# The CUORE pulse tubes noise cancellation technique

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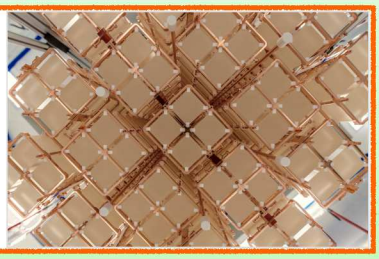
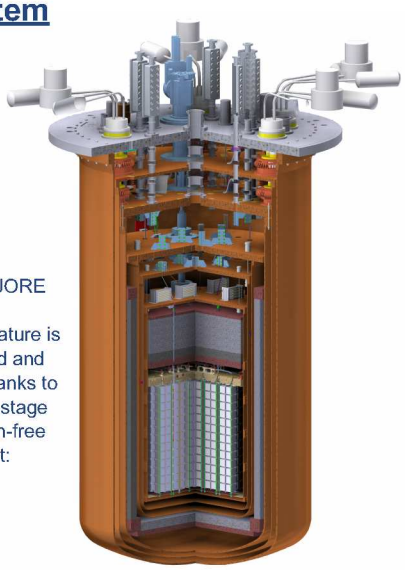
## The CUORE experiment

- CUORE (Cryogenic Underground Observatory for Rare Events) is a 1-ton scale bolometric experiment searching for neutrinoless double beta decay in $^{130}$Te, and it is located at the Gran Sasso National Laboratories in Italy.
- CUORE detector: 988 $TeO_2$ crystals arranged in 19 towers, operated as cryogenic bolometers at ~10 mK.



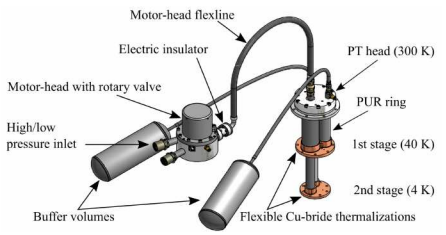
## The CUORE cryogenic system

The CUORE base temperature is reached and kept thanks to a multi-stage cryogen-free cryostat:



- Six copper vessels thermalized at different T
- Two lead shields at cryogenic temperatures + room T lead + borated polyethylene shield
- **5 Pulse Tube (PT) cryocoolers** → 4 K
- Dilution Refrigerator with $^3He$-$^4He$ mixture → 10 mK

## The CUORE pulse tubes




- Custom adapted PT415-RM by Cryomech
- Cooling power: 1.2 W @ 4.2 K and 32 W @ 45 K for each PT
- Cooling power provided by *He* gas periodic expansions → working frequency: 1.4 Hz
- Pressure cycles by a valve rotating at 0.7 Hz, alternatively connecting the PT to the high and low pressure sides of a compressor (1 rotation = 2 pressure cycles)

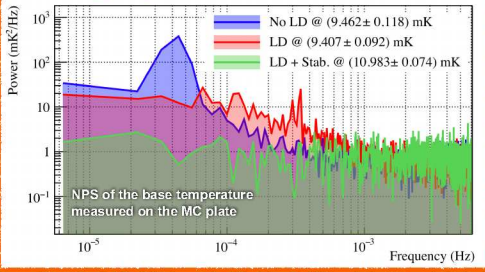
⚠ **This is a source of vibration at 1.4 Hz and related harmonic**

⚠ **In CUORE, 4 PTs work simultaneously with slightly different frequencies**

➡ **generation of beating frequencies**

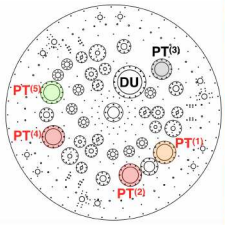
## Noise cancellation techniques

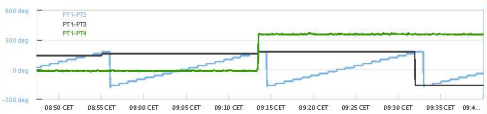
- Passive vibrations suppression: mechanical decouplers, sandbox for the PT flex lines, polyurethane ring, suspended rotary valves, soft bellows, Cu braids
- The **Linear Drives (LD)**:
  - Each PT rotary valve driven by its own Linear Drive (LD), a low-noise stepper motor device
  - Micro-stepping precision (1 step = 360°/25600 = **0.014°**): accurate control of the valve rotation frequency and of the relative phases of the PT pressure waves
  - LDs strongly reduce low frequencies and reduce the RMS **(red)**
  - **Driving and stabilizing the PT phases at the minimum noise configuration suppresses the beating frequencies and further reduces the overall RMS (green).**




## Driving the pulse tube phases: the PT scan

- Take advantage of the destructive interference of the different noise sources
- Find the configuration of the relative PT phase that maximizes the noise cancellation
- The CUORE system is complex and asymmetric, so a **scan of the whole configuration parameters space** is required.

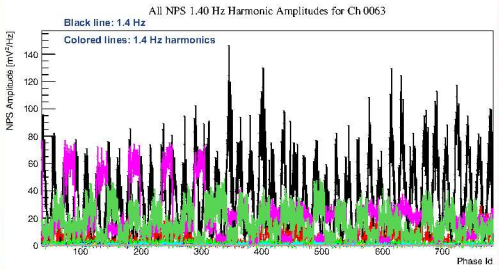


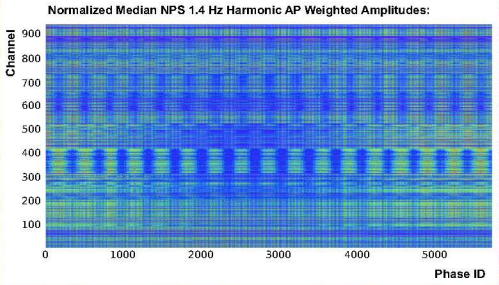

- Driving the phase shift of 3 PTs with respect to a reference one (PT1-PT2, PT1-PT3, PT1-PT4) → N=3
- 20 deg step: $\left(\frac{360}{step\ size}\right)^N$ = 5832 configurations
- 4 to 5 10-seconds noise waveforms acquired for each PT phase configuration and for each bolometer
- Data analysis to determine the configuration that minimizes the detector noise.

## Analysis

- Evaluation of the 1.4 Hz and first 10 harmonics contribution to the NPS → **for each channel** **for each PT phase configuration**

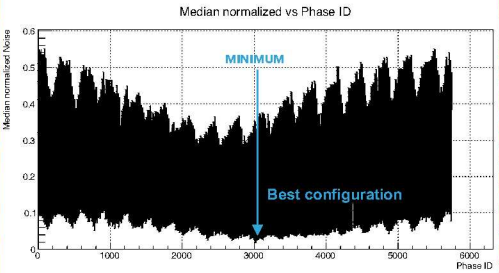


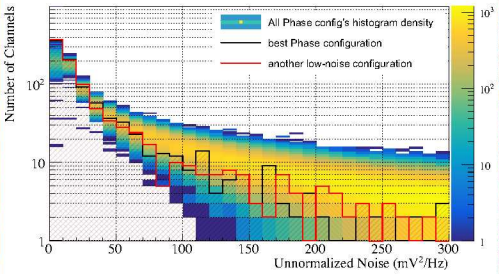

- Weighted sum of the harmonics NPS
- Weighted by the signal spectrum in frequency domain
- Normalization procedure to compare all the channels




## Optimization

- Median all over the channels to get the **detector's typical normalized response to a given PT phase configuration**:




**The optimal configuration minimizes the noise for the largest number of channels.**

**References:**

[1] C. Alduino et al.,Phys. Rev. Lett. **120**, 132501 (2018)
[2] C. Alduino et al., Int.J.Mod.Phys. A **33** 1843002 (2018)
[3] A. D'Addabbo et al., J. Low Temp. Phys. **193** 867–875 (2018)
[4] A. Alessandrello et al., Nucl. Instrum. Meth. B **142** 163 (1998)
[5] A. D'Addabbo et al., Cryogenics **93** 56-65 (2018)