Thermal calculation of crystal module

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$$C = \gamma T + \beta T^3$$ [1]

C_{e}
Electronic Specific Heat

C_l
Lattice Heat Capacity

$$C_e = \frac{(\pi/3)^{2/3} k_b^2 m_e^*}{\hbar^2} n^{1/3}\ T\ \mathrm{J}/(cm^3 \cdot \mathrm{K})$$

m_e^* electron effective mass

n free electron density

$$C = n \times \frac{12}{5} N_A K_B \pi^4 \frac{m}{M_{mole}} (\frac{T}{\theta_D})^3$$

$$= n \times 1944 \frac{m}{M_{mole}} (\frac{T}{\theta_D})^3$$

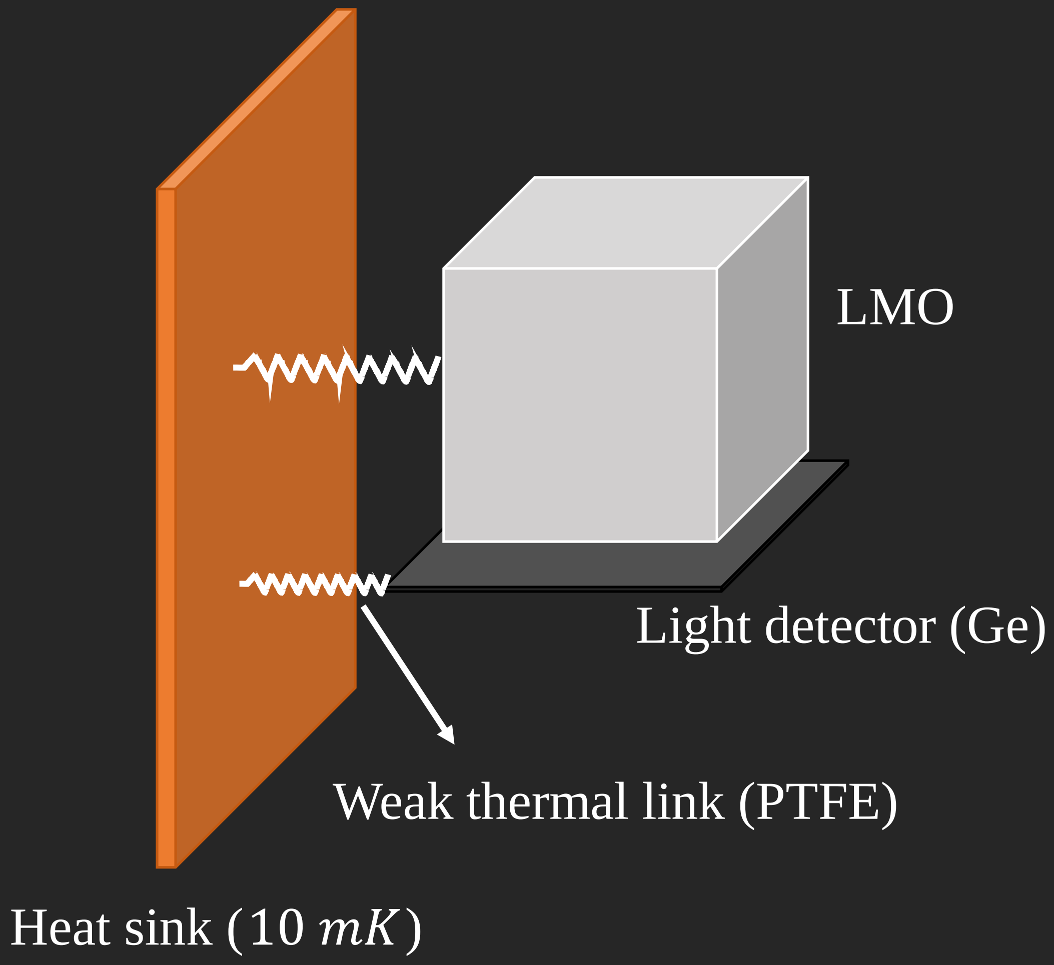
n : number of atoms in each cell

θ_D : Debye temperature

[1] E. S. R. Gopal, Specific Heats at Low Temperatures (Springer US, Boston, MA, 1966).

[2] C. A. Bryant and P. H. Keesom, Phys. Rev. 124, 698 (1961).

[3] F. Pobell, Matter and Methods at Low Temperatures, 3rd, rev.expanded ed ed. (Springer, Berlin ; New York, 2007).



$$C = n \times \frac{12}{5} N_A K_B \pi^4 \frac{m}{M_{mole}} (\frac{T}{\theta_D})^3$$

For $8cm^3$ LMO;

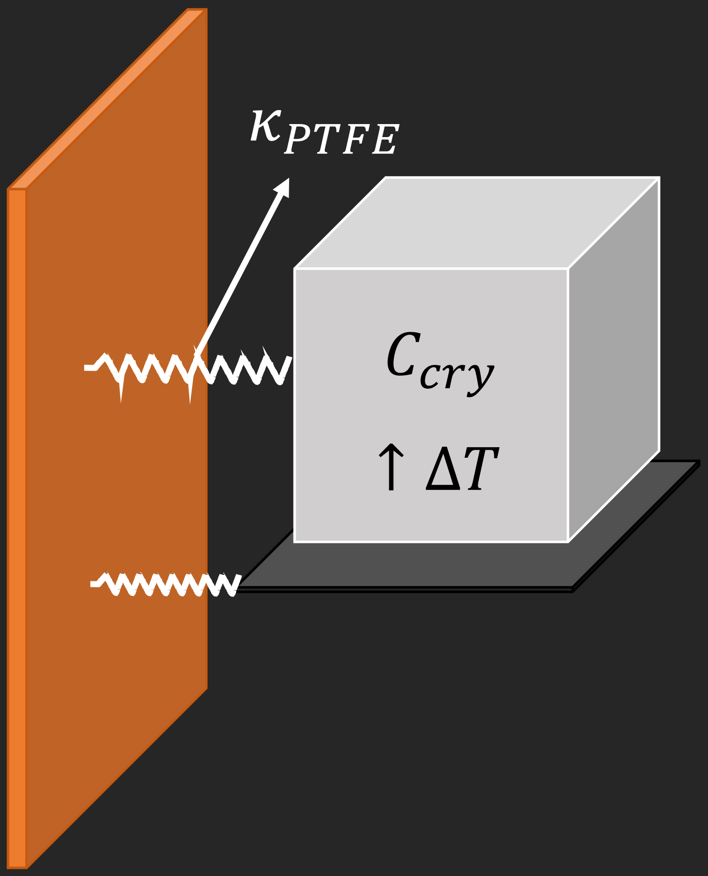
$$C_{cry} = 7 \times 1944 \times \frac{21.28}{177.882} \times (\frac{0.001}{316.15})^3 J/K$$

$$= 5.152 \times 10^{-11} J/K$$

$1\ MeV\ deposited$

$$E = 1.6022 \times 10^{-13}\ J$$

$$\Delta T = 3.110\ mK$$



$$T_{cry}(t)$$

$$\frac{dQ}{dt} = \kappa_{PTFE} \cdot A \cdot \frac{T_{cry}(t) - 10mK}{l}$$

$$\frac{dT_{cry}(t)}{dt} = \frac{dQ}{C_{cry}dt} = \frac{\kappa_{PTFE} \cdot A}{l \cdot C_{cry}}\left(T_{cry}(t) - 10mK\right)$$

$$T_{cry}(t) = 10mK + \Delta T e^{-\frac{\kappa_{PTFE} \cdot A}{l \cdot C_{cry}}t}$$

For amorphous materials
$T \leq 1\ K$: Tunneling Processes

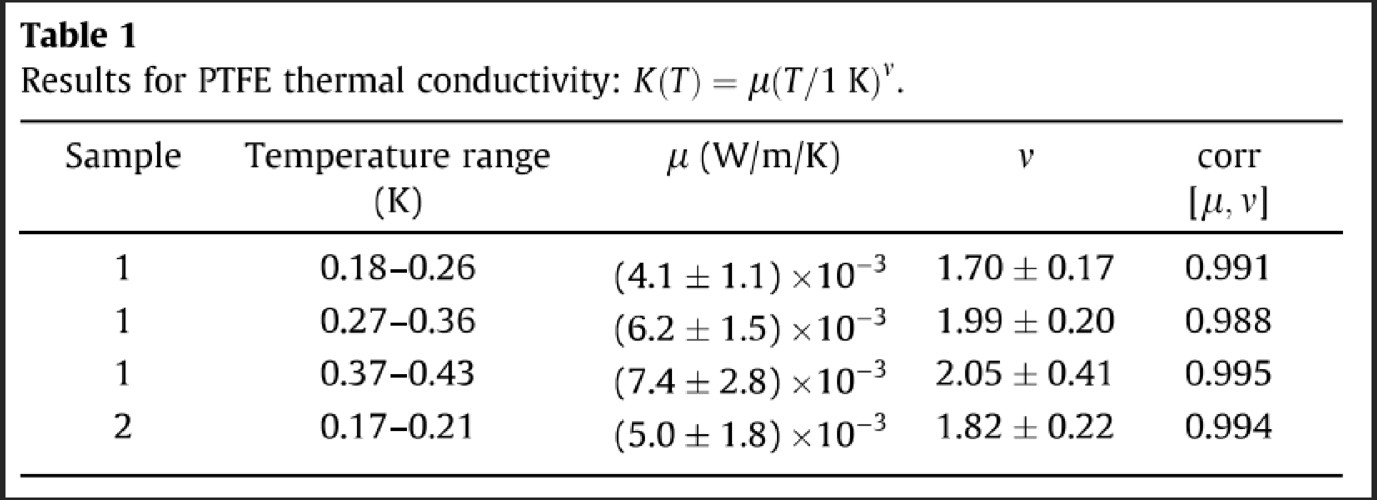


Table 1
Results for PTFE thermal conductivity: $K(T) = \mu(T/1\ \mathrm{K})^{\nu}$.

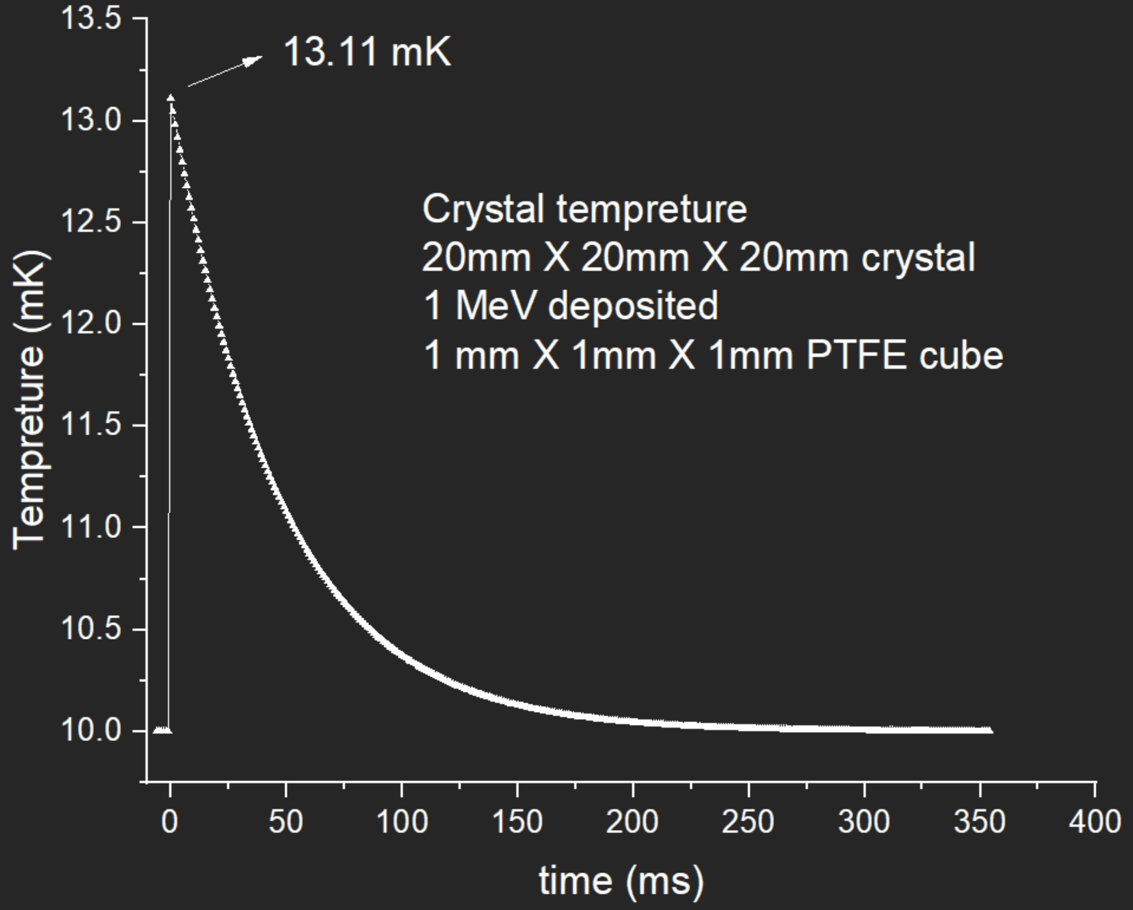
Sample	Temperature range (K)	μ (W/m/K)	ν	corr $[\mu, \nu]$
1	0.18–0.26	$(4.1 \pm 1.1) \times 10^{-3}$	1.70 ± 0.17	0.991
1	0.27–0.36	$(6.2 \pm 1.5) \times 10^{-3}$	1.99 ± 0.20	0.988
1	0.37–0.43	$(7.4 \pm 2.8) \times 10^{-3}$	2.05 ± 0.41	0.995
2	0.17–0.21	$(5.0 \pm 1.8) \times 10^{-3}$	1.82 ± 0.22	0.994

$$\kappa_{PTFE} = (5.0 \pm 0.8) \times 10^{-3} T^{1.83 \pm 0.11} \mathrm{Wm^{-1}K^{-1}}$$

for 10mK

$$\kappa_{PTFE} = 1.09 \times 10^{-6} \mathrm{Wm^{-1}K^{-1}}$$

B, Alexey Drobizhev A , et al. Thermal conductivity measurements of PTFE and Al2O3 ceramic at sub-Kelvin temperatures. Cryogenics 85(2017).



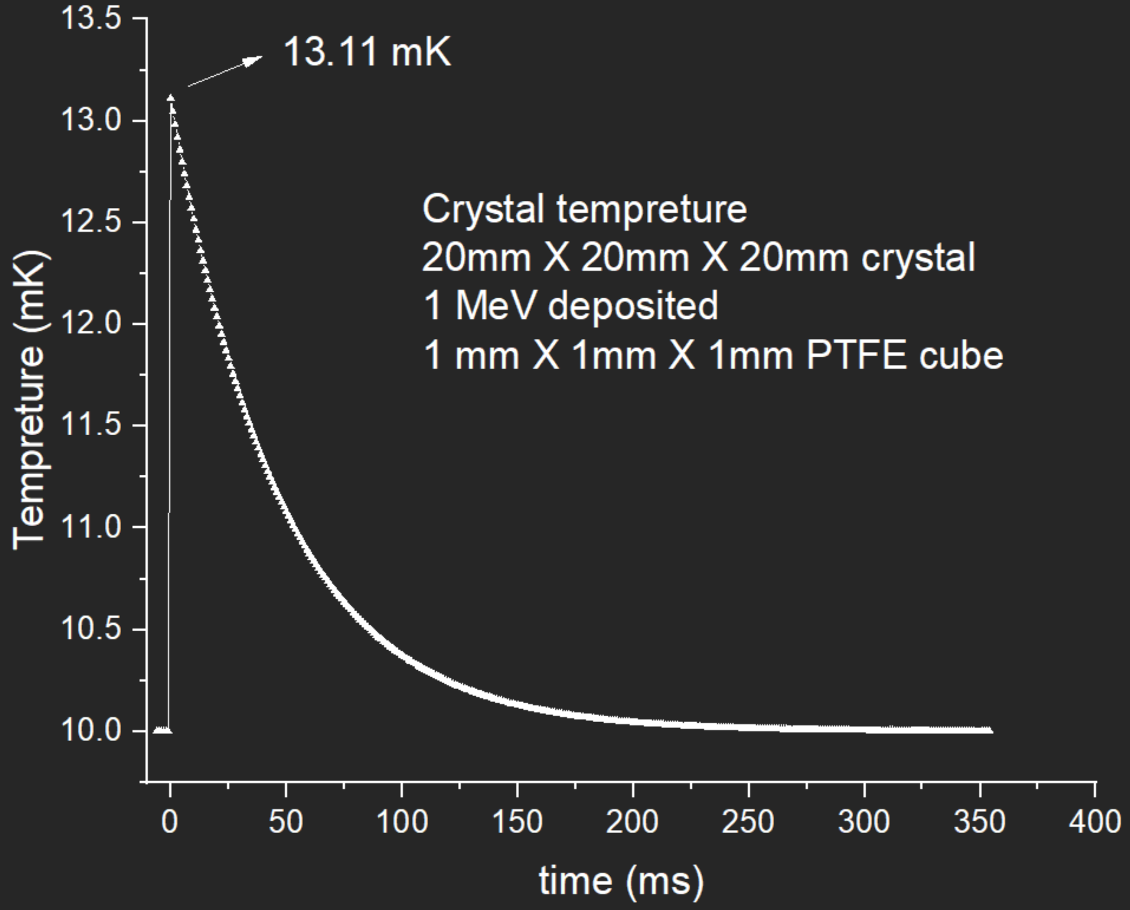
$$T_{cry}(t) = 10mK + \Delta T e^{-\frac{\kappa_{PTFE}\cdot A}{l\cdot C_{cry}}t}$$

When $A = 1\,mm^2 \quad l = 1\,mm$

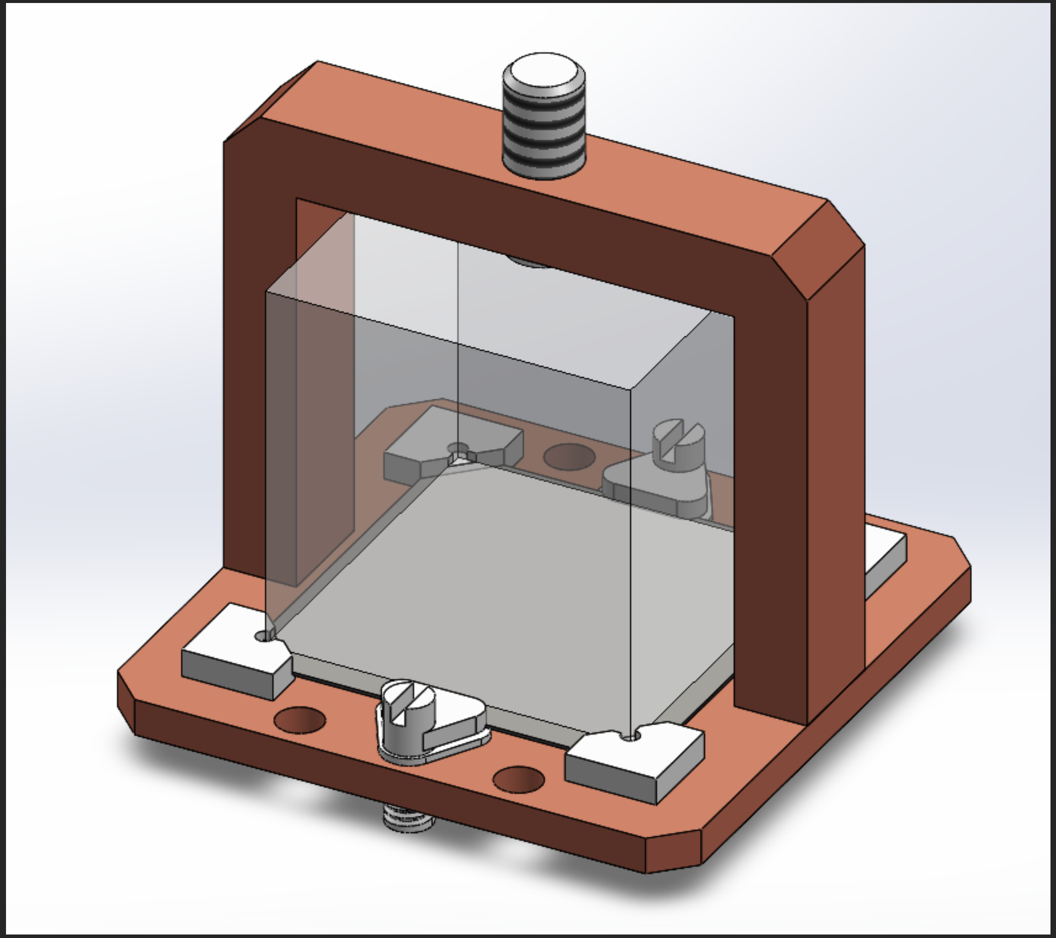
$$C_{cry} = 5.152 \times 10^{-11} J/K$$

$$\Delta T = 3.110\,mK$$

$$\kappa_{PTFE} = 1.09 \times 10^{-6}\mathrm{Wm^{-1}K^{-1}}$$

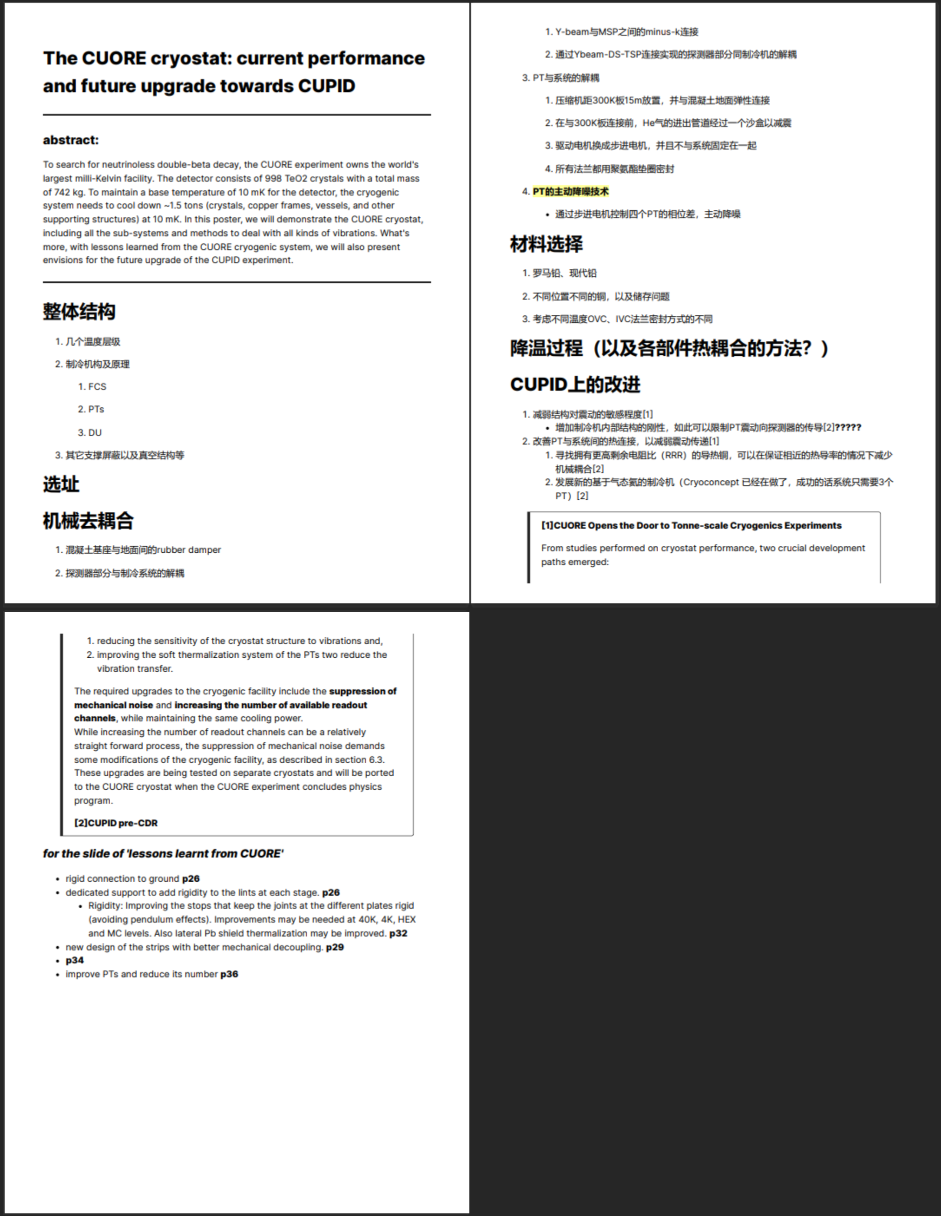


Crystal tempreture
20mm X 20mm X 20mm crystal
1 MeV deposited
1 mm X 1mm X 1mm PTFE cube



$$e^{-\frac{\kappa_{PTFE}\cdot A}{l\cdot C_{cry}}t}$$

CUORE cryostat poster



The CUORE cryostat: current performance and future upgrade towards CUPID

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abstract:

To search for neutrinoless double-beta decay, the CUORE experiment owns the world's largest milli-Kelvin facility. The detector consists of 998 TeO2 crystals with a total mass of 742 kg. To maintain a base temperature of 10 mK for the detector, the cryogenic system needs to cool down ~1.5 tons (crystals, copper frames, vessels, and other supporting structures) at 10 mK. In this poster, we will demonstrate the CUORE cryostat, including all the sub-systems and methods to deal with all kinds of vibrations. What's more, with lessons learned from the CUORE cryogenic system, we will also present envisions for the future upgrade of the CUPID experiment.

整体结构

1. 几个温度层级
2. 制冷机构及原理
    1. FCS
    2. PTs
    3. DU
3. 其它支撑屏蔽以及真空结构等

选址

机械去耦合

1. 混凝土基座与地面间的rubber damper
2. 探测器部分与制冷系统的解耦
    1. Y-beam与MSP之间的minus-k连接
    2. 通过Ybeam-DS-TSP连接实现的探测器部分同制冷机的解耦
3. PT与系统的解耦
    1. 压缩机距300K板15m放置，并与混凝土地面弹性连接
    2. 在与300K板连接前，He气的进出管道经过一个沙盒以减震
    3. 驱动电机换成步进电机，并且不与系统固定在一起
    4. 所有法兰都用聚氨酯垫圈密封
4. **PT的主动降噪技术**
    - 通过步进电机控制四个PT的相位差，主动降噪

材料选择

1. 罗马铅、现代铅
2. 不同位置不同的铜，以及储存问题
3. 考虑不同温度OVC、IVC法兰密封方式的不同

降温过程（以及各部件热耦合的方法？）

CUPID上的改进

1. 减弱结构对震动的敏感程度[1]
    - 增加制冷机内部结构的刚性，如此可以限制PT震动向探测器的传导[2]**?????**
2. 改善PT与系统间的热连接，以减弱震动传递[1]
    1. 寻找拥有更高剩余电阻比（RRR）的导热铜，可以在保证相近的热导率的情况下减少机械耦合[2]
    2. 发展新的基于气态氦的制冷机（Cryoconcept 已经在做了，成功的话系统只需要3个PT）[2]

> **[1]CUORE Opens the Door to Tonne-scale Cryogenics Experiments**
>
> From studies performed on cryostat performance, two crucial development paths emerged:
>
> 1. reducing the sensitivity of the cryostat structure to vibrations and,
> 2. improving the soft thermalization system of the PTs two reduce the vibration transfer.
>
> The required upgrades to the cryogenic facility include the **suppression of mechanical noise** and **increasing the number of available readout channels**, while maintaining the same cooling power.
> While increasing the number of readout channels can be a relatively straight forward process, the suppression of mechanical noise demands some modifications of the cryogenic facility, as described in section 6.3. These upgrades are being tested on separate cryostats and will be ported to the CUORE cryostat when the CUORE experiment concludes physics program.
>
> **[2]CUPID pre-CDR**

for the slide of 'lessons learnt from CUORE'

- rigid connection to ground **p26**
- dedicated support to add rigidity to the lints at each stage. **p26**
    - Rigidity: Improving the stops that keep the joints at the different plates rigid (avoiding pendulum effects). Improvements may be needed at 40K, 4K, HEX and MC levels. Also lateral Pb shield thermalization may be improved. **p32**
- new design of the strips with better mechanical decoupling. **p29**
- **p34**
- improve PTs and reduce its number **p36**

Thanks