

CERES: Cryogenic Experiment to Reconstruct Energy Systematics in TeO_2 Bolometers

Berkeley
UNIVERSITY OF CALIFORNIA



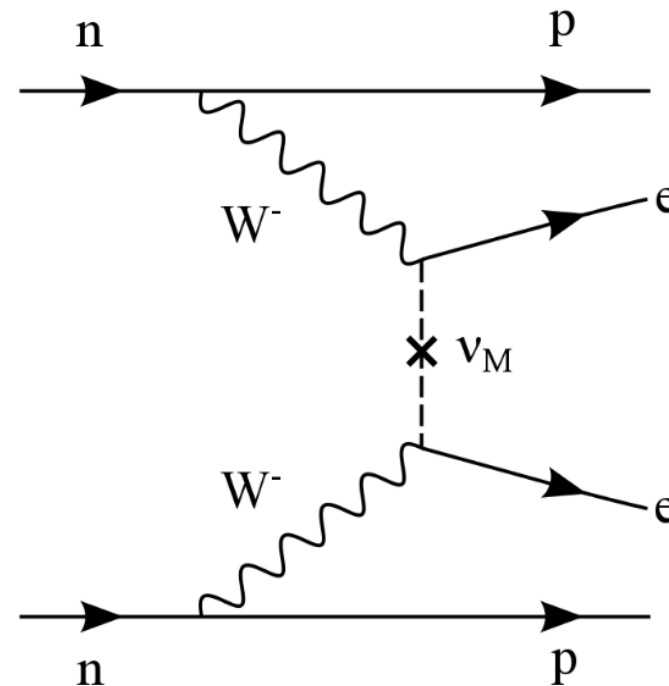
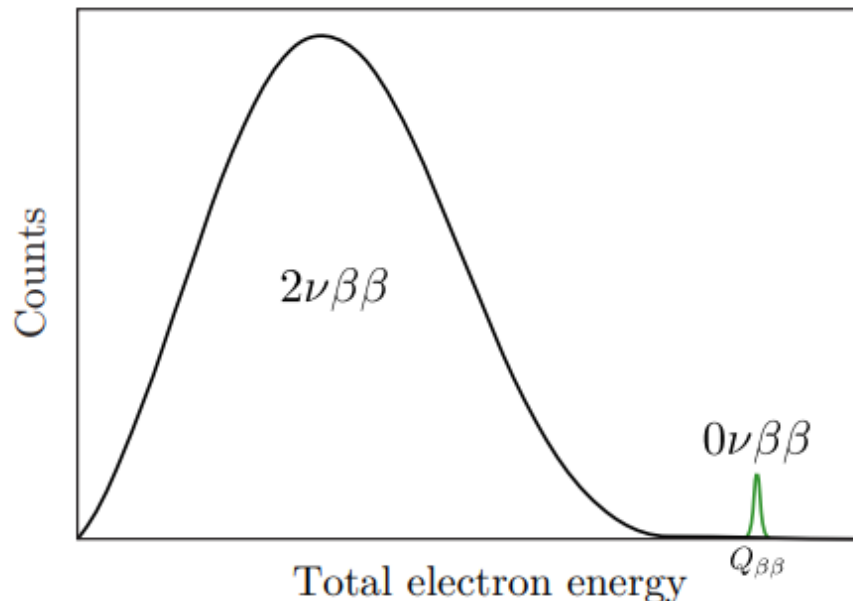
NNPSS
Student Talks
07/03/26

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Tong Zhu
Yury Kolomensky



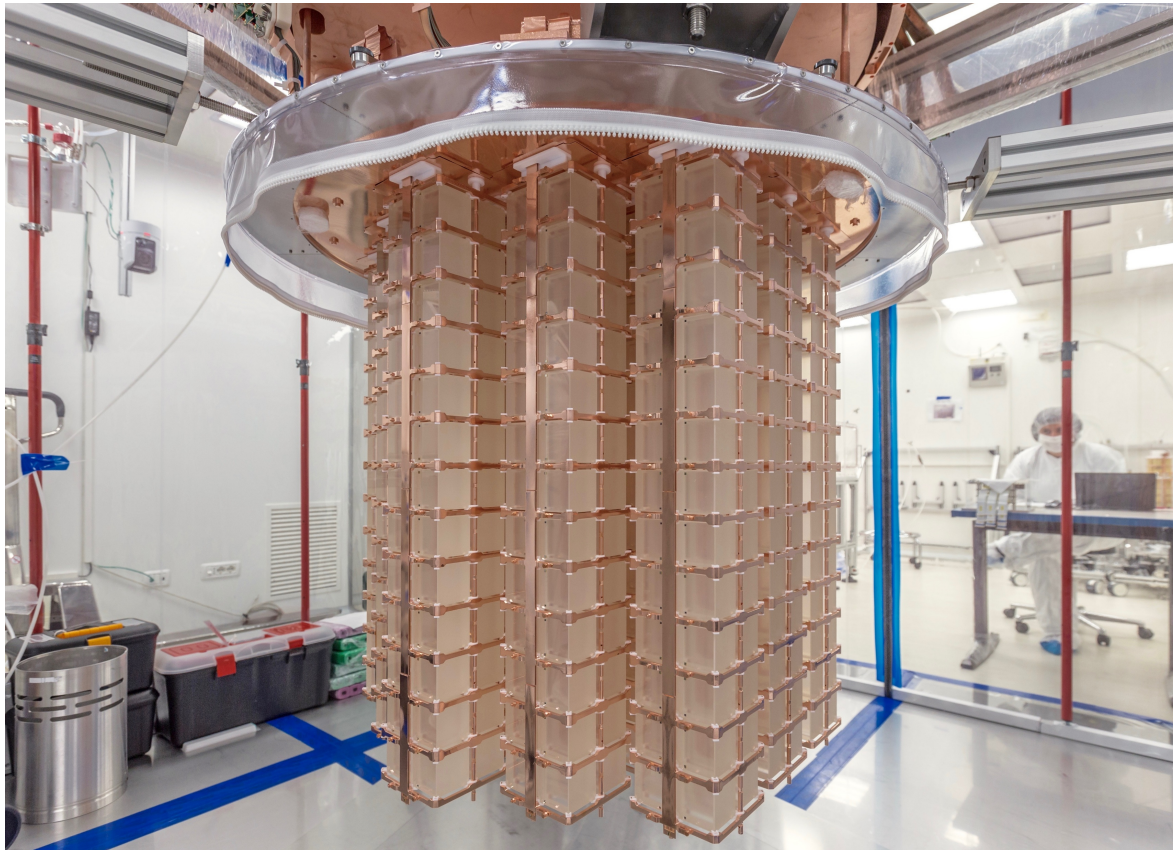


- Beyond Standard Model nuclear decay $(A,Z) \rightarrow (A,Z+2) + 2e$
- Observation would:
 - Determine Majorana nature of neutrino
 - Violate lepton number symmetry
 - Contribute to understanding of matter/antimatter asymmetry





Cryogenic Underground Observatory for Rare Events



- Searching for neutrinoless double beta decay
- Employs array of 988 TeO_2 crystal bolometers at $\sim 10\text{mK}$
- $Q_{\beta\beta} \sim 2530 \text{ keV}$ for $\text{Te}130$

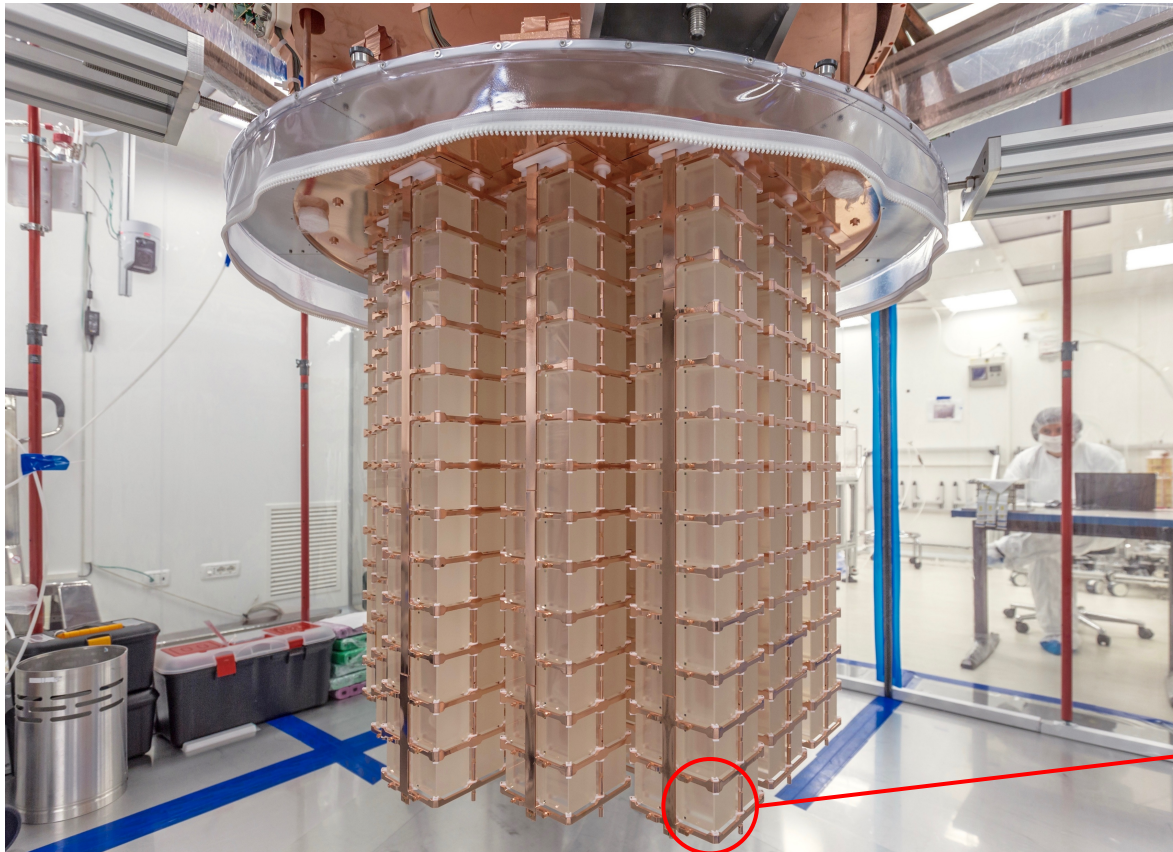
Cryostat construction | CUORE

Background: CUORE Experiment

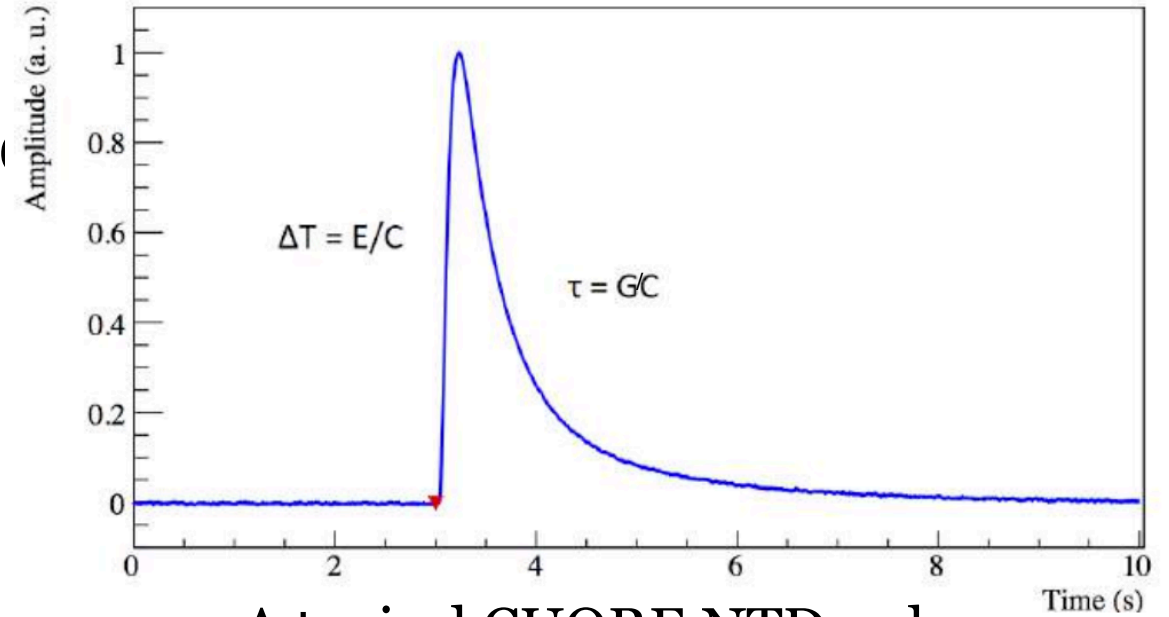
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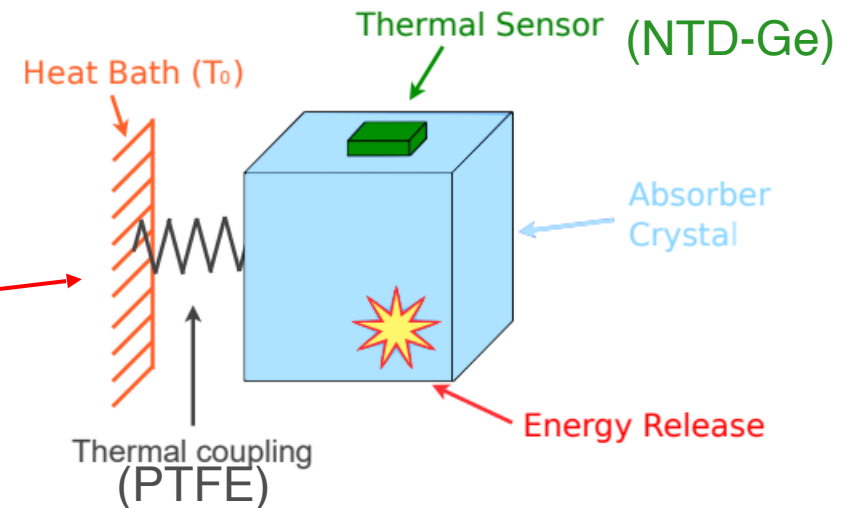
Cryogenic Underground Observat



Cryostat construction | CUORE

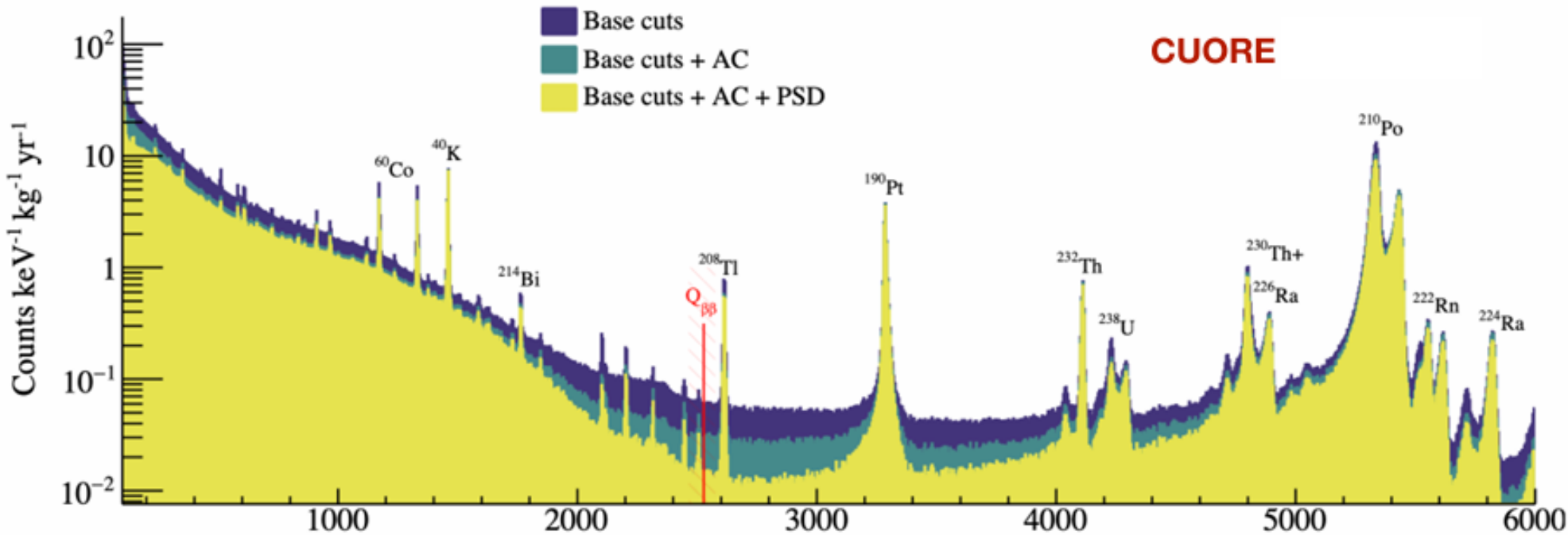


A typical CUORE NTD pulse





Extract energy from bolometer signals and compile to reconstruct spectrum



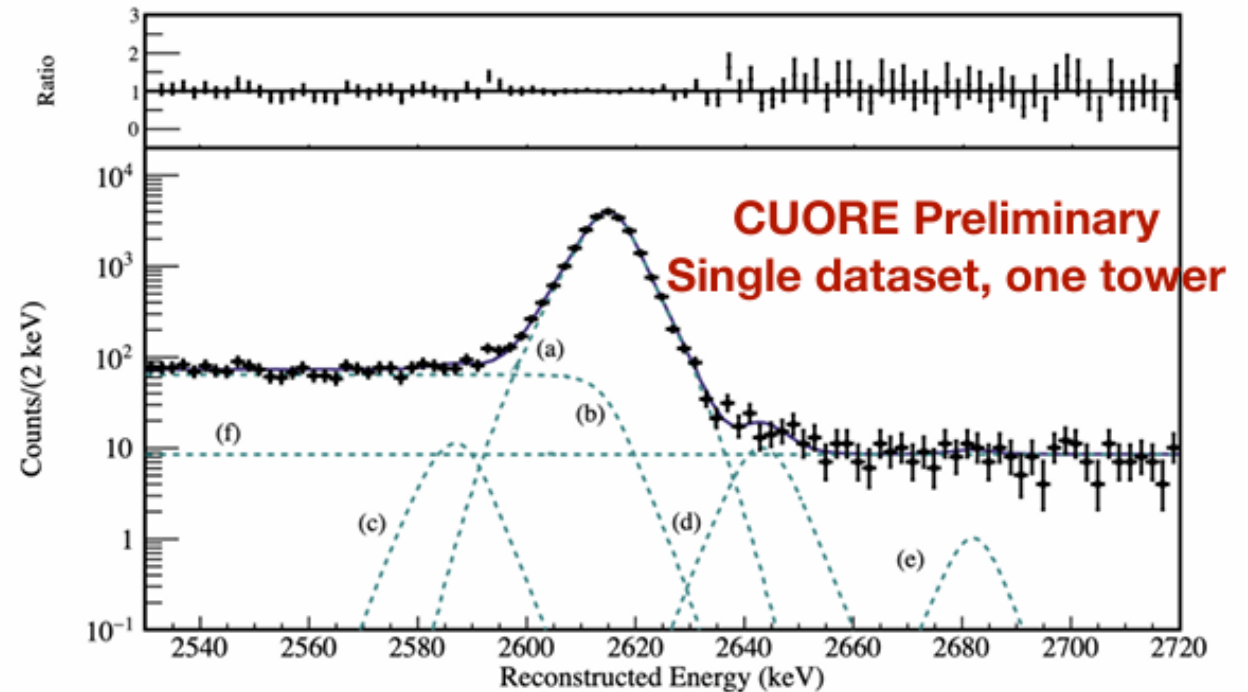
- Empirical model used to calibrate energy resolution close to $Q_{\beta\beta}$ using high statistic photopeak

CUORE Collaboration, Constraints on lepton number violation with the 2 tonne-year CUORE Dataset. *Science* **0**, eadp6474 DOI:10.1126/science.adp6474

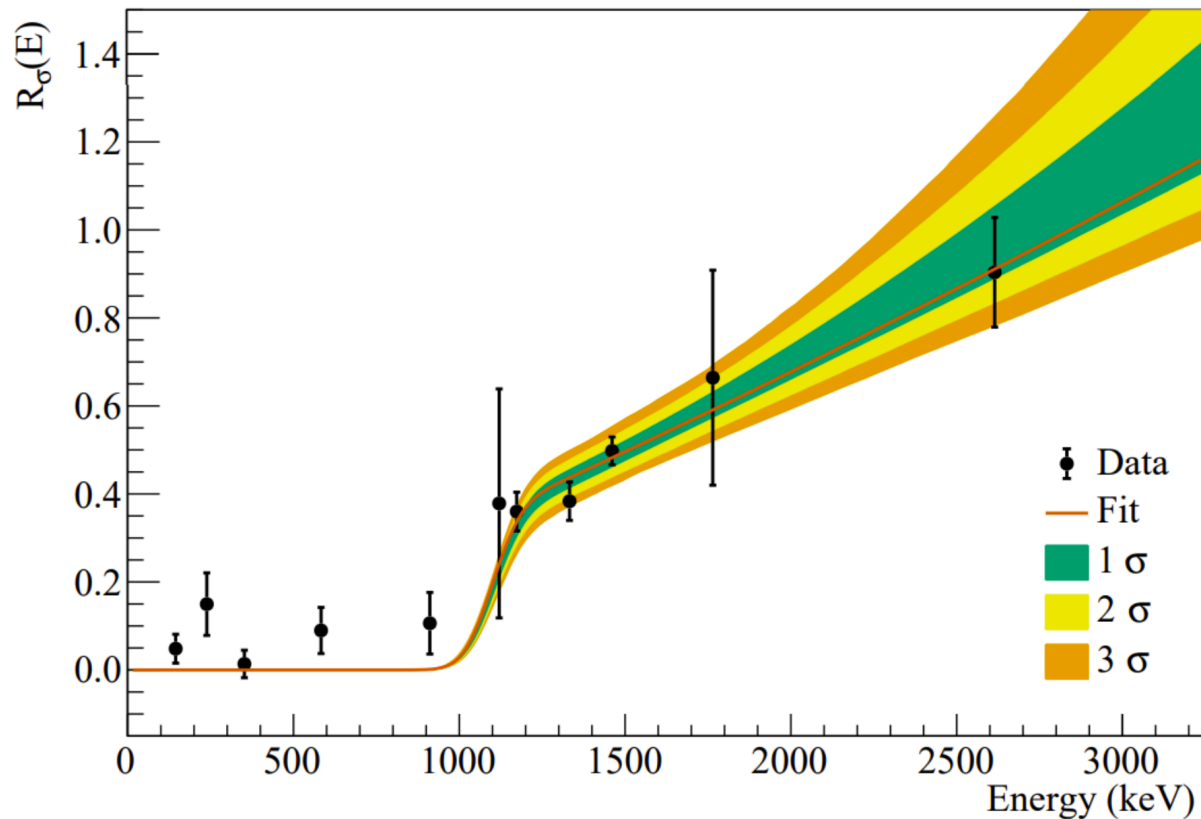


The model consists of:

- Multi-Gaussian response function (a)
 - purely phenomenological!
- Multi-Compton background (b)
- Flat background (f)
- Coincidence/escape peaks (c,d,e)



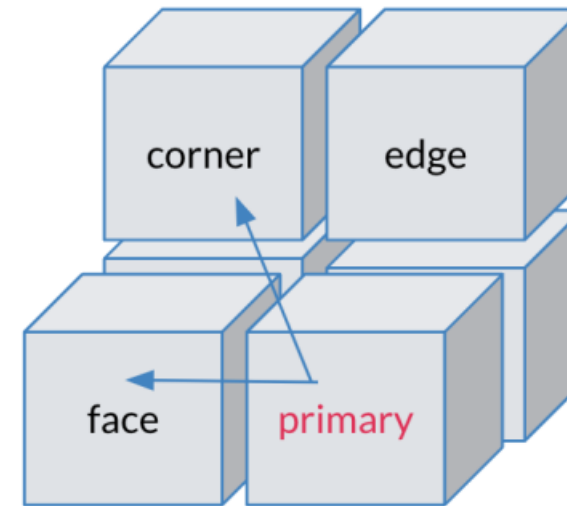
σ of multi-gaussian tells us the energy resolution



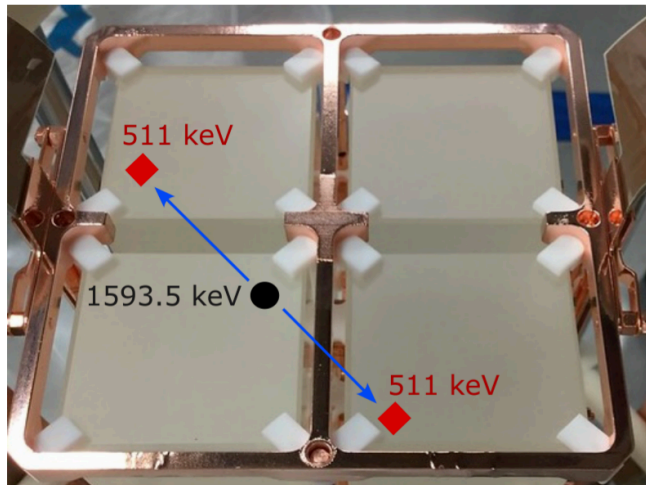
- Unexpected nonlinear dependence on energy in energy resolution
- Resolution gets **worse** with increasing energy!
- Hypothesize that site of energy deposition contributes to this effect
 - related to energy dep. of Compton scattering/multisite events



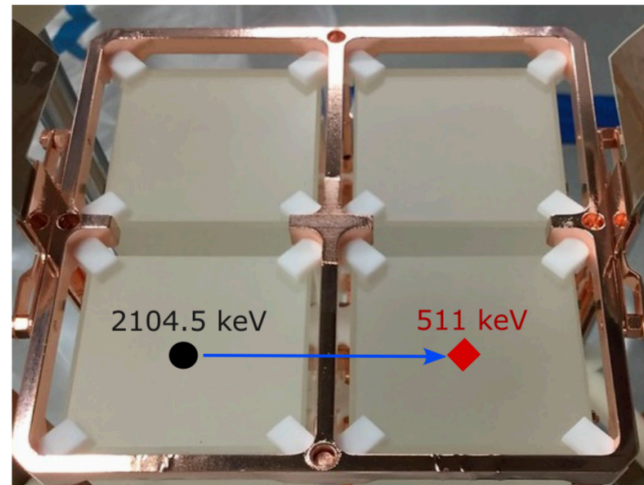
- Position dependence unexpected in slow detectors/thermal phonon propagation
- Initial investigation => high multiplicity study



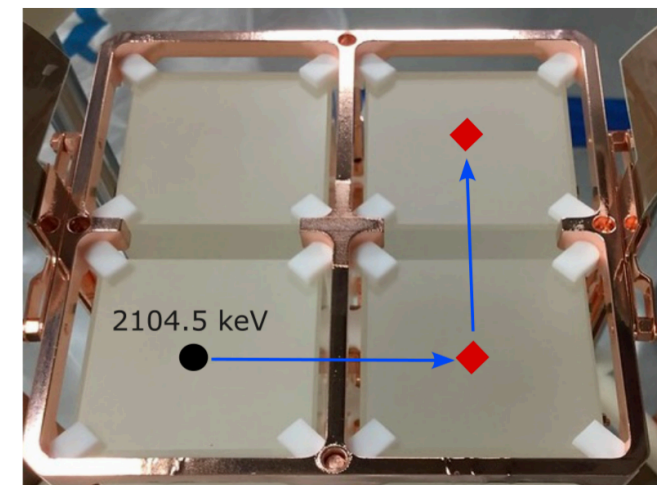
Categorization of topologies considered: Face (F), Corner (C), Edge (E), and None (N)



Multiplicity 3: Double Escape



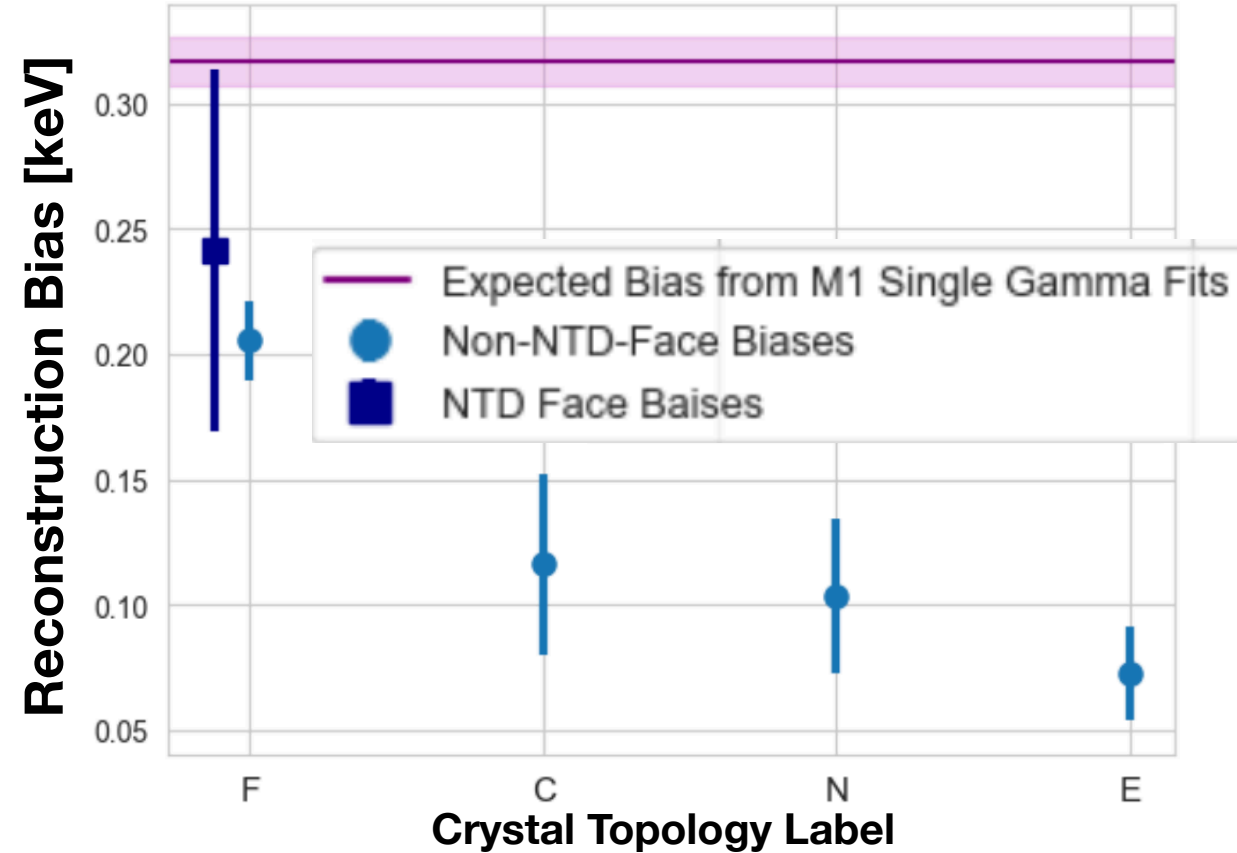
Multiplicity 2: Single Escape
Anisha Yeddanapudi, UC Berkeley Honors Thesis 2024



Multiplicity 3: Single Escape



- Small effect (order sub-KeV) on reconstructed mean + resolution, but profound impact!
- Challenges assumptions/ understanding of our detector microphysics
- Requires precision measurement





Next phase: CERES (Cryogenic Experiment to Reconstruct Energy Systematics) to quantify + understand effects

- intrinsic to the crystal?
- Related to single- vs multi- vertex events (β vs γ)?
- Effect from thermal links?
- Ballistic to thermal phonon conversion?

Main backgrounds in low energy cryogenic calorimetric experiments:

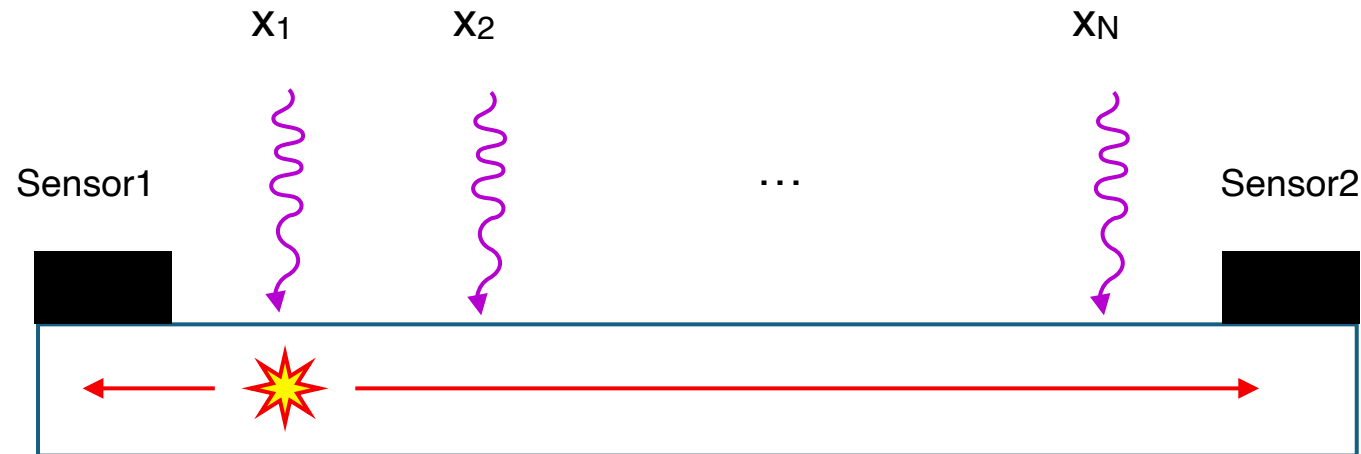
- Surface alphas (enclosure contaminants)
- High energy gammas in ROI

Potential to fully eliminate both with robust position resolution!



Want to:

- Study position dependence of CUORE crystals in 1 and 2 dimensions along relevant crystal axes



How?

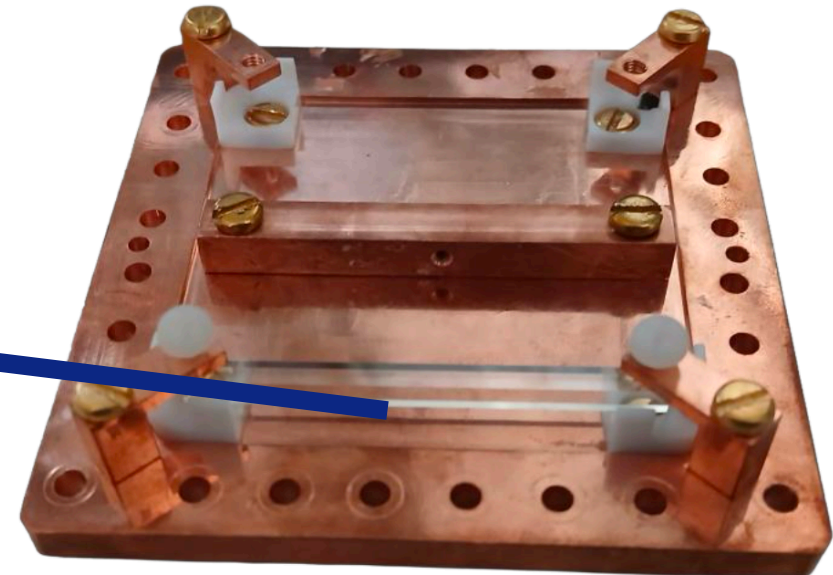
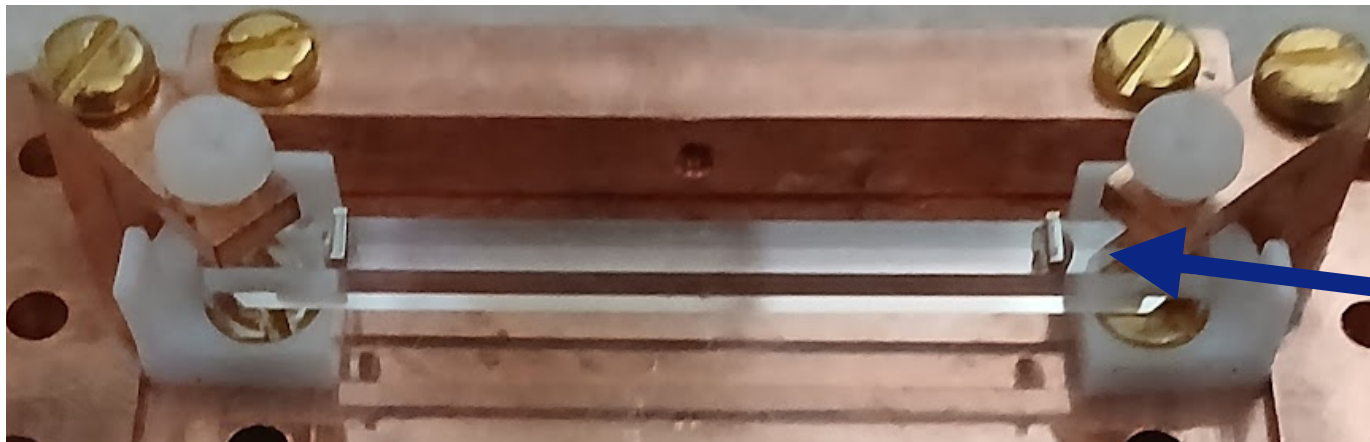
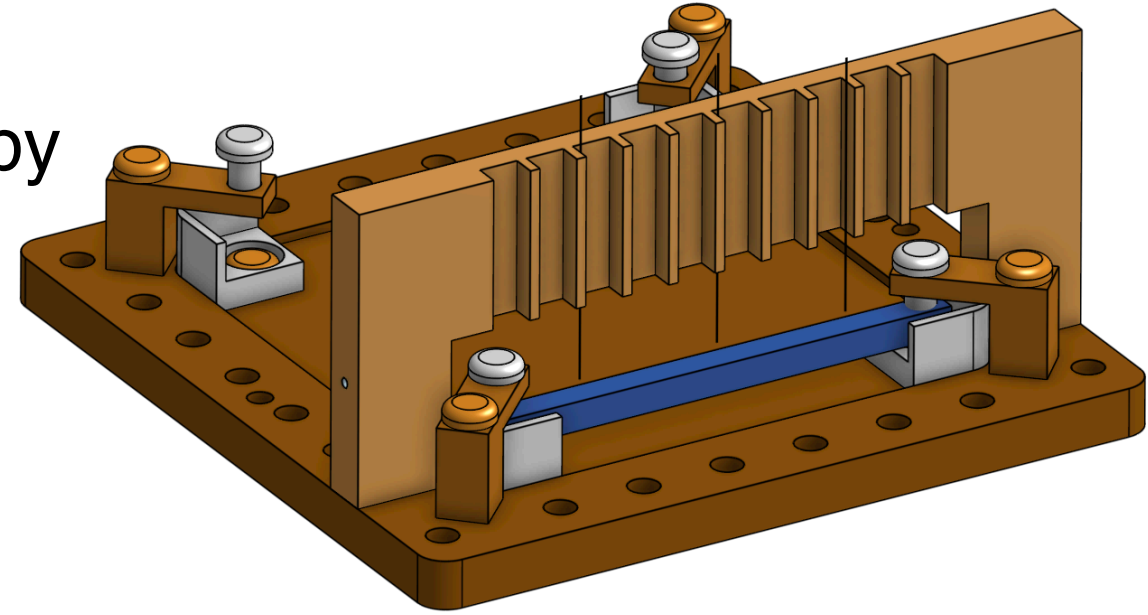
- Deposit energy at localized sites in crystals
- Scan with UV light source above TeO_2 band gap
 - 255 ± 5 nm LED
- Place sensors at corners/edges of crystals
- Measure timing difference, amplitude difference, etc in pulses as function of E deposition position

CERES: Experimental Design

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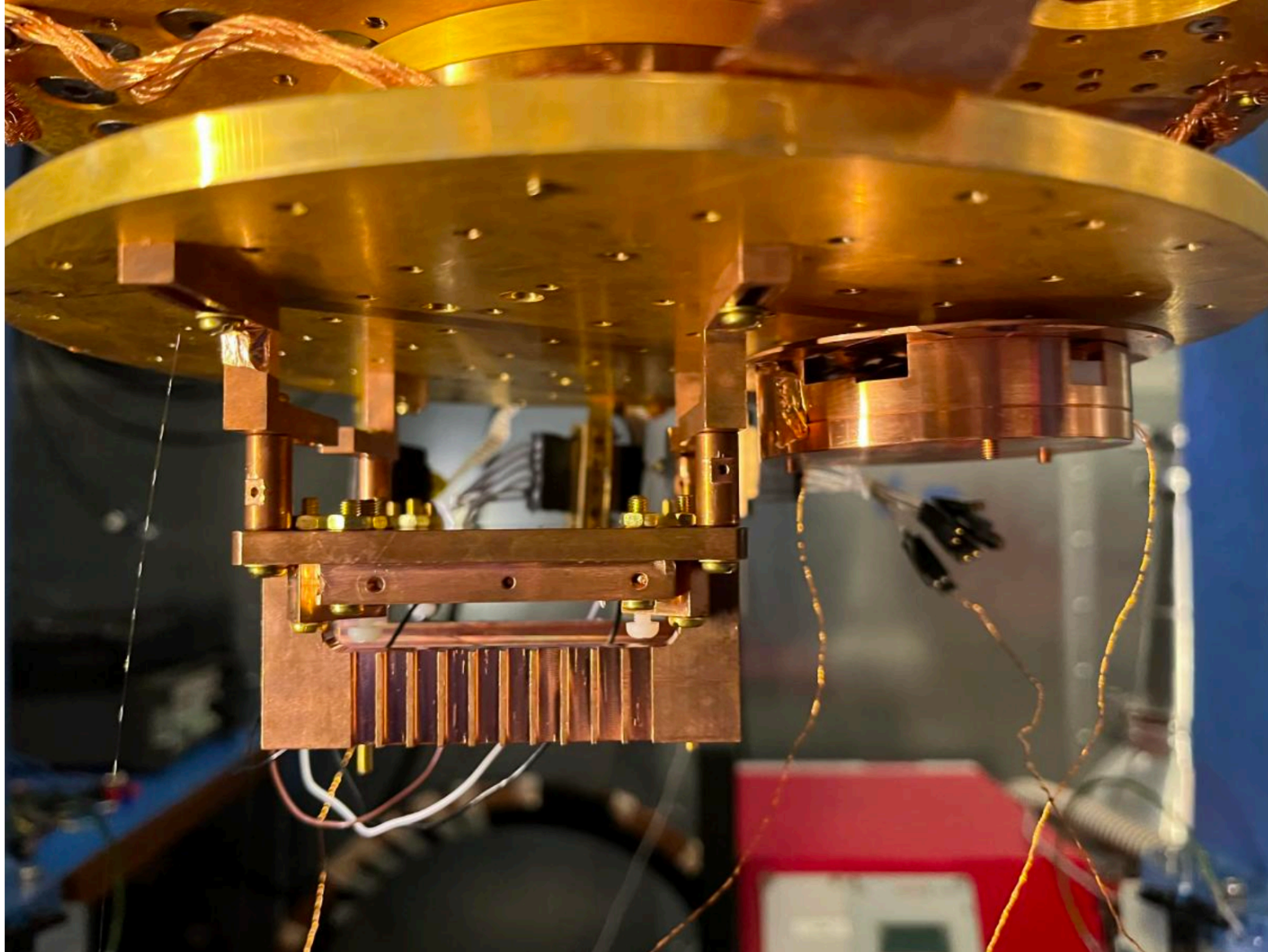


- Crystals lie on Teflon corners secured by nylon screws
- Use single ended optical fibers to transmit photons
- Plan runs with NTDs and Transition Edge Sensors (TES)



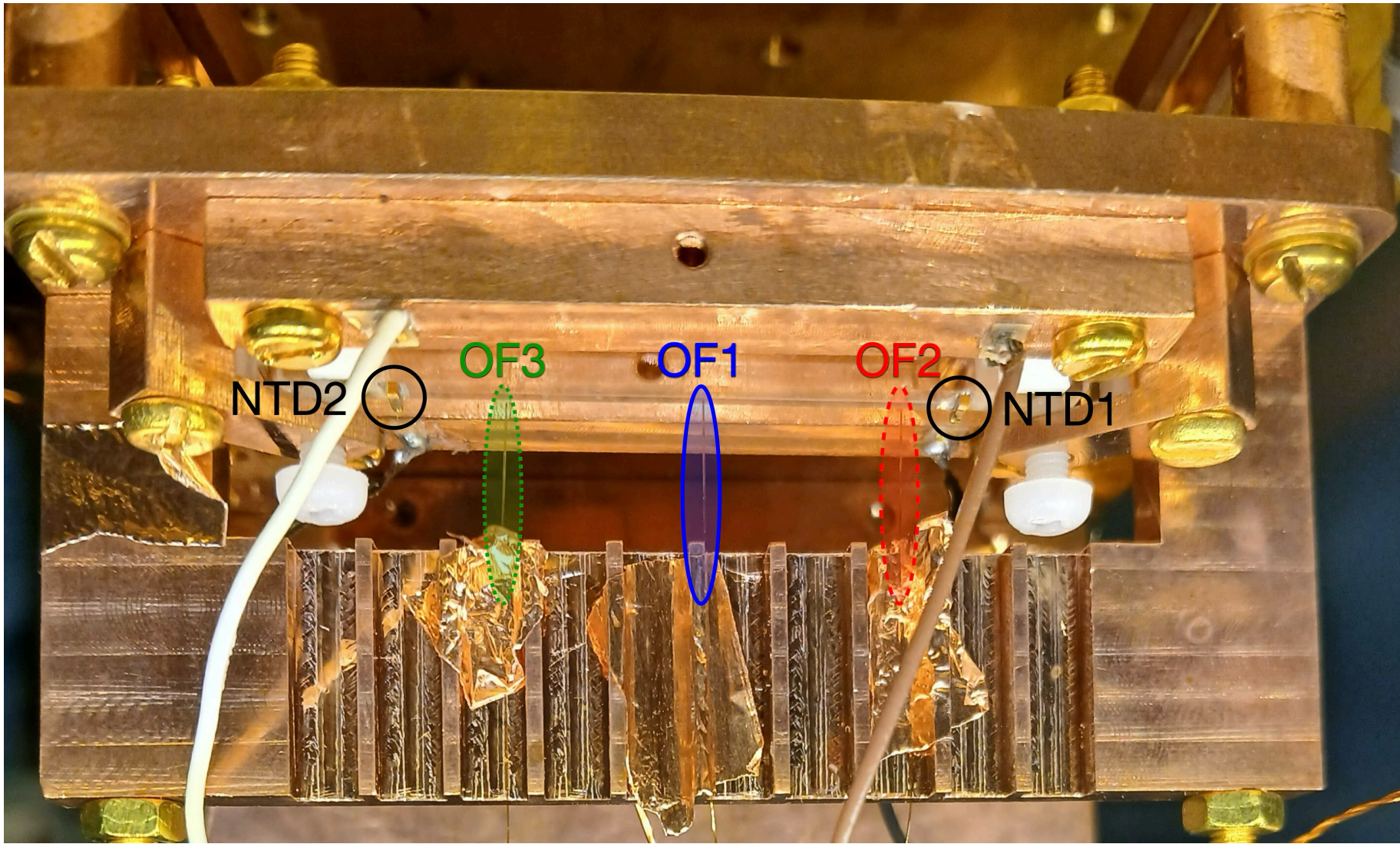
CERES: First Runs

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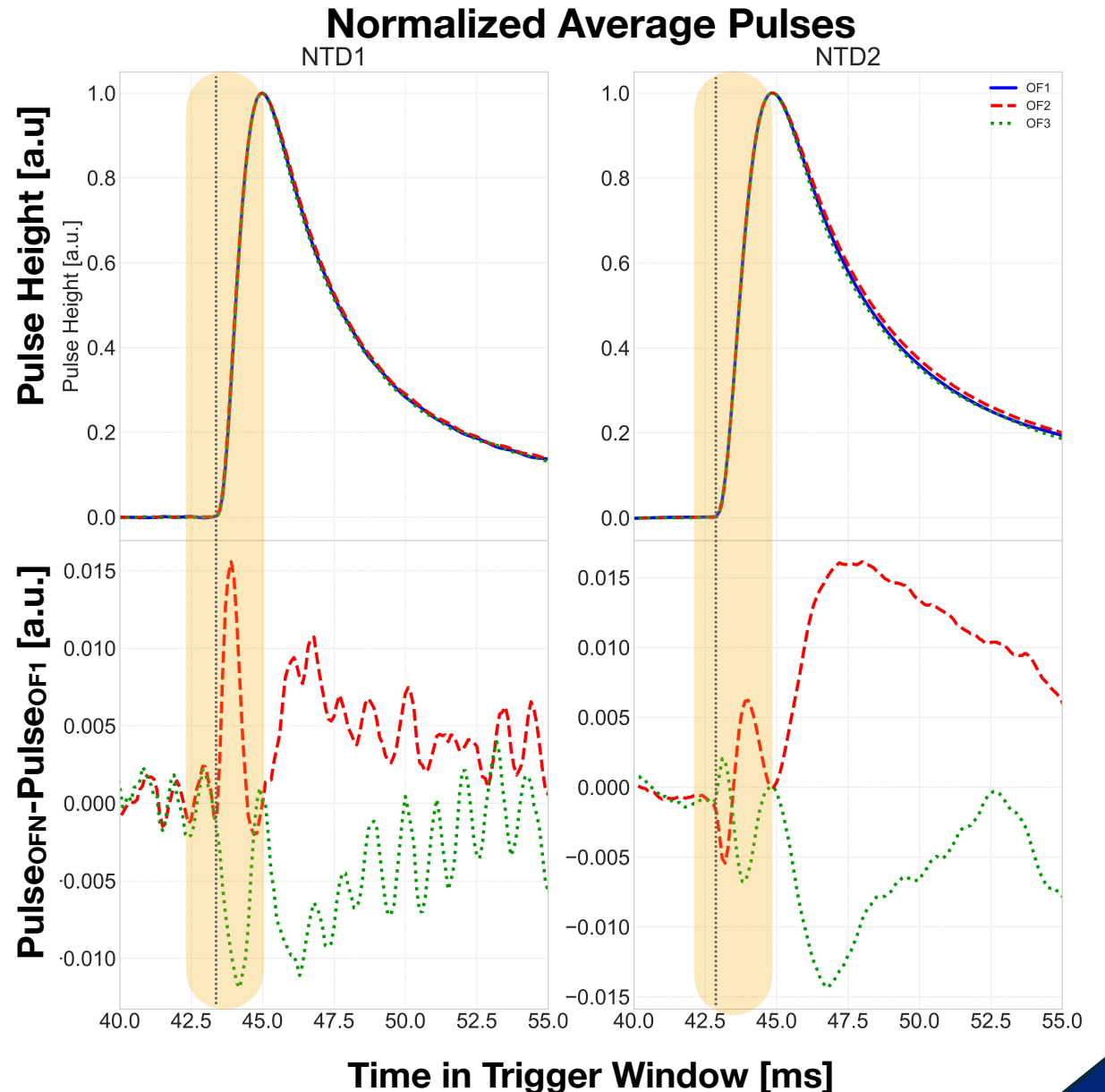


- 3 UV optic fibers in symmetric configuration





- Looking at amplitude normalized average pulses
 - NTD1 noisier than NTD2
- Visual position dependent pulse shape characteristics!
 - Arrival time reversed for OF2/3 in NTD1/2
 - decay time $OF2 > OF1 > OF3$?
 - Likely artifact of OF attenuation

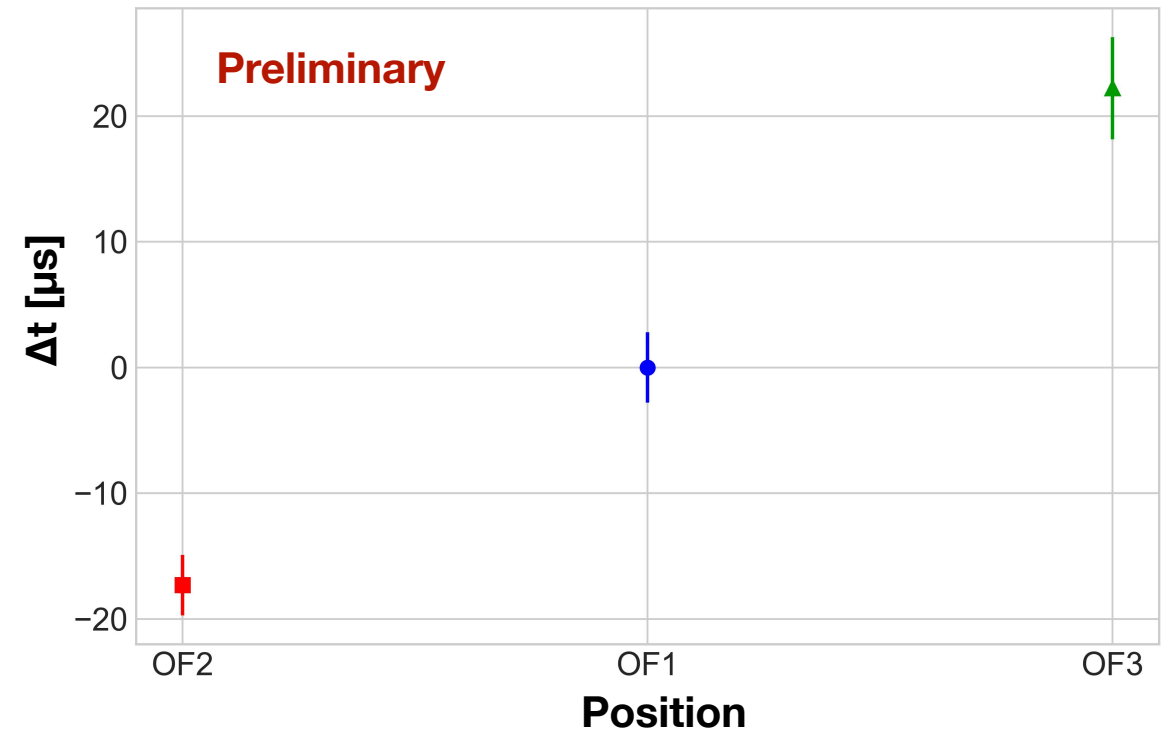
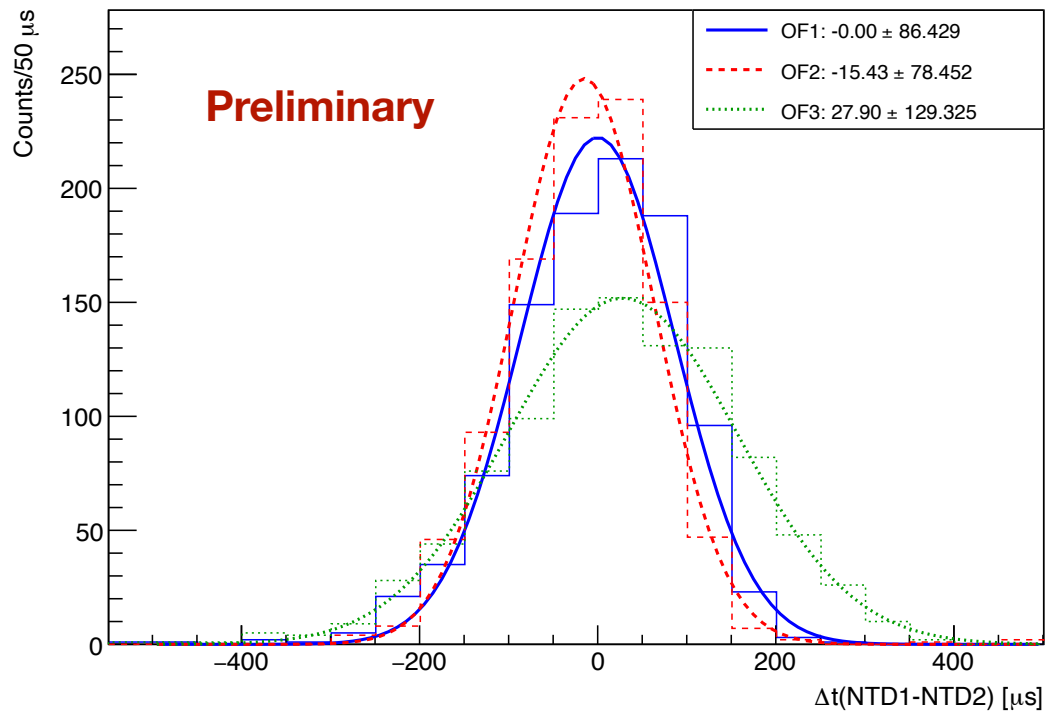


CERES: (VERY) Preliminary Results

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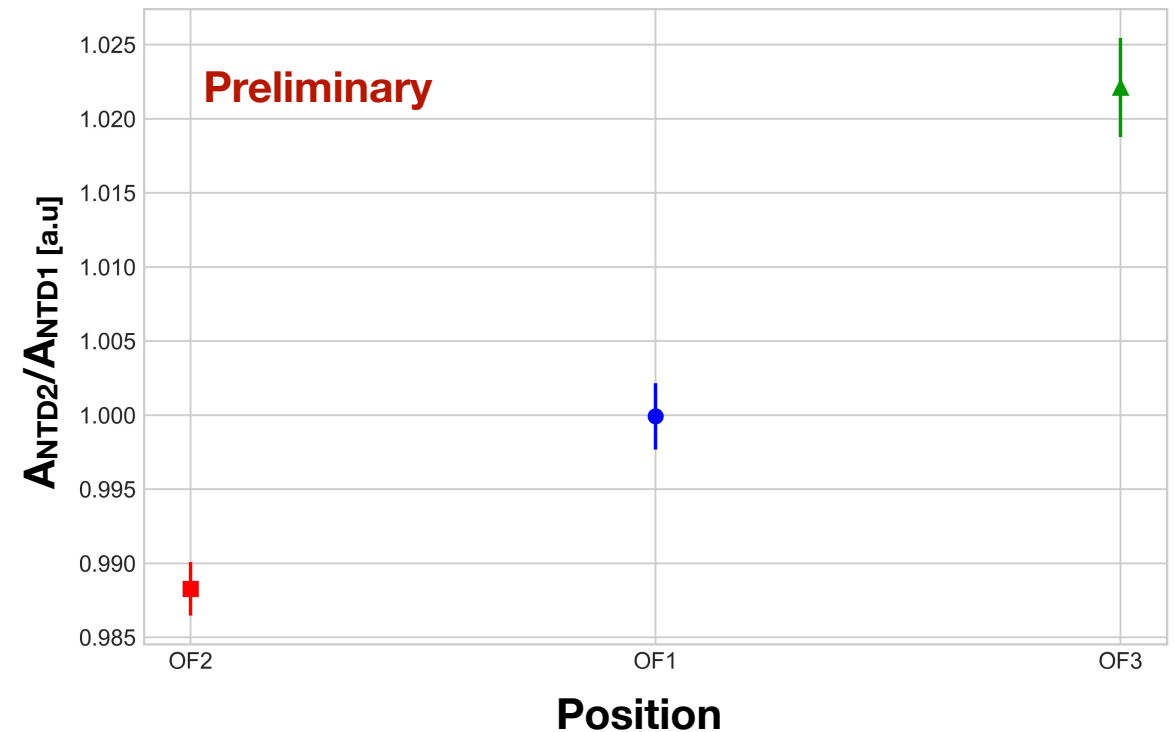
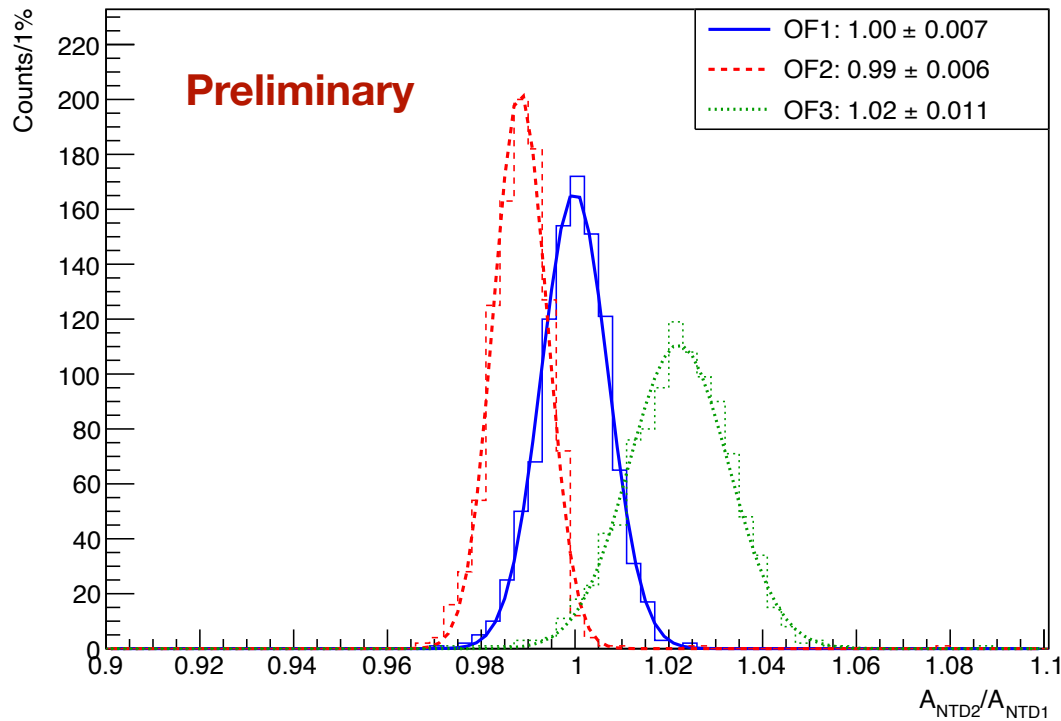


- Looking at arrival time for each fiber, see shifts in peak
 - Closer to NTD, sooner response
 - ~ 40 us effect over ~ 4 cm NTD separation



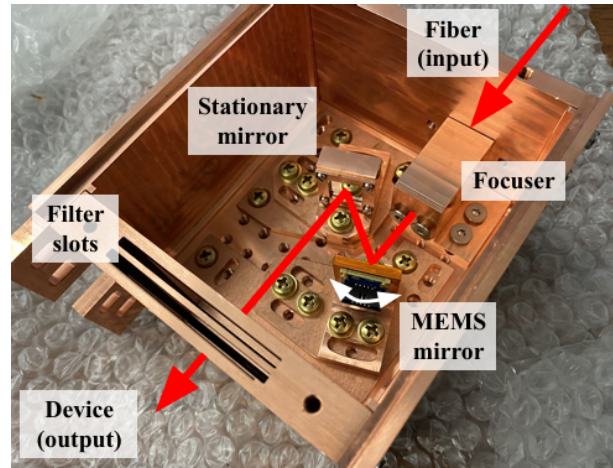
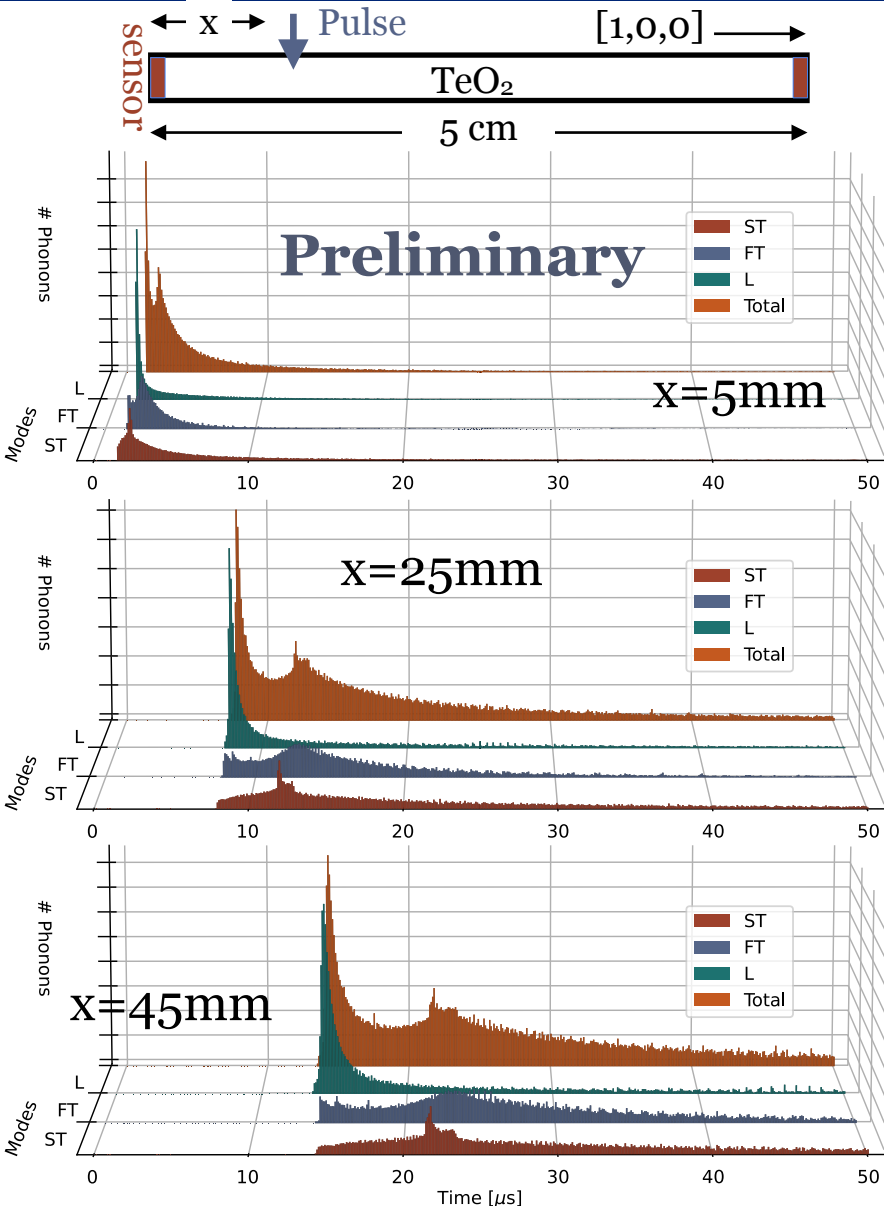


- Observe similar trend in energy sharing, even more stark
 - Developing further procedure to calibrate for differences in NTD nonlinearities and differences in OF attenuation



CERES: Status + Future Work

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Collaboration with SLAC on MEMS mirror optical set up

Microphysics simulations

- Phonons in GEANT4
- Finite element analysis for thermal propagation

[arXiv:2405.02258](https://arxiv.org/abs/2405.02258) [quant-ph]

- Once procedure well defined, repeat experiment for CUPID LMO, Ge crystals



Concept paper in preprint :)



Acknowledgements

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This work makes use of both the DIANA data analysis and APOLLO data acquisition software packages, which were developed by the CUORICINO, CUORE, LUCIFER and CUPID-0 Collaborations.



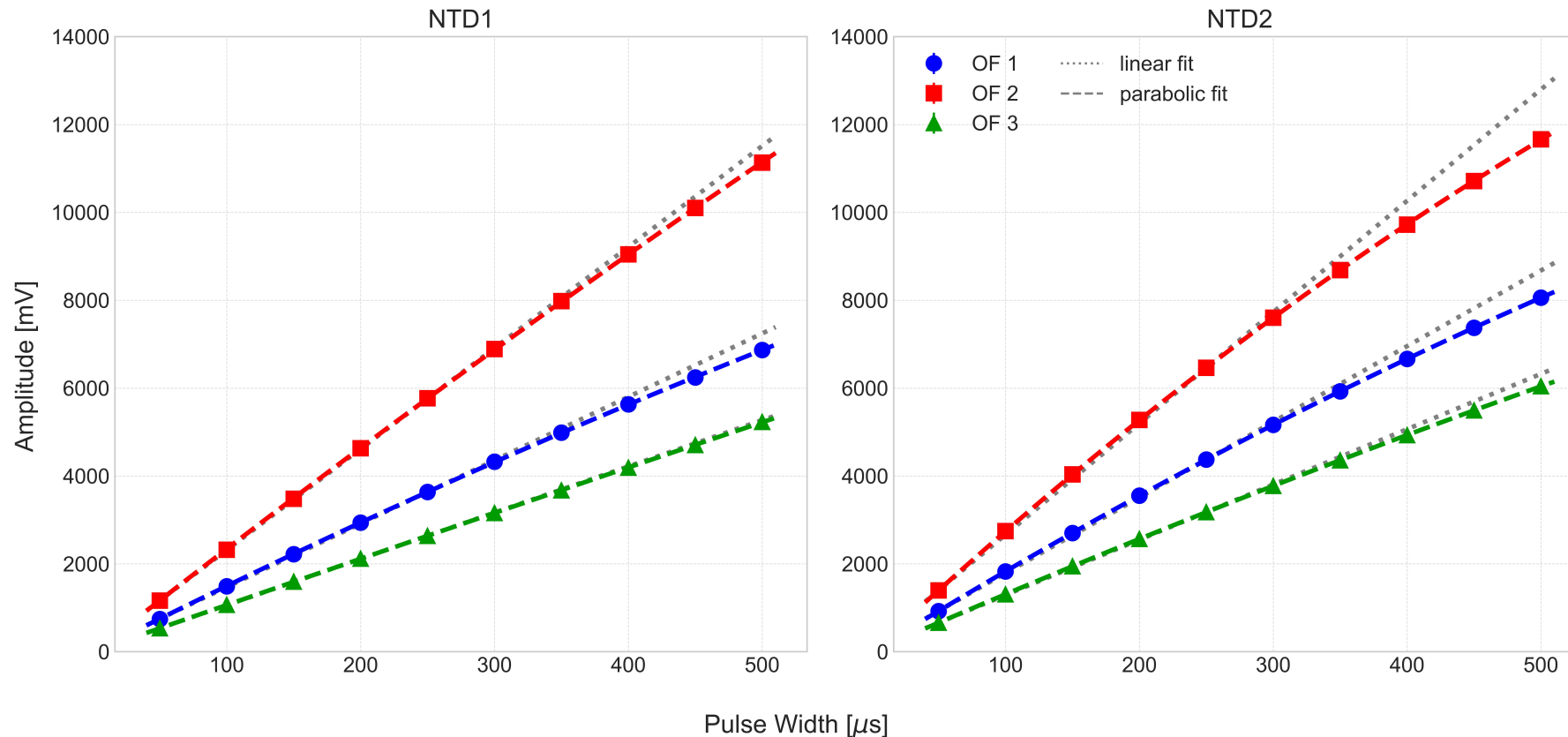
Questions?

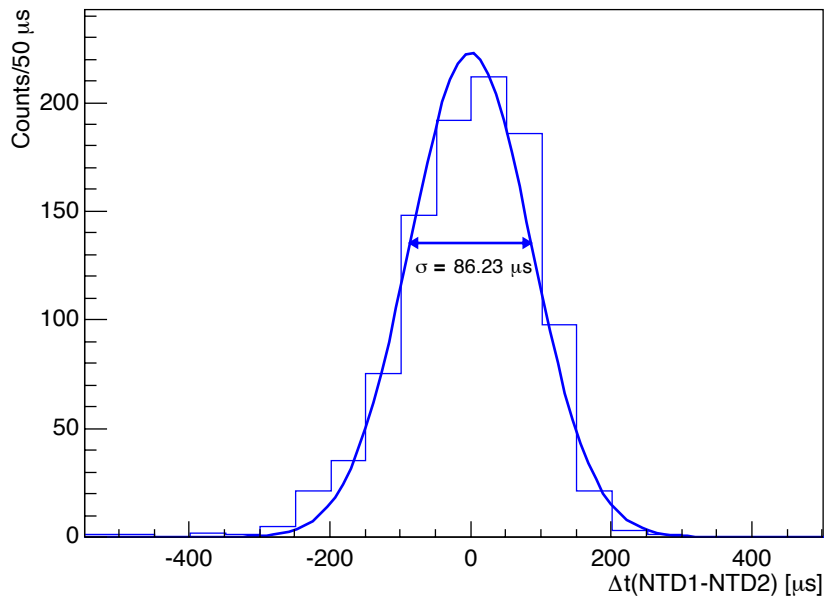
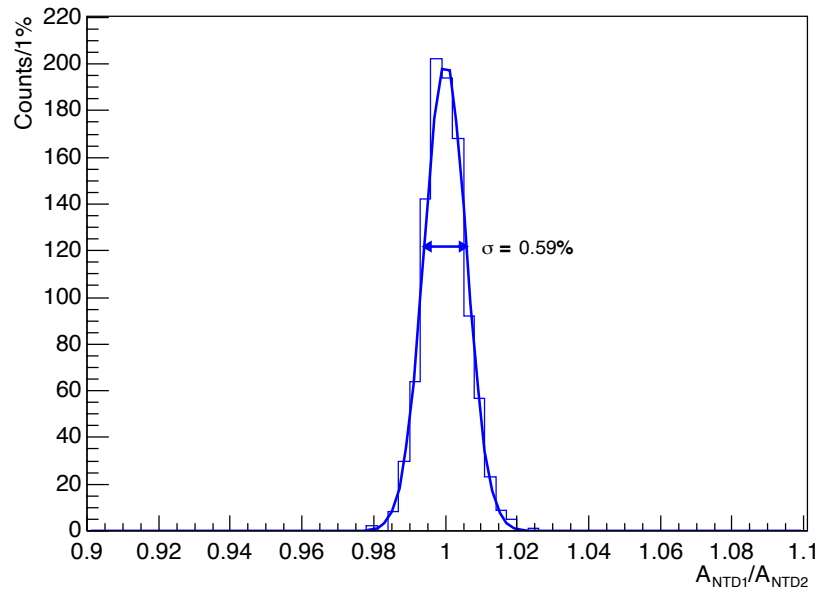
CERES: Initial Commissioning

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- Pulse width (PW) linear with LED energy
- Calibrate linear regime of NTDs with PW scan of amplitude
 - Constrain linear fit to first 6 points including origin
 - Compare to parabolic -> choose 200 us to safely operate in linear regime





- Examine energy sharing and time resolution at middle fiber
 - time resolution defined by difference in arrival time ($t@10\%$ max amplitude) between NTD1 and NTD2
 - Distribution shifted to 0 to remove electronic offset
 - Energy sharing defined by ratio of amplitude of NTD1 to NTD2
 - Distribution normalized to 1 to account for differences in NTD responses



- Finite element analysis in COMSOL
- Using measured pulses to model thermal properties of detectors + position response



1D TeO2 coupled to bath by PTFE modeled in COMSOL

