Experimental study and modelling of cryogenic detectors decoupling within dry cryostat

R. Maisonobe[a], J. Billard[a], M. De Jesus[a], L. Dumoulin[b], A. Juillard[a], S. Marnieros[b], C. Nones[c], D. Misiak[a], S. Sayah[a], L. Vagneron[a] , A. Zolotarova[c]

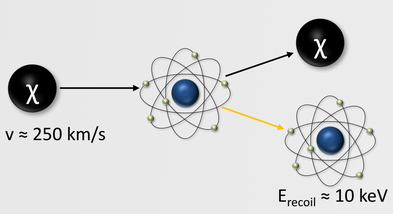
[a]Univ. Lyon, Université Lyon 1, CNRS/IN2P3, IPNL-Lyon, F-69622 Villeurbanne, France

[b]CSNSM, Univ. Paris Sud, CNRS/IN2P3, Université Paris-Saclay, 91405 Orsay, France

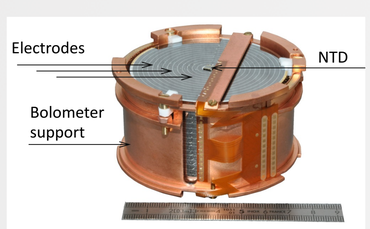
[c]IRFU, CEA, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France

Direct dark matter detection

Elastic scattering of a WIMP on nuclei:
- scintillation,
- heat,
- ionisation.

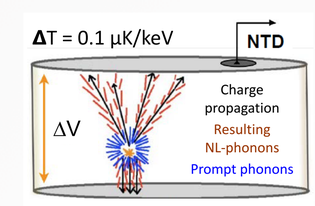


Within the EDELWEISS experiment, detectors are germanium cryogenic bolometers.



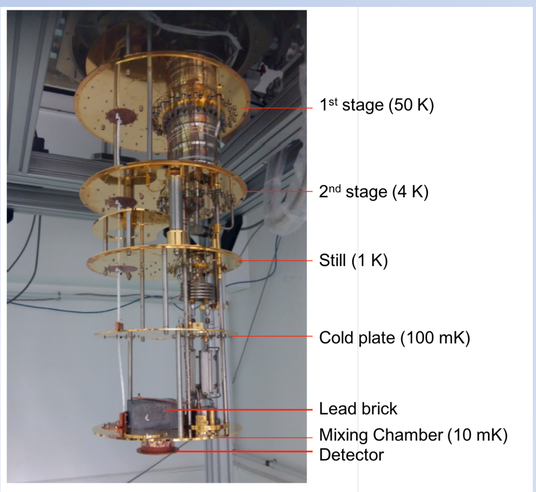
Heat channels:
- Phonon thermalization → 2 NTD (Neutron Transmutation Doped).

Ionization channels:
- Charges collection → Al concentric electrodes.



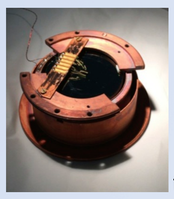
Problem: high impedance heat channel is sensitive to microphonic.

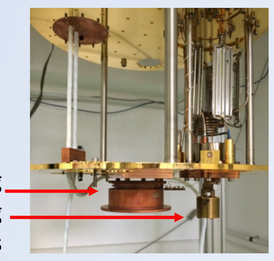
Dry cryostat @ Lyon



Dry Dilution Refrigerators (DDR) are based on pulse tube cryo-coolers using ^{3}He/^{4}He in close circuit.

Cryostat **Hexadry Standard (Hex std)** produced by Cryoconcept with 50K/4K decoupling:
- ➢ thermal coupling via low-pressure gas-exchangers (Hexagas^{TM}).





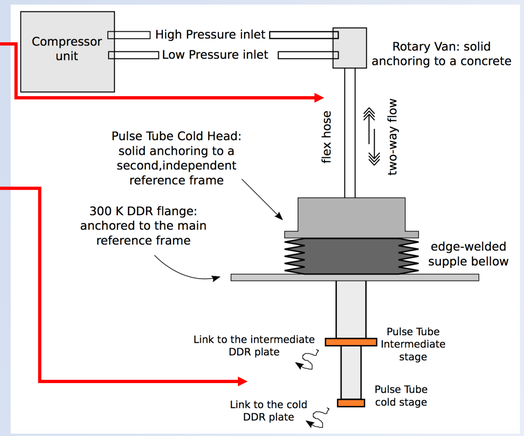
200g and 30g test detectors

"Quiet" dry cryostat

Stirling cycles within [9-18] bars.

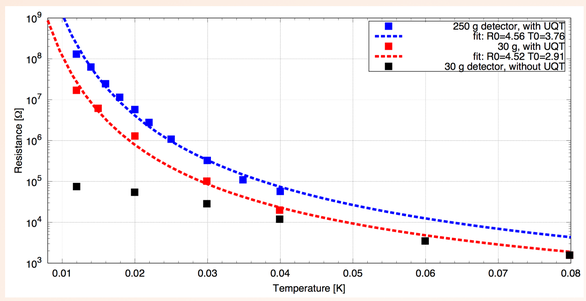
Gas exchange

Hexadry Ultra Quiet Technology (Hex UQT):
- Edge-welded supple below,
  - ➢ low mechanical contact,
- Pulse-tube head on 2nd frame physically separated from cryostat,
- Rotary valve mounted on the ceiling.



Detector and vibrations

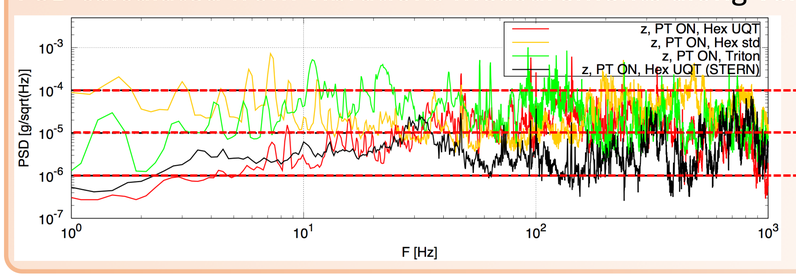
Effect of pulse-tube configuration on the detectors performances.



Before Hex UQT upgrade (black points), 30 g bolometer temperature levels off around 100 kΩ → 30 mK (T_{MC}= 12 mK).

Mott-Anderson law: $R(T) = R_0 \exp\left(\sqrt{T_0/T}\right)$

PSD calculated from vibrations measurements along vertical axis of cryostat:



Noisy
Upper "acceptable" limit

Typical
Low noise measurements

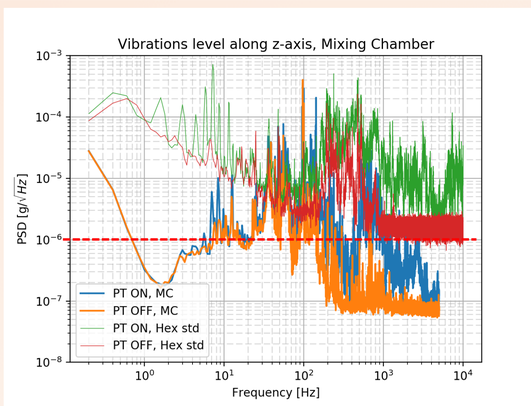
Quiet
Goal

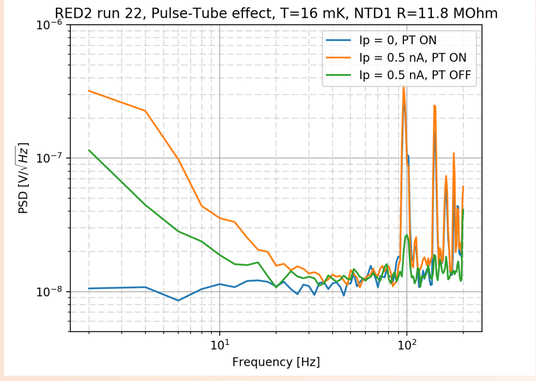
E. Olivieri, J. Billard, M. De Jesus, A. Juillard, A. Leder, Nucl. Instr. Meth. Phys. Res., A, vol. 858, June 2017, 73-79

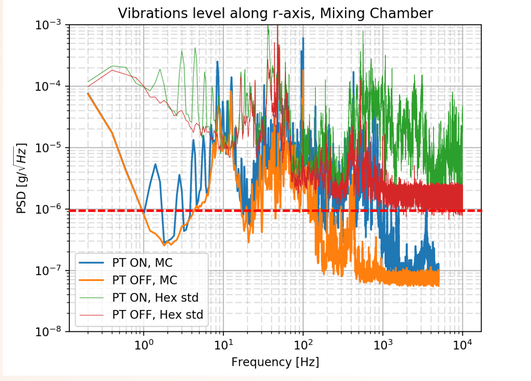
"Residual" vibrations

Even with the configuration Hex UQT, the pulse-tube (PT) generates some vibrations:
- vertical at 8 Hz,
- radial at 1.4 Hz,

with an effect on the PSD noise measured from polarized NTD (Ip).

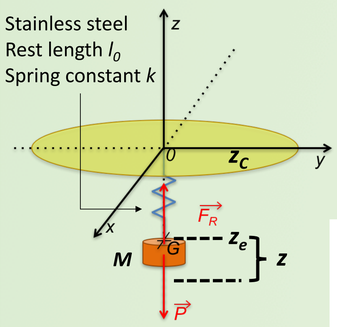






Suspended pendulum

Proposal: mount the detector on a suspended system.

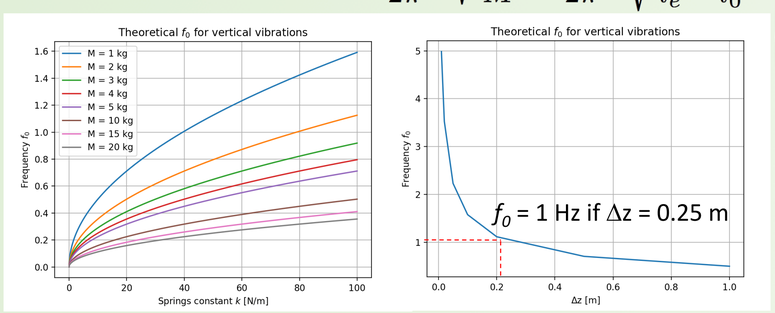


Vertical motion induced by vertical perturbations: $\ddot{z} + \frac{k}{M} \cdot (z + z_C) = 0$

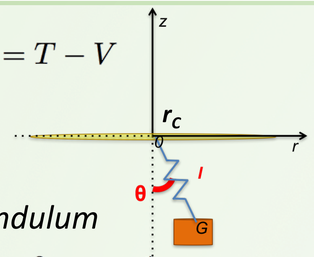
Natural frequency: $f_{0,z} = \frac{1}{2\pi} \cdot \sqrt{\frac{k}{M}} \equiv \frac{1}{2\pi} \cdot \sqrt{\frac{g}{l_e - l_0}}$

Equilibrium state: $\vec{P} + \vec{F_R} = \vec{0}$

$M \cdot g = k \cdot (l_e - l_0)$



Radial motion induced by radial perturbations:



Approximation of wire-pendulum

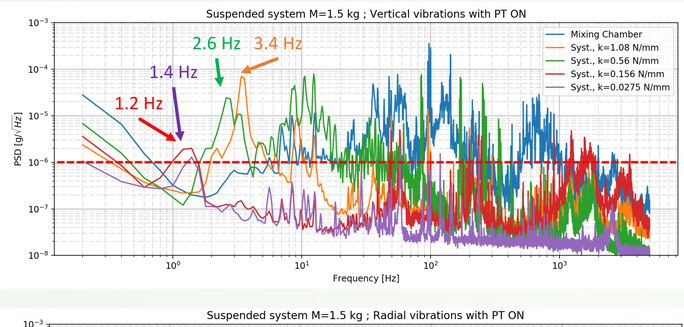
$\frac{\mathrm{d}}{\mathrm{d}t}\left(\frac{\partial L}{\partial \dot{\theta}}\right) - \frac{\partial L}{\partial \theta} = 0 \rightarrow \ddot{\theta} + \frac{g}{l} \cdot \theta + \frac{2}{l} \cdot \dot{l} \cdot \dot{\theta} + \frac{1}{l} \cdot \ddot{r}_C = 0$

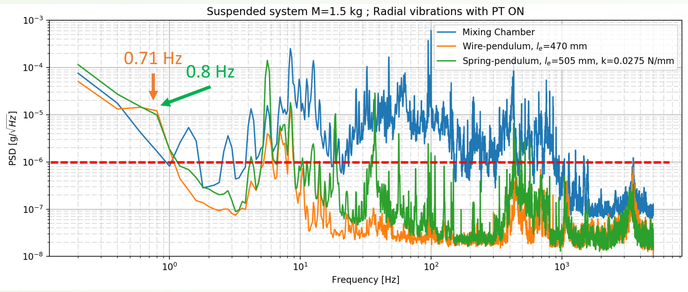
Approximation of spring-pendulum

$\frac{\mathrm{d}}{\mathrm{d}t}\left(\frac{\partial L}{\partial \dot{l}}\right) - \frac{\partial L}{\partial l} = 0 \rightarrow \ddot{l} + \frac{k}{M} \cdot (l - l_0) - g + l \cdot \dot{\theta}^2 + \ddot{r}_C \cdot \theta = 0$

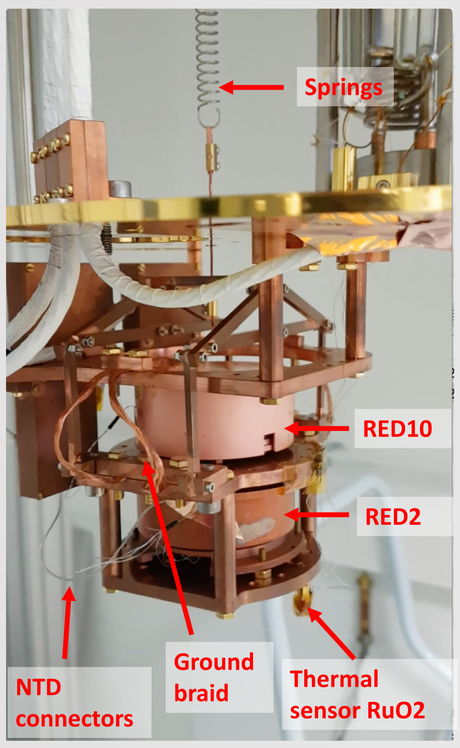
Natural frequency: $f_{0,r} = \frac{1}{2\pi} \cdot \sqrt{\frac{g}{l}}$

f_0 = 1 Hz if l = 0.25 m

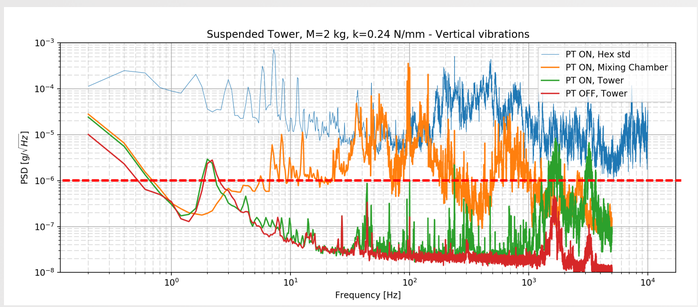


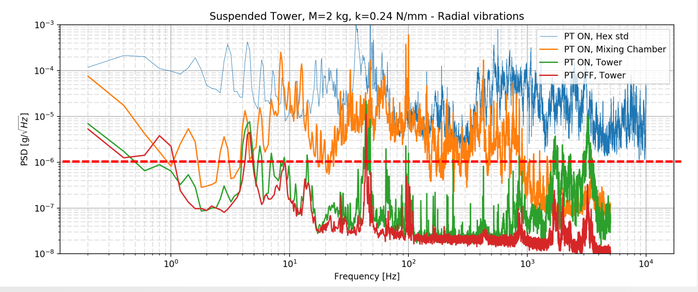


Detector on suspended tower

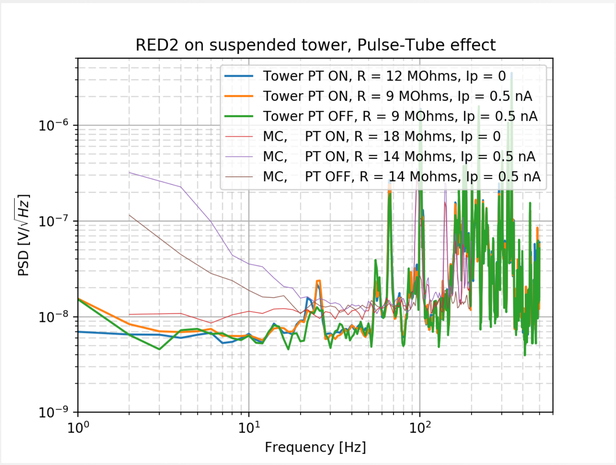


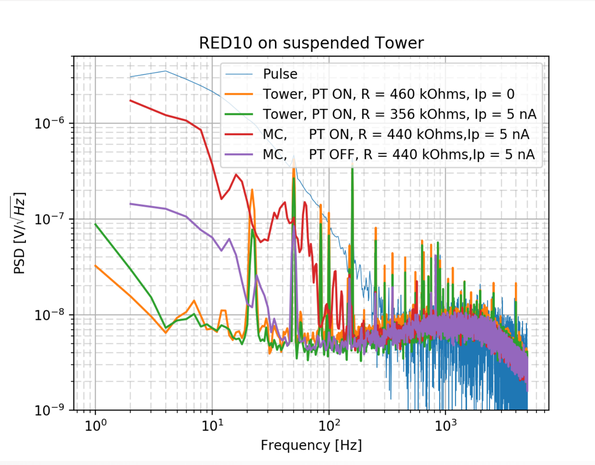
The suspended tower was designed following the first theoretical and experimental investigations:
- low vibrations level both in vertical and in radial,
- high attenuation of the effect from pulse-tube.





The suspended tower allows to attenuate the vibrations effects on the PSD noise measured for two tests detectors.





Conclusion:
- ➢ No more effect of the pulse-tube on the detector,
- ➢ Better environmental decoupling (even PT OFF),
- ➢ Improvement on the detectors bandwidth up to 2 order of magnitude.