20th Patras Workshop on Axions, WIMPs and WISPs
22-26 September 2025
Tenerife, Canary Islands, Spain
https://agenda.infn.it/event/46273/

Grenoble Axion Haloscope (GrAHal) projects in collaboration with DMAG/IBS for Axion Dark Matter Search

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C. Hoarau, C. Smith — LPSC, Univ. Grenoble-Alpes & CNRS
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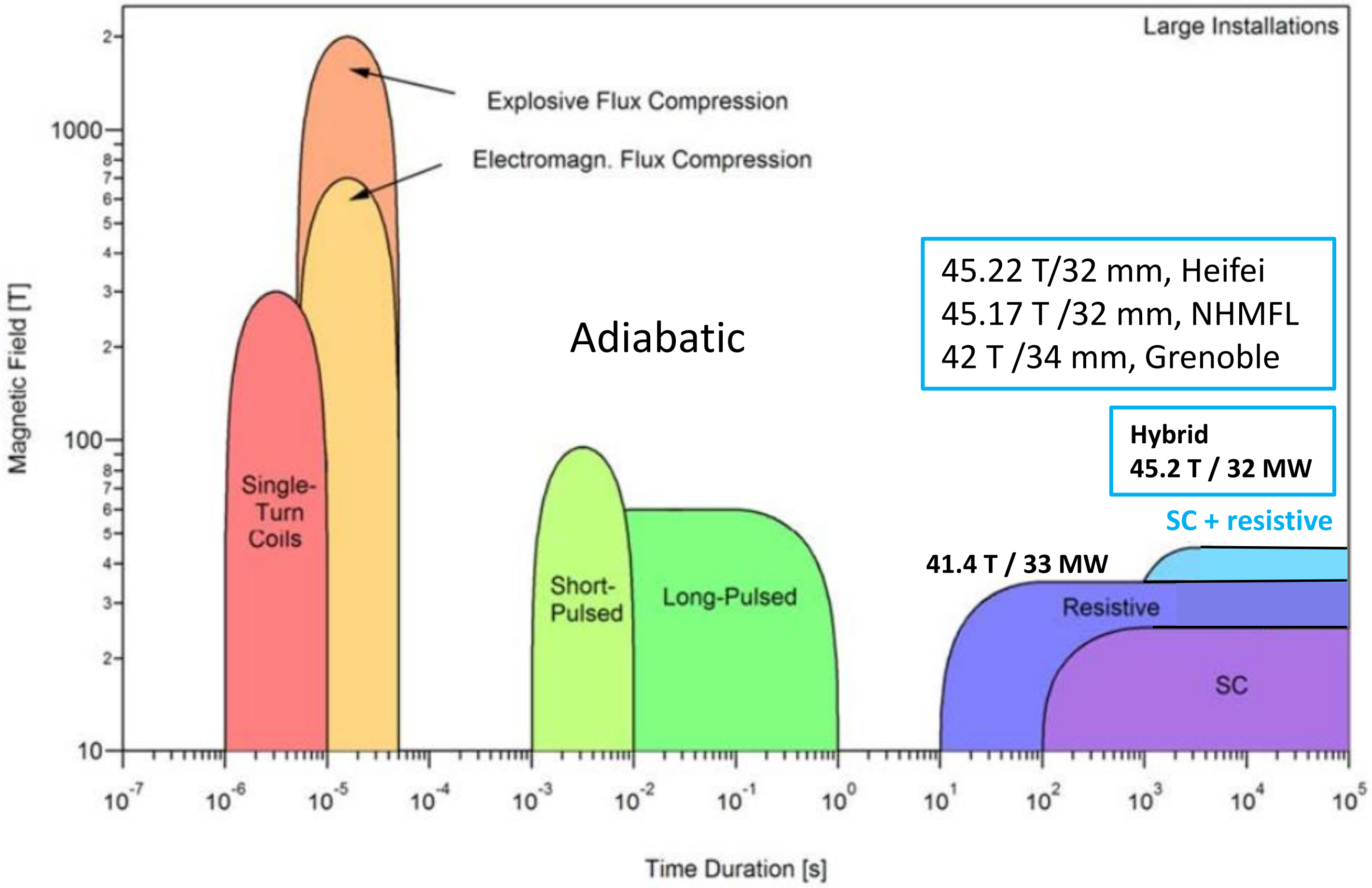
Outline

- Introduction
- 42+T Grenoble Hybrid Magnet
    - Conception
    - Commissioning
    - Toward routine operation
- Grenoble Axion Haloscope (GrAHal)
    - GrAHal/DMAG – HF
    - GrAHal/DMAG – LF
- Summary & short term perspectives

High Magnetic Fields for Science Today



Adapted from K. Matsui, et al. *Review of Scientific Instruments* 92(2):024711 (2021)
https://doi.org:10,1063:5,0032895

Remarks on DC field produced by water cooled resistive magnets

1/ B $\propto$ Power$^{1/2}$

2/ There is a
"No Field Limit Theorem"*

But…

$\phi_{out} / \phi_{in} = \exp (B/B_S)^2$

with $B_S = (2\mu_0 \lambda \sigma_{Hoop, max})^{1/2}$ & considering a constant « Hoop stress current distribution »

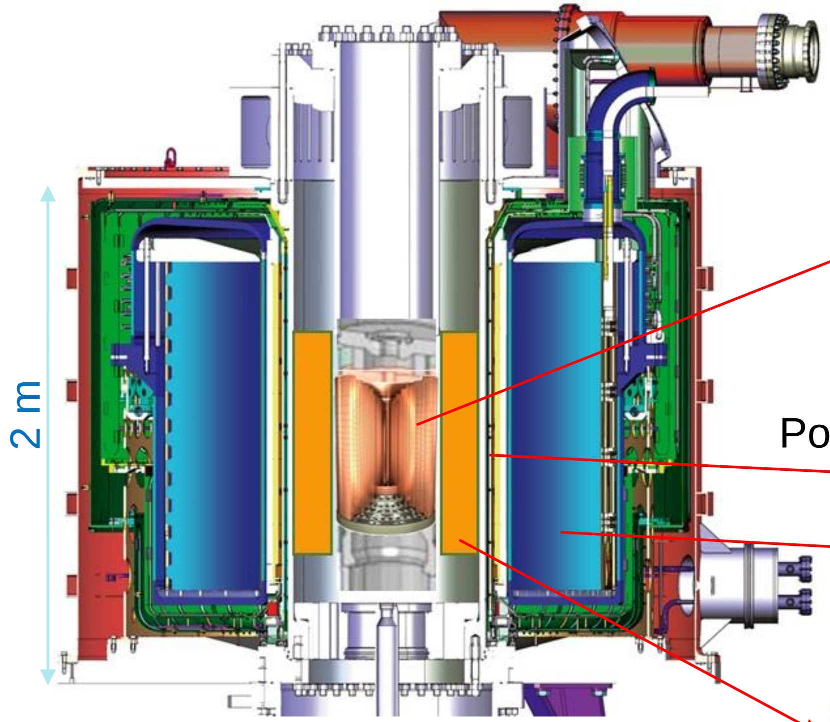
Typically, for 41.4 T, ϕ_{out} = 1 m & $\phi_{out} / \phi_{in} \approx 31$

*From G. Aubert, http://dx.doi.org/10.1088/0031-8949/1991/T35/036
Assuming appropriate water cooling…

Resistive & Superconducting Coils separated by EC shield

Resistive Bitter & Polyhelix inserts ($CuAg_{5\%}$) designed for 12 + 12 MW

► Upgrade to 12 + 18 MW for Phase-2



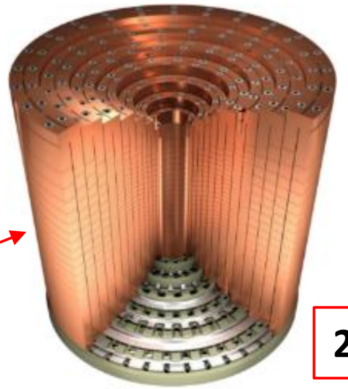
43 T/ ϕ = 34 mm

Technologies : SC Nb-Ti/Cu & superfluide He

Hydraulic : 2 x 150 l/s

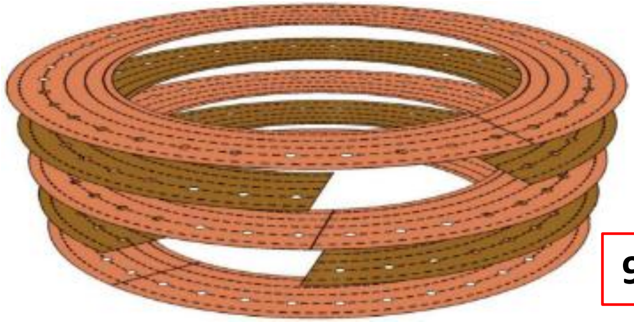
Stored Energy @ 43 T : 108 MJ

~ 26 kg de TNT



25.5 T

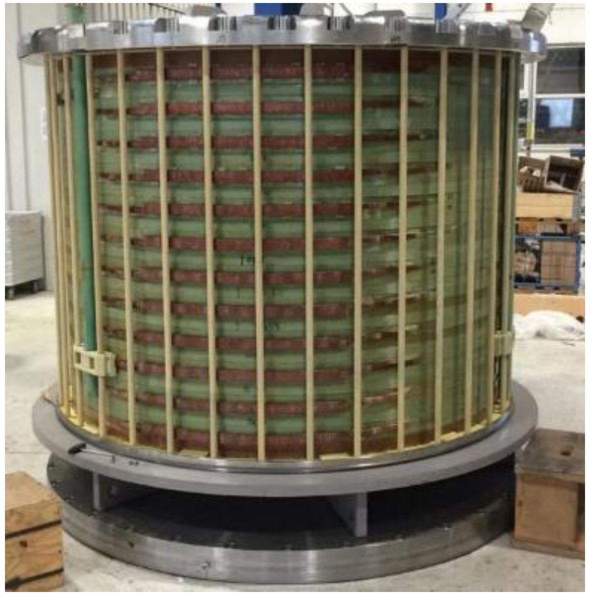
Polyhelix coil, $Ø_{ext.}$= 372 mm



9 T

Bitter coils (x2), $Ø_{ext.}$= 750 mm

Stainless Steel re-inforced Cu shield at T= 50 K to reduce dB/dt in case of trip of resistive inserts from about - 9 T/s → - 0.5 T/s



Superconducting coil made of 37 double-pancakes connected in series $Ø_{int/ext.}$= 1100/1868 mm

8.5 T

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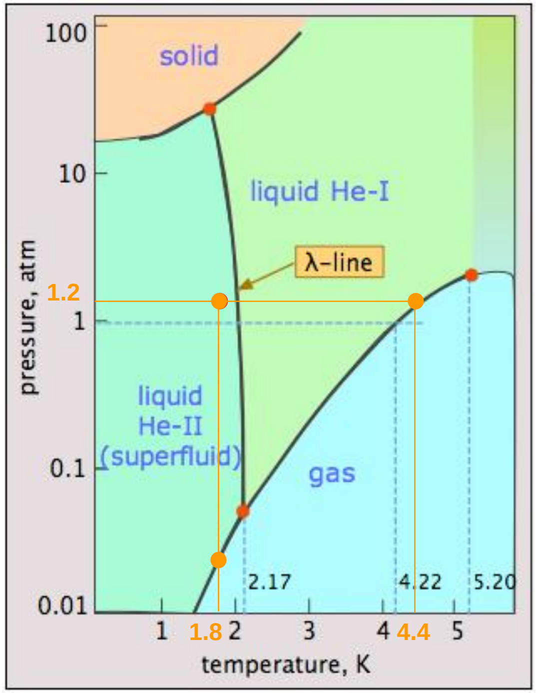
Key Technologies for the Superconducting Outsert

Nb-Ti/Cu Rutherford Cable On Conduit Conductor (RCOCC) specially developed with in-house assembly

- Internal cooling with stagnant superfluid He connected to the external bath
- Strict control of AC-losses

P. Pugnat, R. Pfister, *et al.*, *IEEE Trans. Appl. Supercond.* 28, 4301005 (2018)
https://indico.cern.ch/event/659554/contributions/2714073/
https://indico.cern.ch/event/445667/contributions/2562521/

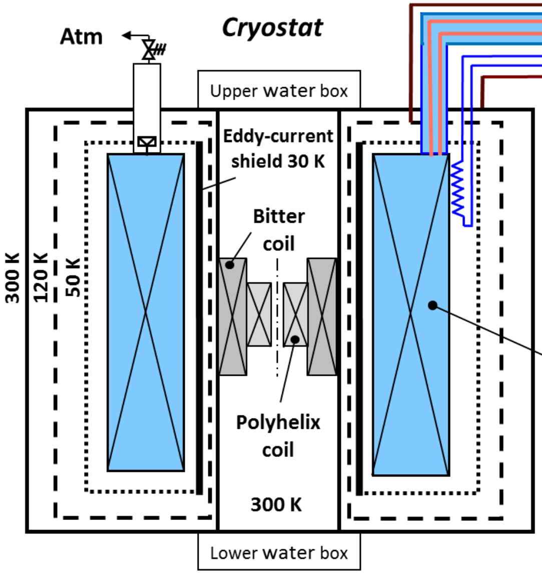
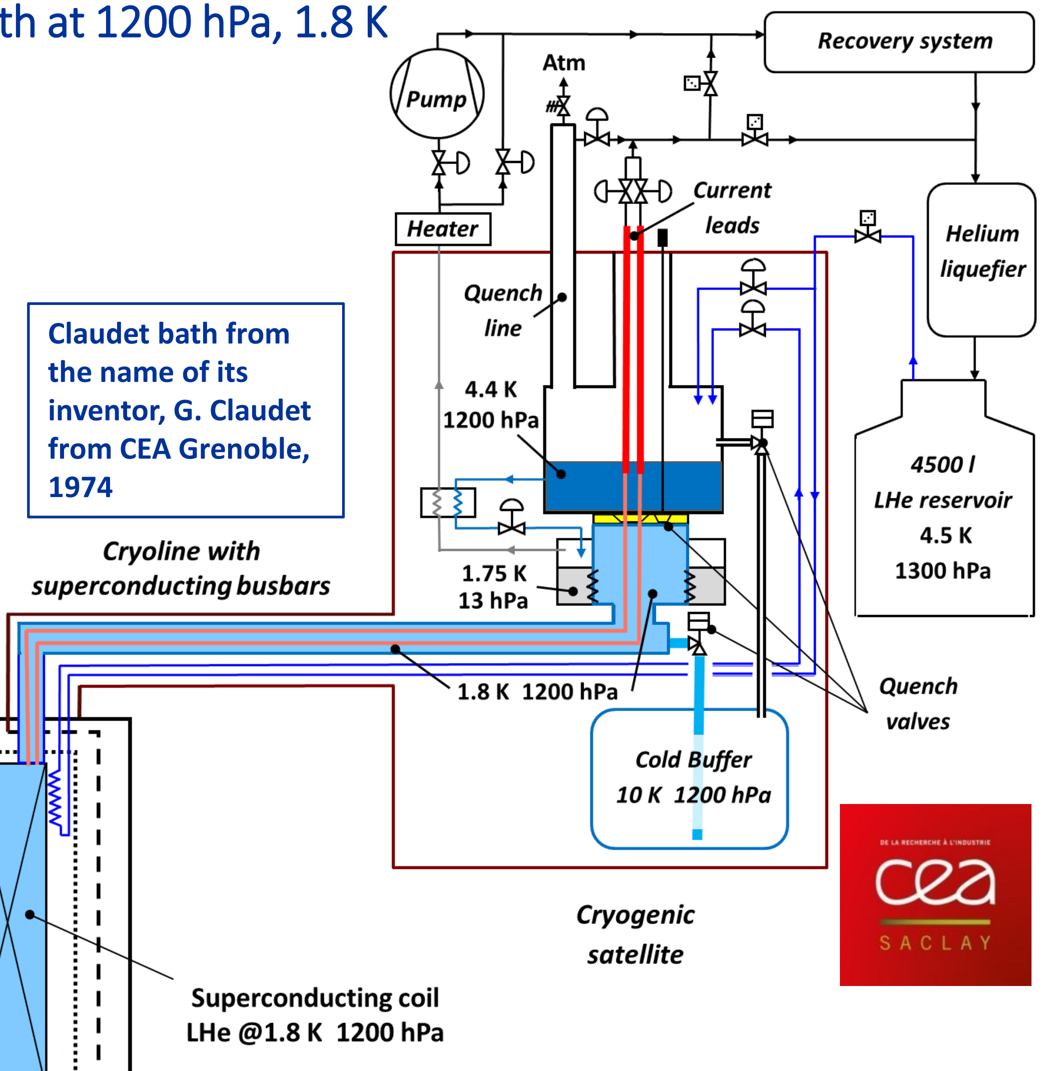
18 x 13 mm^2



Superfluid pressurized LHe bath @ 1200 hPa , 1.8 K

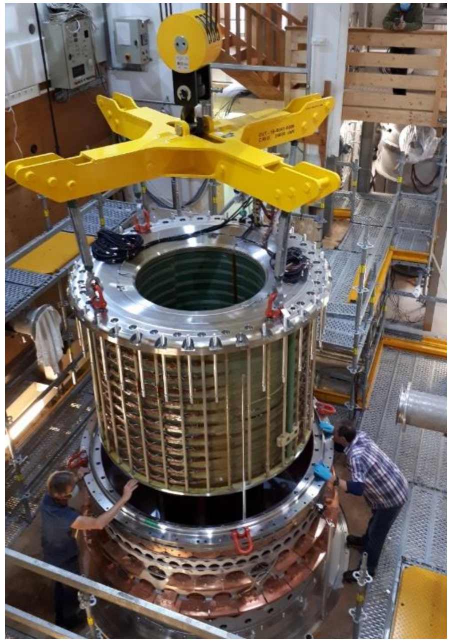
Cooling of the sc. coil with
- 1420 l/60 l of pressurize/pumped superfluid He
- 155 LHe @4.4 K

The cryogenic system principle: Pressurized superfluid He bath at 1200 hPa, 1.8 K

L. Ronayette, S. Crispel, B. Hervieu, P. Pugnat *et al.*, IOP Conf. Series: Mater. Sci. Eng. **171** 012107, (2017)

Some Assembly Steps of the Cryomagnet



Insertion of the superc. coil inside the He vessel

LNCMI

sdms la chaudronnerie blanche

Welding of the He vessel

Assembly of the thermal shields

Installation of the last MLI sheet

Installation of the OVC

IEEE Transactions on Applied Superconductivity, vol. 32, no. 6, pp. 1-7, Sept. 2022, Art no. 4300607, doi: 10.1109/TASC.2022.3151838

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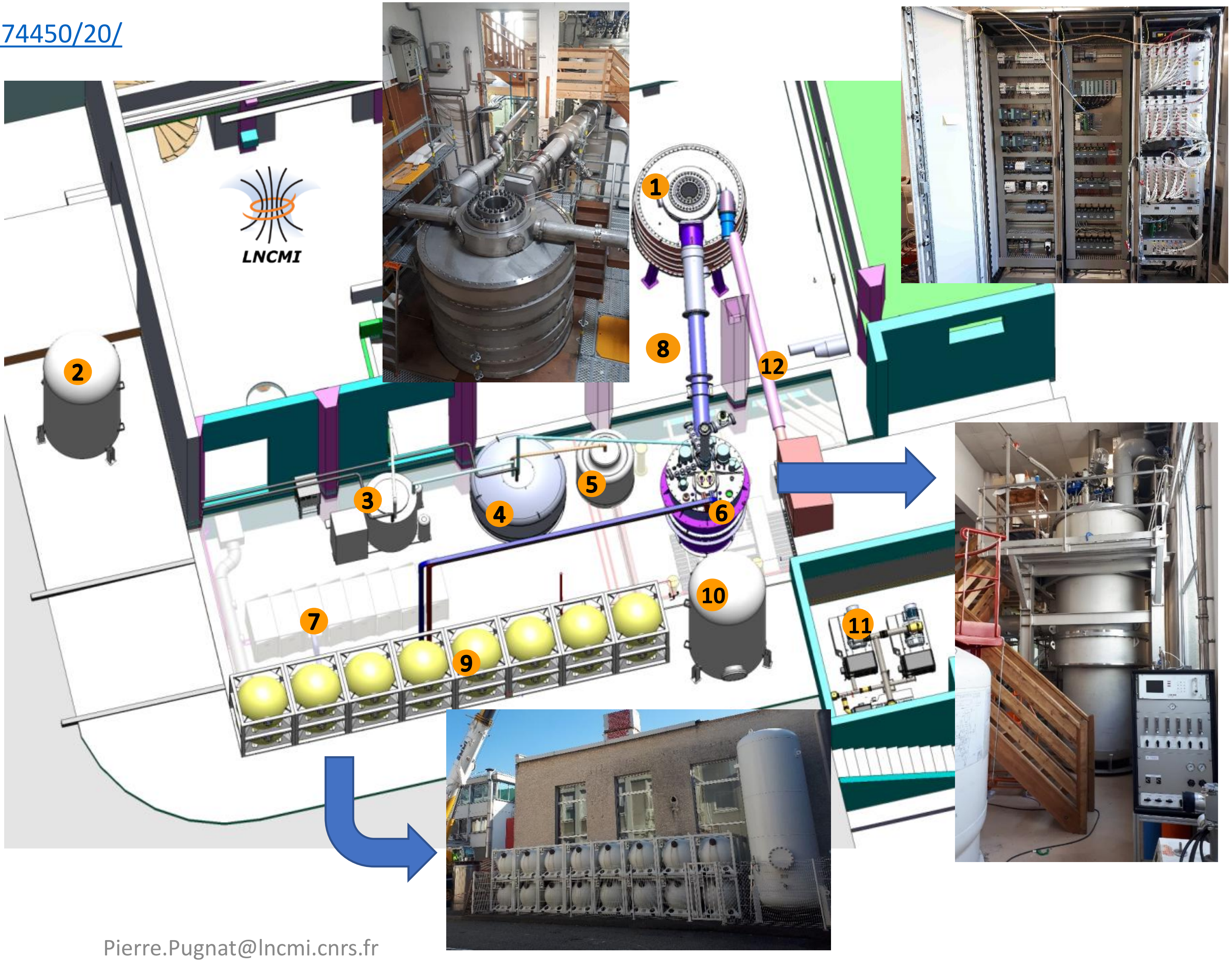
Integration of the Grenoble Hybrid Magnet with its Cryogenic Plant

Virtual Tour : https://storage.net-fs.com/hosting/6174450/20/

1. Superconducting Magnet
2. LN_2 tank 27 000 litres.
3. He liquefier coldbox
   150 l/h @ 4.5 K , 1.3 bar
4. Main LHe Dewar 4500 litres
5. Secondary LHe Dewar 1700 litres
6. Cryogenic satellite to produce
   the 1.8 K LHe bath
7. DC power converter
   7500 A , 30 V (underground)
8. Cryoline with busbars @ 1,8 K
9. High pressure gaseous He tanks
   16 x 1 m^3 @ 200 bars
10. Liquefier pure He buffer tank
    15 m^3 @ 20 bars
11. Helium pumping system
    6000 m^3/h @ 10 mbar, 20 °C
12. Quench line



Not shown (located in other areas)
- Liquefier cycle compressor @ 14.5 bars
- He recovery balloon : 30 m^3 @ Patm
- He recovery compressor @ 200 bars
- 32 x 0.5 m^3 high pressure gaseous He tanks @ 200 bars
- Magnet Safety and Magnet Control Systems

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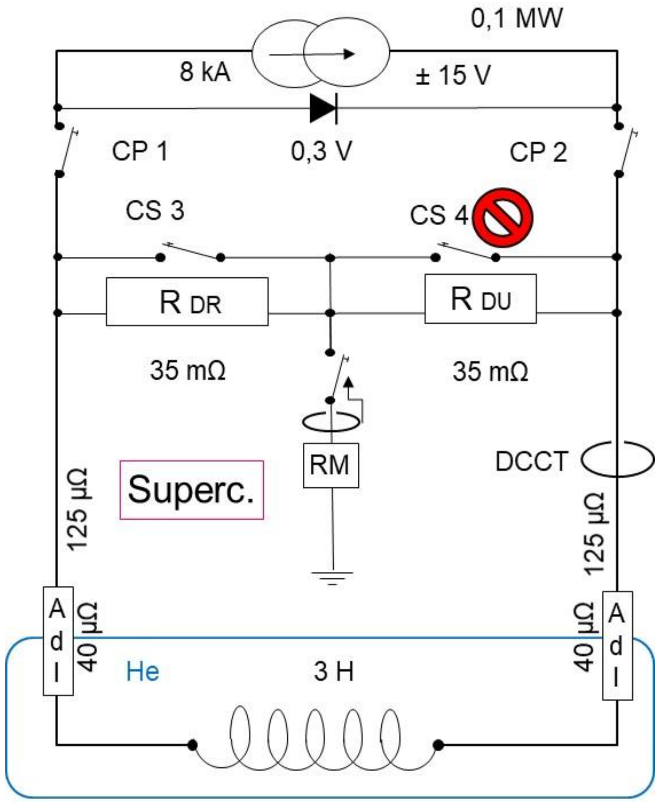
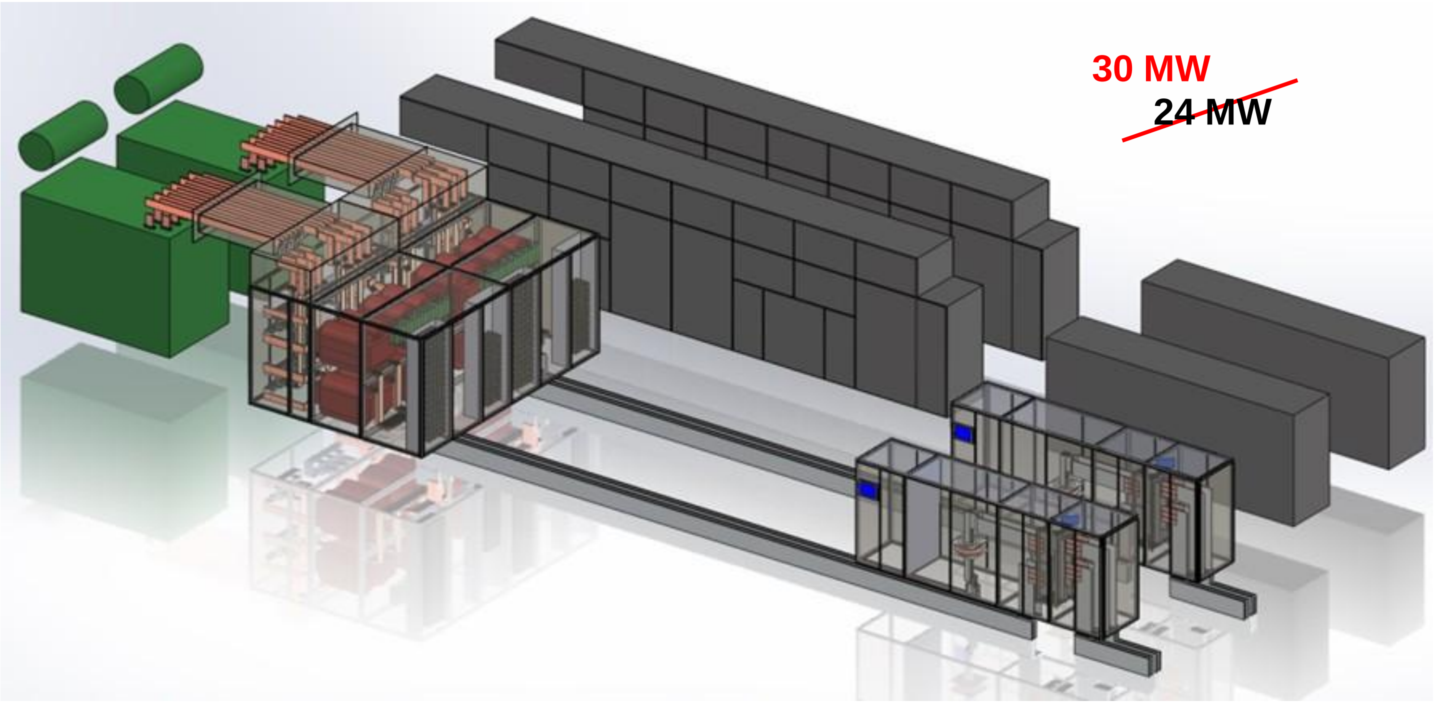
Electrical Power Installation & Circuits

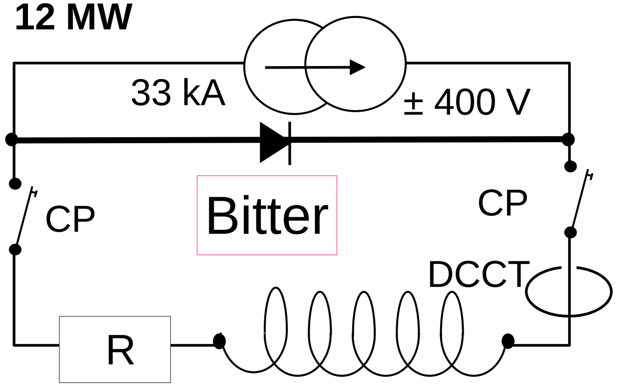


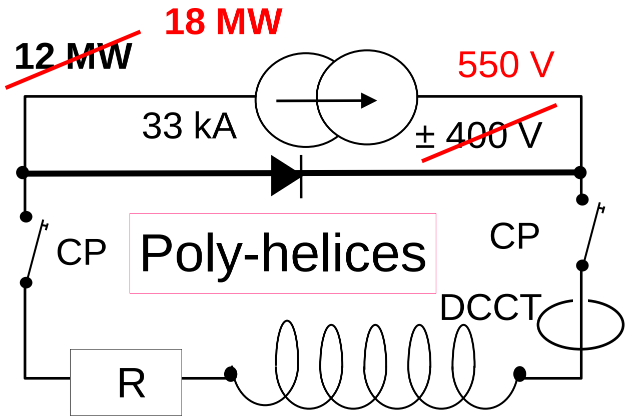
Upgrade in 2024



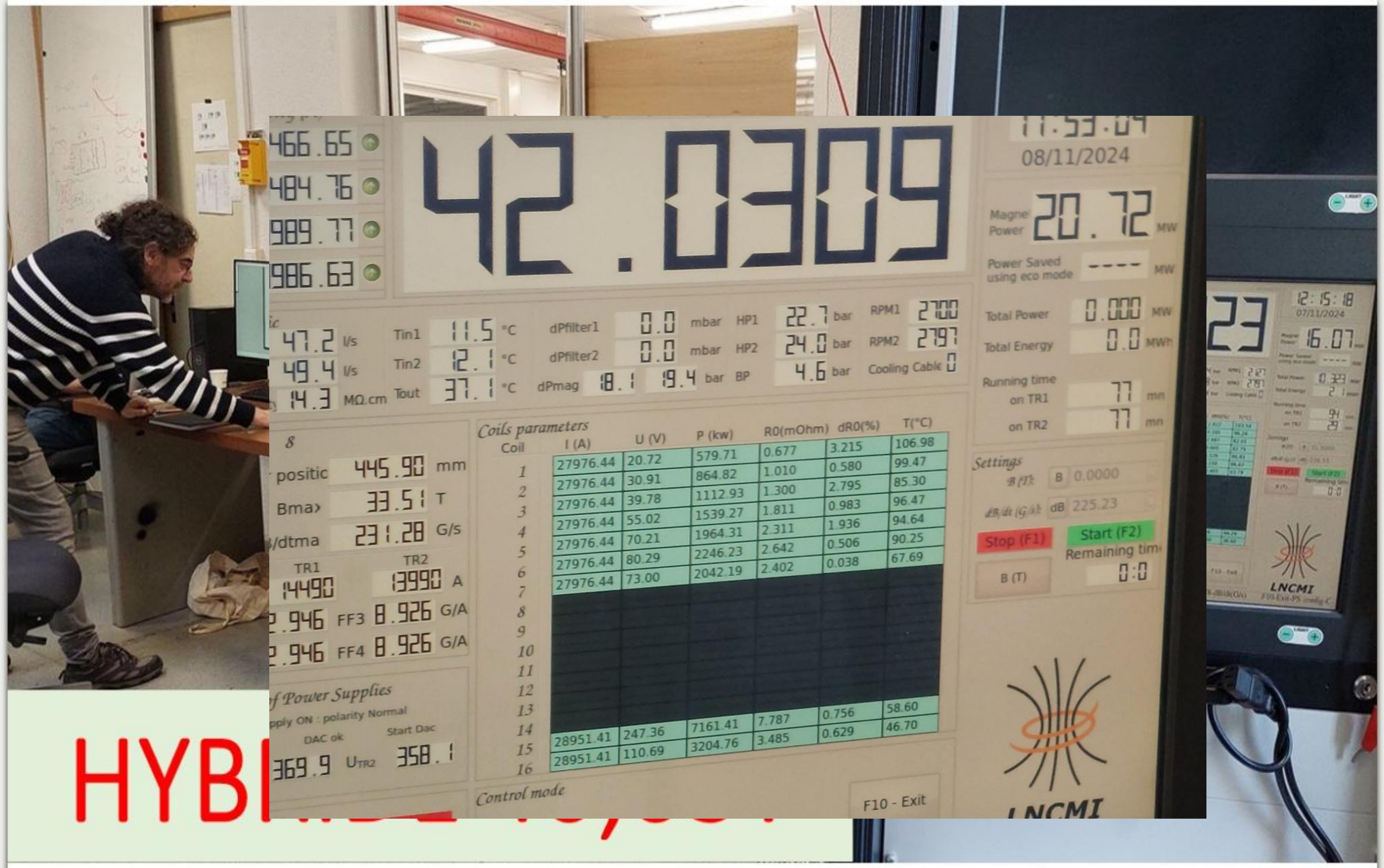
R_{DR} + R_{DU}

8 kA / ±15 V for Superconducting magnet





Result of 8 Nov. 2024 : 8.5 + 8.5 + 25 = 42 T reached



As a 1st step,

There is still Room to go to Higher Field(s)… But priority given to Science Runs

1st time that such High DC magnetic field is reached in Europe

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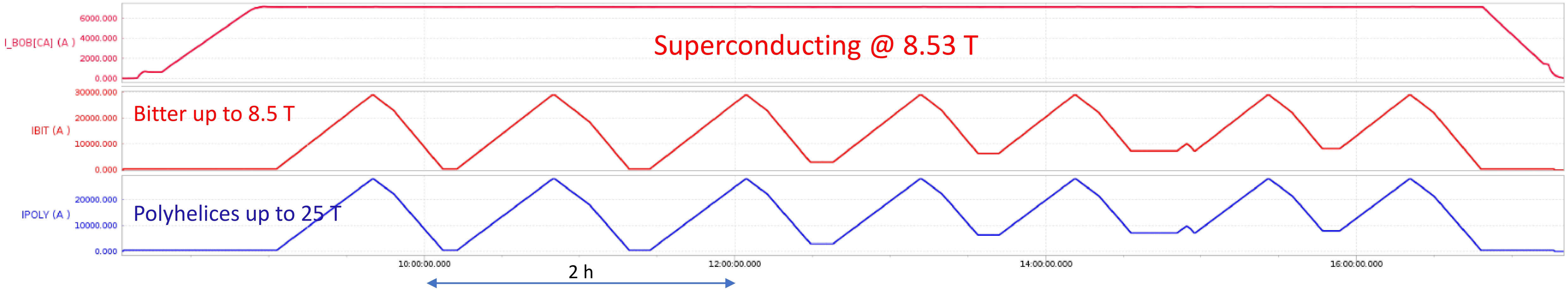
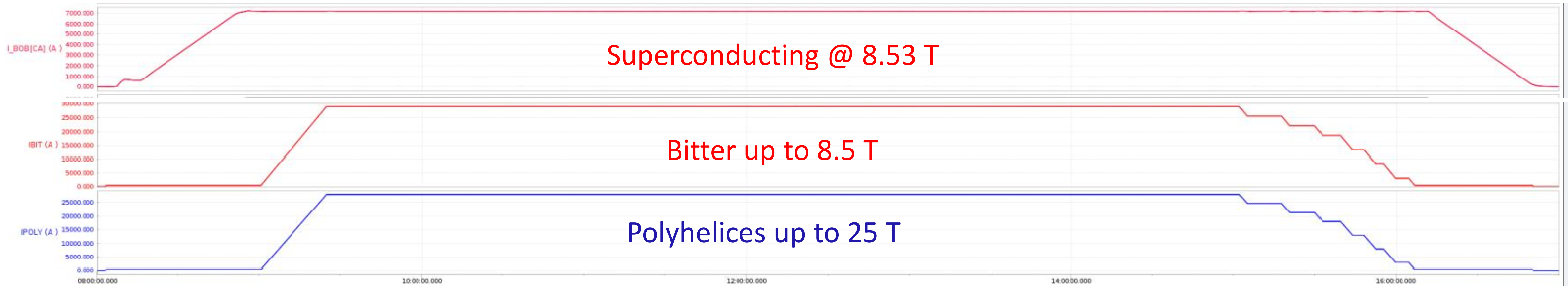
Exemples of Hybrid Magnet Powering Cycles during Science Runs

► **Typical 8 h-day running up to 42 T with 7 powering cycles of resistive inserts for transport measurements**



► **Typical 6 h-day running up to 42 T with a single powering cycle for RMN measurements**



Summary of 1st science runs: 2 experiments in May-June 2025 (transport & RMN) requiring 46 cycles up to 42 T in total, with flat top duration ranging from few seconds up to ~ 6.6 h with no time limitation detected.

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Early 2025, two experiments in condensed matter physics performed up to 42 T and many more to come !!!

The quest for the GrAHal

Grenoble Axion Haloscopes

GrAHal-DMAG/HF

- 1st run planned in 42 T/12.25 GHz
  14-28 Oct. 2025

GrAHal-DMAG/LF

- 200-600 MHz in preparation

GrAHal

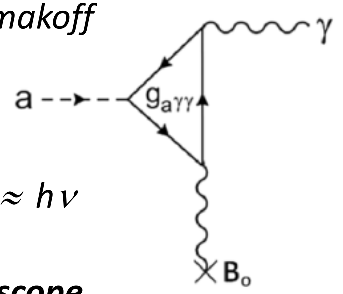
Grenoble Axion Haloscopes

► **Scientific case within the European Strategy of Particles Physics (ESPP) - https://www.nature.com/articles/s41567-020-0838-4**

$m_a = (1 - 1000)\,\mu eV$

$\rightarrow \rho_{DM} \approx (10^{11} - 10^{14})\, axions / cm^3$

Inverse Primakoff Effect



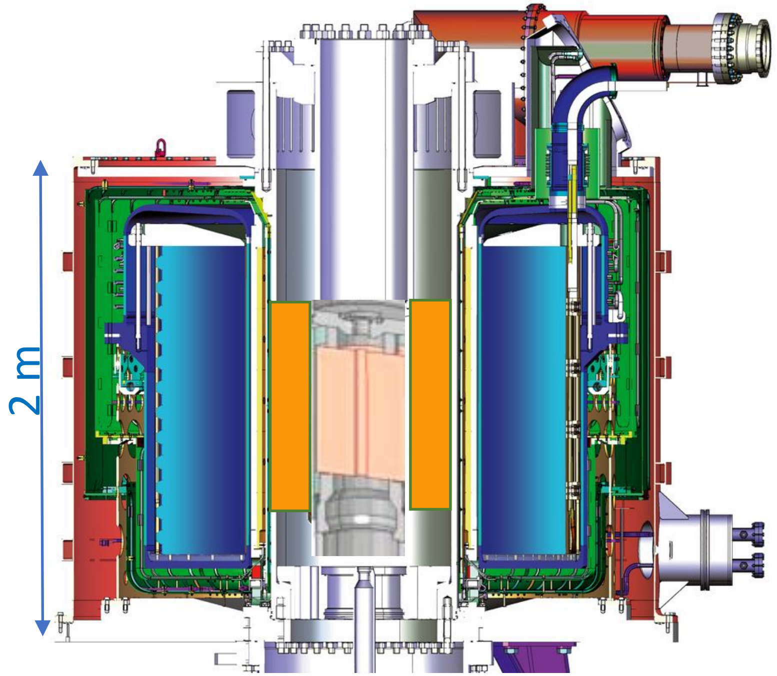
$m_a c^2 \approx h\nu$

Sikivie's haloscope

i.e. with RF cavity

11.5 GHz/f_{TM010} = R/1 cm

P α $g_{a\gamma\gamma}^2 B_0^2$ V Q ≈ 10^{-21}-10^{-24} W



Field	Warm dia.	RF-cavity dia.	Frequency	Axion mass
43 T	34 mm	20 mm	12.25 GHz	50.3 μeV
40 T	50 mm	34 mm	6.76 GHz	27.8 μeV
27 T	170 mm	86 mm	2.67 GHz	11 μeV
17.5 T	375 mm	291 mm	0.79 GHz	3.2 μeV
9 T	812 mm	675 mm	0.34 GHz	1.4 μeV

LNCMI cnrs NÉEL institut

Grenoble Hybrid now in routine operation, 1st run of GrAHal in October 2025

► BabyGrAHal is running

https://arxiv.org/abs/2110.14406

https://indico.in2p3.fr/event/33627/contributions/154650/

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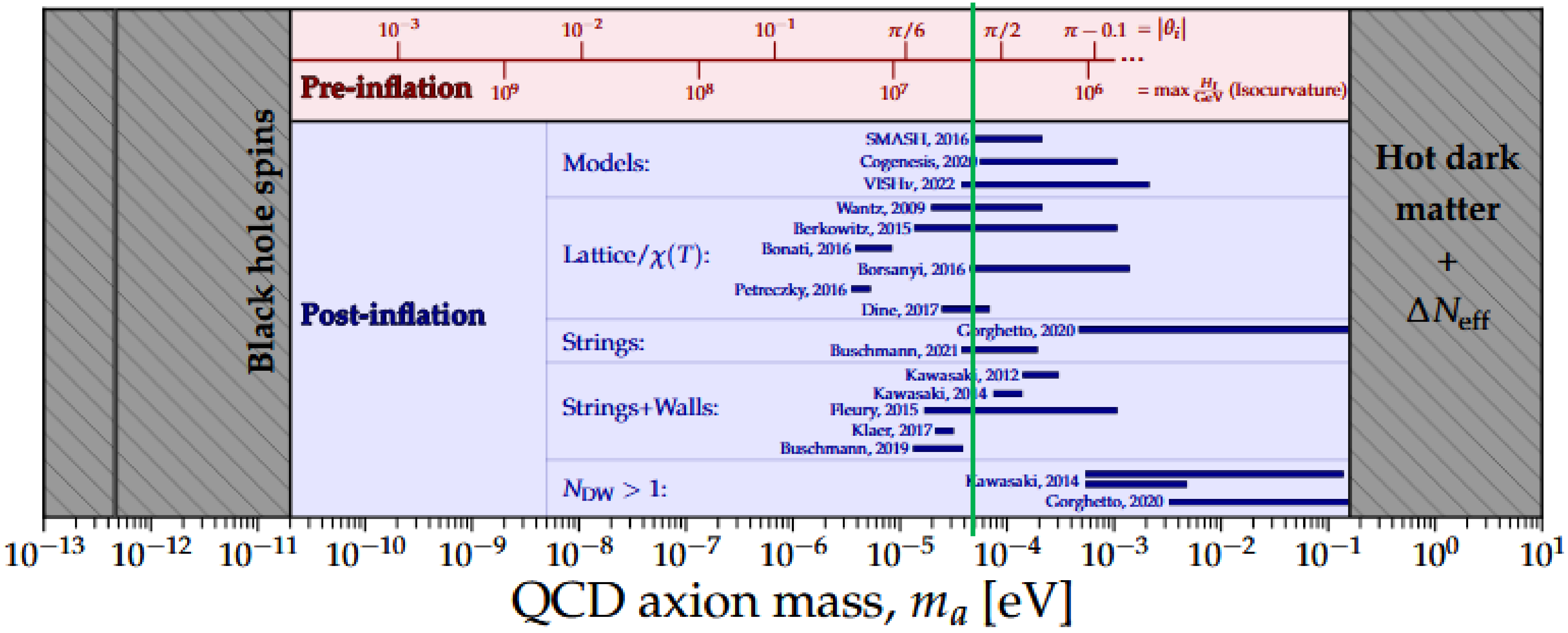
GrAHal - HF (~ 12.25 GHz/50.3 μeV with SHTc or Cu RF-cavity)

DMAG/IBS

Theoretical motivations → *9/19 models & computations will be tested partially*

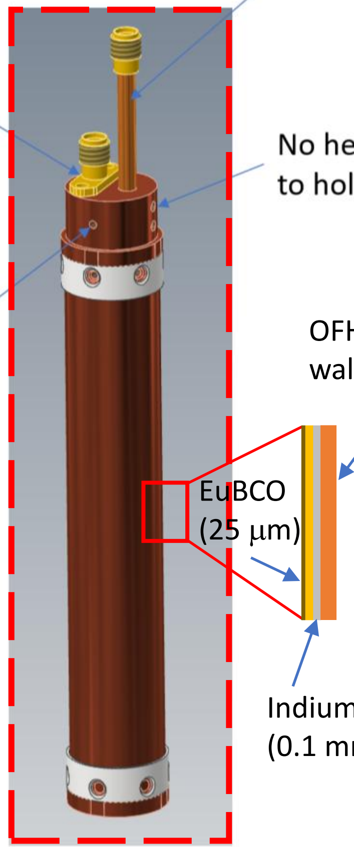


https://pdg.lbl.gov/2024/reviews/rpp2024-rev-axions.pdf

Also 1st time than a HTS RF-cavity will be tested up to 42 T around 12.25 GHz

GrAHal - HF (~ 12.25 GHz/50.3 μeV with HTS or Cu RF-cavity)

2 HTS RF-cavities of 100 mm & 275 mm length



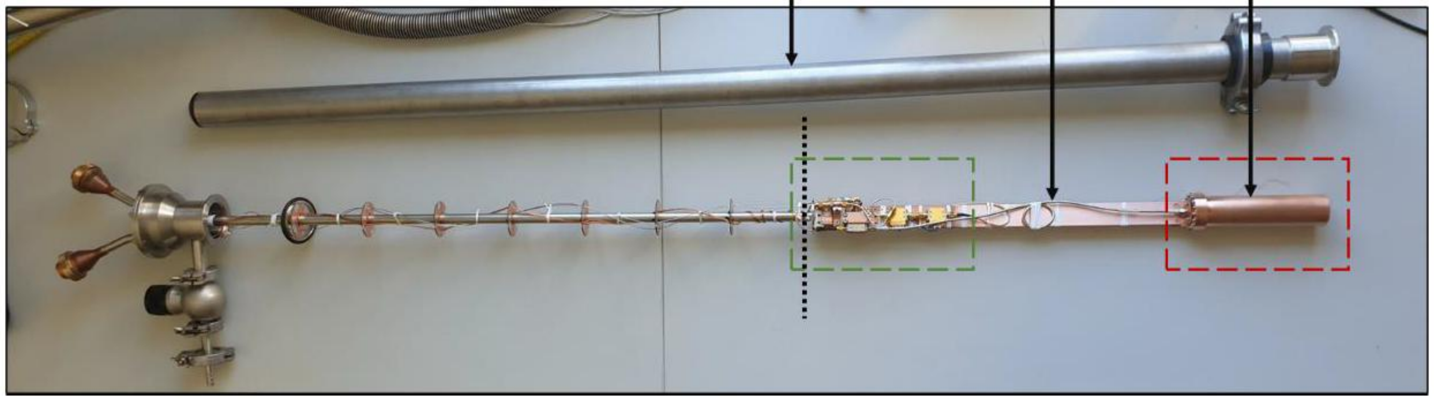
ϕ_i = 18.75 mm
ϕ_e = 20 mm

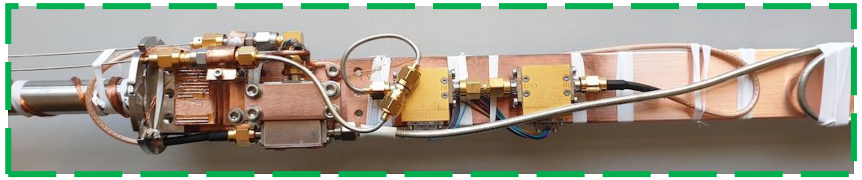
EuBCO layers from Fujikura

DMAG
Ohjoon Kwon

Q-factor of about 330 k at 4 K
(X 10 of Cu), cf. talk of SW. Youn

Experimental shaft with casing inserted within LHe cryostat





T. Grenet, CNRS-Grenoble

Cryogenic frequency tuning via ε_{He}(P,T,V)
- GHe Pressure : https://arxiv.org/pdf/2110.14406
- LHe Volume : https://indico.in2p3.fr/event/33627/contributions/154650/

User platform on the top of the LNCMI hybrid magnet with ^{4}He bath cryostat attached to xy-table

We are ready to start, magnet in re-cooling phase

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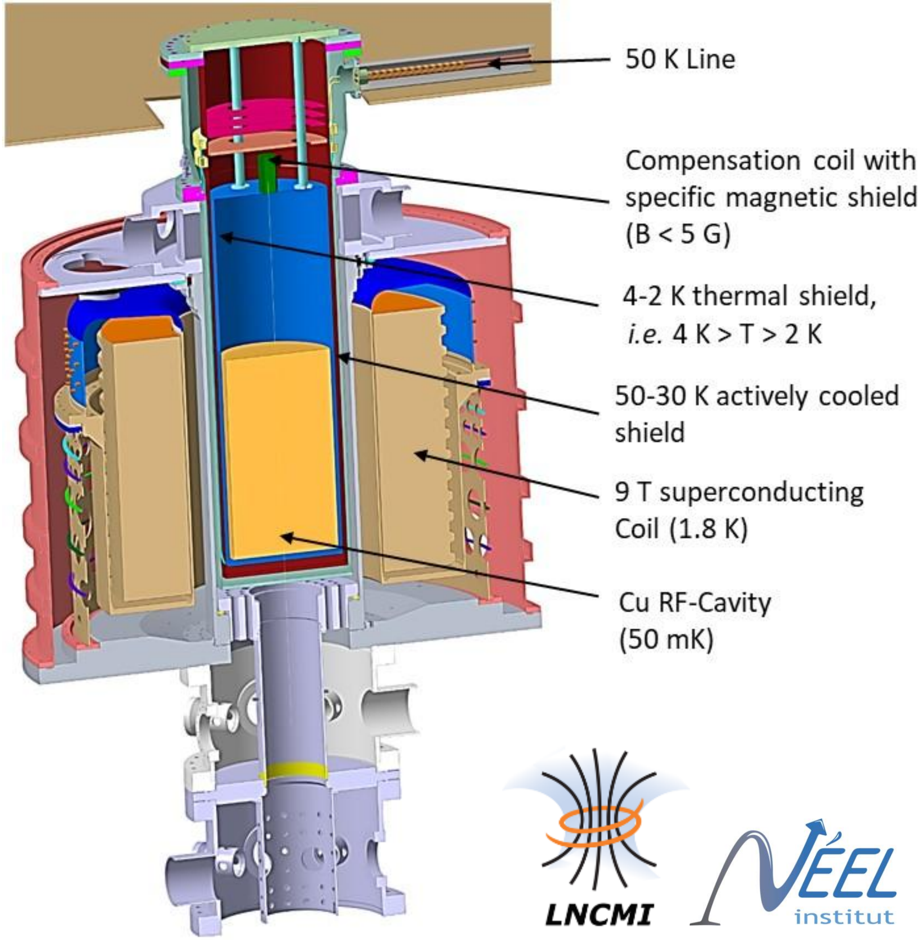
GrAHal-DMAG/LF ► *Focus on 1-3 μeV axion mass (200-600 MHz)*



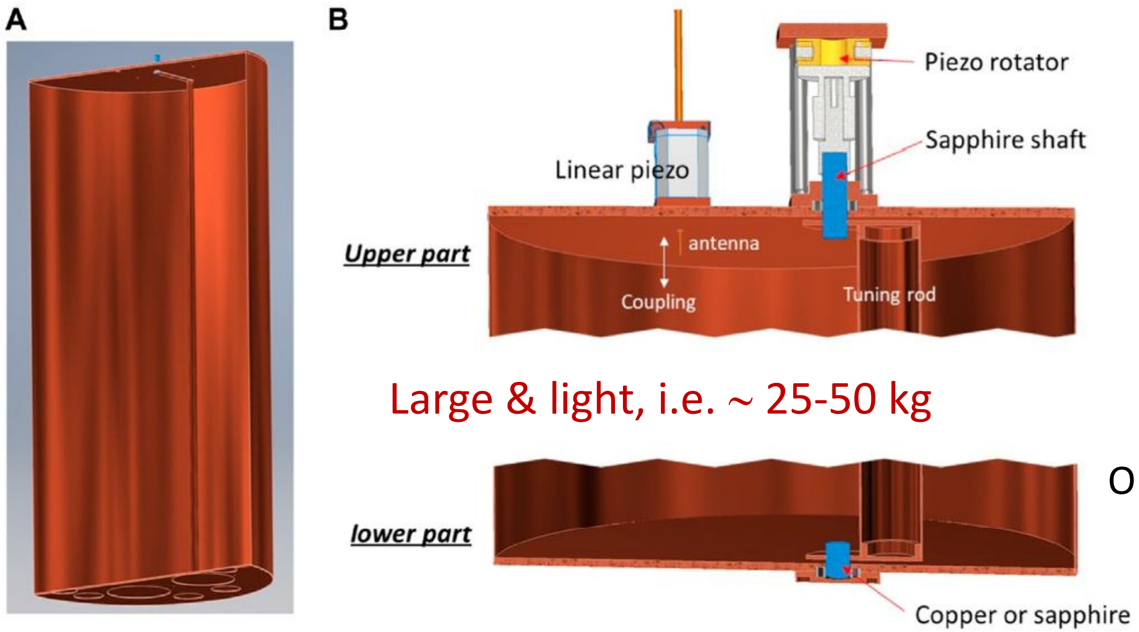
LNCMI

NÉEL institut

Cryogenic challenge : 2 dilution refrigerators

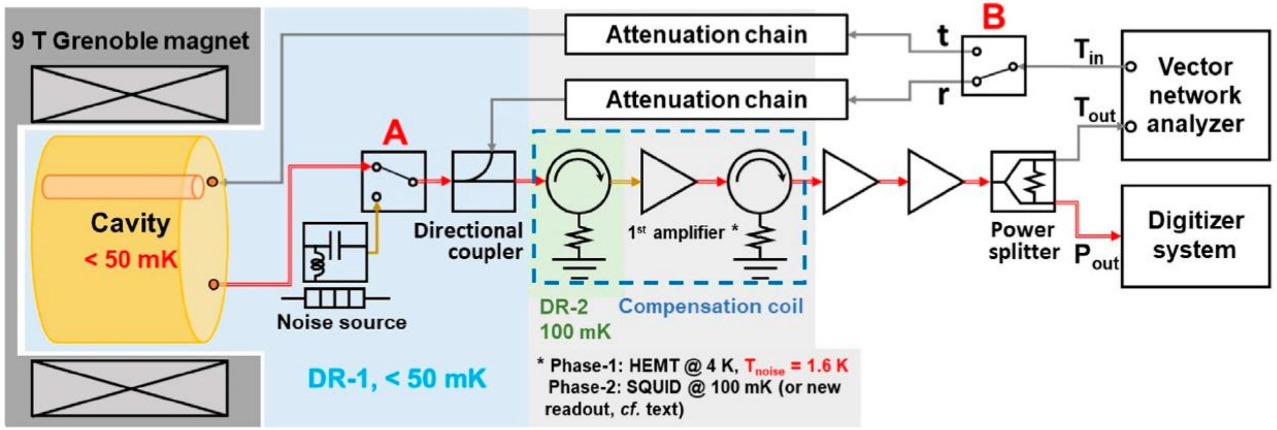
T ≤ 50 mK in 466 liters with ^{3}He dilution refrigerator

Ph. Camus & J. Vessaire (Institut Néel)



Large & light, i.e. ~ 25-50 kg

DMAG
Ohjoon Kwon

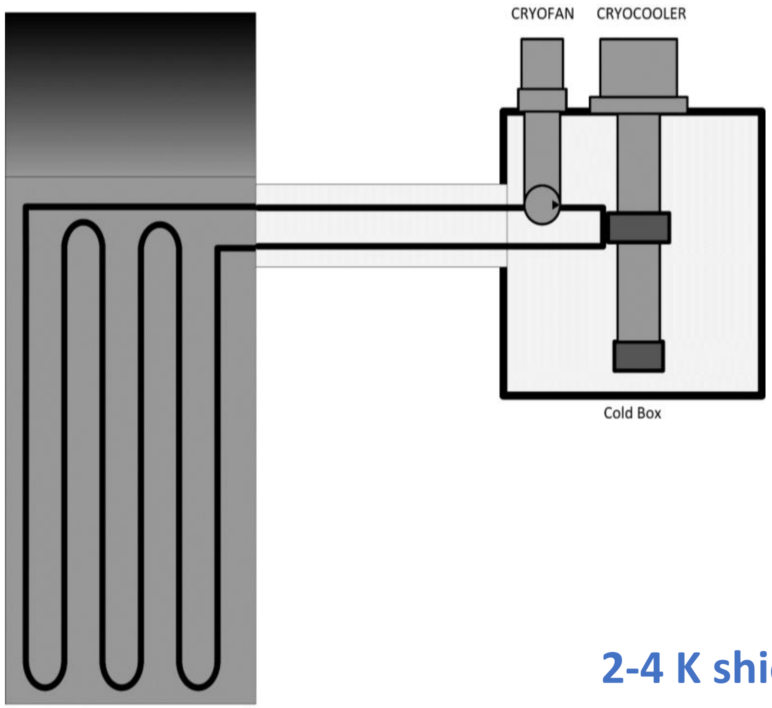


https://doi.org/10.3389/fphy.2024.1358810

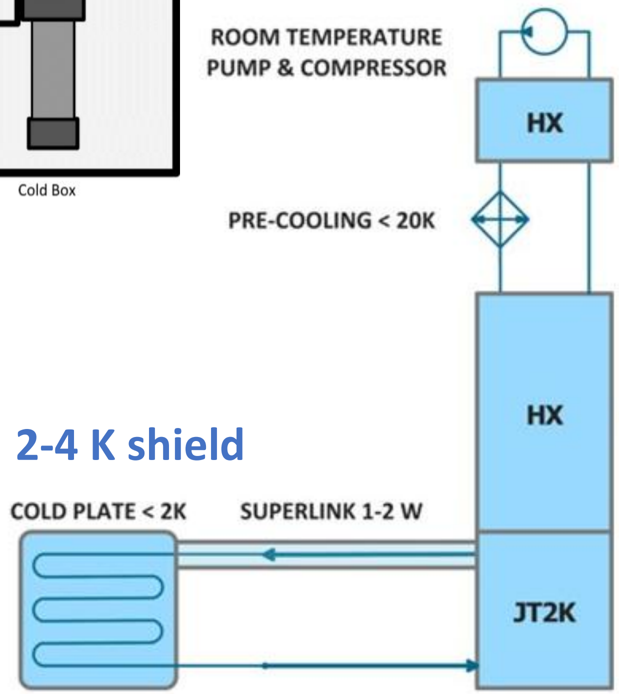
GrAHal-DMAG/LF

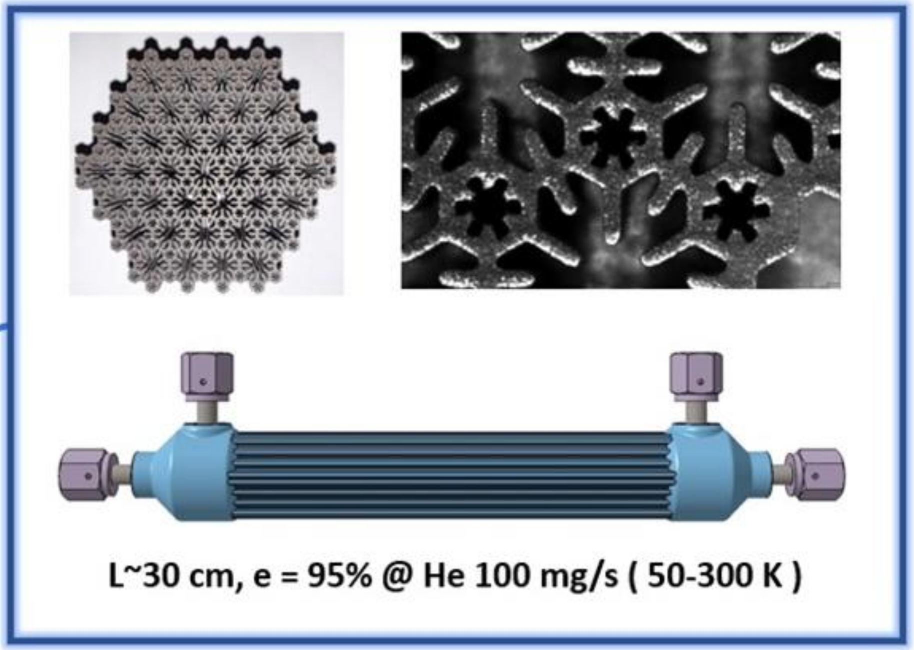
► *Cryogenic developments; to go down to 50 mK requires intermediate steps*

Synergy with quantum computing needs within CRYONEXT (Ph. Camus & J. Vessaire, Institut Néel)



30-50 K shield





3D printing from 3D NewShape factory

Toward the most sensitive Haloscope worldwide

► *Focus first on 1-3 μeV axion mass (200-600 MHz)*

GrAHal
Grenoble Axion Haloscopes
IBS
Dark Matter Axion Group

LNCMI NÉEL institut LPSC Grenoble ibs

GrAHal-DMAG : Phase 1 @ 4K

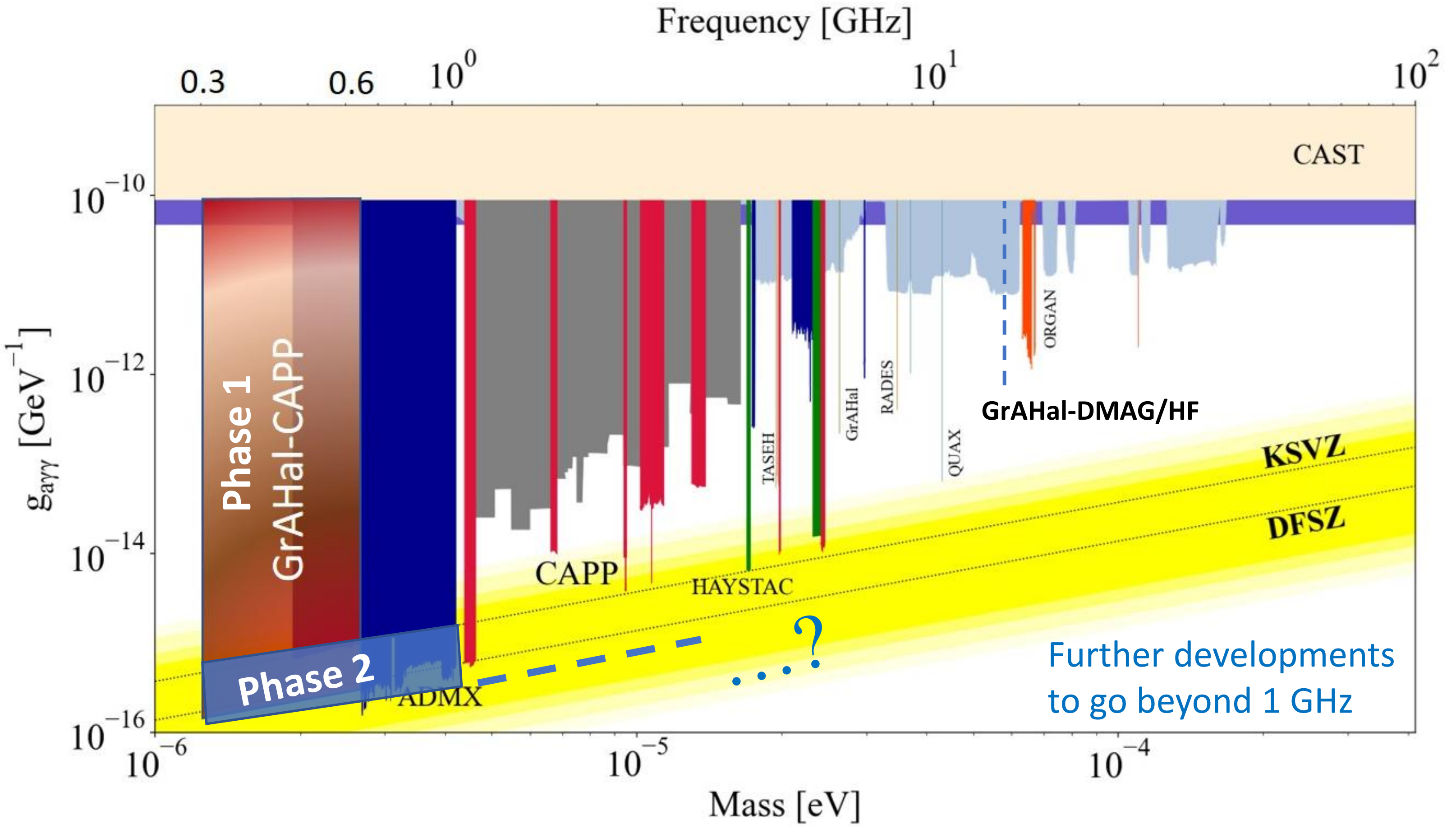
- 30-50 K cryo-stage operational @ t_0+18 months
- 2-4 K cryo-stage operational @ t_0+24 months

→ *1^{st} run*

GrAHal-DMAG : Phase 2 @ 50 mK

- Operational @ t_0 + 42 months

→ *2^{nd} run reaching DFSZ, in 2-year integration time*



https://doi.org/10.3389/fphy.2024.1358810

More Information / Outline

Few references

- *"High magnetic fields for fundamental physics":* *https://arxiv.org/pdf/1803.07547.pdf*
- *OSQAR:* *https://ep-news.web.cern.ch/content/osqar-experiment-sheds-light-hidden-sector-cerns-scientific-heritage* , *https://arxiv.org/abs/1506.08082*
- GrAHal: *https://bib-pubdb1.desy.de/record/395493* ; *https://arxiv.org/abs/2110.14406* ; *https://www.frontiersin.org/journals/physics/articles/10.3389/fphy.2024.1358810/full*
- VMB@CERN: *https://cds.cern.ch/record/2649744*

CERN PBC Study Group defining the European strategy of Particle Physics

- *https://pbc.web.cern.ch/*
- *https://indico.stfc.ac.uk/event/268/attachments/522/909/Vallee_PBC_RAL.pdf*
- *https://www.nature.com/articles/s41567-020-0838-4*
- *https://indico.cern.ch/event/1369776/contributions/5795144/attachments/2827635/*
- *https://indico.cern.ch/event/1418701/contributions/5965951/attachments/2933887/*

New EU COST Action : COSMIC WISPers in the Dark Universe: Theory, astrophysics and experiments

- *https://www.cost.eu/actions/CA21106/* *(Chairman/Co-Chair, MoU, Objectives)*
- ***You can apply to working groups of the network from*** *https://www.cost.eu/actions/CA21106/#tabs+Name:Working%20Groups%20and%20Membership*
- *Kick-off Meeting at Rome* 23-24 February 2023 https://agenda.infn.it/e/CosmicWispersKickOff

News: Dark Waves under preparation

High Field Magnet Proposal submission open twice a year: *https://emfl.eu/apply-for-magnet-time/*

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