CERES: Cryogenic Experiment to Reconstruct Energy Systematics in TeO2 Bolometers

Tong Zhu (朱彤), Enzo Brandani, Yael Zayats, Bradford Welliver, Yury Kolomensky

Department of Physics, University of California, Berkeley, CA 94720, USA

zhutong@berkeley.edu

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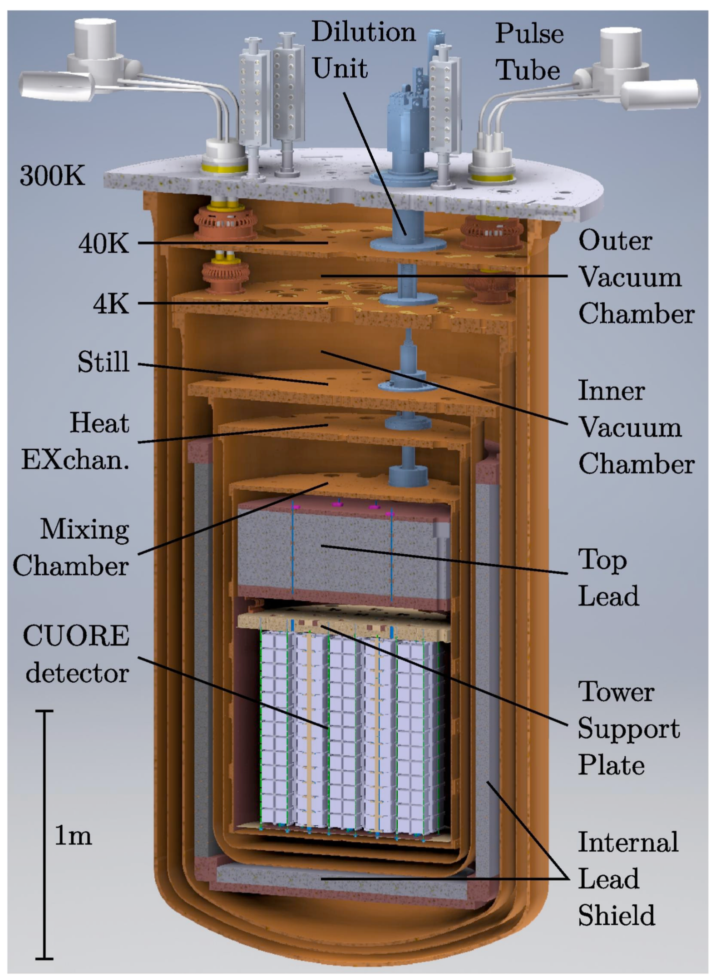
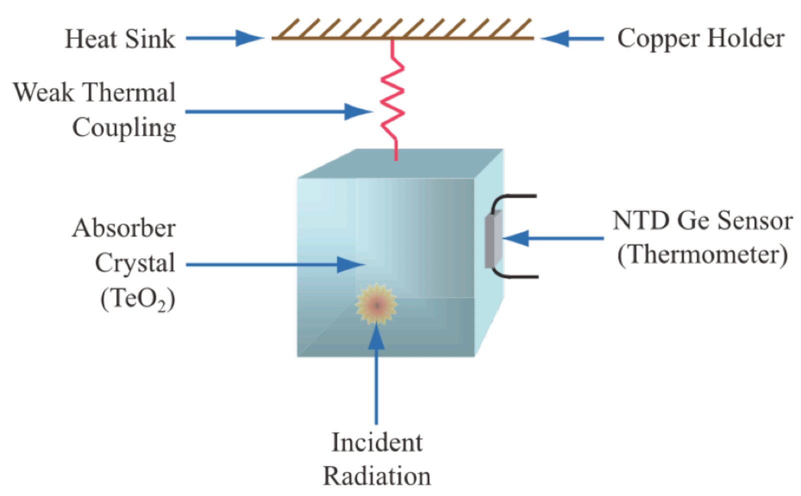
XICHANG CHINA

Introduction: CUORE Detector Response

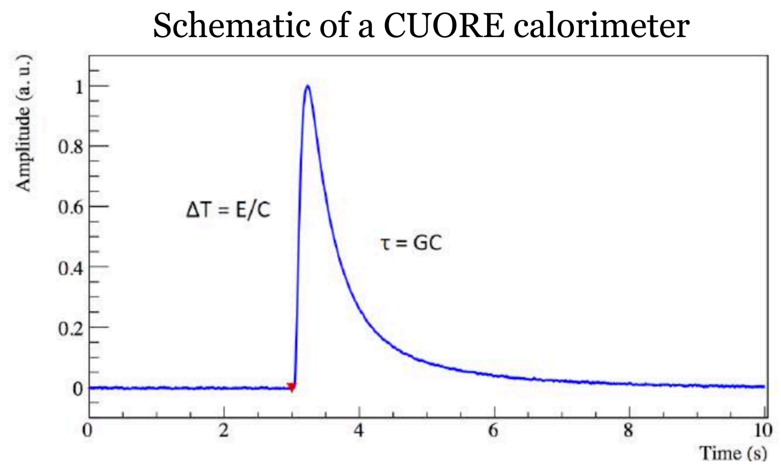
- The Cryogenic Underground Observatory for Rare Events (CUORE) is an experiment searching for $0\nu\beta\beta$ in a ton-scale detector consisting of 19 towers of 988 TeO_2 crystals (206 kg ^{130}Te), located at the Gran Sasso National Laboratory in Italy.
- Each crystal is both a source of ^{130}Te and a calorimeter to record energy deposition by measuring temperature fluctuations at ~ 10 mK.
- For ^{130}Te, the Q value of $0\nu\beta\beta$ is at 2527.5 keV.



Rendering of the CUORE cryostat
Reference: Cryogenics 102 (2019) 9-21



Schematic of a CUORE calorimeter

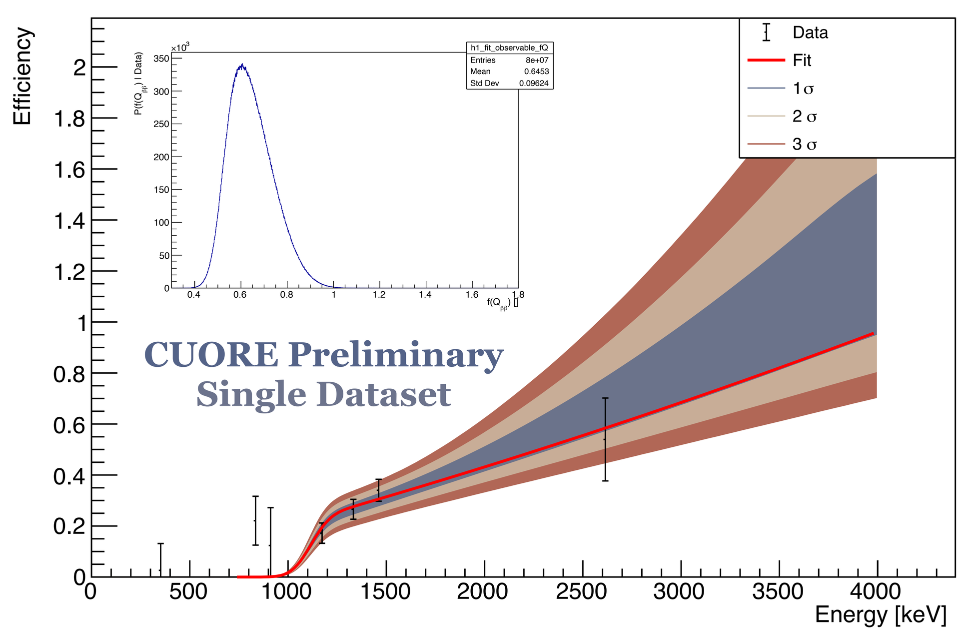


A typical CUORE pulse

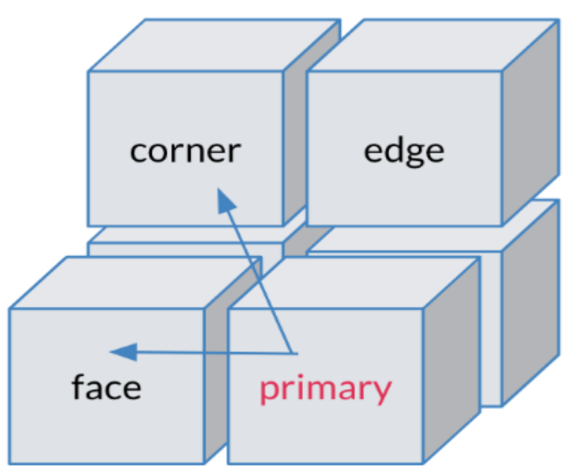
Credit: The CUORE Collaboration

Previous studies from CUORE suggest possible position-dependent effects in bolometers:

- **Energy Systematics:** Energy resolution starts at baseline, and beyond a turn-on point around 0.8-1 MeV, increases with energy following a square-root quadratic. Detector response to gamma/ escape events shows differences.
- **Topological Analysis:** For Multiplicity-2/3 escape events, different event topologies show reconstructed energy discrepancies.



Resolution scaling function of CUORE detectors.



Credit: Anisha Yeddanapudi
Schematic of event topologies.
Multiplicity-i events have i hits in adjacent crystals.

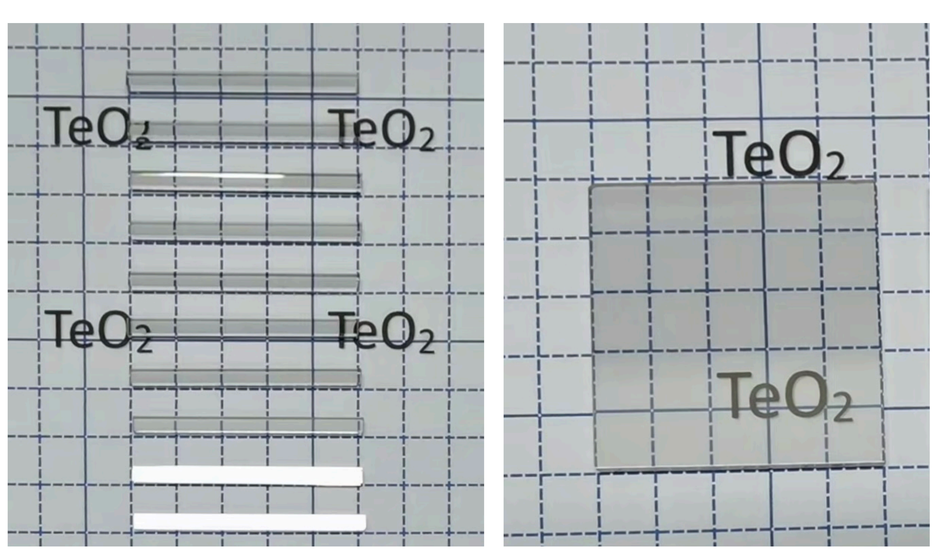
⇒ Those phenomena may arise from the spatial distribution of energy deposition sites within the crystals. To investigate further, we design this controlled single-crystal experiment.

Methodology

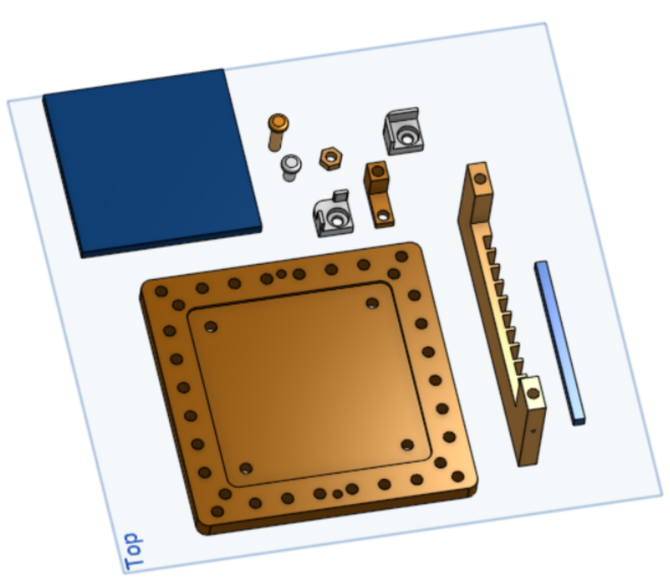
The goal of this experiment is to characterize pulse shapes and energy as a function of the primary interaction point. Measurements with 1D- and 2D-like crystals will yield a response map for TeO2 bolometers and serve as valuable input for phonon simulations.

Experimental setup:

- High-purity TeO_2 Crystals produced from SICCAS in strip (5*0.3*0.3 cm) and slice(5*5*0.3 cm) geometries.



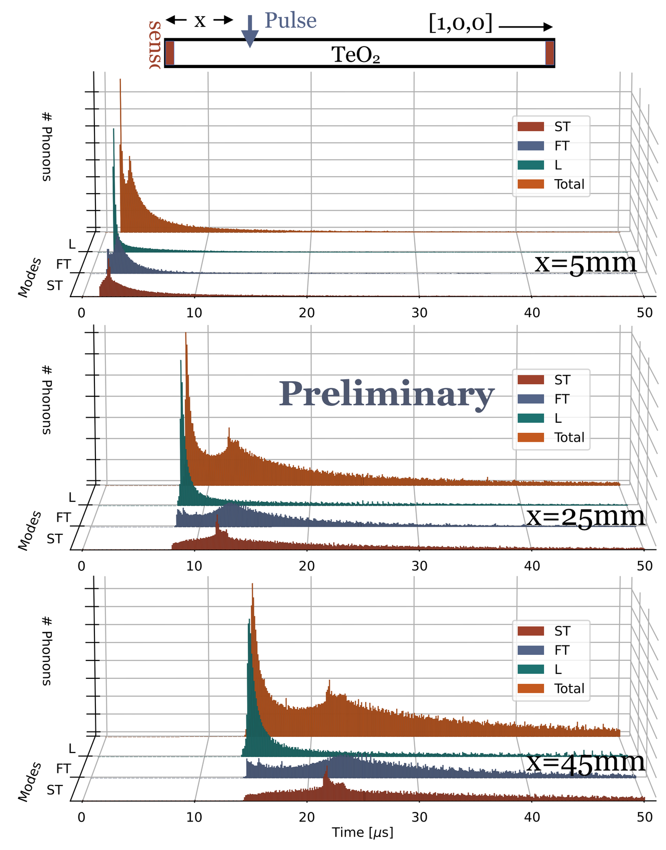
Credit: SICCAS



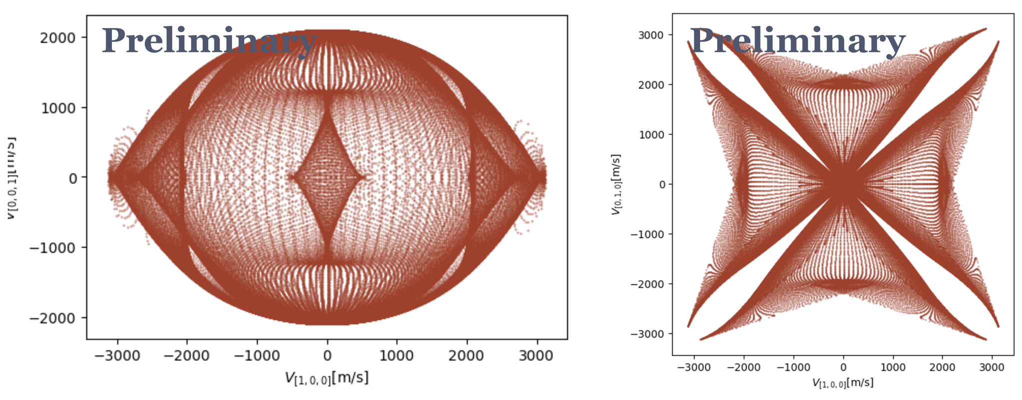
Design of the copper holder.

- Neutron-transmutation doped (NTD) germanium thermistors, identical to those used in CUORE, are employed. We also plan to implement Transition Edge Sensors (TESs) for faster response.
- Measurements are performed in an Oxford Instruments Triton 400 dilution refrigerator with a cryogen-free pulse tube cooler that reaches temperatures down to ~10 mK.
- An off-the-shelf LED serves as a controllable light source. The photons are then delivered via a multimode fiber optic cable inside the cryostat, enabling pulse injection at different crystal positions.

Simulation



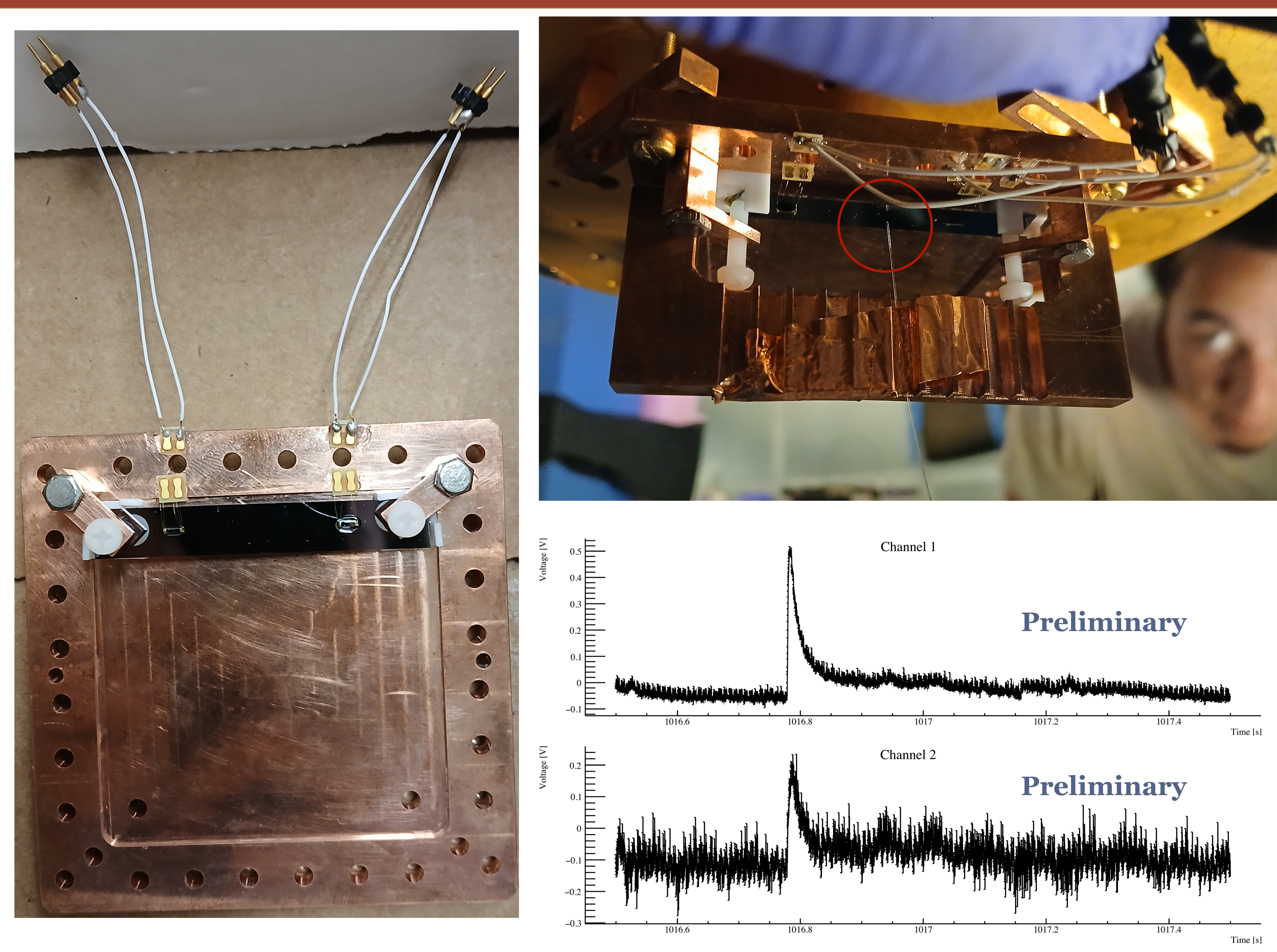
Phonon collection simulation in a TeO_2 strip oriented along [1,0,0]



ST phonon group velocity distribution for TeO_2

Simulation of ballistic phonons predicts position-dependence in phonon collection. Note that refinement of microphysical parameters (e.g. phonon mode fractions) will rely on measurements from this experiment, which will also serve to validate the model.

Validation with Silicon



Experimental setup and a first-run signal.

- Testing with silicon strips produced coincident signals on both channels, confirming proper system operation.
- Control mechanisms for positioning the optical fibers at millikelvin temperatures are being investigated.

Conclusions and Outlook

- We present the design and testing results of a cryogenic single crystal experiment exploring position-dependent effects in TeO2 bolometers.
- TeO_2 strips will be implemented in upcoming runs, and MEMS (micro-electro-mechanical systems) mirrors for fine optical control are currently under development.
- In parallel, we are advancing the phonon simulation, improving the model by incorporating additional physical information. As experimental data become available, these results will be used as inputs to investigate the underlying microphysics

Acknowledgement

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