The CUORE cryostat: current performance and future upgrade towards CUPID

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FUDAN UNIVERSITY

CUORE

CUPID

The CUORE (Cryogenic Underground Observatory for Rare Events) experiment is a ton-scale detector [1] , operating at a cryogenic temperature of around 10 mK, searching for neutrinoless double-beta decay of ^{130}Te and other rare events. CUORE experiment is the world's largest bolometric experiment [2] . We envision an upgrade of the CUORE cryostat in order to host the new CUPID (CUORE Upgrade with Particle IDentification) [3,4] array and read-out system [5] . The CUPID array will account for about 1600 bolometers, each served by a light detector; the read-out system will consequently lead to ~ 3 times higher thermal load coming from the CUPID wiring with respect to CUORE.
In this poster the cryogenic upgrades will be mainly introduced, with a particular focus on the Pulse Tube system and wiring thermalization enhancements.
We foresee further improvements dedicated to the abatement of the vibrational noise, which in turn will improve the achievable energy resolution of bolometers. Thanks to the experience provided by CUORE, we can clearly demonstrate the effectiveness of the active Pulse Tube noise cancellation technique [6] , which will also be strengthened and applied in CUPID.

References

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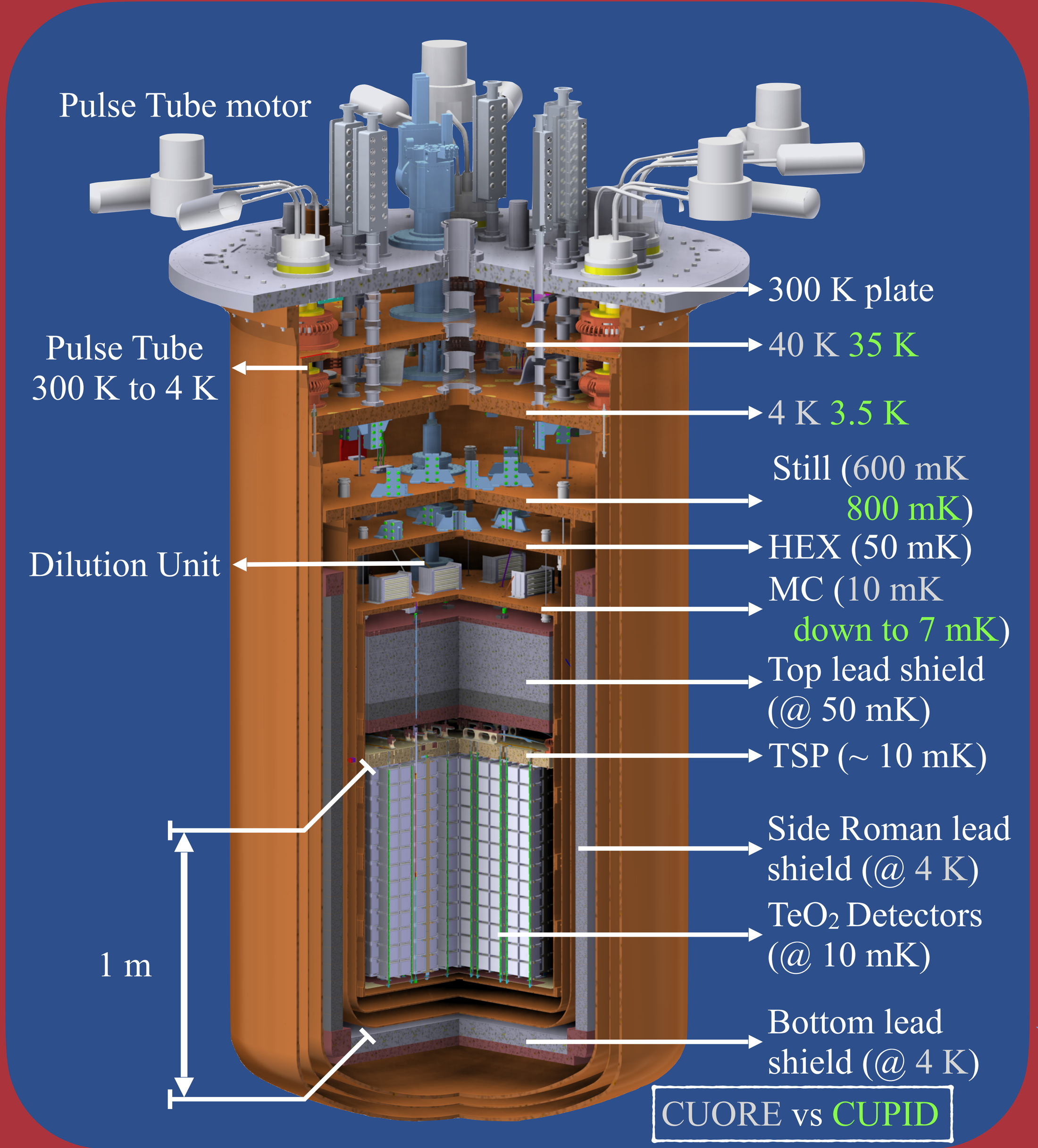
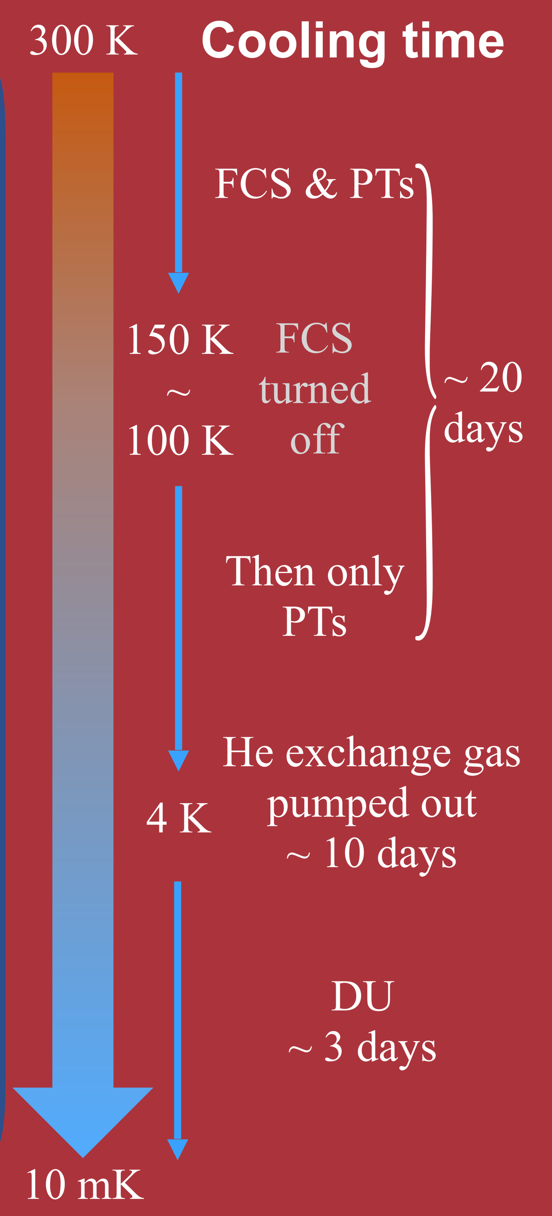
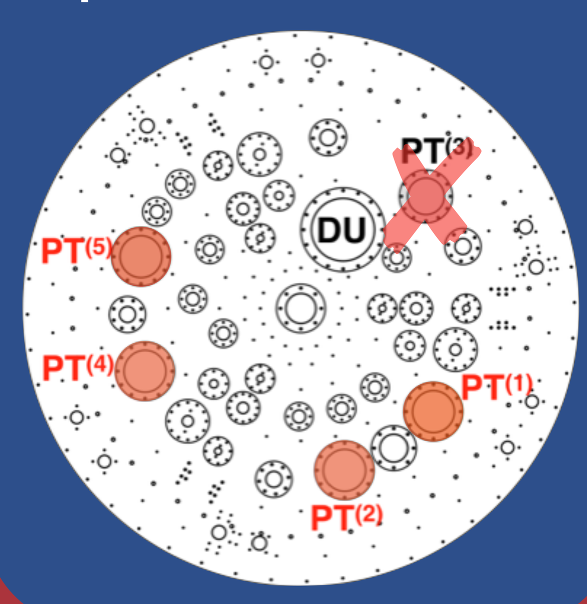
[4]: CUPID Collaboration, Optimization of the first CUPID detector module. arXiv:2202.06279
[5]: CUPID Collaboration, Toward CUPID-1T. arXiv:2203.08386
[6]: A. D'Addabbo, C. Bucci, L. Canonica, S. Di Domizio, P. Gorla, L. Marini, A. Nucciotti, I. Nutini, C. Rusconi, and B. Welliver. An active noise cancellation technique for the CUORE Pulse Tube cryocoolers. Cryogenics 93, 56-65 (2018).

The CUORE Cryostat





Top View of 300 K Plate

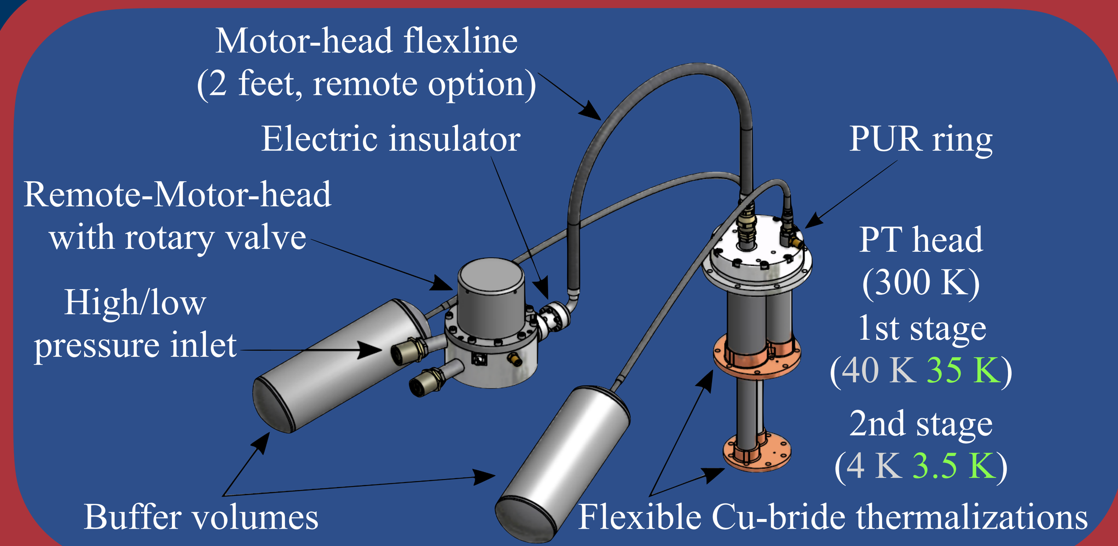


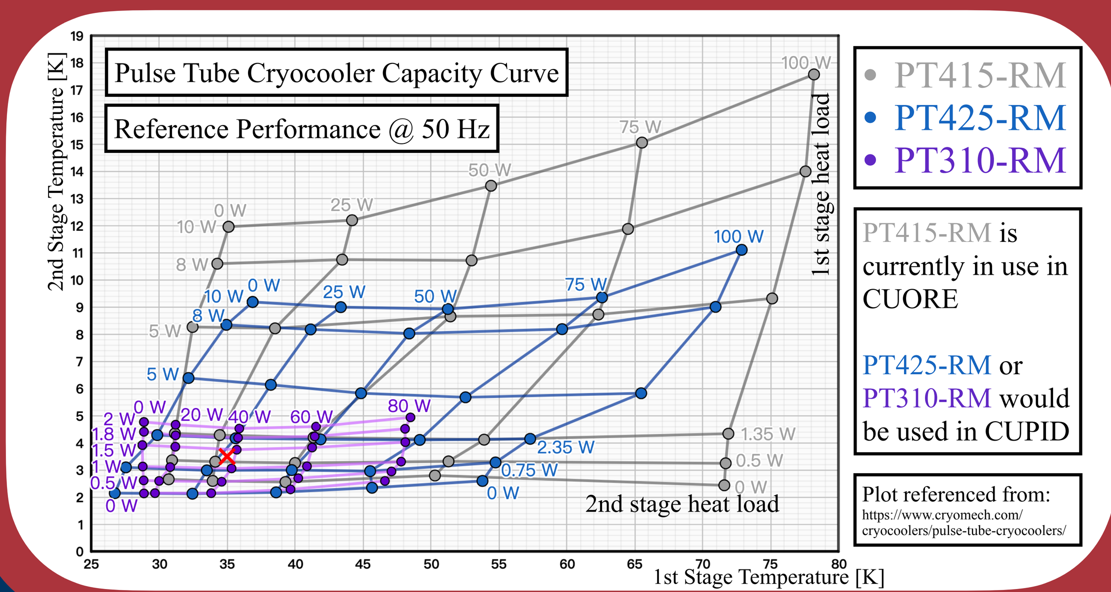
Foreseeing to reduce 1 PT in CUPID
(This blue color represents CUPID in this poster)

The multistage refrigerator

- Fast Cooling System (FCS) down to ~ 50 K
  - Cooling power: 1800 W @ 300 K; 350 W @ 50 K
- Pulse Tubes (PTs) down to ~ 4 K (~ 3.5 K)
  - 4 PTs plus 1 backup (Cryomech 415-RM)
  - 3 PTs plus 1 backup (Cryomech 425-RM)
  - Cooling power: (4 × 32 W) - 16 W = 112 W @ 45 K;
    - (4 × 1.2 W) - 0.6 W = 4.2 W @ 4 K
    - (3 × 40 W) - 20 W = 100 W @ 45 K;
    - (3 × 2 W) - 1 W = 5 W @ 4 K
- Dilution Unit (DU) down to ~ 10 mK (down to 7 mK)
  - Cooling power: 2 mW @ 120 mK;
    - > 4 μW (up to 6 μW) @ 10 mK

Pulse Tube Cryocoolers Preliminary





Cooling Power Estimation

- PT415-RM (4 PTs + 1 backup)
- 28 W @ 35 K (98 W)
- 0.6 W @ 3.5 K (2.1 W)

- PT425-RM (3 PTs + 1 backup)
- 27 W @ 35 K (67.5 W)
- 1.4 W @ 3.5 K (3.5 W)
  - ≥ 150% @ 3.5 K

- PT310-RM (3 PTs + 1 backup)
- 37 W @ 35 K (92.5 W)
- 1.3 W @ 3.5 K (3.25 W)
  - ≥ 150% @ 3.5 K

The above estimates are based on 2-feet Remote Motor option.

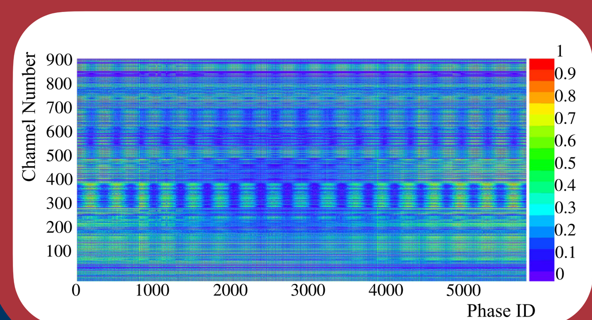
PT Noise Mitigation Strategy

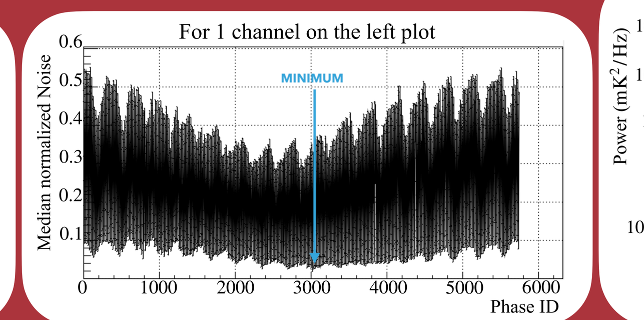
PT passive noise suppression

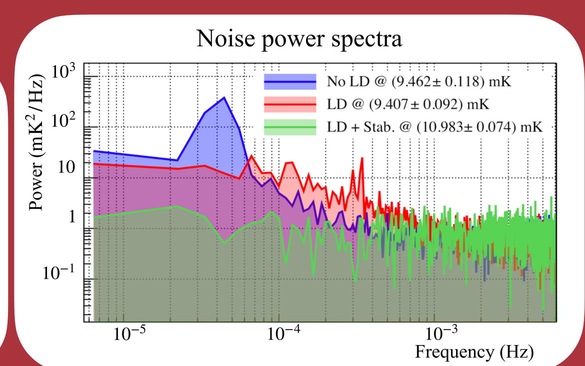
- 1.4 Hz working frequency and related harmonics from PTs remote motor and rotary valve
  - Which will vary, e.g. : 1.27 Hz for PT310-RM
- Polyurethane (PUR) ring decouple PT head
- Sandbox absorb vibration from inlets
- Cu-bridge as mechanical decouplers
- Foreseeing to replace with ultra pure aluminum
- More flexible, same or better conductivity

PT active noise cancellation

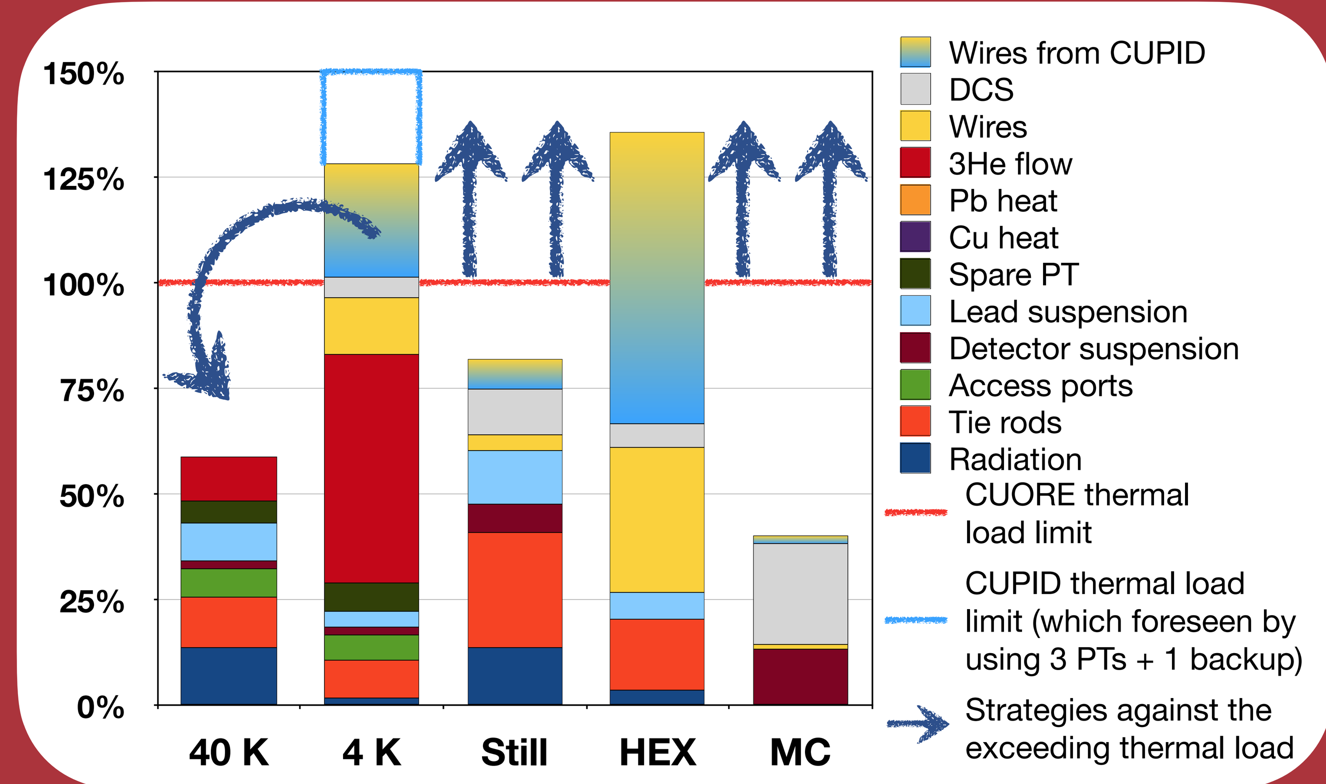
- Linear driver to suppress beating noise
- Control the phases of running PTs
- PT Phase Scan to find the best phase configuration

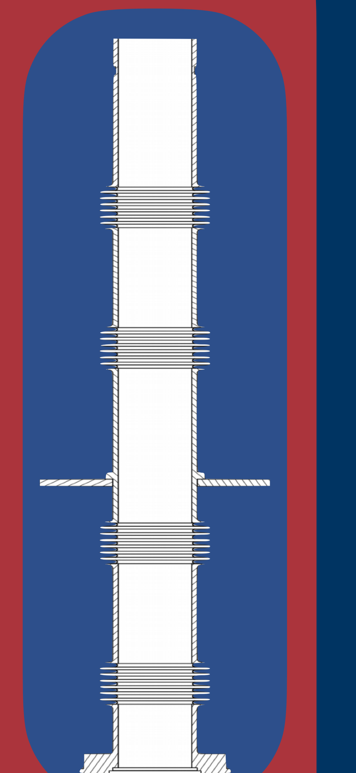






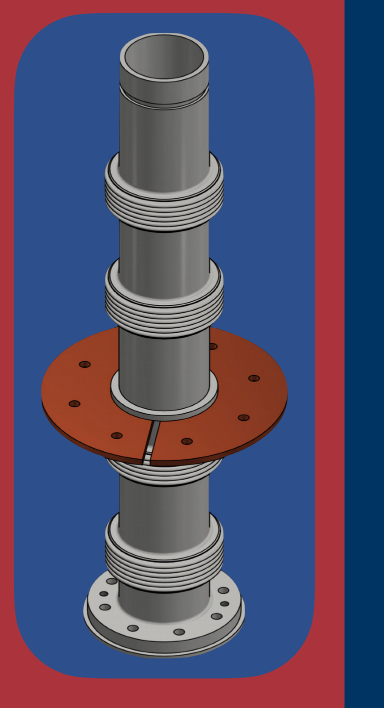
Preliminary CUPID Thermal Budget





CUORE thermalization & wiring

- Twisted pairs of NbTi wires (NOMEX texture) thermalized by:
- Radiation exchange between 300 K and 4 K (no thermal anchoring at 40 K)
- Below 4 K: thermal anchoring at Still (800 mK), HEX (50 mK), MC (10 mK)



Better cooling power distribution

- The thermal load on 4 K stage is already critical ~ 100%
- Assuming CUPID would have 3 times more wires than CUORE and no thermalization at 40 K
- From preliminary thermal budget, wires have ~ 15% impact on total cooling power at 4 K
  - → 4.2 W × 15% = 0.63 W @ 4 K (0.63 W × 3 = 1.89W @ 4 K)
- So total thermal load in CUPID is estimated to be 5.5 W at 4 K
- Move part of the thermal load from the 4 K stage to the 40 K stage
  - Could unload the wires thermal load adding an intermediate thermalization at 40 K stage (Designing scheme see right)
    - Optimization → First prototype with 3D printer → Cryogenic test
- Increase the cooling power at 4 K by using more powerful PTs
- Increase the cooling power at Still, HEX, MC by impelling the Dilution Unit
- Detector Calibration System (DCS) will not be present anymore in CUPID

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