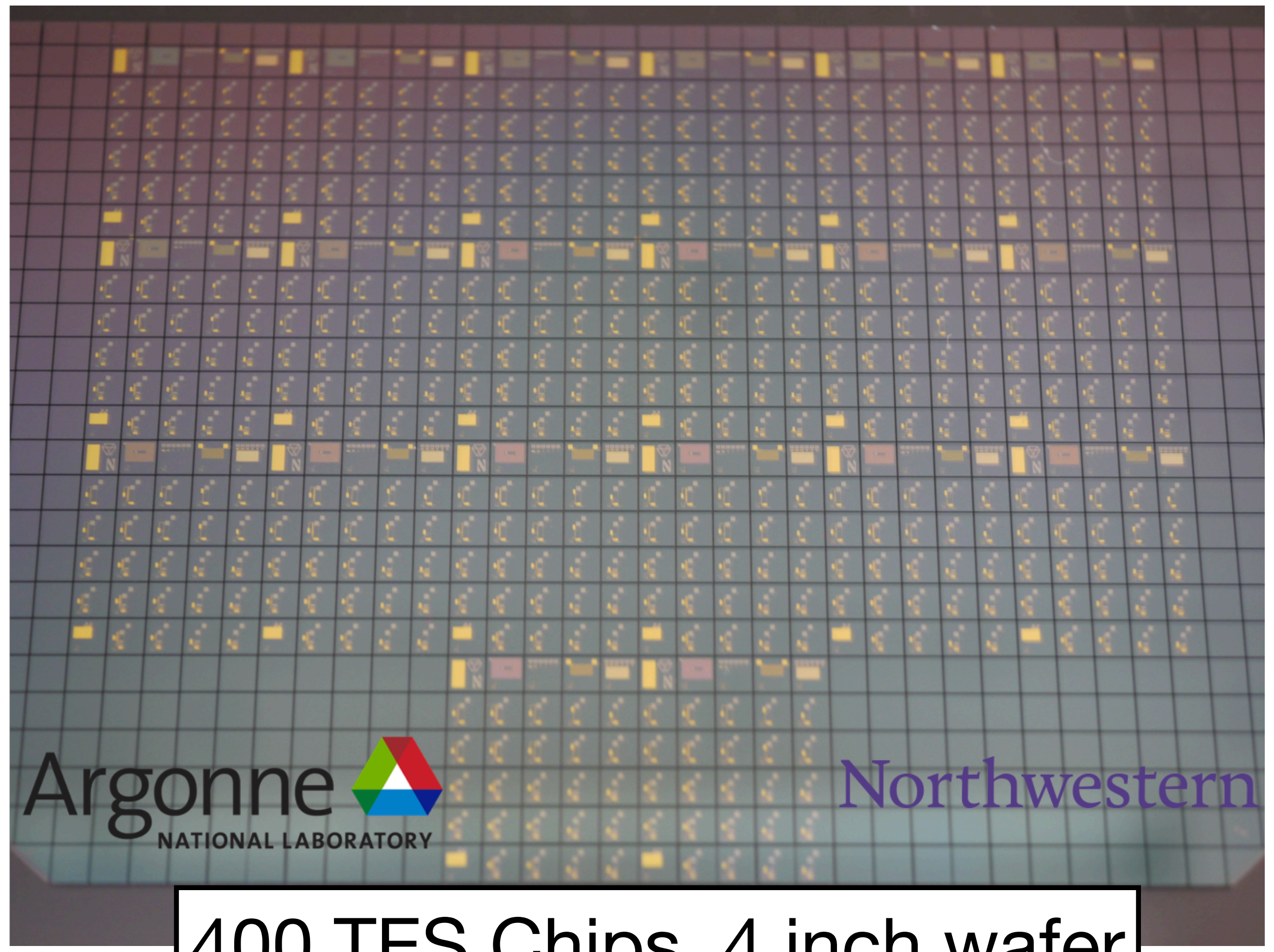


Without Absorber

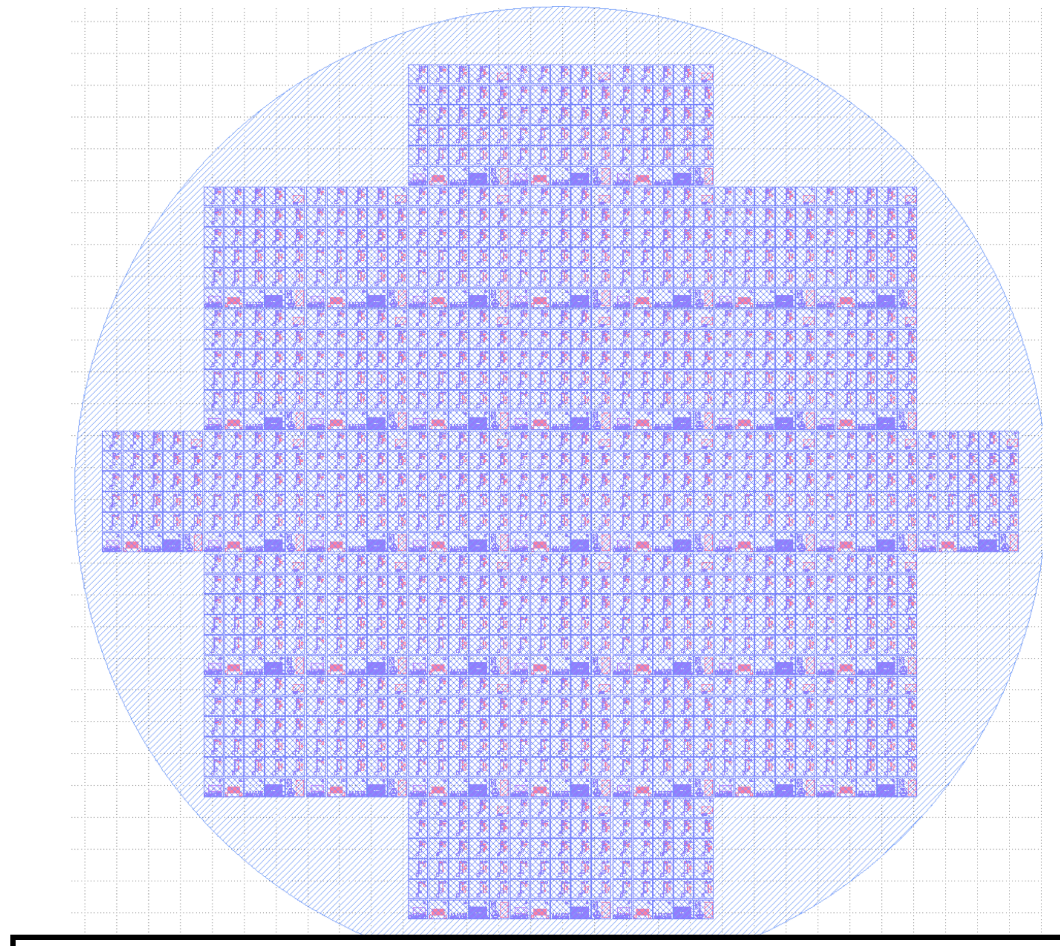
The Prototype Setup: TESs

- TESs fabricated at Argonne National Laboratory
    - AlMn films, bilayers with different levels of the Mn dopant
- Tc of “with absorber” detector approximately 20 mK
- Tc of “without absorber” detector was raised to ~40 mK through post-deposition heating





400 TES Chips, 4 inch wafer

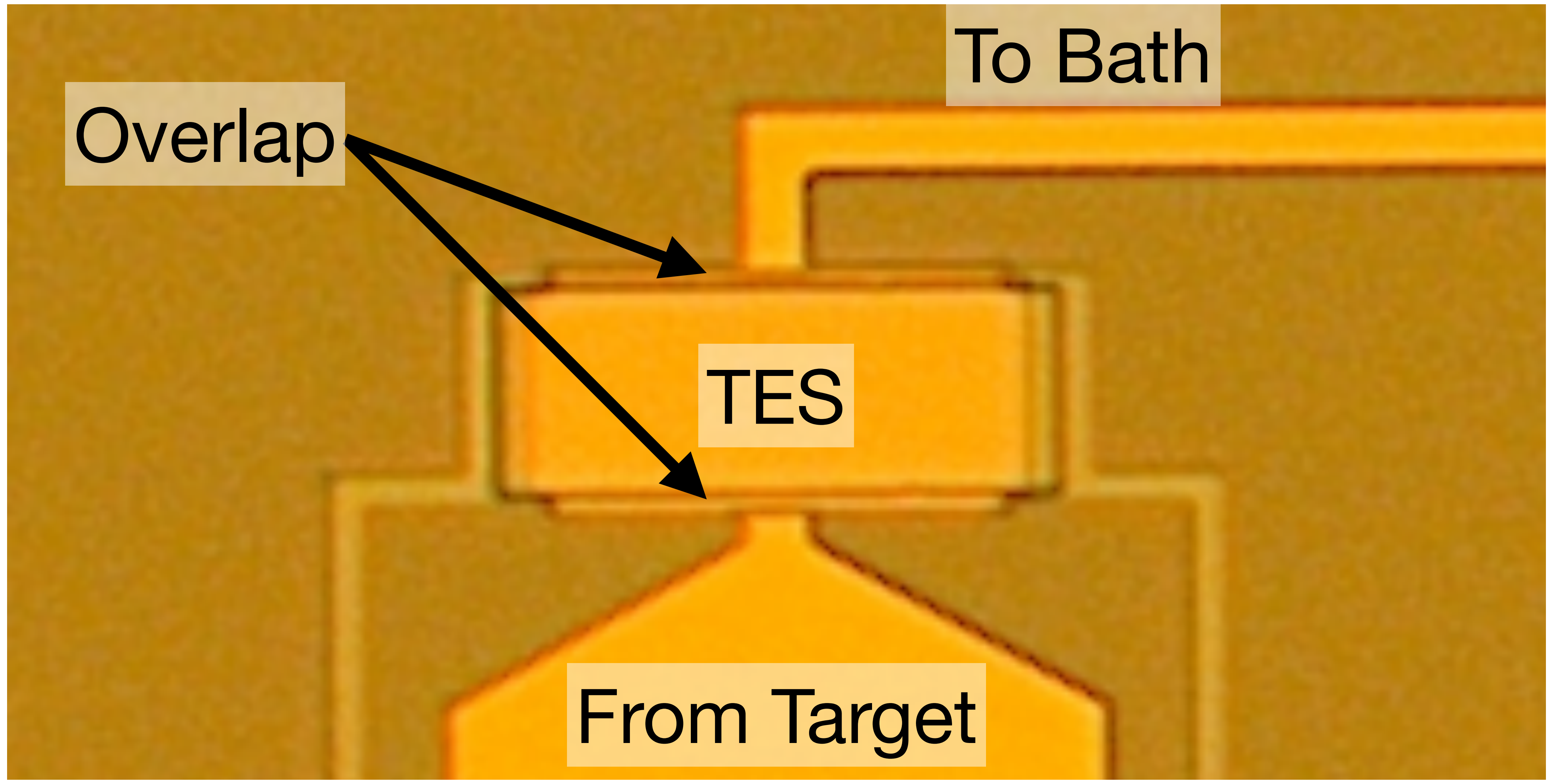


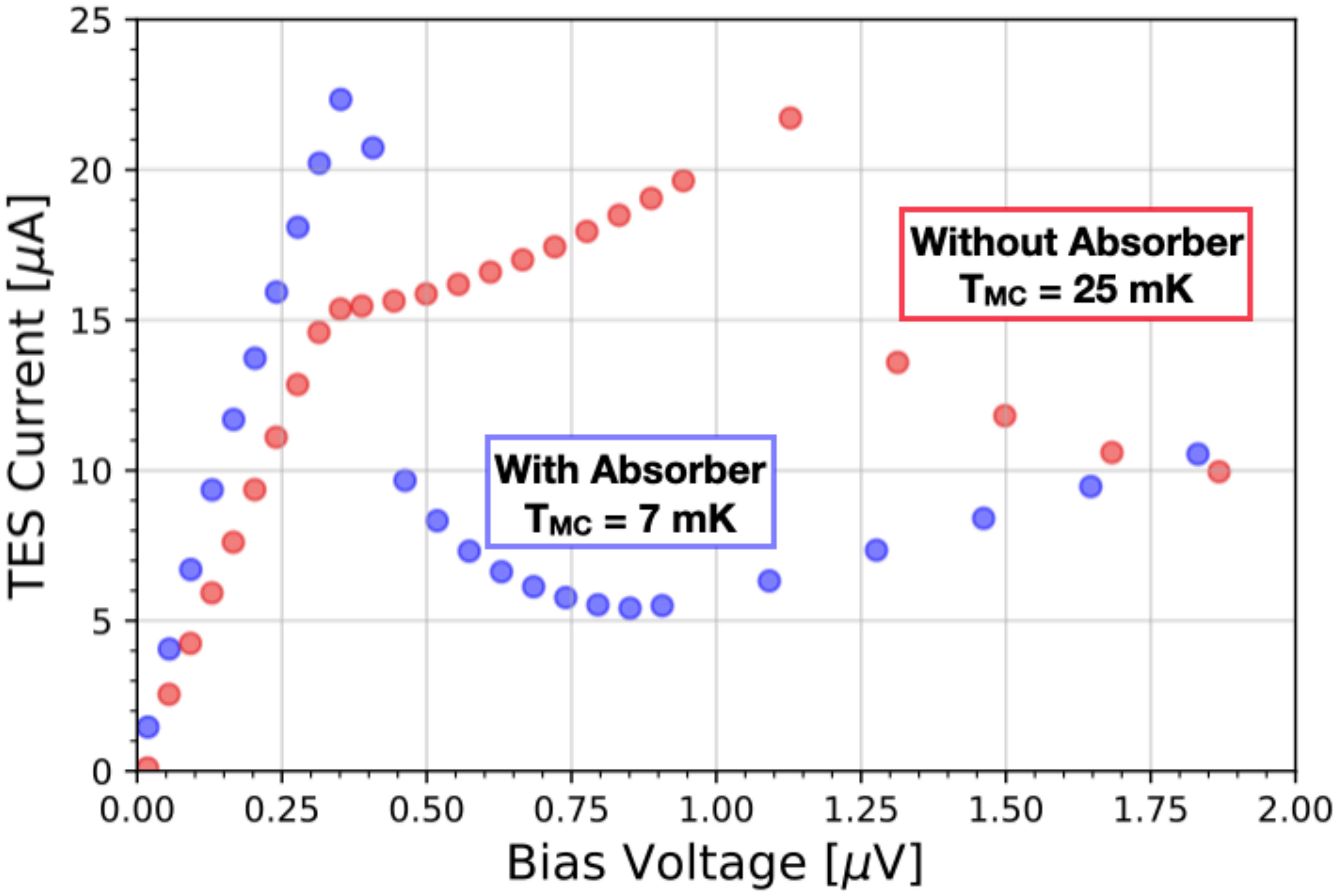
1000 TES Chips, 6 inch wafer

RICOCHET
A Coherent Neutrino Scattering Program

TES Performance

- Two transition features in each curve
  - Proximity effects from gold/TES overlap?





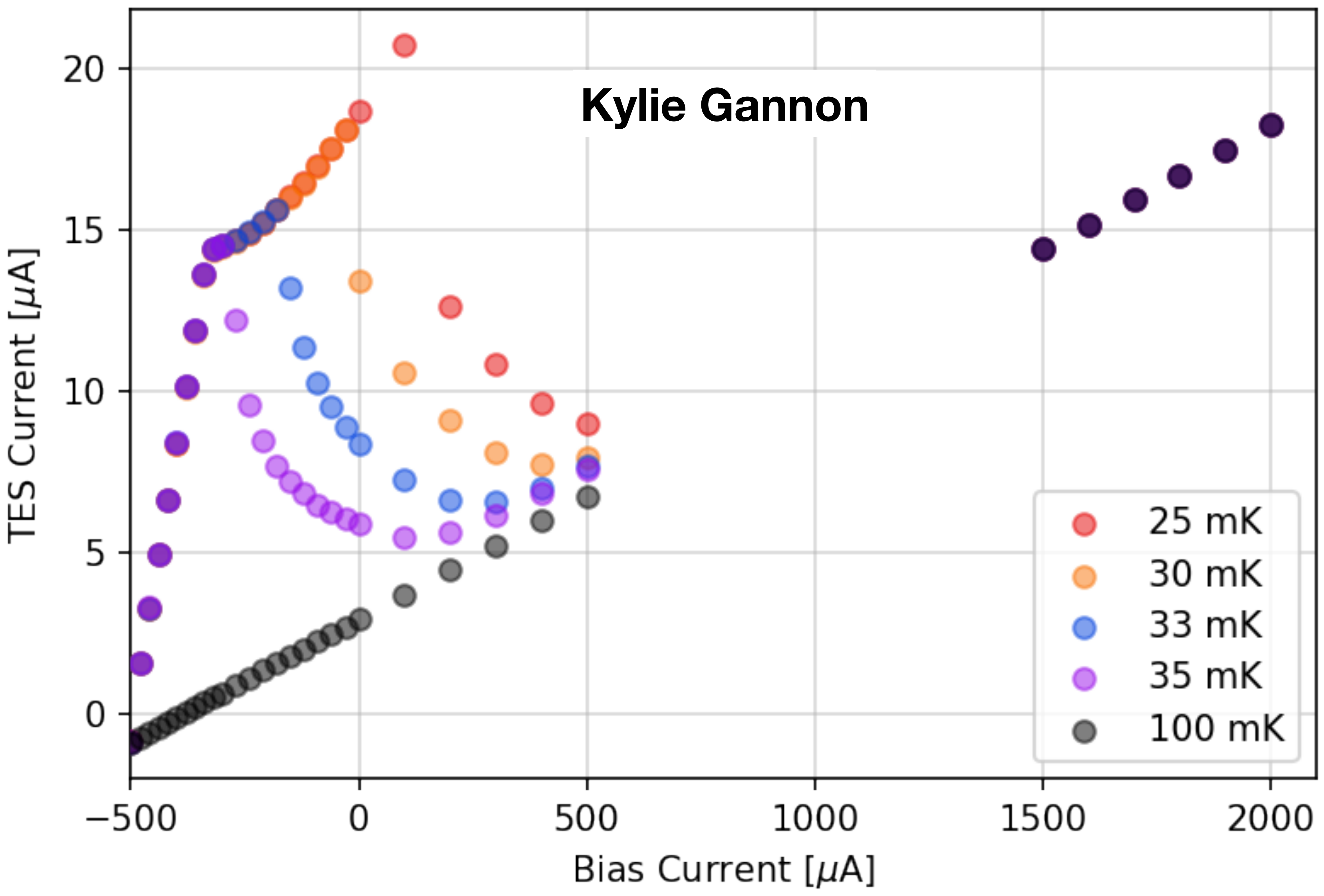
TES Channel	Rn [mΩ]	Tc [mK]	Bias Power [pW]
With Absorber	160 ± 20	20 ± 2	3.3 ± 0.3
Without Absorber	220 ± 20	38 ± 4	15 ± 2

Thermal Conductances

- Measure IV curves at different temperatures to estimate power-vs-temperature
- Fit to find conductance and temperature scaling
- While these are within a factor of a few of expectation, lots of room to improve our understanding through modeling

$$P = K(T_c^n - T_b^n)$$

Without Absorber Detector



TES Channel	G at T_c [pW/K]	G at 20 mK [pW/K]
With Absorber	470 ± 200	470 ± 200
Without Absorber	1600 ± 400	390 ± 100

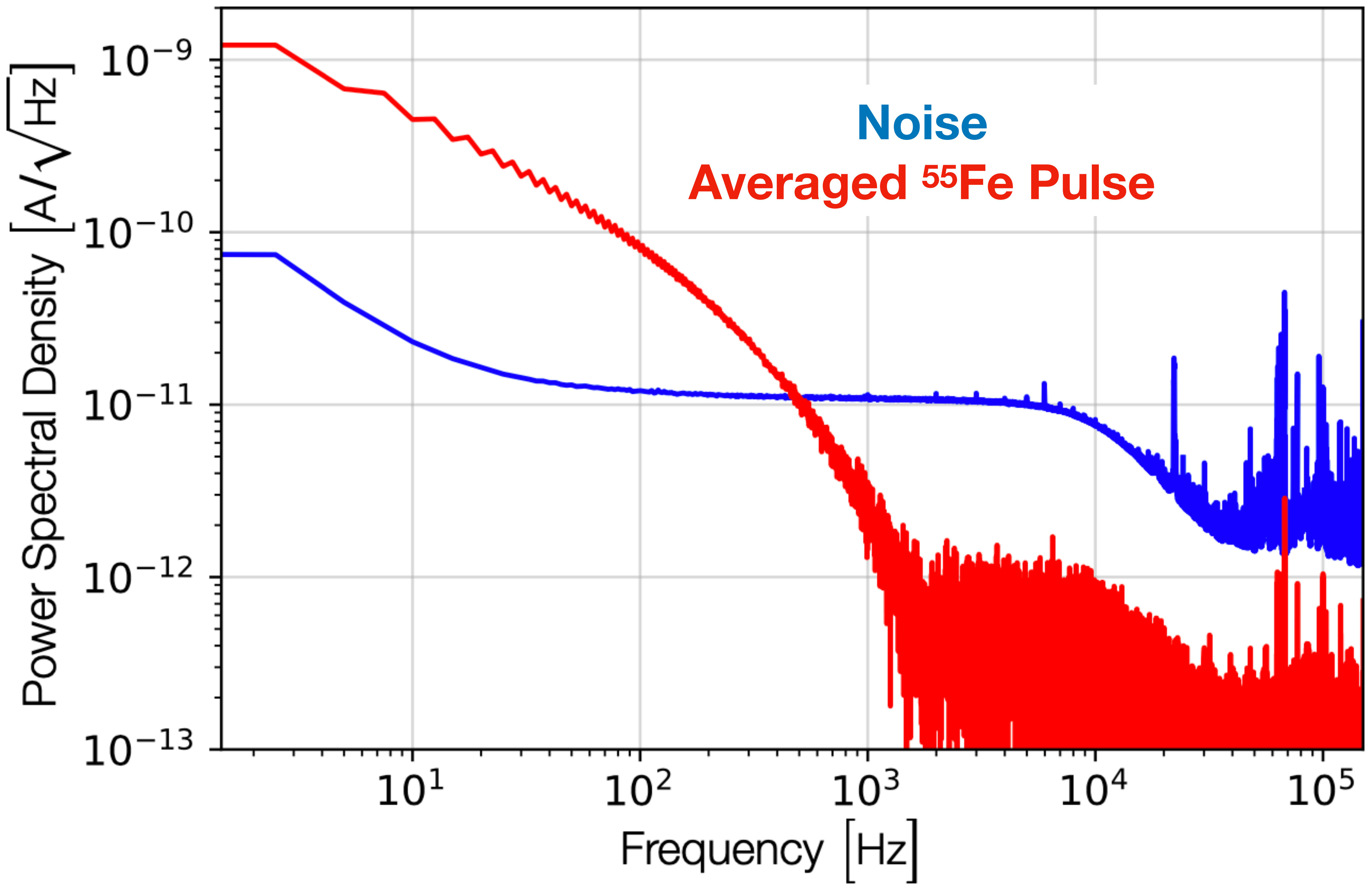
Data, Noise and Optimal Filtering

- Data continuously recorded at 300 kHz
- Triggering performed offline
- Energy estimation done through an optimal filtering framework
- Pulse shape taken to be an ^{55}Fe X-ray incident on the silicon target (with absorber detector)

Fit Amplitude

$$\chi^2 = \int \frac{df}{J(f)} \left| \tilde{V}(f) - A\tilde{S}(f) \right|^2$$

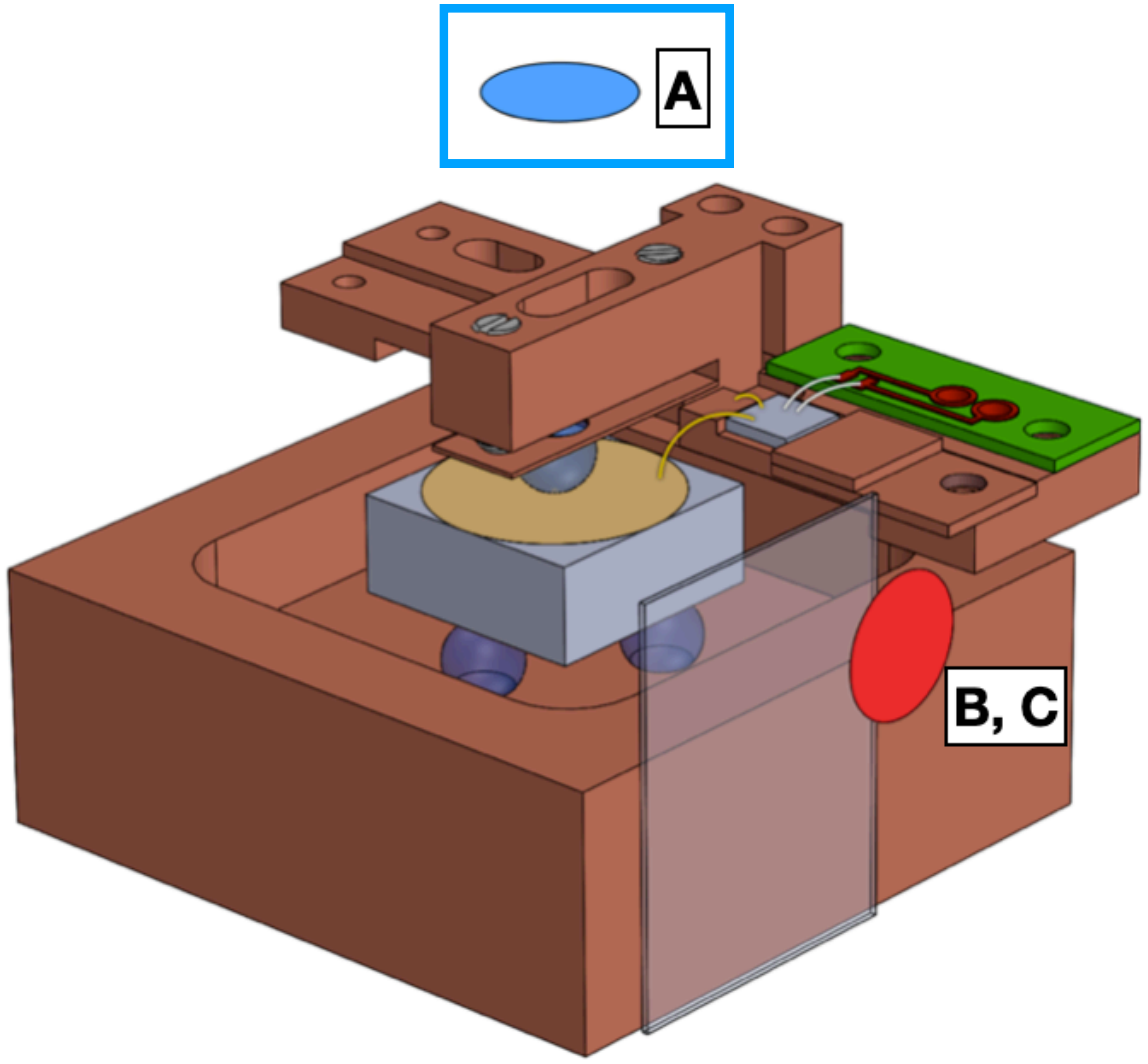
Noise Signal Template

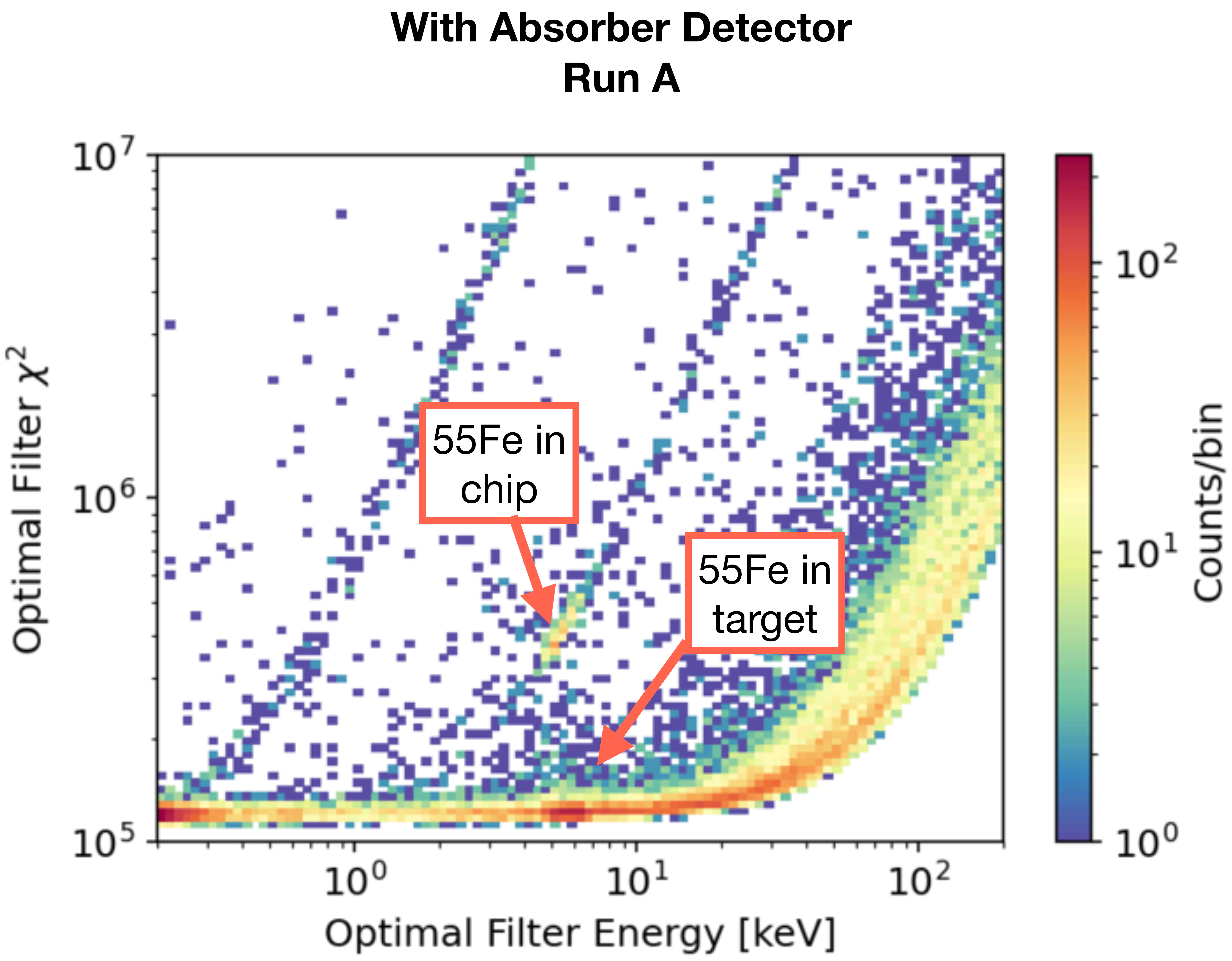


RICOCHET
A Coherent Neutrino Scattering Program

Optimal-Filtered Space

- See peaks from our X-ray source

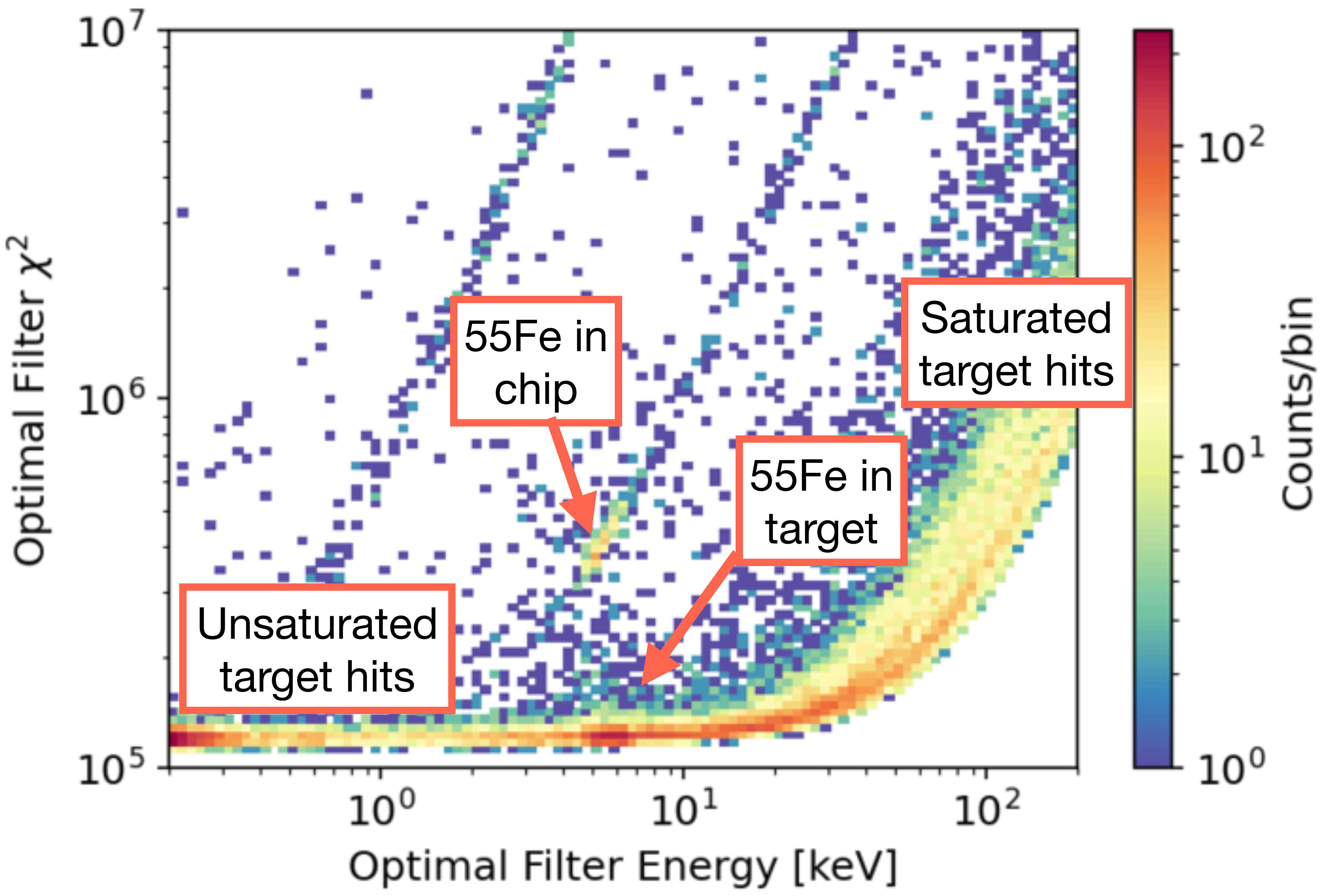




Optimal-Filtered Space

- See peaks from our X-ray source
- Three main branches in the data
- "Target hit" branch, events interacting in the Si

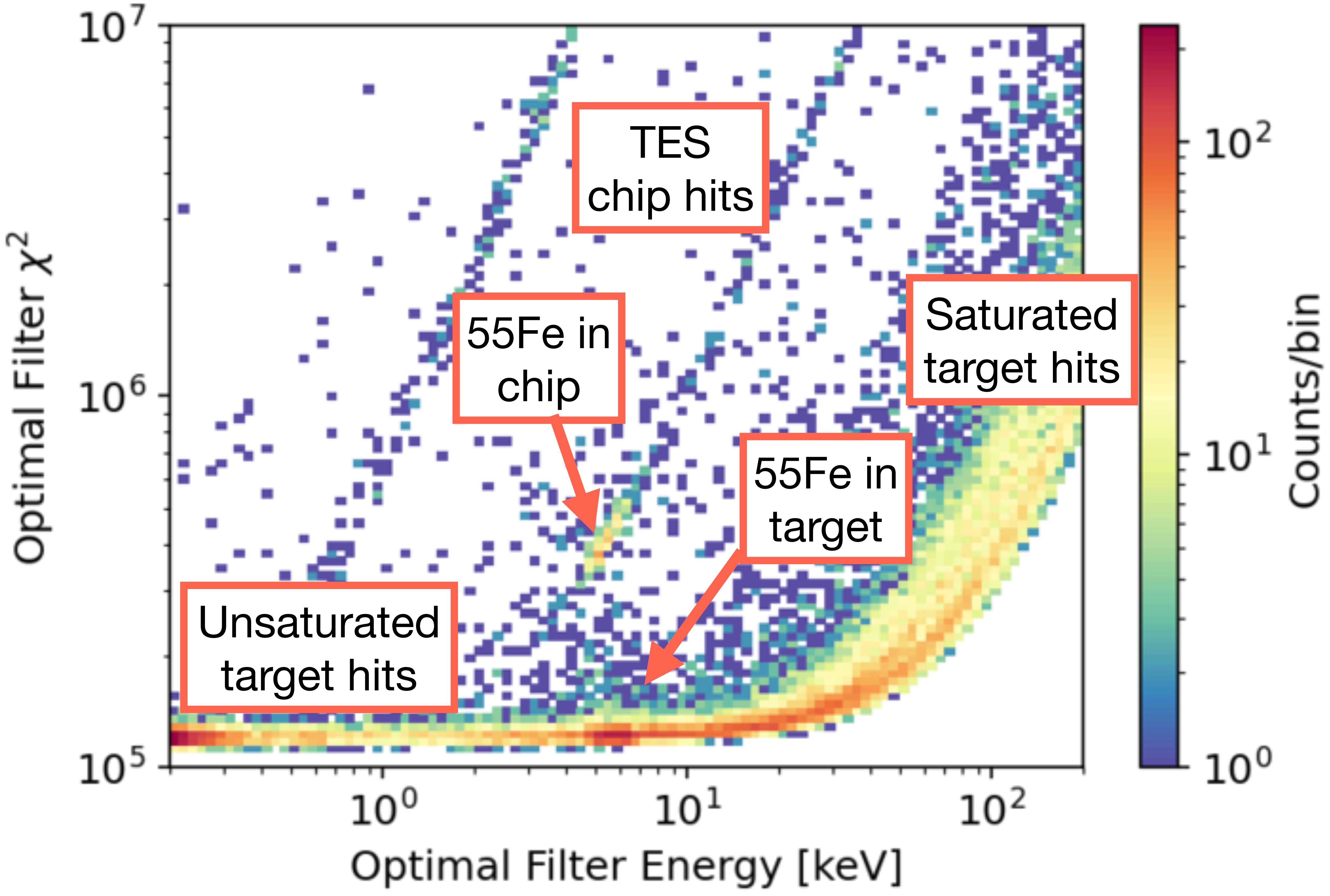
With Absorber Detector
Run A



Optimal-Filtered Space

- See peaks from our X-ray source
- Three main branches in the data
- “Target hit” branch, events interacting in the Si
- “Chip hit” branch of events hitting just the TES chip

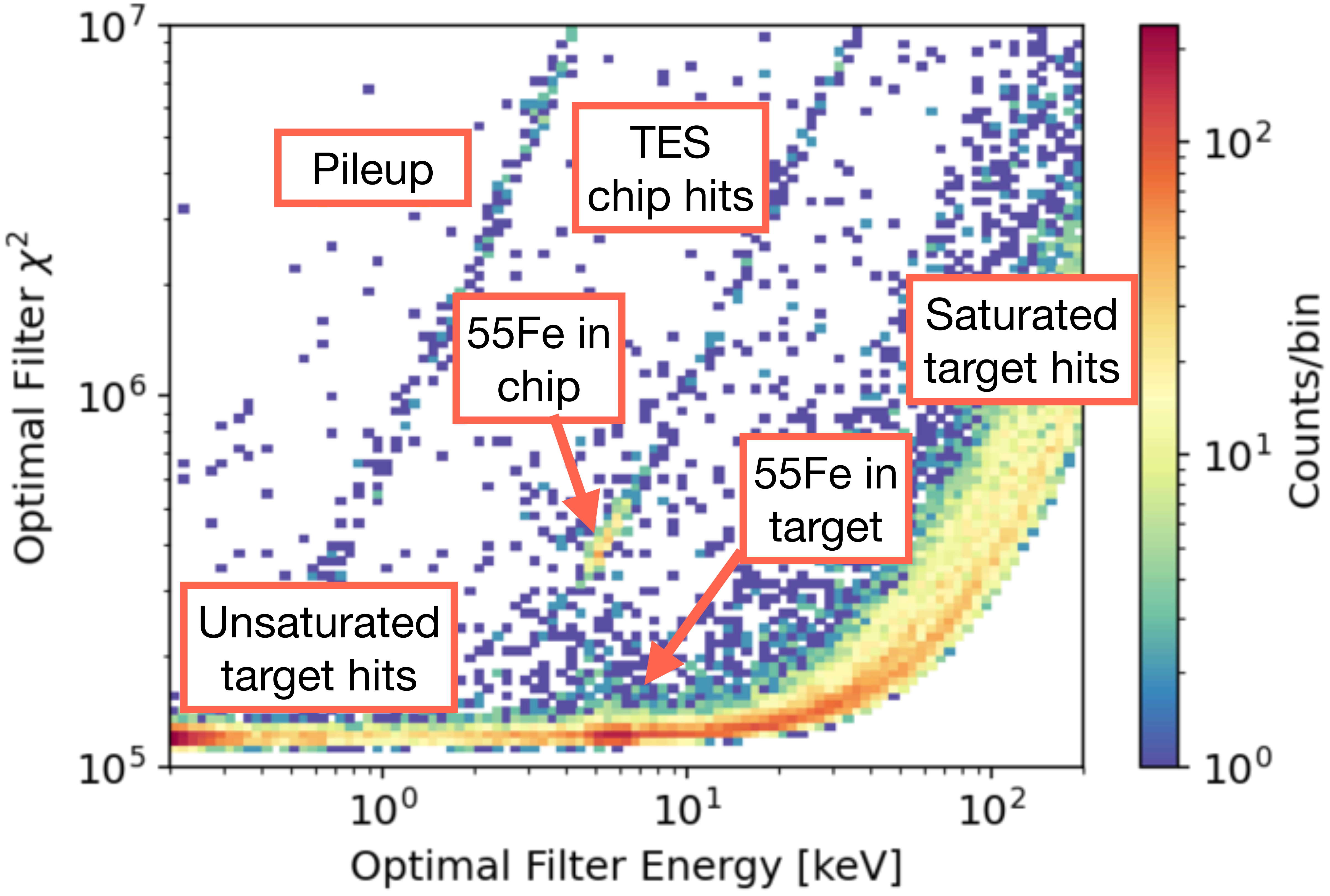
With Absorber Detector
Run A



Optimal-Filtered Space

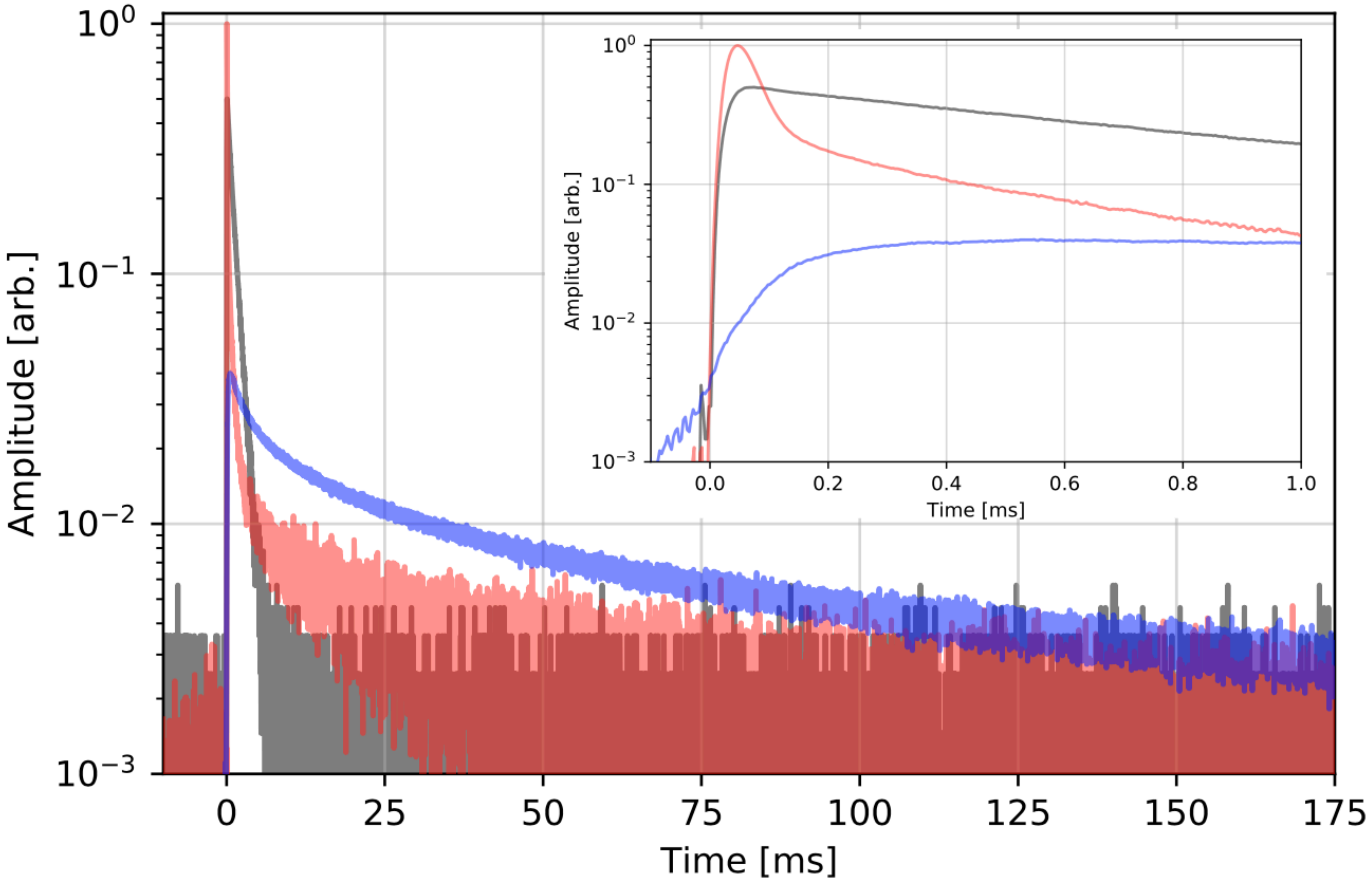
- See peaks from our X-ray source
- Three main branches in the data
- “Target hit” branch, events interacting in the Si
- “Chip hit” branch of events hitting just the TES chip
- “Pileup” events

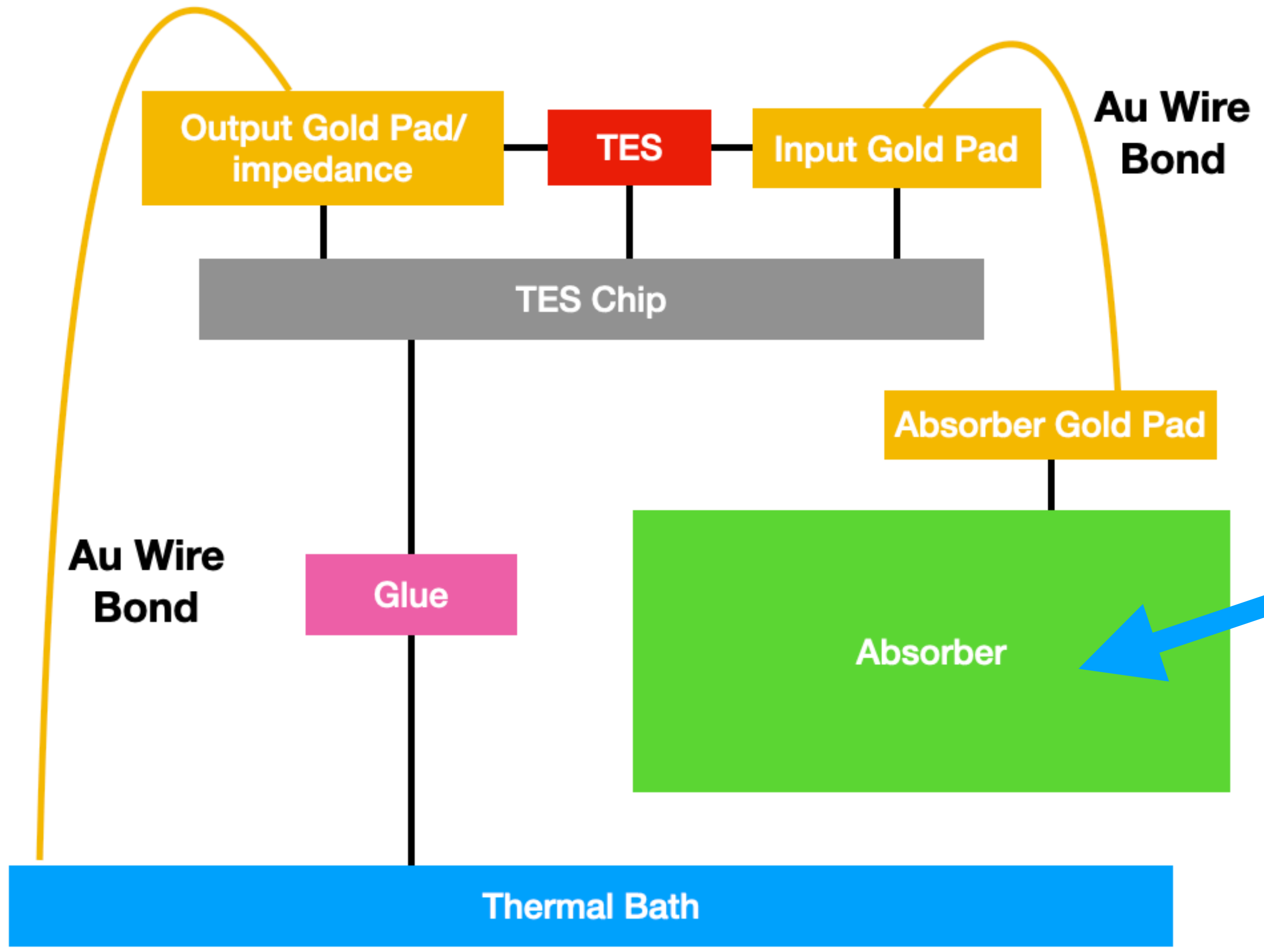
With Absorber Detector
Run A

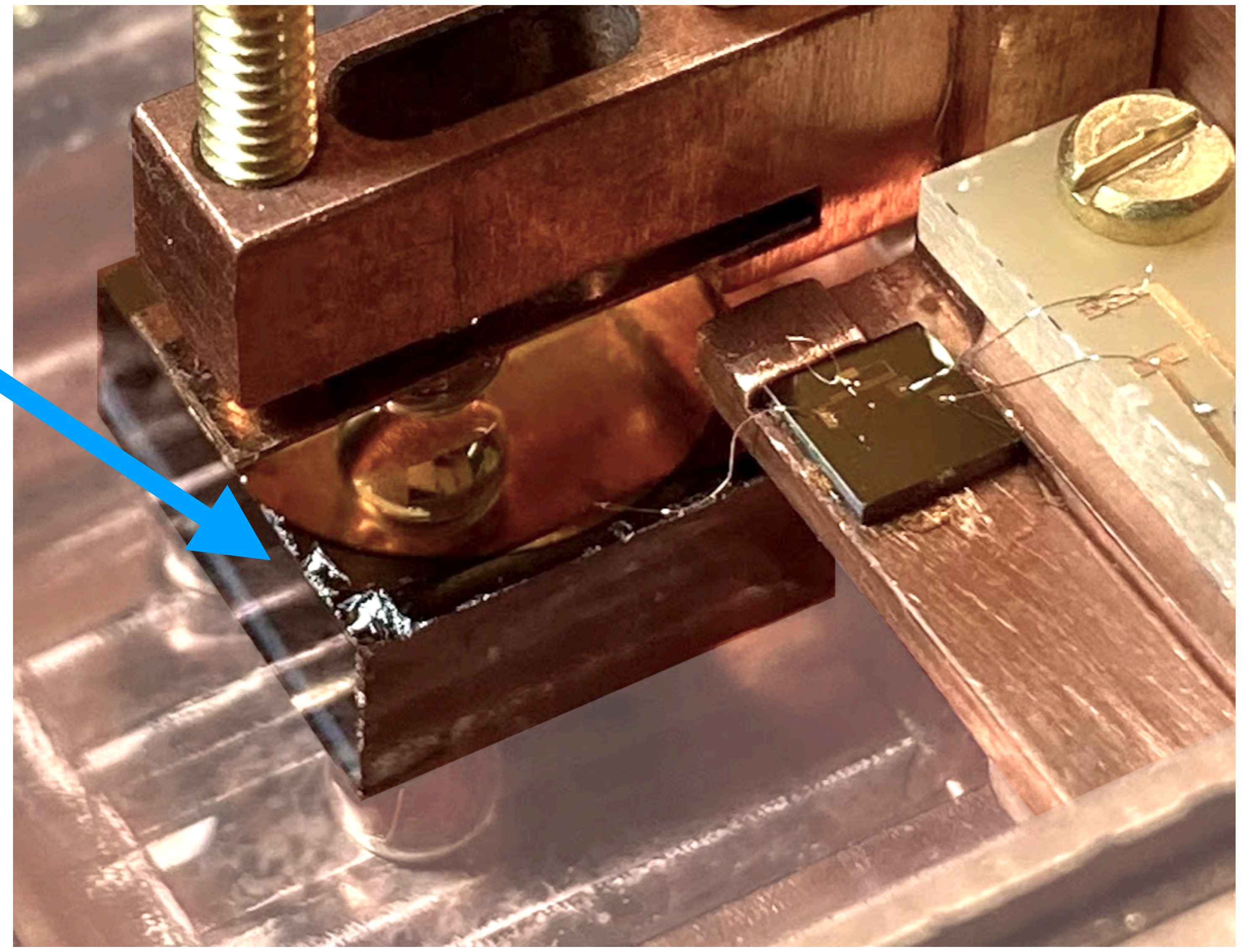


Pulse Shapes

- Blue: Si target hit





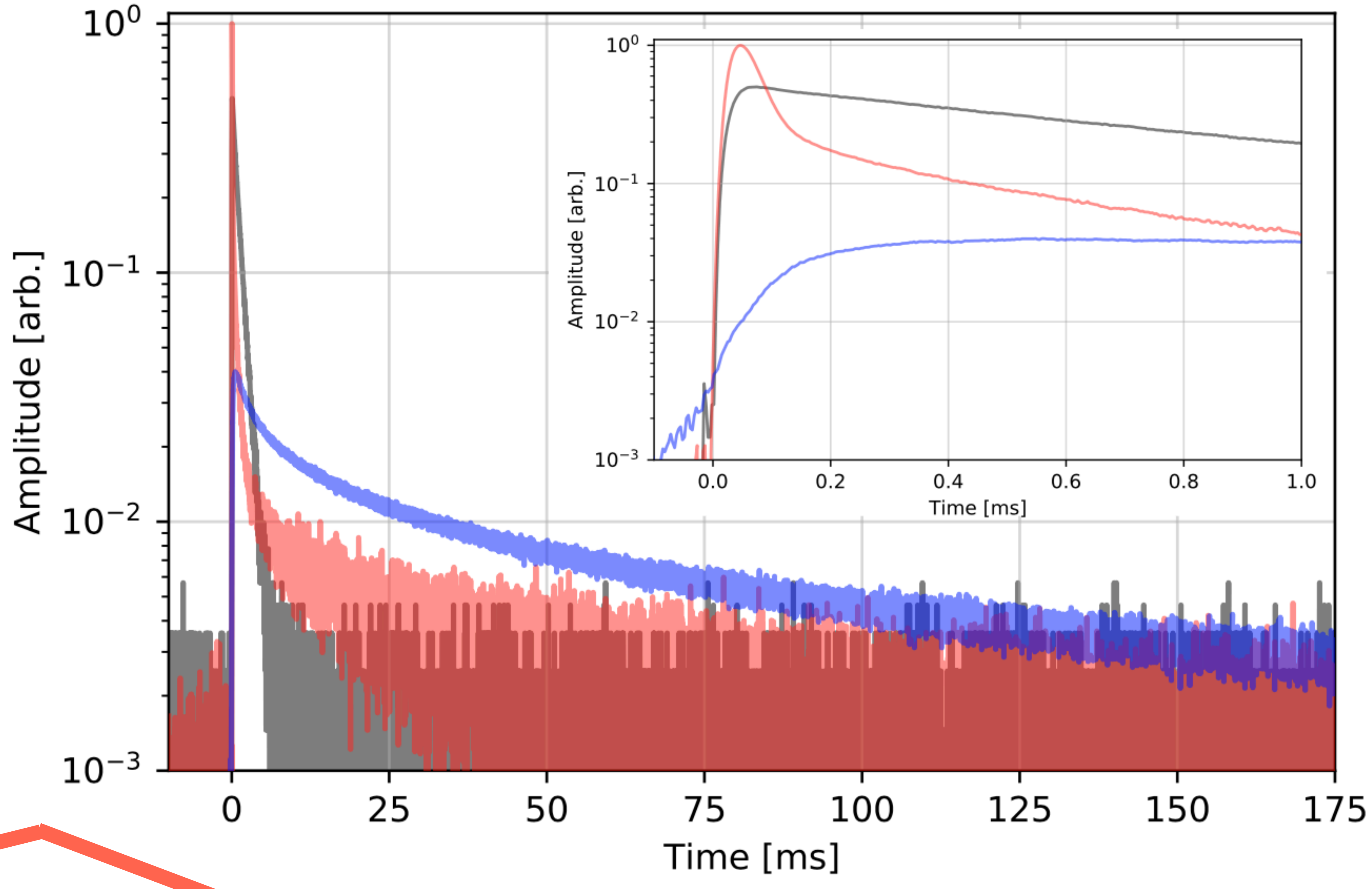


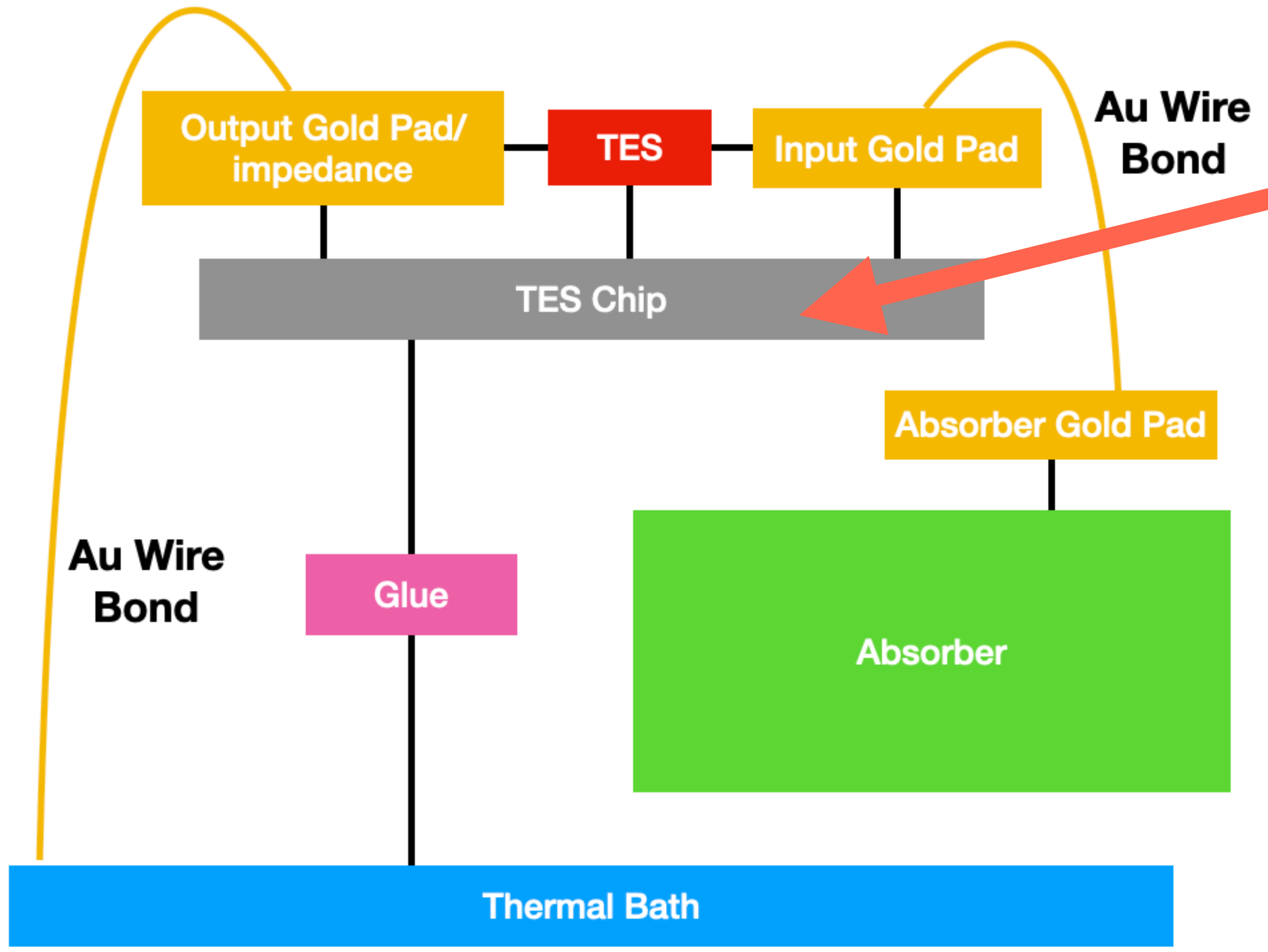
RICOCHET
A Coherent Neutrino Scattering Program

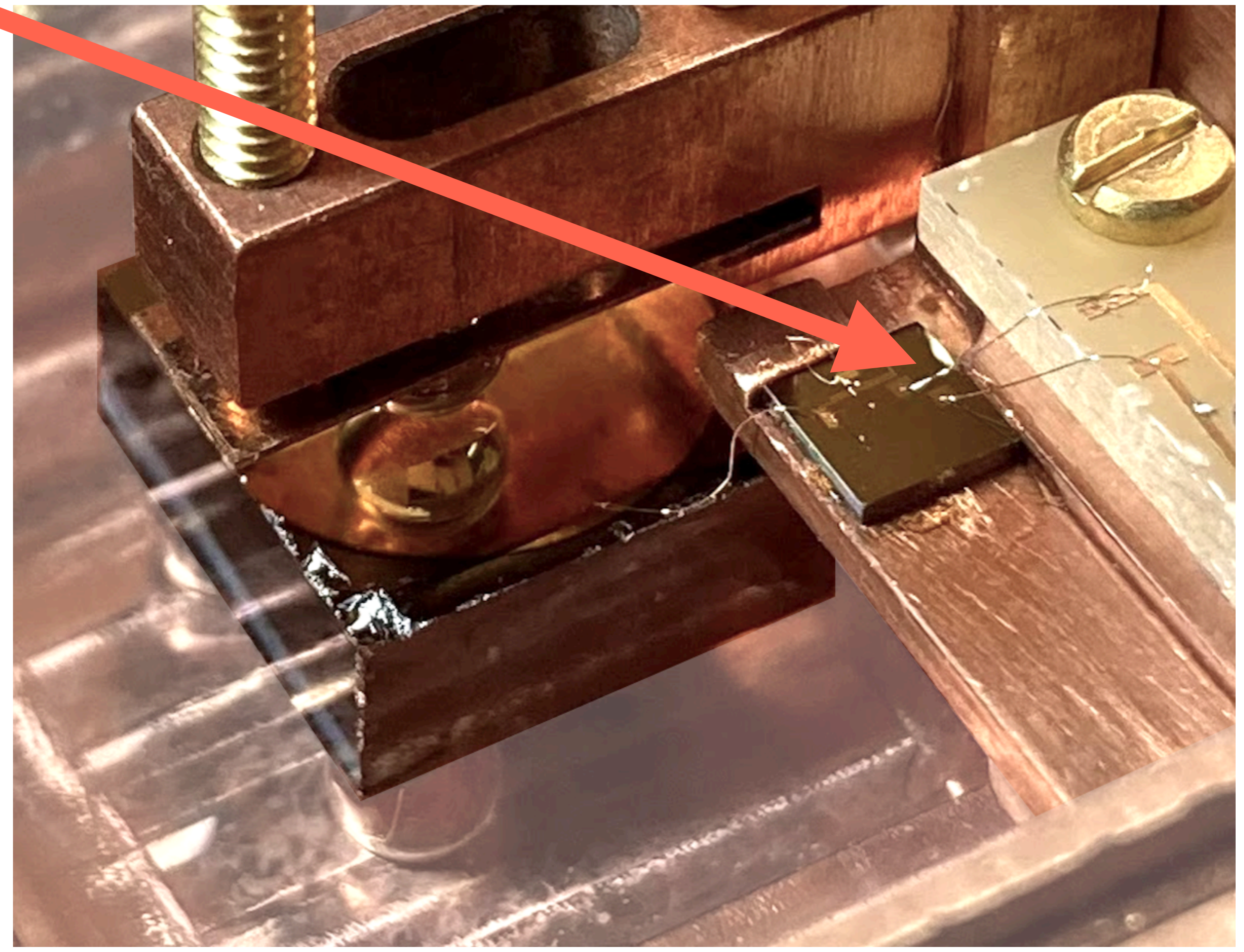
Doug Pinckney hpinckney@umass.edu

Pulse Shapes

- Blue: Si target hit
- Red: TES chip hit



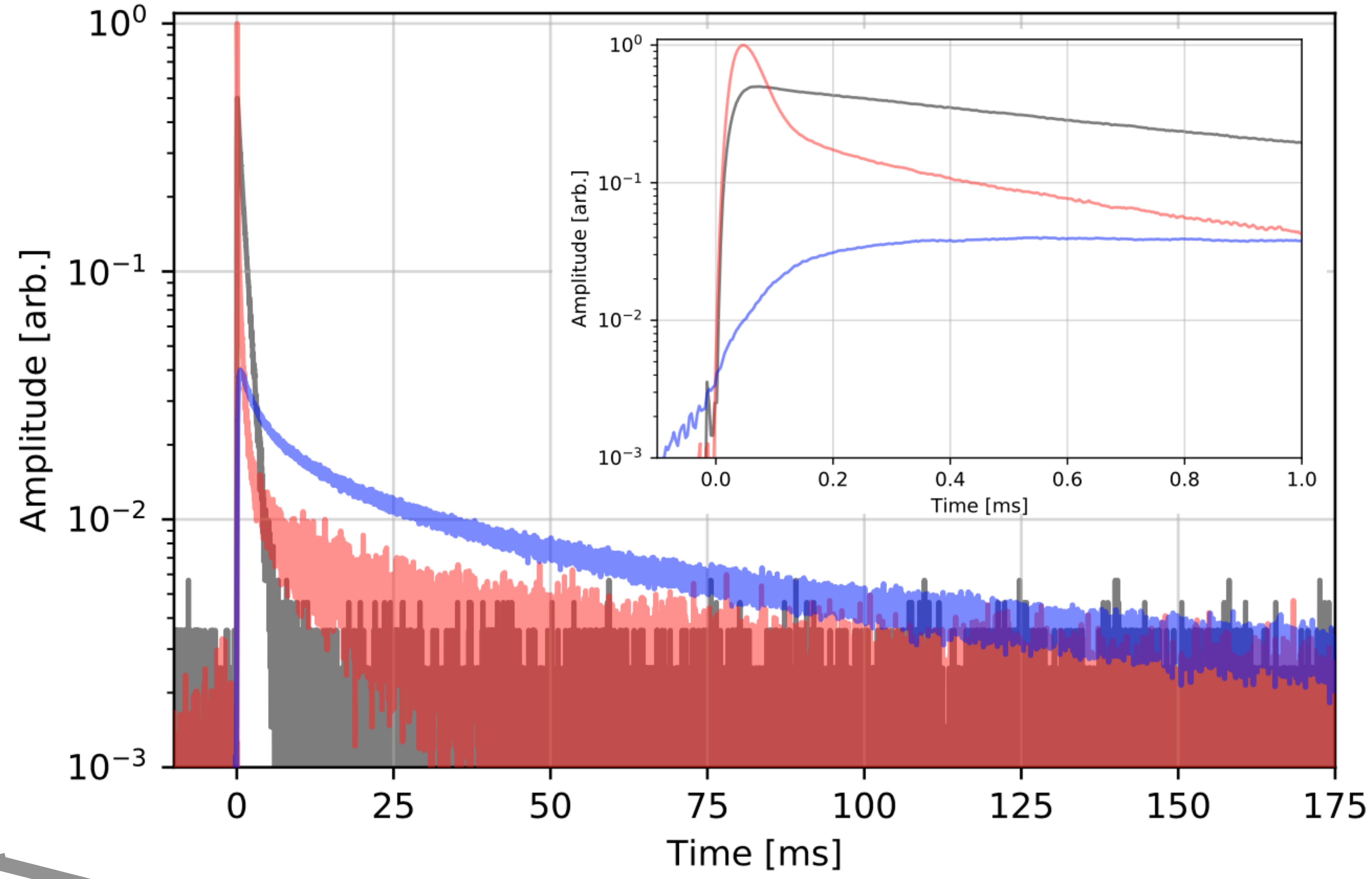


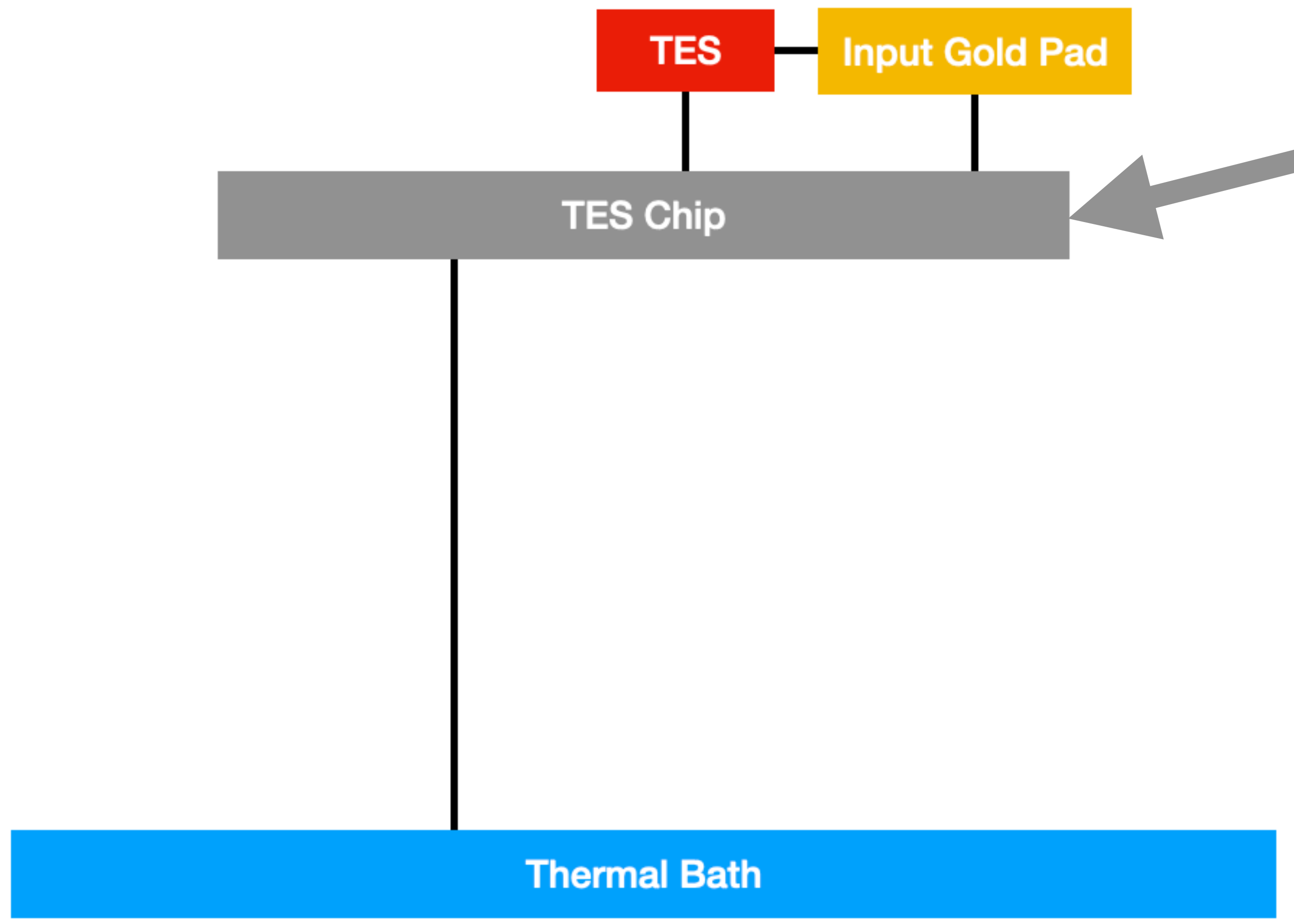


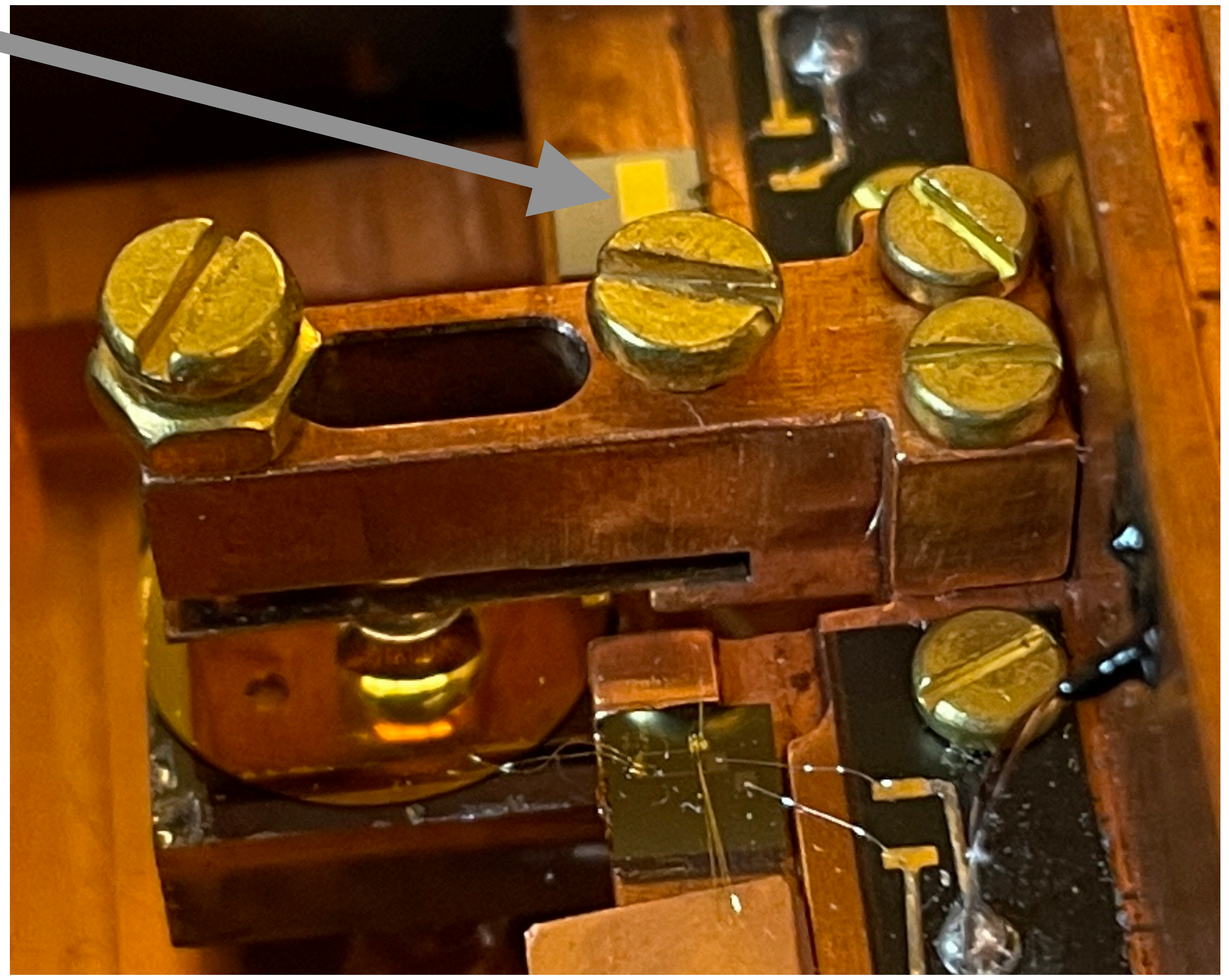
RICOCHET
A Coherent Neutrino Scattering Program

Pulse Shapes

- Blue: Si target hit
- Red: TES chip hit
- Black: Without absorber detector hit

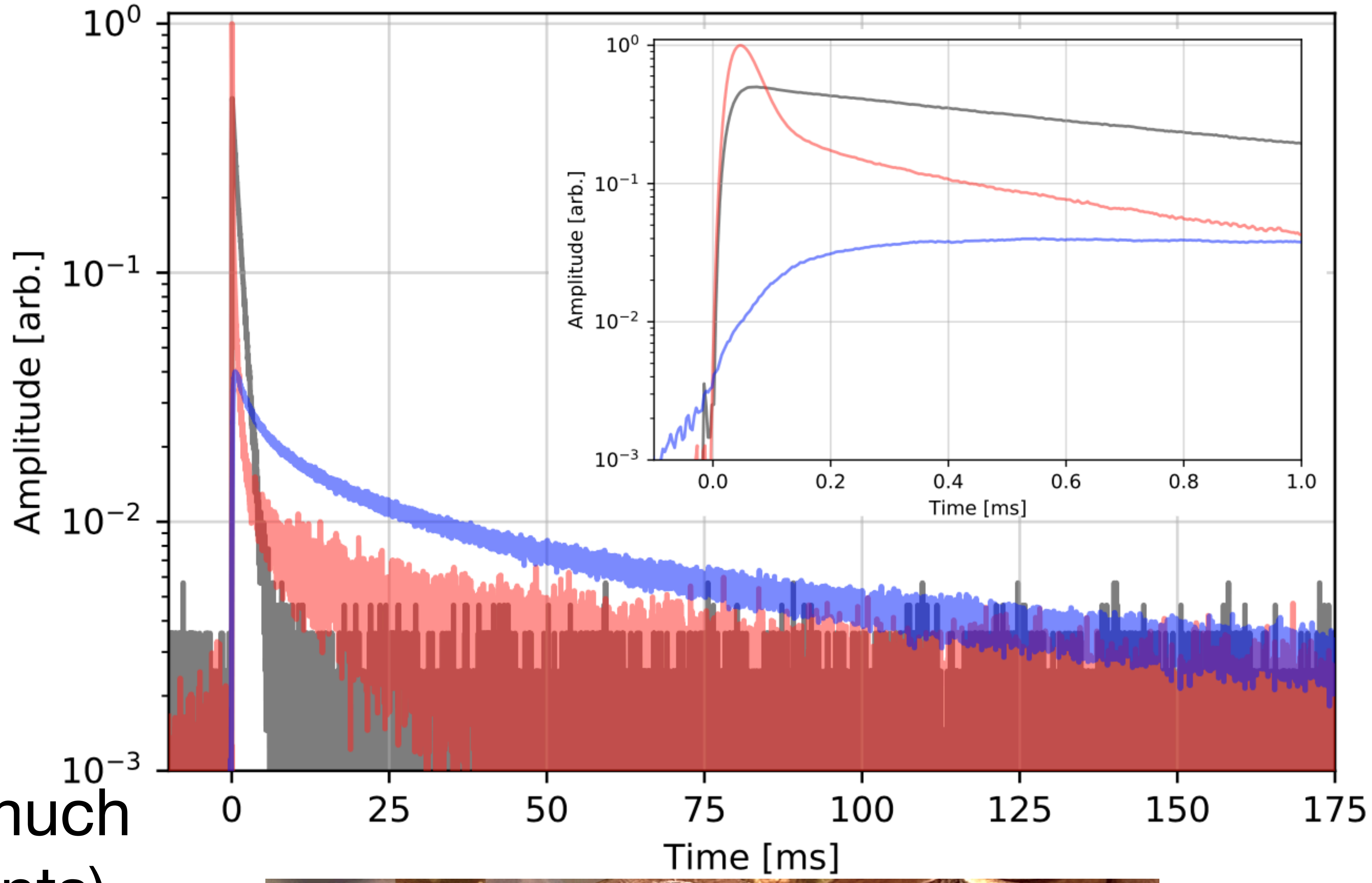


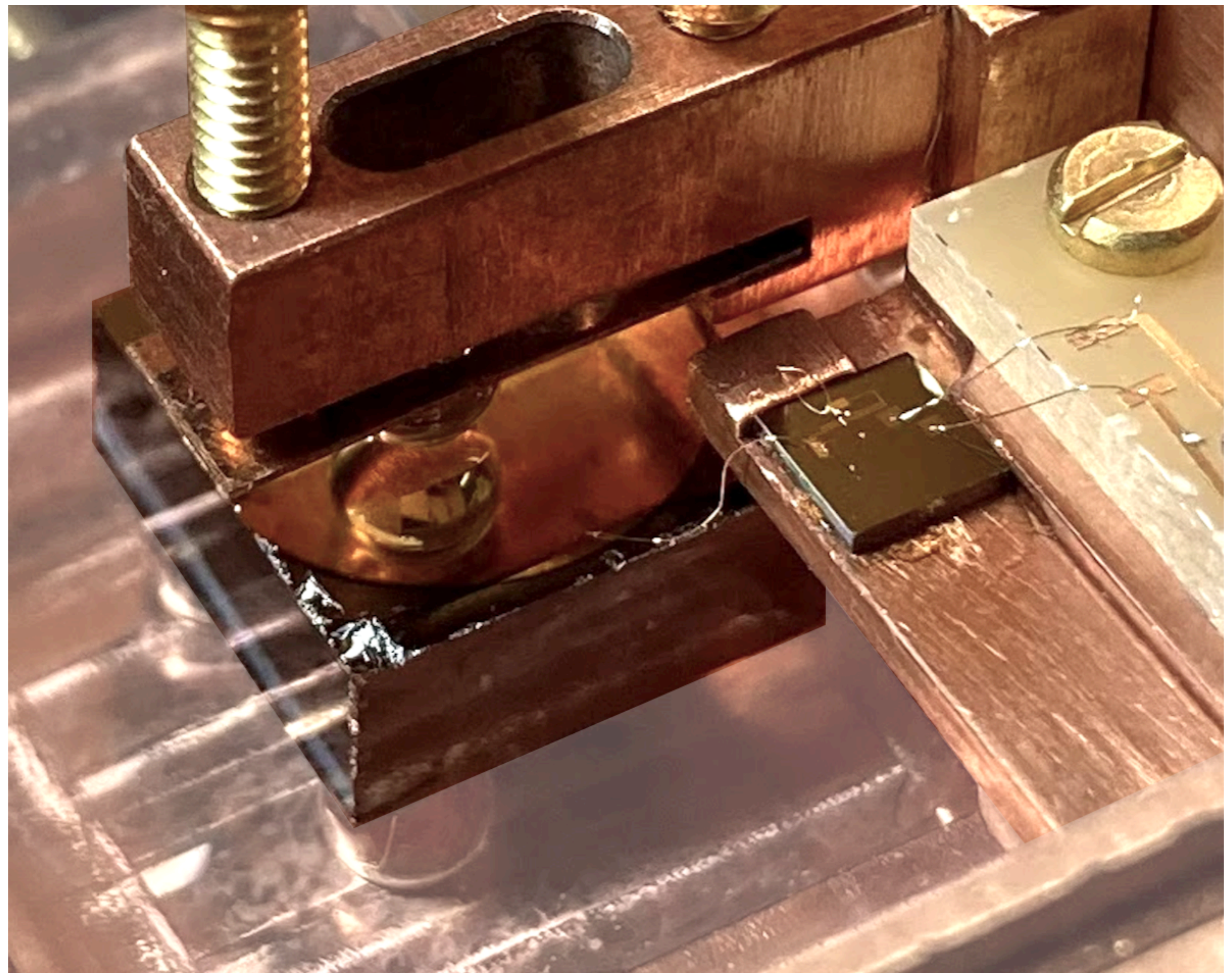




Pulse Shapes

- Blue: Si target hit
- Red: TES chip hit
- Black: Without absorber channel hit
- Events on the with absorber detector are much more complex (large variety of time constants) compared to the single fall time constant of the without absorber detector
- Again, lots of interesting modeling to do to understand these detectors



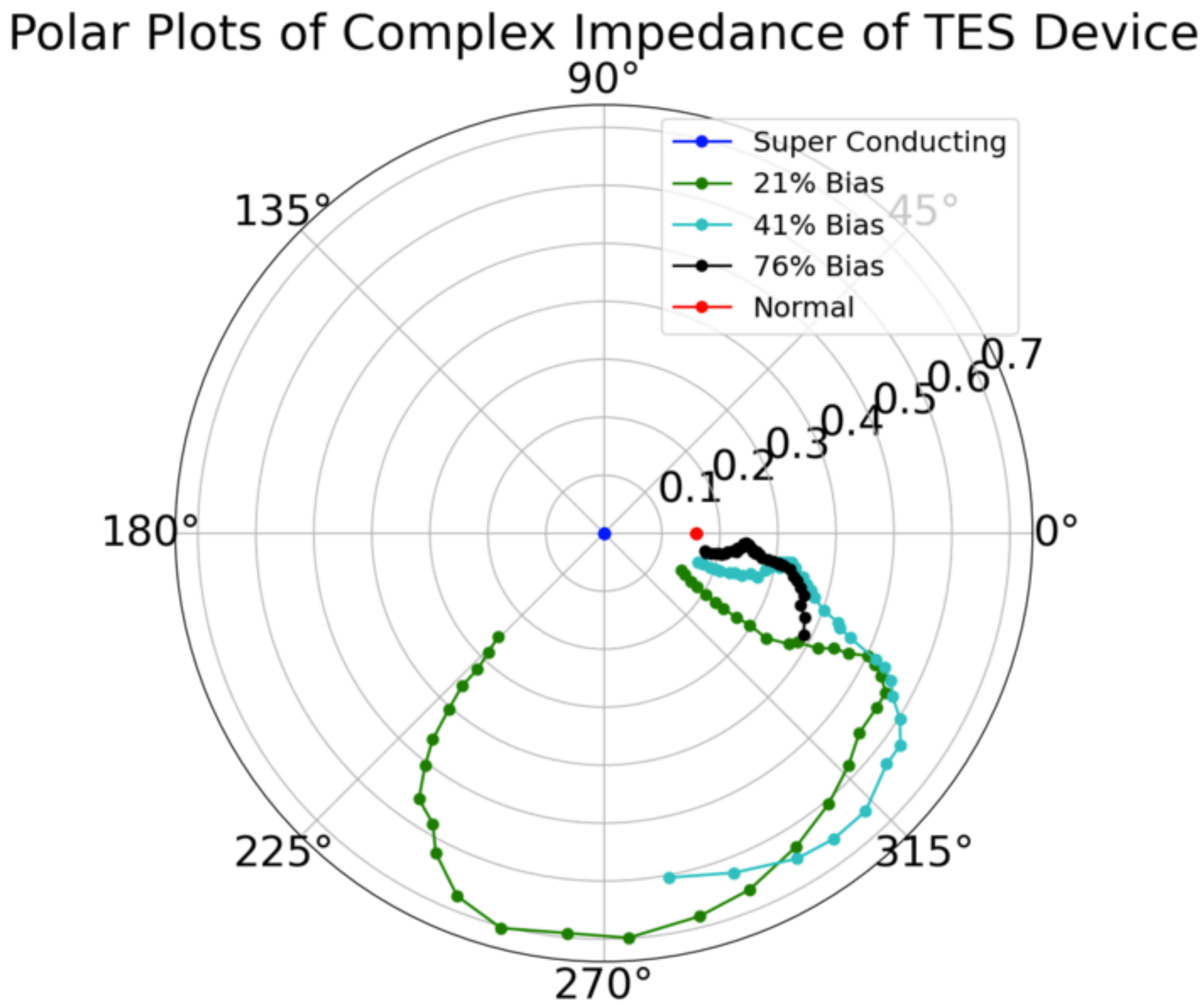


RICOCHET
A Coherent Neutrino Scattering Program

Next Steps: Modeling

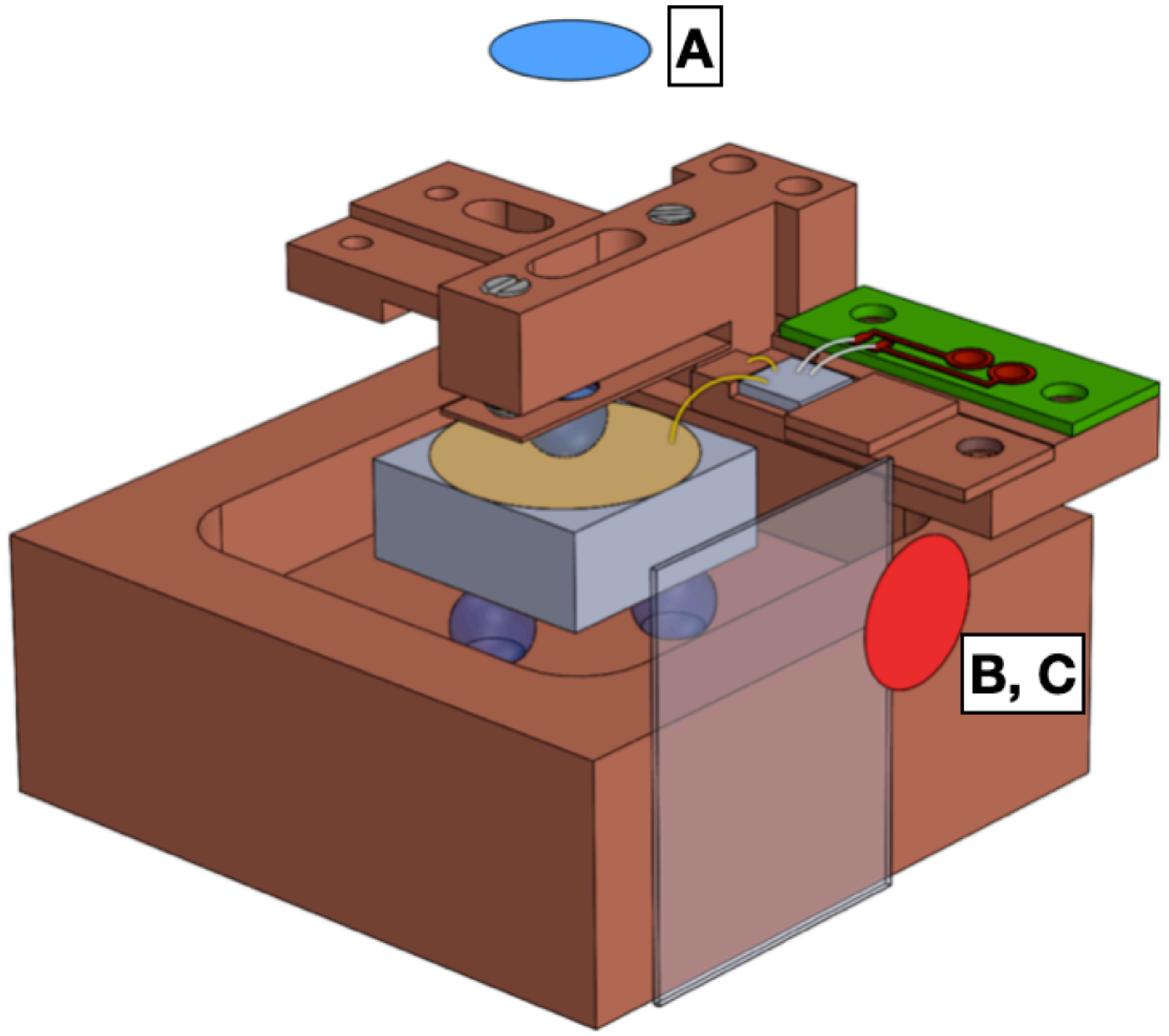
- Compare in greater detail our data with the thermal model
- Includes the pulse data, as well as some initial complex impedance data
  - Collected at UMass Amherst (Charlie Veihmeyer) and Argonne National Lab (Ran Chen)
- More data with lower frequencies has been collected and is being analyzed

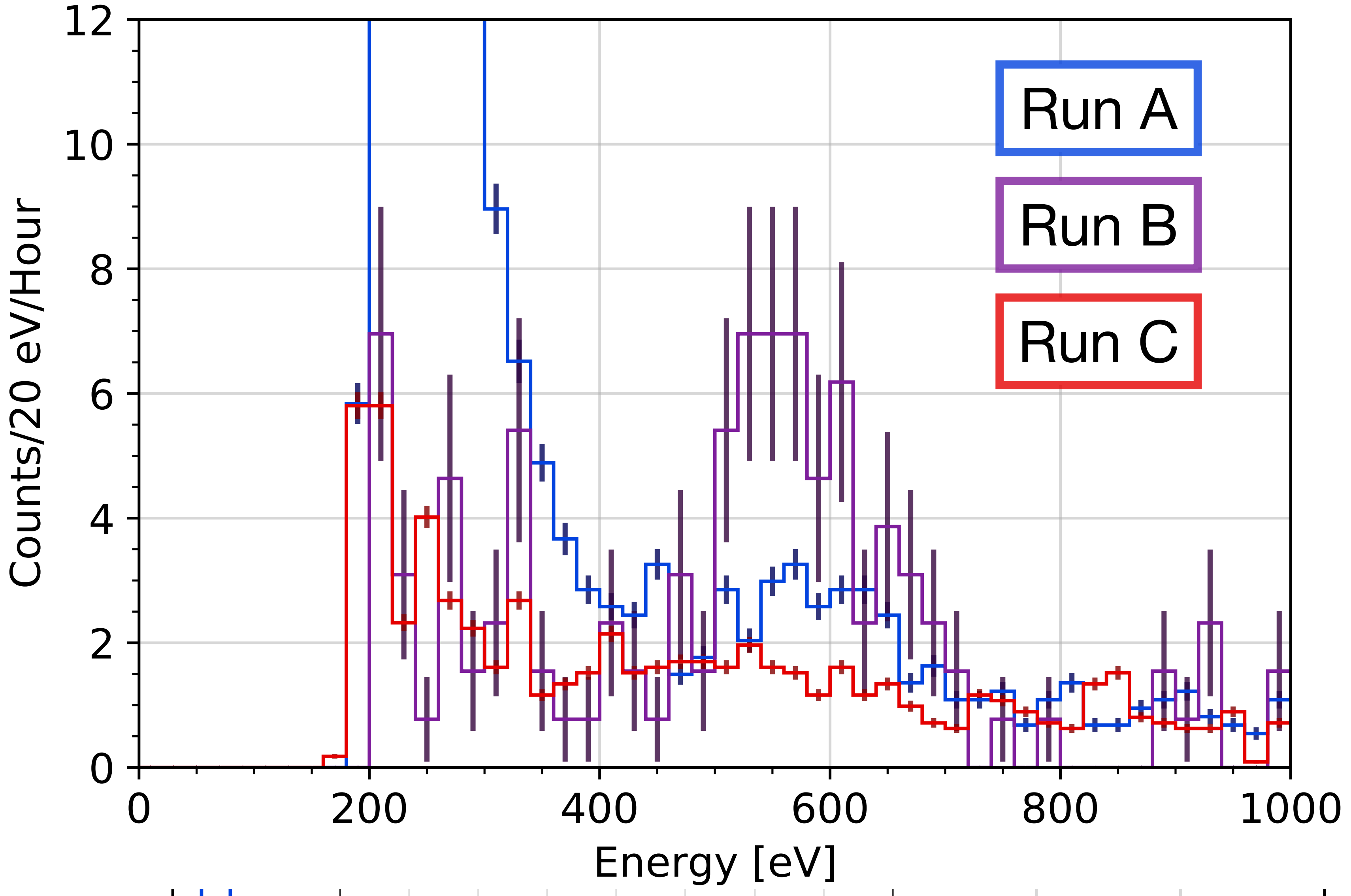
Charlie Veihmeyer

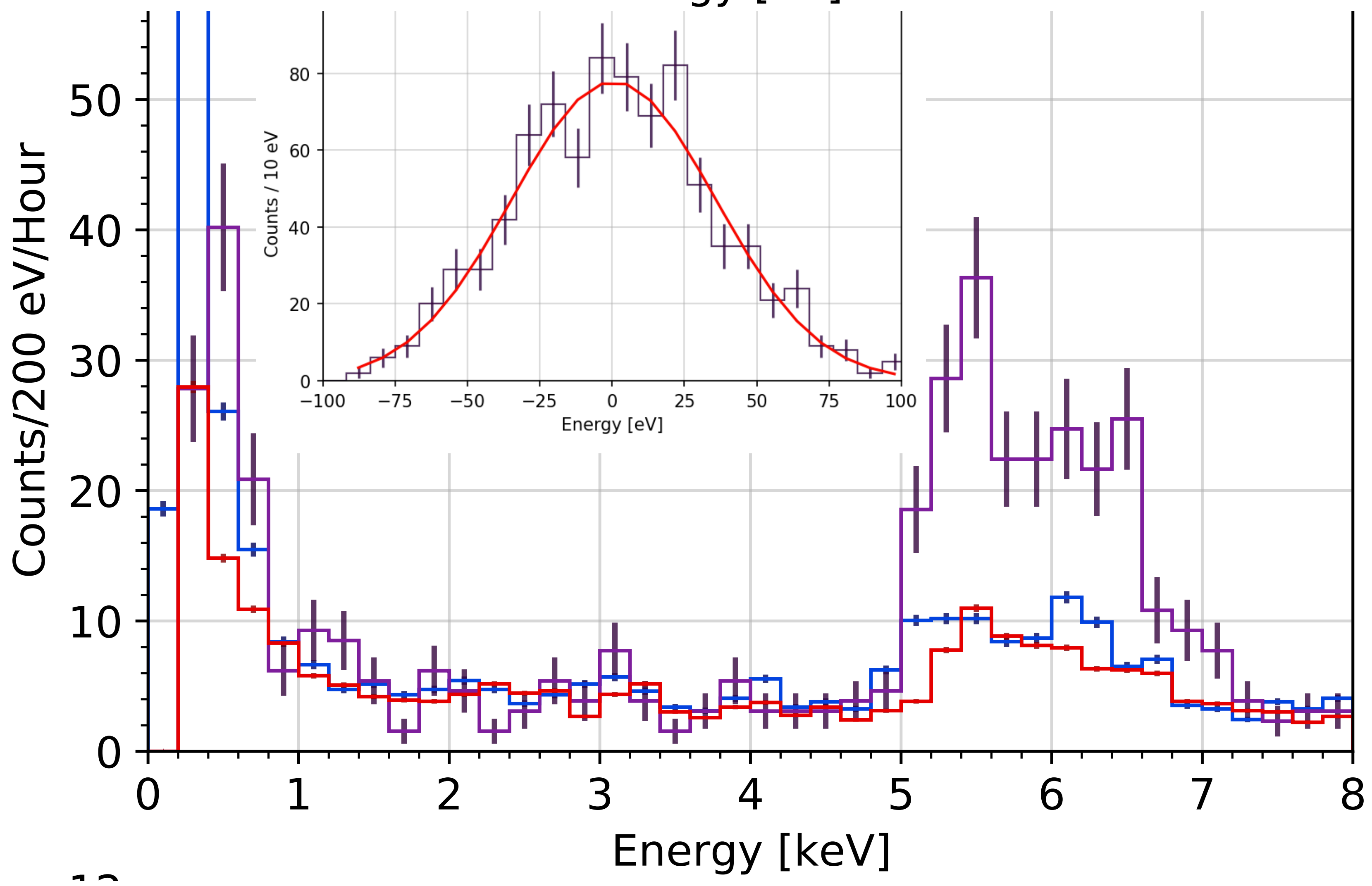


Spectra

- Energy resolution ~35 eV sigma baseline
- X-ray peak width significantly larger than this! (order ~1 keV)
  - Position dependence or some other effect?

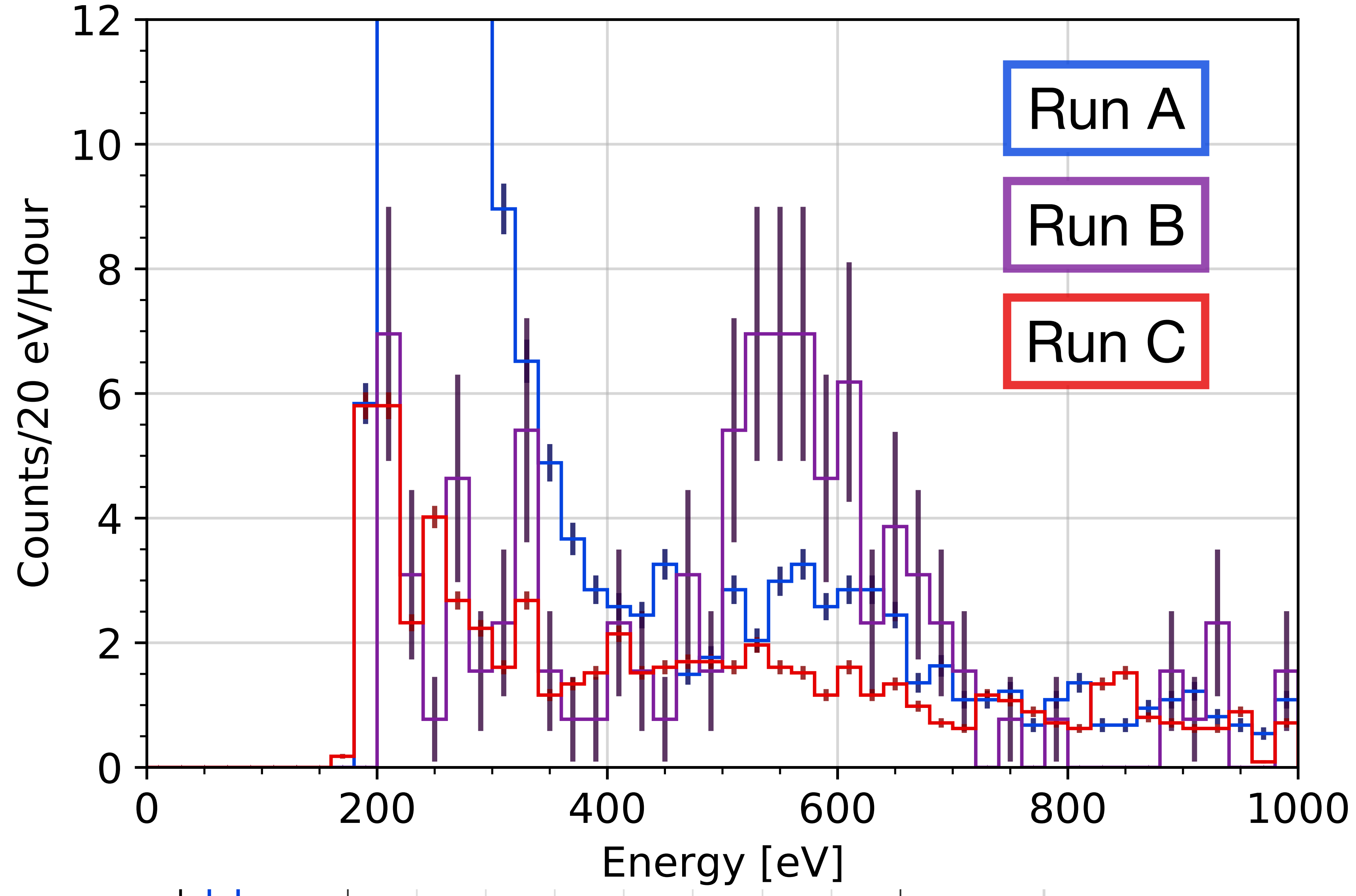


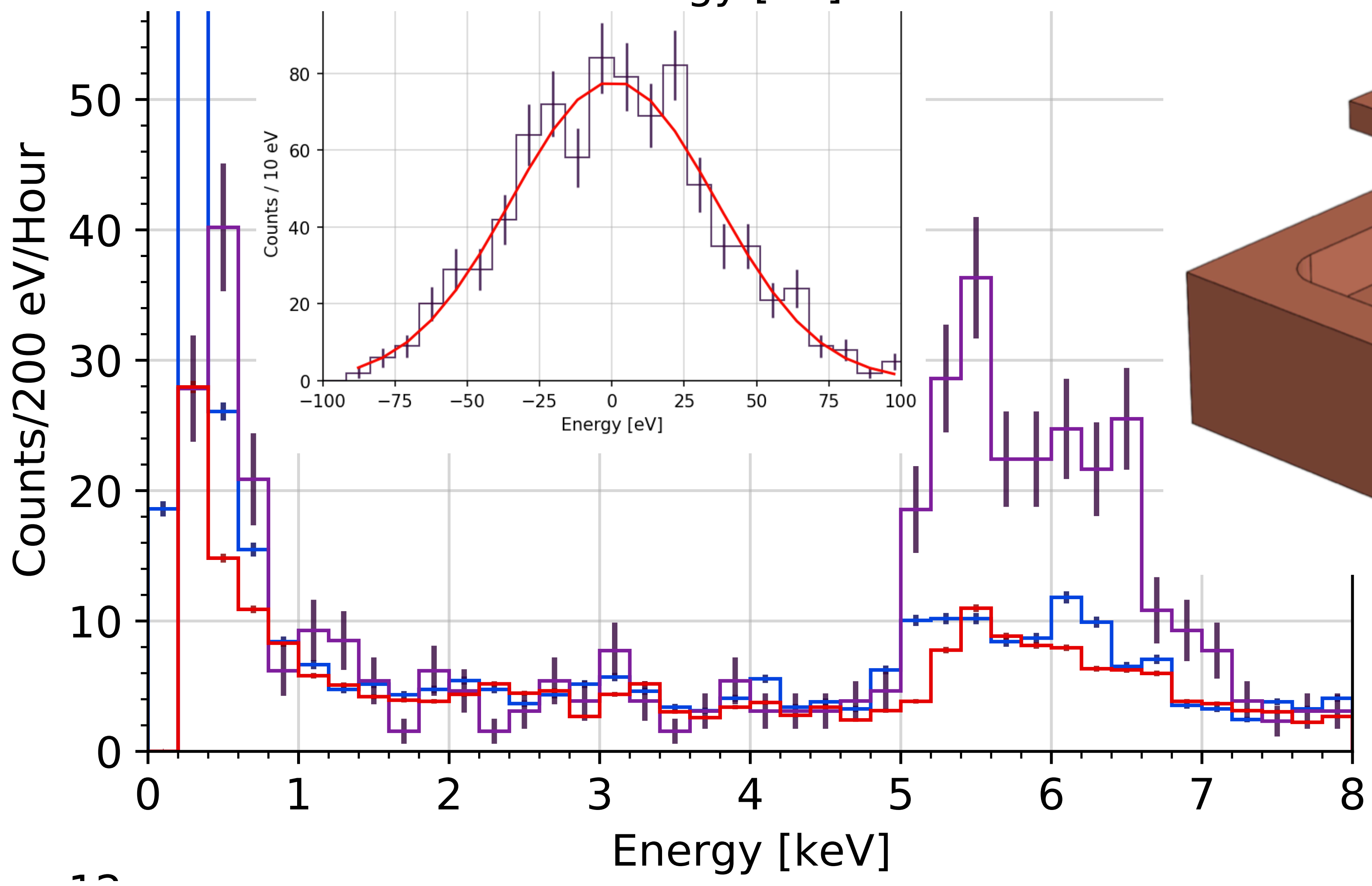


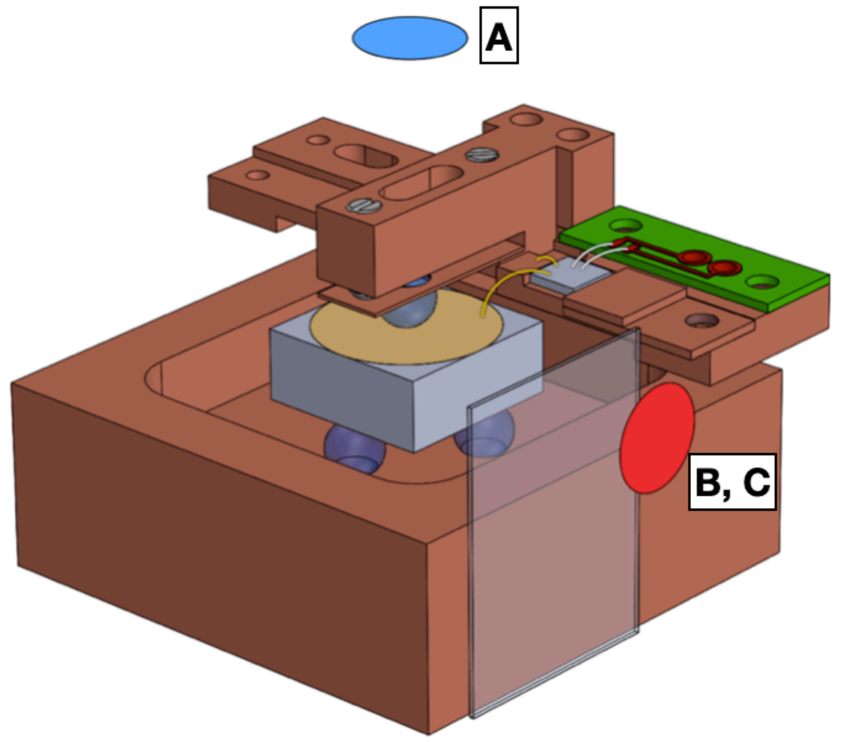


Spectra

- Energy resolution ~35 eV sigma baseline
- X-ray peak width significantly larger than this! (order ~1 keV)
    - Position dependence or some other effect?
- Peak at 550 eV? Disappears when blocking line of sight between X-ray source and sapphire ball
    - Sapphire scintillation? Heat conductance between sapphire and target?







Conclusions

- Several successful runs at UMass studying the modular TES design
- Many un-answered questions, modeling in particular
- Paper with details coming to an arXiv near you

Extras

Doug Pinckney hpinckney@umass.edu

Optimal-Filtered Space

- Three main branches in the data
- “Target hit” branch, events interacting in the Si
- “Chip hit” branch of events hitting just the TES chip
- “Pileup” events