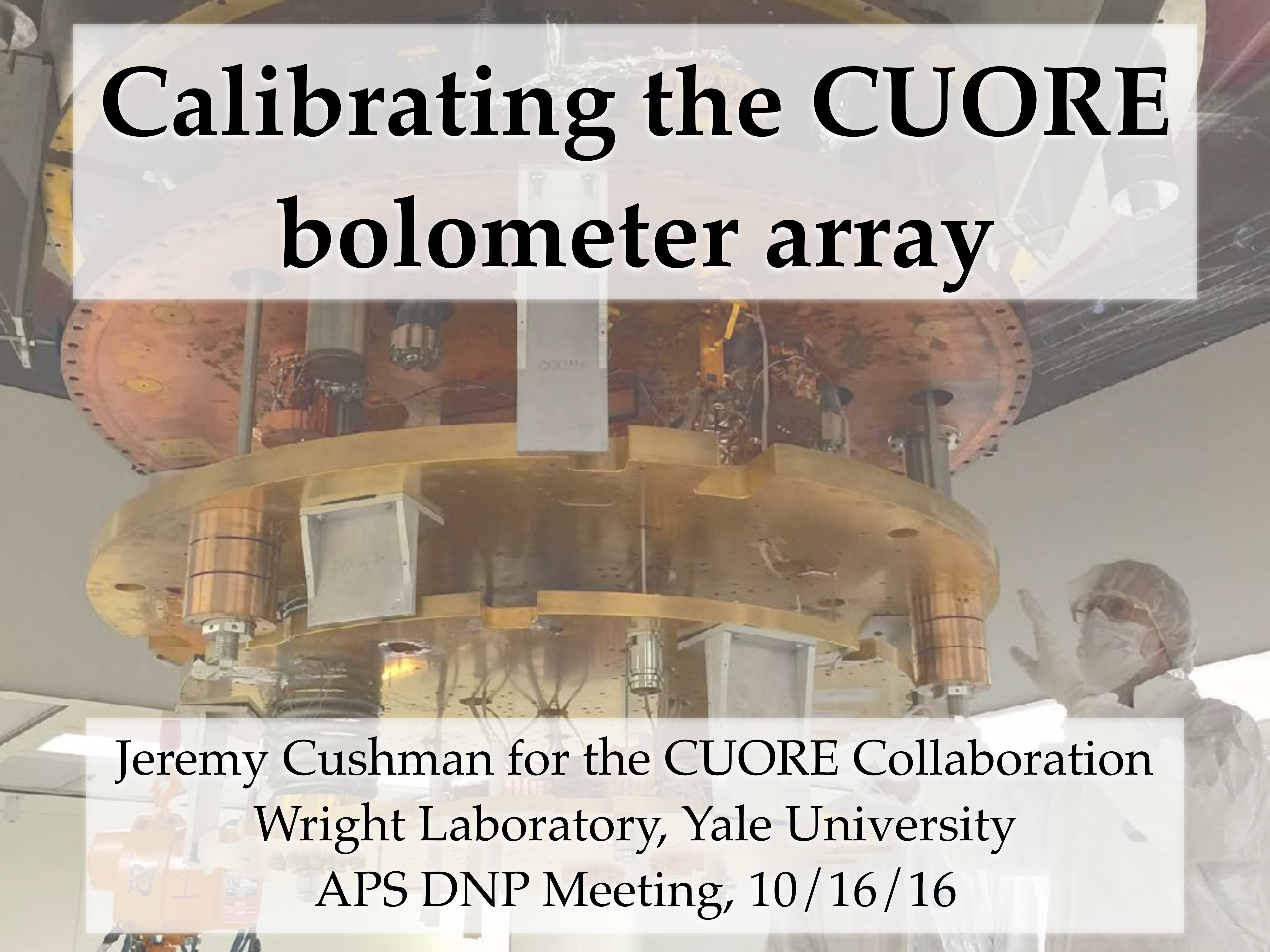


Calibrating the CUORE bolometer array

Jeremy Cushman for the CUORE Collaboration
Wright Laboratory, Yale University
APS DNP Meeting, 10/16/16

Cuoricino to CUORE

Cuoricino
(2003-2008)

Astropart. Phys. **34**, 822–831 (2011)

+

CUORE-0
(2013-2015)

Phys. Rev. Lett. **115**, 102502 (2015)

$T_{1/2}^{0\nu\beta\beta} > 4.0 \times 10^{24}$ y (90% C.L.)

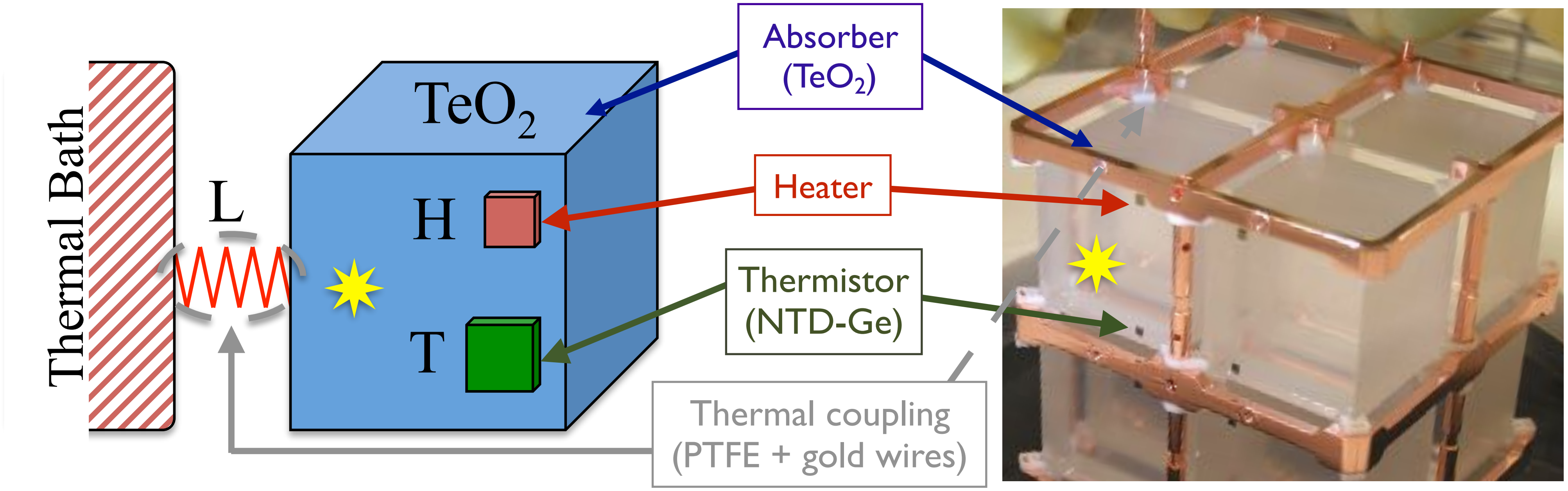
CUORE
(starting 2016)

Adv. High Energy Phys. **2015**, 879871 (2015)

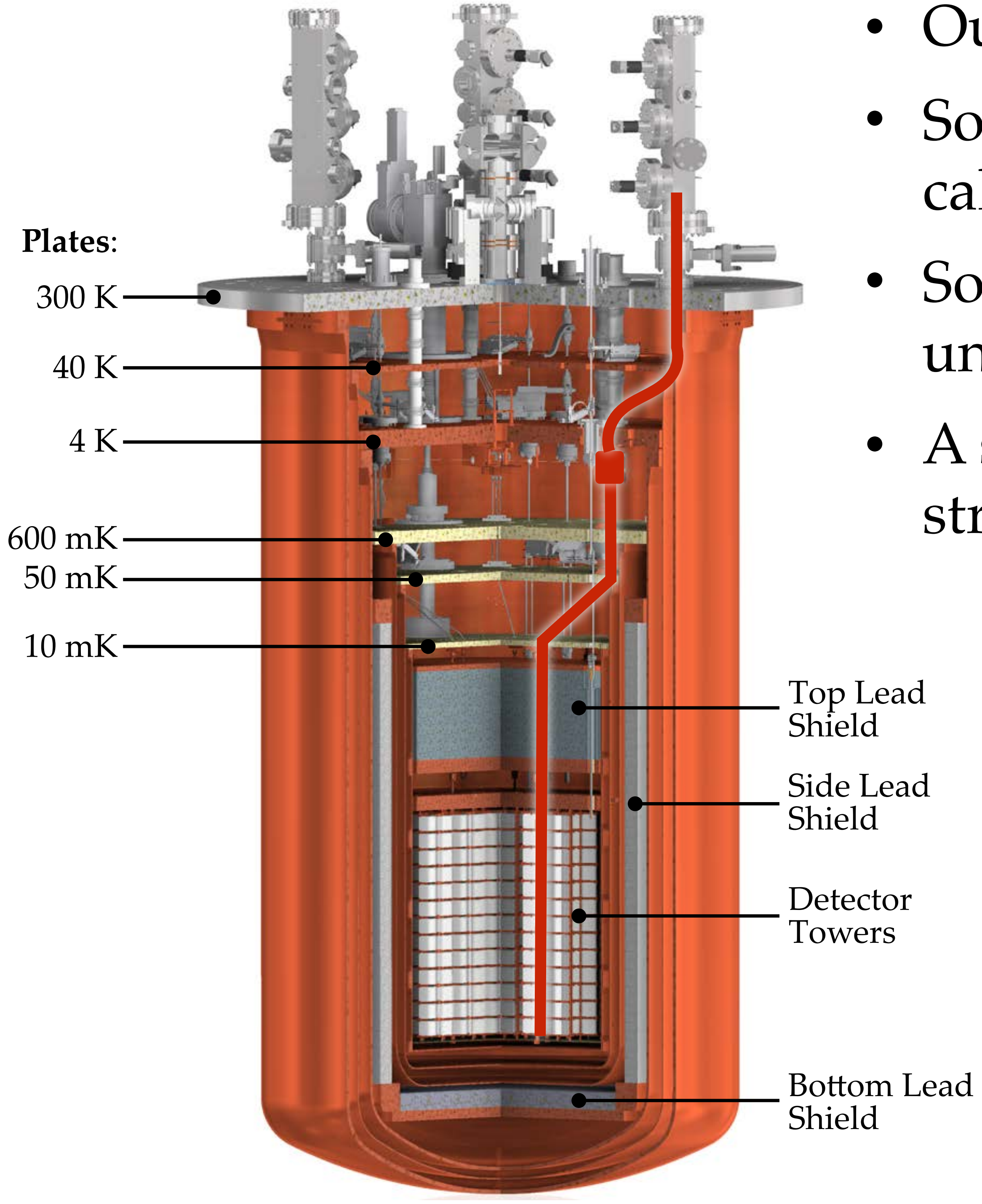
Projected:
$T_{1/2}^{0\nu\beta\beta} > 9.5 \times 10^{25}$ yr (90% C.L.)
$m_{\beta\beta} < 50 - 130$ meV

Bolometer calibration

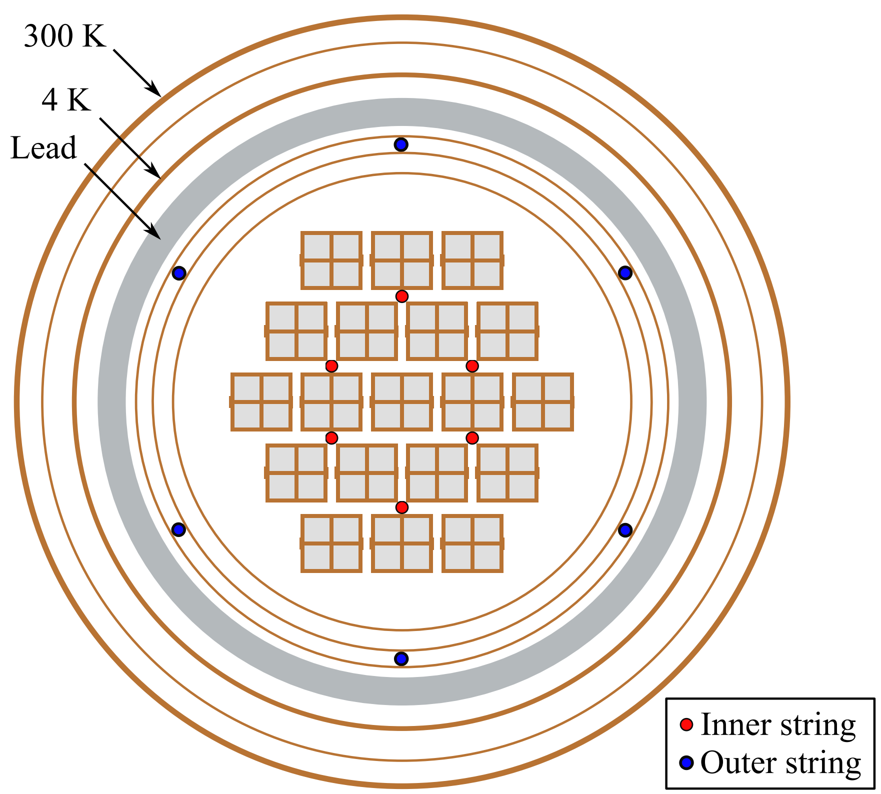
- Bolometers are operated at ~10 mK
- Temperature rises ~0.1 mK per MeV of energy deposited
- Temperature is measured with temperature-dependent resistors (thermistors)
- Bolometers require independent *in situ* energy calibration
- For CUORE, we will use:
  - ^{232}Th γ-ray sources approximately every month
  - Constant-energy pulser to measure detector stability and correct for variations in detector gain



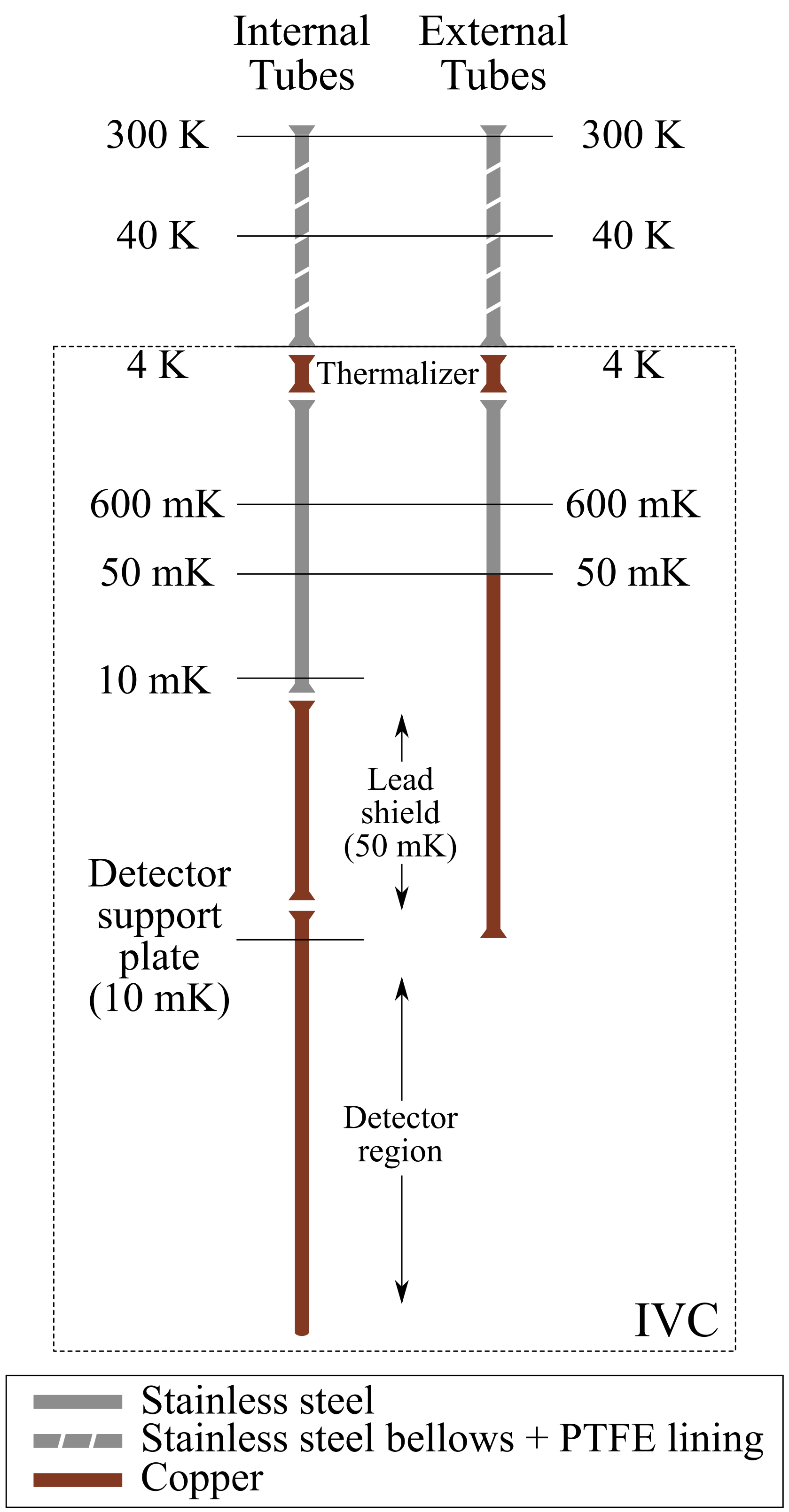
Calibration source deployment



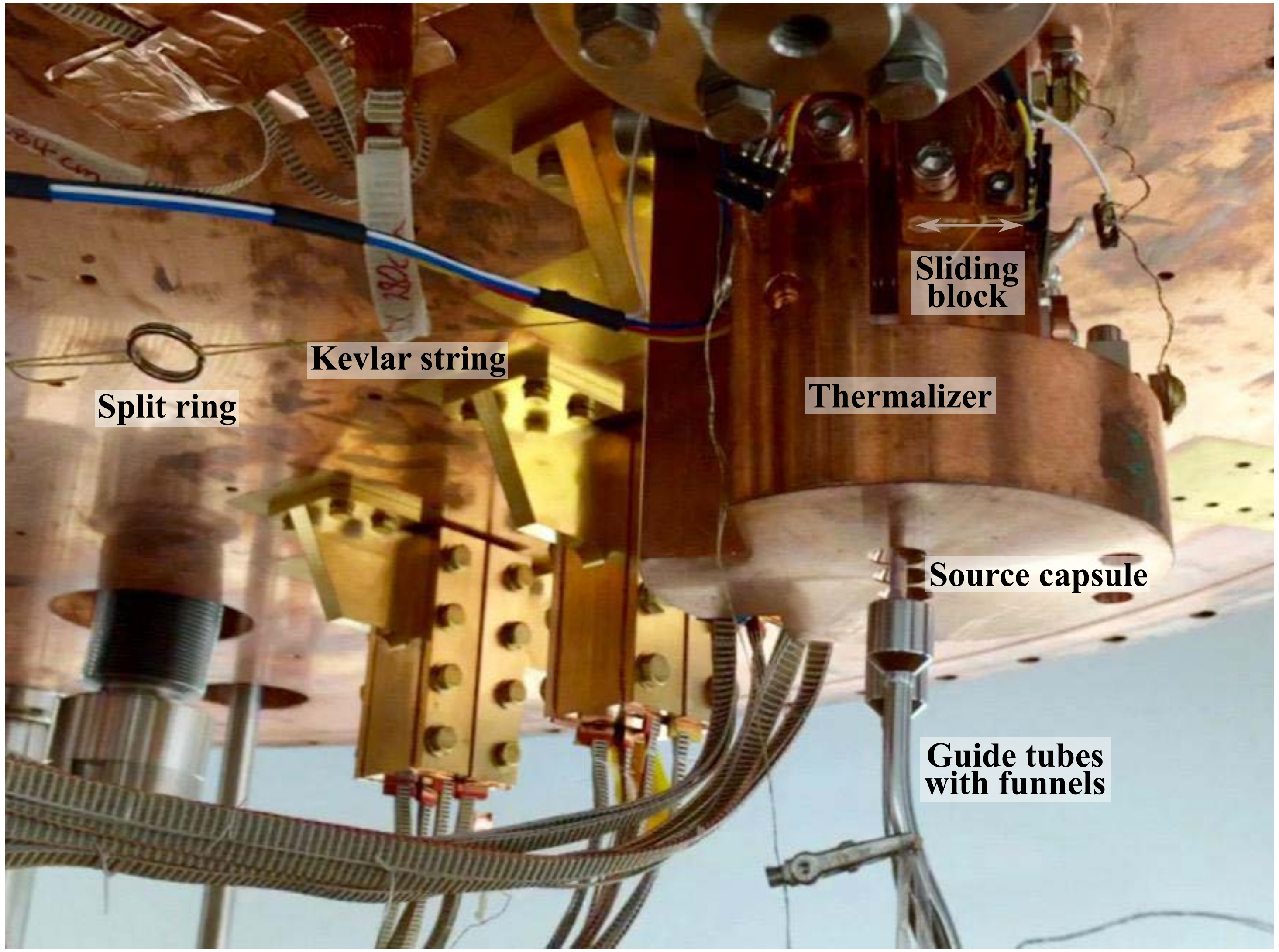
- Sources are outside cryostat during physics data-taking
- Outer bolometers shield inner bolometers
- Sources must be lowered into cryostat for calibration and cooled to 10 mK
- Sources are put on strings and are lowered under their own weight
- A series of tubes in the cryostat guide the strings



Cooling the sources

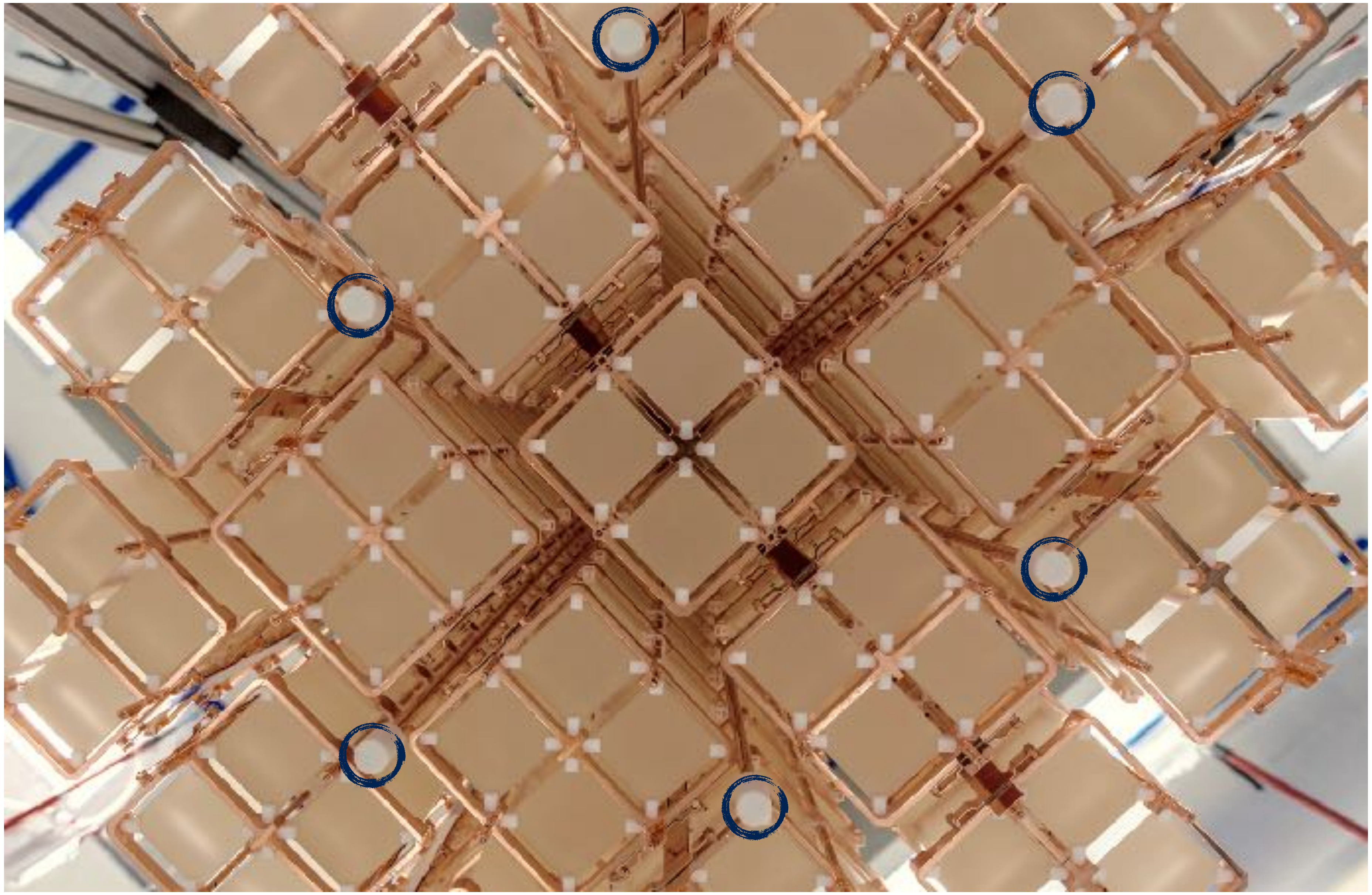


- We remove heat from sources with:
  - A pair of copper blocks (the "thermalizer") that mechanically squeezes on the sources at 4 K
  - Contact between the sources and their guide tubes, which are thermalized to different cryostat stages



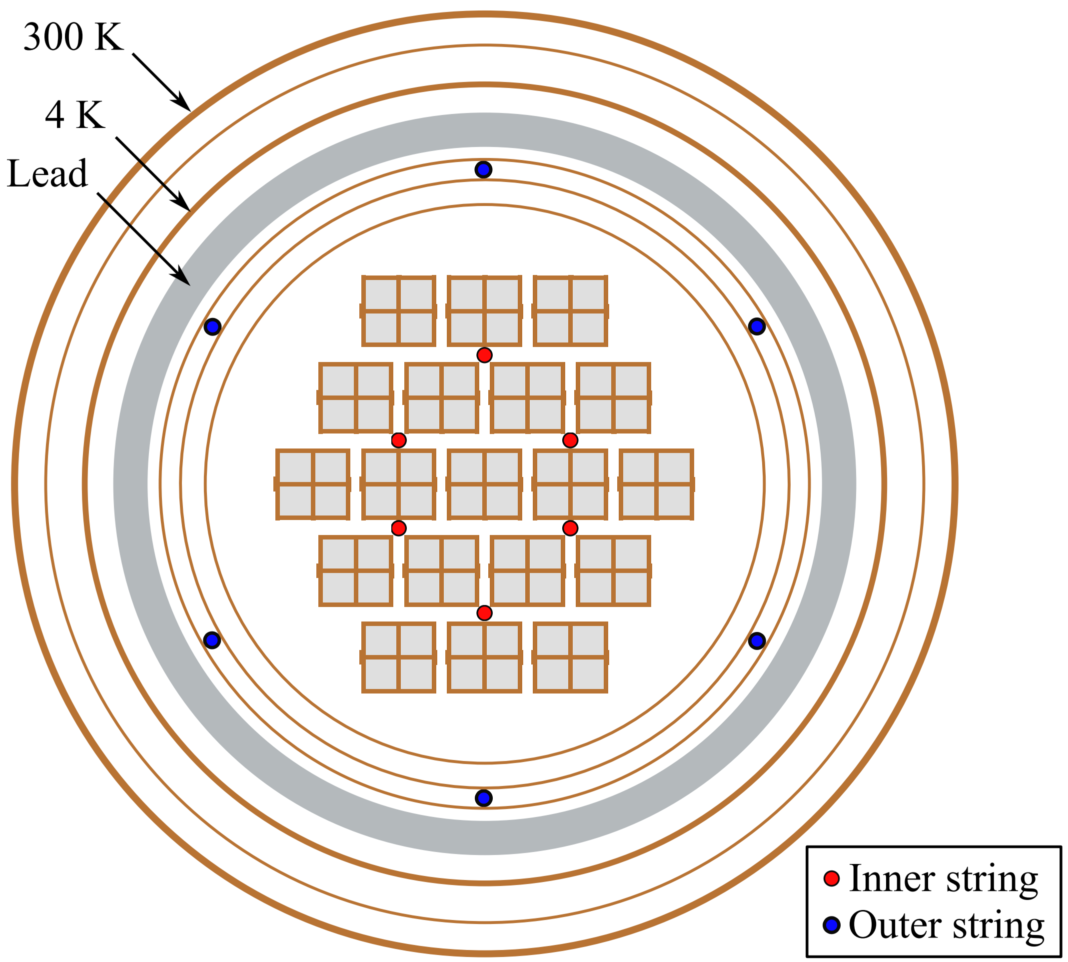
Detector region

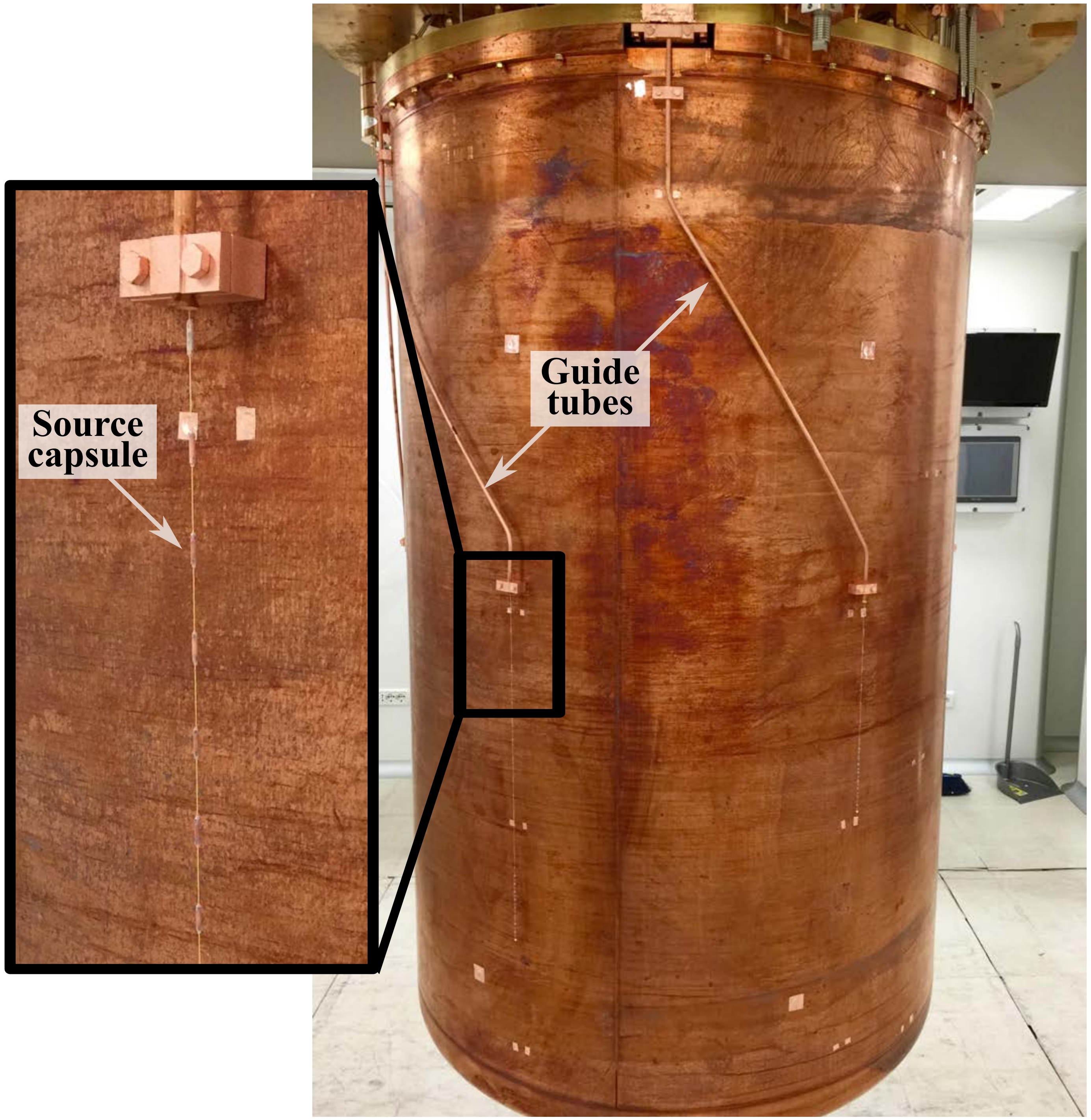
- All detectors are now installed in cryostat
- 6 inner guide tubes are installed alongside the detector towers in the cryostat



Outer calibration sources

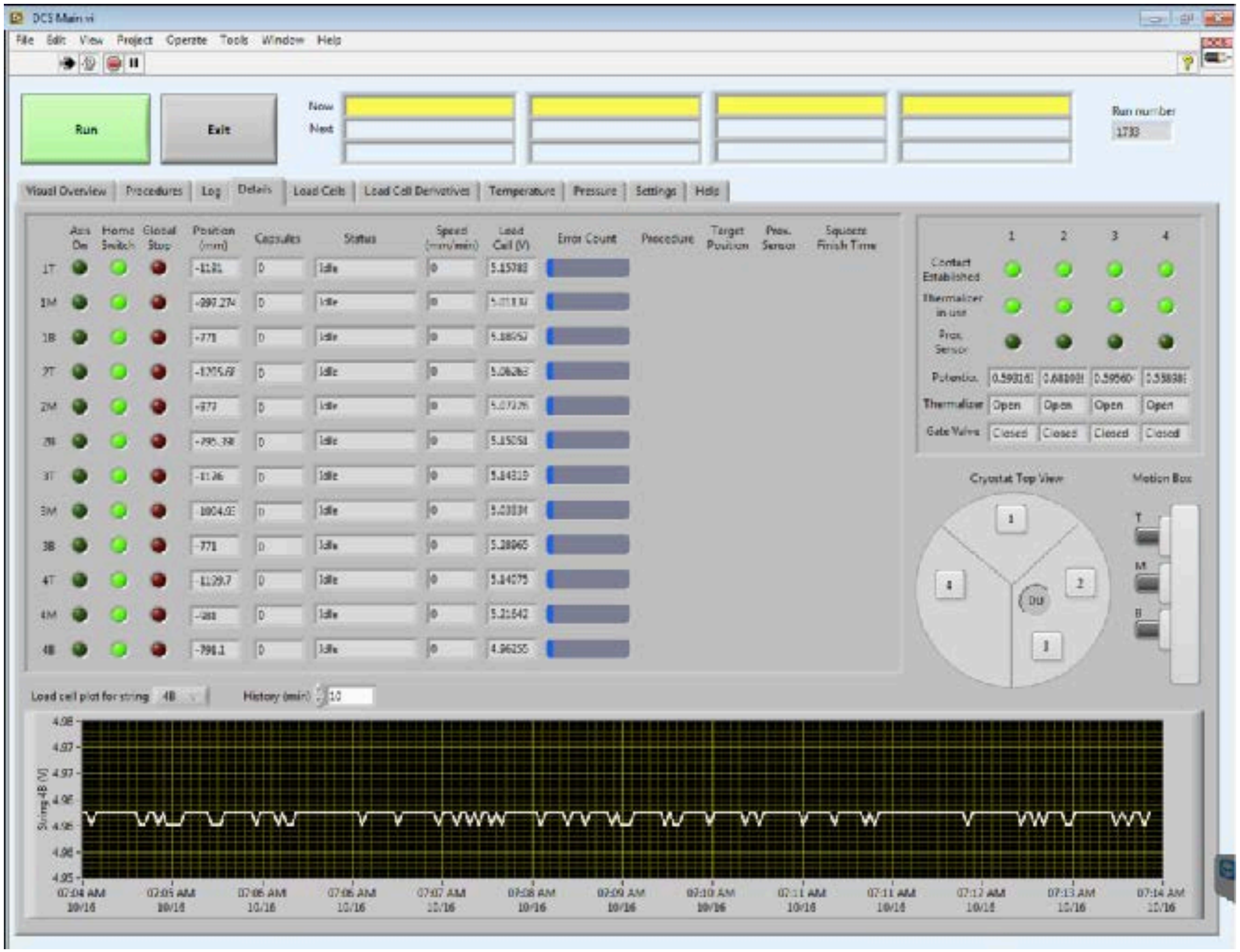
6 outer guide tubes run along the outside of the copper 50-mK shield

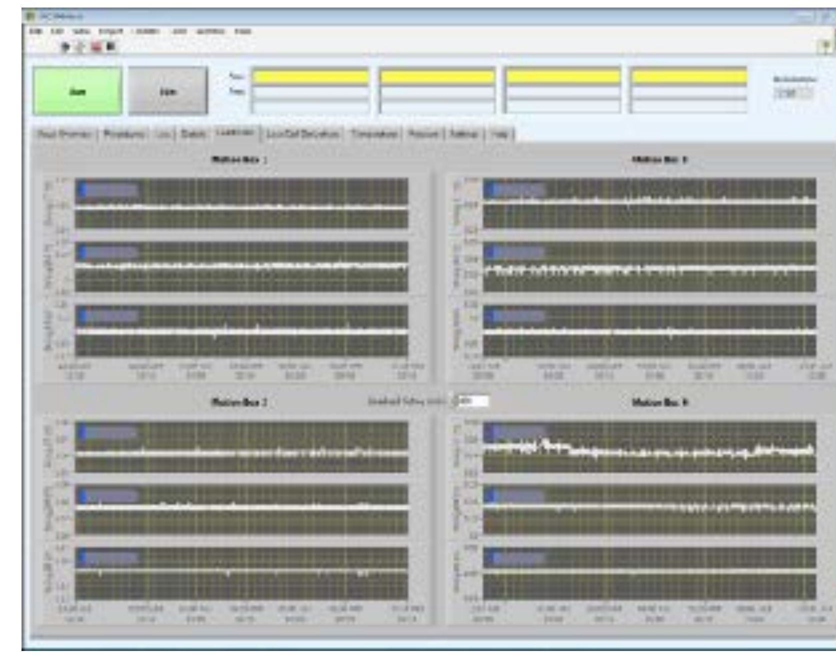




Control system

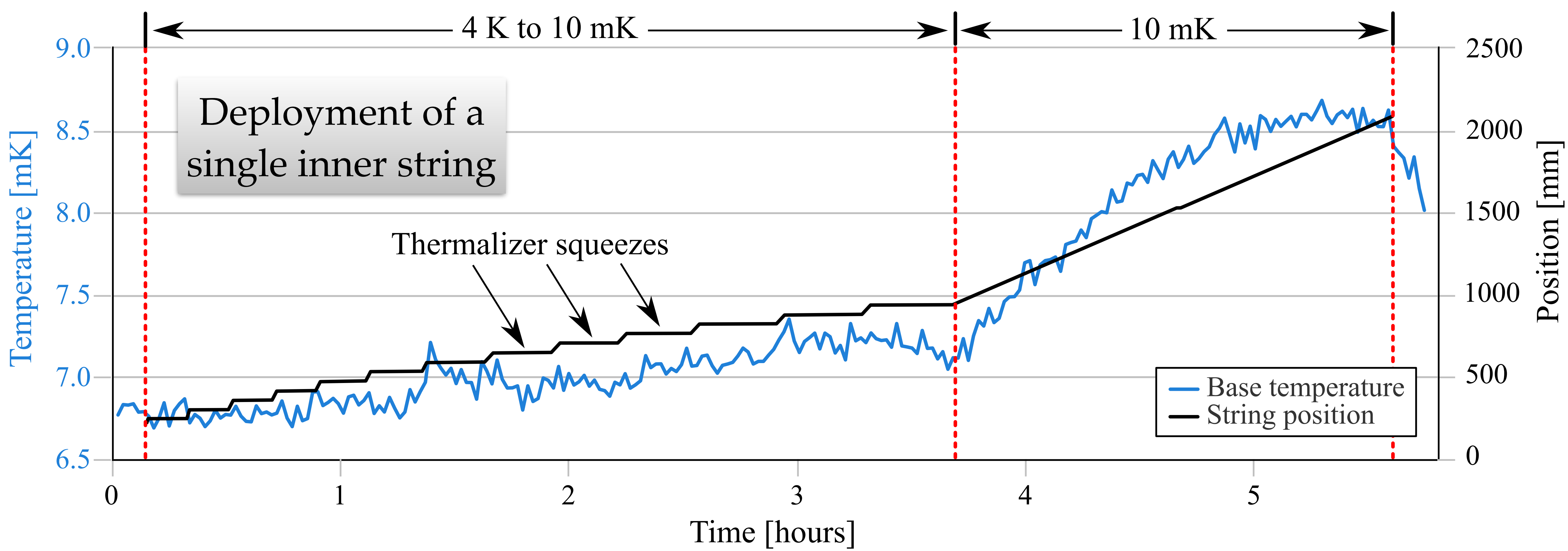
Calibration source deployment is automatic and can be monitored remotely





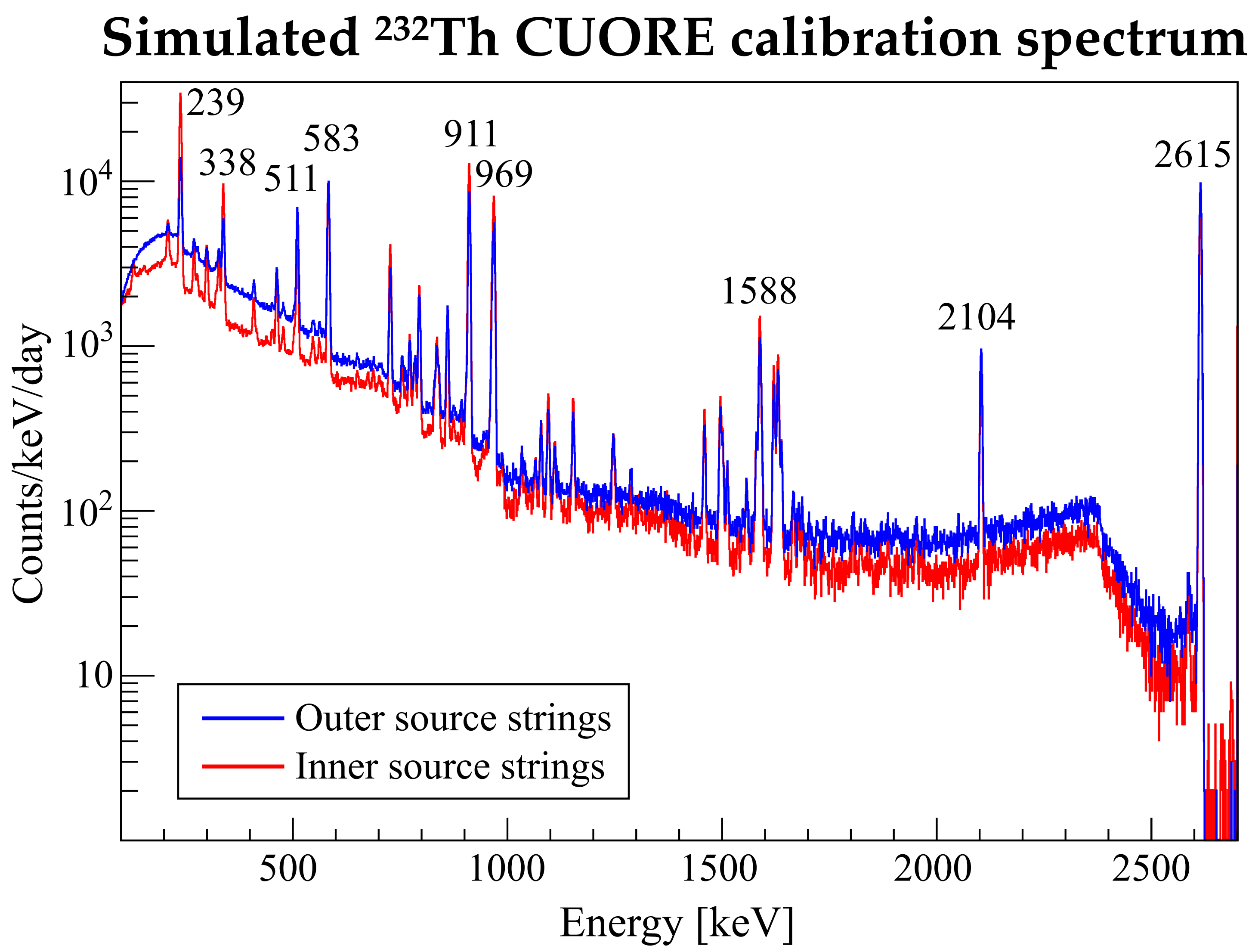
Commissioning

- We have operated the full calibration system at base temperature (<10 mK)
- Deployment takes ~6 hours per string (24 hours for all strings in parallel)
- In commissioning, we have been able to stay below target temperature of 10 mK
- Withdrawing the strings takes a similar amount of time, due to frictional heating



Simulated calibration spectrum

- Many γ lines are available from the ^{232}Th chain for calibration with CUORE

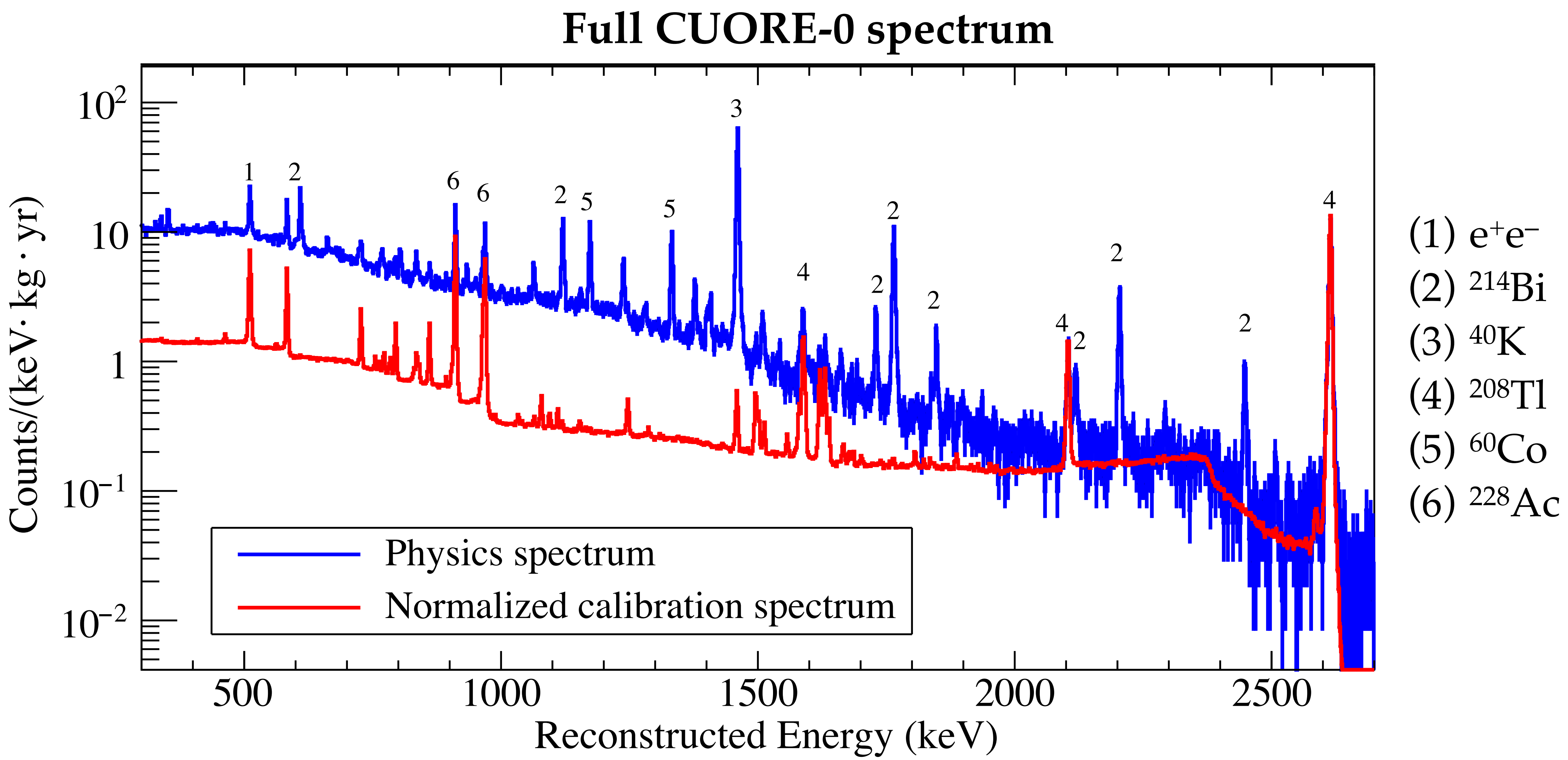


- Lines span a range of energies from 239 keV to 2615 keV
- Single-escape and double-escape lines are visible at 2104 keV and 1593 keV

- We are planning a single ^{56}Co calibration to study response to higher-energy γ-rays and a variety of double-escape lines

Calibration in CUORE-0

- Calibration performance can be tested by measuring residuals (i.e., reconstructed energy – true energy) in the physics data



- In CUORE-0, the single-γ energy scale uncertainty was 0.1 keV

Phys. Rev. Lett. **115**, 102502 (2015)

Conclusions

- CUORE will calibrated with ^{232}Th sources contained inside copper capsules on Kevlar strings
- Constant-energy pulsers will measure gain and stability between calibrations
- We have operated the full calibration system in cryostat commissioning runs at base temperature
- Calibration system is ready for CUORE detector commissioning

J. S. Cushman *et al*, "The Detector Calibration System for the CUORE cryogenic bolometer array", arxiv:1608.01607 [physics.ins-det]

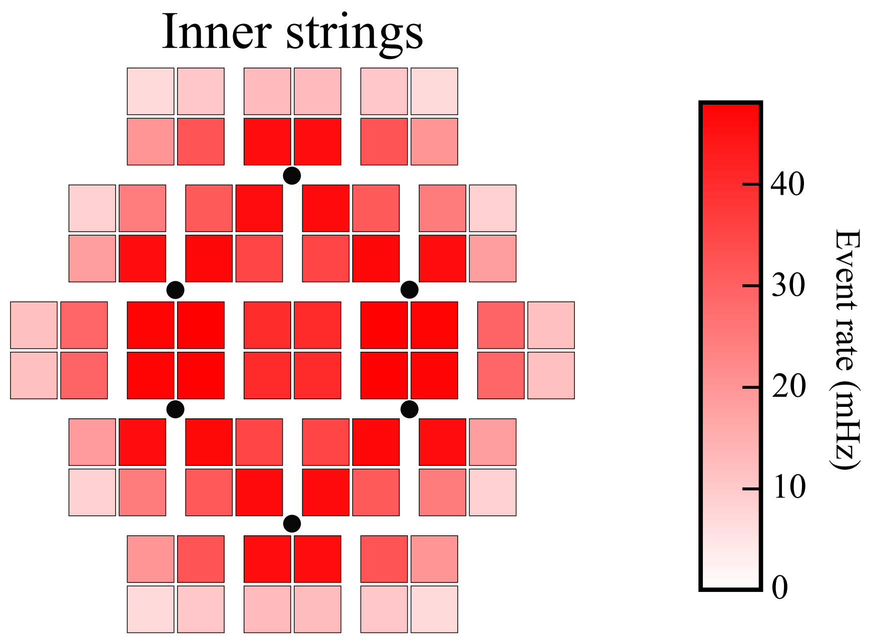
CUORE

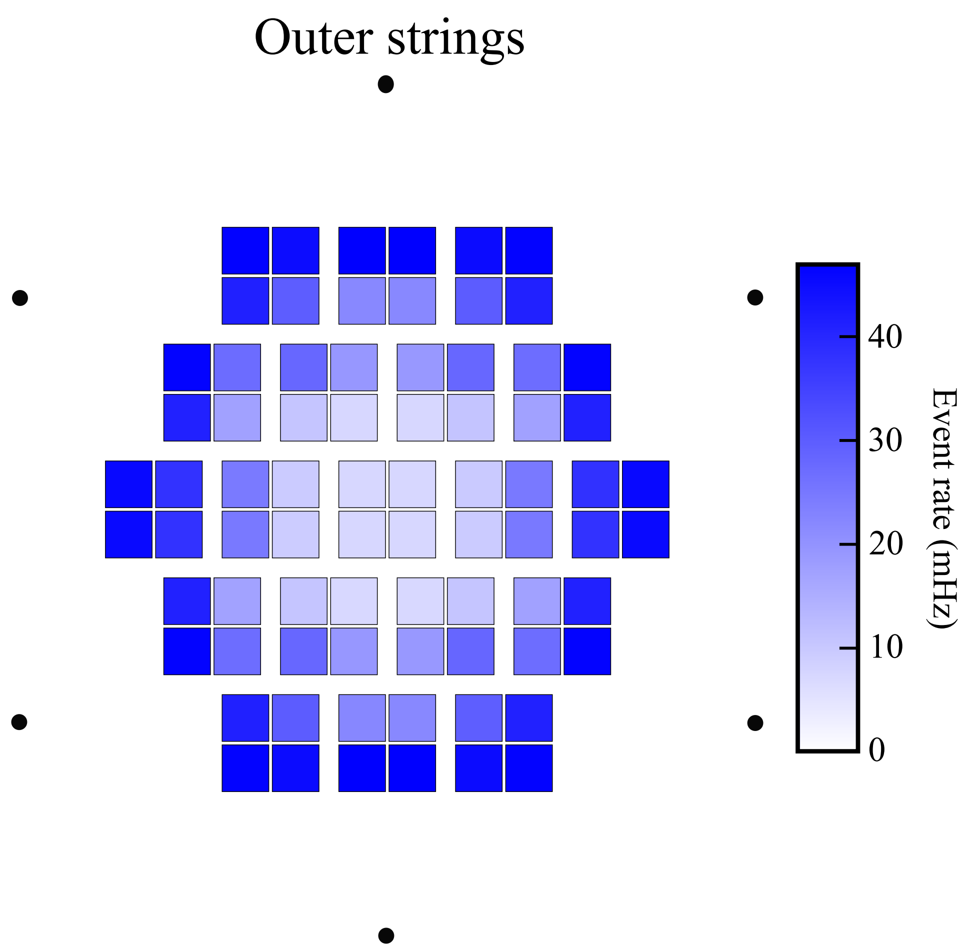
Also at DNP:

DD.00003	V. Singh: *Search for Neutrinoless Double Beta Decay with CUORE*
EA.00066	N. Deporzio: *Scintillating Bolometer Monte Carlo for Rare Particle Event Searches*
EA.00080	S. Dutta: *Slow Monitoring Systems for CUORE*
EA.00081	B. Daniel: *Simulations toward Effective Calibrations of the CUORE Detector*
FD.00003	C. Davis: *CUORE-0 Measurement of $2\nu\beta\beta$ decay*
FD.00004	K. E. Lim: *Search for WIMP-Induced Annual Modulation with the CUORE-0 Experiment*
HH.00004	R. Hennings-Yeomans: *CUPID: CUORE Upgrade with Particle IDentification*
NF.00005	B. Schmidt: *Optimizing the CUORE data processing in search for $0\nu\beta\beta$ decay*
NF.00006	B. Welliver: *Online Data Quality and Bad Interval Detection for CUORE*
NF.00009	E. Hanson: *Characterization of single layer anti-reflective coatings for Ge and Si substrates*

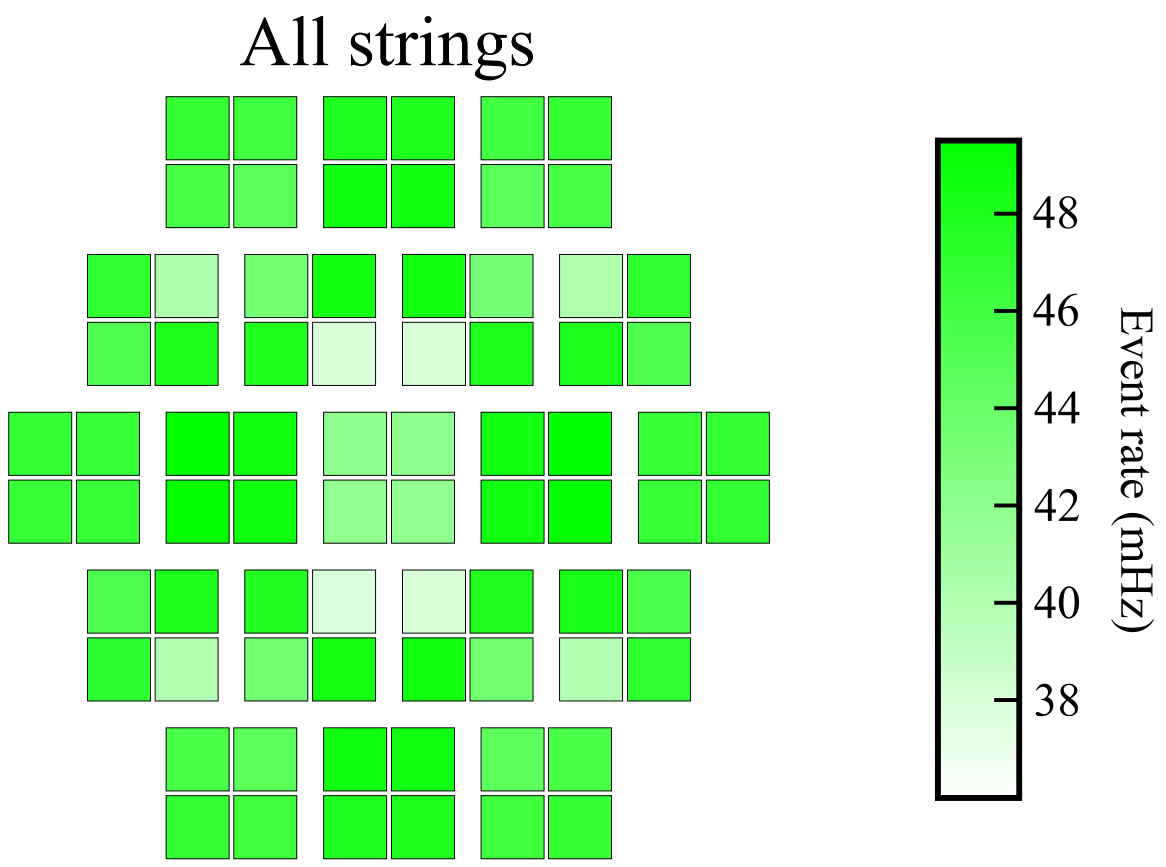
Backup

Rate uniformity

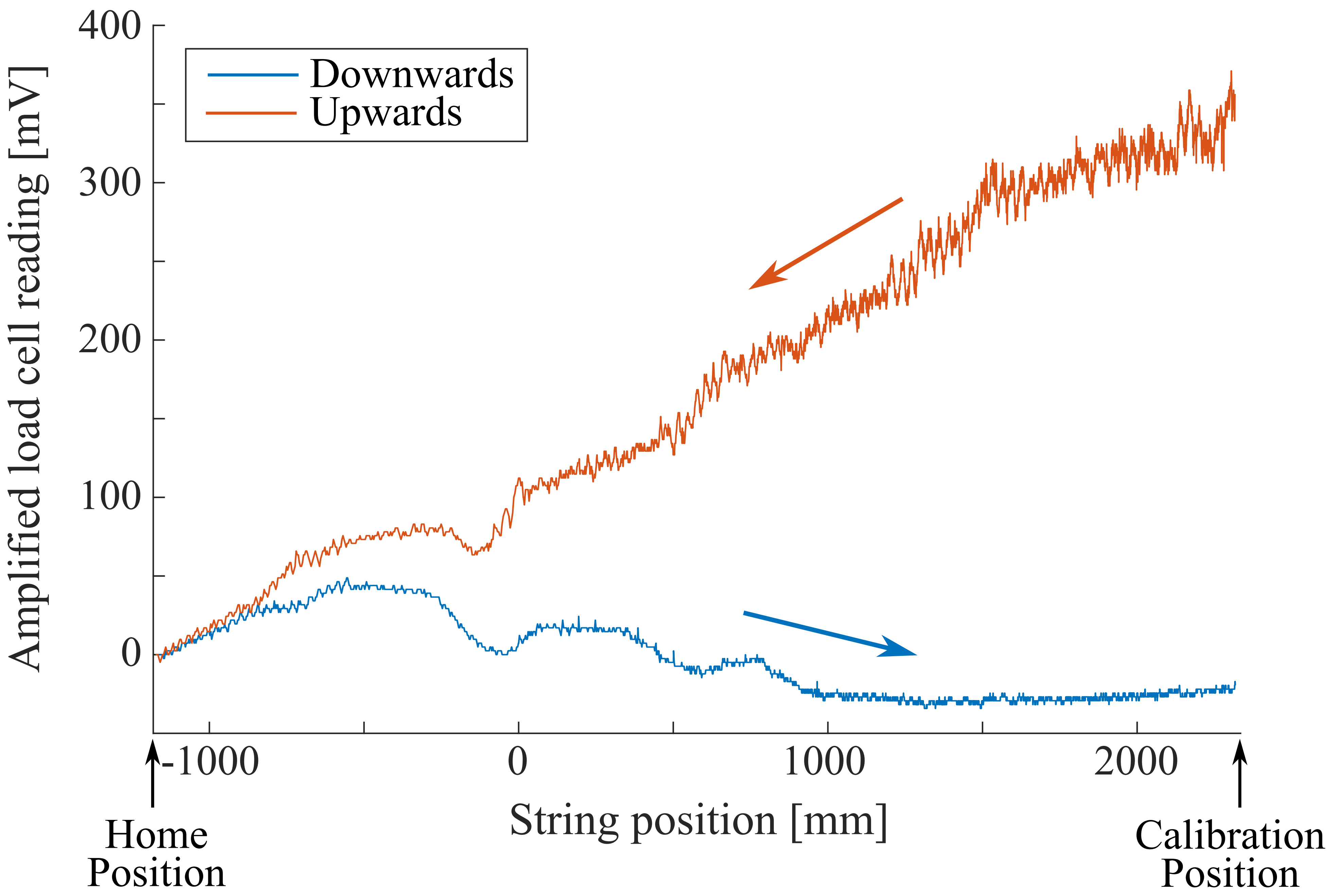




- Monte Carlo simulations show that the average event rate per each column of crystals is between 38 and 49 mHz (after pileup cuts)
- We expect a rate uniformity of within ~25% between the different columns of crystals



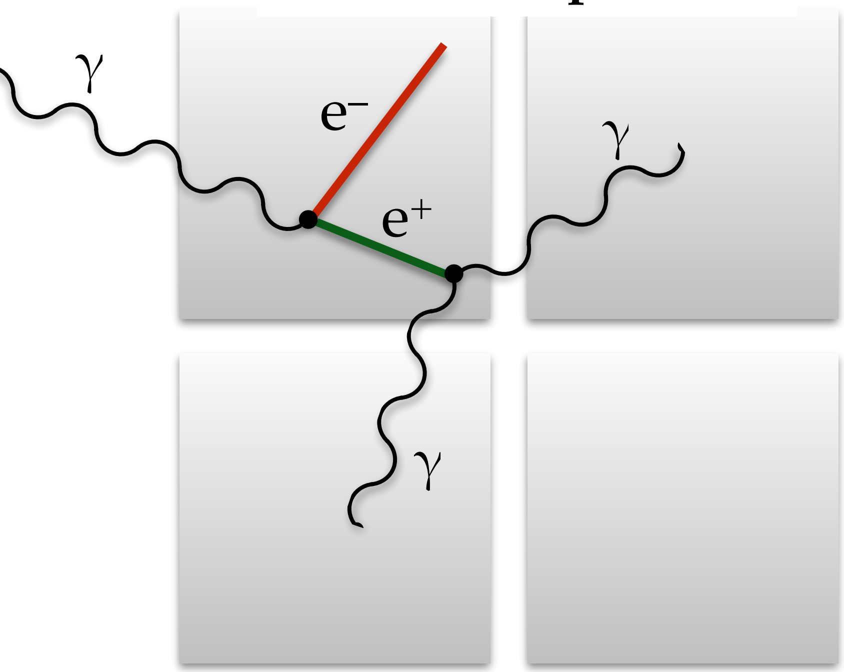
Load cell profile



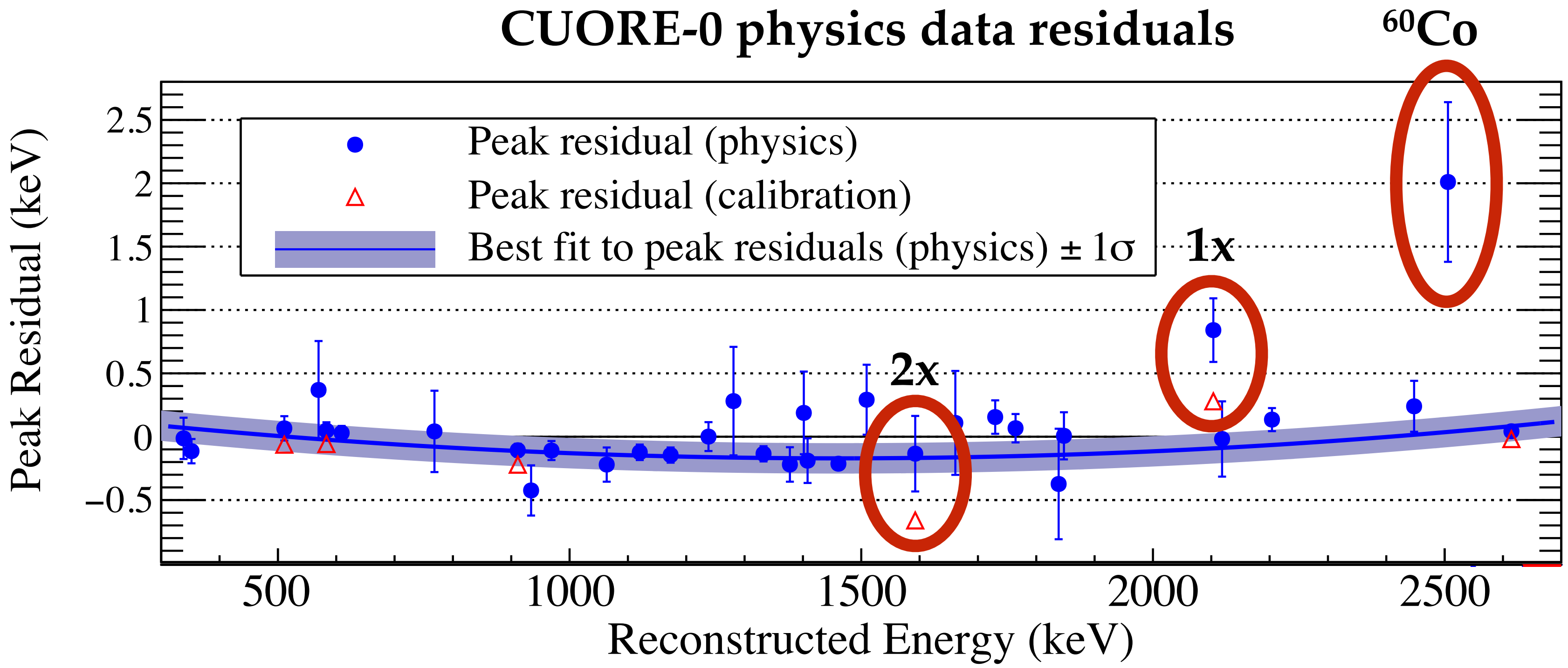
Calibration challenges

- Coincident gammas and single and double escape peaks can be reconstructed with different energies

Double escape event:



CUORE-0 physics data residuals

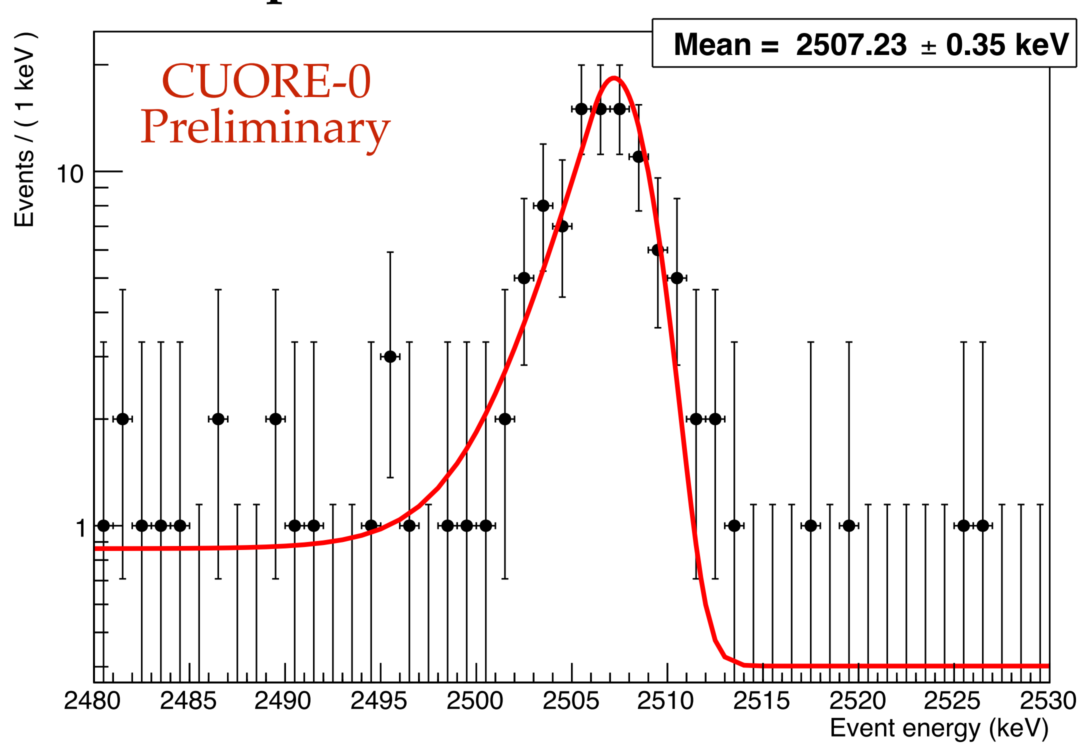


- Peak at 2505 keV is the result of coincident 1173 and 1332 keV γ-rays from ^{60}Co, and it is reconstructed 1.9 ± 0.7 keV too high
- Double escape events most resemble neutrinoless double beta decay (0νββ) events, so understanding their energy reconstruction is crucial

Measurements with ^{56}Co and ^{60}Co

- Dedicated calibrations were performed with ^{60}Co and ^{56}Co sources in CUORE-0, and a similar effects were observed
- Higher-statistics ^{56}Co calibration in CUORE is planned
  - ^{56}Co offers higher energy γ-rays with many single and double escape peaks
- Residuals cannot currently be reproduced in Monte Carlo, but their physical cause is under investigation

Coincident peak from dedicated ^{60}Co calibration



^{56}Co spectrum in CUORE-0