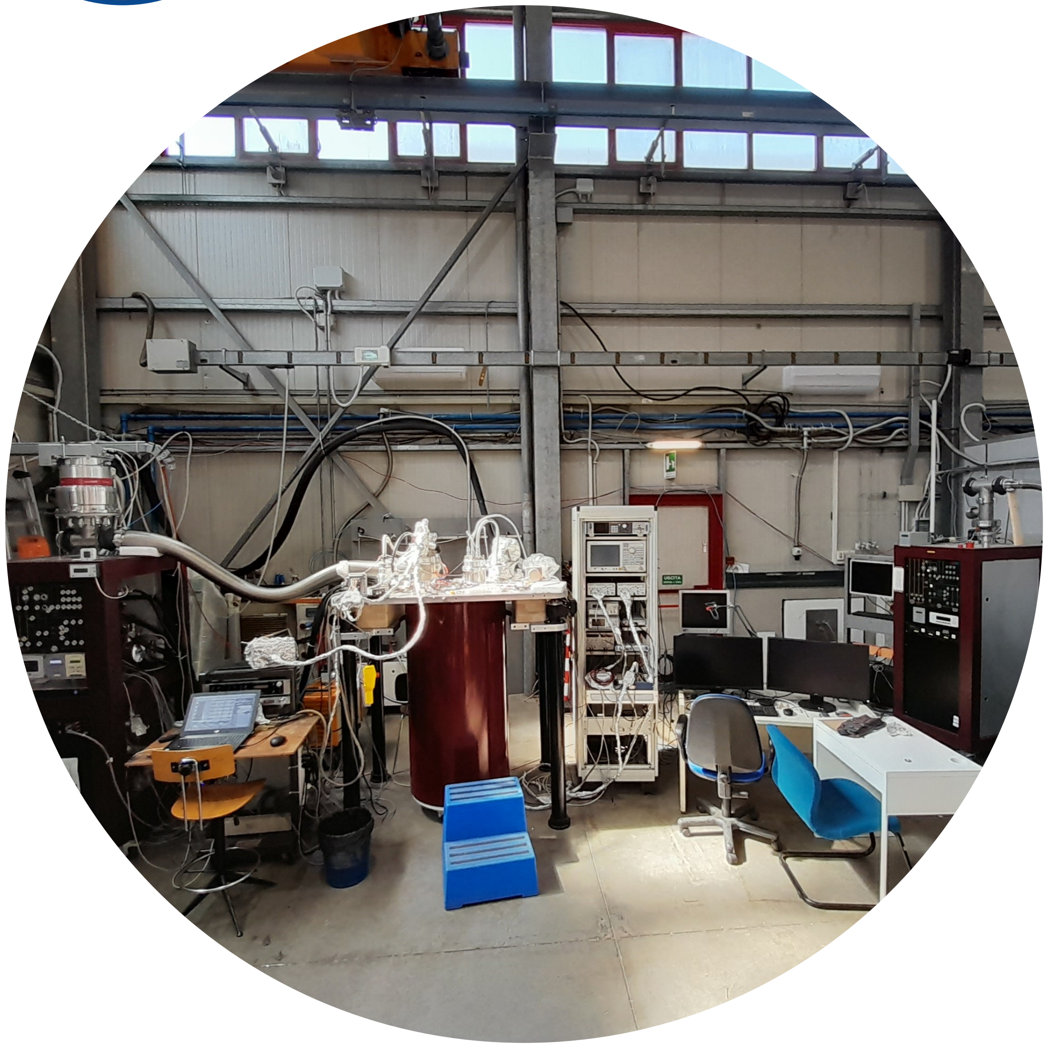
COLD LAB ACTIVITY REPORT

CLAUDIO GATTI

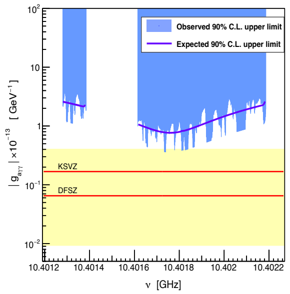
63nd LNF Scientific Committee – May 2022

COLD - Cryogenic Laboratory for Detectors

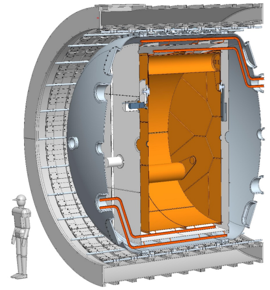
- Axion Experiments
- Superconducting Quantum Devices
- Superconducting Cavities
- Magnetic Measurements



EXPERIMENTS



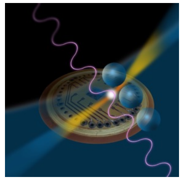
QUAX – QUest for AXions
Search for galactic axions with Sikivie's Haloscopes at 10 GHz (Ongoing experiments at LNL and LNF).



(K)FLASH
Search for galactic axions with a Sikivie's Haloscope at 100 MHz (Design Study).

Superconducting Devices

DART WARS (Detector Array Readout with Travelling Wave AmplifieRS)
Development of wide band quantum amplifiers for multi-channel detector readout (Ongoing).



SIMP (Single Microwave Photon detectors)
Development of single-microwave photon detector (Ends 2021)

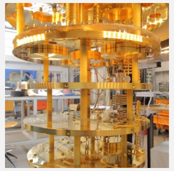
Qub-IT Quantum Sensing with superconducting qubits (Started 2022).

Supergalax FET H2020 Project
SC-qubits array photon-detector for axion experiments

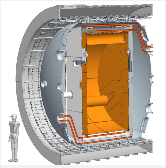
SAMARA
SC materials for cavities

SQMS USA DOE Project
Superconducting Quantum Materials and Systems

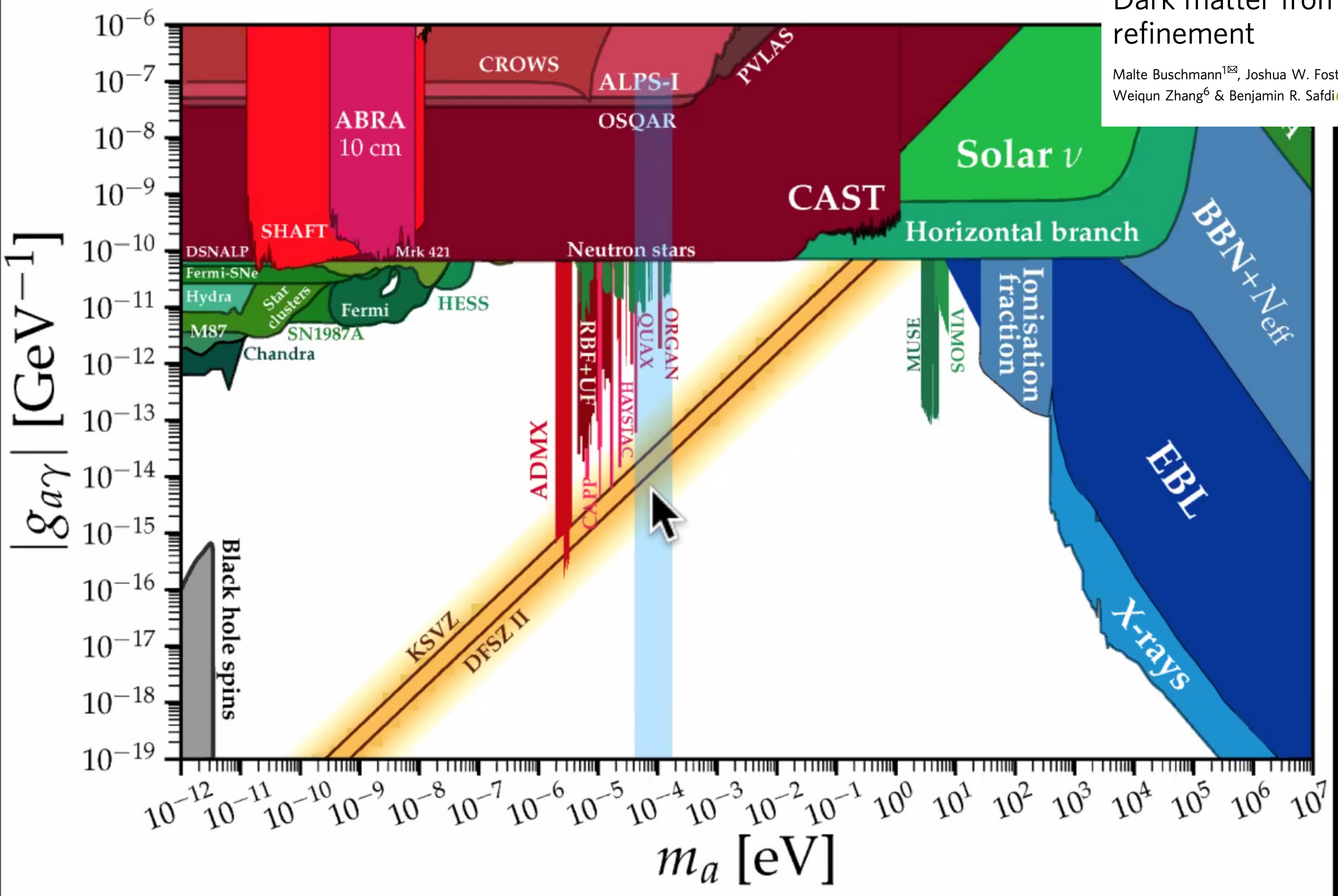
OUTLINE



QUAX - Galactic Axion Search at 10 GHz (35-50 μeV)



FLASH - Galactic Axion Search at 100 MHz (0.5-1.5 μeV)



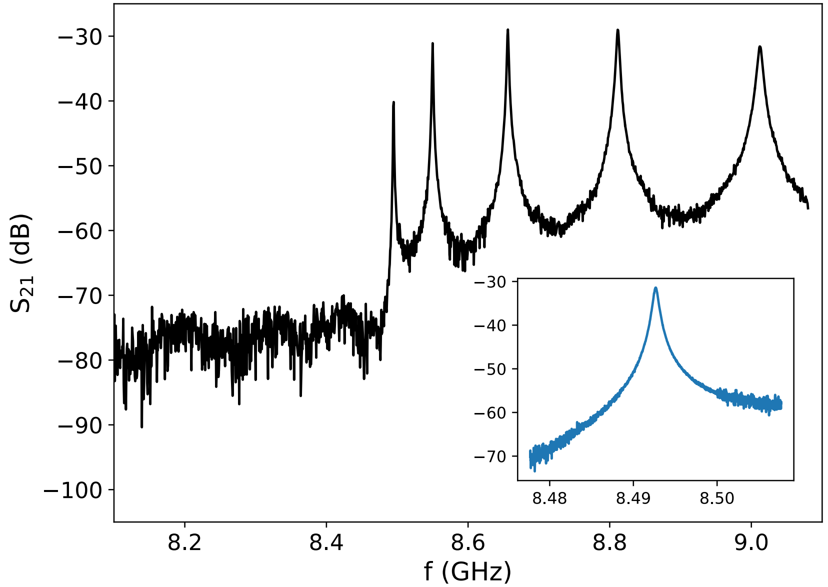
https://doi.org/10.1038/s41467-022-28669-y OPEN

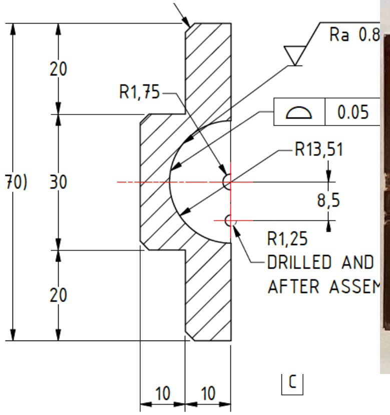
Dark matter from axion strings with adaptive mesh refinement

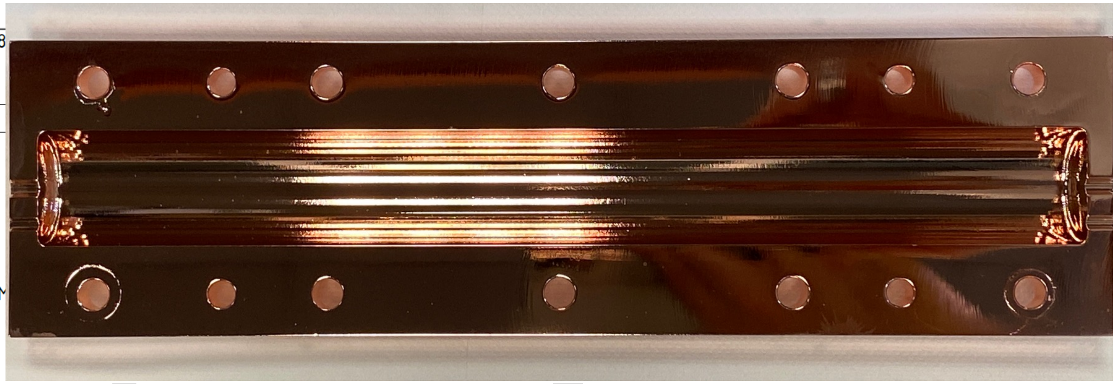
Malte Buschmann[1✉], Joshua W. Foster[2,3,4✉], Anson Hook[5], Adam Peterson[6], Don E. Willcox[6], Weiqun Zhang[6] & Benjamin R. Safdi[3,4✉]

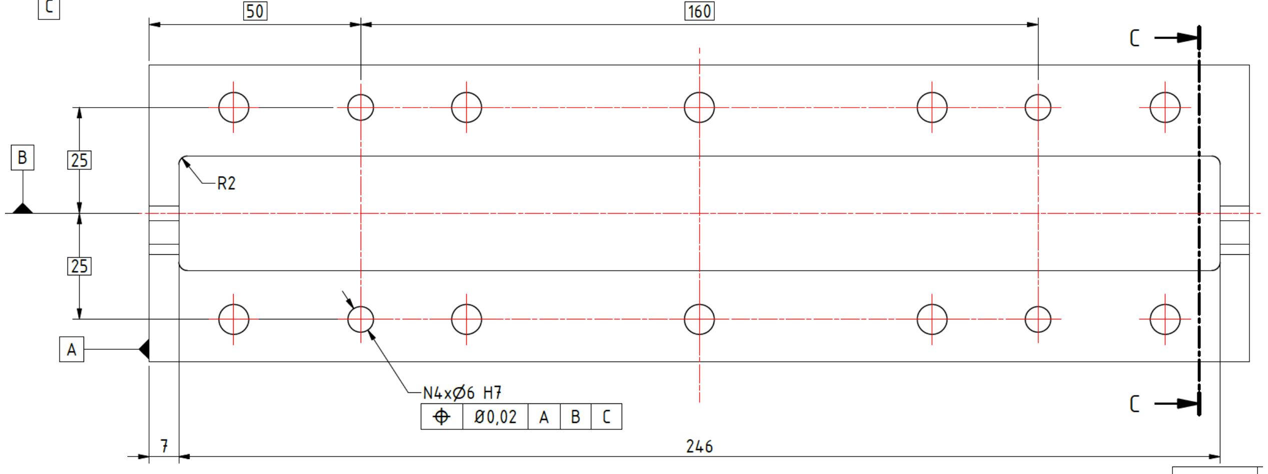
Wilczek's seminar on February 2022

Resonant Cavity - Cu 8.5 GHz



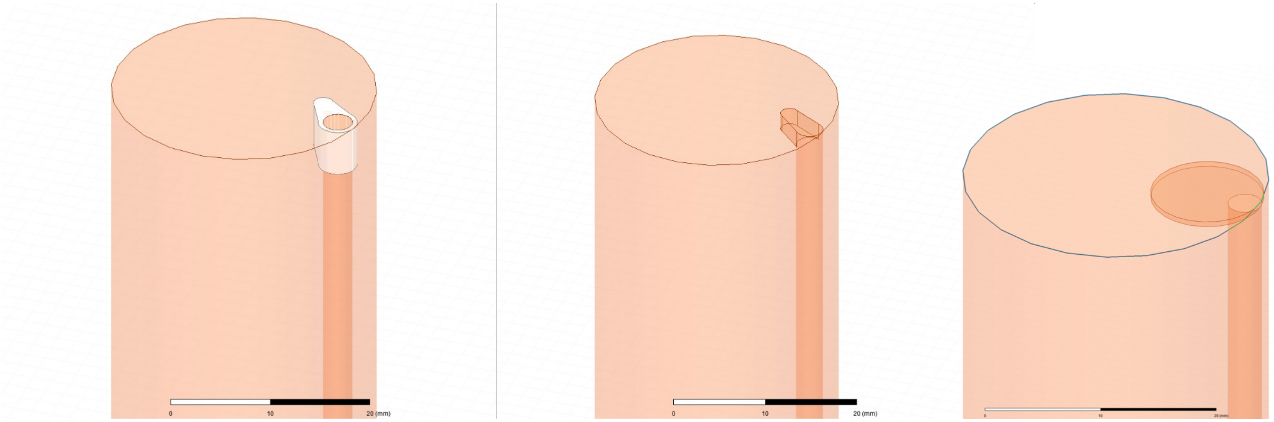


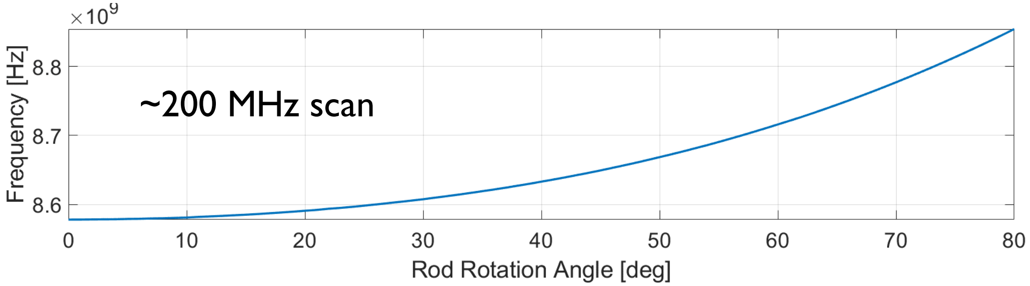


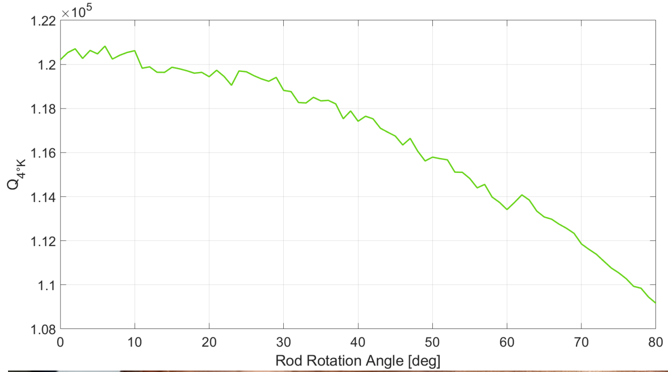


- Simulations S. Tocci
- Technical design S. Lauciani
- Fabrication LNF workshop
- Chemical polishing LNL

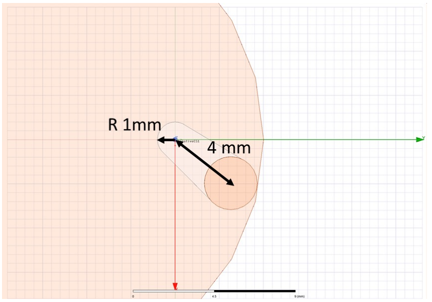
Tuning

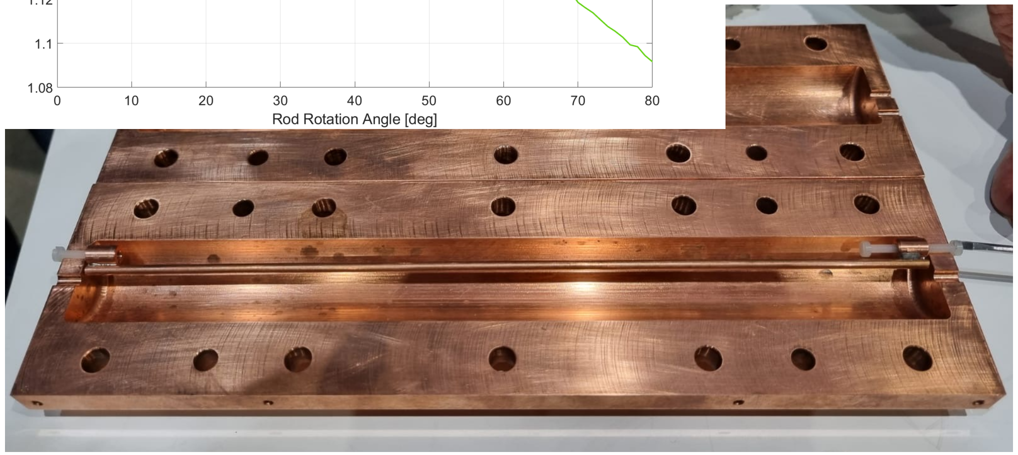




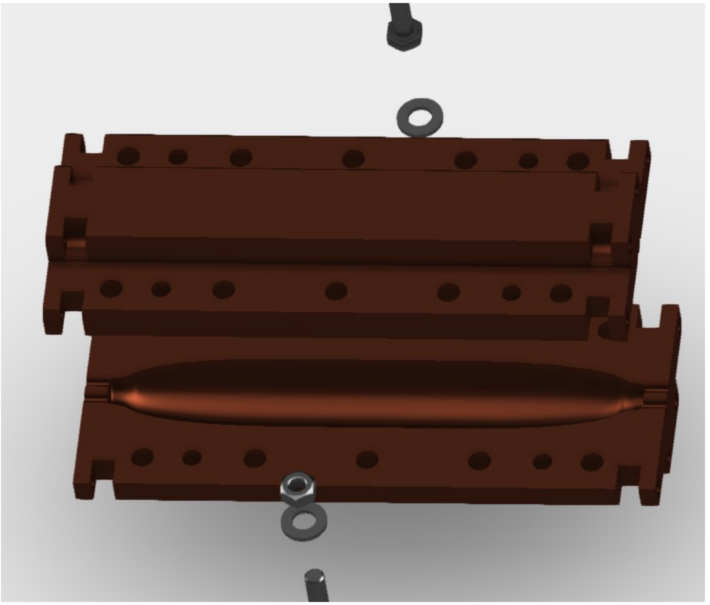


Type	Q	C_{010}
Ideal	117,000	0.669
Allumina	114,000	0.665
Copper	114,000	0.666
Cu Disk	115,000	0.663

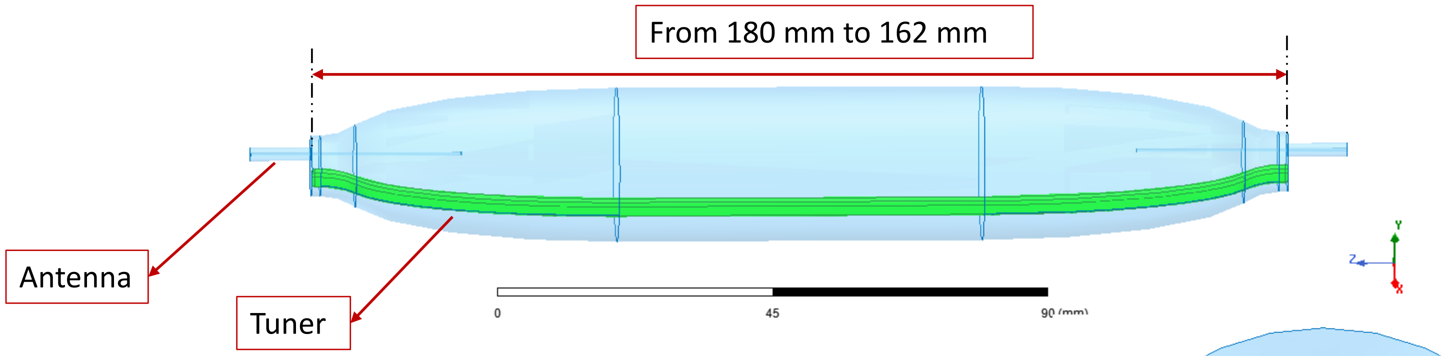


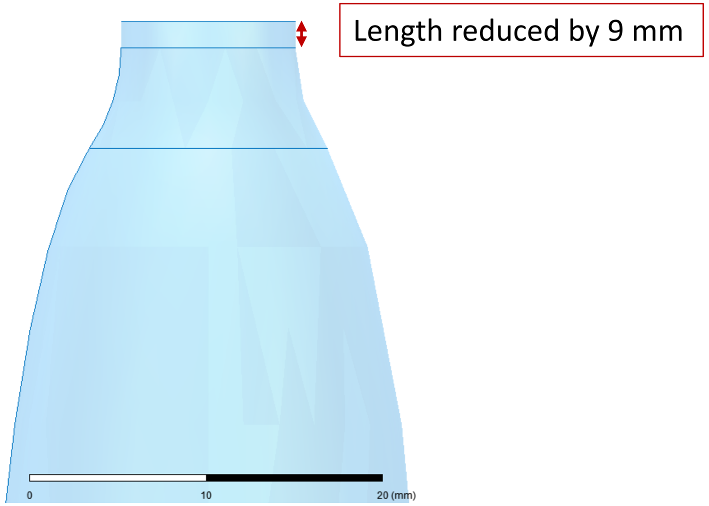


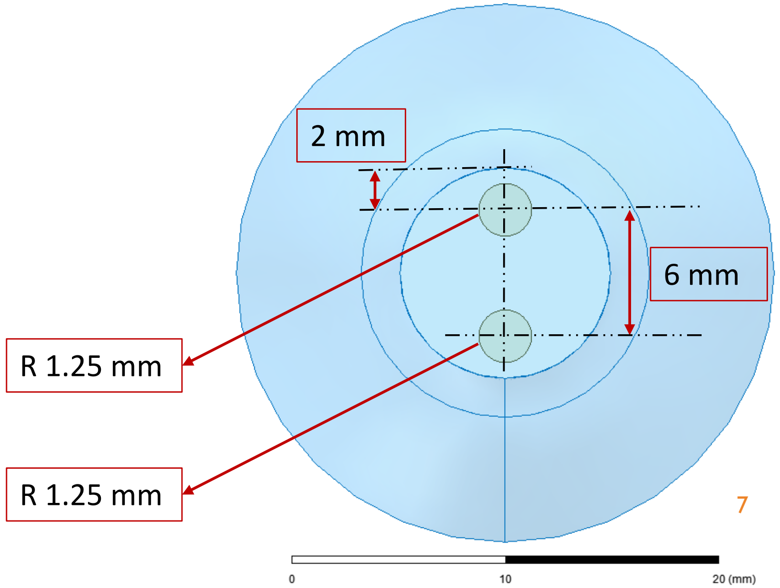
Superconductive Cavity: Nb_3Sn (SQMS)



9.08 GHz cavity : Variations



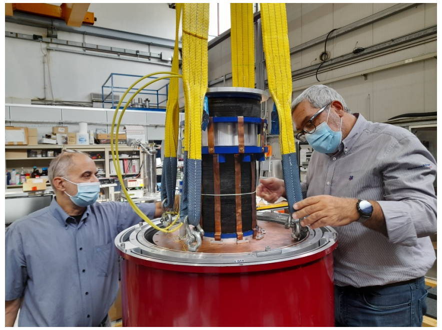


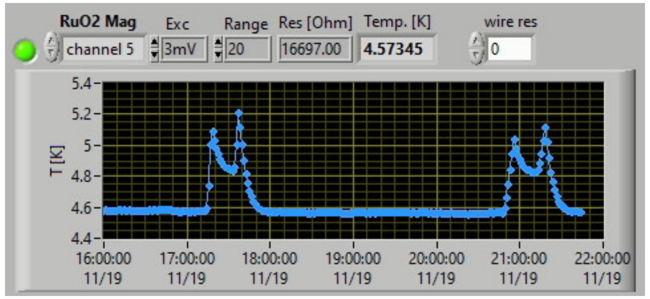


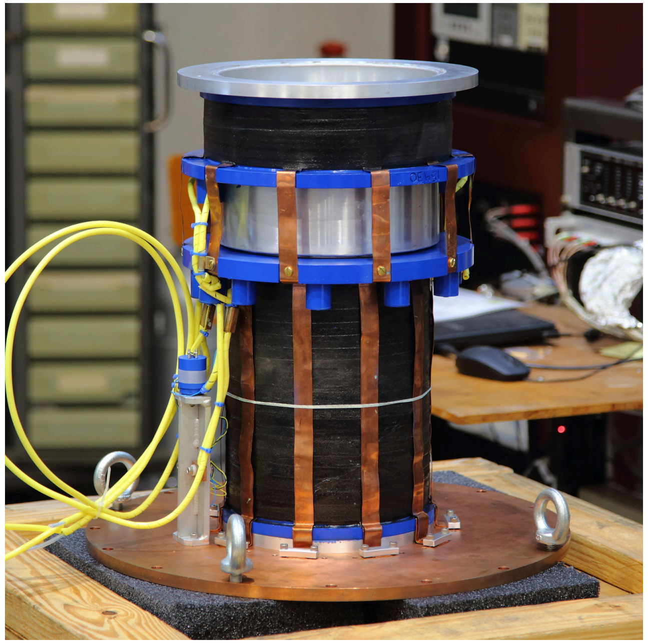
- Design di M. Checchin (FNAL)
- Tuning S.Tocci
- Technical design S. Lauciani
- Fabrication in progress at FNAL

TEST OF 9T MAGNET

- New 9T NbTi magnet from AMI succesfully installed in the cryostat
- I=10 Ampere/Tesla
- Succesfully ramped to 5 T (50 Amps) and set in persistent mode
- Above 50 amps, the temperature of the 4K plate increases by more than 1K
- New Pulse Tube (~1.5 W@ 4K) purchased. Delivery expected this summer

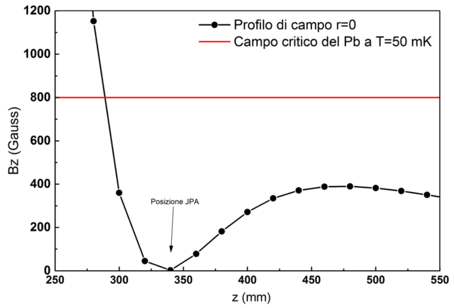


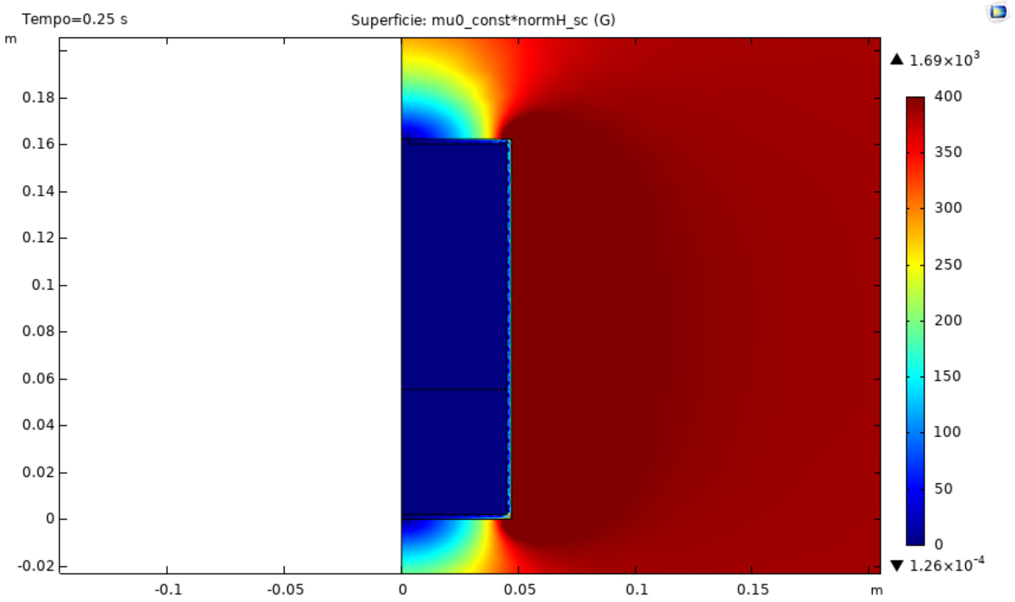


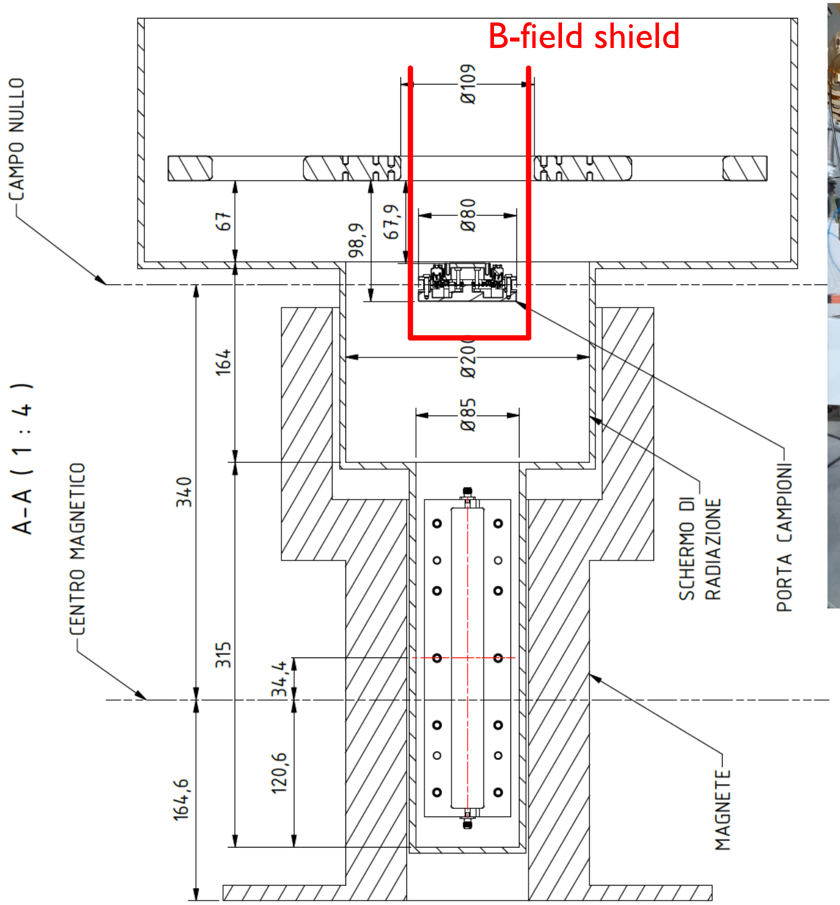


B Field Shield For SC Electronics

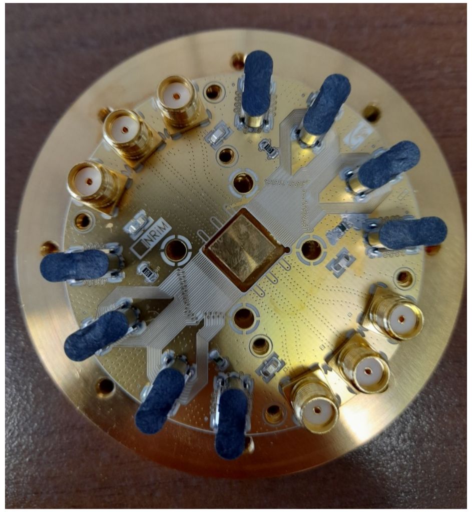
- Shield simulation G. Iannone (Salerno)

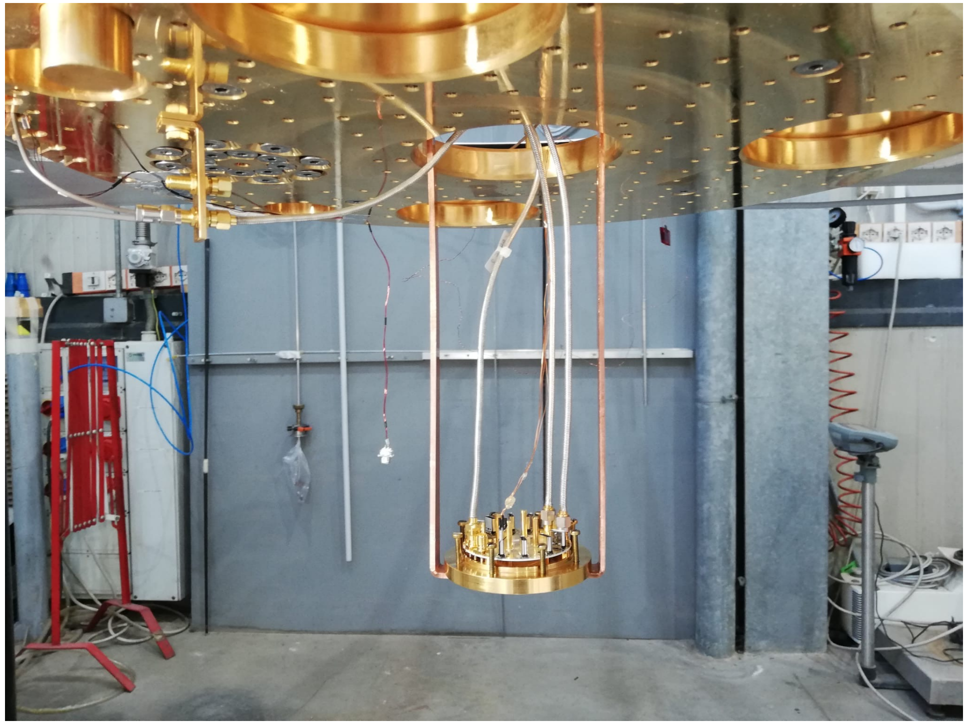




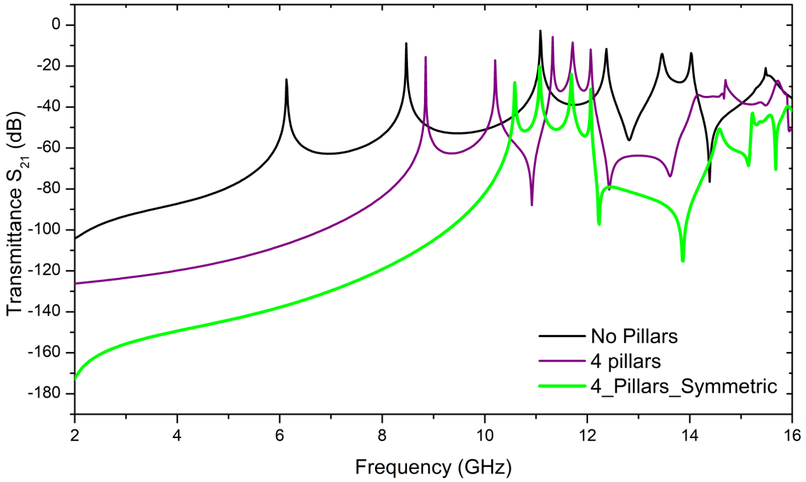


New Sample Holder



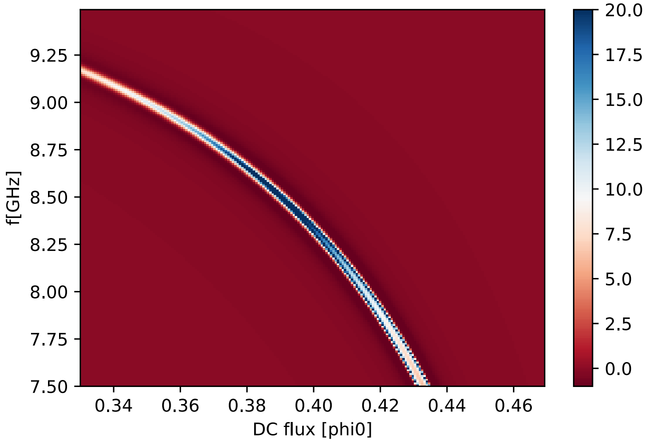


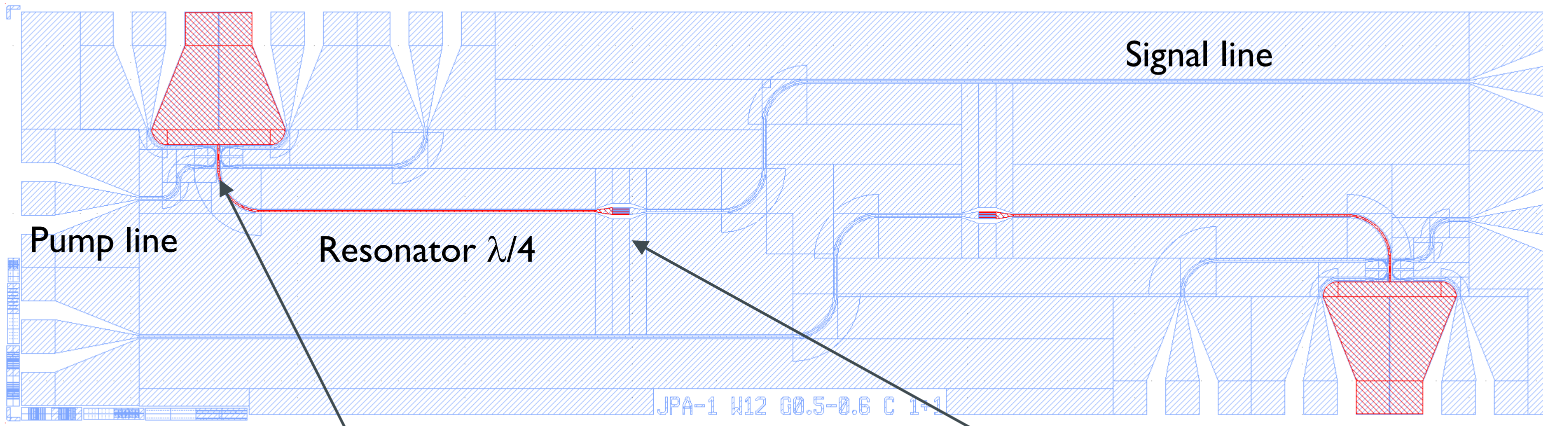
Simulation of "cavity" mode removal by pillars



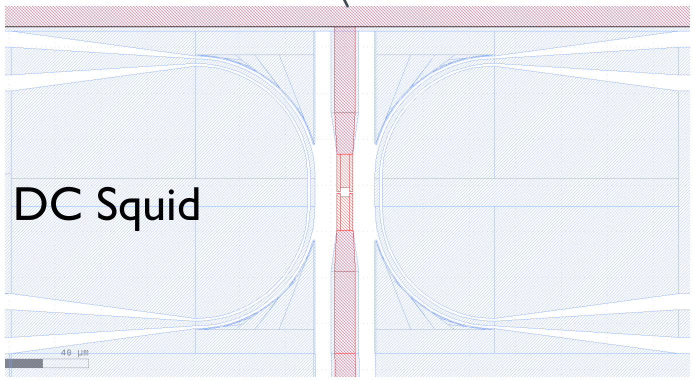
- Simulations by Nassim Chikhi, CNR (Supergalax)

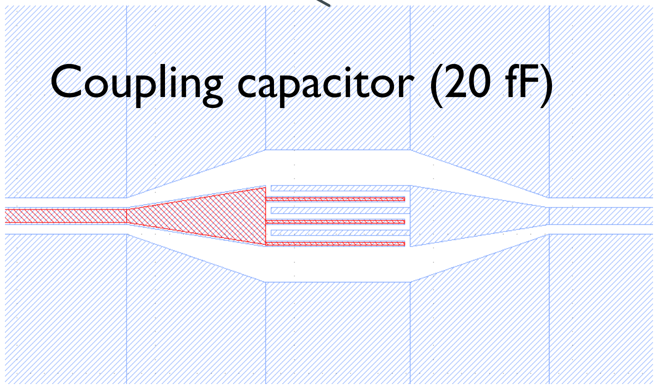
Quantum Limited Amplification: Flux JPA (QUBIT)





- Circuit design LNF
- Chip design FBK
- E.M. simulation Uni Fi
- Device simulation Salerno
- Fabrication FBK/CNR-IFN





First device at 8.5 GHz in fabrication now at FBK!

Sensitivity of LNF Haloscope

Gagg 90% cl	T_{noise}	Q	B(T)
1.6×10^{-13}	8 K (HEMT)	120,000 Cu Cavity	5
9×10^{-14}	8 K (HEMT)	120,000 Cu Cavity	9
2×10^{-14}	SQL (JPA)	120,000 Cu Cavity	9
1.3×10^{-14}	SQL (JPA)	300,000 SC Cavity	9

1h data taking

Multi-cavity: with 4 cavities at differet frequencies, 4 times the scan speed with same sensitivity.

Gagg(KSVZ)=1.3×10^{-14} GeV^{-1} m_a=35 μeV

→ Ready for the first experimental run (Summer 2022)!

→ After new Pulse Tube commissioning

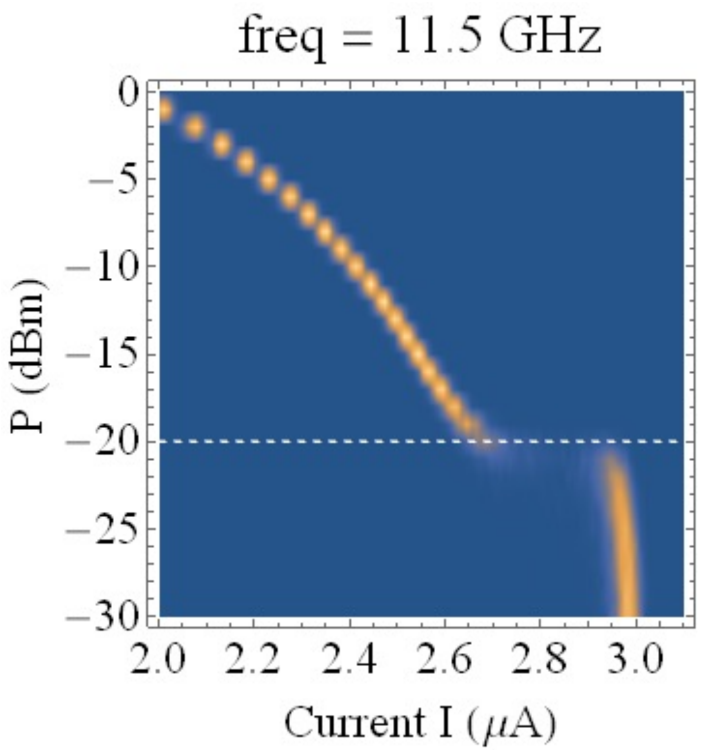
→ With JPA

→ With SC cavity

$$P_{a\gamma} \simeq 4.7\times10^{-24}\ \mathrm{W}\left(\frac{g_\gamma}{0.97}\right)^2\left(\frac{\rho_a}{0.45\ \mathrm{GeV\,cm^{-3}}}\right)\left(\frac{V}{0.141\ \mathrm{l}}\right)\left(\frac{B}{9\ \mathrm{T}}\right)^2 \times\left(\frac{C}{0.69}\right)\left(\frac{f_c}{8.58\ \mathrm{GHz}}\right)\left(\frac{Q}{1.2\times10^5}\right).$$

Single Photon Detection

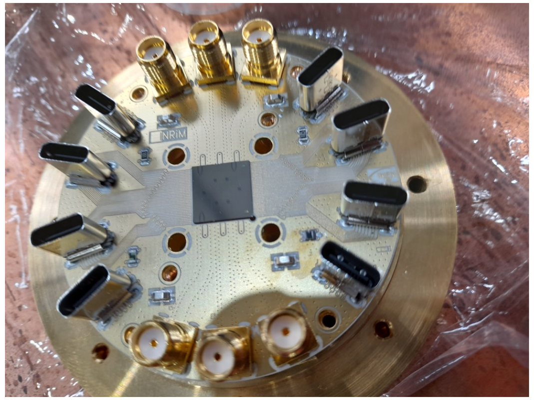
- Observed Resonant Activation of a CBJJ

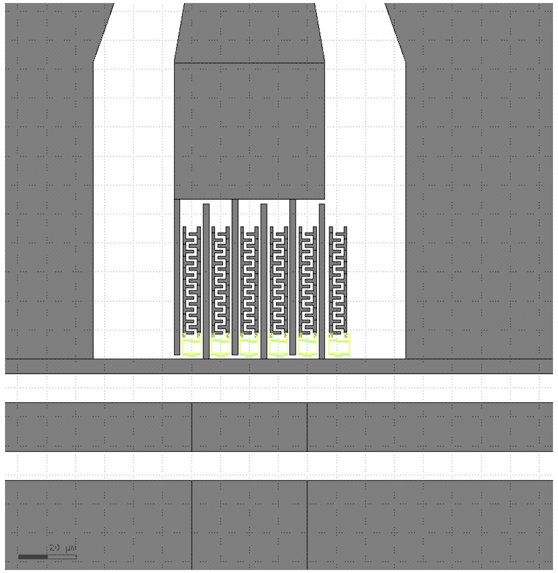


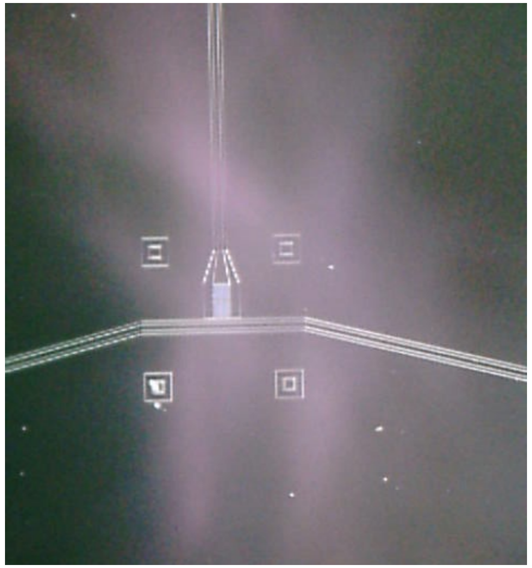
IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 32, NO. 4, JUNE 2022

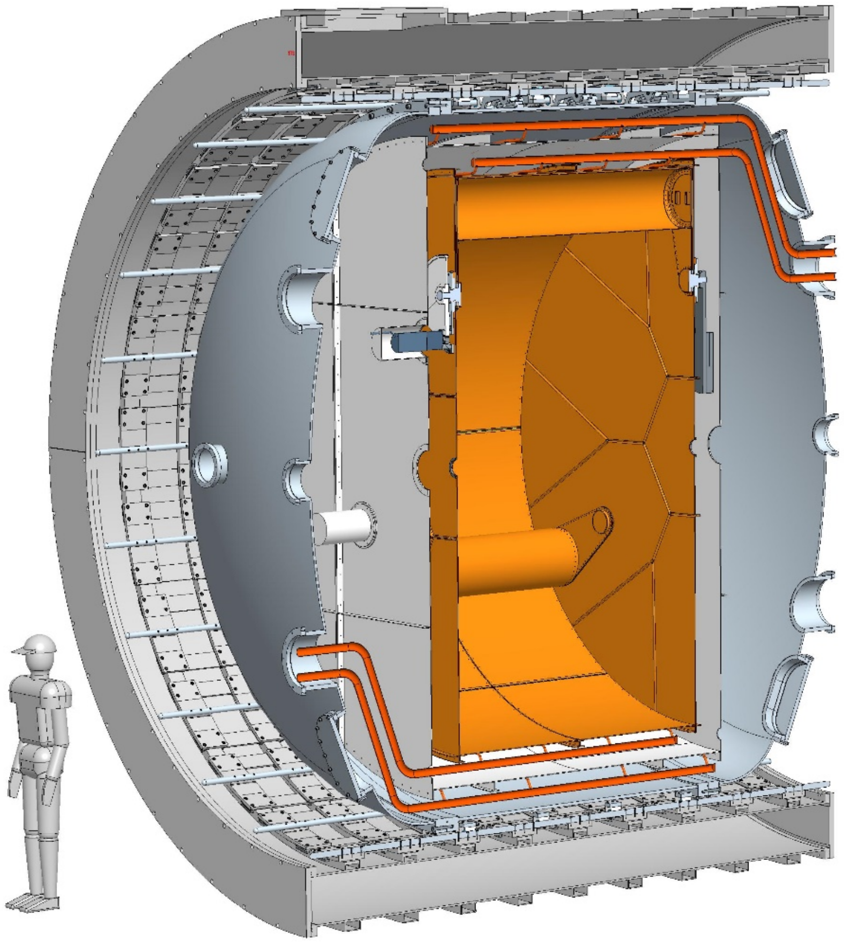
A. Rettaroli Ph.D. Thesis "Study of devices based on Josephson junctions for galactic axion search" Uni Roma Tre (2022)

- Two resonators coupled by 5 qubits
- Test at LNF in preparation (end of May)









FLASH FINUDA MAGNET FOR LIGHT AXION SEARCH

GALACTIC AXION SEARCH AT 100 MHZ (0.4-1.1 MEV)

THE FLASH

- FLASH - Finuda magnet for Light Axions SearcH
- Proposal of a large Haloscope
- Search of galactic axions in the mass range 0.5-1.5 μeV
- Large volume RF Cavity (4 m^3)
- Moderate magnetic field (1.1 T)
- Copper rf cavity Q~500,000
- T 4.5 K

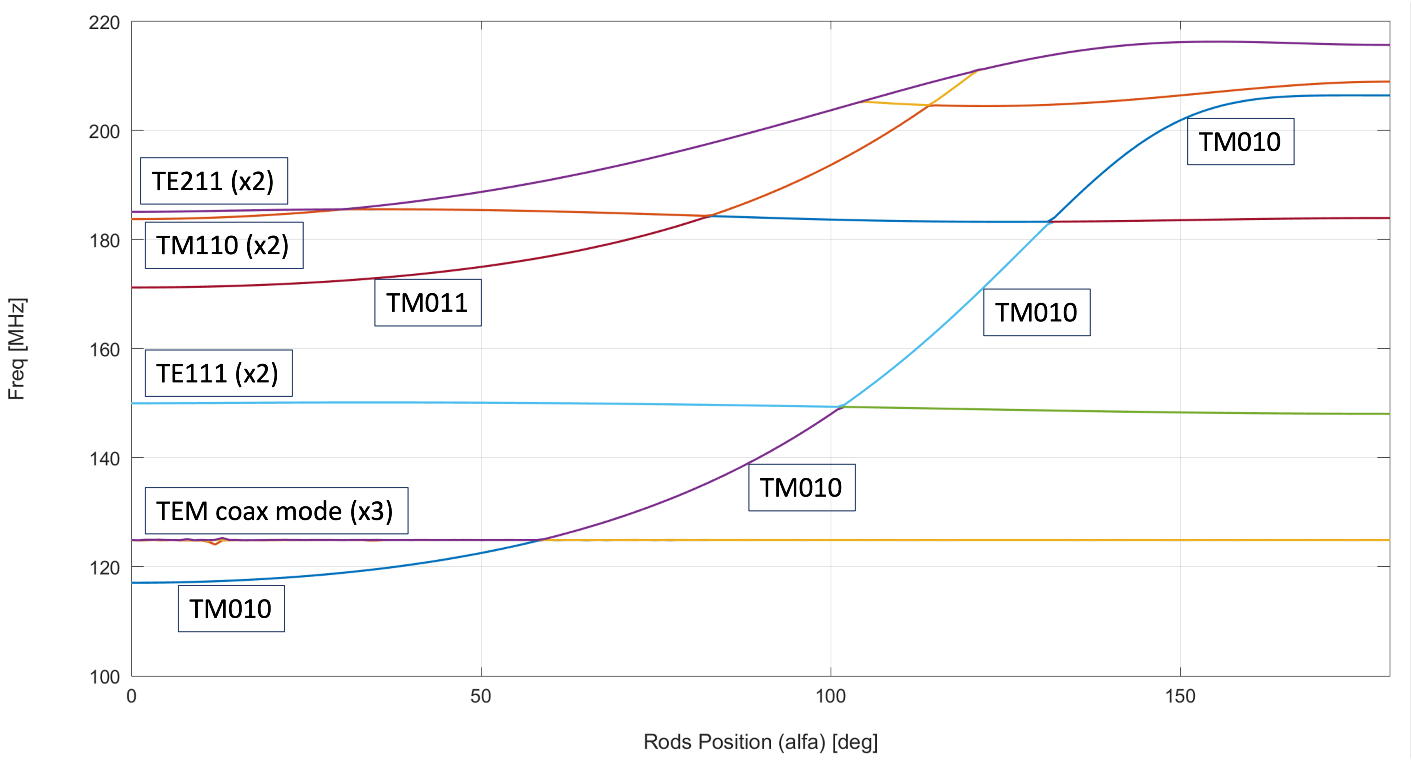
$$P_{\text{sig}} = \left(g_\gamma^2 \frac{\alpha^2}{\pi^2} \frac{\hbar^3 c^3 \rho_a}{\Lambda^4} \right) \times \left(\frac{\beta}{1+\beta} \omega_c \frac{1}{\mu_0} B_0^2 V C_{mnl} Q_L \right)$$

$$SNR = \frac{P_{\text{sig}}}{k_B T_{sys}} \sqrt{\frac{\tau}{\Delta\nu_a}}$$

Experiment	ω B^2 V Q (rad T^2m^3/s) (×10^{15})
The FLASH	1.5
ADMX	5
HAYSTAC	0.2

THE FLASH Frequency Tuning - LF

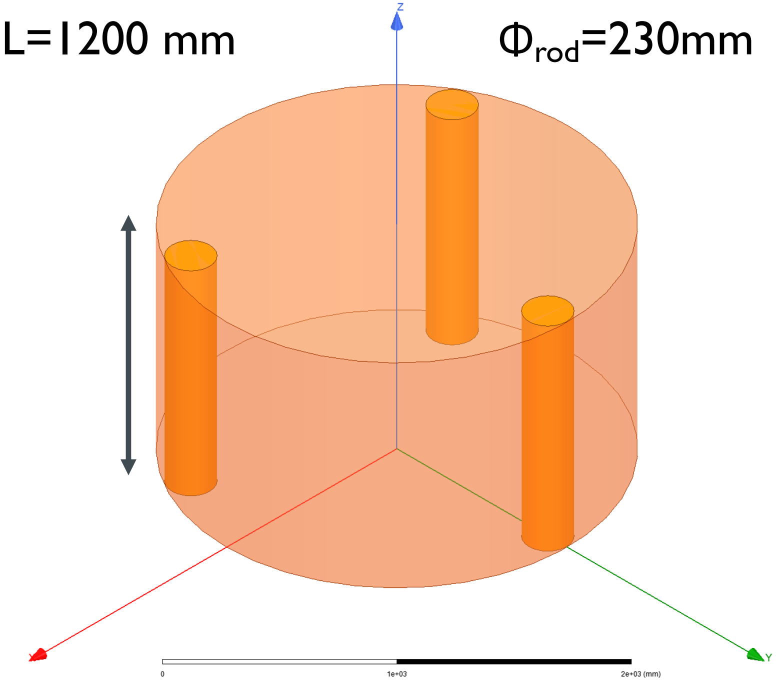
From 117 to 206 MHz



Simulations S.Tocci

L=1200 mm

Φ_{rod}=230mm

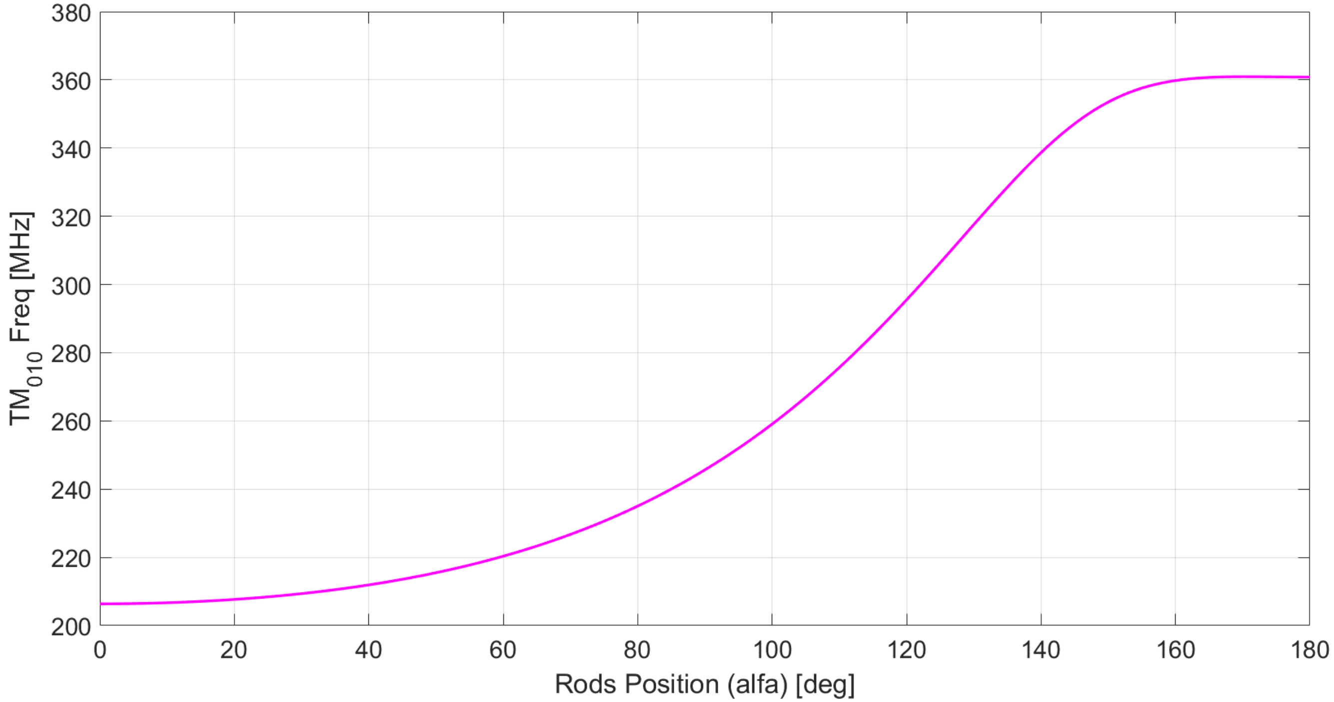


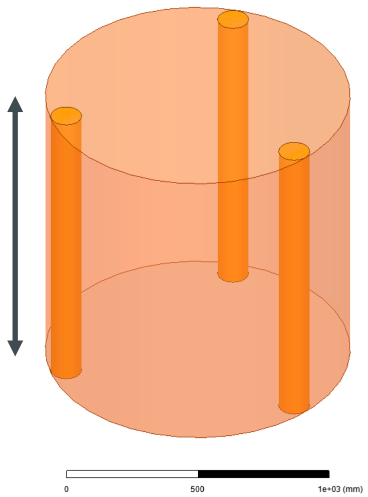
R_{cav}=1050 mm

$$f_{TM_{010}|\alpha=0^\circ} \cong 117\ MHz$$

THE FLASH Frequency Tuning - HF

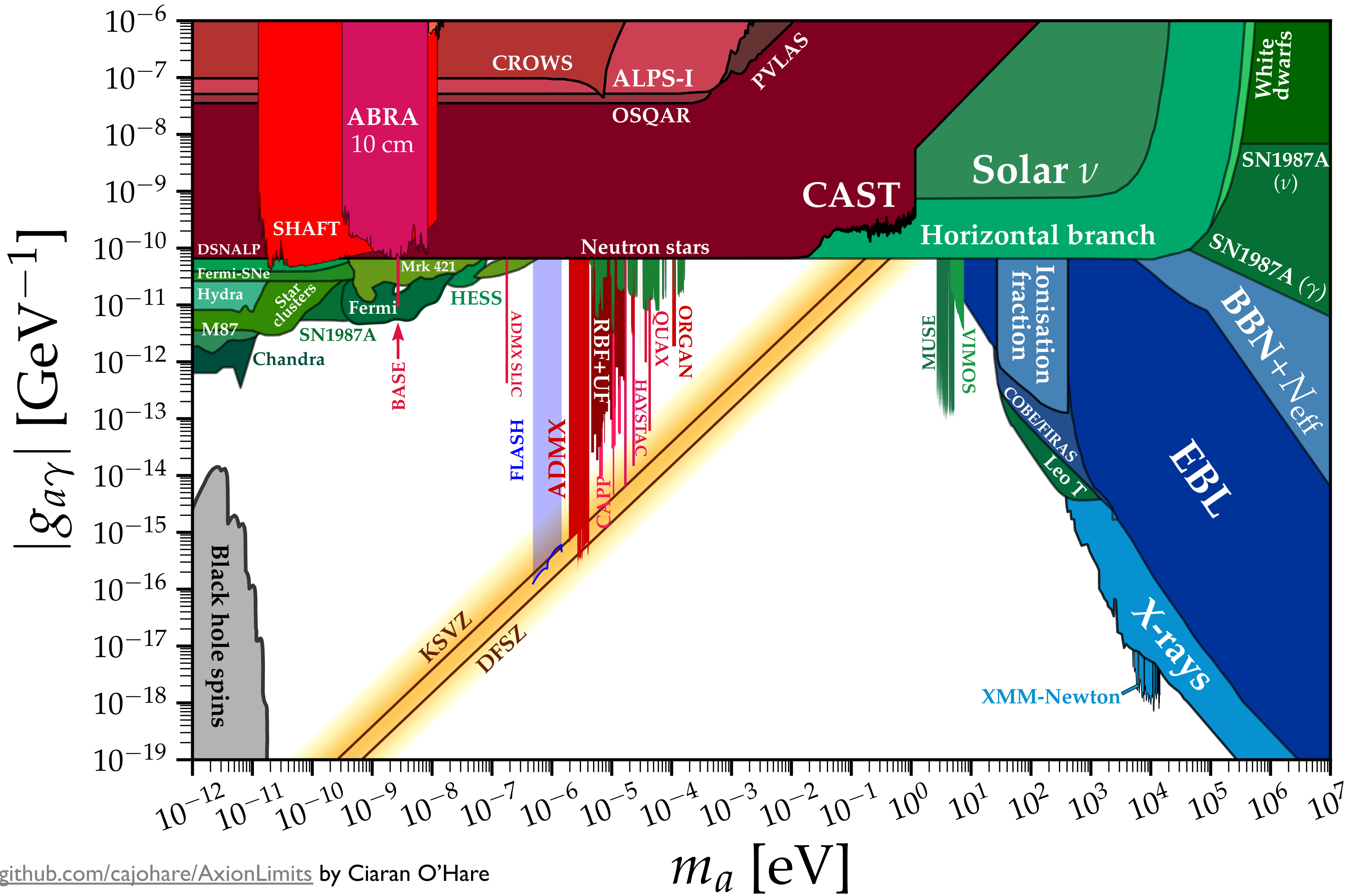
From 206 to 360 MHz (preliminary)





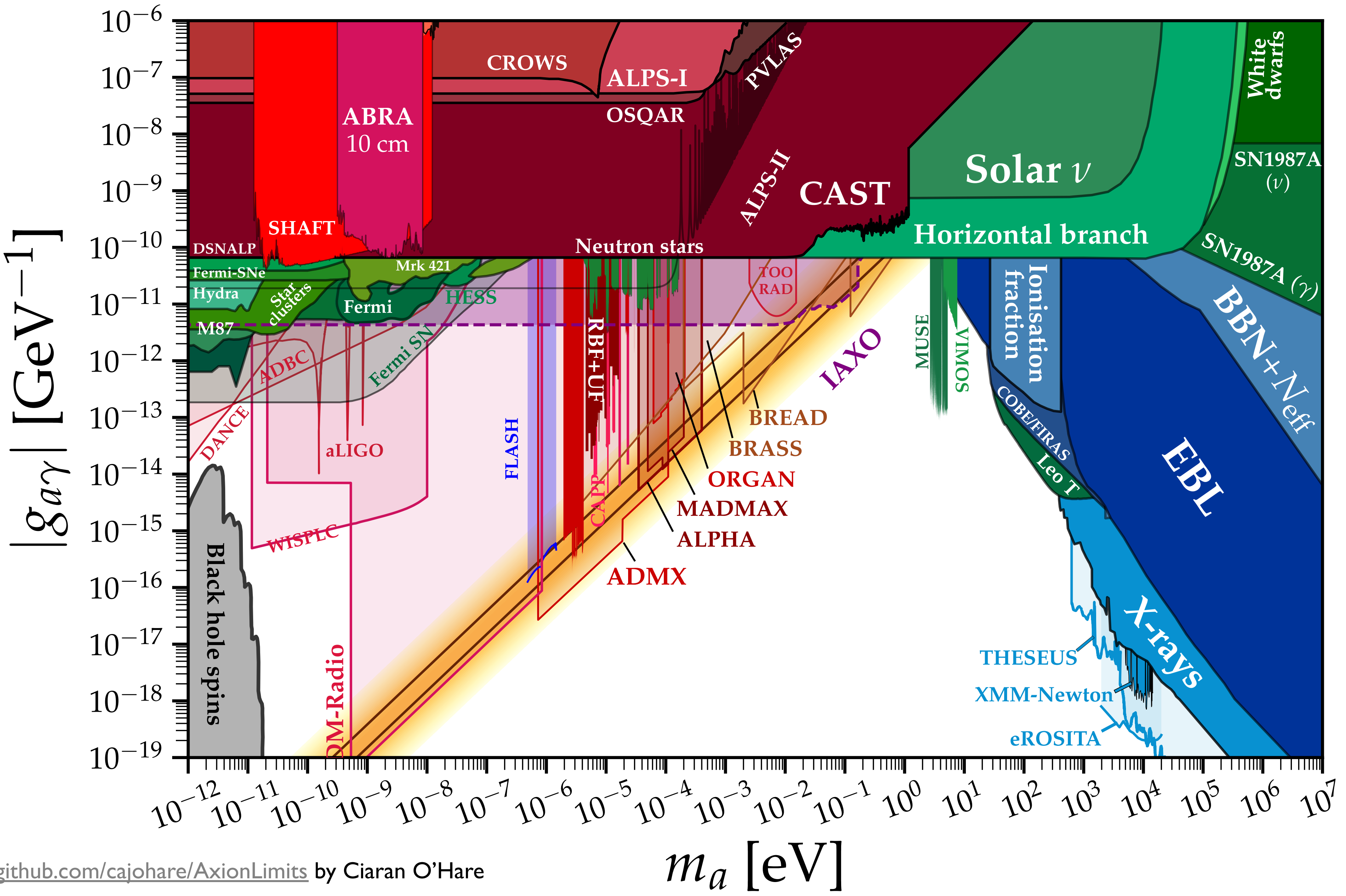
$$f_{TM_{010}}\big|_{\alpha=0^\circ} \cong 206\ MHz$$

FLASH sensitivity 0.5 – 1.5 μeV



Generated with https://github.com/cajohare/AxionLimits by Ciaran O'Hare

With projections from other experiments



Generated with https://github.com/cajohare/AxionLimits by Ciaran O'Hare

Physics Opportunities at 100-500 MHz Haloscopes

17 Feb 2022, 14:00 → 18 Feb 2022, 17:30 Europe/Zurich

online

Babette Dobrich (CERN), Carlo Ligi (INFN - LNF), Claudio Gatti (INFN e Laboratori Nazionali di Frascati (IT)), Giovanni Mazzitelli (INFN)

Description In the last decade an increasing interest in axion and axion-like particles as a possible explanation to the nature of the dark matter in our galaxy led to the proposal of several experiments aiming at their detection. Among these, KLASH [1], now evolved into FLASH, and babyIAXO-RADES [2] are two haloscopes proposed to operate in the frequency region between 100 and 500 MHz, corresponding to the mass region between 0.5 and 2 micro-eV. While being away from the preferred region for QCD-axions (10<ma<100 micro-eV), the search is still motivated by pre-inflationary models, models with modified cosmological-evolution or in extended-axion models. The workshop is intended to review the theoretical motivations and the experimental prospects to probe this mass region by experiments such as ADMX, Abracadabra, DMRadio and Casper as well as FLASH and babyIAXO-RADES. Furthermore, results from axion experiments have been recently used to set limits on high frequency gravitational waves (HFGW) [3-4-5] and new ideas have been proposed to use haloscope-like detectors for their detection[6-7]. Having detectors of meter size and strong magnetic fields, FLASH and babyIAXO-RADES could be particularly suitable for HFGW detection. This possibility will be further investigated during the workshop.

1.The KLASH Conceptual Design Report https://arxiv.org/abs/1911.02427

2.BabyIAXO RADES https://arxiv.org/abs/2010.12076 ; https://arxiv.org/abs/2111.14510

3.A. Ejilli et al. Eur. Phys. J. C. (2019) 79:1032.

4.A. Ito et al. Eur. Phys. J. C. (2020) 80:179.

5.N. Aggrawal et al. arXiv:2011.12414.

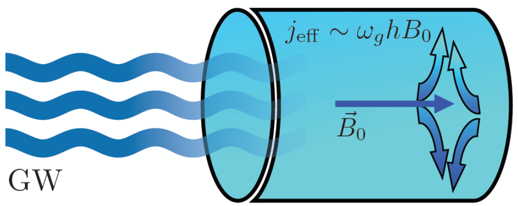
6.N. Herman et al. Phys. Rev. D 104, 023524 (2021).

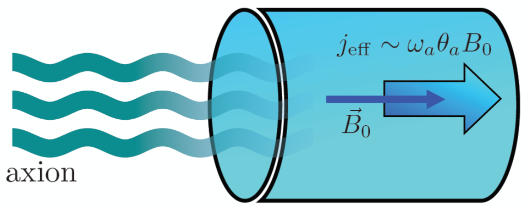
7. A. Berlin et al arXiv:2112.11465

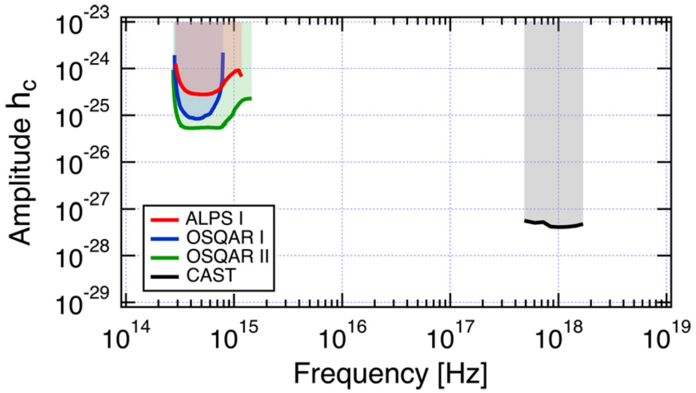
- Two days workshop to discuss physics opportunities at 100-500 MHz Haloscopes
- 115 registered people
- FLASH (Design study;120-1360 MHz; 4K;1.1T)
- Baby Iaxo-RADES (Design study; 200-500 MHz; 6K; 2.5 T)
- ADMX Low Frequency (Design study, 9T MRI magnet, 100 mK, 160-500 MHz)
- DMRadio-ABRACADABRA (TDR in preparation; 4 T; mK; 5-200 MHz)

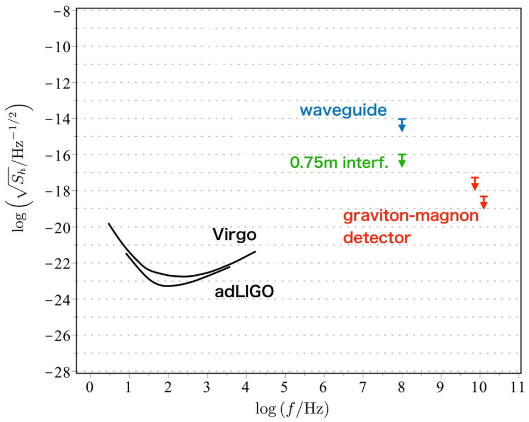
https://indico.cern.ch/e/MHzHaloscope

High Frequency Gravitational Waves









PHYSICAL REVIEW D **104,** 023524 (2021)

Detecting planetary-mass primordial black holes with resonant electromagnetic gravitational-wave detectors

Nicolas Herman[1,*] André Fűzfa[1,2,†] Léonard Lehoucq[1,3,‡] and Sébastien Clesse[4,2,§]

Eur. Phys. J. C (2019) 79:1032
https://doi.org/10.1140/epjc/s10052-019-7542-5
THE EUROPEAN PHYSICAL JOURNAL C
Check for updates
Regular Article - Theoretical Physics

Upper limits on the amplitude of ultra-high-frequency gravitational waves from graviton to photon conversion

A. Ejlli[1,a], D. Ejlli[3], A. M. Cruise[2], G. Pisano[1], H. Grote[1]

Eur. Phys. J. C (2020) 80:179
https://doi.org/10.1140/epjc/s10052-020-7735-y
THE EUROPEAN PHYSICAL JOURNAL C
Check for updates
Letter

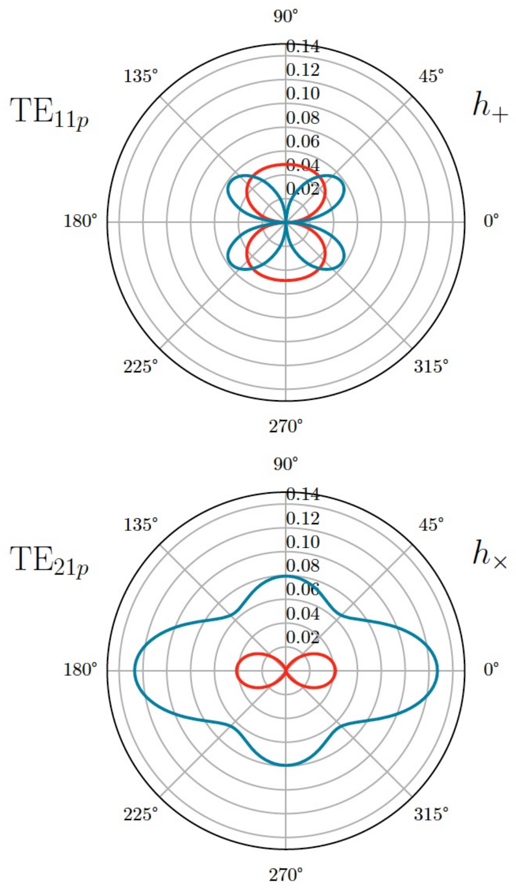
Probing GHz gravitational waves with graviton–magnon resonance

arXiv:2112.11465 FERMILAB-PUB-21-724-SQMS-T

Detecting High-Frequency Gravitational Waves with Microwave Cavities

Sensitivity to HFGW

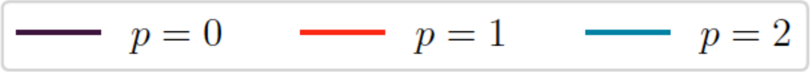
Mode	Resonant Frequency [MHz]	Q factor (@4°K)
TE111	150.4	711e3
TE112	263.5	871e3
TE211	186.9	735e3
TE212	285.9	817e3

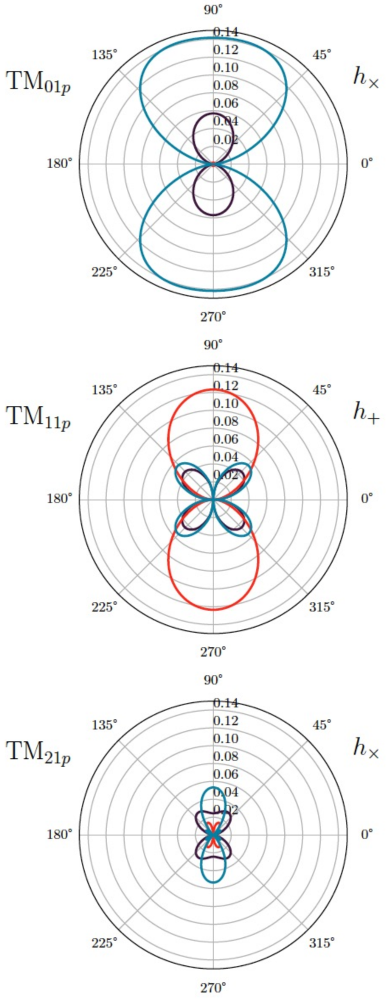


arXiv:2112.11465

Sensitivity to HFGW

Mode	Resonant Frequency [MHz]	Q factor (@4°K)
TM010	109.5	626e3
TM011	166.1	526e3
TM012	272.3	752e3
TM110	174.4	790e3
TM111	214.5	598e3
TM112	304.7	712e3
TM210	233.7	915e3
TM211	264.9	664e3
TM212	342.1	755e3



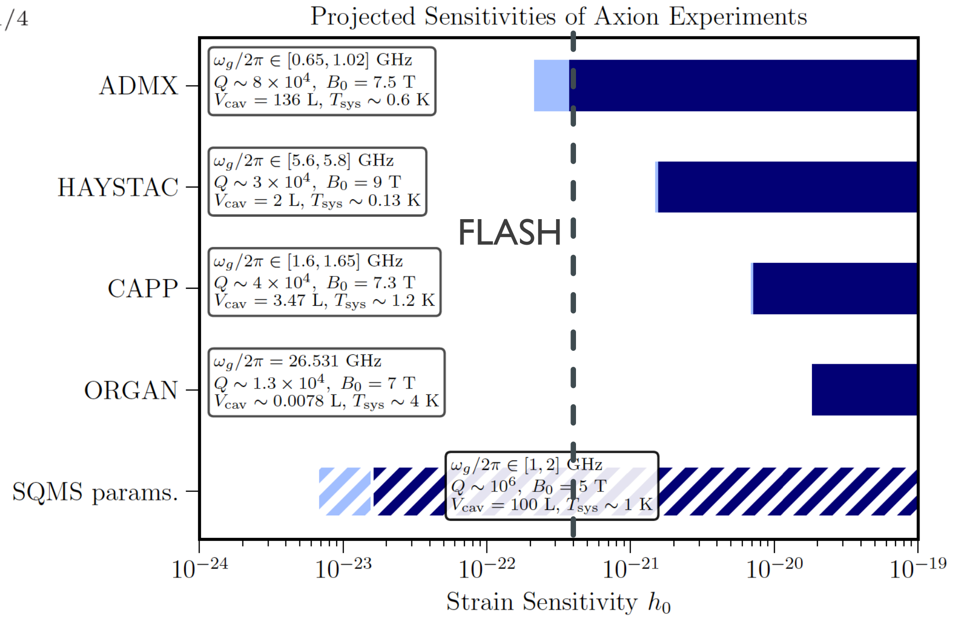


Sensitivity to HFGW

$$h_0 \gtrsim 3\times10^{-22} \times \left(\frac{1\ \mathrm{GHz}}{\omega_g/2\pi}\right)^{3/2}\left(\frac{0.1}{\eta_n}\right)\left(\frac{8\ \mathrm{T}}{B_0}\right)\left(\frac{0.1\ \mathrm{m}^3}{V_{\mathrm{cav}}}\right)^{5/6}\left(\frac{10^5}{Q}\right)^{1/2}\left(\frac{T_{\mathrm{sys}}}{1\ \mathrm{K}}\right)^{1/2}\left(\frac{\Delta\nu}{10\ \mathrm{kHz}}\right)^{1/4}\left(\frac{1\ \mathrm{min}}{t_{\mathrm{int}}}\right)^{1/4}$$

Mode	TM012
frequency	270 MHz
η_n	0.14
B_0	1.1 T
V_{cav}	4.15 m^3
Q_0	7×10^5
T_{sys}	4.9 K
$\Delta\nu$	10 kHz
t_{int}	1 min

FLASH strain sensitivity $h_0 \sim 4\times10^{-22}$



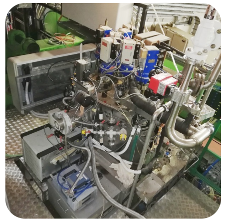
arXiv:2112.11465

Plan for the Test of the Finuda Magnet

Test of pumping system
- June

Repair of control panel
- July

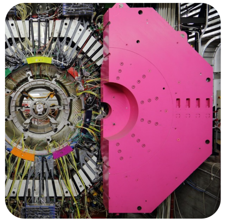
Revision of He Buffer
- September



Revision of safety valves
- September

Elongation of He transfer line
- September - October

New cooling system of magnet power supply and test
- September 2022- January 2023



Endcaps closing
- January 2023

Conclusion

- Ready for the first QUAX@LNF run with sensitivity 10×KSVZ (June-July)
- Roadmap to KSVZ:
  1. Tuning system
  2. Quantum limited amplification (JPA/TWPA)
  3. Superconducting cavity (Nb_3Sn, NbTi, YBCO)
  4. Multicavity
  5. Single microwave photon counters (CBJJ, SC qubits)
- Estimate of FLASH sensitivity to axions and HFGW with e.m. simulations
- Large attendace at 100 MHz Haloscopes Workshop!
- Ongoing work to prepare the test of the FINUDA magnet at beginning of 2023