Axion search at the Grenoble Axion Haloscope platform

The GrAHal – CAPP project

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Brief reminder: cavity haloscopes

Sikivie Phys. Rev. D 32, 2988 (1985)

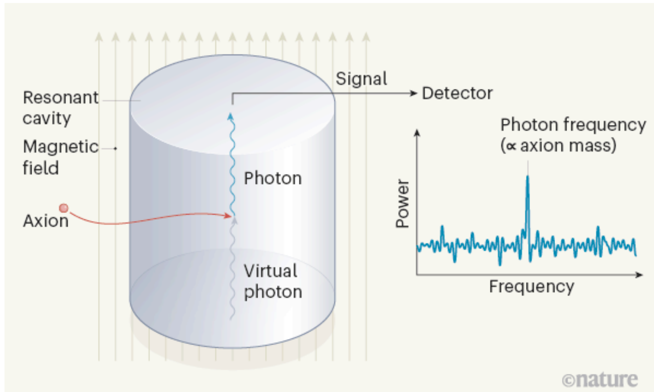
Axion electrodynamics :

$$\nabla \cdot \mathbf{E} = g_{a\gamma\gamma} \mathbf{B} \cdot \nabla a$$

$$\nabla \times \mathbf{B} - \partial_t \mathbf{E} = g_{a\gamma\gamma} \left(\mathbf{E} \times \nabla a - \mathbf{B} \partial_t a \right)$$

$$\nabla \times \mathbf{E} + \partial_t \mathbf{B} = 0$$

$$\nabla \cdot \mathbf{B} = 0$$



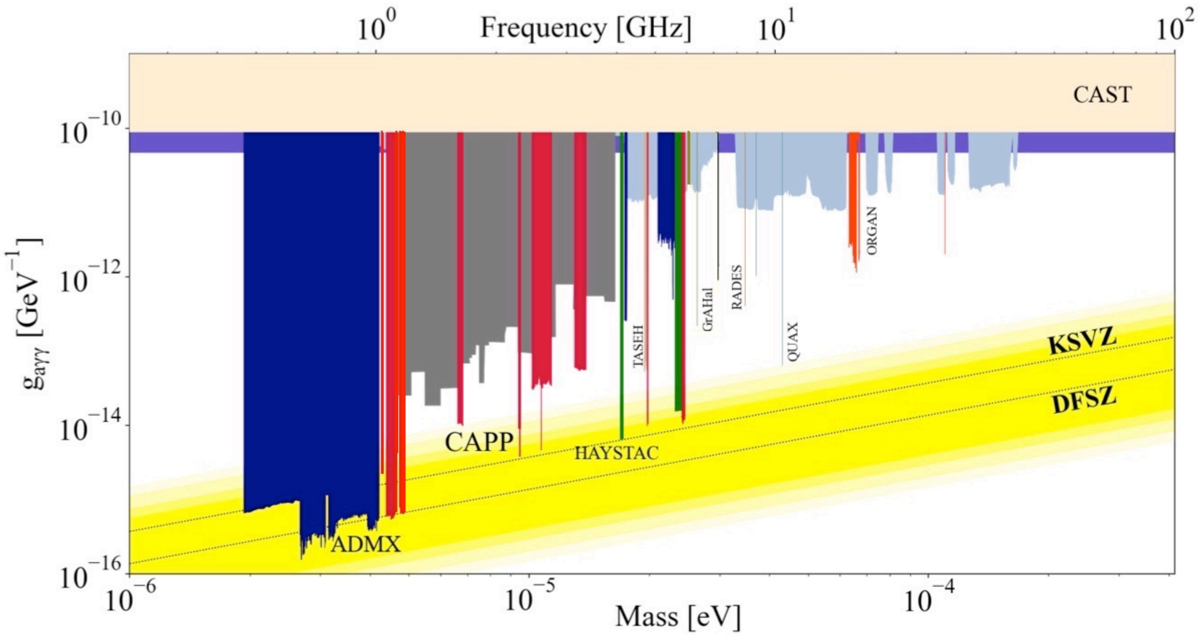
Picture from I. G. Irastorza, *Nature* **590**, 226-227 (2021)

Resonant conversion to RF photon in a strong magnetic field :

$$P = 2{,}67.10^{-25} (Watt) \left(\frac{g_\gamma}{0.97} \right)^2 \left(\frac{\rho_a}{0.45 GeV / cm^3} \right) \left(\frac{\beta / (1+\beta)^2}{2/9} \right) \left(\frac{C}{0.5} \right) \left(\frac{f}{1GHz} \right) \left(\frac{B_0}{10T} \right)^2 \left(\frac{V_{ol}}{1L} \right) \left(\frac{Q_L}{10^4} \right) \quad (Q_L << Q_a)$$

$$SNR \propto \frac{f C B_0^{\,2} V_{ol} Q_{eff}}{k_B T_{noise}} \sqrt{\frac{t}{\Delta f}}$$

Haloscope axion-diphoton coupling exclusions



$$SNR \propto g_{a\gamma\gamma}{}^{2} \frac{f C B_0{}^{2} V_{ol} Q_{eff}}{k_B T_{noise}} \sqrt{\frac{t}{\Delta f}}$$

$$scanrate \propto g_{a\gamma\gamma}{}^{4} \frac{B_0{}^{4} V_{ol}{}^{2} Q_{eff}}{\left(k_B T_{noise}\right)^{2}}$$

DFSZ sensitivity on the whole range using cylinder copper cavity ?

Count integration time in kiloyears !

→ Large $B_0{}^2 V$ is crucial.

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Key expertise at CNRS-Grenoble for High magnetic fields, Extreme Low Temperatures, Quantum Detectors and Theory.

CNRS
UGA Université Grenoble Alpes
anr agence nationale de la recherche

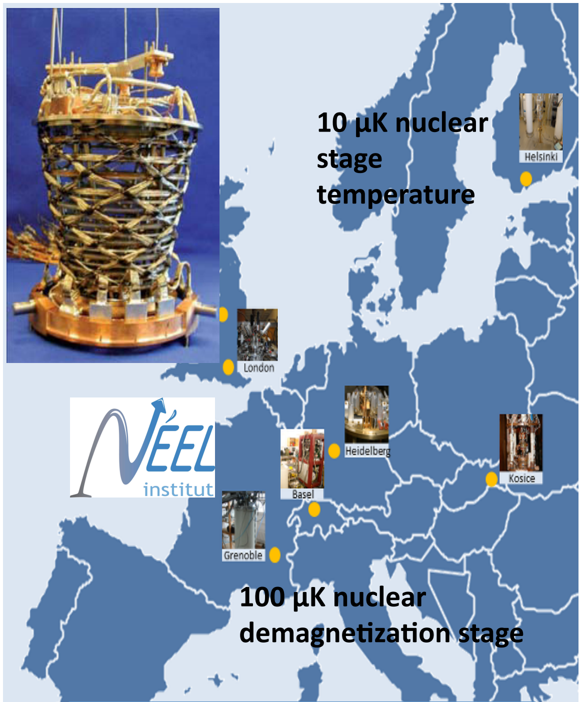
EMFL European Magnetic Field Laboratory
LNCMI

43+T Grenoble Modular Hybrid Magnet

Néel institut

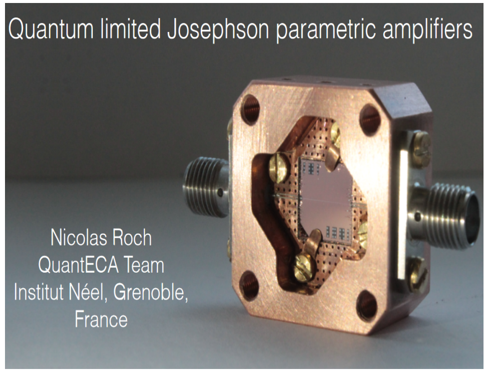
European Microkelvin Platform

20 leading ultralow temperature physics & technology Institutes in Europe including 7 submilliK facilities



Expertise for dilution fridges & cryostats (Planck, Edelweiss, CUT, SuperCDMS …)

JPA Achievements



LPSC Grenoble

Theory group :

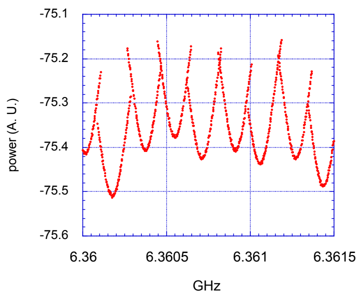
- Beyond the SM Physics
- Cosmology, BHs, Q. Grav.

“Baby GrAHal” @ Neel Institute

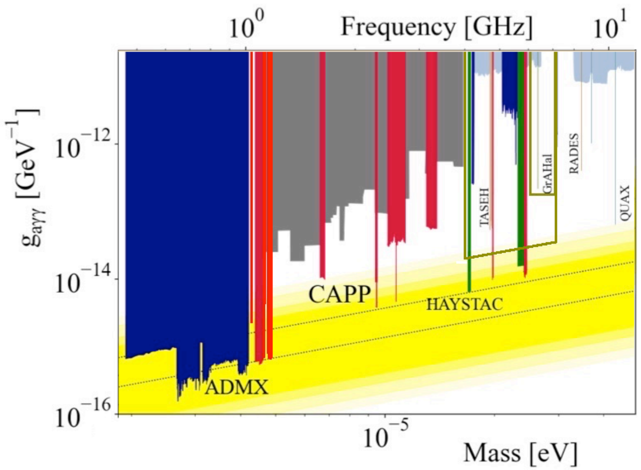
50 mK – 14T haloscope (4-7 GHz range)

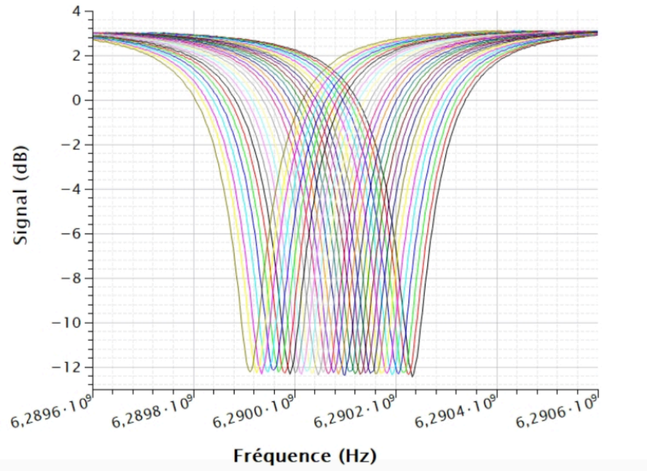
4K He tuned Baby GrAHal

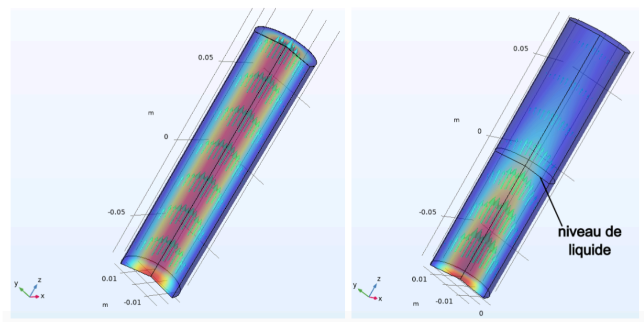
Very first test run of Baby GrAHal
https://arxiv.org/pdf/2110.14406.pdf



14 T @ 4 K, He gas tuning exclusion over 20 MHz (around 6.365 GHz)







14 T @ 4 K, liquid He tuning exclusion over ≈ 100 MHz (around 6.315 GHz)

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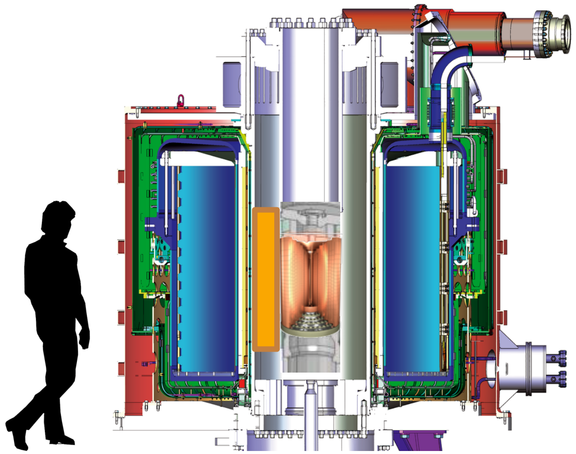
cnrs

UGA Université Grenoble Alpes

anr agence nationale de la recherche

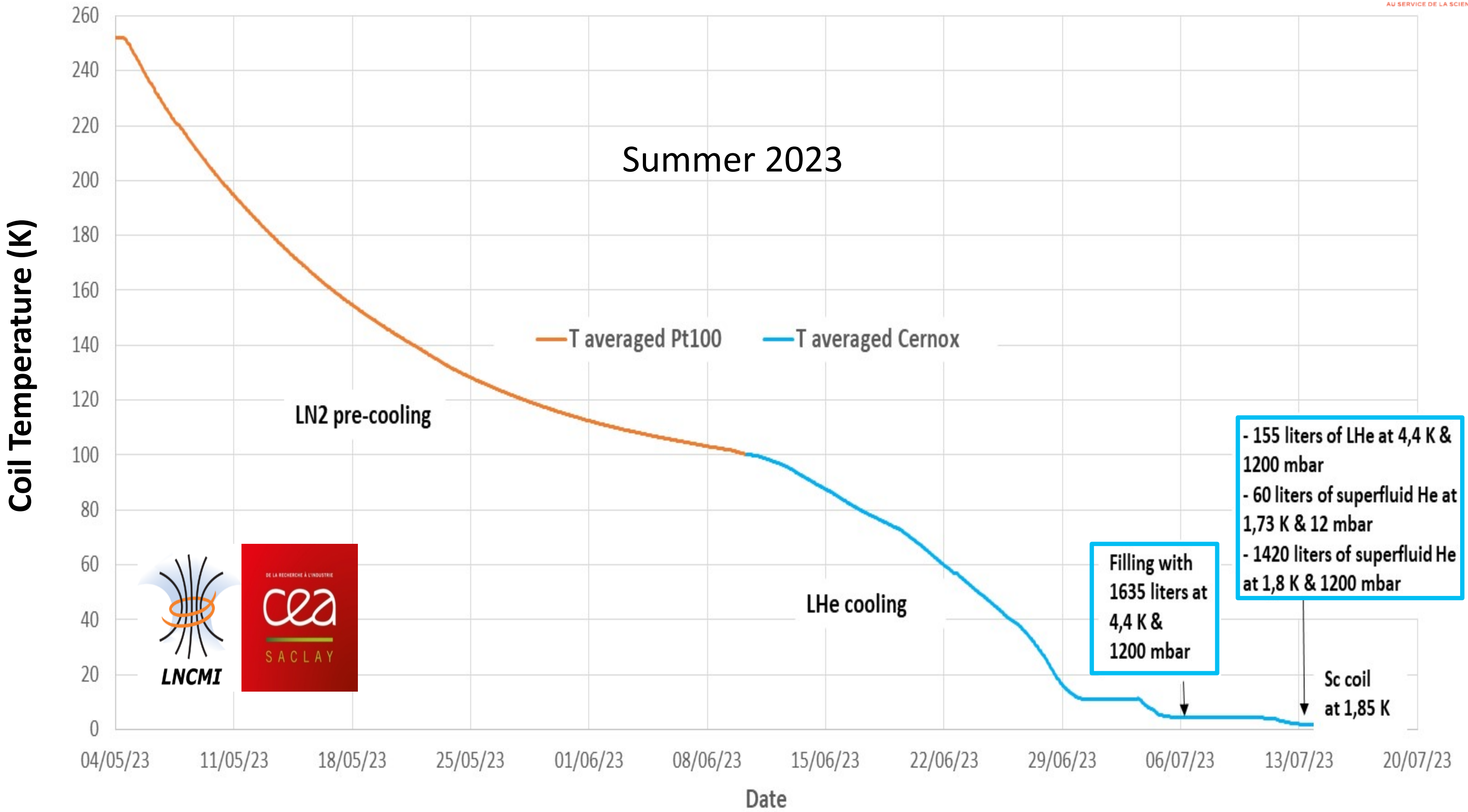
Grenoble new big hybrid magnet



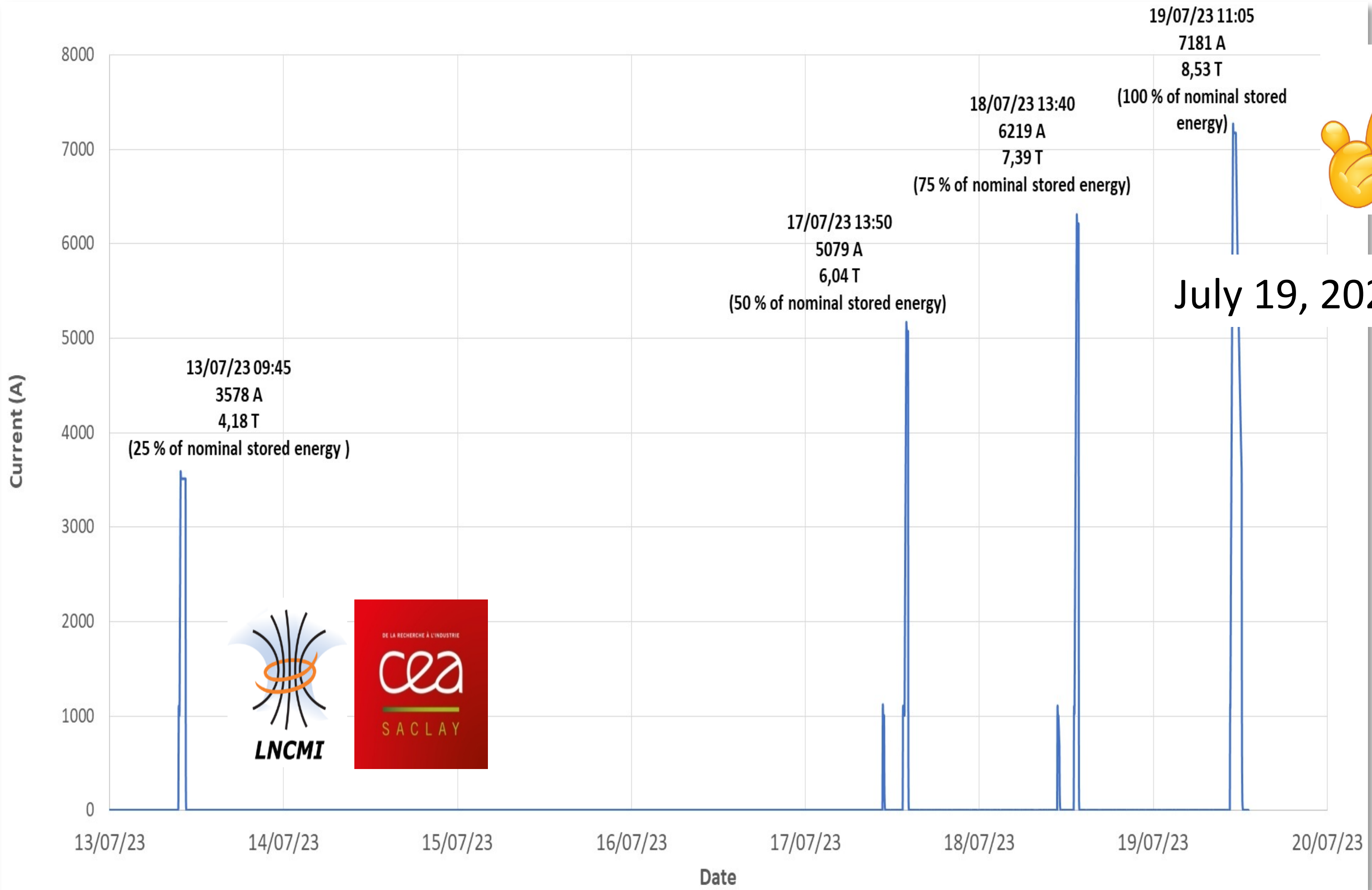
Various high magnetic Flux configurations

Field	Warm dia.	RF-cavity dia.*	Frequency TM010	Height**
43 T	34 mm	20/12/8 mm	11-29 GHz	157 mm
40 T	50 mm	34/26/20 mm	5-11 GHz	157 mm
27 T	170 mm	86 mm	2.67 GHz	315 mm
17.5 T	375 mm	291 mm	0.79 GHz	484 mm
9 T	812 mm	675 mm	0.34 GHz	1400 mm

Magnet cooldown :



Powering of the 812 mm diam. Superconducting coil :



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The GrAHal-CAPP project

GrAHal

- Powerful ultra-large magnet
- Cryogenics

CAPP

- Haloscope mastering
- Ultra-light cavities

GrAHal-CAPP : axion search at the highest sensitivity

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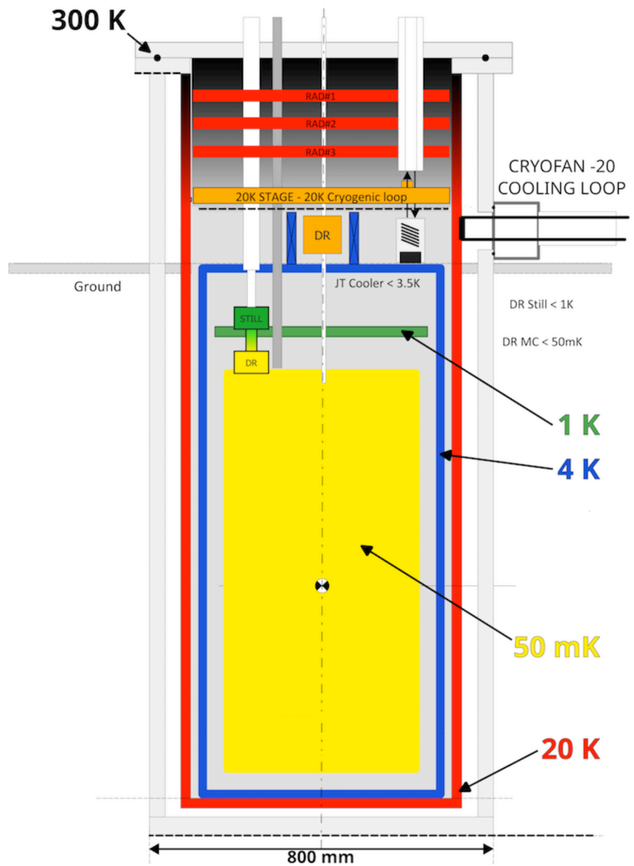
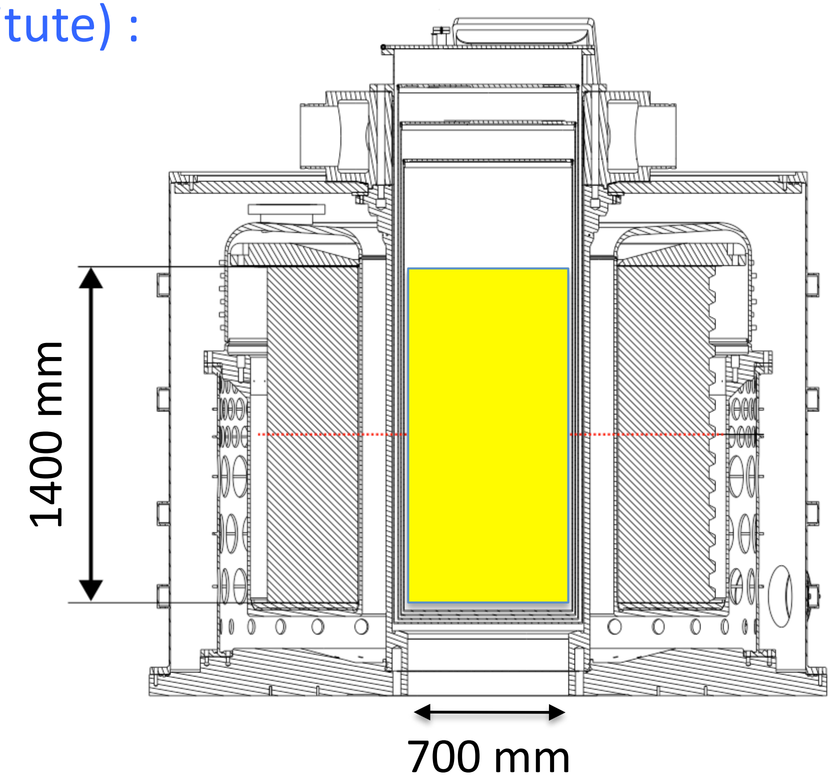
Cryogenic pre-design (Neel Institute) :





Compact shielding for maximum cold volume :

Cavity volume = 538 liters !

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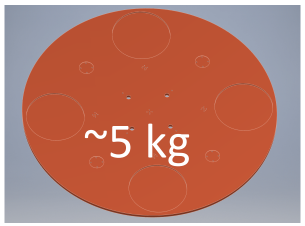
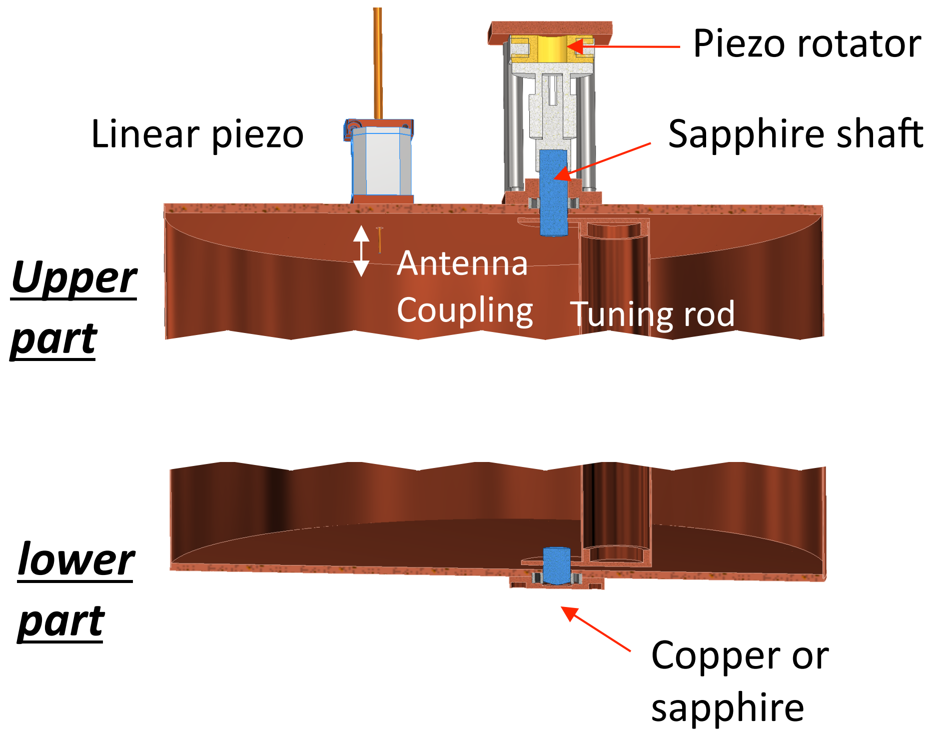
Ultra-light copper cavity (CAPP) :

0.5-(1.0) mm thick OFHC foil

Rod ~ 0.5 kg (ex.)



Total ~ 25 kg



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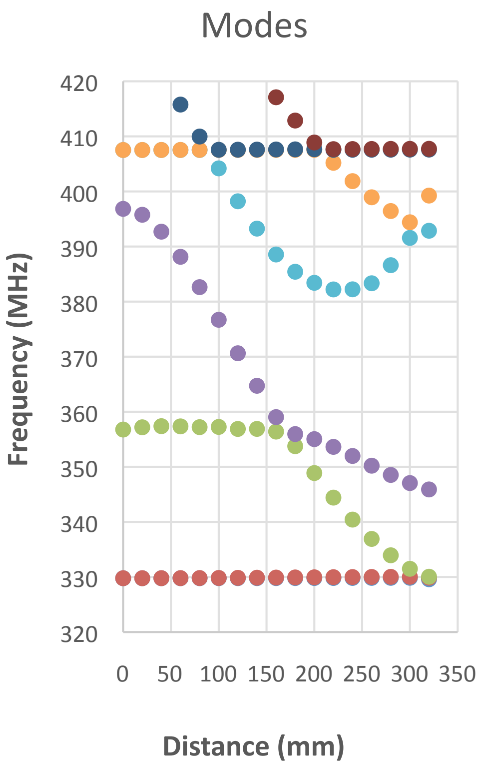
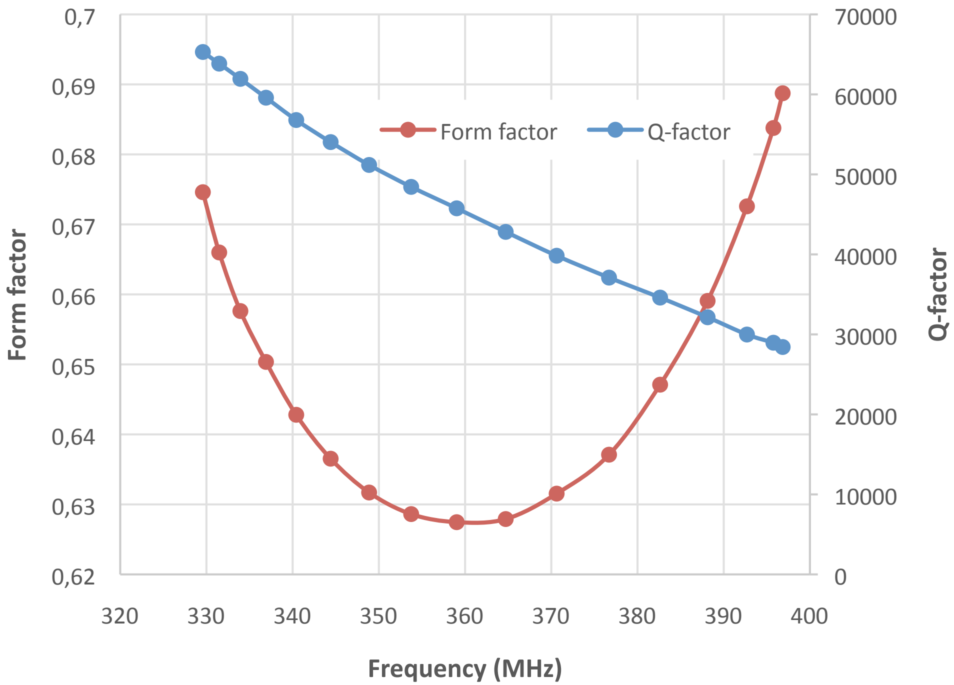
Example of electromagnetic simulation (CAPP) :





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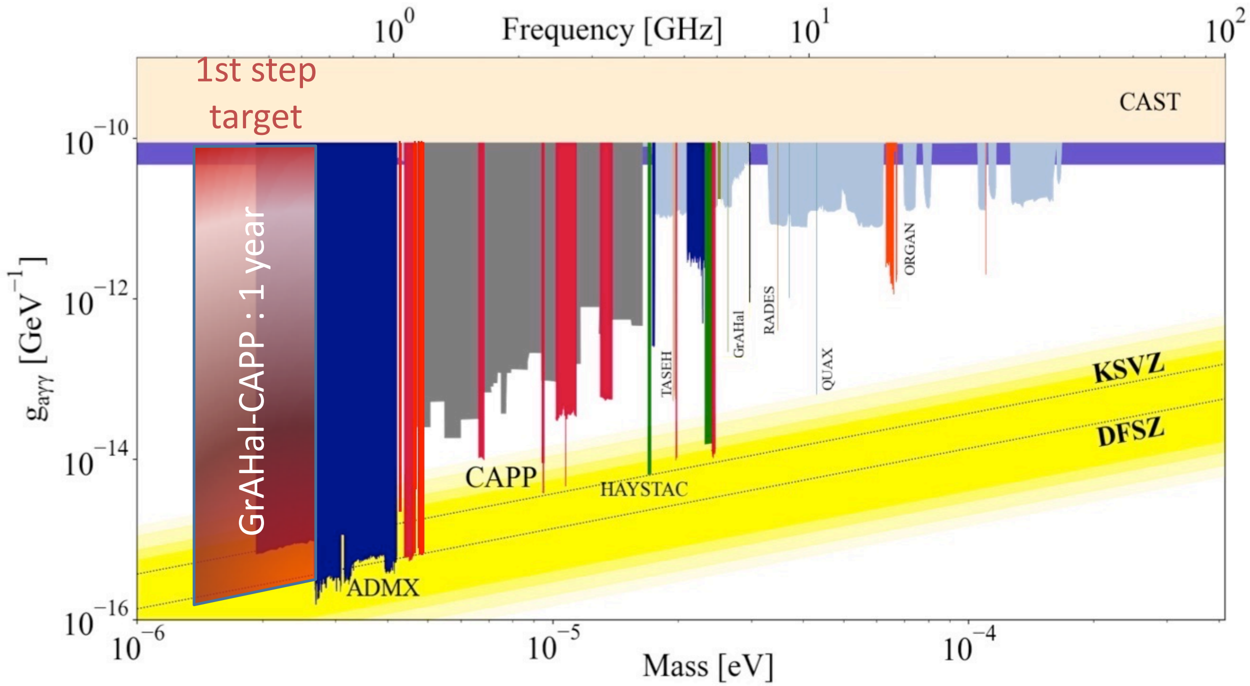
Expected performance :

parameters	value
B-field (T)	8
Cavity diameter (mm)	700
Cavity height (mm)	1400
Form factor	>0.6
Q-factor (@4K)	150k
Frequency (MHz)	330 – 600
Target sensitivity	DFSZ
System noise temperature (K)	1
Scan rate (MHz/day)	>~1



- DFSZ sensitivity expected at ~1 MHz/day even w/o Quantum Noise limited detection (T_{noise}=1K)

- Ongoing R&D at CAPP targets total system noise below 100mK → DFSZ/3

https://grahal.neel.cnrs.fr/

Summary :

- DM Axion search development in Grenoble (+ theory !)
- Large superconducting magnet commissioned :
  → large ~ 500 L RF cavities in nom. 8-9 Teslas.
- GrAHal-CAPP project :
  - DFSZ search in 330-600 MHz range.
  - axion search in big magnet can be extended to higher frequencies.